Институт физики им. Б. И. Степанова
Национальная академия наук Беларуси

Мы вправе ждать от ученых Беларуси открытий на грани невозможного
А.Г. Лукашенко 2/02/2018

INSTITUTE OF PHYSICS NAS OF BELARUS IN THE ATLAS AT LHC

TO 25TH ANNIVERSARY OF THE EXPERIMENT ATLAS

YURI KULCHITSKY [*]), YURI KUROCHKIN

INSTITUTE OF PHYSICS, NATIONAL ACADEMY OF SCIENCES, MINSK, BELARUS
[*]) JINR, DUBNA, RUSSIA

26.02.2018, LHC Days in Belarus 2018, Minsk, Belarus

Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
China
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

ATLAS Collaboration

ATLAS COLLABORATION

Belarus Institutes in the ATLAS Collaboration

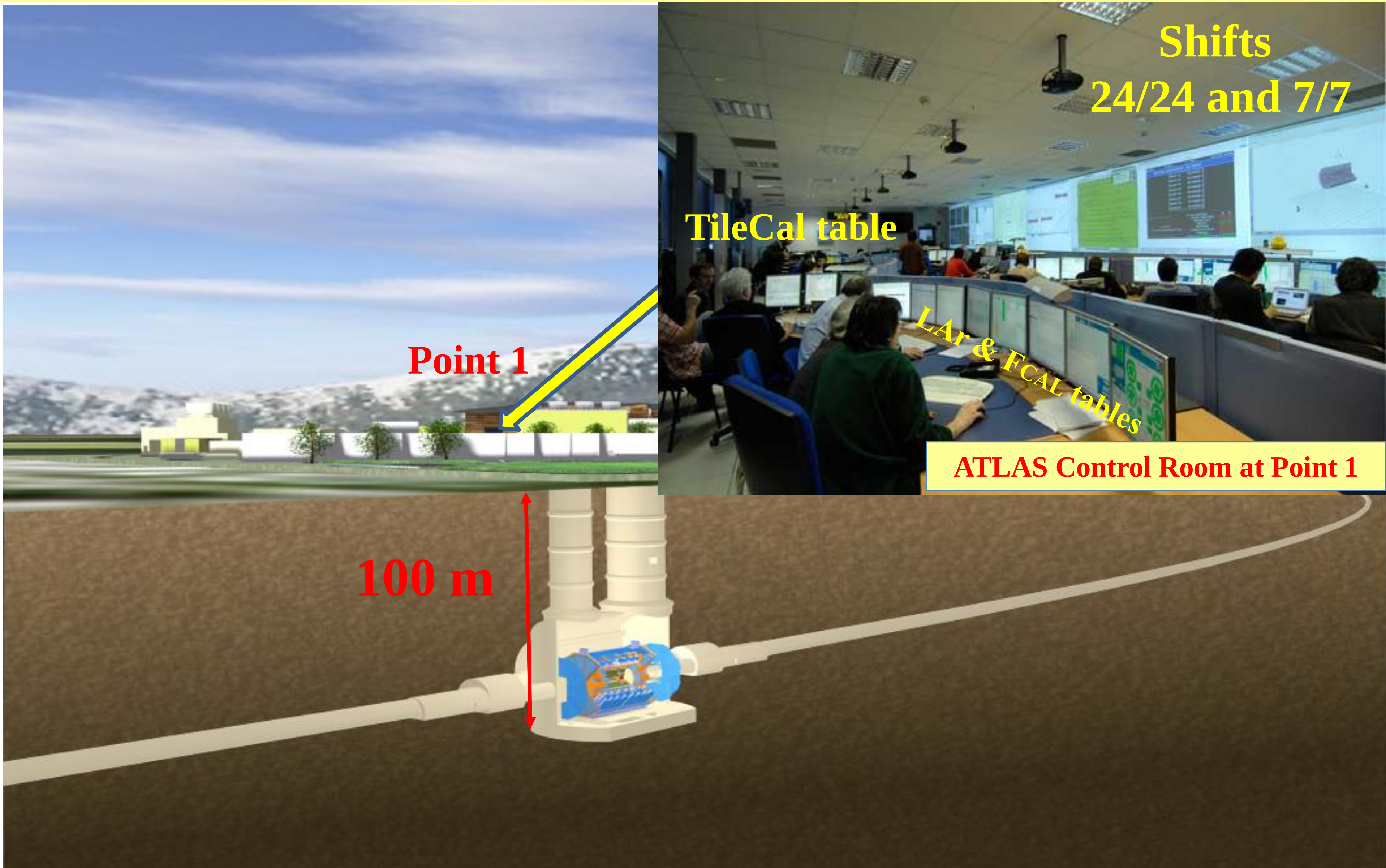
- **B.I.Stepanov Institute of Physics, National Academy of Sciences of Belarus, since 1994**
- National Centre of Particle and High Energy Physics at BSU, since 1996

ATLAS Collaboration comprises ~2900 scientists (~1000 PhD students); ~1900 authors from about 210 institutions around the world, representing 38 countries from all the world's populated continents

Large Hadron Collider

ATLAS & CMS IN COMPARISON WITH BLD.40 AT CERN

ATLAS CONTROL ROOM IN POINT 1



REQUEST OF IP NASB DIRECTOR FOR PARTICIPATION IN THE ATLAS COLLABORATION

ИНСТИТУТ ФИЗИКИ им. Б. И. СТЕПАНОВА АКАДЕМИИ НАУК
БЕЛОРУССКОЙ ССР

ІНСТЫТУТ ФІЗІКІ імя Б. І. СЦЯПАНАВА АКАДЭМІІ НАВУК
БЕЛАРУСКАЙ ССР

220602, г. Минск, ГСП, Ленинский пр., 70. Тел. 39-47-55
Р/с № 000120217 в Первомайском отд. Промстройбанка г. Минска

№ 03.08.1994
На №

Исх 60/1451.2-284
3.08.94г.

Professor *F.Dydak*
Professor *P.Jenni*

Dear colleagues!

Institute of Physics of the Academy of Sciences of Belarus (Minsk, Republic of Belarus) is interested to participate in ATLAS project.

We can contribute to the simulation and to the design and fabrication of calorimeters and connected subsystems.

For the long period of time our Institute is cooperating in its research program with our Joint Institute for Nuclear Research (Dubna) coleagues from the group of *prof.J.A.Budagov*. As a result of such collaboration our Institute has a large group of experienced physicists. We think joining of Minsk efforts with efforts of Dubna colleagues will bring good results in our cooperation for ATLAS project realization.

Necessary information conserning our group you may request from *dr.N.A.Russakovich*.

Please be so kind to initiate the consideration of our request to join ATLAS project by ATLAS scientific community.

Our coordinates at Minsk are	*Institute of Physics of the Academy of Sciences of Belarus (IP ASB) Avenue F.Skorina 70, Minsk 220602 Republic of Belarus*
E-mail is	*ifanbel@adonis.ias.msk.su*
Fax is	*007 - 0172 - 393131*

Contact person from our side is *dr.Yuri Kulchitsky* who is now a long term visiting scientist to *prof.J.A.Budagov* group.

His present mail address is	*Laboratory of Nuclear Problems Joint Institute for Nuclear Research Dubna, Moscow reg., 141980, Russia*
His e-mail is	*kulchitsky@main1.jinr.dubna.su*

Sincerely,

Director of Institute of Physics of ASB
Akademician of ASB P.A.Apanasevich

A. Bogush

Head of Laboratory of High Energy Physics
Korresponding member of ASB A.A.Bogush

Participation of the Corresponding Member NANB, head of laboratory of high energy physics IP NASB Prof. A.A.Bogush and leader scientist, IP NASB ATLAS team leader Yu.A.Kulchitsky on an international conference "ATLAS Collaboration week of meetings" for presentation of theoretical and Tile Calorimeter analysis results, CERN, Geneva 1996

BELARUSSIAN PHYSICISTS IN LHC EXPERIMENTS

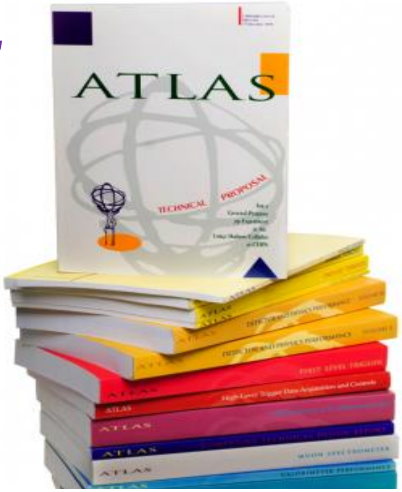
14 physicists from 8 Belarussian scientific organizations took part in the ***1st ATLAS – JINR International Conference*** ***"JINR and Member States cooperation with ATLAS experiment at LHC" Dubna, 28-29 October 1994***

Y. Kulchitsky was the member of the Conference organizine committee

Participants of the Workshop *"Belarus–CERN cooperation for experiments at LHC"*, National Center for Particle and High Energy Physics, Minsk, **1996**

IP NASB PARTICIPATION IN THE ATLAS EXPERIMENT

- ***15 December 1994:* ATLAS submits the Technical Proposal for the experiment to the LHC Experiments Committee**
- Approval to proceed with Technical Design Reports (TDR) granted in early **1996**, followed by the submission of one of the ATLAS first TDRs "**ATLAS Tile Calorimeter**"
- Teams all over the world built detector components and worked on final technical developments



Corresponding Member NANB, head of laboratory of high energy physics, Prof. **A.A. BOGUSH**

Team of IP NASB in the ATLAS Collaboration

1994 – ATLAS Technical Proposal:

A.Bogush, A.Dajneko, Y.Kulchitsky (Team Leader), I.Satsunkevich, M.Sergeenko, F.Zyazyulya

1996 – ATLAS Tile Calorimeter TDR:

M.Baturitsky, A.Bogush, A.Gazizov, V.Gilevsky, Y.Kulchitsky (Team Leader), M.Kuzmin, M.Levchuk, I.Satsunkevich

(Y.Kulchitsky contributed as an editor to the Calorimeter Performance section)

ATLAS nowadays members: S.Harkusha, Y.Kulchitsky (Team Leader), Yu.Kurochkin, M.Levchyuk, P.Tsiareshka, D.Shoukovy, Ya.Saprunou

- **ATLAS: Technical Proposal for a general-purpose pp experiment at the Large Hadron Collider at CERN,** *CERN-LHCC-94-43, LHCC-P-2 (Geneva, CERN, 1994), 272 pp.*
- **ATLAS Tile Calorimeter: Technical Design Report,** *CERN-LHCC-96-042, ATLAS-TDR-3 (CERN, 1996), 333 pp*

SCSTB SUPPORT BELARUS ORGANIZATIONS TO PARTICIPATE IN THE ATLAS EXPERIMENT

КАМІТЭТ ПА НАВУЦЫ І ТЭХНАЛОГІЯХ
Міністэрства адукацыі і навукі Рэспублікі Беларусь
220040, г.Мінск, вул. М.Багдановіча, 155
тэл. 34-90-52, факс 62-34-31

КОМИТЕТ ПО НАУКЕ И ТЕХНОЛОГИЯМ
Министерства образования и науки Республики Беларусь
220040, г.Минск, ул. М.Богдановича, 155
тел. 34-90-52, факс 62-34-31

06.01.1995

№ 6
от 6.01.95 г.

Директору Объединенного Института
Ядерных исследований члену-
корреспонденту РАН
В.Г.Кадышевскому

Глубокоуважаемый Владимир Георгиевич !

Информирую Вас, что в рамках координационного плана научных исследований, выполняемых в ОИЯИ, ряд крупных научных центров Республики Беларусь проводит работы в рамках эксперемента Atlas (тема № 02-2-1007-94/95 ПТП ОИЯИ), который готовится на создаваемом в CERN pp-колайдере LHC (Женева, Швейцария).

Комитет по науке и технологиям Республики Беларусь поддерживает усилия белорусских ученых по выполнению этой фундаментальной научно-исследовательской программы XXI века.

Комитет подтверждает готовность ученых Беларуси работать совместно с ОИЯИ и CERN над выполнением физических и технологических задач, определяемых программой ATLAS.

С глубоким уважением,

Председатель Комитета по науке
и технологиям, член-корреспондент
АНБ

Н.В.Румак

1994 – 1995 Chairmen of the State Committee of Sciences and Technology of Belarus, Corresponding Member NANB, **Prof. N.V. RUMAK**

THE CONSTRUCTION MOU WAS SIGNED BY SCSTB

The Construction MoU was signed by all initial ATLAS Funding Agencies in 1998-1999

And new partners also signed Addenda to the MoU when they joined later on

1997-2000 Chairmen of the State Committee of Sciences and Technology of Belarus, **Prof. V.A.GAISYONOK**

	signed date	signed by
Armenia	10/7/98	R. Mkrtchyan
Australia	26/5/98	S. Tovey
Austria	18/6/98	R. Kneuker
Azerbaijan	30/6/98	N. Guliyev
Belarus	24/6/98	V.A. Gaisyonok
Brazil	6/9/99	E. Mirra de Paula e Silva
Canada	26/4/99	N. Lloyd
China	30/11/99	N. Wang
Czech Republic	26/5/98	F. Suransky, J. Niederle
Denmark	26/5/98	E. Larsen
Finland	26/5/98	E. Byckling
FRANCE CEA	6/1/99	C. Cesarsky
France IN2P3	8/6/98	C. Detraz
Georgia	22/11/99	A. Tavkhelidze
Germany BMBF	12/6/98	H. Schunck
Germany MPI	22/4/99	V. Soergel
Greece	15/6/98	E. Floratos
Israel	1/6/98	D. Horn
Italy	28/5/98	L. Maiani
Japan	23/6/98	H. Sugawara
JINR	10/6/98	A.N. Sissakian
Morocco	1/6/98	S. Belcadi
Netherlands	15/10/98	G. van Middelkoop
Norway	22/6/98	K. Kveseth
Poland	28/5/98	J. Frackowiak
Portugal	5/6/98	A. Trigo de Abreu
Romania	30/7/98	V. Lupei
Russia	10/10/98	N. Kirpichnikov
Slovak Republic	7/7/98	O. Nemcok
Slovenia	15/12/99	L. Marincek
Spain	30/4/98	F. Aldana
Sweden	29/4/99	G. Oequist
Switzerland	26/5/98	B. Fulpius, Ch. Schäublin
Turkey	2/6/98	D. Ulkü
United Kingdom	14/7/98	I.G. Halliday
US DoE + NSF	26/10/98	. O'Fallon, N. Lightbody, T. Kirk, W. Willis
CERN	26/6/98	V.G. Goggi

SCSTB AGREEMENT ON MOU OF ATLAS EXPERIMENT

The European Organization for Nuclear Research (CERN)

and

State Committee for Science and Technology of the Republic of Belarus, Minsk

declare that they agree on the present Memorandum of Understanding for the ATLAS Experiment.

Done in Geneva

on 30th April, 1998

For CERN

Lorenzo Foà
Director of Research

Done in Geneva

on 24th June, 1998

For State Committee for Science and Technology of the Republic of Belarus

V.A. Gaisyonok

The European Organization for Nuclear Research (CERN)

and

The State Committee on Science and Technologies of the Republic of Belarus

declare that they agree on the present Memorandum of Understanding for the ATLAS Experiment.

Done in Geneva

on 14th March 2005

For CERN

Jos Engelen
Chief Scientific Officer
Deputy Director-General

Done in Minsk

on 25.03.05

For the State Committee on Science and Technologies of the Republic of Belarus

Yury Pleskachevsky
Chairman

Since 1995 there are ATLAS Resources Review Board meetings twice a year

IP NASB DIRECTOR SUPPORT TO PARTICIPATION IN THE ATLAS COLLABORATION

**ИНСТИТУТ ФИЗИКИ им. Б. И. СТЕПАНОВА АКАДЕМИИ
БЕЛОРУССКОЙ ССР**

**ІНСТЫТУТ ФІЗІКІ імя Б. І. СЦЯПАНАВА АКАДЭМІІ Н
БЕЛАРУСКАЙ ССР**

220602, г. Минск, ГСП, Ленинский пр., 70. Тел. 39-47-55
Р/с № 000120217 в Первомайском отд. Промстройбанка г. Минска

№__________

На №__________

06.01.1995

Вице-директору ОИЯИ
проф. Сисакяну А.Н.

Директору ЛЯП ОИЯИ,
руководителю работ по проекту
доктору ф.-м. наук Русаковi

Копия: начальнику НЭОМАП Л
проф. Будагову Ю.А.

Глубокоуважаемый Алексей Норайрович!
Глубокоуважаемый Николай Артемьевич!

Институт физики Академии наук Республики Беларусь заинтересован в участии совместно с *Объединенным Институтом Ядерных Исследований* в работах по проекту *ATLAS* и в проведении экспериментов на pp коллайдере *LHC (ЦЕРН, Женева)*.

Обращаемся к Вам с просьбой рассмотреть вопрос о включении *ИФ АНБ* в проблемно-тематический план *ОИЯИ* по теме *ATLAS* (тема № 02 — 2 — 1007 — 94/95) в состав ее исполнителей совместно с *Лабораторией Ядерных Проблем* (отдел **проф. Будагова Ю.А.**).

В случае Вашего согласия предлагаем заключить договор о сотрудничестве между нашими организациями, в котором будут конкретизированы содержание и этапы совместных работ.

Руководителем работ от *Институт физики Академии наук Республики Беларусь* по проекту *ATLAS* является старший научный сотрудник Лаборатории физики высоких энергий *Кульчицкий Юрий Александрович*.

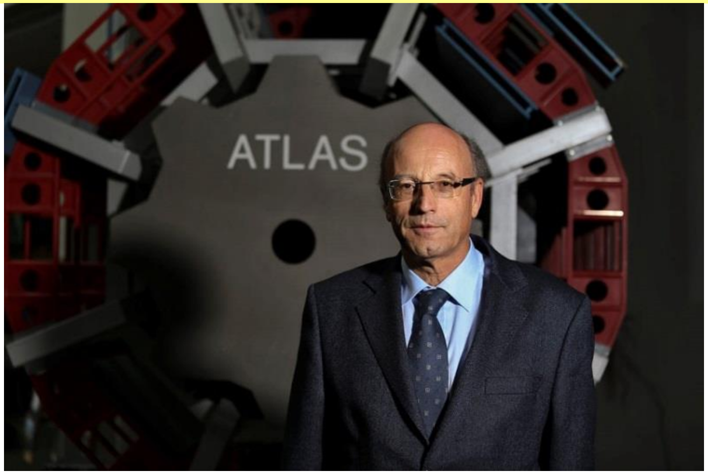
С уважением,

Директор ИФ АНБ,
академик АНБ Апанасевич П.А.

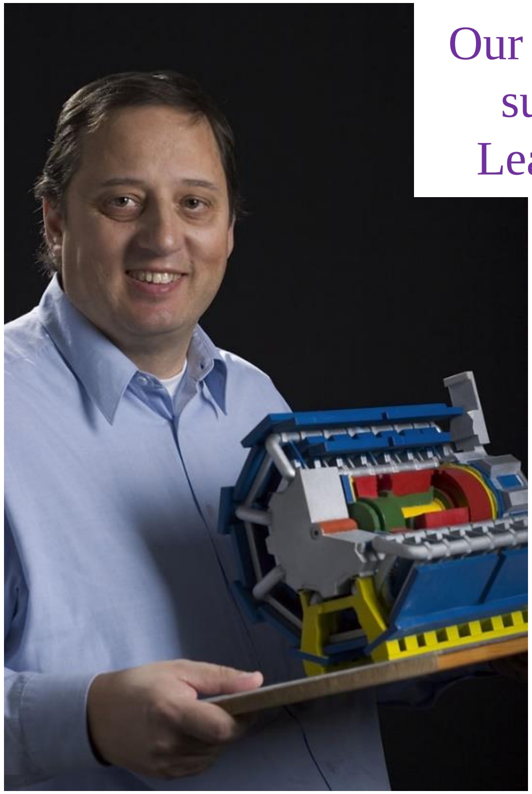
Согласен
Заведующий ЛЯВЭ (Будагов А.А.)
6.01.1995г.

Visit in 1995 of JINR delegation in Minsk for discussion of the TileCal Module-0 production. Persons from left to right: prof. N.M. Shumeiko *(Director, National Centre for Particle and High Energy Physics)*, Y.A. Kulchitsky *(leader scientist of IP NASB)*, cand. of phys.-math. sciences Yu.F. Lomakin *(head of scientific sector, LNP JINR)*, prof. J.A. Budagov *(head of Department LNP JINR)*,

COOPERATION WITH CERN ATLAS TEAM



Our participation in the ATLAS Collaboration was in close contact with the ATLAS Collaboration Spokespersons Prof. Peter Jenni and Prof. Fabiola Giannoti



Our participation in the ATLAS hadronic barrel scintillator-tile calorimeter subsystem was very fruitful in close cooperation with TileCal Project Leaders: Dr. Marcio Nessi, Dr. Ana Henriques and Dr. Oleg Solovianov

COOPERATION WITH JINR FOR TILE CALORIMETER

In period of 1993 – 2010 our team works in the close contact with JINR ATLAS Team under leadership of ***Prof. Nikolai Russakovich,*** the former member of the IP NANB

Science 2010 our team works in the close contact with JINR ATLAS Team under leadership of ***Prof. Vadim Bednyakov***

For Tile Calorimeter design development, modules production, calorimeter construction and performance study our team works in close contact with JINR TileCal team under the leadership of ***Prof. Julian Budagov and Prof. Jemal Khubua***

ATLAS EXPERIMENT SUPPORT FROM BELARUS

Chairmen of **the State Committee of Sciences and Technology of Belarus (SCSTB)** supports the participation of the Belarus institutes in the ATLAS Collaboration: N. Rumak, V. Gaisenok, A.Lesnikovich, I. Voitov, A. Shumilin and Deputy Chairman of SCSTB V.Nedilko.

Vise-Chairman of NASB Academician **S.Kilin** supports the participation of the Belarus institutes in the ATLAS at LHC.

Visit of the Deputy Chairman of SCSTB V.Nedilko to the ATLAS at LHC in period of Tile Calorimeter construction in the cavern in 2006. Y. Kulchitsky discusses the subject.

The meeting in the Directorate of IP NASB during the visit of ATLAS Collaboration Spokesman Prof. P. Jenny to Minsk in 2006

BELARUS ACADEMY OF SCIENCES ABOUT LHC AT CERN

As Vice-Chairman of the NASB Presidium Sergei Kilin said before the *meeting NANS Belarus – JINR at 19.11.2015*: "*Belarusian researchers would be discussing* ***the possibility of participation in new projects at the Large Hadron Collider***. Belarusian science works in a range of areas: ***high energy physics***, solid state physics, including elements of microelectronics and microtechnology.

Ander the leadership of **Vice-Chairman of the NASB Presidium Sergei Kilin** the ***"Integration of Belarusian Scientists into Research Programs of Leading International Nuclear Physics Centers"*** was held at 26-28/04.2017 in NANB. The final Declaration adopted by the Symposium participants states that Belarusian scientists are interested in involving our industrial capabilities in ***the development and creation of large-scale experimental physical facilities, as well as in processing data being obtained with their use.*** One of the proposals received during the summing up of the Symposium was to create a ***Coordinating Committee*** in order to better organize scientific activities in the field of nuclear physics. *NASB would like to install* ***closer cooperation with CERN***, ***JINR,*** … and we suppose that ***Coordination Committee*** will play here crucially important role.

A TOROIDAL LHC APPARATUS (ATLAS)

Muon spectrometer
(*μ Trigger/tracking and Toroid Magnets*)
Precision Tracking:
- **MDT** (Monitored Drift Tubes)
- **CSC** (Cathode Strip Chambers) |η| >2.4

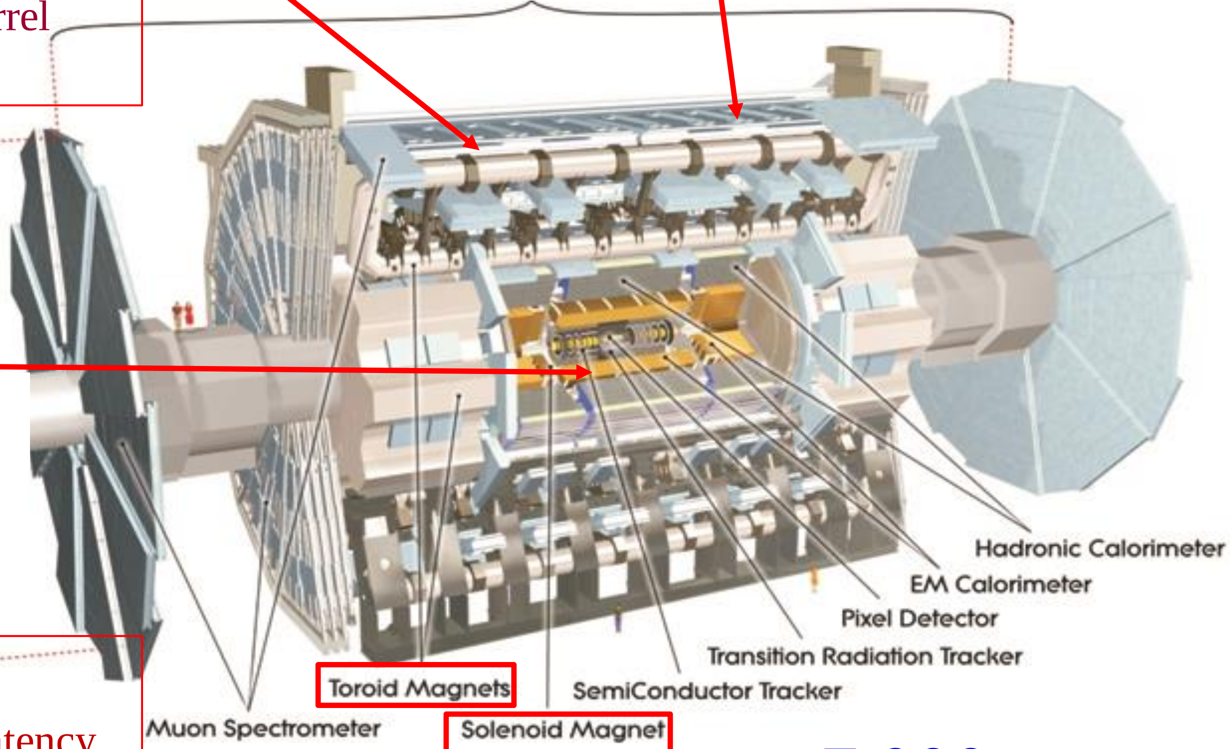
Trigger:
- **RPC** (Resistive Plate Chamber) barrel
- **TGC** (Thin Gas Chamber) endcap

Calorimeter: EM and Hadronic energy
- **Liquid Ar** (LAr) EM barrel and End-cap & Hadronic End-cap
- **Tile** calorimeter (Fe-scintillator) Hadronic barrel

46 m

Inner Detector (ID)
Tracking; 2T Solenoid Magnet
- **Silicon Pixels** 50 x 400 μm^2
- **Silicon Strips** (SCT) 40 μm rad stereo strips
- **Transition Radiation Tracker** (**TRT**) up to 36 points/track

