The ATLAS/Demokritos and the ELEA Lab activities

Theodoros Geralis
NCSR Demokritos
11/04/2018

2001: Micromegas is introduced for a **first time in GREECE in Demokritos (George Fanourakis)**

2001 – 2018 : Work on many R&D projects (see next pages)
Diffusion of Micromegas activity: NTUA, NKUA, AUTH, Univ. Patras

2009 Organize the "1st International Conference on Micro Pattern Gaseous Detectors – MPGD2009, Kolympari, Crete, Greece

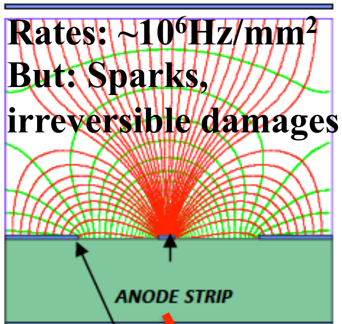
MPGD is the most recognized Conference on Micro Pattern Gas Detectors

MPGD2009 (Kolympari, Greece) :
G. Fanourakis, T. Geralis (Members of the Organizing Committee)
T. Geralis (Editor with refereed proceedings – JINST)

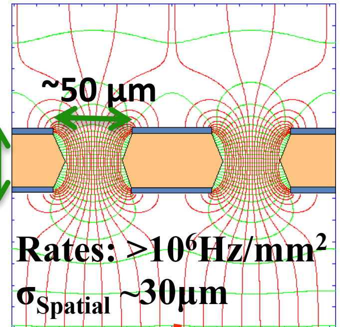
MPGD2011(Kobe, Japan), **MPGD2013** (Zaragoza, Spain),
MPGD2015 (Trieste,Italy), **MPGD2017**(Philadelphia, USA)
T. Geralis (Member of the International Organizing Committee),
G. Fanourakis (Member of the International Advisory Committee)

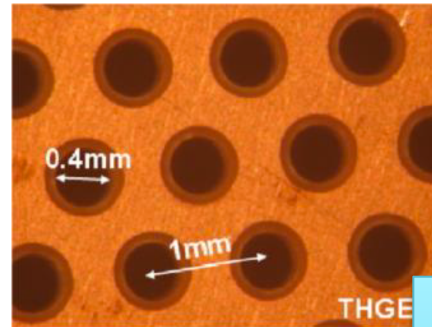
From Multi-Wire Proportional Chambers to Micro Pattern Gaseous Detectors

MSGC: Oed 1988

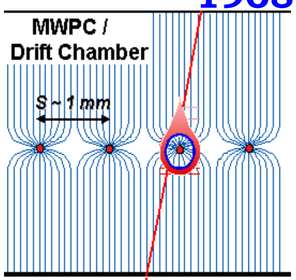


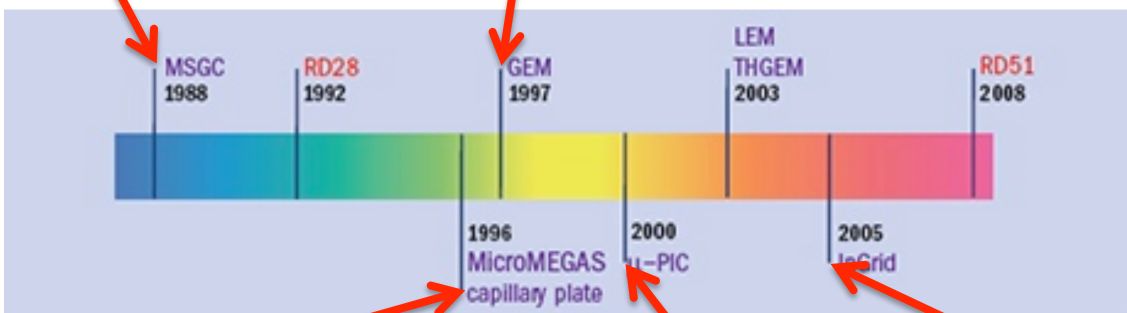
GEM:Sauli 1997





MWPC: Charpak 1968

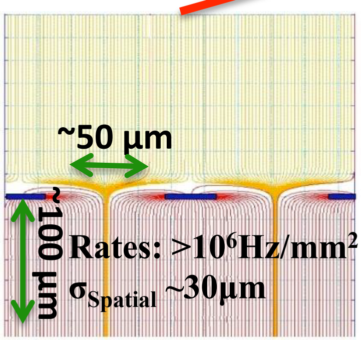




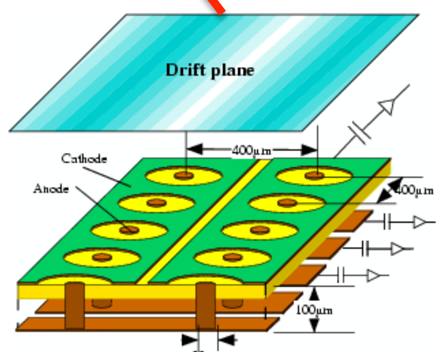
RD51 Collaboration:
86 Institutions

500 Scientists

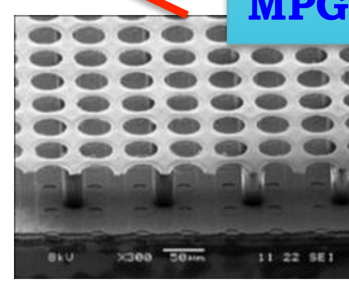
Development of Micro Pattern Gaseous Detectors MPGD technologies



Micromegas: Giomataris 1996

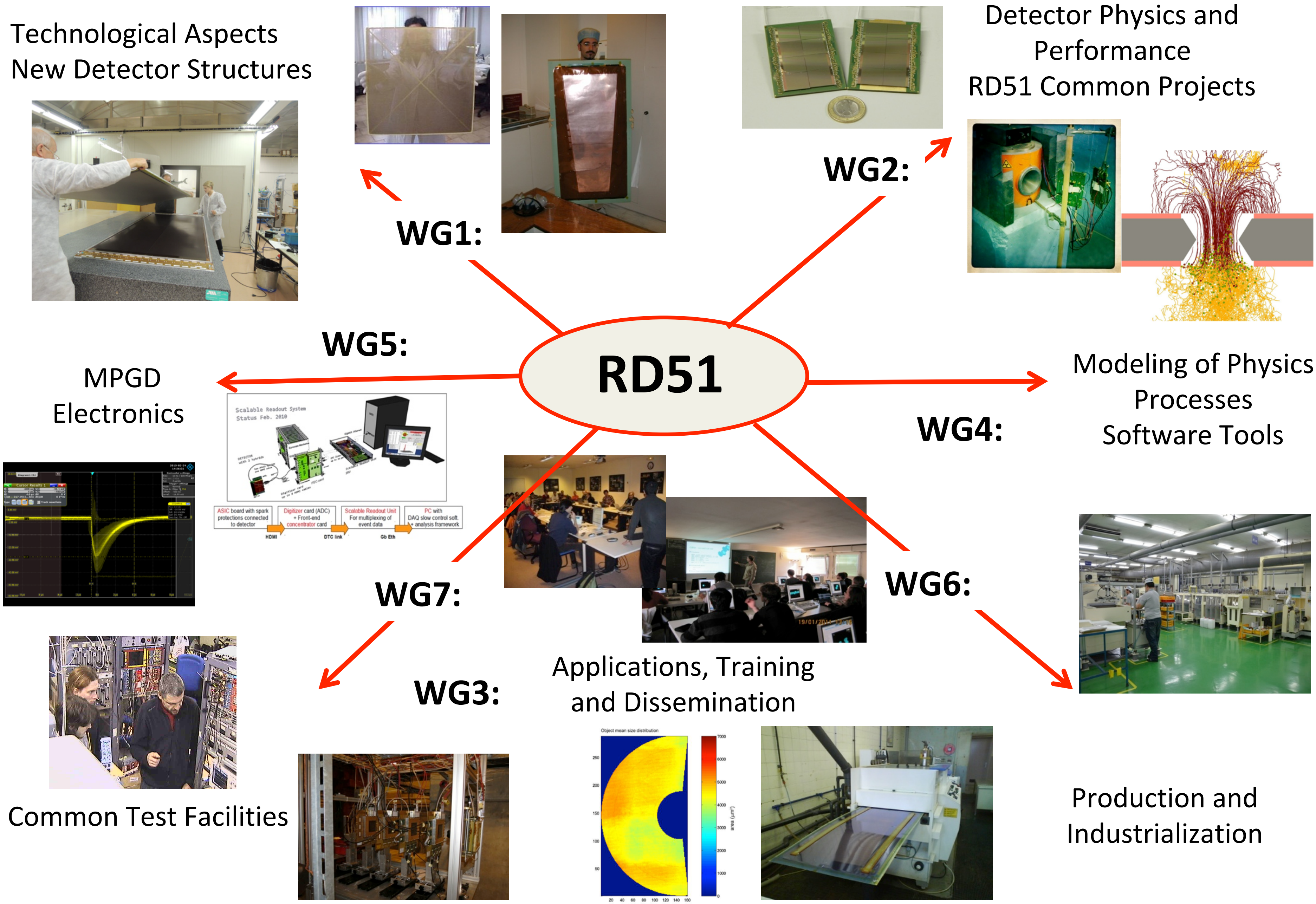


μ -PIC



Ingrid

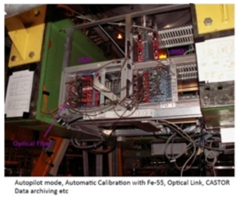
RD51 Collaboration



ELEA past Activities

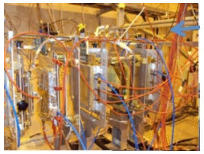
- **Manufacturing and testing the CAST Micromegas detectors (2001 – 2005)**

