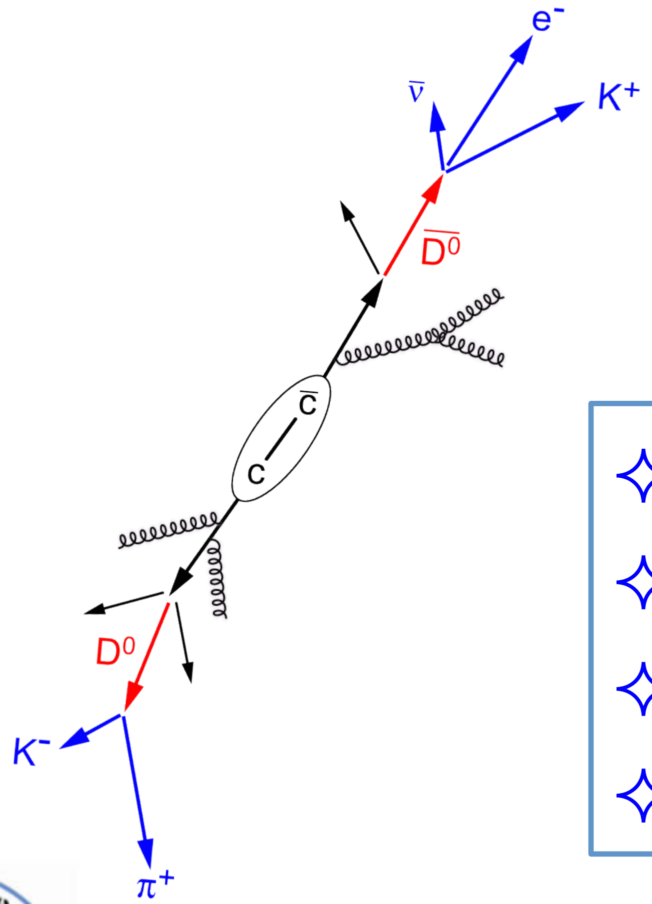
Open Heavy Flavor Production In Heavy-Ion Collisions from STAR



Yifei Zhang (for the STAR Collaboration)

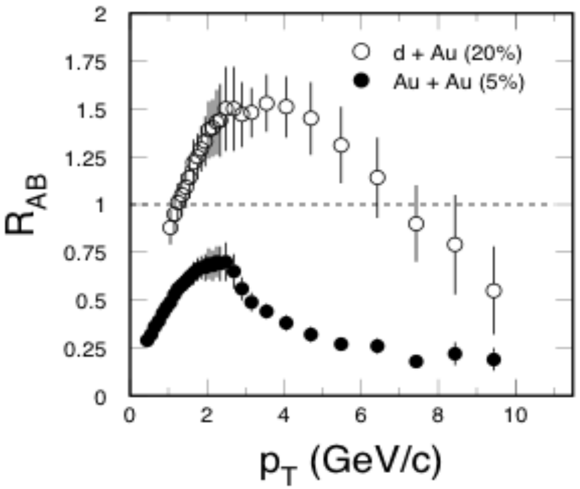
University of Science and Technology of China

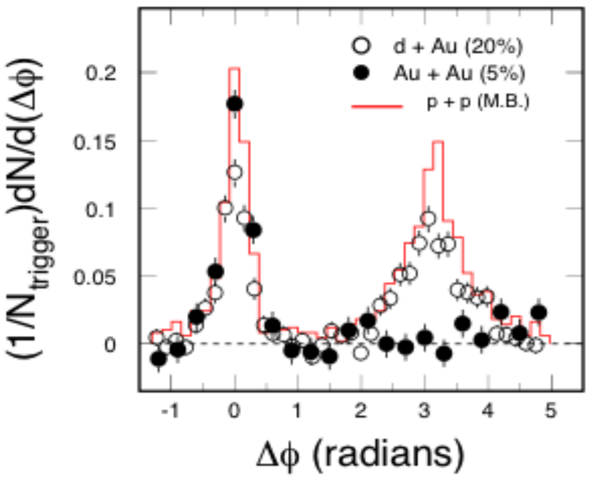
- Introductions
- Recent measurements
- Near future HF program
- Summary

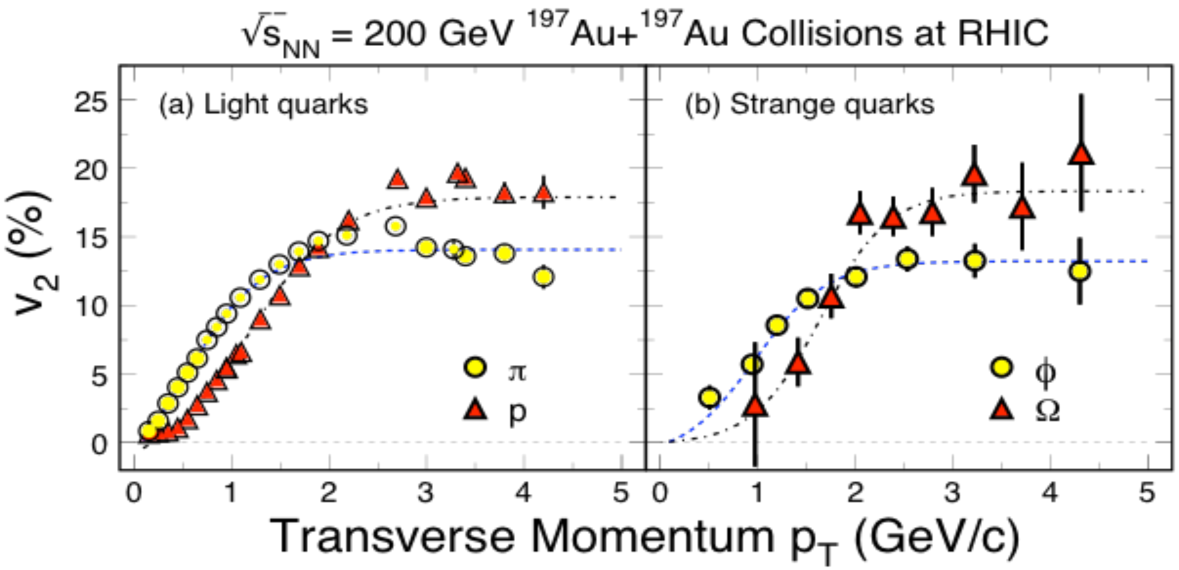
BIRMINGHAM SQM 2013

U.S. DEPARTMENT OF ENERGY

Light flavor behavior in strongly coupled medium



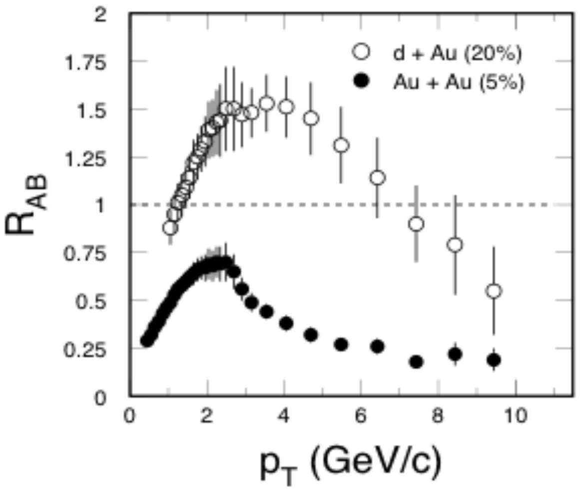


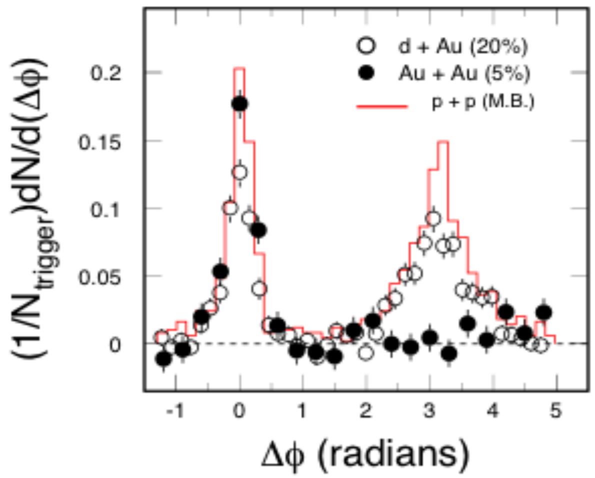


- High p_T:
  - Light quark e-loss, Jet quenching
- Low p_T:
  - Hydrodynamics works
  - Multi-strange hadrons flow
- Intermediate p_T:
  - Number of Constituent Quark scaling
  - flow s ~ u,d

STAR: Nucl. Phys. ***A757***, 102(2005).
QM09

Light flavor behavior in strongly coupled medium





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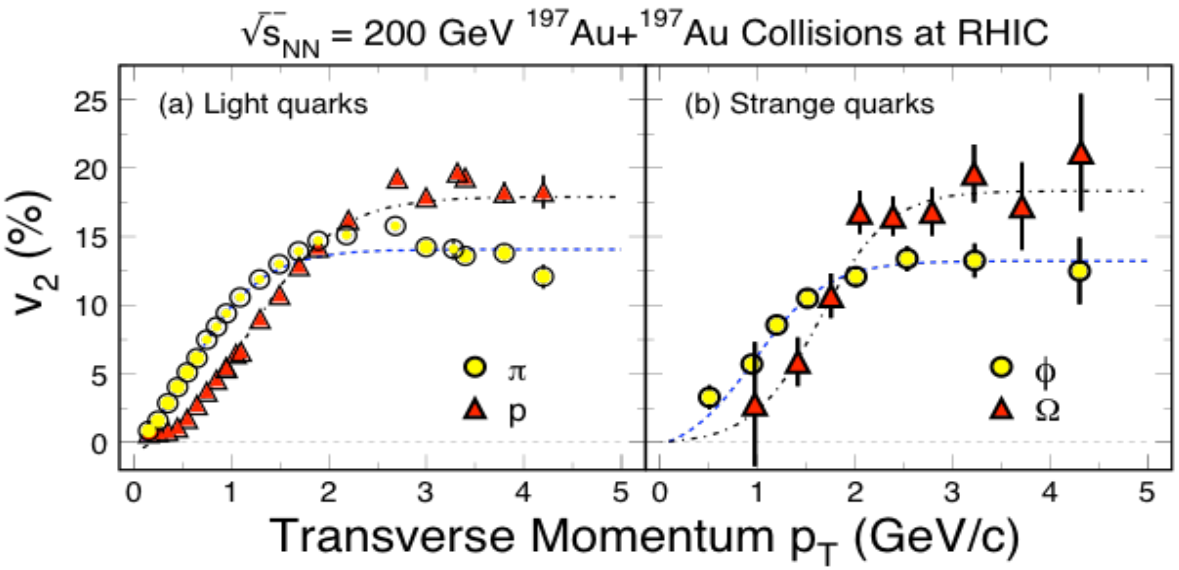


Large partonic collective flow observed. u, d, s quarks strongly interact with hot/dense medium.

What about heavy quarks?

Is the medium hot/dense enough to modify heavy quarks at RHIC energy?

STAR: Nucl. Phys. ***A757***, 102(2005).
QM09

Why are heavy quarks important?

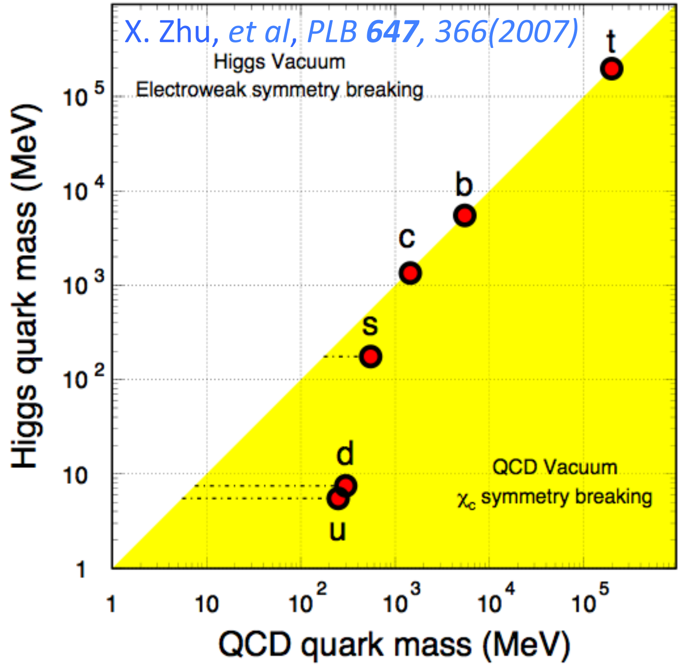
- Higgs mass: electro-weak symmetry breaking (current quark mass).
- QCD mass: Chiral symmetry breaking (constituent quark mass).
- Strong interactions impact little on heavy quark mass.

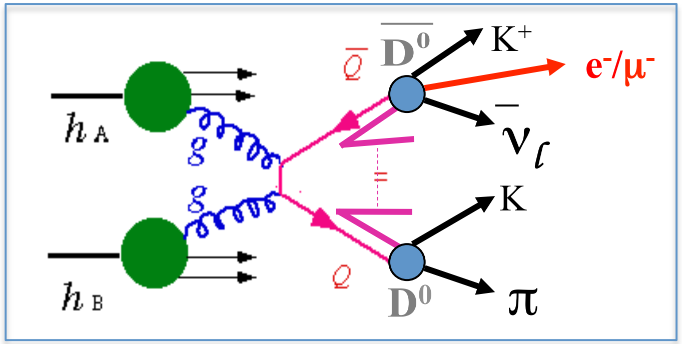
➢ Production cross section can be evaluated by pQCD. Provide reference for charmonium calculations.

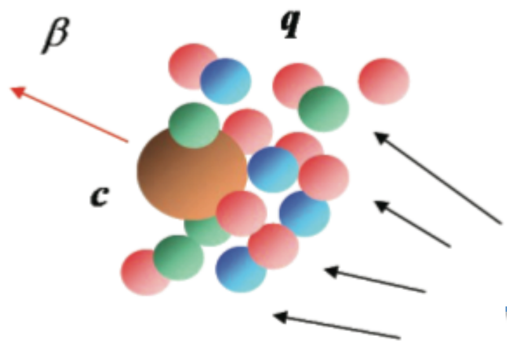
➢ Sensitive to initial gluon density and distribution.

➢ Probe for studying medium properties.

➢ Charm collectivity => sensitive to the thermalization of the medium.



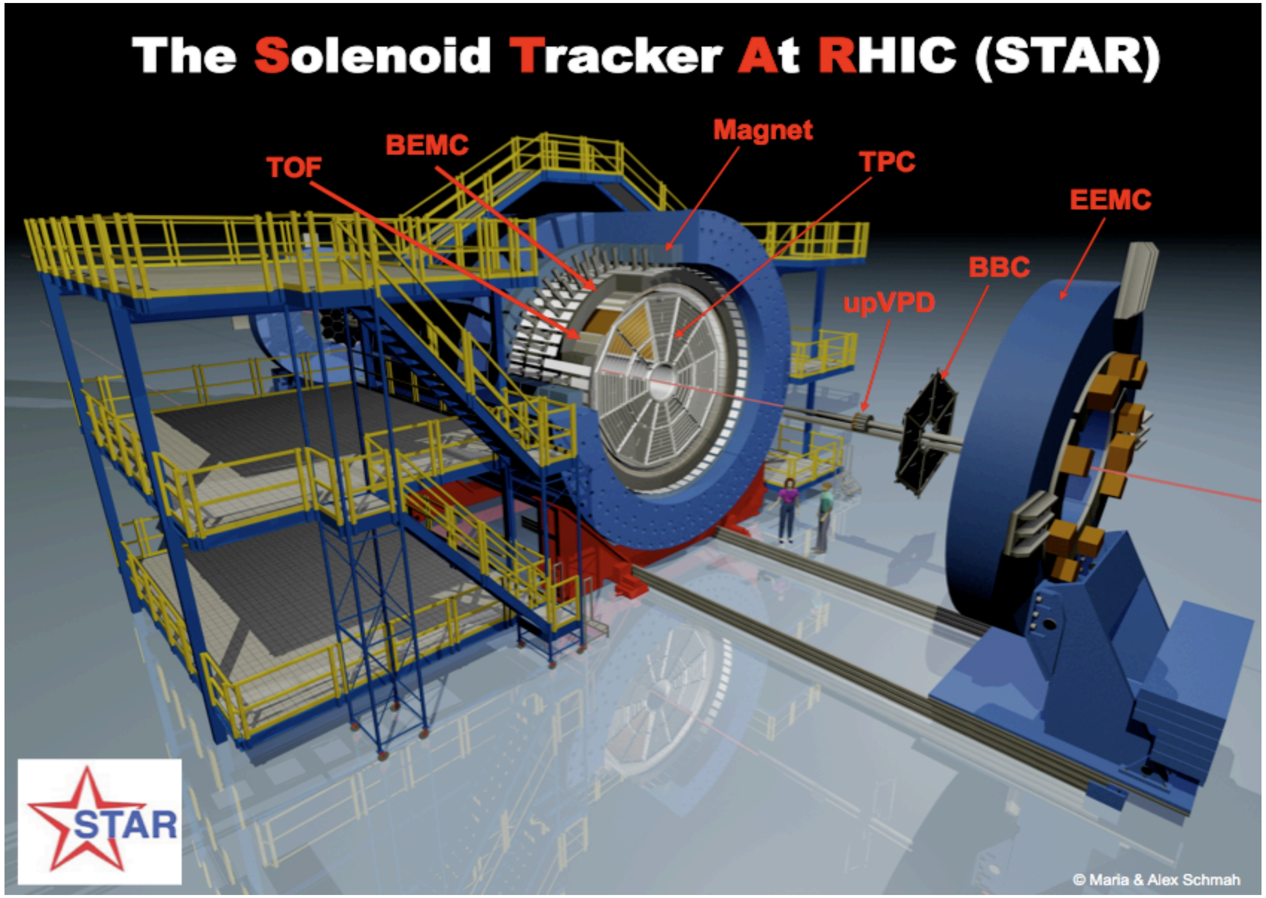




The STAR detector for open HF measurement

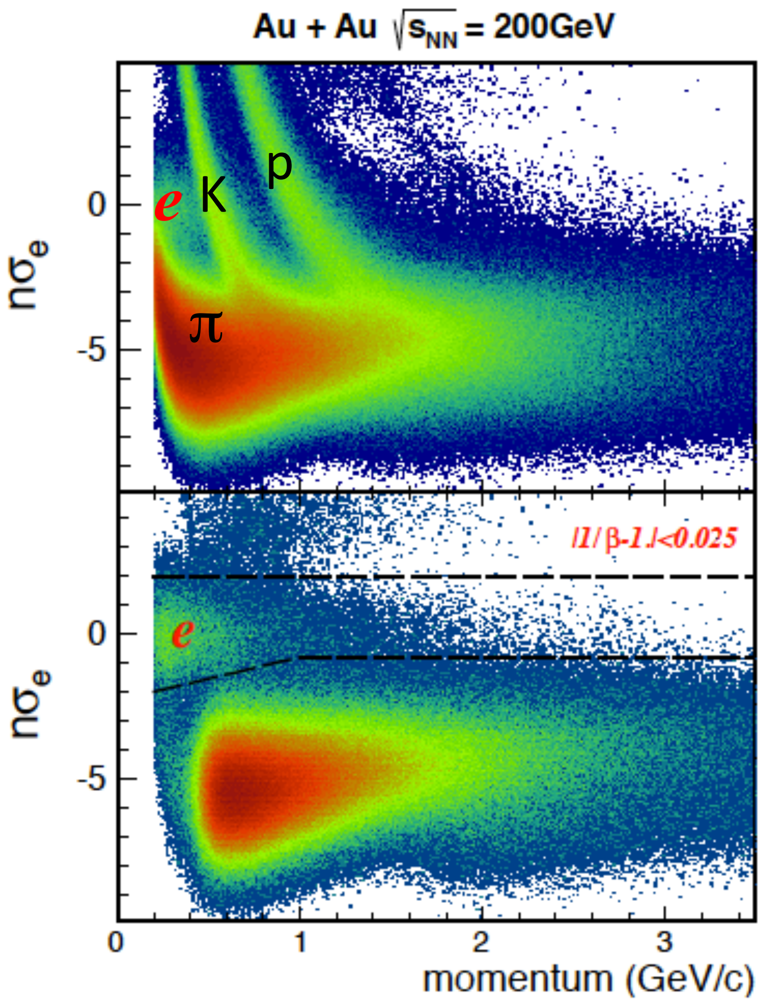
Time Projection Chamber:
- |eta|<1, full azimuth
- Tracking.
- PID through dE/dx

Time of Flight:
- |eta|<1, full azimuth .
- PID through TOF
- Timing resolution: ~85 ps.



