Single Electron and Charm Production at RHIC

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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

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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

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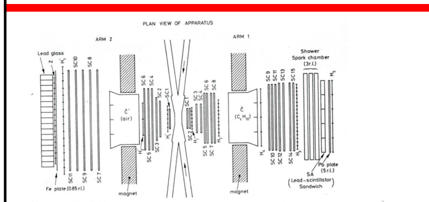
History
single electron at the ISR



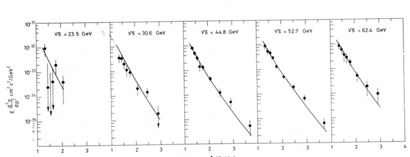


Fig. 7. The charge-averaged invariant cross section for electron production, plotted as a function of the c.m. momentum p_T^* for five values of $\sqrt{s}$. The curve represents a fit of the charge-averaged pion data of the BS Collaboration [22], and has been multiplied by 10^{-4}.

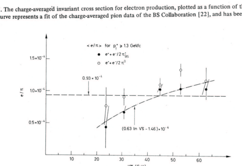


Fig. 9. The ratio of the invariant cross sections of electrons to pions of $p_T^* \geq 1.3$ GeV/c plotted as a function of c.m.s. energy $\sqrt{s}$. The pion data were obtained from the work of the British-Scandinavian Collaboration [22] (solid points) and from the spectrum of selected conversions measured 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/π~1-2x10^{-4} at the ISR
  - Higher signal level is expected at RHIC

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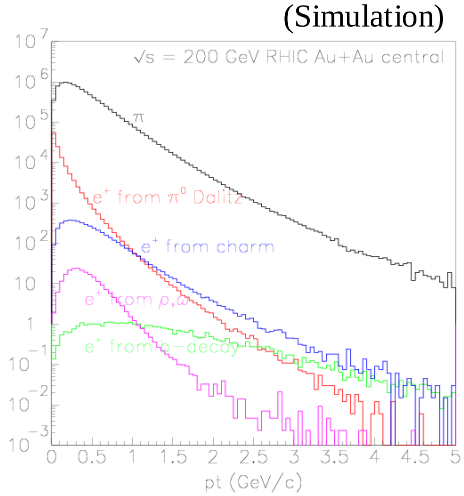
single electrons at high pt

- 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 $\times10^{-4}$ 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)



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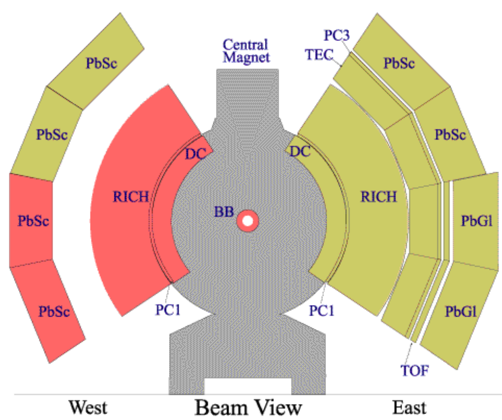
PHENIX in RUN-1

- 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



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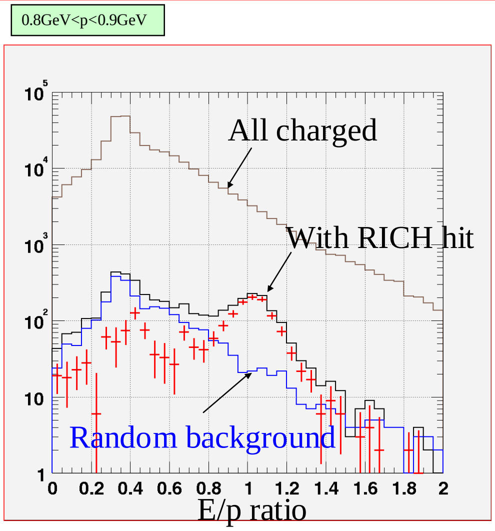
Electron Identification



- 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

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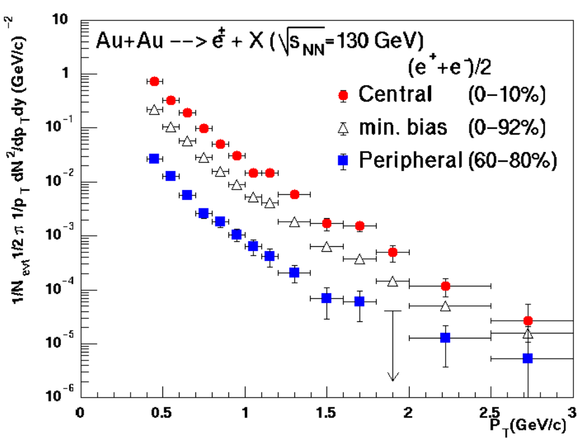
Single electron spectrum