- **Built VME DAQ for Micromegas (LabView and C++ parallel threads) – CAST, SPS test beams (2003, 2012)**

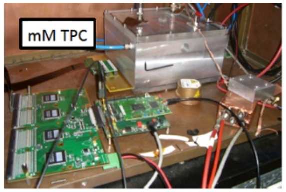


- **Design and built the Global Trigger Processor Emulator (GTPe) for CMS (2005 – 2010) – 10 complete systems**

- **Build the first RD51 telescope with Micromegas, for the SPS test beam (2010)**



- **Build Micromegas TPC for fission studies FIDIAS project (2012)**



- **Participate in the MAMMA collaboration for The ATLAS New Small Wheel upgrade (2010)**

INPP/NCSR Demokritos
ELEA personnel (2015 - 2017)

Permanent Staff (Researchers)

1) Fanourakis Georgios
2) Geralis Theodoros
3) Stavropoulos Georgios

Post Docs (2015 – KRIPIS I)

1) Nikas Dimitris
2) Psallidas Andreas

Doctoral Students (2015 – KRIPIS I)

1) Kouris Ilias
2) Kalamaris Athanasios

Electronics Engineer (2015 – KRIPIS I)

Vassou Chryssa

Technician

Saragas Lefteris (retired)

Students/year

1 – 2 Master Thesis
1 – 2 Diplomas
2 – 4 Practical work

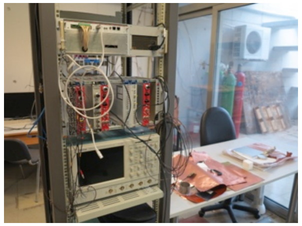
Master Thesis:	Chara Giakoumogiannaki
Diploma:	Georgios Papadopoulos
	Costas Moustakas
Practical work:	Georgios Chaidas

ELEA aim at:

1) Innovative R&D on Micro Pattern Gaseous Detectors - MPGDs
2) Development of MPGD related electronics and DAQ systems
3) Dedicated detectors for HEP, Nuclear Physics and applications


INFRASTRUCTURE

- THREE FULLY EQUIPPED TEST BENCHES FOR STUDYING MPGDs
  - Electronics Rack, Gas distribution, Workstation, Osciloscope
- GAS MIXER and distribution of premixed gases

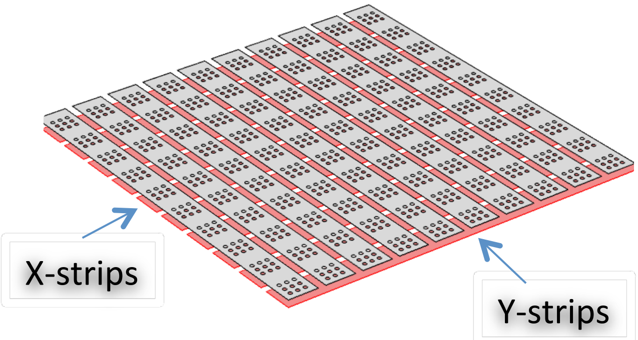



- ELECTRONICS AND DAQ SYSTEMS
  - VME Data Acquisition (CAEN controller, optical fiber connection CRAMS, sequencer, ADC unit, Gate generator, etc)
  - SRS - Scalable Readout System (APV FE, 2000 channels readout)
  - FEMINOS readout for TPC mode
  - Electronics: Racks (1 VME and 4 NIM crates), NIM units (Multifunction NIM modules, Amplifiers, Discrim., HV PS, LV PS, Pulse generators, NIM/TTL/NIM conv, etc), MCAs (2), Preamps
  - Faraday cage
- DESIGN PACKAGES
  - Electronics design (Europractice packages)
  - Finite Element Analysis (COMSOL, ANSYS)
  - DAQ software (Labview version, C++ version)
  - FPGA (Altera, Xilinx) design workstations
  - FPGA Design platforms
- CLEAN ROOM (12 m^2 – two rooms Class 10,000 and Class 100,000)
  - Microscope

ELEA recent projects

Real x-y Segmented Mesh Microbulk Micromegas

Aim of the project → To develop microbulk Micromegas detectors with segmented mesh



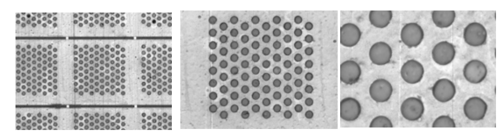
1) Real x-y structure
   (old topology ➔ systematic bias in x, y)
2) Mass minimization
3) Production Simplification
4) Large surface detectors

RD51 Common Fund Project

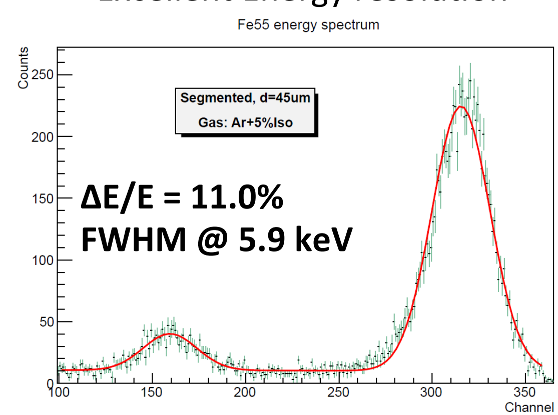
Collaborating groups

- **NCSR Demokritos (Leading Institute)**
  T. Geralis, A. Kalamaris, C.Giakoumogiannaki
  Design, mounting, tests, readout
- **IRFU Saclay**
  First characterization, inspection
- **Univ. of Zaragoza**
  FE Electronics design
- **CERN**
  Manufacturing, tests

RD51 Common fund project
Budget: 32.5 kCHF



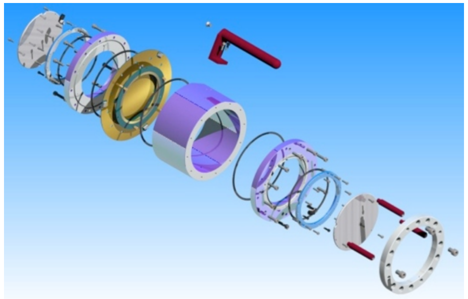
Excellent Energy resolution

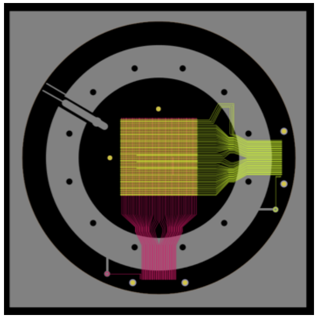


Applications

1) Rare searches (axion, dark matter)

Microbulk background: ~ 10^{-6} cnts/keV/cm^2/s
The segmented microbulk background → ~ 10^{-7} cnts/keV/cm^2/s





2) Neutron Beam profiler (nTOF)

Very adequate due to very low material
Budget: 5 μm + 5 μm of Cu only
The thinest ever neutron detector worldwide

Presentation in TIPP2014 Conference, 2 – 6 June 2014, Amsterdam :
T. Geralis et al., "A real x-y Microbulk Micromegas with segmented mesh"

Published in PoS (TIPP2014)055.

ELEA recent projects

Resistive Bulk Micromegas for High Rate applications

Collaboration

INPP
G. Fanourakis
T. Geralis
A. Kalamaris
D. Nikas
Ch. Vassou

LAPP Annecy
M. Chefdeville
I. Karyotakis
2 Engineers

IRFU Saclay
M. Titov

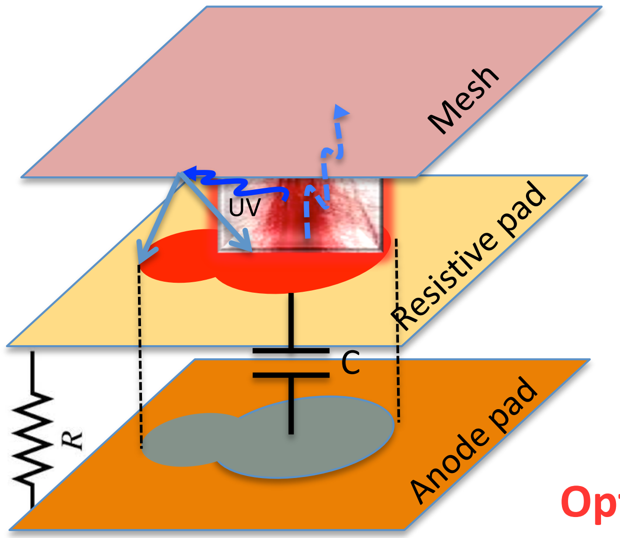
Future Resistive Micromegas applications

1) At future linear colliders
   HCAL with 1x1 cm2 pads, high granularity for PF both in transverse and longitudinal direction, small sensitive area thickness (< 1cm)
   ➔Removes spark protection diodes from pcb, more cost effective
2) At HL-LHC (ATLAS upgrade)
   Muon High-Eta Tagger (rates up to 10 MHz/cm^2)

3) At the Future Circular Collider (FCC)

R&D on Resistive Micromegas for High Rate Calorimetry

Resistive layers prevent streamers to develop to sparks by quenching it at an early stage



