The PHENIX Hadron Blind Detector

Craig Woody

PHENIX Focus

February 9, 2010

The HBD Team

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  - C-Y. Chi

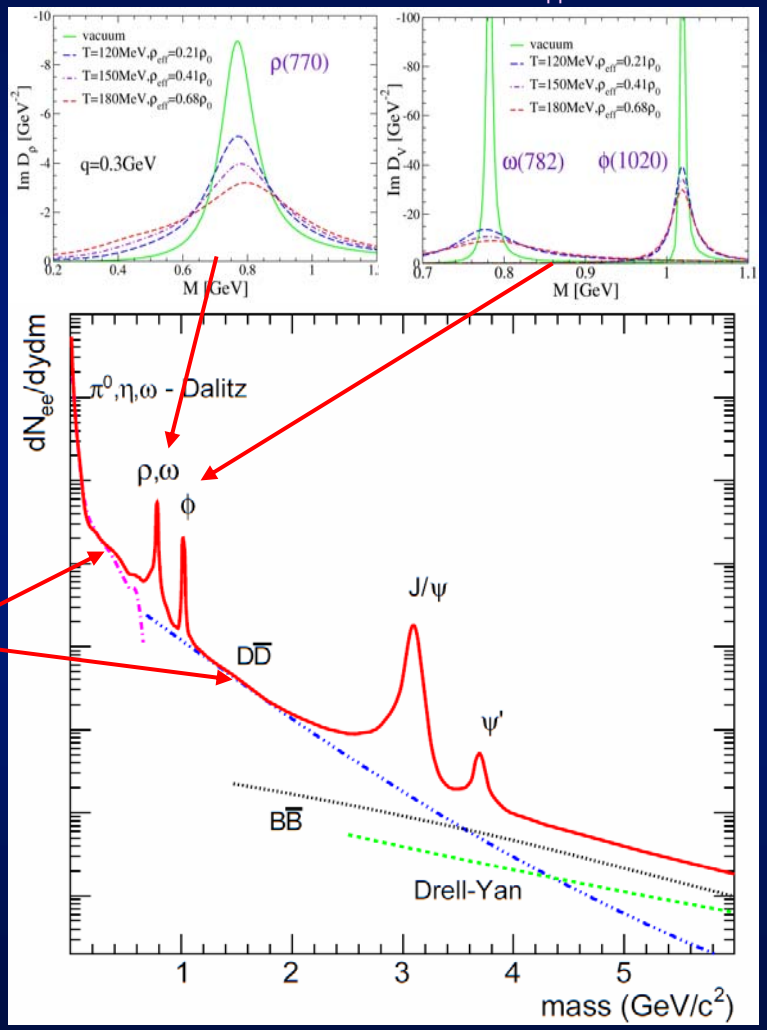
Motivation

To Measure Low Mass Dilepton Pairs in Heavy Ion Collisions

- Low mass dilepton pairs are the best probe for studying chiral symmetry restoration and in-medium modifications of light vector mesons
  - ρ (m = 770MeV τ ~ 1.3 fm/c) → e^+e^-
  - ω (m = 782MeV τ ~ 20fm/c) → e^+e^-
  - φ (m =1020MeV τ ~ 40fm/c) → e^+e^-
- Dilepton pairs are also a probe of thermal radiation from the QGP and Hadron Gas and can produced enhancements in the dilepton pair spectrum

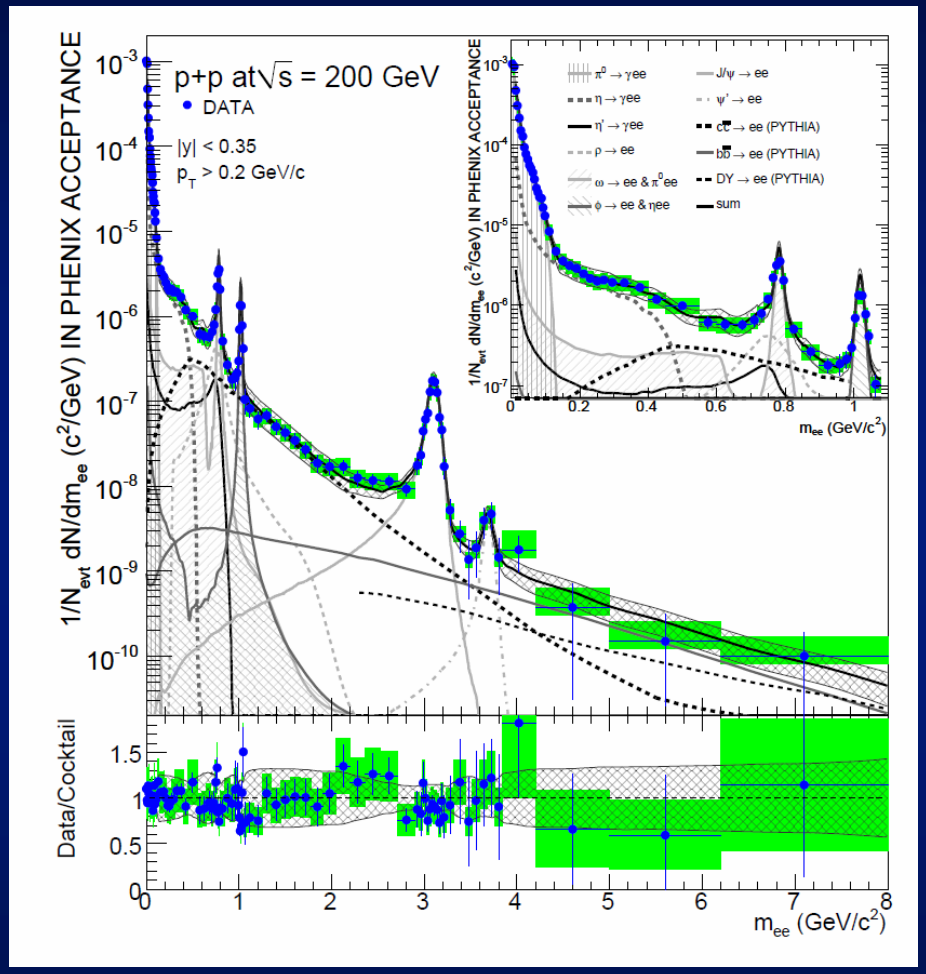
QGP: $q\bar{q} \rightarrow \gamma^* \rightarrow e^+e^-$
HG: $\pi^+\pi^- \rightarrow \rho \rightarrow \gamma^* \rightarrow e^+e^-$

Rapp nucl-th/0204003



Low Mass Pairs in p-p Collisions

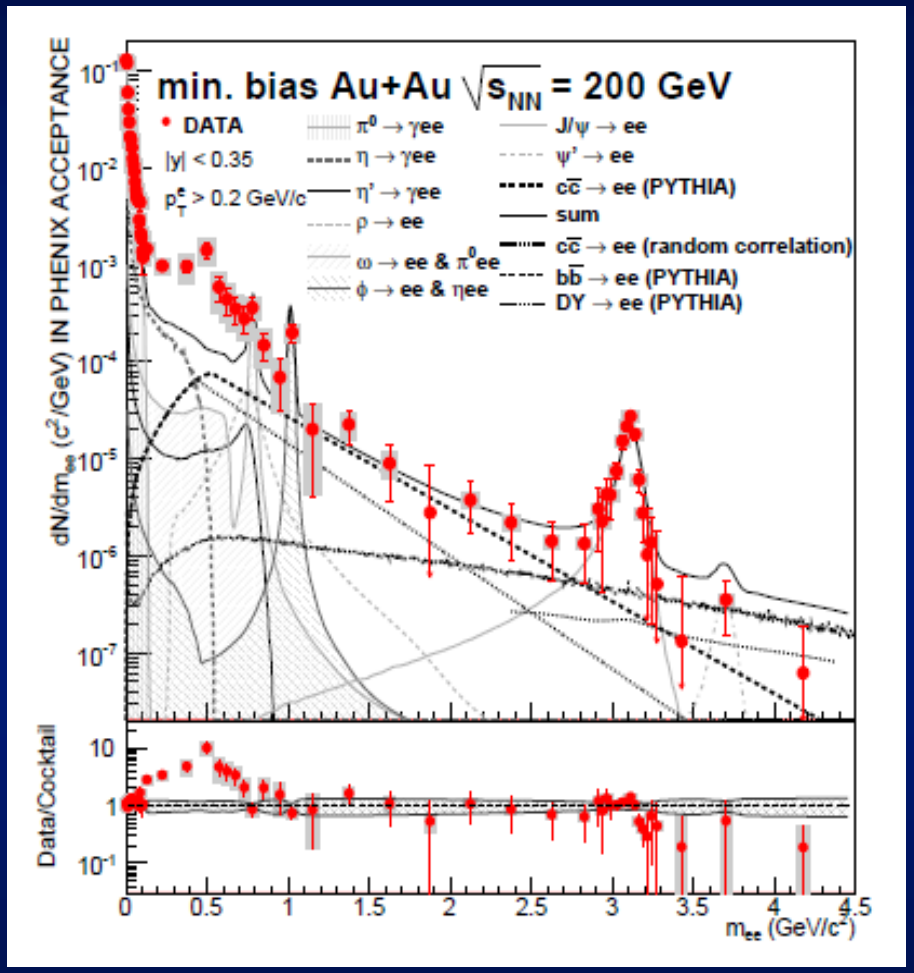
PPG088 – Fig. 25



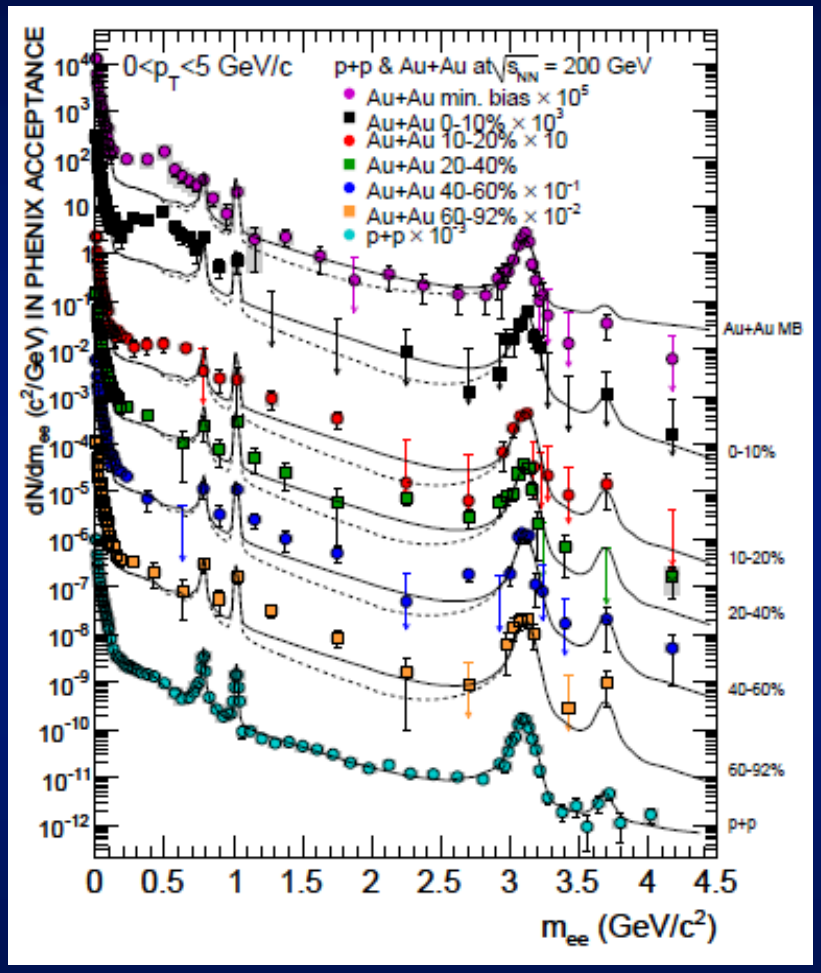
Excellent agreement between measured data and cocktail predictions

Low Mass Pairs in Au-Au Collisions

PPG088 – Fig. 26



PPG088 – Fig. 27



Measurement limited by systematic errors due to large combinatorial background

Measuring Low Mass Electron Pairs in Heavy Ion Collisions

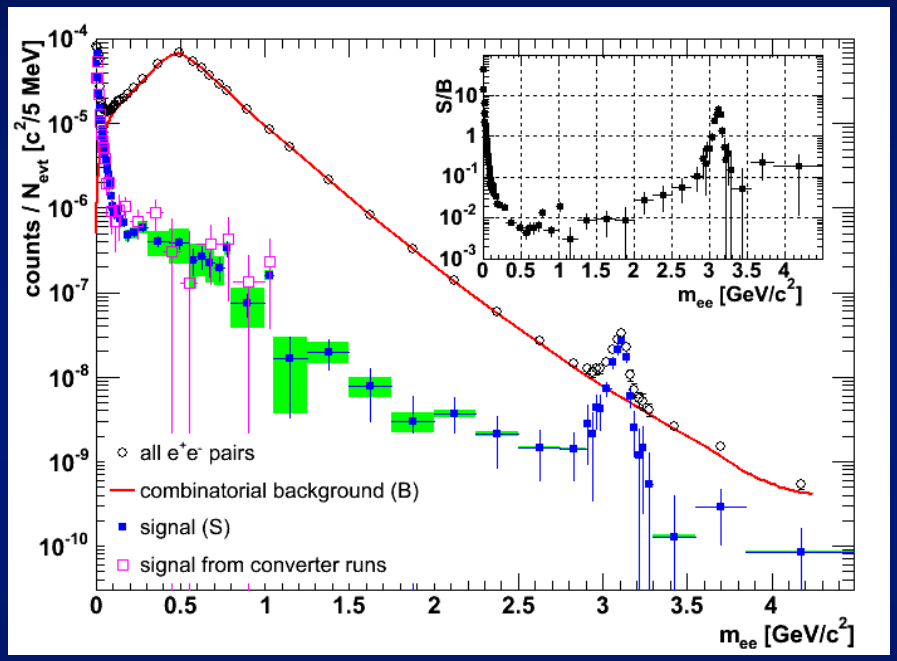
Measurement of low mass pairs and vector mesons in heavy ion collisions is limited by large combinatorial background from π^0 Dalitz decays and γ conversions

Would like to reduce this background by a factor of ~ 20 or better

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

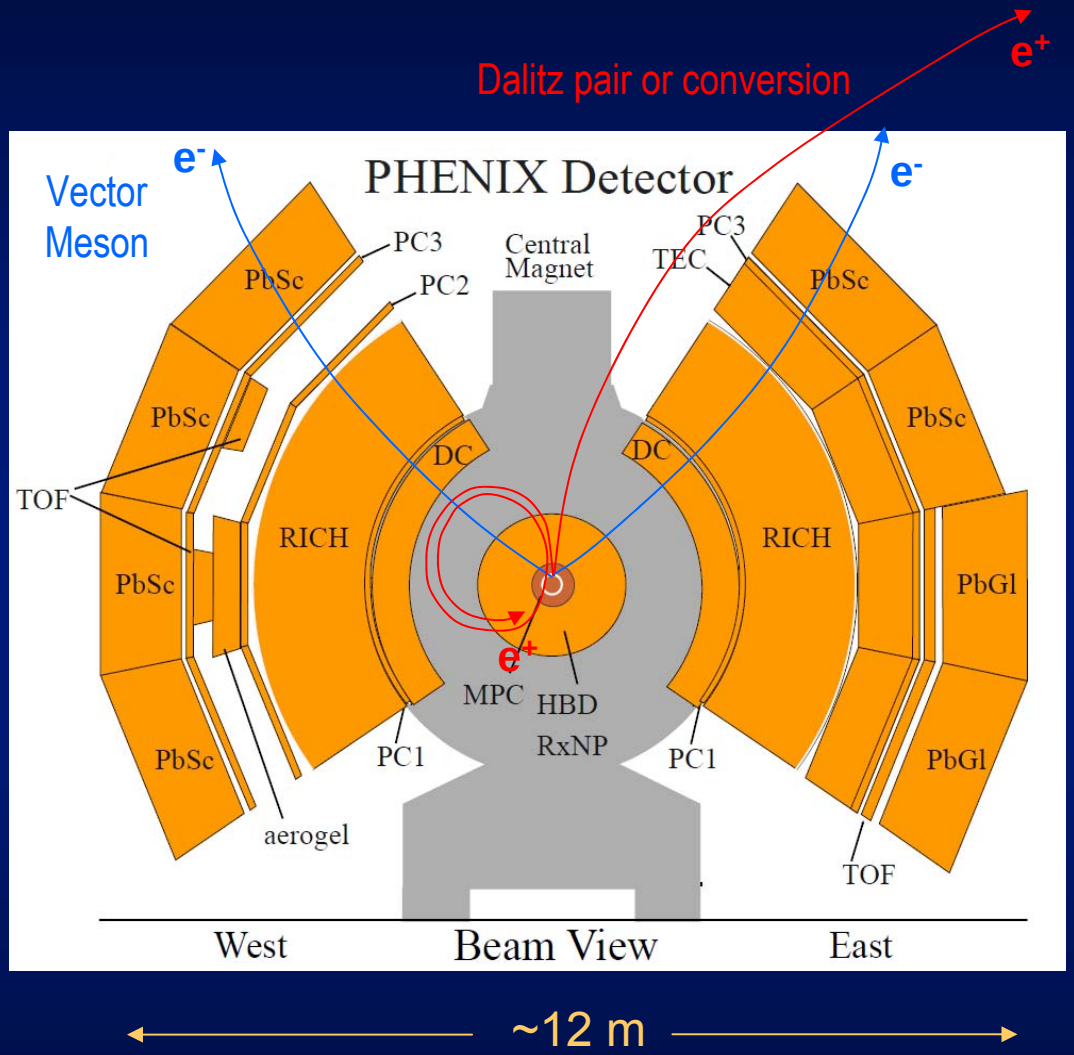
Requires single electron efficiency > 90% (pairs > 80%)

PPG088 – Fig 16



Electrons pairs measured in PHENIX without HBD in Run 4 (200 GeV Au-Au)

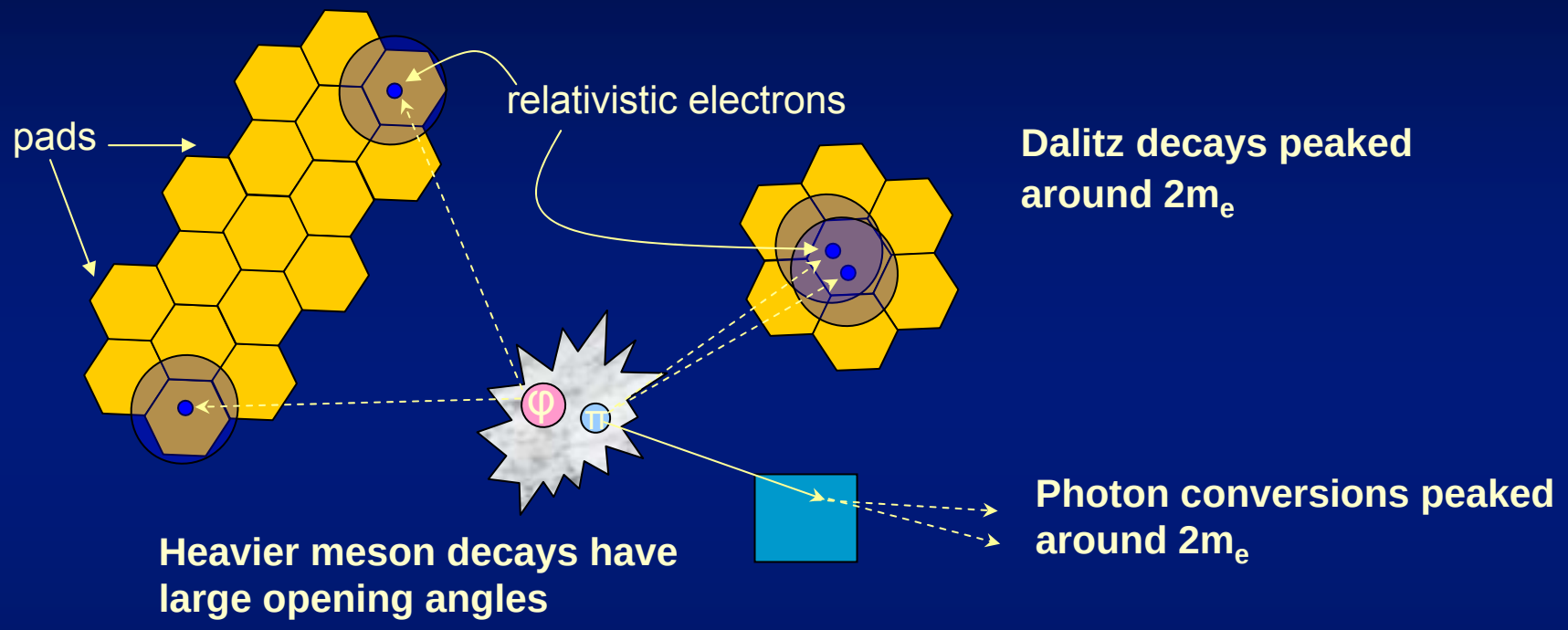
Strategy



Problem: Low momentum electrons from Dalitz pairs and conversions are easily wrapped up by the central field and do not reach the PHENIX tracking detectors. Electrons from vector mesons generally have higher momentum and larger opening angles.

