Performance study of COMPASS RICH-1 detector with 2016-17 physics data and R&D for future EIC RICH

Second year-end presentation

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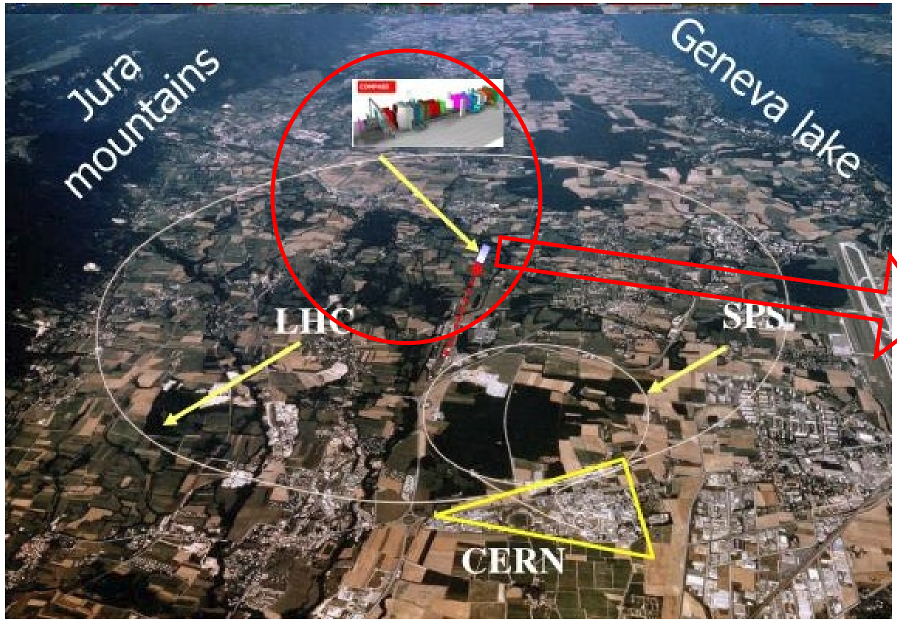
UNIVERSITÀ DEGLI STUDI DI TRIESTE

Outline

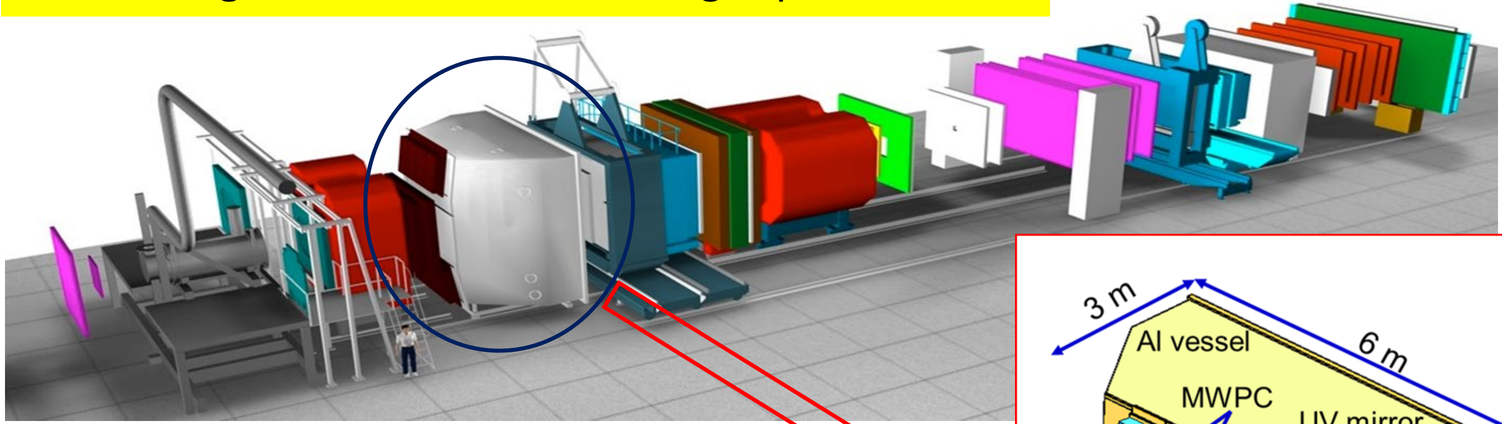
- Introduction to COMPASS
- Fundamental physics COMPASS addresses
- The physics motivation
- Analysis
  - RICH performance
  - Characterization of Newly installed hybrids.
- R&D for a future Electron Ion Collider (EIC) RICH.
- Conclusion and future Plans.

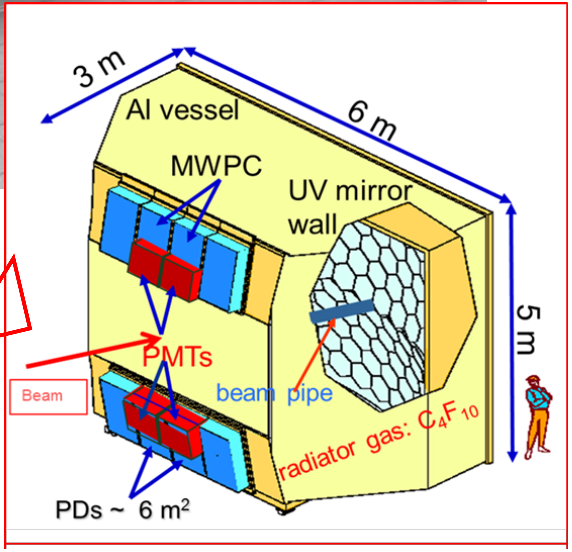
Introduction to COMPASS

COMPASS is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN in Geneva, Switzerland. The purpose of this experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.



50 mt. long State of the art two stage spectrometer



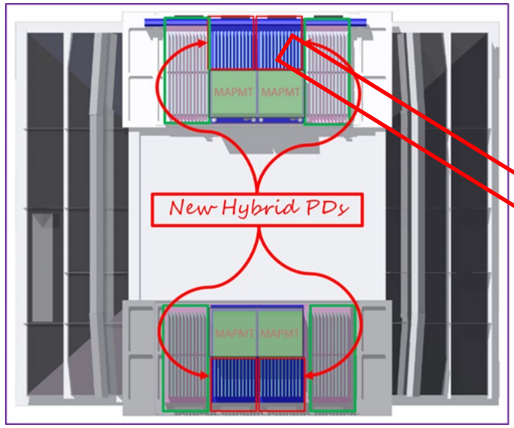


hadron PID from 3 to 60 GeV/c

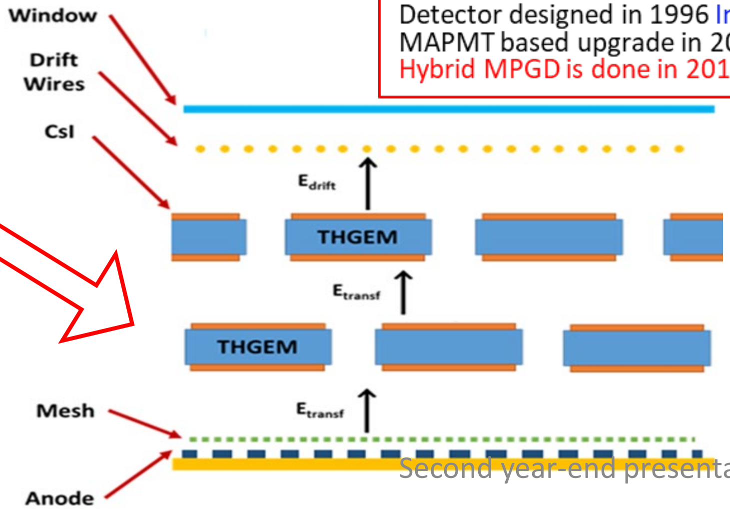
acceptance: H: 500 mrad V: 400 mrad

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

Detector designed in 1996 In operation since 2002
MAPMT based upgrade in 2006 A new upgrade with Hybrid MPGD is done in 2016



RICH Front view. (beam direction inside the page)



In summary: Compass is a 2 stage spectrometer. Each with Magnets, ECAL, HCAL and Muon walls, Several trackers. The first stage is equipped with a RICH, upgraded with novel MPGD based single photon detectors.

Fundamental physics goals of COMPASS

With a collaboration of 250 Physicists:24 institutes:13 countries
COMPASS addresses many fundamental questions of particle physics.

Measurements with muon beam:	Measurements 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 PDFs	Baryon Spectroscopy
COMPASS - II (2012 – 2018)	
DVCS and DVMP	Pion and Kaon Polarizabilities
Unpolarized SIDIS and TMDs	Drell-Yan Studies

Approval of one more year running (2021) with deuteron target for SIDIS physics.
Proposal for measuring proton radius by muon-proton scattering.

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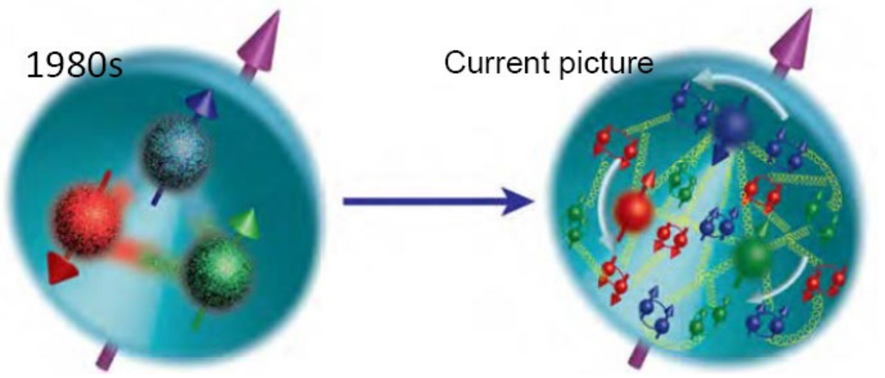
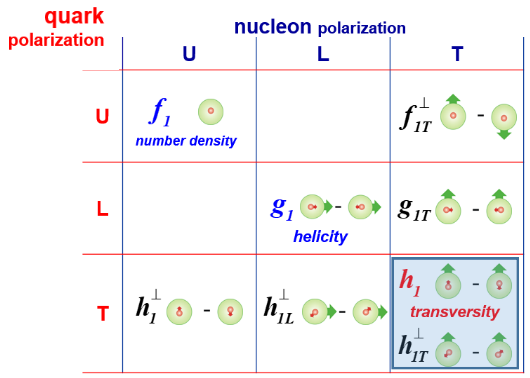
Evolution of our understanding of nucleon structure

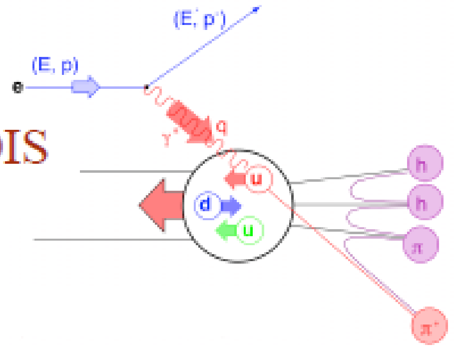




The **unpolarized** quark density in **unpolarized** nucleon and **longitudinally** polarized quark density in **longitudinally** polarized nucleon **are not sufficient!!**
TRANSVERSITY is a fundamental quantity of nucleons.
Semi Inclusive DIS is applied to extract the distribution functions.

Physics motivation to use a RICH

Semi-Inclusive DIS



$$Q^2 = -(p' - p)^2;$$

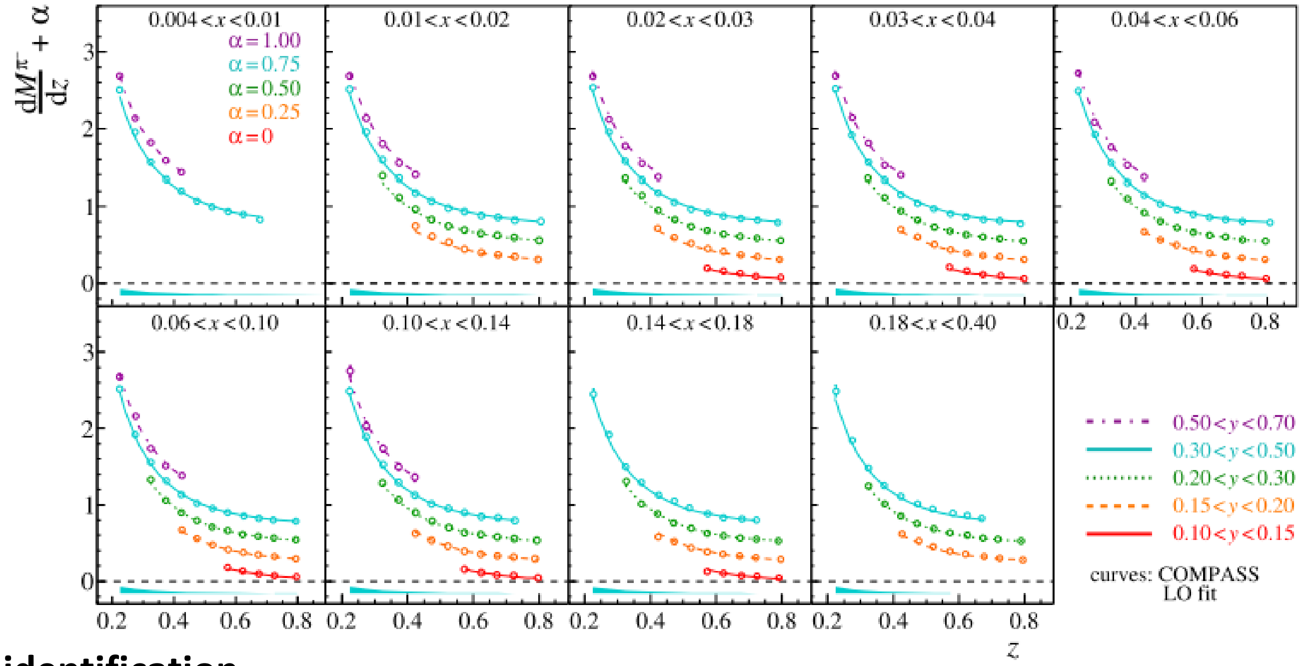
$$x = \frac{Q^2}{2P \cdot q}$$

$$z = \frac{P \cdot p_h}{P \cdot q}$$

Interpretation of SIDIS the data in context of the perturbative Quantum Chromodynamics (small α_s)
→ Extraction of fragmentation function D_q^i (Non Perturbative object).
(In leading order (LO) the QCD F.F. describe the probability density for a quark of flavor q to fragment into a hadron of type i.)
→ Extraction is not straight forward. Convolution of F.F. with P.D.F.

Number of hadrons per DIS event: multiplicity
→ In LO the observed multiplicity is related in the following way with the parton distribution function $q(x)$, and fragmentation functions

$$\frac{dM^i(x,Q^2,z)}{d(x,Q^2,z)} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^i(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$



Simply, **identification** of **at least one hadron in coincidence** with the scattered muon is mandatory in SIDIS. In order to tag the struck quark of the nucleon via virtual gamma interaction.

