Non-Photonic Electron-Hadron Correlations measured by STAR/RHIC

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High-pT Probes of High-Density QCD at the LHC
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Outline

1: Introduction

2: Analysis methods for Non-Photonic Electrons (NPE)

3: NPE-hadron correlation:

use the **near side in p+p** collisions to separate bottom/charm

4: NPE-hadron correlation:

use the **away side in Au+Au** collisions to study heavy flavor tagged jet-medium interaction

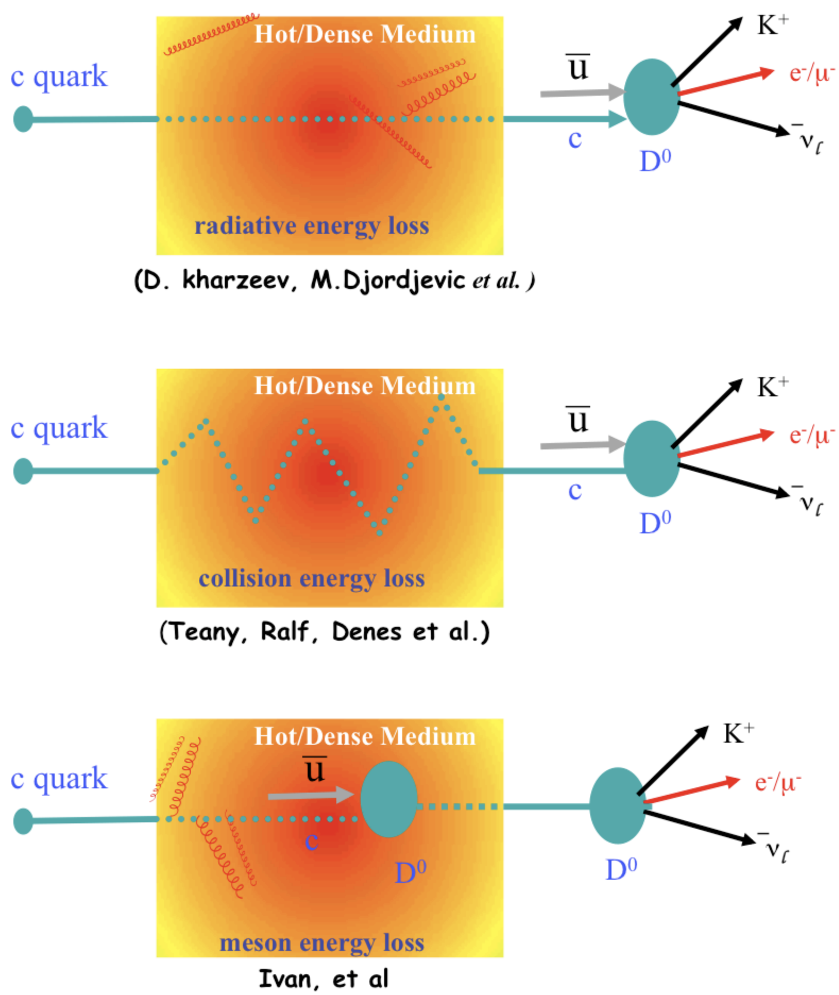
5: Summary

Motivation for NPE studies

NPE: semi-leptonic decays of open heavy flavor hadrons

$c \rightarrow e^{+} + anything(9.6\%)$ $B \rightarrow e^{+} + anything(10.86\%)$ PDG2010

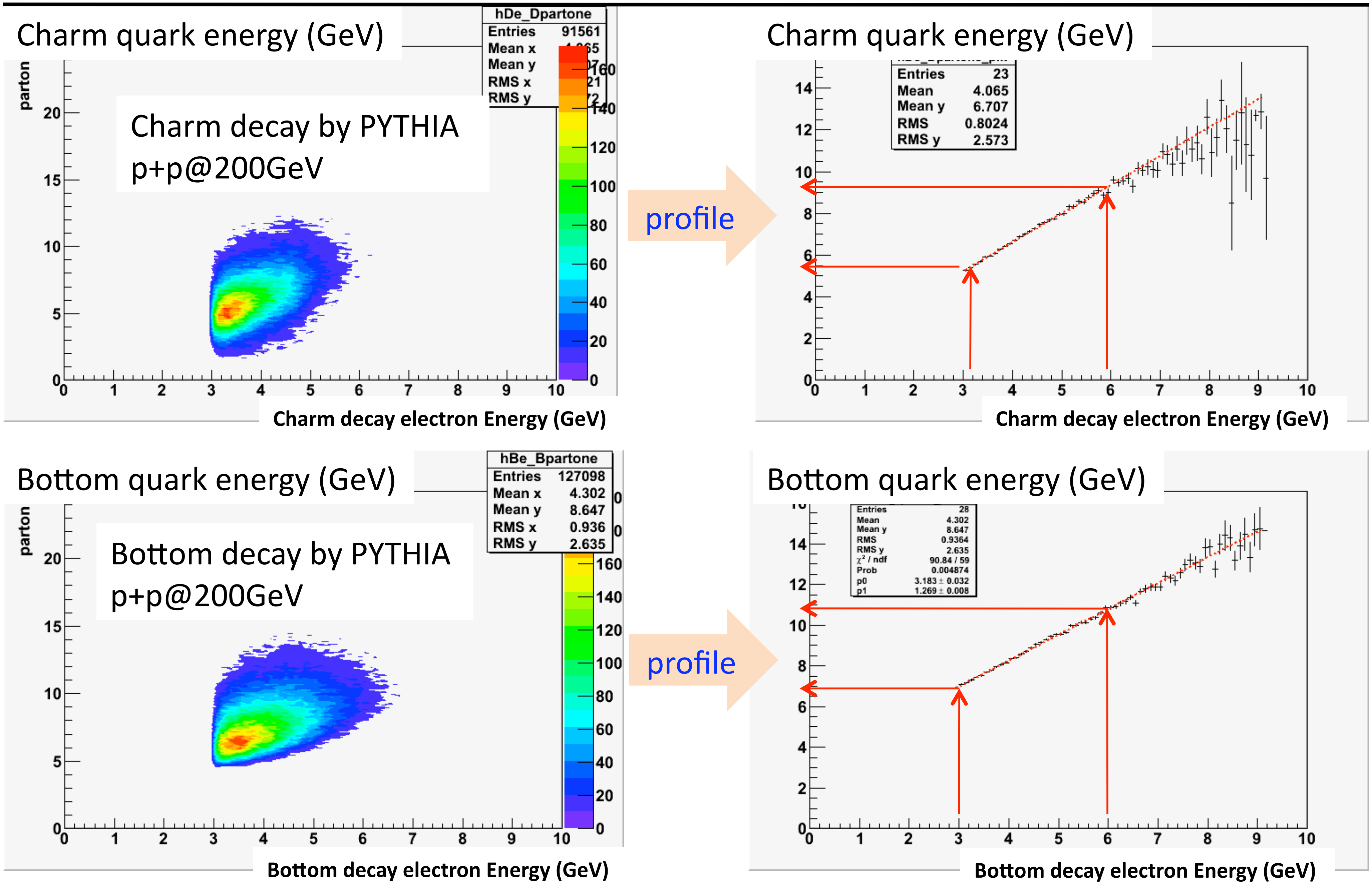
NPE is the proxy of heavy flavor quarks



Picture courtesy of Wei Xie @ HP2010

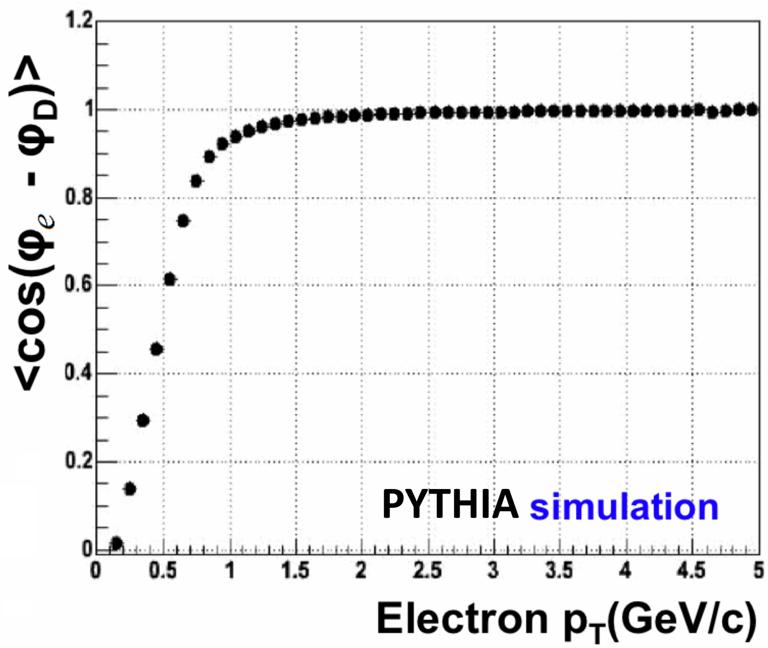
- Initial gluon fusion (hard process) dominates heavy flavor production – pQCD applicable.
- Study the interactions of heavy quarks with the hot and dense medium.
- Access to high p_T regime of heavy flavor quarks

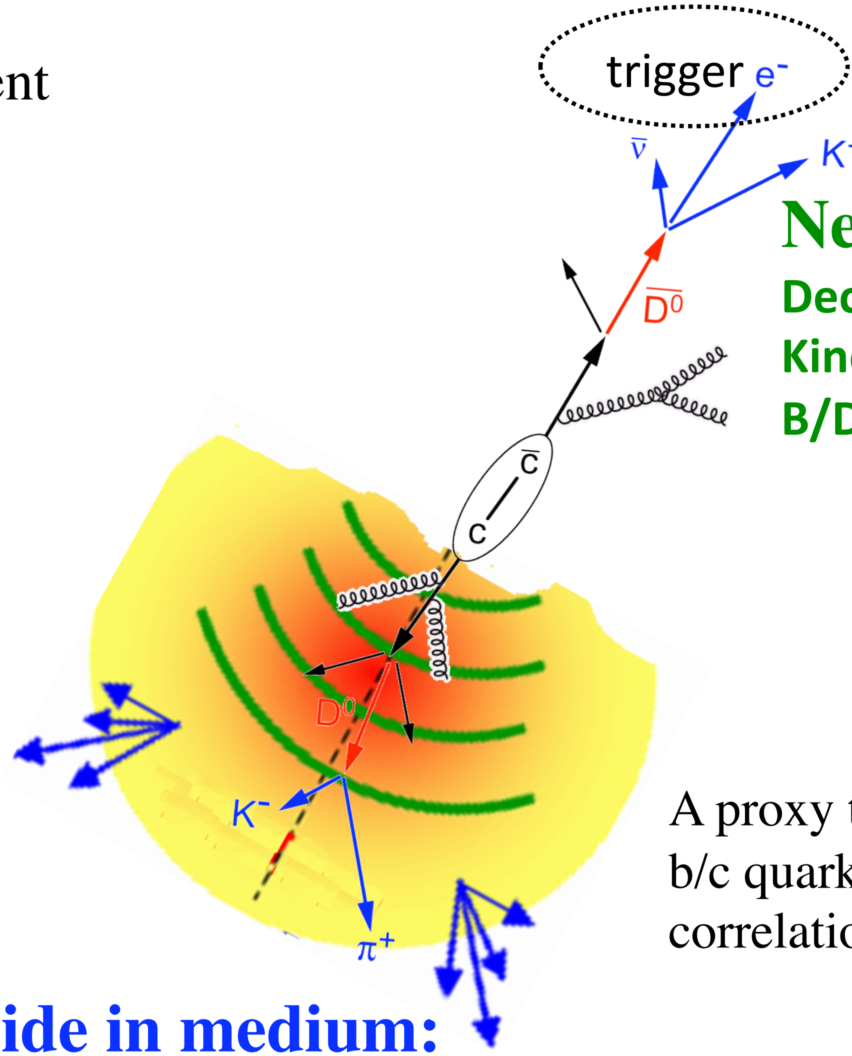
Access to high p_T regime of heavy flavors



NPE-hadron azimuthal correlations

Heavy flavor daughter electrons represent parent momentum directions well, when p^e_T>1.5 GeV/c for D case, and when p^e_T > 3 GeV/c for B case.





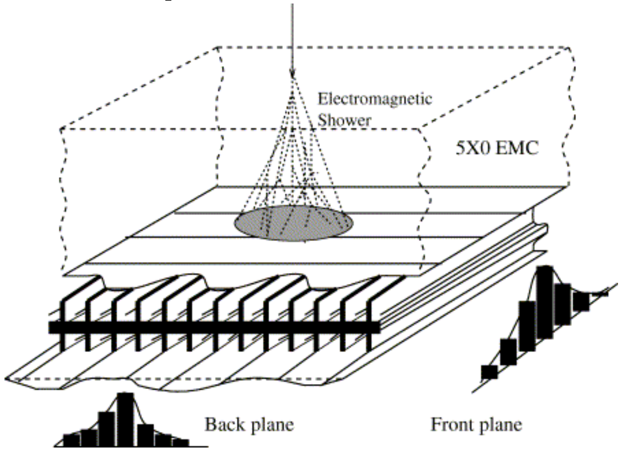
Near Side:
Decay
Kinematics
B/D separation

A proxy to b/c quark-hadron correlation

Away Side in medium:
How does B/D lose energy?
Any pattern like what seen in di-hadron?

