ALICE overview

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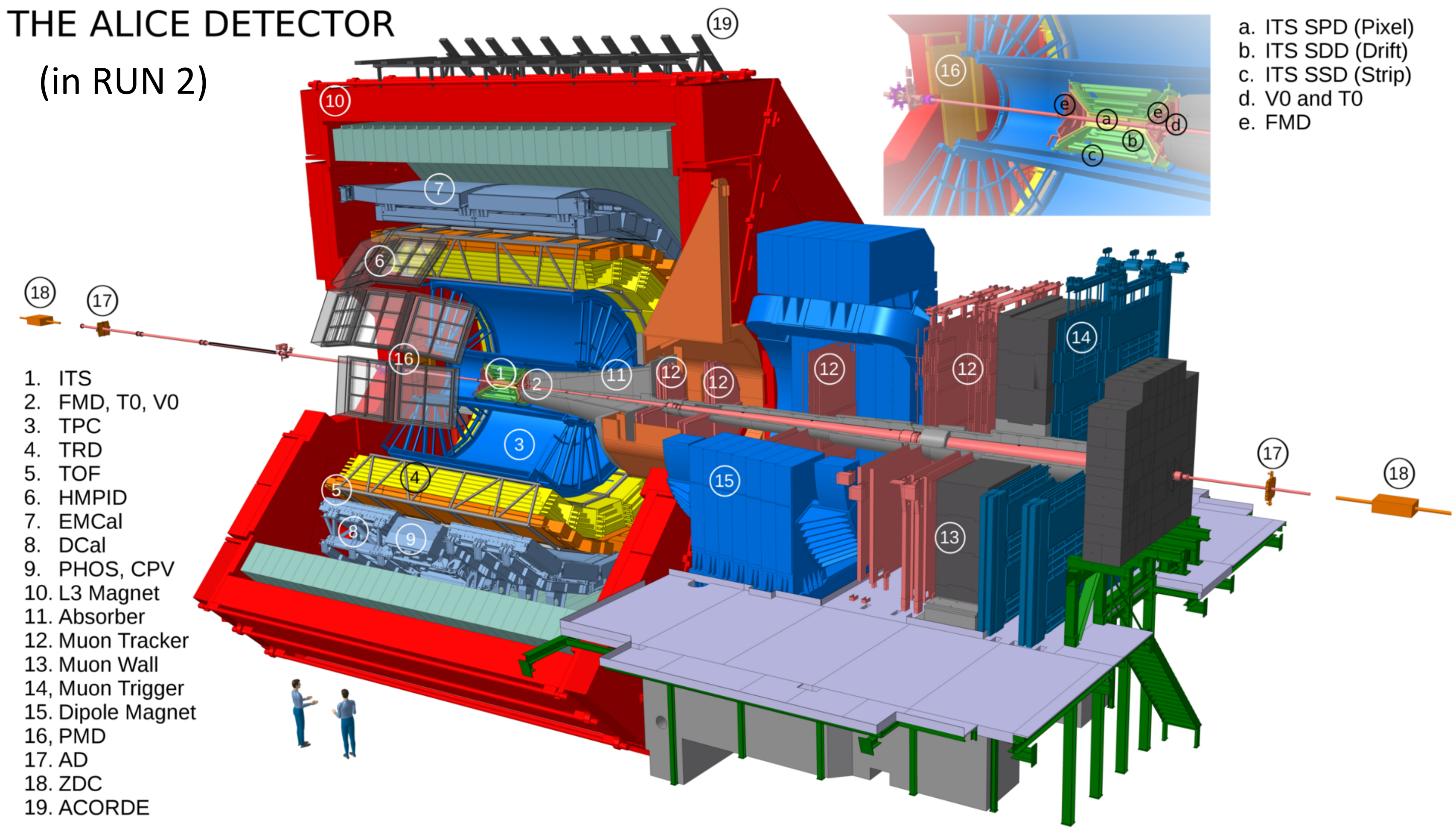
ALICE experiment



ALICE:

- 40 countries
- 177 institutes
- 1917 members
- 283 papers
  (by 4.11.2019)

ALICE – Finnish team today

3 seniors and 4 PhD-students:

- Sami Räsänen, HIP project leader
- Wladyslaw Trzaska, CERN project leader of FIT,
  represents forward detectors in ALICE Management Board
- DongJo Kim, coordinator of physics analysis group on flow in ALICE
- Maciej Slupecki, PhD-student, FIT
- Jasper Parkkila, PhD-student, flow analysis
- Heidi Rytkönen, PhD-student, FIT
- Oskari Saarimäki, PhD-student, jet analysis

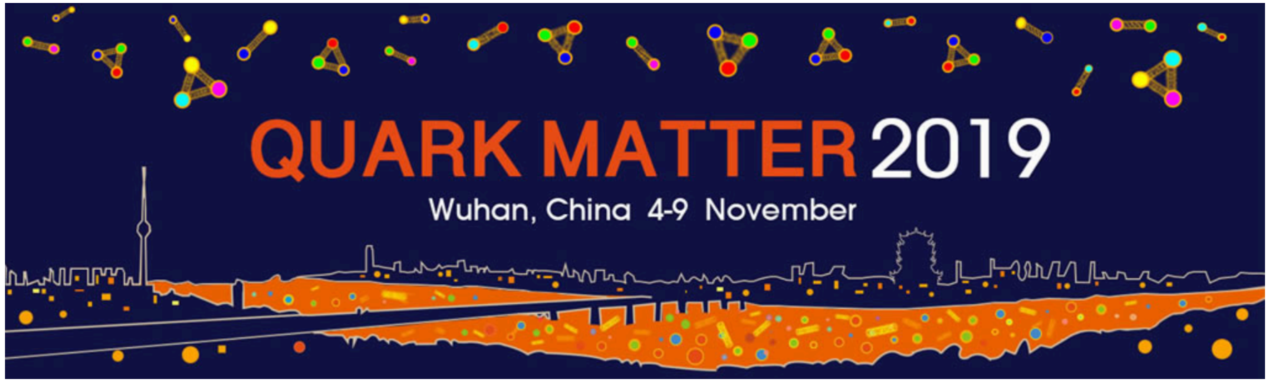
Main involvement in ALICE:

- Physics data analysis: collective flow and jets
- Fast Interaction Trigger (FIT) detector

  FINLAND: conceptual design of the detector!

ALICE @ Quark Matter 2019

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb–Pb	2010,2011	2.76	~75 μb^{-1}
	2015	5.02	~250 μb^{-1}
	2018	5.02	**~1 nb^{-1}**
Xe–Xe	2017	5.44	~0.3 μb^{-1}
p–Pb	2013	5.02	~15 nb^{-1}
	2016	5.02, 8.16	~3 nb^{-1}; ~25 nb^{-1}
pp	2009-2013	0.9,2.76,7,8	~200 μb^{-1}; ~100 nb^{-1}; ~1.5 pb^{-1}; ~2.5 pb^{-1}
	2015,2017	5.02	~1.3 pb^{-1}
	2015-2018	13	**~40 pb^{-1}**



ALICE @ QM19:

- 27 talks
- 90 posters
- 57 new analysis to be approved (internally)

Finnish team:

- 1 talk: Jasper Parkkila, collective flow
- 2 posters: Oskari Saarimäki, di-jet mass
  DongJo Kim, flow harmonic spectra

ALICE @ Quark Matter 2019

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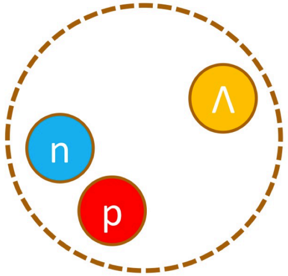
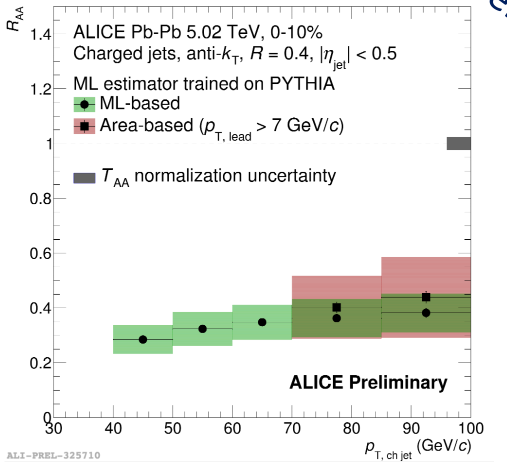
”Disclaimer”: Different person would have chosen different results

Selection of ALICE results at QM19:

ALICE strengths: particle identification and tracking



Backup 24: Hypertriton lifetime measurement
- exclude large deviation from free Λ lifetime
- exotic nuclei one of the key areas for ALICE in Run 3 and 4



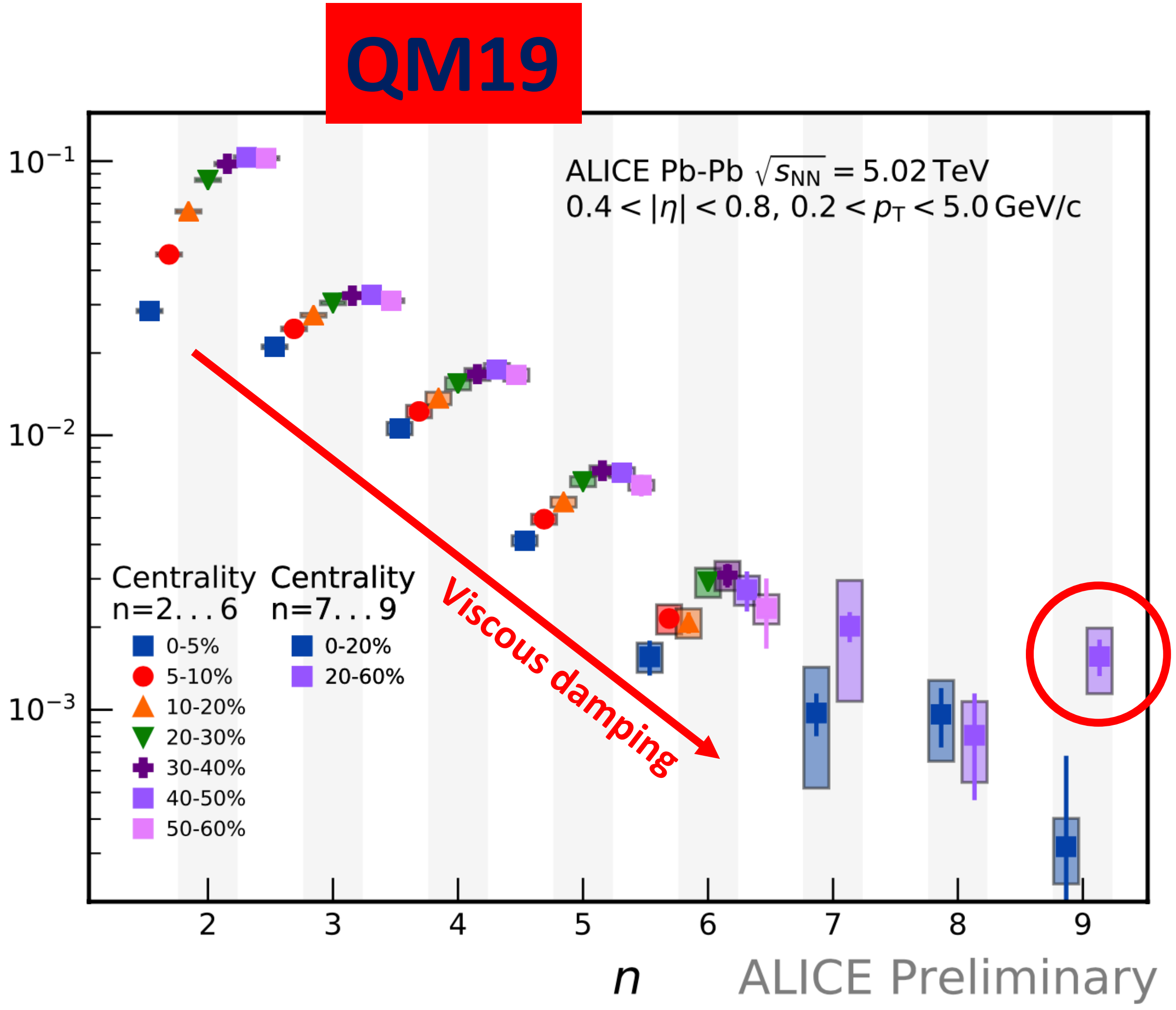
Backup 25: mass ordering of the non-linear flow coefficients – first measurement

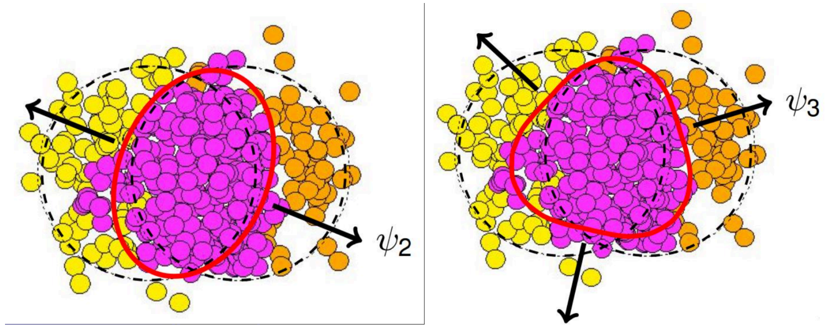
Backup 26: Using machine learning techniques to study jets down to $p_{T,jet}$ = 40 GeV in Pb+Pb

Backup 27: hadron-jet correlations, novel way to do data driven background subtraction in Pb+Pb

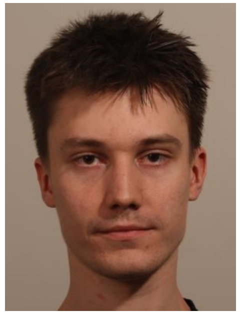
Backup 28: Jet physics with particle identification of the constituents
- D^0 fragmentation. ALICE also made first measurement in dead cone effect!

