LONG TERM EXPERIENCE AND PERFORMANCE OF COMPASS RICH-1

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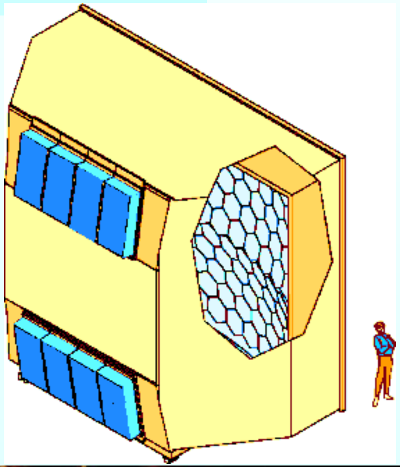
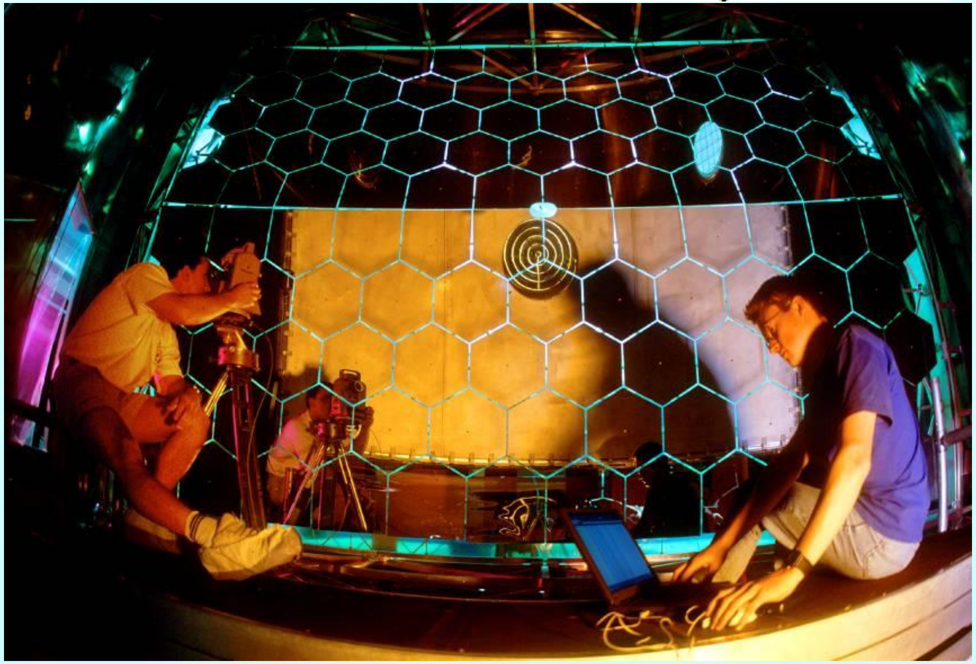
(I.N.F.N. – Trieste)
For the COMPASS RICH Group





COMPASS RICH-1

Vessel, radiator gas and mirror system

MWPC's with CsI photocathodes

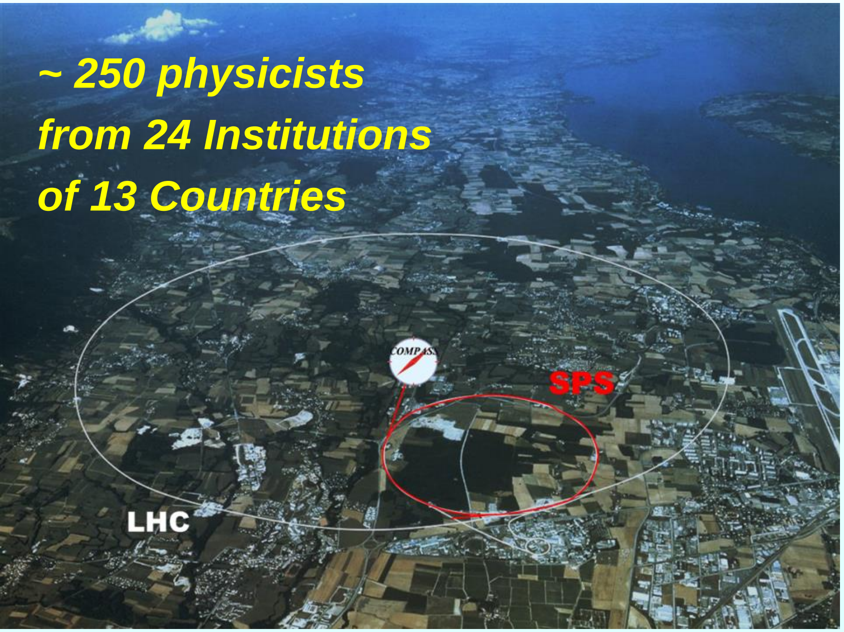
The MAPMT based detectors

PID Performances of COMPASS RICH-1

The upgrade with MPGD-based PDs

COMPASS II Collaboration

~ 250 physicists
from 24 Institutions
of 13 Countries



Дубна (LPP and LNP), Москва (INR, LPI, State University), Протвино

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:**

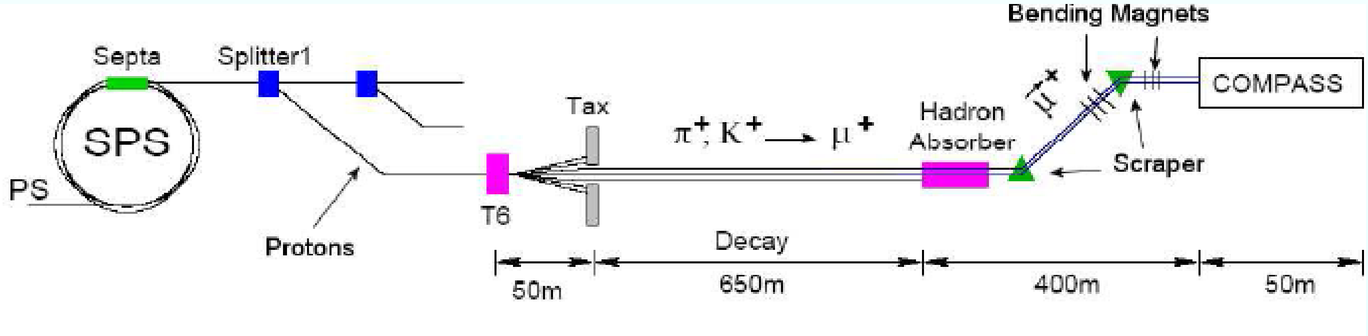
COMPASS - I (2002 – 2011)

Spin structure, Gluon polarization	Pion polarizability
Flavor decomposition	Diffractive and Central production
Transversity	Light meson spectroscopy
Transverse Momentum-dependent PDF	Baryon spectroscopy

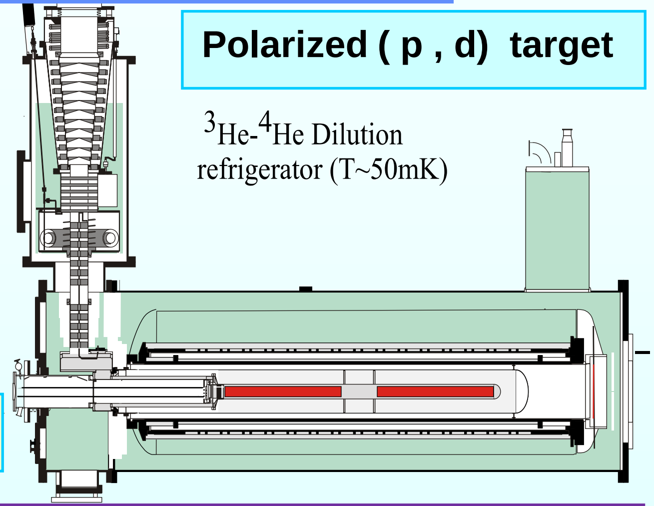
COMPASS - II (2012 – 2017) …

DVCS and HEMP	Pion and Kaon polarizabilities
Unpolarized SIDIS and TMDs	Drell-Yan studies

BEAM, TARGET AND SPECTROMETER



Polarized (p , d) target

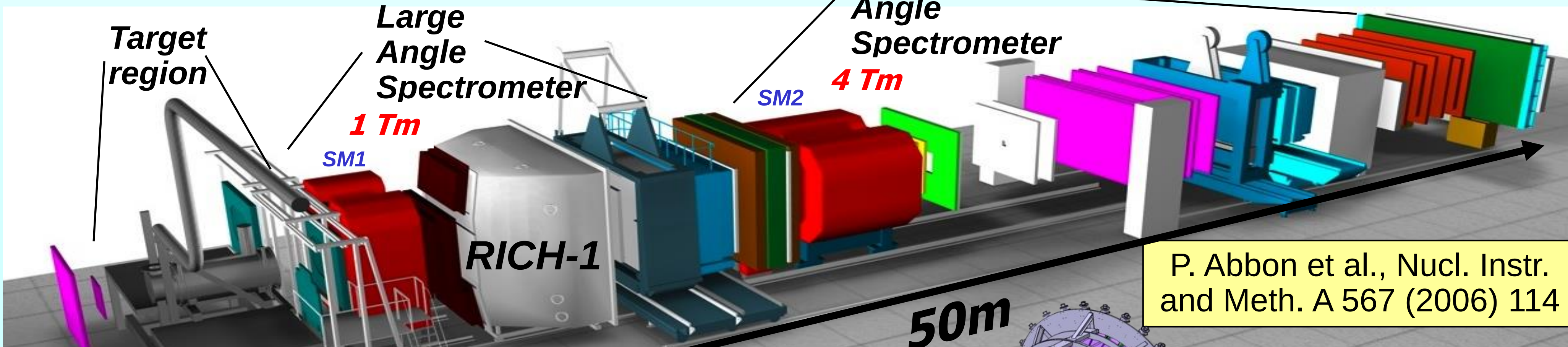


160 or 190 GeV/c μ$^+$ (or μ$^-$), 4 · 10^8 μ/spill, P$_\mu$ ~ 80%
190 GeV/c p, π$^+$, π$^-$, K$^+$,K$^-$ beams

Various targets used

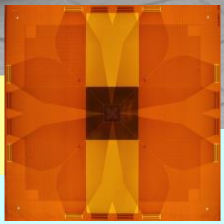
first GEMs and Micromegas used in a HEP Experiment

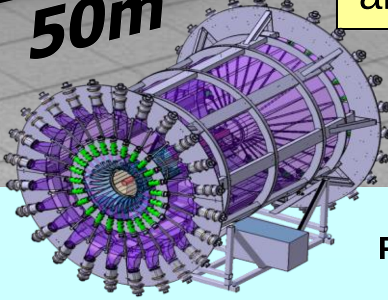
DAQ: 40 kB, 30 kHz, O(PB)



P. Abbon et al., Nucl. Instr. and Meth. A 567 (2006) 114

new: pixel GEMs
(not in scale)





Proton recoil detector

COMPASS RICH-1

is a large gaseous RICH
with two kind of photon detectors
providing:

hadron PID from 3 to 60 GeV/c

acceptance: H: 500 mrad V: 400 mrad

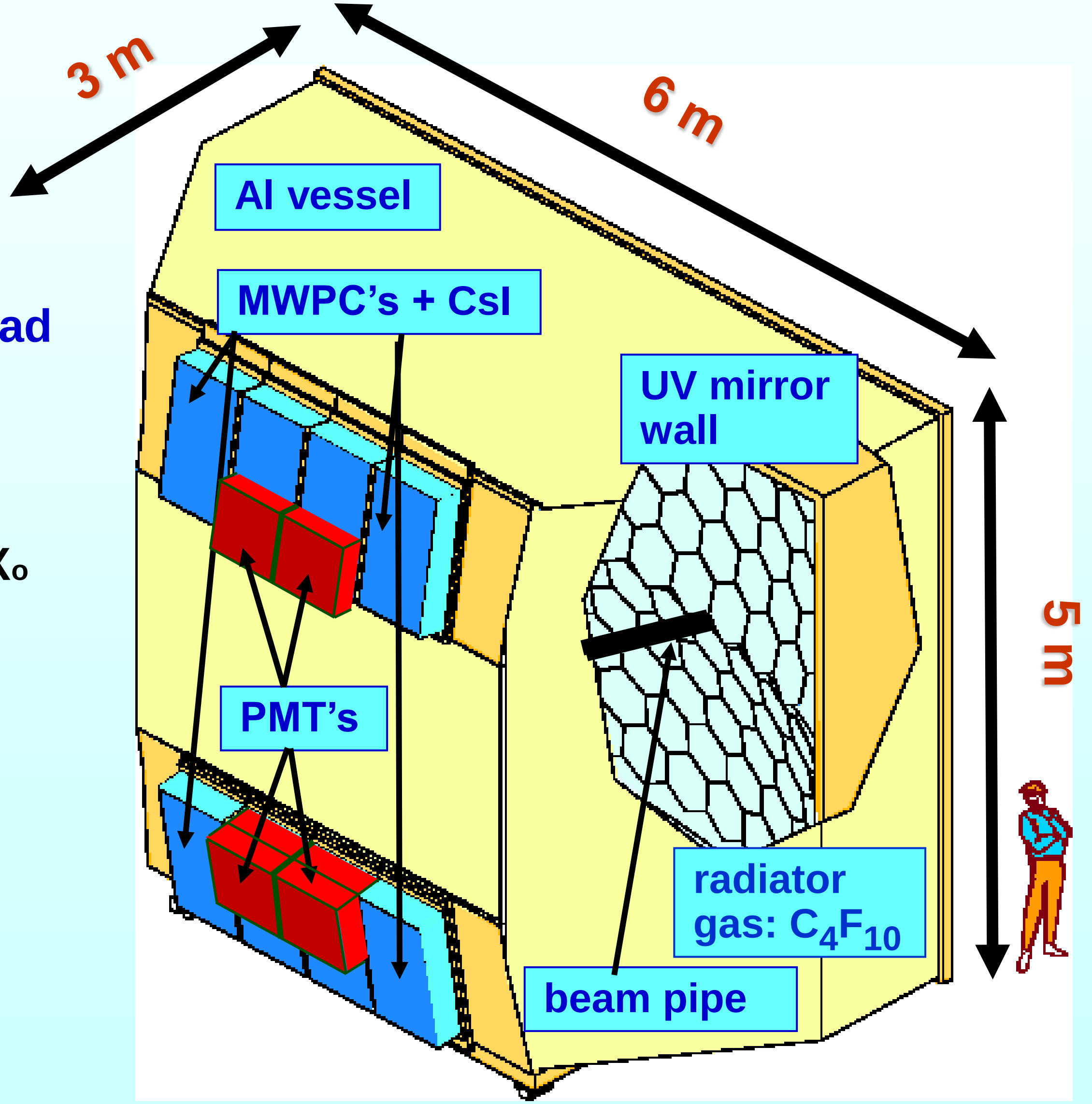
trigger rates: up to ~50 KHz
beam rates up to ~10^8 Hz

material in the beam region: 1.2% X_o
material in the acceptance: 22% X_o

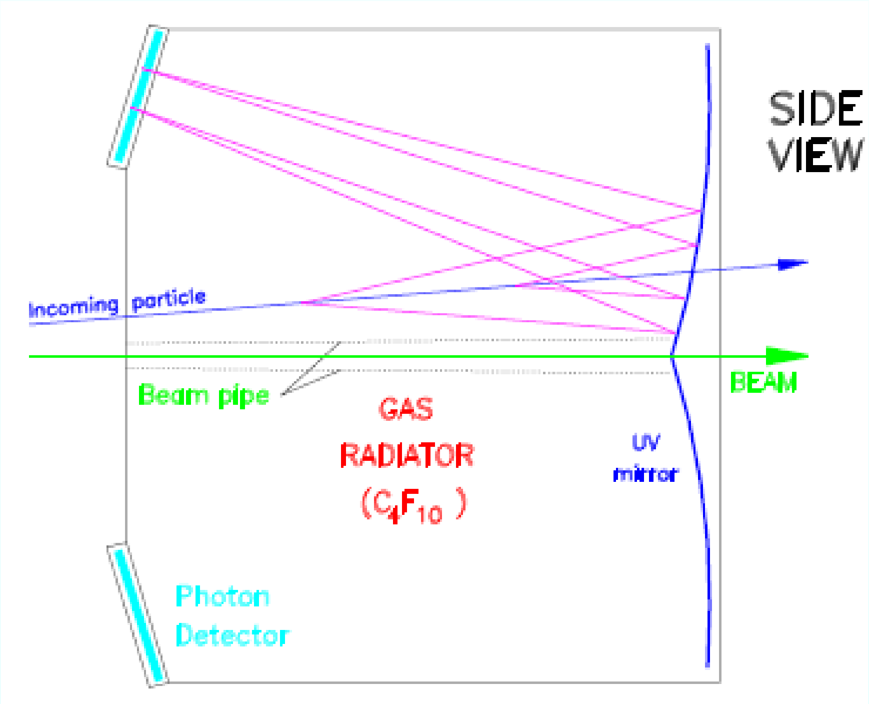
detector designed in 1996
in operation since 2002
upgraded in 2006

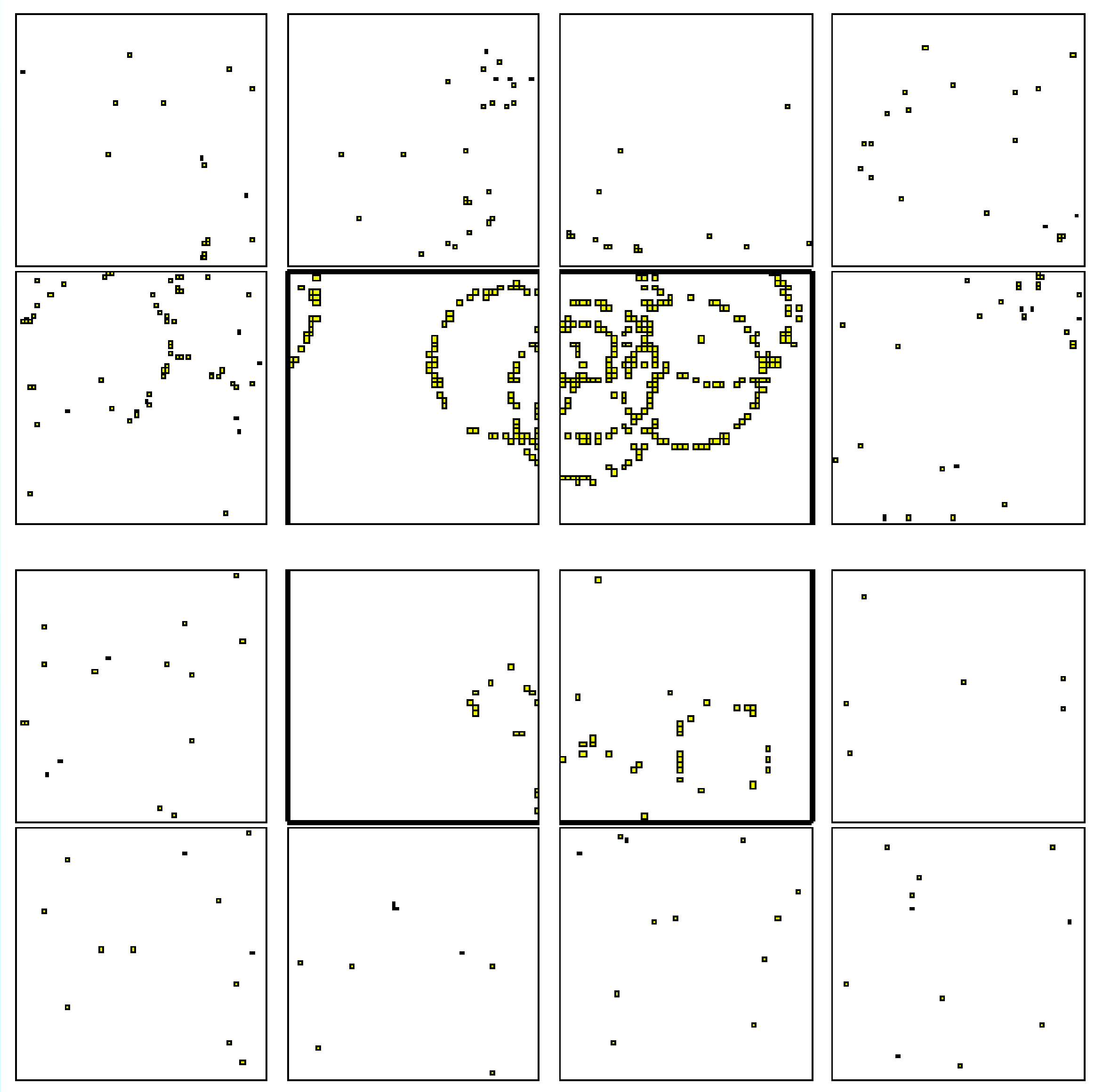
total investment: ~ 4 M €

a new upgrade is foreseen in 2016

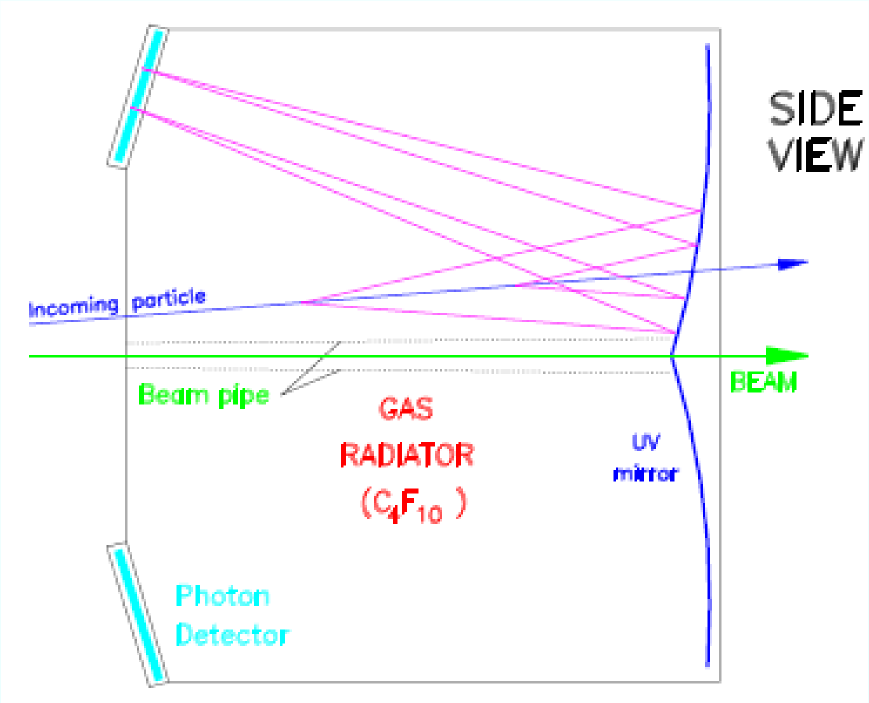


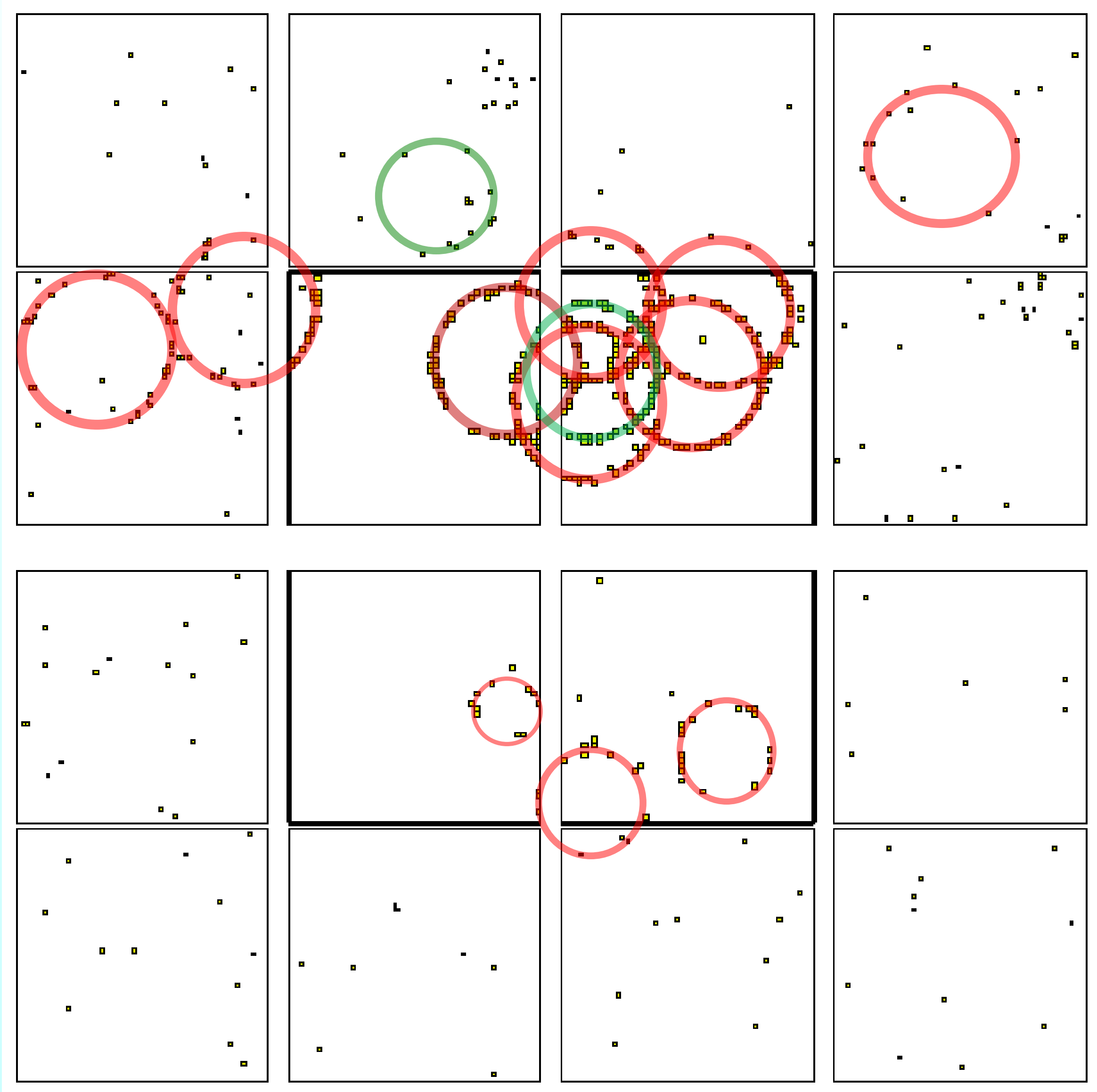
The principle and a typical event





The principle and a typical event



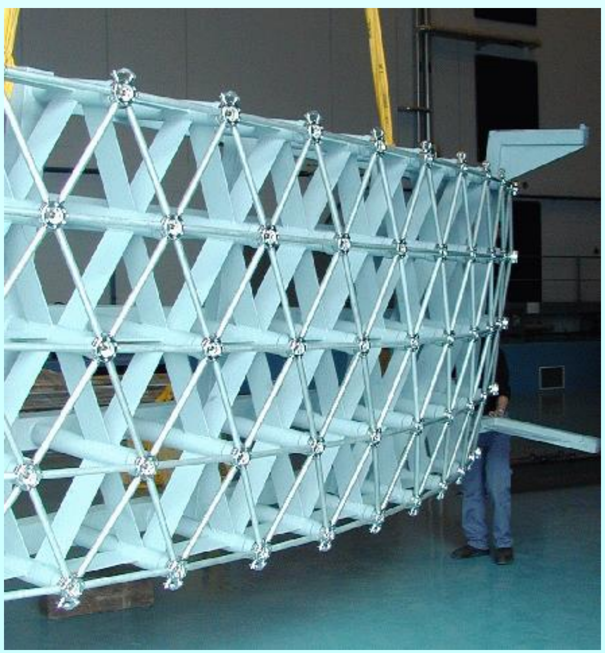


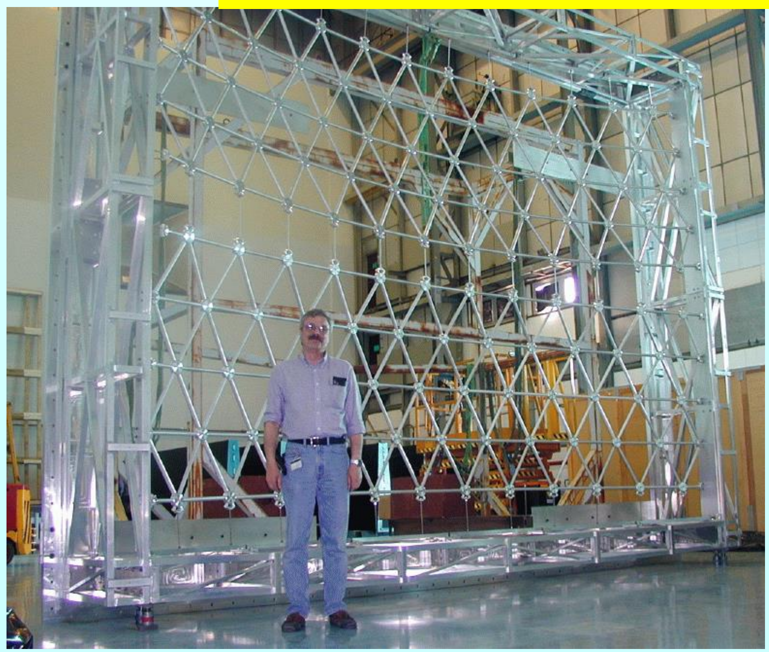
the vessel and the mirror support wall

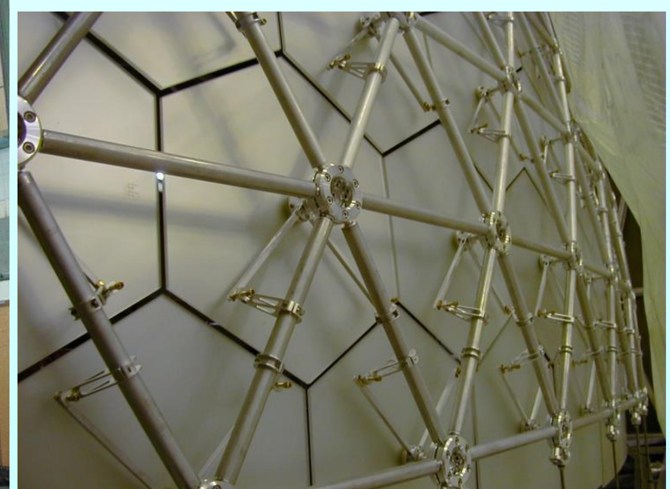
Large and accurate mechanics

light front and rear windows

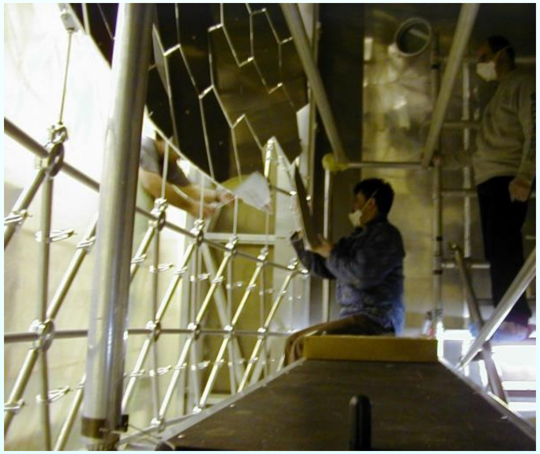
100 m of O-rings, 80 m^3 C_4F_{10}

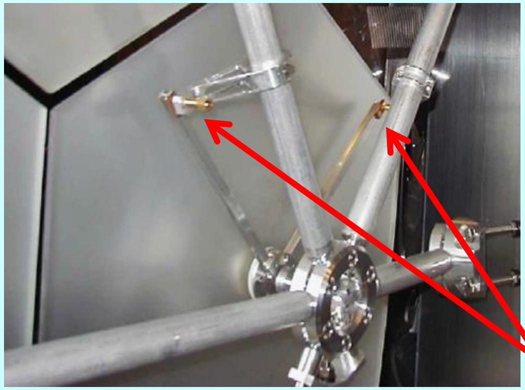




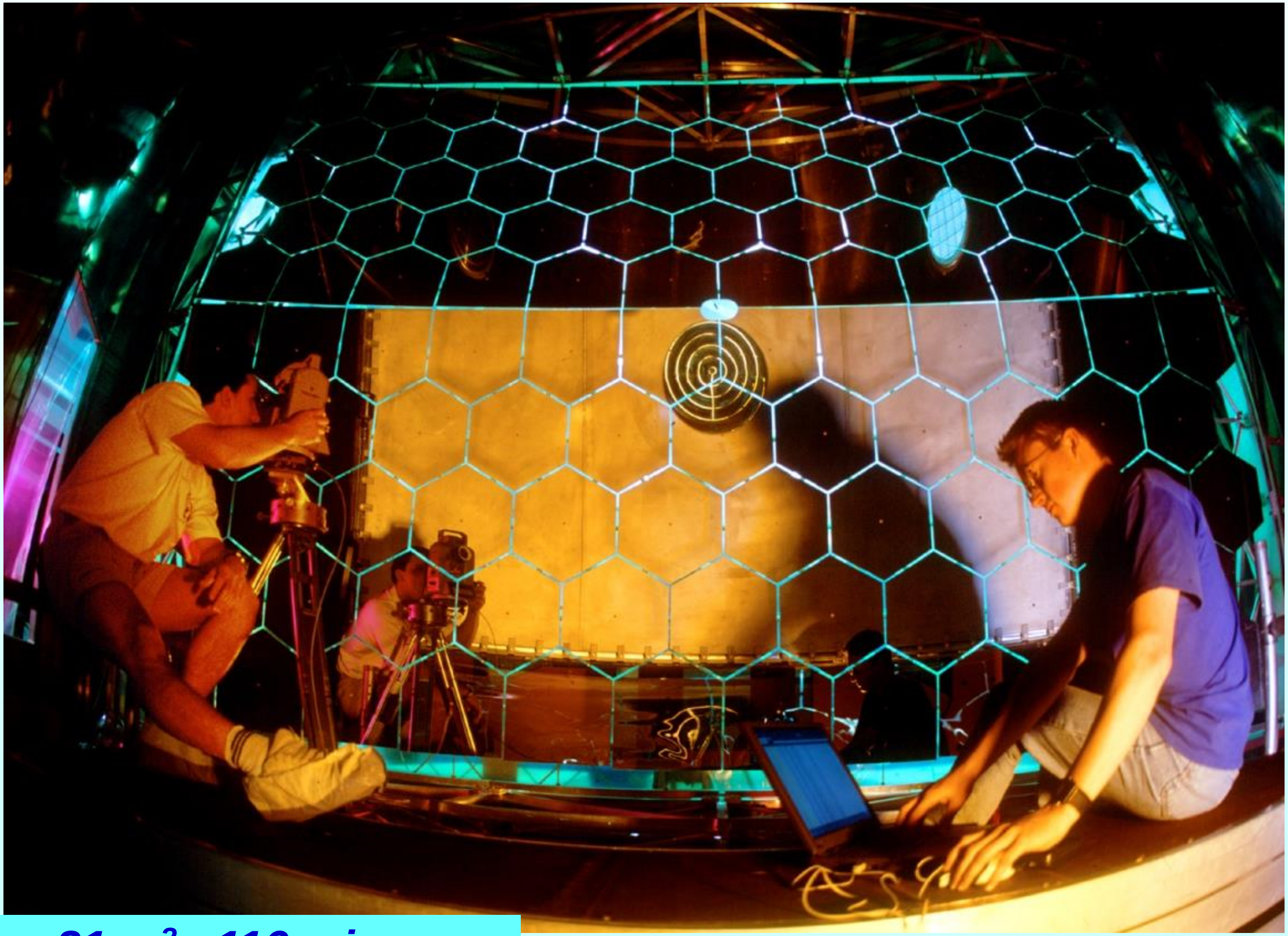


mirrors and alignment





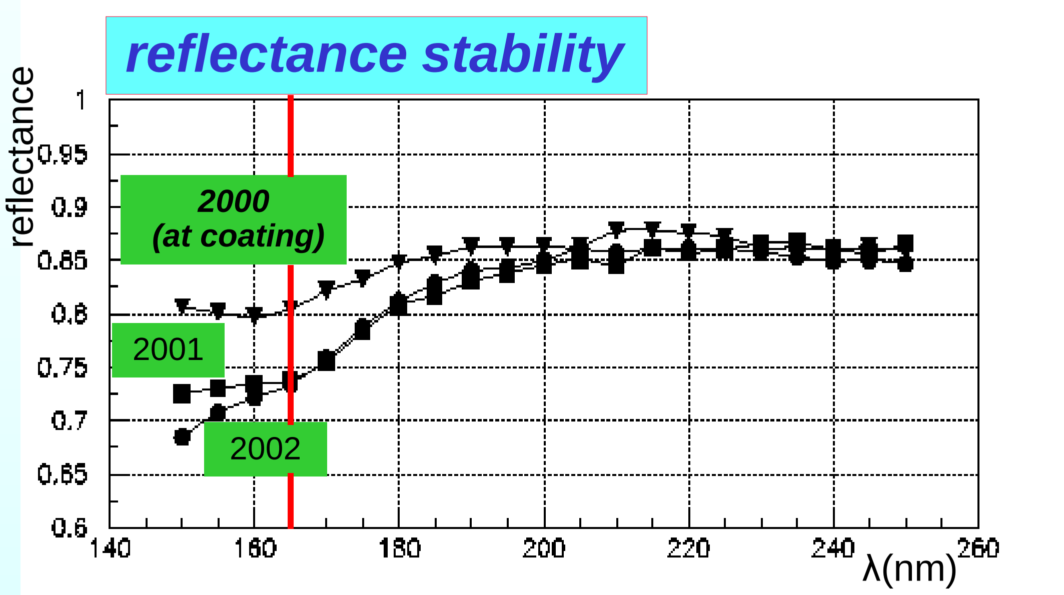
angular regulation screws



21 m², 116 mirrors
radius: 6.6 m

measurement of mirror alignment
via laser autocollimation

problems with mirrors

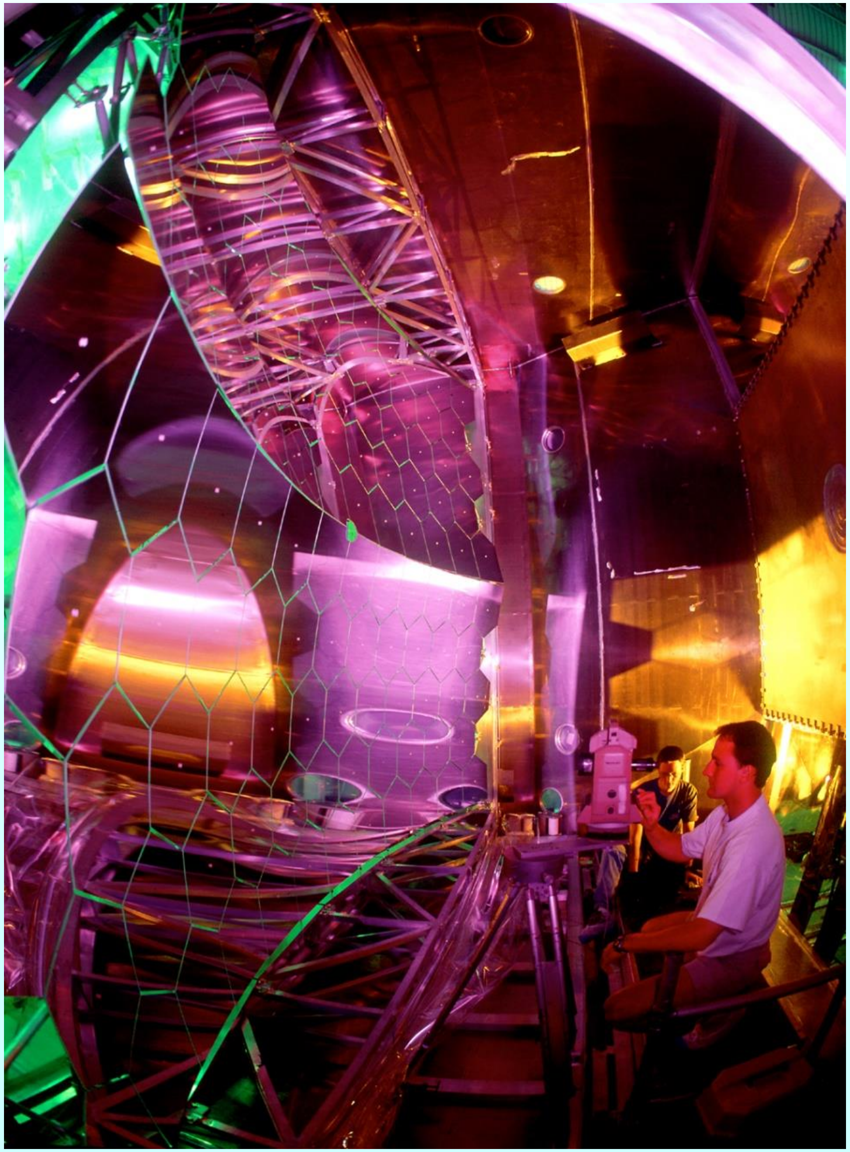


initial alignment accuracy: ~100 μrad

surveying accuracy: ~ 60 μrad

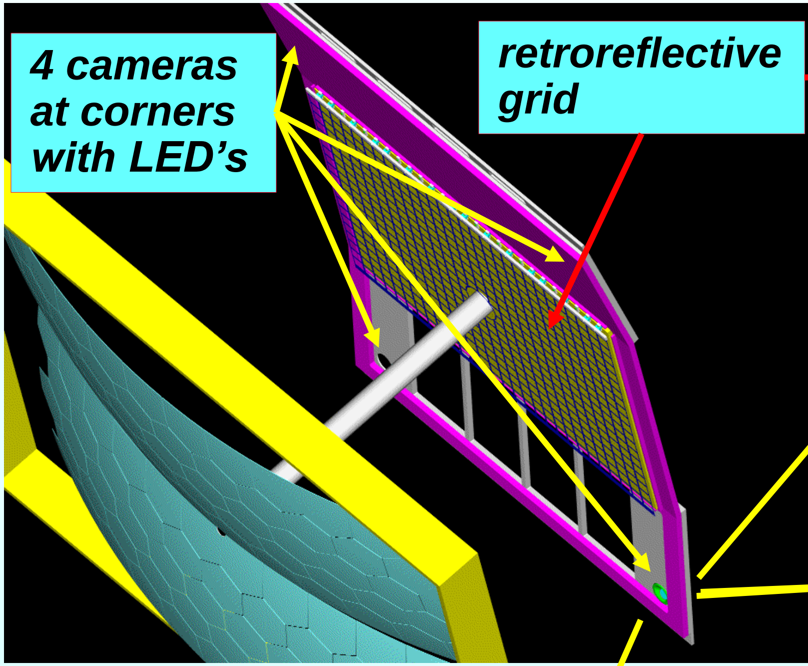
alignment instability: 1 mrad (first year)