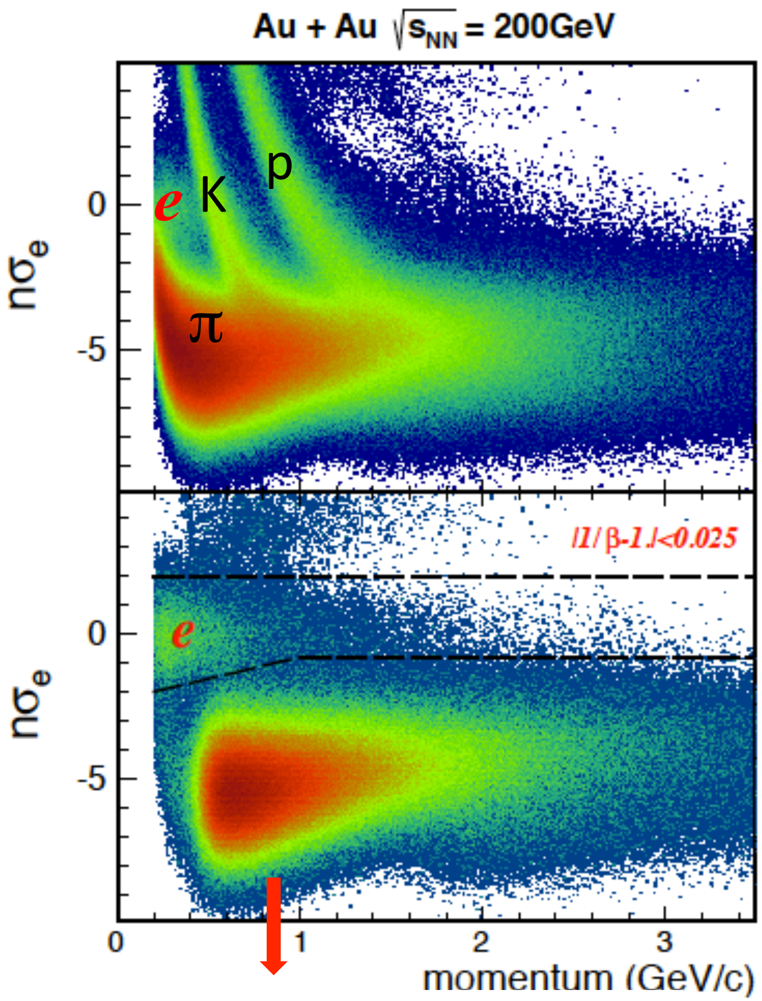
Barrel Electromagnetic Calorimeter
- |eta|<1, full azimuth
- **BTOW**:
  - Tower matching
  - p/E for electron ID
  - Fast online trigger
- **BSMD**:
  - Double layer High spatial resolution MWPC.
  - e/h separation.

Particle Identification

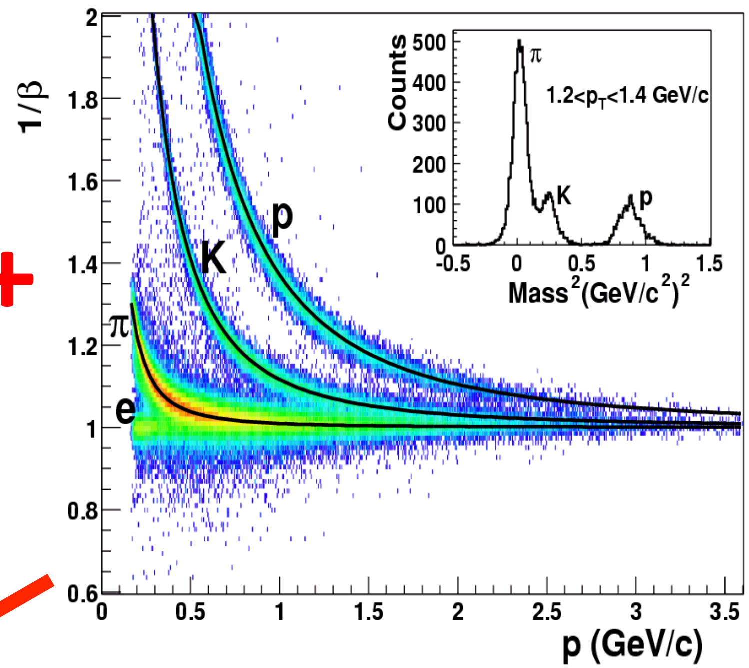


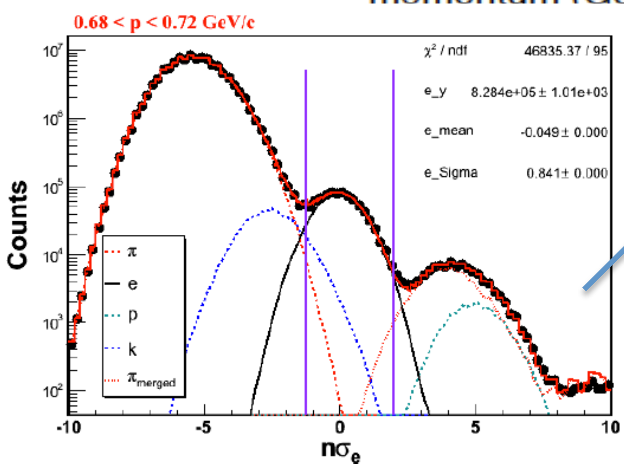
$$n\sigma = \ln(dE^{Measured}/dx - dE^{Exp}/dx)/\sigma$$

Particle Identification



+





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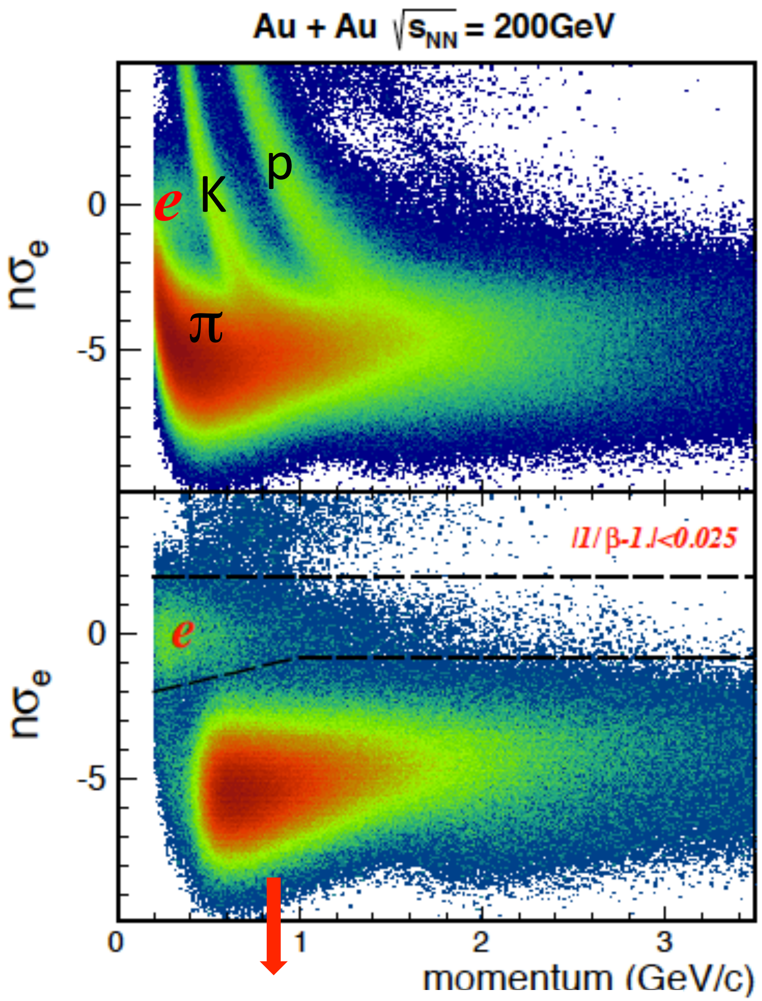
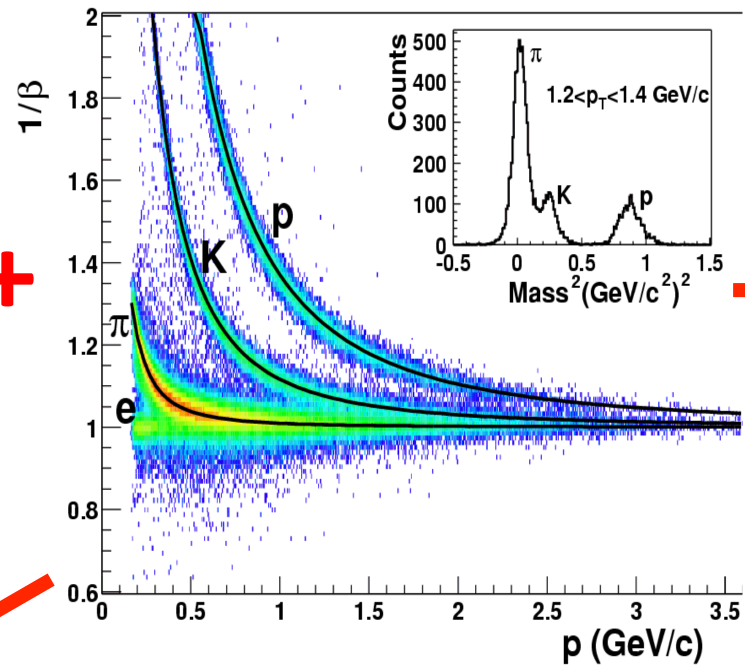
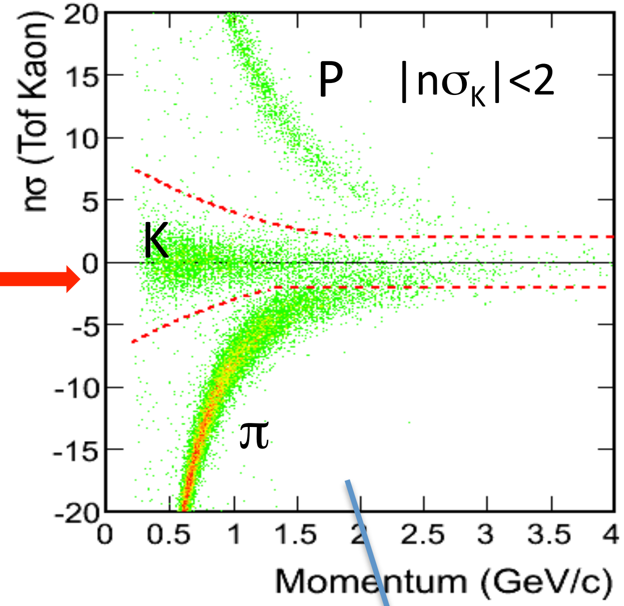
Low p_T e

Particle Identification







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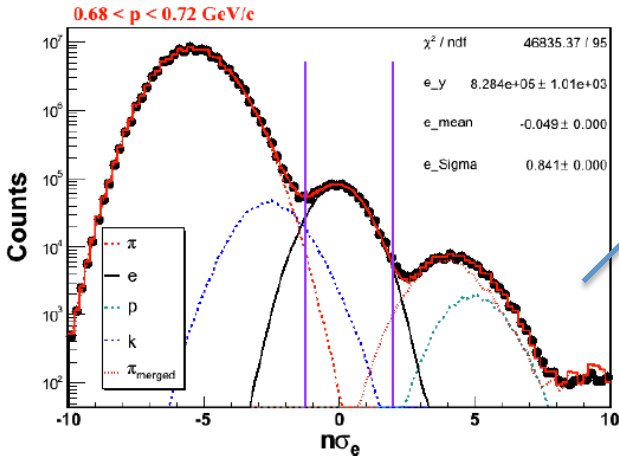
D meson hadronic daughter ID.



Low p_T e

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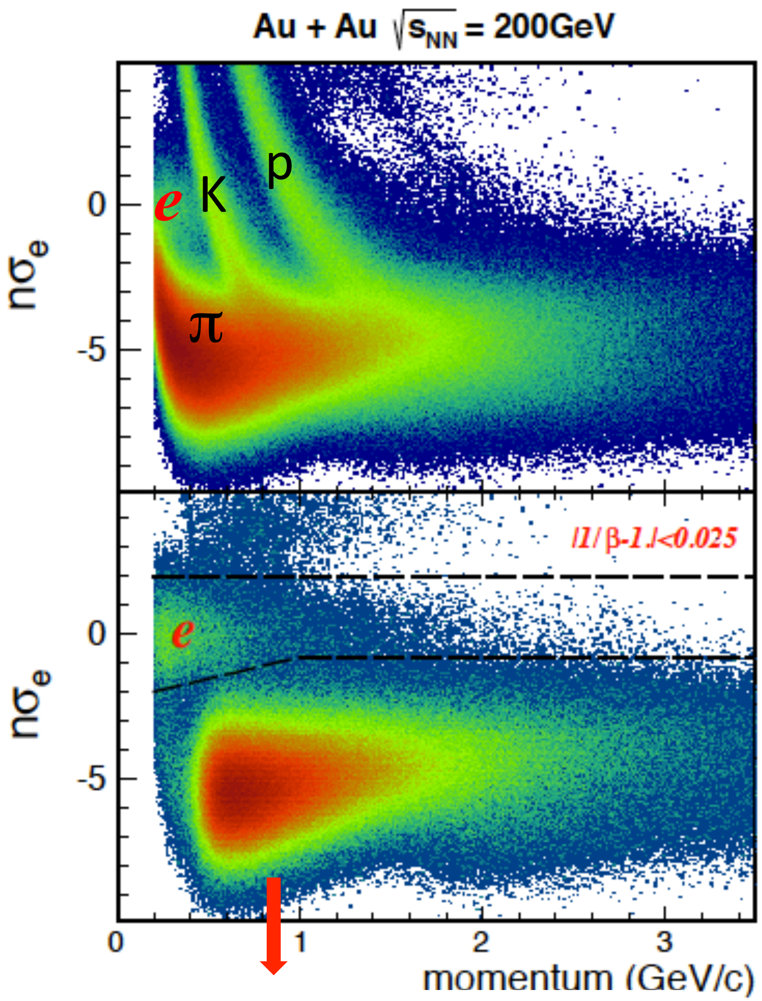

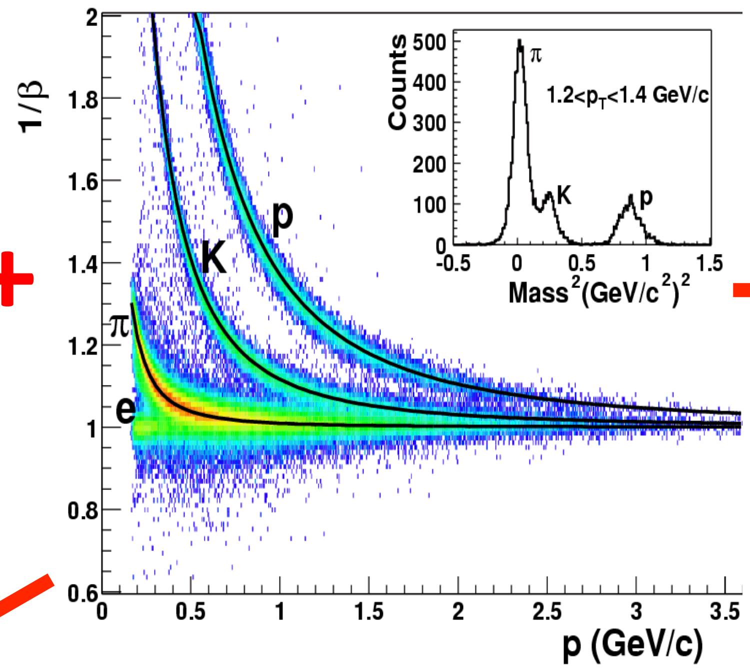

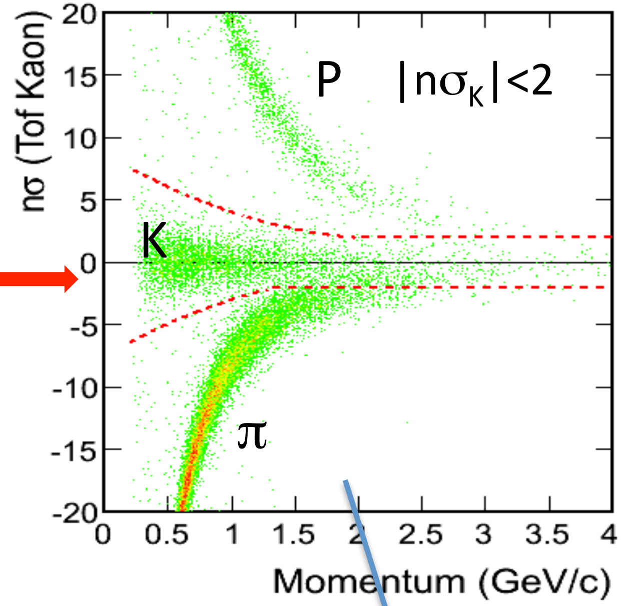

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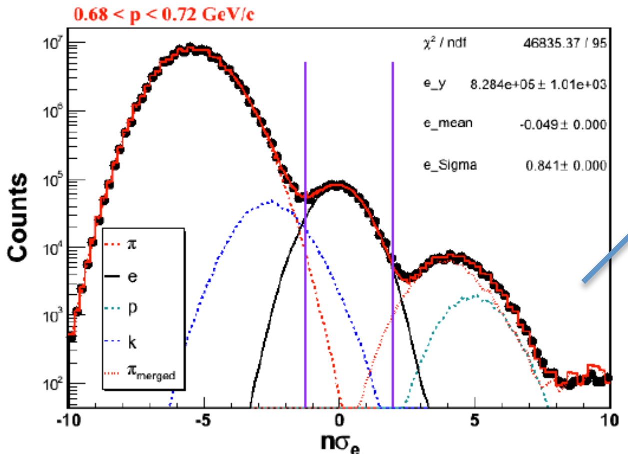

