A Hadron Blind Detector for the PHENIX Experiment at RHIC

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Instrumentation Seminar
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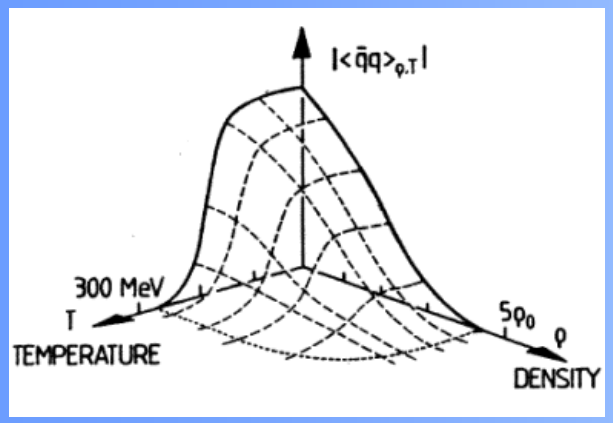
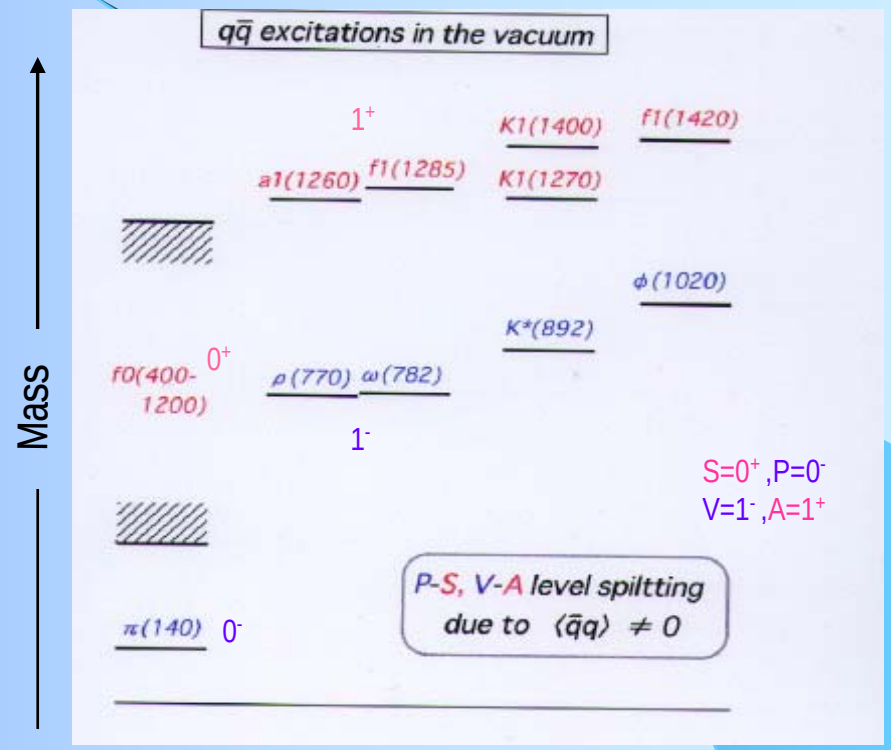
Motivation

- Chiral symmetry, which is the symmetry between light quark flavors, is normally broken due to the finite value of the constituent quark masses. However, at high temperatures and/or high baryon densities, such as those produced in relativistic heavy ion collisions at RHIC, this symmetry may be at least partially restored.
- Low mass e^+e^- pairs are the best probe for Chiral Symmetry Restoration
- Effects of CSR may have been seen in CERN SPS results
- The same effects are predicted to occur at RHIC, but will be difficult to detect
- PHENIX is the only experiment at RHIC that could perform this measurement

Chiral Symmetry Restoration



Isospin Parity → Chiral J^P doublets



- Chiral Symmetry is a symmetry of light flavors due to small quark masses (m_u,m_d)
- Spontaneously broken in nature due to finite quark masses (<qqbar> ≠0)
- Causes splitting of scaler/pseudo-scaler and vector/axial vector mesons
- Expected to be approximately restored at high temperature and/or baryon density

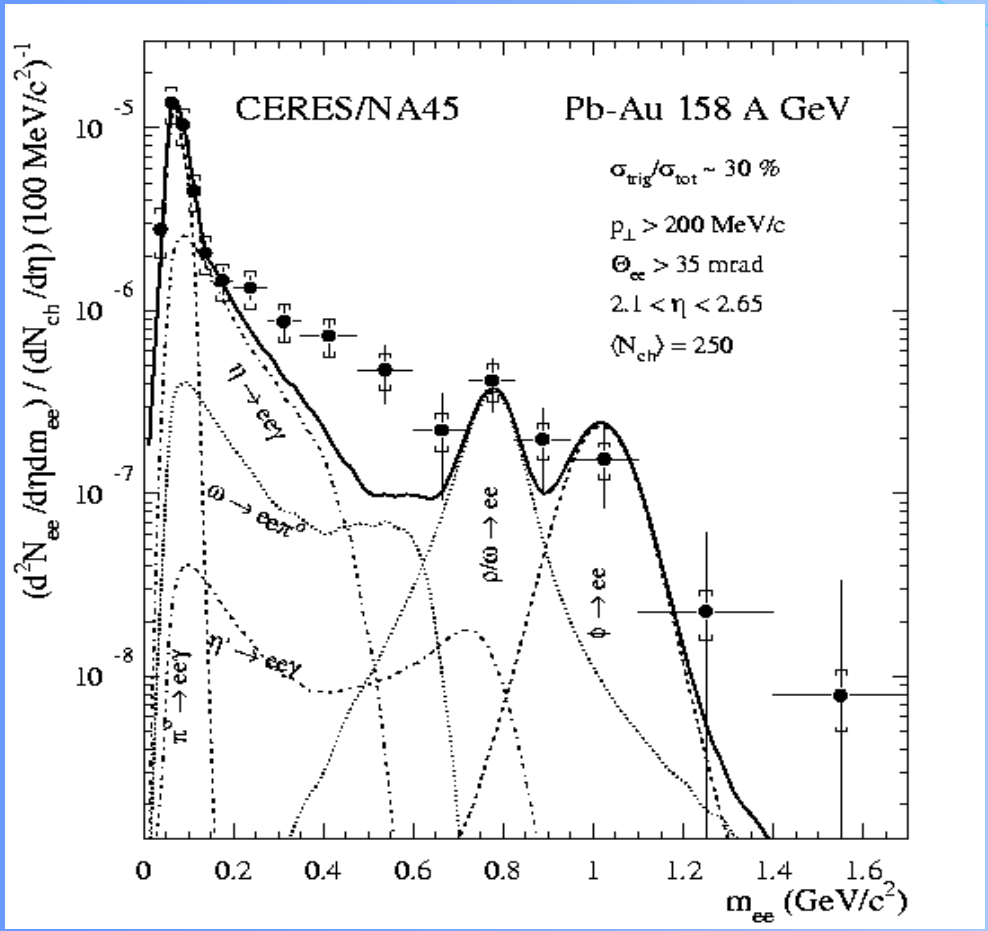
Best candidate is the ρ (τ_ρ ~ 1.3 fm/c)

τ_ω ~ 23 fm/c, τ_ϕ ~ 44 fm/c

Also: $\frac{\phi \to KK}{\phi \to ee}$

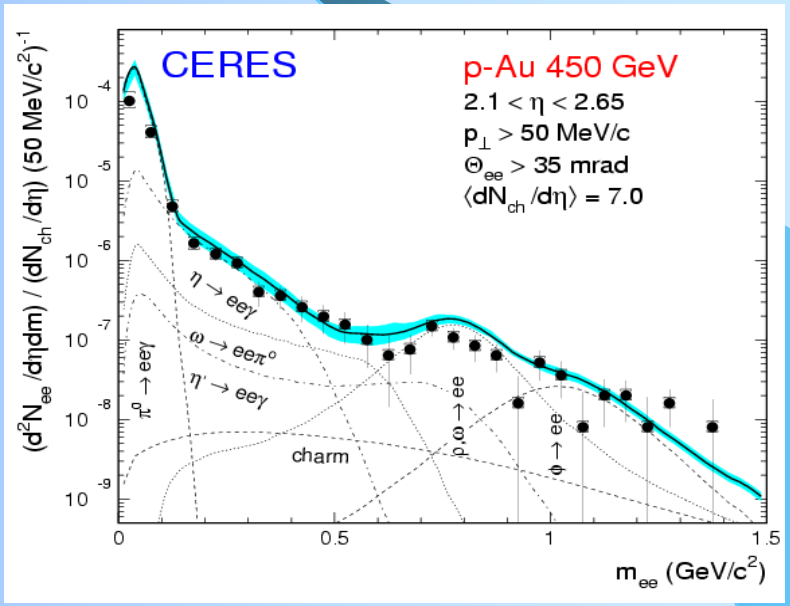
⇒ in-medium modification of mass, Γ of light vector mesons

Low Mass Electron Pairs at the SPS



Enhancement factor (.25 <m<.7GeV/c^2) :
2.6 ± 0.5 (stat) ± 0.6 (syst)

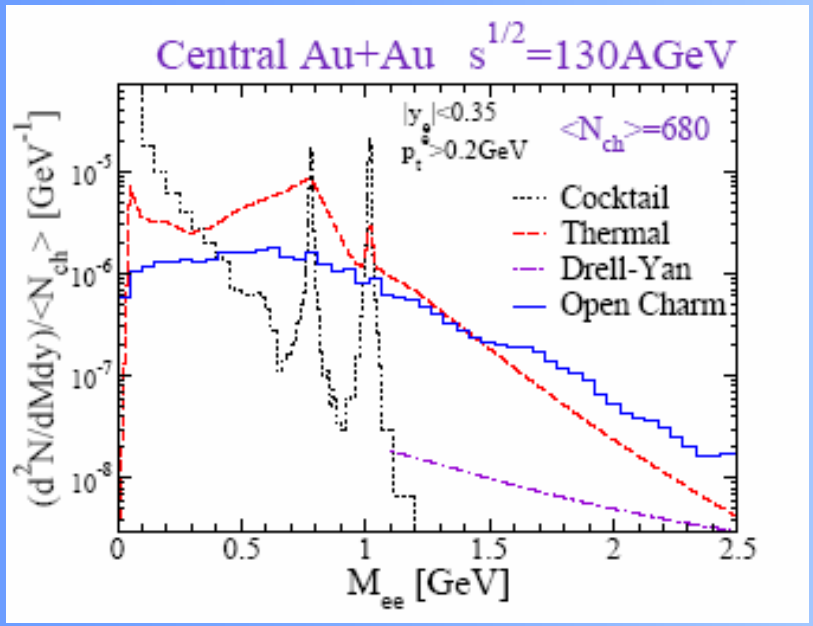
Strong enhancement of low-mass e^+e^- pairs in A-A collisions
(wrt to expected yield from known sources)



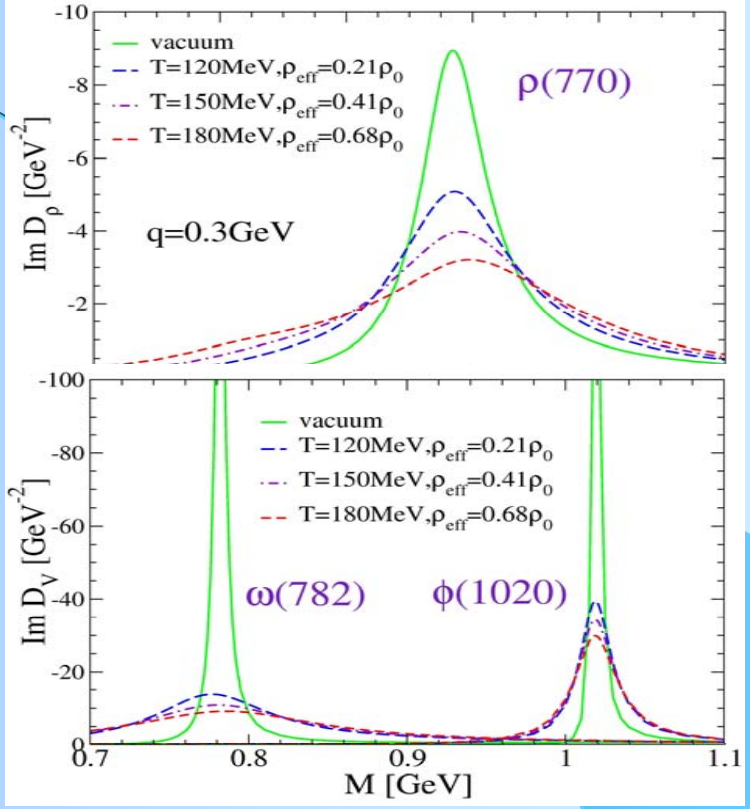
No enhancement
in pp and pA collisions

Low Mass Electron Pairs at RHIC

- Strong enhancement of low-mass pairs persists at RHIC
- Contribution from open charm becomes significant

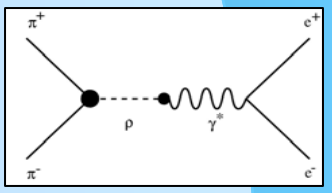


R. Rapp nucl-th/0204003



- Possibility to observe in-medium modification of the intermediate vector mesons (ρ,ϕ,ω):
  - **Dropping of ρ invariant mass (Rapp & Wambach)**
  - **Broadening of vector meson (ρ, ω, ϕ) invariant masses (Brown et.al)**
  - **Thermal radiation from hadron gas (small…)**

$\pi\pi \rightarrow \rho \rightarrow \gamma^* \rightarrow e^+e^-$



Experimental Challenges at RHIC

Large combinatorial pair background due to copiously produced photon conversions and Dalitz decays :

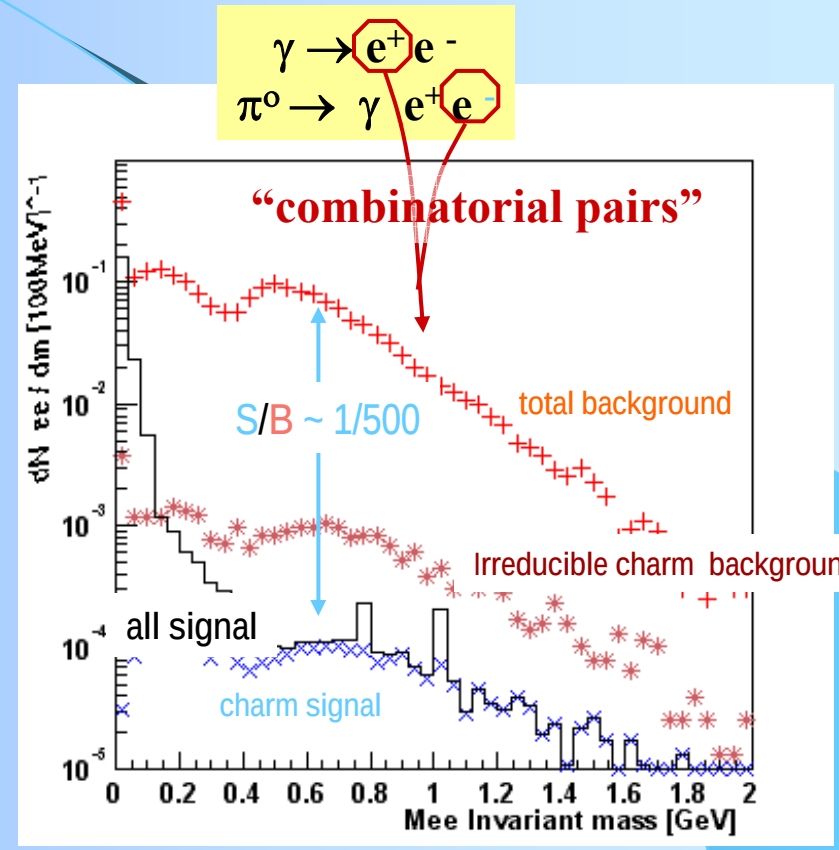
- *Both members of the electron pair are needed to reconstruct the Dalitz pair or conversion.*
- *Single electron pair members contribute to background:*
- *Limited by:*

