Quintuple GEM CsI Ring Imaging Cherenkov Detector

11th RD51 Collaboration Meeting :: Zaragoza, Spain :: July 2013

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Stony Brook
University

Motivation: PID @ EIC

Proposed:

eRHIC @ BNL →

MEIC @ J-Lab →

“The Next QCD Frontier”

Physics Goals:

- Matter at high gluon density
- Nucleon spin
- Spatial Parton Distributions

https://wiki.bnl.gov/eic/

Motivation: PID @ EIC

Particle Identification: Two step process

Velocity
Momentum
} → Mass

π, K, p Separation	5 GeV x 50 GeV	20 GeV x 250 GeV
$-5 < \eta < -1$	< 10 GeV/c	< 30 GeV/c
$-1 < \eta < 1$	< 5 GeV/c	< 10 GeV/c
$1 < \eta < 5$	< 50 GeV/c	< 100 GeV/c

Especially challenging

How do we accomplish either, at high momentum, for reasonable cost in a compact length (~1 meter)??

Motivation: PID @ EIC

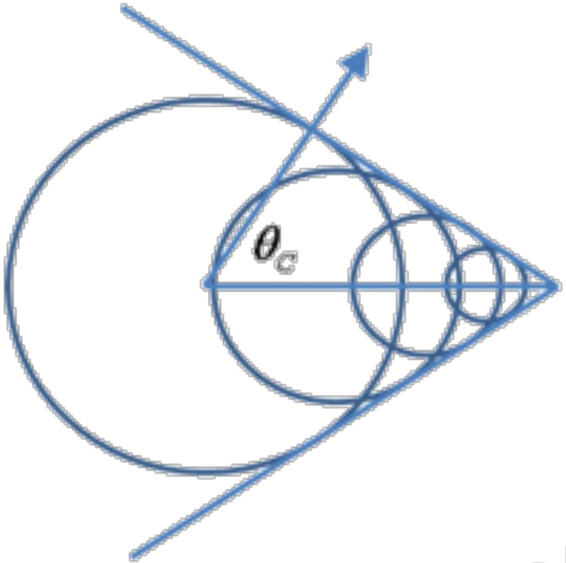
Particle Identification:

$$\left.\begin{array}{l}\textbf{Velocity}\\ \text{Momentum}\end{array}\right\} \rightarrow \text{Mass}$$

Proposal: Use a Ring Imaging Cherenkov (RICH) detector to accomplish the velocity determination

Objective: Demonstrate necessary RICH performance by utilizing

- A GEM stack for signal gain
- A mirror that reduces detector size and maximizes photon yield in the deep UV
- CF_4 as the radiating gas



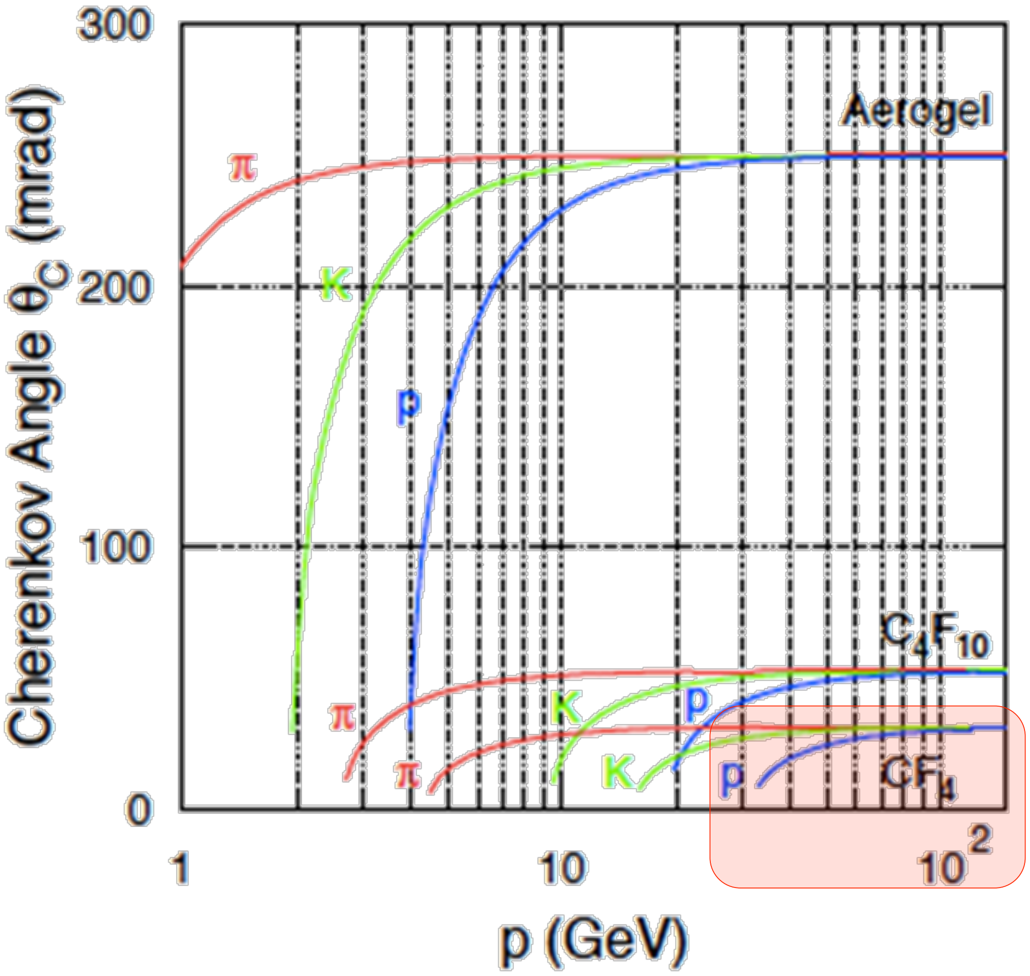
$$\theta_C = \cos^{-1}\left(\frac{1}{\beta n}\right)$$

Building an EIC-ready RICH

Why CF_4:

- $n = 1.000625$
- Low n allows for highest p

BUT: low n means dim light



Building an EIC-ready RICH

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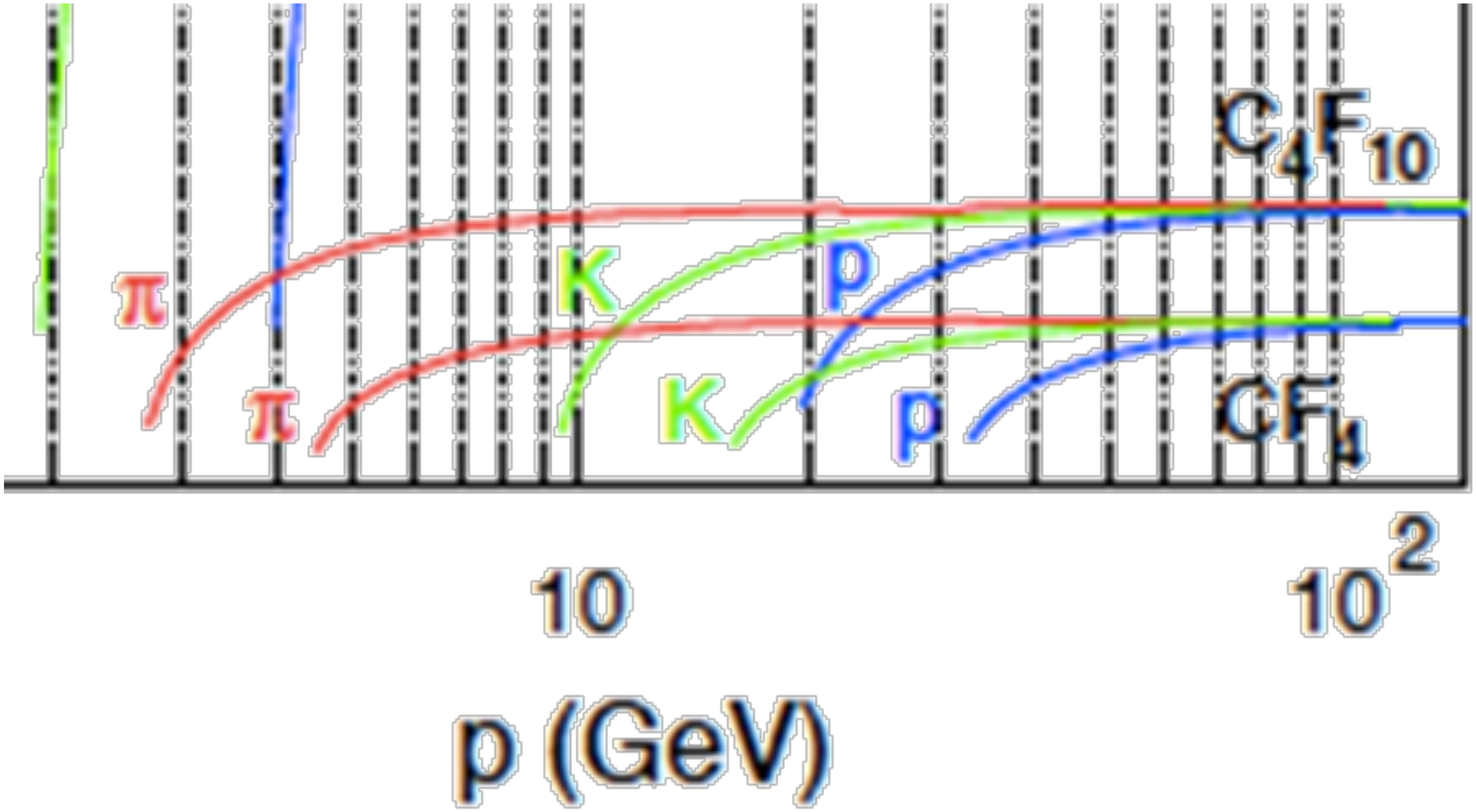

Building an EIC-ready RICH

Why CF_4:

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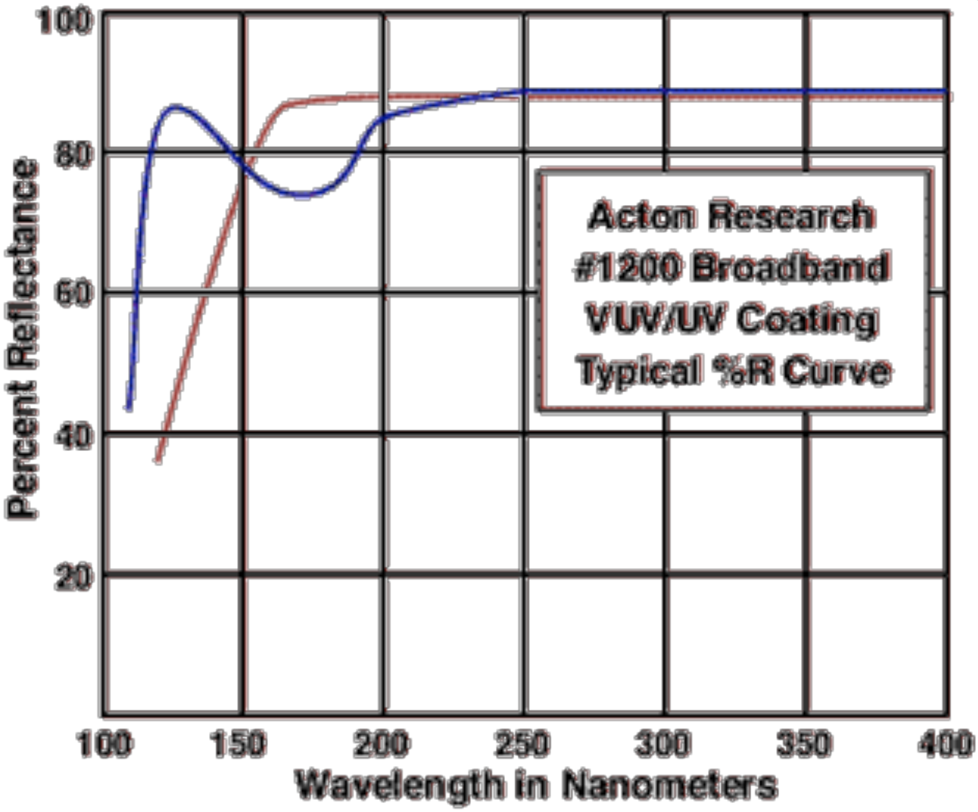
BUT: low n means dim light

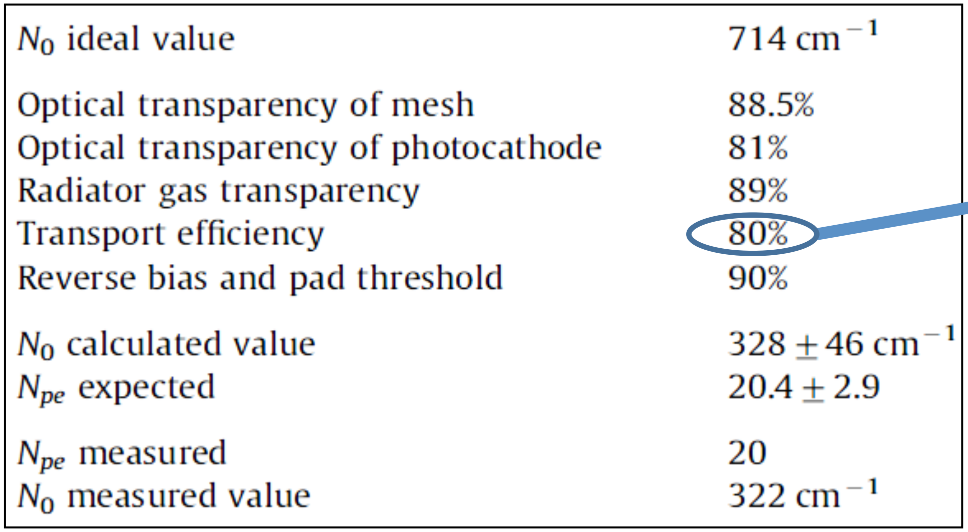
How to maximize photon yield in 1-meter with a low n gas?

- Use a mirror that reflects in the deep UV with MgF_2 thin-film coating



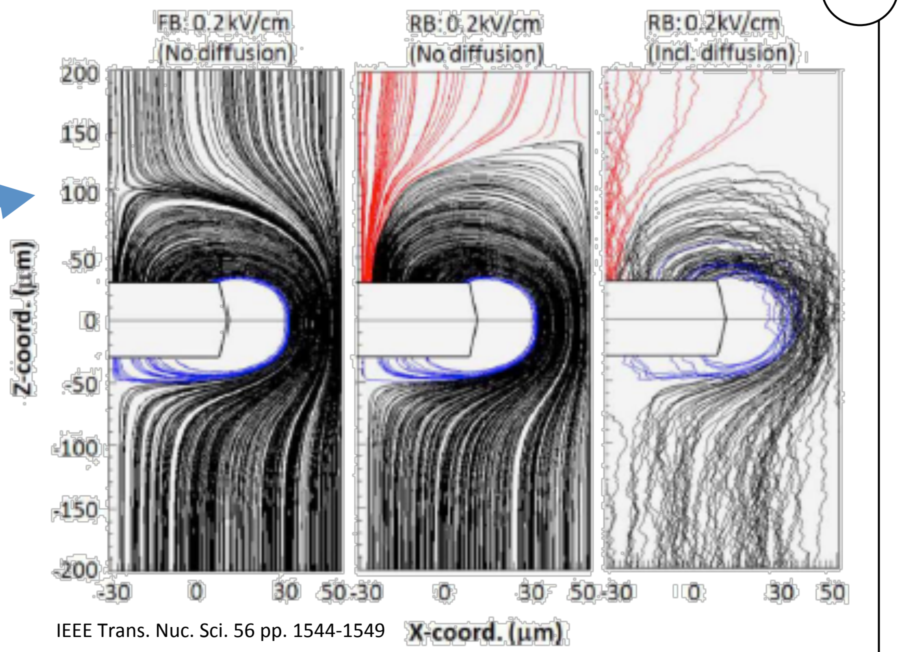
$$\frac{dN}{dL} = 2\pi\alpha_{EM}\sin^2\theta_C\int_{\lambda_{\min}}^{\lambda_{\max}} QE(\lambda)\frac{1}{\lambda^2}d\lambda$$

World-Record N_0: The PHENIX HBD



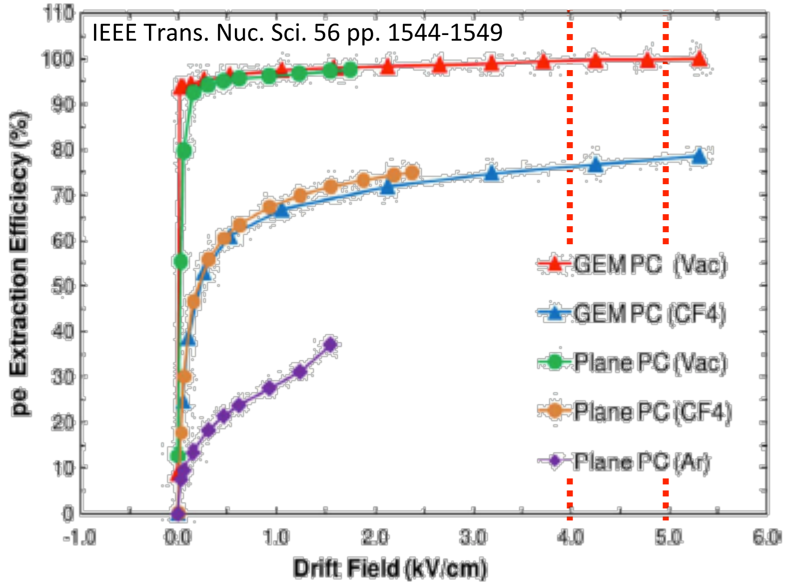
N_0 ideal value	714 cm^{-1}
Optical transparency of mesh	88.5%
Optical transparency of photocathode	81%
Radiator gas transparency	89%
Transport efficiency	80%
Reverse bias and pad threshold	90%
N_0 calculated value	328 ± 46 cm^{-1}
N_{pe} expected	20.4 ± 2.9
N_{pe} measured	20
N_0 measured value	322 cm^{-1}

NIM A 646 pp. 35-58



IEEE Trans. Nuc. Sci. 56 pp. 1544-1549

Transport efficiency includes loss to mesh and failure to enter hole & avalanche… Impossible to improve by a significant factor.



IEEE Trans. Nuc. Sci. 56 pp. 1544-1549

- Std GEM, Full gain 5 kV/cm
- Std GEM, Gain=1 4 kV/cm
- High extraction efficiency

Other than possible Ion Back Flow, the standard GEM is a nearly ideal photocathode

The Instrument

Put everything together and what do you get....

- 1-meter stainless-steal chamber with recirculating CF_4
- Mirror reflective in deep UV
- Five-layer GEM stack with CsI photocathode
- Hexagonal array of signal readout pads and an SRS

