Recent STAR results on heavy-flavor correlation measurements using leading electrons

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Outline

- Motivation
- Correlation technique
- Data analysis
- Results
- Data-model comparison
- Summary and conclusions

XII. INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY

8-13 OCTOBER 2007

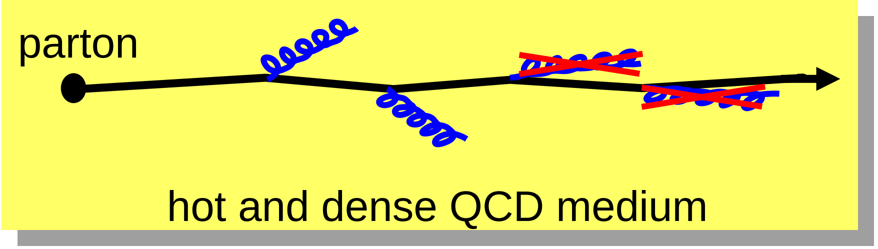
HADRON 07

Laboratori Nazionali di Frascati (Rome)

Energy loss of heavy quarks in the medium

- Due to their large mass, heavy quarks are predominantly produced by gluon fusion
  - → production rates can be calculated in pQCD
  - → sensitivity to initial state gluon distribution

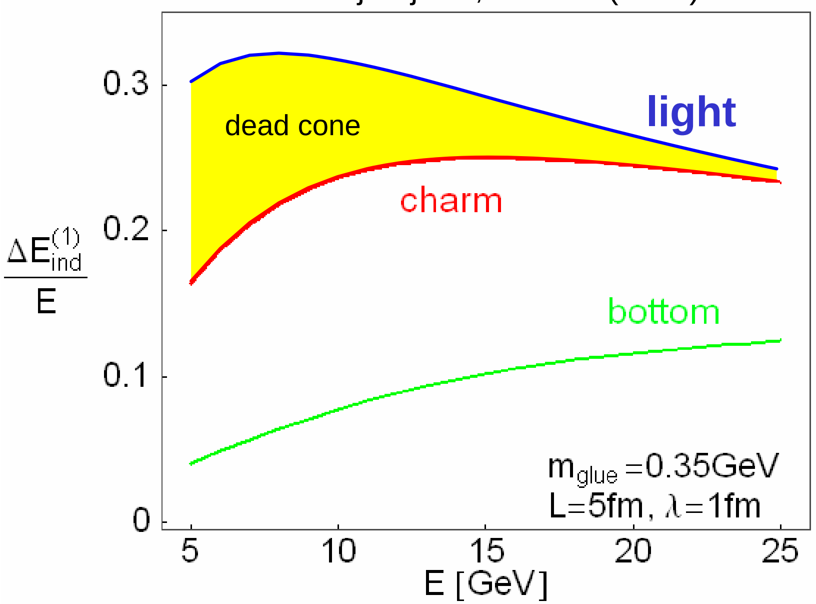
S. Frixione et al., Adv. Ser. Dir. HEP 15, 609 (1998)
M. Gyulassy and Z. Lin, PRC 51, 2177 (1995)



- Heavy quarks lose less energy due to suppression of small angle gluon radiation (dead-cone effect)

Dokshitzer and Kharzeev, PLB 519, 199 (2001)

M. Djordjevic, PRL 94 (2005)



- Amount of collisional and radiative energy losses seems to be similar

A. Adil and I. Vitev, Phys. Lett. B649, 139 (2007)
M. Djordjevic, Phys. Rev. C74, 064907 (2006)

Non-photonic electron spectra in central Au+Au collisions

• Non-photonic electrons exhibit a similar yield suppression at high-p_T in central Au+Au as light hadrons

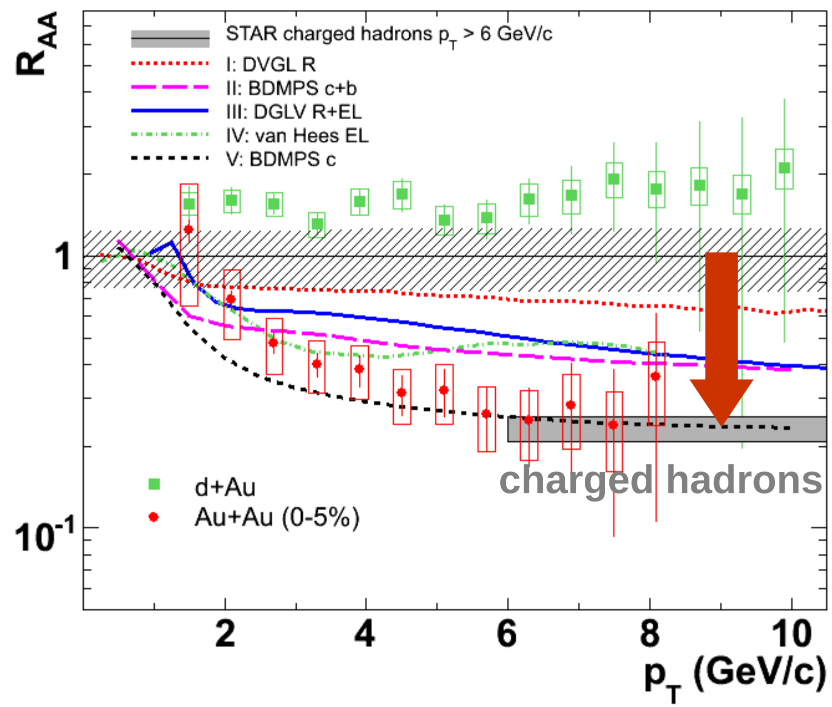
• Models implying D and B energy loss are inconclusive yet

→ Disentangle D and B contribution to non-photonic electron spectrum experimentally

→ At which p_T does B contribution start to dominate ?

• <u>Approach:</u> Non-photonic electron - D^0 meson azimuthal correlations

Phys. Rev. Lett. ***98****, 192301 (2007)*



Large suppression not expected due to dead-cone effect

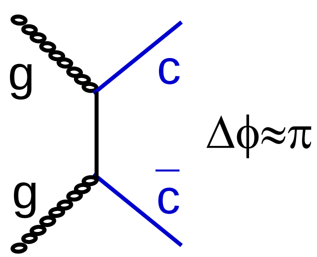
Electron tagged correlations

- Experimental approach

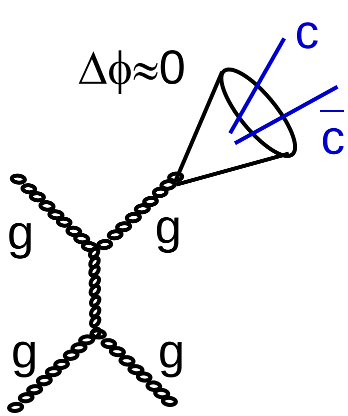
  - non-photonic electrons from semi-leptonic D/B decays are used to trigger on charm or bottom quark pairs

  - associate D^0 mesons are reconstructed via their hadronic decay channel (probe)

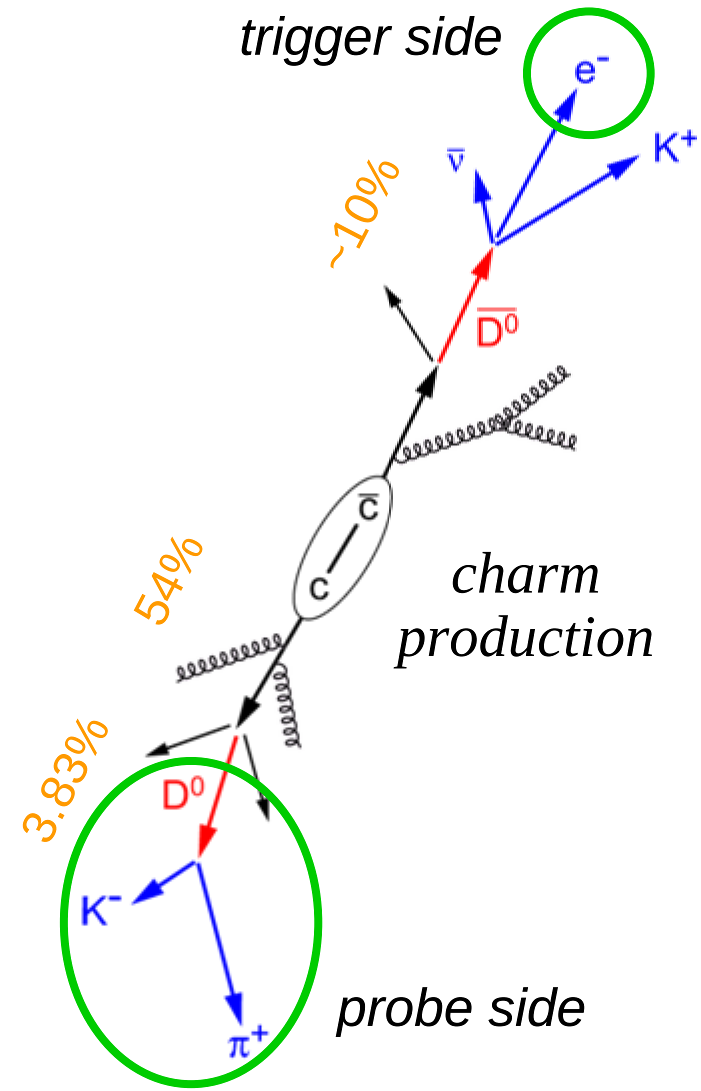
- Underlying production mechanism can be identified using second c/b particle



