Measurement of single electron and implications for charm production in Au+Au collisions at $s_{NN}^{1/2}$=130 GeV

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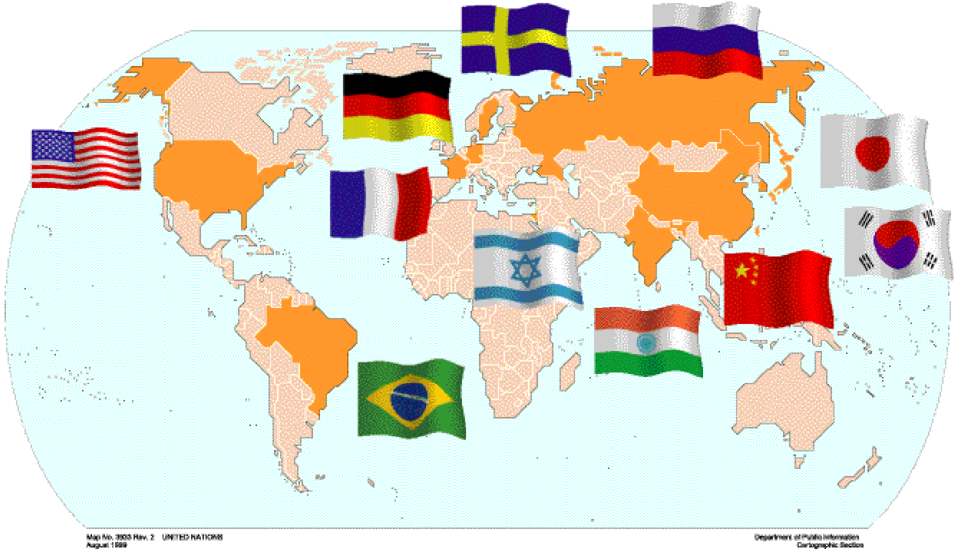
for the PHENIX Collaboration

The PHENIX Collaboration



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Outline of the talk

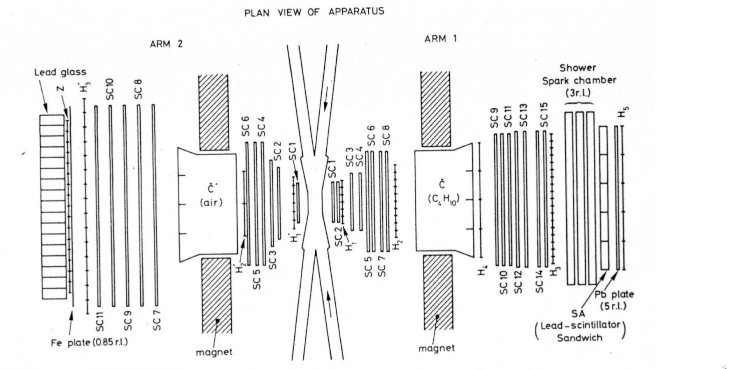
- Motivation
  - open charm as probe of H.I. Collision
  - single electrons in high pt
- Single Electron measurement in PHENIX
  - Data analysis
  - (Raw) electron spectrum in PHENIX
- Background subtraction
  - background from light hadron decays and photon conversion
  - Data/background ratio
- Charm decay contribution
  - Electron signal compared with charm decay
  - charm cross section corresponding to the data
  - comparison with lower energy charm/electron data
- Summary

Motivation

- Lepton and lepton pairs are "clean" probes of early stage of heavy ion collision
  - J/Ψ production → Deconfinement
  - Thermal lepton pair → Direct radiation from QGP
  - ρ, ω, φ in dense matter → Chiral symmetry restoration
  - Etc.
- High pt single electron (p_t > 1 GeV/c)
  - Heavy quark semi-leptonic decays (c→eX, b→eX) have significant contributions to high pt electrons.

  → Heavy quark production can be studied by single electron spectrum
  - From heavy quark production, one can study
    - Initial gluon density in high energy heavy ion collision
    - Thermal production of heavy quarks in very high temperature
    - Energy loss of heavy quarks traversing the dense matter
    - Base line for J/Ψ suppression

History
single electron at the ISR



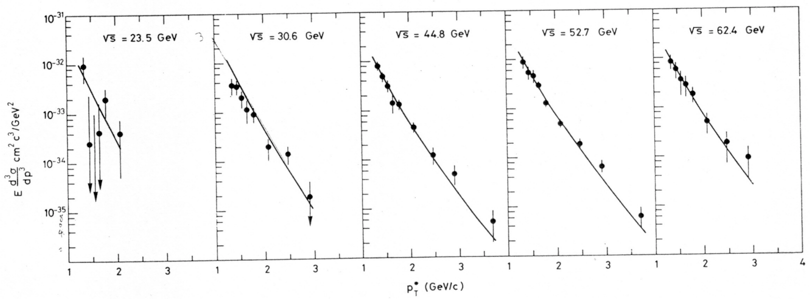


Fig. 7. The charge-averaged invariant cross section for electron production, plotted as a function of the c.m. momentum p_T^* for five values of $\sqrt{s}$. The curve represents a fit of the charge-averaged pion data of the BS Collaboration [22], and has been multiplied by 10^{-4}.

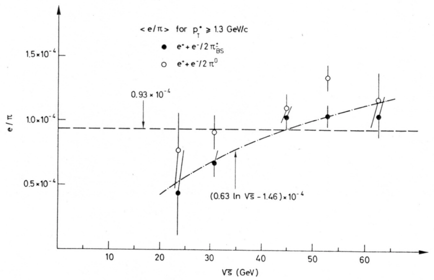


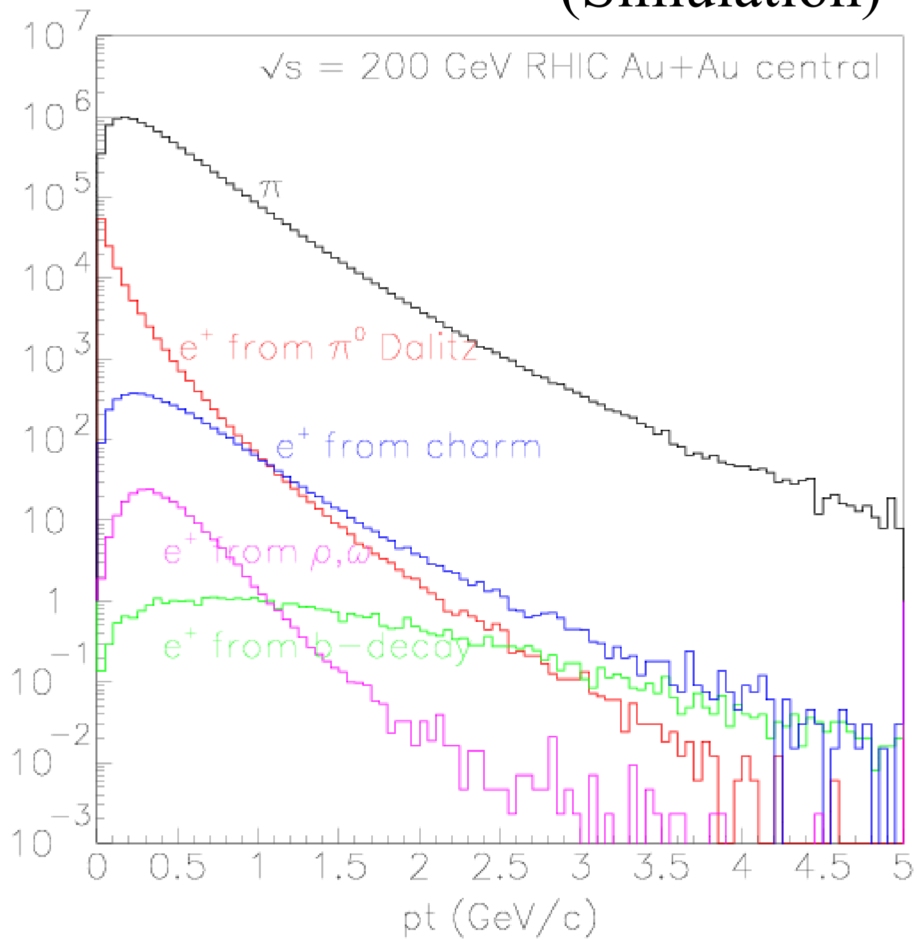
Fig. 9. The ratio of the invariant cross sections of electrons to pions of $p_T^* \geq 1.3$ GeV/c plotted as a function of c.m.s. energy $\sqrt{s}$. The pion data were obtained from the work of the British-Scandinavian Collaboration [22] (solid points) and from the spectrum of selected conversions measured in this experiment (open points). The two curves shown are fits to the solid points.