Solution: Create an essentially field free region with the central part of PHENIX. Then both electrons from Dalitz pairs and conversions travel together and appear as two overlapping electrons as they exit this region, where electrons from vector mesons appear as singles

Separating Signal from Background



Identify electrons with P > 200 MeV/c in Central Arms, project back and match to HBD. Reject if there is another electron within θ < 200 mrad

The PHENIX Hadron Blind Detector

Proximity Focused Windowless Cherenkov Detector

- Electrons produce Cherenkov light
- Pions with P < 4 GeV/c do not

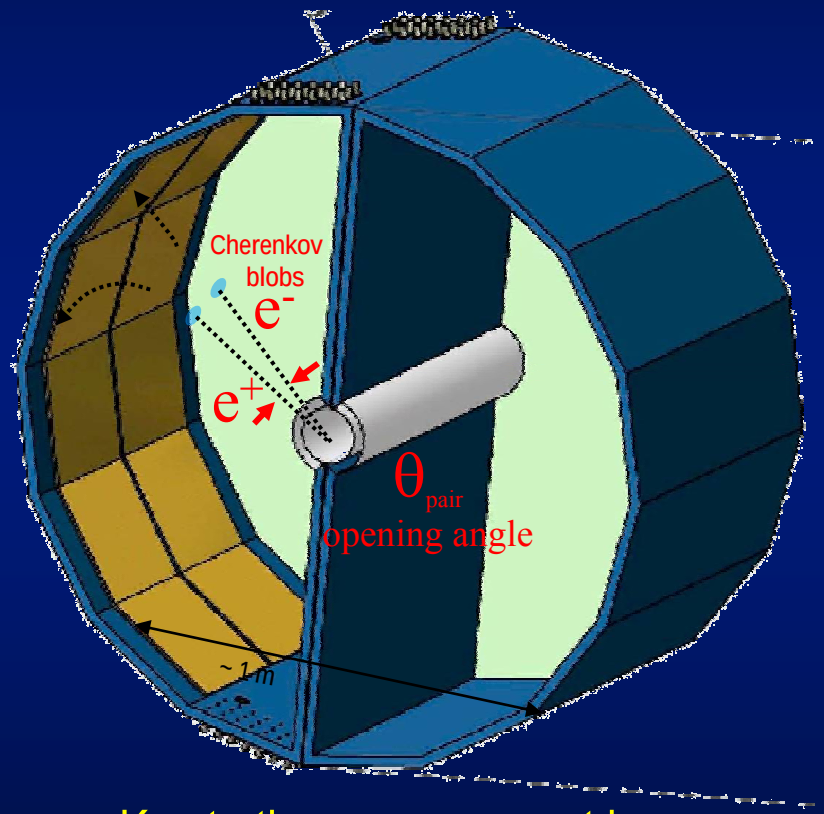
However, we don't want to detect the ionization signal from the hadrons !

Radiating tracks form "blobs" on an image plane

$\Theta_{max} = \cos^{-1}(1/n) \sim 36$ mrad → Blob diameter ~ 3.6 cm)

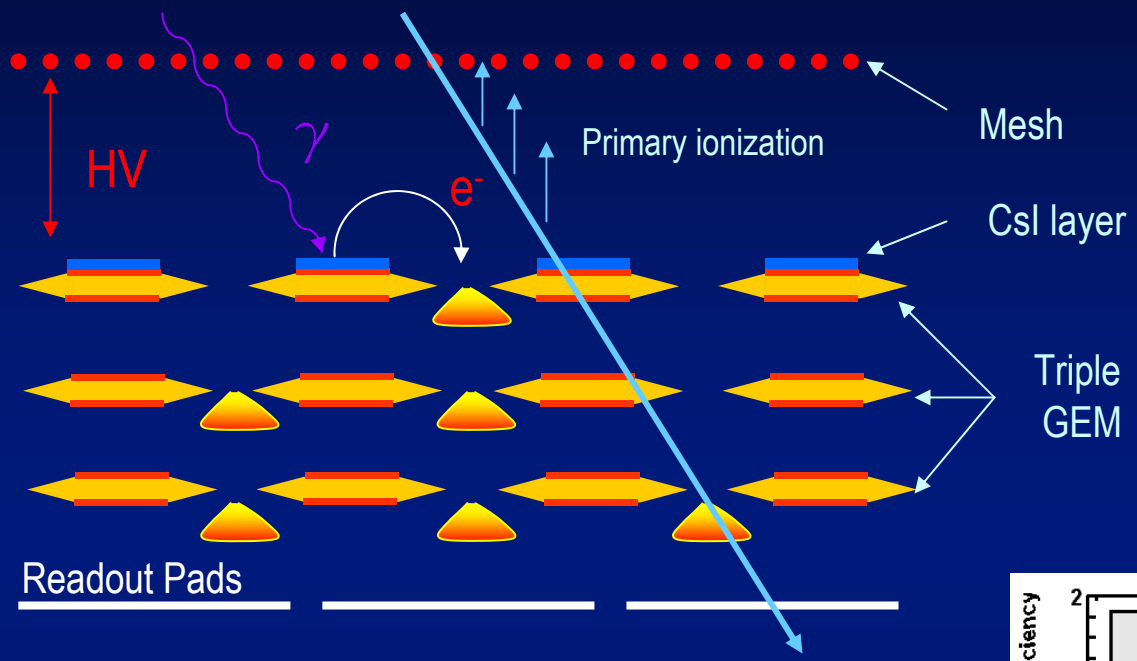
Dalitz pairs & conversions make two overlapping blobs, single electrons from vector meson decays make only one

Radiator gas = Working gas
Gas volume filled with pure CF_4 radiator
(n_{CF4}=1.000620, $L_{RADIATOR}$ = 50 cm)



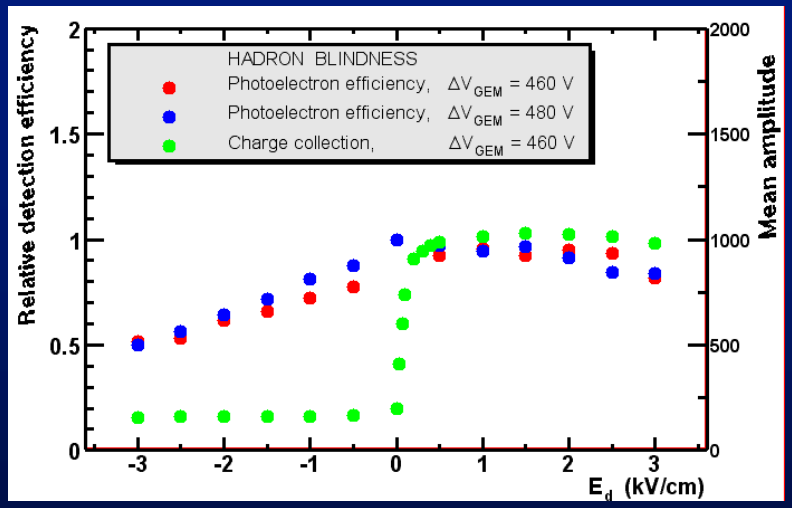
⇒ Key to the measurement is distinguishing one blob from two

The Hardon Blind Concept



Primary ionization signal is greatly suppressed at slightly negative drift field while photoelectron collection efficiency is mostly preserved

Collection efficiency for photoelectrons and ionization



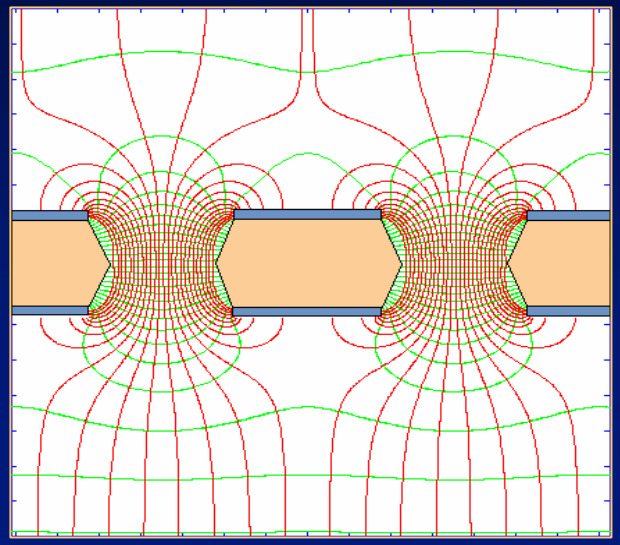
Z.Frankel et.el., NIM A546 (2005) 466-480.
A.Kozolov et.al. NIM A523 (2004) 345-354.

- **Primary ionization is drifted away from GEM and collected by a mesh**
- **UV photons produce photoelectrons on a CsI photocathode and are collected in the holes of the top GEM**
- **Triple GEM stack provides gain ~ few x10^3**
- **Amplified signal is collected on pads and read out**

Challenges as a Cherenkov Detector

- High purity gas radiator (deep VUV cutoff)
- GEMs
- Operation in pure CF_4
- CsI photocathodes (w/GEMs)
- Detect single photoelectrons
- Be essentially blind to hadrons

Gas Electron Multipliers



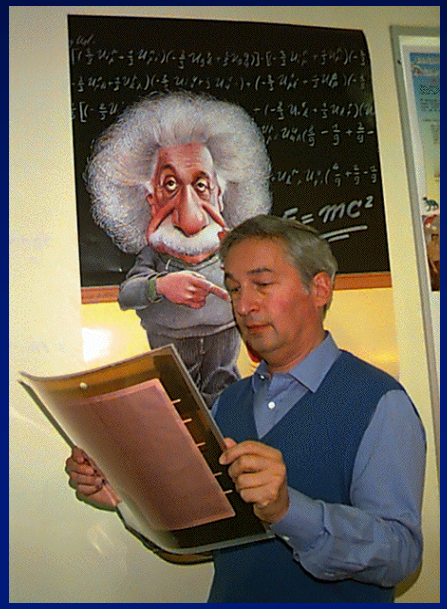
Invented by F.Sauli at CERN

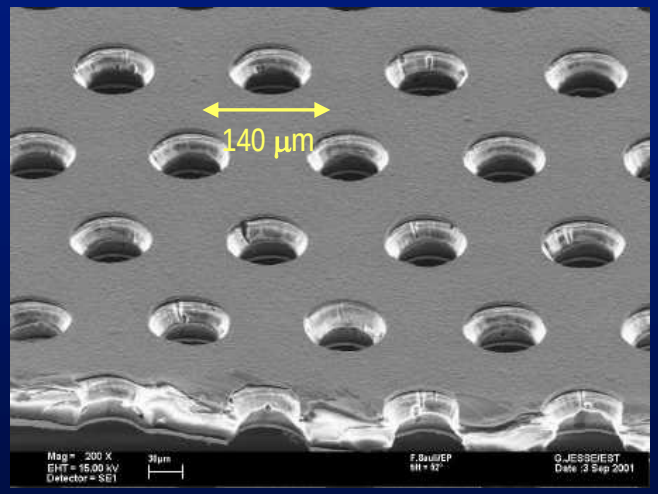
NIM A386 (1997) 531-534

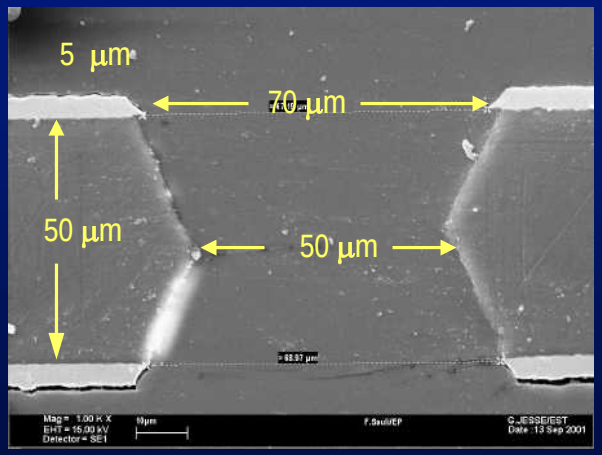
V ~ 300-500 V
E ~ 60-100 KV/cm

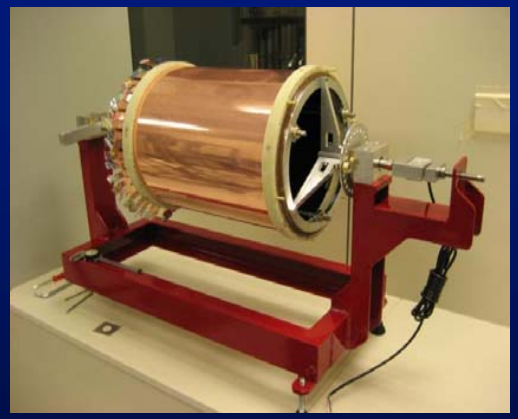
Achieve gas gains ~ 10-20 per foil

~ 10^3-10^4 or higher in triple GEM structures





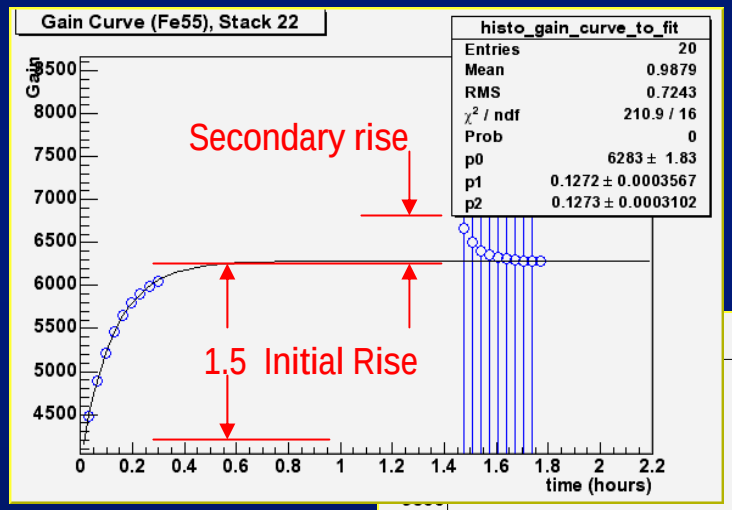




Cylindrical GEM Tracker for KLOE2

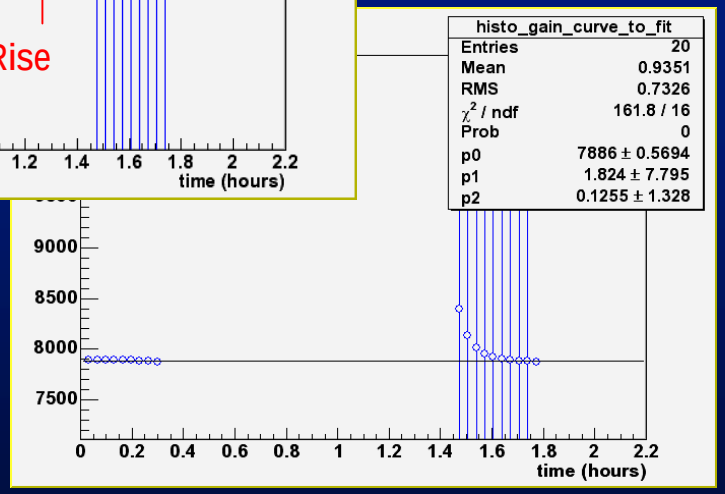
Gain Uniformity and Stability

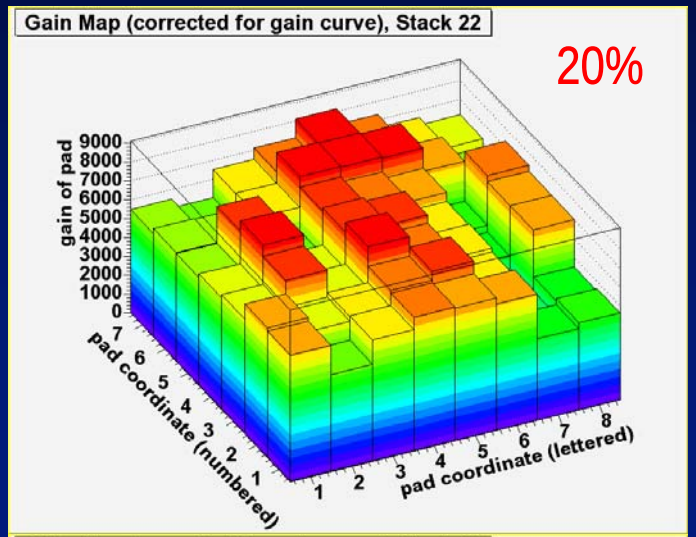
Most GEMs show an initial charge-up effect where the gain increases with time with voltage on and then levels out. Effect not completely understood, but probably due charge build up on inner kapton holes

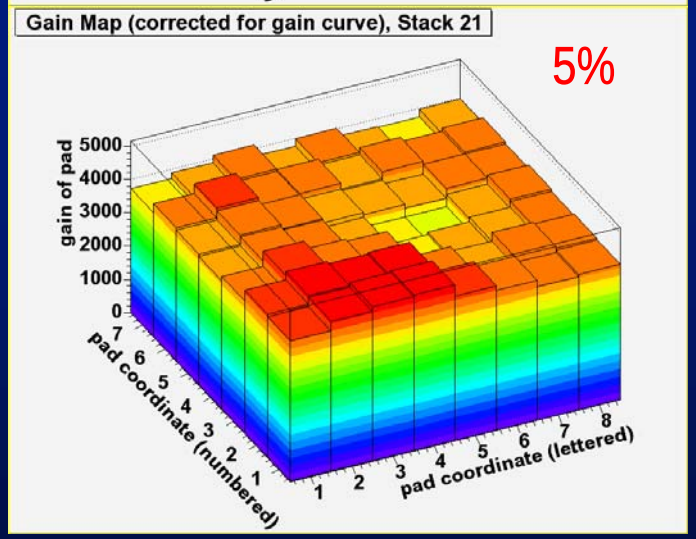


Single pad is irradiated with a 8 KHz ^{55}Fe source for ~ 20 min. Then all other pads are measured, and the source is returned to the starting pad.

J.Kamin (Stony Brook)



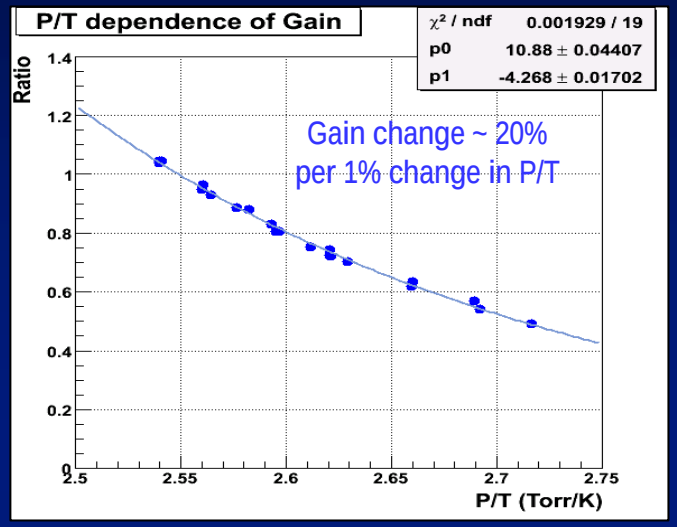


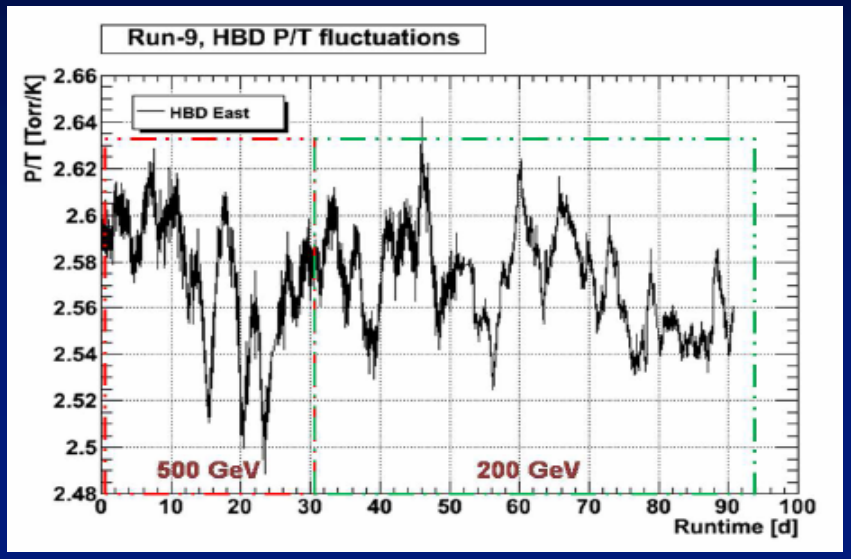


HBD GEMs
Gain increases range from a few % to ~ 2

Gain Stability vs Pressure and Temperature

Large intrinsic gain variation due to P/T

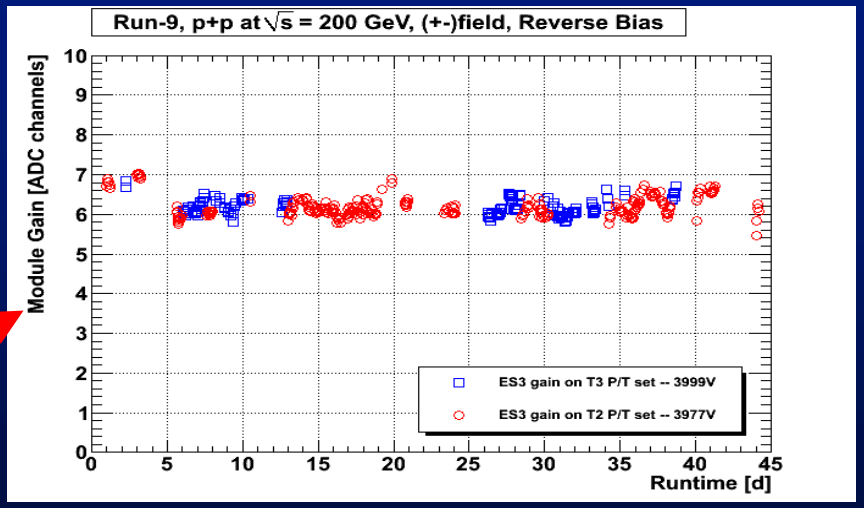




P/T variation at BNL over Run 9

HV was adjusted whenever P/T changed by more than ~ 1% (five P/T HV settings)

Gain generally remained stable to < 10% for all properly working modules



Photoelectron Yield for the HBD

$$N_{pe} = N_0 L \langle \sin^2 \theta_c \rangle$$

Yield = convolution of:

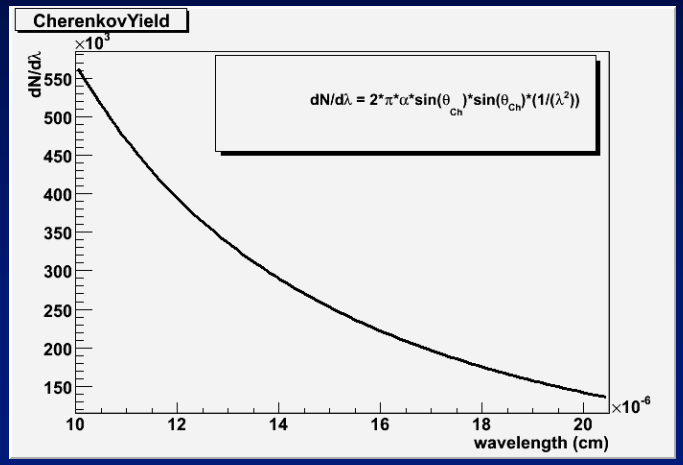
- ⊗ N_γ produced in Cherenkov radiator (50 cm CF_4, $N_\gamma/d\lambda \sim 1/\lambda^2$)
- ⊗ Absorption in gas (cutoff ~ 108 nm, ppms of O_2 and H_2O)
- ⊗ Transparency of mesh (0.9) and GEM (0.80)
- ⊗ CsI QE (~ $1/\lambda$ from 200 nm $\rightarrow$ 108 nm)
- ⊗ $\varepsilon_C = \varepsilon_{ext}(E,\lambda) \times \varepsilon_{trans}(E)$
- ⊗ Pad threshold (readout electronics and cluster reconstruction)

Expected ~ 20-25 p.e in Run 9 and measured ~ 22 p.e.