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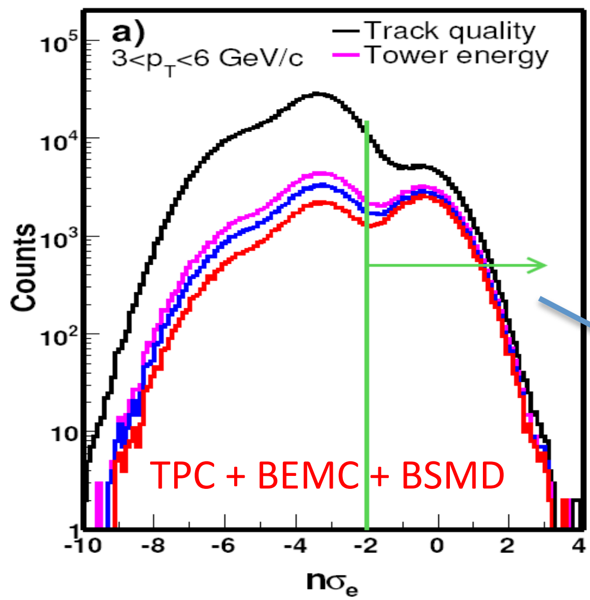
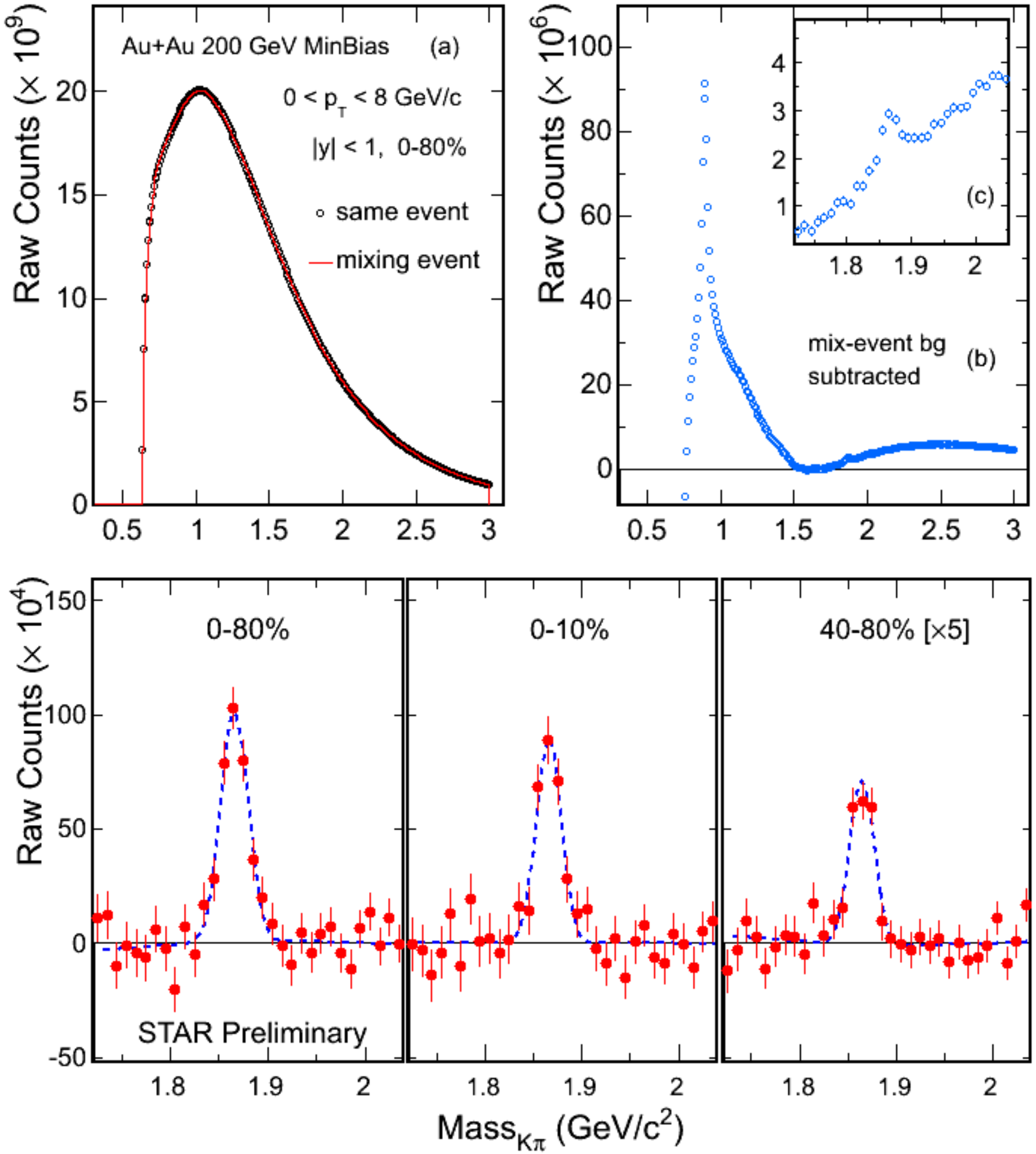


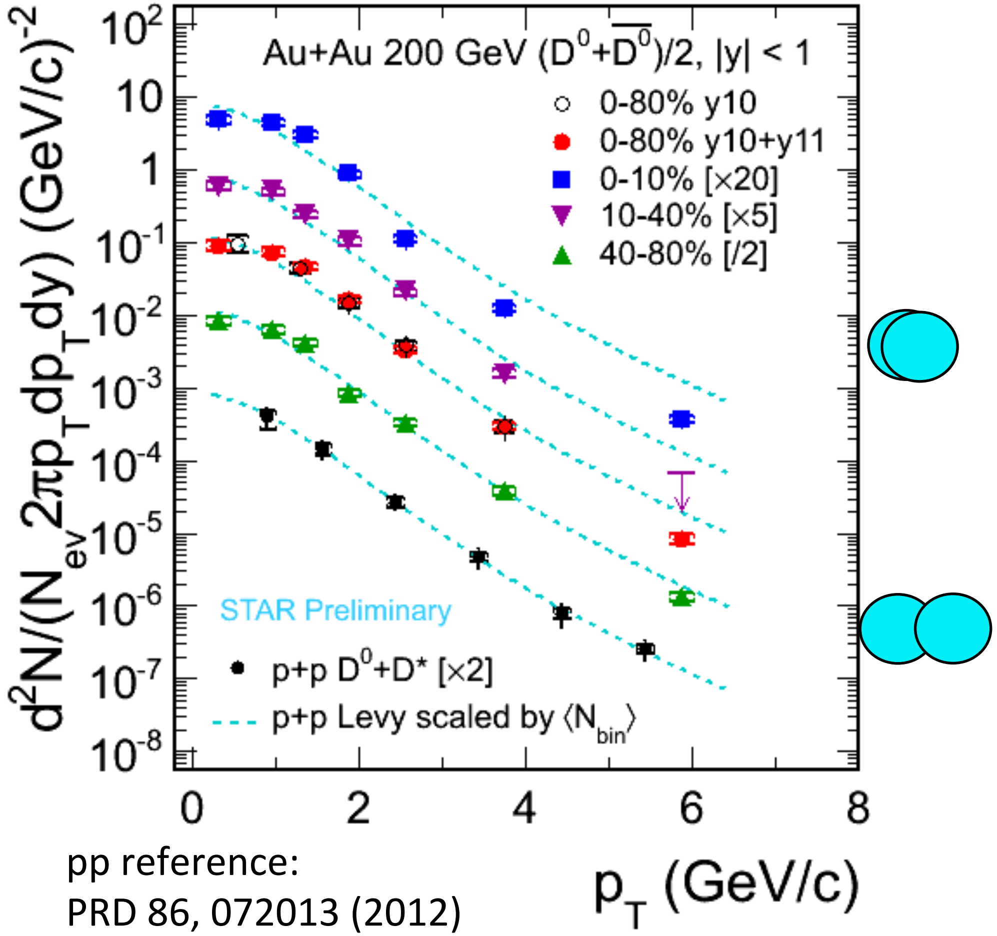
High p_T e

D^0 signals in Au+Au 200 GeV



- Combining data from Year2010 & 2011.
- **Total: ~ 800 M Min.Bias events**
- **Significant signals are observed Total ~ 14σ in 0<p_T<8 GeV/c.**

Nuclear modification of D^0



pp reference:
PRD 86, 072013 (2012)

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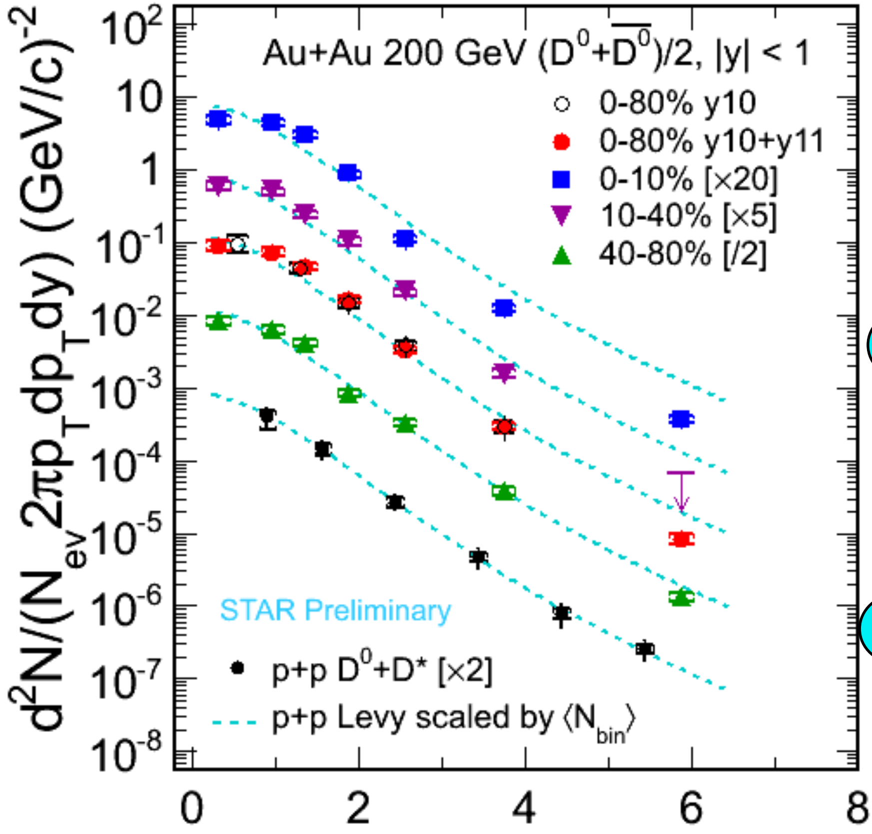

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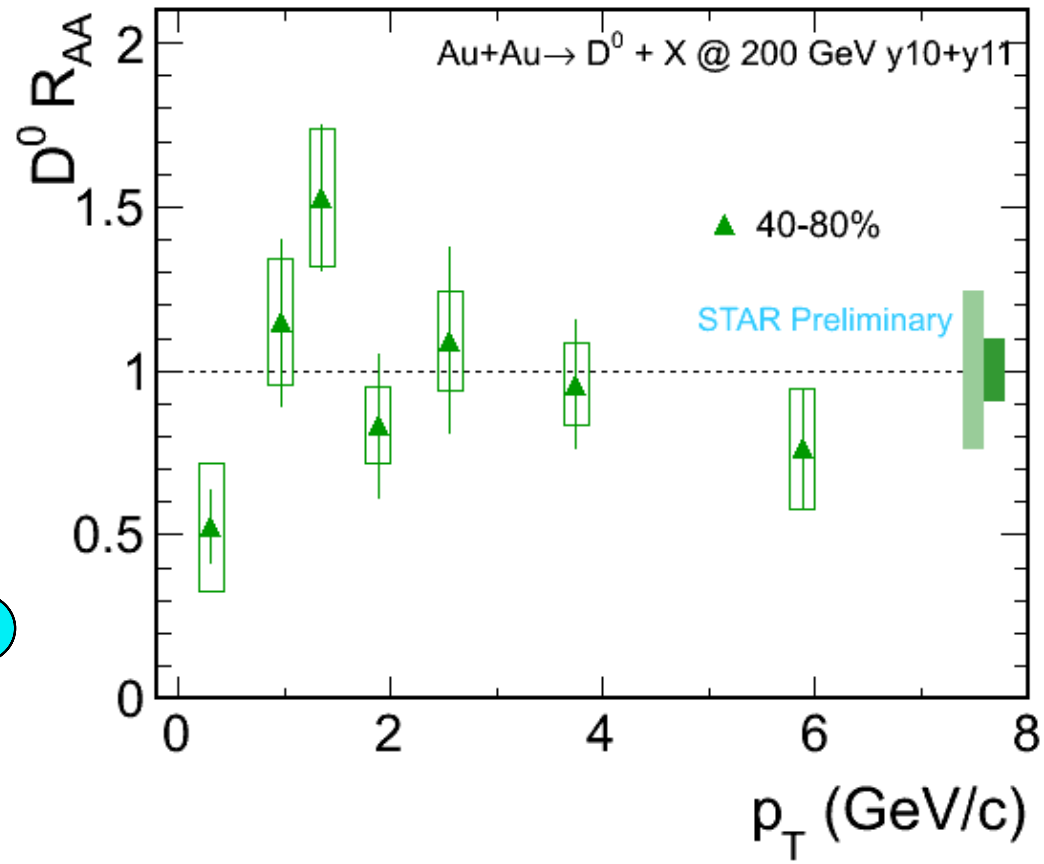

- No obvious suppression observed in peripheral collisions.

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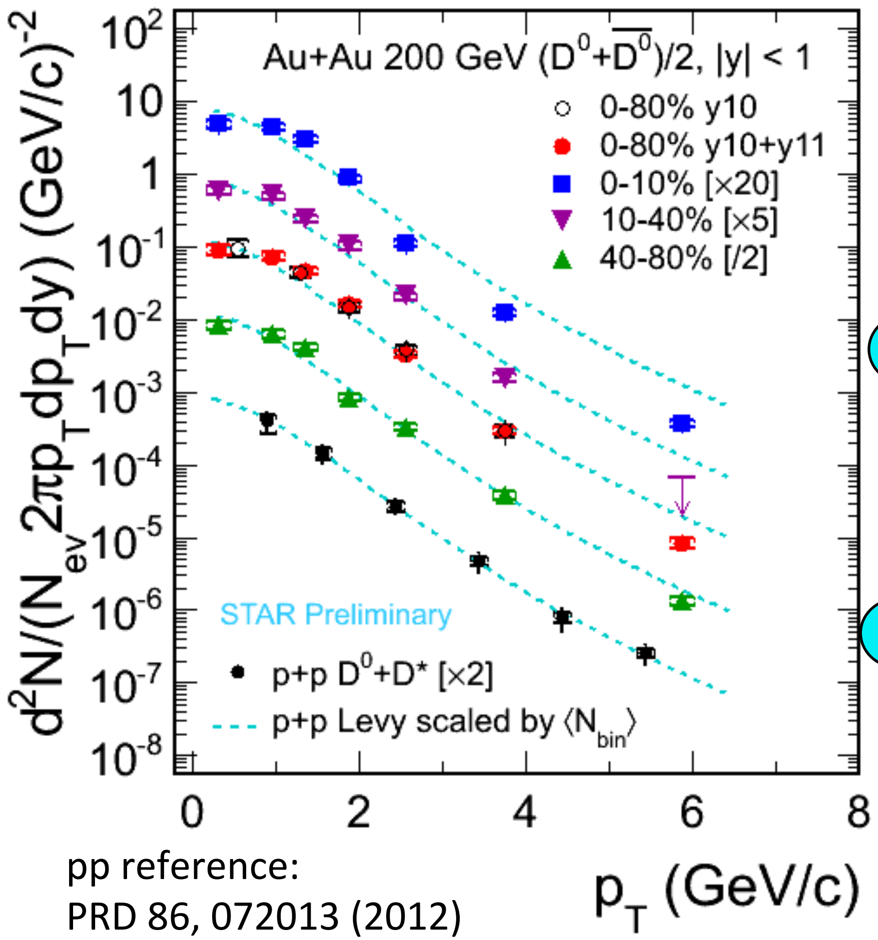

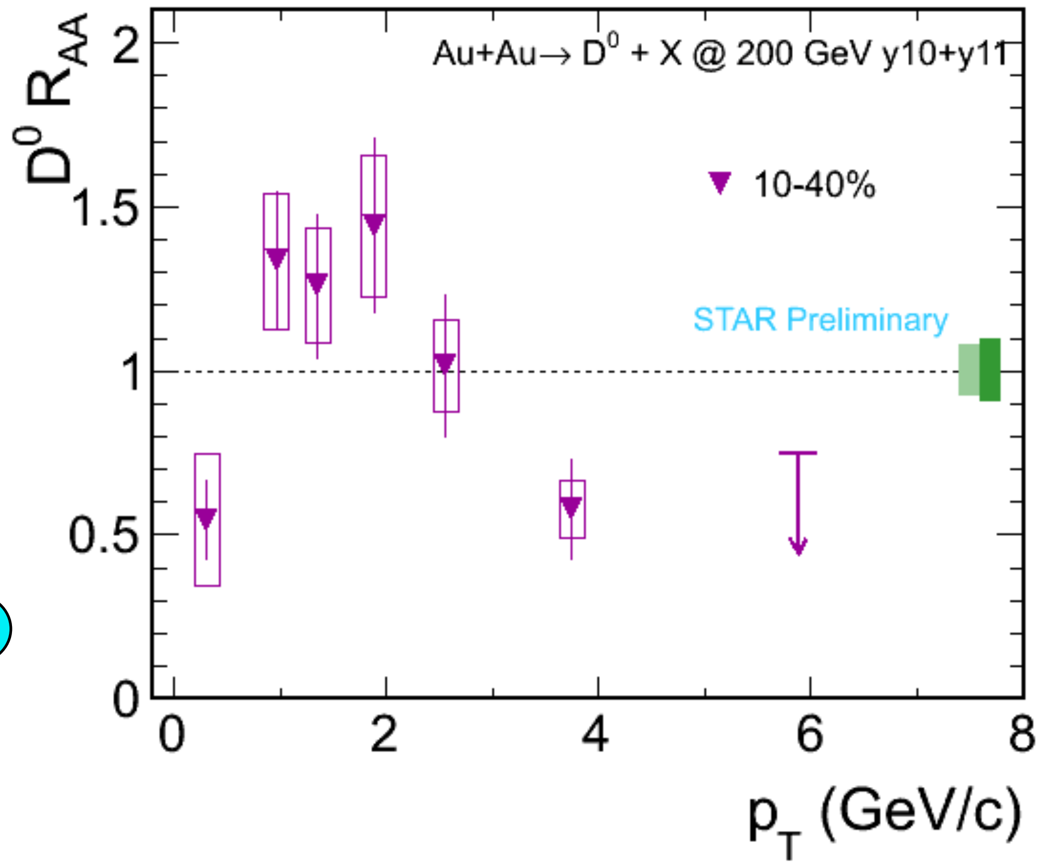

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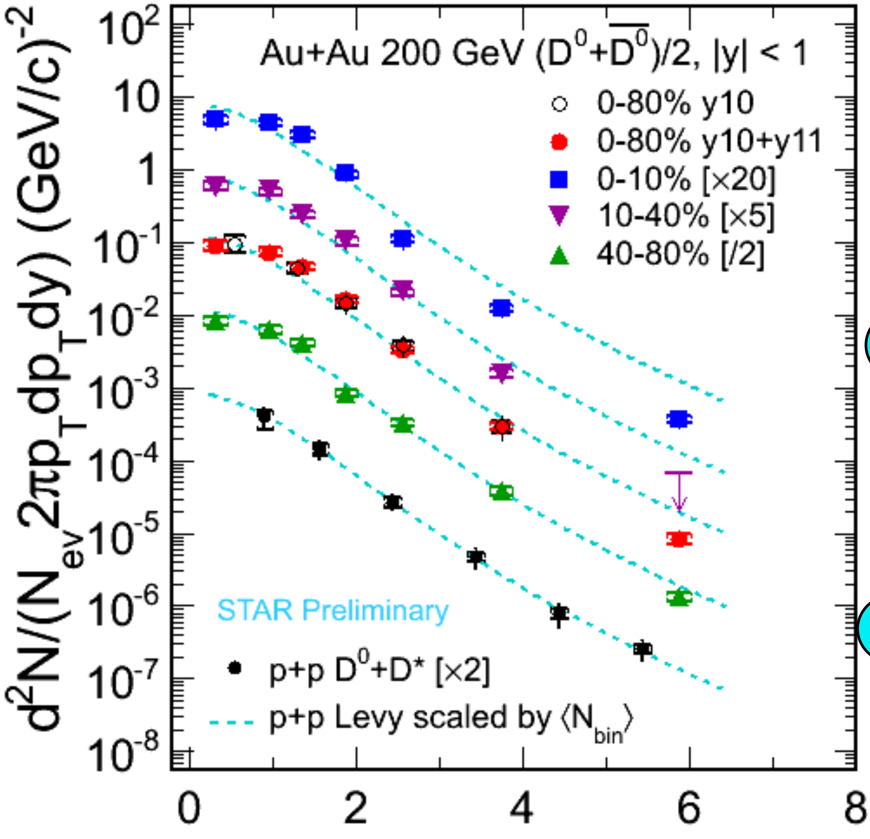

