The RICH prototype

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Prototyping activity

July-August 2011 exploratory test beam at CERN (hadrons)
- small scale prototype
- encouraging results

July 2012 test beam at Frascati BTF (electrons)
- setup of DAQ and electronics

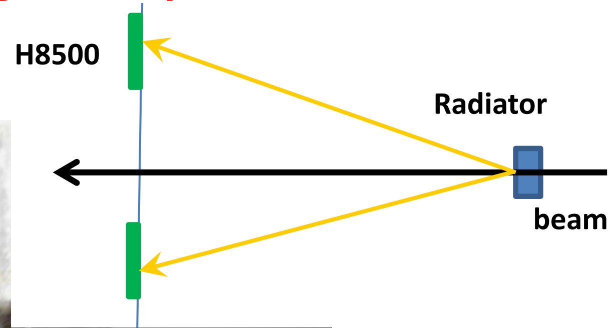
July-August 2012
Nov-Dec 2012 test beam of a large scale prototype (hadrons)
- test of the direct light configuration
- proof-of-principle of the reflected light configuration
- exploratory test of SiPM

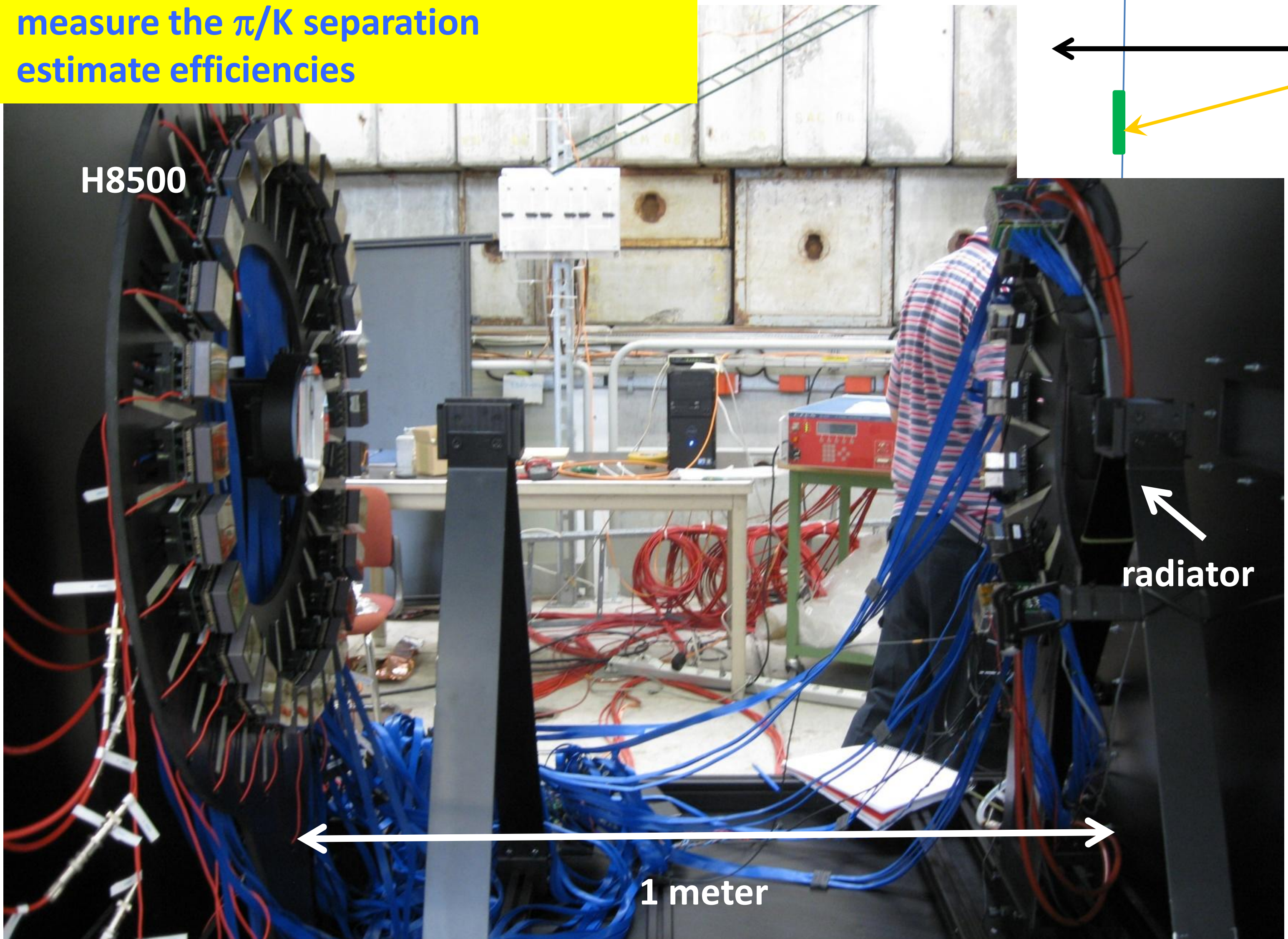
July-August 2013 test beam at Frascati BTF (electrons)
- digital readout of MAROC

Prototype construction: direct light

Goal of the test
- study the Cerenkov angle resolution vs aerogel ref. index, thickness, quality
- measure the π/K separation
- estimate efficiencies

Same geometry as in the CLAS12 RICH



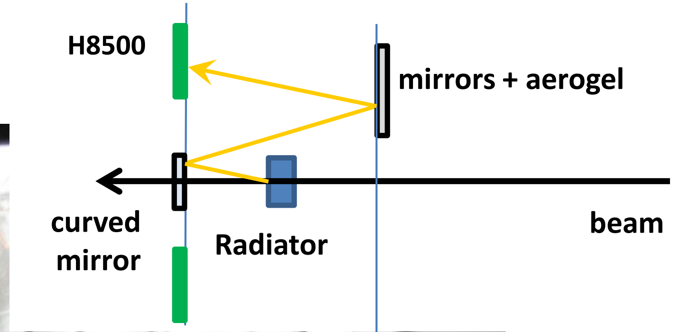


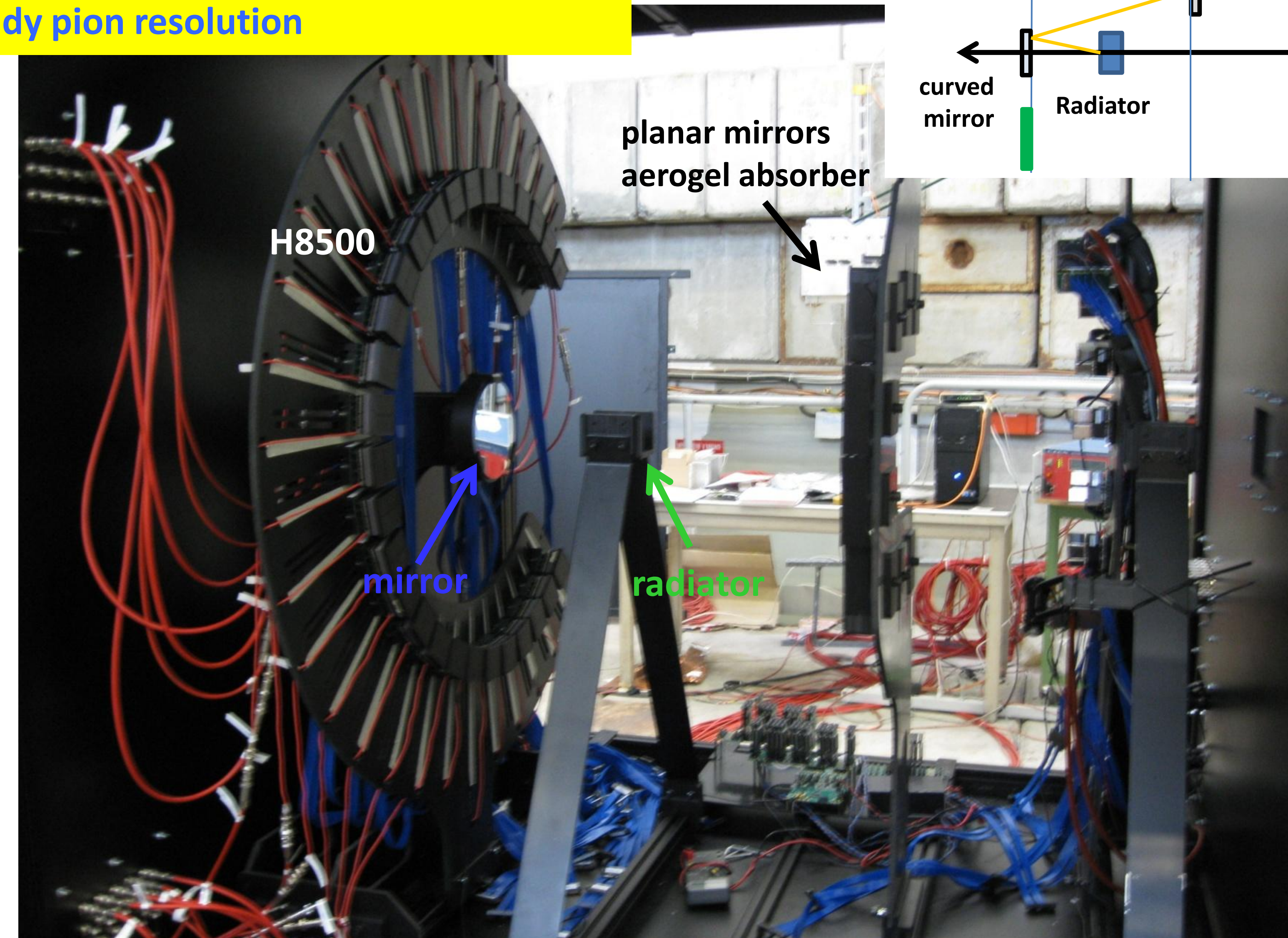
Prototype construction: reflected light

Goal of the test

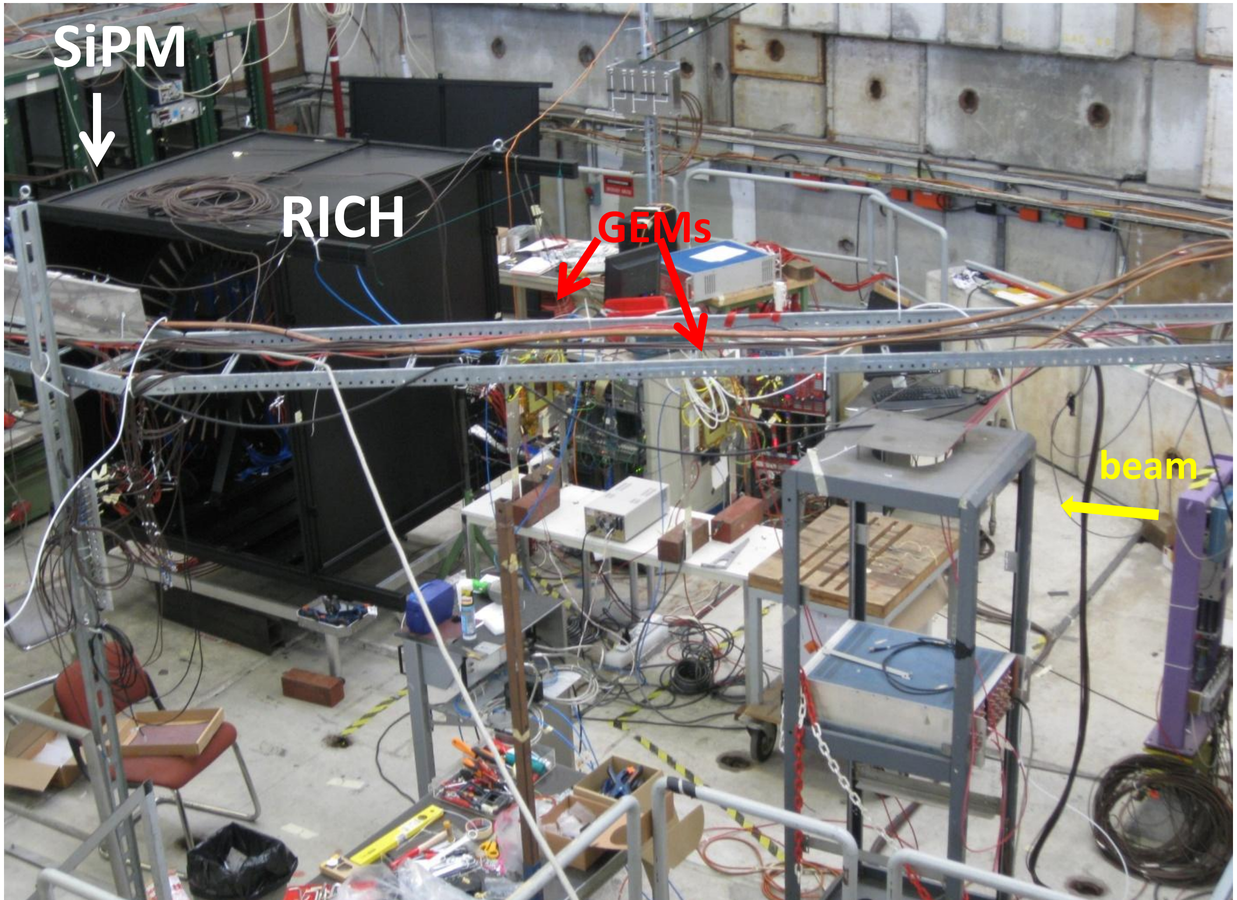
- estimate the yield loss due to double pass through the aerogel
- study pion resolution