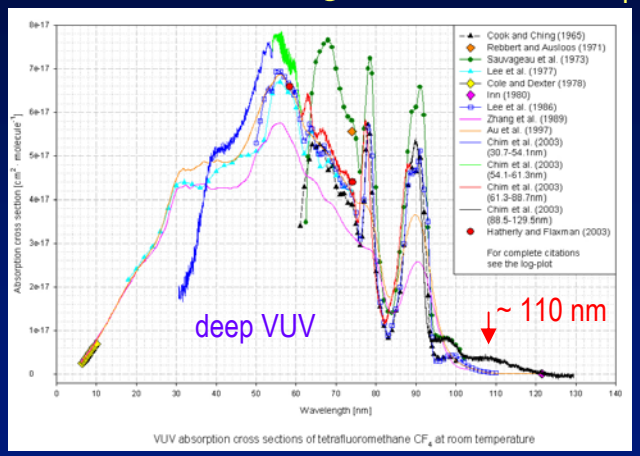
Figure of Merit : $N_0 \sim 380\ cm^{-1}$ (Wow !)

Production and Collection of Cherenkov Light

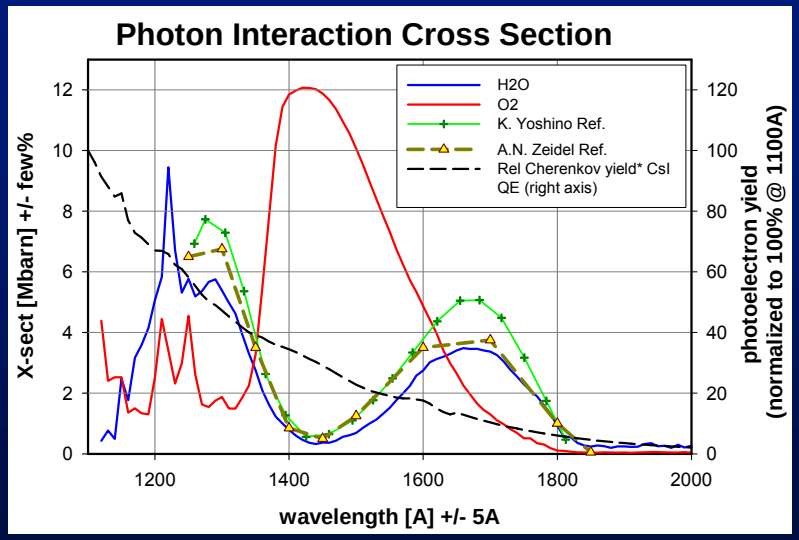
Cherenkov ~ 1/ λ^2



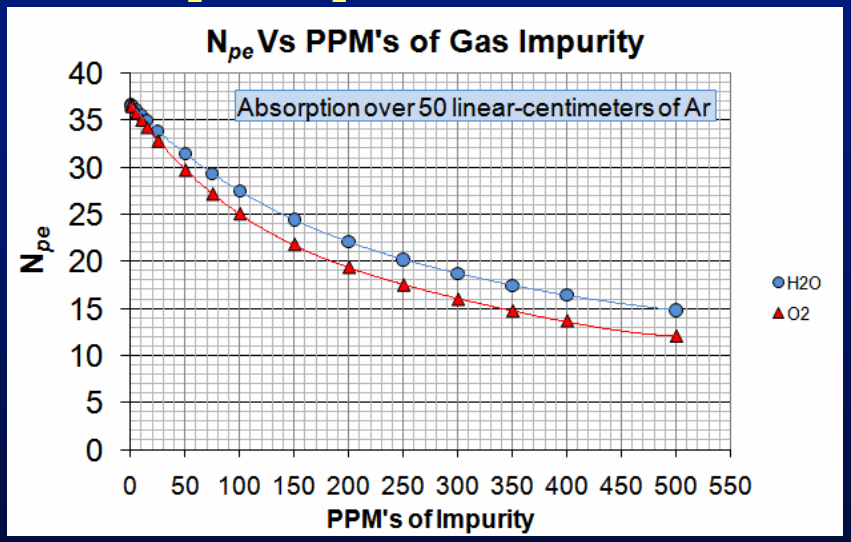
Intrinsic wavelength cutoff in CF_4



Absorption in gas due to impurities

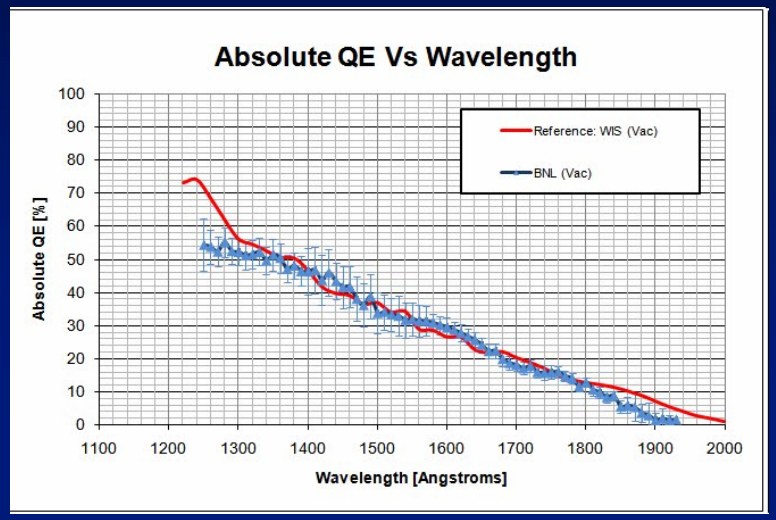


Loss of primary photoelectrons due to O_2 and H_2O absorption



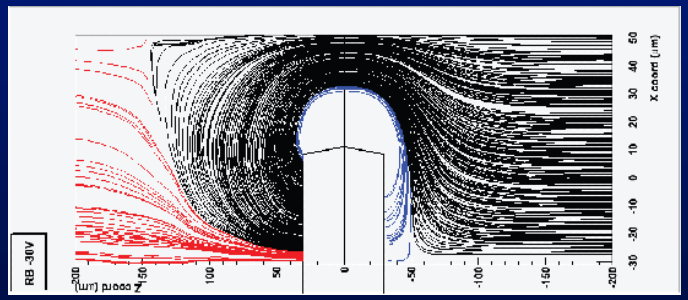
CsI Quantum Efficiency and Photoelectron Extraction Efficiency

CsI QE(λ)



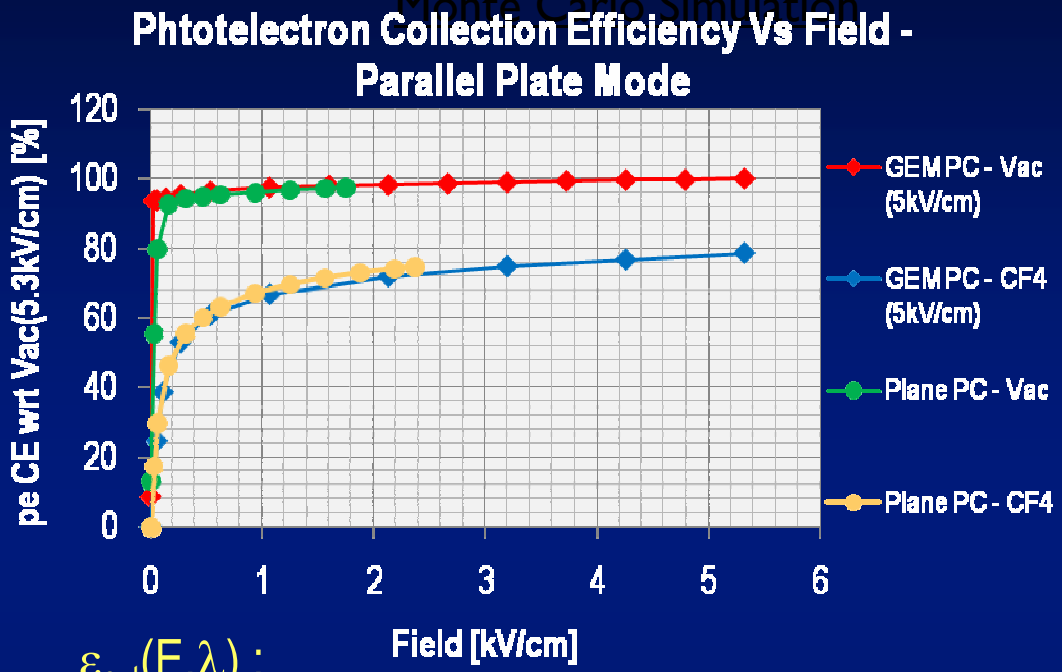
Measured on VUV Spectrometers at BNL and WIS

$\varepsilon_{trans}(E) \sim 0.8$



B.Azmoun et.al., IEEE Trans. Nucl. Sci. Vol 36, No. 3 (2009) 1544-1549

Monte Carlo Simulation

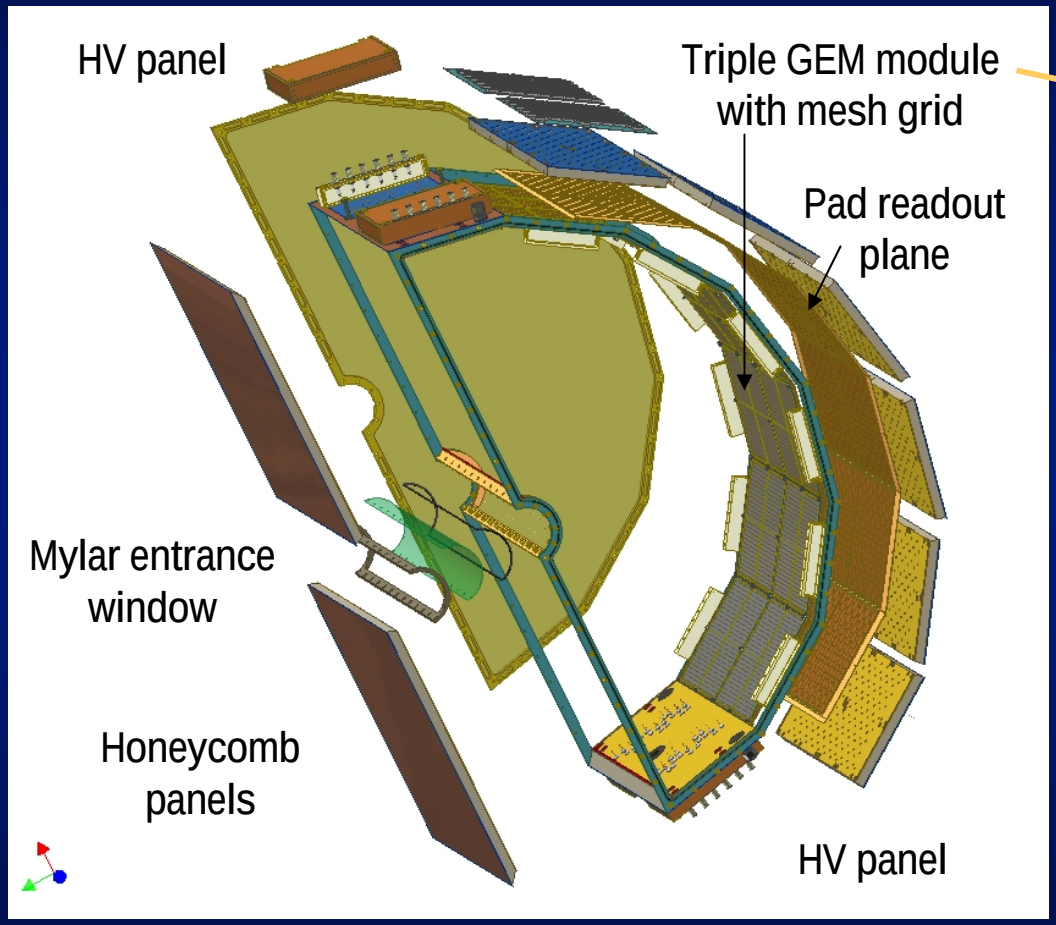


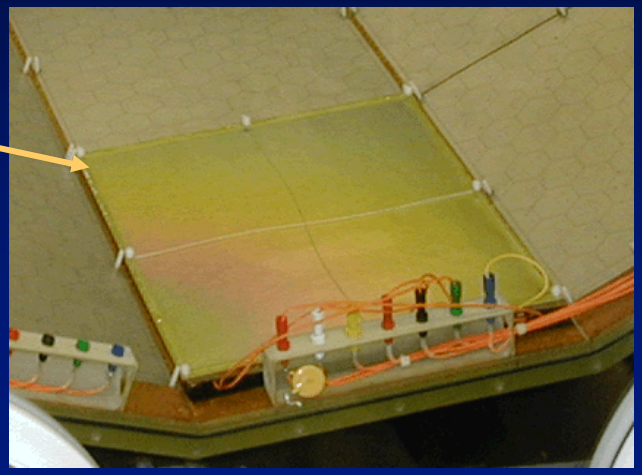
$\varepsilon_{ext}(E,\lambda)$:

- Depends strongly on the extraction field
- Quickly rises to 100% in vacuum
- Slower rise to lower efficiency in gas due to backscatter of photoelectrons off of gas molecules (small λ dependence)
- Plateau value depends on gas

Detector Construction

Detector designed and built at the Weizmann Institute





20 Triple GEM Detectors
(10 modules per side)

- Mesh electrode
- Top gold plated GEM for CsI
- Two standard GEMS
- Kapton foil readout plane
  One continuous sheet per side
  Hexagonal pads (a = 15.6 mm)

Very low mass (< 3% X_0 including gas)

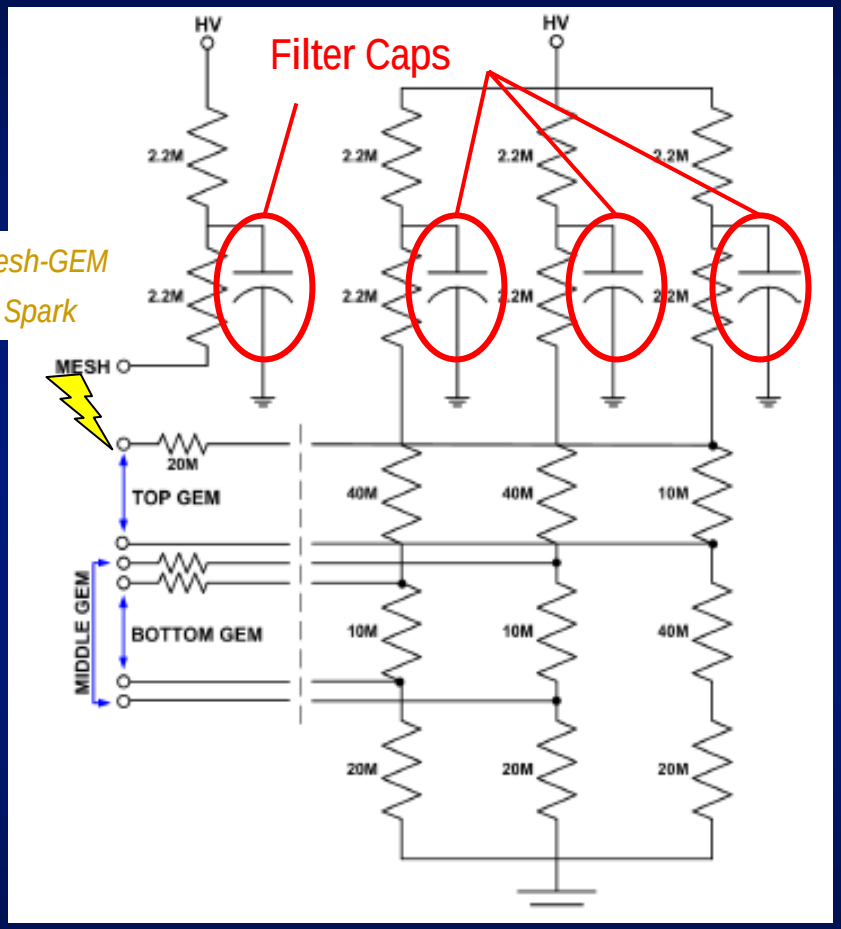
HBD Detector Parameters

Acceptance	$\|\eta\| \leq 0.45$, $\Delta\phi = 135^o$
GEM size (ϕ,z)	23 x 27 cm^2
Segmentation	26 strips (0.80 x 27 cm) 2 strips (0.65 x 27 cm)
Number of detector modules per arm	10
Frame	5 mm wide, 0.3mm cross
Hexagonal pad size	a = 15.6 mm
Number of pads per arm	960
Dead area within central arm acceptance	6%
Radiation length within central arm acceptance	box: 0.92%, gas: 0.54%, preamps+sockets: 0.66% Total: 2.12%
Weight per arm (including accessories)	<10 kg

History

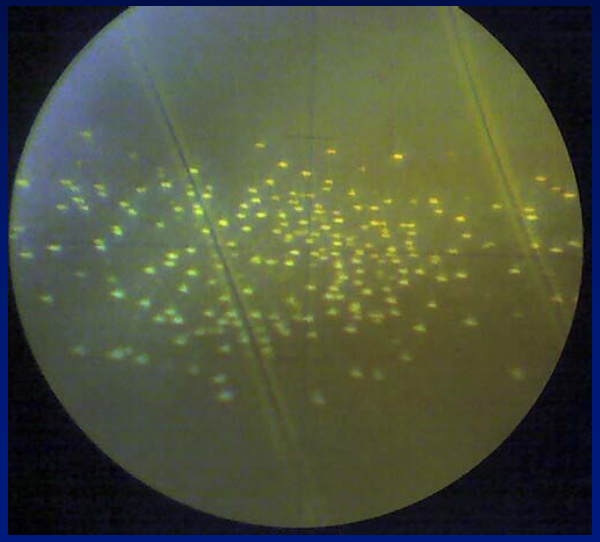
- The HBD was originally installed into PHENIX in the fall of 2006 for Run 7 (2006-2007) at RHIC
- The detector encountered several severe high voltage problems which ultimately damaged many of the GEM foils
  - Minor GEM sparks induced larger, more damaging mesh to GEM sparks due to large stored energy in filter capacitors
  - Spark in one module would induce sparks in other modules due to photon propagation in CF_4
  - Problem found with LeCroy 1471N modules that allowed HV to be reapplied after a trip causing spurious HV spikes
- Some very useful data was taken with the detector during Run 7, but the entire detector was subsequently rebuild and reinstalled for Run 9 (Feb - July 2009, 200 & 500 GeV pp)

GEM Foil Damage



Run 7 Voltage Divider

Spark Damage
On Top GEM



GEMs segmented on one side to limit stored energy

Improvements and Lessons Learned

- We believe the main problem with GEM sparking was due to dust !
- New Rapid Method procedure was instituted to build the detector
  - Most of the assembly is done near laminar flow table (clean)
  - Only CsI coated GEMs were installed inside glove box (dusty)
  - No testing of individual stacks inside glove box (only after assembly)
  - Used only for the West Detector for Run 9. East Detector was rebuilt almost entirely inside the glove box and did not perform as well. East was rebuilt again using the Rapid Method during '09 shutdown and reinstalled for Run 10
- New voltage divider
  - Zeners installed to limit mesh to GEM voltage
  - Increased field in 1st transfer gap. Enabled us to achieve same gain ($G \sim 10^3$) at lower dV across GEMs
- HV relay box installed between LeCroy HV PS and detector
  - Discharges both mesh and GEM divider chain if either one trips
- New sophisticated HV control program
- Increased gas flow through detector to improve transparency

