Upgrade Plans for PHENIX

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PHENIX Upgrade Plan

Complete the PHENIX Baseline Detector

- Presently running with the Central Spectrometer and South Muon Spectrometer

- North Muon Spectrometer will be installed during the next RHIC shutdown

This will complete the main items of the PHENIX Baseline Detector

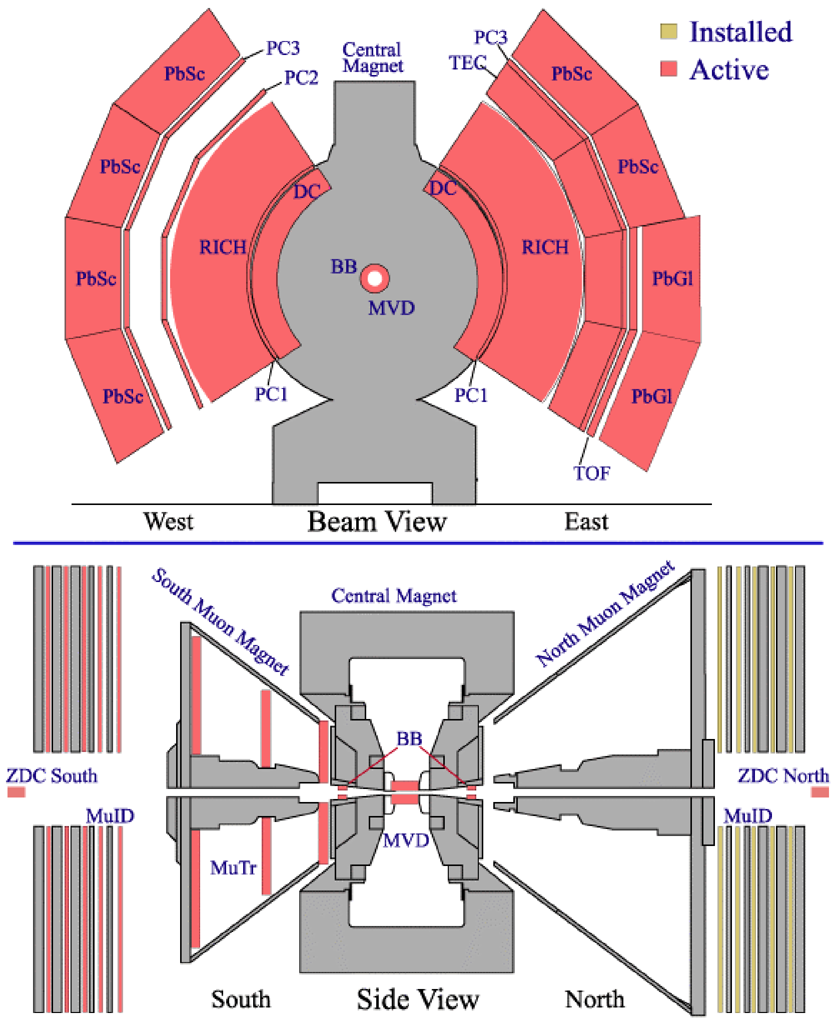
- Future upgrades will focus on enhancing the physics capability and and extending the physics reach of the baseline detector.

2001-2002 Run

New detectors:

- 8 complete sectors of EMCAL (6 PbSc, 2 PbGl)
- Rebuilt drift chamber
- Multiplicity and Vertex Detector (MVD)
- South Muon Spectrometer
- NTC and T0 counters for pp
- Upgraded trigger capabilities (Level 2, EMCAL-RICH)
- Upgraded data acquisition

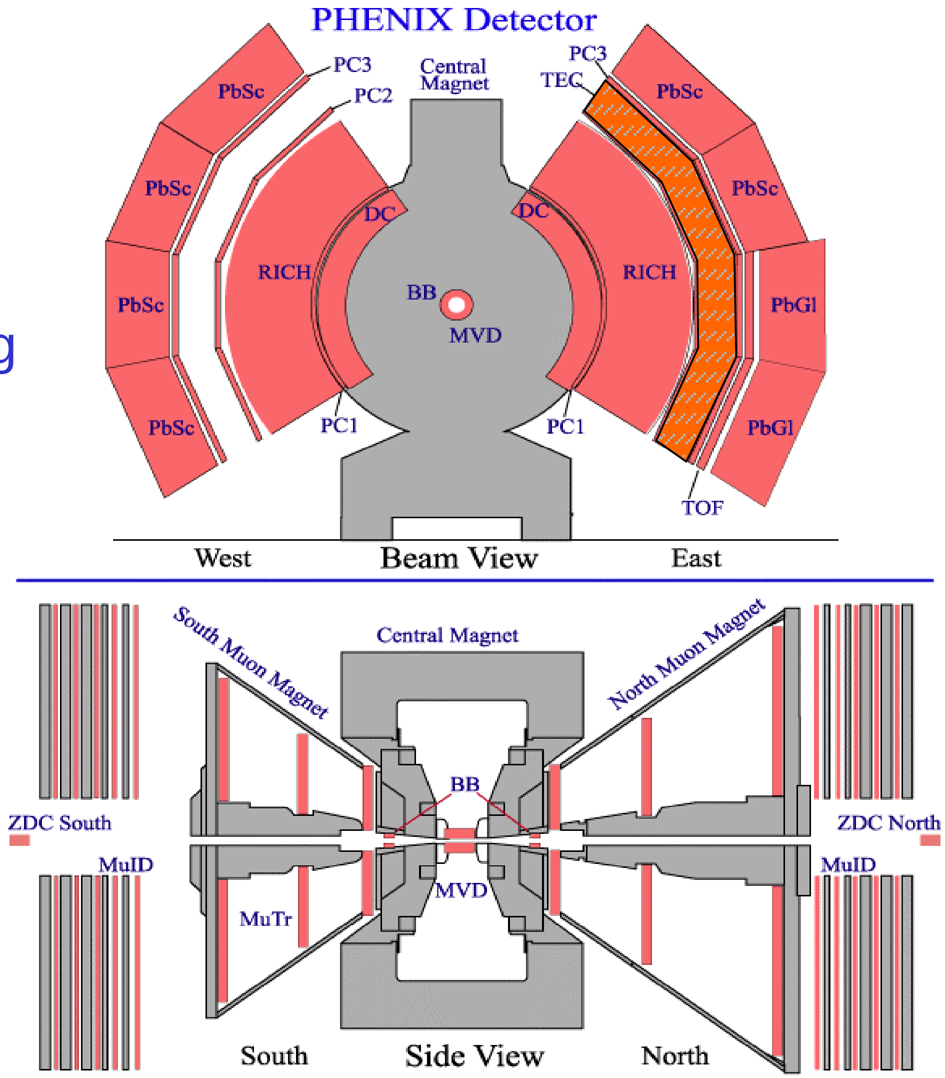
PHENIX Detector - Second Year Physics Run



2003 Run

New detectors:

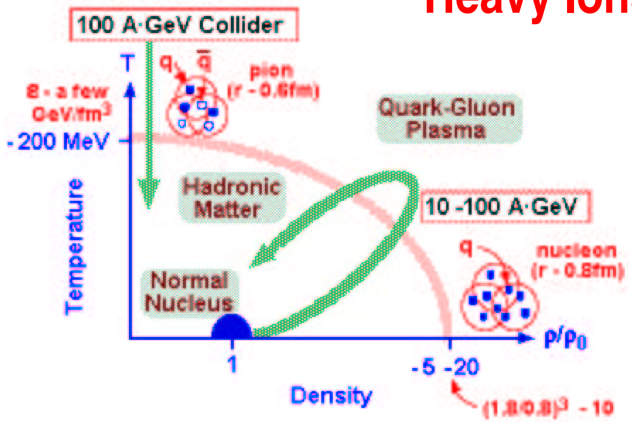
- North Muon Spectrometer
  3 stations of muon tracking chambers + muon ID chambers
- TEC upgraded to TRD
- Upgraded trigger
- Upgraded data acquisition



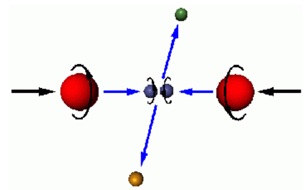
Physics with the PHENIX Baseline Detector

