Proposed Detector Upgrade for Measuring Low-Mass Lepton Pairs in PHENIX

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CIPANP 2003, NYC

Why measure low-mass lepton pairs?

In heavy ion collisions, low-mass lepton pairs provide a clean signal for studying

- chiral symmetry restoration and in-medium effects on low-mass vector mesons
  - ρ, ω, ϕ
- thermal radiation from the hadron gas
- strangeness production (ϕ)

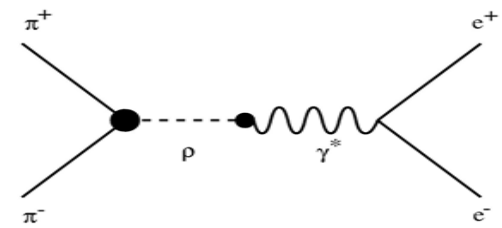
Unique PHENIX potential: can measure the whole dilepton spectrum from the π^0 Dalitz decays up to above the J/ψ.

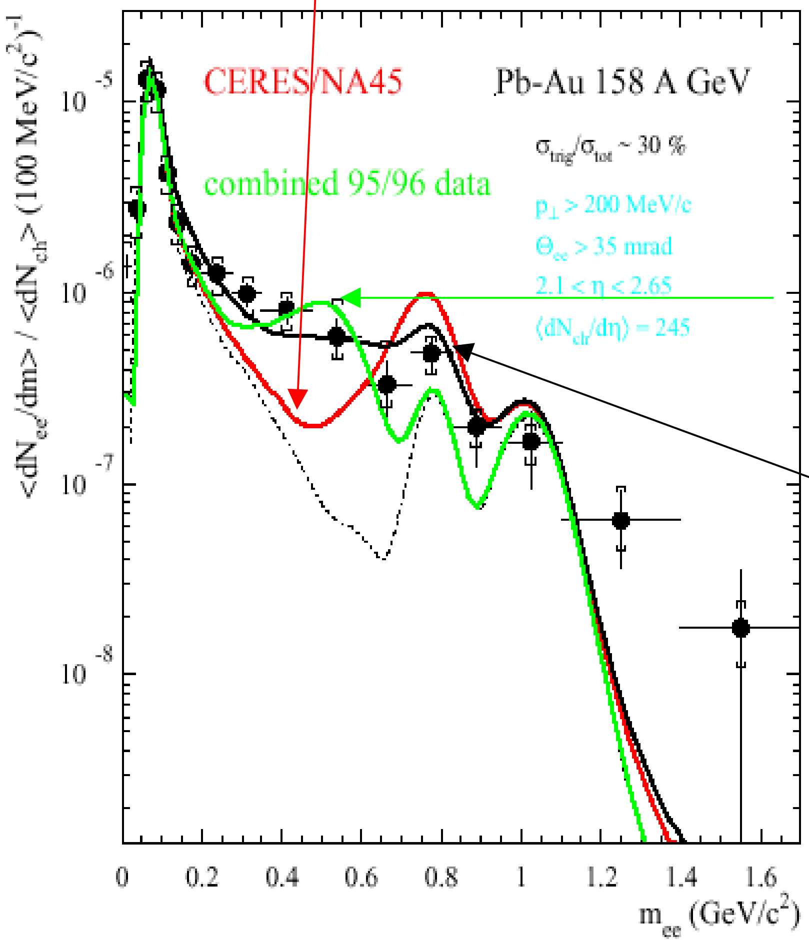
RHIC program would be incomplete without a good measurement of low-mass electron pairs!

CERN Excess in e+e- Spectrum

$\pi^+\pi^- \rightarrow \rho \rightarrow \gamma^* \rightarrow e^+e^-$ **(thermal radiation from hadron gas)**

– **But pion annihilation alone not enough to reproduce the data**





Add in-medium modifications of ρ:

- dropping ρ meson mass **(Brown et al)**

OR

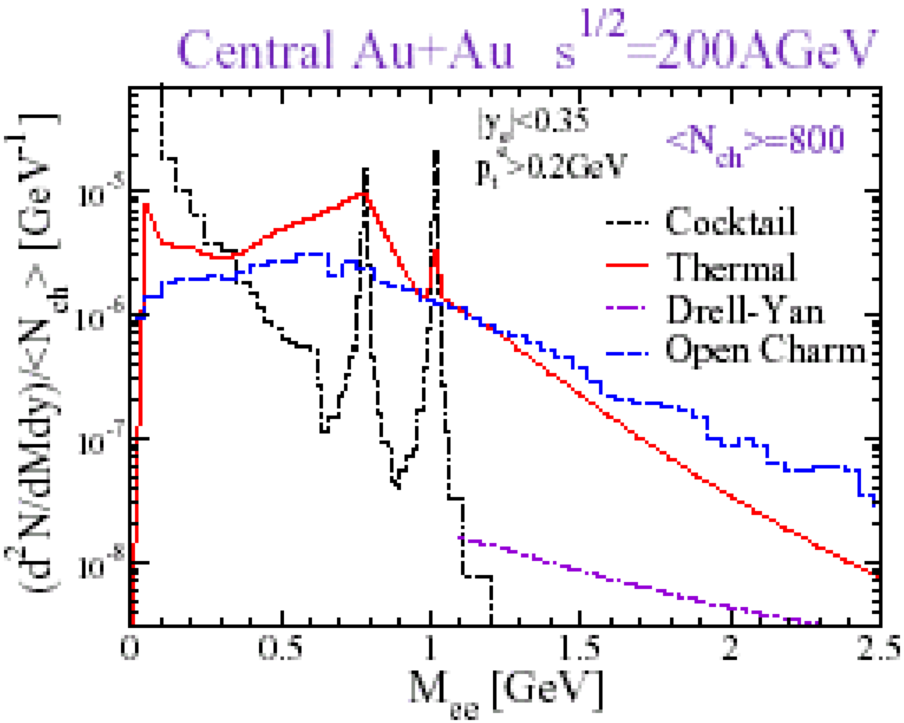
- broadening ρ spectral shape

(Rapp and Wambach)

No excess in pp

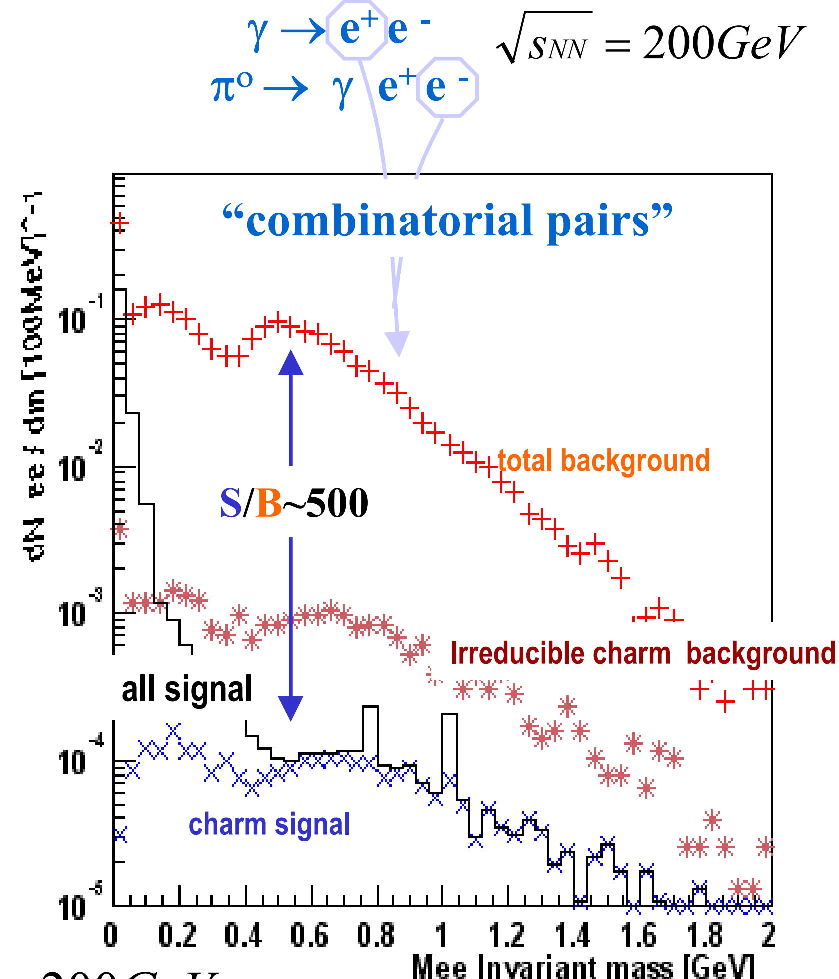
⇨ *this is a nuclear effect!*

Electron pairs @ RHIC from theory . . .