– *Low p_T acceptance of outer PHENIX detector:*

(p_T > 200MeV)

– *Limited geometrical acceptance of present PHENIX configuration*

Need rejection factor > 90% of $\gamma \rightarrow e^+ e^-$ and $\pi^0 \rightarrow \gamma\ e^+ e^-$



Would like to improve S/B by ~ 100-200

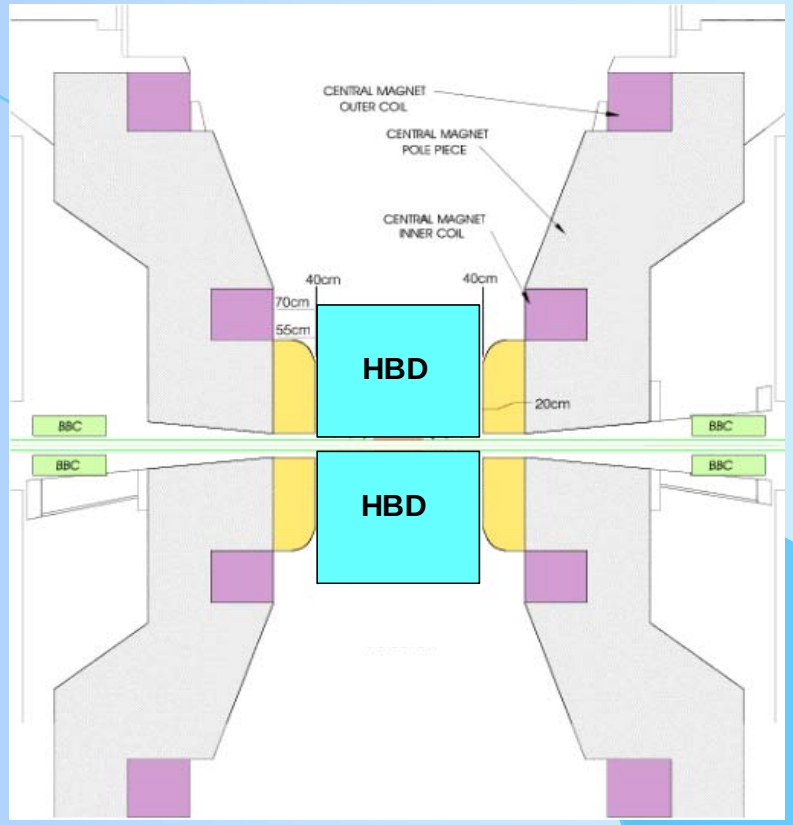
Measuring Low Mass Electron Pairs in PHENIX

Hardware

- Compensate magnetic field with an inner coil to preserve e^+e^- pair opening angle (foreseen in original design → B~0 for r ≤ 50-60cm)
- Compact HBD in inner region (possibly to be complemented by a TPC or other tracking detector in the future).

Strategy

- Identify signal electrons with p > 200 MeV/c from vector mesons in the outer PHENIX detectors
- Identify low momentum electrons with p < 200 MeV/c (mainly from Dalitz pairs and conversions) in the HBD
- Reject pair if opening angle < 200 mrad (for ~ 90% rejection).



Requirements

* Electron efficiency ≥ 90%
* Double hit recognition ≥ 90%
* Modest π rejection ~ 200

The HBD Detector

HBD Gas Volume: Filled with CF_4 Radiator
(n_{CF4}=1.000620, $L_{RADIATOR}$ = 50 cm)

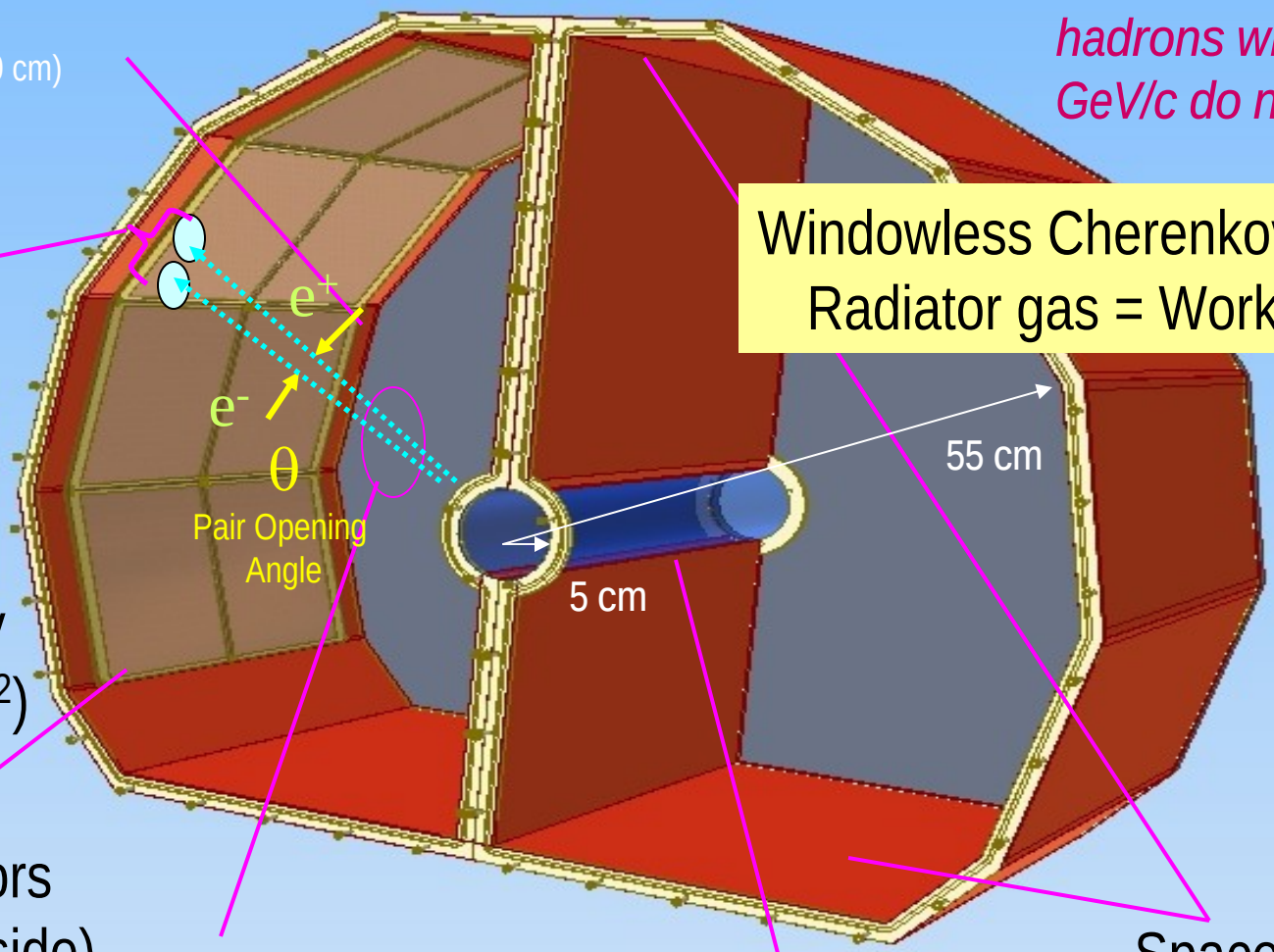
Proximity focused Cherenkov forms "blobs" on an image plane
($\Theta_{max} = \cos^{-1}(1/n) \sim 36$ mrad $\rightarrow r_{BLOB} \sim 3.6$cm)

Coarse granularity readout (~ 2x2 cm^2)

Triple GEM detectors (8-12 panels per side)

Electron pairs produce Cherenkov light, but hadrons with P < 4 GeV/c do not

Windowless Cherenkov Detector
Radiator gas = Working Gas



Dilepton pair

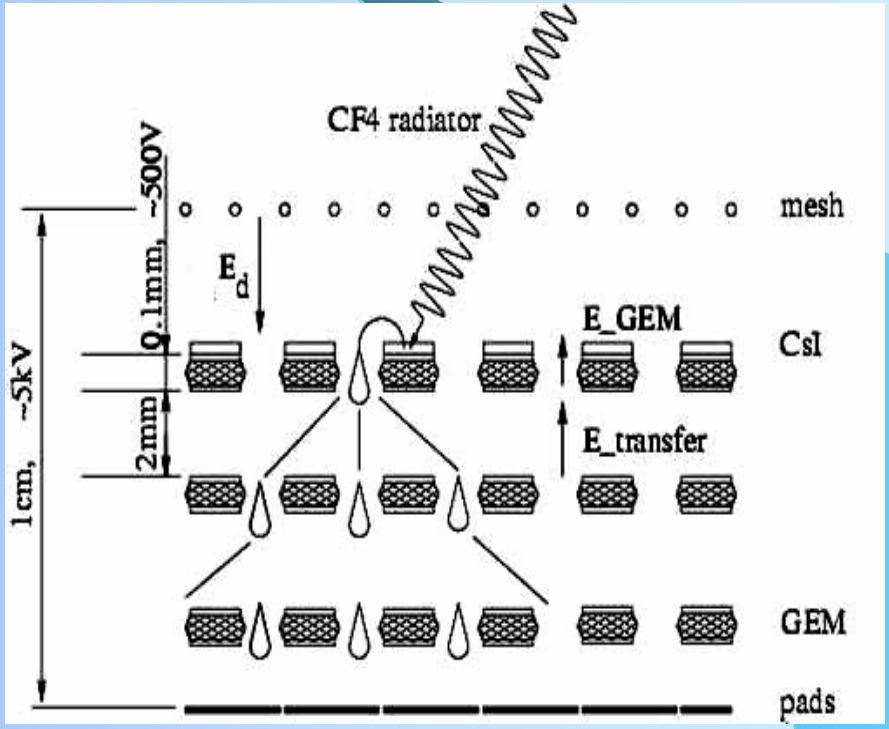
Beam Pipe

Space allocated for services

Is the HBD Really Hadron Blind ?

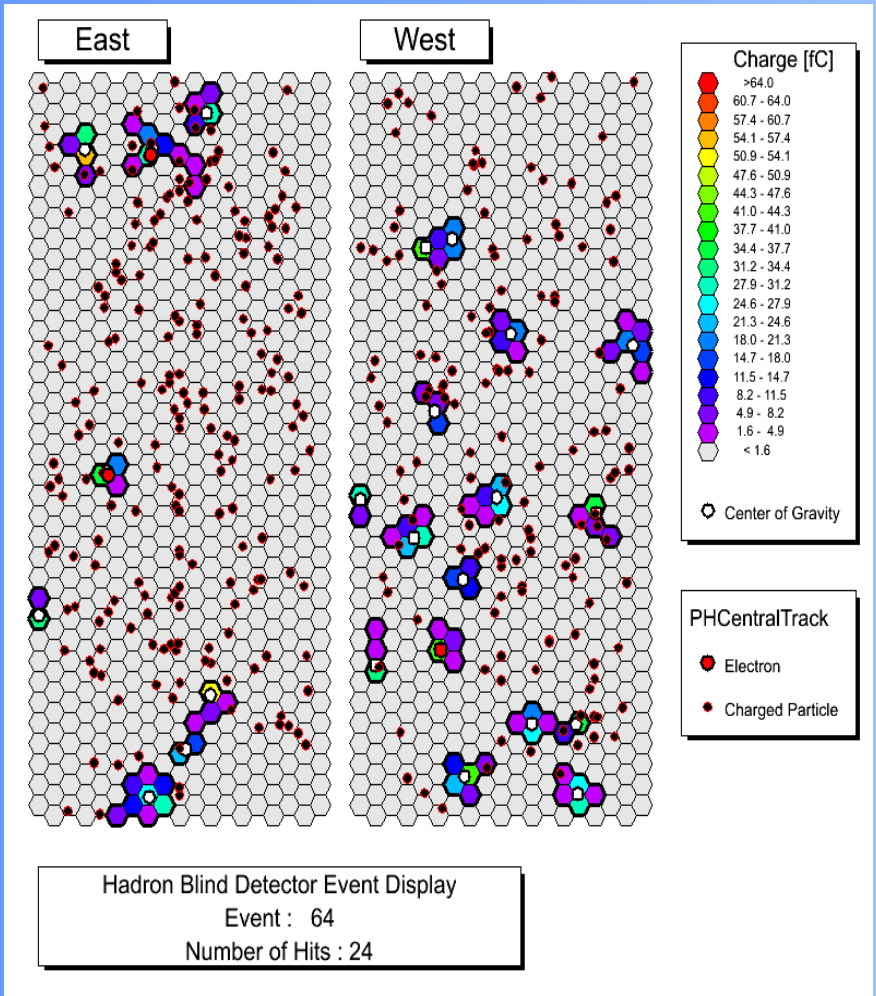
- Gain ~ 10^4 to detect few (~ 5-10) photoelectons (multistage GEM minimizes photon feedback and ion backflow
- Most of the ionization in the collection region is drifted away from the GEM stack and is collected by the mesh
- Some ionization (from a region ~ 100 μm thickness) is collected by the GEM stack
- Additional ionization is produced in the lower transfer regions, but receives less gain (÷ ~ 10)

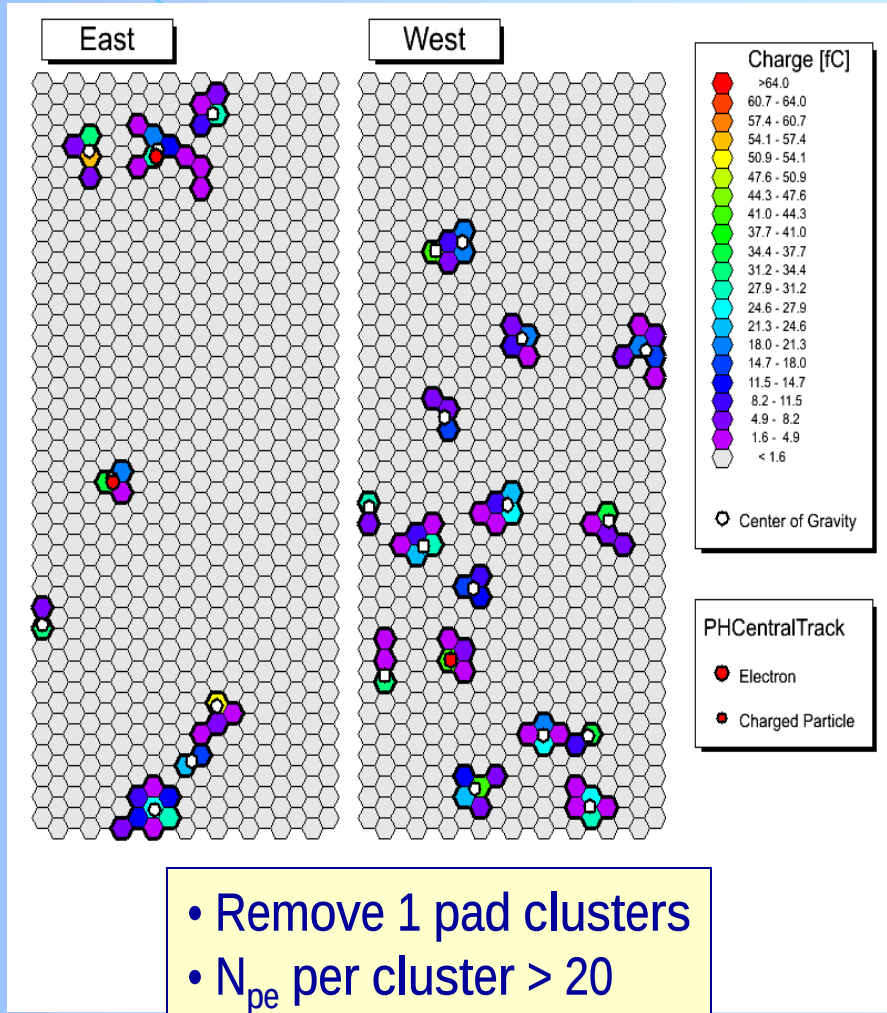
Multistage GEM detector with CsI photocathode deposited on outer GEM foil detects Cherenkov light from electrons



