Particle identification using Ring Cherenkov detector technology at COMPASS

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2. RIng Imaging CHerenkov Detectors Basics

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Spin observables →experiments

pp

@RHIC:

PHENIX

STAR

BRAHMS

sidis

NICA&NUCLOTRON @JINR

hermes @DESY

COMPASS @CERN

Jefferson Lab @6GeV

e^+e^-

BELLE

@KEK

far future

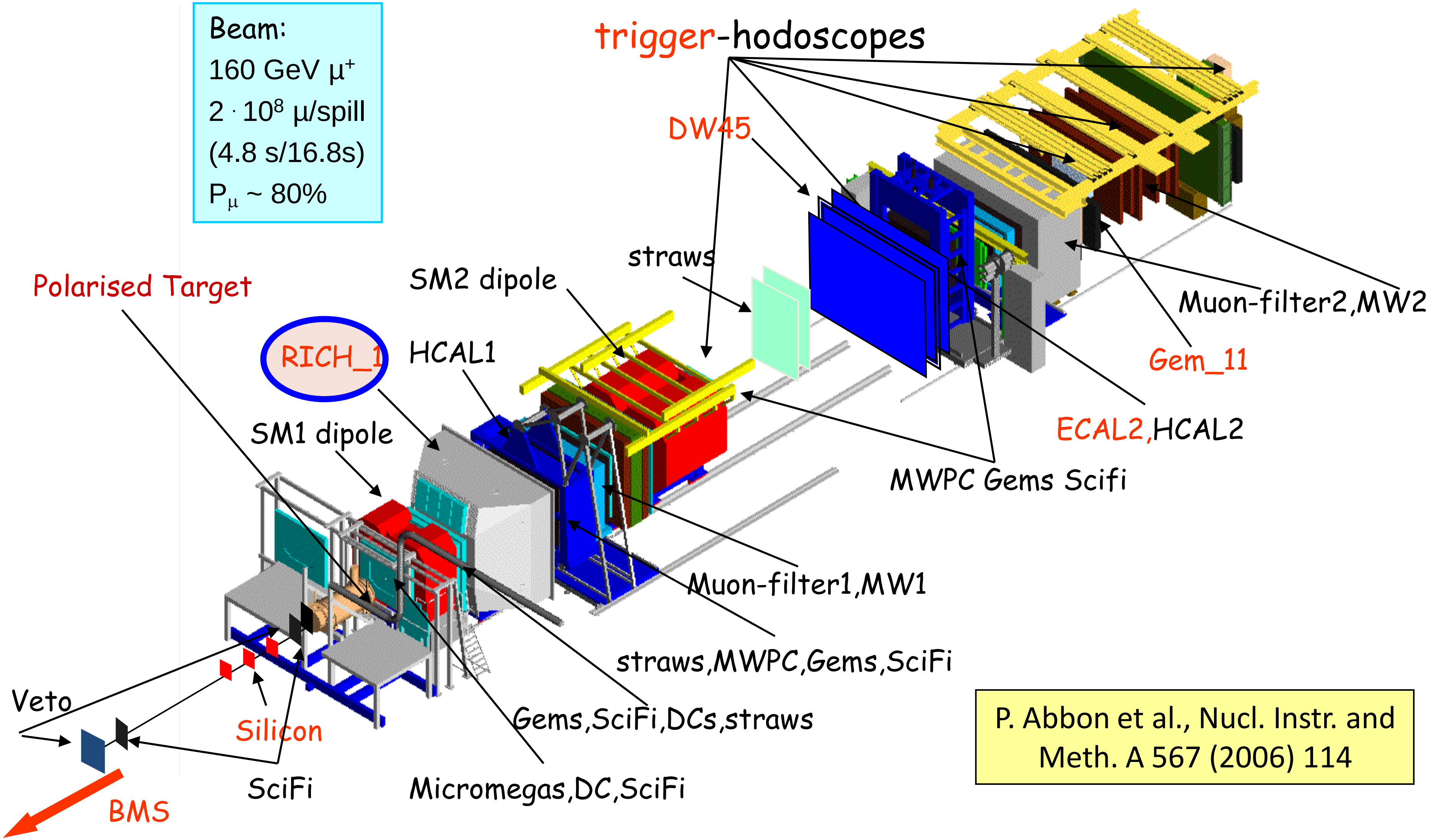
PANDA&PAX@GSI *JLab*@12GeV *EIC* *JParc* *IHEP*

COMPASS Experiment at SPS CERN

Prague, December 19, 2006

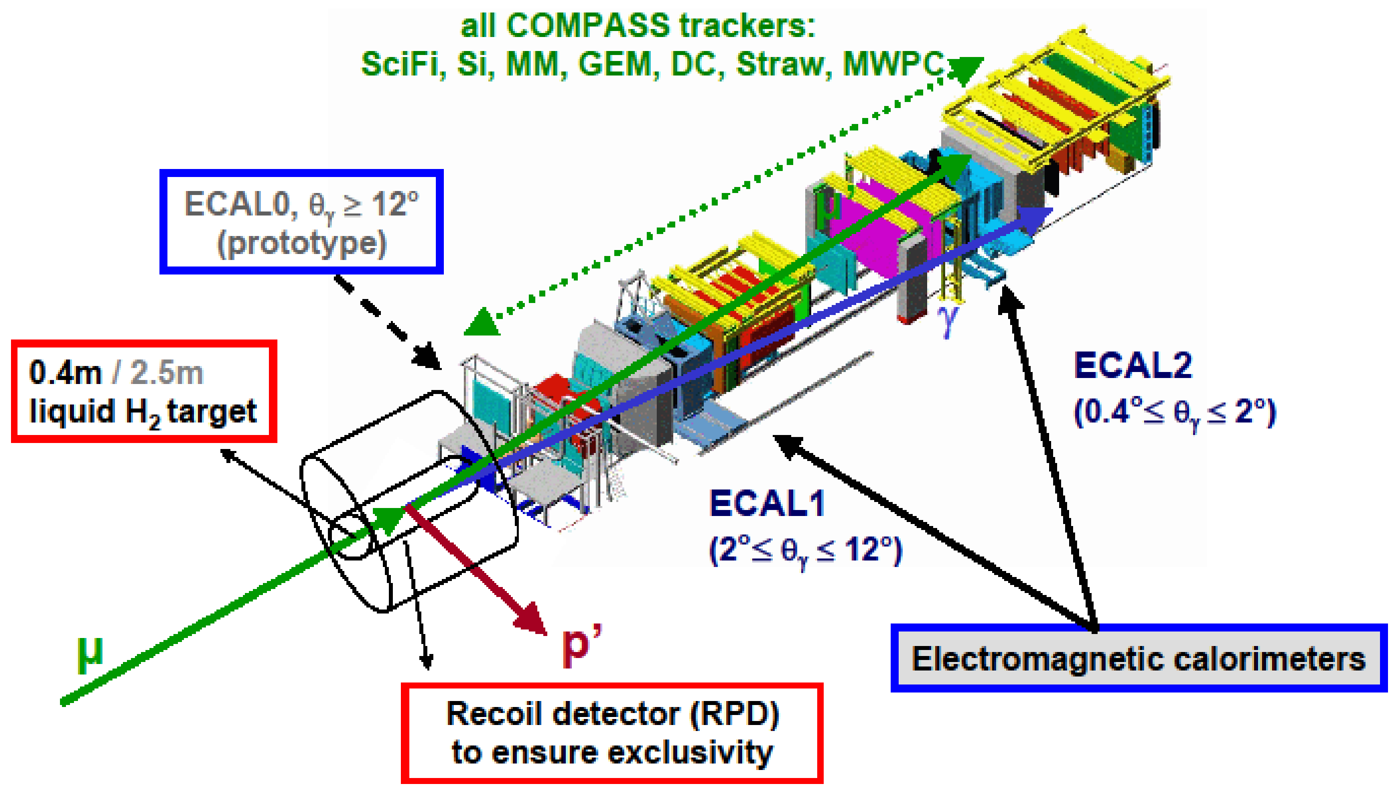
THE COMPASS SPECTROMETER

Beam:
160 GeV μ^+
$2 \cdot 10^8$ μ/spill
(4.8 s/16.8s)
P_μ ~ 80%

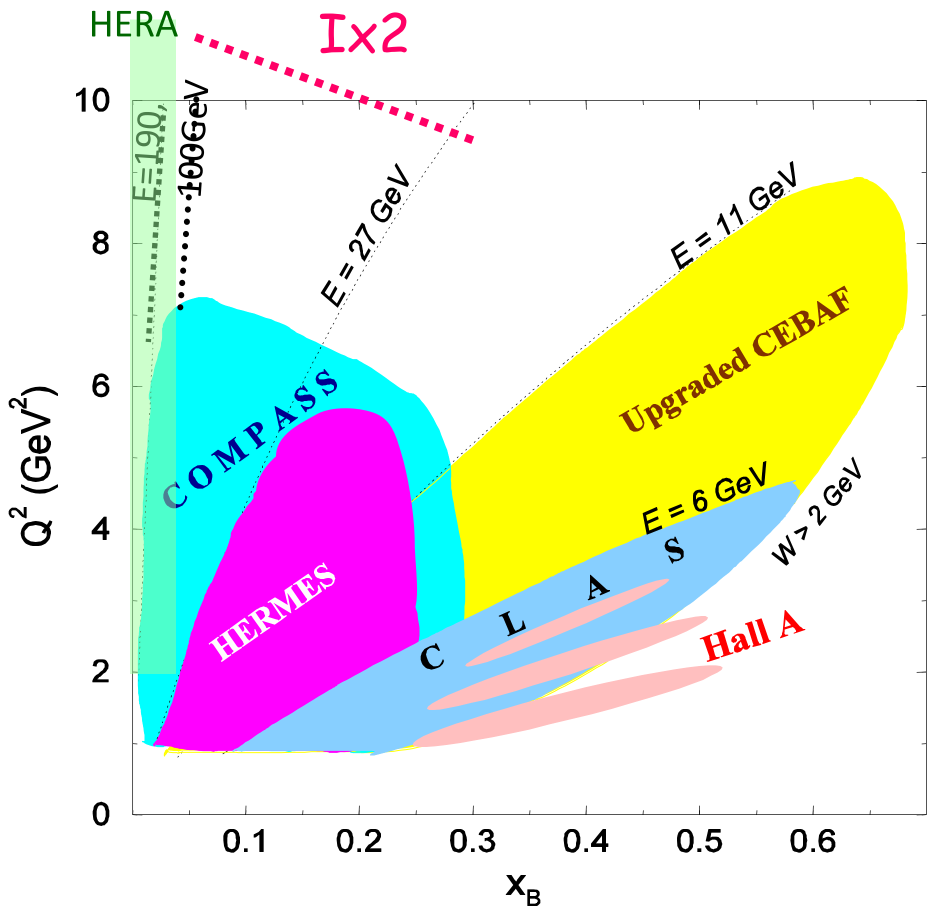


P. Abbon et al., Nucl. Instr. and Meth. A 567 (2006) 114

COMPASS: Setup 2008 and beyond



Competition in the world and COMPASS role



Gluons valence quarks and sea quarks and gluons valence quarks

COMPASS 2010

JLab 12 GeV, FAIR,... 2014

COMPASS at CERN-SPS

High energy muon beam 100/190 GeV

μ+ or μ-

change once per day

polar(μ+)=-0.80

polar(μ-)=+0.80

2.10^8 μ per SPS cycle

if intensity × 2, Q^2 range up to 11 GeV^2

after 2010, which improvements on the muon line ?

Physics program of COMPASS - 1

- Experiments with muon beam
  - $\Delta G/G$
  - g_1
  - Transverse spin effects
  - Flavor decomposition of spin distribution functions
  - Vector meson production
  - Spin transfer in Λ-hyperon production

- Experiments with hadron beams
  - Pion and Kaon polarizabilities
  - Diffractive production of exotic states
  - Search for glueballs
  - Light meson spectroscopy
  - Production of double charmed baryons

RIng Imaging CHerenkov Detectors

Basics

Prague, December 19, 2006

A charged particle with a velocity *v larger than* the velocity of light in a medium emits light.

Pavel A. Cherenkov, Ilja M. Frank, Igor Y. Tamm
Nobel Price 1958



Basic Formulas

Threshold: $\beta_{\text{thres}} = \frac{v_{\text{thres}}}{c} = \frac{1}{n} \quad \gamma_{\text{thres}} = \frac{n}{\sqrt{n^2-1}}$

Angle of emission: $\cos\theta_c = \frac{1}{\beta n} = \frac{1}{\frac{v}{c} n}$

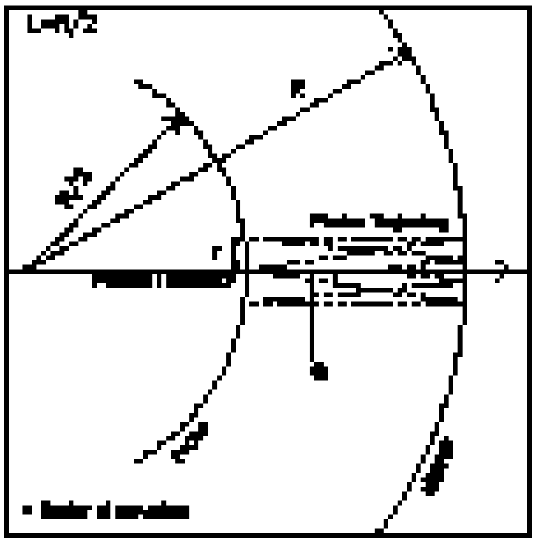
Number of photons:

$$\frac{d^2N}{dE\,dl} = \frac{\alpha z^2}{\hbar c}\left(1 - \frac{1}{(\beta n)^2}\right) = \frac{\alpha z^2}{\hbar c}\sin^2\theta_c$$

$$\frac{d^2N}{d\lambda\,dl} = \frac{2\pi\alpha z^2}{\lambda^2}\sin^2\theta_c$$

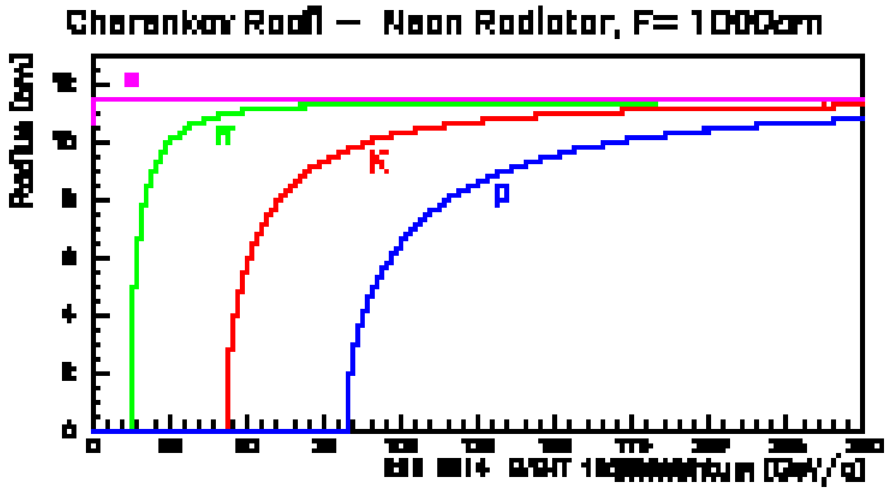
Ring Imaging Cherenkov – The Basics

$$\cos\theta_c = \frac{1}{\beta \cdot n} \qquad r = F \cdot \tan\theta_c = \frac{R}{2} \cdot \tan\theta_c \qquad N_{ph} = N_0 \cdot L \cdot \sin^2\theta_c$$