R. Rapp

Invariant mass distribution of electron pairs at RHIC



Simulated electron pair spectrum and combinatorial background in PHENIX

RHIC: estimated 10-20 c-cbar/event @$\sqrt{s_{NN}} = 200GeV$

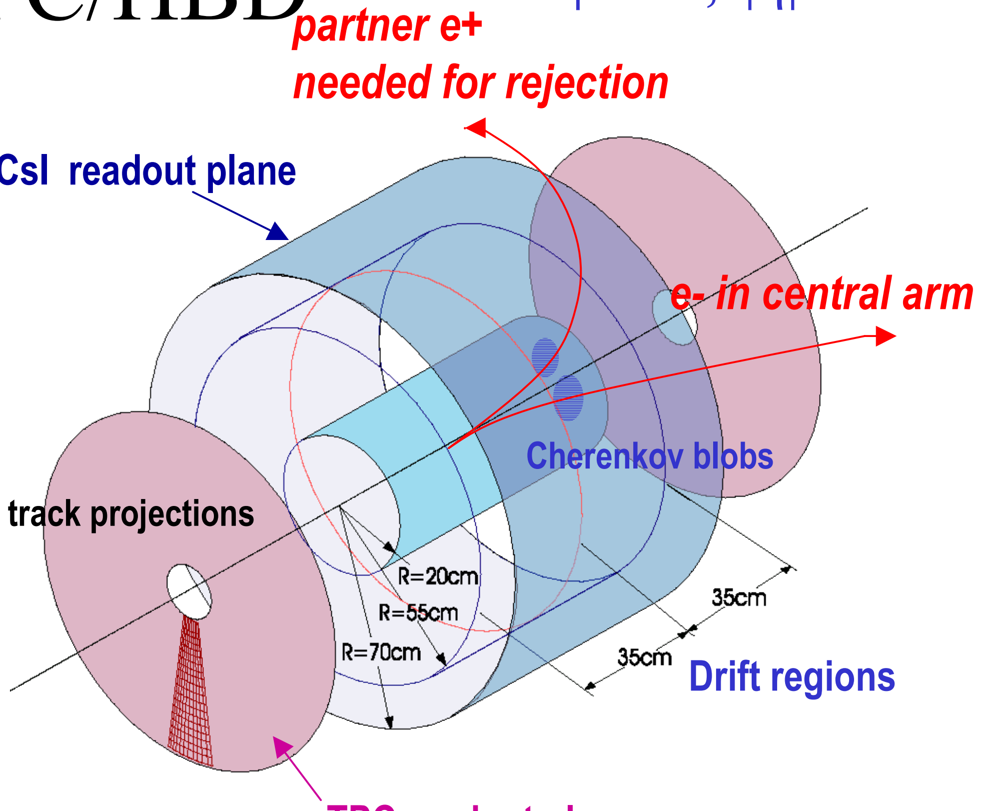
K. Ozawa

How to lower the combinatorial background?

Proposed Upgrade: Hadron Blind Detector (HBD) or combined TPC/HBD

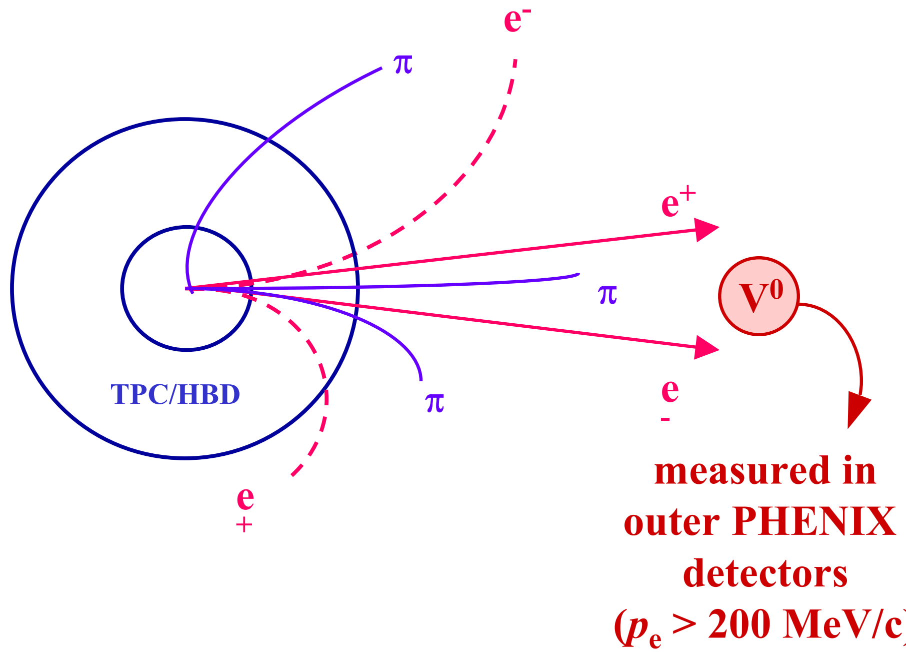
$\Delta\phi = 2\pi, \ |\eta| < 1.0$

- "Hadron Blind Detector": identify electrons by their Cerenkov radiation detected by a photocathode layer
  - minimal signal for other particles
- Could additionally get tracking information from a fast, compact Time Projection Chamber within the HBD radius



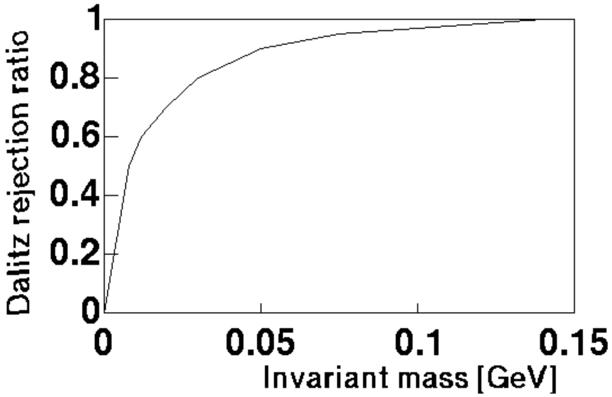
Strategy for Identification and Rejection of Background Electrons