- Temperature and Energy Density
  - dN/dy, E_T, Single particle spectra
- Jet Quenching, Medium Effects
  - High p_T jets using leading $\pi^o, \pi^{\pm}$
  - Direct γs
- Space-Time Evolution
  - HBT($\pi\pi$, KK,pp), Flow
  - Event by Event Fluctuations
- Deconfinement
  - $J/\Psi, \Psi' \rightarrow e^+e^-, \mu^+\mu^-, \Upsilon \rightarrow \mu^+\mu^-$
- Chiral Symmetry Restoration
  - ρ, ω, ϕ mass, width
  - ϕ branching ratios
- Heavy Quark Production
  - K, ϕ, J/Ψ, Ψ', Υ, open charm

Heavy Ions



Spin



- Gluon spin: ΔG
  - Direct γ, high p_T π's
- Sea quark spin: Δu, Δd
  - W^+/W^- production
  - Drell-Yan Polarization

New Physics to be Addressed with an Upgraded PHENIX Detector

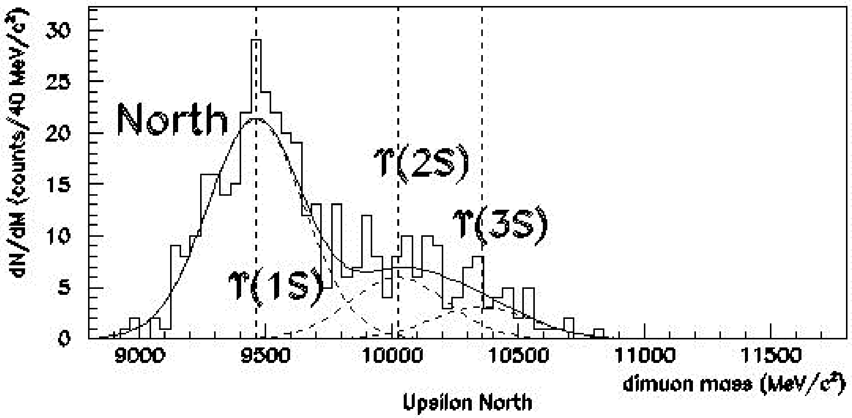
- Low mass dilepton pairs
- Improved measurements of heavy flavor (c,b) production
- Jet studies and γ-jet correlations
- High p_T identified particles
- Rare processes

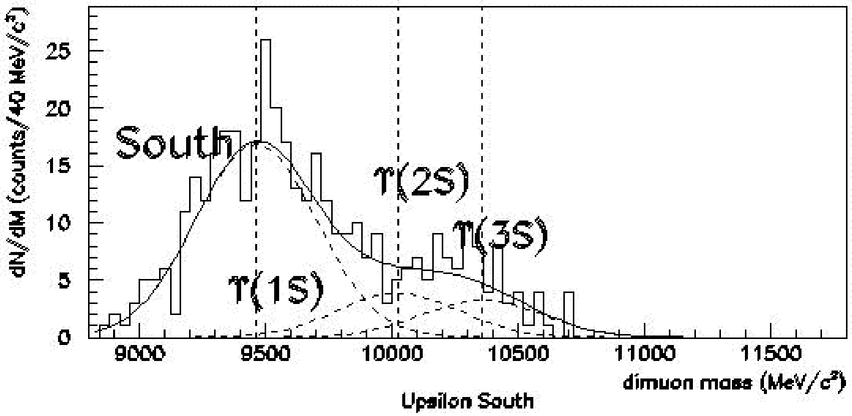
  Inclusive particle spectra and direct γs out to high p_T
  Drell-Yan continuum above the J/Ψ
  Upsilon spectroscopy - $\Upsilon(1S),\Upsilon(2S),\Upsilon(3S)$
  W-production
  …

Detector Requirements for New Physics

- Good rejection against Dalitz pairs and conversions, along with good electron efficiency down to low momentum, to measure low mass electron pairs
- Excellent vertex resolution to directly measure open charm and bottom decays by measuring displaced secondary verticies
- Increased tracking coverage over 2π in azimuth and larger rapidity to measure jets and γ-jet correlations
- Good particle id out to high p_T
  - π/K/p separation to $p_T \sim 10$ GeV/c
  - electron identification to $p_T > 10$ GeV/c
- High rate data acquisition and triggering capabilities for studying rare processes

Upsilon Spectroscopy with North and South Muon Arms





Upsilon	mass (GeV)	Br(μμ) %	relative yield
Y(1S)	9.460	2.48	1
Y(2S)	10.023	1.31	0.36
Y(3S)	10.355	1.81	0.27

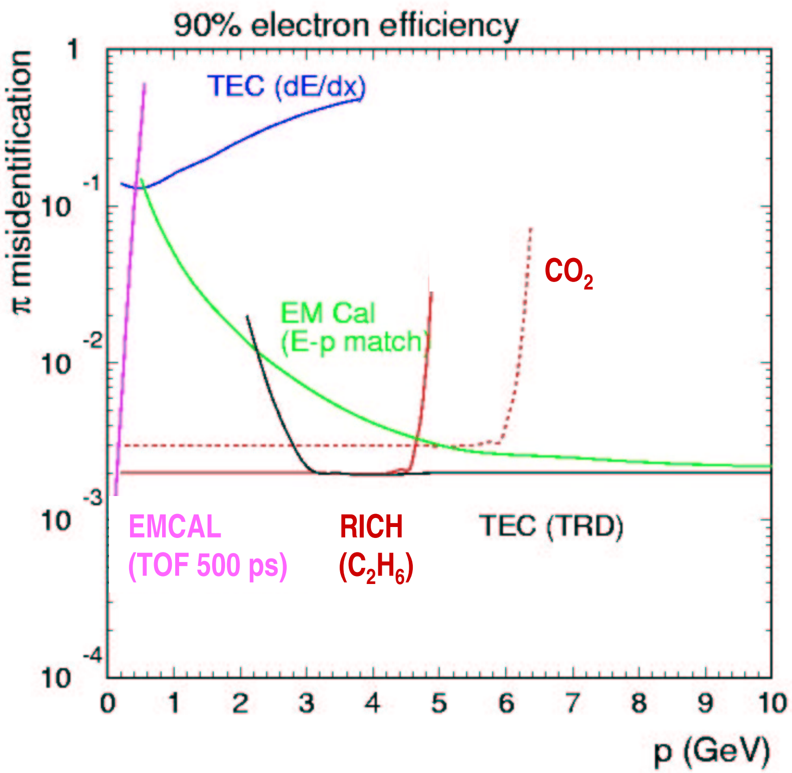
North Muon Arm: σ_m ~ 190 MeV

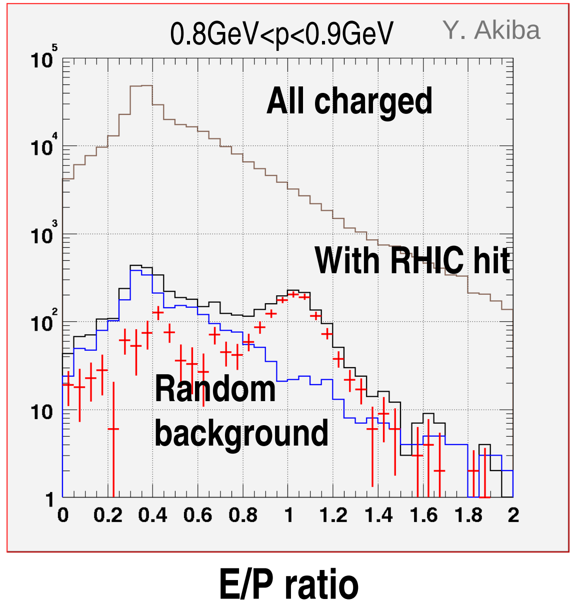
South Muon Arm: σ_m ~ 240 MeV

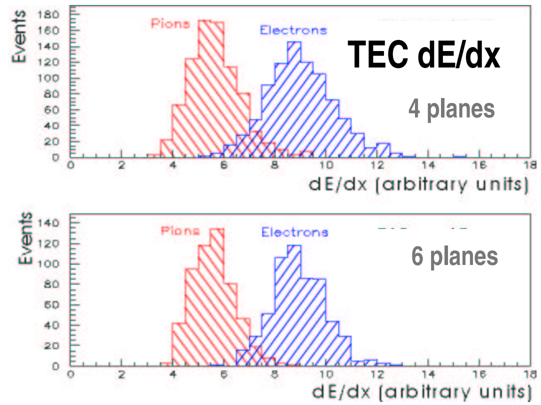
Number of ϒs accumulated in a 22 week run

Luminosity ($cm^{-2}s^{-1}$)	**$2x10^{26}$**	**$8x10^{27}$**
Muon spectrometer	**400**	**16000**
Central spectrometer	**40**	**1600**