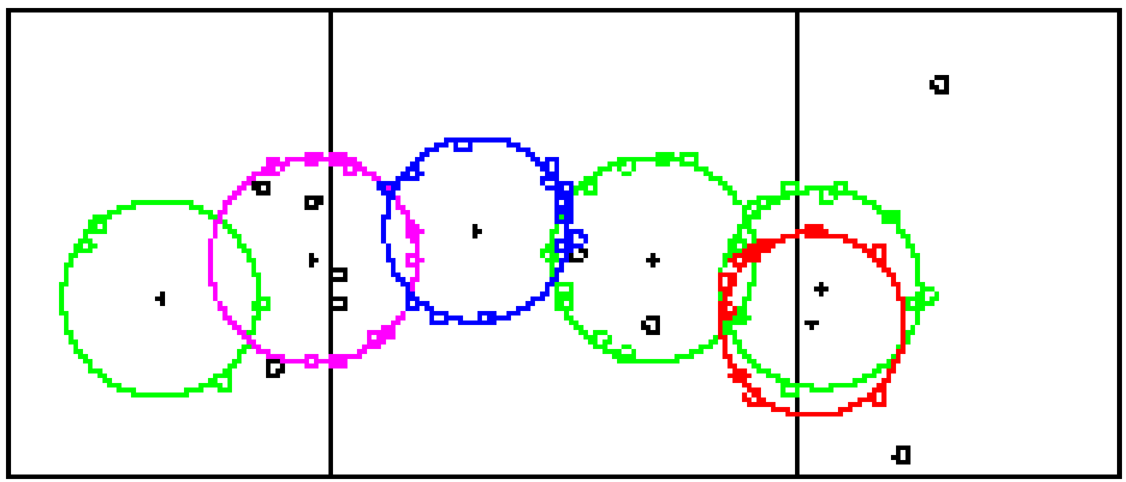
- θ_c: Cherenkov angle
- β: velocity
- n: refractive index
- r: Radius of ring on focal surface
- R: Radius of curvature of spherical mirror(s)
- F: Focal length ($F = R/2$)
- L: Radiator length (usually $L = F$)

Parallel particles have the same ring image



small angle approximation:

$$r = \frac{R}{2}\sqrt{2 - \frac{2}{n}\sqrt{1 + \frac{m^2c^2}{p^2}}}$$



- $$r = F\tan\Theta_c \approx \frac{R}{2}\sqrt{2 - \frac{2}{n}\sqrt{1 + \frac{m^2c^2}{p^2}}}$$

Knowing R and n, and measuring r, we can identify a particle of mass m.

$$\Theta_c \Delta\Theta_c = \frac{m_1^2 - m_2^2}{2p^2}$$

Usually (production experiments):
Most difficult to separate pions and kaons
μ and e are identiffied by other means

But really: Most difficult is μ-π, key features of Velocity Spectrometer (CKM, NA62)

A RICH Detector is as simple as

- a box
- some mirrors
- and a few phototubes?

NO!

Short History of RICHes in Experiments

First Generation: Beginning of 1980's.
Examples: E605, Omega (WA69, WA82), E665.

Second Generation: End-of 80's beginning of 90's.
Examples: Upgraded Omega (WA89, WA94), Delphi, SLD–GRID, CERES, SPHINX.

Third Generation: Mid-End 90's.
Examples: SELEX, Hermes, Hera-B.

Fourth Generation: BaBar–DIRC, PHENIX, CLEO–III, COMPASS, ...

New Generation: LHCb, ALICE, *BTeV*, *CKM*, ...

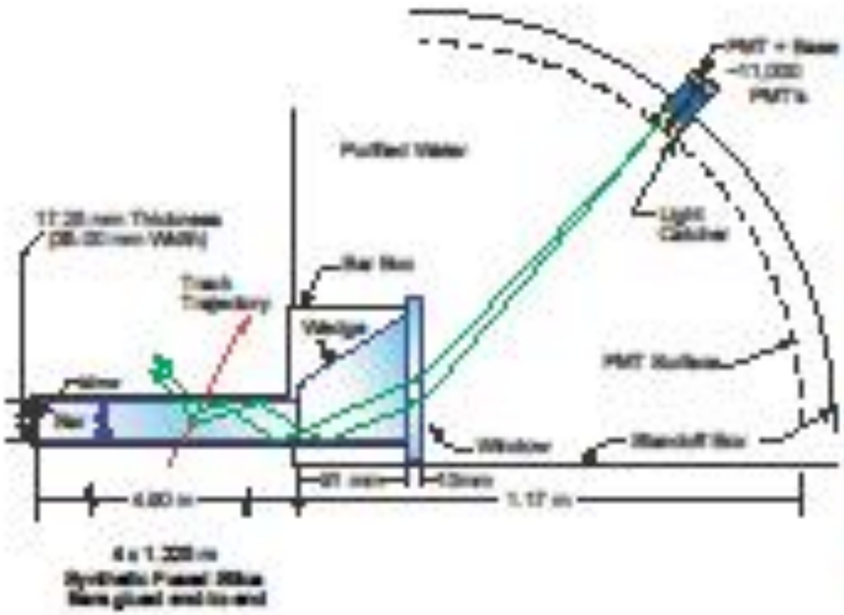
Future: NA62, Panda, WASA, CBM, ...

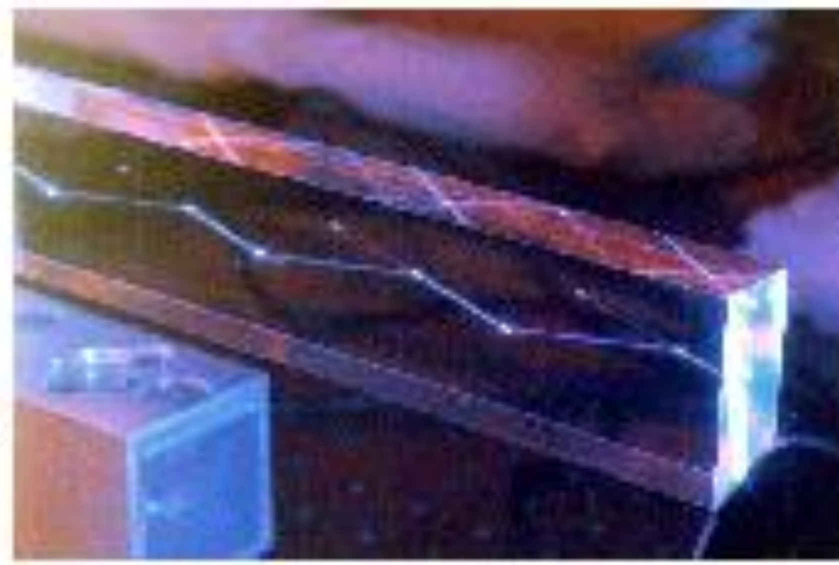
How to select *n*?

- Usually: RICH after magnetic field
  $\Rightarrow$ Minimum Momentum is $\pi^{\pm}$ Threshold
- But also reverse: CERES RICH
- Use pressure or mixture
- Carefull with sensitive range: Chromatic Dispersion and absorption.

Material	$n-1$	γ_{thres}
Diamond	1.42	1.10
ZnS (Ag)	1.37	1.10
Lead Fluoride	0.80	1.20
Glass	0.46-0.75	1.22-1
Water	0.33	1.52
Aerogel	0.025-0.075	4.5-2.
CO_2 (STP)	430×10^{-6}	34.1
N_2 (STP)	300×10^{-6}	45
Ne (STP)	65×10^{-6}	90
He (STP)	33×10^{-6}	123