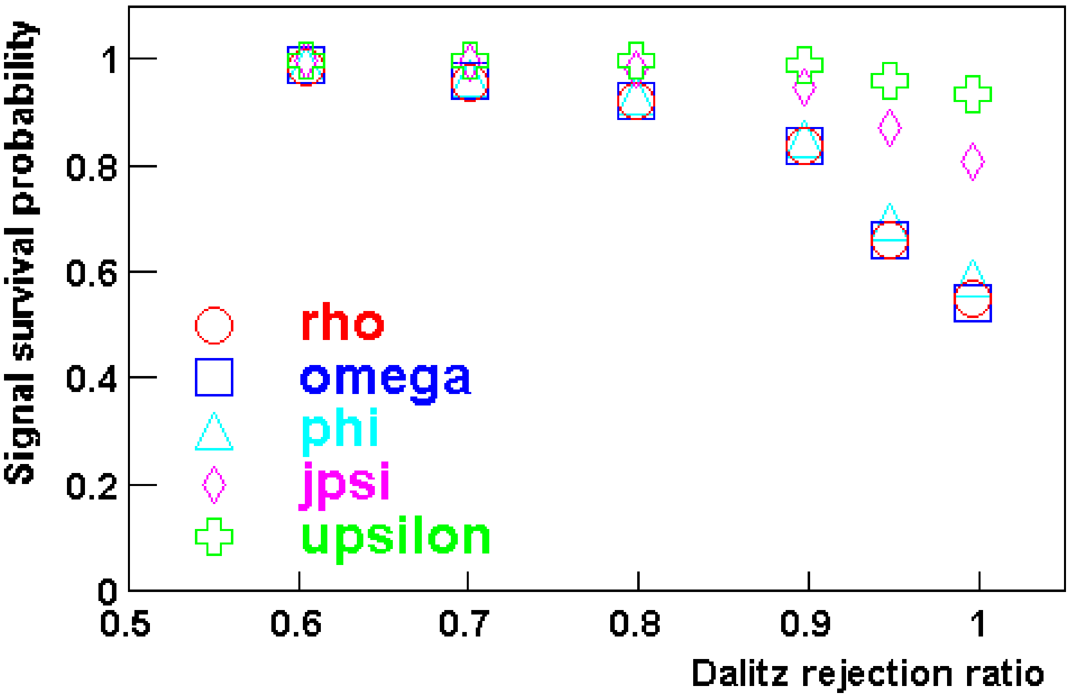
- Run with low inner magnetic field—optimize measurement of low momentum tracks
- Electron ID for signal electrons (vector mesons, low mass pairs) from outer PHENIX detectors
- Electron ID for low momentum electrons (p < 200 MeV/c) from Cerenkov blob on HBD and/or *dE/dx* in TPC
- Measure opening angle and/or reconstruct invariant mass of opposite-sign pairs identified as electrons



Reject pairs which have an opening angle < ~200 mrad and/or reconstruct to an invariant mass < ~130 MeV/c^2 ($\varepsilon_e > 90\%$, $\pi_{rej} > 200:1$ for particles outside main PHENIX acceptance)

Dalitz Rejection and Survival Probability of Vector Mesons





Survival probability of ρ,ω,ϕ is >~85% for Dalitz rejection ratio of 90%.

K. Ozawa

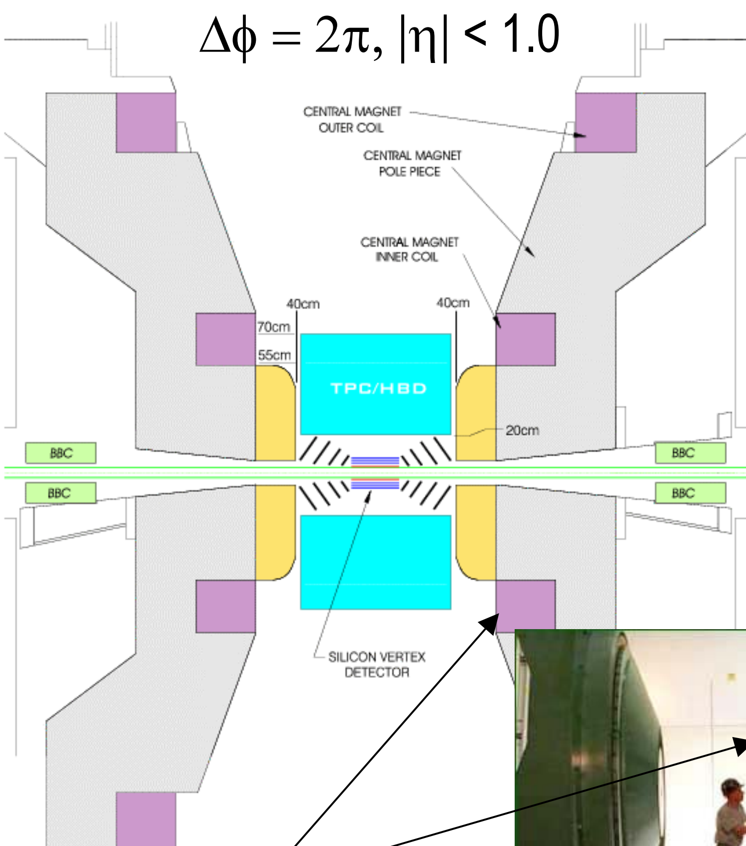
Institutions Involved, Related R&D

- HBD
  - BNL, Weizmann Institute of Science, SUNY Stony Brook, University of Tokyo
- TPC
  - BNL (Physics, Instrumentation), University of Tokyo, Florida Institute of Technology
- Electronics
  - BNL Instrumentation, Columbia University (Nevis)

Related R&D Efforts

- STAR (joint effort)
- LEGS TPC
- TPC with GEM readout for NLC/TESLA

The new inner field coil and the TPC: Enhanced tracking in PHENIX



Inner Coil can create a zero-field integral or enhanced-field region inside the Central Magnet

The TPC:

Not just for Dalitz rejection! Also important in future high-p_T, jet, and charm measurements

- PHENIX currently has no tracking inside the magnetic field
  - –Decay/conversion backgrounds limit the high-p_T charged particle measurements
  - –Tracking in the TPC in the magnetic field will eliminate background
- inner coil can also enhance outer field: improved momentum resolution at high p_T
- TPC alone can provide a good momentum measurement in large solid angle ⇨ Jets measurement
- help identify displaced vertices from charm in conjunction with Si upgrade
- particle ID from *dE/dx*

R & D Issues

Performance of GEM detectors

- Stability, gain uniformity, aging
- Optimize spatial resolution
- Multi-GEM configurations

Gas properties (CF_4, CH_4, mixtures…)

- Drift velocities, drift lengths, *dE/dx*, diffusion parameters
- Ion feedback, scintillations, optical transmission into the VUV

TPC detector component design

- Readout plane
- Field cage
- Understand **E** x **B** effects for drifting charge in non-uniform magnetic field
- Understand space charge effects

HBD Hardware

- Detector configuration
- Aging of CsI
- Response to electrons and MIPs

Simulations

- More realistic Monte Carlo with full detector response
- Detector granularity
- Various magnetic field configurations

Electronics

Infrastructure issues

- Compatibility with silicon upgrade

Detector Readout: TPC

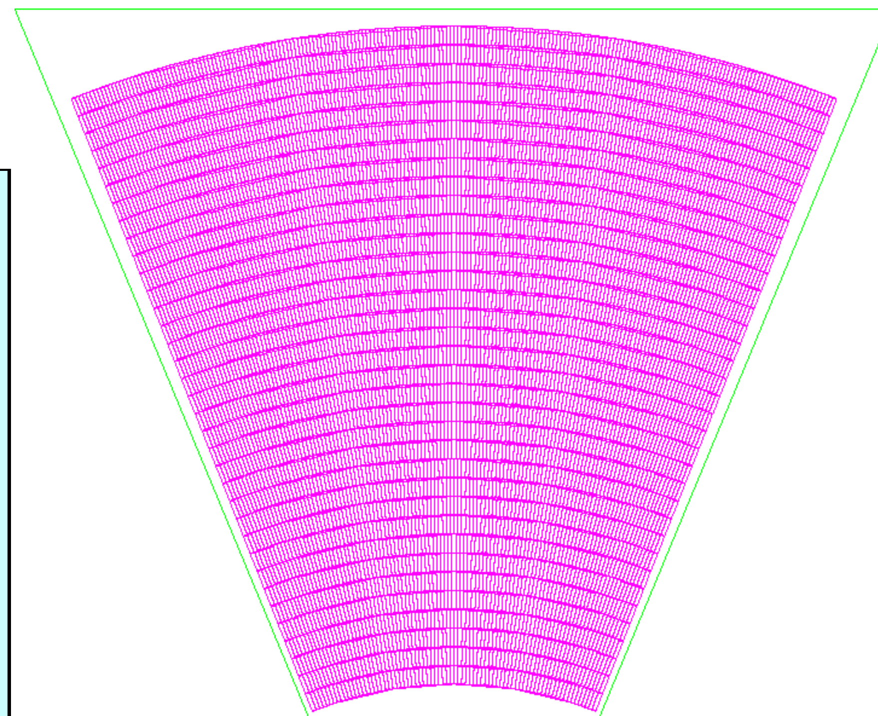
Micropattern readout detector:

Gas Electron Multiplier (GEM)

– Use for both TPC and HBD

Axial drift in TPC: readout on two endplanes

35 TPC pad rows



One octant of TPC

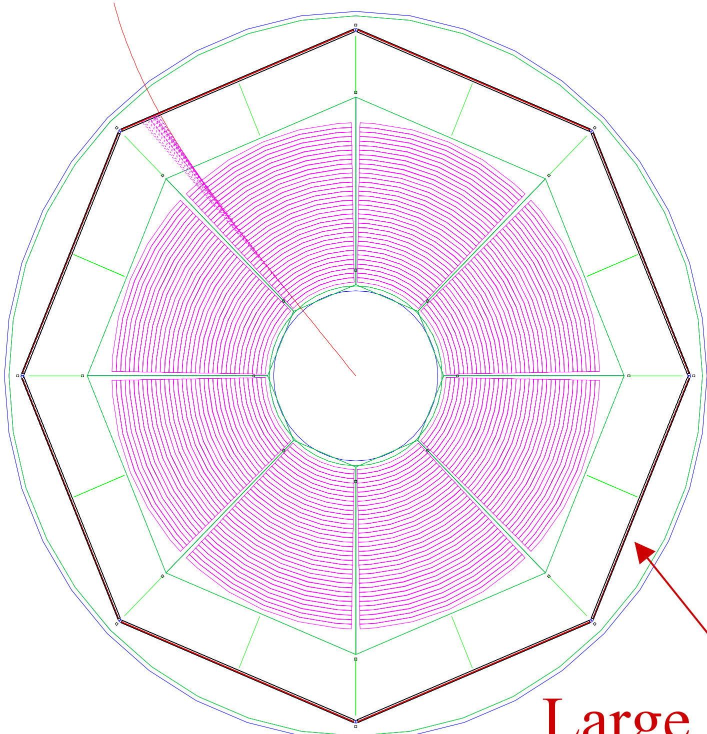
TPC Readout Features

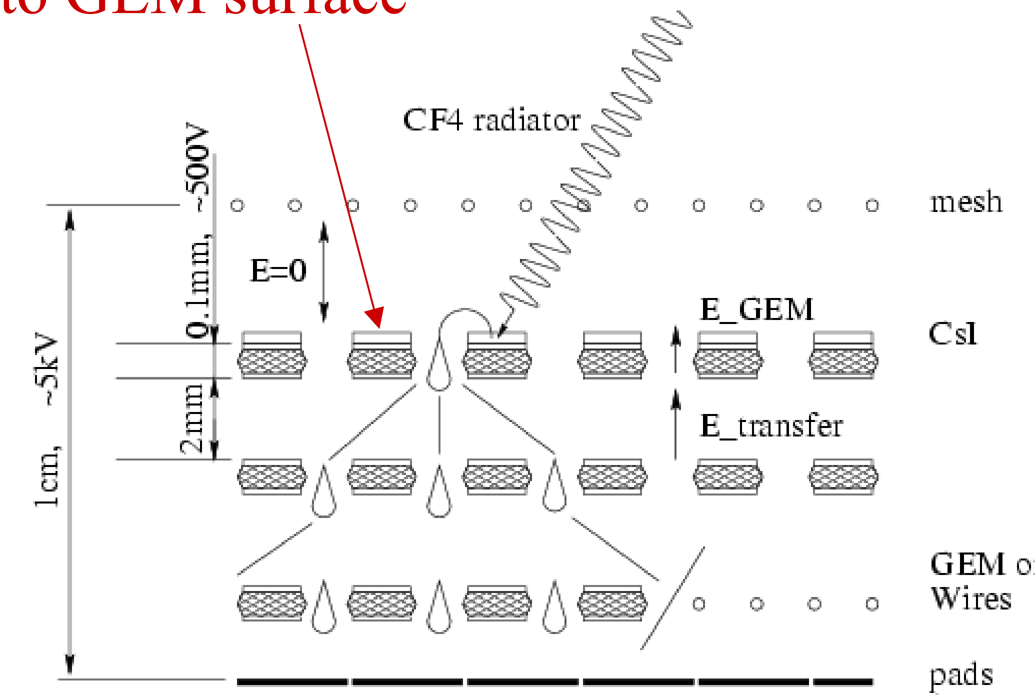
Number of pads	80k
Pad size	2x10 mm^2
Drift time	4 μsec
Sampling rate	50 MHz
Sampling resolution	2 mm(20 ns), 8 bits
Number of samples	200
Unsuppressed data volume	16 MB
Suppressed data volume (1/20)	800 kB
Readout time	40 μsec
Data transmission rate	160 Gbit/sec
Power per channel	100 mW
Total power	8 kW

Detector Readout: HBD

100 MeV electron producing a Cerenkov blob on the HBD image plane

CsI photocathode deposited directly onto GEM surface





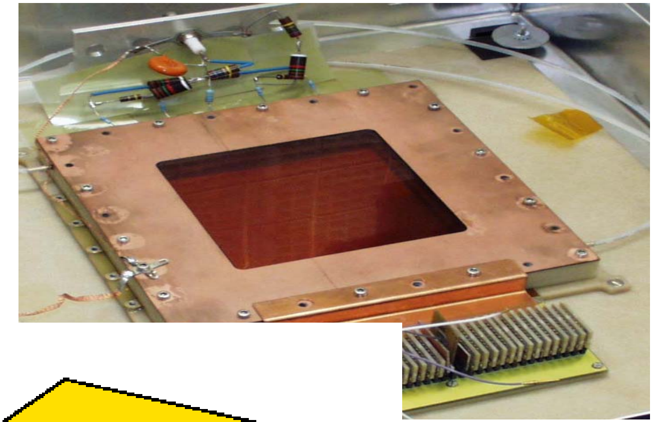
A. Breskin

CF_4 for Cerenkov radiator and detector gas

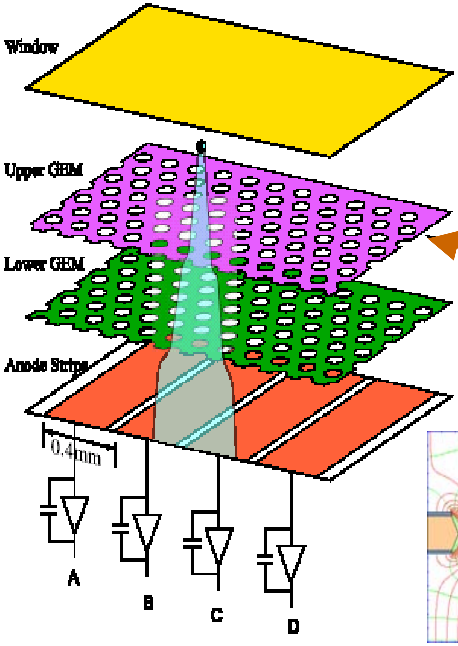
Large area photocathode: CsI

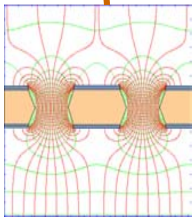
HBD/TPC R&D at BNL

GEM prototype assembly (BNL)

