MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond

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INFN TRIESTE

In behalf of COMPASS RICH – 1 collaboration

Outline

- Introduction
- COMPASS RICH-1
- MPGD based Hybrid photon detectors
- Commissioning and performance of the PDs
- Results
- More we're doing after the upgrade
- Conclusion

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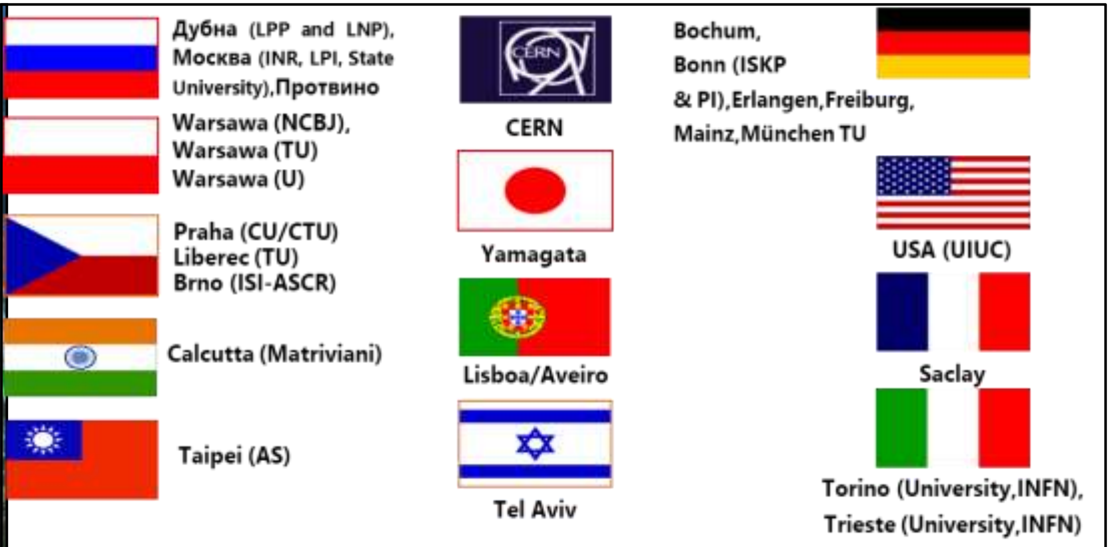
COMPASS Experiment @ CERN



Experiments with muon beam:

COMPASS - I (2002 – 2011)

- Spin structure, Gluon polarization
- Flavor decomposition
- Transversity
- Transverse Momentum-dependent PDF

COMPASS - II (2012 – 2018)

- DVCS and HEMP
- Unpolarized SIDIS and TMDs

COMPASS - II (2021 – 2022)

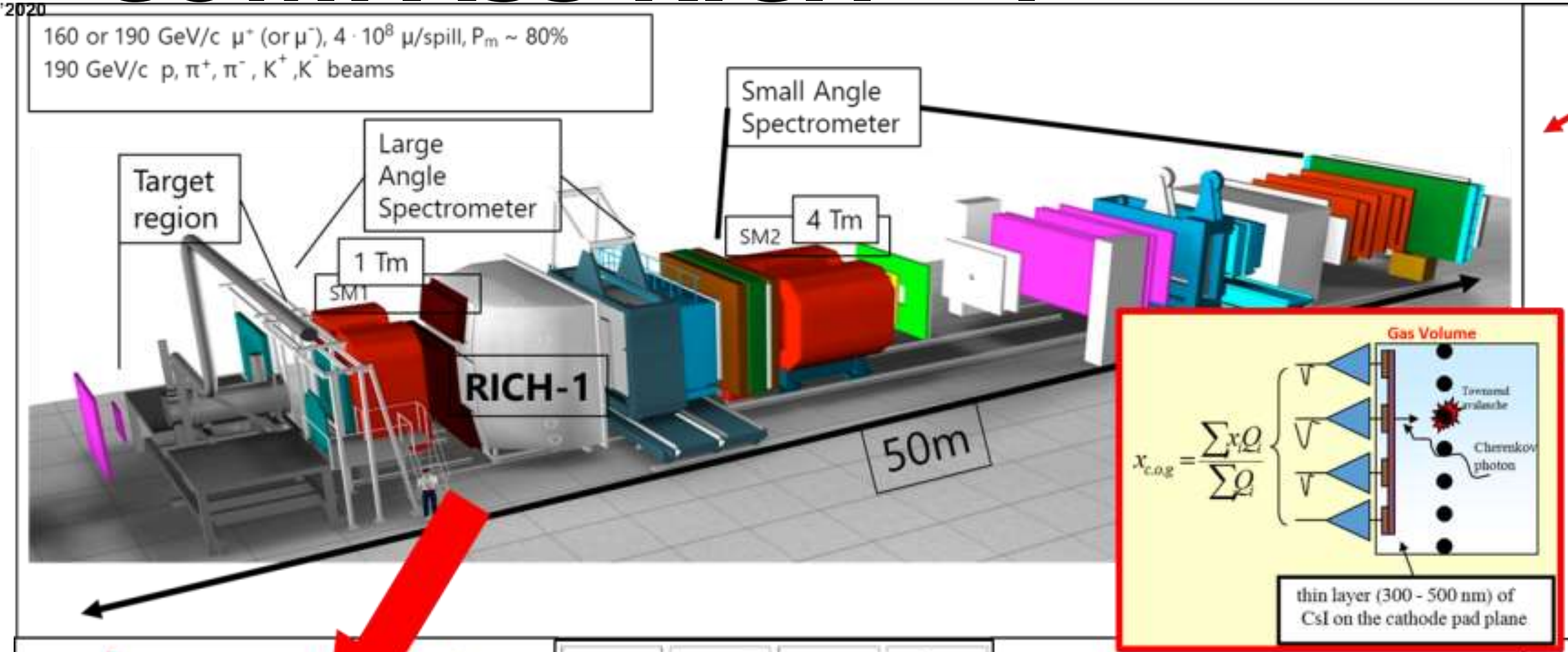
- TMDs and Proton Radius

Experiments with hadron beams:

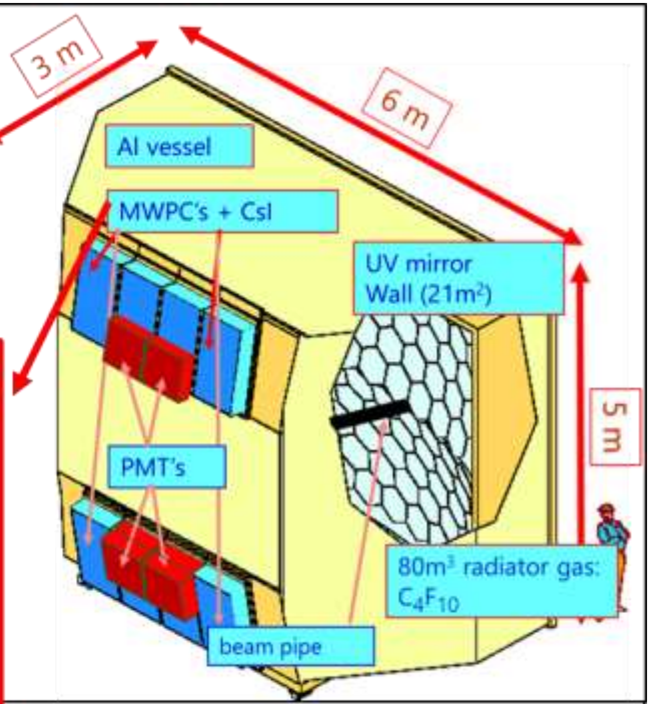
- Pion polarizability
- Diffractive and Central production
- Light meson spectroscopy
- Baryon spectroscopy

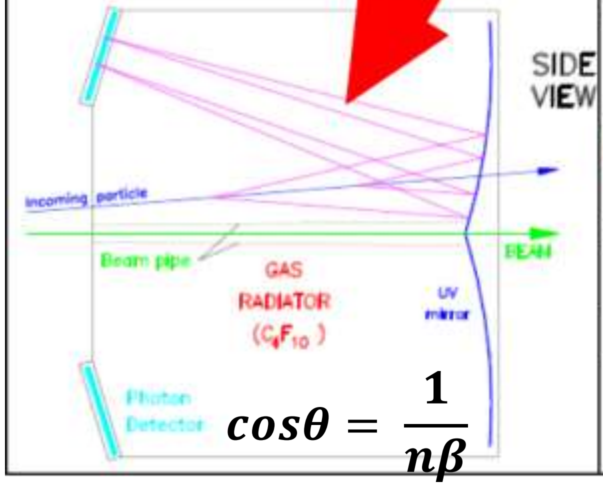
- Pion and Kaon polarizabilities
- Drell-Yan studies

COMPASS RICH – 1

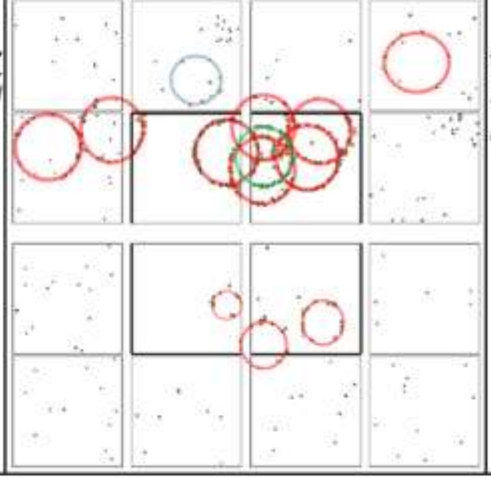


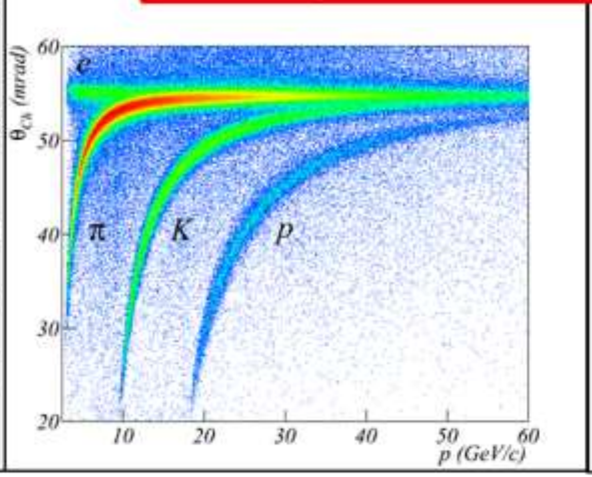
$$x_{c.o.g} = \frac{\sum x_i Q_i}{\sum Q_i}$$





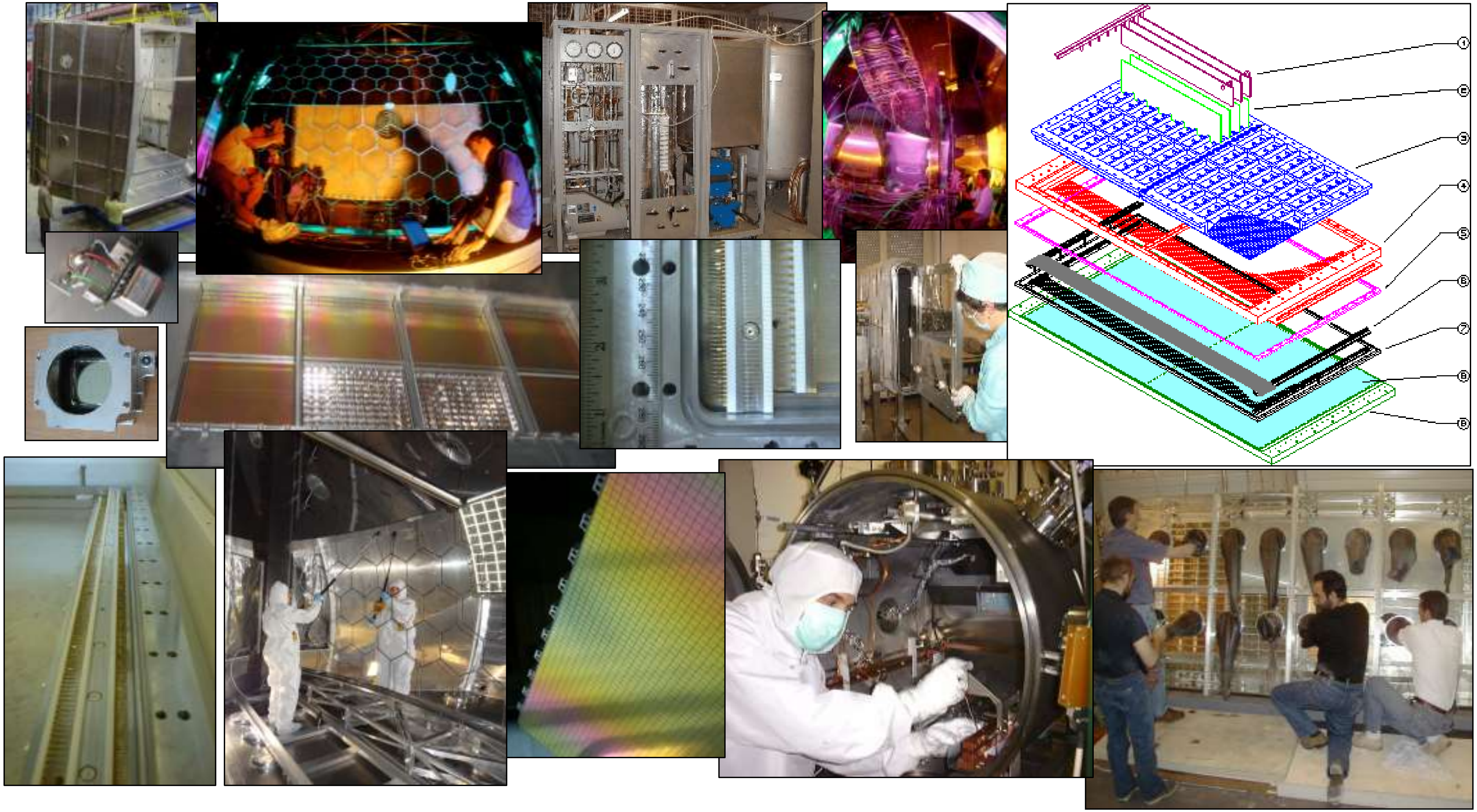
$$cos\theta = \frac{1}{n\beta}$$





- **hadron PID from 3 to 60 GeV/c acceptance: H: 500 mrad V: 400 mrad**
- **trigger rates: up to ~50 KHz beam rates up to ~10^8 Hz**
- **material in the beam region: 1.2% Xo**
- **material in the acceptance: 22% Xo**
- **detector designed in 1996 and in operation since 2002**
- **upgraded in 2006 total investment: ~ 5 M €**
- **A NEW UPGRADE HAS BEEN DONE IN 2016**

