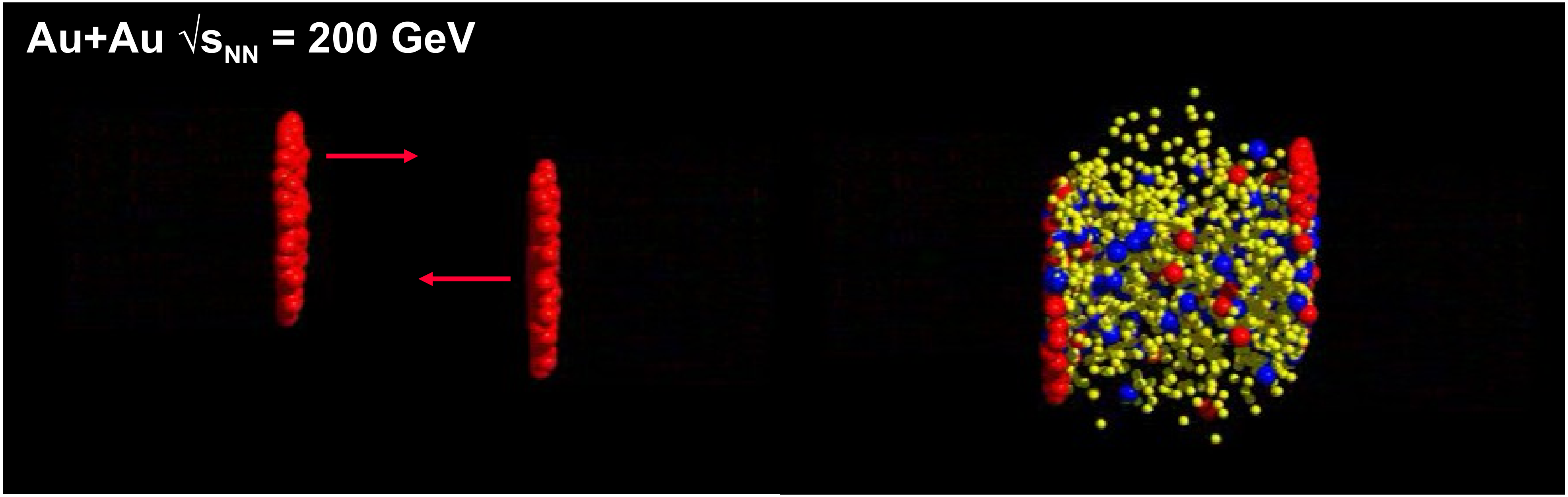
Open heavy flavor production at STAR

Daniel Kikoła for the STAR collaboration

Purdue University

Relativistic Heavy Ion Collisions



UrQMD Frankfurt

- **c, b** quarks produced in initial hard interactions:
  - pQCD cross-sections
  - probing early stage of the partonic medium evolution

→ good probes of the created medium

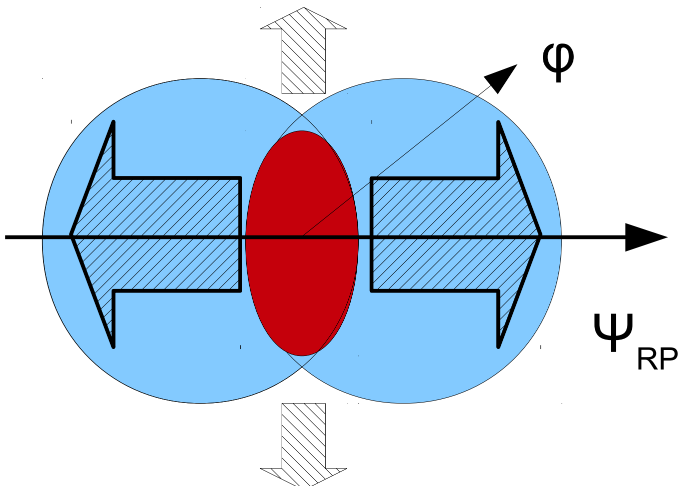
Heavy quarks as a probe of Quark-Gluon Plasma

- Production at high p_T.
  - Energy loss of heavy quarks in the QGP → independent way to extract properties of the medium

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{AuAu}}{dN/dy^{pp}}$$

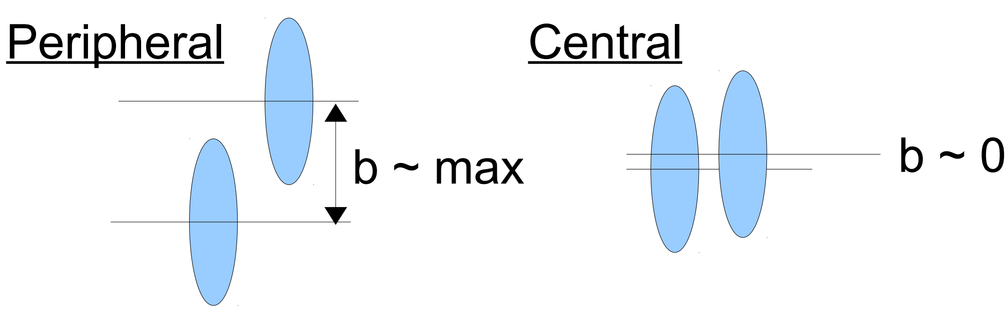
$R_{AA} = 1$ if no modification in the medium

- Azimuthal momentum anisotropy
  - Low p_T: charm flow → degree of medium thermalization
  - High p_T: path length dependence of the energy loss



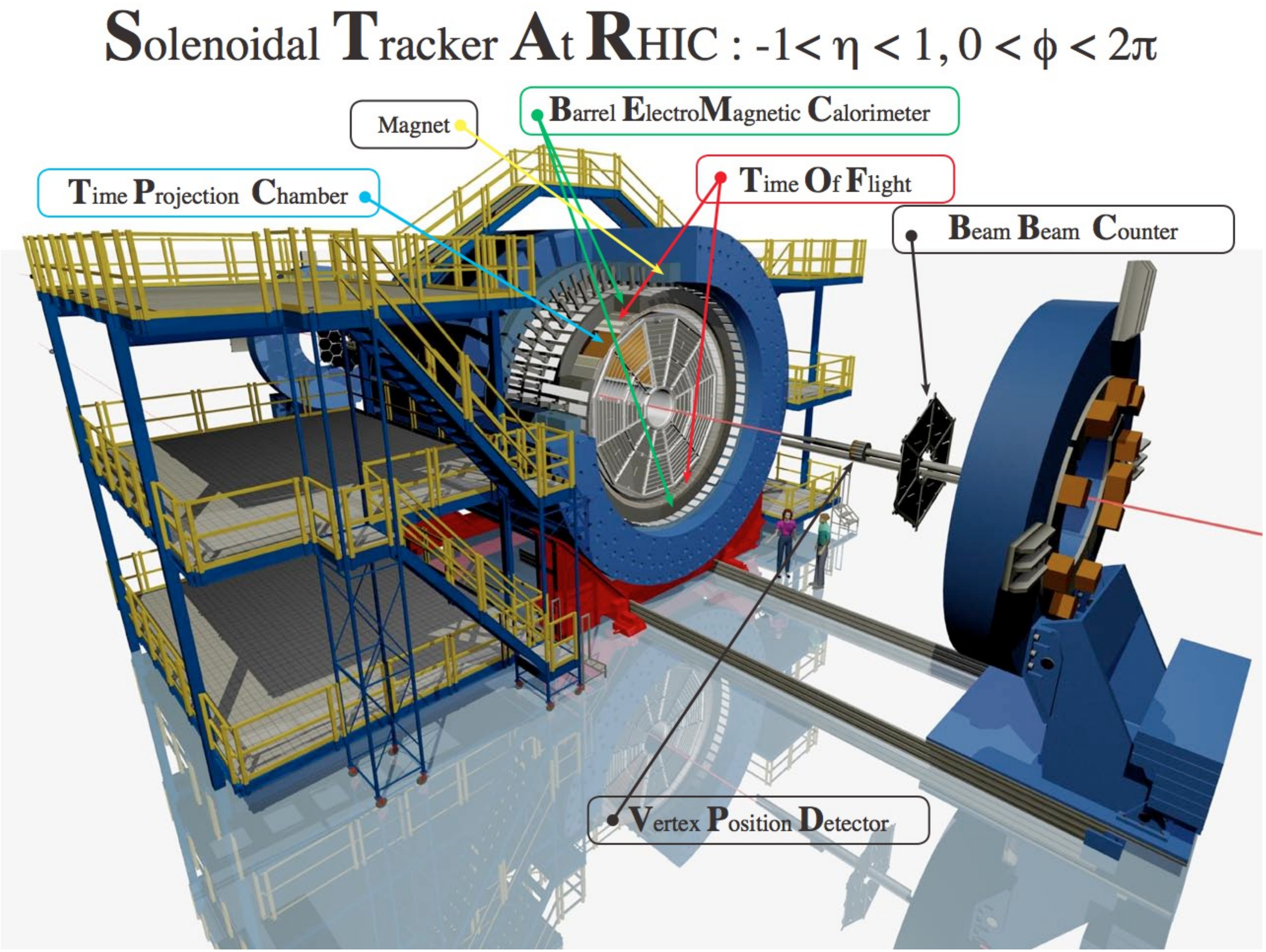
$$\frac{dN}{d(\phi - \Psi_{RP})} \propto 1 + 2 v_2 \cos 2(\phi - \Psi_{RP})$$

- Collision geometry



b – impact parameter

The STAR detector



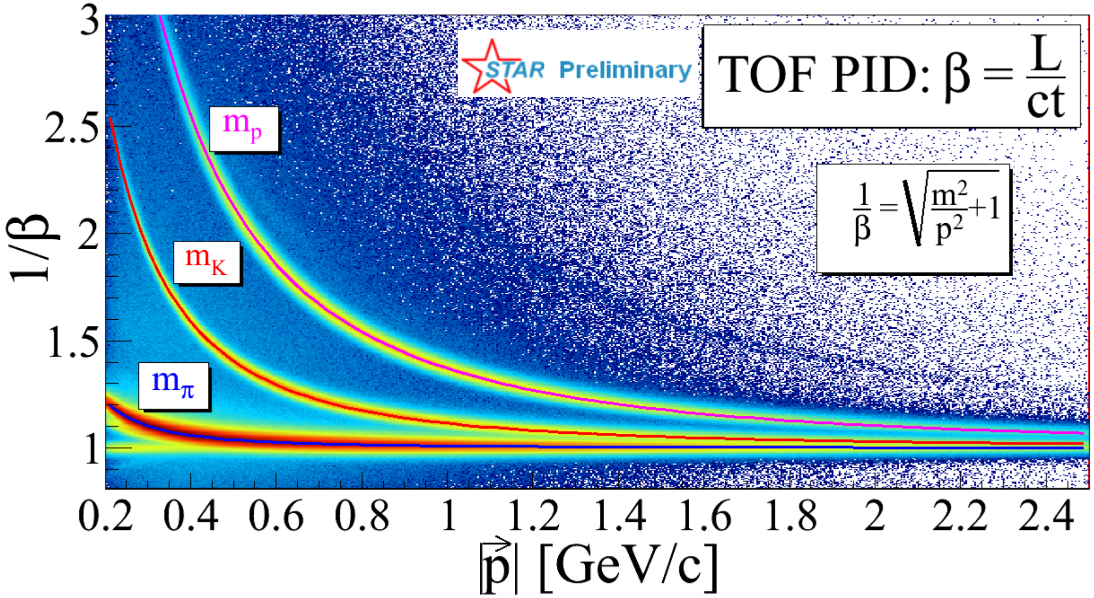
VPD: minimum bias trigger.

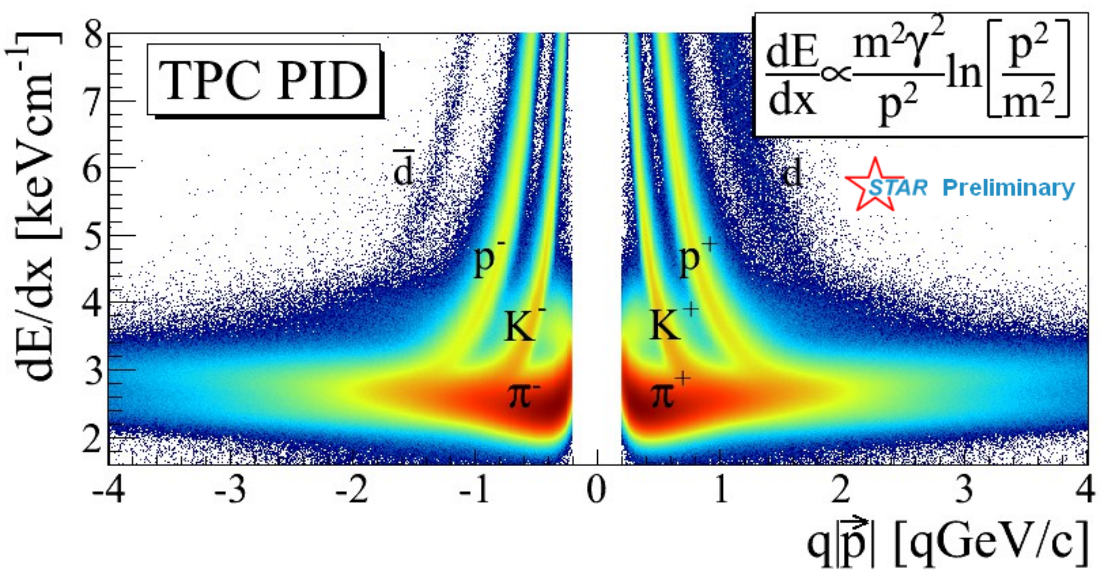
TPC: PID via dE/dx, tracking

TOF: PID.