- Single electron was observed at the ISR in early 1970's, before charm discovery.
  - F. W. Busser et al,PLB53,212
  - F.W.Busser et al,NPB113,189
- It has been later interpreted as a signal of open charm.
  - I.Hunchlife and C.H.Llewellyn Smith, PLB61,472
  - M. Bourquin and J.-M.Gaillard, NPB114,334
- Signal level is $e/\pi \sim 1\text{-}2\times10^{-4}$ at the ISR
  - Higher signal level is expected at RHIC

single electrons at high pt

- At ISR($s_{NN}^{1/2}$~60GeV), “prompt” electron signal is observed at e/π ~ 2×10^{-4}.
  - The most likely source of the electrons is charm semi-leptonic decay
- At RHIC ($s_{NN}^{1/2}$~200GeV) , the electron signal from charm is expected at e/π ~ 3-4 $\times 10^{-4}$ in p+p
- The e/π ratio can be as high as 10^{-3} in Au+Au collision
  - Production of charm quark is expected to scale with binary collisions.
  - Production of the high pt pions is suppressed relative to binary scaling by about factor 3

(Simulation)

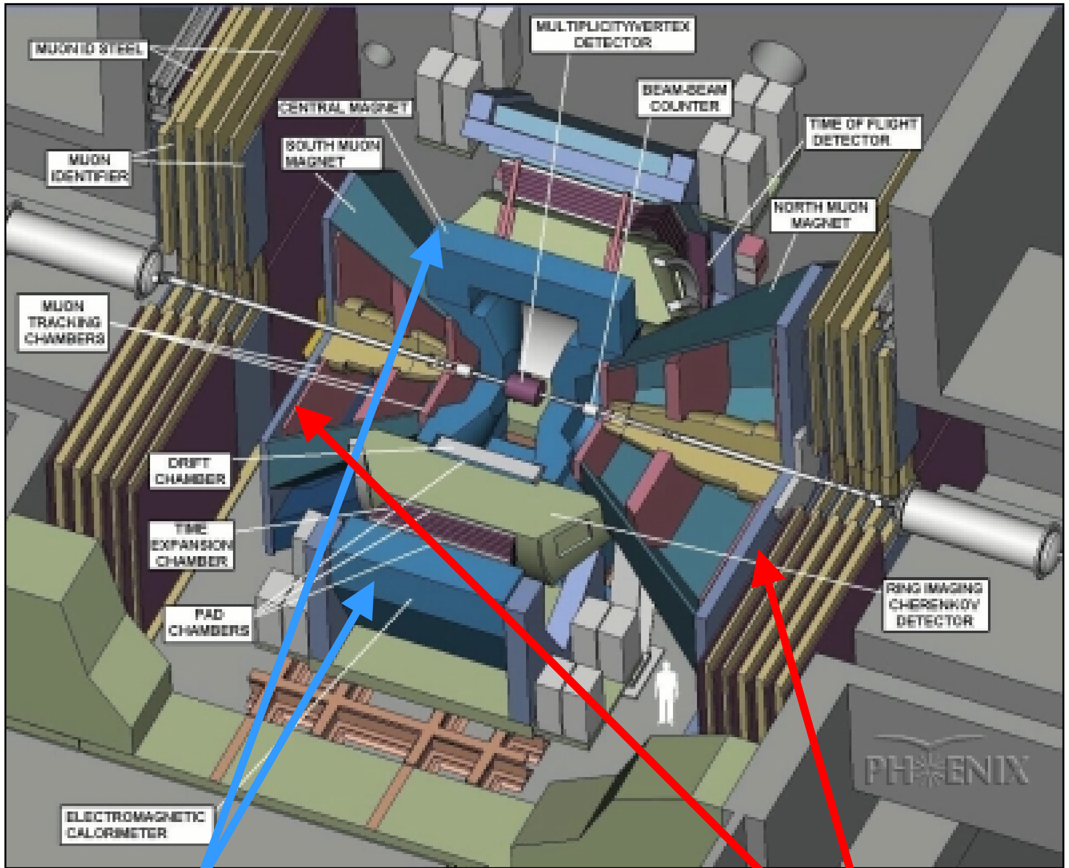


PHENIX Experiment

PHENIX - only RHIC experiment specifically designed to measure leptons.

Electrons are measued by the two central arms. Muons are measured by the two forward arms.

In Run-1, a part of central arm is operational for electron measurement.