Electron ID in PHENIX





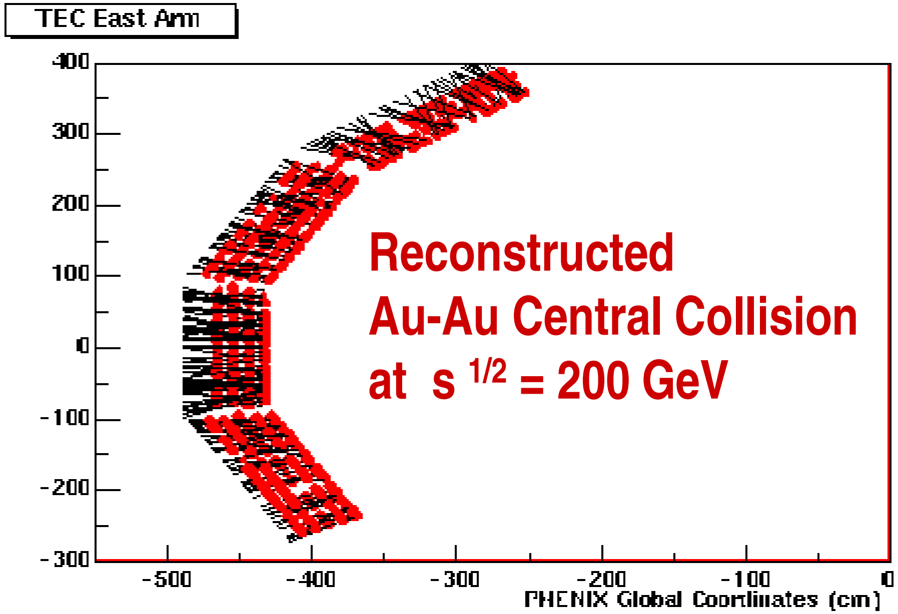


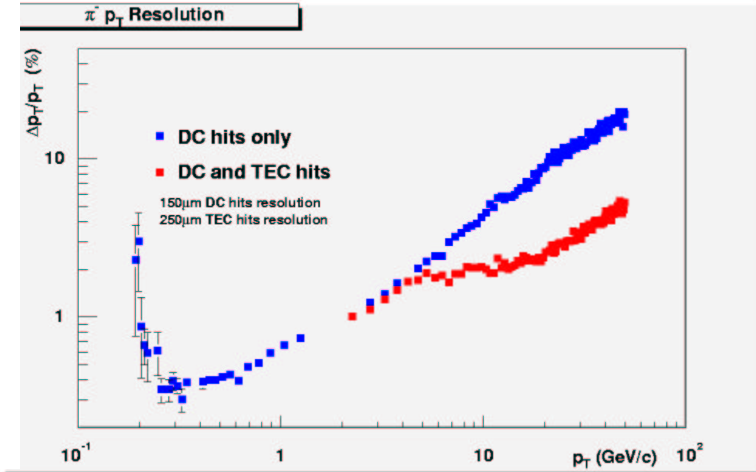
Electron ID at low momentum

- RICH
- EMCAL E-p matching
- EMCAL TOF
- TEC dE/dx

PHENIX Time Expansion Chamber

- 24 TEC Chambers arranged in four 6-Chamber sectors
- Each 3.7m x 2.0 m chamber contains 2700 wires
- Used for tracking and PID (dE/dx). σ_x = 260 μm
- dE/dx: e/π = 5% at 500 MeV/c (4 planes), e/π = 1.5% (6 planes)
- Important for momentum resolution p_T > 4.0 GeV/c



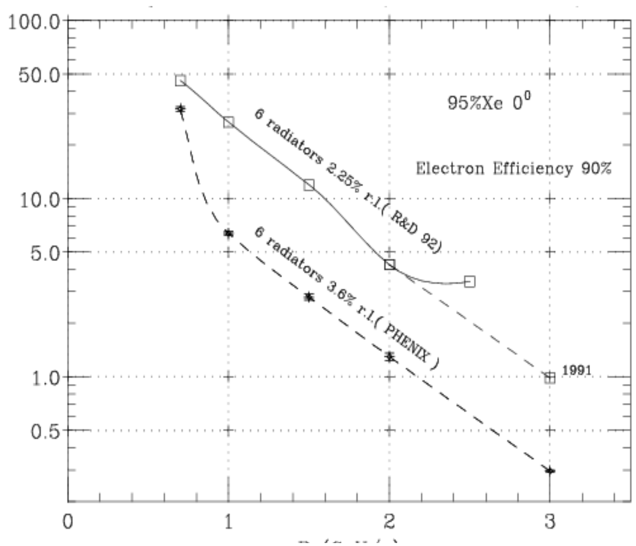


Electron ID at High Momentum with TRD

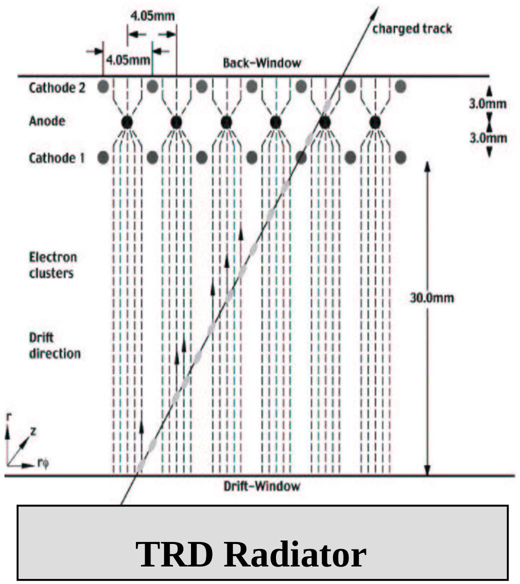
PHENIX TEC/TRD Radiators

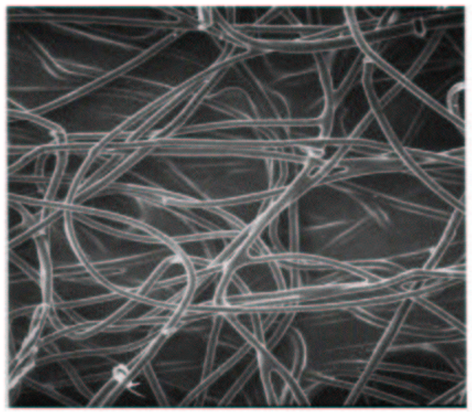
- Polypropylene fiber/foam module packs
- Self supporting
- Recirculating Xe gas system
- Goal is complete installation prior to start of RHIC Fall 2002 run.

π efficiency (%)