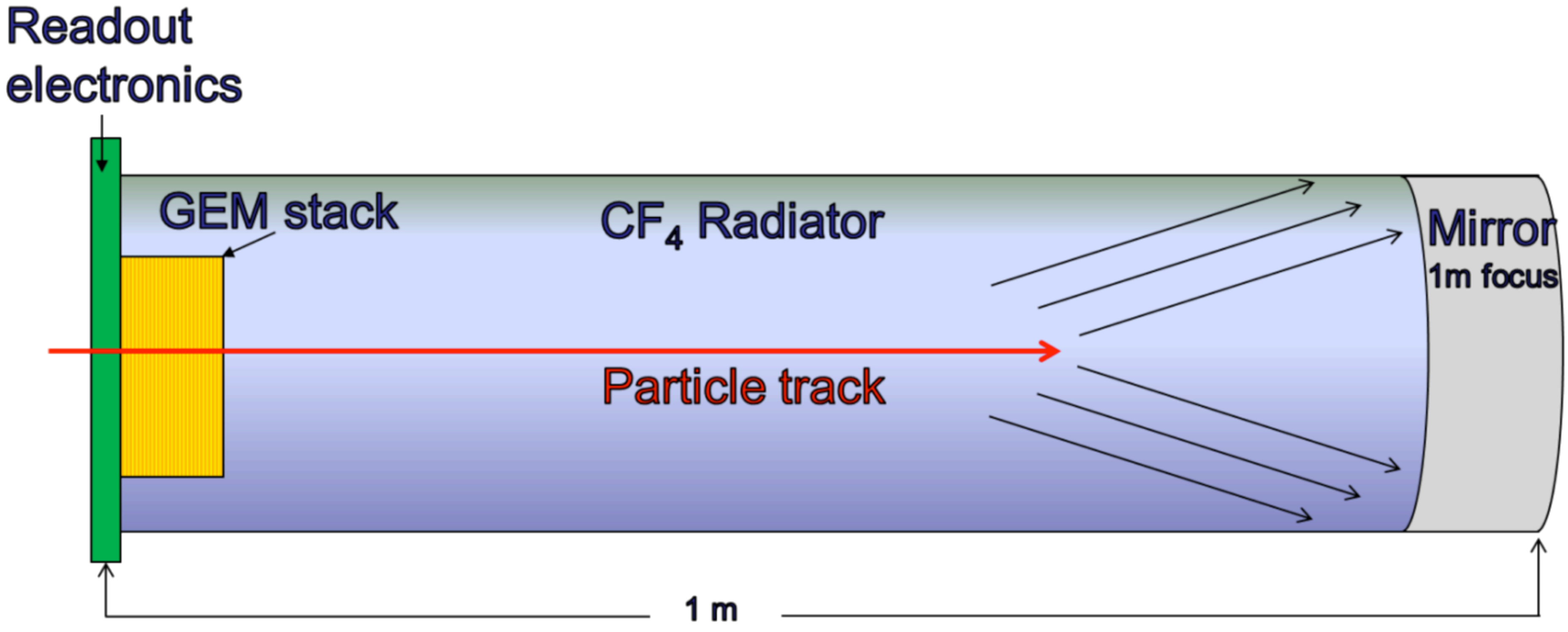


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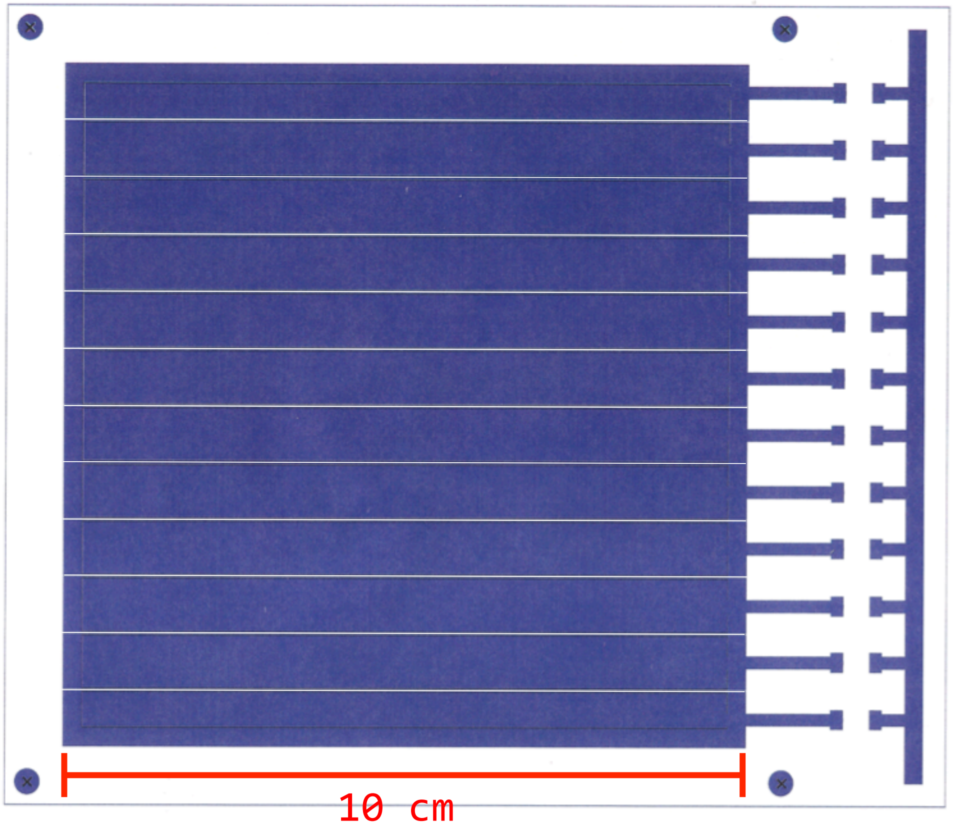
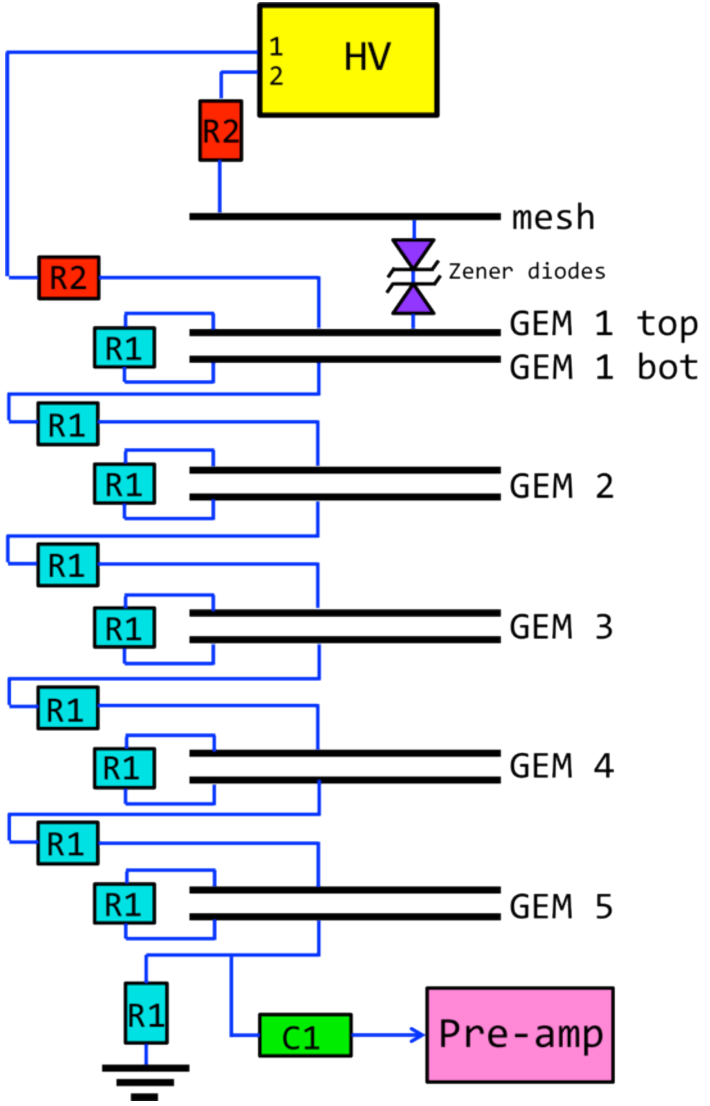
Photo credit: Matt Beardsley/SLAC Multimedia

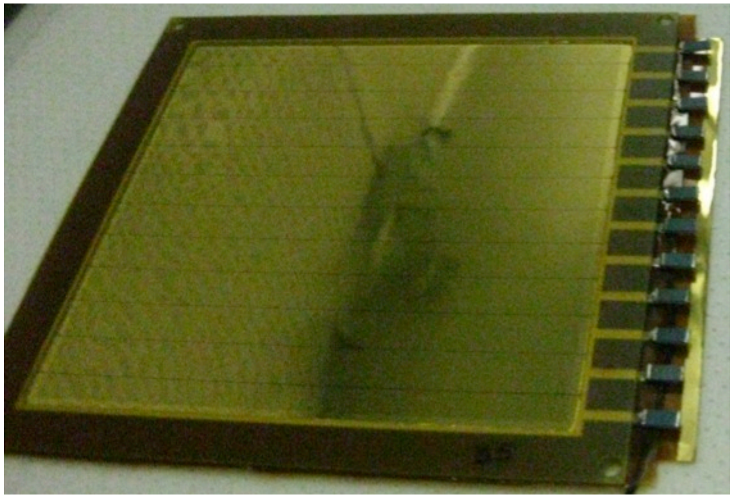
A Few Words About Our GEM Stack…

- Highly segmented GEMs reduce stored energy (V_{CF4} = 2x V_{ArCO2})
- Resistive divider chain with spark detection, Zener protection, and signal pick-off





Why 5 GEMs?



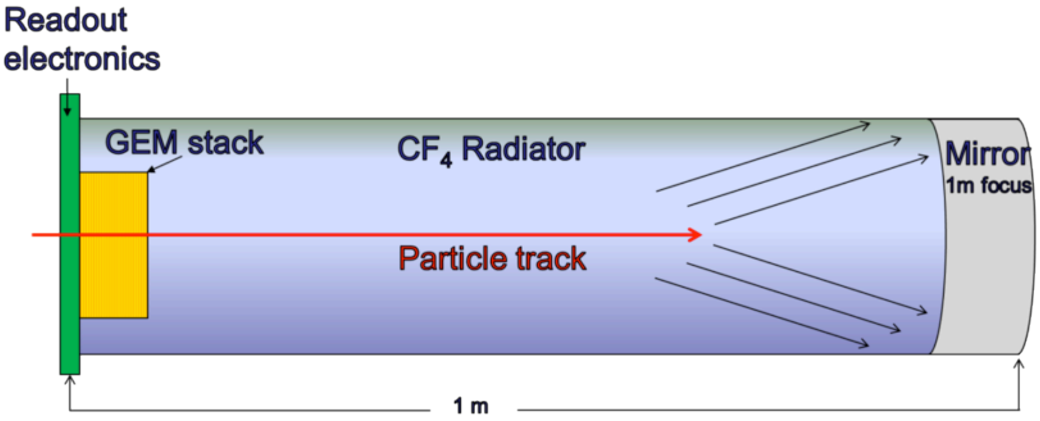
Measuring single photons with high efficiency requires high gain.

Position of the CsI photocathode, one focal length from and orthogonal to the mirror, creates the possibility for photon feedback from the avalanche.

Not to worry:

- Option to run top GEM at gain= 1 (no light)
- Option to stabilize stack voltage by running low gain on bottom gain

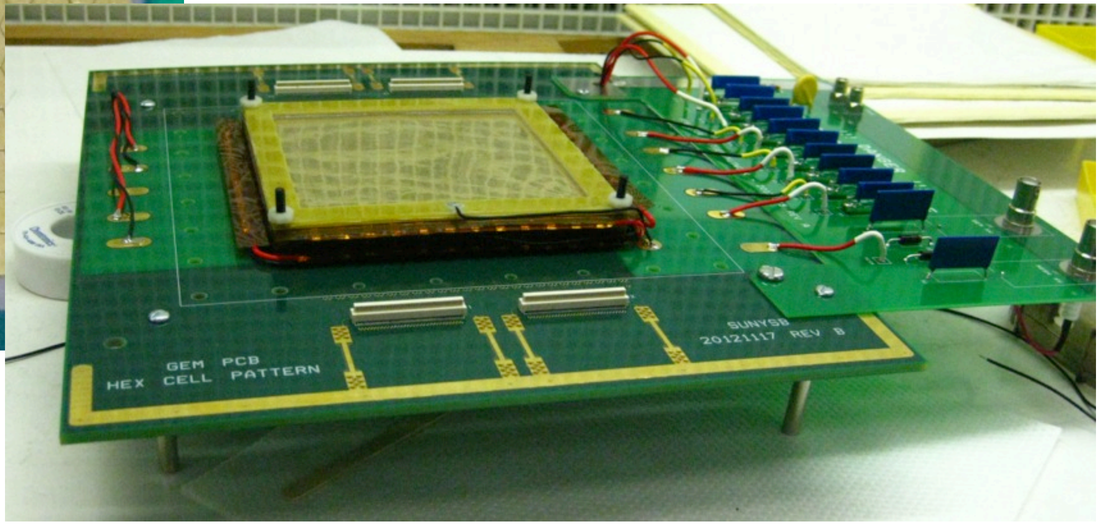
NOTE: PHENIX HBD had 4000 gain…we wanted our detector to work with perfect stability on the first try…
WE SUCCEEDED.



