RICH Collaboration

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The CBM RICH Detector

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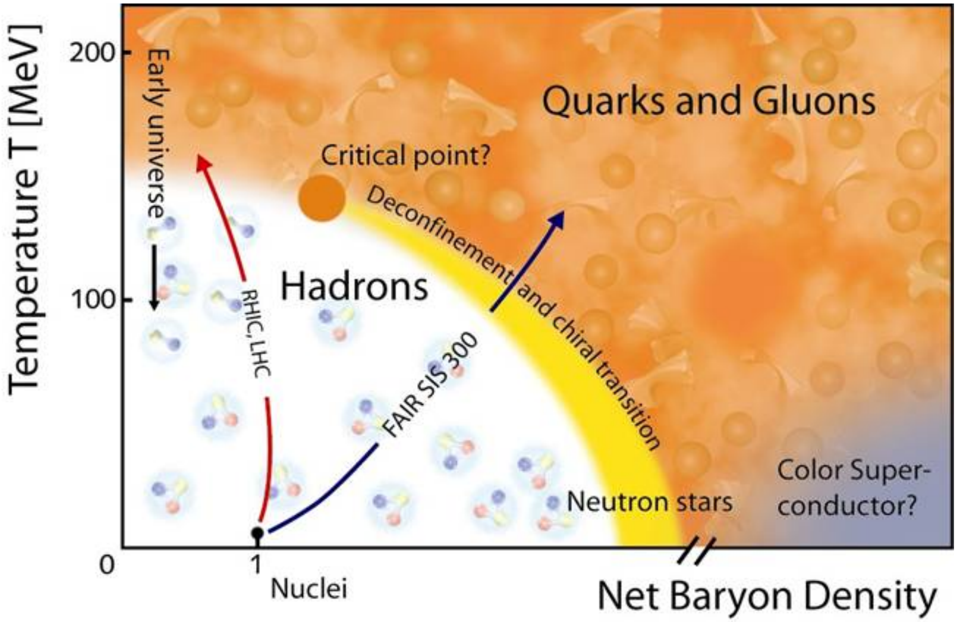
Helmholtz International Center

Outline

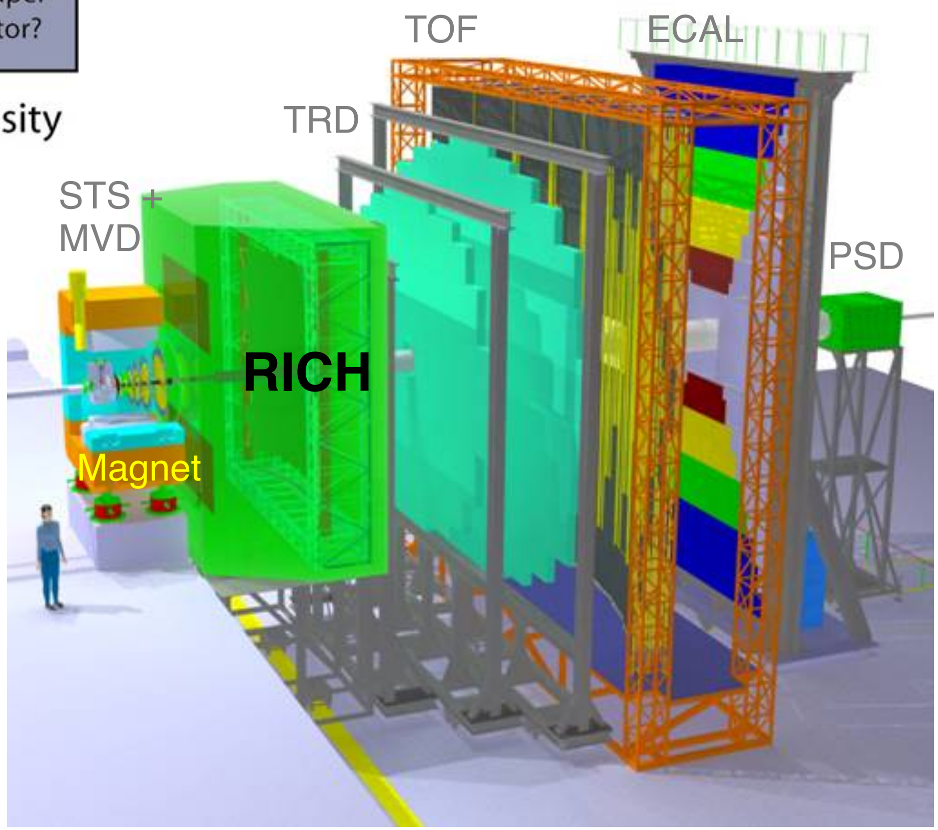
What I want to tell you ...

- Introduction & motivation
- The concept of the CBM-RICH detector
- R&D, RICH components
- RICH prototype
- Physics performance
- Summary



QCD Phase Diagram:

- Labels indicate the phase of matter, which describes the system in given regions of temperature and Baryon density.
- Curves indicate transitions between the various phases.
- The most essential insight into the physics of a system comes from a study of the transitions between phases.



CBM Physics:

- Investigation of dense baryonic matter:
- Phase transitions? critical/ triple point? new phases? in-medium changes of hadronic properties?

Experimental challenge:

Systematic exploration of A+A collisions measuring hadrons, leptons, correlations, fluctuations including rare probes such as charm and low-mass vector mesons

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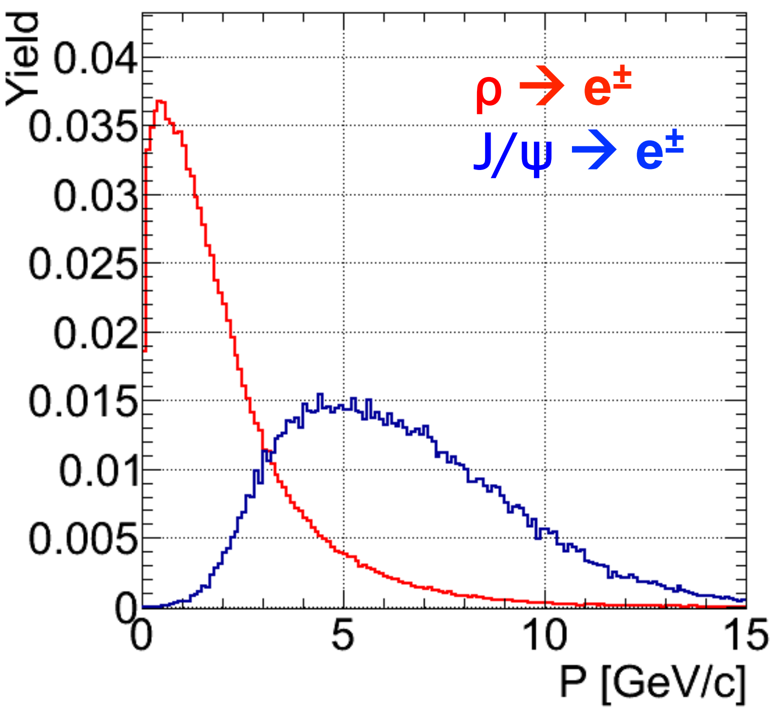
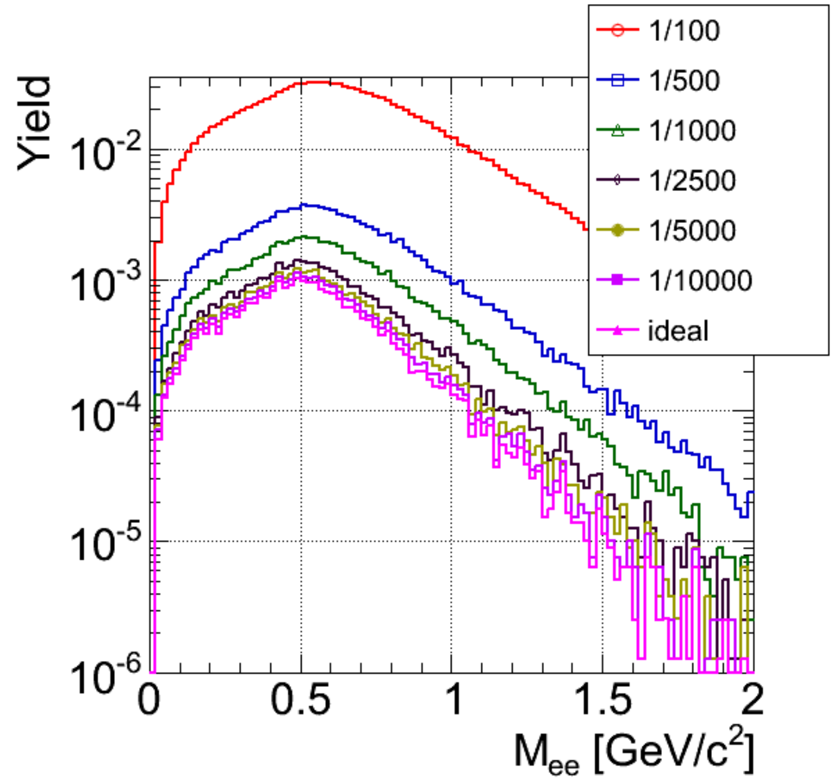
Rare probes: ρ,ω,ϕ → e±, J/ψ, ψ' → e±



Momentum spectrum of decay-electrons from the ρ and J/ψ mesons

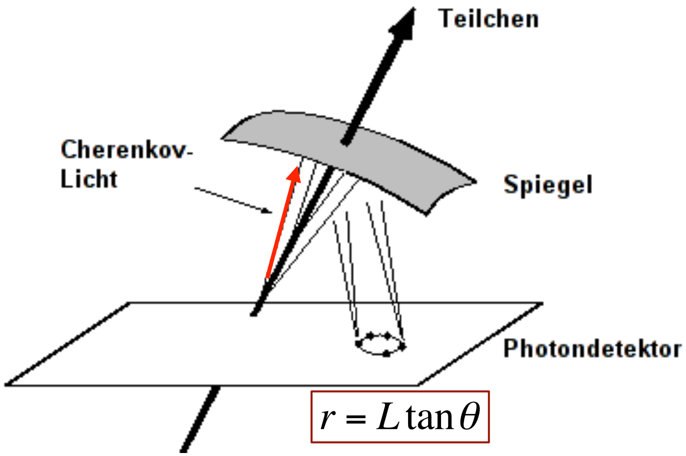


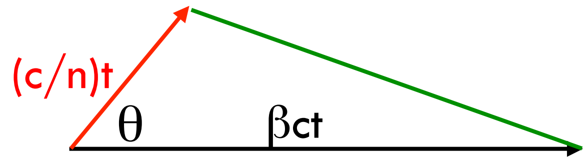
Combinatorial background for low-mass di-electron pairs assuming various pion misidentification levels

- Central Au+Au at 25AGeV:
- 700 pions are produced
- 310 lie in the RICH acceptance.

Identification of e± with p<10GeV

pion rejection factor of ≥ 10^4



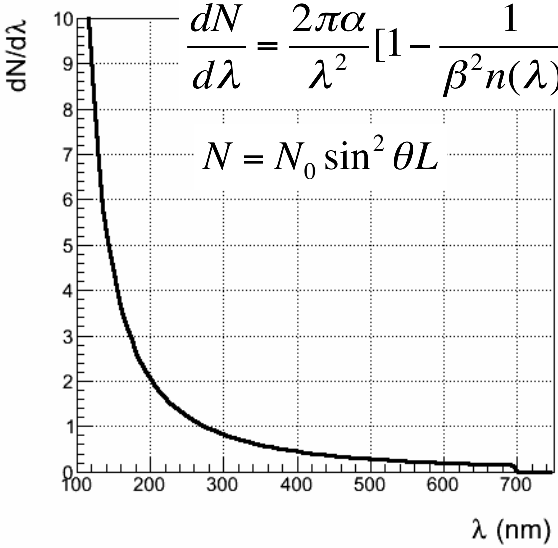


$$\cos\theta = \frac{ct/n}{\beta ct} = \frac{1}{\beta n} \rightarrow \beta_{th} = \frac{1}{n} \Rightarrow \gamma_{th} = \frac{1}{\sqrt{1-\beta_{th}^2}} = \frac{n}{\sqrt{n^2-1}} = \frac{1}{\beta_{th}\sqrt{n^2-1}}$$

$$\Rightarrow \beta_{th}\gamma_{th} = \frac{1}{\sqrt{n^2-1}} = \frac{1}{\sqrt{(n-1)(n+1)}} = \frac{1}{\sqrt{\delta(\delta+2)}} \Rightarrow p_{th} = m\beta_{th}\gamma_{th} = \frac{m}{\sqrt{\delta(\delta+2)}} \approx \frac{m}{\sqrt{2\delta}}$$

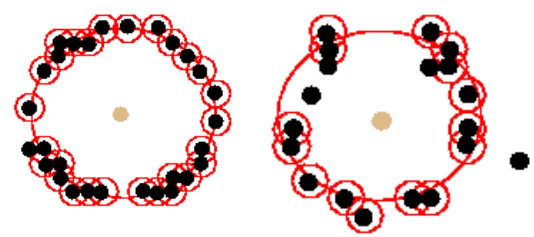
	N_2	CO_2	C_4F_{10}	Aerogil	C_5F_{10}	Quartz
δ $[10^{-4}]$	2.98	4.3	14	300	2700	4700
$p_{th}(e)$ [GeV]	0.02	0.017	0.01	0.002	$7 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
$p_{th}(\pi)$ [GeV]	5.72	4.76	2.64	0.57	0.19	0.14

To separate electrons from pions we need a gas radiator!



$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2}\left[1 - \frac{1}{\beta^2 n(\lambda)^2}\right]L$$

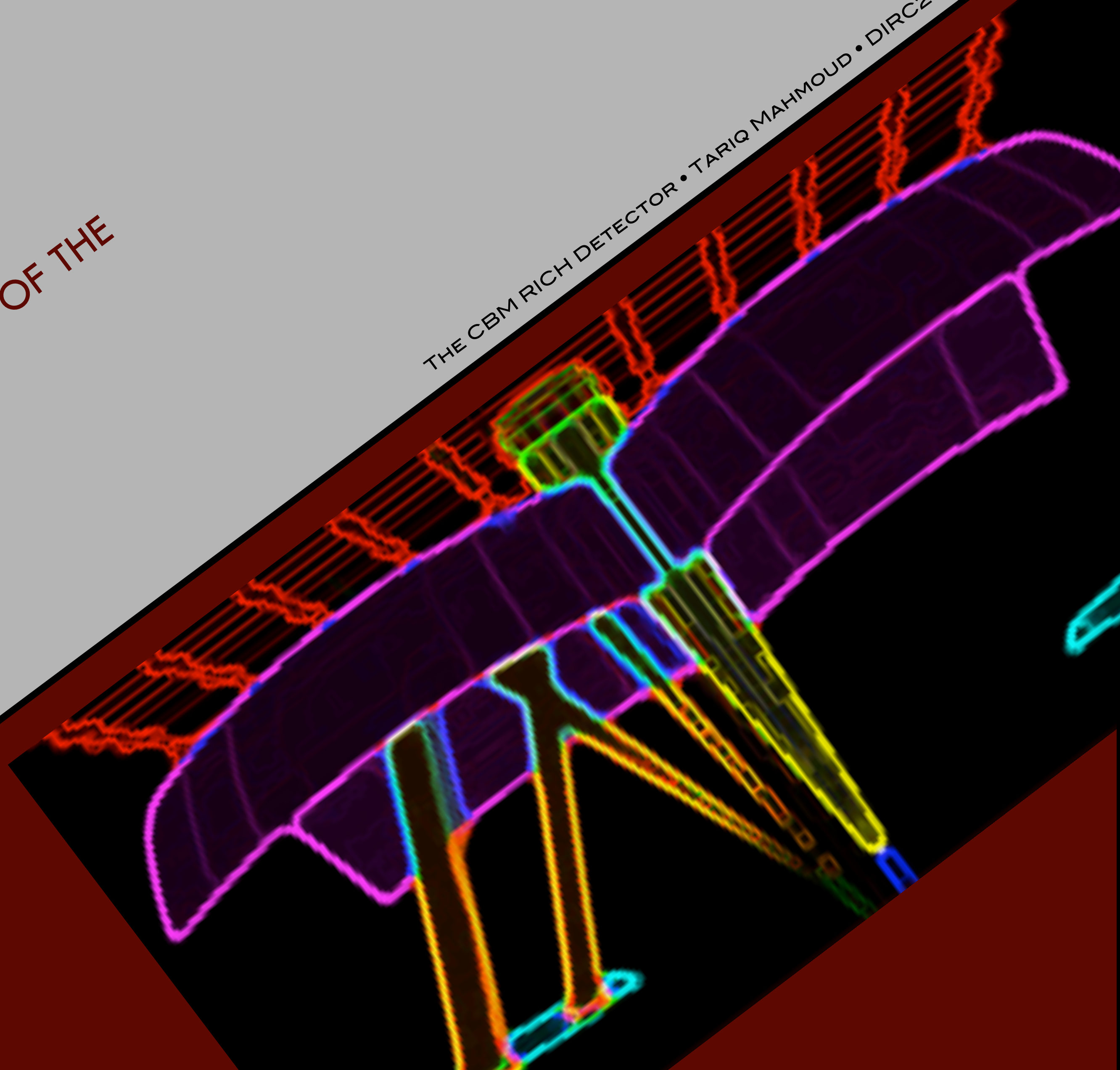
$$N = N_0 \sin^2\theta L$$



Need:

- Collect at many photons as possible.
- Good single photon measurement.
- Low fluctuations of the photons around the ring.
- Resistance in magnetic field.

THE CONCEPT OF THE CBM-RICH



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The Concept

Three main components

$p_{th} = \frac{m}{\sqrt{2\delta}}$, $\delta_{CO_2} = 4.3 \times 10^{-4}$

e^- 17.4 MeV $K^{\pm}$ 17 GeV

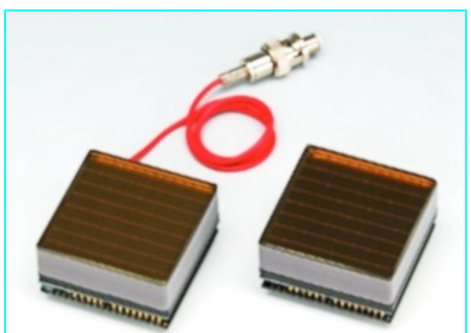
$\pi^{\pm}$ 4.6 GeV p 32 GeV

Radiator

- CO_2; $\gamma_{th} = 33$
- $p_{\pi,th} = 4.65$ GeV/c
- $V \approx 30\ m^3$
- Length=1.7 m

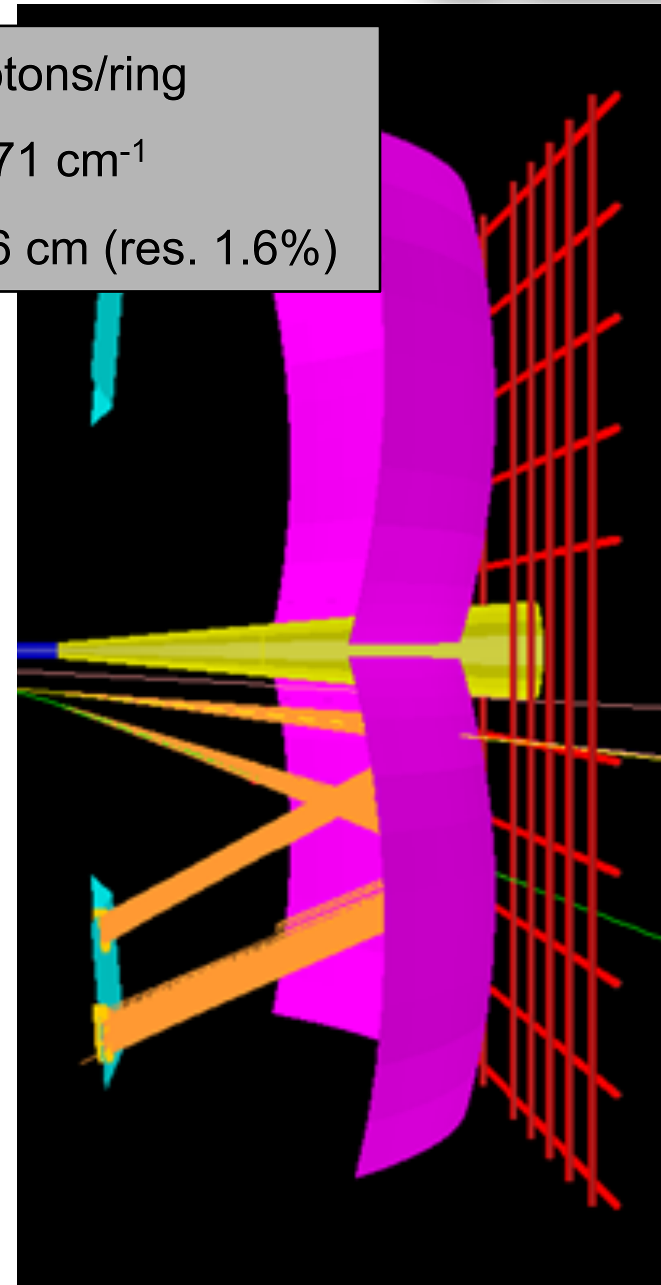
Mirror

- SIMAX-glass, $Al+MgF_2$
- R = 3m, d ≤ 6mm
- 11.8 m^2
- Tiles of 40×40 cm^2



Camera

- 2.4 m^2, 55k Ch.
- MAPMT: H8500 series (Hamamatsu)?