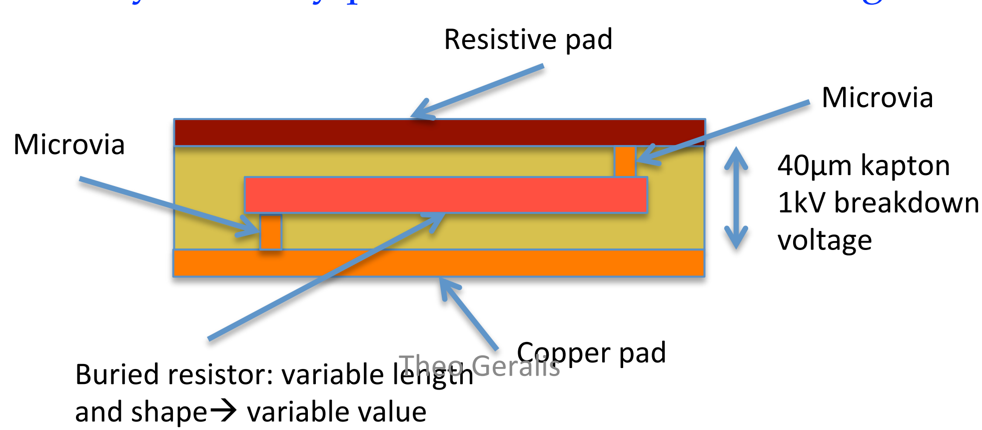
R: Resistance to ground
C: Capacitance between resistive coating and ground
f(cascade (~100 μm), dielectric)
Relaxation RC: gives typical time of the charge evacuation

High charge deposition deforms locally the E field → lower Gain → Quench spark → loss of linearity
τ : time of cascade development ~ 10 ns
RC > τ → Spark quenching
RC ~ τ → Spark develops

Optimization: Response linearity vs Discharge rate.
Low R High R
Vary RC (effectively vary R) and specify working point

Charge evacuation:

- Sideways, horizontal: not adequate for large surfaces and high rates (steady state charge)
- Individual surface resistivity for every pad with buried resistor to ground (Rui De Oliveira)

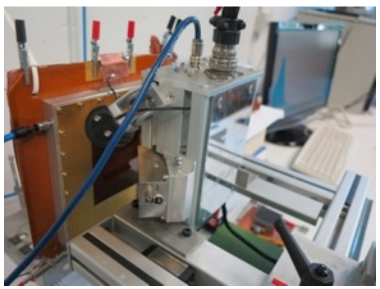


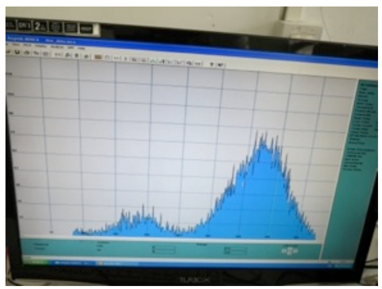
Linearity tests: Resistive Micromegas High rate tests with X-rays

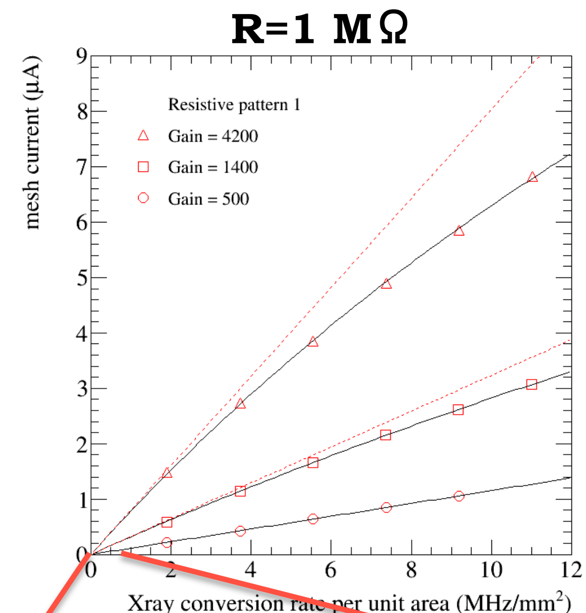
X-ray Gun tests at the RD51 lab: Cu 8 keV at very high rates

Measure the Mesh current as a function of the X-ray tube current

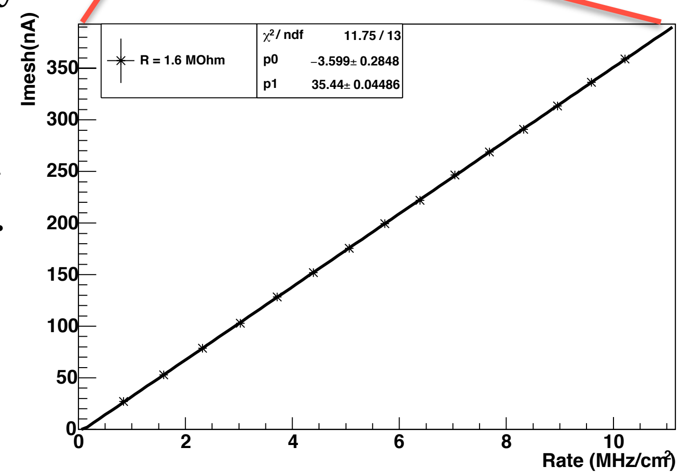
Intermediate R: excellent linearity up to rates 1 MHz/mm^2
25% lower gain for rates 10 MHz/mm^2







X-ray Gun tests at Demokritos: Rh 3 keV at very high rates
Energy Resolution not very good → should improve homogeneity
Test linearity and measure the discharge rate and the Mesh Voltage drop spectrum (rates up to 11 MHz/cm^2)

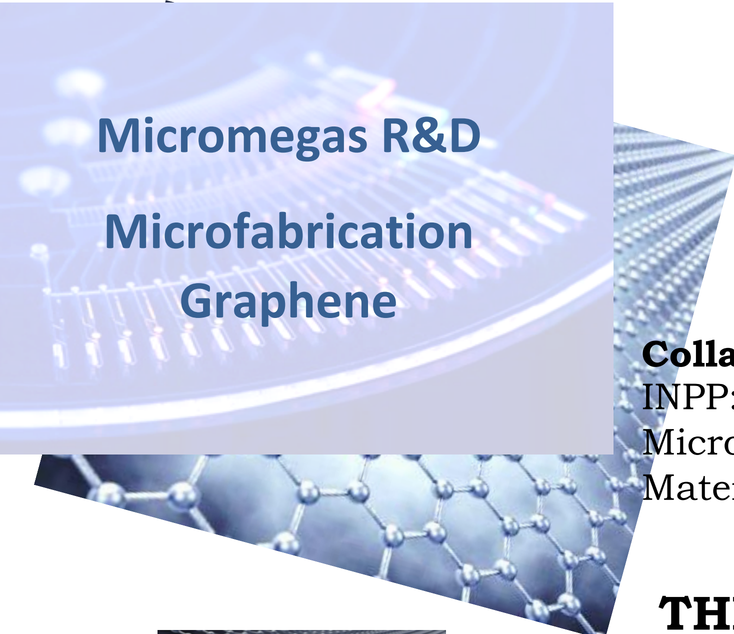


THANKS to Andeas Karydas and Viki Kantarellou
For providing the X-Ray gun and their know how.

Linearity test at
Rates: 0 – 0.1 MHz/mm^2

Or 0 - 10 MHz/cm^2

Excellent linearity

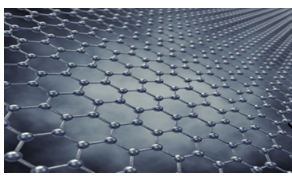


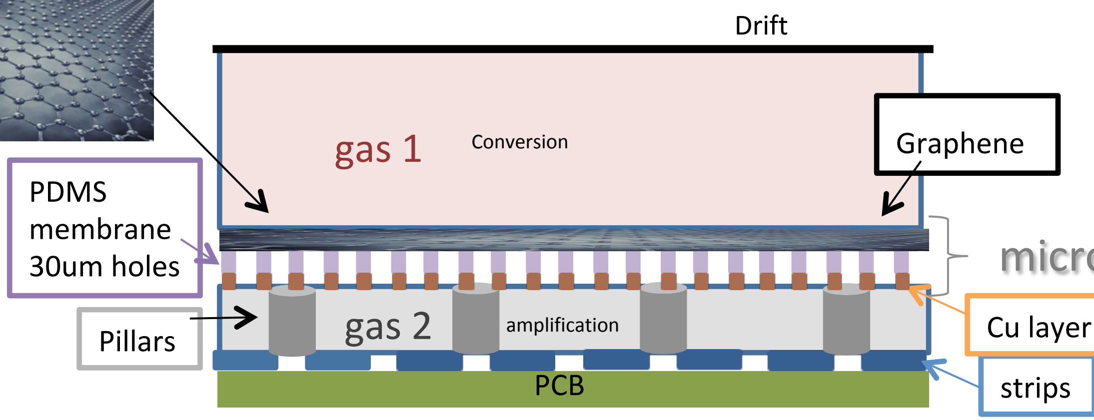
Aim: Build Micromegas Using microfabrication Techniques and Graphene

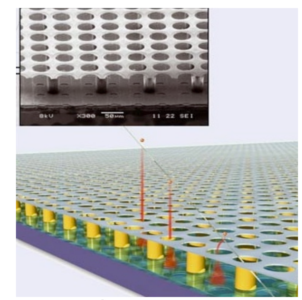
Collaboration (is within Demokritos Institutes):

INPP: T. Geralis (Researcher), Ch. Vassou (Master)
Microelectronics: A. Tserepi (Researcher), M. Vlachopoulou (PhD)
Material Science: A. Dimoulas (Researcher), Jose Marquez Velasco (PostDoc), S. Giamini (Post Doc)

THIS IS WHAT WE DREAM !