High order flow harmonics





Jasper



- Initial state models: geometrical anisotropy, hot spots
- Hydrodynamics: conversion to momentum anisotropies

$$\frac{dN}{d\phi} \propto \sum_{n=0}^{\infty} 2v_n \cos(n(\phi - \psi_n))$$

- Viscous damping (see DongJo's poster):

Shuryak, PRC84 (2011) 044912; Lacey *et al.*, arXiv: 1301.0165

$$v_n \propto e^{-\lambda n^2}$$

- Hint: $v_9 > v_8$, while in hydro goes down monotonically
Acoustic peak? **Shuryak, arXiv: 1710.03776**

Symmetric Cumulants SC(*k*,*l*,*m*)

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QM19

Poster by
Cindy Mordasini (TUM)

New in QM19:

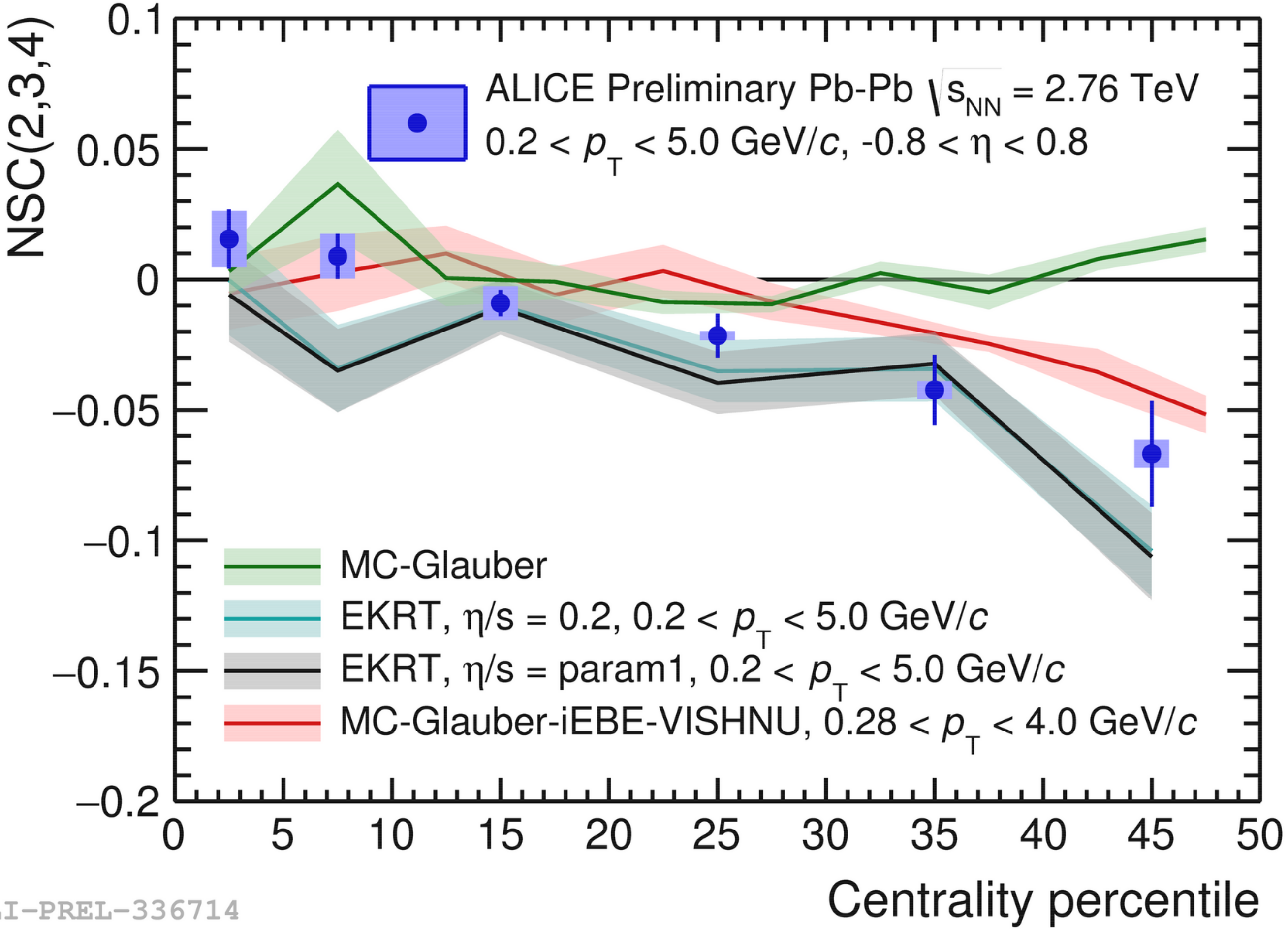
The first measurement of correlation between three flow amplitudes

$$\mathrm{SC}(k,l,m) = \langle v_k^2 v_l^2 v_m^2 \rangle - \langle v_k^2 v_l^2 \rangle \langle v_m^2 \rangle - \langle v_k^2 v_m^2 \rangle \langle v_l^2 \rangle - \langle v_l^2 v_m^2 \rangle \langle v_k^2 \rangle + 2 \langle v_k^2 \rangle \langle v_l^2 \rangle \langle v_m^2 \rangle$$

$$\mathrm{NSC}(k,l,m) = \frac{\mathrm{SC}(k,l,m)}{\langle v_k^2 \rangle \langle v_l^2 \rangle \langle v_m^2 \rangle}$$

SC(2,3,4) = 0 IF correlations originate from elliptic geometry only
→ not observed

Finnish contributions:
- Harri Niemi: EKRT calculations
- DongJo Kim: ALICE

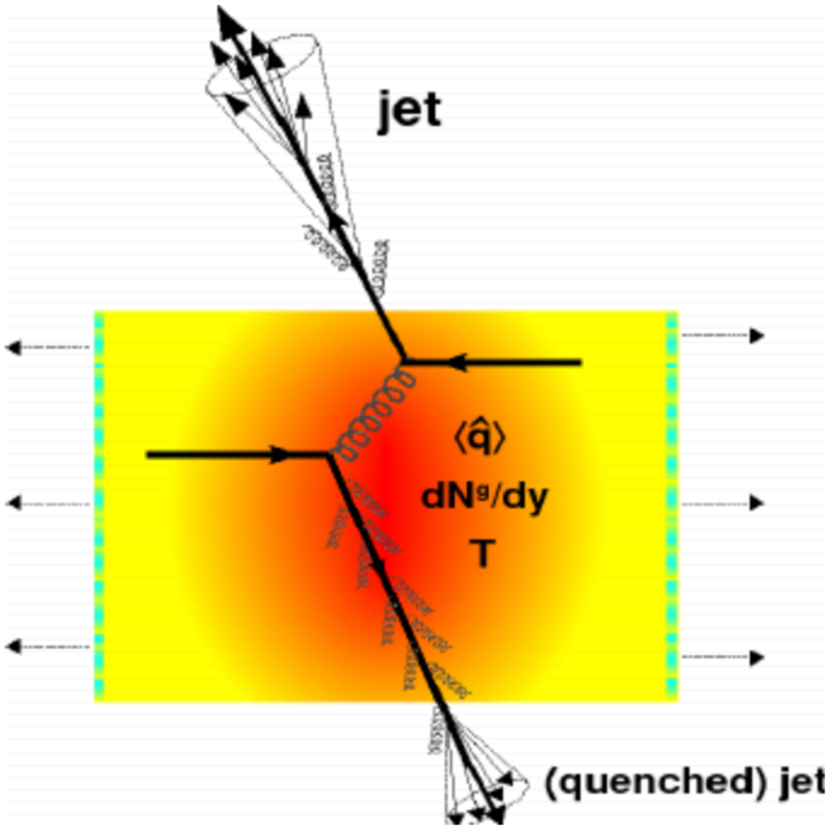


ALI-PREL-336714

Di-jet studies by Oskari

Oskari

”Centrality dependence of di-jet invariant mass in Pb+Pb”



Di-jets in Pb+Pb : Motivation

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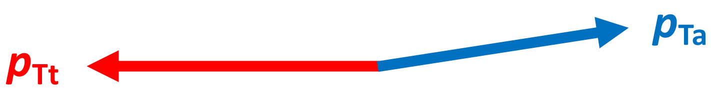


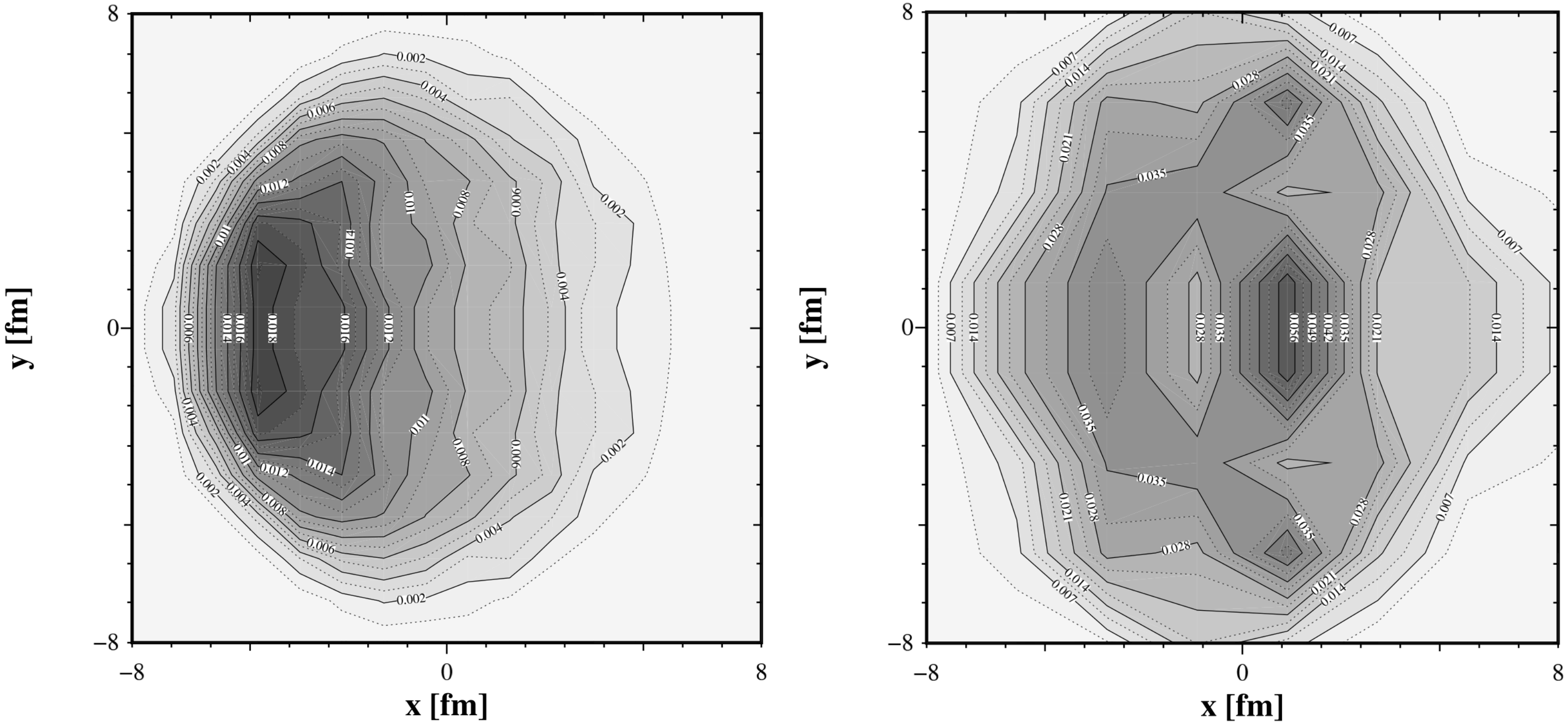
Theoretical premise:

Di-jet production vertices may lie deeper in the medium

=> on the average, di-jet *may have* a longer in-medium path length

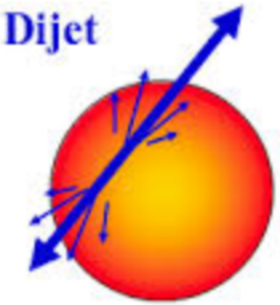
=> new constraints to energy loss

Eskola and Renk, Phys.Rev. C75 (2007) 054910

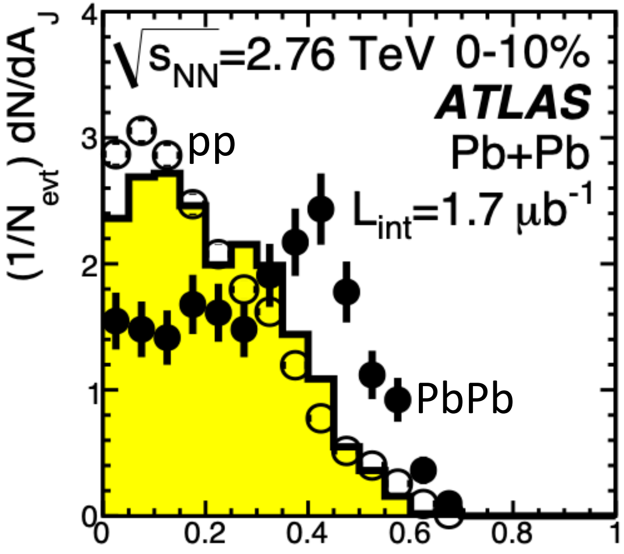


Probability density of finding a parton production vertex at (x,y) given in event with
(left) with **8 < p_{Tt} < 15 GeV** (to –x direction)
(right) with **8 < p_{Tt} < 15 GeV** and back-to-back hadron with **4 < p_{Ta} < 6 GeV**

Di-jets in Pb+Pb : Motivation

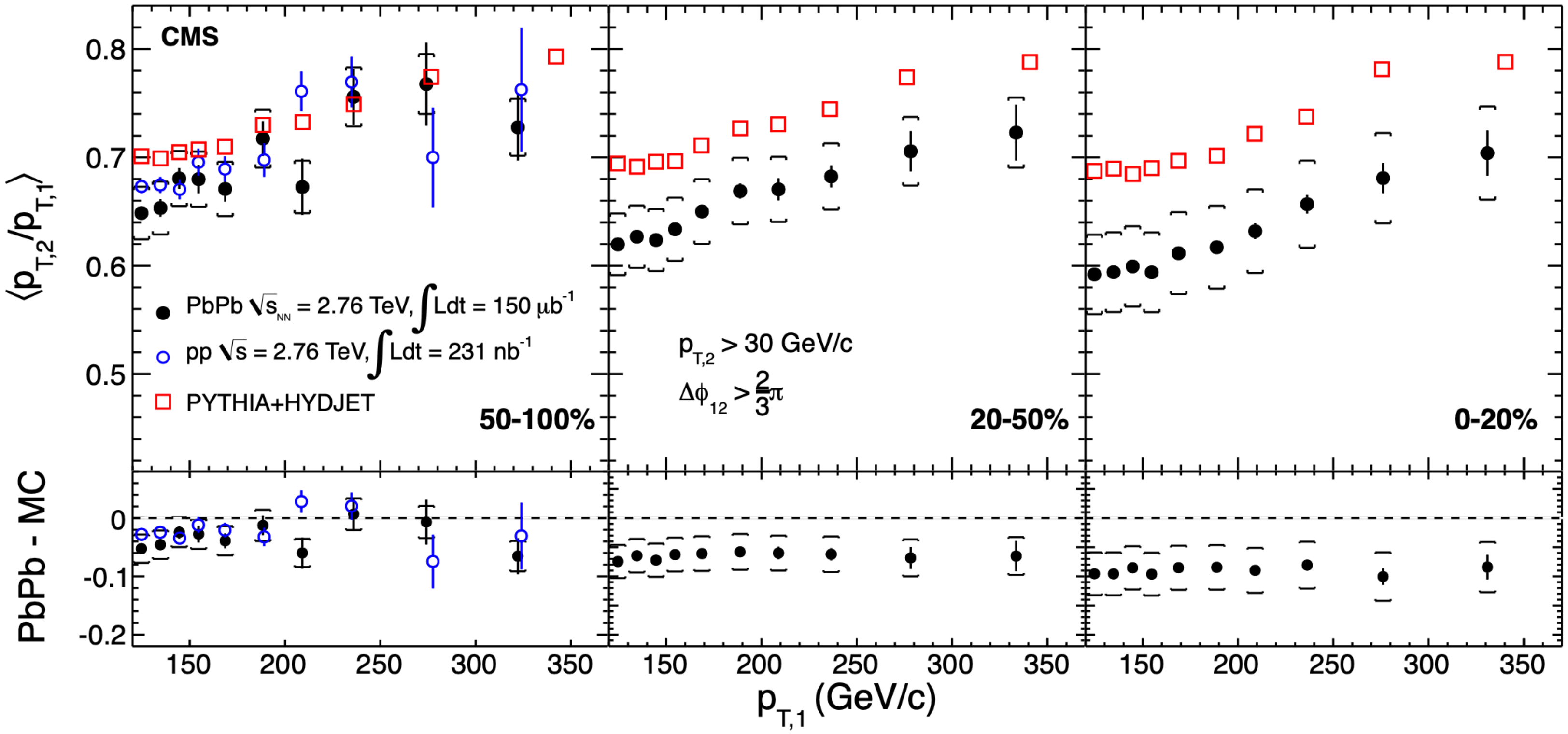


ATLAS, Phys. Rev. Lett. 105 (2010) 252303



$$A_J = \frac{E_1 - E_2}{E_1 + E_2}$$

CMS, Phys. Lett. B 712 (2012) 176



Experimentally known:

Di-jet partner heavily supressed in Pb+Pb
=> clear imbalance => mass modified

Di-jet mass analysis in ALICE

Di-jet invariant mass:

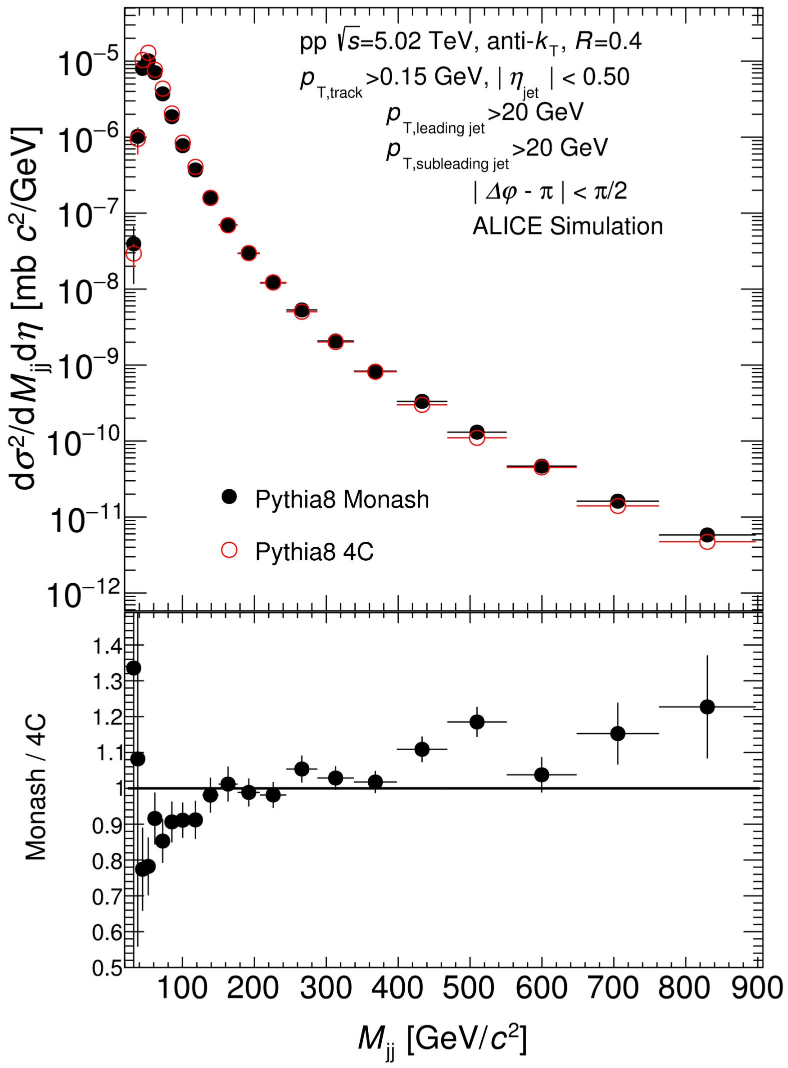
$$M_{jj}^2 = m_1^2 + m_2^2 + 2(m_{T1}m_{T2}\cosh(\Delta y) - p_{T1}p_{T2}\sin(\Delta\phi))$$
$$\approx 2\,p_{T1}p_{T2}(\cosh(\Delta\eta) - \sin(\Delta\phi)) \xrightarrow{\text{ideal 2-to-2}} 4p_T^2$$

ATLAS PRL105, 252303 : $E_{T1} > 100$ GeV and $E_{T2} > 25$ GeV
CMS PLB712, 176 : $p_{T1} > 130$ GeV and $p_{T2} > 30$ GeV

ALICE $p_{T1,2} > 20$ GeV in pp, p+Pb; to be studied in Pb+Pb
⇔ push down to low masses

Current situation:

- Study cold nuclear matter effects with R_{pA}
- p+Pb and pp results close to final
- Response matrix and MC data (Figure) approved



ALICE upgrade at LS2

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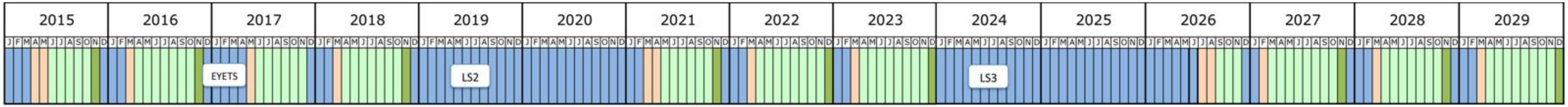