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

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Sources of electrons

- Dalitz decays of $\pi^0,\eta,\eta',\omega,\phi$ ($\pi^0 \rightarrow ee\gamma$, $\eta \rightarrow ee\gamma$, 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

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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

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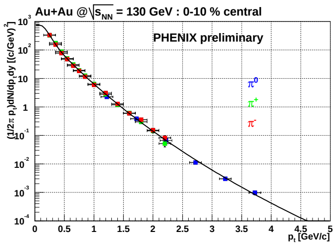
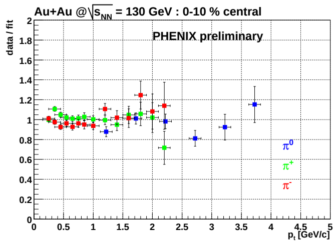
Background: π^0 Dalitz





- 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.

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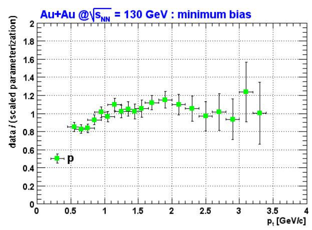
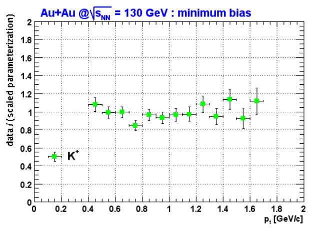
Background: other hadrons

Data/Mt scaled spectrum (p)



data/Mt scaled spectrum (K^+)



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

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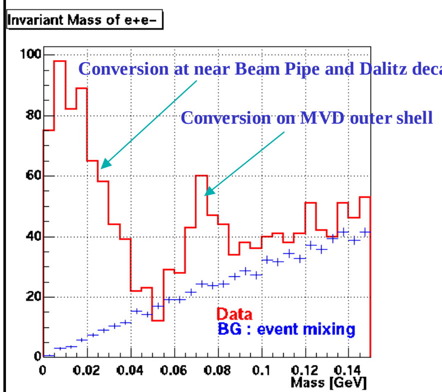
Background: Photon conversion



- 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.
- $R=1.9\pm0.2x(1-0.0718p_t^{-0.76})$

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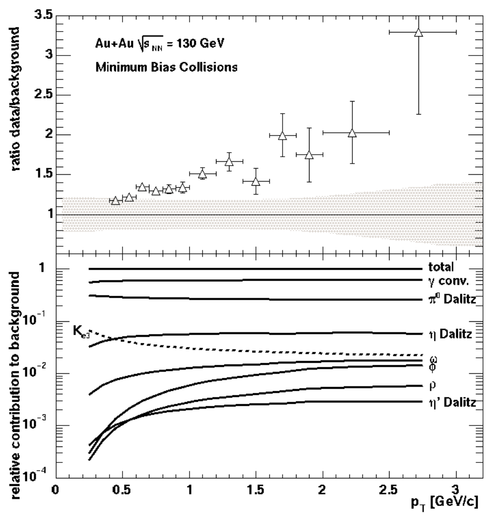
Data/background ratio



- 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.
- Pheripheral data do not have enough statistics
- The low panel shows the relative contribution to the background from various sources.

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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

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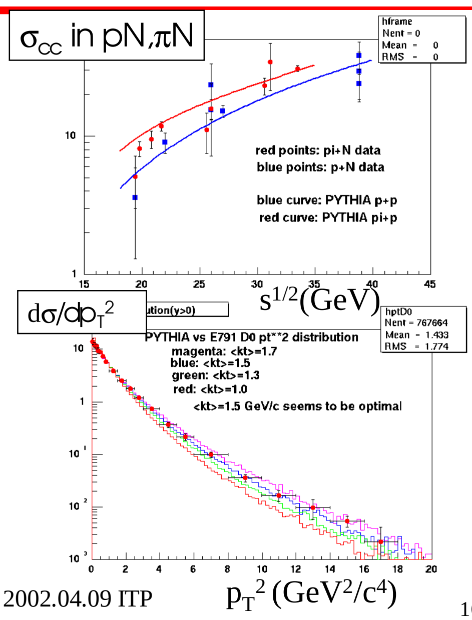
PYTHIA and charm data



- Use PYTHIA 6.152
- Modified parameters
  - Mc = 1.25 GeV
  - K = 3.5
  - $\langle kt \rangle$ = 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.

