3rd International Conference on New Frontiers in Physics
Κολυμπάρι Χανιά, Greece

Open Heavy Flavor Measurements at STAR

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Heavy Flavor Physics at RHIC

- ★ Topics to Research
  - ★ properties of the strongly-coupled system produced at RHIC
  - ★ weak or strong interactions of heavy quarks with QCD matter
  - ★ detailed mechanism of heavy quark energy loss

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- ★ Heavy Quarks c, b
  - ★ produced in initial hard processes
  - ★ probe the strongly interacting Quark-Gluon Plasma
  - ★ modified spectrum: access to energy loss
  - ★ flow: sensitive to dynamics, thermalization

Outline

sQGP signatures and properties using

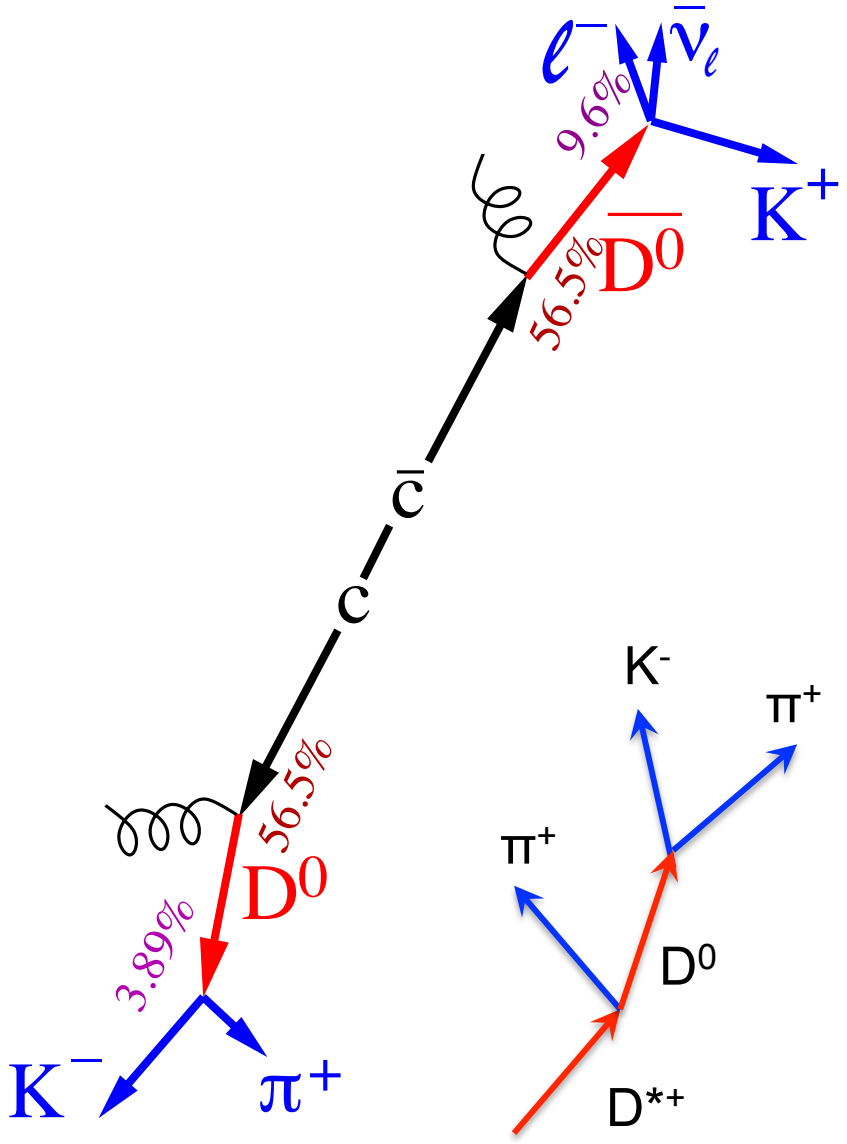
★ open charm mesons

- ➡ p+p 200 and 500 GeV
- ➡ Au+Au 200 GeV
- ➡ U+U 193 GeV

★ non-photonic electrons (NPE)

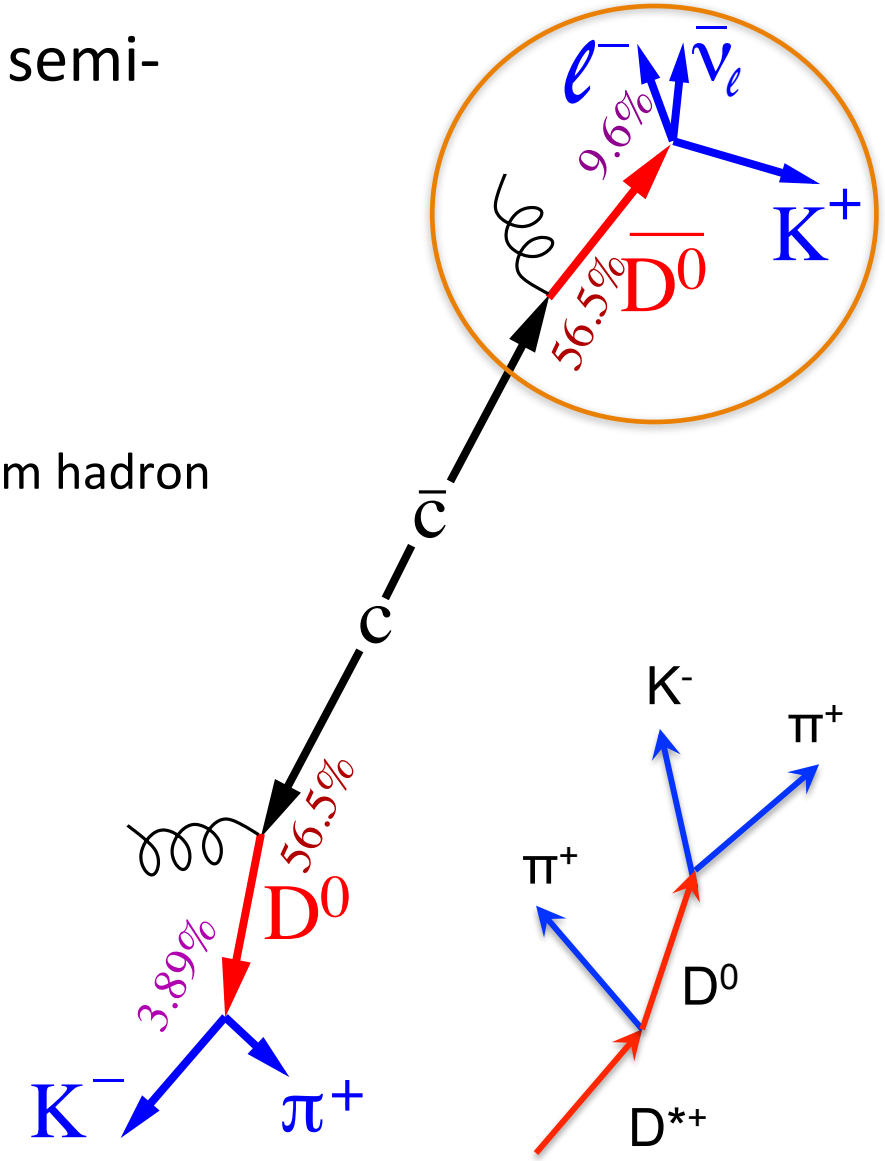
- ➡ Au+Au 39, 62.4 and 200 GeV

How to Measure Charm Quarks



How to Measure Charm Quarks

- ★ Indirect measurements through semi-leptonic decay (NPE)
  - ☺ can be triggered easily (high p_T)
  - ☺ higher Branching Ratio
  - ☹ can't reconstruct invariant mass
  - ☹ contribution from both charm and bottom hadron decays