↑ **Now.** **START high-luminosity heavy ion**

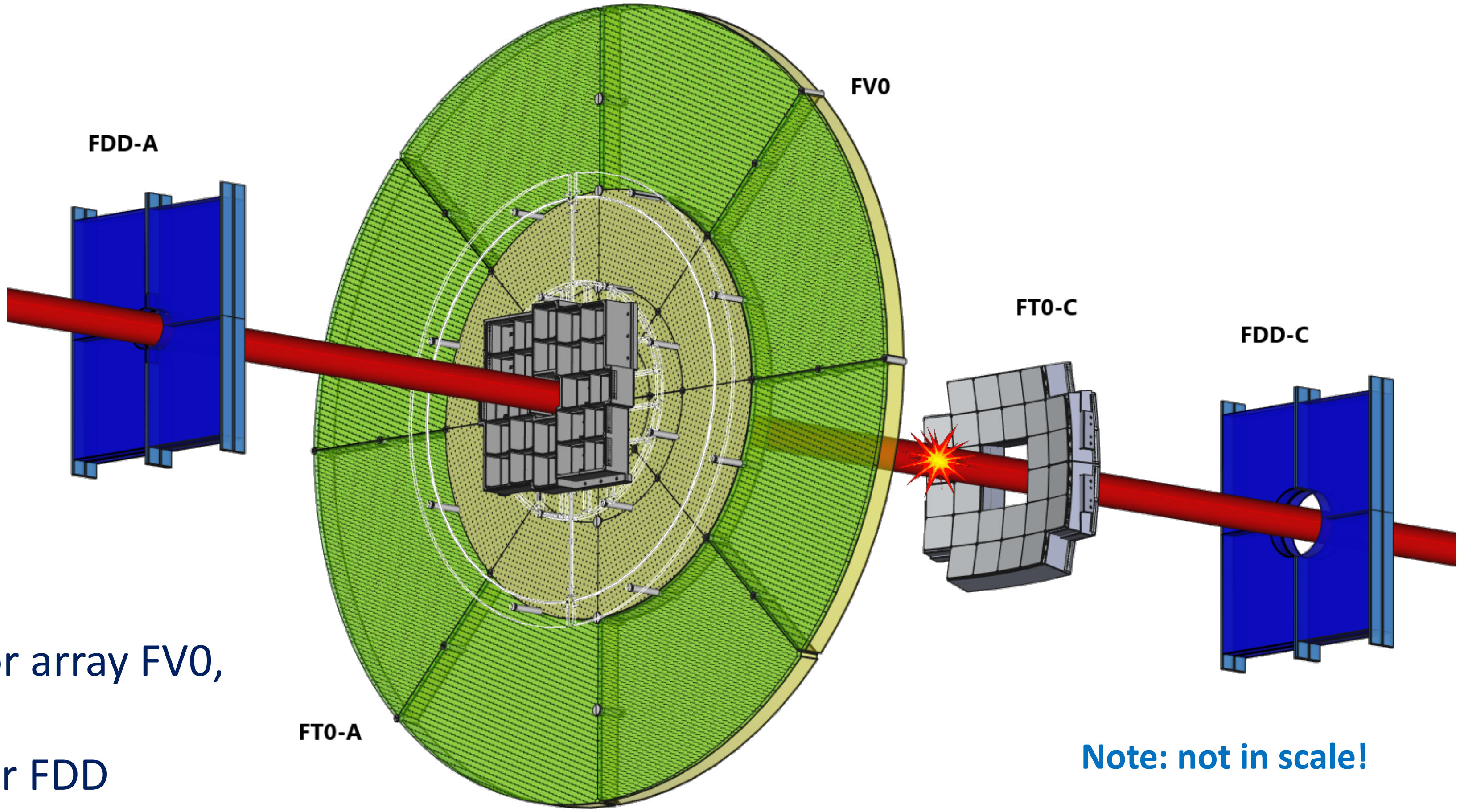
CERN-LHCC-2012-012 CERN-LHCC-2013-023 CERN-LHCC-2013-013 CERN-LHCC-2013-019 CERN-LHCC-2015-006 CERN-LHCC-2015-001

Finnish contributions:

- QA of GEM foils used in the readout of the new ALICE TPC at HIP detector lab (finished in 2017)
- **Fast Interaction Trigger (FIT) detector upgrade**
  - CERN level project leadership, conceptual design of the detector!

- The main Finnish contribution

Fast Interaction Trigger - FIT



Note: not in scale!

FIT consists of:

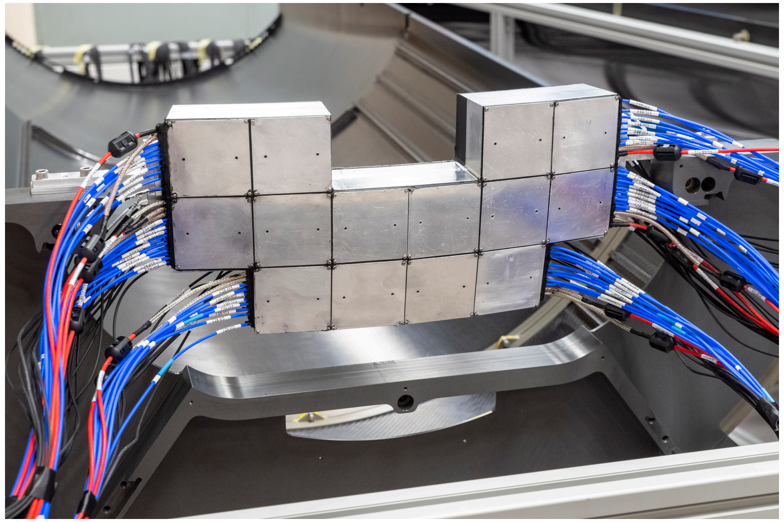
- Timing detector FT0
- Large acceptance scintillator array FV0, particularly for centrality
- Forward Diffractive detector FDD

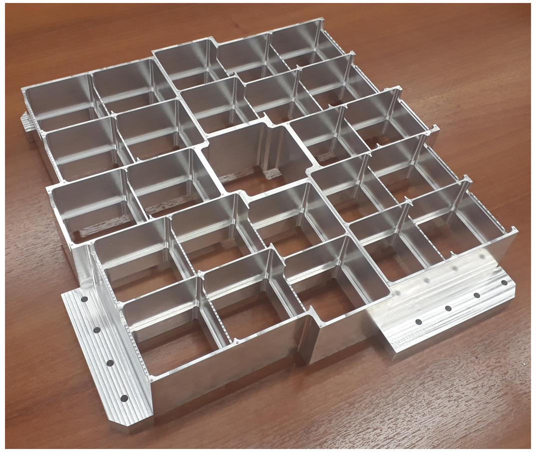
FIT – commissioning in time

FV0 frame ready

FV0 scintillators arrived to CERN

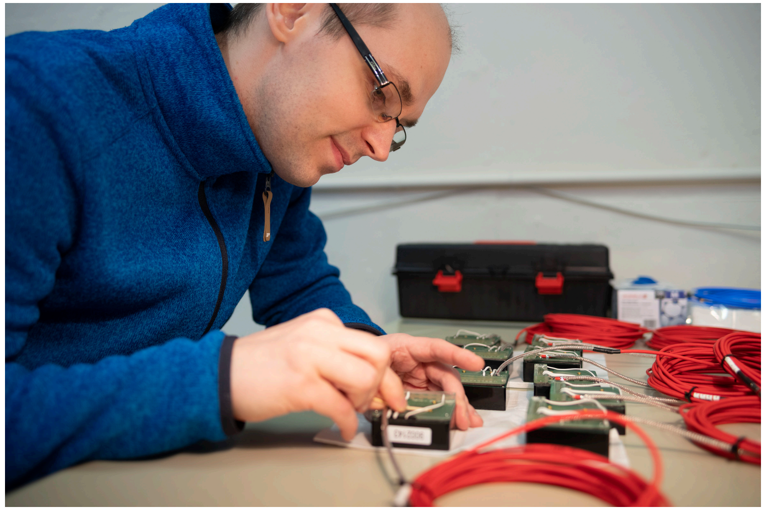
FT0-C integrated with MFT barrel



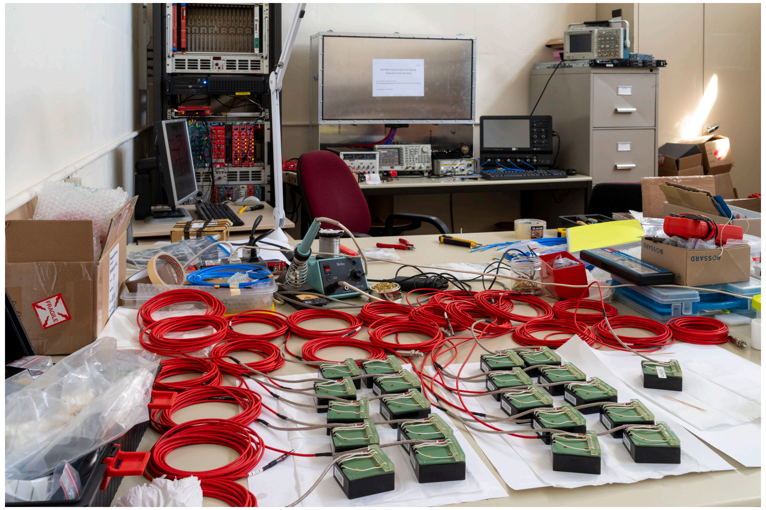


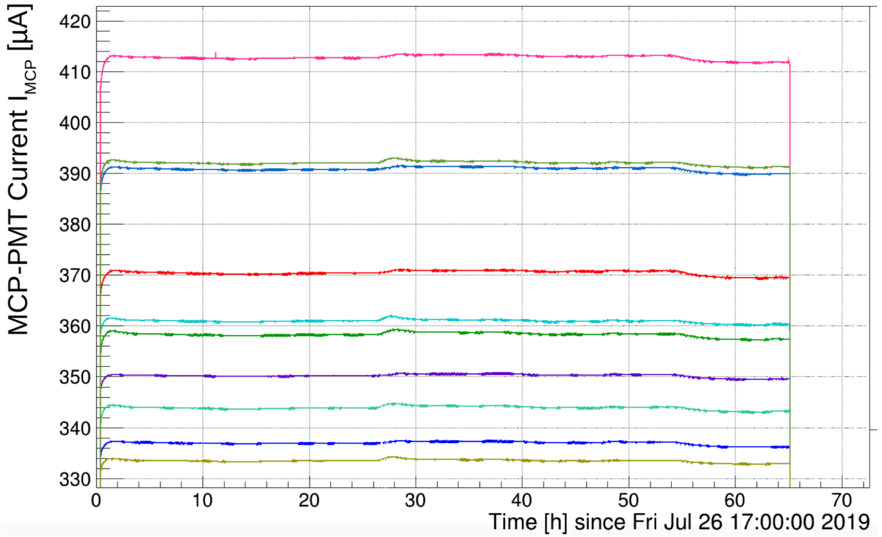
FT0-A frame ready for assembly

FIT – Finnish team at the moment



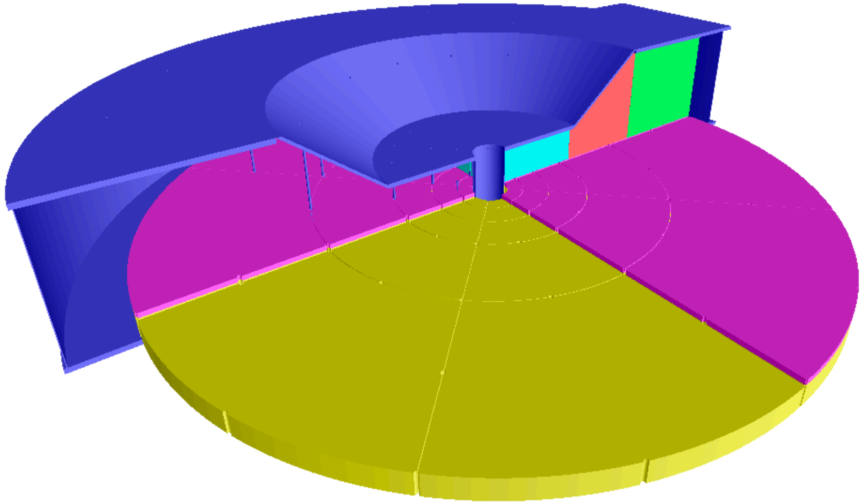
Maciej





Versatile tasks in commissioning

- Simulations of performance of FIT
- FIT-T0 MCP-PMT characterization
- FIT-V0 geometry to O^2
- raw data from FIT, detector level code
- event plane and centrality resolution studies

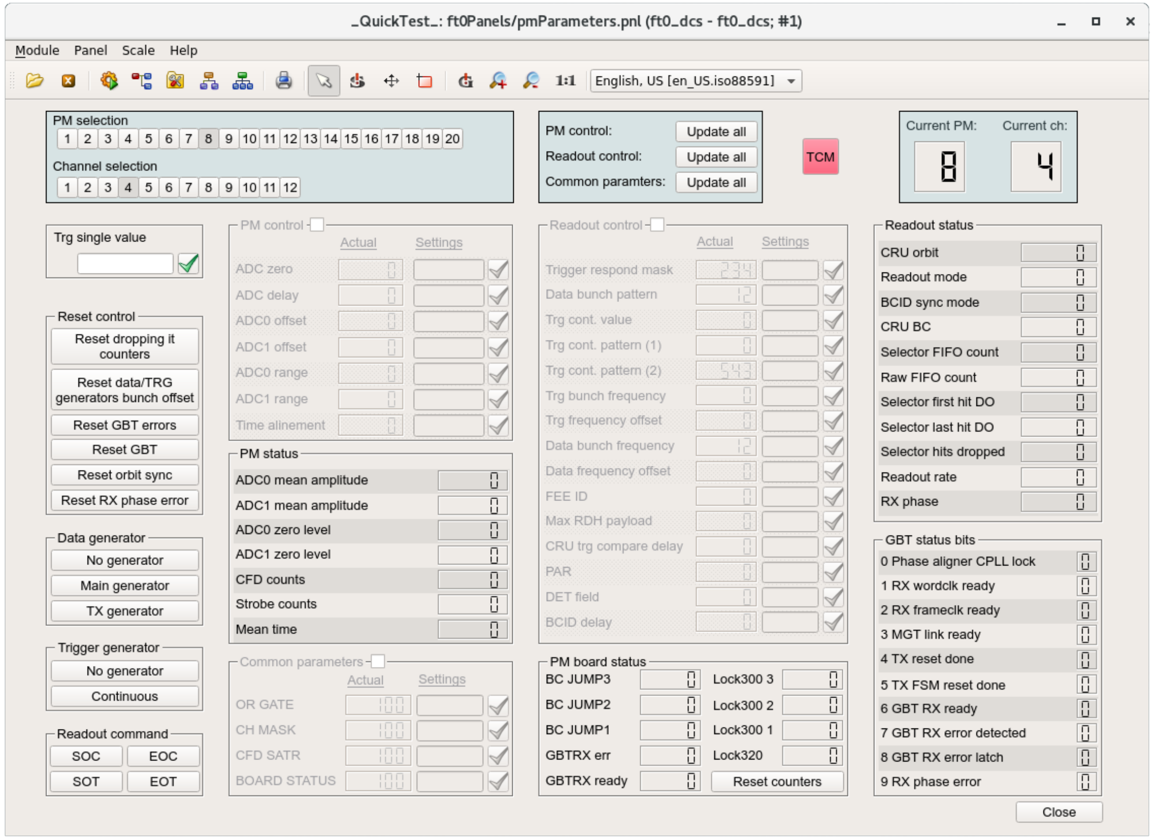


FIT – Finnish team at the moment

Heidi

Develop Detector Control System (DCS):