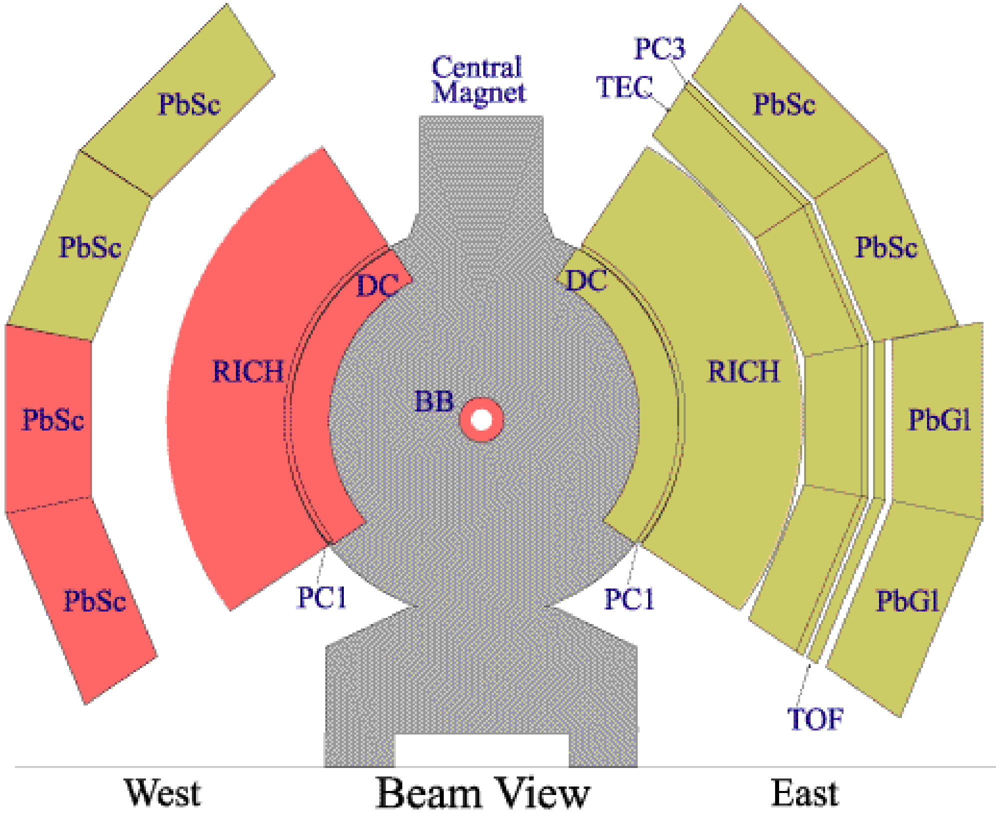


Two central electron/photon/hadron spectrometers

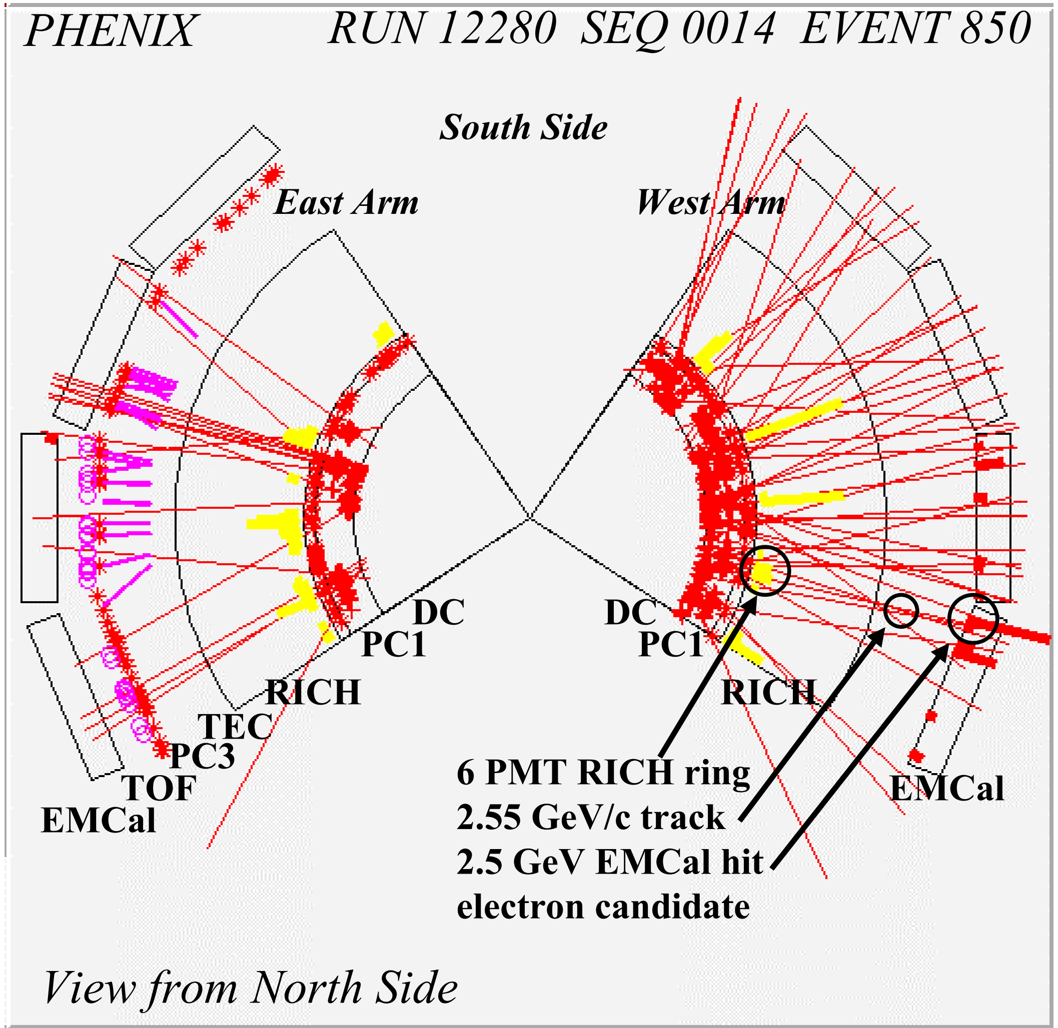
Two forward muon spectrometers

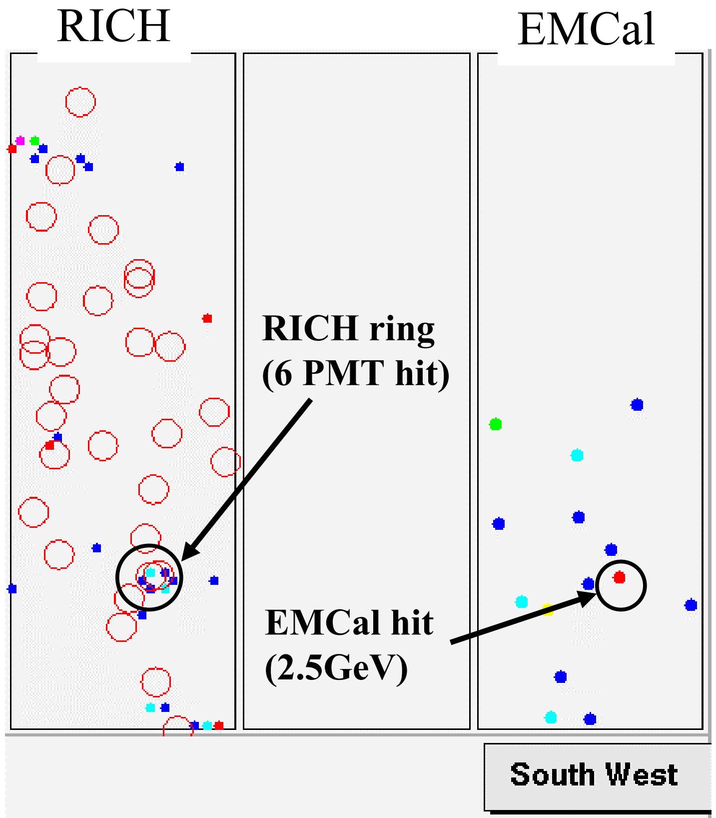
PHENIX in RUN-1

- Data is from RHIC run-1, Au+Au at $s_{NN}^{1/2} = 130$ GeV
- 1.23 M events with $|z_{vertex}|<30$ cm
- Detectors for the electron measurement
  - BBC
    - Trigger
    - Vertex position
  - DC and PC1 (W)
    - Track reconstruction
    - Momentum measurement
  - RICH(W)
    - Electron ID
  - PBSC(W):
    - Electron ID
    - Energy measurement



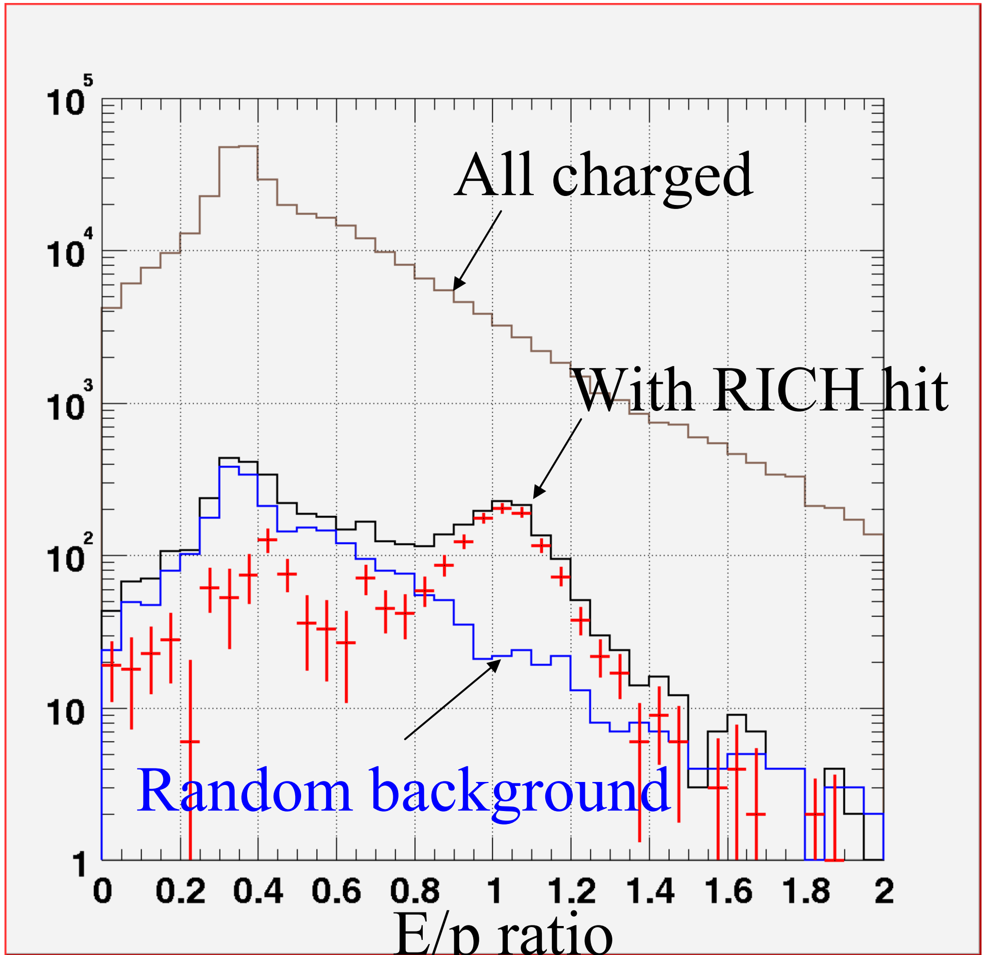
High Pt electron in PHENIX





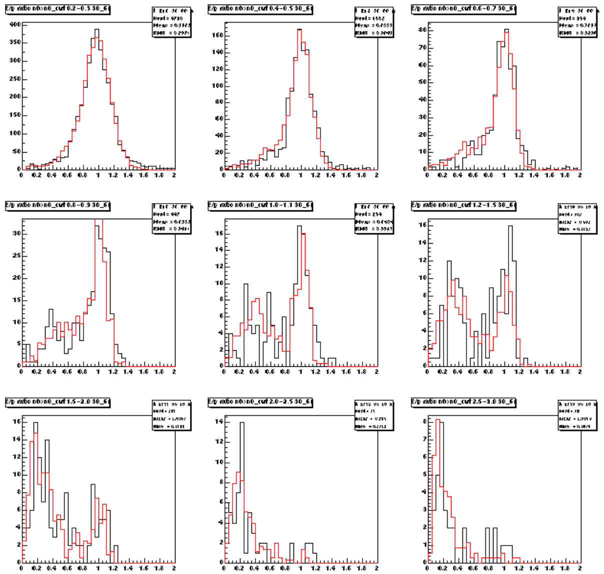
Electron Identification

0.8GeV<p<0.9GeV

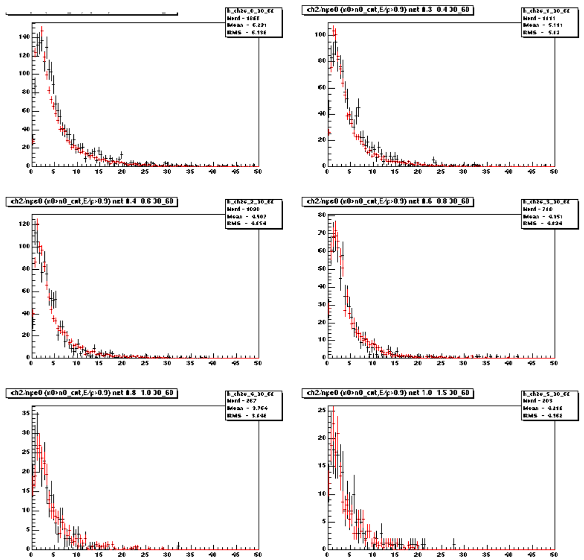


- Electrons are identified by RICH and EMCAL
- A clear peak in energy/momentum (E/p) ratio is seen at 1.0 after RICH hit is required
- EMCAL E/p cut cleans up the rest of the background.
- Random background is also subtracted by an event mixing method