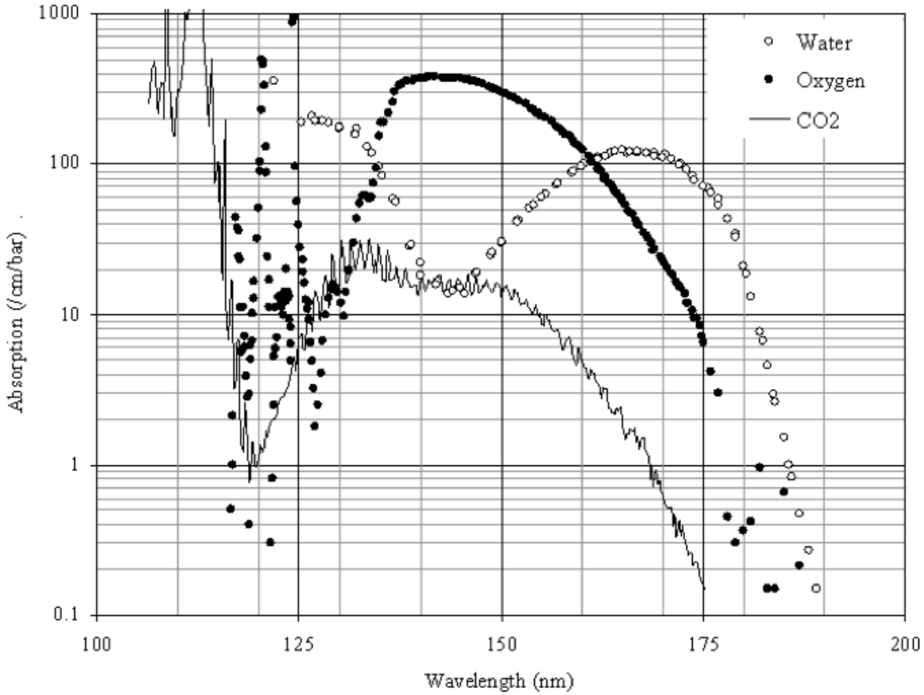


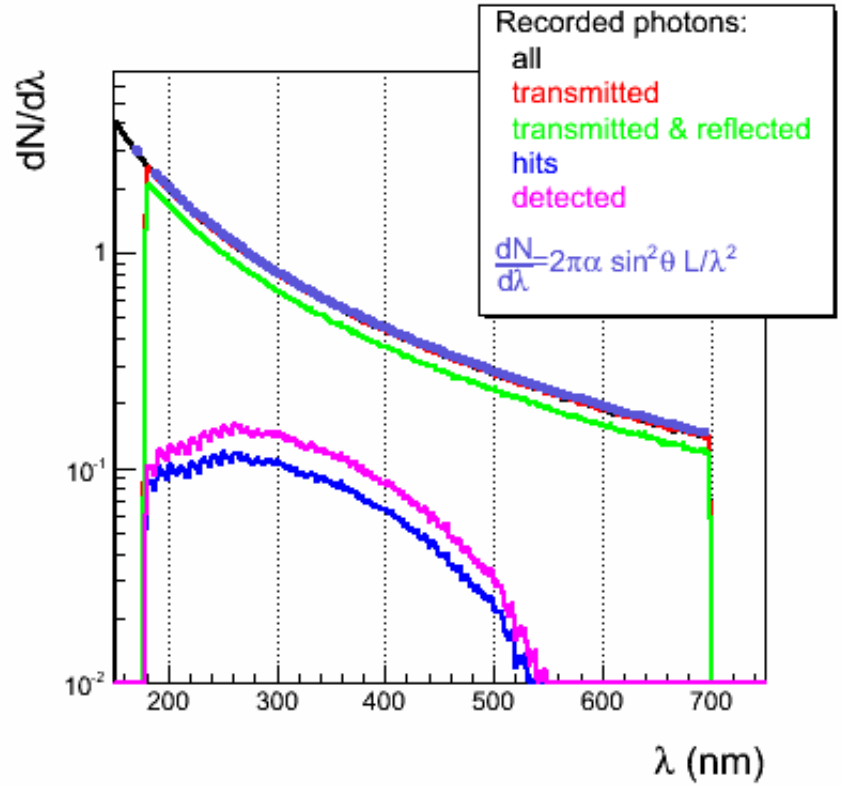
- 28 photons/ring
- $N_0 \approx 171\ cm^{-1}$
- r_e=4.56 cm (res. 1.6%)

RADIATOR

CO_2 is our choice

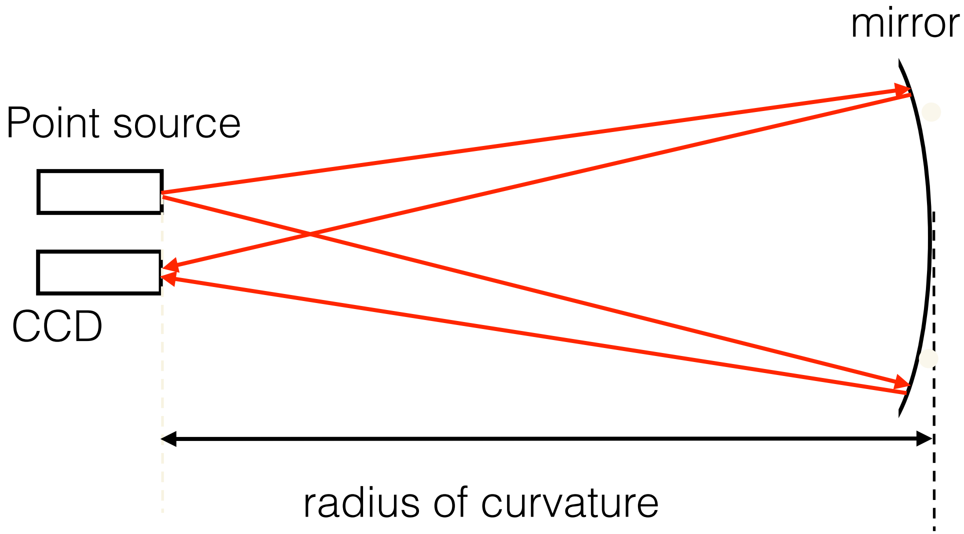
	n-1 [10^{-4}]	γ_{th}	λ_{th} [nm]	$p_{th}(e)$ [GeV]	$P_{th}(\pi)$ [GeV]
CO_2	4.3	33.3	~180	0.017	4.76

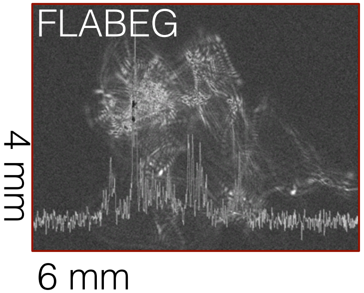


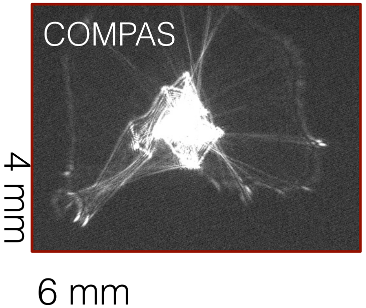


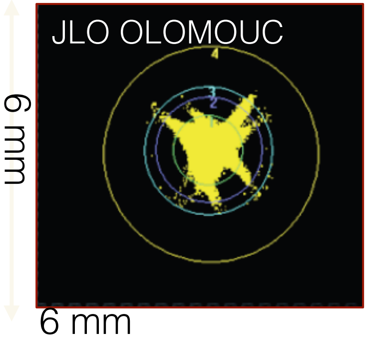
	Radiator length [m]	Full length [m]	Mirror radius [m]	Mirror size [m^2]	Photon detector plane [m^2]	# of channels
CO_2	1.7	2.1	3	11.8	3.7	55k

Homogeneity: Influences the photons distribution → ring fitting performance
Reflectivity: Influences the number of photons → ring quality









Homogeneity:

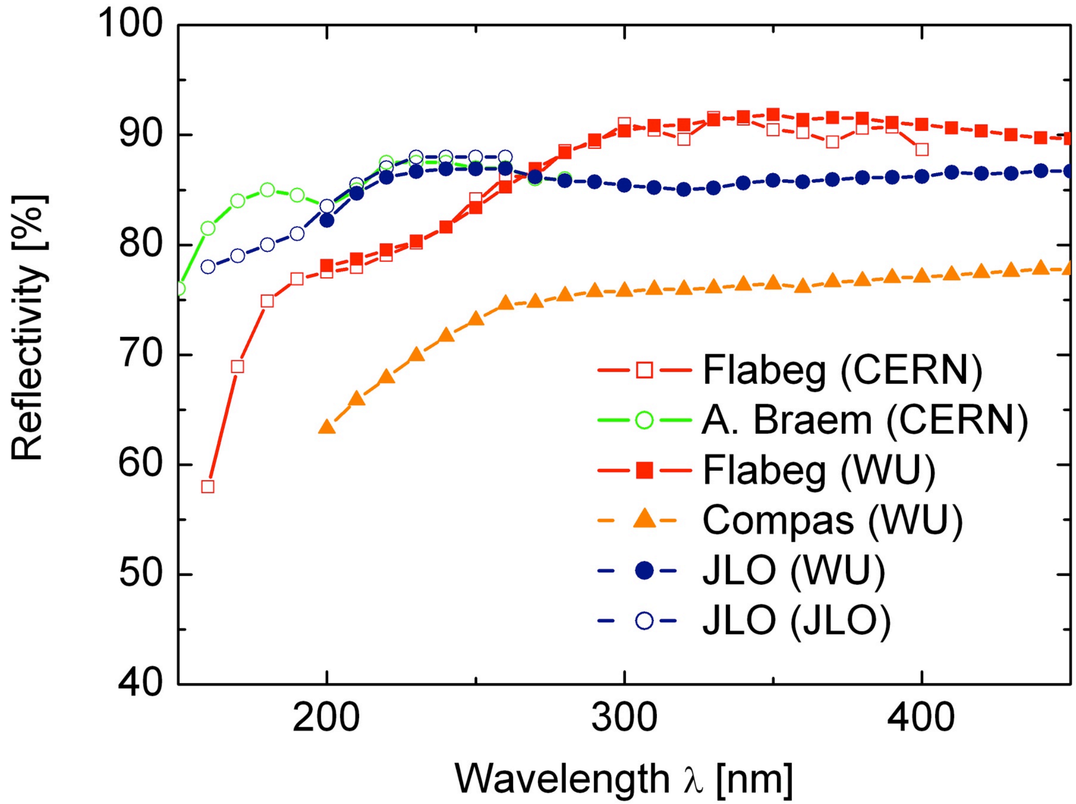
- D_0 as a measure of the mirror homogeneity.
- Reflect a point-like source on the mirror and record its image.
- Ideally the image is also point-like. In Reality, inhomogeneity causes a non-homogenous spot (picture).
- D_0 is the diameter, of a circle, which contains 95% of the reflected light

	required	FLABEG	COMPAS	JLO OLOMOUC
D_0 (mm)	≤3	Very bad	2.3	2.3

Mirror

Two main properties …

Homogeneity: Influences the photons distribution → ring fitting performance
Reflectivity: Influences the number of photons → ring quality

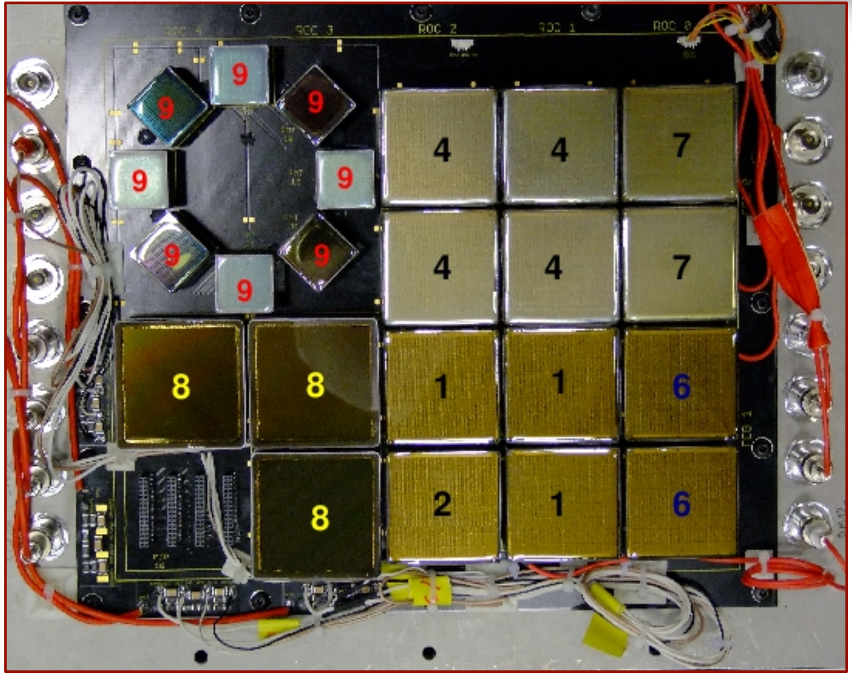


Reflectivity:

- Compas: <80%
- Flabeg: >90% (λ>270nm) and ≈60% (λ=160nm)
- OLOMOUC: ≈85% (λ>200nm) and ≈80% (λ≤200nm)

Photon Detector

Three main properties …



- Quantum efficiency (QE)
- Tolerance of magnetic field
- Single photon detection

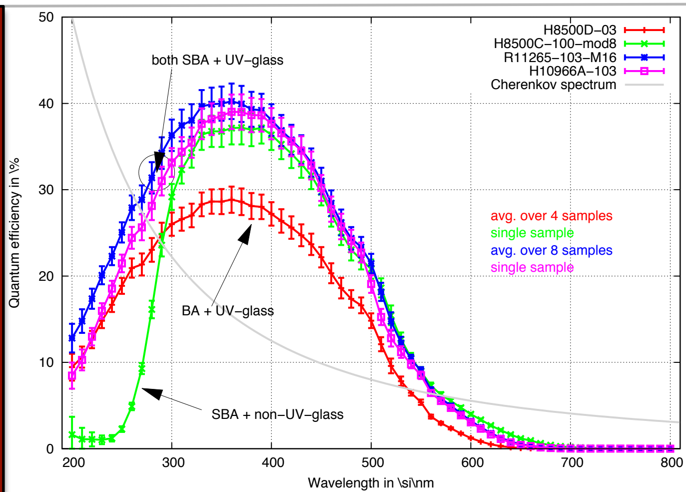
Hamamatsu: Multi-anode Photomultiplier Tubes (MAPMT)

- Baseline: H8500 (1,2): 12-dynodes and Bialkali photo cathode
- H10966: H8500 with 8-dynodes and Super-Bialkali photo cathode (7)
- R11265: 12-dynodes and Super-Bialkali photo cathode (9).

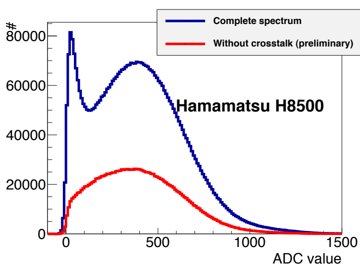
Photonis: Micro Channel Plate (MCP)

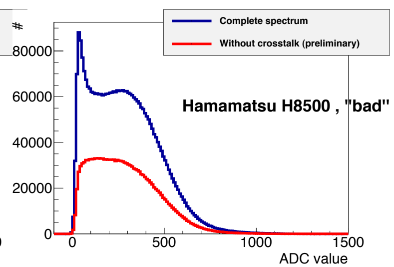
- XP85012 (8)

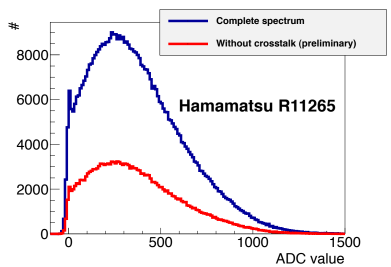
Photon Detector

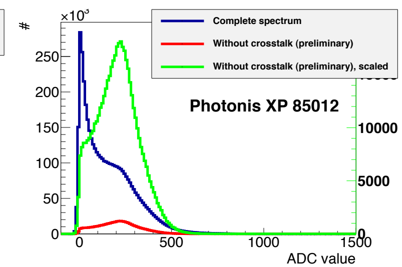


- Borosillicate: low gain in the UV range → excluded.
- Significant gain in QE with SBA cathode.
- → optimum: SBA & UV glass







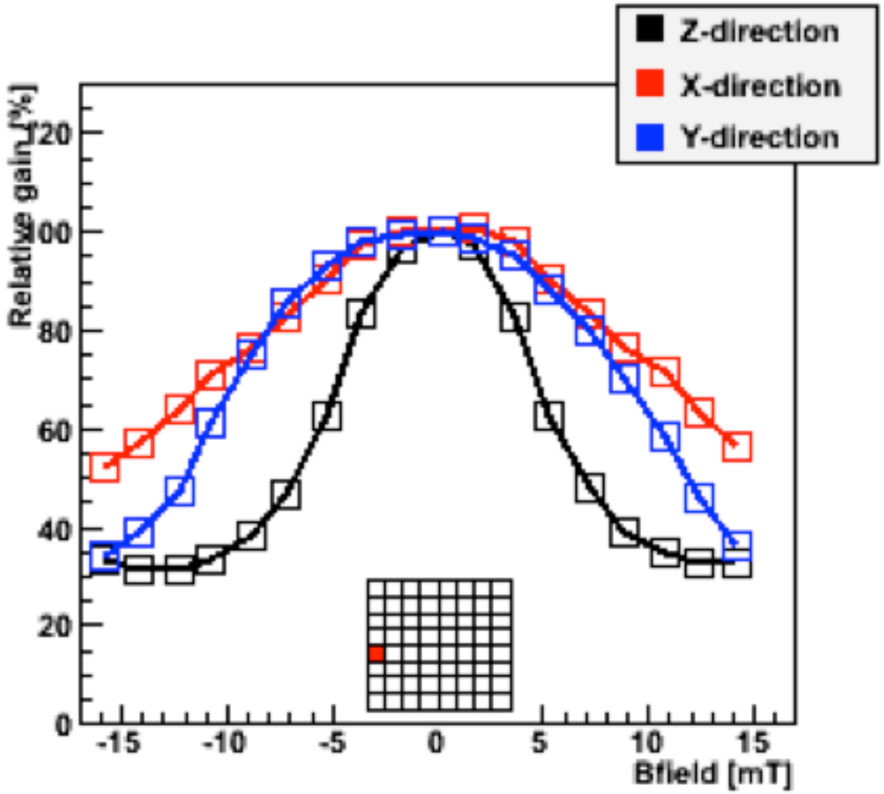


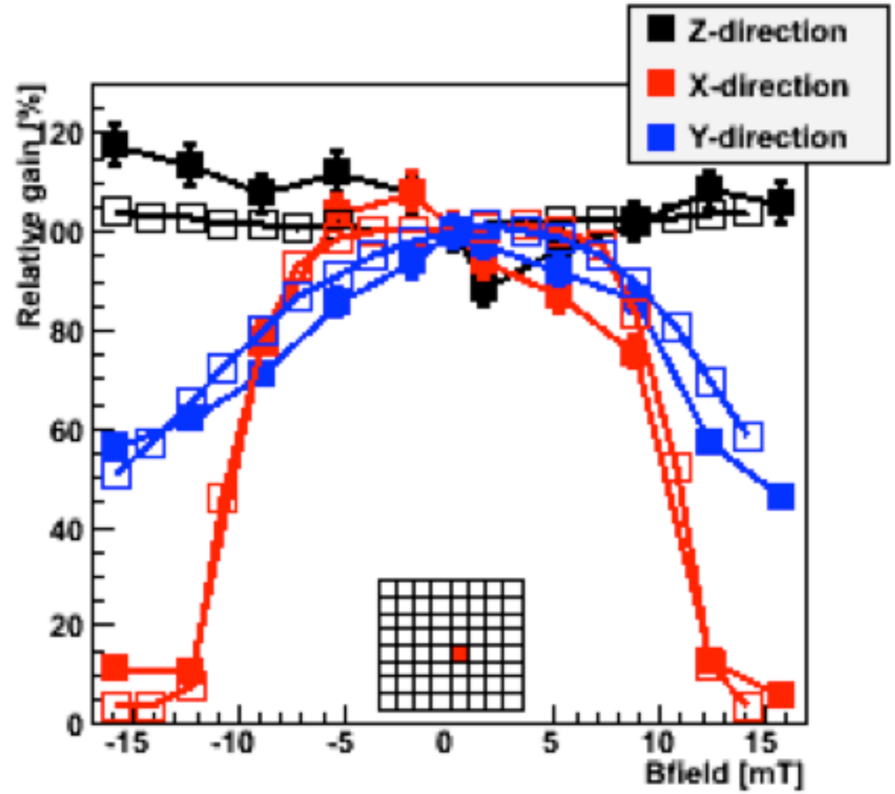
- Peak at 0 due to crosstalk, not noise.
- Shape of R11265 spectra with and without crosstalk suppression almost Identical.
- Hamamatsu's "bad"-marked H8500 of relatively good quality compared to normal H8500 but the 8-stage versions does not seem to be promising.
- XP85012 MCPs show significantly high crosstalk.

- Baseline MAPMT (H8500, 12 stages, BA) has good QE and shows nice single photon spectrum. New developments from Hamamatsu promise better performance (H12700).
- MCP has good QE especially in the UV region and shows nice single photon spectrum BUT with high rate of crosstalk.