“Clean Tent” at Stony Brook

Laminar Flow Hood

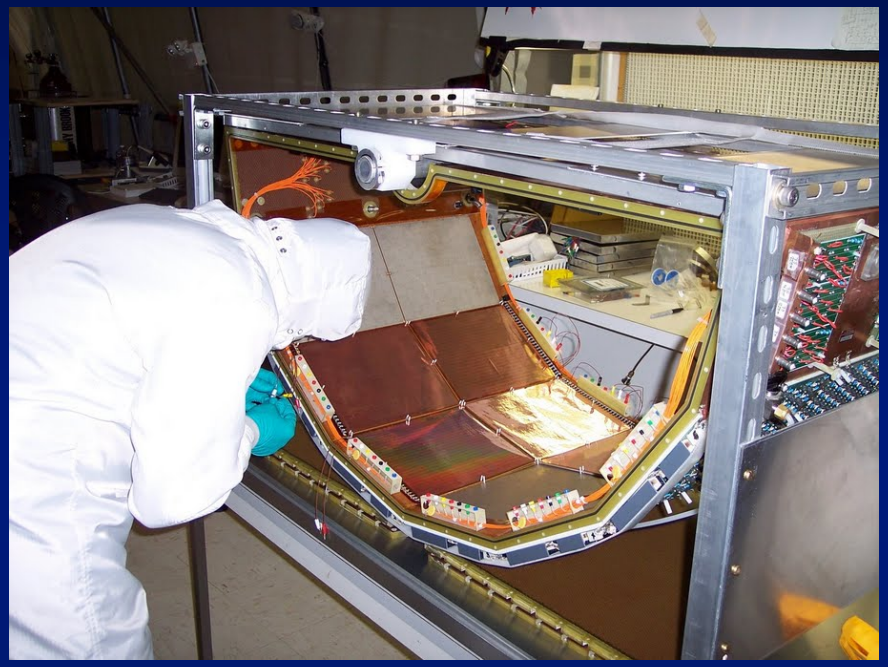
High Vacuum GEM Storage Container

CsI Evaporator and quantum efficiency measurement

Large glove box
O_2 < 5 ppm
H_2O < 10 ppm

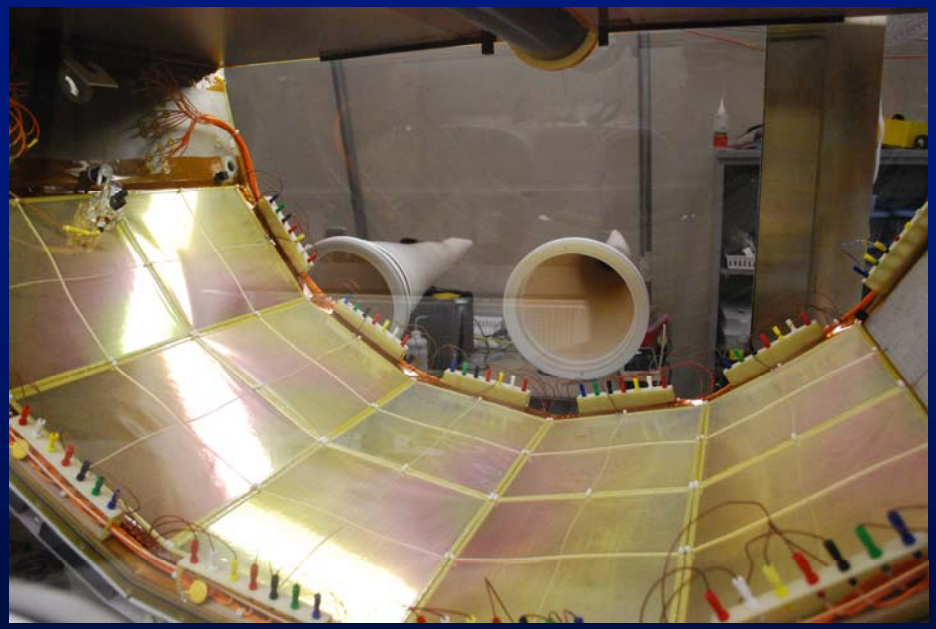
Class 10-100 (N < 0.5 μm particles/m^3)

Rebuilding the East Detector (Aug ’09)

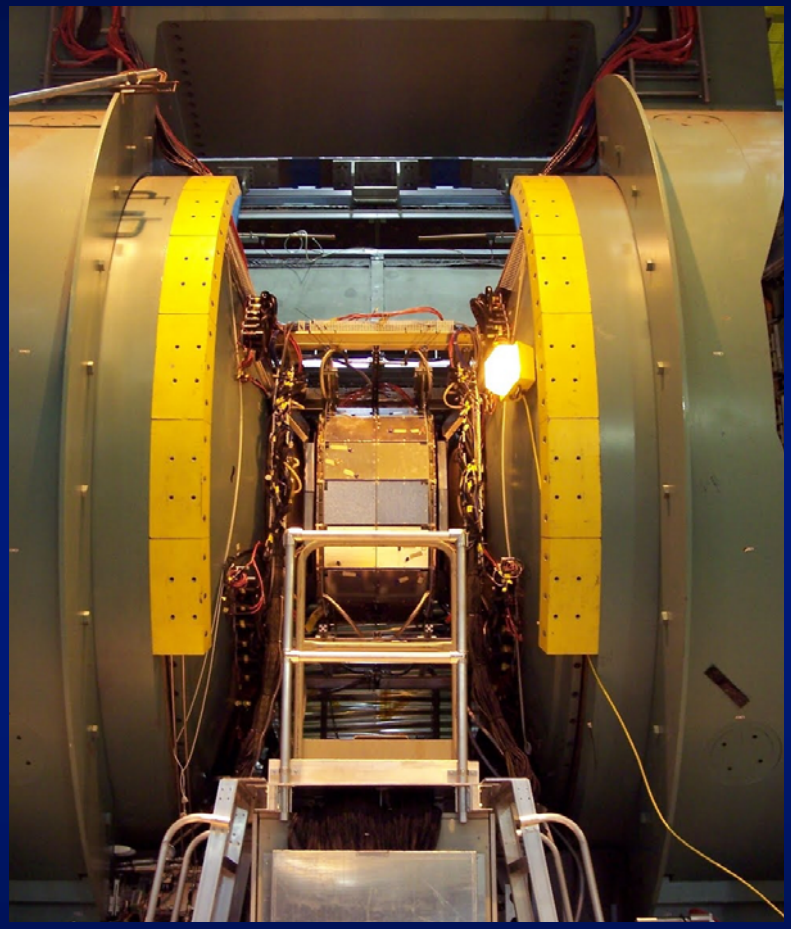


Standard GEMs installed near laminar flow table
(cleanest area inside tent)

CsI coated GEMs installed inside glove box
(minimize exposure time)



HBD East Reinstalled for Run 10



HBD East in PHENIX 10/1/09
after refurbishing at Stony Brook

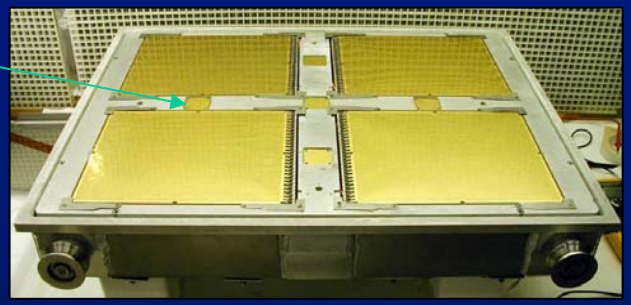
Evaporator and QE Measurement

Complete CsI evaporation station was given on loan to Stony Brook from INFN/ISS Rome (>$1M)

Produces 4 photocathodes per evaporation

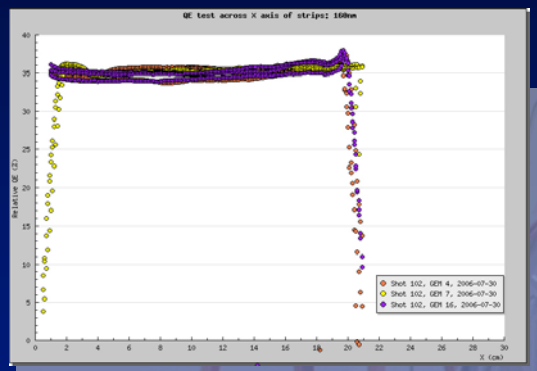
- Deposit 2400 – 4500 Å CsI @ 2 nm /sec
- Vacuum ~ 10^{-7} Torr
- Contaminants measured with RGA (virtually no water)

Small "chicklets" evaporated at same time for full QE measurement (120-200 nm)

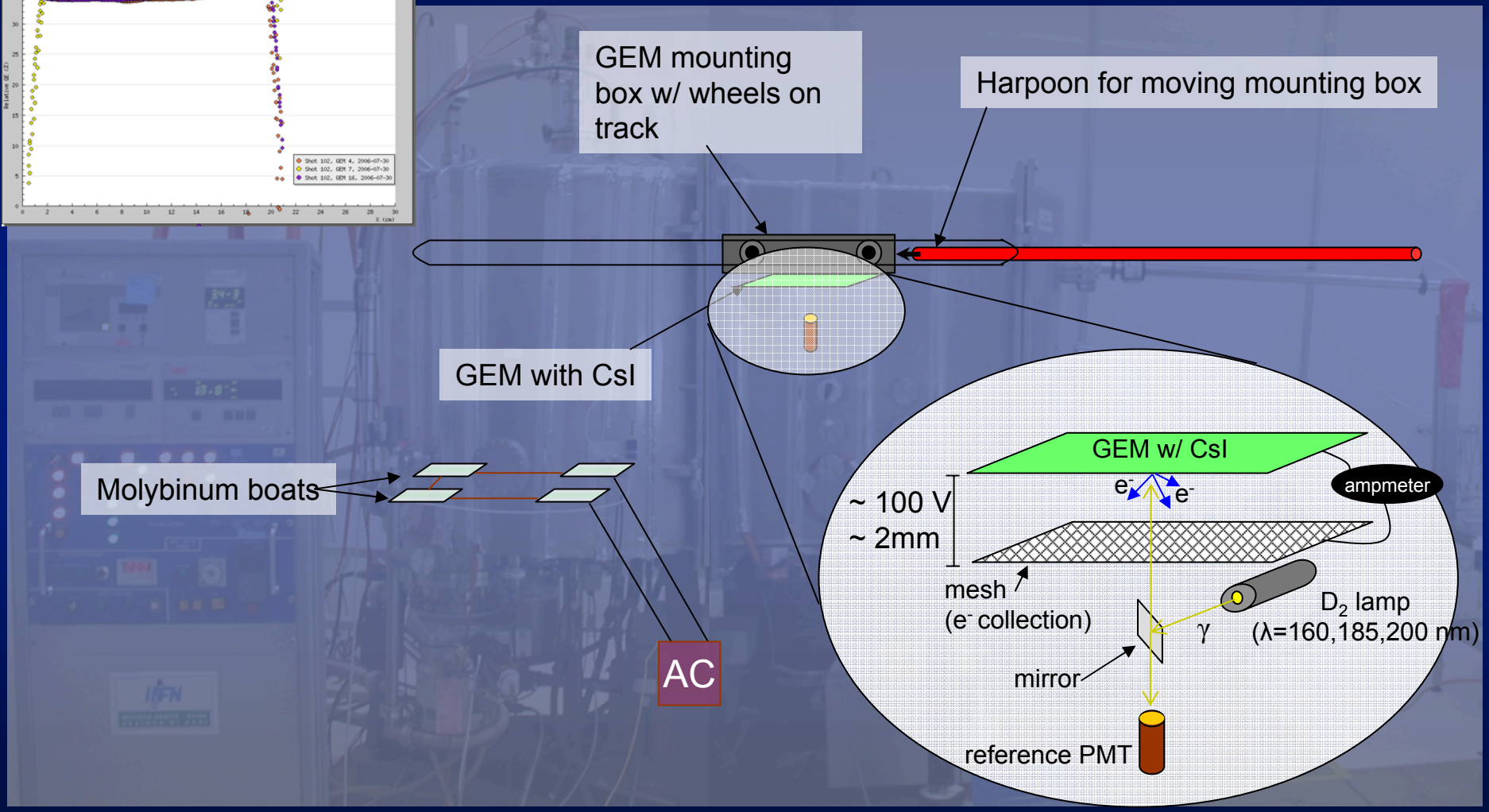


- Measures photocathode quantum efficiency in situ from 165-200 nm over entire area
- Photocathodes transported to glove box without exposure to air

Quantum Efficiency Measuring Station

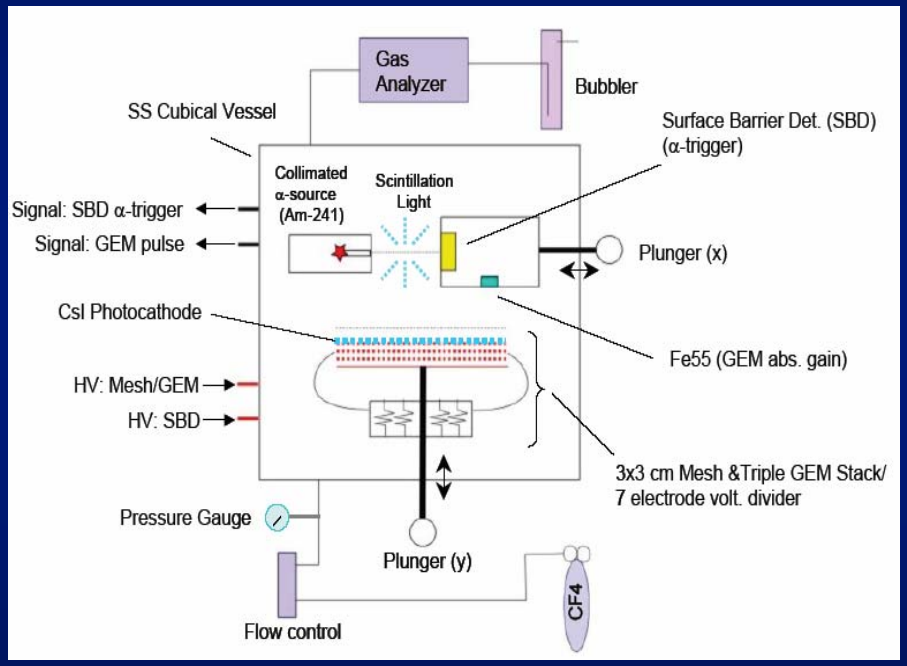


← Uniform relative quantum efficiency across the GEM

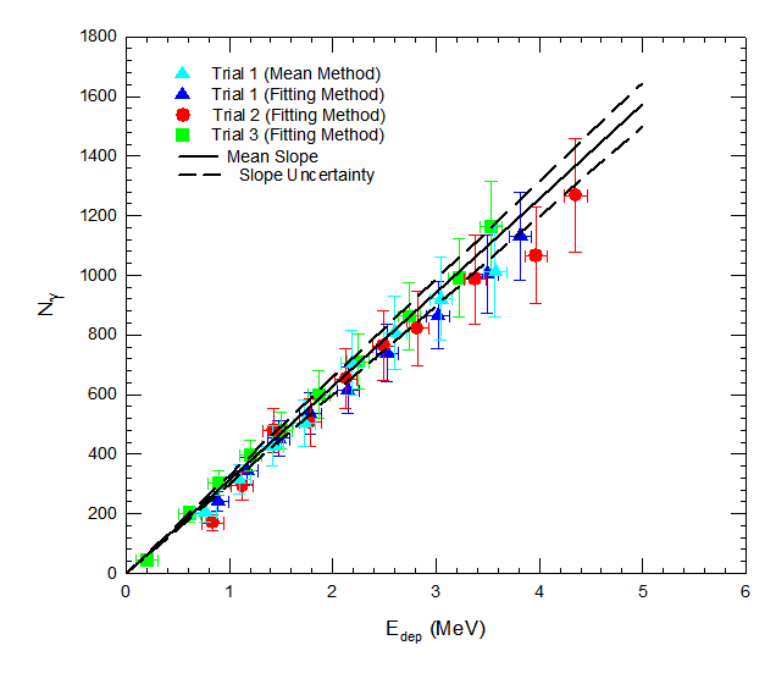


Scintillation Light Yield in CF_4

CF_4 has a strong scintillation emission at 160 nm
Use this to measure and monitor CsI photocathodes in situ



Setup to measure scintillation yield in CF_4 using a CsI photocathode GEM

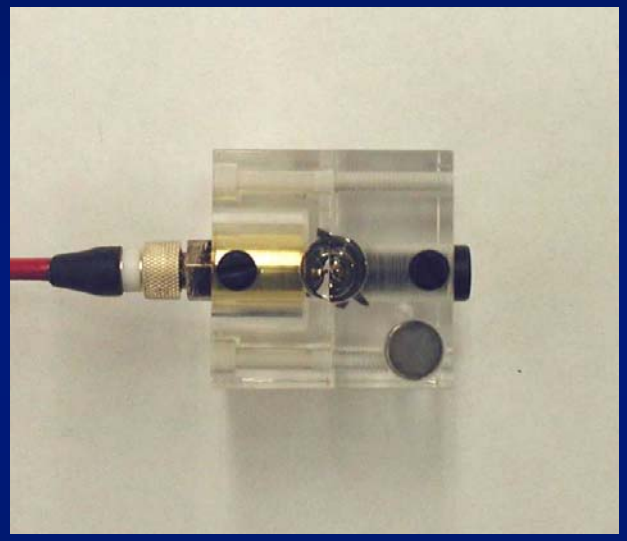


Scintillation Yield = $dN\gamma/dE$
314 ± 15 γ / MeV

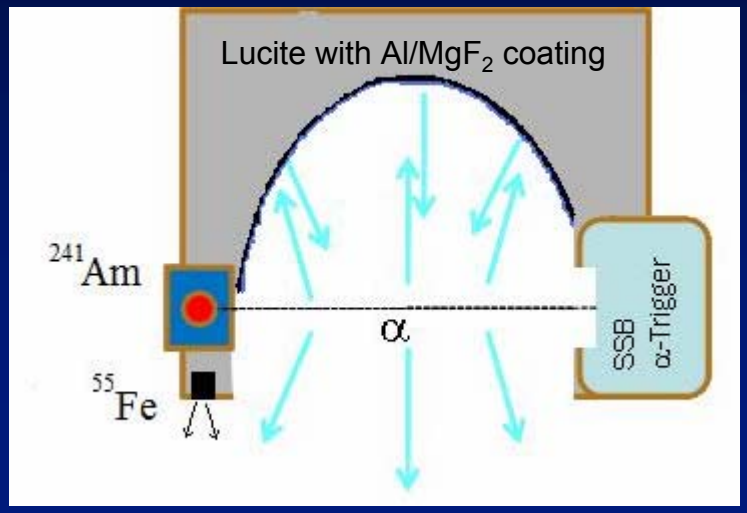
B.Azmoun et.al., IEEE Trans. Nucl. Sci. April-May 2010

Scintillation Cube

Use CF_4 scintillation as a calibrated light source

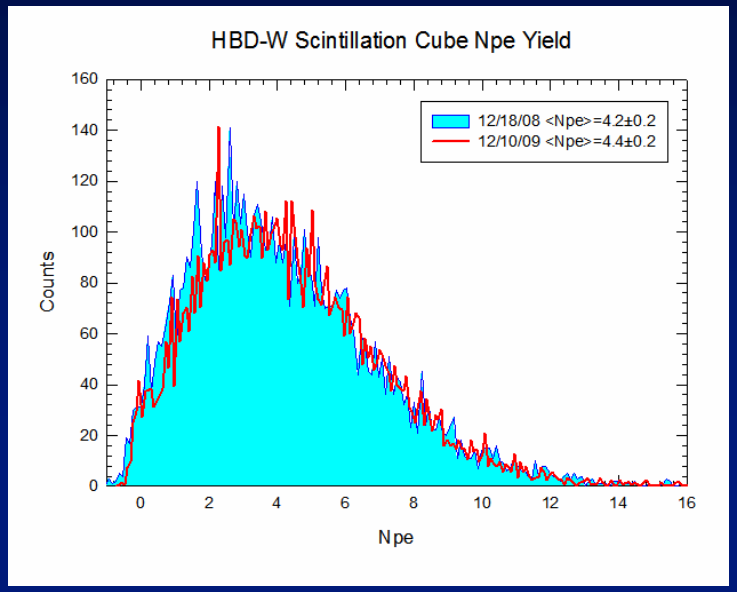


One of these devices is installed in each of half of the HBD to monitor the QE of the photocathodes

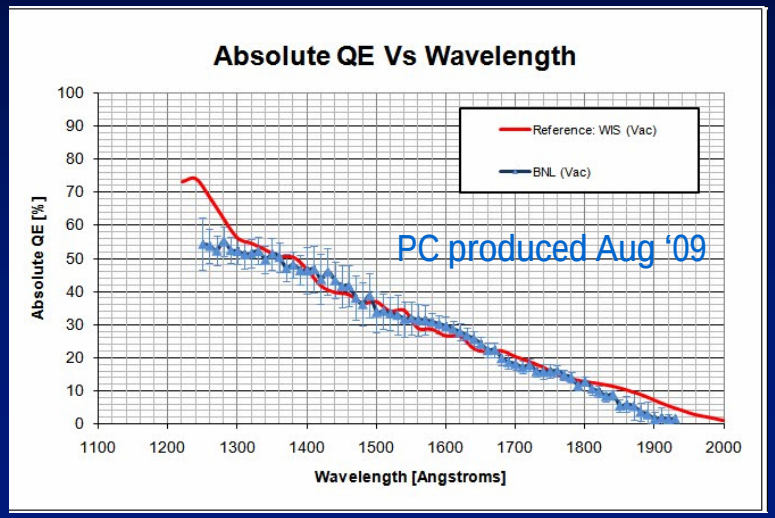


- α particles from an ^{241}Am source traverse ~ 1 cm of CF_4 gas depositing several MeV
- Energy of the α particle is measured with a silicon surface barrier detector
- Light is collected by a reflecting cavity
- ^{55}Fe source mounted to base of cube allows simultaneous measurement of the gas gain

CsI Photocathodes

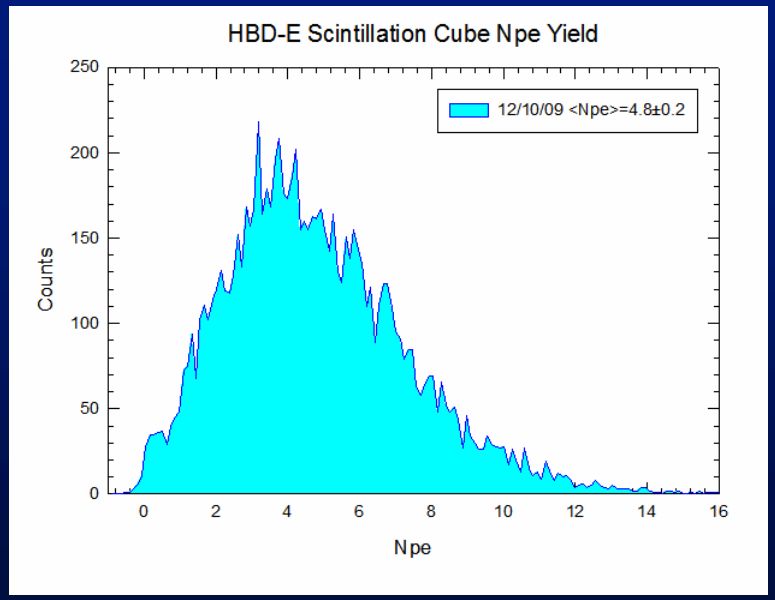


Measured on VUV Spectrometer



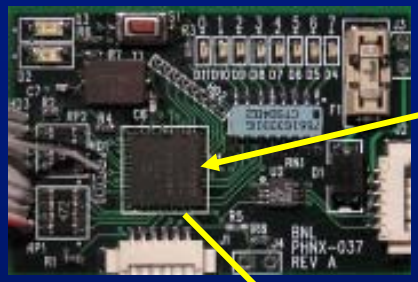
Photocathodes produced over one year ago have not deteriorated in terms of their QE