Electron detection efficiency



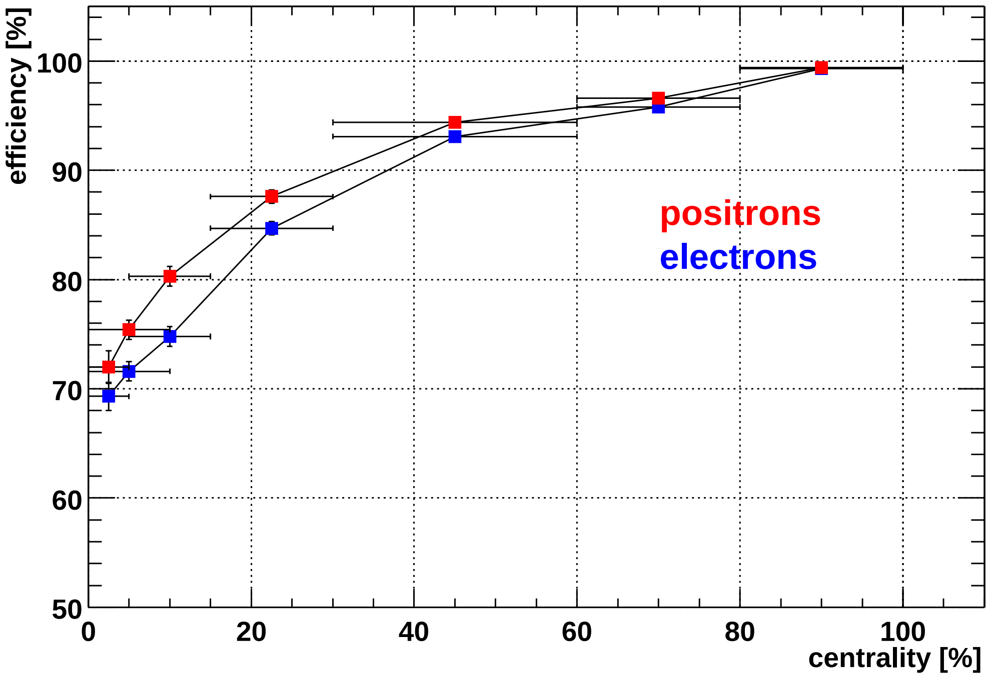
E/p ratio
Data vs MC



RICH χ^2
Data vs MC

- Acceptance and electron reconstruction efficiency are determined using a detailed GEANT Simulation.
- The simulation well reproduces the detector response to electron.
- The simulation is checked with the comparison with the real data.

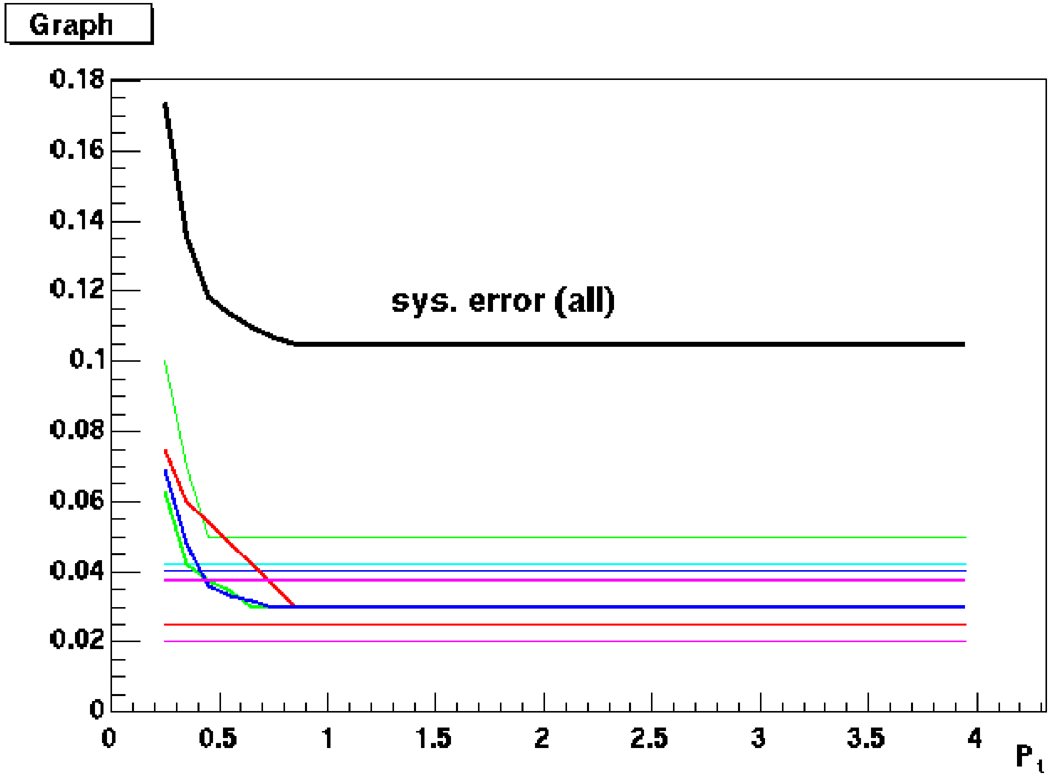
Multiplicity dependent corrections



Tracking efficiency loss due to high multiplicity was studied by a track embedding method.

The loss (~30% at the most central bin) was corrected in the data.

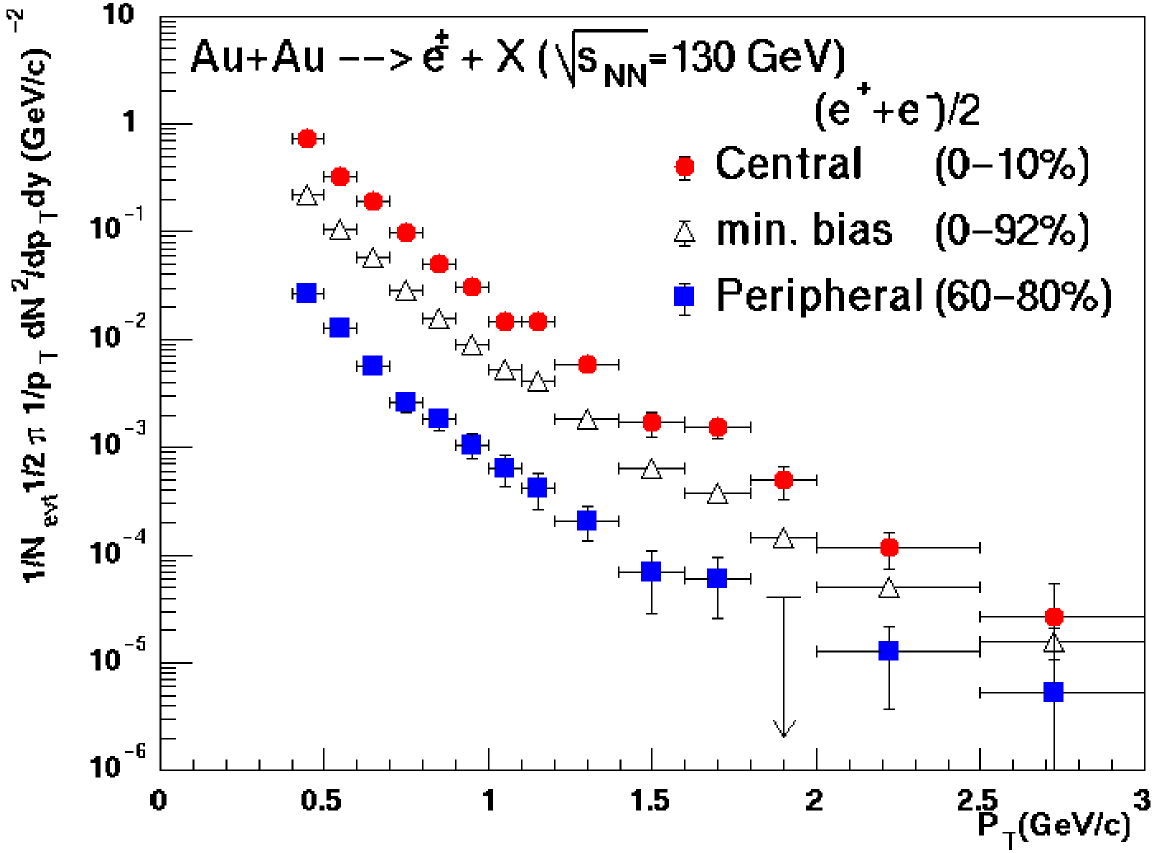
Systematic uncertainties



Contributions from electron ID efficiency, acceptance, tracking efficiency, hadron background, etc.