Using Hexagons

Detector’s “pad plane” is an array of hexagonal pads which respond to “hits” from the electrons

- SRS and other electronics give us a picture of the electron signal

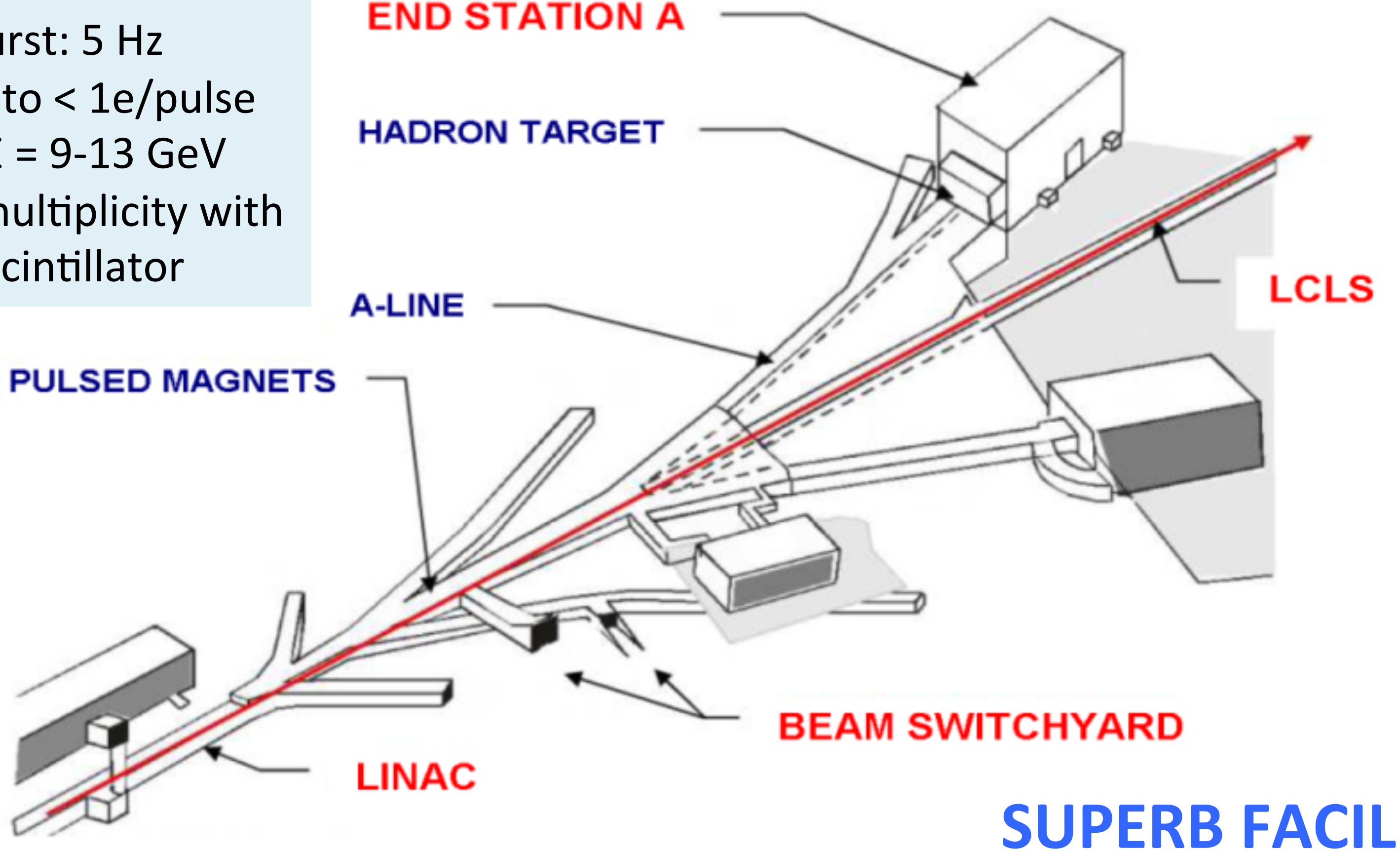


Test Beam @ ESTB

Our RICH saw “first light” at the End Station Test Beam (ESTB) facility at the SLAC National Accelerator Laboratory in Menlo Park, CA in May 2013.

Beam Parameters:

- Beam burst: 5 Hz
- Tunable to < 1e/pulse
- Typical E = 9-13 GeV
- Define multiplicity with PbGl & Scintillator



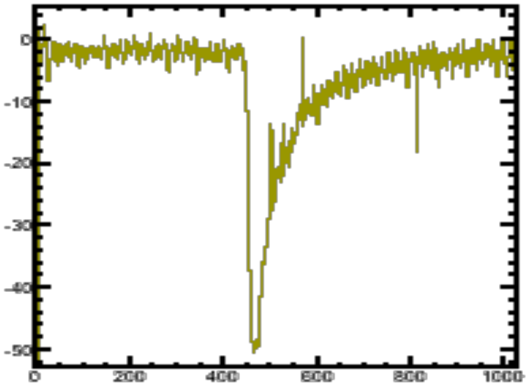
SUPERB FACILITY!!

https://portal.slac.stanford.edu/sites/ard_public/estb/Pages/default.aspx

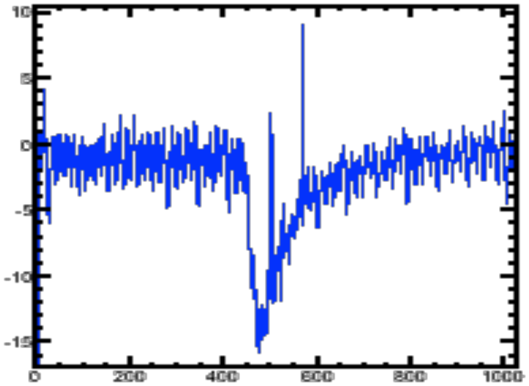
Data Acquisition

- BNL-RCDAQ software, by Martin Purschke et al.
- Flash ADC & SRS provide single data stream
- Automated, digital logbook
- **Scriptable:** trigger timing, high voltage control and recording, channel ring-out, writing of auxiliary info to data files