25 m

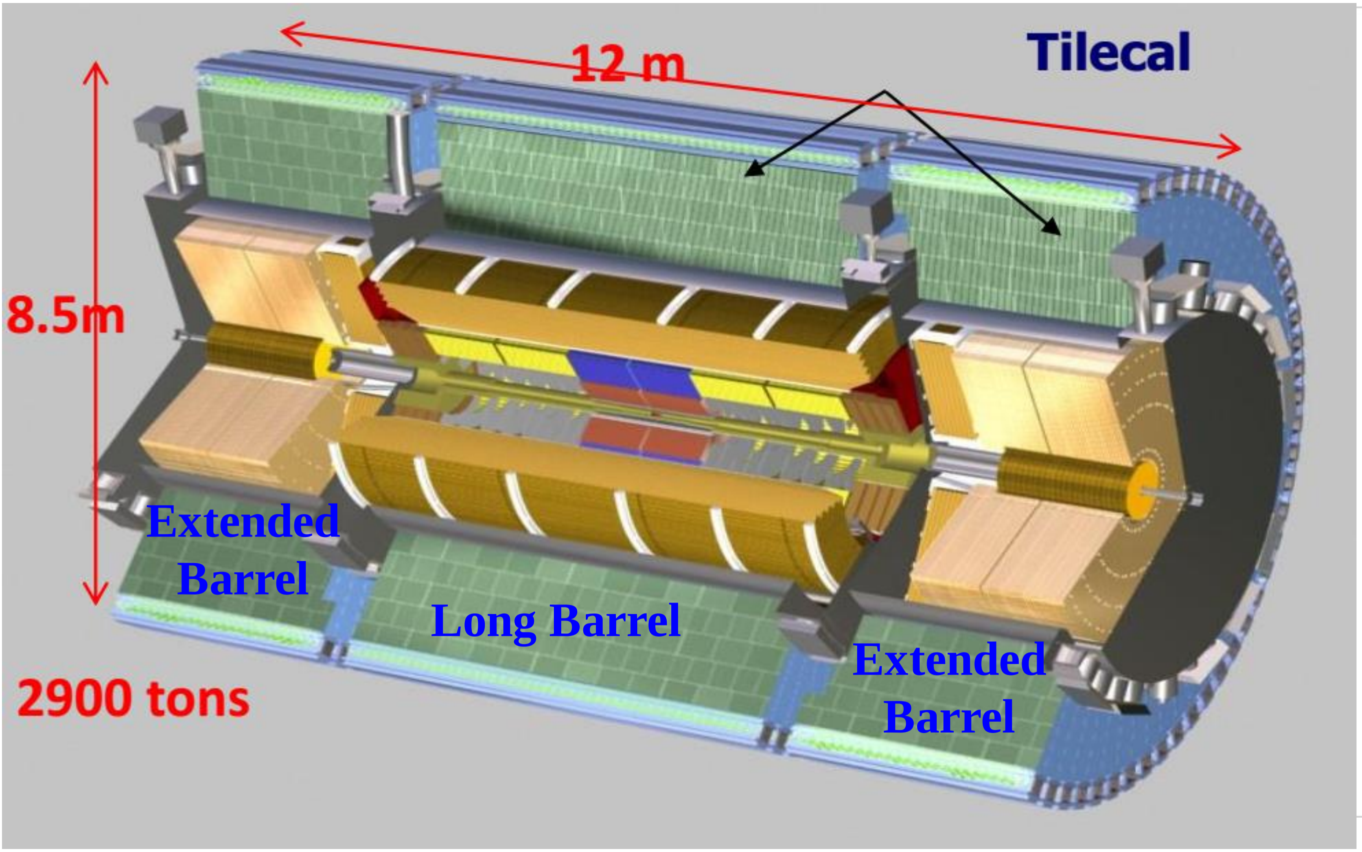


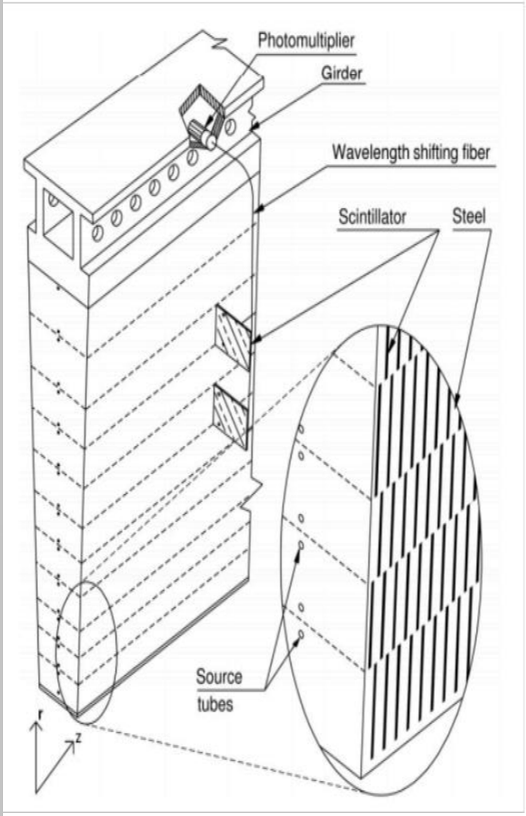
Two Level Trigger system
- **L1 – hardware**: **100 kHz, 2.5 μs** latency
- **HLT – farm**: merge the former **L2** and **Event Filter 1.5 kHz, 0.2 s** latency

7 000 tons

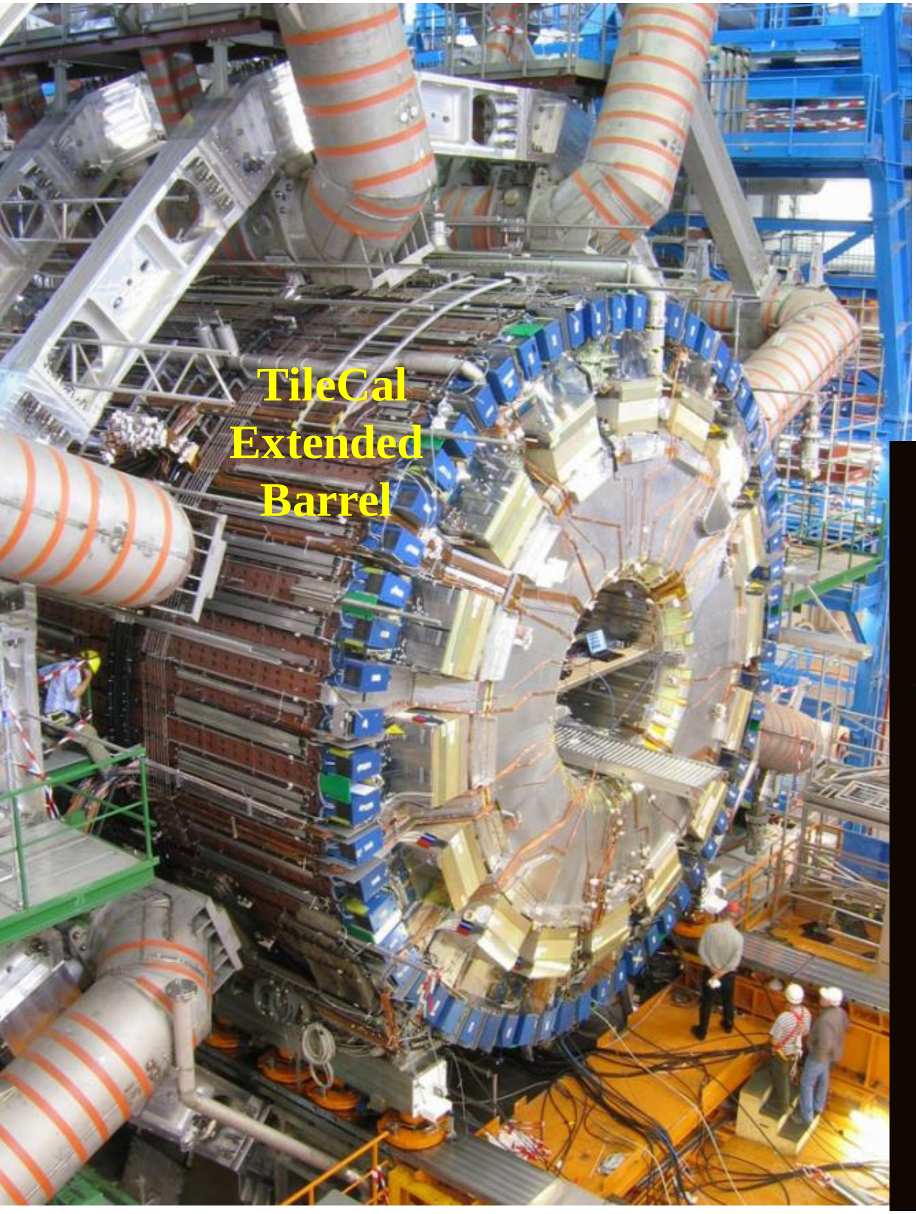
ATLAS IRON-SCINTILLATOR HADRON TILE CALORIMETER

Barrel and Extended barrel Tile iron-scintillation hadron calorimeter is the most central region of the ATLAS detector. It uses **iron plates as absorber** and **plastic scintillating tiles** as the **active material**. Scintillation light produced in the tiles is transmitted by **wavelength shifting fibers** to **photomultiplier tubes** (PMTs). The resulting electronic signals from the approximately **10 000 PMTs** are measured and digitized every **25 ns** before being transferred to **off-detector data-acquisition systems**.

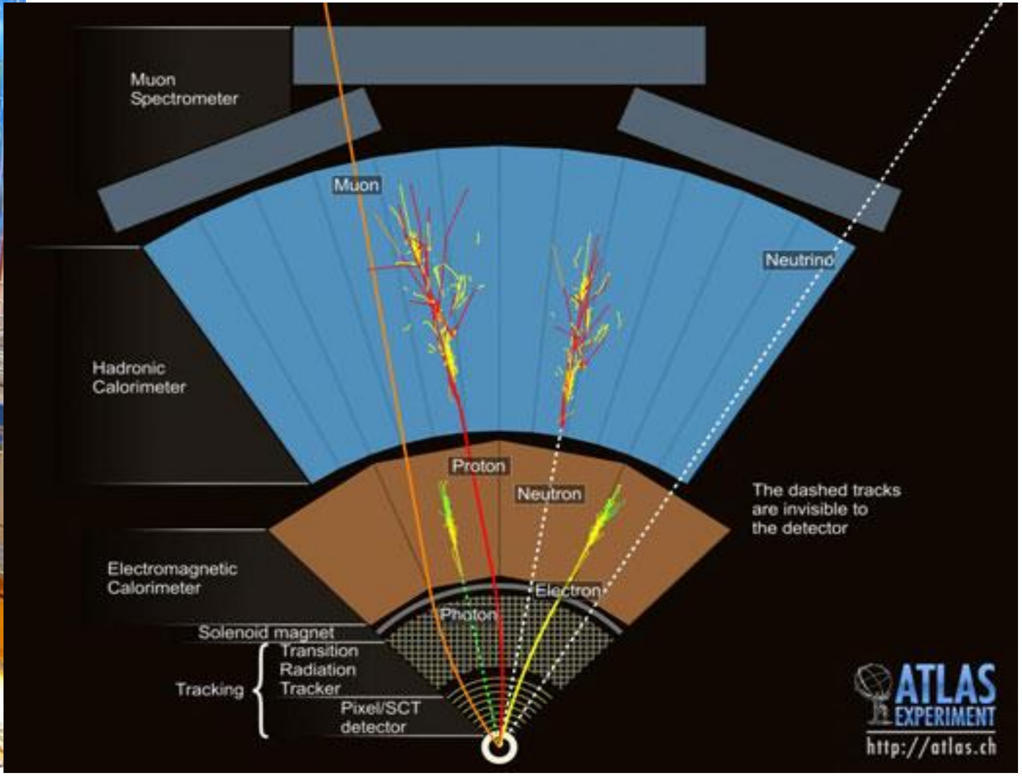




ATLAS CALORIMETERS



- **Very stable** performance
- **Improved stability** of new Tile power supplies
- Good operation efficiency: 99.4% LAr and **100% Tile**
- LAr using 4 sample readout to achieve 100 kHz

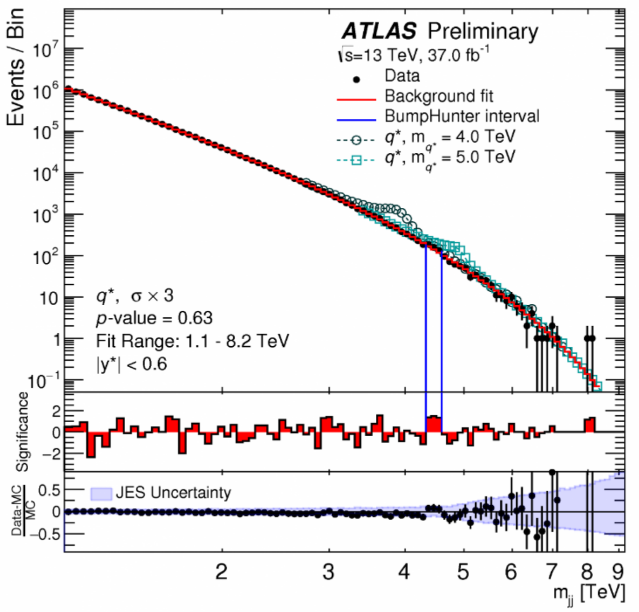


THE HIGHEST-MASS DIJET EVENT AT 13 TEV

These jets can provide a window into new physics phenomena, and allow ATLAS physicists to search for mediators between Standard Model and dark matter particles or other hypothetical objects such as non-elementary quarks, heavy “partners” of known Standard Model particles or miniature quantum black-holes

ATLAS EXPERIMENT

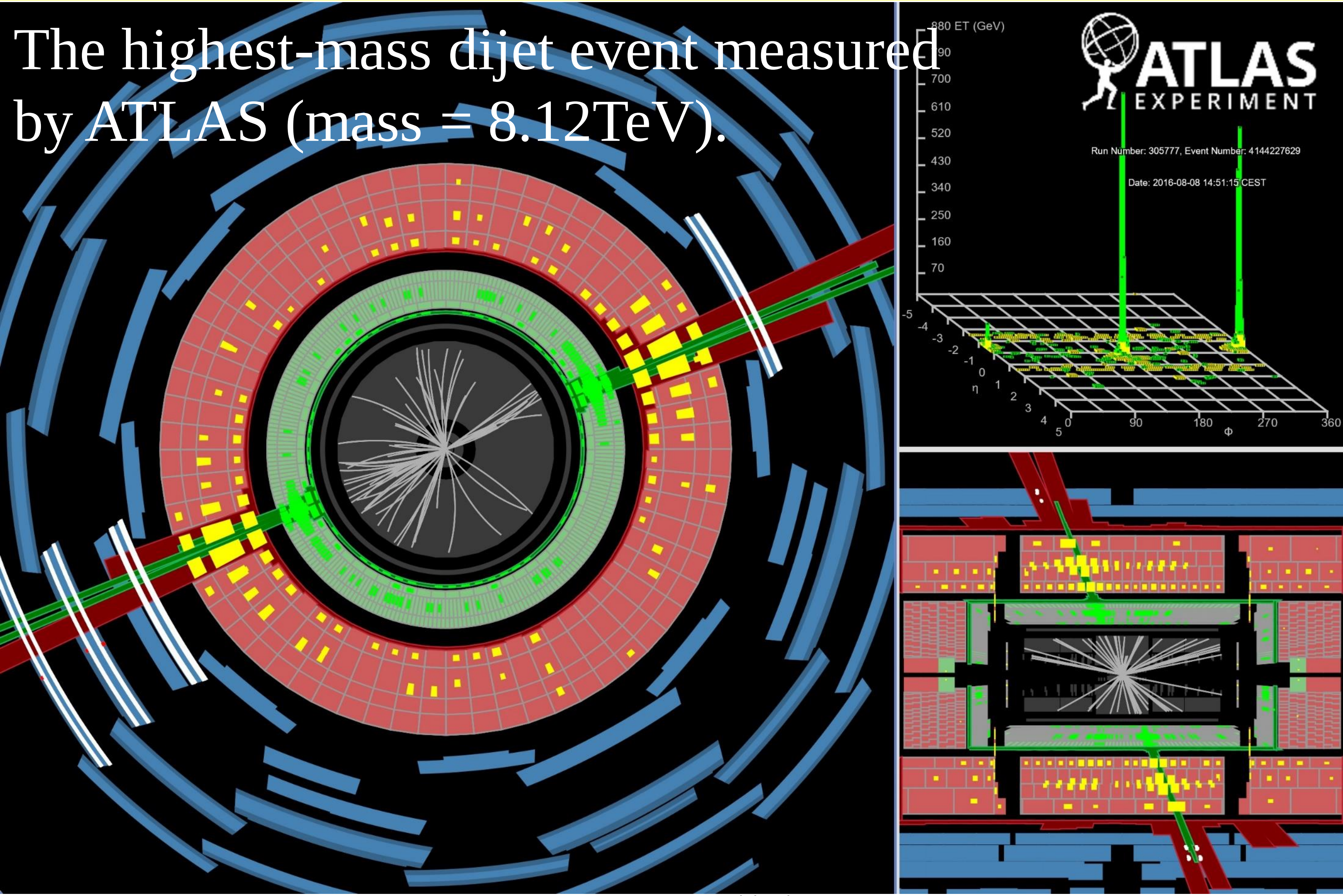
Run: 305777
Event: 4144227629
2016-08-08 08:51:15 CEST



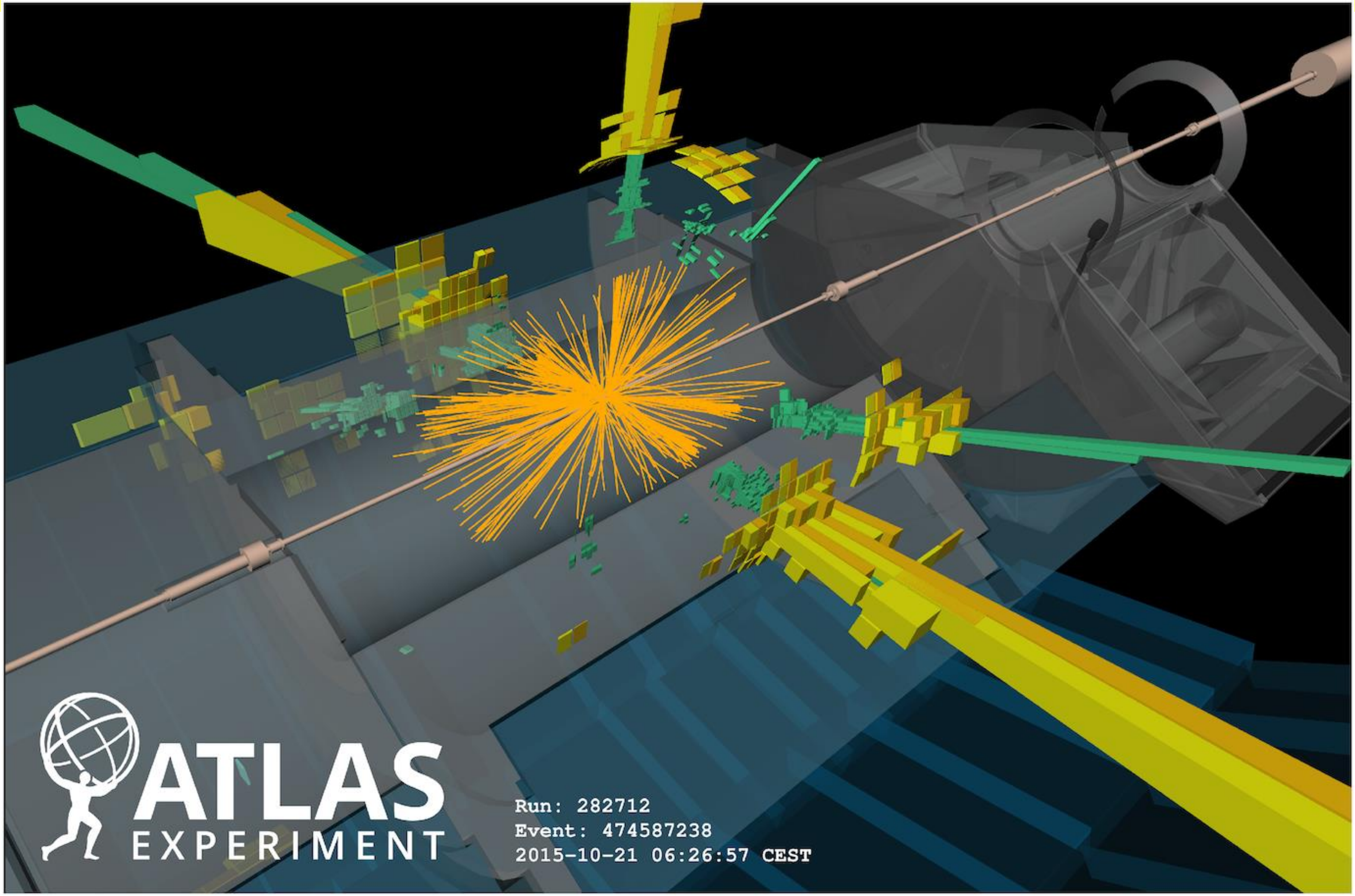
Dijet resonance search results.

THE HIGHEST-MASS DIJET EVENT AT 13 TEV

The highest-mass dijet event measured by ATLAS (mass = 8.12TeV).



HIGH P_T MULTI-JET EVENT AT ATLAS AT 13 TEV

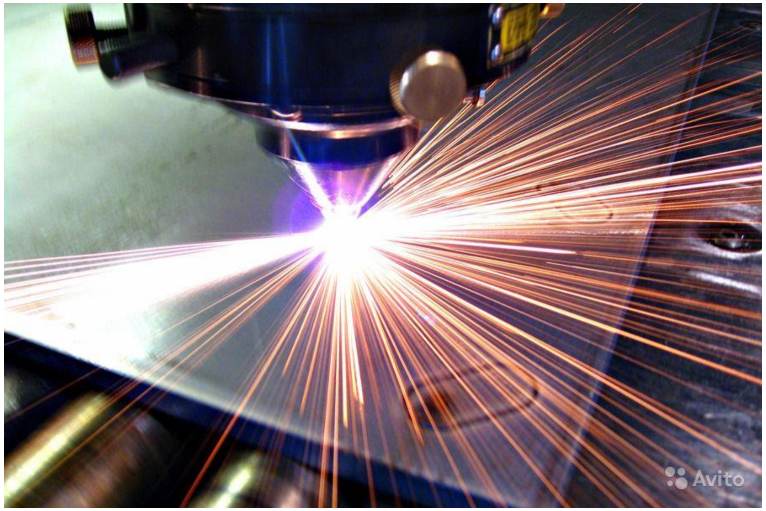


ATLAS HADRONIC TILE CALORIMETER MODULE-ZERO

In cooperation of IP NASB and JINR with Physical Technical Institute National Academy of Sciences of Belarus:

Study of the possibility to use a laser cutting system for production of **master** and **spacer** plates for ATLAS Tile Calorimeter Module-zero.

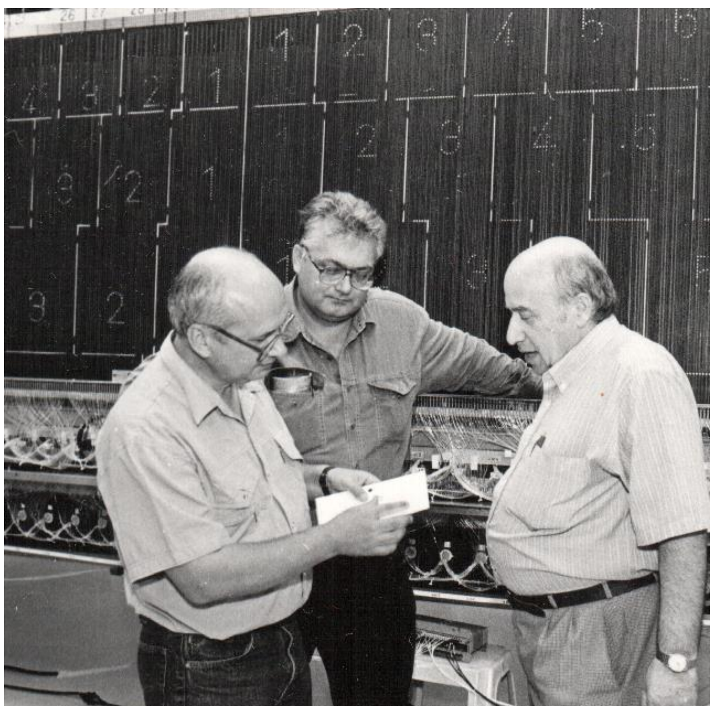
1.5 m



The team of PTI NASB was under direction of Prof. Alexander Alifanov and Dr. Valery Golubev

ATLAS HADRONIC TILE CALORIMETER MODULES

For the ATLAS hadronic barrel iron-scintillator Tile Calorimeter (RD34): we took active part in the design, modules mass production, construction, installation in the cavern, study of the ATLAS combined barrel Calorimeter and Tile Calorimeter performance in the test beam on SPS (CERN) in pion, proton, electron and muon beams with energy 3–350 GeV



Main publications:

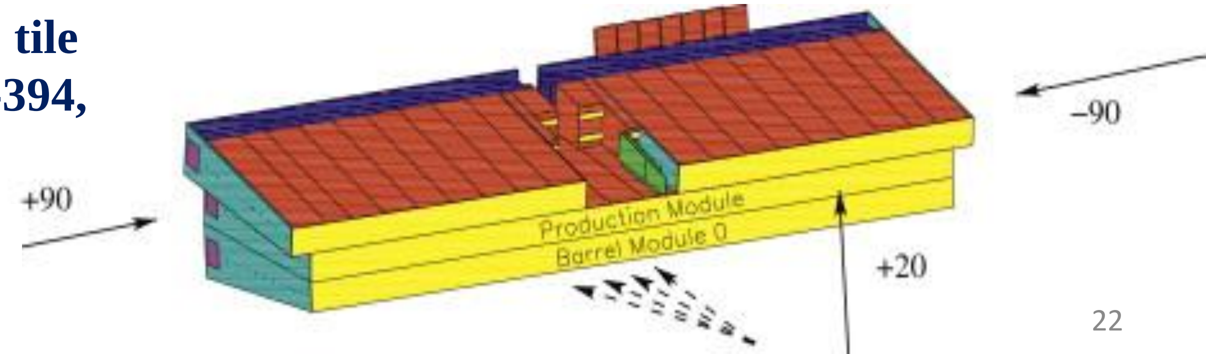
1. **J. Abdallah *et al*, JINST 8 (2013) T11001**
2. **J. Abdallah *et al*, JINST 8 (2013) P01005, ATL-TILECAL-PUB-2008-005, CERN, Geneva**
3. **J. Abdallah *et al*, ATL-TILECAL-PUB-2008-001 (2008)**
4. **V.Batusov, Yu.Budagov, Y.Kulchitsky *et al*, Phys.Part.Nucl. 37 (2006) 785-806**
5. **J. Abdallah *et al*, Trans. Nucl. Sci. 53 (2006) 1275-1281**

ATLAS HADRONIC TILE CALORIMETER TEST BEAM

Study of Tile Calorimeter performance using barrel module-zero, production barrel module and two extended barrel modules on SPS (CERN) pions, protons, electrons and muons beams with energy from 10 to 350 GeV. The Tail calorimeter energy resolution, and linearity were investigated. The electromagnetic calibration of 11% of TileCal modules has been made.