Monte Carlo Simulation of the HBD

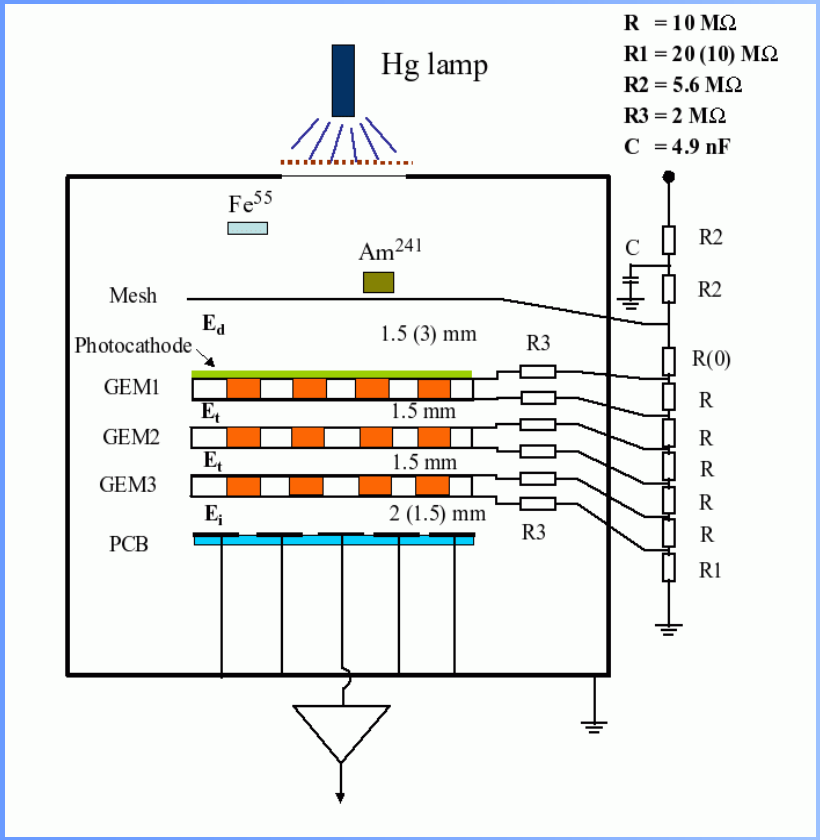
Event display: central HIJING event





- Remove 1 pad clusters
- N_{pe} per cluster > 20

Tests with a Prototype HBD

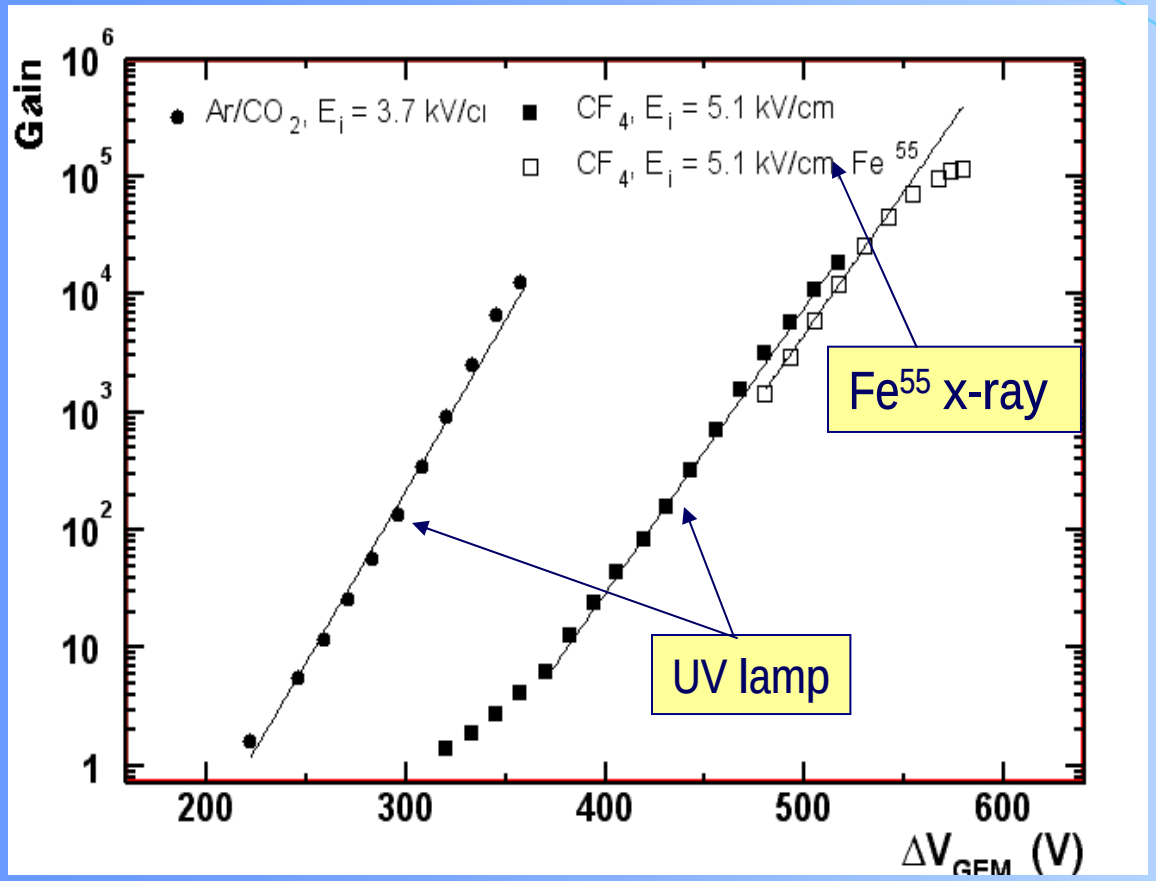


Prototype HBD detector at the WIS
(similar prototype at BNL)

- Triple GEM detector
- CsI photocathode deposited on top surface of uppermost GEM foil
- Operate in pure CF_4
- Gain < 10^4
- Hg lamp to study photocathode
- ^{55}Fe source to monitor gas gain

Gain Curve: Triple GEM with CsI and CF_4:

measured with Fe^{55} and with UV lamp



NIM A523(2004)345

- GEMs work with CsI and CF4 !
- Reasonably good agreement between gain measured with Fe^{55} and UV lamp.
- Gains in excess of 10^4 are easily attainable.
- Voltage for CF_4 is ~140 V higher than for Ar/CO_2 but slopes are similar for both gases.
- Gain increases by factor ~3 for ΔV = 20V

Total Charge in Avalanche

in Ar-CO_2 and CF_4 measured with Am^{241}

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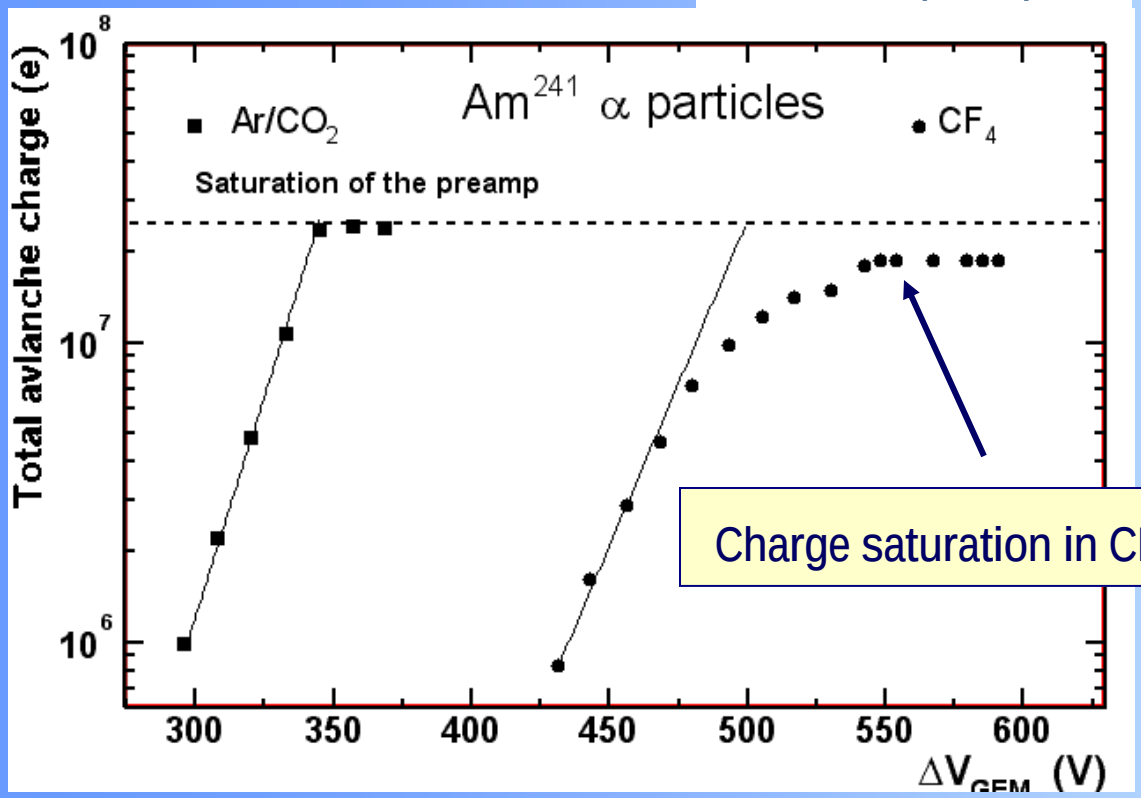
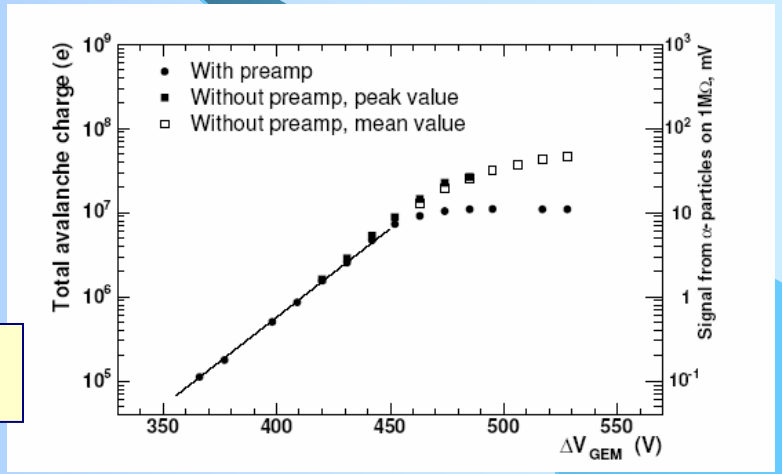
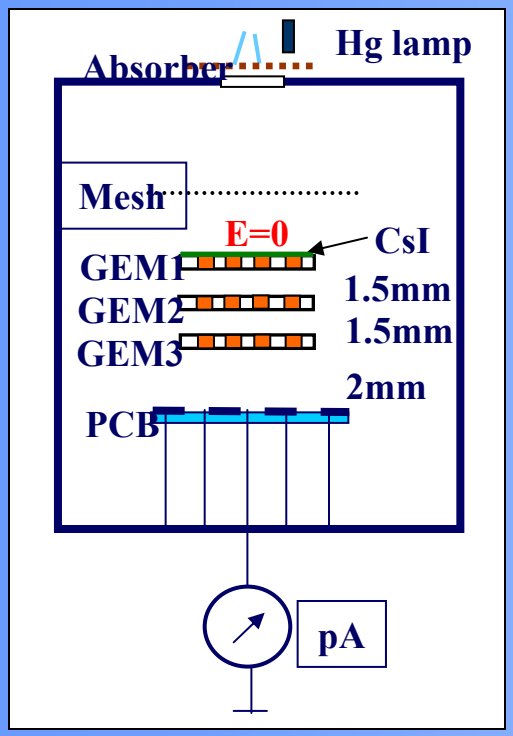


Charge saturation in CF_4



When the total charge in CF_4 exceeds ~ 4 x 10^6 a deviation from exponential growth is observed leading to gain saturation when the total charge is ~2 x 10^7.

Ion Back Flow



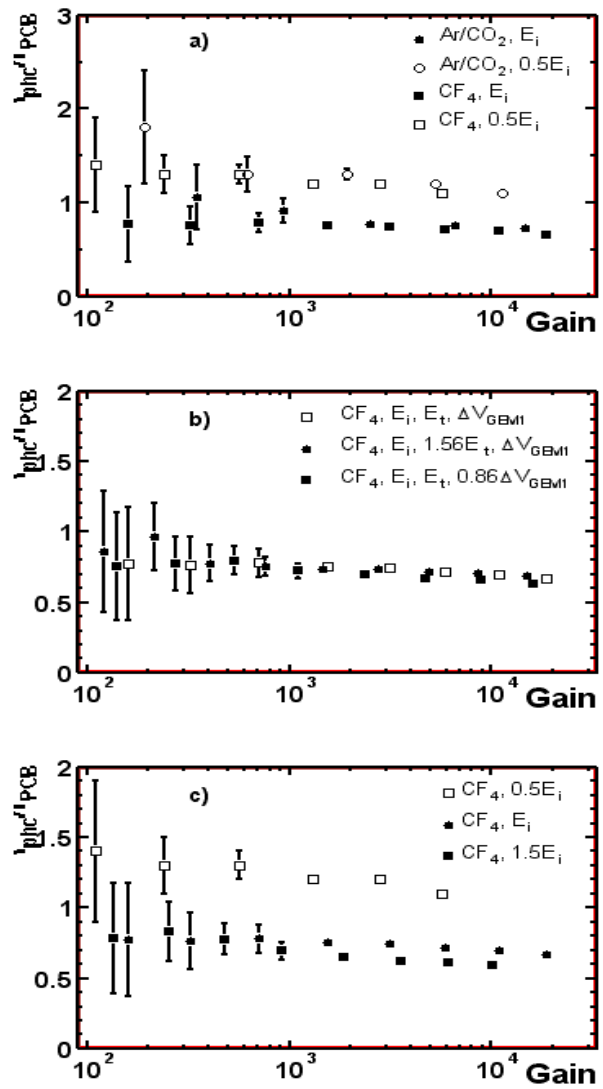
Fraction of ion back-flow defined here as:

I_{phc} / I_{PCB}

Independent of gas

Independent of E_t

Depends only on E_i
(at low E_i some charge is collected at the bottom face of GEM3)



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Ions seem to follow the electric field lines.
In all cases, ion back-flow is of order 1!!!