PHOTON DETECTOR magnetic field response of H8500

Baseline PMT: H8500, 12 stages, BA:



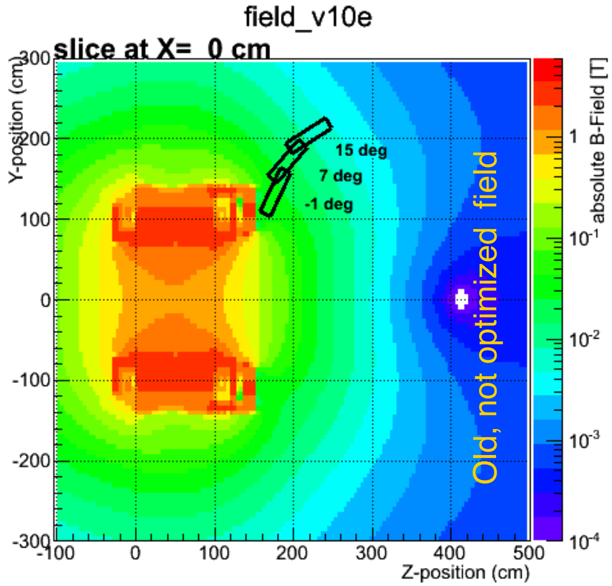


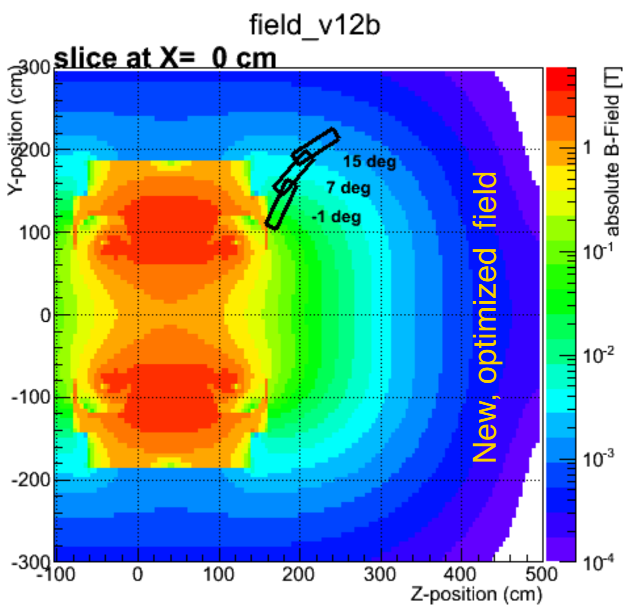
Open symbols: overall gain
Full symbols: single-photon detection efficiency
z along the PMT axis

PROBLEM:

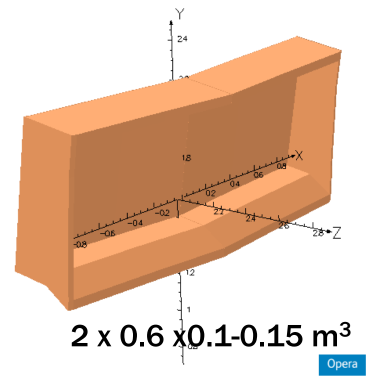
- B influences the overall gain and the single-photon detection efficiency.
- Strongest effect along the PMT axis (z) and at the PMT edges.
- Tolerable fields below 1mT.

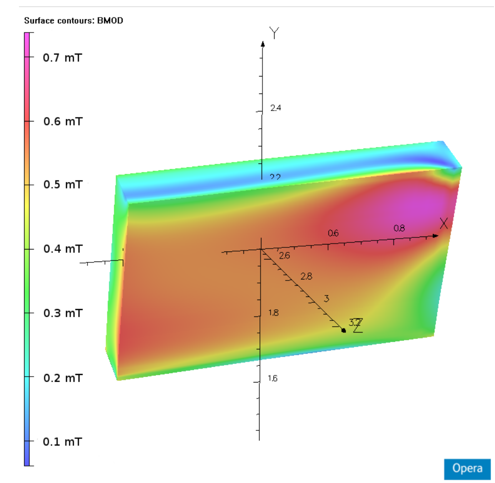
1. Rotation: $\alpha \geq 10$ degrees





2. Shielding: Steal 08: 2.5-5cm thick → 1000kg





3. Combine 1 & 2: Maximum stray field is 1mT

4. MCP

Cherenkov Angle

Resolution

$$\sigma = \frac{\sqrt{\sigma_{mirror}^2 + \sigma_{disp}^2 + \sigma_{pixel}^2 + \sigma_{MS}^2 + \sigma_B^2}}{\sqrt{N}}$$

Cherenkov angle resolution for N photons

σ_{mirror} due to mirror quality. It is negligible.

σ_{disp} due to chromatic dispersion. Can be estimated to 1 mrad.

P. Glässel. In: Nucl. Instr. Meth. A 433 17 (1999).

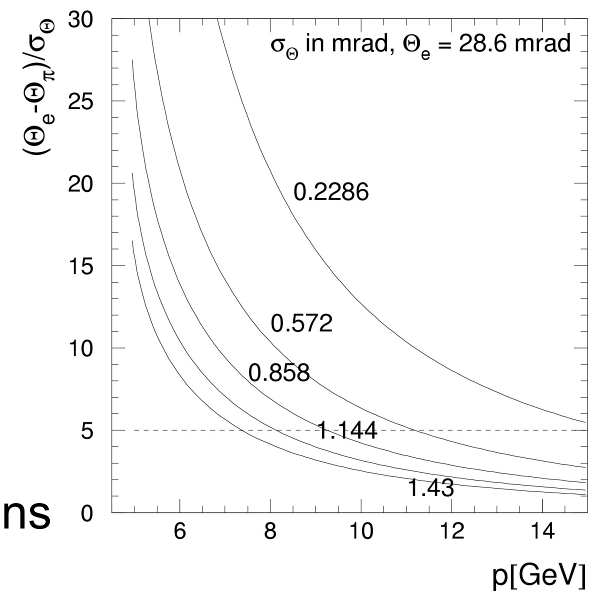
σ_{pixl} due pixel size. It is about 1 mrad.

$$\sigma_{MS} = \frac{2}{3} MeV/c \bullet \sqrt{\frac{L}{X_0}} \bullet \frac{1}{p} = 0.874 MeV/c \bullet \frac{1}{p}$$

p [GeV]	0.4	1	8
σ_{MS} [mrad]	2.2	0.9	0.1
σ_B [mrad]	18	7.2	0.9

$$\sigma_B = 55.1 \frac{MeV}{Tm} \bullet \frac{LB_T}{p}$$

$B_T = 0.077 Tm$

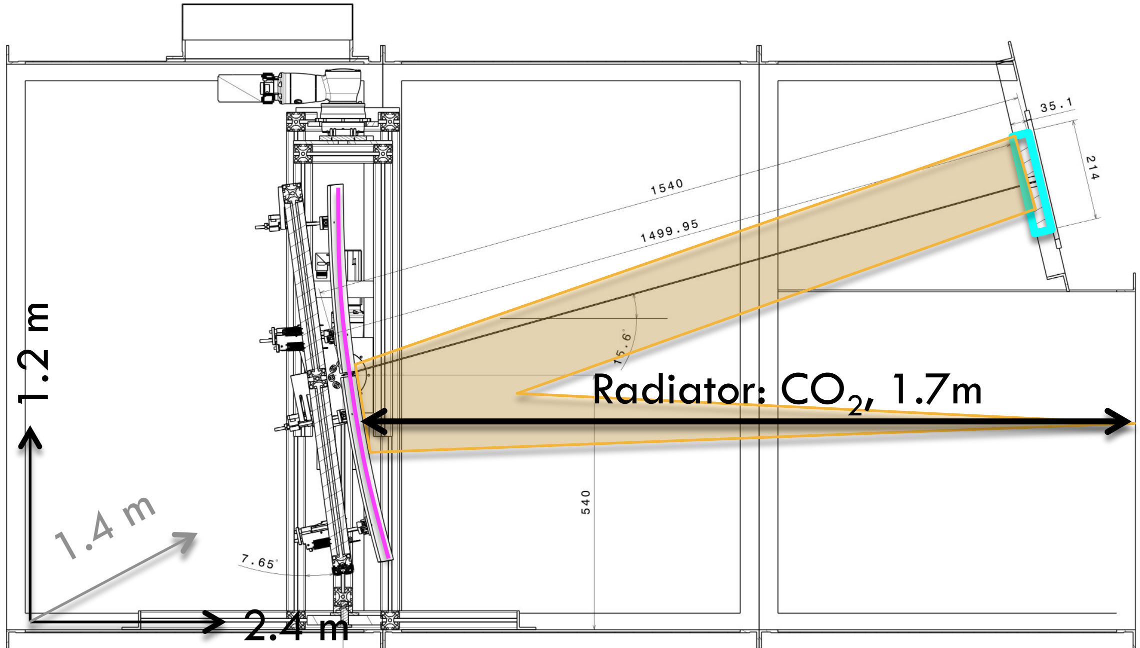


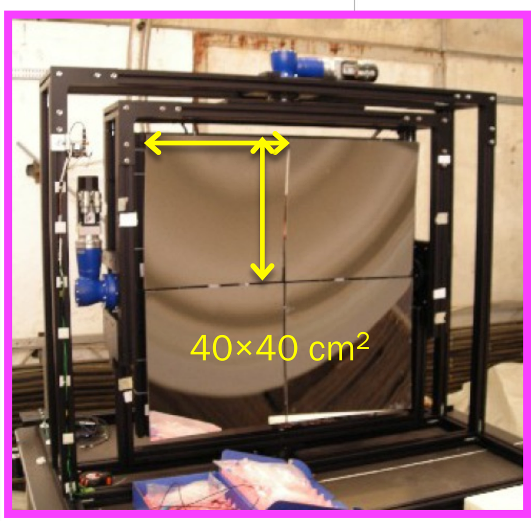
$$\sigma(p = 8GeV, N = 20) = 0.38 mrad$$

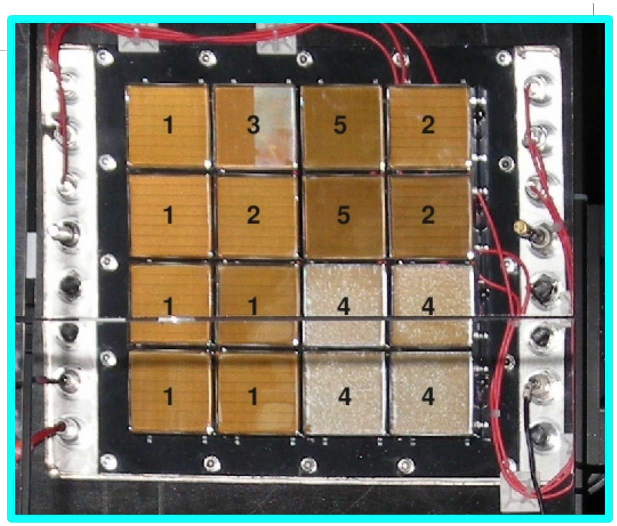
For a σ = 0.572 mrad (2% resolution), pions and electrons are separated by 5 sigma up to about 11 GeV/c.

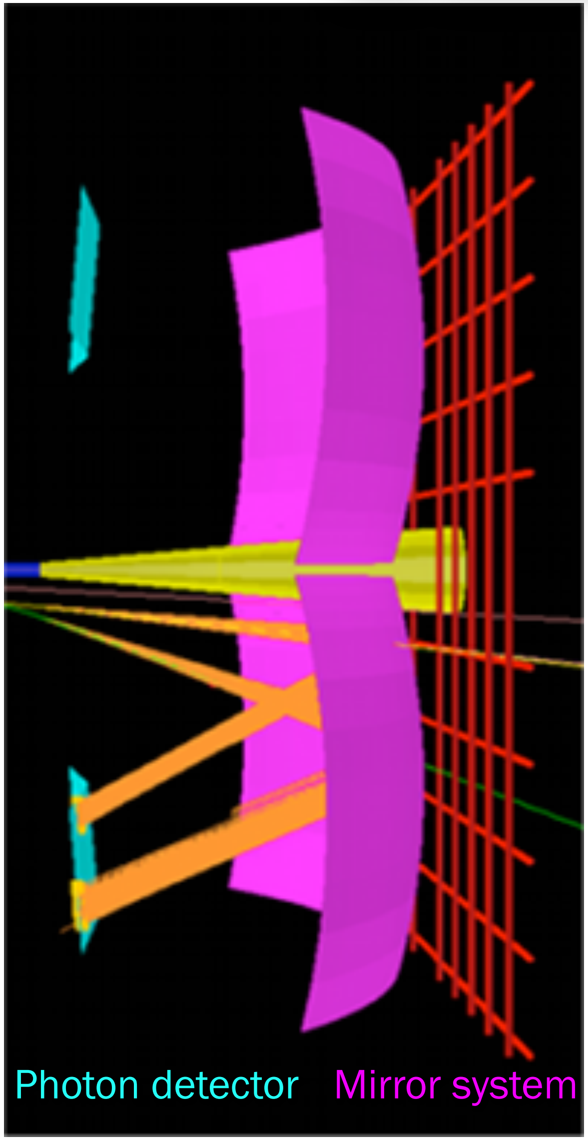
The concept of the real size prototype

Prototype Concept: Same properties and dimensions









Modules of the main components have the <u>same dimensions and properties</u> as foreseen in the RICH concept

Why Prototype?

Verify the concept

- Study detector performance under realistic conditions.
- Components interplay, study first system integration effects (2x2 mirror plane, rows of MAPMT on a plane).
- Performance of WaveLength Shifting films (WLS).

Determine components

- Evaluate and compare alternative MAPMT/MCP.
- Test new FPGA-TDC read-out electronics under beam conditions.

Fix tolerances

- Mirror misalignments, gas impurities, …

Software

- Test software: hit & ring finder & ring fitter
- Get input for realistic detector response

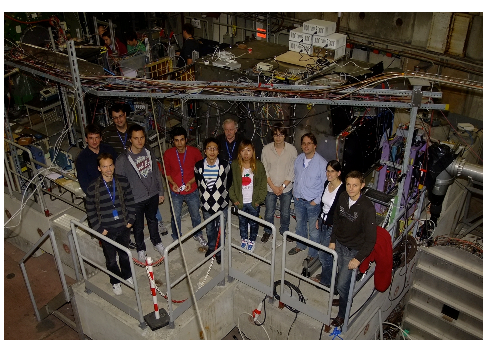
Gain experience

- Mirror mount
- Gas system

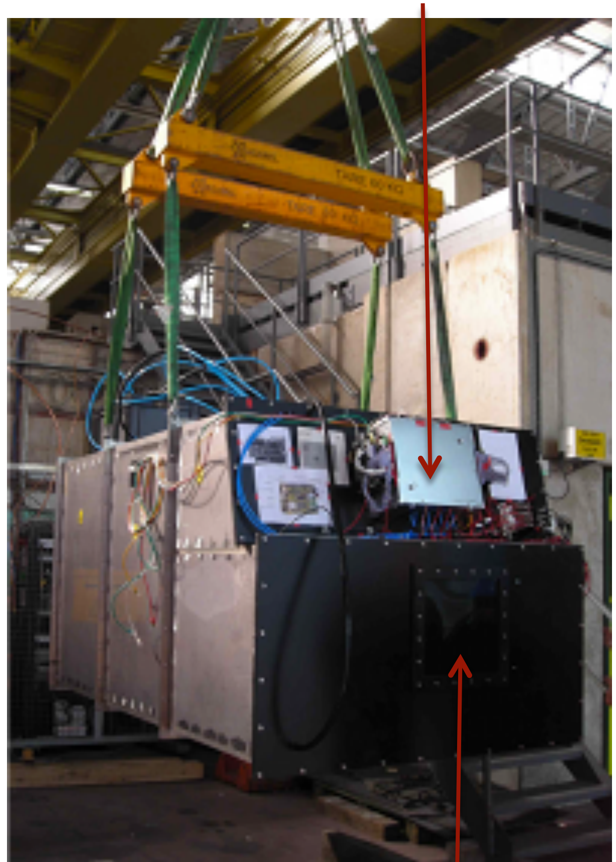
Prototype

Construction and in beam

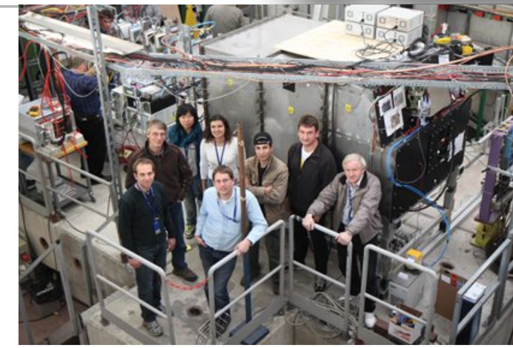
In x- and y- direction movable table

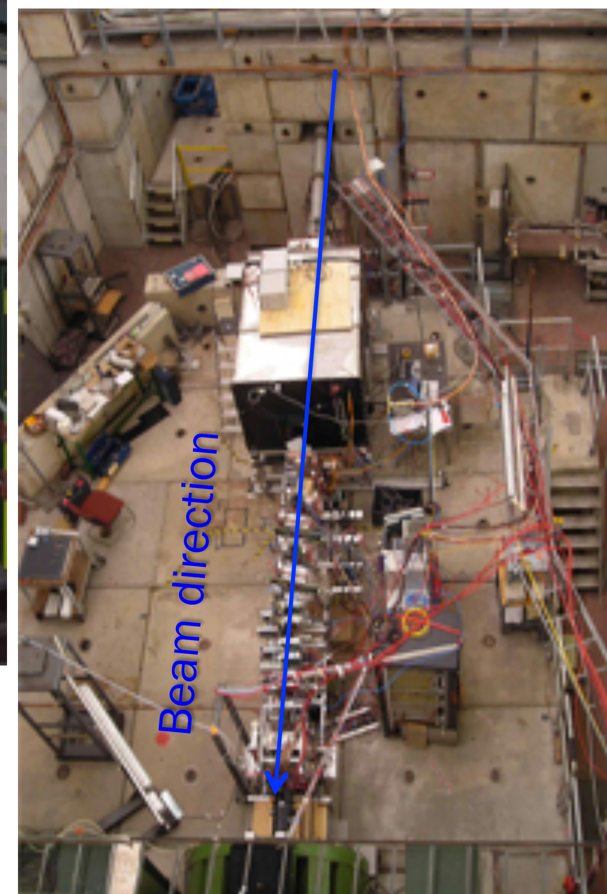


Photon detector

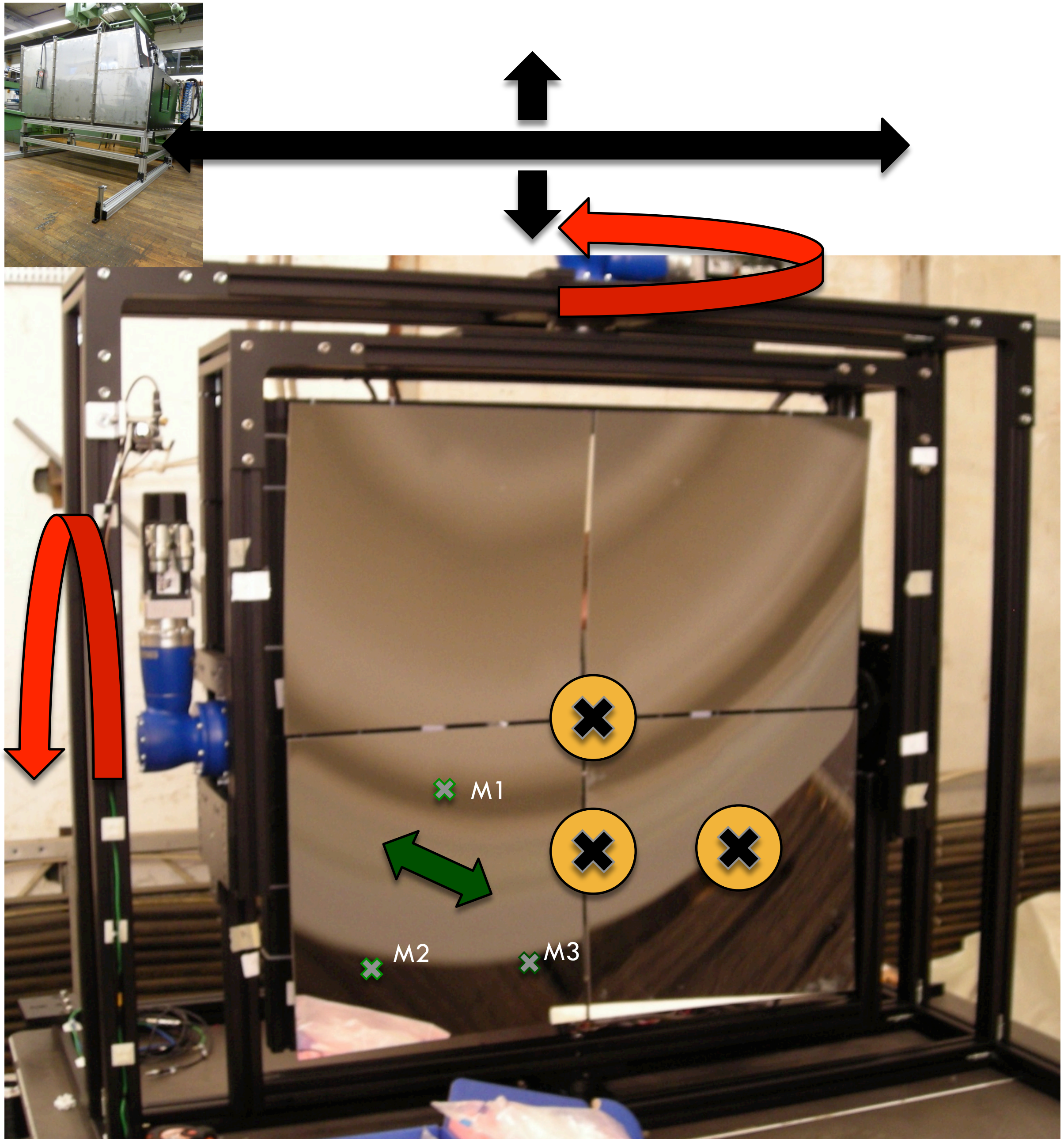


Beam entrance window

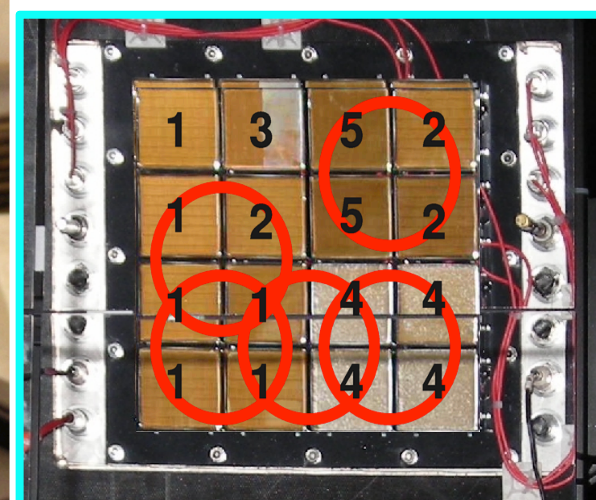




Scanning of components

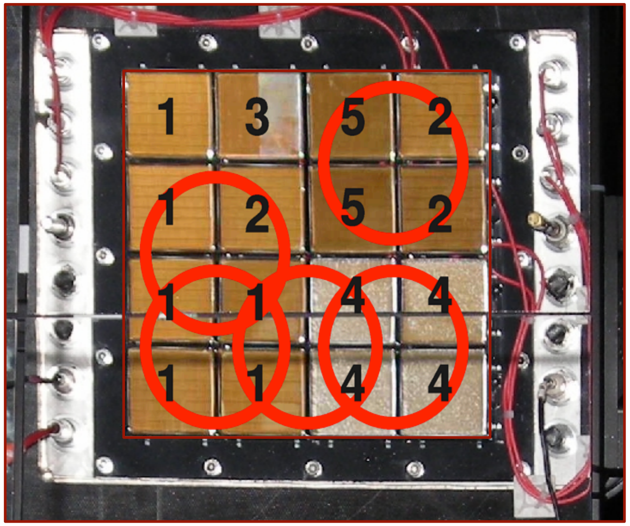


- Mirror tiles adjustable via three actuators.
- Mirror scan is achieved via movable prototype a long x- and y-axis.
- Camera scan is achieved via rotatable mirror system around x- and y-axis.