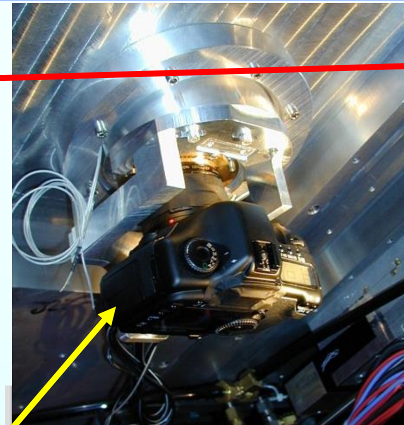
alignment instability: ~ 100 μrad after 2002

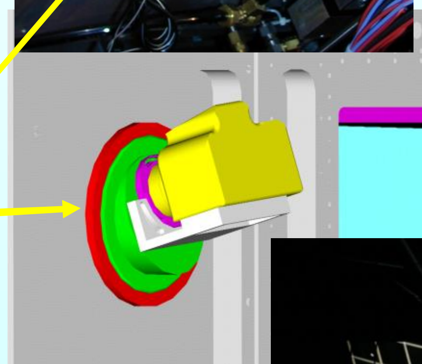


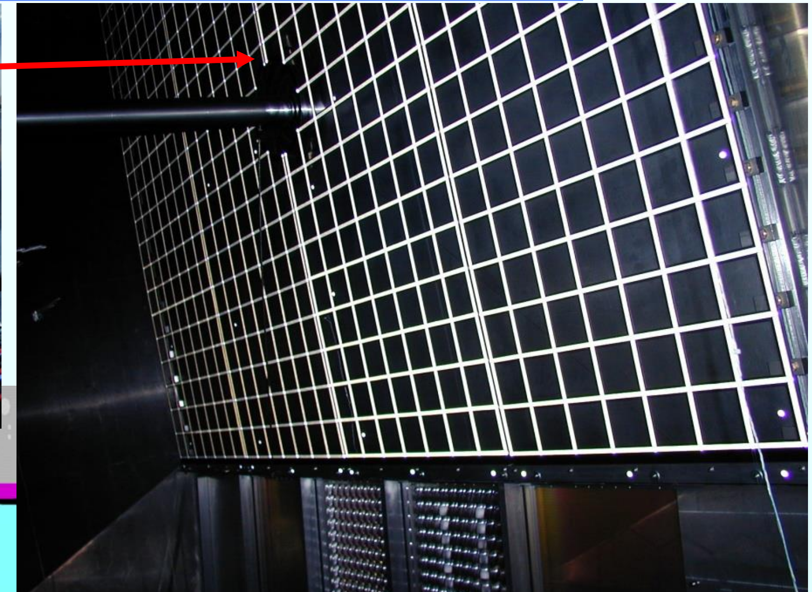
alignment check → surveyors inside → opening the vessel: contamination, dust, risky operations, work load, expenses.

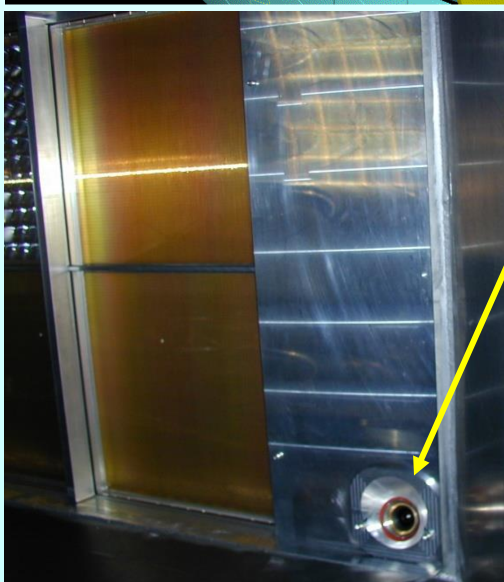
CLAM: mirror alignment monitoring







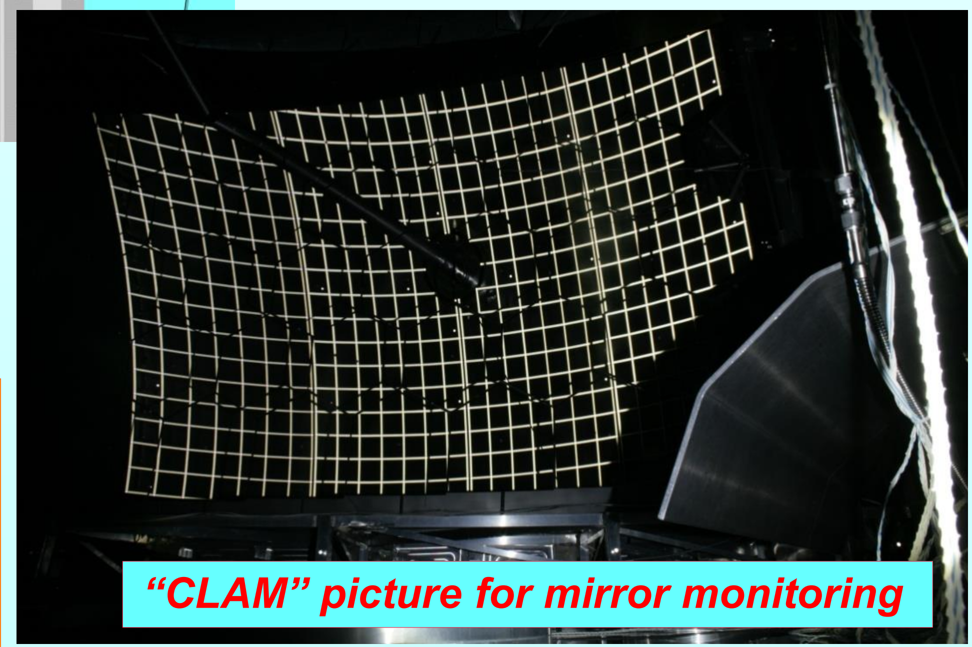




CLAM system in operation since 2007

accuracy: 30 μrad

photogrammetric calibration of cameras → measurement of absolute mirror tilt

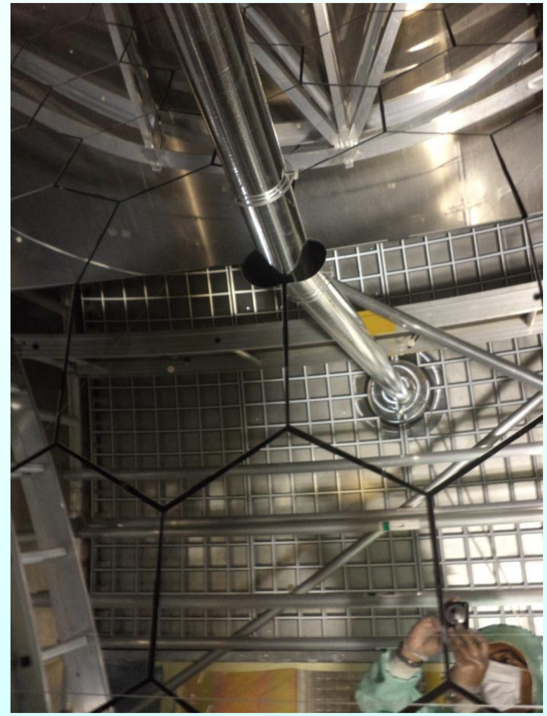


"CLAM" picture for mirror monitoring

2012: a new light beam pipe

Old: 150 µm thick stainless steel pipe: 0.85 % X_0 for orthogonal crossing

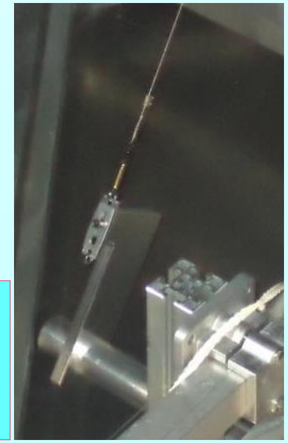
New pipe: 0.044 X_0 for orthogonal crossing



Material: 4 x 25 µm thick Mylar + 200 nm Al coating (by Sheldahl) ***winding by Lamina (6 µm glue)***

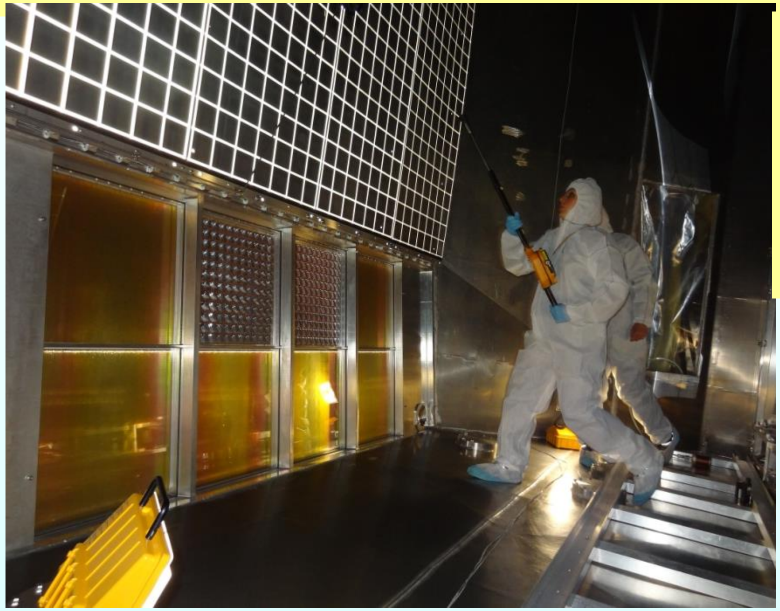
1 microflange for suspension + gas connection + window holding

weight = 15 g

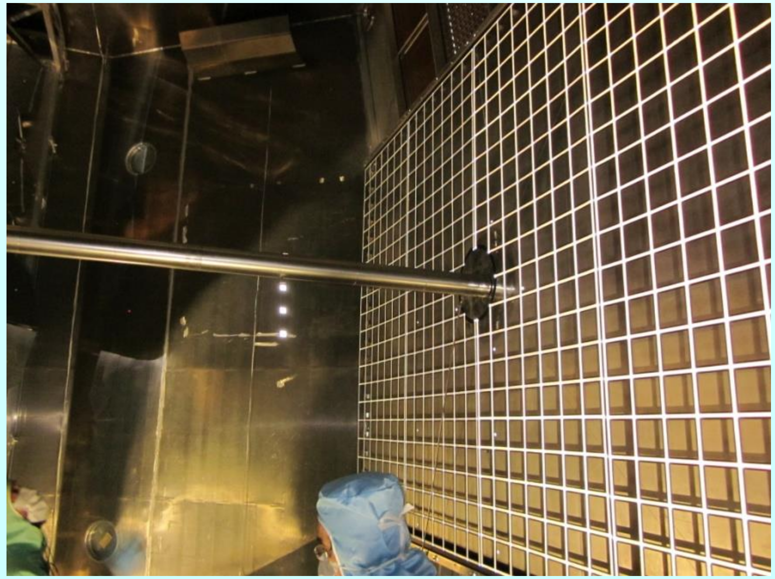


Suspension and tensioning system:
1 x 7 wires ss rope 30 µm diam.
1 microflange and 1

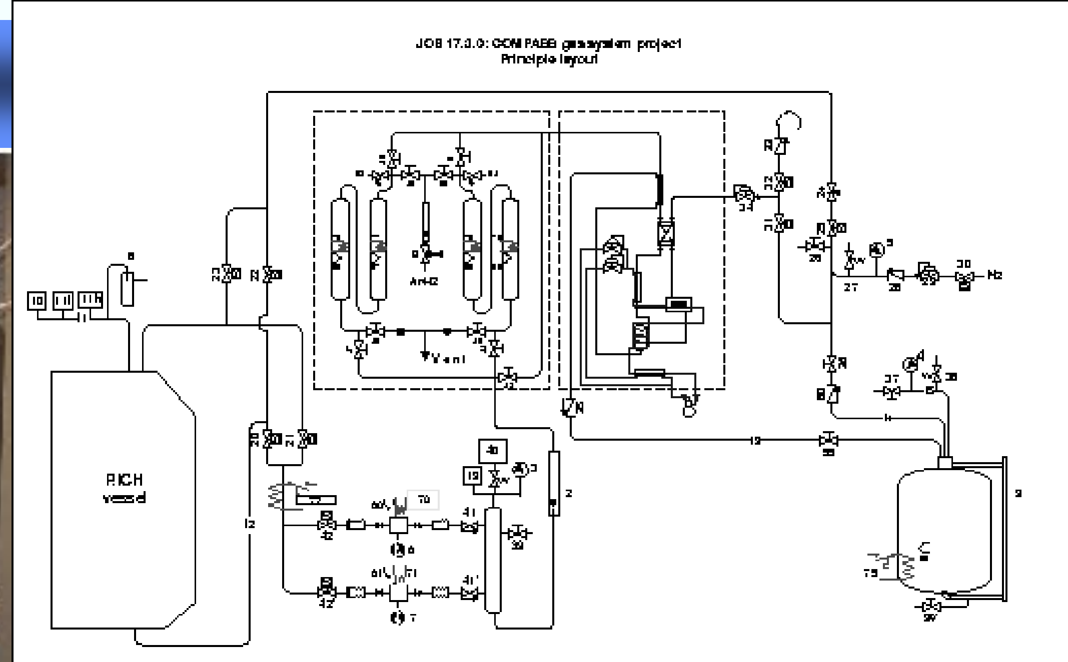
Safety issues for working inside the RICH



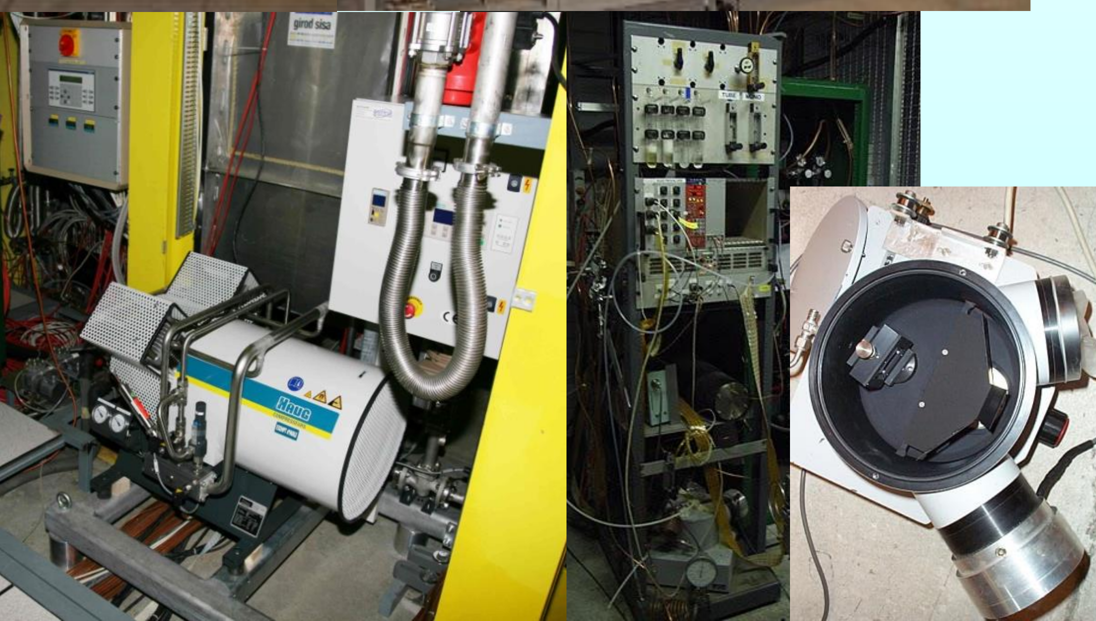
1) Radiation level: < 2 μSv/h
2) Scaffolding installation
3) Old pipe removal
4) Mirror alignment measurement
5) New pipe installation + alignment
6) Removal of scaffolding +cleaning

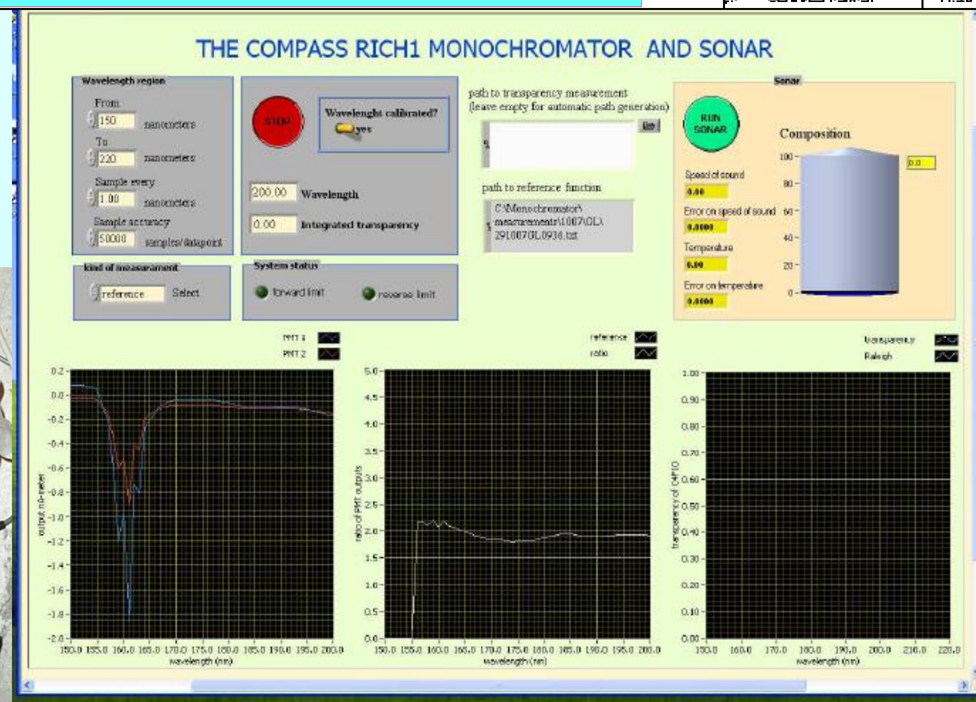


The radiator gas system

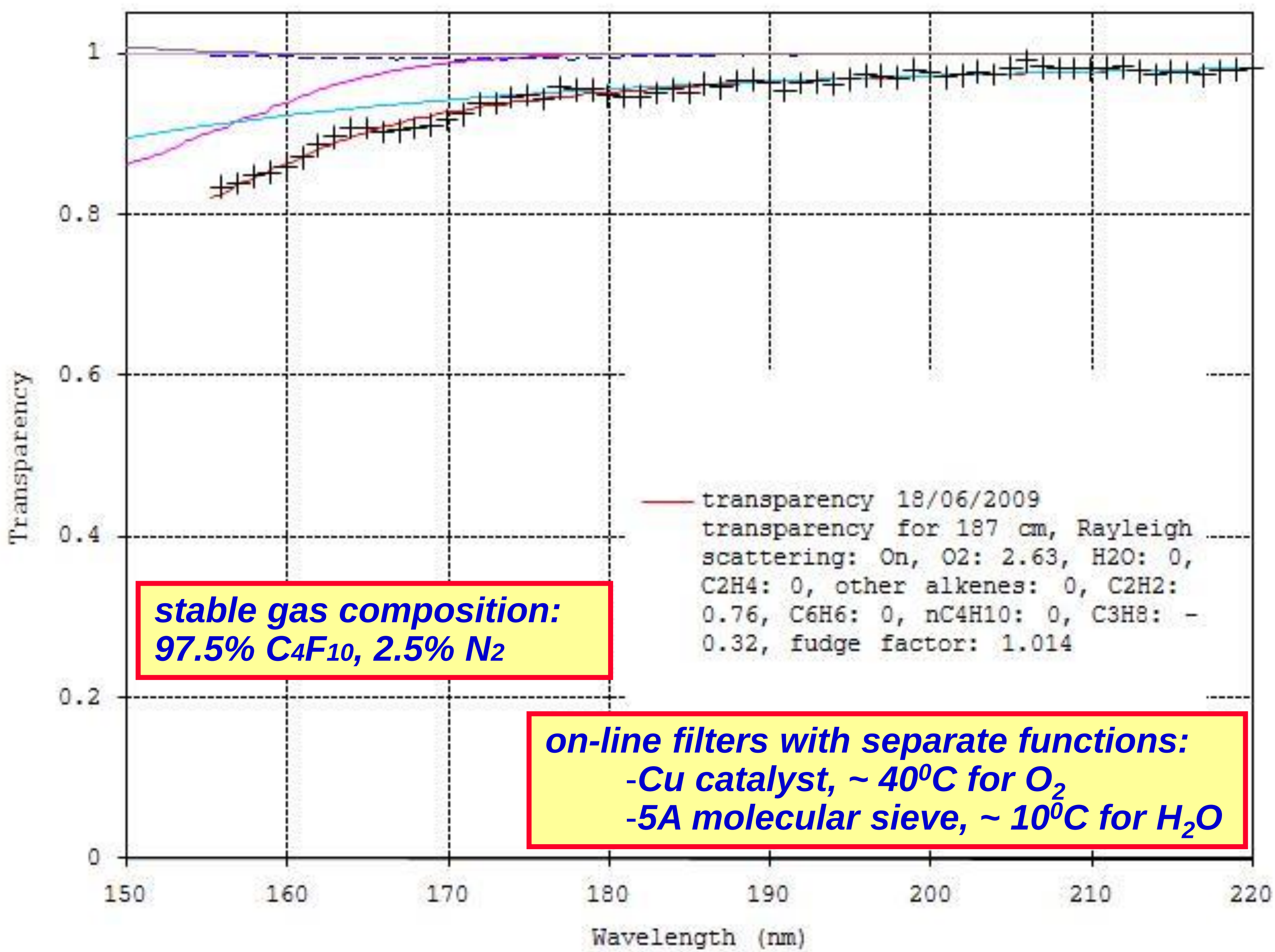


has excellent performance





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

Buying C_4F_{10} is non trivial (out of market for years)

It comes dirty (very dirty sometimes): pre-cleaning is a must (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 (50 l/day): 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

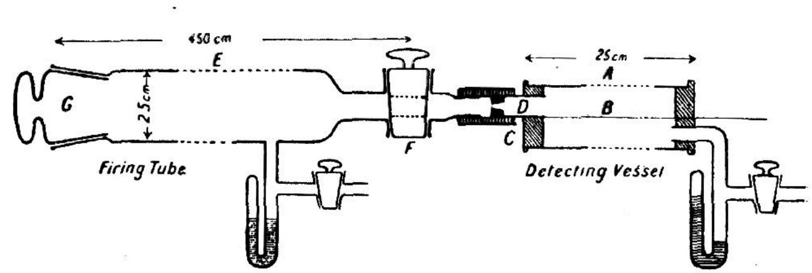
Monitoring the transparency is a must (dedicated system, expert manpower, significant gas consumption for each measurement)

Thermal gradients problem: → fast circulation (20 m^3/h) implemented in 2009

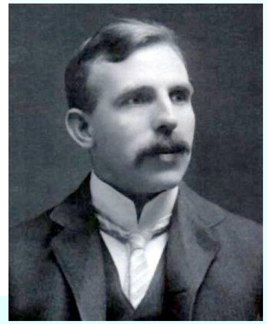
<u>Accidents can become disasters; emergency intervention to be granted in short time: EXPERT ON CALL 24 h/day, 7 days/week for 7 months/year: heavy load on experts</u>

In the family of gaseous detectors, with a glorious tradition

1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY

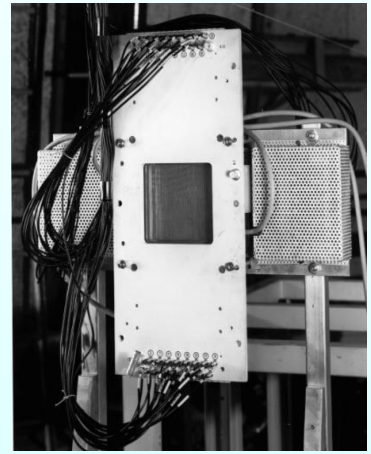


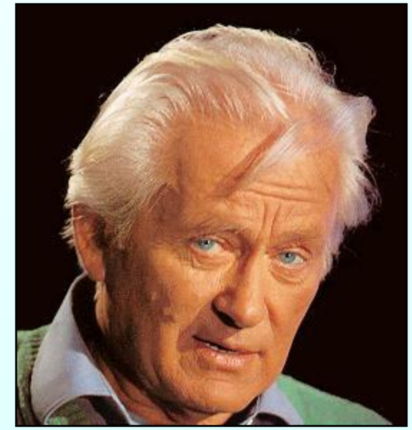
E. Rutherford and H. Geiger ,
Proc. Royal Soc. A81 (1908) 141



Nobel Prize in Chemistry in 1908

1968: MULTIWIRE PROPORTIONAL CHAMBER

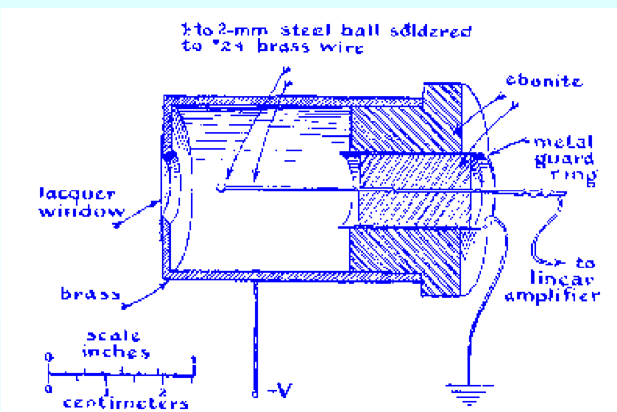




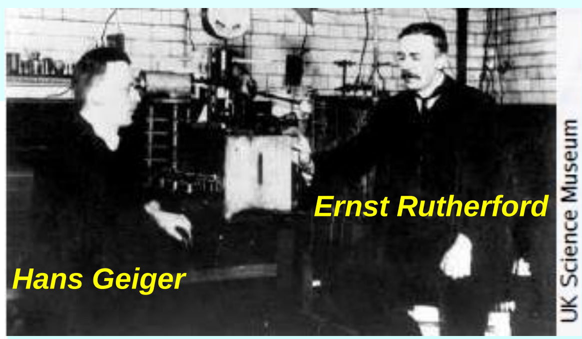
Nobel Prize in 1992

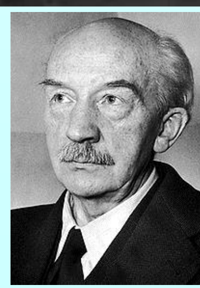
G. Charpak, Proc. Int. Symp. Nuclear Electronics
(Versailles 10-13 Sept 1968)

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY

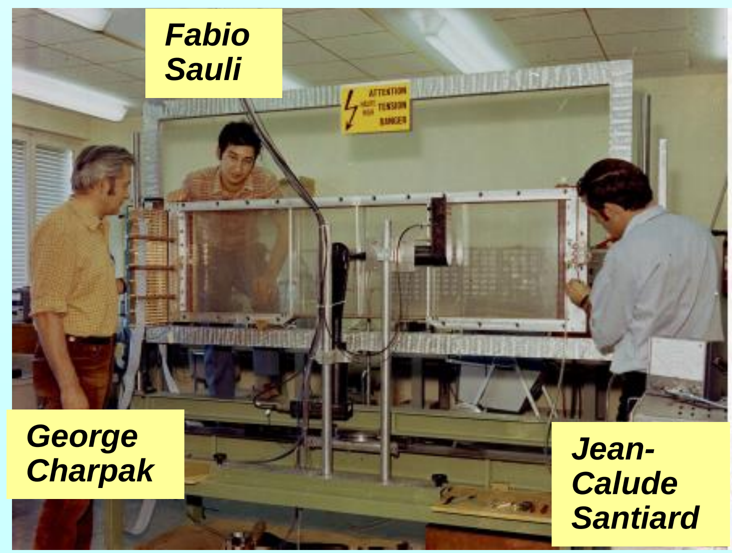


H. Geiger and W. Müller,
Phys. Zeits. 29 (1928) 839





Walther Bothe
Nobel Prize in 1954 for the "coincidence method"



Gaseous photon detectors use

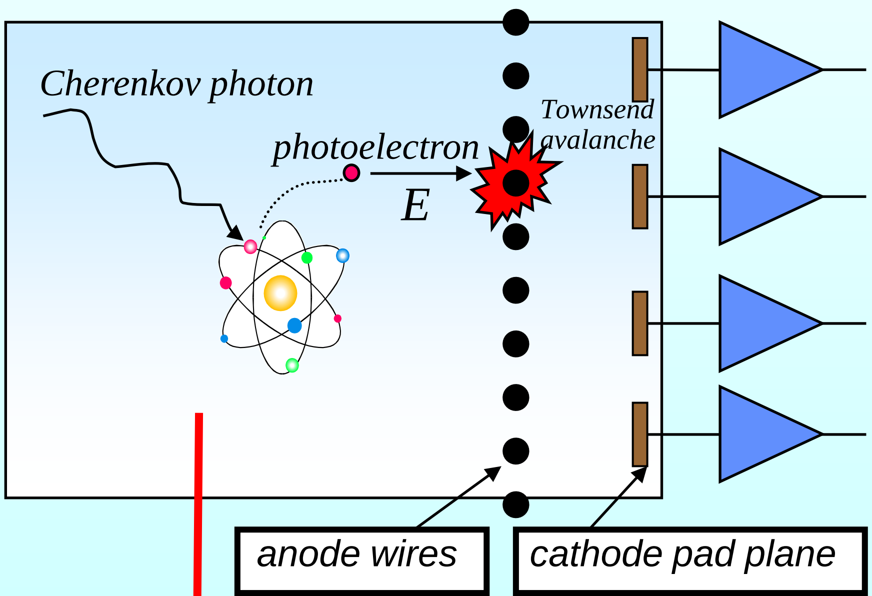
PHOTOELECTRIC ABSORPTION :

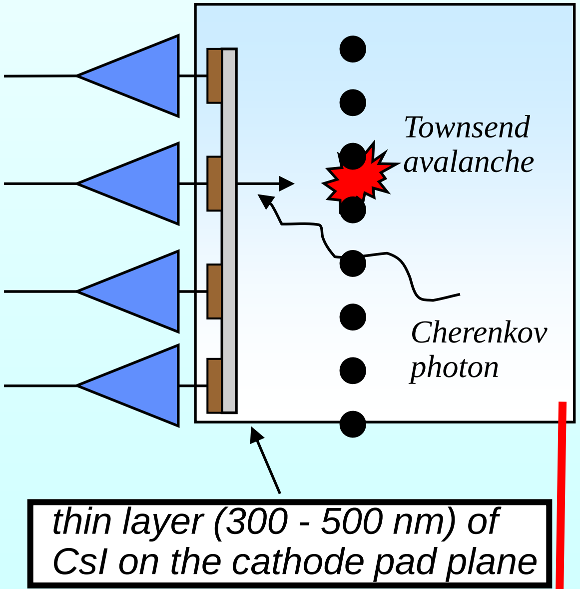
gas photoionization

gas volume: photosensor (TMAE or TEA)
+ carrier (CH_4 or C_2H_6)

photoelectric effect

gas volume: CH_4





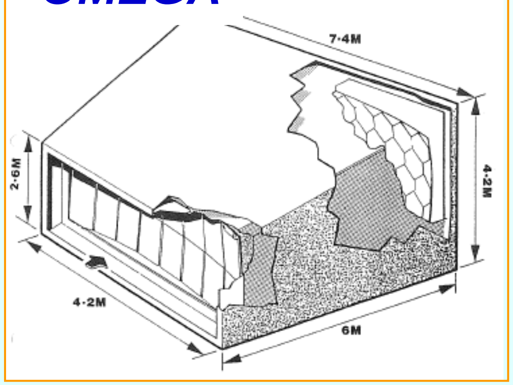
Albert Einstein

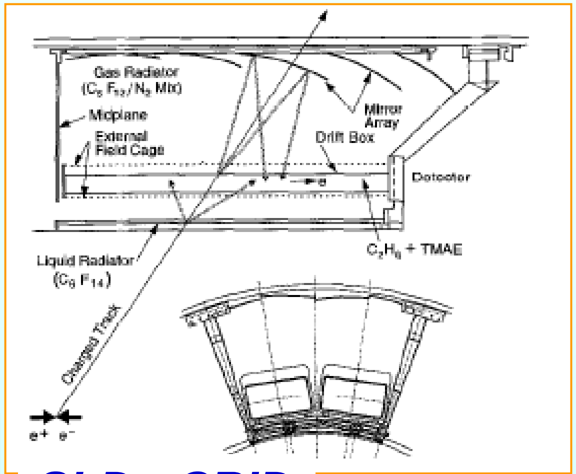
Tom Ypsilantis

the past and the present

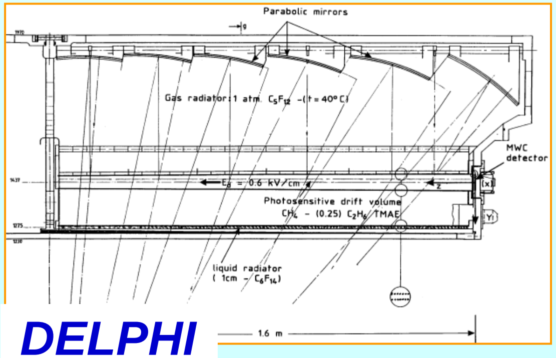
RICH with gaseous PD's
the first generation: photoconverting vapours