Discharge Probability

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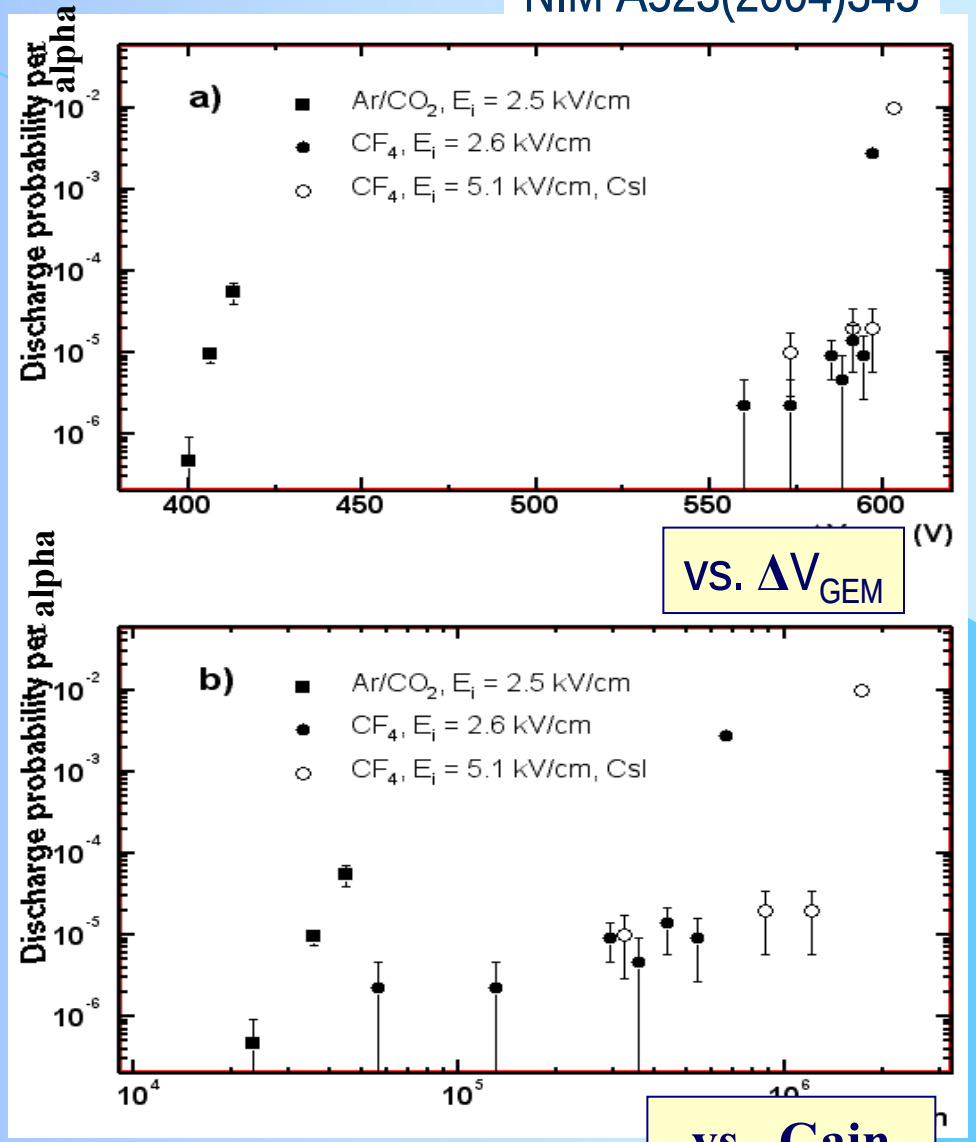
- Stability of operation and absence of discharges in the presence of heavily ionizing particles is crucial for the operation of the HBD at RHIC.
- Use Am^{241} to simulate heavily ionizing particles.

CF_4 more robust against discharges than Ar/CO_2 .

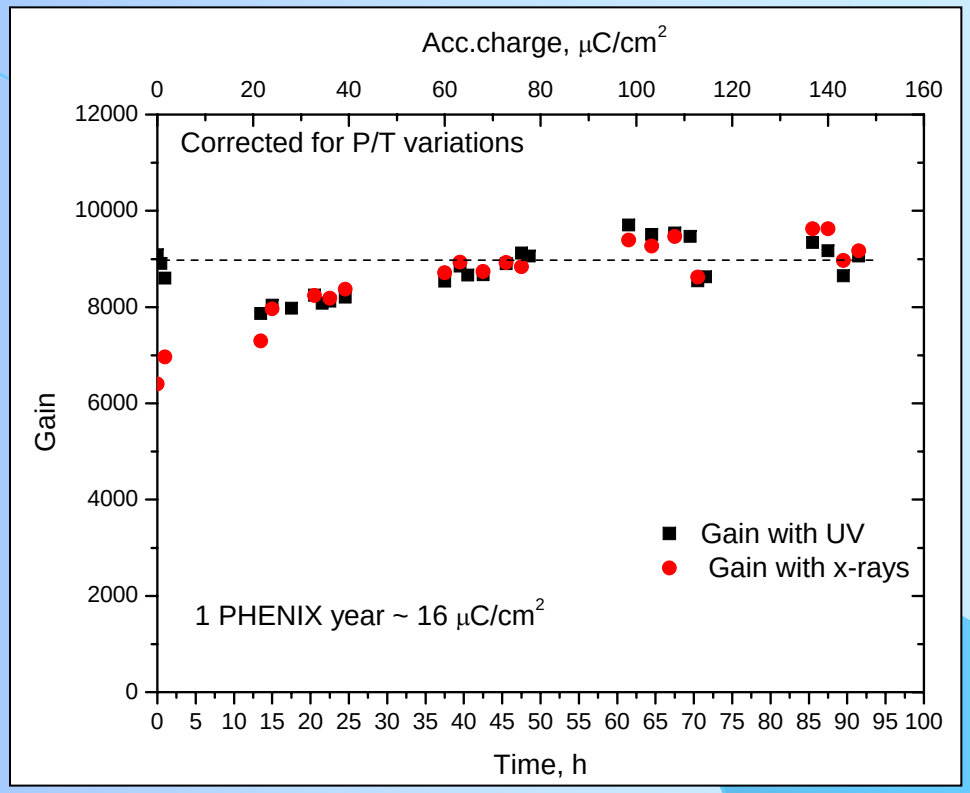
HBD expected to operate at gains < 10^4 i.e. with very comfortable margin below the discharge threshold



Aging Tests

Test both GEM and CsI photocathode

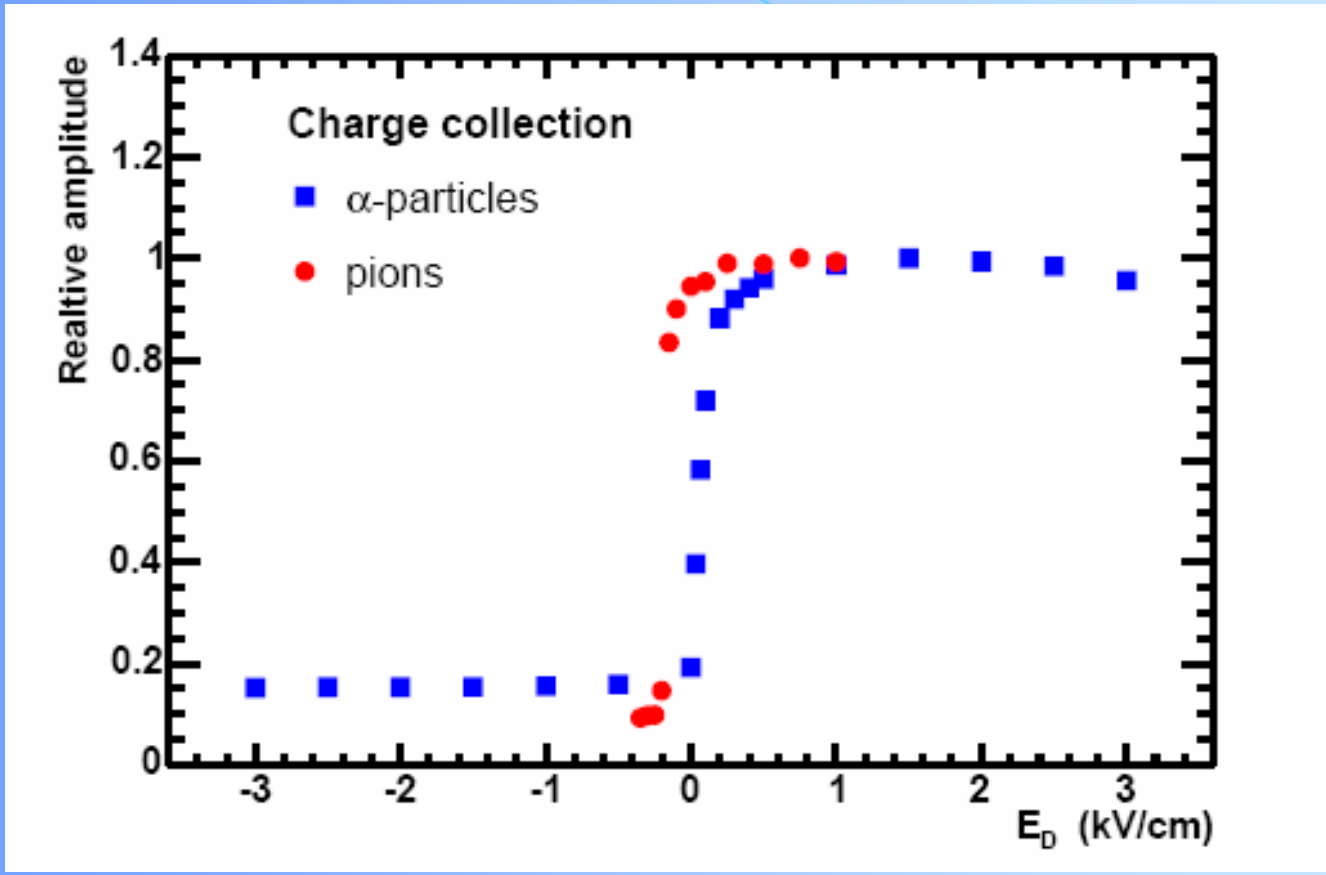
- Illuminate photocathode with UV lamp, measure DC current to mesh
- Measure gain with ^{55}Fe source
- Keep $I_{mesh} < 1$ nA/cm^2, gain ~ 5-10 x 10^3
- Continuously irradiate photocathode, measure gain periodically



- No significant aging effects of either the GEM or CsI photocathode were observed up to ~ 150 μC/cm^2 (~ 10 years at RHIC)
- Gain was found to increase with exposure time
  (Possible charging effect in GEM foils ?)

Charge Collection in Drift Gap

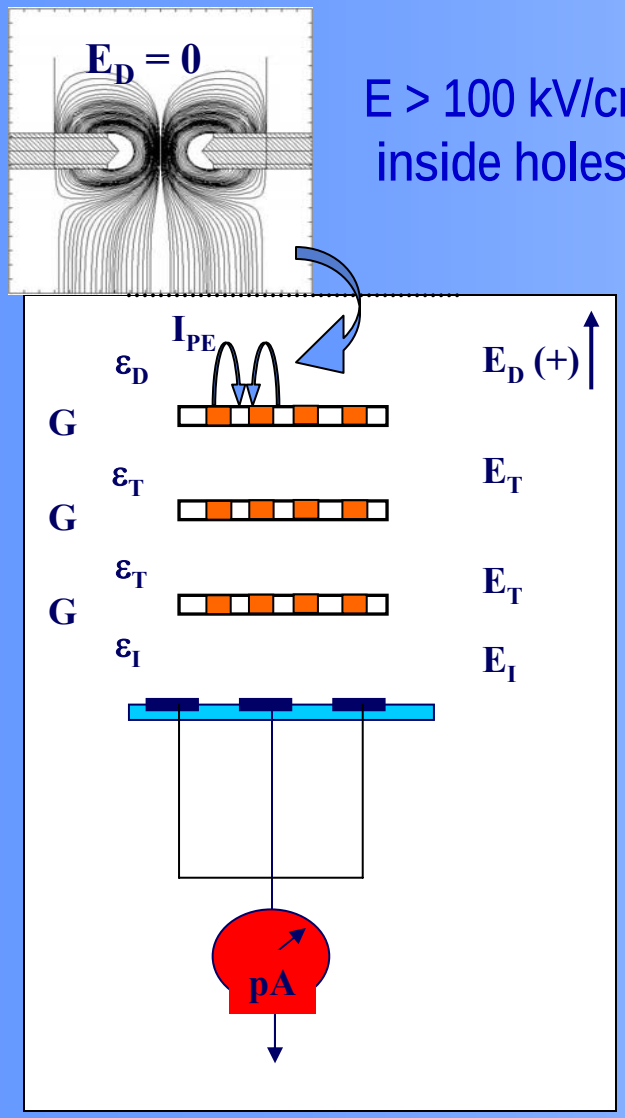
Response to α particles and pions vs E_d



For $E_d < 0$, signal drops dramatically as anticipated.