Figure 17 Estimated relative systematic uncertainties of inclusive electron yield. The total systematic uncertainty is shown as black line as function of pt. The other lines are break-down of the contributions: red (MC statistics) green (geometrical acceptance) blue (track EMCAL association cut) magenta (embedding statistics) light blue (embedding systematic), thick red (n0 cut) thick green (chi2 cut) thick blue (E/p matching) and thick magenta (hadron background)

Single electron spectrum



- Fully corrected single electron spectra in PHENIX.
- The spectra includes background such as Dalitz decays and photon conversions.

Sources of electrons

- Dalitz decays of π^0,η,η',ω,ϕ ($\pi^0 \rightarrow ee\gamma$, $\eta \rightarrow ee\gamma$, etc)
- Di-electron decays of ρ,ω,ϕ
- Photon conversions
- Kaon decays

} background

- Charm decays
- Bottom decays
- Other
  - Thermal di-leptons
  - Conversion of direct photons

} signal

Background from light hadron decays

$\pi^0 \rightarrow e^+e^- \gamma$
$\pi^0 \rightarrow \gamma\gamma$, $\gamma \rightarrow e^+e^-$

- ~80% of background
- Proportional to pion
- conversion ~ 1.9 x Dalitz in PHENIX

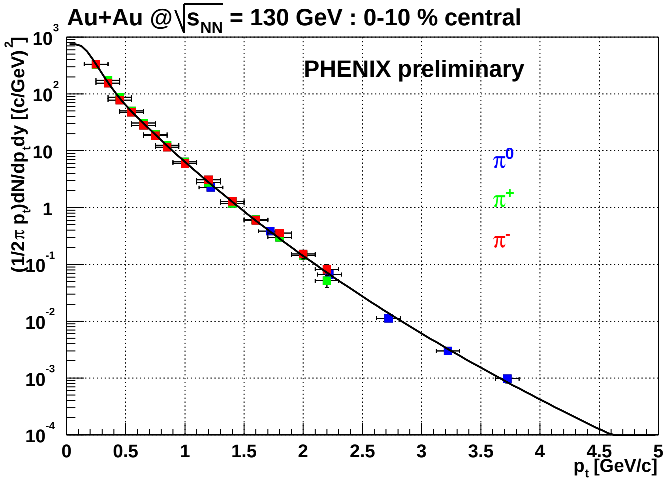
$\eta \rightarrow e^+e^- \gamma$
$\eta \rightarrow \gamma\gamma$, $\gamma \rightarrow e^+e^-$

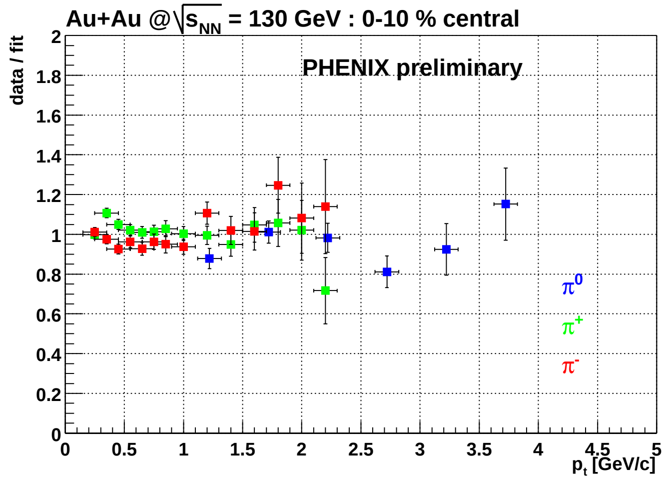
~20% of π^0 contribution at high pt

Other contributions: small

- The measured electron spectra includes trivial background from light hadron decays such as π^0 Dalitz decay and photon conversions.
- The background is estimated using a hadron decay generator that is constrained by pion measurement by PHENIX

Background: π^0 Dalitz

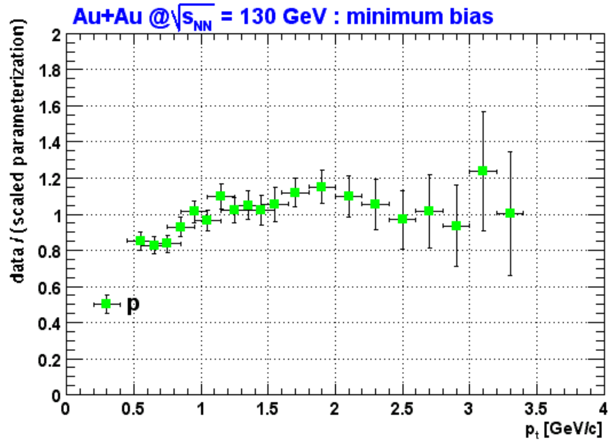




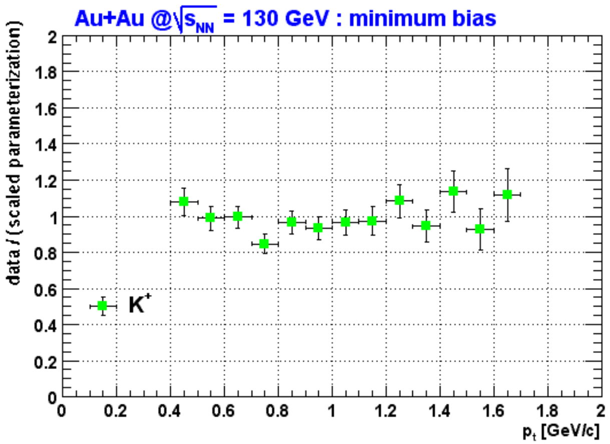
- Background from Dalitz decays and di-electron decays are calculated using a hadron decay generator.
- The π^0 spectrum of the generator is determined by combined fit to PHENIX π^0 and $\pi^{\pm}$ data.
- The systematic in the spectrum is estimated by changing the input $\pi^{\pm}$ and π^0 spectrum within their systematic errors.

Background: other hadrons

Data/Mt scaled spectrum (p)

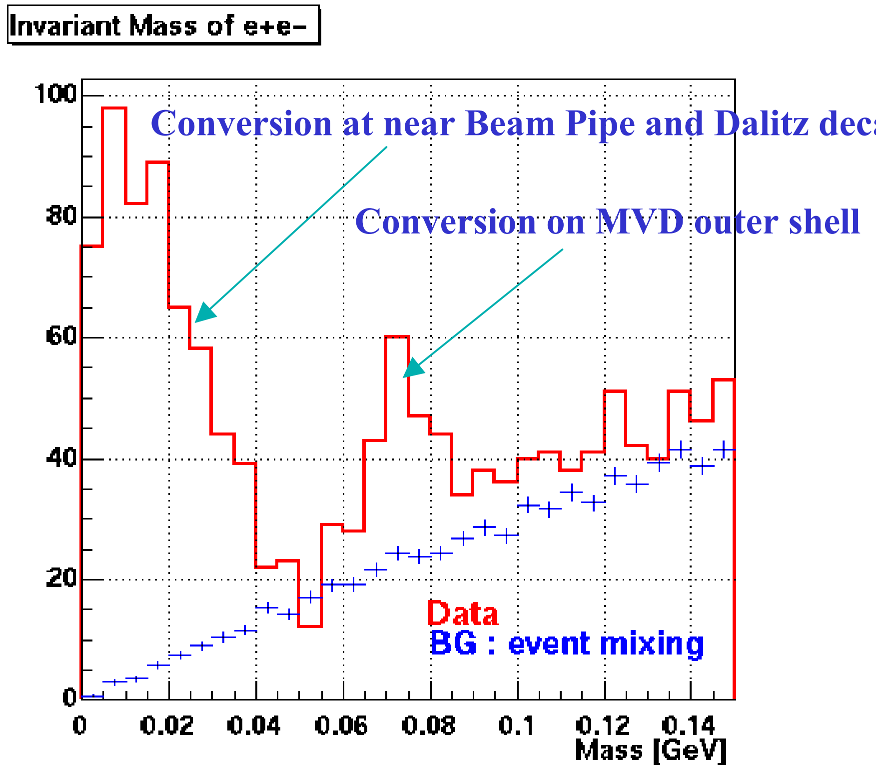


data/Mt scaled spectrum (K^+)