Participation of physicists from IP NASB (Y.Kulchitsky, M.Kuzmin) in the performance studies of Tile Calorimeter production modules

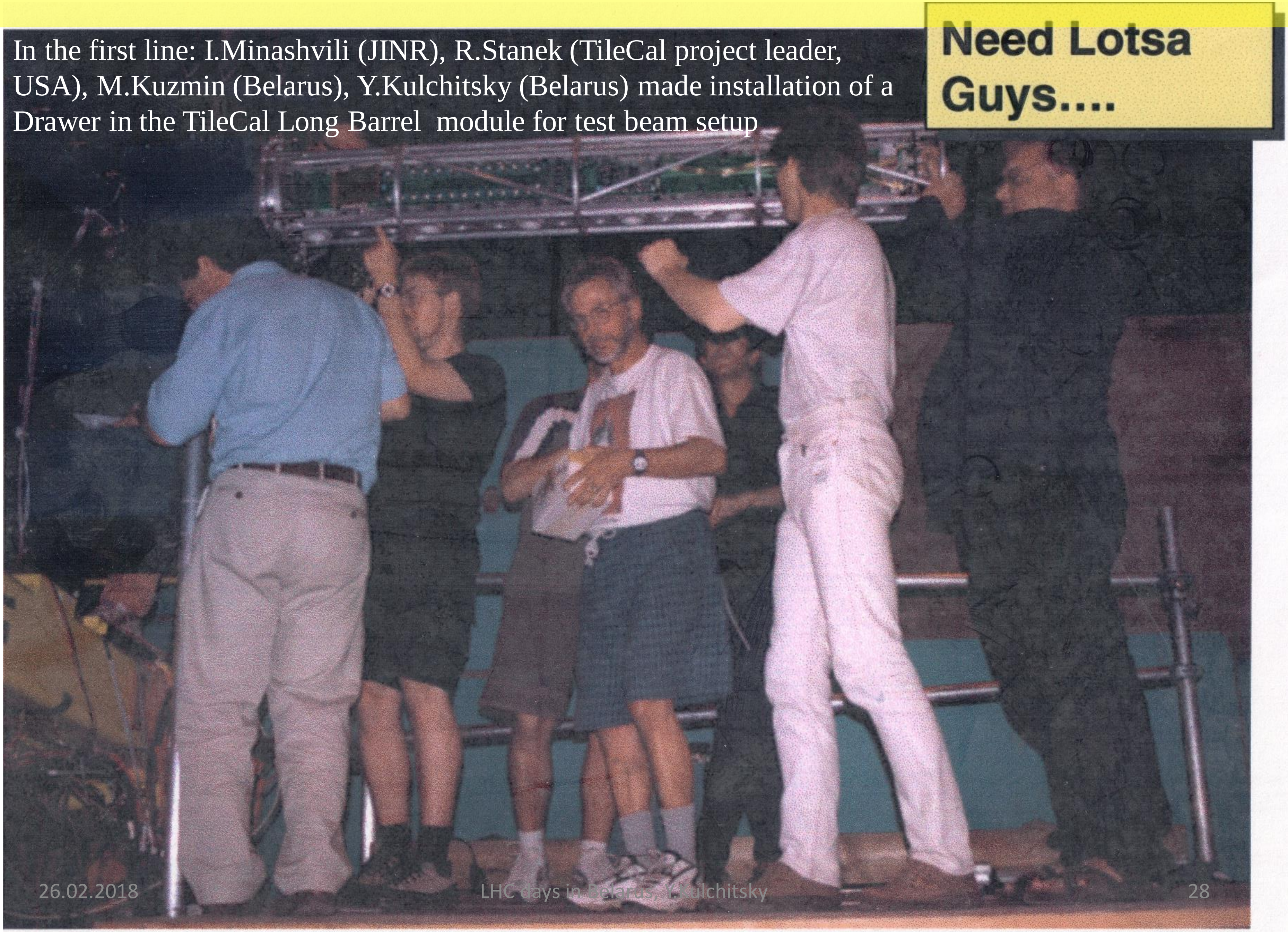
P.Adragna et al, Test beam studies of production modules of the ATLAS tile calorimeter, NIMA606 (2009) 362-394, ATL-TILECAL-PUB-2009-002



Scratch of the test beam set-up for TileCal modules in 1996 – 2004

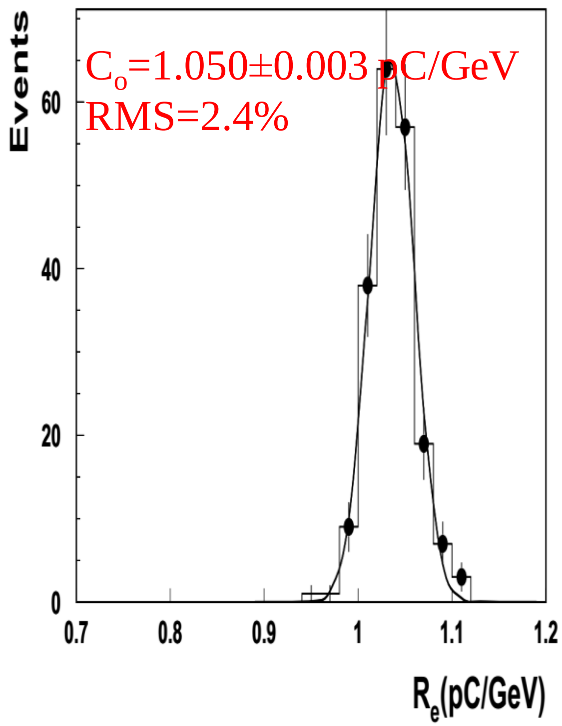
PREPARATION TileCal MODULES TO TEST BEAM

In the first line: I.Minashvili (JINR), R.Stanek (TileCal project leader, USA), M.Kuzmin (Belarus), Y.Kulchitsky (Belarus) made installation of a Drawer in the TileCal Long Barrel module for test beam setup



ELECTROMAGNETIC CALIBRATION OF TILECAL

With the aim of establishing of electromagnetic scale and understanding of performance of the Tile calorimeter to electrons 11% of modules have been exposed in electron beams with energies from 10 to 180 GeV by three possible ways: cell-scan at $\theta = 20^o$ at the centers of the front face cells, η-scan and tile-row scan at $\theta = 90^o$ for the module side cells.



The energy resolution for electron at 20^o is

$$\frac{\sigma}{E} = \frac{28\ \%}{\sqrt{E}} \oplus 1.2\%$$

The electromagnetic calibration constants for electrons at $\theta = 20^o$

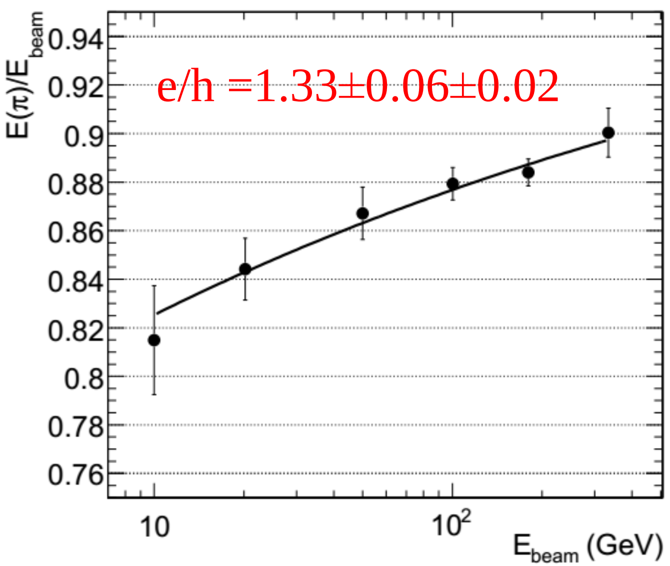
The obtained calibration constants have been included in the TileCal calibration database

D.Pantea (Romania), Y.Kulchitsky (Belarus), J.Budagov (JINR), and S.Tokar (Slovakia) studied TileCal performances in the test beam control room on SPS CERN

Y.Kulchitsky *et al*. Electromagnetic cell level calibration for ATLAS TileCal modules, ATL-TILECAL-PUB-2007-001

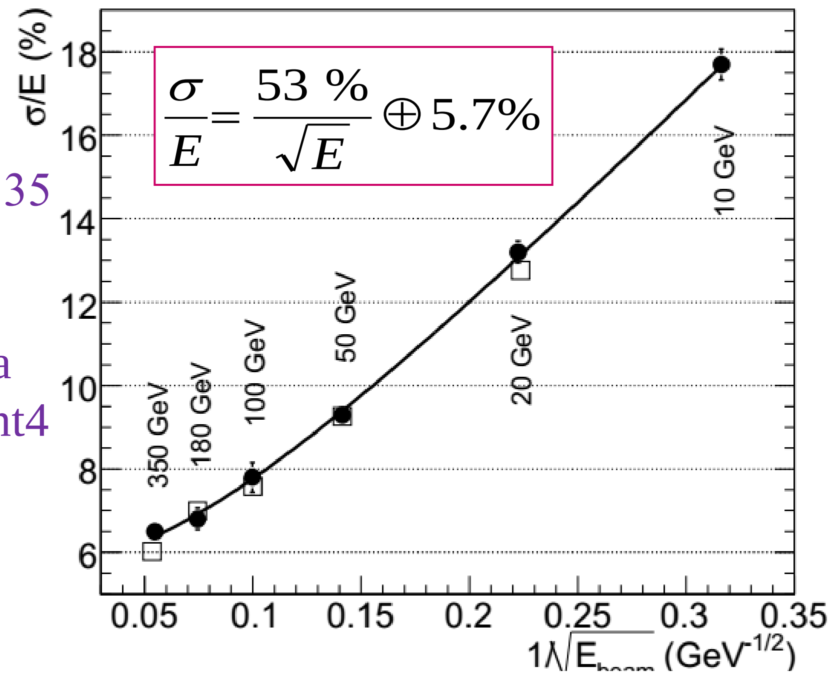
TEST BEAM STUDIES OF THE TILE CALORIMETER

The test beam studies of 11% of the production ATLAS Tile Calorimeter modules has been performed. The studies used muon, electron and hadron beams ranging in energy from 3 to 350 GeV. Over 200 calorimeter cells **the variation of the response was 2.4%.** The energy linearity and resolution with energy were measured. **The mean response to hadrons of fixed energy had an RMS variation of 1.4% for the modules.** The response to hadrons normalized to incident beam energy showed an **8% increase between 10 and 350 GeV**, consistent with expectations for a non-compensating calorimeter.



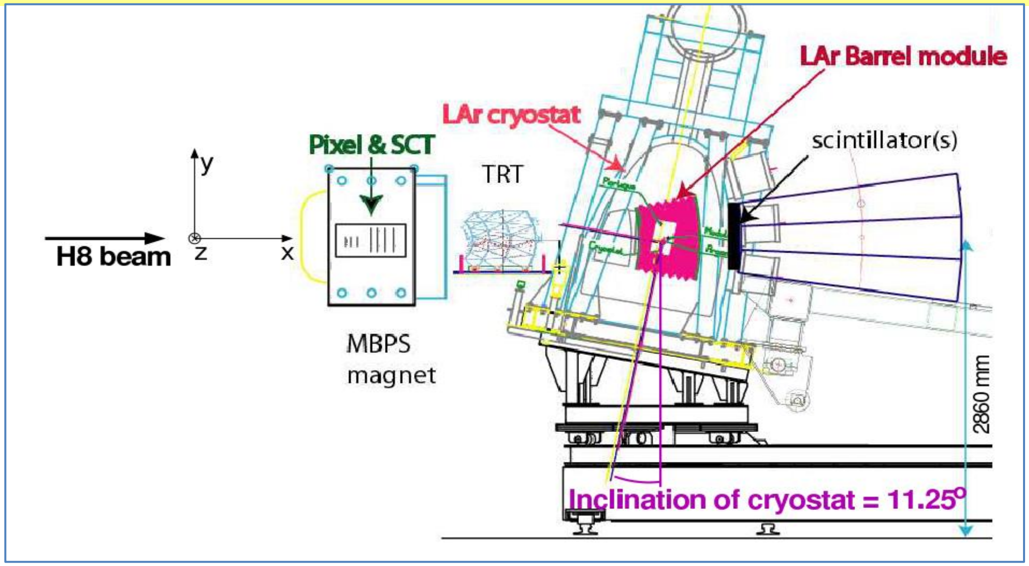
Normalized pion response vs. energy of incident pions at η=0.35. The non-compensation of tile calorimeter is e/h =1.33±0.06±0.02.

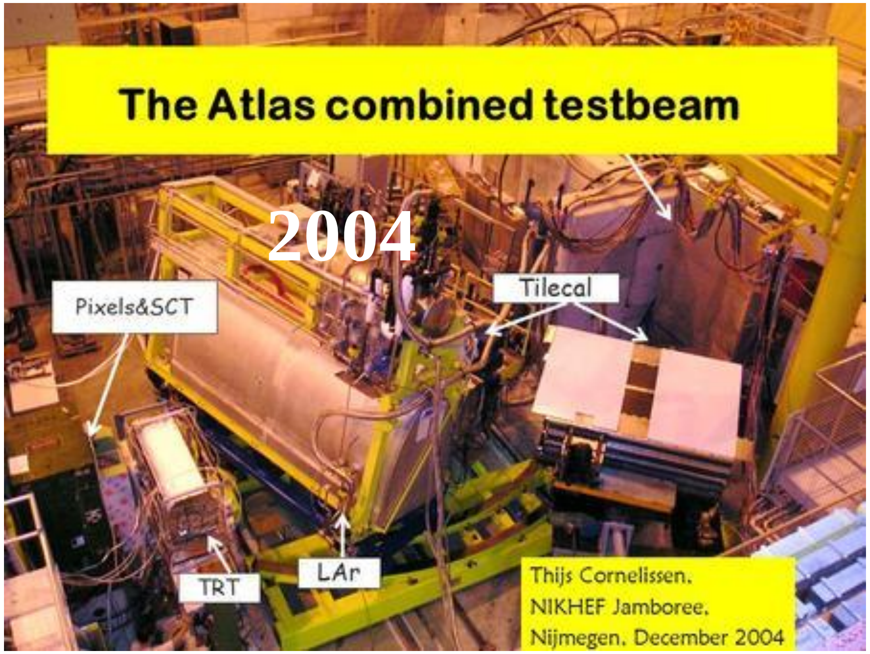
The fractional energy resolution for pions at η = 0.35 as a function of beam energy. Experimental data (circles) and Geant4 simulations (squares) are in good agreement.



P. Adragna et al, Test beam Studies of Production Modules of the ATLAS Tile Calorimeter, NIM A606 (2009) 362; TILECAL-PUB-2009-002

ATLAS COMBINED (LAR & TILE) CALORIMETER TEST BEAMS





Schematic of the test beam setup 2004

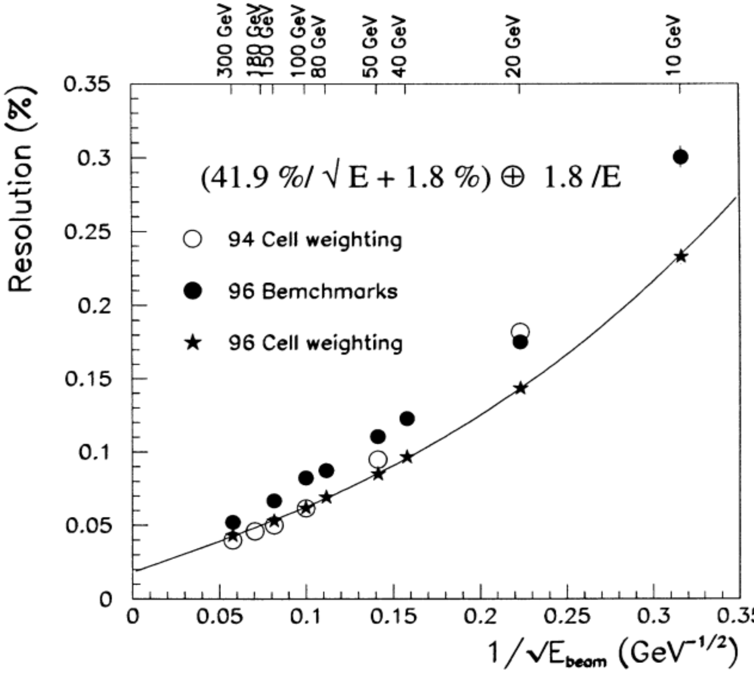
1. Response and Shower Topology of 2 to 180 GeV Pions Measured with the ATLAS Barrel Calorimeter at the CERN Test–beam and Comparison to Monte Carlo Simulations, **ATL-CAL-PUB-2010-001**
2. Results from a new combined test of an electromagnetic liquid argon calorimeter with a hadronic scintillating-tile calorimeter, **NIM A449 (2000) 461-477**
3. Results from a combined test of an electro-magnetic liquid argon calorimeter with a hadronic scintillating tile calorimeter, **NIM A387 (1997) 333-351**
4. Study of the response of the ATLAS central calorimeter to pions of energies from 3 to 9 GeV, **ATL-COM-GEN-2009-001**

ATLAS COMBINED CALORIMETER TEST BEAMS

A combined tests of an electromagnetic liquid argon accordion calorimeter and a hadronic scintillating-tile calorimeter was carried out at the CERN SPS. These devices are prototypes of the barrel calorimeter of the future ATLAS experiment at the LHC. The energy resolution of pions in the energy range from 10 to 300 GeV at an incident angle of about 12^o is well described by the expression where E is in GeV. Shower profiles, shower leakage and the angular resolution of hadronic showers were also studied.

$$\frac{\sigma}{E} = \left[\frac{41.9\ \%}{\sqrt{E}} + 1.8\%\right] \oplus \frac{1.8\%}{E}$$

M.Kuzmin, Y.Kulchitsky (Academy, Belarus) and S.Malyukov (JINR) in the test beam control room



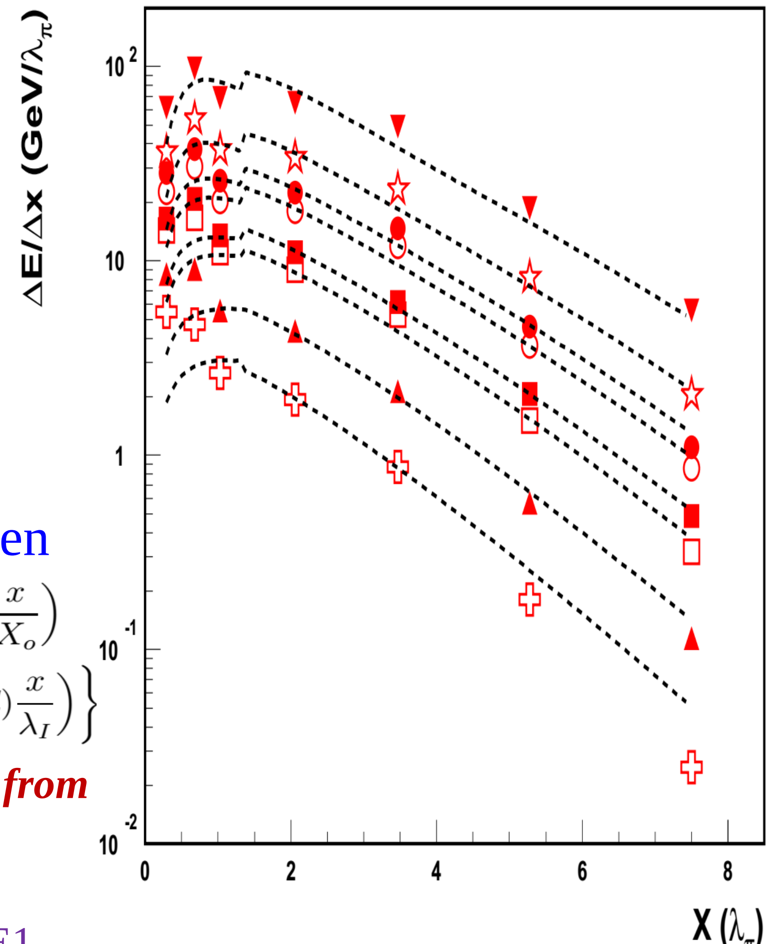
Pion fractional energy resolution obtained with the cell weighting technique. The results are compared with those obtained by applying the benchmark method

HADRONIC SHOWER DEVELOPMENT

The lateral and longitudinal profiles of hadronic showers detected by a prototype of the ATLAS Tile Calorimeter and Combined calorimeter have been investigated. Using a fine grained pion beam scan at 100 GeV, a detailed picture of transverse shower behavior is obtained. The underlying radial energy densities for four depth segments and for the entire calorimeter have been reconstructed. A three-dimensional hadronic shower parametrization has been developed

$$\frac{dE(x)}{dx} = N\left\{\frac{wX_o}{a}\left(\frac{x}{X_o}\right)^a e^{-b\frac{x}{X_o}}{}_1F_1\left(1,a+1,\left(b-\frac{X_o}{\lambda_I}\right)\frac{x}{X_o}\right) + \frac{(1-w)\lambda_I}{a}\left(\frac{x}{\lambda_I}\right)^a e^{-d\frac{x}{\lambda_I}}{}_1F_1\left(1,a+1,-(1-d)\frac{x}{\lambda_I}\right)\right\}$$

The formula for description of hadronic shower development from the beginning of a calorimeter



Longitudinal profiles of the hadronic showers for ATLAS combined calorimeter with pion energy from 20 GeV to 300 GeV

1. Y.A.Kulchitsky, M.V.Kuzmin, V.B.Vinogradov, Longitudinal hadronic shower development in a combined calorimeter, JINR-E1-99-326, hep-ex/9912028

2. ATLAS TileCal Collaboration, Hadronic shower development in iron scintillator tile calorimetry, NIM A443 (2000) 51-70

3. Y.A.Kulchitsky, V.B.Vinogradov, | Analytical representation of the longitudinal hadronic shower development, NIM A413 (1998) 484-486, JINR-E1-98-47, hep-ex/9903019

E/H METHOD OF COMBINED CALORIMETER ENERGY RECONSTRUCTION

The non-parametrical method (e/h method) of a combined calorimeter energy reconstruction utilizes only the known e/h ratios and the electron calibration constants and does not require the determination of any parameters by a minimization technique. Thus, this technique lends itself to an easy use in a first level trigger. The reconstructed mean values of the hadron energies are within ±1% of the true values and the fractional energy resolution is **[(58 ± 3)%/√E + (2.5 ± 0.3)%] ⊕ (1.7 ± 0.2)/E.**

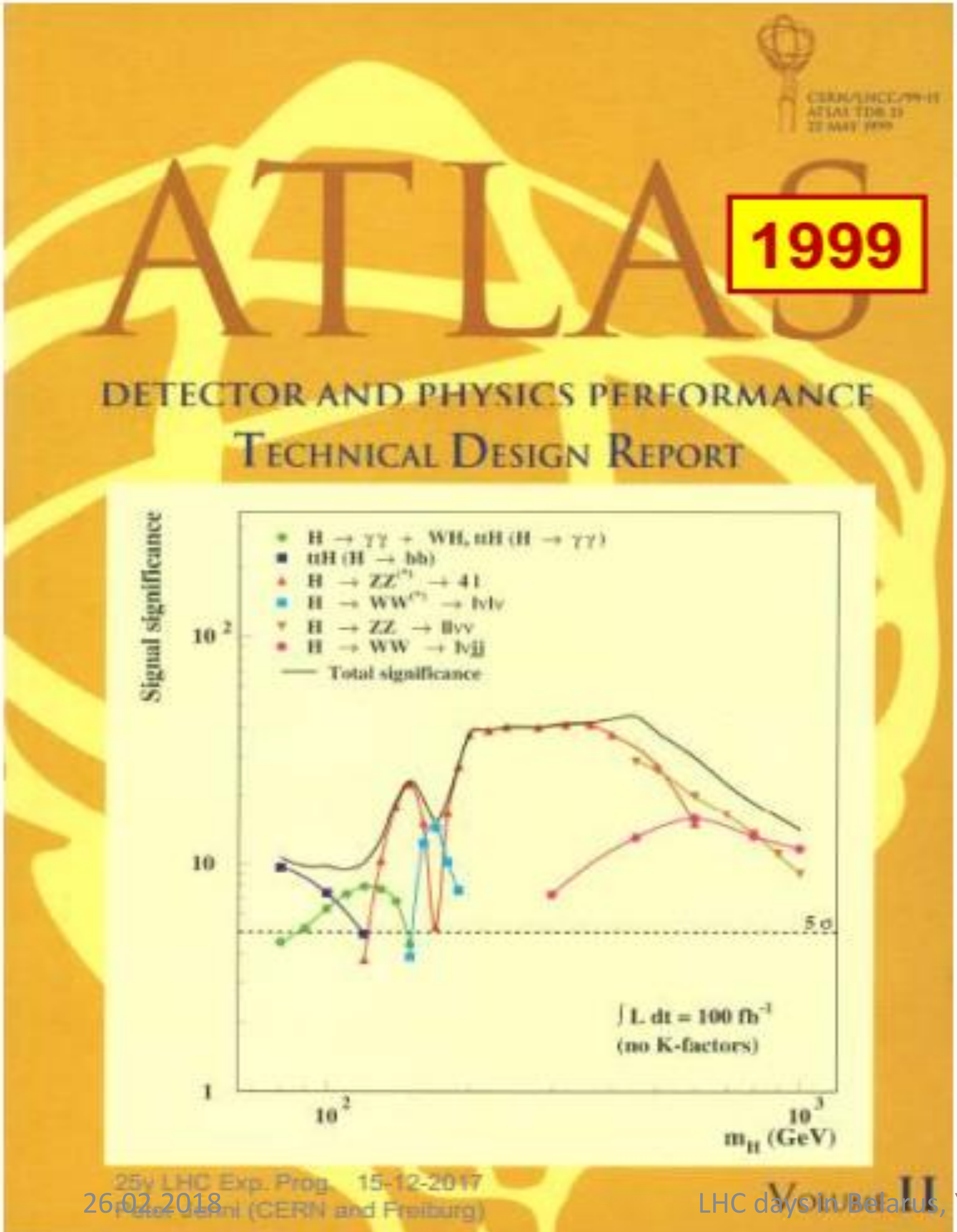
$$E = E_{LAr} + E_{dm} + E_{Tile} = \frac{1}{e_{LAr}} \left(\frac{e}{\pi}\right)_{LAr} R_{LAr} + E_{dm} + \frac{1}{e_{Tile}} \left(\frac{e}{\pi}\right)_{Tile} R_{Tile}$$

The value of the e/h ratio obtained for a thin electromagnetic compartment (Lar) of the ATLAS combined calorimeter is 1.74±0.04.

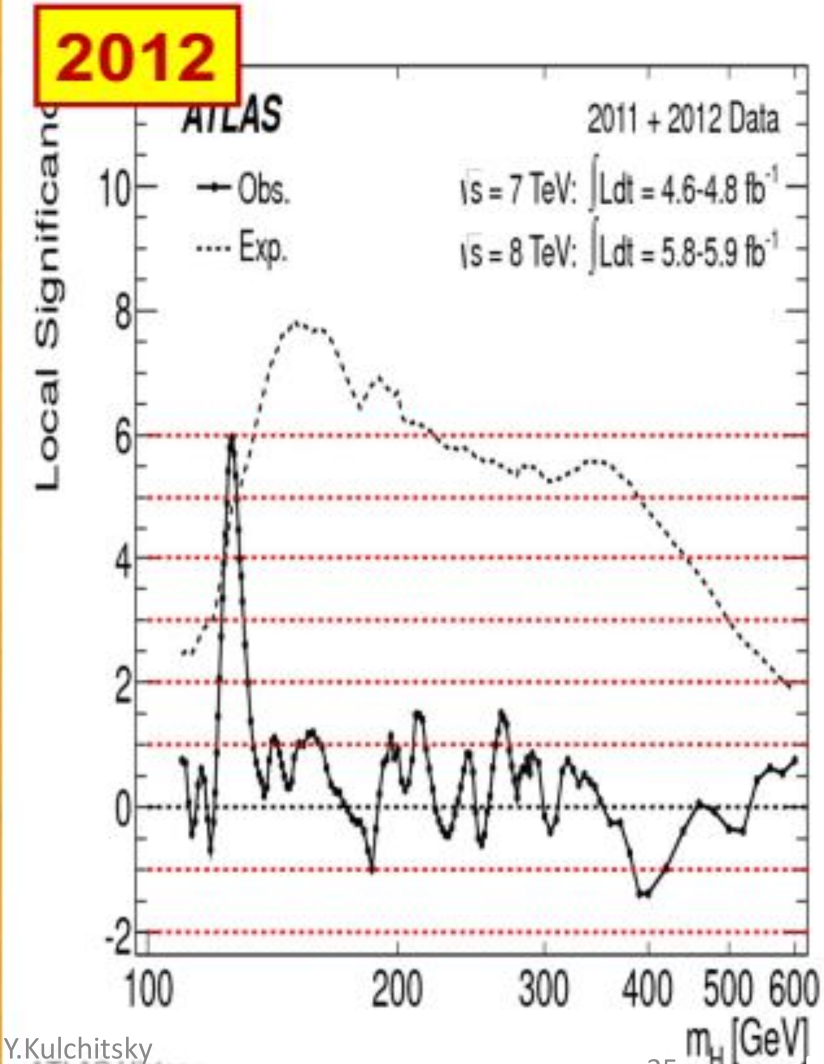
$$\left(\frac{e}{\pi}\right)_{LAr} = \frac{E_{beam} - E_{dm} - E_{Tile}}{R_{LAr}/e_{LAr}}$$

1. ATLAS Collaboration, Hadron energy reconstruction for the ATLAS calorimetry in the framework of the non-parametrical method, NIM A480 (2002) 508-523, hep-ex/0104002
2. Y.A.Kulchitsky, M.V. Kuzmin, J.A.Budagov, V.B.Vinogradov, M. Nessi, Hadron energy reconstruction for the ATLAS barrel prototype combined calorimeter in the framework of the non-parametrical method, JINR-E1-2000-73, hep-ex/0004009