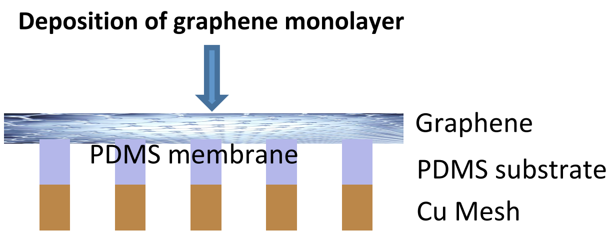




1) Two-gas phase detector separated by a Graphene layer
2) Exploit differences in gas properties to improve performance
3) Should have high electron transparency (test to be performed)
4) It may be used to eliminate ion backflow

4) Transport Graphene on PDMS

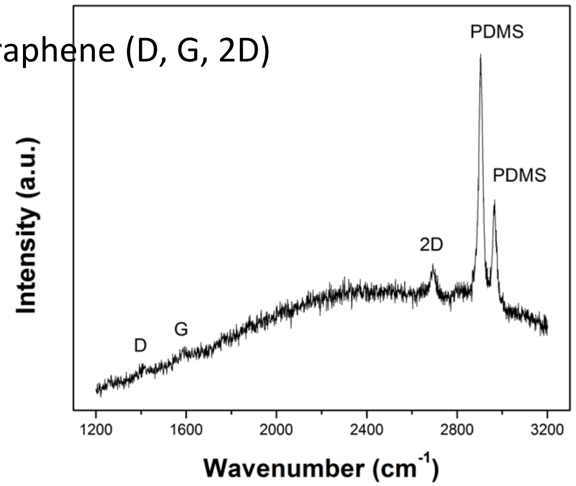
i) Produce Graphene on Cu foil
ii) Cover it with PMMA
iii) Dissolve Cu
iv) Place PMMA+Graphene on PDMS
v) Dissolve PMMA



- Raman spectroscopy was used to confirm the graphene transfer uniformly on the PDMS membrane

We have placed a graphene surface of 1 x 1 cm^2 on to of the PDMS substrate

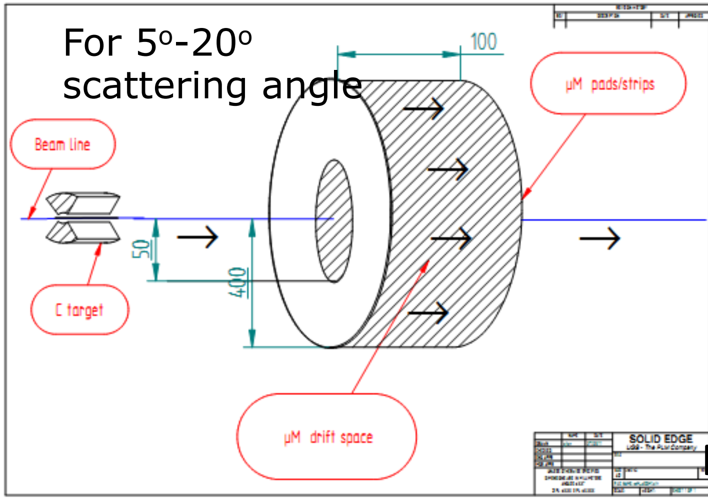
Graphene (D, G, 2D)

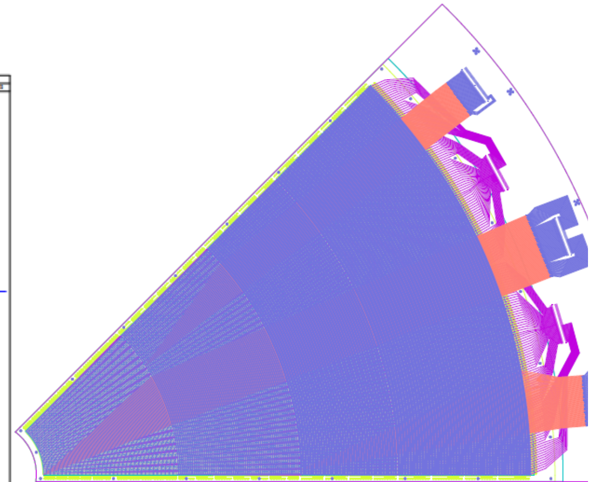


Future plans
1) Measure electron transparency with and without Graphene
2) Investigate for defects
3) Measure gas diffusion through Graphene
4) Possibly lay double or triple layers

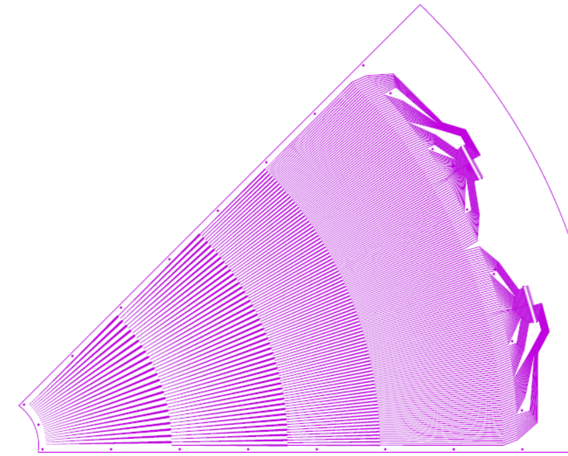
R-ϕ Micromegas

G. Fanourakis

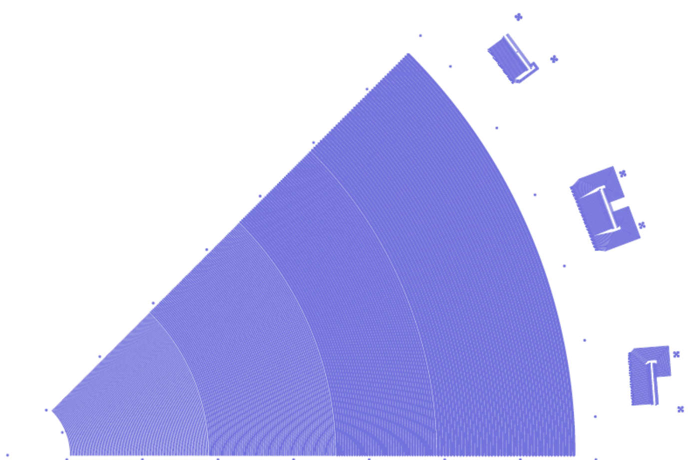




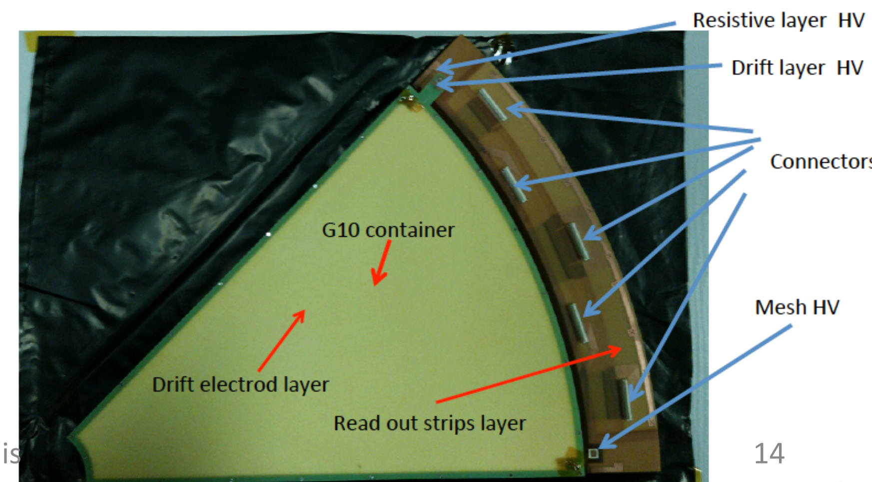
Readout routing to Panasonic connectors



R and phi strips



Two r-phi prototype octants have been ordered and constructed in the electronics lab of CERN. One with a 10 MOhm/sq and one with a 100MOhm/sq resistivity of the resistive layer, to test the behavior in various beam density situations (fast or less fast operation).

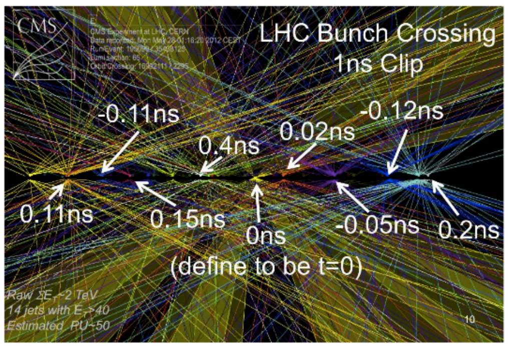


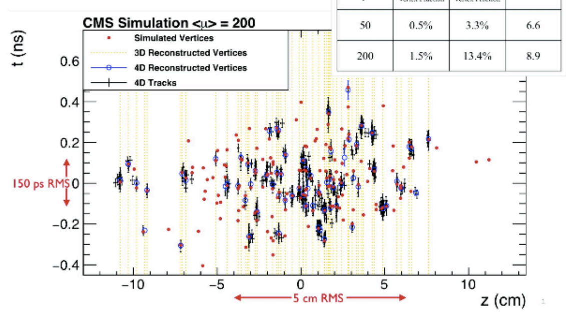
The Picosecond Micromegas
G. Fanourakis

Timing detectors at High Luminosity Colliders

Challenges at future colliders:

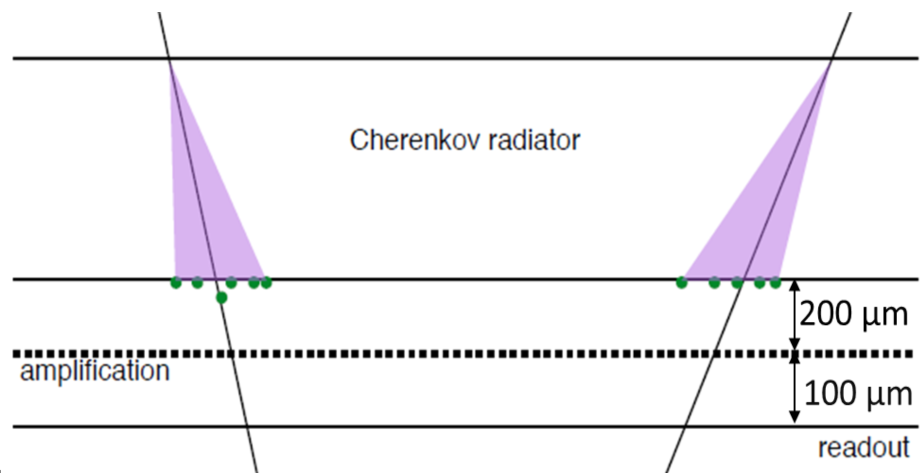
- High luminosity (200 pile up events within 150 ps RMS predicted for HL-LHC)
- High radiation environment
- Precision timing of ~25 ps can reduce pile up effects by improving vertex reconstruction with TOF information