BEMC: PID via E/p, fast online trigger

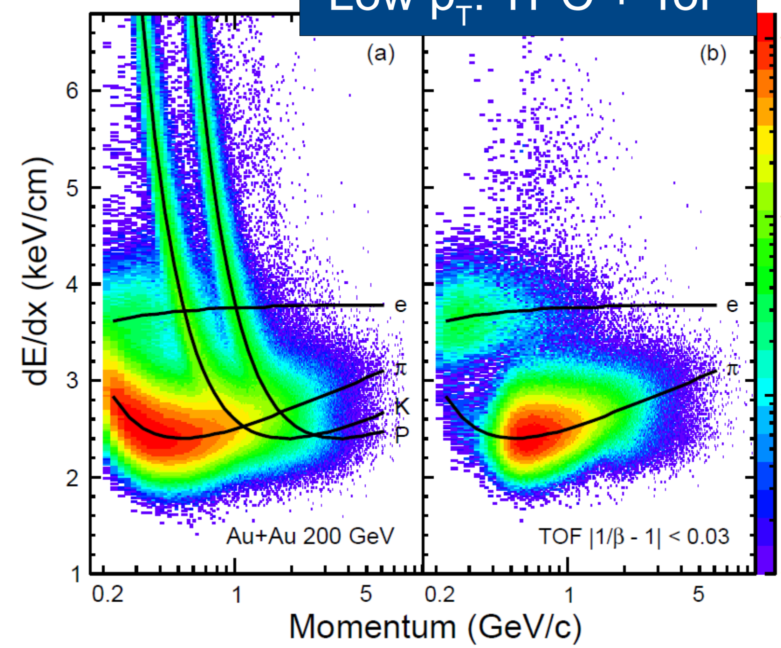
Particle Identification



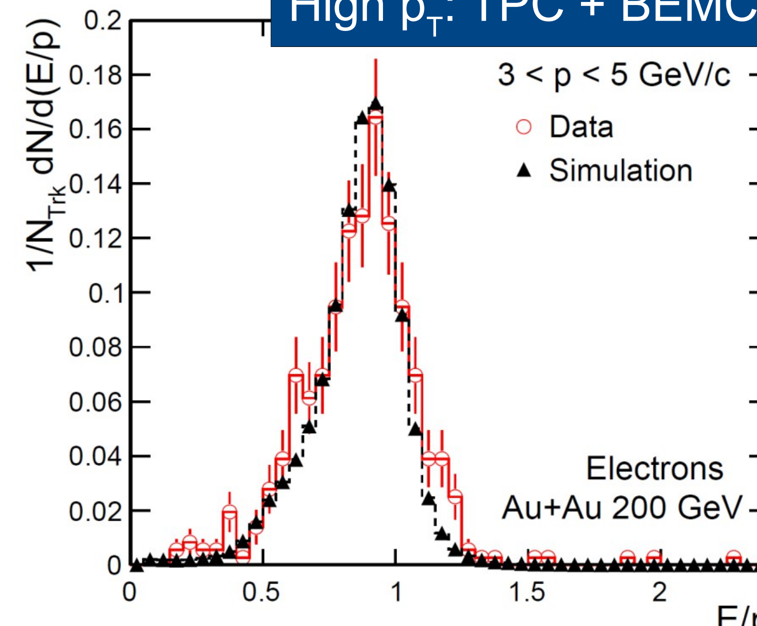


Electron Identification

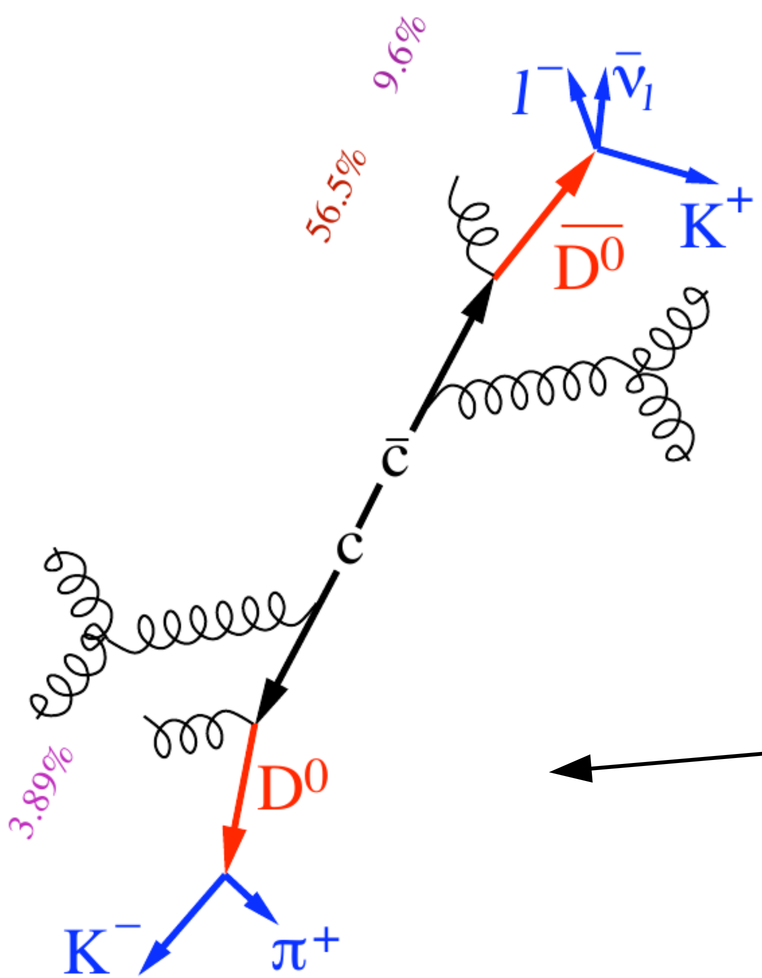
Low p_T: TPC + ToF



High p_T: TPC + BEMC



Open heavy flavor at STAR



Courtesy of David Tlusty

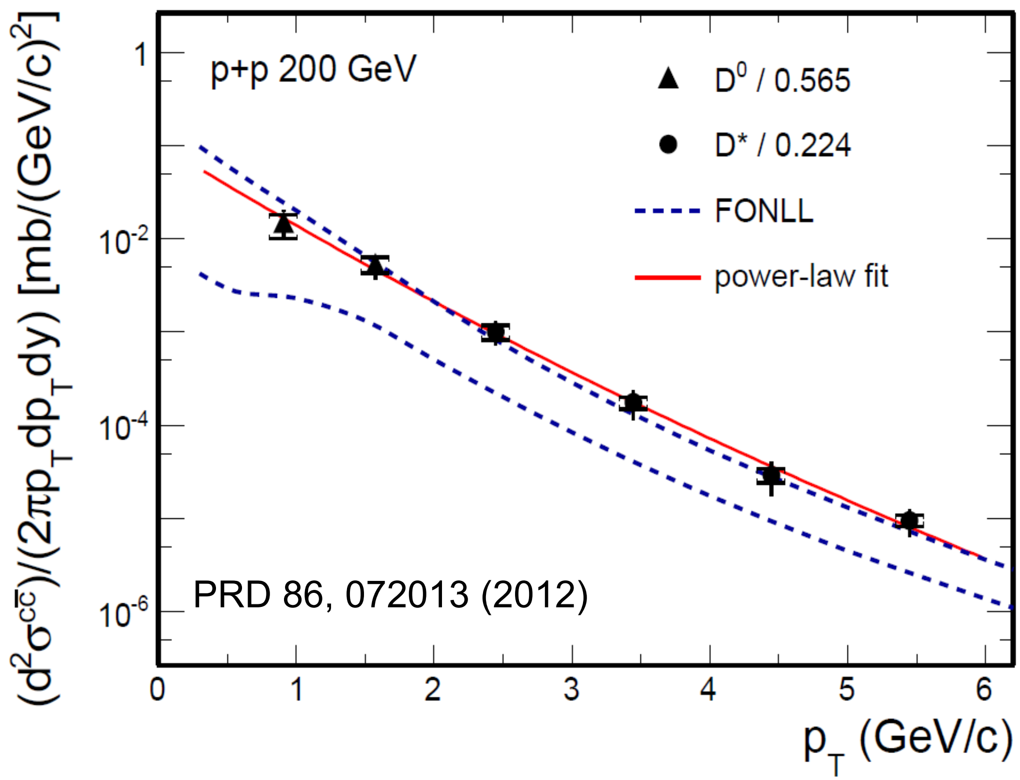
<u>Electrons from semi-leptonic heavy flavor hadrons decay (Non-photonic electrons)</u>

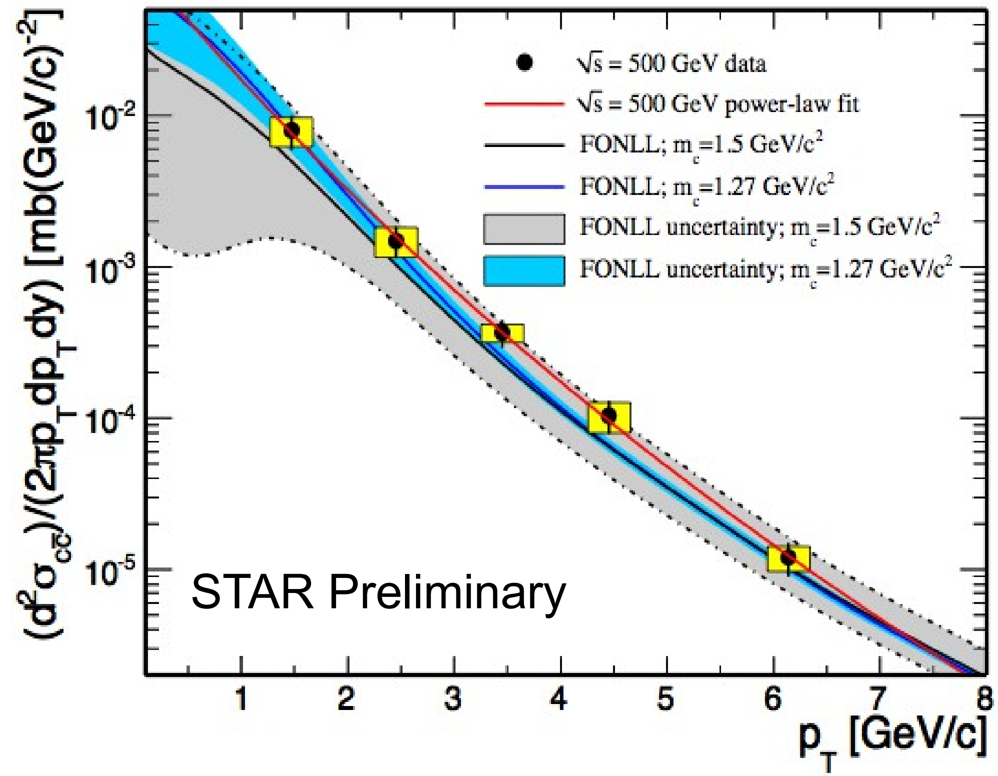
- easy to trigger
- indirect access to the heavy quark kinematics

<u>Direct open charm reconstruction</u>

- direct access to the heavy quark kinematics
- large background without vertex detector
- difficult to trigger

D^0 and D^* p_T spectra in p+p 200 and 500 GeV





$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{y=0}^{\sqrt{s}=200\mathrm{GeV}} = 170 \pm 45^{+38}_{-59}\,\mu b$$

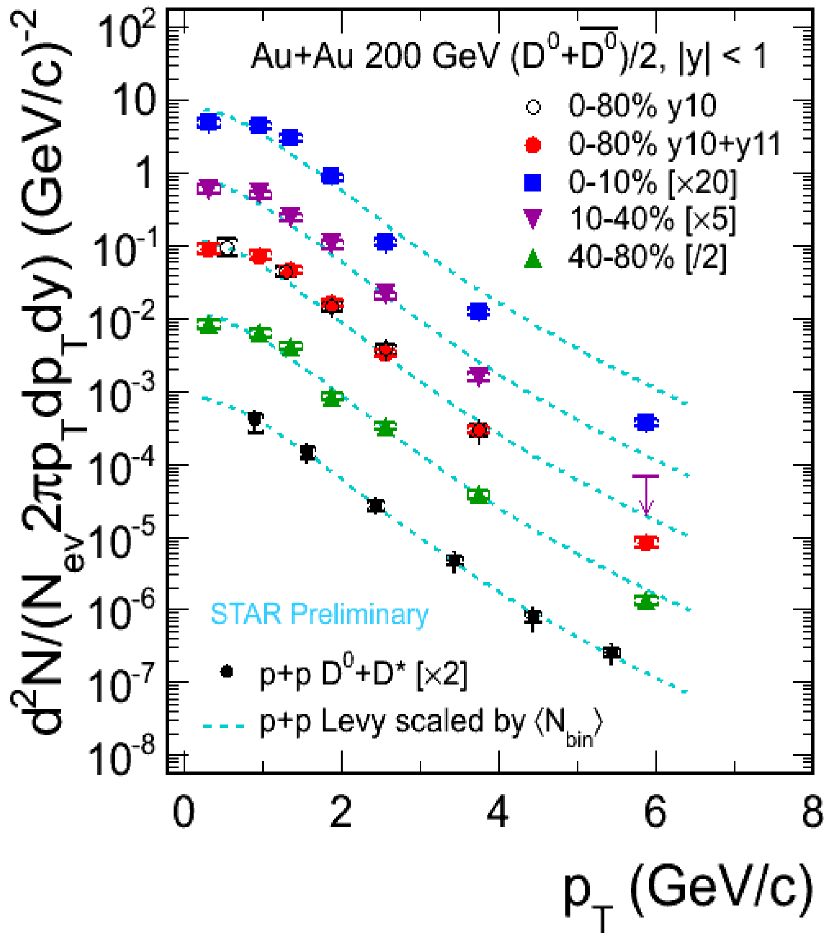
$$\left.\frac{\mathrm{d}\sigma_{c\bar{c}}}{\mathrm{d}y}\right|_{y=0}^{\sqrt{s}=500\mathrm{GeV}} = 217 \pm 86(\mathrm{stat.}) \pm 73(\mathrm{sys.})\ \mu\mathrm{b}$$

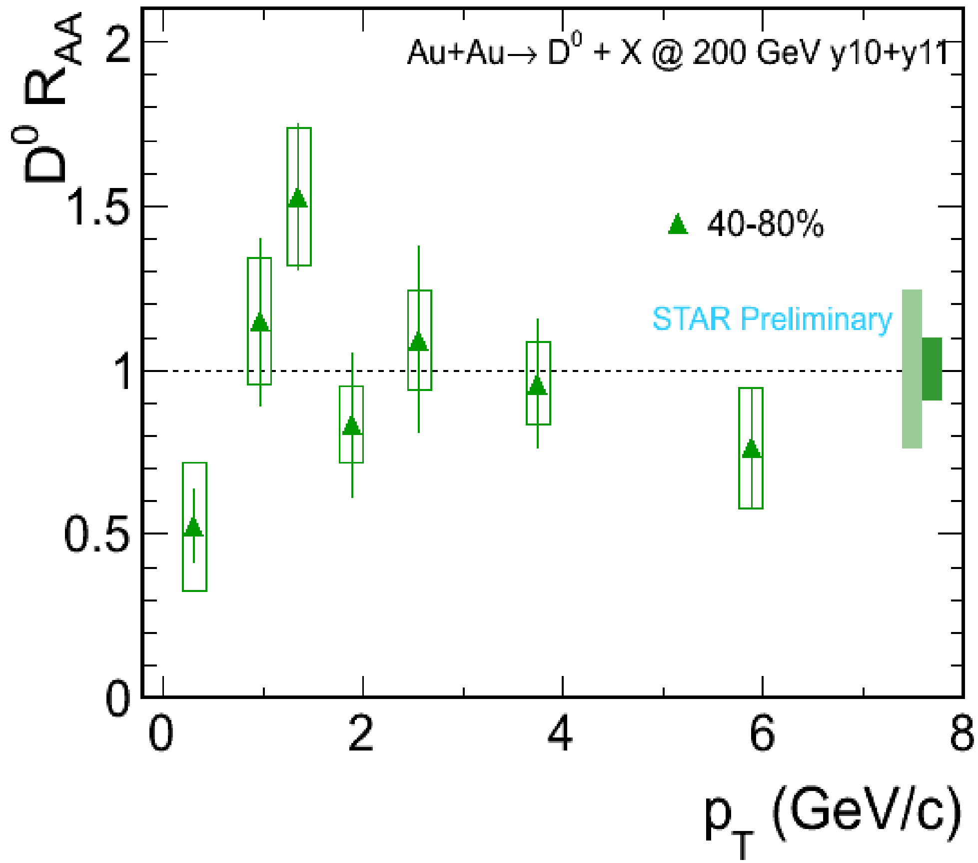
Constraints for the pQCD calculations.