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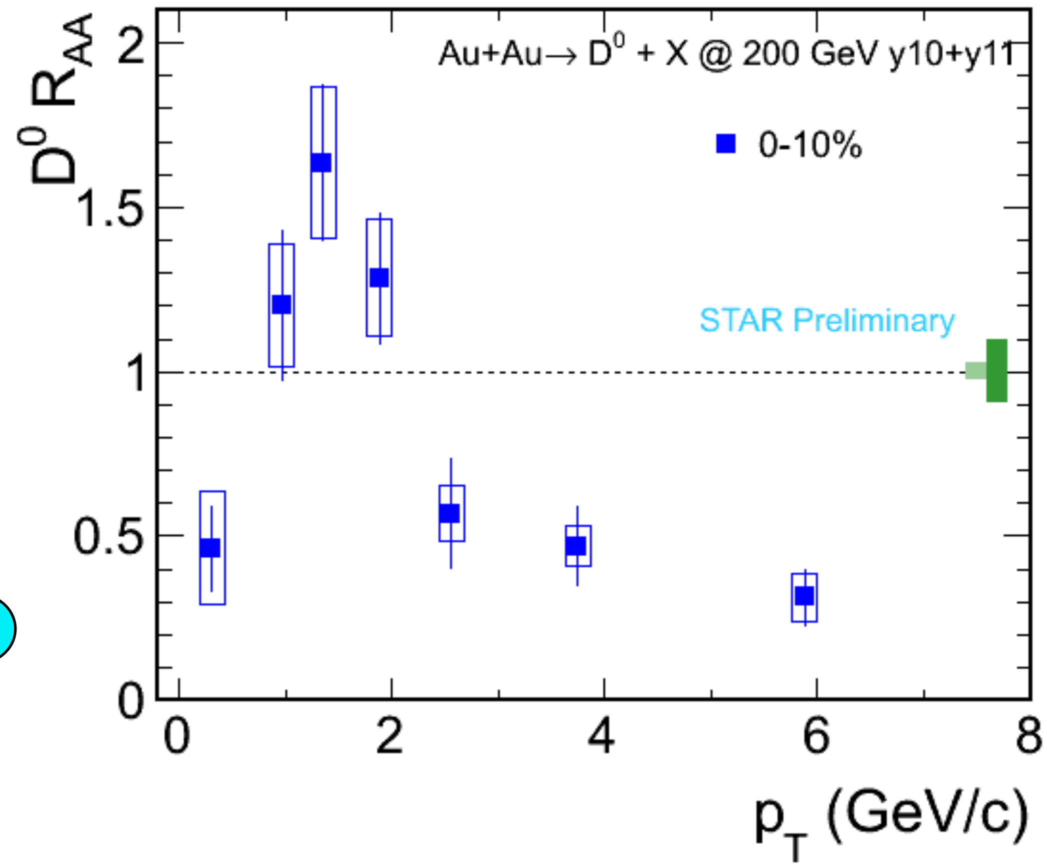

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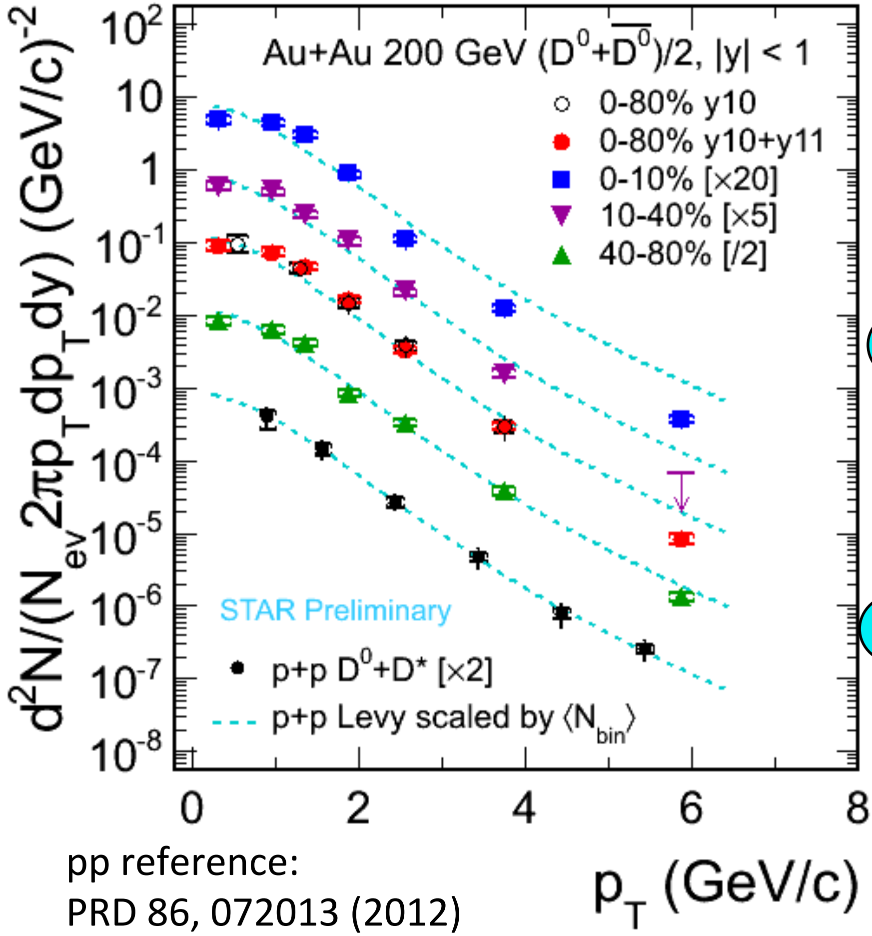

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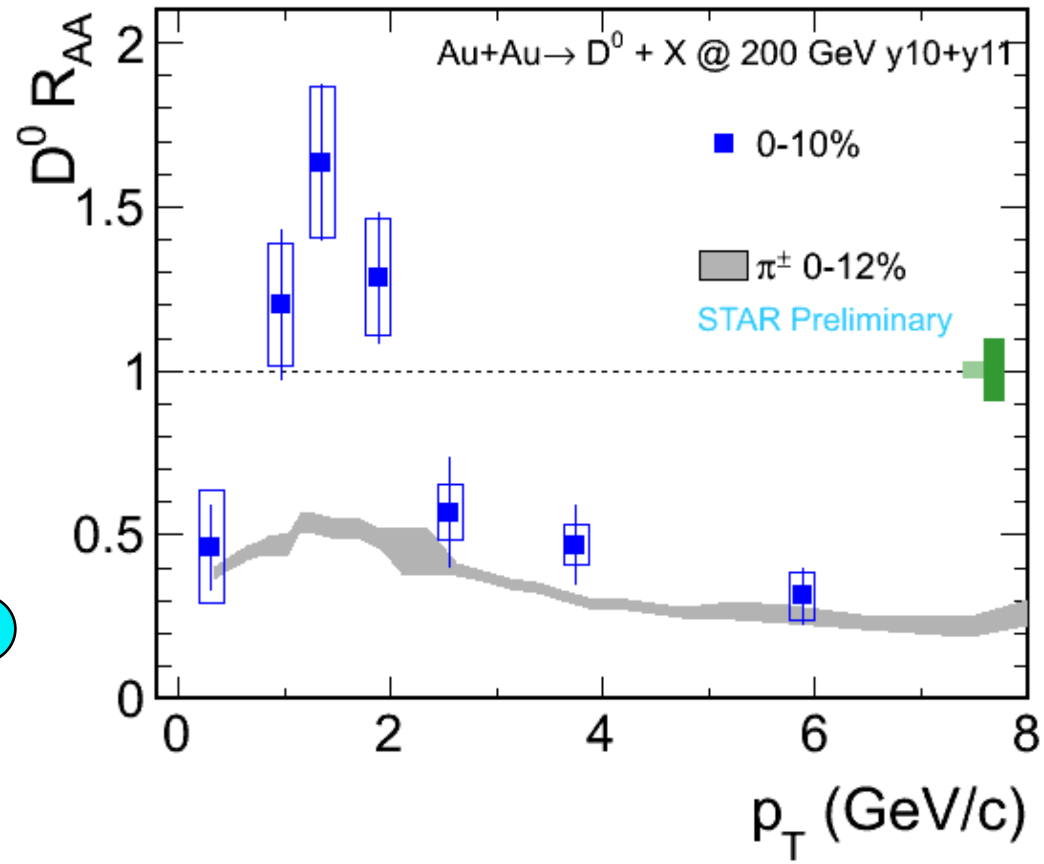

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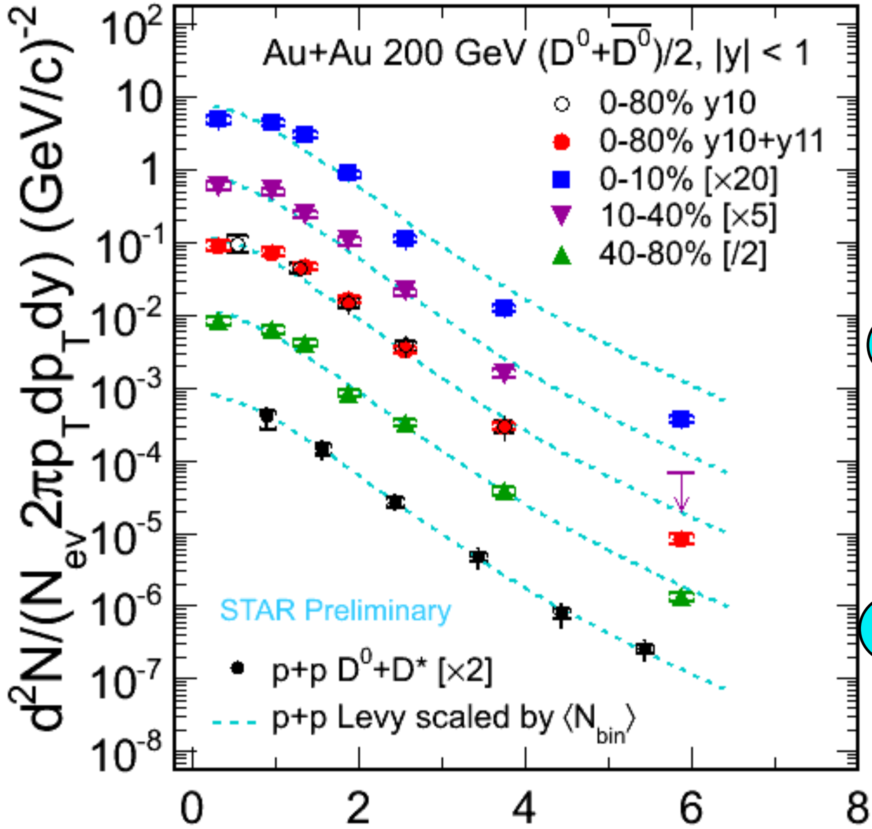

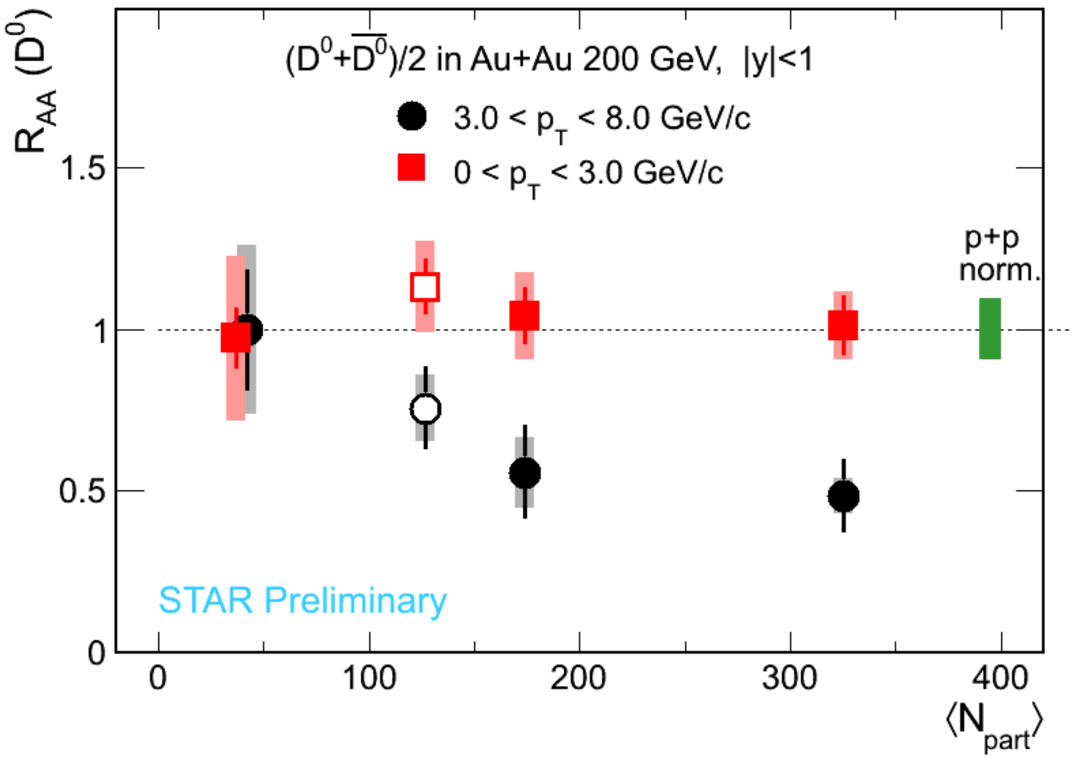

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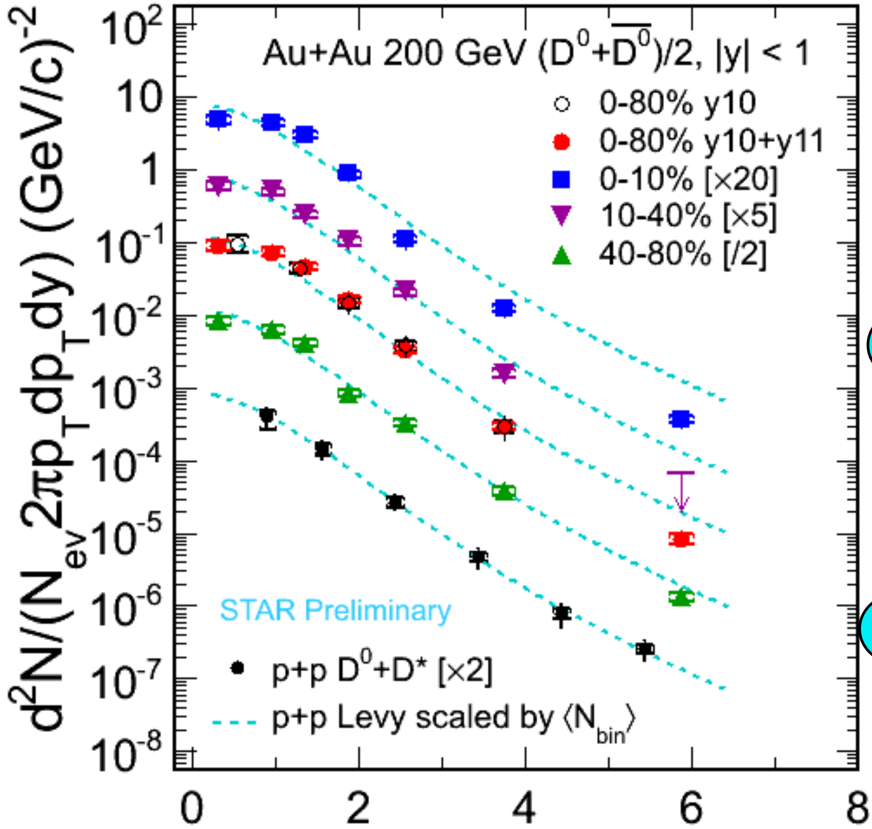
Nuclear modification of D^0



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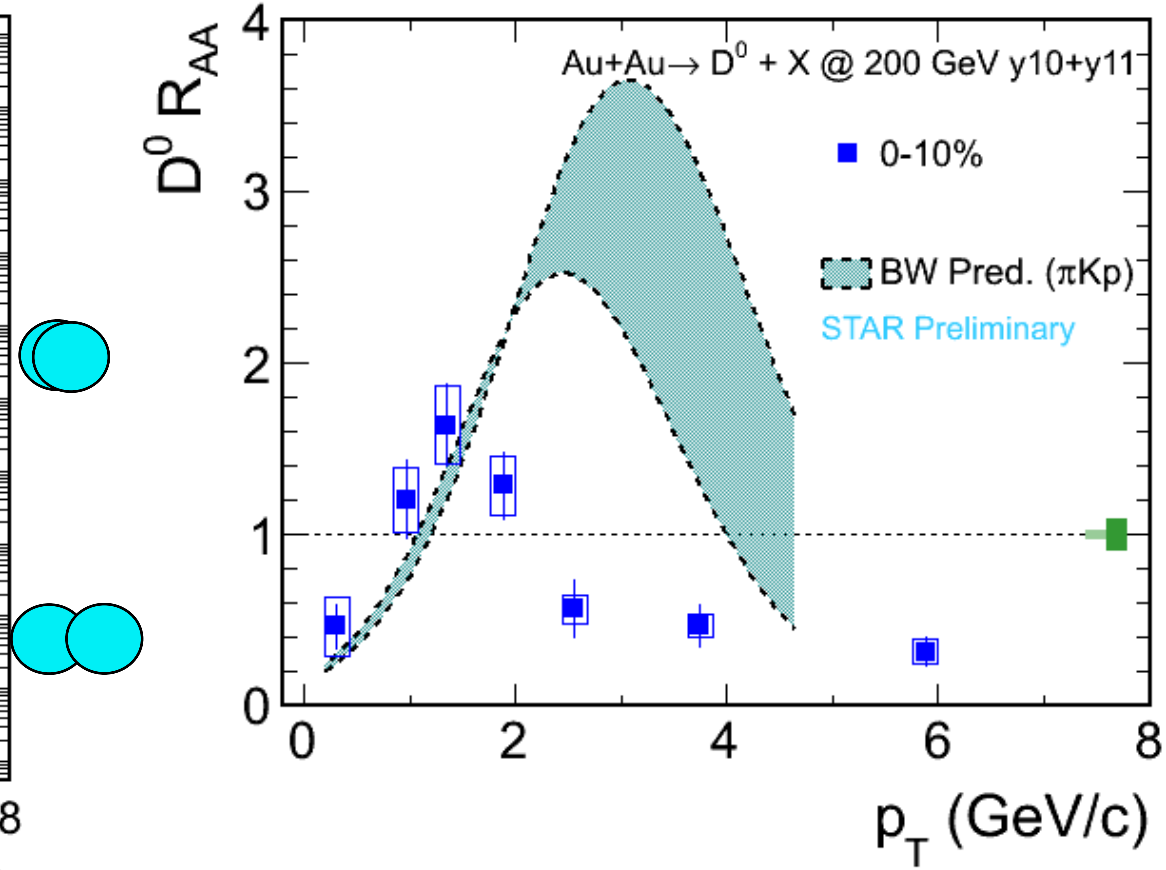