- Now: communication between FIT front end electronics (Processing Module, PM) and control server
- Example: control panel of FIT PM →



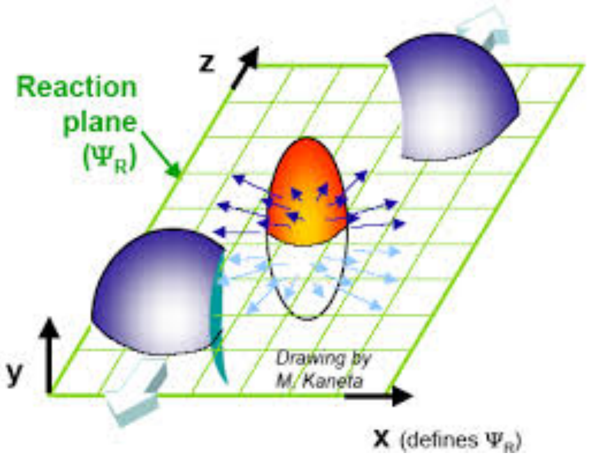
Event plane studies:

- Determination and resolution
- Detector calibration
- Together with Oskari Saarimäki

Event plane determination

Reaction plane Ψ_R = plane determined by impact parameter and beam

- Ψ_R cannot be determined experimentally
- Fluctuations => Participant Plane Ψ_{PP} != Ψ_R
  => observed flow coefficient v_n needs to be corrected

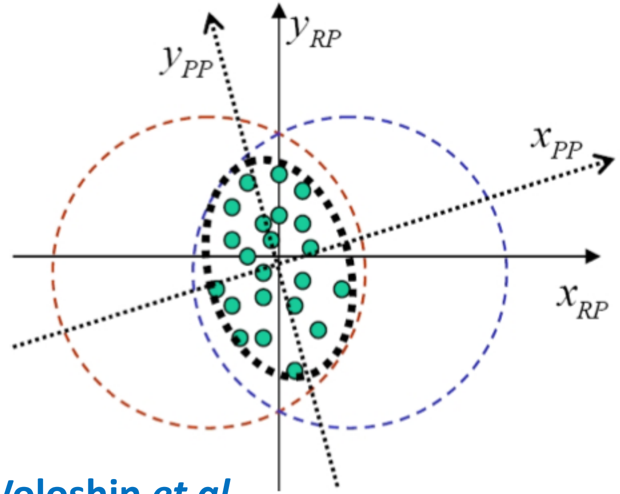


Experimentally one measures flow vectors with components:

$$Q_{n,x} = \sum_{i \in particles} w_i \cos(n\phi_i) \;\; ; \;\; Q_{n,y} = \sum_{i \in particles} w_i \sin(n\phi_i)$$

Where (most often) weight w_i = 1 or $p_{T,i}$. Event Plane (EP) angles ψ_n:

$$\psi_n = \frac{1}{n} \tan^{-1}\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$



Typical language, when power n not stated: ("event plane") = ψ_2

S.A. Voloshin *et al.*, Landolt-Bornstein 23 (2010) 293-333, arXiv: 0809.2949 [nucl-ex]

Event plane resolution

With event plane angles, *observed* flow coefficients:

$$v_n^{obs} = \langle \cos(n(\phi_i - \psi_n)) \rangle$$

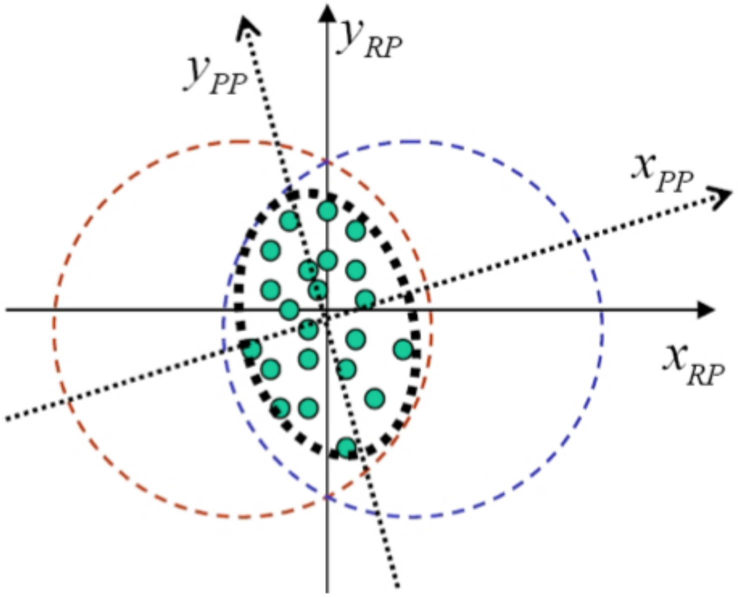
However, since ψ_n != Ψ_R , the flow coefficient needs to be corrected with resolution parameter

$$v_n^{true} = \frac{v_n^{obs}}{R_n^{true}}$$

where true event plane resolution

$$R_n^{true} = \langle \cos(n(\psi_n - \Psi_R)) \rangle$$

We still have unmeasurable Ψ_R. Get rid of with *sub event method* such that $R_n^{true} \approx R_n^{sub}$. Details of the method not discussed here.



S.A. Voloshin *et al.*, Landolt-Bornstein 23 (2010) 293-333, arXiv: 0809.2949 [nucl-ex]

Toy Monte Carlo simulation

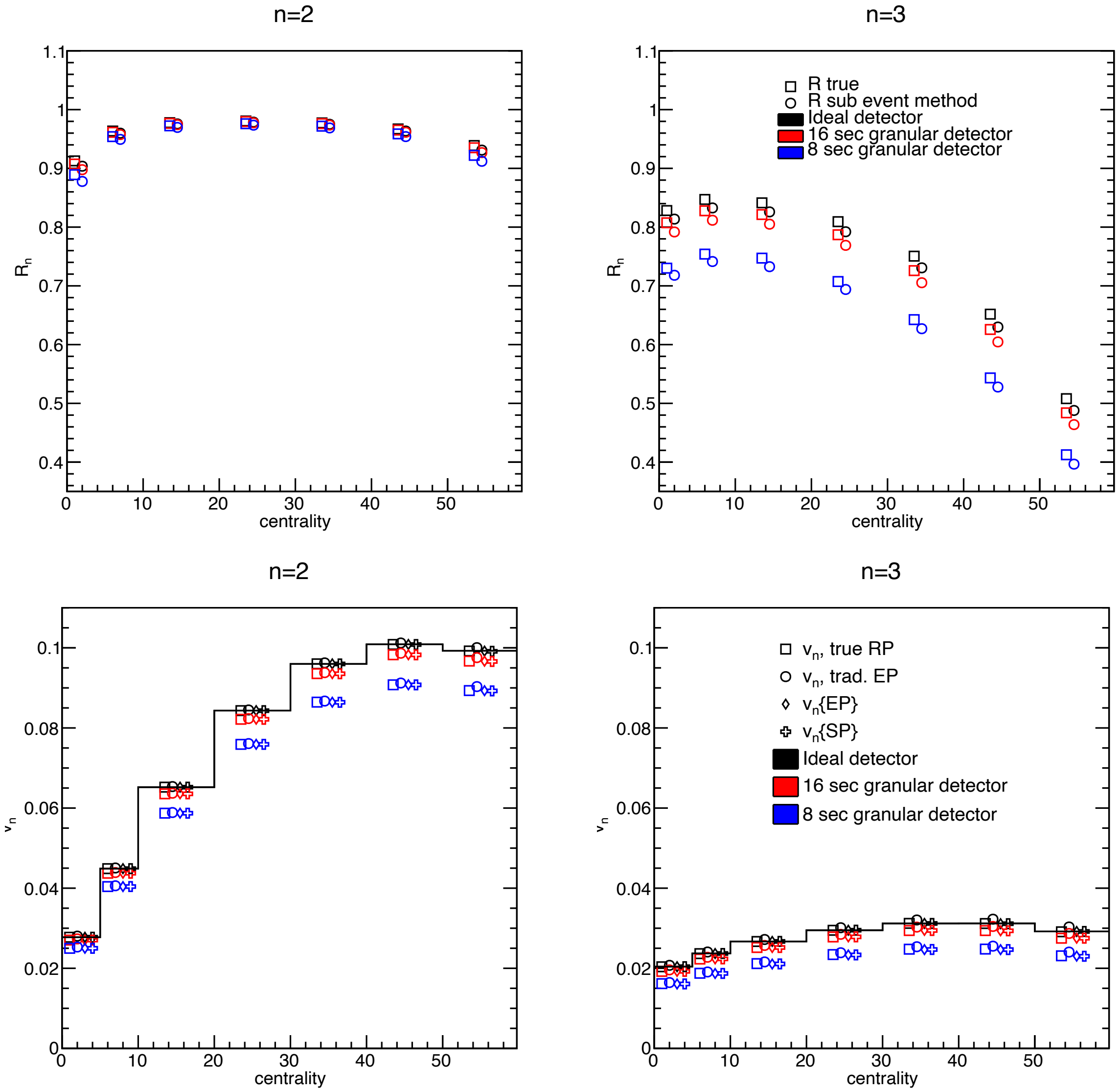
Validate flow methods with toy MC simulation:

- Semi-realistic input for
  - multiplicity as function of centrality
  - flow coefficients and rapidity distribution
  - https://github.com/hrytkone/ToyFlow

- Generate events and find ”detector hits”
- In the Monte Carlo simulation, we know non-measurable true values $v_n^{input}, v_n^{true}, R_n^{true}$

- Construct with flow methods measurable values v_n^{obs}, R_n^{sub} *and* $v_n^{cor} = v_n^{obs} / R_n^{sub}$.

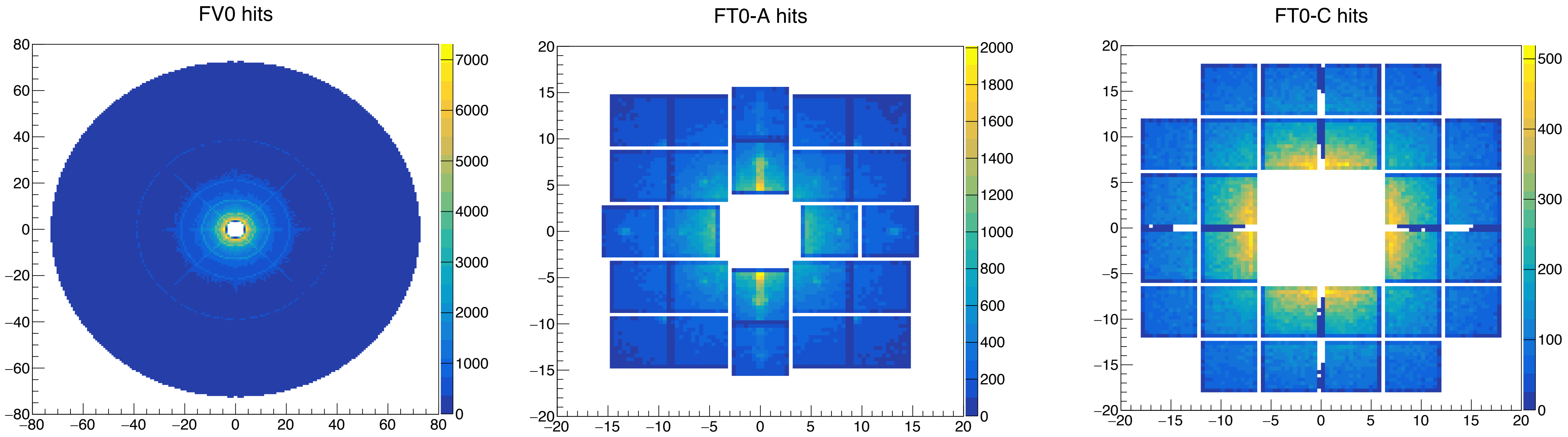
- Add detector properties, like finite granularity of FV0 detector (Figures)