Results consistent with FONLL upper limit.

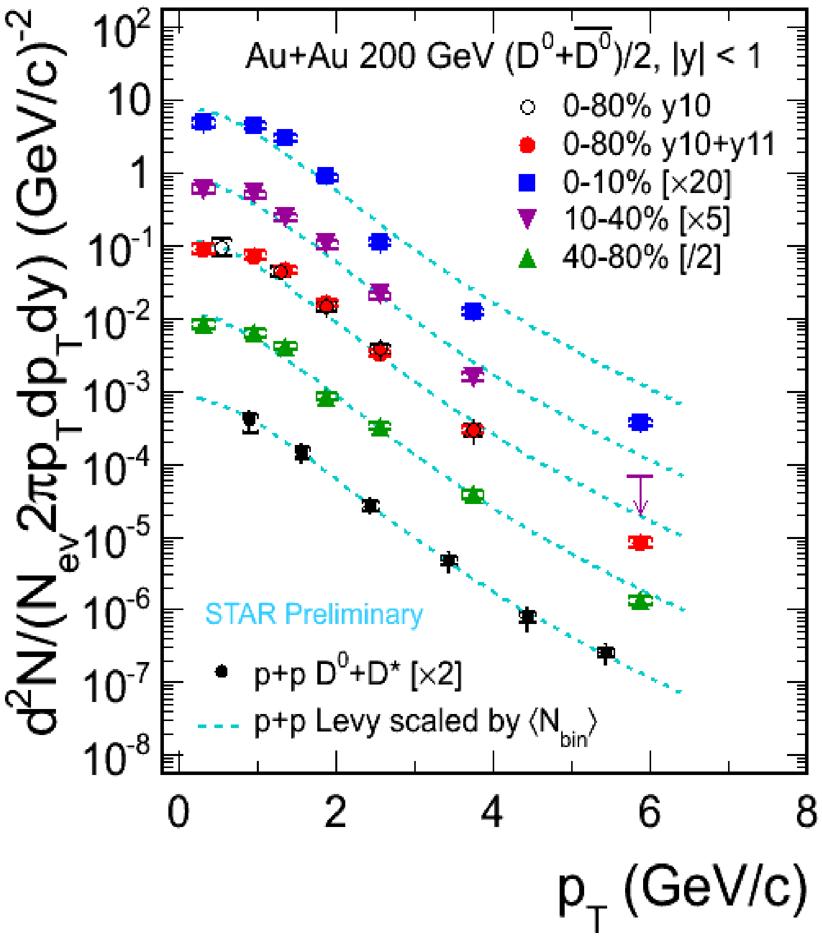
(FONLL: Fixed Order plus Next-to-Leading Logarithms calculation, $\mu_F = \mu_R = m_c$, $|y| < 1$,
R. Nelson, R. Vogt, A. D. Frawley, arXiv: 1210.4610)

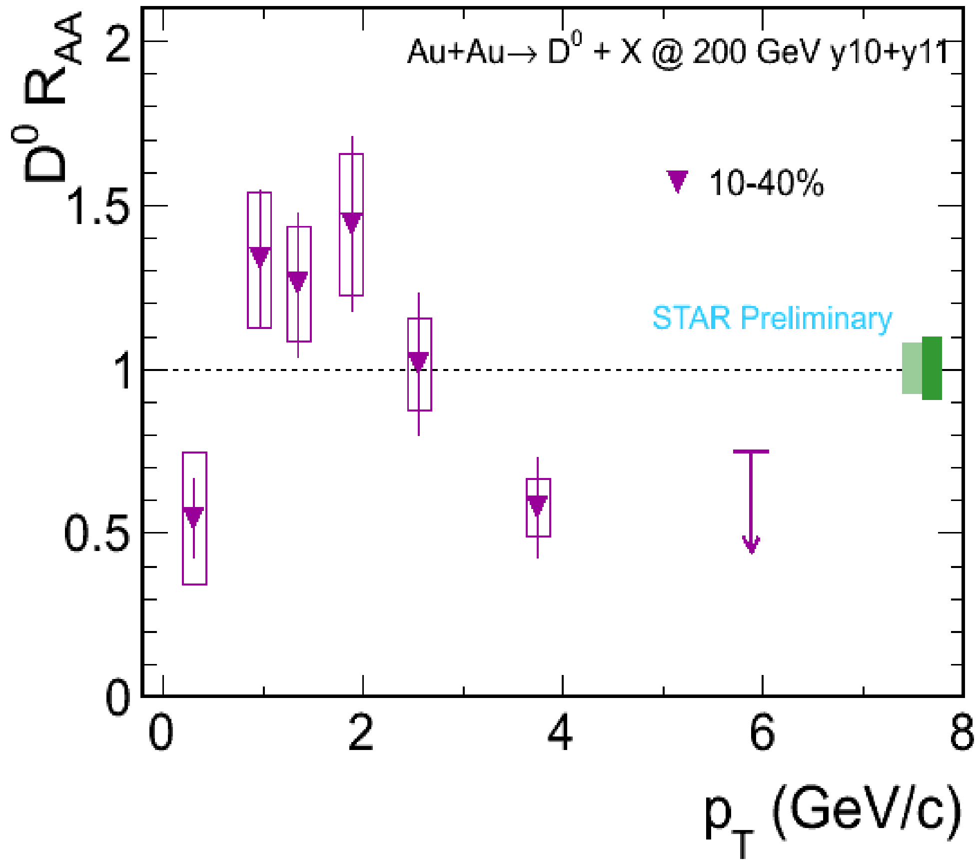
D^0 spectra in Au+Au 200 GeV



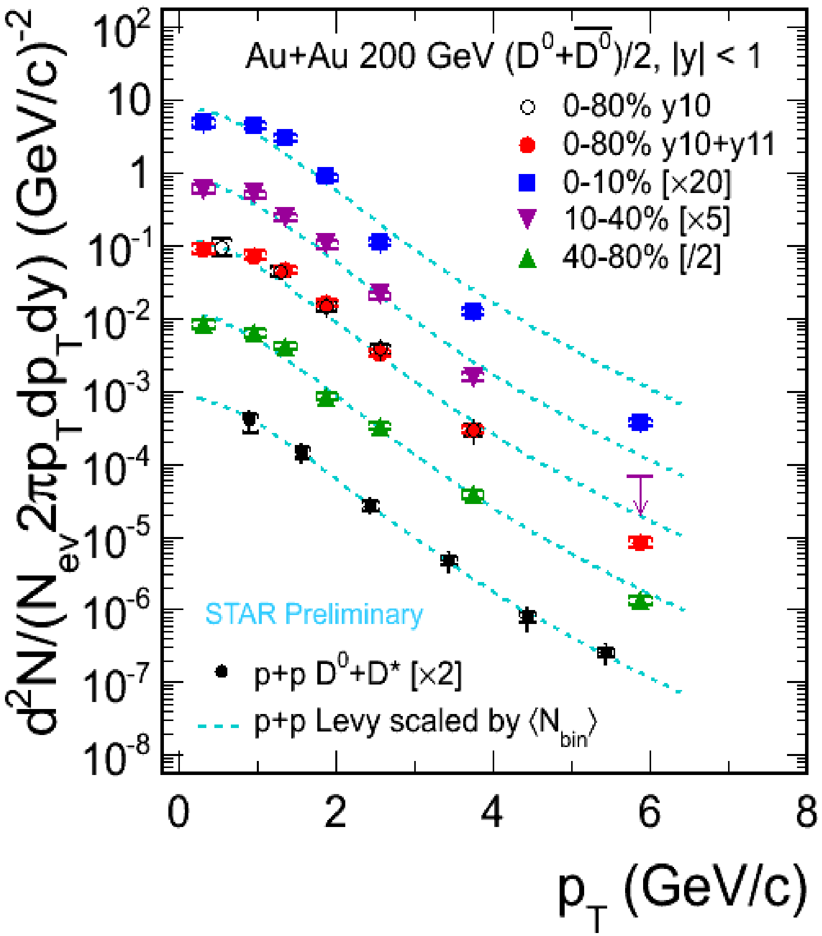


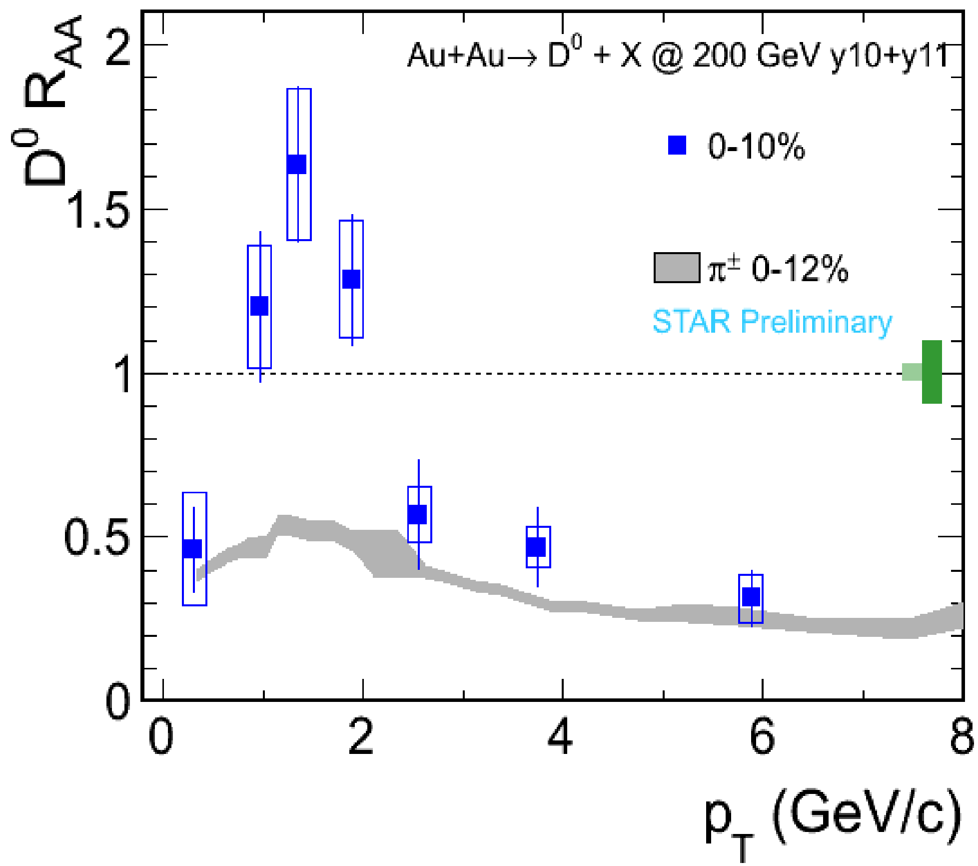
D^0 spectra in Au+Au 200 GeV





D^0 spectra in Au+Au 200 GeV

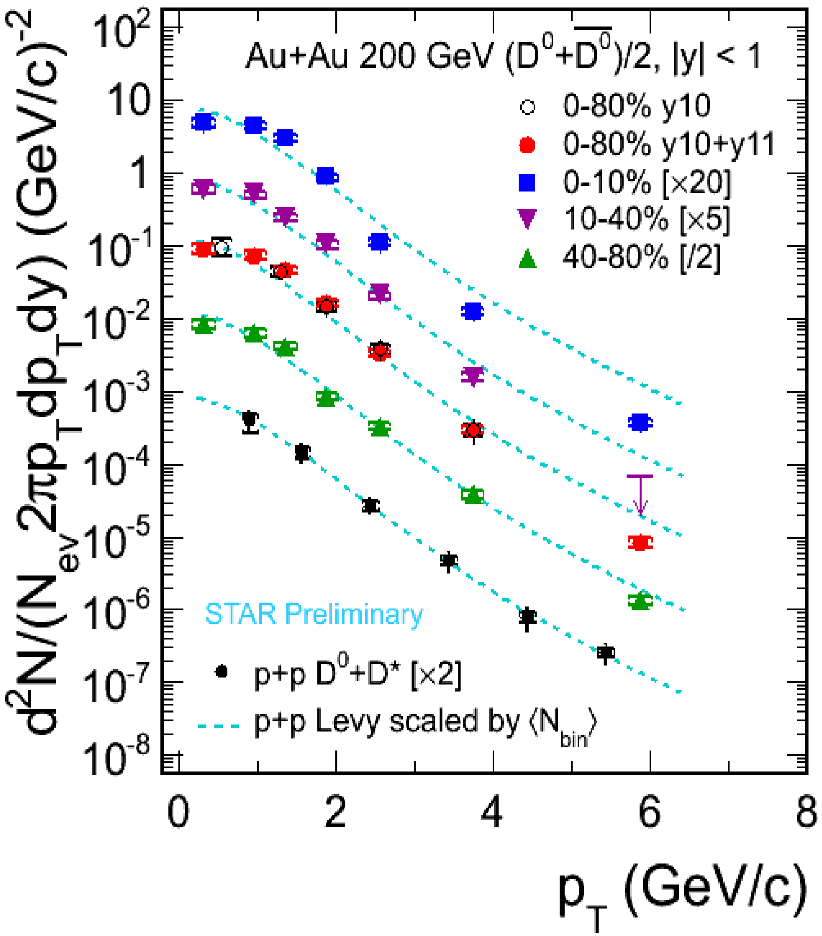


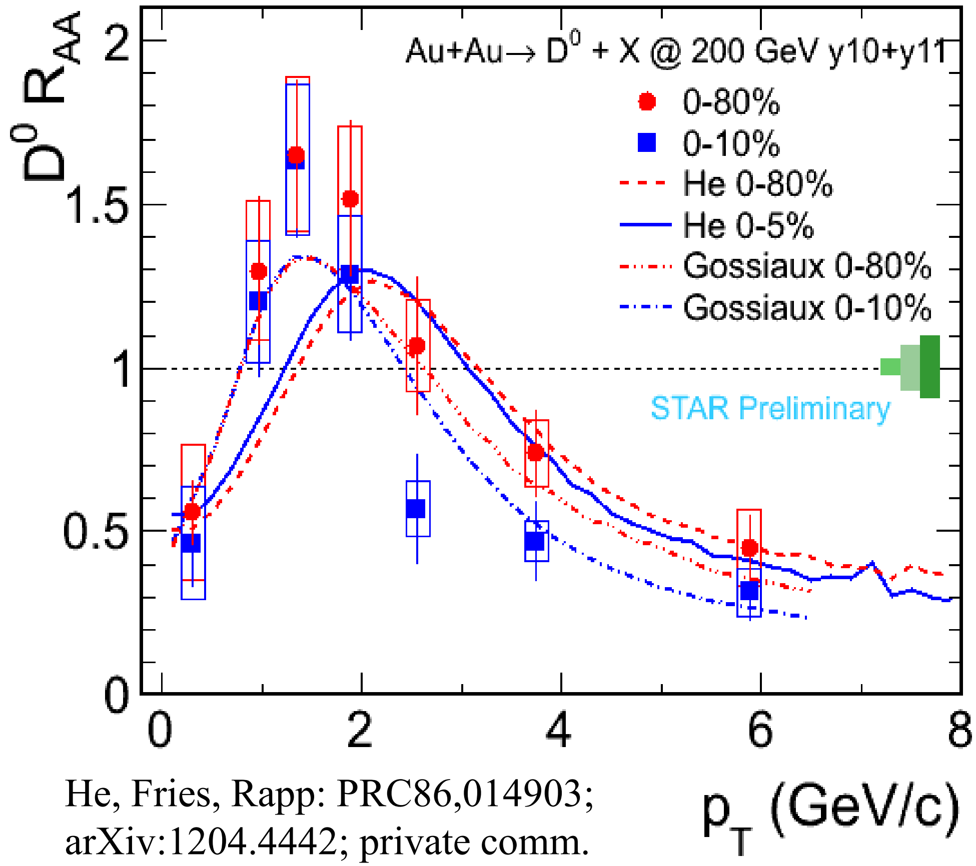


Suppression at high p_T in central and mid-central collisions.