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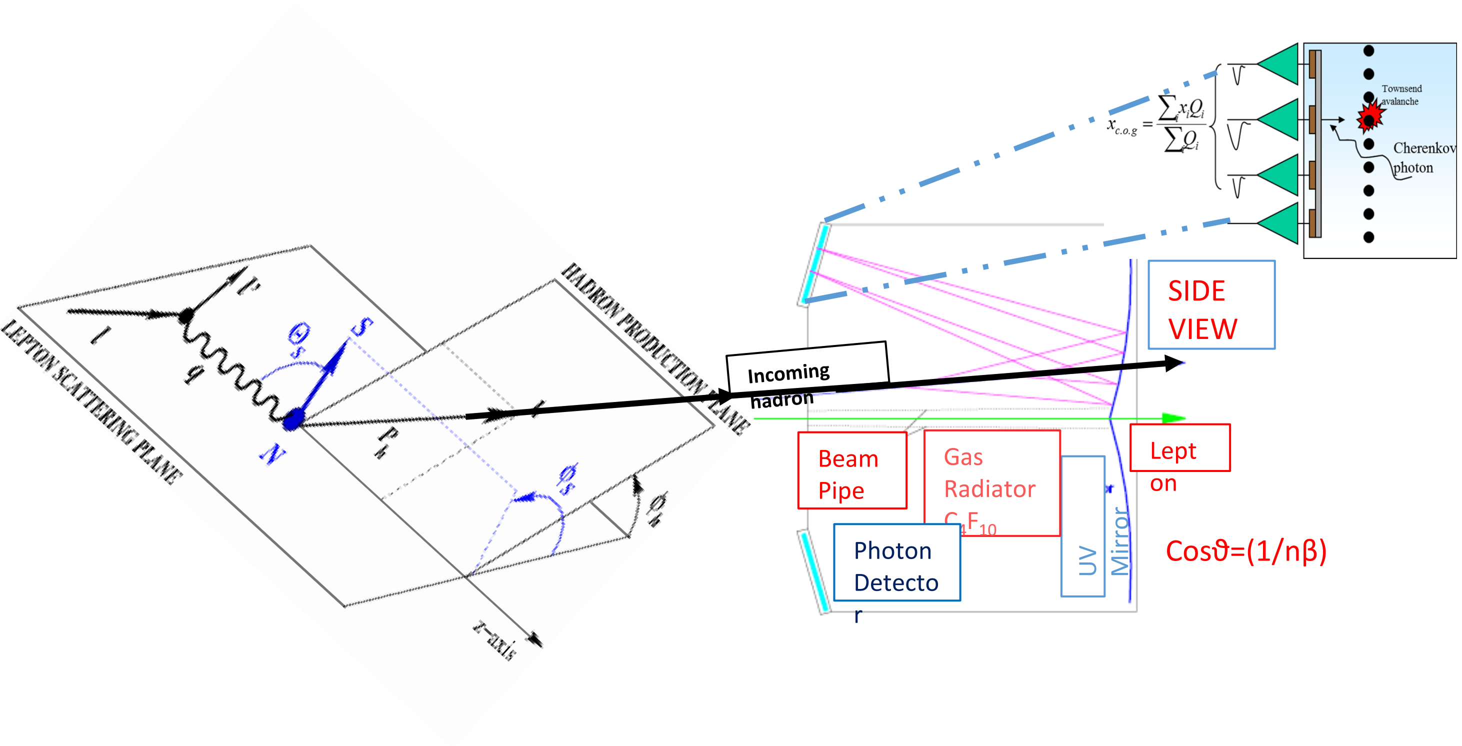
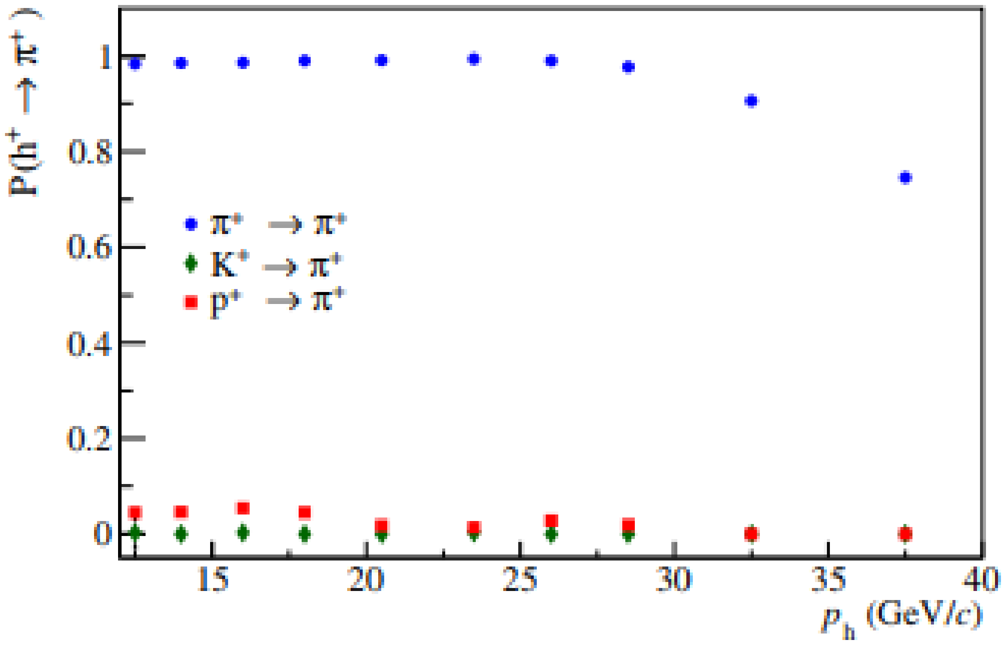
Negative pion multiplicities versus z for x bins and y bins. The bands correspond to the total systematic uncertainties for the range 0.30 < y < 0.50. The curves correspond to the COMPASS LO fit

Corrections for Raw multiplicities: spectrometer acceptance, **the RICH efficiency and particle misidentification probability**, the contribution from decay products of diffractive mesons, radiative corrections.

Efficient performance of a RICH is crucial.

PID performance of RICH-1





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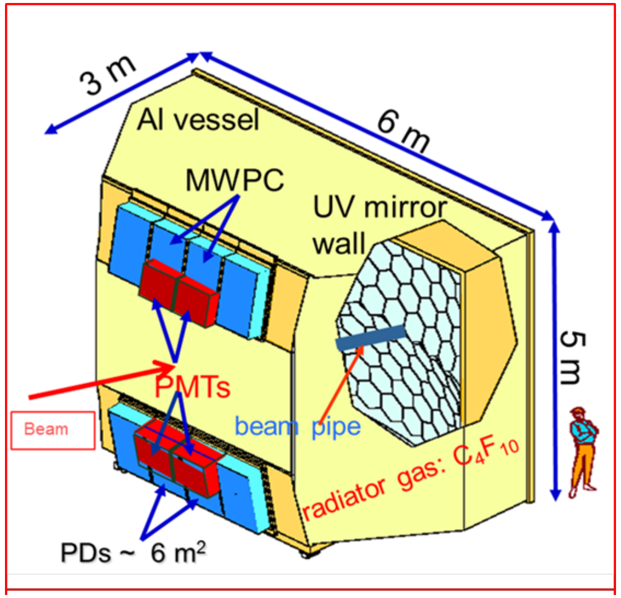
Efficient performance of RICH includes→ understanding of RICH-1 Geometry, Radiator gas, reconstruction algorithm, RICH data analysis… But, most important the photon detection techniques,

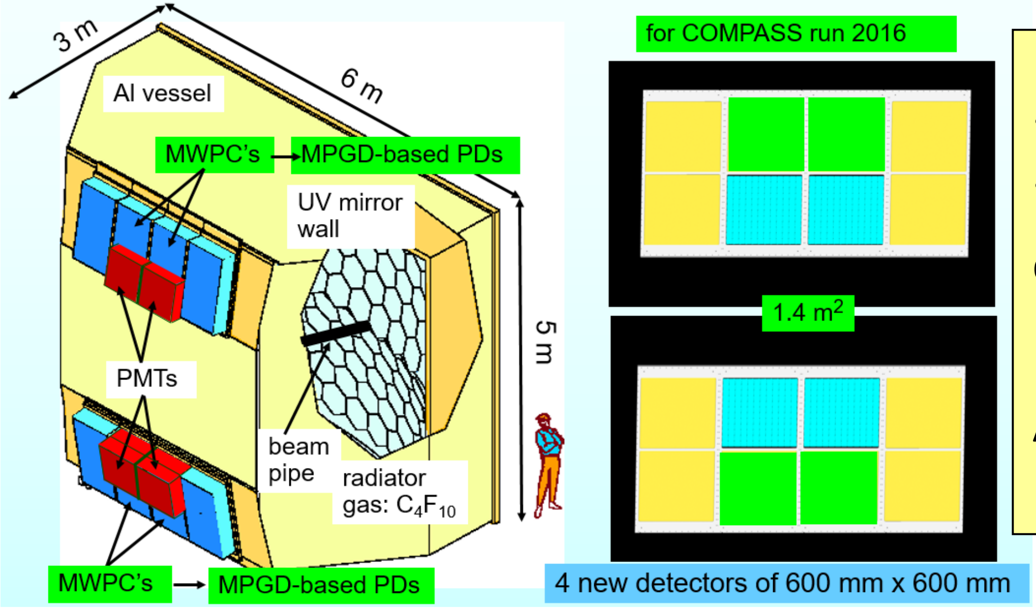
Probabilities of RICH identification of π +, K+ and p as a π + versus momentum for the smaller θ bin 10mrad < θ < 40mrad. Statistical uncertainties are lower than the size of the symbols.

I am currently working to improve the performance of RICH-1

RICH-1 upgrade



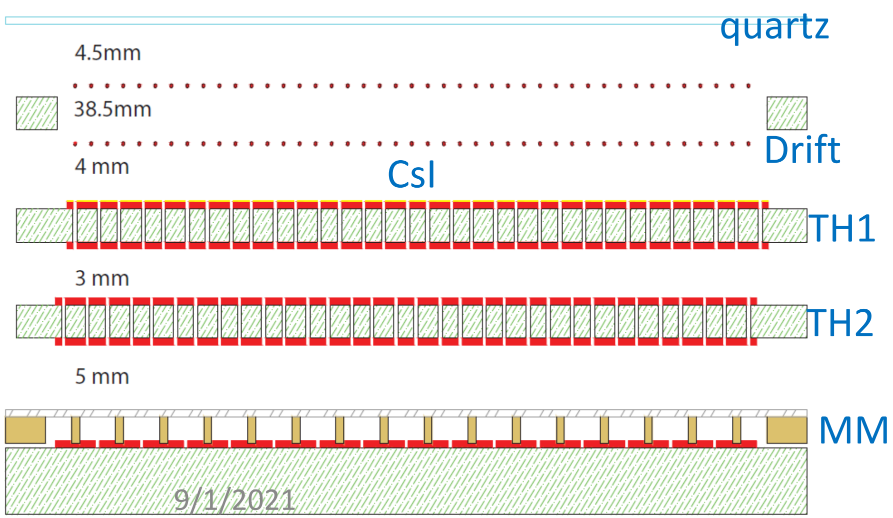
Before 2016



After 2016

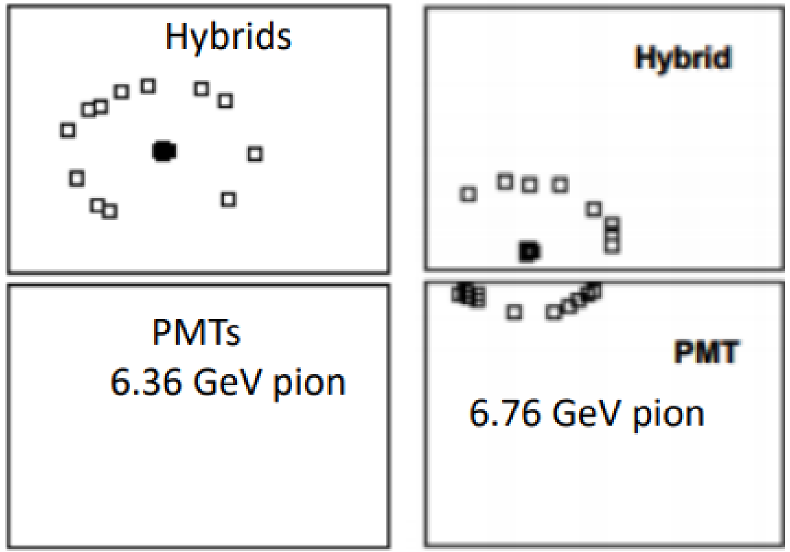
MWPCs + CsI: successful but with important performance limitations, in particular in the case of the 4 central chambers.

Decreased number of photons.
Aging due to ion-back flow.
Long recovery time after discharge.



COMPASS has pioneered GEMS, MicroMegas and THGEM-Micromegas based hybrids for detecting single photons in real experiment!!

I did the characterization of the newly installed hybrids with Yuxiang Zhao.



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- Introduction to COMPASS
- Fundamental physics COMPASS addresses
- SIDIS and Particle Identification
- **Analysis**
  - Performance of RICH-1: refractive index issues.
  - Understanding physics background refractive index of the radiator gas.
  - Requirements to characterize new photon detectors.
  - Characterization outcome.
- Requirement of an EIC.
- R&D for EIC.
- Participation in hardware activity of COMPASS and ongoing work .
- Future Plans.

Estimation of n-1

- For each detected photon the polar and azimuthal angle θ and ϕ can be geometrically reconstructed.
- This photon theta can be used along with particle momentum to monitor the refractive index of the radiator gas. Using Cherenkov formula.

Tracking→ Particle momentum and direction.

Mirror centre of curvature→ Reflected track: Centre of our ring.

Distance between Centre of the ring and detected photon hits→ Estimation of Single photon Cherenkov theta.

Independent of radiator refractive index!

Precise knowledge of n, Cherenkov angle and momentum → mass of the particle.

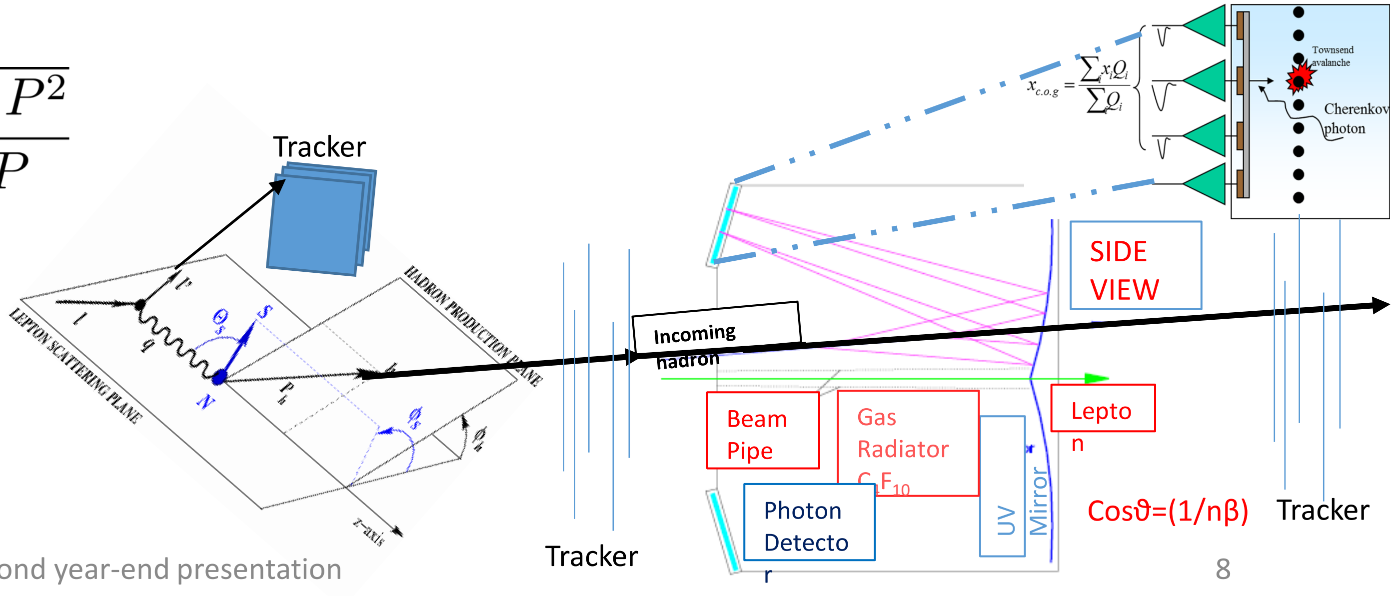
$$m_{particle} = \frac{P}{n} \cdot \sqrt{1 - n^2 \cdot cos^2\theta}$$

$$cos\theta = \frac{1}{n\beta}; \beta = \frac{P}{E}$$

$$E = \sqrt{m^2 + P^2}$$

$$n_{\pi-hypo} = \frac{\sqrt{m_\pi^2 + P^2}}{cos\theta \cdot P}$$

Retrieving n-1 of radiator indicates performance of RICH



Performance of RICH-1: refractive index issues

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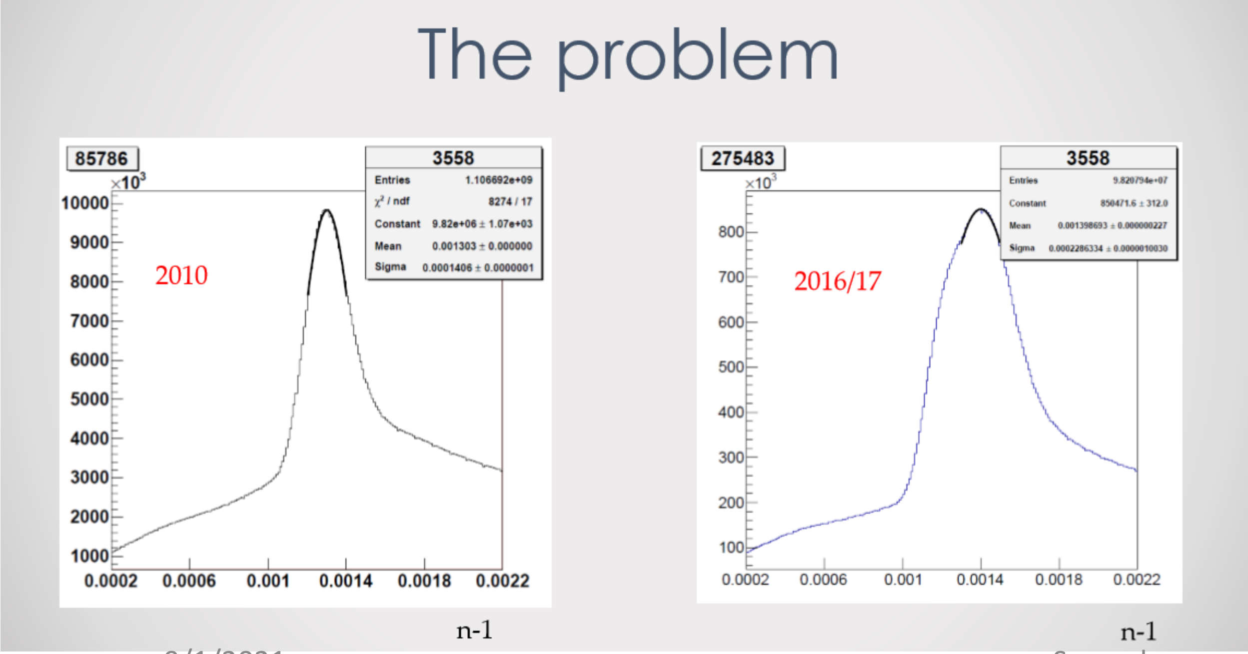
$$cos\theta = \frac{1}{n\beta}; \beta = \frac{P}{E} \qquad E = \sqrt{m^2 + P^2}$$