CMS Simulation

<μ>	4D Merged Vertex Fraction	3D Merged Vertex Fraction	Ratio of 3D/4D
50	0.5%	3.3%	6.6
200	1.5%	13.4%	8.9

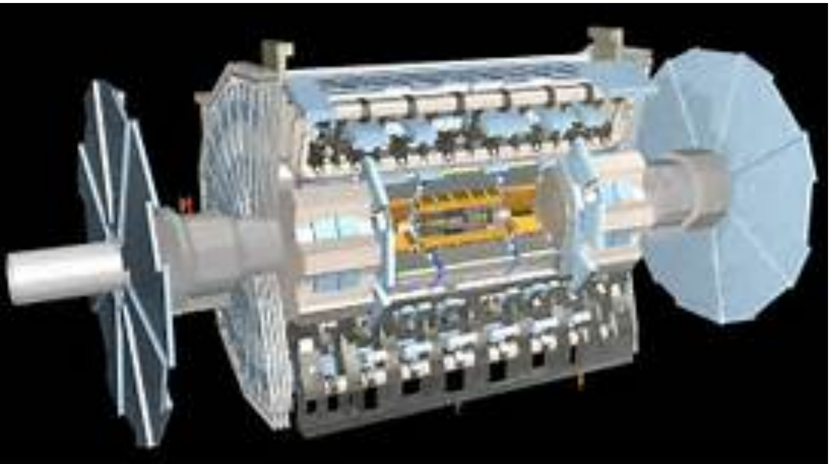


Demokritos membership in ATLAS

National Center for Scientific Research Demokritos – NCSR Demokritos

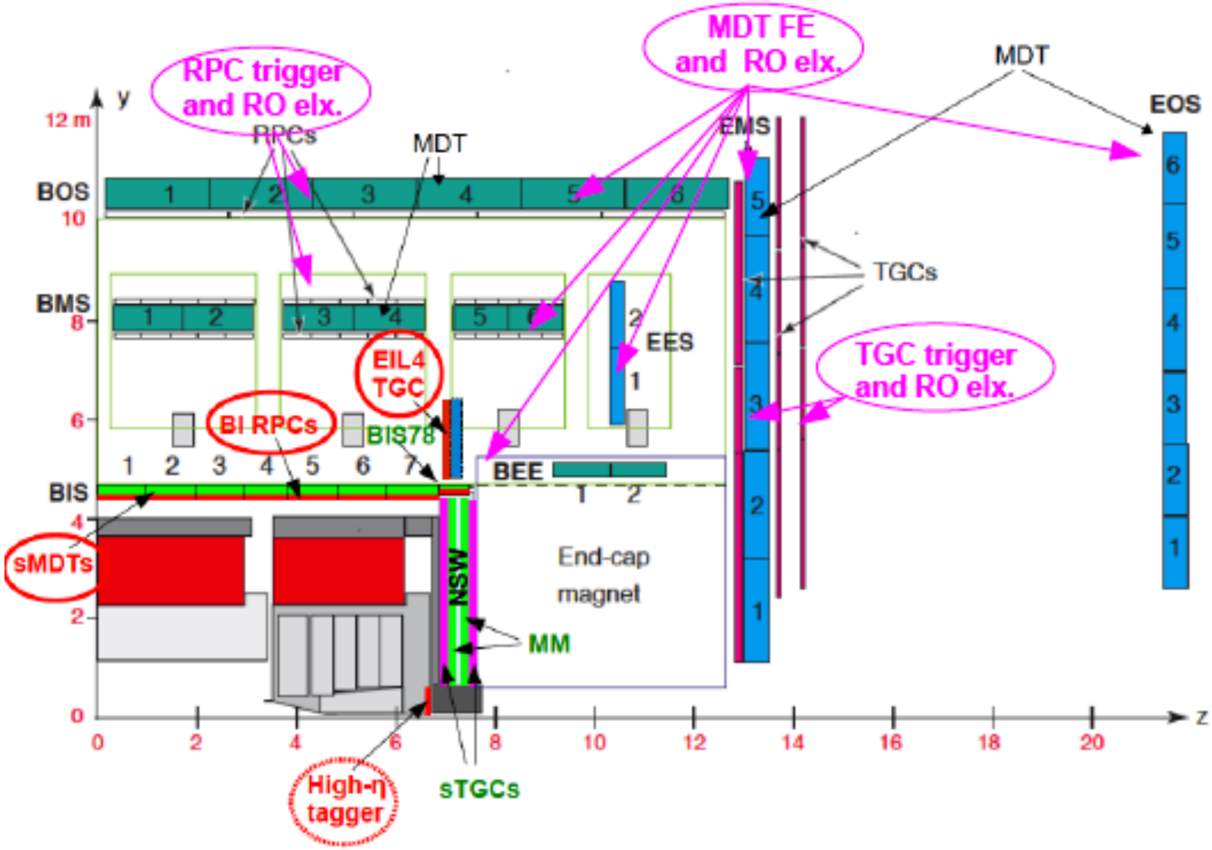
- CB February 2017: Associate Institute of ATLAS (affiliated with NTU Athens)
- June 2017: Expression of Interest to join ATLAS as full member
- CB June 2017: The CB was asked to take note and vote in the next CB
- **CB October 2017**: NCSR Demokritos was accepted as **full member** of the **ATLAS** Collaboration
- November 2017: Member of the ATLAS Muon Project

Team representative: Theo Geralis (Dir. Research)
Additional group members: Georgios Fanourakis (Dir. Research) and Georgios Stavropoulos (Sen. Researcher), PhD student + Engineer



Muon Detector Upgrade: New Small Wheel

Two technologies selected: Micromegas and sTGC



Very active participation
Of the Greek groups

1) NTUA, NKUA, TEI Piraeus, Demokritos: Electronics
2) AUTH: Construction center

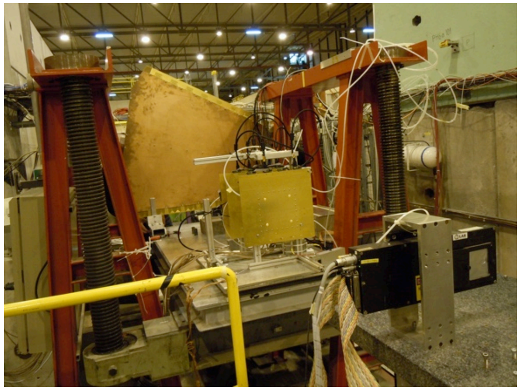
Demokritos has participated In the MAMMA group, i.e. the R&D phase of the resistive Micromegas studies

NSW muon end cap detector will provide:

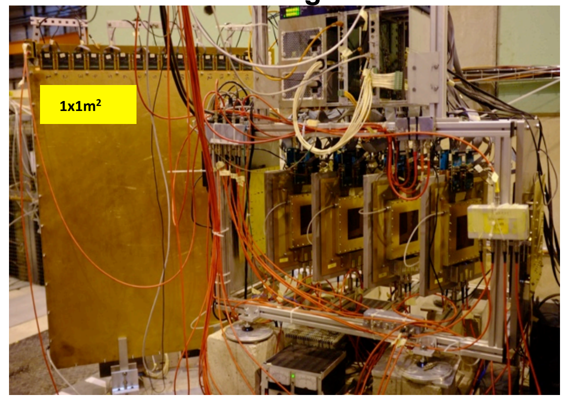
1) Tracking at a difficult B field region
2) Triggering capability
3) Operation at high rates (20 kHz/cm2)
4) Radiation tolerance

Full Micromegas Development Time-Plan

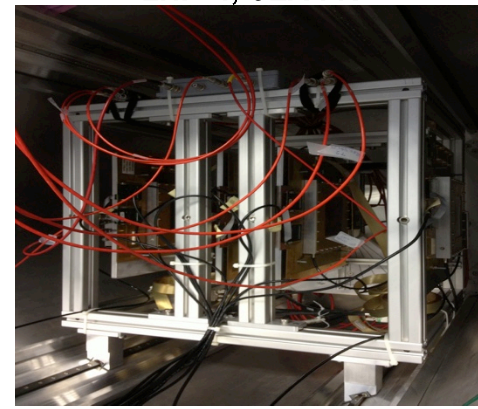
non-resistive MM, SPS/CERN, Demokritos-GR



resistive MM, SPS/CERN, Demokritos-GR, Garching-GE

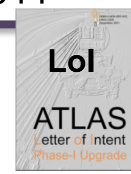


resistive MM, DESY II/DESY, LNF-IT, CEA-FR



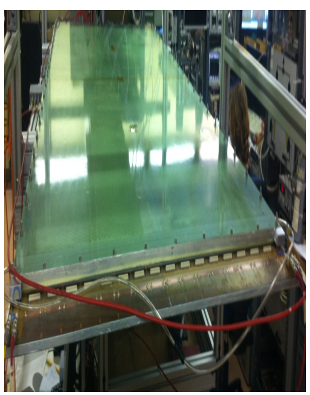
2008 — 2009 — 2010 — 2011 — 2012 — 2013

developed new MM technology

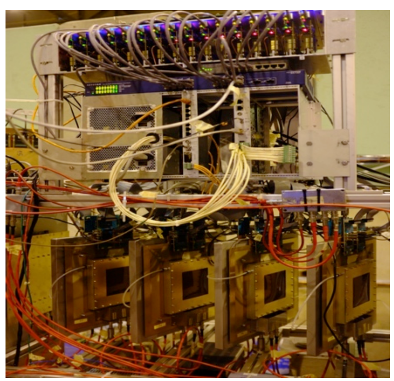


approved by ATLAS

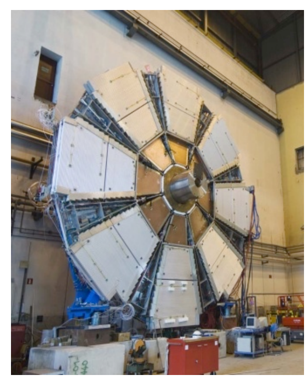
module-0 production & qualification



Full-production of chambers and electronics



Full commissioning on surface



Full installation in cavern

Running...