flavor creation

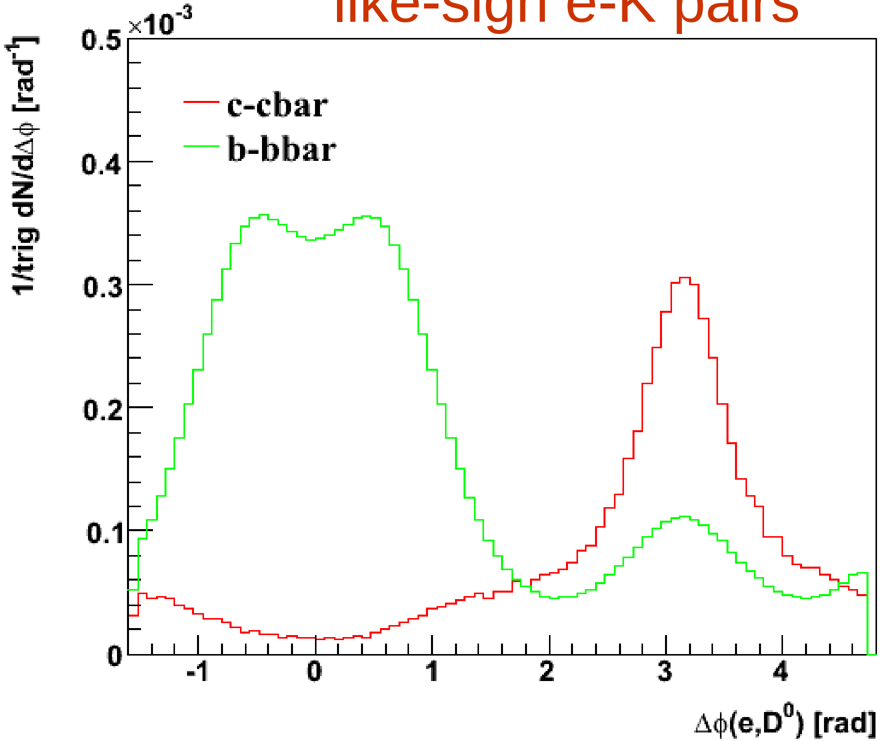


gluon splitting/fragmentation

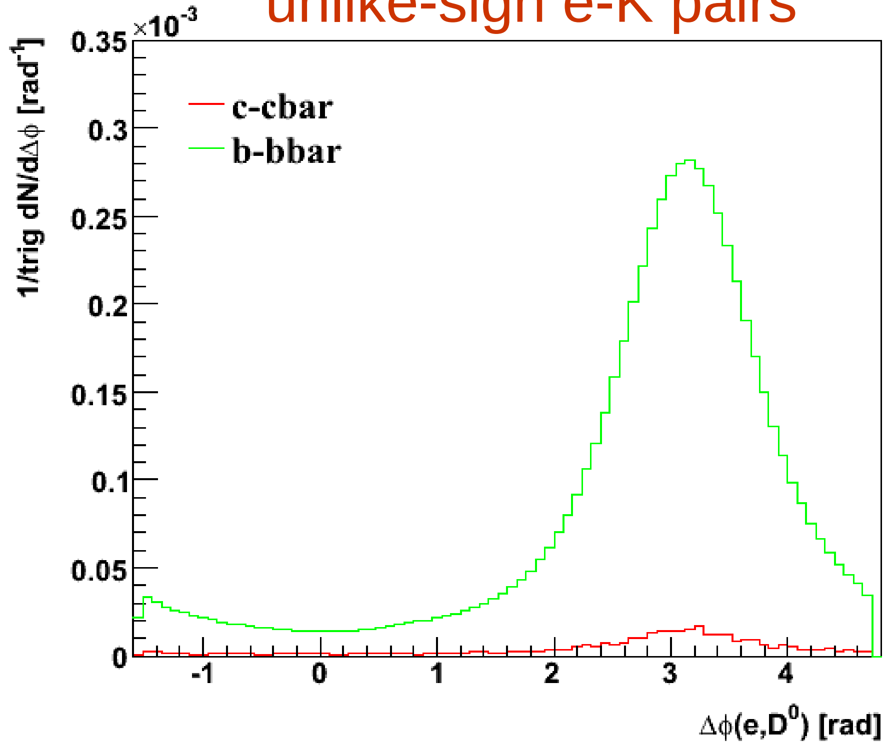


PYTHIA simulations: $3<p_T^{trg}<7$ GeV/c

like-sign e-K pairs



unlike-sign e-K pairs



- Different decay topology for charm and bottom production events
- Charge-sign requirement on electron-Kaon pairs gives additional constraint on production process
  - Like-sign e-K pairs means charge(electron) = charge(Kaon)

$\rightarrow$ Clear separation of charm and bottom contributions

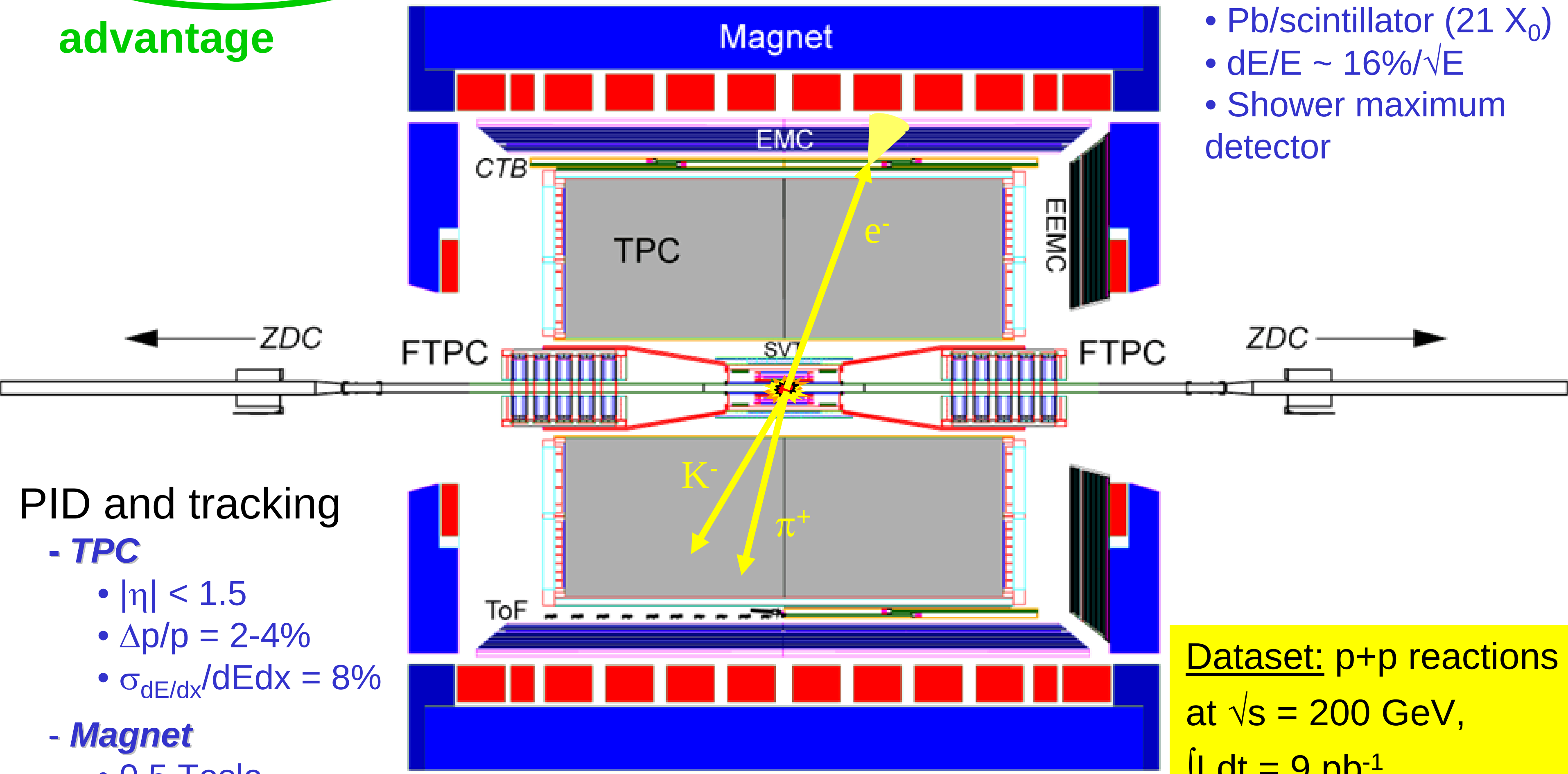
Data analysis

STAR experiment

Solenoidal Tracker at RHIC

Large acceptance magnetic spectrometer

advantage



Energy measurement

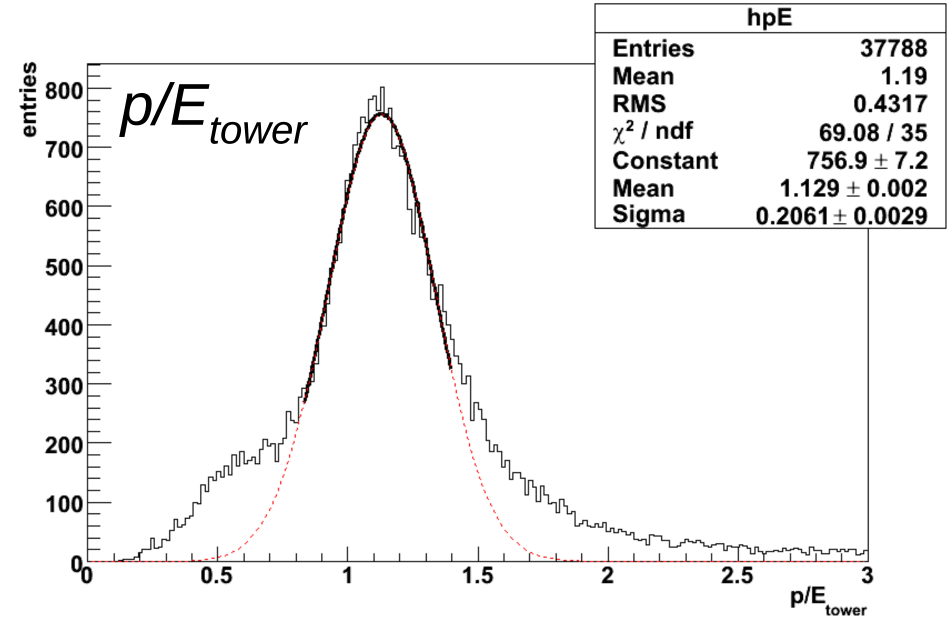
- ***Barrel EMC***
  - $|\eta| < 1$
  - Pb/scintillator (21 X_0)
  - $dE/E \sim 16\%/\sqrt{E}$
  - Shower maximum detector

PID and tracking

- ***TPC***
  - $|\eta| < 1.5$
  - $\Delta p/p$ = 2-4%
  - $\sigma_{dE/dx}/dEdx$ = 8%
- ***Magnet***
  - 0.5 Tesla