Building COMPASS RICH – 1

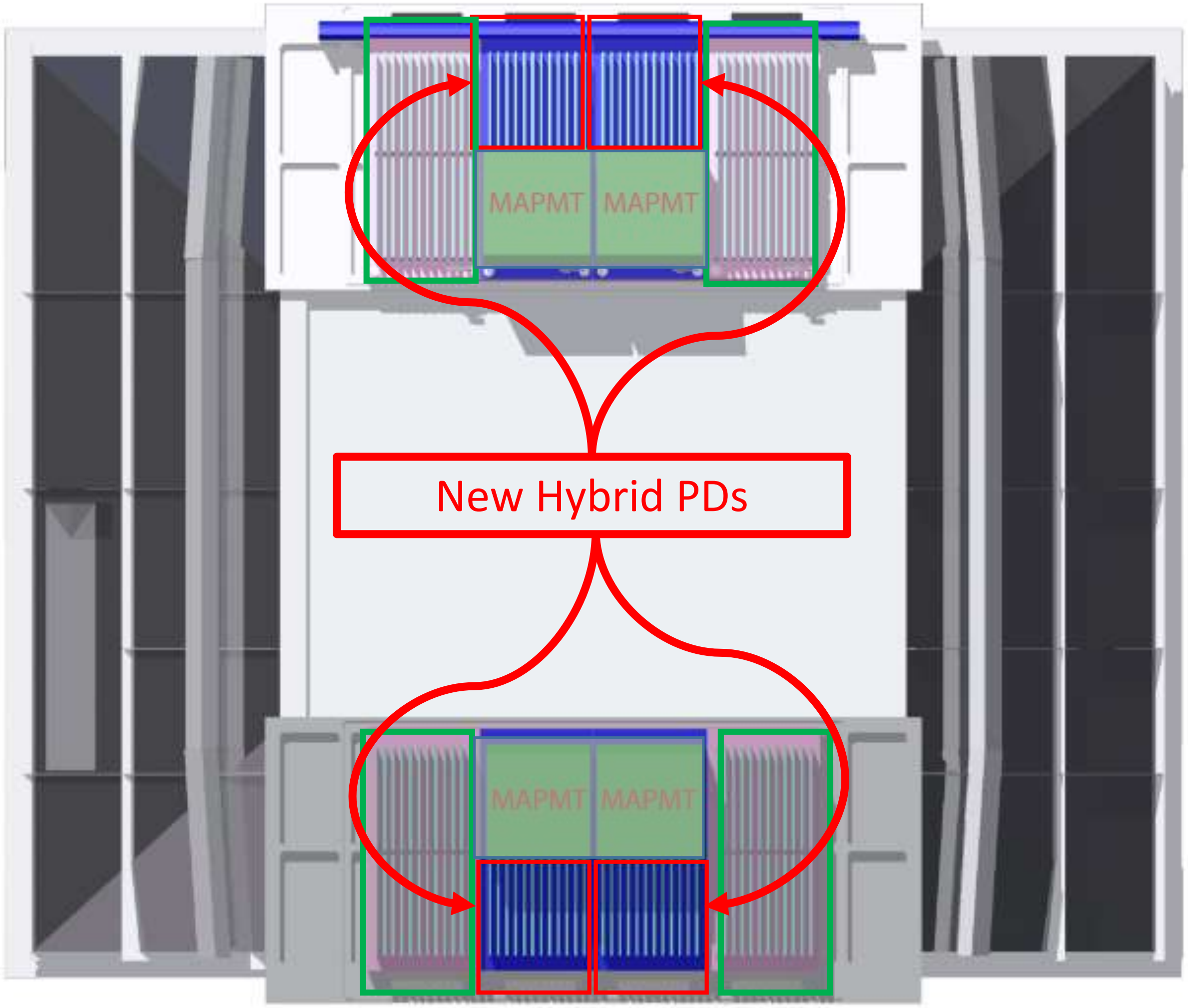


Motivation for upgrading COMPASS RICH-1

- In order to cope with the challenging requests posed by the future physics program of COMPASS a set of new generation, high performing photon detectors with an active area of 576X576 mm^2 will be installed. The characteristics of the new detectors are:

1. A small time resolution $\leq 10\ ns$.
2. A closed geometry to avoid photon feedback.
3. A large gain $(\geq 10^5)$.
4. A reduced Ion Back – Flow (IBF) to the CsI photocathode $(\leq$

MPGD based PDs:
Chosen ->
HYBRID: THGEMs + MICROMEGAS based PDs of single photons



The MPGD-based hybrid photon detector

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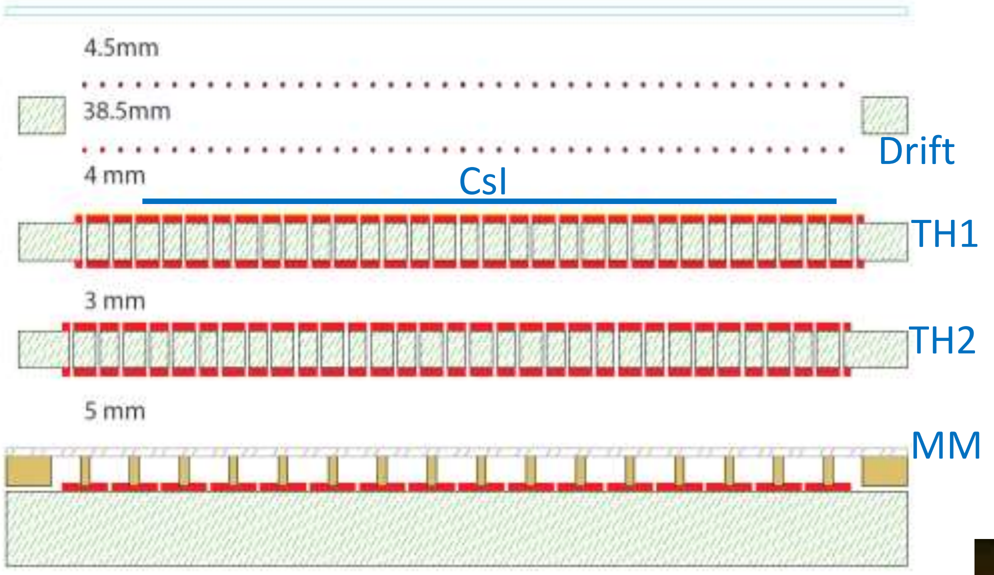
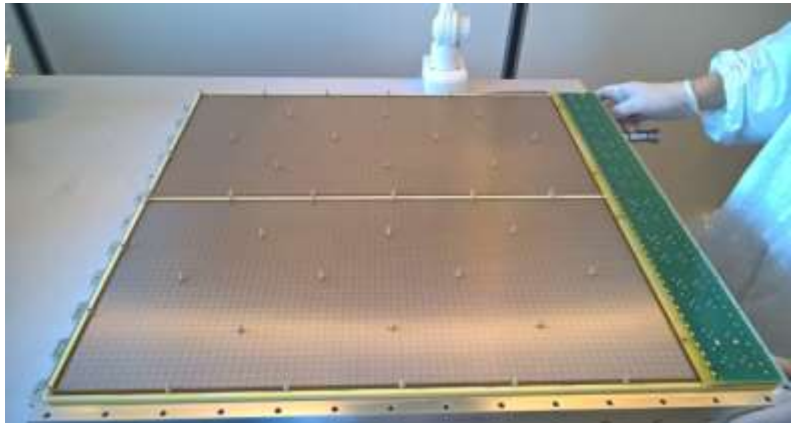
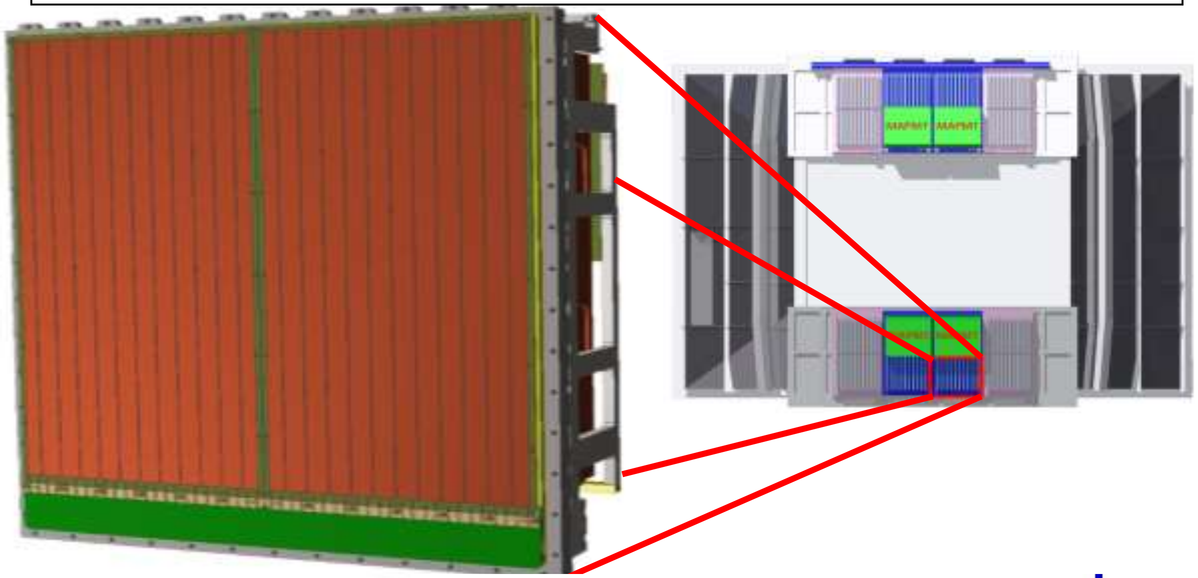
Hybrid PD scheme



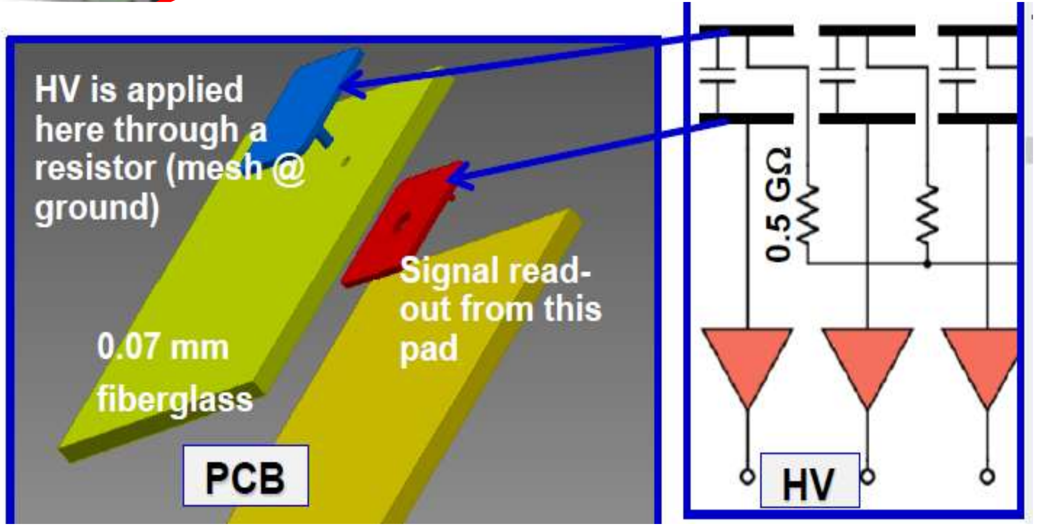
Standard Bulk Micromegas produced at CERN



modular structure: one module = 600x300 mm^2



8mm X 8mm pads
at positive HV



Capacitive coupling → APV25

Component Quality Control

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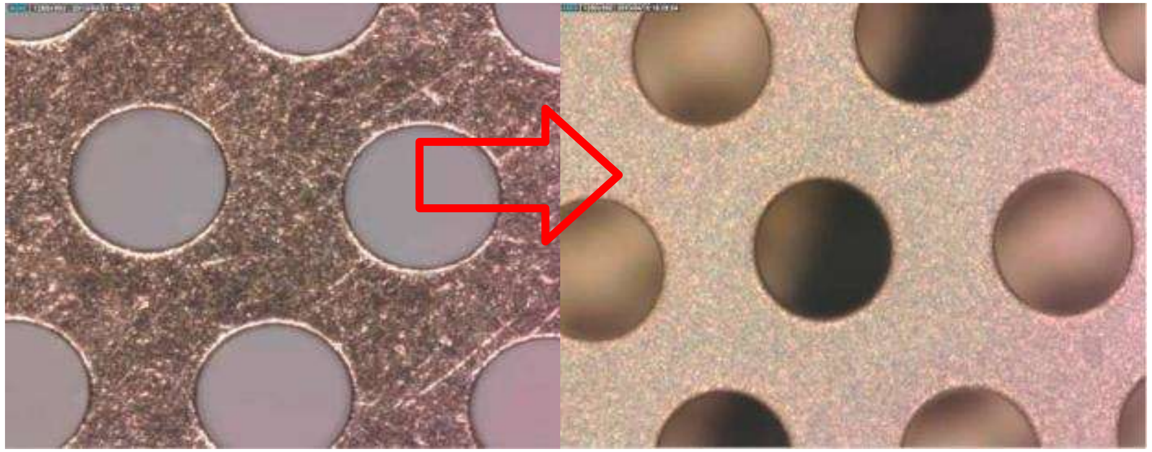
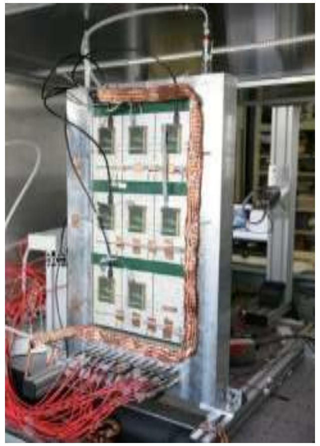
THGEM polishing with an "ad hoc" protocol setup by us including baking:

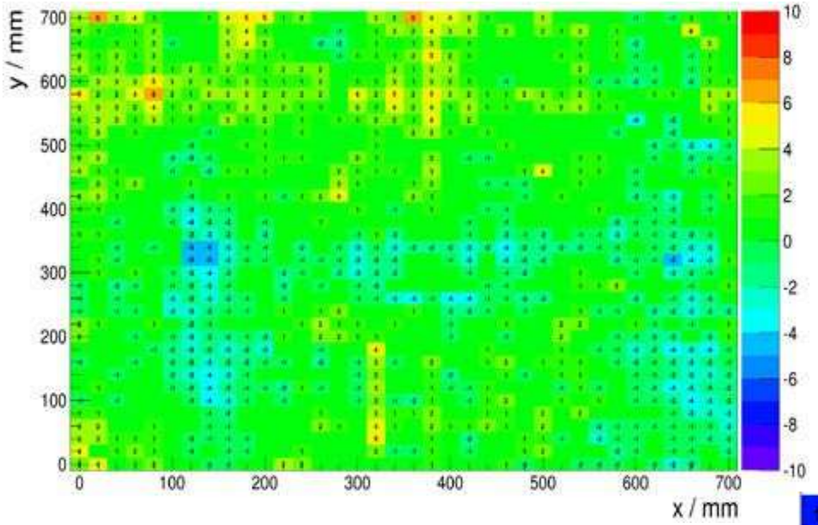
>90% break-down limit obtained



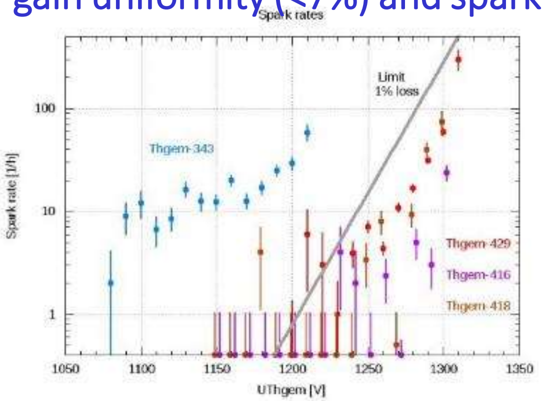
Measurement of the raw material thickness before the THGEM production, accepted:

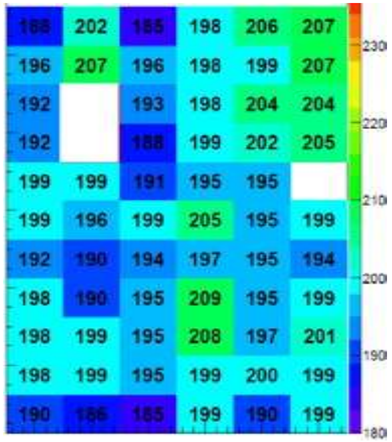
± 15 μm ↔ gain uniformity σ < 7%





X-ray THGEM test to access gain uniformity (<7%) and spark behaviour

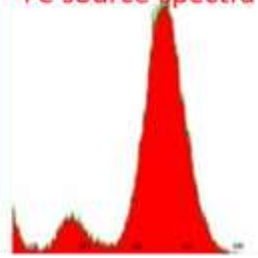


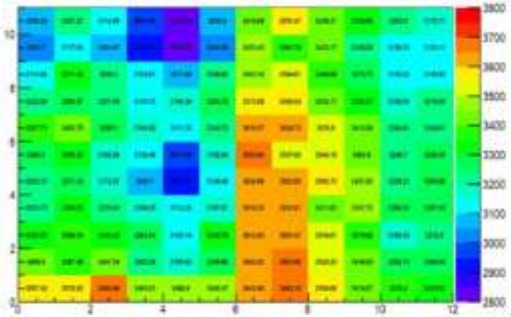


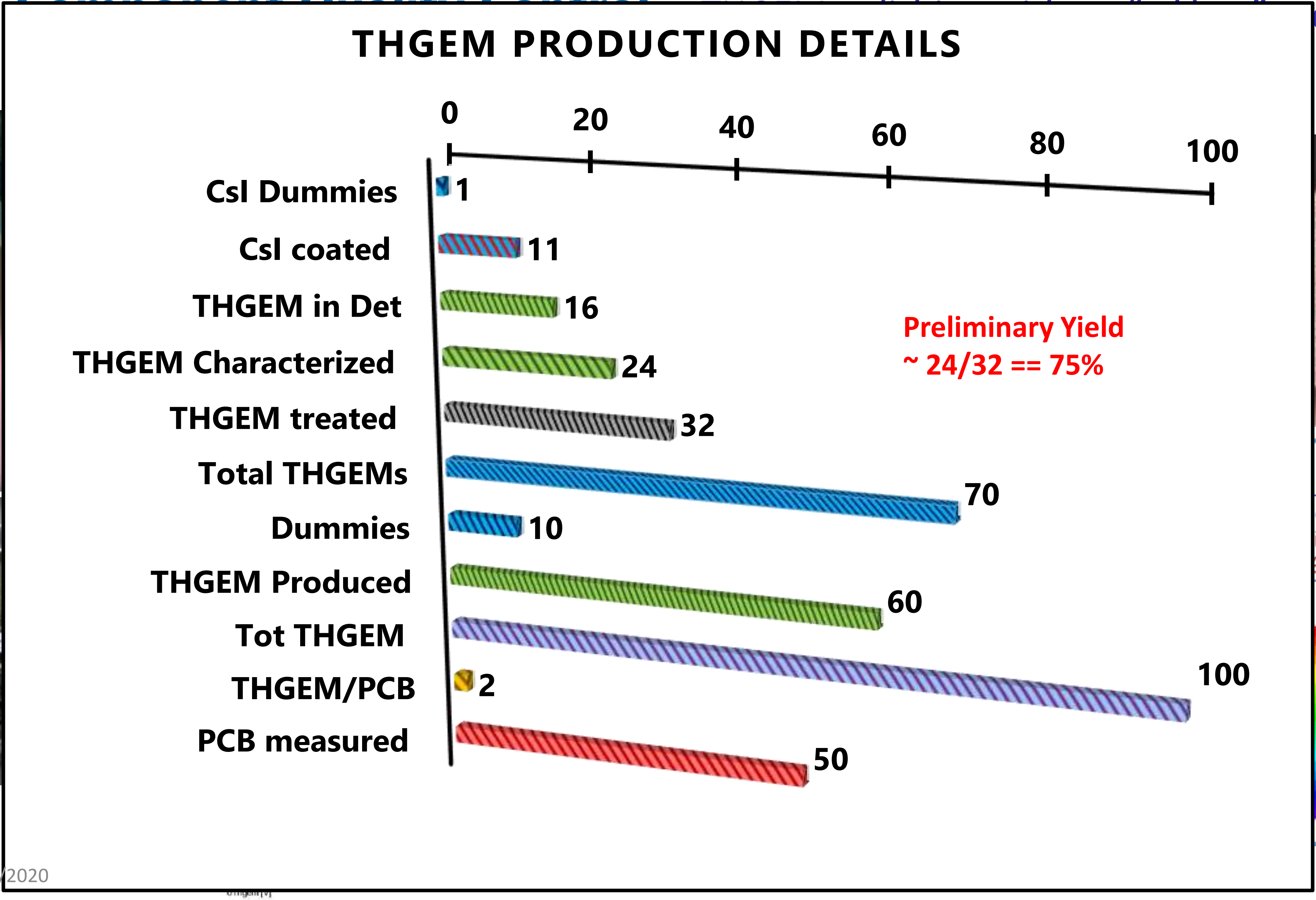
MICROMEGAS

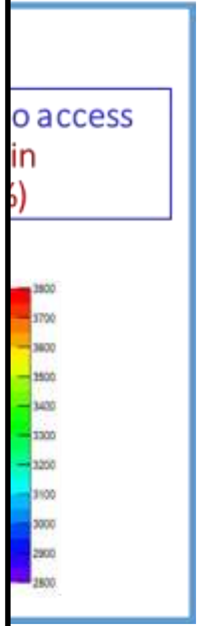
X-ray MM test to access integrity and gain uniformity (<5%)

^{55}Fe source spectra

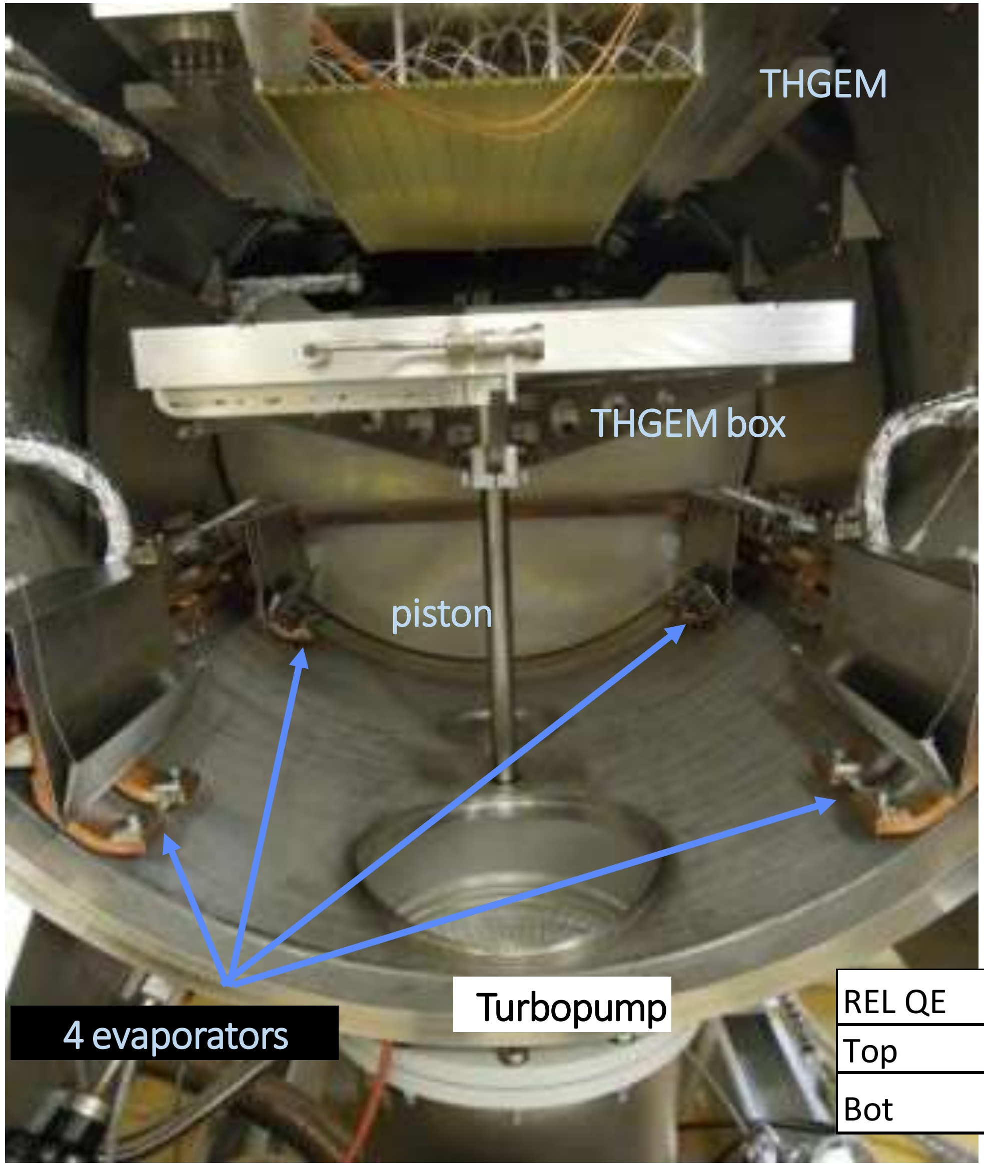


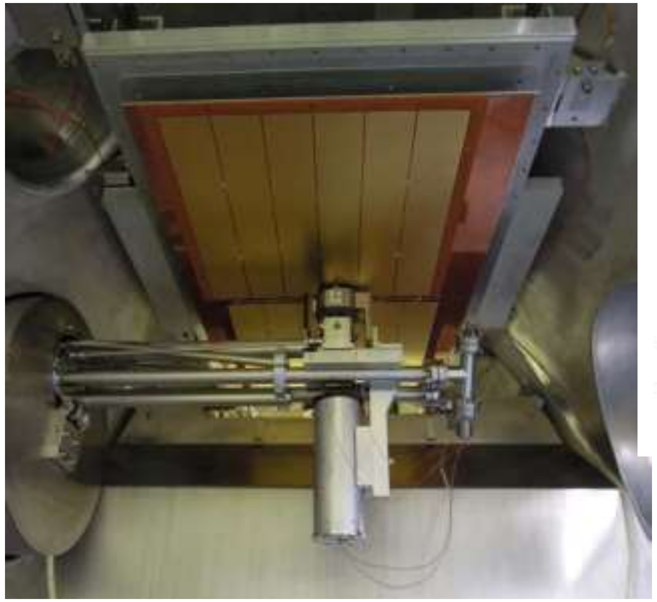



THGEM PRODUCTION DETAILS
0
20
40
60
80
100
CsI Dummies
1
CsI coated
11
THGEM in Det
16
THGEM Characterized
24
THGEM treated
32
Total THGEMs
70
Dummies
10
THGEM Produced
60
Tot THGEM
100
THGEM/PCB
2
PCB measured
50
Preliminary Yield
~ 24/32 == 75%

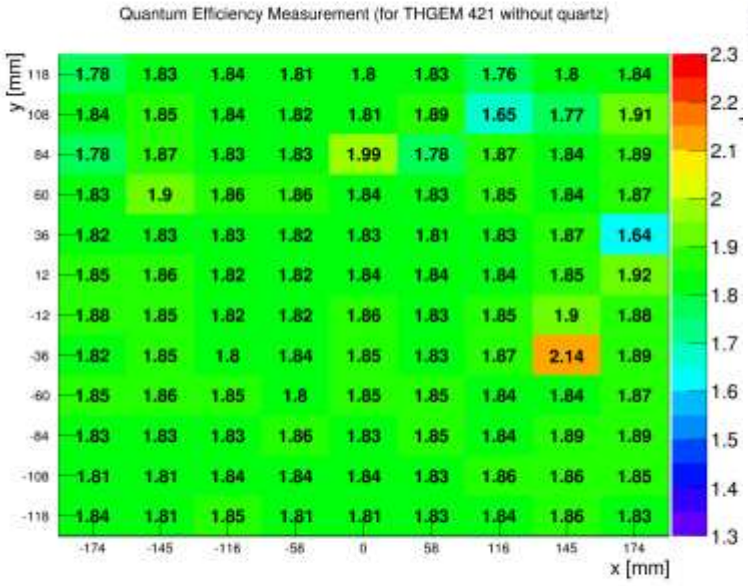


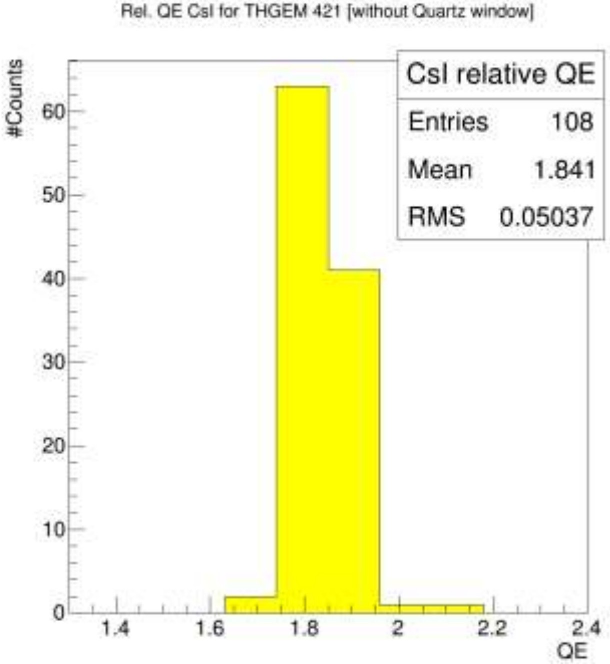
THGEM CsI coating at CERN





QE measurement





QE uniformity

- ✓ **3 % r.m.s. within a photocathode**
- ✓ **10 % r.m.s. among photocathodes**
- ✓ **mean value: 93% of reference**

REL QE	Jura		Saleve	
Top	3	3.14	2.83	2.74
Bot	2.47	2.44	2.47	2.98

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Dismantling OLD PDs from RICH