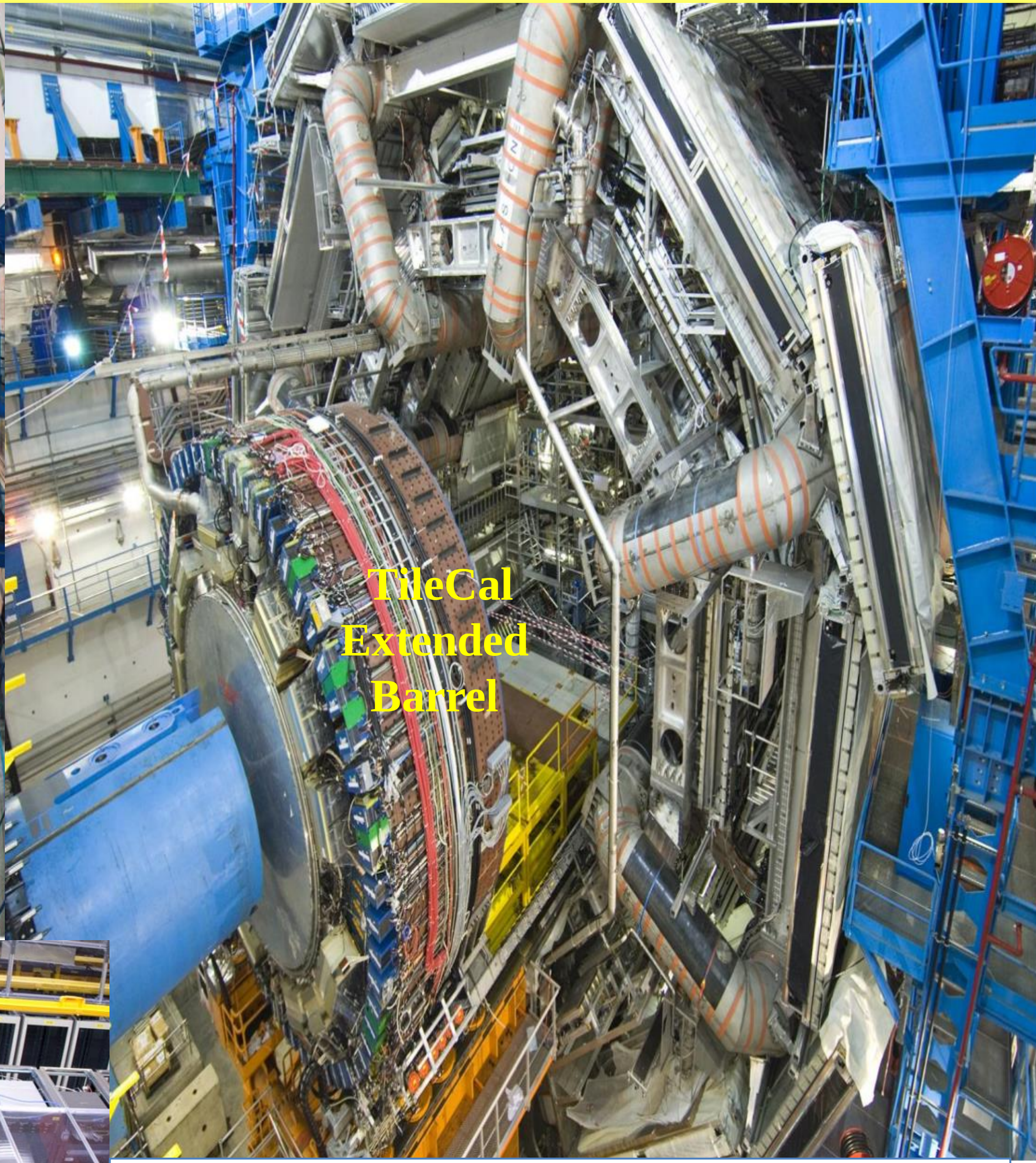
ATLAS DETECTOR AND PHYSICAL PERFORMANCE TDR



A dream becoming true much faster than anticipated long ago



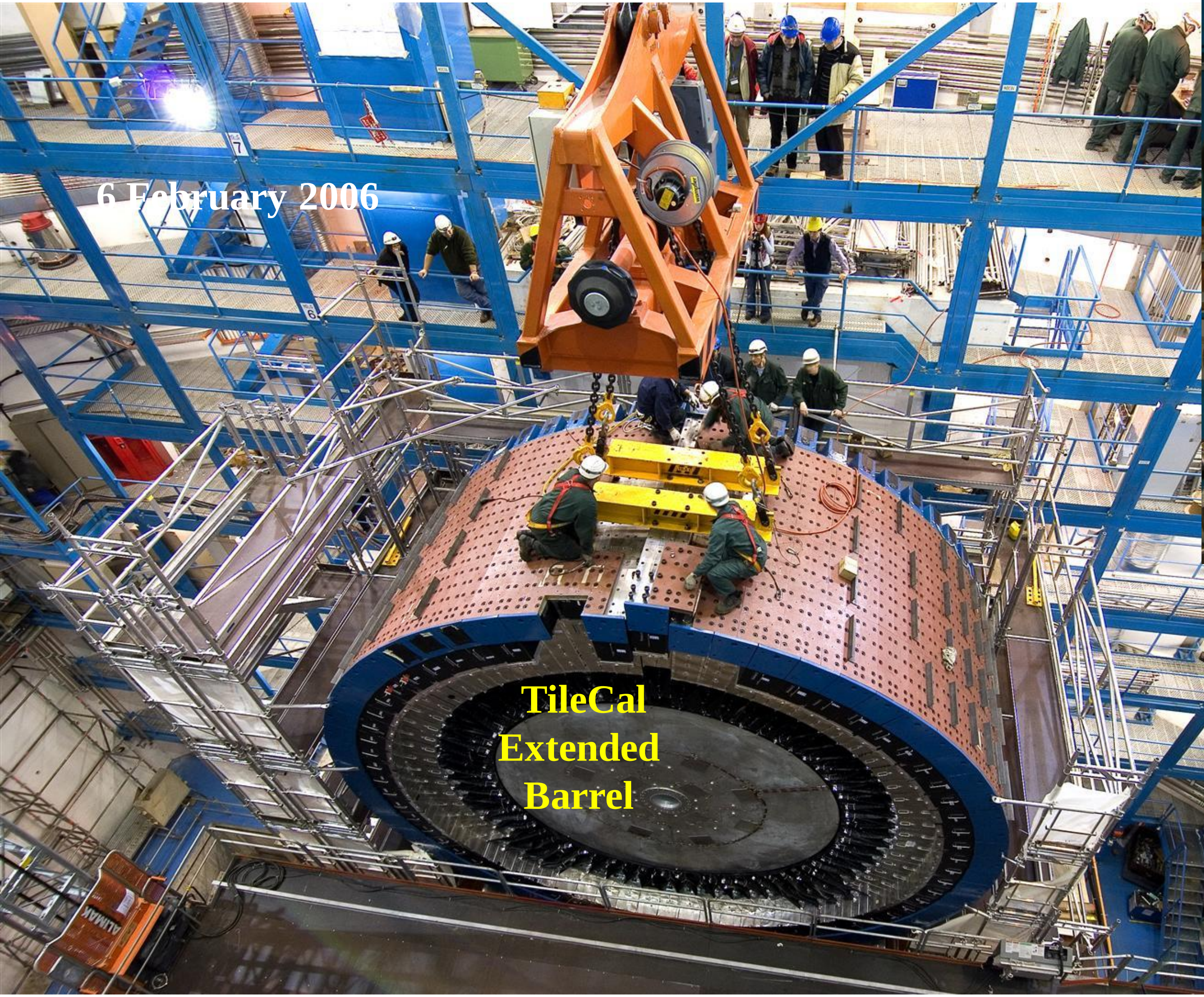
ATLAS 2004 – 2007



ATLAS CAVERN FEBRUARY 2007

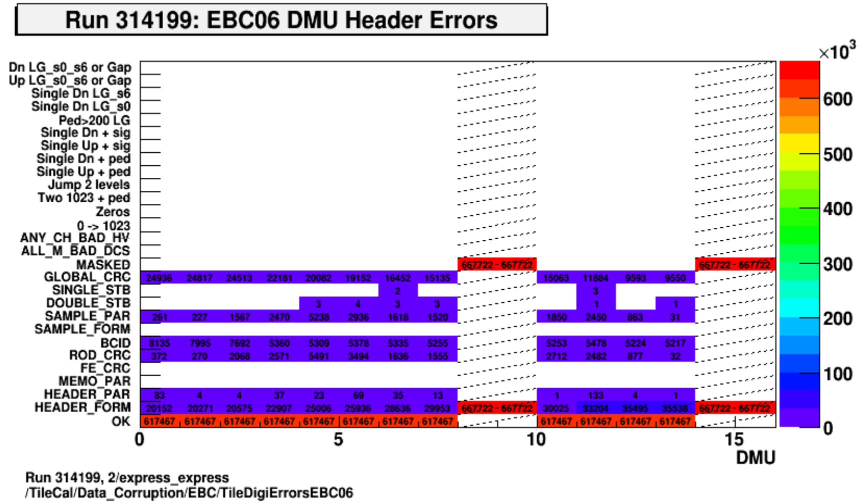
TILE CALORIMETER INSTALLATION

TileCal Extended Barrel installation in the ATLAS cavern at February 2006

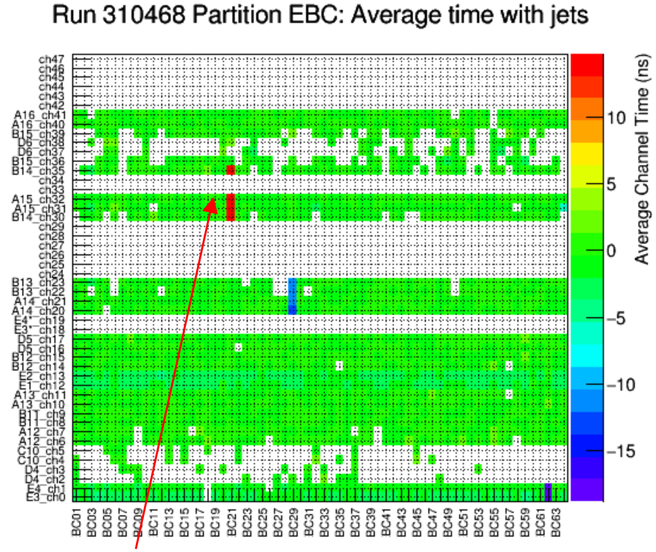


EXPERIMENTAL DATA PREPARATIONS

- Participation in the **ATLAS Control room shifts** in period of Physics Runs for collecting experimental data with investigation of calorimeters Data Quality and TileCal calibrations
- Work as **TileCal Data Quality Leader** or **Validator** on shifts for analysis data quality of Tile Calorimeter information

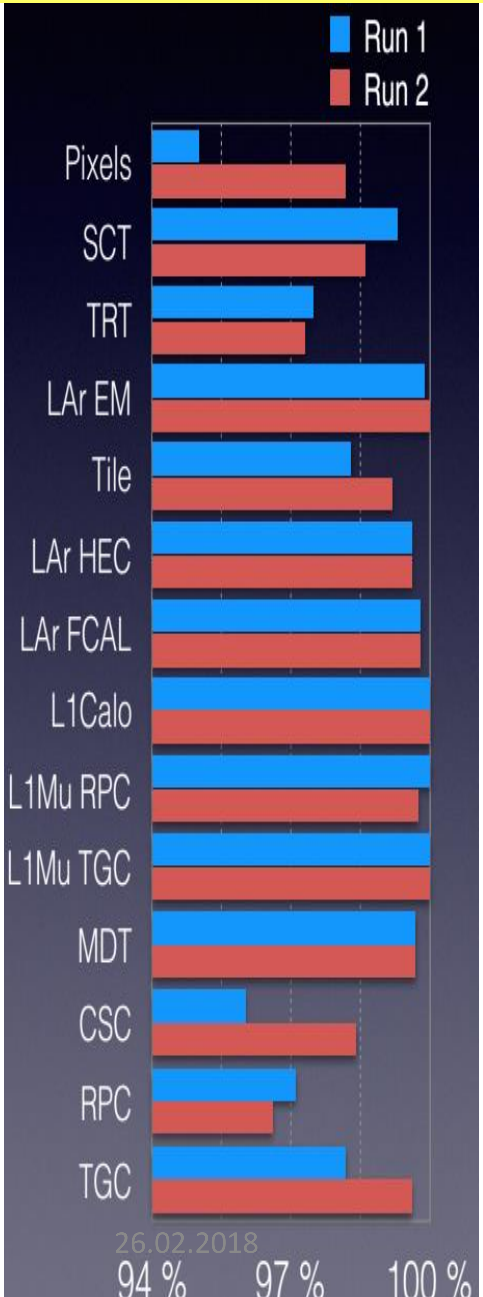


The module response for power trip



Timing jump in channels of a module

ATLAS DETECTOR PERFORMANCE

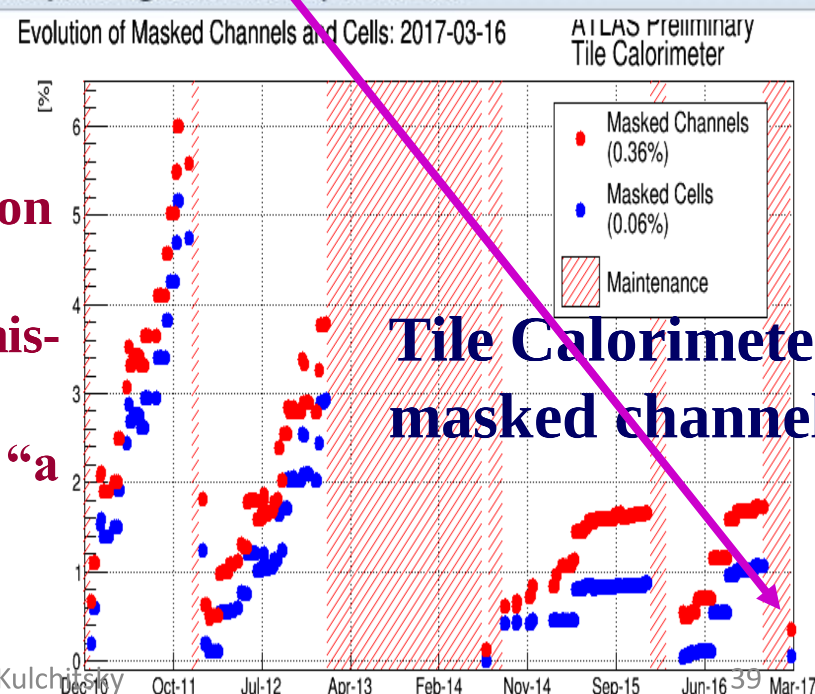


ATLAS pp 25ns run: August-November 2015

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8
All Good for physics: 87.1% (3.2 fb^{-1})										

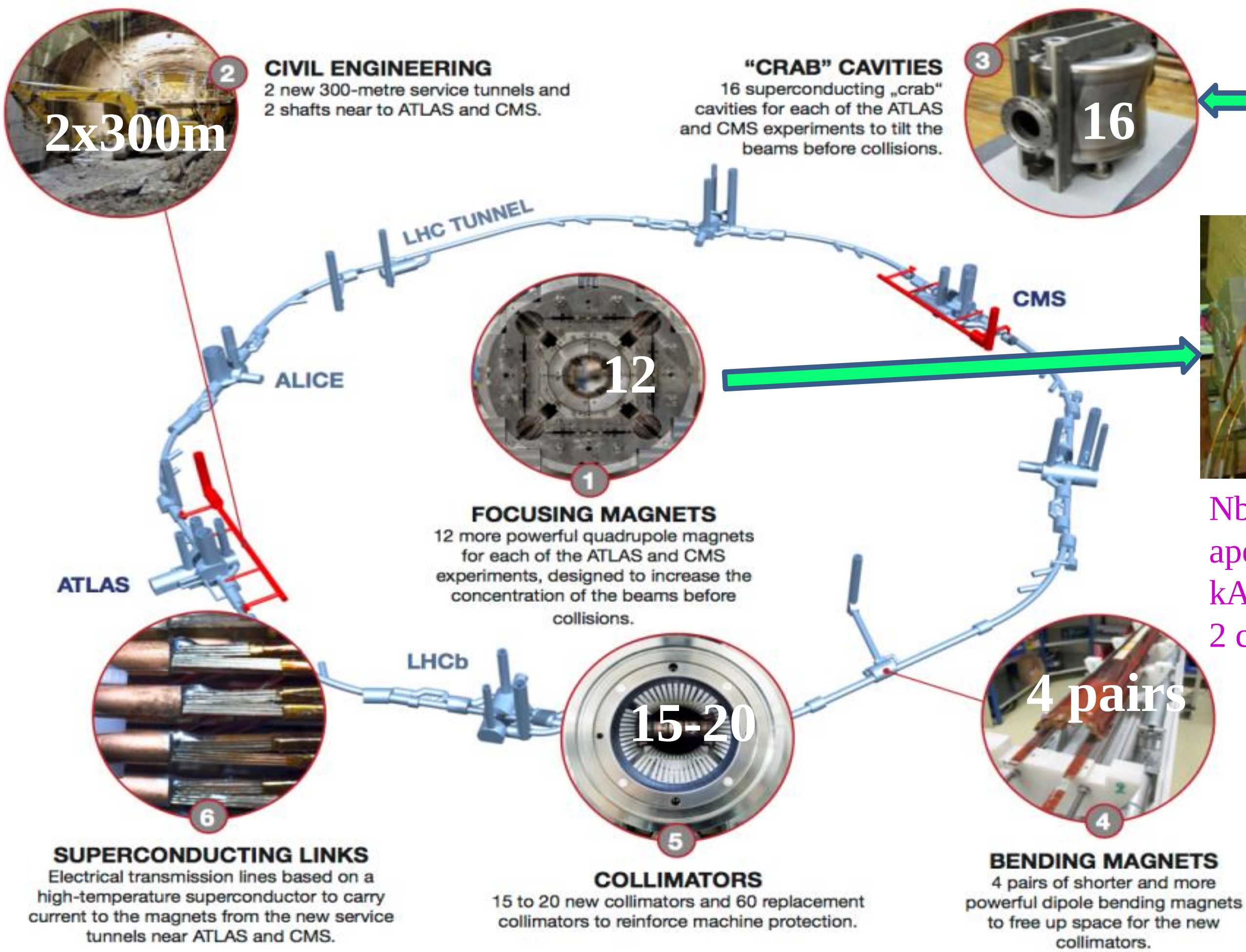
Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between August-November 2015, corresponding to an integrated luminosity of 3.7 fb^{-1}. The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 fb^{-1}. Analyses that don't rely on the IBL can use those runs and thus use 3.4 fb^{-1} with a corresponding DQ efficiency of 93.1%.

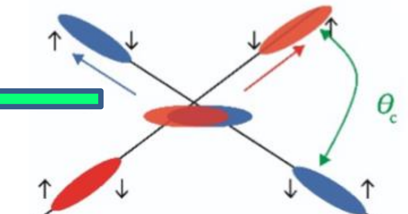
- **Overall smooth operation**
- **Constant live fraction of channels**
- **Important re-commis-sioning with data**
- **Learned to operate "a new detector"**



Tile Calorimeter masked channels

Approval of the HL-LHC project by CERN





Nb_3Sn quadrupole model (1.5 m long, aperture = 150 mm) reached current of 18 kA (nominal: 16.5 kA) at FNAL.
2 coils from CERN + 2 coils from US.

End 2015: Nb_3Sn dipole (1.8 m) reached 11.3 T (> nominal) without quenches.

"Next 10 years dominated by construction of HL-LHC (950 MCHF), which will be realised within a constant CERN Budget" **CERN Director General 23/06/2016**

LHC & ATLAS TIMELINE

Detector challenges:

- ***x10 more radiation***
  ($\sim 10^{16}$neq/cm^2; 10 MGy)
- ***x10 more pile-up***

2009 — LHC startup, √s 900 GeV

2010 — **Run 1**

$\sqrt{s}$ = 7 - 8 TeV, L ~ 2×10^{33} cm^{-2}s^{-1}, *BS = 50/25 ns*

Total L1A rate limited to ≈100 kHz until LS3

2013–2014 — LS1 — Go to design energy, nominal luminosity

Run 2

Enhancements to trigger and detector

$\sqrt{s}$ = 13 - 14 TeV, L ~ 1×10^{34} cm^{-2}s^{-1}, *BS = 25 ns*

2017

2019–2020 — LS2 — Injector and LHC Phase-1 upgrade to full design luminosity

Run 3

Mainly more trigger upgrades

$\sqrt{s}$ = 14 TeV, L ~ 2×10^{34} cm^{-2}s^{-1}, *BS = 25 ns*

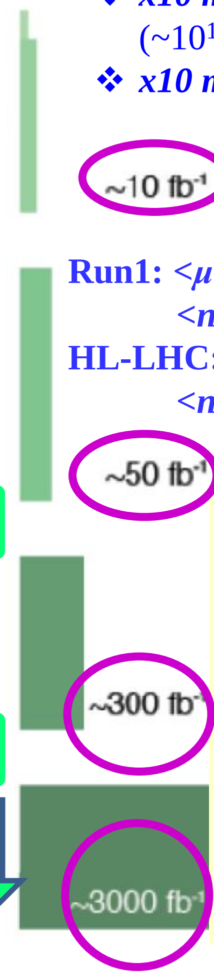
2024–2026 — LS3 — HL-LHC Phase-2 upgrade, crab cavities

Run 4

Major upgrades for HL-LHC

$\sqrt{s}$ = 14 TeV, L ~ $5\text{-}7\times10^{34}$ cm^{-2}s^{-1}, *BS = 25 ns*

2035



Run1: *<μ>=20;*
$\langle n_{PU}$(jets p_T>30 GeV)$\rangle$~0.04

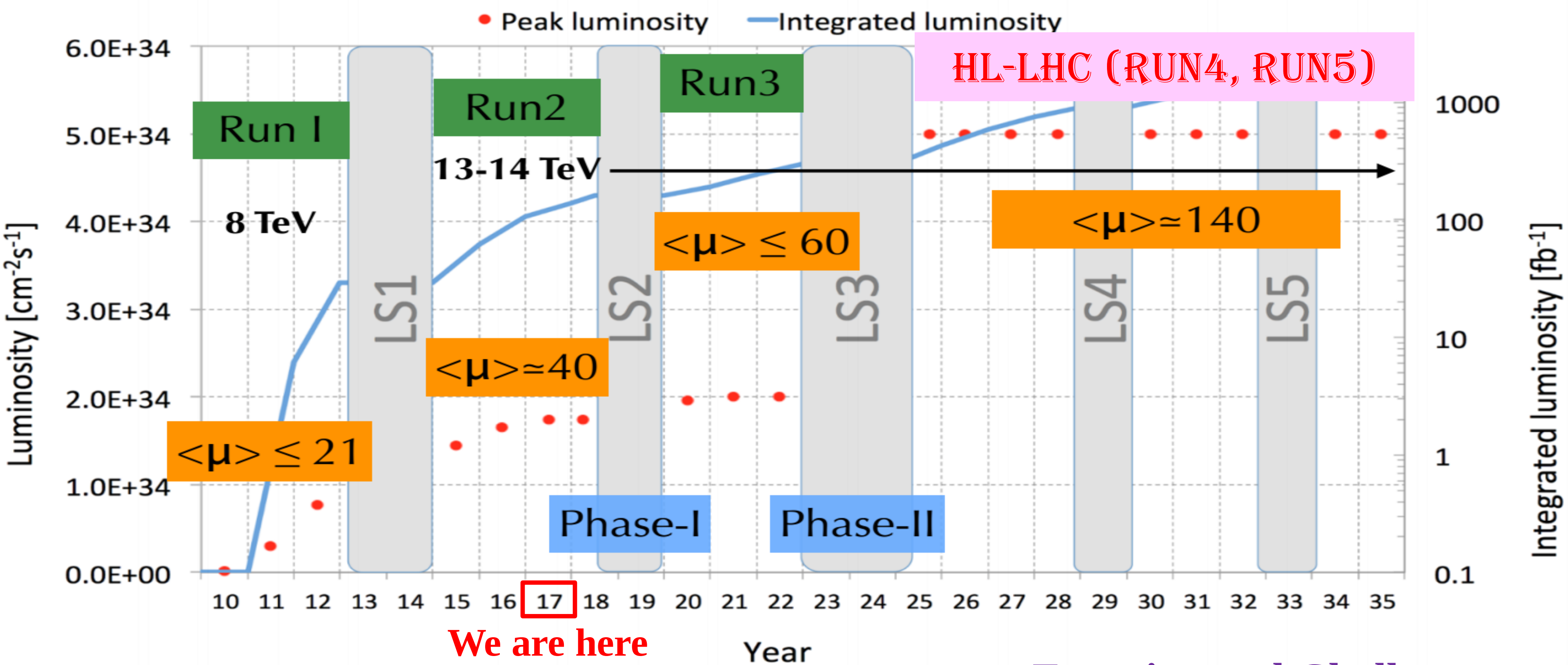
HL-LHC: *<μ>=200; (increase in 10)*
$\langle n_{PU}$(jets p_T>30 GeV)$\rangle$~7.4
(increase in 185)

ATLAS Upgrades needed to:

- ***Keep performance***
- ***Trigger rates acceptable with low p_T thresholds***
- ***Pile-up mitigation up to large η is needed!***

The LHC and its HL-LHC phase are CERN's flagship project for the next 20 years
→ crucial for the future of the Organization and particle physics worldwide !

HIGH LUMINOSITY (HL) LHC PROJECT TIMELINE



- **HL-LHC** will ***start in mid-2025*** after ~2.5 years of shutdown
- Levelled Luminosity of **$5\cdot10^{34}$ cm^{-2} s^{-1}.** Max. Lumi **$7\cdot10^{34}$ cm^{-2} s^{-1}**
- **Average number of pile-up** interactions per bunch crossing **<μ> ≃140**
- **Expect to collect** ~300 fb^{-1} with LHC and **~3000 fb^{-1} with the HL-LHC**

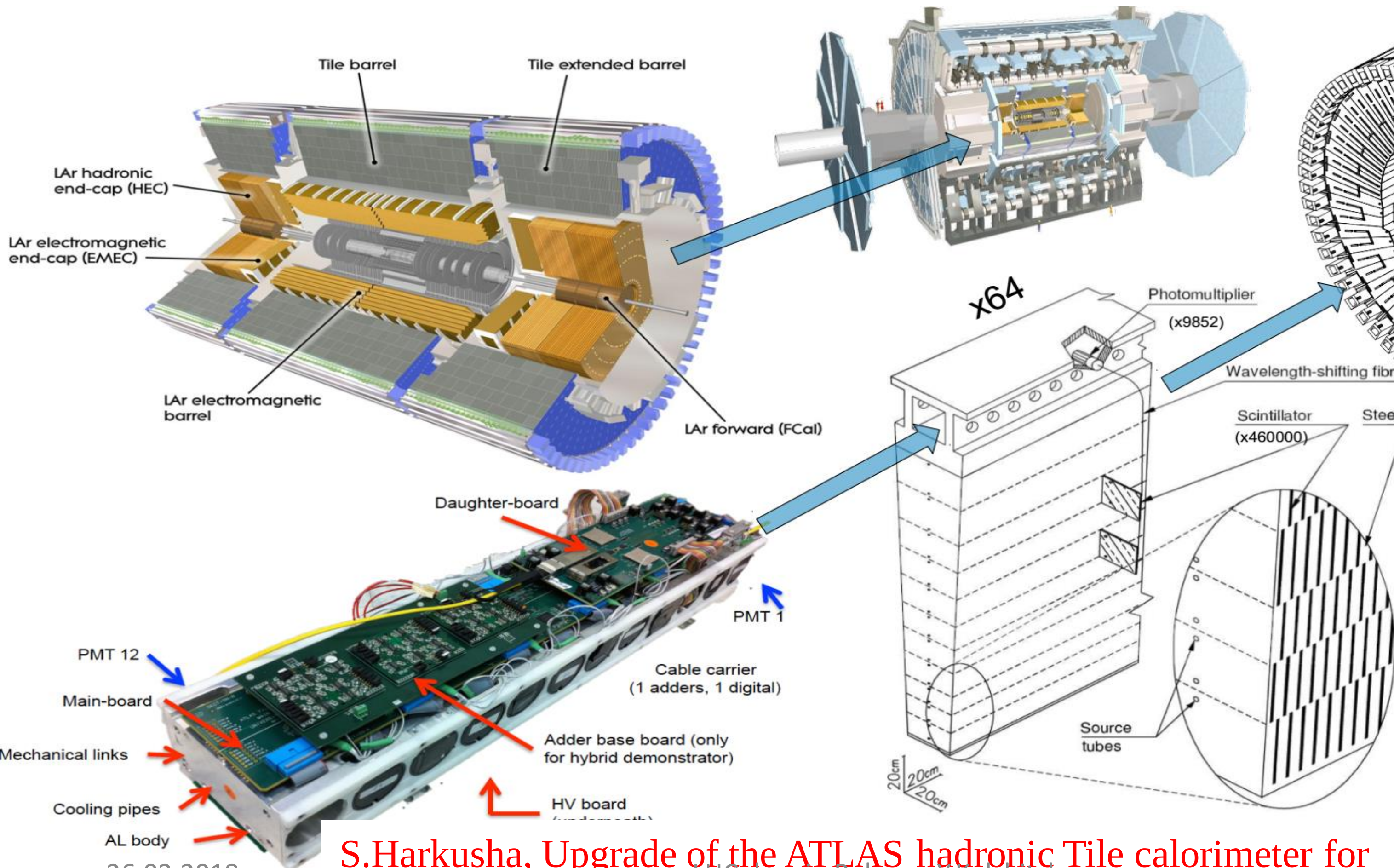
Experimental Challenges

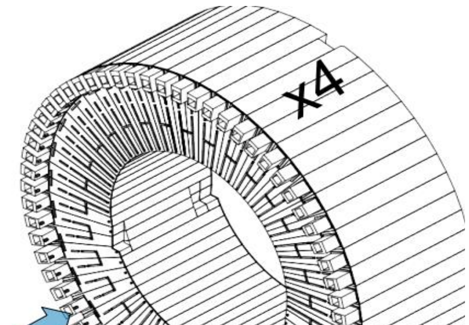
- High pile-up ⇒ *detector and trigger improvements needed*
- High radiation level ⇒ *detector damage*
- **Goal:** *keep detectors performance at the same level as today*

UPGRADE OF THE TILECAL FOR THE HL LHC

In 2024 the TileCal will get a major replacement of its on- and off detector electronics

- All signals will be digitized and then transferred directly to the off-detector electronics, where the signals will be reconstructed, stored, and sent to the L1 of trigger at a rate of 40 MHz
- **This will provide better precision of the calorimeter signals used by the trigger system and will allow the development of more complex trigger algorithms**



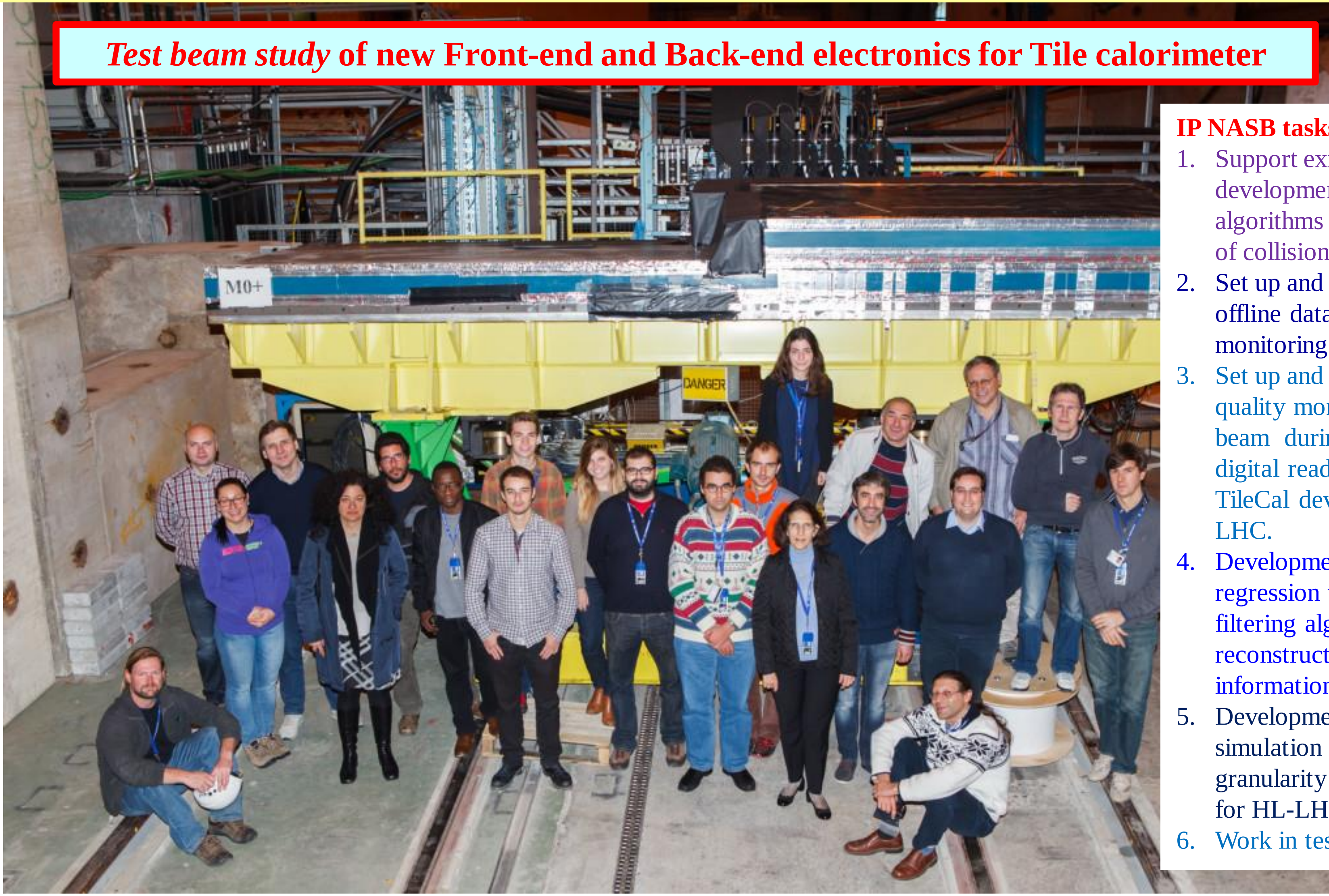


Three different frontend options are presently being investigated for the upgrade and a final solution will be chosen after extensive laboratory and test beam studies that are in progress.

