Towards a future upgrade of LHCb-RICH

Theatre of Dreams
LHCb workshop: Manchester

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Science & Technology Facilities Council

Preamble

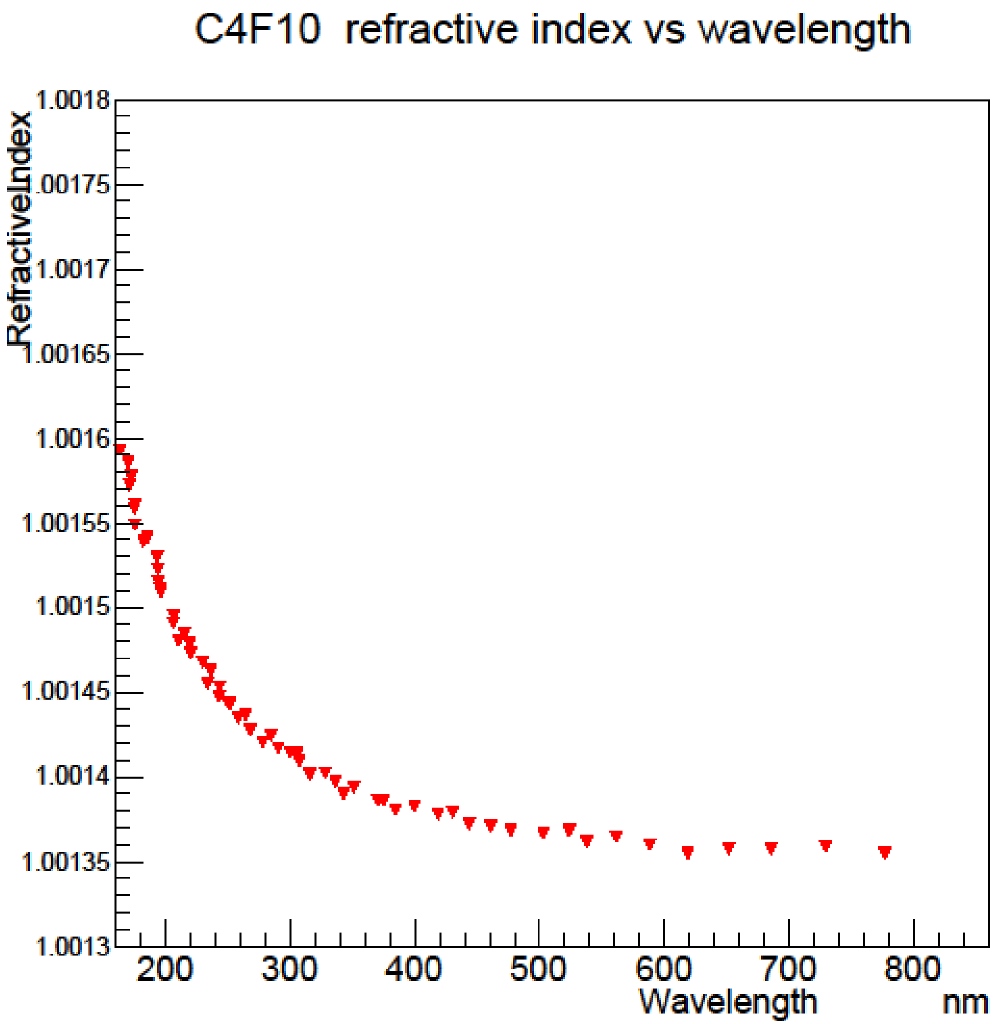
- Part 1: Ideas to re-design the LHCb-RICH system for 10^{34} cm^{-2} s^{-1} luminosity
  - Follow up from the presentation of Carmelo
  - Introduction of Silicon photomultipliers in LHCb-RICH
  - All the results shown are from recent studies and are preliminary

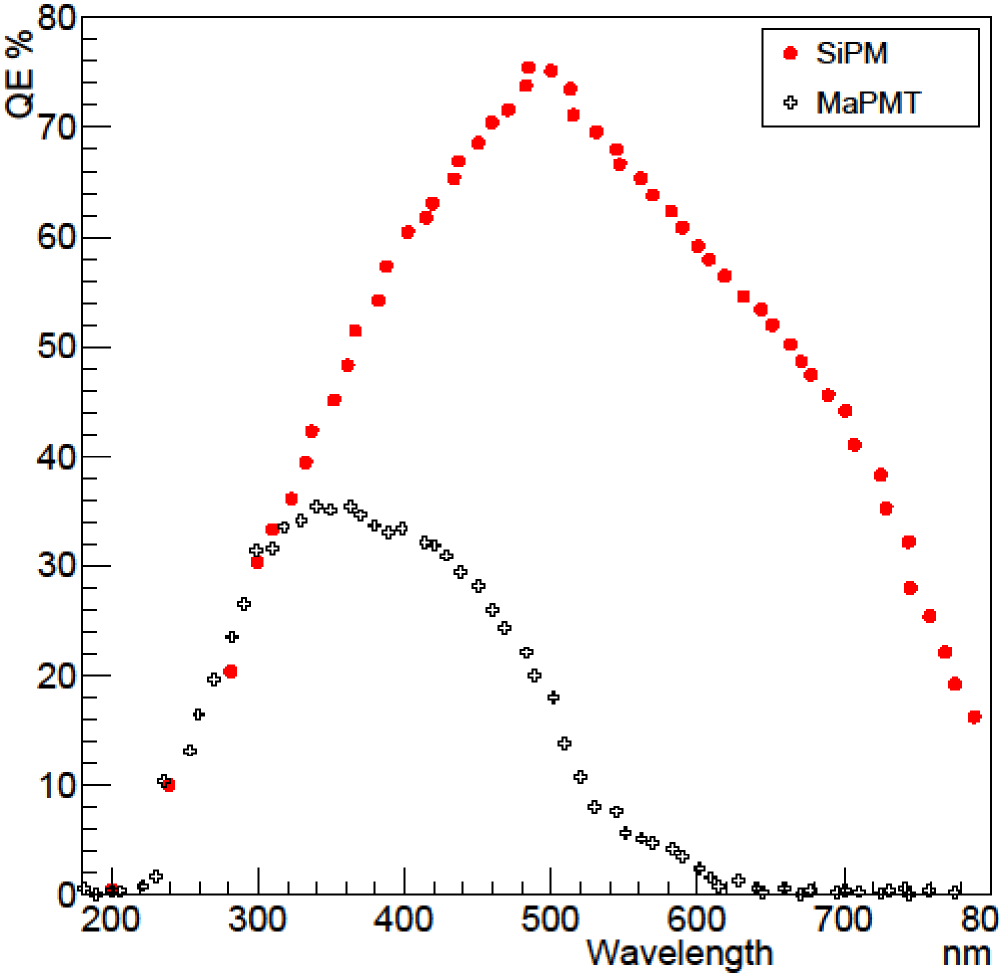
- Part 2 : A new paradigm for Cherenkov detector in the future
  - Introduction of Photonic crystal as Cherenkov radiator in RICH

Preamble

- The current RICH upgrade designed for a luminosity of 2 X 10^{33} cm^{-2} s^{-1}
- RICH performance depends on various factors:
    - Occupancy of hits in the detector plane
    - Cherenkov angle resolutions: *(a) Chromatic uncertainty (b) Emission point uncertainty (c) Uncertainty from pixel size in the photon detector*
    - Resolution of the charged track direction in the RICH
    - Photon yield : Number of hits per charged track
- The design also need to take into account various constraints:
    - Minimize the number of photon detectors and hence detector plane area
    - Interference with other sub-detectors in terms of space
    - Shielding from magnetic field , ease of installation , detector cooling etc.
- This presentation:
    - Explore the option to use Silicon photomultiplier: Better QE and pixel size than that of MaPMT
    - Other options to improve the performance

Refractive index and QE



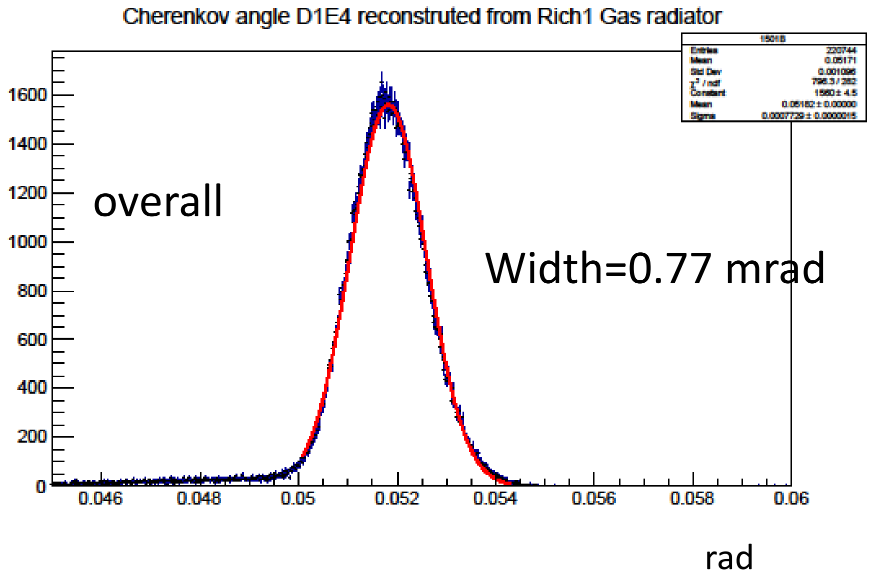


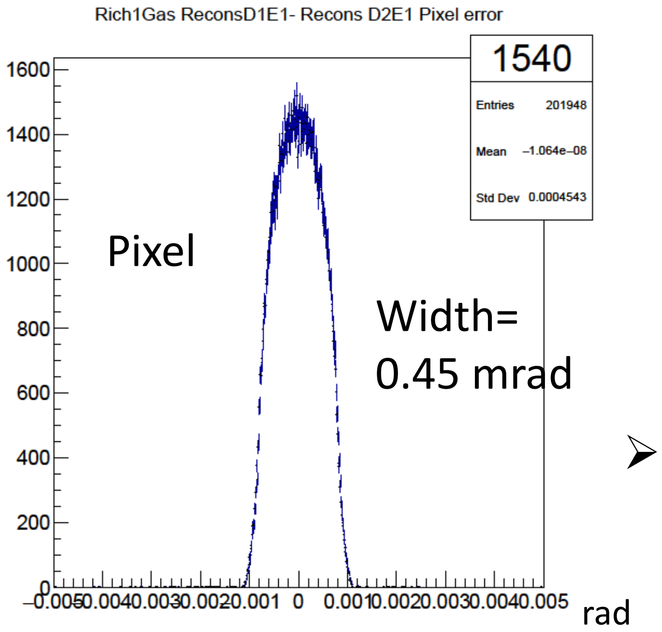
Simulation of Silicon Photomultiplier

- For now using a pixel size of 1 mm * 1mm
- In order to see the effects in a short time period, with minimum changes to existing software structure:
    - *Set the pixel size for the "MaPMT" in the database to 1 mm * 1mm*
    - *Set 25 X 25 pixels in each 'MaPMT'.*
    - *All this done only for the small MaPMTs in RICH1 and RICH2.*
    - *The large MaPMT in RICH2 kept unchanged for now.*
    - *The rest of the geometry is unchanged for now*
- Use particle gun and B-events as appropriate
- Reconstruct the Cherenkov angle to estimate the resolutions
- Run the Gauss-Boole-Brunel chain to test the PID performance
- For now use Lumi20 luminosity for testing PID performance.