2014 — 2015 — 2016 — 2017 — 2018 — 2019

ATLAS Demokritos group projects

VMM ASIC irradiation studies (2013 – 2017)

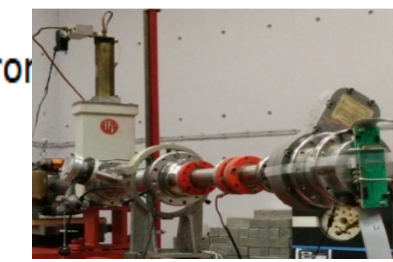
Collaboration
INPP: A. Kourkoumeli (PhD), G. Fanourakis, T. Geralis
NTUA: T. Alexopoulos, M. Kokkoris, G. Tsipolitis
Aegean Univ.: K. Papageorgiou, I. Gialas

VMM will be used at the s-LHC➔ Should test radiation tolerance and SEU ASIC specifications: 130 nm Technology, 64 channels, BNL design
VMM will be used by ATLAS muon Micromegas group and also as the SRS FE chip
Irradiation took place at the Tandem Accelerator

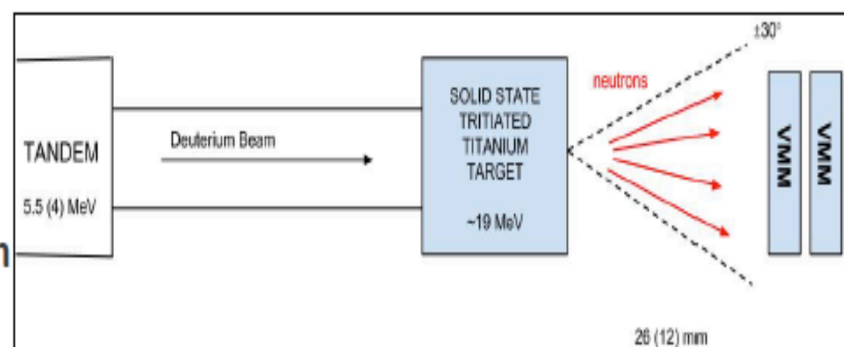
Credits: T.Alexopoul

Nuclear Reaction	Energy Range (MeV)	Range (MeV)
$^{7}Li(p,n)^{7}Be$	1.9 to 8.4	0.1 to 6.7*
$^{2}H(d,n)^{3}He$	0.8 to 8.4	3.9 to 11.5**
$^{3}H(d,n)^{4}He$	0.8 to 8.4	16.4 to 25.7***

[0.1,0.5] MeV & quasimonoenergetic up to ~2.5 MeV
** Quasimonoenergetic neutron up to ~7.5 MeV
*** Monoenergetic neutrons [16.4,22] MeV

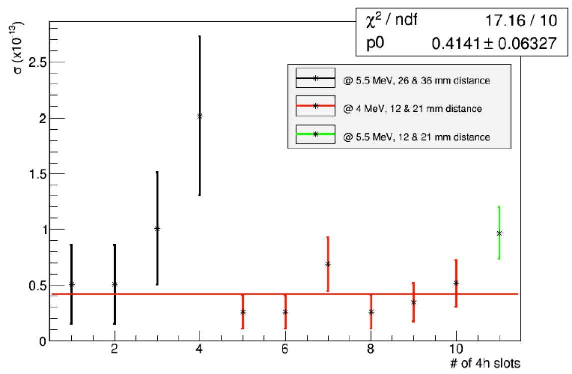


Tritium target (10 ci):
~10^{6} neutrons/cm^{2}s of 18-22 MeV
Testing:
2 days @ E_d = 5.5 MeV, VMMs @ 26,36 mm
3 days @ E_d = 4 MeV, VMMs @ 12,21 mm



Irradiate VMM1 with high energy neutrons (~ 20 MeV)

SEU cross Section



Use Tritiated solid target $^3H(d,n)^4He$
Instantaneous flux(max): 1.8 x 10^7 n/cm^2/s
Total flux: 3.1 x 10^{11} n/cm^2
SEU Cross section = (4.1 +-0.7) x 10^{-14} cm^2/bit

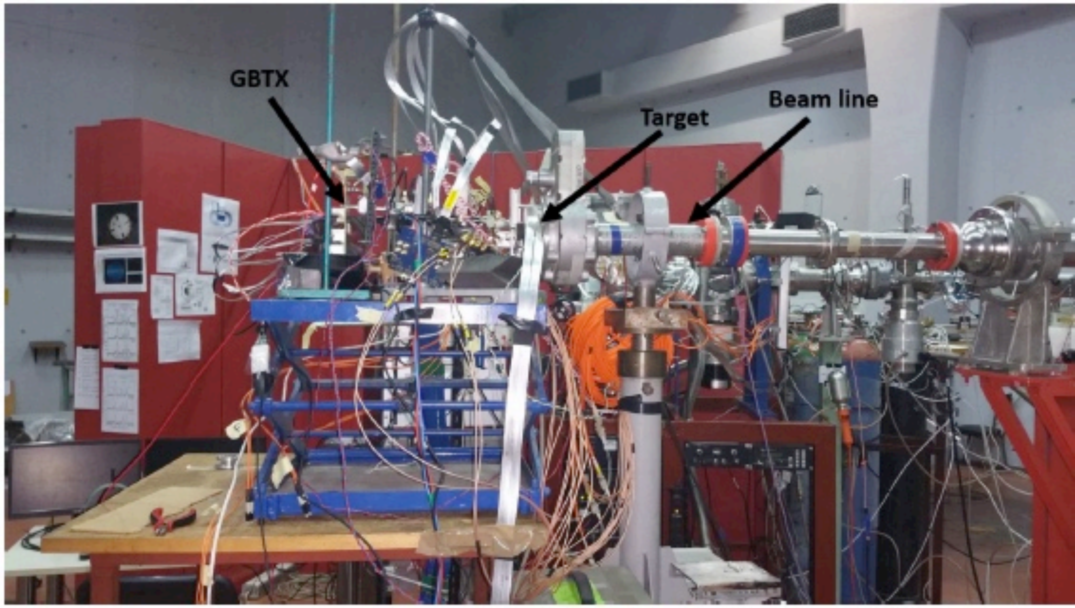
Conclusion: SEU occurrences non tolerable , provision for auto-correction in new VMM2, VMM3 versions.

Work published in JINST

DAY	Distance (cm)	Fluence (n/cm^{2}s)	Time (s)	Neutrons (n/cm^2)
1-2	29.8	5.26E+03	53280	3.36E+08
3	14.5	2.22E+04	39540	8.78E+08
4	16.7	1.67E+04	36180	6.04E+08
5	14.4	1.32E+05	8940	1.18E+09
Total			173220	4.99E+05