OMEGA

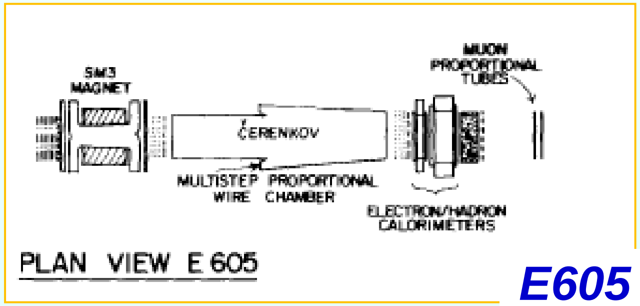




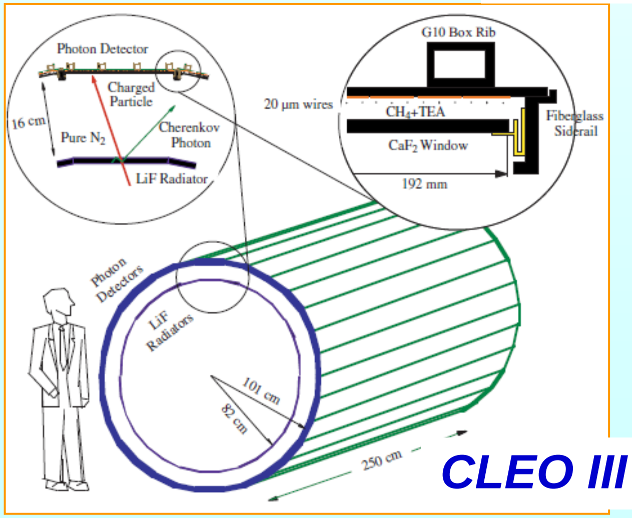
SLD - CRID



DELPHI



E605



CLEO III

TMAE *(Tetrakis-Dimethylamine-Ethylene)*

TEA *(Tri-Ethyl-Amine)*

Thanks to RD26

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

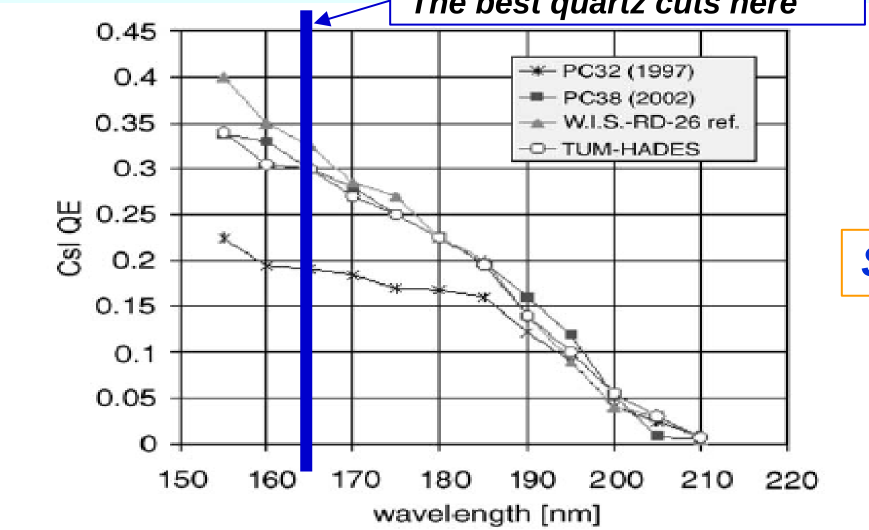
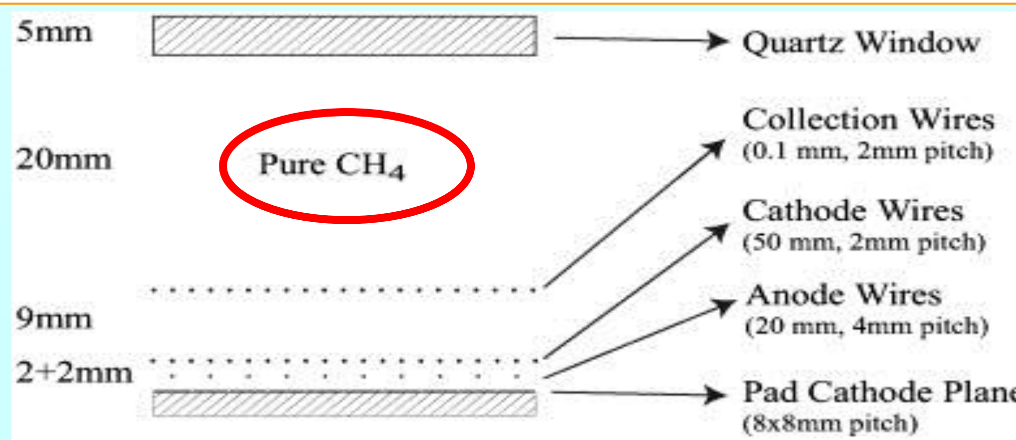


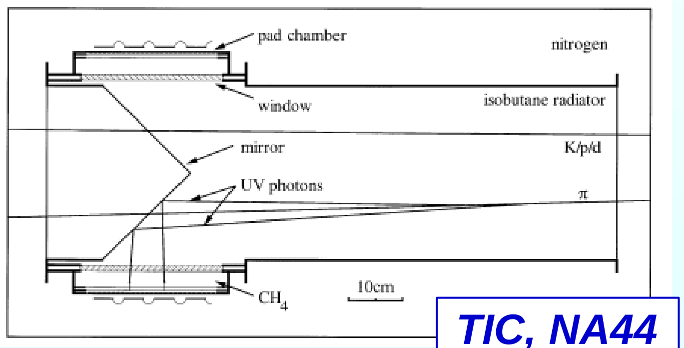
Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

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

Schematic structure of the COMPASS Photon Detector:



RICH with gaseous PD's
the second generation: MWPC's + CsI

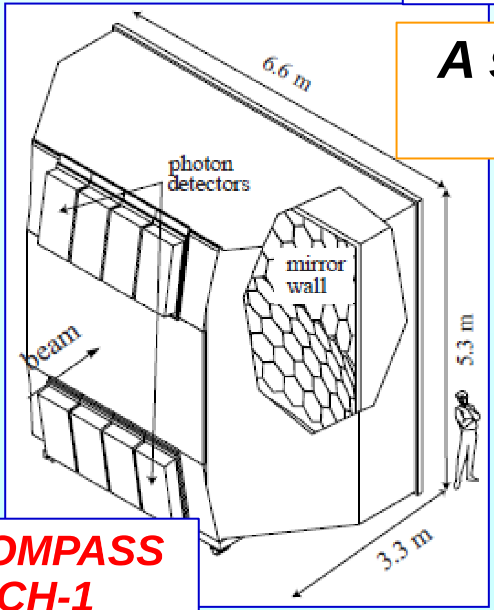


TIC, NA44

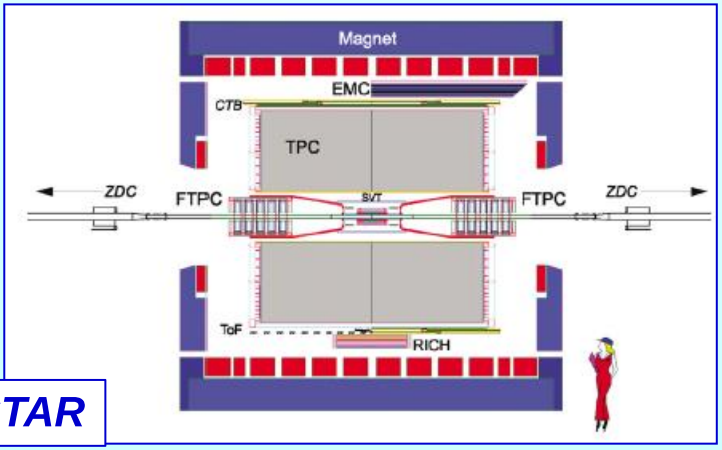
ALICE-HMPID

JLAB-HALL A

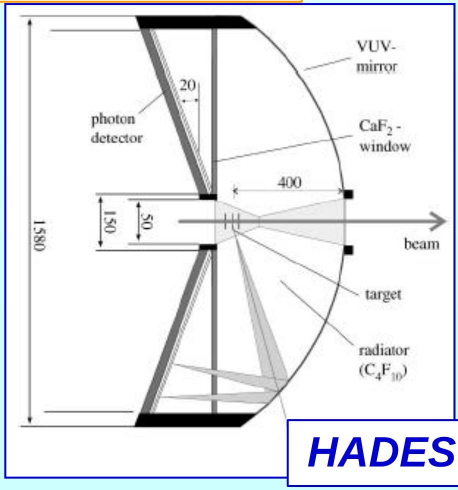
A solid state photocathode exposed to a gaseous atmosphere in an effective PD: a success !



COMPASS RICH-1



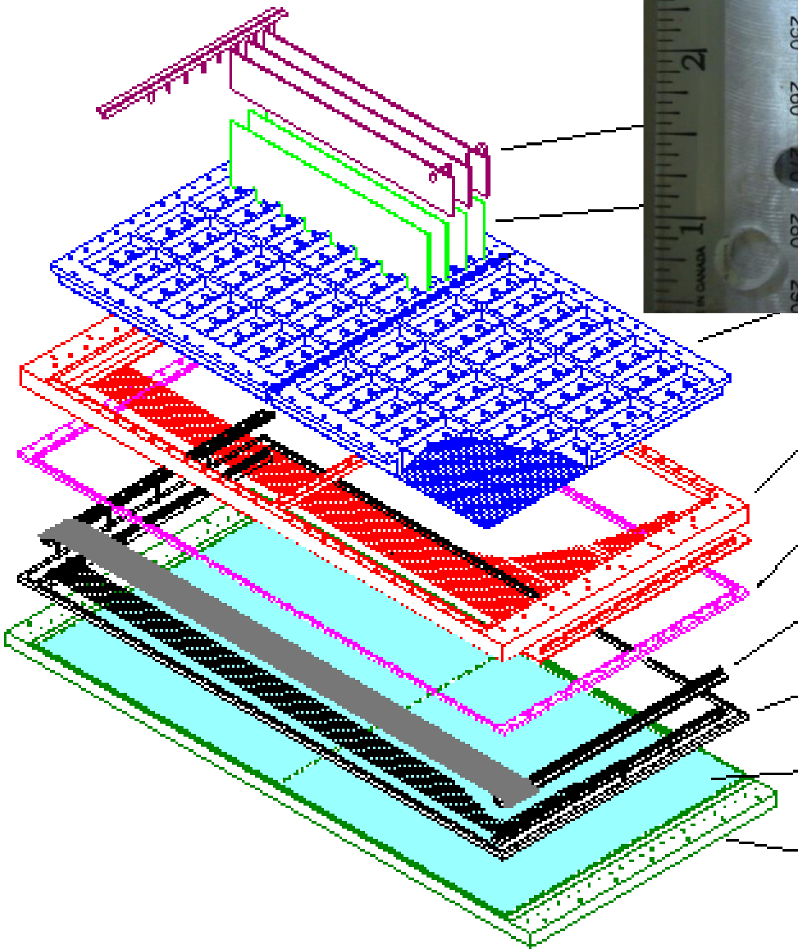
STAR

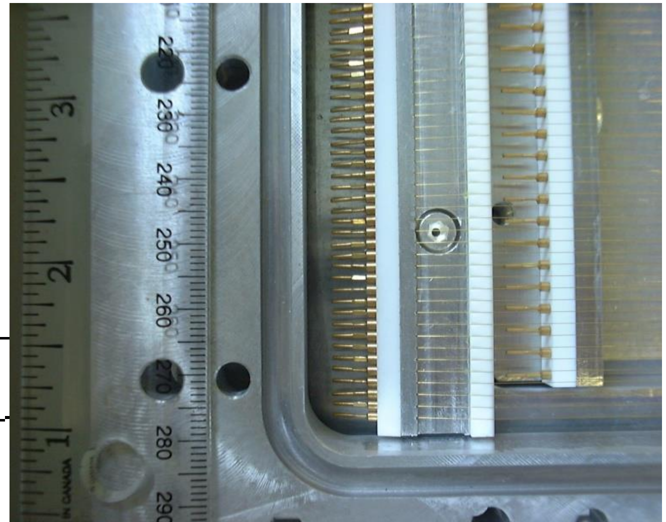


HADES

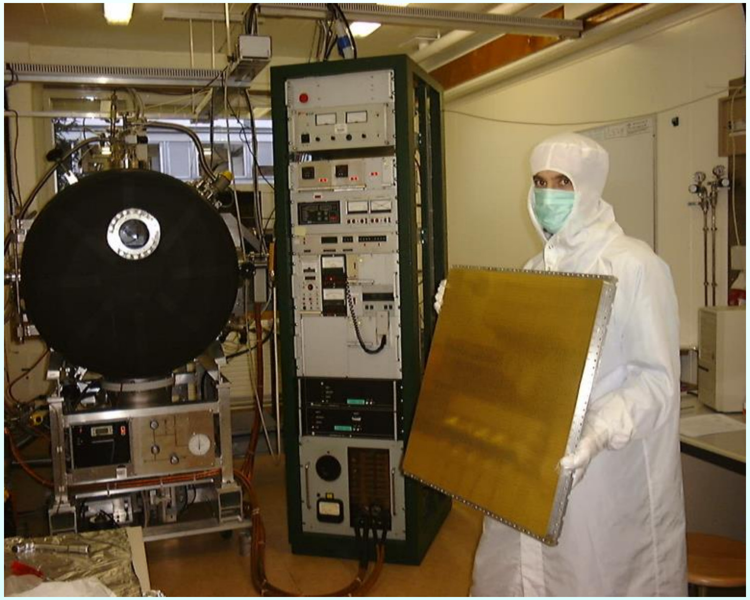
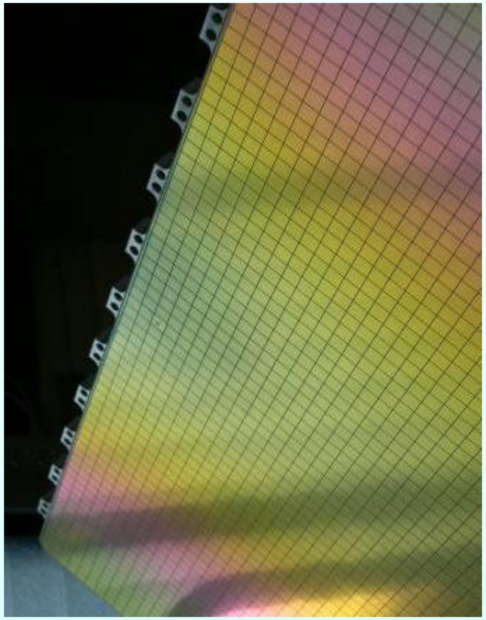
COMPASS: 8 MWPC's with CsI

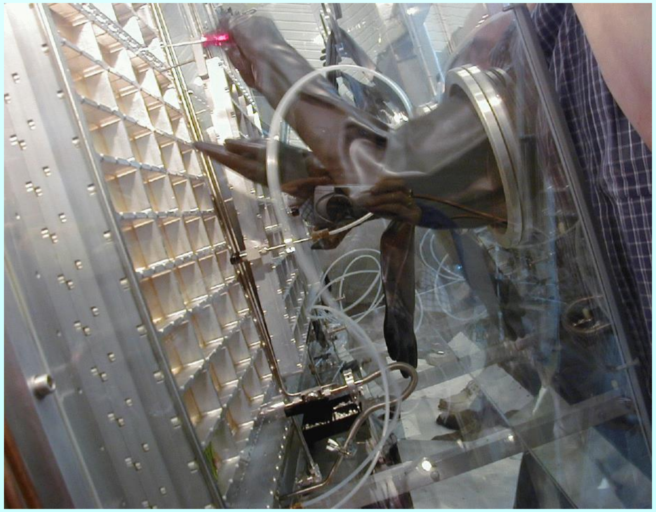
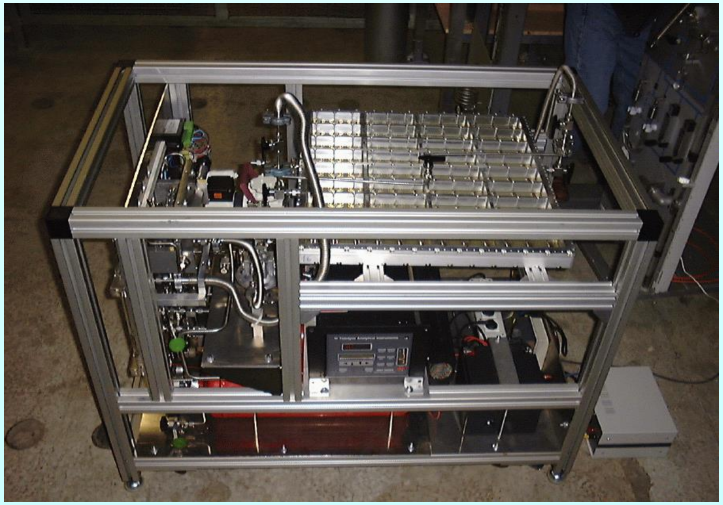
built in 1999 – 2000, after prototypes tests (RD26 development)





The CsI photocathodes

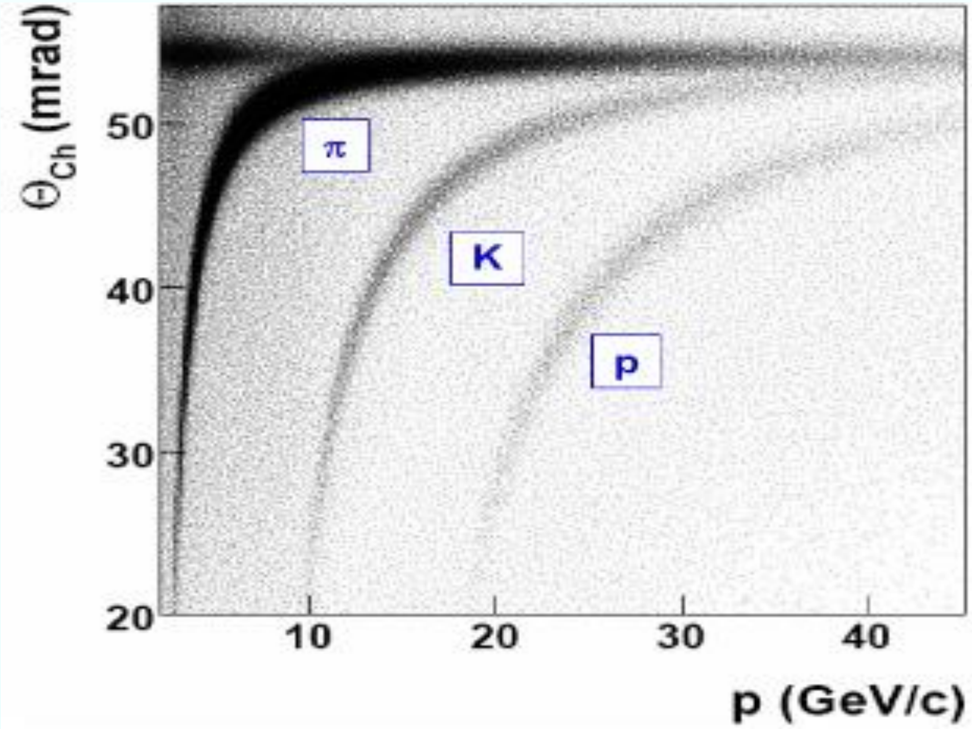



Good performance in low gain configuration

- 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

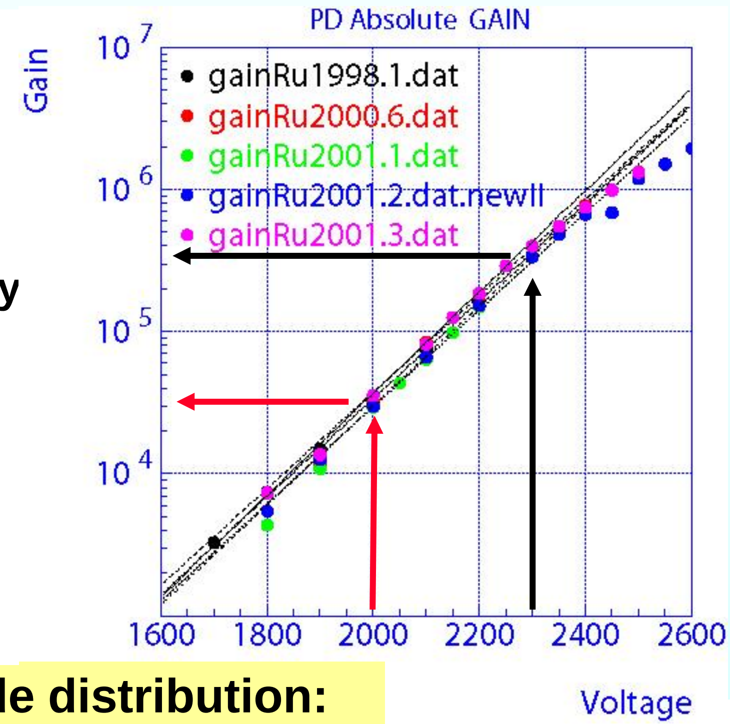
beam on: stable operation only up to ~2000 V

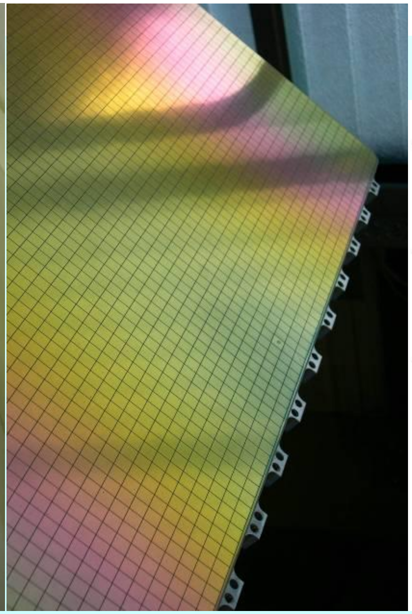
(in spill→ ph. flux: 0 - 50 kHz/cm^2 , mip flux: ~1 kHz/cm^2)

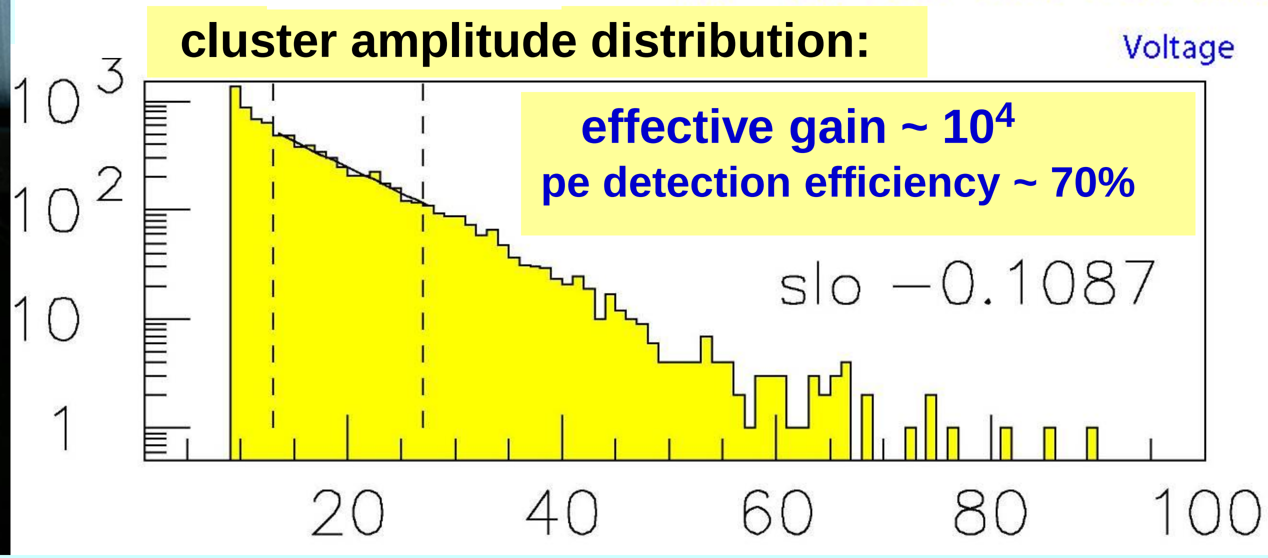
Whenever a severe discharge happens, recovery takes ~1 day

2) **Photocathode aging:**

- **our information from accidental contamination**
- **very detailed study by Alice team**





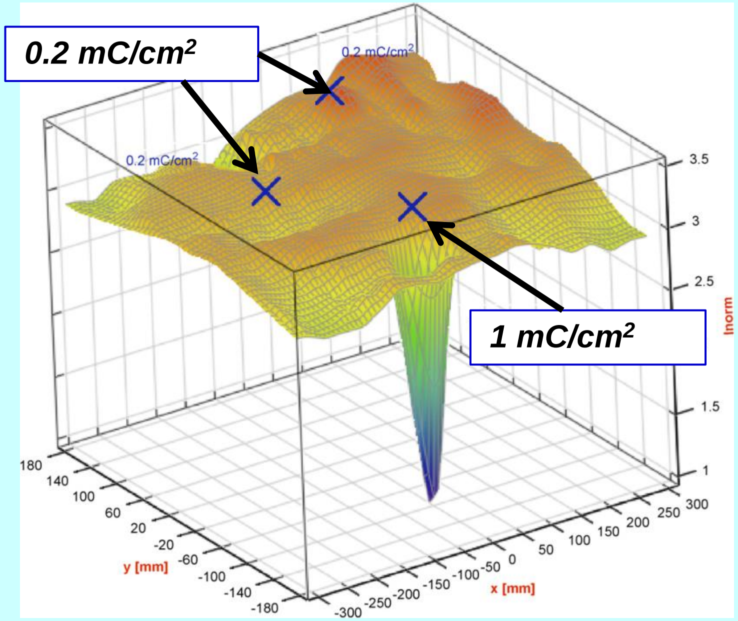


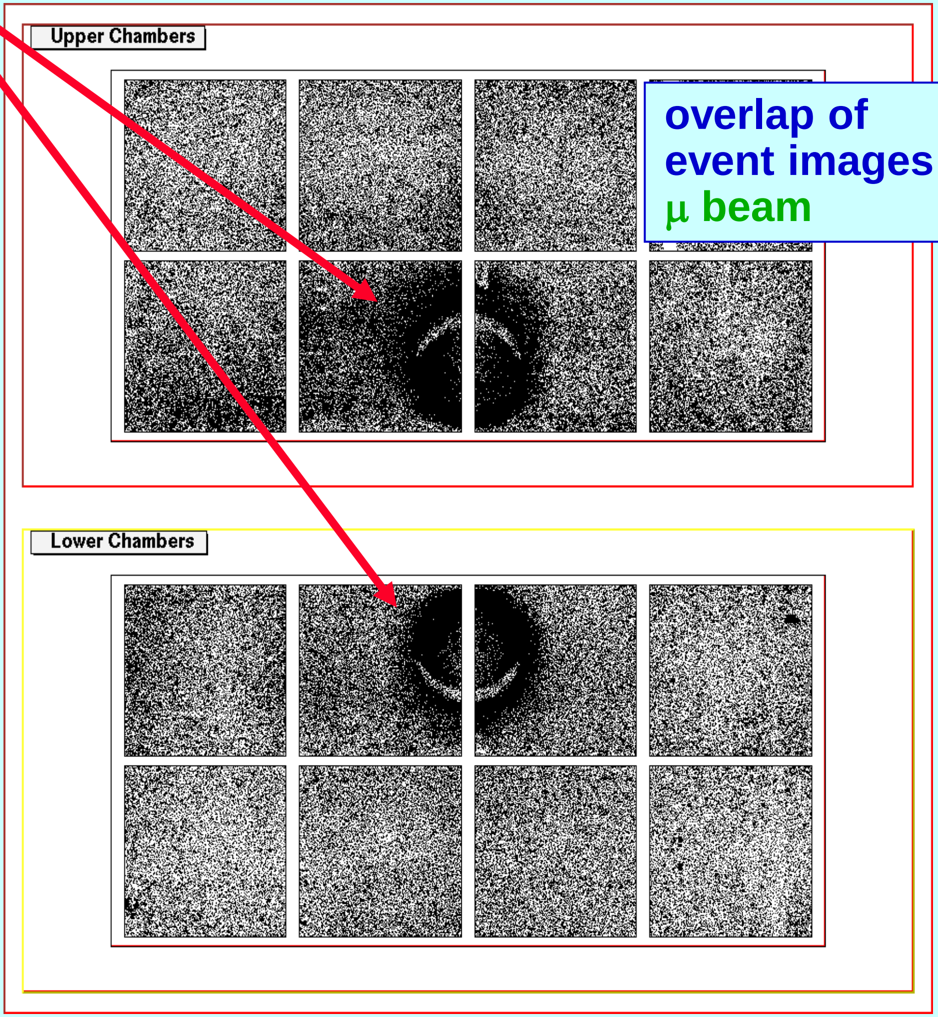
the central region before 2006

THE EXPERIMENTAL ENVIRONMENT

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

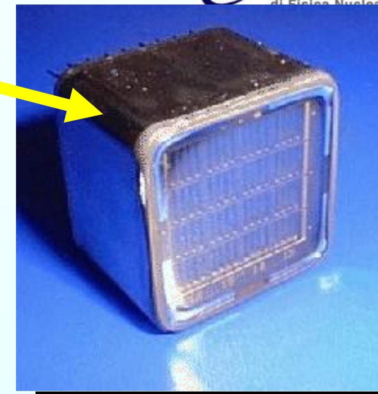
Accelerated ageing test
H. Hoedlmoser et al., NIM A 574 (2007) 28.





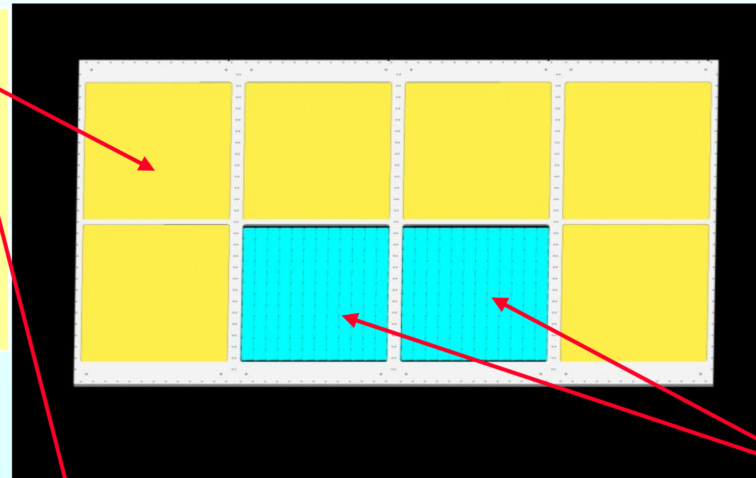
overlap of event images
μ beam

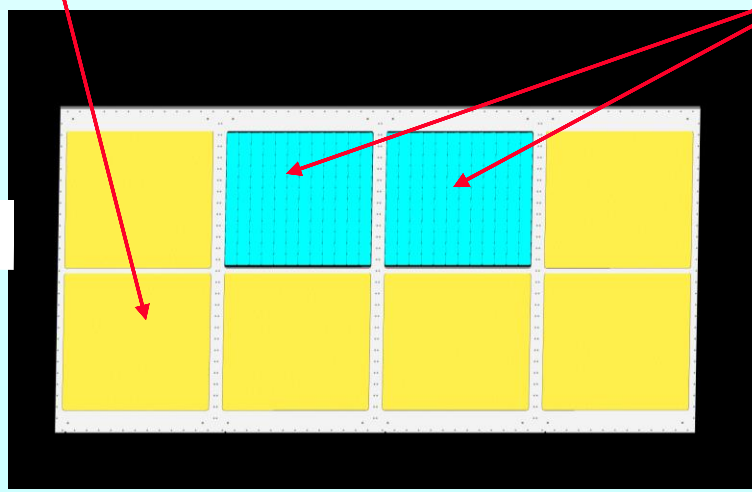
upgrade of RICH-1 with MAPMT's in the central region (2006)

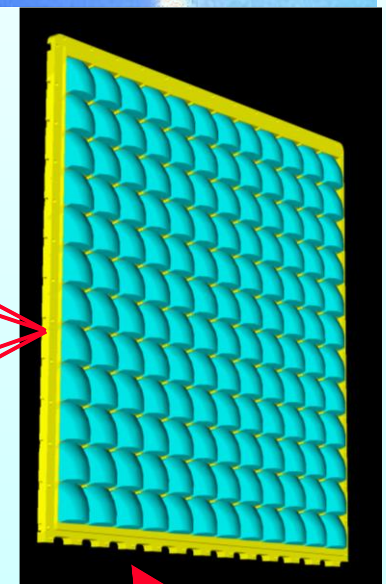


12 outer CsI cathodes: change electronics (use APV25-S1)

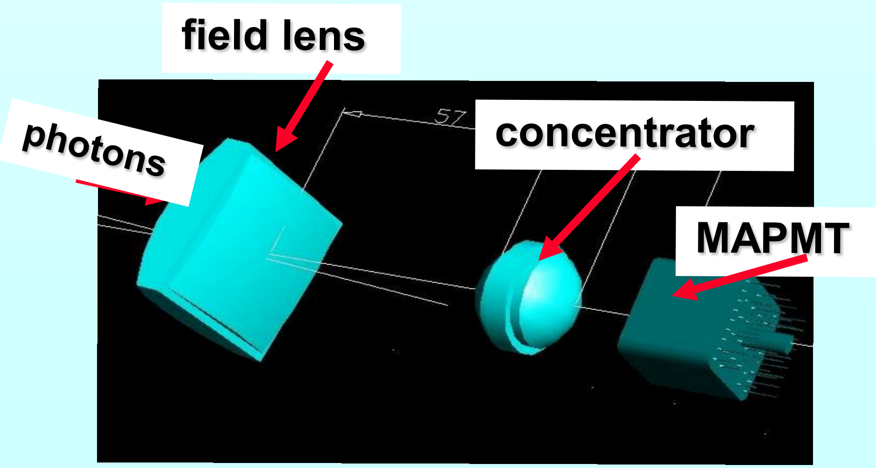
4 central CsI cathodes: remove and insert frames with MAPMTs and lense telescopes







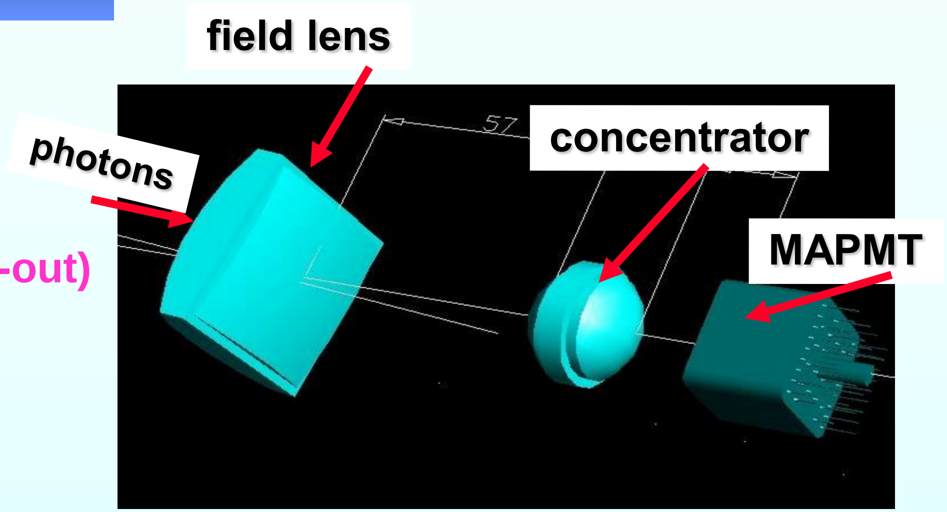
Same mechanics as CsI photo-cathode frame

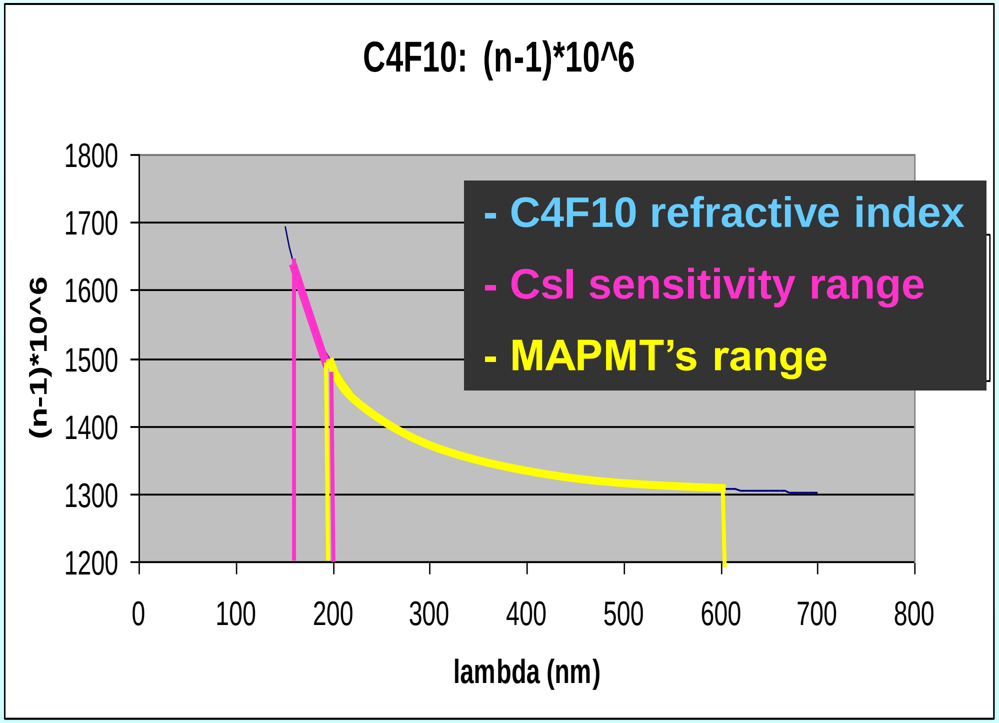


The difference

MAPMT's have:

- wide wavelength range
- time resolution < 1 nsec
- short detection system memory (MAPMT + read-out)
- adequate for high rate operation
- robustness
- high efficiency for single photon detection





challenges:

large ratio of the collection and photocathode areas with minimal image distortion