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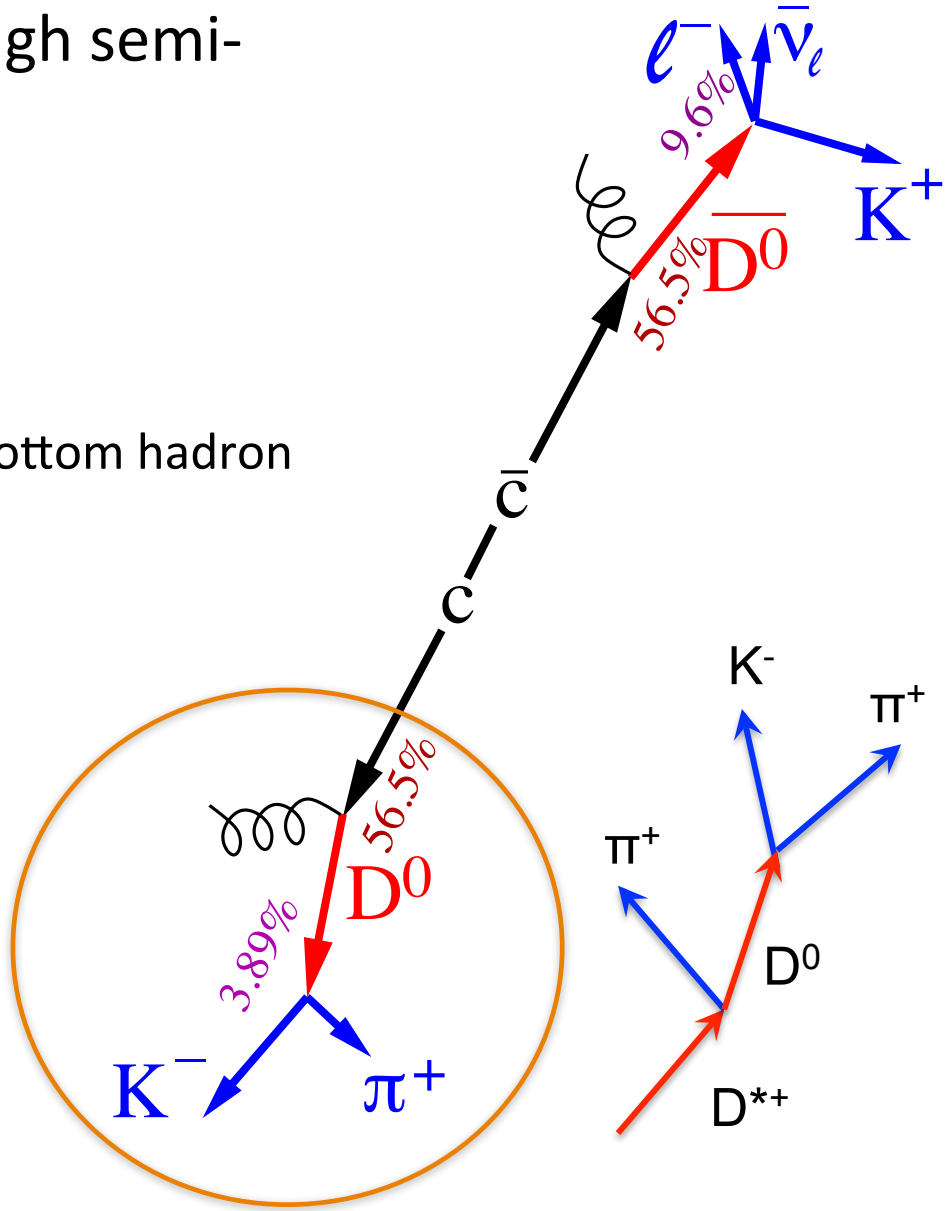
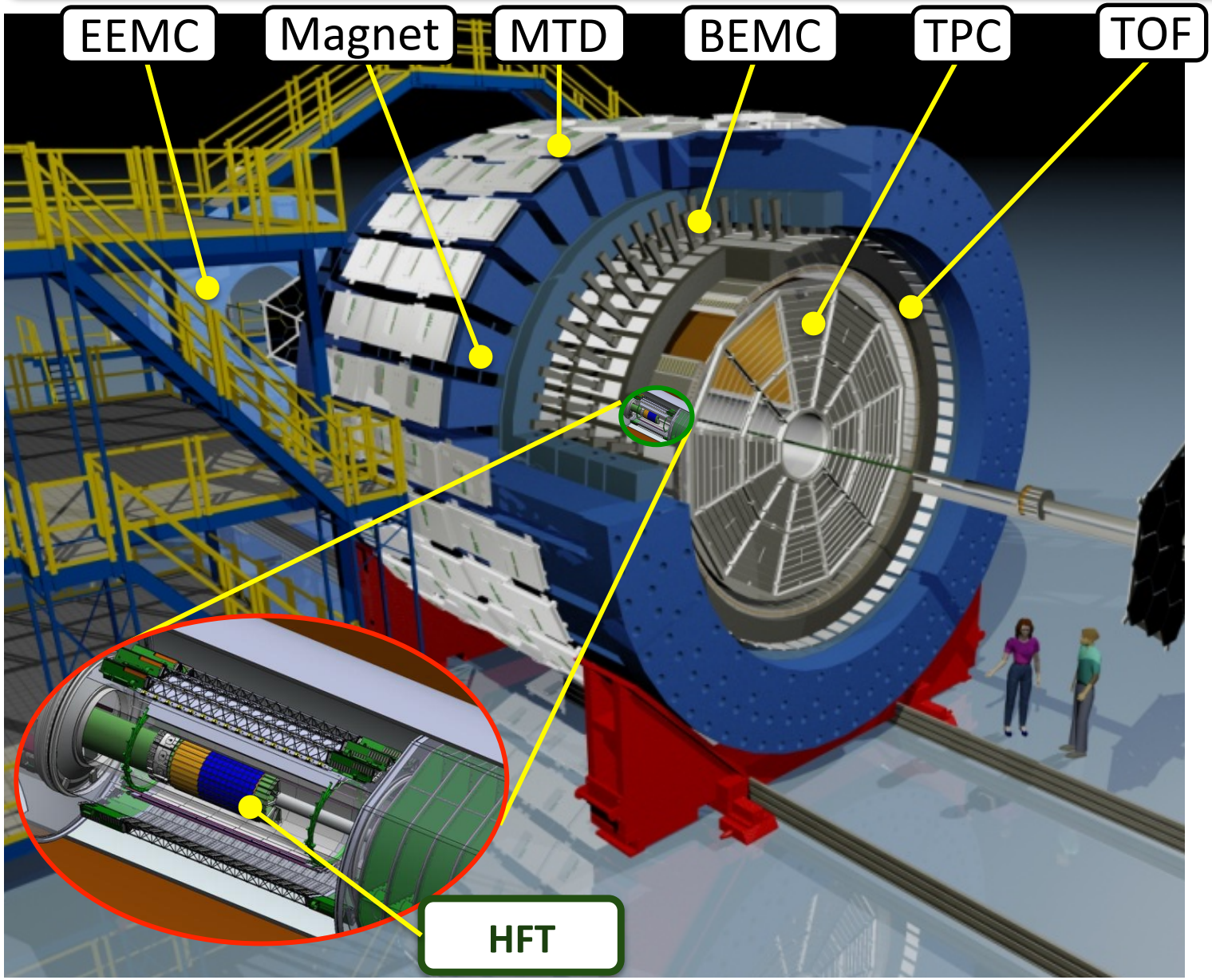
- ★ Indirect measurements through semi-leptonic decay (NPE)
  - ☺ can be triggered easily (high p_T)
  - ☺ higher Branching Ratio
  - ☹ can't reconstruct invariant mass
  - ☹ contribution from both charm and bottom hadron decays
- ★ Direct reconstruction
  - ☺ can reconstruct invariant mass
  - ☺ STAR has ability to collect large amount of data
  - ☹ smaller Branching Ratio
  - ☹ large combinatorial background (until 2014)



The STAR Detector



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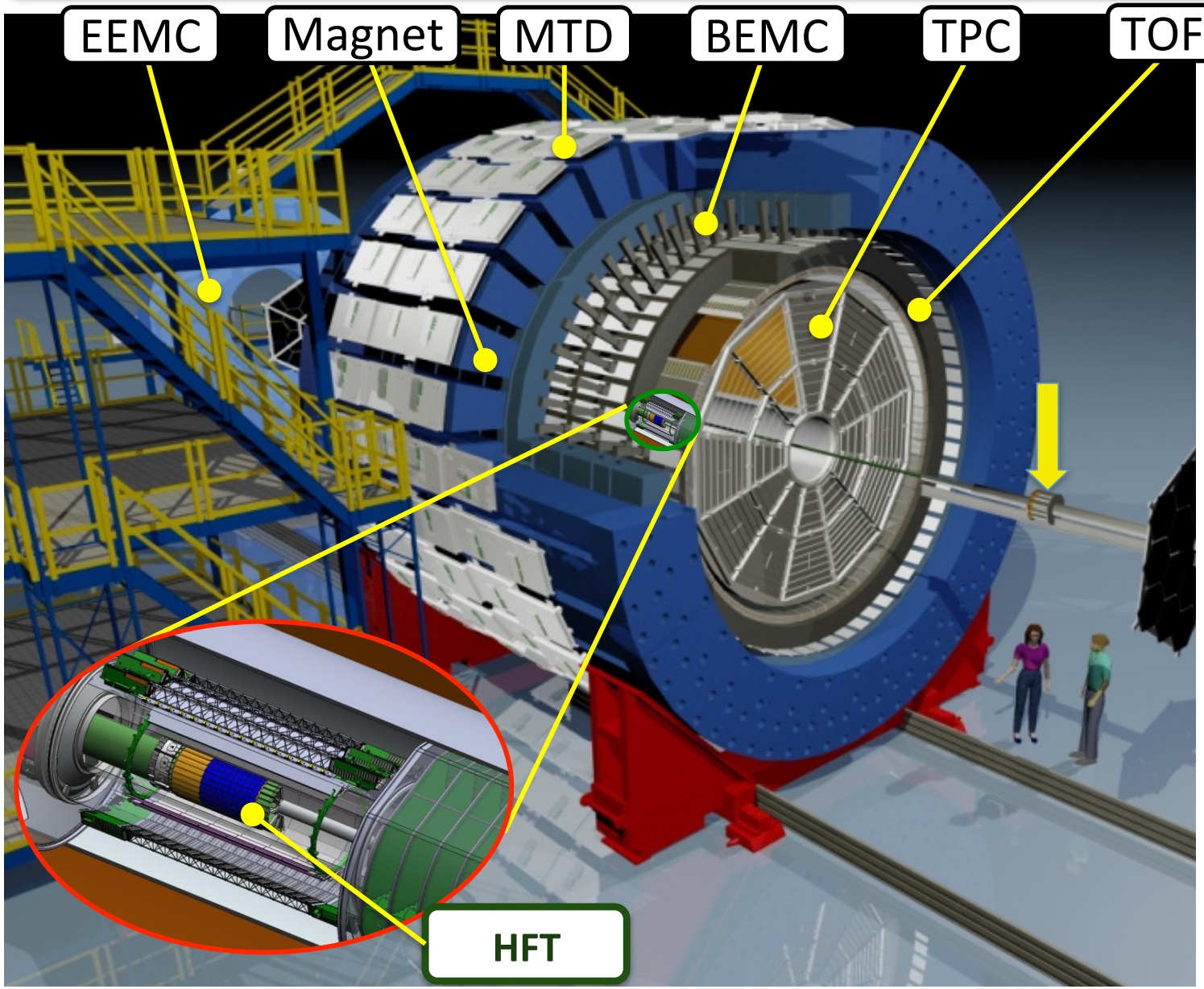

★ **VPD: minimum bias trigger**

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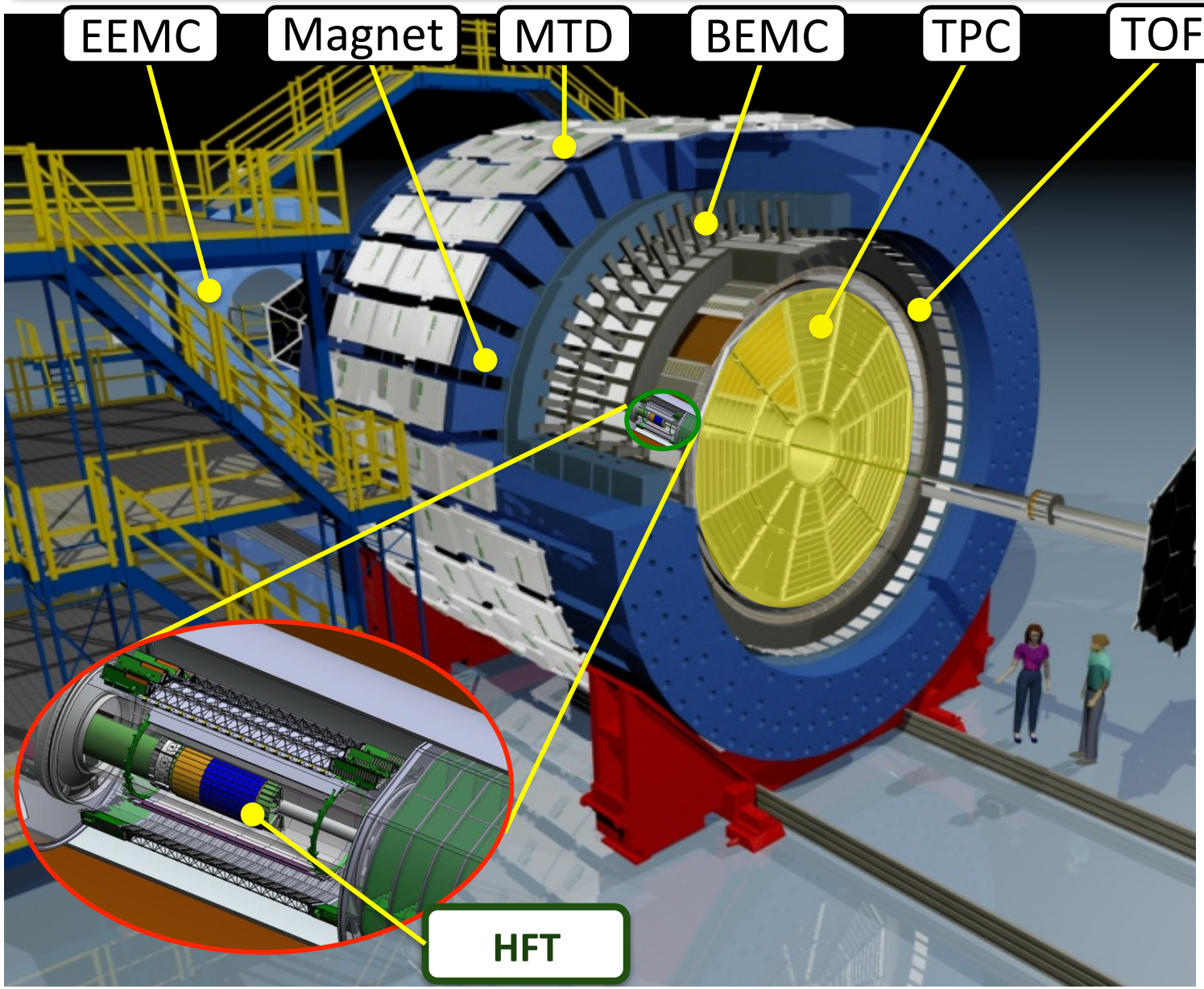