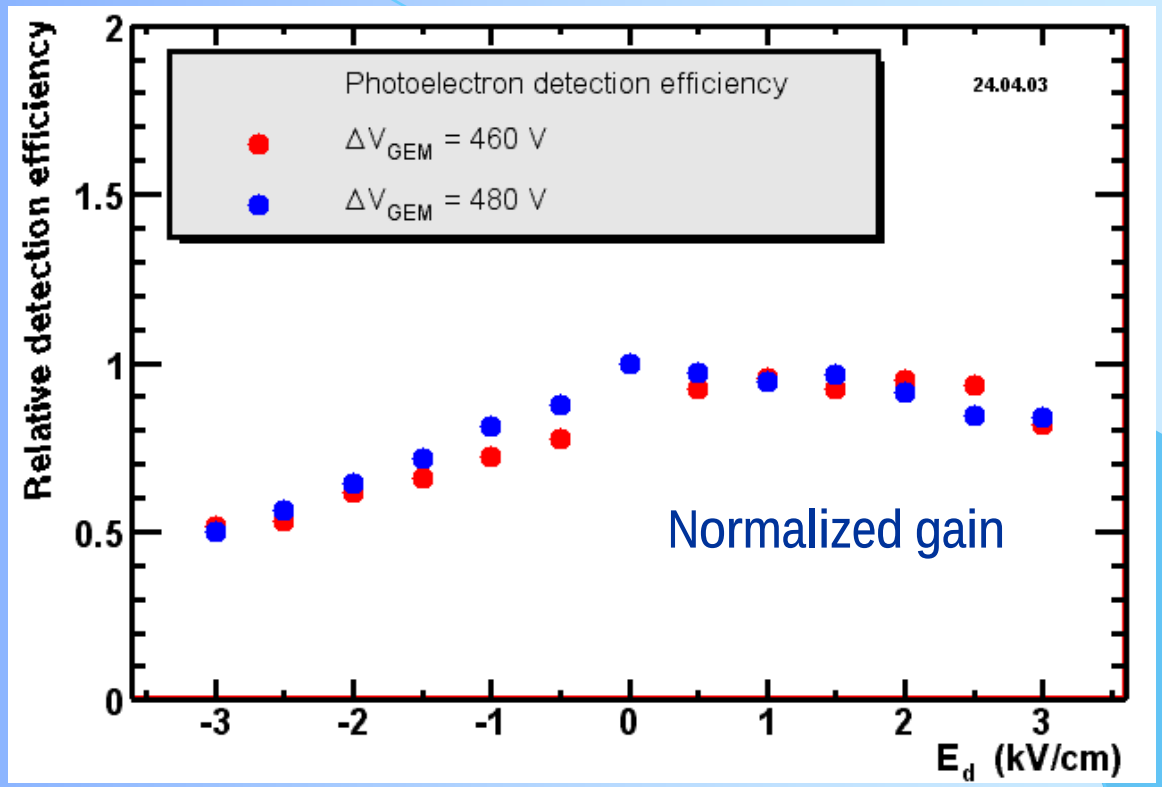
$\Rightarrow$ large hadron suppression

Single Photoelectron Detection Efficiency



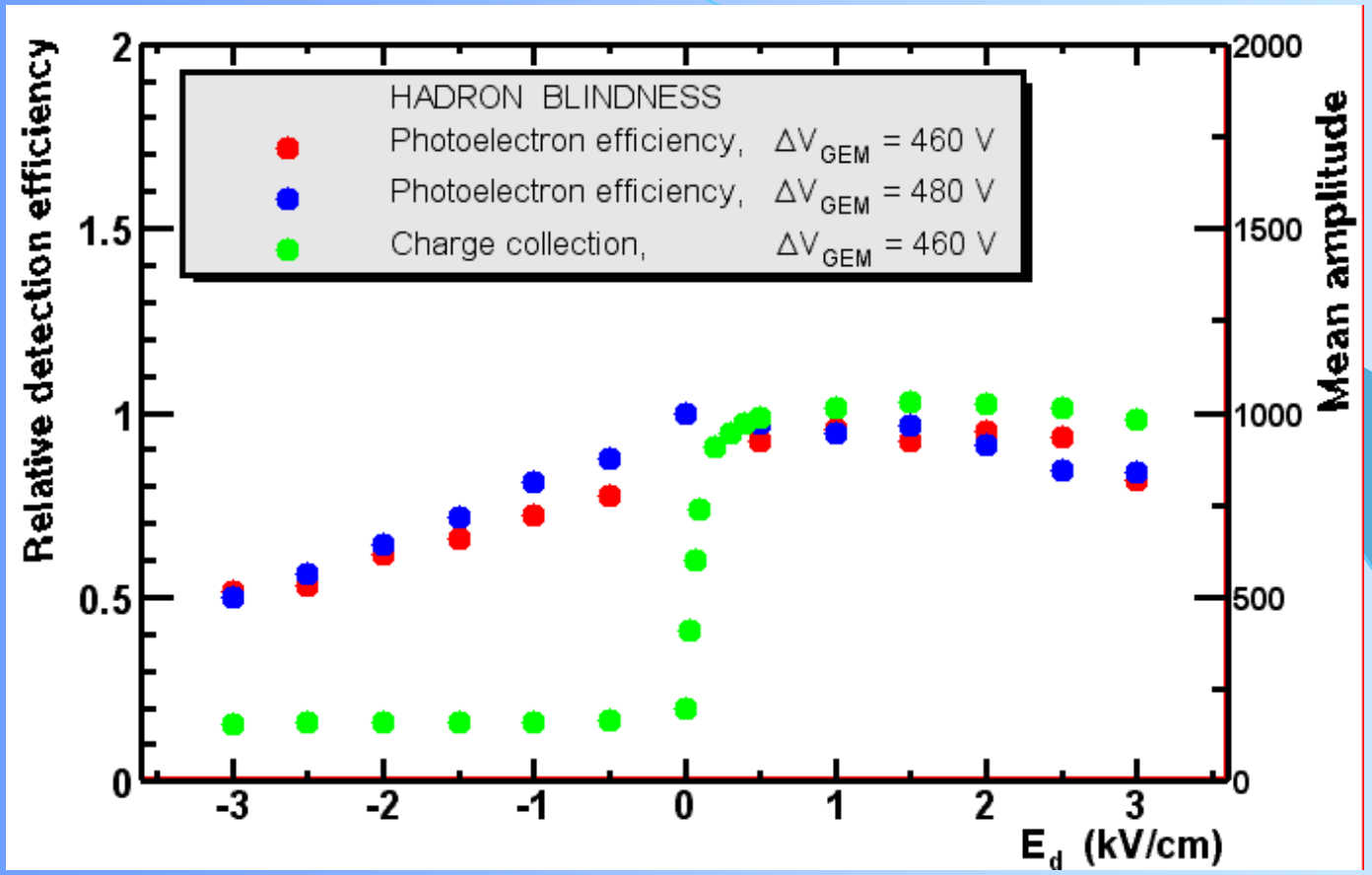
E > 100 kV/cm inside holes

Response to UV photons vs E_d



⇒ Efficient detection of photoelectrons even at negative drift fields

Hadron Blindness: UV photons vs α particles

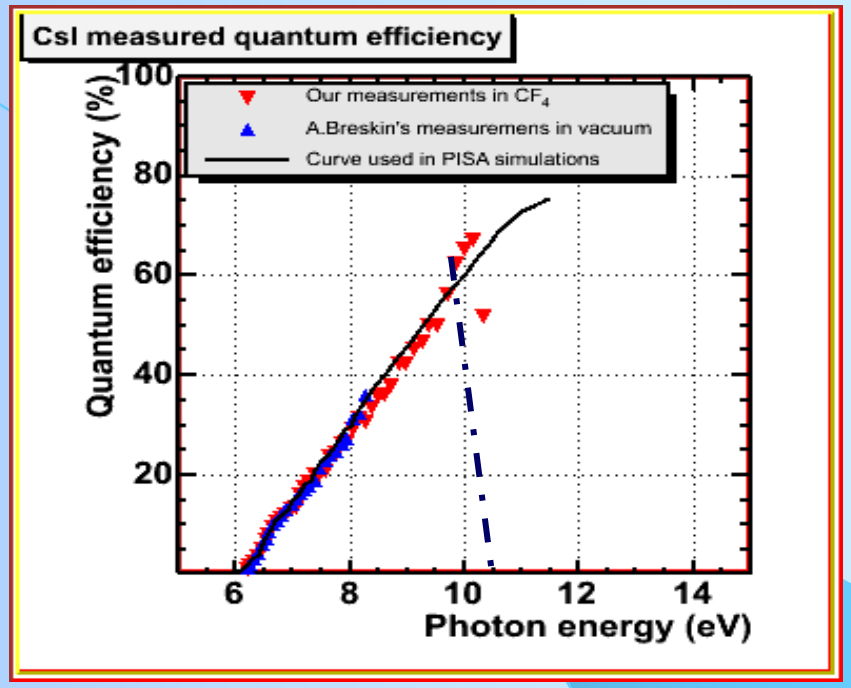


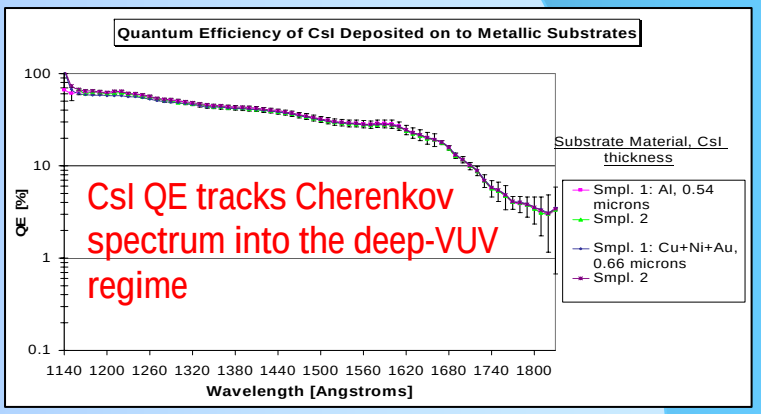
At slightly negative E_d, photoelectron detection efficiency is preserved whereas charge collection is largely suppressed.

CsI Quantum Efficiency Measurements

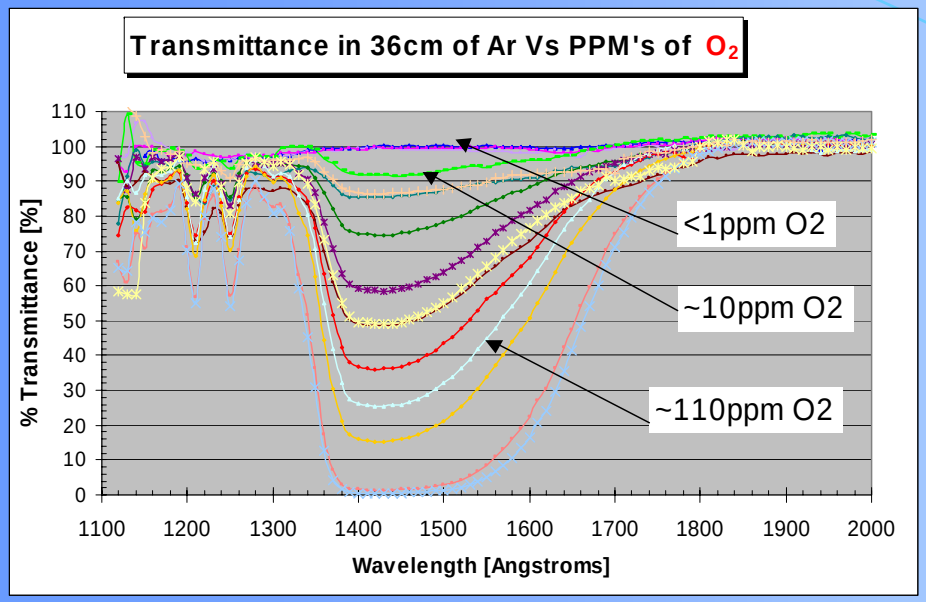
- QE measurement is limited by wavelength range of spectrometer (LiF windows)
  λ_{cutoff} ~120 nm → ~ 10.3 eV
- Folding CsI QE with transparency of CF_4 gives effective N_0
- QE measured in range 6.2-10.3 eV
  $\Rightarrow N_0 = 459\ cm^{-1}$ in CF_4
- N_0 extrapolated to 11.5 eV (CF_4 cutoff)
  $\Rightarrow N_0 = 822\ cm^{-1}$

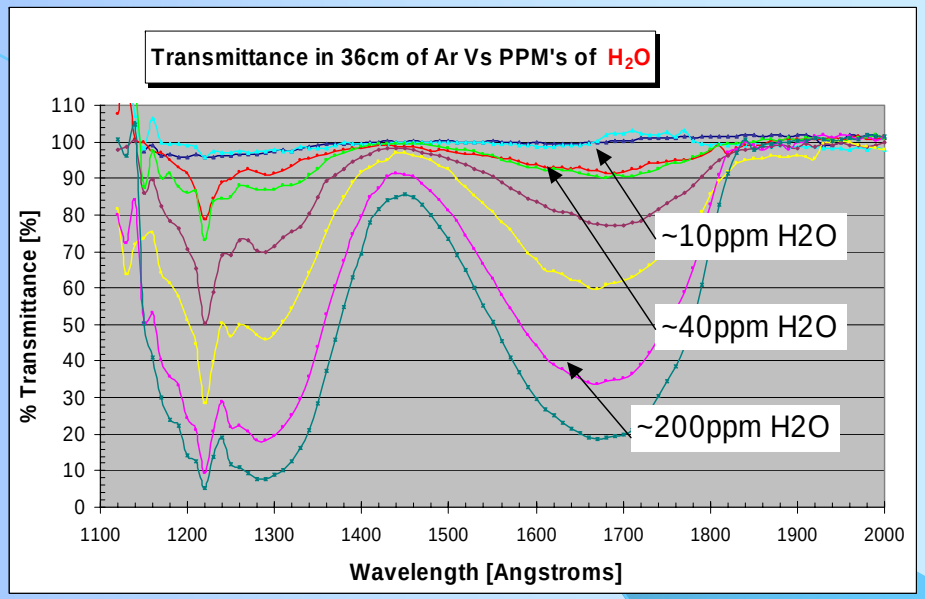
$\Rightarrow N_{pe} = N_0\ L \sin^2\theta_c \sim 35$ p.e.





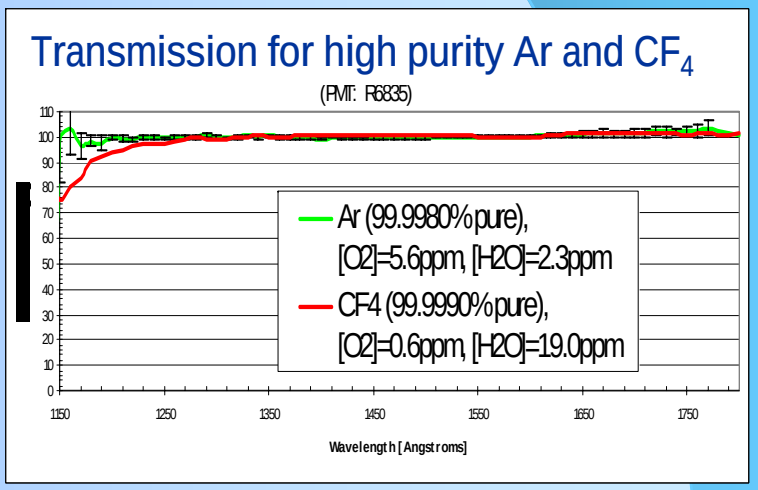
Affect of Impurities on VUV Transmission