→ ratio = 7.3 ←→ critical LENS SYSTEM design

UV range ←→ fused silica LENSES

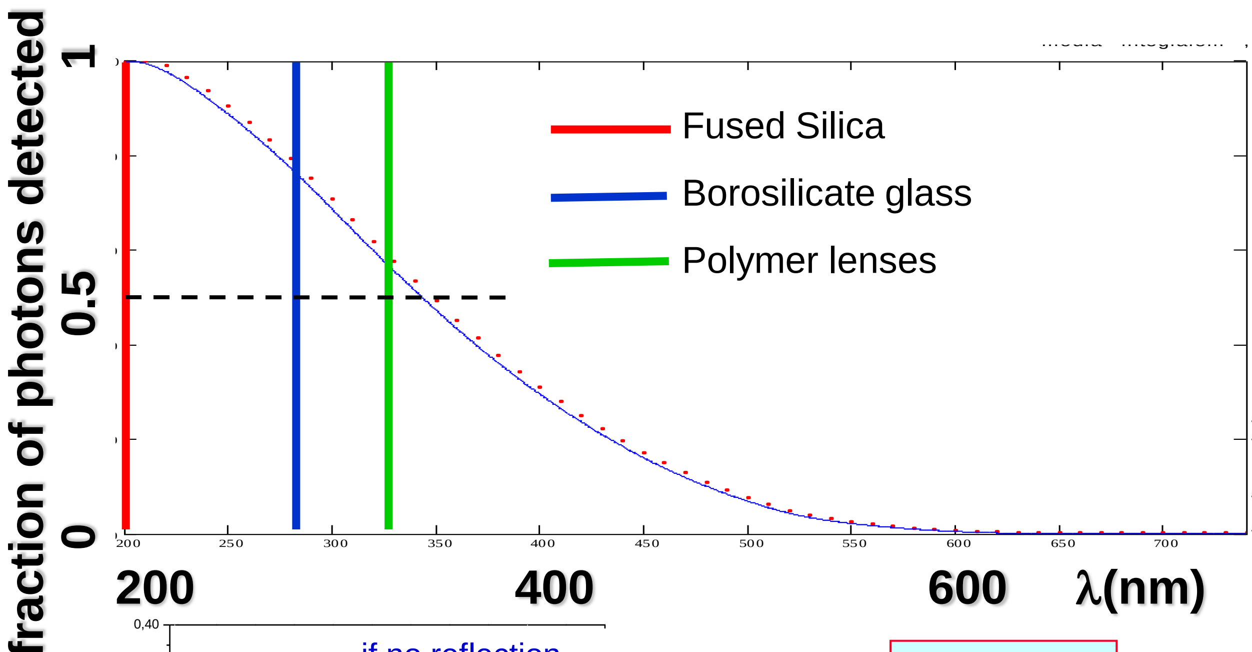
couple to a read-out system able to guarantee efficiency, high rate operation and to preserve time resolution

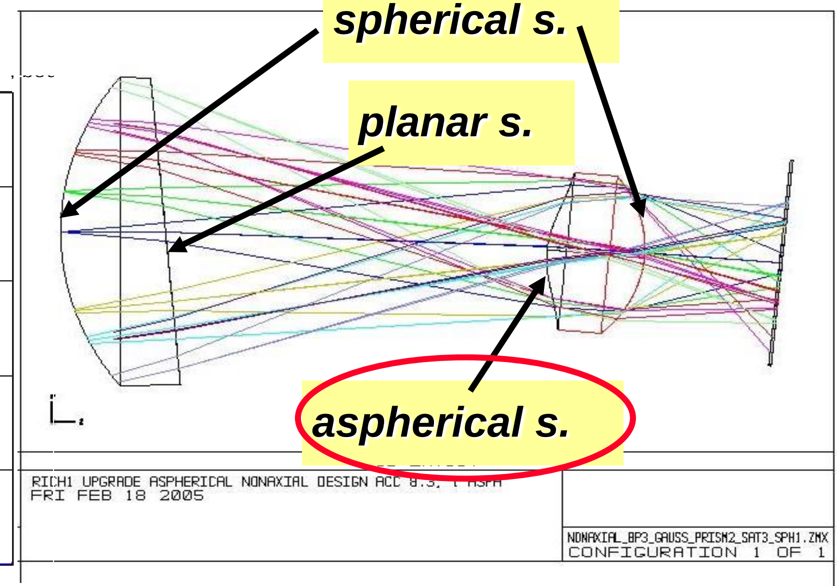
THE LENSES

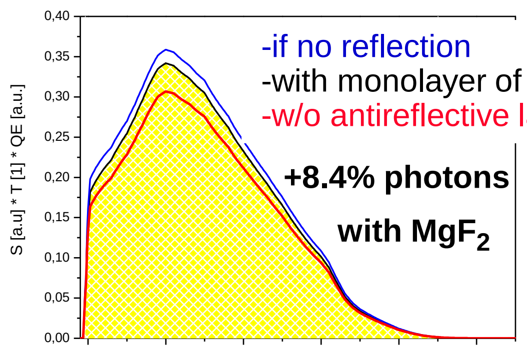
$$\int_{\lambda}^{800} QE(\lambda)\cdot S(\lambda)\cdot d\lambda \Big/ \int_{200}^{800} QE(\lambda)\cdot S(\lambda) d\lambda$$

material:
fused silica, Corning 7980,

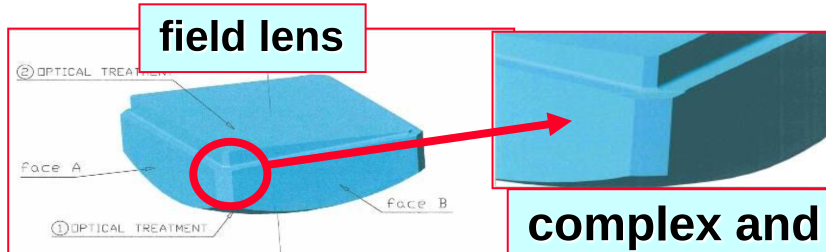
ZEMAX optimization:



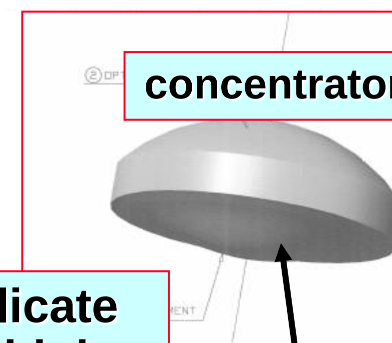




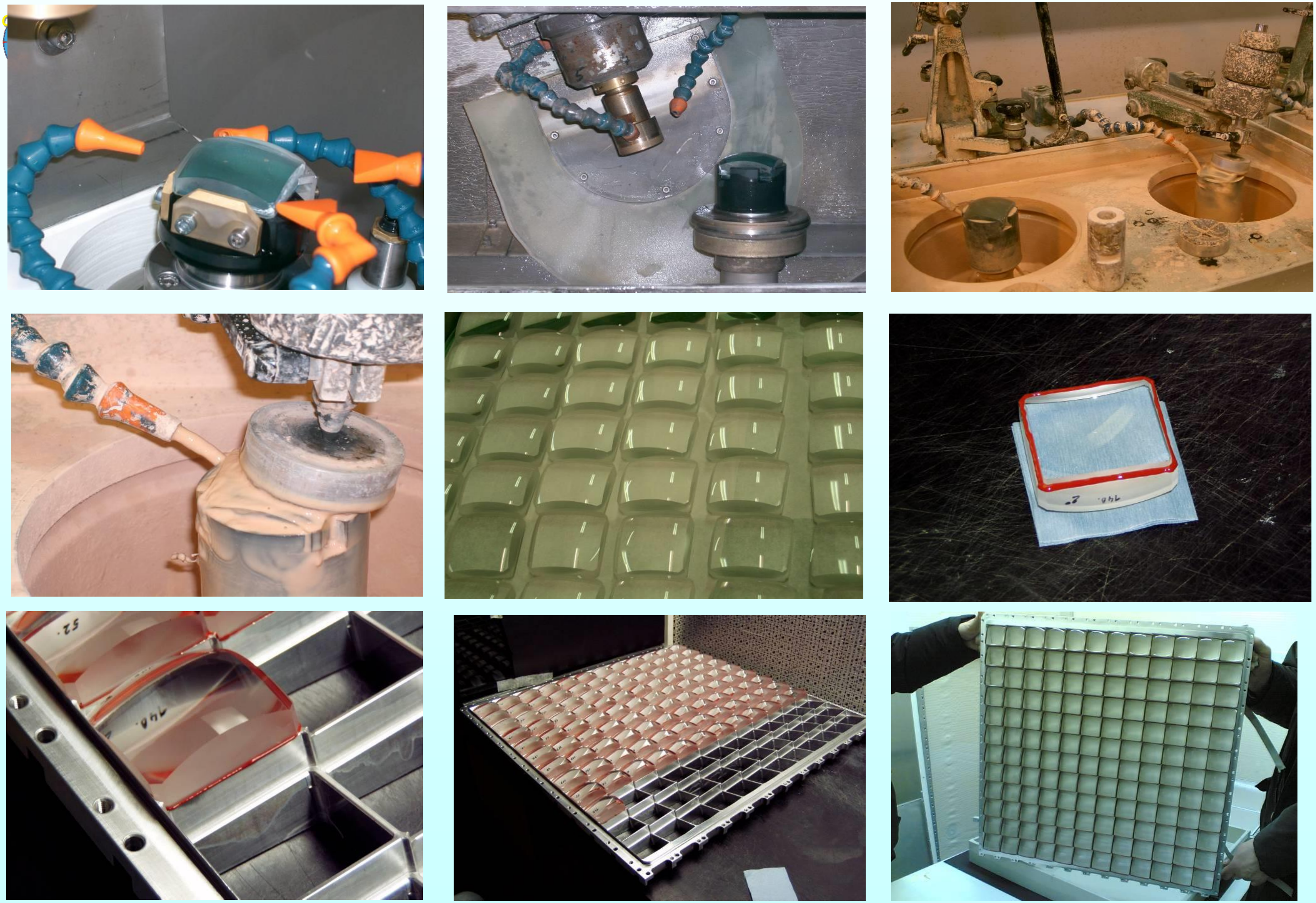
Convolution of Cherenkov light and effective QE



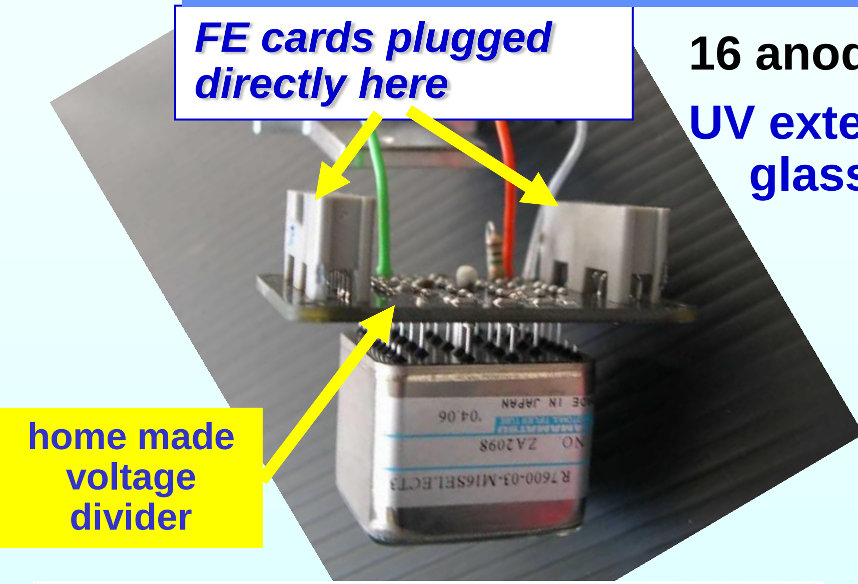
complex and delicate mechanical machining



Fulvio TESSAROTTO

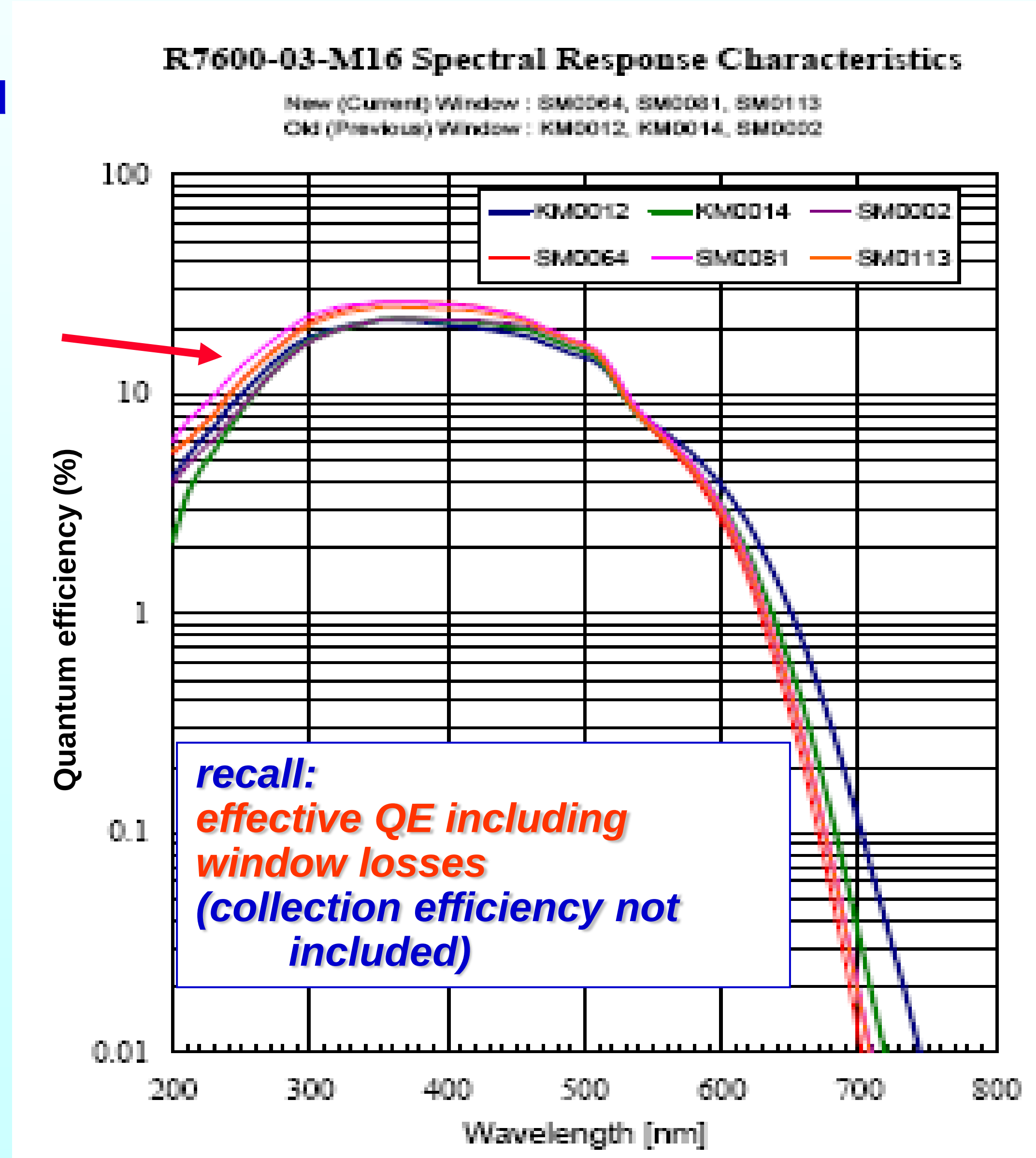


MAPMT: HAMAMATSU R7600-03-M16



16 anodes

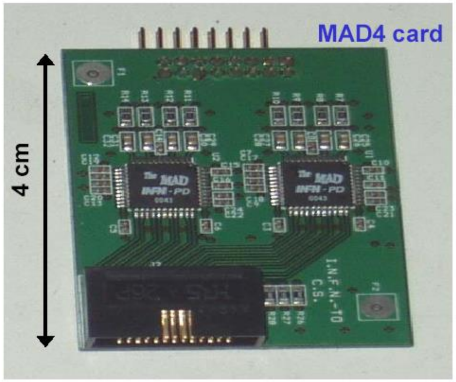
UV extended glass

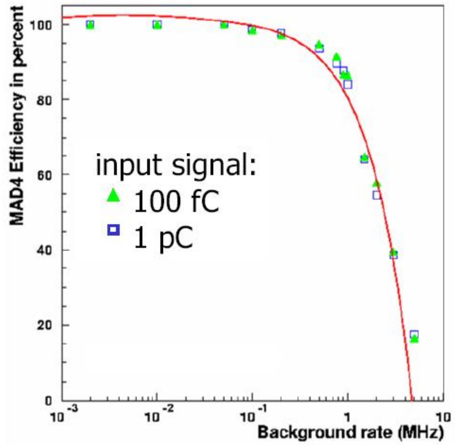


Analogue read-out electronics: MAD4 preamplifier

- up to ≈ 1 MHz / channel
- low noise ≈ 5-7 fC
- single photon PMT signal ≈ 1 pC (at 900 V)
- clear separation signal / noise

further development by INFN TORINO: CMAD in 2007
up to 5 MHz / channel

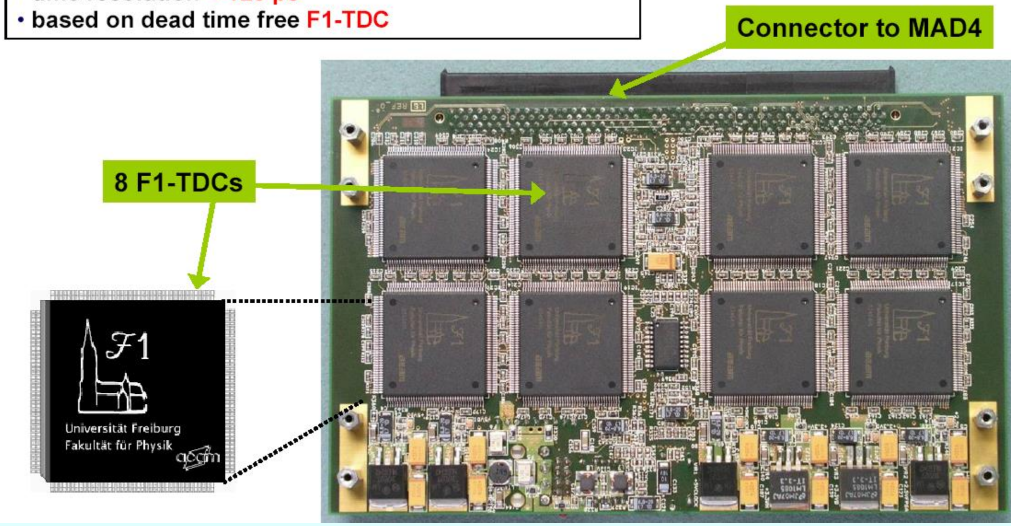


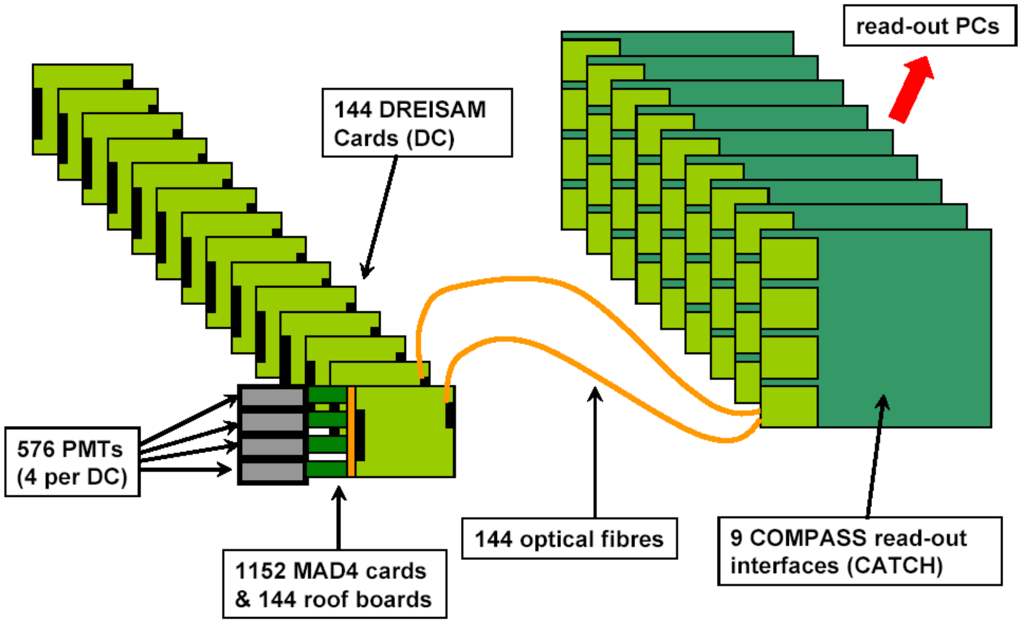


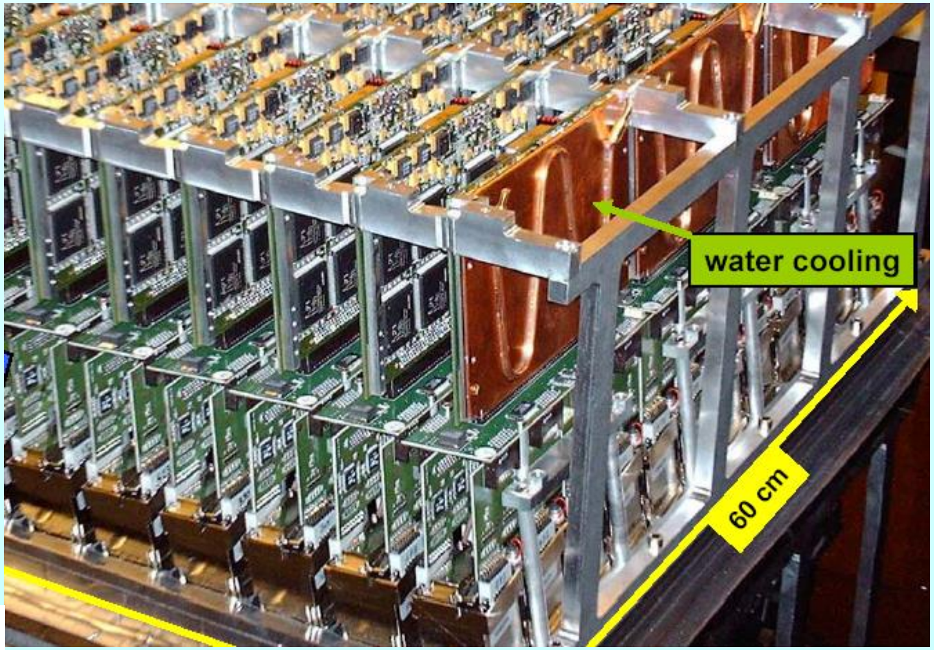
Digital read-out electronics: DREISAM card

- 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



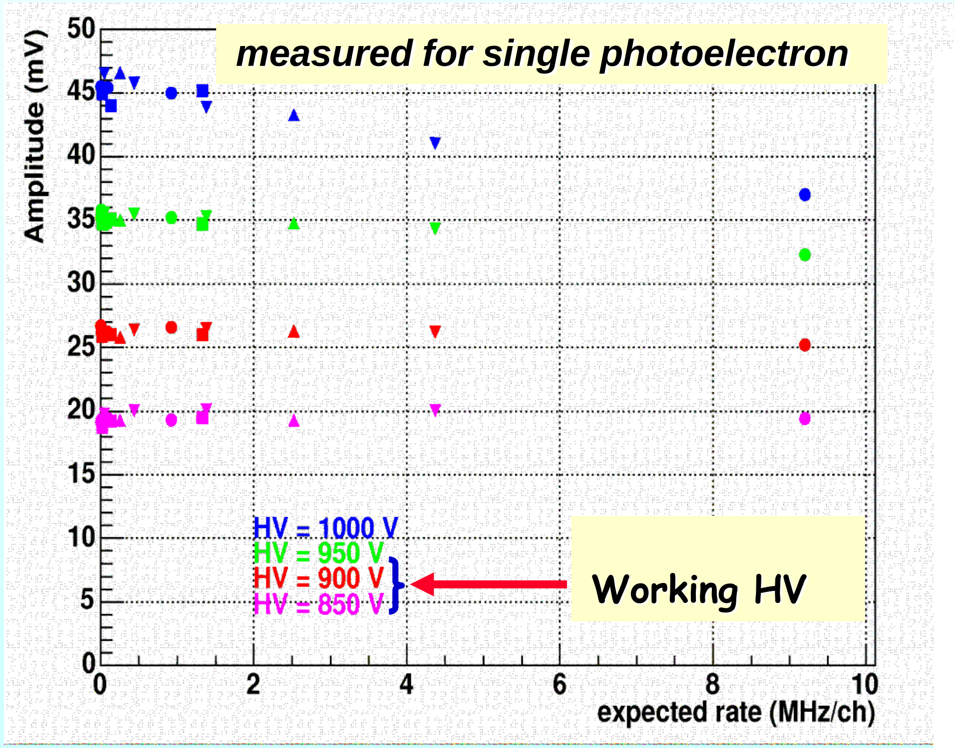




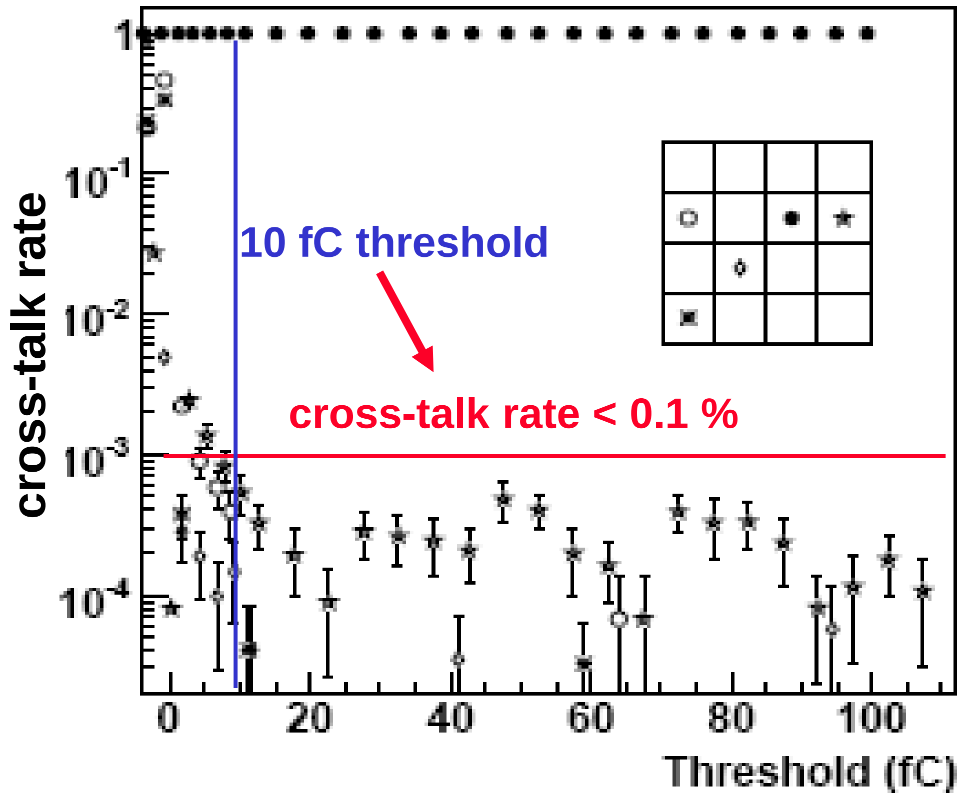
MAPMT GAIN AT HIGH RATE AND CROSS-TALK RATE