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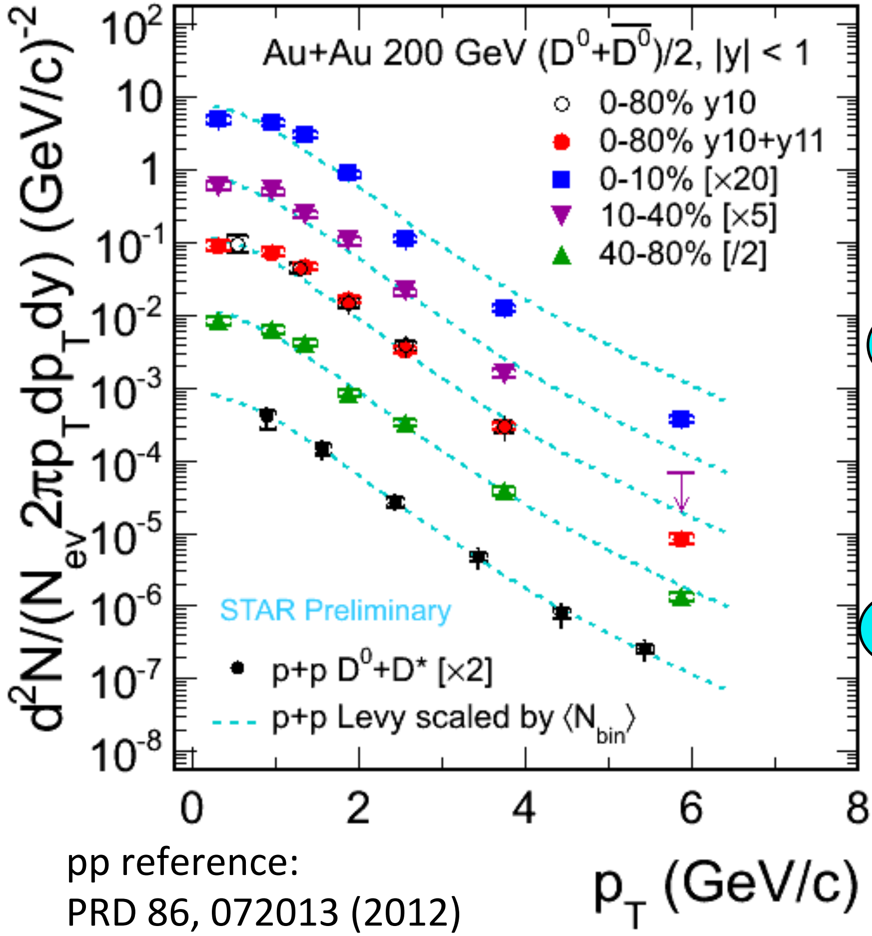

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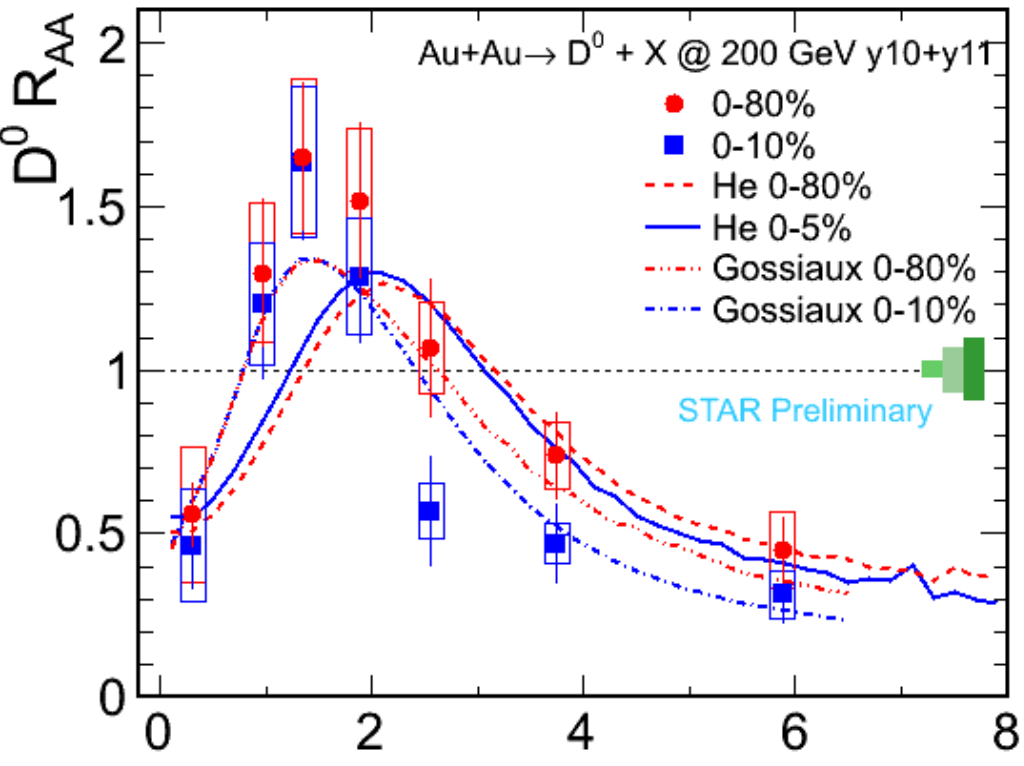

He,Fries,Rapp: PRC86,014903;
arXiv:1204.4442; private comm.
P. Gossiaux: arXiv: 1207.5445

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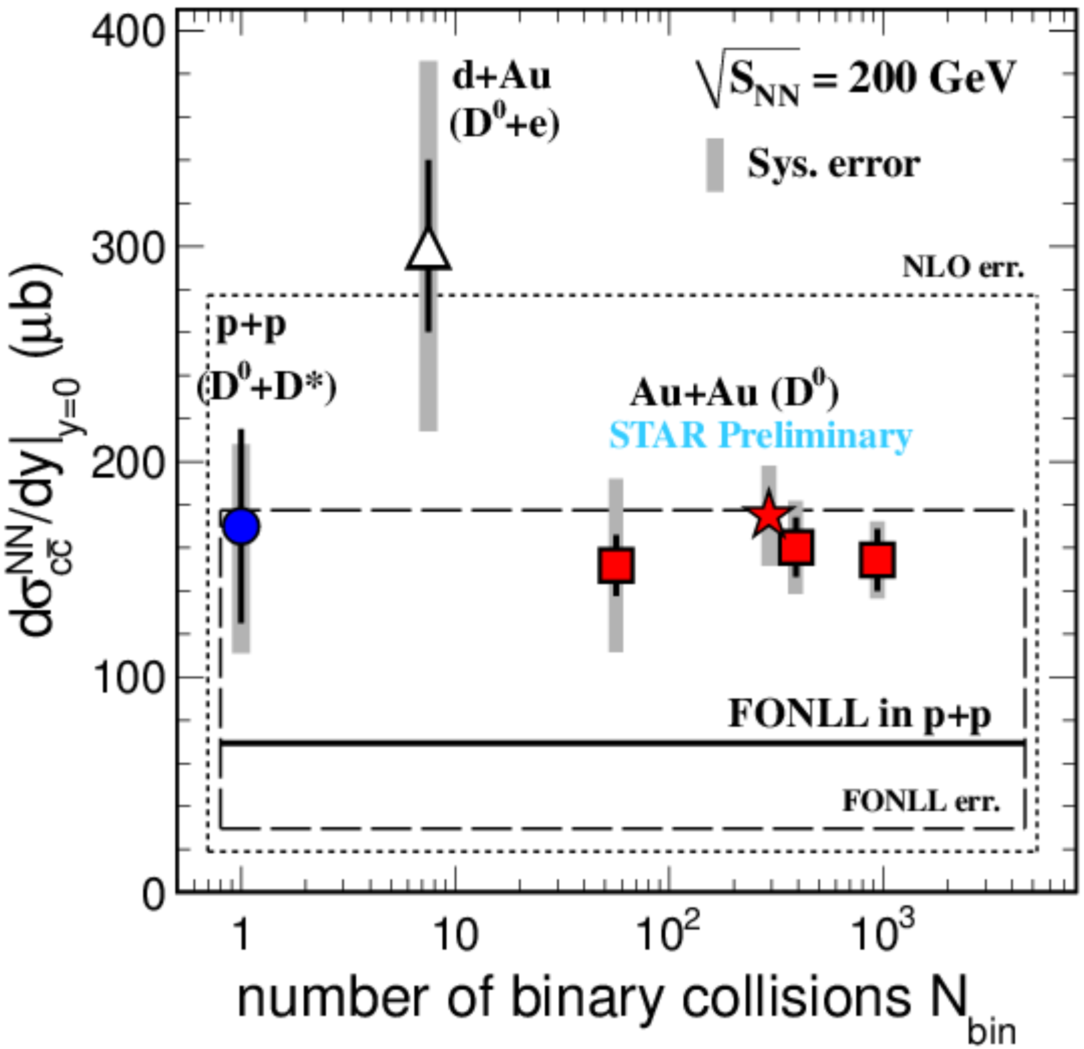
- Integrated yields below 3 GeV/c is number of binary scaled.
- D^0 may freeze out earlier and/or charm does not have much radial flow as light quarks.
- Low p_T enhancement, radial flow of light quarks coalescence with charm (models).

Charm cross section versus N_{bin} at 200 GeV



Year 2003 d+Au 16M : D^0 + e

Year 2009 p+p 105M : D^0 + D*

Year 2010 + 2011 Au+Au 800M : D^0

Assuming N_{D0} / N_{cc} = 0.56 does not change for total cross section.

The charm cross section at mid-rapidity:

$$\left.\frac{d\sigma}{dy}\right|_{y=0}^{pp} = 170 \pm 45^{+38}_{-59}\,\mu b \qquad \left.\frac{d\sigma}{dy}\right|_{y=0}^{AuAu} = 175 \pm 13 \pm 23\,\mu b$$

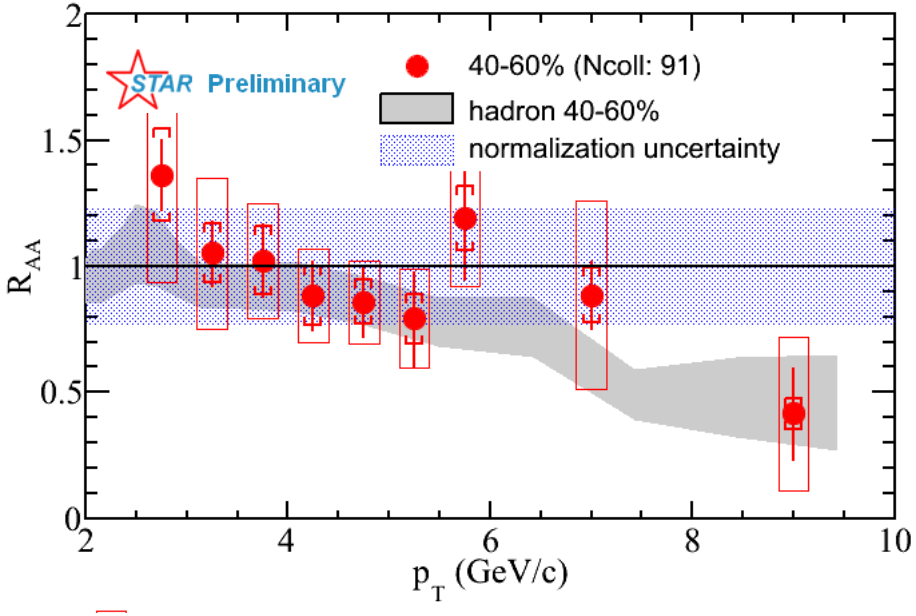
The total charm cross section（extrapolate from PYTHIA F~4.7）:

$$\sigma_{c\bar{c}}^{pp} = 797 \pm 210^{+208}_{-295}\,\mu b \qquad \sigma_{c\bar{c}}^{AuAu} = 822 \pm 62 \pm 192\,\mu b$$

[1] STAR d+Au: J. Adams, et al., PRL 94 (2005) 62301
[2] STAR p+p: PRD 86 (2012) 072013.
[3] FONLL: M. Cacciari, PRL 95 (2005) 122001.
[4] NLO: R. Vogt, Eur.Phys.J.ST 155 (2008) 213

Charm cross section follows number of binary collisions scaling =>
Charm quarks are mostly produced via initial hard scatterings

Non-photonic electron R_{AA} in Au+Au 200 GeV



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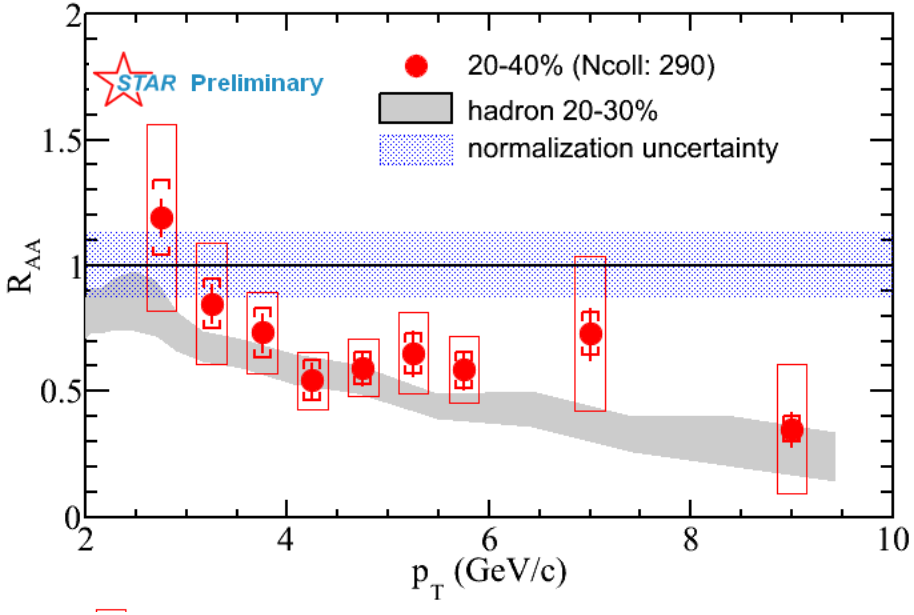

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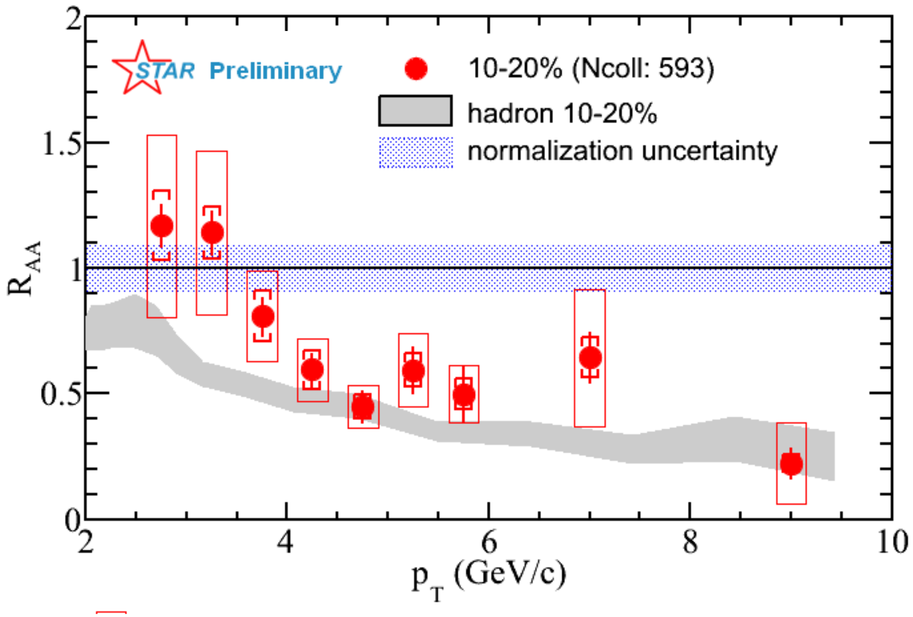

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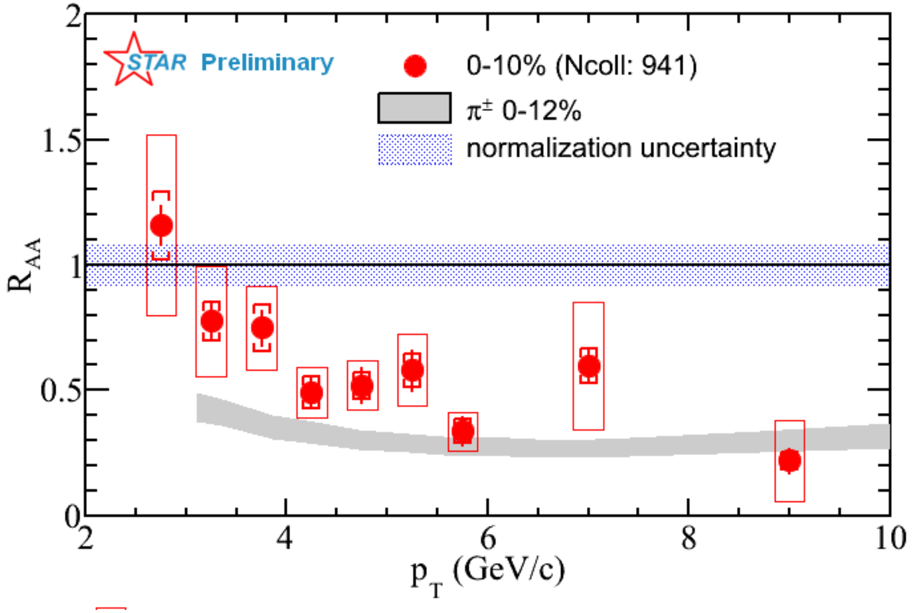

- Strong suppression at high p_T in central collisions

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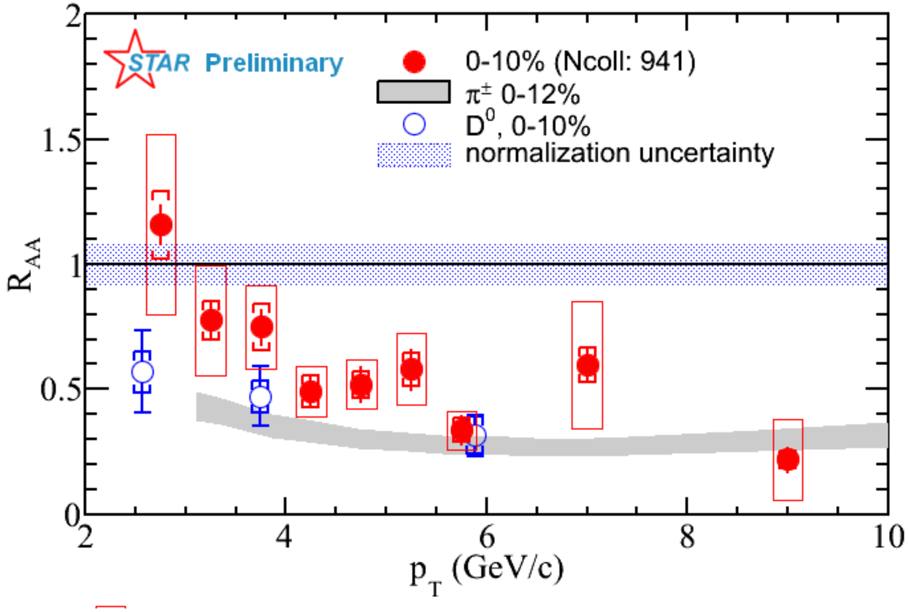

- Strong suppression at high p_T in central collisions
- D^0, NPE results seems to be consistent, in spite of kinematics smearing & charm/bottom mixing