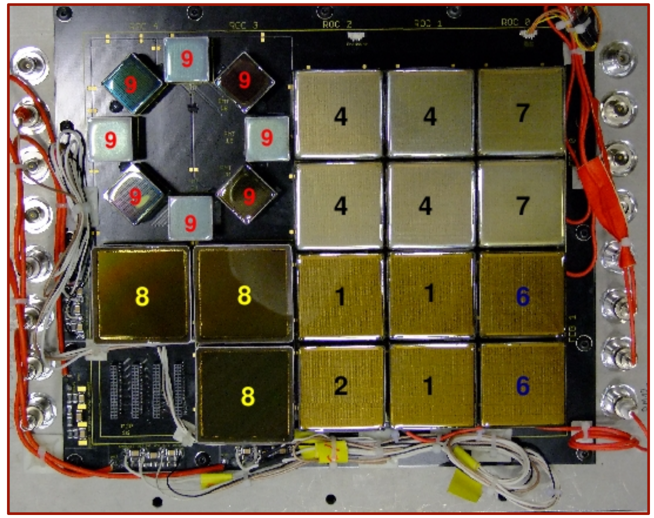


PROTOTYPE

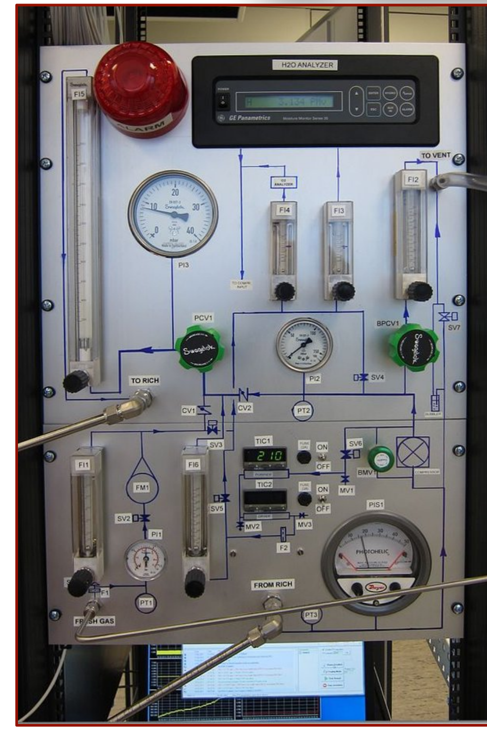
Farther components



2011

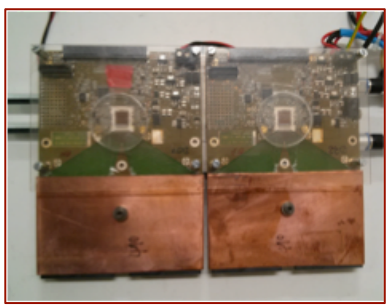


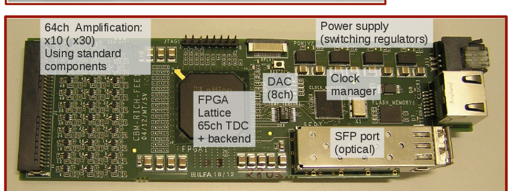
2012



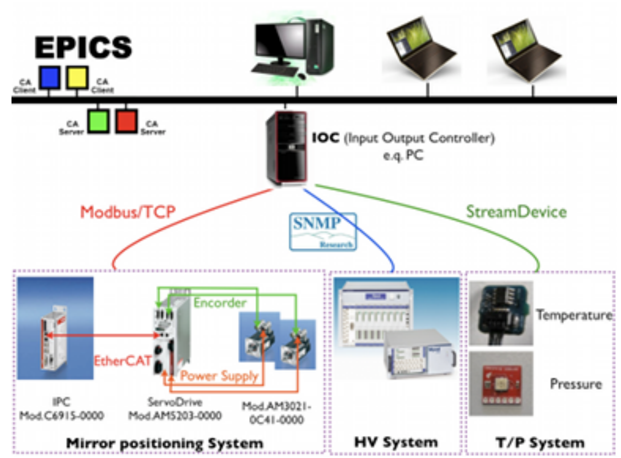
Gas system

- Different photon detectors are used in test beams 2011 and 2012
- Some are covered with Wavelength Shifting films (WLS)



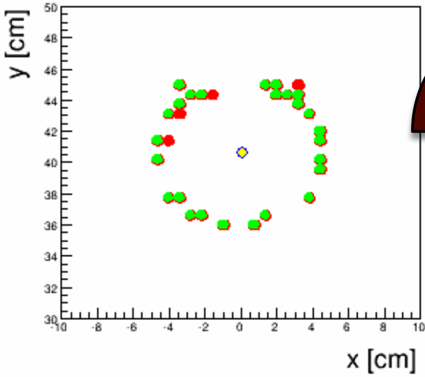


Readout electronics: nXYter and FPGA

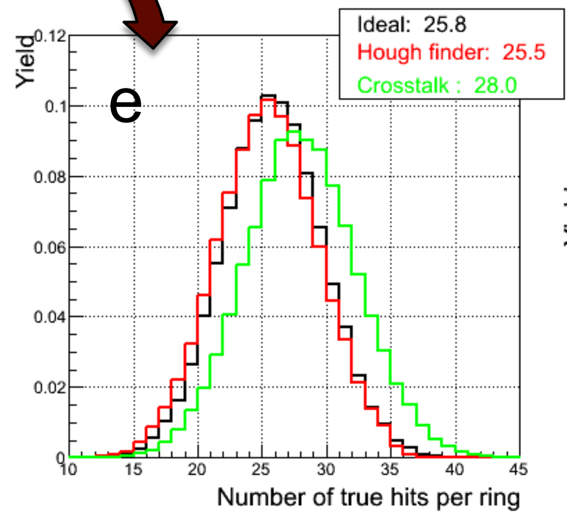


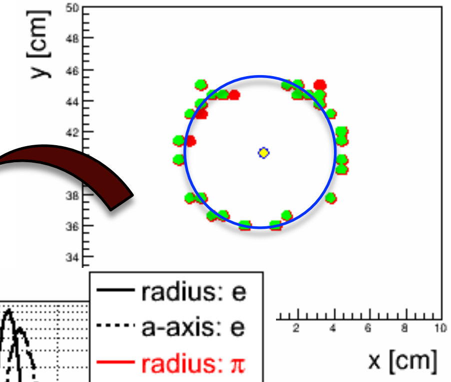
Slow control via EPICS

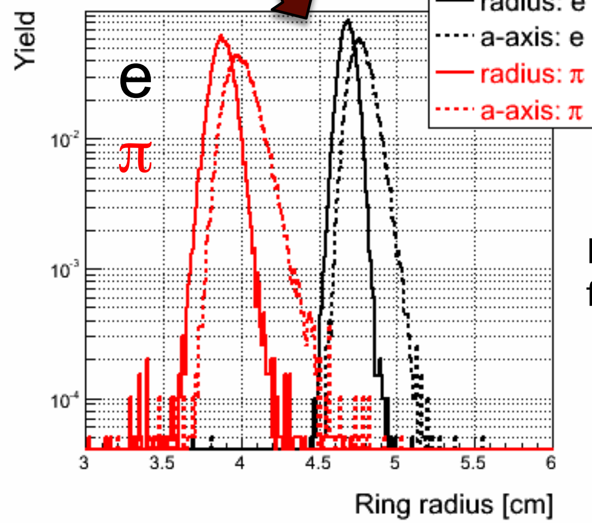
Prototype: Performance



1 Number of photons per ring







2 Radius of fitted ring

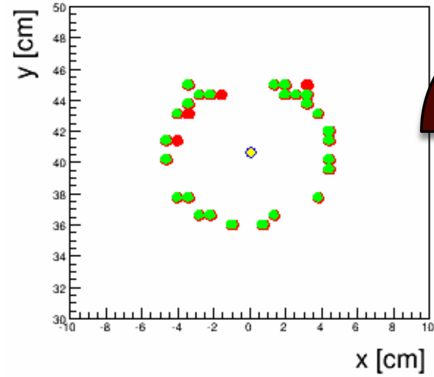
p=8GeV/c, r_e=4.68 cm, r_π=3.88 cm

Ring reconstruction with the Hough Transport Algorithm:

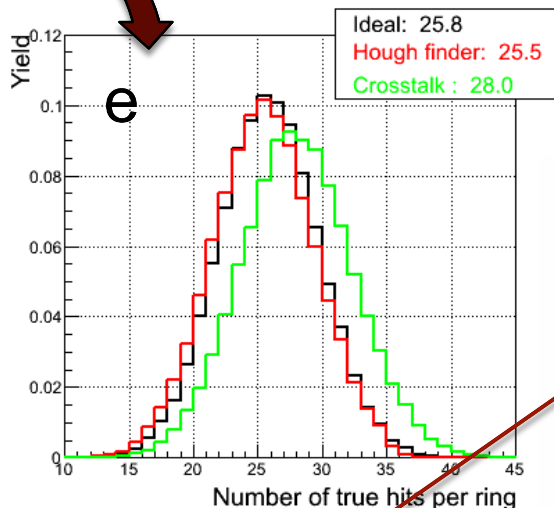
1
- → determine number of hits per ring = 25.5 (without crosstalk).
- → determine number of hits per ring = 28.0 (with crosstalk).

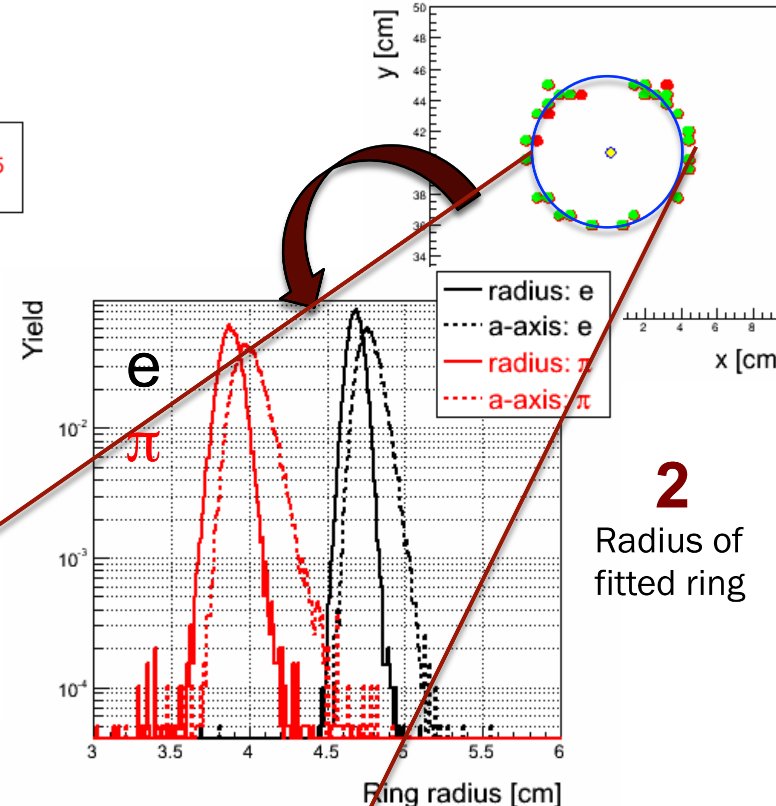
2
- Ring fitting with a circle and an ellipse → Radius and major/manor axis.

Prototype: Performance



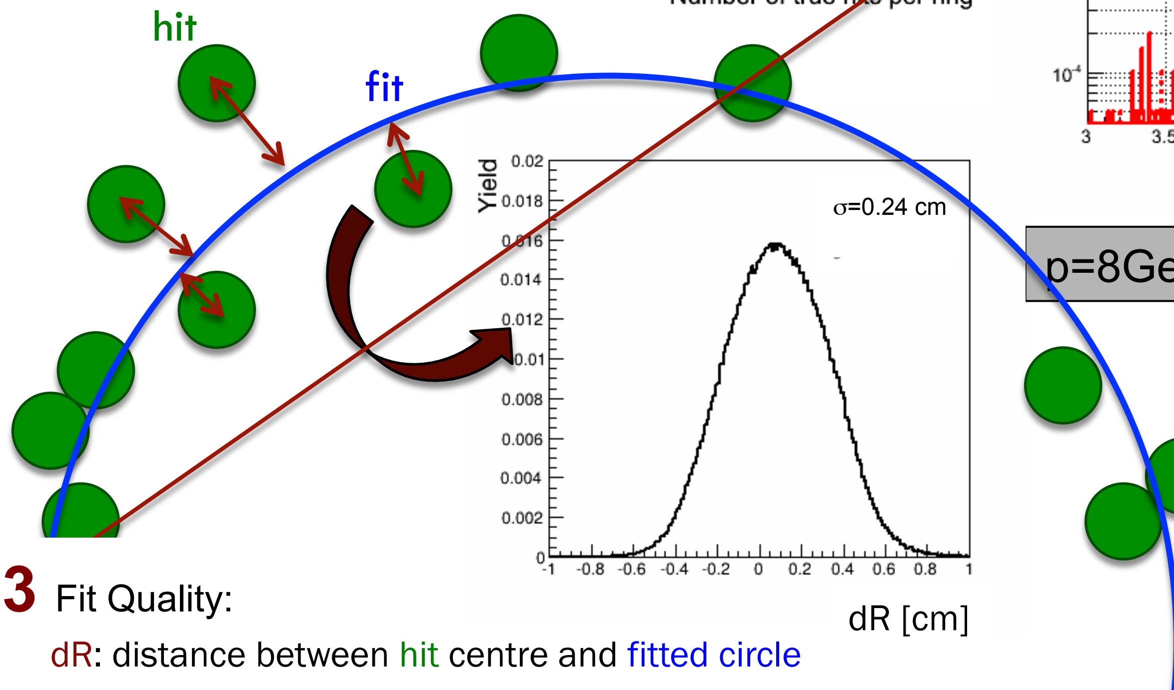
1 Number of photons per ring





2 Radius of fitted ring

p=8GeV/c, r_e=4.68 cm, r_π=3.88 cm



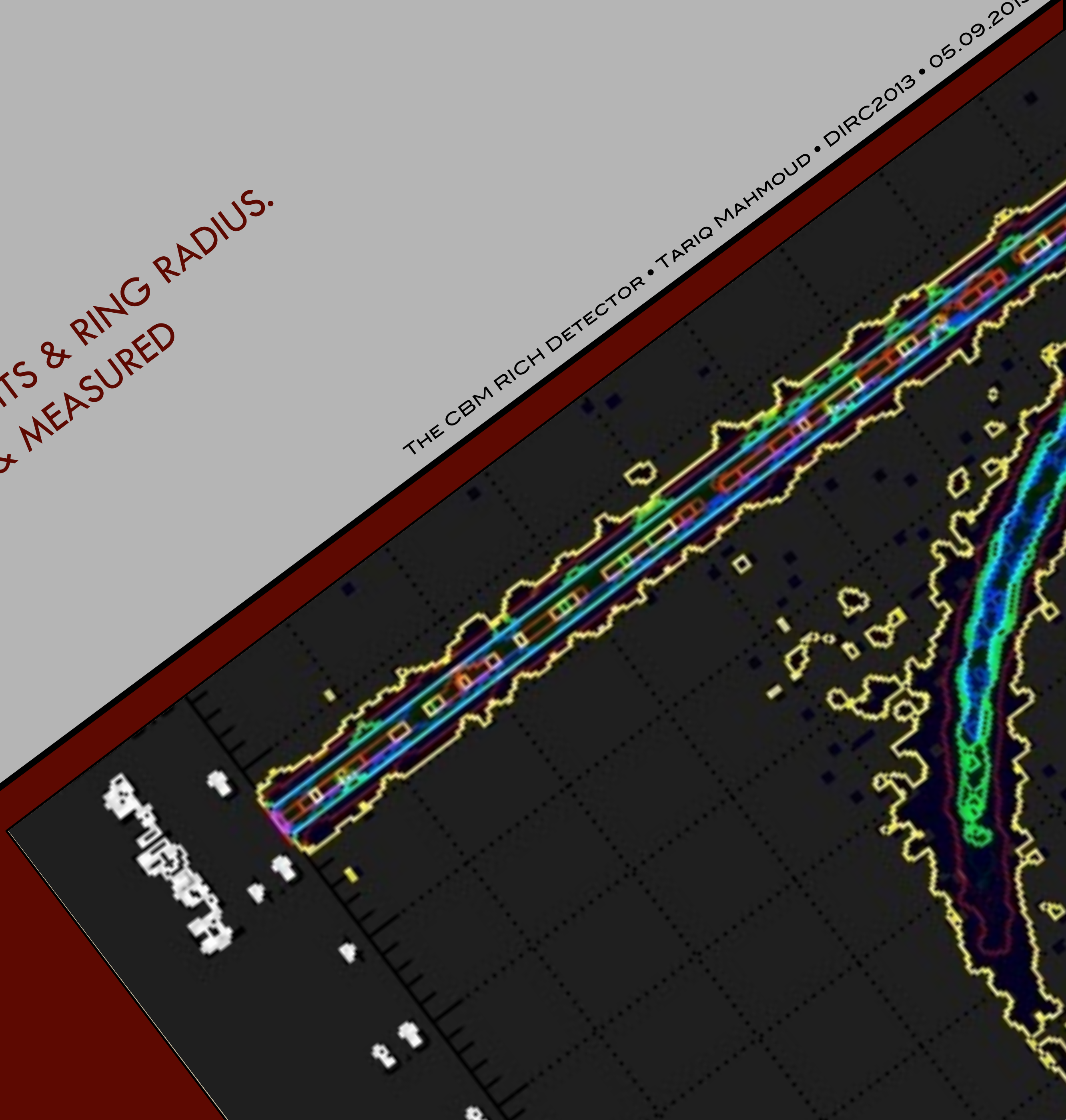
3 Fit Quality:

dR: distance between hit centre and fitted circle

σ_{dR} = 0.24 cm < pixel size of the PMTs (0.6125 cm)

NUMBER OF HITS & RING RADIUS.