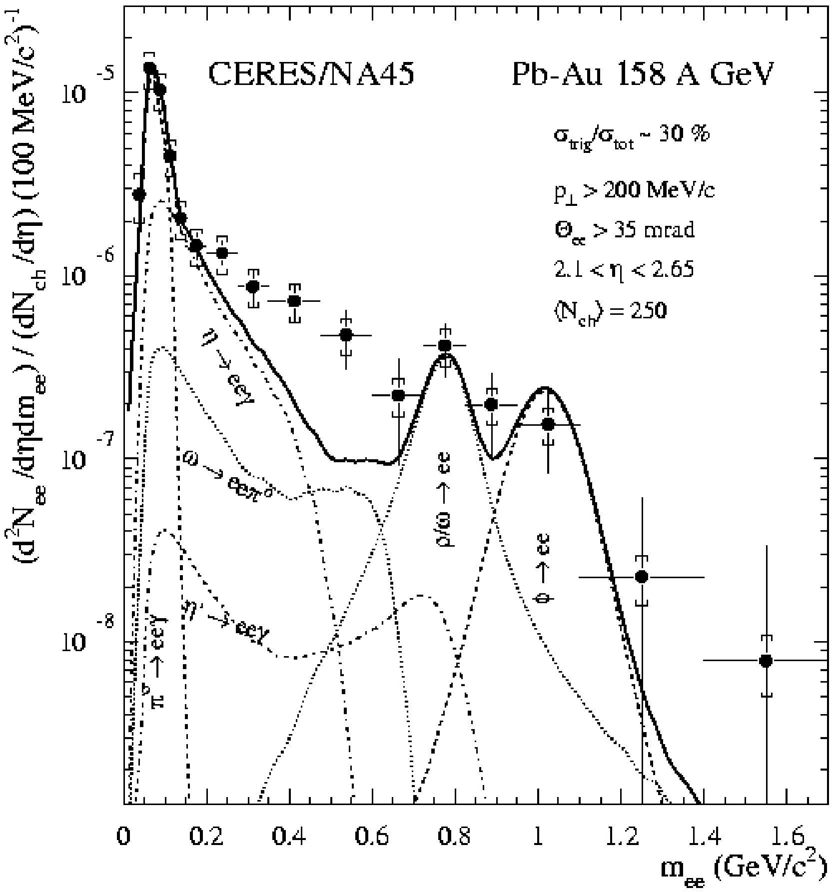


P_π GeV/c



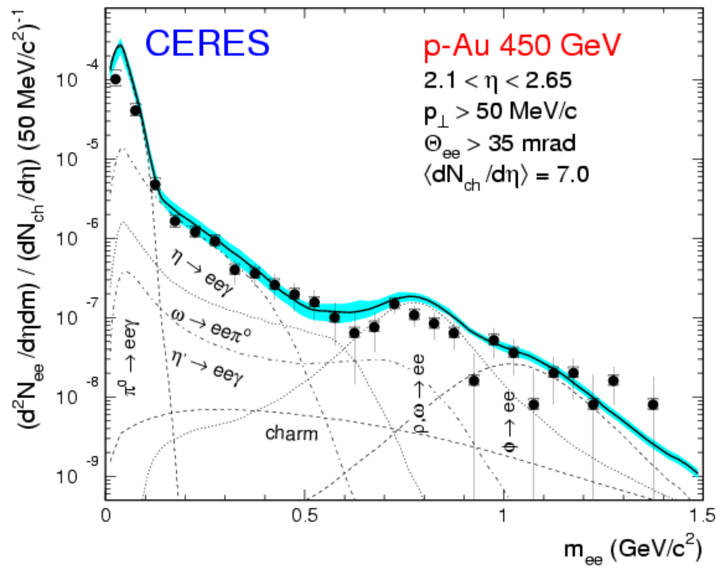


Low Mass Electron Pairs



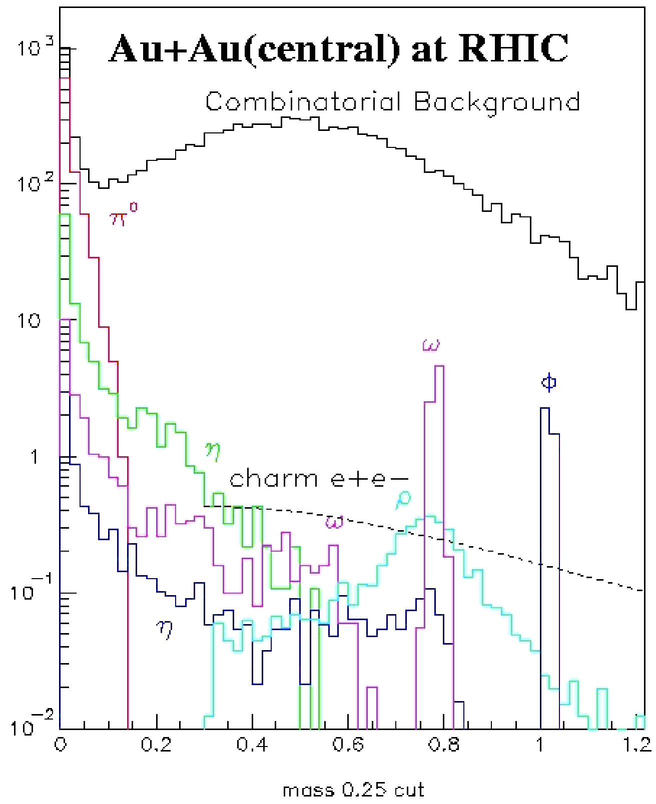
Enhancement factor (.25 <m<.7GeV/c²) :
2.6 ± 0.5 (stat) ± 0.6 (syst)

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 in PHENIX



Single electrons from Dalitz Decays

$N_e = dN_{\pi^0}/d\eta$ x acc x BR x $f(p_T>200)$

350   1/2x0.7   .012   .32   = 1.2 trks/evt

Combinatorial background ~ 0.1 pairs/evt

Expected signal (m>200, p_T>200) ~ 4.2 x 10^{-4} pairs/evt

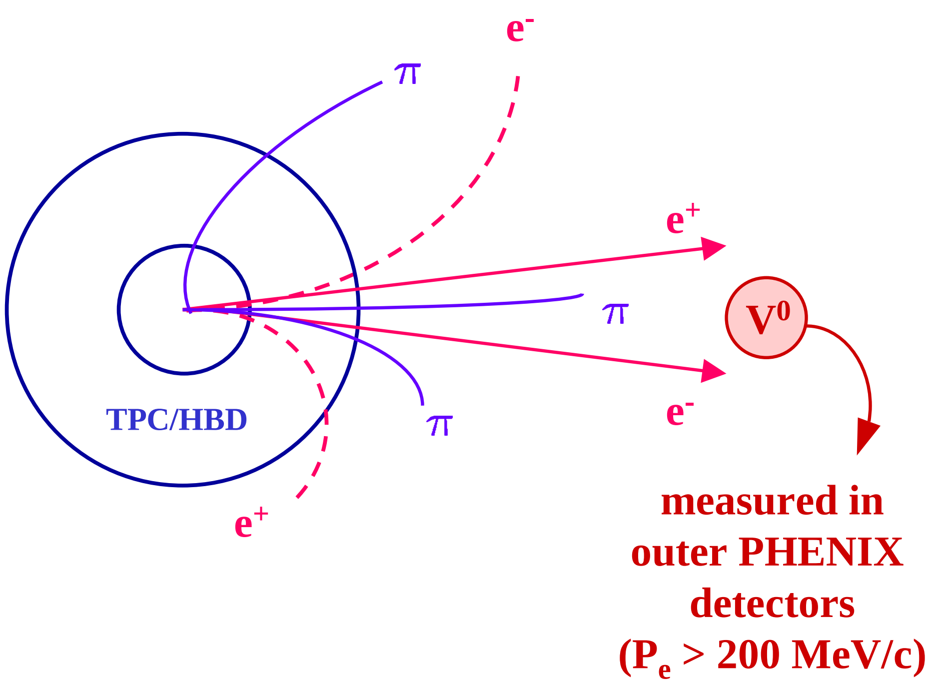
Signal/Background ~ 1/250

Must improve S/B by at least 2 orders of magnitude

Note: charm contribution is significant

Strategy for Low Mass Pair Measurement

- Operate PHENIX with low inner B field to optimize measurement of low momentum tracks
- Identify signal electrons (low mass pairs, ρ, ω, φ, ...) with p>200 MeV in outer PHENIX detectors
- Identify low momentum electrons (p<200 MeV) using dE/dx from TPC and/or Cherenkov light in HBD
- Calculate effective mass (or opening angle) between all opposite sign tracks identified as electrons ($\varepsilon_{electron} > 0.9$, $\pi_{rej} > 1:200$)
- Reject pair if mass < 130 MeV (or $\vartheta < 200$ mrad)



Must provide sufficient Dalitz rejection (>90%) while preserving the true signal

Signal and Background Rates

Ideal Case

Central AuxAu events
Assume for inner detector

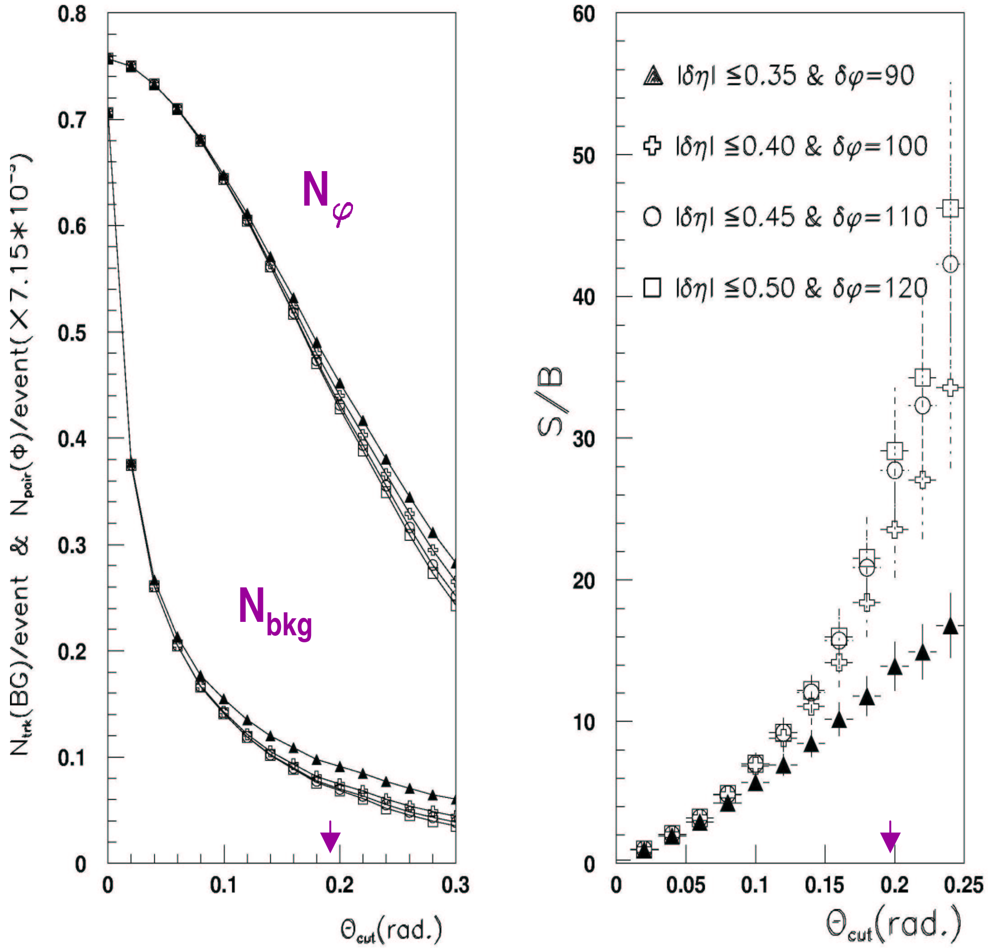
Perfect electron id (ε_e = 100%)
Perfect π rejection
Perfect double hit resolution