Towards full detector simulations

Status at the moment:

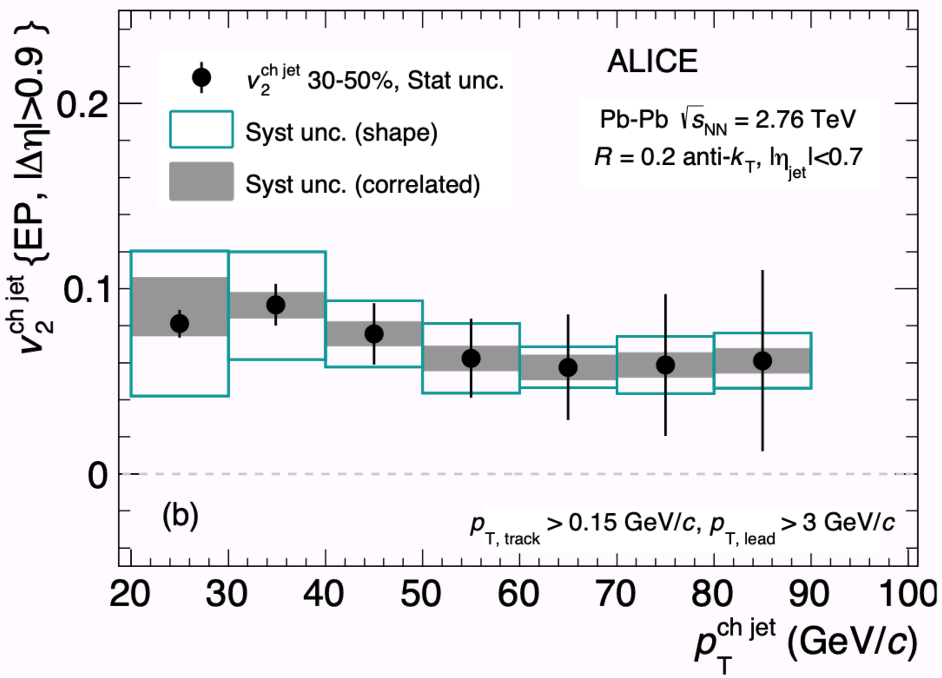
- Flow methods are validated with simple Monte Carlo
- True Monte Carlo + full detector simulations in ALICE O^2 framework
  - => realistic hit maps and signals in the detectors
- Need (fairly) significant CPU-time to produce enough heavy ion events (JU cluster/CSC/GRID?)
- Next step: compare Monte Carlo truth to detector level simulation



Event plane information in ALICE

- **Note:** modern flow analysis with cumulants, two-particle correlations or scalar product methods (most often) does not explicit reconstruction of events planes $\psi_{2,3}$.
- Need comes in analysis where one aims to study flow of a rare probes when aforementioned methods do not work.
- Finnish team aims to take the responsibility over on-line / offline framework (=ALICE O^2) code of the FIT event plane determination with FIT subdetectors and their combinations.
- With real detector, calibration constants needs to be determined period-by-period. For example, gain of the FV0 sectors need to be equalized to avoid artificially preferred direction ("event plane flattening").

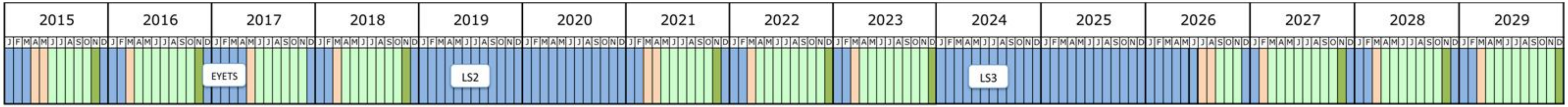
Selyuzhenkov and Voloshin, Phys.Rev.C77 (2008) 034904



Example: charged jet v_2 used V0 event plane to avoid autocorrelations

ALICE Collaboration, Phys.Lett. B 753 (2016) 511-525

OUTLOOK : ALICE upgrade at LS3



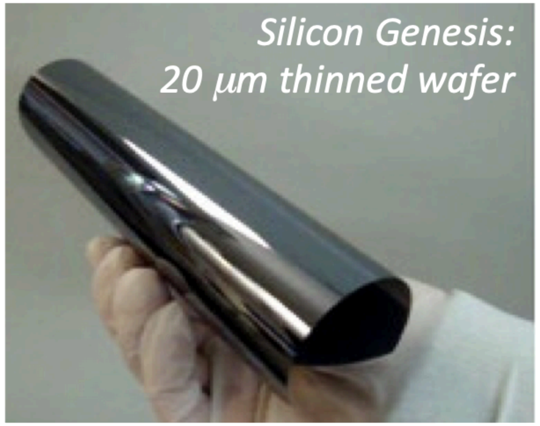
Coming upgrade **START HL-LHC (in pp)**

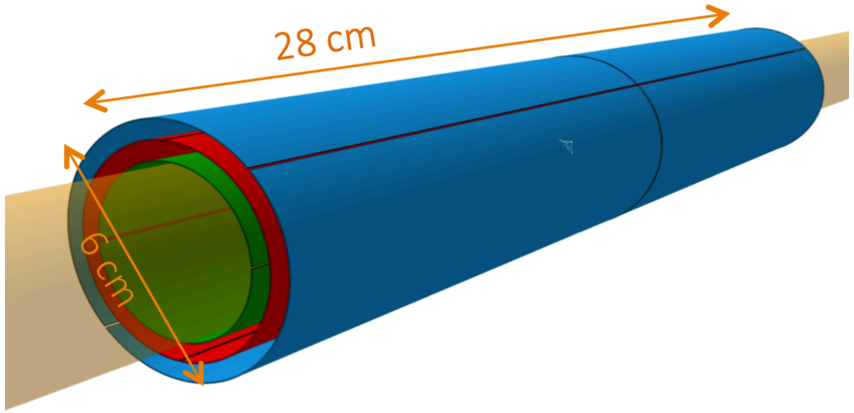
NEW ITS3:

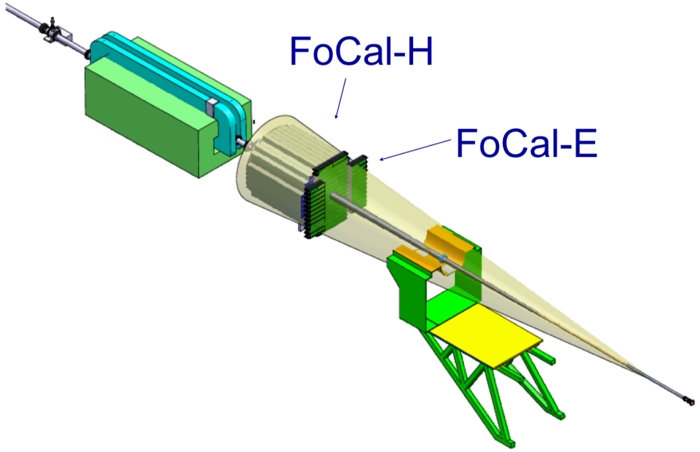
- Replace inner barrel of ITS
- 3 truly cylindrical layers, thickness 20-40 μm
- All material at r < 4 cm with X_0 ~ 0.3 %
- LoI: ALICE-PUBLIC-2018-013

NEW Forward Calorimeter (FoCal):

- Rapidity range $3 < \eta < 5$
- High granularity EMCal for π^0 and γ
- HCal for isolation, both for jets
- LoI in preparation, Finland interested







SUMMARY

- LHC in middle of the LS2, Run 3 starting 2021

- FIT in construction and commissioning phase
  Finland: characterization, raw data, geometry, DCS, event plane, …

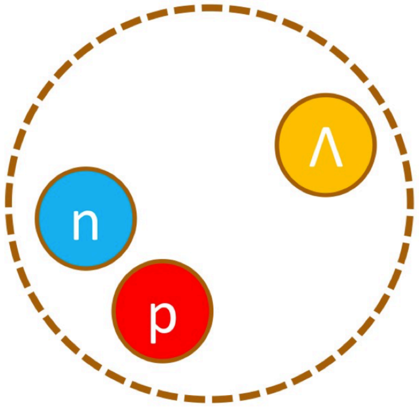
- Physics data analysis: high-order flow harmonics, di-jet mass analysis

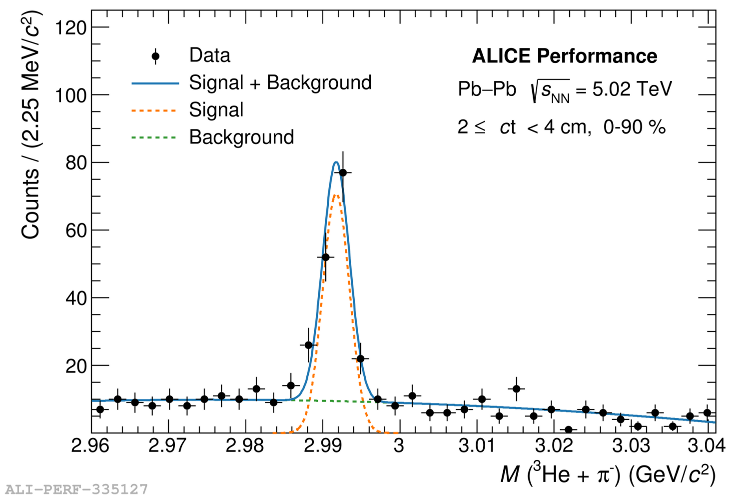
BACKUP

ALICE @ QM19 : Hypertriton

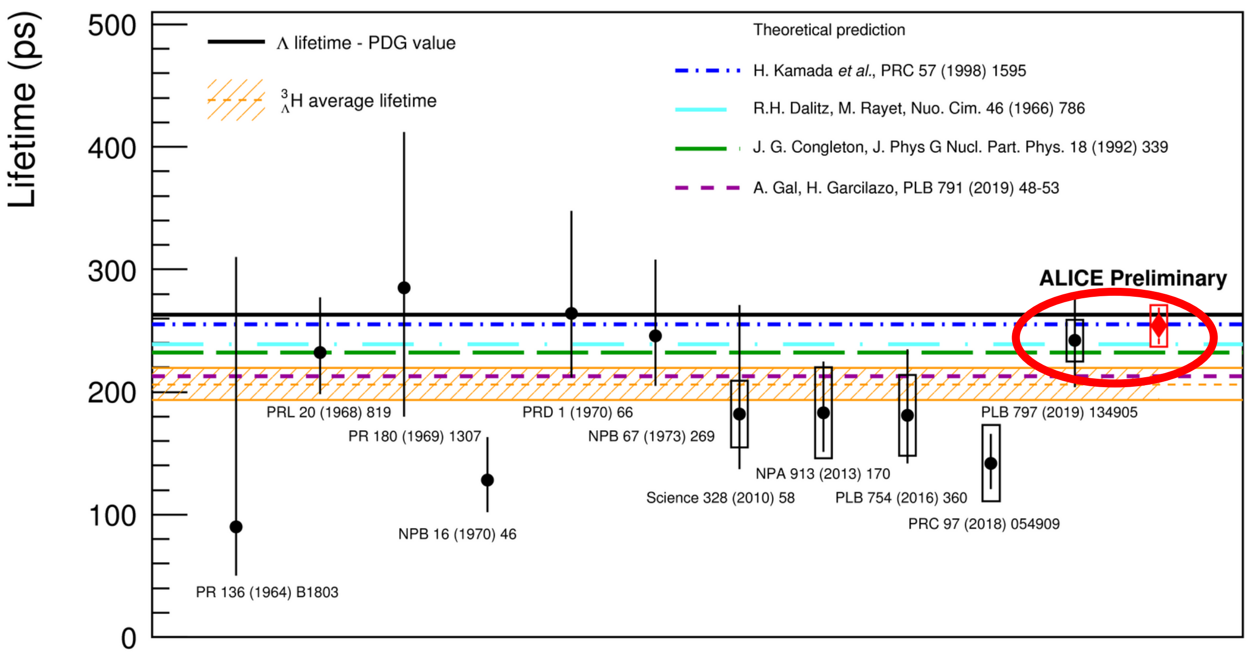
"Disclaimer": Different person would have chosen different results

- Tracking capabilities and large data sample open unique possibilities
- **Exotic nuclei are one of the key motivations for ALICE in Run 3 and 4**





Exclude large deviation from free Λ lifetime



ALI-PREL-342050

ALICE, Phys.Lett. B797 (2019) 134905
New preliminary using ML for QM2019!