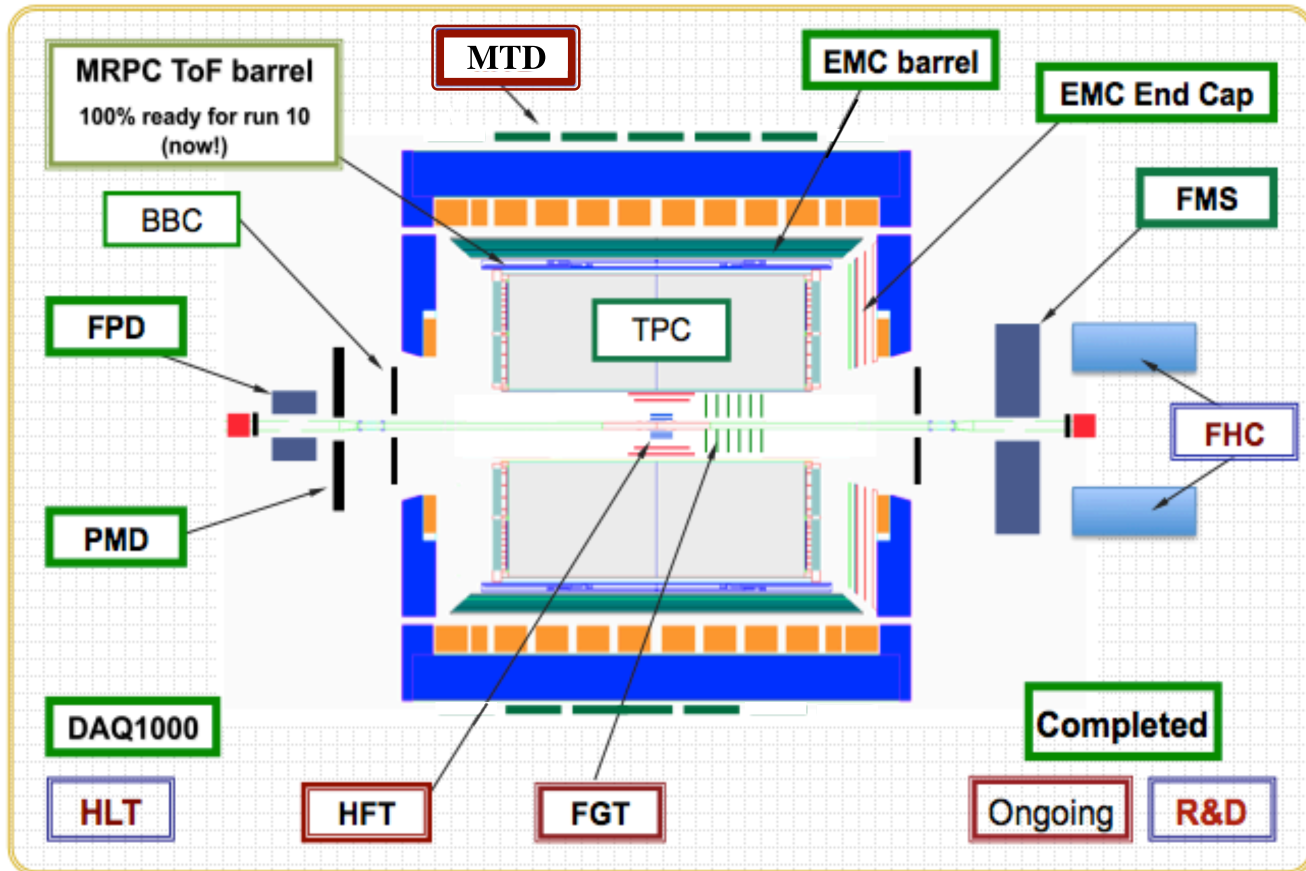
STAR detector

Large acceptance:
$-1 < \eta < 1,\ 0 < \phi < 2\pi$



BSMD: a wire proportional counter - strip readout detector, embedded at ~5.6 radiation lengths depth in BEMC. Two layers/planes of strips, along eta and phi directions.

NIM A 499 (2003) 725–739



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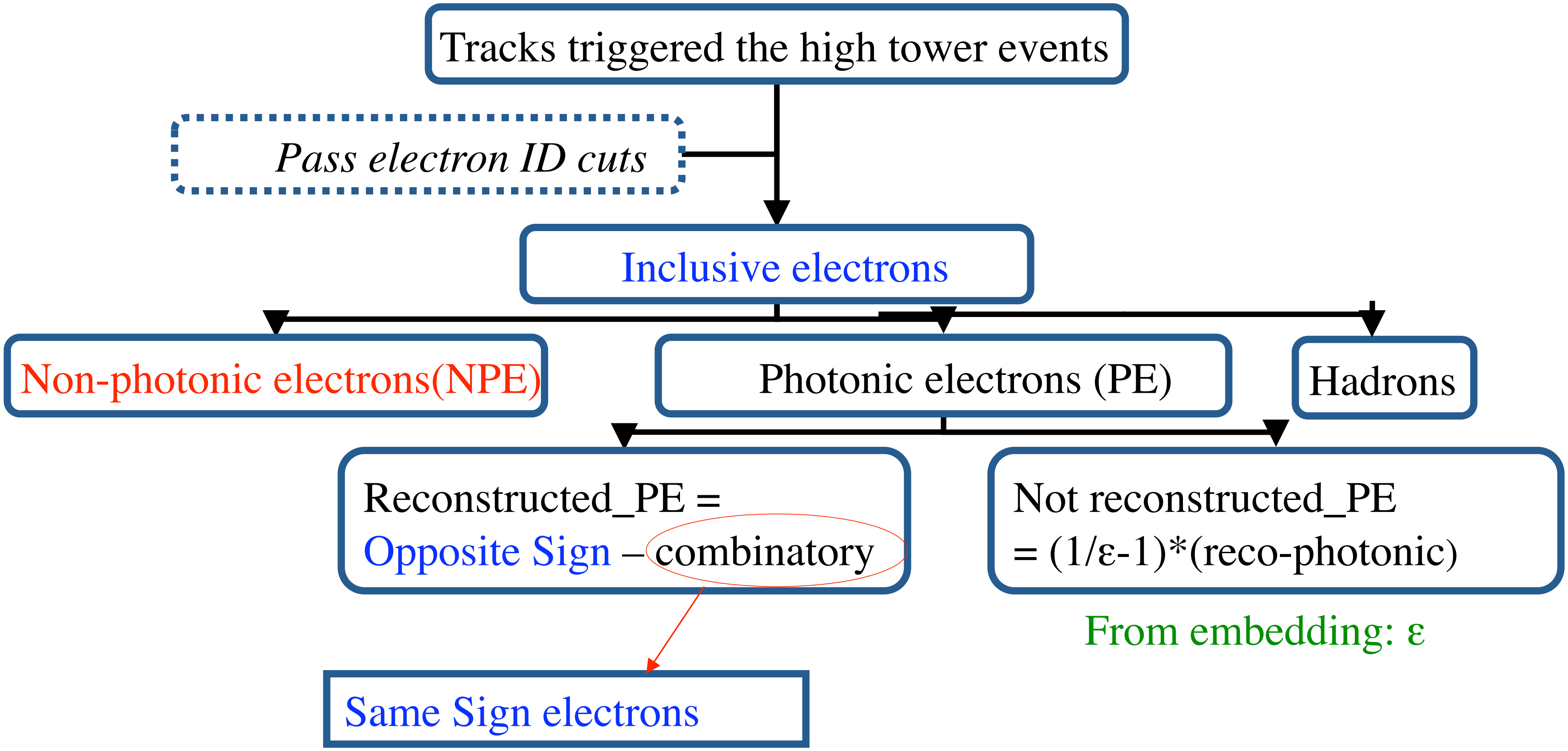
Common Detectors in NPE analyses:
Time Projection Chamber(TPC)
Barrel Electromagnetic Calorimeter(BEMC)
Barrel Shower Maximum Detector(BSMD)

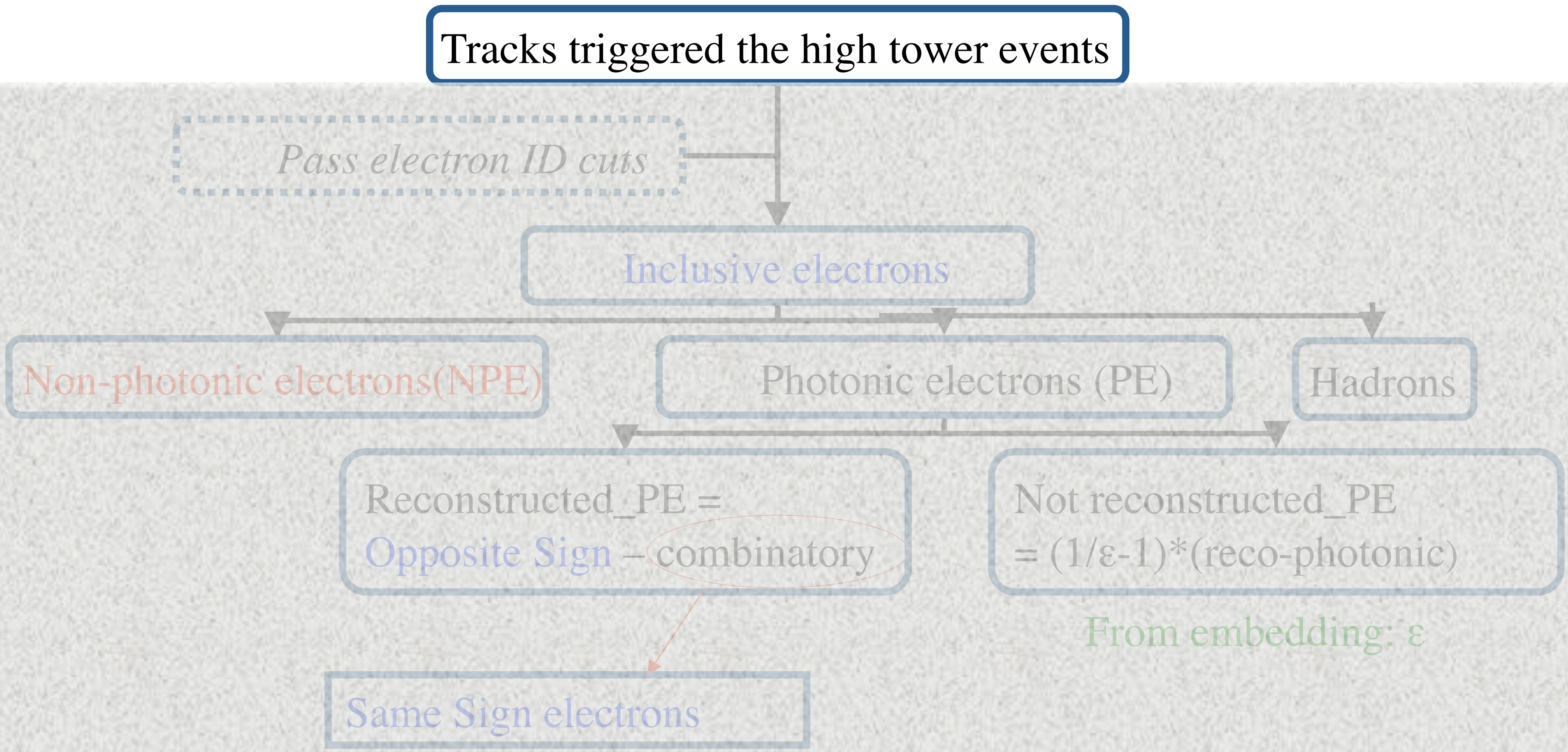
Analysis principle



$$\Delta\phi_{NPE} = \Delta\phi_{inclusive} - (\Delta\phi_{OppoSign} - \Delta\phi_{SameSign})/\varepsilon - \Delta\phi_{hadron}$$

$\Delta\phi$ could be other common variables, e.g. yield, ellitpical flow (v_2), etc

Analysis principle



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$\Delta\phi$ could be other common variables, e.g. yield, ellitpical flow (v_2), etc

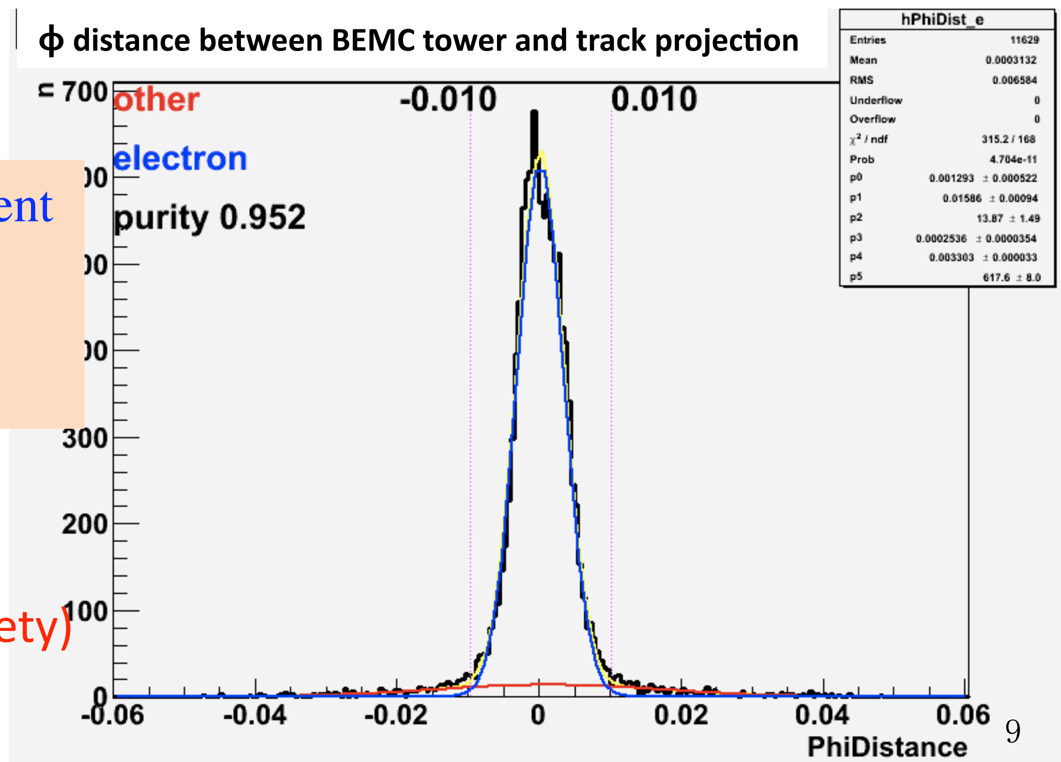
High tower triggers

High tower triggers (equivalently) require the highest transverse energy (E_T) measured by BEMC towers in an event exceeding certain energy thresholds