New photocathodes have good QE

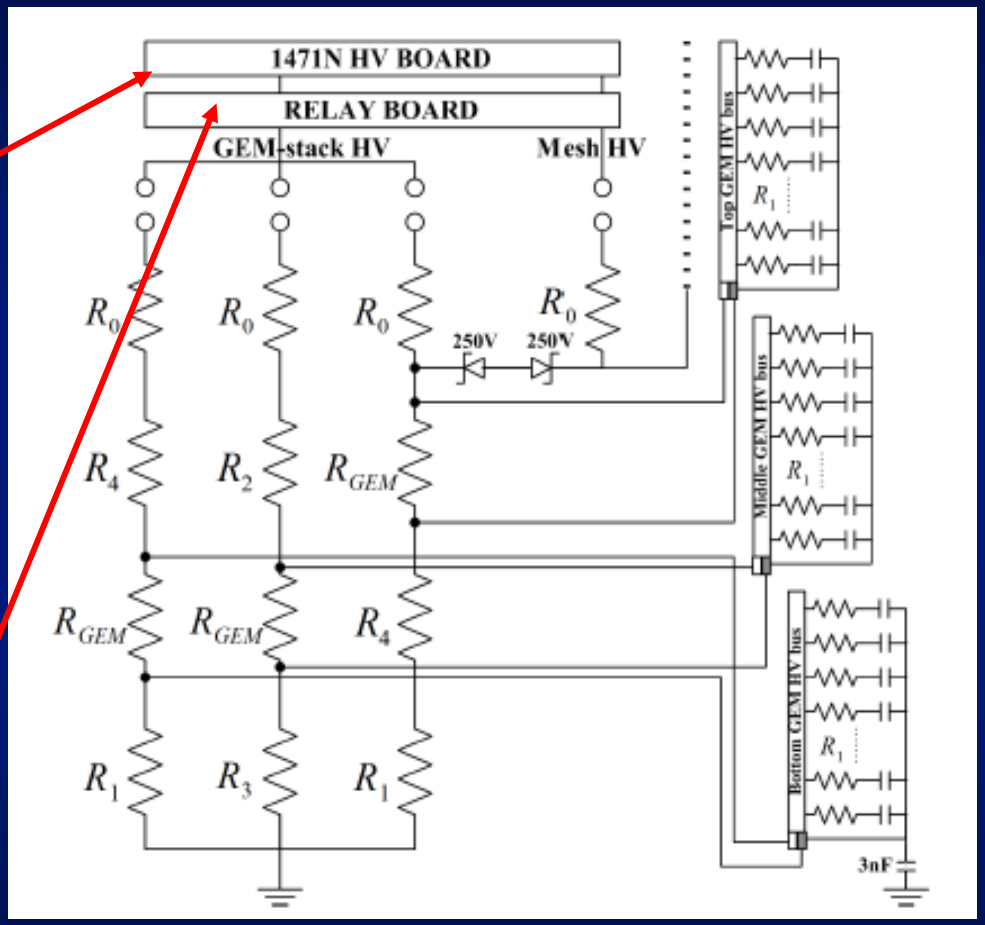


New Voltage System

LeCroy 1450 HV System



1471N HV Module
Added Trip
Detection Circuit

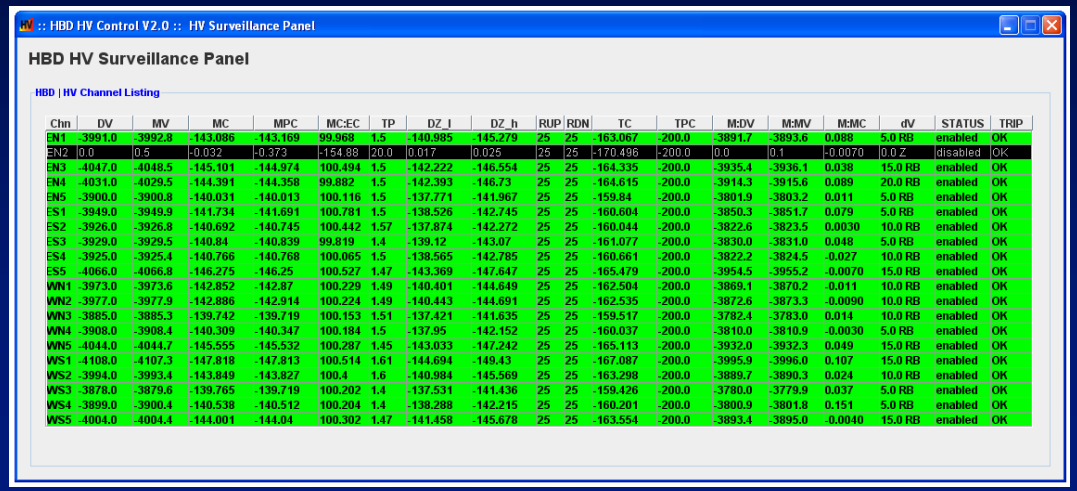


Relay Board trips mesh + GEM whenever either trip

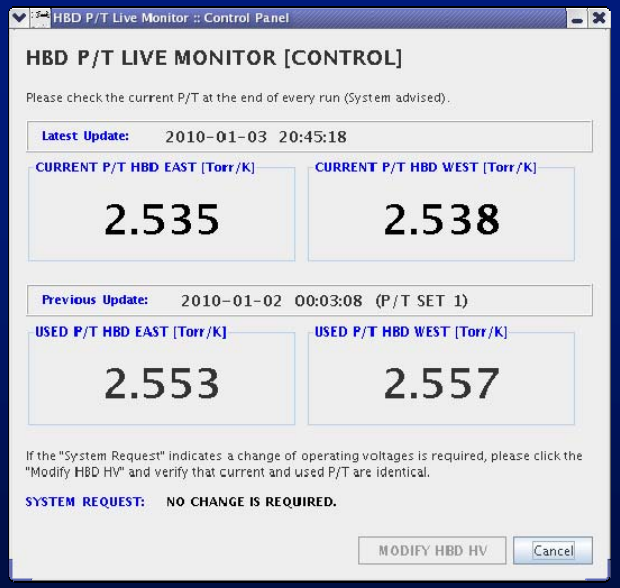
M.Proissl

HBD HV Control System

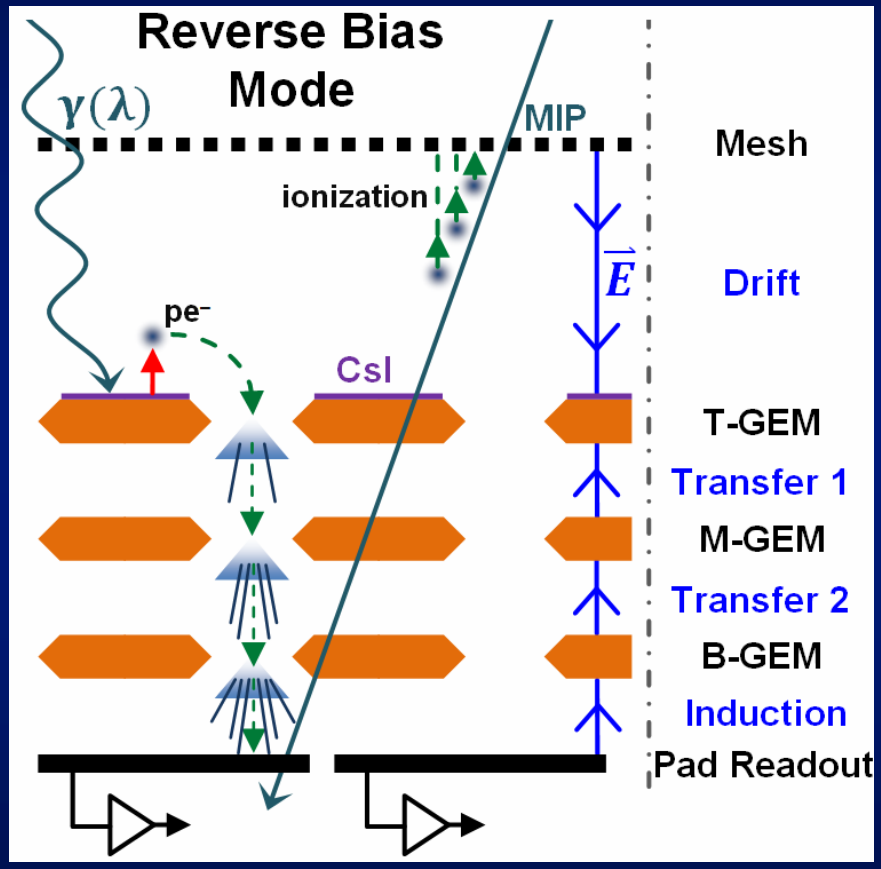
M.Proissl



Chn	DV	MV	MC	MPC	MC:EC	TP	DZ_l	DZ_h	RUP	RDN	TC	TPC	M:DV	M:MV	M:MC	dV	STATUS	TRIP
EN1	-3991.0	-3992.8	-143.086	-143.169	99.968	1.5	-140.985	-145.279	25	25	-163.067	-200.0	-3891.7	-3893.6	0.088	5.0 RB	enabled	OK
EN2	0.0	0.5	-0.032	-0.373	-154.88	20.0	0.017	0.025	25	25	-170.496	-200.0	0.0	0.1	-0.0070	0.0 Z	disabled	OK
EN3	-4047.0	-4048.5	-145.101	-144.974	100.494	1.5	-142.222	-146.554	25	25	-164.335	-200.0	-3935.4	-3936.1	0.038	15.0 RB	enabled	OK
EN4	-4031.0	-4029.5	-144.391	-144.358	99.882	1.5	-142.393	-146.73	25	25	-164.615	-200.0	-3914.3	-3915.6	0.089	20.0 RB	enabled	OK
EN5	-3900.0	-3900.8	-140.031	-140.013	100.116	1.5	-137.771	-141.967	25	25	-159.84	-200.0	-3801.9	-3803.2	0.011	5.0 RB	enabled	OK
ES1	-3949.0	-3949.9	-141.734	-141.691	100.781	1.5	-138.526	-142.745	25	25	-160.604	-200.0	-3850.3	-3851.7	0.079	5.0 RB	enabled	OK
ES2	-3926.0	-3926.8	-140.692	-140.745	100.442	1.57	-137.874	-142.272	25	25	-160.044	-200.0	-3822.6	-3823.5	0.0030	10.0 RB	enabled	OK
ES3	-3929.0	-3929.5	-140.84	-140.839	99.819	1.4	-139.12	-143.07	25	25	-161.077	-200.0	-3830.0	-3831.0	0.048	5.0 RB	enabled	OK
ES4	-3925.0	-3925.4	-140.766	-140.768	100.065	1.5	-138.565	-142.785	25	25	-160.661	-200.0	-3822.2	-3824.5	-0.027	10.0 RB	enabled	OK
ES5	-4066.0	-4066.8	-146.275	-146.25	100.527	1.47	-143.369	-147.647	25	25	-165.479	-200.0	-3954.5	-3955.2	-0.0070	15.0 RB	enabled	OK
WN1	-3973.0	-3973.6	-142.852	-142.87	100.229	1.49	-140.401	-144.649	25	25	-162.504	-200.0	-3869.1	-3870.2	-0.011	10.0 RB	enabled	OK
WN2	-3977.0	-3977.9	-142.886	-142.914	100.224	1.49	-140.443	-144.691	25	25	-162.535	-200.0	-3872.6	-3873.3	-0.0090	10.0 RB	enabled	OK
WN3	-3885.0	-3885.3	-139.742	-139.719	100.153	1.51	-137.421	-141.635	25	25	-159.517	-200.0	-3782.4	-3783.0	0.014	10.0 RB	enabled	OK
WN4	-3908.0	-3908.4	-140.309	-140.347	100.184	1.5	-137.95	-142.152	25	25	-160.037	-200.0	-3810.0	-3810.9	-0.0030	5.0 RB	enabled	OK
WN5	-4044.0	-4044.7	-145.555	-145.532	100.287	1.45	-143.033	-147.242	25	25	-165.113	-200.0	-3932.0	-3932.3	0.049	15.0 RB	enabled	OK
WS1	-4108.0	-4107.3	-147.818	-147.813	100.514	1.61	-144.694	-149.43	25	25	-167.087	-200.0	-3995.9	-3996.0	0.107	15.0 RB	enabled	OK
WS2	-3994.0	-3993.4	-143.849	-143.827	100.4	1.6	-140.984	-145.569	25	25	-163.298	-200.0	-3889.7	-3890.3	0.024	10.0 RB	enabled	OK
WS3	-3878.0	-3879.6	-139.765	-139.719	100.202	1.4	-137.531	-141.436	25	25	-159.426	-200.0	-3780.0	-3779.9	0.037	5.0 RB	enabled	OK
WS4	-3899.0	-3900.4	-140.538	-140.512	100.204	1.4	-138.288	-142.215	25	25	-160.201	-200.0	-3800.9	-3801.8	0.151	5.0 RB	enabled	OK
WS5	-4004.0	-4004.4	-144.001	-144.04	100.302	1.47	-141.458	-145.678	25	25	-163.554	-200.0	-3893.4	-3895.0	-0.0040	15.0 RB	enabled	OK



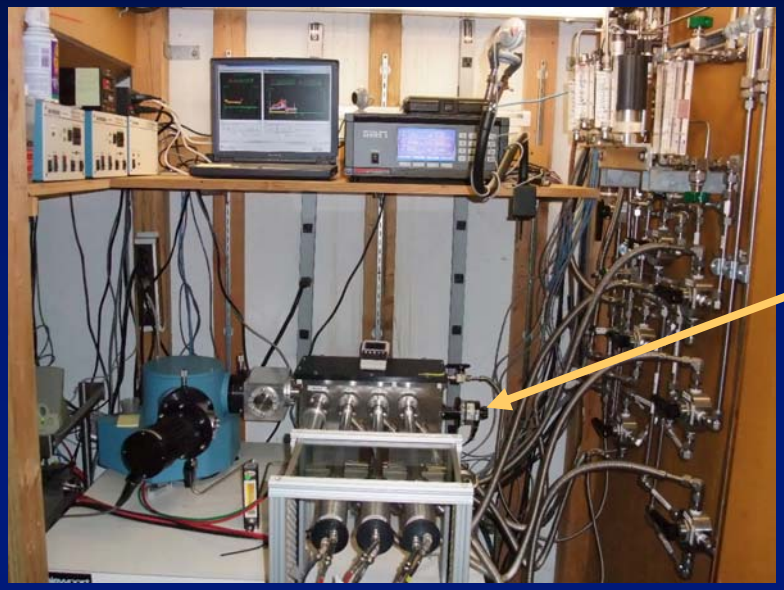
Problem with EN2



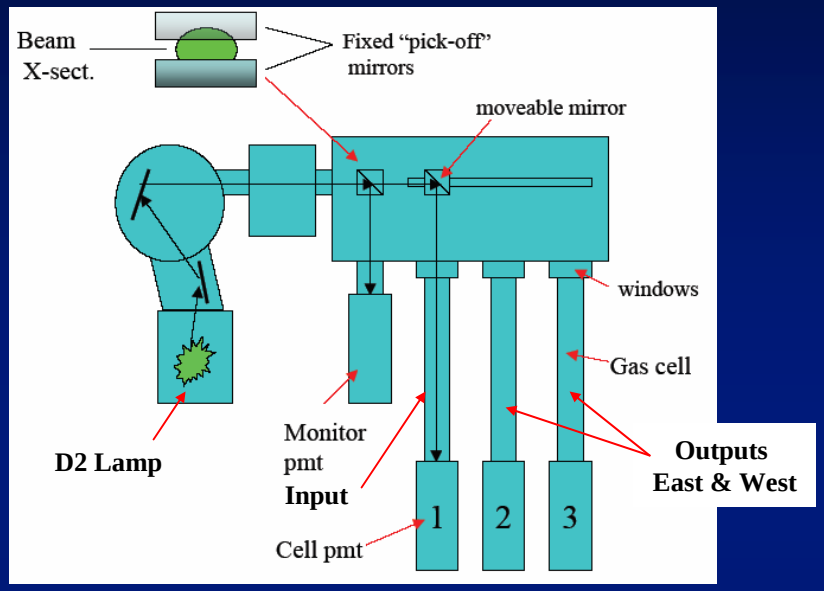
- GEMs held voltage well beyond operating, but first transfer gap would not
- Due to time constraints, we adopted a workaround solution: Go back to old voltage divider with lower voltage in 1st transfer gap and compensate with higher gain in GEMs
- Initial testing and diagnosis resulted in some damage to top and middle GEMs (2 partial shorts), but seemed ok
- After going to full operation at the start of Run 10, EN2 developed several additional shorts
- Several attempts have been made to try and fix EN2, including installing a zener voltage divider, but it still has problems

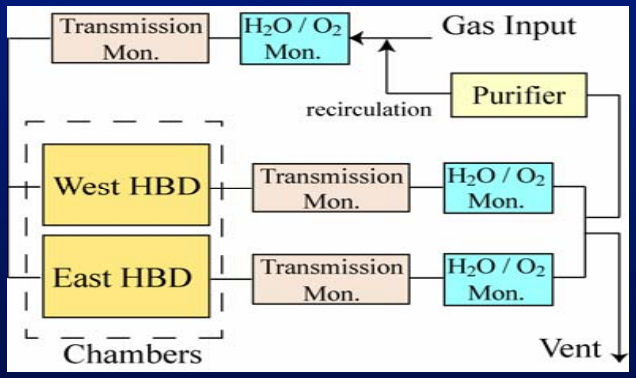
Gas Transmission Monitor

The HBD "Hutch"



Scanning VUV Monochrometer (120-200 nm)

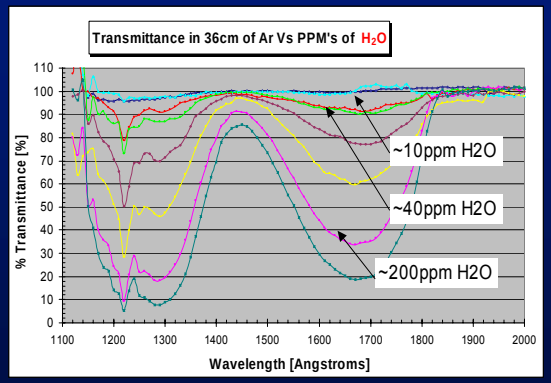




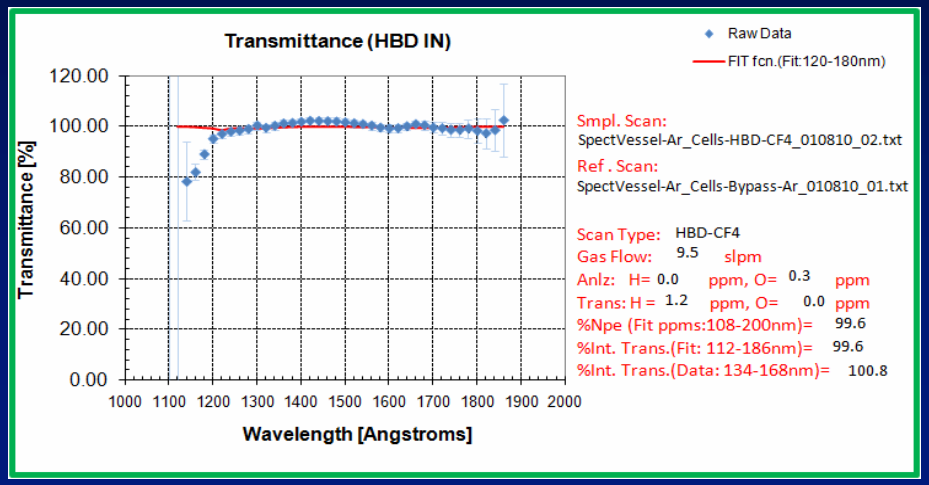
Recirculating gas system
(~ 5 lpm to each detector)