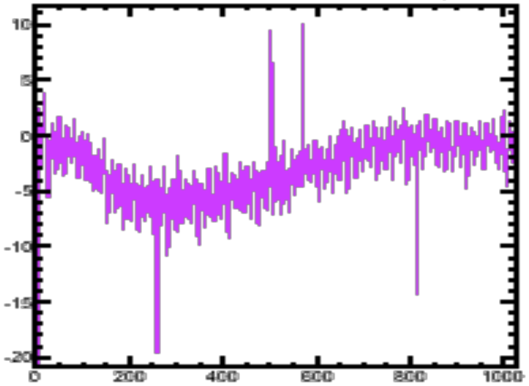
Scintillator



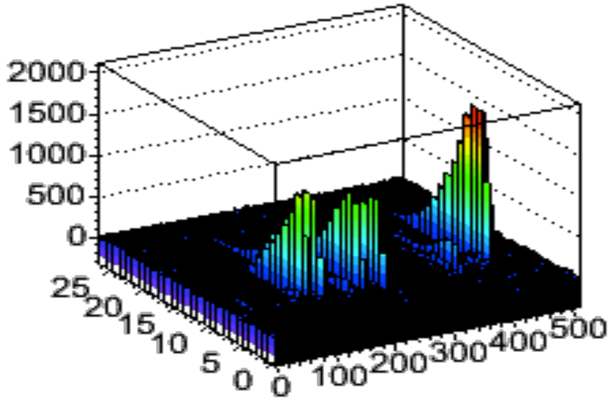
Lead Glass



GEM Pick-off Signal

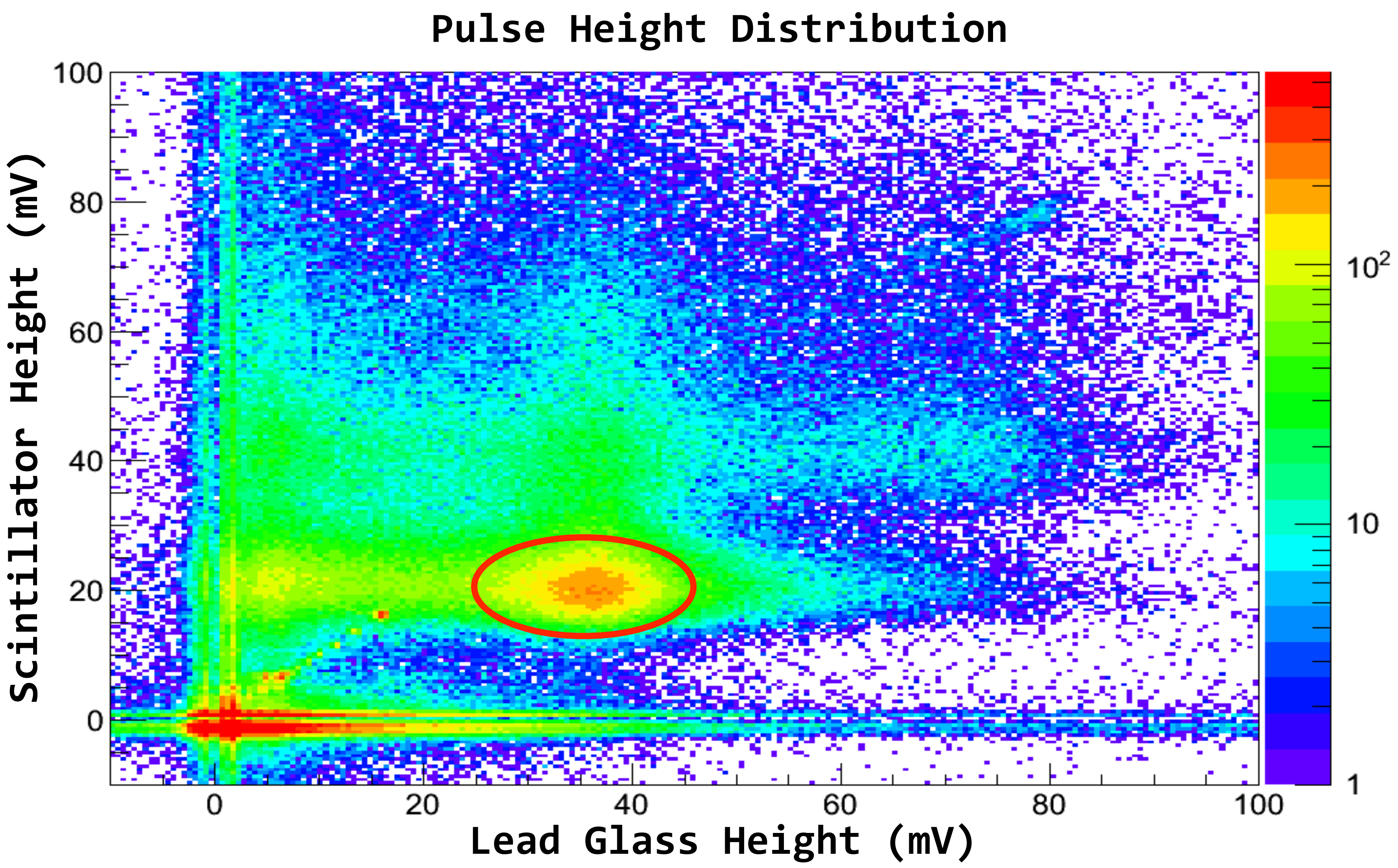


Pad Plane via SRS

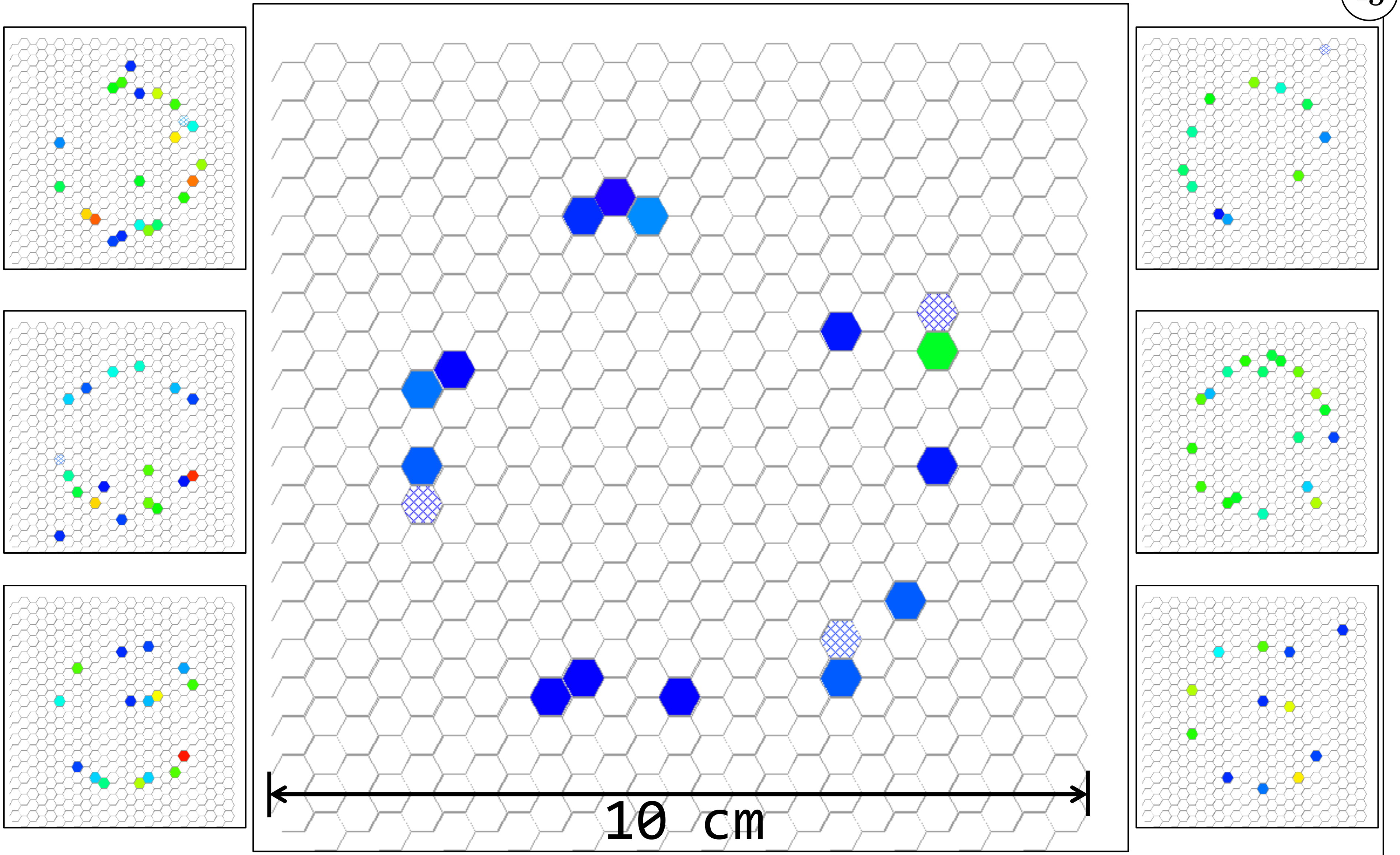


- **Metadata in data files: ANY output from any shell command**

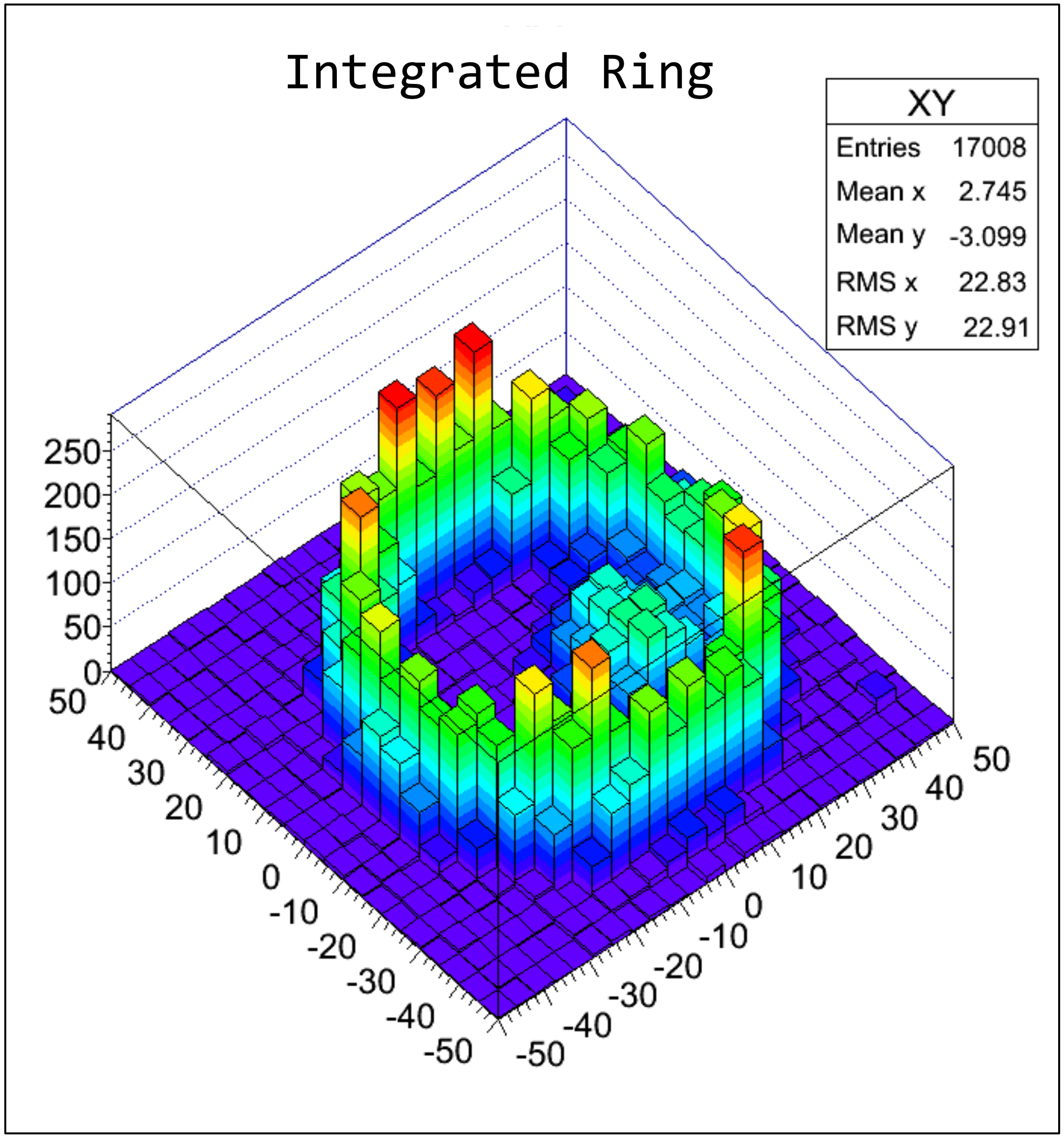
Results & Analysis: Finding Single Electrons



Results & Analysis: Rings!