For example:
4 different high tower triggers in Run10 at STAR:
NPE11 with $E_T > 2.64$GeV,   NPE15 with $E_T > 3.6$GeV
NPE18 with $E_T > 4.3$GeV,   NPE25 with $E_T > 6.0$GeV
Effectively trigger on the high p_T regime of heavy flavor quarks

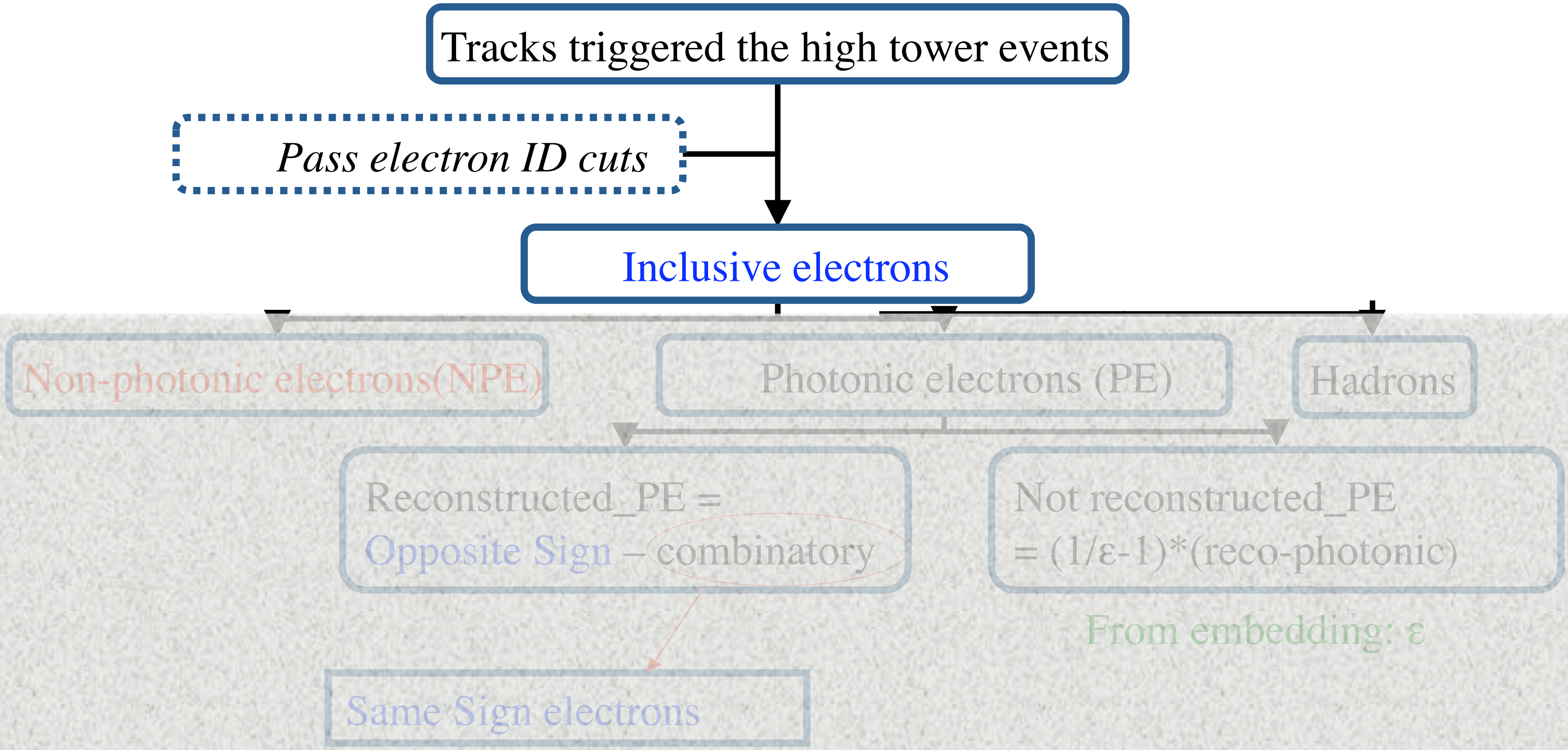
1: identify BEMC tower(s) that triggered the event
2: match the TPC tracks with the BEMC towers

*BEMC tower positions are given by BSMD



Wenqin Xu APS
(American Physical Society)
April meeting 2011

Analysis principle

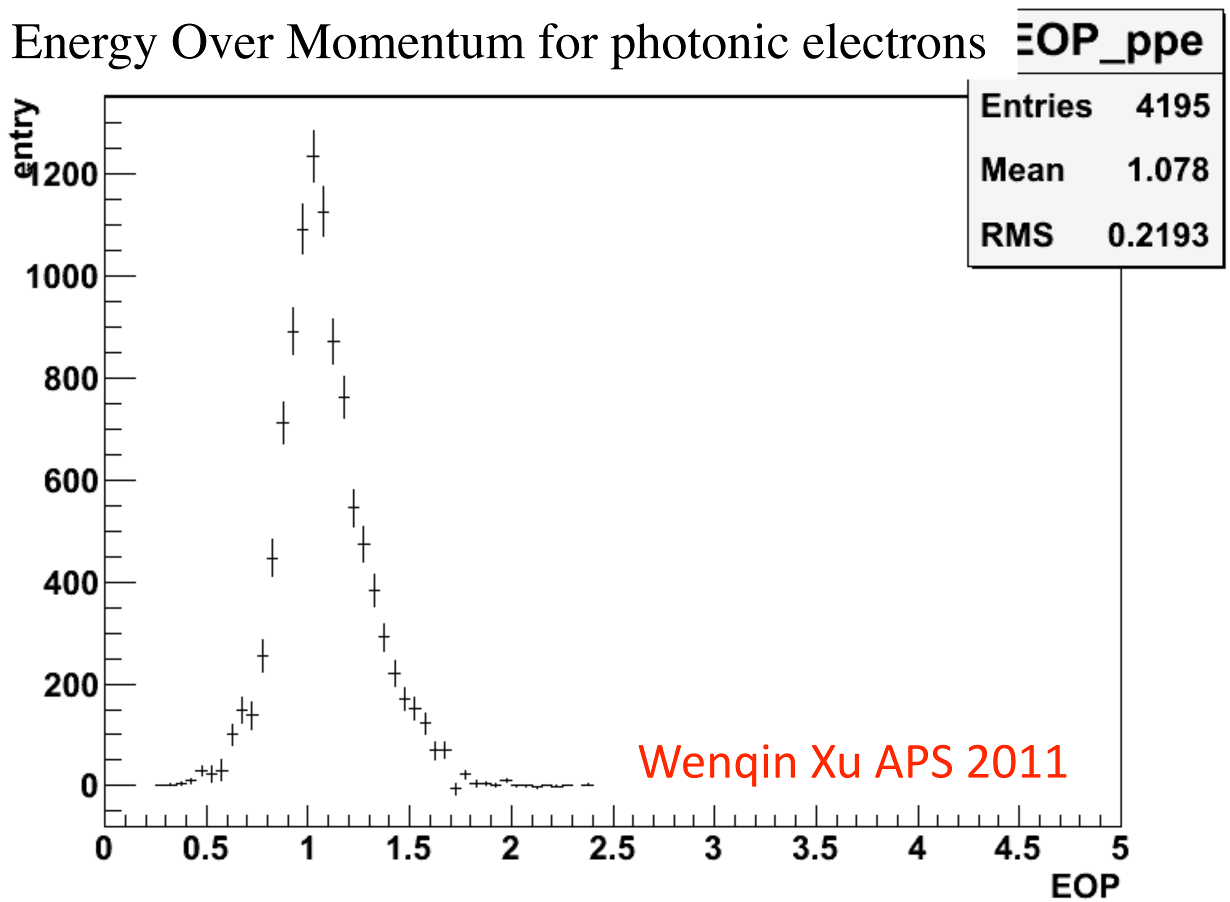


$$\Delta\phi_{NPE} = \Delta\phi_{inclusive} - (\Delta\phi_{OppoSign} - \Delta\phi_{SameSign})/\varepsilon - \Delta\phi_{hadron}$$

$\Delta\phi$ could be other common variables, e.g. yield, ellitpical flow (v_2), etc

Electron identification: Tower Energy over TPC momentum ratio

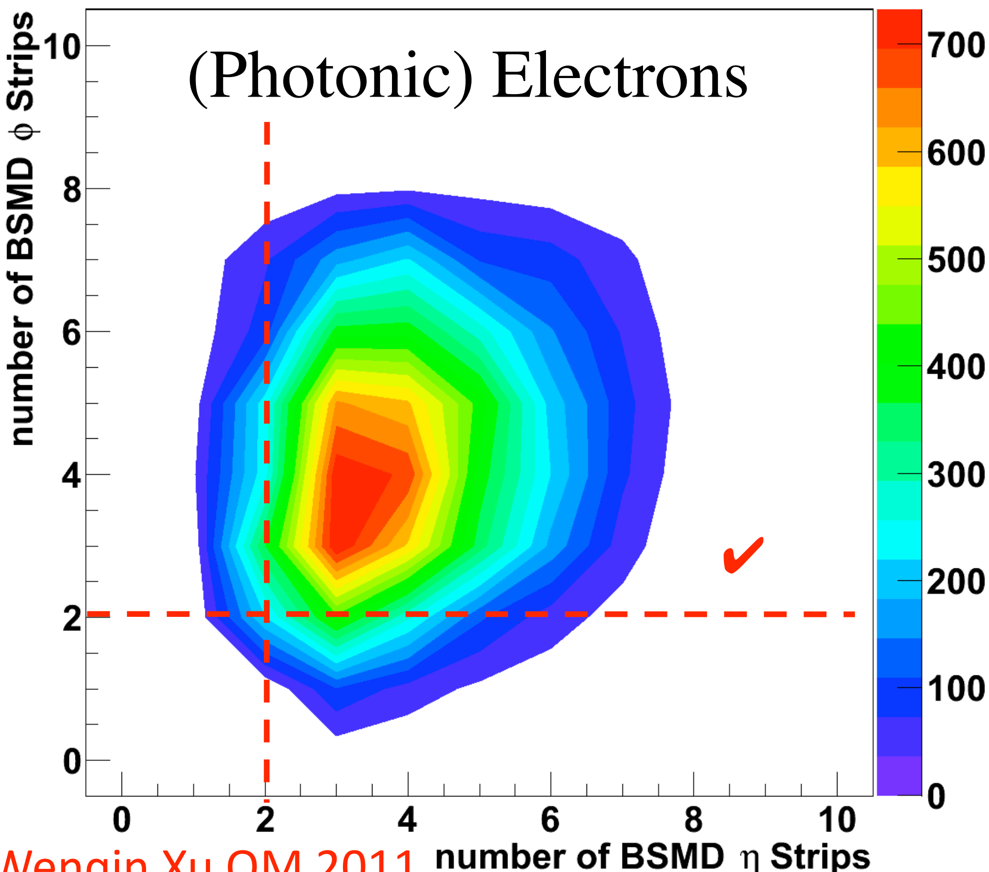
Electrons deposit most of their energy into BEMC
->
Tower Energy over TPC momentum ratio (E/P) ~ 1 Not necessary for hadrons!



Electron identification: shower profile

Electron showers are widely developed, firing several BSMD strips.

Hadron showers are much less developed, firing mostly one or zero strip.