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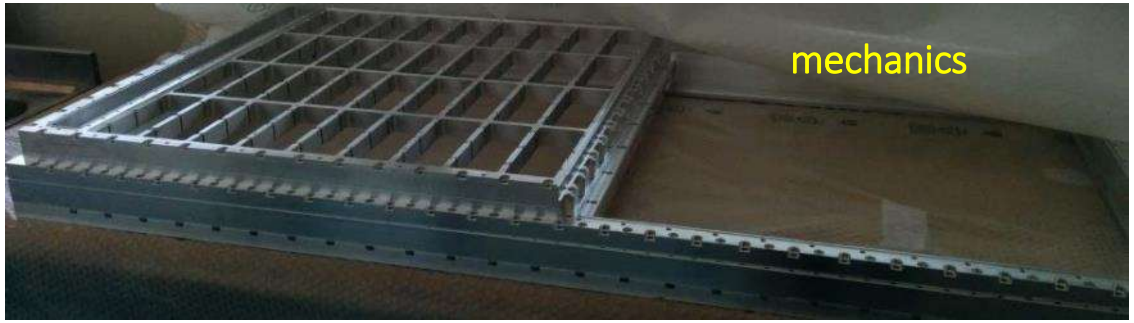
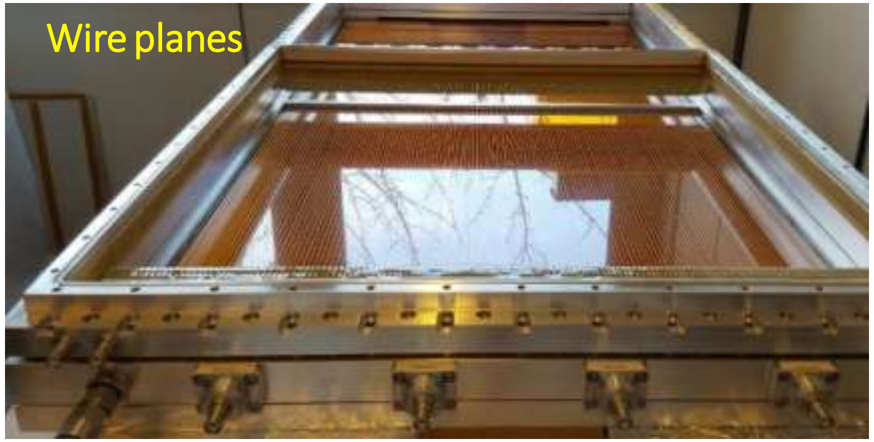
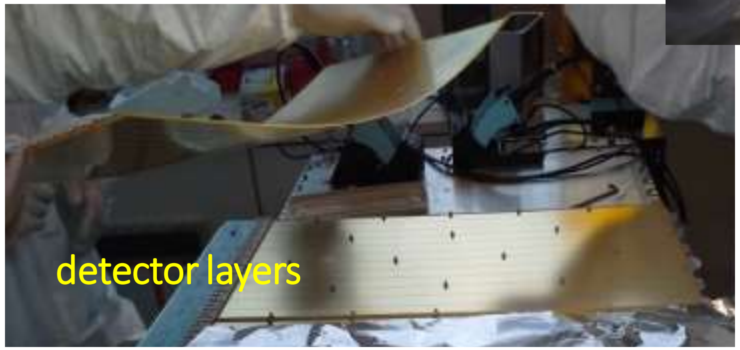
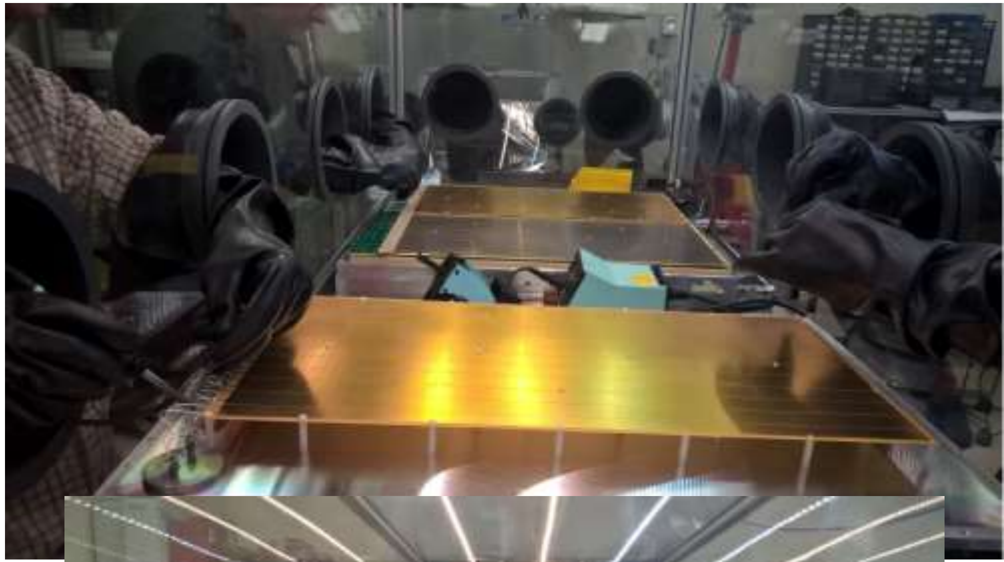
Detector assembling









Assembling CsI coated THGEM in a dedicated Glove box flushing with N2 gas

Integration of new PDs on the RICH

HV control for the hybrid detectors

Electrode	Protection wire plane	Drift wire plane	THGEM1 top	THGEM1 bottom	THGEM2 top	THGEM2 bottom	mesh	MM anode
Voltage	-300 V	-3520 V	-3320 V	-2050 V	-1750 V	-500 V	grounded	+620 V
Number of HV channels per detector	1	1	4	4	4	4	0	4

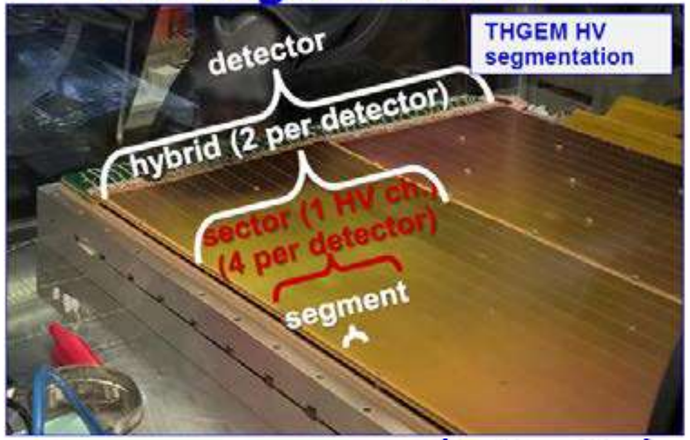
Gain stability vs P, T:

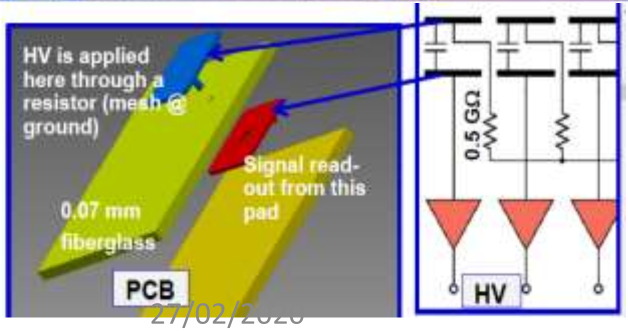
- G = G(V, T/P)
- Enhanced in a multistage detector
- ΔT = 1 degree → ΔG ≈ 12 %
- ΔP = 10 mbar → ΔG ≈ 20 %

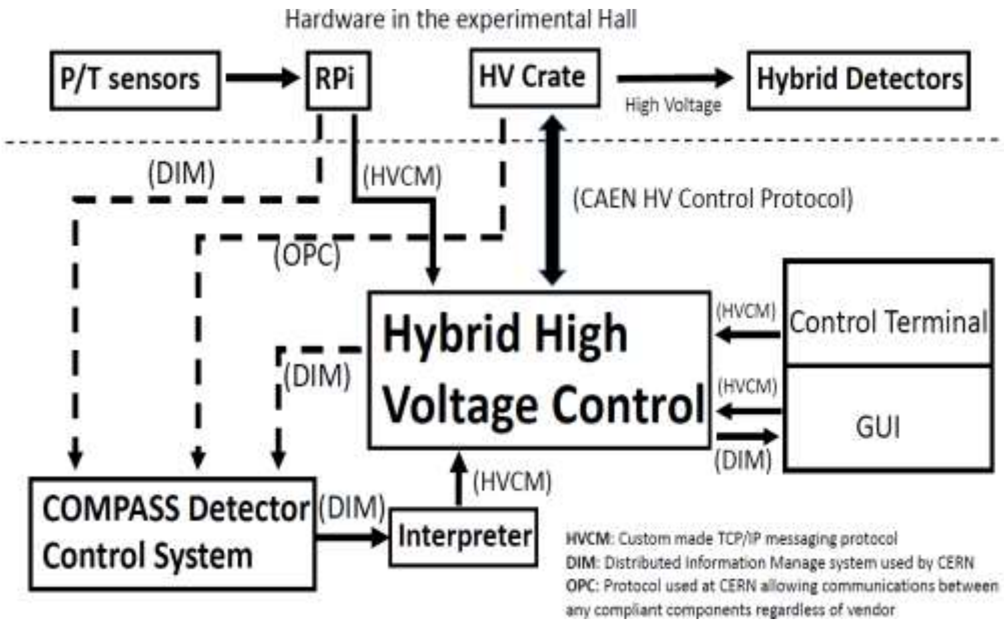
THE WAY OUT:

- Compensate T/P variations by V

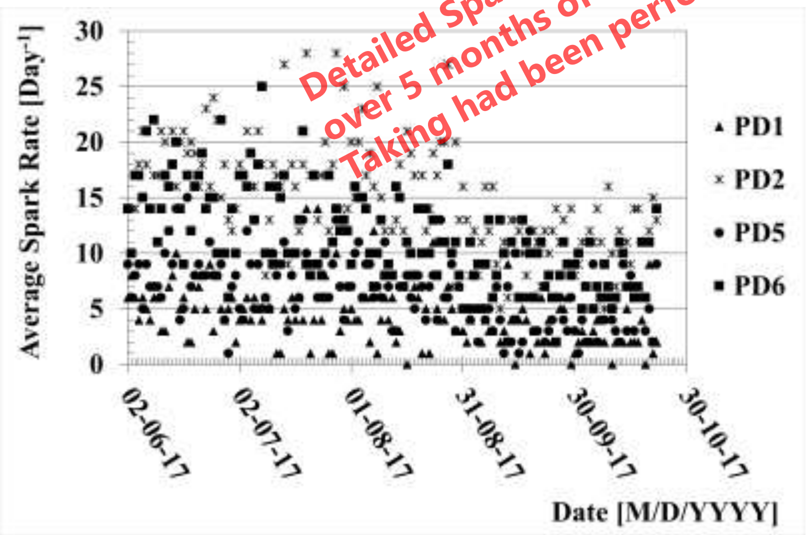
- HV segmentation







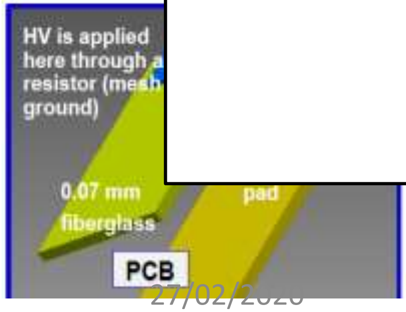
Detailed Spark Rate analysis over 5 months of Data Taking had been performed

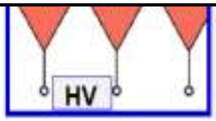


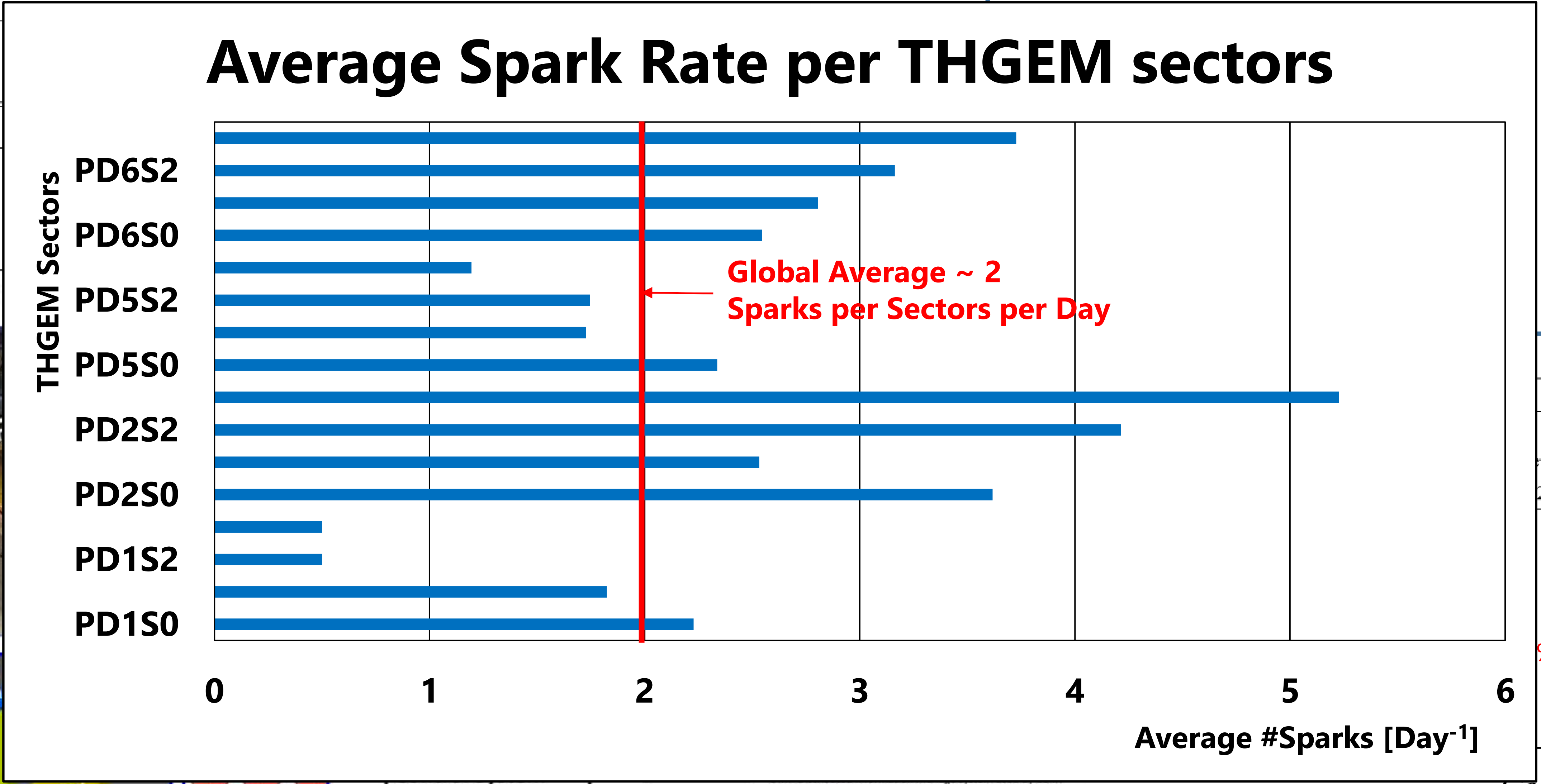
HV control for the hybrid detectors

Electrode
Voltage
Number of HV channels per detector

- HV







75
+04
25.3
%
×10^3
17
Gain

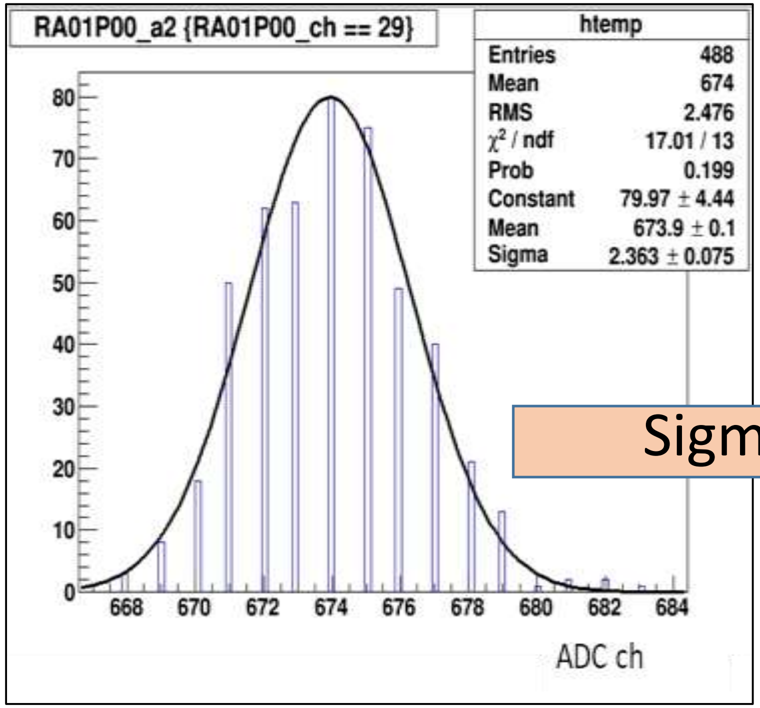
OPC: Protocol used at CERN allowing communications between any compliant components regardless of vendor