	Luminosity $cm^{-2}\ s^{-1}$	# bunches	L_B $cm^{-2}\ s^{-1}$	Beam Energy (TeV)	ν
Lumi20	20×10^{32}	2400	0.834×10^{30}	7	7.6
Lumi100	100×10^{32}	2400	4.17×10^{30}	7	38

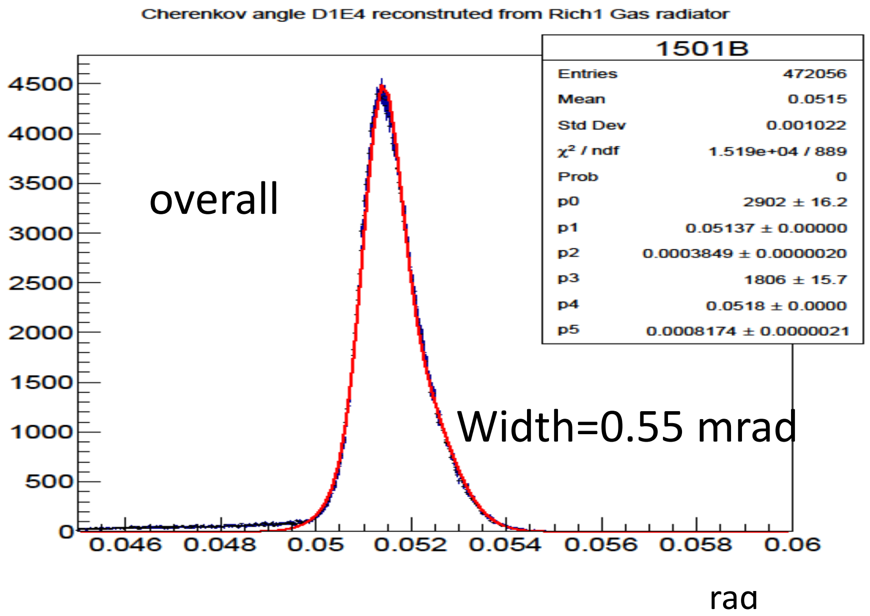
RICH1 resolutions

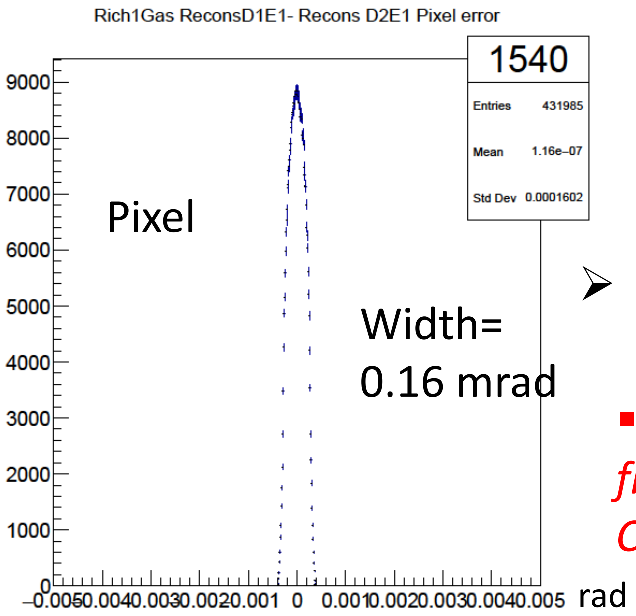




- Using particle gun at 80 GeV/c

➢ Current standard upgrade using MaPMT (pixel size ~ 2.8 mm)

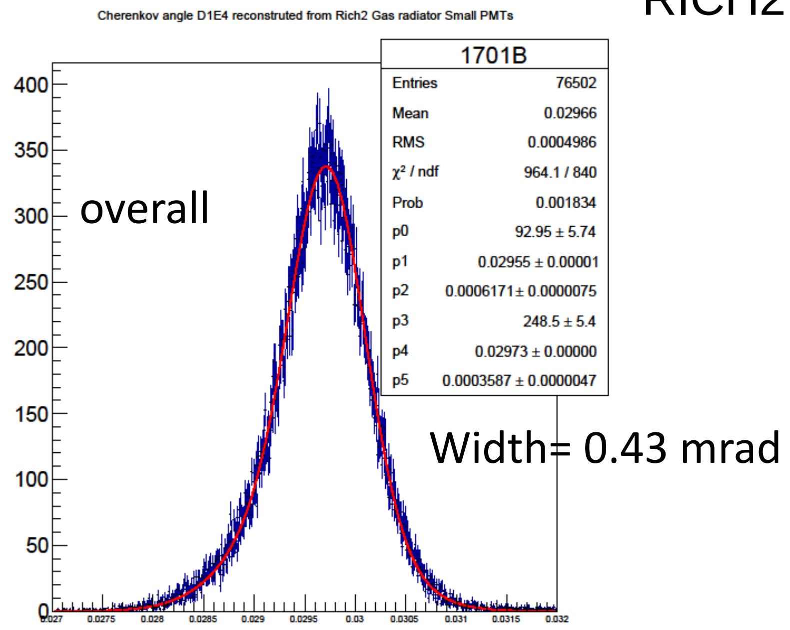


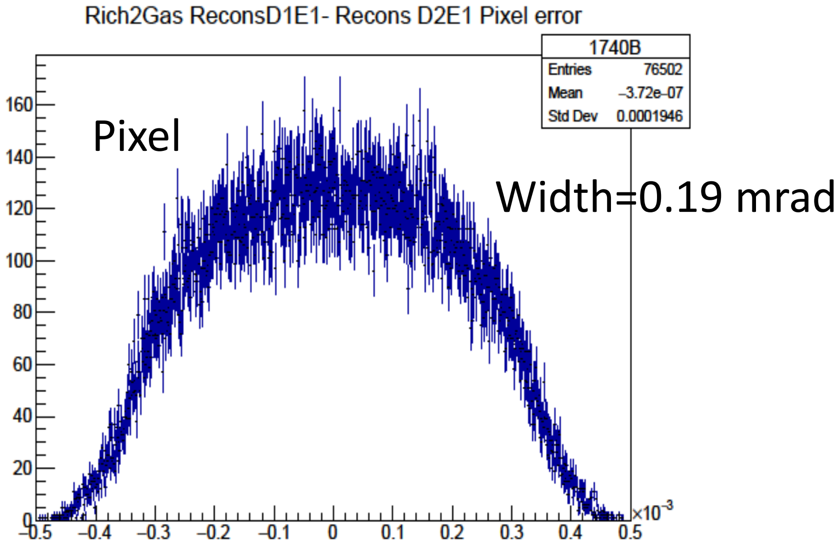


➢ Using Silicon PM (pixel size ~ 1 mm)

- *Improvement in resolution mainly from pixel size and a small part from Chromatic*