Suppression at high p_T in central collisions similar to light hadrons.

D^0 spectra in Au+Au 200 GeV





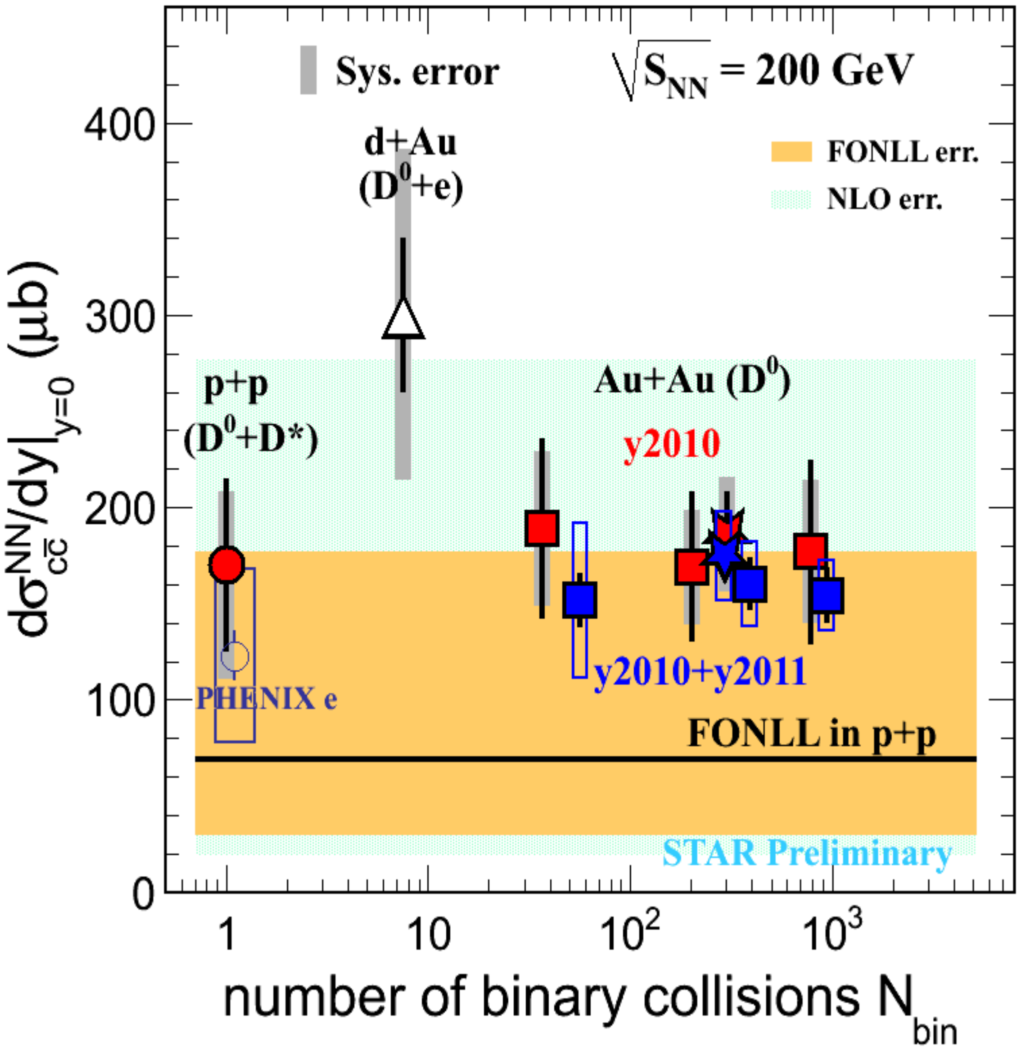
He, Fries, Rapp: PRC86,014903;
arXiv:1204.4442; private comm.
P. Gossiaux: arXiv: 1207.5445

Suppression at high p_T in central and mid-central collisions.

Suppression at high p_T in central collisions similar to light hadrons.

Enhancement at intermediate p_T suggests radial flow of light quarks which coalesce with charm.

Charm cross section at 200 GeV



Charm cross section at mid-rapidity:

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

Total charm cross section:

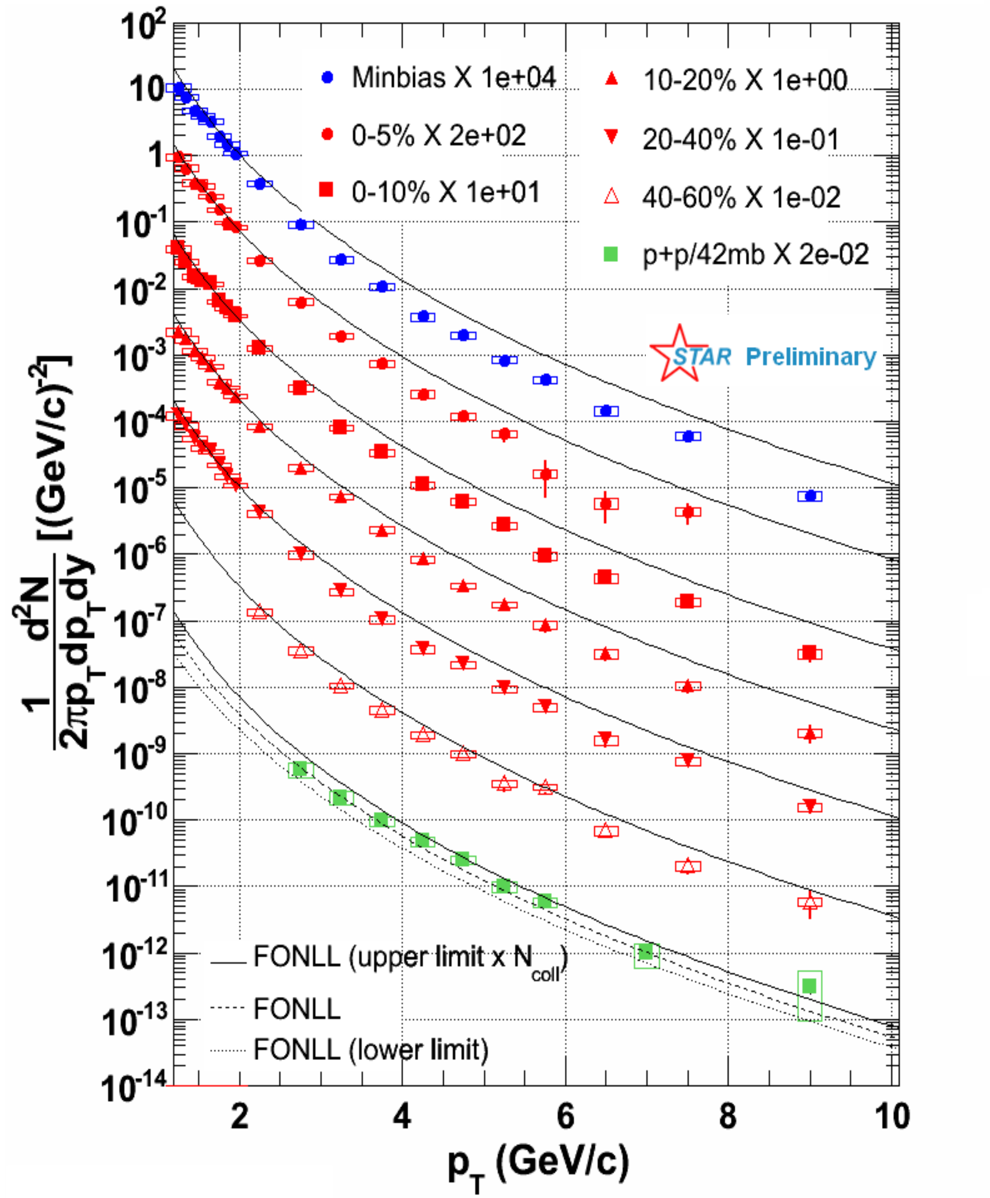
$$\sigma_{c\bar{c}}^{pp} = 797 \pm 210^{+208}_{-295}\,\mu b \qquad \sigma_{c\bar{c}}^{AuAu} = 822 \pm 62 \pm 192\,\mu b$$

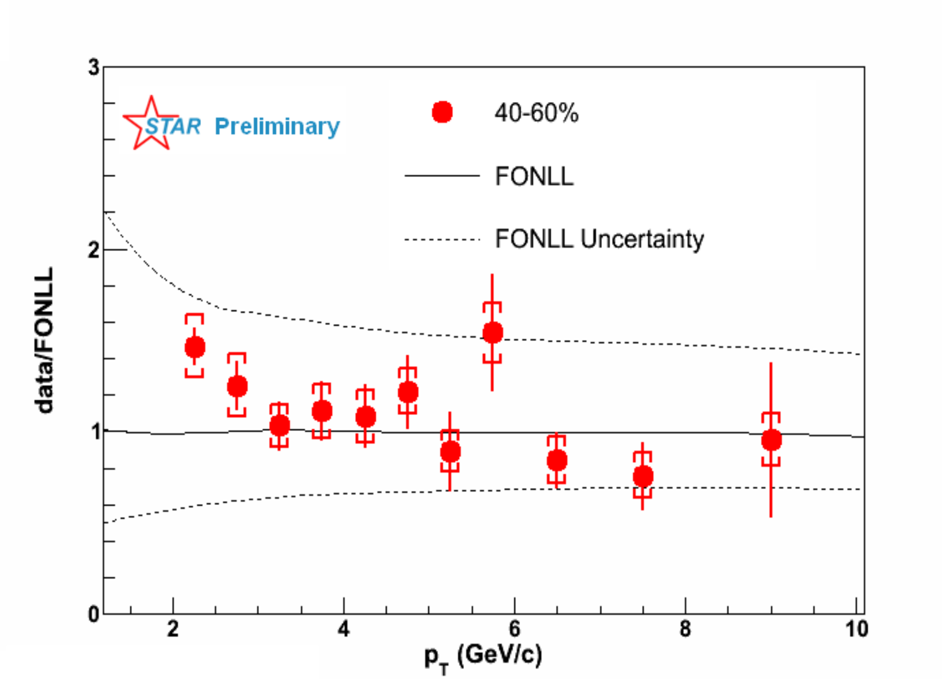
Charm cross section follows number of binary collisions scaling

→ Charm quarks produced mostly via initial hard scatterings

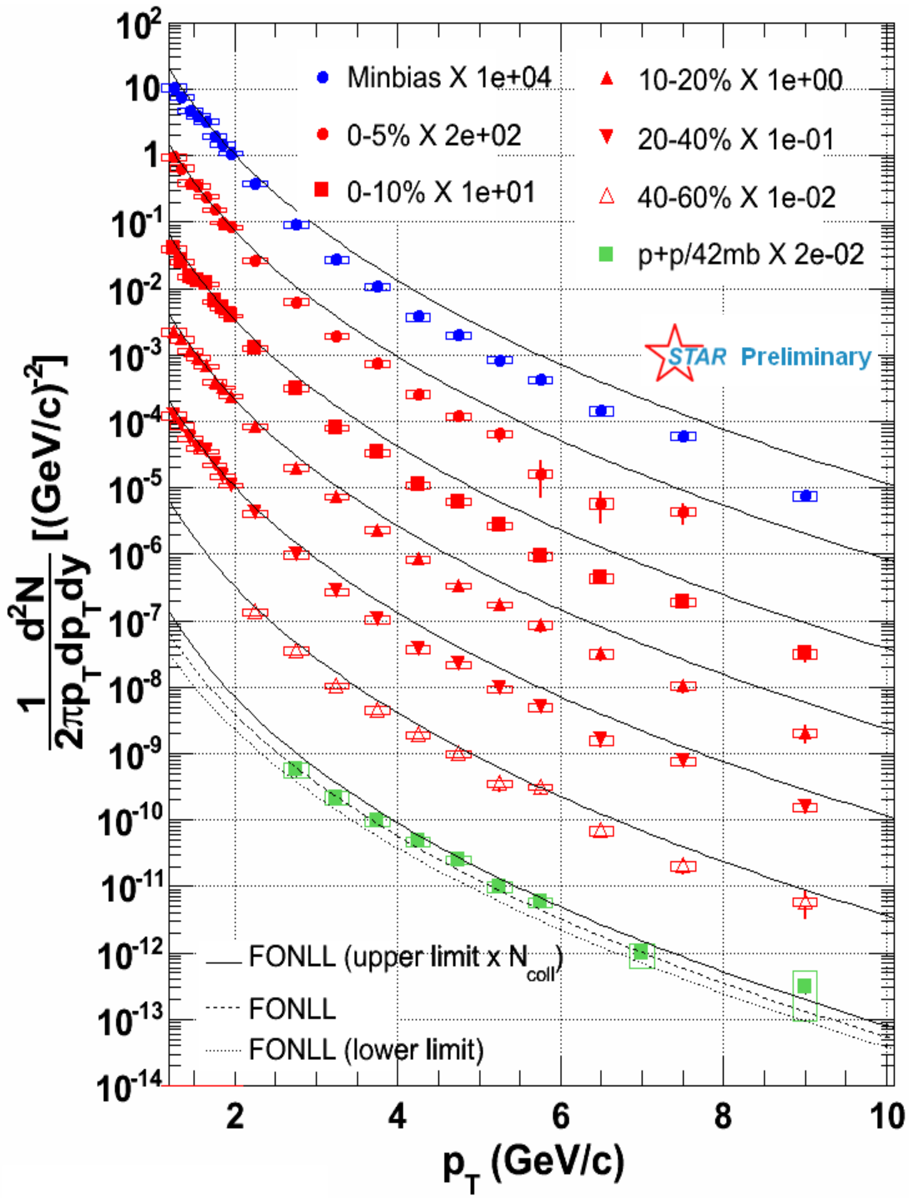
[1] STAR d+Au: J. Adams, et al., PRL 94 (2005) 62301
[2] FONLL: M. Cacciari, PRL 95 (2005) 122001.
[3] NLO: R. Vogt, Eur.Phys.J.ST 155 (2008) 213
[4] PHENIX e: A. Adare, et al., PRL 97 (2006) 252002.