Detection of internally reflected Cherenkov light

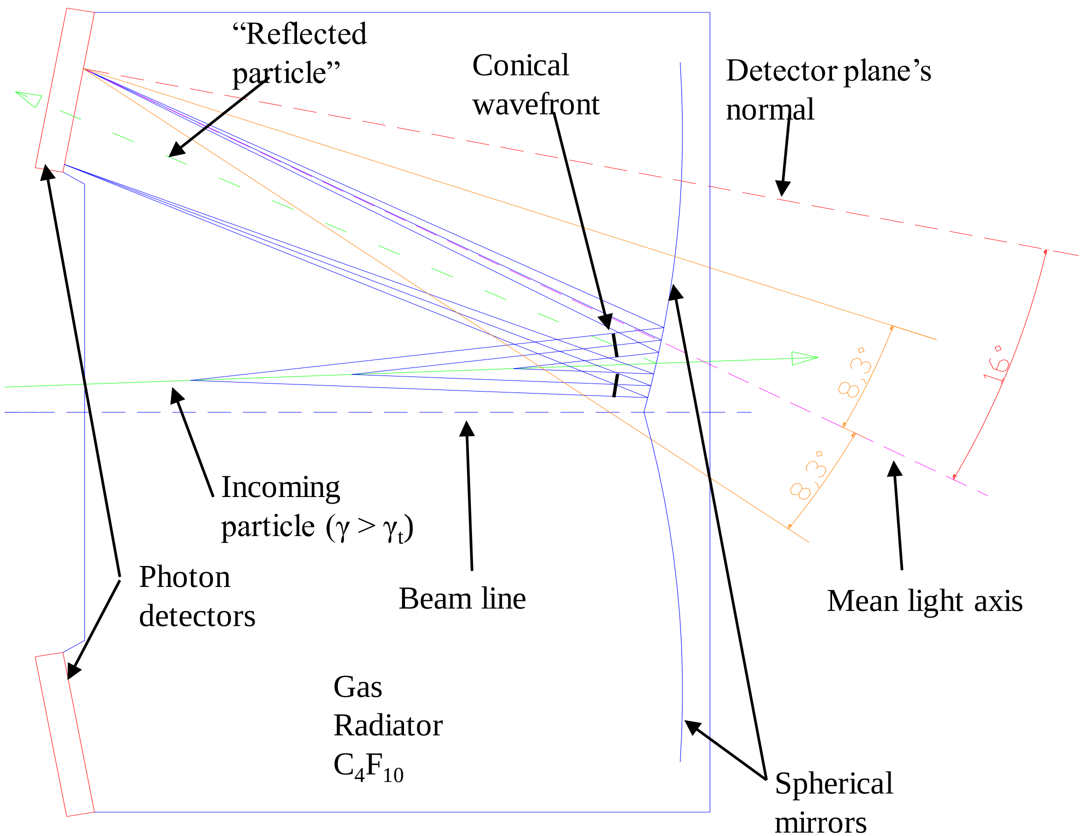




COMPASS RICH-1 Detector for Particle Identification 2009/2010

Prague, December 19, 2006

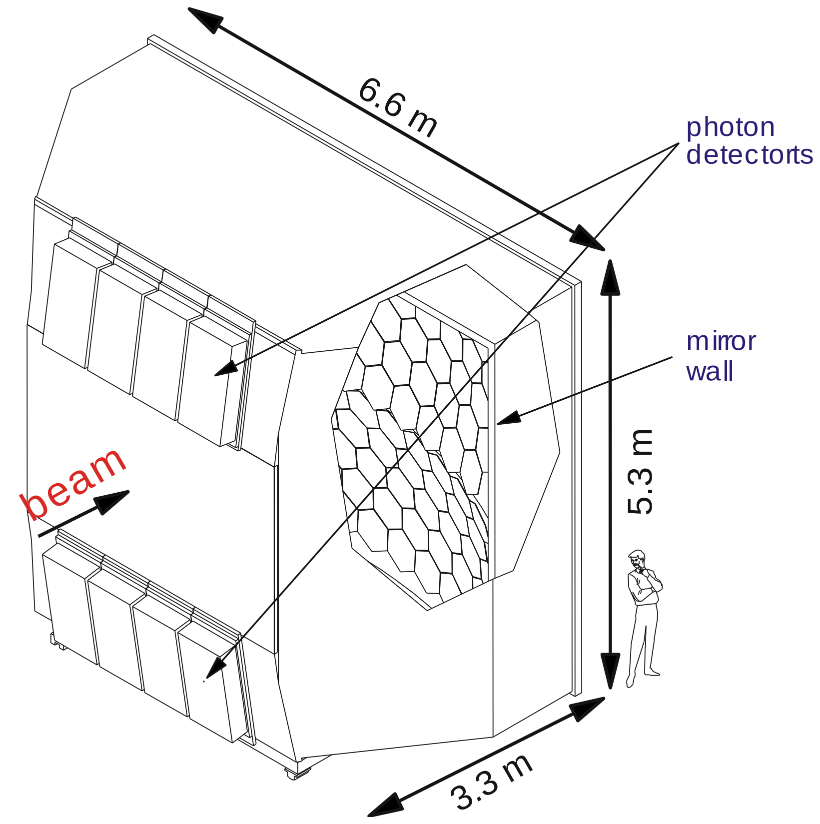
COMPASS RICH Detector



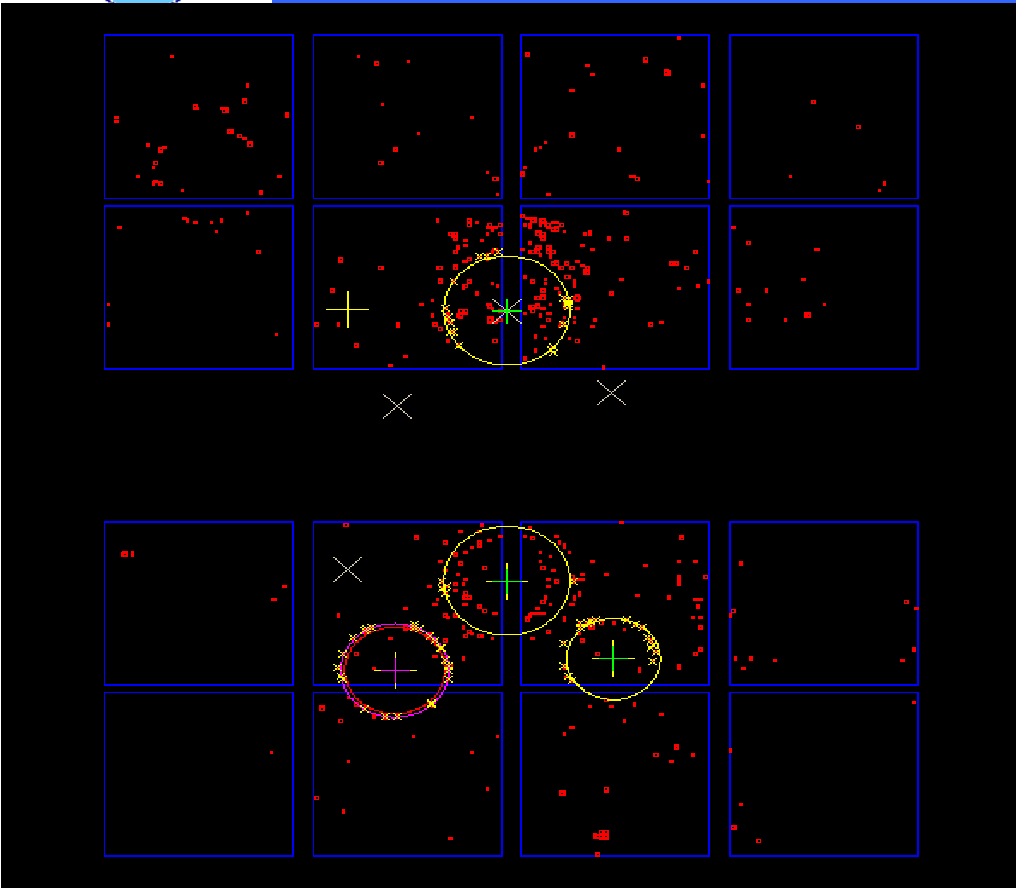
RICH-1

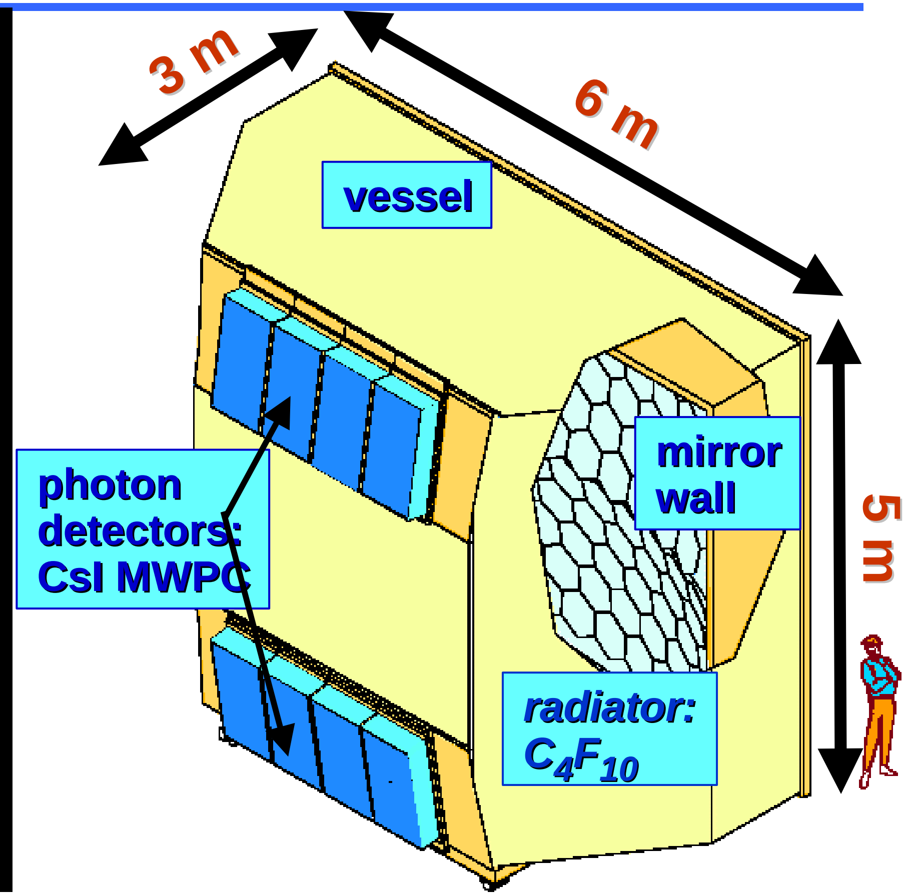
Ring Imaging Cherenkov

- 80 m^3 (3 m C_4F_{10})
- 116 VUV mirrors (3.3 m focal length)
- 5.3 m^2 VUV detectors
  - MWPC CsI photon-sensitive cathodes
  - 8x8 mm^2 pads
- 84k channels of analog read-out



COMPASS





Photon detection

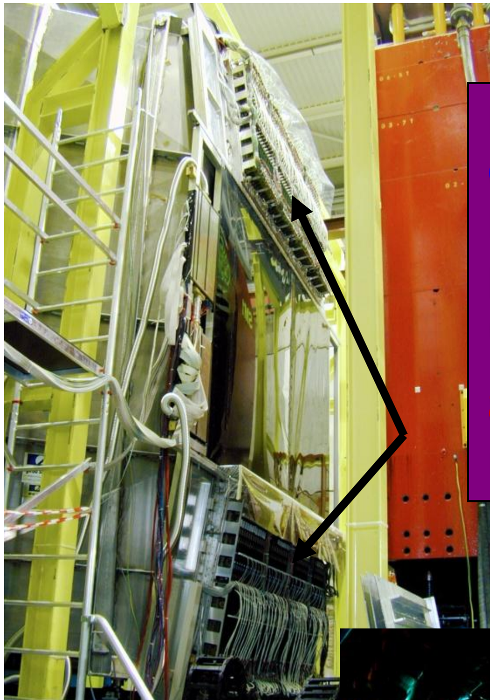
5.3 m^2 MWPCs

16 CsI Photocathodes

84,000 analog readout channels

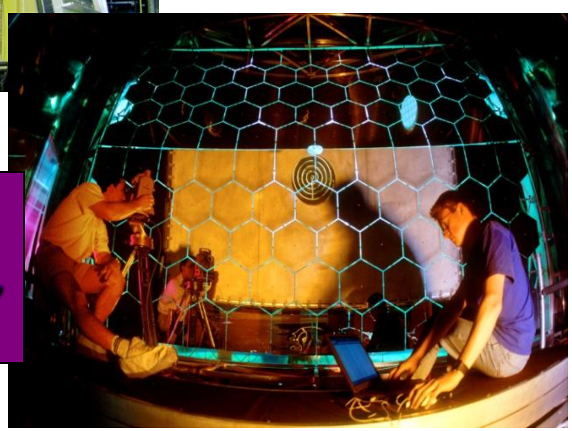
single photon:	σ =1.2 mrad
ring:	σ =0.4 mrad
photons/ring	n ~14
3σ π /K sep.	up to 40 GeV/c

RICH-1



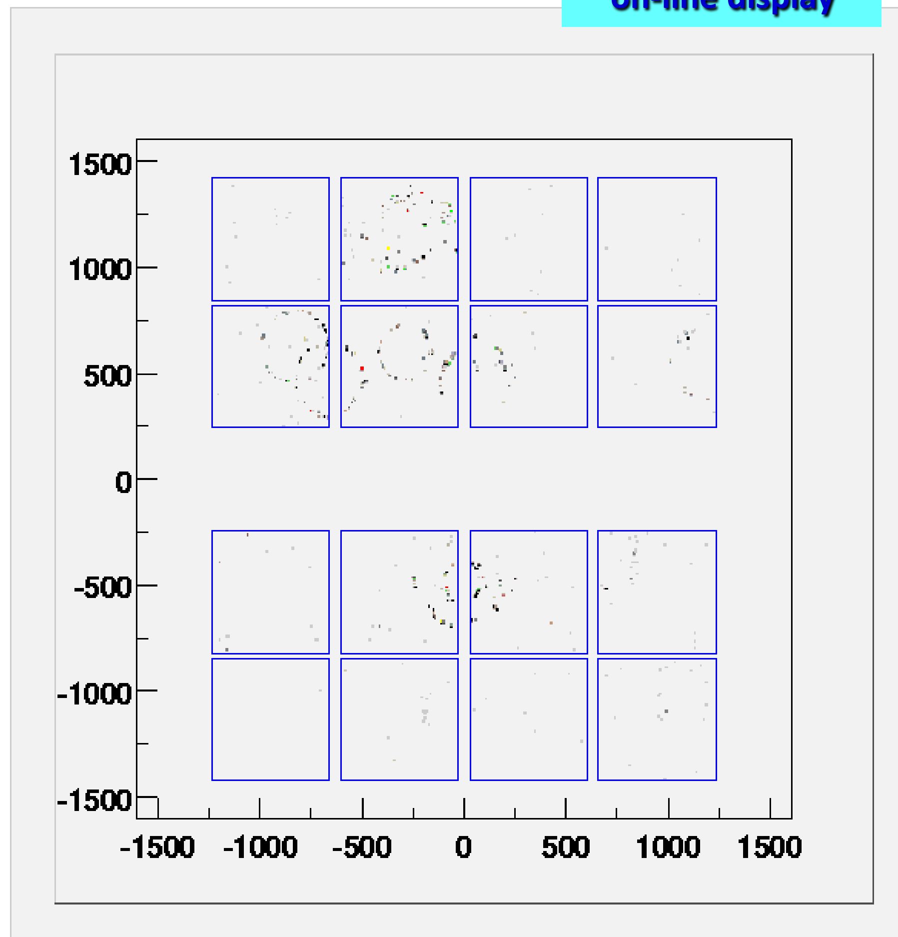
Photon detectors (PD) : MWPCs with CsI photocathodes ($5.3\ m^2$),

84,000 analog read-out ch.s

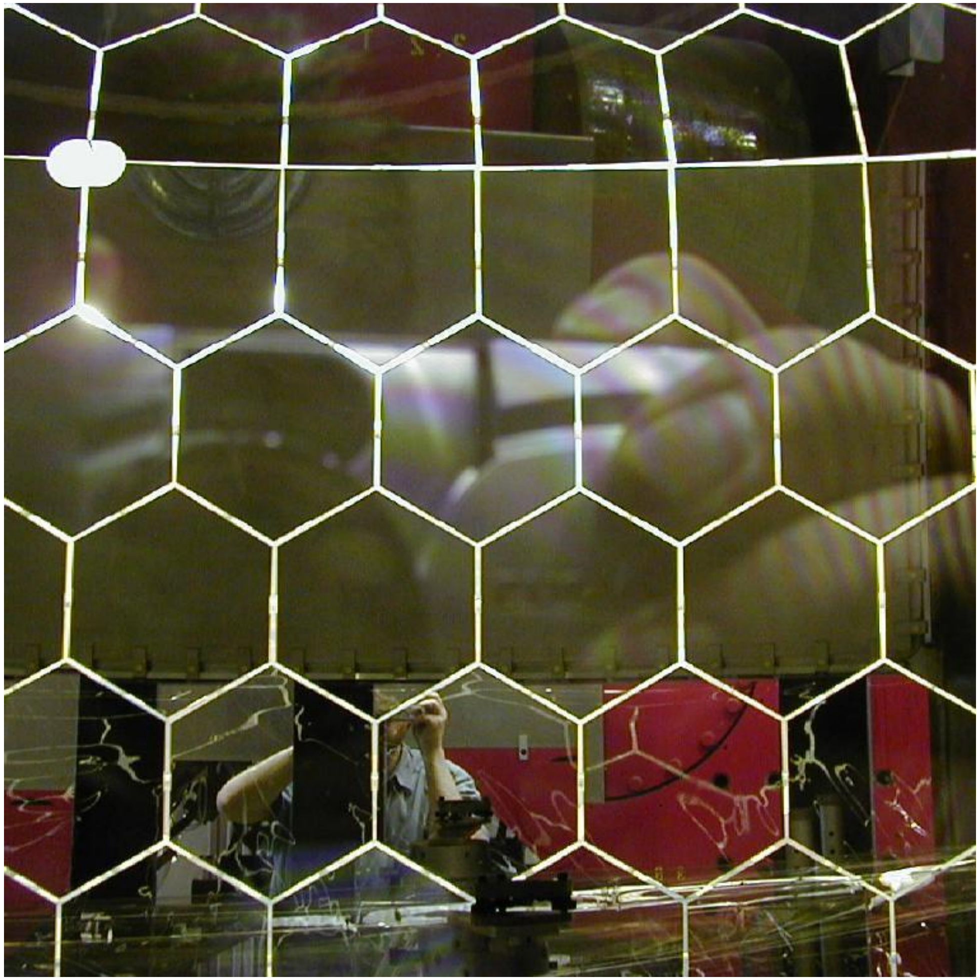


VUV mirror wall, $21\ m^2$, 116 mirrors

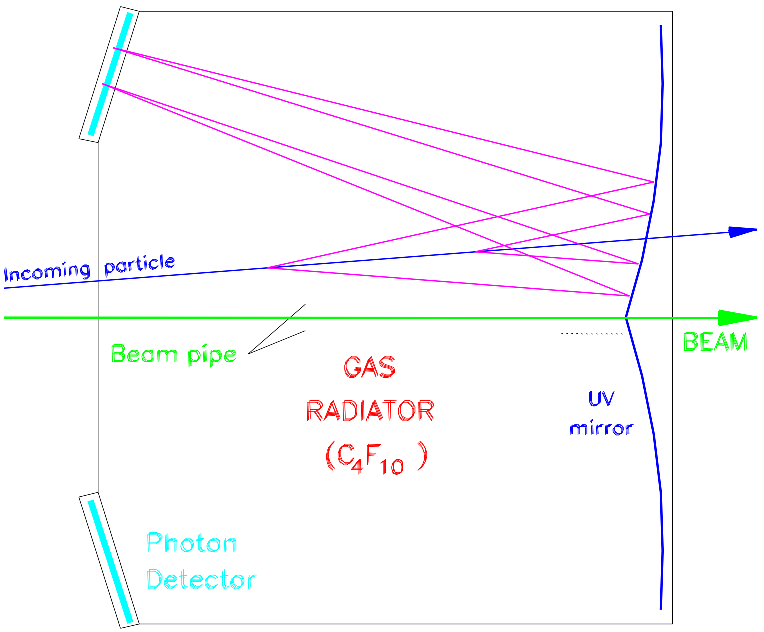
an event from on-line display

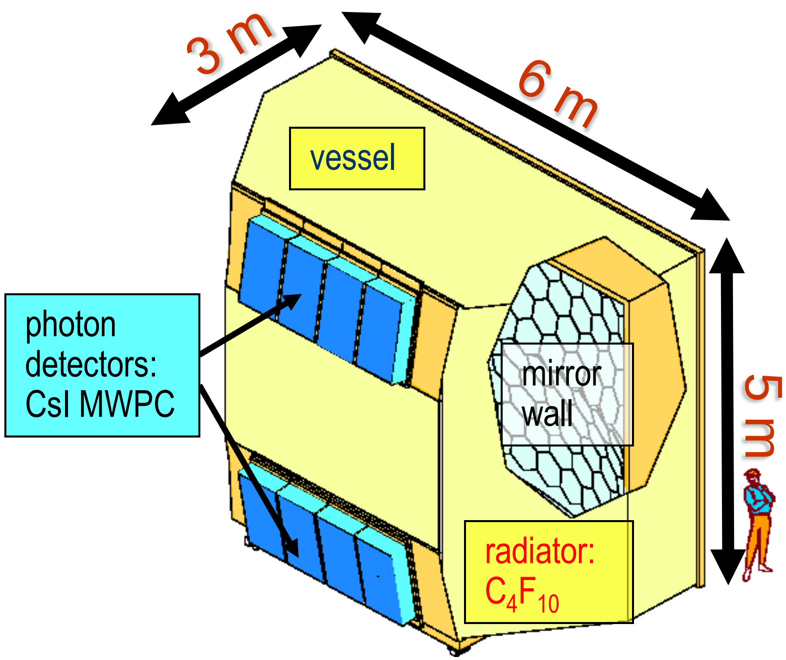


RICH-1 Mirror Wall



The COMPASS RICH detector
(2003-2004, before upgrade)