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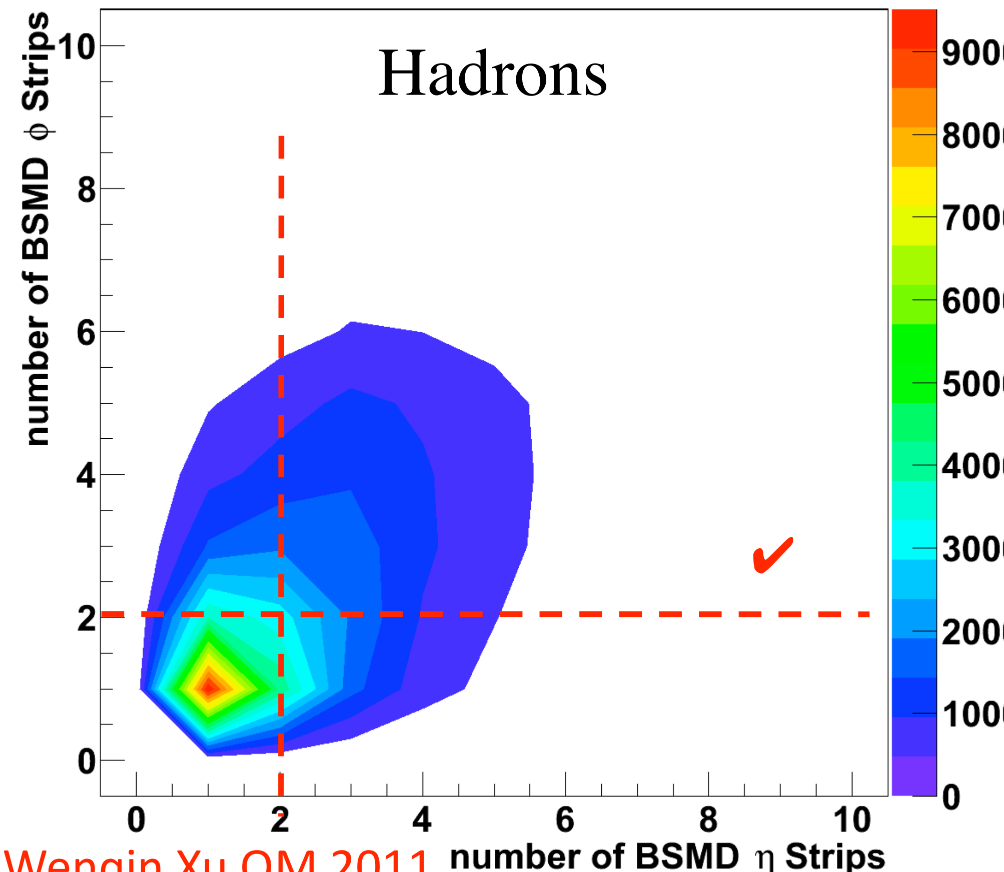

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Electron identification: energy loss $n\sigma_{electron}$

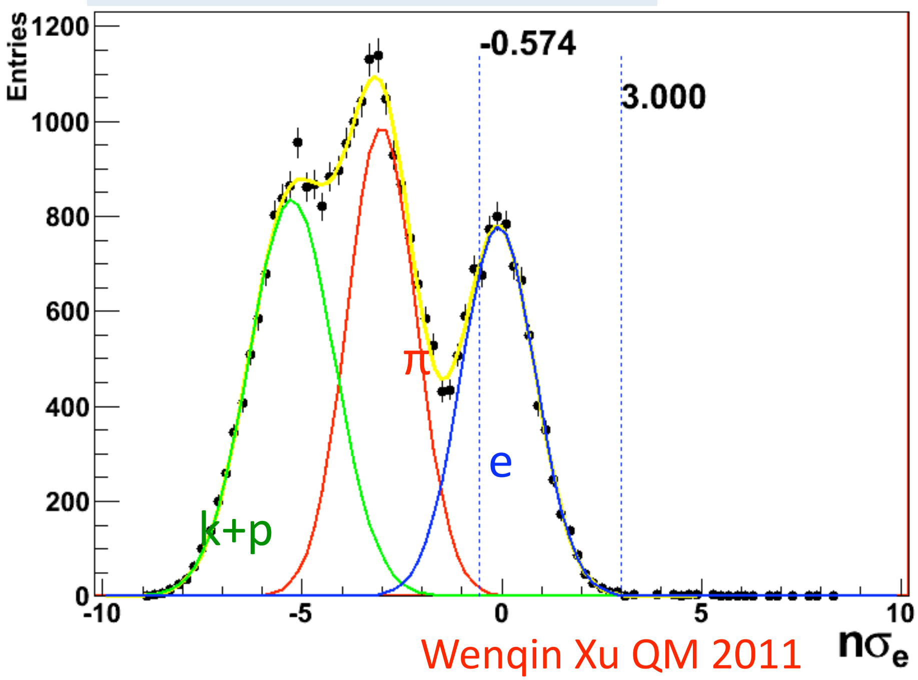
$$n\sigma_e = \frac{\log\left(\frac{dE/dx}{B_e}\right)}{\sigma_e}$$

"B_e is the expected mean electron dE/dx from Bichsel[1] function, and σ_e is TPC resolution of $\log((dE/dx)/B_e)$"

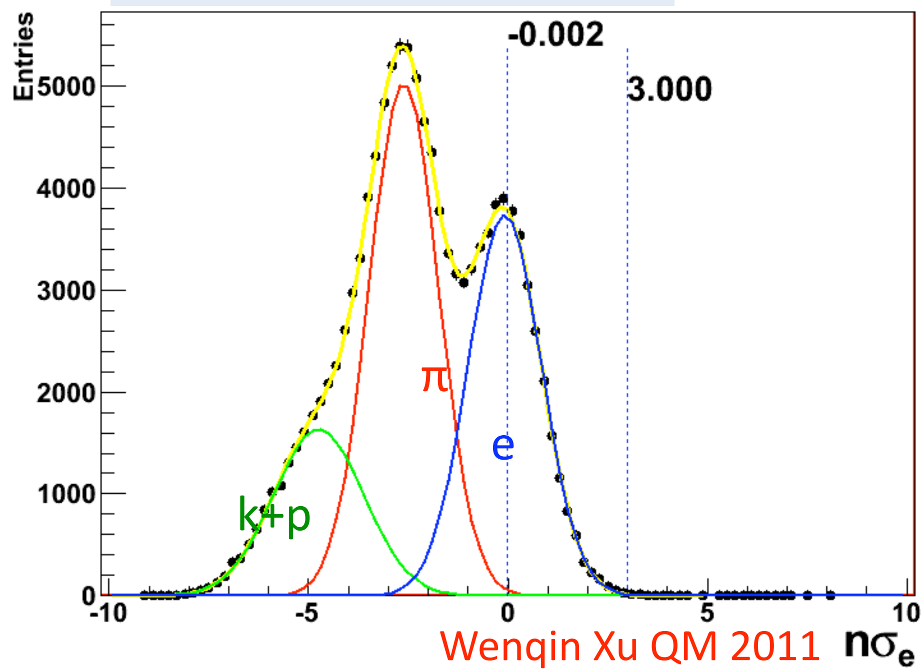
STAR Phys. Rev. D 83 (2011) 052006

Hadron contamination< 1%

$n\sigma_e$ for $3<p_T<4$GeV

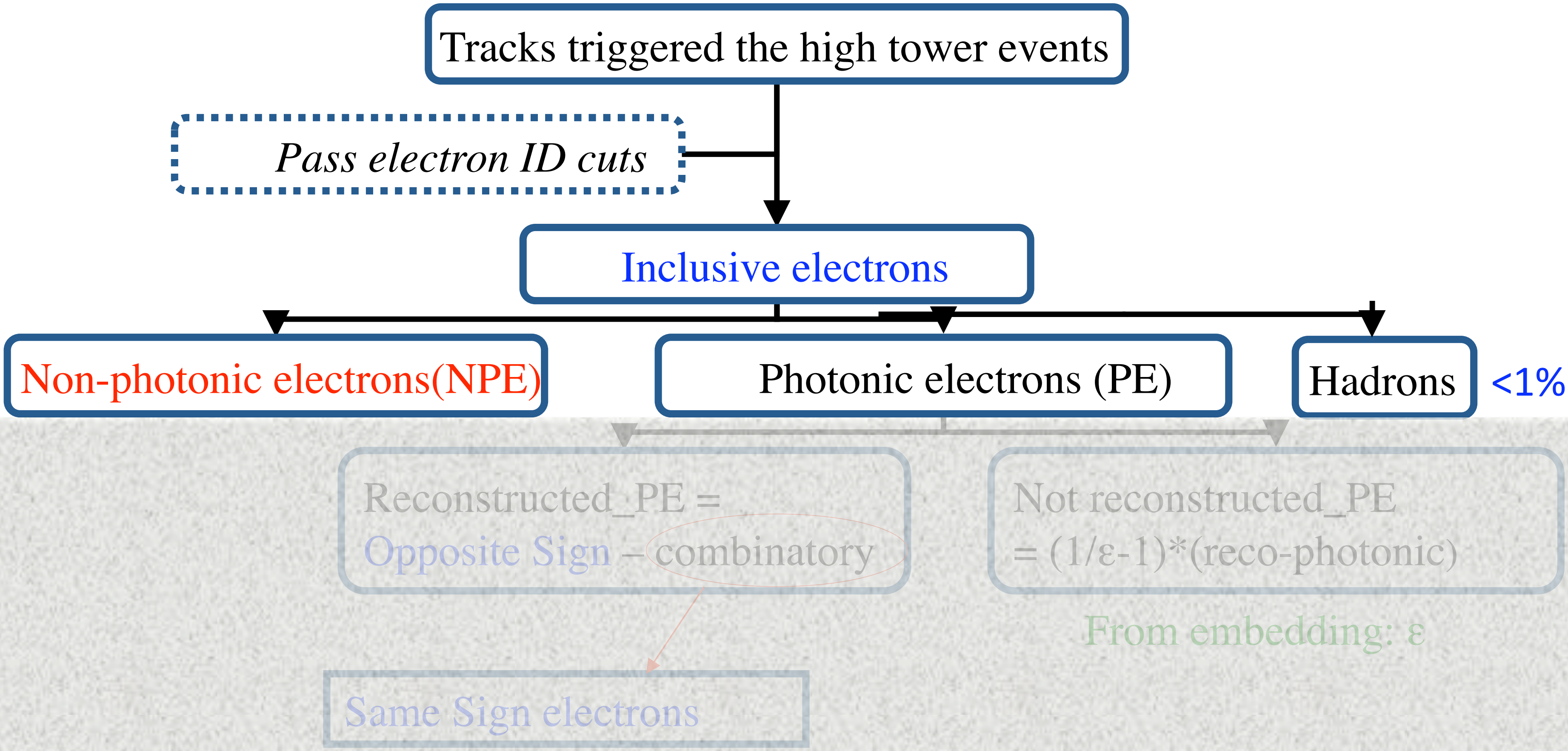


$n\sigma_e$ for $4<p_T<6$GeV



[1]:H. Bichsel, Nucl. Instrum. Methods Phys. Res., Sect. A 562, 154 (2006).

Analysis principle



$$\Delta\phi_{NPE} = \Delta\phi_{inclusive} - (\Delta\phi_{OppoSign} - \Delta\phi_{SameSign})/\varepsilon - \Delta\phi_{hadron}$$

$\Delta\phi$ could be other common variables, e.g. yield, ellitpical flow (v_2), etc

Photonic electrons

The main background is photonic electrons (PE):

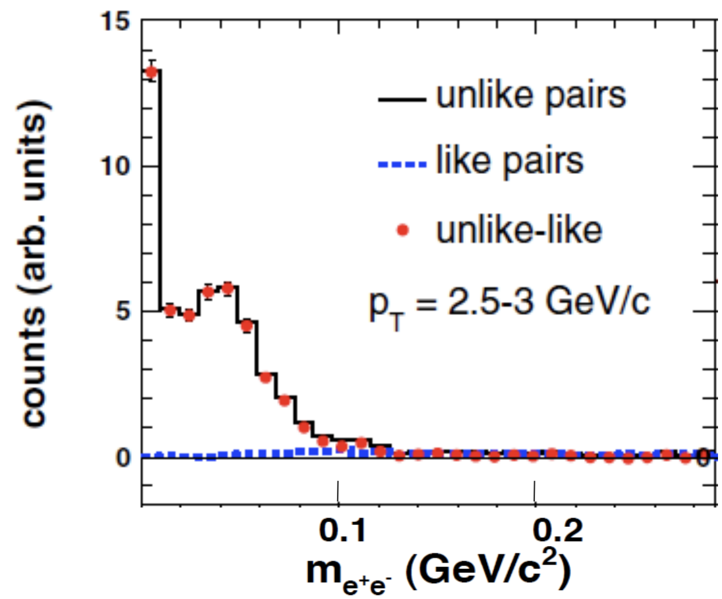
Photon conversions in material	$\gamma \rightarrow e^{+} + e^{-}$
Dalitz decays of pseudoscalar mesons	$\pi^{0}, \eta \rightarrow \gamma + e^{+} + e^{-}$

- Reconstruct the invariant masses of electron pairs (unlike/like sign), apply opening angles cuts

- PE = unlike sign pairs - like sign pairs

- The efficiency of PE reconstruction is evaluated by studying PYTHIA+GEANT tracks embedded into real events

- Next: Statistical subtraction



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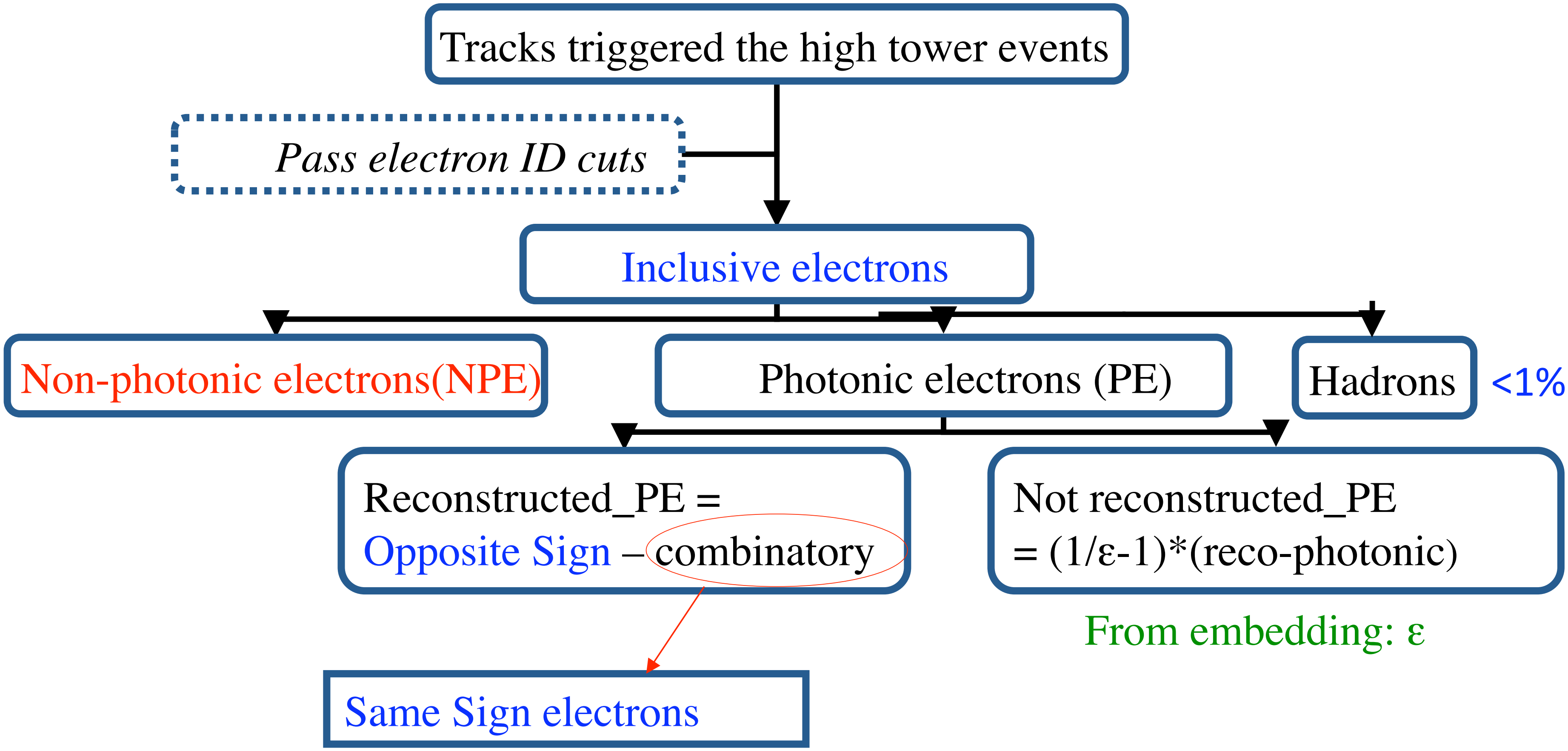
Analysis principle