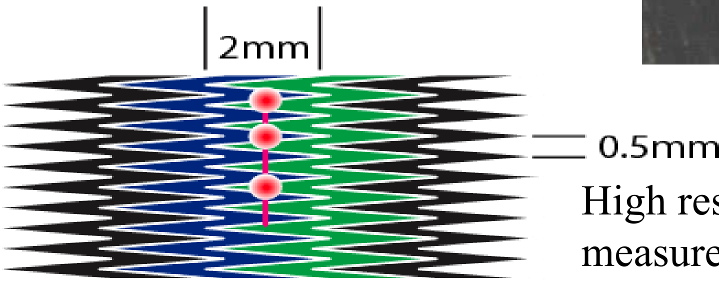


VUV Spectrometer for gas studies





Fine "Zigzag" pattern



GEM read-out

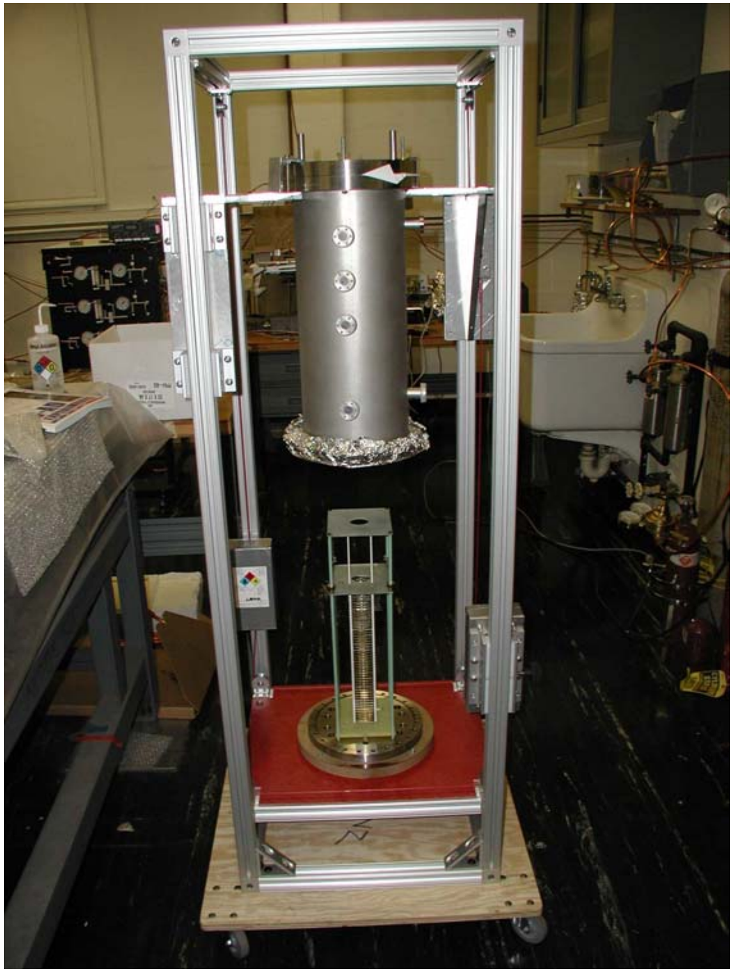
High resolution position measurements by zigzag cathode pad

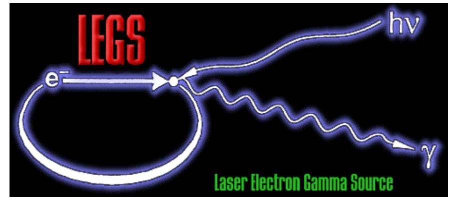
Overall position error: 93µm rms

Including ~ 100µm fwhm x-ray p.e. range, 100µm beam width, alignment errors

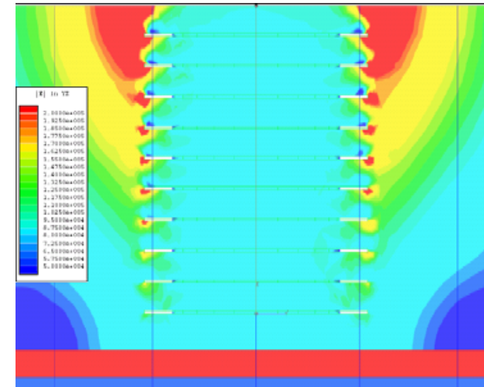
TPC Test Drift Cell (BNL)

C. Thorn



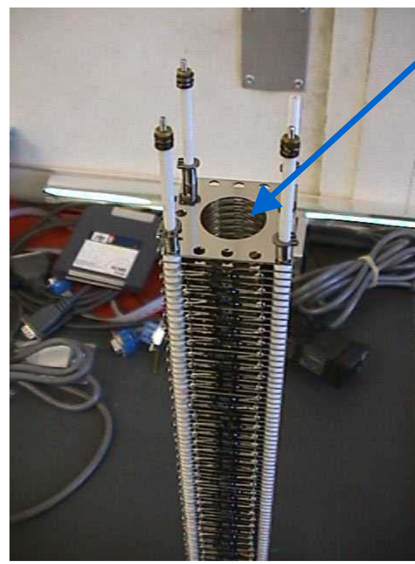


Joint R&D with LEGS



E-Field calculation

Drift Stack



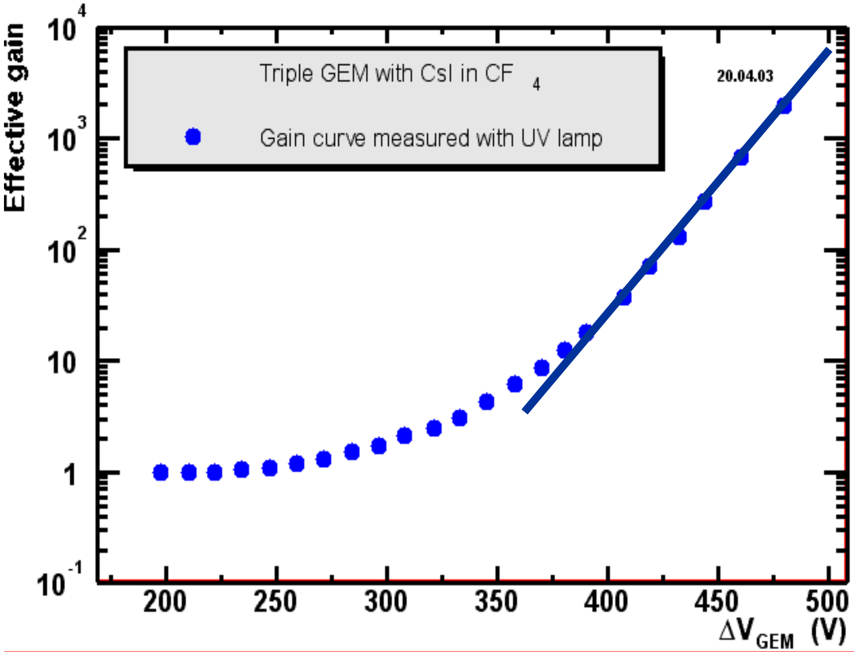
Will be used to study

- Drift velocities
- Drift lengths
- Diffusion parameters
- Energy loss (*dE/dx*)
- Impurities
- Readout structures
- Field cage design