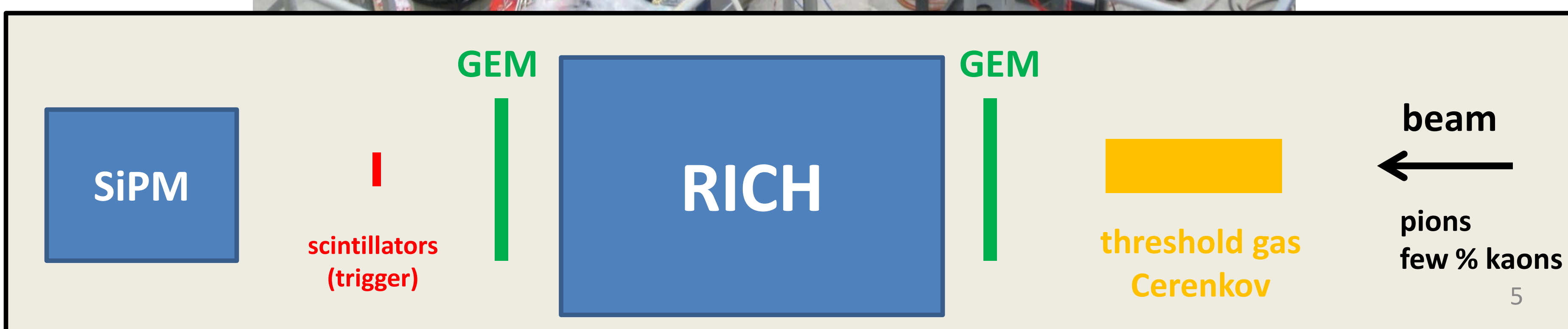
Different geometry from the CLAS12 RICH





The prototype in the T9 experimental Hall at CERN



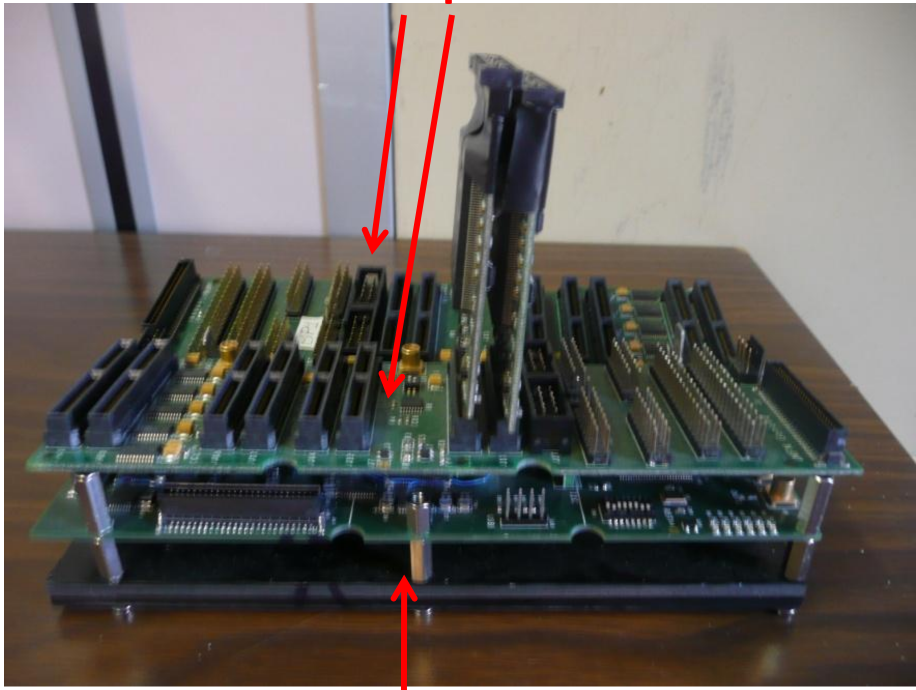


The MAPMT electronics

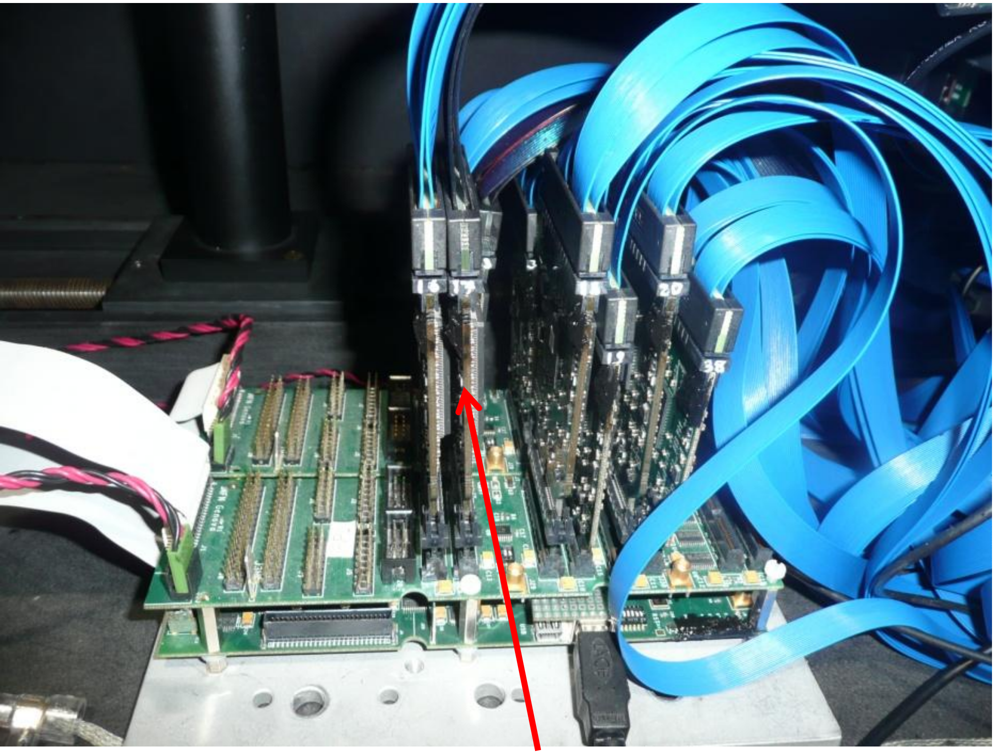
Maroc3 front end electronics

- 2 control board with 4 back planes
- up to 16 front end cards per back plane
- 64 channels per card, 4096 total channels
- preamplifier, adjustable from 1/8 to 4
- ADC

back planes



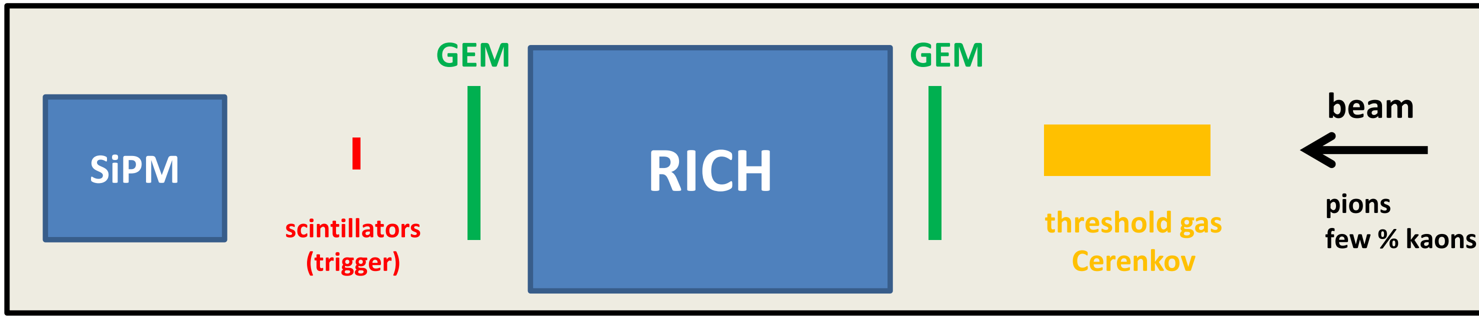
control board



MAROC front end cards

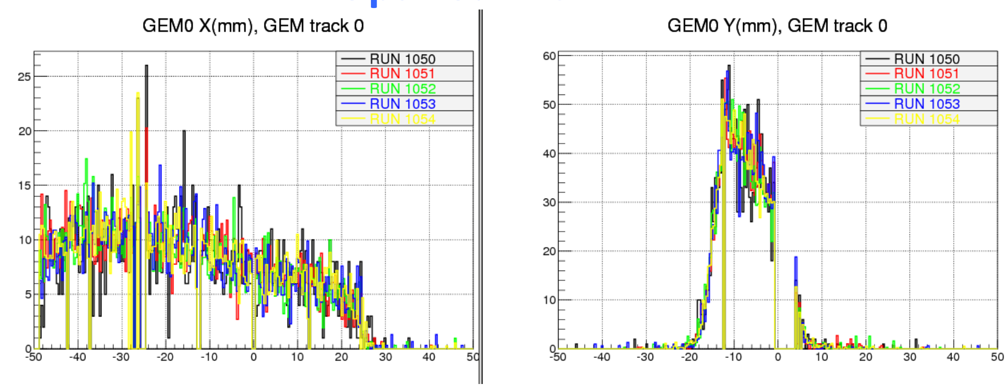
- Linux DAQ program (MAROC+GEM+CC)
- Event transfer to disk in single or multi event mode