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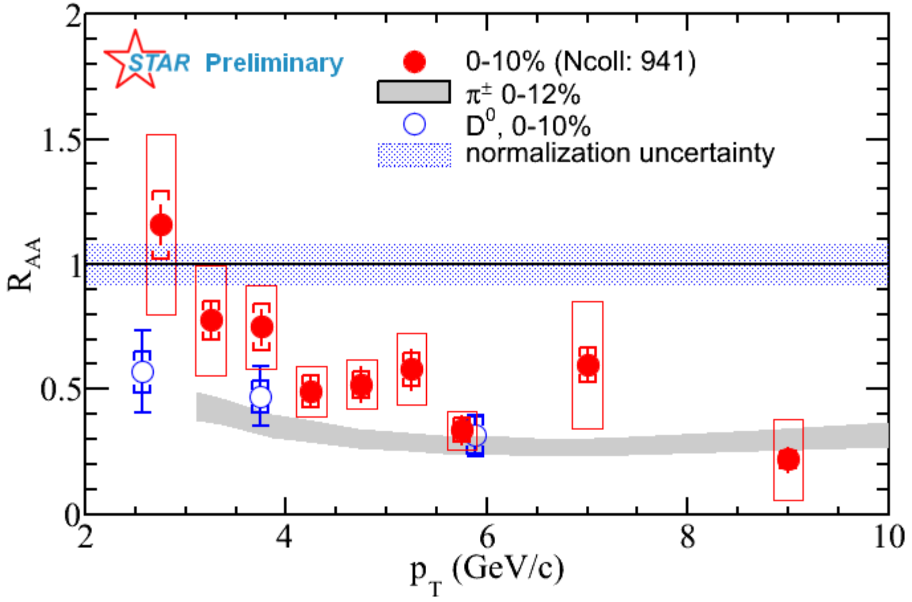
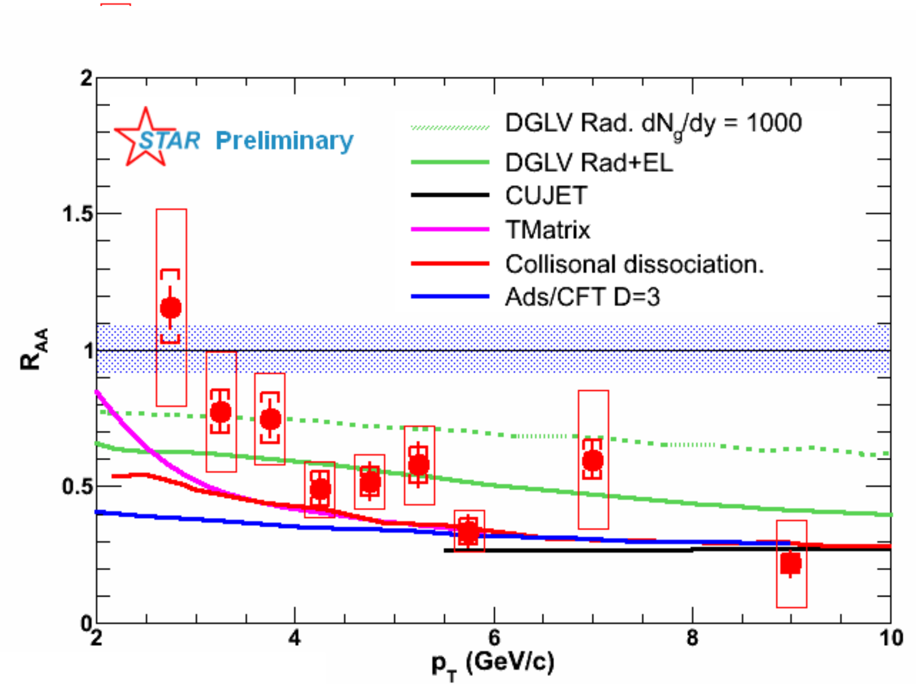


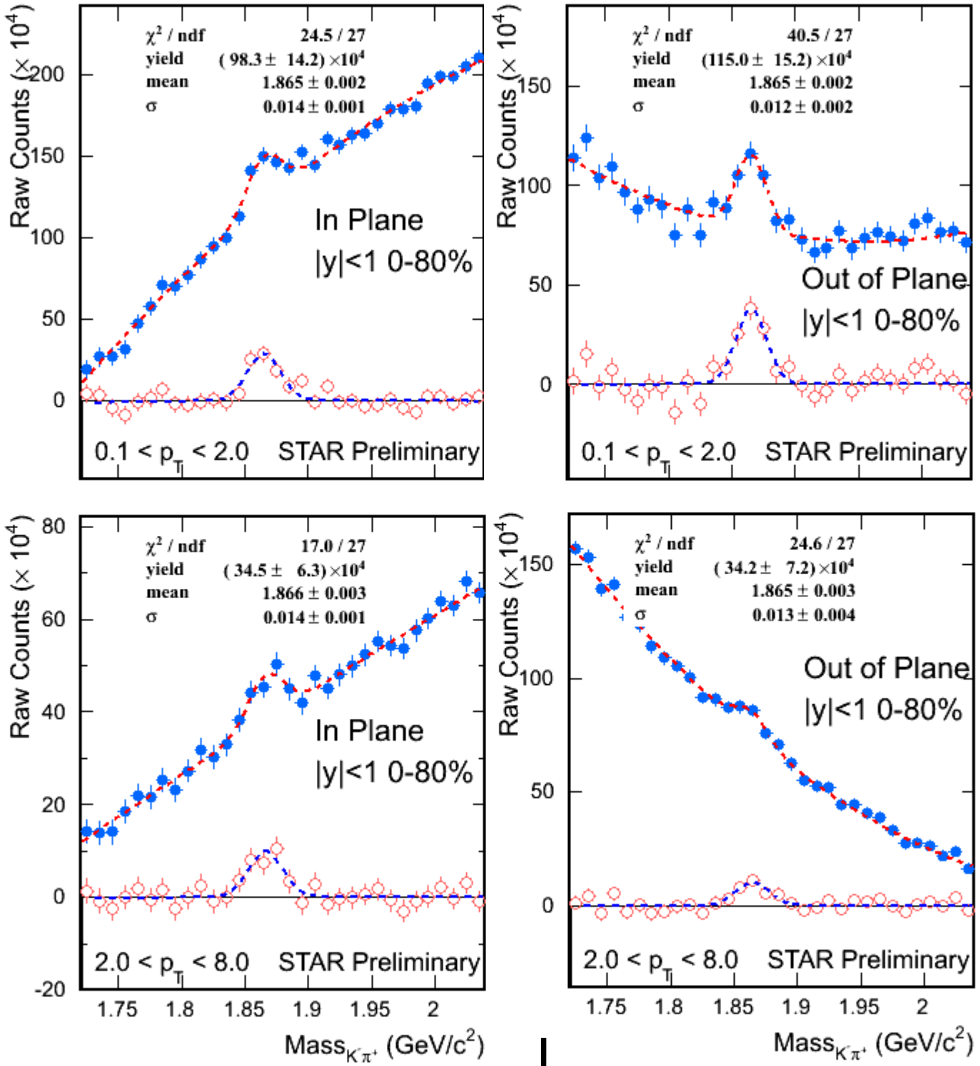


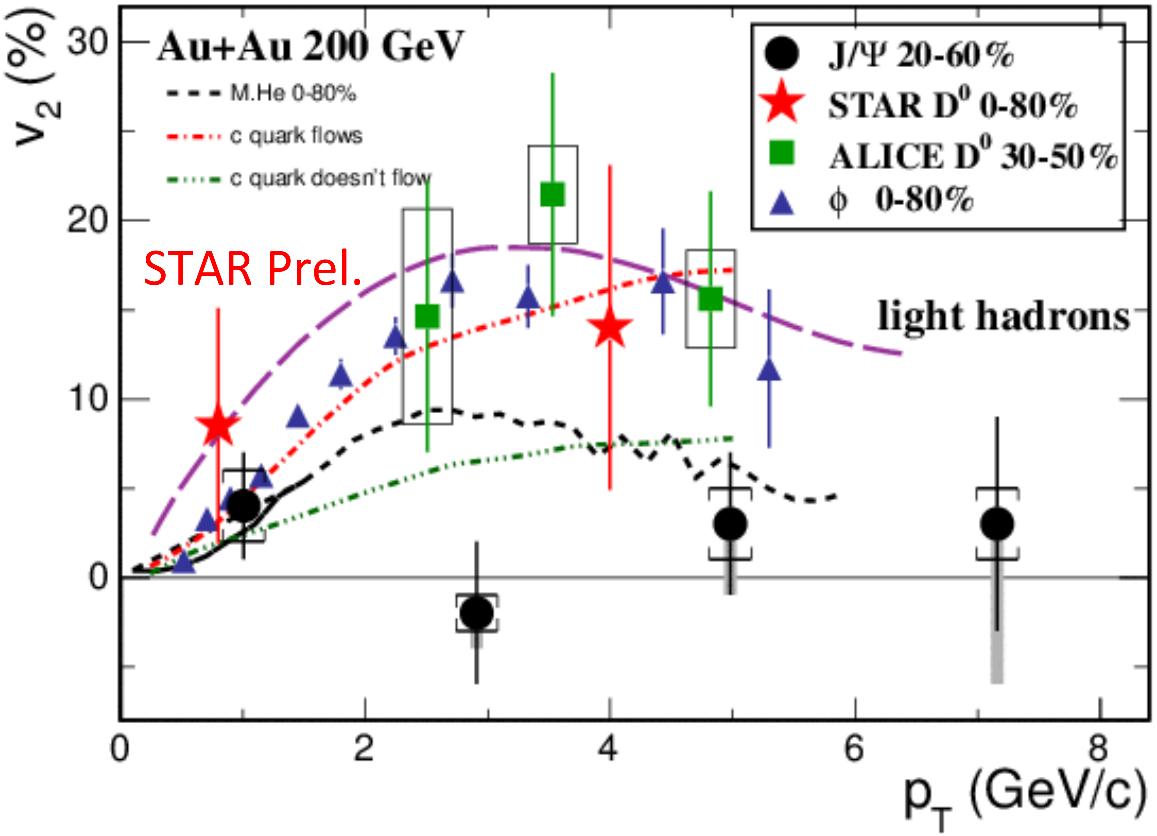
- Strong suppression at high p_T in central collisions
- D^0, NPE results seems to be consistent, in spite of kinematics smearing & charm/bottom mixing

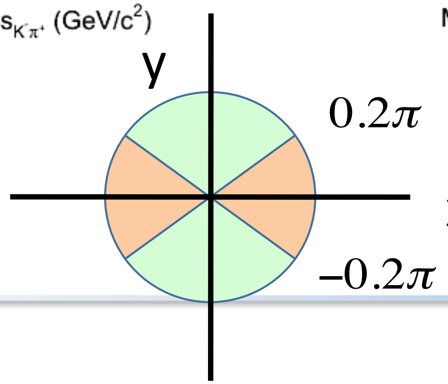
- Models with radiative energy loss underestimate the suppression
- Uncertainty dominated by p+p result.
- High quality p+p data from Run12 are on disk.

DGLV: Djordjevic, PLB632, 81 (2006)
CUJET: Buzzatti, arXiv:1207.6020
T-Matrix: Van Hees et al., PRL100,192301(2008).
Coll. Dissoc. R. Sharma et al., PRC 80, 054902(2009).
Ads/CFT: W. Horowitz Ph.D thesis.

D^0 v_2 measurement in Au+Au 200 GeV

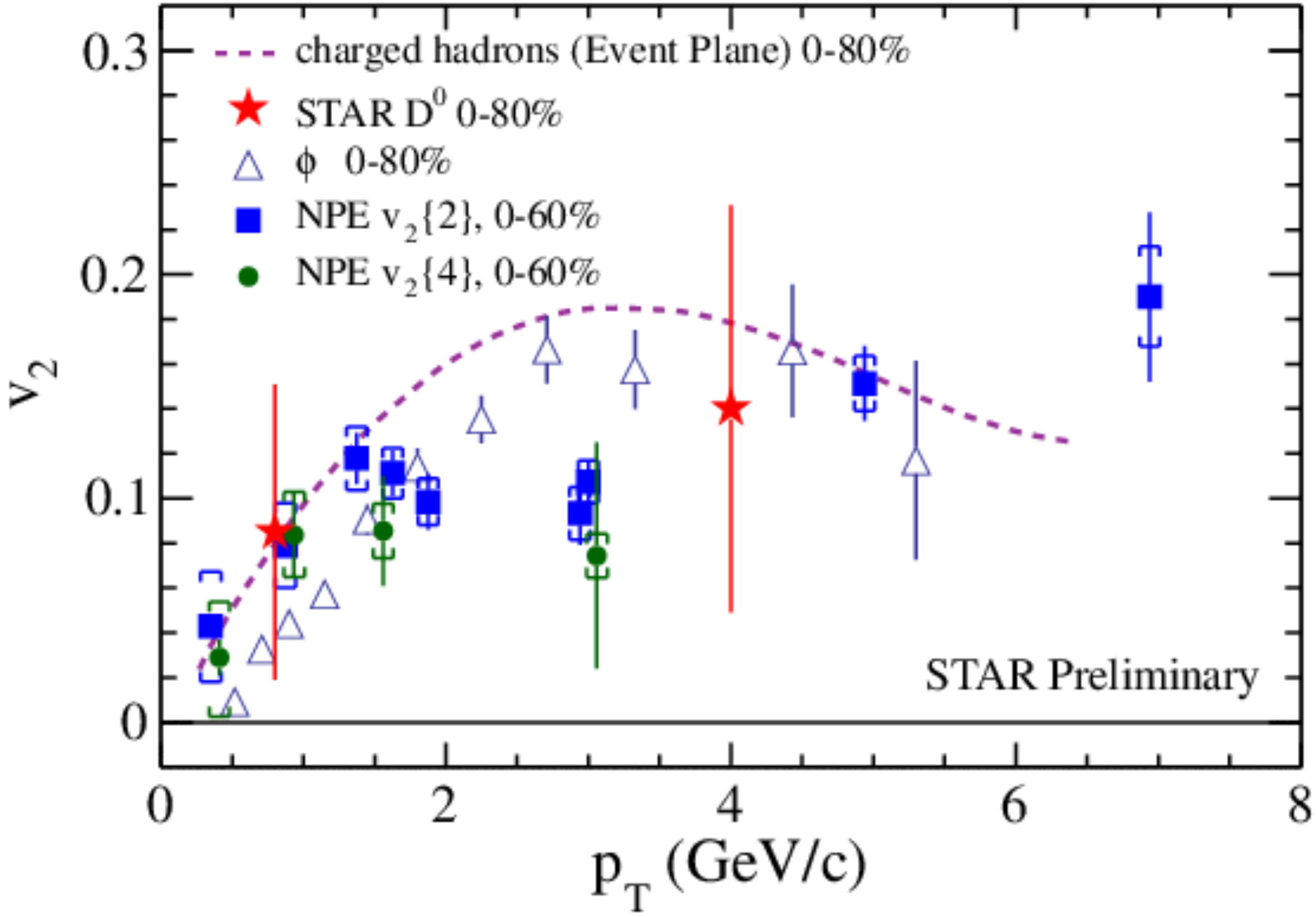






- ✧ **Need HFT for more precise measurement:**
  - to confirm the coalescence scenarios.
  - to confirm the energy dependence.
- ✧ **Different production mechanisms compared with hidden charm?**

NPE v_2 in Au+Au 200 GeV



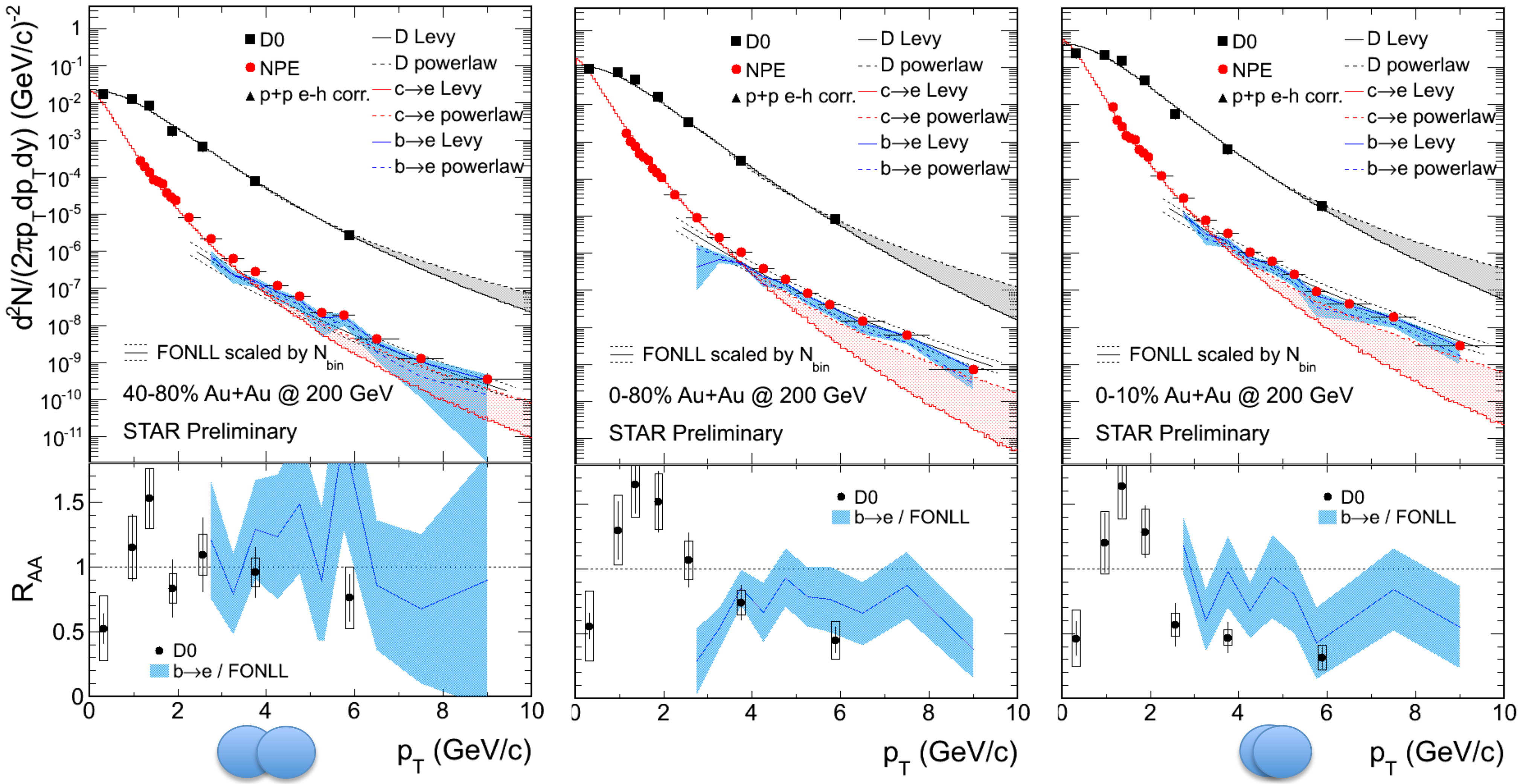
200 GeV Au+Au:

❑ **Large NPE v_2 observed at low p_T => strong charm-medium interaction**

❑ **v_2 increase at p_T > 3 GeV/c**

- path length of energy loss
- Jet-like correlation.