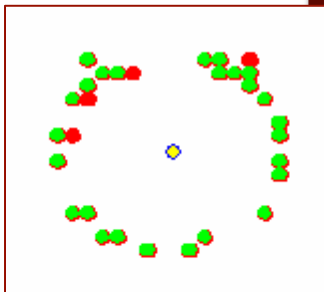
SIMULATED & MEASURED

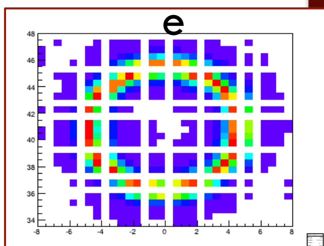


Prototype: Performance

Nice agreement between simulations and data

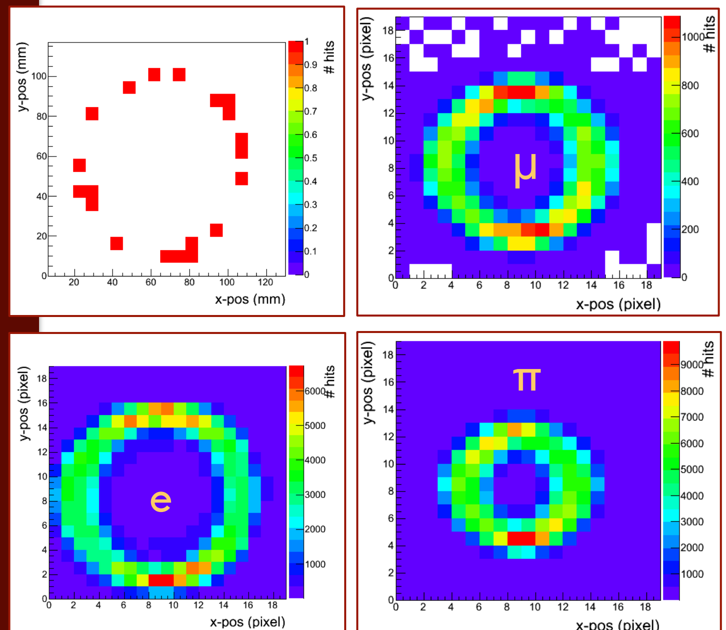
Simulation

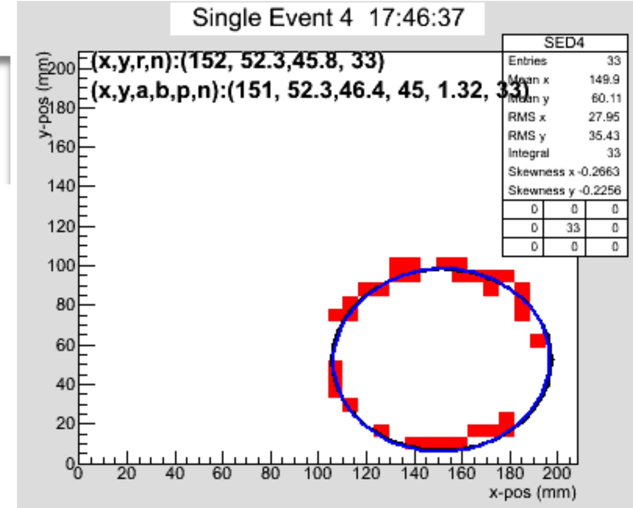


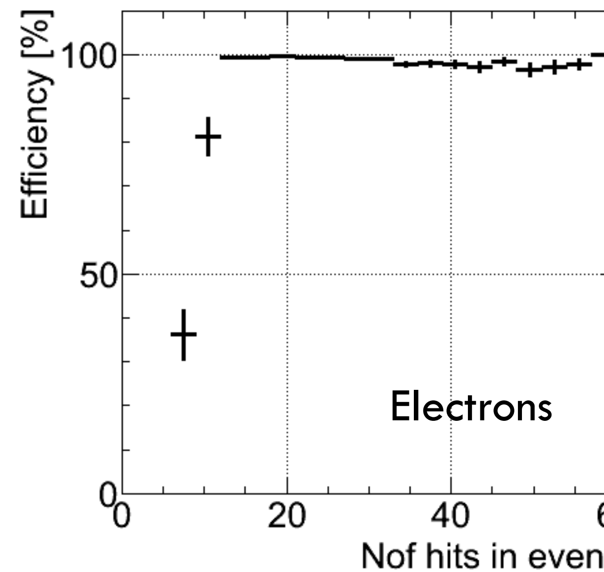


Data

2011





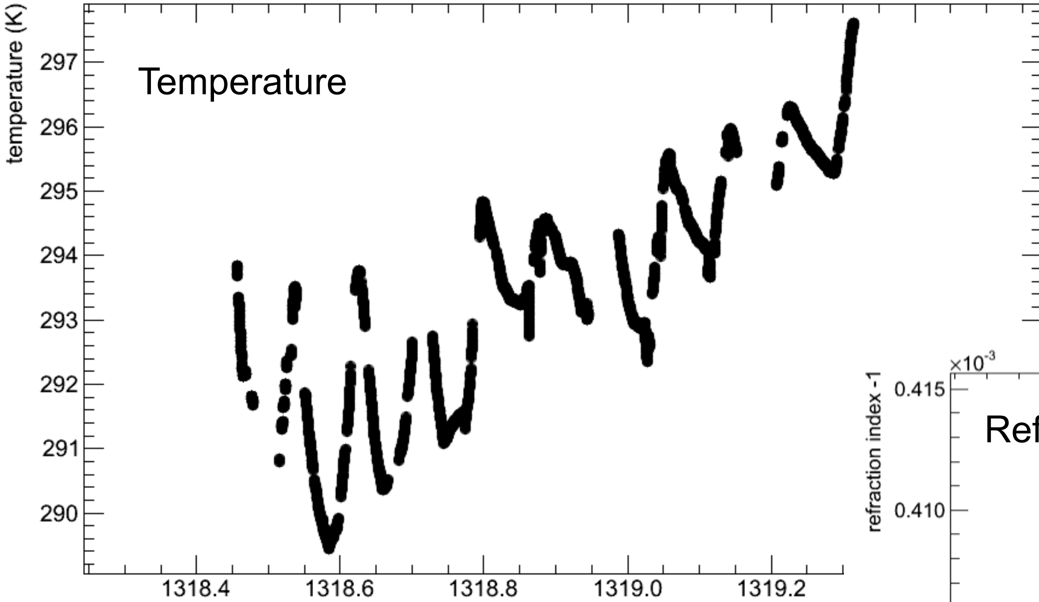


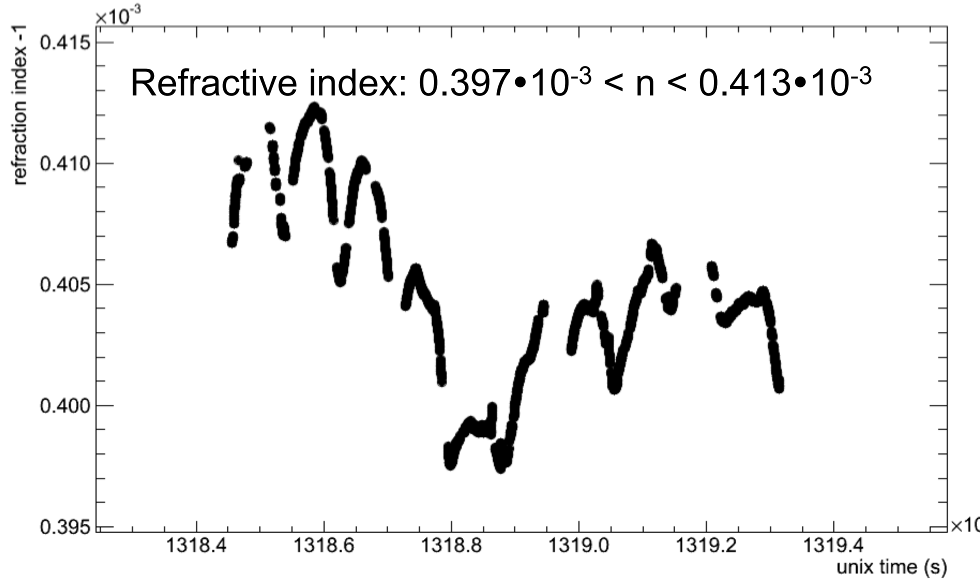
- Qualitative agreement between simulation and data.
- High performance of ring finding and fitting
  → 100% efficiency for number of hits above 6.
- Total “dark rate” ~5500 Hz from 1024 channels
  → Below 10 Hz/pixel in most of channels

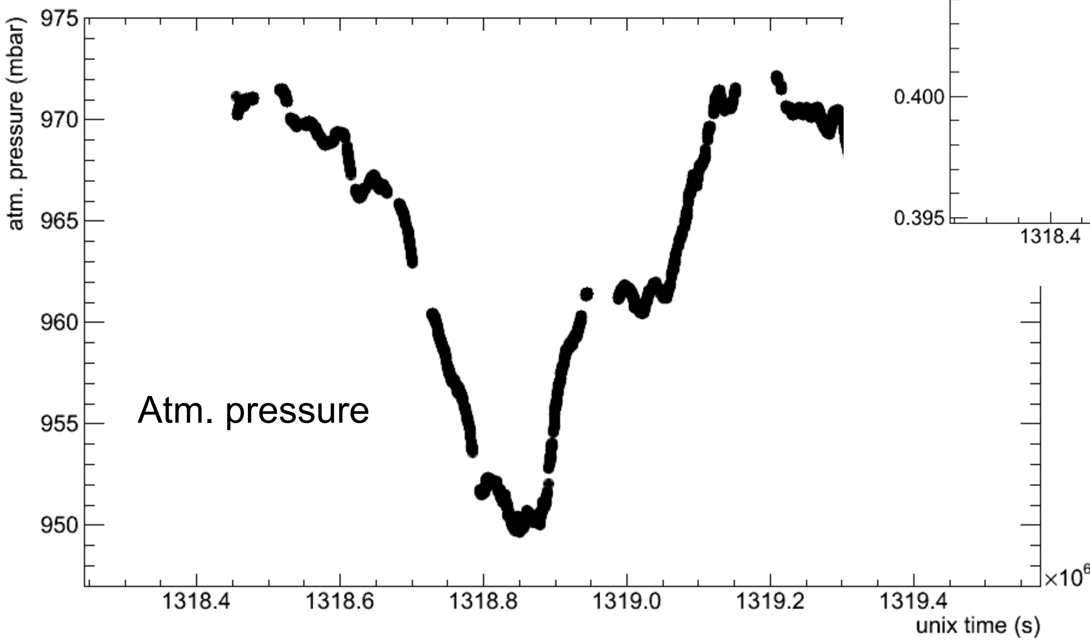
Correction for temperature and pressure

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2}\left[1 - \frac{1}{\beta^2 n(\lambda)^2}\right]L$$

$$n(T,p) = 1 + (n_0 - 1)\bullet\frac{T_0}{p_0}\bullet\frac{p}{T}$$



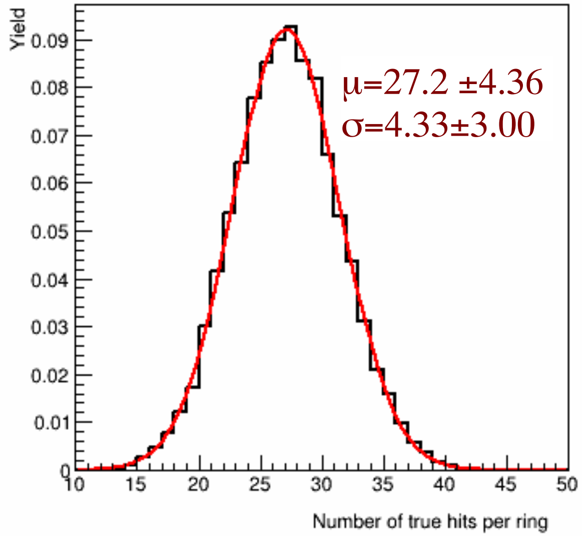




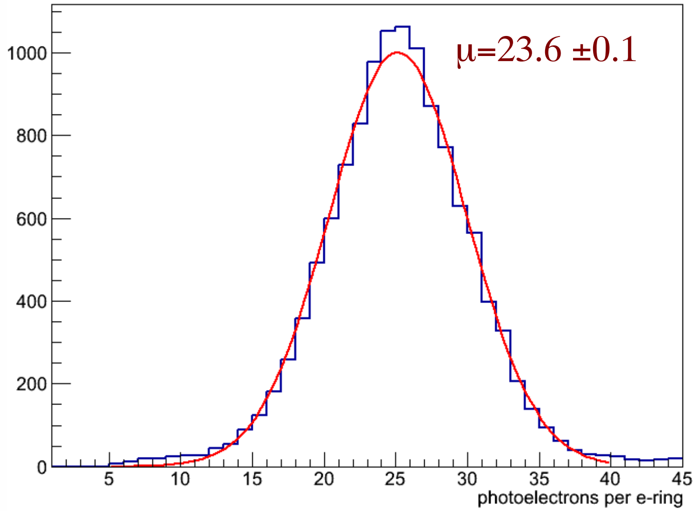
Prototype: NHits

Quantitative comparison MC-data

Simulation T=273 K, p=1 bar



Data T=293 K, p=0.96 bar



$$n(T,p) = 1 + (n_0 - 1) \bullet \frac{T_0}{p_0} \bullet \frac{p}{T}$$

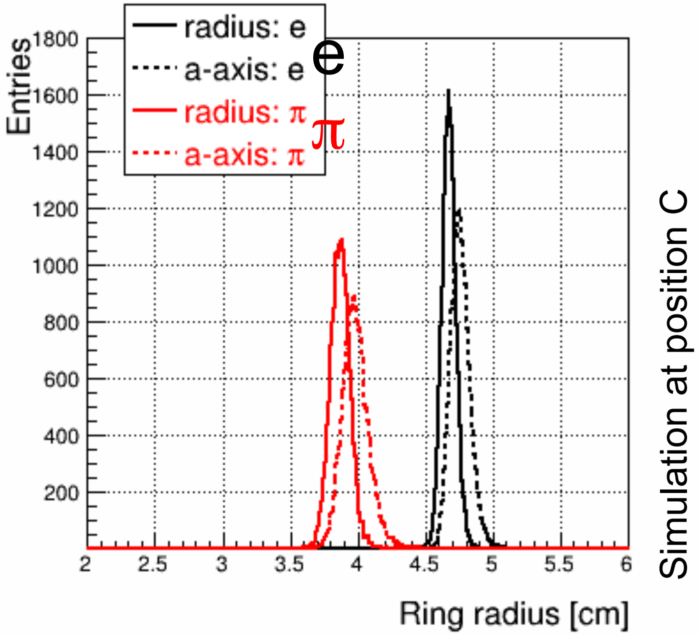
Data = 0.867 • MC

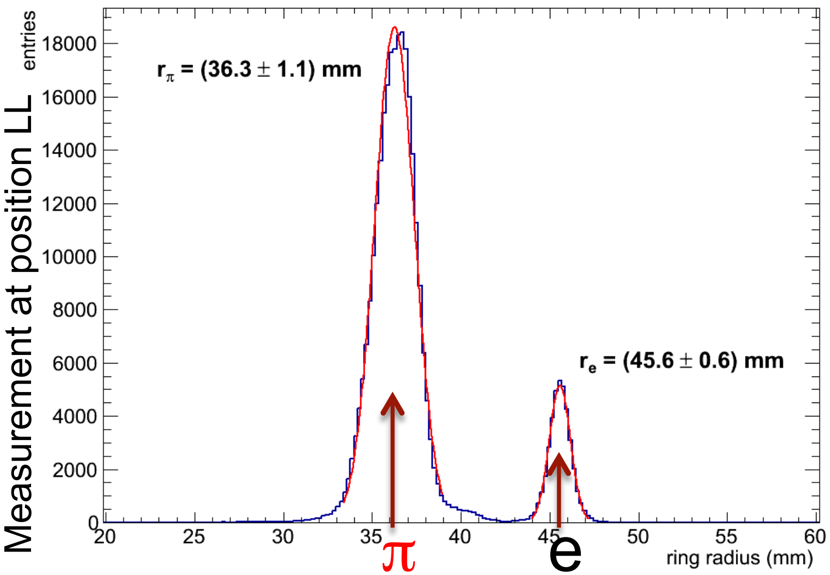
- Does the discrepancy come from the collection efficiency of the PMTs? (set to 100% in the simulations)
- Is the discrepancy constant for all PMTs [types]?

Good agreement after p-T corrections

Simulation T=273 K, p=1 bar, p=8 GeV/c

Data T=293 K, p=0.96 bar, p=8 GeV/c





r_e=4.68 cm

r_π=3.88 cm

r_e= (4.56±0.6±0.11) cm

r_π= (3.63±1.1±0.09) cm

$d_{e\pi} > 7\sigma_\pi$

$$r(n) = L \bullet \tan\theta_c = L \bullet \tan\left(\arccos\frac{1}{\beta n}\right)$$

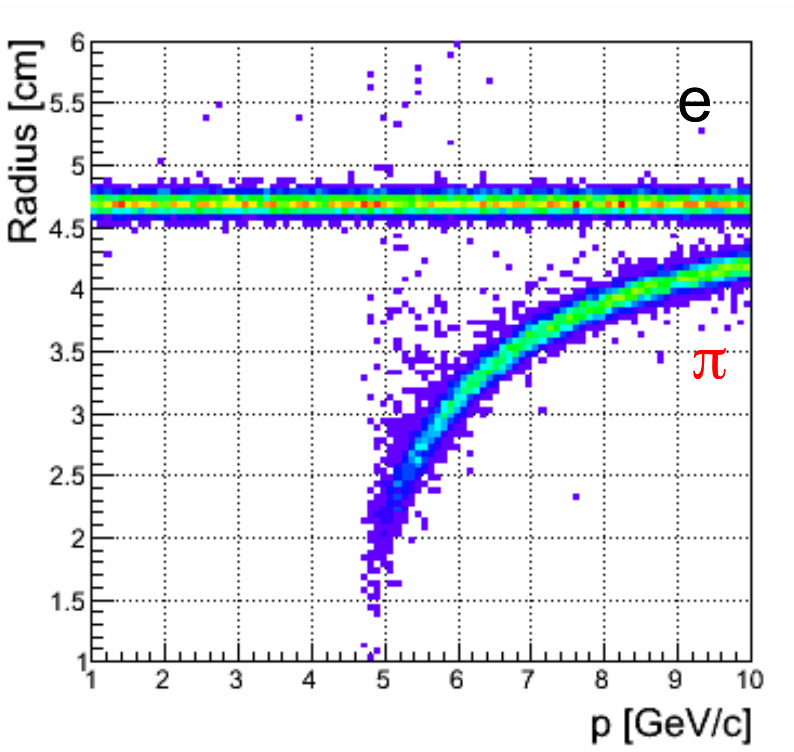
Pressure and temperature correction → r_{MC}=1.04*r_{data}

One finds: r_{MC}=1.05*r_{data}

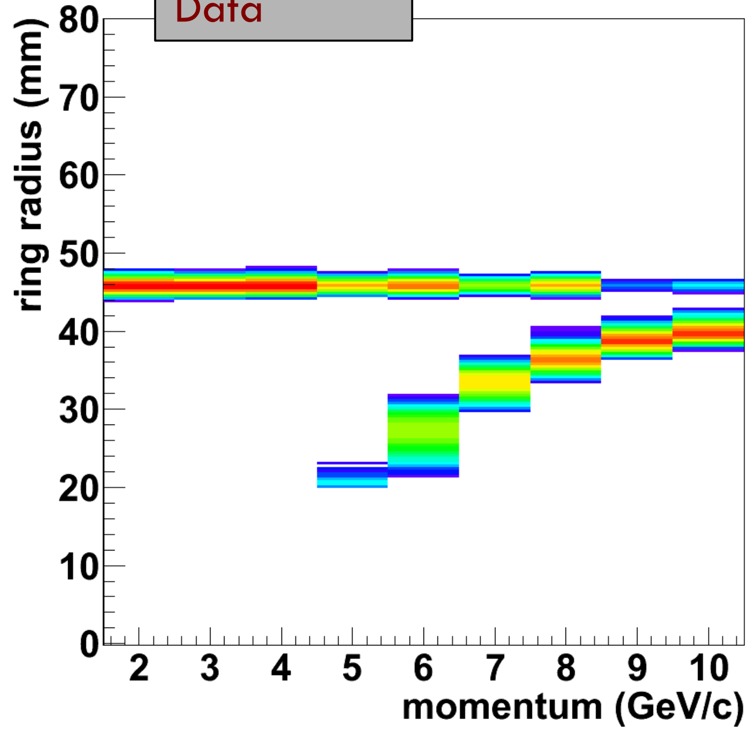
Prototype: Radius

Momentum scan

Simulation



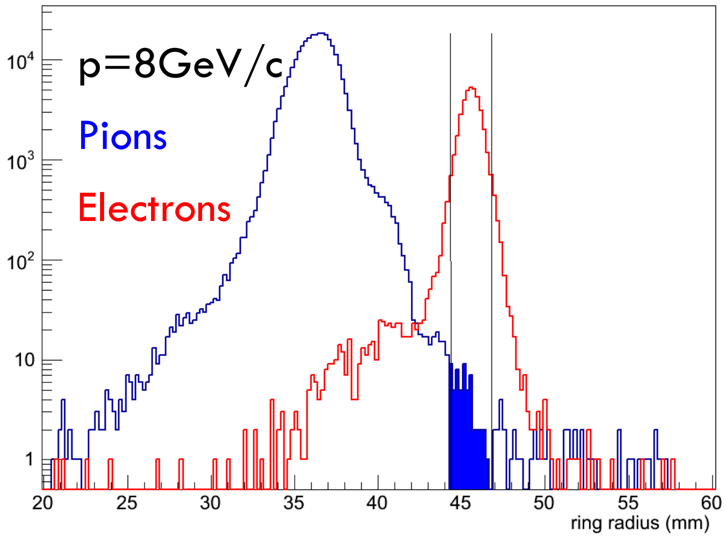
Data



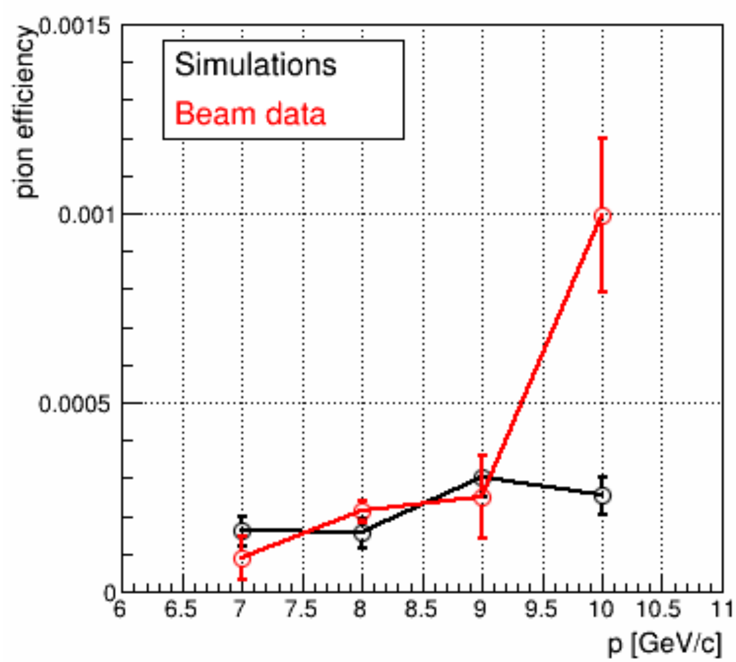
- Very good qualitative agreement between data and simulations is observed.
- Wider distribution in ring (y-) direction because of muons.