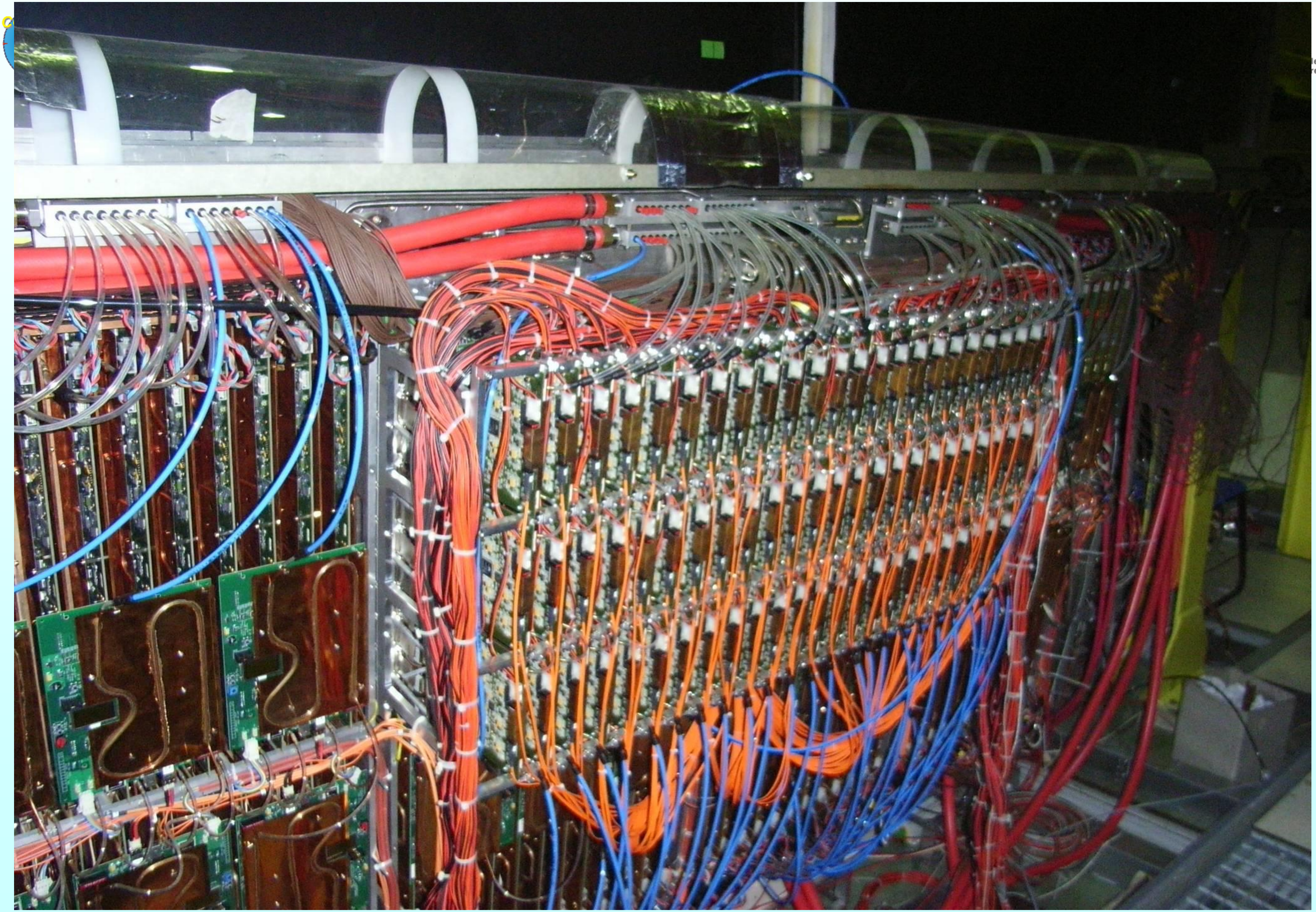
mean signal amplitude versus rate/pixel

pulsed light source synchronous to trigger + random background from lamp

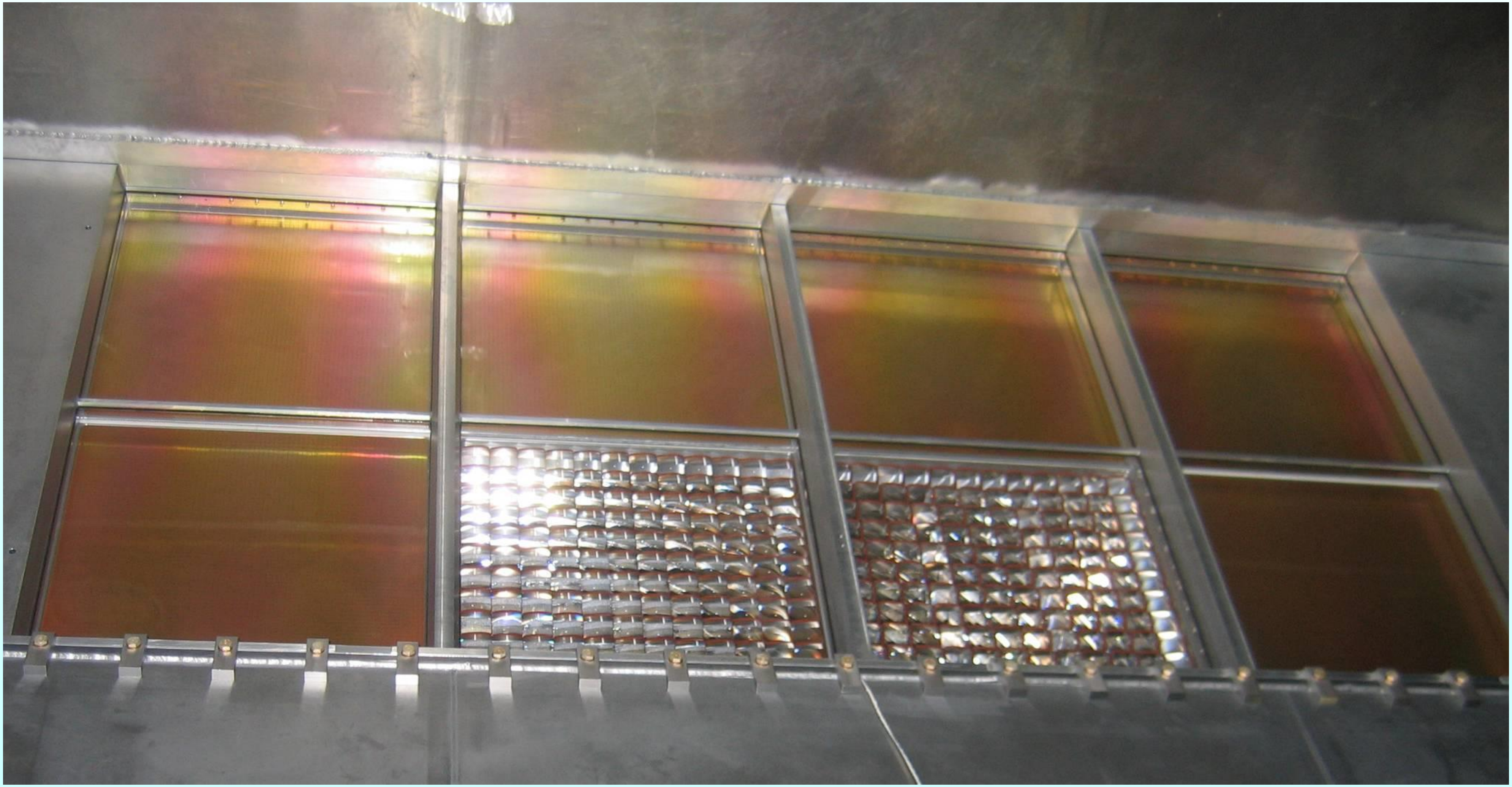


operate with single photoelectron rates up to 5MHz/pixel

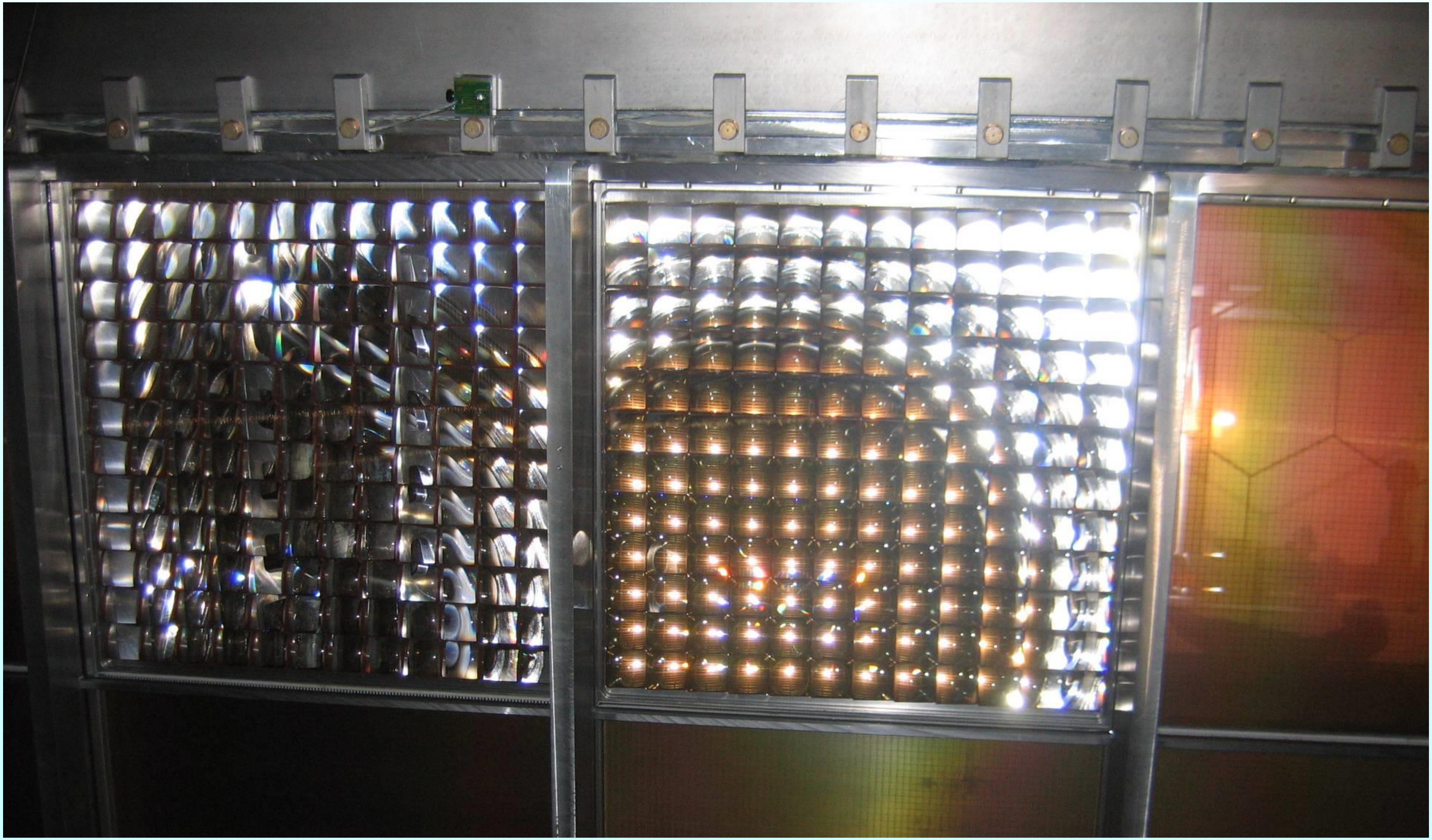




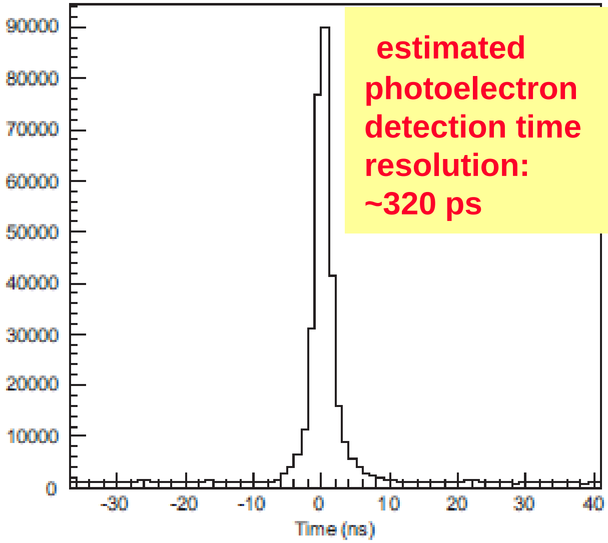
The Upper Detector from inside

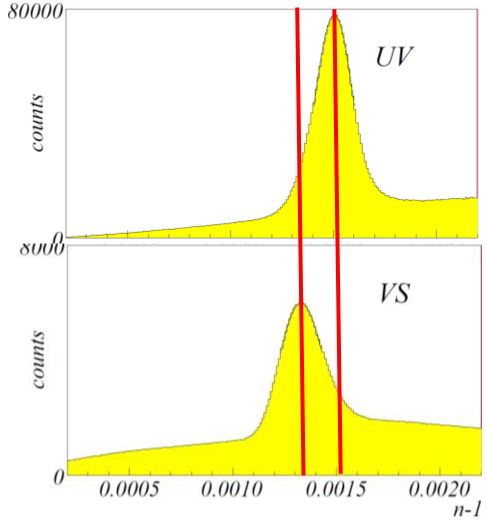


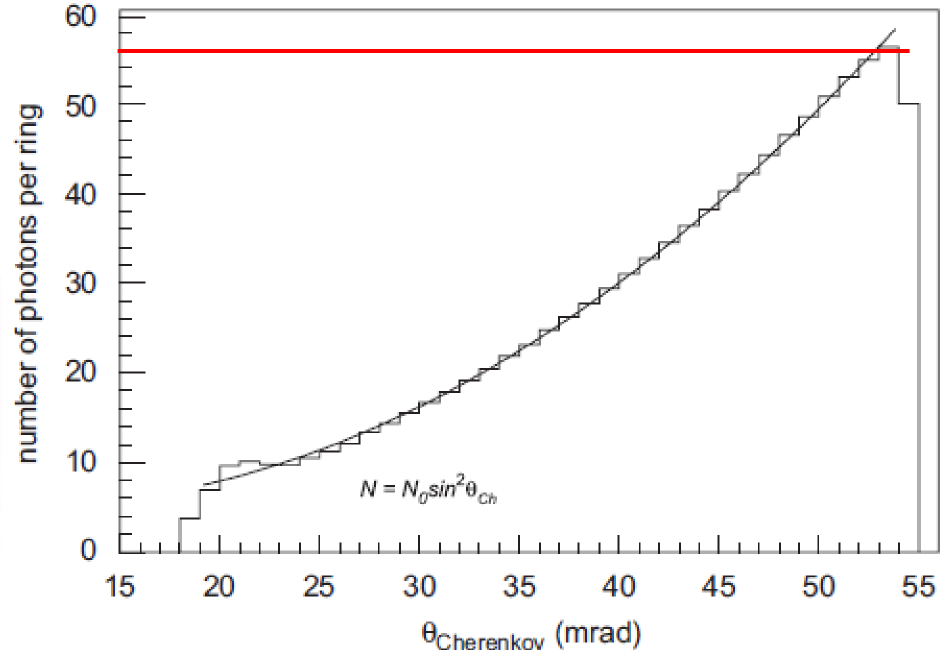
The central part of the lower detector

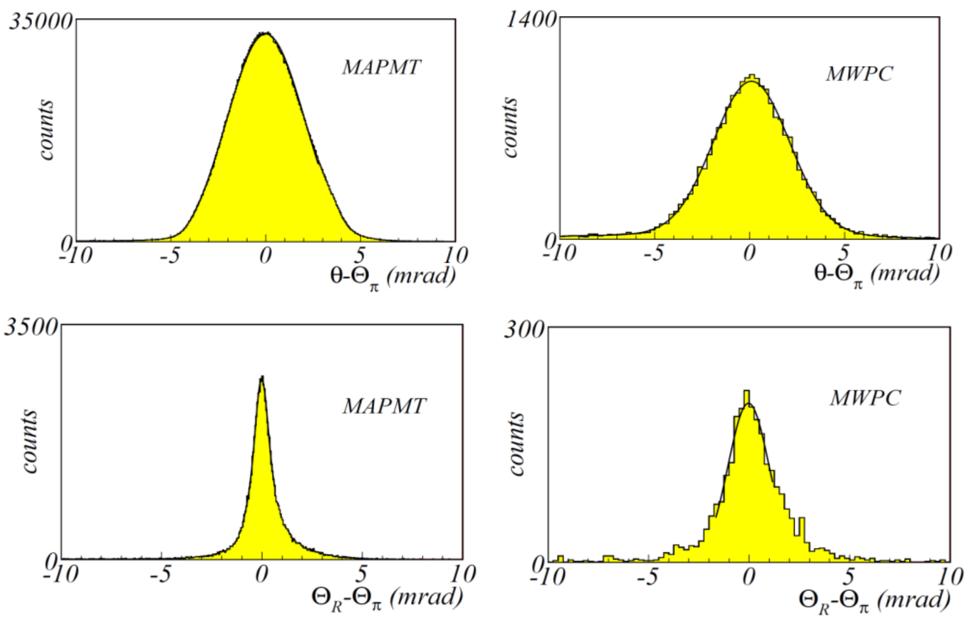


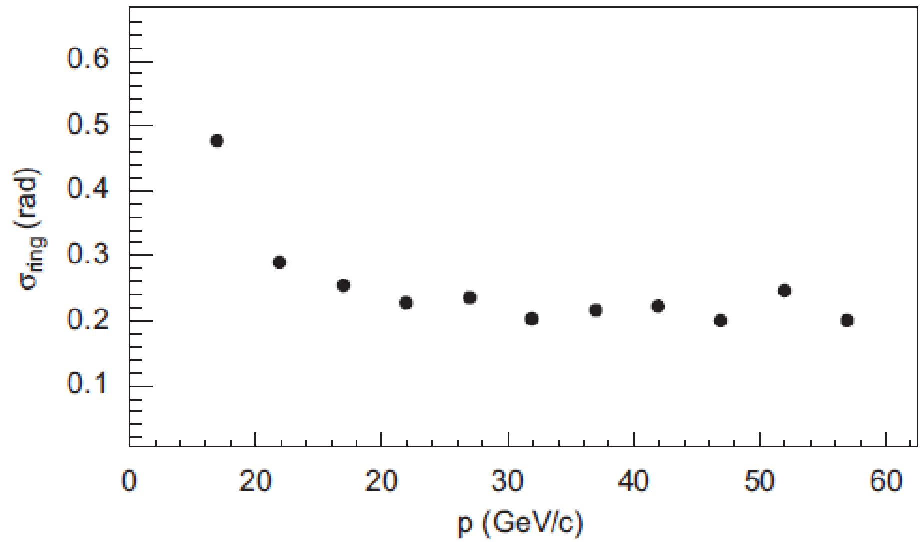
number of photons and resolutions



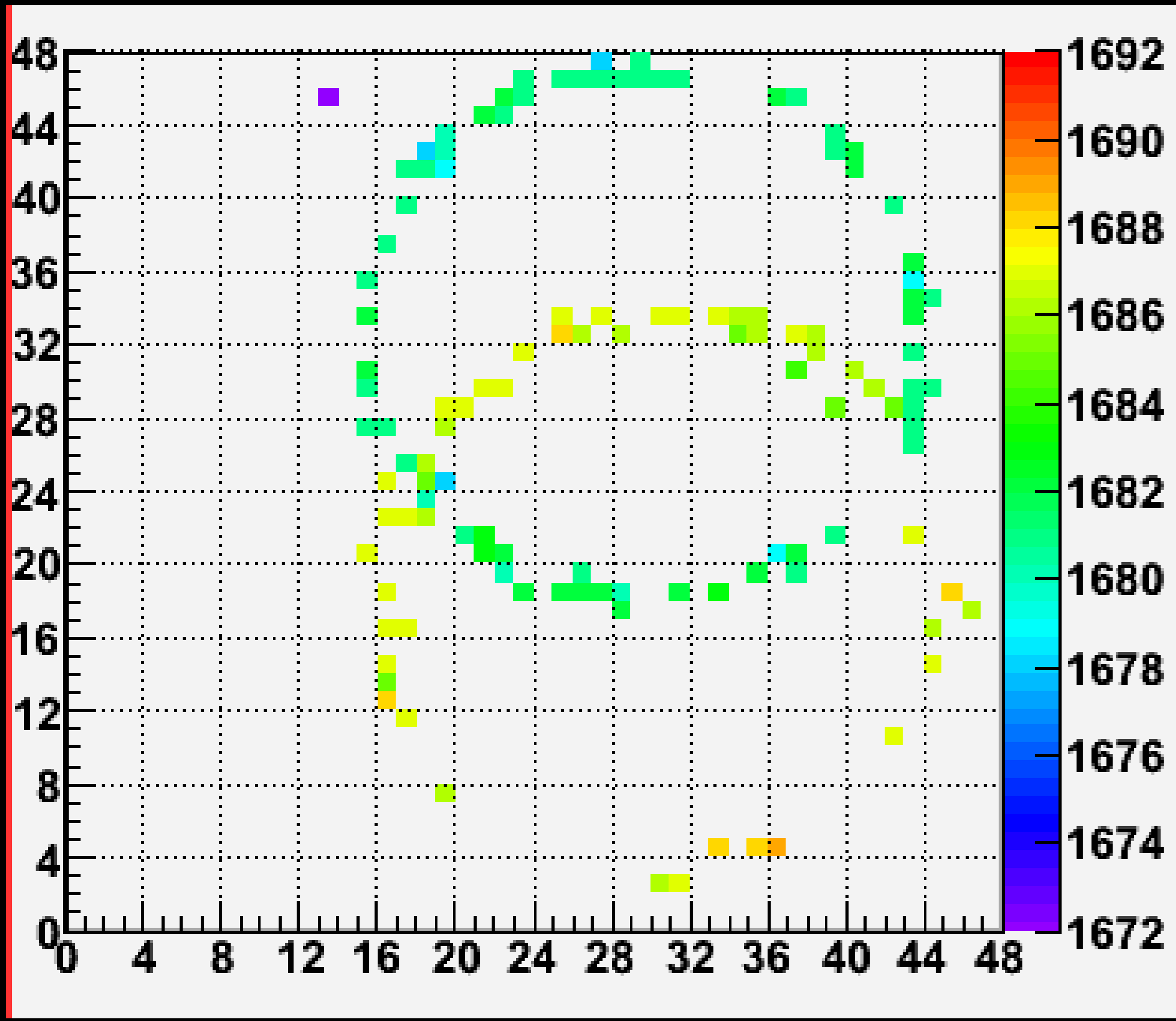








time resolution is useful for correctly assigning hits to rings



PID from the likelihood function

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

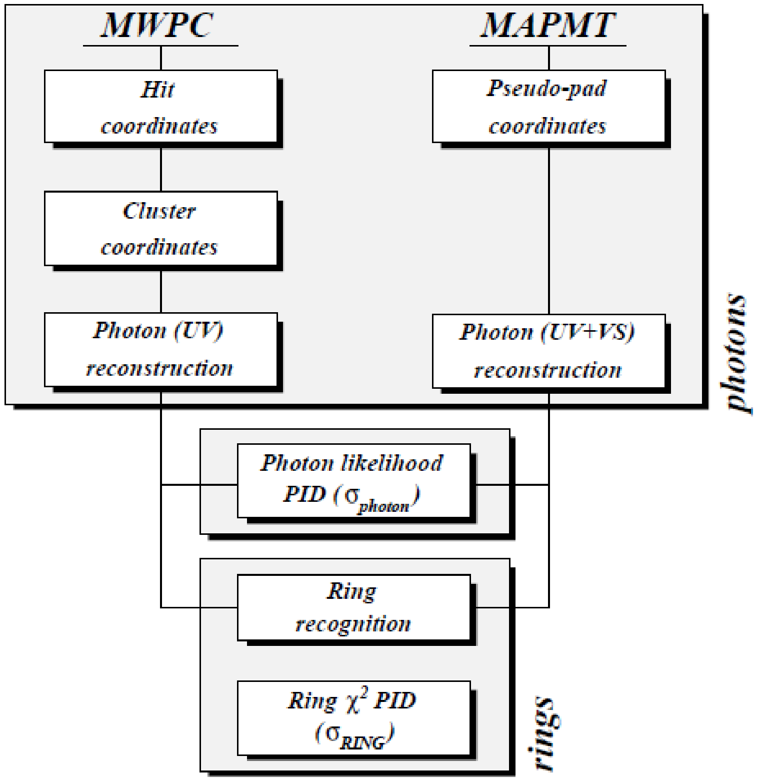
no reference to a reconstructed ring

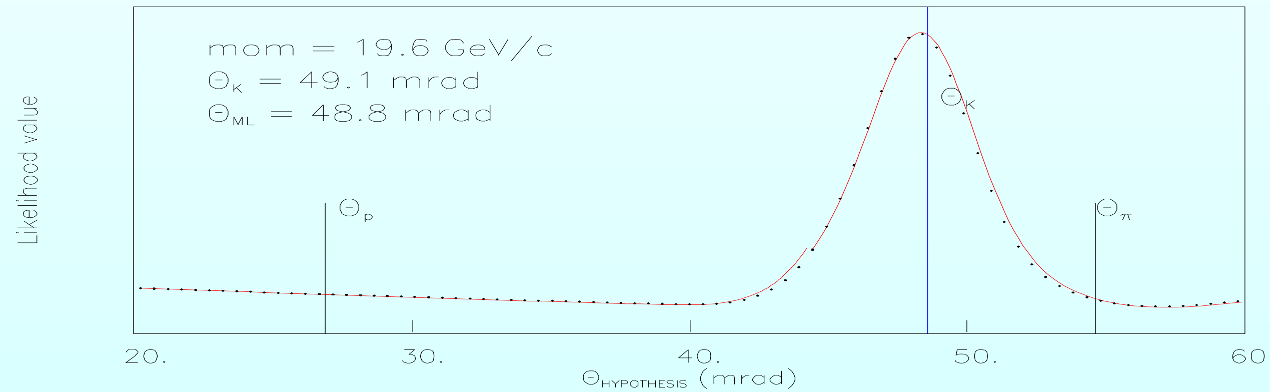
$$L_M = \prod_{j=1}^{N} \frac{s_M(\theta_j, \varphi_j) + b(\theta_j, \varphi_j)}{S_M + B}$$

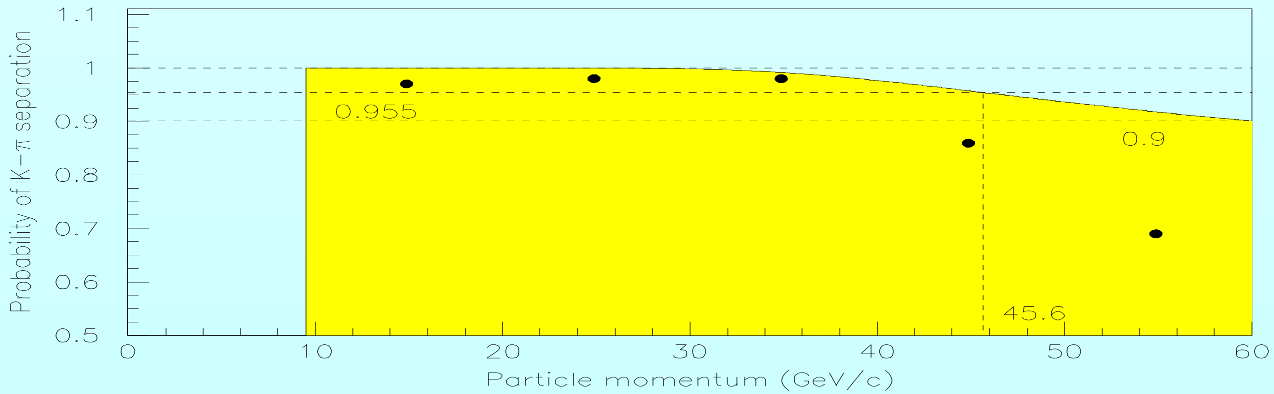
Computed for

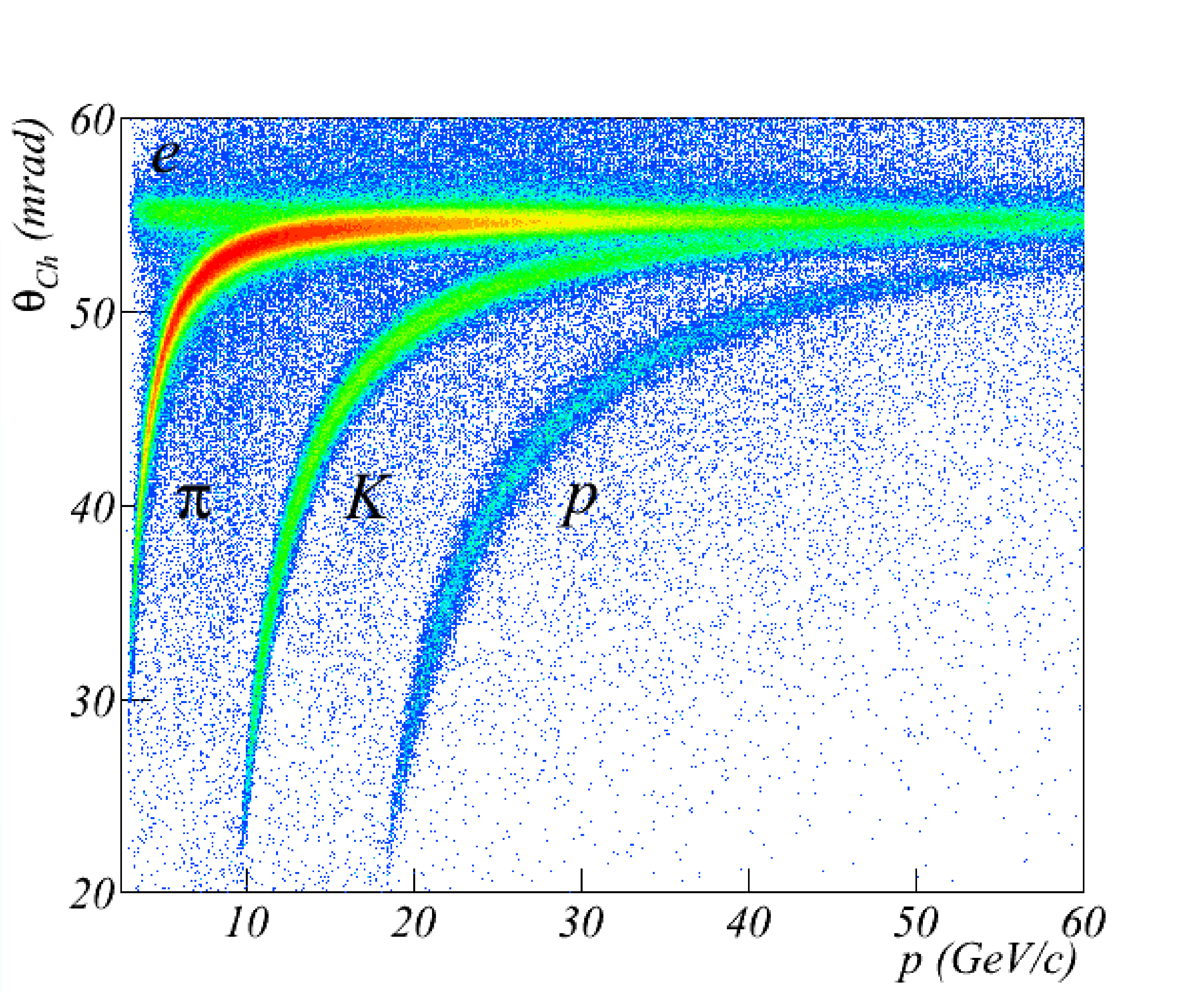
5 mass hypothesis $M = e, \mu, \pi, K, p,$

+ background hypothesis (no signal)



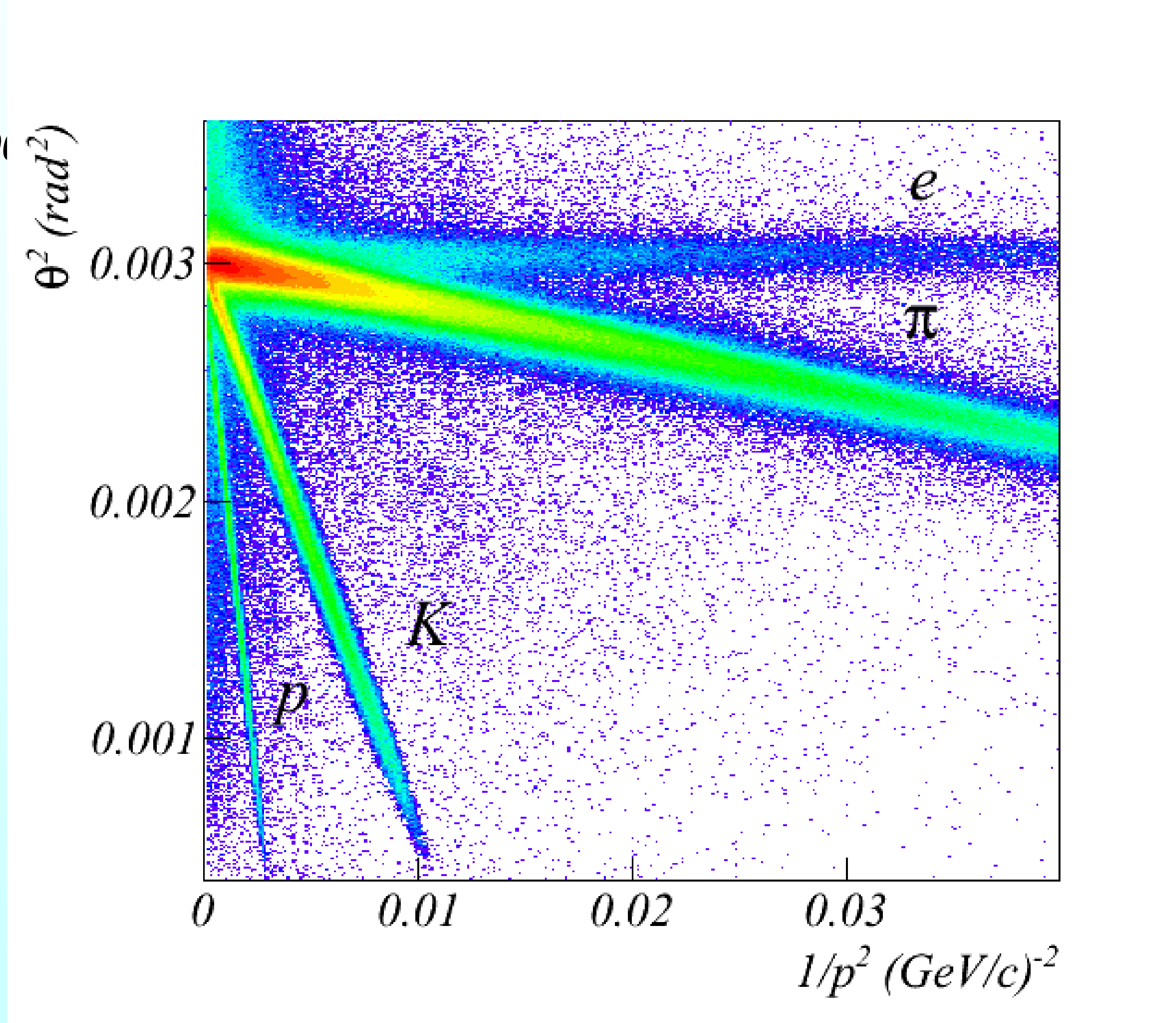






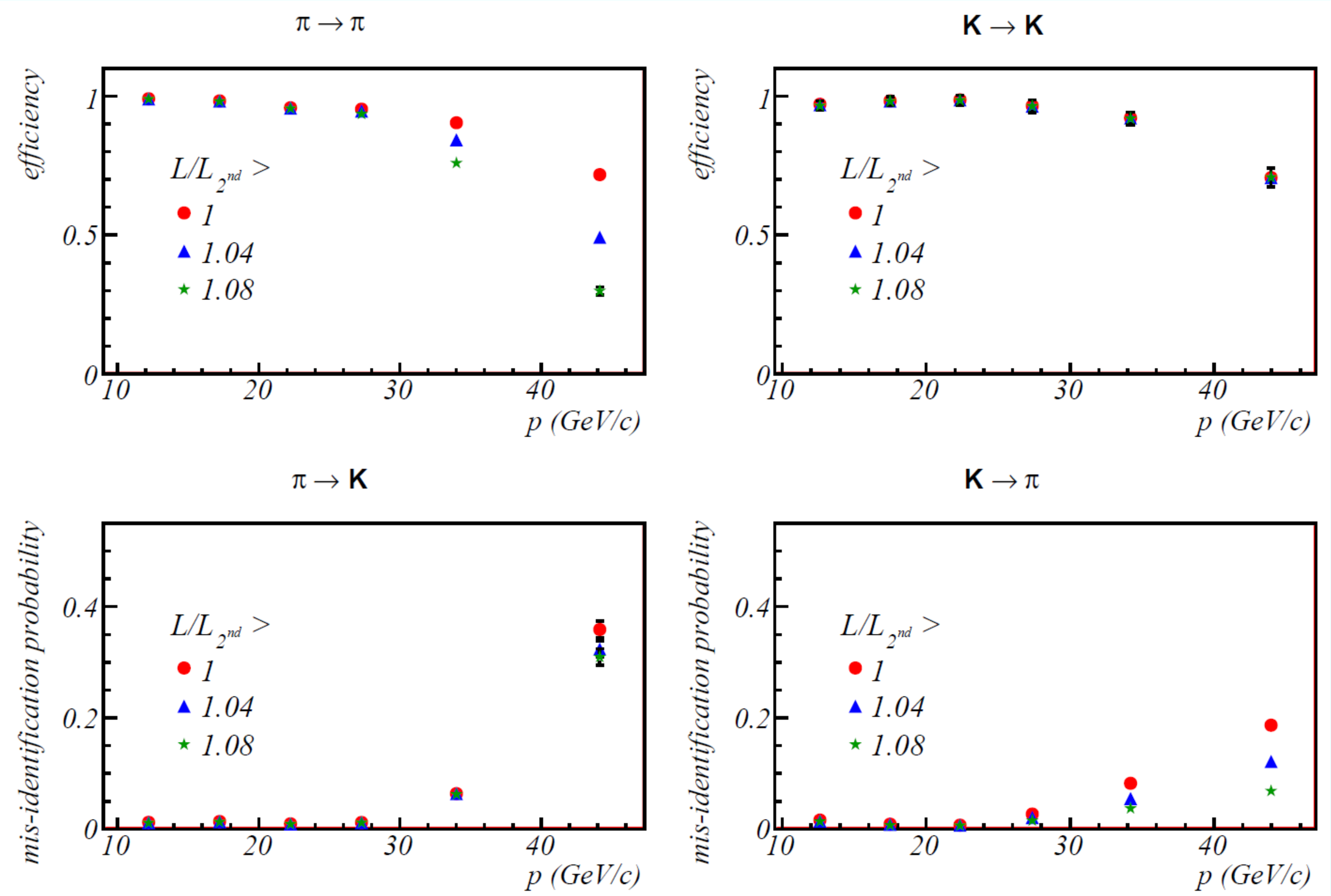
M (GeV/c²)

20

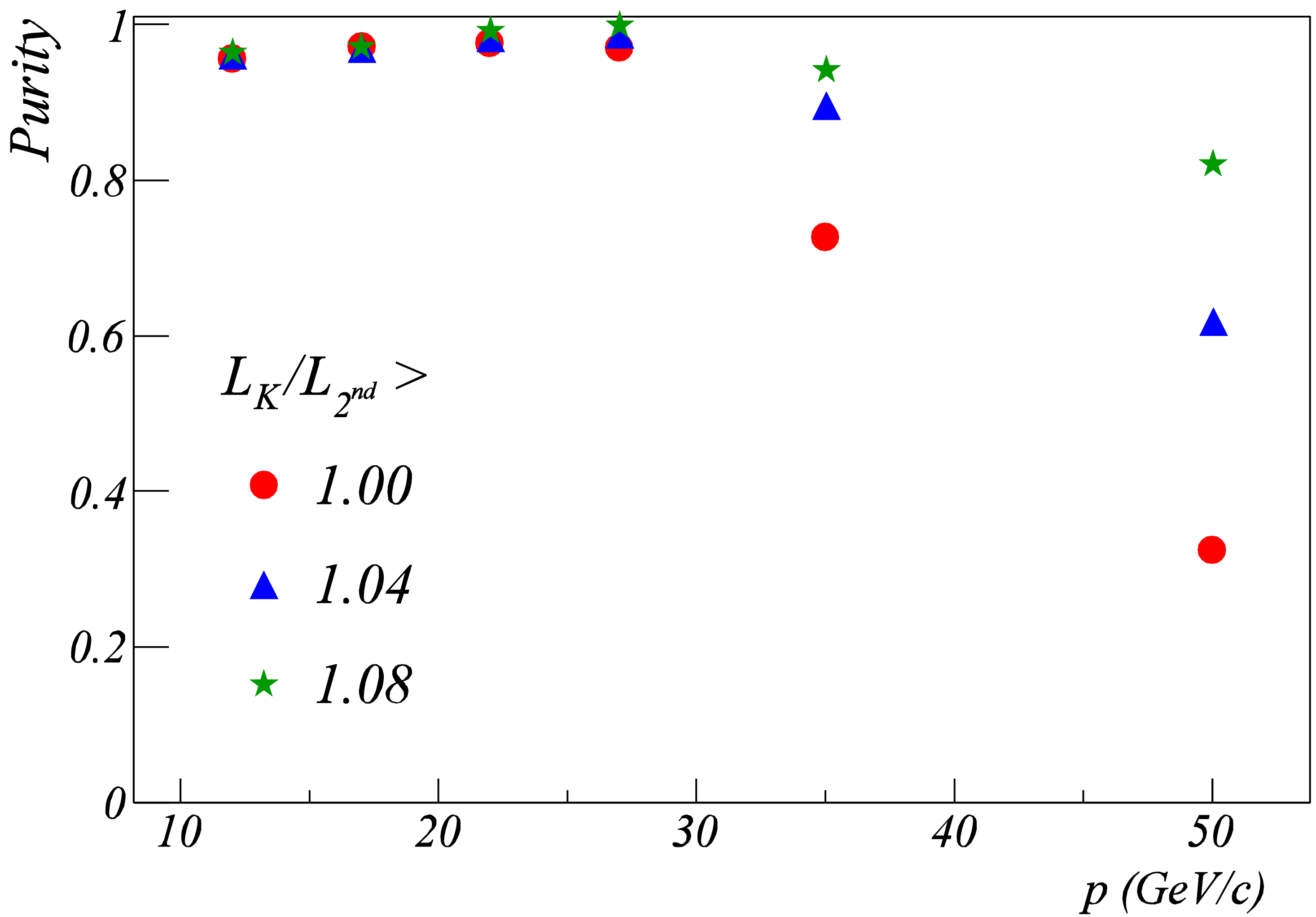


M
(GeV/c^2)

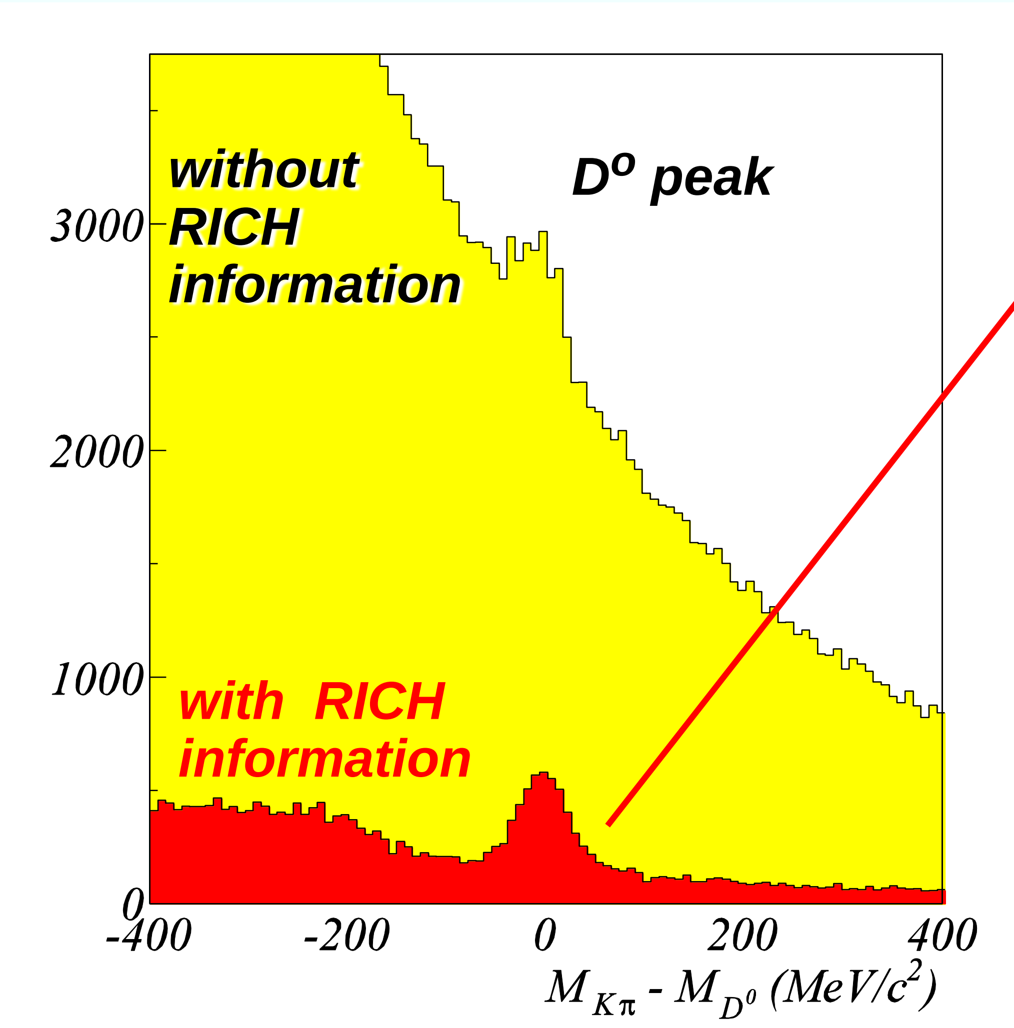
Identification and misidentification probability

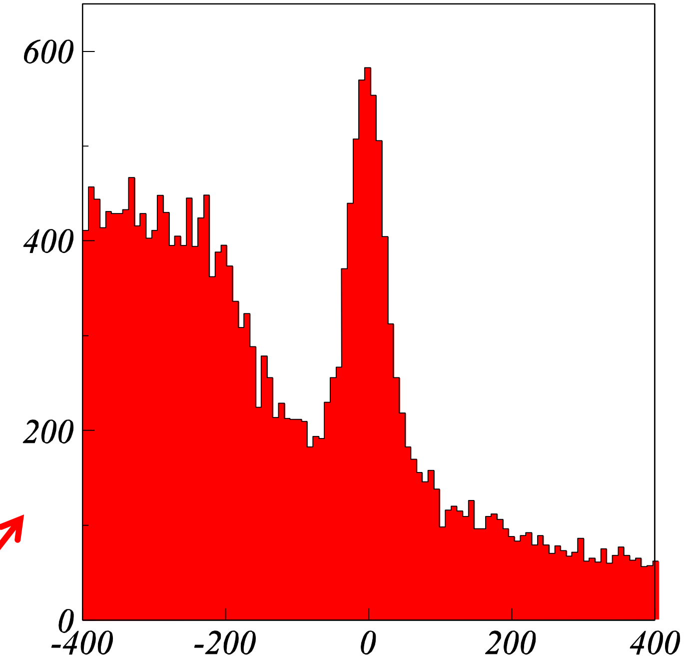


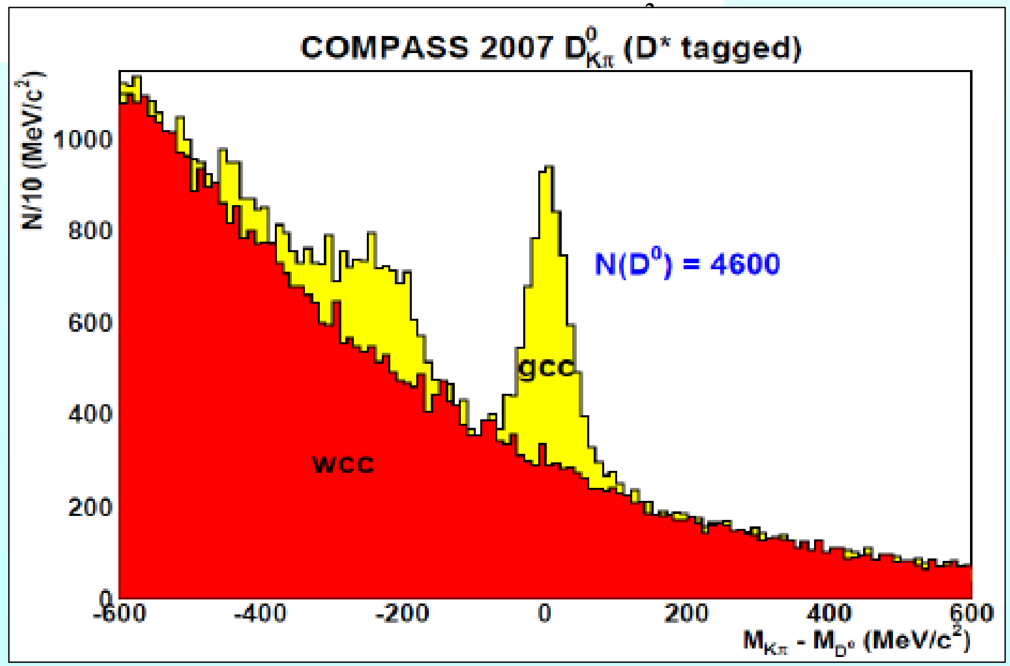
Purity of K samples



RICH PID information in the D^0 analysis







Study of long term CsI QE variations

M. Alexeev et al, 2014 JINST 9 P01006

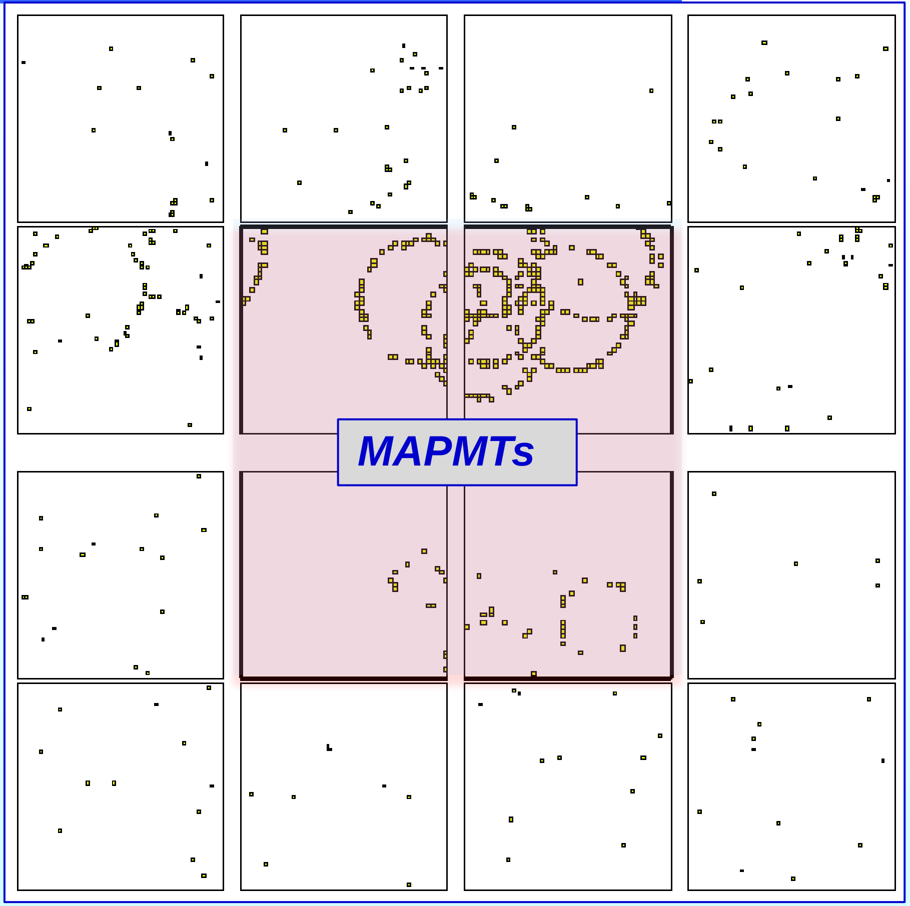
Principle:
Extract the mean number of detected photons per particle from the data collected during six years of COMPASS data taking