Dataset: p+p reactions at $\sqrt{s}$ = 200 GeV, $\int L dt = 9\ pb^{-1}$

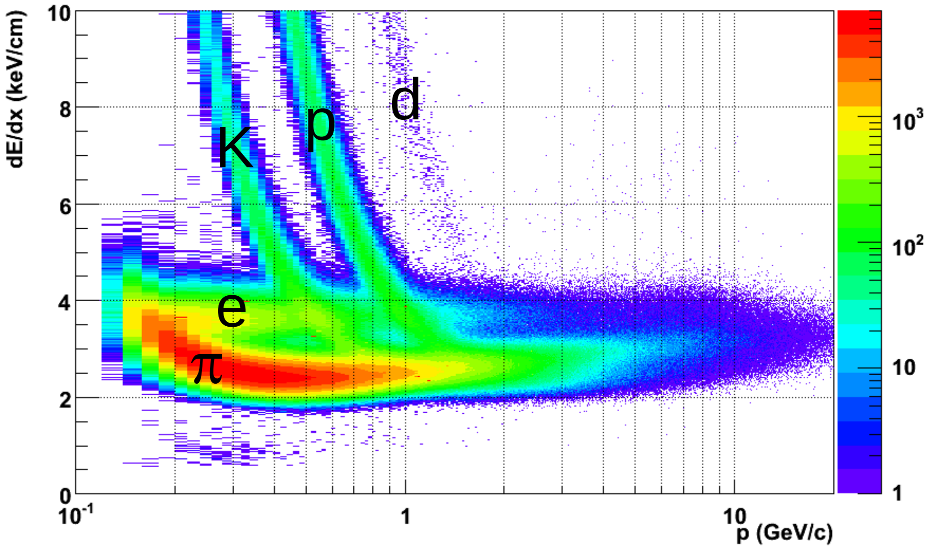
Electron identification



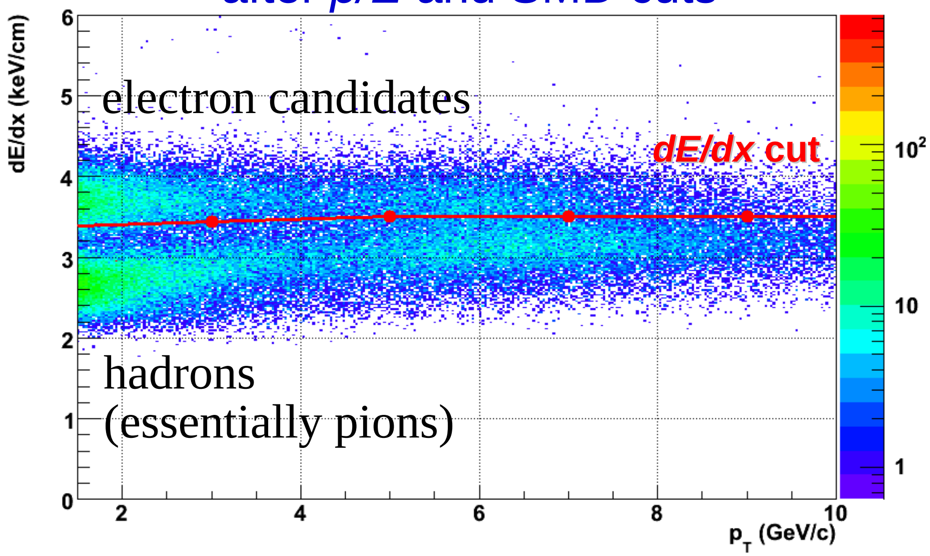
- Ratio of momentum and tower-energy should be one for electrons

$\rightarrow$ cut: $0 < p/E_{tower} < 2$

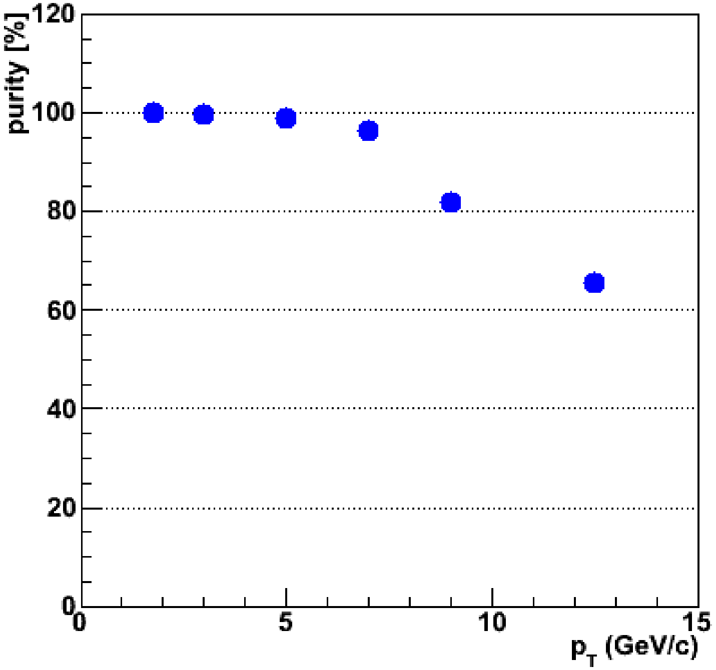
- $3.5 < dE/dx < 5.0$ keV/cm

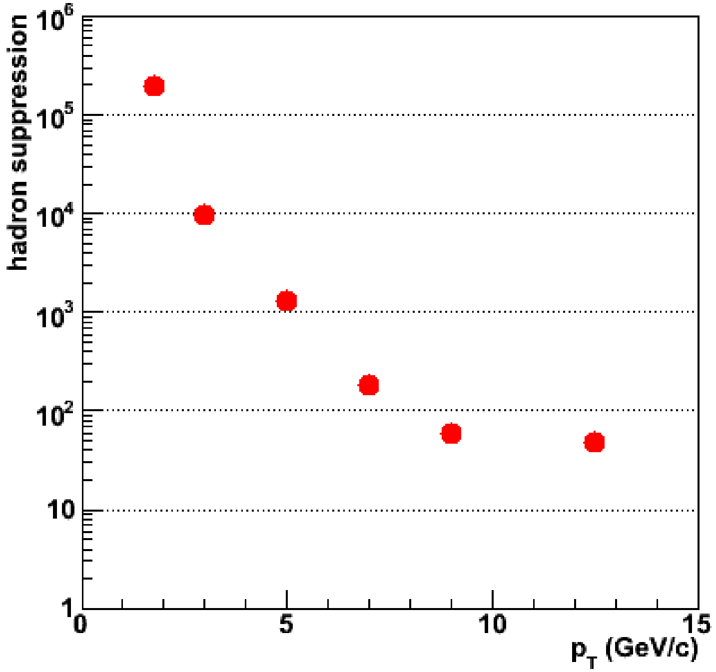


after *p/E* and SMD cuts



Electron purity and hadron suppression





- Purity: ~100% for $p_T < 7$ GeV/c
- Hadron suppression factor: 10^2 - 10^5

→ Clean electron sample

Photonic background

• Most of the electrons in the final state are originating from other sources than heavy-flavor decays

• Photonic contribution from gamma conversions and π^0 and η Dalitz decays

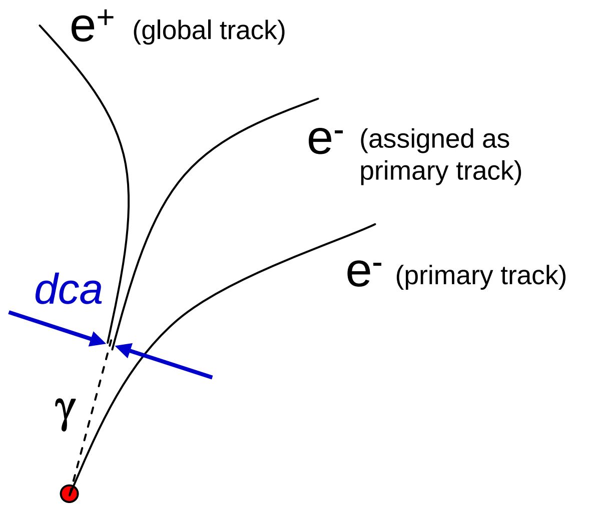
• Procedure

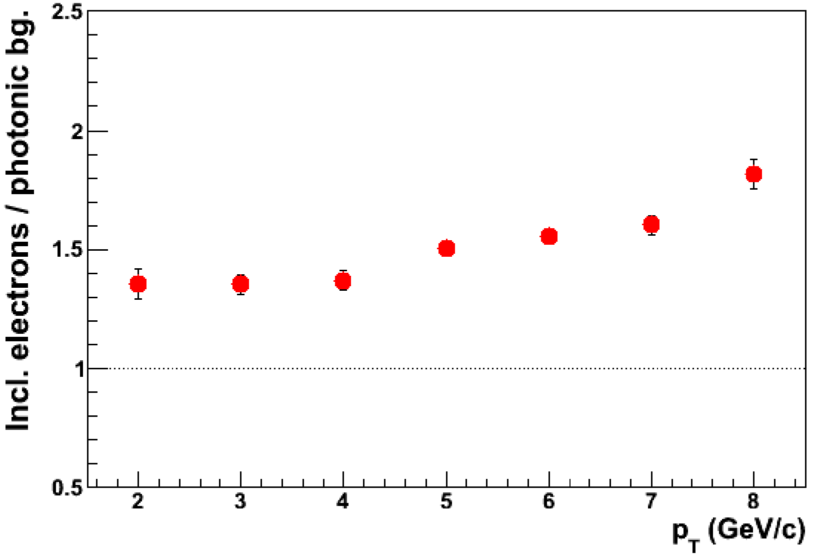
- electron candidates are combined with TPC tracks which passed loose *dE/dx* cuts around the electron band
- invariant mass is calculated at *dca* of these pairs

• Electrons having a low invariant mass ($m_{inv} < 150$ MeV/c^2) are excluded

• Correction for background rejection efficiency not implemented yet

→ Non-photonic electron excess at high-p_T

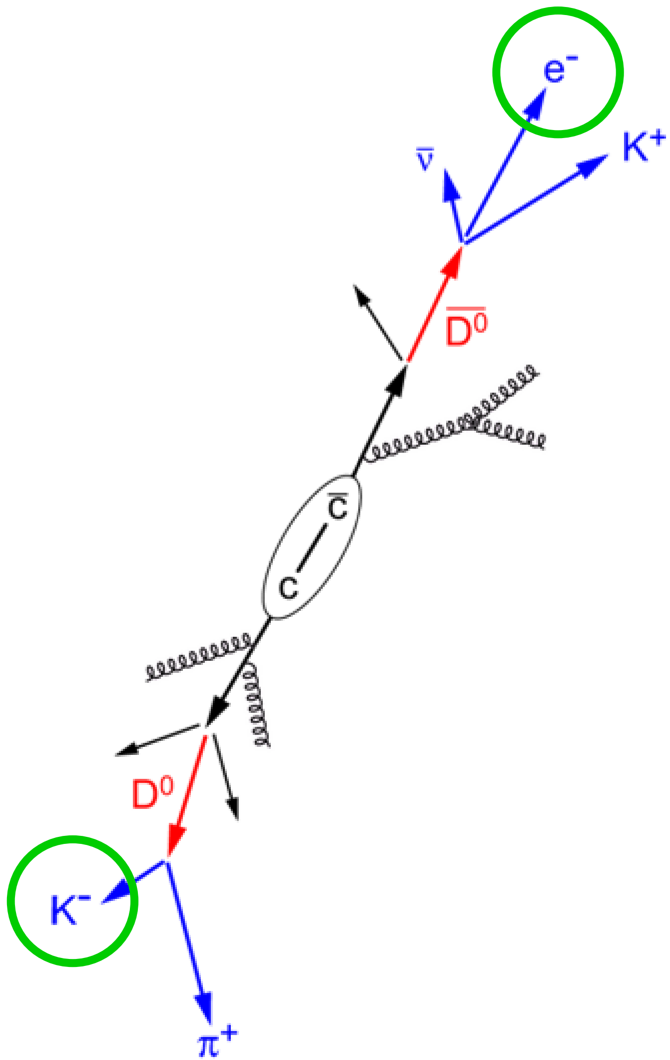




Topological reconstruction of open charm mesons

- Non-photonic electron trigger (leading particle) present in event
- No measurement of decay vertex
- *dE/dx* cut ($\pm 3\sigma$) around Kaon band
- Charge-sign requirement: *sign(e) = sign(K)*
- K-π invariant mass:

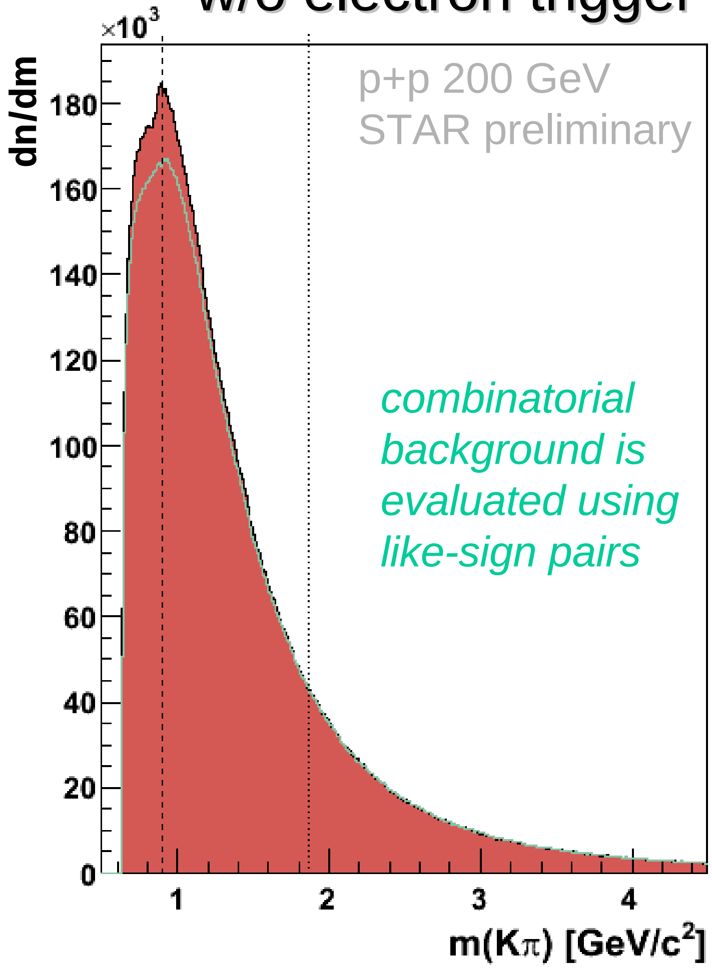
$$m = \sqrt{m_1^2 + m_2^2 + 2\left(E_1 E_2 - \vec{p}_1 \cdot \vec{p}_2\right)}$$



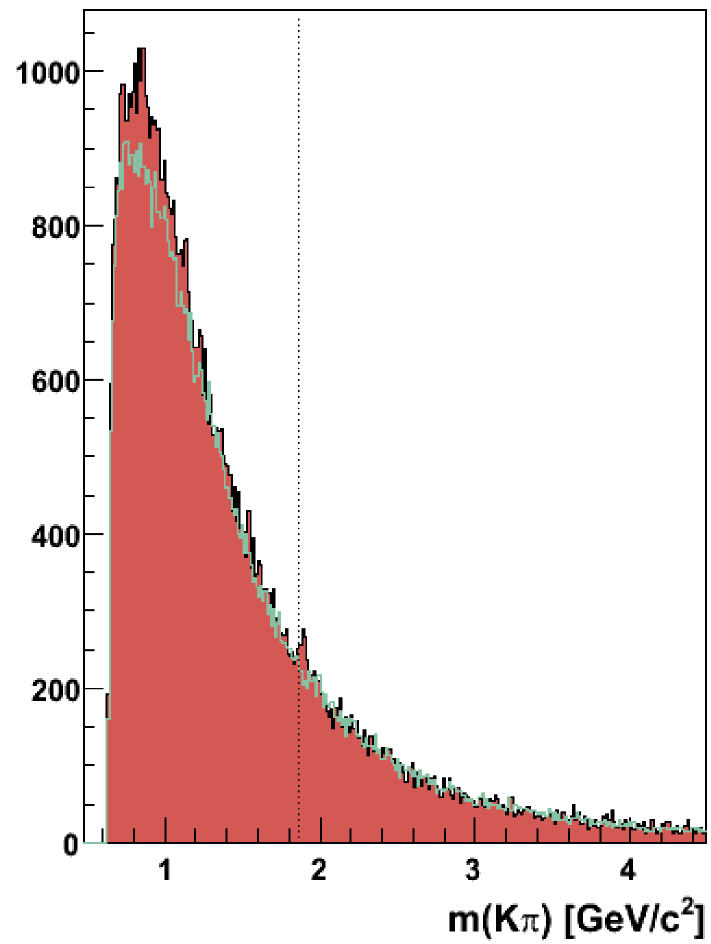
Results

K-π invariant mass distribution

w/o electron trigger

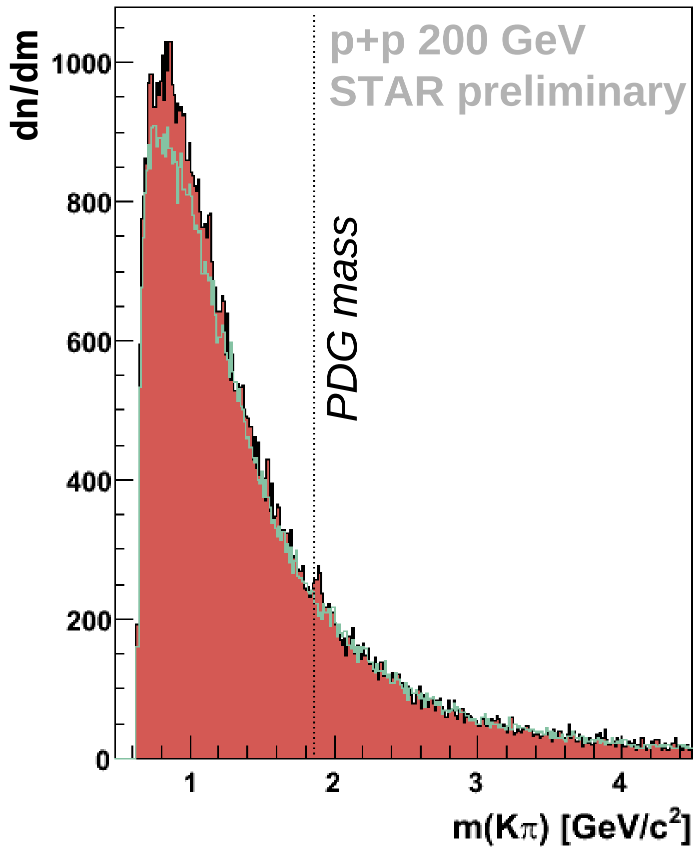


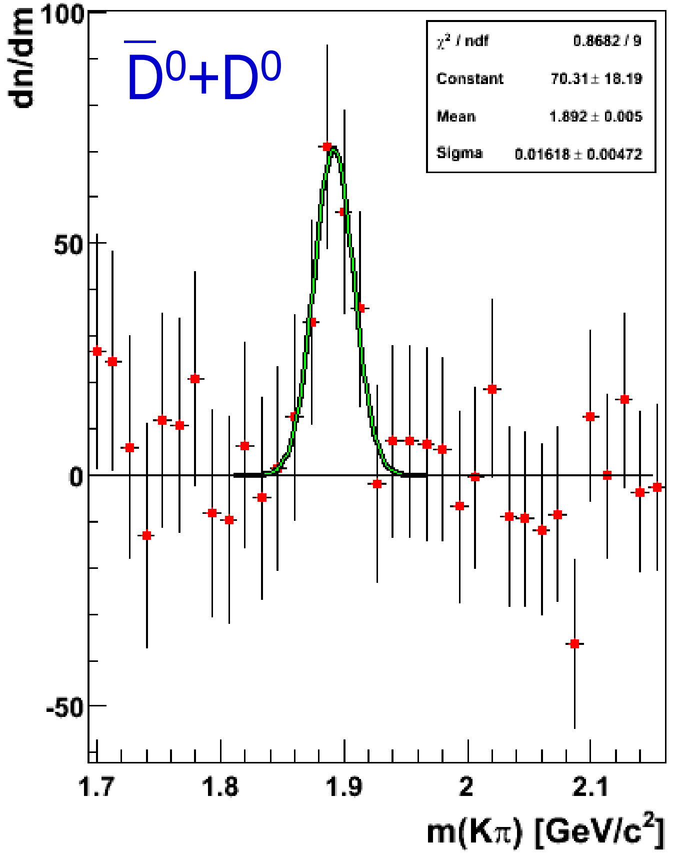
w/ non-photonic electron trigger



Significant suppression of the combinatorial background

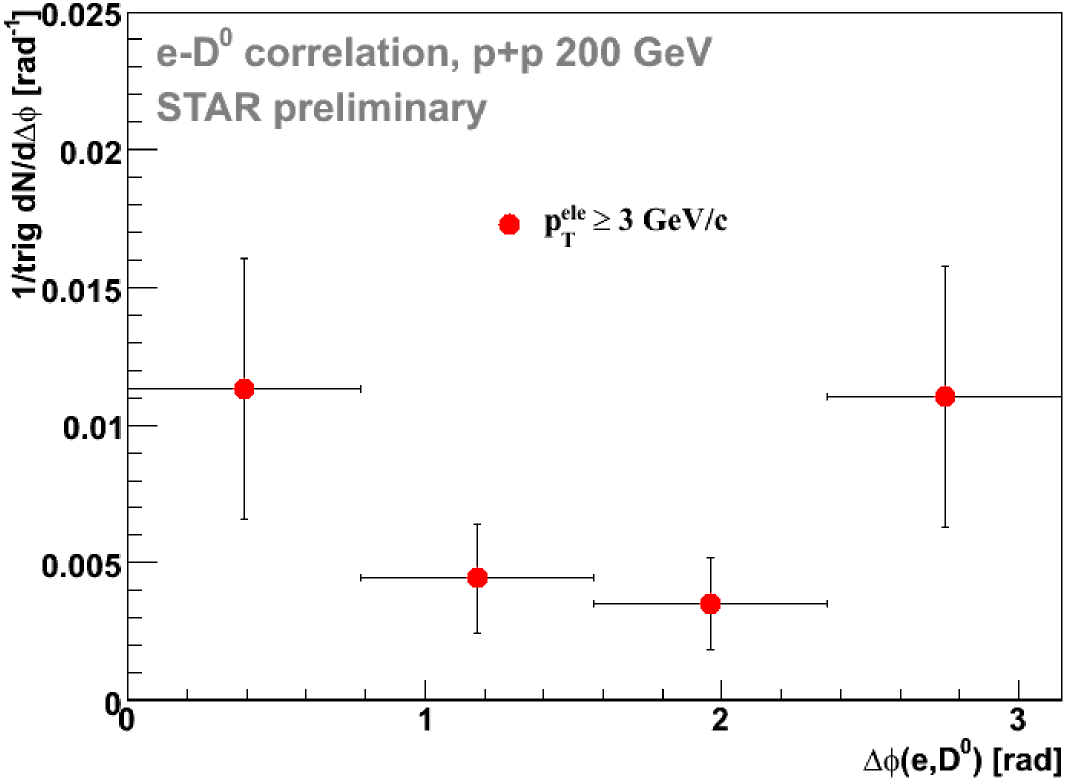
D^0 mesons in p+p collisions





- S/B = 1/7 $\rightarrow$ factor ~100 better than in d+Au w/o trigger
- Signal significance = 3.7
- Peak content ~200