S/B ~ 10

Effect of increased acceptance "veto region"

S/B ~ 20-30

Needs more detailed calculation with realistic assumptions about ε_e, π_{rej} and real backgrounds to estimate the true S/B ratio

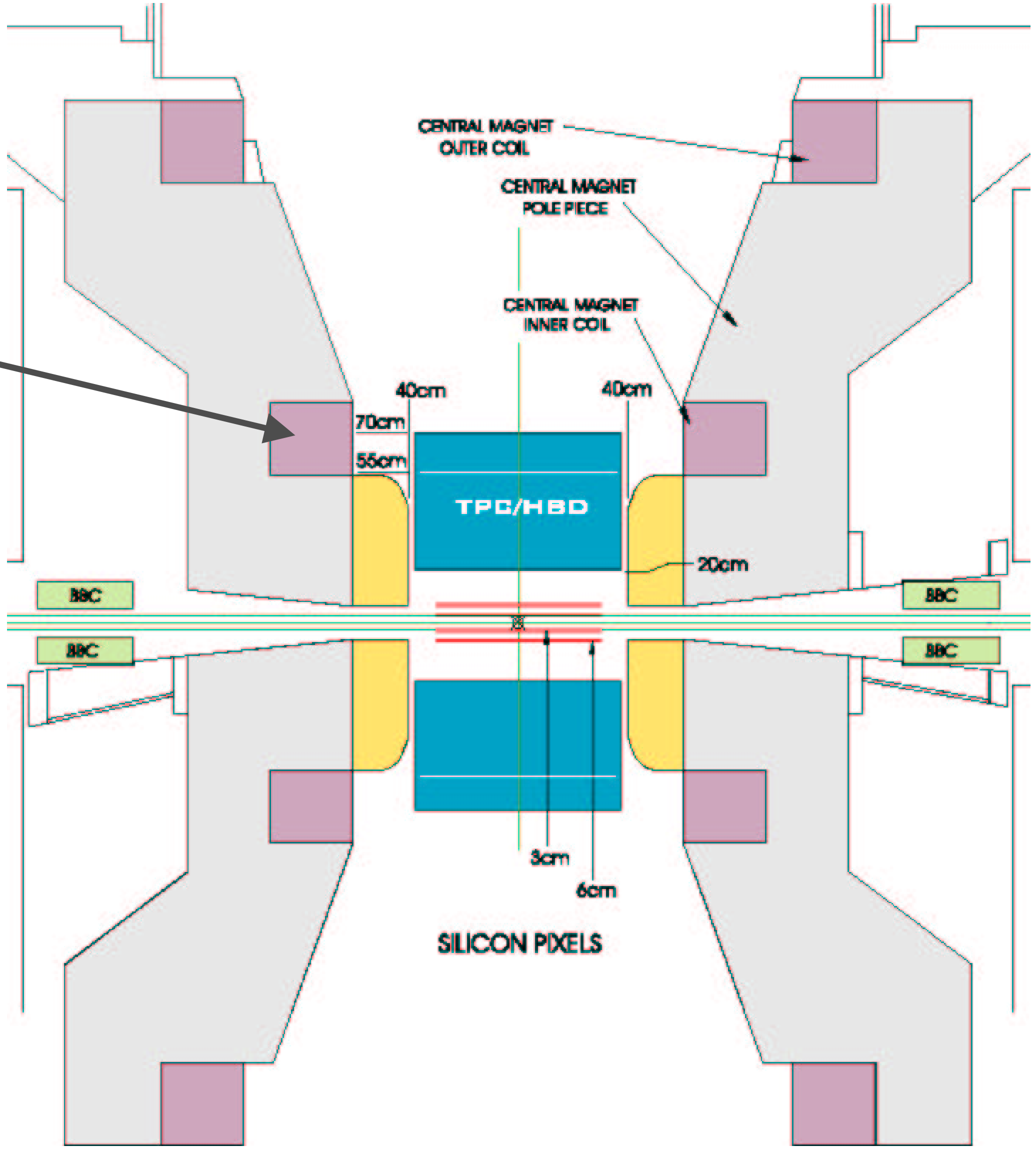


Opening angle cut

PHENIX Inner Detector

Inner Coil creates a "field free" ($\int Bdl=0$) region inside the Central Magnet

will be installed during 2002 shutdown



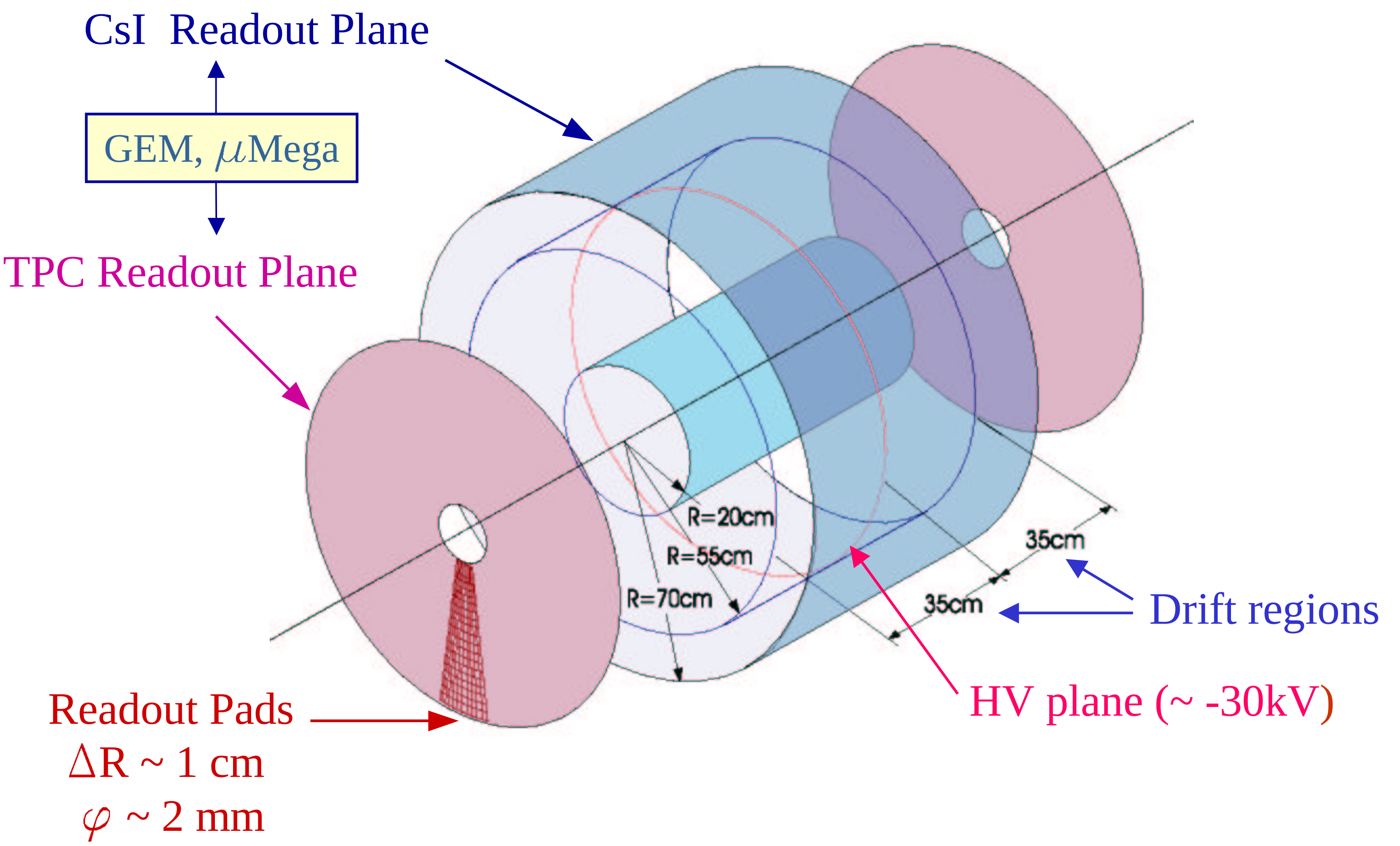
TPC tracking coverage

$\Delta\varphi = 2\pi$

$-0.7 < |\eta| < 0.7$

$\delta p_T / p_T \sim 0.02$

TPC/HBD Conceptual Design
(PHENIX + STAR)