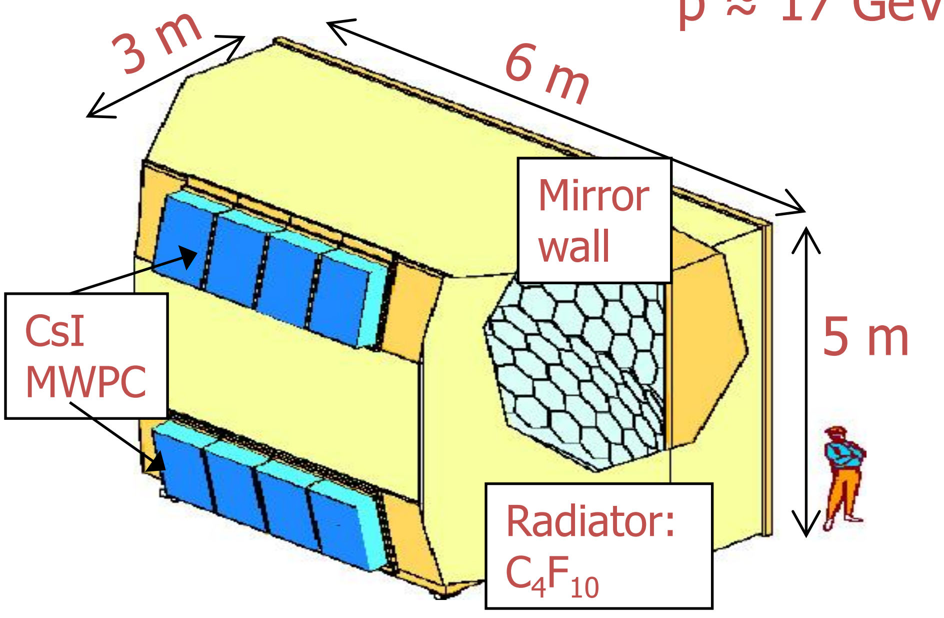


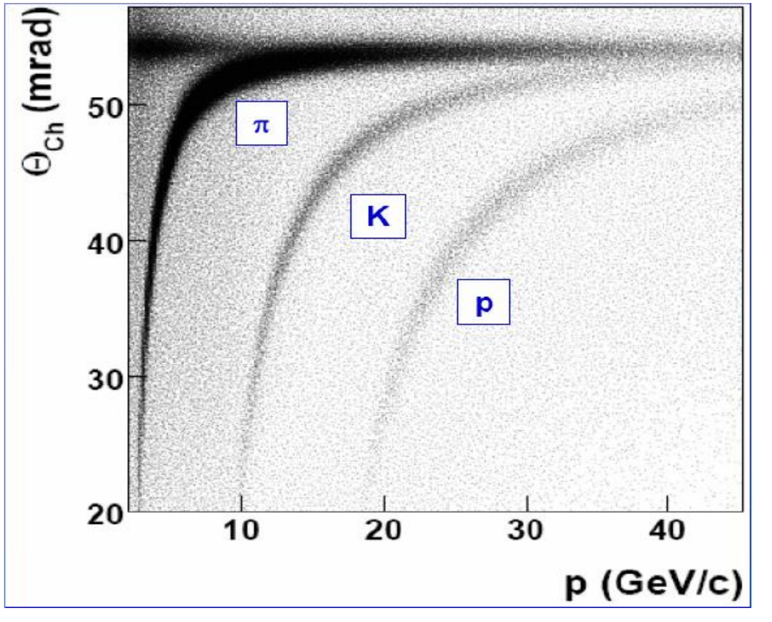
- radiator gas: $C_4 F_{10}$, good transparency > 160 nm, low chromaticity
- mirror: 20 m^2 surface, VUV reflectance (160-210 nm) > 80%
- photon-detectors: Multi Wire Proportional Chamber, total surface 5.3 m^2
- angular acceptance: ± 250 mrad horizontal, ± 200 mrad vertical
- read-out: 83.000 channels (pixels)

particle identification with Compass RICH

identification of π, K and protons
Cherenkov thresholds: π ≈ 3 GeV/c
K ≈ 9 GeV/c
p ≈ 17 GeV/c

2σ π/K separation at 43 GeV/c



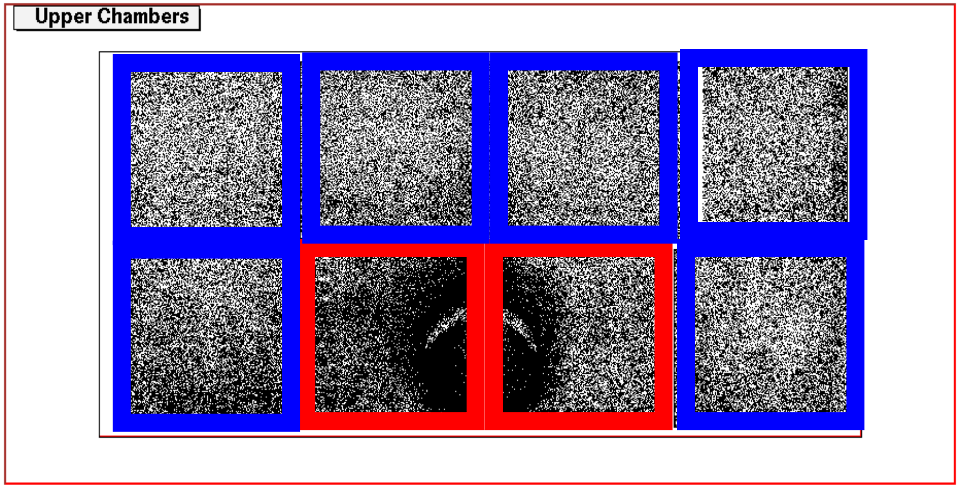


	without PID	π+ π-	π+ K-	K+ π-	K+ K-
total	$5.3*10^6$	$3.7*10^6$	$2.4*10^5$	$3.0*10^5$	$8.7*10^4$

The upgrade project for 2006 data taking

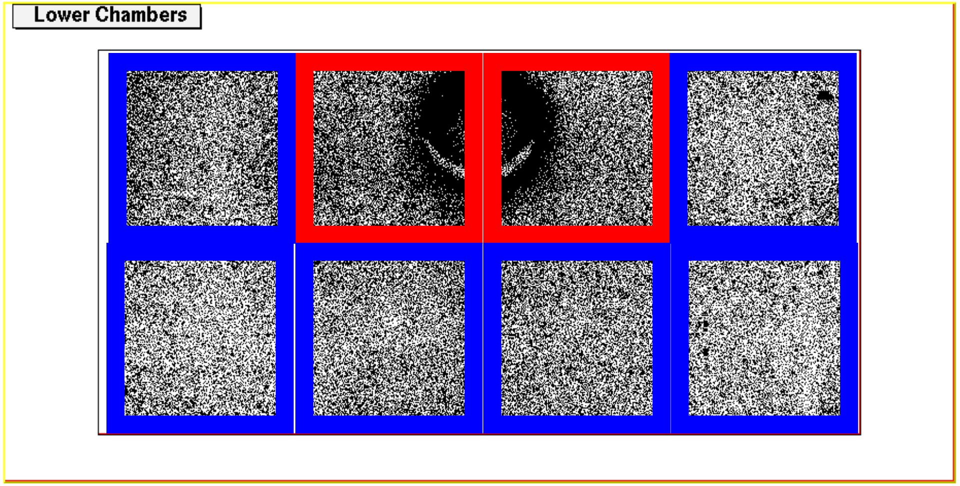
Multi Wire Proportional Chambers:
(MWPC, in use since 2001)

- CsI photo cathodes
- new read-out system: APV chip
  (negligible dead time)
- time resolution (CsI with MWPC + ro):
  ~ 3 μs → < 40 ns

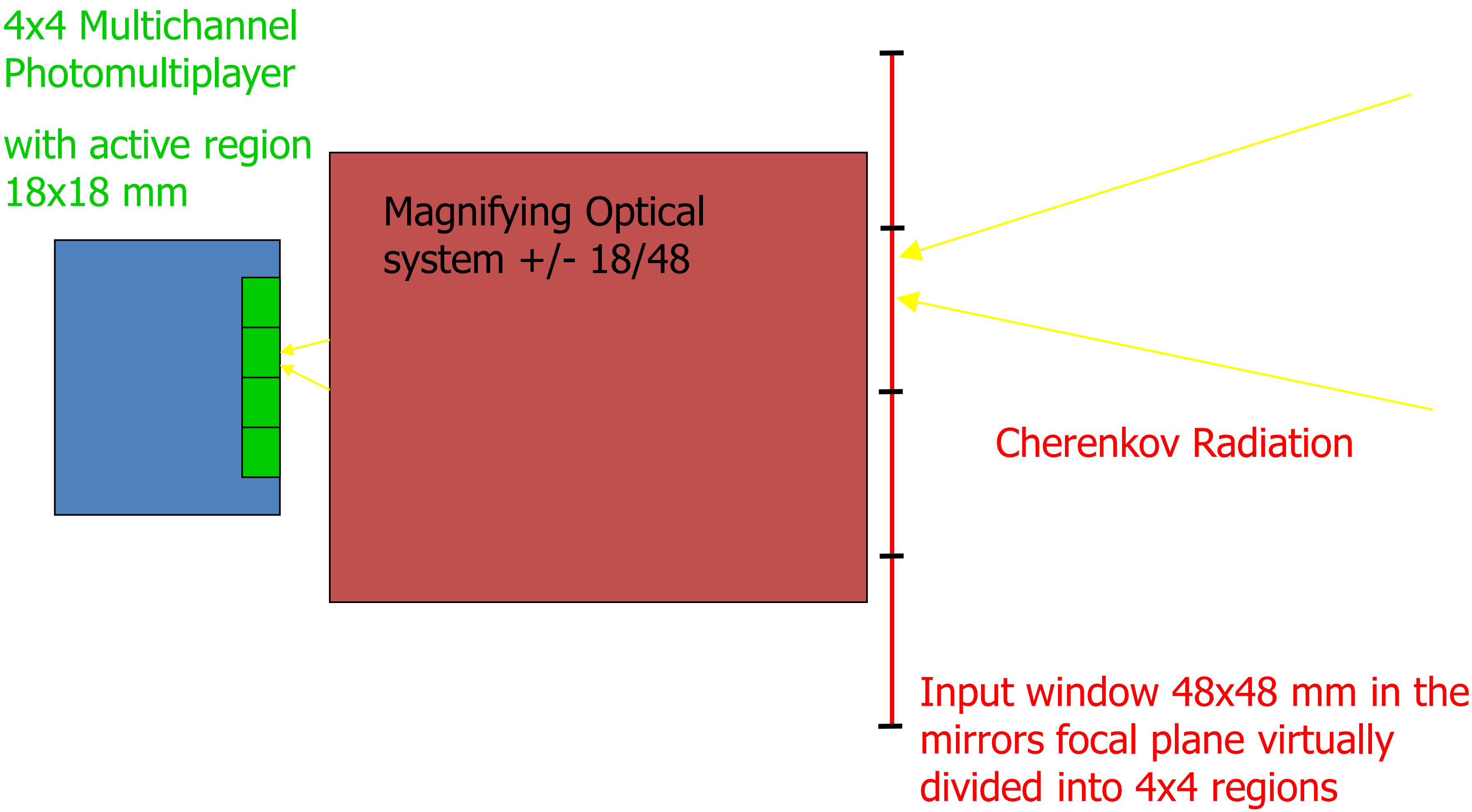


Fast photon detection:

- Multi Anode PMTs (MAPMT, 576 pc)
- individual telescopes
- read-out
  → sensitive FE: MAD chip
  → high resolution TDC: F1 chip
- time resolution: few ns
- no MWPC