Azimuthal correlation of non-photonic electrons and D^0 mesons

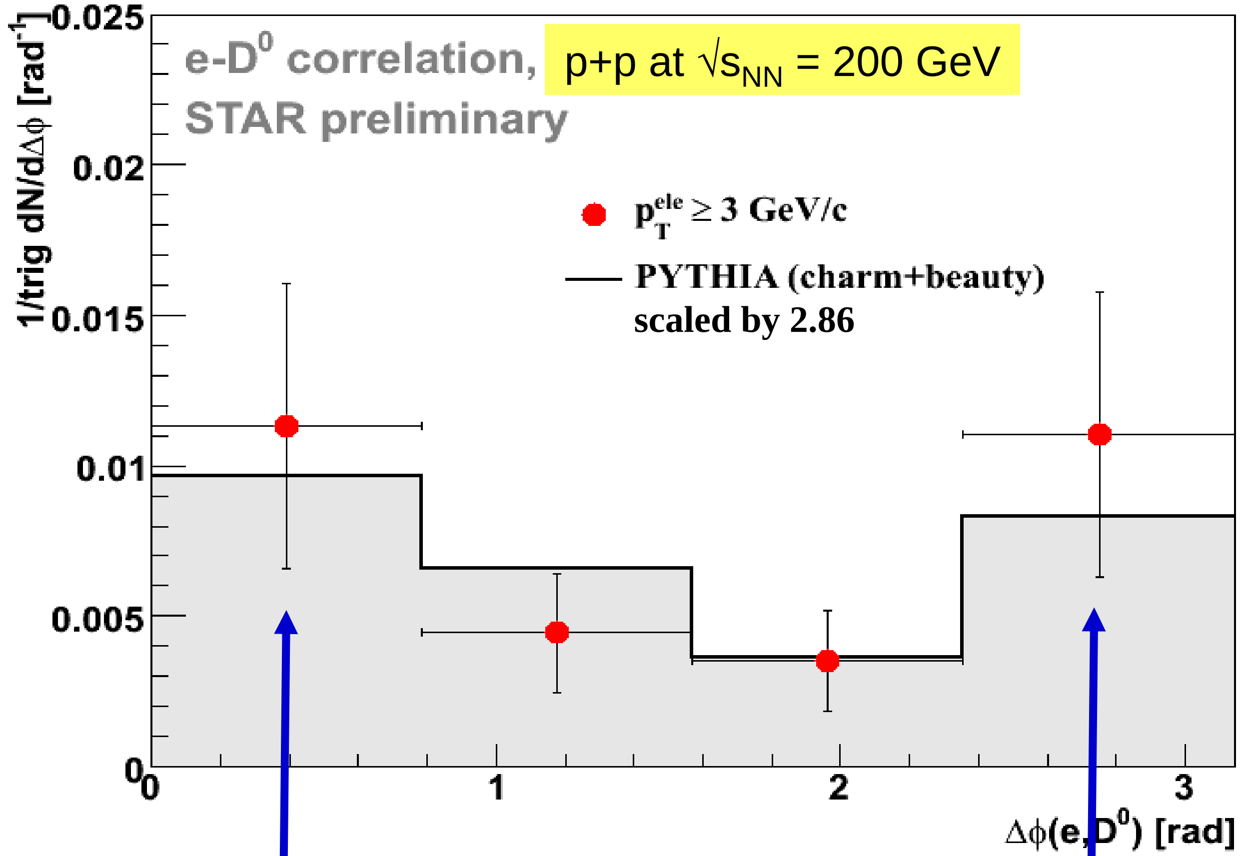


like-sign e-K pairs:
$(e^- - D^0) + (e^+ - \bar{D}^0)$

statistical errors only

- Near- and away-side correlation peak; yields are about the same
- First heavy-flavor correlation measurement at RHIC

Data-model comparison for like-sign electron-Kaon pairs



essentially from
B decays only

~70% from charm
~30% from beauty

Summary and conclusions

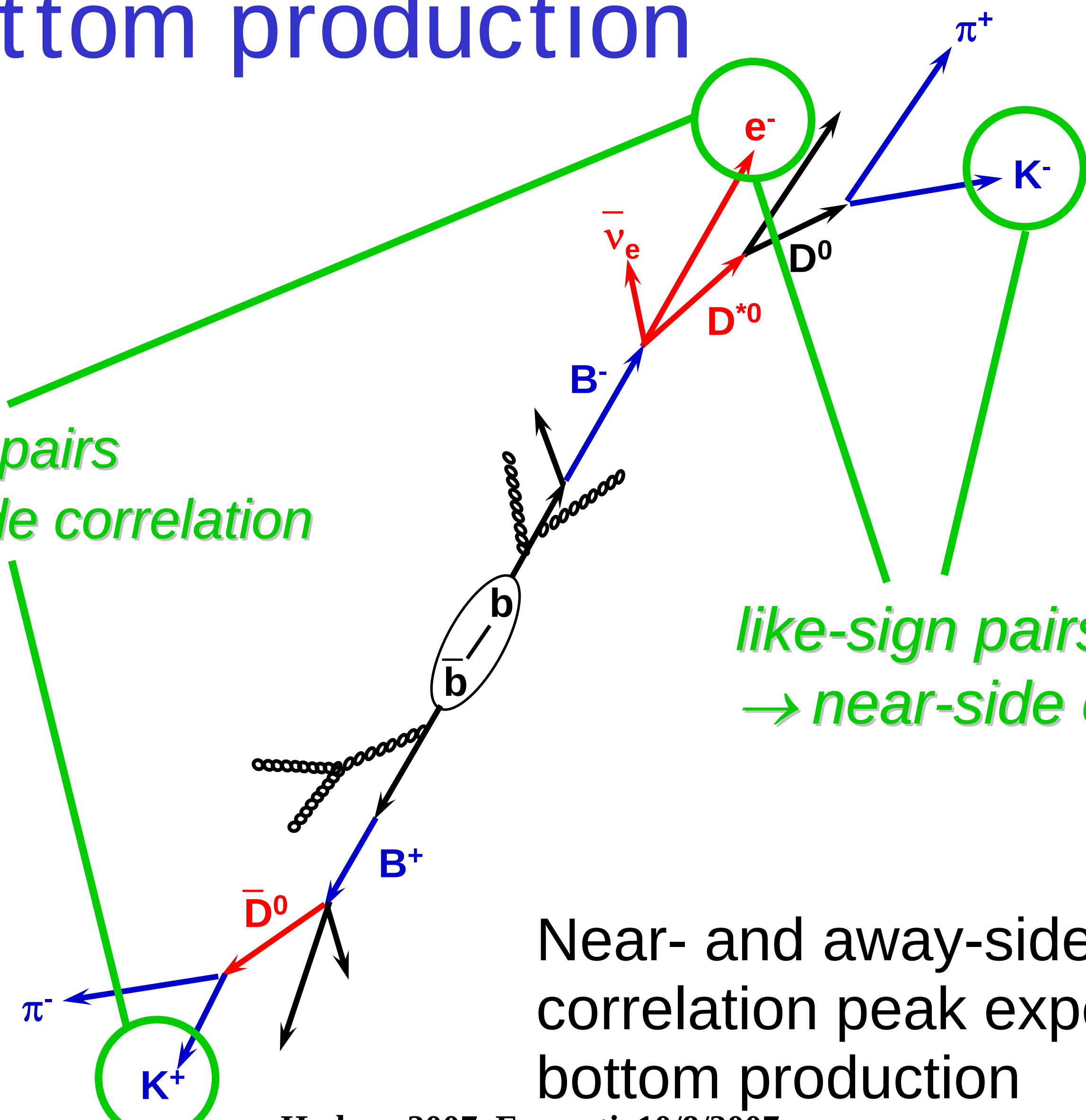
- First heavy-flavor correlation measurement in p+p collisions at RHIC
- Non-photonic electron trigger
    - allows to efficiently identify heavy-flavor production events
    - helps to suppress the combinatorial background significantly (S/B ratio = 1/7 and signal significance = 3.7)
- Azimuthal correlations of non-photonic electrons and D^0 mesons allow the separation of charm and bottom production events
    - near-side: essentially from B decays
    - away-side: large contribution from prompt charm meson pair production
- This novel correlation technique is a powerful tool for comprehensive energy-loss measurements of heavy-quarks in heavy-ion collisions