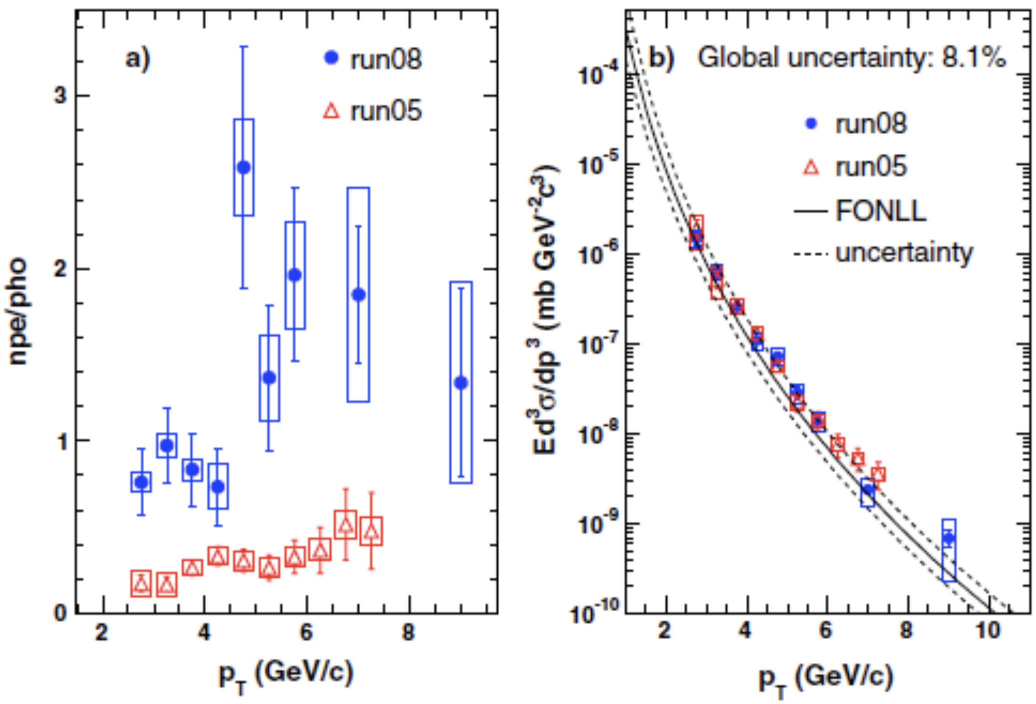
In case of <1%

$$\Delta\phi_{NPE} = \Delta\phi_{inclusive} - (\Delta\phi_{OppoSign} - \Delta\phi_{SameSign})/\varepsilon - \Delta\phi_{hadron}$$

$\Delta\phi$ could be other common variables, e.g. yield, ellitpical flow (v_2), etc

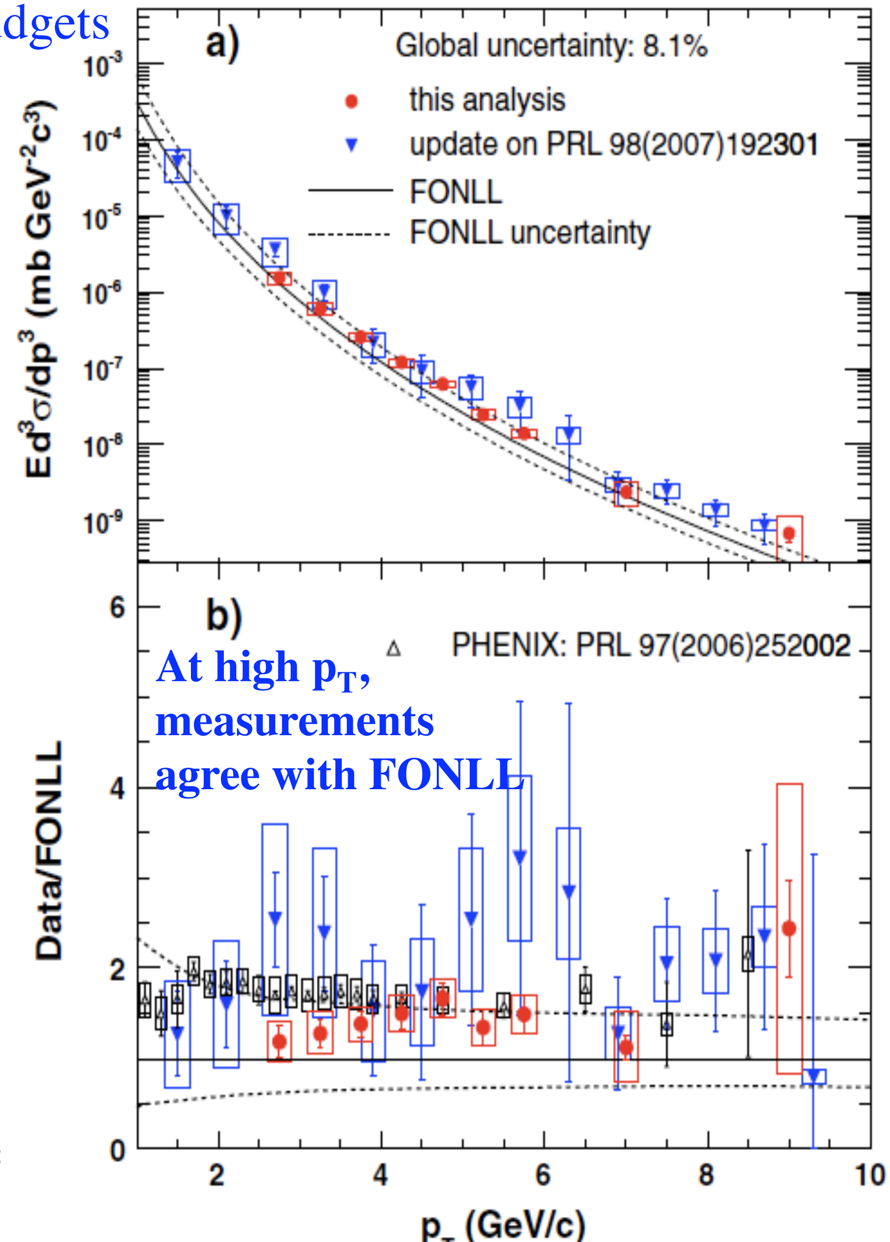
NPE spectrum in p+p at 200GeV

- Run05 and Run08 have very different material budgets
- i.e.: very different photonic electron backgrounds
- NPE measurements at p_T>2.5GeV/c agree with each other



STAR Phys. Rev. D 83 (2011) 052006

FONLL: M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. **95, 122001 (2005);** M. Cacciari, R. Vogt, private communications.



At high p_T, measurements agree with FONLL

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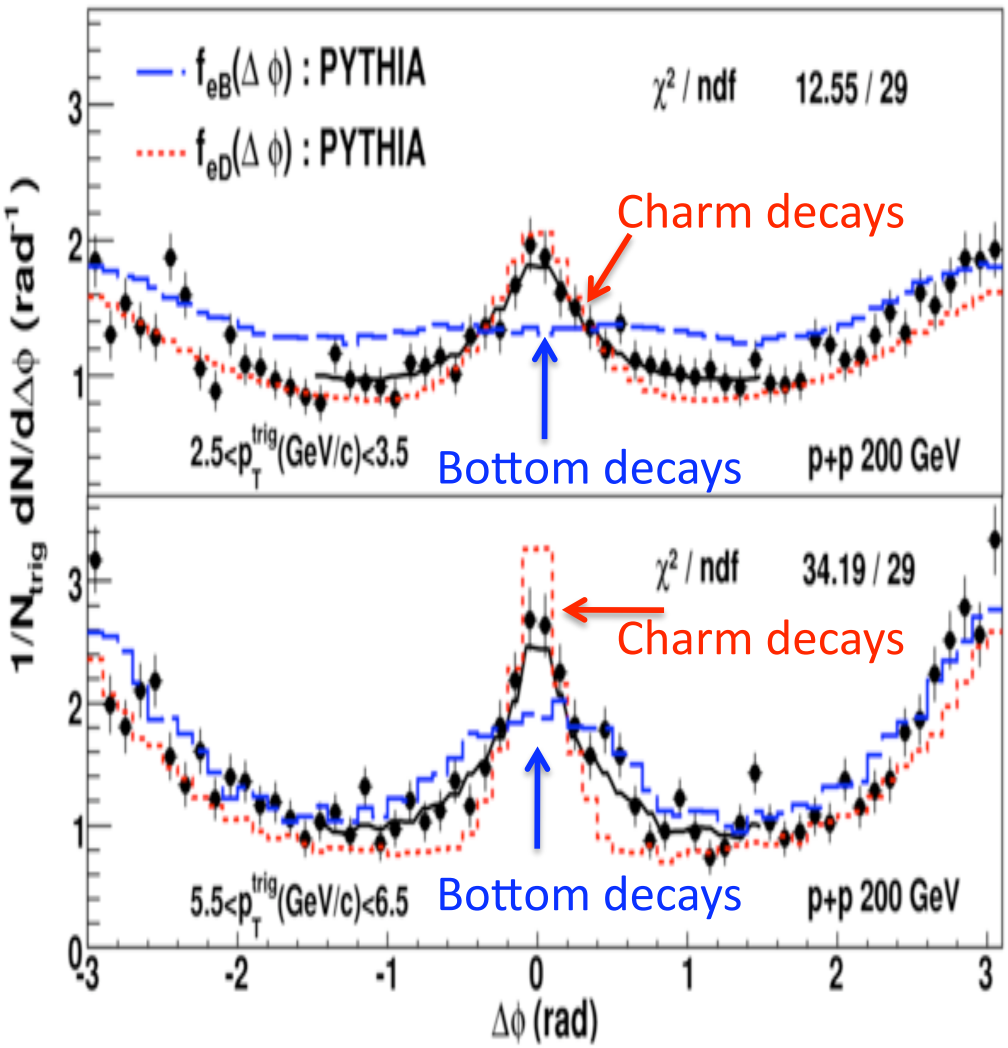
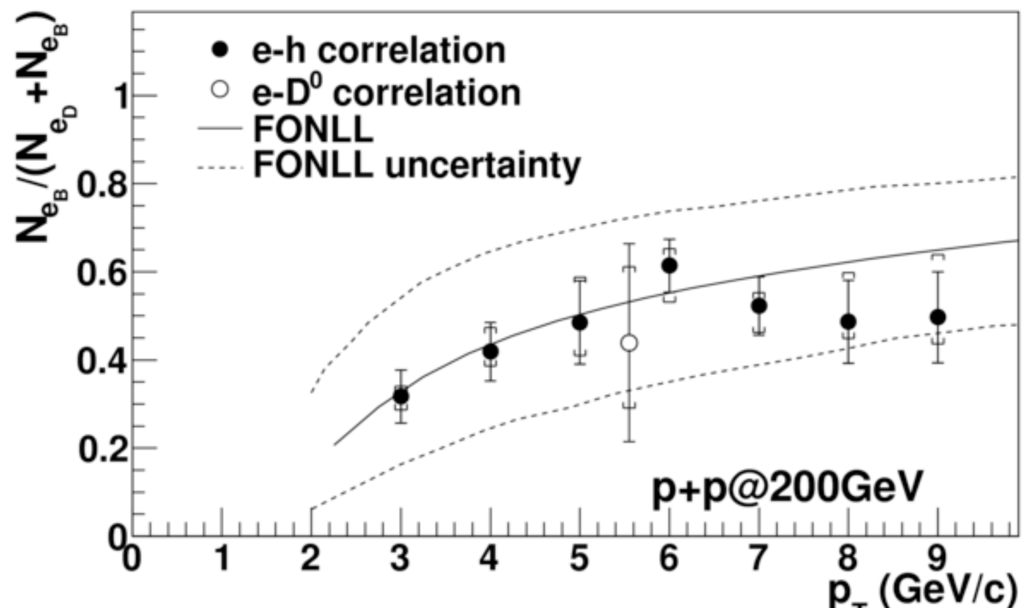
Near side correlation in p+p 200 GeV

Different decay kinematics for charm and bottom hadrons
→Crucial for charm and bottom discrimination.