Noise level for the APV based readout

12 Gaseous Photon Detectors using APV based readout
(4 hybrid, 12 MWPC), 6144 Channels/detector

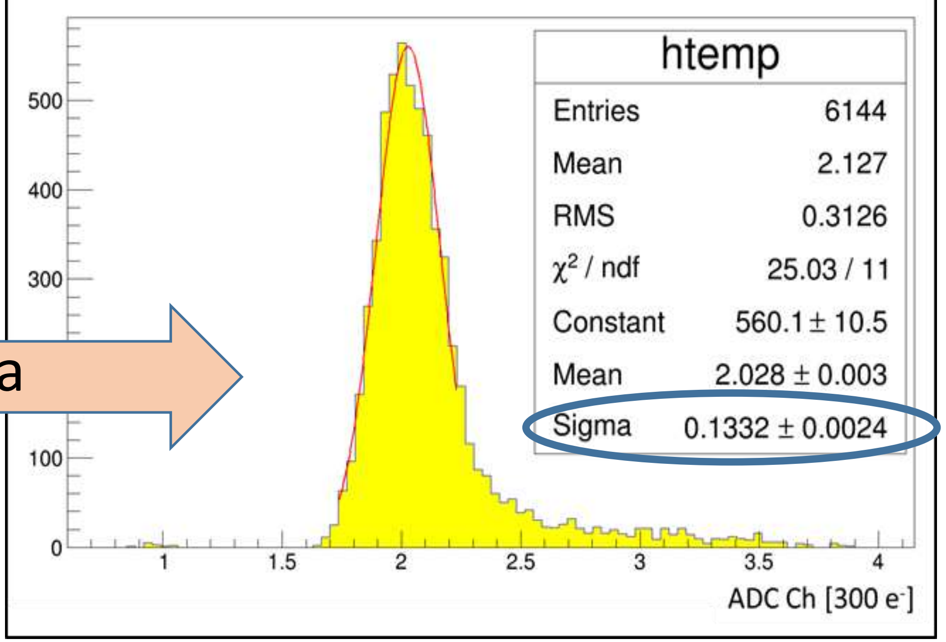
39 pedestal runs in 2017 COMPASS run

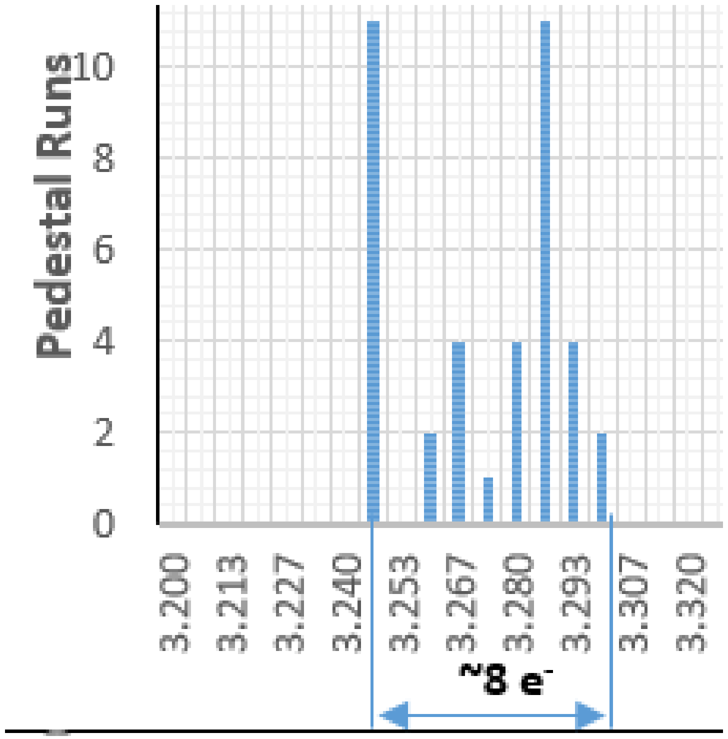
1 channel in a particular pedestal run



Sigma

6144 channels for 1 detector in a particular pedestal run



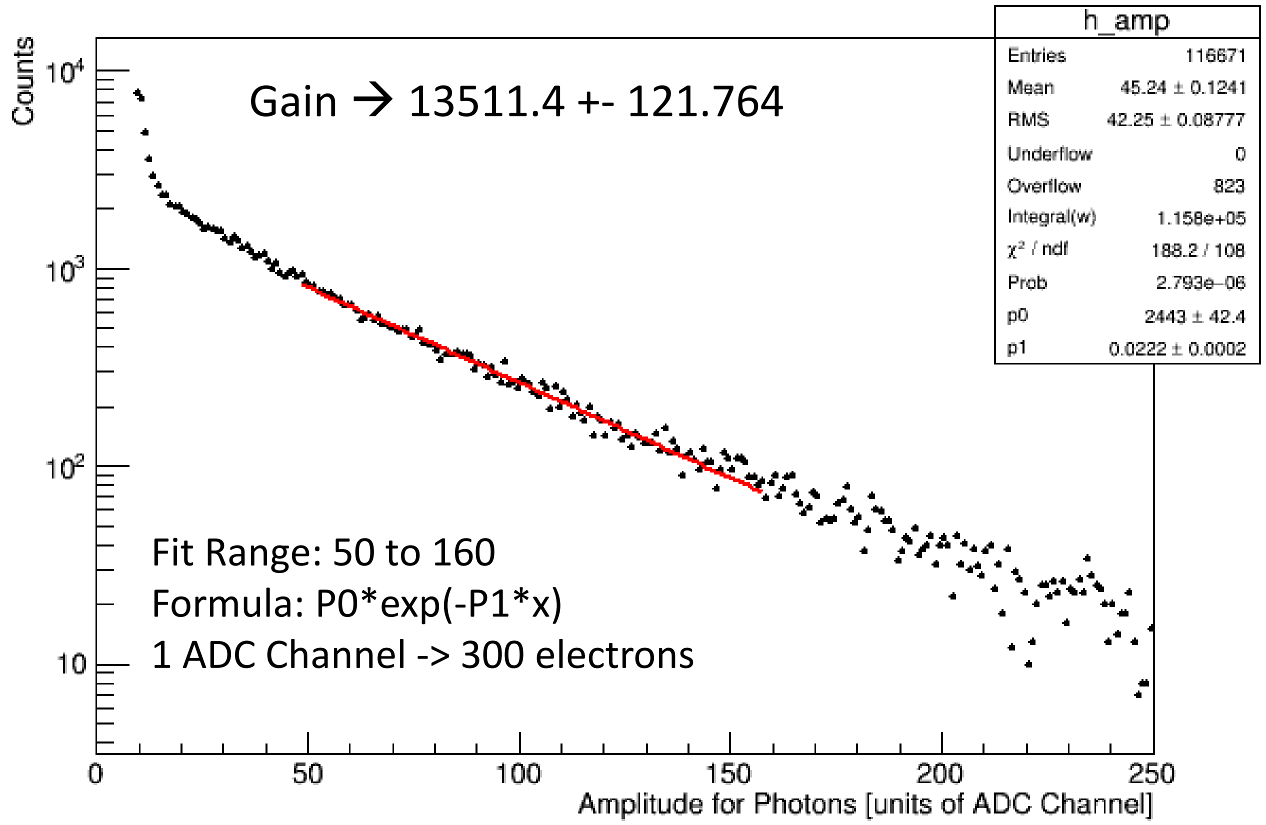


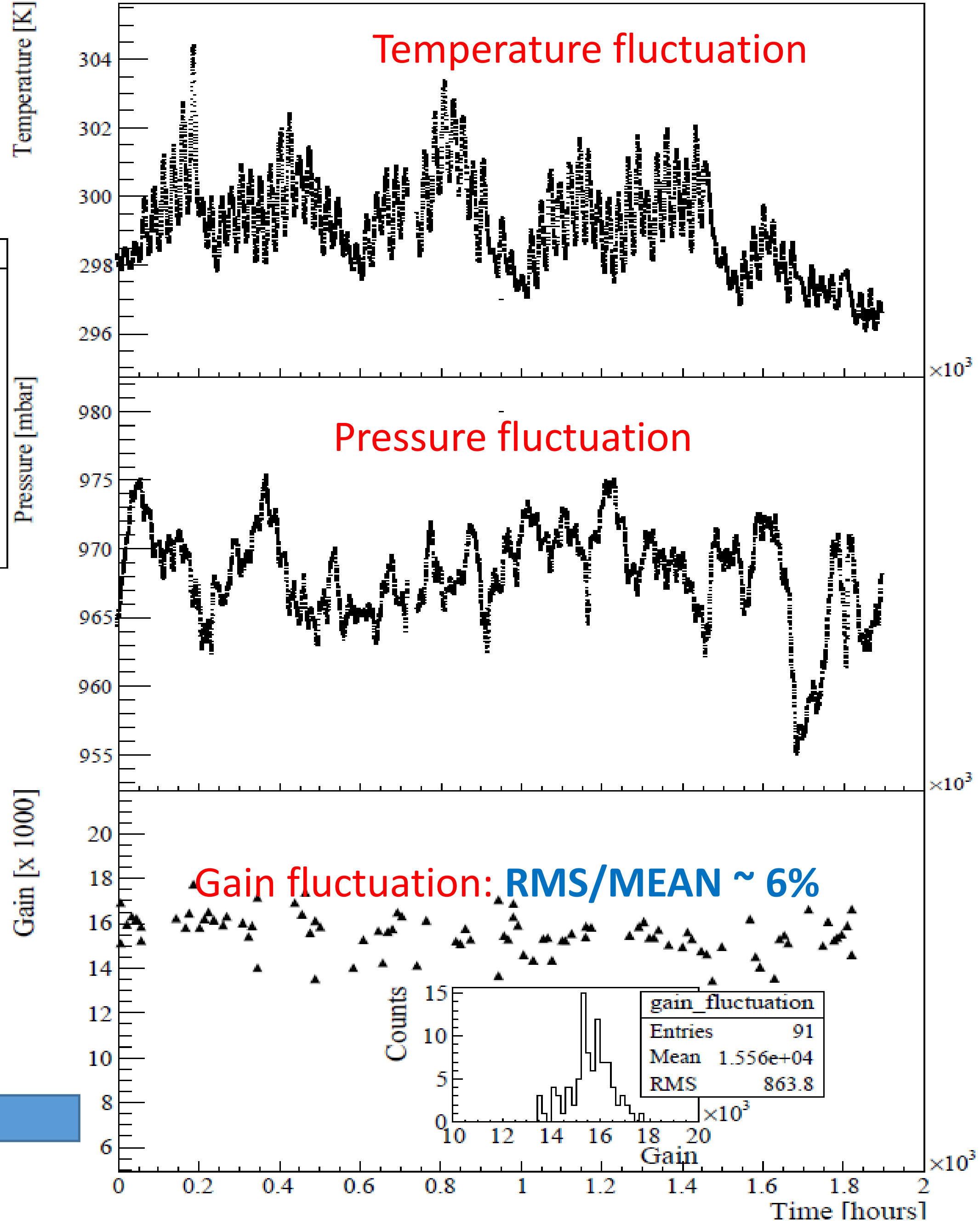
The niose levels are:

- MWPC: ~ 600 e^-
- Hybrid: ~ 900 e^-

The noise levels are very stable in time

Gain of hybrid detectors

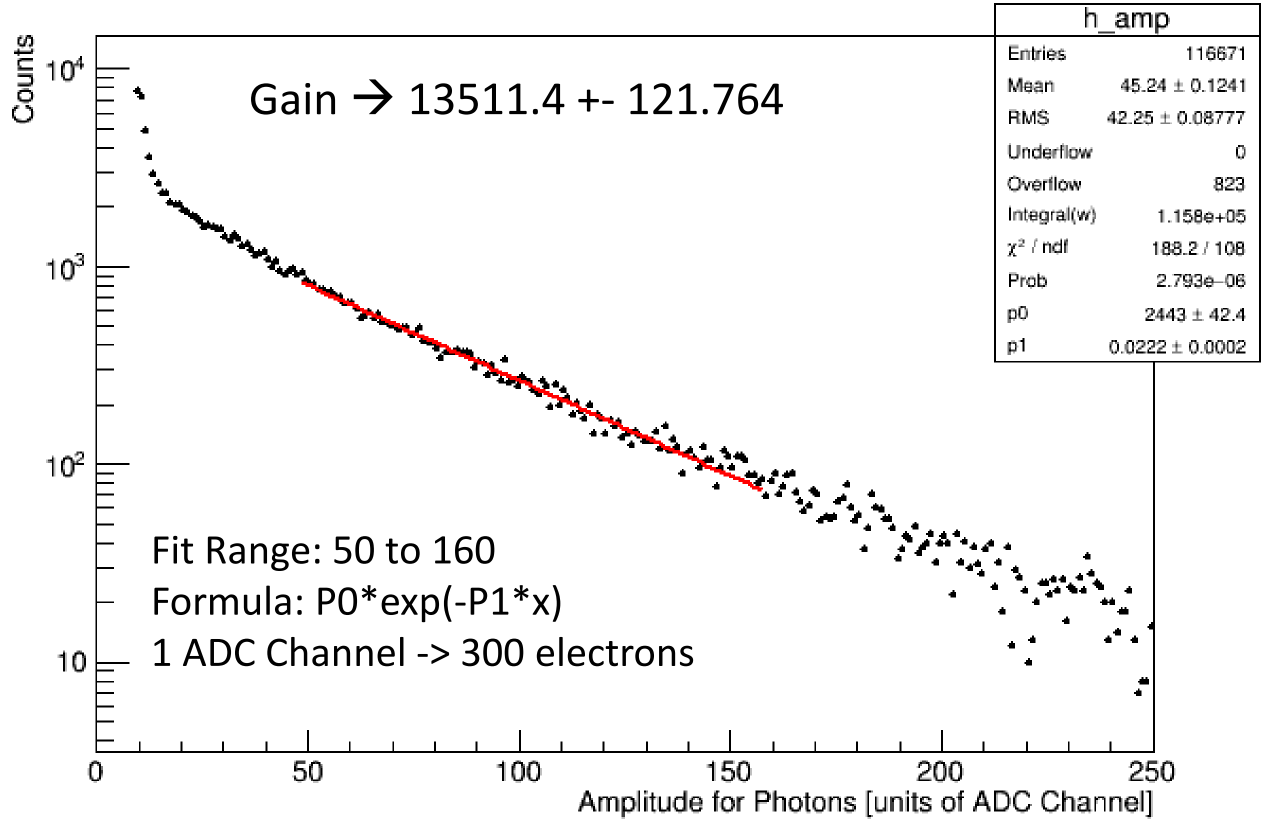


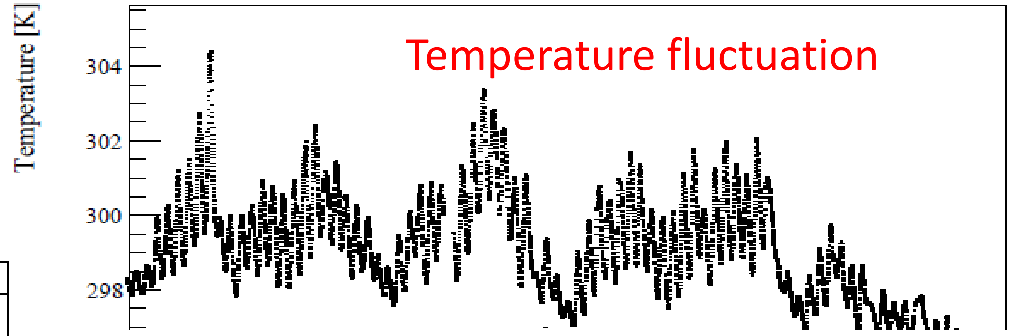


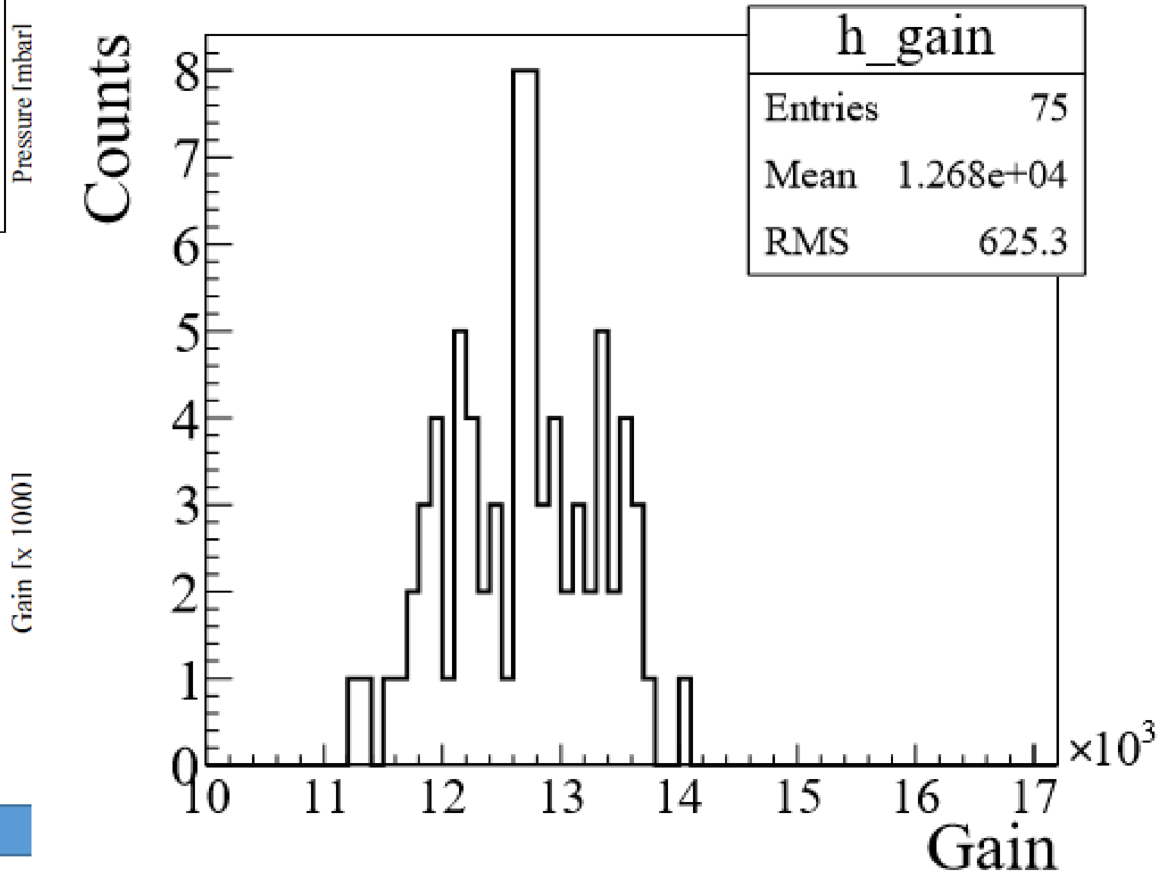
2000 hours of running

A non-negligible achievement due to P, T corrections on HV application

Gain of hybrid detectors







A non-negligible achievement due to P, T corrections on HV application

Event displays

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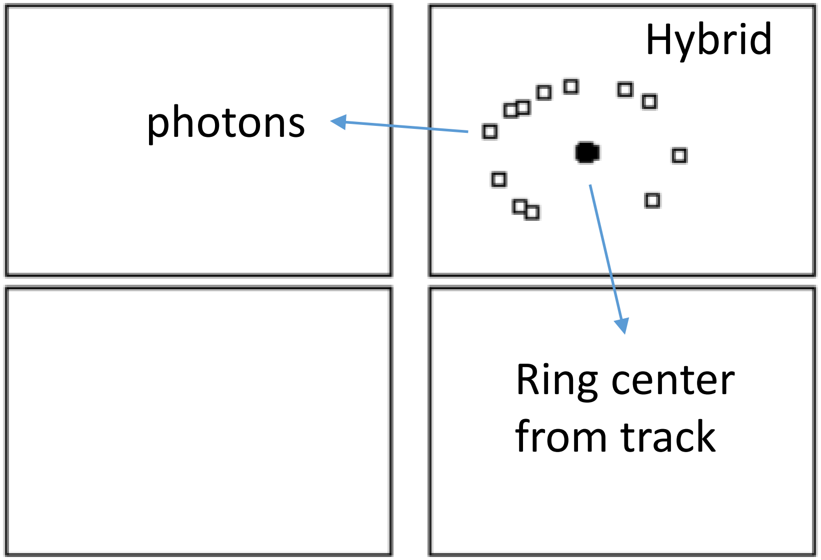
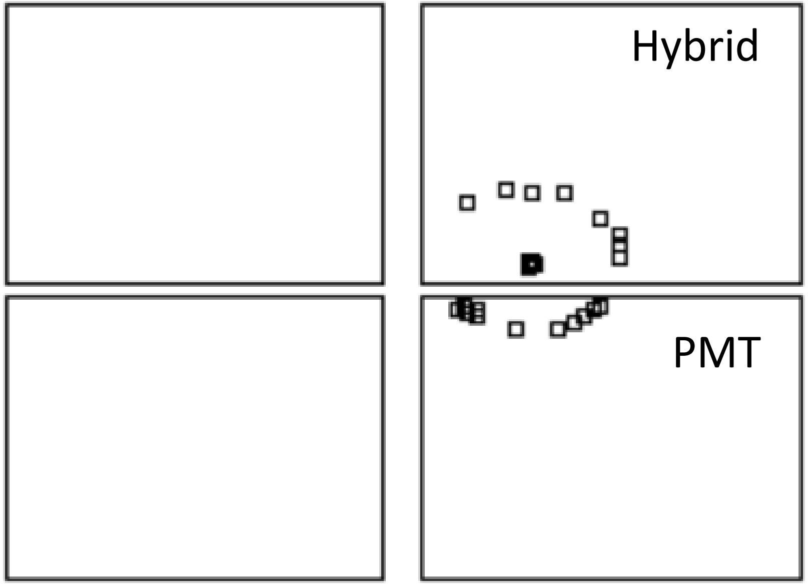
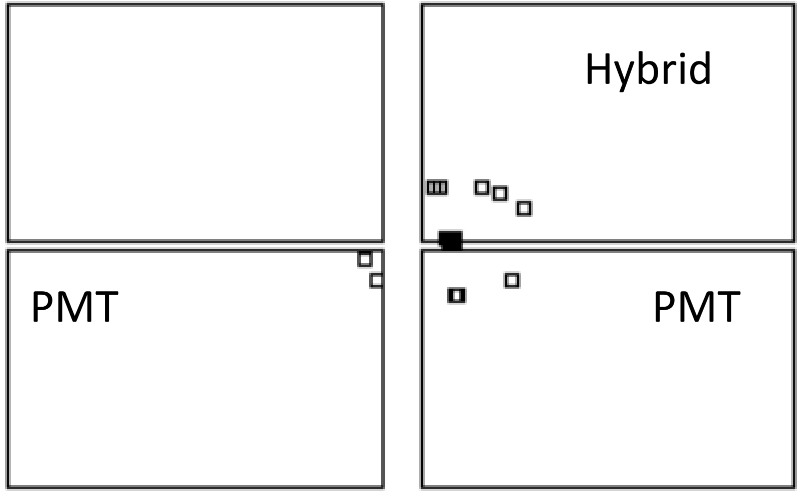
6.36 GeV pion

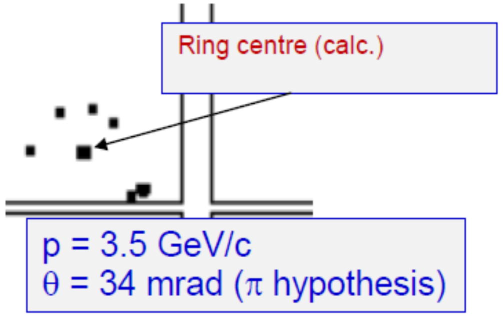


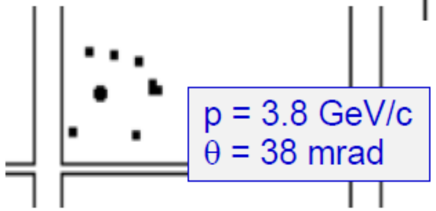
6.76 GeV pion

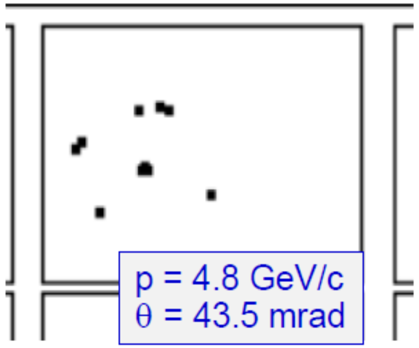


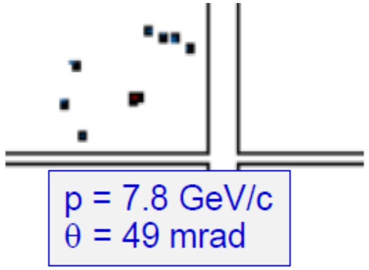
6.4 GeV pion

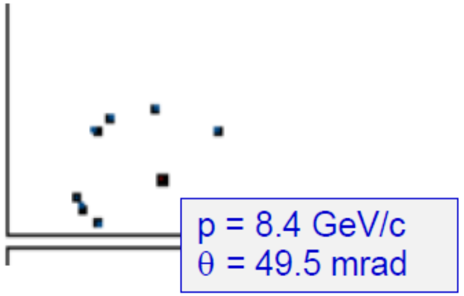










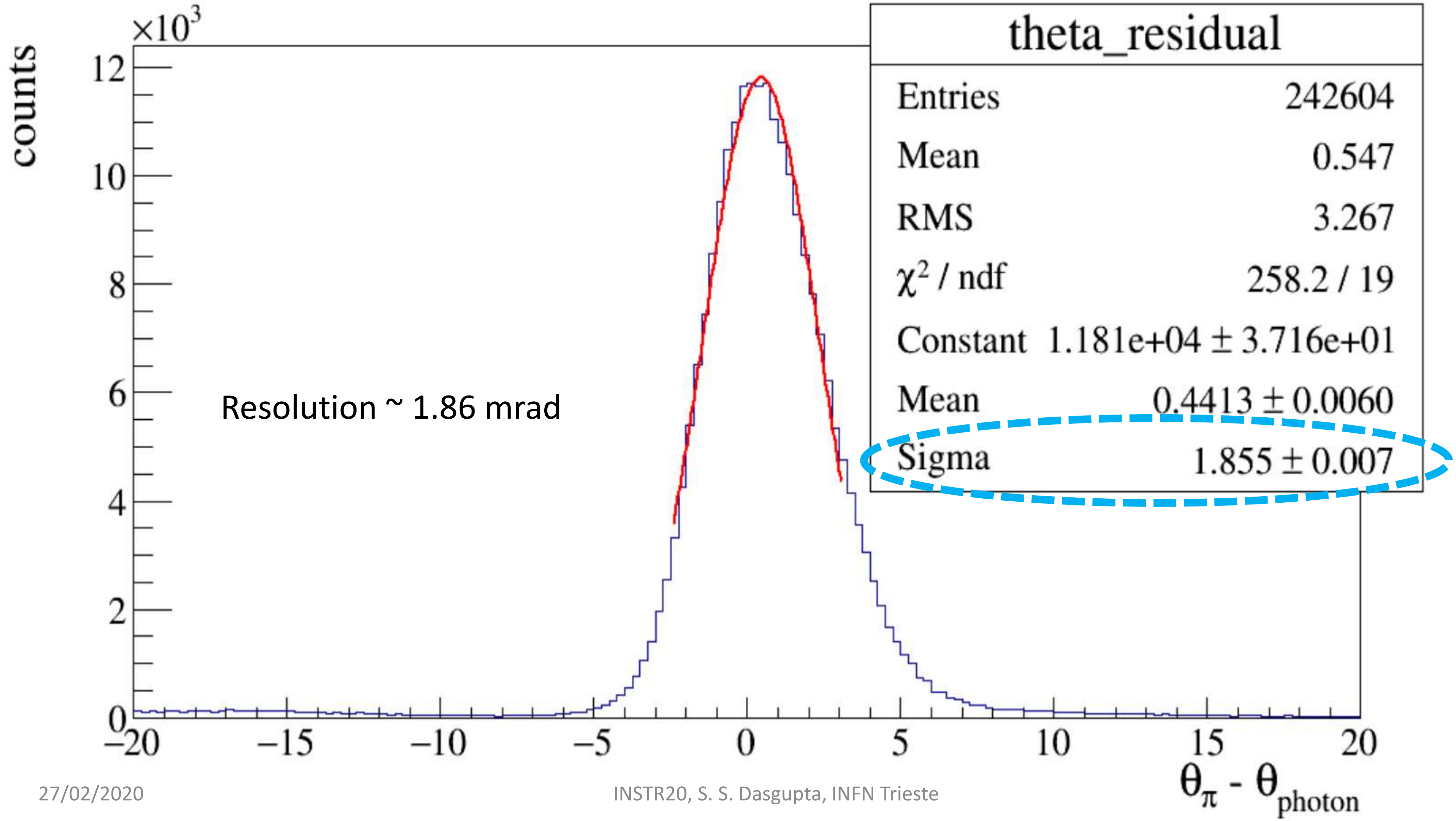


For reference:

Θ (β = 1) = 52.5 mrad

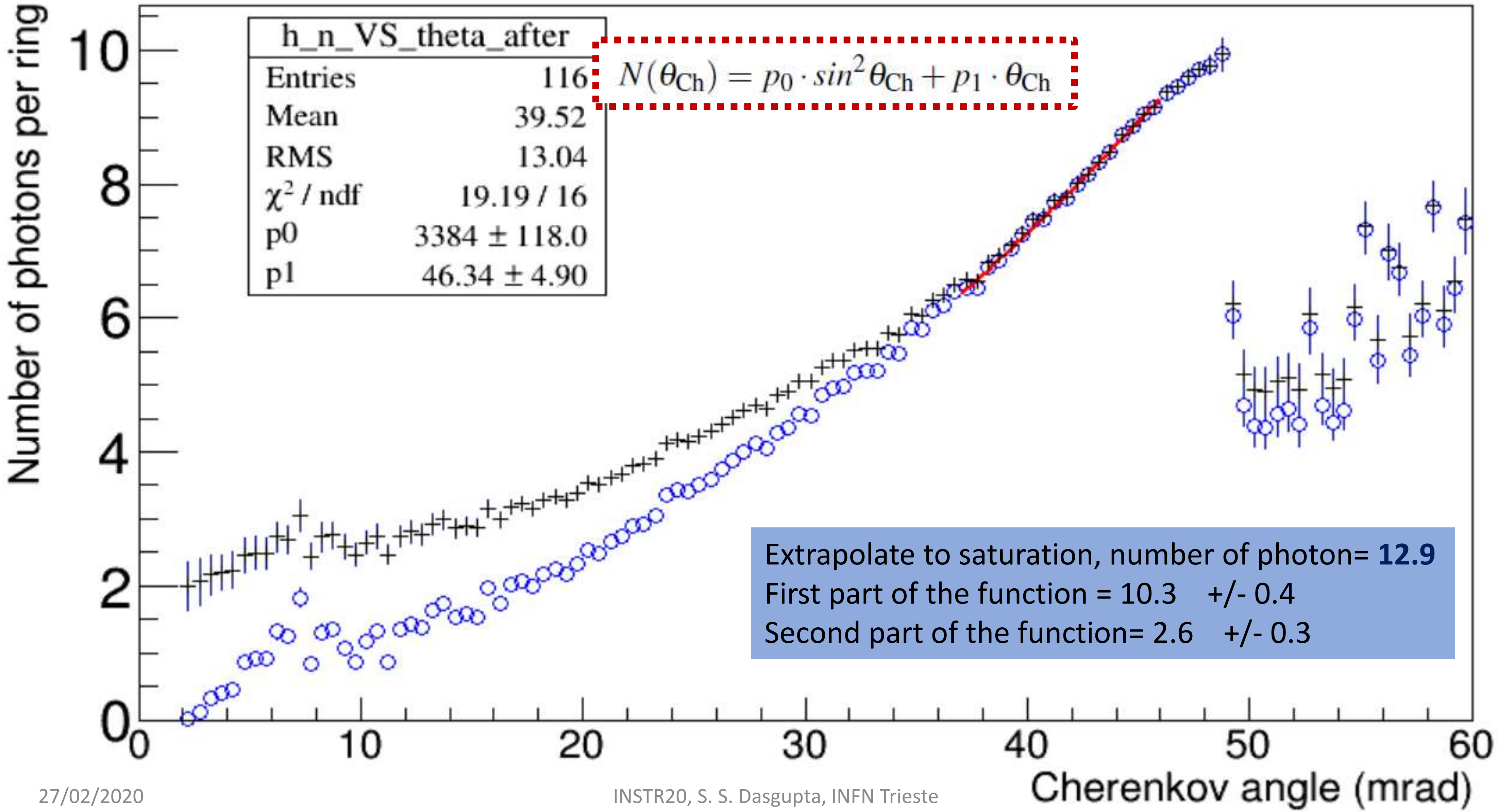
- **Ring center calculated from particle trajectory**
- **Detected photoelectrons : hits on the sensors**

Angular resolution for photon detection



Resolution ~ 1.86 mrad

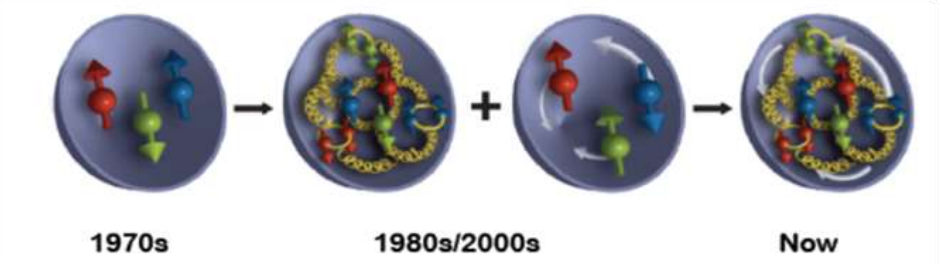
Number of photons



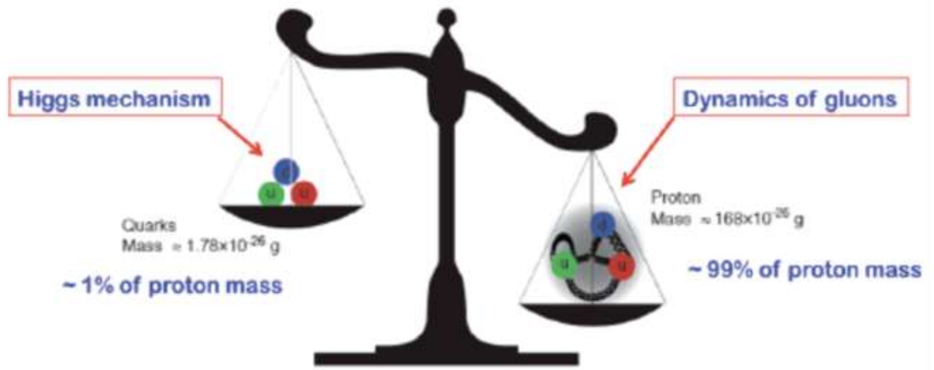
Extrapolate to saturation, number of photon= **12.9**
First part of the function = 10.3 +/- 0.4
Second part of the function= 2.6 +/- 0.3

Future → RICH application → Electron-Ion Collider (EIC)

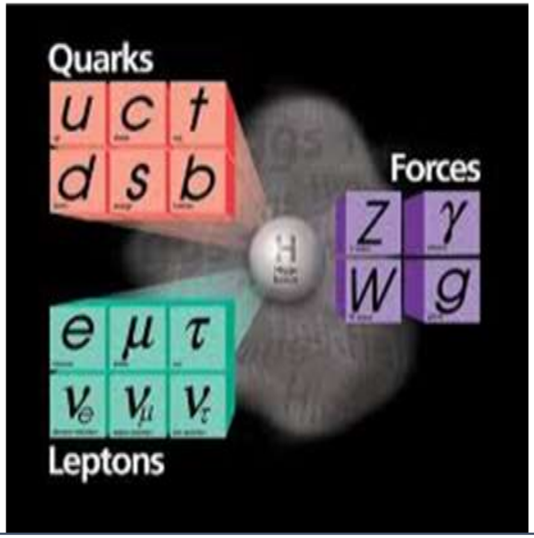
We know very little ...

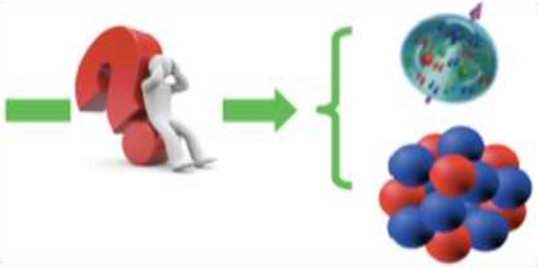


$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + [\Delta g + L_G]$$



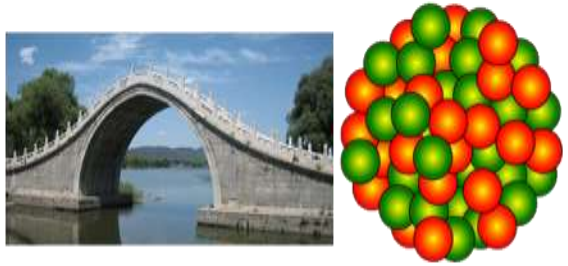
Standard Model: The most successful theory so far ... However ...





Spin structure

Mass structure



What does a proton look like in terms of quarks & gluons?

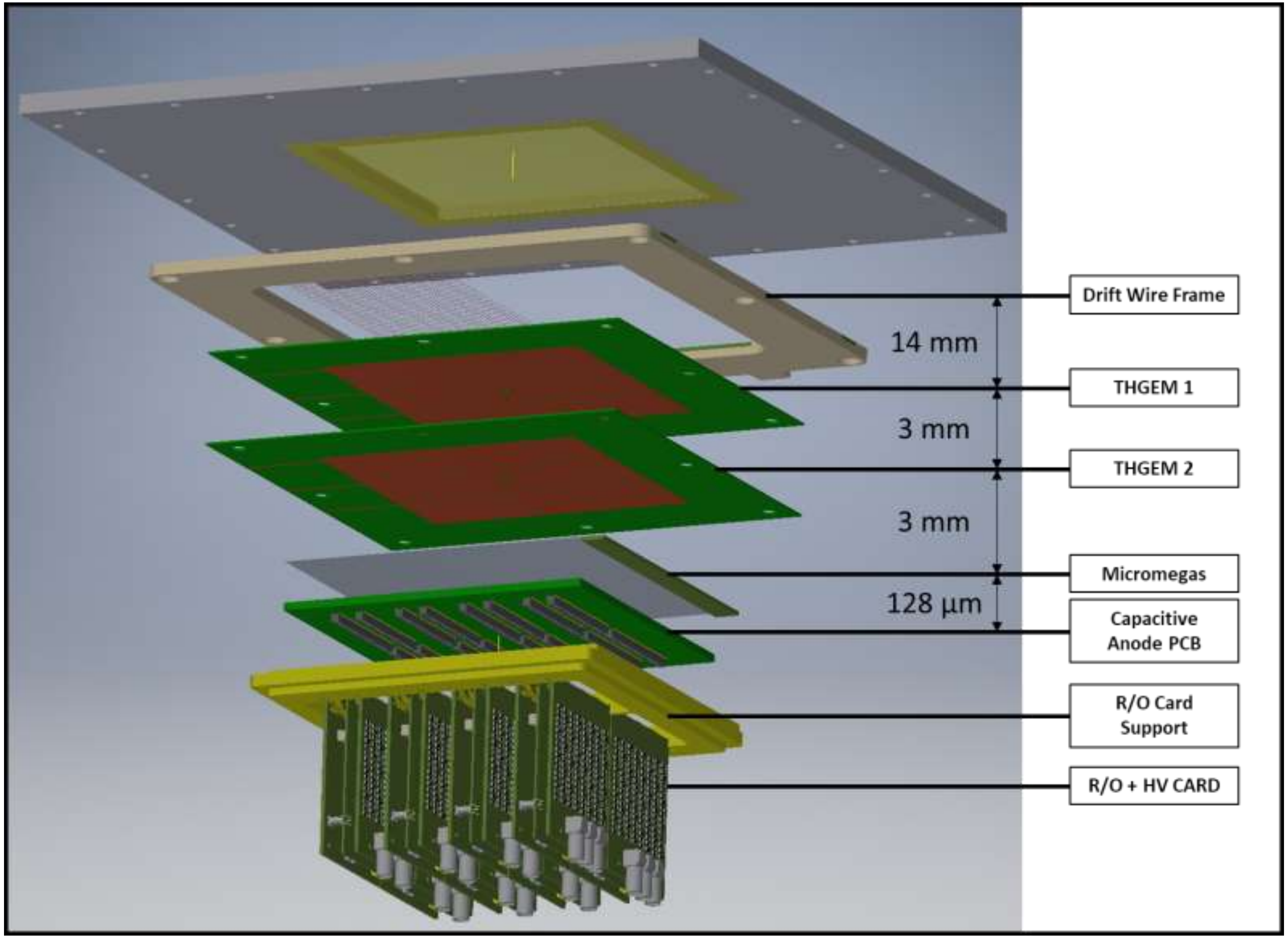
- **EIC: The next QCD frontier, understanding the glue that binds us all**
- **Collider requirements: High luminosity & energy, variable CM energy, all- A nuclear beams, polarization in e- and light ions**
- **Detector requirements: Hermetic detector, low mass inner tracking, good PID (electron/pion/kaon/proton) in wide range, calorimetry, forward & backwards tracking**

Motivation of this specific R & D

- Demand of a compact RICH for the future EIC ►short radiator length (Limited number of Photons)
- As standard quartz window is opaque below 165 nm ► **windowless RICH** is a possible approach ►Gaseous detectors
- **CsI** most used, however ageing due to **humidity and ion bombardment** ► quest for novel PC with sensitivity in the far UV region
- H-ND powder as possible alternative photocathode of CsI
- Our R&D; H-ND coupled to THGEM
- We report here some preliminary results on the initial phase of these studies

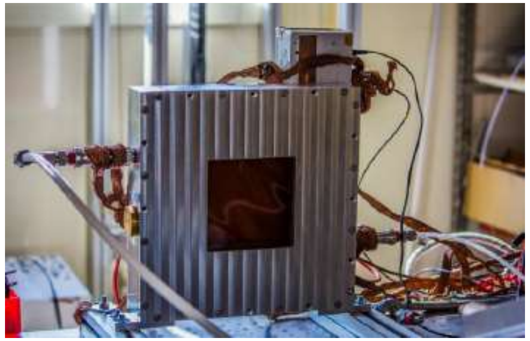
The Hybrid PD with MiniPADs

- The requirement for future EIC is to have large area Detector of single photons with small pads (3×3 mm^2) over several m^2.
- Mosaic architecture with all the components and services installed within the active area has been developed.
- 100×100 mm^2 active area hybrid modules with 32×32 3×3 mm^2 Pads are built for lab tests.
- Each components of the hybrid modules are characterized separately in the lab and then the full module was characterized.
- The R/O is with APV – 25 based Scalable Readout System (SRS).