Detector Requirements for TPC/HBD

- Must have short drift time to work at the highest luminosities planned for RHIC
  < 4μsec => fast gas (e.g., CF_4)
- Require sufficient two track resolution to handle high track densities and possible space charge limitations
- Must have sufficient charge deposition and sampling to do good dE/dx measurement for electron id below 200 MeV
- CsI photocathode layer provides additional independent electron id
- Should have minimal material to minimize conversions and multiple scattering for outer detectors (< 0.1 - 0.2% X_0)
- Must keep the number of readout channels to a "reasonable" number
  ~ 50-100K with high density readout planes
  (=> significant development in integrated electronics)

Enhanced Physics Capabilities with a High Precision Vertex and Tracking Detector

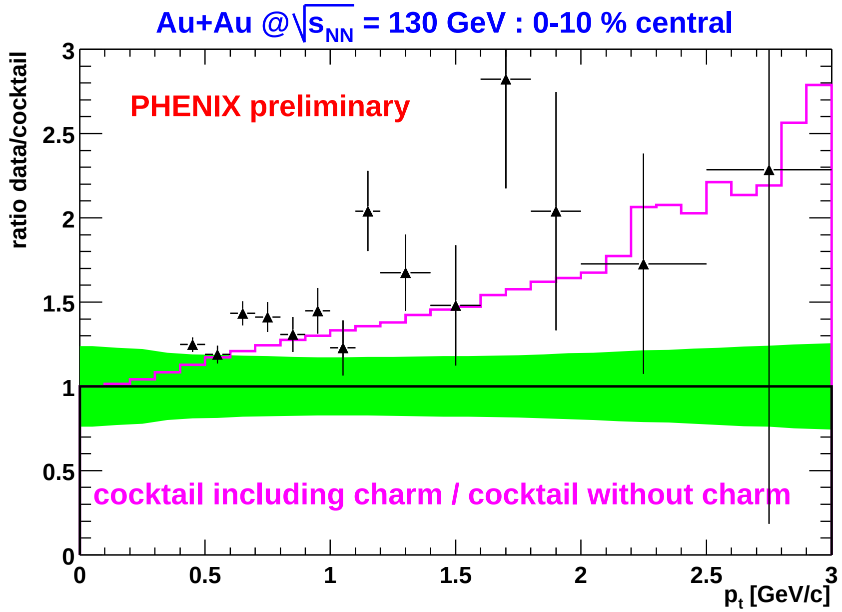
- **Separation of charm and bottom decays by measuring displaced secondary vertex**
  improve measurement accuracy of c and b cross sections to < 10%
  separate c and b contribution in each p_T bin (flavor dependence of QCD energy loss)
- **Direct measurement of D mesons**
  combined with particle id, can measure D -> $K\pi$ modes
  => p_T spectrum of D's (flavor dependence of QCD energy loss)
- **Open heavy flavor (Muon Arms)**
  D-> μX, B -> J/ψ -> $\mu^+\mu^-$
- **Improved momentum resolution for Upsilon spectroscopy**
- **Enhanced capabilities for spin physics**
  wider acceptance (γ-jet & jet-jet studies, c,b-tagging, etc)
- **Enhanced physics capabilities for charm and bottom in pA**

Charm and B Decays

A high precision vertex detector will allow a clean separation of charm and bottom decays

	m GeV	cτ μm	→ eX %
D^0	1865	125	6.75
$D^\pm$	1869	317	17.2
B^0	5279	464	5.3
$B^\pm$	5279	496	5.2

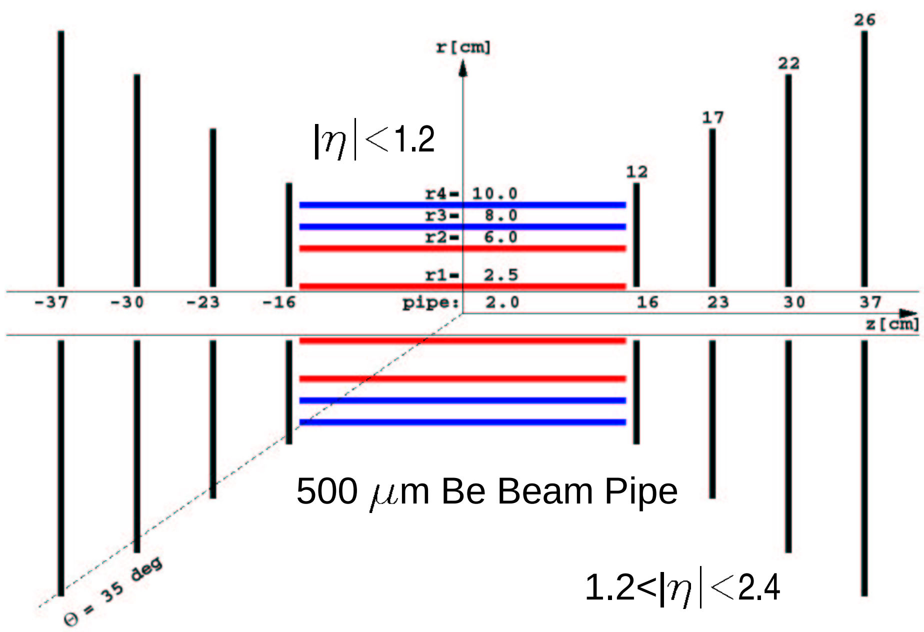
Need secondary vertex resolution ~ 30 - 50 μm



PHENIX already sees evidence for open charm production

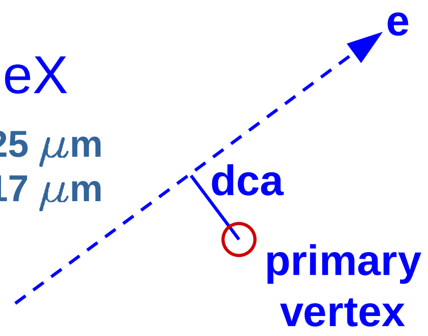
Y. Akiba, DNP Oct 2001
Paper in preparation for submission to PRL