Track reconstruction and PID

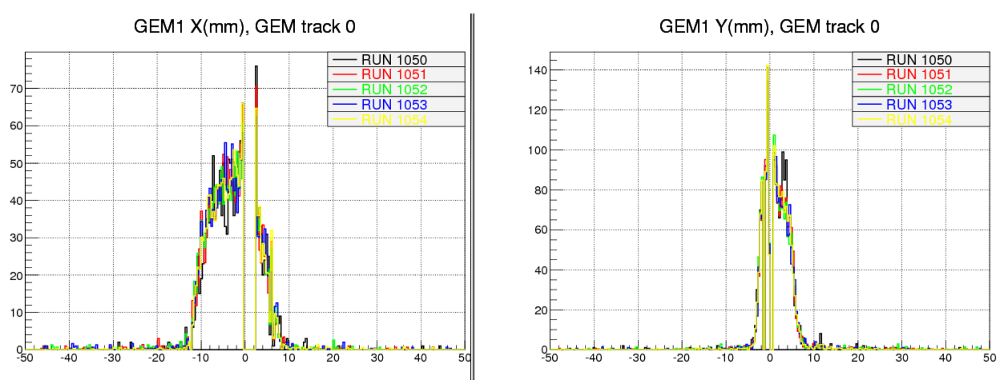


GEM for track reconstruction

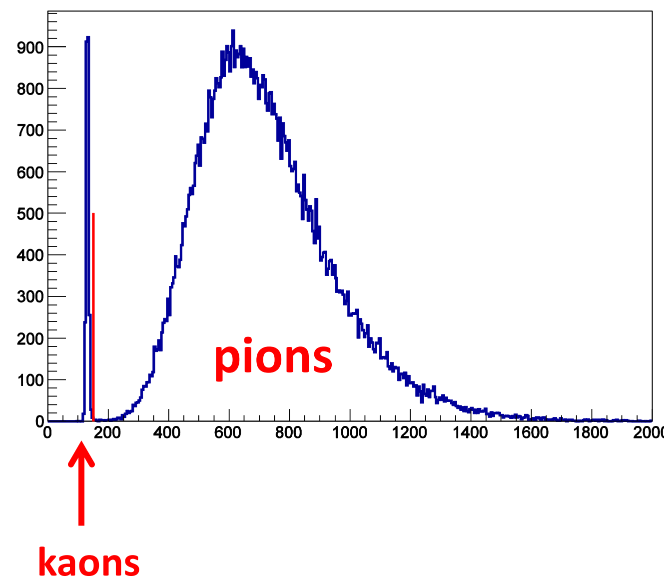
Upstream GEM



Downstream GEM

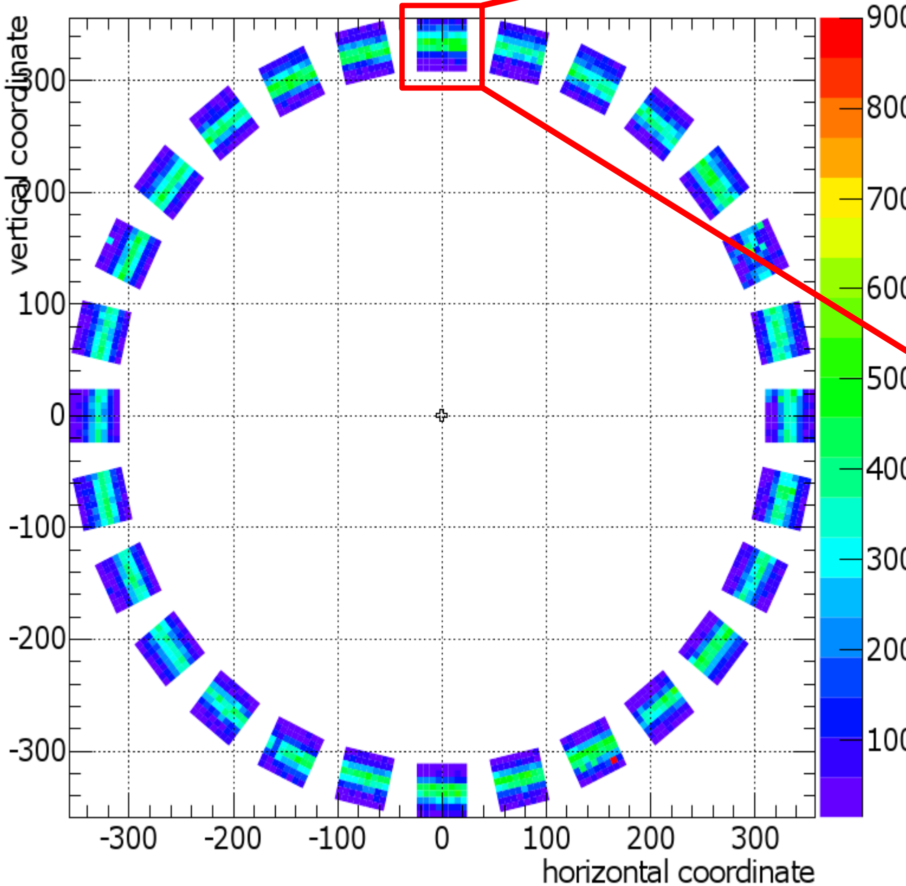


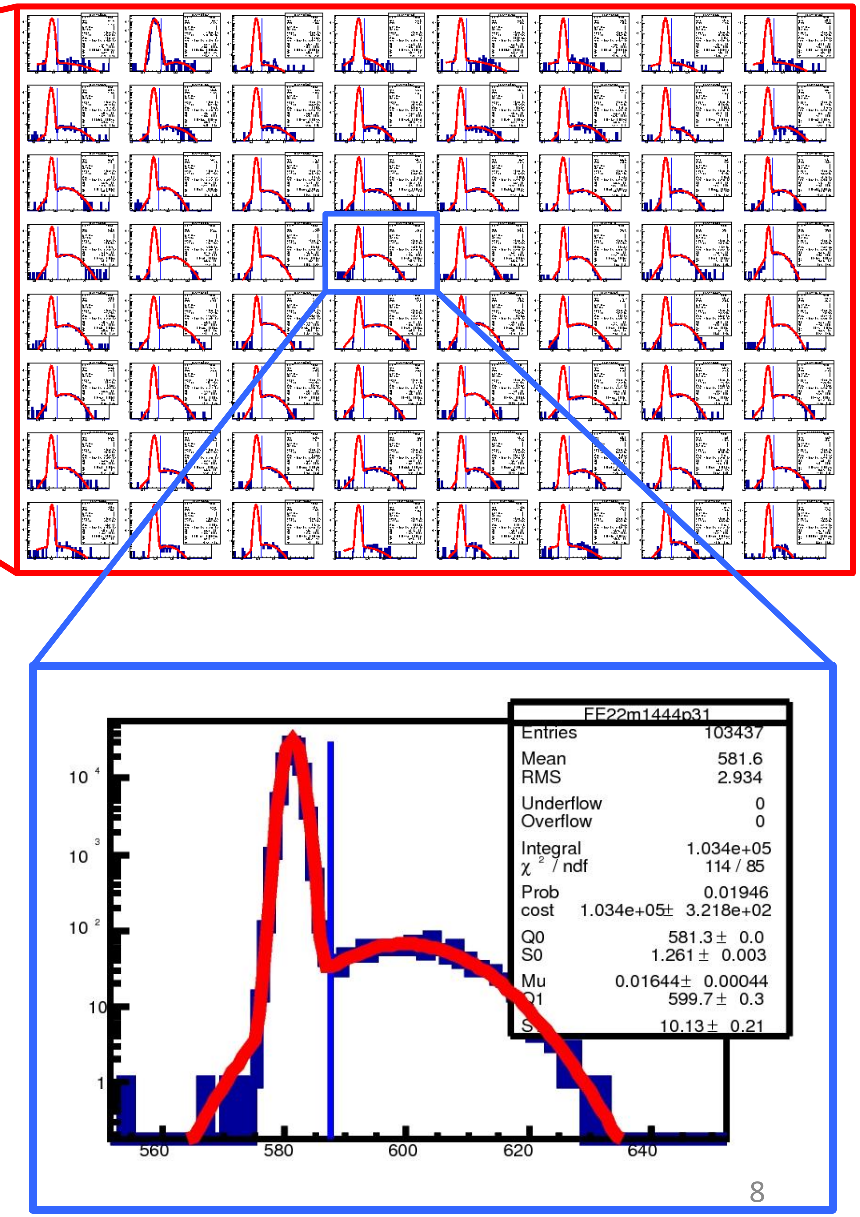
Threshold Cerenkov counter for PID



MAPMT signal reconstruction

On-line event display

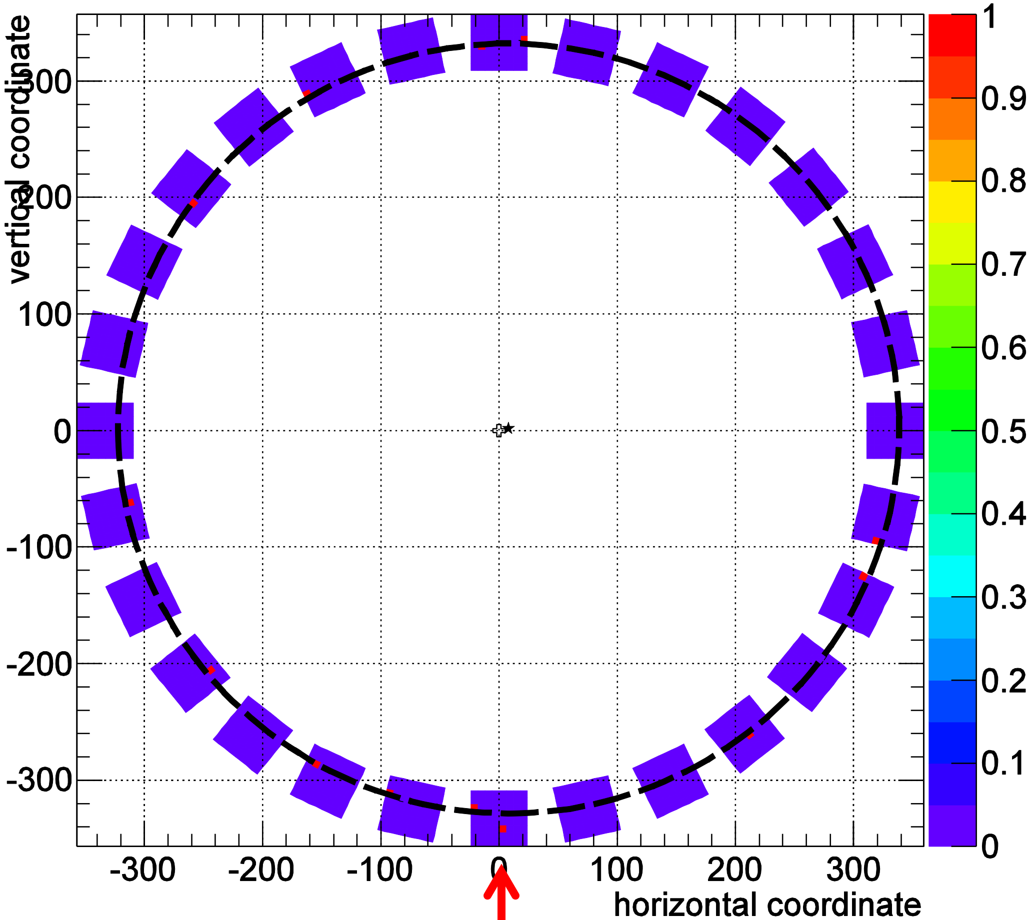




Event reconstruction

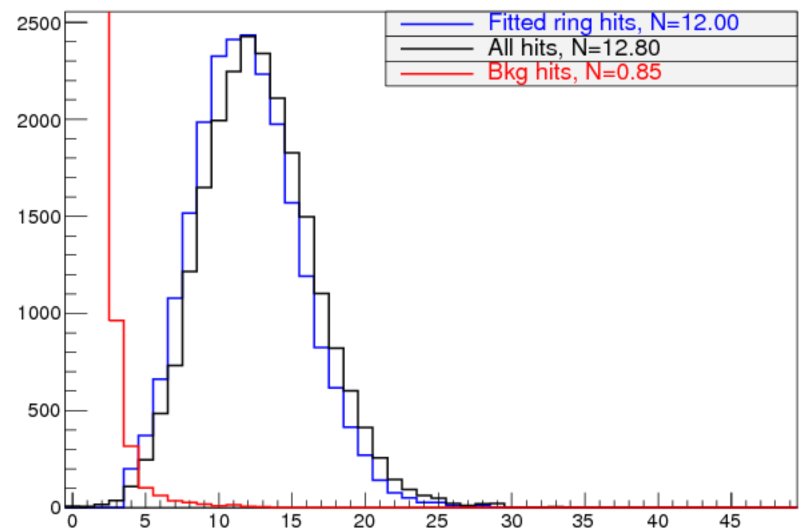
pions	p=8 GeV/c
aerogel	n=1.05
	t=2 cm

Hit patterns are rings centered to the beam line



background hit

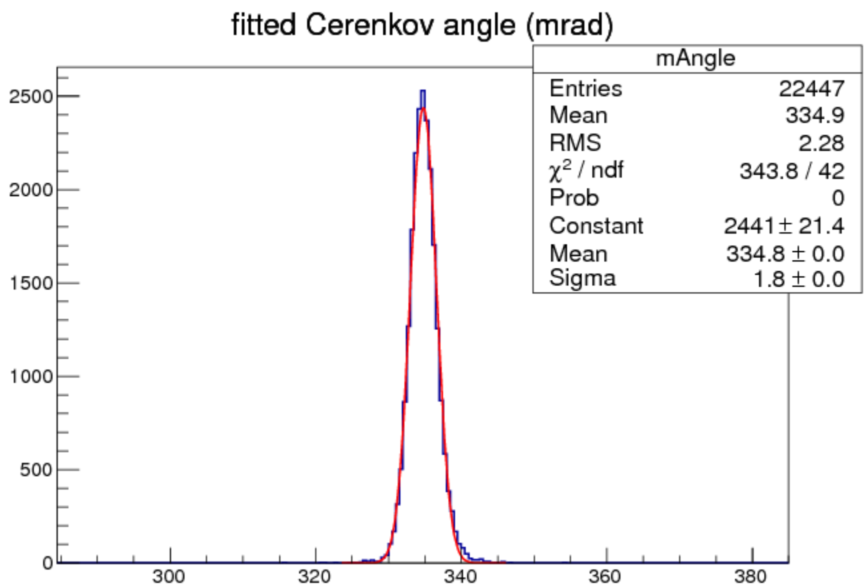
- ***3par fit***
  - **Ring center and radius fitted with MAPMT hits**
- ***1par fit***
  - **Ring center fixed from GEM track**
  - **Ring radius fitted with MAPMT hits**

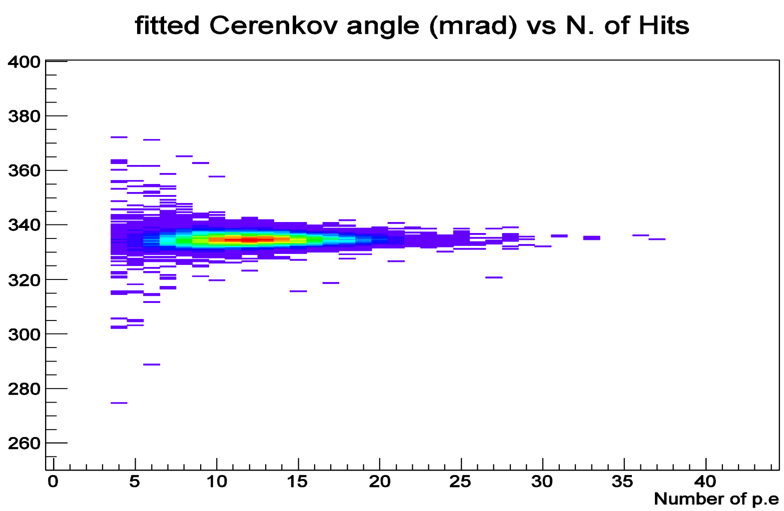


Direct light measurements

Pion resolution

pions	p=8 GeV/c
aerogel	n=1.05
	t=2 cm

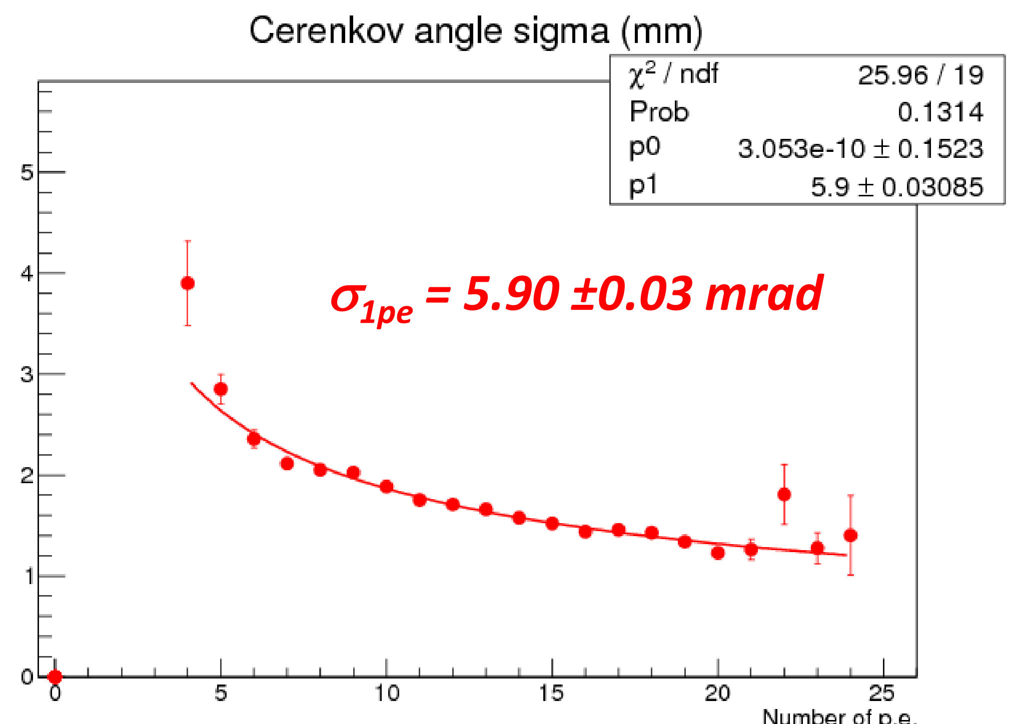




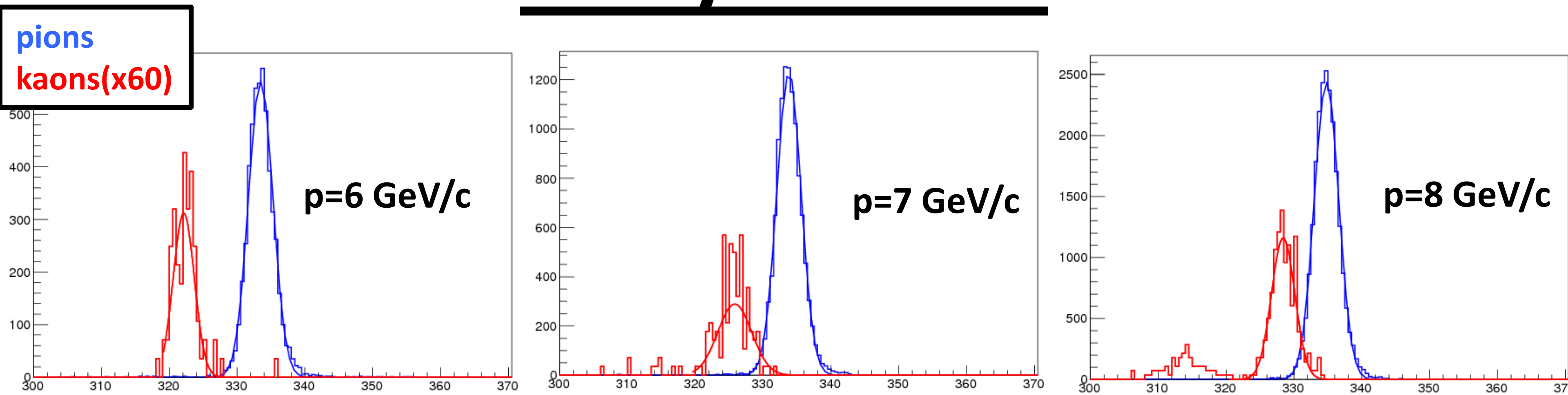
Number of p.e. dependence

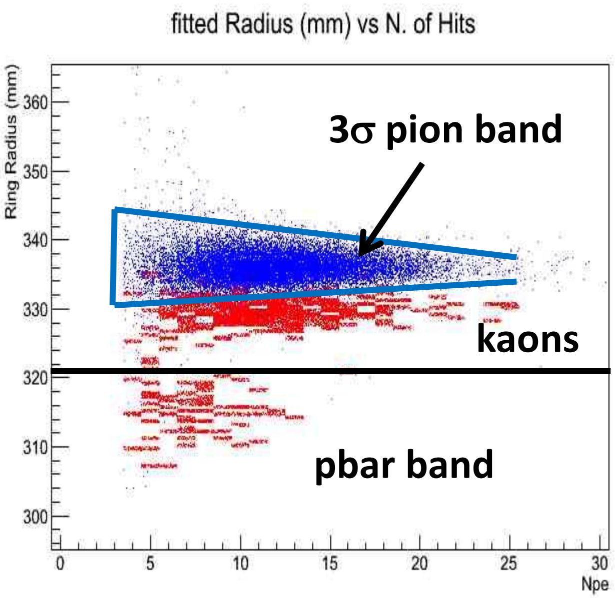
$$\sigma_\theta = \sigma_0 + \frac{\sigma_{1pe}}{\sqrt{N_{pe}}}$$

single photon angular resolution



Pion/Kaon ID





Number of σ separation

$$n_\sigma = \frac{\theta_C(\pi) - \theta_C(K)}{[\sigma_\theta(\pi) + \sigma_\theta(K)]/2}$$

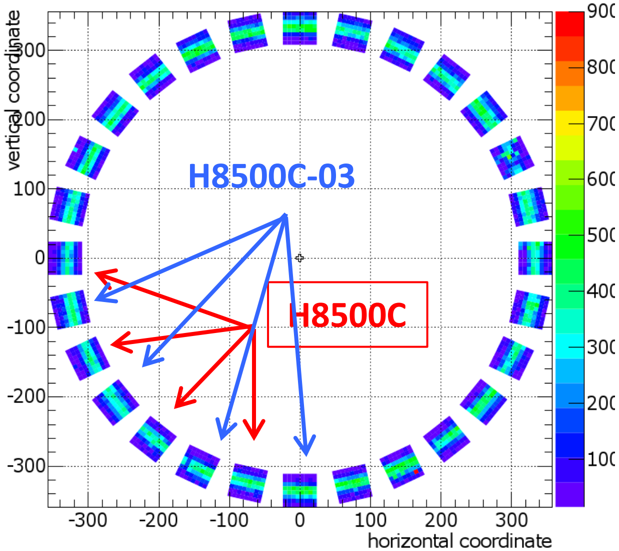
For calculation: $\sigma_\theta(K) = \sigma_\theta(\pi)$

P (GeV/c)	$\theta_C(\pi)$ (mrad)	$\sigma_\theta(\pi)$ (mrad)	$\theta_C(K)$ (mrad)	$\sigma_\theta(K)$ (mrad)	n_σ
6	333.47±0.03	1.81±0.02	322.13±0.04	1.56±0.04	6.3
7	333.79±0.02	1.79±0.02	325.79±0.05	2.50±0.05	4.4
8	334.80±0.01	1.80±0.01	328.41±0.02	1.72±0.02	3.5

Efficiencies

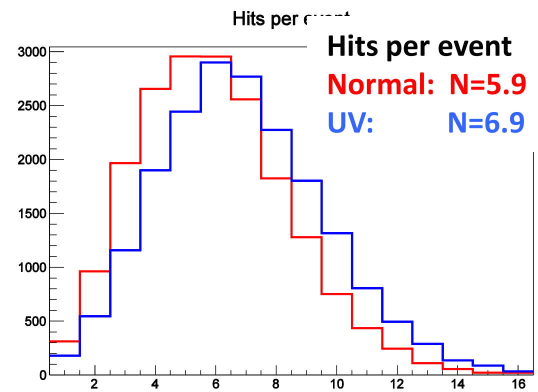
P (GeV/c)	$\epsilon(\pi)$ (%)	$\epsilon(K)$ (%)
6	98.1±0.2	99±2
7	98.3±0.1	95±2
8	98.8±0.1	67±3