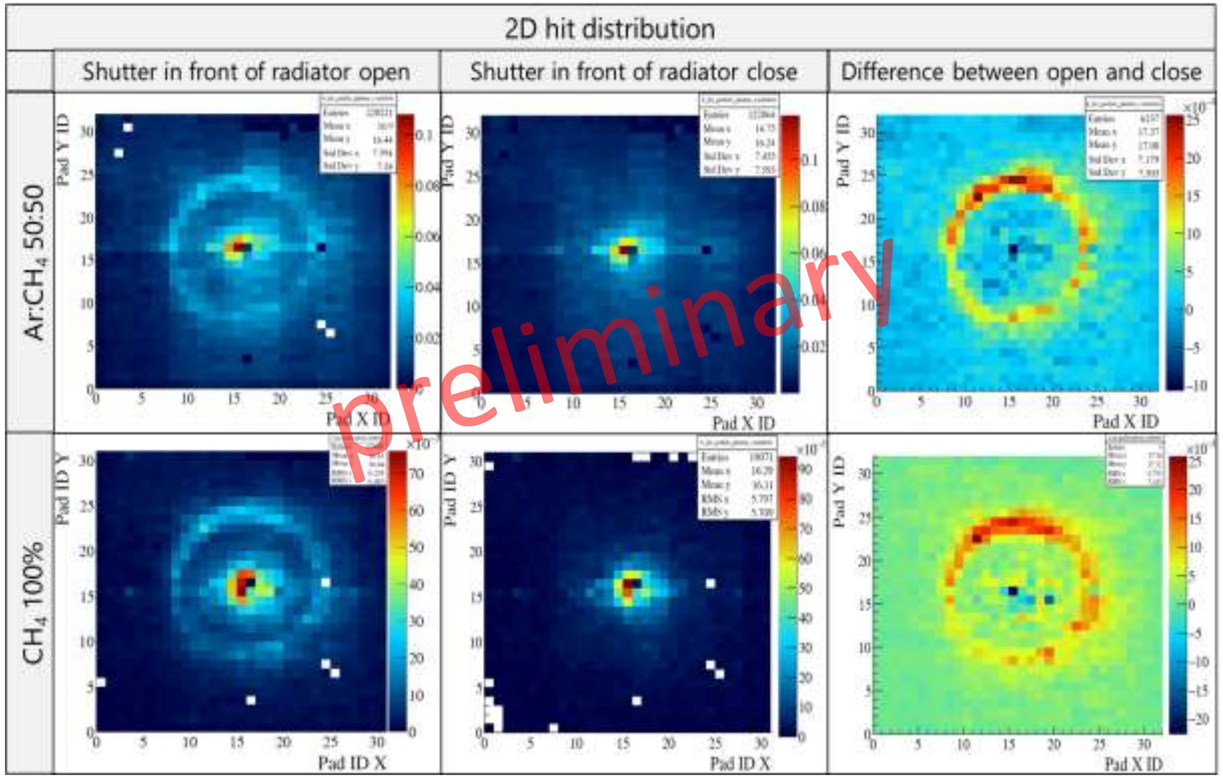
Ongoing R&D efforts at INFN Trieste

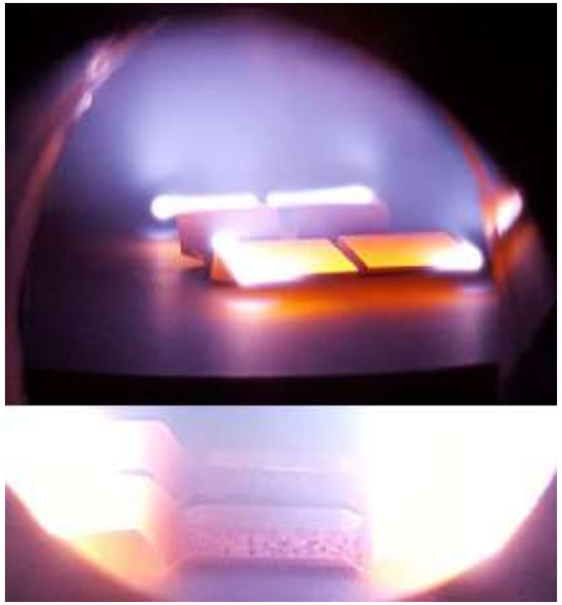
INSTR'2020

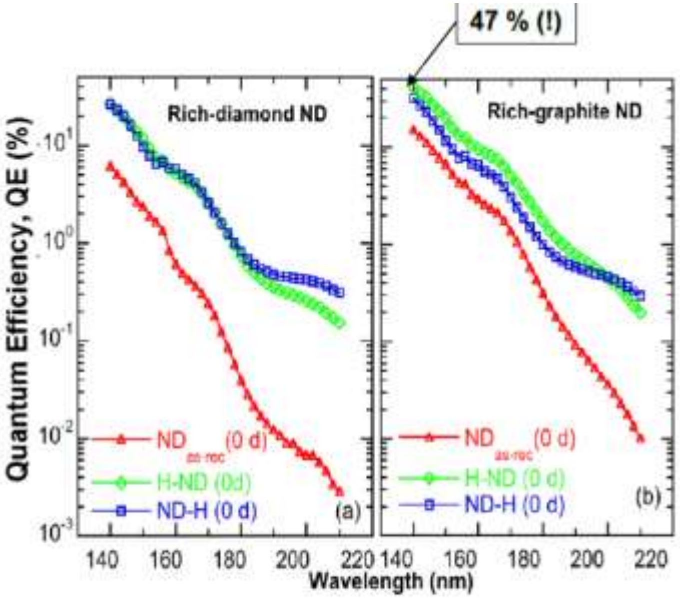


- Development of an optimized detector for finer spatial resolution based on the hybrid THGEM + MM and "mini-pads" of size 3mm x 3mm
- Study the compatibility of these hybrid PDs with CF_4 for a windowless RICH for the future Electron Ion Collider
- Exploring the possibility to use a more robust photocathode in the far UV: hydrogenated nano-diamond crystals

Beam test @ CERN SPS T10 beam line with Pion Beam







Diamond & Related Materials 76 (2017) 1

Nano Diamond Photo cathodes → Poster Presented by Dr. Triloki Pandit → Poster No. 40

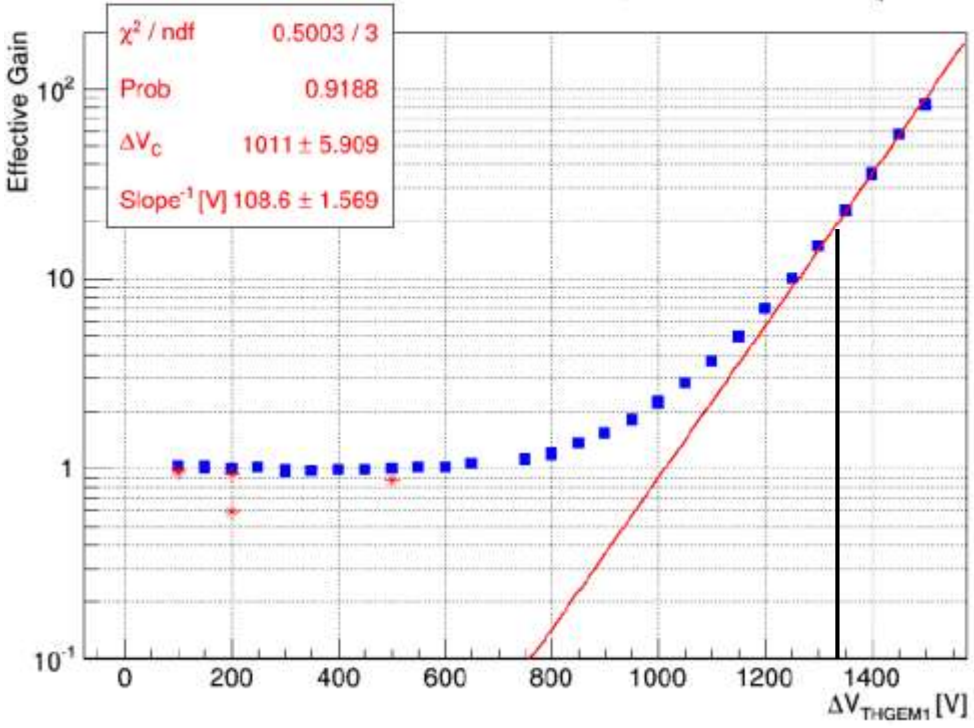
Conclusion

- The MPGD based [THGEMs plus Micromegas] Hybrid Detectors of Single Photons have been built and implemented in real experiments.
- The detector fine tuning has been done with big care.
- Hybrids are running successfully, and Cerenkov Rings have been observed.
- The future R&D [MINIPAD version] of this novel technology has already been started for possible use in future EIC experiments.
- In recent TEST beams Cerenkov rings are observed also with the first prototype.
- A separate R&D for a quest to find a robust photocathode having significant QE at lower wavelength has been started and preliminary interesting results have been observed.

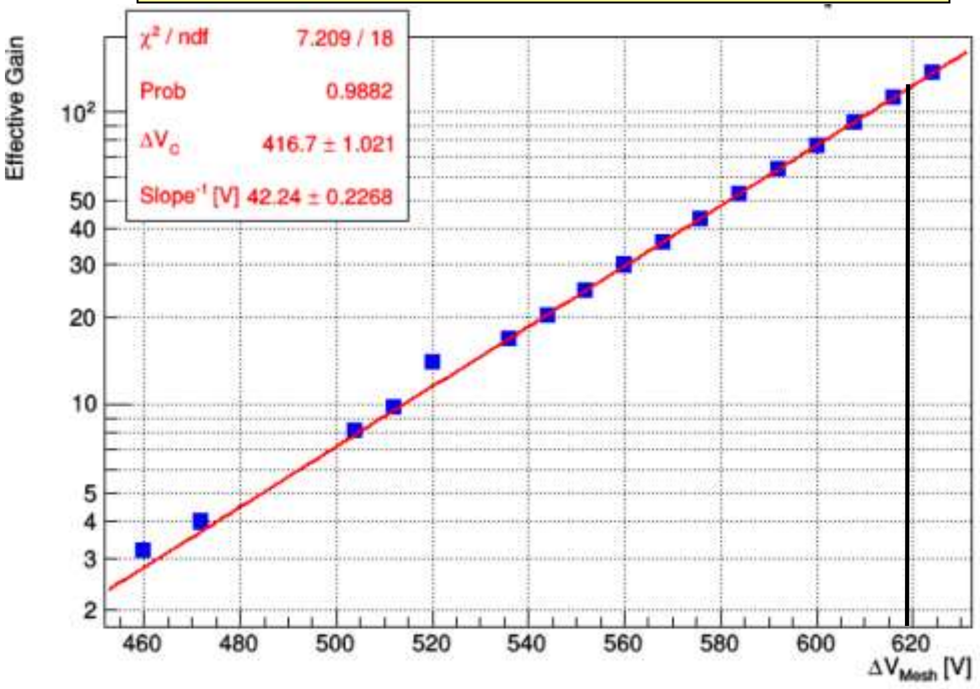
THANK YOU

Backup: Gain Sharing

Effective gain*transfer of THGEM1 in Ar/CH4, with THGEM2 and MM at nominal voltages



Effective gain of Mcromegas in Ar/CH4, with THGEM1 and THGEM2 at nominal voltages



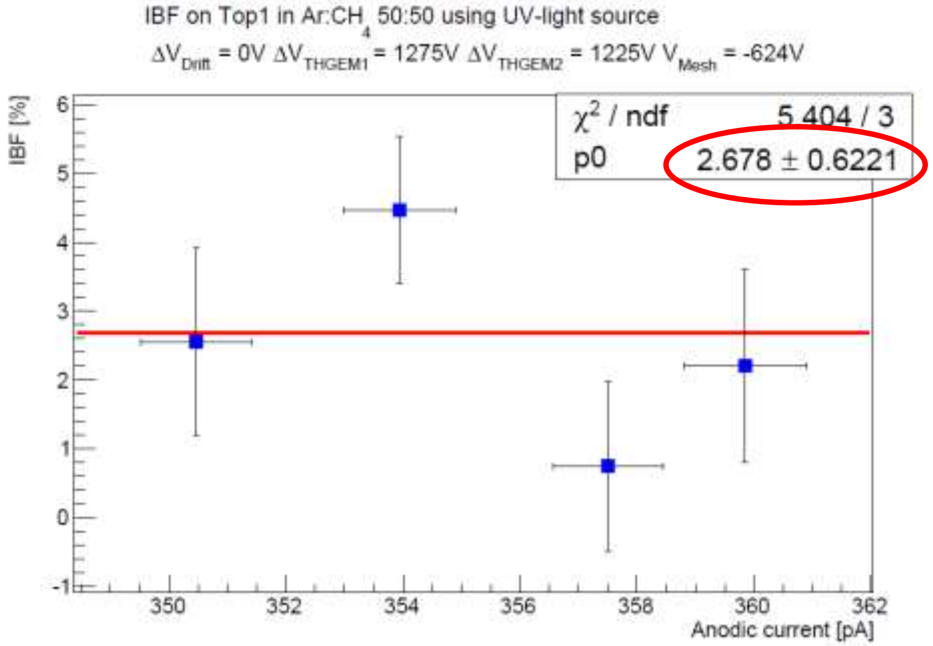
Nominal gain: ~30000 with:

THGEM1 gain* transfer1: ~ 20

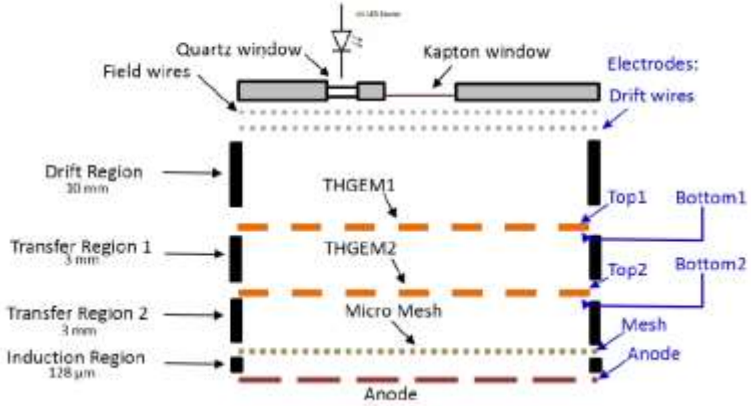
THGEM2 gain*transfer2 ~ 15

Micromegas gain ~100

BACKUP: IBF



The result of the direct measurement: 3% nicely matches the expectation



Trieste home-built picoammeters

The Bulk Micromegas with MiniPADs

- 4 PCBs have been produced and two of them have been equipped with a bulk Micromegas.
- For each the capacitance between the Readout pads and HV PADs have been measured.
- A variation ~ 3 – 5 % have been noticed.