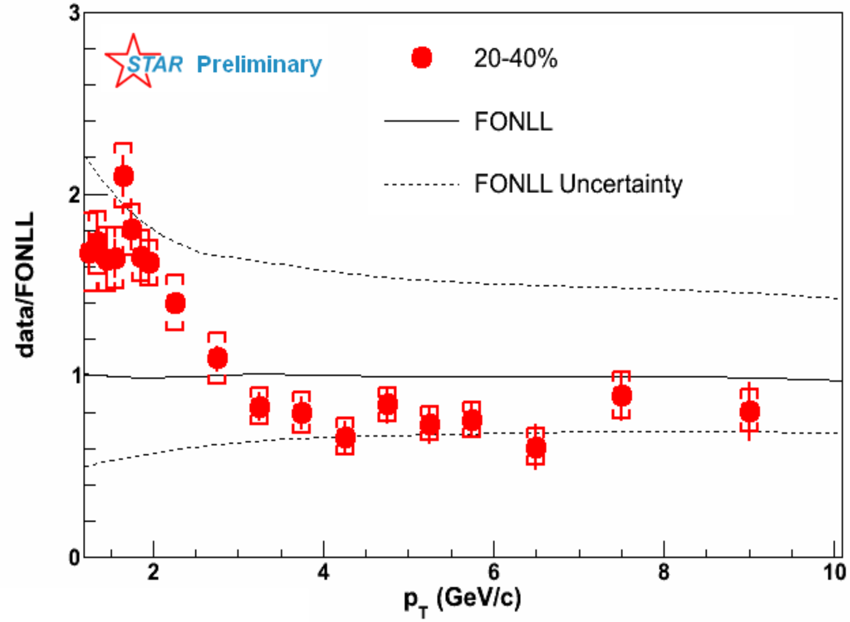
Non-photonic electron spectra in Au+Au 200 GeV



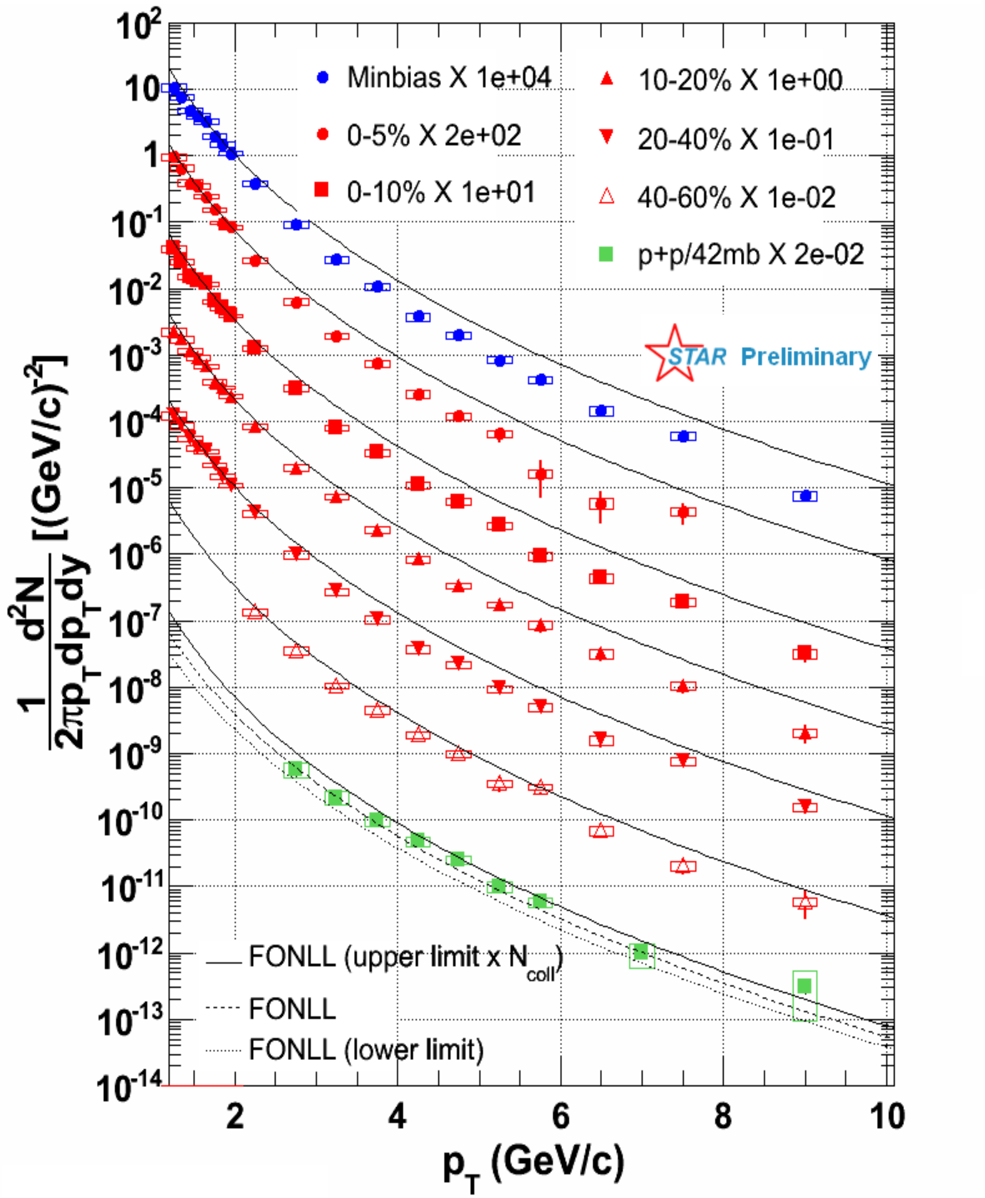


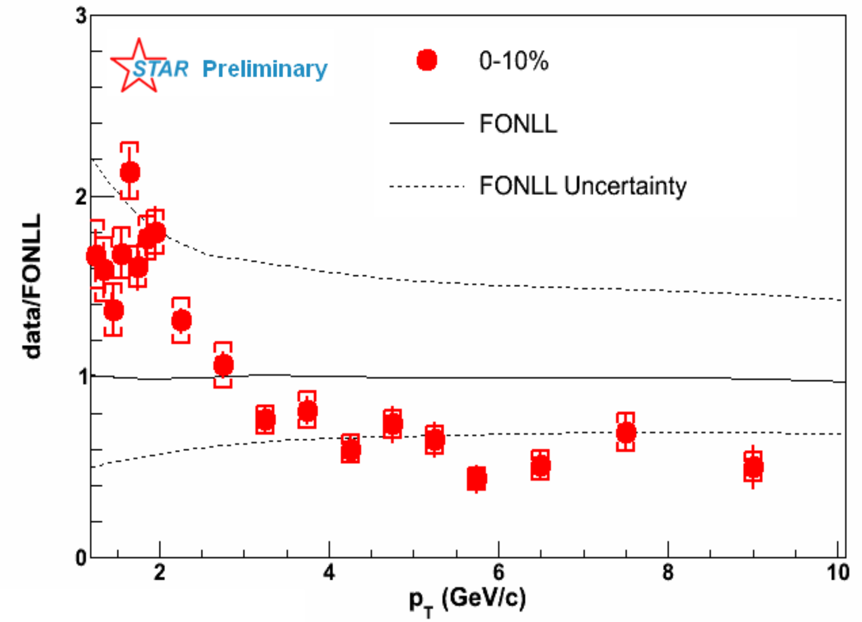
Non-photonic electron spectra in Au+Au 200 GeV



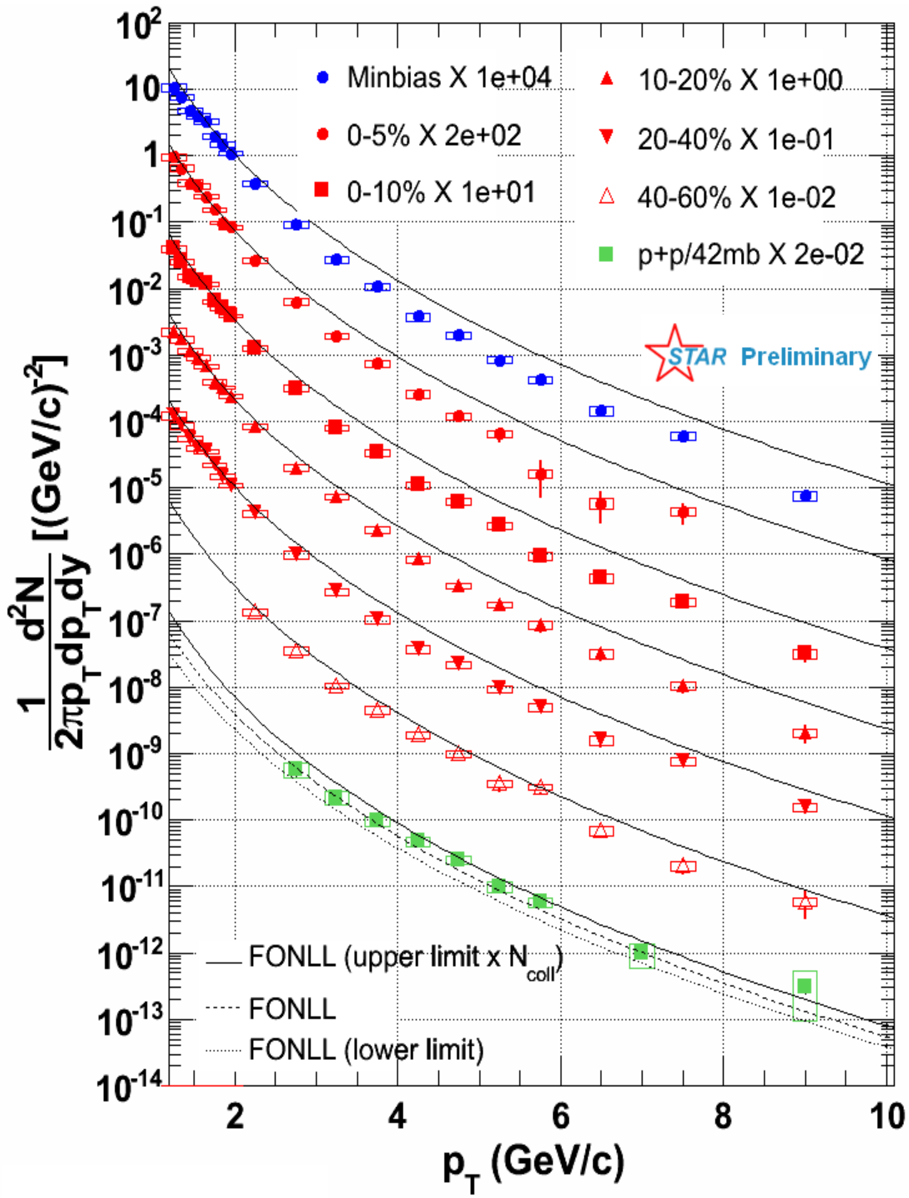


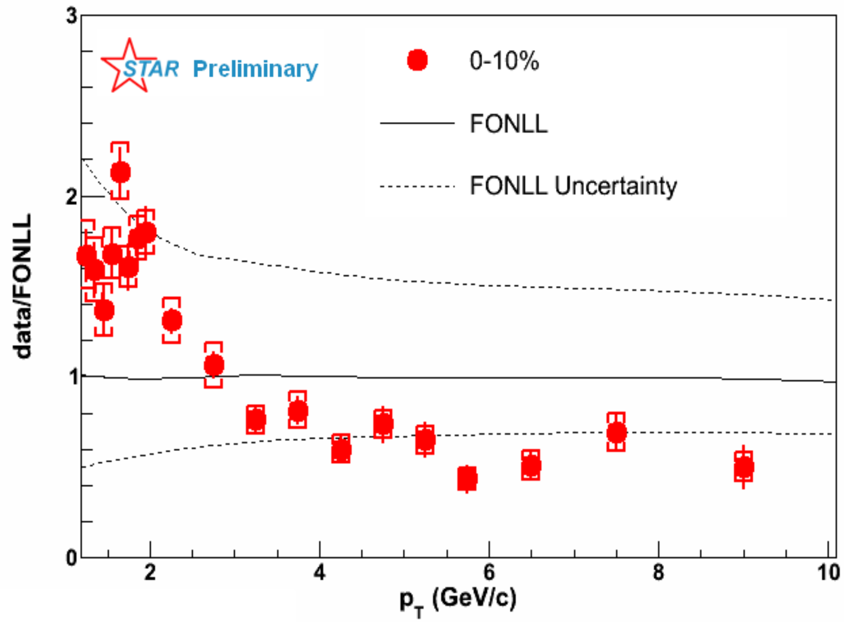
Non-photonic electron spectra in Au+Au 200 GeV





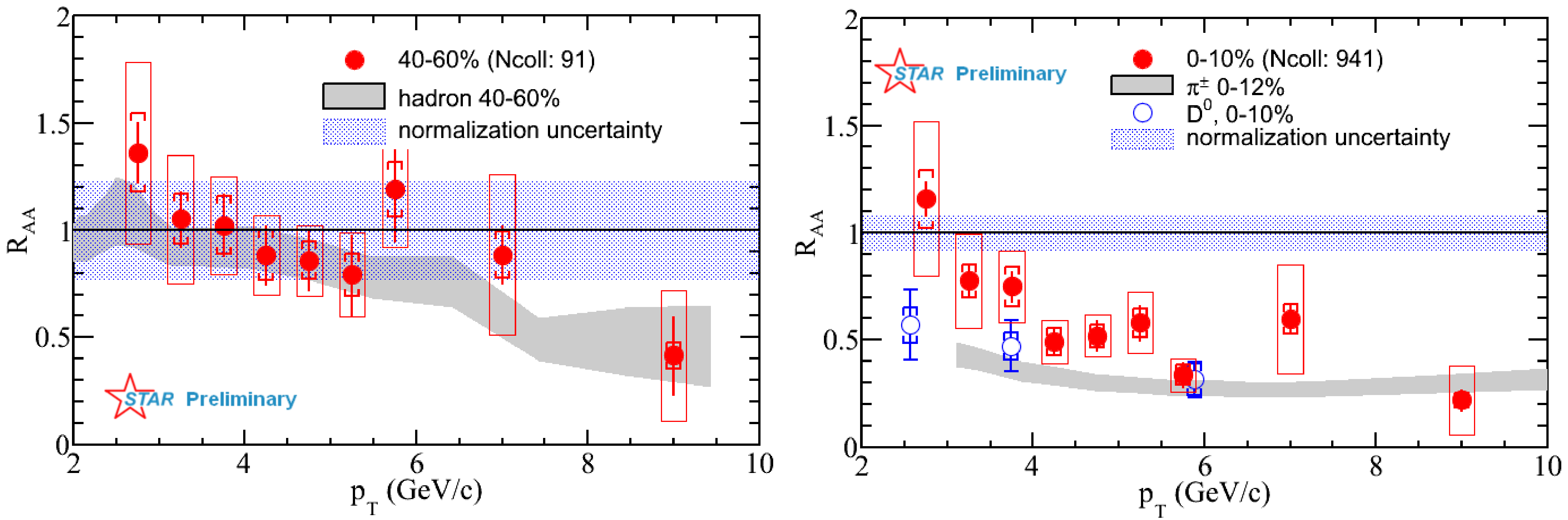
Non-photonic electron spectra in Au+Au 200 GeV