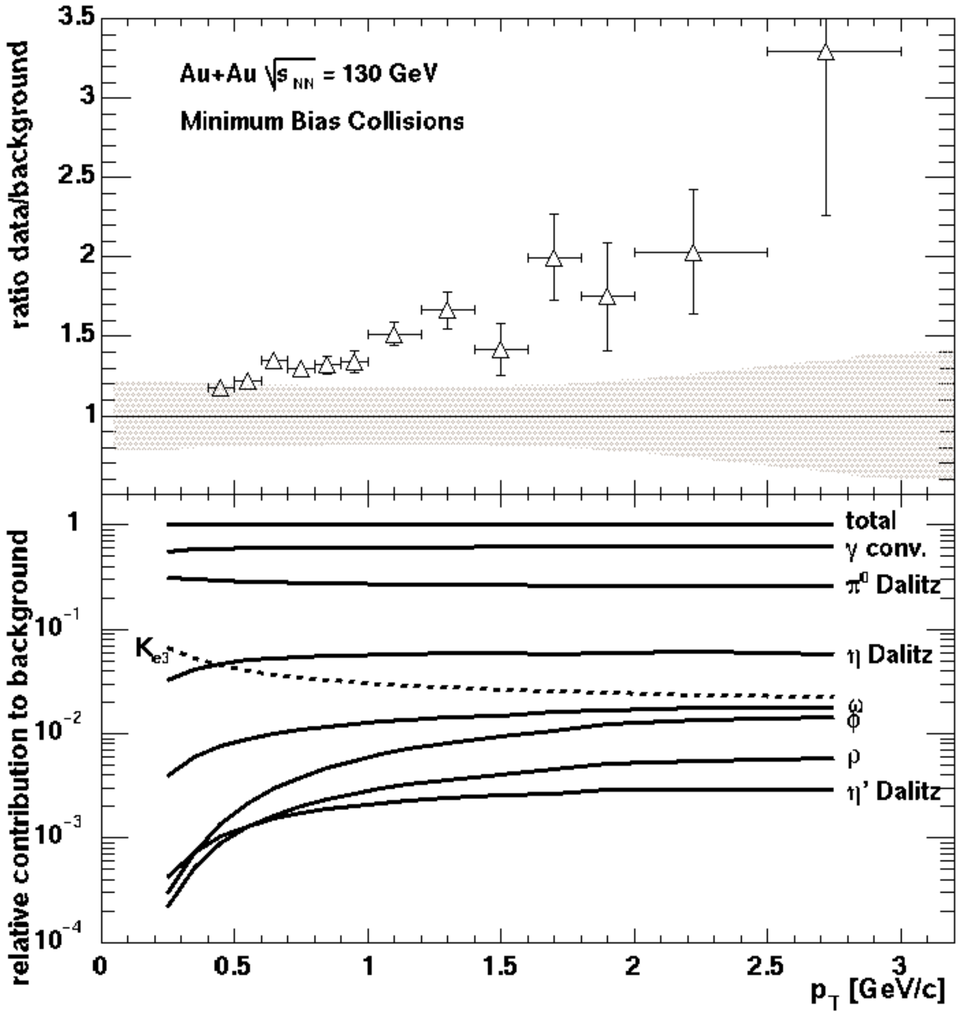
- Pt distribution of other hadrons are obtained from pi0 spectrum by m_T scaling
  $p_t \rightarrow sqrt(p_t^2+m_h^2-m_\pi^2)$
- Spectra shapes of $K^\pm$,$p^\pm$ agree with this scaling within 20%
- Particle ratios at high pt:
  - η/π = 0.55
  - η'/π = 0.25
  - $\rho/\pi = \omega/\pi$ = 1.0
  - ϕ/π = 0.40
- Assign conservative systematic error of 50% to these ratios

Background: Photon conversion



- Single electron spectrum conversion ~ R*Dalitz
- The re-scaling factor, R, is determined from the GEANT simulation.
- The simulation is cross checked by comparing the relative yield of Dalitz pairs and conversion pairs in the real data and in the simulation.
- $R=1.9\pm0.2x(1-0.0718p_t^{-0.76})$

Data/background ratio

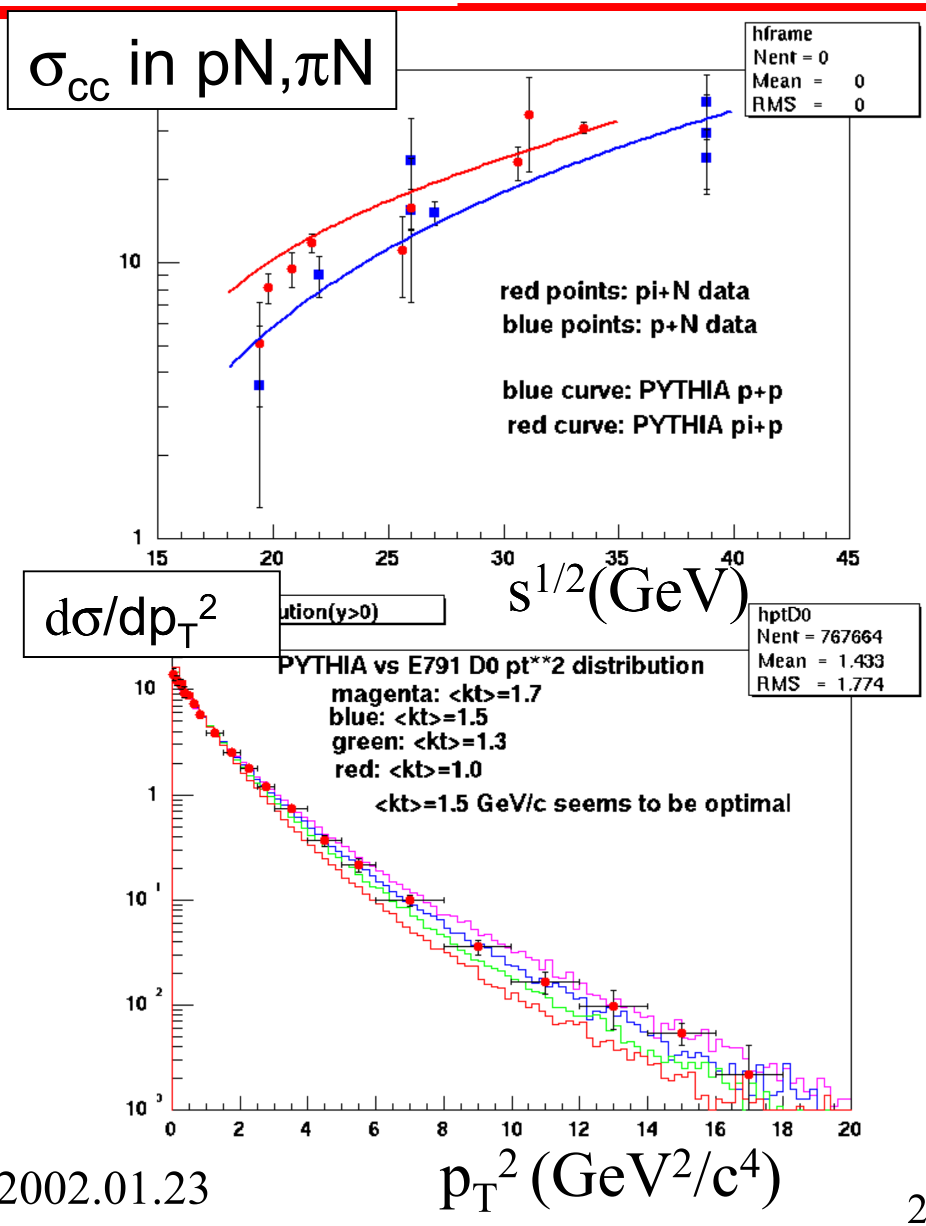


- The Upper panel shows data/background ratio as function of p_t for min. bias collisions.
- The data show excess above background in pt>0.6 GeV/c.
- Central collision data also show similar excess.
- Peripheral data do not have enough statistics
- The low panel shows the relative contribution to the background from various sources.