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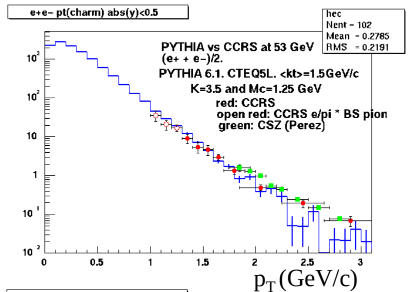
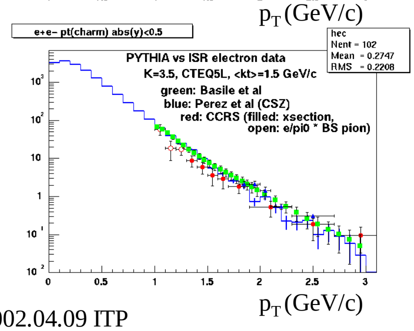
PYTHIA and ISR single electron





- 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.

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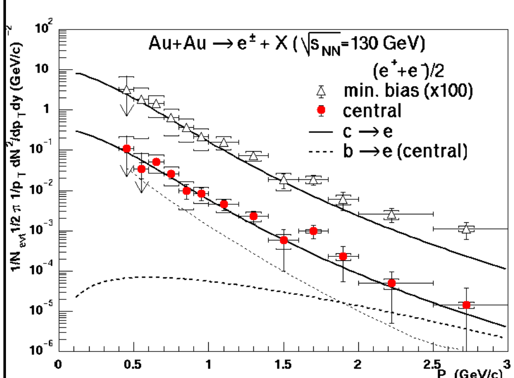
Background-subtracted single electron spectra



- Spectra of single electron signal is compared with the calculated charm contribution.
- Charm contribution calculated as

  $EdN_e/dp^3 = T_{AA} Ed\sigma/dp^3$

  - T_{AA}: nuclear overlap integral
  - $Ed\sigma/dp^3$: electron spectrum from charm decay calculated using PYTHIA
- The agreement is reasonably good.

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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

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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

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

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

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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.

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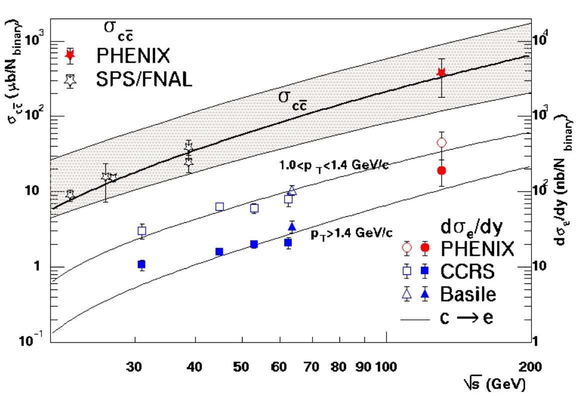
Comparison with other experiments



- 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

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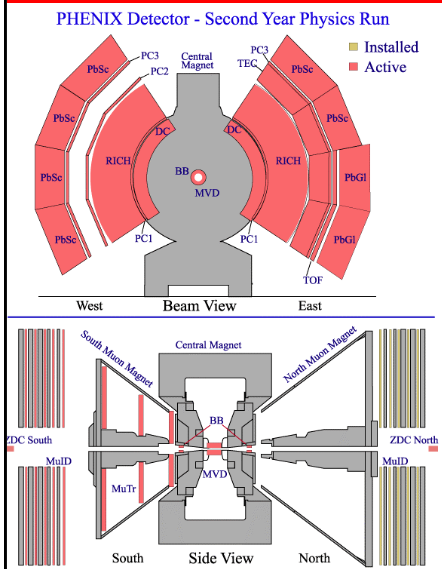
RUN-2



- 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

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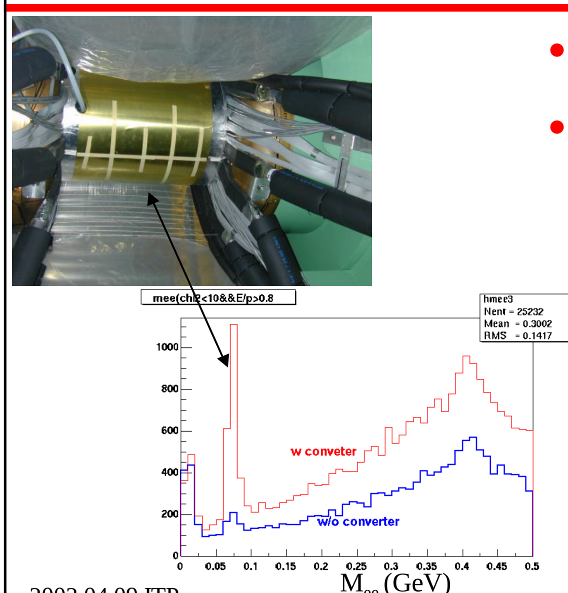
Converter run in RUN-2



- 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

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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

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