6 consecutive years of COMPASS data taking

up to 15 days of data taking per sample

identical cuts applied to the reconstructed particle trajectories (track quality)

YEAR	BEAM	BEAM MOMENTUM (GeV/c)
2006	mu	160
2007	mu	160
2008	h (pion)	190
2009	h (pion)	190
2010	mu	160
2011	mu	200



RATES IN THE EXTERNAL DETECTORS during SPS spills:

Photoelectrons < 10 *Hz / cm²*

MIPs < 10 Hz / cm²

→ Integrated charge over 6 years < 10 μC/cm²

Data selection, correction and fit

only identified π's

only rings fully contained in a single cathode

count N_{ph} (detected photons) of each ring

(background cannot be disentangled at this stage)

1 mrad wide θ_{Ch} bins → $N = < N_{ph} >$

Cherenkov photons : Poisson distribution

→ detected photons : Poisson distribution

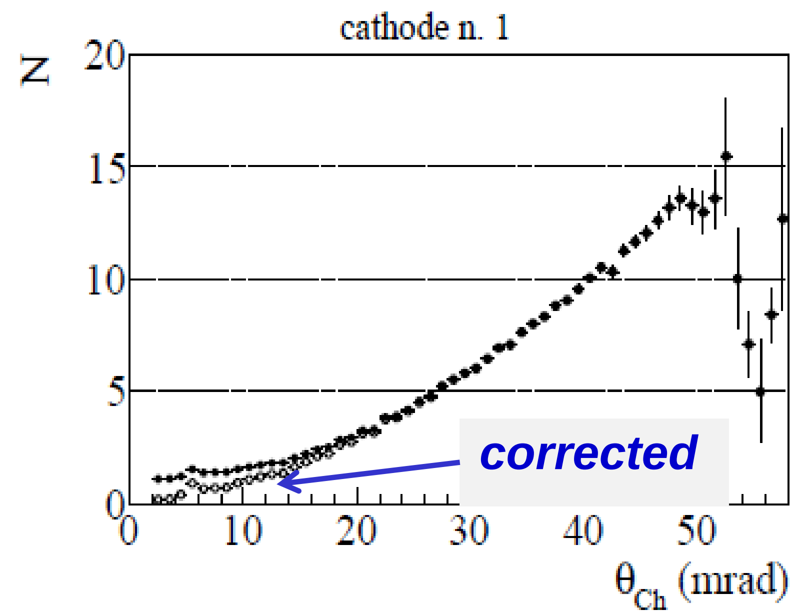
<u>at least 1 detected photon</u>

→measured N is biased, corrected

$$\mu'(nc=1) = \frac{\mu}{1-e^{-\mu}}$$

measured: μ'

μ solving numerically the equation

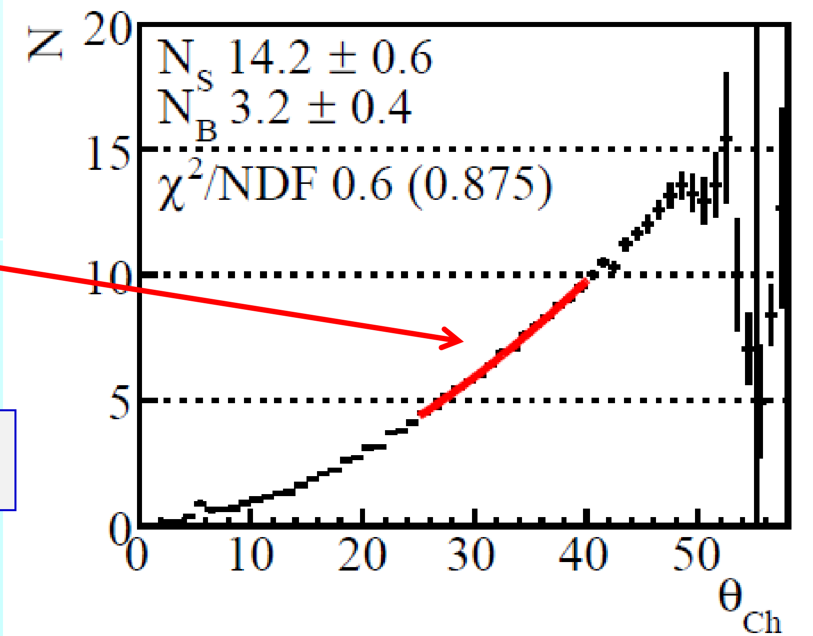


FIT THE DISTRIBUTION:

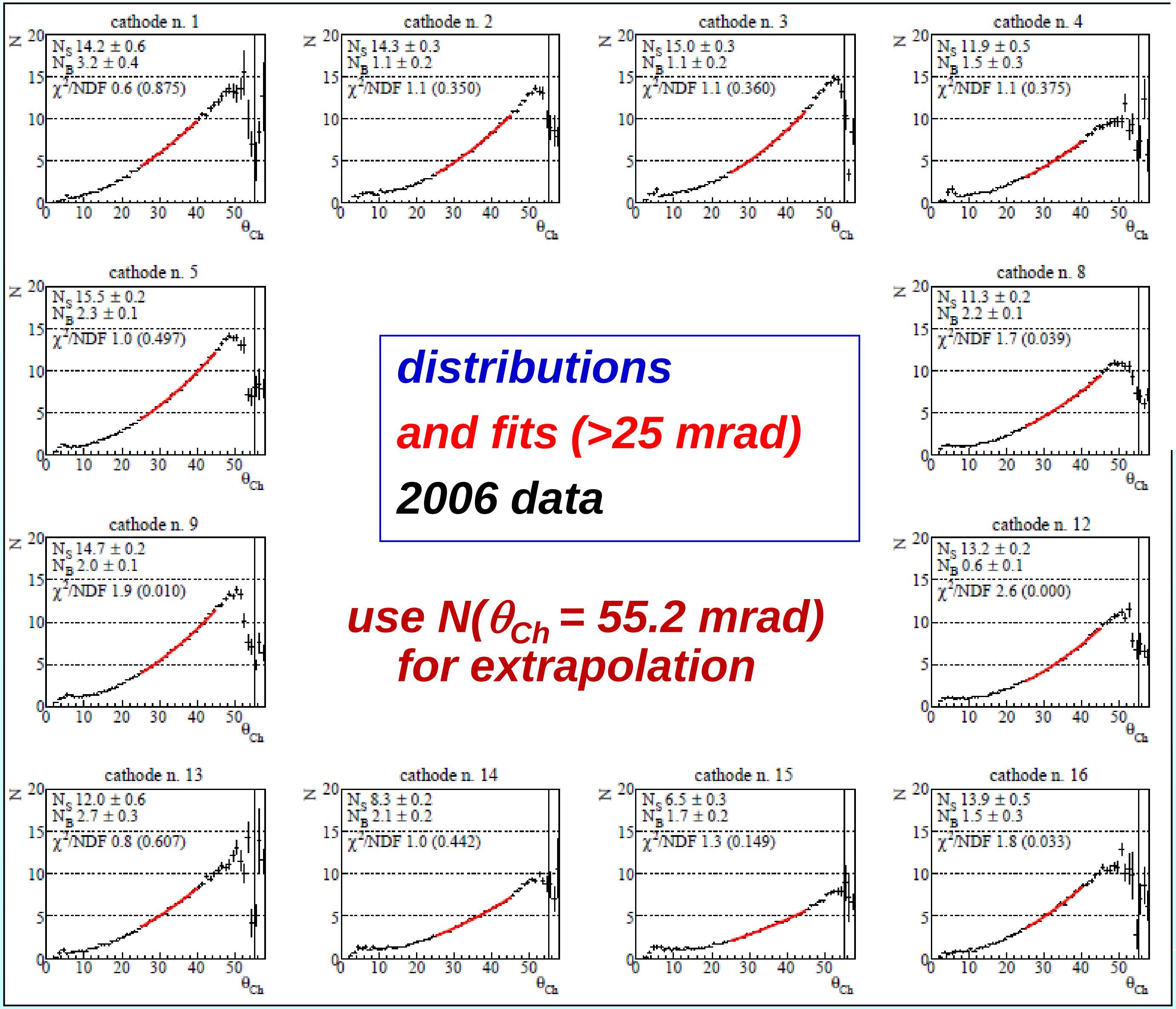
$$N(\theta_{Ch}) = p_0 \cdot \sin^2\theta_{Ch} + p_1 \cdot \theta_{Ch}$$

Frank and Tamm distribution

Background (flat distribution assumed)



Fit quality, consistency and stability

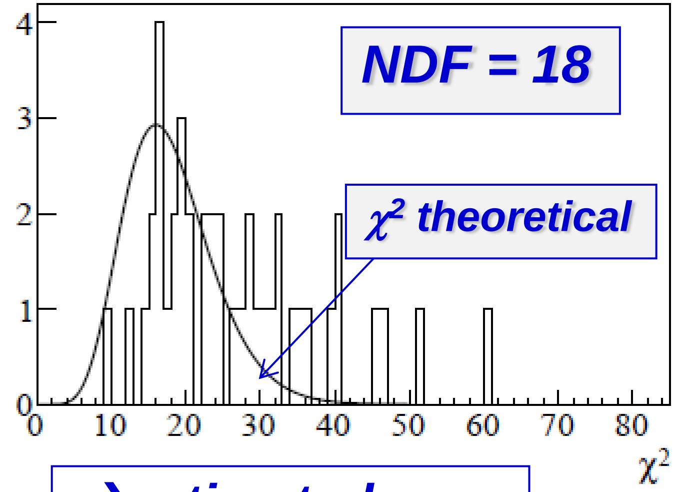


distributions

and fits (>25 mrad)

2006 data

use $N(\theta_{Ch} = 55.2$ mrad) for extrapolation



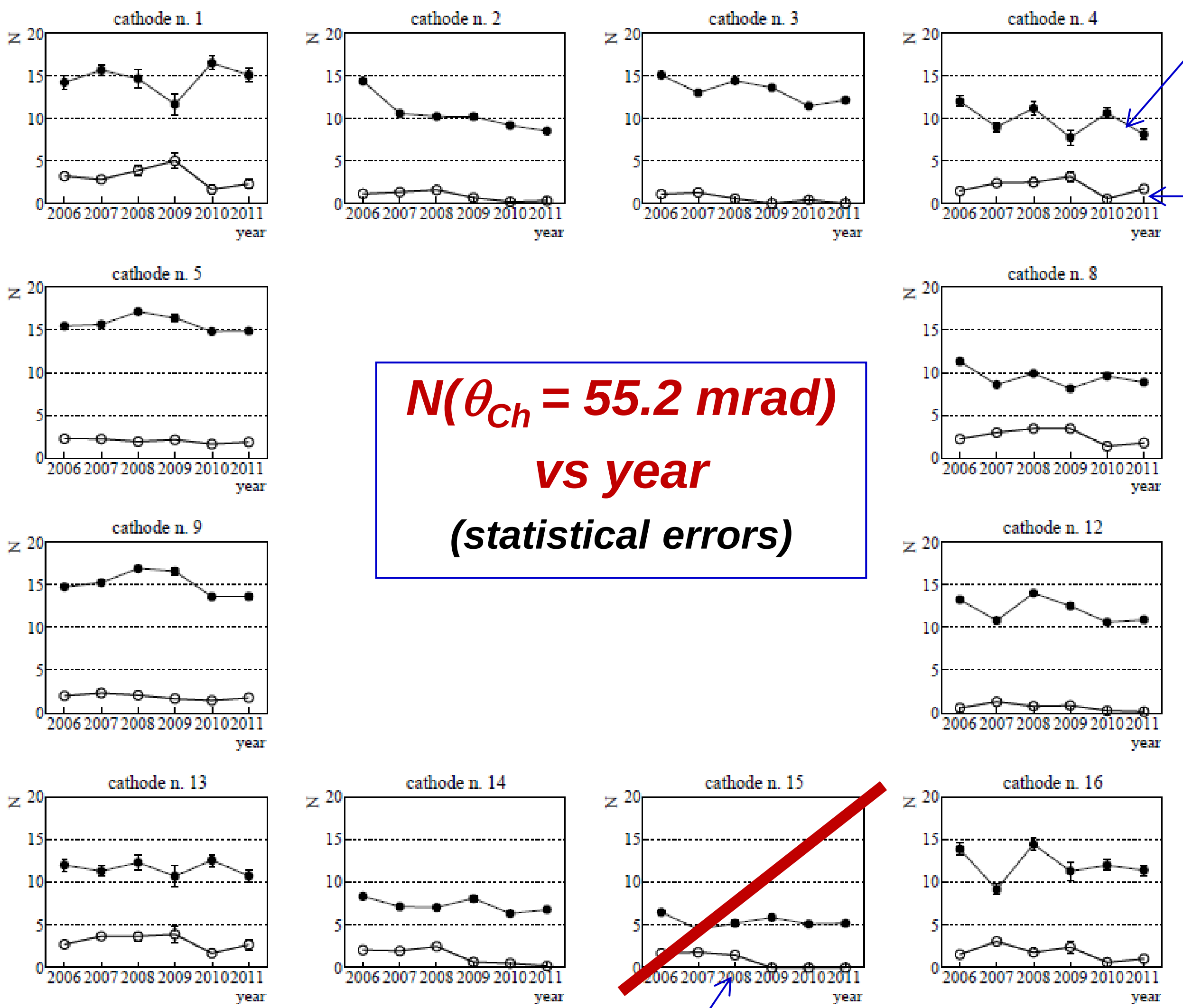
→estimated systematic error: 0.7 x σ_{stat}

Fit results stable versus:

- ***fit range variations***
- ***different ring selection:***

  at least 2, 3 photons

results



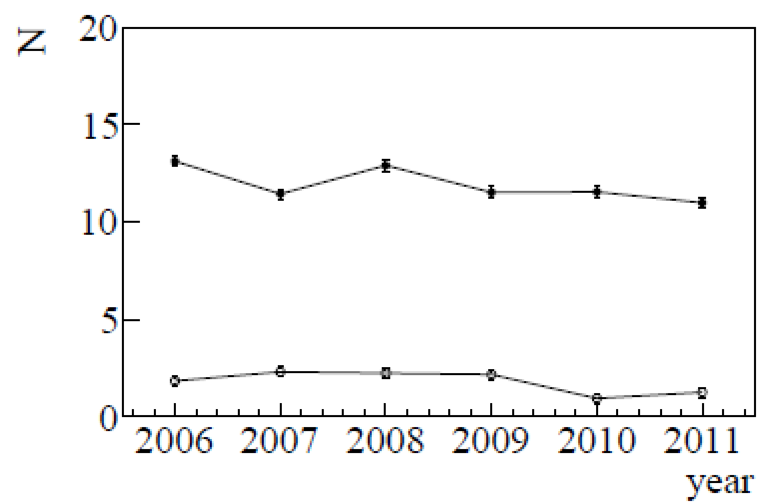
Frank and Tamm

background

$N(\theta_{Ch} = 55.2$ mrad)
vs year
(statistical errors)

Too few photons:
not used in the following

MEAN OVER 11 CATHODES
(statistical & systematic errors)

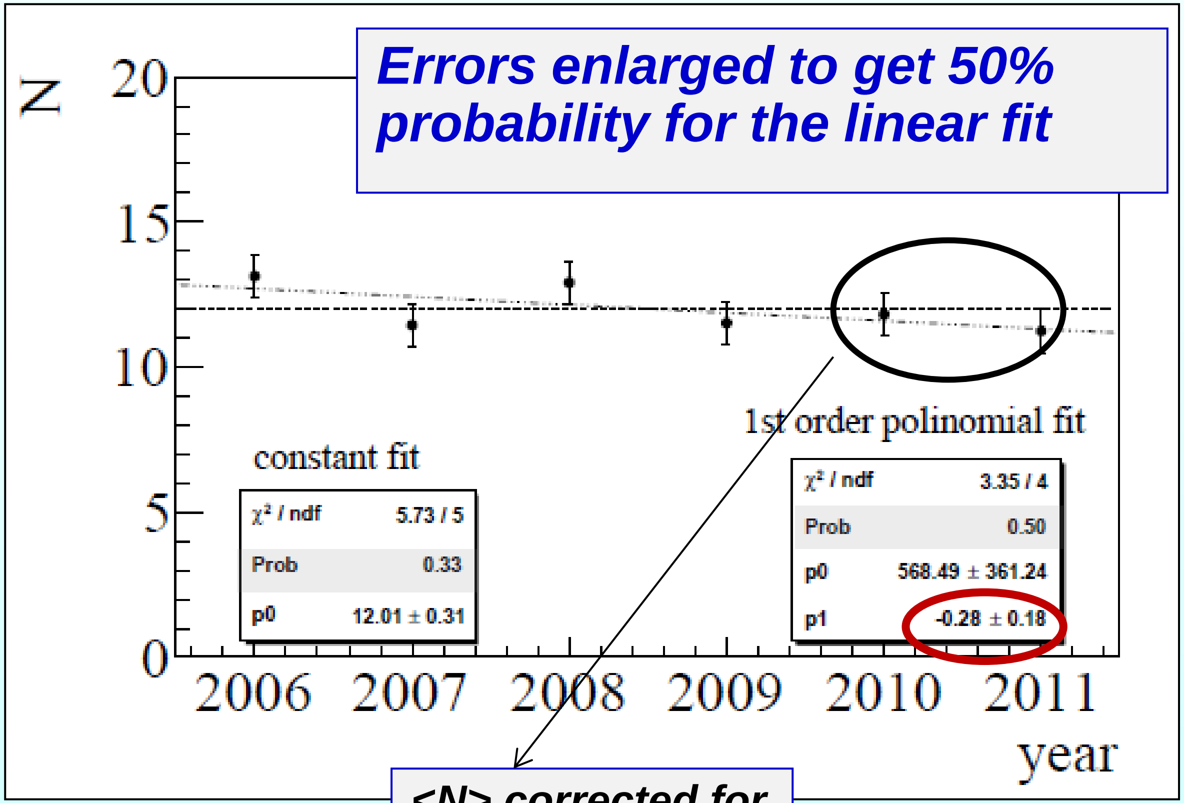


CsI photocathodes can preserve QE over years

<N> vs year is compatible
with no CsI QE variation

max CsI QE variation
rate : 2.3 % / year
[1 “COMPASS year” :
~6 months of data taking]

For the 3 most critical cathodes:
max CsI QE variation rate : 5.2 % / year



Estimated systematic error of the measurement: 2 % /year

The CsI QE decrease is modest

COMPASS II PID requirements

Exclusive meson production channels have low cross-section

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

MWPC + CsI operate at low gain ➔ depend on p, T, threshold 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 small demagnification factor of optical system allowed (large distortions); 5 m^2 of PMTs not affordable.

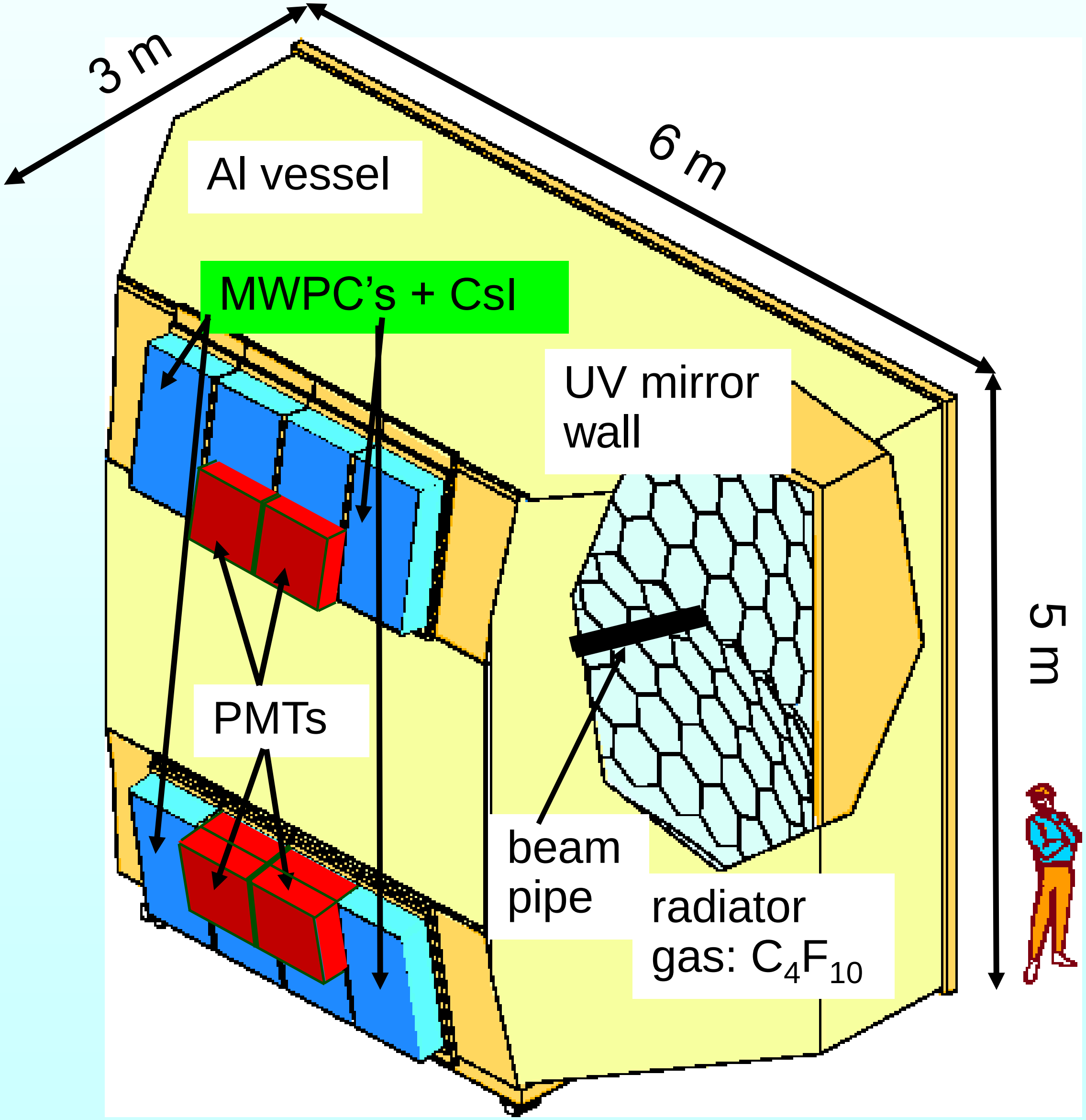
MPGD-based Photon Detectors are the best option

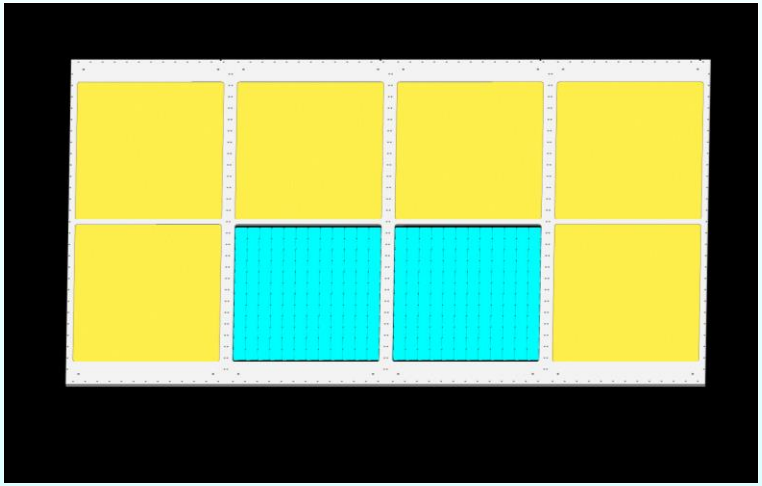
A dedicated R&D project to develop THGEM-based PDs started 6 years ago and rececently achieved positive conclusions

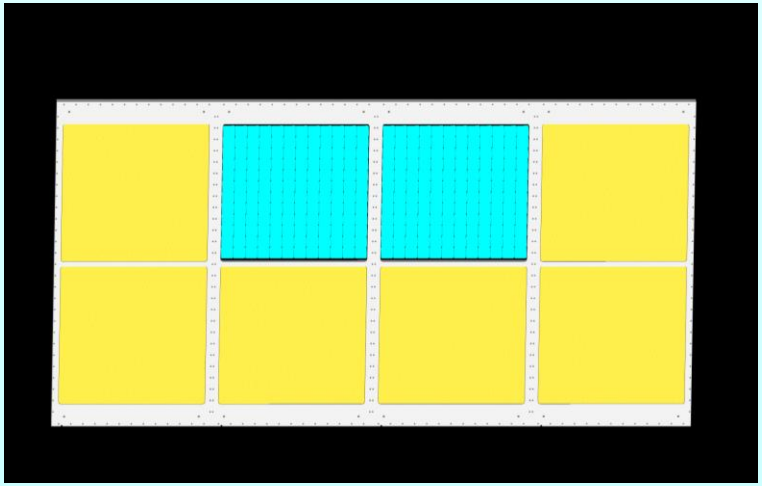
The R&D status and progress will be presented by Stefano Levorato on Friday

