COMPASS RICH-1 and Novel Gaseous Photon Detectors

Fulvio Tessarotto

(I.N.F.N. – Trieste)

COMPASS RICH-1

Vessel, radiator gas and mirror system

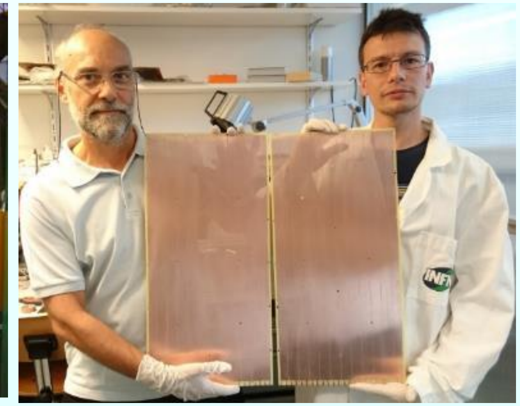
MWPC's + CsI photocathodes

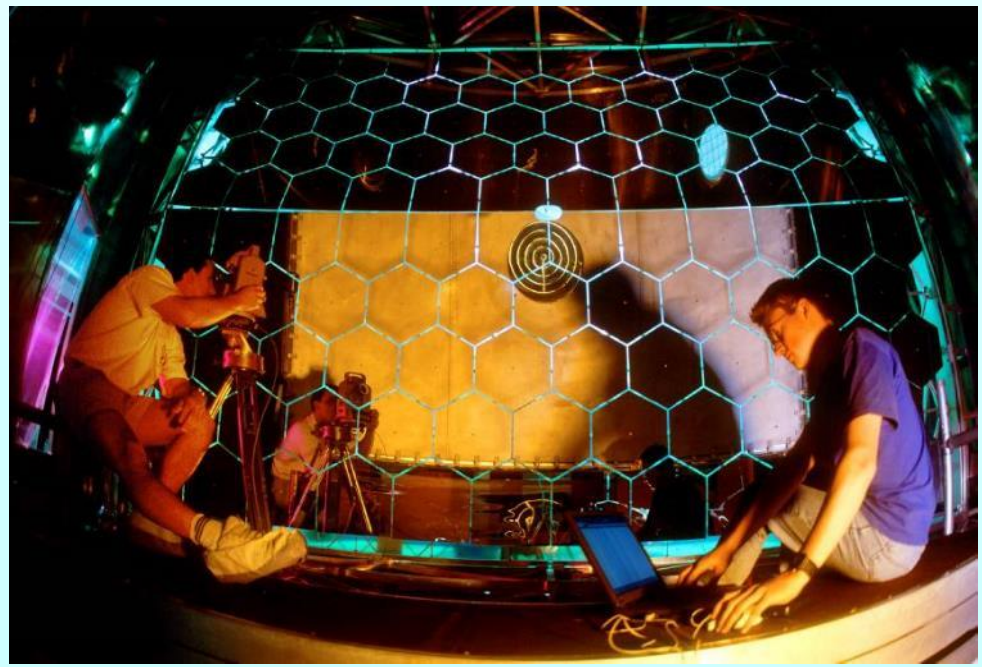
The MAPMT based detectors

THGEM-based PD's

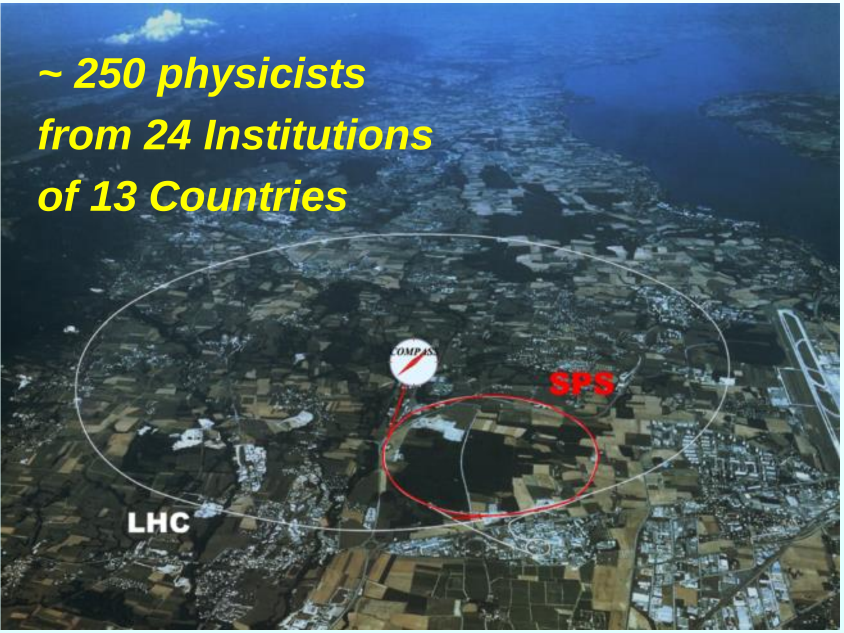
The upgrade with THGEM-based PDs

Promising developments in gaseous PD's





COMPASS Collaboration



Дубна (LPP and LNP), Москва (INR, LPI, State Univ.), Протвино, Tomsk

Warsawa (NCBJ), Warsawa (TU) Warsawa (U)

Praha (CU/CTU) Liberec (TU) Brno (ISI-ASCR)

Calcutta (Matriviani)

Taipei (AS)

CERN

Yamagata

Lisboa/Aveiro

Tel Aviv

Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Mainz, München TU

USA (UIUC)

Saclay

Torino (University, INFN), Trieste (University, INFN)

Experiments with muon beam:

Experiments with hadron beams:

COMPASS - I (2002 – 2011)

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

Pion polarizability
Diffractive and Central production
Light meson spectroscopy
Baryon spectroscopy

COMPASS - II (2012 – 2018) …

DVCS and HEMP
Unpolarized SIDIS and TMDs

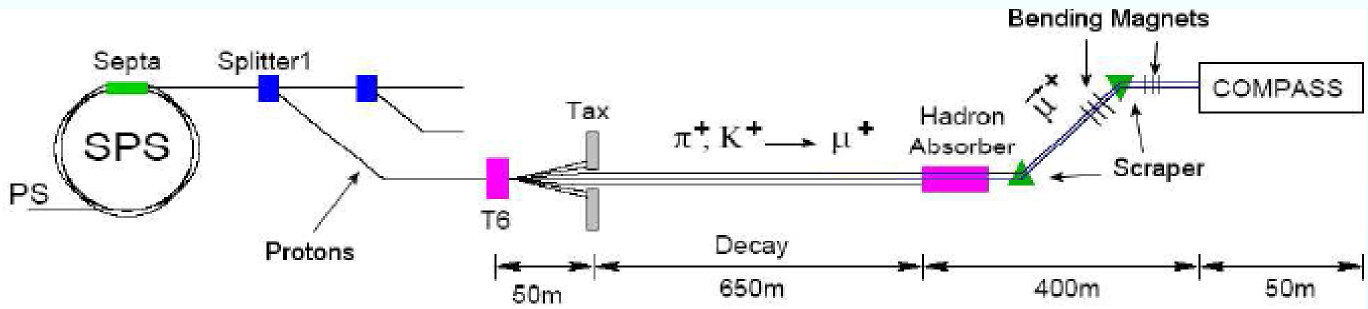
Pion and Kaon polarizabilities
Drell-Yan studies

(2021 – 2022) …

Transversity, proton radius

→ (2023 – …) LoI in preparation

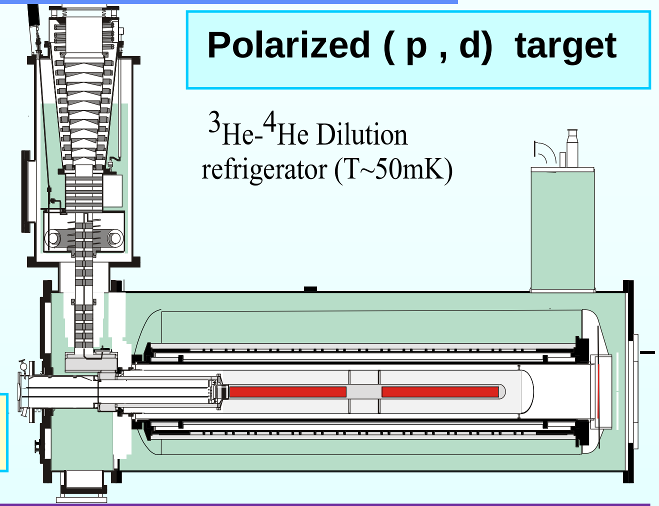
BEAM, TARGET AND SPECTROMETER



160 or 190 GeV/c μ^+ (or μ^-), $4 \cdot 10^8$ μ/spill, $P_\mu \sim 80\%$
190 GeV/c p, π^+, π^- , K^+ ,K^- beams

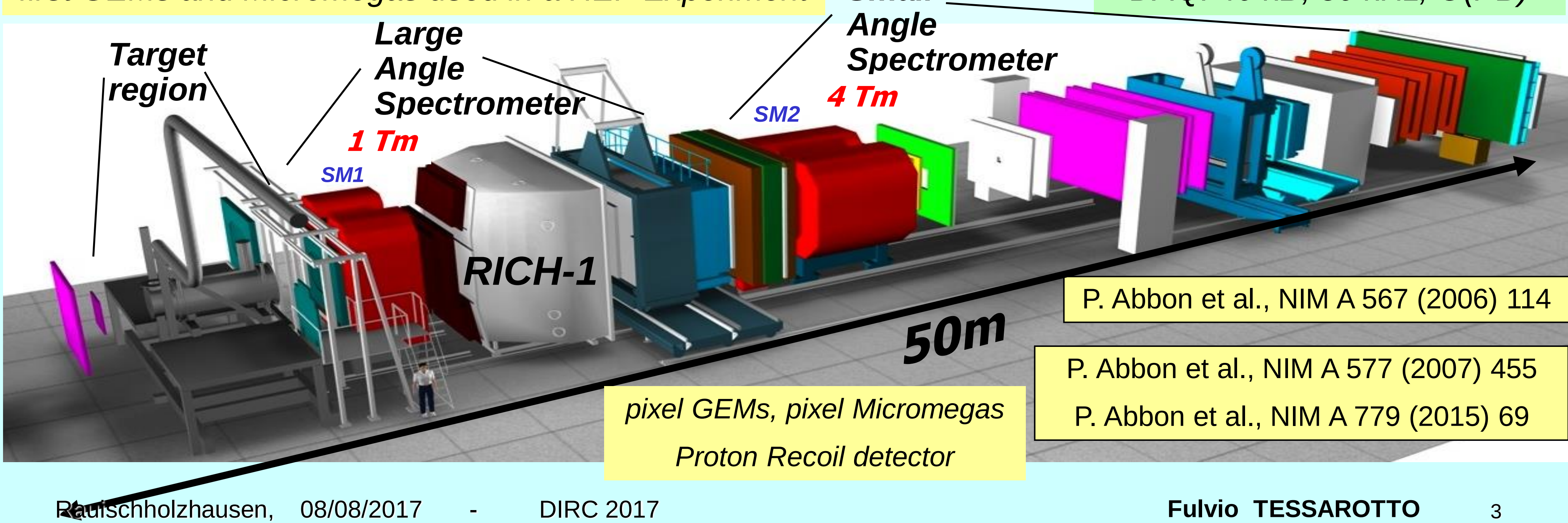
Various targets used

Polarized (p , d) target



first GEMs and Micromegas used in a HEP Experiment

DAQ: 40 kB, 50 kHz, O(PB)



pixel GEMs, pixel Micromegas

Proton Recoil detector

P. Abbon et al., NIM A 567 (2006) 114

P. Abbon et al., NIM A 577 (2007) 455

P. Abbon et al., NIM A 779 (2015) 69

COMPASS RICH-1

F. Tessarotto et al., JINST 9 (2014) C09011

is a large gaseous RICH

with three kind of photon detectors

providing:

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% X_o

material in the acceptance: 22% X_o

detector designed in 1996

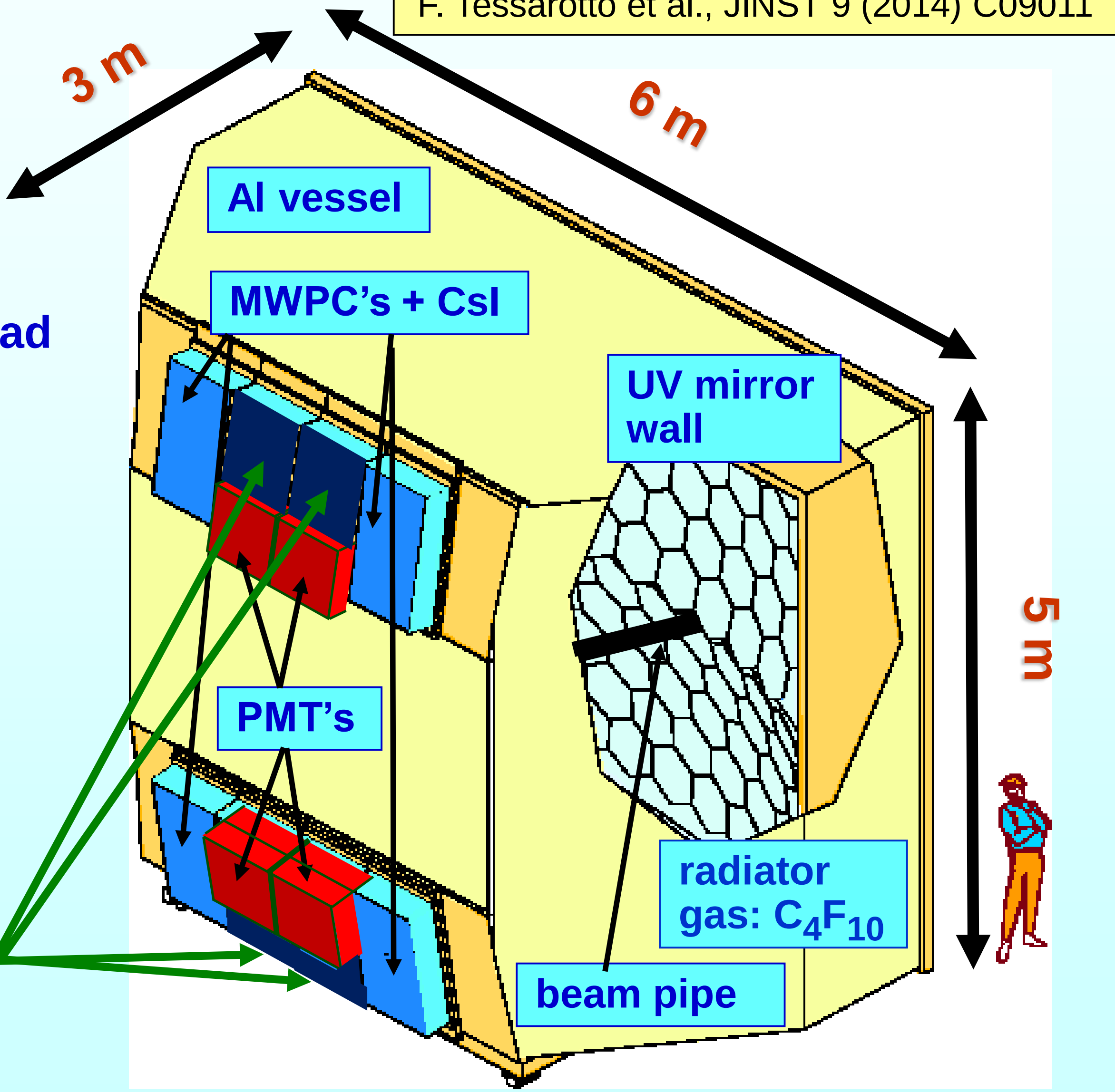
in operation since 2002

upgraded in 2006 with MAPMTs

and newly upgraded in 2016 with

hybrid THGEM+Micromegas PDs

total investment: ~ 5 M €

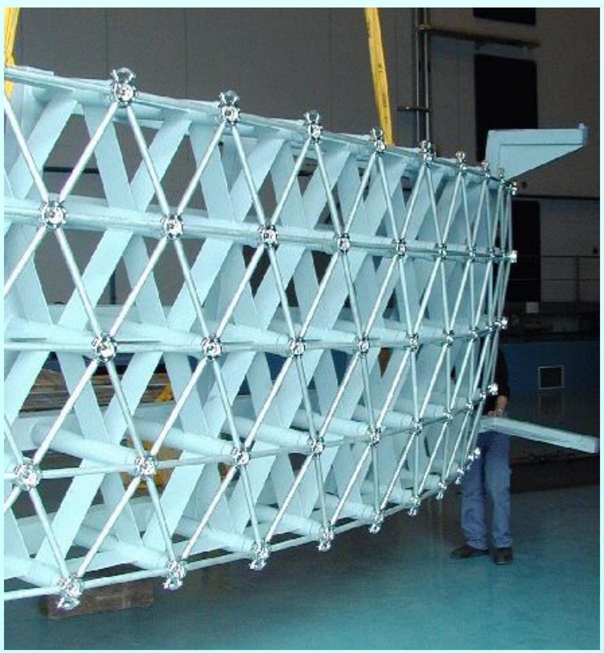


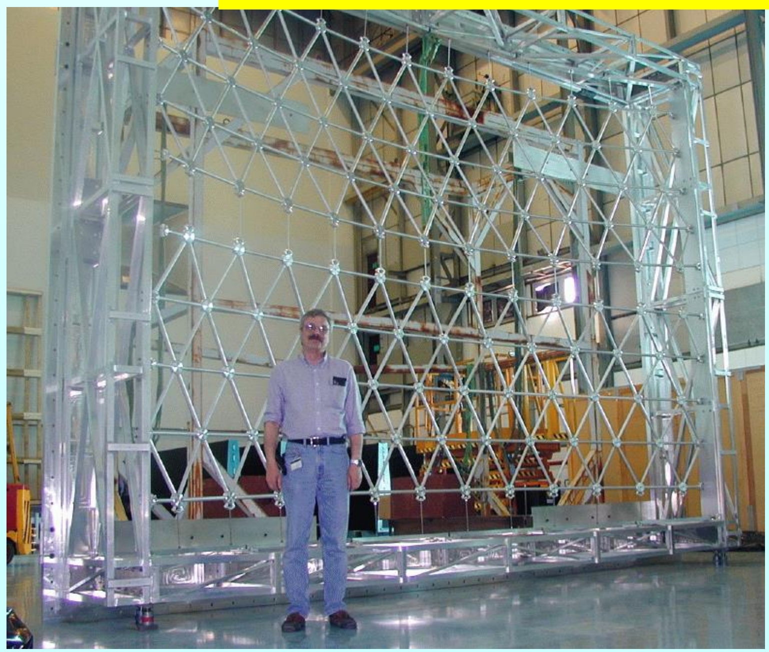
the vessel and the mirror support wall

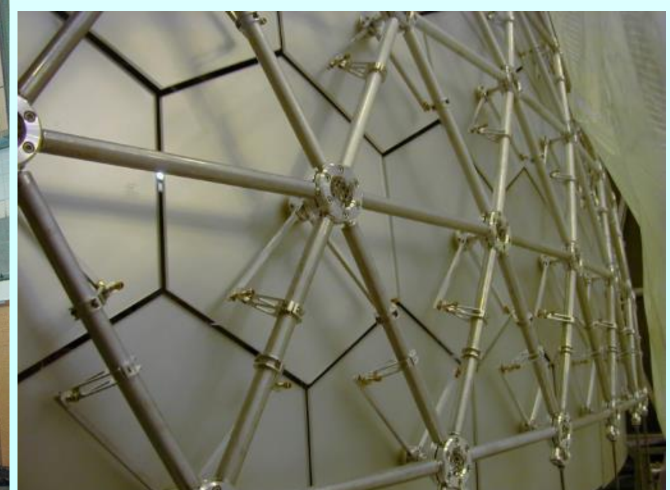
Large and accurate mechanics

light front and rear windows

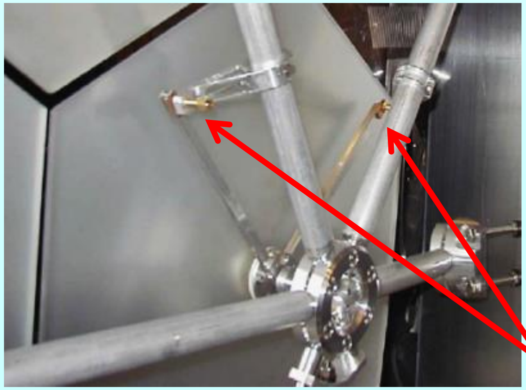
100 m of O-rings, 80 m^3 C_4F_{10}

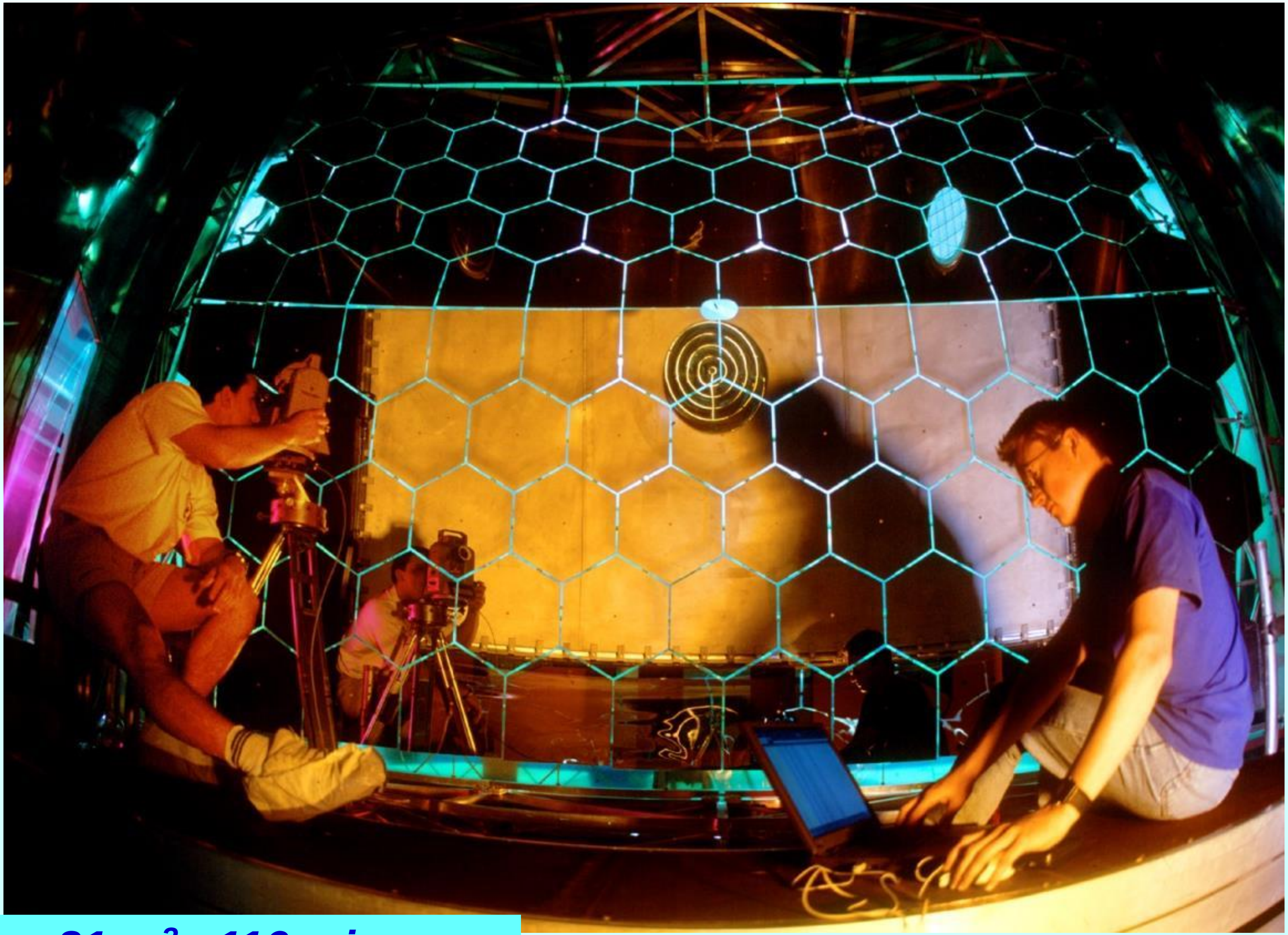






mirrors and alignment



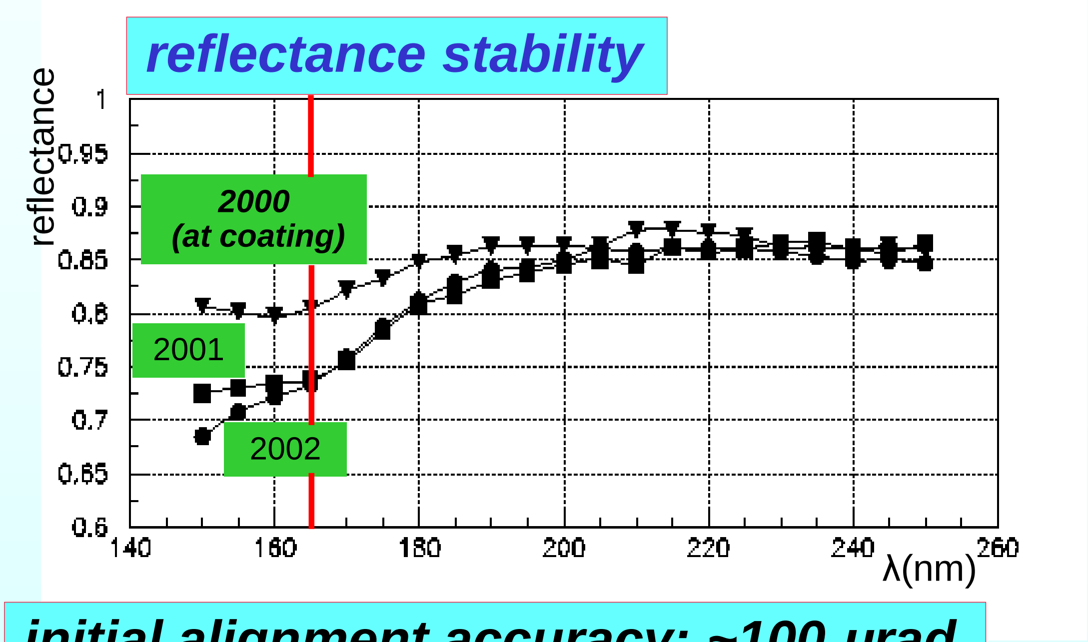


21 m^2, 116 mirrors
radius: 6.6 m

angular regulation screws

measurement of mirror alignment via laser autocollimation

problems with mirrors



initial alignment accuracy: ~100 μrad

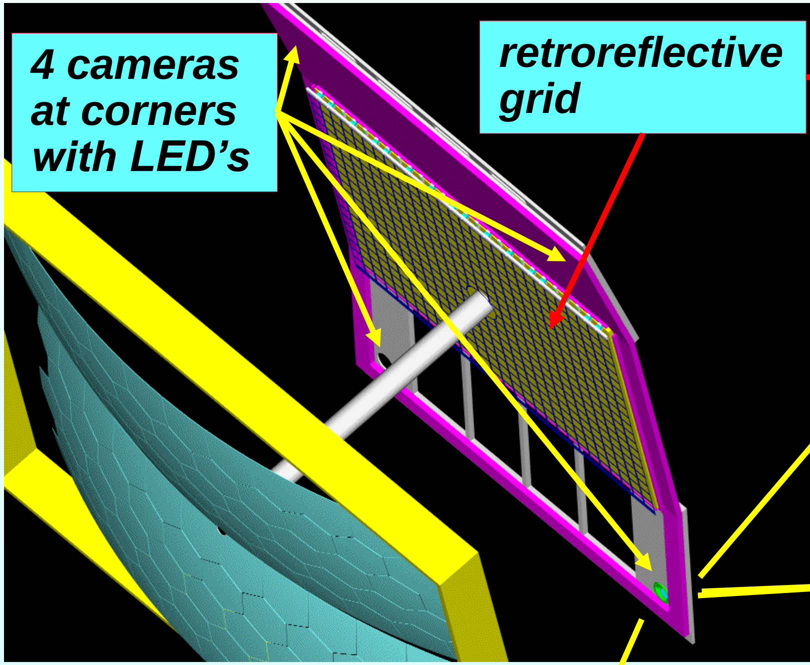
surveying accuracy: ~ 60 μrad

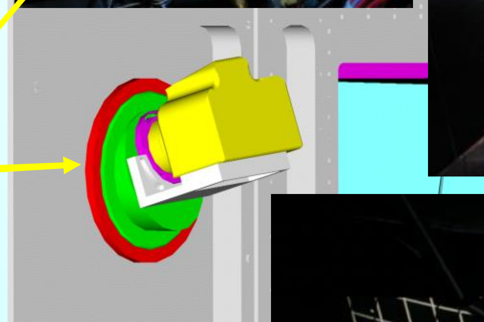
alignment instability: 1 mrad (first year)

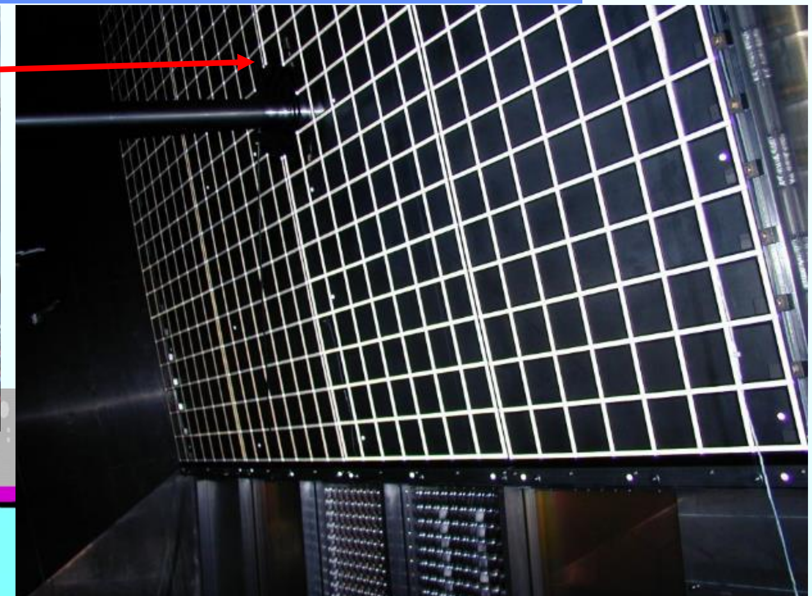
alignment instability: ~ 100 μrad after 2002

alignment check → surveyors inside → opening the vessel: contamination, dust, risky operations, work load, expenses.