Results & Analysis



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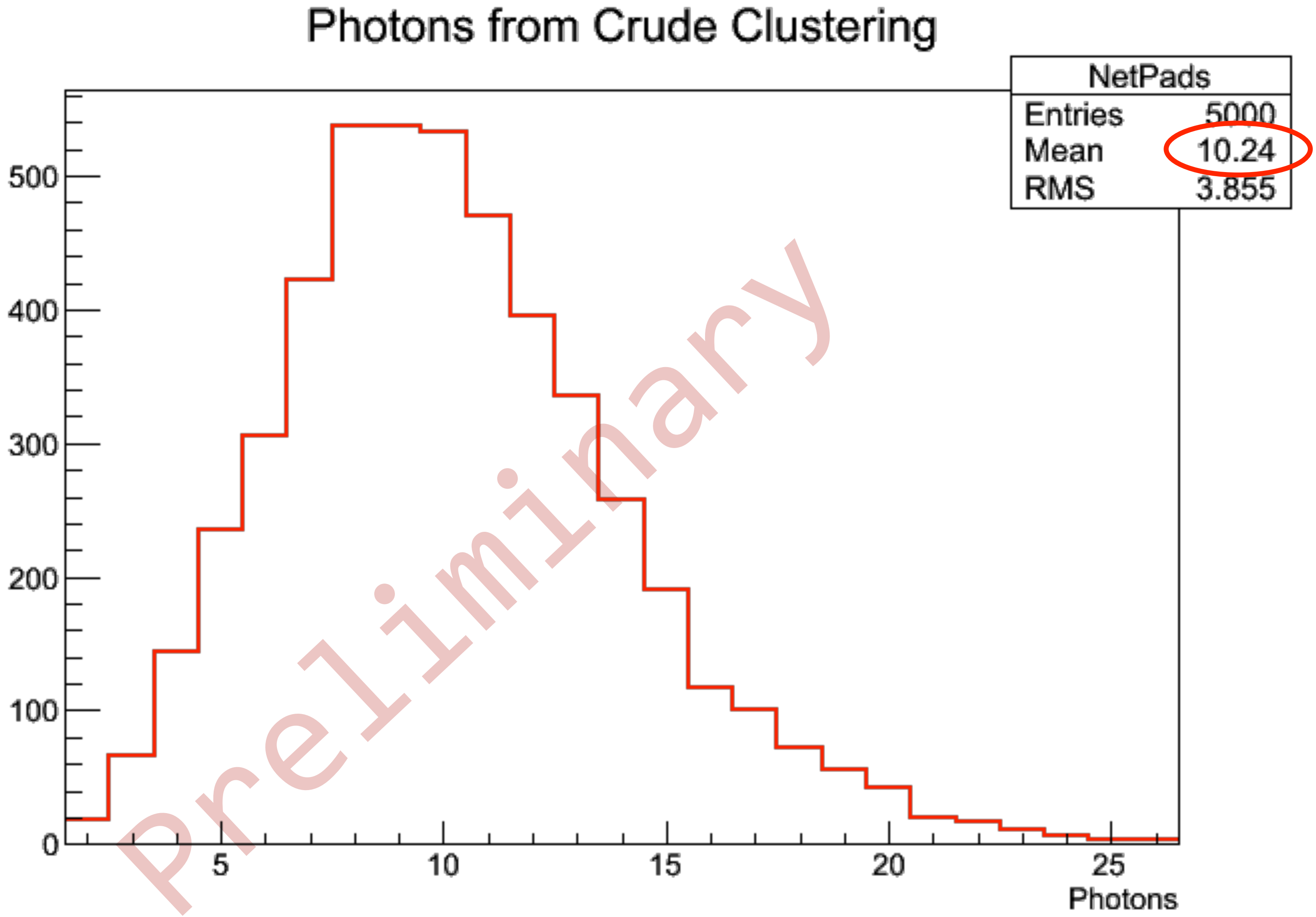
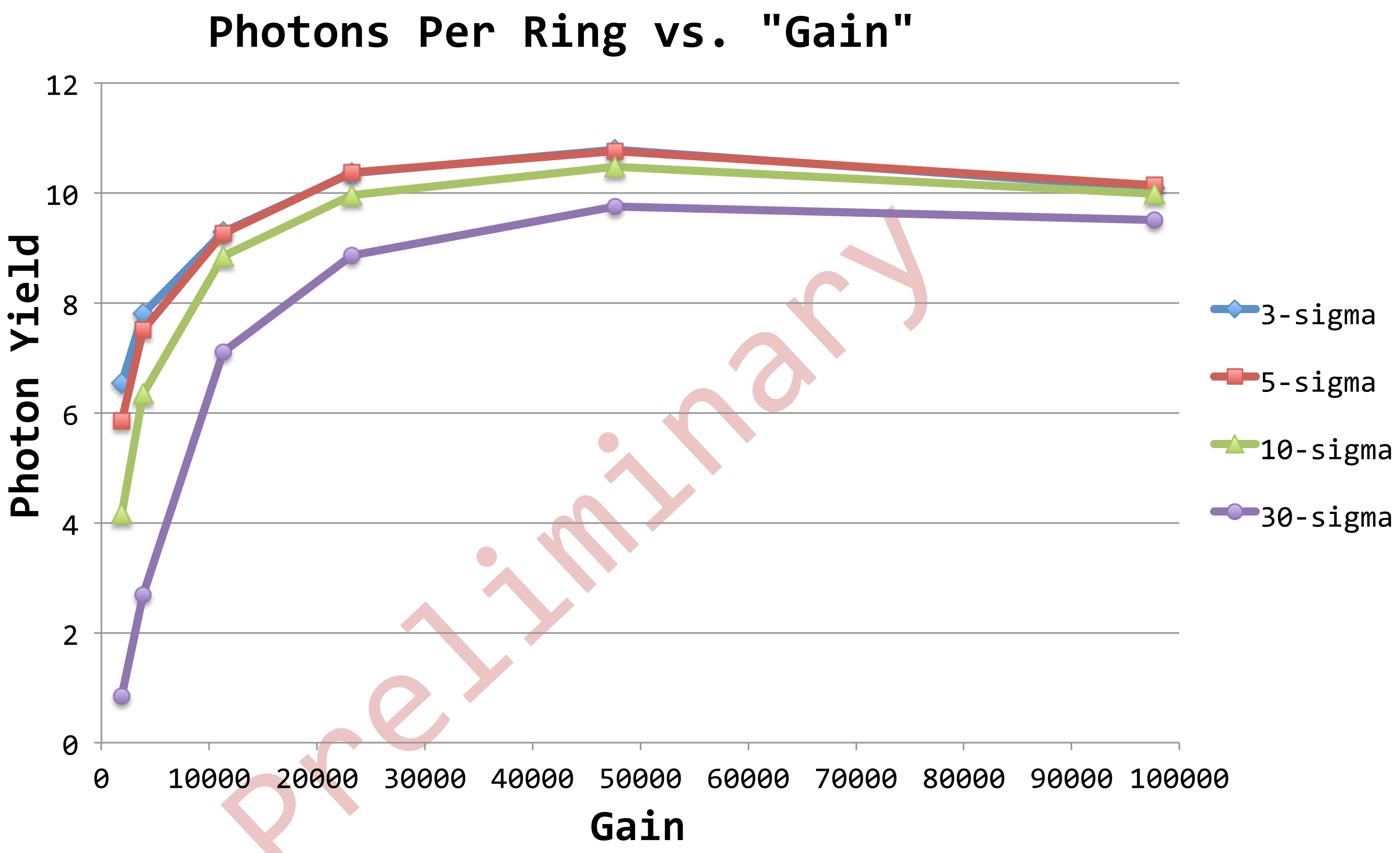


Results & Analysis



Conclusions and Outlook

- **Successful “proof of concept” with this prototype**

- Optimization of parameters:
  - Alternative pad plane for improved radius resolution and to allow for charge sharing
  - Potential integration of other gain mechanisms (e.g., THGEMs, MicroMegas, Cobra, etc.)
  - Tune mirror design to shift dielectric peak point

- Test beam @ FermiLab in October 2013
  - EIC Sector Test: Tracking & RICH
  - Hadron beam up to 60 GeV

Notice: Ample opportunities for R&D funding for EIC

Acknowledgement

- This material is supported by the United States Department of Energy under Award No. 200934
- Martin Purschke & BNL team of RCDAQ developers
- Special thanks to the EIC RICH R&D Group @ Stony Brook:

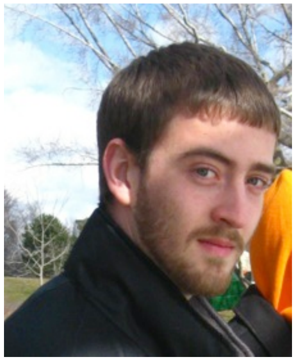
Tom Hemmick

Abhay Deshpande

Klaus Dehmelt

Nils Feege

Thomas Videbaek



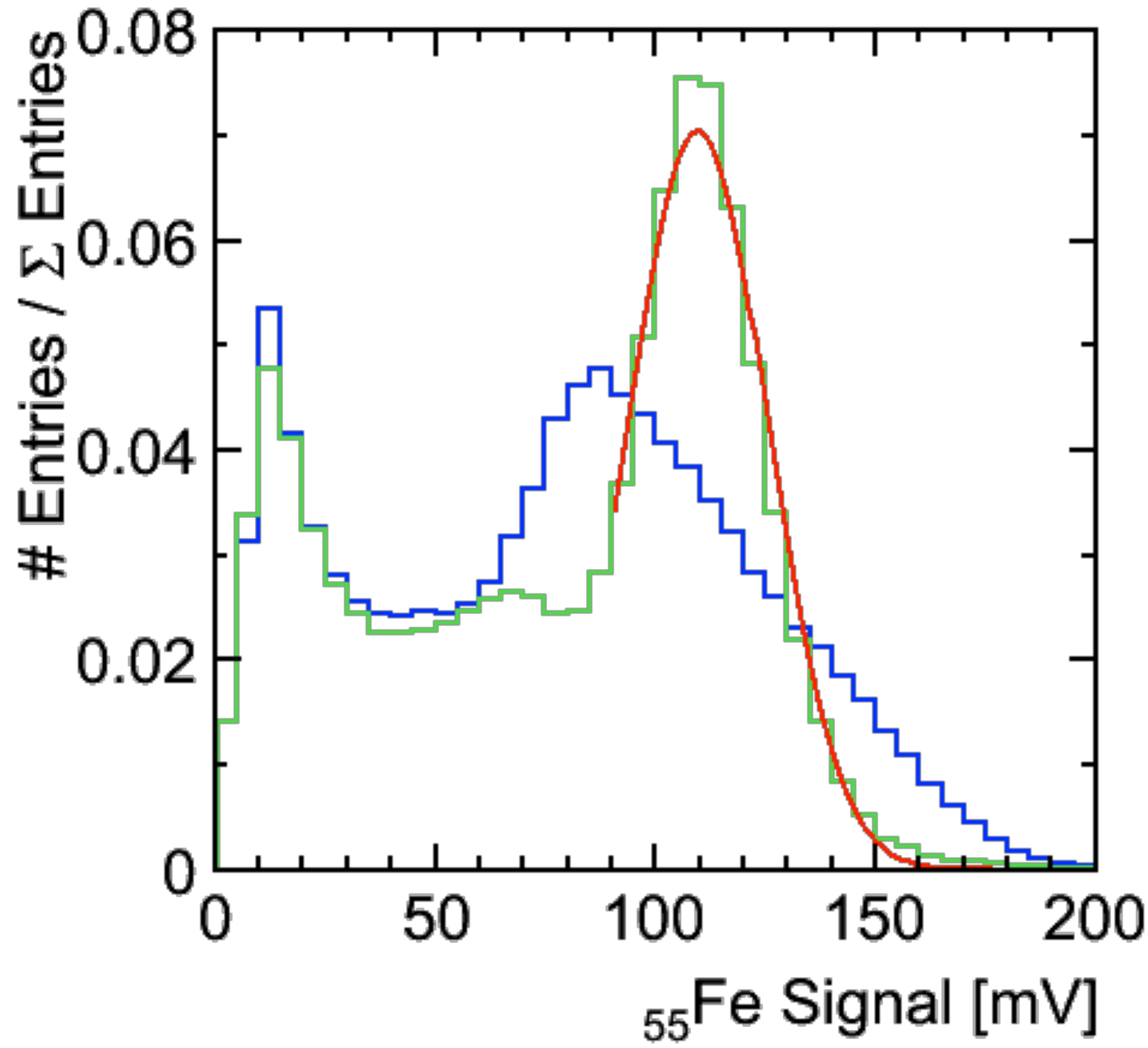
(graduated)

Marie Blatnik

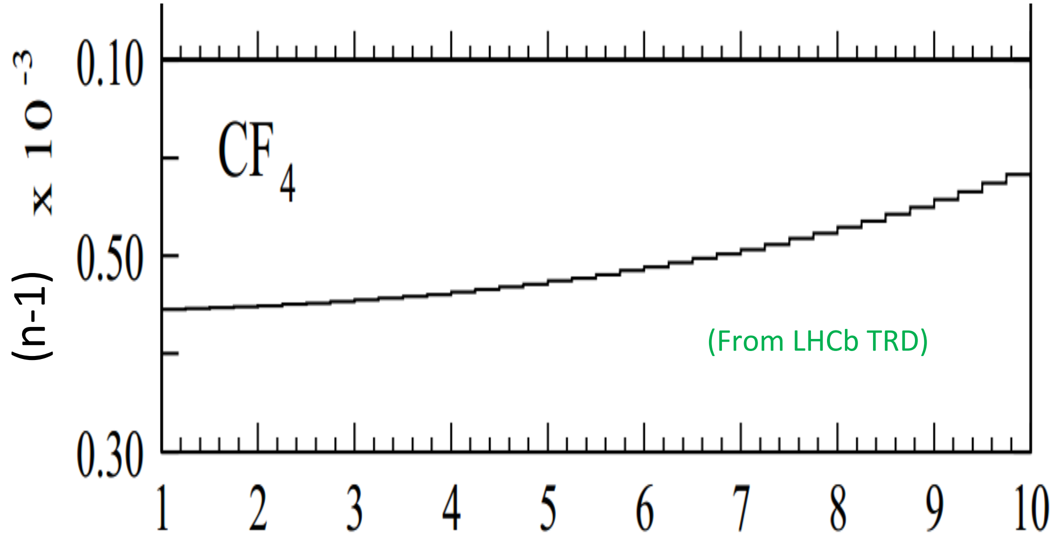
Thank you!