S.Harkusha, Upgrade of the ATLAS hadronic Tile calorimeter for the High luminosity LHC, ATL-TILECAL-PROC-2016-009

TILE CALORIMETER TEST BEAM SETUP 2015/17

***Test beam study* of new Front-end and Back-end electronics for Tile calorimeter**



IP NASB tasks for TileCal:

1. Support existing and development of new tools and algorithms for reconstruction of collisions data.
2. Set up and support online and offline data quality monitoring.
3. Set up and support online data quality monitoring at the Test beam during testing the new digital readout system of the TileCal developed for the HL-LHC.
4. Development and support of regression tests for optimal filtering algorithms used to reconstruct timing and energy information.
5. Development of software for simulation of the high granularity Tile calorimeter for HL-LHC.
6. Work in test beam shifts

The scratch is for the test beam set-up of TileCal modules on SPS (CERN) in 2016. Main task is to study of TileCal performance with new **Front-end and Back-end** electronics. S.Harkusha and Y.Kulchitsky from IP NASB took part in the test beams.

SUMMARY

- B.I.Stepanov IP NASB team participates **since 1994** in the ATLAS experiment – largest HEP collider experiment
- Supported by Directorate of the Institute of Physics NASB, National Academy of Sciences of Belarus, State Committee of Science and Technology of Belarus
- Since 1994 we work in the close contact with JINR & CERN for the ATLAS Tile Calorimeter design, modules mass production, calorimeter construction & installation in cavern
- Complex systematic studies of ATLAS Tile Calorimeter and combined calorimeter performance in test beams at SPS
- The development and application of new precision methods for calorimeters performance study
- Development and implementation of software for TileCal collision data collection and upgrade for HL-LHC

Thank You Very Much for Attention!

ATLAS EXPERIMENT

http://atlas.ch

BACKUP SLIDES

Thank you to CERN, the Funding Agencies, and all the other bodies which made this possible

ATLAS Collaboration

(Status October 2017)

38 Countries
183 Institutions
2900 Scientific authors total
(1000 Students)

Adelaide, Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, UT Austin, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brazil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, China IHEP-NJU-THU, China USTC-SDU-SJTU, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, NCSR Demokritos, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Harvard, Heidelberg, Hiroshima IT, Hong Kong, NTHU Hsinchu, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Kyushu, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Louisiana Tech, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, LMU Munich, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, LPNHE Paris VI and VII, Pavia, Pennsylvania, NPI Petersburg, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, Irfu Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Tomsk, Toronto, Trento, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBCVancouver, Victoria, Warwick, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

INAUGURATION OF THE ATLAS EXPERIMENT

ATLAS PHASE II UPGRADES FOR HL-LHC (2024-2026)

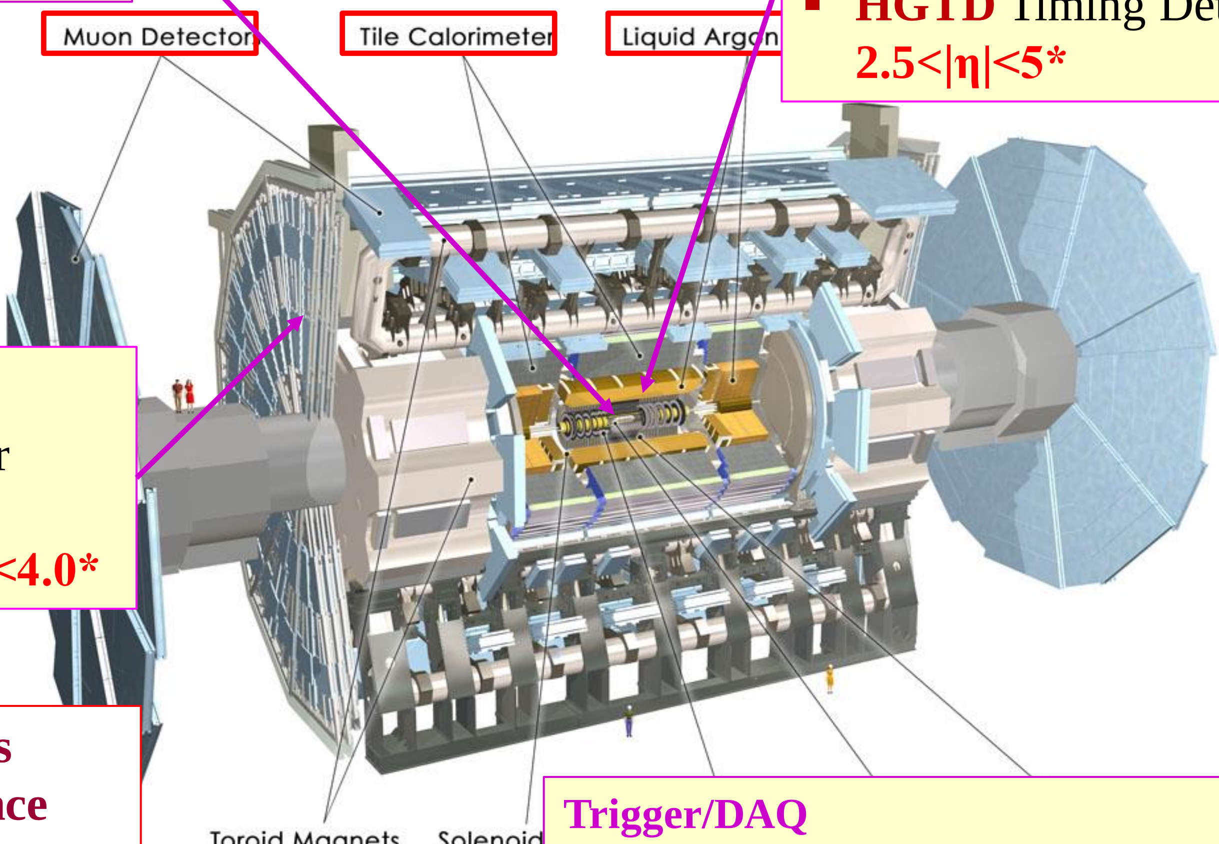
CERN-LHCC-2012-022; CERN-LHCC-2015-020

ITK- Inner tracker

- Pixels + Strips (Si)
- $|\eta|<2.7 \rightarrow |\eta|< 4.0$*

Calorimeters:

- **LAr/Tilecal** FE, BE electronics
- **HGTD** Timing Detector
  $2.5<|\eta|<5$*



Muons:

- Inner Barrel Layer
- Electronics
- Muon tag **$2.7<|\eta|<4.0$***

*** Large η scenarios (part of the reference detector layout)**

Trigger/DAQ

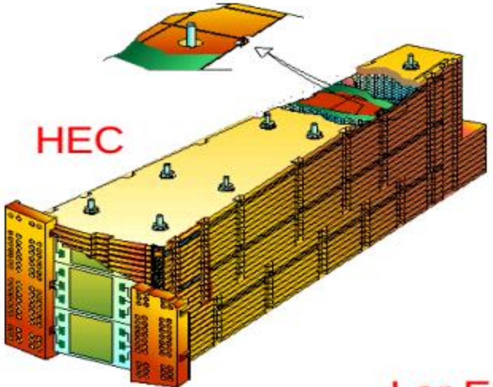
- **L0** (**calo+muon**): **1 MHz**; **10 μs** latency
- **L1** (**calo+muon+ITK**): **400 kHz**; **60 μs** latency
- **HLT/EF**: **10 kHz**

Refs: ATLAS Phase II LoI [CERN-LHCC-2012-022]; IDRs and preparation of design choices →Tech. Design Reports-TDRs (end 2016-end 2017); Impact of different cost scenarios on physics/perf. [scoping doc. CERN-LHCC-2015-020]

UPGRADE OF ATLAS CALORIMETERS FOR HL LHC

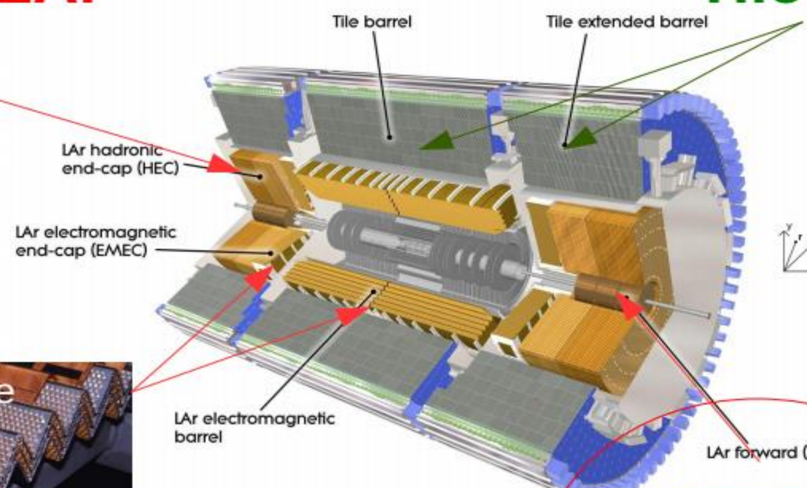
New for Calorimeters: LAr and Tile power supply replacements

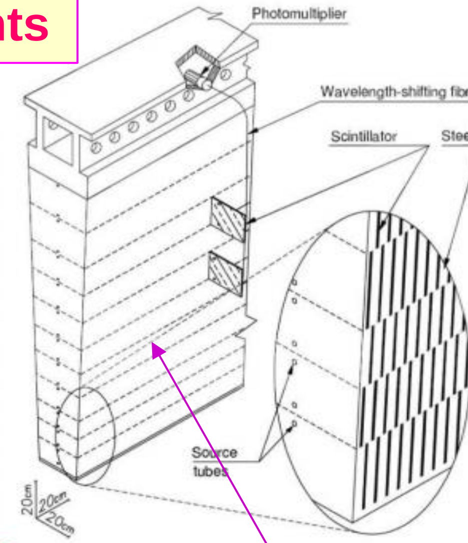
HEC



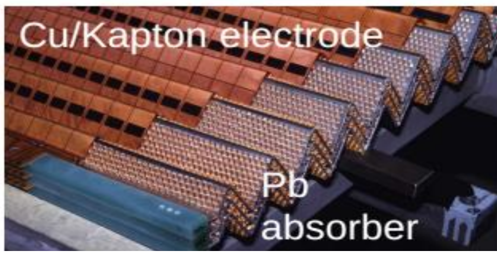
LAr

Tile

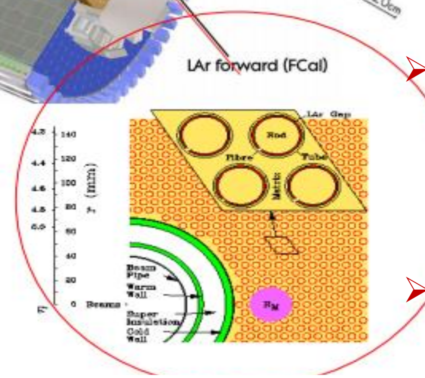




Lar EM



FCAL



ATLAS Calorimeters:

- ✓ **Very hermetic**
  - ❖ **Gaps partially instrumented**
  - ❖ **Small dead regions which did not significantly impact physics**
- ✓ **Excellent shower containment**
- ✓ **Fine granularity**
- ✓ **Good resolution and small noise**

- ➢ **Mass production (stamping) of master and spacer iron plates for Tile Calorimeter Modules in Minsk.**
- ➢ **Production of Tile Calorimeter Barrel Modules in JINR**
- ➢ **Transportation of TileCal Barrel Modules from Dubna to CERN by JINR.**

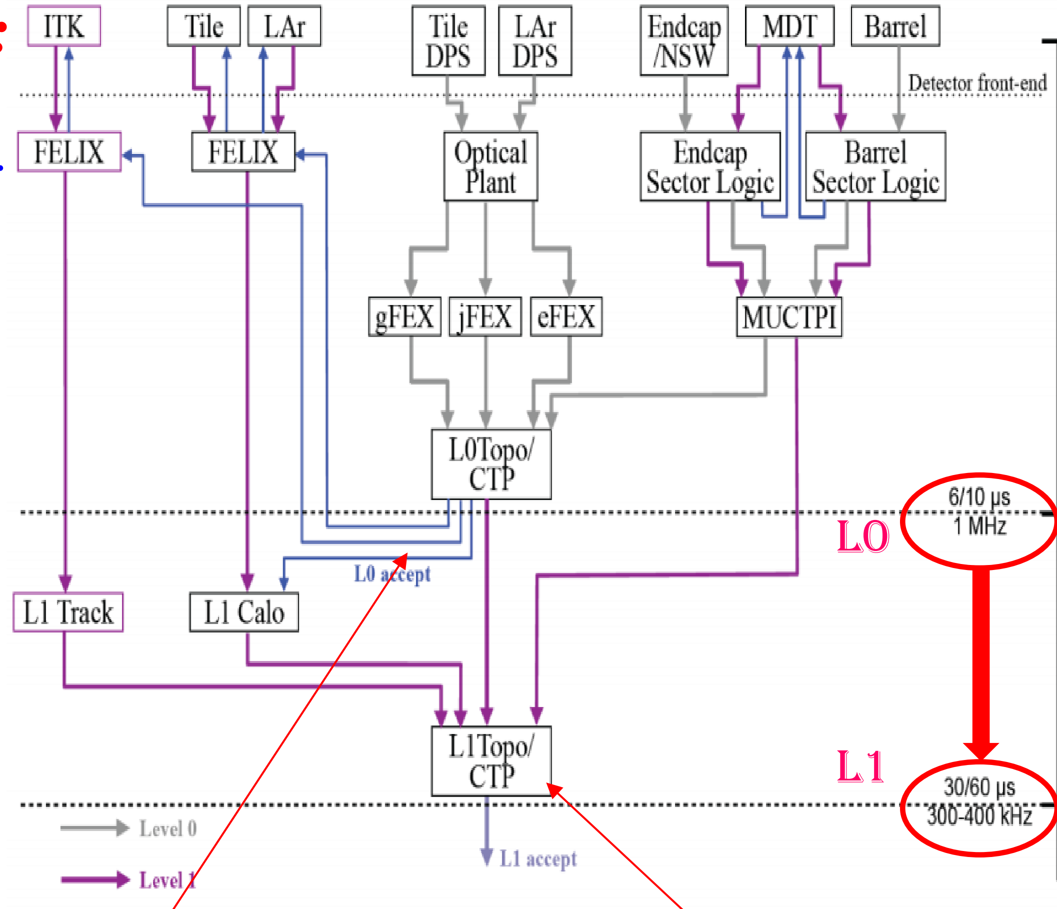
Test beam study **of new FE and BE electronics for Tile and Lar calorimeters**

TRIGGER/DAQ AT HL-LHC

New design of hardware trigger:

Move part of the High Level Trigger (**HLT**) reconstruction into the early stage of trigger.

- ***Goal:*** ***keep thresholds on p_T of triggering leptons and L1 trigger rates low***



Triggering sequence

- **L0** trigger (Calo/Muon) *reduces* rate within **~6 µs to 1 MHz** and defines ***Regions of Interests*** (RoIs)
- **L1** track trigger extracts tracking info inside RoIs from readout electronics

Challenge:

- Finish processing within the latency constraints
- Requires changes to electronics feeding trigger system

LEVEL-0 (L0)
Calo+Muon
Latency~**6 µs**, rate~**1 MHz**
Define RoIs for **L1**

LEVEL-1 (L1)
Calo+Muon+ITK
Latency~**30 µs**, rate~**400 kHz**
All data are moved off detector

Method of local hadronic calibration

The pion energy reconstruction by the **local hadronic calibration method** on the basis of the combined test beam data with energy 10–350 GeV (η=0.25) is performed.

In this method energies deposited in each cell are weighted. The weights are determined by the Monte Carlo simulation using Calibration Hits software. We have modified this method by applying cuts in weights. The obtained fractional energy resolution with the conventional method of determination of the energy deposit in the dead material between LAr and Tile calorimeters is $\boldsymbol{\sigma/E = 67\%/\sqrt{E} \oplus 4\% \oplus 95\%/E}$.

The energy linearity is within **±1%.** We have corrected the cesium mis-calibration of the $Tile_1$ and $Tile_2$ longitudinal samplings. The mean value of energy linearity has been increased by about 1% and becomes equal to **1.002±0.002**. The energy resolution did not change. We have performed weighting without knowing of the beam energies. In this case the energy resolution shows 9% degradation. Linearity are within **± 1%.** We have applied the **Neural Networks to the determination of the energy deposit between LAr and Tile calorimeters**. The essential improvement of energy resolution is obtained. ***In this case we have reached the projected energy resolution for hadrons in the ATLAS detector*** $\boldsymbol{\sigma/E = 50\%/\sqrt{E} \oplus 3\%}$**.**

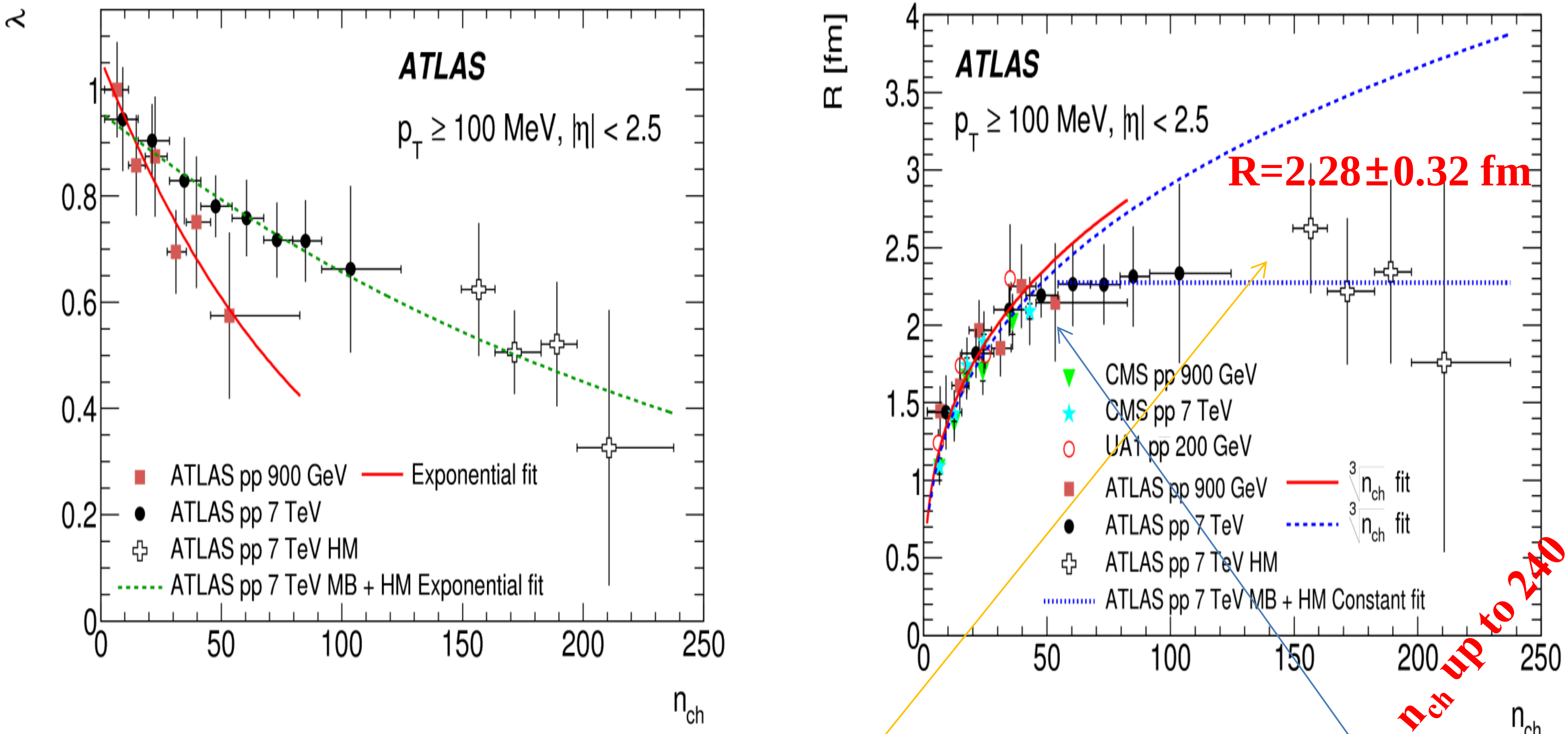
Y.Kulchitsky, P.Tsiareshka, J.Khubua, N.Russakovich, V.Shigaev, V.Vinogradov, Pion energy reconstruction by the local hadronic calibration method with ATLAS combined test beam 2004 data, ATL-TILECAL-PUB-2008-009

MOTIVATION FOR BOSE-EINSTEIN CORRELATIONS

- Bose-Einstein correlations (BEC) represent a unique probe of the *space-time geometry* of the *hadronization region* and allow the *determination the size and shape of the source* from which particles are *emitted*.
- Studies of the dependence of BEC on *particle multiplicity* and *transverse momentum* are of special interest. They help in the understanding of multiparticle production mechanisms.
- High-multiplicity data in proton interactions can serve as a reference for studies in nucleus-nucleus collisions. The effect is reproduced in hydrodynamical and Pomeron-based approaches for hadronic interactions where high multiplicities play a crucial role.

MULTIPLICITY DEPENDENCE OF λ AND R BEC PARAMETERS

EPJC 75 (2015) 466



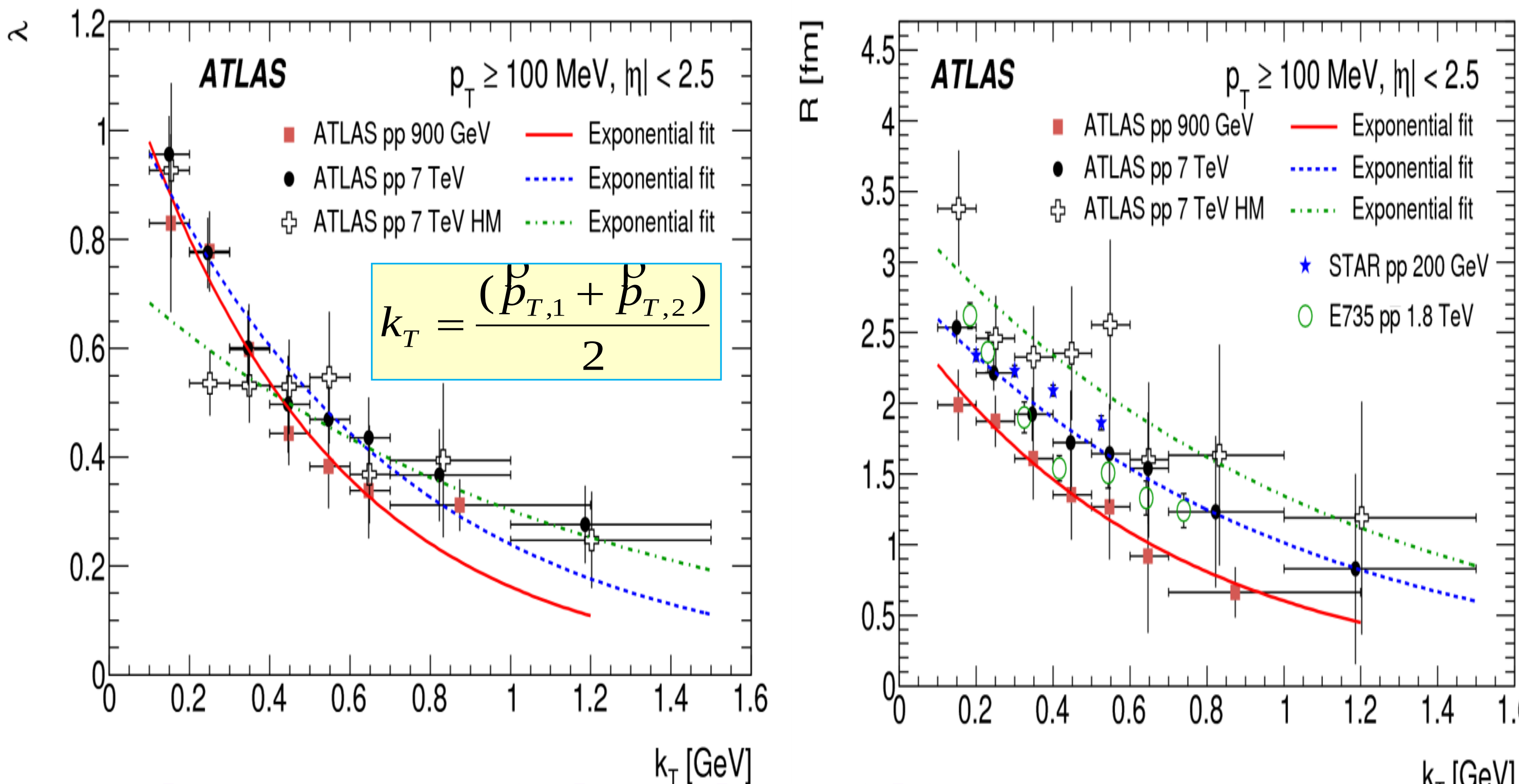
- ► λ and R are energy independent within the uncertainties
- ► λ exponentially decrease with multiplicity

Good Agreement with CMS & UA1

- ► R of the $\alpha \cdot n_{ch}^{1/3}$ fit for $n_{ch} \leq 55$: *0.9 TeV is α=0.64±0.07 fm, 7 TeV is α=0.63±0.05 fm*
- ► R is a ***Constant*** for n_{ch}>55 at 7 TeV ***R=2.28±0.32 fm*** **observed for the first time**

BEC parameters k_T dependence of λ and R parameters

EPJC 75 (2015) 466



$$k_T = \frac{(p_{T,1} + p_{T,2})}{2}$$

- ►λ and *R* are energy-independent within uncertainties
- ►λ and R decrease exponentially with k_T
- ►Good agreement with earlier (non-LHC) measurements

TILECAL UPGRADE TASKS FOR IP NASB

1. **Support** existing and development of **new tools and algorithms** for reconstruction of collisions data in the ATLAS Tile calorimeter.
2. **Optimization** memory consumption and CPU usage in software used for reconstruction of collisions data in the ATLAS Tile calorimeter.
3. **Set up and support** online and offline data quality monitoring in the ATLAS Tile calorimeter.
4. **Set up and support** online data quality monitoring at the Test beam during testing the new digital readout system of the ATLAS Tile calorimeter developed for the High Luminosity LHC.
5. **Development and support** of regression tests for optimal filtering algorithms used to reconstruct timing and energy information in the ATLAS Tile calorimeter.
6. **Development** of software for simulation of the high granularity ATLAS Tile calorimeter for HL LHC.
7. **Coordination** of software development activity in the ATLAS Tile calorimeter.