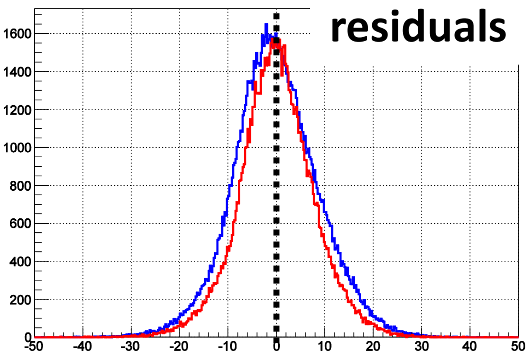
Systematic studies: UV photons

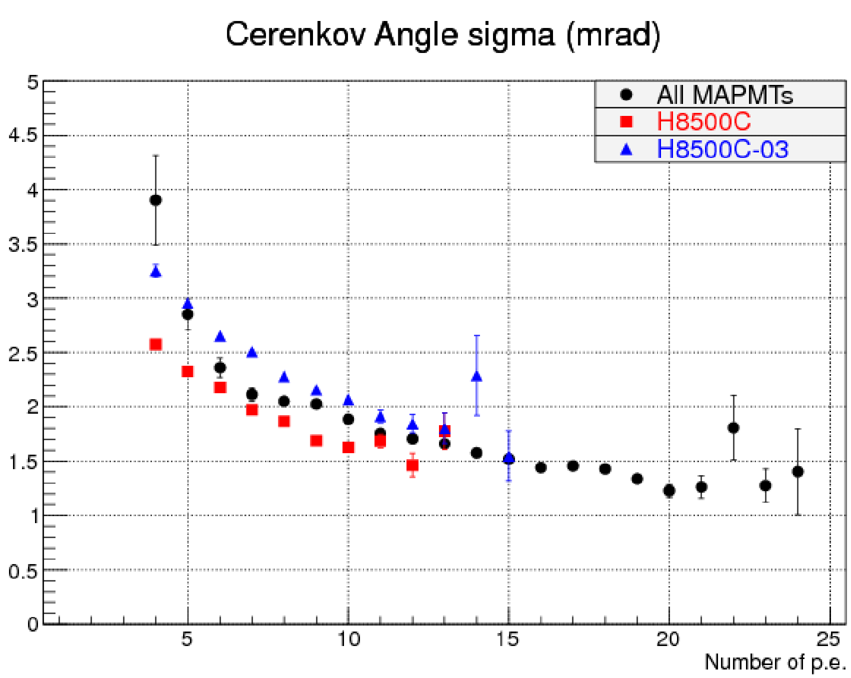


14+14 MAPMT with normal/UV glass in alternated positions

Compare ring reconstruction







Single photon resolution

	$\sigma_{1\gamma}$ (mrad)
14 H8500C	5.07±0.21
14 H8500C-03	6.53±0.04
All 28	5.90±0.03

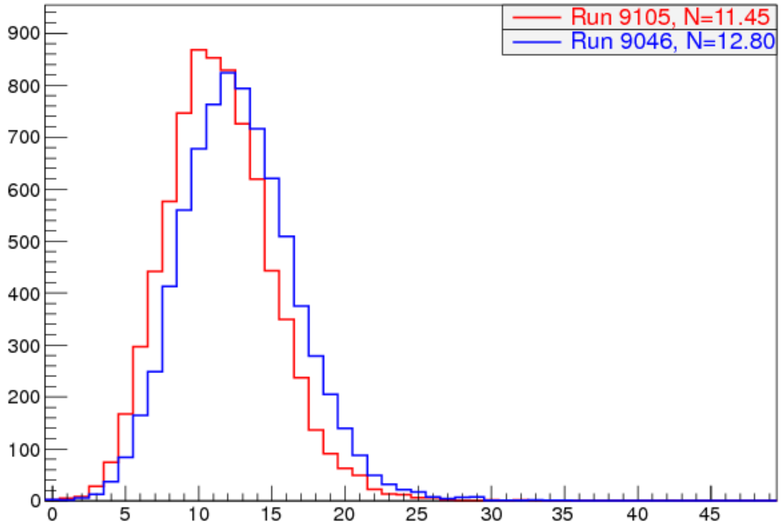
normal glass MAPMTs produce 1 photon less but 30% better resolution

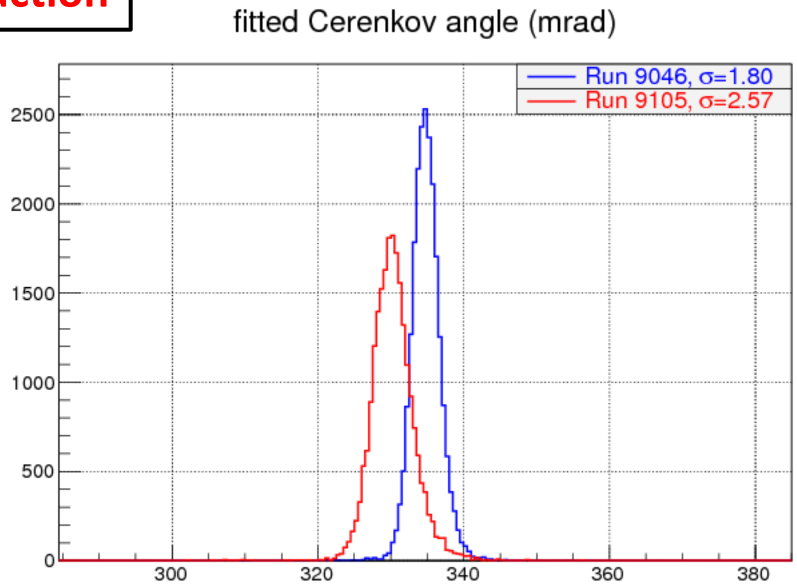
Systematic studies: aerogel production

pions	p=8 GeV/c
aerogel	n=1.05
	t=2 cm

- same "nominal" characteristics
- different production date

BLUE: latest production RED: older production





With newest production techniques:
- more photon yield
- better chromatic performances

Summary from direct light tests

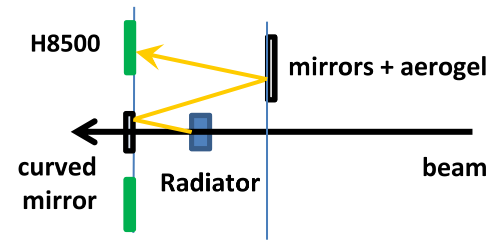
- **Prototype results**
  1. **Pion/Kaon separation achieved up to the highest momentum**
  2. **pion efficiency bigger than 90% in the whole range**
  3. **kaon efficiency bigger than 90% up to momentum of 7 GeV/c**

- **The geometry of the prototype mimic that of the CLAS12 RICH**
  - **similar expected performances**

- **Room for improvement**
  - **better coverage of the ring: +20% photons**
  - **suppress UV photons: +15% single photon resolution**
  - **aerogel quality**
  - **use new H12700**

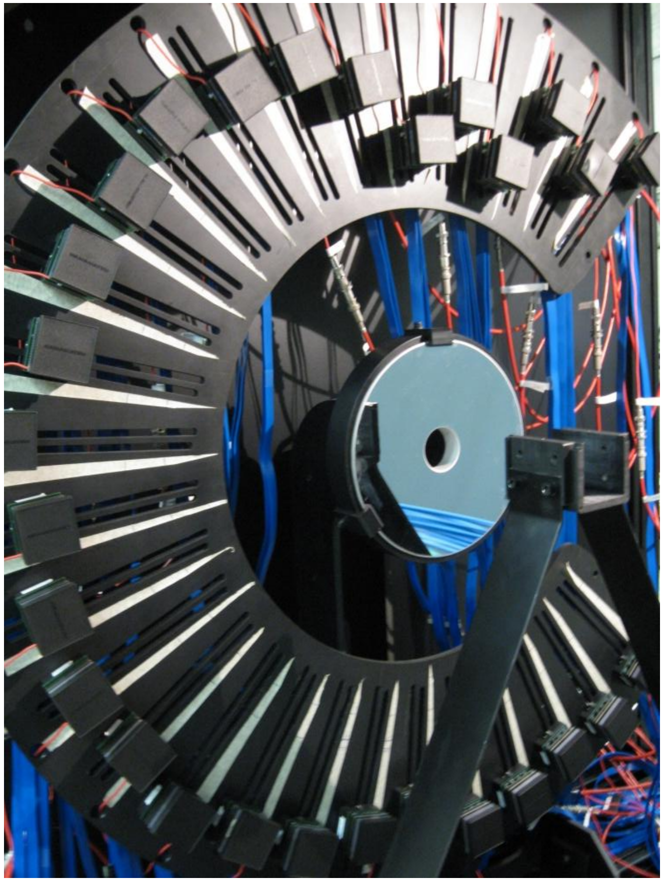
Reflected light measurements

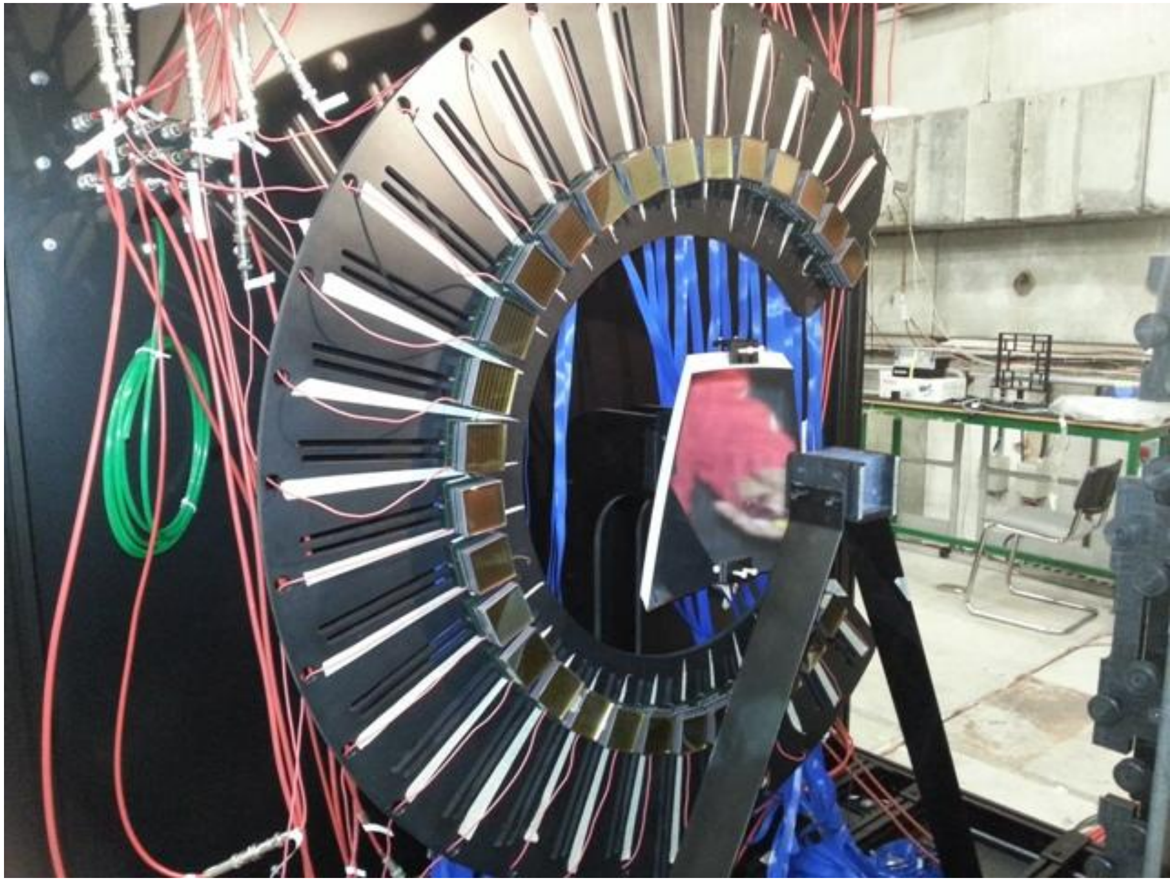
The curved mirrors



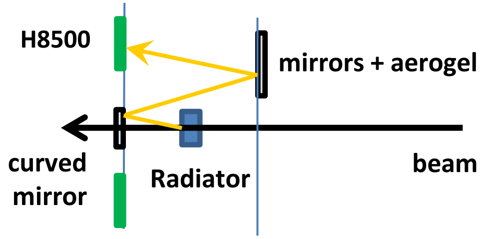
Glass mirror
- spherical: f=900 mm

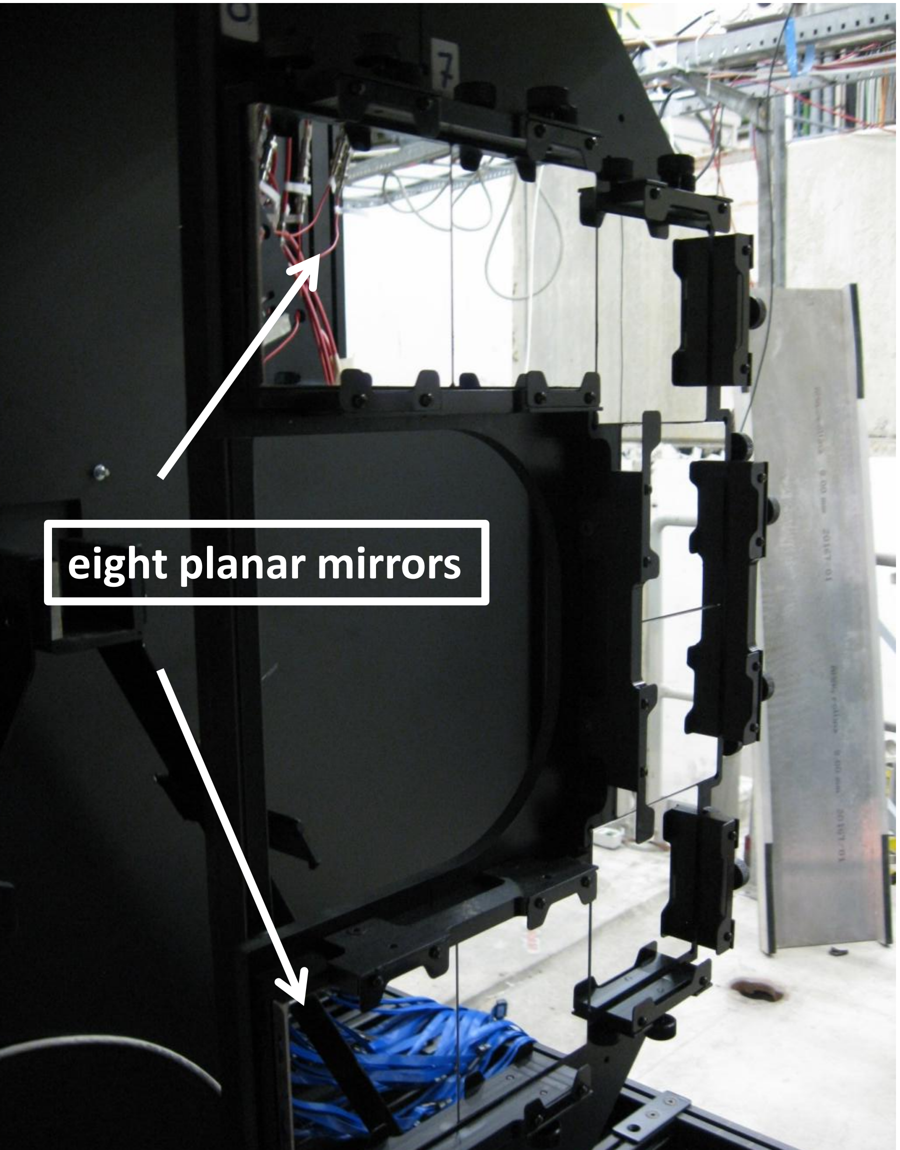
JLab mirror: prototype of HTCC mirrors
- elliptical: f1=1850 mm f2=1613 mm