We have decided to replace COMPASS RICH-1 MWPC's with the new detectors

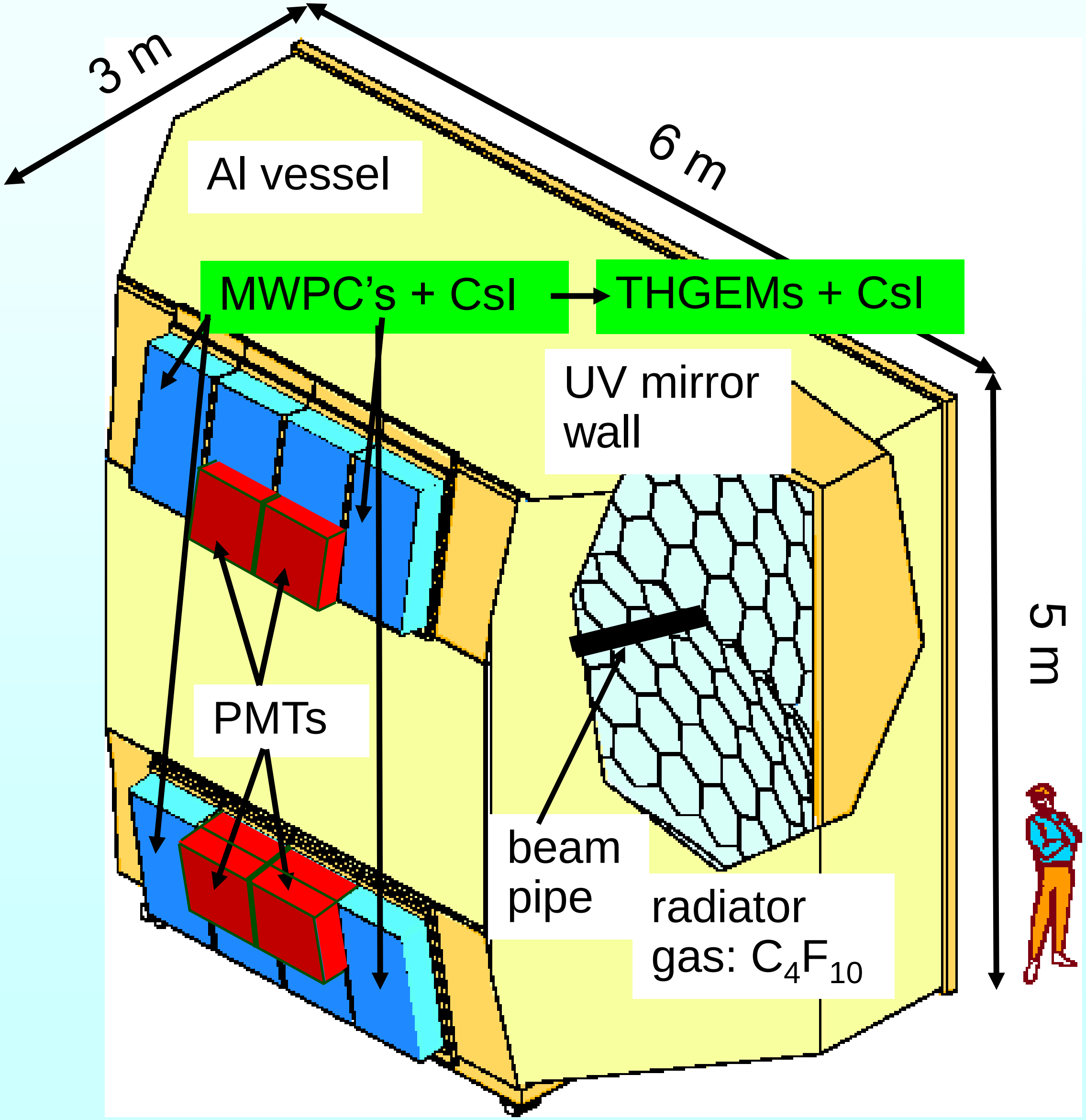
2016 COMPASS RICH-1 upgrade



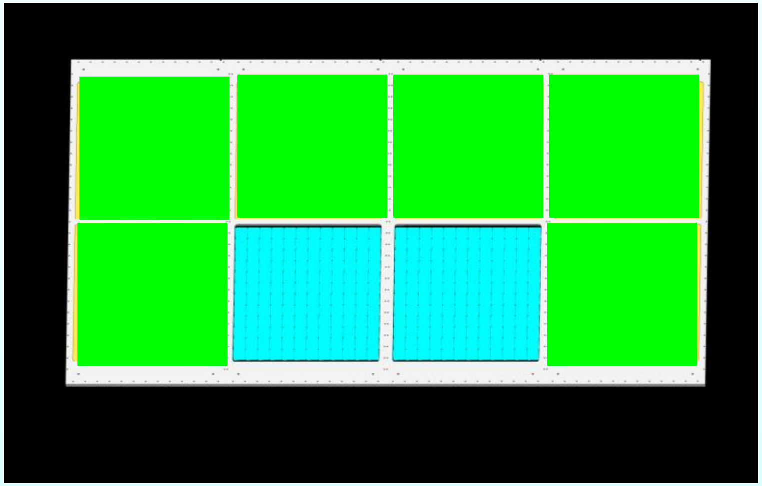


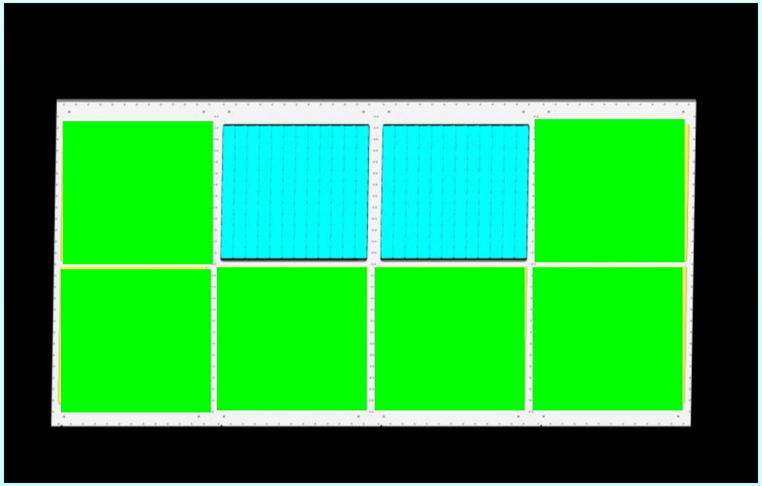


2016 COMPASS RICH-1 upgrade

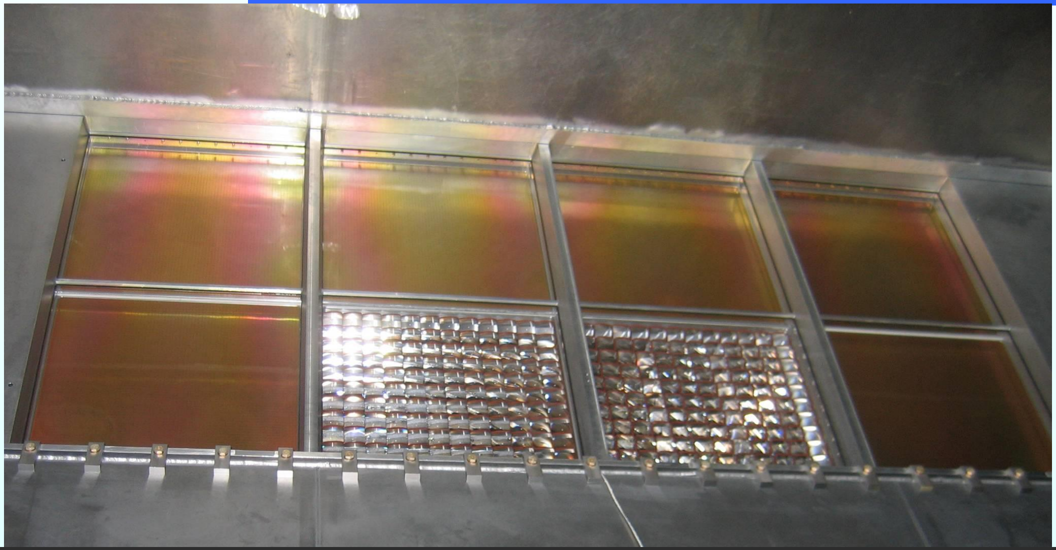


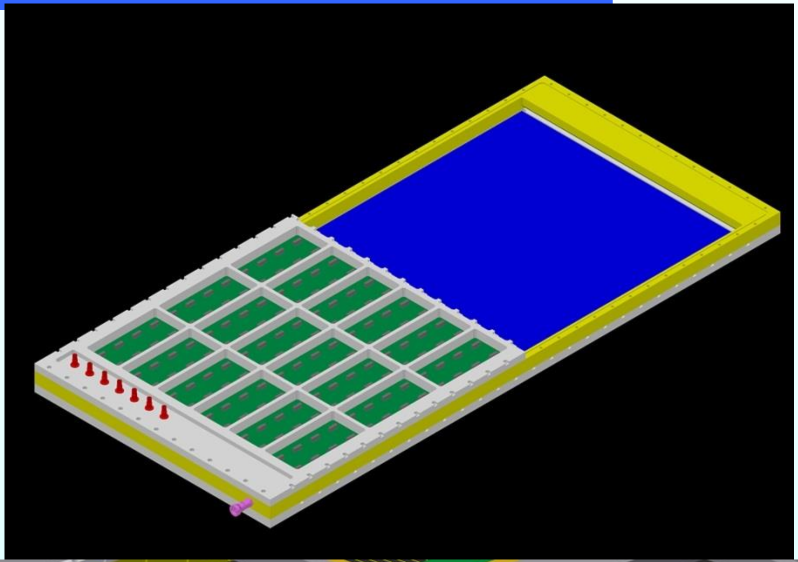
Foreseen for 2016-2017

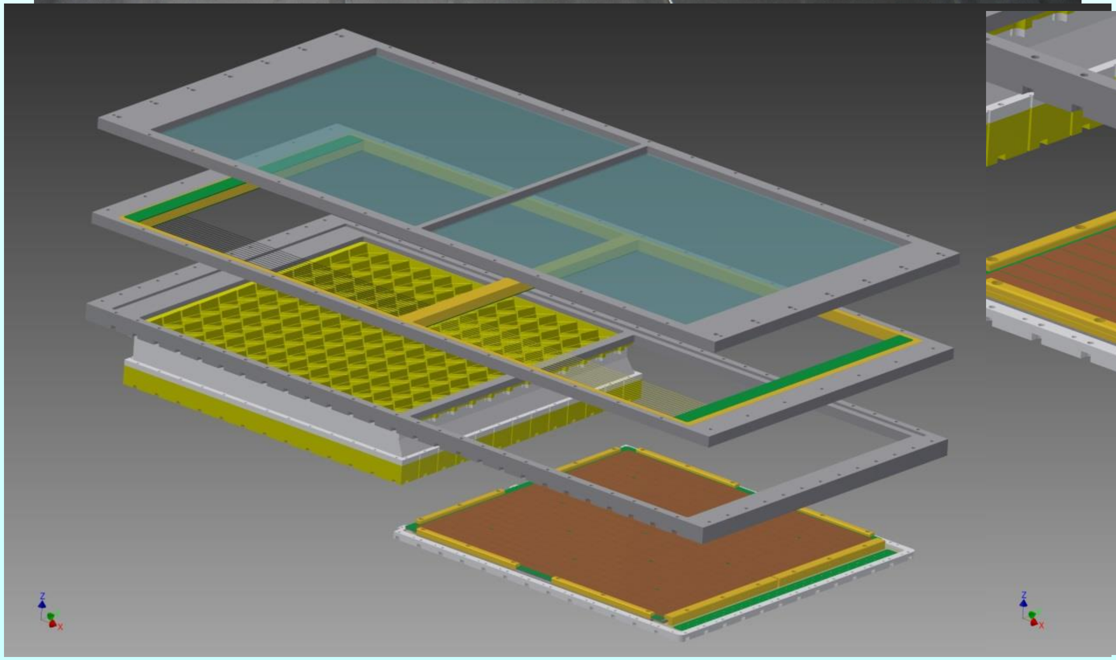


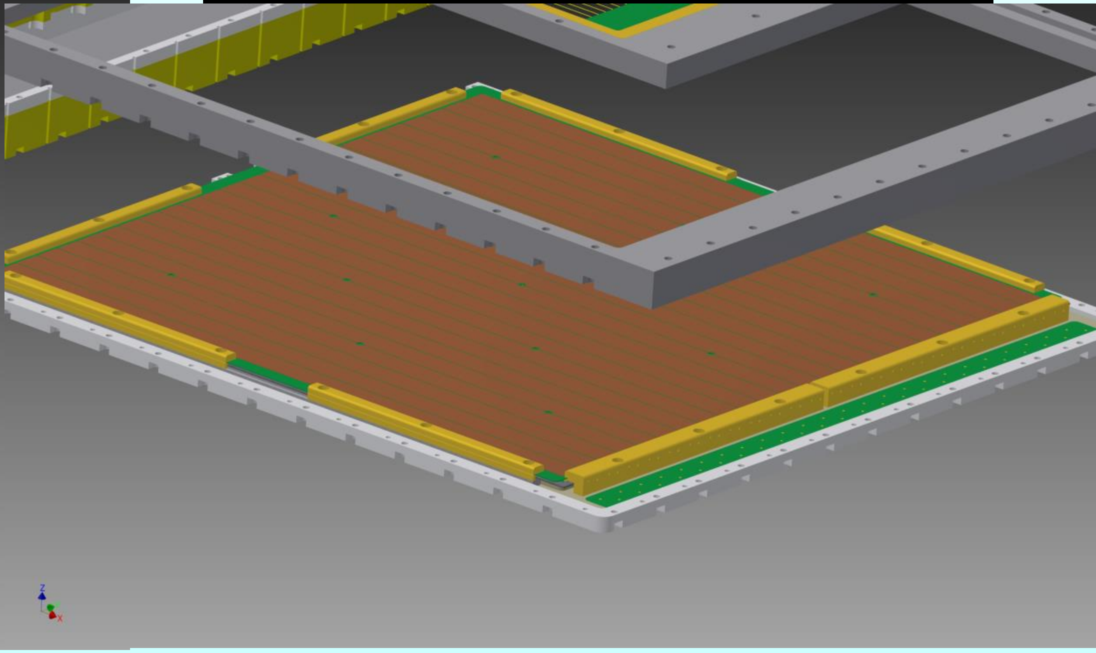


New PD's

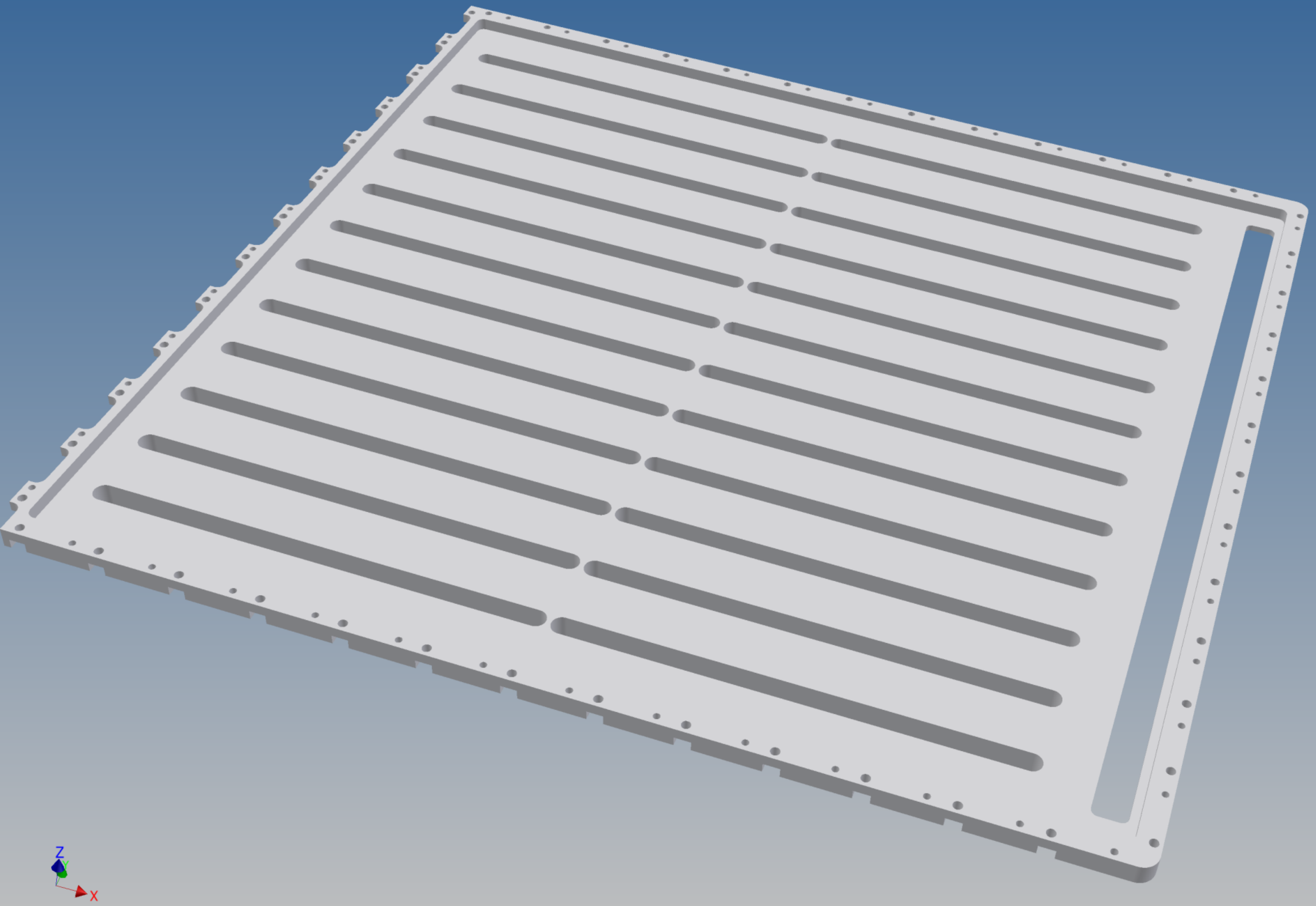




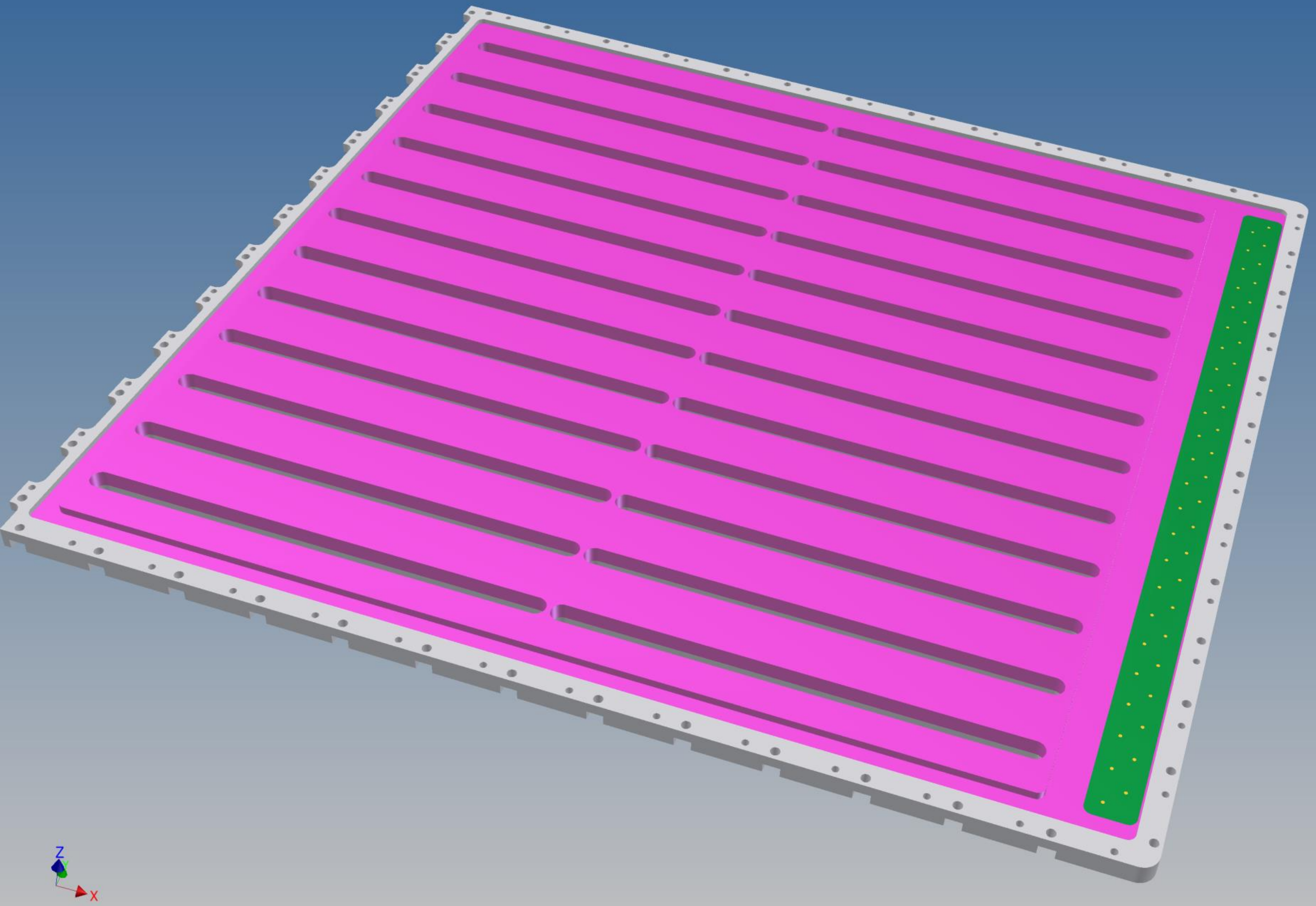




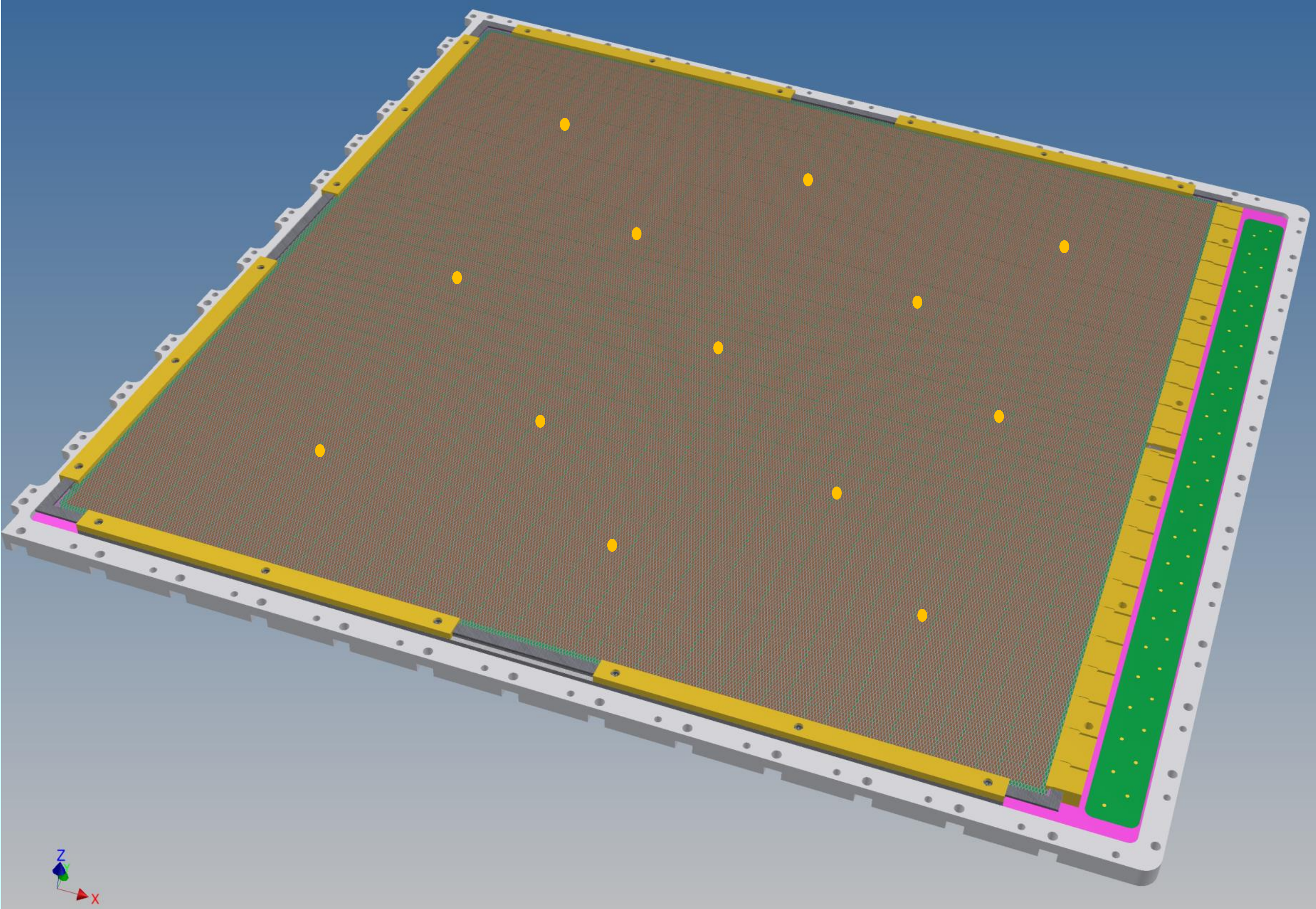
The THGEM+Micromegas version



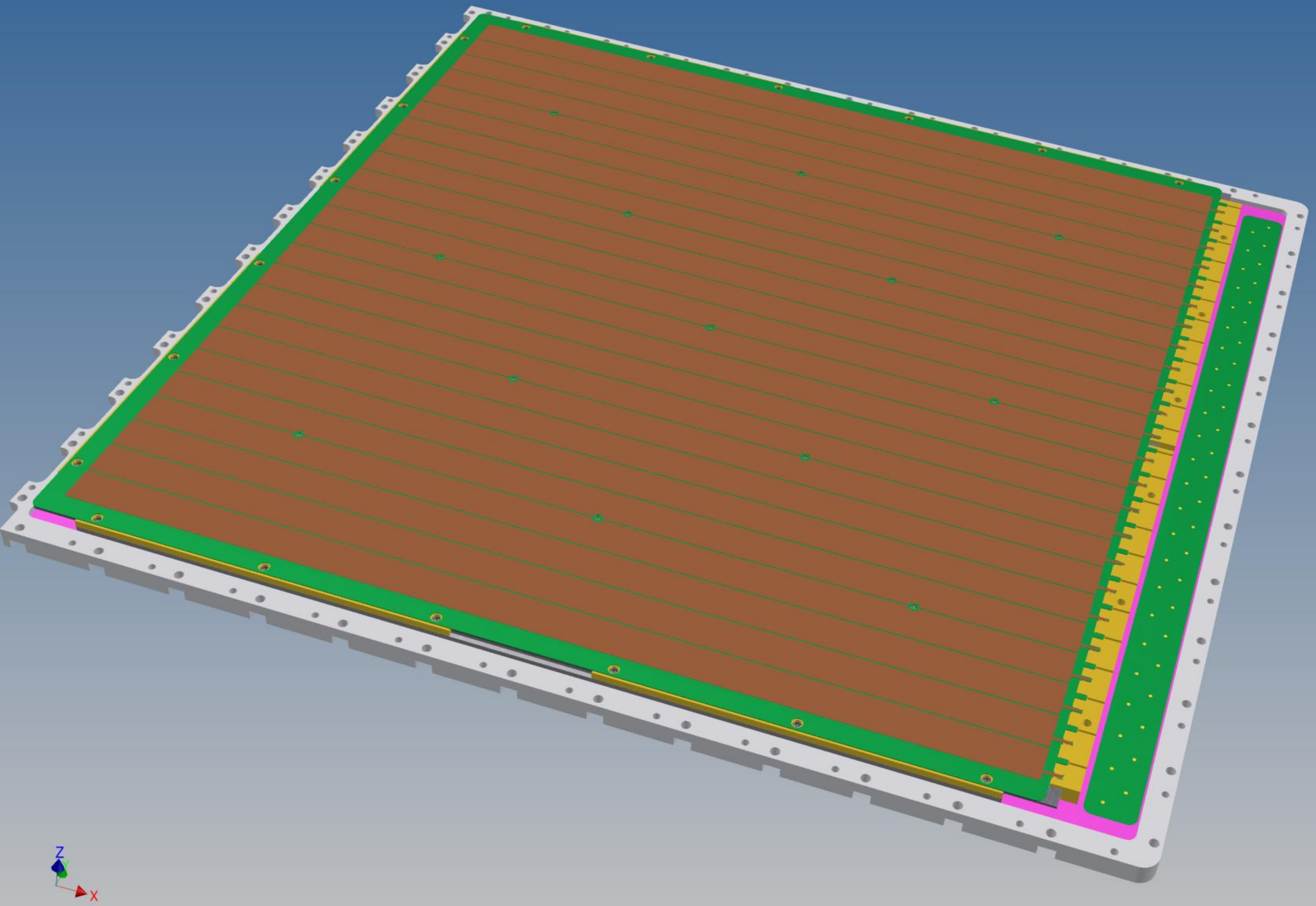
The THGEM+Micromegas version



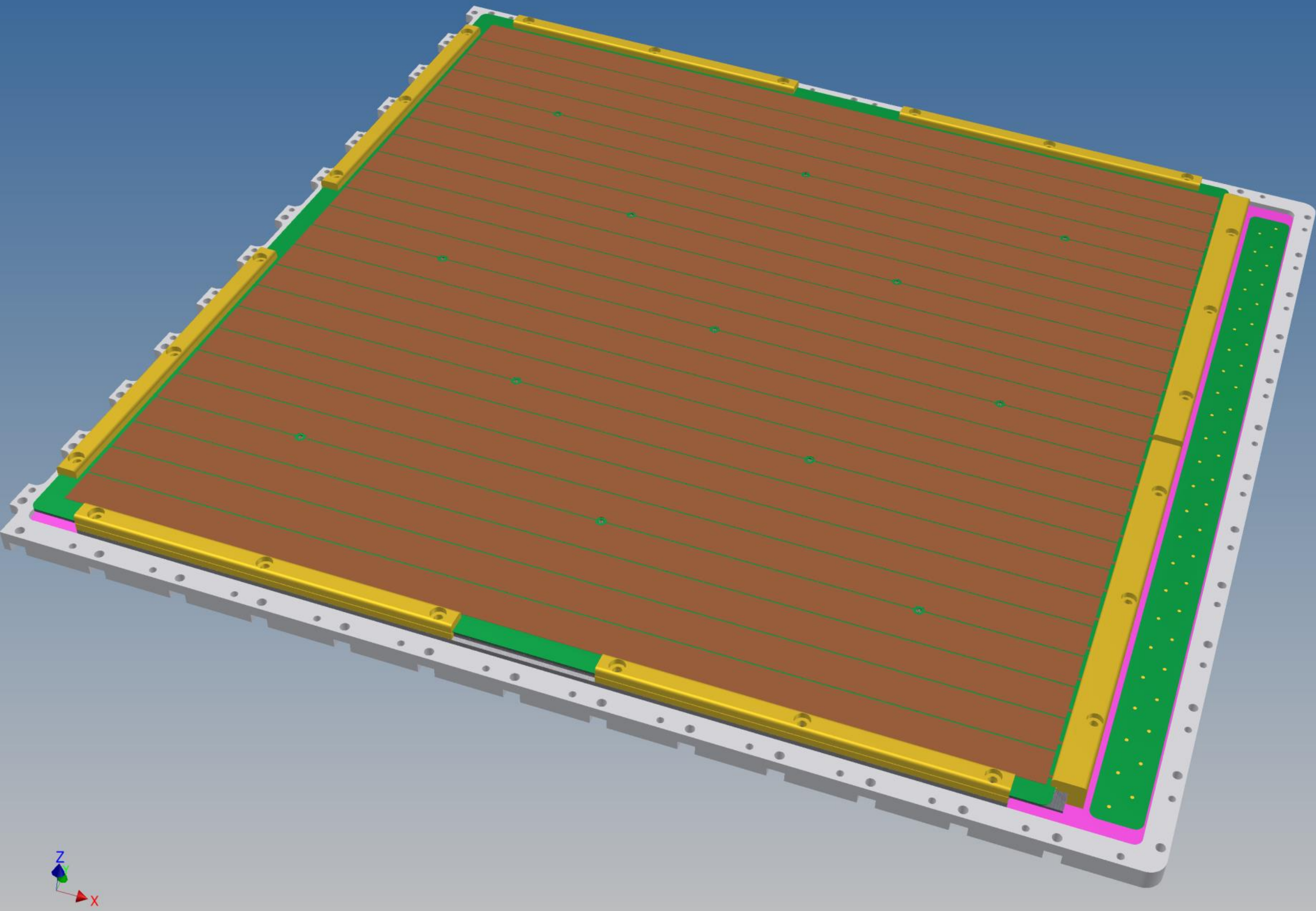
The THGEM+Micromegas version



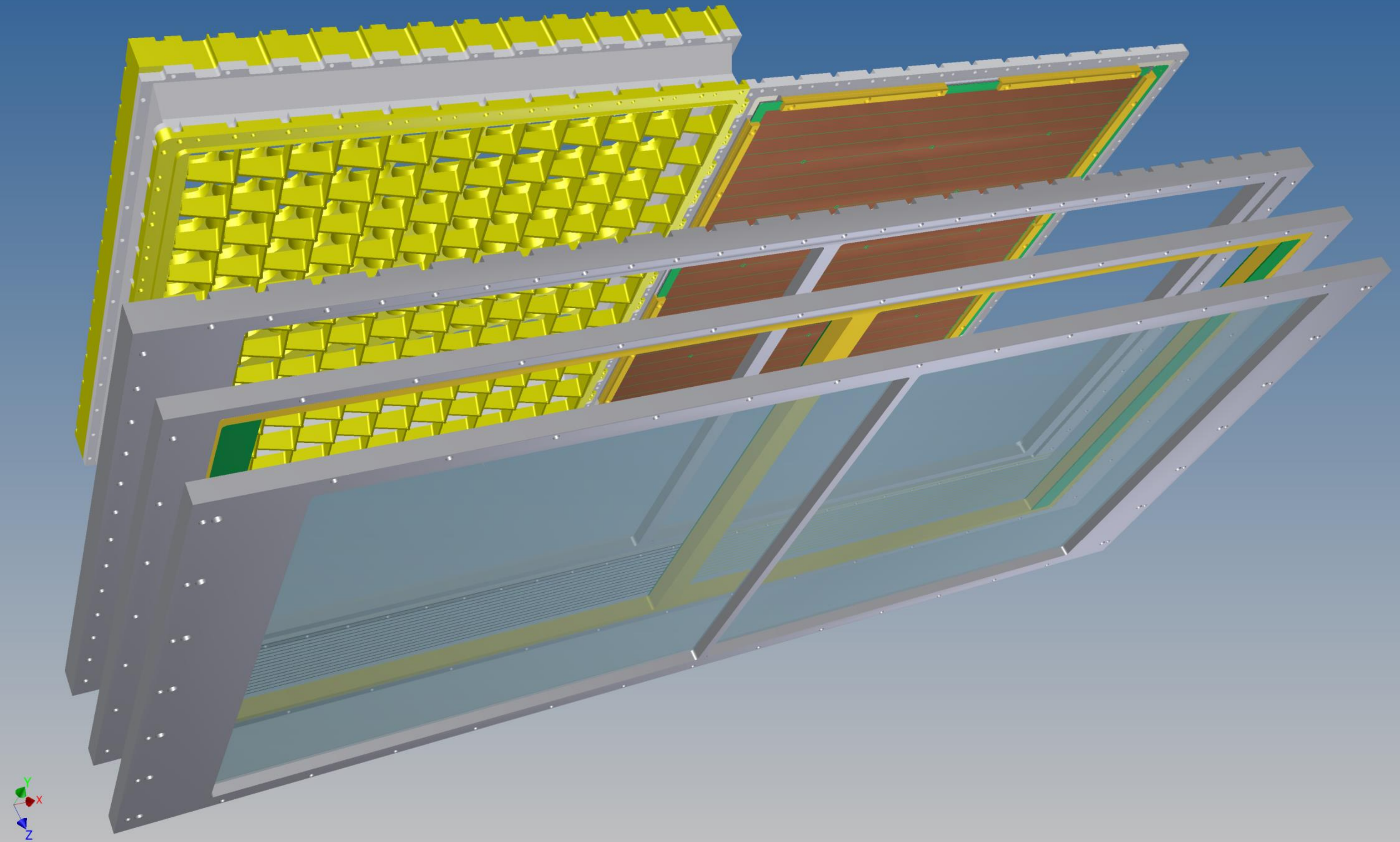
The THGEM+Micromegas version



The THGEM+Micromegas version



The THGEM+Micromegas version



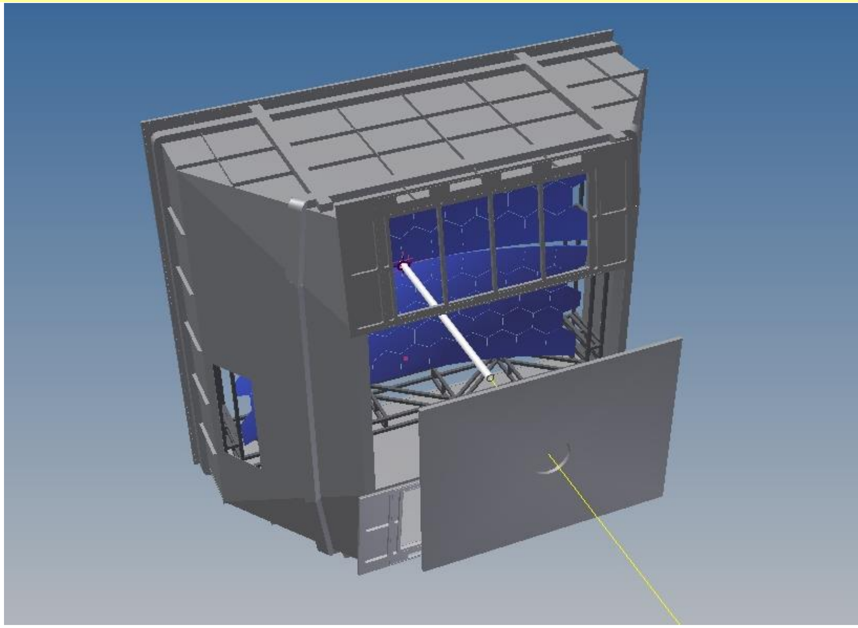
spares

The keys of the success

- A strong physics case
- An outstanding project leader
- A dedicated, highly motivated team
- A constant support from the Institutes and the Experiment
- <u>The enthusiastic contribution from many colleagues:</u>

P. Abbon [k], M. Alexeev [a,1], H. Angerer [i], R. Birsa [o], P. Bordalo [g,2], F. Bradamante [n], A. Bressan [n], M. Chiosso [l], P. Ciliberti [n], M. Colantoni [m], T. Dafni [k], S. Dalla Torre [o,*], E. Delagnes [k], O. Denisov [m], H. Deschamps [k], V. Diaz [o], N. Dibiase [l], V. Duic [n], W. Eyrich [d], A. Ferrero [l], M. Finger [j], M. Finger Jr. [j], H. Fischer [e], S. Gerassimov [i], M. Giorgi [n], B. Gobbo [o], R. Hagemann [e], D. von Harrach [h], F.H. Heinsius [e], R. Joosten [b], B. Ketzer [i], V.N. Kolosov [c,3], K. Königsmann [e], I. Konorov [i], D. Kramer [c,f], F. Kunne [k], A. Lehmann [d], S. Levorato [n], A. Maggiora [m], A. Magnon [k], A. Mann [i], A. Martin [n], G. Menon [o], A. Mutter [e], O. Nähle [b], F. Nerling [e], D. Neyret [k], D. Panzieri [a], S. Paul [i], G. Pesaro [n], C. Pizzolotto [d], J. Polak [f,o], P. Rebourgeard [k], F. Robinet [k], E. Rocco [l], P. Schiavon [n], C. Schill [e], P. Schoenmeier [d], W. Schröder [d], L. Silva [g], M. Slunecka [j], F. Sozzi [n], L. Steiger [j], M. Sulc [f], M. Svec [f], S. Takekawa [n], F. Tessarotto [o], A. Teufel [d], H. Wollny [e]

To work safely inside our "confined space"



COMPASS RICH is a CONFINED SPACE: authorized people only can enter .

- authorization requires a formation course and a medical certification: for the first time CERN asked for the latter to be done by the institute.

- a scaffolding had to be mounted inside the RICH (the old one does not conform to the new rules).

We managed to provide:

1) formation: general confined space course from CERN

2) formation: specific course on risks inside COMPASS RICH

3) definition and agreement on the medical protocol

4) medical exams and production of medical certificates

4) detailed definition of the activity and formalization of the specific procedures.

5) opening of the RICH with Fire Brigades, GLIMOS, Supervisor, TSO, CERN confined space responsible, etc.

6) authorization to enter by radiation protection personnel, formed, checked and authorized for entrance

7) special formation course and authorization for us to mount a borrowed scaffolding (it can only be mounted by authorized personnel, but they were not authorized for confined space …)

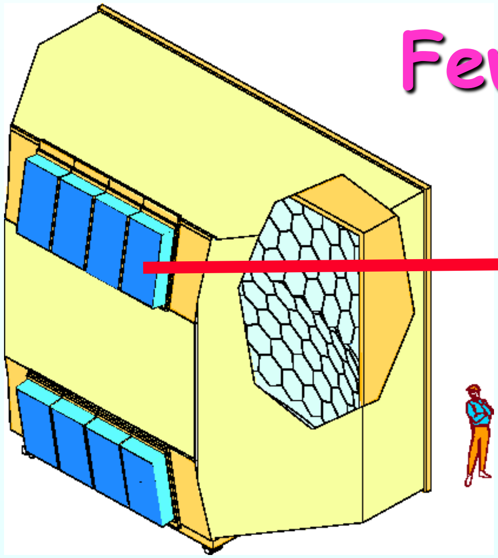
8) mounting of the scaffolding by ourselves

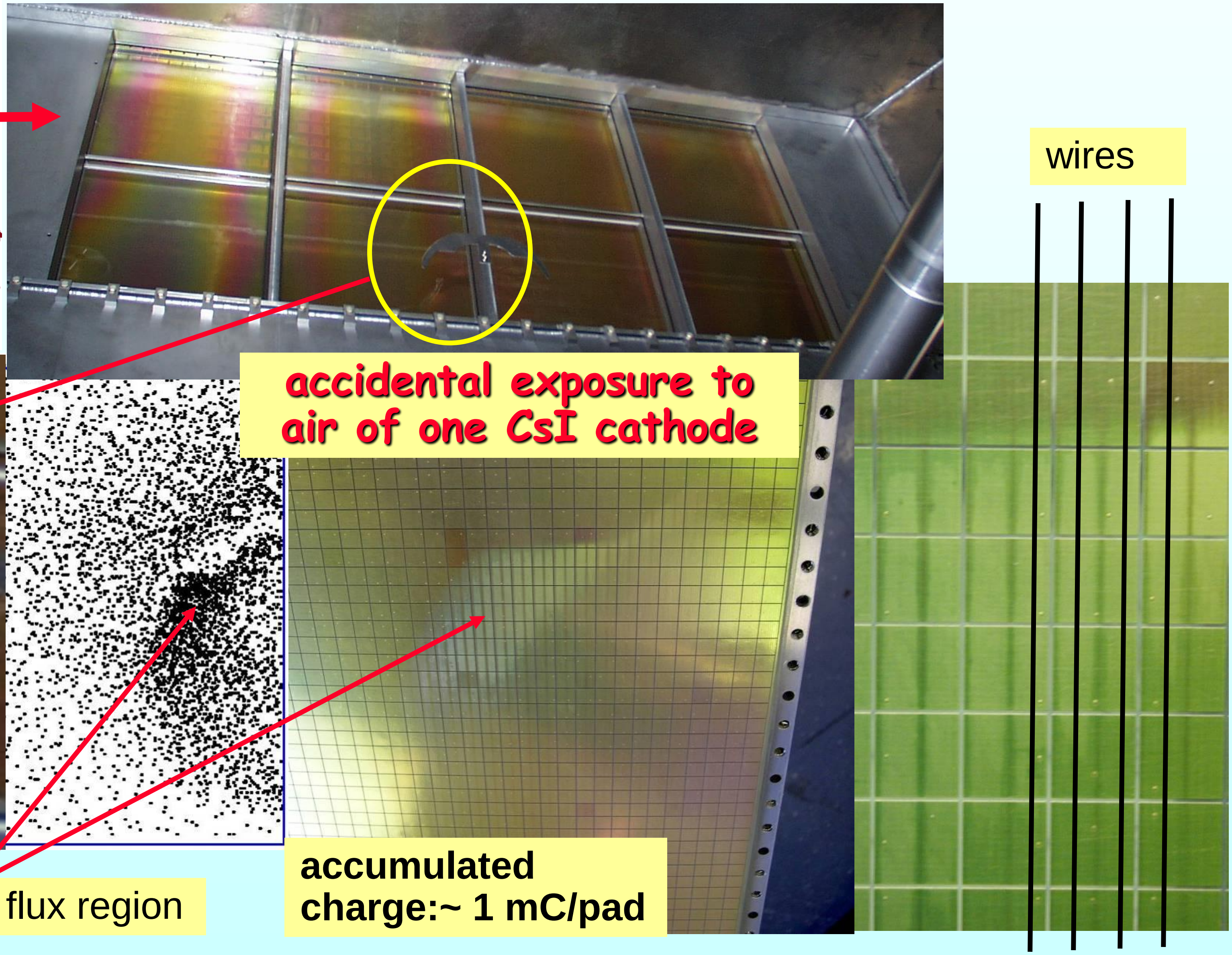
6) formation and authorization to enter for the responsible of the scaffolding to check our mounting and authorize using it

7) … 8) … 9) … 10) …

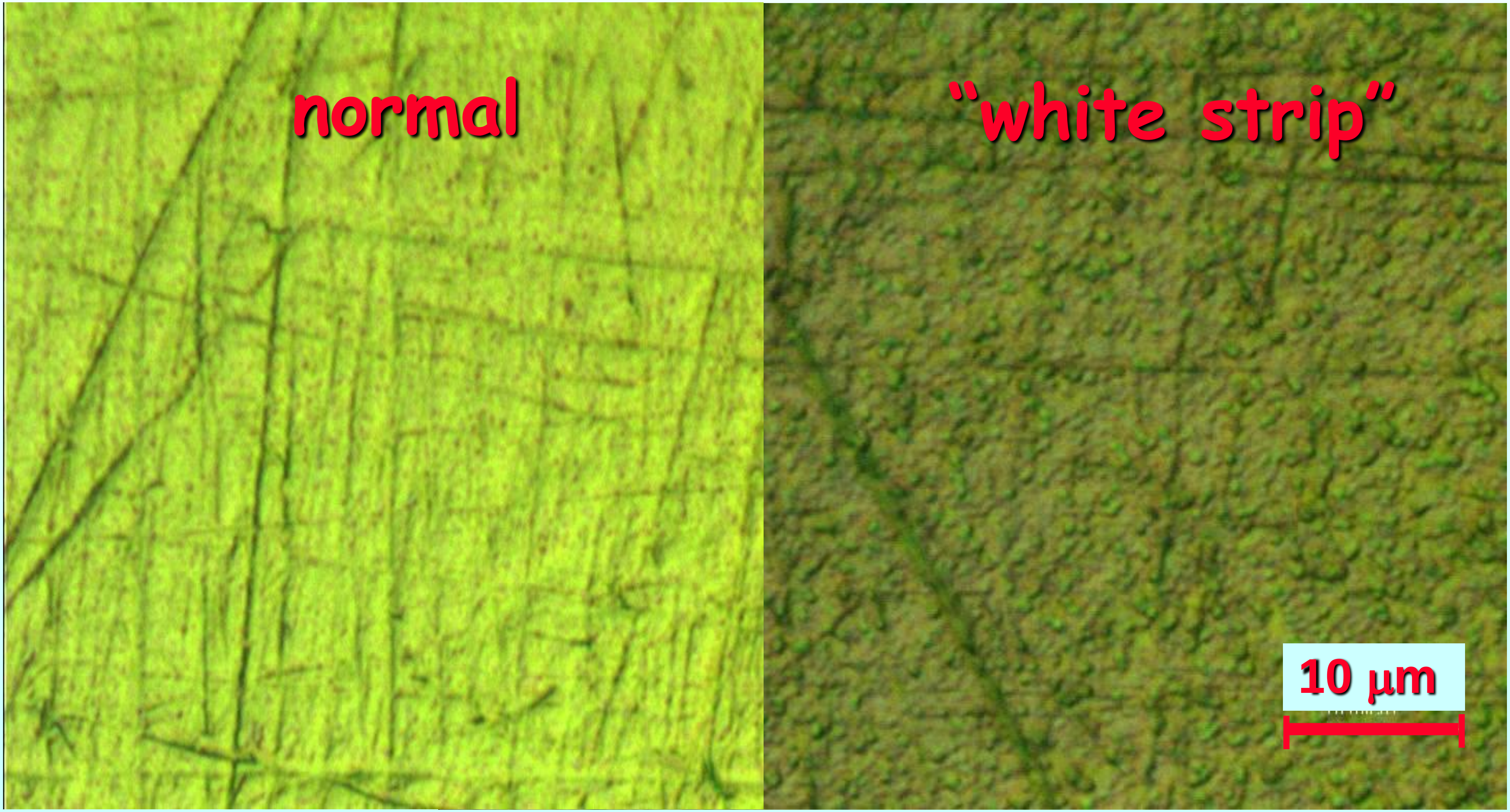
EVERYBODY (CERN Medical Service, TIS, GLIMOS, …) have been extraordinarily collaborative…