Bottom R_{AA}

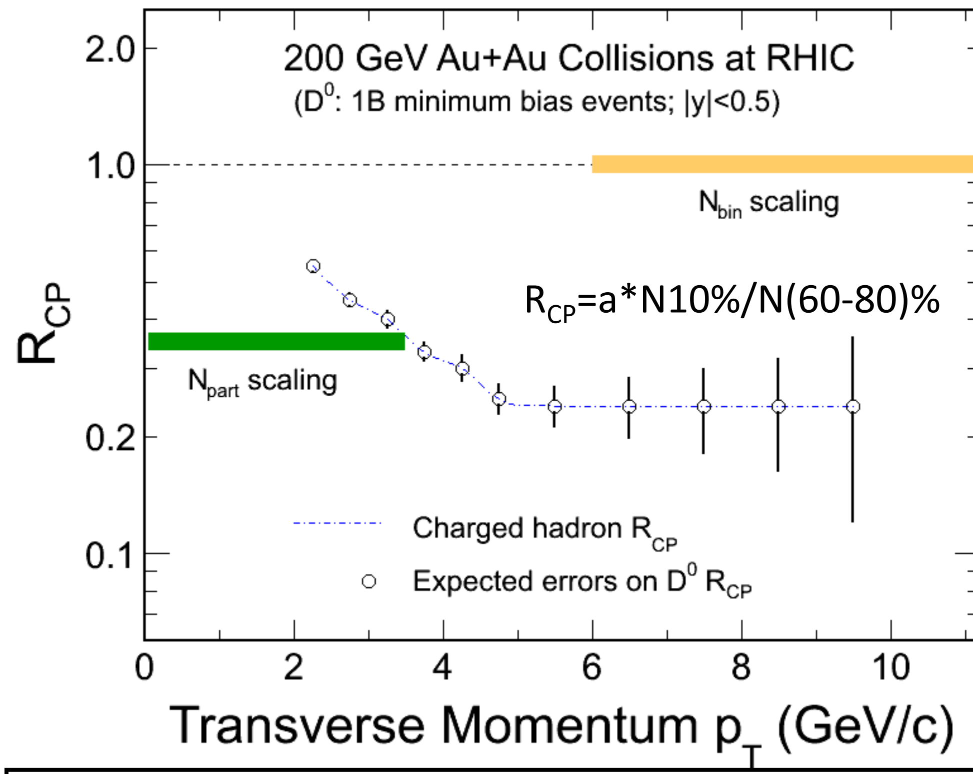


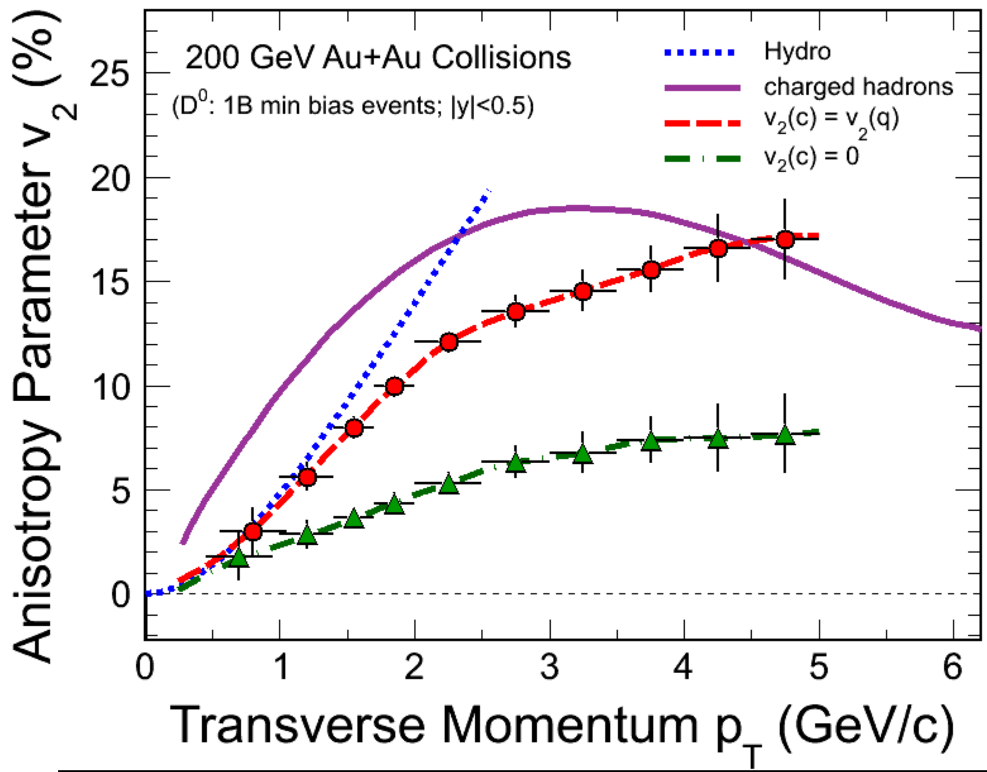
Peripheral is consistent with no suppression.

Minbias and central 0-10% show no obviously larger suppression compared with D^0 R_{AA}.

We expect more precise measurement with Heavy Flavor Tracker.

Physics projections with HFT





Assuming D^0 R_{cp} distribution as charged hadron.

1B Au+Au m.b. events at 200 GeV.

- Charm R_{AA} ⇨

Energy loss mechanism!
Charm interaction with QCD matter!

Assuming D^0 v_2 distribution from quark coalescence.

1B Au+Au m.b. events at 200 GeV.

- Charm v_2 ⇨

Medium/light flavor thermalization
Drag coefficients!

12 weeks, expected to get ~1B MB events

Summary

◆ Charm cross sections at mid-rapidity follow number of binary collisions scaling, which indicates charm quarks are mostly produced via initial hard scatterings.

◆ Observed large high-p_T suppression of heavy quark production via NPE and D^0 meson measurement in 200 GeV central Au+Au collisions.

◆ Low-p_T enhanced structure of D^0 R_{AA} is consistent with coalescence picture that charm recombined with thermalized light quarks in the medium.

◆ First separation of b & c contribution in NPE analysis directly from experiment although with limited statistics. Bottom does not suppress more in central collisions compared to charm, but no suppression is seen in peripheral collisions.

◆ HFT upgrade with increasing RHIC luminosity is expected to provide much more precise measurement on open heavy flavor properties.

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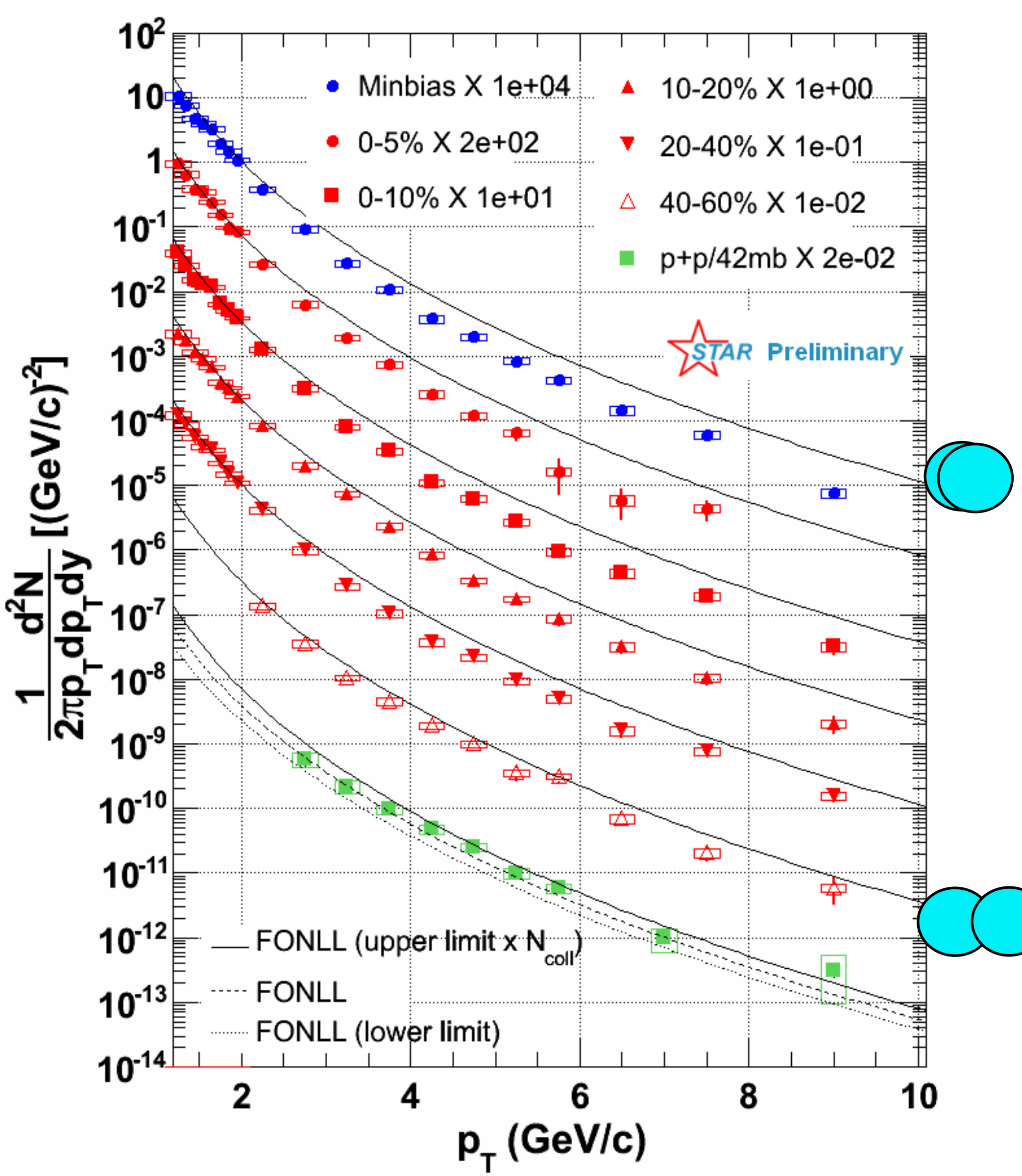
More exciting results are coming soon !

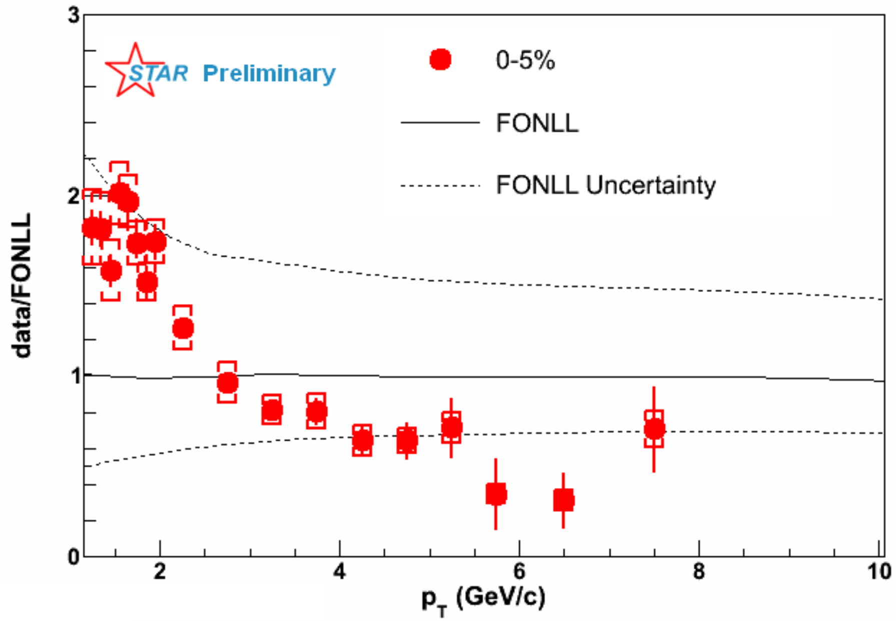
Thank you for your attention !

Backup Slides

Non-photonic electron spectra in Au+Au 200 GeV

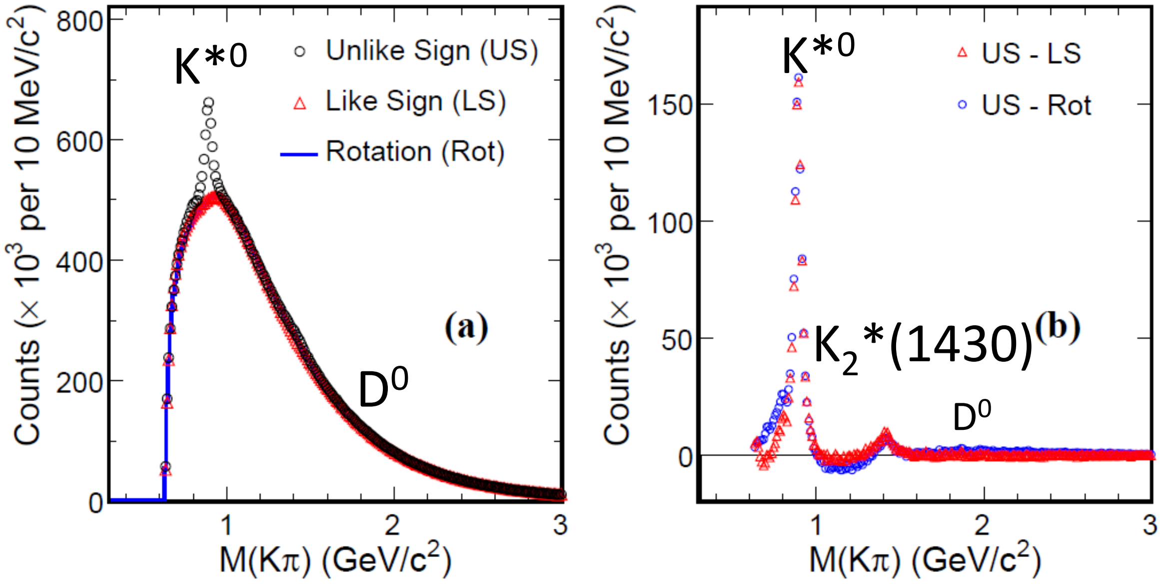
Non-photonic electron (NPE): electron from HF decays



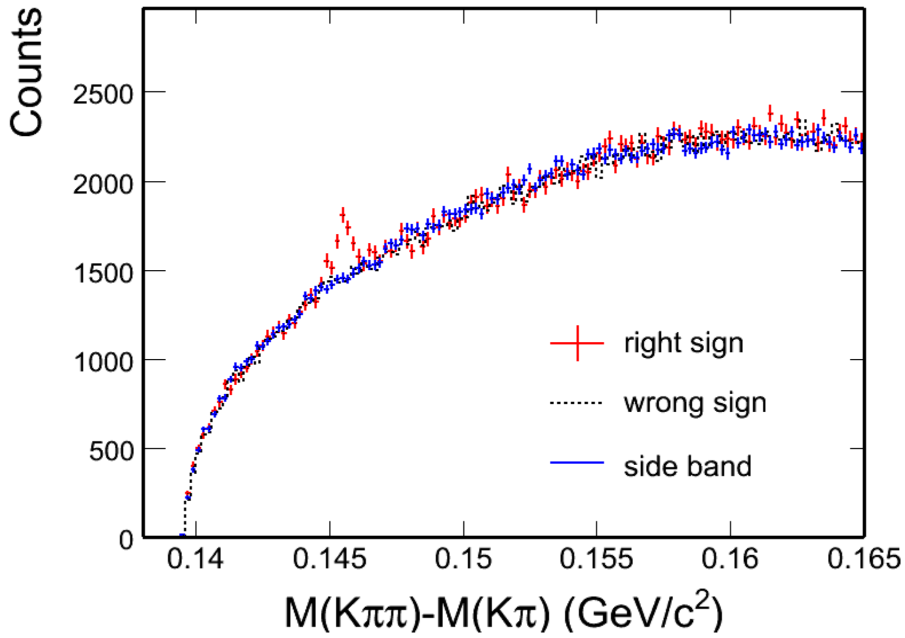


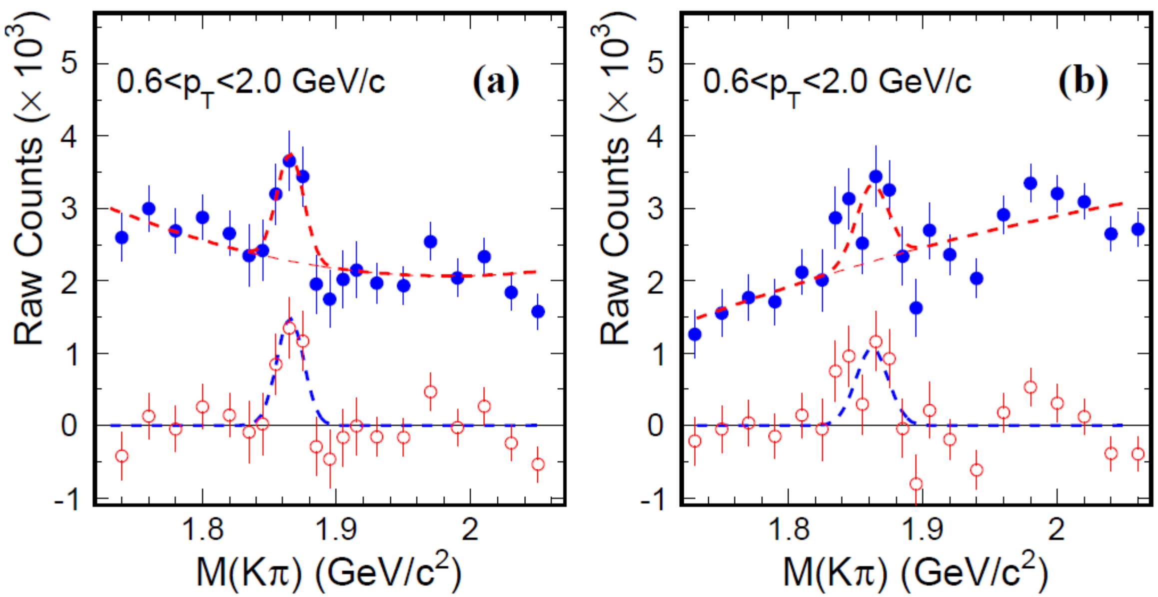
- ~1 nb^{-1} sampled luminosity in Run2010 Au+Au collisions.
- ~6 pb^{-1} sampled luminosity in Run2005 and Run2008 p+p collisions.

D^0 and D* signals in p+p 200 GeV



$D^{*\pm} \rightarrow D^0(\overline{D^0}) + \pi^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$





p+p minimum bias 105 M

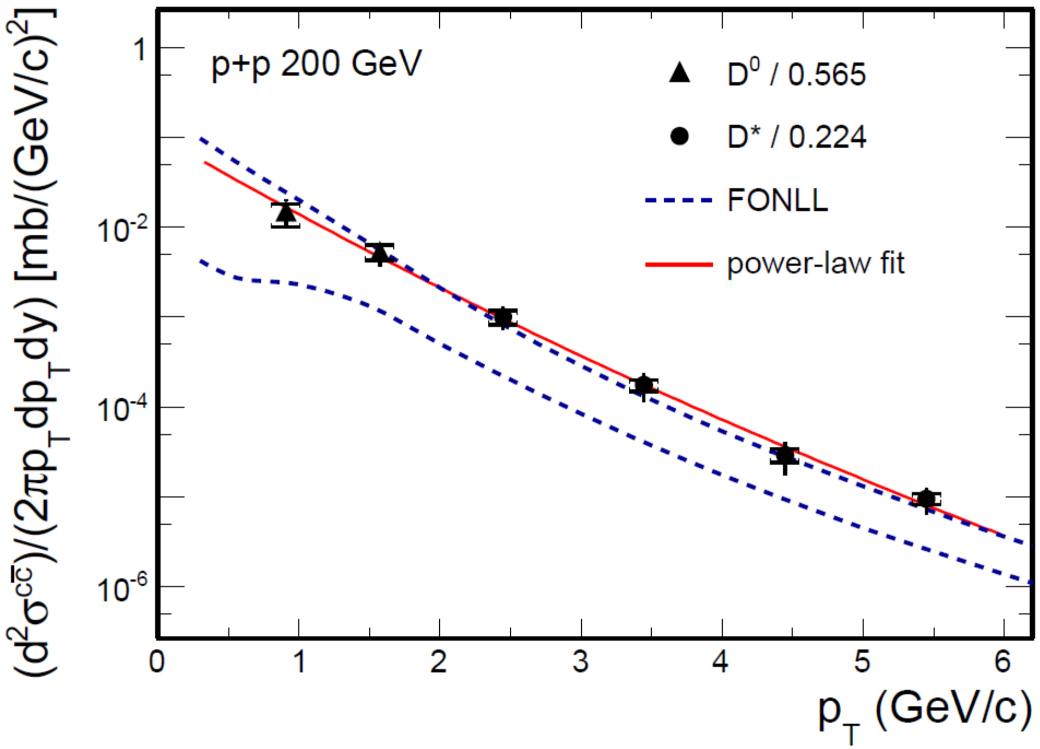
Different methods reproduce comb. background.