$$n_{\pi-hypo} = \frac{\sqrt{m_\pi^2 + P^2}}{cos\theta \cdot P}$$

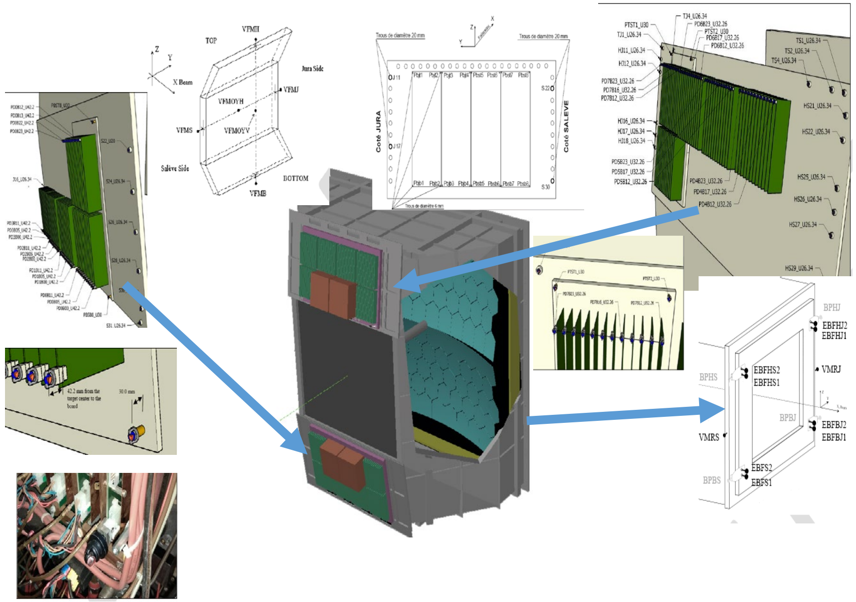
The n-1 histograms showed incompatibility to old data.

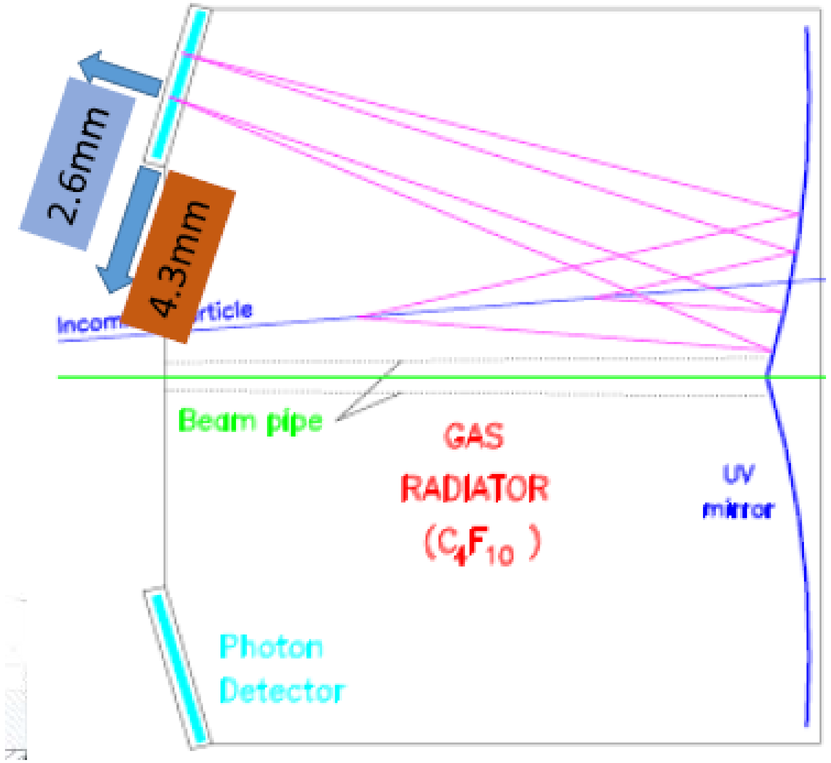


Suspected candidates are:
Wrongly computed Cherenkov angle!! → Detector Position
Wrongly computed Momentum!! → Tracking
After 2010 →unmount the MWPC detector frames containing the MAPMTs to replace MWPCs with the new Hybrid detectors (Major Change).
Several campaign of surveys → check detector positions on the RICH

Analysis of RICH-1 survey : analysis and outcome

Center of the detector frame and the relative positions of the cathode w.r.t the frame center : inputs in the geometry file → reconstruction software.





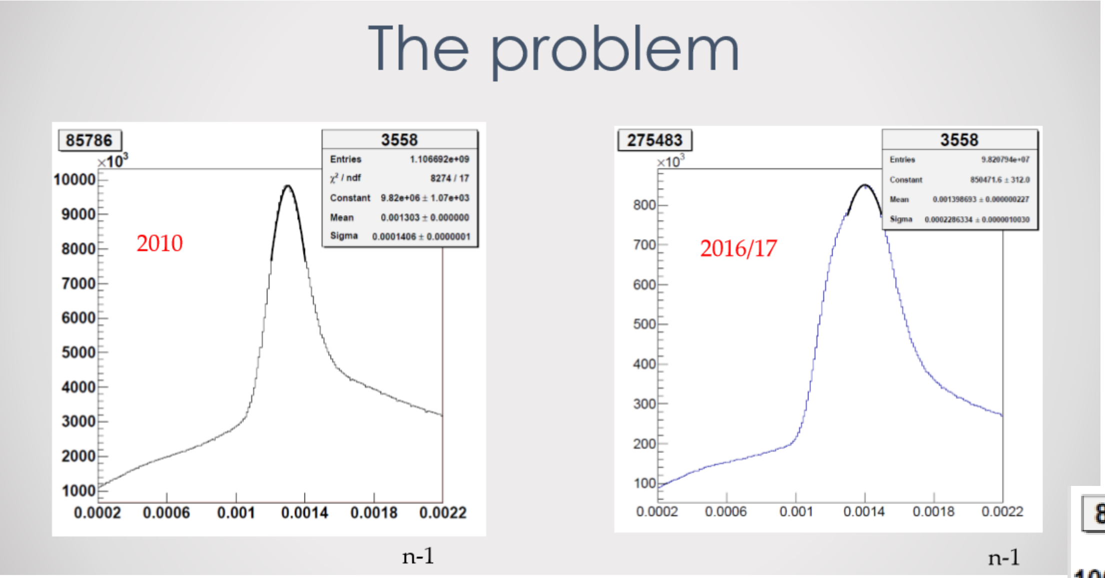
Arrows show the difference wrt 2015 MWPC+MAPMT.
4.3 mm is toward beam axis, 2.6 mm is upstream outside vessel.

New detector table has been made and geometry file was updated.

174 data points measured all over the RICH (Front and rear sides)

Cross-checking nominal values from survey data and compared to the nominal values of the CAD drawings!
Compatibility with survey precision

Estimation of n-1 from physics data



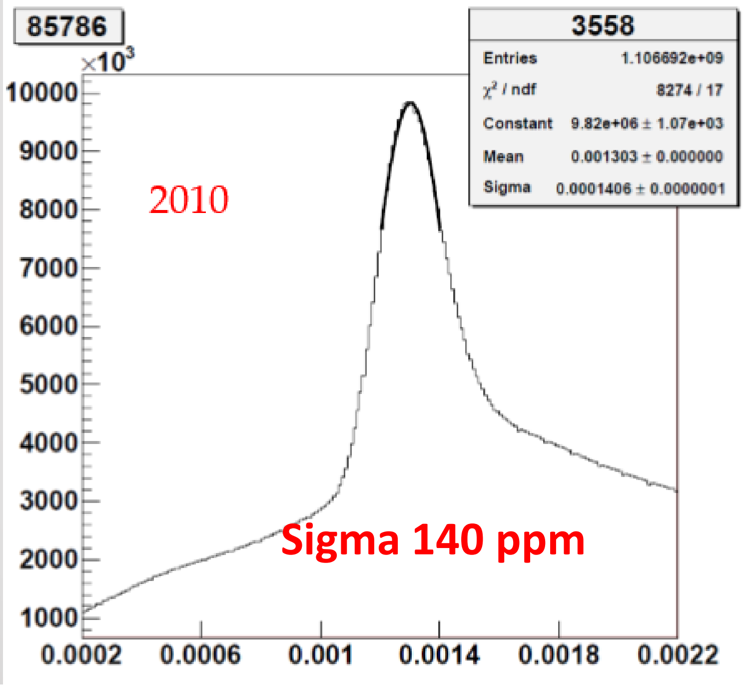
$$n_{\pi-hypo} = \frac{\sqrt{m_\pi^2 + P^2}}{cos\theta \cdot P}$$

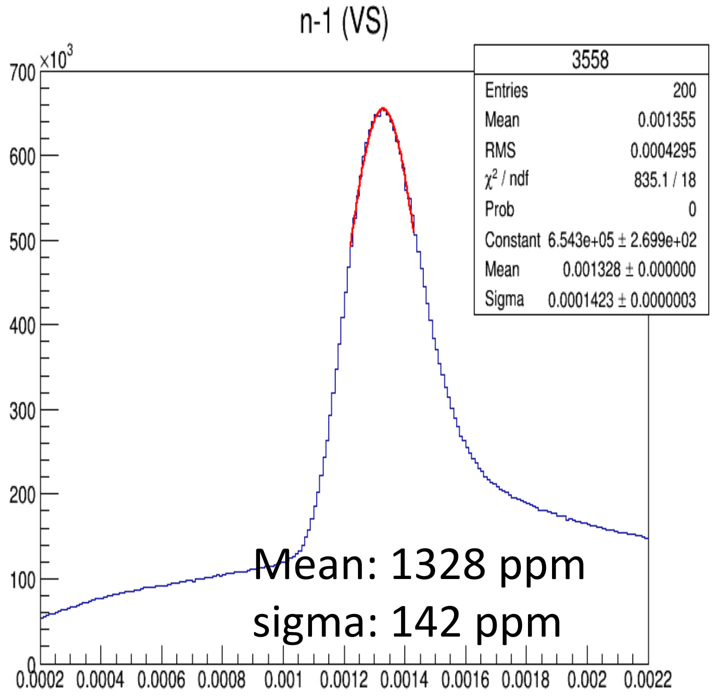
Current situations: We can reproduce n-1 histograms similar to 2010 .

Possible further improvements:

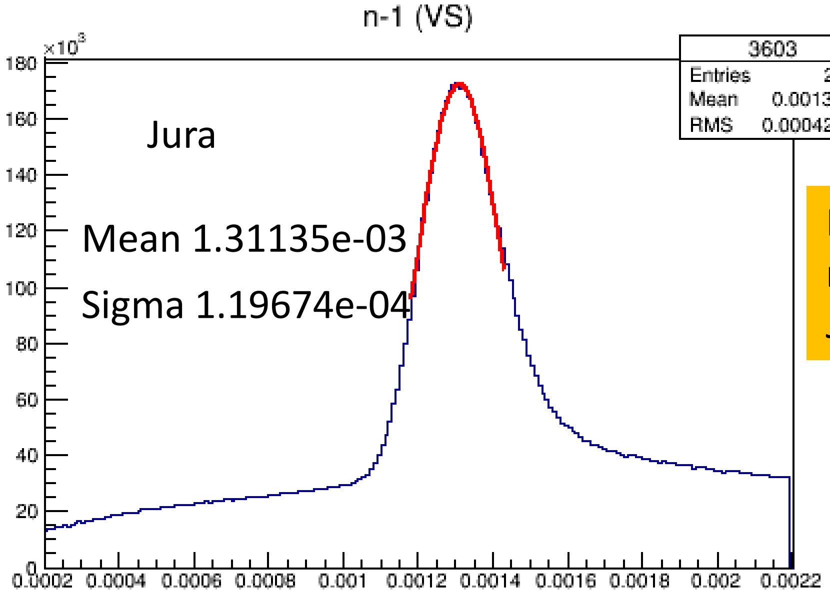
Detail study of the code ongoing.

MAPMT and mirror geometry under investigation.