Must maintain careful control of oxygen and water levels

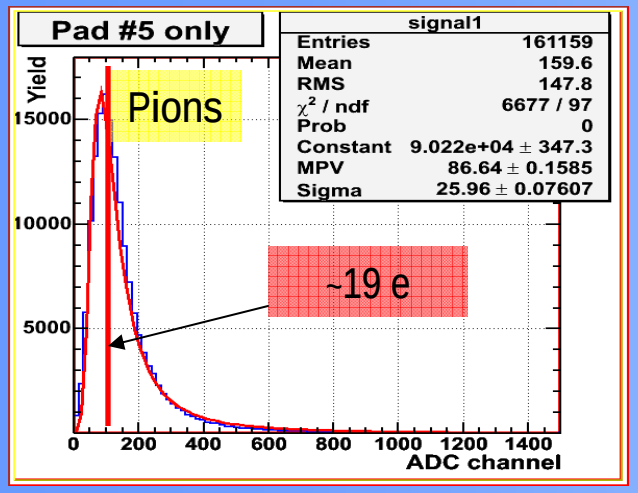
- $H_2O \leq 10$ ppm
- $O_2 \leq 5$ ppm

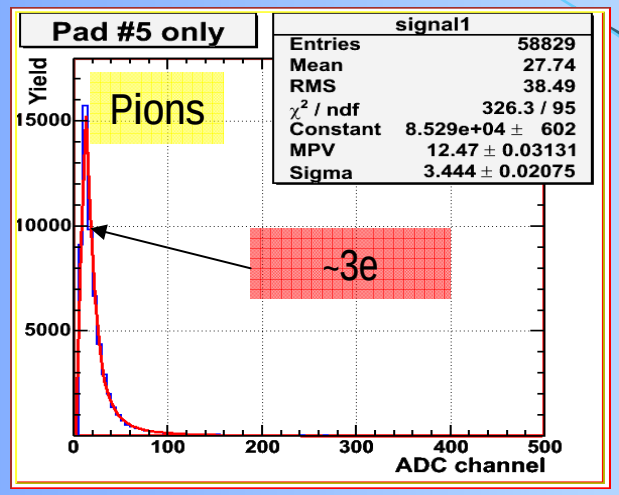


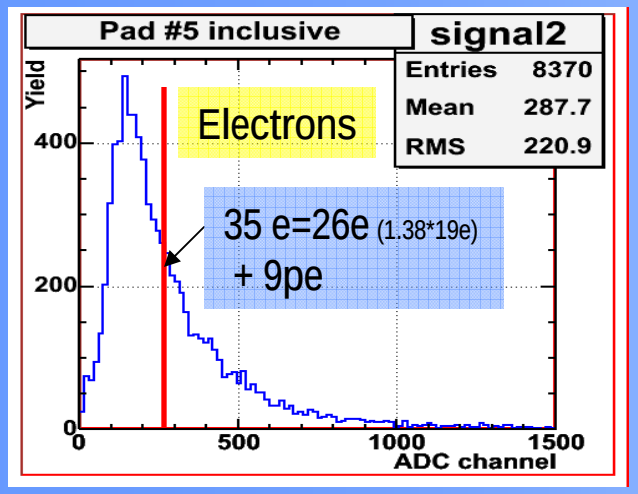
HBD Beam Test at KEK

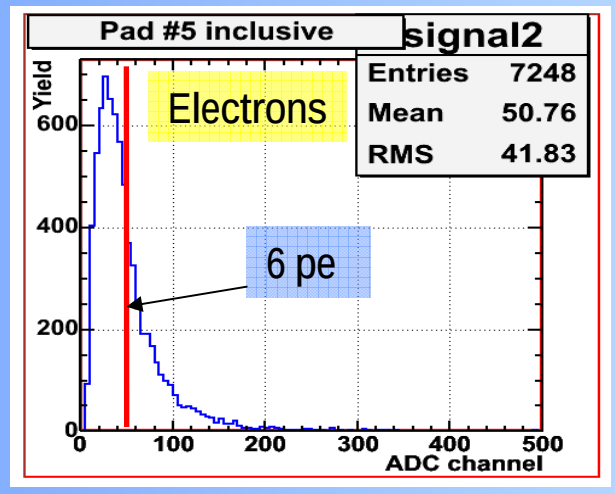
E_D = +1 KV/cm

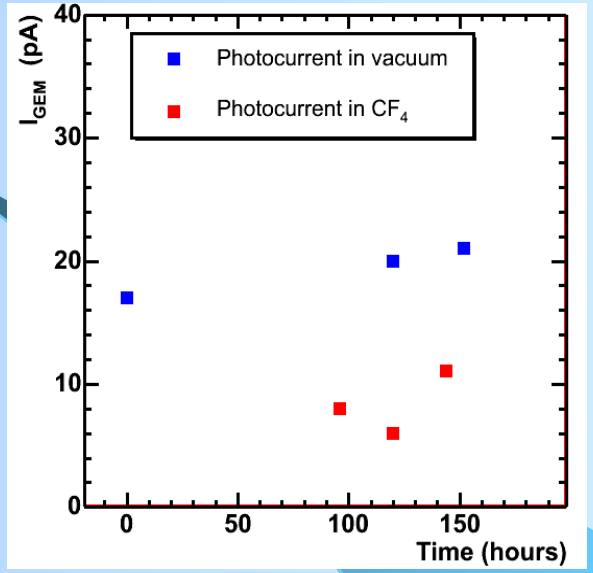
E_D = -0.3 KV/cm









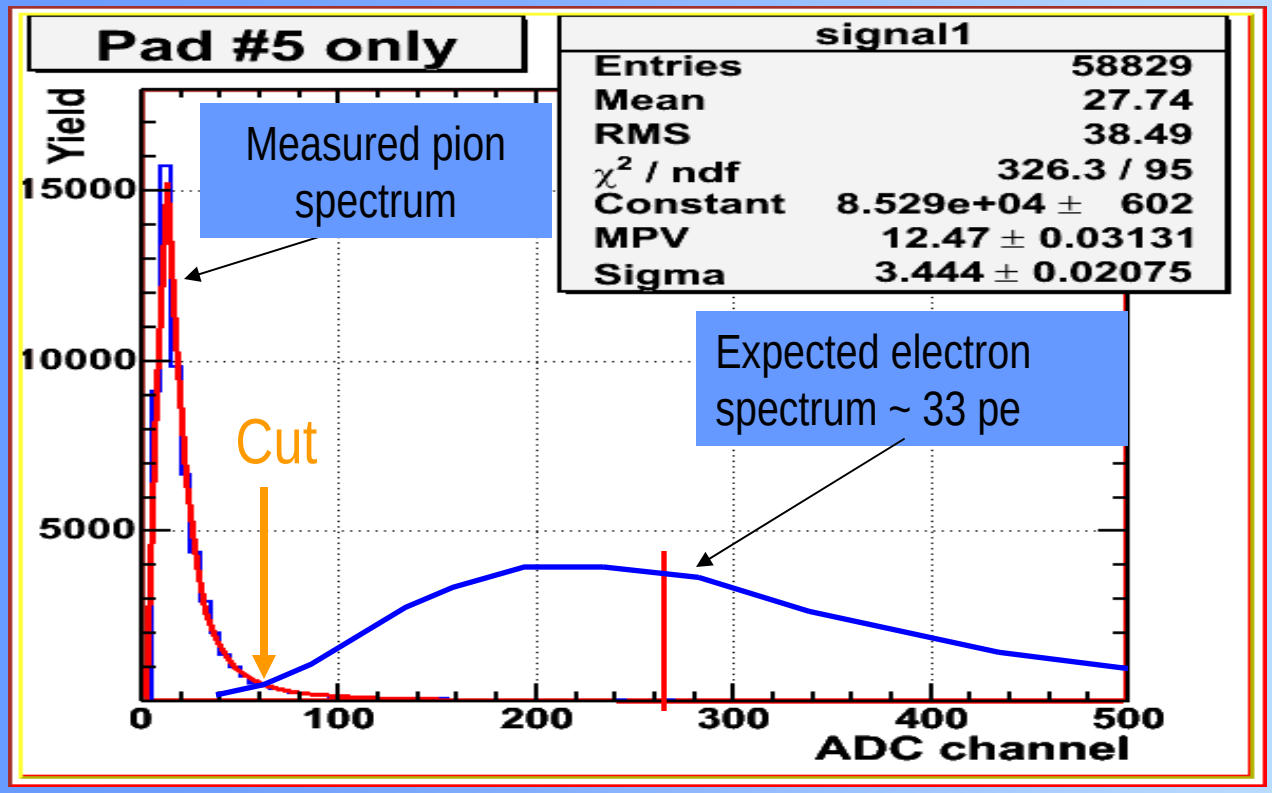


- Low number of pe's is due to absorption within the gas (presumably because of O_2 and H_20 impurities)
- It was therefore not possible to make a definitive measurement of N_0

Pion Rejection

Pion rejection factor will depend on the threshold one can apply that will reject pions and minimize the loss of electrons

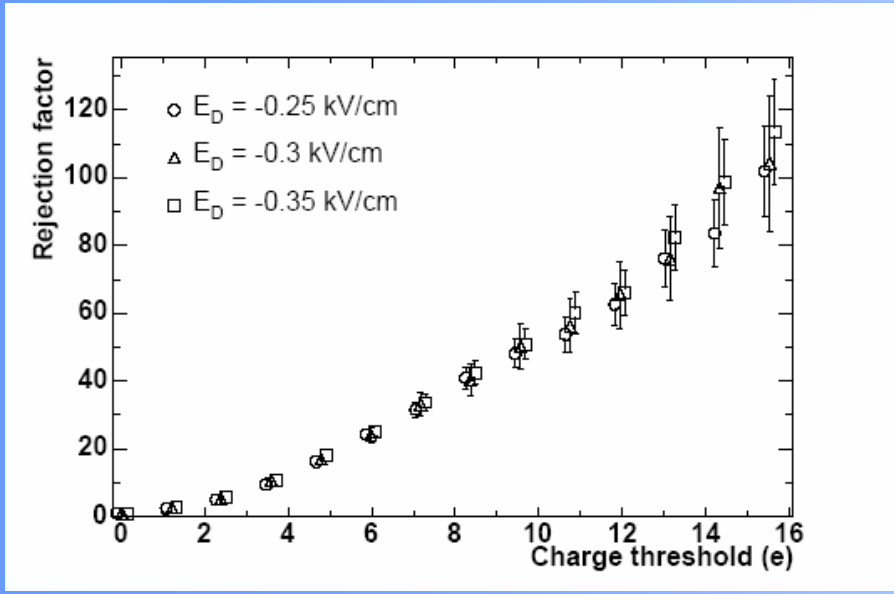
E_D = -0.3 KV/cm

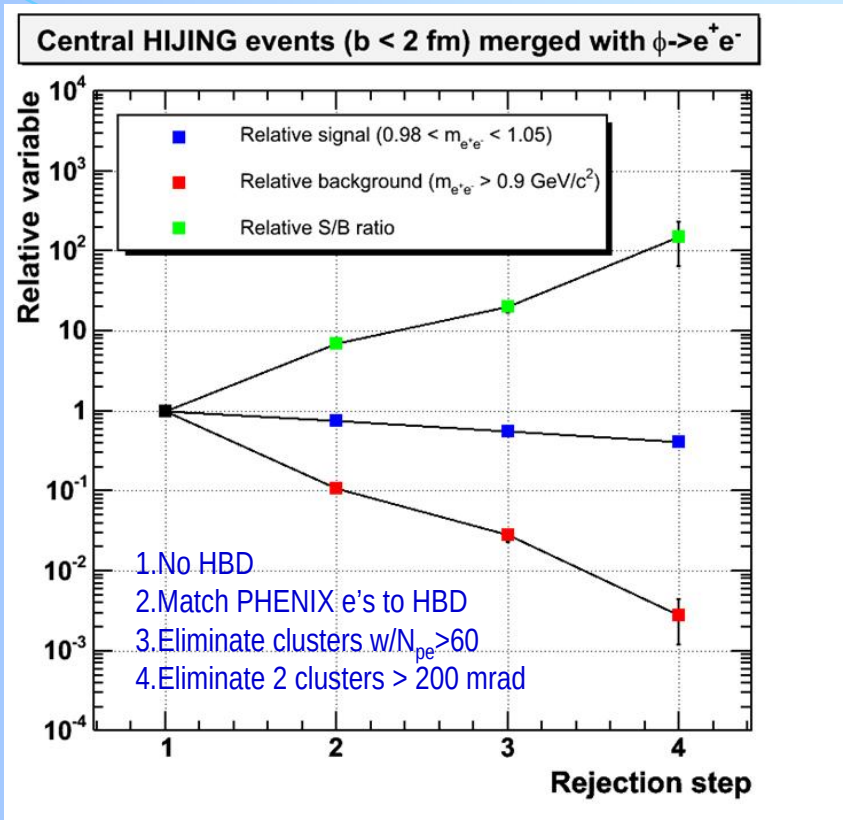


- blob signal is shared among 3-4 pads ⇒ ~10 pe's per pad
- Pion signal is contained within a single pad
- The total pe signal will also receive a noise contribution from adding the noise from 3-4 pads
  ⇒ actual peak separation may be slightly worse

Expected Background Rejection

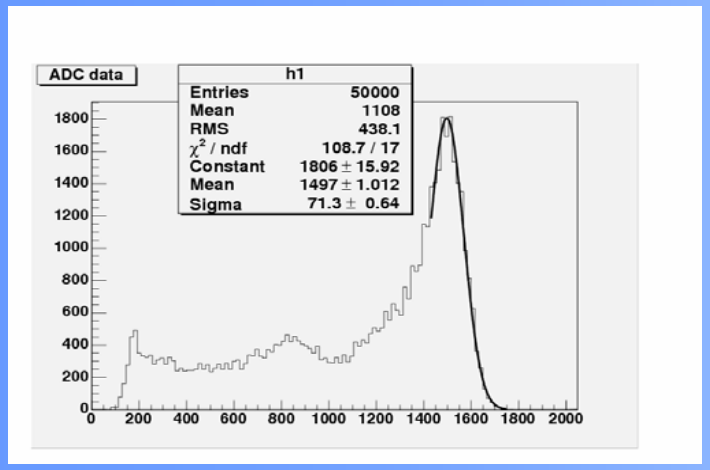
Hadron rejection vs charge threshold



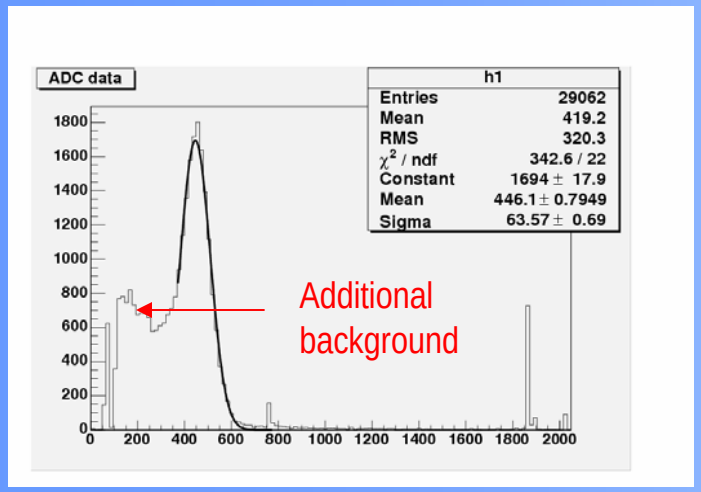


Total background rejection and improvement in signal/background ratio (from Monte Carlo)

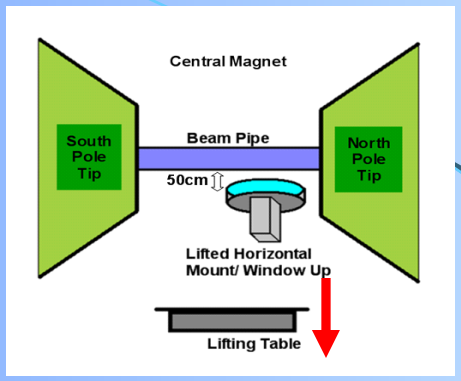
Test of a Triple GEM Detector in PHENIX

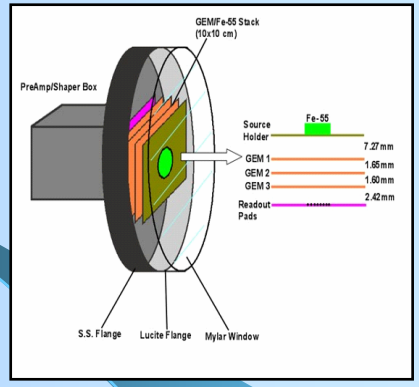


^{55}Fe spectrum with Ar/CO2 in Lab



^{55}Fe spectrum with full luminosity Au-Au collisions at RHIC





- Triple GEM detector performed smoothly within the PHENIX IR using both Ar/CO_2 (70/30) and CF_4
  - exhibited no sparking or excessive gain instabilities.
- In close proximity to the beam pipe (50cm), the detector was sensitive to some soft beam related background
  - low signal (< 50 e's)
  - depended strongly on beam conditions.
  - mostly out of time with beam-beam collisions

Conclusion:

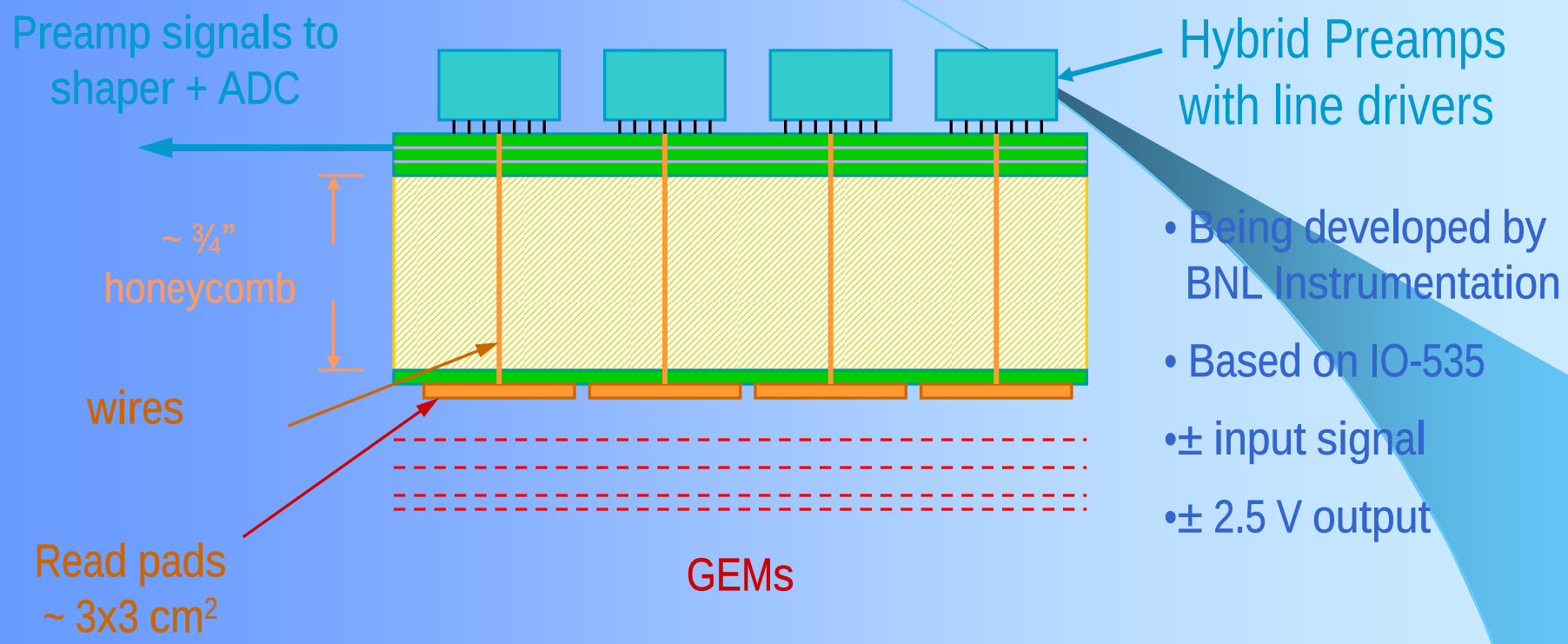
- There appears to be no fundamental problem with operating a GEM detector close to the beam pipe at RHIC

Conclusions

- Strong hadron rejection can be achieved with good photoelectron efficiency
- High gain/stable GEM operation can be obtained in pure CF_4
- A windowless Cherenkov detector can in principle achieve a very high N_0 when used in conjunction with a with deep VUV transmitting gas such as CF_4 However, impurities such as O_2 and H_2O can cause a significant loss of Cherenkov light (O_2 and H_2O must be kept at the few ppm level)
- GEM detectors work in the high multiplicity environment at RHIC
- No significant aging effects are observed in either GEMs or CsI photocathodes for intergated charges well in excess of what is expected to be reached at RHIC
- Need to measure N_0 in a realistic detector and test a fully functional prototype in the PHENIX

Additional Slides

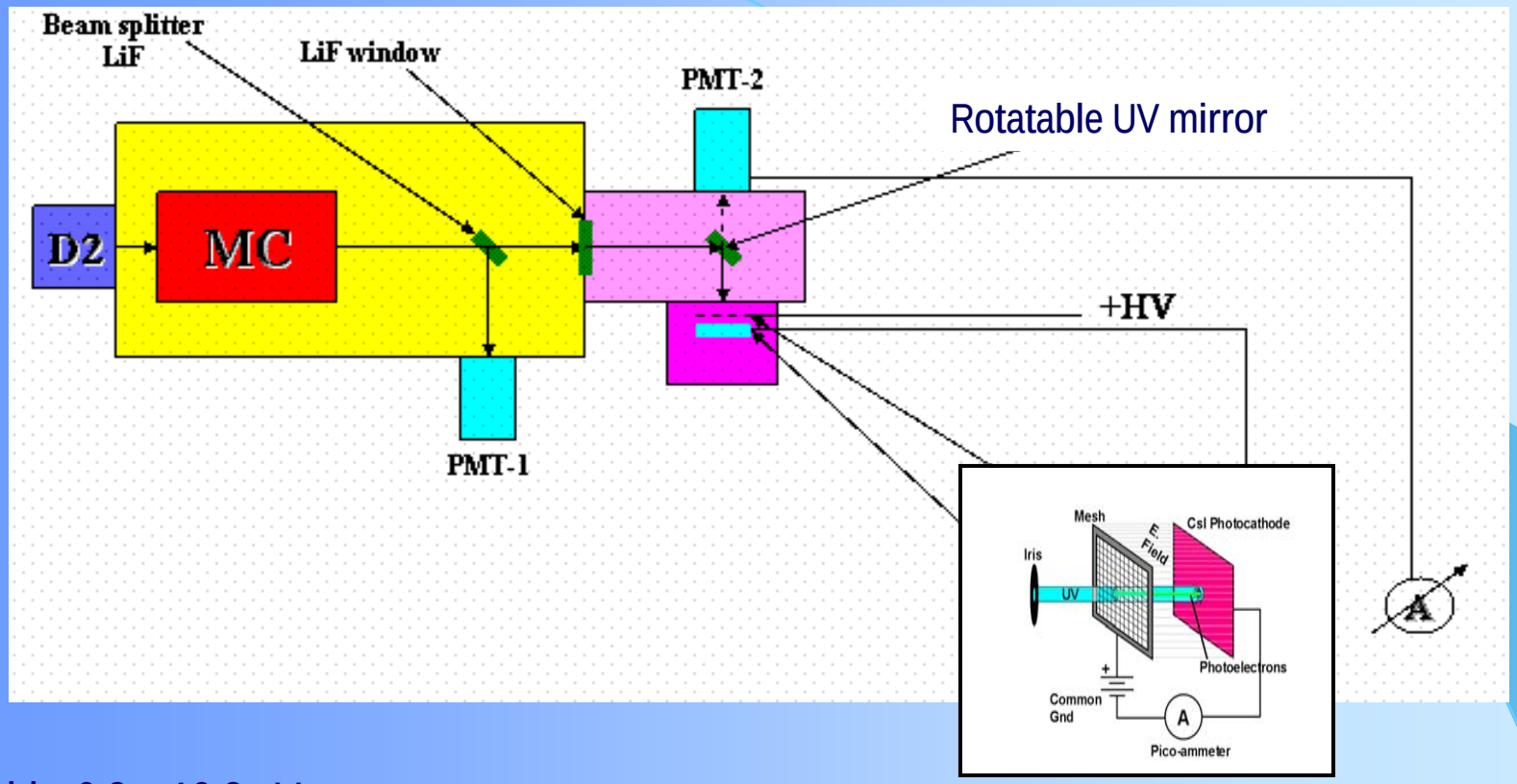
Readout Board and Preamps



- Being developed by BNL Instrumentation
- Based on IO-535
- ± input signal
- ± 2.5 V output

- **Need almost one full rack for the readout electronics**

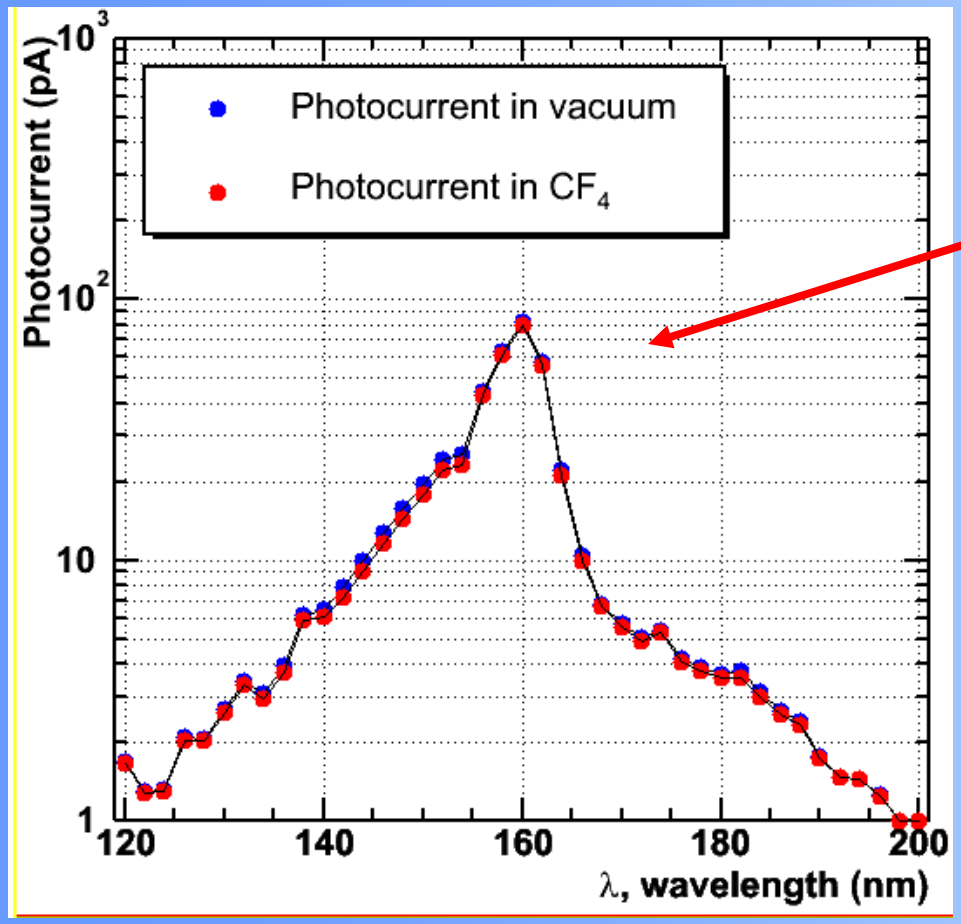
Spectrometer to Measure Absolute CsI QE

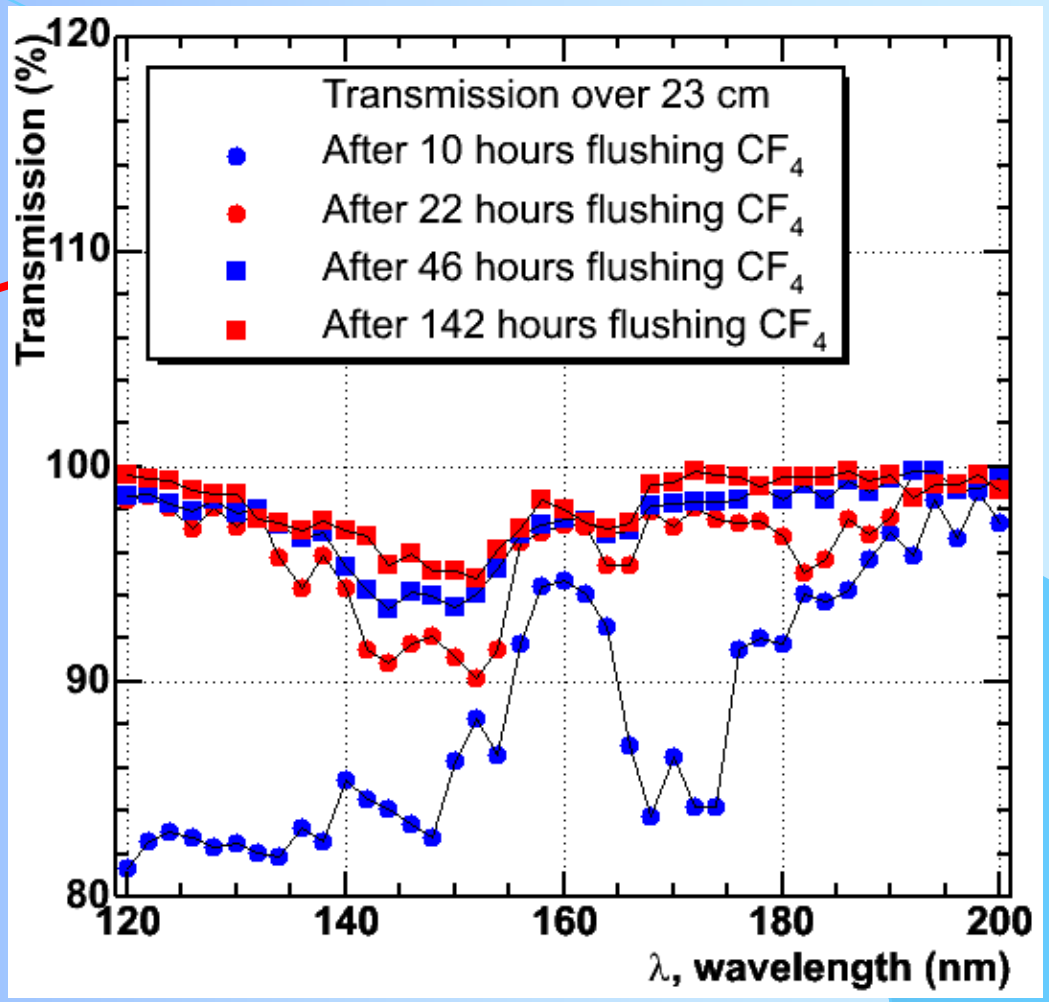


Bandwidth: 6.2 – 10.3 eV
PMT-2 and CsI have same solid angle
C1 optical transparency of mesh (81%)
C2 opacity of GEM foil (83.3%)
All currents are normalized to I(PMT-1)

QE(CsI) = QE(PMT-2) x I(CsI) / I(PMT-2) x C1 x C2

CF_4 Transparency to UV Photons



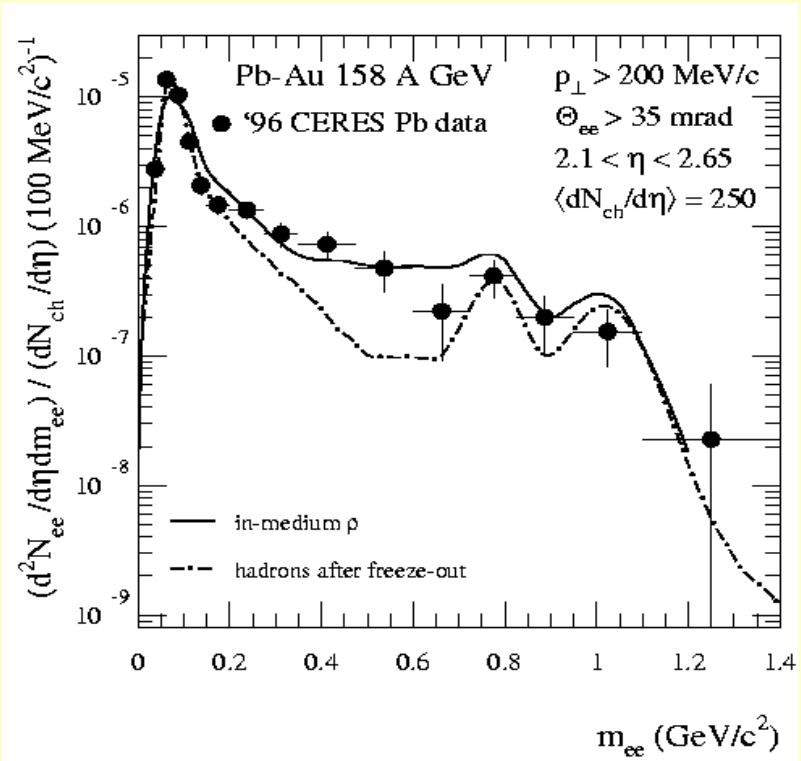


CF_4 is transparent

Interpretation of Low Mass Pairs

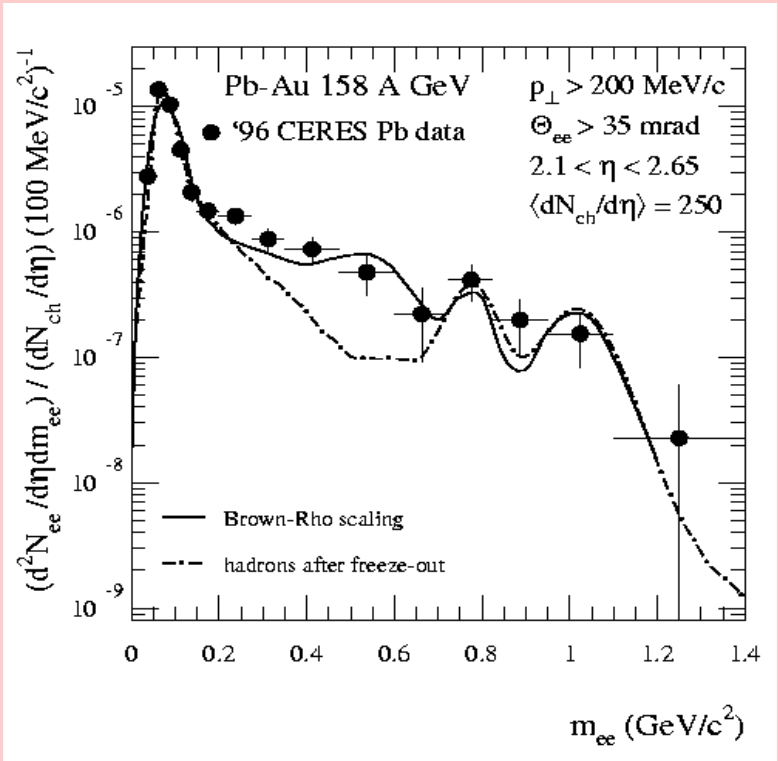
1. Thermal radiation from the hadron gas

$\pi\pi$ annihilation: $\pi^+\pi^- \rightarrow \gamma^* \rightarrow e^+e^-$



2. In-medium ρ broadening

Rapp, Wambach et.al.