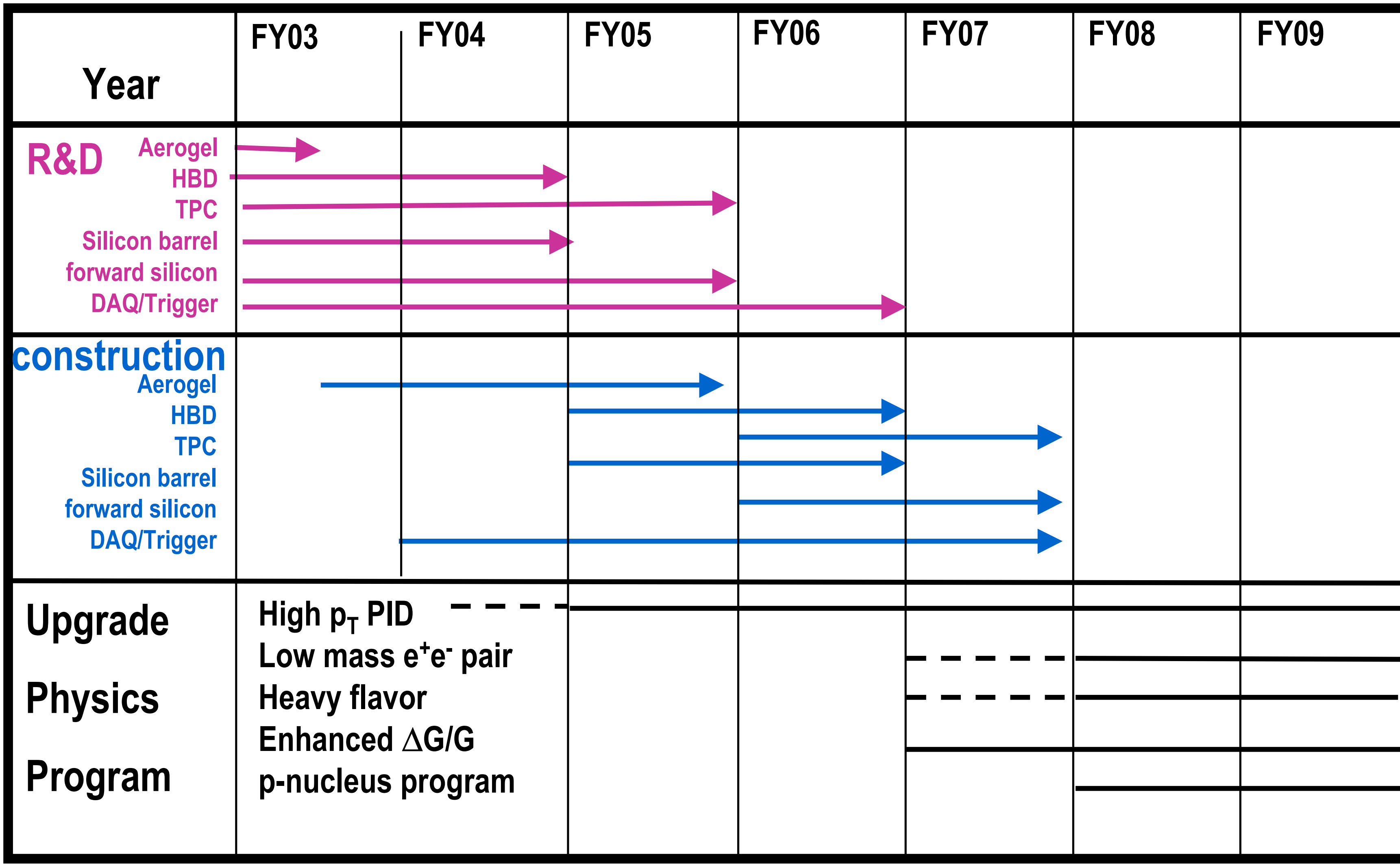
HBD/TPC R&D at Weizmann Institute

HBD test setup and GEM + CsI layout

- Large gain by triple GEM with CsI in CF_4 gas has been observed



Time Line for PHENIX Upgrades



Conclusions

- The measurement of low-mass lepton pairs requires excellent rejection of Dalitz pairs and conversions to reduce the combinatorial background.
- Novel detectors to reduce this background have been proposed consisting of either a hadron-blind detector (HBD) or combined HBD/TPC.
- Collaborative R&D is ongoing.
- The prospects look good for investigating the low-mass dilepton spectrum at PHENIX.

Additional Slides

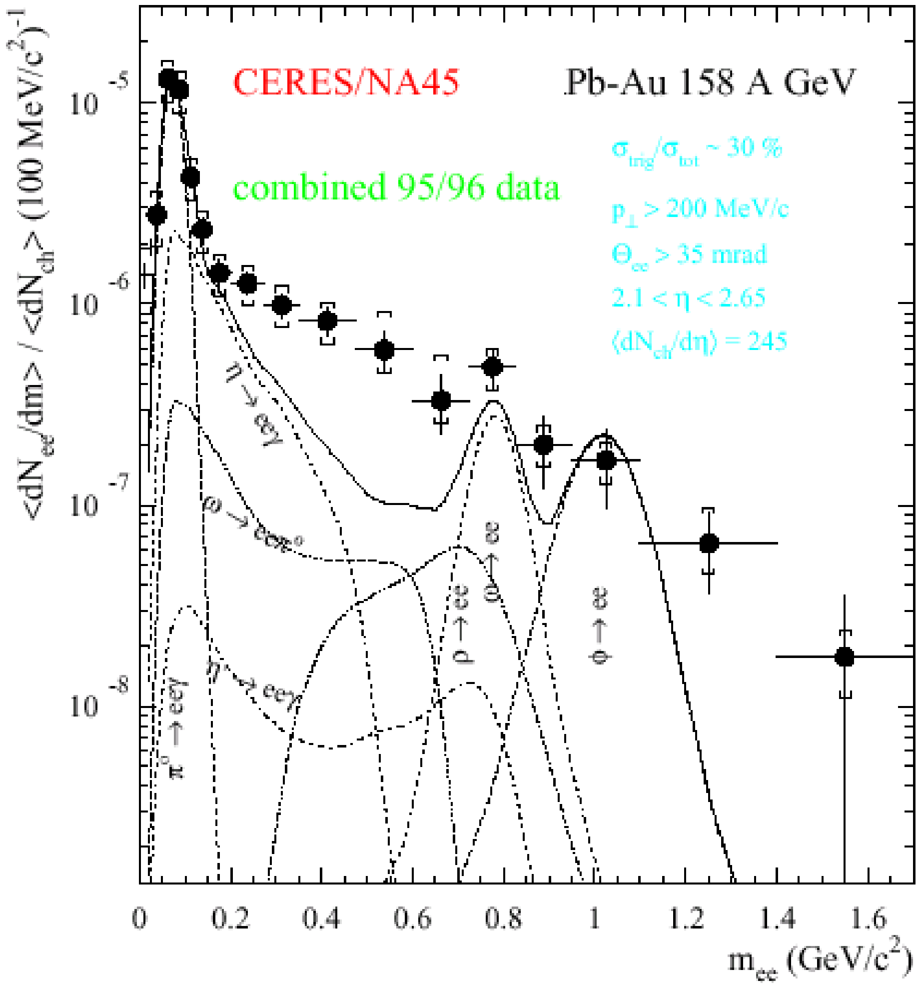
R&D Budget Request

Category	Description	FY03 ($K)	FY04($K)	FY05($K)
Salaries	Post Doc	45	45	45
(incl. fringe)	Electrical Engineer (1.0-1.25 FTE)	100	125	125
	Electrical Tech (0.25 FTE)	20	20	20
	Mechanical Engineer (0.25 FTE)	25	25	25
	Mechanical Designer (0.25 FTE)	20	20	20
	Mechanical Tech (0.25 FTE)	20	20	20
Supplies	Lab equipment	30	20	15
Electronics	ASIC fabrication	30	60	75
	Test equipment	15	25	15
Total		**305**	**360**	**360**
Total (incl 40% overhead)		**427**	**504**	**504**