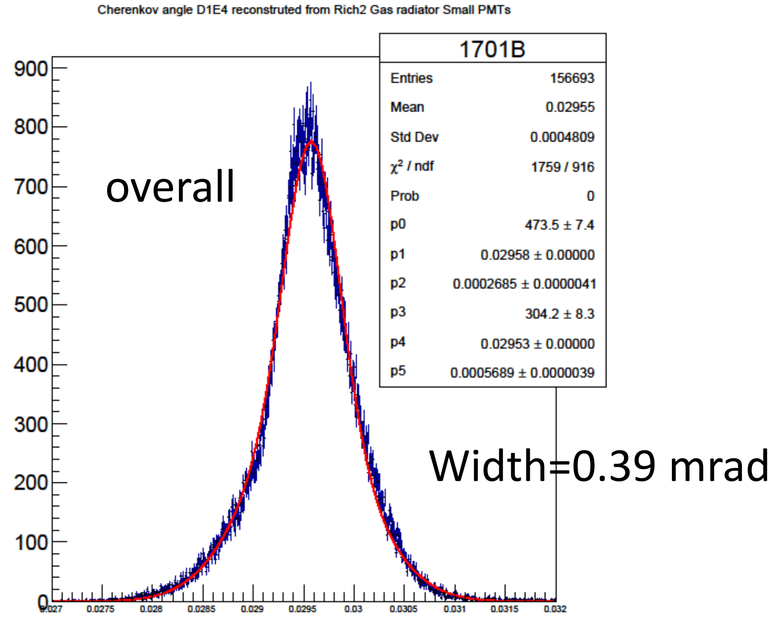
RICH2 Resolutions

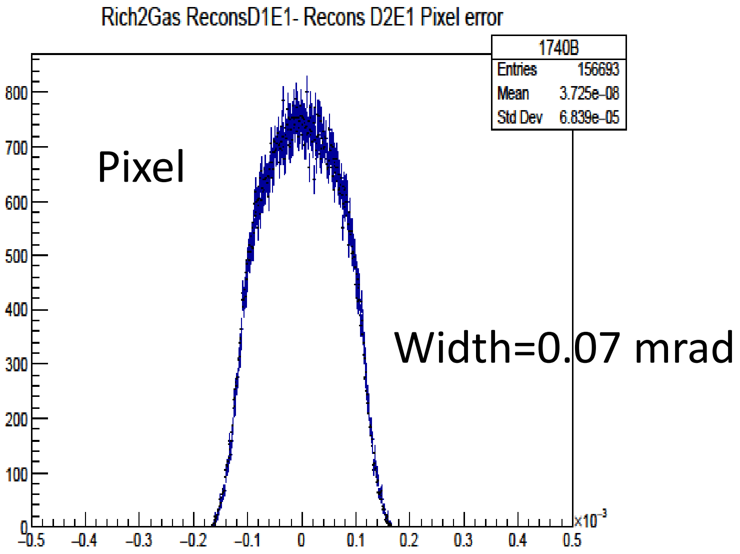




- All plots for only the small PMTs

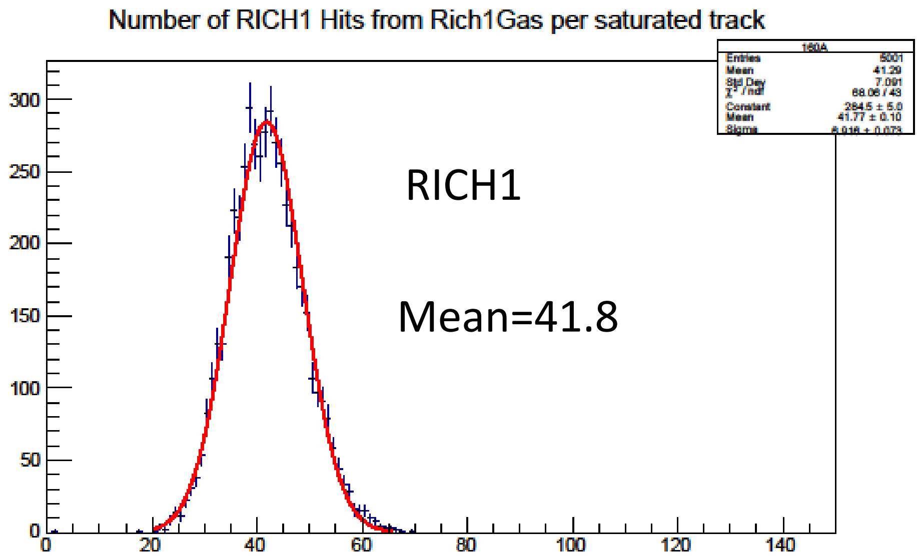
- Using MaPMT

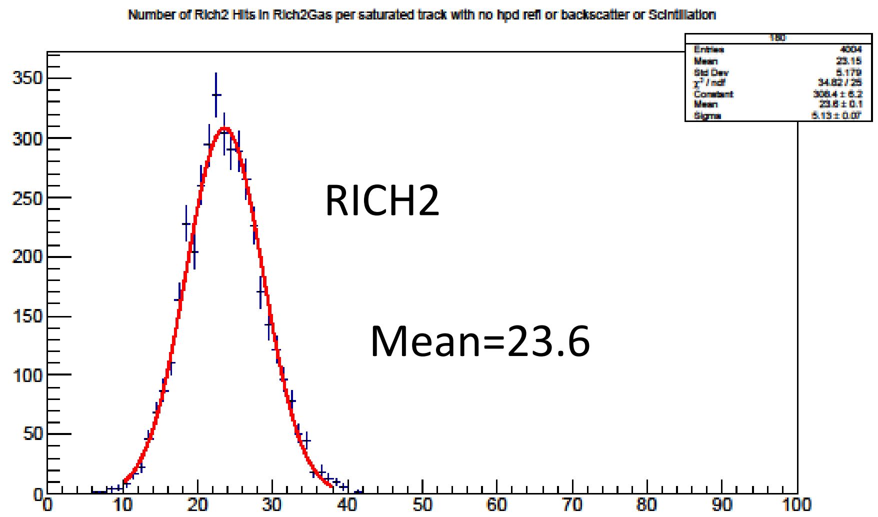




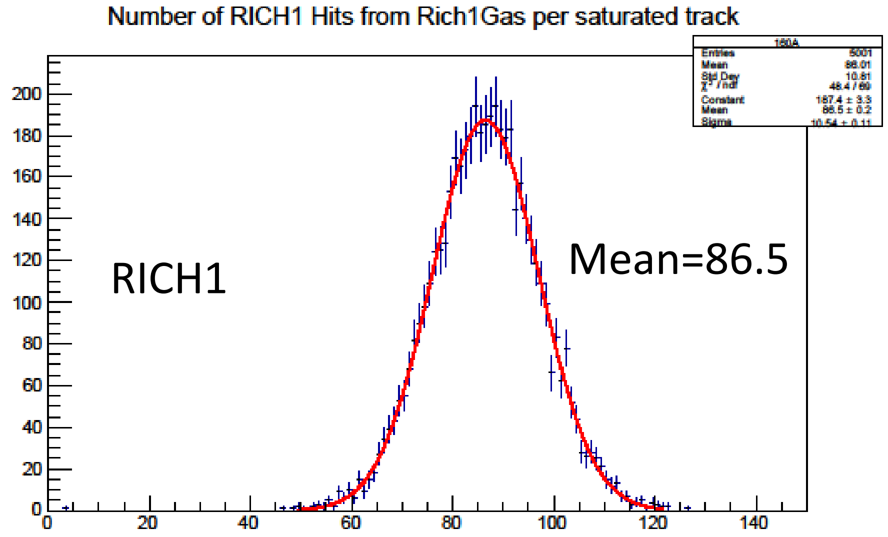
- Using silicon PM in the inner part

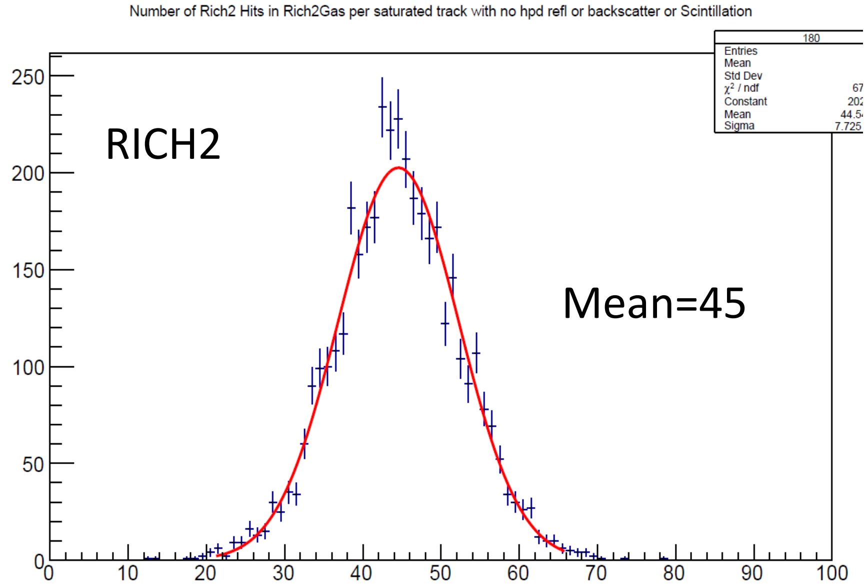
RICH Yield





Using MaPMT