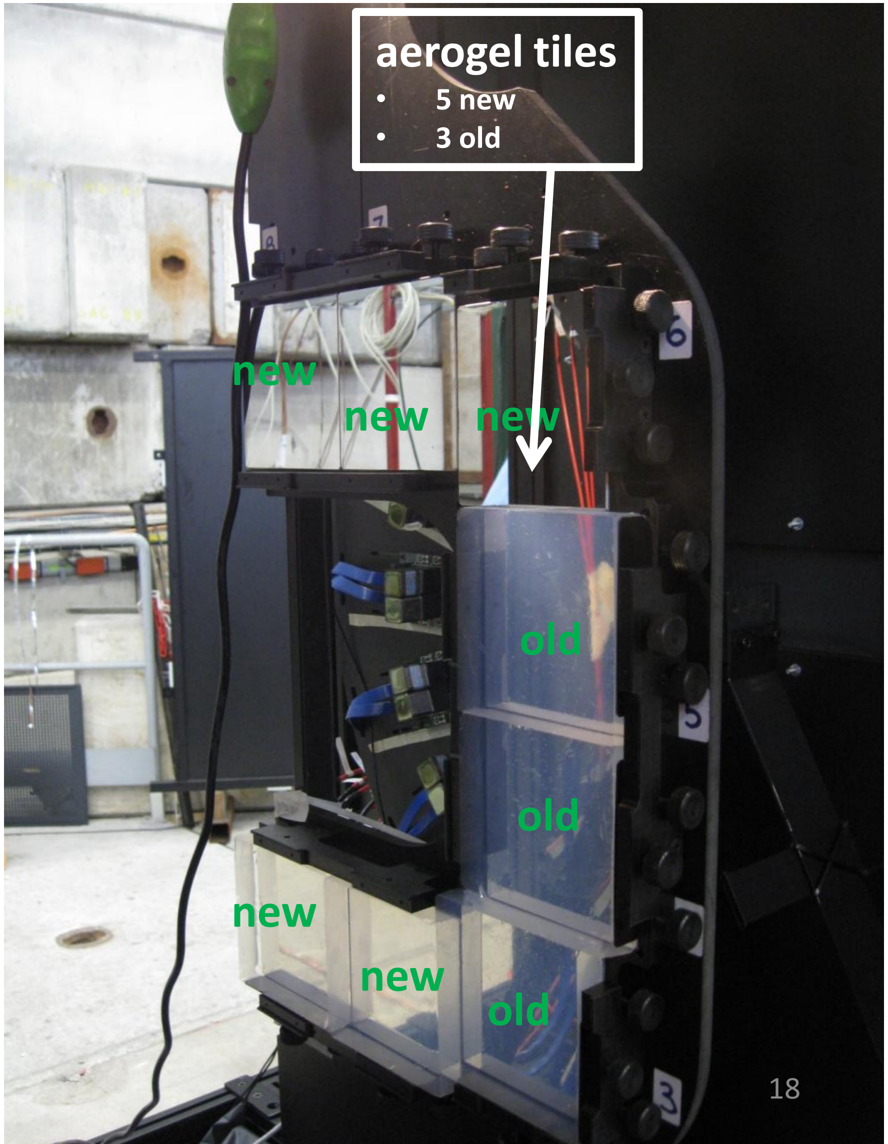




The planar mirrors

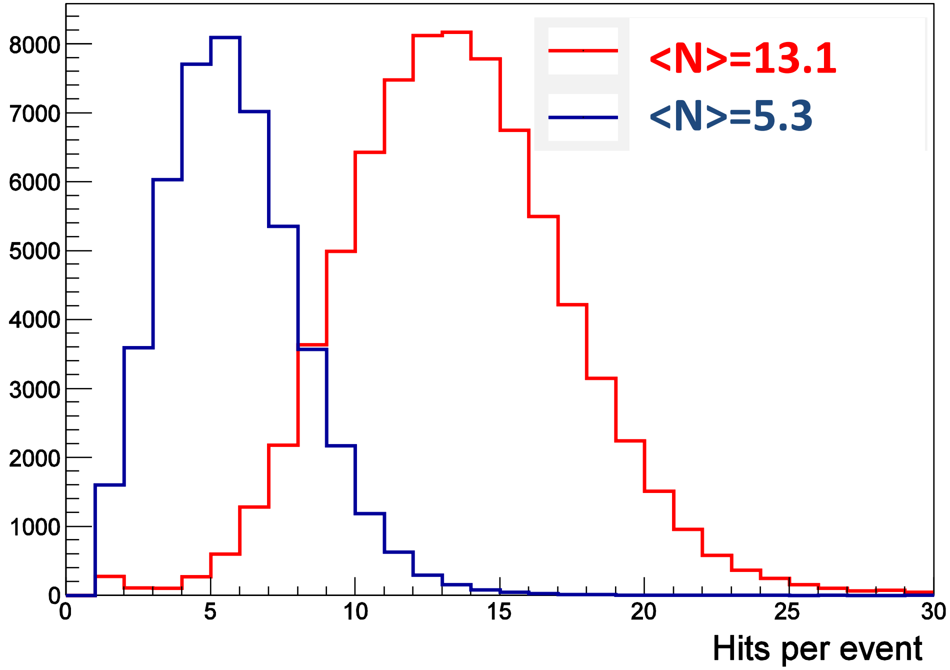




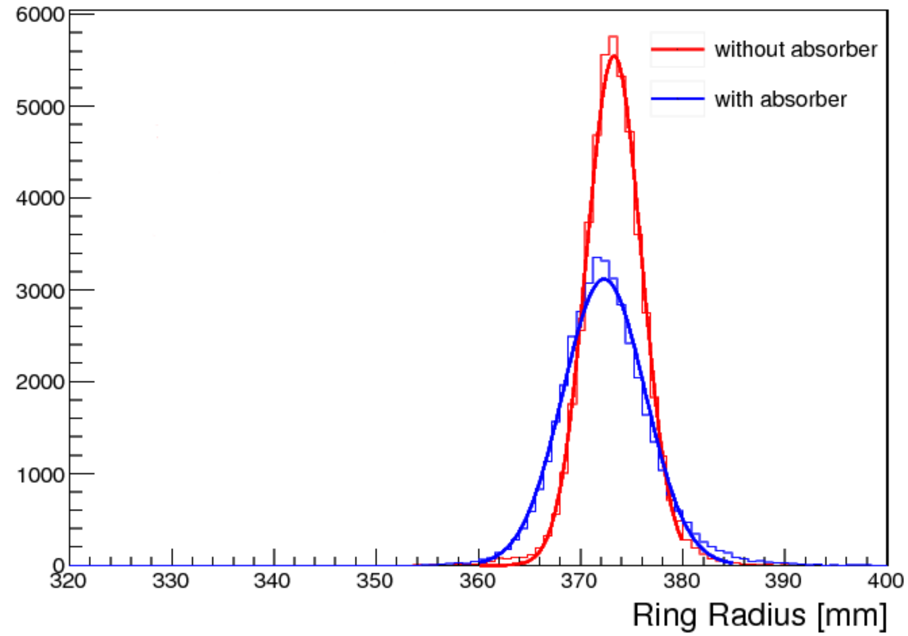


Comparison without/with absorbers

- beam: P=6 GeV/c
- glass spherical mirror
- aerogel radiator: n=1.05 t=6cm
- aerogel absorbers: n=1.05 t-2 cm
  - In/Out



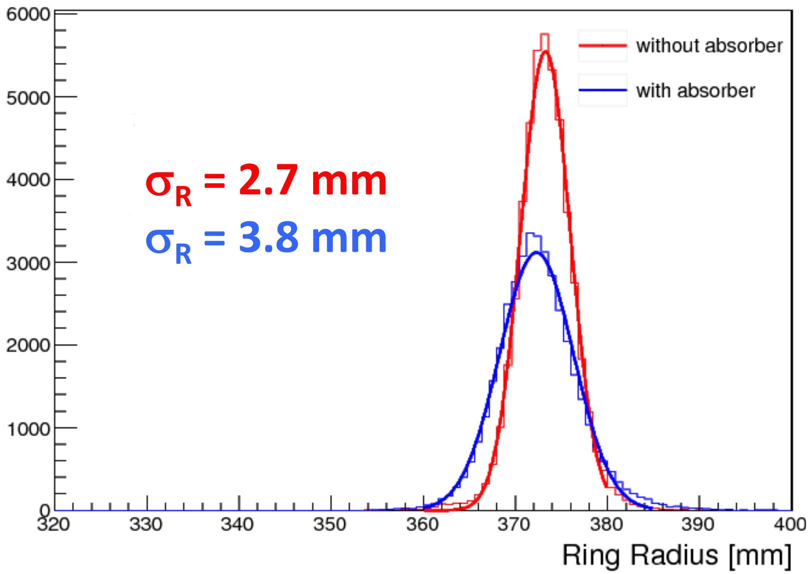
Fitted ring radius distribution (mm)



Yield reduction: 60%

- significant amount of light survives

Pion ring resolution



Without absorbers:

σ_{1pe}=9.55±0.04 mm

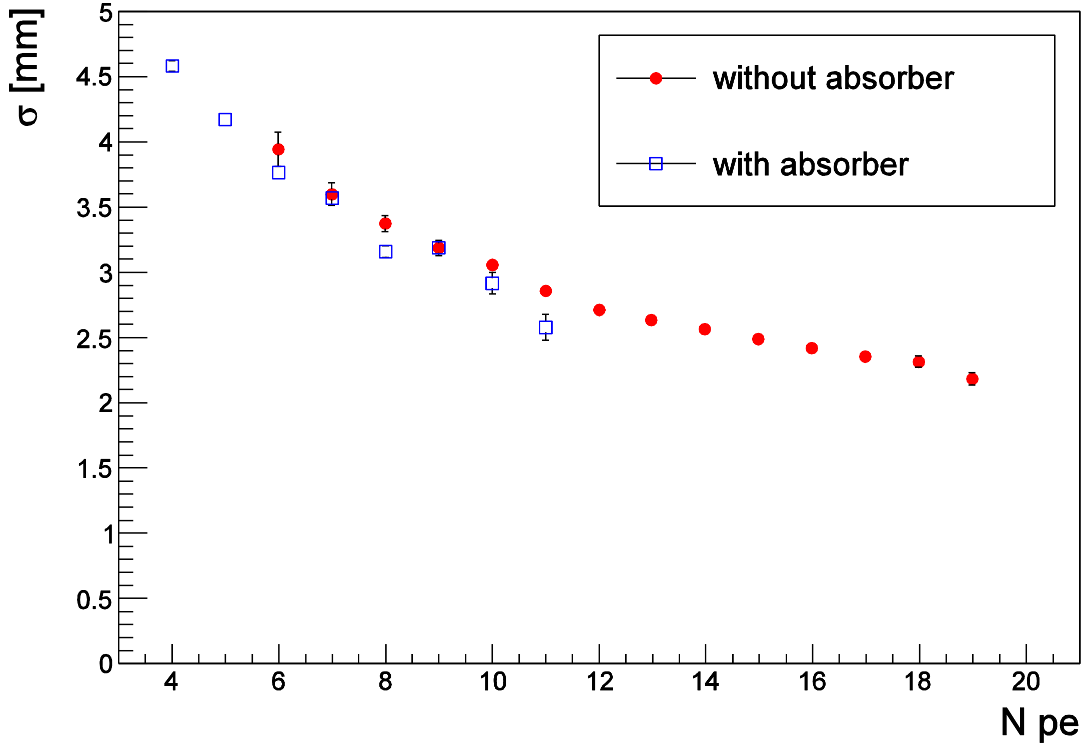
With absorbers:

σ_{1pe}=9.25±0.04 mm

The only effect is in the of the photons yield

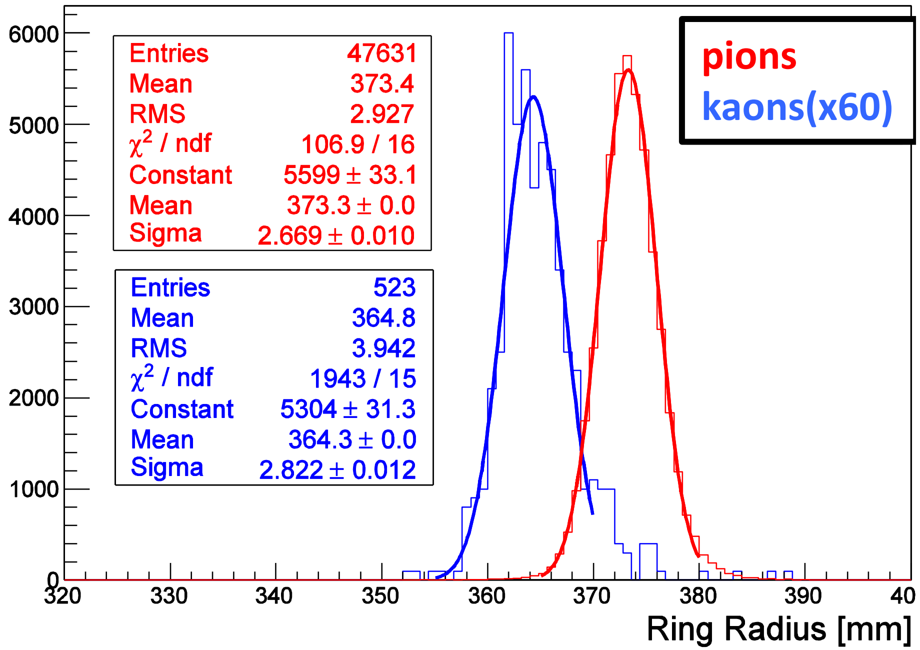
Resolution vs N_{pe}

$$\sigma_R = \sigma_0 + \frac{\sigma_{1pe}}{\sqrt{N_{pe}}}$$

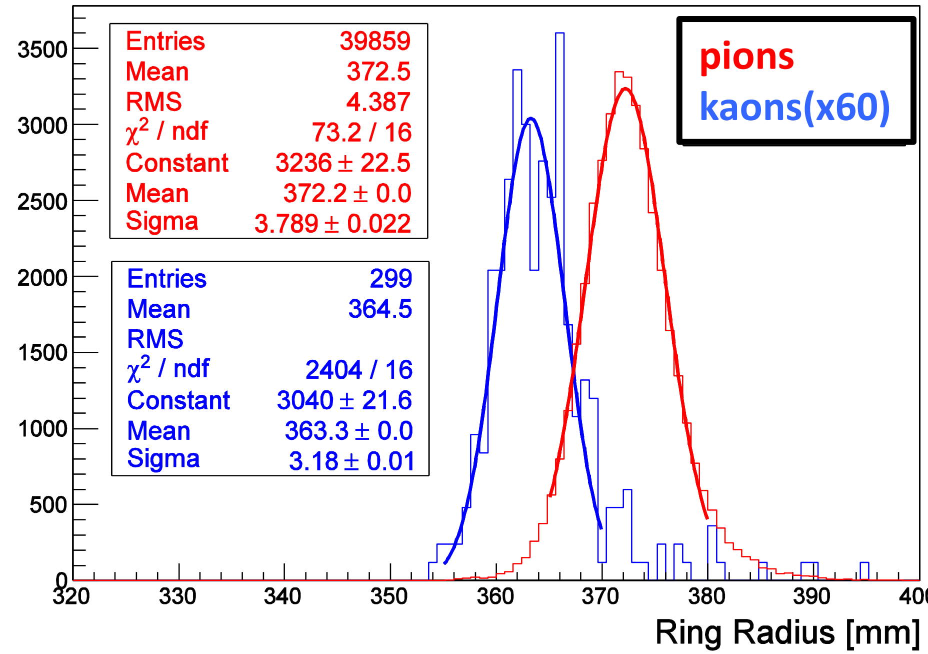


Pion/kaon separation

Without absorbers



With absorbers



Number of σ separation

$$n_\sigma = \frac{\theta_C(\pi) - \theta_C(K)}{[\sigma_\theta(\pi) + \sigma_\theta(K)]/2}$$