The STAR collaboration

51 institutes from 12 countries, 544 collaborators

Backup

Electron tagged correlations: bottom production



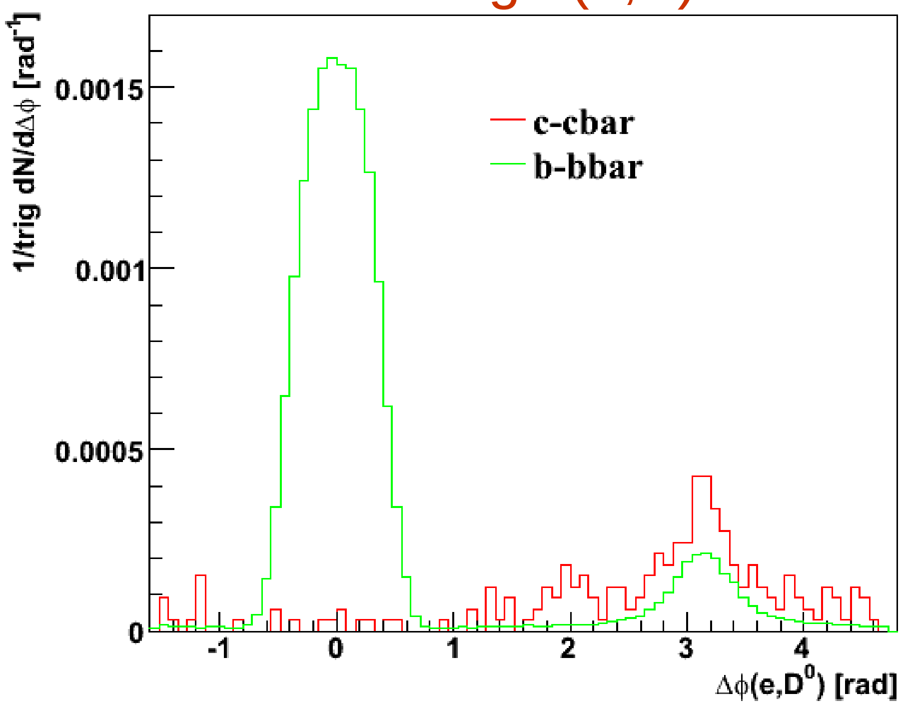
unlike-sign pairs
→ away-side correlation

like-sign pairs
→ near-side correlation

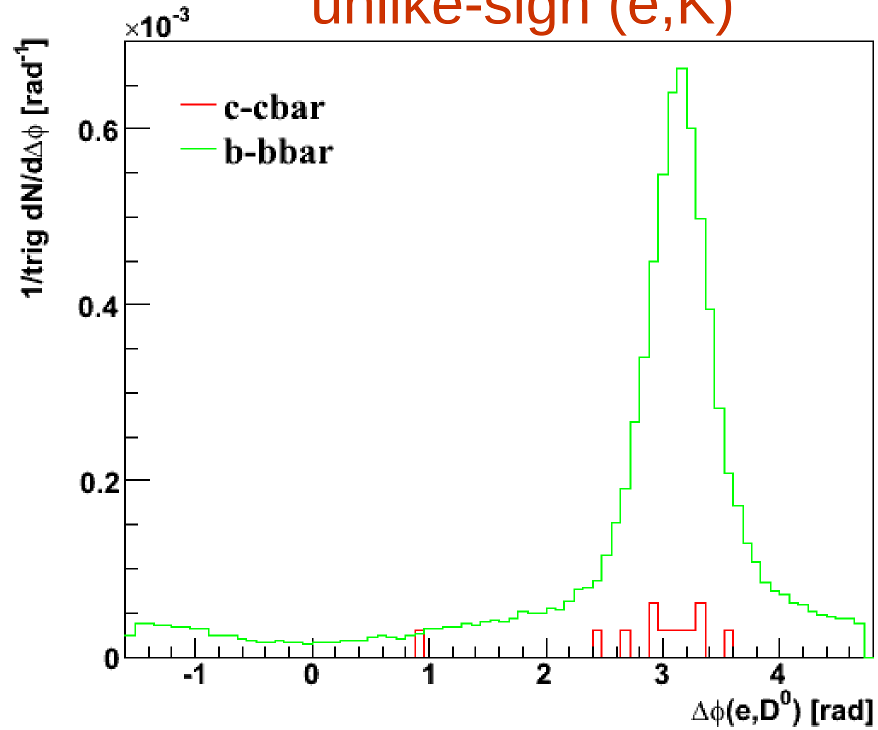
Near- and away-side correlation peak expected for bottom production

PYTHIA simulations: Electron triggers with $8<p_T^{trg}<20$ GeV/c

like-sign (e,K)



unlike-sign (e,K)

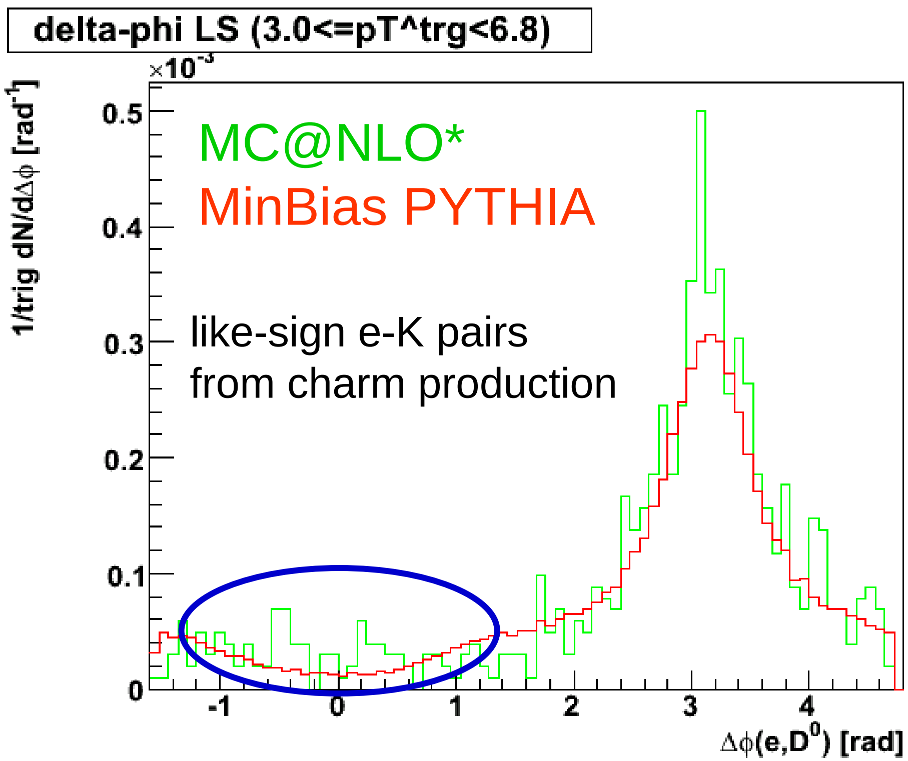


- Near-side:
  - B decays (dominant)
- Away-side:
  - charm meson pair production (dominant)
  - small B contribution

- Away-side:
  - B decays (dominant)
  - small charm contribution

MC@NLO simulations for charm production

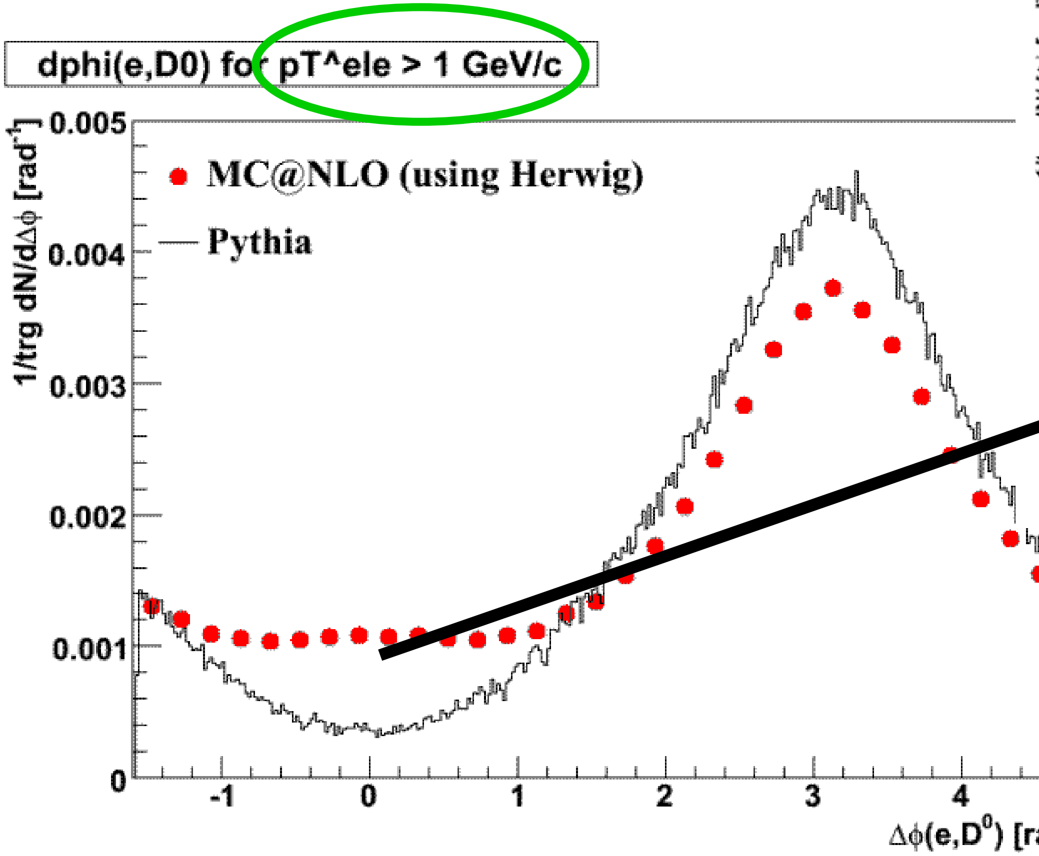
- Near-side yield for like-sign (e,K) pairs
  - yield$_{data}$ ~ 0.011 ± 0.0046
  - yield$_{PYTHIA\ (scaled)}$ = 0.0096
- Difference is attributed to gluon splitting