Measure absorption spectra to determine ppms of H_2O and O_2

B.Azmoun, R. Pisani, S.Stoll



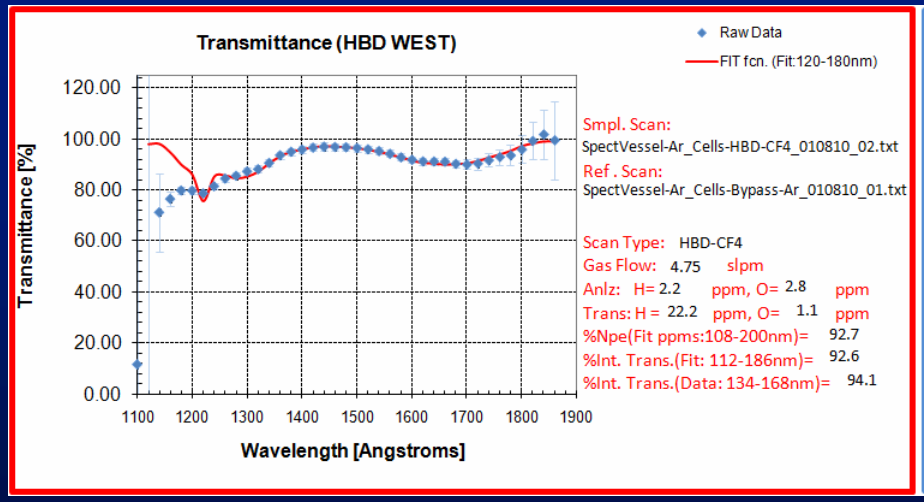
Gas Transmittance

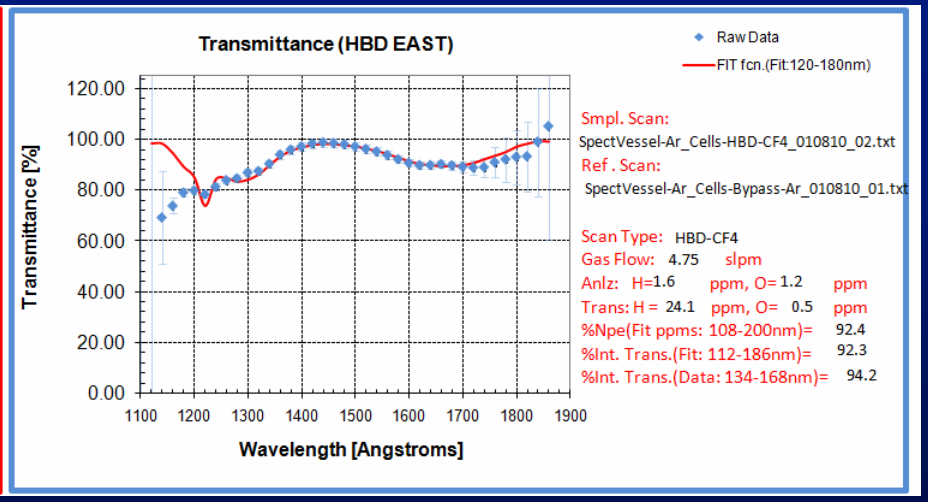


Input ~ 0 ppm H_2O and O_2

Flow rate ~ 4.75 lpm to each detector

Output ~ 20 ppm H_2O and ~ 1 ppm O_2

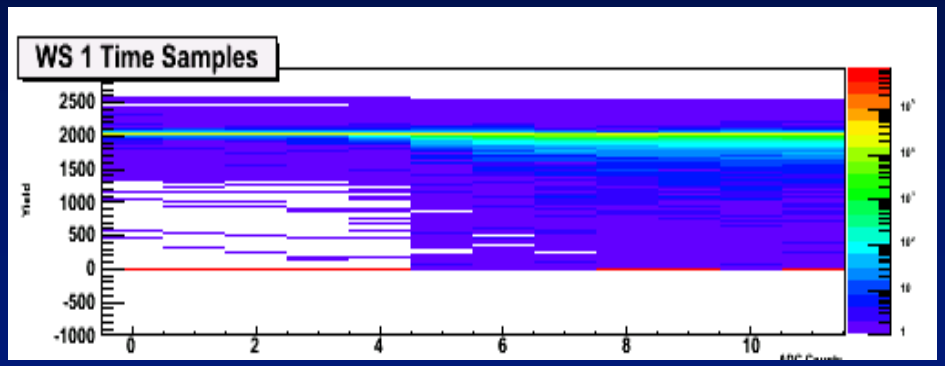




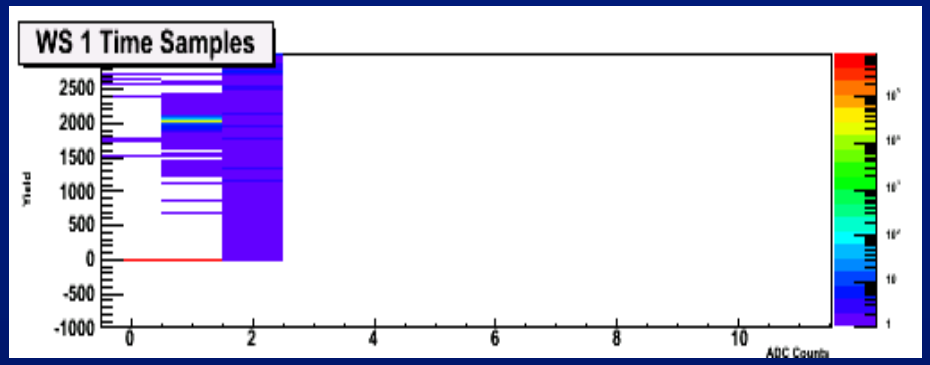
1/8/10

B.Azmoun, S.Stoll

New Reduced Data Format for Run 10

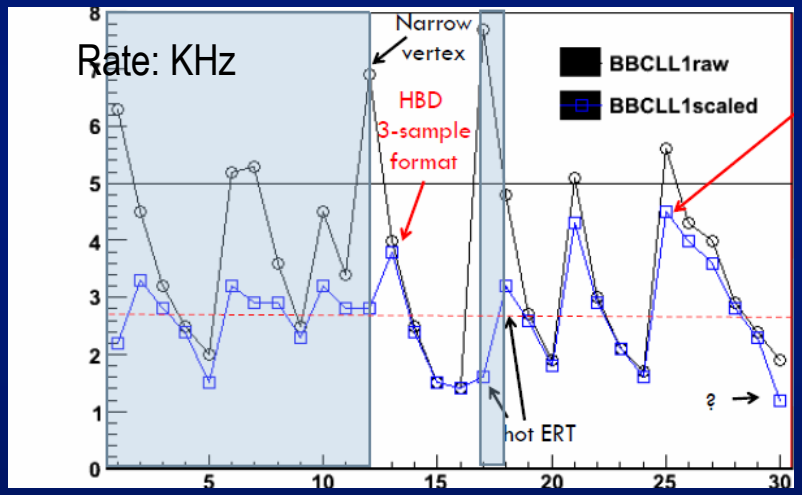


Old 12 sample format
Data volume ~ 20-24 KB/ev



C-Y. Chi

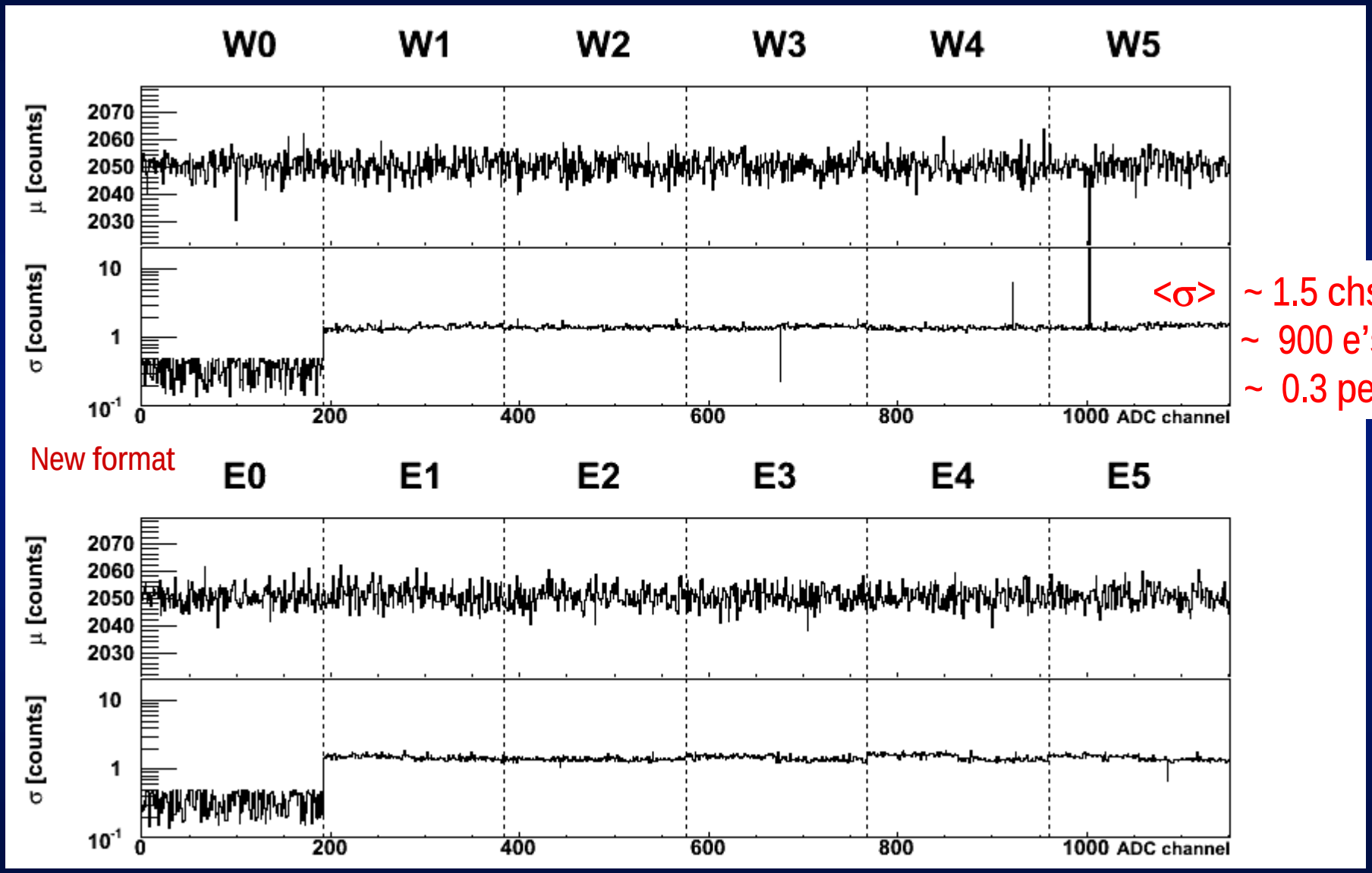
New 3 sample format
Data volume ~ 7-8 KB/ev



Run Number

S.Bathe

Pedestals and Noise



T.Sakaguchi

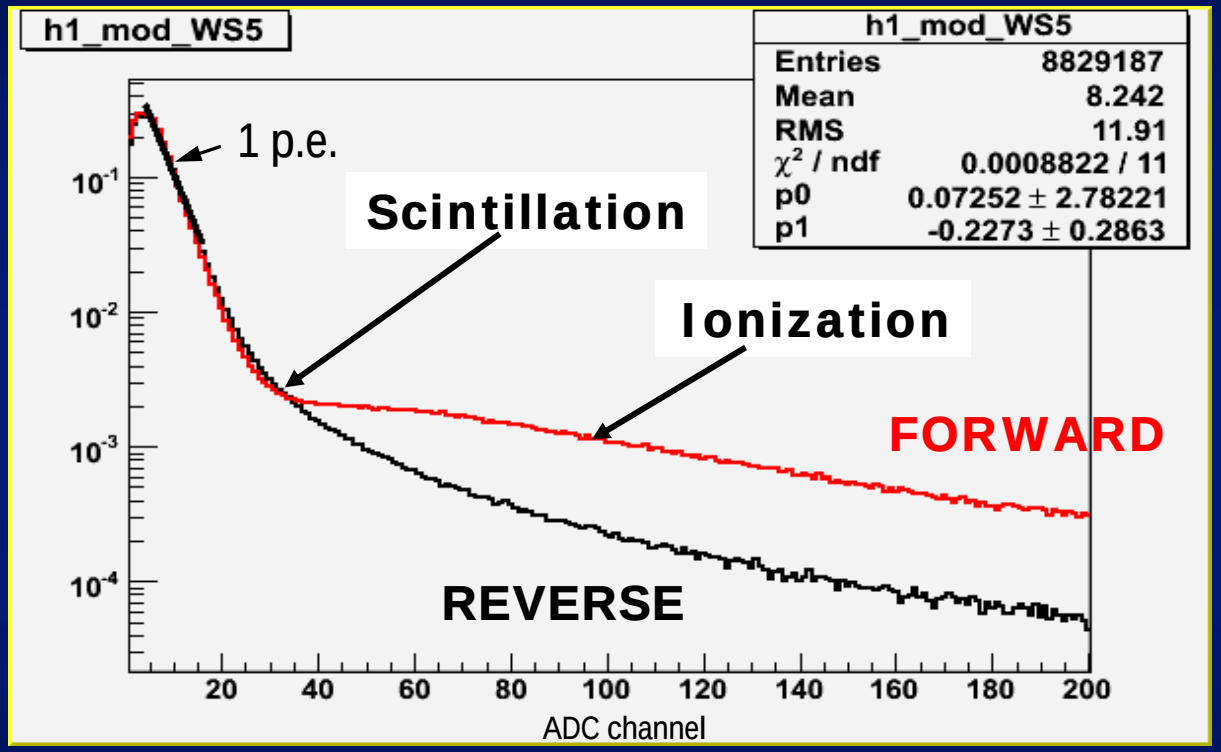
Gain Determination Using Scintillation in CF_4

For low multiplicity events, scintillation produces essentially single photoelectrons on each pad

Fit single p.e. distribution to an exponential

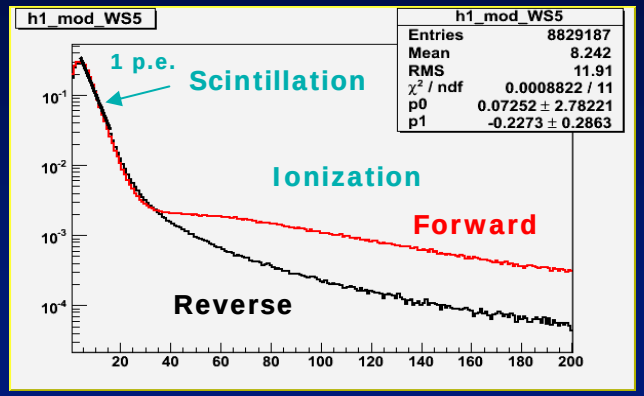
Gain ~ 1/slope

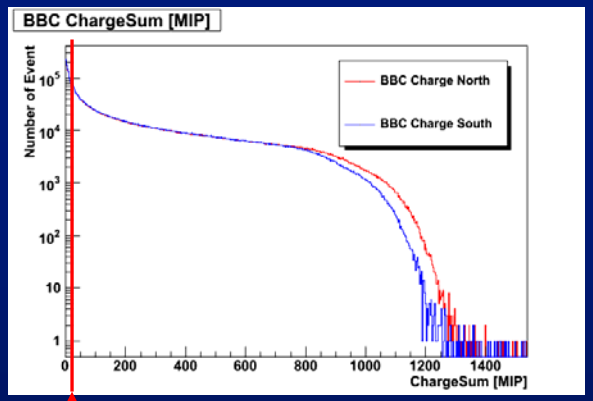
Allows pad by pad calibration



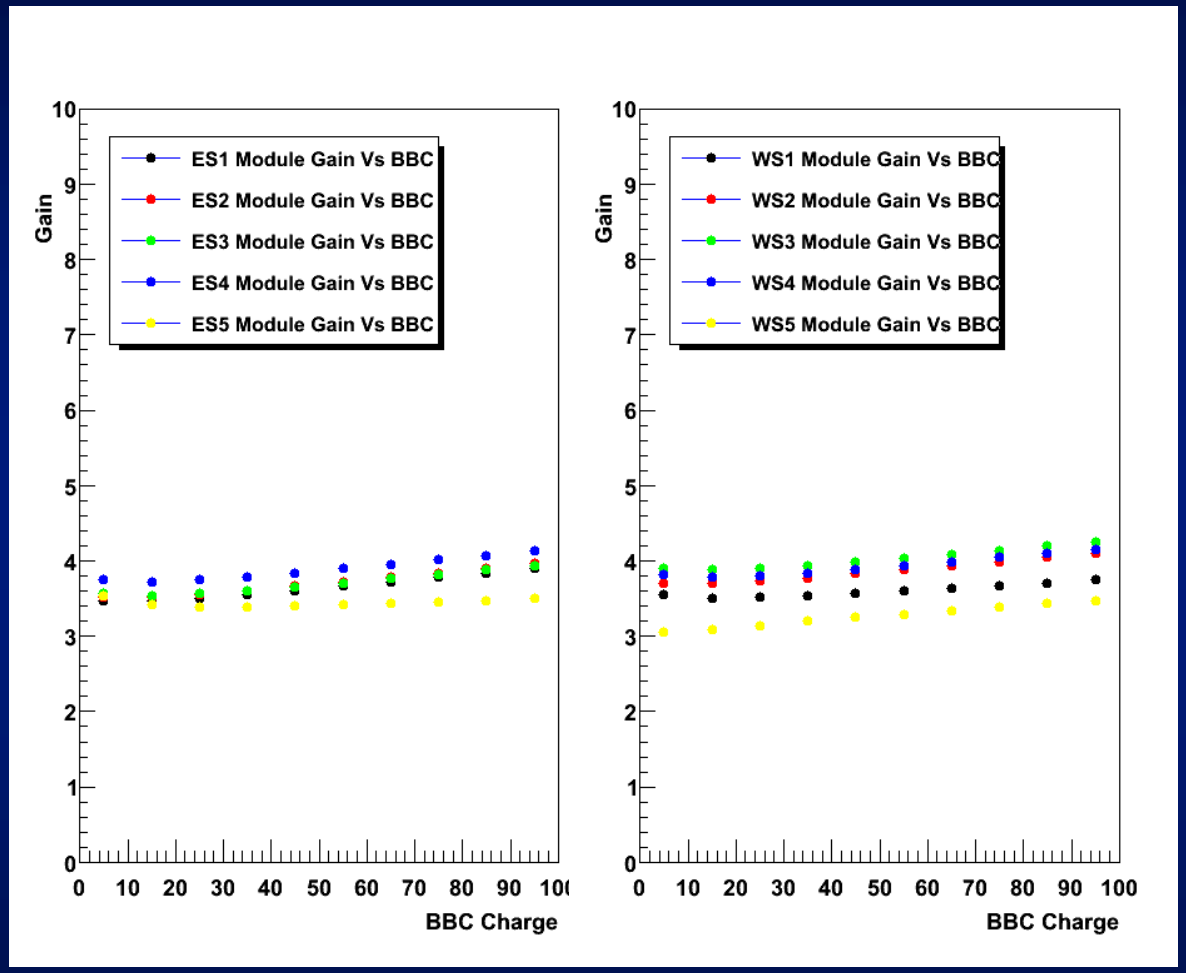
Used as a gain monitor throughout the run