CLAM: mirror alignment monitoring



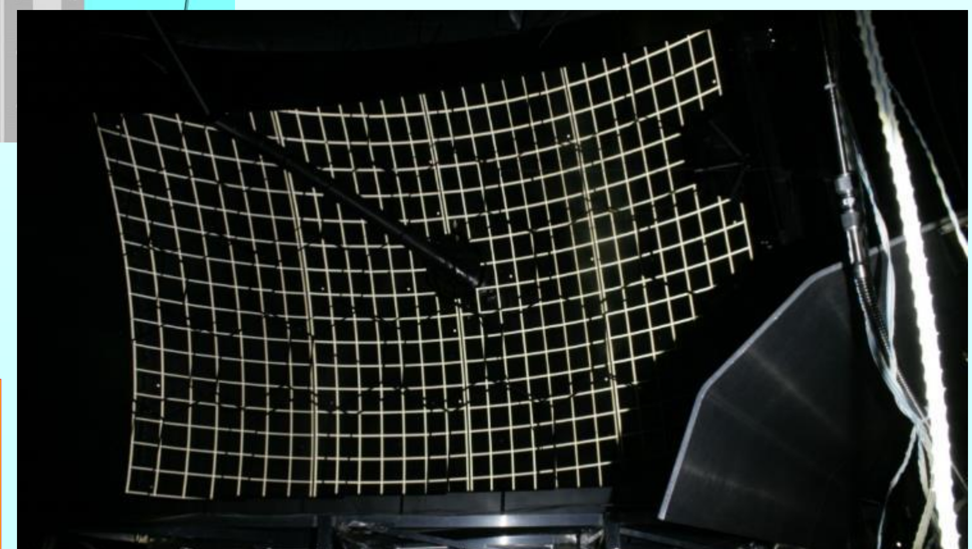




CLAM system in operation since 2007

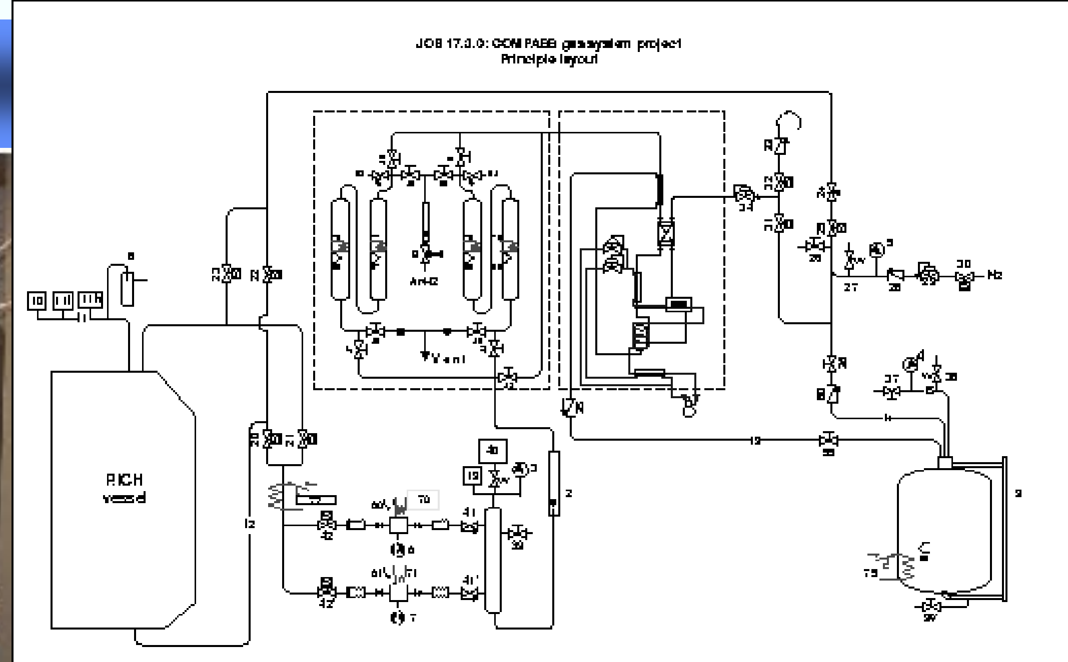
accuracy: 30 μrad

photogrammetric calibration of cameras → measurement of absolute mirror tilt

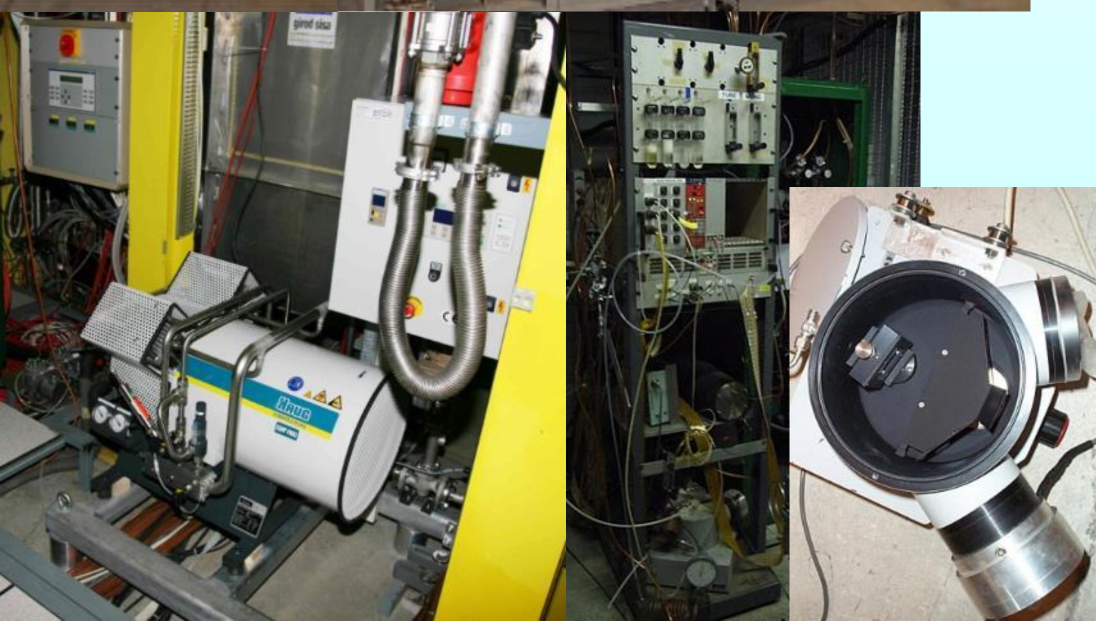


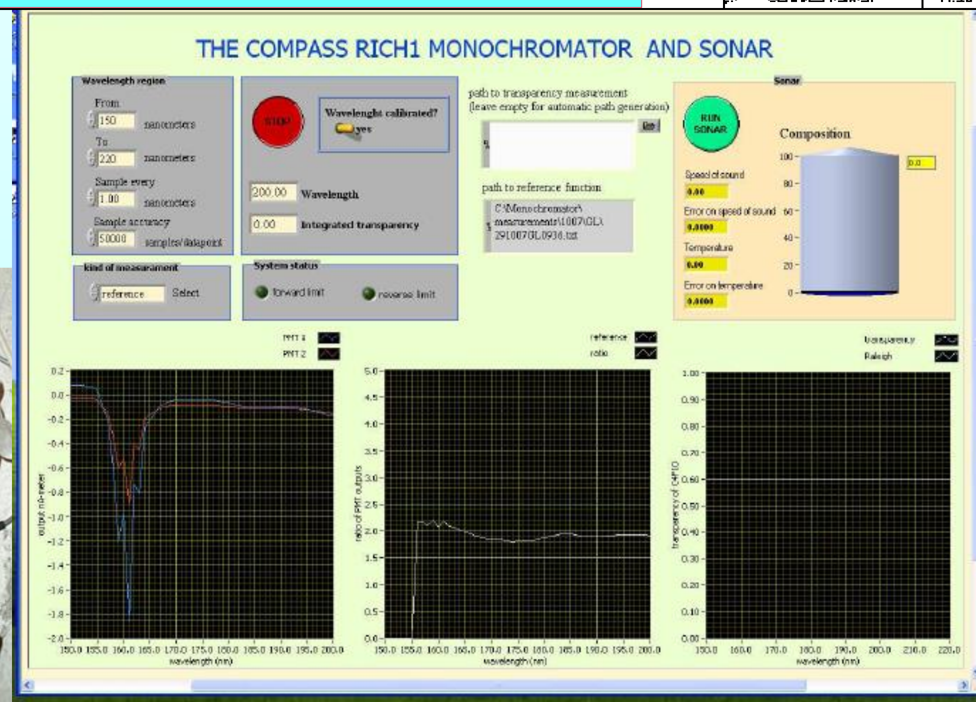
“CLAM” picture for mirror monitoring

The radiator gas system

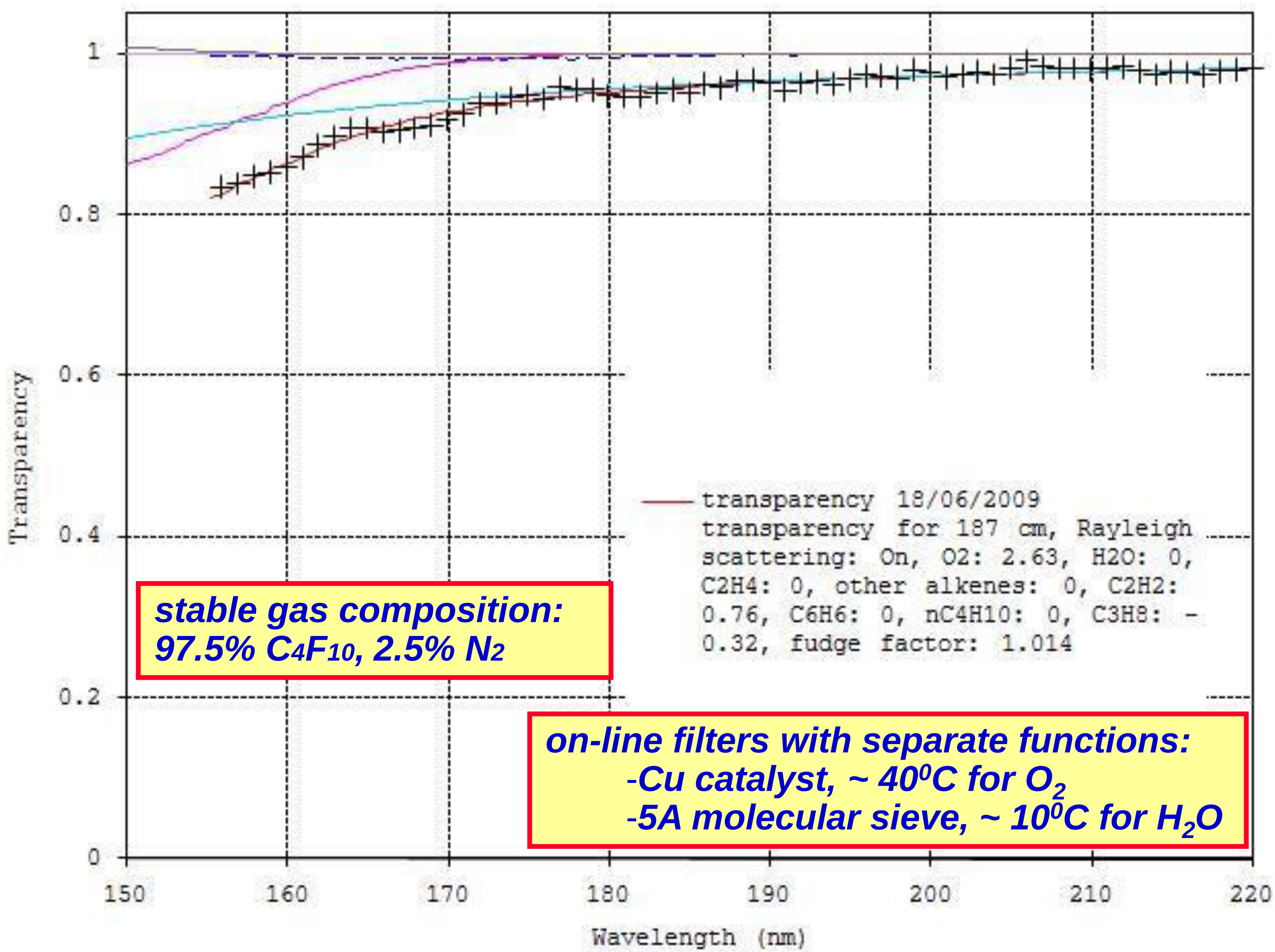


has excellent performance





Typical RICH-1 C_4F_{10} transparency



stable gas composition:
97.5% C_4F_{10}, 2.5% N_2

on-line filters with separate functions:
- ***Cu catalyst, ~ 40^0C for O_2***
- ***5A molecular sieve, ~ 10^0C for H_2O***

Problems with the radiator gas

C_4F_{10} is out of production (→ new radiator gas: C_4F_8O ?)

It comes dirty (very, very dirty sometimes): pre-cleaning is needed: dedicated system, unavoidable losses, expert manpower

Inserting it into the vessel (and recovering it) is delicate, losses ~ 2%, incomplete (97.5% maximum)

Critical circulation system with feedback to keep $\Delta p < 0.1$ mbar challenged by weather

C_4F_{10} leaks out (60 l/day): regular refill is needed

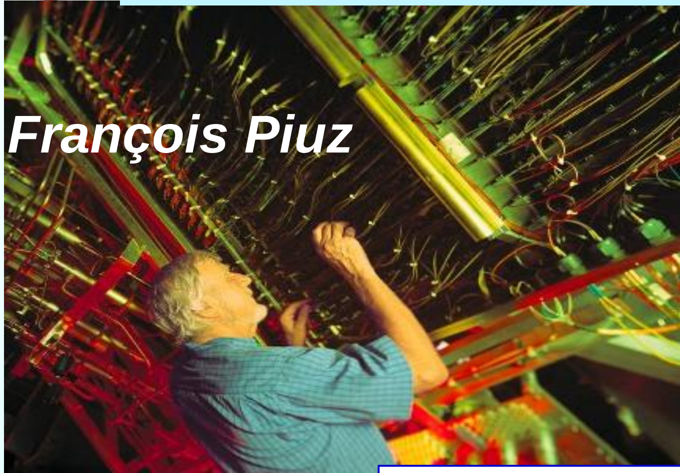
It integrates contaminants: some can be accepted (N_2, Ar), others need continuous filtering out (O_2, H_2O) ; the filters have limited capacitance (significant contaminations fill them quickly); regeneration takes several days

Monitoring the transparency is a must (dedicated system, expert manpower, significant gas consumption for each measurement)

Thermal gradients problem: → fast circulation (20 m^3/h)

<u>Accidents can become disasters; emergency intervention to be granted in short time: EXPERT ON CALL 24 h/day, 7 days/week for 7 months/year: heavy load on experts</u>

RD26: MWPCs +CsI



1992, F. Piuz et al. Development of large area advanced fast-RICH detector for particle identification at LHC operated with heavy ions

TO ACHIEVE HIGH CsI QE:

Substrate preparation:

Cu clad PCB coated by Ni (7 µm) and Au(0.5 µm), surface cleaning in ultrasonic bath, outgassing at 60 ºC for 1 day

Slow deposition of 300 nm CsI film:

1 nm/s (by thermal evaporation or e⁻-gun) at a vacuum of ~ 10^{-7} mbar, monitoring of residual gas composition

Thermal treatment:

after deposition at 60 ºC for 8 h

Careful Handling:

measurement of PC response, encapsulation under dry Ar, mounting by glove-box.

The best quartz cuts here

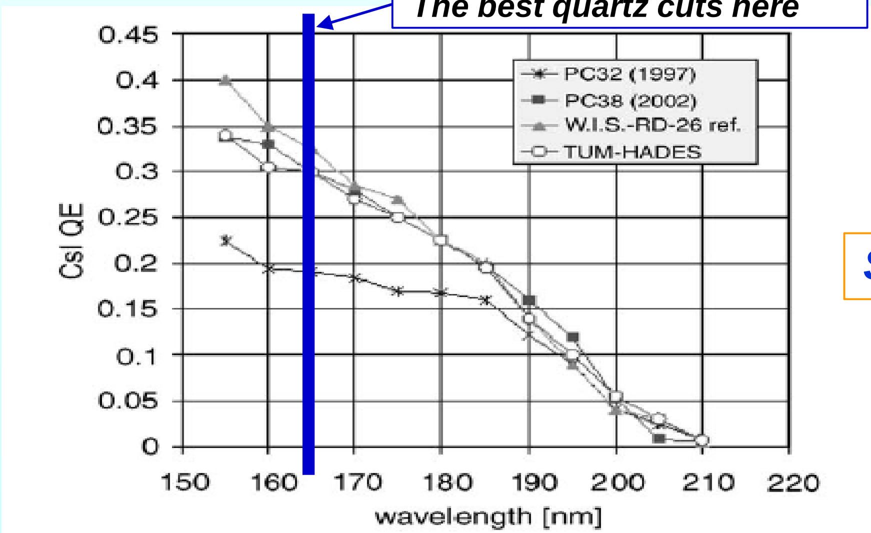
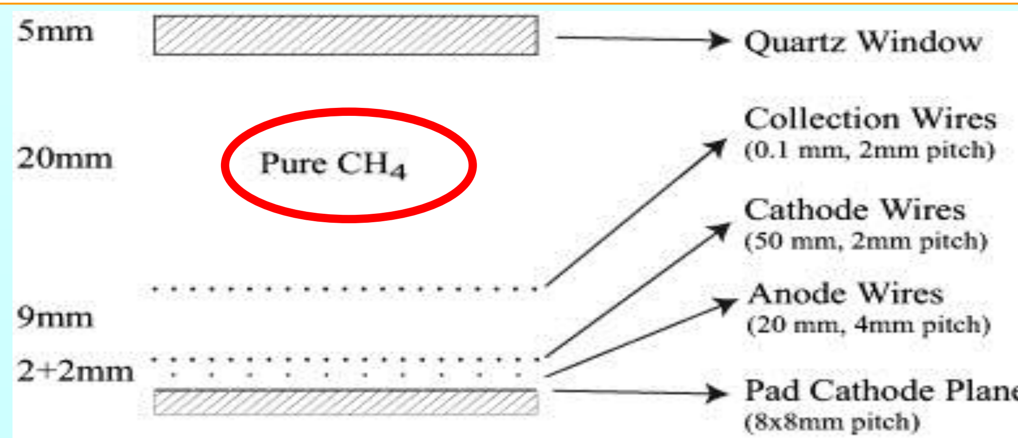


Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

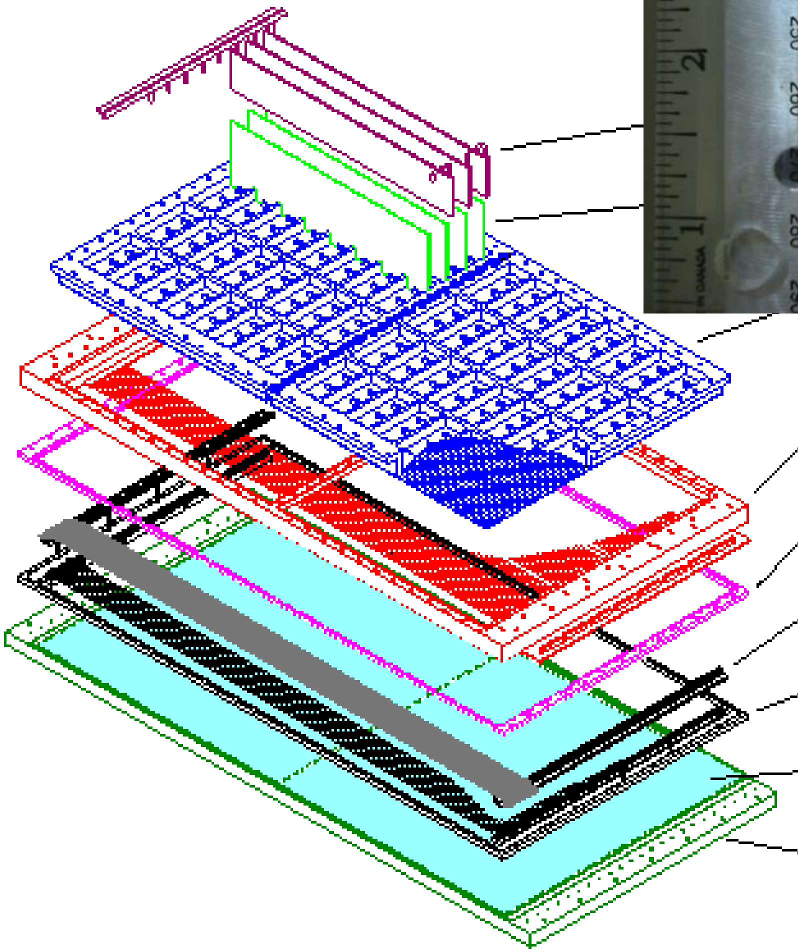
A. Di Mauro, NIM A 525 (2004) 173.

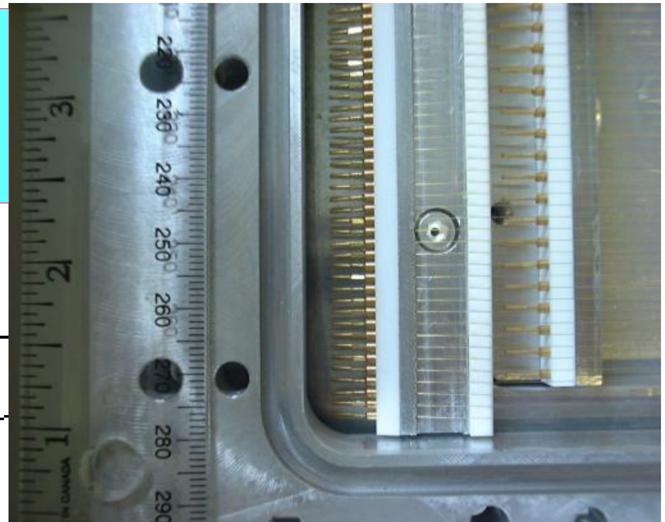
Schematic structure of the COMPASS Photon Detector:



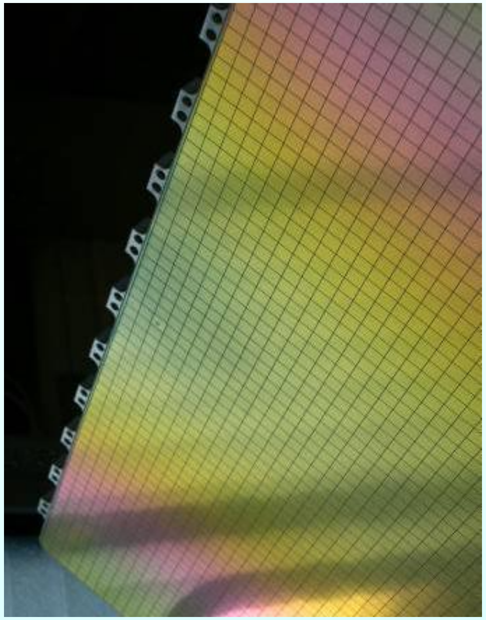
COMPASS: 8 MWPC's with CsI

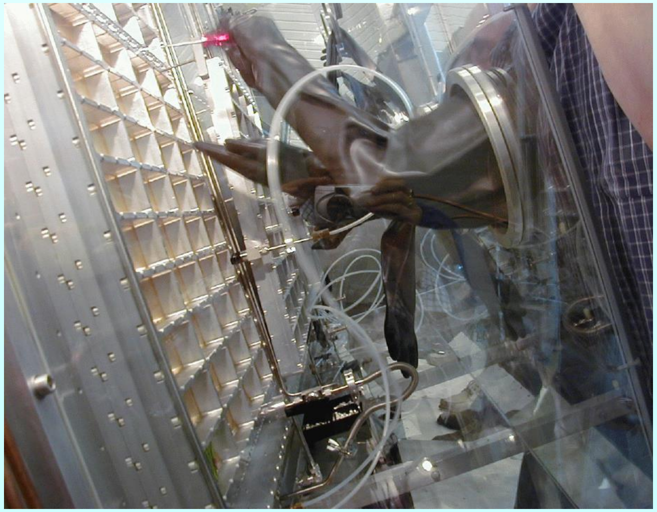
built in 1999 – 2000,
in operation since 2002
more than 5 m²

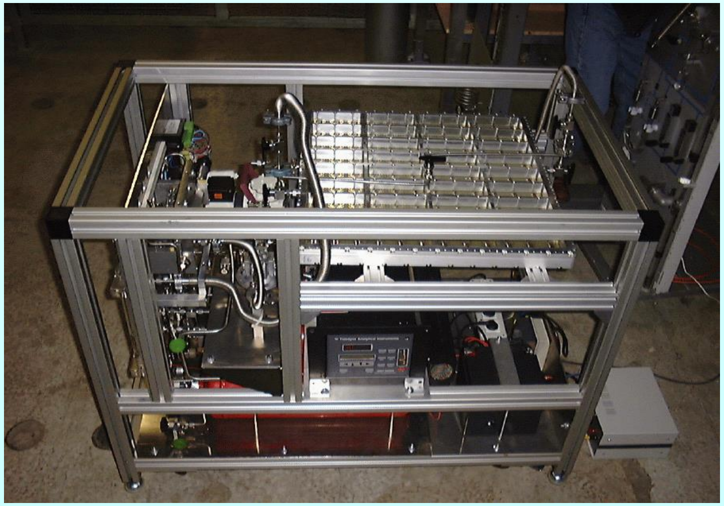




The CsI photocathodes



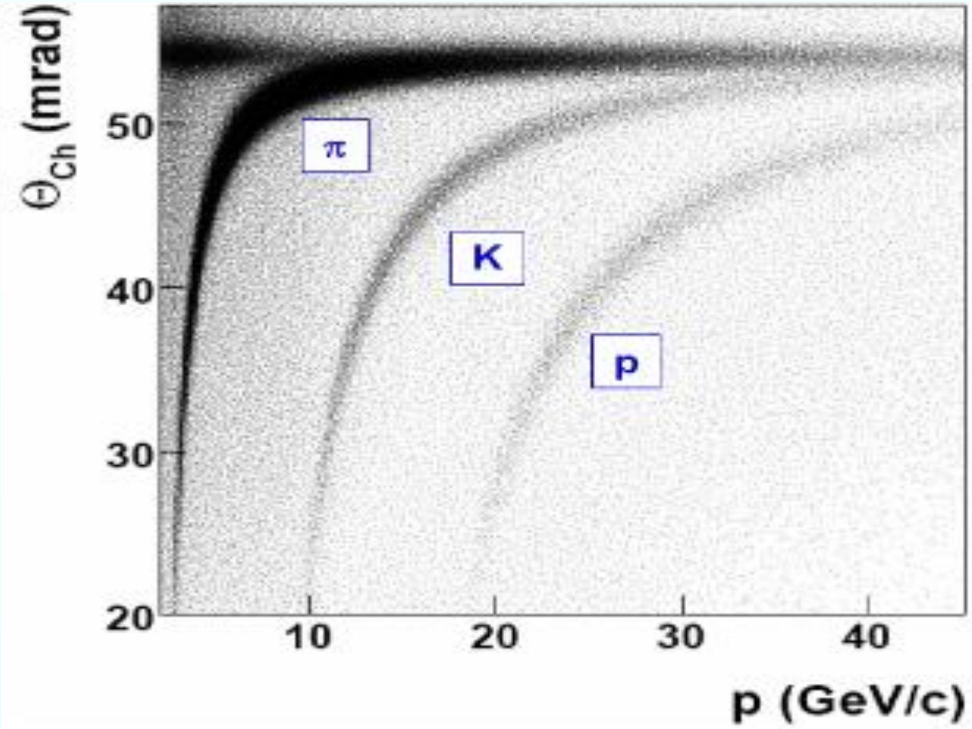




Good performance in low gain configuration

- photons / ring ($\beta \approx 1$, complete ring in acceptance) : 14
- $\sigma_{\theta\text{-ph}}$ ($\beta \approx 1$) : 1.2 mrad
- σ_{ring} ($\beta \approx 1$) : 0.6 mrad
- 2σ π - K separation @ 43 GeV/c
- PID efficiency ~ 95% for θ_{Ch} > 30 mrad

  except for the very forward region



After a long fight for increasing electrical stability at high m.i.p. rates and systematic studies at the CERN GIF we came to the same conclusion as Ypsilantis and Seguinot:

J. Seguinot et al., NIM A 371 (1996), 64:

CsI-MWPC with 0.5 mm gap to minimize ion collection time, fast front-end electronics (20 ns int. time): stable operation is not possible at 10^5 gain because of photon feedback, space charge and sparks

limits of MWPC's with CsI in COMPASS

1) MWPCs with CsI photocathodes in COMPASS:

beam off: stable operation up to > 2300 V

beam on: stable operation only up to ~2000 V

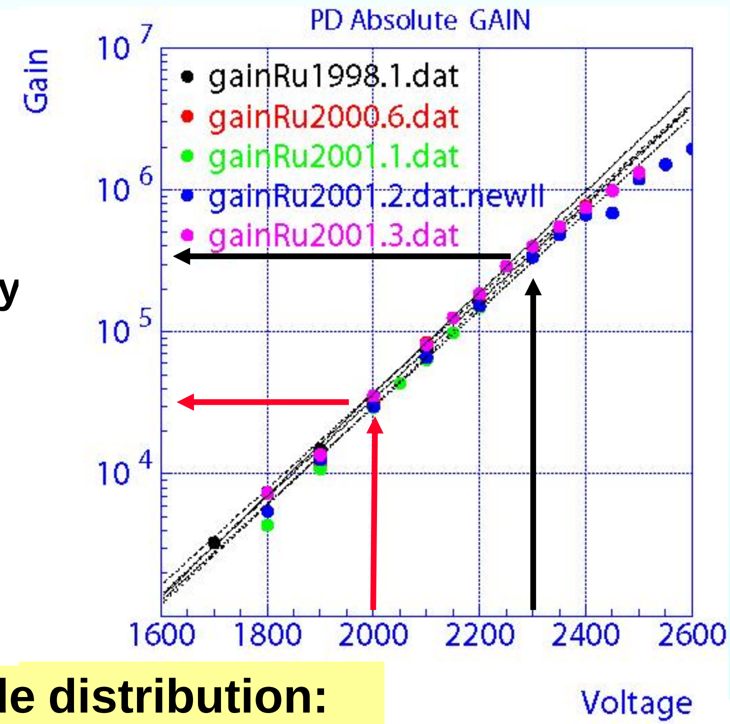
(in spill→ ph. flux: 0 - 50 kHz/cm^2 , mip flux: ~1 kHz/cm^2)

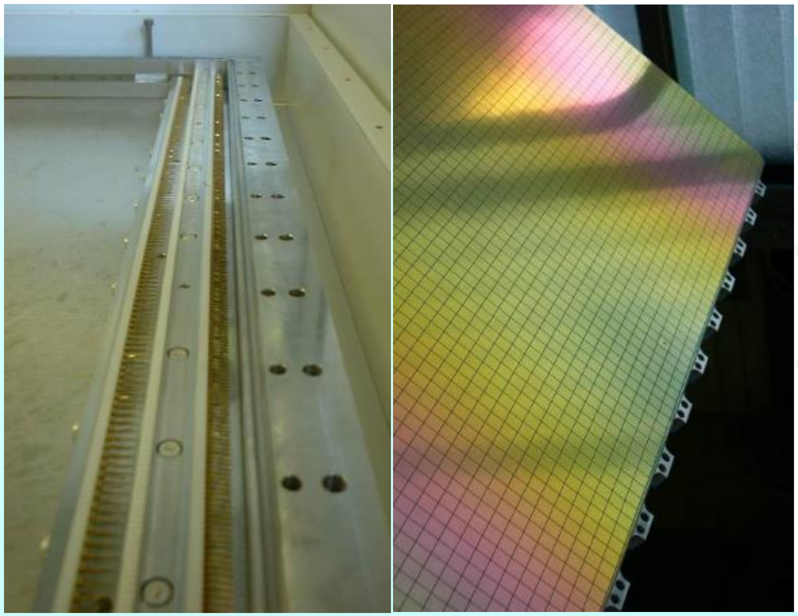
Whenever a severe discharge happens, recovery takes ~1 day

2) Photocathode aging:

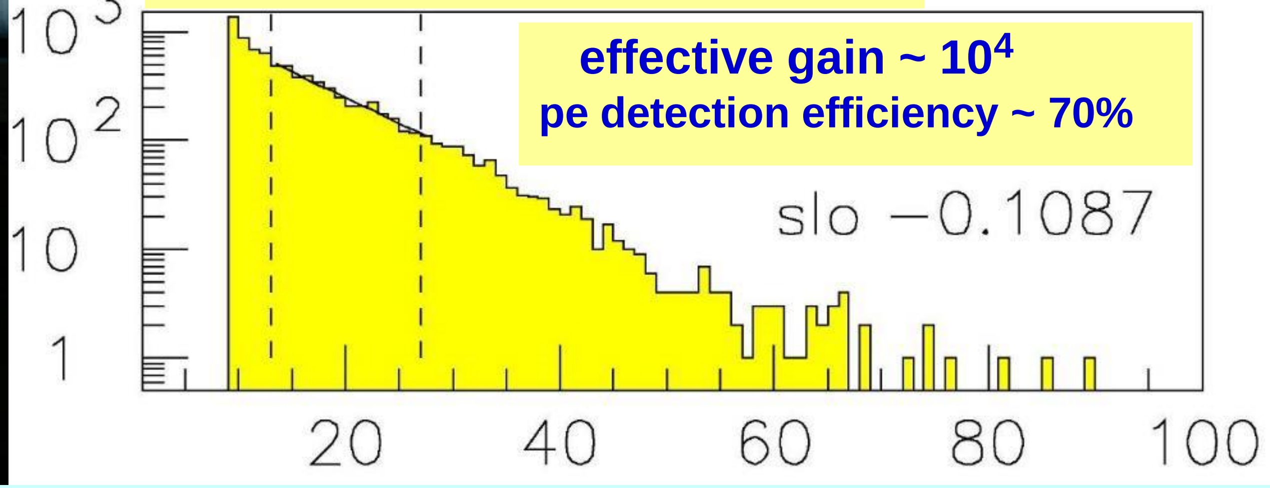
- our information from accidental contamination

- very detailed study by Alice team





cluster amplitude distribution:

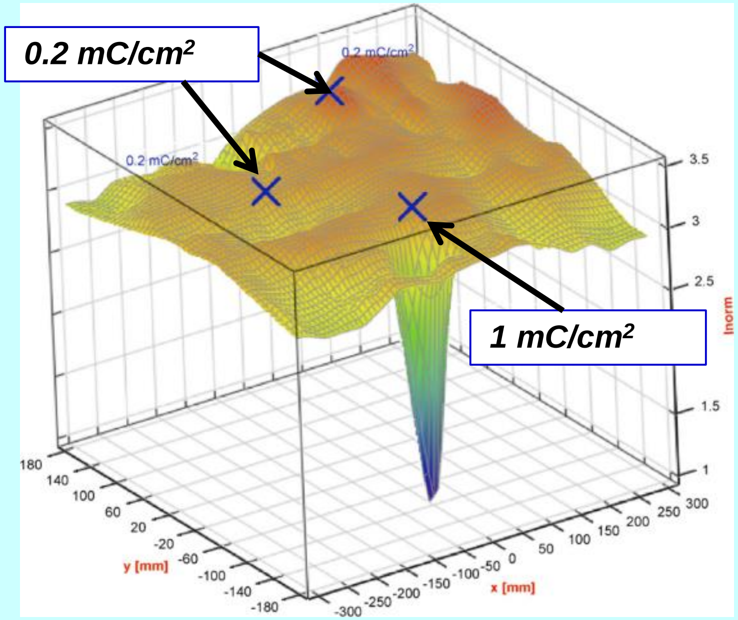


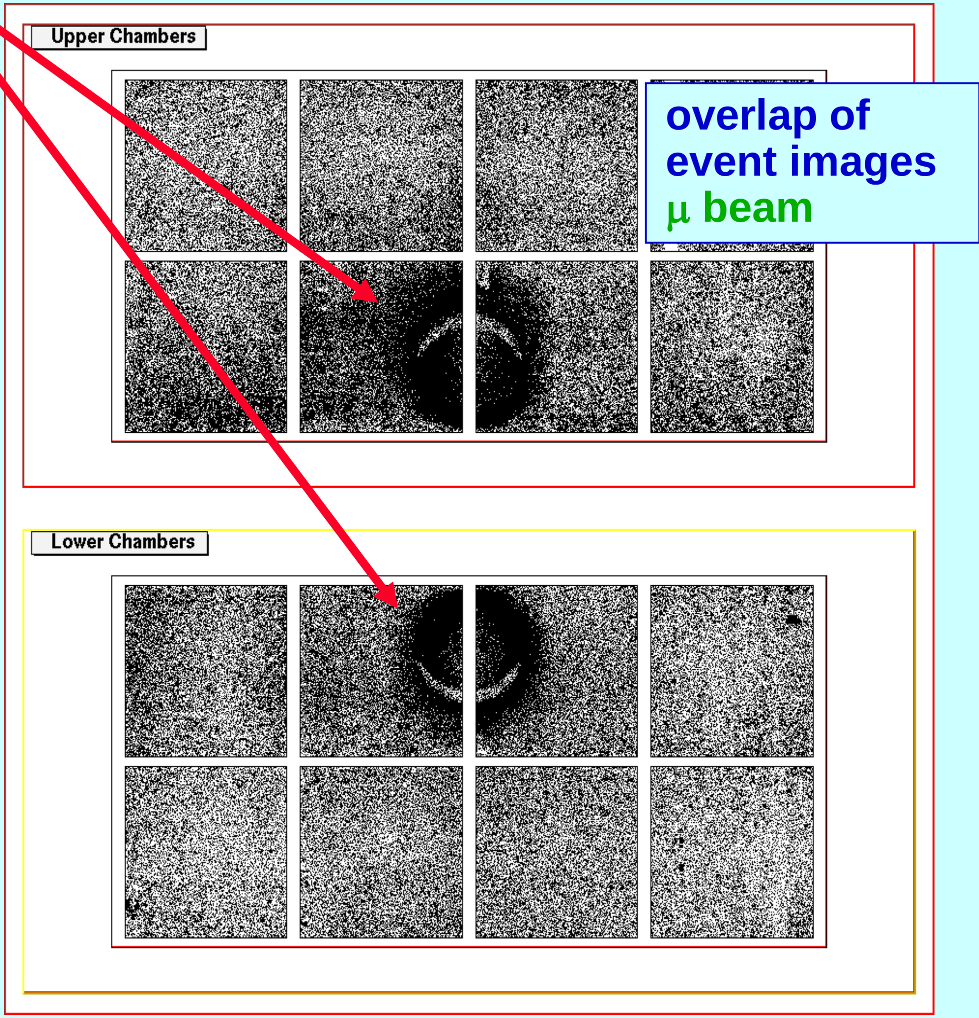
the central region before 2006

THE EXPERIMENTAL ENVIRONMENT

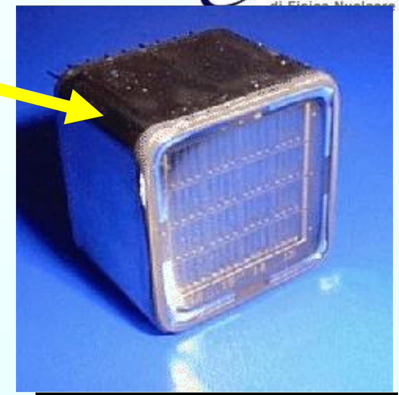
huge uncorrelated background related to the memory of the MWPCs + read-out

Accelerated ageing test
H. Hoedlmoser et al., NIM A 574 (2007) 28.



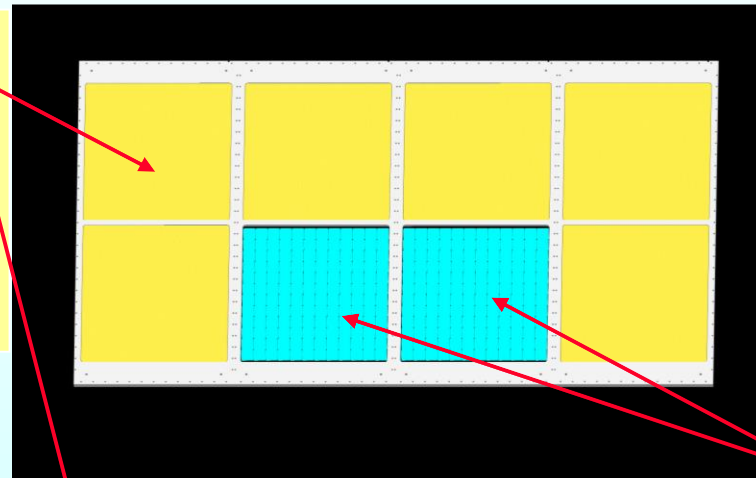


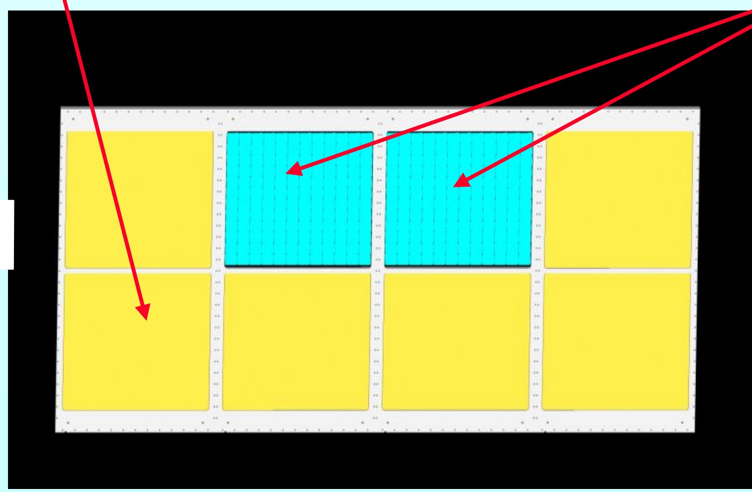
upgrade of RICH-1 with MAPMT's in the central region (2006)

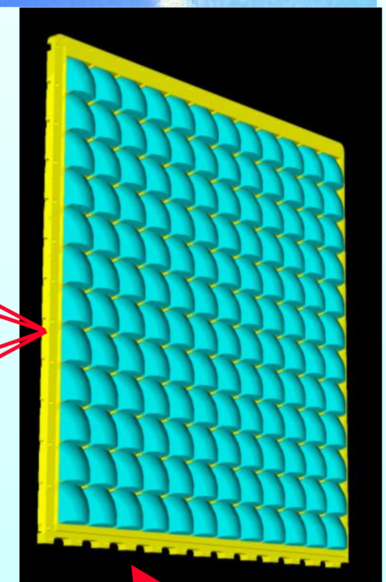


12 outer CsI cathodes: change electronics (use APV25-S1)

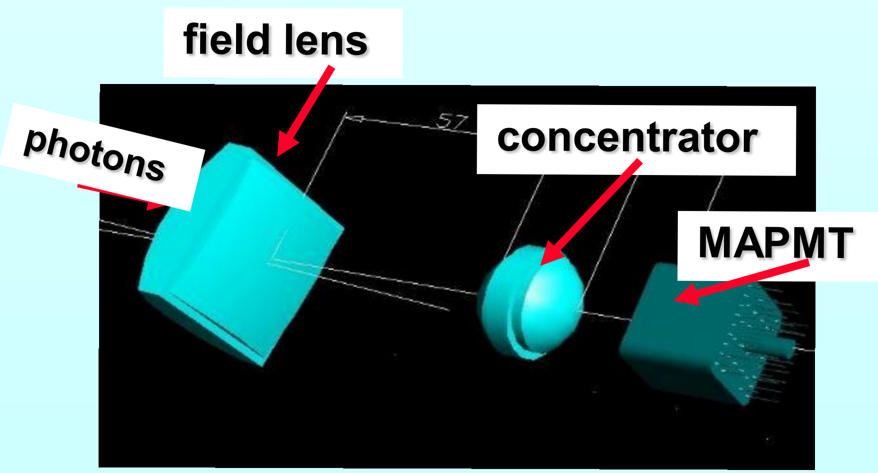
4 central CsI cathodes : remove and insert frames with MAPMTs and lense telescopes







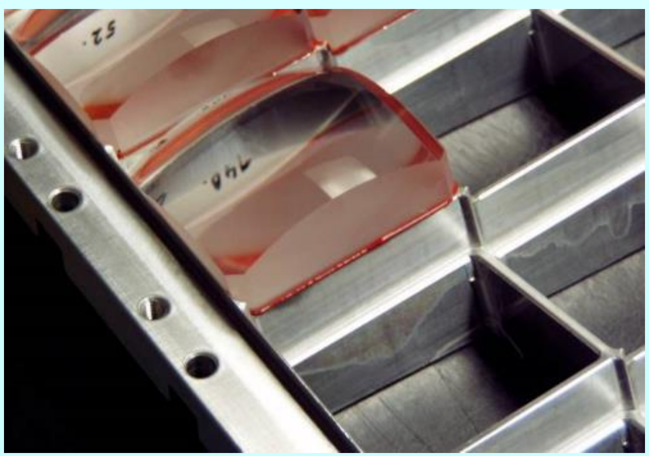
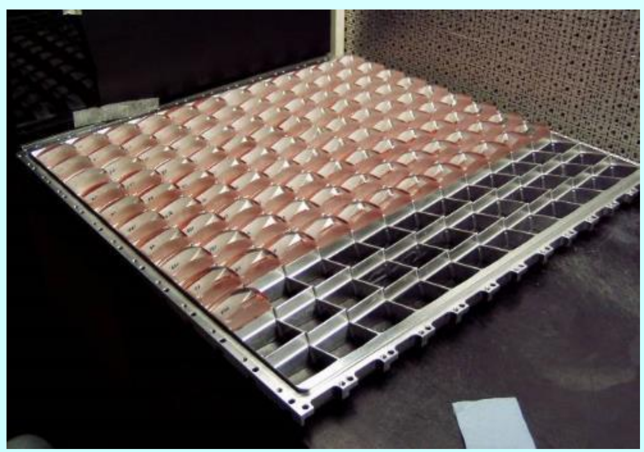
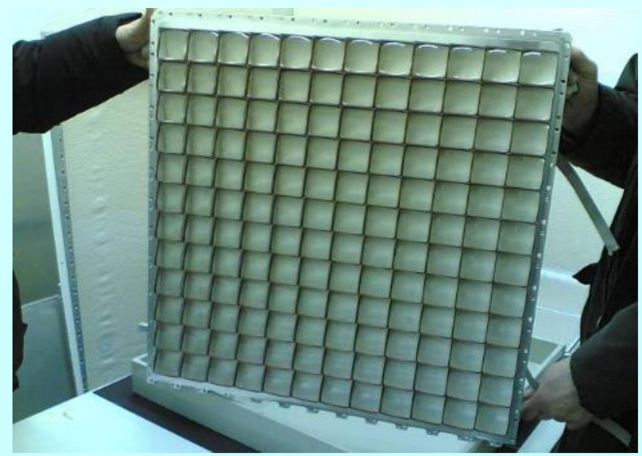
Same mechanics as CsI photo-cathode frame



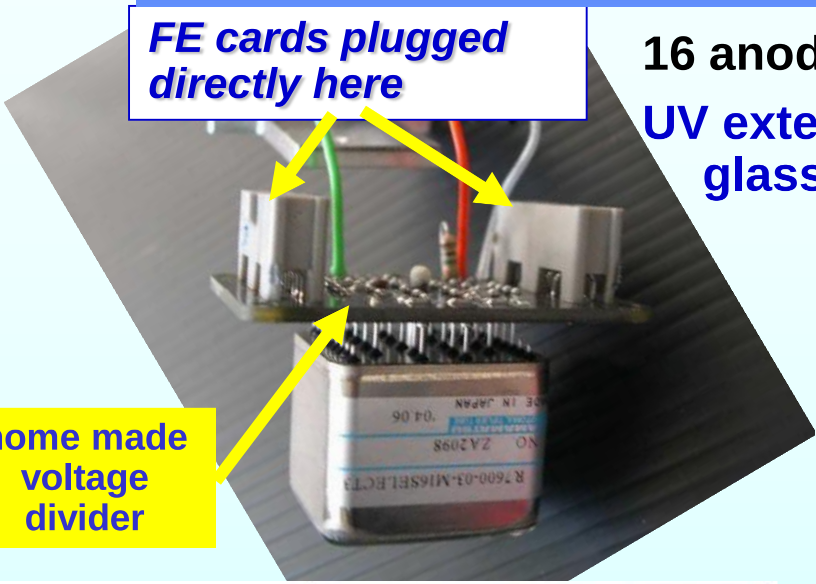






MAPMT: HAMAMATSU R7600-03-M16



home made voltage divider

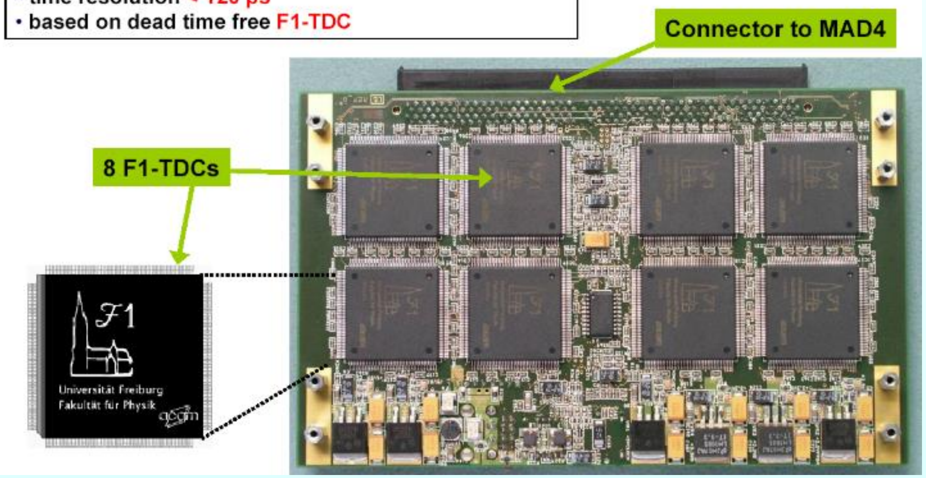
16 anodes

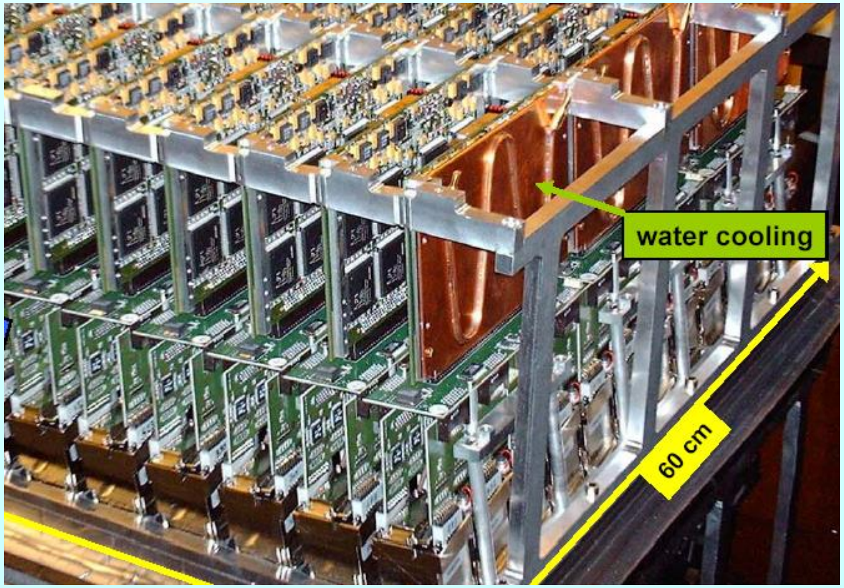
UV extended glass

Digital read-out electronics: DREISAM card

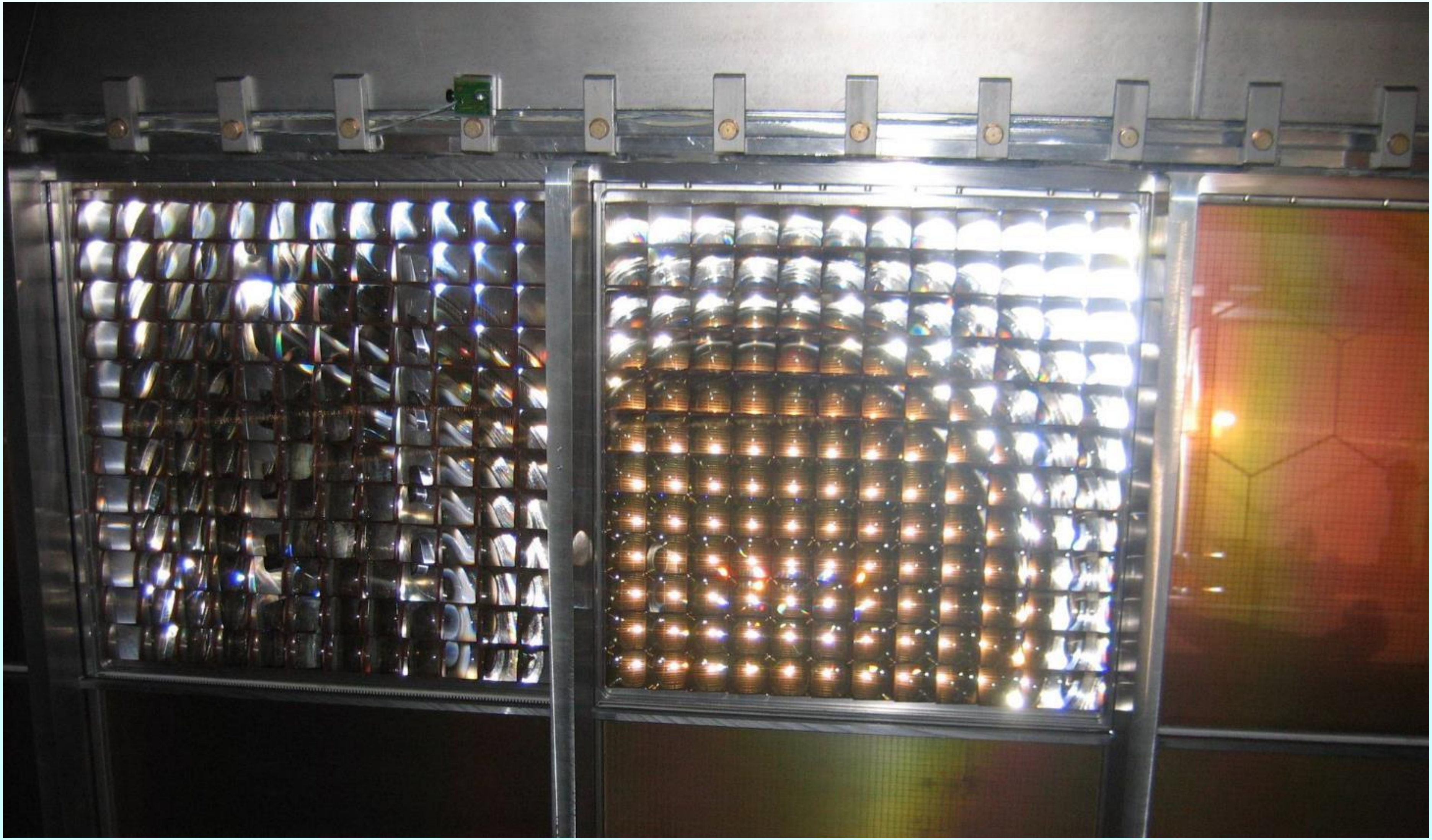
- 64 channels per card, compact solution
- optical data transfer (40 MByte/s)
- high rates per channel 10 MHz @ 100 kHz trigger rate
- time resolution < 120 ps
- based on dead time free F1-TDC

complete digitalisation on the detector

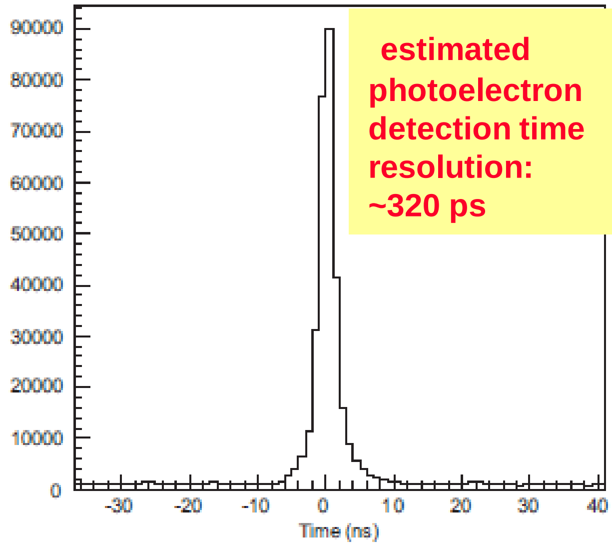


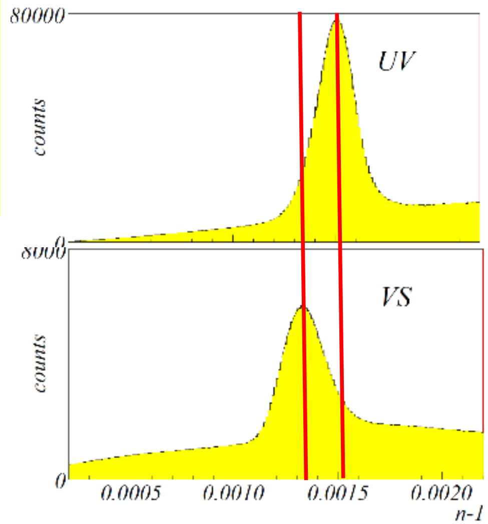


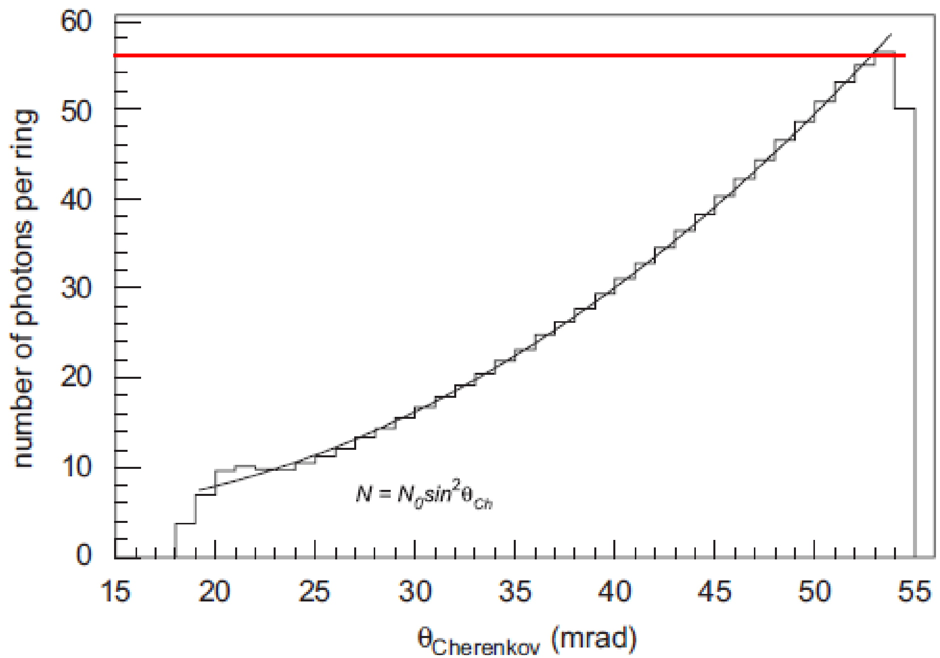
The central part of the lower detector

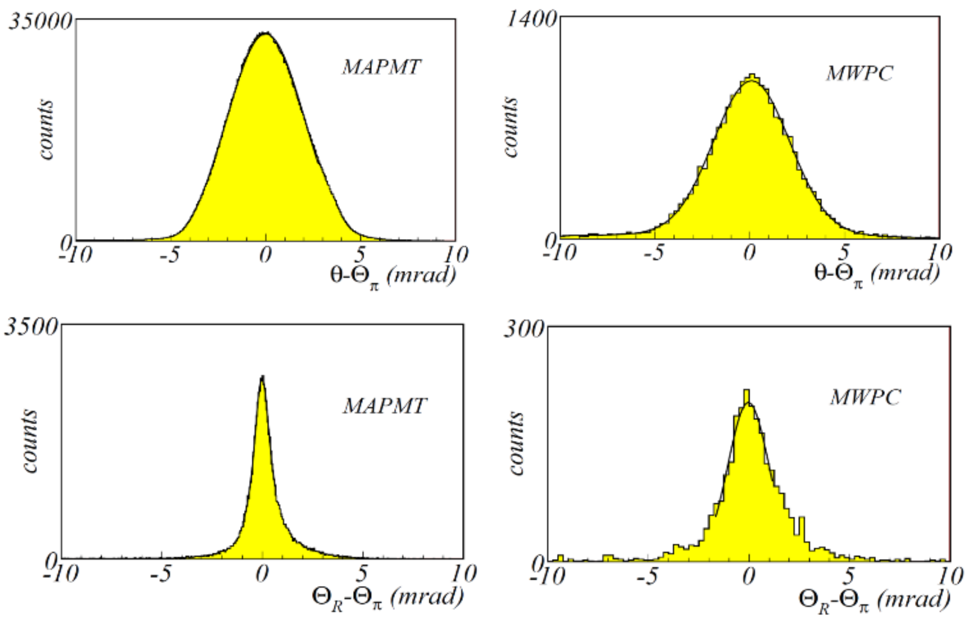


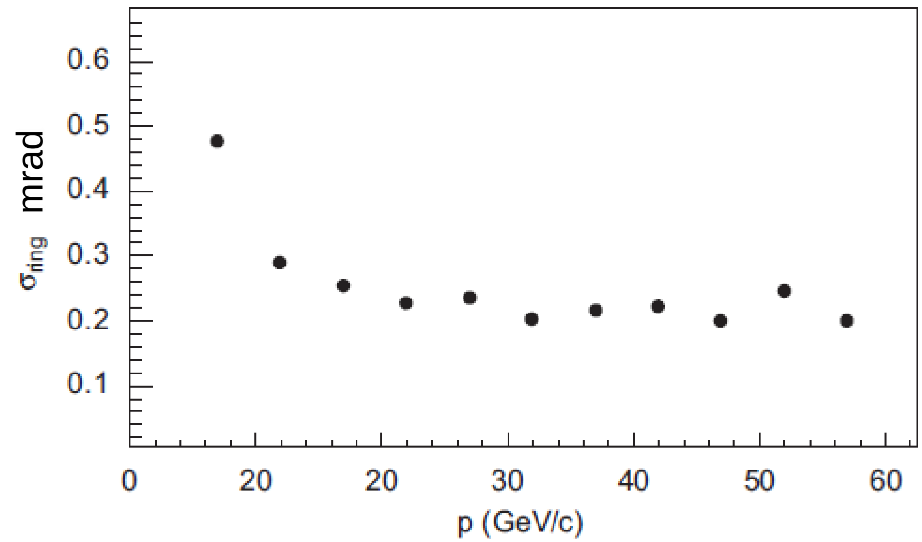
number of photons and resolutions



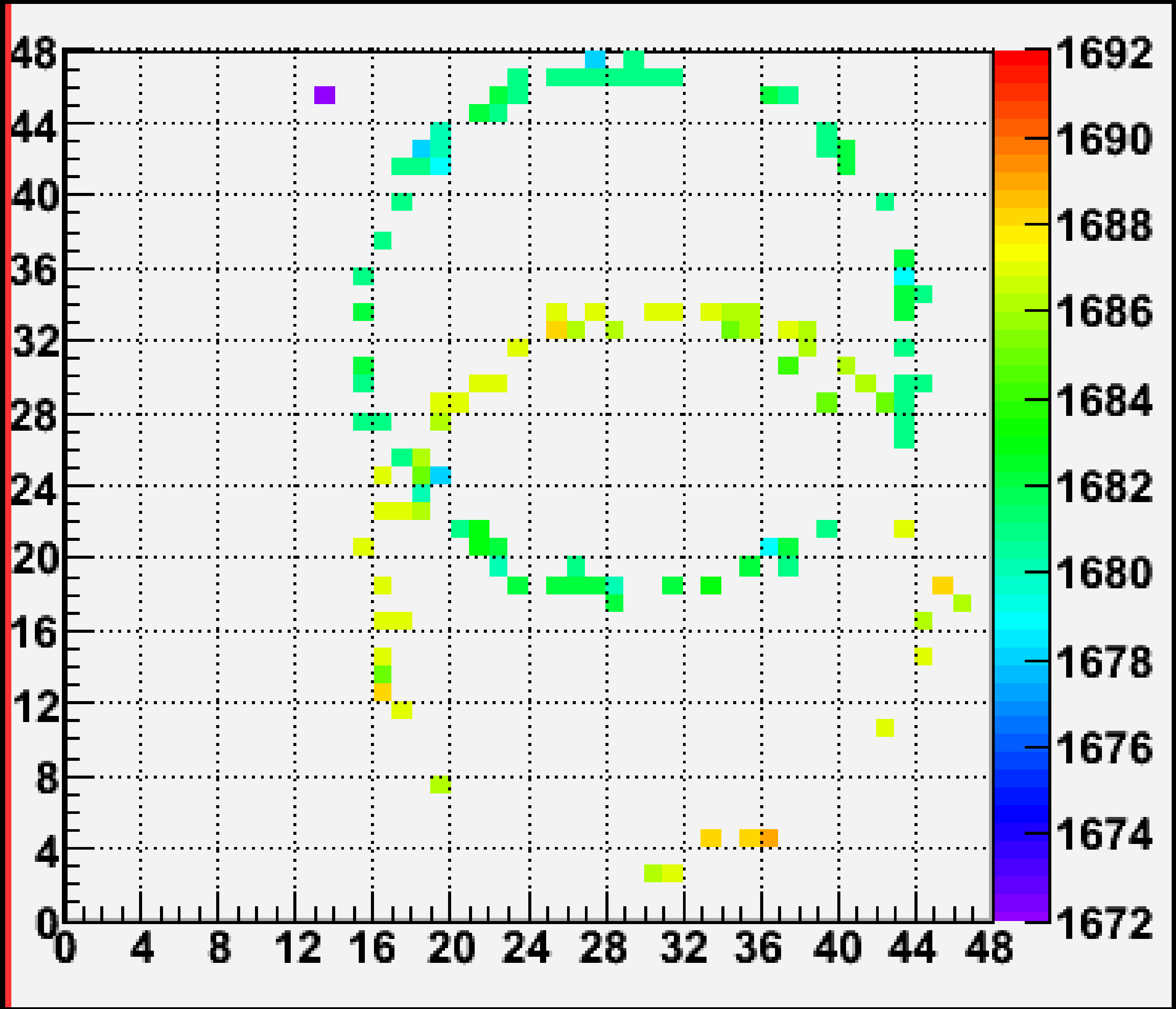








time resolution is useful for correctly assigning hits to rings



PID from the likelihood function

PID relies on a Likelihood function, built from all the photons associated to the particle