- ★ **VPD: minimum bias trigger**

- ★ **TPC: particle identification, momentum**

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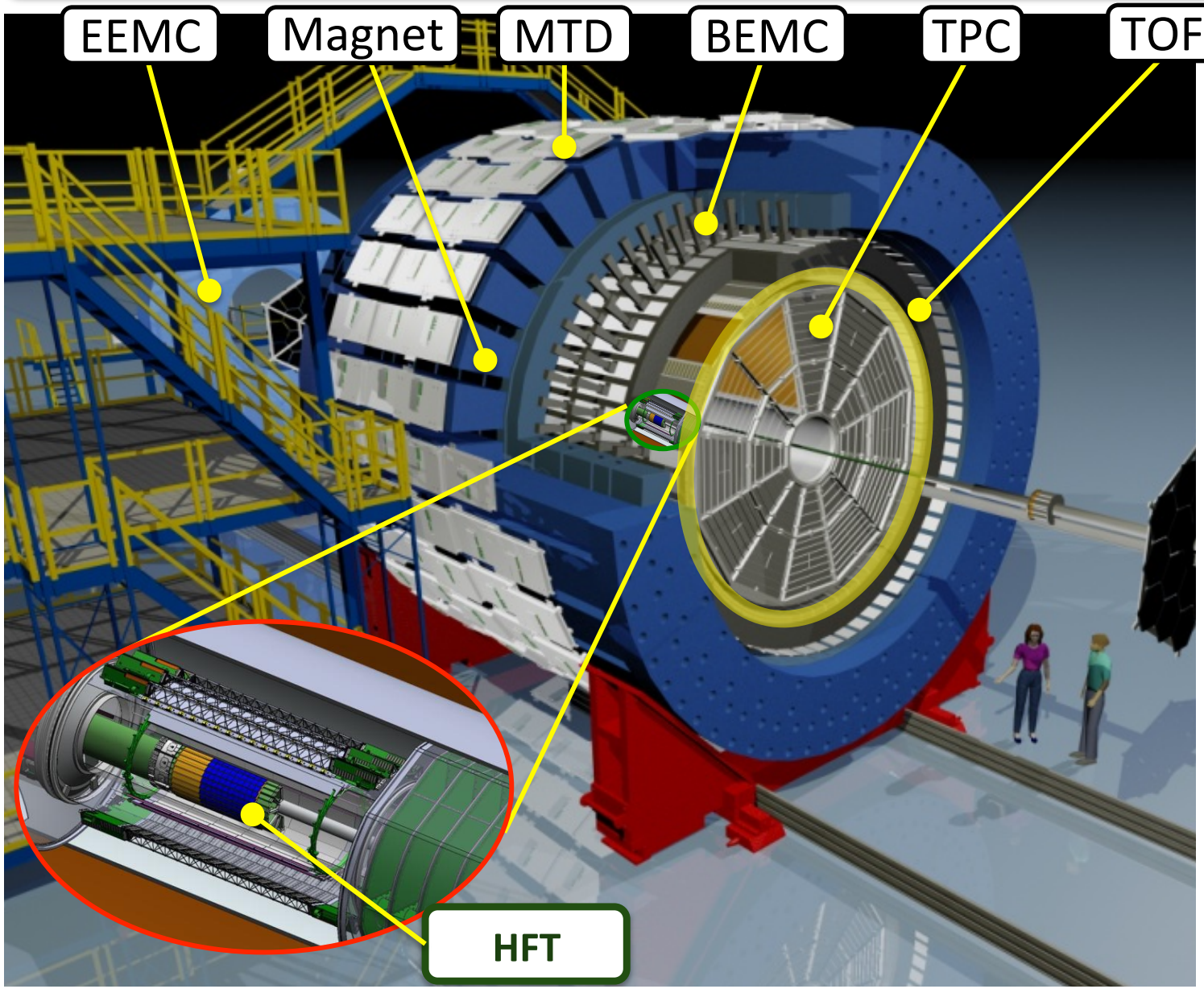

- ★ **VPD:** minimum bias trigger
- ★ **TPC:** particle identification, momentum
- ★ **TOF:** particle identification (time resolution 110 ps in p+p, 87 ps in Au+Au)

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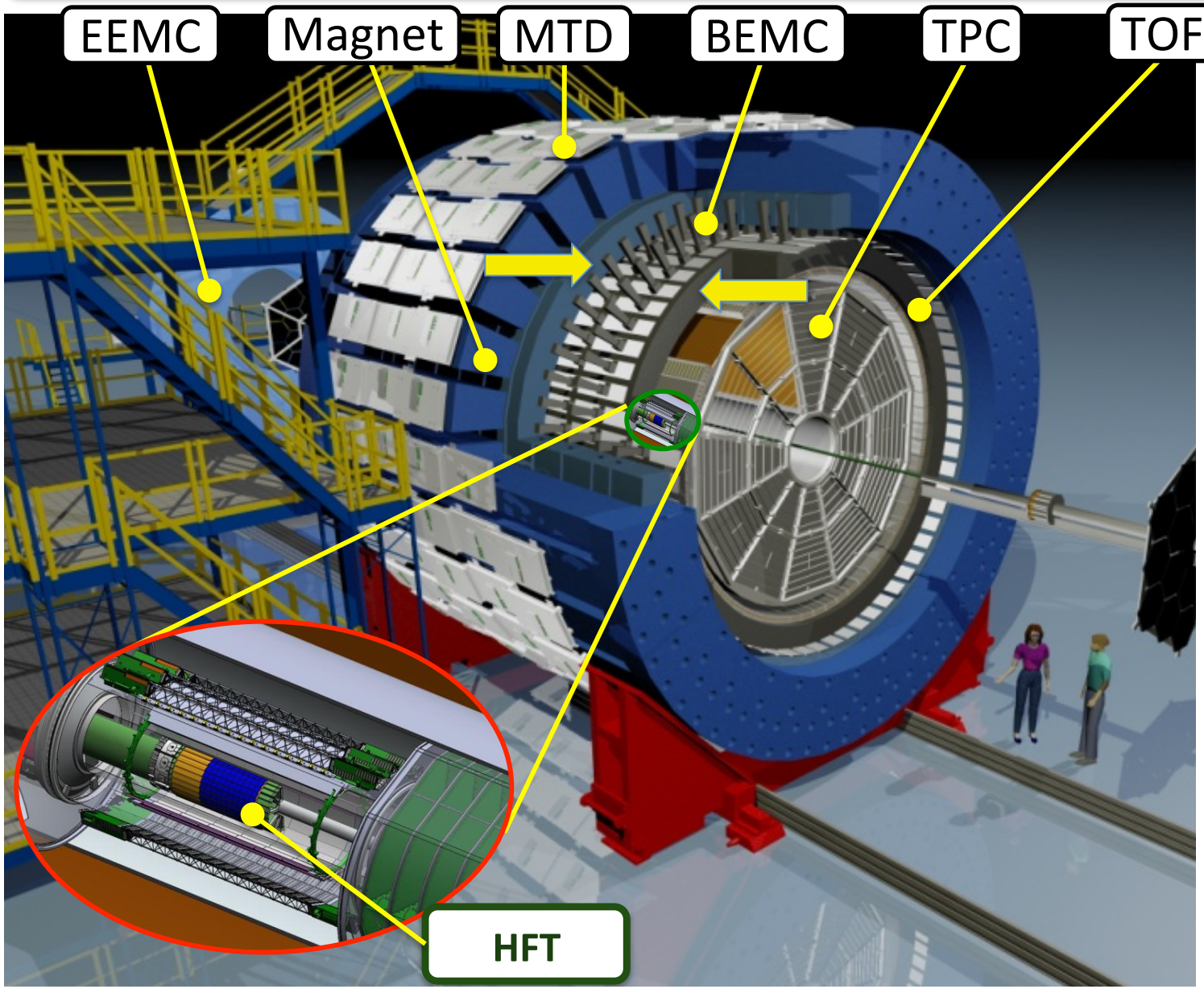
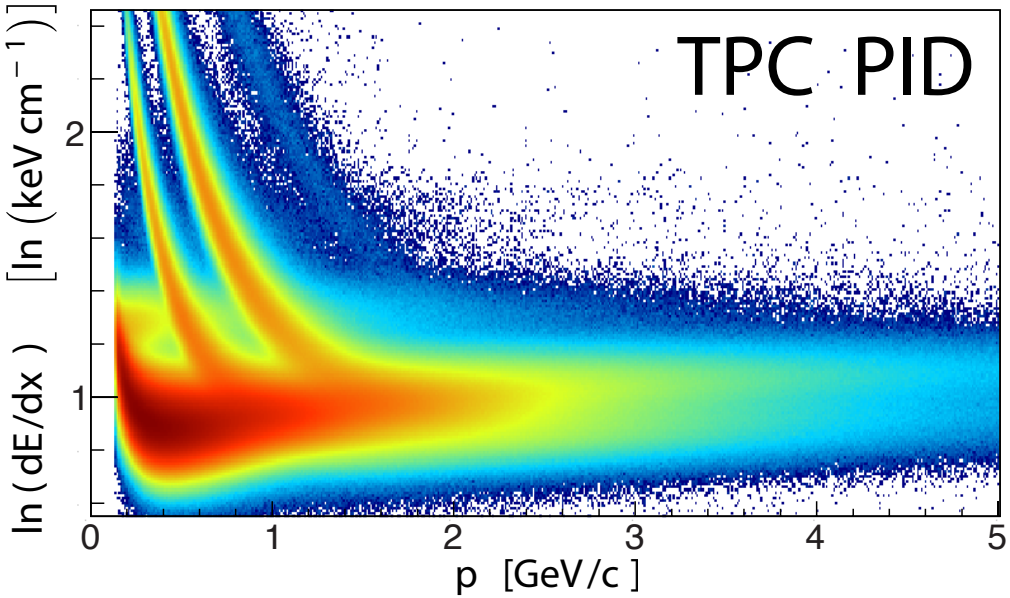
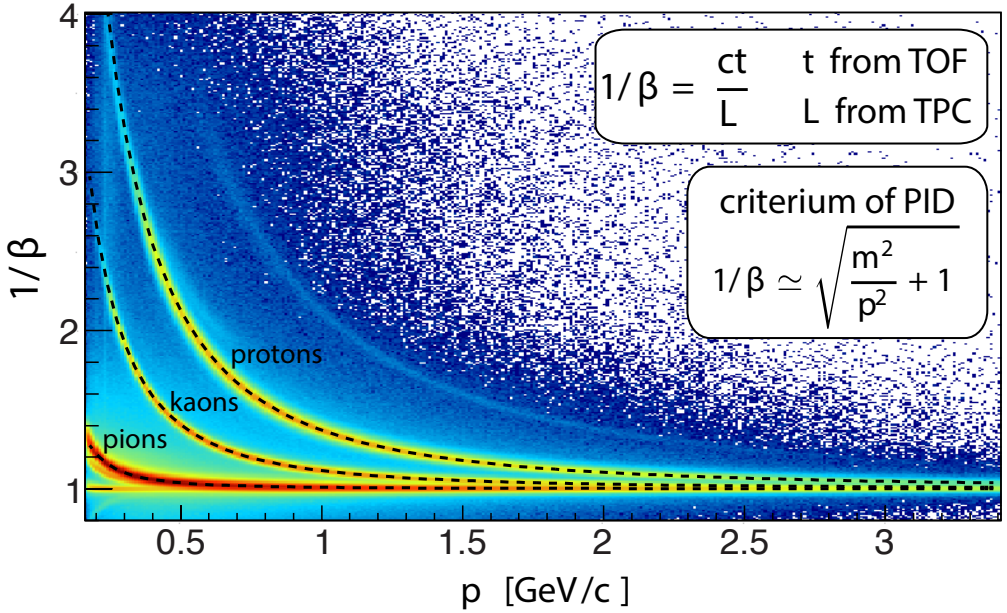