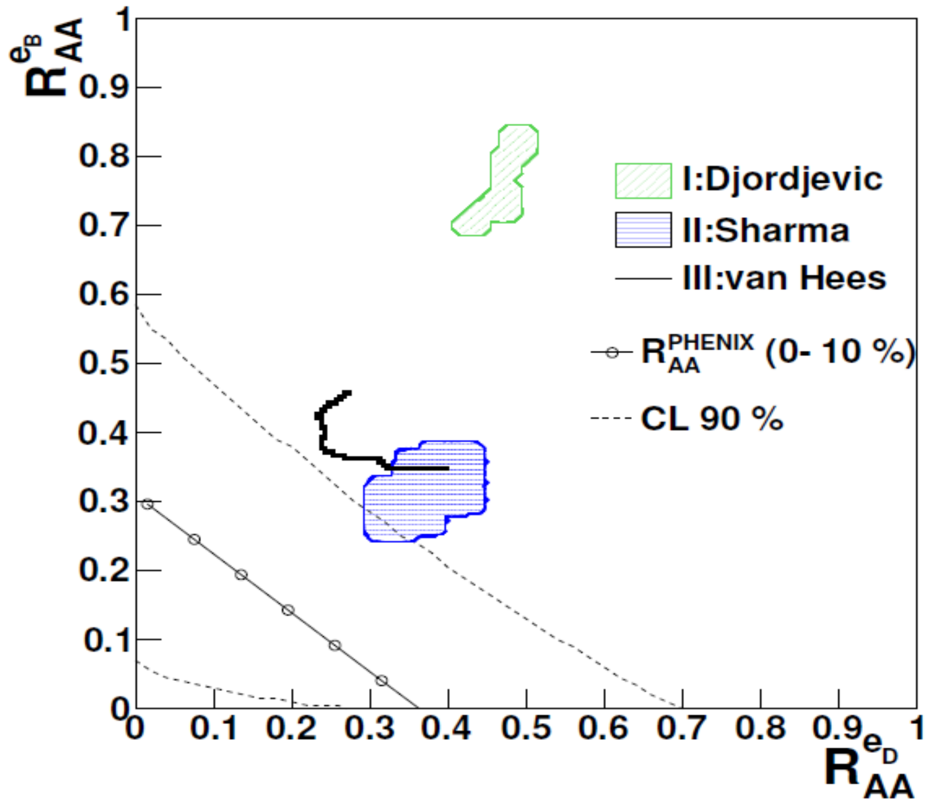
➢Bottom quark contributes significantly in interested p_T ranges

STAR: PRL 105, 202301 (2010)

Bottom electron is suppressed

Combine the obtained b/c separation with NPE R_{AA} (PHENIX:arXiv:1005.1627)

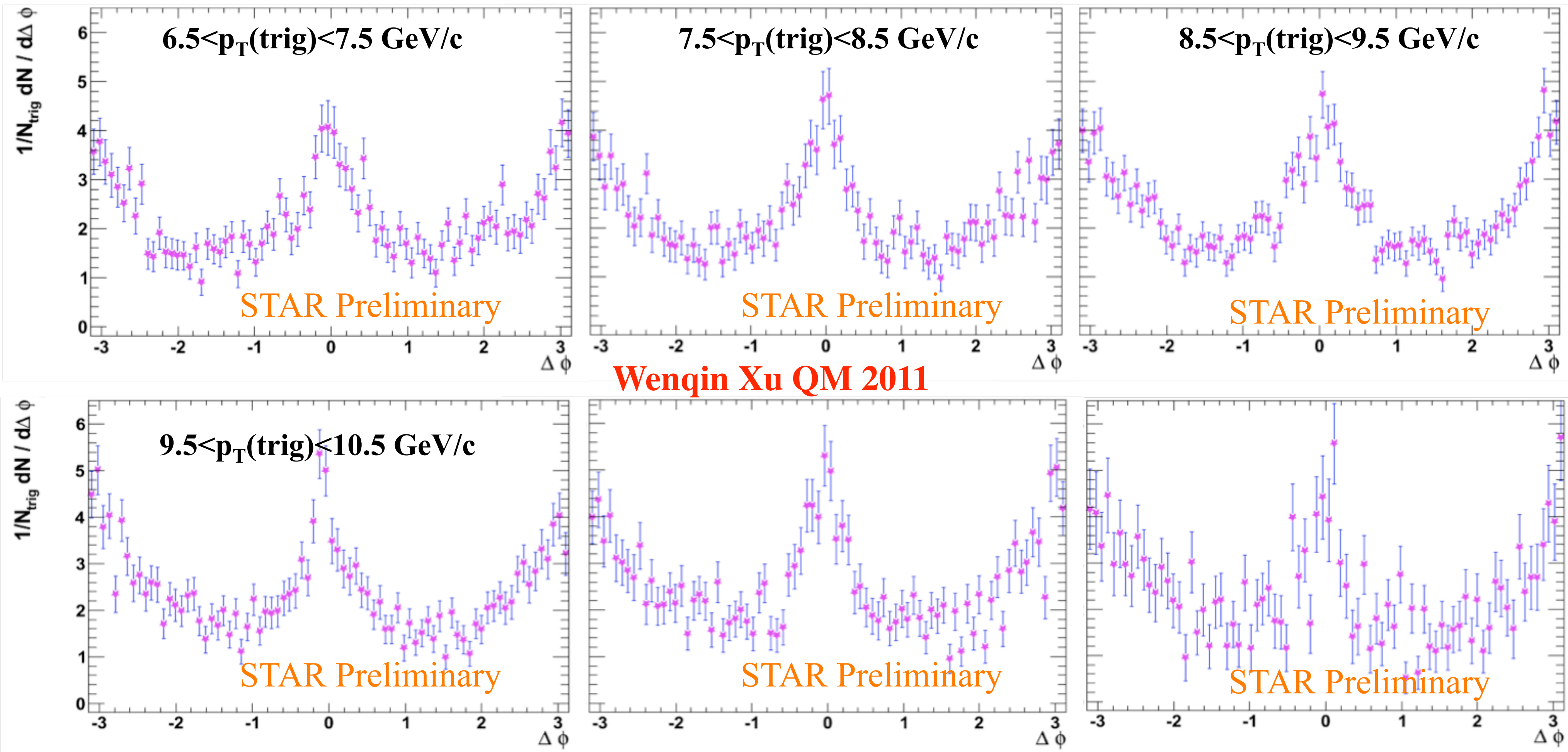
$$R_{AA}^{NPE} = (1 - r_B) R_{AA}^{e_D} + r_B R_{AA}^{e_B}$$



p_T > 5 GeV/c, Bottom electron R_{AA} <1

STAR: PRL 105, 202301 (2010)

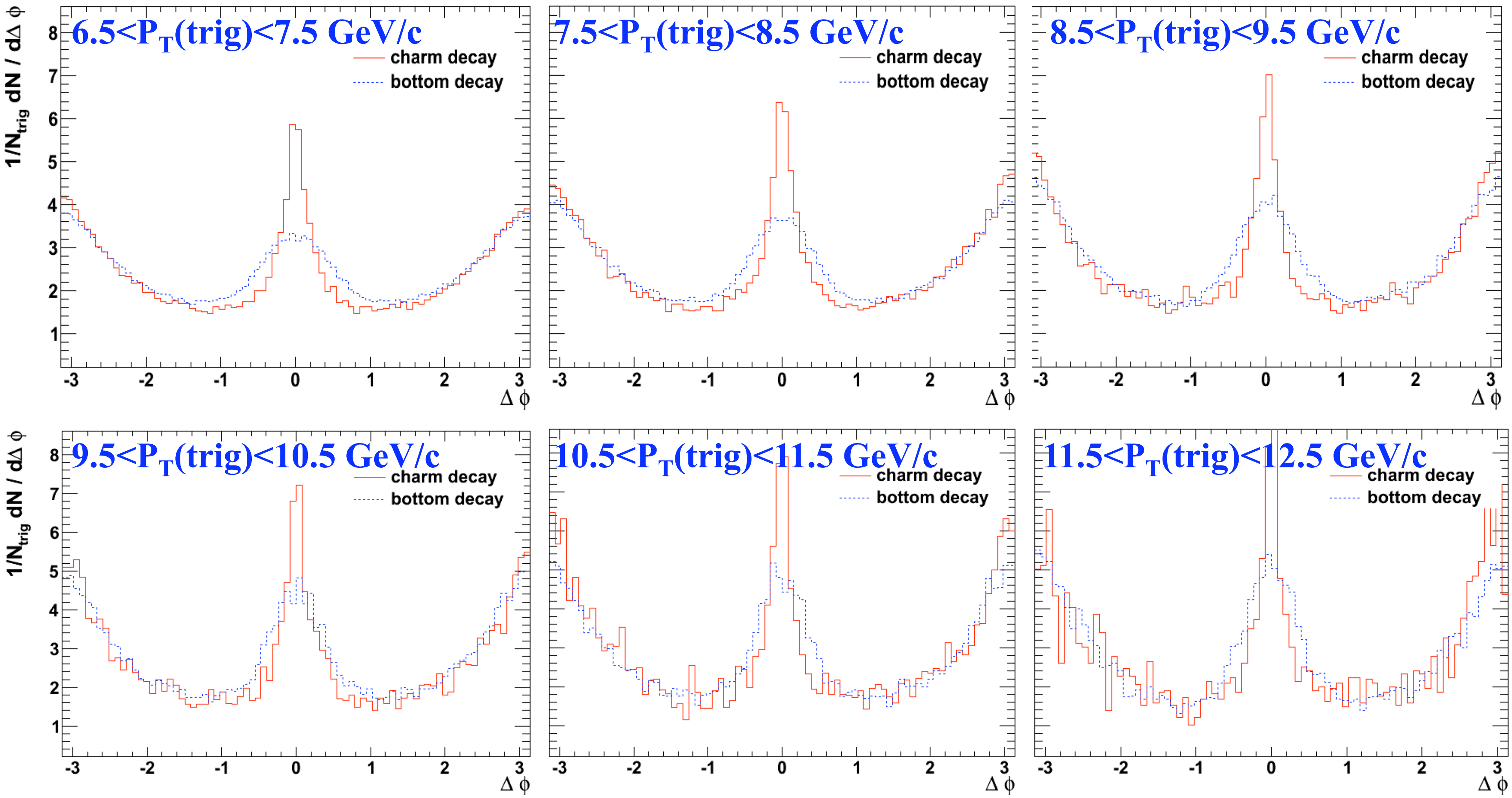
Near side correlation in p+p 500 GeV



HT3 triggered events with max E_T > 7.4GeV.
Trigger tracks are NPE at different p_T.

Associated p_T > 0.3 GeV/c

PYTHIA p+p 500 GeV

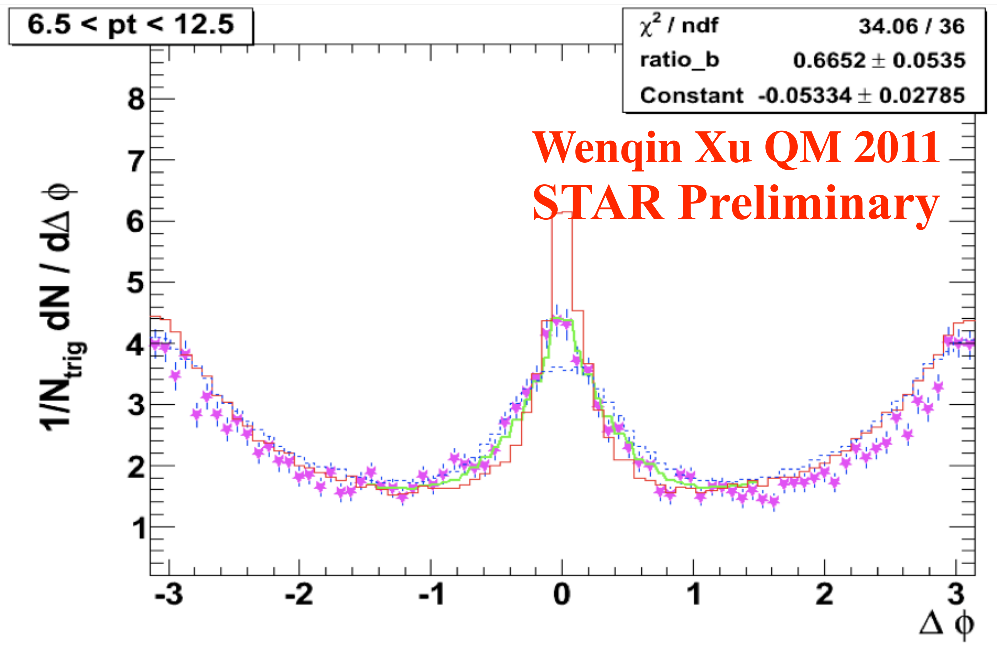


PYTHIA8: e(D)-h and e(B)-h correlation in 500 GeV p+p collisions at 500GeV

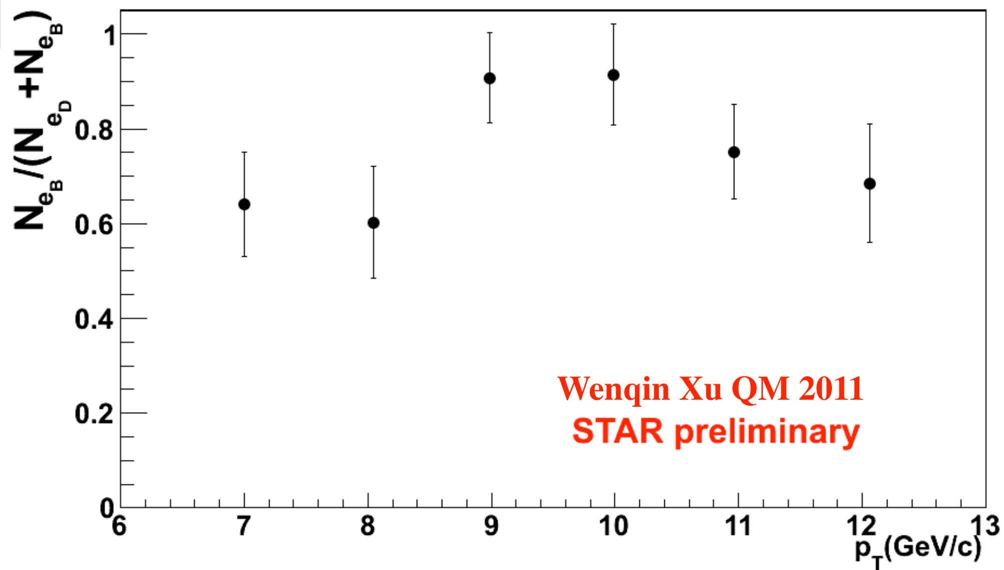
STAR Heavy Flavor Tune v1.1   *Mini Bias Mode*