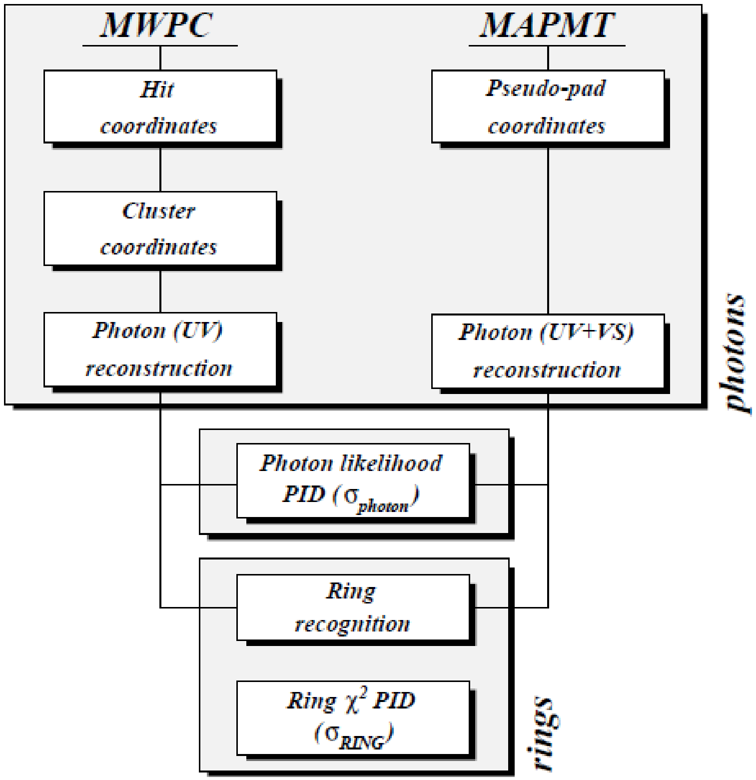
no reference to a reconstructed ring

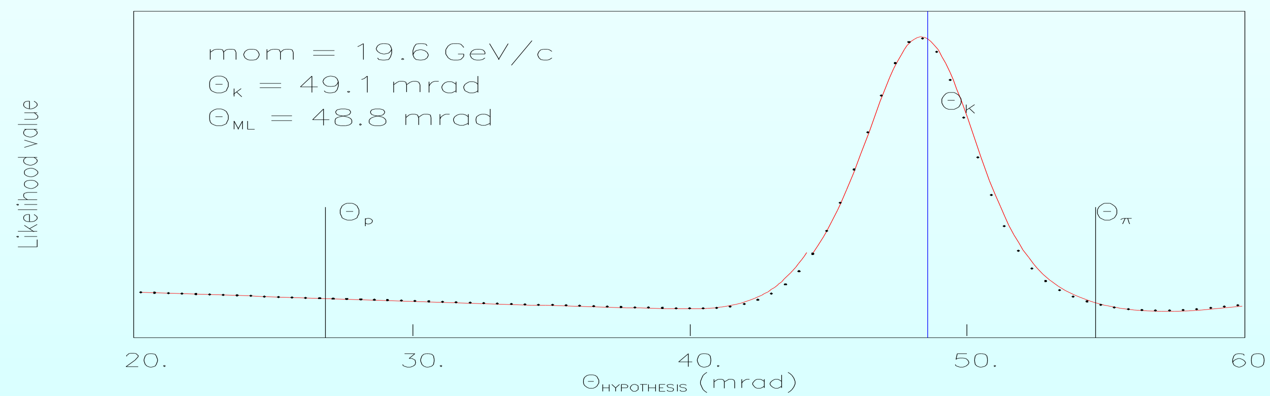
$$L_M = \prod_{j=1}^{N} \frac{s_M(\theta_j, \varphi_j) + b(\theta_j, \varphi_j)}{S_M + B}$$

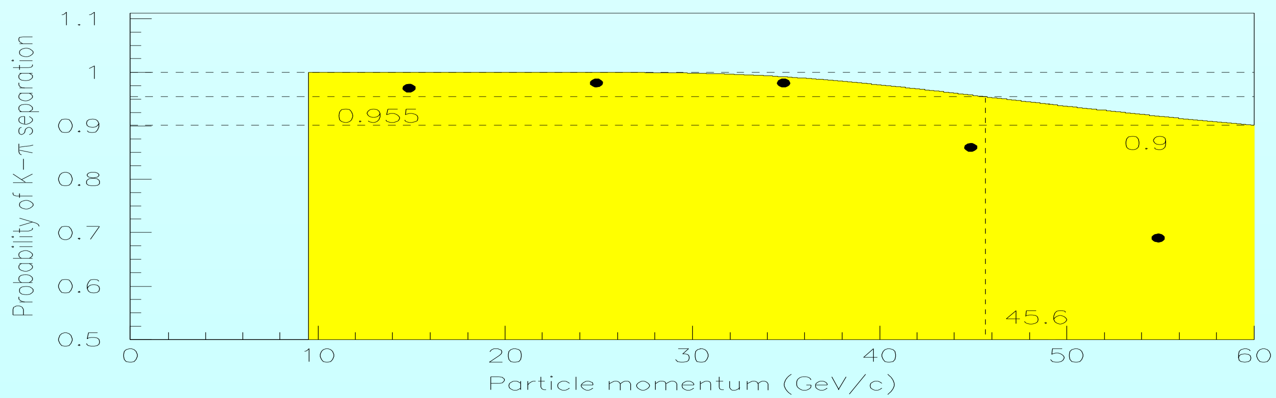
Computed for

5 mass hypothesis $M = e, \mu, \pi, K, p,$

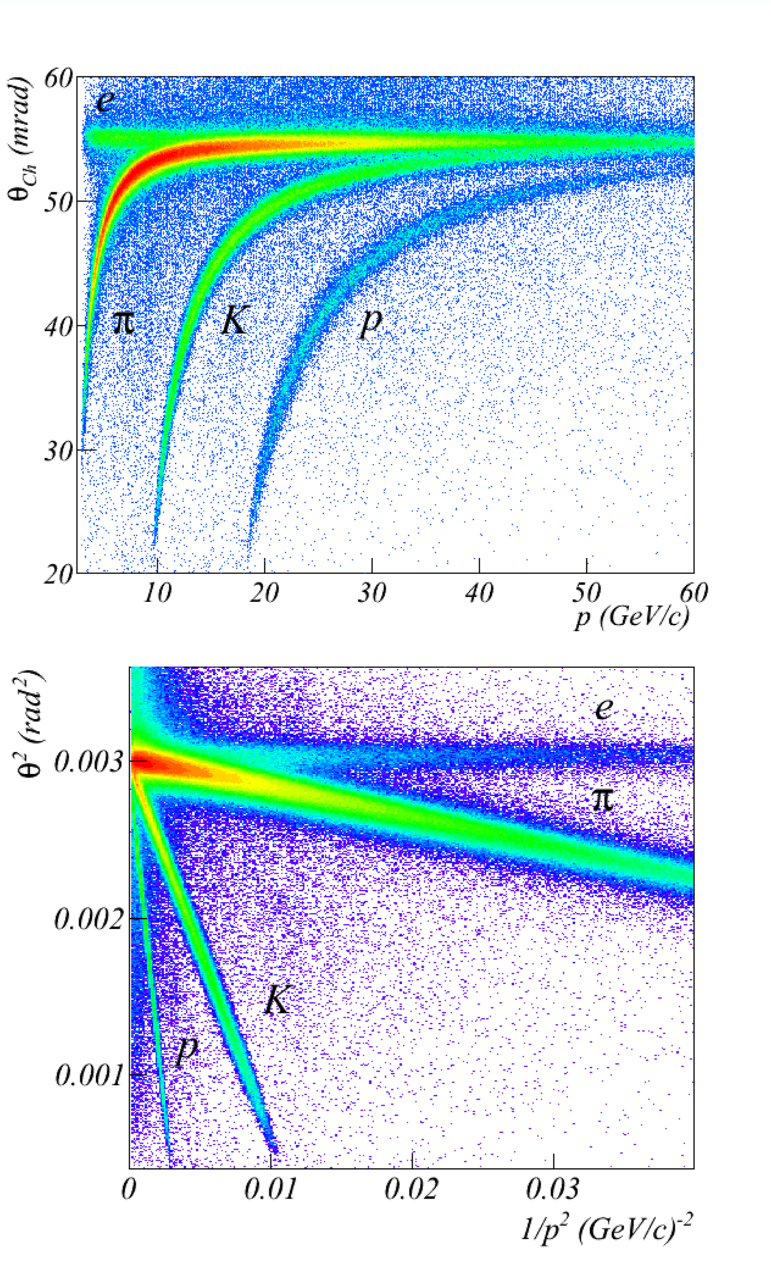
+ background hypothesis (no signal)

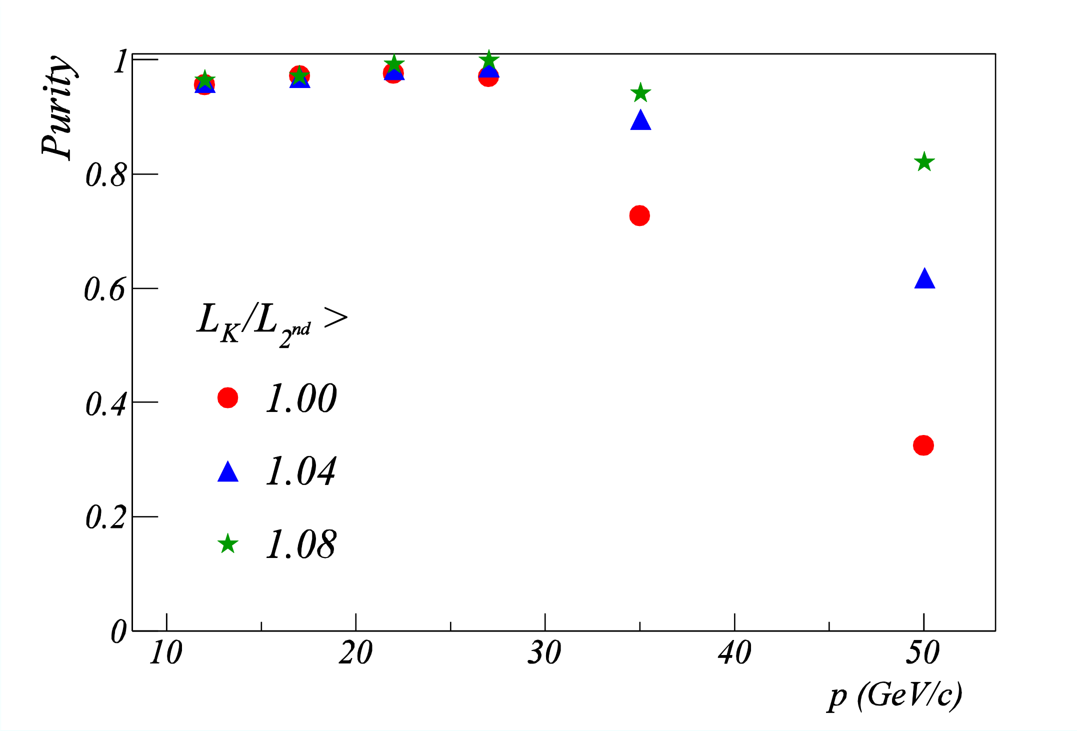






PID performance and purity of K samples





New COMPASS PID requirements

Precision measurements require not just high efficiency but also very stable response

MWPC + CsI operate at low gain ➔ depend on p, T, threshhold and background stability but we need precise comparison of data with different background levels

Reduction of systematics from photon detectors ➔ larger gain and faster signals

PMTs not adequate because of large angular acceptance ➔ only a small demagnification factor of optical system is allowed (large distortions);
5 m^2 of PMTs are not affordable.

A dedicated R&D project to develop THGEM-based PDs did choose a hybrid MPGD architecture as the best option.

THGEMs

GAS ELECTRON MULTIPLIER FORMED BY A RIGID DIELECTIC FOIL BETWEEN ELECTRODES, PROVIDED WITH A PATTERN OF HOLES.

In a proper gas and with electric bias it can provide large electron multiplication

- **Material: - FR4, permaglass, ARLON …**
- **- PTFE, PET, …**
- **- glass, PEG3 (etchable glass), …**
- **- ceramic**
-
- **Holes: - mechanical drilling (1 € per 1000 holes, 30000 hole/h)**

  - water jet

  - laser

  - chemical etching

  - preformed (capillary plates)

Classical THGEMs

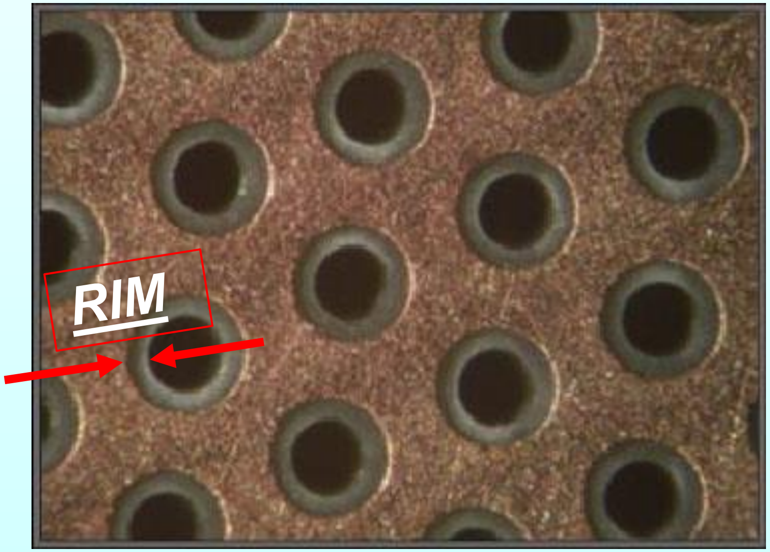
Standard PCB foil:

robust

- **mechanically self supporting**
- **large size**
- **industrially produced**

About PCB geometrical dimensions:

Hole diameter :	0.2 – 1 mm
Pitch :	0.4 – 4 mm
Thickness :	0.2 – 2 mm

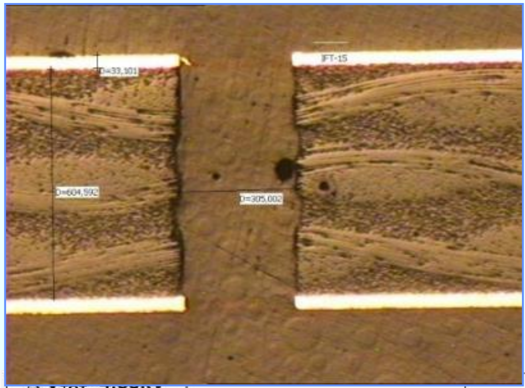


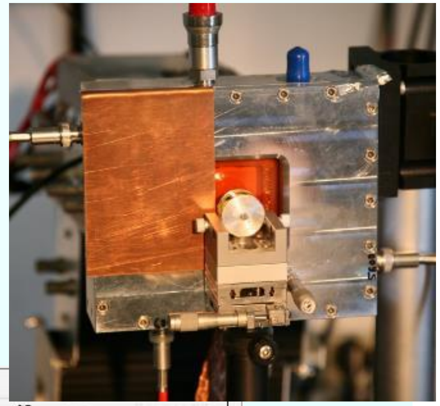
Comparing to GEMs:

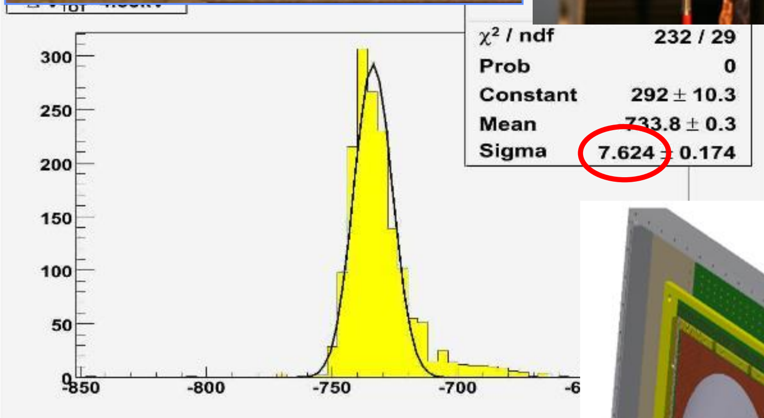
- **Geometrical dimensions X ~10**
  - **But e^- motion/multiplic. properties do not!**
  - **Larger holes:**
    - **dipole fields and external fields are strongly coupled**
    - **e^- dispersion plays a minor role**

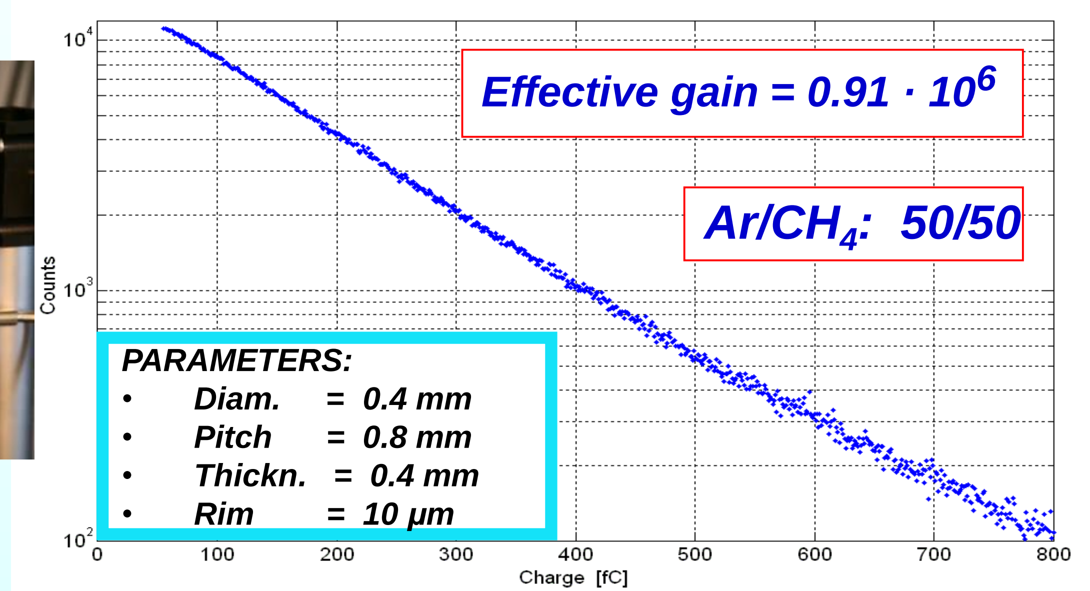
introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al, .NIMA 535 (2004) 303

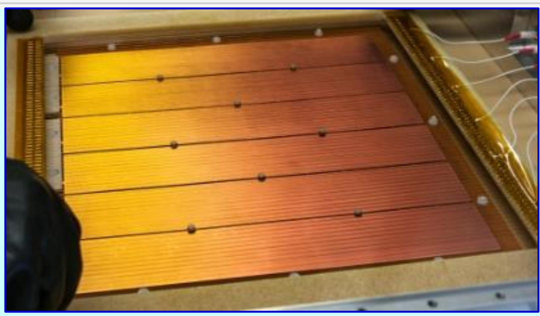
THGEM +CsI: 8 years of dedicated R&D

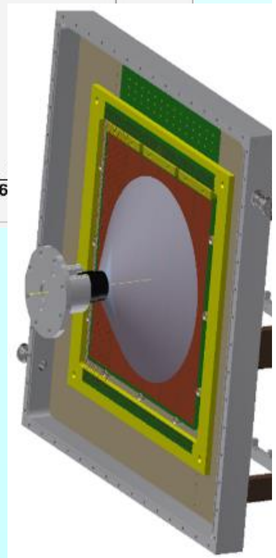


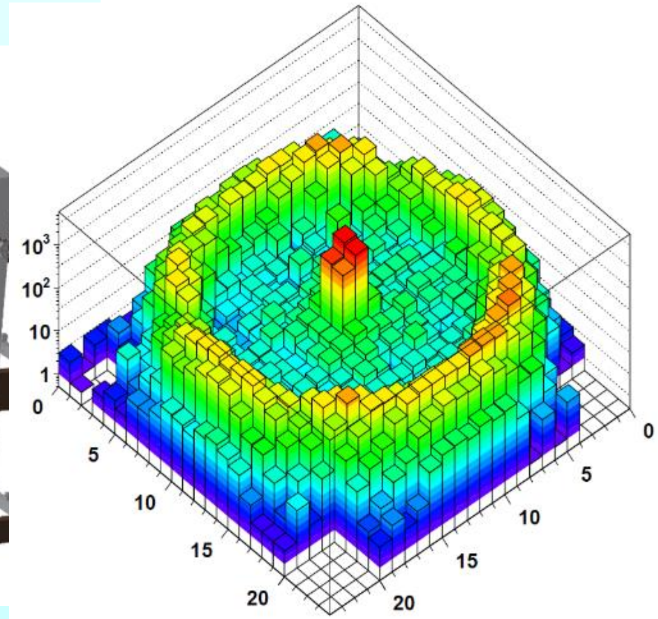




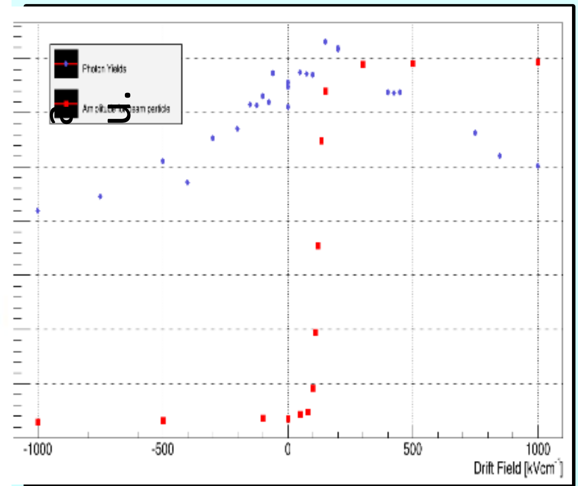






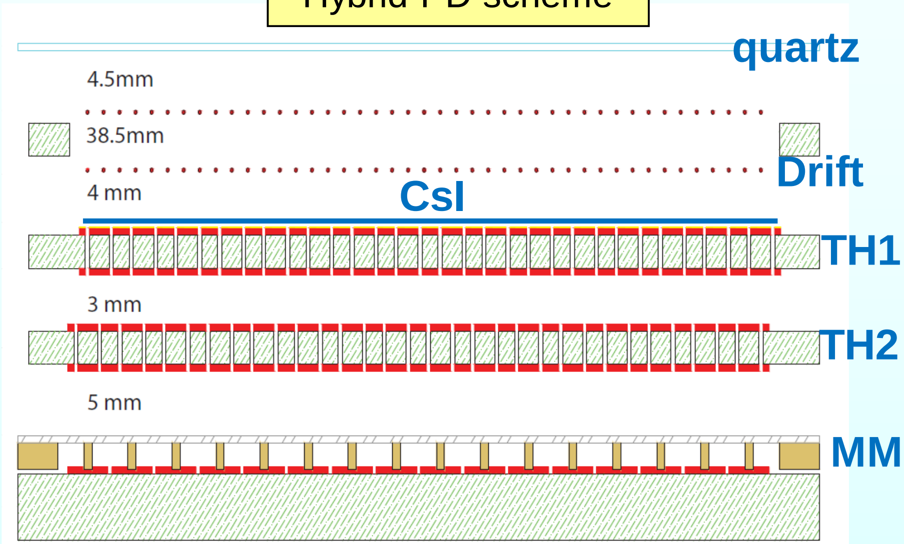


Photon yield & Charged Particles vs Drift Field

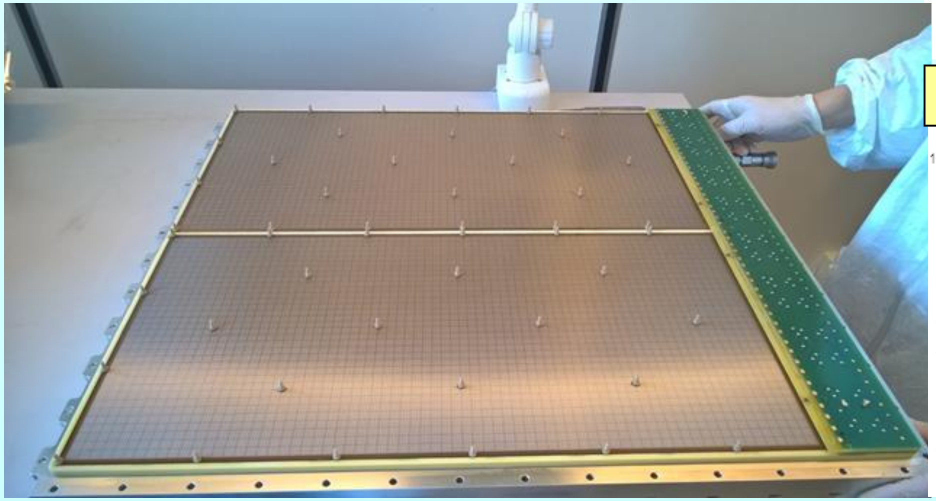


The new hybrid THGEM+Micromegas PDs

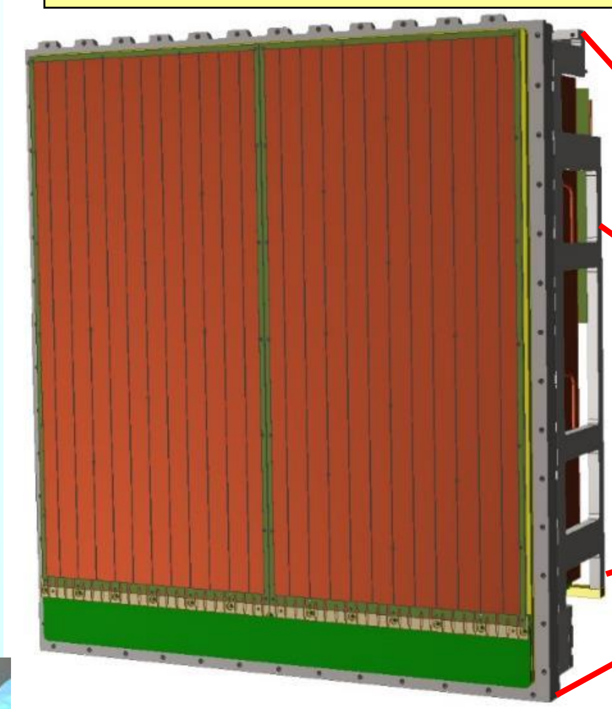
Hybrid PD scheme

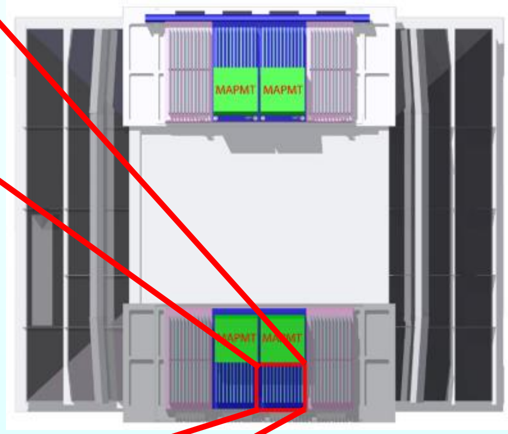


Standard Bulk Micromegas produced at CERN

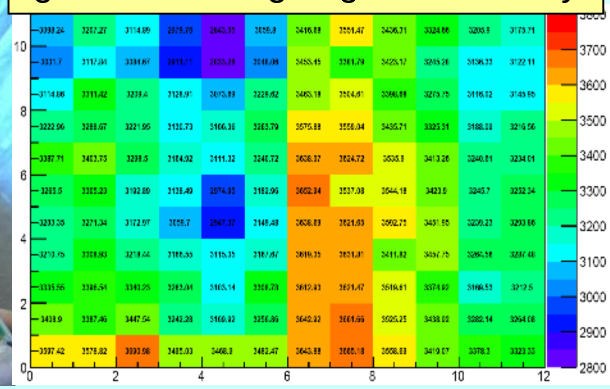


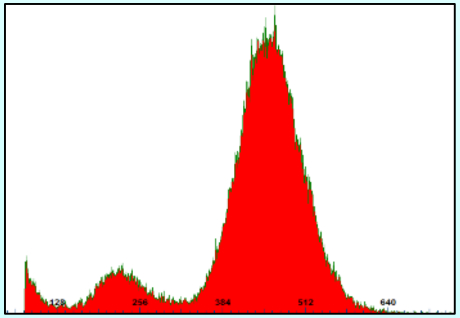
modular structure: one module = 600x300 mm^2





good Micromegas gain uniformity





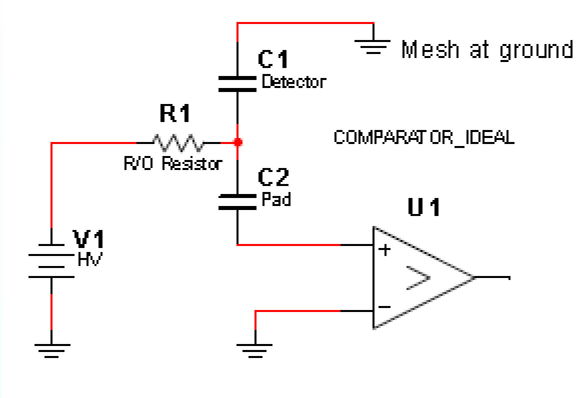
$$\delta_G = \frac{G_{max} - G_{min}}{G_{min}} < 5\ \%$$

The anodic PCB

anodic pad PCB produced by TVR

8mm X 8mm pads at positive HV

Signal read out via capacitive coupling pad readout and APV25 F/E boards



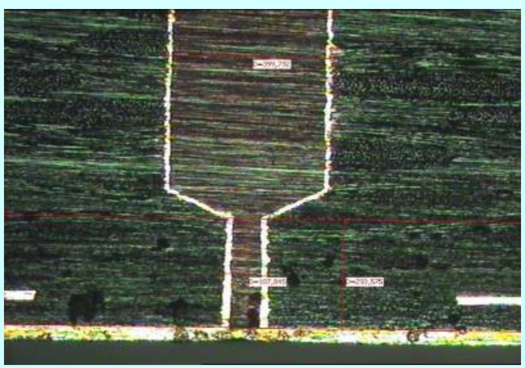
Strong technological effort from TVR Company for the PCB (multilayer 3.2 mm thick) to comply with specific requirements of planarity, surface quality, layer thickness uniformity, surface irregularities (E field).