- ★ **VPD: minimum bias trigger**
- ★ **TPC: particle identification, momentum**
- ★ **TOF: particle identification** (time resolution 110 ps in p+p, 87 ps in Au+Au)
- ★ **BEMC: high-energy trigger, electron identification**

Daughter Particle Identification





TOF provides clean sample of kaons with momentum up to ~1.6 GeV/c

kaon - pion separation better by TPC than by TOF for track with momentum above ~2.5 GeV/c

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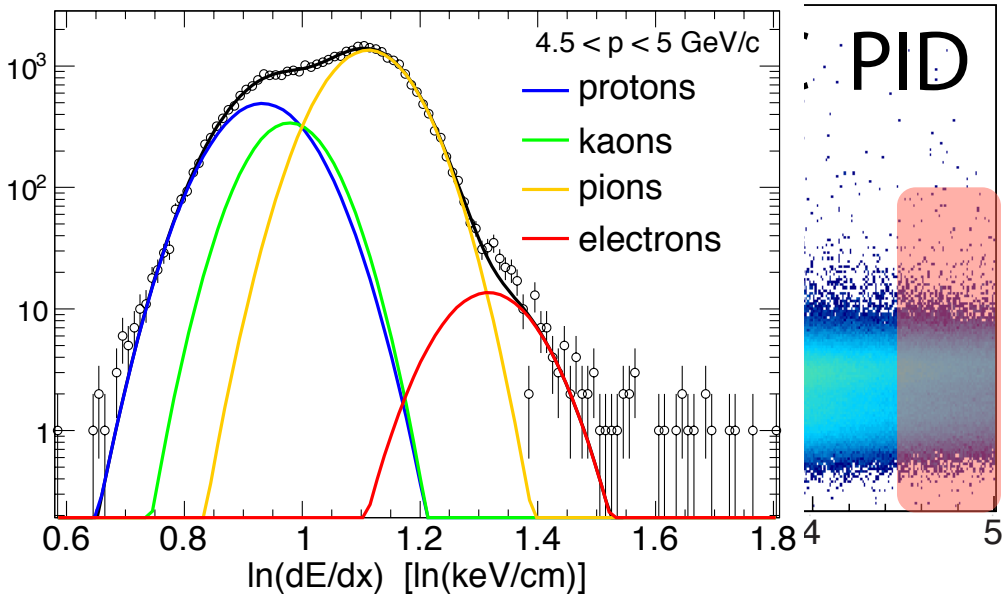

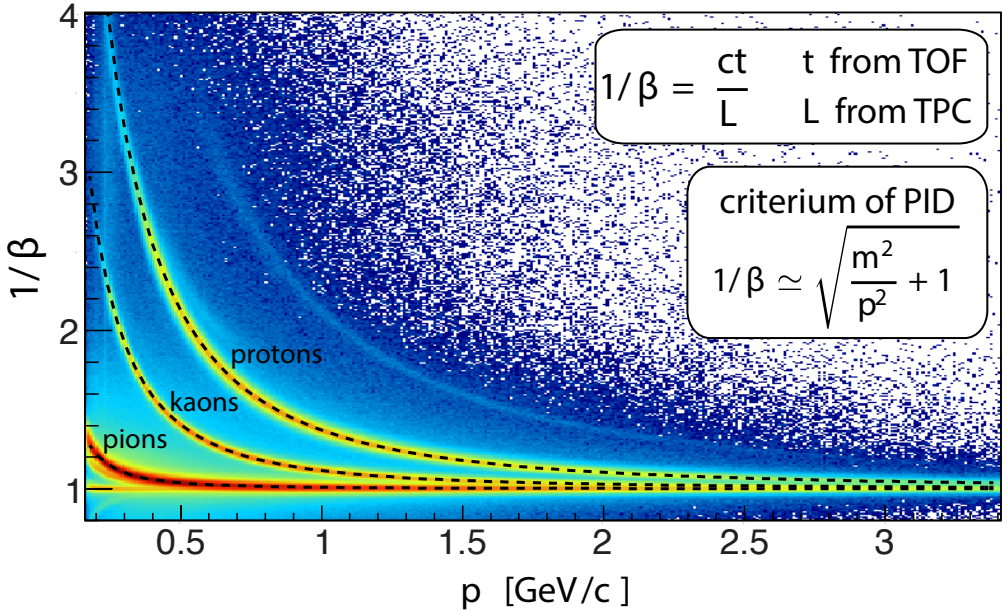

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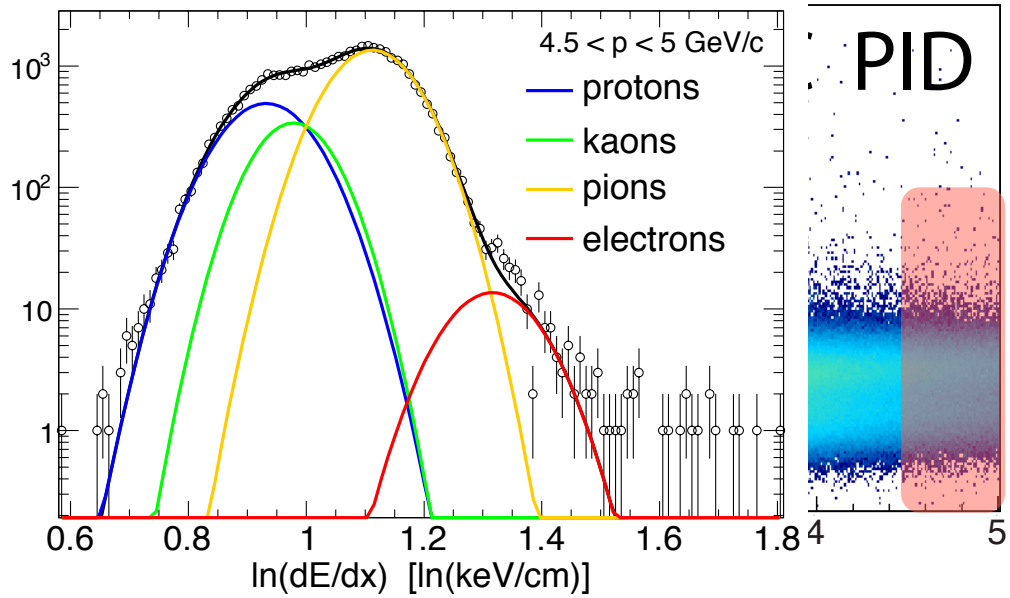
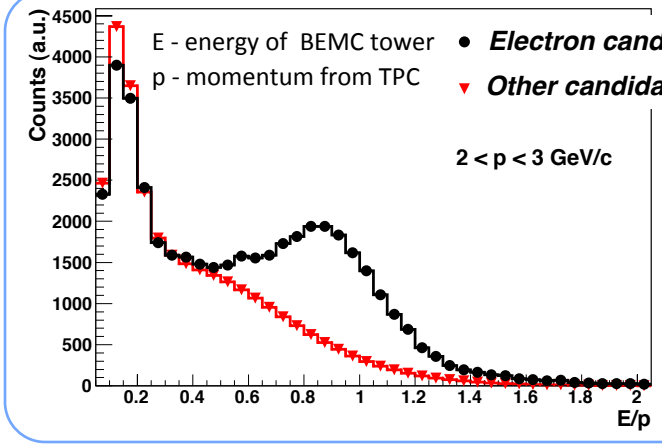
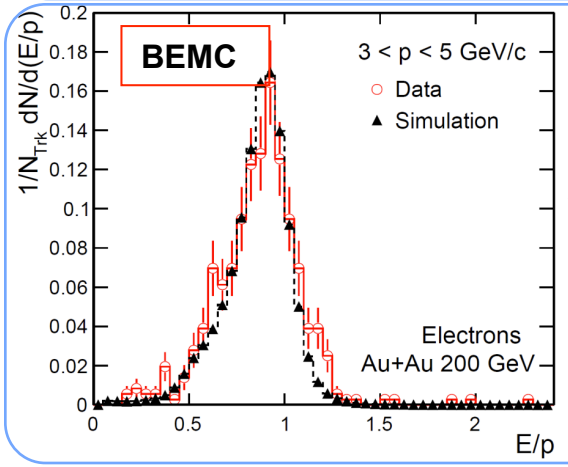