ATLAS TRIGGER/DAQ PHASE–I UPGRADE

ATLAS-TDR-023-2013

Trigger/DAQ

L1 (HW): **2.5 μs** latency; **100 kHz**

HLT/Event Filter: **1 kHz**

- Centre-of-mass **8→13 TeV**: **2-2.5x increase** in trigger rates
- Peak luminosity **0.8→ 1.7e^{34}: ~2x higher** trigger rates

Possible options:

Increase output rate

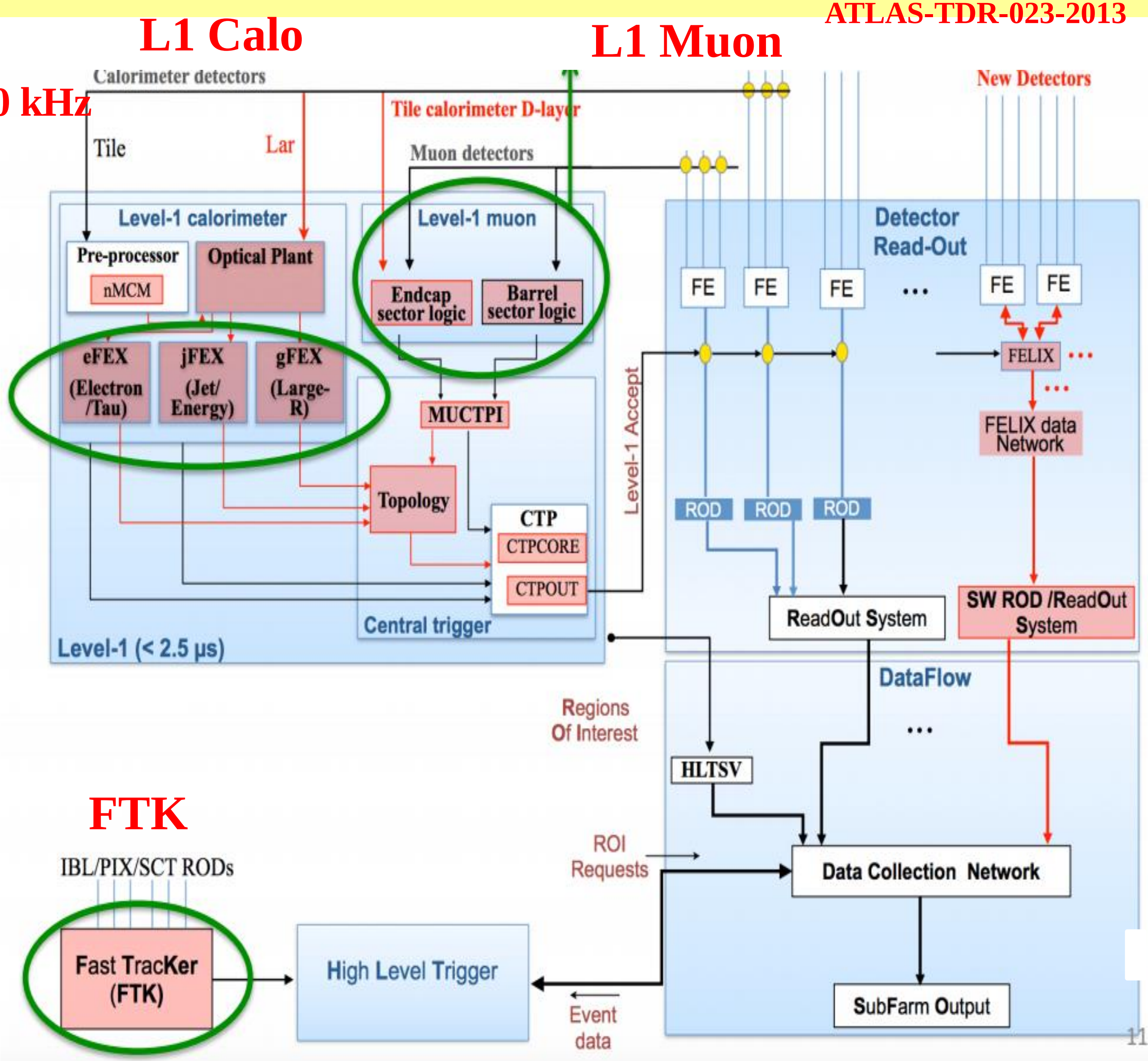
➡ Challenge for offline computing

Increase thresholds

➡ Lose interesting physics

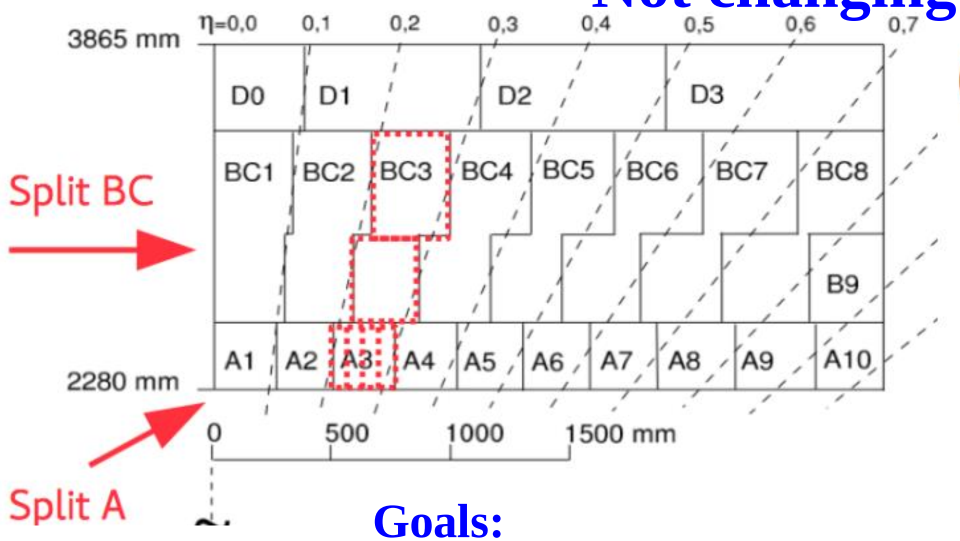
Increase rejection

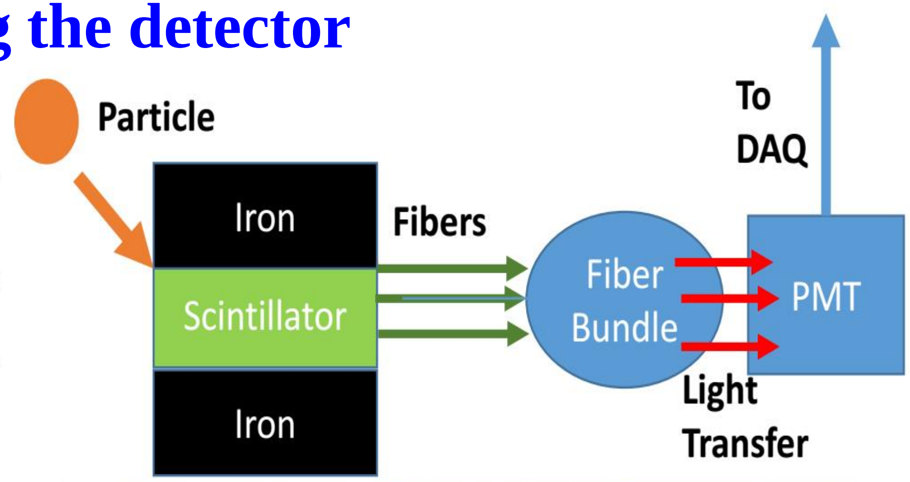
➡ Better **hardware** and **software**

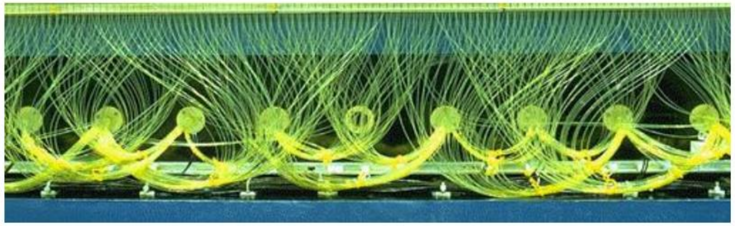


TILE CALORIMETER GRANULARITY IMPROVING

Not changing the detector

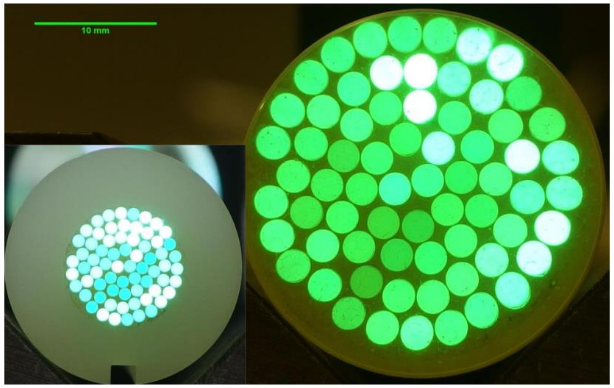




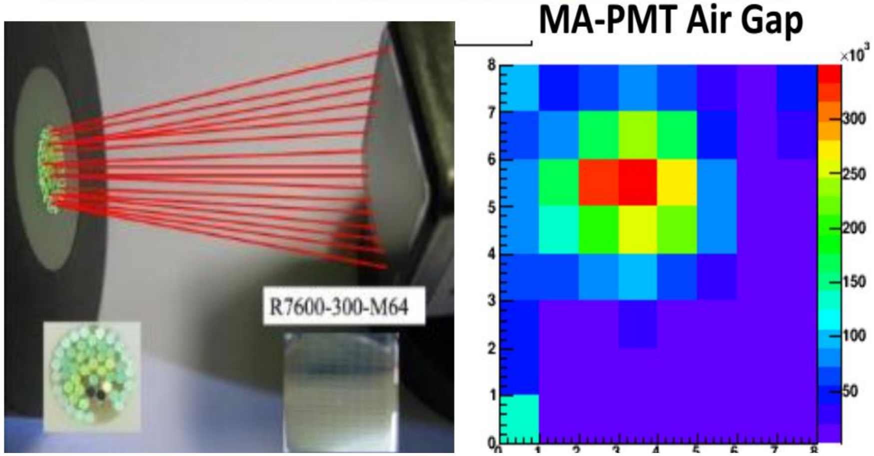


Goals:

1. *Split A Cells (x4): 0.1 ->0.025 η*
2. *Split BC Cells (x2): 3-> 4 layers*
3. *Software development for simulation and reconstruction for new A-cell, B and C-cells*
4. *Updates of Tile Monitoring for new cells*

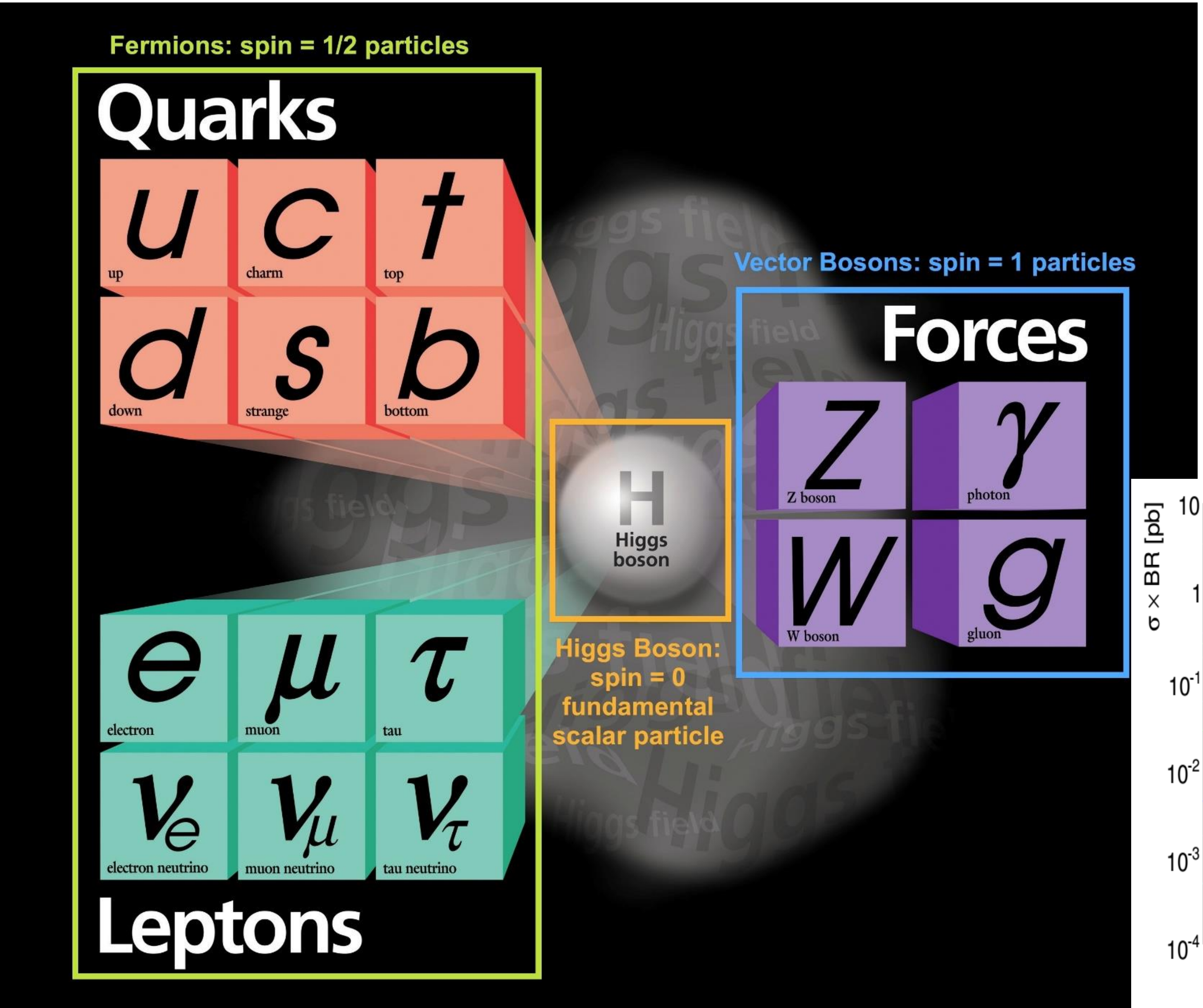


Fiber Bundle Left, Focon magnification on right



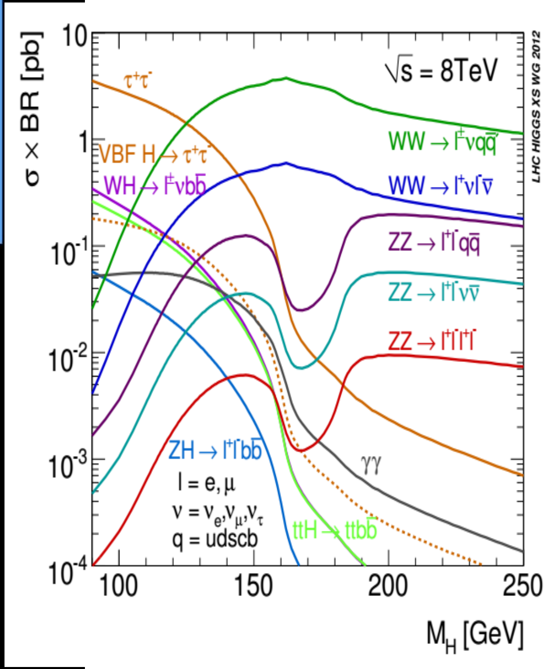
Current system of collected information from Tile calorimeter

STANDARD MODEL

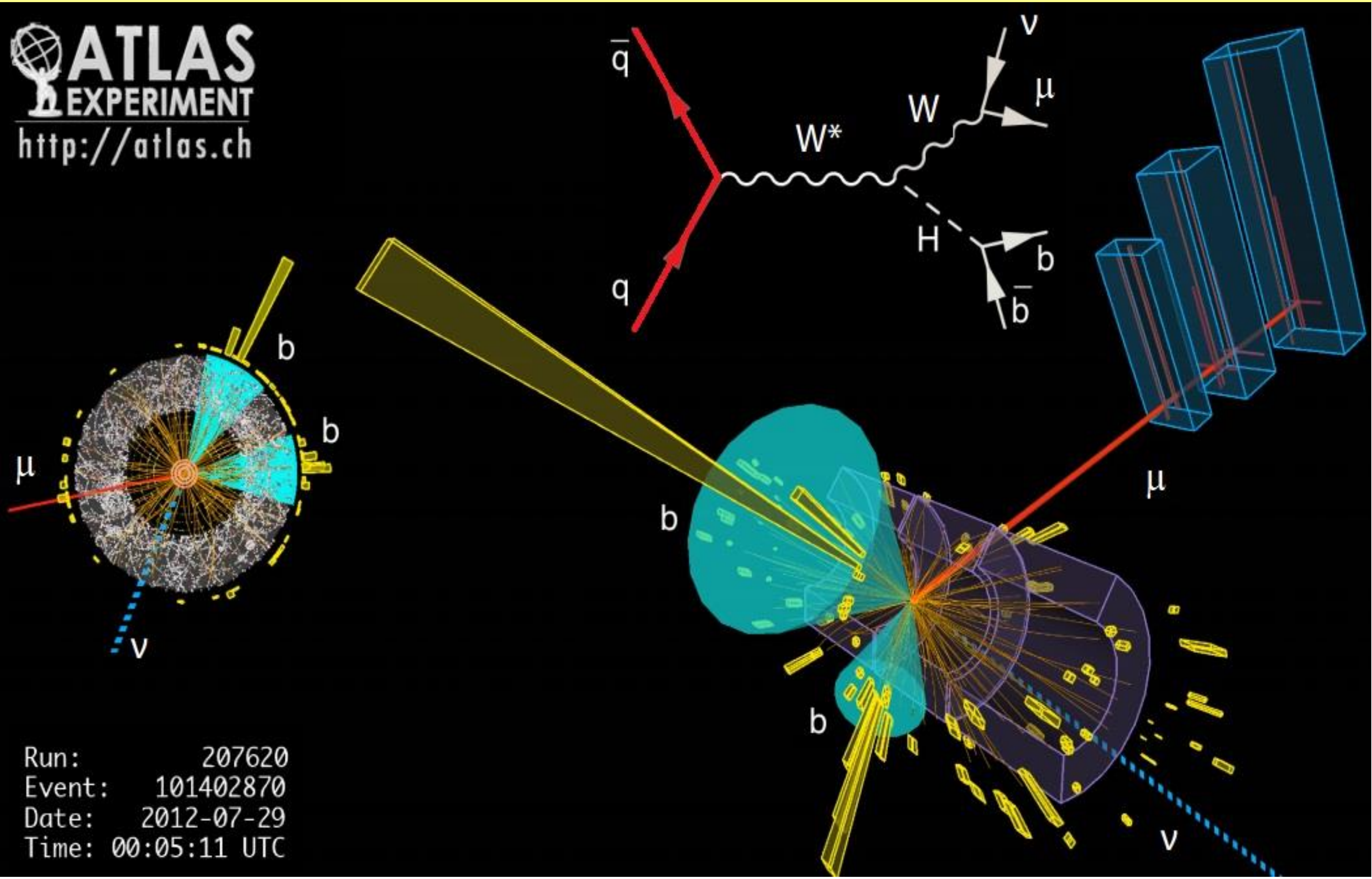


Mass of the Higgs boson was not predicted!

Higgs Decay Channels prediction for Higgs boson mass from 90 to 250 GeV



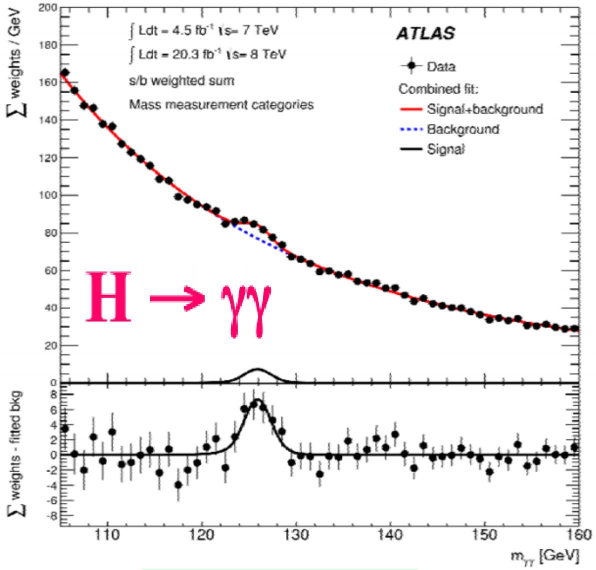
Higgs boson production: $q\bar{q} \to W^* \to WH$, $W \to \nu\mu$, $H \to b\bar{b}$



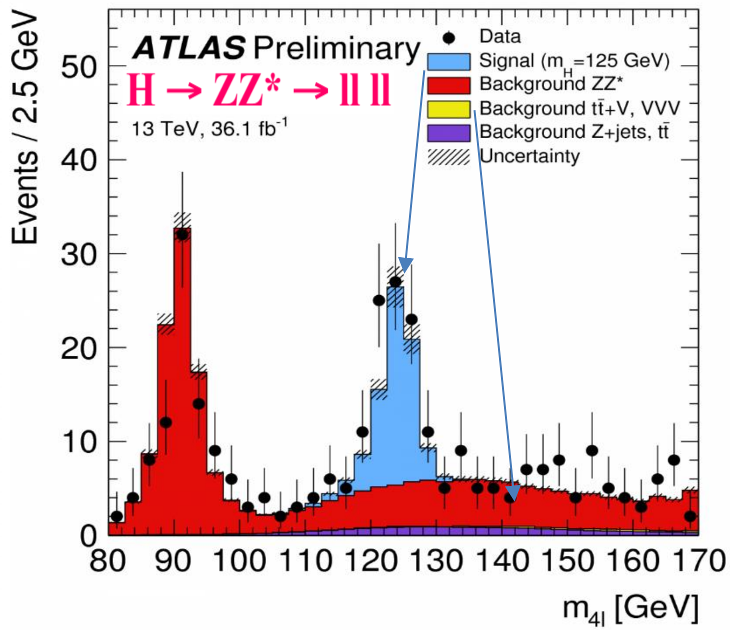
DISCOVERY OF HIGGS BOSON

PRD 90, 052004 (2014)

Chin. Phys. C. **38**, 090001 (2014) and 2015 update



Diphoton Channel



Distribution of the invariant mass of the four leptons selected in the ATLAS measurement of H→ZZ →4l using the full 2015+ 2016 data set. The Higgs boson corresponds to the excess of events with respect to the non resonant ZZ* background observed at 125 GeV.

The discovery of a **Higgs boson** in 2012 by the ATLAS and CMS experiments marked a milestone in the history of particle physics. It confirmed a long-standing prediction of the Standard Model, the theory that comprises our present understanding of elementary particles and their interactions. With the huge amount of proton–proton collisions delivered by the LHC in 2015 and 2016 at the increased collision energy of 13 TeV, ATLAS has entered a new era of Higgs boson property measurements. The new data allowed ATLAS perform measurements of inclusive and differential cross sections using the "golden" H->ZZ*->4l decay.