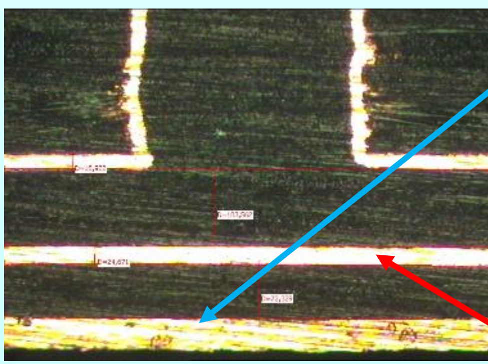
Tests on 2500 pads: electrical continuity and capacity meas. → 38-42 pF/pad

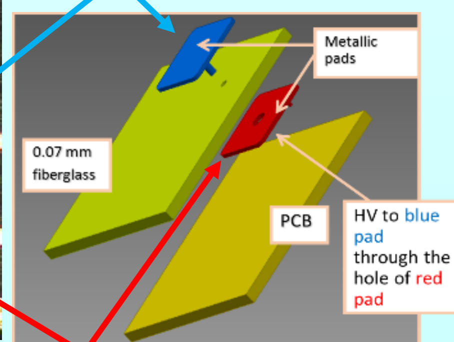
470 MΩ resistor for each anodic pad

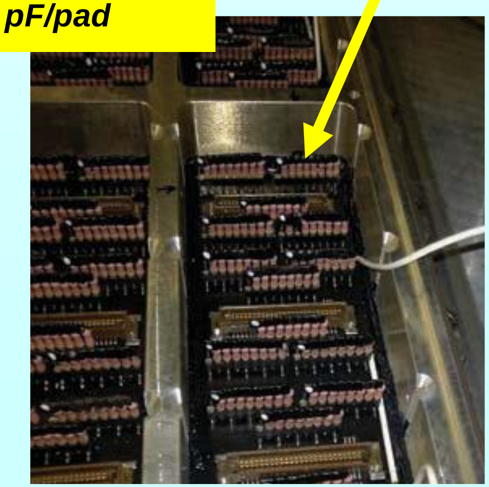
"Z drilling controlled via" → planarity issue

"surface anode" pad



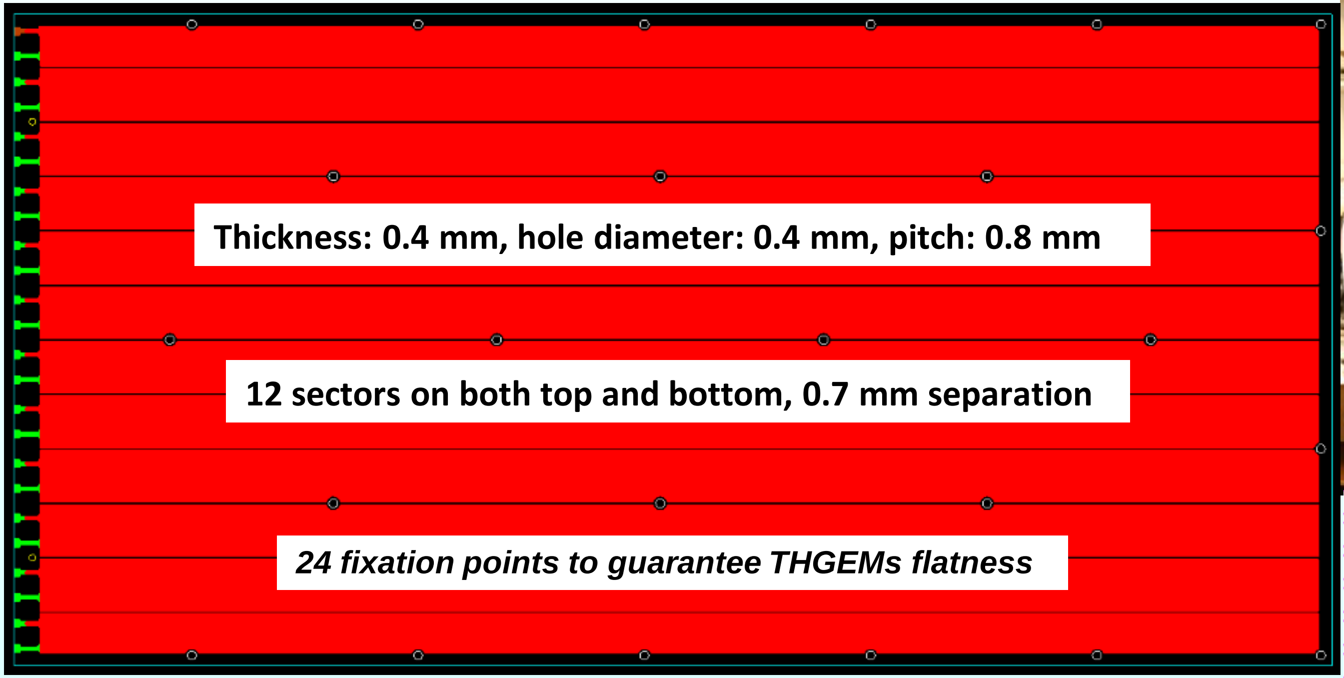






"buried pad"

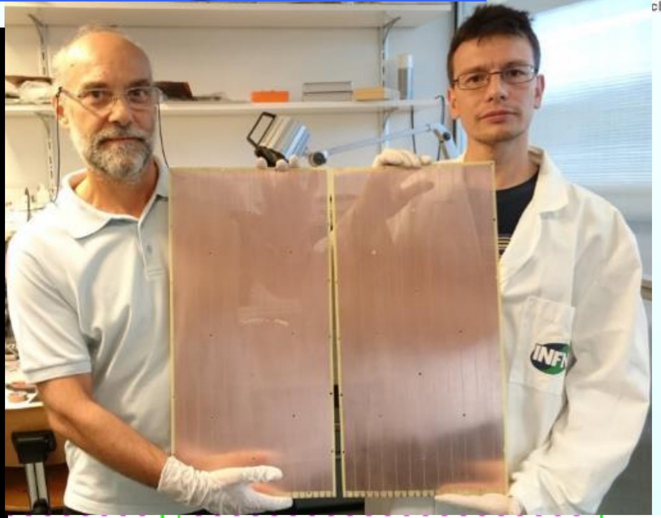
The COMPASS THGEM design

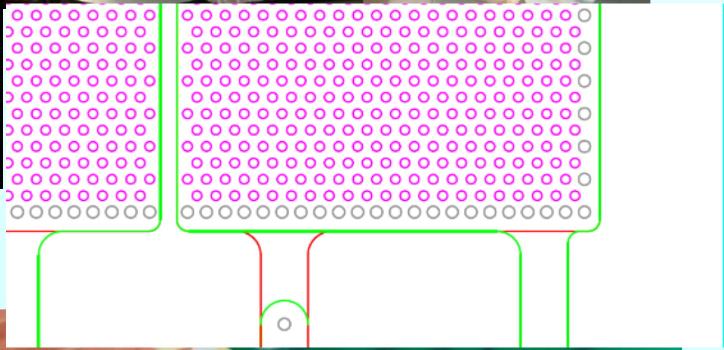


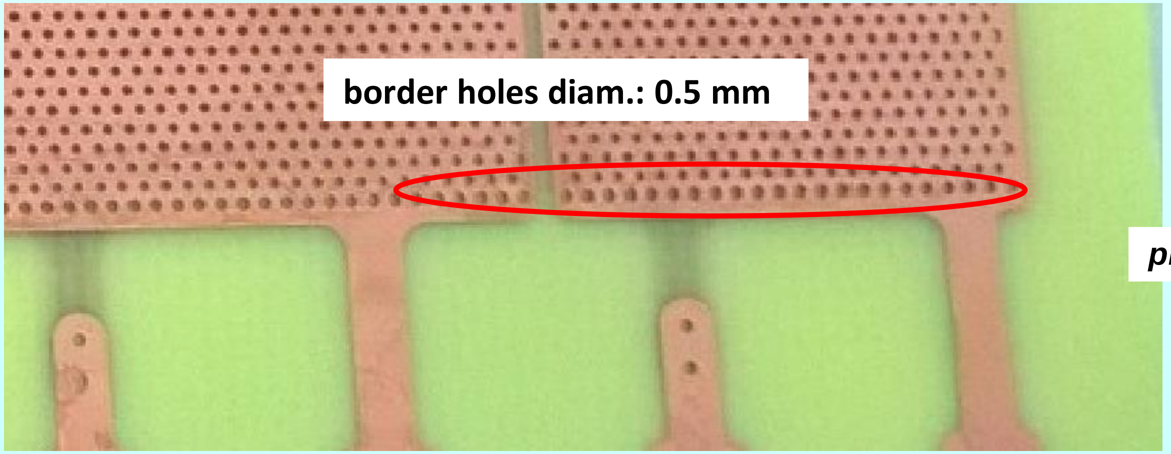
Thickness: 0.4 mm, hole diameter: 0.4 mm, pitch: 0.8 mm

12 sectors on both top and bottom, 0.7 mm separation

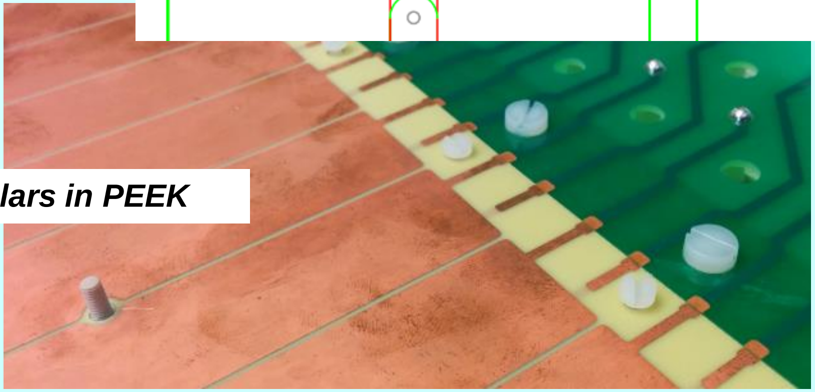
24 fixation points to guarantee THGEMs flatness







border holes diam.: 0.5 mm



pillars in PEEK

THGEM raw material selection

Our thickness uniformity requirements are stricter than those offered by producers → material selection

50 foils of 1245 mm x 1092 mm → cut out borders → 800 mm x 800 mm → thickness measurement

Elite Material Co., Ltd. Technical Data

http://www.emctw.com

Lead-free , Halogen-free Material

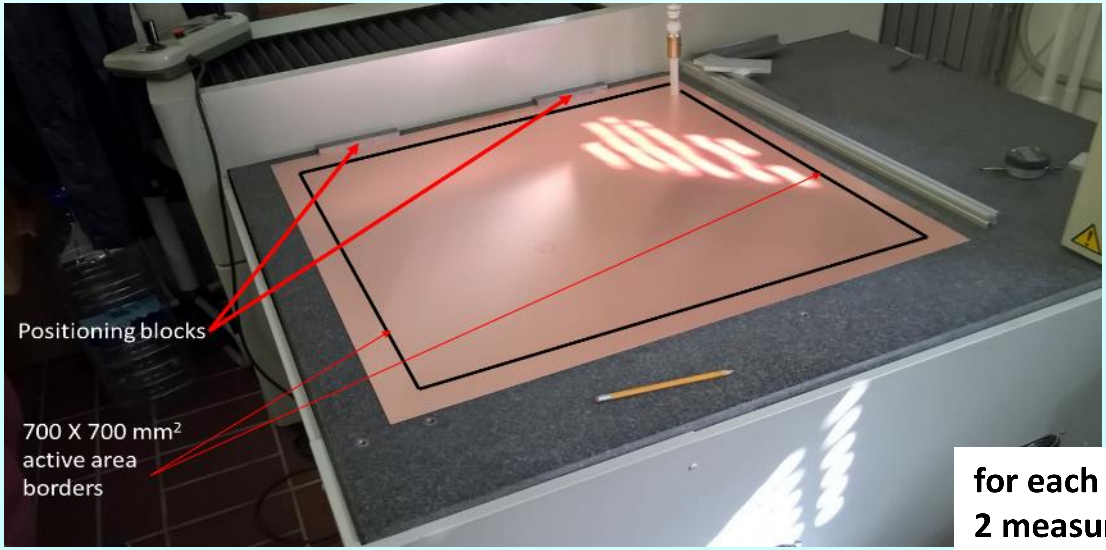
PRODUCT					EM 370-5
Thickness					0.407 mm
Copper					35μ / 35μ
Sheet Size					1 245 x 1 092 mm
Permittivity (RC 50%)	1 MHz	2.5.5.9	C-24/23/50	–	4.8
	1 GHz			–	4.3
Volume resistivity		2.5.17.1	C-96/35/90	MΩ-cm	$>10^{10}$
Surface resistivity		2.5.17.1	C-96/35/90	MΩ	$>10^{9}$



Mitutoyo EURO CA776

coordinate measuring machine with ruby touch probe,

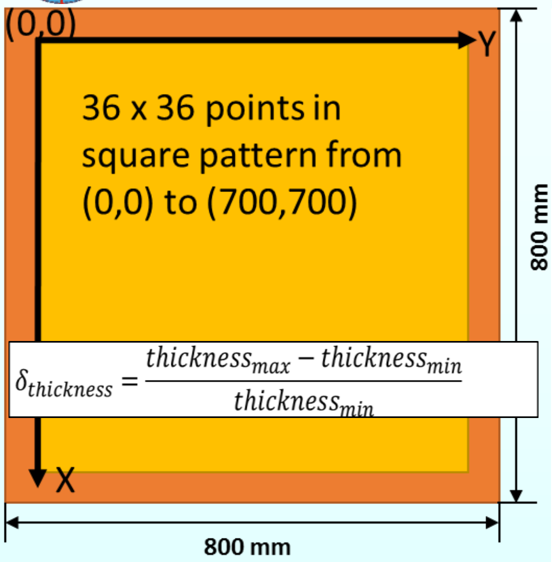
hosted in a thermalized room

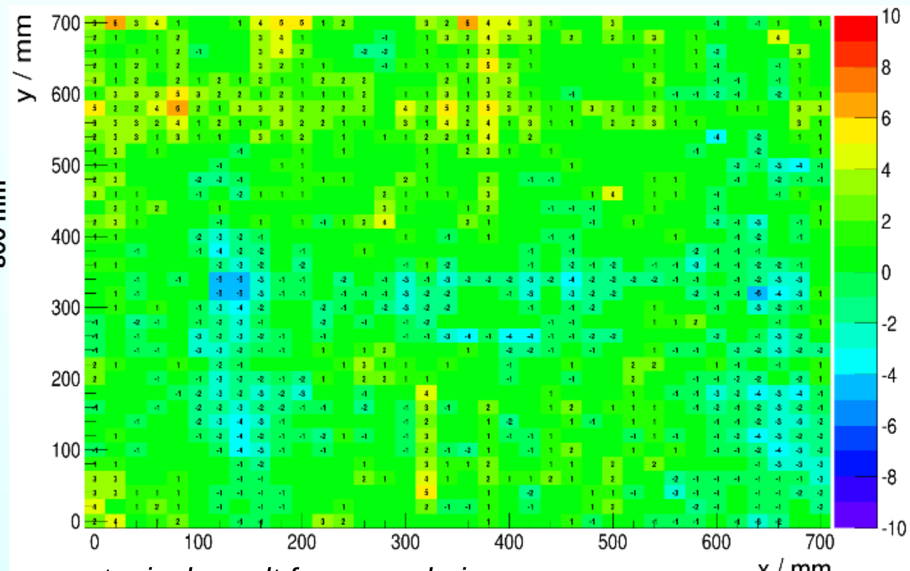



underpressure induced flatness

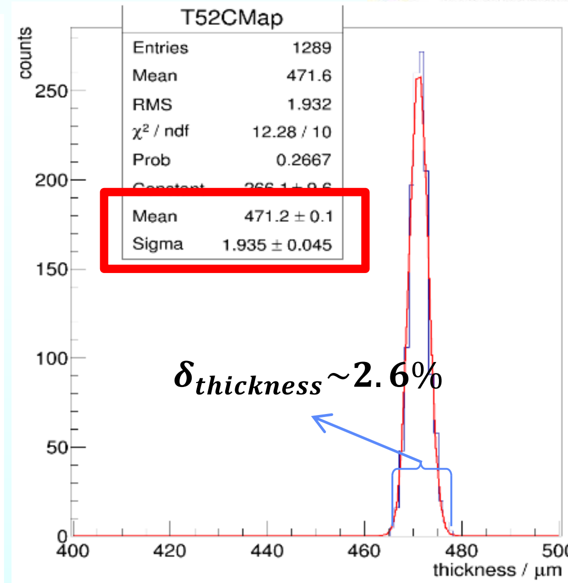
for each foil 36 x 36 points in square pattern are measured
2 measurements (direct and reversed) to allow consistency checks.

THGEM raw material selection

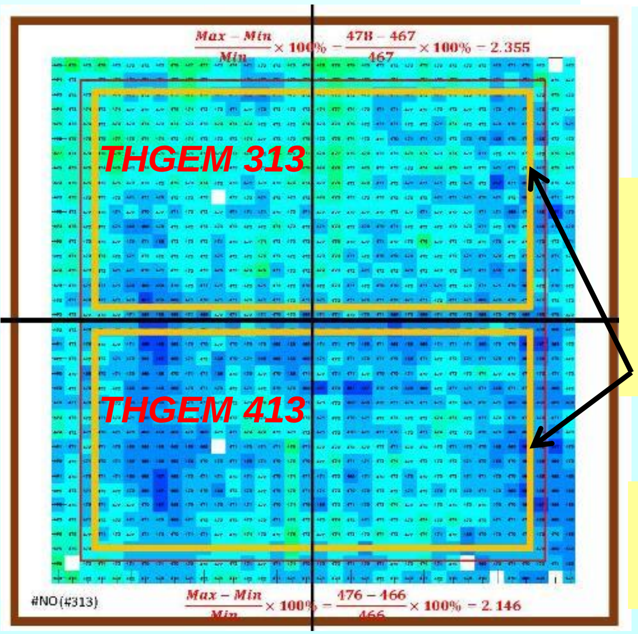




typical result for a good piece.



all foils have been labelled and measured → database of local thickness of all THGEMS



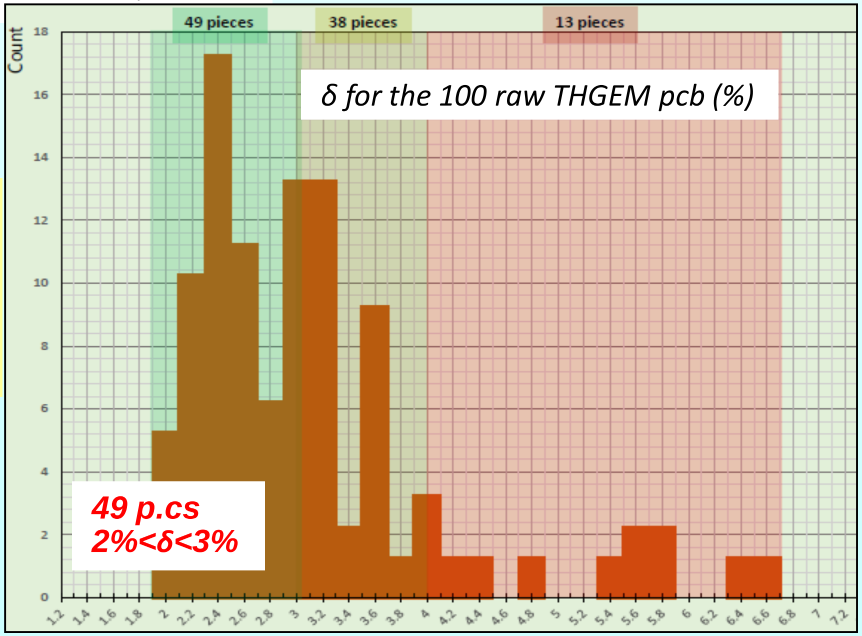
from each foil twoTHGEMS can be produced:

50 foils → 100 raw THGEM pcb

THGEM pcb size = 620 mm x 320 mm,

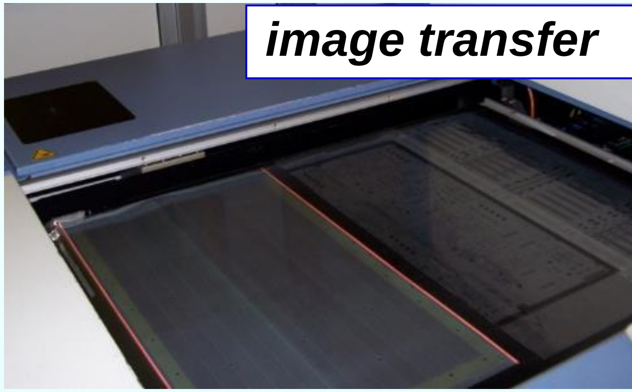
active area = 581 mm x 287 mm

60 THGEMs have been produced by ELTOS



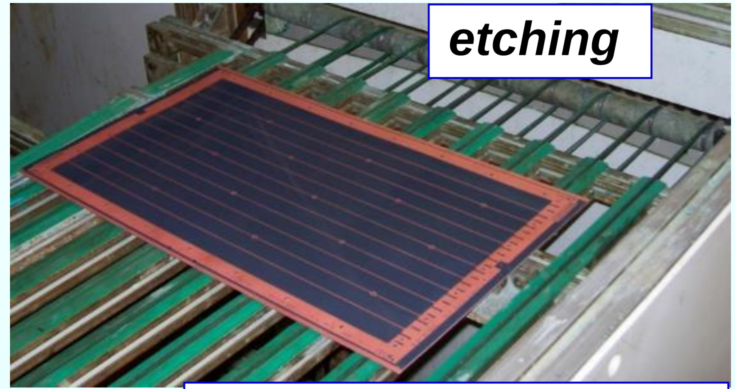
Production of the THGEMs at ELTOS

image transfer

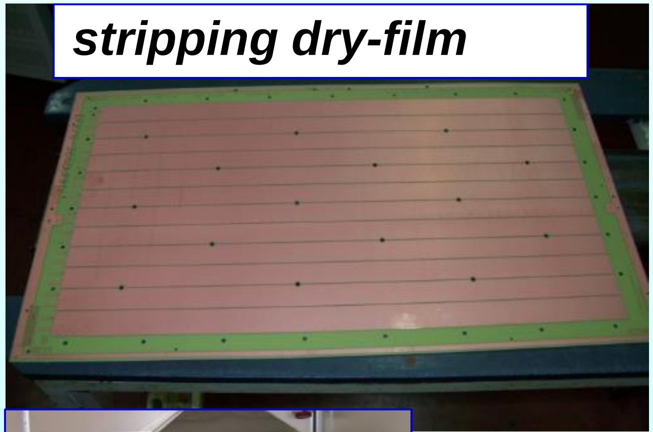


development

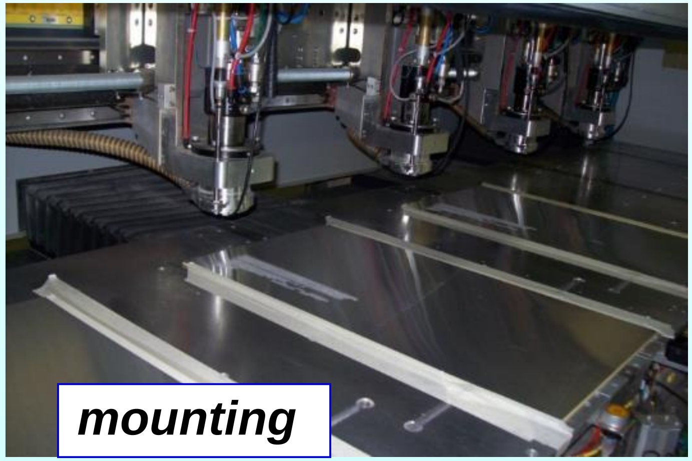
etching



stripping dry-film

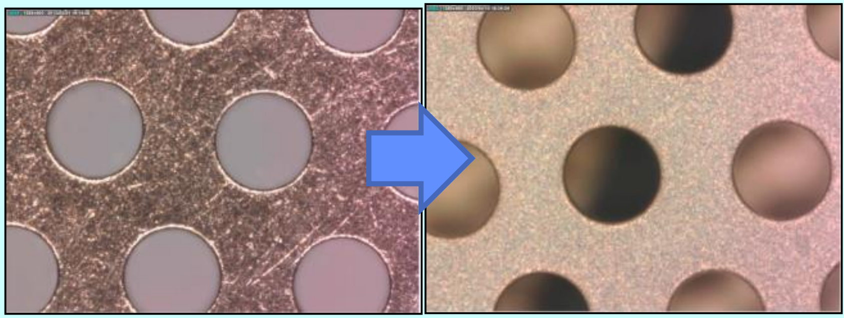


mounting



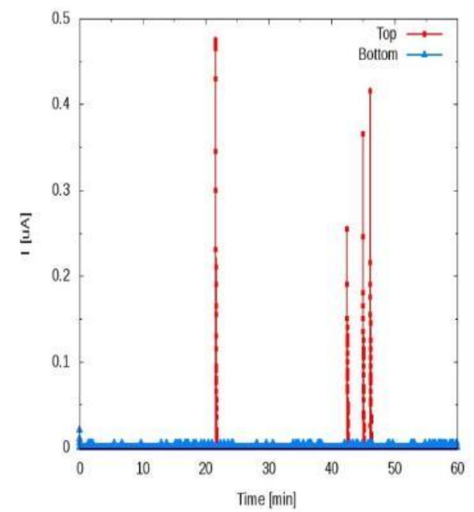
multi-spindle drilling

In Trieste a specific cleaning procedure is applied : polish with fine grain pumice powder, pressure water cleaning, ultrasonic Bath with Sonica PCB solution (PH11), distilled water rinsing and oven @ 160 ºC



THGEM quality assessment

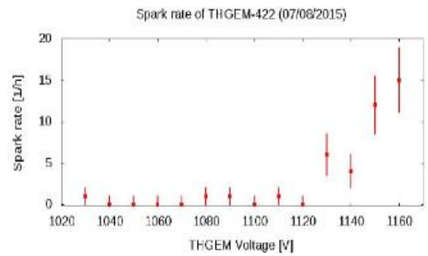
current monitor recording, discharge counting



THGEM : 422
- dV=1000V : 4 hours : 0 sparks/h
- dV=1150V : 6 hours : 70 sparks/h

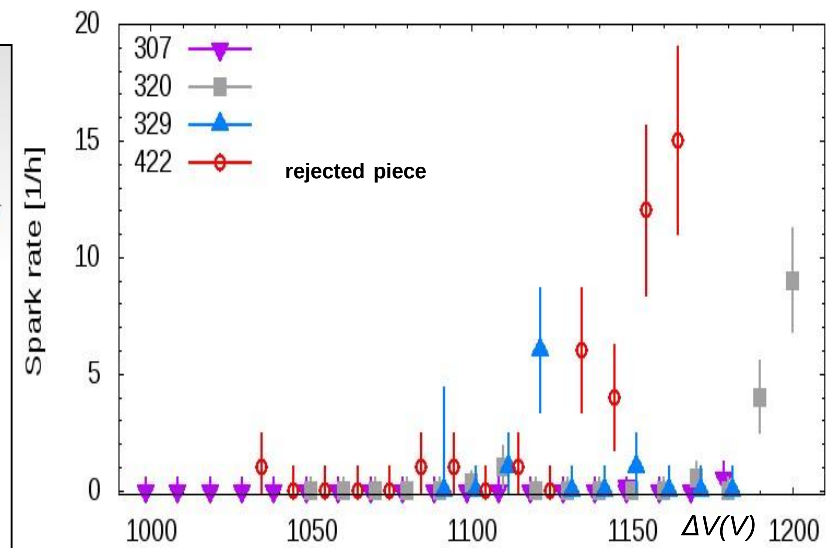
rejected

- dV=1030V .. 1160V / 10V steps , 1 hour for all dV



THGEM : 307
- dV=1100V : 74 hours : 0.27 sparks/h
- dV=1150V : 14 hours : 0.29 sparks/h

accepted

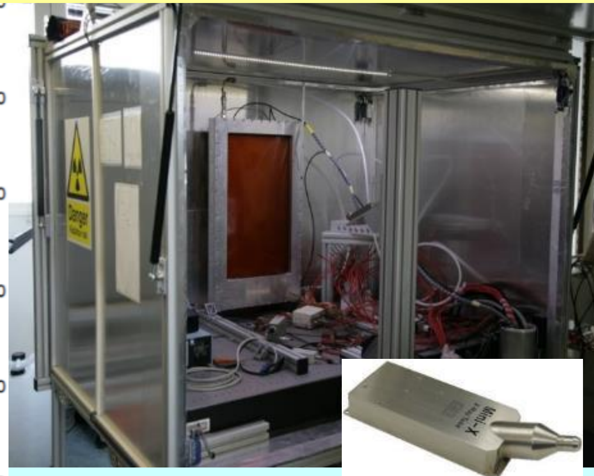


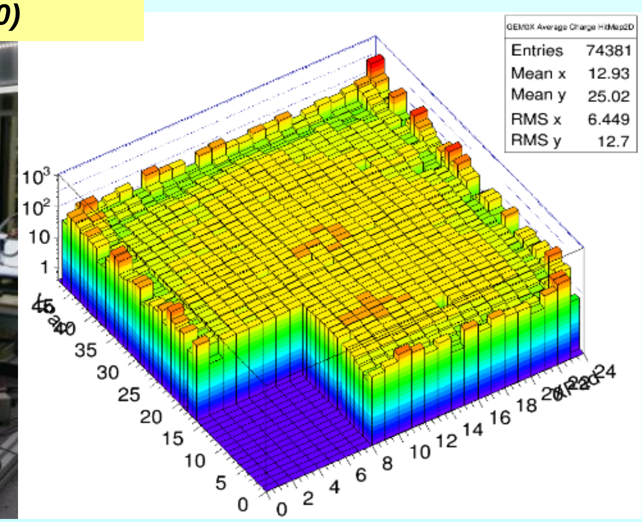
first 4 pieces: 1 rejected. Possibly recovered by repeating the cleaning treatment

Gain uniformity measurement

188	202	185	198	206	207
196	207	196	198	199	207
192		193	198	204	204
192		188	199	202	205
199	199	191	195	195	
199	196	199	205	195	199
192	190	194	197	195	194
198	190	195	209	195	199
198	199	195	208	197	201
198	199	195	199	200	199
190	186	185	199	190	199