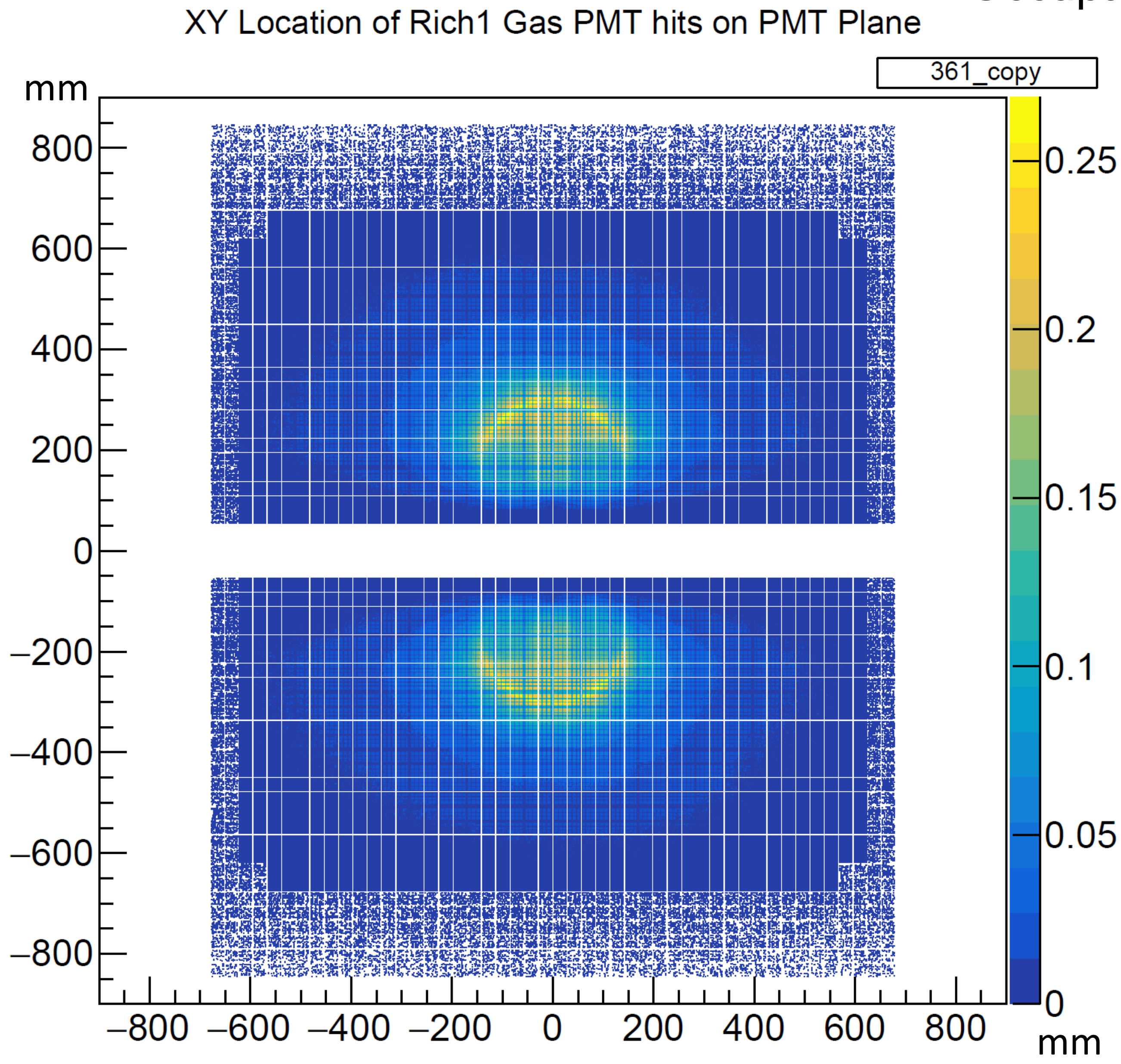


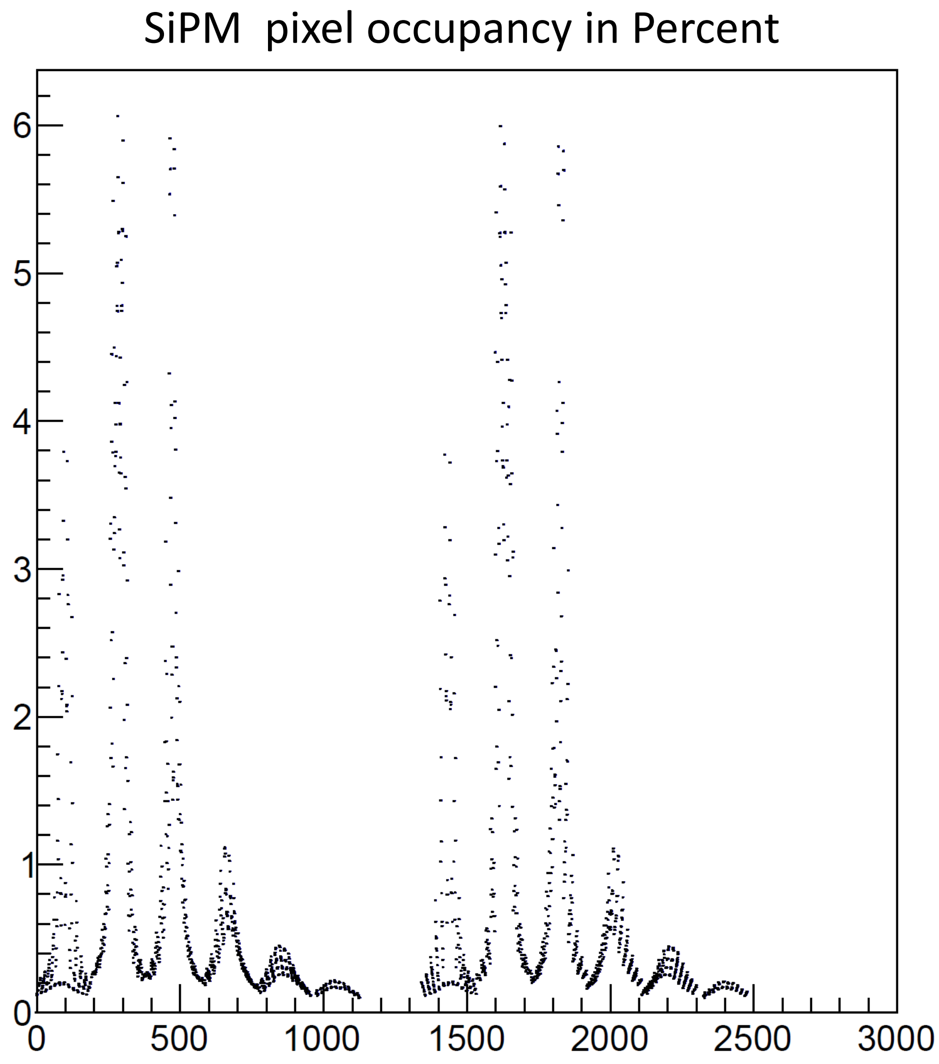


Using SiPM

SiPM has better QE than MaPMT

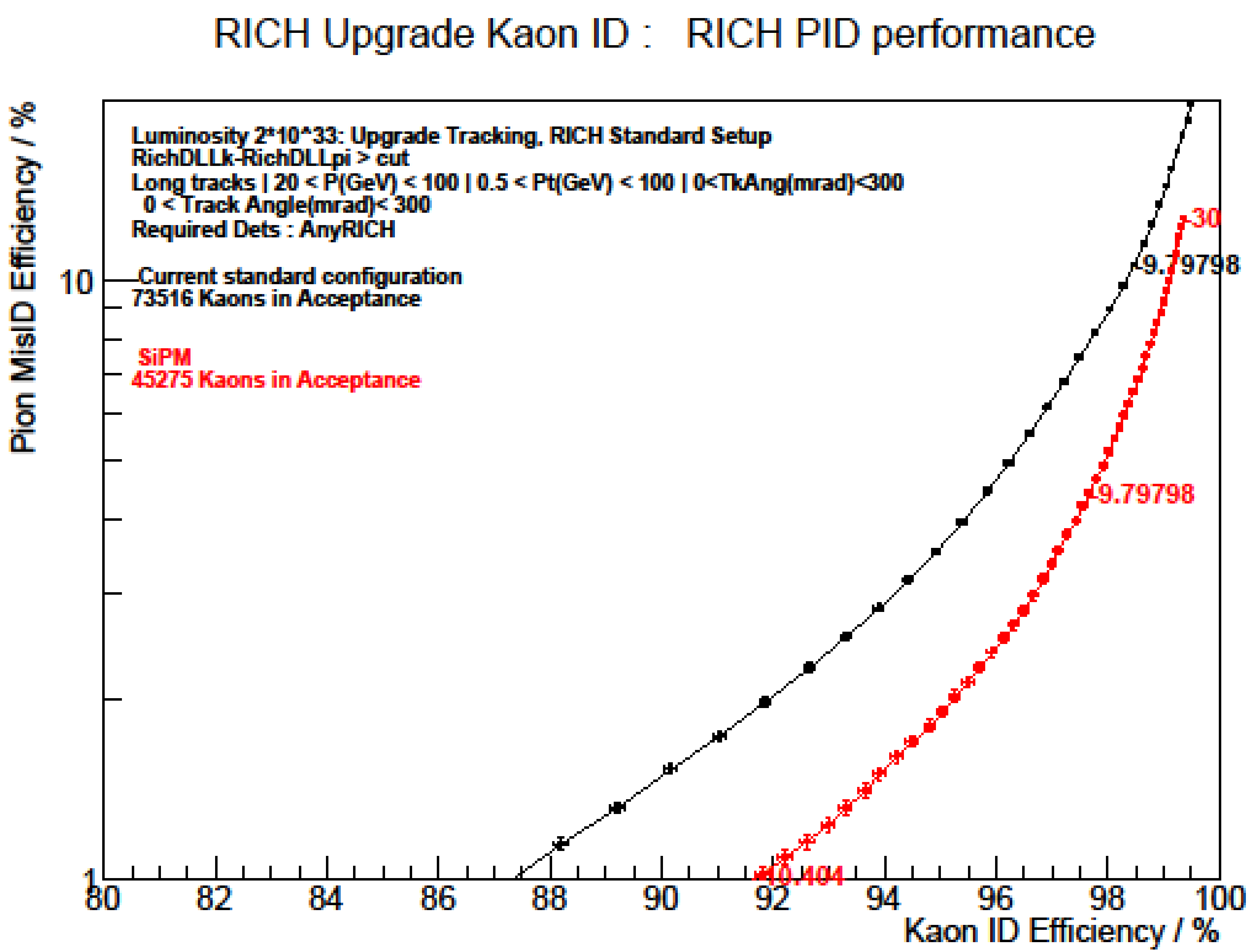
Occupancy



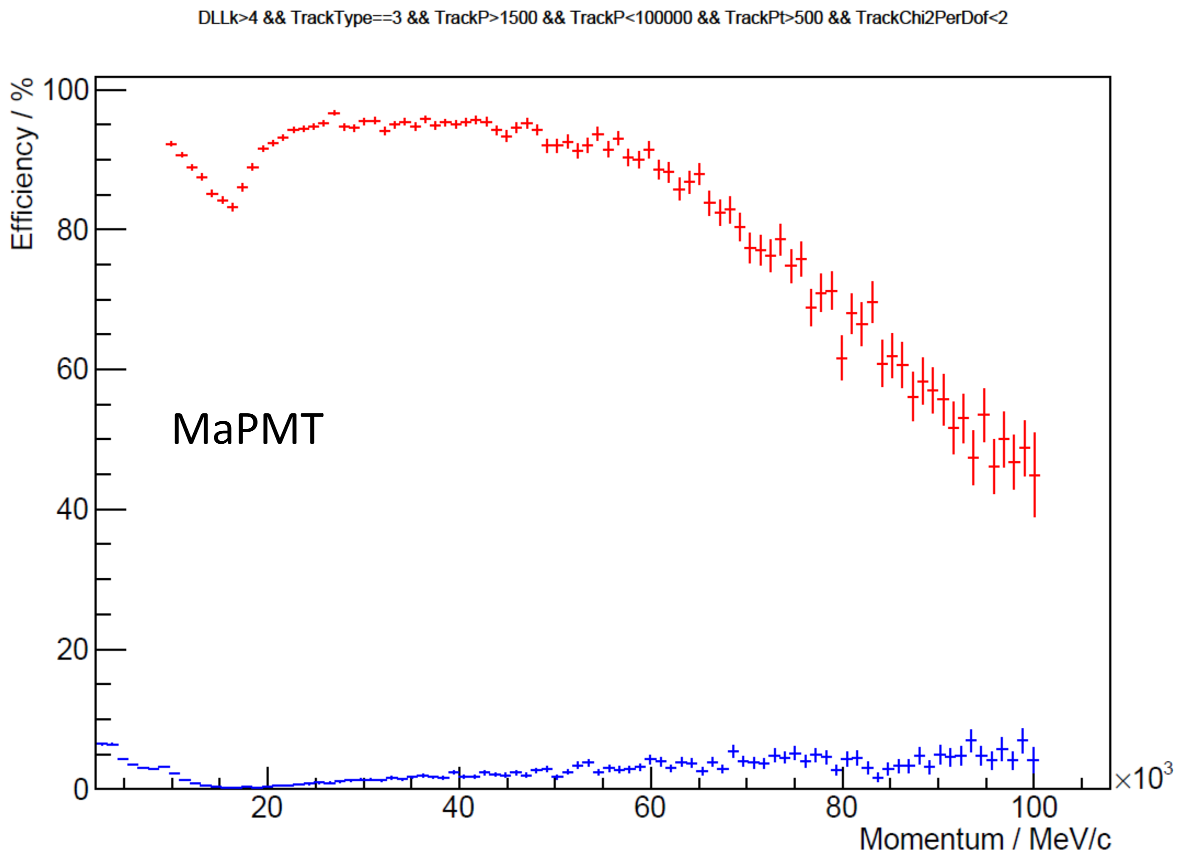


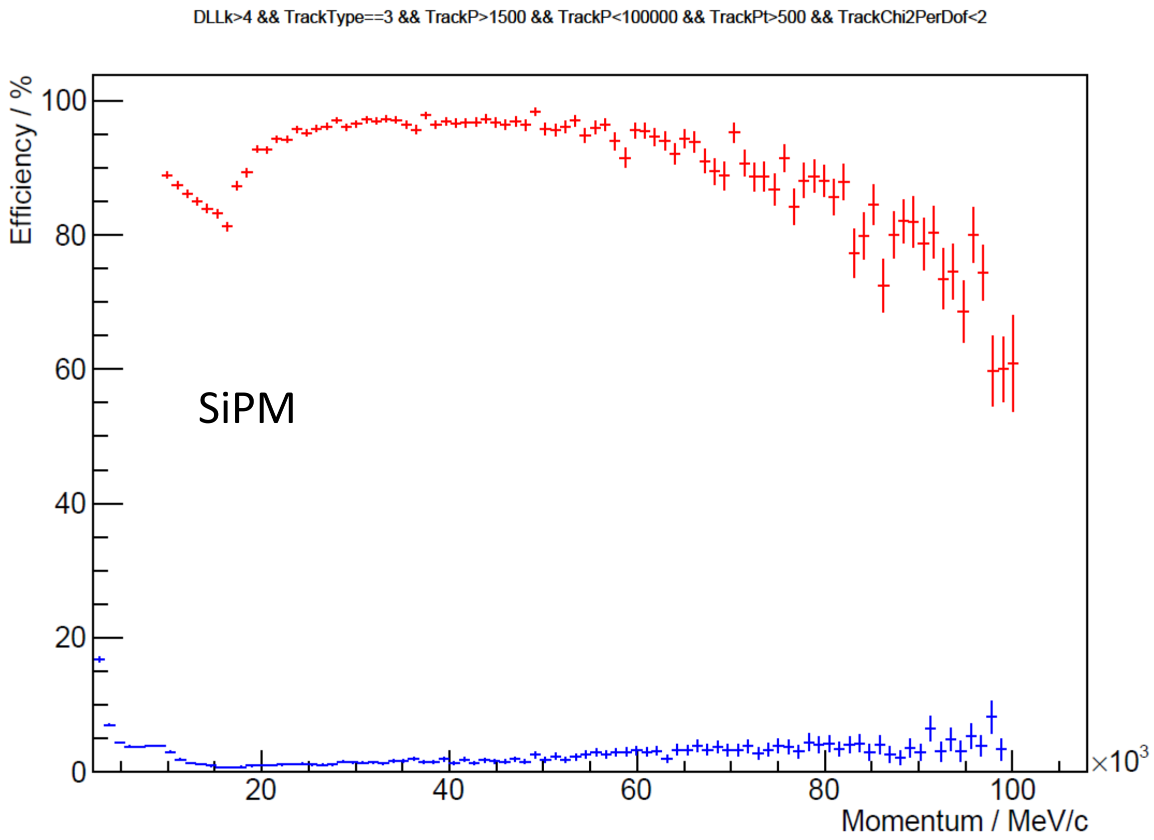
Occupancy averaged over pixels=
Number of hits in SiPM X 100/(25 X 25)

Lumi20



- Improvement in PID in the 20-100 GeV/c region,when using SiPM.