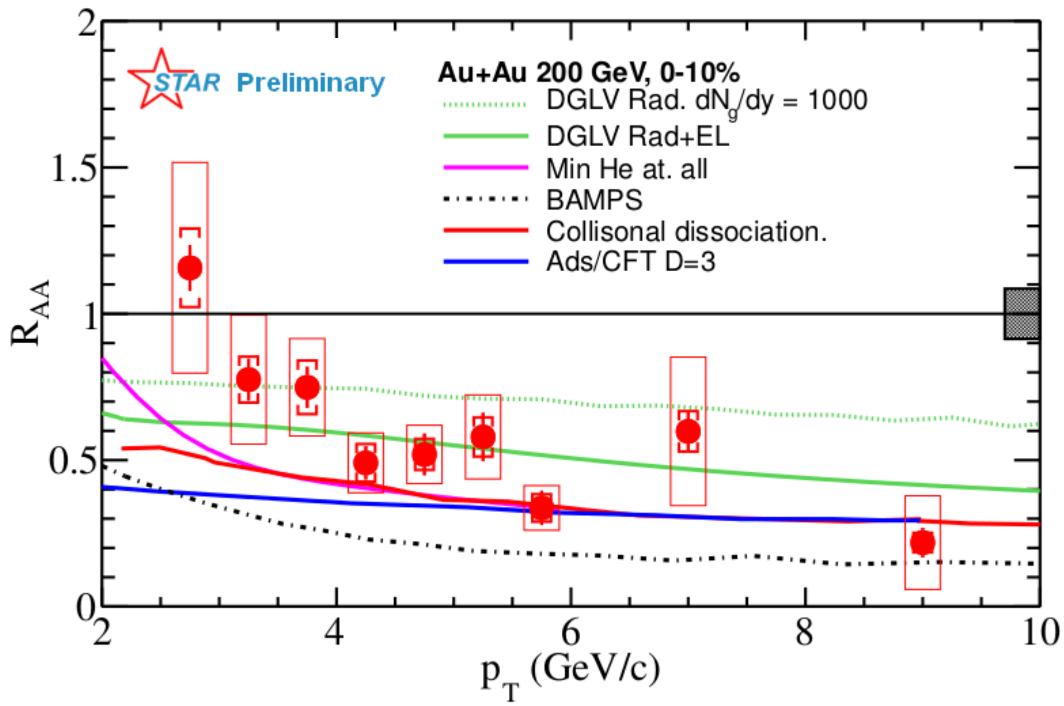
NPE production suppressed at high p_T at 200 GeV compared to pQCD calcuations

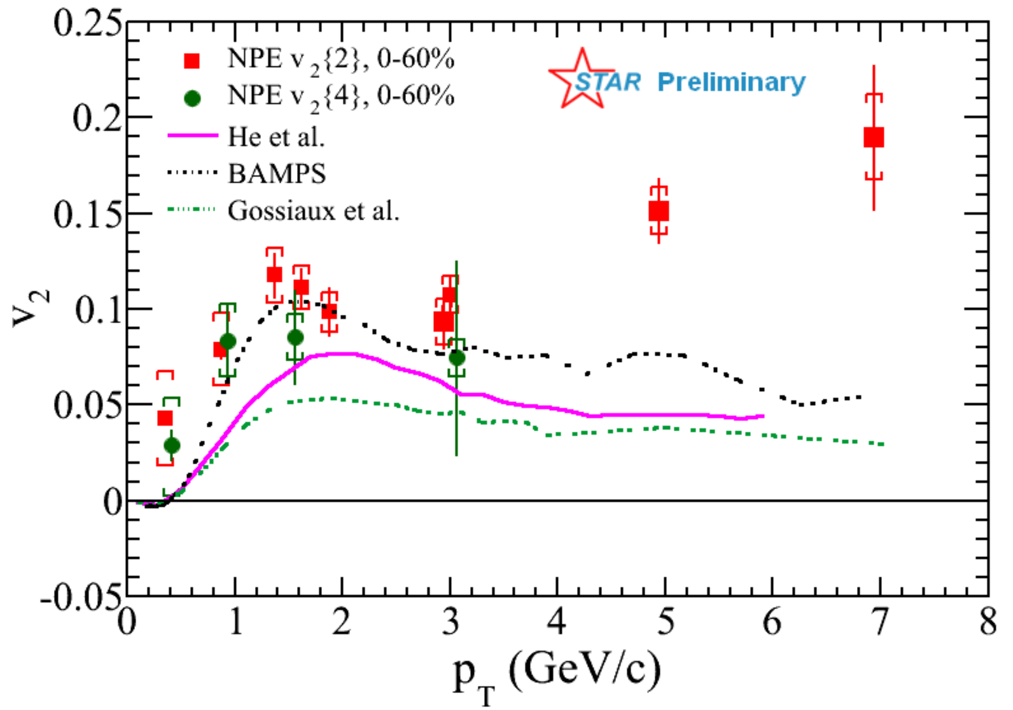
Non-photonic electron R_{AA} in Au+Au 200 GeV



- Strong suppression at high p_T in central collisions
- D^0 and NPE suppression is similar
- Uncertainty dominated by p+p baseline

NPE v_2 and R_{AA} in Au+Au 200 GeV



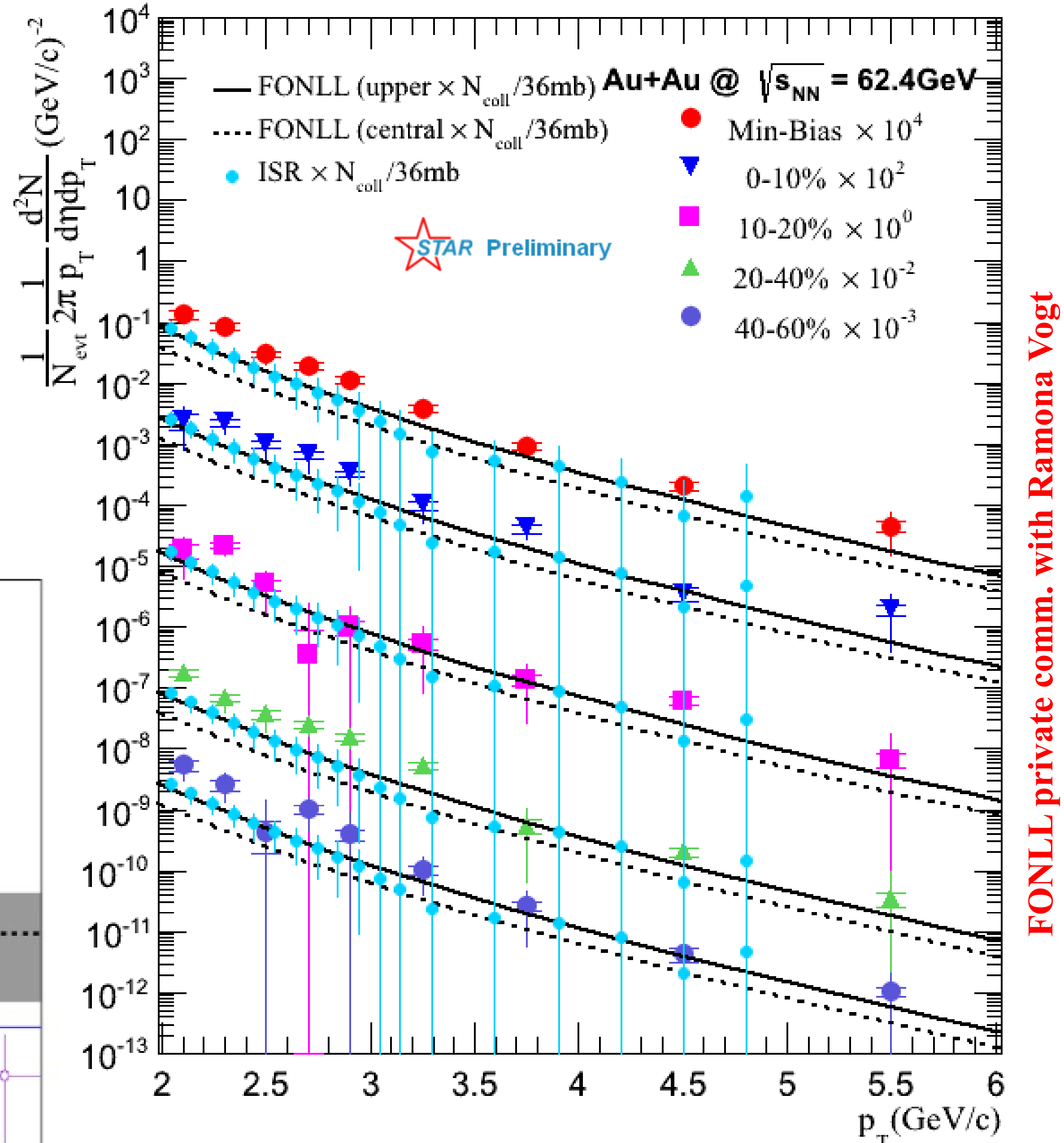


- Data disfavor radiative energy loss as the only energy loss mechanism
- Finite v_2 at low and intermediate p_T
- No model so far can describe the suppression and v_2 simultaneously
- Increase of v_2 at high p_T due to jet-like correlation

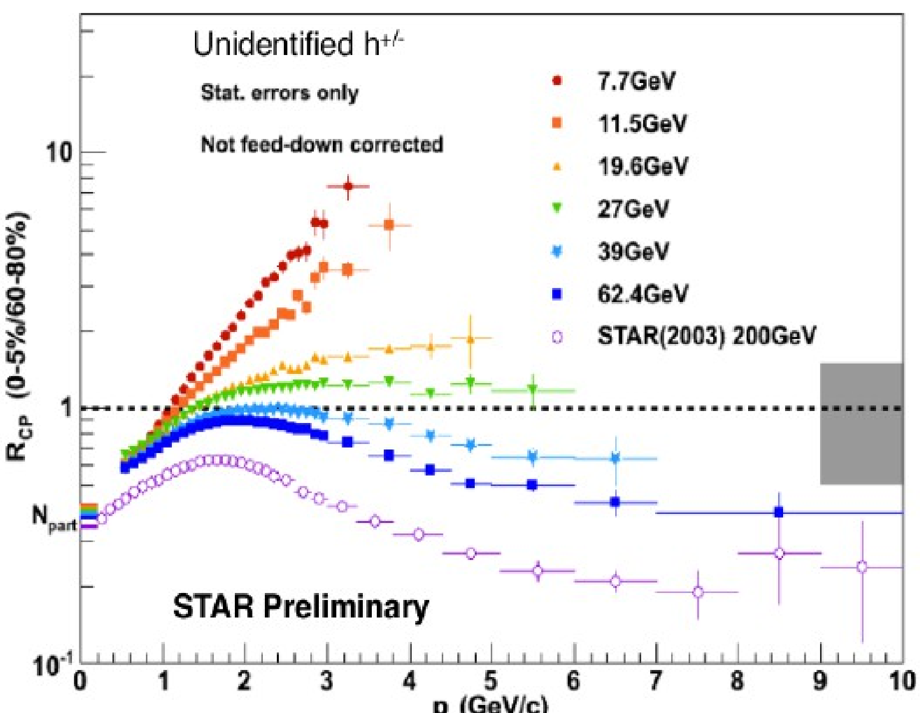
DGLV: Djordjevic, PLB632, 81 (2006), **BAMPS**: arXiv:1205.4945.
He et al.: PRC 86, 014903 (2012), **Coll. Dissoc.** R. Sharma et al., PRC 80, 054902(2009).
Ads/CFT: W. Horowitz Ph.D thesis, **Gossiaux et al.** : PRC 78, 014904 (2008)

NPE spectra in Au+Au at $\sqrt{s_{NN}}$ = 62 GeV

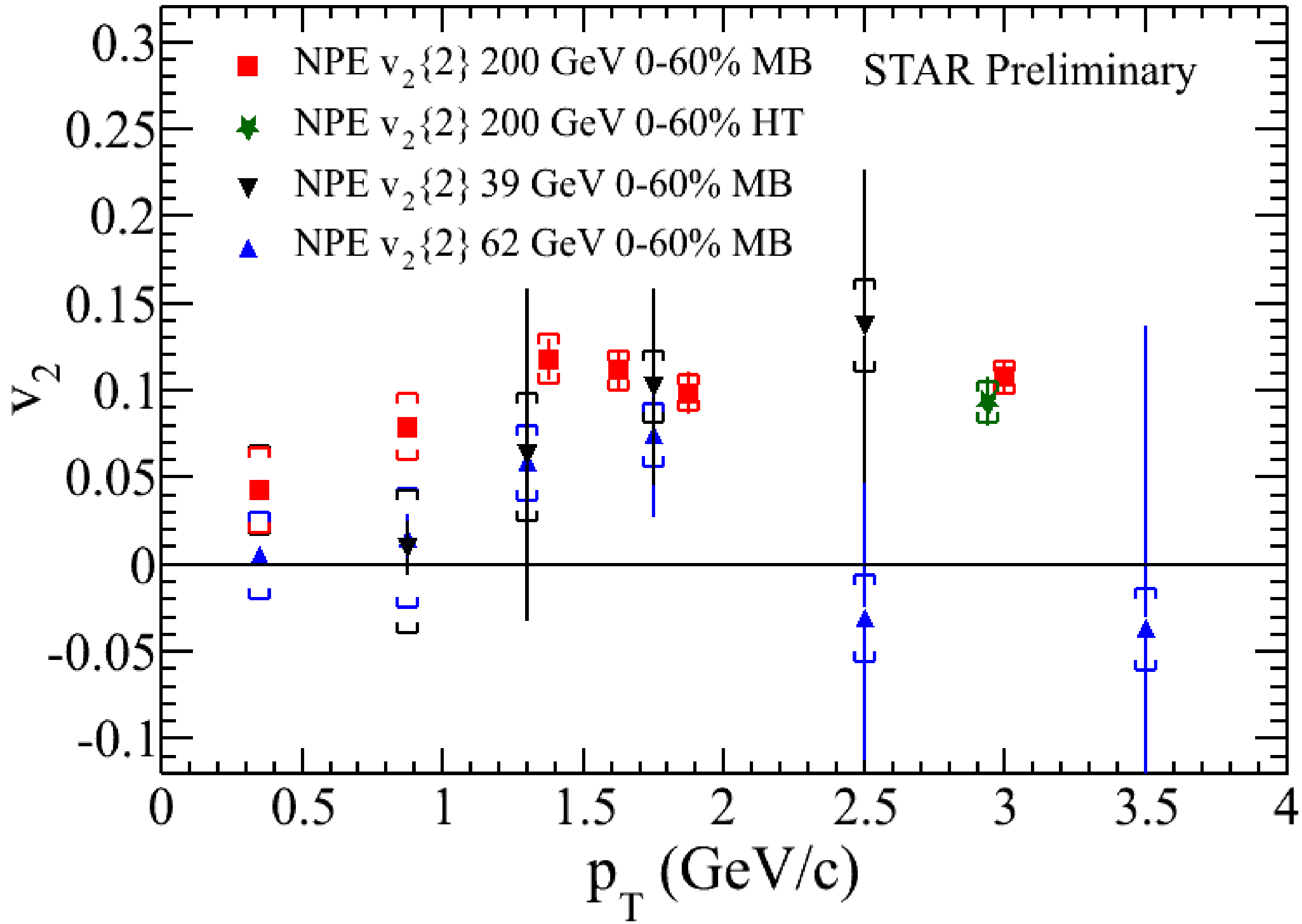
Measurements are systematically higher than FONLL upper limit:
→ no suppression compared to FONLL predictions