3. Dropping of the ρ mass

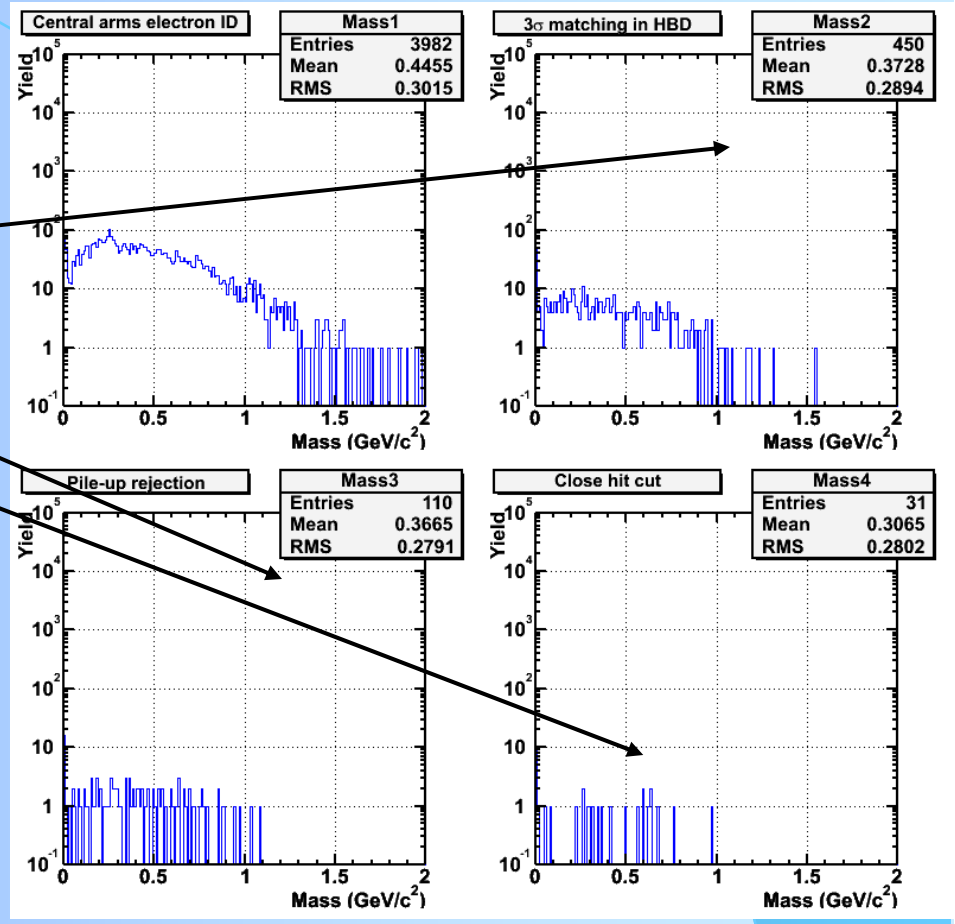
G.E.Brown et.al.

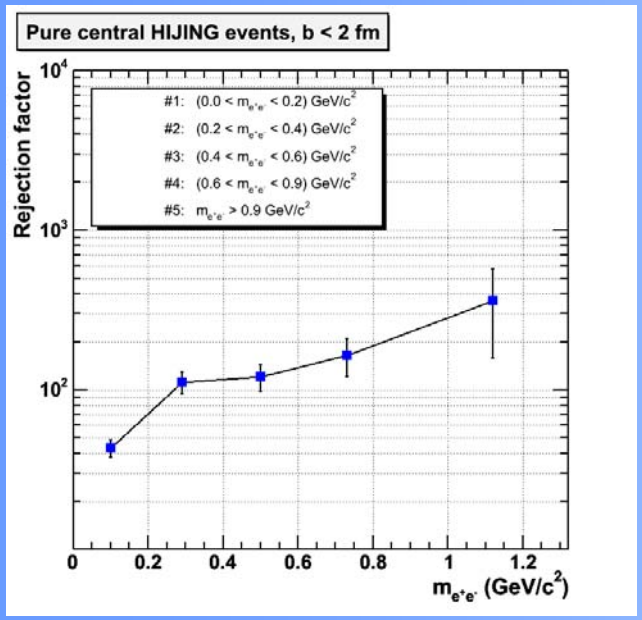
CB from central HIJING events (b<2fm)

Pattern recognition:

- **Remove one pad clusters.**
- **Cluster charge > 20 p.e.**
- **Match Central Arms electron tracks to HBD with 3s p-dependent cuts. This matching reduces the number of electrons by a factor of ~3 i.e. the CB by ~10.**
- **Reject "conversions" tracks with amplitude cut (>60 e)**
- **Reject Dalitzes with close hit cut (< 200 mrad)**

18K events

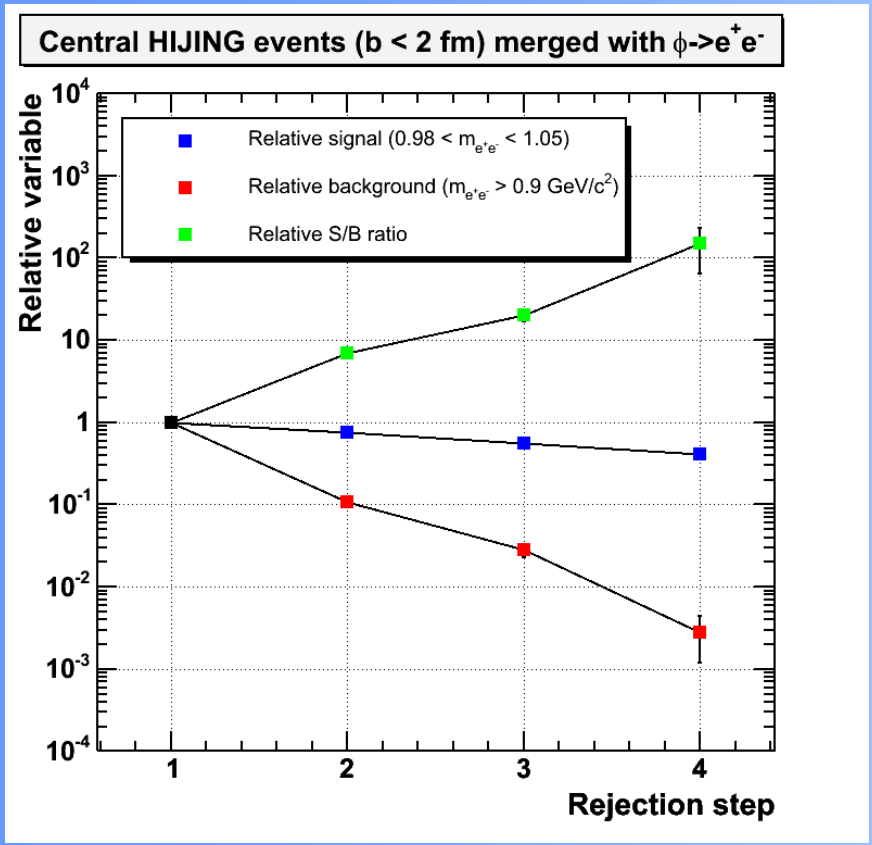


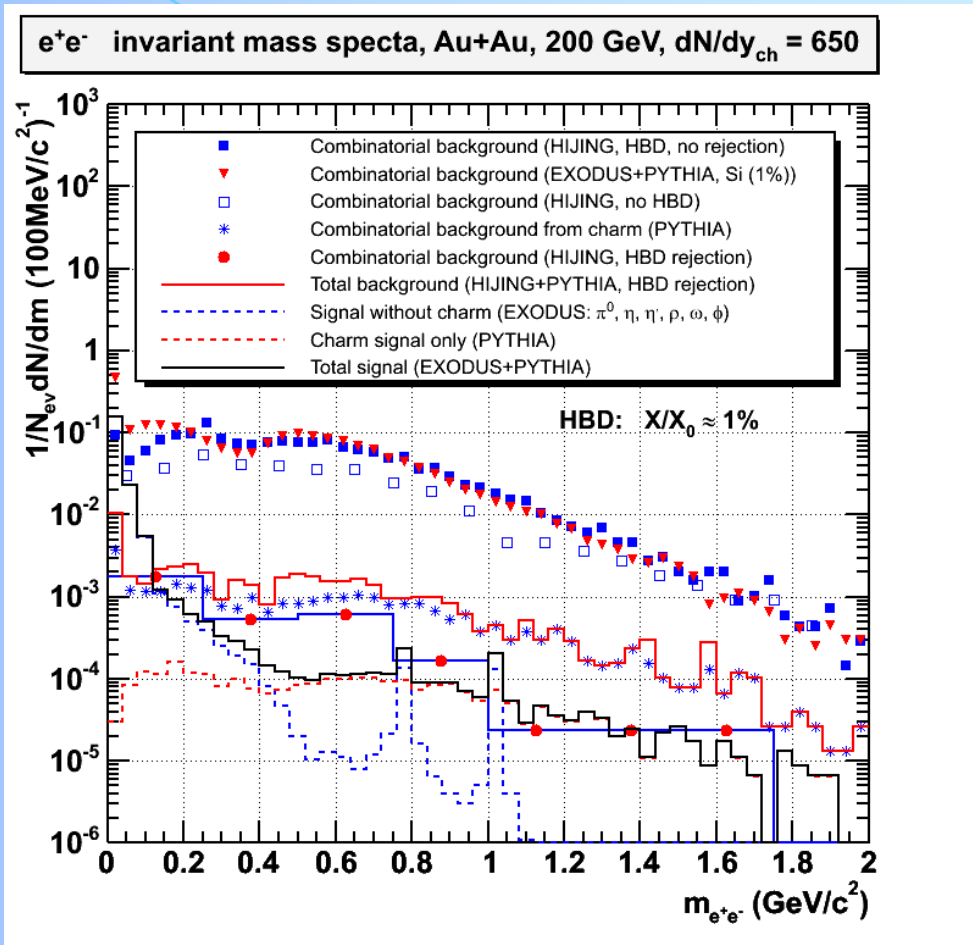


For m > 200 MeV/c² the rejection factor is > 100

Signal and Background

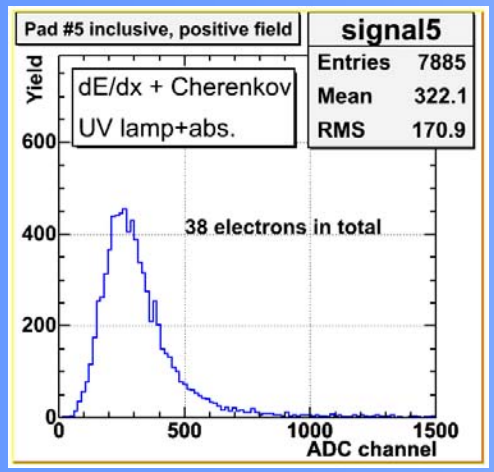
Signal:

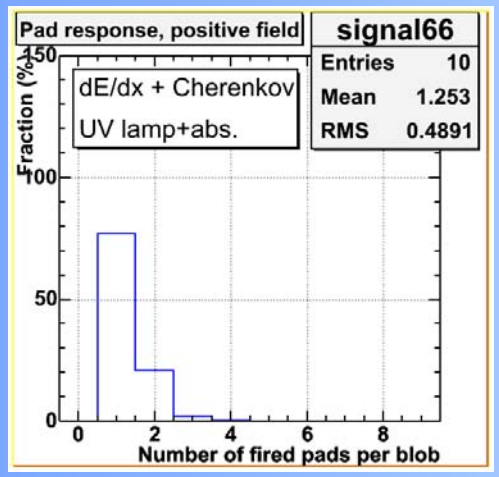




HBD Response Simulation

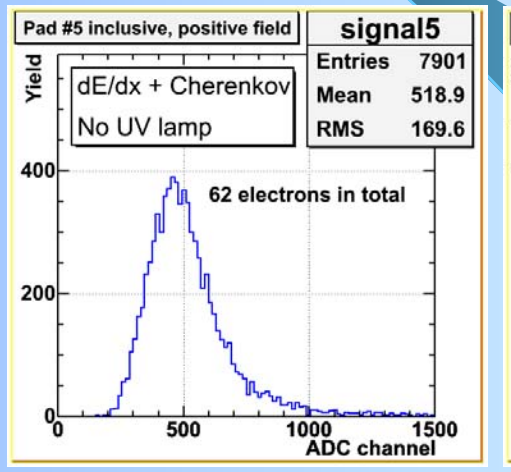
Includes 20 cm absorption length in CF_4, lamp shadowing, realistic losses and conservative N_0 = 840 cm^{-1}

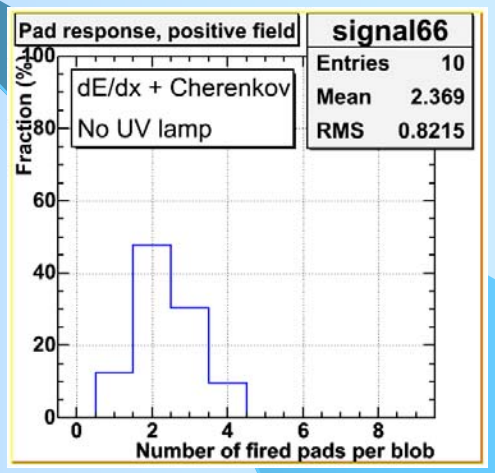




Total signal: 38 e = 29 (dE/dx) + 9 (Cherenkov)
Blob size: single pad response =78%
→ very similar to data

Normal case, no absorption in CF_4, no lamp shadowing, realistic losses and conservative N_0 = 840 cm^{-1}





Total signal: 62 e = 29 dE/dx + 33 Cherenkov
Blob size: single pad 12%, more than one pad 88%