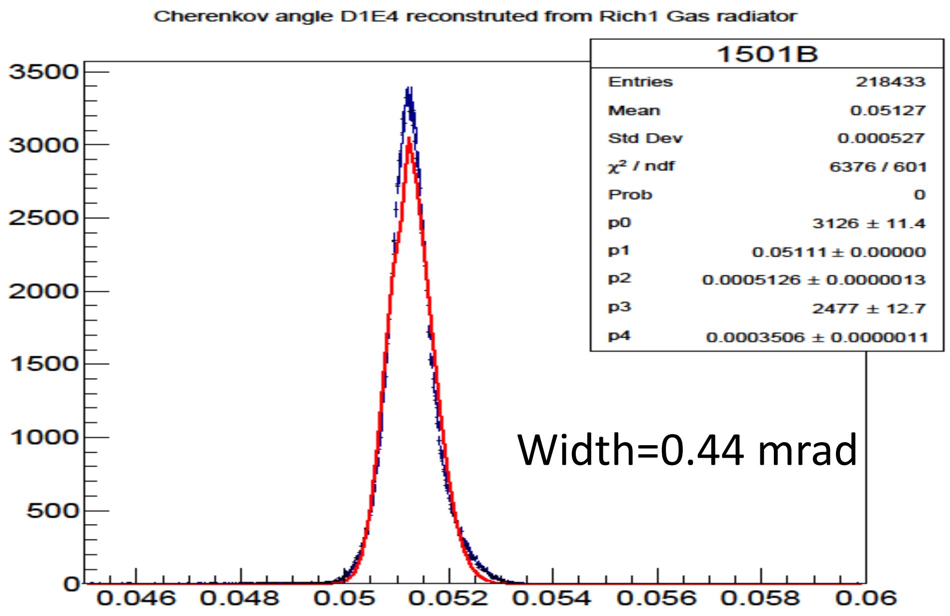


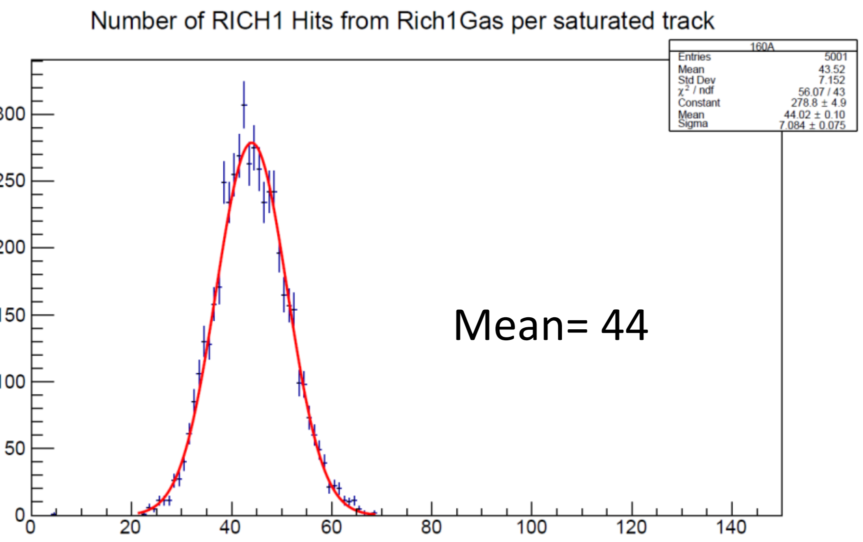
Red : Kaon ID efficiency

Blue: Pion mis-ID probability

- *For the region below 20 GeV/c, further review/work needed to optimize the program for SiPM*

RICH1 SiPM resolutions



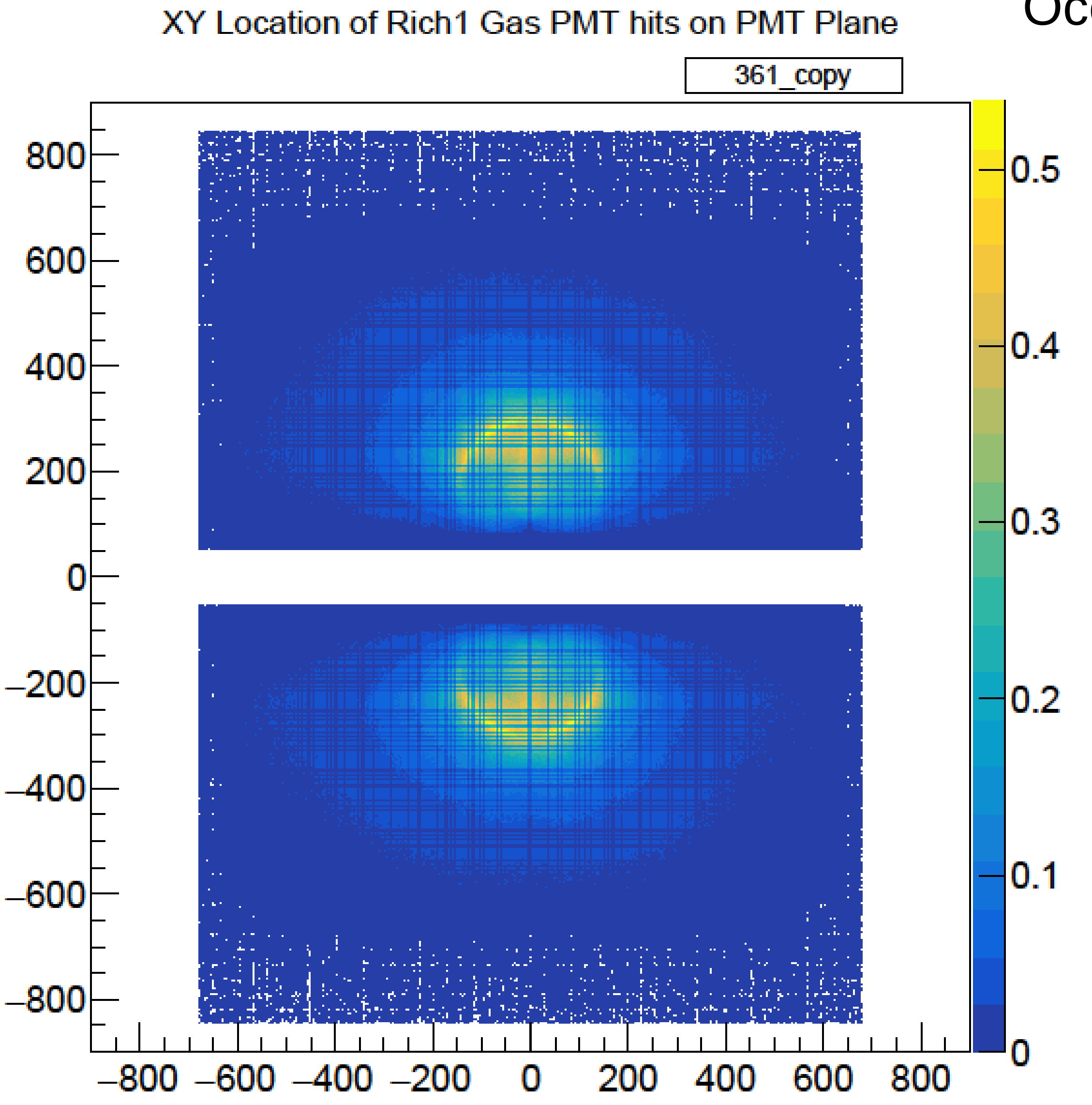


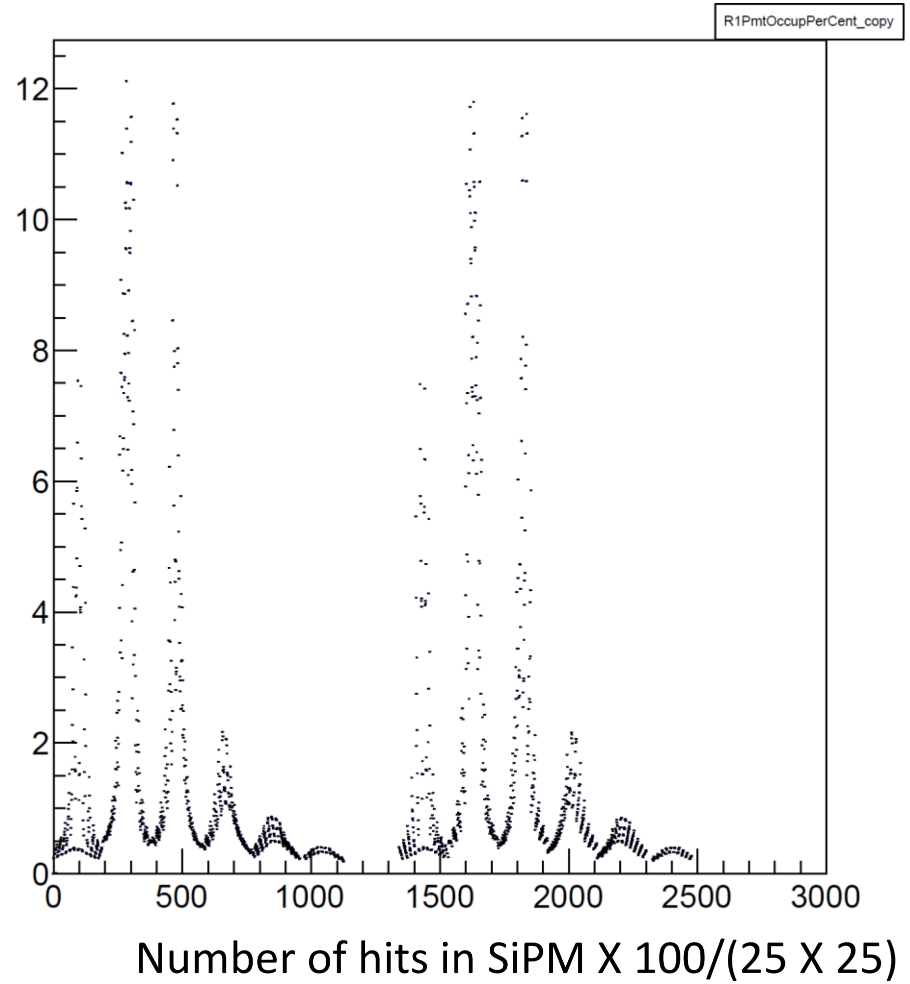
- Wavelengths below 400 nm cut-off using filter.
- Using Particle gun

Source Reslution (mrad)	SiPM >400 nm	SiPM	MaPMT
Emis. pt	0.40	0.38	0.37
Chromatic	0.19	0.43	0.58
Pixel	0.16	0.16	0.45
Overall	0.44	0.55	0.77

- *With 400 nm cut-off, the overall resolution dominated by emission point error.*
- *To further reduce the emission point error, optics geometry would need to be modified.*

Occupancy





- Using SiPM and 400-nm cut-off.
- Luminosity 1X10^{34} cm^{-2} s^{-1} (Lumi100) = 5 * Lumi20.
  With 400 nm-cut off , approx ratio to lumi20= 5/2=2.5.

- *If the current MaPMTs were used for this luminosity with no geometry change, the peak occupancy would exceed 100 %*

Summary of Part 1

- For the upgrade RICH setup , the resolutions and yield improve with using Silicon photomultipliers

- The PID performance with Silicon photomultipliers show improvement in the 20-100 GeV/c region. The optimization of the reconstruction program for the full region is under study

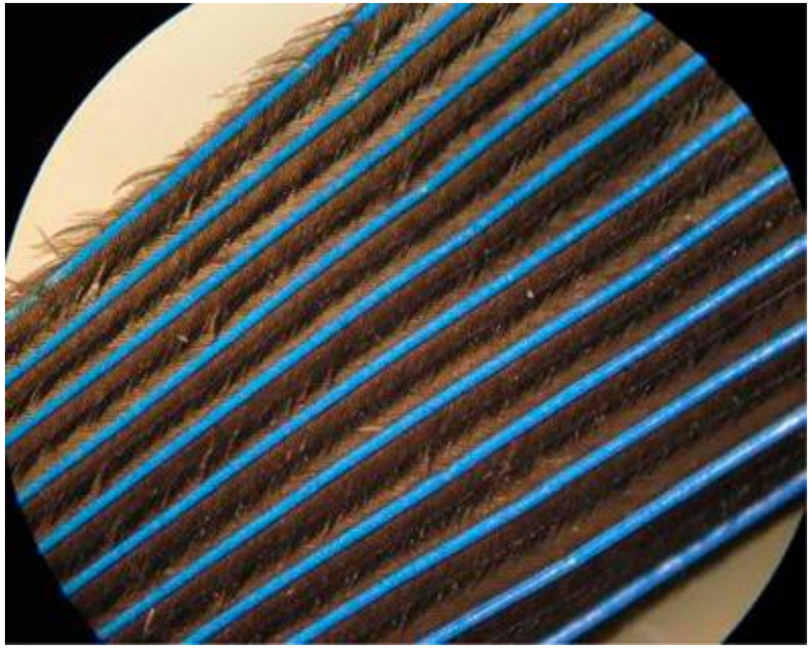
- In order to further improve the resolutions, the geometry of the optics would need to be modified. This is work in progress.

- For evaluating the PID performance at 10^{34} cm^{-2} s^{-1} with in a proper way, solutions to few software issues would need to be implemented.