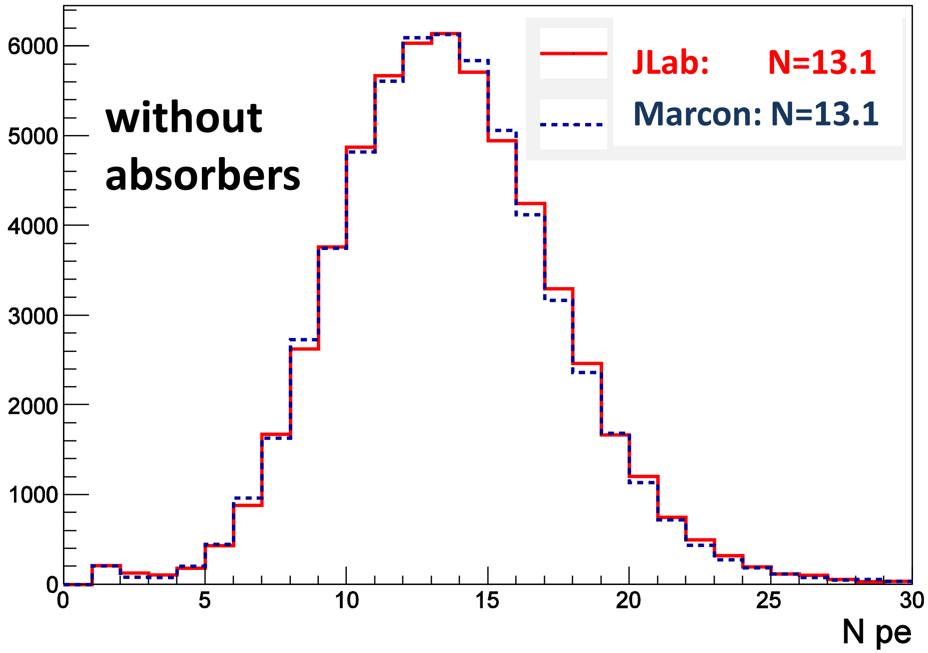
Absorbers	$R(\pi)$ (mm)	$\sigma_R(\pi)$ (mm)	$R(K)$ (mm)	$\sigma_R(K)$ (mm)	n_σ
NO	373.31±0.01	2.67±0.01	364.31±0.01	2.82±0.01	3.3
YES	372.19±0.01	3.79±0.02	363.29±0.01	3.18±0.01	2.5

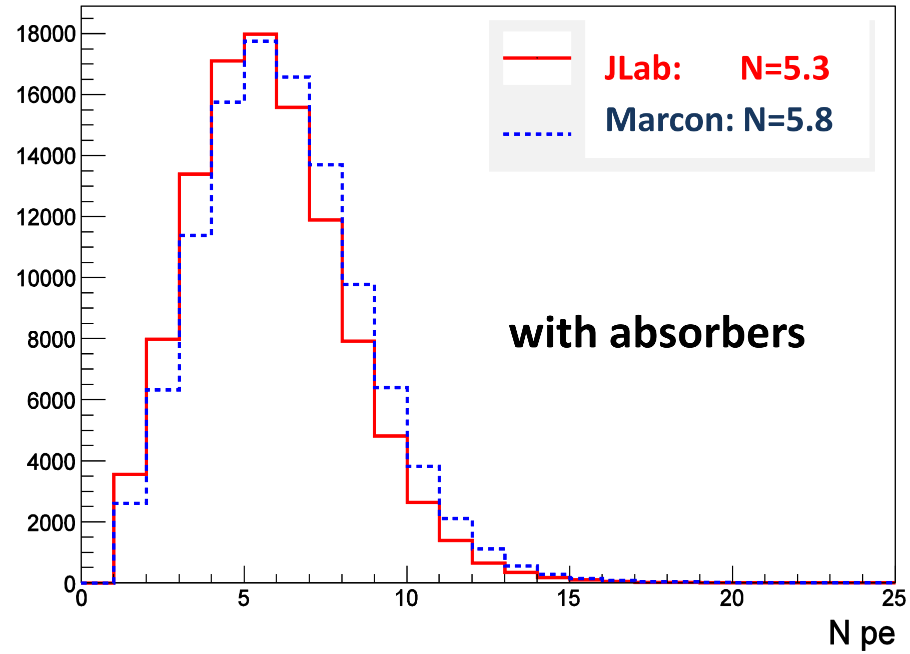
Mirror comparison

Glass spherical vs JLab elliptical

No GEM tracking used for this analysis

- 3par fit: Ring radius and center from fit MAPMT hits
- with JLab mirror scaling factors to compensate for the elliptical shape





Single photon resolution σ_{1pe}

- similar values for the two mirrors

Absorbers	Marcon	JLab
NO	13.38±0.04 mm	14.64±0.06 mm
YES	16.24±0.07 mm	17.29±0.07 mm

Summary from reflected light tests

- Protoype results
  1. significant amount of light (40%) survives the double pass through the aerogel
  2. Pion/Kaon separation achieved at a level of 2.5σ with P=6 GeV/c
     - close to requirements
     - better at lower momentum
  3. no significant differences between JLab and glass mirrors

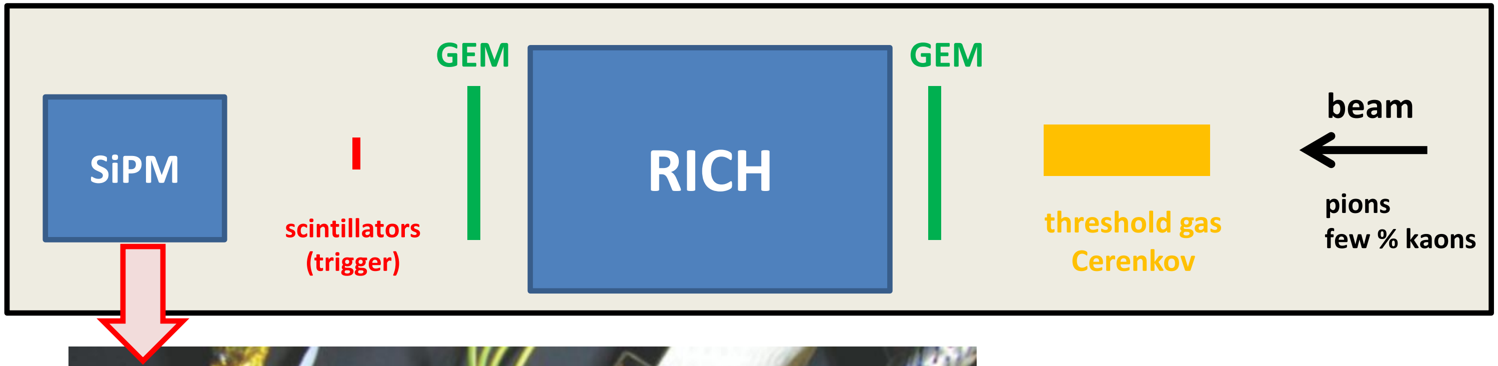
- Room for improvement in the prototype results
  - better coverage of the ring: +20% photons
  - suppress UV photons: +15% single photon resolution
  - aerogel quality: more yield, less absorption
  - use new R12700

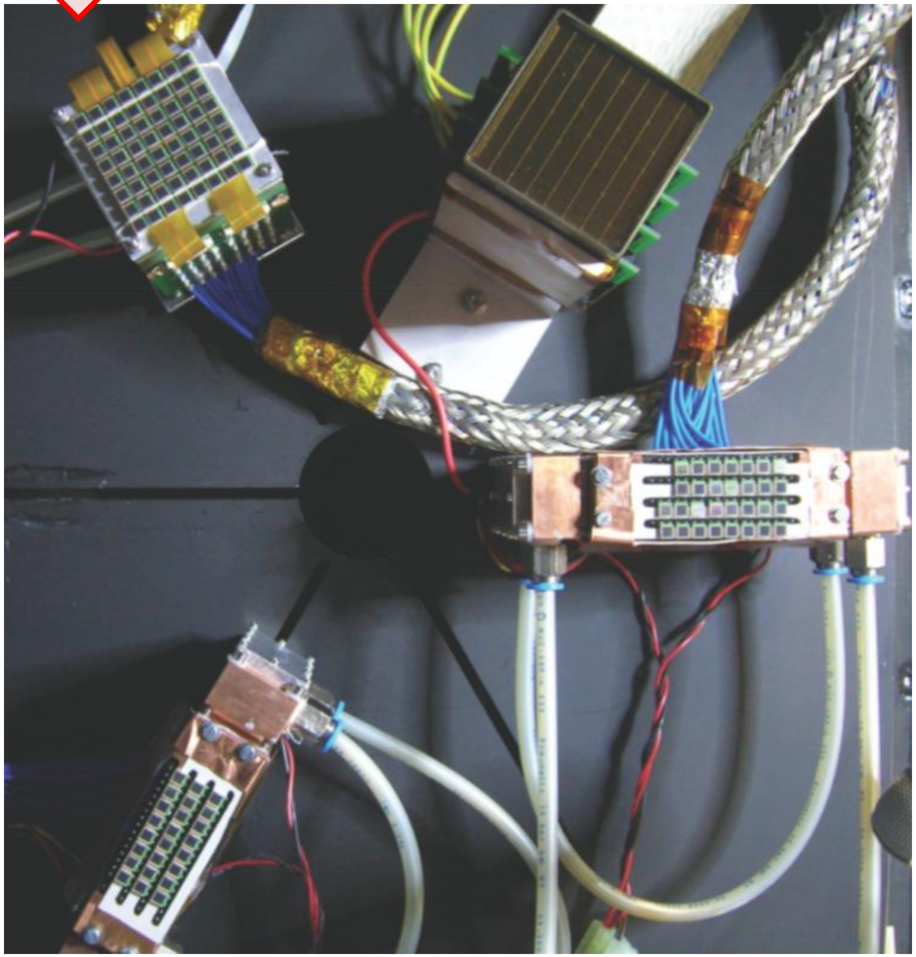
- The geometry of the prototype is different from the CLAS12 RICH
  - expected performances not directly comparable

- Monte Carlo simulation to estimate the performance of the CLAS12 RICH
  - tuning to the test beam results

SiPM measurements

SiPMT setup

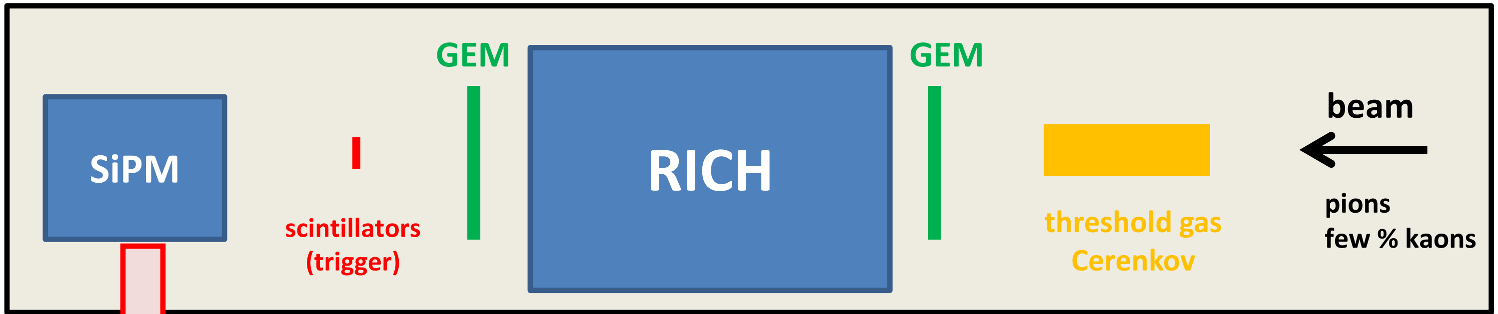


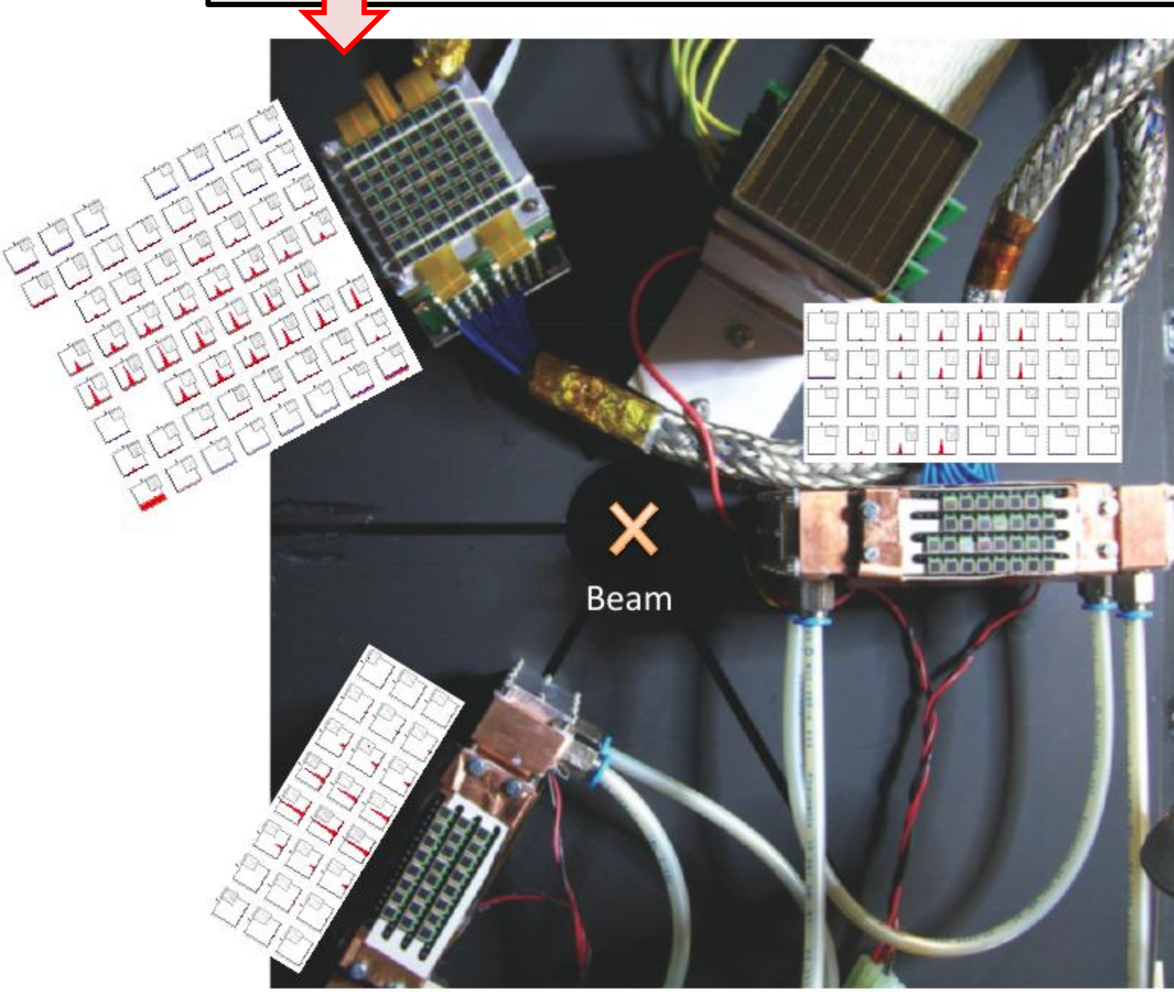


- one commercial 8x8 matrix with 3x3mm^2 pixel size
- two custom 4x8 matrix with 3x3mm^2 pixel size with preamp stage
- water cooling system with a Peltier cell from -25^o to +25^o