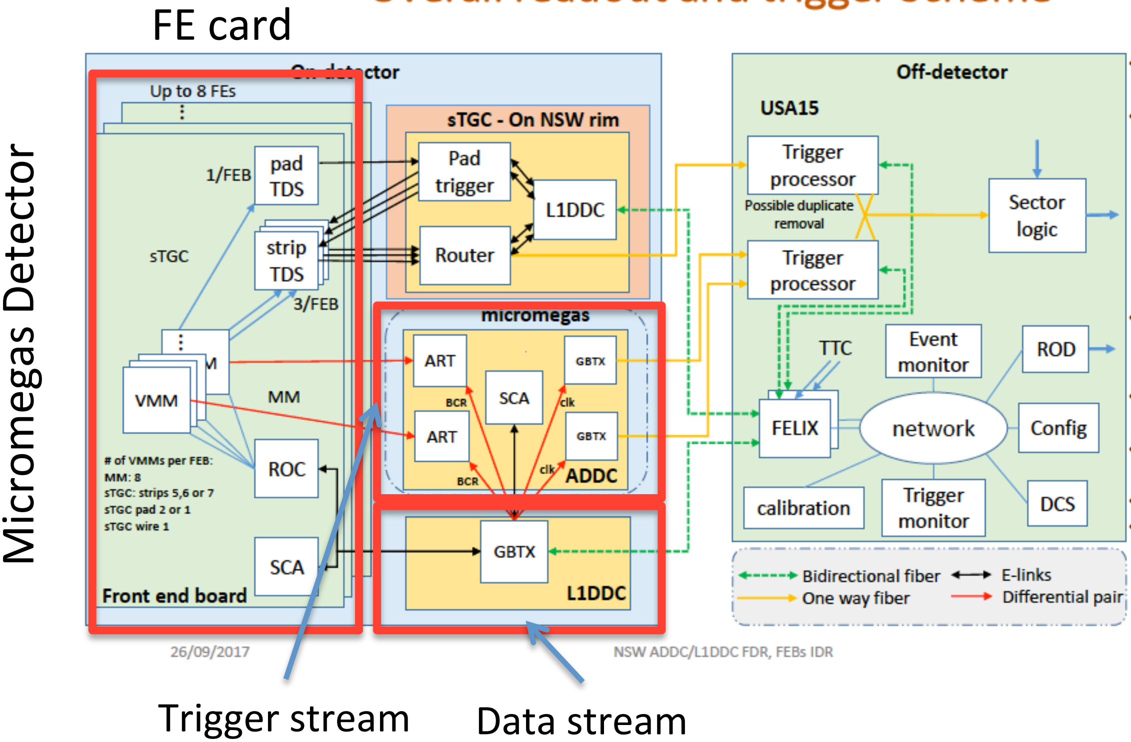
Distance, fluence, time and flux

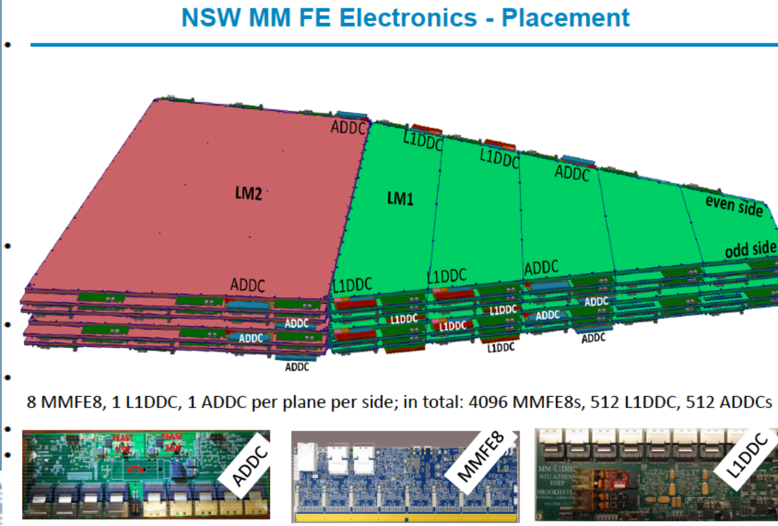
RECENT TESTS: May 2017
and soon new test beam



Setup at Demokritos

Overall readout and trigger Scheme





Demokritos commitmens

A) Qualification

1) QA/QC of 300 L1DDC cards
2) QA/QC of 150 ADDC cards

B) Commissioning

Presence at cern for commissioning and integration of the NSW

C) Involvement in DAQ + Detector develop.

D) Involvement in Physics (at a later stage)

Need for:

Personnel

-PhDs

-PostDocs

-Technician

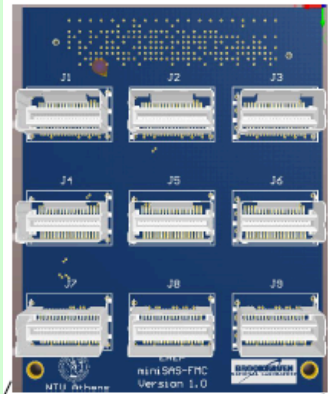
Infrastructure (minimal for qualification to start with)

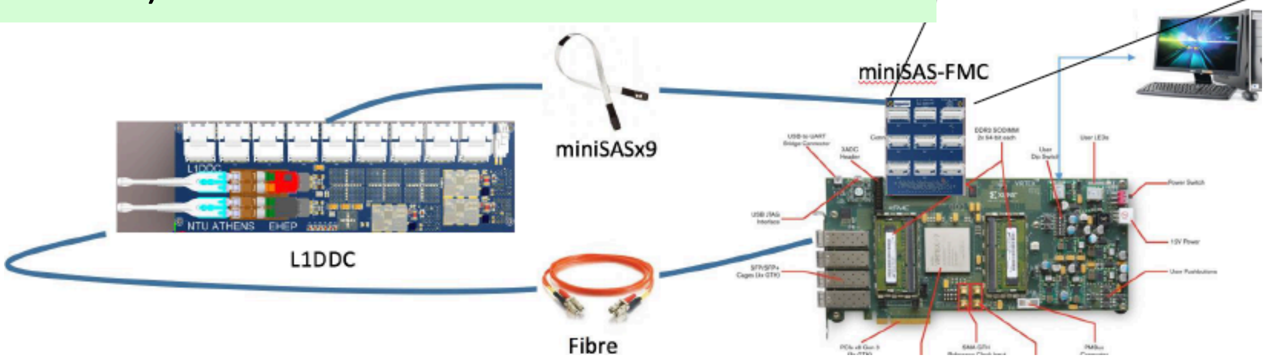
Mobility (2018 – 2019):

3 FTE months at cern/year

L1DDC Testing

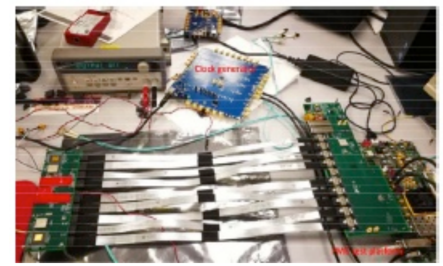
1) Send data through 9 miniSAS connectors and receive Output via fiber
2) Test bench consists of
   i) VC709 evaluation boards
   ii) FMC card with 9 miniSAS
   iii) Fibers and miniSAS cables
   iv) PC workstation



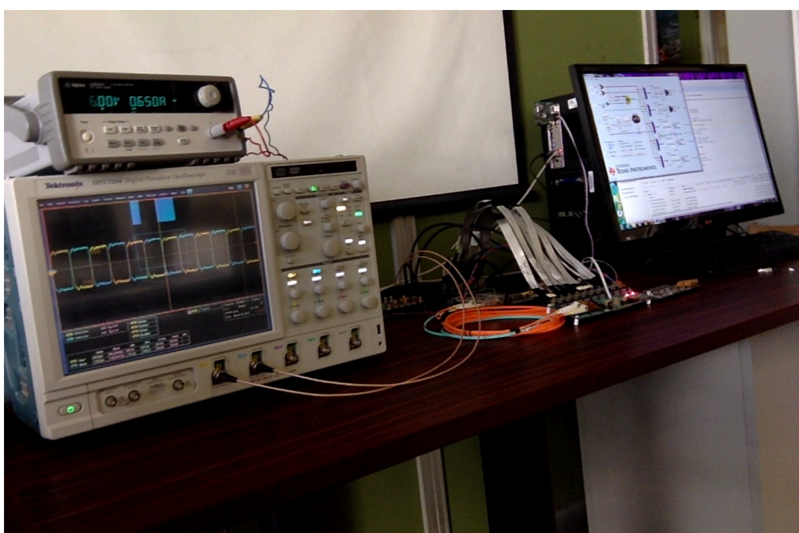


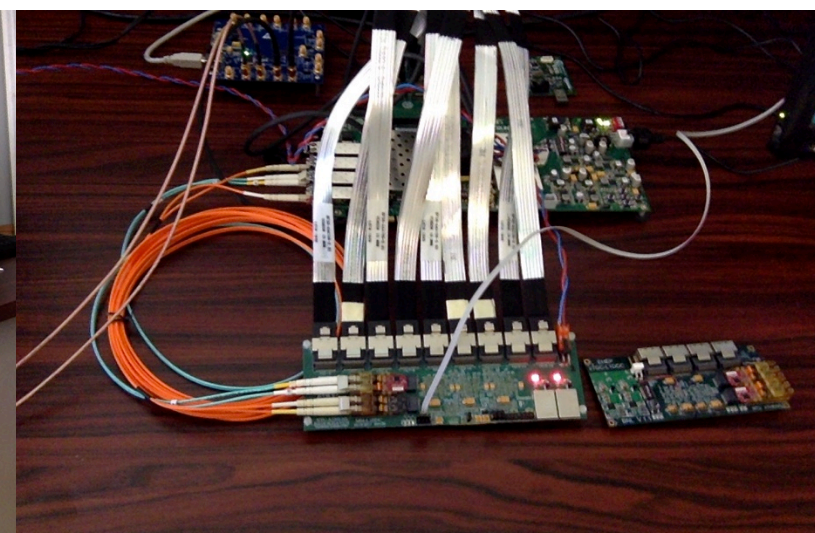
ADDC Testing

1) Closed loop with mezzanine and VC707
2) Test bench consists of
   i) VC707 board
   ii) FMC card
   iii) Fibers/miniSAS cables
   iv) PC workstation



L1DDC setup at Demokritos





SUMMARY

- Important contribution of Demokritos in Micromegas R&D

- Promote Micro Pattern Gas Detector technology in Greece
  1. Training: Practical work (~4 every year)
  2. Education: Diploma (~2 every year), Master (~ 1 year), PhD
  3. Provide access to other Institutes researchers in our Lab

- Important contribution to international projects (Graphene, Picosec Micromegas, Real x-y microbulk, Resistive Micromegas For high rates etc)

- From R&D to physics applications
  Resistive Micromegas → Muon ATLAS Upgrade
  Real x-y →Neutron detector

- Contribution to electronics (irradiations, testing)

- Future projects: High eta muon tagger (Resistive Micromegas For high rates)

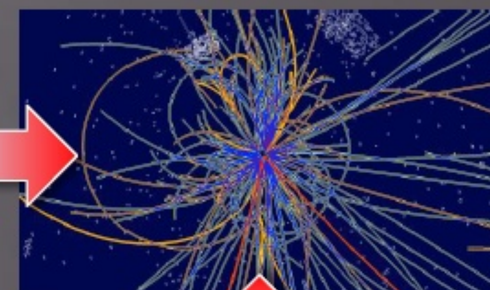
Ανάπτυξη και Μεταφορά Τεχνολογίας Αιχμής

Ιατρική Απεικόνιση

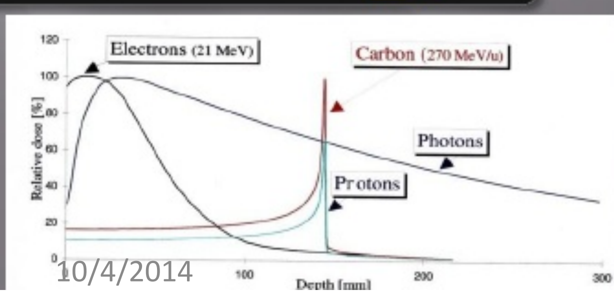
Παράδειγμα: Ιατρική

Επιτάχυνση σωματιδίων

Ανίχνευση σωματιδίων



Μεγάλης κλίμακας υπολογιστών (Grid)