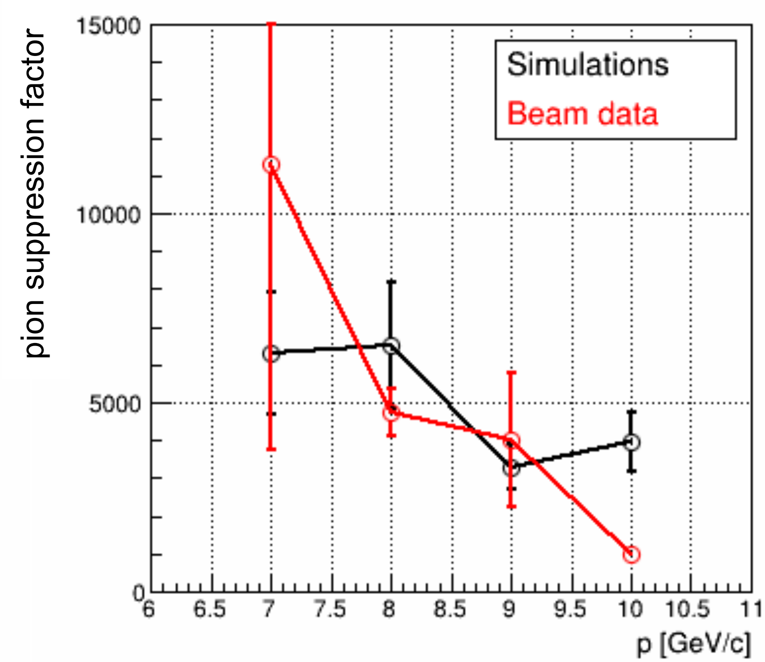
Prototype: π-Efficiency

Performance of electron identification

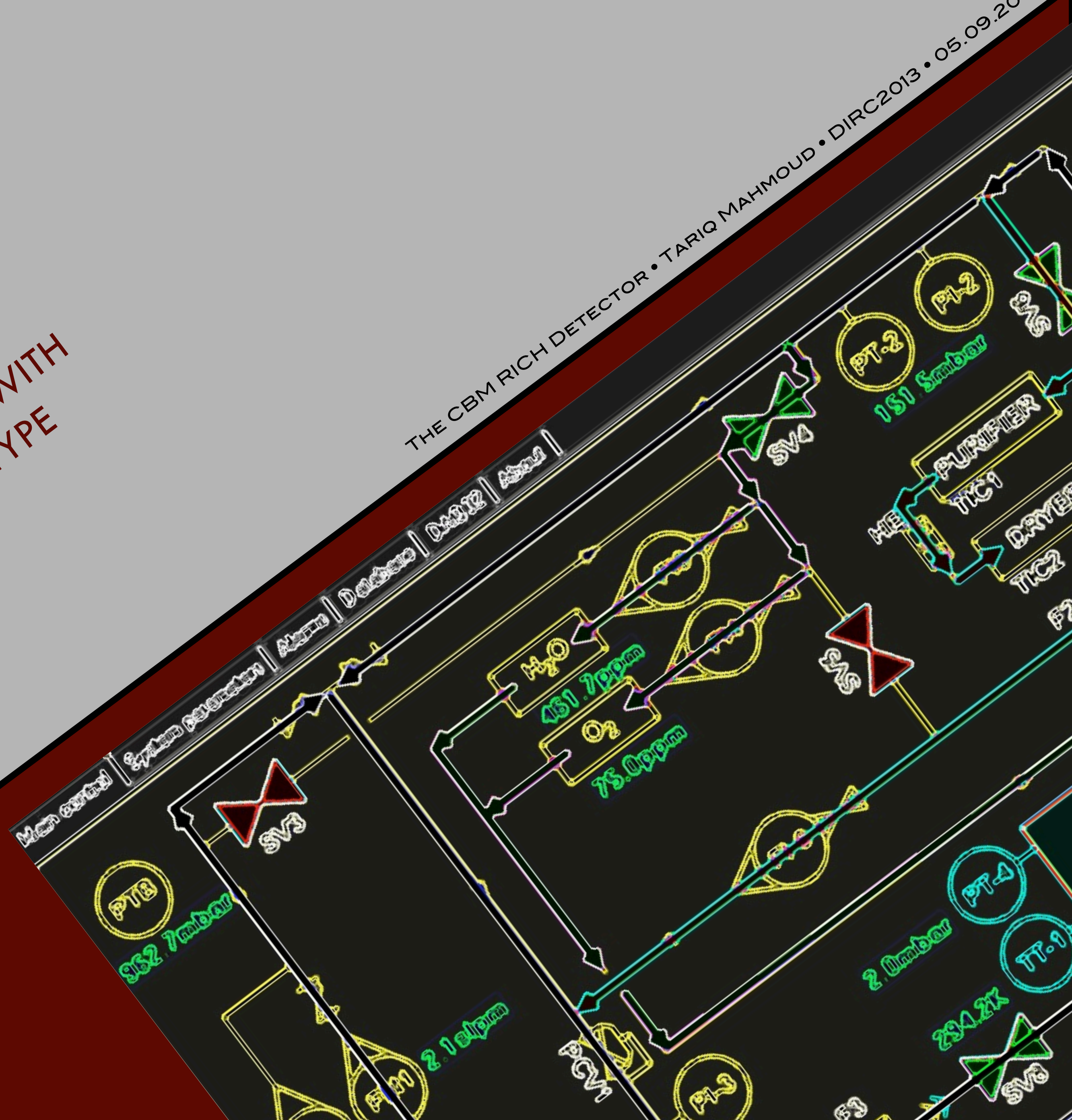


- Determine the pion rejection efficiency at an electron id. Efficiency of 95%.
- Determine a factor *k* such that 95% of the electrons are within the range $(r_e)_{mean} \pm k \bullet \sigma_e$
- $\pi_{eff} = \pi_{mis} / \pi_{all}$ (0.021% @ 8GeV)
- $\pi_{suppression\ factor} = 1/\pi_{eff}$ (4760 @ 8GeV)
- Discrepancy @ 10 GeV is caused by muons





Other tests with the prototype



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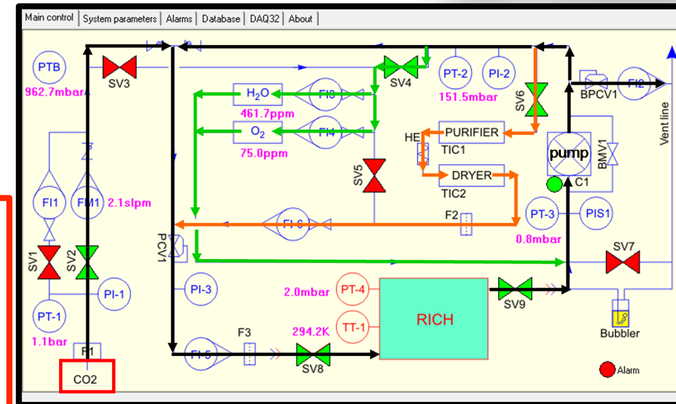
Prototype: Other tests

With the prototype

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

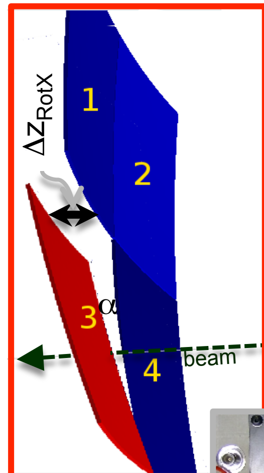
Gas system

- Provides pure CO_2 gas
- Constant over pressure of 2 mbar.
- Determine impurity tolerances



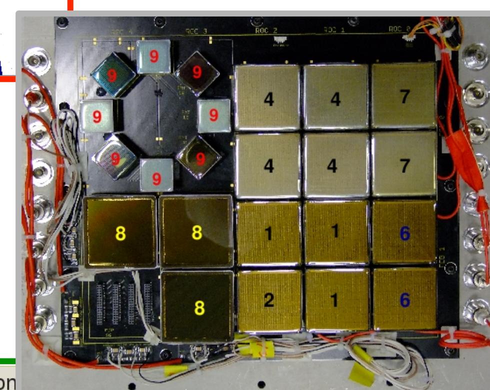
Mirror displacement

- Deteriorate the resolution of ring fit →
- Determine displacement tolerances



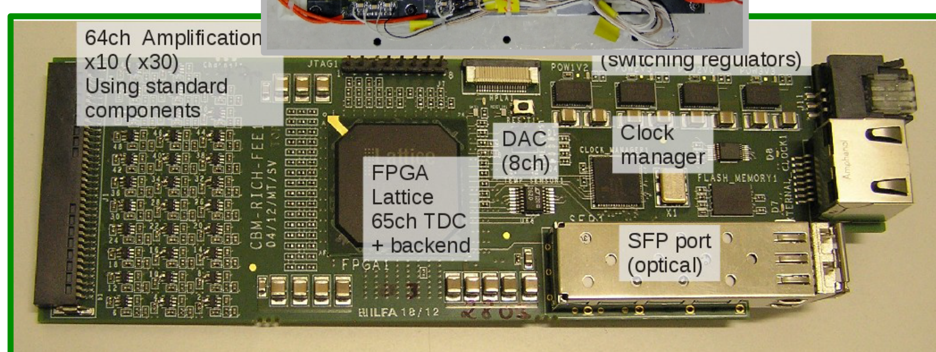
Different photon-detectors

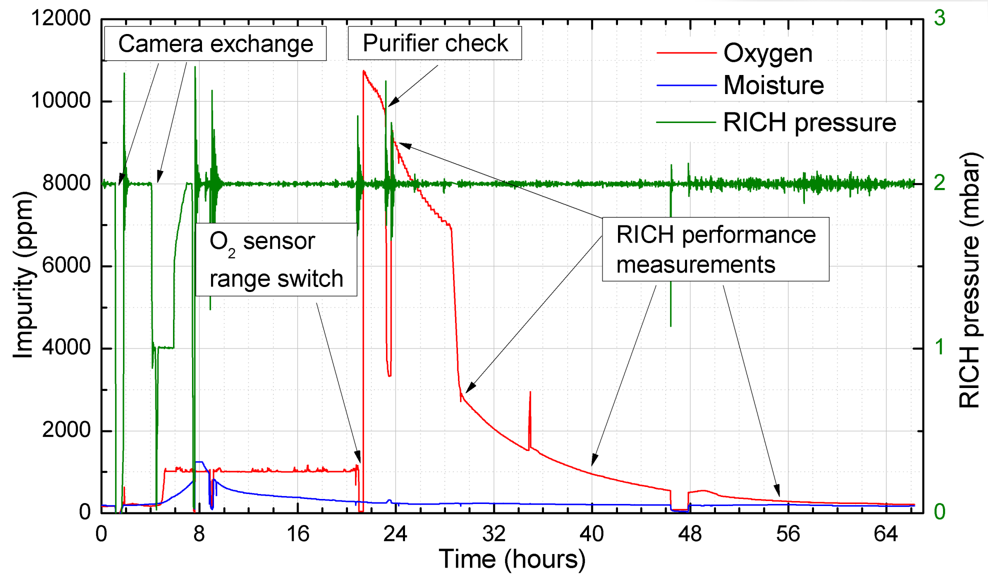
- Single photon spectra
- Number of Hits per ring and ring radius
- WLS



New electronics

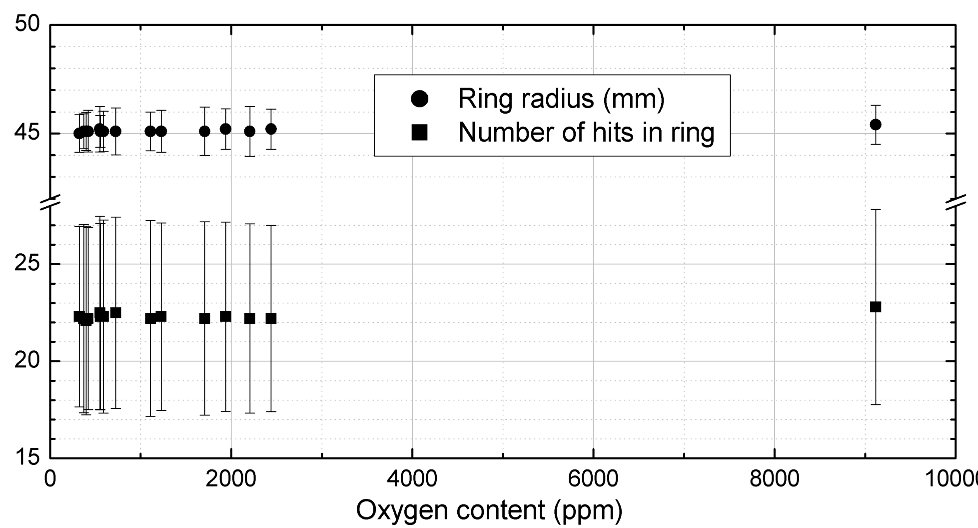
- Compact with good time resolution





Normal operation:

- Constant differential pressure of 2 mbar ± 1%
- O_2 (H_2O) impurity about 80 (250) ppm

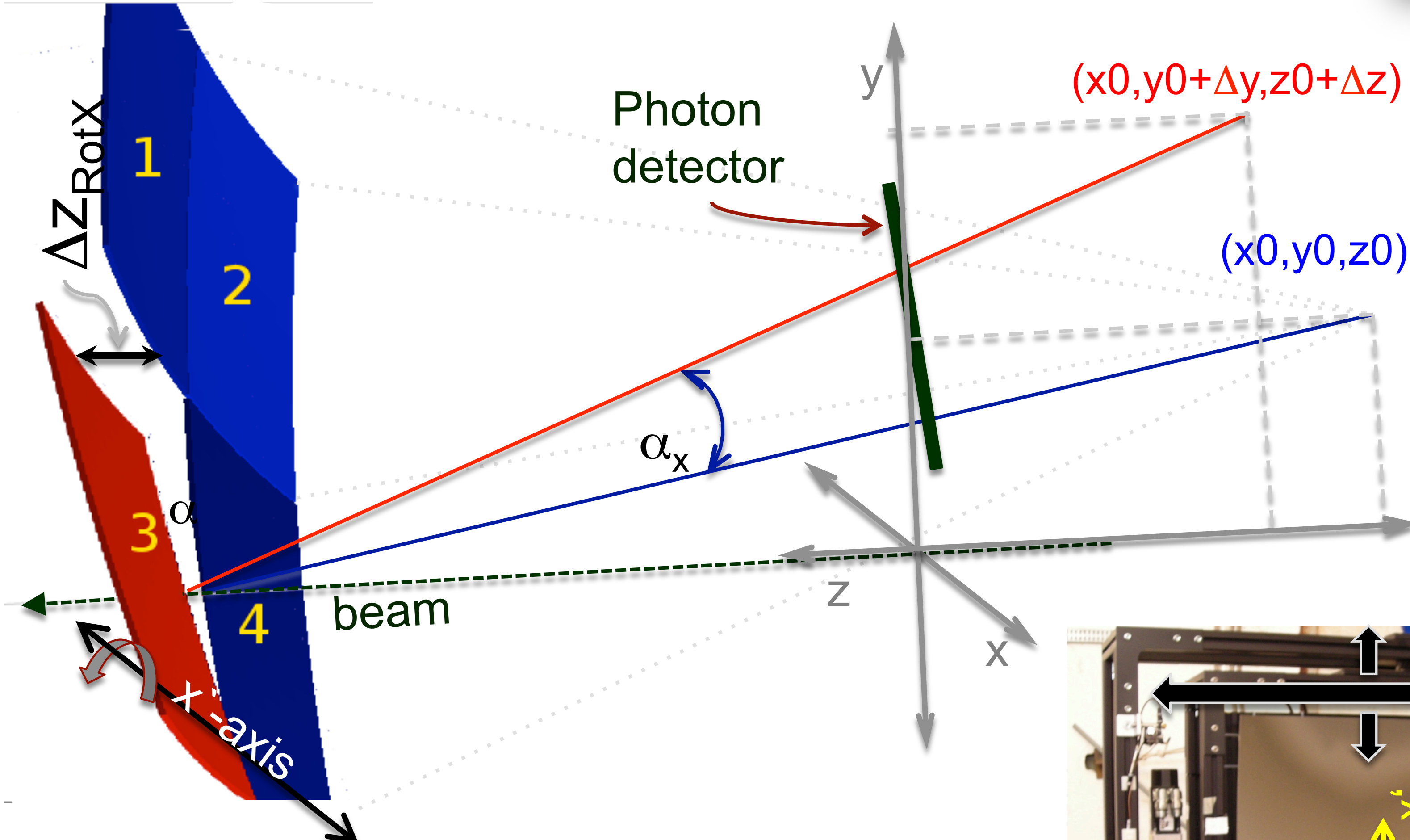


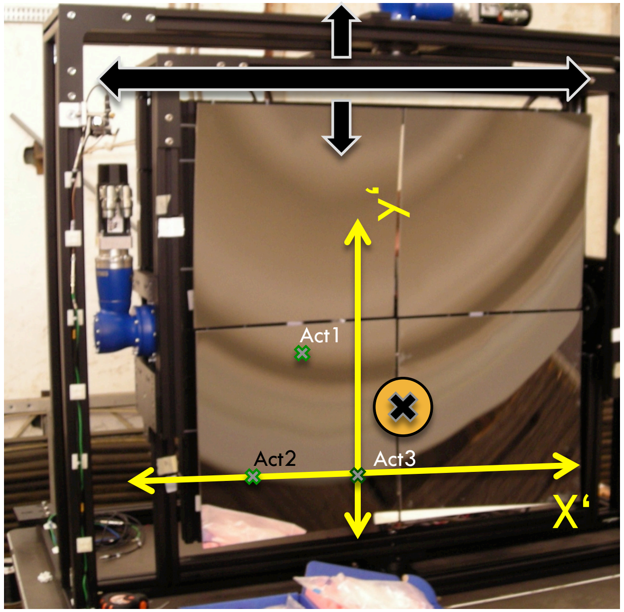
Tested up to:

- O_2 impurity of 10000 ppm
- H_2O impurity of 1100 ppm

Prototype: Mirror Displacement

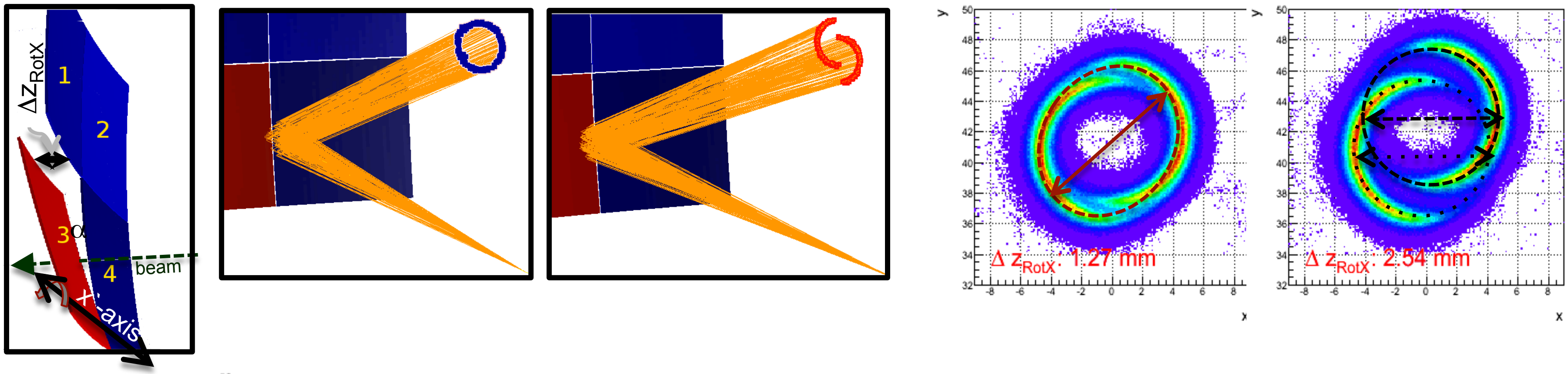
Effects on rings

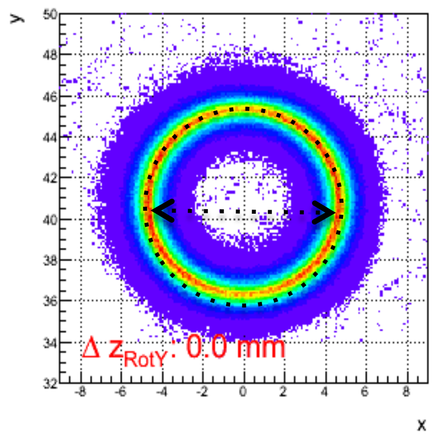




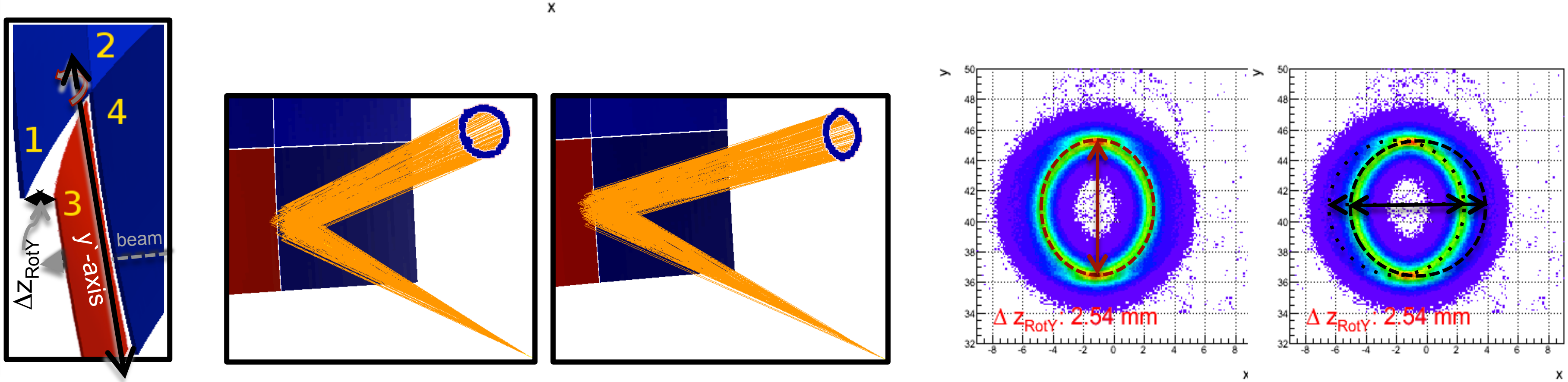
Prototype: Mirror Displacement

Tolerable displacements





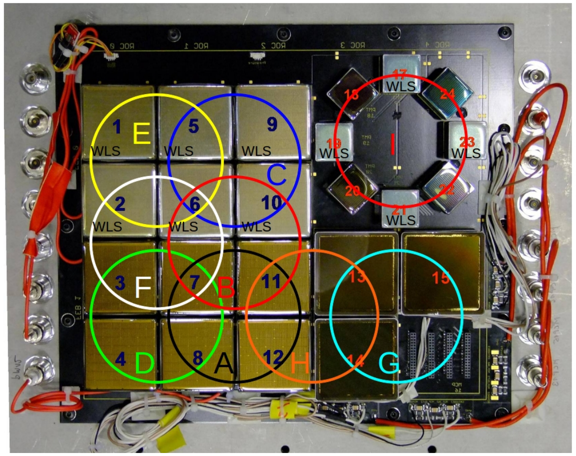
$\Delta Z_{RotX\,(Y)} \leq 0.35$ mm ($\alpha_{X(Y)} \leq 1$ mrad) is tolerable