Setting Gains Using Scintillation



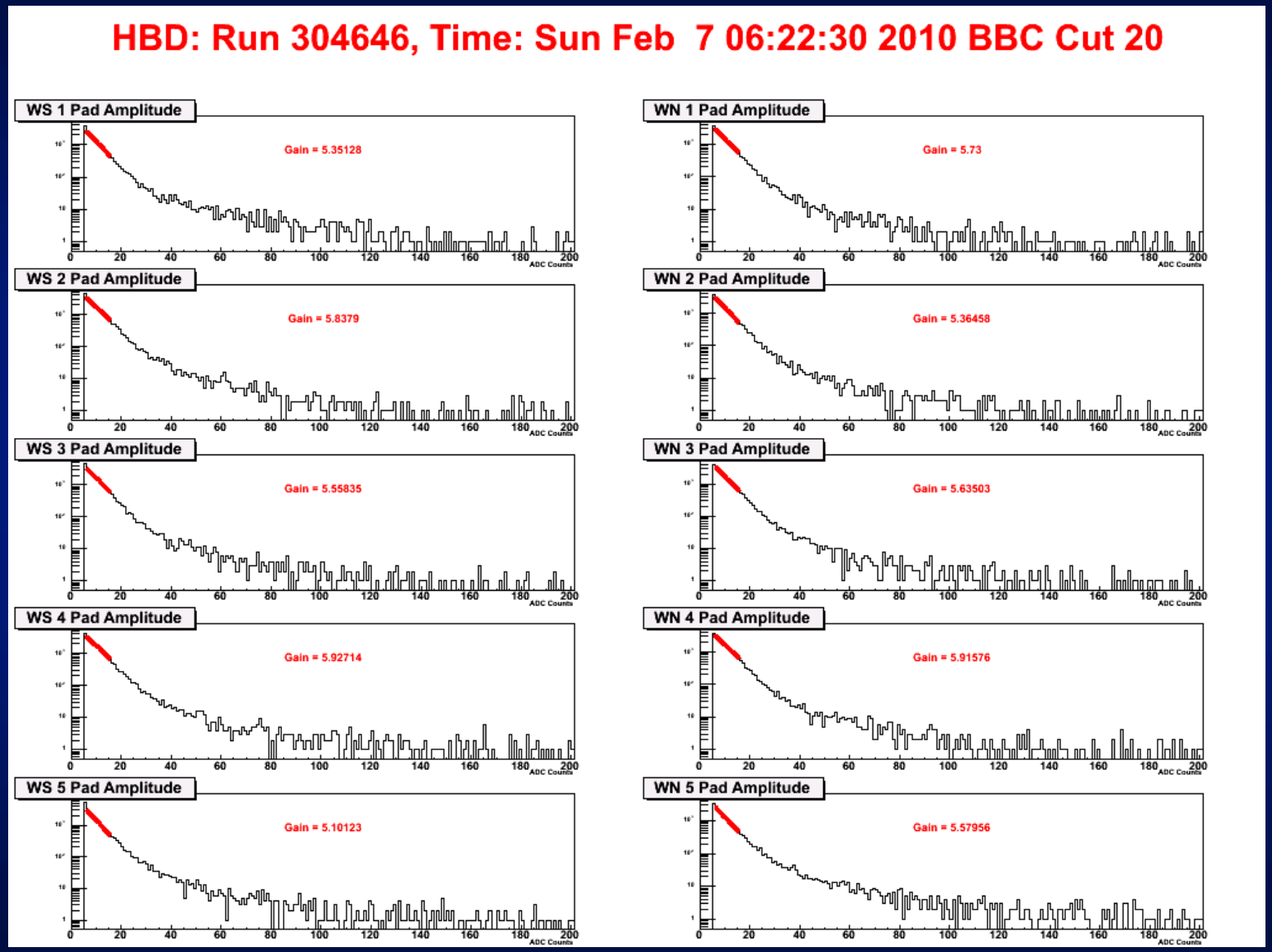


Select on most peripheral events where <Npe> << 1

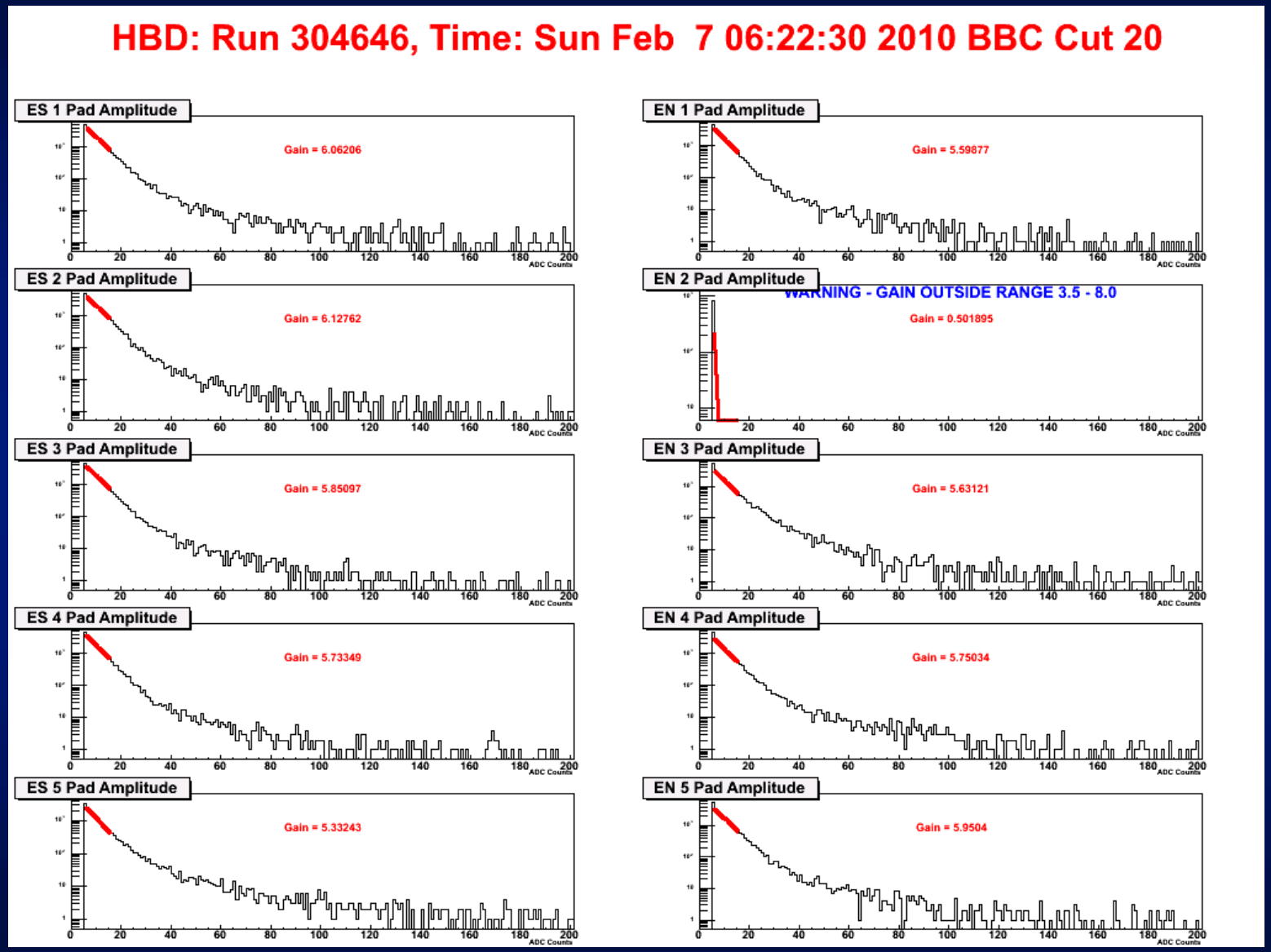


S.Rolnick

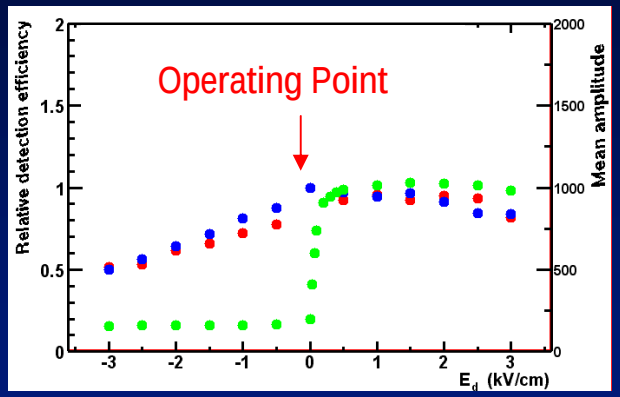
West Gains


HBD: Run 304646, Time: Sun Feb 7 06:22:30 2010 BBC Cut 20
WS 1 Pad Amplitude
Gain = 5.35128
WS 2 Pad Amplitude
Gain = 5.8379
WS 3 Pad Amplitude
Gain = 5.55835
WS 4 Pad Amplitude
Gain = 5.92714
WS 5 Pad Amplitude
Gain = 5.10123
WN 1 Pad Amplitude
Gain = 5.73
WN 2 Pad Amplitude
Gain = 5.36458
WN 3 Pad Amplitude
Gain = 5.63503
WN 4 Pad Amplitude
Gain = 5.91576
WN 5 Pad Amplitude
Gain = 5.57956
ADC Counts

East Gains


HBD: Run 304646, Time: Sun Feb 7 06:22:30 2010 BBC Cut 20
ES 1 Pad Amplitude
Gain = 6.06206
ES 2 Pad Amplitude
Gain = 6.12762
ES 3 Pad Amplitude
Gain = 5.85097
ES 4 Pad Amplitude
Gain = 5.73349
ES 5 Pad Amplitude
Gain = 5.33243
EN 1 Pad Amplitude
Gain = 5.59877
EN 2 Pad Amplitude
WARNING - GAIN OUTSIDE RANGE 3.5 - 8.0
Gain = 0.501895
EN 3 Pad Amplitude
Gain = 5.63121
EN 4 Pad Amplitude
Gain = 5.75034
EN 5 Pad Amplitude
Gain = 5.9504
ADC Counts

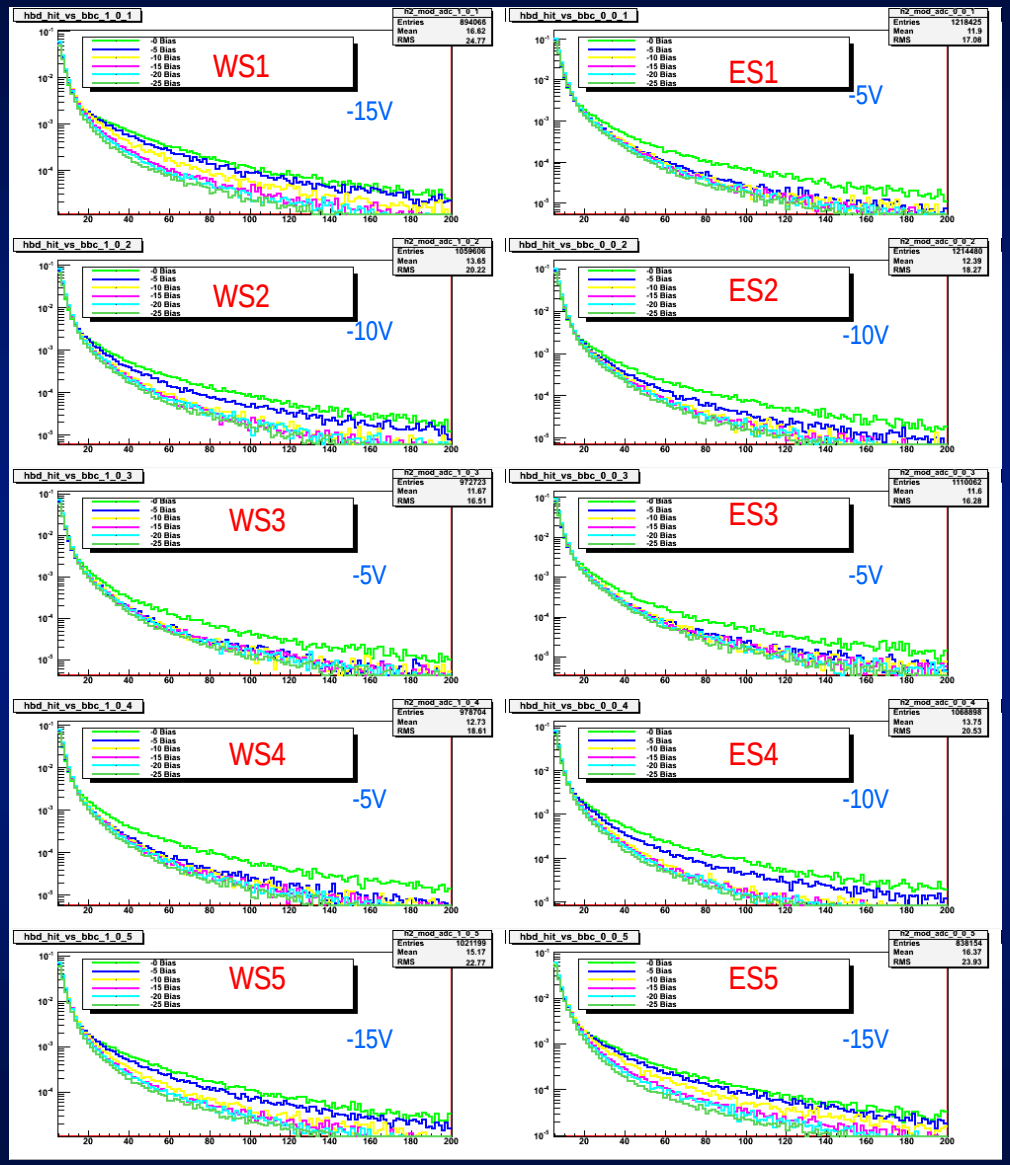
Setting Reverse Bias Voltages (dV Scan)



Need to set reverse bias voltage to optimize pe collection efficiency and minimize hadron response

Requires setting voltage between mesh and top GEM to ~ 5V

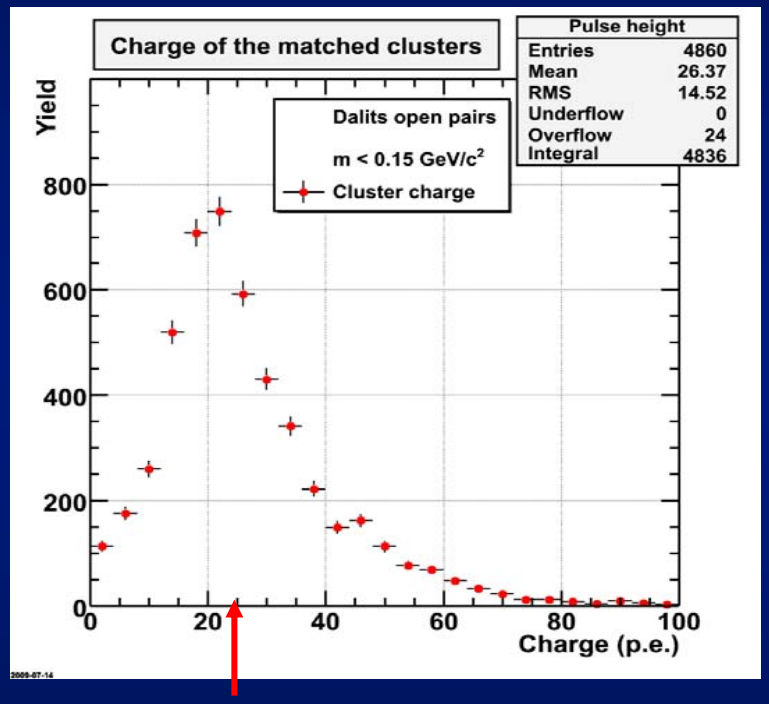
Applied voltage is ~ 4KV, so this requires high precision (~ 0.1%) and good stability in the HV PS

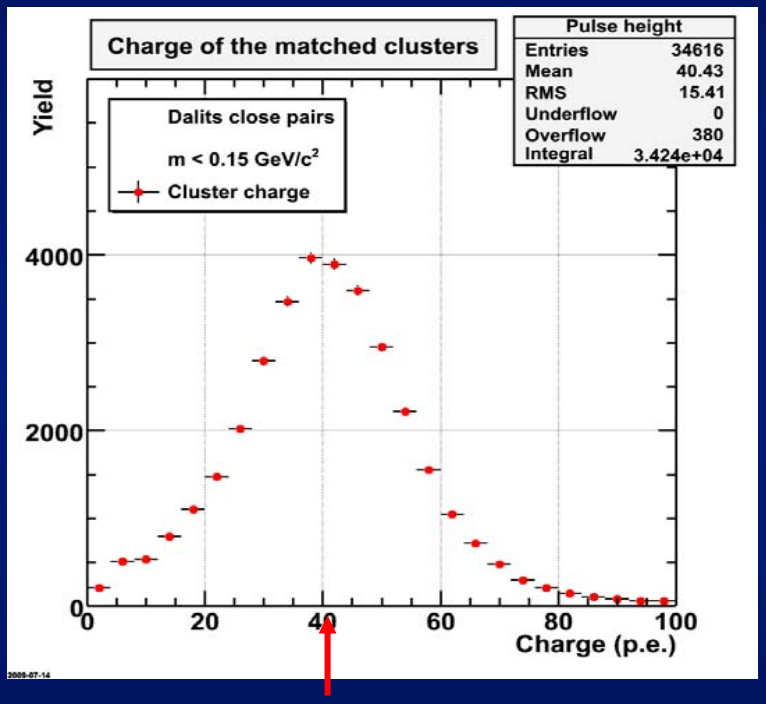


S.Rolnick

Single vs Double Electron Clusters (Run 9)

Use reconstructed Dalitz pairs (M_{ee} < 150 MeV/c) in PHENIX Central Arms
Match to single or double clusters in HBD





~ 22 p.e. per single electron track

~ 40 p.e. per two electron track

Agrees with our expected yield taking into account p.e. collection efficiency and transmission loss in the gas

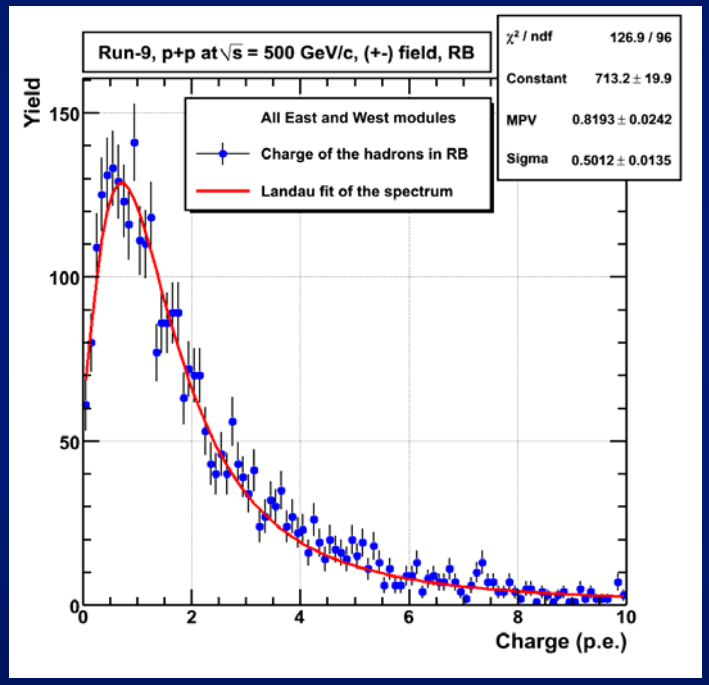
I.Ravinovich

Hadron Rejection (Run 9)

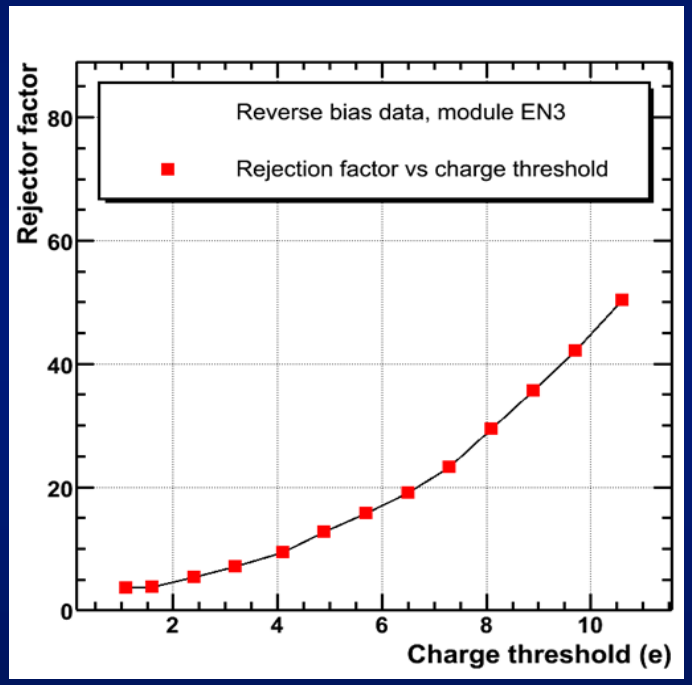
Measured using reconstructed tracks in the PHENIX Central Arm projected to the HBD

Reverse Bias

Hadron Response



Hadron Rejection Factor

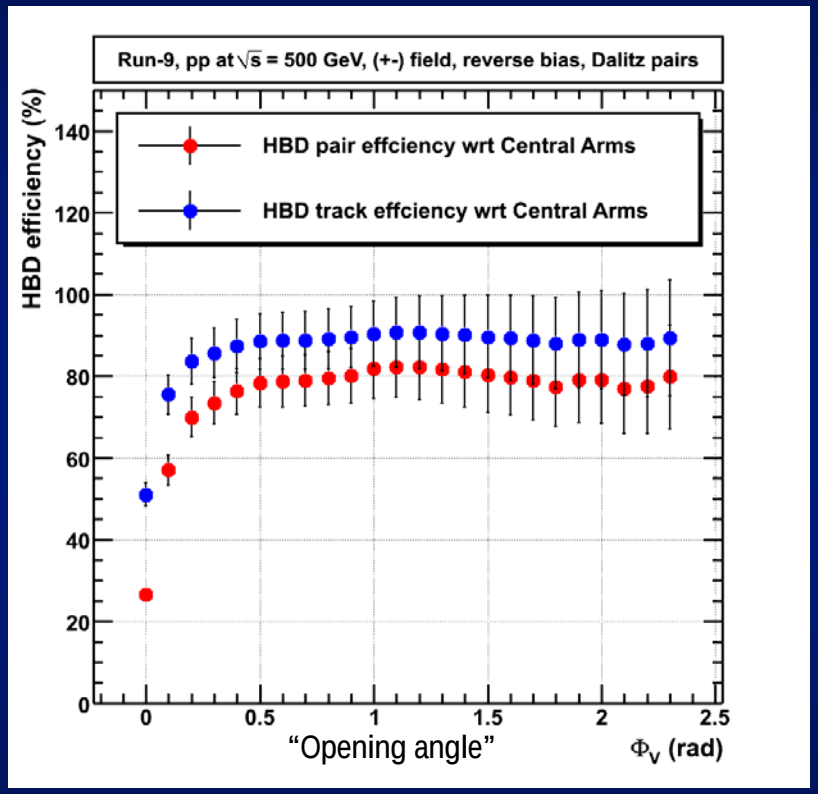


I.Ravinovich

Charge from dE/dx in the small (~ 100 μm) region above the top GEM and in the first transfer gap is very small compared to the Cherenkov signal from electrons

Electron Efficiency (Run 9)

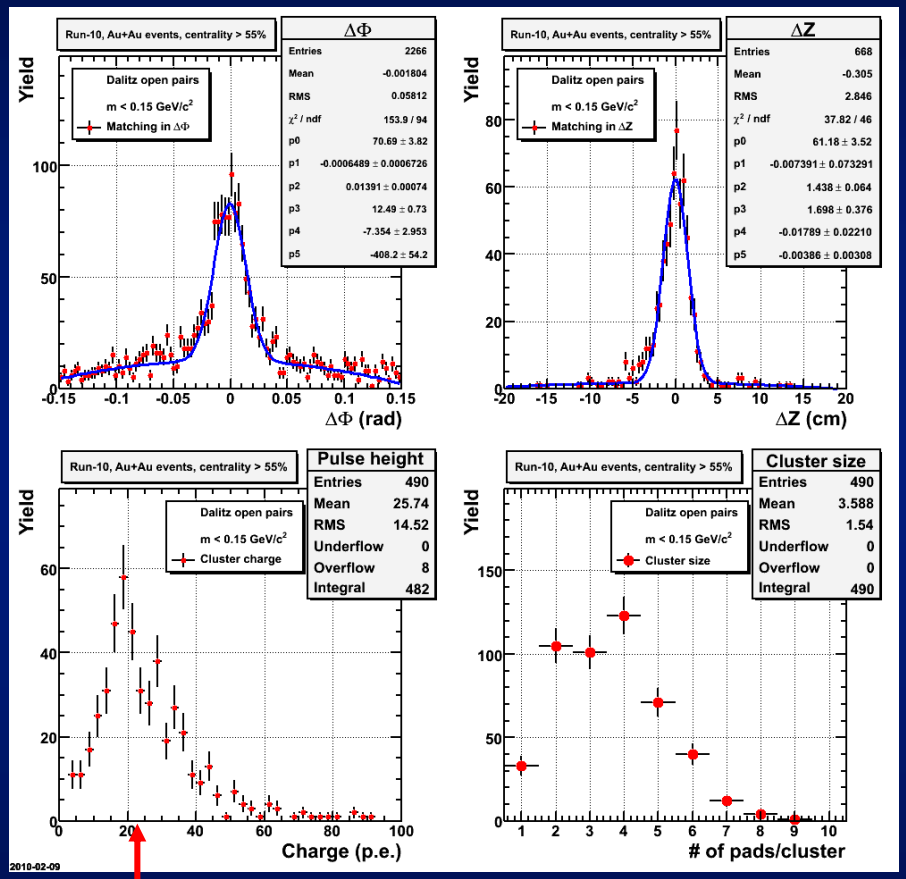
- Measured using well identified electrons in low mass region (0.025 < m < 0.050 GeV) measured in the PHENIX Central Arms and matched with hits in the HBD
- Single electron efficiency > 90%
- Pair efficiency ~ 80%.
- Meets requirements for achieving 90 % rejection of photon conversions and Dalitz decays