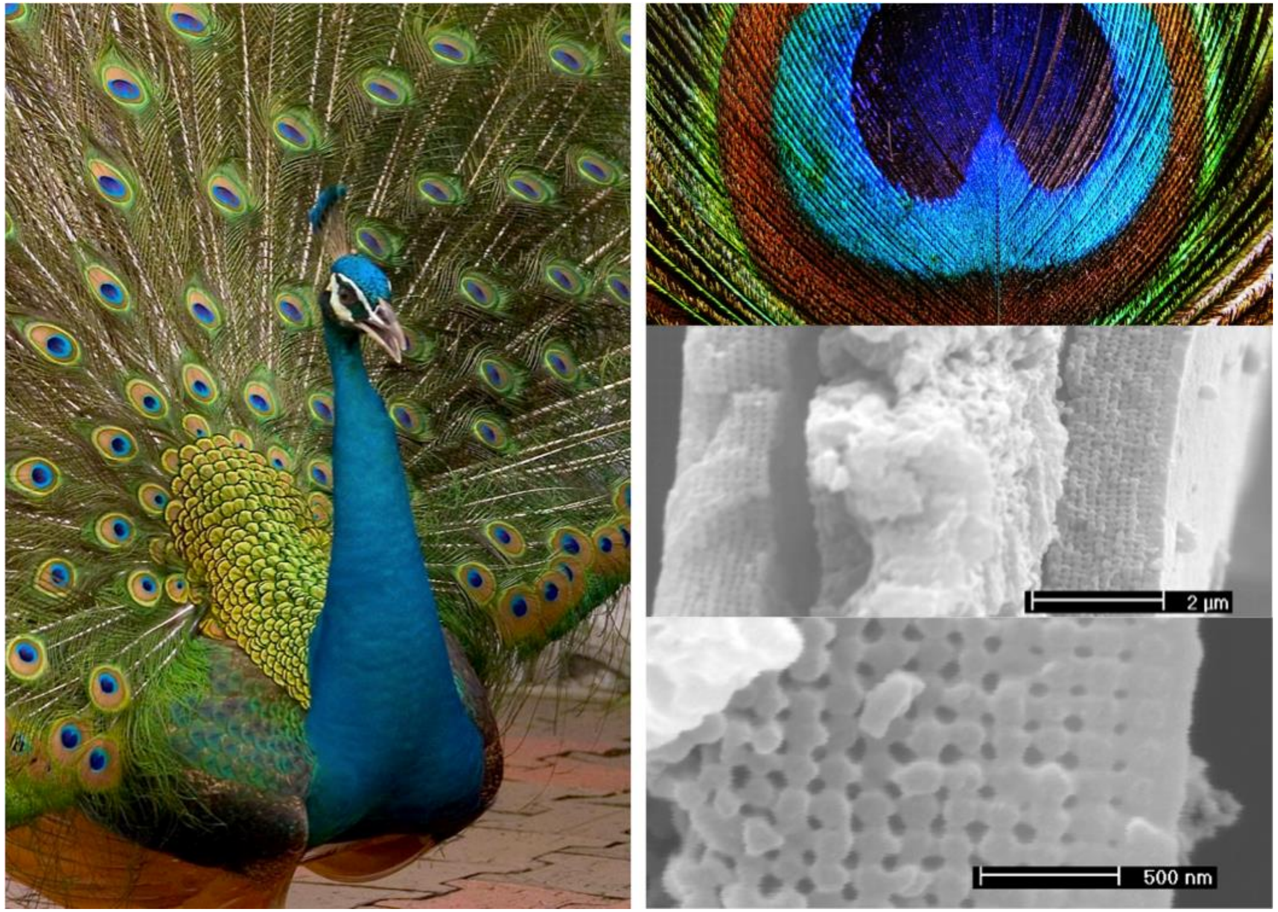
Photonic Crystals for Particle Identification

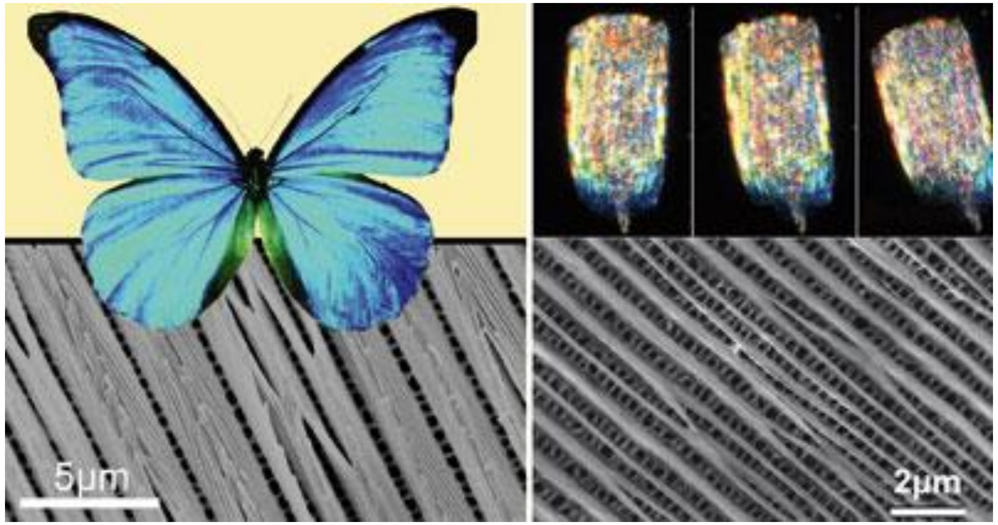
Parrot (scarlet macaw) in a tropical forest

www.pnas.org/cgi/doi/10.1073/pnas.1204383109



Optical micrograph of blue feather barbs





CERN Courier Aug23, 2005
Phys. Rev. E 72, 010902 (2005)

Hint for making Cherenkov detectors ?

Photonic Crystals

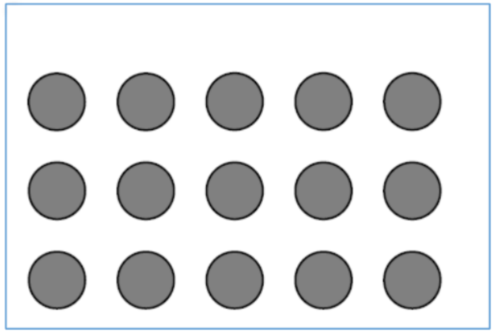
- Periodic arrangement of objects with two different refractive indices.
- Lattice constants comparable to the wavelength of light in the material
- electrons in pure semi-conductor : similar features to photons in photonic crystal

- Cherenkov radiation:
  - Physical origin is a mixture of conventional Cherenkov radiation and Transition radiation
  - Photon propagation in the crystal in the form of Bloch waves
  - All the properties can be derived from solving Maxwell's equations for periodic lattice

arXiV:0808.3519

  - There is no Cherenkov Threshold
  - Cherenkov cone can be forward or backward

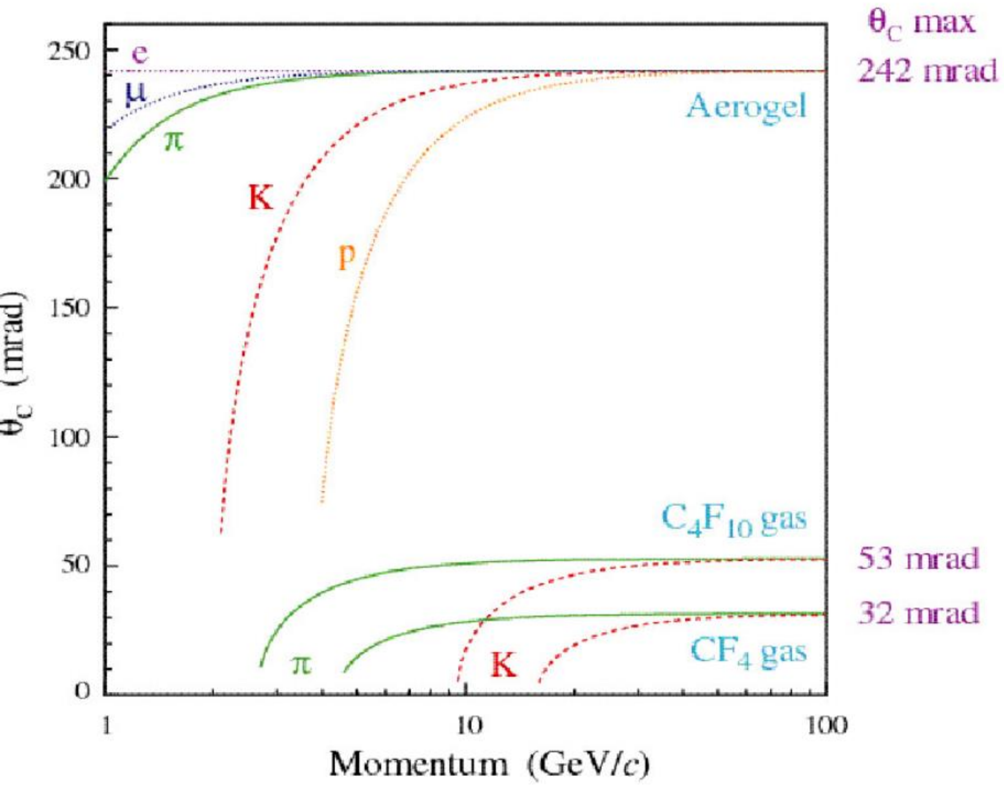
- Starting from two media with refractive indices n_1 and n_2, create a new effective refractive index n_3.



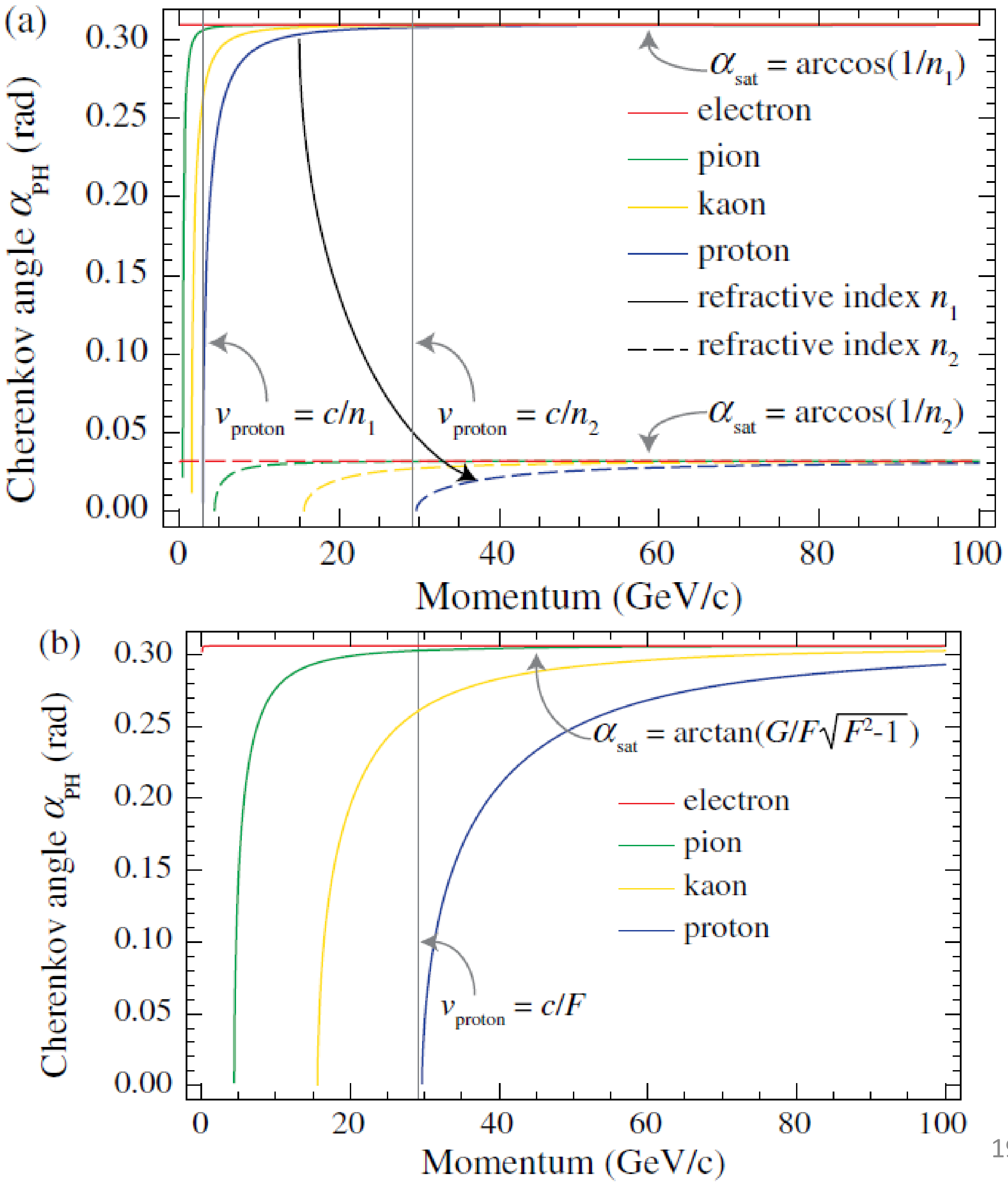
r=cylinder radius
a= lattice constant

Particle Identification

PRL 113, 167402 (2014)