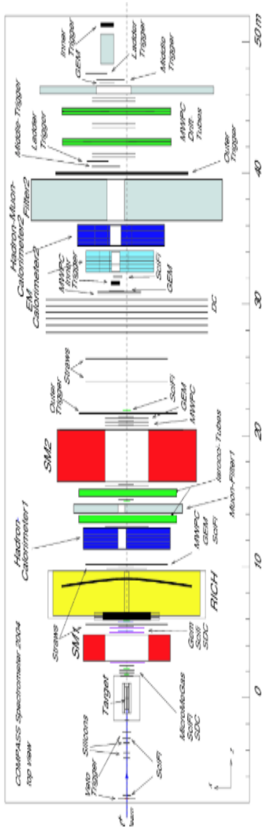




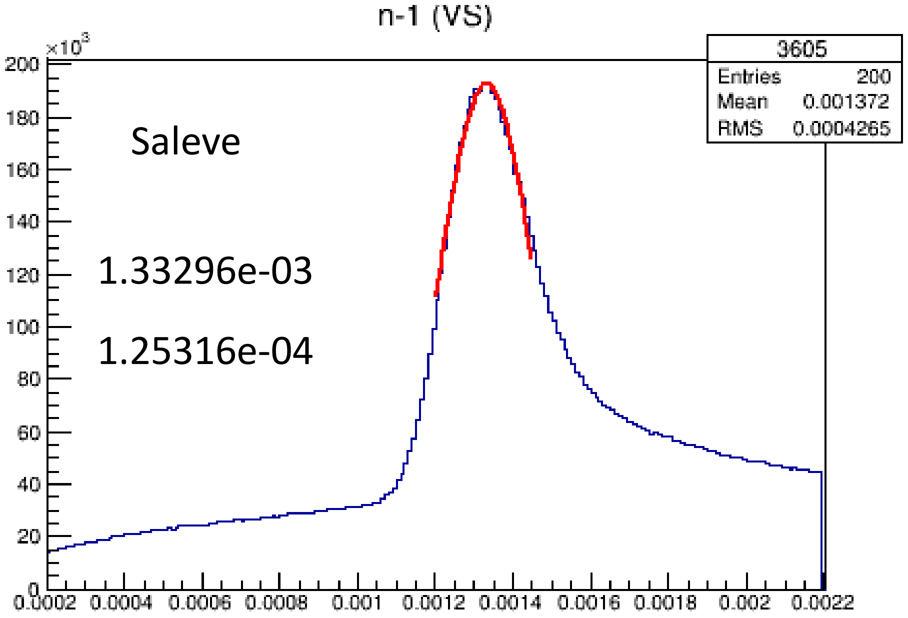
Situation now

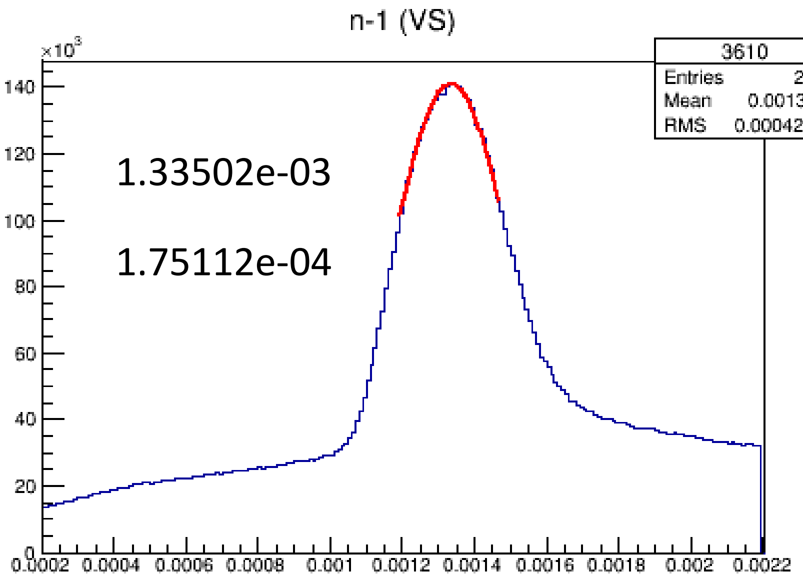


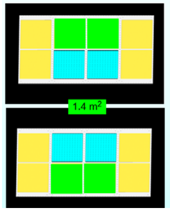
Mountain range: Jura



Mountain range: Saleve





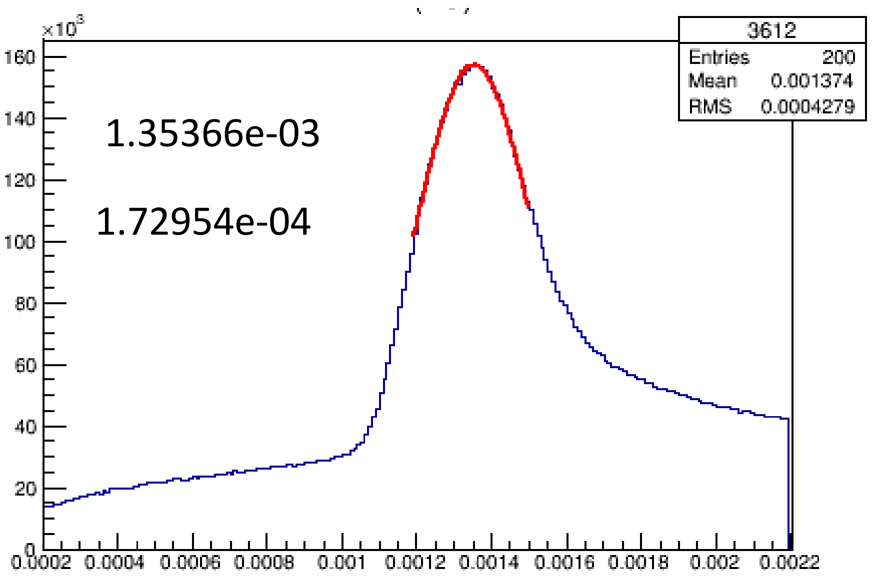


Blue panels are MAPMTS

Greens are newly replaced PDs

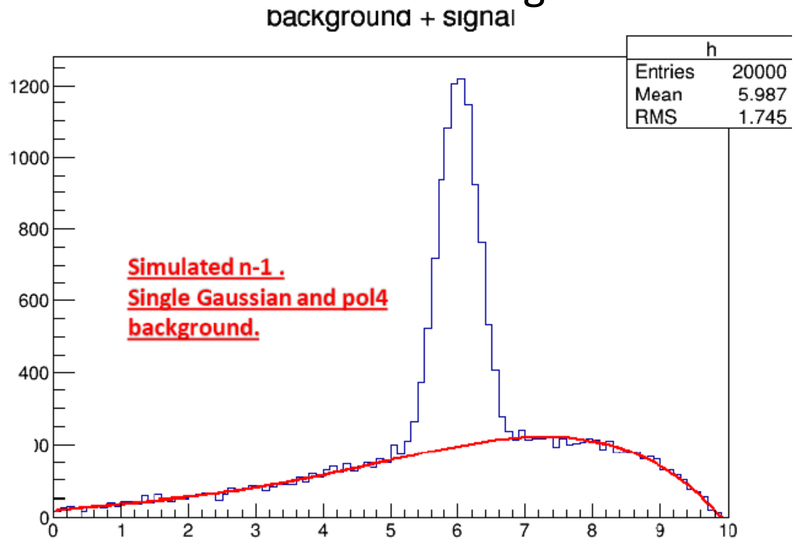
A residual Up-Down Asymmetry is still present.

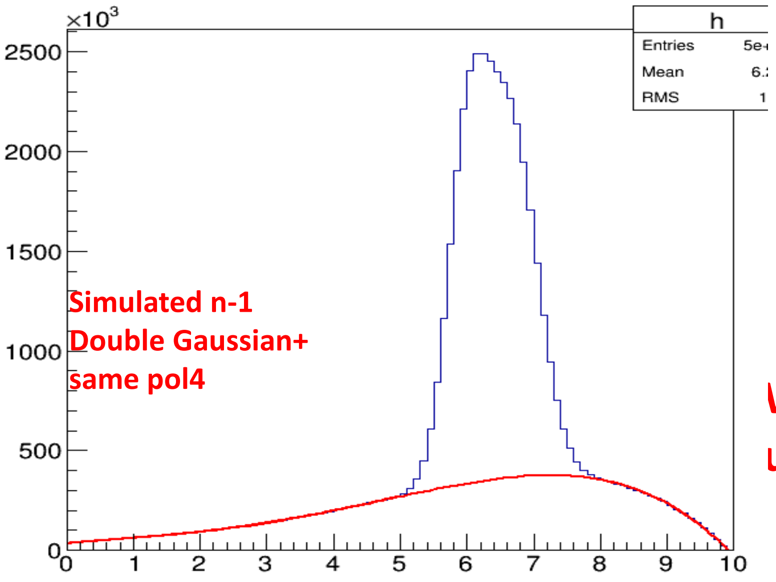
Trying to understand the problem.



Subtraction of the background:

Generated Gaussian +background

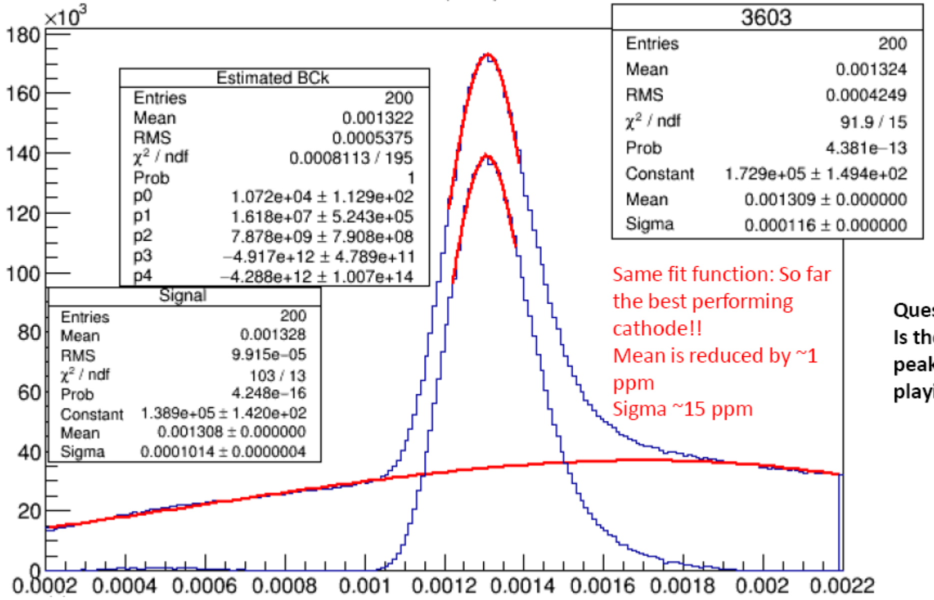




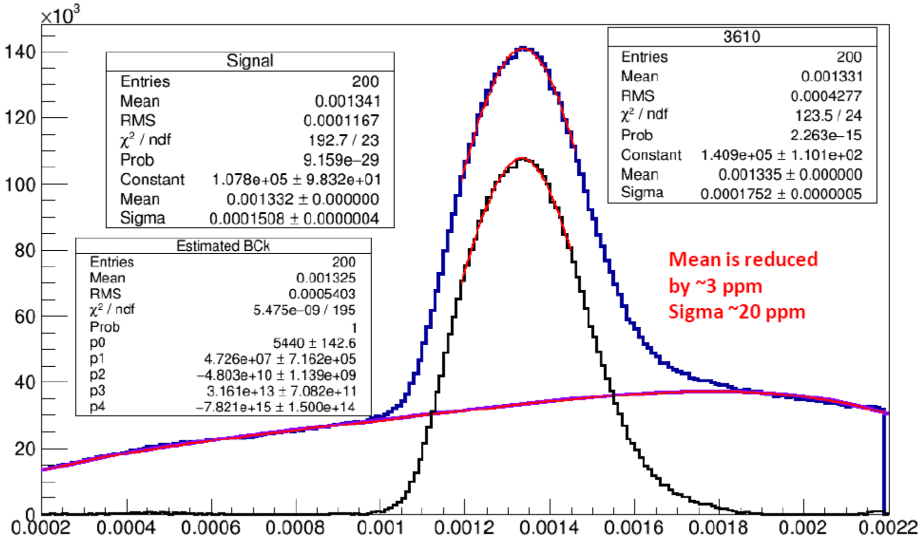
What gives rise this long tail in the unphysical n-1 in the higher range?

Physics data

n-1 (VS)

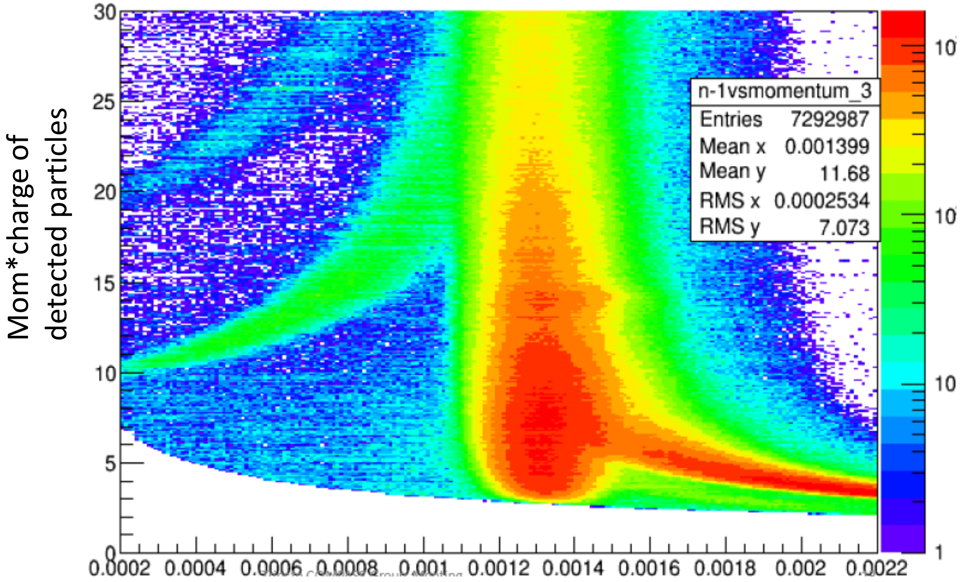


Question: Is the double peak is still playing role?

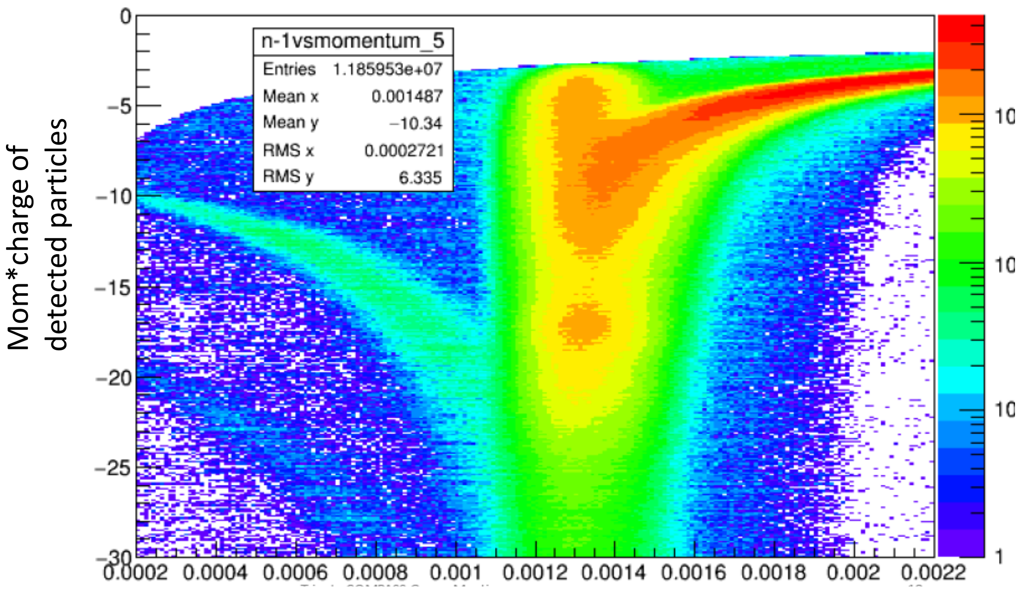


Detailed study of the structure of the "refractive index maps".

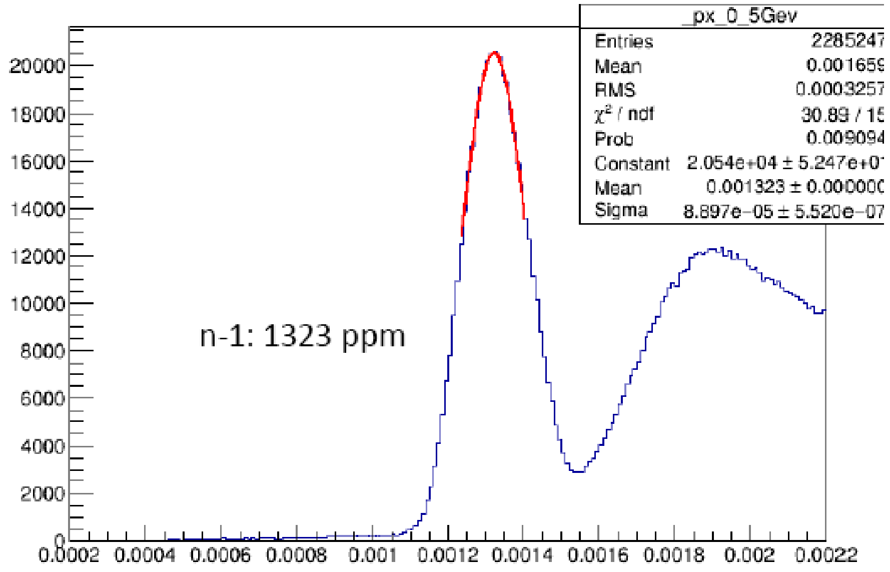
Positive tracks



Negative tracks

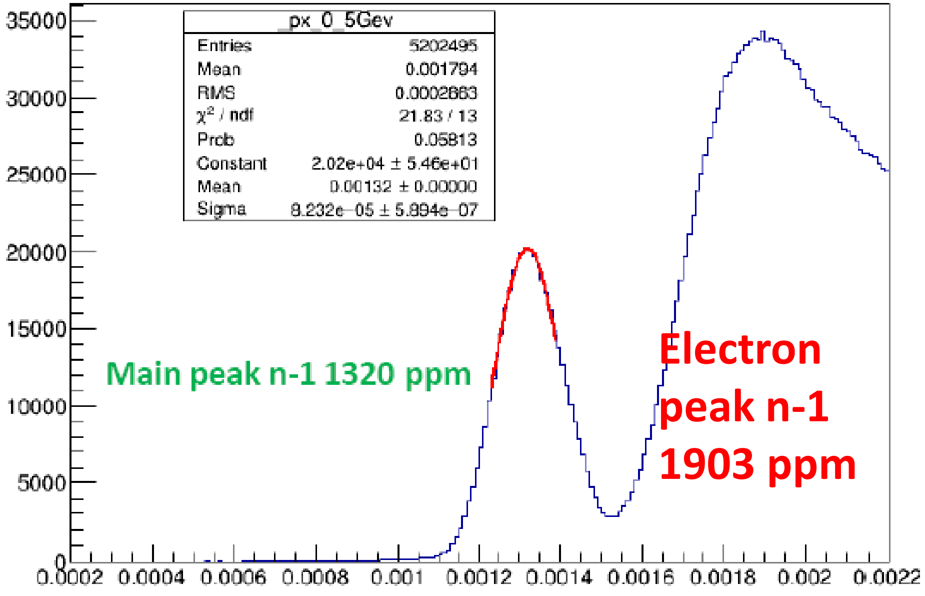


I am currently analyzing the detail structure of the n-1 in different momentum regions.



In future I would like to construct an algorithm to extract n-1 with better accuracy.

To improve PID.