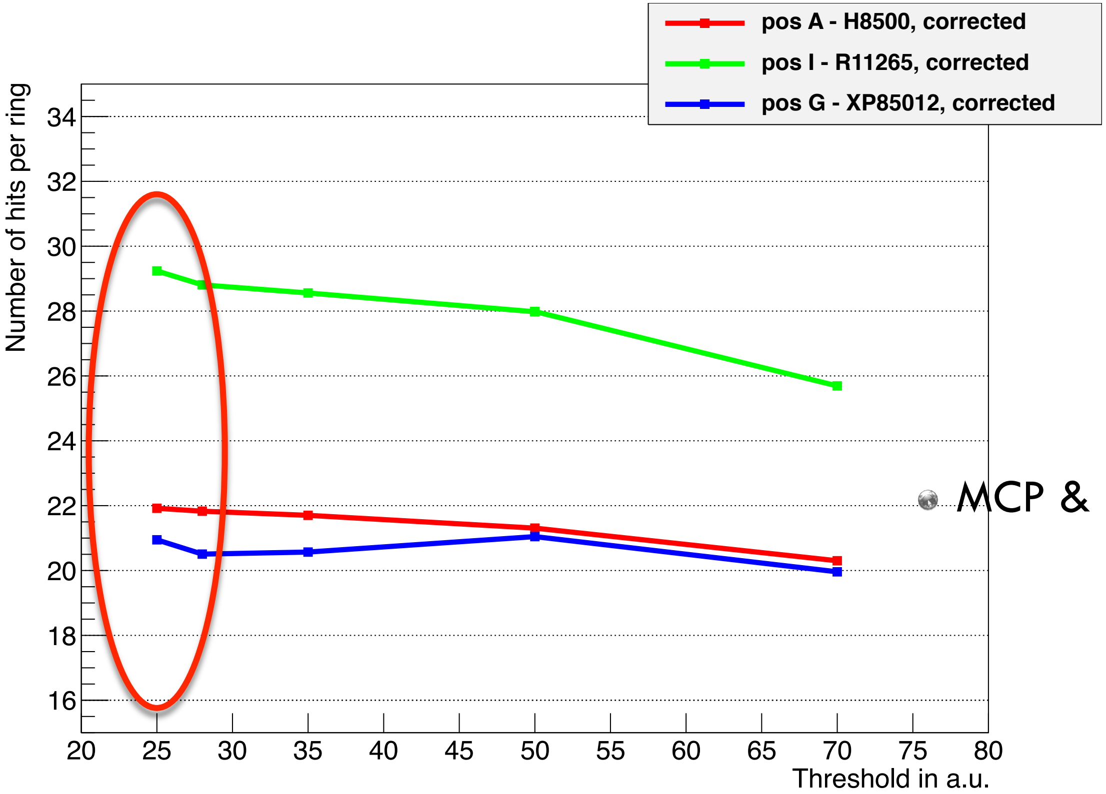
Prototype: Photon detectors

Test of different photon sensors: nHits

- A: H8500, 12-dynodes and Bialkali photo cathode
- I: R11265: 12-dynodes and Super-Bialkali photo cathode
- G: (MCP) XP85012



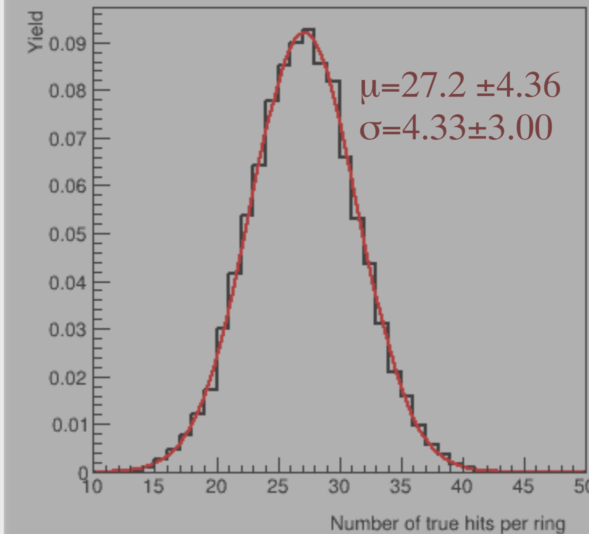
Corrected for T&p and crosstalk



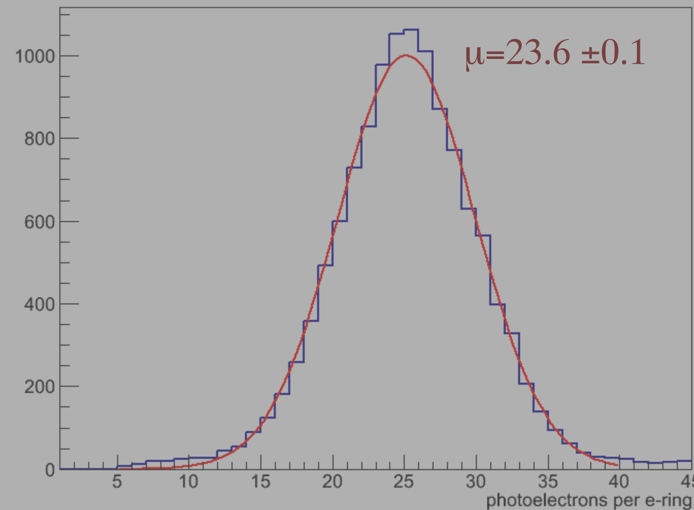
- MCP & H8500 have smae performance

Wavelength shifting films

Simulation T=273 K, p=1 bar



Data T=293 K, p=0.96 bar



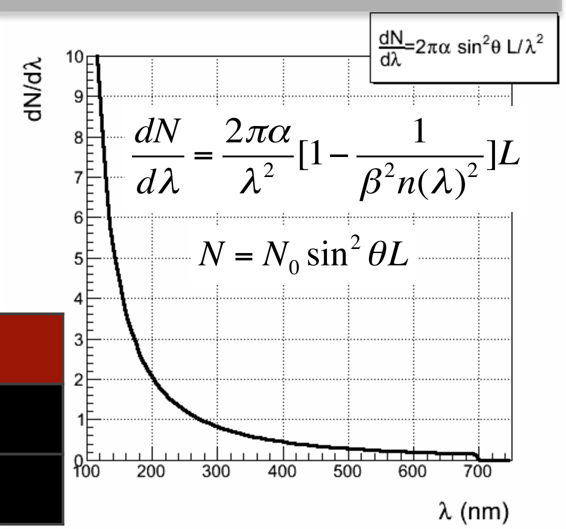
$$n(T,p) = 1 + (n_0 - 1) \bullet \frac{T_0}{p_0} \bullet \frac{p}{T}$$

Data = 0.867 • MC

- Does the discrepancy come from the collection efficiency of the PMTs? (set to 100% in the simulations)
- Is the discrepancy constant for all PMTs [types]?

Wavelength Shifting Films: p-Terphenyl

WLS	Hit/ring MC	Gain	Hit/ring Data	Gain	Hit/ring MC/Data
no	27.2		23.6		-15.3%
yes	31.9	18.1%	28.0	18.6%	-13.9%

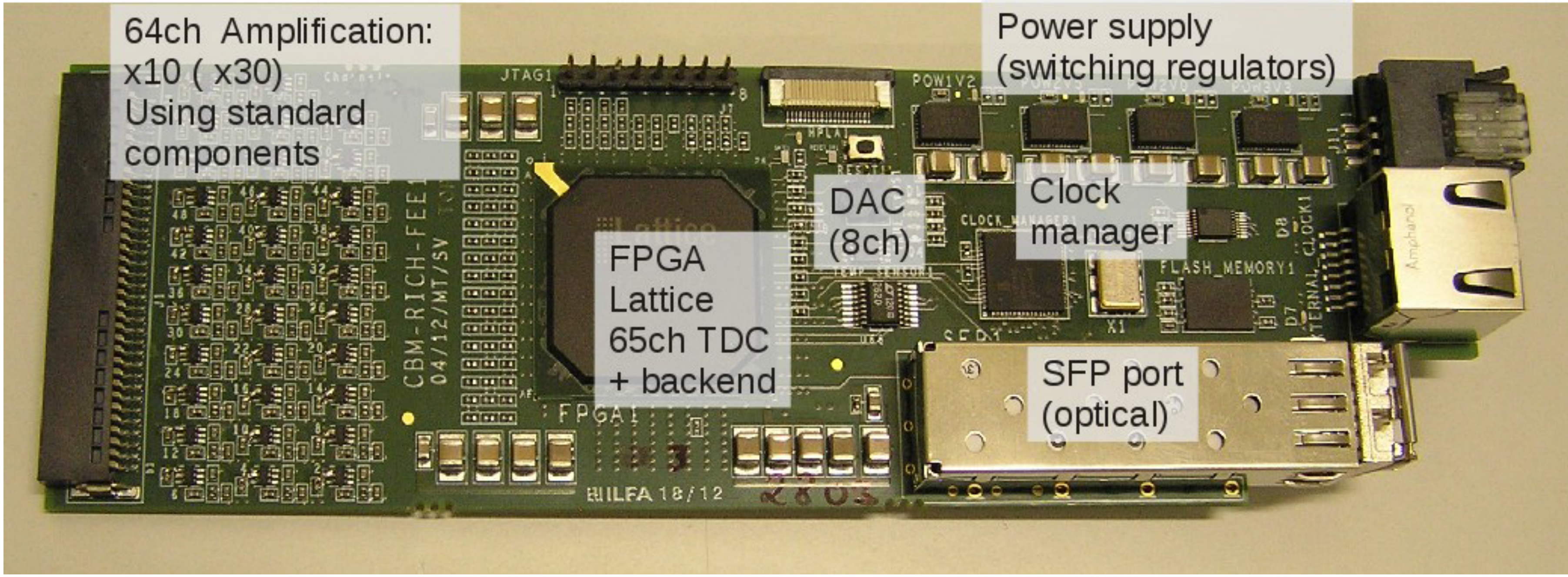


$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2}[1 - \frac{1}{\beta^2 n(\lambda)^2}]L$$

$$N = N_0 \sin^2\theta L$$

Prototype: Electronics

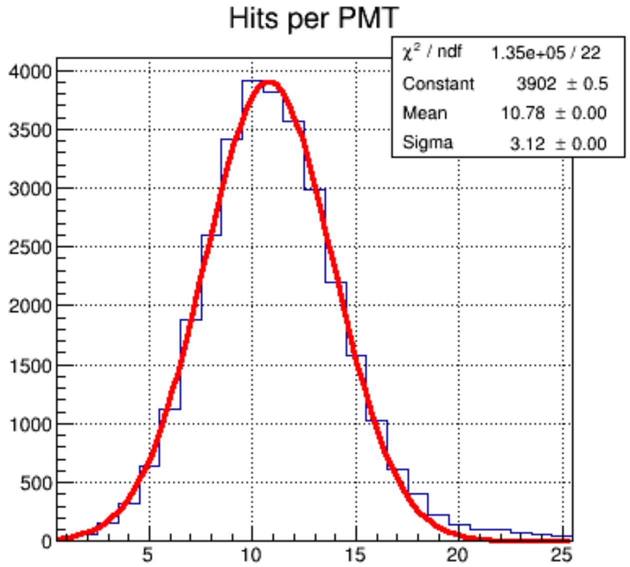
New FPGA-TDC read-out electronics



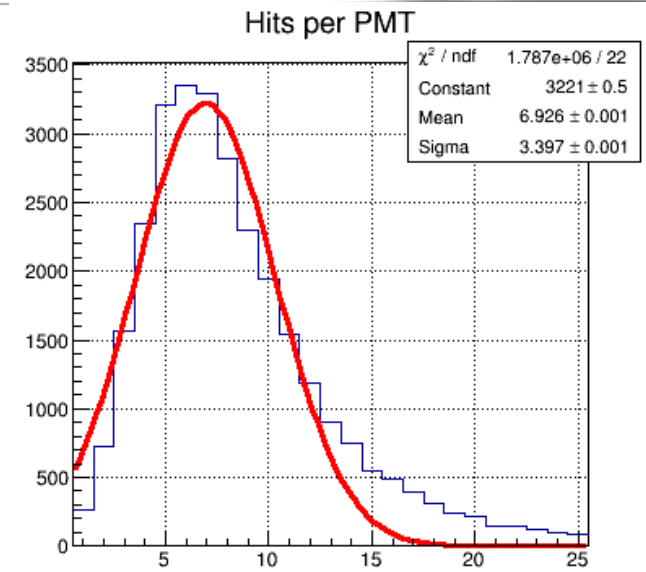
- FPGA-TDC 64 channels/board.
- Signal discrimination using LVDS receivers on FPGA.
- Digital backend included on FPGA.
- Highly integrated and inexpensive approach.
- Only time information, no amplitude measurement → to be evaluated.
- Limited amplitude information could be gained via Time–over-Threshold (ToT).
- Development started Feb. 2012, first prototype already tested in beam Oct. 2012!
- Fruitful collaboration with GSI Experiment-Elektronik division (M. Traxler et al.)

PROTOTYPE: ELECTRONICS

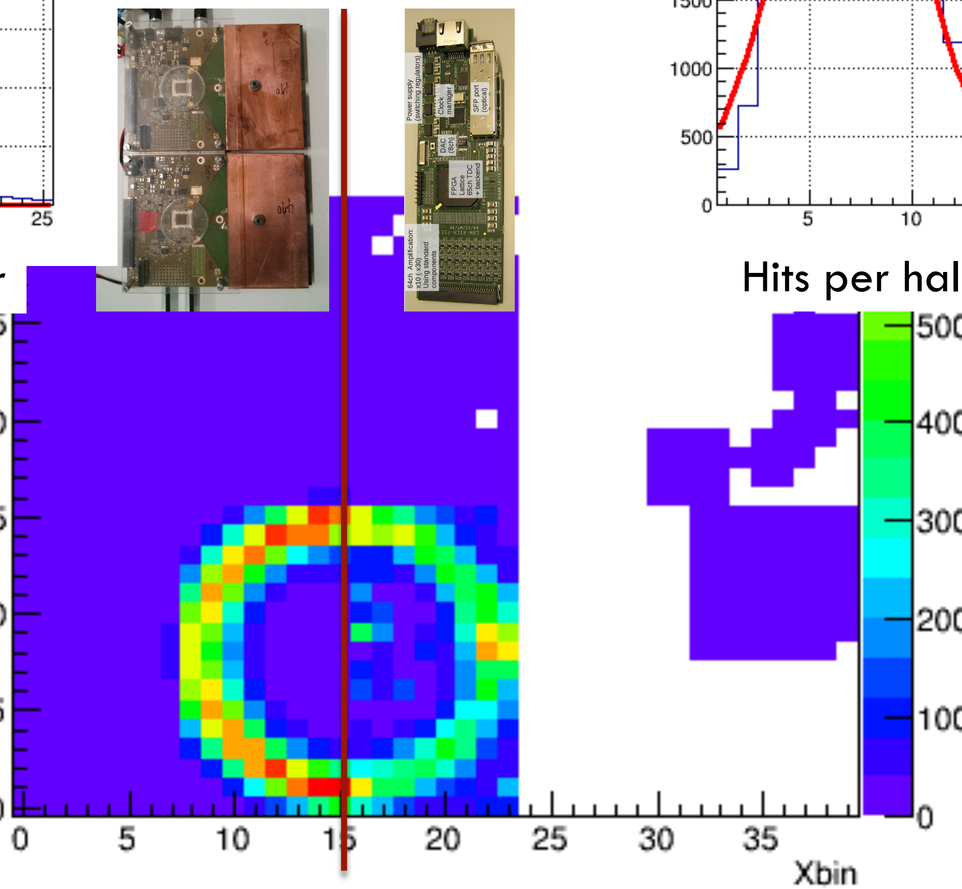
New FPGA-TDC read-out electronics



Hits per half ring: nXYter

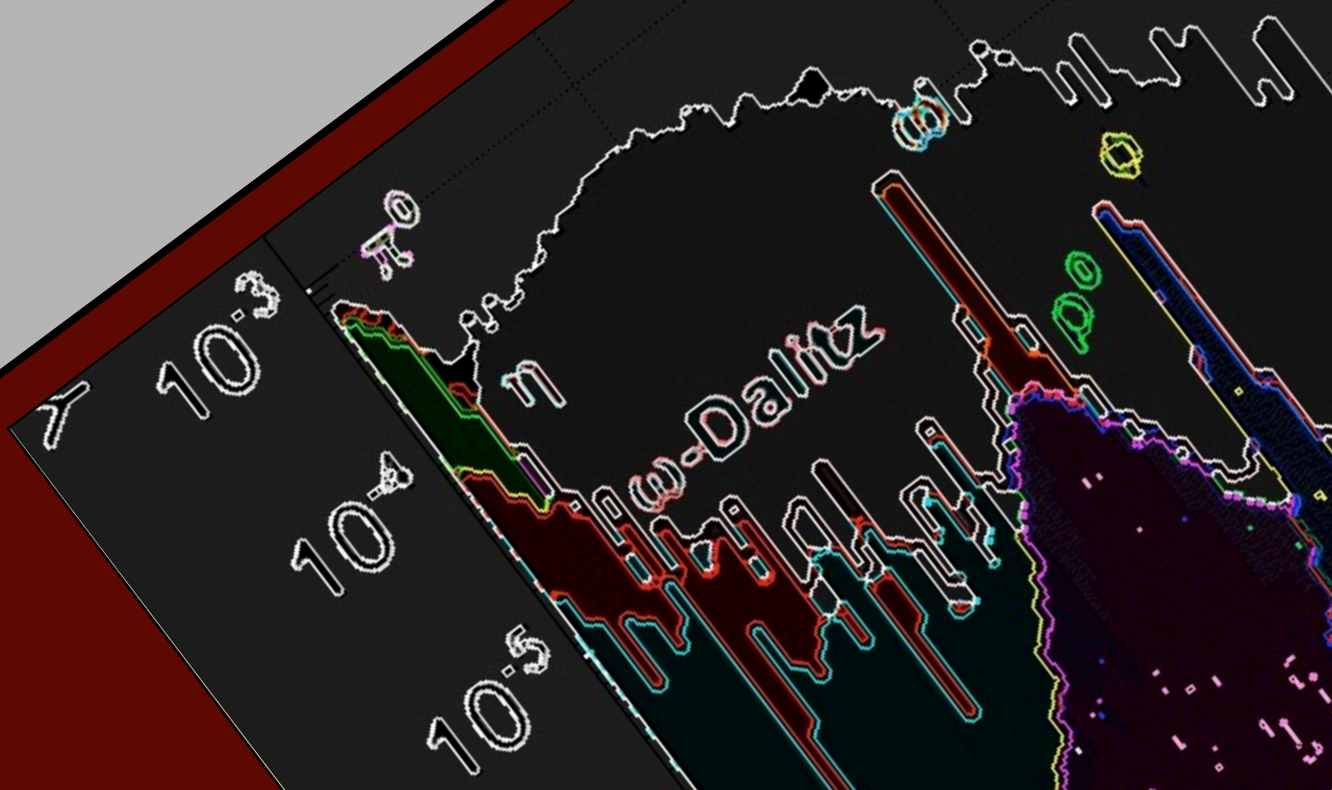


Hits per half ring: TRBRICH



Integrated Cherencov ring: left half nXYter, right half TRBRICH

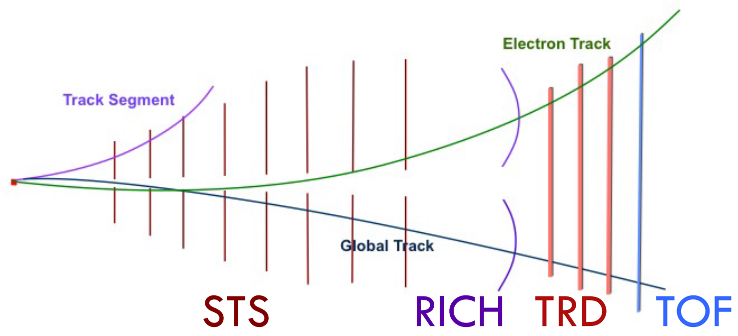
PHYSICS PERFORMANCE, RESPONSE TO HEAVY-ION COLLISIONS



Simulation Environment

Physics topics:

- Low-mass vector mesons: → in-medium properties of the fireball
- Charmonium: → probe the fireball at different energy scale
- Direct photons: → probe the temperature of the fireball