RICH1 EDR: LHCb-2004-121

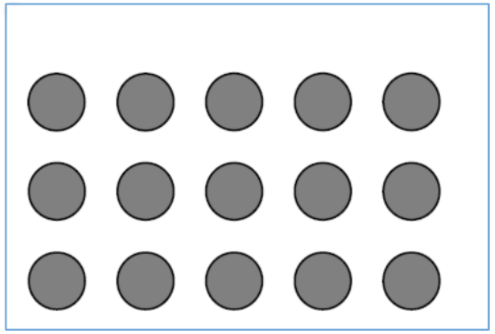


Sensitivity= $\theta_{eletron} - \theta_{proton}$

Transformation optics:

Longitudinal stretching=F=1.005 : Shift curves to right
Transverse stretching = G=10 : Increase θ

Production of Photonic Crystal



- Parameters relevant for Cherenkov photon production
  - *Filling factor : cylinder radius /lattice constant*
  - *Refractive indices of the two media*

- Not many photonic crystals found in nature.

- Production : 3D printers, photolithography etc.

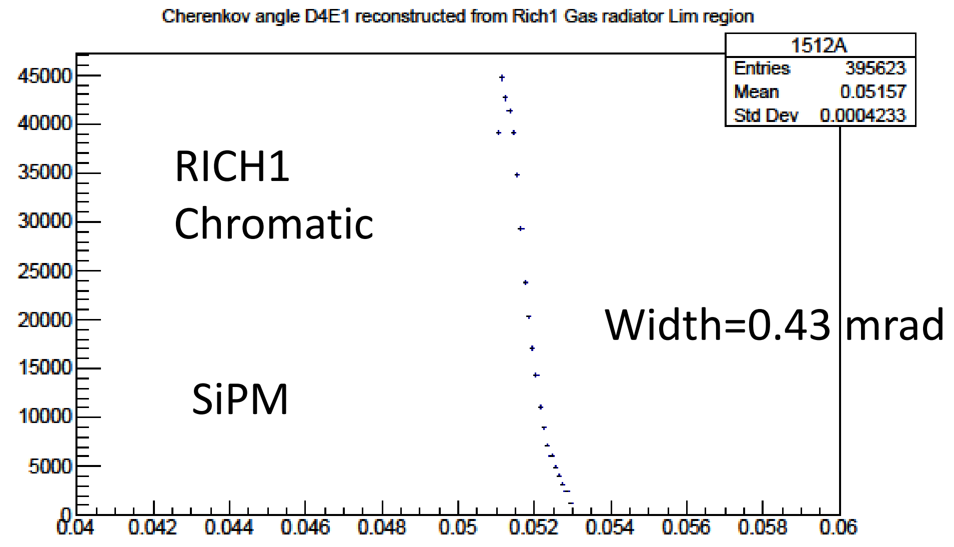
- Detector seminar at CERN: April 15, 11 am
  https://indico.cern.ch/event/516572/

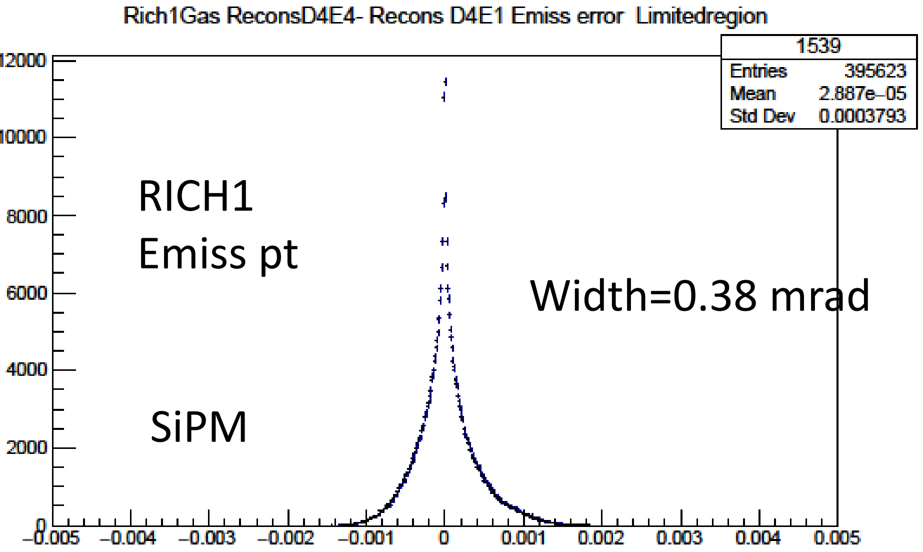
- Plans: Produce prototypes and test them in a testbeam

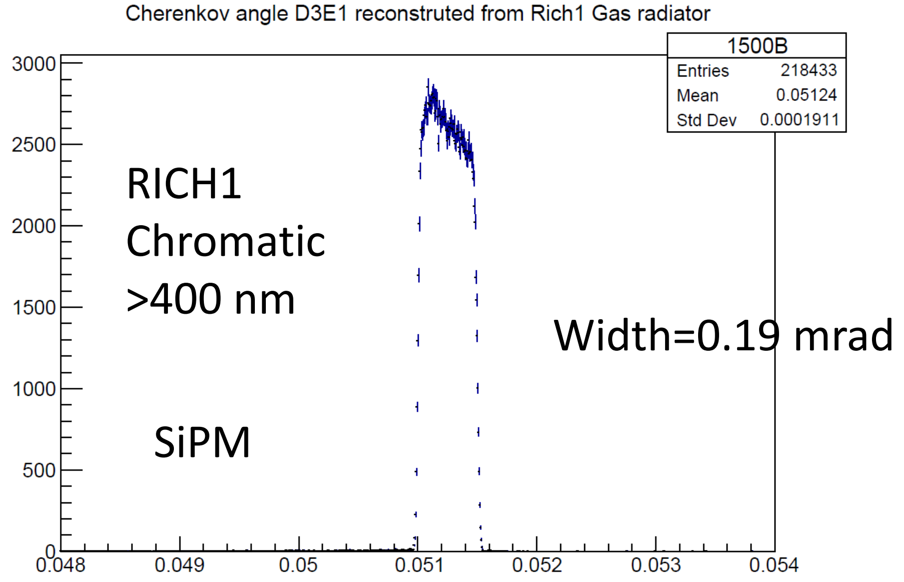
Summary Part 2

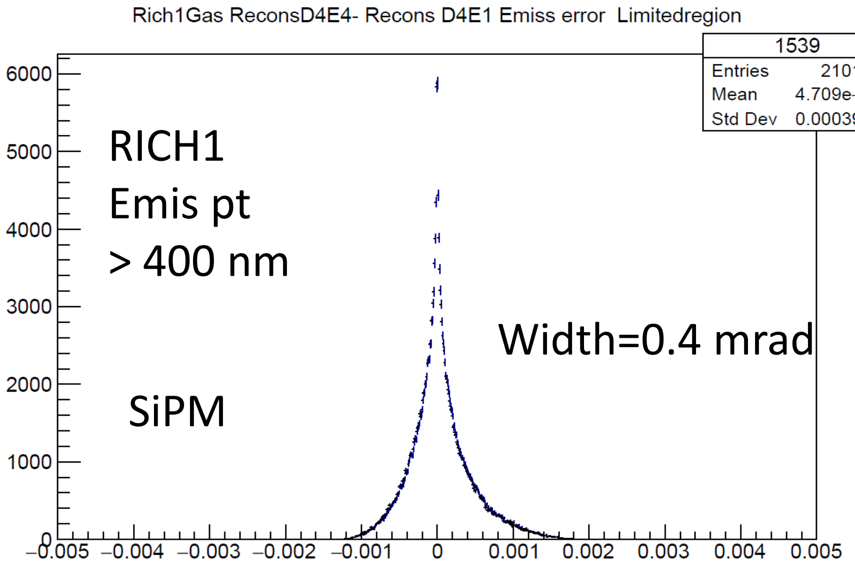
- Using a photonic crystal can potentially extend the momentum range for RICH
- Further investigations underway.