Bottom/Charm contributions in p+p 500 GeV

Bottem/Charm contributions to their decay electrons are obtained by comparison against PYTHIA



PYTHIA 8 STAR Heavy Flavor Tune v1.1 Mini Bias Mode



- **Fit function:**

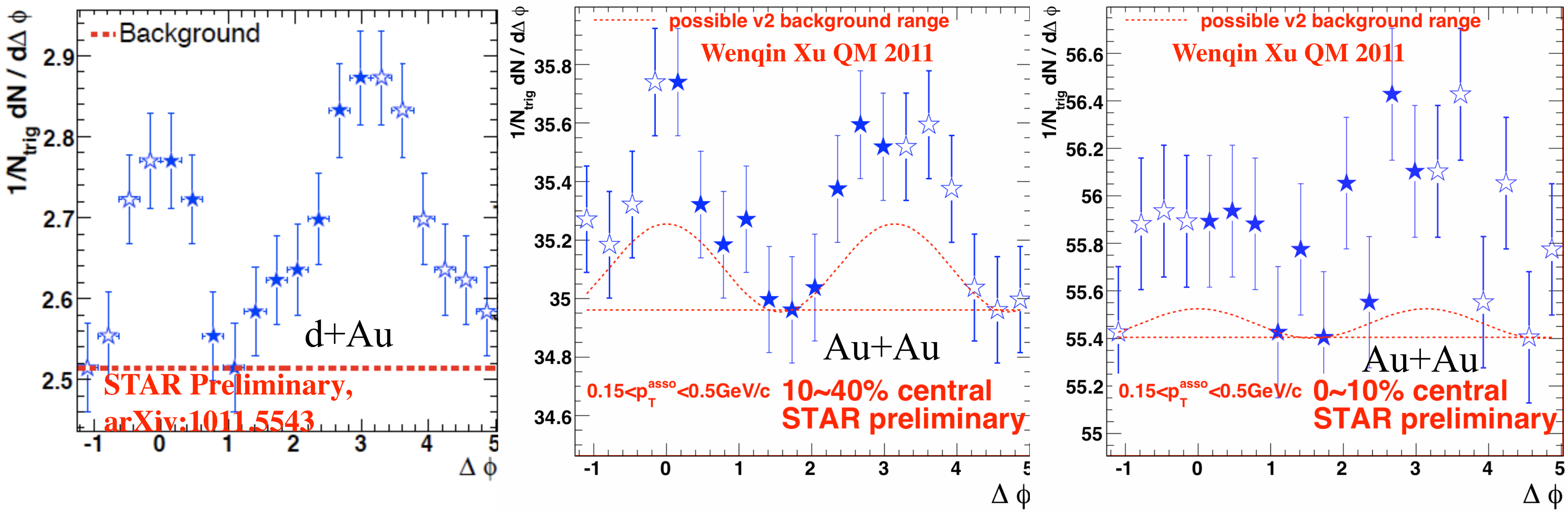
$$r_B f_{e_B}(\Delta\phi) + (1 - r_B) f_{e_D}(\Delta\phi) + const.$$

r_B is relative B contribution

f_{e_B}, f_{e_D} **are the correlations from PYTHIA**

- **The extracted $e_B/(e_B+e_D)$ ratio is higher than 60% within the current statistics.**
- Error bars are statistical only.

Away side correlation: d+Au *vs* Au+Au



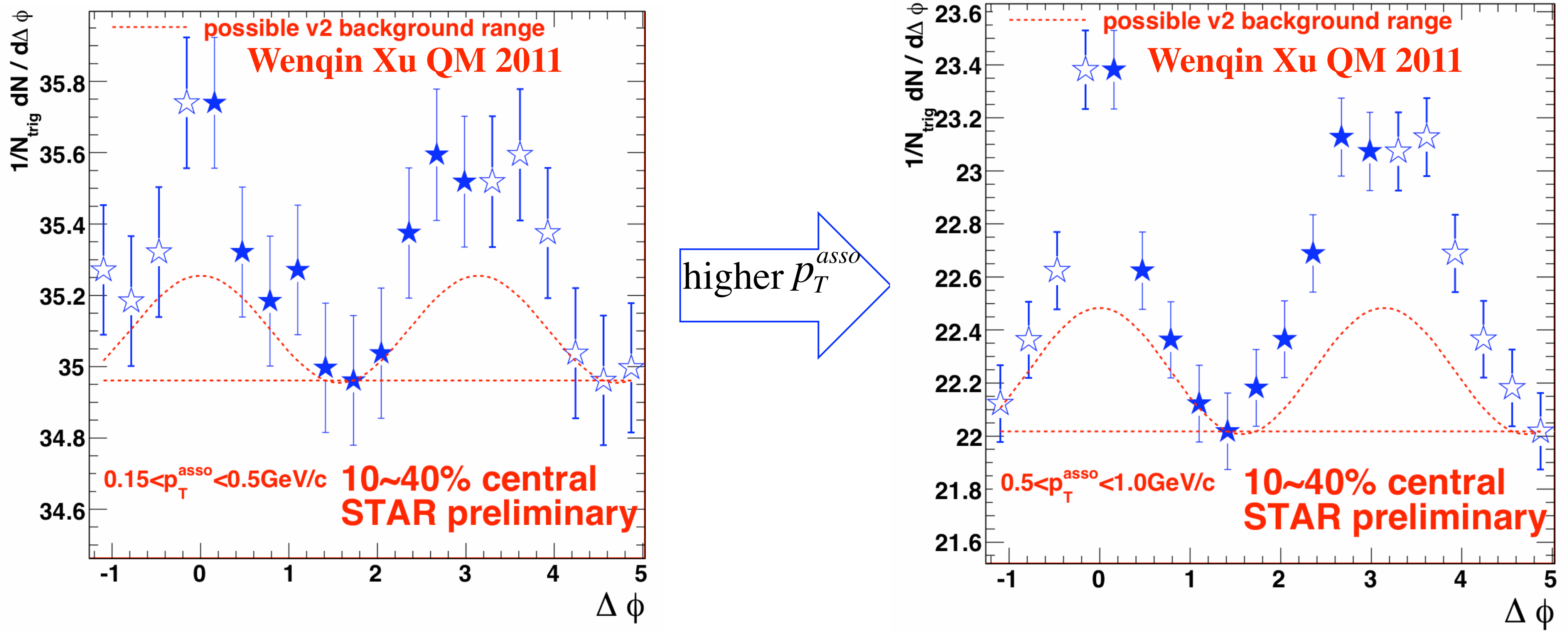
Asso. tracks p_T 0.15 ~ 0.5GeV/c, |η|<1; NPE p_T 3~6GeV/c

Vertical error bars are statistical only. The open star data points are reflected points.

Red dashed curves: v_2 background range set with NPE v_2 being zero and hadron v_2.

Very large uncertainties associated with the background, currently under study, not subtracted.

Associated tracks with higher p_T



Asso. tracks p_T 0.15 ~ 0.5GeV/c, |η|<1   **Asso. tracks p_T 0.5 ~ 1GeV/c, |η|<1**

Vertical error bars are statistical only. The open star data points are reflected points.
Red dashed curves: v_2 background range with by NPE v_2 being zero and hadron v_2.

- ➢**both near side and away side have intriguing correlations**
- ➢Background studies are in progress
- ➢~half statistics in Run10; Run11 will have similar statistics.

Summary

✧The near side of NPE-h correlations in p+p collisions have been used to disentangle bottom/charm contributions.

✧We can study the heavy flavor tagged jet-medium interactions by using the NPE-h correlations in Au+Au 200GeV:

intriguing structures begin to show up.

INFN

La frontière

Of Les corrélations

Federico QM2011

- any residual room for medium response?

→look at the small print on the away side
  - two-dimensional in η,φ
  - use information on direction of recoiling parton
    - around re-emerging away-side jets
    - around away-side heavy flavour

- "Annecy spectrum" promises a beautiful tool

→quantitative comparisons with full hydro
  - extract information on η/s, initial conditions (Glauber, CGC, …)

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Backup

La frontière

- any residual room for medium response?

→look at the small print on the away side
  - two-dimensional in η,φ
  - use information on direction of recoiling parton
    - around re-emerging away-side jets
    - around away-side heavy flavour

- “Annecy spectrum” promises a beautiful tool

→quantitative comparisons with full hydro
  - extract information on η/s, initial conditions (Glauber, CGC, …)

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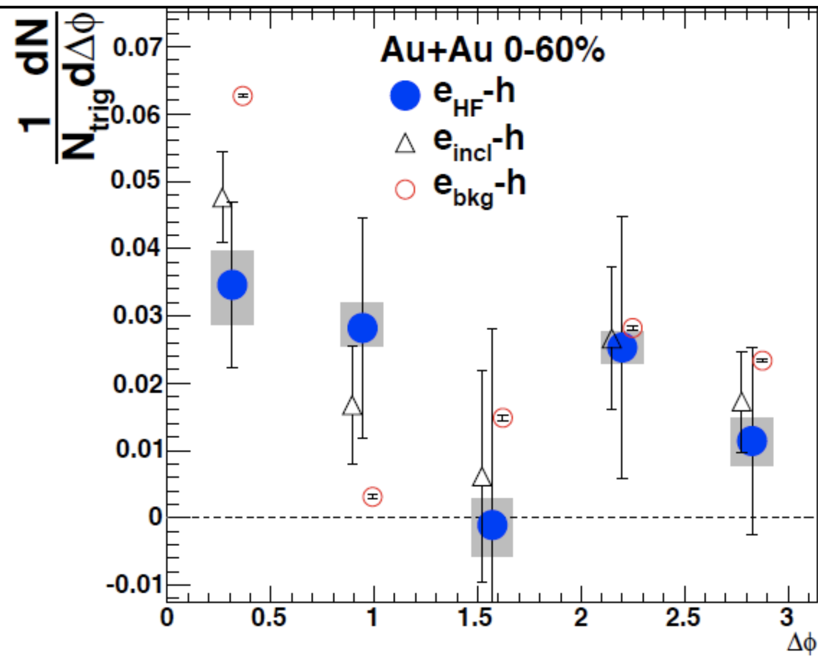
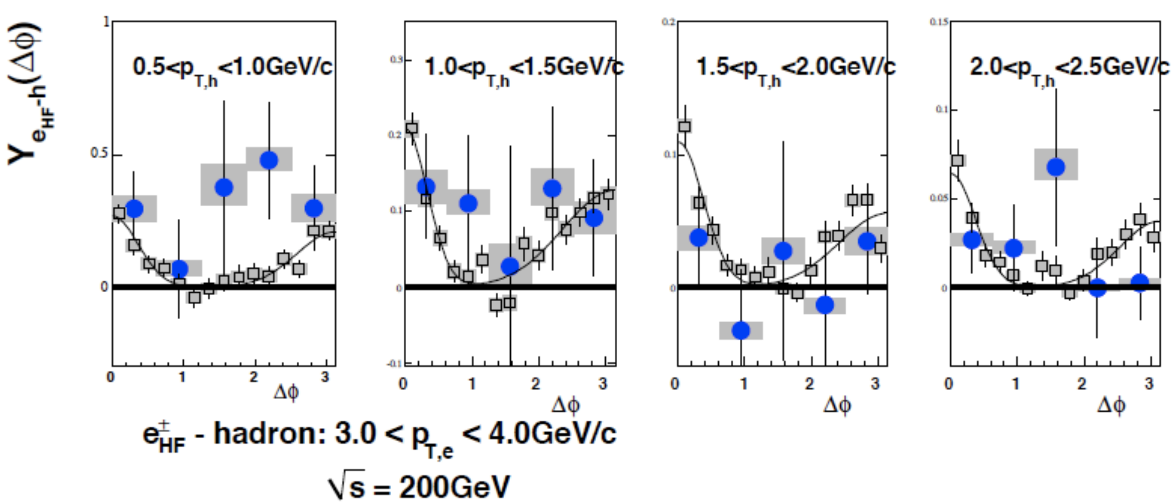
PHENIX NPE-hadron corr