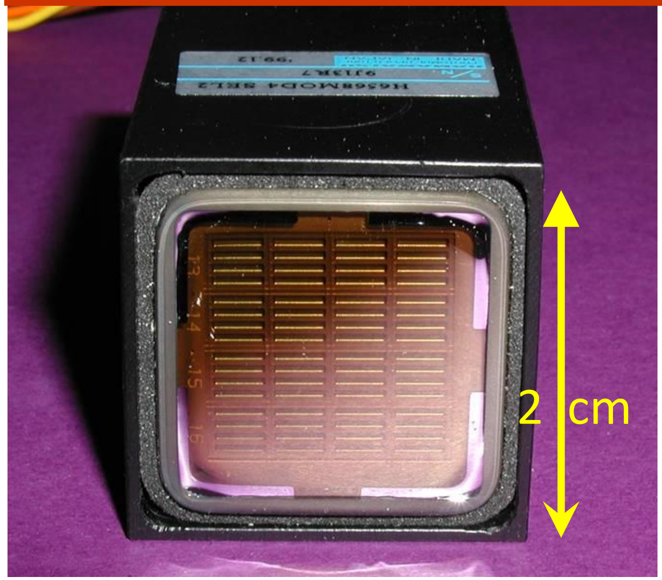


Optical system for upgrade RICH-1 detector

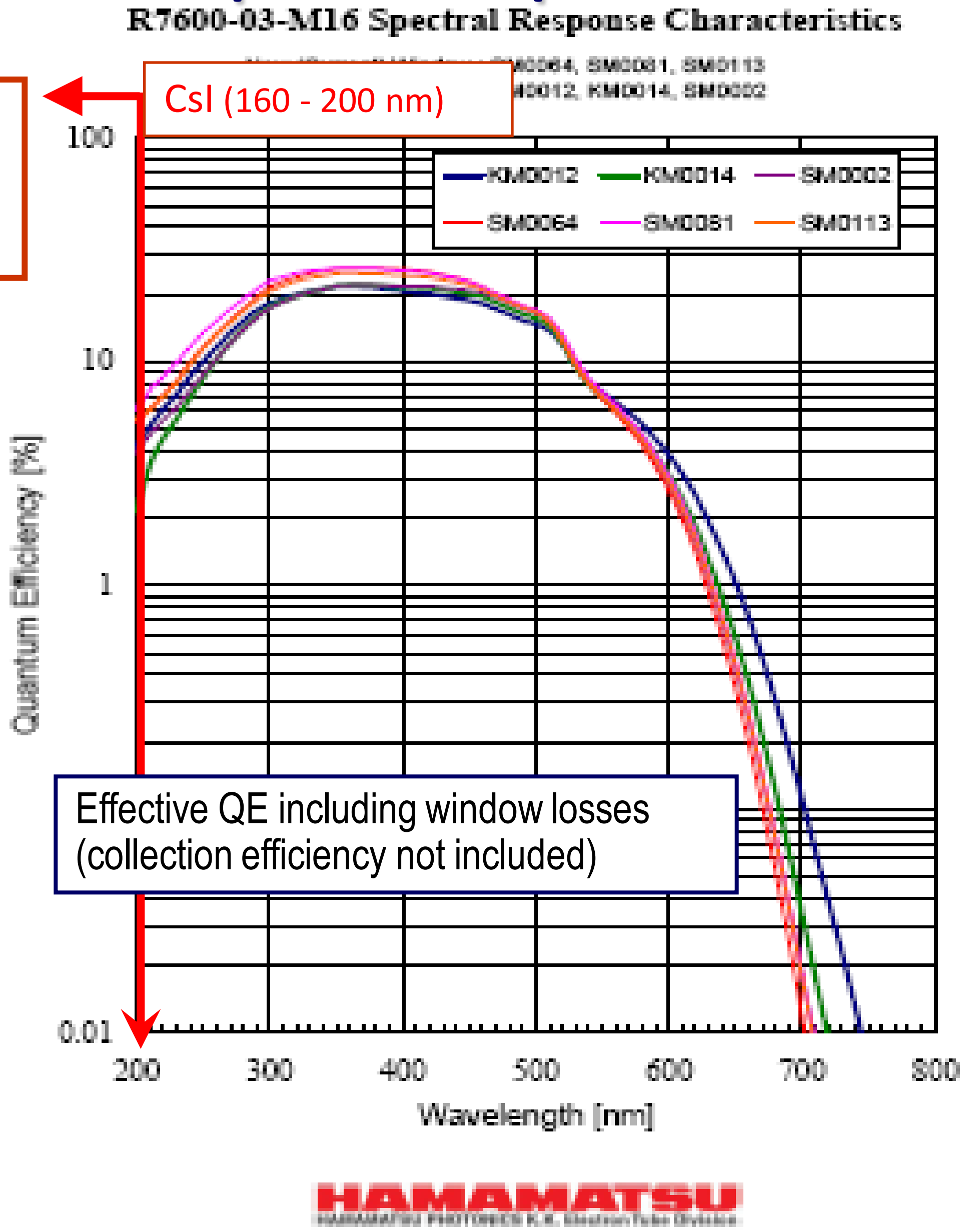


Hamamatsu R7600-03-M16 photomultiplier

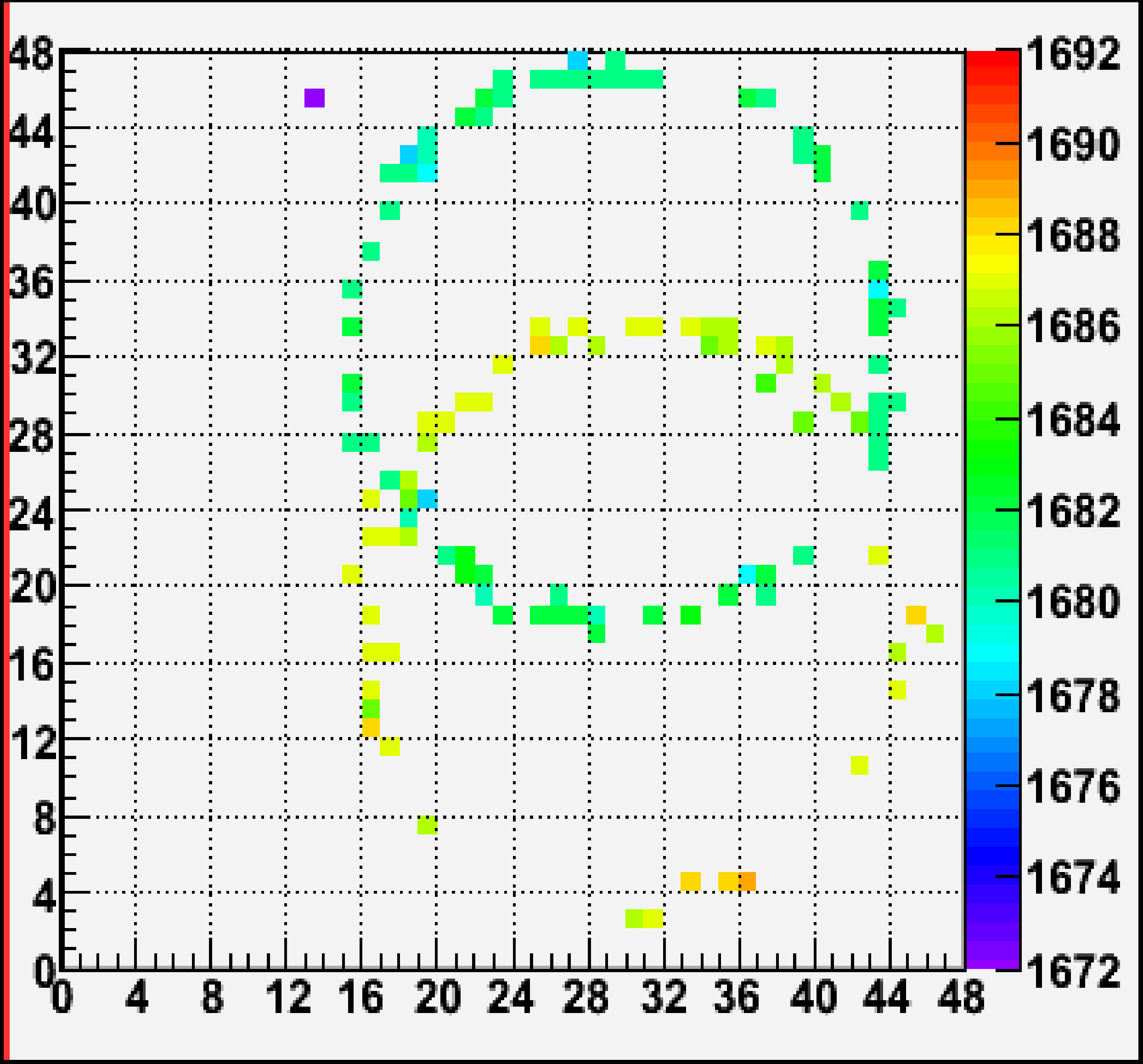
Larger number of detected Cherenkov photons,
due to larger wavelength range:



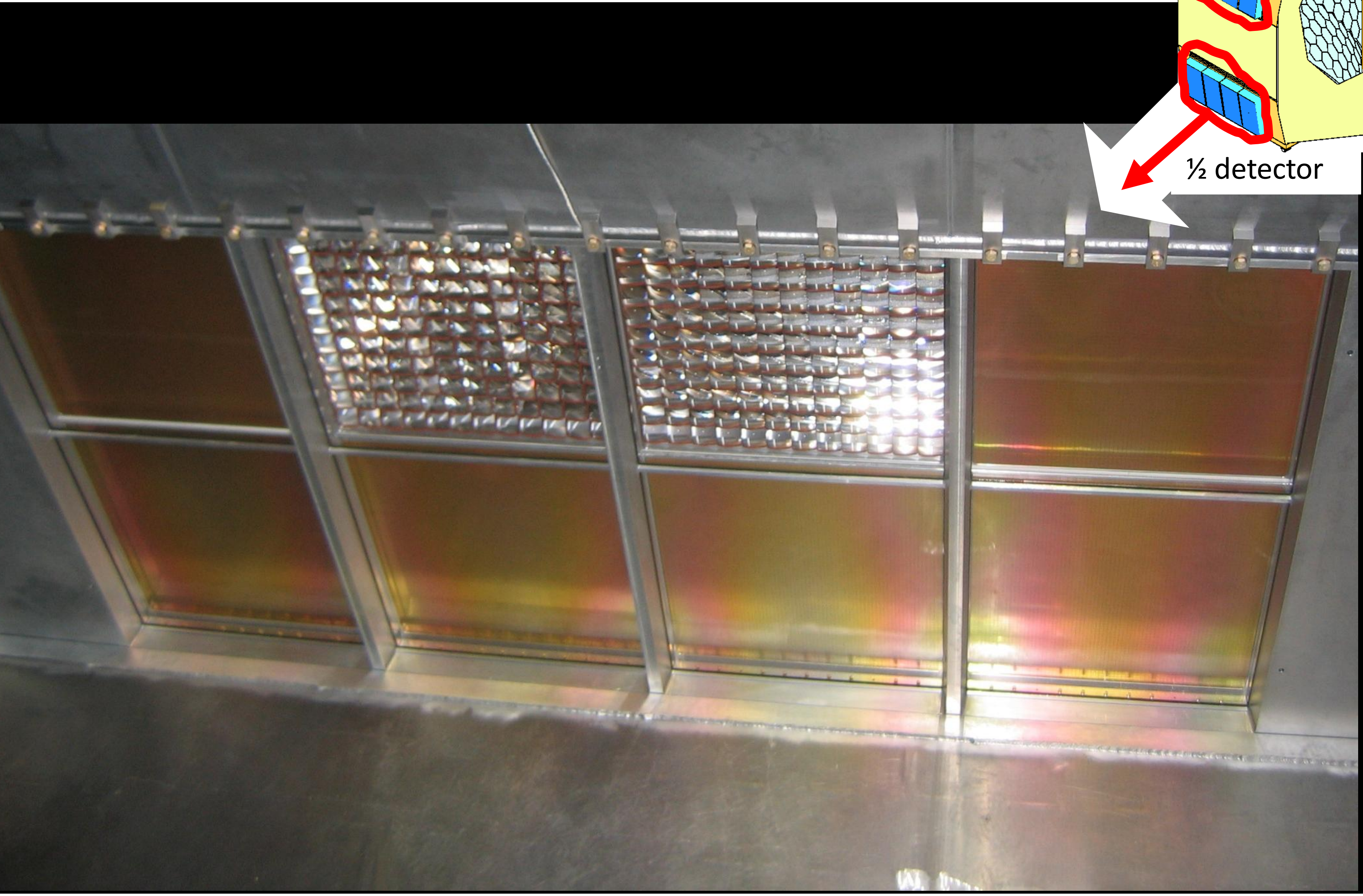
- bialkali photocathode
- 18 x 18 mm^2 active area
- 16 pixel
- time resolution 300 ps
- UV transparent borosilicate glass window

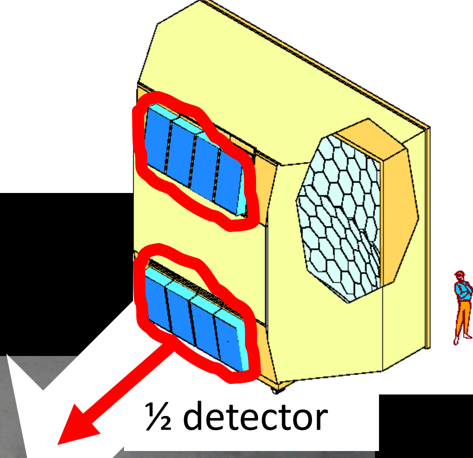


Time resolution is useful for correctly assigning hits to rings:

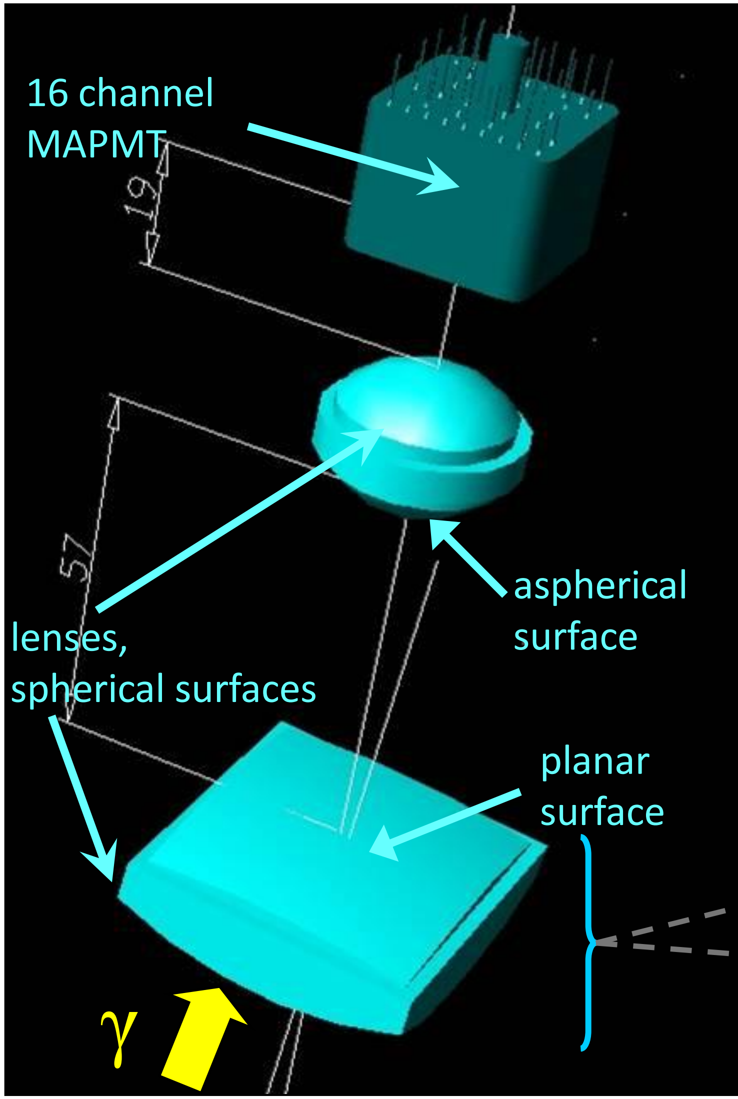


Half upgraded detector- from inside



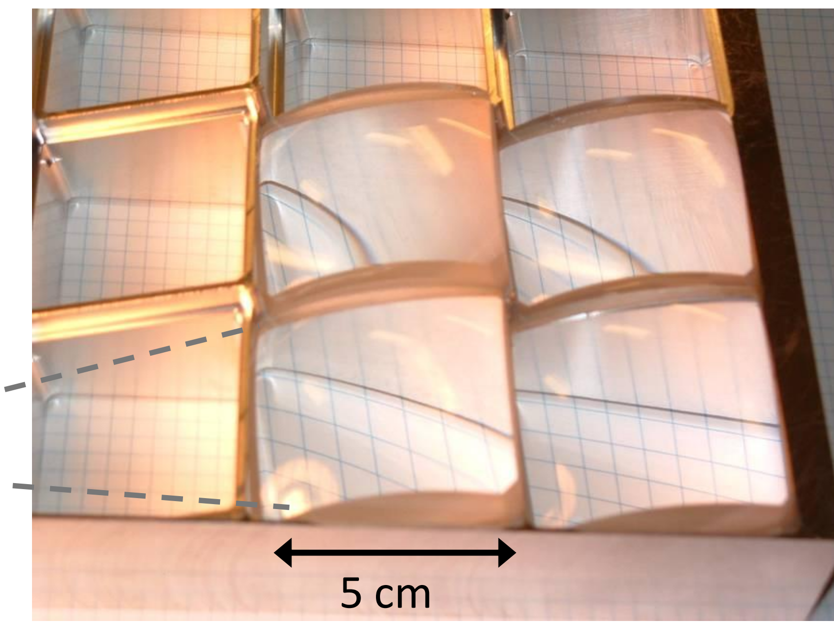


576 telescopes made of silica lenses

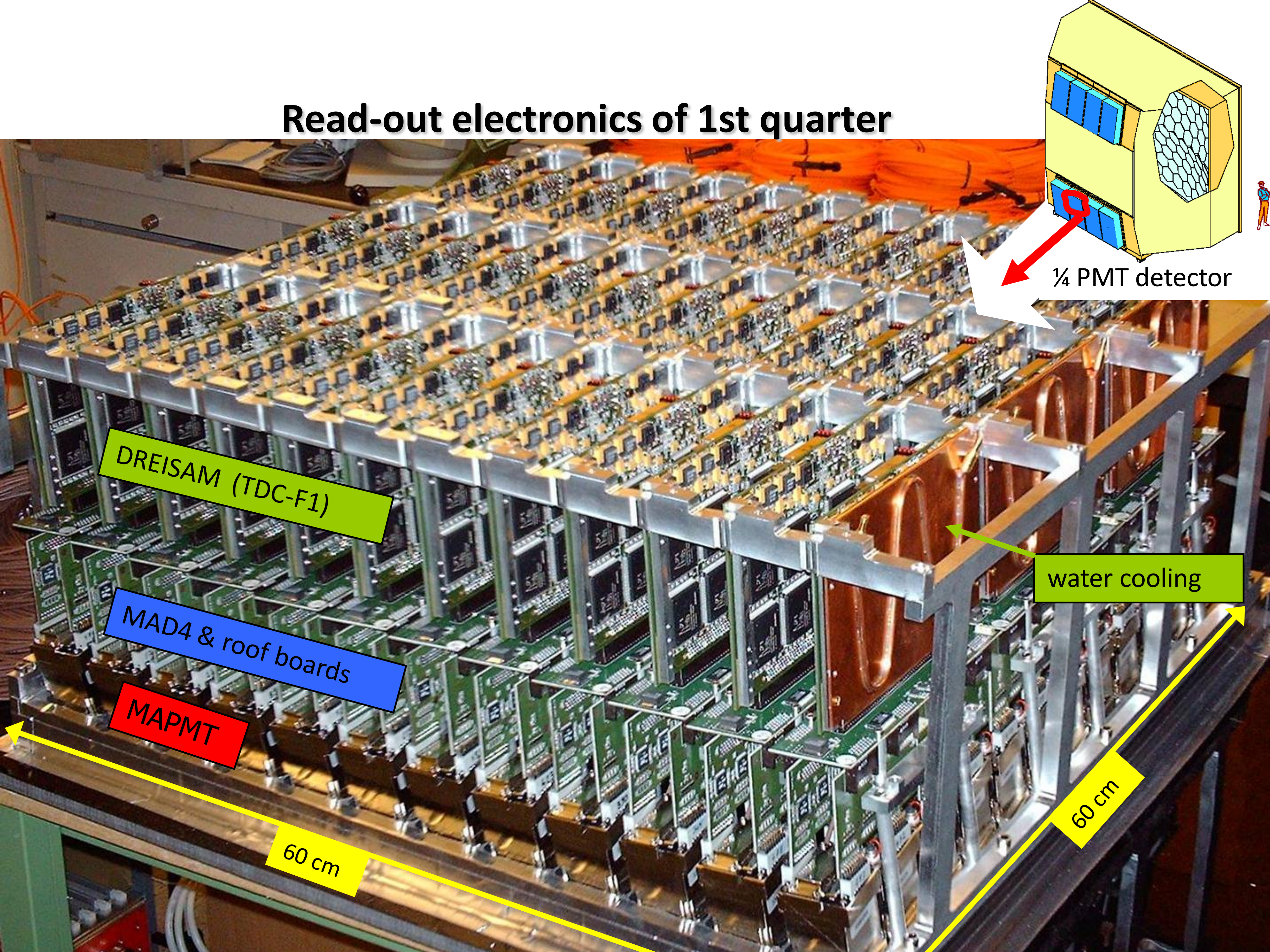


Telescope system consisting of 2 lenses:

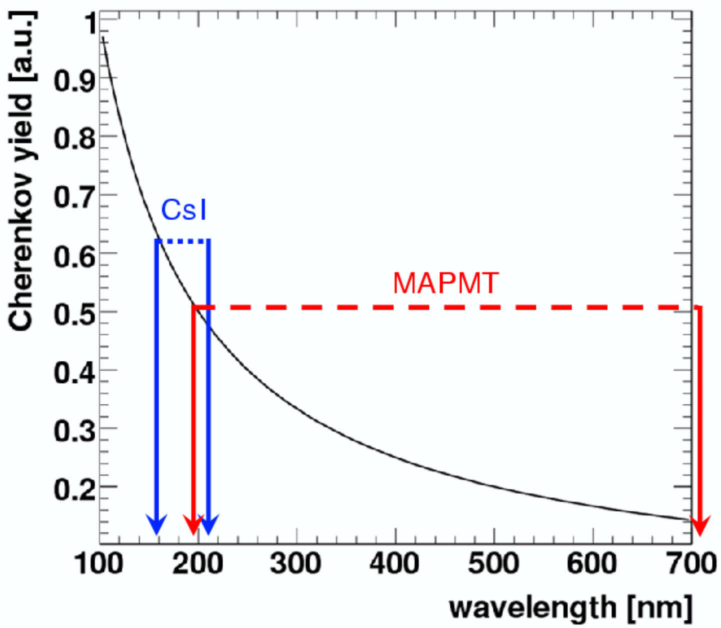
- Purpose: Focussing Cherenkov photons on MAPMTs (factor 7)
- UV transparent quartz lenses
- large geometrical acceptance
- minimum image distortion
- optimised by Zemax simulation



Read-out electronics of 1st quarter



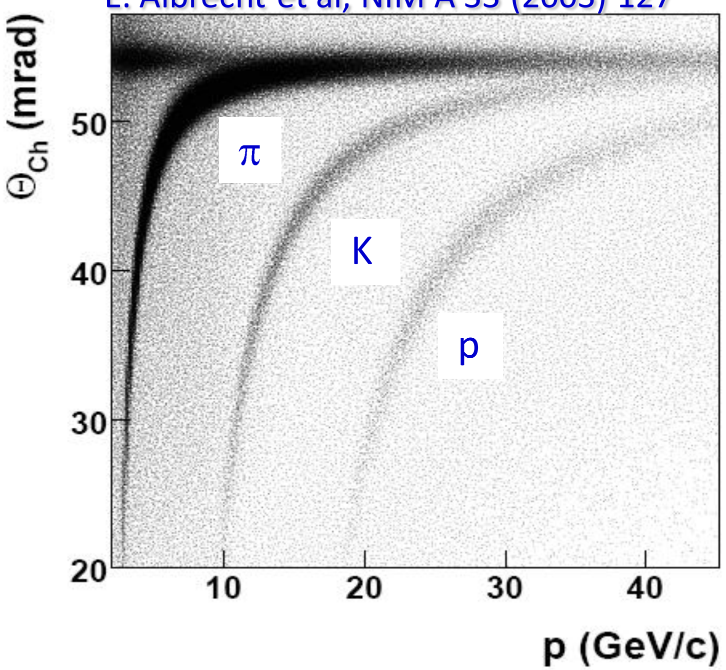
Upgraded RICH resolution

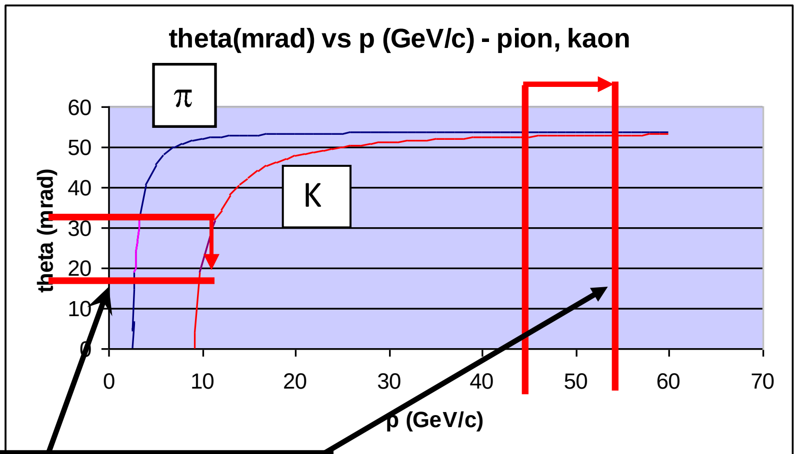


Expected performances:

- σ_{ph} = 2.4 mrad (ß ≈ 1) - before: 1.2 mrad
- N_{ph}/ring ≈ 50 (ß ≈ 1) - before: 14
- σ_{ring} ≈ 0.4 mrad (ß ≈ 1) - before: 0.6 mrad
- 2σ π/K separation at p ≈ 50 GeV/c - before: 43 GeV/c

E. Albrecht et al, NIM A 33 (2003) 127





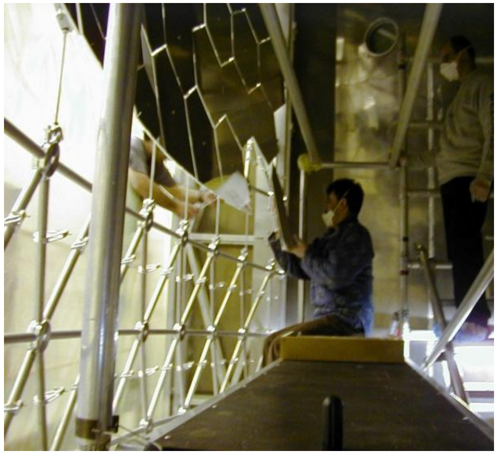
PID capability
extended by upgrade

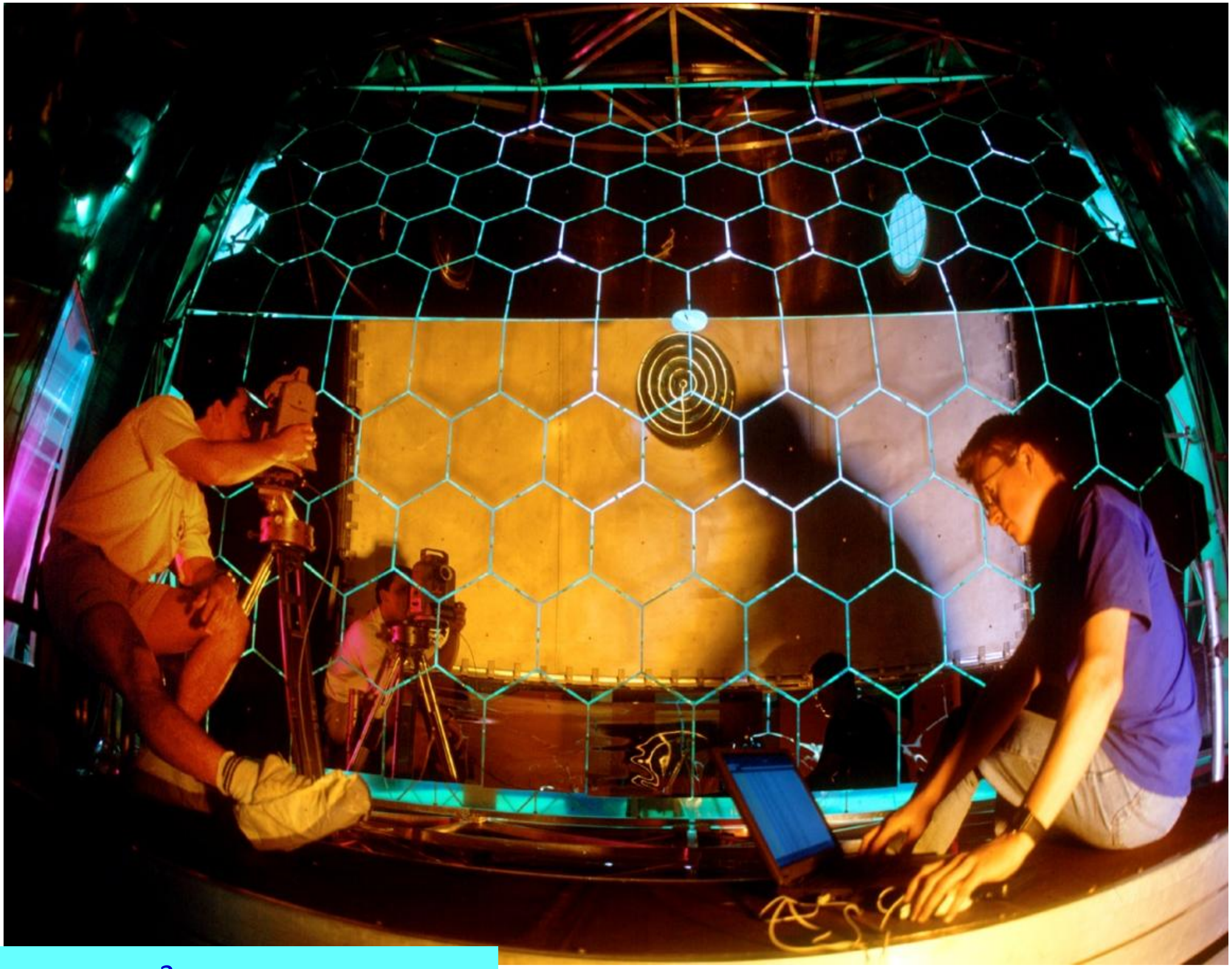
Performances of upgraded RICH detector

Excellent performances:

- N_{ph}/ring (ß≈1) > 60 before upgrade: 14
- time resolution < 1 ns before upgrade: 3 µs
- $\sigma_{ring} \approx$ 0.3 mrad (ß≈1) before upgrade: 0.6mrad
- N_{ph}/ring ≈ 50 (ß ≈ 1) - before: 14
- 2σ π/K separation at p_h >55 GeV/c before upgrade: 43 GeV/c
- excellent suppression of background from µ halo,
- performances as expected (and better)

mirrors and alignment





21 m^2, 116 mirrors
radius: 6.6 m

angular regulation screws

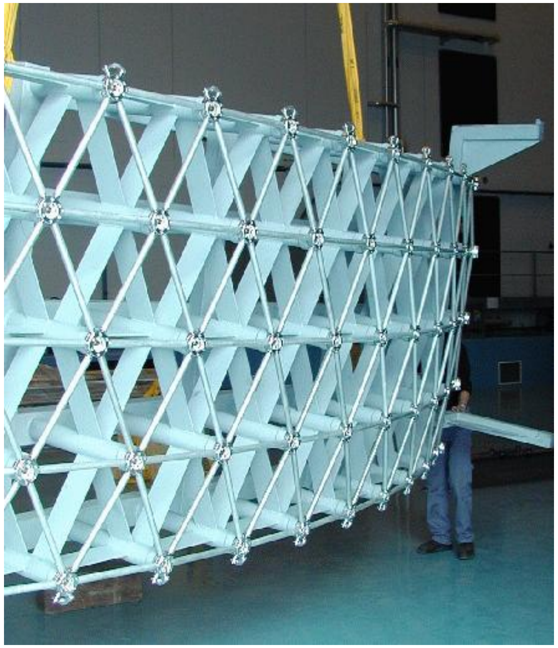
measurement of mirror alignment

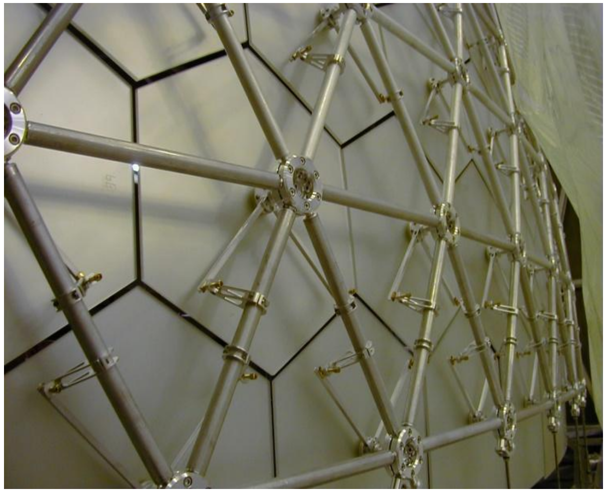
via laser autocollimation

the vessel and the mirror support

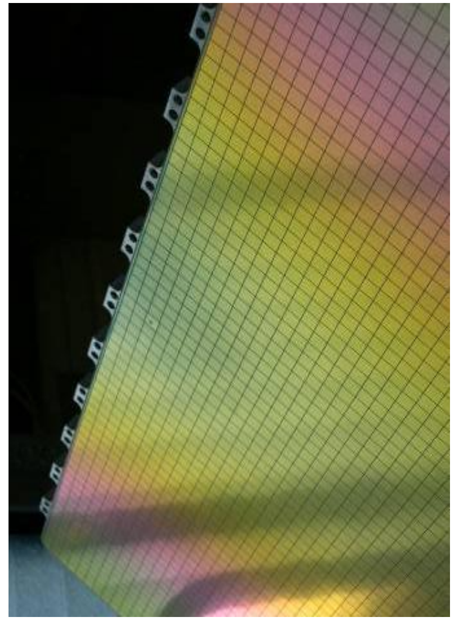
Large and accurate mechanics

light front and rear windows

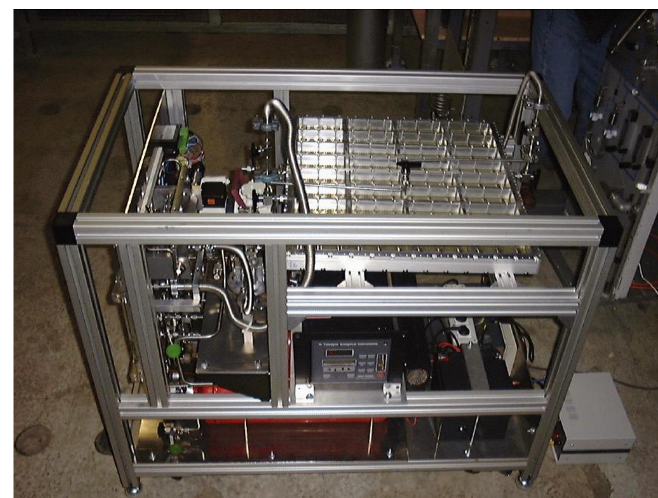




The CsI photocathodes





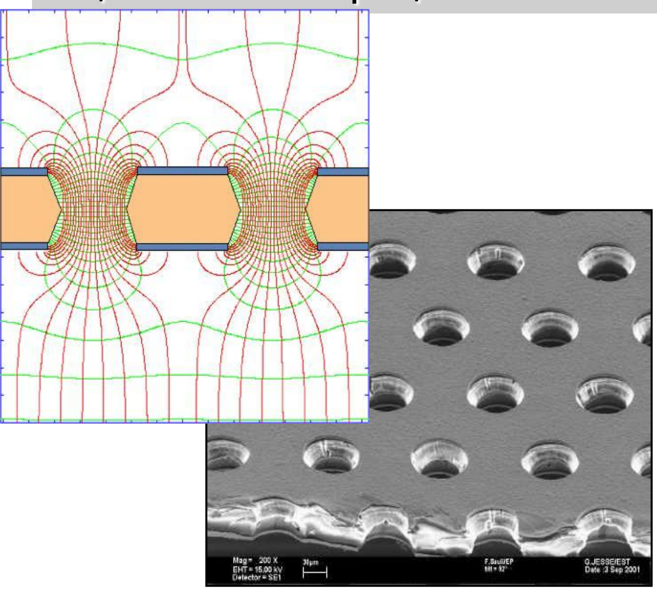
There is need of new technology

to overcome recent limits – fight ion bombardment and photon feedback

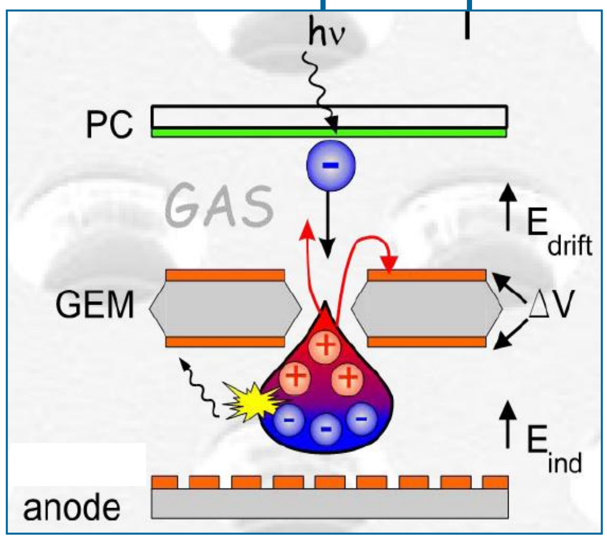
Possible solution – closed geometries

GEMs and THGEMs

GAS ELECTRON MULTIPLIER (GEM)
Thin metal-coated polymer foils
70 μm holes at 140 μm pitch

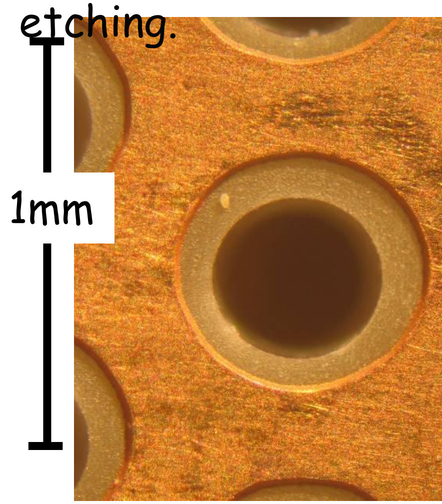


GEM's principle



ECONOMIC & ROBUST

Manufactured by standard PCB techniques of precise drilling and Cu etching.



F. Sauli, NIM A386(1997)531

Chechik et al. NIM A535 (2004) 303
C. Shalem et al. NIM A558 (2006) 475
& NIM A558 (2006) 468

MultiGEM's:
ion blocking + high GAIN

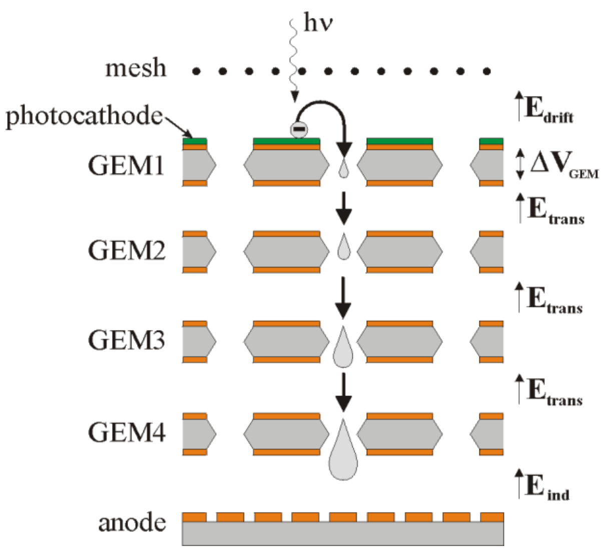
Examples of ion blocking schemes from literature

- Similar schemes can be adopted with THGEM

multiGEM with Reflective photocathode

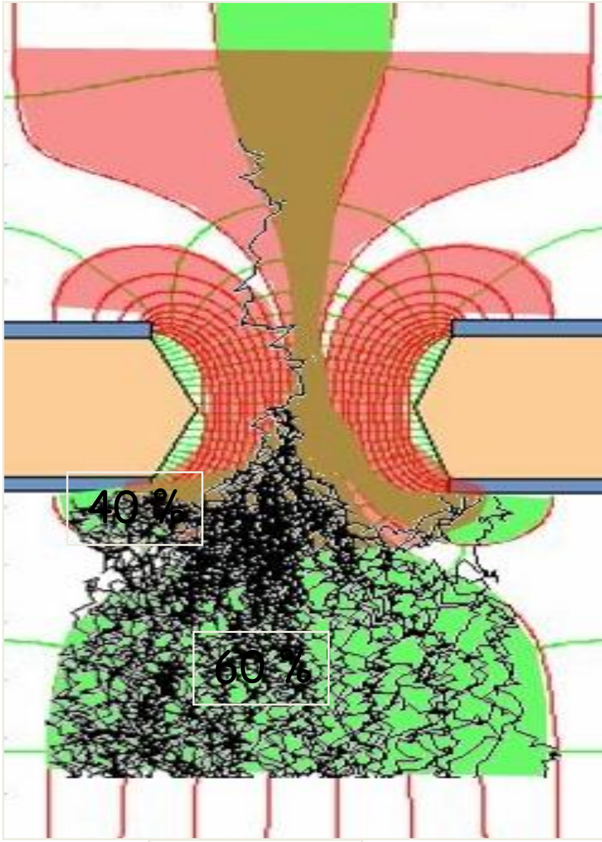
Electron's path

Ion's back-flow



Simulation of avalanche

Ions



Electrons

Perspectives

Short term plans:

- optimize the parameters of the THGEM with photoconverting CsI layer to achieve maximum photoelectron collection efficiency
- optimize the parameters for the (double) THGEM to be used for the amplification of the signal to provide large and stable gain
- produce a set 600 x 600 mm2 THGEMs and assemble them with stesalite spacer frames into first complete “full size” prototype chamber

Possible medium term project:

- Upgrade of COMPASS RICH (~4m2) with the new photon detectors in case the COMPASS Collaboration decides for it.

Longer term dream:

- find a configuration to reduce the ion back-flow down to <10-5 and operate this large area detectors with visible photoconverter

RIng Imaging CHerenkov Detectors

Conclusions

COMPASS RICH-1

is a large gaseous RICH

with two kind of photon detectors

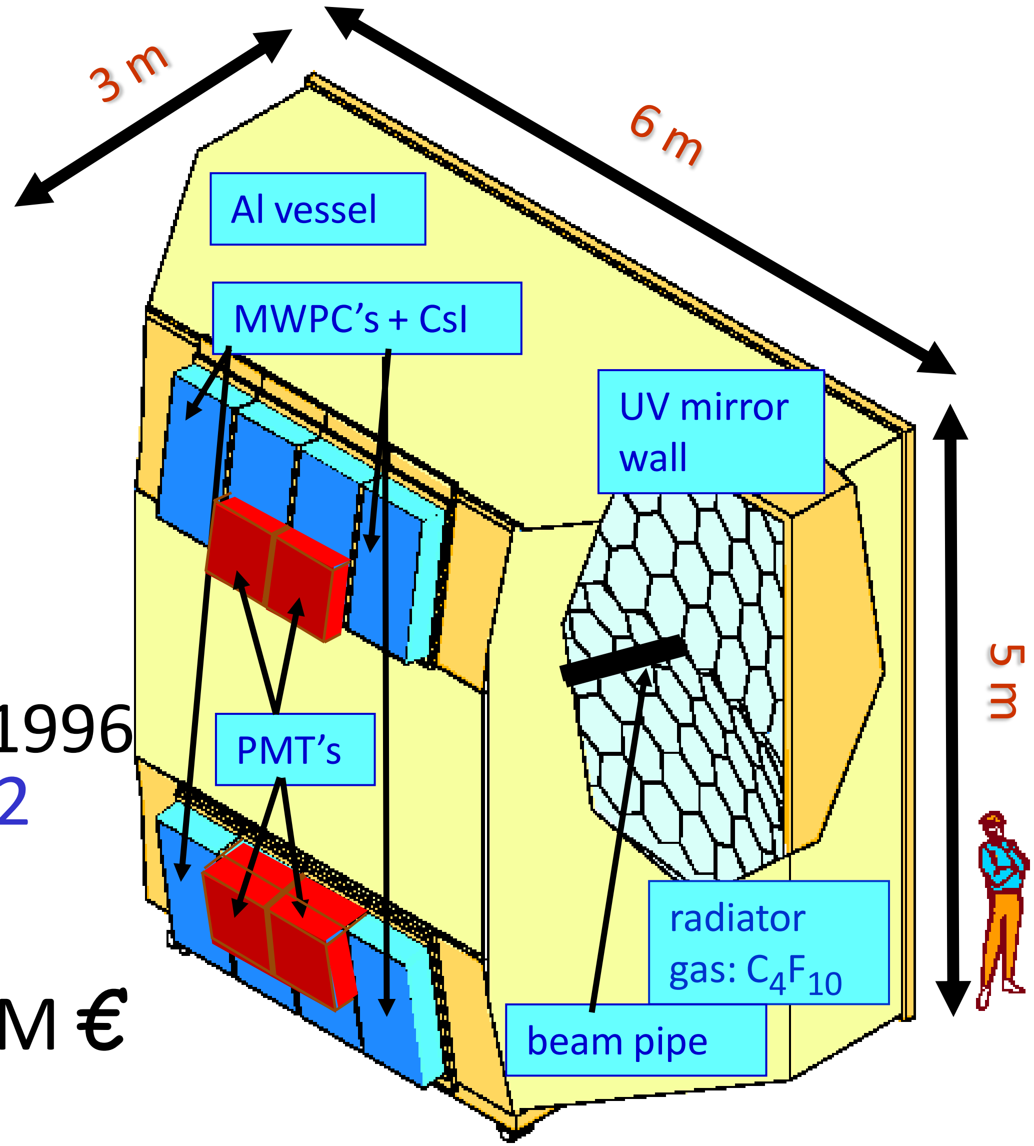
providing:

hadron PID from 3 to 60 GeV/c

acceptance: H: 500 mrad V: 400 mrad

trigger rates: up to ~100 KHz
beam rates up to ~10^8 Hz

material in the beam region: 2.4% X_o
material in the acceptance: 22% X_o



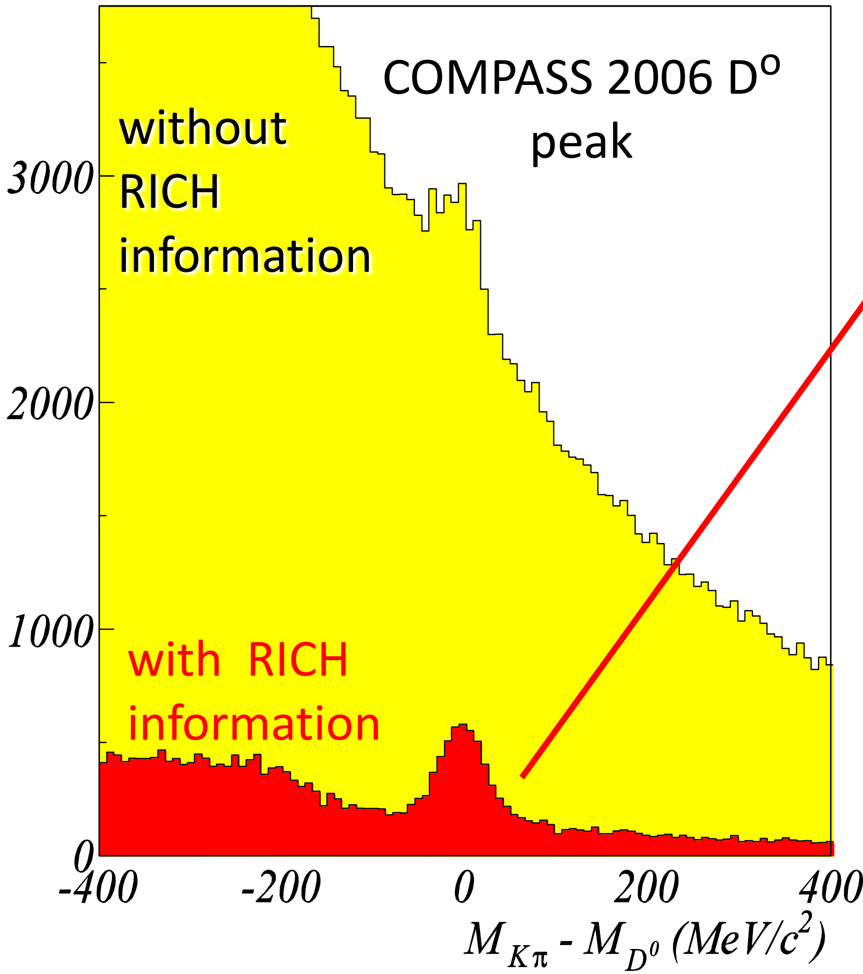
* detector designed in 1996
*in operation since 2002
*upgraded in 2006

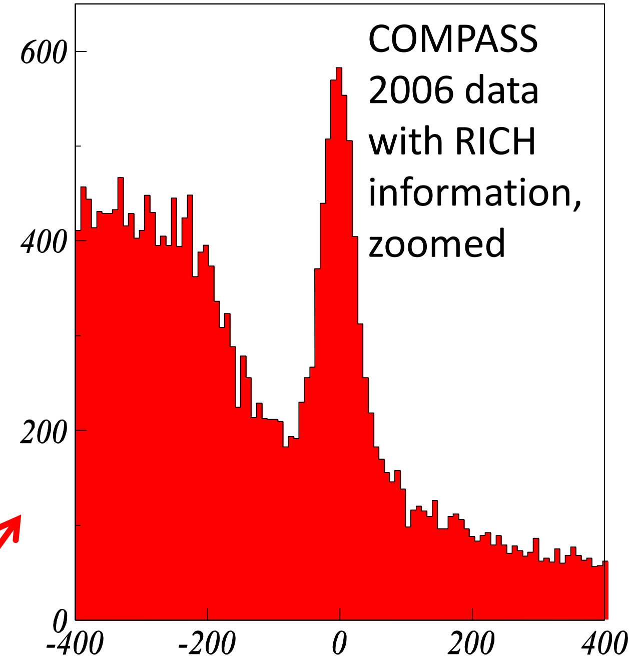
total investment: ~ 4 M €

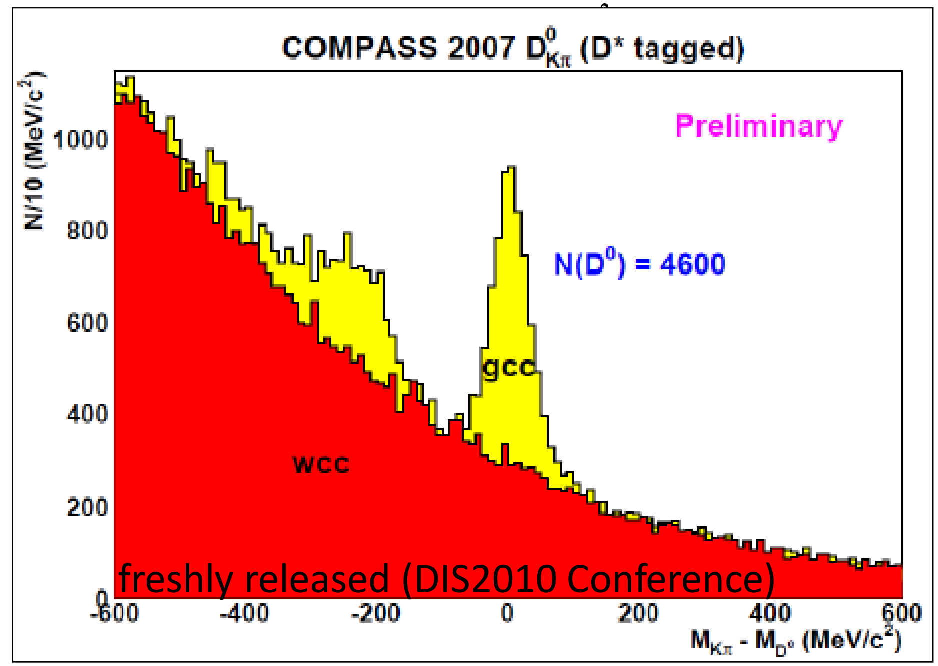
The main components

- Al vessel (80 m^3 C_4F_{10}, 100 m of O-rings) with light windows
- Spherical UV mirrors (21 m^2, split in two halves, 116 mirrors)
- Light beam pipe filled with He
- 16 fused silica windows (600 mm x 600 mm x 5 mm)
- 8 MWPC's with CsI- coated photocathodes (4.3 m^2)
- 62 k analog r/o channels: APV + GESSICA
- 576 MAPMT's with individual fused silica lens telescopes
- 9.2 k TDC channels: MAD + DREISAM + F1
- A complex gas circulation and filtering system

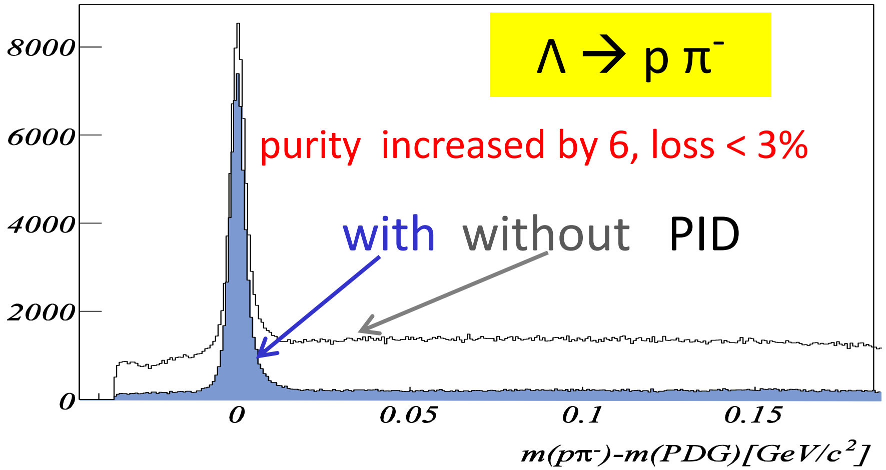
RICH PID information in the D^0 analysis

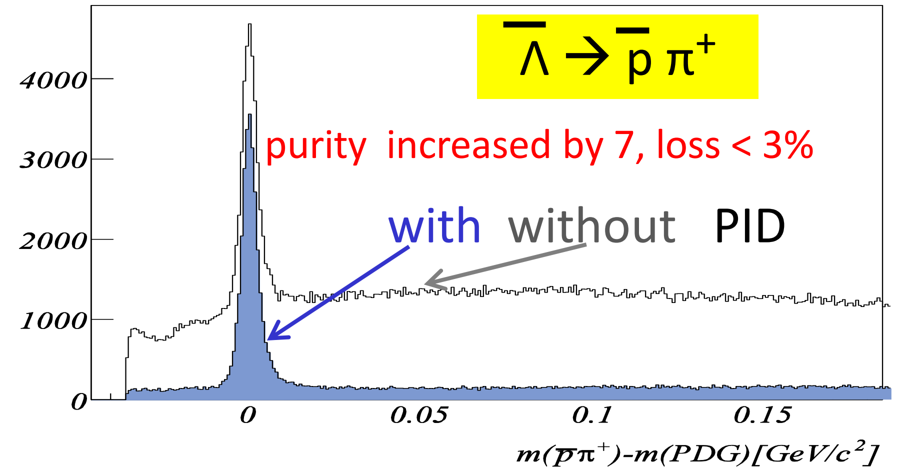


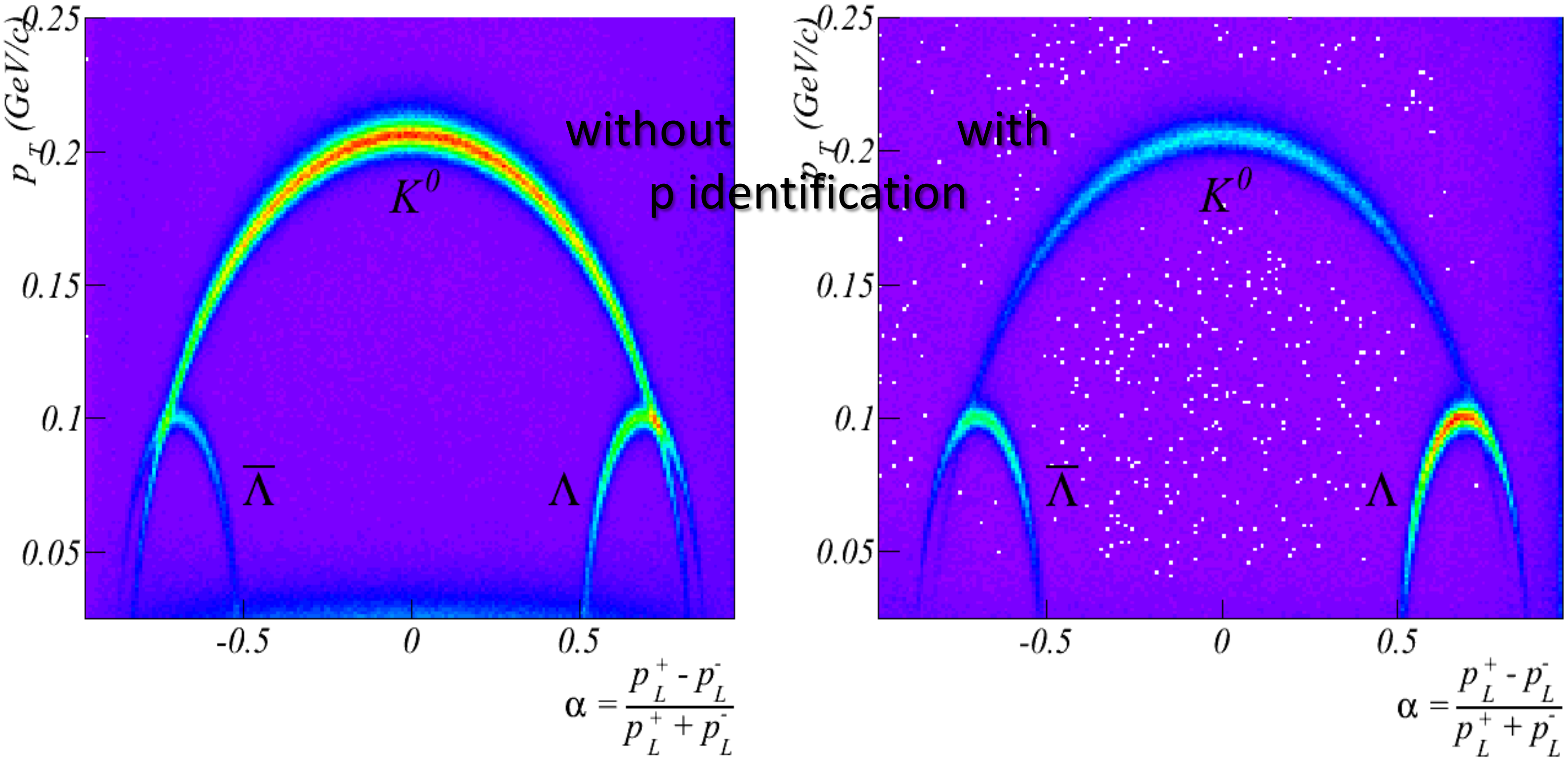




RICH PID information in Λ analysis







The keys of the success

- A strong physics case
- A dedicated, highly motivated team
- A constant support from the Institutes and the Experiment

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Thank You for Your Attention