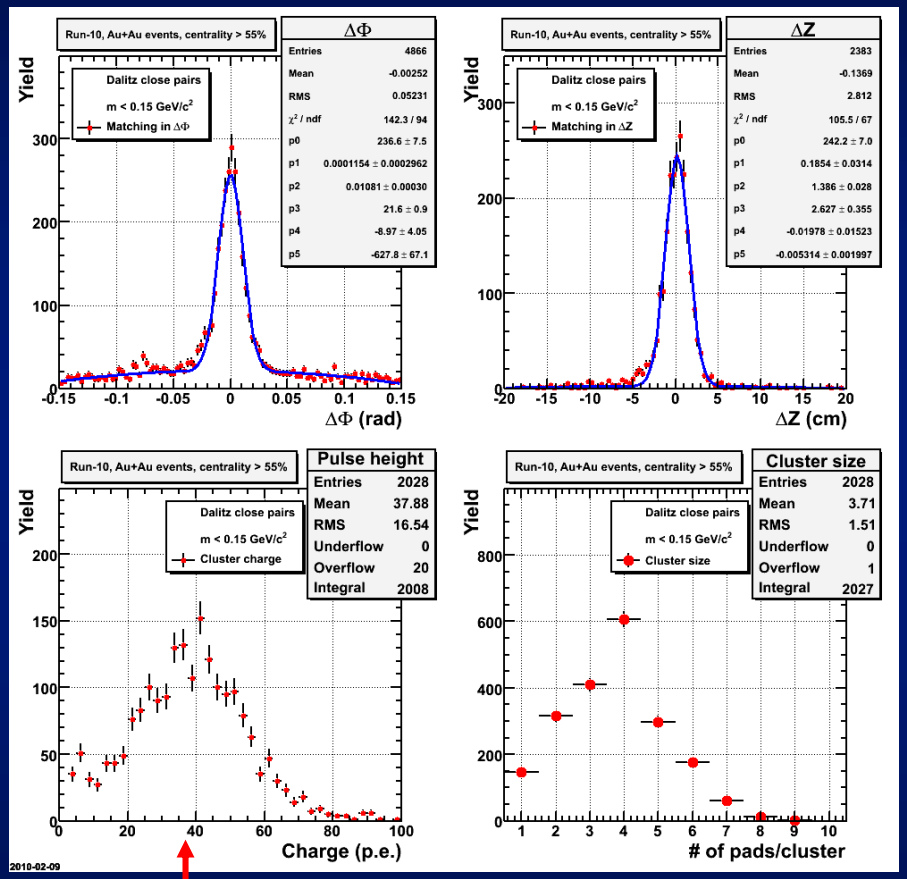


I.Ravinovich

Electron Data from Run 10

Low statistics Need ≥ 200 M peripheral events



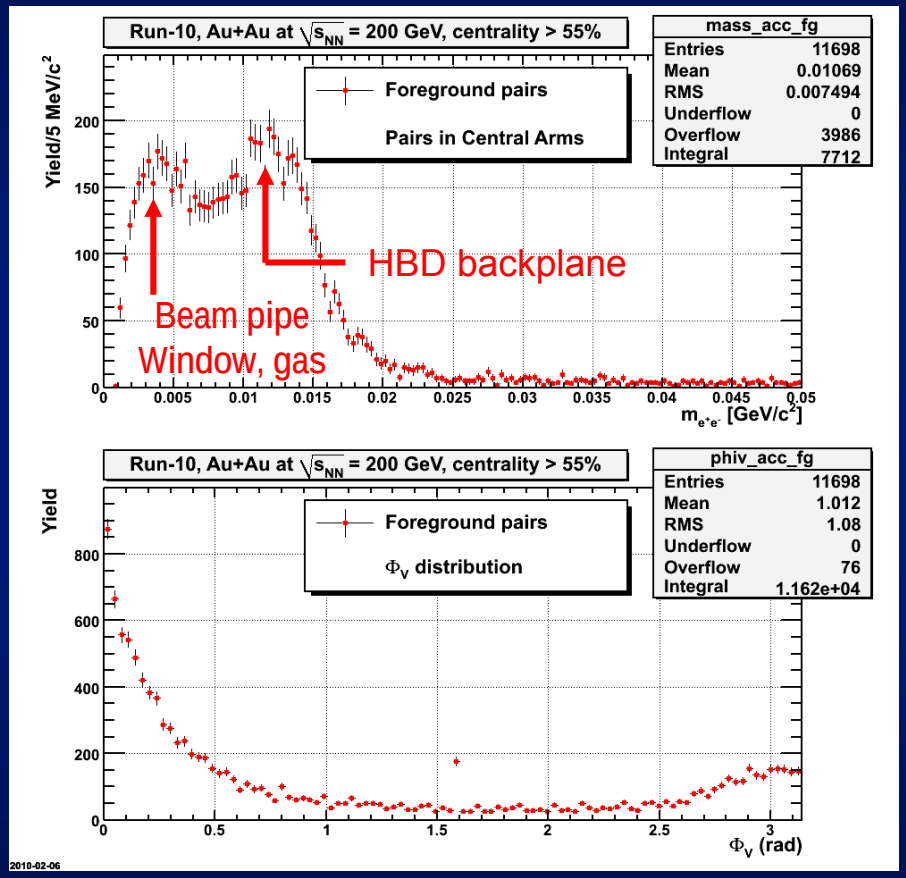


~ 22 p.e. per single electron track ~ 40 p.e. per two electron track

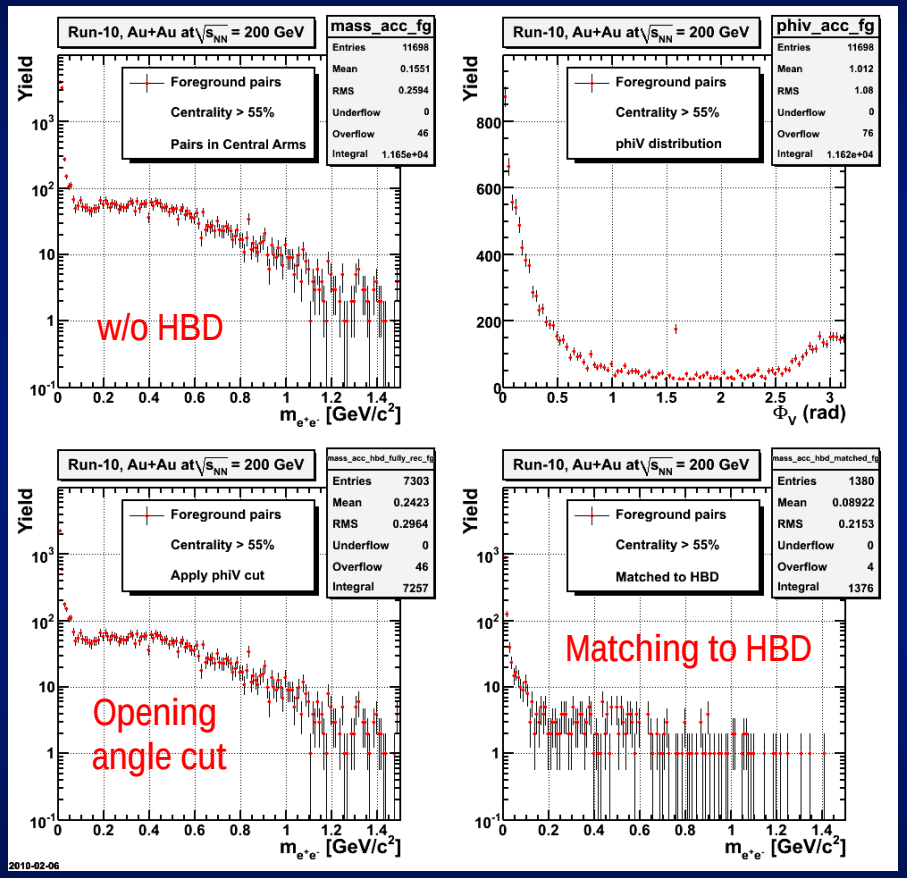
I.Ravinovich

First Look at Low Mass Pairs in Run 10

Conversions



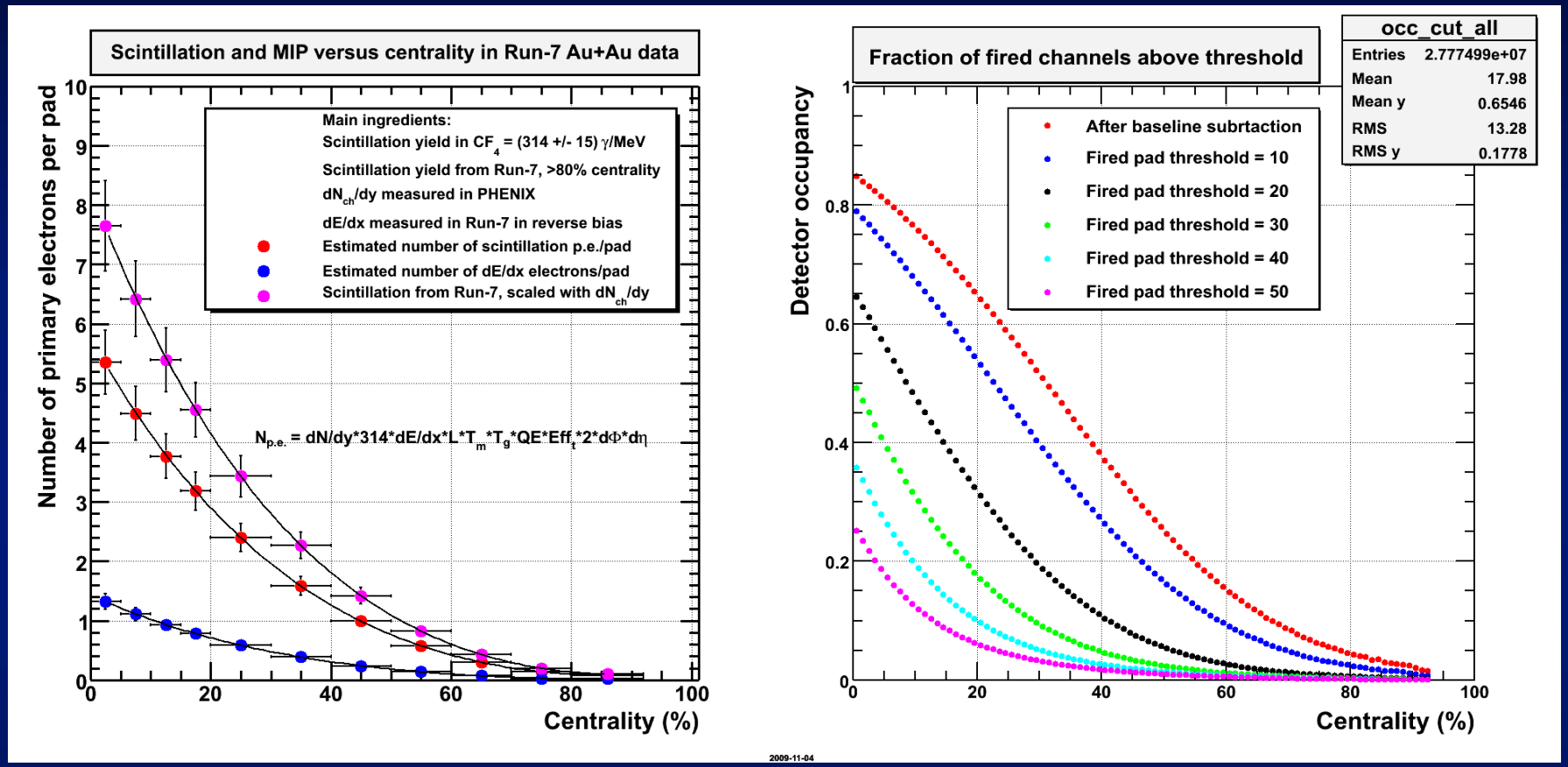
Pair spectrum



Low statistics Need ≥ 200 M peripheral events

I.Ravinovich

Scintillation in Au+Au



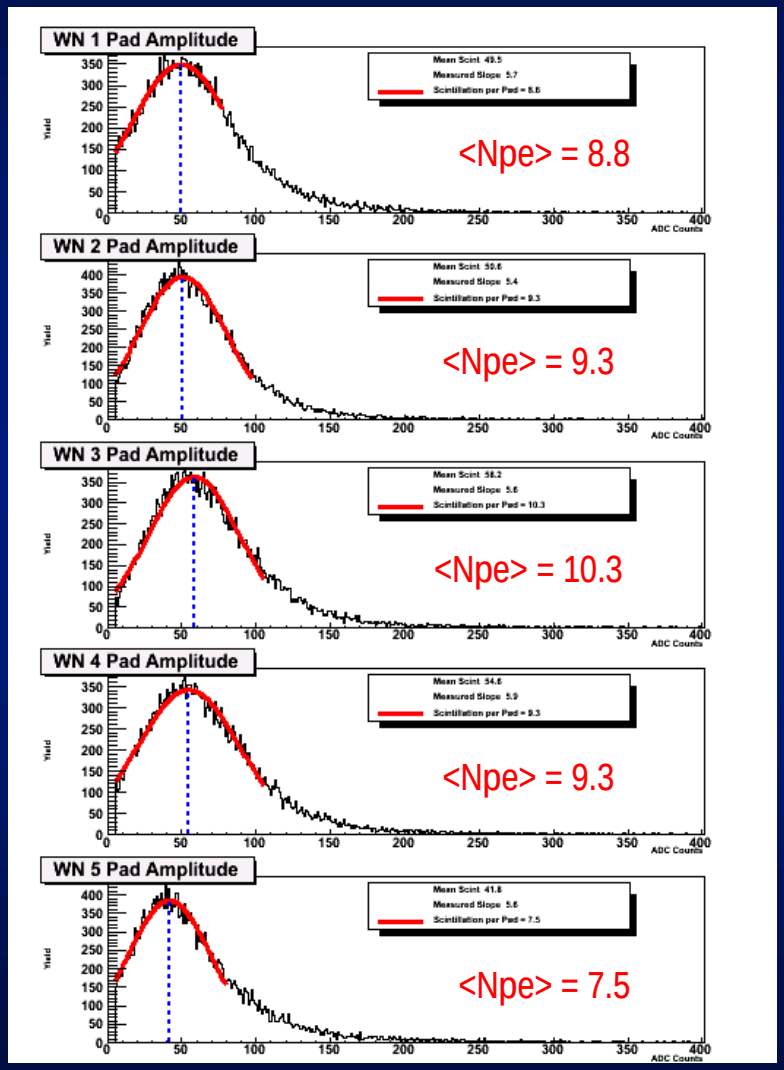
I.Ravinovich

Estimate of Npe per pad due to scintillation in Au-Au using Run 7 data

Occupancy is high in MB → central collisions !

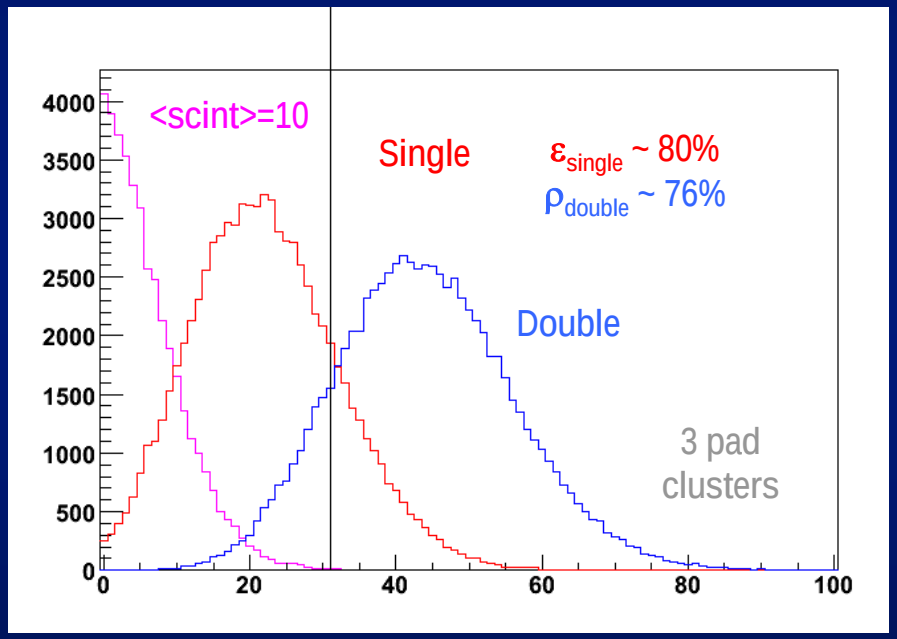
Effect of Scintillation on Single vs Double Separation

<Npe> per pad with high centrality cut



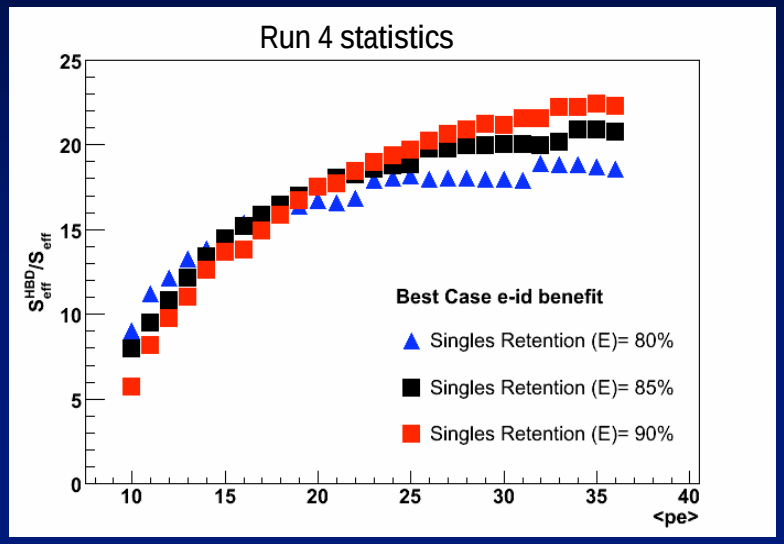
S.Rolnick

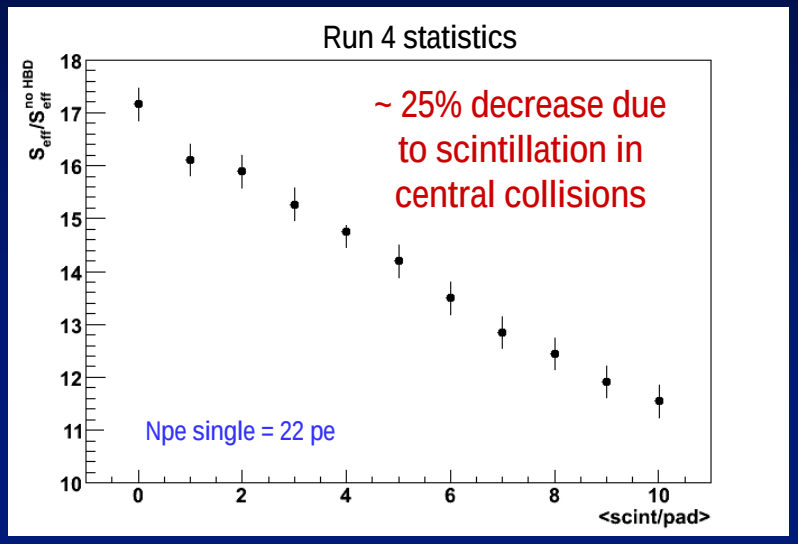
Monte Carlo
Single vs Double Electrons with Scintillation



Z.Citron

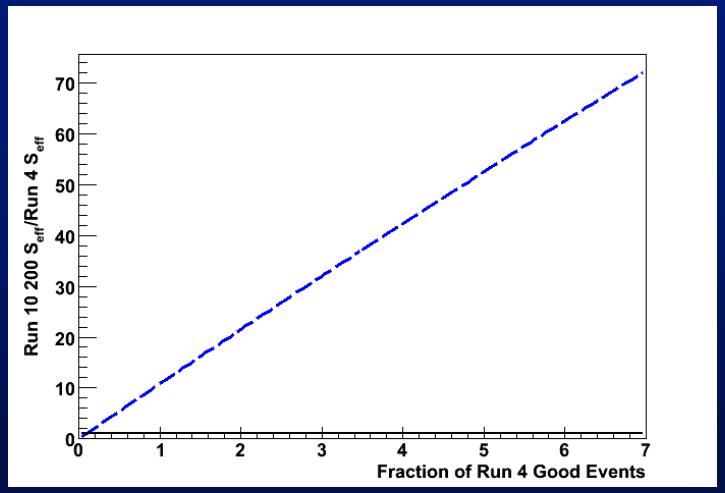
Improvements in S/B with HBD in Run 10





$$\frac{S_{eff}^{HBD}}{S_{eff}} = \frac{1+\frac{BG}{S}(1+c^2BG)}{1+\frac{1}{R}\frac{BG}{S}(1+c^{HBD2}\frac{f\varepsilon}{R}BG)} \times f\varepsilon$$

Z.Citron



Run 4 = 0.8 x 10^9 MB events
Run 7 = 5.4 x 10^9 MB
Run 10 → ~ 6.0 x 10^9 MB
f ~ 7.5

Summary

- The HBD is a first of its kind, very high performance Cherenkov counter that has been very challenging to build an operate.
- The detector performed well in Run 9 in p-p and gave the expected level of performance in terms of p.e. yield, electron efficiency and hadron rejection
- It seems to be performing well again in Run 10 and should give the required level of efficiency and rejection in Au+Au collisions
- Given this level of performance and the added benefit of the HBD in terms of suppressing Dalitz pairs and photon conversions, it should enable a much more sensitive and precise measurement of low mass dilepton pairs in heavy ion collisions at RHIC
- Come back next week for Tom's talk on some of the great physics that we can do now that we have the HBD