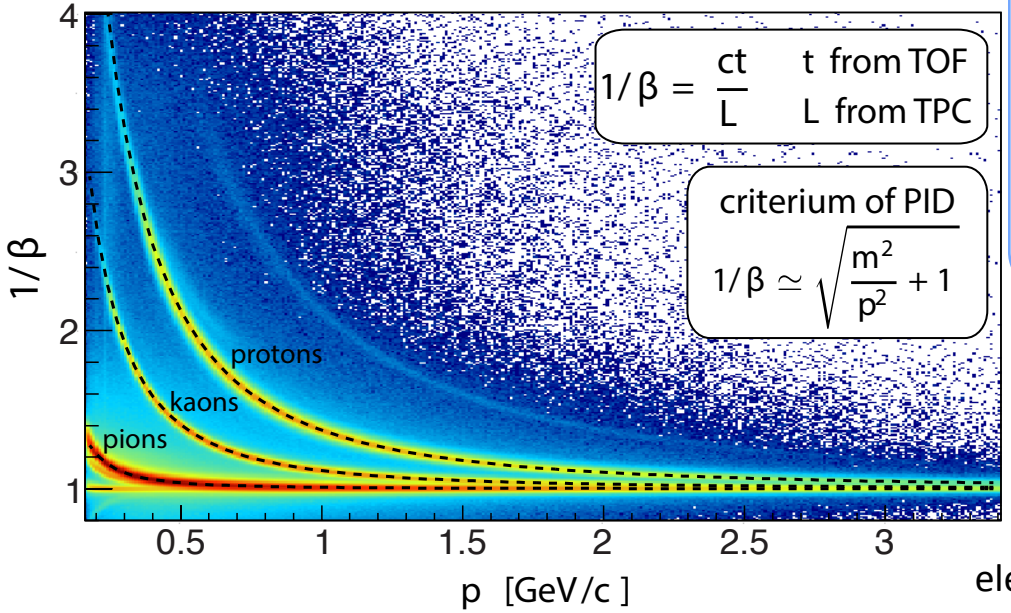




Photonic electron candidates

$M_{e^+e^-} < 0.24\ \mathrm{GeV}/c^2$

E - energy of BEMC cluster
p - momentum from TPC



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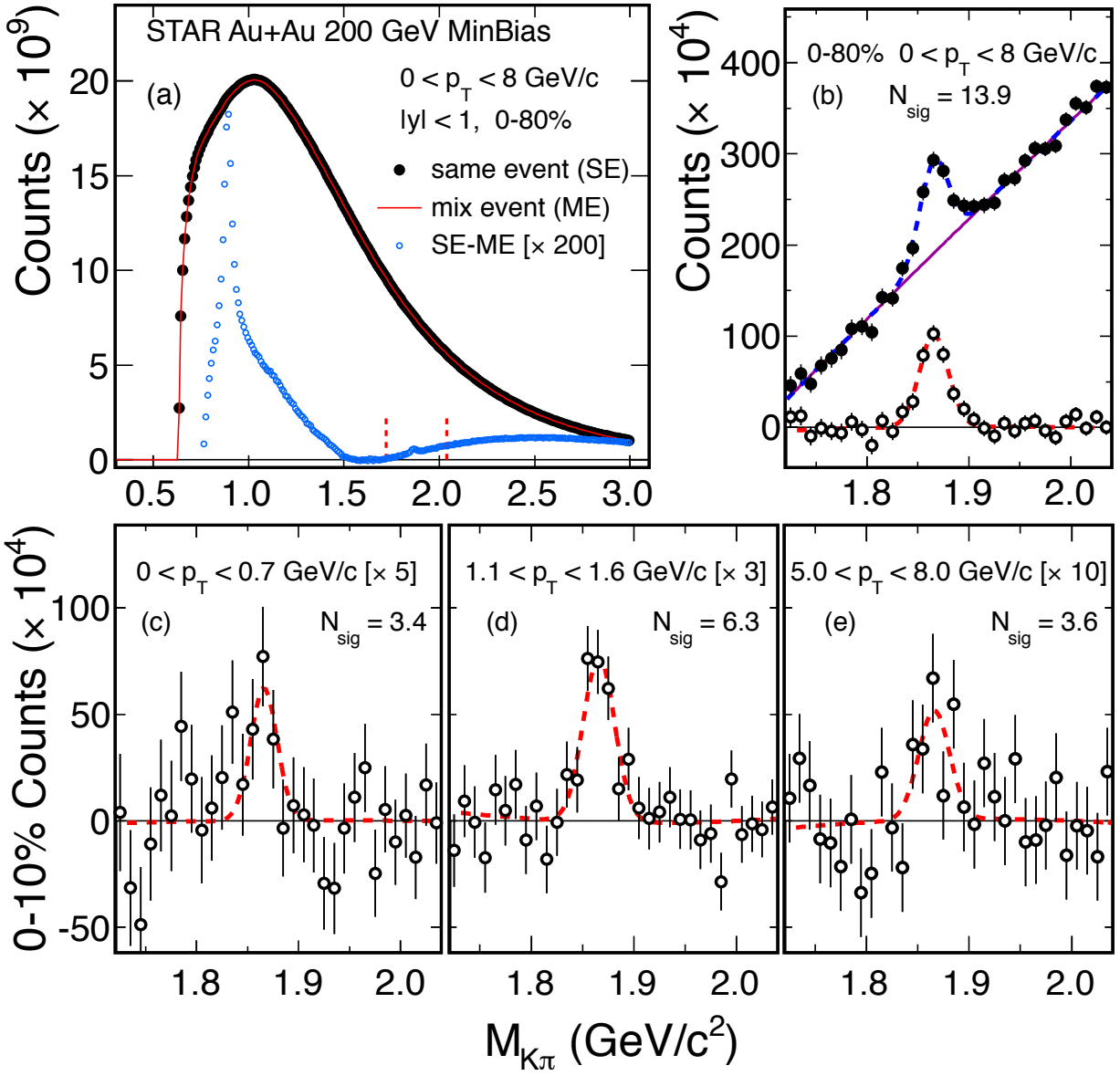
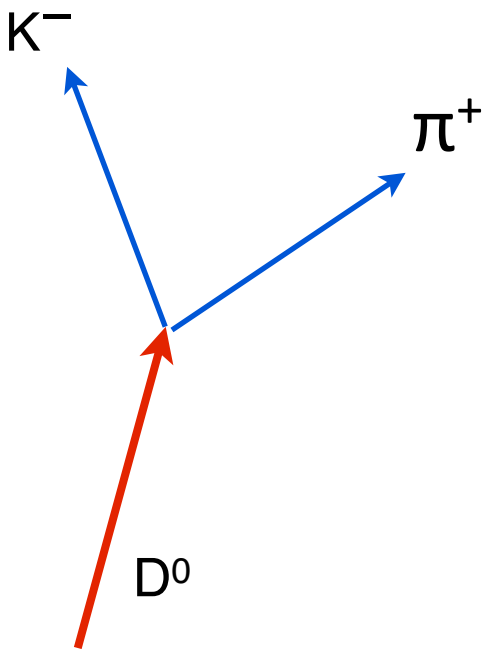
electron/hadron separation with BEMC for p > 2 GeV/c

D^0 Meson Reconstruction



arXiv:1404.6185
submitted to PRL



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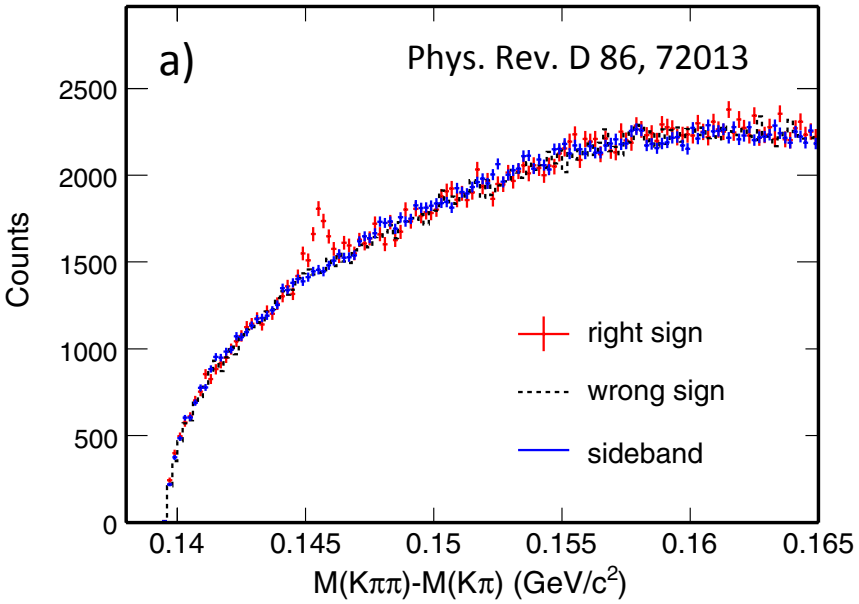

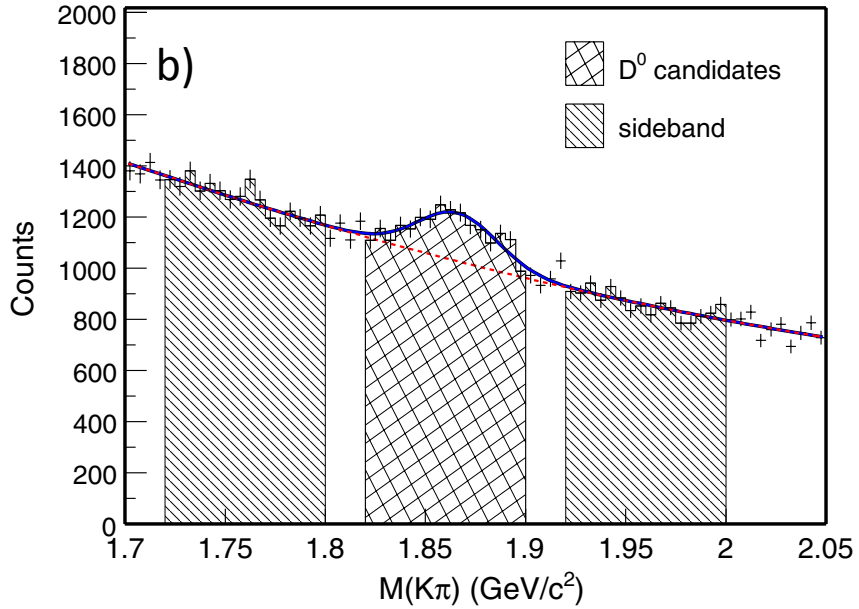

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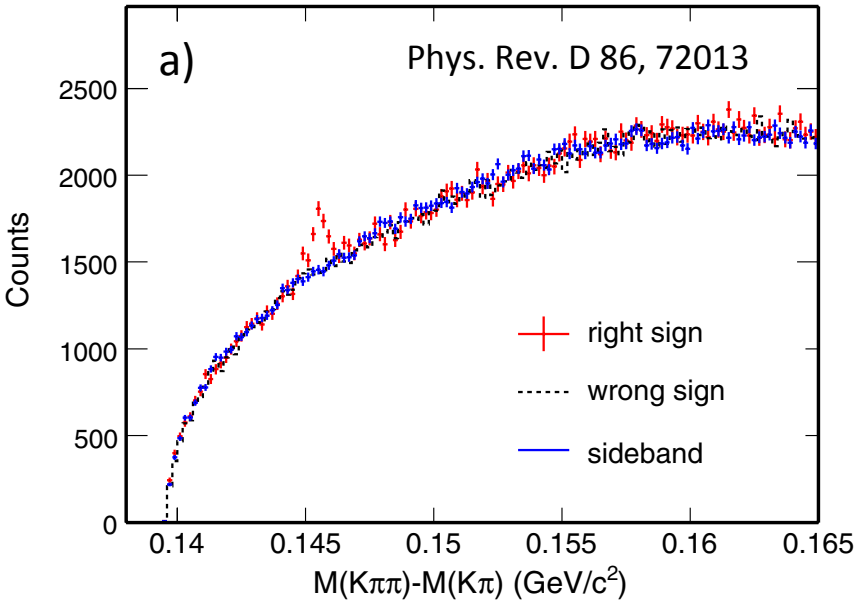