Strong suppression for light hadrons observed at 62 GeV



NPE v_2 62 and 39 GeV



A hint that at **low p_T** (p_T<1 GeV) v_2 at 39 and 62 GeV is lower than at 200 GeV (although systemic errors are sizable)

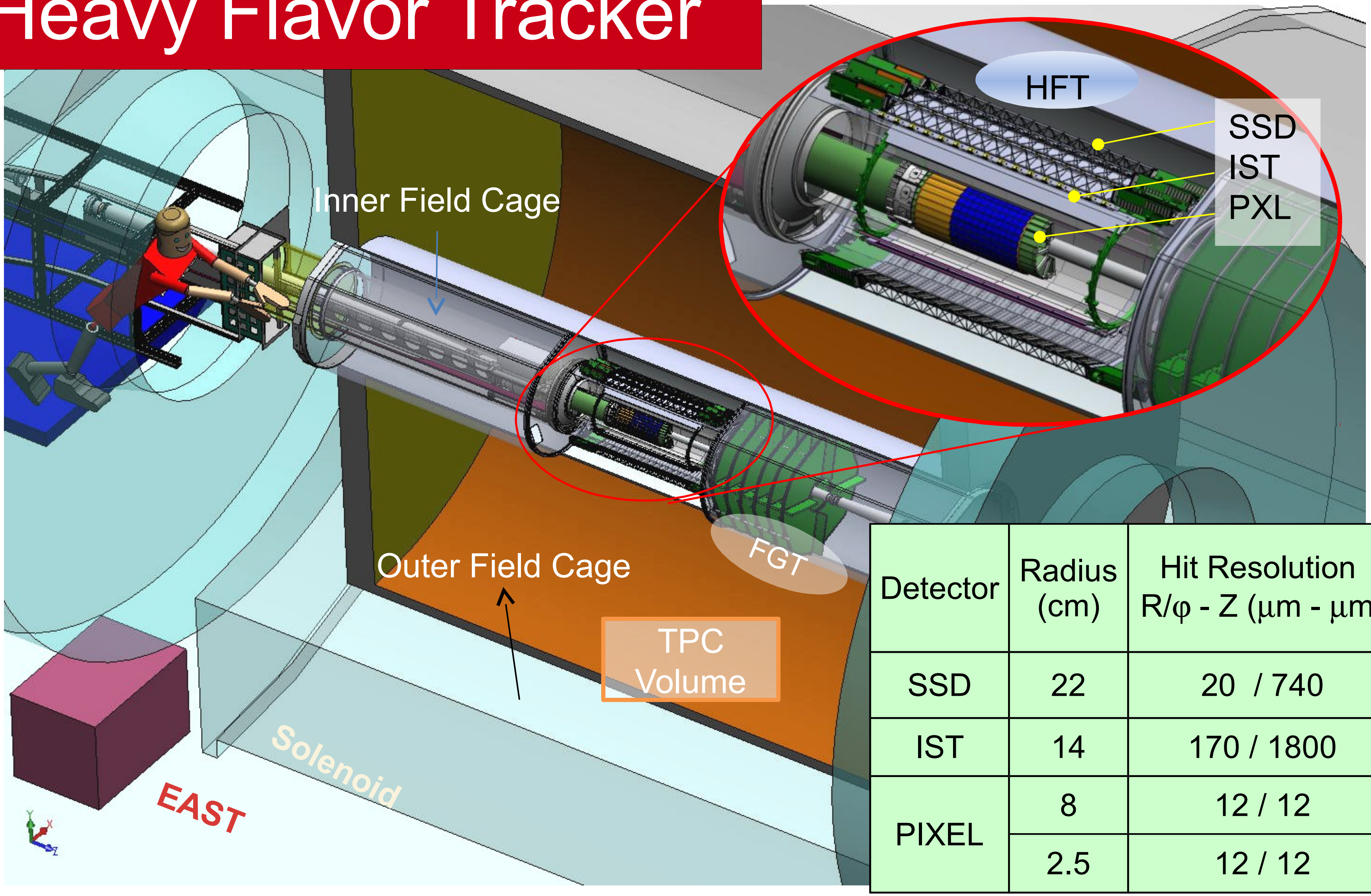
Summary

- At top RHIC energy:
  - strong charm suppression at high-p_T in central Au+Au collisions, similar as for charged hadrons
  - data disfavors radiative energy loss as the only energy loss mechanism for heavy quarks
  - finite azimuthal anisotropy of non-photonic electrons

- 39 and 62 GeV:
  - hint that at p_T<1 GeV NPE v_2 is lower than at 200 GeV
  - no suppression for NPE production at high p_T (compared to FONLL)

→ difference in the degree of charmed-medium interaction at 39 and 62 GeV compared to the top RHIC energy ?

Heavy Flavor Tracker

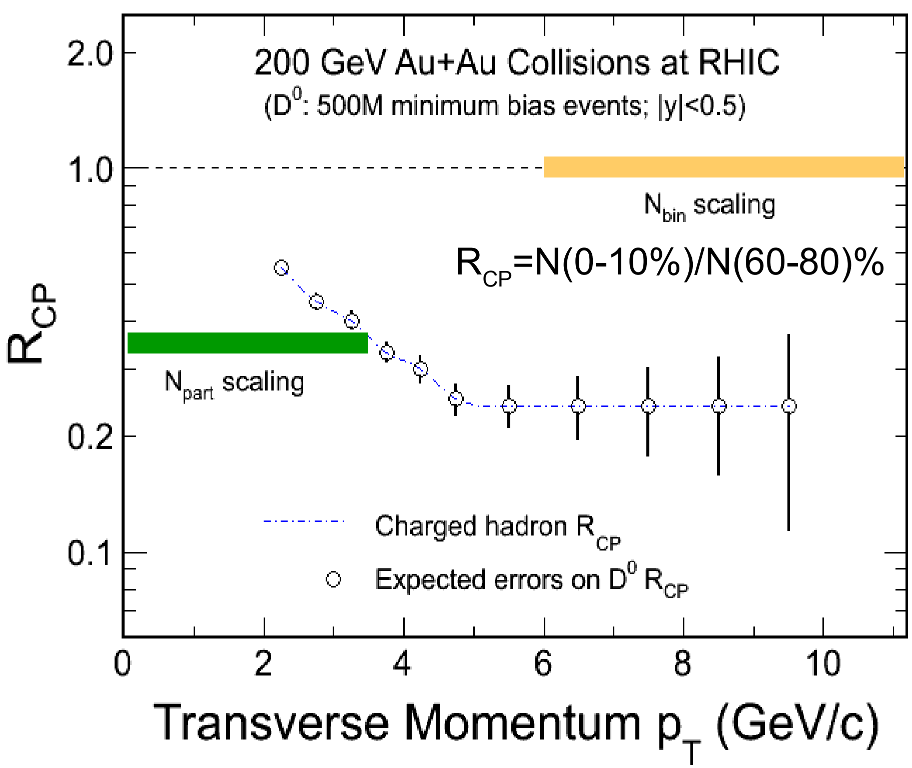


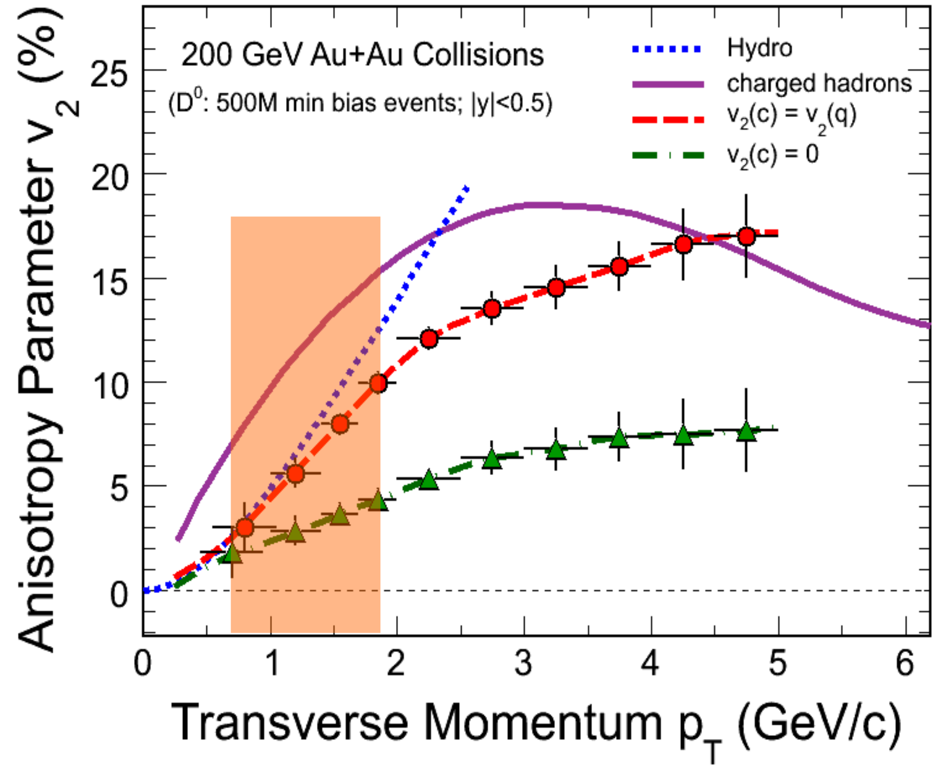
Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X0
IST	14	170 / 1800	<1.5% X0
PIXEL	8	12 / 12	~0.4% X0
	2.5	12 / 12	~0.4% X0

2013: Engineering run (PIXEL prototype with 3+ sectors instrumented) and first data taking in STAR

2014: The full assembly (PXLEL, IST and SSD) will be available for RHIC Run-14, which is planned to be a long Au-Au 200 GeV run

Charm v_2 and R_{AA} – projections for 2014





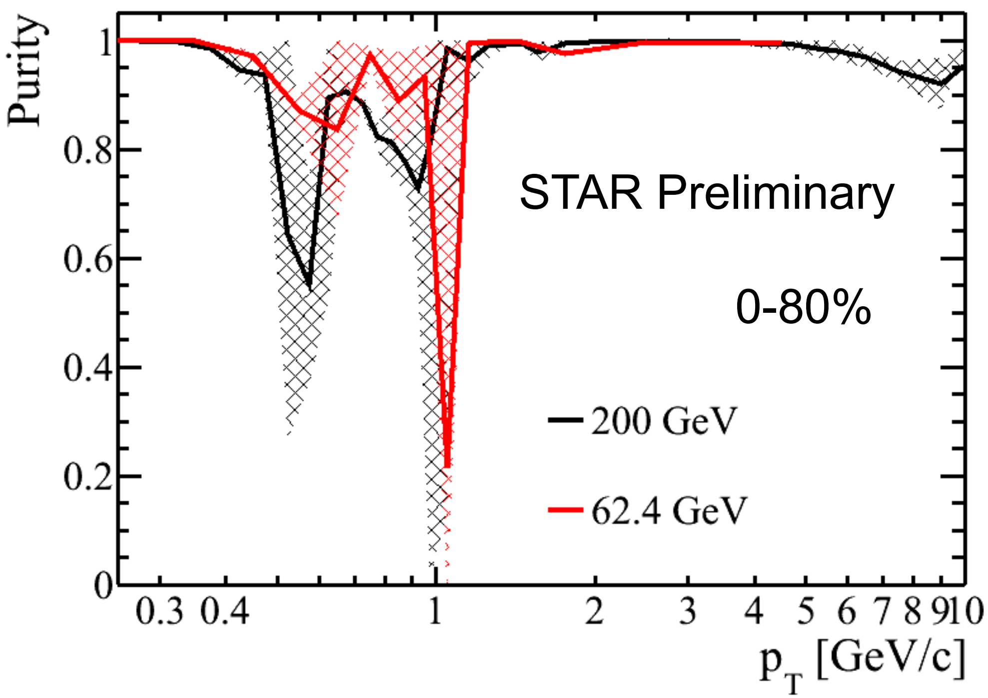
Assuming D^0 v_2 distribution from quark coalescence.

Precision charm v_2 and R_{AA} measurements:

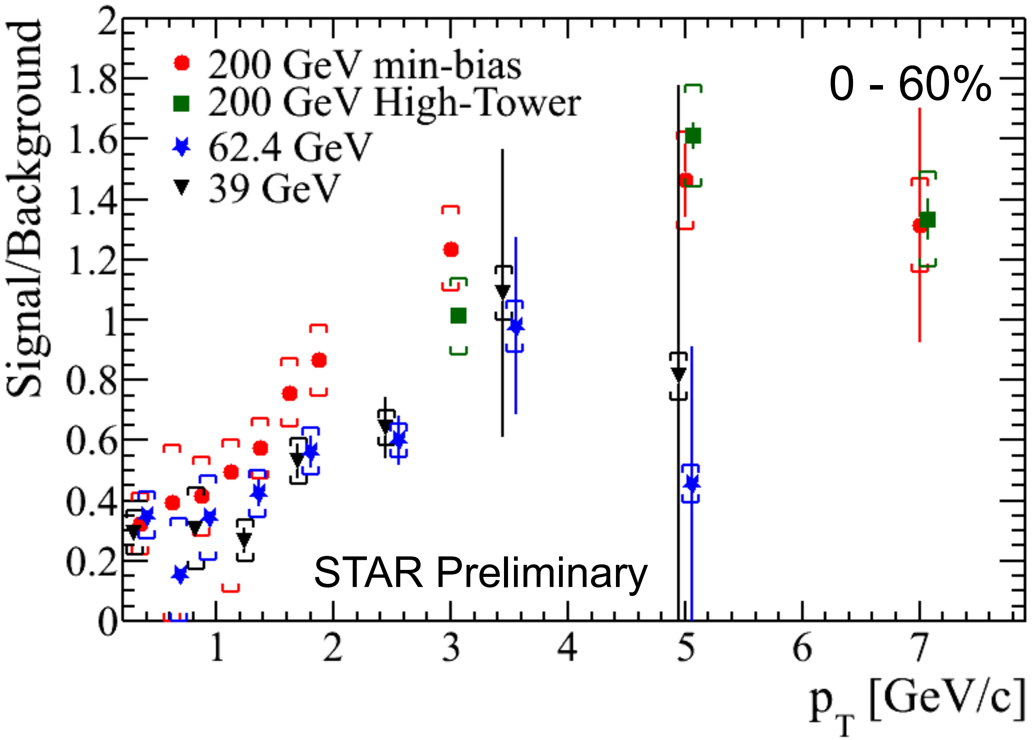
→ energy loss mechanism
→ charm interaction with the QCD matter
→ medium thermalization degree
→ transport coefficients