Few months after the end of the run



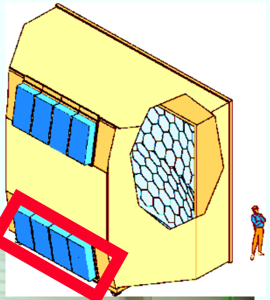


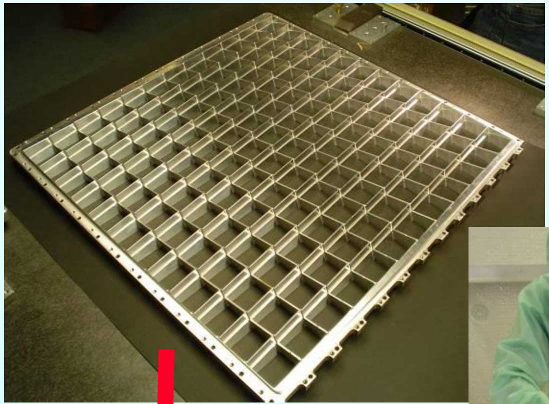
CsI surface at microscope (x 1000)

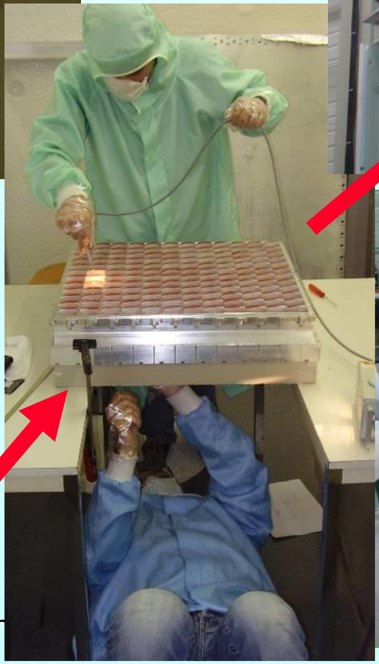


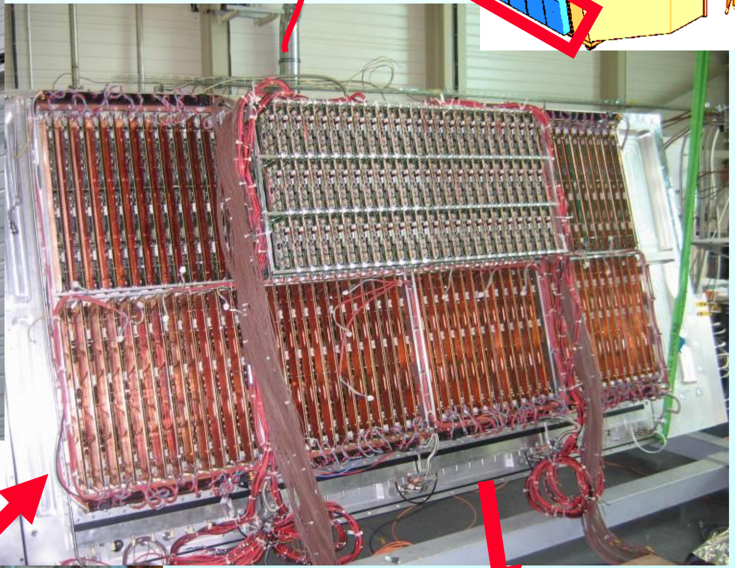
SCHEDULE OF ASSEMBLING

- **Preliminary studies up to October 2004**
- **Project design November 2004 – March 2005**
- **Material procurement and constructions April 2005 - March 2006**
- **Assembly April-May 2006**
- **Ready for beam June 2006**



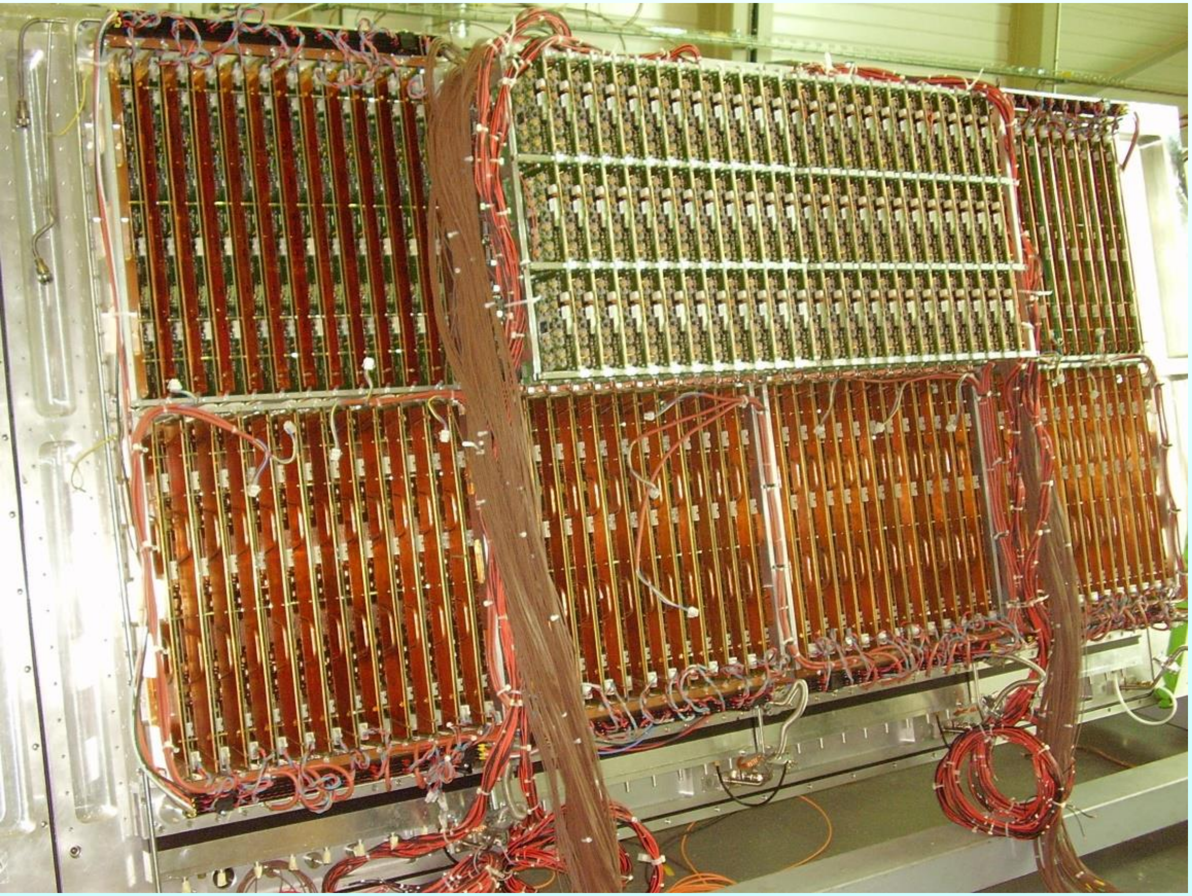


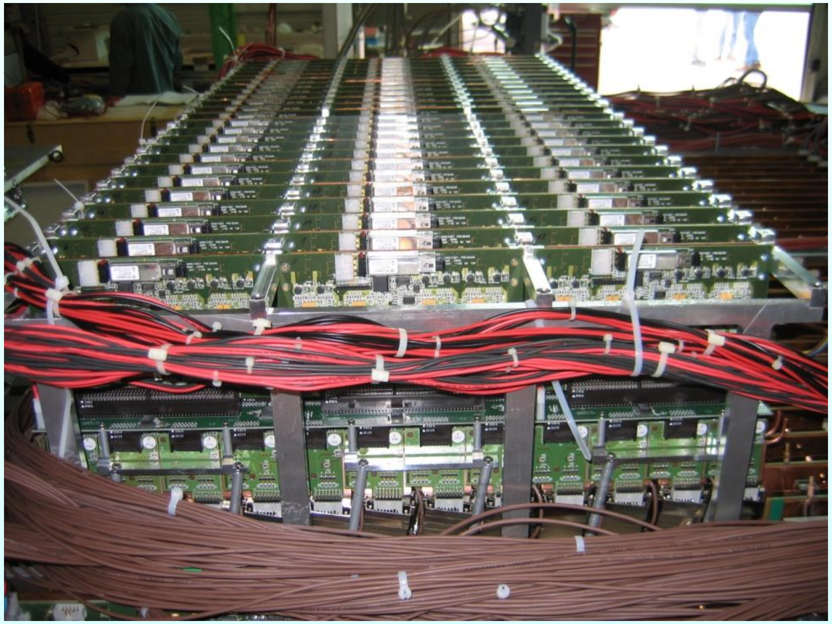


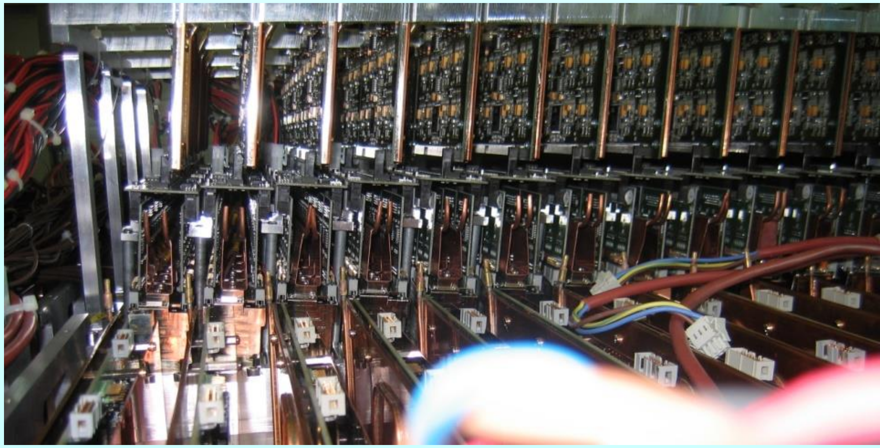


When the detector was ready …

With the MAPMT's and electronics







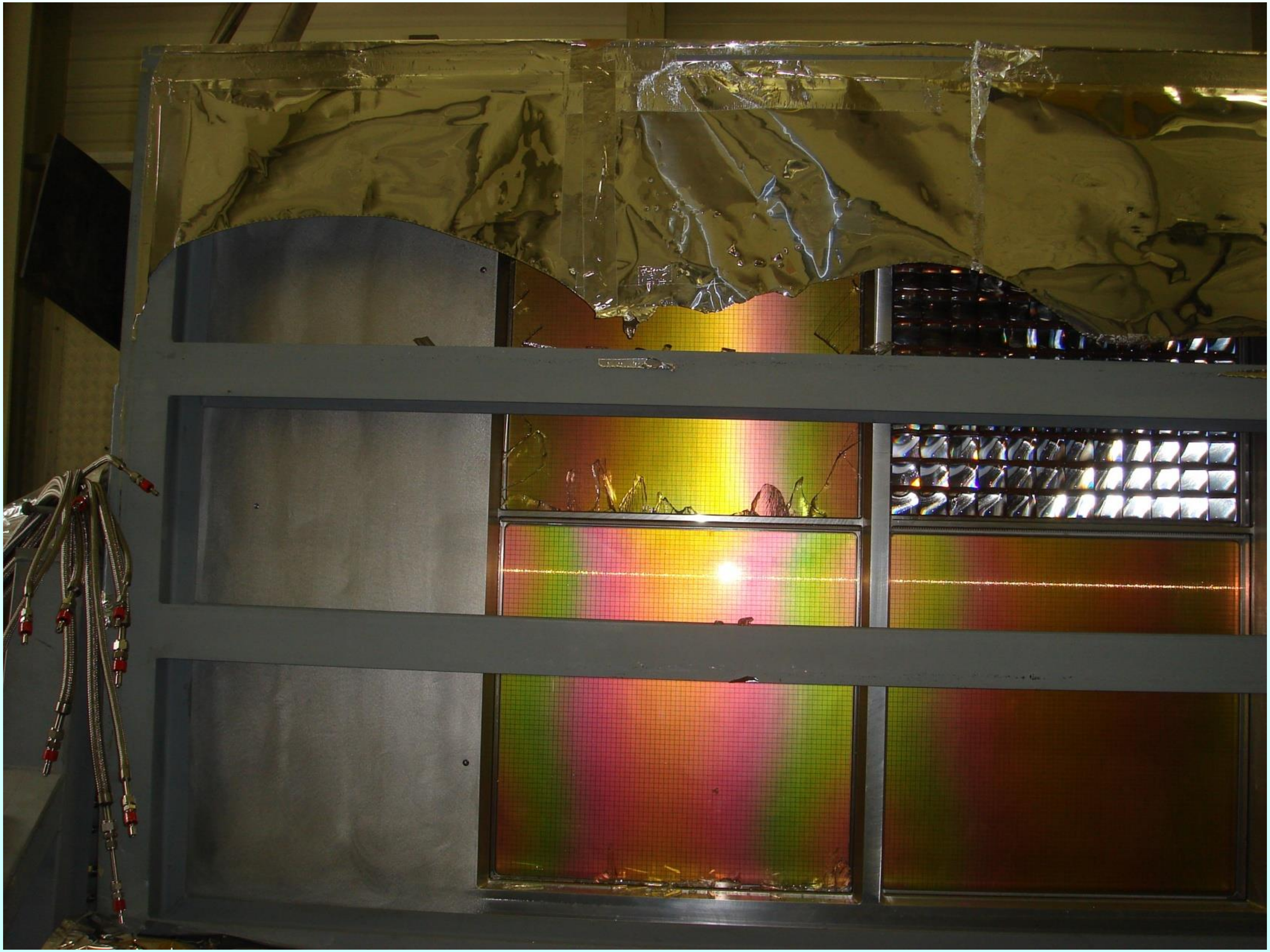
We moved out of the assembling area

It was May 18, 2006. A beautiful sunny day in Geneva.

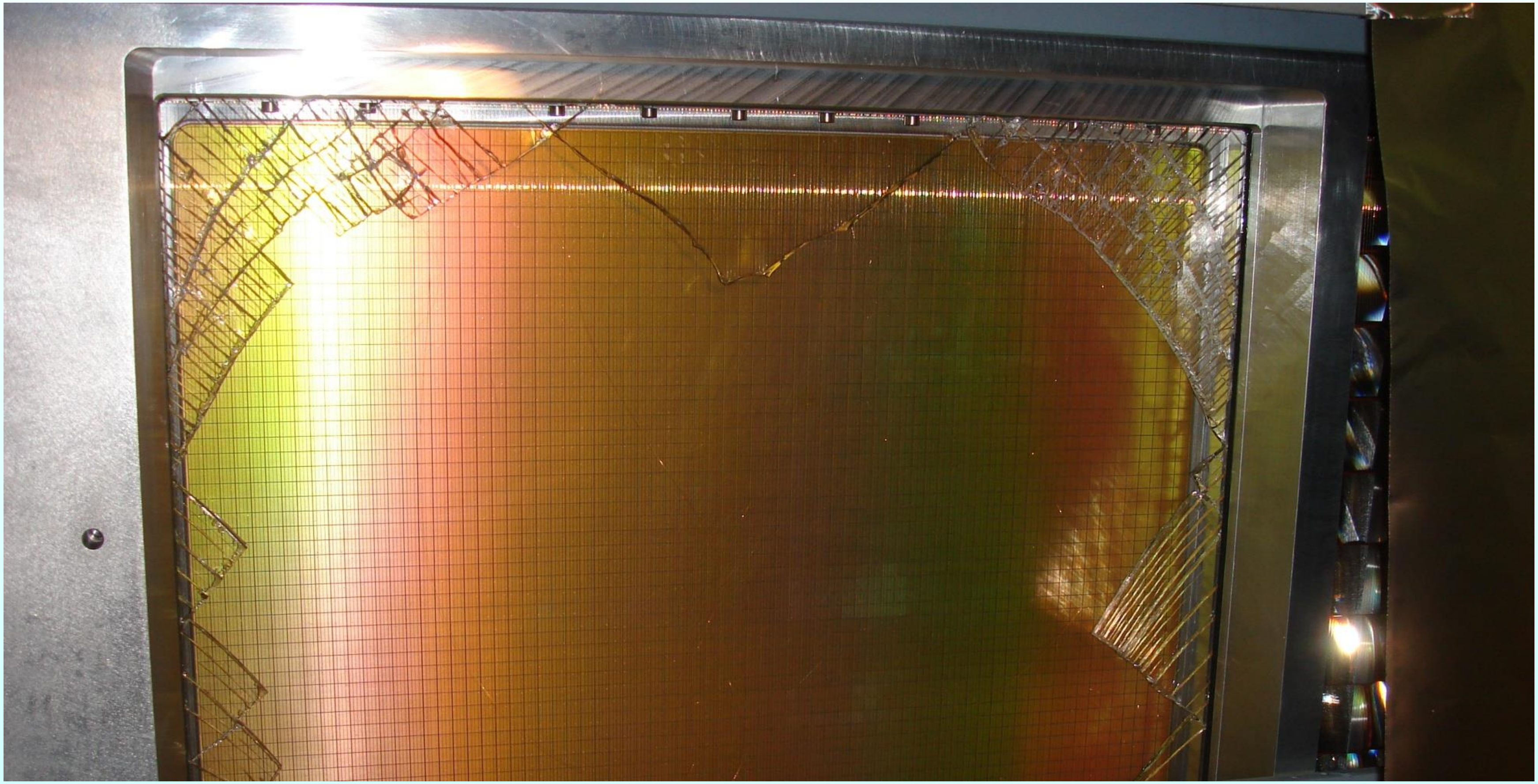
At 11:45 the detector was ready for craning.

Suddenly a bang was heard.

In few seconds the protections were removed and that's what was seen:



Immediate reaction



The repair started on the same day

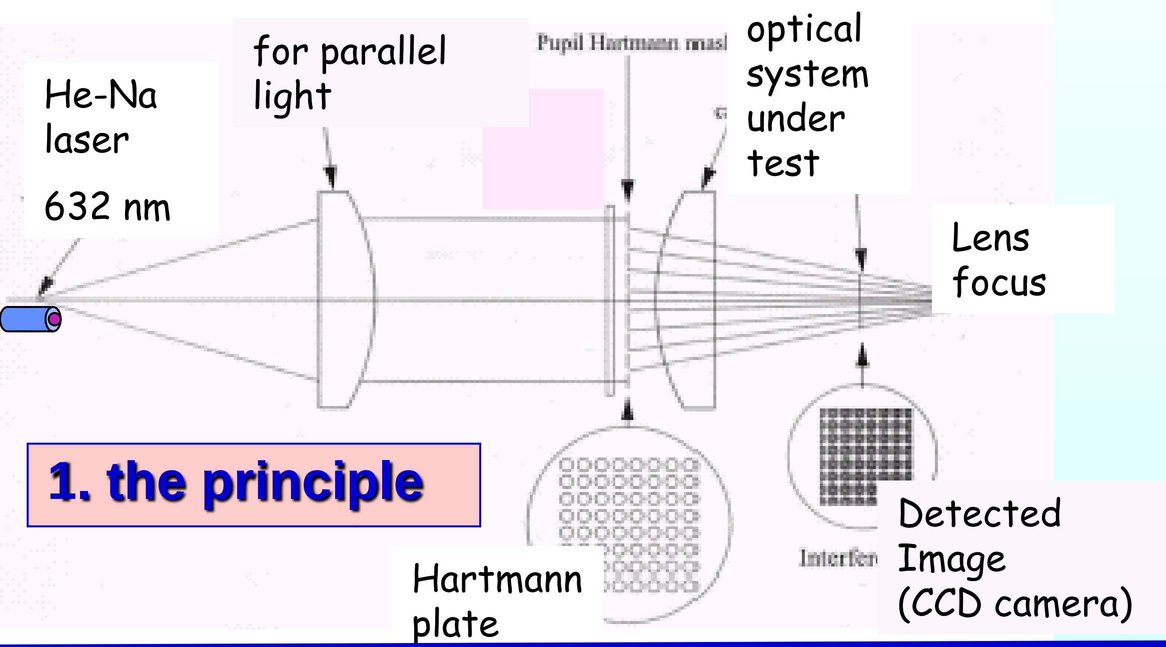
Spares of all pieces, including the large quartz windows were available

The accident was carefully studied and understood in detail (20 mbar overpressure)

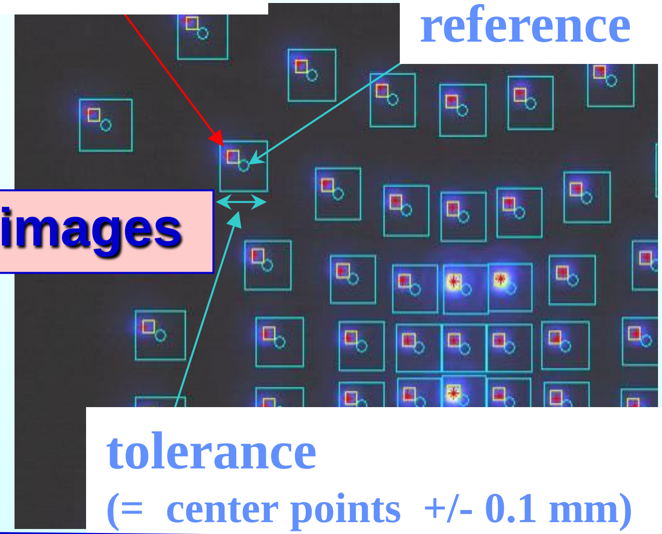
One month later, in time for the start of the run, the repaired detector was installed

OPTICS QUALITY CONTROL WITH THE HARTMANN METHOD

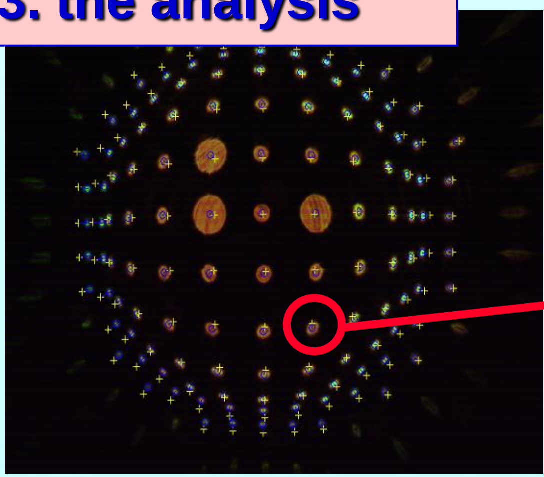
1. the principle

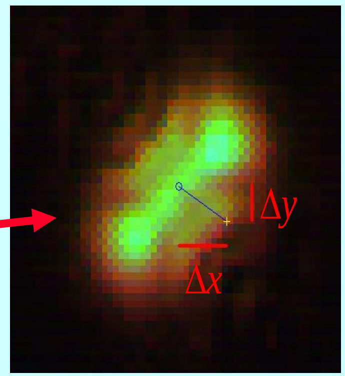


2. the images



3. the analysis



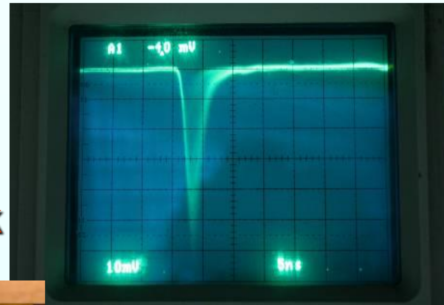


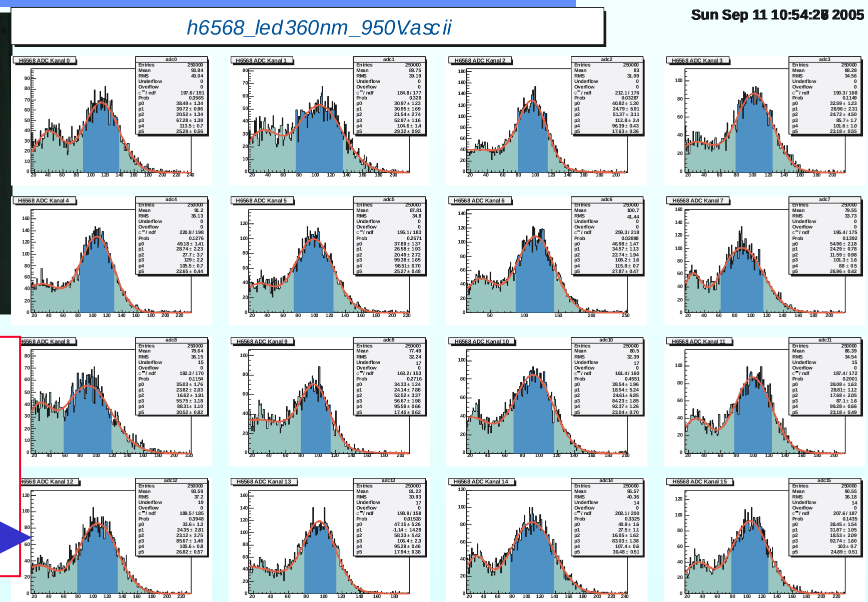
576 TELESCOPES:

A) ~70% within 50 μm tolerance
B) ~20% within 100 μm tolerance
C) ~10% within 150 μm tolerances

MAPMT Quality Control

out of 620 MAPMTs less than 10 MAPMTs not fully satisfactory, mainly due to the dark current requirement:
I dark < 2 nA/ch after ½ h in dark

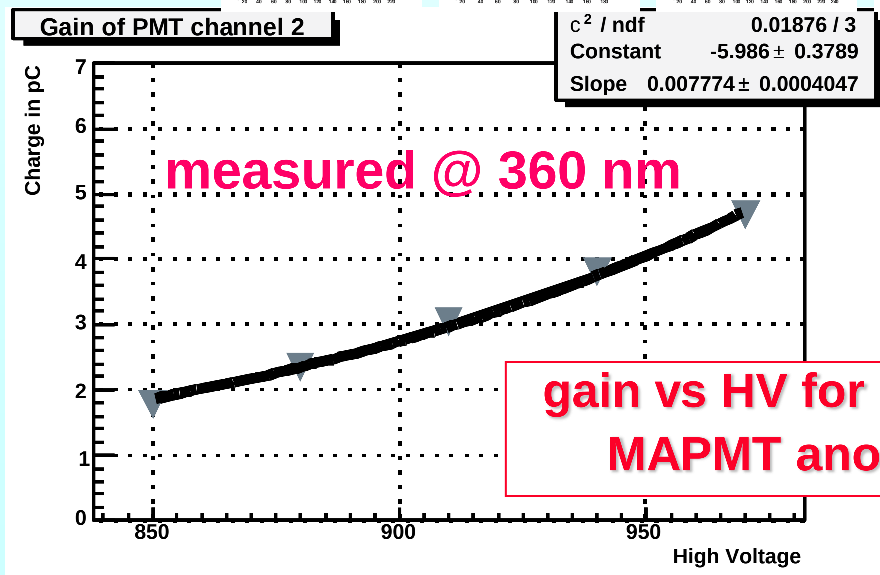




Individual ADC spectra for each channel, voltage, wavelenght

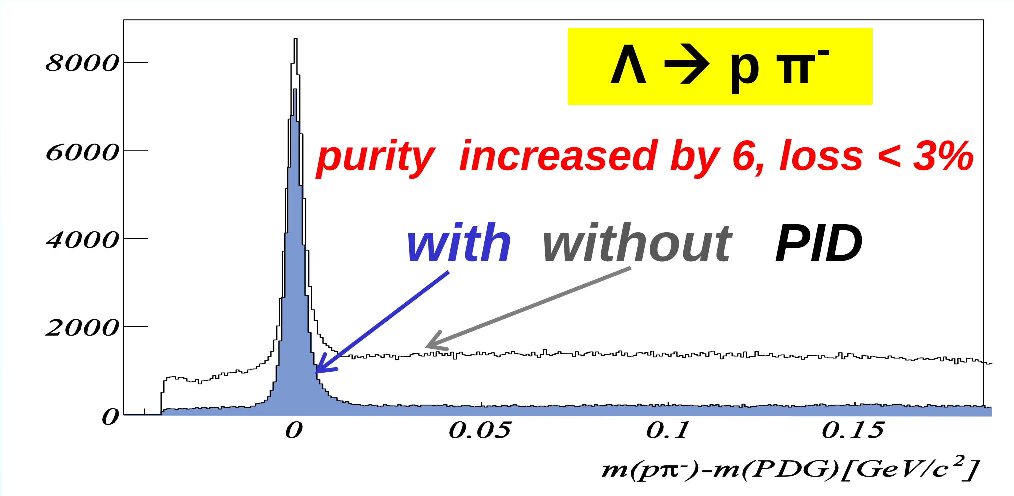
PROTOCOL – 2 h / MAPMT

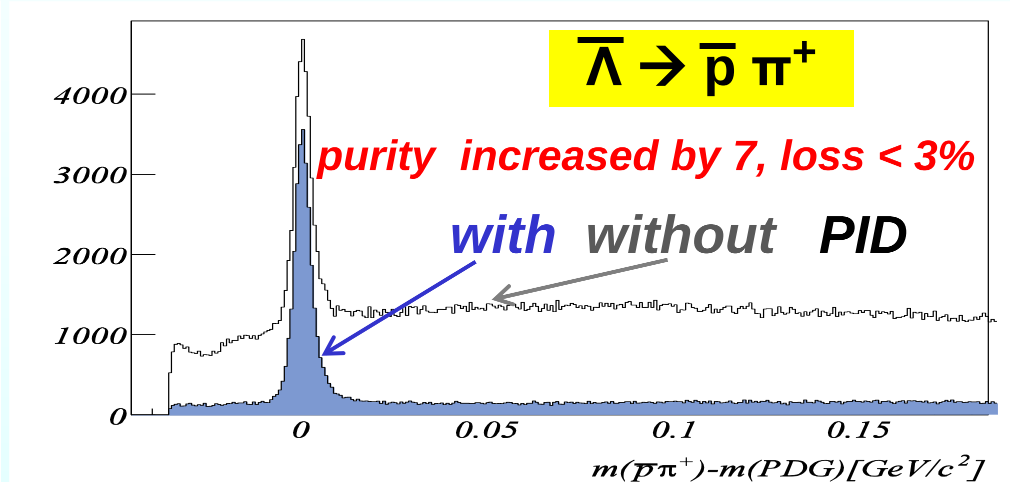
- Visual Inspection (Pixel grid o.k.)
- Noise rates and dark current
- Scope Image stored
- Signal shape, uniformity, gain
  - measuring ADC distribution @ several Voltages
- Quantum efficiency
  - measurement with blue LED and UV LED

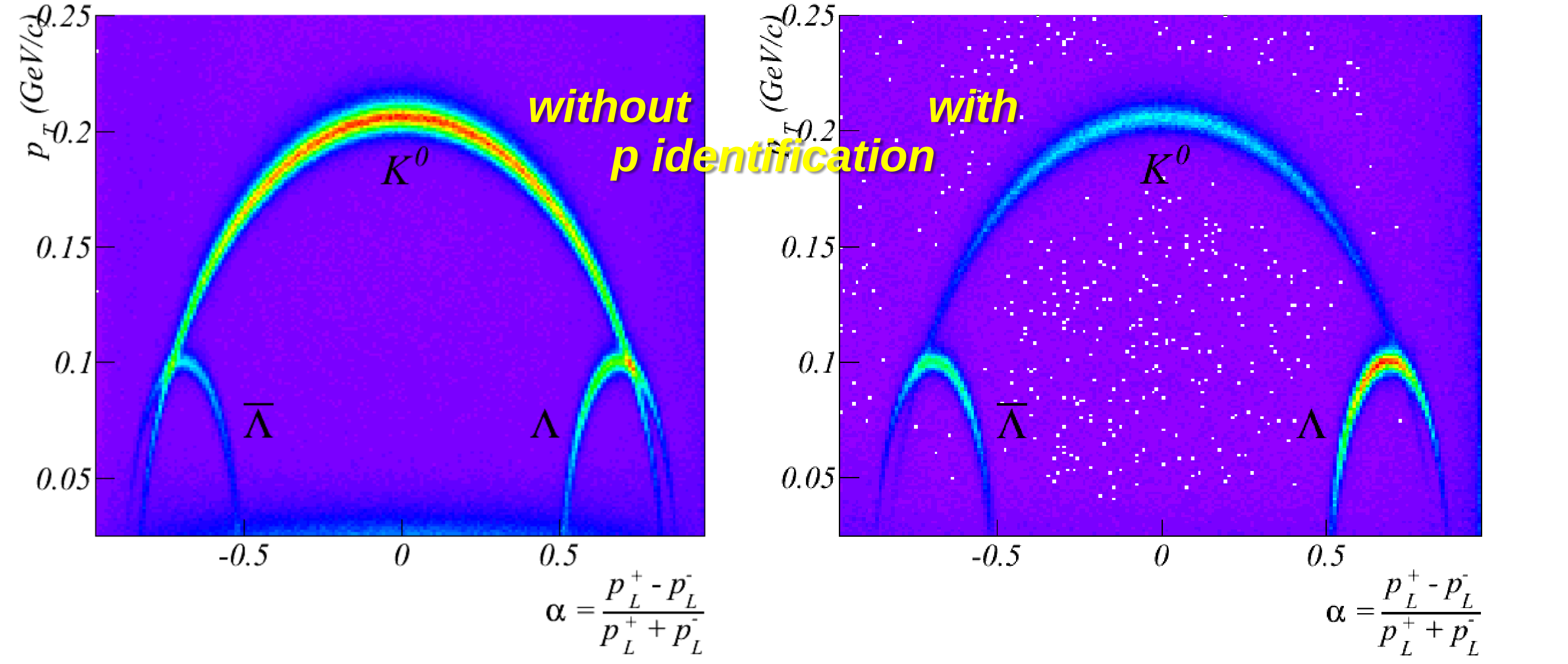


gain vs HV for each MAPMT anode

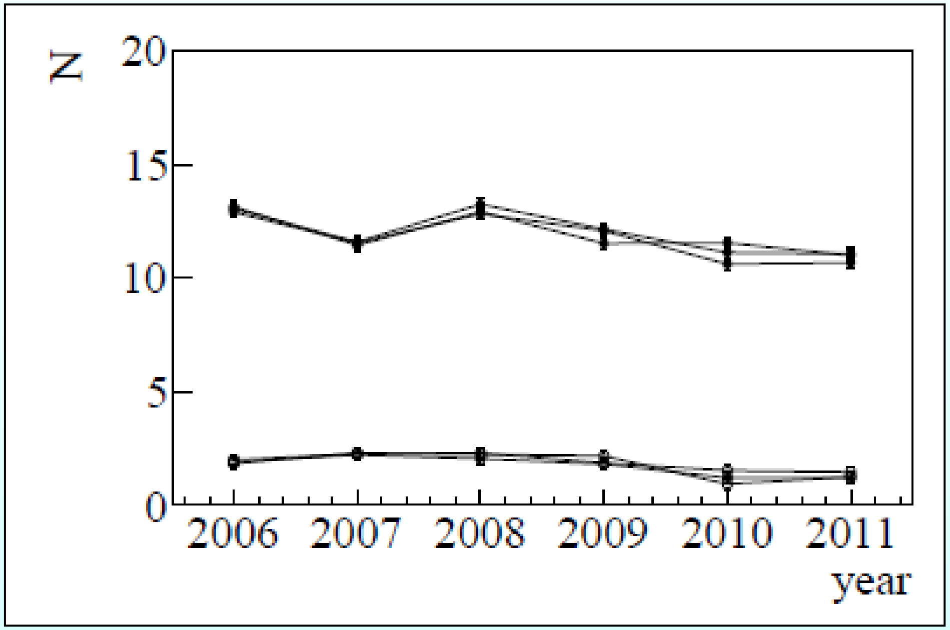
RICH PID information in Λ analysis







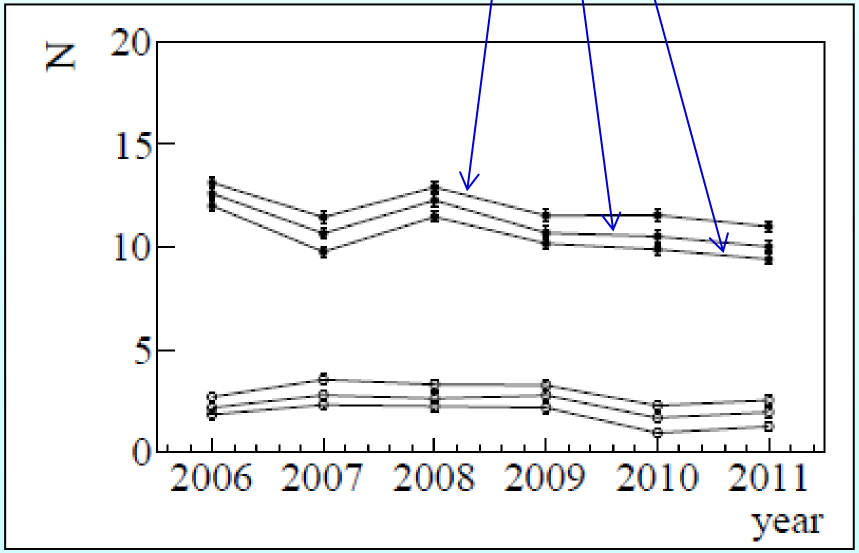
FIT CHECKS



Fit ranges:

- 25 – 45 mrad (25 – 40 mard)
- 20 – 40 mrad (20 – 35 mard)
- 15 – 35 mrad (15 – 30 mard)

Rings with al least
1 2 3 photons



COMPARING THE 6 DATA SETS

POTENTIAL SOURCES OF SYSTEMATIC EFFECTS

- *different beams (μ, h) and beam momentum*
  - *different background and secondary multiplicities*

  → *signal and background contributions are separated in the analysis*
- *HV fixed, -20V (over 2kV) in 2010, 2011: small effect ~ 2.3% N decrease*
- *differences in parameters:*
  - *T, P, electronics threshold*

  → *systematic effect estimated*

source	range of the relevant parameter	r.m.s. / (number of detected photons) (%)
setting of the electronic threshold	(1750 ± 150) electrons	0.7
temperature at the detector (mean on data sample)	(30 ± 2.5) degrees	1.0
atmospheric pressure (mean on data sample)	(960 ± 5) mbar	0.6

- *procedure self-correcting for the variation of the refractive index (P, T, residual N_2 content)*
  - *$n-1 = (1422 - 1537) * 10^{-6}$*
- *gas transparency:*

  → *negligible variations (constant monitoring)*