H^0 $J = 0$

Mass $m = 125.09 \pm 0.24$ GeV

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States = 1.17 ± 0.17 (S = 1.2)

$WW^* = 0.81 \pm 0.16$

$ZZ^* = 1.15^{+0.27}_{-0.23}$ (S = 1.2)

$\gamma\gamma = 1.17^{+0.19}_{-0.17}$

$b\bar{b} = 0.85 \pm 0.29$

$\mu^+\mu^- < 7.0$, CL = 95%

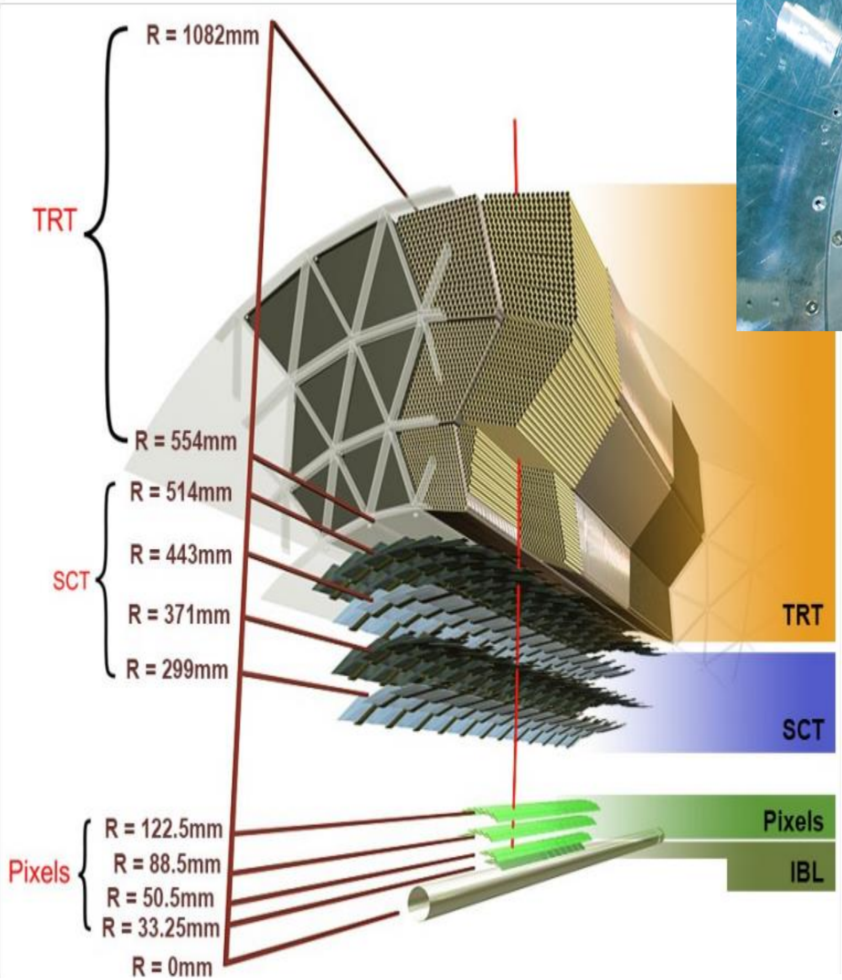
$\tau^+\tau^- = 0.79 \pm 0.26$

$Z\gamma < 9.5$, CL = 95%

$t\bar{t}H^0$ Production = $2.5^{+0.9}_{-0.8}$

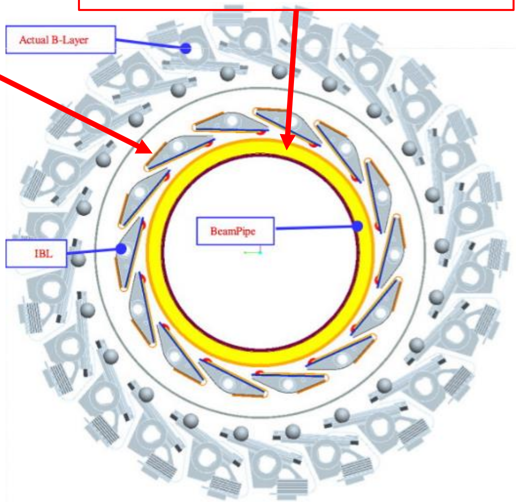
INNER DETECTORS (ID)

ATLAS tracking detectors:
Pixels, SCT & TRT



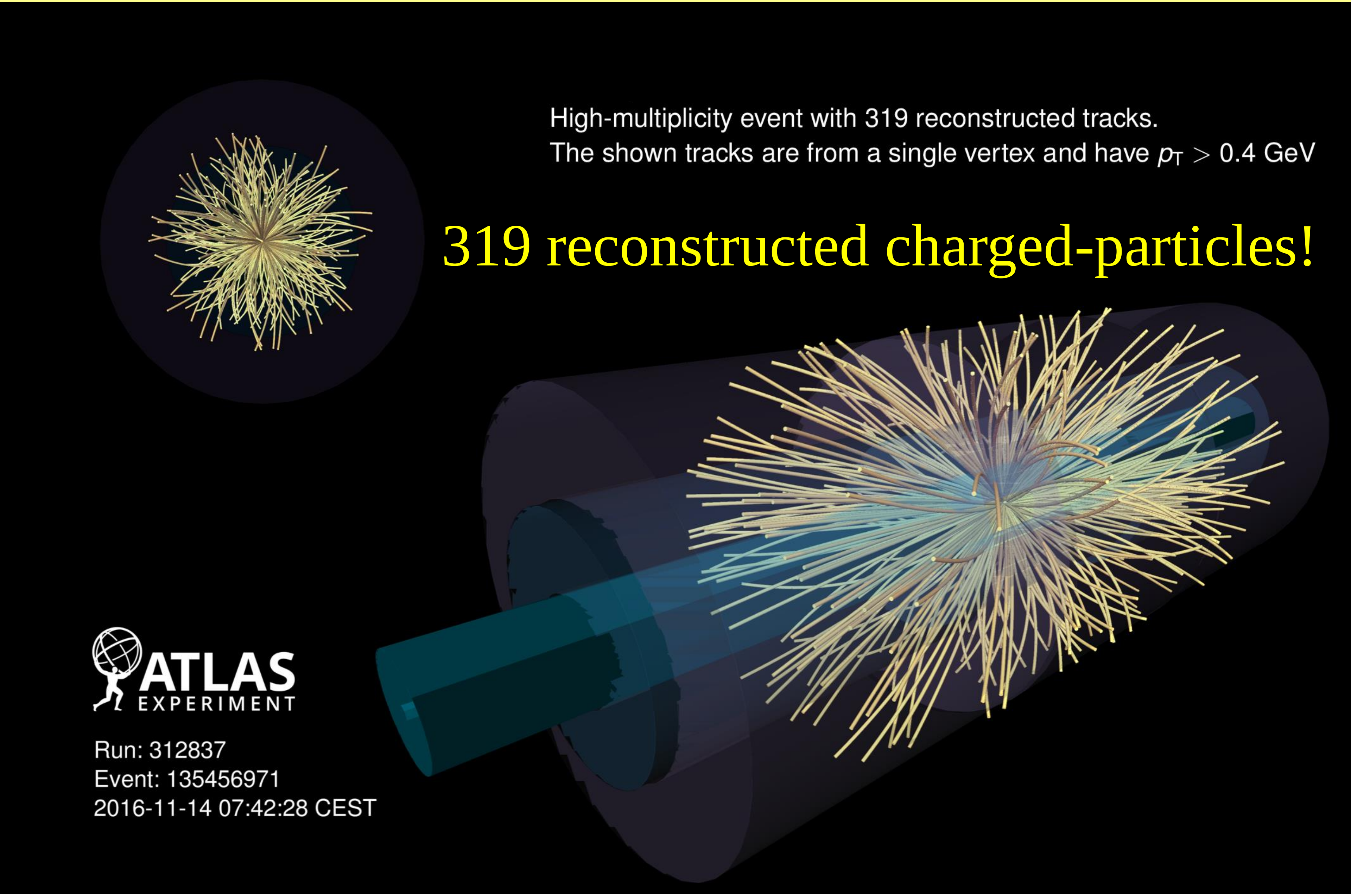
- **New innermost 4-th layer** for the Pixel detector [**IBL** = Insertable B-Layer]
- Required complete removal of the ATLAS Pixel volume
- IBL fully operational

New Be beam pipe



Two times better tracks impact parameters resolution at 13 TeV!

VERY-HIGH-MULTIPLICITY CHARGED-PARTICLE EVENT IN ATLAS



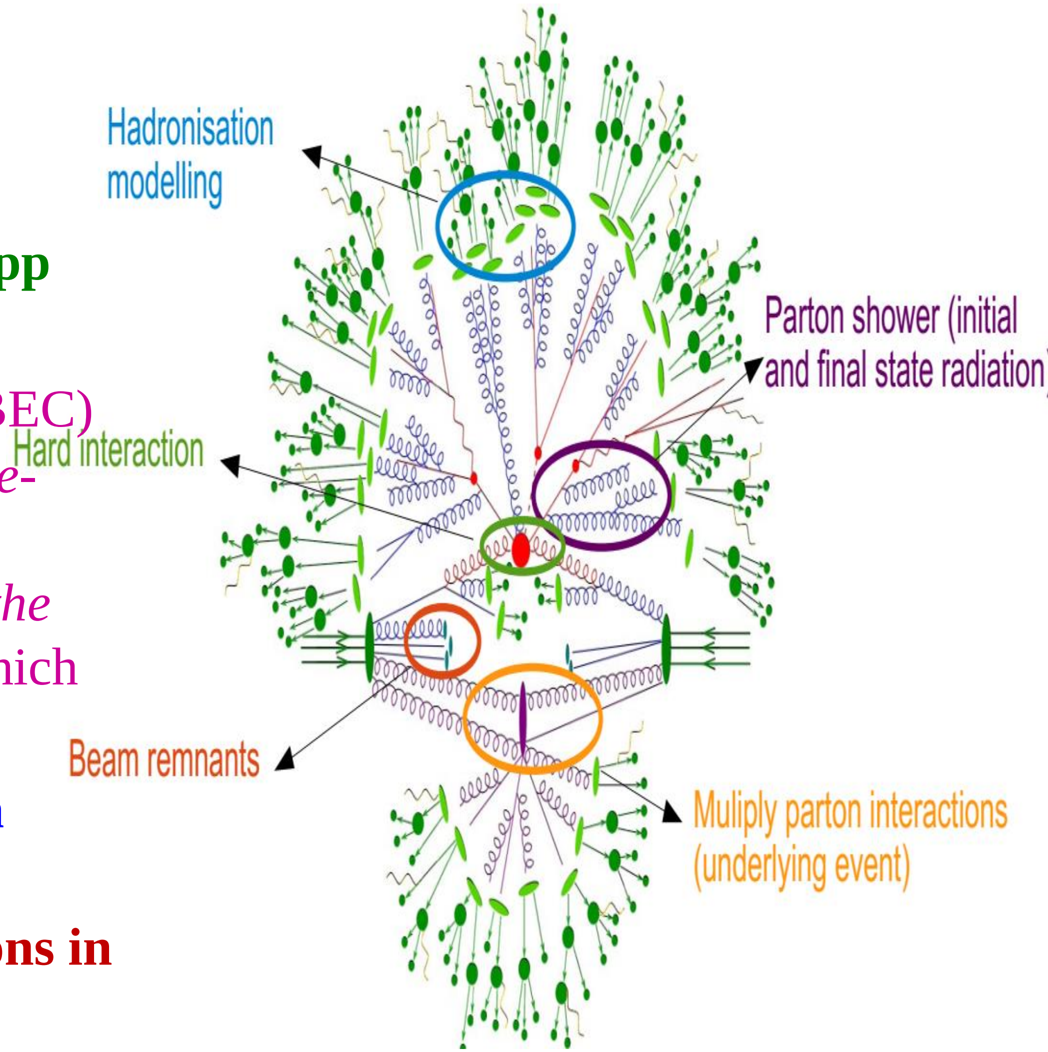
319 reconstructed charged-particles!

STUDY OF MINIMUM-BIAS EVENTS WITH ATLAS

Understanding of soft-QCD interactions has direct impact on

1. **precision measurements,**
2. **searches for new physic**

- **Charged-particle distributions in pp interactions at 0.9 – 13 TeV**
- **Bose-Einstein correlations** (BEC) represent a unique probe of the *space-time geometry* of the *hadronization region* and allow the *determination the size and shape of the source* from which particles are *emitted*.
- **Underlying events distributions in pp interactions**



Provides insight into strong interactions in non-perturbative QCD regime:

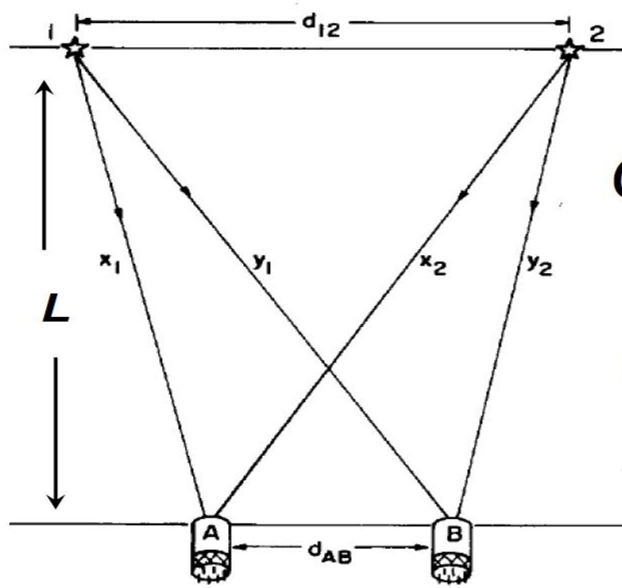
- Soft QCD results used in Monte-Carlo generators tuning,
- Low energy QCD description essential for simulating multiple pp interactions

BOSE-EINSTEIN CORRELATIONS AND HANBURY BROWN – TWISS INTERFEROMETRY

Bose-Einstein correlations (BEC) are often considered to be the analogue of the Hanbury Brown and Twiss effect in astronomy, describing the interference of incoherently-emitted identical bosons.

Intensity interferometry of photons in radio-astronomy: measures angular diameter of two stars, so the physical size of the source

Figure 10.1 The first stellar intensity interferometer; the pilot model of the stellar intensity interferometer at Jodrell Bank in 1955. Two Army searchlights were used to make the first measurement of the angular diameter of a main sequence star (Sirius).



$$C(d) = \frac{\langle I_1 I_2 \rangle}{\langle I_1 \rangle \langle I_2 \rangle}$$

$$= 1 + A\cos(d_{AB})$$

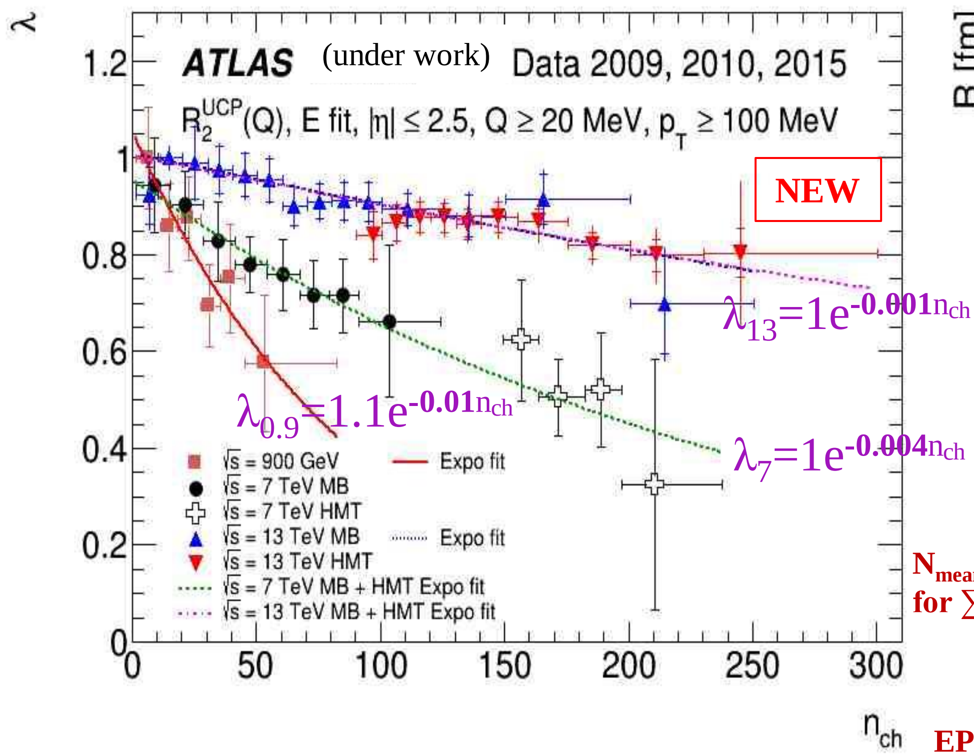
$$d_{AB} = \lambda/\theta$$

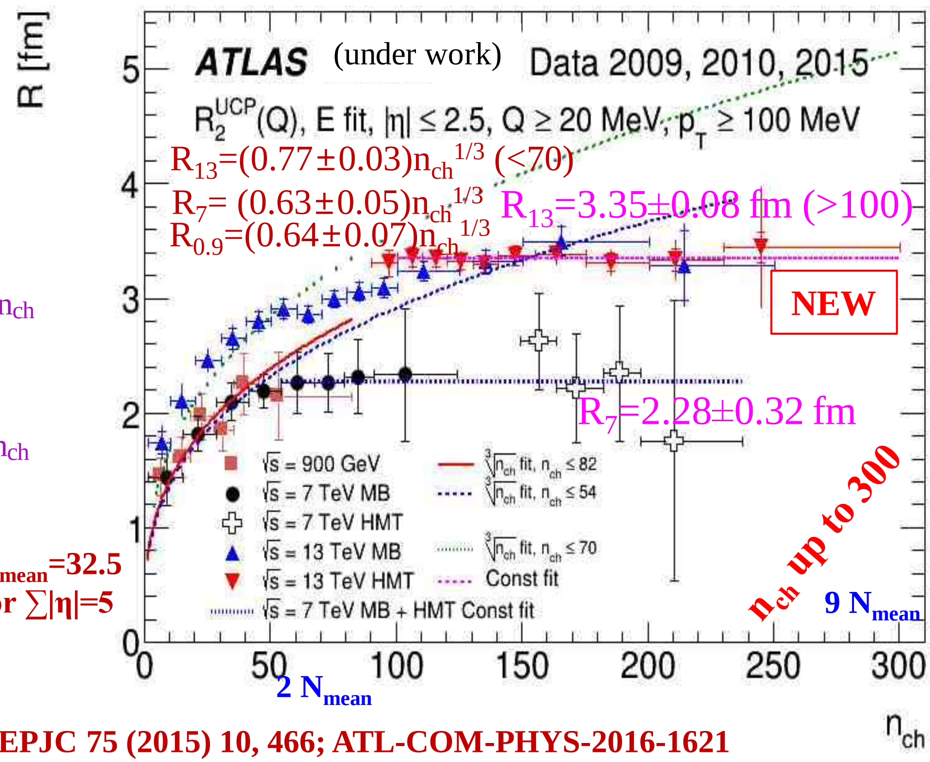
$I_{1(2)}$ - intensities, $\langle x \rangle$ - averaging over random phases
λ is the wavelength of the light, $\theta = d_{12}/L$

Varying d_{AB} one learns the angle, and using the individual wave vectors, the physical size of the source

BOSE-EINSTEIN CORRELATIONS AT 0.9 –13 TEV IN ATLAS

IP NASB (Minsk) & JINR (Dubna) & Comenius University (Bratislava)





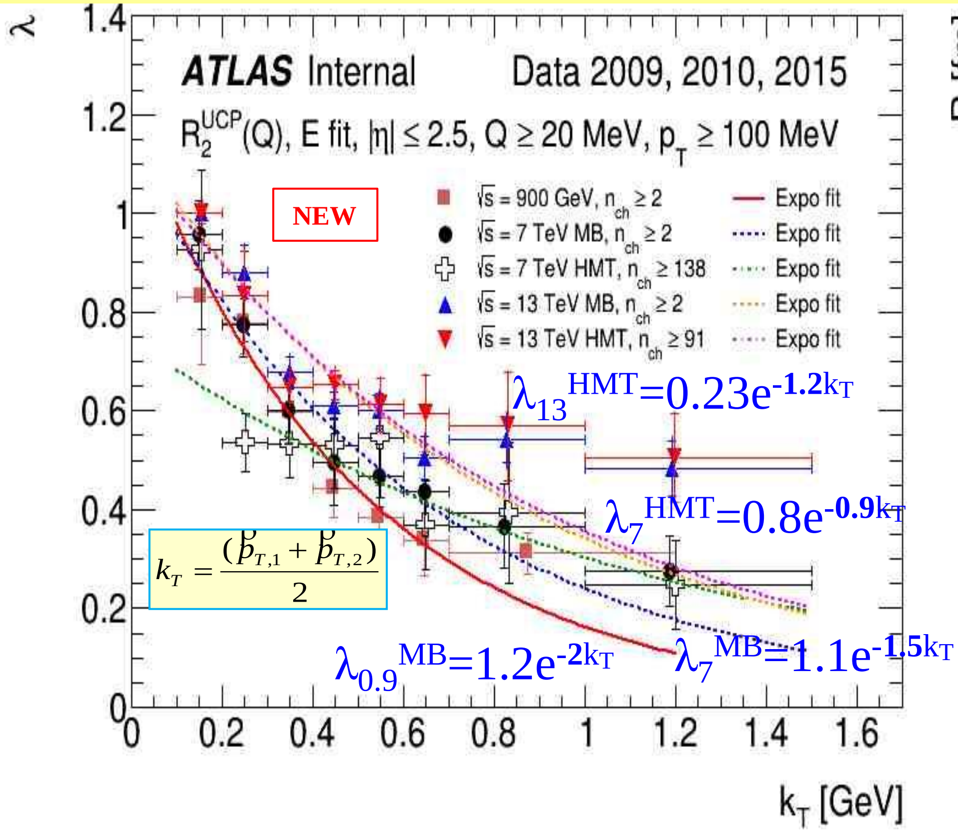
EPJC 75 (2015) 10, 466; ATL-COM-PHYS-2016-1621

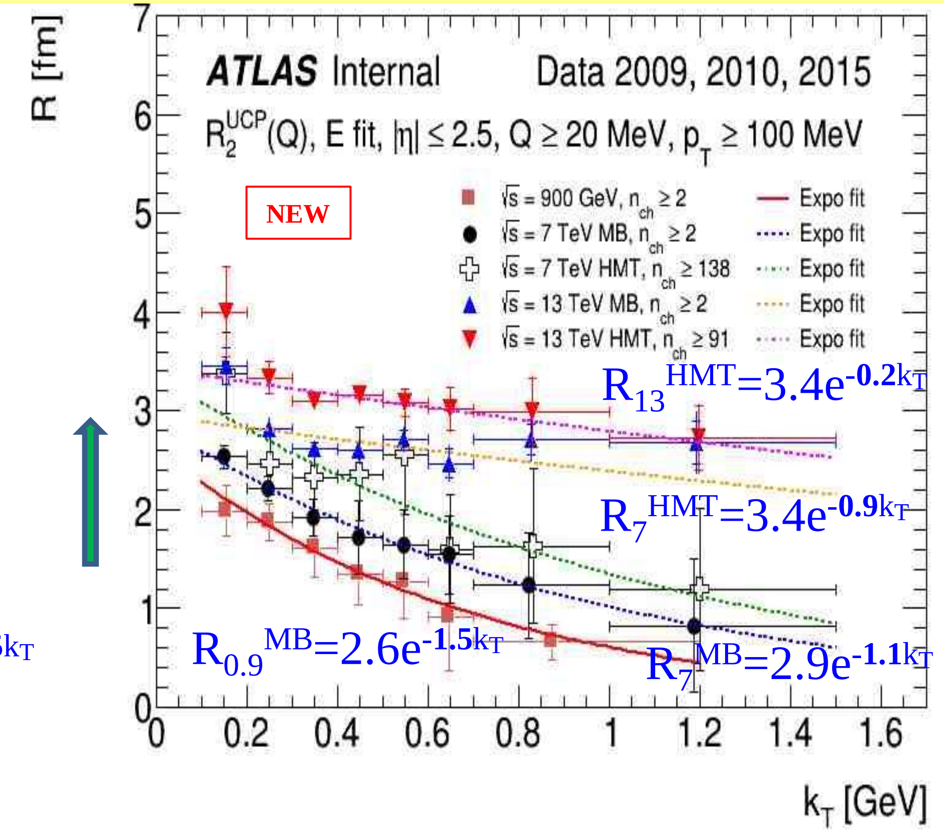
The results for Bose-Einstein Correlations for pairs of like-sign charged particles measured in the kinematic range p_T >100 MeV and |η|<2.5 in pp collisions at energy 0.9 – 13 TeV

- The multiplicity dependence of the BEC parameters characterizing the ***correlation strength*** and the ***correlation source size*** are investigated for multiplicities of up to ***very-high number of charged-particles***, $n_{ch} \approx 300$
- A ***saturation effect*** in the multiplicity dependence of the correlation source-size parameter is ***for the first time observed*** using the minimum-bias and high-multiplicity tracks 7, 13 TeV data

k_T dependence of BEC parameters at 0.9 – 13 TeV

EPJC 75 (2015) 10, 466; ATL-COM-PHYS-2016-1621





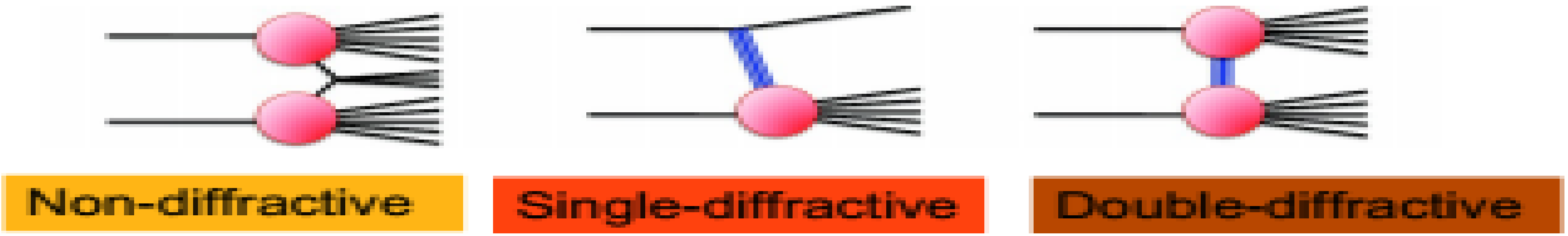
- **The λ values are (trigger) multiplicity-independent within uncertainties at 13 TeV**
- **The R values increase with increasing (trigger) multiplicity region**
- **The λ values decrease exponentially with k_T**
- **The R values decrease exponentially with k_T**

CHARGED-PARTICLE DISTRIBUTIONS AT 13 TEV

PL B758 (2016) 67–88, Eur.Phys.J. C 76 (2016) 502

The composition of inelastic p-p collisions:

Statistics: 9 million inelastic interactions



Perturbative QCD describes only the hard-scattered partons, all the rest is predicted with **phenomenological models.**

ND: QCD motivated models with many parameters; **Background** when >1 interactions per bunch crossing; **SD+DD** not well constrained by models.

Strange baryons with 30 < τ < 300 ps are excluded.

Task: measure spectra of primary charged particles corrected to hadron level.

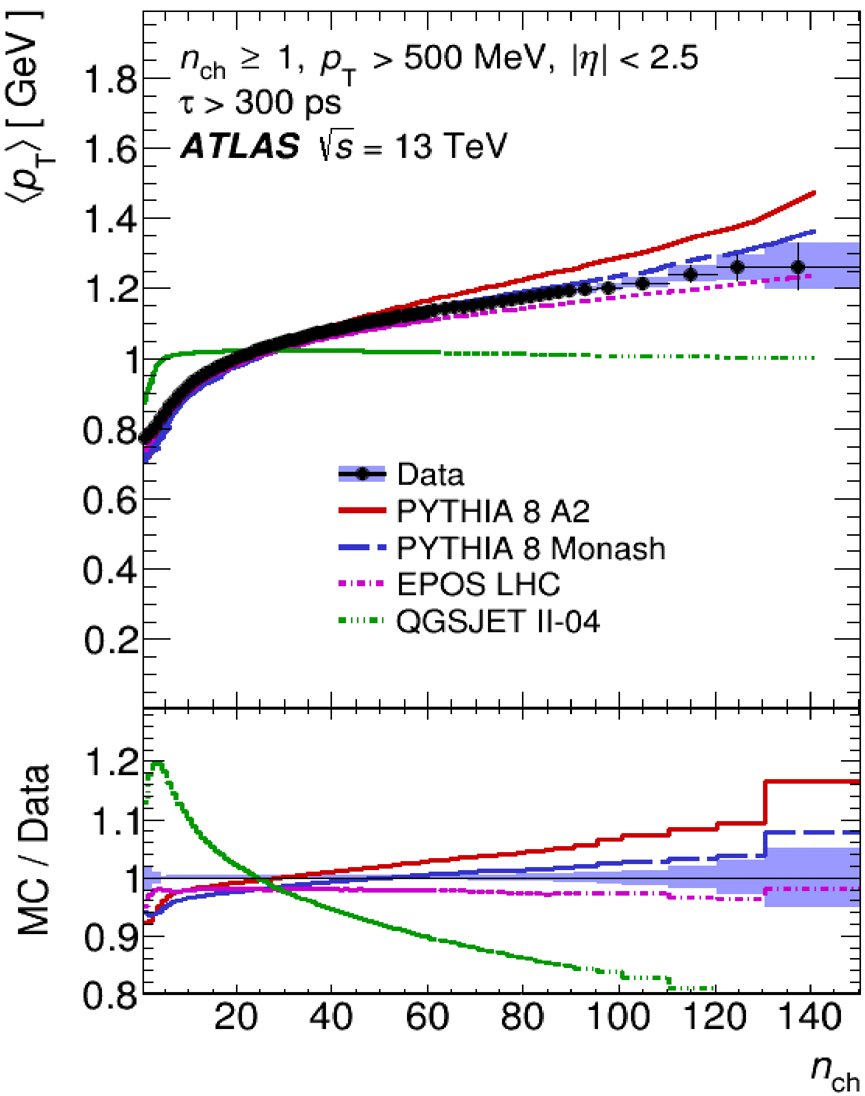
Multiplicity vs. η; Multiplicity vs. p_T; Multiplicity distributions

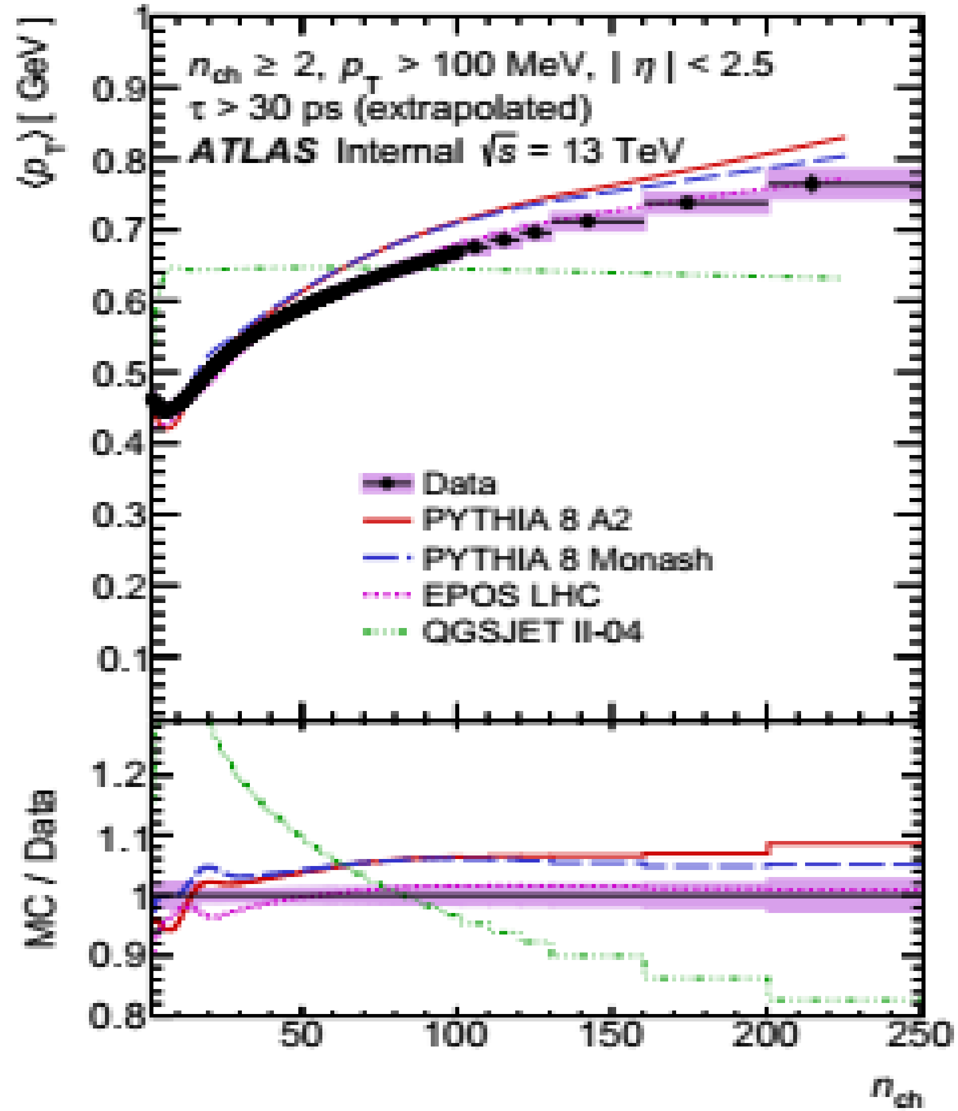
$$\frac{1}{N_{ch}} \cdot \frac{dN_{ch}}{d\eta}, \quad \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2 N_{ch}}{d\eta dp_T}, \quad \frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}}, \quad \langle p_T \rangle \text{ vs. } n_{ch}$$

Measurement – do not apply model dependent corrections and allow to tune models to data measured in well defined kinematic range.