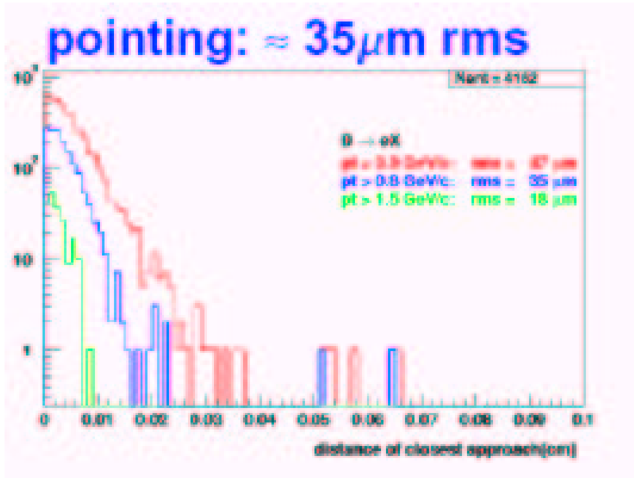
Proposed Silicon Tracker in PHENIX



D → eX

$c\tau_0$ = 125 μm
$c\tau_\pm$ = 317 μm



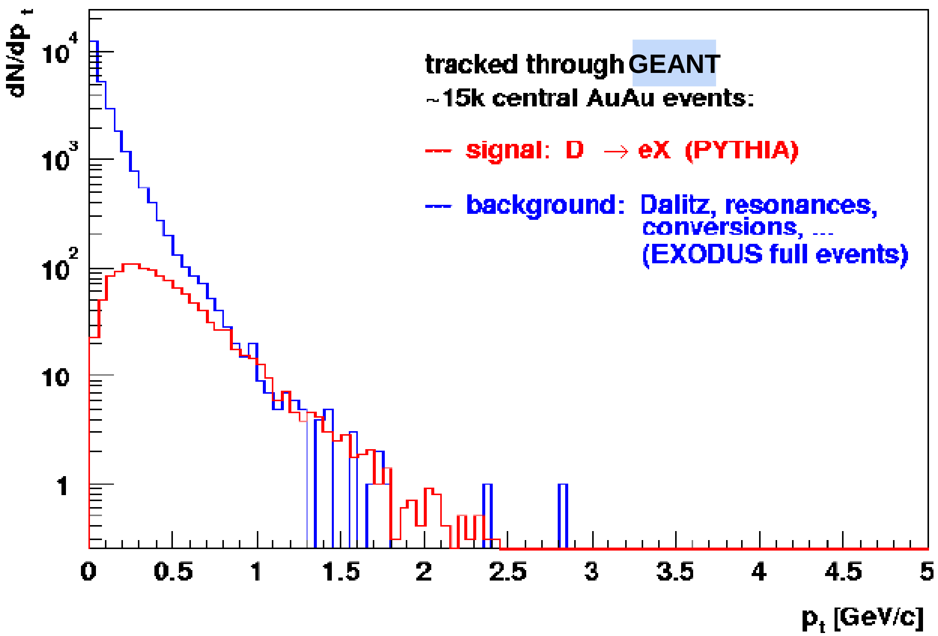


Pixel barrels (50 μm x 425 μm)
Strip barrels (100 μm x 5 cm)
Pixel disks (50 μm x 200 μm)

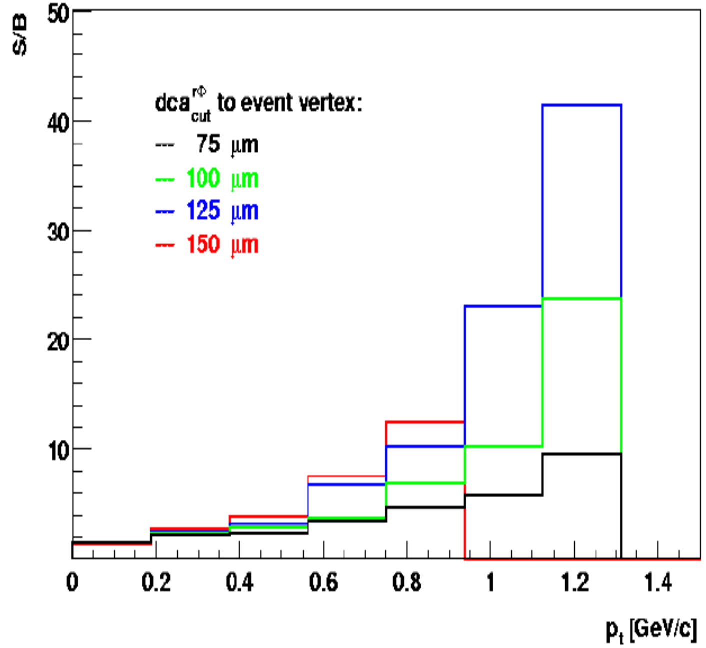
1.0% X_0 per layer

Simulation by J. Heuser

Signal/Background with DCA cut



S/B improves to > 10 for p_T > 1 GeV/c with DCA cut ~ 100 μm



Without cuts on displaced vertex

- **S/B ~ 1 for high-pt**
- **S/B ~ 0.1 p_T = 0.5 GeV/c**

Simulation by J. Heuser

Technology Choices for a Precision Silicon Vertex Tracker

Silicon strips

- implementation of strips is straightforward (but needs electronics)
- mainly for pp (investigating usefulness in HI)

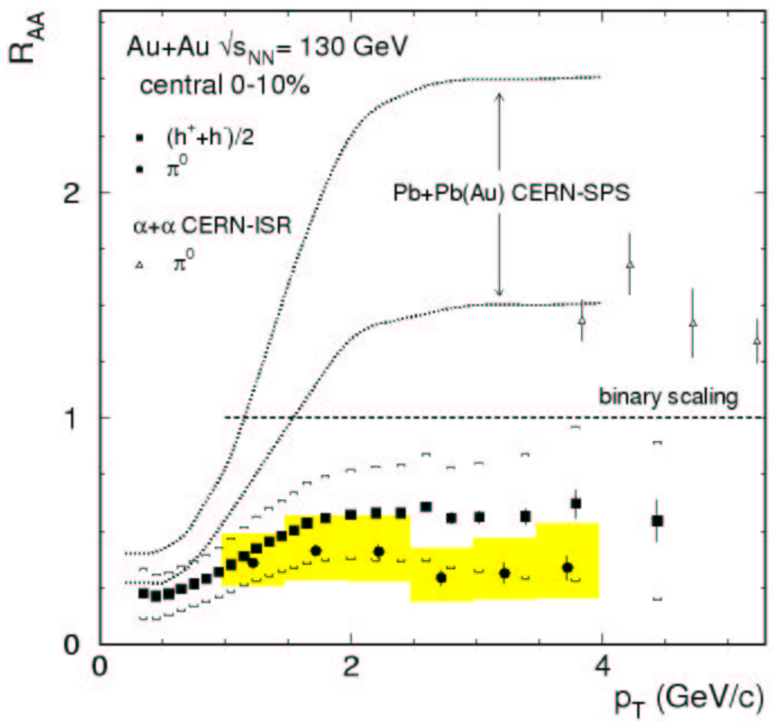
Silicon Pixels (hybrid)

- sensor detectors being developed at BNL for NA60
- hope to use NA60/ALICE readout chip in PHENIX environment
- active participation by PHENIX members in NA60/ALICE hybrid development

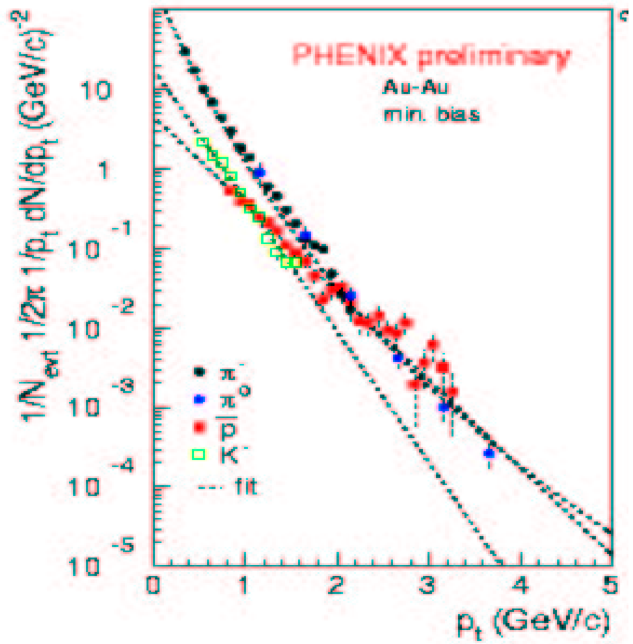
Silicon Pixels (monolithic Active Pixel Sensors)

- ultimately the most desirable solution
- being developed by LEPSI, LBL(STAR), Iowa State (recent)
- presently readout time is a problem
- time scale for implementation may be long