Backup

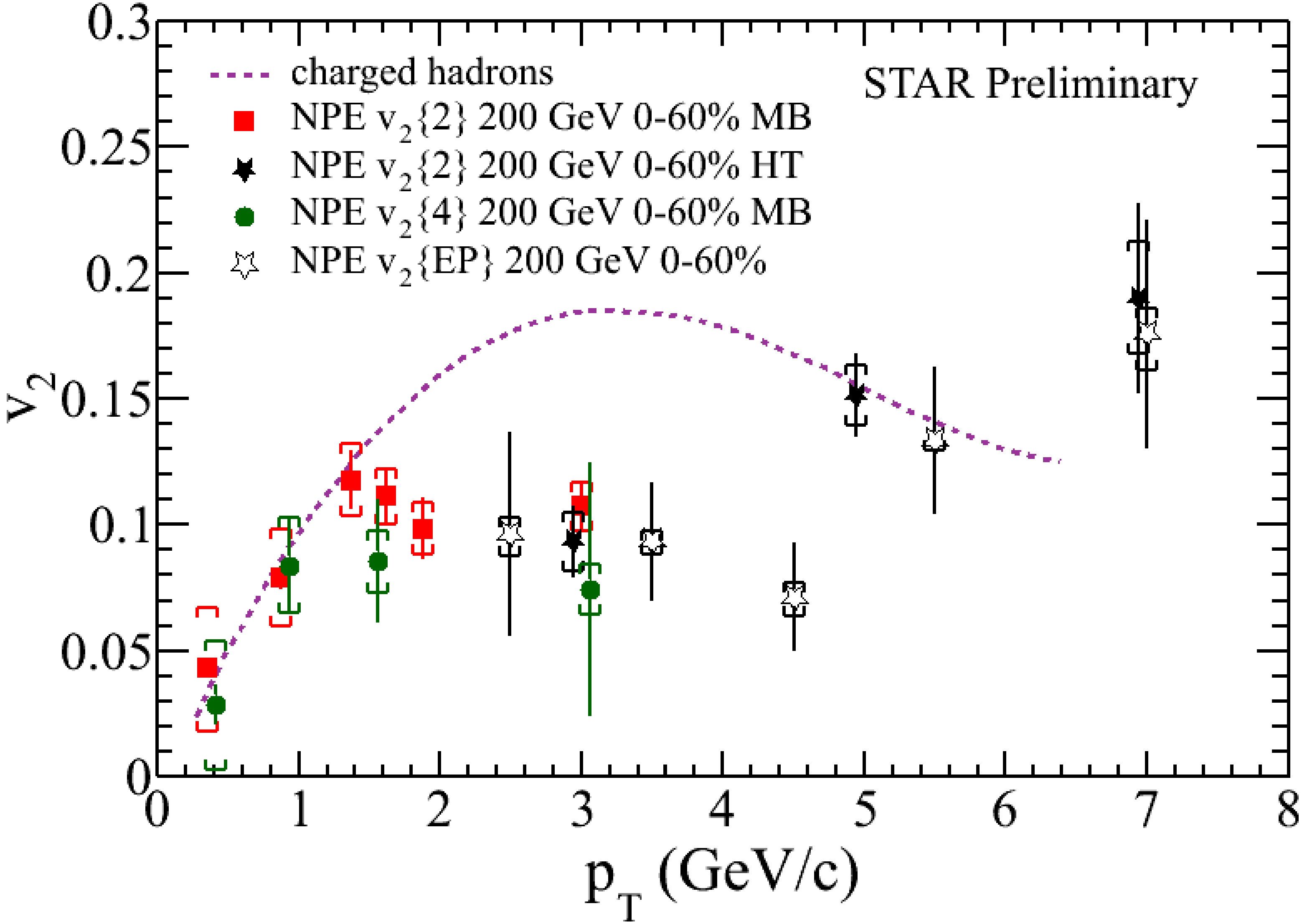
Purity



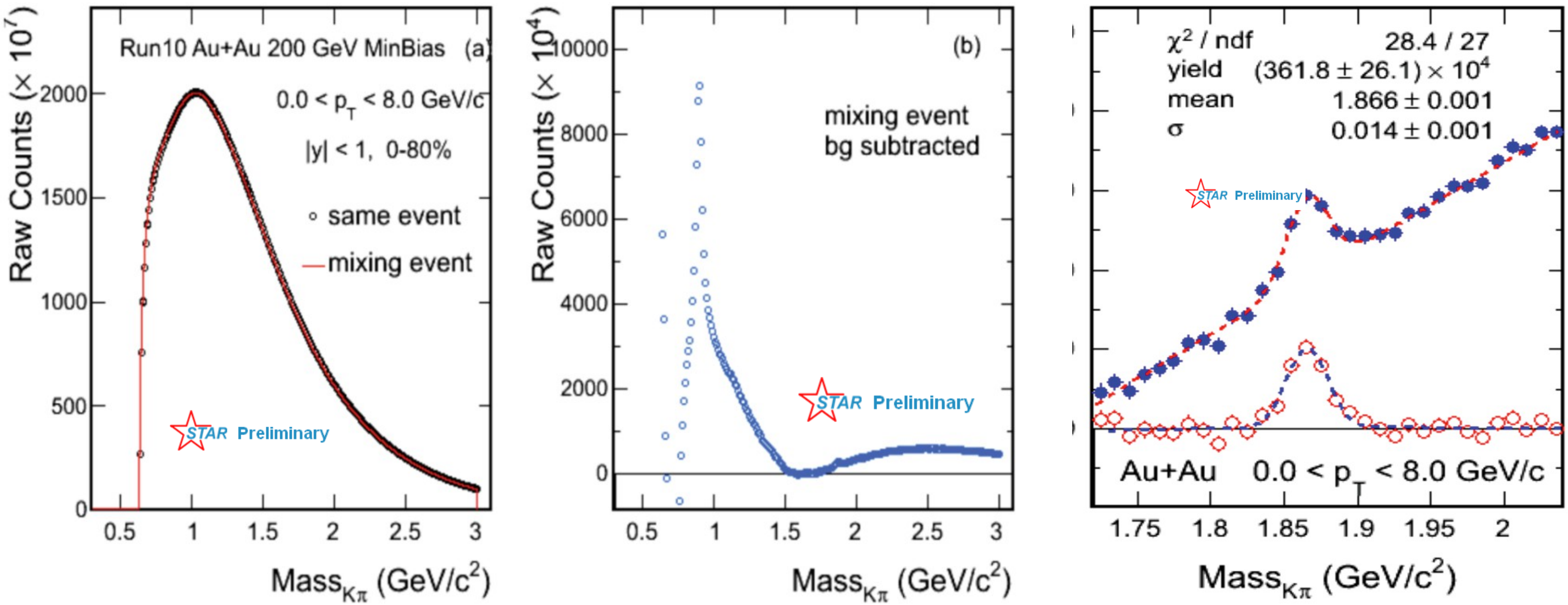
Signal-to-Background ratio



NPE v_2 at 200 GeV



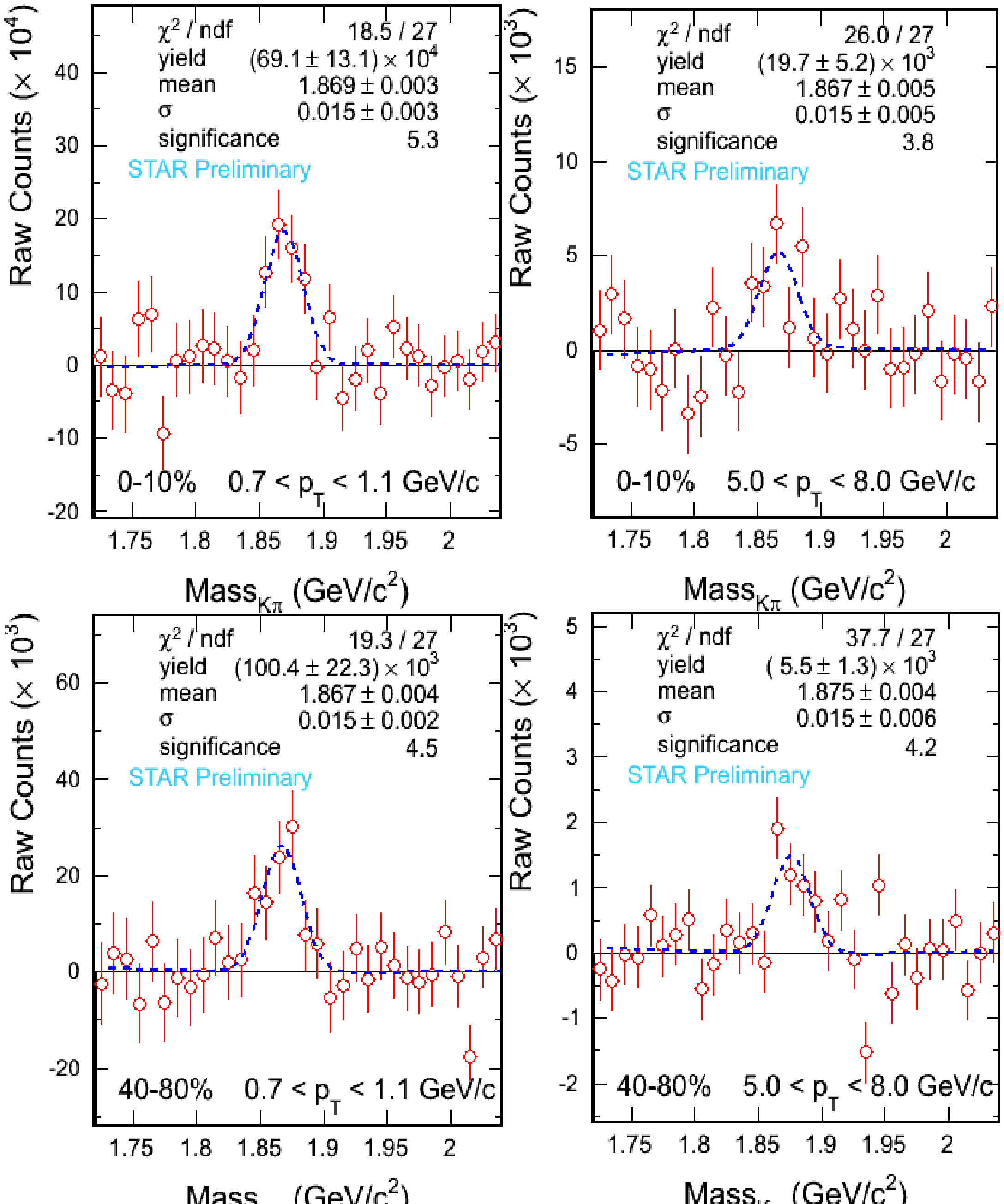
D^0 signal in Au+Au 200 GeV



Combining data from Year2010 & 2011.

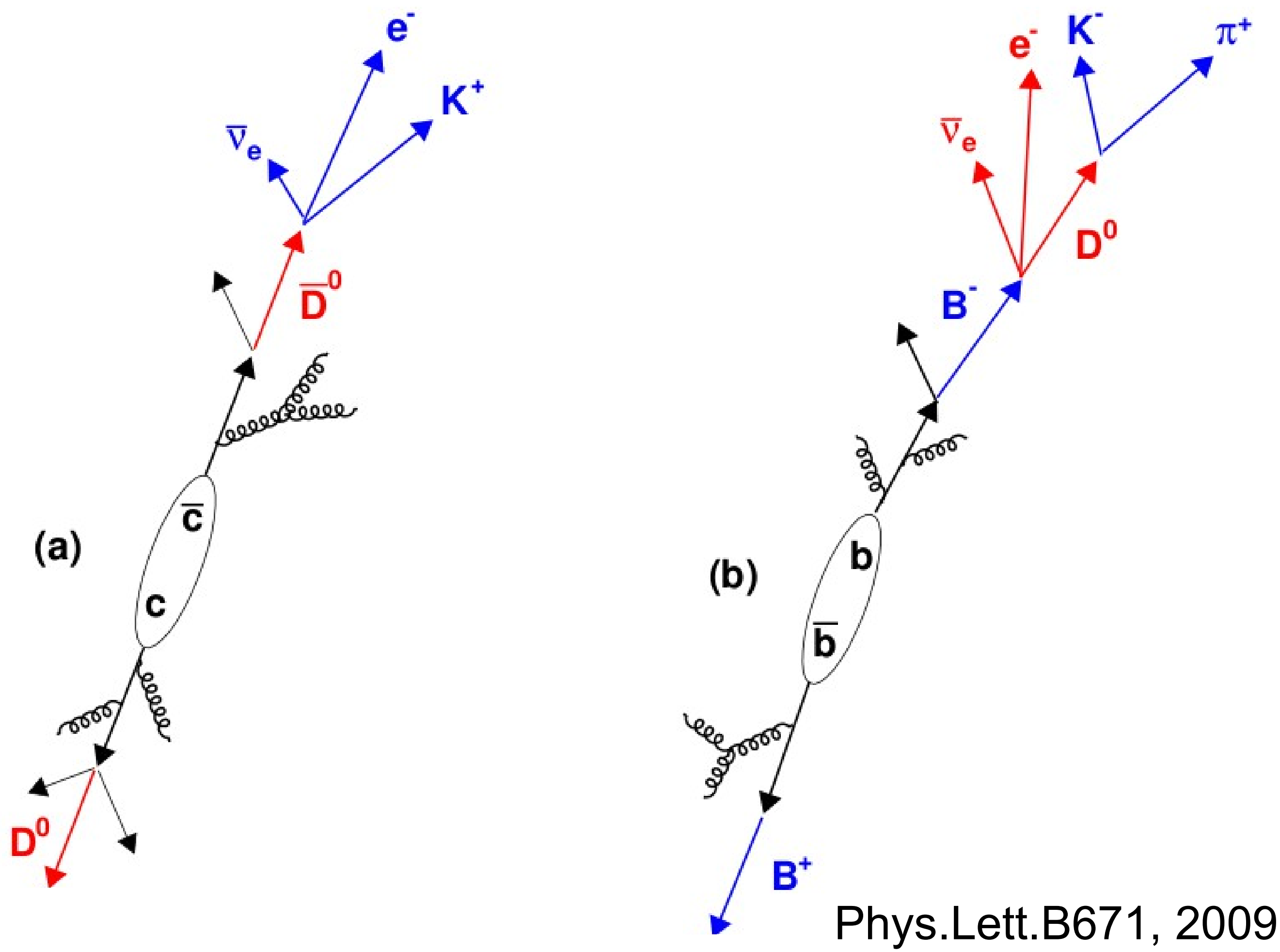
Total: ~ 800 M Min. bias events.

D^0 signal in Au+Au 200 GeV



Non-photonic electrons

Proxies for heavy flavor quarks



Phys.Lett.B671, 2009

Background:

- photonic electrons: $\gamma \rightarrow ee$, $\pi^0 \rightarrow ee\gamma$, $\eta \rightarrow ee\gamma$
- K_{e3} ($K \rightarrow \pi\nu e$)

Photonic electron reconstruction

Statistical approach: low-mass e+e- reconstruction.
Efficiency from simulations

$$N^{\mathrm{NPE}} = N^I p - N^{\mathrm{Pho}} = N^I p - (N^{\mathrm{UL}} - N^{\mathrm{LS}})/\epsilon$$