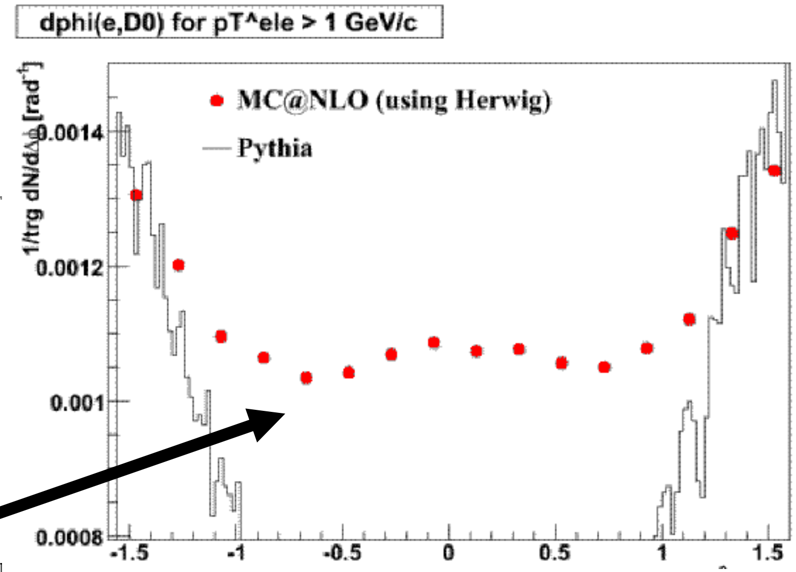


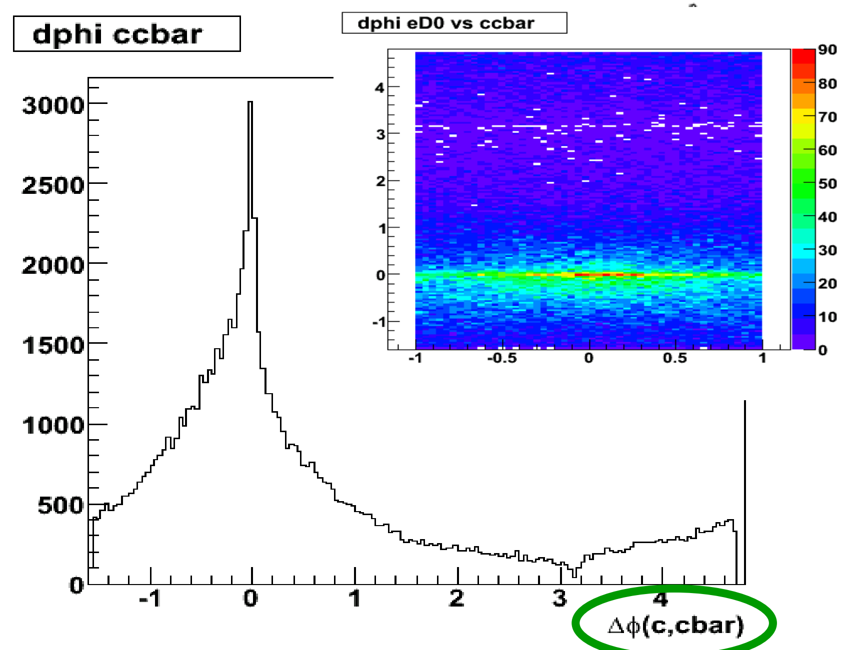
- NLO QCD computations (with realistic parton shower model) plus Herwig event generator
- Remarkable agreement of the away-side peak shape between PYTHIA and MC@NLO
- Indications for small gluon-splitting contribution (~$3 \cdot 10^{-4}$)
- More statistics needed for final conclusions

* private version from S. Frixione (CERN)

MC@NLO simulations

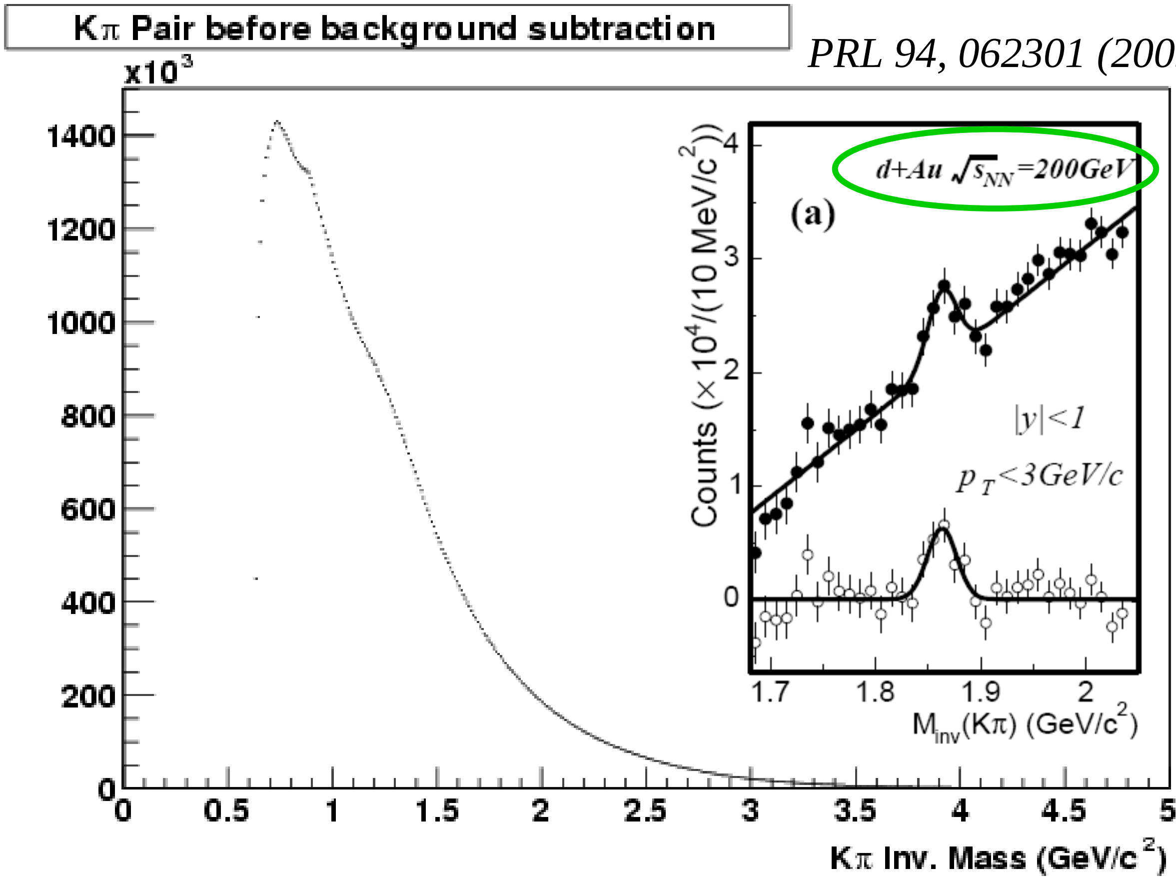






Near-side contribution seems to be from gluon-splitting

Open charm in d+Au



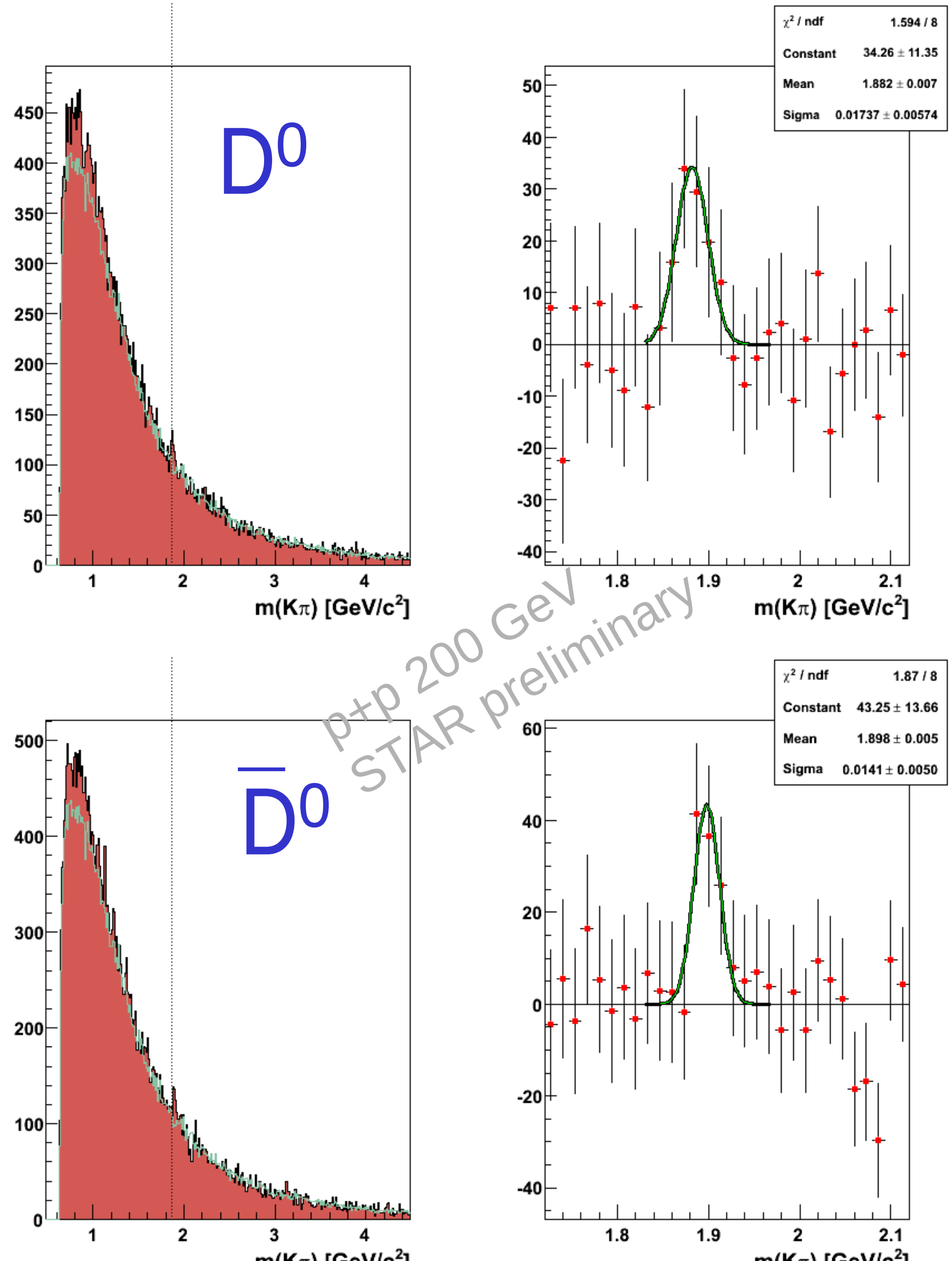
PRL 94, 062301 (2005)

"Conventional" reconstruction technique:

Combination of all positive and negative tracks after quality and dE/dx cuts

Invariant mass spectra

3.1k non-photonic electron trigger, 105 D^0

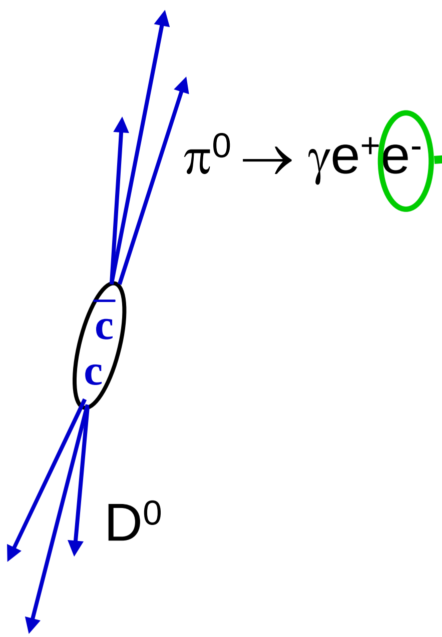


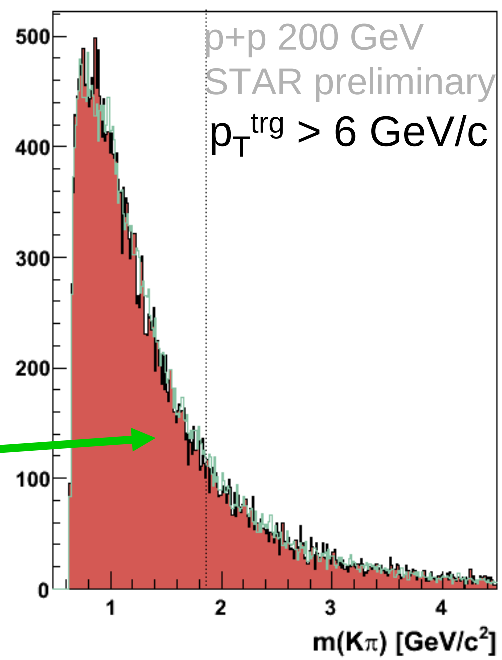
3.3k non-photonic positron trigger, 120 $\bar{D}^0$