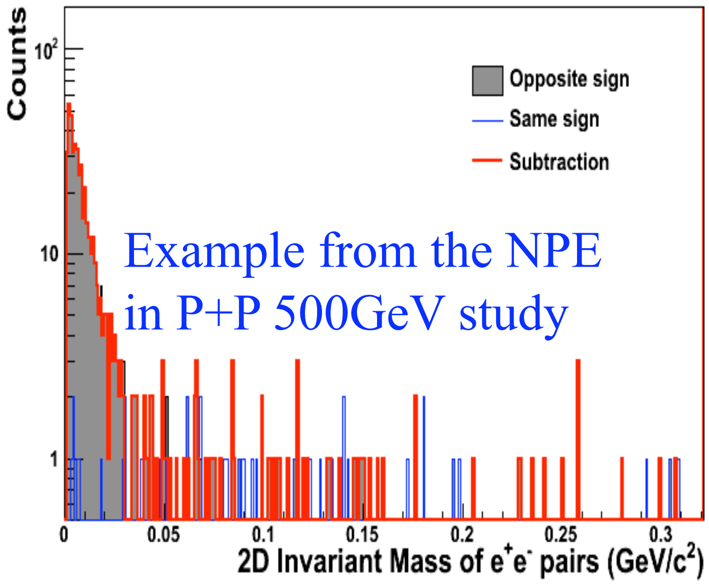
arXiv:1011.1477

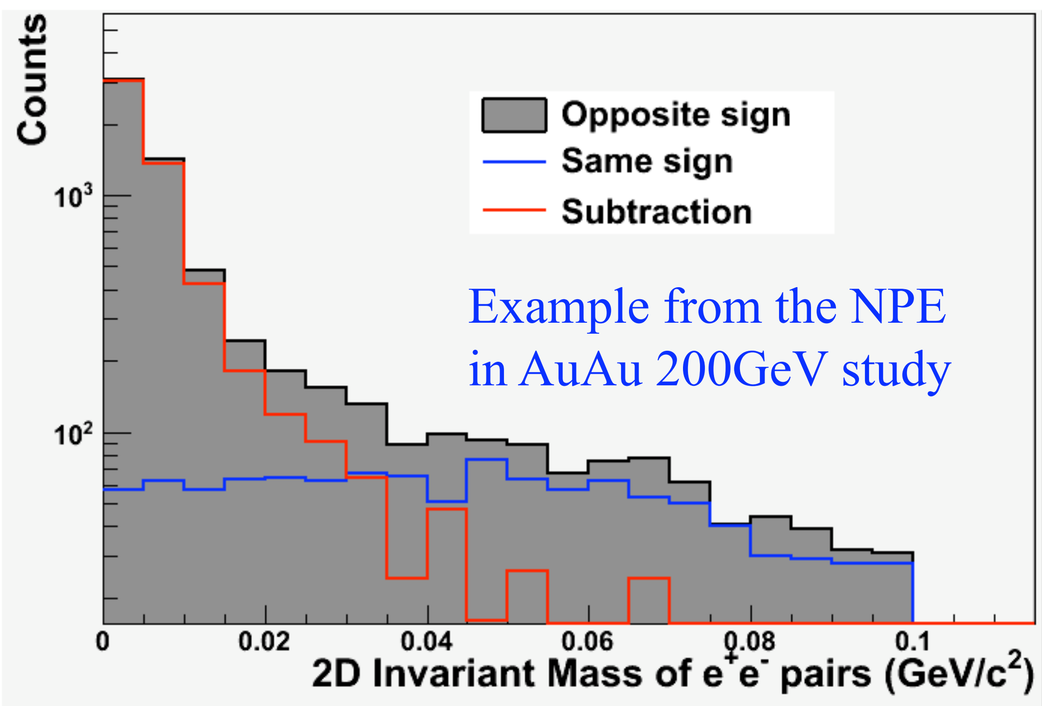
FIG. 4: (color online) $e_{inc} - h$, $e_{bkg} - h$ and $e_{\rm HF} - h$ (solid circles) for p+p (top panel) and Au+Au (bottom panel) collisions for 2.0< $p_{T,e}$ <3.0 GeV/c and 1.5< $p_{T,h}$ <2.0 GeV/c. The overall normalization uncertain of 7.9% in p+p and 9.4% in Au+Au is not shown.

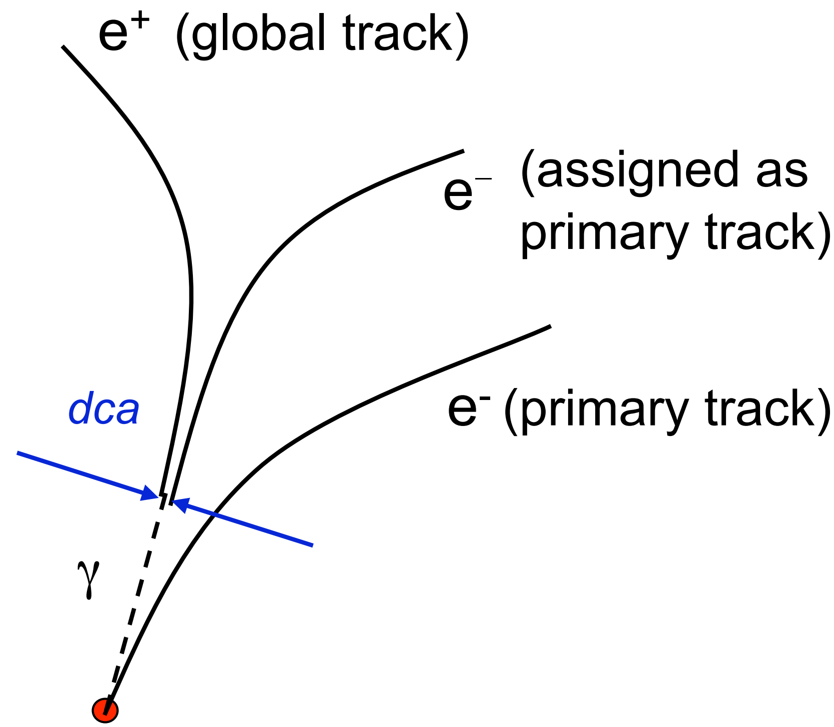


eHF – h jet functions for Au+Au (solid blue circles) and p+p collisions for 3.0–4.0 GeV/c Electron triggers and the hadron-pT bins indicated.

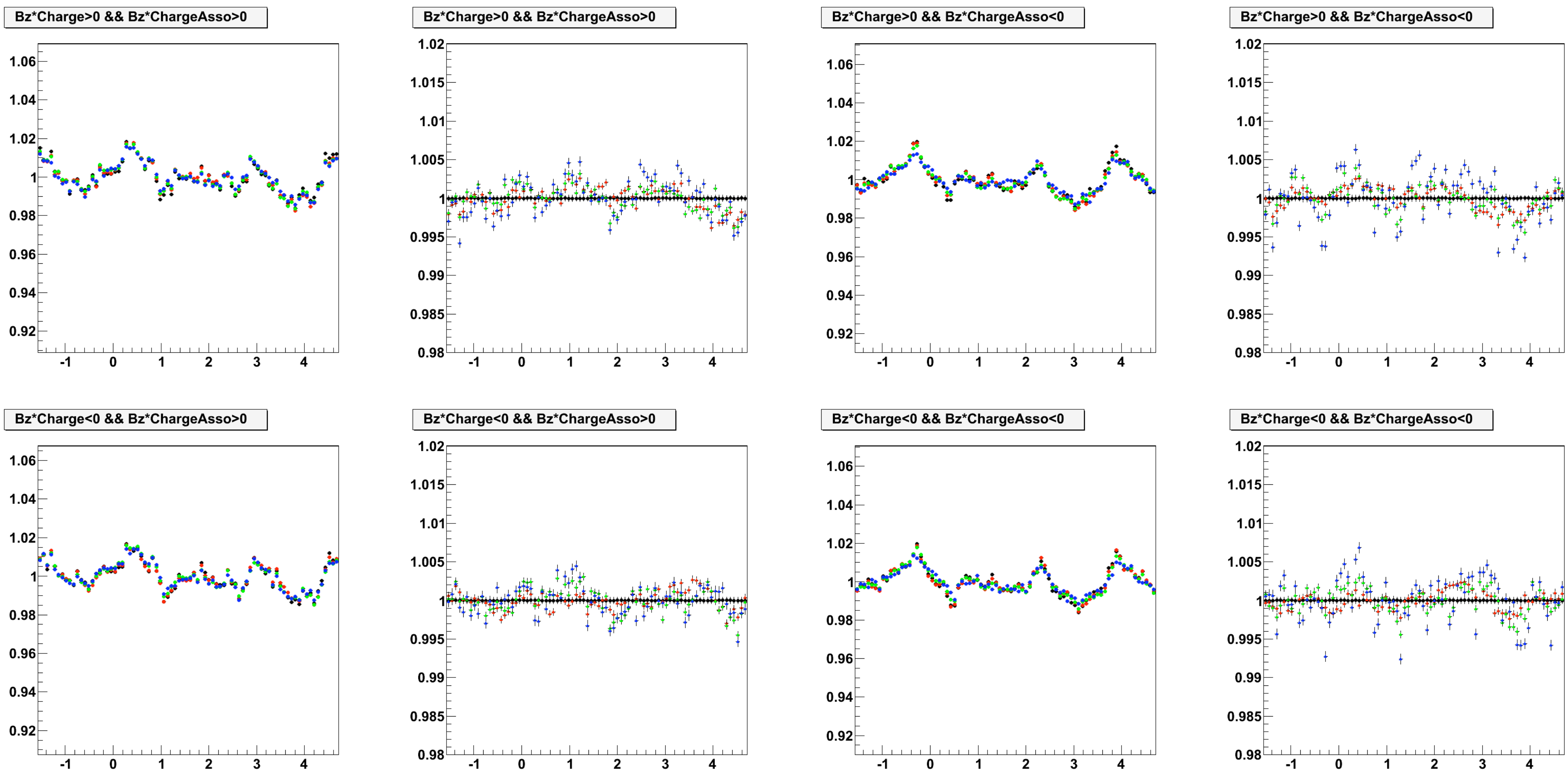
Photonic electron (PE) reconstruction





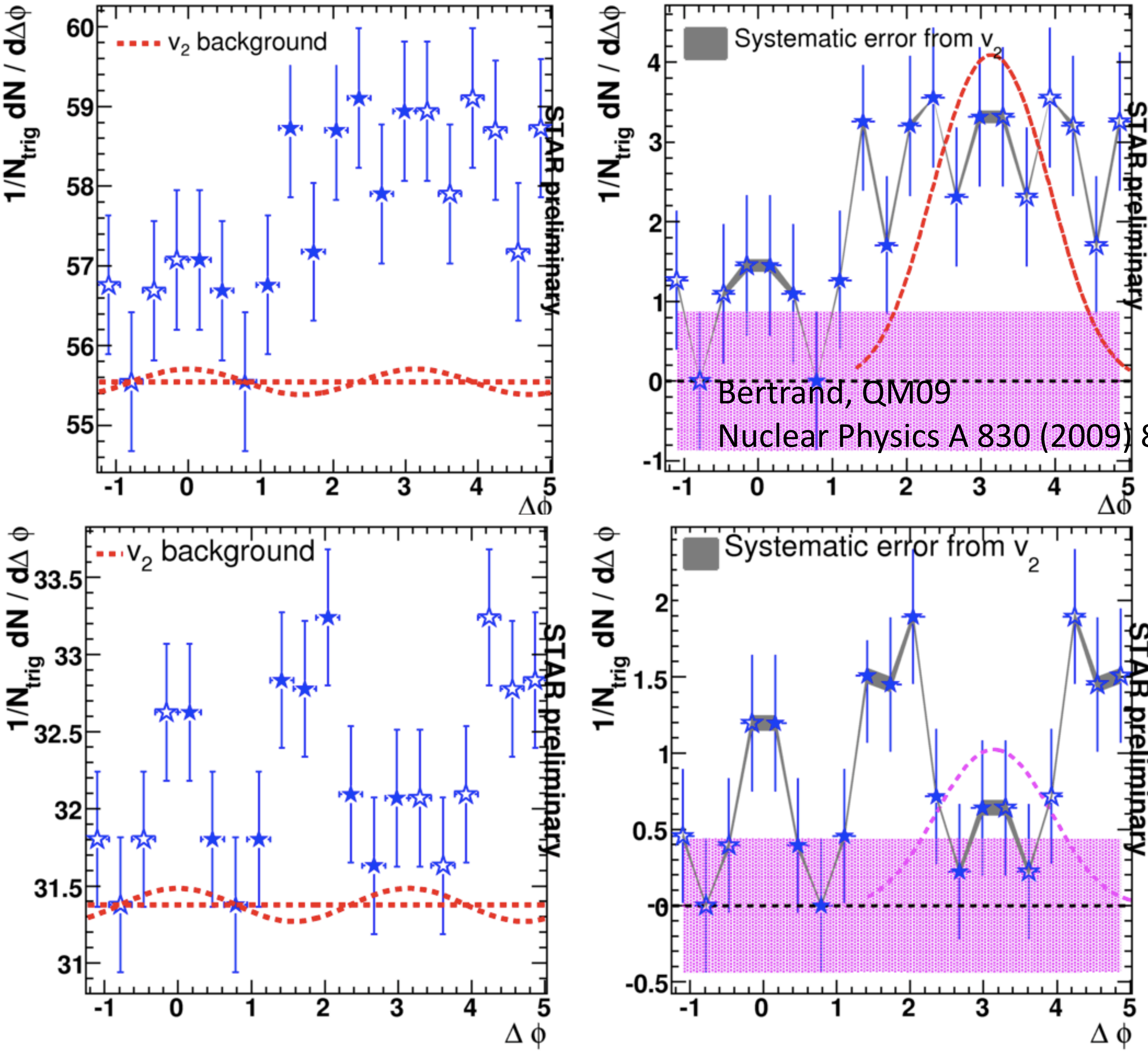


STAR NPE-h correlation mixing event backgrounds



Inclusive trigger tracks-hadron (asso p_T 0.15~0.5GeV) correlations from mixed events
The background for NPE-h correlation.

4 centrality bins:
Black dots: 0~5%
Red dots: 5~10%
Green dots:10~20%
Blue dots: 20~30%



AuAu at 200 GeV

Bertrand, QM09

Nuclear Physics A 830 (2009) 849c–852c

CuCu at 200 GeV