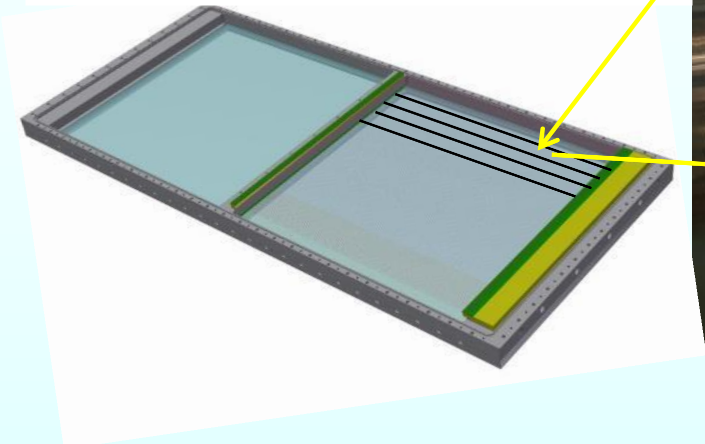
AMPTEK Mini-X Au used at 15 kV, 200μA + Cu foil provides 8 keV X-rays uniform illumination at a rate > 5 kHz cm^{-2} (for 1 cm Ar/CO_2 70/30)

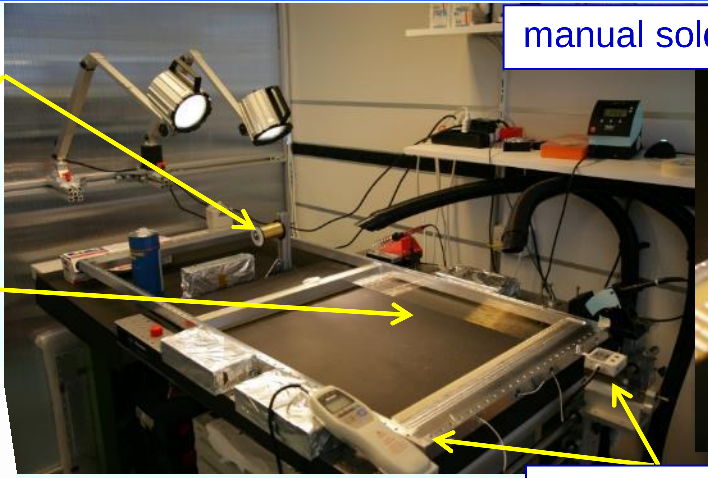


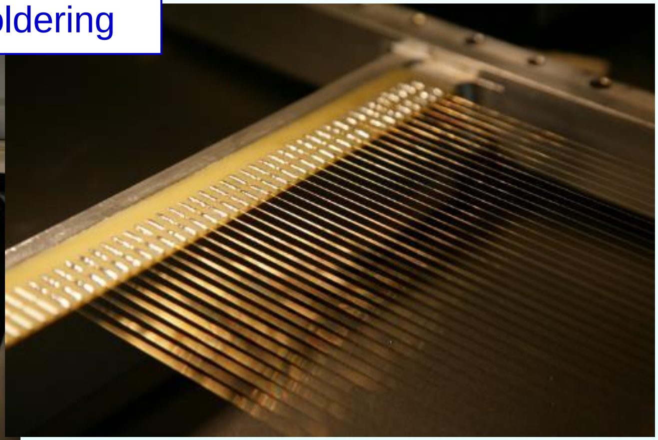


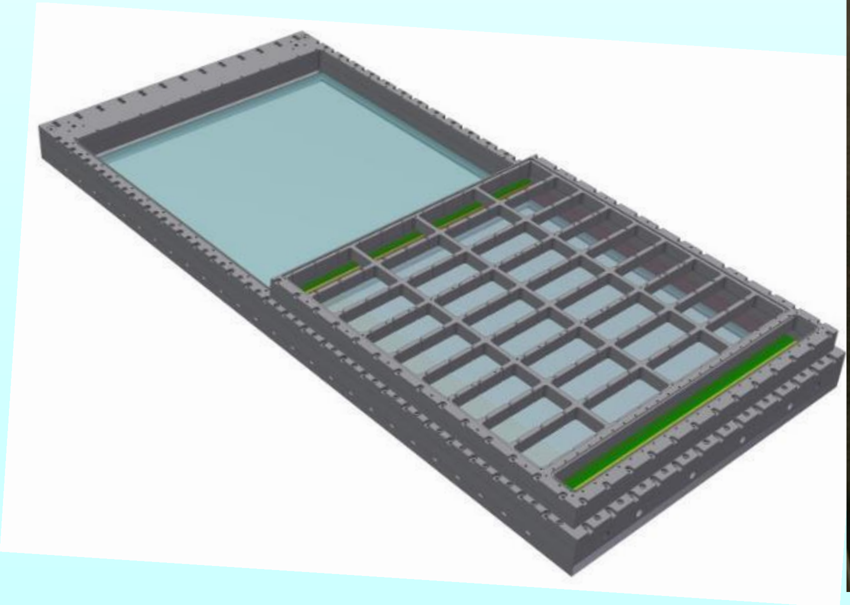
mechanical frames and wires

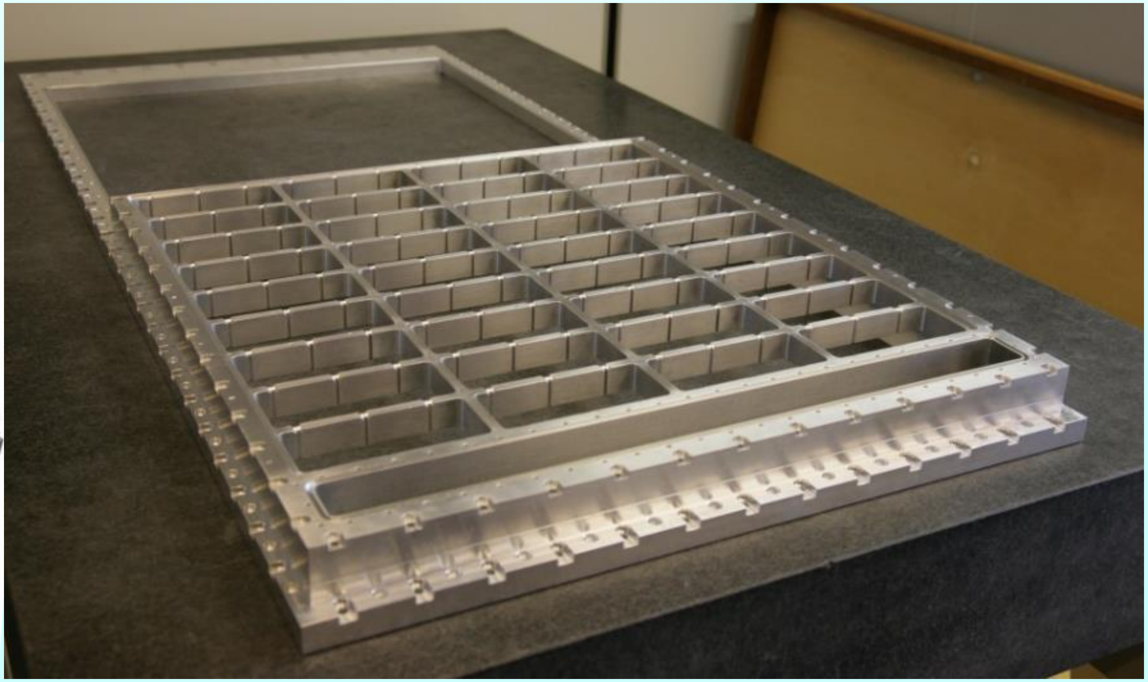
drift and field wires: Cu-Be, Au coated
4 mm pitch, 100 µm diam.





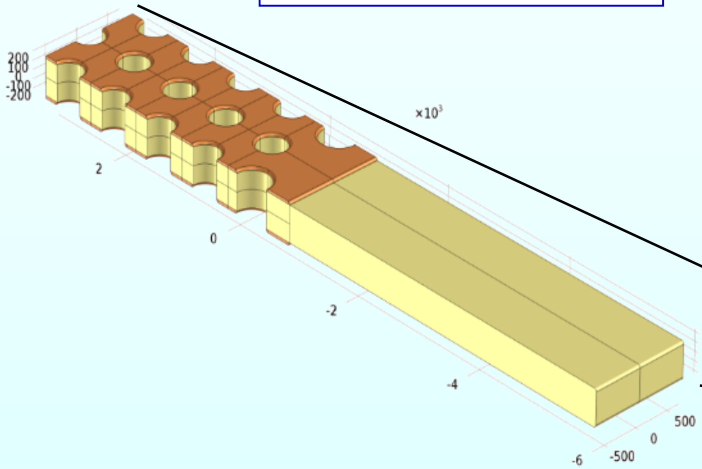


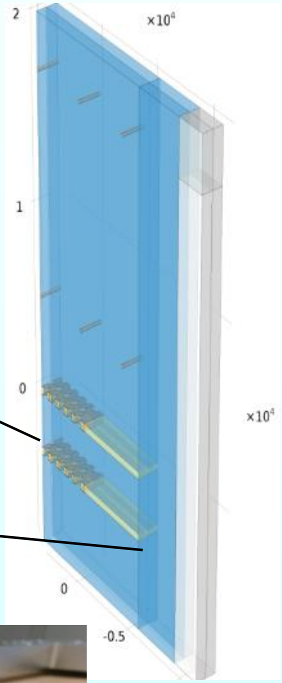


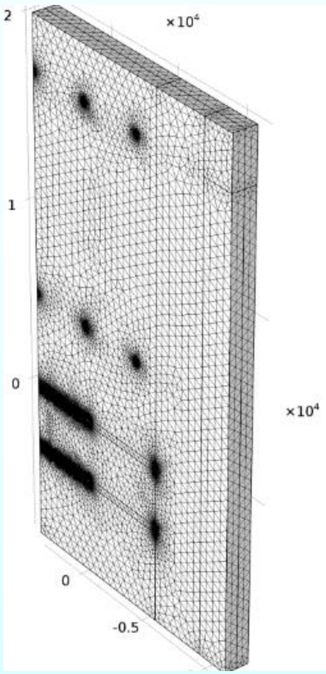


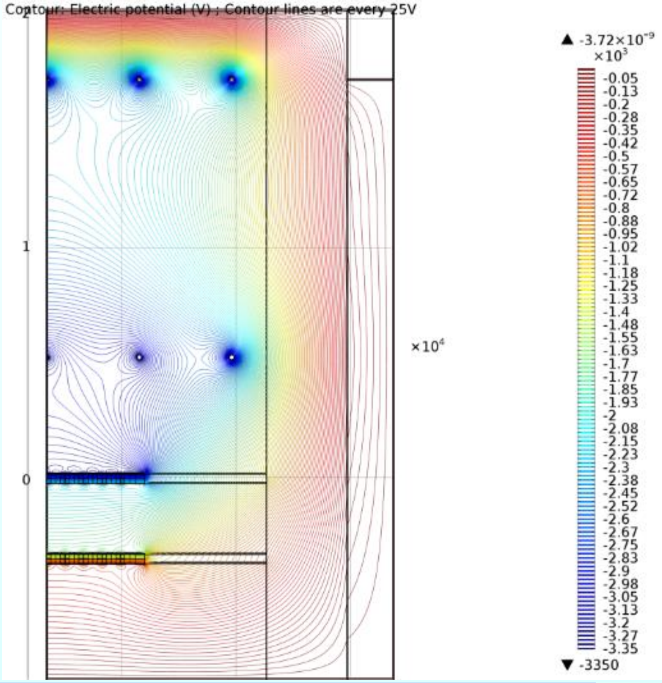
field shaping electrodes

THGEM border study

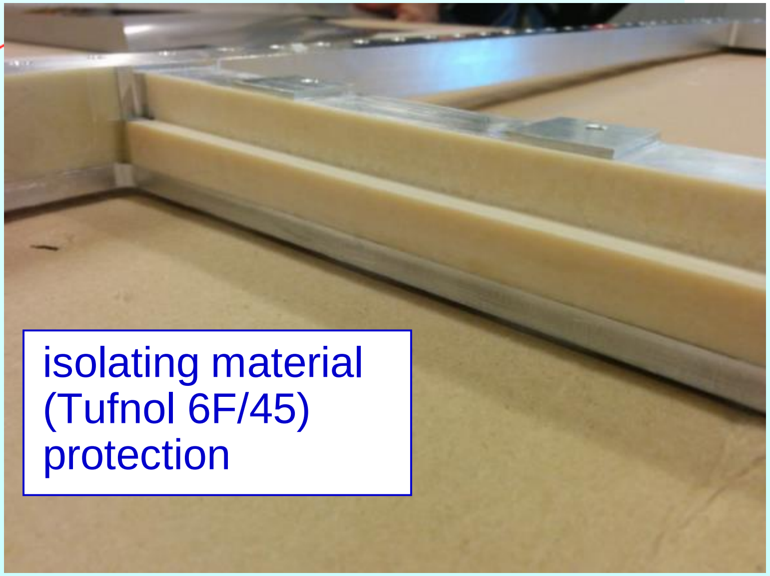








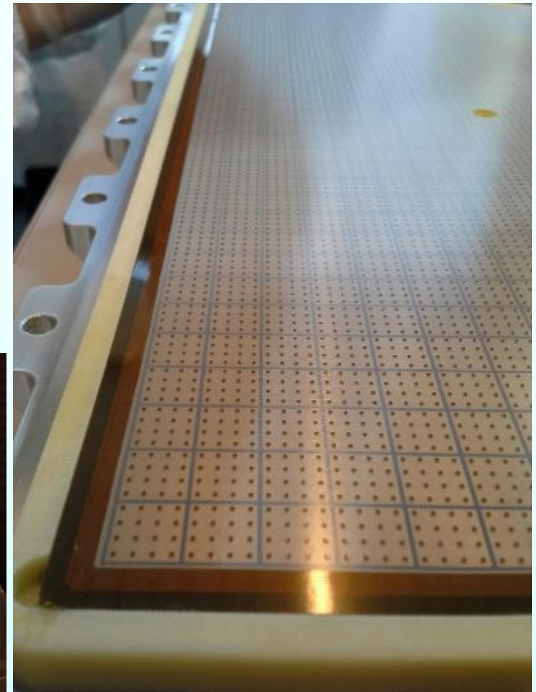
large field values at the chamber edges and on the guard wires

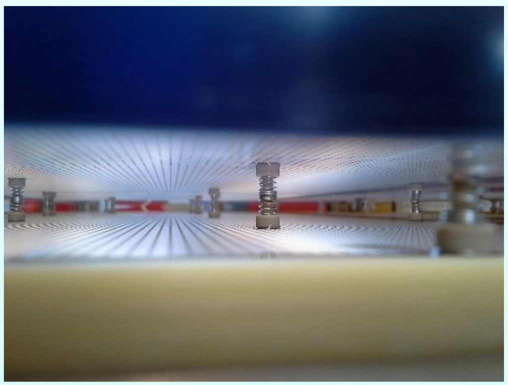


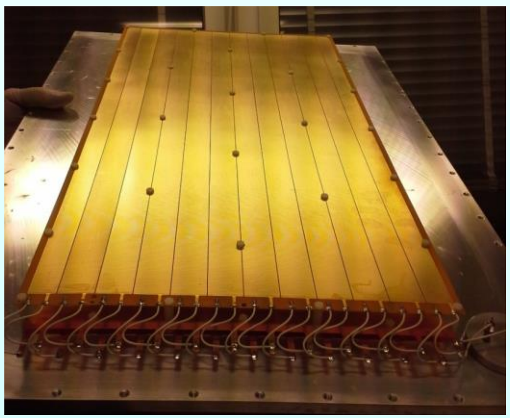
isolating material (Tufnol 6F/45) protection

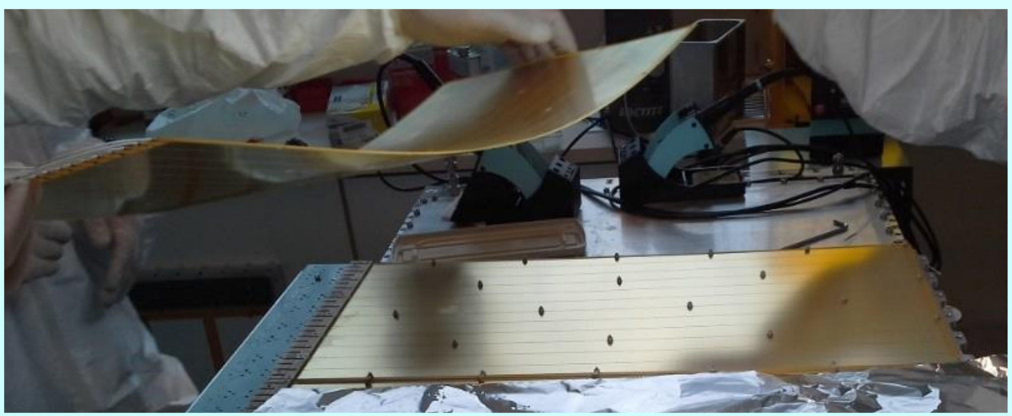
Field shaping electrodes in the isolating material protections of the chamber frames

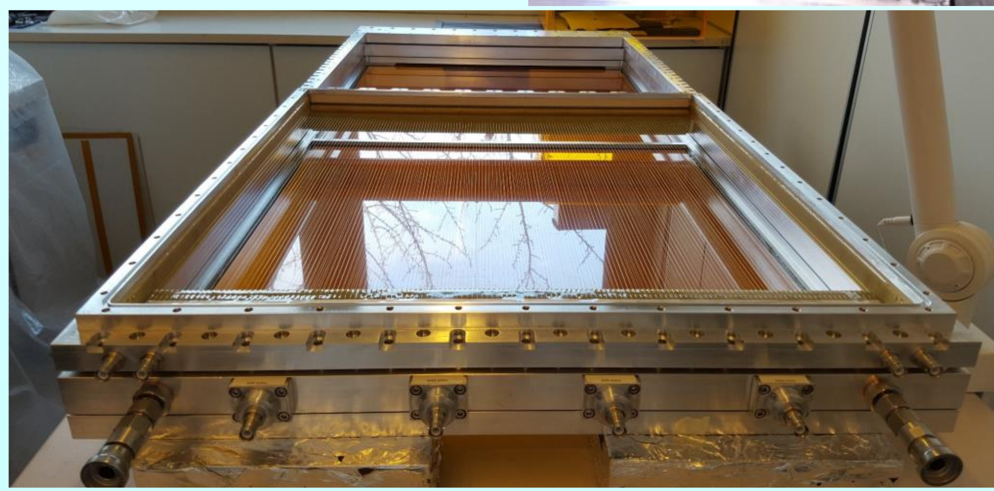
assembling



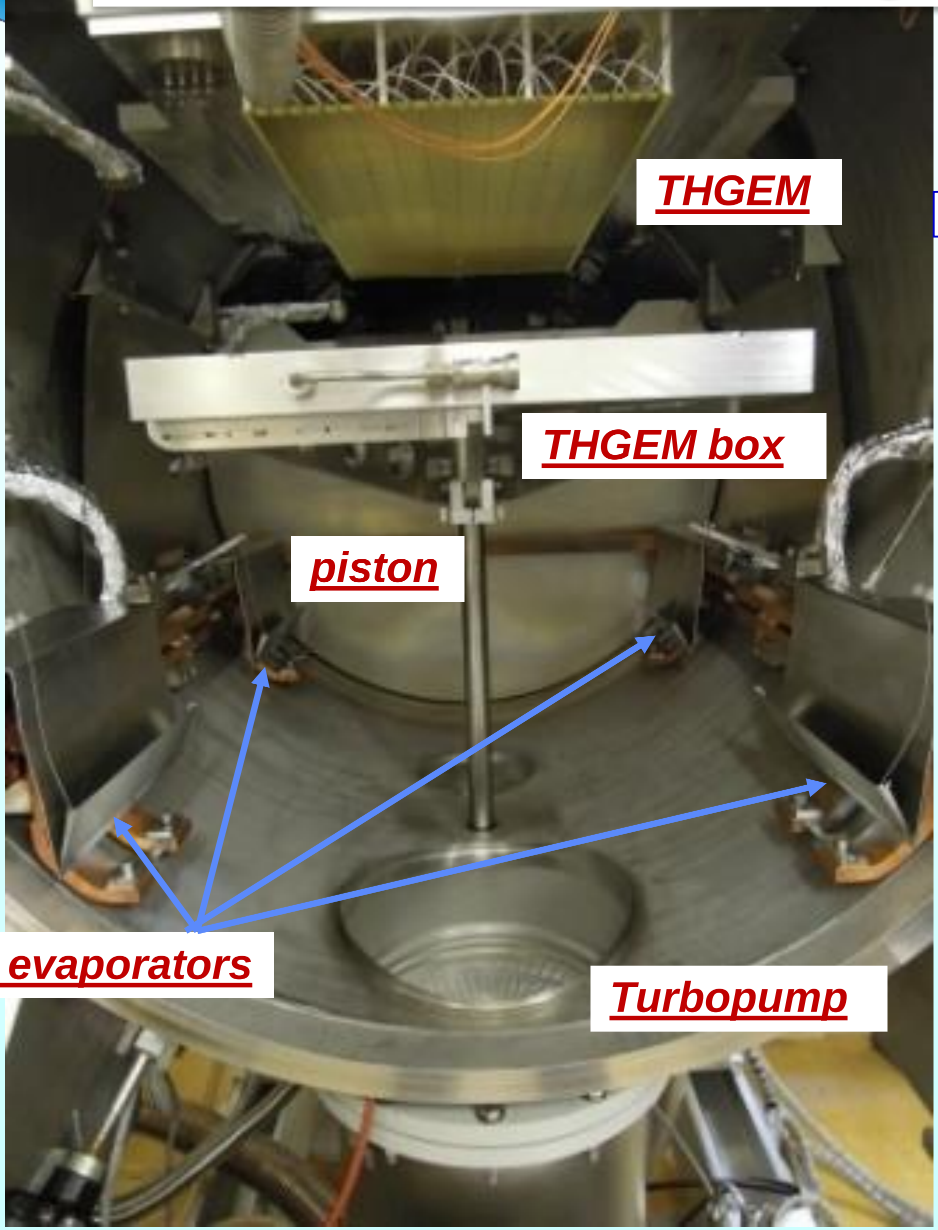








CsI coating of THGEMs

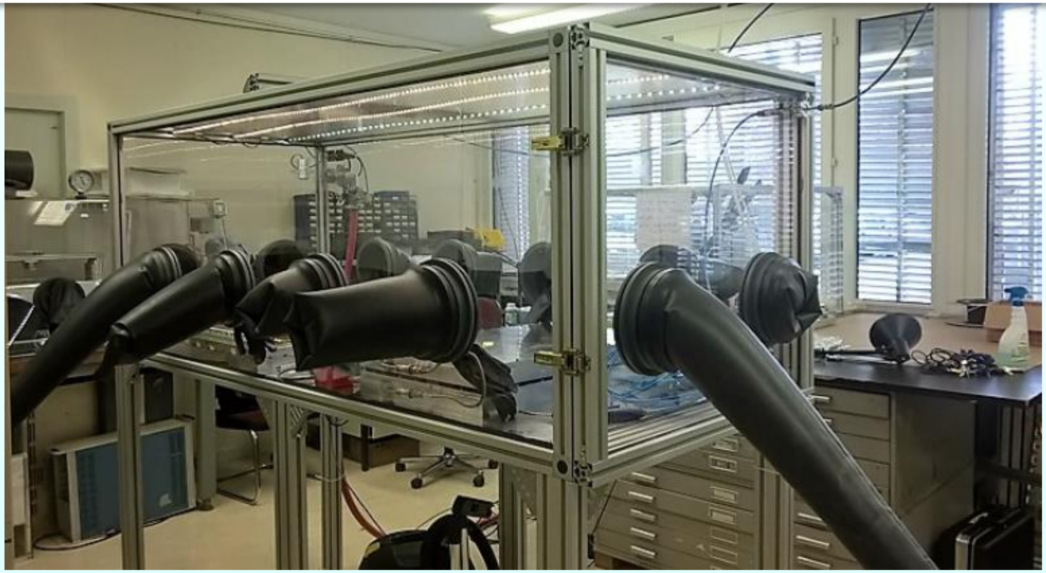


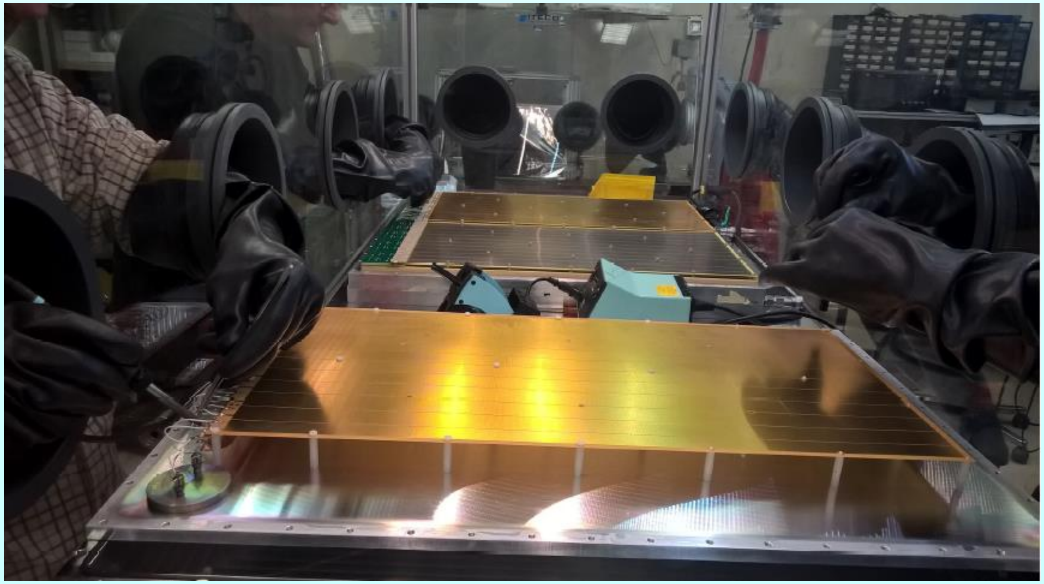
19 CsI evaporations performed in 2015 - 2016 on 15 pieces: 11 coated THGEMs available, 8 used + 3 spares

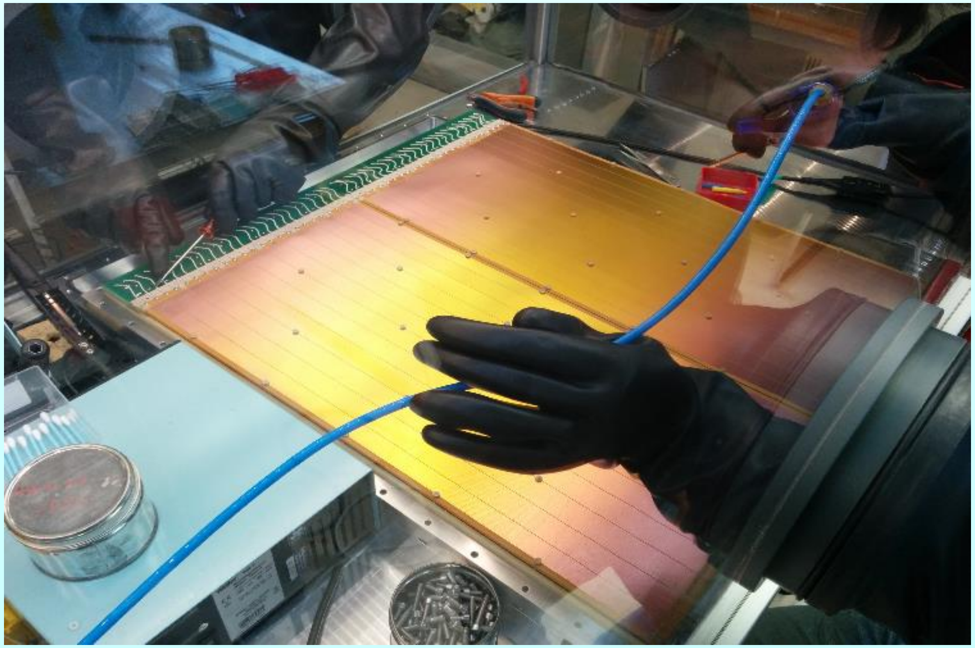
THGEM number	evaporation date	at 60 deg.	at 25 deg.
Thick GEM 319	1/18/2016	2.36	2.44
Thick GEM 307	1/25/2016	2.65	2.47
Thick GEM 407	2/2/2016	2.14	2.47
Thick GEM 418	2/8/2016	2.79	2.98
Thick GEM 410	2/15/2016	2.86	3.14
Thick GEM 429	2/22/2016	2.75	2.74
Thick GEM 334	2/29/2016	2.77	3.00
Thick GEM 421 re-coating	3/10/2016	2.61	2.83
Reference piece	7/4/2016	3.98	3.76

QE measurements indicate an average THGEM QE = 0.73 x Ref. piece QE, in agreement with expectations (THGEM optical transp. = 0.76)