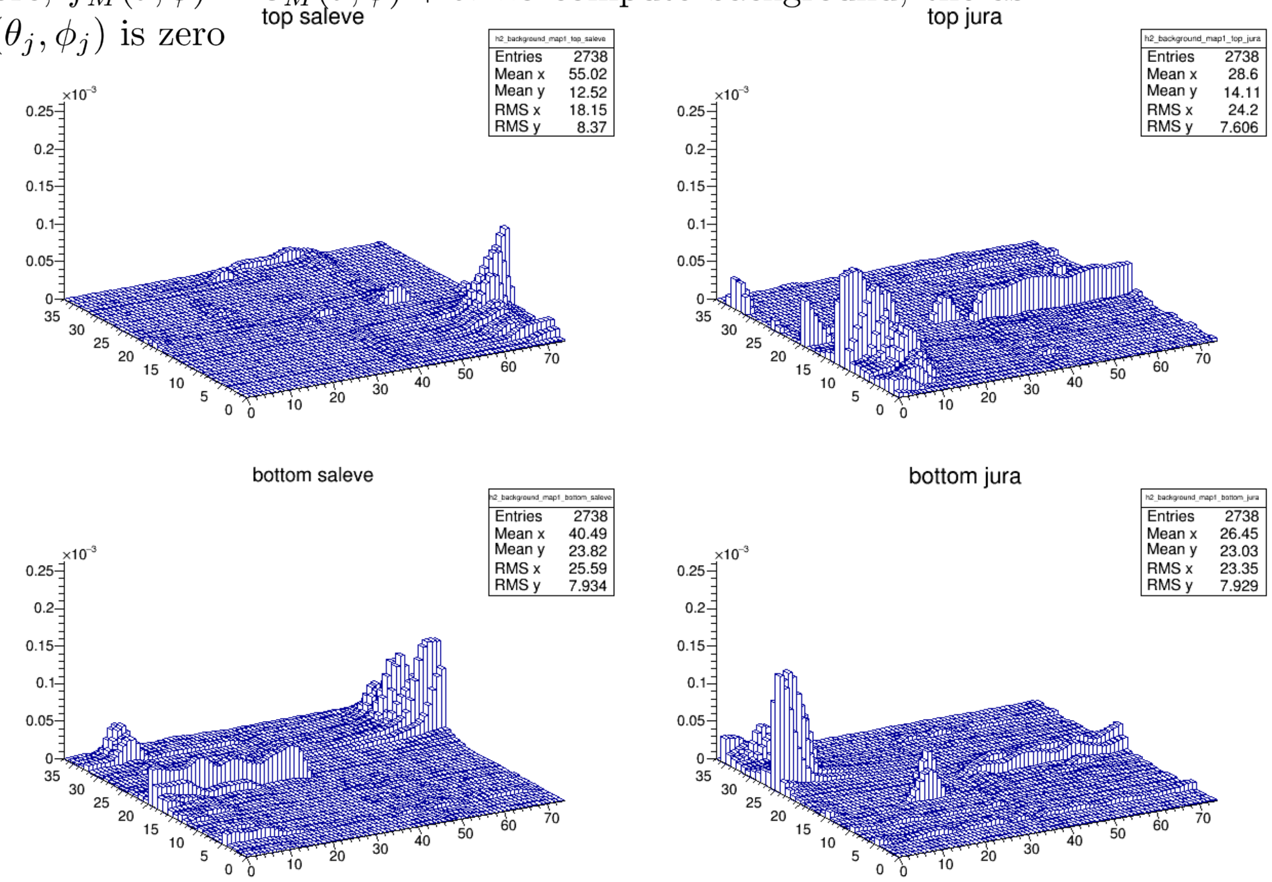


Background Map for RICH

The extended likelihhod for each mass hypothesis M is written as following:

$$L_M = exp[-(S_M + B)] \prod_{j=1}^{N} f_M(\theta_j, \phi_j) \quad (1)$$

where f_M takes into account that each photon belongs to either signal or background. Therefore, $f_M(\theta, \phi) = s_M(\theta, \phi) + b$. To compute background, the assumption is $s_M(\theta_j, \phi_j)$ is zero



- Hit probability/Square area/Event
- Background:
  - Detector noise
  - Cherenkov photons from the other particles in the event
  - Clusters from out-of-time hits.
- In 2016 detector thresholds were tuned many time: optimize stability.
- I am generating background maps for every period for the production of runs.

One Example

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- Introduction to COMPASS
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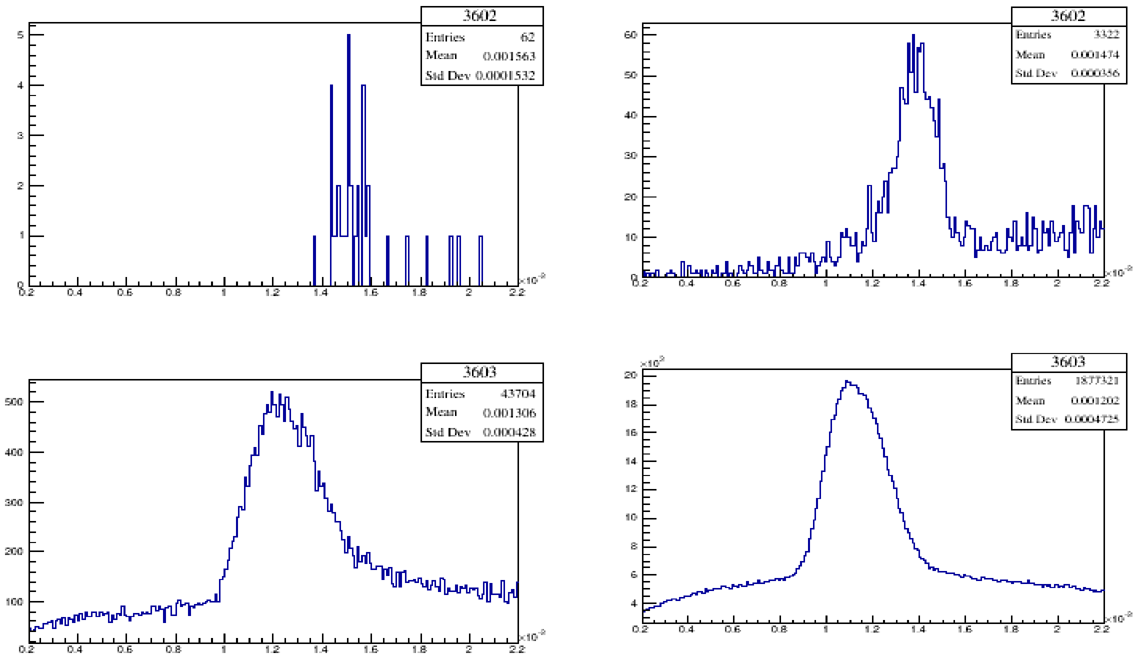
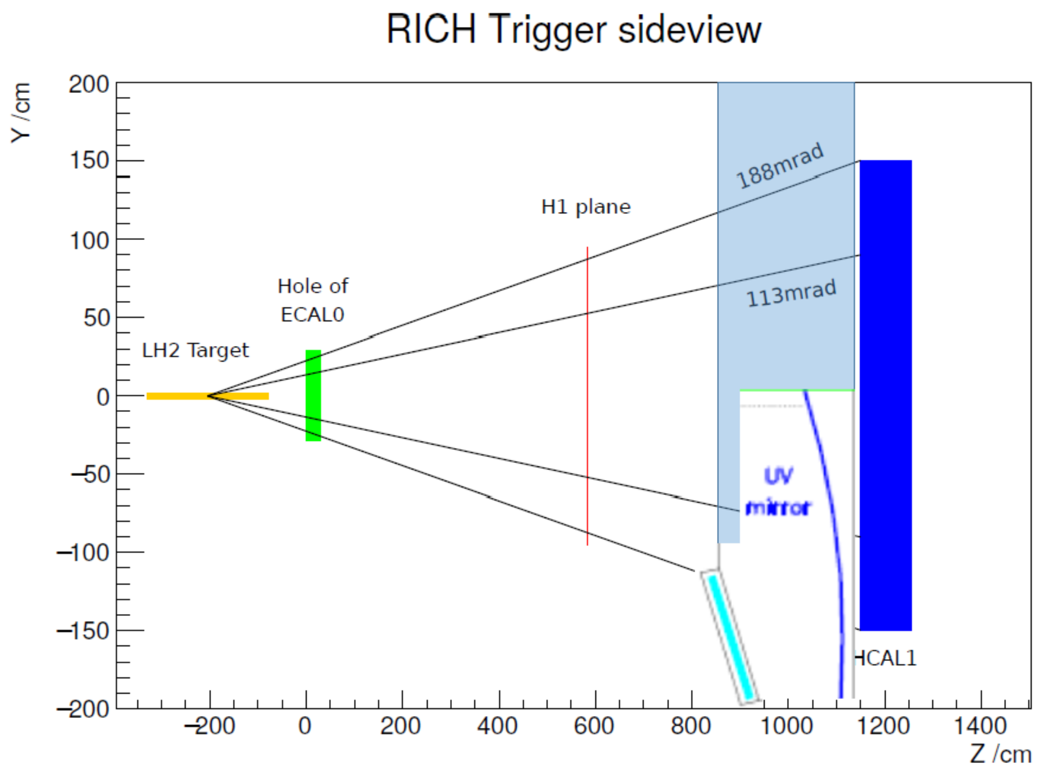
  - **Analysis**
  - Performance of MAPMTs : observation and understanding
  - Analysis of RICH-1 survey : analysis and outcome
  - Post survey modification and outcome
  - Understanding physics background refractive index of the radiator gas
  - **Data-taking to characterize new photon detectors.**
  - **Characterization results.**
- Requirement of an EIC.
- R&D for EIC.
- Participation in hardware activity of COMPASS and ongoing work .
- Future Plans.

Data-taking to characterize new photon detectors.

Pion Data taken in Sep.2017

For Characterization we needed special beam and dedicated trigger. As, 2016-2017 physics trigger only looked into forward charged particle.





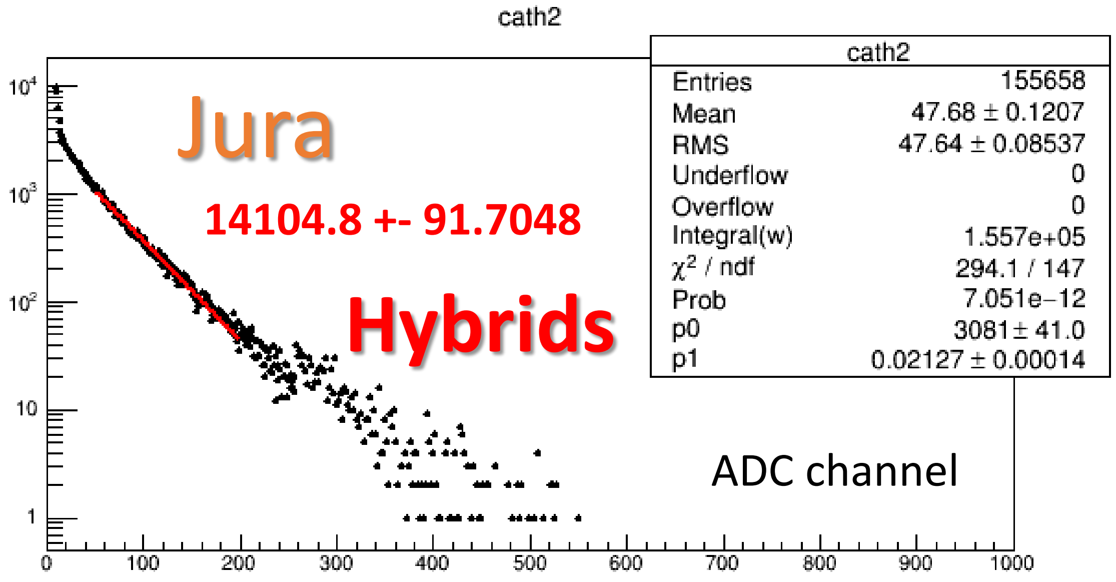
Same number of events processed in reconstruction software.

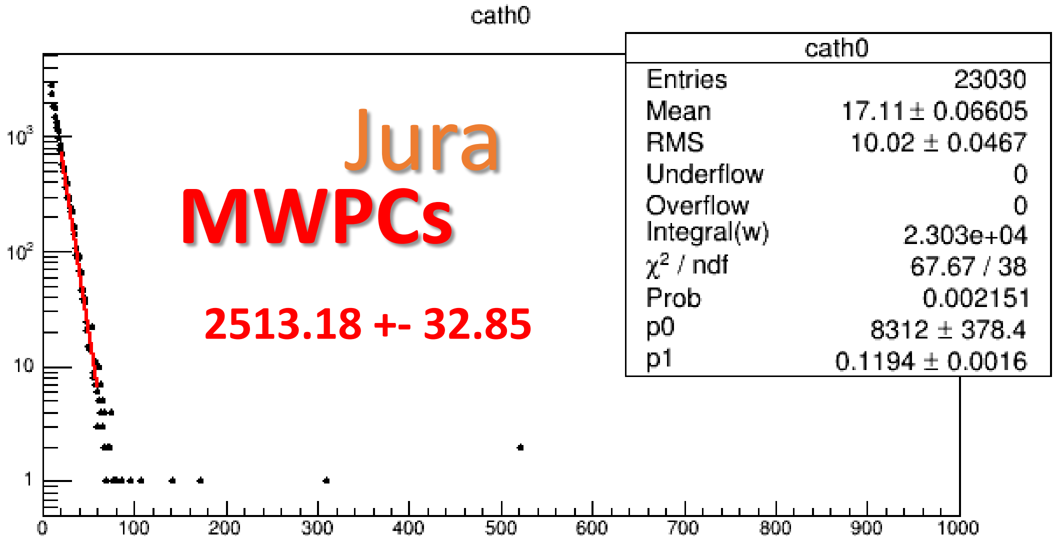
50 times more statistics in hybrid

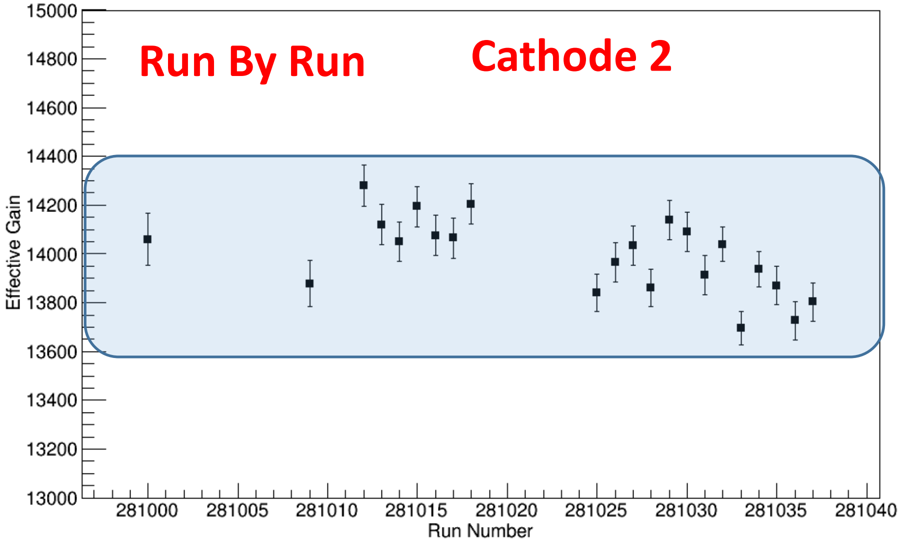
- **dedicated trigger** was set up for large angle coverage in RICH detector
- Negative Pion beam energy = 160 GeV
- Collaboration allowed 2 days of dedicated data taking for this characterization.

Characterization results.

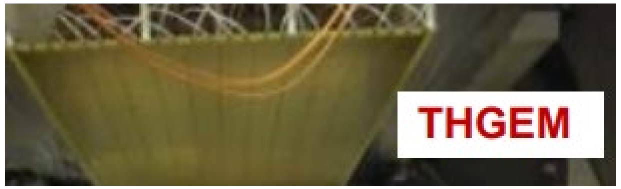
Gain

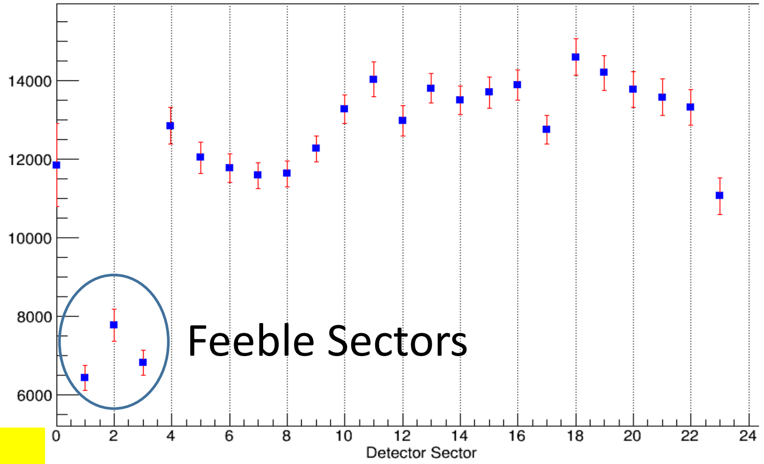






The observed gain during this period is around 14K. Within this 5% band.