- - - - - - - - - - EXTRA SLIDES - - - - - - - - - - - - -

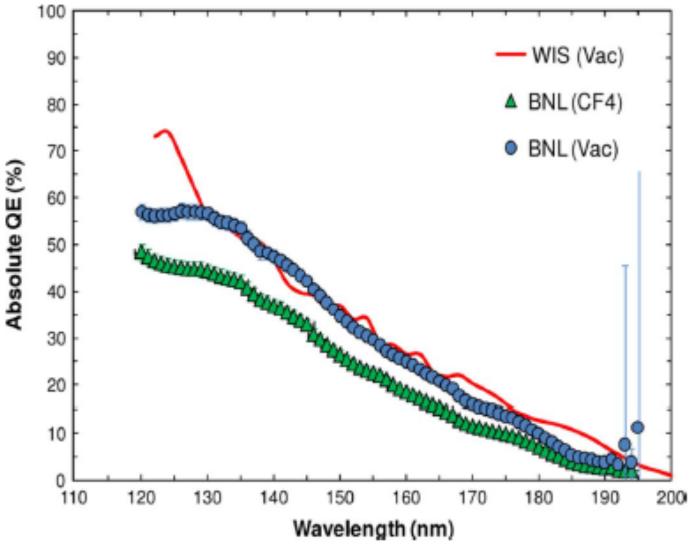
Gain Correction



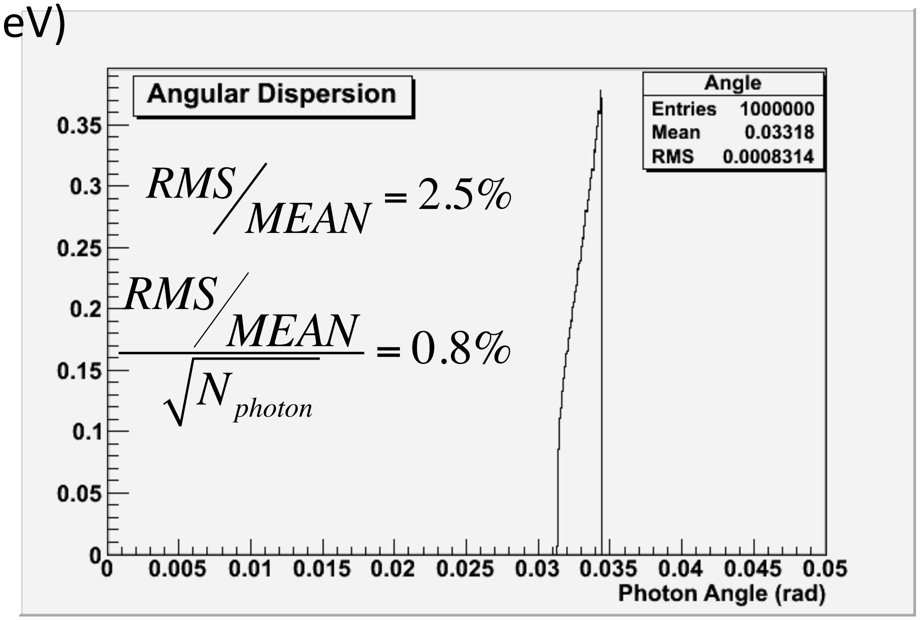
Dispersion Considerations



(From LHCb TRD)



- n varies with λ.
- Rate varies with λ:
  - Cherenkov Flux =
  - QE ~linear with λ.

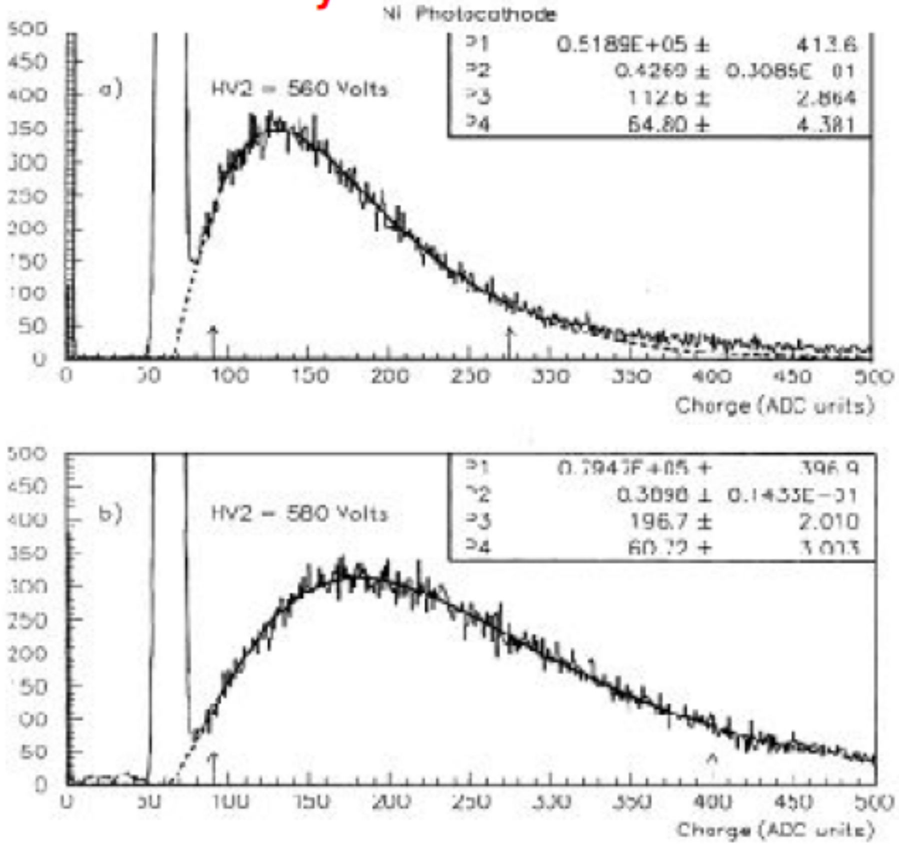


$$RMS/MEAN = 2.5\%$$

$$\frac{RMS/MEAN}{\sqrt{N_{photon}}} = 0.8\%$$

Efficiency (Not the same as gain!)

Polya distribution

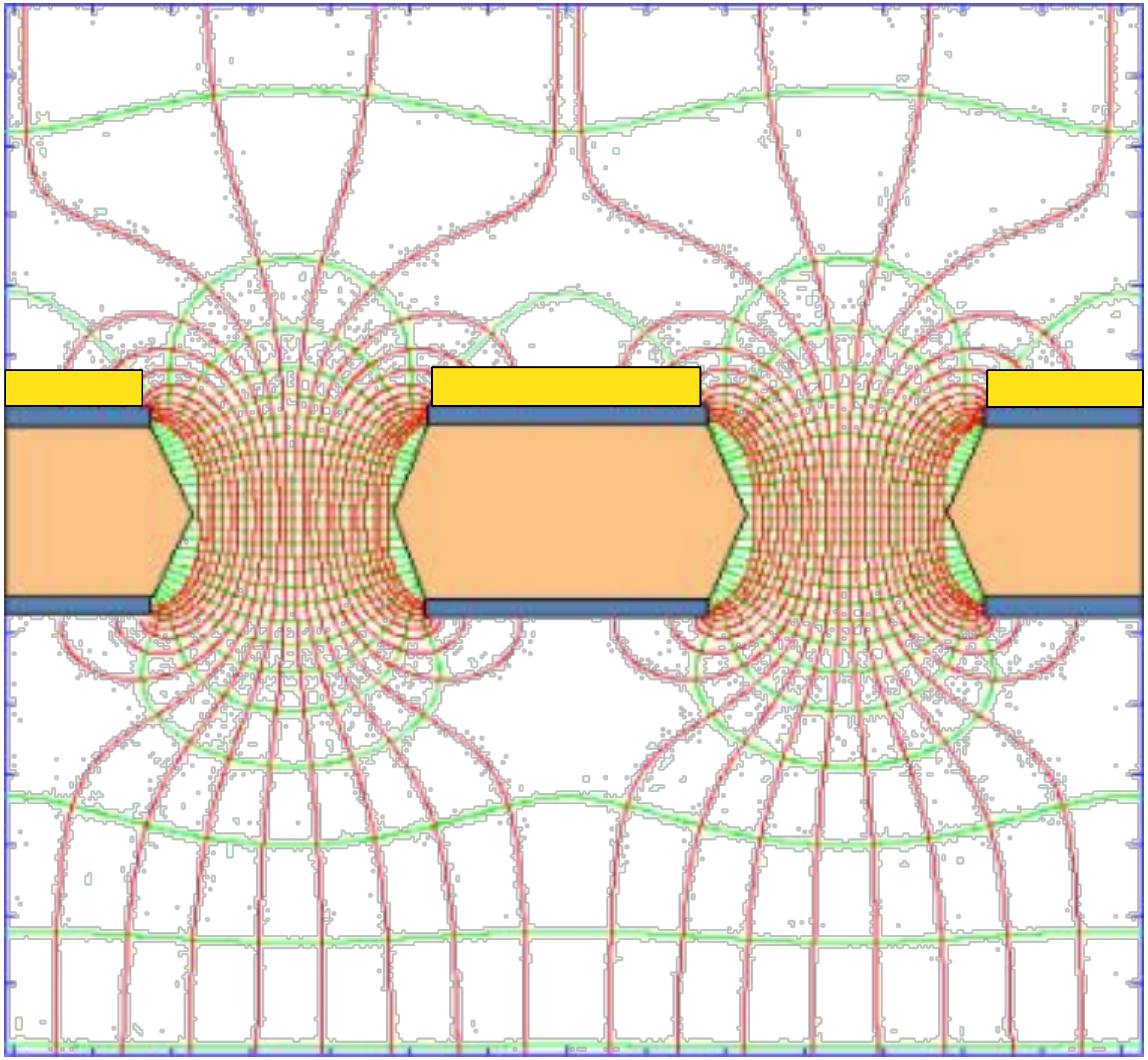


J. Derré et al., NIM A 449 (2000), 314.

MM gain mechanism produces a pulse height spectrum which is more "peaked" than exponential.