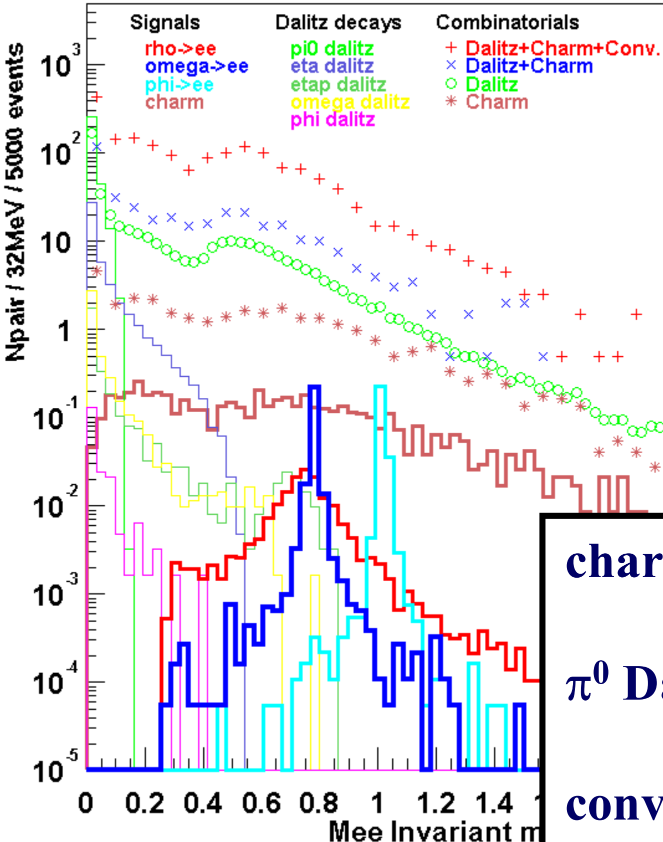
CERES/NA45

Systematic study of low-mass dileptons by the CERES experiment:

- p-Be, p-Au at 450 GeV
- S-Au at 200 A GeV
- Pb-Au at 158 and 40 A GeV



More on Background



Au-Au central $(dN/dy)_{\pi 0} = 350$

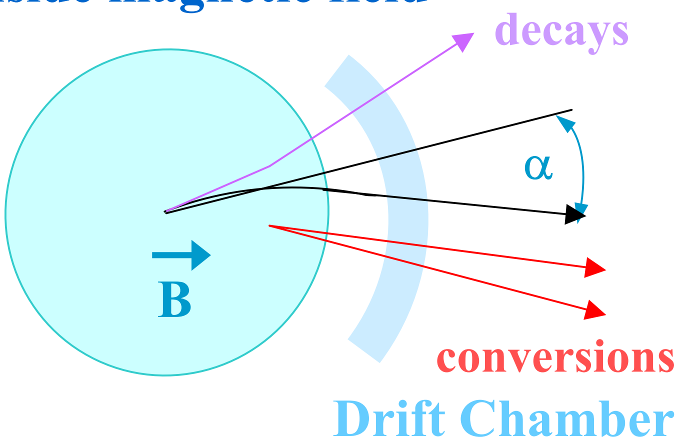
Effective p_T cut of 200 MeV/c

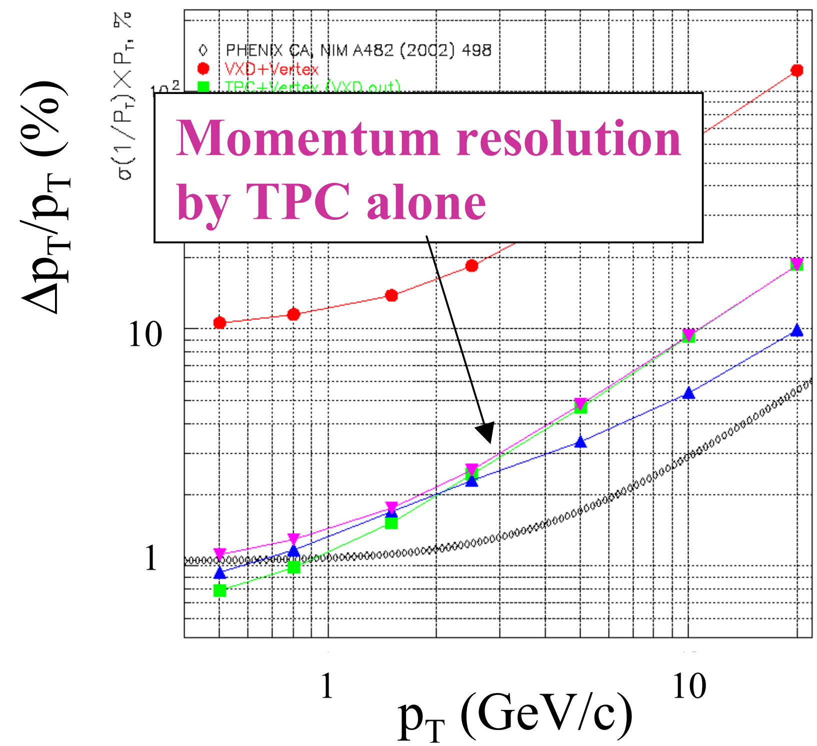
	dN/dy (at HBD)	dN/dy (central arm)	dN/dy (after rej.)
charm	0.68	~0.6	~ 0.6
π^0 Dalitz	8.4	1.1	0.1
conv. $(X/X_0 = 1\%)$	12.0	1.6	0.16
conv. $(X/X_0 = 4\%)$	48	6.4	0.64

Assuming a (feasible) 90% rejection of Dalitz and conv. tracks, open charm is then the dominant source of background and it will limit the quality of the measurement (for central collisions).

High p_T with TPC

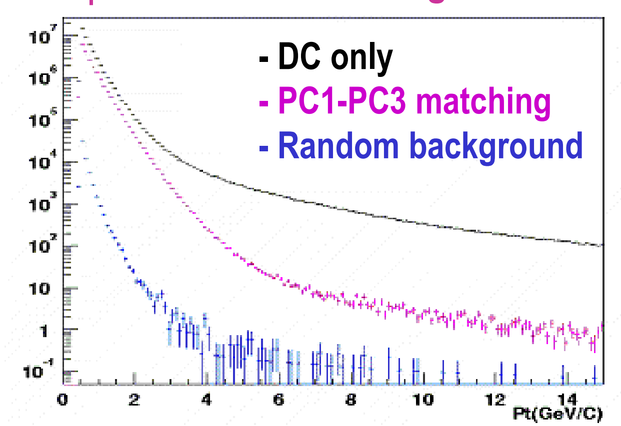
PHENIX presently has no tracking inside magnetic field → **Tracking in the TPC in the magnetic field will eliminate background**





Decay and conversion background limits the high-p_T charged particle measurements

P_T distribution of charged tracks



TPC alone can provide a good momentum measurement over large solid angle → Jets measurement