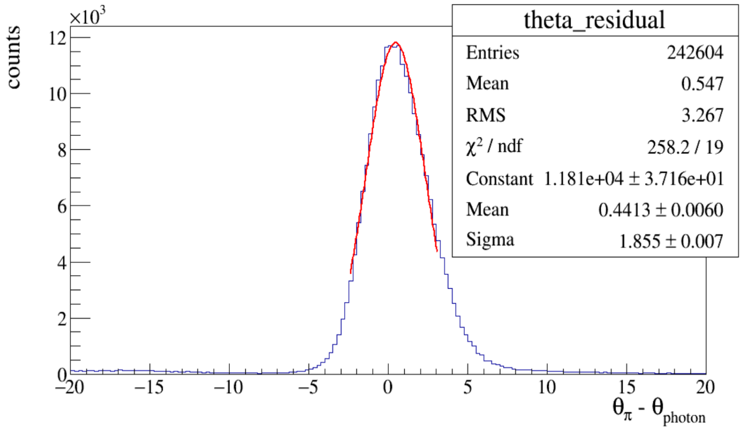




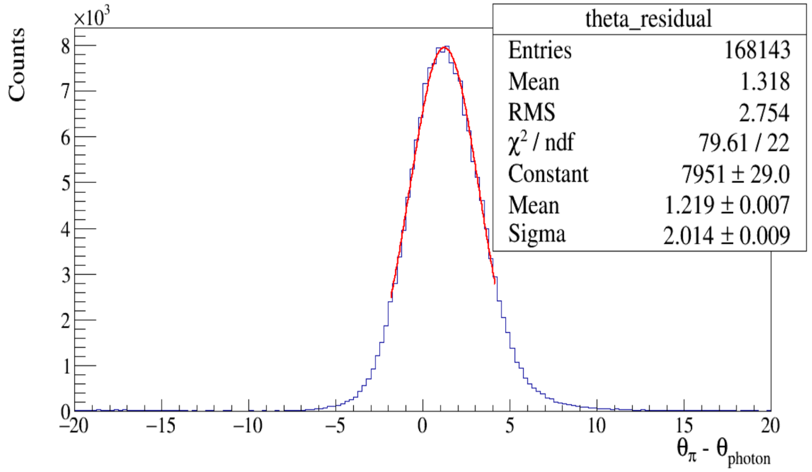
The detectors have good stability and uniformity.

Photon angle reconstruction

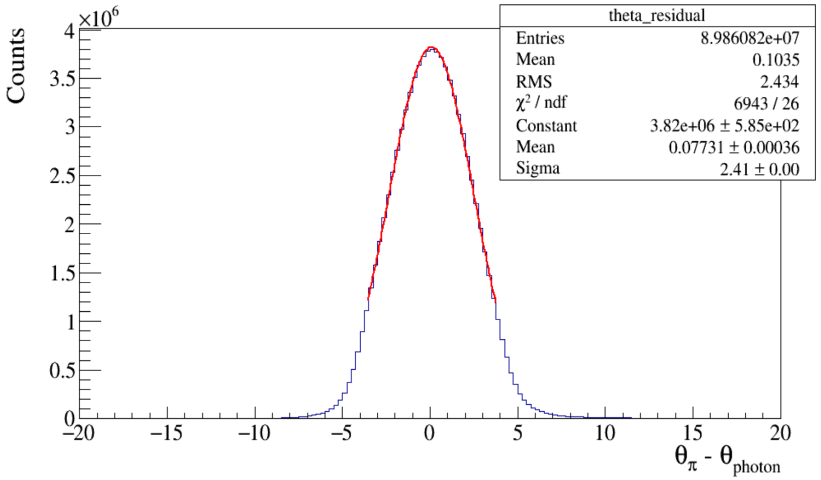
Hybrids combined



MWPC combined



PMT combined



$$\vartheta = arccosine\left(\frac{1}{n\beta}\right)$$

Estimate ϑ_π *and take differences of each photon*

Pion track selection:
pion likelihood > 1.2 * Second likelihood.

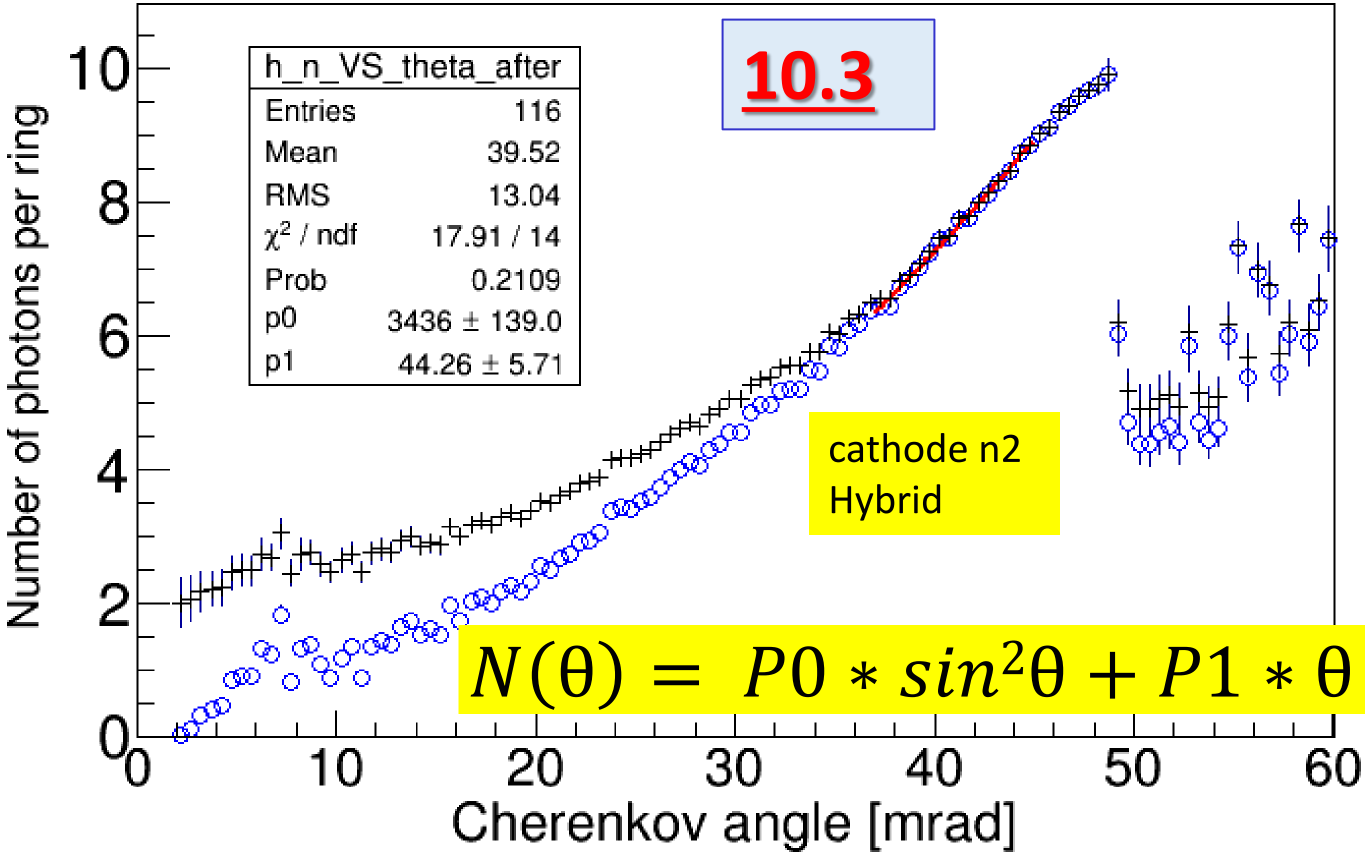
Summary of Angular Resolution :

Hybrids ~ 1.85 mrad

MWPCs ~ 2.0 mrad

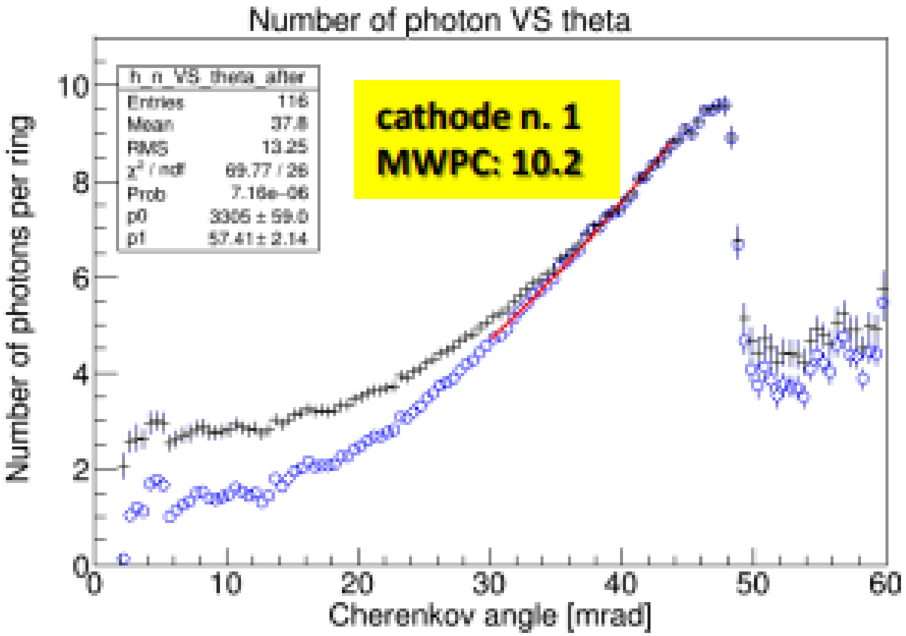
MAPMTS ~2.41 mrad

Number of photons



$$N(\theta) = P0 * sin^2\theta + P1 * \theta$$

Extrapolate to pion saturation angle → 55.2 mrad, no of detected photo electrons = 12.9. First part of the function = 10.3 +/- 0.4; second part of the function= 2.6 +/- 0.3



Results have been presented in RICH2018 conference, I have presented them in COMPASS Analysis and Collaboration meeting

Outline

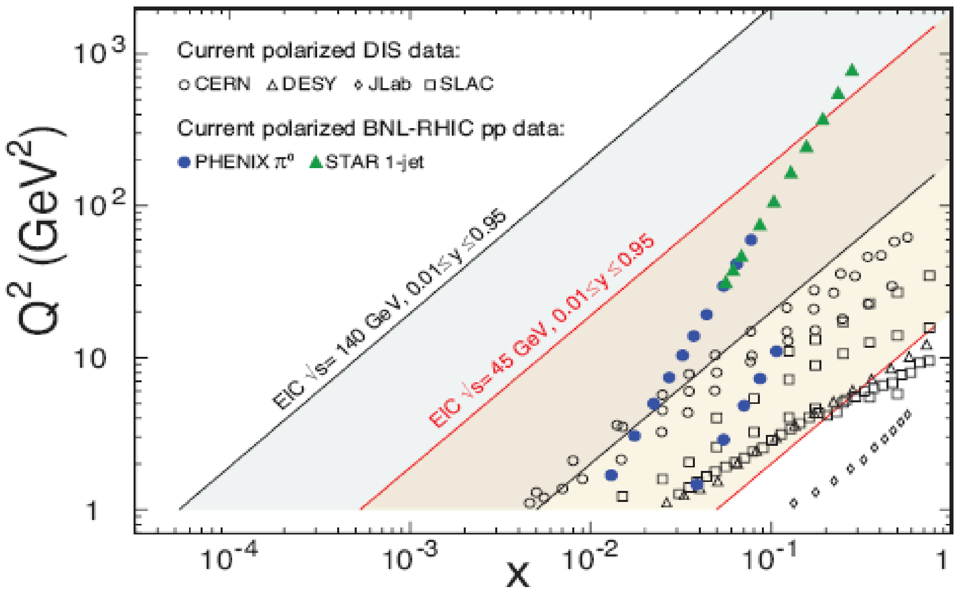
- ❑ Introduction to COMPASS
- ❑ Fundamental physics COMPASS addresses
- ❑ The physics motivation
  - ❖ Analysis
  - ❖ Performance of MAPMTs : observation and understanding
  - ❖ Analysis of RICH-1 survey : analysis and outcome
  - ❖ Post survey modification and outcome
  - ❖ Understanding physics background refractive index of the radiator gas.
  - ➢ Requirement to characterize new photon detectors.
  - ➢ Characterization outcome.
- ❑ **Requirement of an EIC.**
- ❑ **R&D for EIC.**
- ❑ **Participation in hardware activity of COMPASS and ongoing work .**
- ❑ **Future Plans.**

RICH in future Electron Ion Collider(EIC)

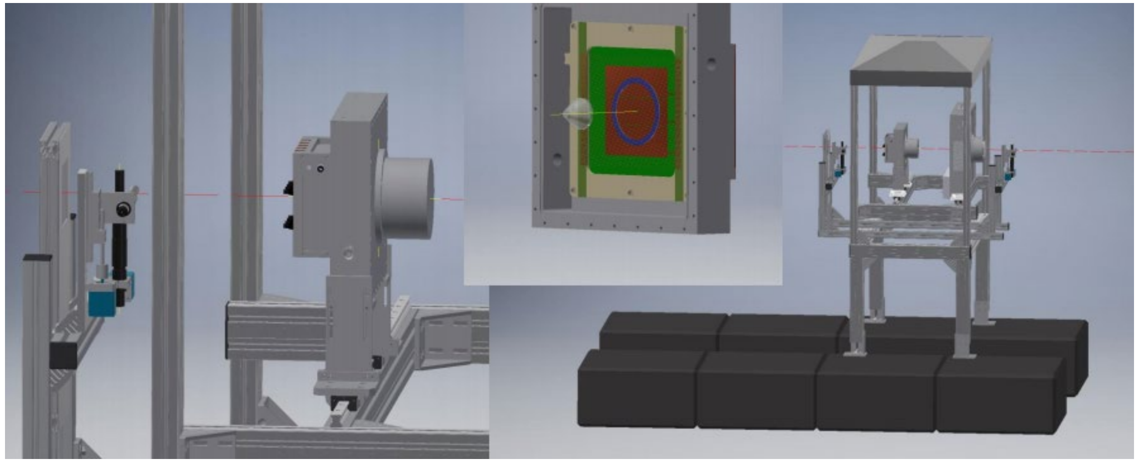
Future EIC detectors need hadron PID in wide momentum range.
Too challenging for present technology!

- ❖ Number of produced photons per unit length is limited for reduced density of gas.
- ❖ **Increasing the radiator length recovers number of photons.** This approach is prohibitive in a collider set up.
- ❖ Alternative approach: Detect photons in low wavelength (~ 120 nm)→ Quest for an alternative photocathode
- ❖ Windowless RICH is an option.
- ❖ To achieve better space resolution small pad size readout is needed. → October test beam.

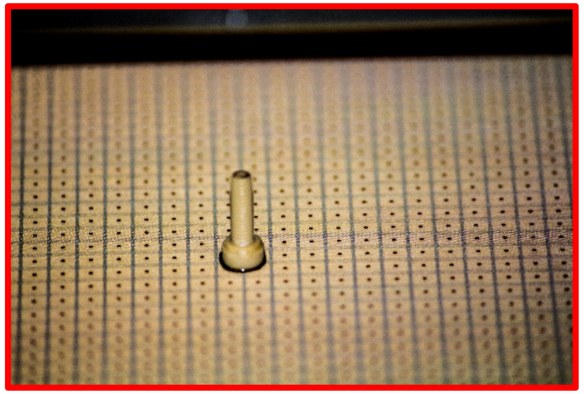
Kinematic coverage

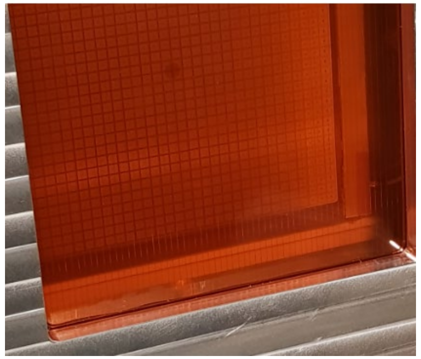


Parton four momentum fraction x vs four momentum transferred by the electron to the proton Q^2 . Current data and the future coverage of an EIC.



Minipad with Micromegas





R&D for diamond photocathodes

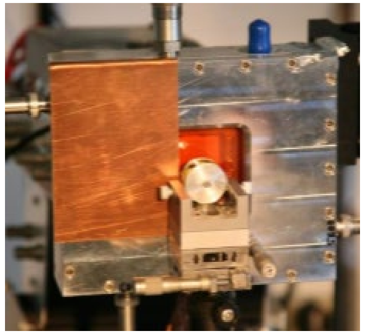
CSI is a very well know photo-cathde for VUV photon detection
Caveat→ Hygroscopic. Air contamination deteriorates quantum efficiency.