Consistent between two background methods.

- No secondary vertex reconstruction so far.
- STAR took advantage of the large acceptance, and beat combinatorial background with statistics

PRD 86, 072013 (2012)

D^0 and D* p_T spectra in p+p 200 GeV



arXiv: 1204.4244.

D^0 scaled by $N_{cc} / N_{D0} = 1 / 0.565$[1]

D* scaled by $N_{cc} / N_{D*} = 1 / 0.224$[1]

Consistent with FONLL[2] upper limit.

Xsec = $dN/dy|^{cc}_{y=0} \times F \times \sigma_{pp}$

F = 4.7 ± 0.7 scale to full rapidity.

σ_{pp}(NSD) = 30 mb

The charm cross section at mid-rapidity:

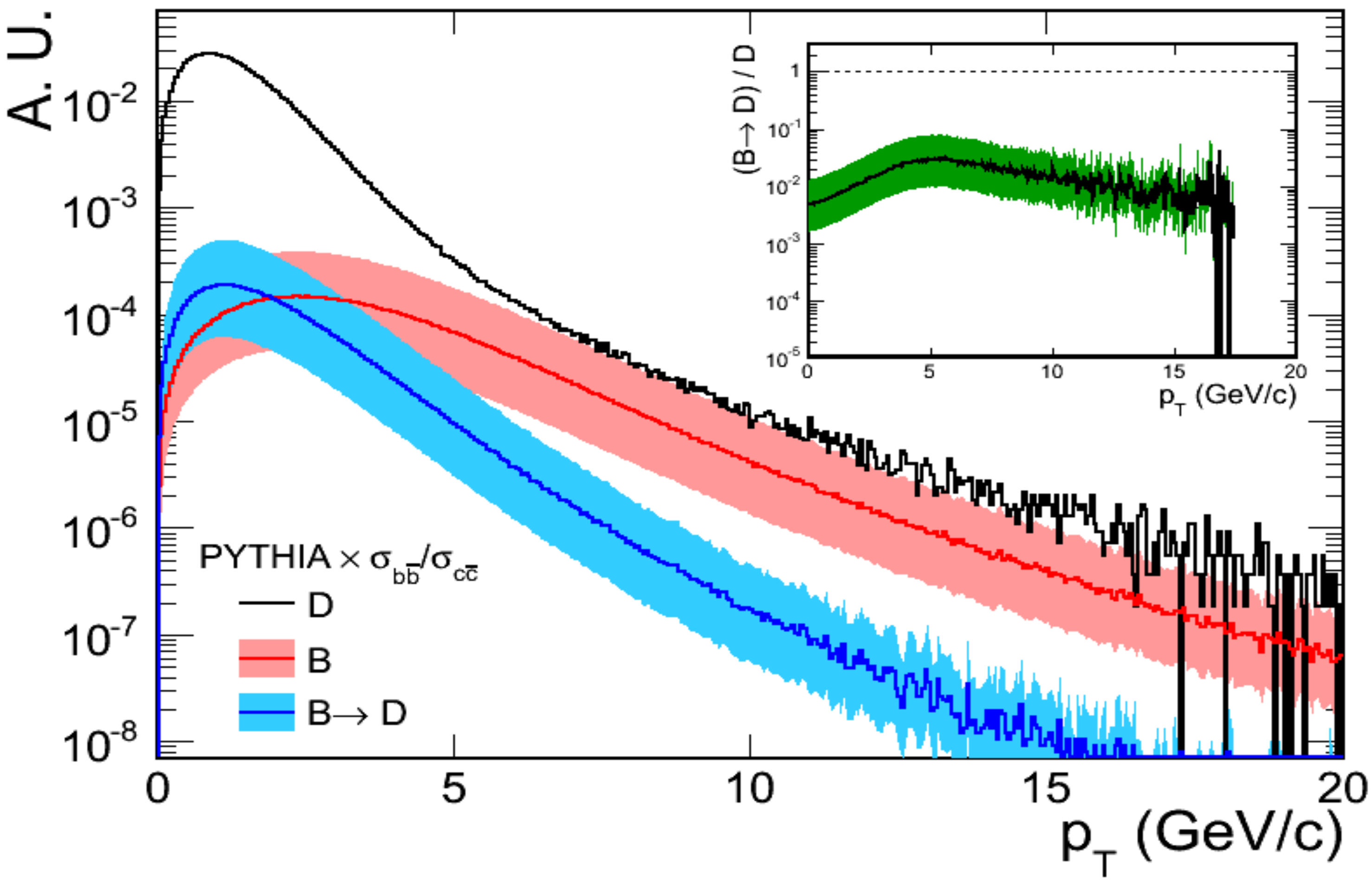
$$\left.\frac{d\sigma}{dy}\right|_{y=0}^{pp} = 170 \pm 45^{+38}_{-59}\,\mu b$$

The total charm cross section:

$$\sigma_{c\bar{c}}^{pp} = 797 \pm 210^{+208}_{-295}\,\mu b$$

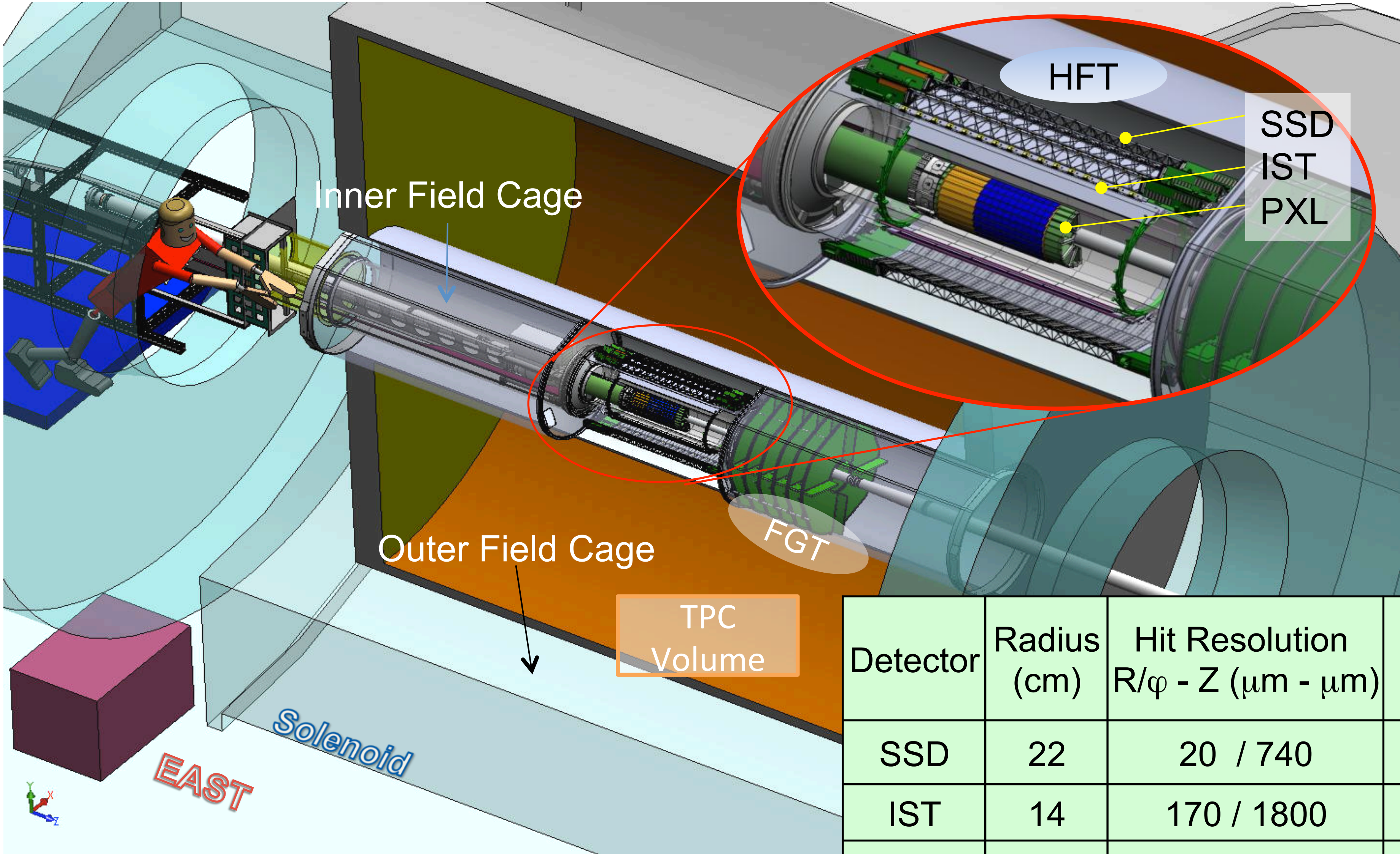
[1] C. Amsler et al. (Particle Data Group), PLB 667 (2008) 1.
[2] Fixed-Order Next-to-Leading Logarithm: M. Cacciari, PRL 95 (2005) 122001.

B feeddown



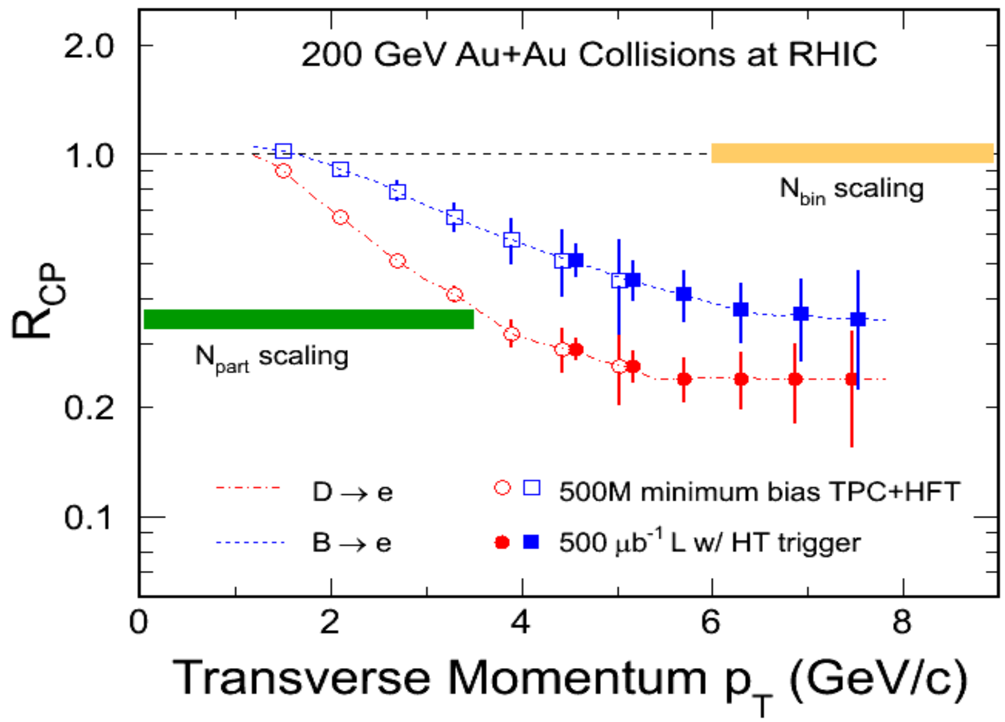
D, B and B->D are generated from PYTHIA.
Normalized by FONLL cross section, the band indicate uncertainty of
Strong pT dependence, but contribution is small, less than 10%.
Low pT only contributes a few percent, which will not affect cross section result.
Assuming B feeddown fraction is the same for p+p and Au+Au, then RAA will not be affected.
The B feeddown will be in the systematic uncertainty.

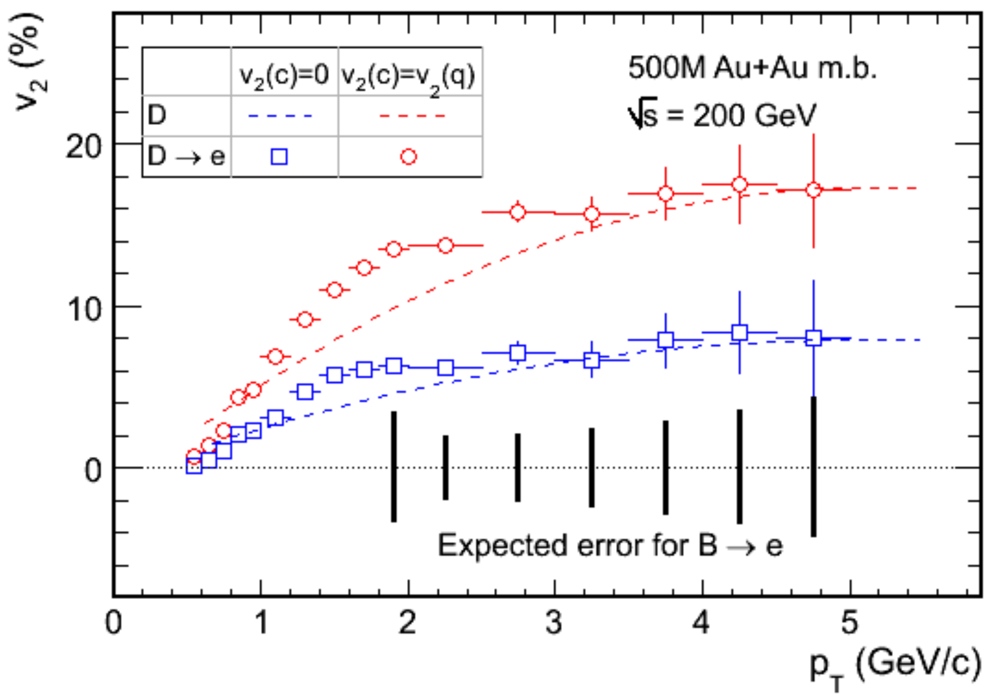
Heavy Flavor Tracker



Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5% X_0
PIXEL	8	12 / 12	~0.4% X_0
	2.5	12 / 12	~0.4% X_0

Statistic projection of e_D, e_B R_{CP} & v_2





Curves: H. van Hees *et al*. Eur. Phys. J. **C61**, 799(2009).

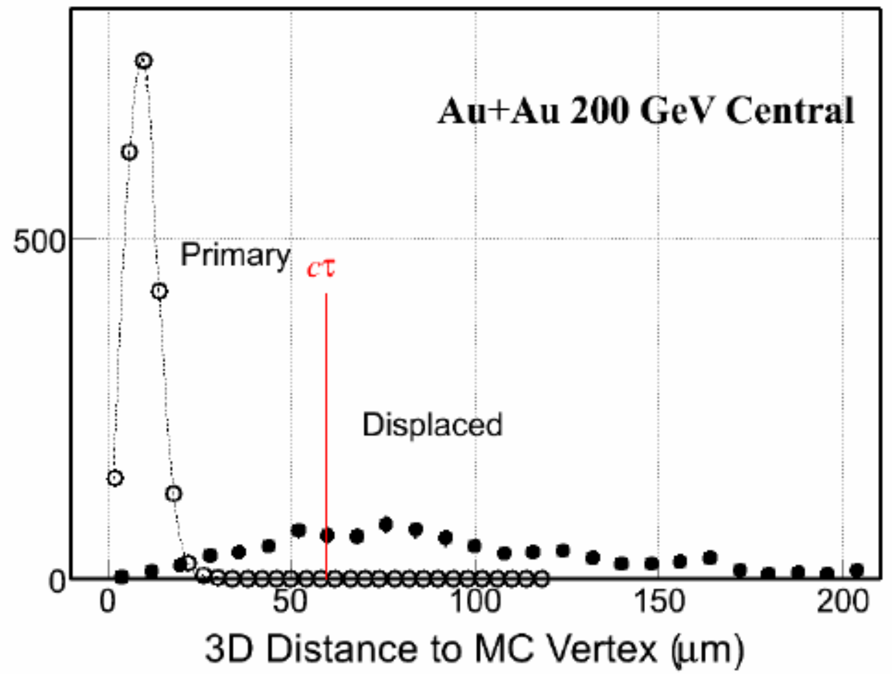
➢ (B→e) spectra obtained via the subtraction of charm decay electrons from inclusive NPEs:

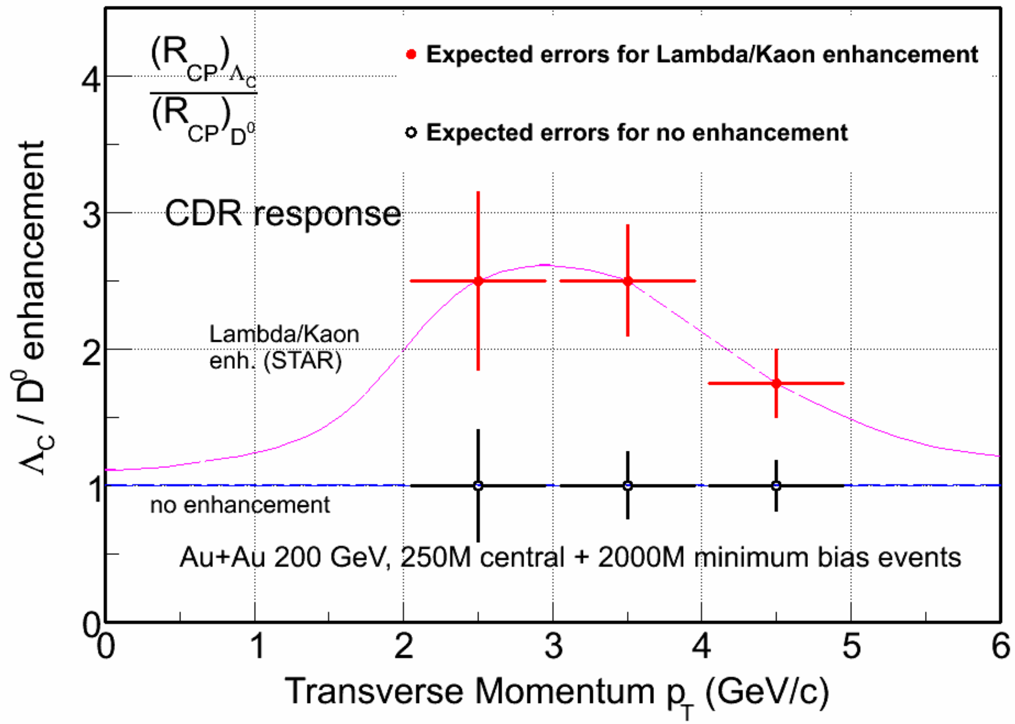
- no model dependence, reduced systematic errors.

➢ Unique opportunity for bottom e-loss and flow.

- Charm may not be heavy enough at RHIC, but how is bottom?

Charmed baryons – Y14





$\Lambda_c \rightarrow pK\pi$ Lowest mass charm baryons cτ = 60 μm

Λ_c/D enhancement?

- 0.11 (pp PYTHIA) → 0.4-0.9 (Di-quark correlation in QGP)
  S.H. Lee etc. PRL 100, 222301 (2008)
- Total charm yield in heavy ion collisions