Grid – για την διαχείριση και ανάλυση ιατρικών δεδομένων

Προγράμματα για Προπτυχιακούς Φοιτητέςκαι Πτυχιούχους

•**Πρόγραμμα Διδακτορικών Φοιτητών:** Εφαρμοσμένη Φυσική, Μηχανική, Υπολογιστές
6 – 36 μήνες για εκπόνηση Διδακτορικής Διατριβής
•**Πρόγραμμα "Δράσεις Marie Curie":** Σε συνεργασία με την Ευρωπαϊκή Ένωση
για εκπόνηση Διδακτορικής Διατριβής (36 μήνες)
•**Πρόγραμμα Τεχνικών Σπουδαστών:** Πρακτική στους ίδιους τομείς (4 – 12 μήνες)
για προπτυχιακούς
•**Πρόγραμμα Σπουδαστών Διοίκησης:** Πρακτική σχετική με Διοίκηση (2 – 12 μήνες)
για προπτυχιακούς
•**Πρόγραμμα Καλοκαιρινού Σχολείου:** Καλοκαιρινό Σχολείο (~ 3 μήνες) για προπτυχιακούς
Από Ελλάδα 7 φοιτητές/χρόνο
•**Πρόγραμμα Ανοικτού εργαστηρίου (openlab) του CERN:** 2 μήνες το καλοκαίρι απασχόληση
σε συγκεκριμένο project

Πρόγραμμα για Διπλωματούχους Τεχνολόγους μηχανικούς

Πρακτική Εκπαίδευση Τεχνικών: Εργασία σε τεχνικά θέματα σε διάφορα project
(24 μήνες)

Περισσότερες πληροφορίες : http://jobs.web.cern.ch/

Προγράμματα για Διδάκτορες

•**Πρόγραμμα Υποτροφιών:** Σωματιδιακή Φυσική ή Εφαρμοσμένες επιστήμες (24 μήνες)
Εργασία σε πείραμα ή πρόγραμμα του CERN

•**Πρόγραμμα "Δράσεις Marie Curie":** Σε συνεργασία με την Ευρωπαϊκή Ένωση
Ως έμπειρος ερευνητής

Άλλα προγράμματα
(αναφέρονται για πληρότητα)

Για εργαζόμενους Ερευνητές σε χώρες μέλη

•**Scientific Associates:** Για Ερευνητές σε χώρες μέλη (12 μήνες)
Εργασία σε πείραμα ή πρόγραμμα του CERN
•**Corresponding Associate:** Για Ερευνητές σε χώρες μέλη (ως 6 μήνες)
Εργασία σε πείραμα ή πρόγραμμα του CERN

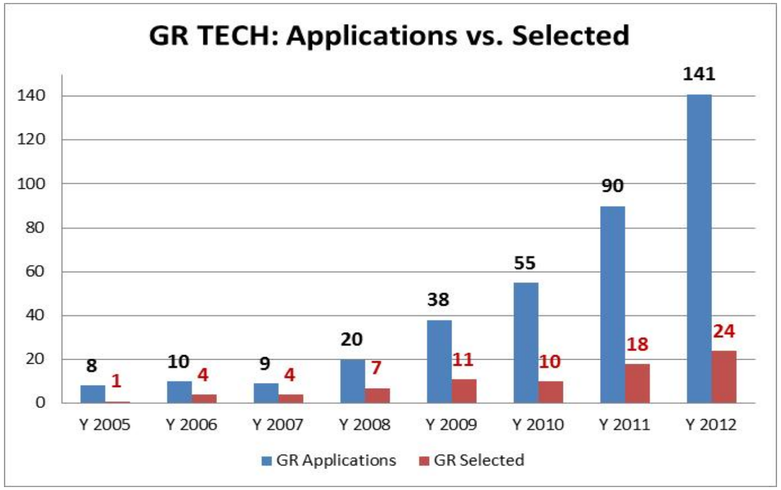
Περισσότερες πληροφορίες : http://jobs.web.cern.ch/

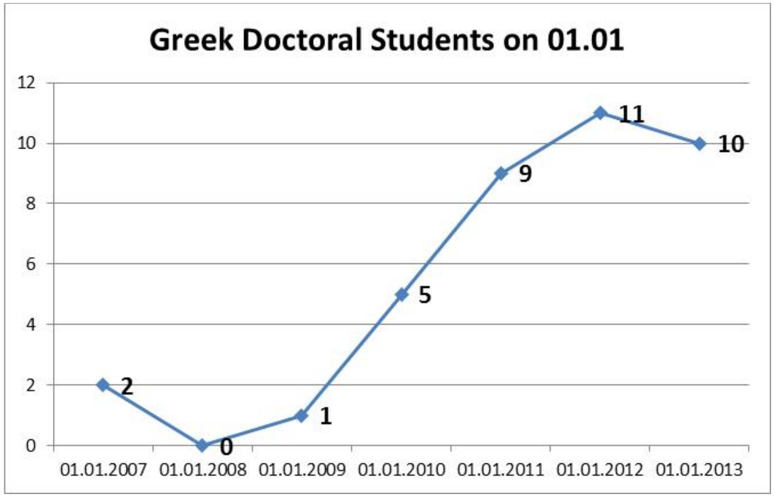
Ερευνητικά Ινστιτούτα και προσωπικό στην Σωματιδιακή και Αστροσωματιδιακή Φυσική

Ερευντητικό προσωπικό στην Σωματιδιακή Φυσική				
Πανεπιστήμιο/Ινστιτούτο	**Δραστηριότητα**	**Ερευνητές**	**Διδακτορικοί φοιτητές**	**Σύνολο**
Αριστοτέλιο Πανεπ.	ATLAS-LHC, CAST	7	6	13
Ελληνικό Ανοικτό Πανεπ.	ATLAS-LHC, KM3	7	1	8
Πανεπ. Αθηνών	CMS-LHC, ATLAS-LHC, ALICE-LHC, KM3	19	10	29
ΕΜΠ	ATLAS-LHC, CAST, ASTRO	9	6	15
ΕΚΕΦΕ Δημόκριτος	CMS-LHC, CAST , KM3, pEDM	14	4	18
Πανεπ. Αιγαίου	ATLAS, KM3	2	1	3
Πανεπ. Ιωαννίνων	CMS-LHC	7	1	8
Πανεπ. Πατρών	CAST, pEDM	1	2	3
Σύνολο Πειραματικών		63	31	**94**
Αριστοτέλειο Πανεπ.	HEP Phenomenology, Cosmology	3	1	4
ΕΚΕΦΕ Δημόκριτος	Beyond SM, Cosmology, HEP Phenomenology	4	4	8
Πανεπ. Αθήνας	Beyond SM, Cosmology	10	7	17
ΕΜΠ	Beyond SM, Cosmology	7	9	16
Πανεπ. Ιωαννίνων	Beyond SM, Cosmology	12	4	16
Πανεπ. Κρήτης	Beyond SM, Cosmology	10		10
Πανεπ. Πάτρας	Beyond SM, Cosmology	8	5	13
Σύνολο Θεωρητικών		54	30	**84**
Σύνολο		117	61	**178**

Έλληνες εργαζόμενοι στο CERN (έως 2013)

	Έλληνες/ Σύνολο	Ποσοστό Επί συνόλου
Σπουδαστές σε Τεχνικά θέματα	**32/189**	**17%**
Διδακτορικοί Φοιτητές	**10/164**	**6%**
Μεταδιδακτορικοί	**28/549**	**5%**
Μόνιμο προσωπικό	**27/2455**	**1.1%**
Προσωπικό PJAS	**15/236**	**6%**
Προσωπικό SASS	**4/50**	**8%**
Χρήστες	**177/11129**	**1.6%**
Ετήσια Συνδρομή Ελλάδας για το 2013		**1.78%**





Greek Contribution vs Return

Εισφορές της Ελλάδας στο CERN το 2018 φαίνονται στον πίνακα 2.

Κατηγορία	**2018**	**2017**
Ετήσια εισφορά	10.62 MCHF	11.44 MCHF
M&O-A/B	00.35 MCHF	00.35 MCHF
ΣΥΝΟΛΟ	**10.97 MCH**	**11.79 MCH**

Τα έξοδα του CERN για Έλληνες ερευνητές στο CERN το 2017 φαίνονται στον Πίνακα-1

Κατηγορία	**Αριθμός 2016**	**Κόστος 2016**	**Αριθμός 2017**	**Κόστος 2017**
CERN FELLOWS	43	3.72 MCHF	53	4.59 MCHF
TECH. STUDENTS	36	1.53 MCHF	27	1.15 MCHF
PH.D STUDENTS	13	0.62 MCHF	15	0.71 MCHF
CERN STAFF	30	3.60 MCHF	38	4.56 MCHF
ΣΥΝΟΛΟ		**9.47 MCHF**		**11.01 MCHF**

Κατηγορία	**2018**
Ελληνική Ετήσια εισφορά και M&O-A/B	**10.97 MCH**
Εισφορά CERN (υποτροφίες, Μισθοί)	11.01 MCH
Βιομηχανική Επιστροφή από CERN	2.37 MCH
ΣΥΝΟΛΟ από CERN προς Ελλάδα	11.01+2.37 = **13.38 MCH**

Πίνακας 3: Η Ελληνική εισφορά στο CERN σε σύγκριση με την επένδυση του CERN σε ελληνικό επιστημονικό προσωπικό, εκπαίδευση και βιομηχανία.