Gas Studies

Gas requirements

Use **single** gas as

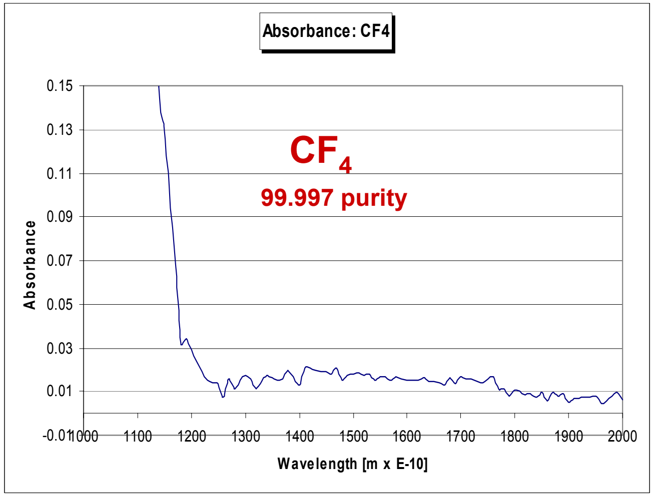
- TPC drift gas
- HBD radiator gas
- operating gas for readout detector
  - must be fast, VUV transparent, work well in readout detector:

CH_4, CF_4,…

Currently studying:

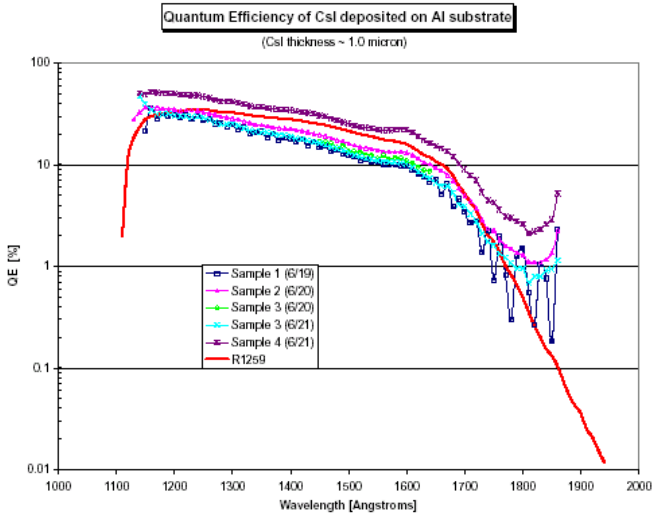
- Drift velocity, diffusion, dE/dx
- Gas scintillation and timing
- Different gas mixtures

Absorbance of CF_4



B. Azmoun

Quantum efficiency of CsI

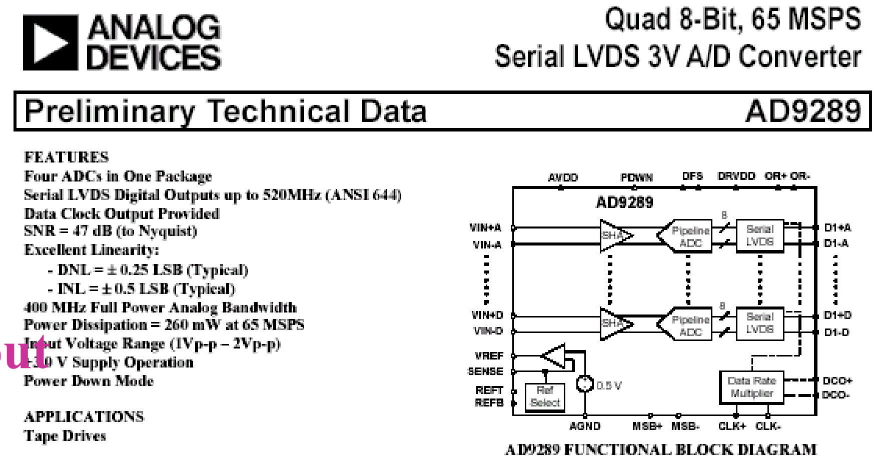


Transparency of CF_4 down to wavelengths of ~120 nm allows more photoelectrons to be produced on the CsI—region of highest Q.E.

TPC Readout Electronics

Considerations

- Speed (need ~ 40-50 MHz)
- Power (< 100 mW/ch total)
- Compatibility w/PHENIX readout
- Cost and availability


ANALOG DEVICES

Quad 8-Bit, 65 MSPS
Serial LVDS 3V A/D Converter

Preliminary Technical Data AD9289

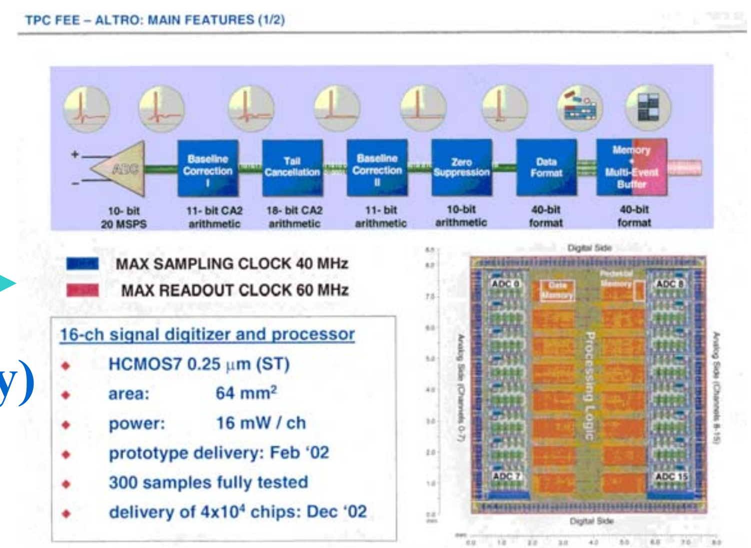
FEATURES
Four ADCs in One Package
Serial LVDS Digital Outputs up to 520MHz (ANSI 644)
Data Clock Output Provided
SNR = 47 dB (to Nyquist)
Excellent Linearity:
- DNL = ± 0.25 LSB (Typical)
- INL = ± 0.5 LSB (Typical)
400 MHz Full Power Analog Bandwidth
Power Dissipation = 260 mW at 65 MSPS
Input Voltage Range (1Vp-p – 2Vp-p)
3.0 V Supply Operation
Power Down Mode

APPLICATIONS
Tape Drives

AD9289 FUNCTIONAL BLOCK DIAGRAM

Options

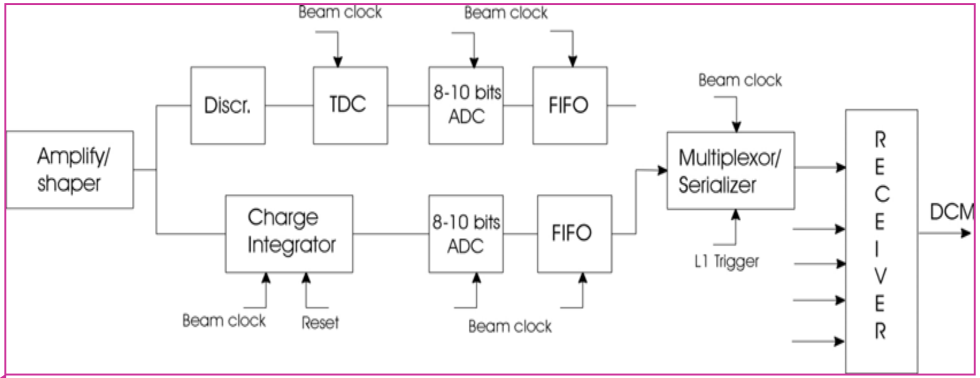
- Commercial ADC + FPGA
- ALICE ALTRO chip
- Custom ASIC (may not be necessary)



HBD Readout Electronics

Considerations

- Low noise (signal ~ 40-50 p.e.'s)
- Low mass (inside PHENIX accept.) (signals brought to edge of detector)
- Too few channels for ASIC
- Needs time measurement ~ few ns



Options

- Separate (slow) ADC + TDC
- Fast ADC used to extrapolate T0 measurement