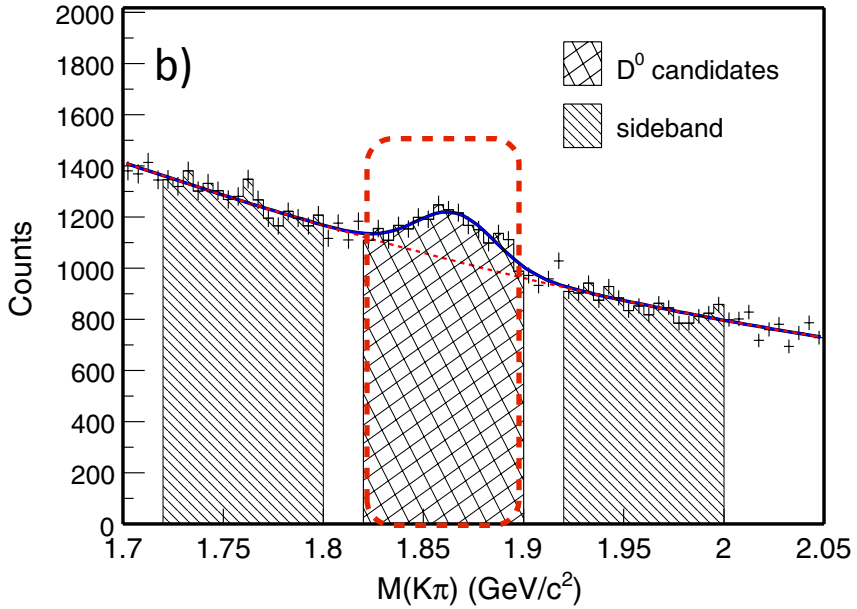

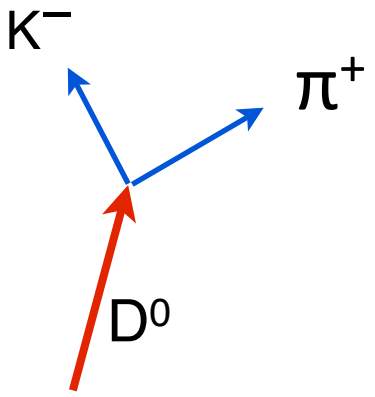

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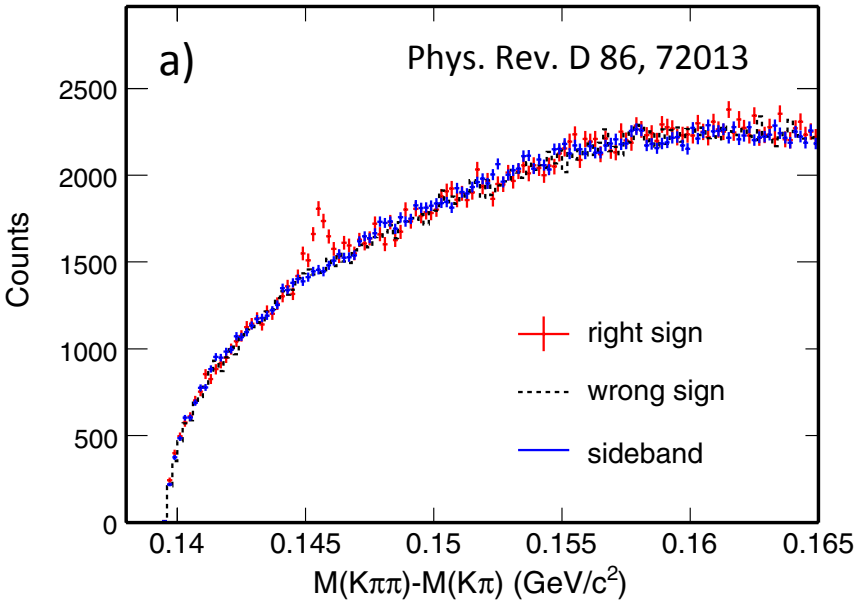

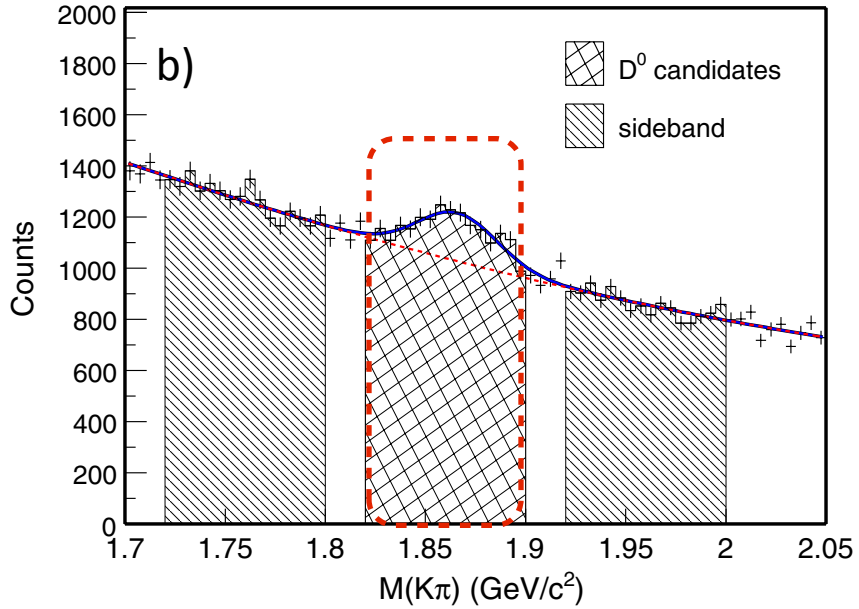

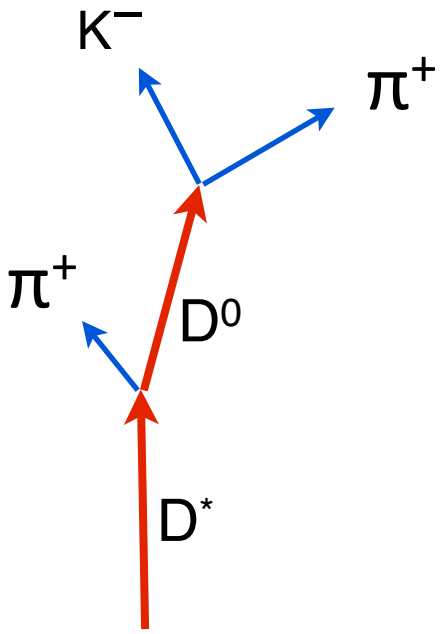

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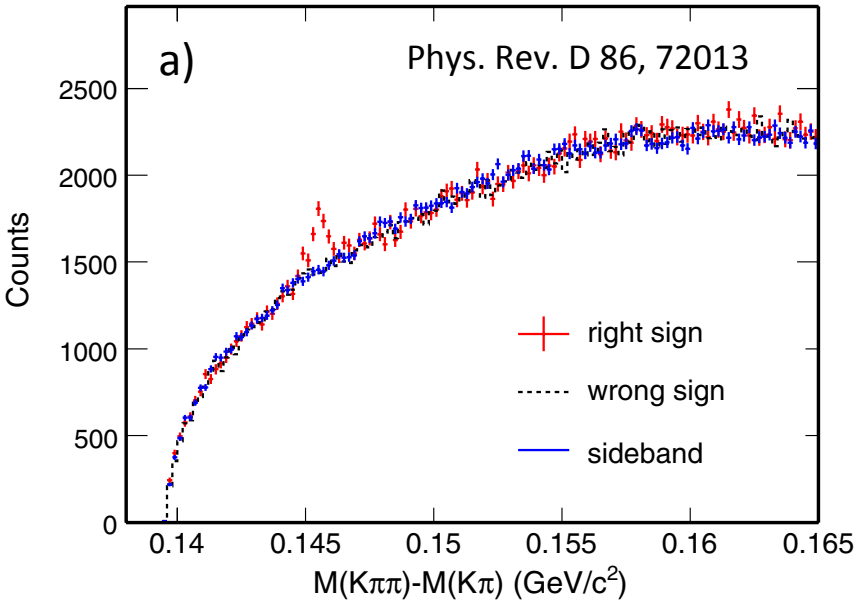
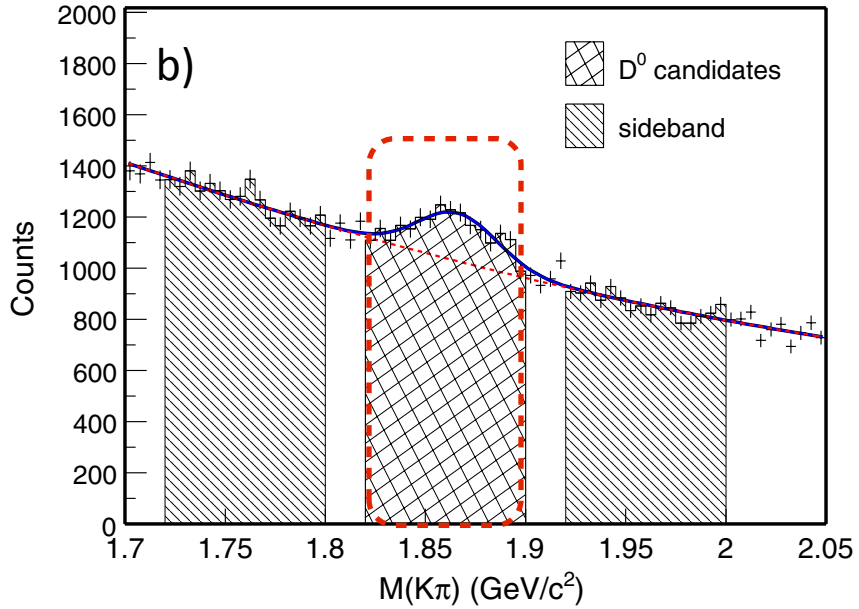
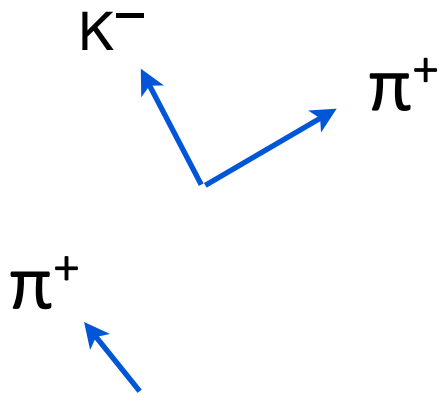




$$M\left(\uparrow_{D^*}\right) - M\left(\nearrow_{D^0}\right)$$



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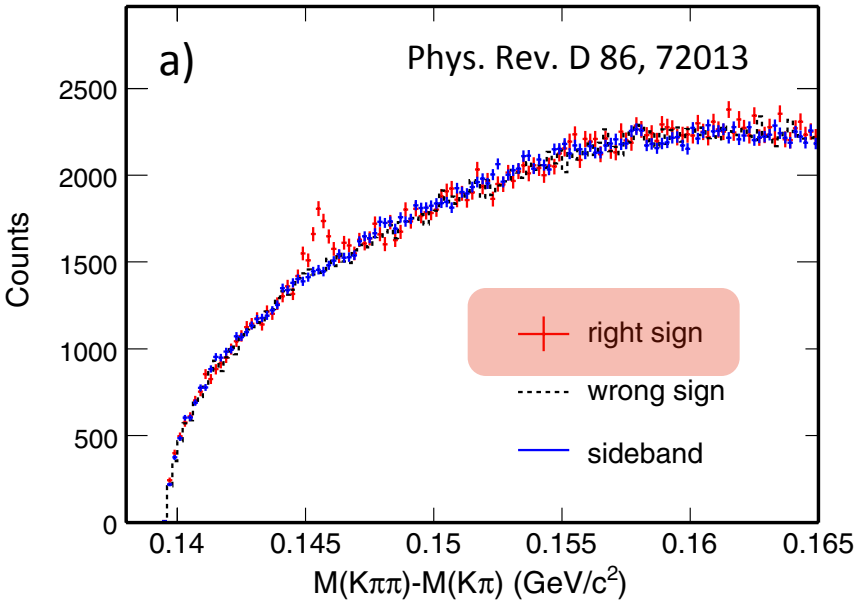