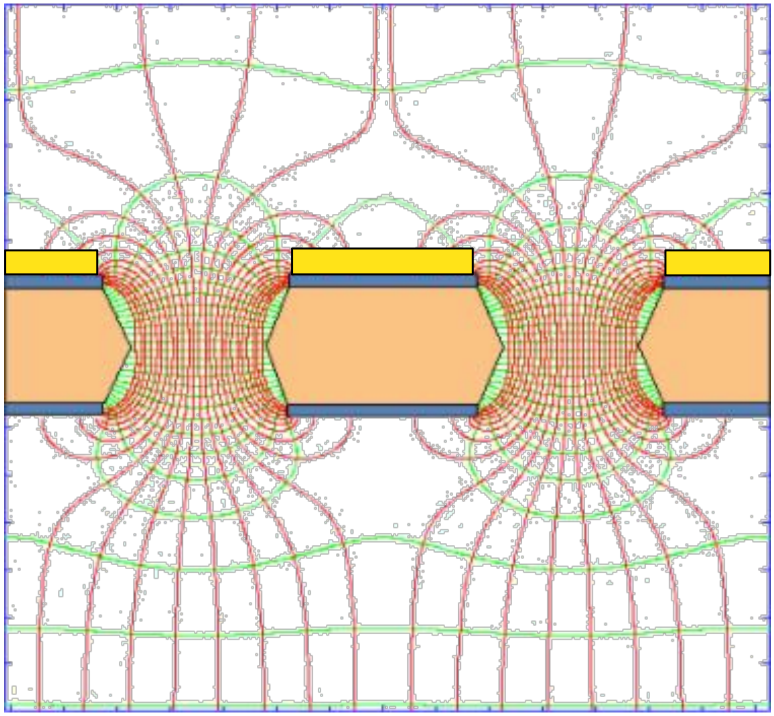
- The goal of any RICH is to get high efficiency for single photo-electron detection.
- Often gain is the only tool.
- Notice that avalanche mechanism can alter the single electron response and thereby get higher efficiency at any given gain.
- This is among the reasons that we are flexible in our choice of avalanche technology moving forward.

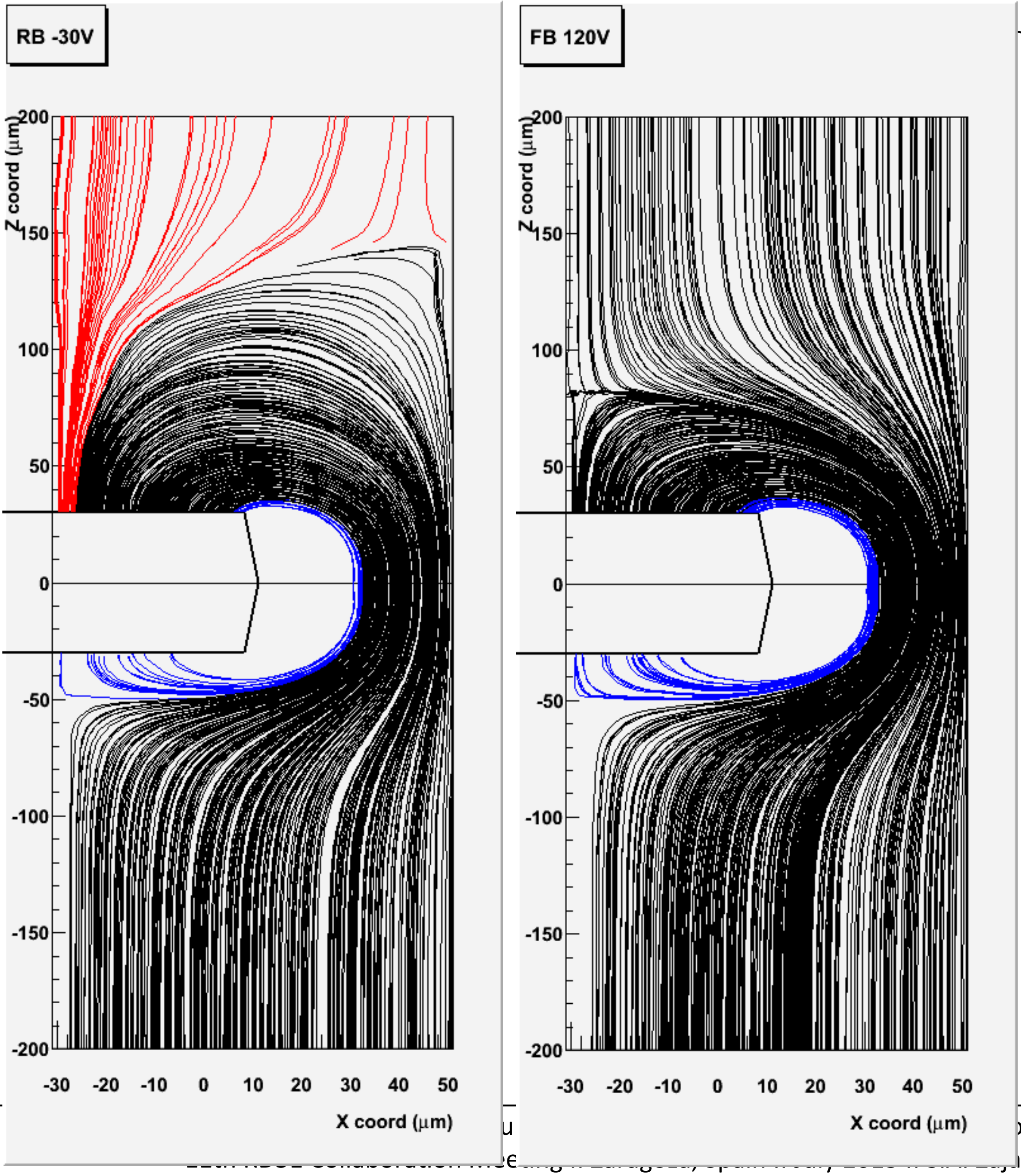
Slide Title



Slide Title

Lines go to mesh
Lines go to pad
Lines go to GEM bottom



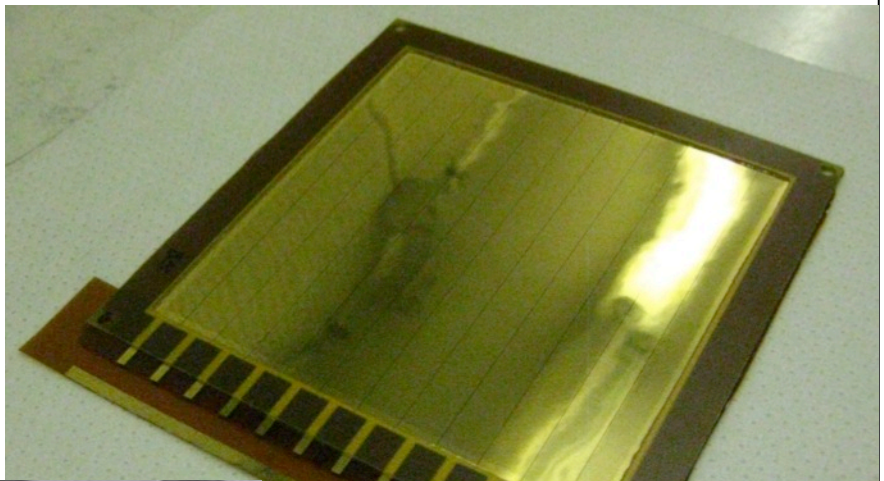


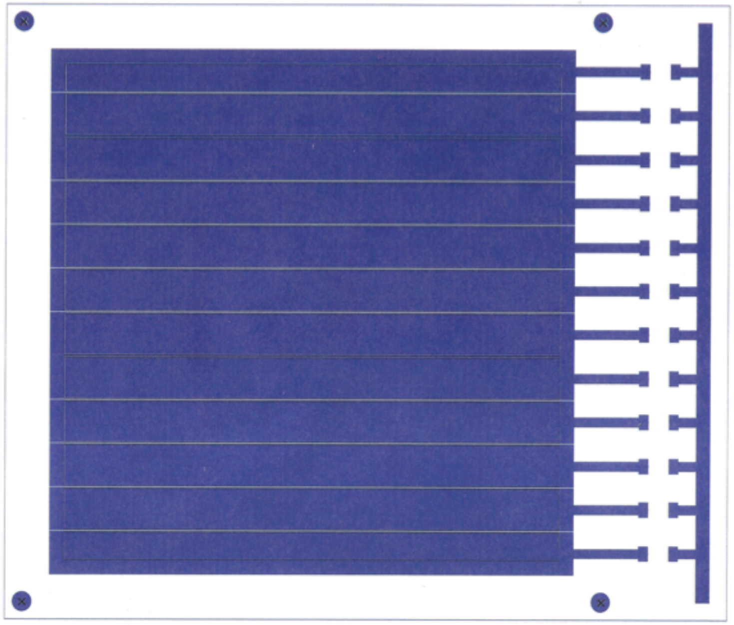
Motivation: Building an EIC-ready RICH

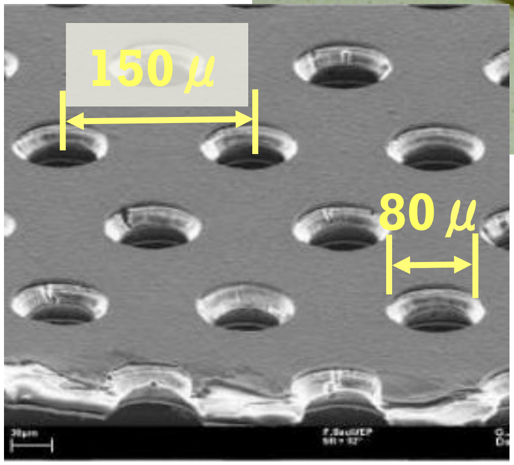
Present-Day RICH technology:

- Large
  - Use mirror to reduce physical size while not reducing path length
- Photomultiplier Tubes ($$$)
  - **Use GEMs to achieve high signal gain**
- Velocity resolution limited at higher *p*

- Photon yield not optimized in deep UV







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