ALICE @ QM19 : Flow studies

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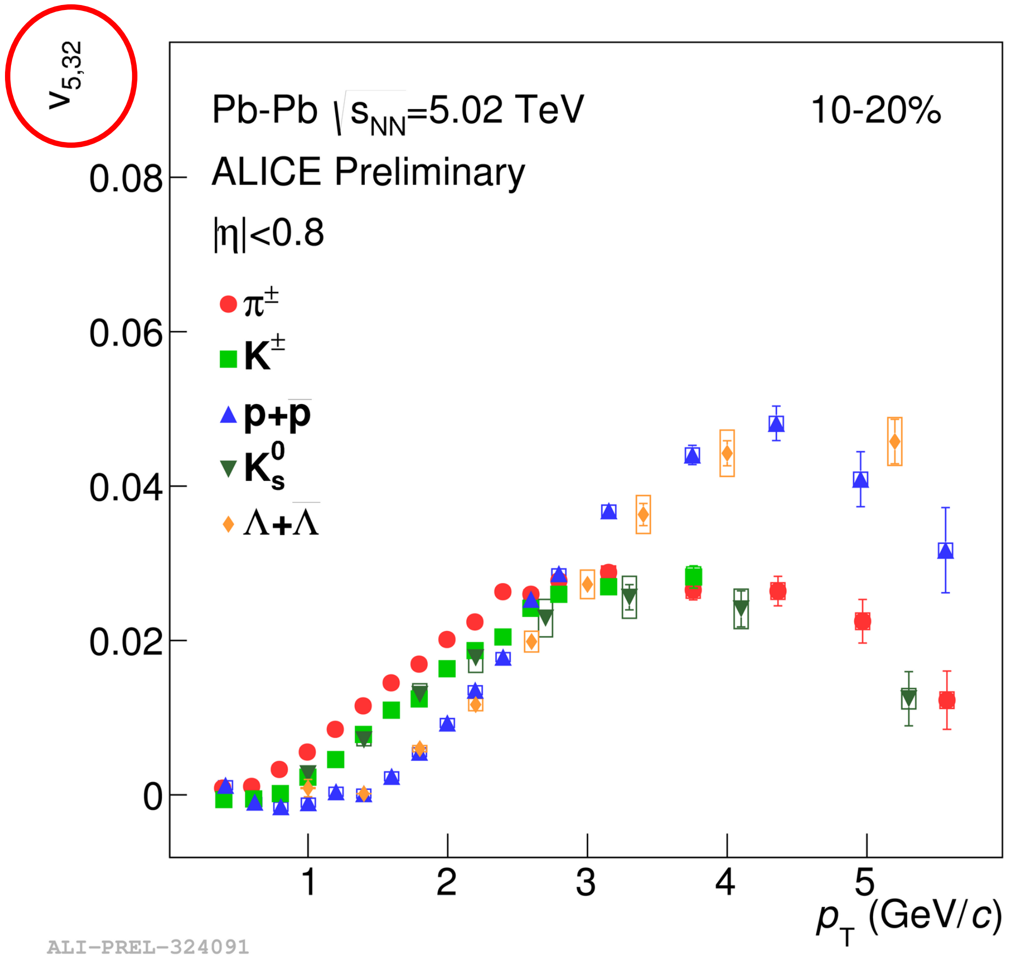
Talk: Jasper Parkkila @ QM19

"Disclaimer": Different person would have chosen different results



First observation:

Mass ordering of non-linear flow coefficients

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi - \psi_n))$$

$$V_n = V_n^L + V_n^{N-L}, \qquad V_n = v_n e^{in\psi_n}, n > 3$$

Here: "non-linear contribution from 2nd and 3rd order flow to 5th order."

(PPD 18 @ Jyväskylä, unidentified coefficients)

ALICE @ QM19 : Jets

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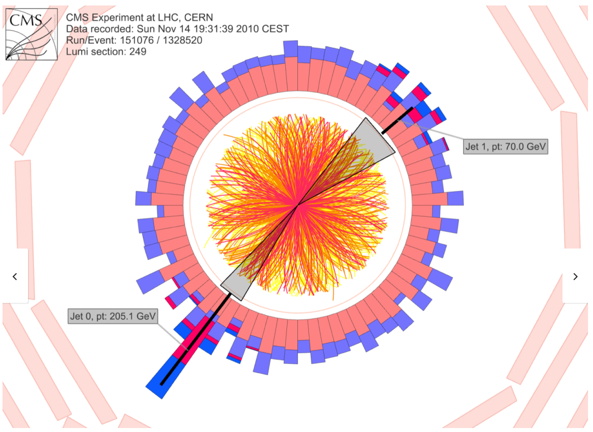
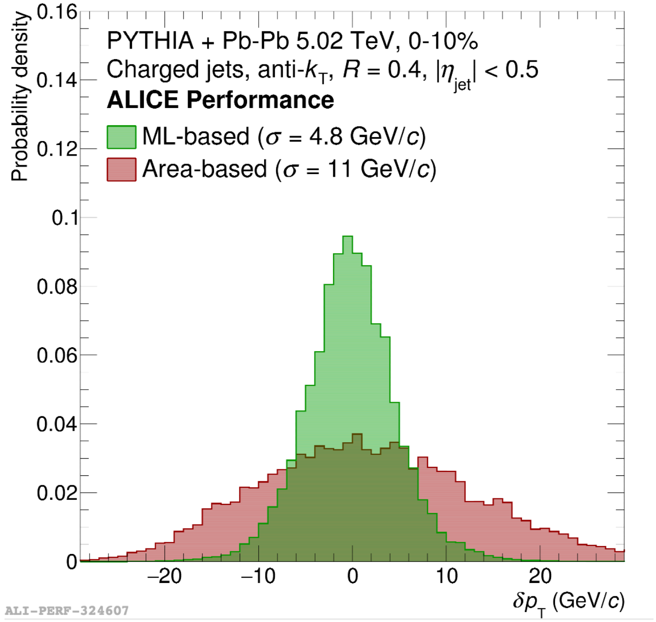
”Jet machines” CMS and ATLAS beat us in acceptance, luminosity, HCAL, …
=> In my opinion, ALICE has for example following natural directions:

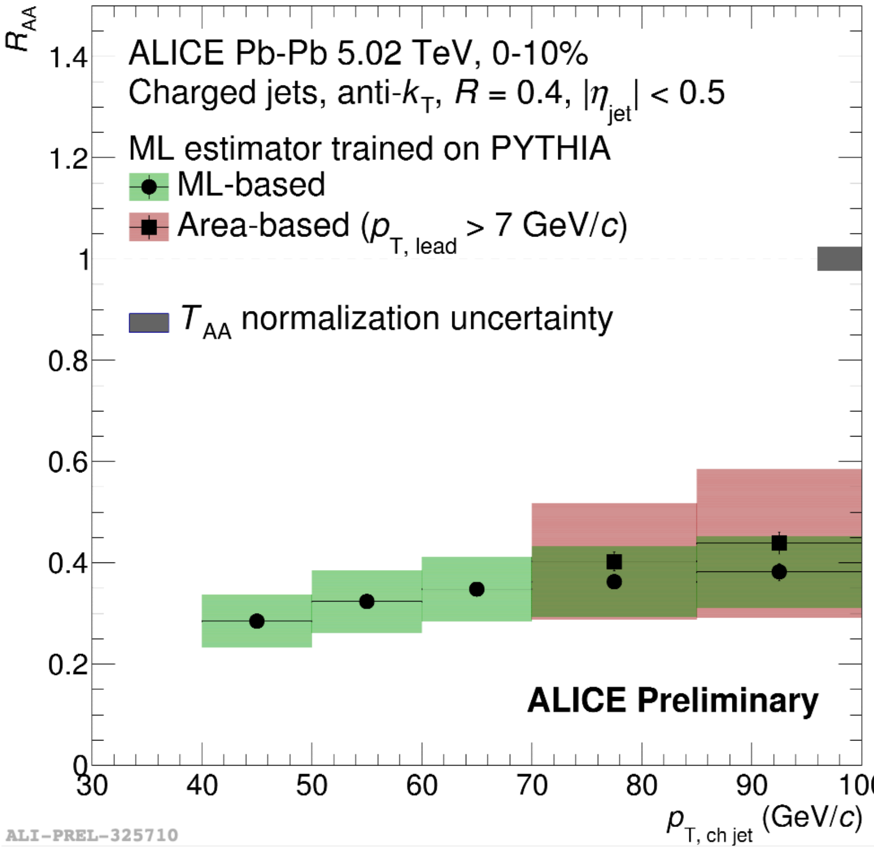
”Disclaimer”: Different person would have chosen different results

Very low $p_{T,jet}$ with Machine Learning …

δp_T = ((jet area)x(density) by FastJet) - (sum p_T in random cone), measures fluctuations of background determination in Pb+Pb





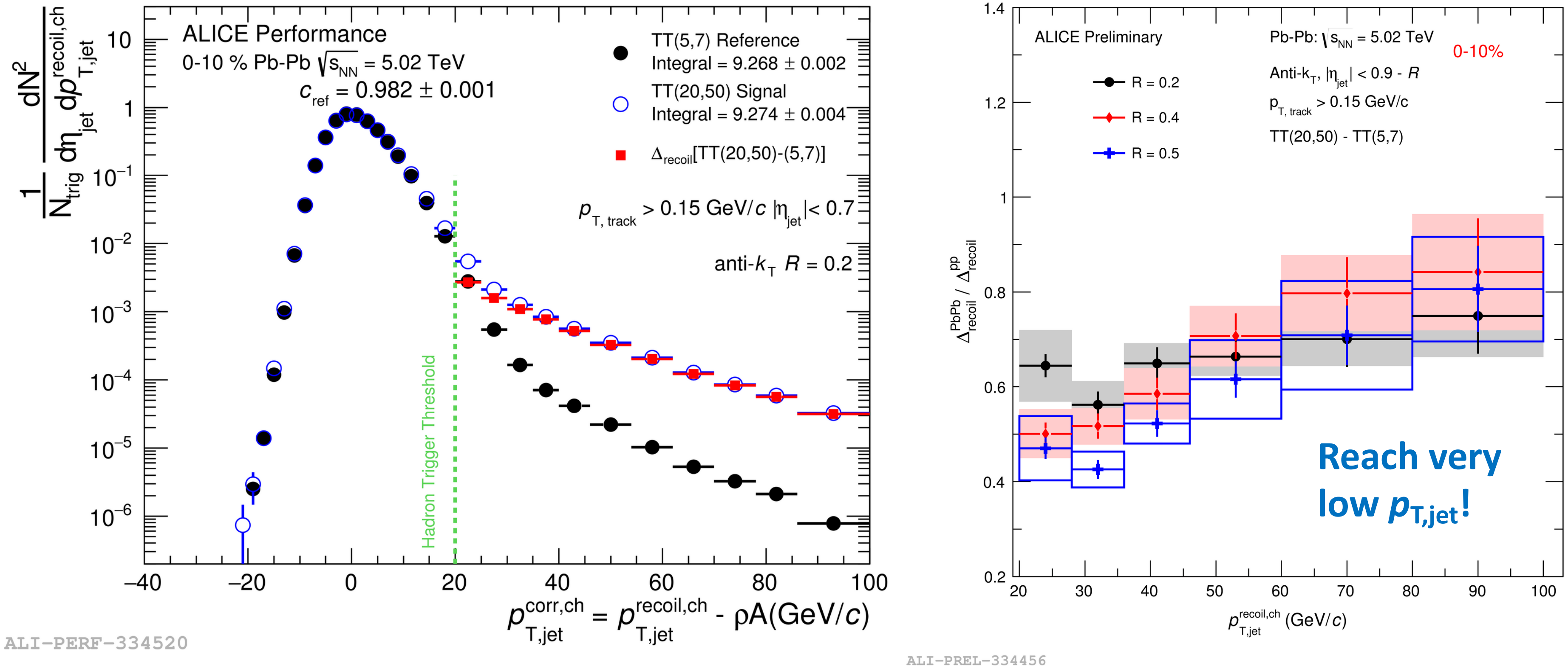


ALICE @ QM19 : Jets

"Disclaimer" : Different person would have chosen different results

… or hadron-jet correlations : novel way to subtract the background

Δ_{recoil} = (jets associated with high-p_T trigger hadron) - (jet associated with low-p_T trigger), such that jet is back-to-back with the trigger hadron