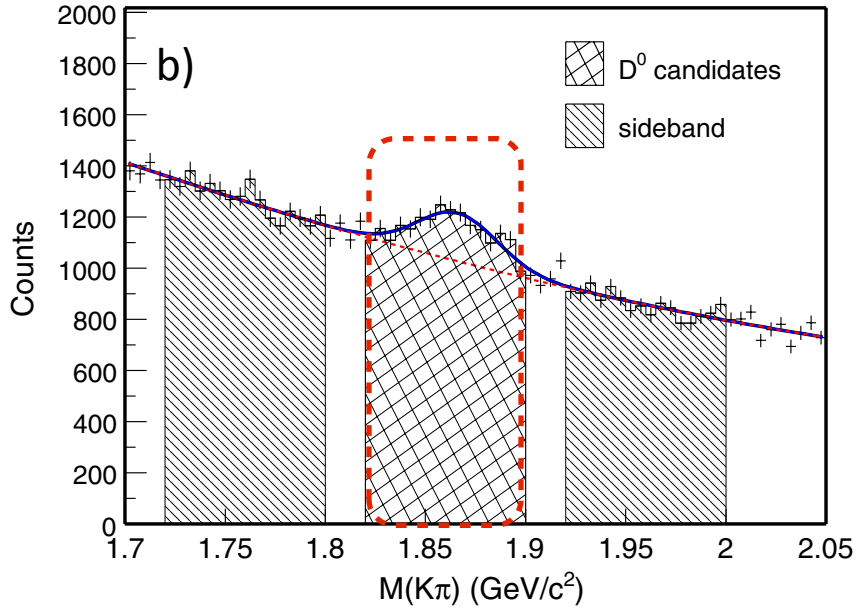

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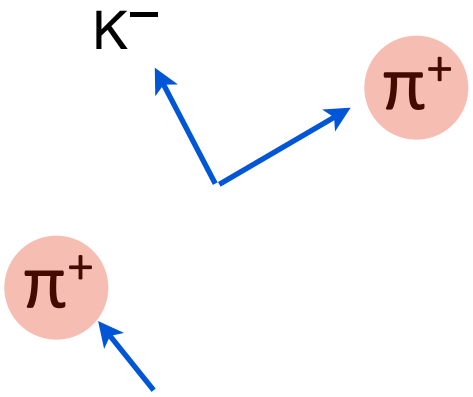

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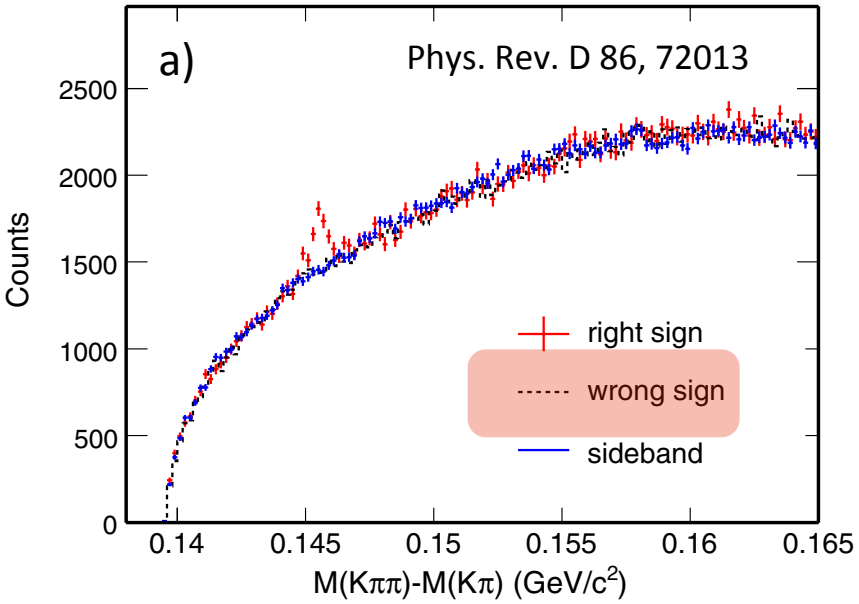

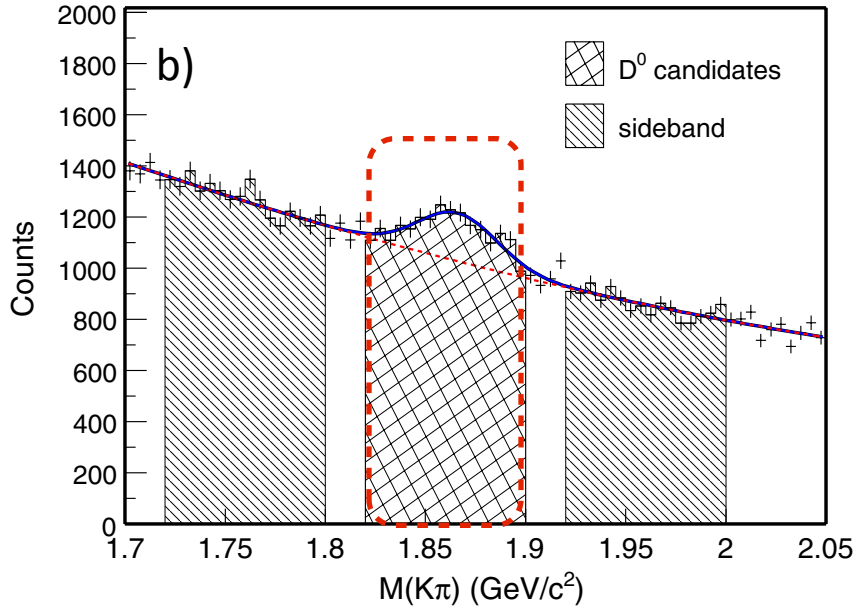

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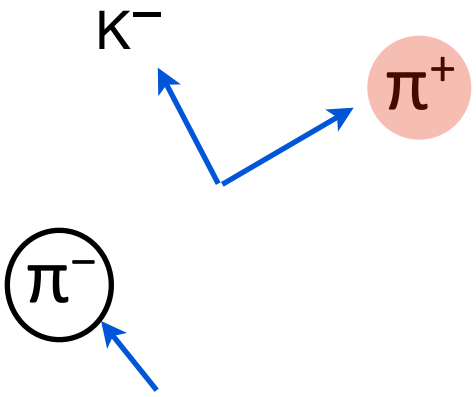

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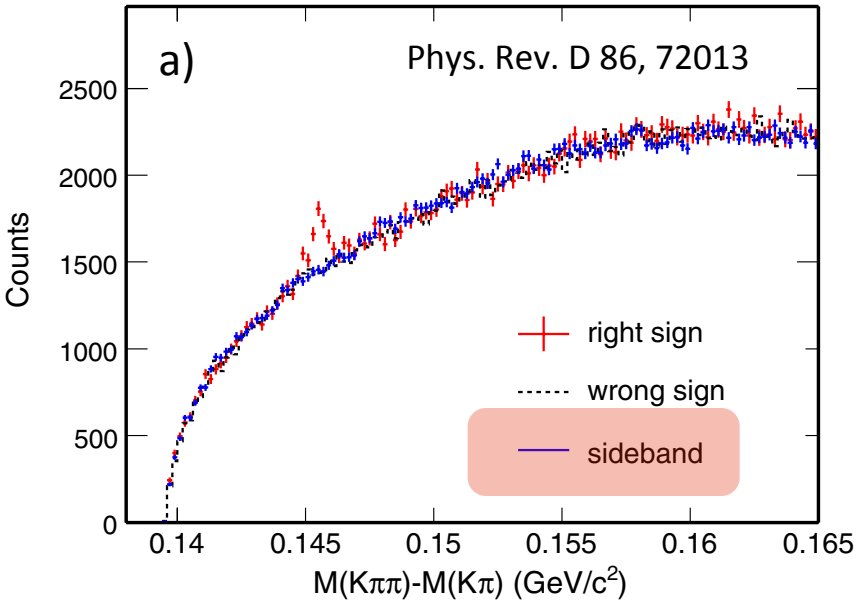

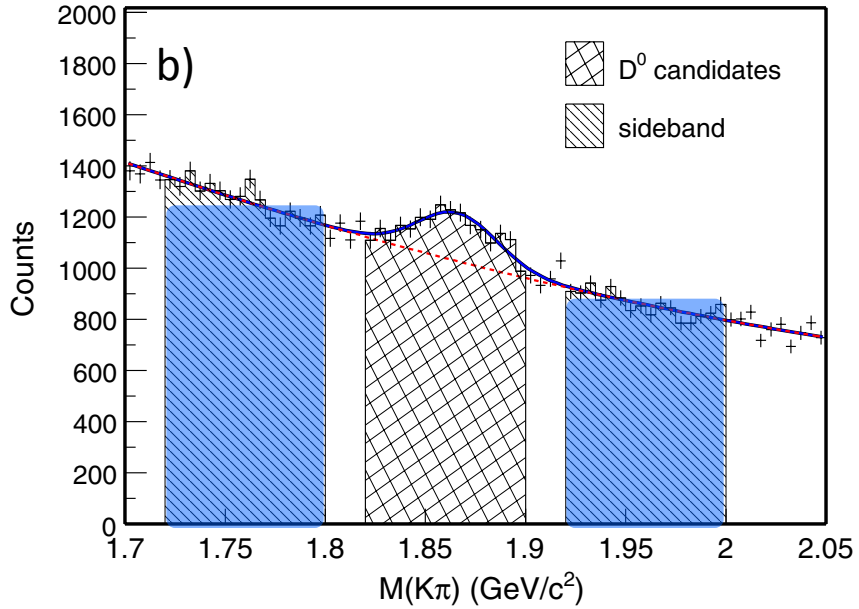

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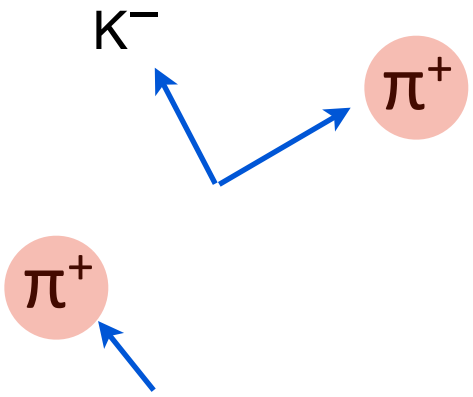