Charm contribution to the signal

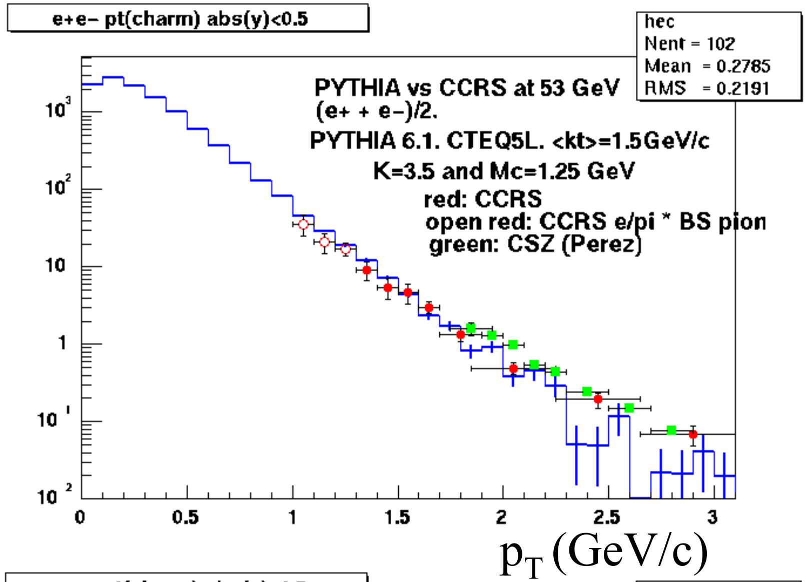
- Semi-leptonic decay of charm is an expected source of the electron signal above the background.
- The electron spectrum from charm decay is evaluated by PYTHIA
- PYTHIA parameters are tuned such that fixed target charm data and ISR single electron data are well reproduced.
  - PYTHIA6.152+CTEQ5L, Mc=1.25 GeV, K=3.5, $\langle k_t \rangle$=1.5 GeV/c
  - $\sigma(pp \rightarrow cc)$=330 μb at 130 GeV by this PYTHIA calculation

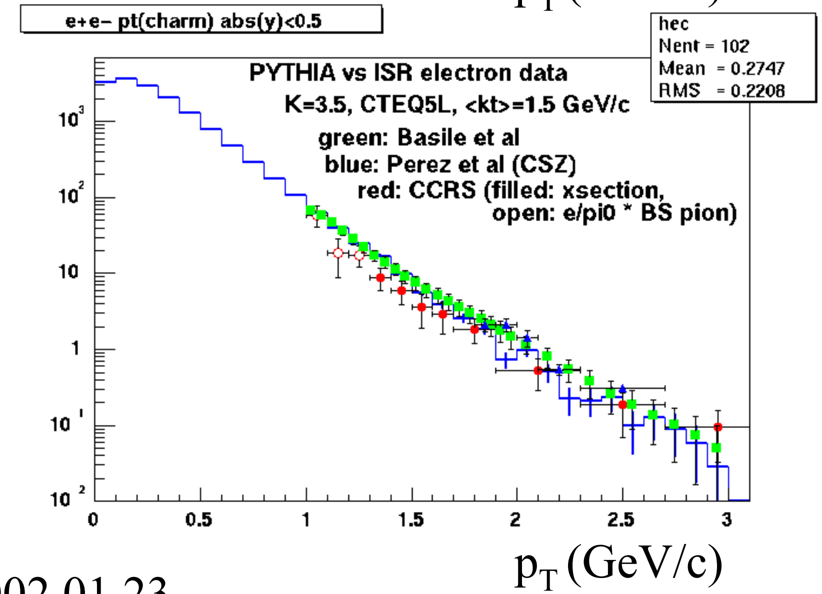
PYTHIA and charm data



- Use PYTHIA 6.152
- Modified parameters
  - Mc = 1.25 GeV
  - K = 3.5
  - <kt> = 1.5 GeV/c
- Charm cross section by fixed target experiments are reasonably reproduced.
- Pt distribution of D-mesons by E791 and BEATRICE are also reproduced.

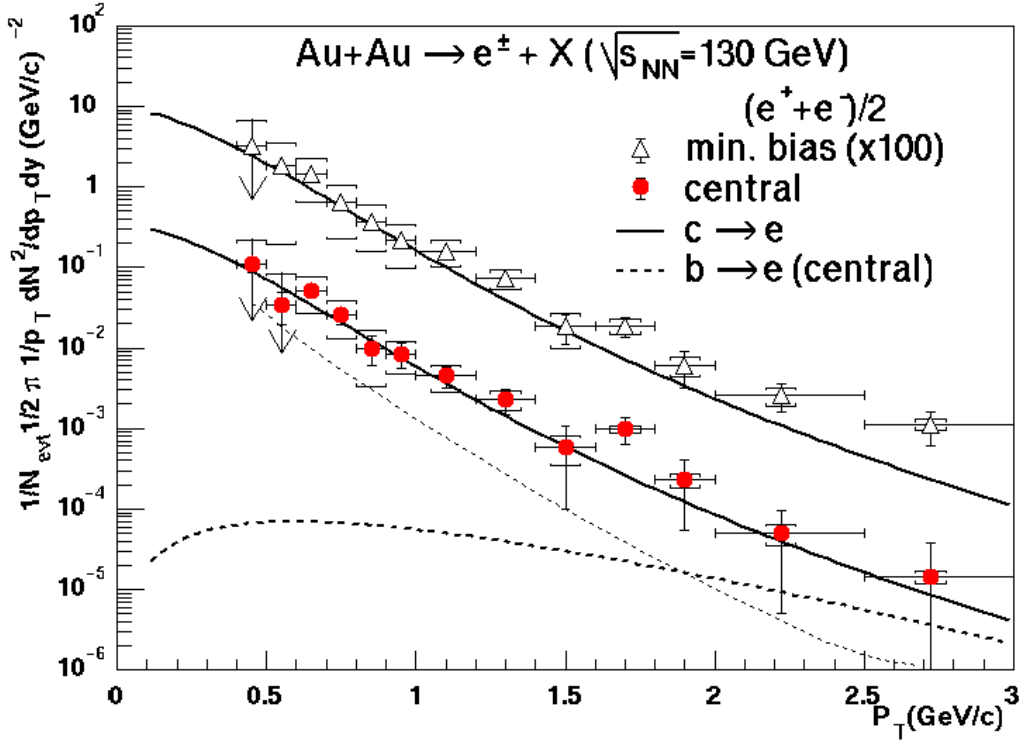
PYTHIA and ISR single electron





- Electron spectrum from charm decay calculated with the tuned PYTHIA is compared with the single electron data at the ISR.
- The calculation reasonably reproduces the single electron data.

Background-subtracted single electron spectra



- Spectra of single electron signal is compared with the calculated charm contribution.
- The agreement is reasonably good.

Other sources of signal

- b-decays
  - Becomes significant only in higher pt.
- J/Psi decays
  - negligible compared with the signal.
- Thermal di-leptons
  - $\rho \rightarrow ee$ contribution is less than 1% of background
  - A large contribution from $\pi\pi \rightarrow \rho \rightarrow ee$ (dominant source of low mass pair) is unlikely.
- Conversion of direct photons
  - Can contribute 10-20% to the signal.
  - Large uncertainty in theoretical predictions

Charm cross section from the electron data

- We can estimate the charm yield by assuming that all single electrons above the background are from charm
  - Neglect other possible sources such as thermal γ and di-leptons
  - Charm yield can be over-estimated.
- By fitting the PYTHIA electron spectrum to the data for pt>0.8 GeV/c, we obtained charm yield Ncc per event.
- The charm cross section per binary NN collision is obtained as

$$\sigma_{c\bar{c}} = \frac{1}{T_{AA}} N_{c\bar{c}}$$

- TAA is nuclear overlap integral ~ NN integrated luminosity per event
  - TAA=22.6±1.6/mb (central 0-10%)
  - TAA=6.2±0.4/mb (min. bias 0-92%)

Derived charm cross section

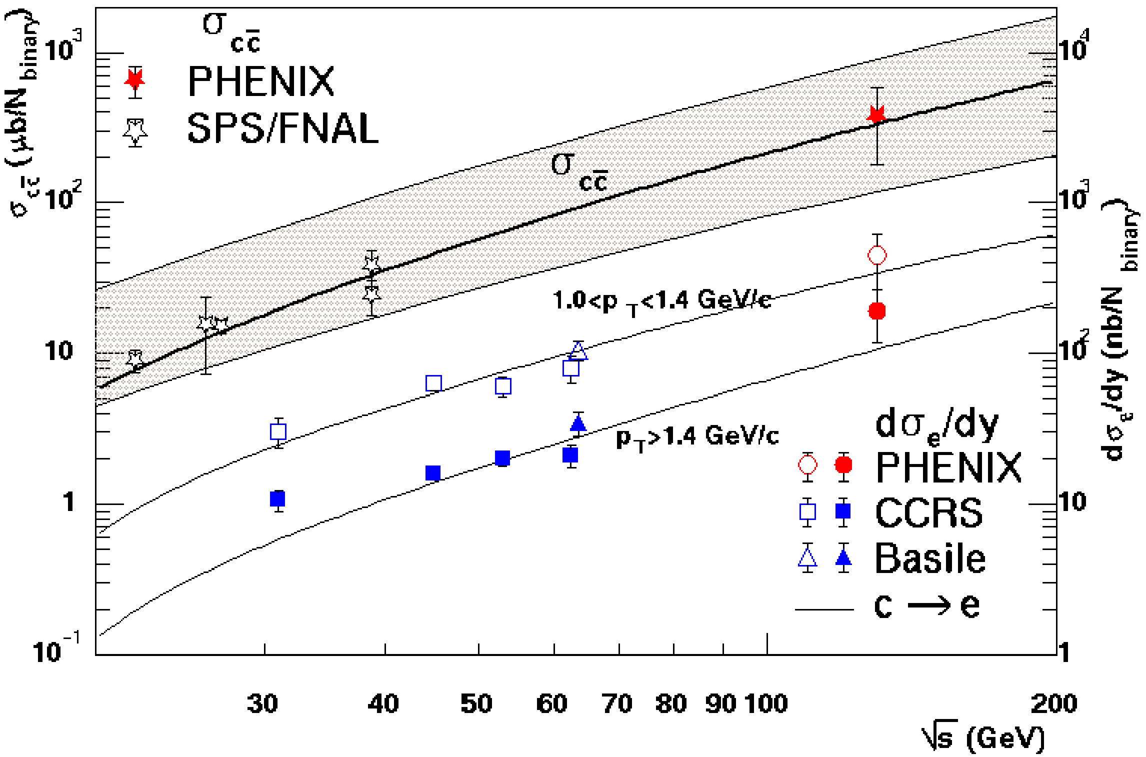
- **Charm cross section per NN collision in central and minimum bias collision are obtained as**