Diamonds can be an alternative for the following properties (For Comparison CsI properties in Red):

1. Band Gap of 5.5 eV (6.2 eV)
2. Low Electron Affinity 0.35-0.5 eV (0.1 eV)
3. Chemical inertness. (Hygroscopic)
4. Radiation hardness.(Degradation under intense photon and ions flux)
5. Good Thermal conductivity.

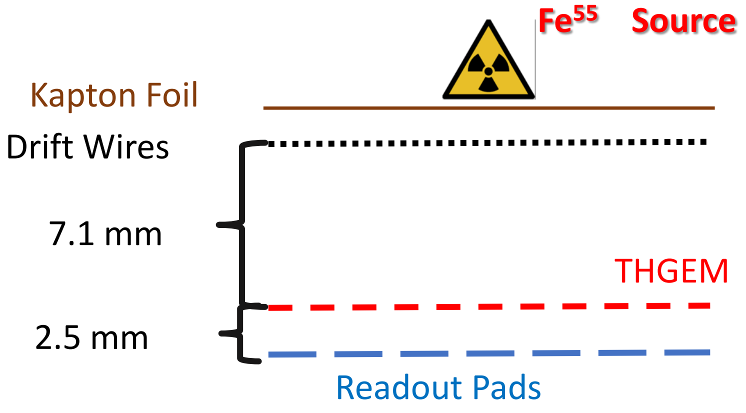
- **Recently Novel Photocathode Production technique** (**international patent: Patent n. WO 2017/051318 A9 - INFN-CNR**) developed in Bari, Italy.
- Deposition : layers of **hydrogenated nano-diamond** powder.
- Powder filtering (grain size selection)
- Plasma Treatment (Hydrogenation)
- Water emulsion.
- Sprayed at T~120^{O}C (instead of 800^{O}C in standard technique).

R&D activity ongoing for the future EIC RICH foresees to use a less critical photocathode to work in the very far UV domain.



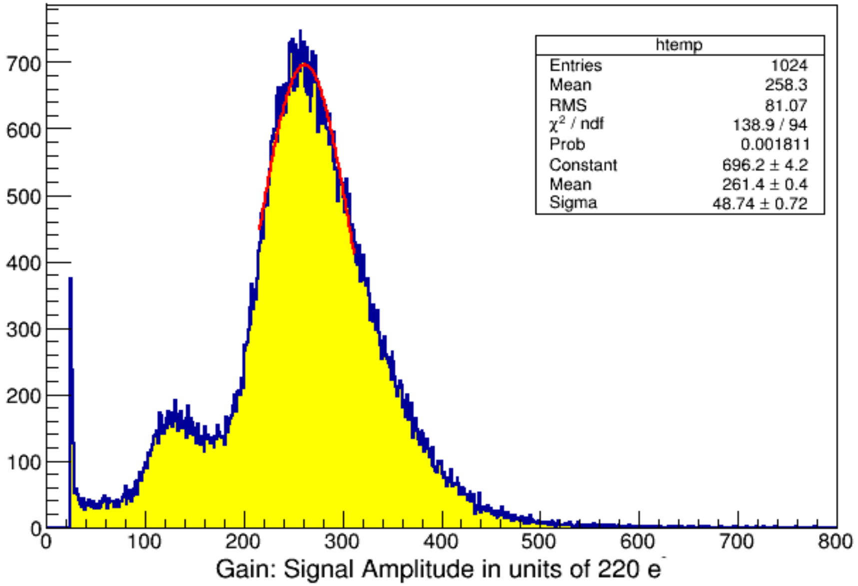
Mounting CsI coated detector is non trivial

Schematic Diagram of the Chamber



THGEMs of active area 30X30 mm^2

Fe^{55} Source Ar/CO_2 70/30
Before Coating

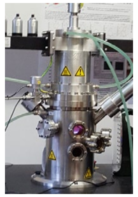
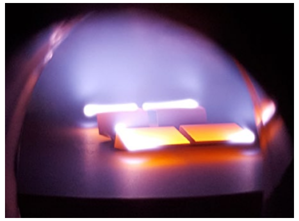
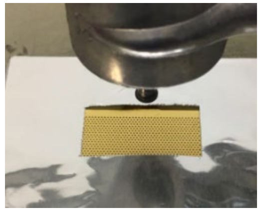
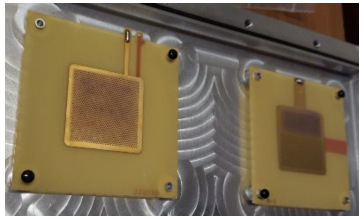


Drift -2940 V THGEM Top -1840 V
THGEM Bottom -500 V

THGEMs of different types have been characterized before and after:

1)	0 µm rim ID1	H-ND	1/2 coating
2)	0 µm rim ID2	ND	1/2 coating
3)	10µm rim ID1	H-ND	full coating
4)	10µm rim ID2	CsI	full coating
5)	20µm rim ID1	ND	1/2 coating

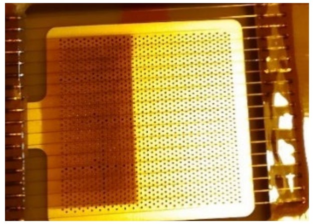
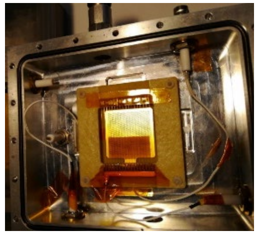
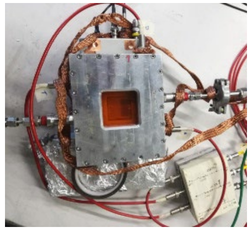
R&D for Future EIC RICH

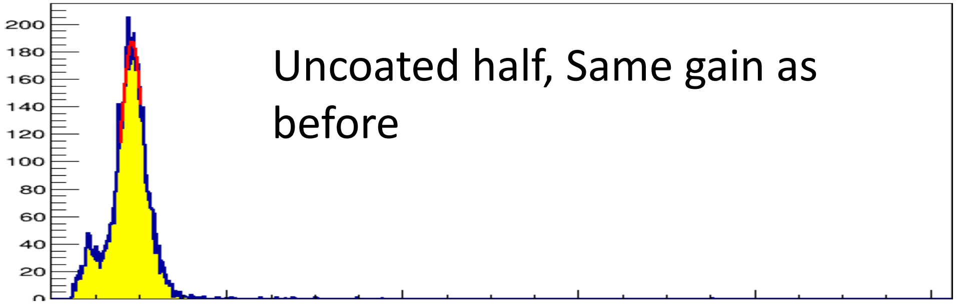






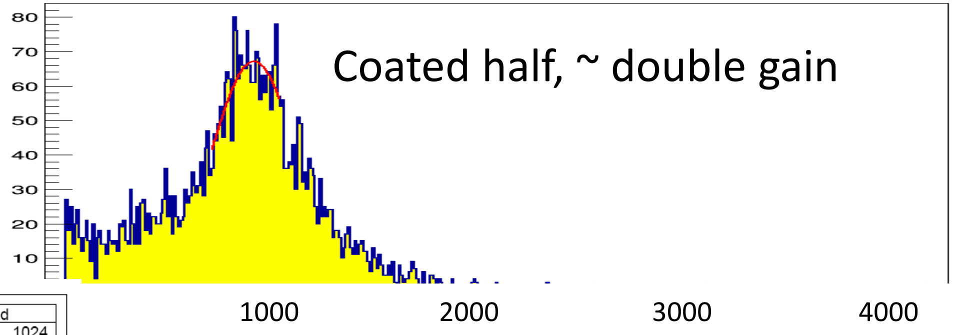
Standard Nano Diamond

The Surprise !!

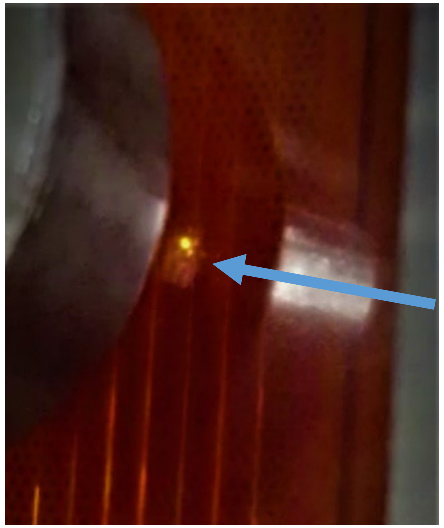
Post coating characterization→ Voltage configuration was used as before coating. Same setup → One to One comparison.

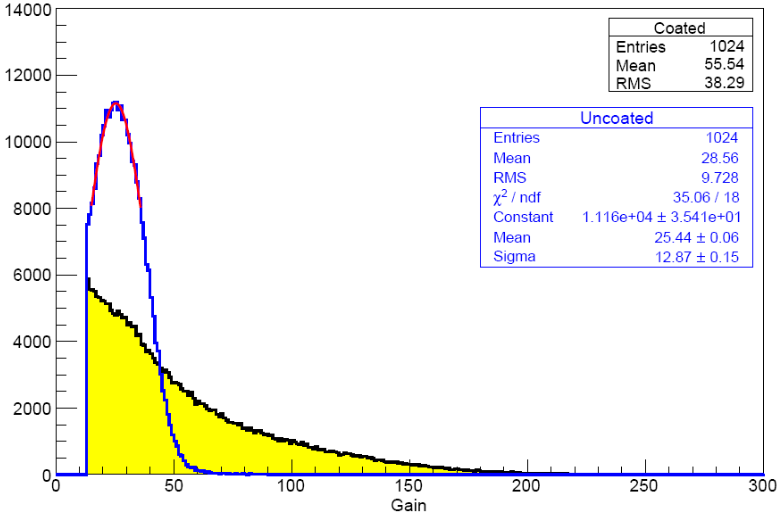




Hydrogenated Nano Diamond



Fully coated with **hydrogenated Nano diamond**. After coating did not stand voltage (sparks).



Voltage Stability has decreased.
Frequent sparks have been observed.
Can not reach nominal voltage obtained before coating.

About factor of 2 increase in amplification for the coated part

Promising technology!!

A lot or R&D required to understand the open questions.

I reported these results in the RICH2018 conference

Conclusions

I took active part in the analysis of RICH performance with physics data and in R&D lab activities:

- ❑The n-1 issue of 2016 has been identified and fixed.
- ❑A better procedure to estimate the n-1 is under investigation.
- ❑The new hybrid photon detectors have been characterized.
- ❑An R&D on diamond nano-grain photocathode is ongoing in the lab.

Future Plans:

1. **Study the performance of RICH (tuning likelihood values: already started, very very preliminary) in different periods of data taking.**
2. **Construct an algorithm for extraction of n-1 from physics data, which is more precise.**
3. **To study the systematics of the hybrid detectors in detailed fashion.**
4. **To take part in the novel techniques of photon detection by converging the parallel R&D activities.**

Thanks for your attention

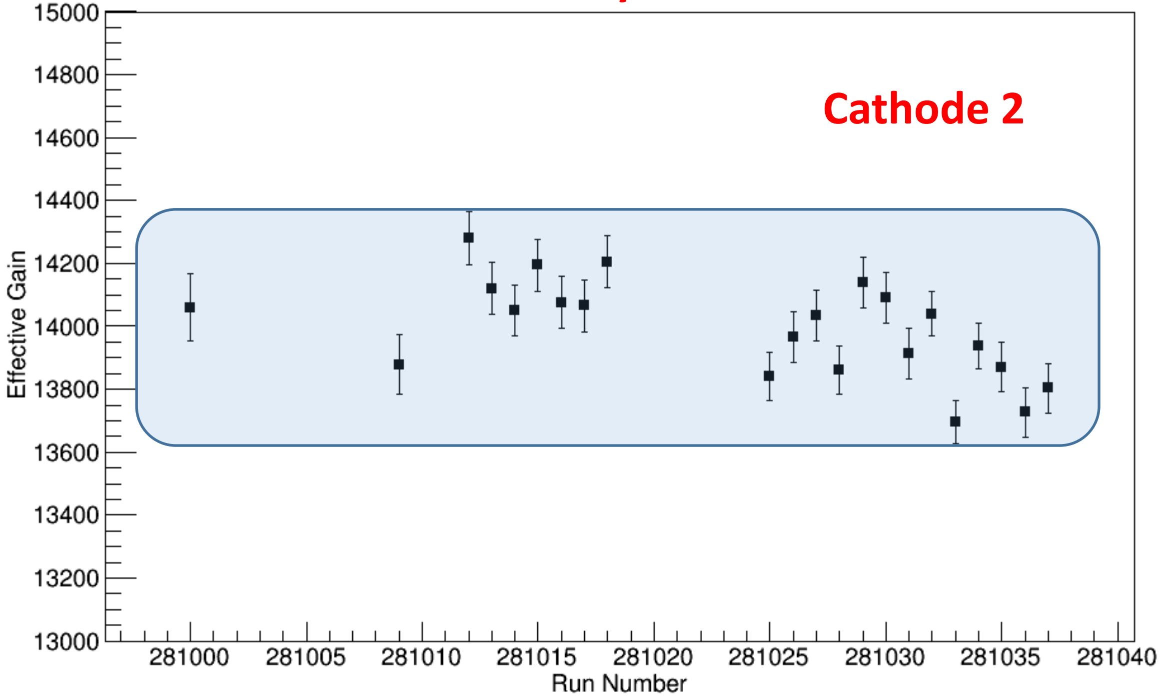
Photons

- For each valid track, selected hits in the photon detector are associated as Cherenkov photons.
- The photon impact position is called cluster. If the photon signal is shared between adjacent pixels, a weighted average determines the hit position. For the MAPMTs, cluster size is 1. Probability of adjacent sharing is negligibly small.
- The trajectory of a photon candidate is reconstructed from the position of its cluster, measured on the photon detector plane, and from its emission point. For each photon the polar and azimuthal angle θ and ϕ can be geometrically reconstructed.
- This photon theta can be used along with particle momentum to monitor the refractive index of the radiator gas. Using Cherenkov formula.

$$cos\theta = \frac{1}{n\beta}; \beta = \frac{P}{E}$$

Gain Stability

Run By Run

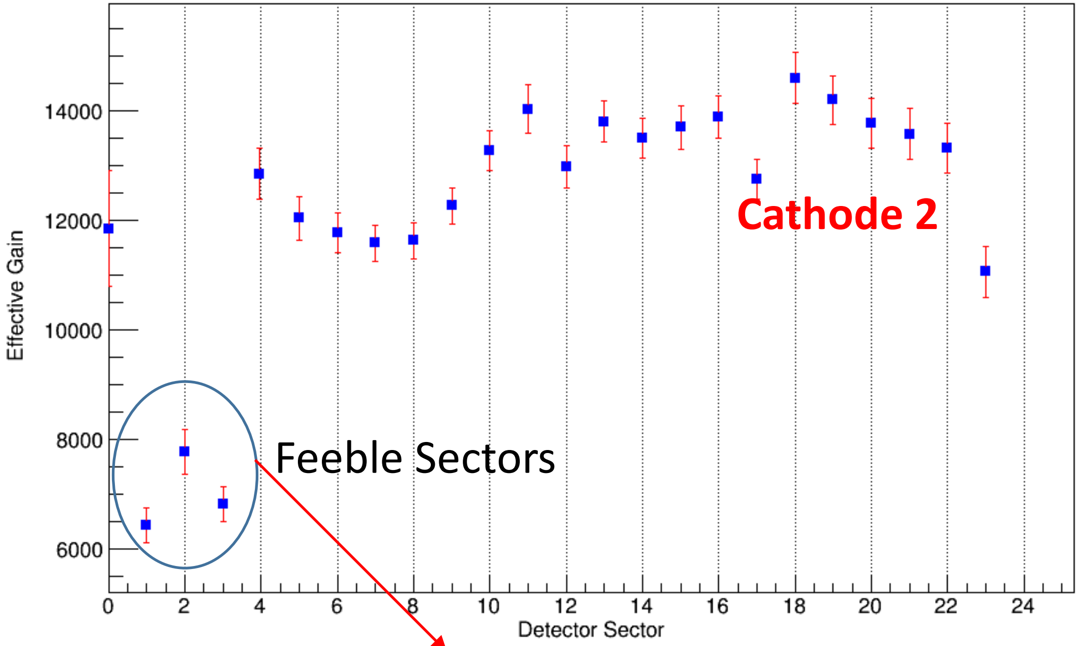


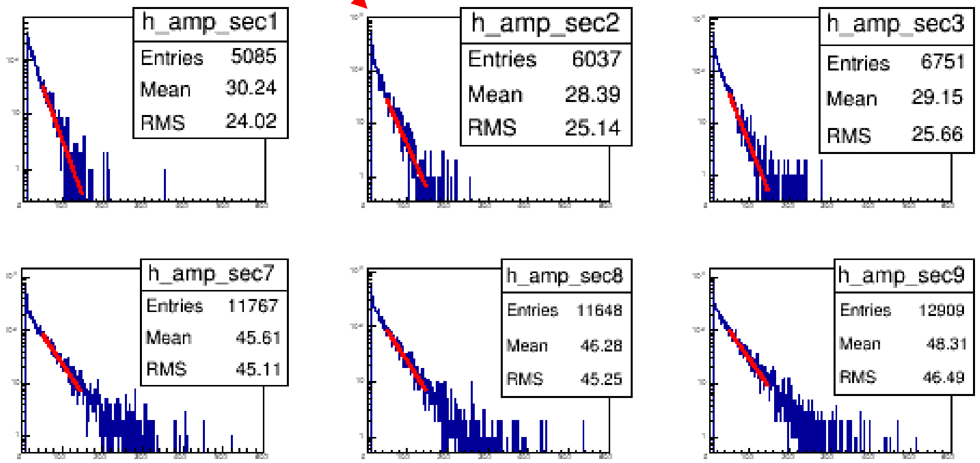
The observed gain during this period is around 14K.
The fluctuation is less than 5%.