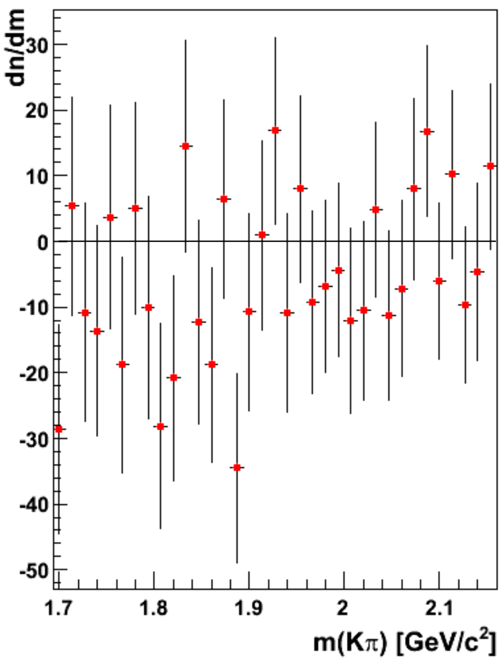
$m_{inv}(K\pi)$ for photonic e^- trigger

p+p at $\sqrt{s_{NN}}$ = 200 GeV

- Di-jet events produce many pions, which can make a, e.g., Dalitz decay
- What is the correlation contribution from these photonic electrons?

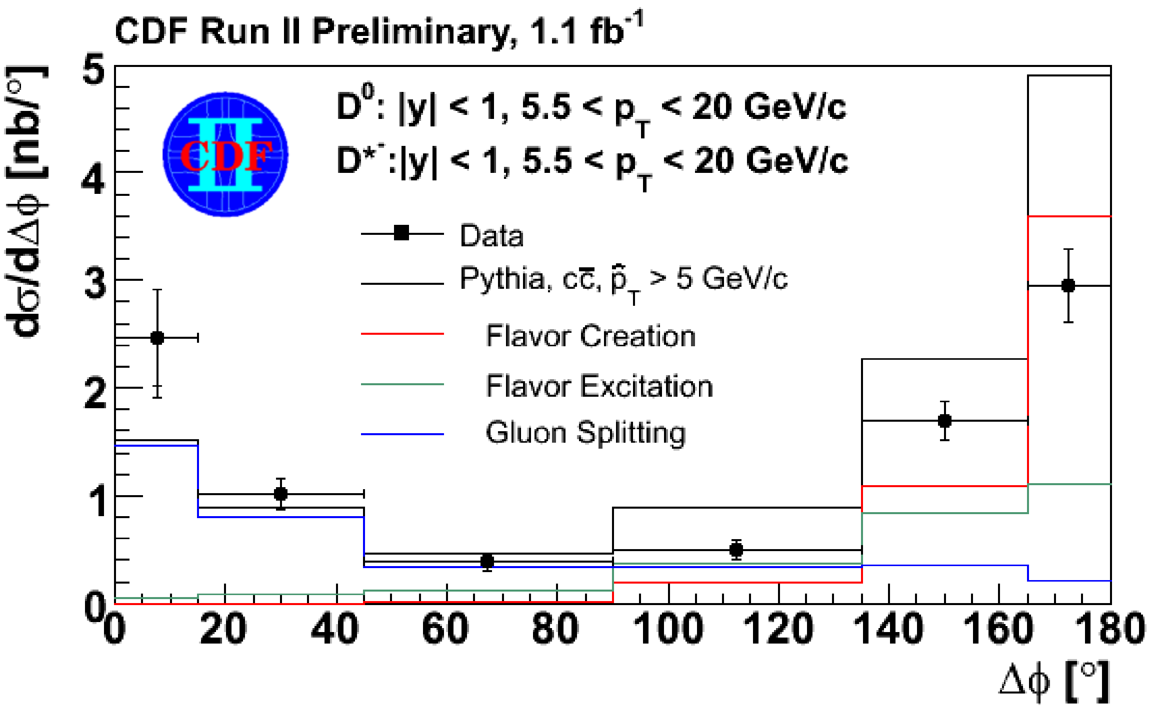


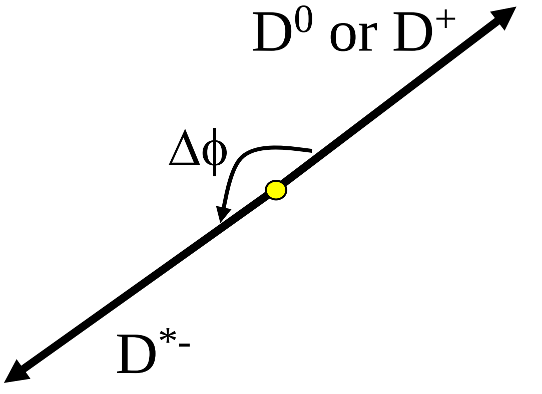




No D^0 signal observed

D^0D^{*-} cross section measurement at the Tevatron





B. Reisert et al., Beauty 2006, to be published in Nucl. Phys. B (Proc. Suppl.)

- Within errors near- and away-side yields are the same
$\rightarrow$ gluon splitting as important as flavor creation

- Near-side yield: PYTHIA underestimates gluon splitting

Note: Results are obtained at 10 times higher collision energy than at RHIC

Electron identification

- TPC tracks are extrapolated onto EMC surface

- Select tracks with well developed shower in SMD

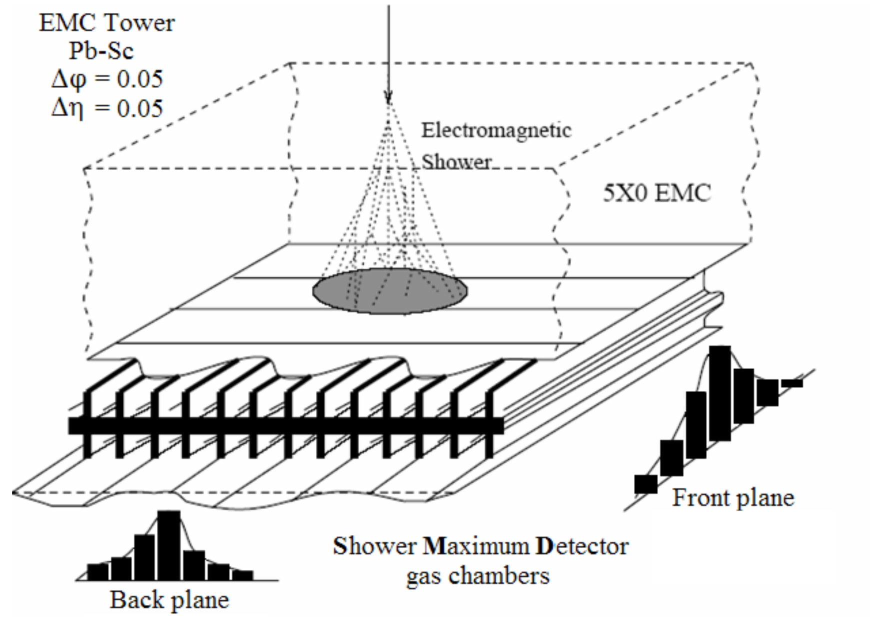
    - *p* measurement in TPC

    - *E* measurement in EMC

- Quality cuts:

    - p/E_{tower} ratio

    - specific energy loss *dE/dx*



Shower Maximum Detector (SMD)

– wire proportional counter with strip read-out

– located after 5 X_0

– $\Delta\eta\times\Delta\phi$ = 0.007 x 0.007

Heavy flavor measurement

- Hadronic decay channels

$D^0 \rightarrow K\pi$ B.R.: 3.83%

$D^\pm \rightarrow K\pi\pi$ B.R.: 9.51%

$D^* \rightarrow D^0\pi$ B.R.: ~65%

→ Difficulty: large combinatoric background, especially in high multiplicity environments

→ Event-mixing and/or vertex tracker needed to obtain a signal

- Semi-leptonic channels (inclusive modes)

$c \rightarrow e^+ + X$ B.R.: 9.6%

$D^0 \rightarrow e^+ + X$ B.R.: 6.87%

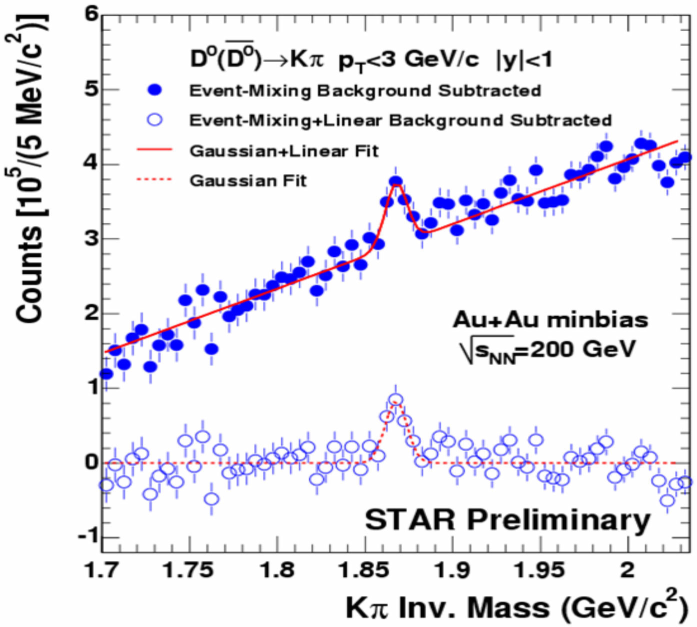
$D^\pm \rightarrow e^\pm + X$ B.R.: 17.2%

$b \rightarrow e^- + X$ B.R.: 10.9%

$B^\pm \rightarrow e^\pm + X$ B.R.: 10.2%

→ Single (non-photonic) electrons sensitive to charm and beauty

QM 2005, Nucl. Phys. A774 (2006) 701, publication in preparation



D^0 yield versus $\Delta\phi$(e,hadron pair)

- Calculate $\Delta\phi$ between non-photonic electron trigger and hadron pair p_T
- Extract D^0 yield from invariant mass distribution for different $\Delta\phi$ bins