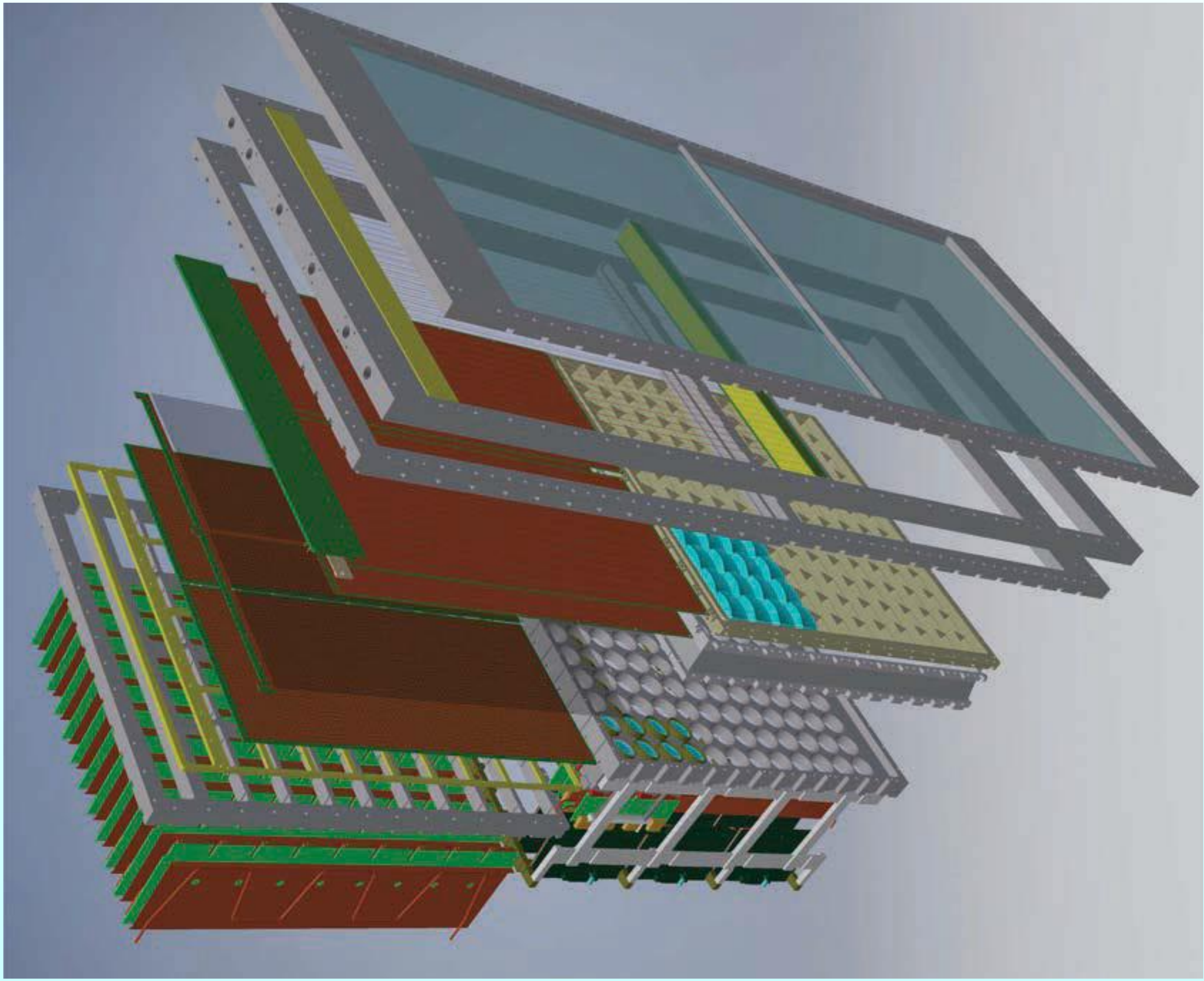
CsI THGEM mounting



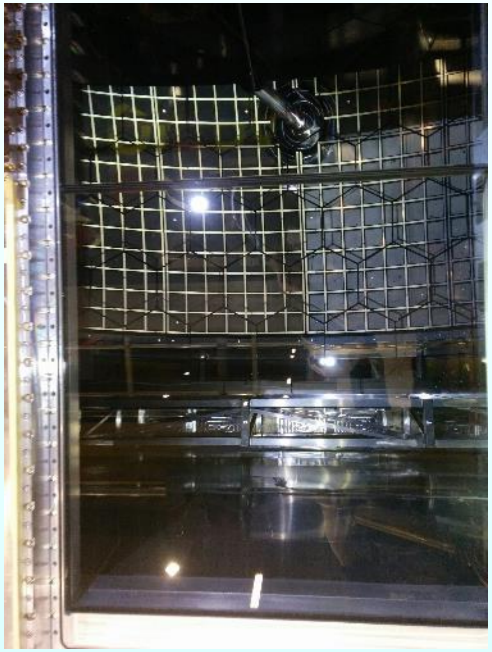




The new COMPASS PDs



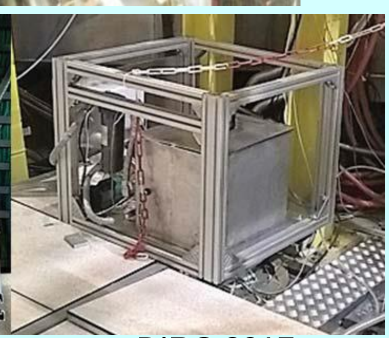
Installation of hybrids on RICH_1

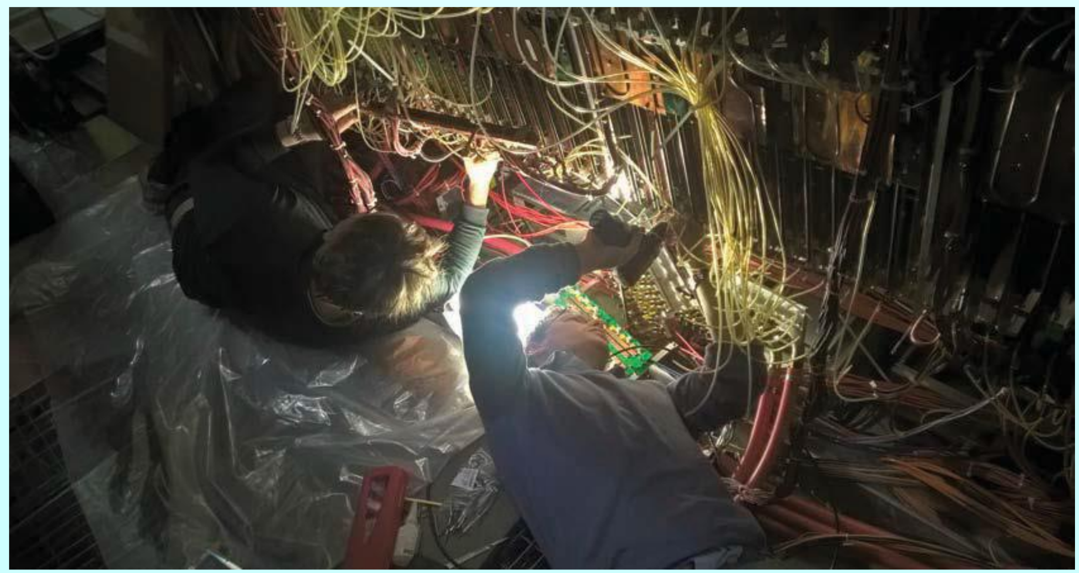




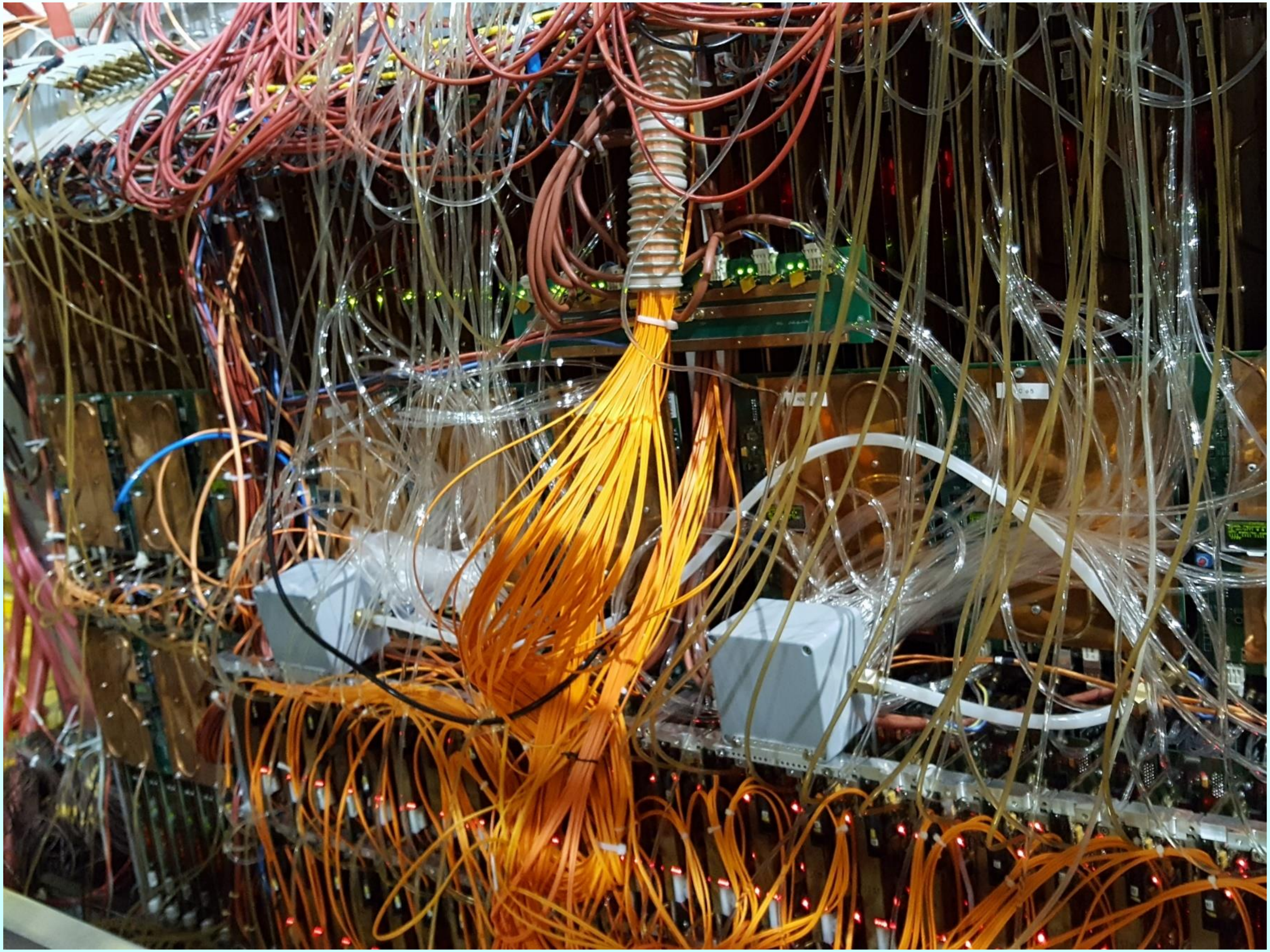


Equipping the hybrids on RICH_1



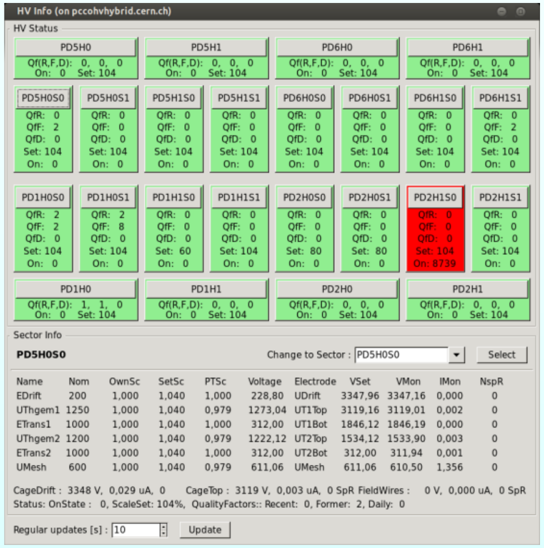


The PD readout and services

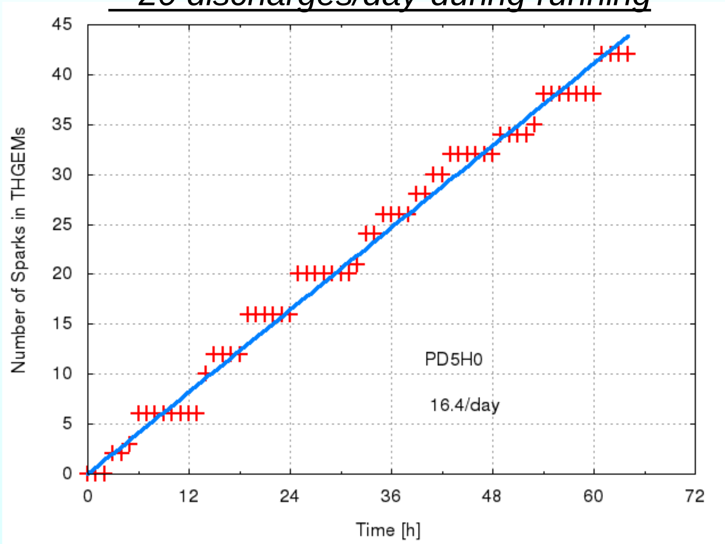


Commissioning and 2016 COMPASS run

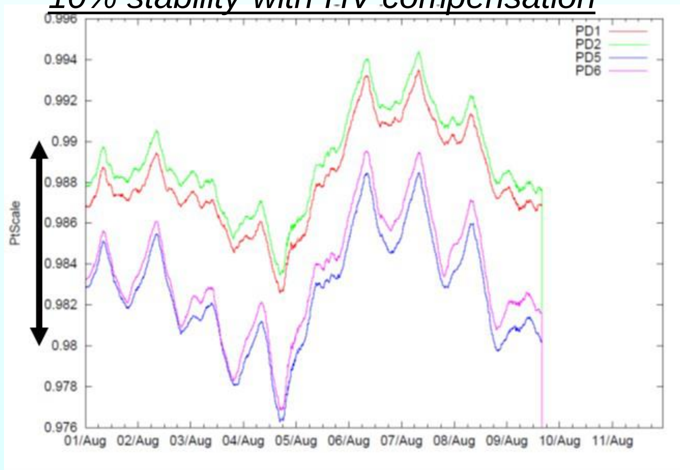
HV monitor and control system

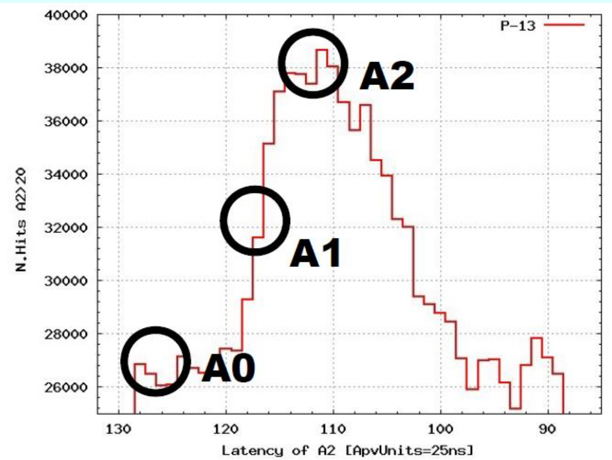


~ 20 discharges/day during running

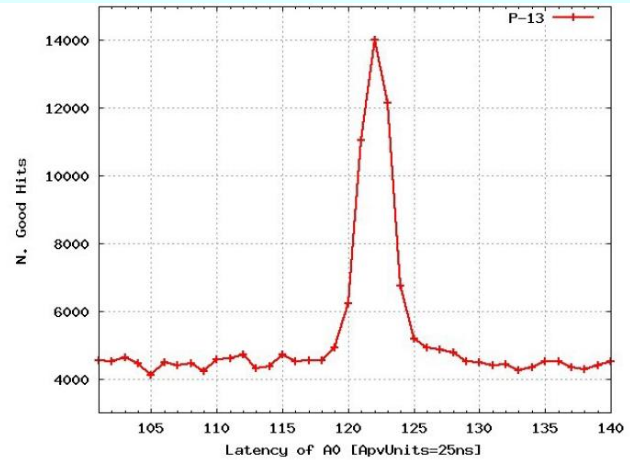


1% p,T variation → ~ 40 % gain variation without HV compensation, → 10% stability with HV compensation





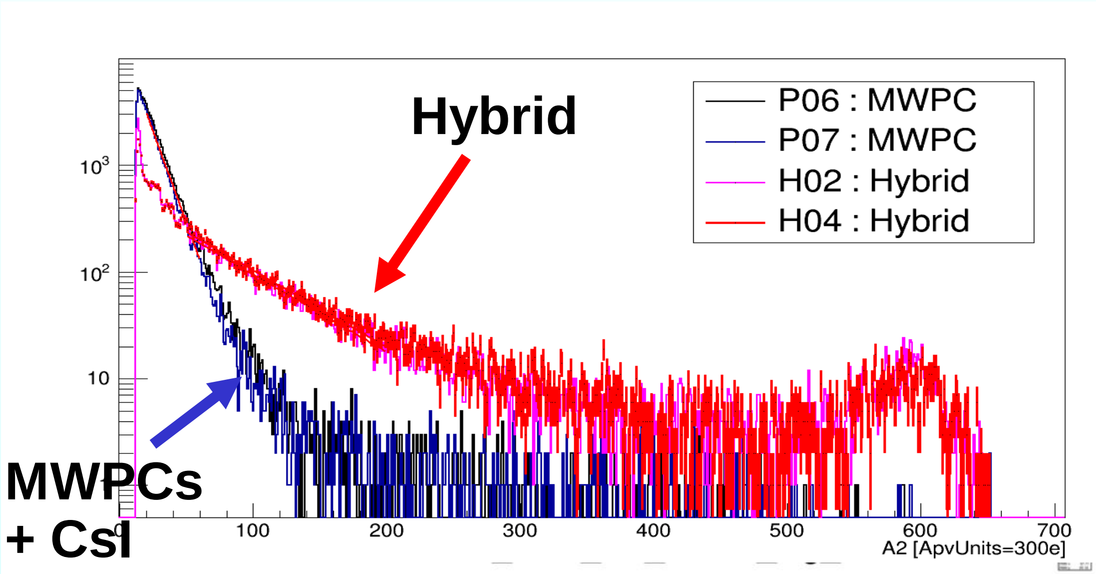
APV25 samples the signal waveform



Cherenkov signals are clearly seen

- **1.4 m^2 of hybrid PDs operated**
- **Stable data taking conditions**
- **Effective suppression of signals from charged particles**
- **Ion Back-Flow < 3%**
- **More Cherenkov photons seen with respect to MWPCs + CsI**

Running at gain of ~30k

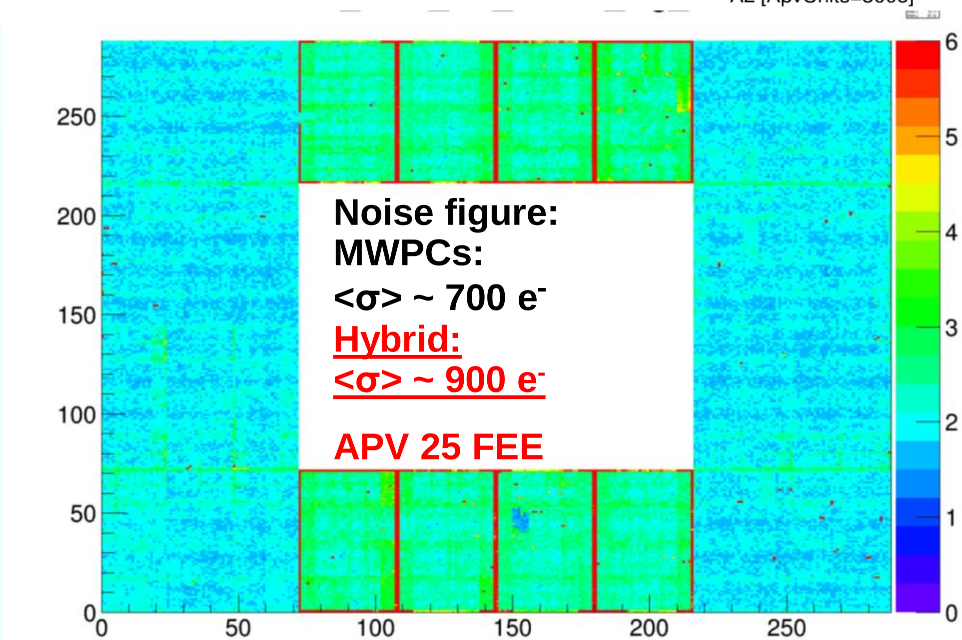


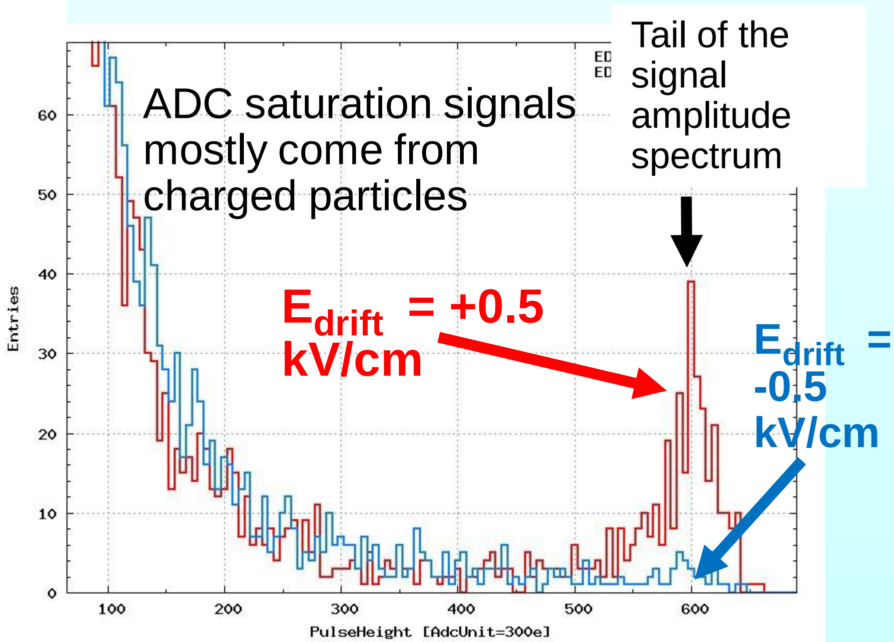
Nominal gain: ~30000 with:

THGEM1 gain* transfer1: ~ 20

THGEM2 gain*transfer2 ~ 15

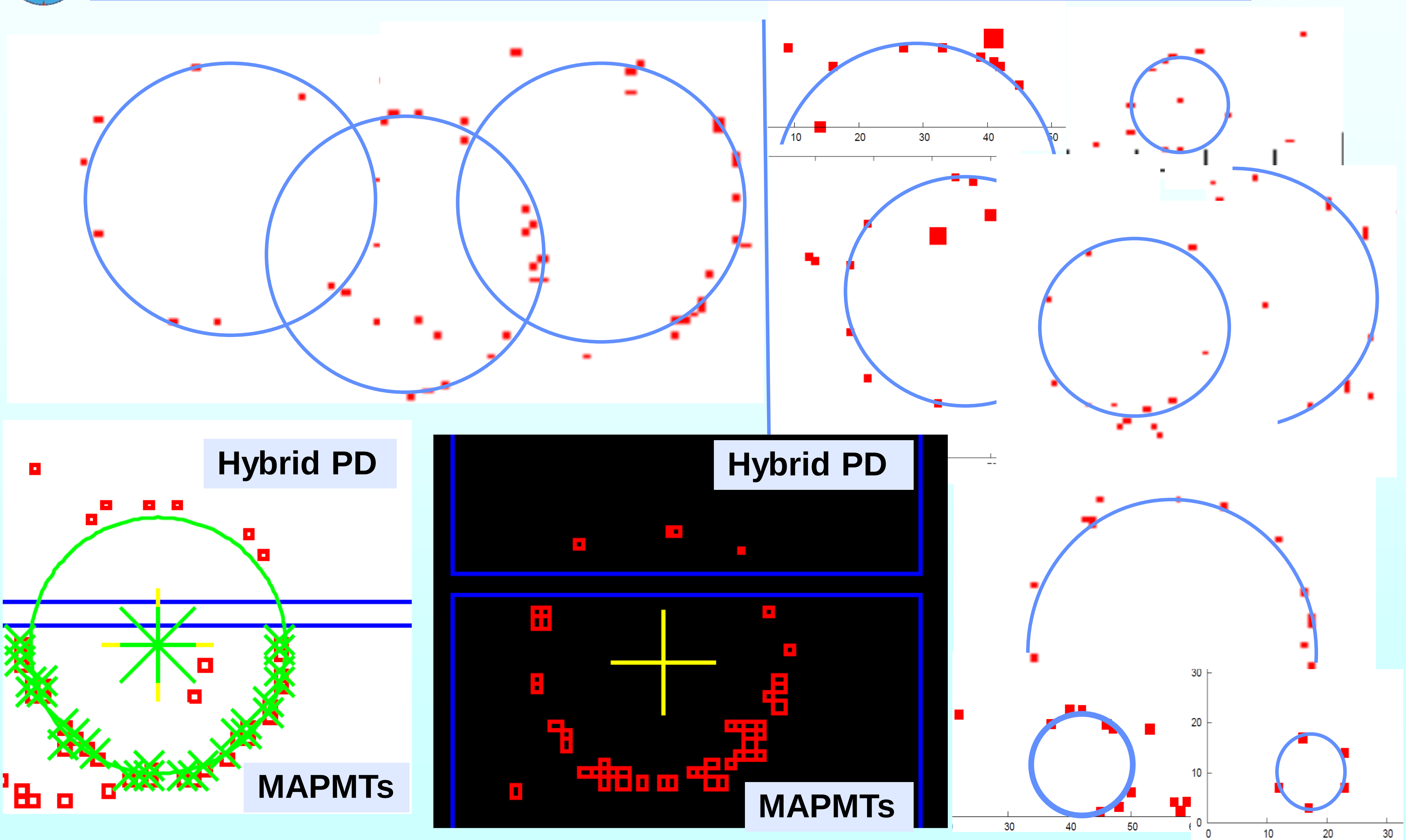
Micromegas gain ~100



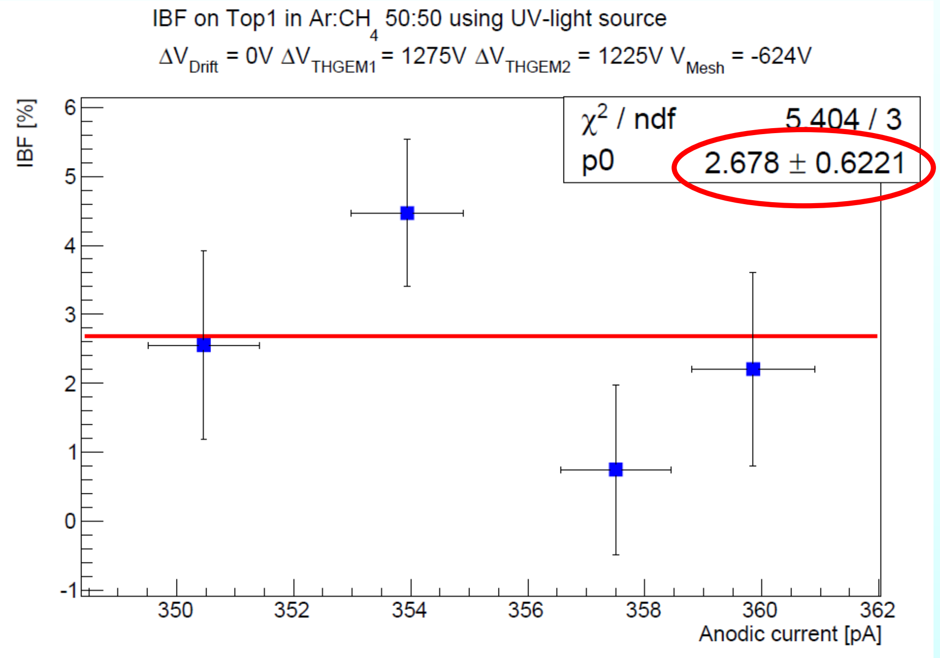


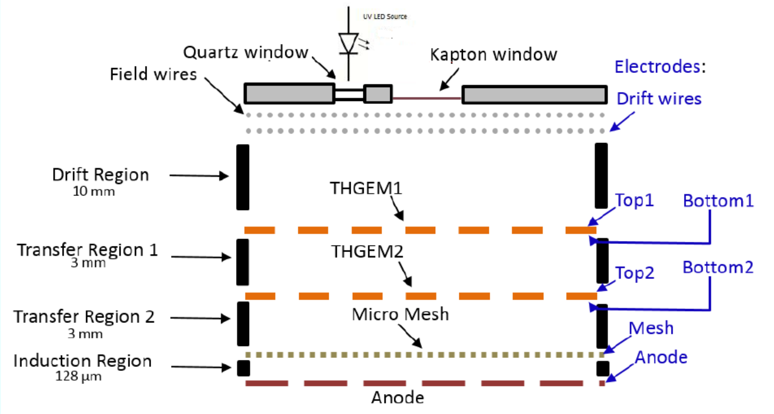
Efficient suppression of charged particle signals

RINGS



IBF to photocathode (meas. in lab.)





Trieste home-built picoammeters

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

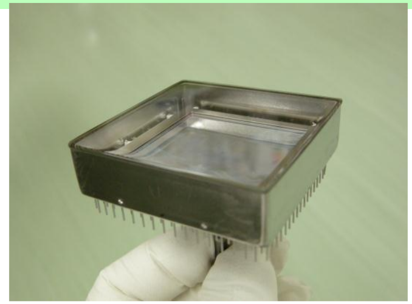
GASEOUS DETECTORS FOR VISIBLE LIGHT

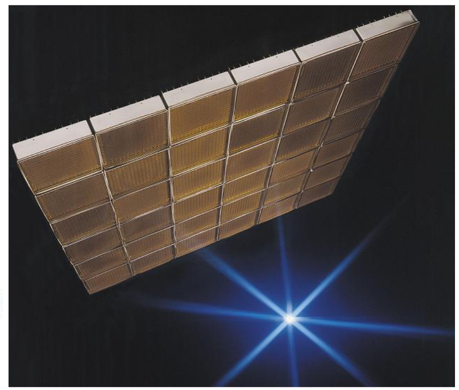
Gaseous PMT

Yamagata U. TMU, HAMAMATSU

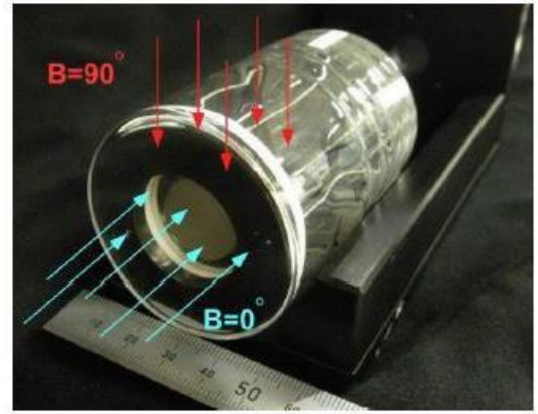
Sensor type	Sensitivity	Position Resolution	Timing Resolution	Uniformity	Price	Magnetic Field	Effective Area
Vacuum PMT	◎	△	◎	△	○	△	○
CCD / CMOS	△	◎	×	◎	△	◎	×
Gaseous PMT	○	○	○	○	◎	◎	◎

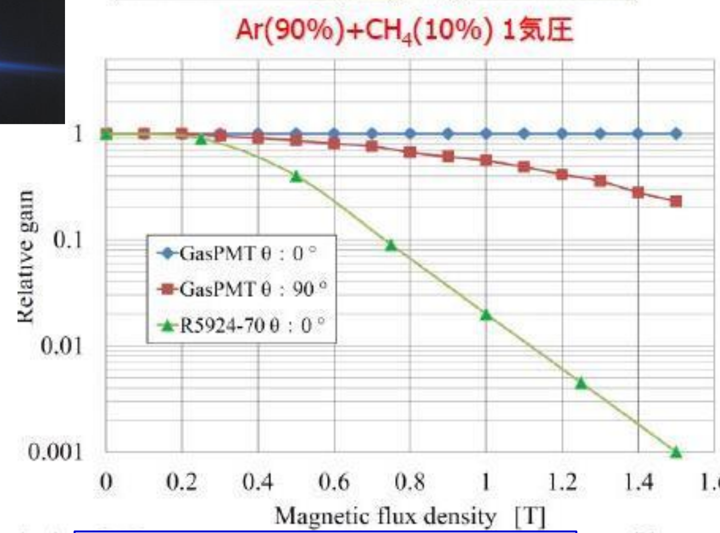
- The advantage of the **gaseous PMT**:
  - ✓It can achieve a **very large effective area** with moderate **position** and **timing** resolutions.
  - ✓It can be easily operated under a **very high magnetic field**.