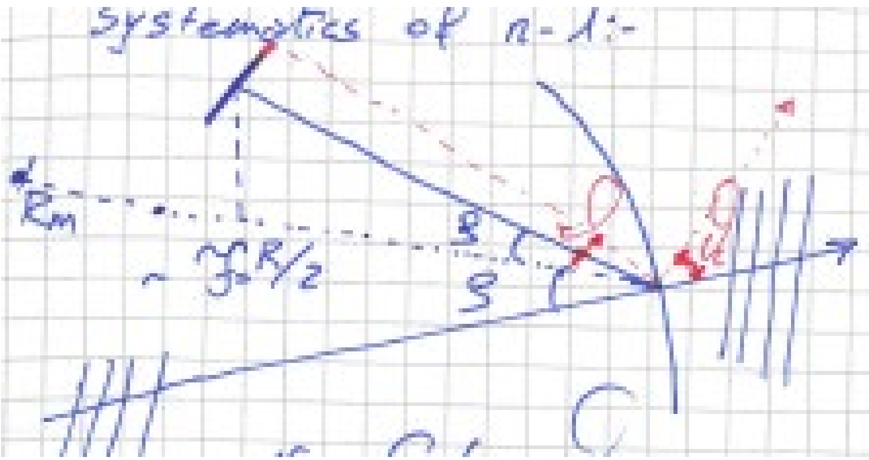
The detectors have good stability and uniformity.

Gain Uniformity

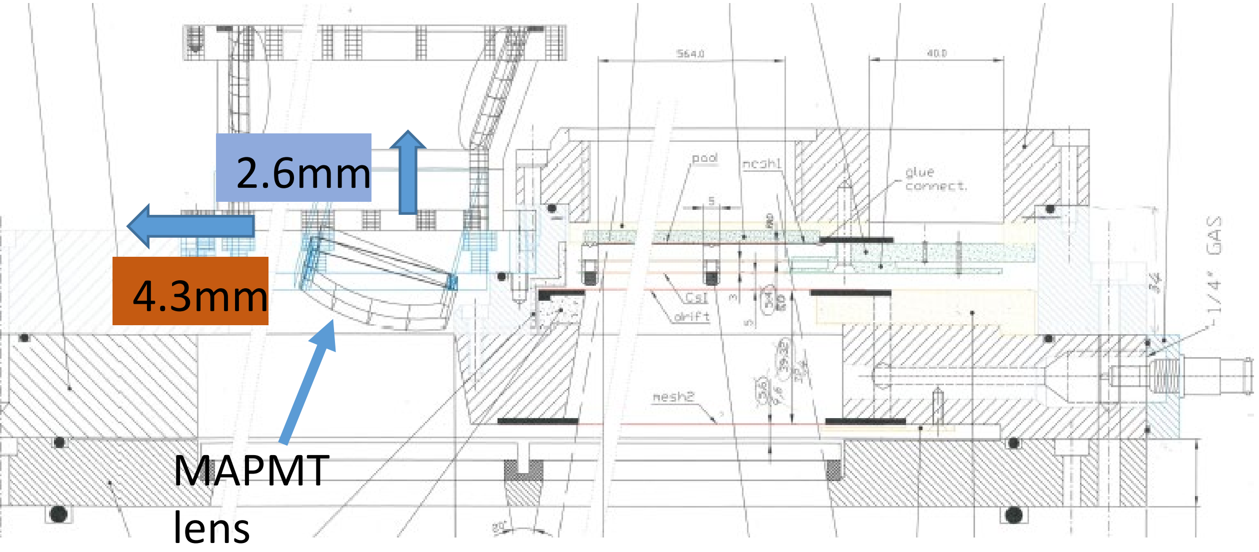
Sector by Sector

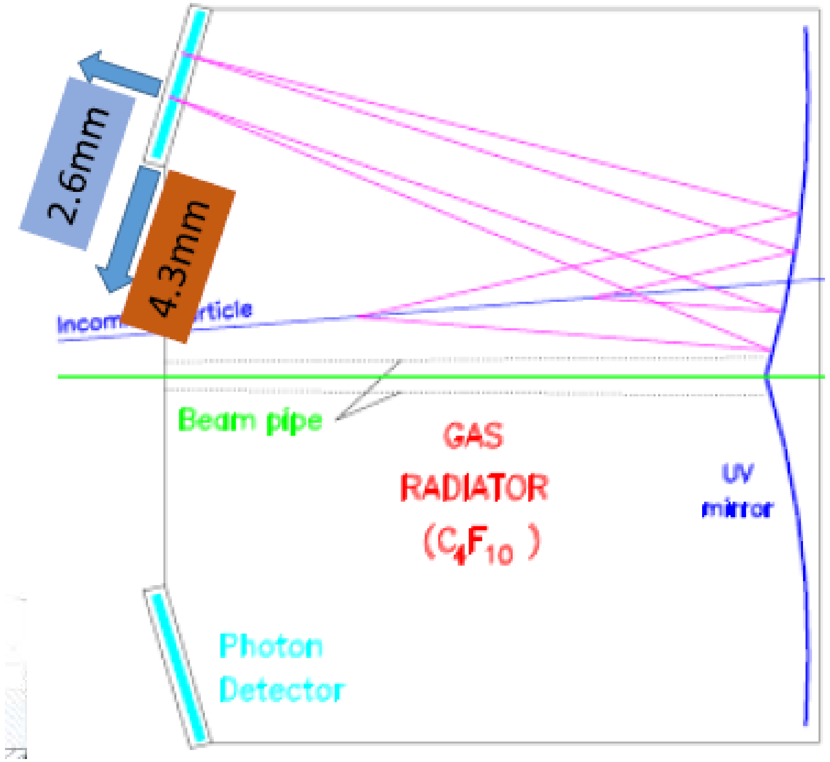





Systematics of n-λ:-

Comparison of mechanical drawings before and after 2016upgrade

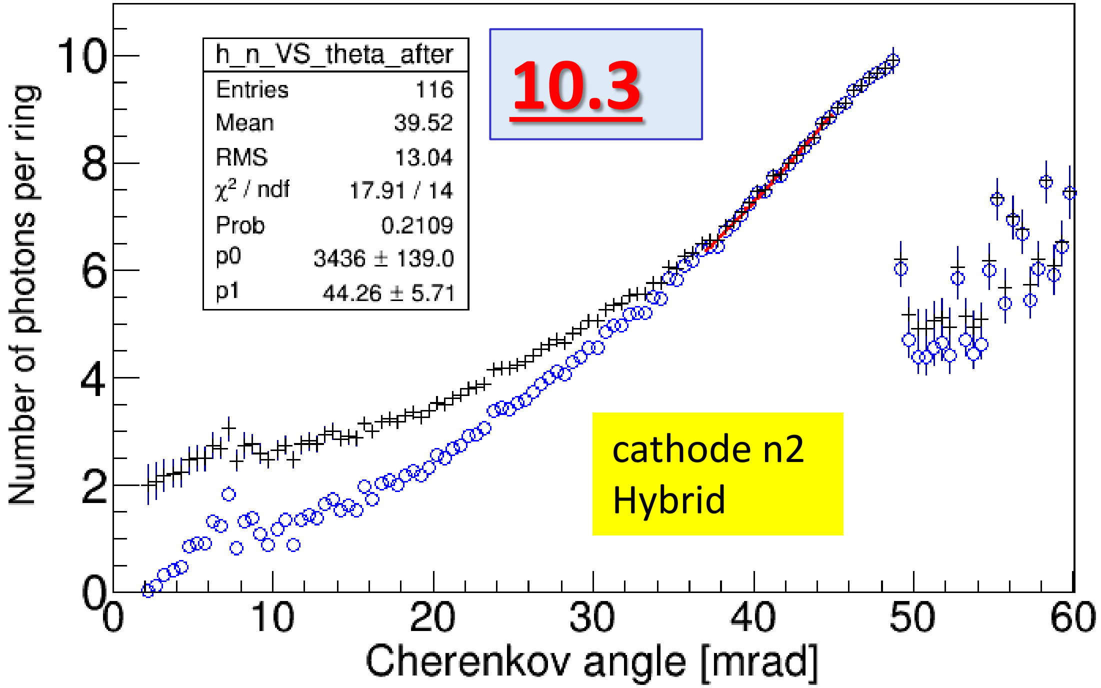




Section of 2016 hybrid+MAPMT Chamber.
Arrows show the difference wrt 2015 MWPC+MAPMT.
4.3 mm is toward beam axis, 2.6 mm is upstream outside vessel.

New detector table has been made and geometry file was updated.

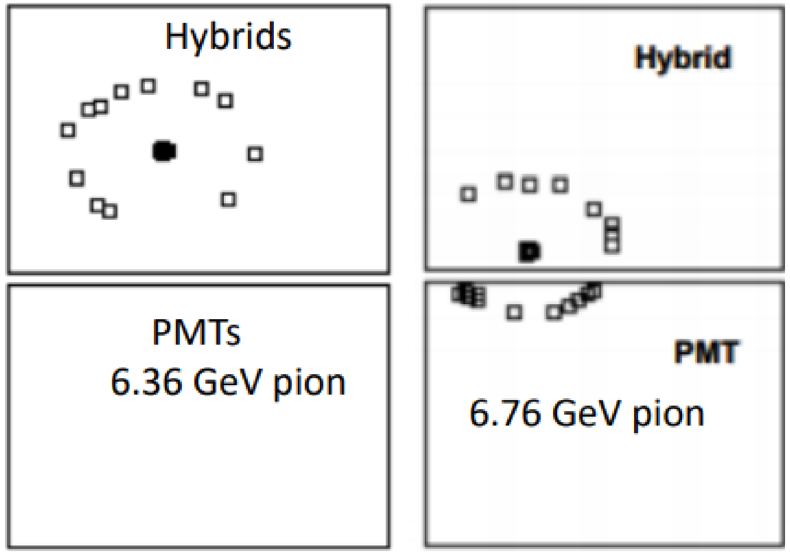
Number of photons



$$N(\theta) = P0 * sin^2\theta + P1 * \theta$$

Extrapolate to pion saturation angle → 55.2 mrad, no of detected photo electrons = 12.9. First part of the function = 10.3 +/- 0.4; second part of the function= 2.6 +/- 0.3

- ✓ Algorithm selects rings in the hybrid which contain 95% of arc length of a half ring within the active are.
- ✓ For the hybrids the standard Poisson correction has been modified to Poisson + Binomial.
- ✓ pion likelihood > 1.2 * second likelihood.

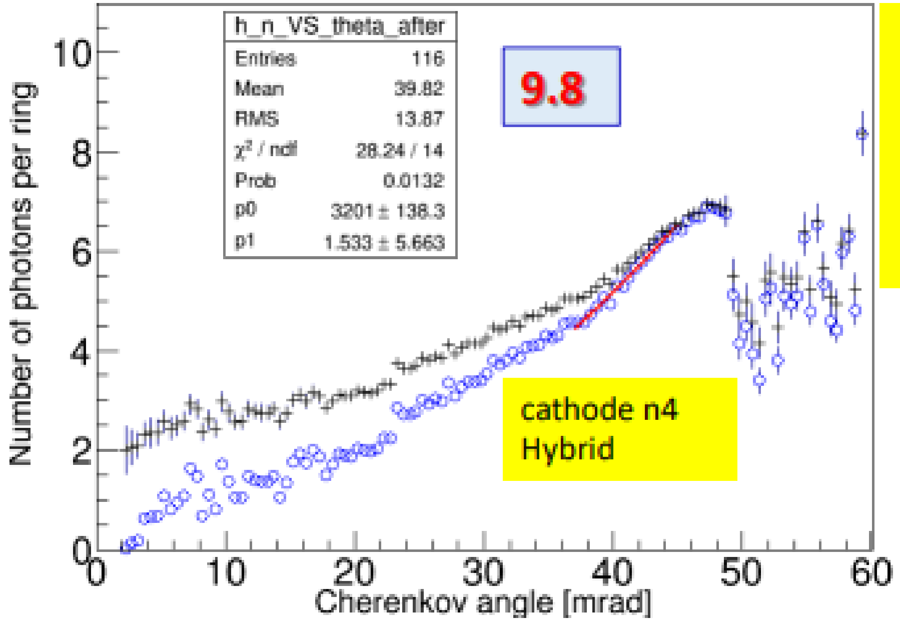


Inaccessibility of transversity from inclusive DIS

$$\int \mathrm{d}y \left[G_D(x,y) + \widetilde{G}_D(x,y)\right] = x\, g_T(x) - \frac{m_q}{M}\, \Delta_T f(x)\,. \qquad (3.5.7)$$

By virtue of this constraint, the transverse polarisation distributions of quarks, that one could naïvely expect to be probed by DIS at a subleading level, turn out to be completely absent from this process.

Number of photons : other cathodes



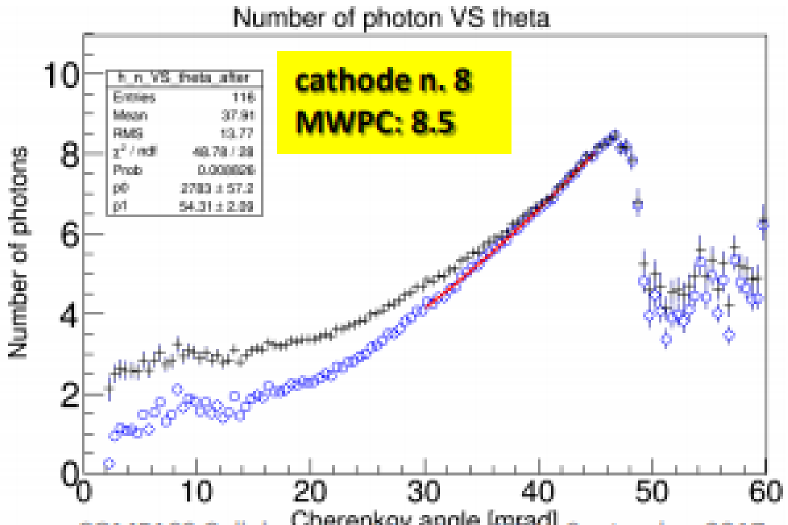
$QE_2/QE_4 = 1.10$

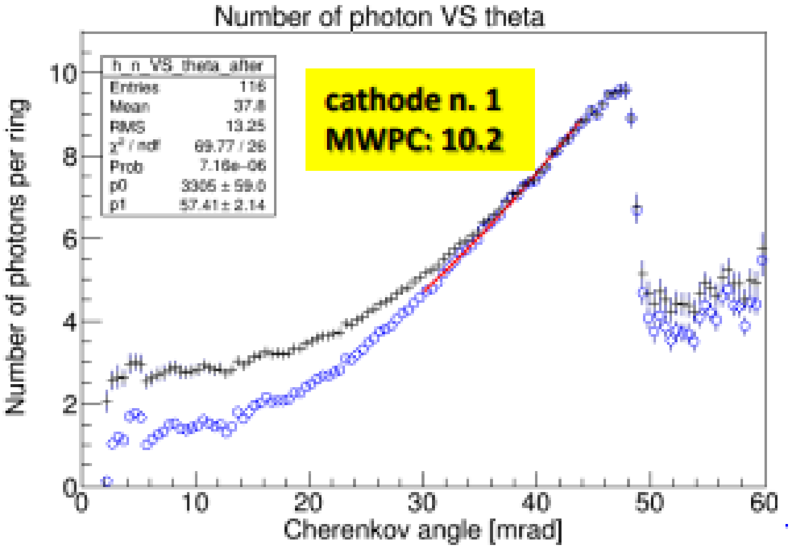
$\frac{\text{No of photon}_{Cath2}}{\text{No of photon}_{Cath4}}$

=1.05

For the Saleve side MWPCs, we have not observed many events. The statistics were to low for doing this analysis.

Extrapolate to 55.2 mrad, n. of det. ph.e.= 9.83. First part of the function = 9.74 +/- 0.4; second part of the function= 0.08 +/- 0.3





9/6/2018 COMPASS Collaboration Meeting, CERN, September 2017