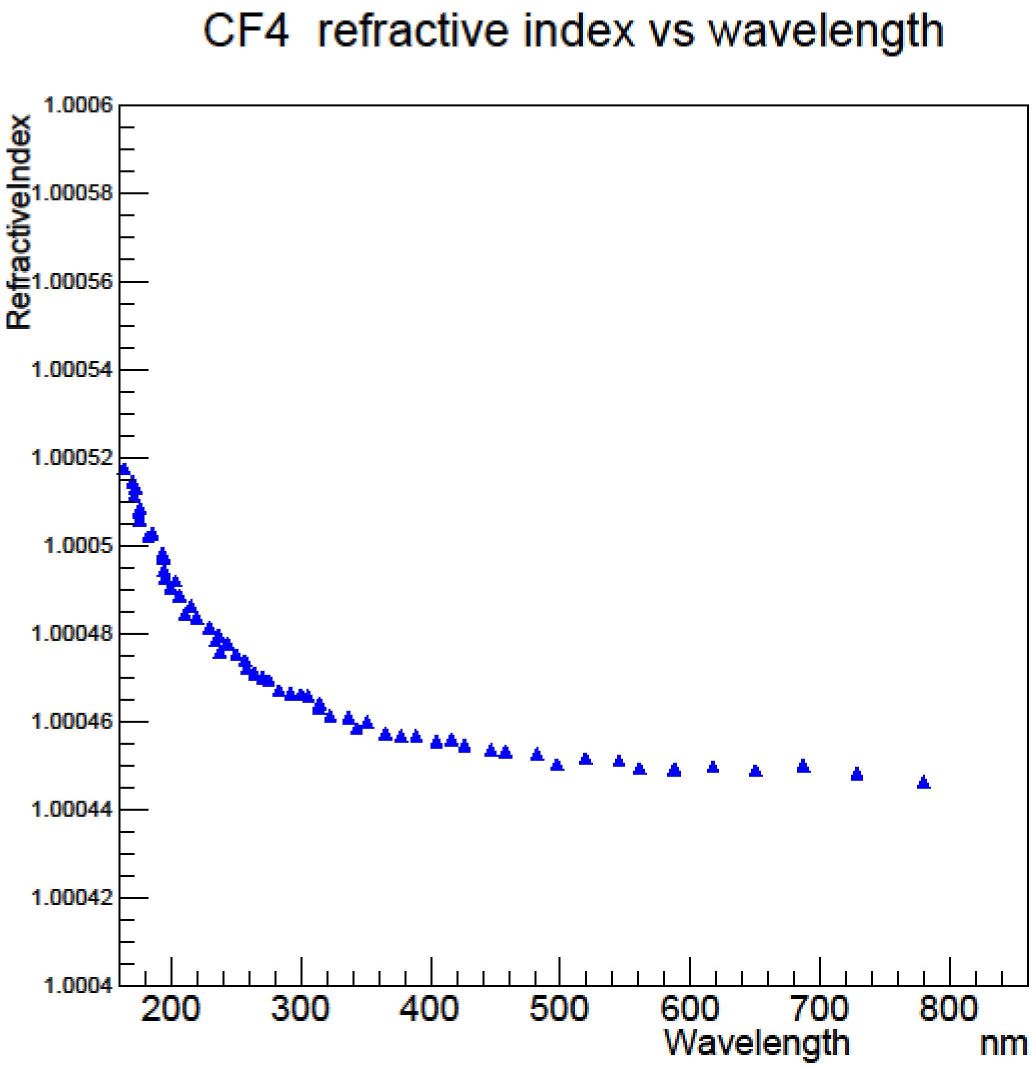
BACKUP SLIDES

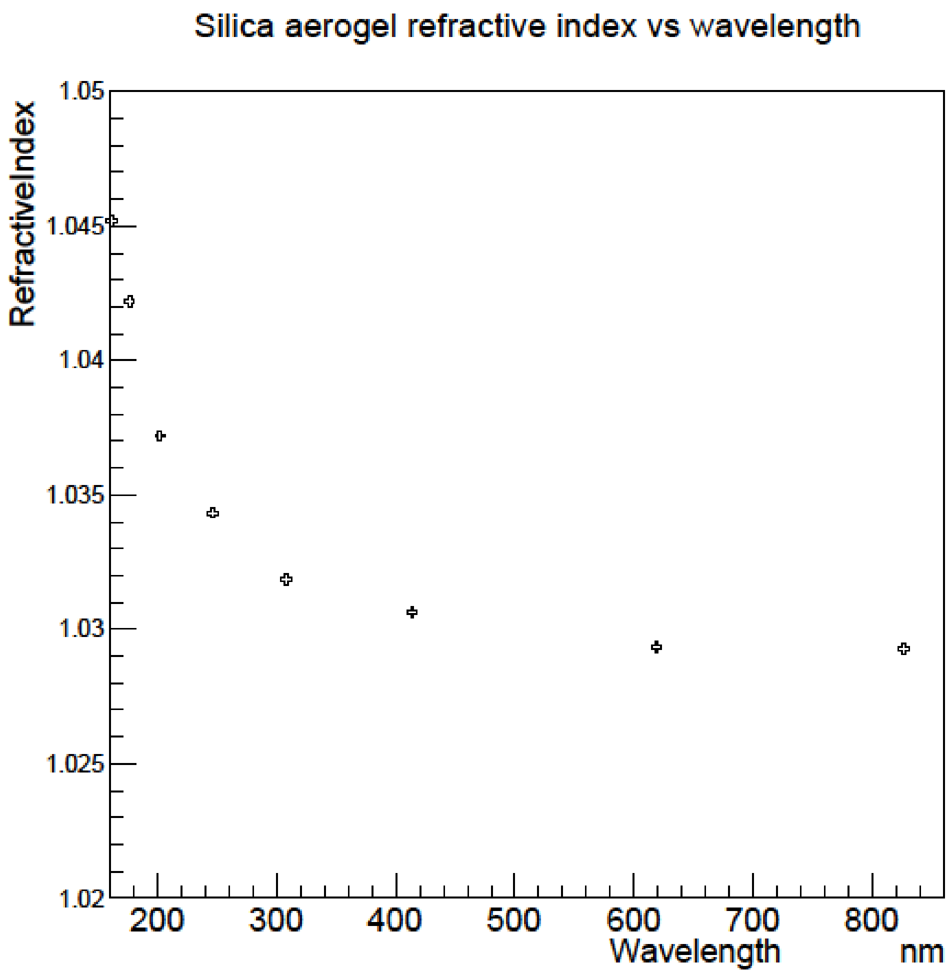

Cherenkov angle D4E1 reconstructed from Rich1 Gas radiator Lim region
1512A
Entries 395623
Mean 0.05157
Std Dev 0.0004233
RICH1
Chromatic
SiPM
Width=0.43 mrad
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.04
0.042
0.044
0.046
0.048
0.05
0.052
0.054
0.056
0.058
0.06


Rich1Gas ReconsD4E4- Recons D4E1 Emiss error Limitedregion
1539
Entries 395623
Mean 2.887e−05
Std Dev 0.0003793
RICH1
Emiss pt
SiPM
Width=0.38 mrad
0
2000
4000
6000
8000
10000
12000
−0.005
−0.004
−0.003
−0.002
−0.001
0
0.001
0.002
0.003
0.004
0.005

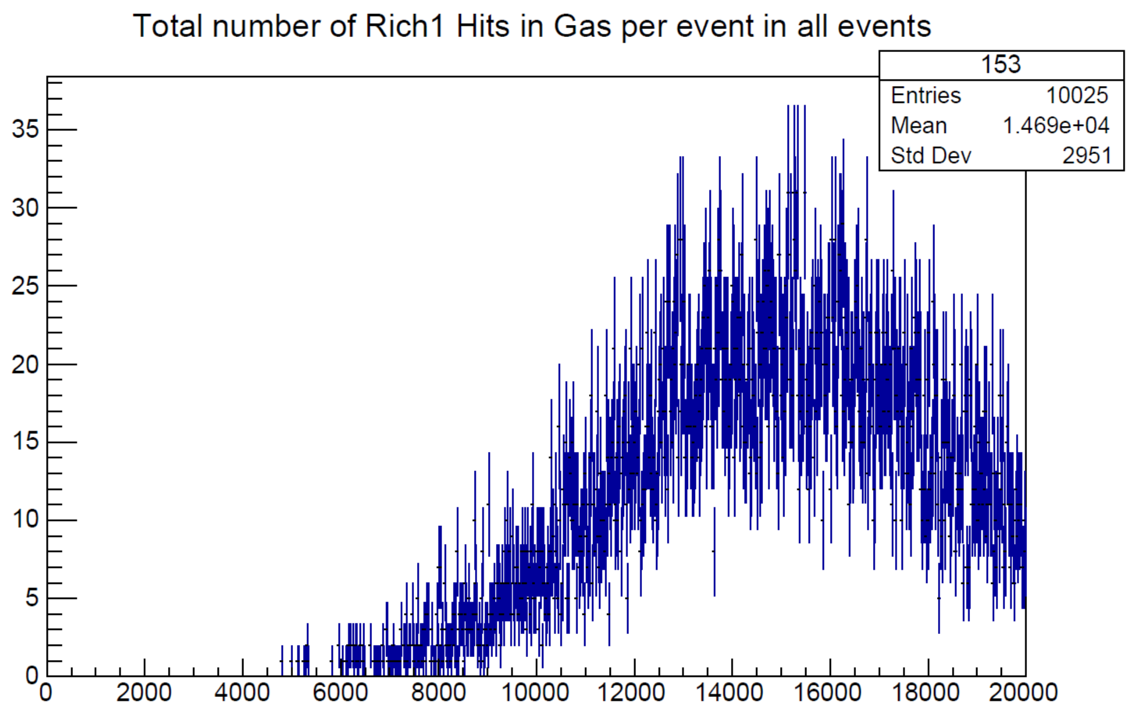

Cherenkov angle D3E1 reconstruted from Rich1 Gas radiator
1500B
Entries 218433
Mean 0.05124
Std Dev 0.0001911
RICH1
Chromatic
>400 nm
SiPM
Width=0.19 mrad
0
500
1000
1500
2000
2500
3000
0.048
0.049
0.05
0.051
0.052
0.053
0.054

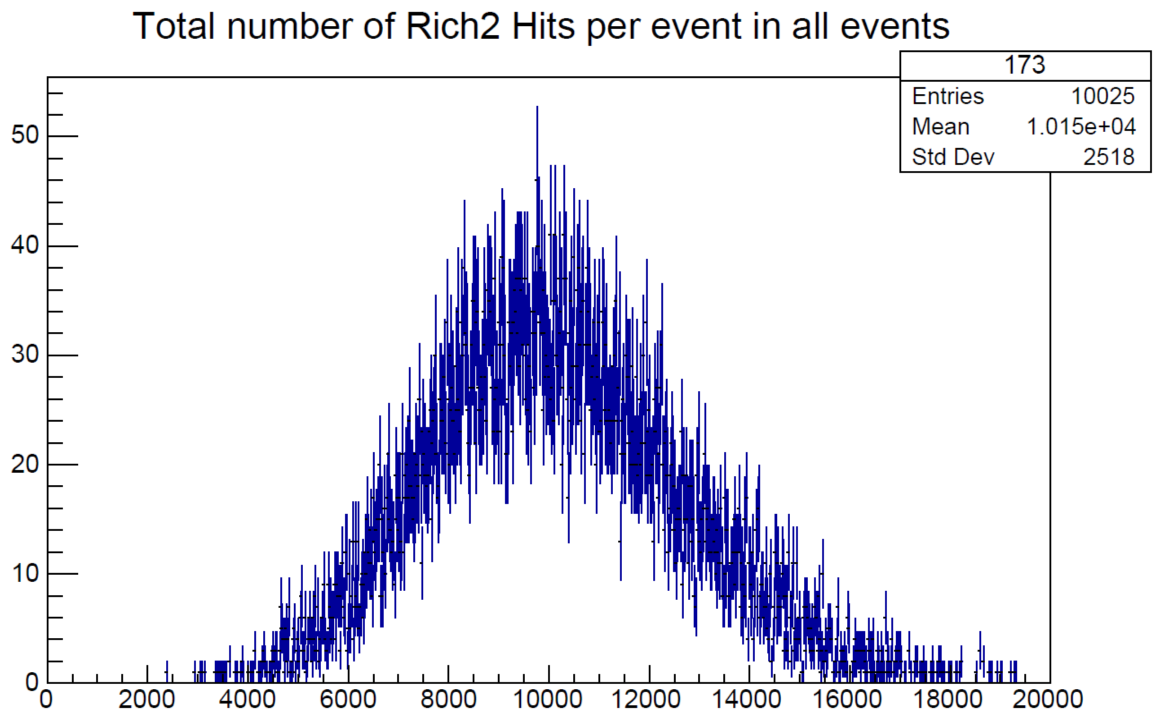

Rich1Gas ReconsD4E4- Recons D4E1 Emiss error Limitedregion
1539
Entries 210155
Mean 4.709e−05
Std Dev 0.0003956
RICH1
Emis pt
> 400 nm
SiPM
Width=0.4 mrad
0
1000
2000
3000
4000
5000
6000
−0.005
−0.004
−0.003
−0.002
−0.001
0
0.001
0.002
0.003
0.004
0.005


CF4 refractive index vs wavelength
RefractiveIndex
1.0006
1.00058
1.00056
1.00054
1.00052
1.0005
1.00048
1.00046
1.00044
1.00042
1.0004
200
300
400
500
600
700
800
Wavelength
nm


Silica aerogel refractive index vs wavelength
RefractiveIndex
1.05
1.045
1.04
1.035
1.03
1.025
1.02
200
300
400
500
600
700
800
Wavelength
nm

Number of hits





Lumi-100 with 400-nm wavelength cut-off and using SiPM