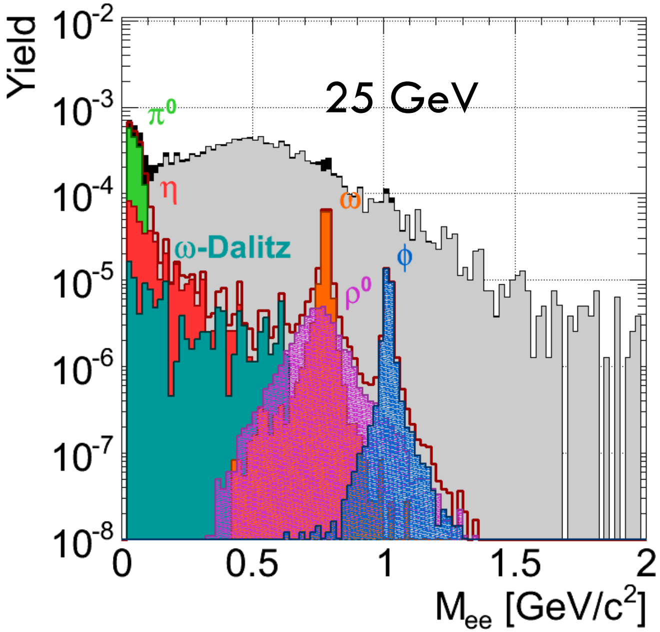
Low-mass vector mesons:

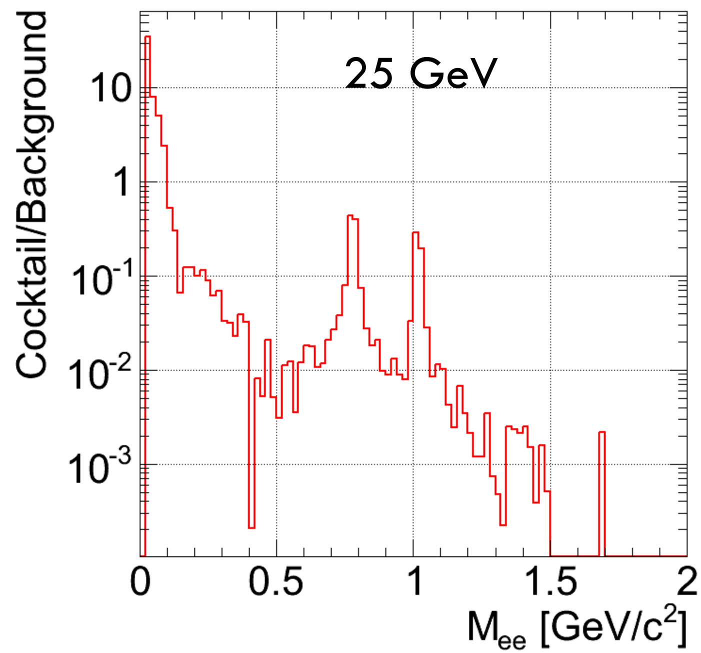
- Use the CbmRoot framework
- 200k central events of Au+Au collisions at 8AGeV (SIS100) and 25AGeV (SIS300)
- Detector setup includes STS, RICH, TRD and TOF
- 25 μm gold target

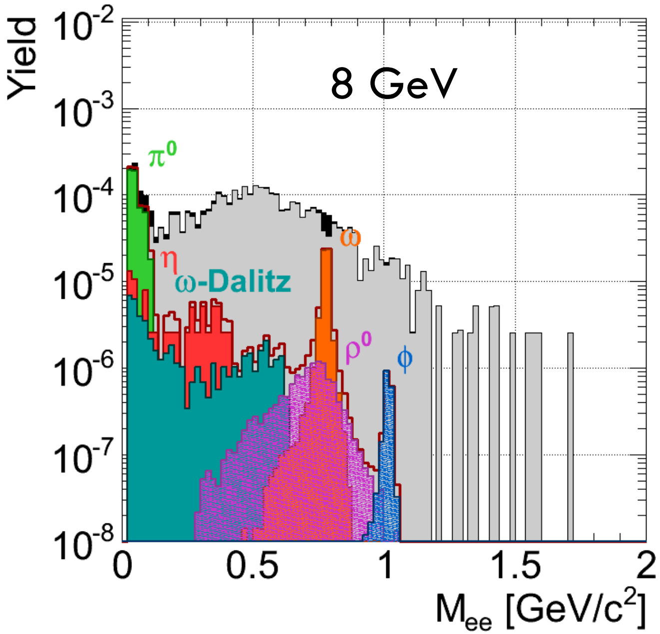
- Background: UrQMD events ($e^{\pm}$ from γ-conversion, π^0, η-Dalitz decays)
- Signal: ρ, ω, ω-Dalitz, φ decays generated by PLUTO

Results

@8 GeV (SIS100) & 25 GeV (SIS300)







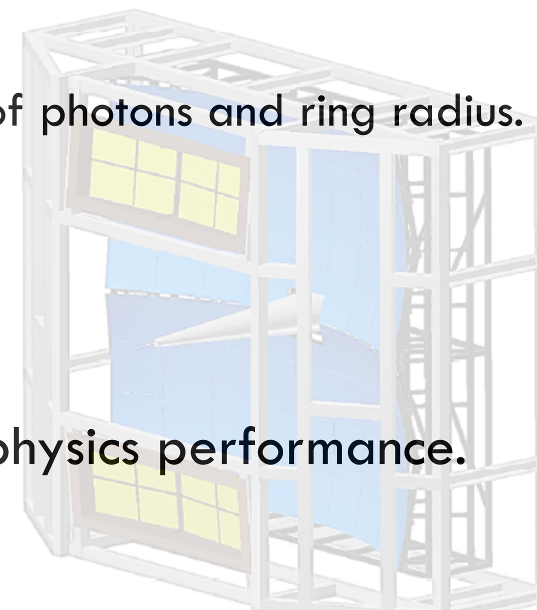
- Very good performance for anticipated measurement (S/B ratio ~ 100 around 500 MeV)
- Investigate further optimization

SUMMARY

- A RICH concept is established.
- Individual components tested and chosen.
- Real dimension RICH prototype successfully build and tested.

- Test beam:
  - Excellent qualitative and quantitative performance: number of photons and ring radius.
  - WLS test → up to 18% more photons.
  - Comparison of different photon sensors.
  - Up to 1% of O_2 impurity with no effects on number of photons and ring radius.
  - Fixing tolerances of mirror misalignment.
  - Test of new electronics.

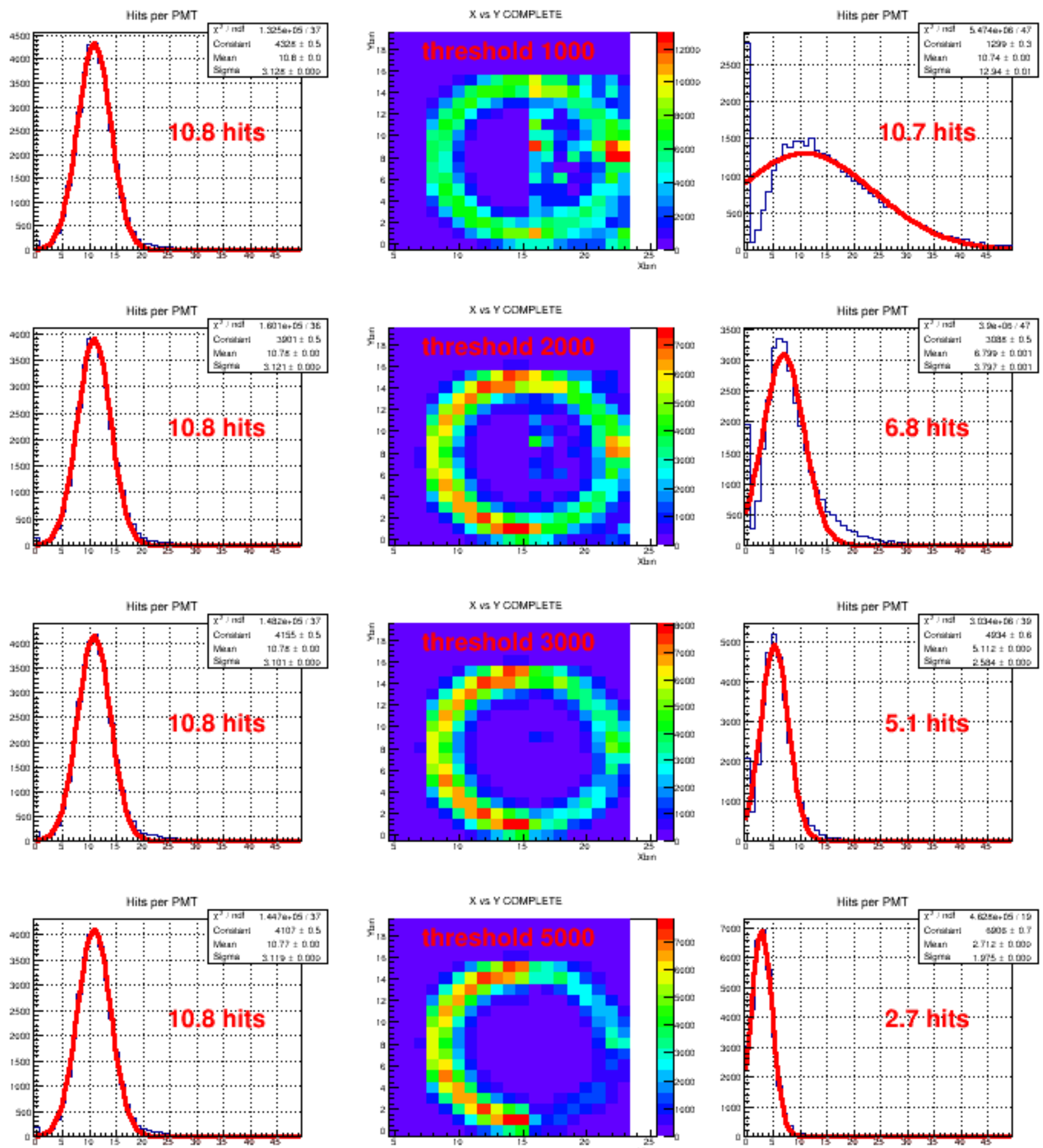
- Very good working gas system.
- Simulation under realistic conditions show good physics performance.
- TDR delivered in June 2013.



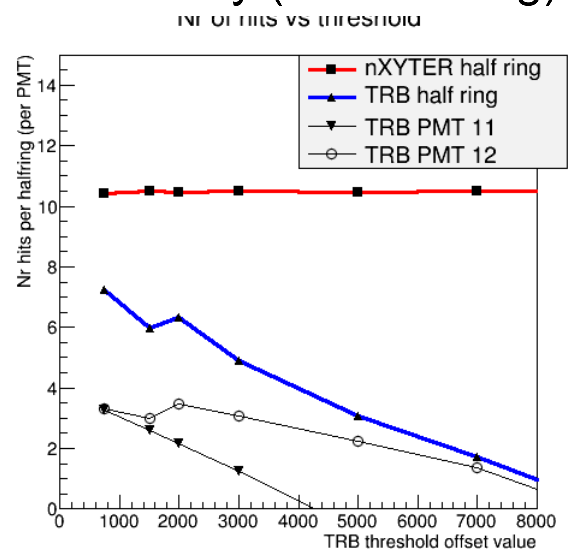
CBM RICH

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

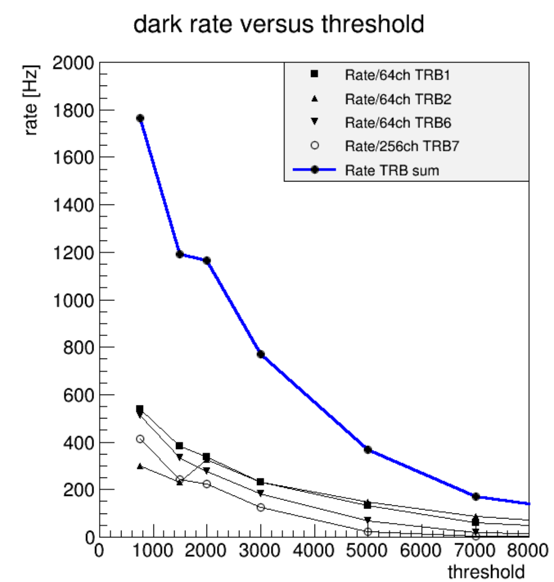
Give me a home and let me there



Efficiency (hits/half ring)

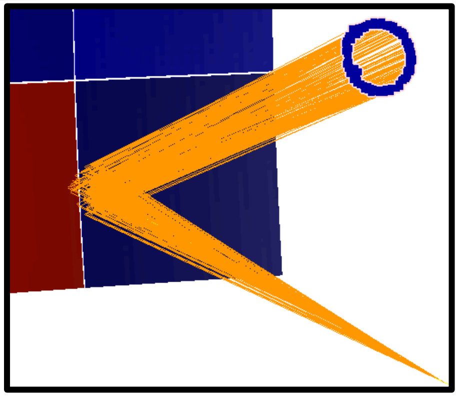


Dark rate



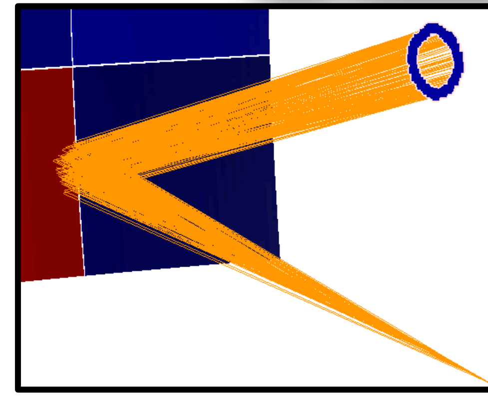
Prototype: Mirror Displacement

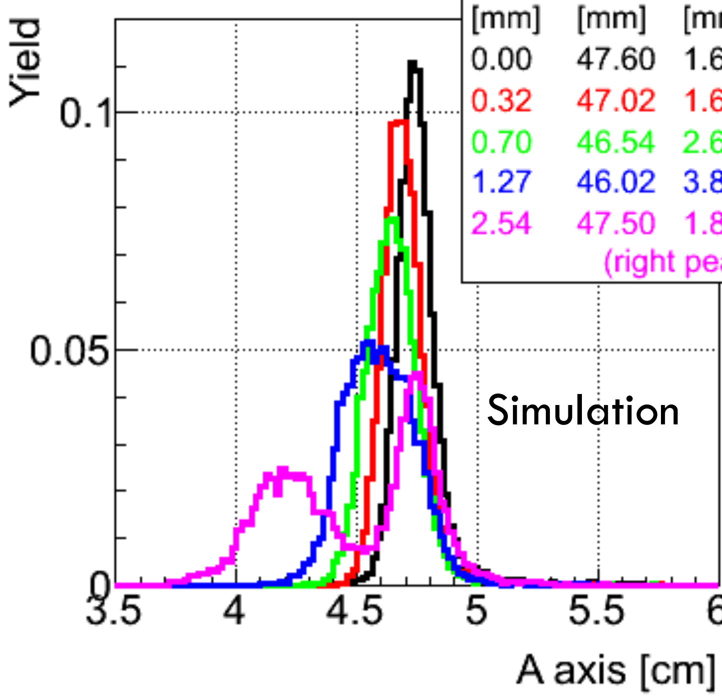
Tolerable displacements



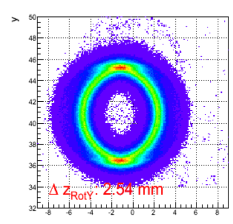
Beam cross section

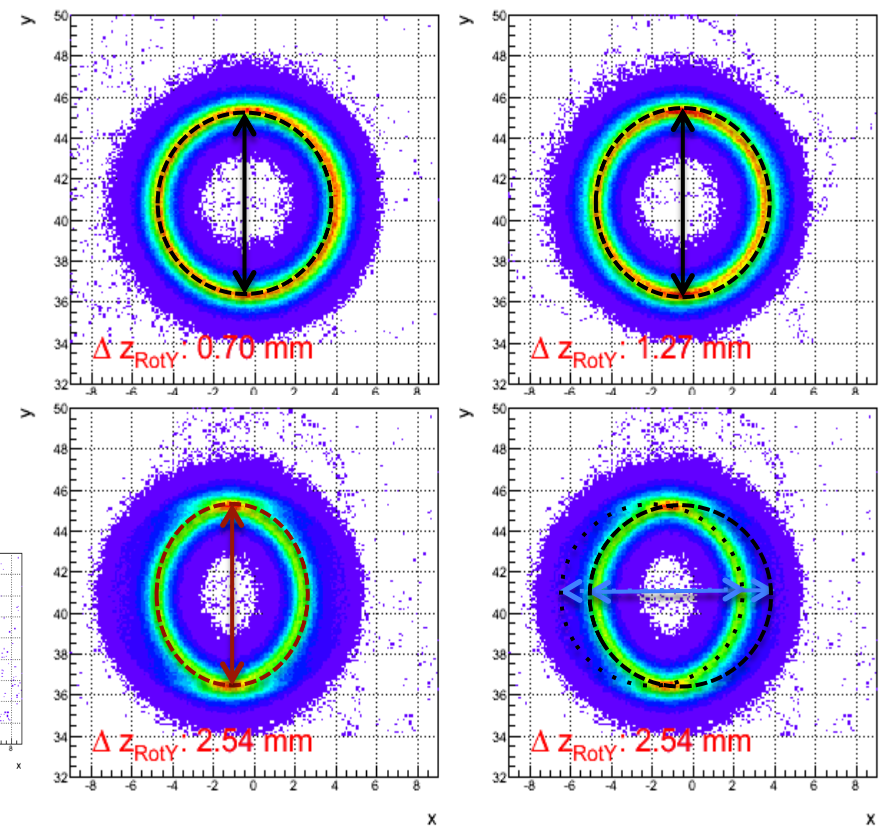
$1.3*1.2\ cm^2$





ΔZ_{RotY} [mm]	Mean [mm]	FWHM [mm]
0.00	47.60	1.60
0.32	47.02	1.60
0.70	46.54	2.60
1.27	46.02	3.80
2.54	47.50	1.80 (right peak)





Prototype: Mirror Displacement

Tolerable displacements

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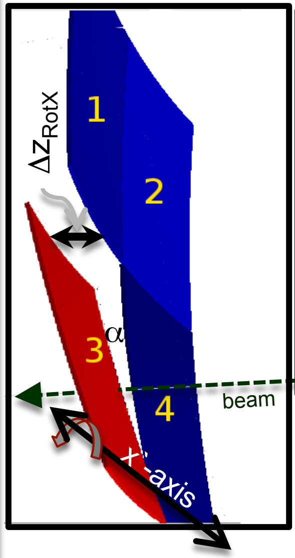
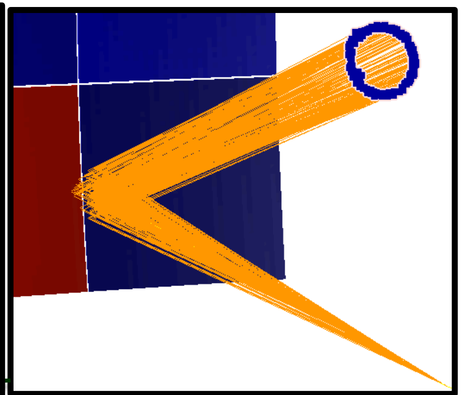
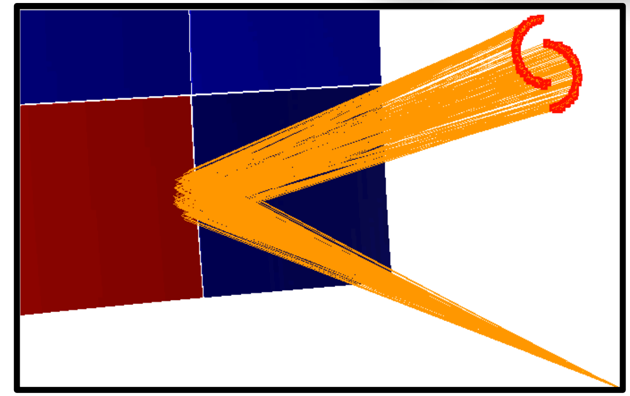
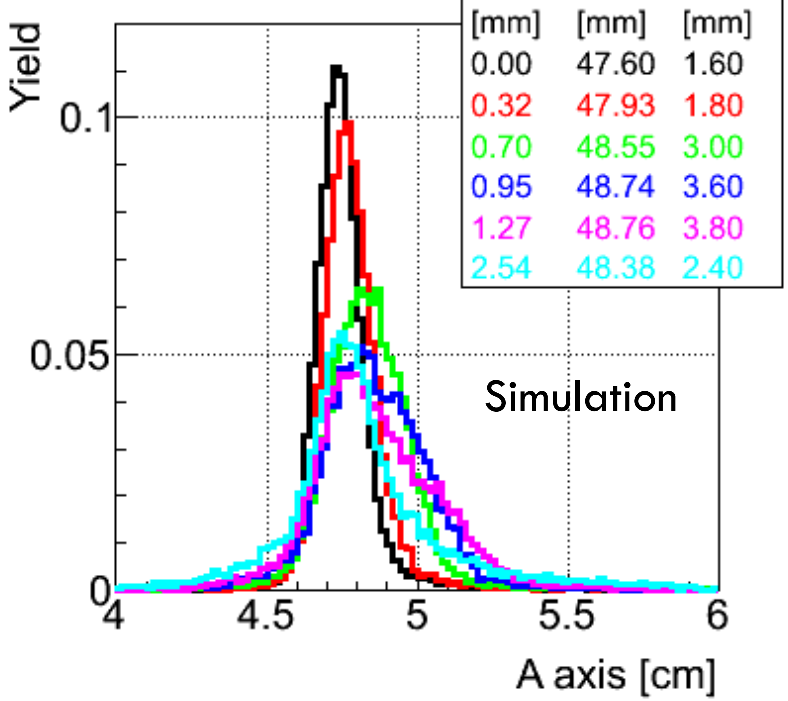




Beam cross section
$1.3*1.2\ cm^2$





ΔZ_{RotX} [mm]	Mean [mm]	FWHM [mm]
0.00	47.60	1.60
0.32	47.93	1.80
0.70	48.55	3.00
0.95	48.74	3.60
1.27	48.76	3.80
2.54	48.38	2.40