- TDC spectra measured in 3ns window

SiPMT test



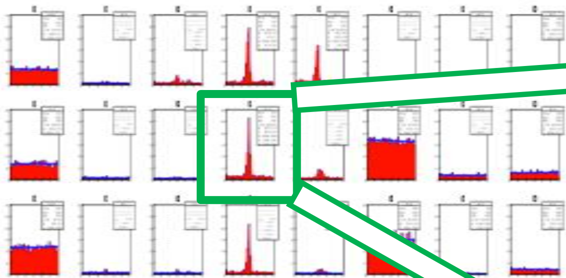


- one commercial 8x8 matrix with 3x3mm² pixel size
- two custom 4x8 matrix with 3x3mm² pixel size with preamp stage
- water cooling system with a Peltier cell from -25° to +25°

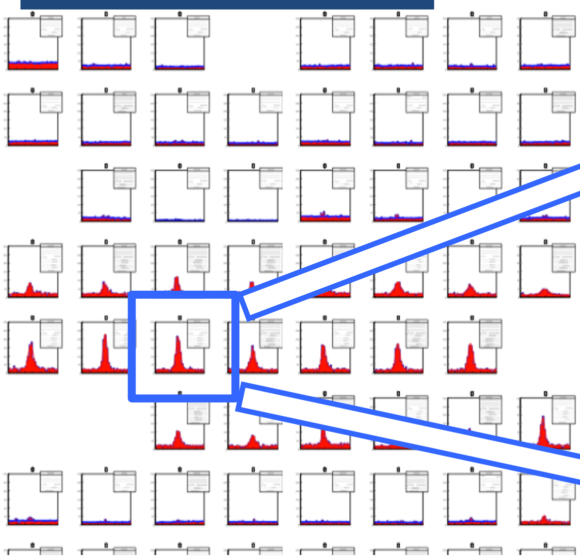
- TDC spectra measured in 3ns window

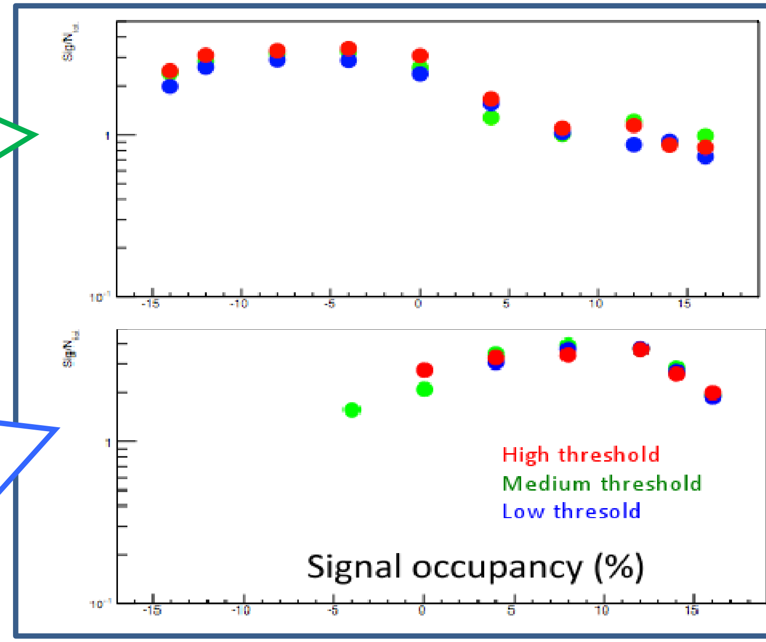
Measurements at +25°

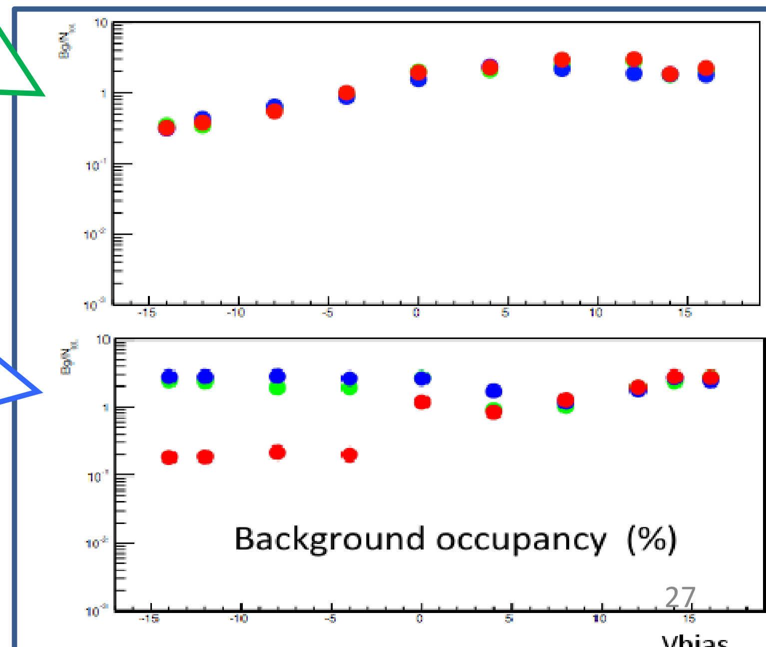
custom matrix + preamp



commercial matrix







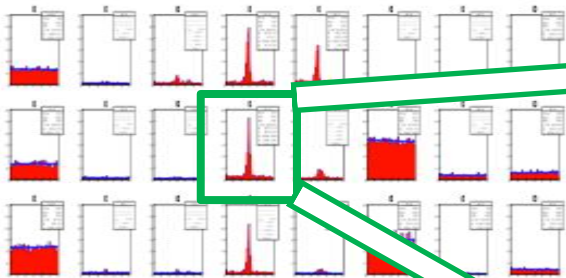
Best pixel:

- strong variations of signal with the bias

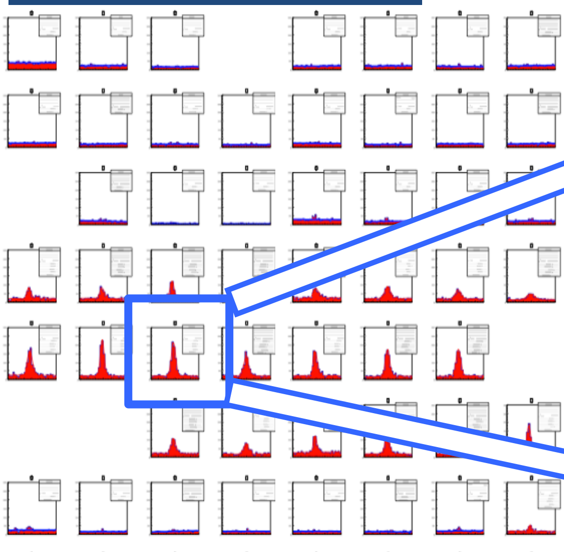
  4% occupancy ⇒ about 24 p.e. in full ring
- preamp important
- high level of bkg, reduction with high threshold

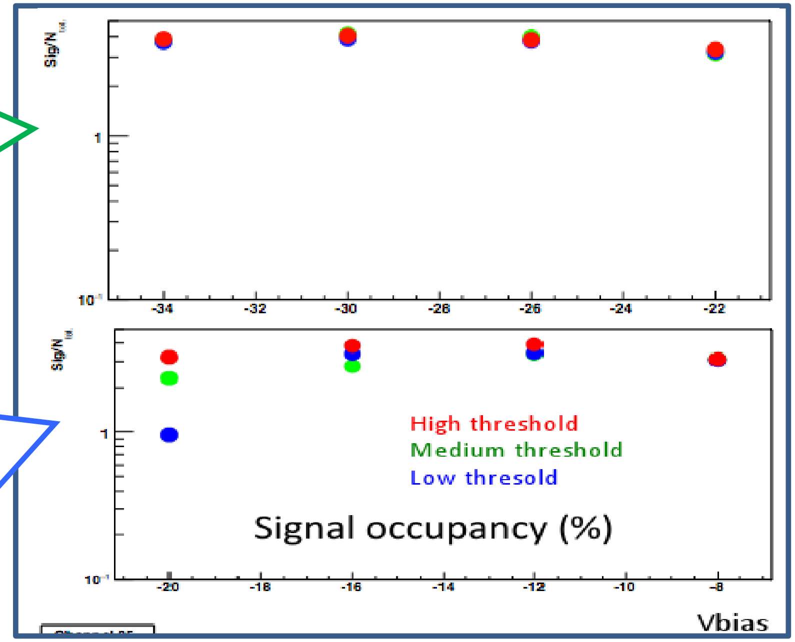
Measurements at -25º

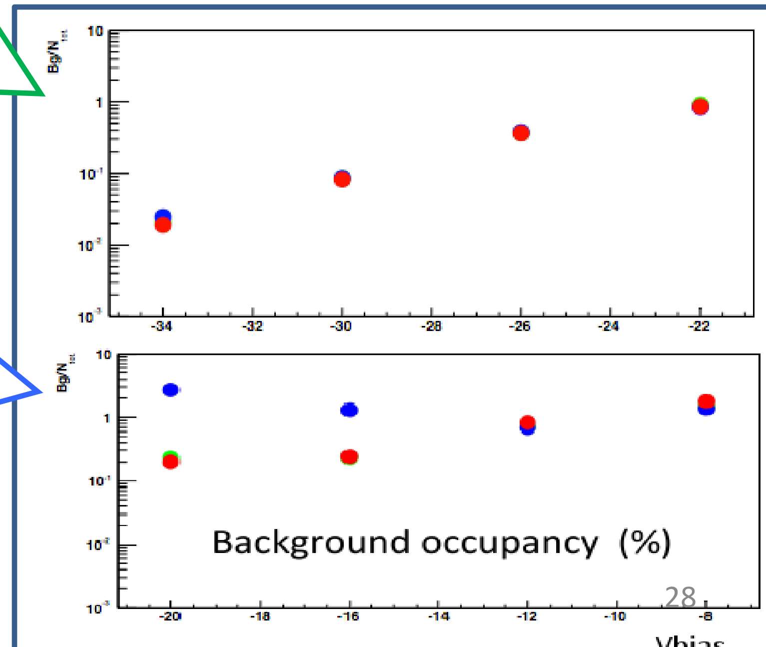
custom matrix + preamp



commercial matrix







Best pixel:

- more stable behaviour with bias
- reduction of bkg even at lower thresholds

10^{-4} bkg comparable with H8500

Summary from SiPM tests

- Prototype results
  1. at room temperature, difficult tuning of the operating point
  2. when cooled at -25º, the response is not too far from MAPMTs

- Costs are becoming competitive with MAPMTs, but more progress are necessary
  - cooling system may be complicated
  - integrated electronics for 25000 channels

- They may become an option for the future extension of the RICH to other sectors

Conclusions

We had a successful campaign of test beam to study the various features of the foreseen RICH detector

- **no issues have been found for the direct light configuration**
  - **achieved the required performances**

- **encouraging results for the reflected light configuration**
  - **prototype data close to the requirements at the highest momentum**
  - **Monte Carlo simulation for the CLAS12 RICH expected performances**

- **SiPM may become a good option for future extensions of the RICH**

backup slides

Ring fit

(x_i, y_i) hits of the event, i=1,N

(X_C, Y_C) ring center

R ring radius

Minimization of

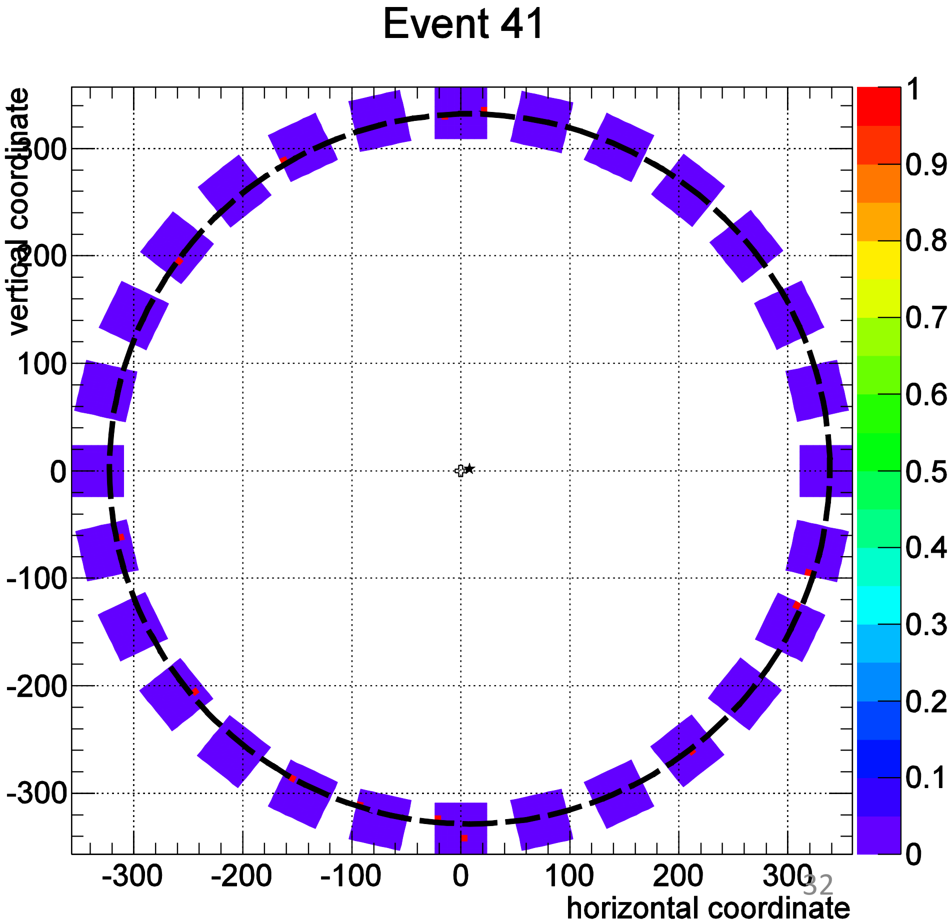
$$S(R, X_C, Y_C) = \sum_{i=1}^{N} [(x_i - X_C)^2 + (y_i - Y_C)^2 - R^2]^2$$