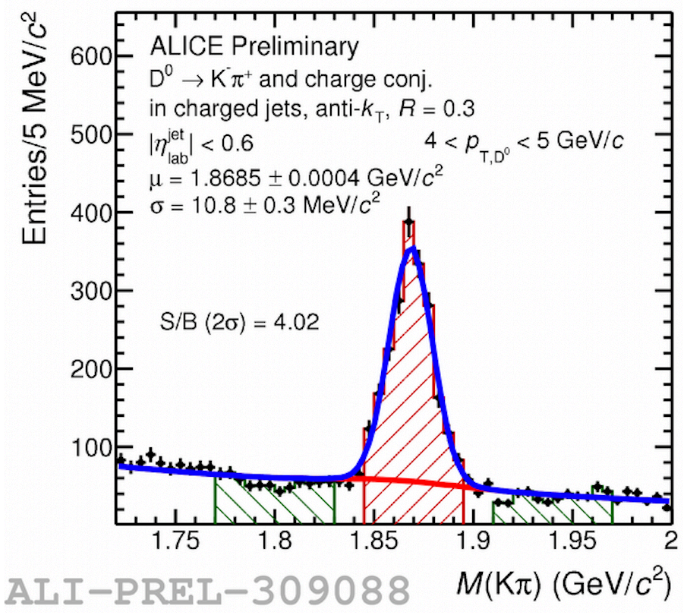
ALICE @ QM19 : Jets

… or particle identification of constituents :

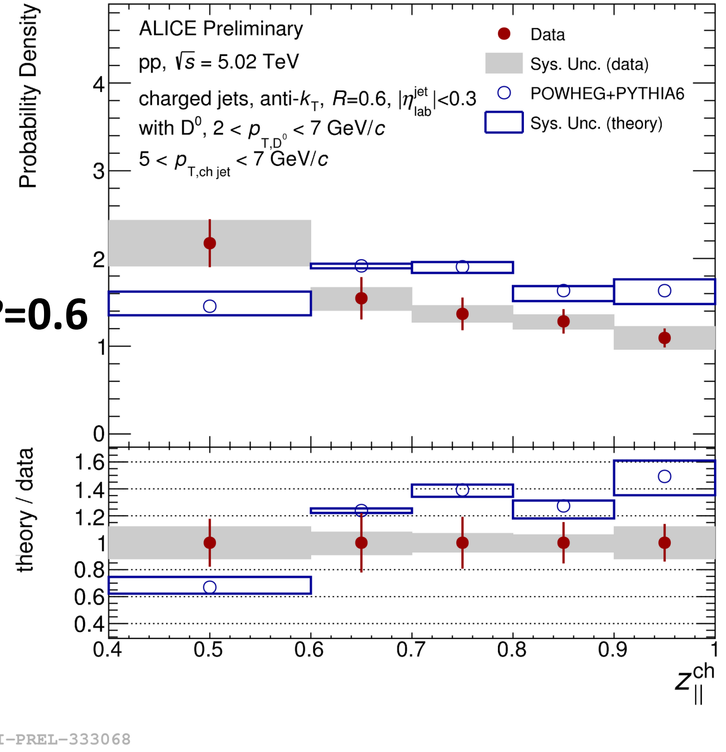
Here D0 fragmentation functions in pp @ 5.02 TeV:
- generators agree at high-p_T, at low tension?

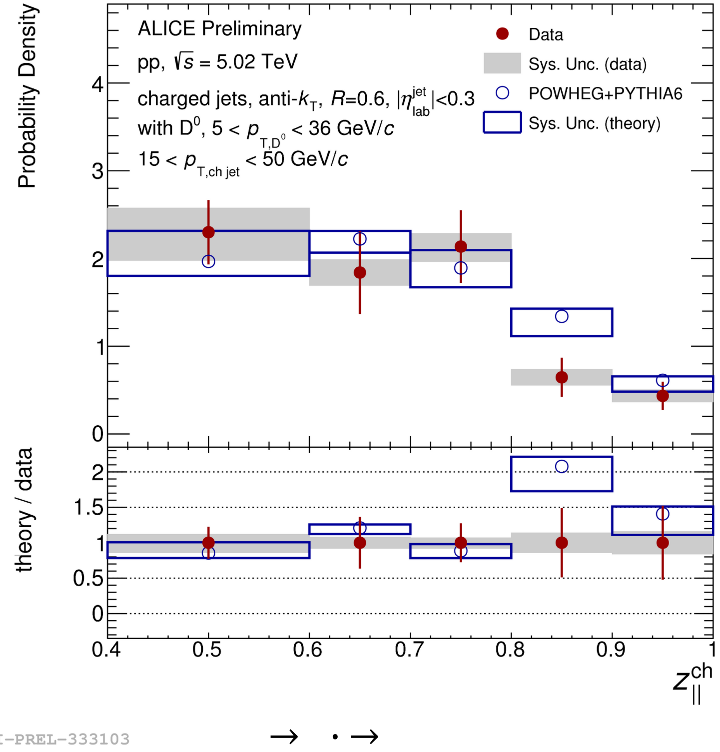
"Disclaimer":
Different person would have chosen different results

Replace tracks of every D^0 candidate as D^0
=> every D^0 belong into some jet



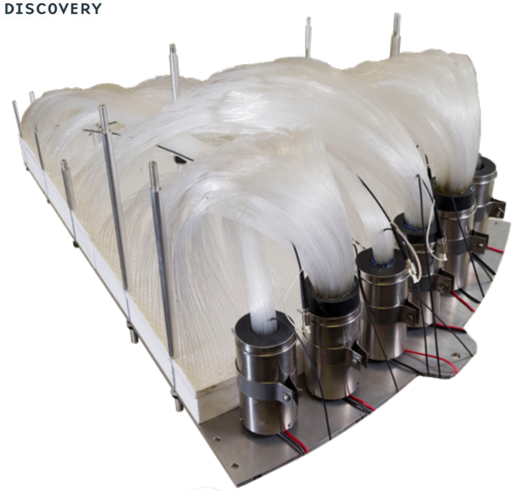
***R*=0.6**



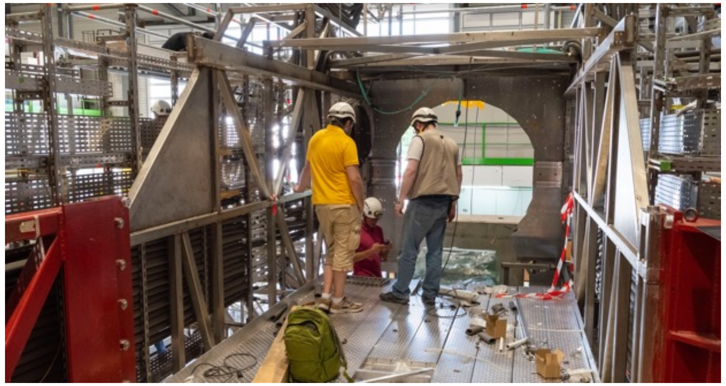


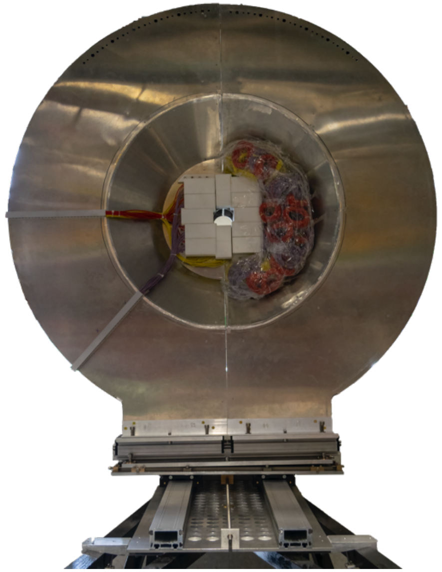
$$z = \frac{\vec{p}_D \cdot \vec{p}_{jet}}{p_{jet}^2}$$

FIT – commissioning in time

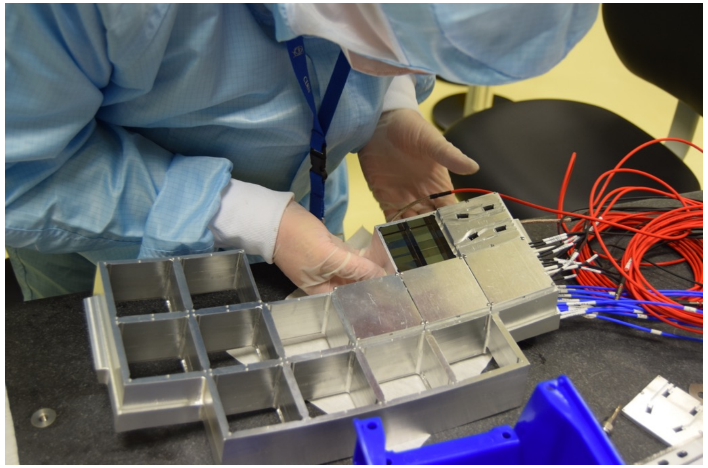


FV0 in-beam sector test completed

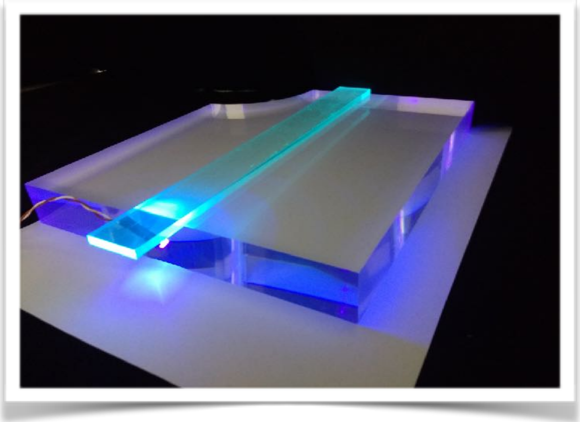




FITA mockup ready

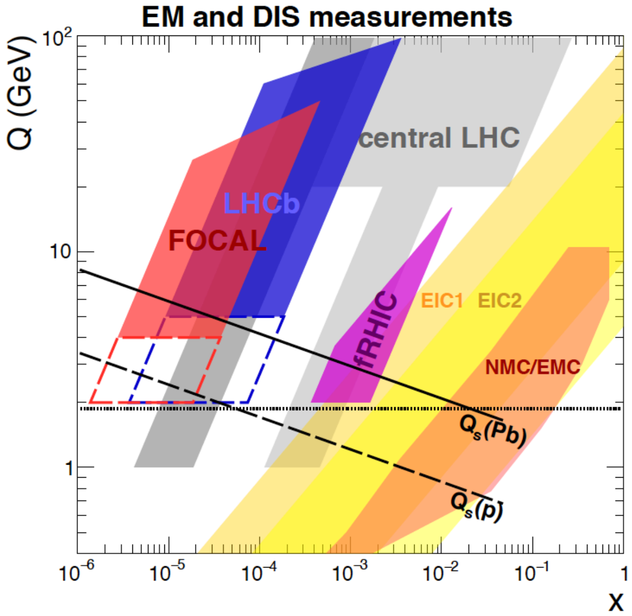


FITC fully assembled

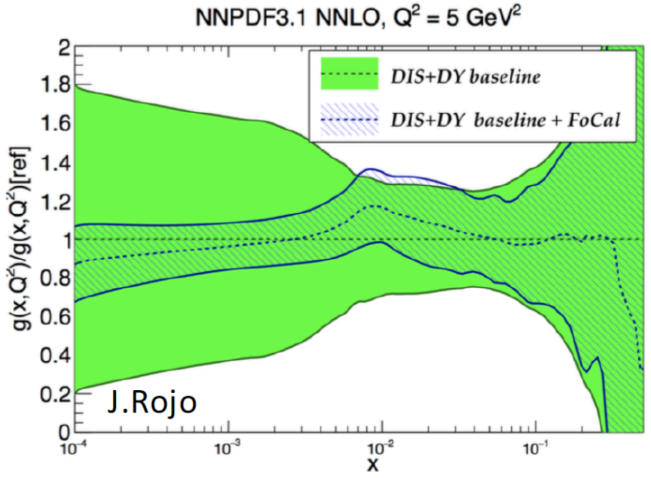


FDD prototype test at CERN

FoCal upgrade for Run 4



Impact on gluon nuclear PDF



Forward calorimeter at 3 < η < 5:

- Letter of Intent in preparation in ALICE
- High-granularity EMCal for π^0 and photon measurements, HCal for photon isolation, both for forward jets
- Small-x physics
- Good synergy with theory group:
  - CGC studies – enter to saturation region (prof. Tuomas Lappi)
  - Nuclear PDF's – constraints to gluon distributions (prof. Kari Eskola)
- One feasible analysis topics to Jyväskylä
  - Forward π^0-π^0 or forward π^0 central hadron correlations (CGC)

Timetable:

- FoCal is not yet approved in ALICE
- First prototype of EMCal has first test beam results
- Commissioning during 2024-2025 (LS3), running 2026-2028 (Run 4)