AVERAGE TRANSVERSE MOMENTUM DISTRIBUTION

PL B758 (2016) 67–88



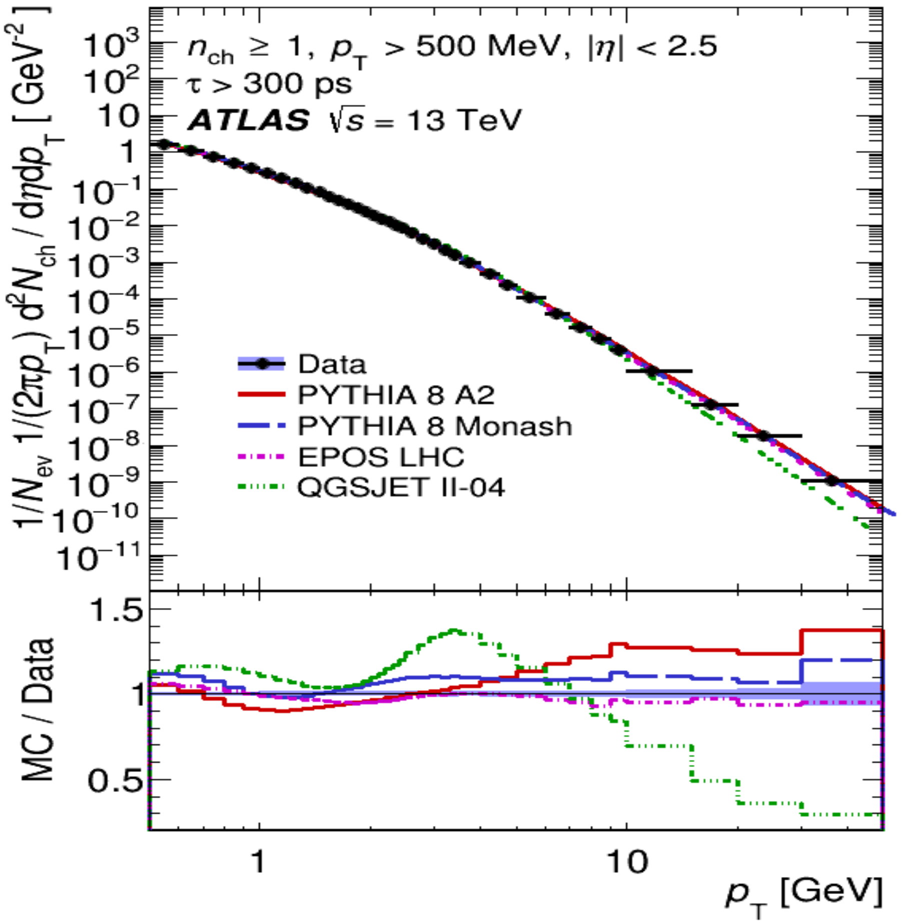


Mean p_T versus the charged-particle multiplicity distribution for p_T>0.1& 0.5 MeV

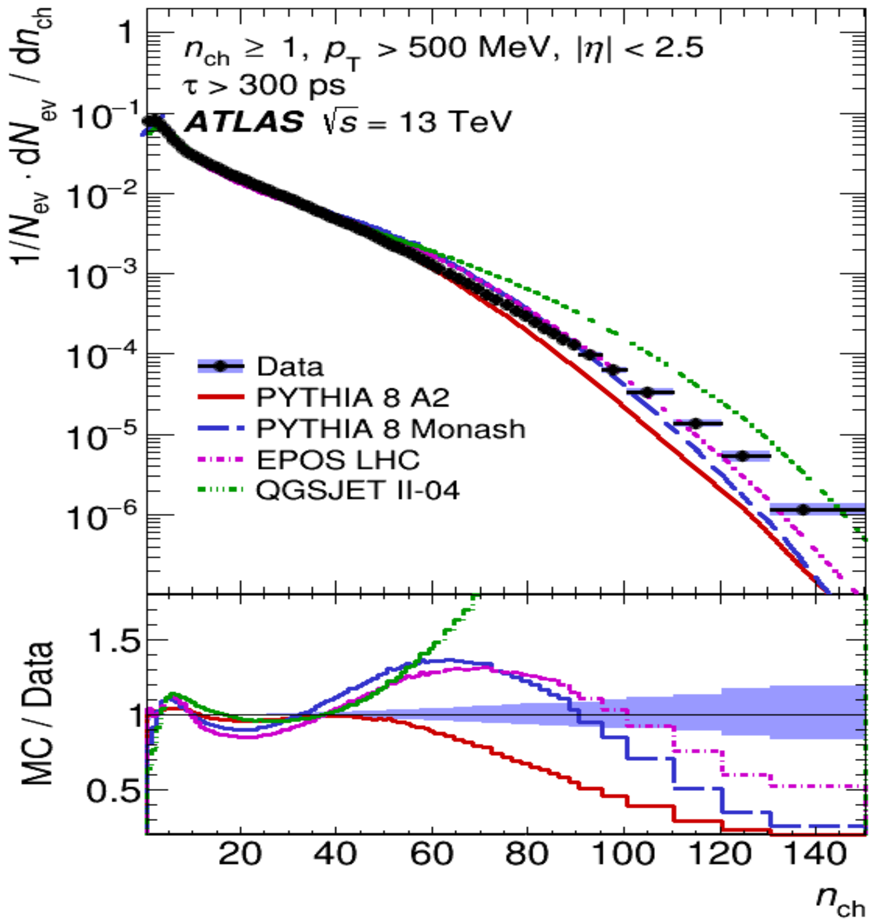
Models without colour reconnection, **QGSJET,** fail to model scaling with n_{ch} very well.

Charged-particle multiplicities vs p_T and multiplicity

PL B758 (2016) 67–88



Charged-particle multiplicity as a function of the p_T distribution for p_T>0.5 MeV



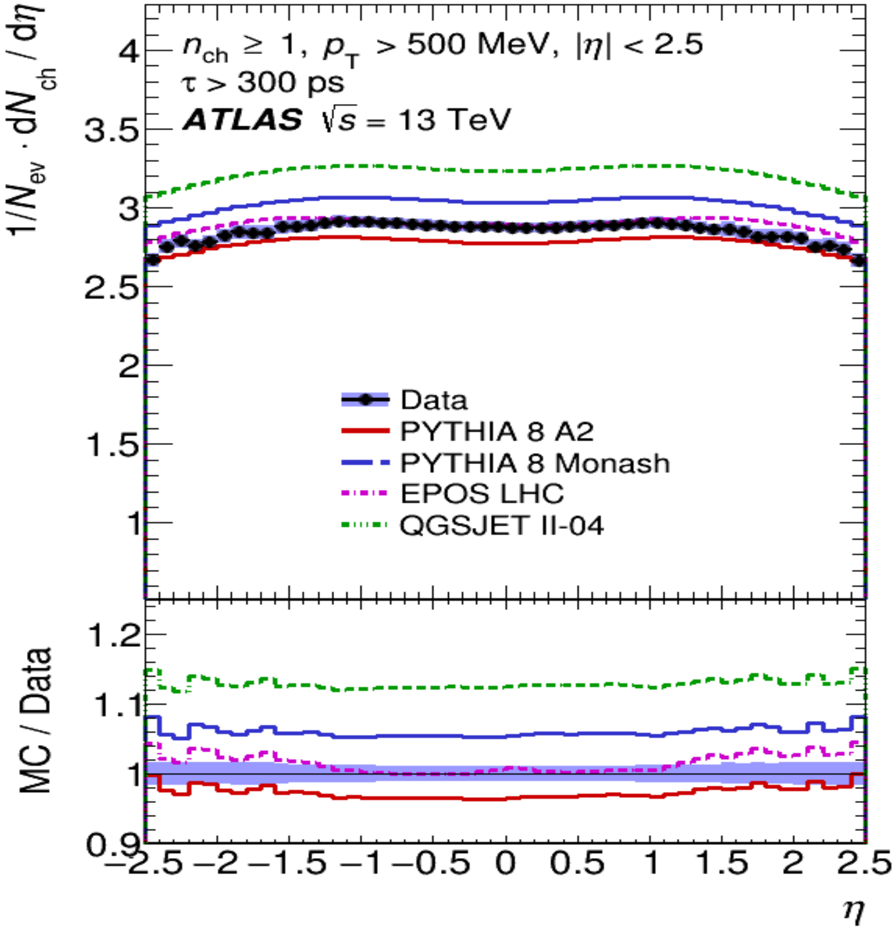
Charged-particle events as a function of the multiplicity distribution for p_T>0.5 MeV

Measurement spans 10 orders of magnitude. **EPOS** and **Pythia 8 Monash** give remarkably good predictions.

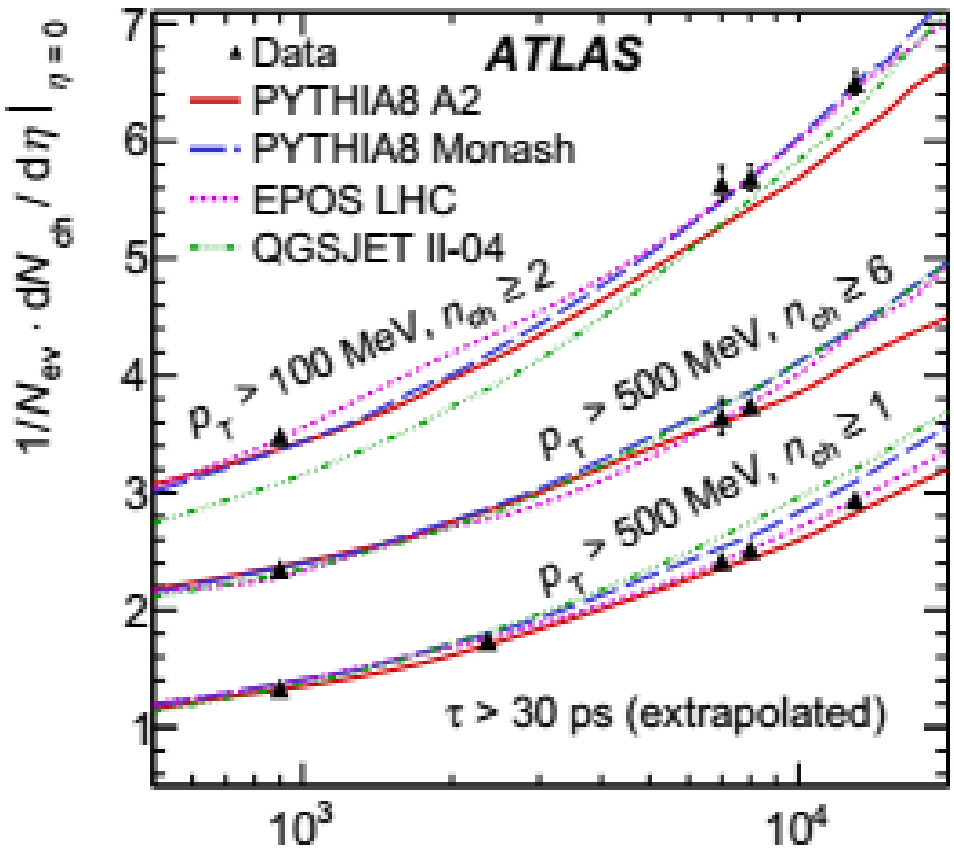
Low n_{ch} not well modelled by any MC; because of large contribution from diffraction.

CHARGED-PARTICLE MULTIPLICITIES VS η AND ENERGY

PL B758 (2016) 67–88, Eur.Phys.J. C 76 (2016) 502



Charged-particle multiplicity as a function of the η distribution for p_T>0.1& 0.5 MeV



The same shape in Models but different normalisation. **EPOS** and **Pythia8 Monash & A2** (p_T≥500 MeV) give remarkably good predictions.

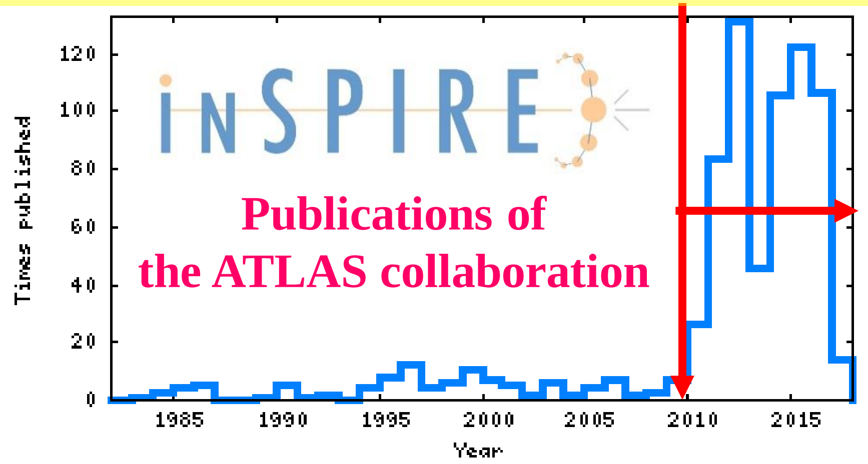
The mean number of primary charged particles increases by a factor of **2.2** when $\sqrt{s}$ increases by a factor of about **14** from **0.9 to 13 TeV**. EPOS and Pythia 8 A2 describe the dependence on $\sqrt{s}$ very well, while Pythia 8 Monash and QGSJET-ii predict a steeper rise in multiplicity with $\sqrt{s}$.

ATLAS COLLABORATION PUBLICATIONS

Citations Summary

	Citeable papers	Published only
Number of papers analyzed:	722	650
Number of citations:	70926	66575
Citations per paper (average):	98.2	102.4
h_{HEP} index [?]	123	122

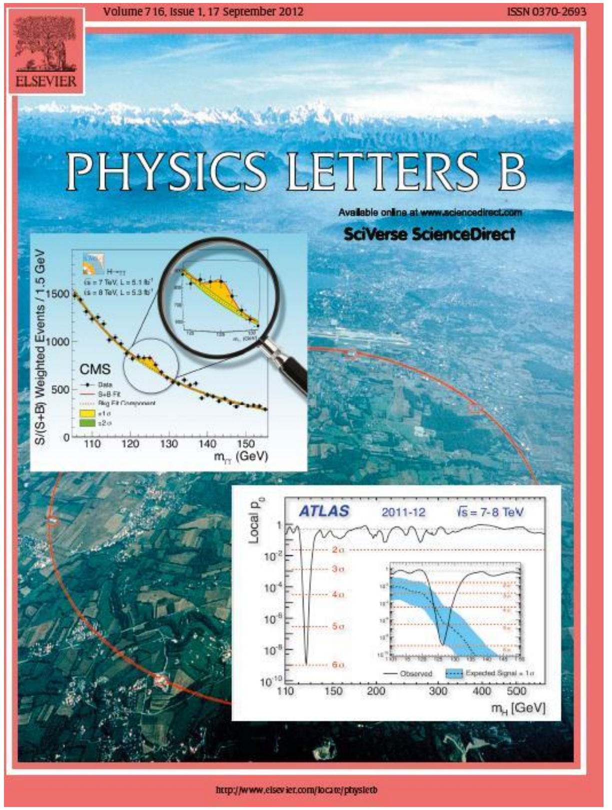
The h-index (or simply, 'h') is defined as the number of papers with citation number higher or equal to h.



Breakdown of papers by citations:

	Citeable papers	Published only
Renowned papers (500+)	17	13
Famous papers (250-499)	25	25
Very well-known papers (100-249)	122	121
Well-known papers (50-99)	162	161
Known papers (10-49)	263	258
Less known papers (1-9)	91	60
Unknown papers (0)	42	12

1. ATLAS Collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, **Phys. Lett. B716 (2012) 1-29, Cited by 7218**
2. ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, 437 pp., JINST 3 (2008) S08003, **Cited by 5467**
3. ATLAS Collaboration, The ATLAS Simulation Infrastructure, 53 pp., Eur. Phys. J. C70 (2010) 823-874, **Cited by 1565**



BONUS: PHYSICS MOTIVATION AT HL-LHC

The name of this game is Precision

Electroweak symmetry Breaking

1. **Higgs precision measurements** (coupling and spin-CP quantum numbers)
2. **Higgs rare and invisible decays** (H->μμ , H->Zγ,…)
3. **Top Yukawa coupling** (SH)
4. **Higgs self coupling**

Beyond the Standard Model

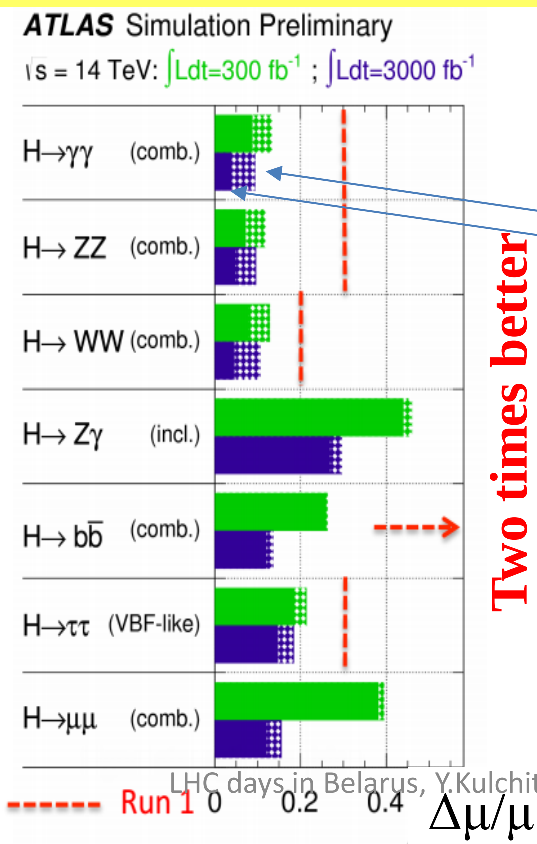
- **Higgs sector** (search for deviations from SM)
- **Dark matter**
- **SUSY**
- **Exotics**

HIGGS PRESISSION MEAGUREMENT

ATL-PHYS-PUB-2014-016

At HL-LHC:

- **100 million** SM Higgs bosons
- **~4-5%** precision for main channels
- **~10-20%** precision for rare modes
- will be able to quantify **small deviations from the SM**
- **3-4 times** more sensitivity in direct searches for additional Higgs bosons than at LHC



Two times better signal strength precision

Signal strength precision Δμ/μ *				
H→	L = 300 fb-1 (run 3)		L = 3000 fb-1 (LH-LHC)	
	w/o theory Δ (%)	w/ theory Δ (%)	w/o theory Δ (%)	w/ theory Δ (%)
γγ	9	13	4	9
WW	8	13	5	11
ZZ	7	11	4	9
bb	26	26	12	14
ττ	18	21	15	19
Zγ	44	46	27	30
μμ	38	39	12	16

* $\mu = \sigma x BR_{obs} / \sigma x BR_{SM}$

BONUS: EXOTIC & SUSY MOTIVATION AT HL-LHC

Heavy Kaluza–Klein gluons, g_{KK}, as produced in Randall–Sundrum (RS) models with a single warped extra dimension

ATL-PHYS-PUB-2013-003, ATL-PHYS-PUB-2014-007

ATLAS Mass reach for Exotic signatures

ATLAS @14 TeV	Z' → ee SSM 95% CL limit	g_{KK} → t t RS 95% CL limit	Dark matter M* 5σ discovery
300 fb^{-1}	6.5 TeV	4.3 TeV	2.2 TeV
3000 fb^{-1}	7.8 TeV	6.7 TeV	2.6 TeV

ATL-PHYS-PUB-2013-011, ATL-PHYS-PUB-2014-010, ATL-PHYS-PUB-2015-032

ATLAS Mass reach for SUSY particles

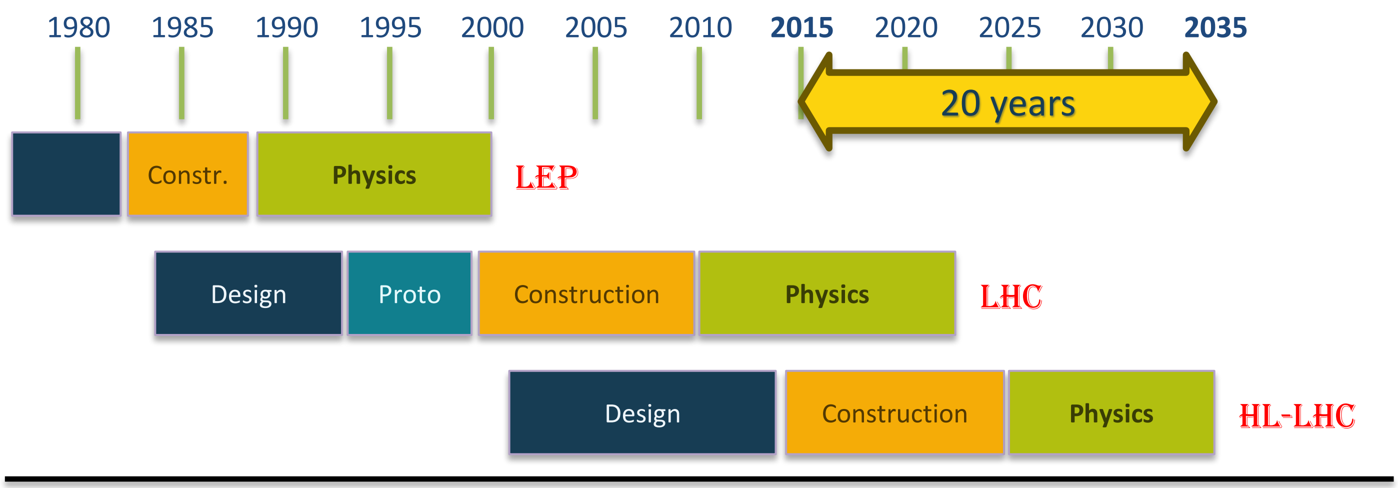
ATLAS projection	gluino mass	squark mass	stop mass	sbottom mass	χ_1^+ mass WZ mode	χ_1^+ mass WH mode
300 fb^{-1}	2.0 TeV	2.6 TeV	1.0 TeV	1.1 TeV	560 GeV	None
3000 fb^{-1}	2.4 TeV	3.1 TeV	1.2 TeV	1.3 TeV	820 GeV	650 GeV

Significant increase in mass reach for Exotics and SUSY signatures at HL-LHC (3000 fb^{-1})

BONUS: CERN CIRCULAR COLLIDERS + FUTURE CIRCULAR COLLIDER (FCC)

Challenge against time…

1. Detector degradation and ageing → **inject new technologies**

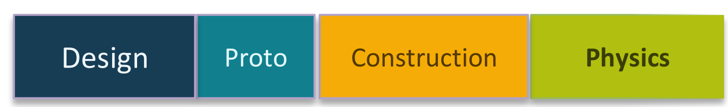


Challenge against time…

2. Developer community need to **transfer knowledge to the next generation**

3. Develop ***HL-LHC*** *detectors* **not forgetting what will come NEXT**

FUTURE CIRCULATED COLLIDER



“***Preparation of CERN’s future:*** **design studies for future accelerators: CLIC, FCC (includes HE-LHC)”**

CERN DG Fabiola Gianotti 23/06/2016

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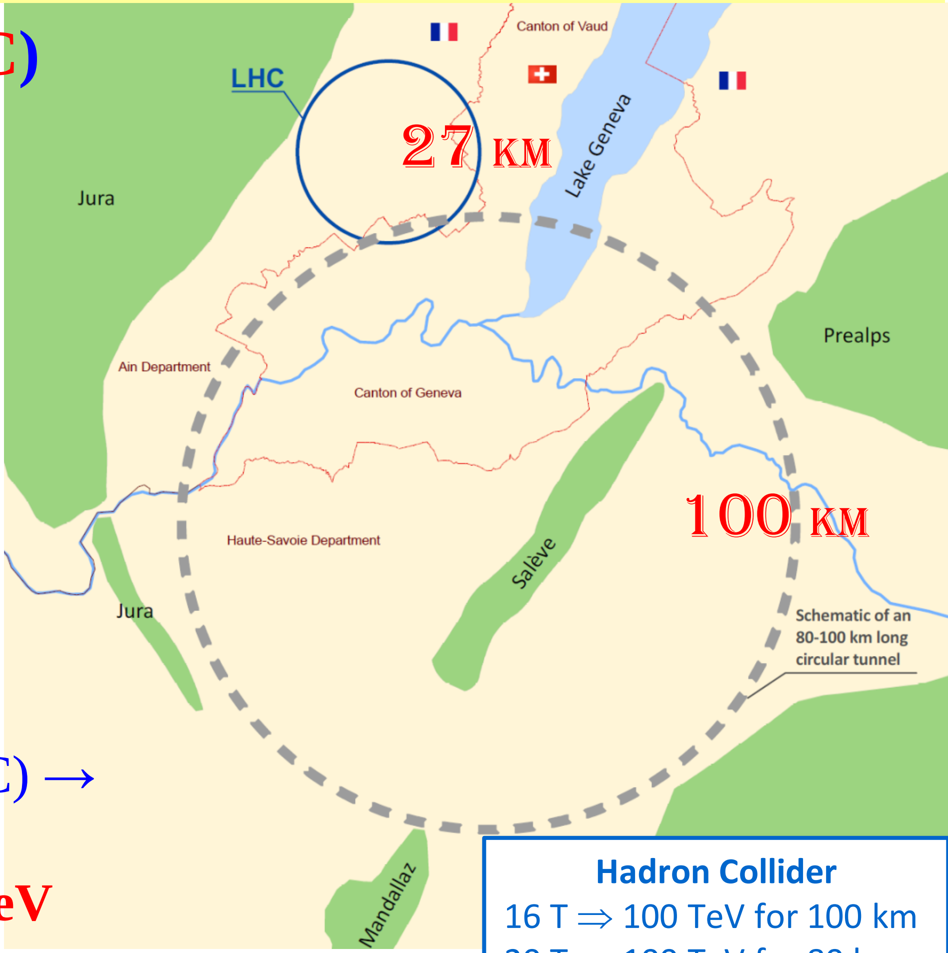
BONUS: FCC INFRASTRUCTURE & OPERATION

Future Circulated Collider (FCC) performance

- Center of mass energy: **100 TeV**
- Peak luminosity ultimate: **$\leq 30\text{x}10^{34}$**
- Bunch Crossing **<5 ns**
- Integrated luminosity ultimate **$\sim 1000\ fb^{-1}$** (average per year)
- 25 years operation, leading to **$\sim 20\ ab^{-1}$**



Hadron Collider
16 T ⇒ 100 TeV for 100 km
20 T ⇒ 100 TeV for 80 km

Consequence on detectors

- Boosted objects → up to **|η|=6** coverage
- High pileup and fast Bunch-Crossing (BC) → very fast and granular detectors
- Momentum resolution **≈15% at p_T=10 TeV**
- **~1 ns** sharp Bunch-Crossing Identification (BCID)
- Particle flow capability for calorimeters with high granularity **25 mrad^2**
- Fine timing against pileup → **< 100 ps**

Unit	Symbol	cm^2
femtobarn	fb	10^{-39}
attobarn	ab	10^{-42}

THANK YOU VERY MUCH FOR ATTENTION!

WELCOME TO THE IP NASB TEAM (MINSK ACADEMY) AT THE ATLAS EXPERIMENT AT LHC

ATLAS EXPERIMENT

http://atlas.ch