***3par fit*:**

- **X_C, Y_C and R are fit using the MAPMT data**

***1par fit*:**

- **X_C, Y_C are fixed from GEM tracking and R is fit using the MAPMT data**



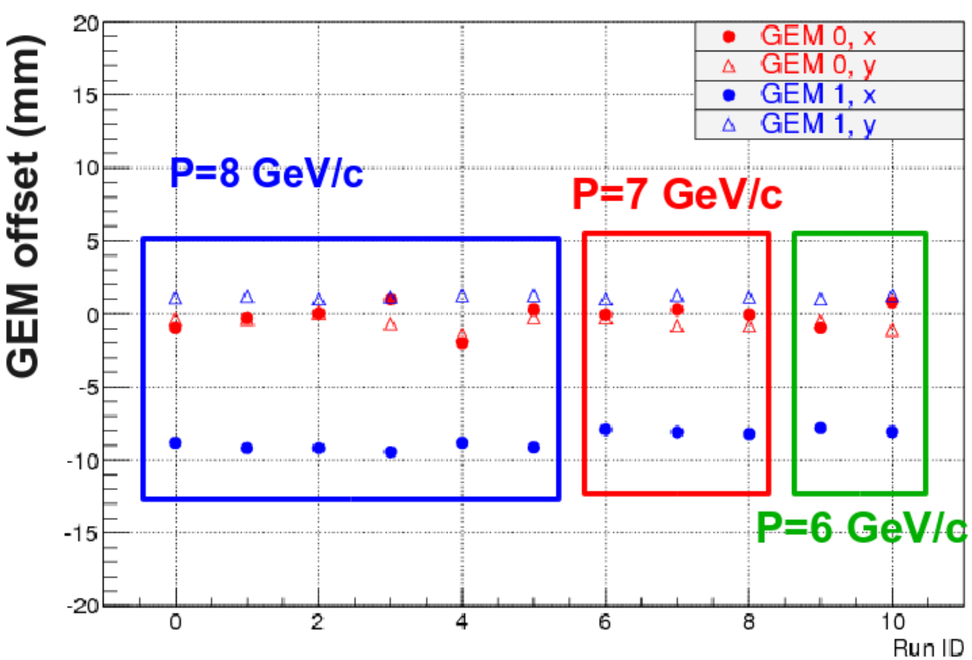
GEM alignment

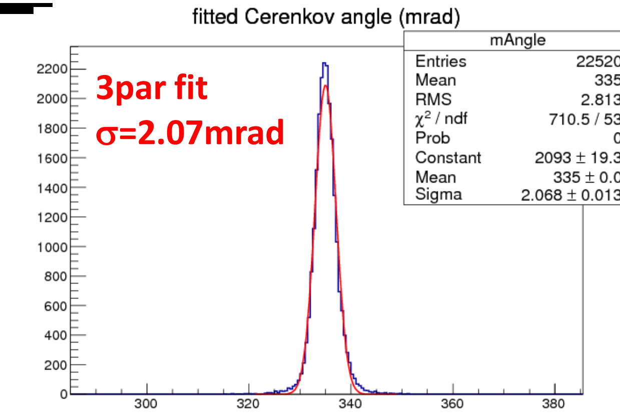
Alignment constants for the GEM position

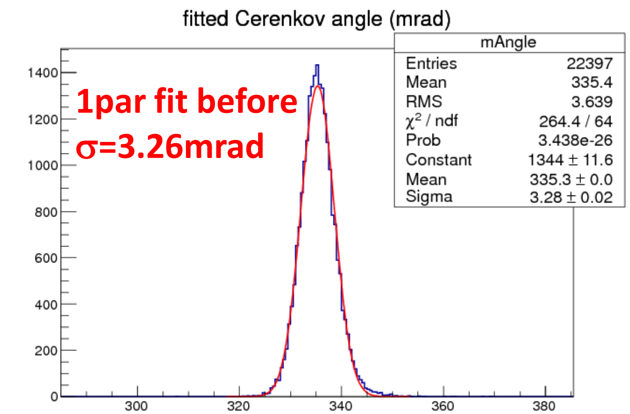
(X_0, Y_0) (X_1, Y_1)

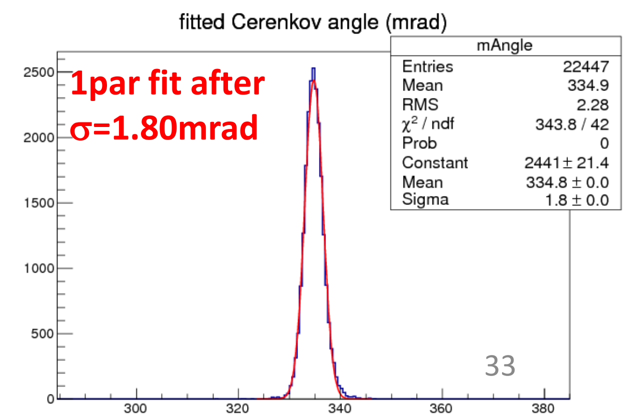
dermined by minimization of

$$Q(X_0, Y_0, X_1, Y_1) = RMS(R) + Mean^2(\Delta X) + Mean^2(\Delta Y)$$



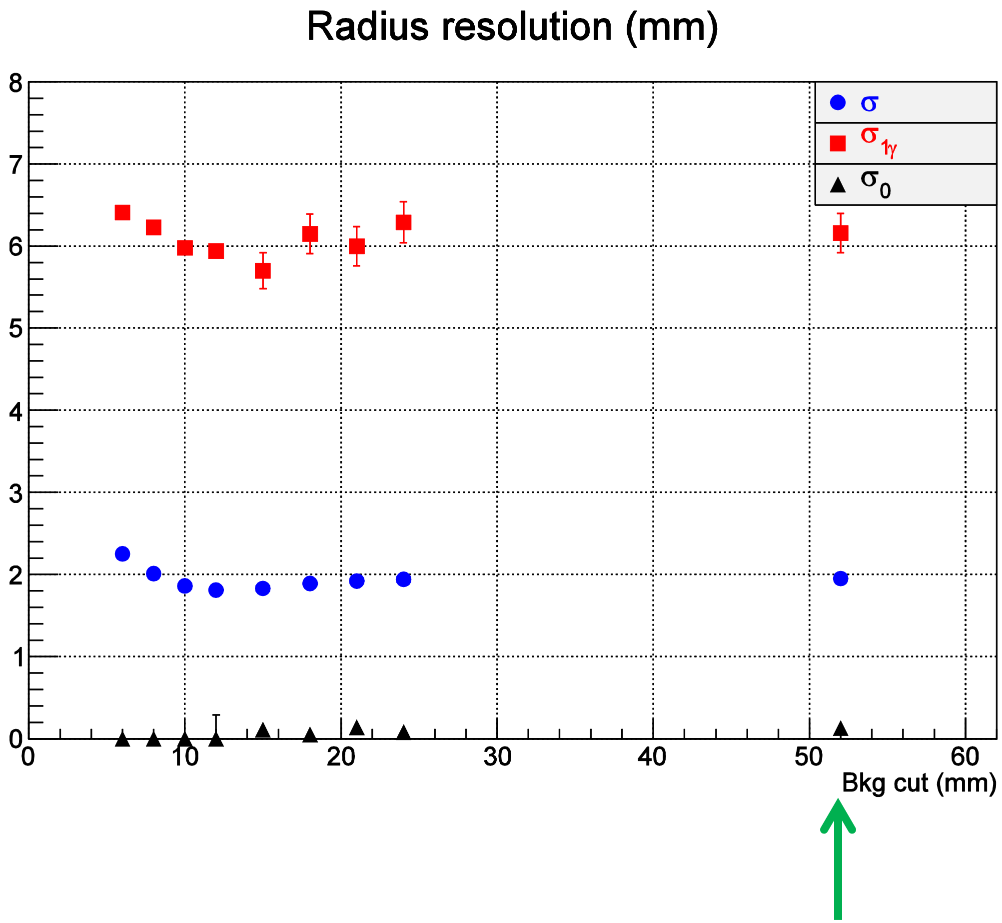






Background cut

Ring radius resolution vs cut to remove bkg hits



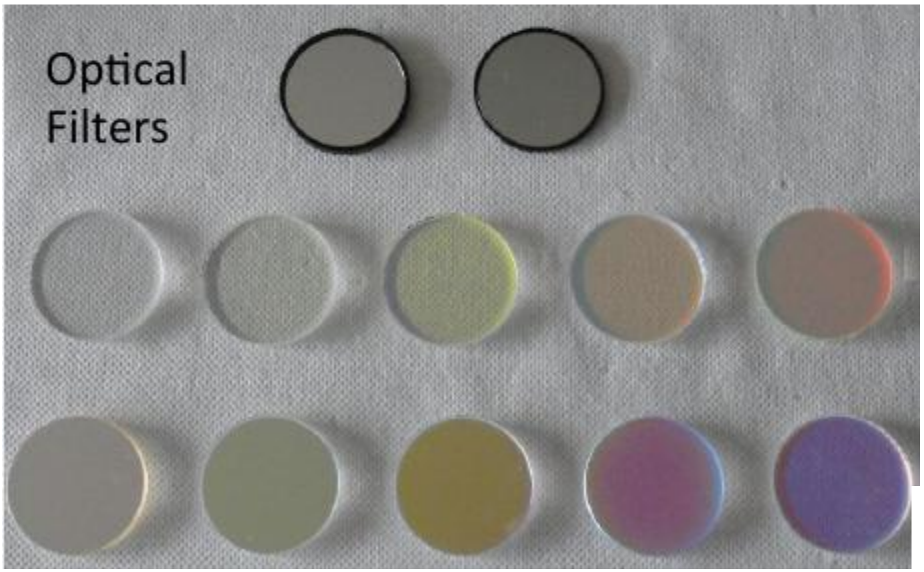
No cut results

σ = res. of integrated distribution

$$\sigma_\theta = \sigma_0 + \frac{\sigma_{1pe}}{\sqrt{N_{pe}}}$$

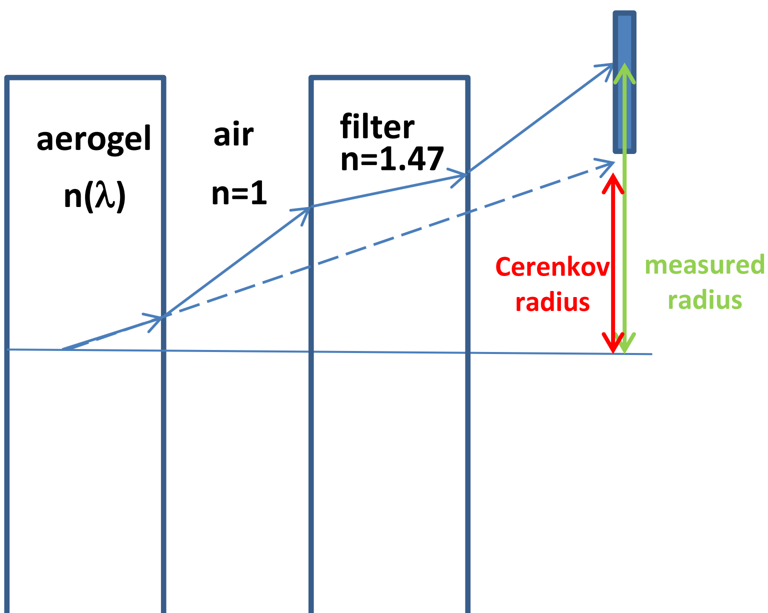
Chromatic studies

Study of Cherenkov ring radius as a function of λ

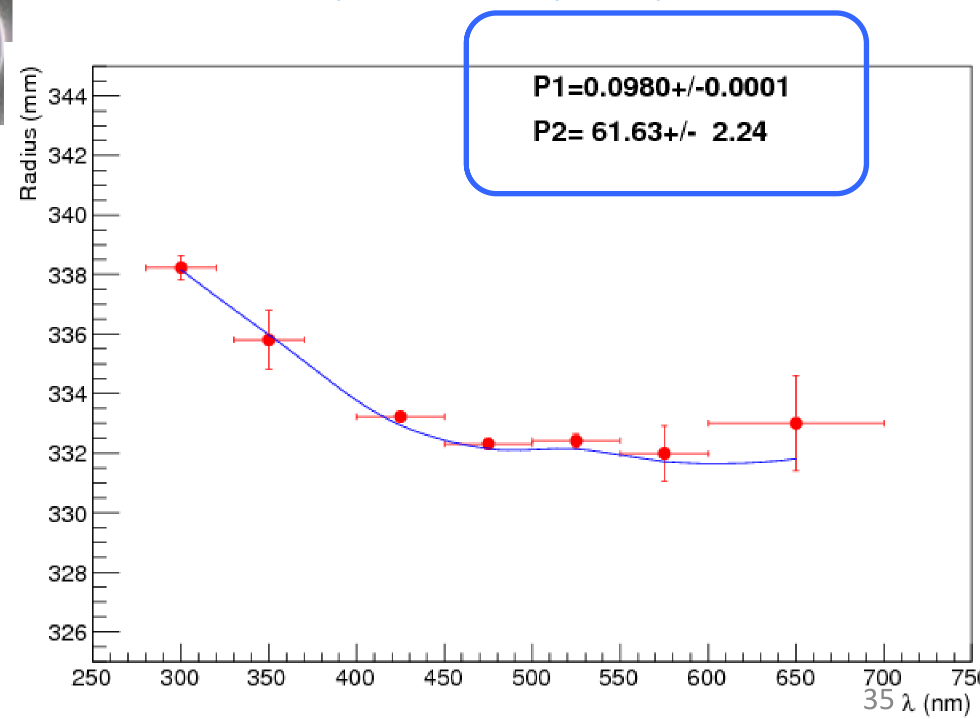


$$\cos\theta_C = {}^{1}/_{\beta n(\lambda)}$$

with $$n(\lambda) = \sqrt{1 + \frac{P_1\lambda^2}{\lambda^2 - {P_2}^2}}$$

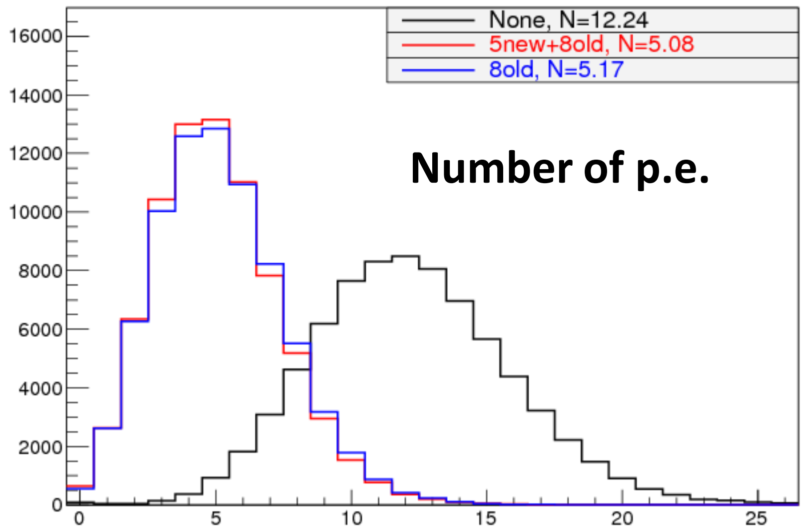


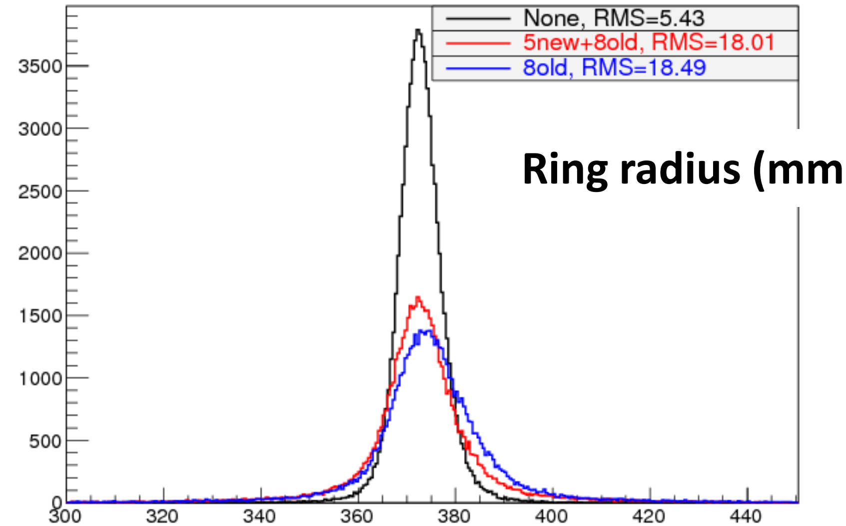
comparable with spectrophotometer results



Aerogel quality – reflected light

- 1par fit: no GEM tracking information
  - no absorbers
  - 8old absorbers
  - 5new+3old absorbers (the best old tiles)





- comparing old/new absorbers:
  same yield, better resolution
- comparing without/with(5new+3old) absorber
  40% photons surviving
  no single photon degradation

- With new aerogel production, absorption results in yield reduction only
- With old aerogel production, there is also degradation of resolution