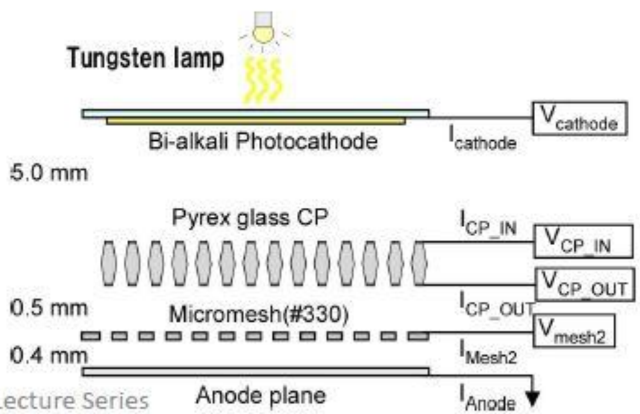


Operation in magnetic field environmen

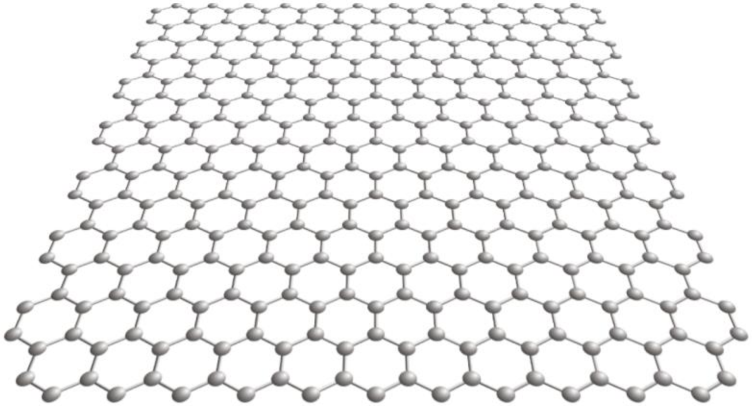




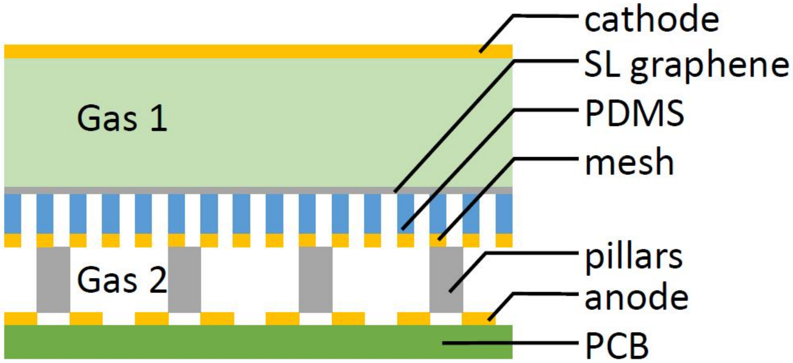
H. Sugiyama et al., NIMA (2016)

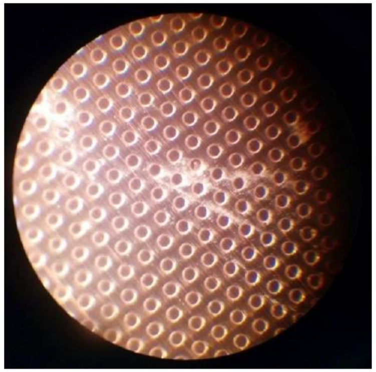


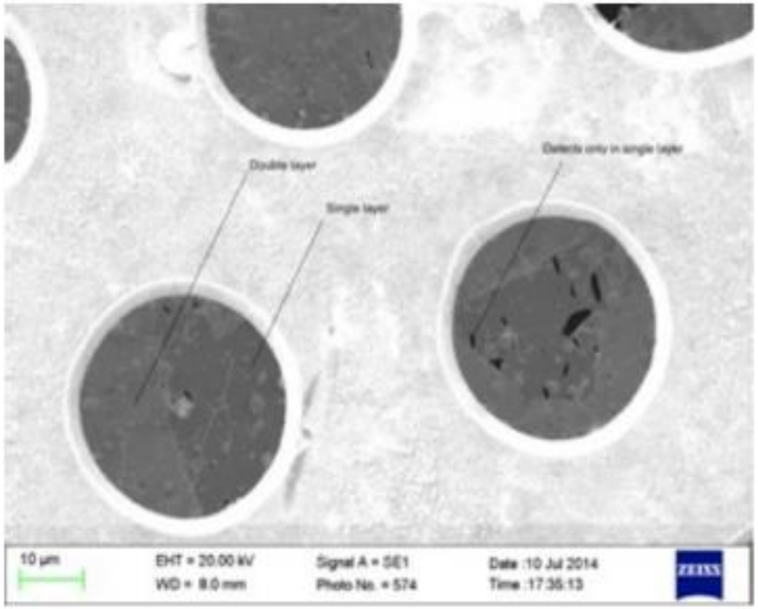
GRAPHENE



- *Single layer of C atoms in hexagonal lattice*
- *Thinnest possible conductive mesh with 0.6 Å pores*
- *Very good ion blocking*
- *Charge transfer properties through graphene layers have been measured*





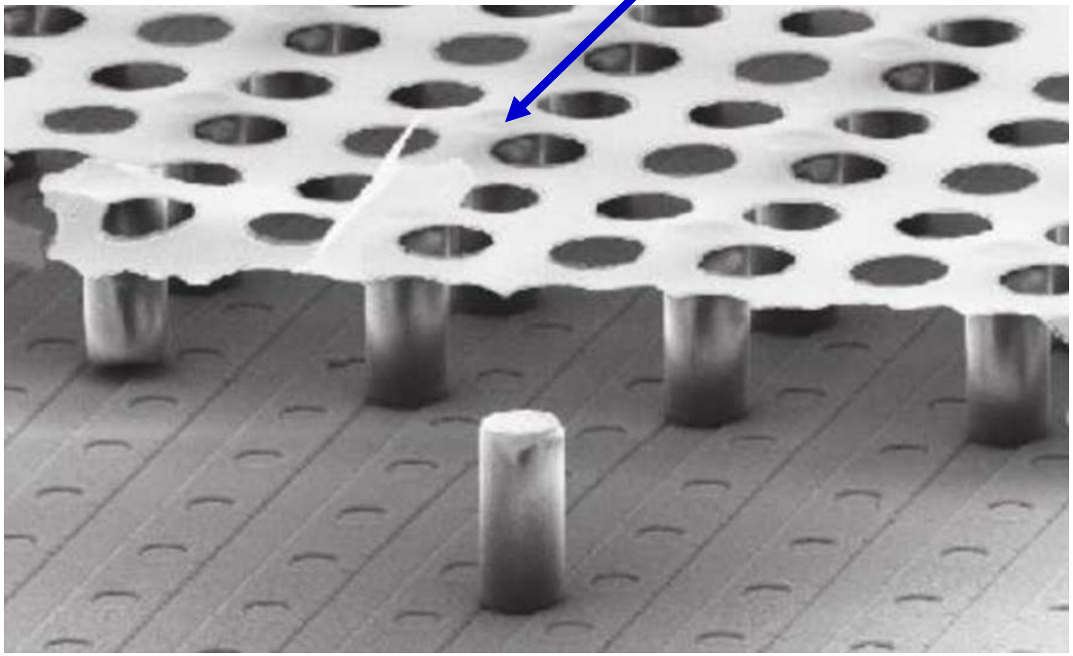


P. Thuiner[1,2], R. Hall-Wilton[3], R. B. Jackman[4], H. Müller[1], T. T. Nguyen[4], R. de Oliveira[1], E. Oliveri[1], D. Pfeiffer[1,3], F. Resnati[1], L. Ropelewski[1], J. A. Smith[4], M. van Stenis[1], R. Veenhof[5]

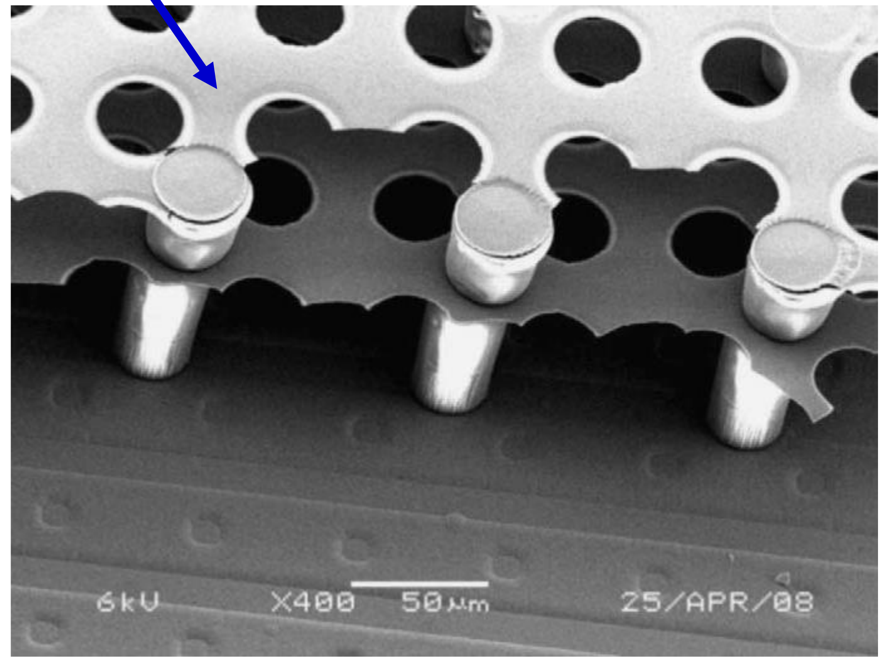
[1]CERN, [2]Technische Universität Wien, [3]ESS, [4]University College London, [5]Uludağ University

Promising new idea

InGrid and TwinGrid



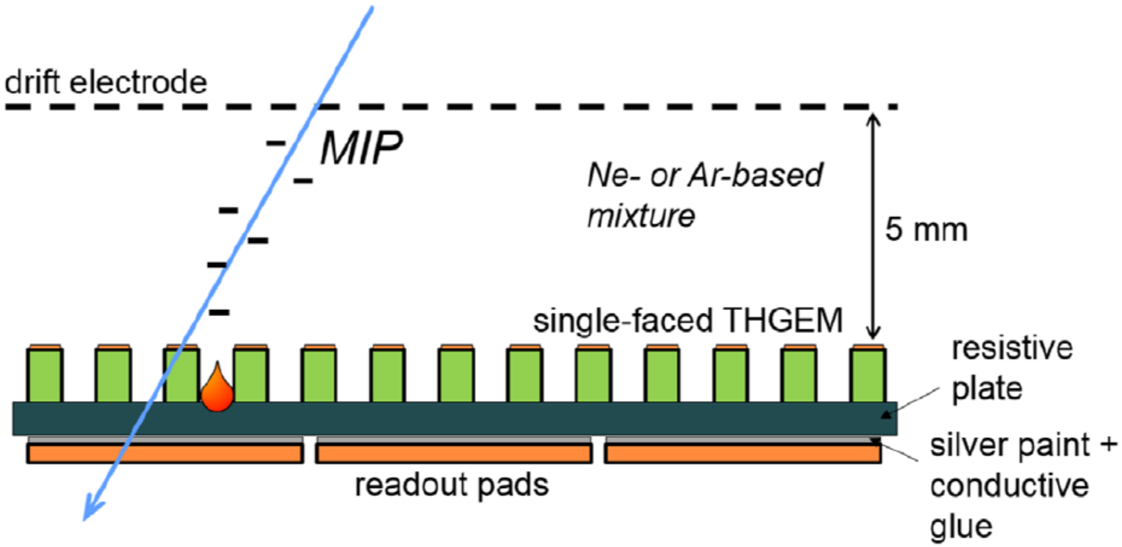
M.Chefdeville et al., Nucl. Instrum. Meth. A 556 (2006) 490.

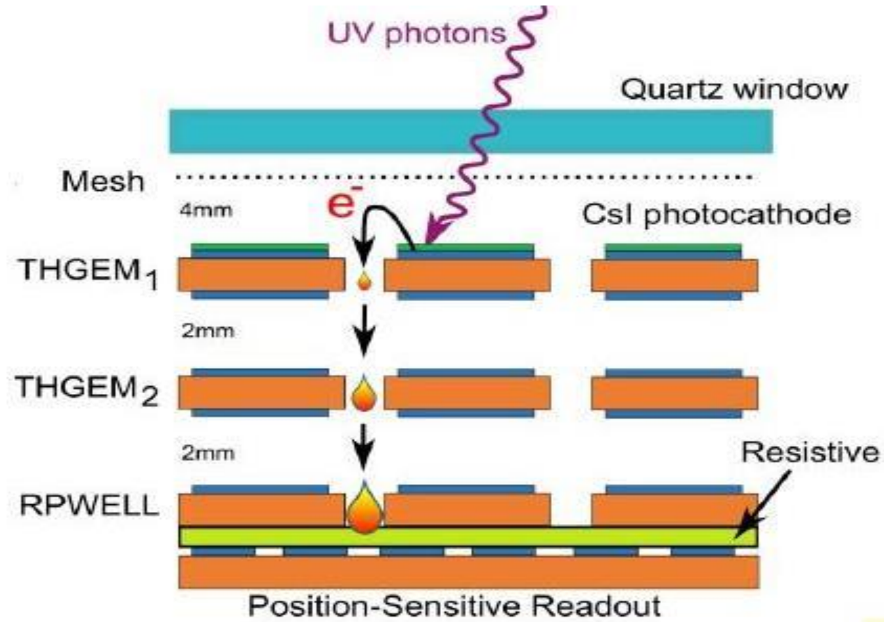


Y.Bilevych et al., Nucl. Instrum. Meth. A 610 (2009) 644.

Excellent space resolution for single UV photons provided by InGrid with CsI coating of a micro-grid directly integrated by wafer post-processing production onto a CMOS pixel detector with the complete readout system.
The array of microgrid round holes corresponds to the array of CMOS pixel centers

RPWELL





10^9 Ω cm resistive plate → discharge free operations. 99% eff. up to ~ 10^5 Hz/cm^2

proposed for digital hadron calorimetry

L. Moleri et al.,NIMA 845 (2017) 262

proposed for UV photon detection

S. Bressler et al. JINST July 2013 arXiv:1305.4657

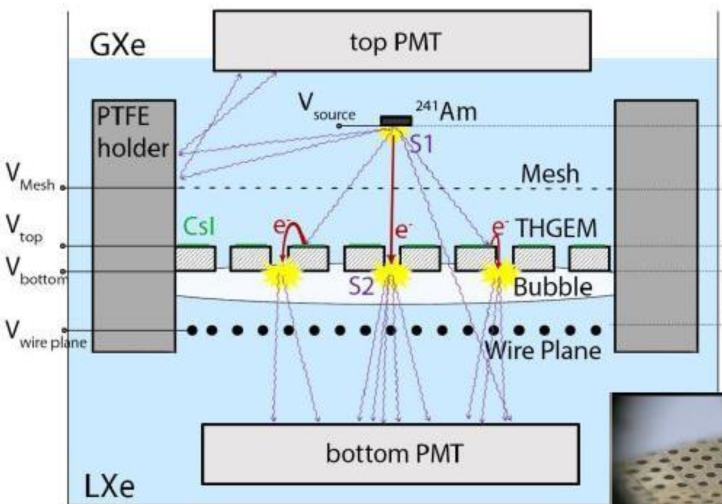
L. Arazi et al. 2012 JINST 7 C05011 arXiv:1112.1915

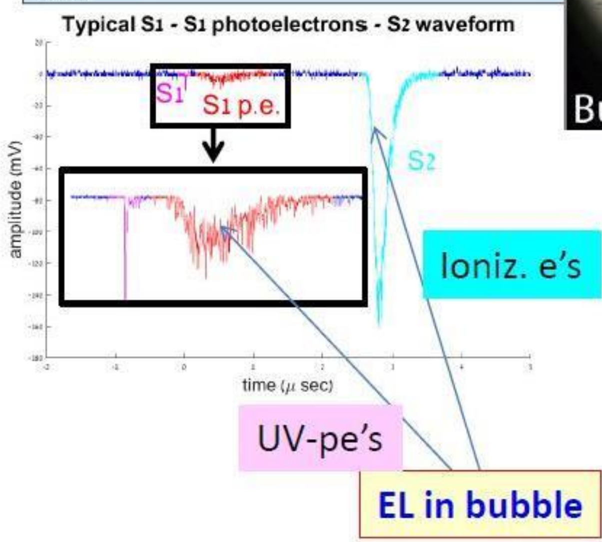
Bubble-assisted electroluminescence in LXe

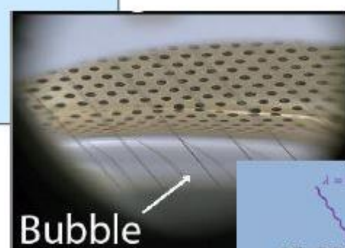
A "local dual-phase" noble-liquid detector

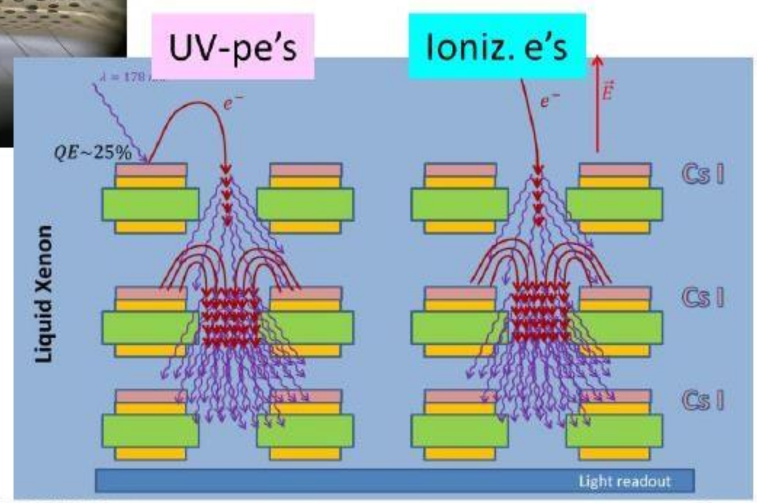
TOWARDS LARGE-SCALE NOBLE-LIQ DETs

Energy resolution 5MeV alphas: $\sigma/E=7.5\%$
Time resolution: $\sigma=10ns$
Bubble (under THGEM, GEM) stable for days
CsI on THGEM: high pe extraction









A Breskin MPGD 2015 Trieste 33

Breskin, *J. Phys. Conf. Ser.* 460(2013) 012020

Scintillating Glass-GEM imager

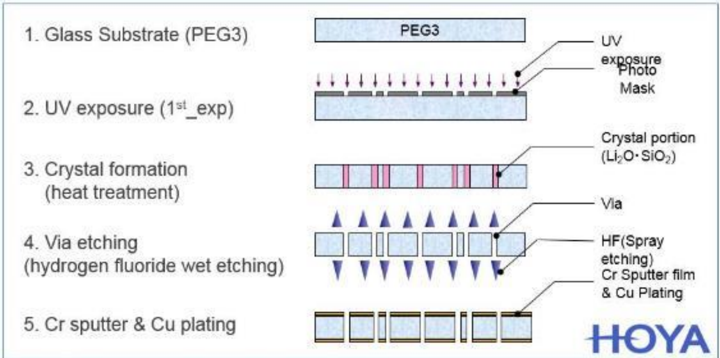
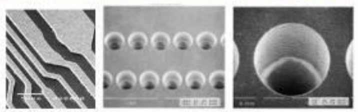
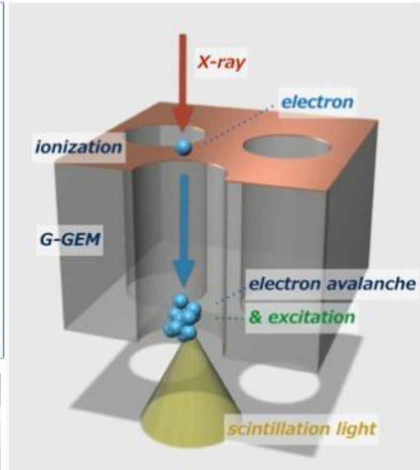
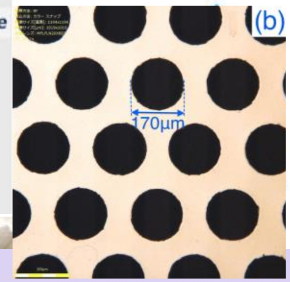


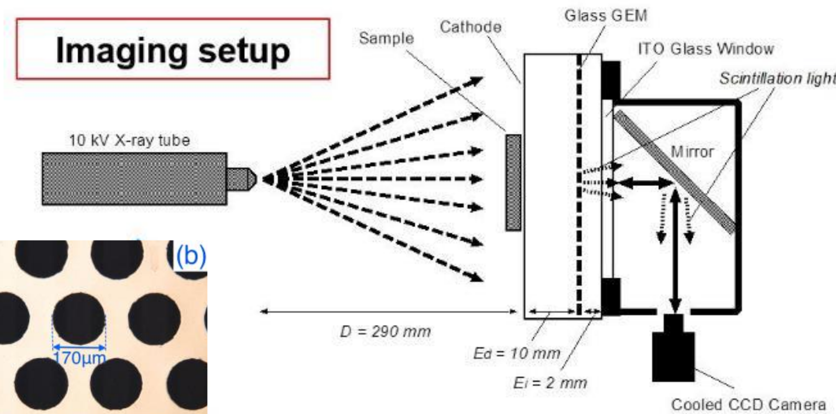
Photo Etchable Glass 3 : PEG3

- Promising technique for precise patterning
- Able to drill high aspect hole
- 680μm deep hole (ex. CERN GEM: 50μm)



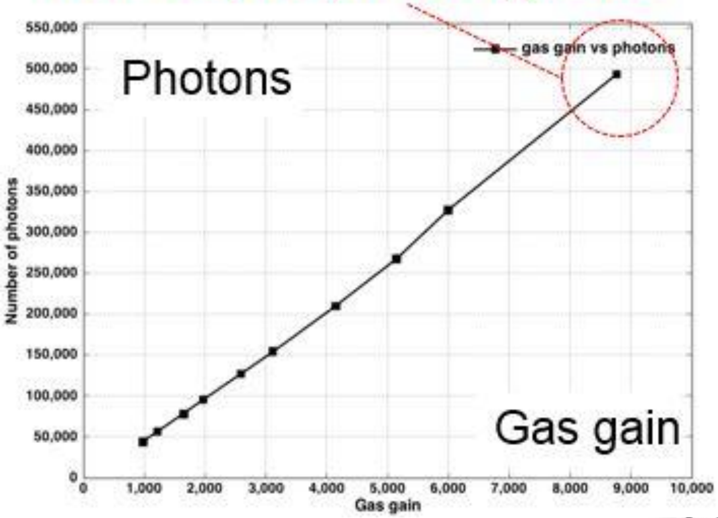


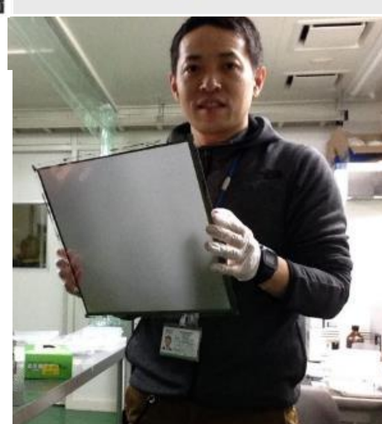


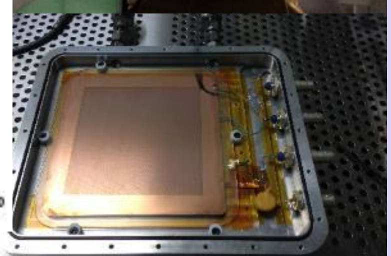


T. Fujiwara, et al., JINST 8 C12020, 2013

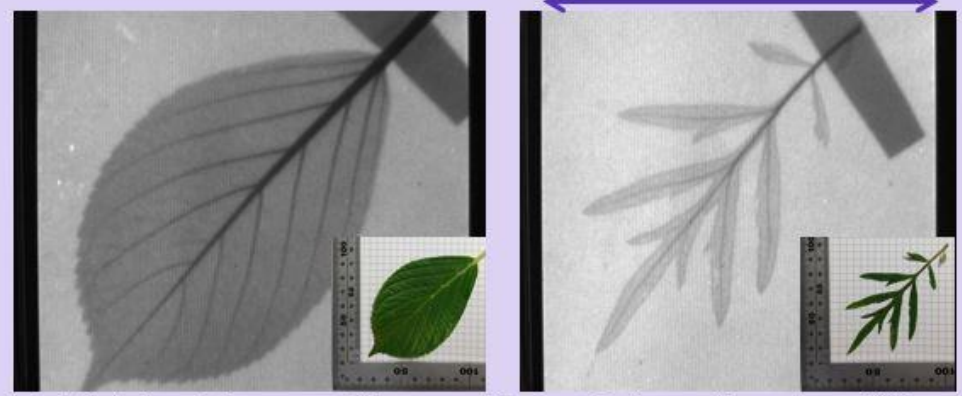
Max: 500,000 photons @5.9keV







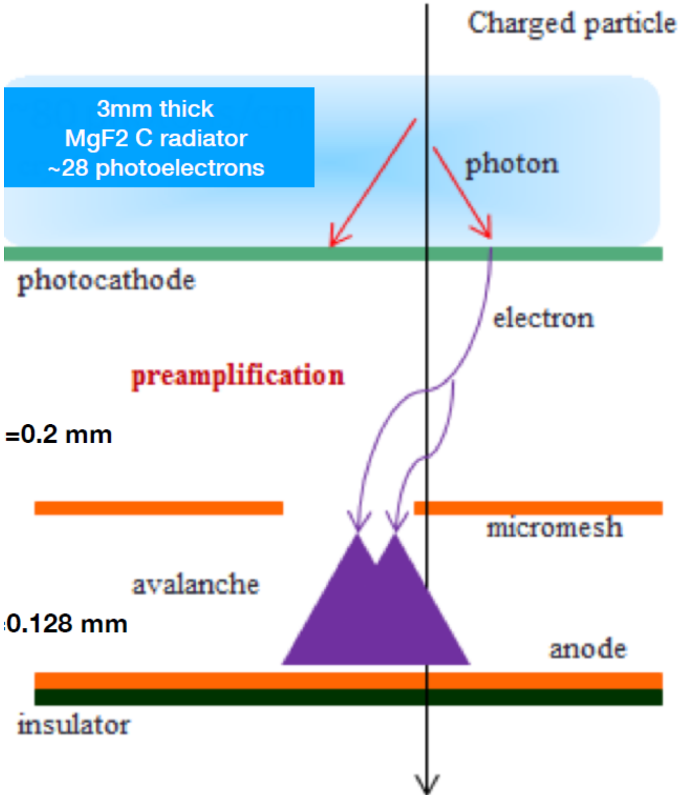
100mm

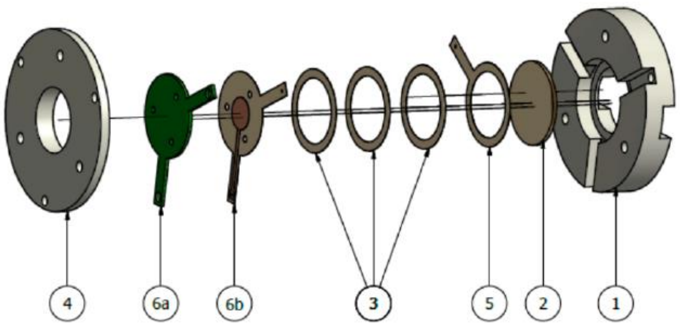


Obtained image of leaves (2 sec integration time)[10]

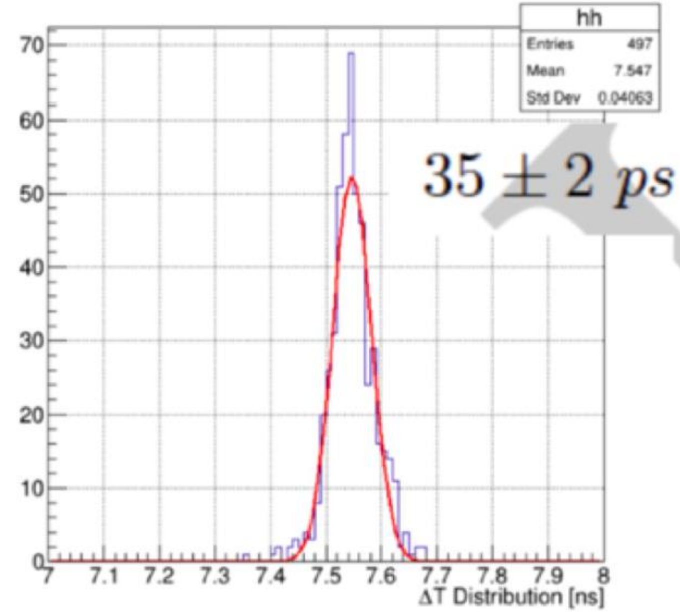
Excellent spatial resolution ≈500μm
Quick imaging of low Z material with low energy X-rays (≈7 keV)

“picosecond” timing with MPGDs?





$t_{PICOSEC}$-t_{MCP}



T.Papaevangelou et al, Fast Timing for High-Rate Environments with Micromegas, arXiv:1601.00123 (Jan. 2016).

Presentation by Sebastian White at NDIP 2017

Many configuration tested

Successfully achieved ~35 ps resolution in test beam.

Puzzling shift in spite of CF.

A NEW PHOTOCONVERTER: Rich-graphite Nano-Diamond film

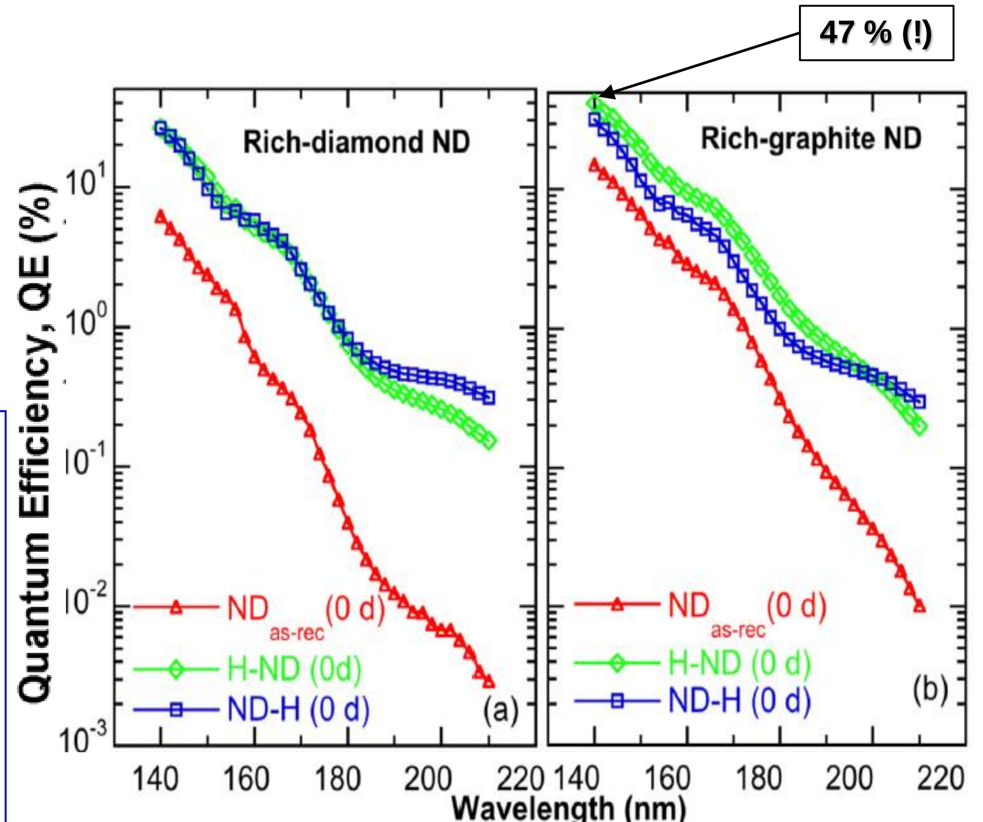
CsI bandgap: 6.2 eV; electron affinity: 0.1 eV; hygroscopic; ages by ion bombardment (~mC/cm^2)

Diamond bandgap: 5.5 eV; chemically inert and robust; if hydrogenated: electron affinity -1.27 eV

Hydrogenated chemical vapor deposited diamond films (4-6 μm) known to have QE ~15% @ 140 nm.

Heterogranular-structured diamond-gold nanohybrids proposed as stable field emission cathode material

Nano-Diamond grains (size: ~250 nm), with variable sp^2 (graphite phase) and sp^3 (diamond phase) hybridized carbon contents treated in H2 microwave plasma show large QE: ~50% @ 140 nm



L.Velardi, A.Valentini, G.Cicala, Diamond & Related Materials 76 (2017) 1

NEW !!!

Photocatodes: diamond film obtained with Spray Technique

Spray technique: T ~ 120° (instead of ~800° as in standard techniques)

SUMMARY / CONCLUSIONS

- **COMPASS RICH-1**
  - Provides outstanding PID performance
  - Has progressively improved and undergone two major upgrades
- **MPGD-BASED PHOTON DETECTORS**
  - Allow to overcome the limitations of MWPC-based PDs
  - A wide effort has refined and consolidated the THGEM technology
- **Hybrid THGEM + Micromegas PDs**
  - Have been implemented on COMPASS RICH-1 in 2016 for 1.4 m^2
  - They provide efficient single UV photon detection
- **GASEOUS PDs are expected to allow**
  - Inventions: new ideas, new techniques
  - Technology consolidation, new applications
  - Large scale projects