Enhanced High p_T Physics

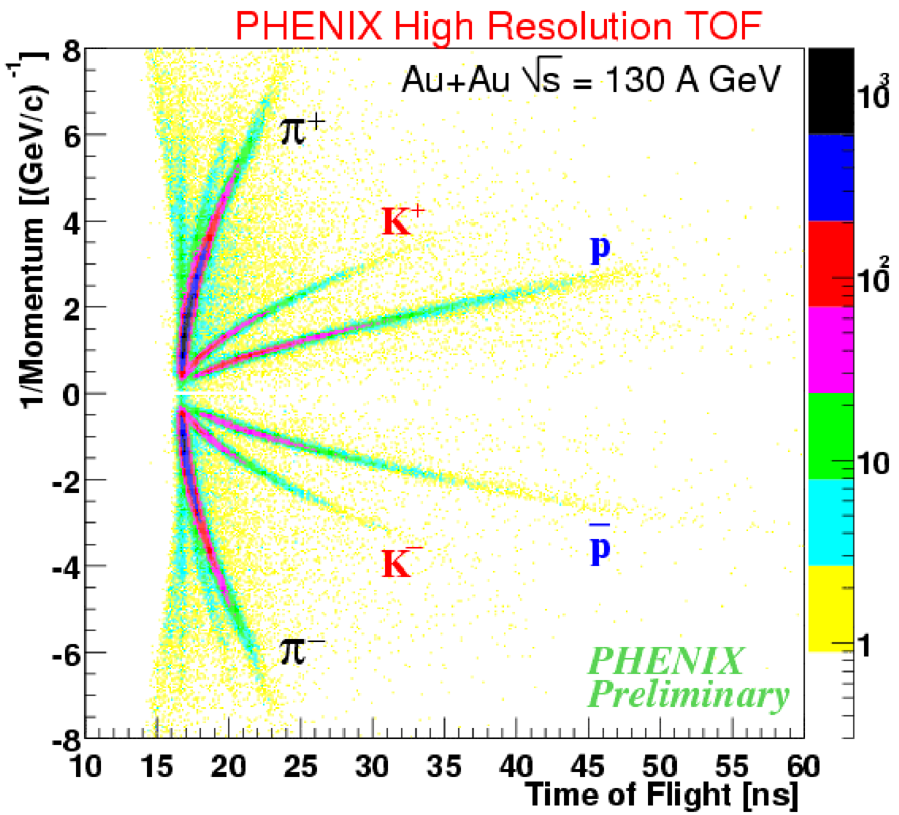


Study flavor dependence of jet quenching
(tag with *identified* high p_T particle)



Important to extend spectra of identified charged particles out to as high p_T as possible

PHENIX PID



TOF resolution < 100 ps
π/K < 2.5 GeV
K/p < 4.5 GeV

EMCAL TOF resolution ~ 500 ps
< 1 GeV

RICH	Threshold (GeV/c)		
	π	K	p
CO_2	4.7	17.3	32.8
C_2H_6	3.4	12.4	23.5

Extended PID with Aerogel

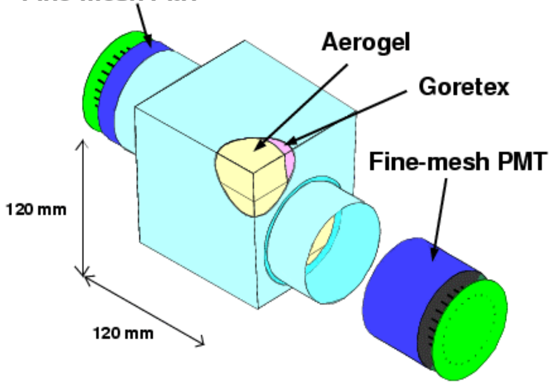
		Pion-Kaon separation	Kaon-Proton separation
TOF	σ~100 ps	0 - 2.5	0 - 5
RICH	n=1.00044 γth~34	5 - 17	17 -
Aerogel	n=1.007 γth~8.5	1 - 5	5 - 9

Y. Miake

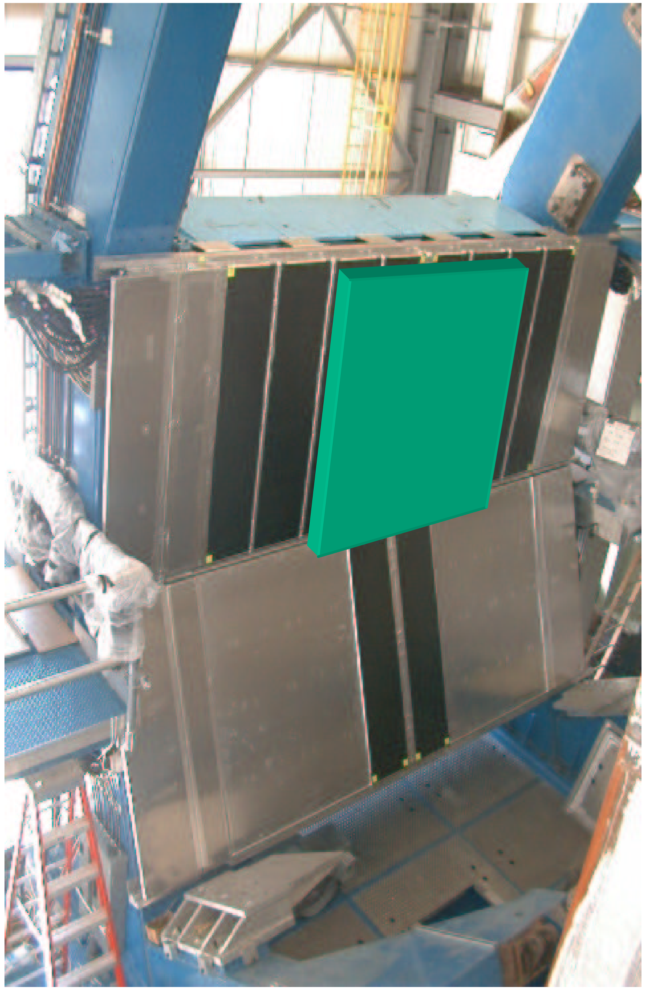
Aerogel together with TOF can extend the PID capability up to ~ 10 GeV/c

Aerogel +TOF

- Coverage of 4 TOF panels
- Since no space on the East, install on the West.
  - Remove 2 lower TOF panels from East after pp run
  - 1 spare panel
  - 1 panel to be constructed



BELLE Aerogel Module



Present PHENIX DAQ Capabilities

RHIC luminosity reached in Run 2

Au-Au L ~ 2×10^{26} $cm^{-2}s^{-1}$ (blue book - briefly)
p-p L ~ 1×10^{30} $cm^{-2}s^{-1}$ (~ 10% blue book, 1% spin design)

Trigger rates:
- Ran with up to 1.2 kHz rate in Run 2
- Expect possible raw trigger rates of ~ 11 kHz (HI) and 800 kHz (pp) in Run 3
- PHENIX should be able to take ~ 8 kHz (limited mainly by multiplexing of FEMs)
- Maximum Level-1 trigger accept rate = 25kHz (requires demultiplexing)

Data volume:	Au-Au	pp
Event size	~ 150-200 kB	~ 50 kB

Level 2 Trigger (Event Builder): Au+Au: 150kB x 8 kHz = 1200 MB/s

Archiving rate at RCF ~ 20(40)MB/s => Need factor ~ 60(30) rejection at Level 2

Conclusion: PHENIX already has a very good high rate DAQ system

DAQ and Trigger Upgrades

New physics requires high luminosity
New detectors produce large data volumes (silicon, TPC)

Expected luminosity upgrades at RHIC (RHIC-II)

Au-Au	L ~ 8×10^{27} $cm^{-2}s^{-1}$	(x40)
O-O	L ~ 1.6×10^{29} $cm^{-2}s^{-1}$	
p-p	L ~ 4×10^{32} $cm^{-2}s^{-1}$	(possibly -> 4×10^{33} $cm^{-2}s^{-1}$)

Changes and Improvements to DAQ

- Zero suppression in FEMs
- Upgraded DCM modules
- Gigabit ethernet to replace ATMs
- Level 3 trigger
- Up to 100 MB/s data logging rate at RCF
  (similar to ATLAS + CMS; ALICE ~ 1250 MB/s)

Other Possible Upgrades

- High resolution crystals ($PbWO_4$)
  - presently being used in polarimeter for spin
  - forward calorimeter (γ-jet tagging, μ-isolation, b-tagging)
  - high resolution π^0, η^0, direct gamma measurements (low p_T)
  - possible collaboration with ALICE (PHOS detector)

- Very forward hadron calorimeter (pA)

  tag forward "gray" nucleons for better centrality measurement

- Very forward muon spectrometer (pA)

  extend x_2 coverage below 10^{-3}

Time Scale and Cost

2002 - Completion of Baseline Detector
Install North Muon Spectrometer
Upgrade TEC to TRD

2003-2004
Silicon strip detectors
Prototype silicon pixel detector
Prototype HBD (upgradable to TPC)
Prototype aerogel detector

2005-2007
Complete silicon pixel detectors
Complete TPC/HBD
Complete aerogel detector

R&D 2002-2005
- presently supported by various institutional funds (LDRDs,RIKEN)
- requires ~ 3-4 $M over 3-4 yrs
- needs DOE funding to continue

Construction 2004-2007

- Staged approach, with detectors requiring less R&D to be implemented first
- Rough estimate of detector construction costs ~ $10-15M
- NSAC plan shows $80M in RHIC II detector upgrades over 7 years starting in FY05