$$\sigma_{c\bar{c}}(0-10\%) = 380 \pm 60 \pm 200 \mu b$$

$$\sigma_{c\bar{c}}(0-92\%) = 420 \pm 33 \pm 250 \mu b$$

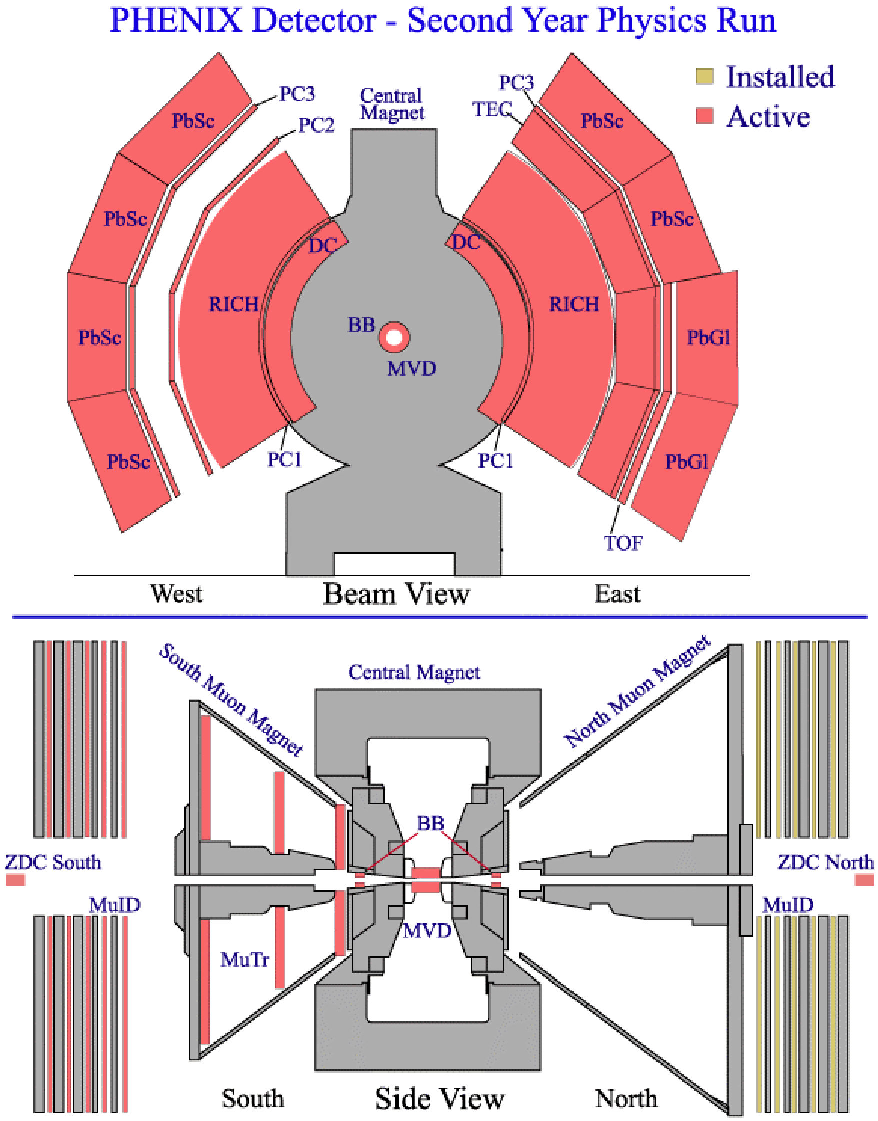
- **If charm production follows binary scaling, cross section per NN cross section should be independent of centrality**
- **The data is consistent with the binary scaling (i.e. no nuclear or medium effects), but with large uncertainties.**

Comparison with other experiments



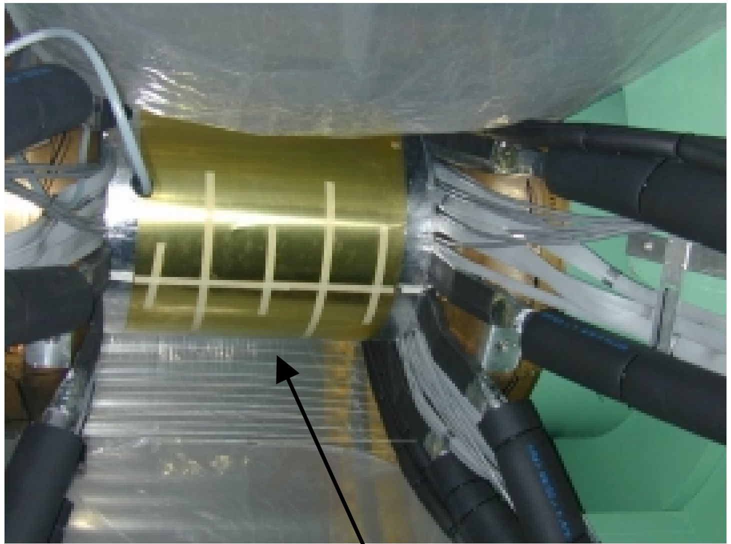
- PHENIX single electron cross section is compared with the ISR data
- Charm cross section derived from the electron data is compared with fixed target charm data
- Solid curves: PYTHIA
- Shaded band: NLO QCD

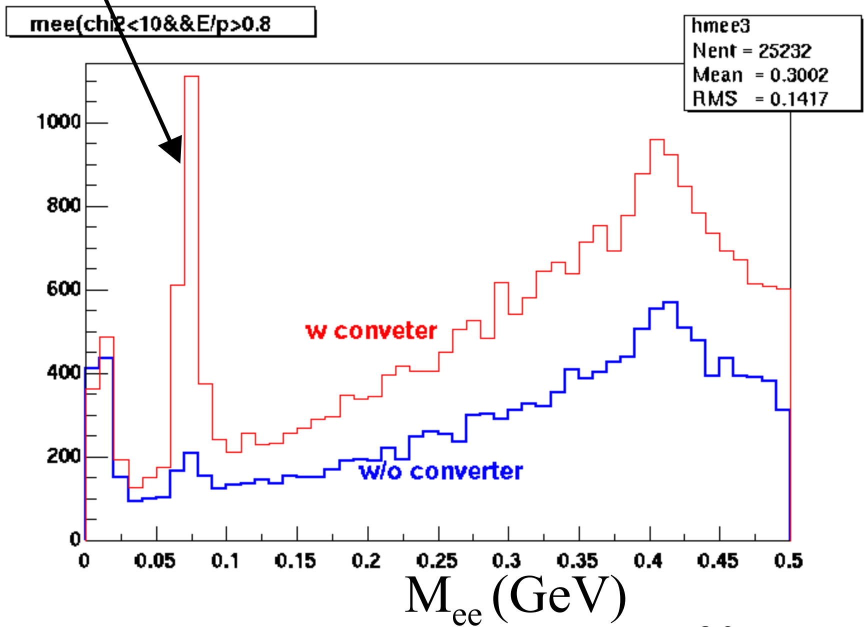
RUN-2



- Central arms fully instrumented
- South muon arm installed
- LVL-2 triggers for
  - Single electrons
  - Electron pairs
  - Single muons
  - Muon pairs
- Much higher statistics than RUN-1
  - 170 M events sampled
  - More than 100 times of RUN-1 data set.
- Comparison data in p+p

Converter run in RUN-2





- Special runs with a photon converter
- By comparing data set with and without the converter, we can directly measure the background from photon conversion.

→ We can determine non-photonic source of electron ~ charm decay

PHENIX

Summary

- We have observed single electron above the expected background from decays of light hadrons and photon conversions in Au+Au collisions at $s_{NN}^{1/2}$ =130 GeV.
- The observed signal is consistent with electron from semi-leptonic decay of charm.
- The charm cross section corresponding to the observed signal in central collision is 380±60±200μb per binary collisions.
- The forthcoming RUN-2 data will be useful to clarify the nature of single electron signal and open charm production in Au+Au collisions at RHIC

Backup slides

Shift of Invariant Mass

Our tracking algorithm require position of collision vertex.
For photon conversion at R!=0, opening angle of e+e- pair is reconstructed
Effectively large. It is affected to Mee position