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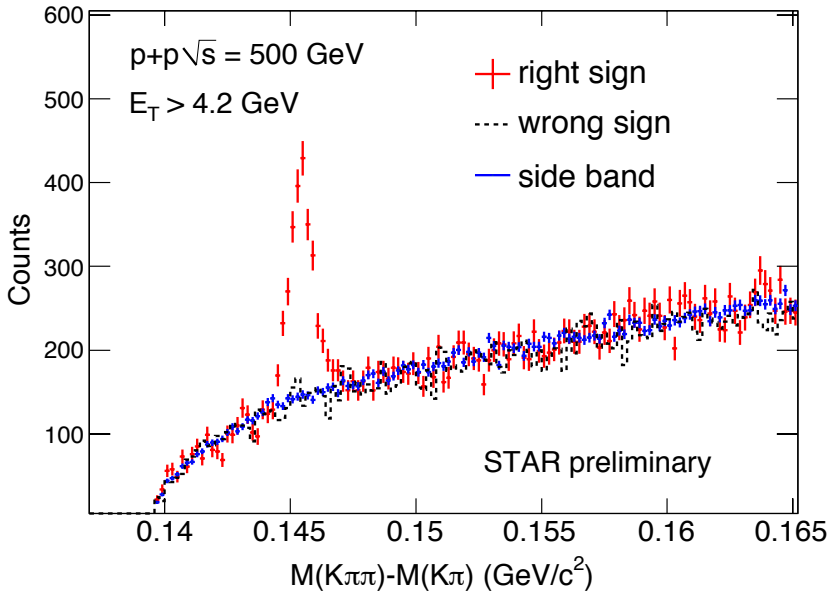

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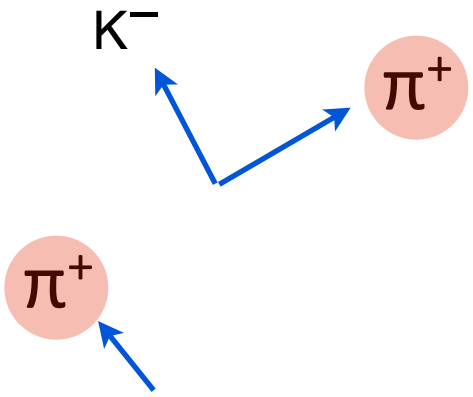
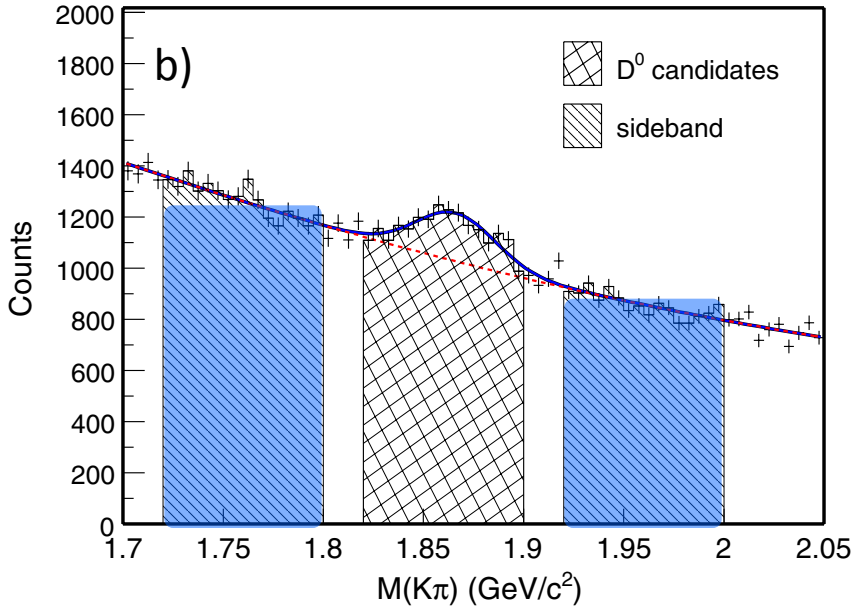
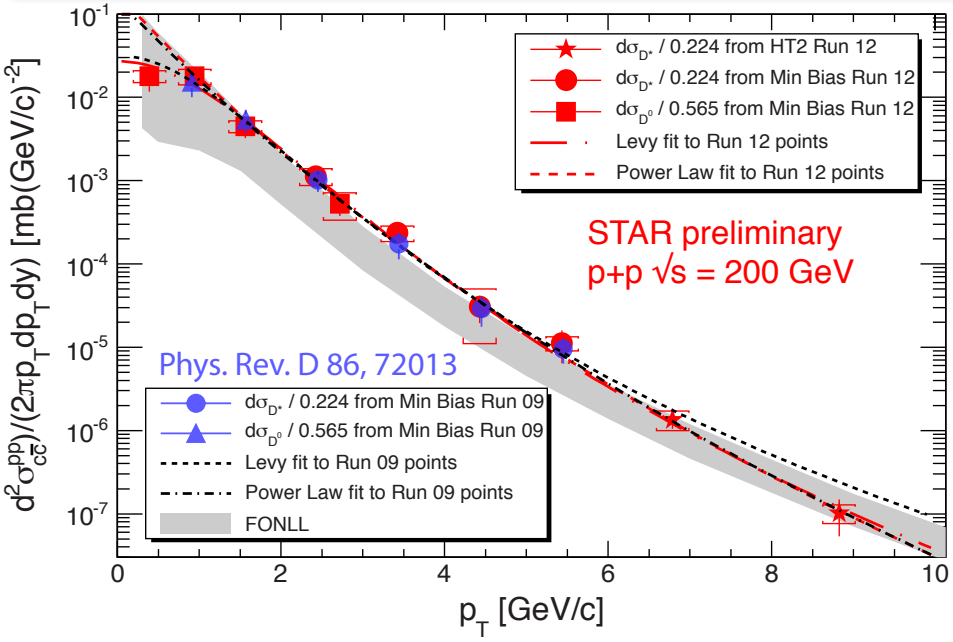
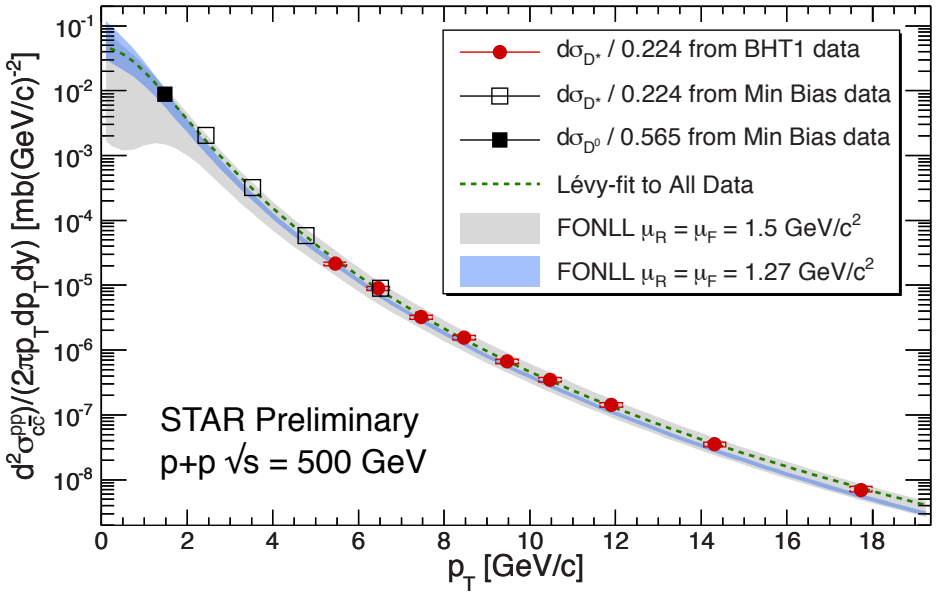
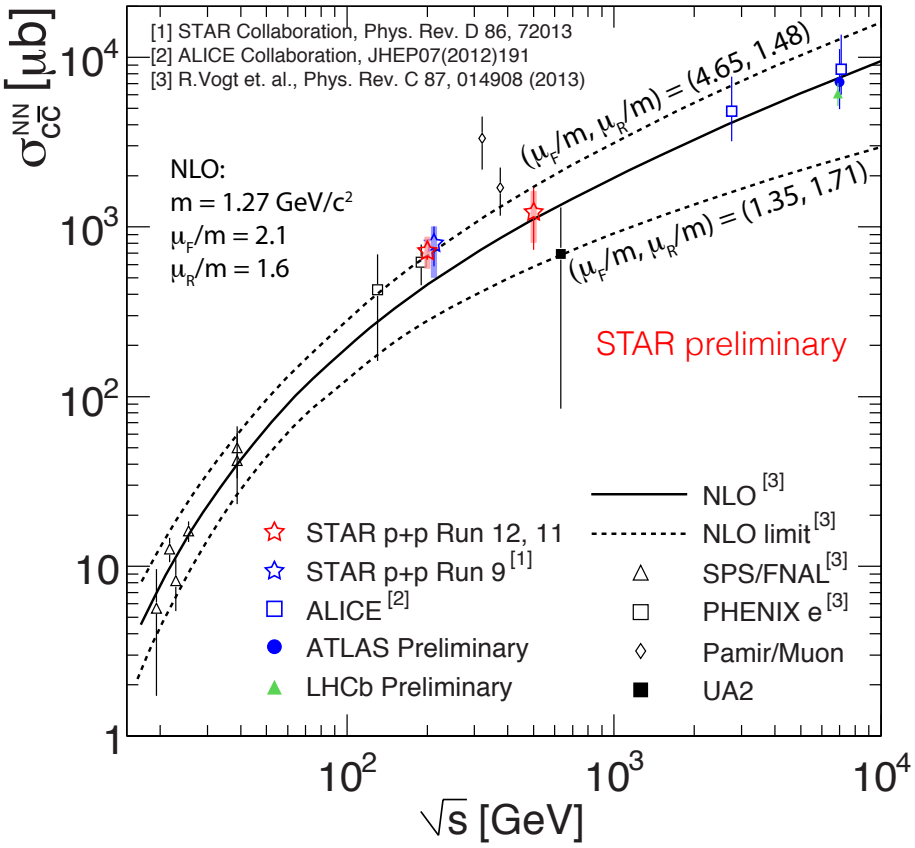




Production Cross Section in p+p collisions

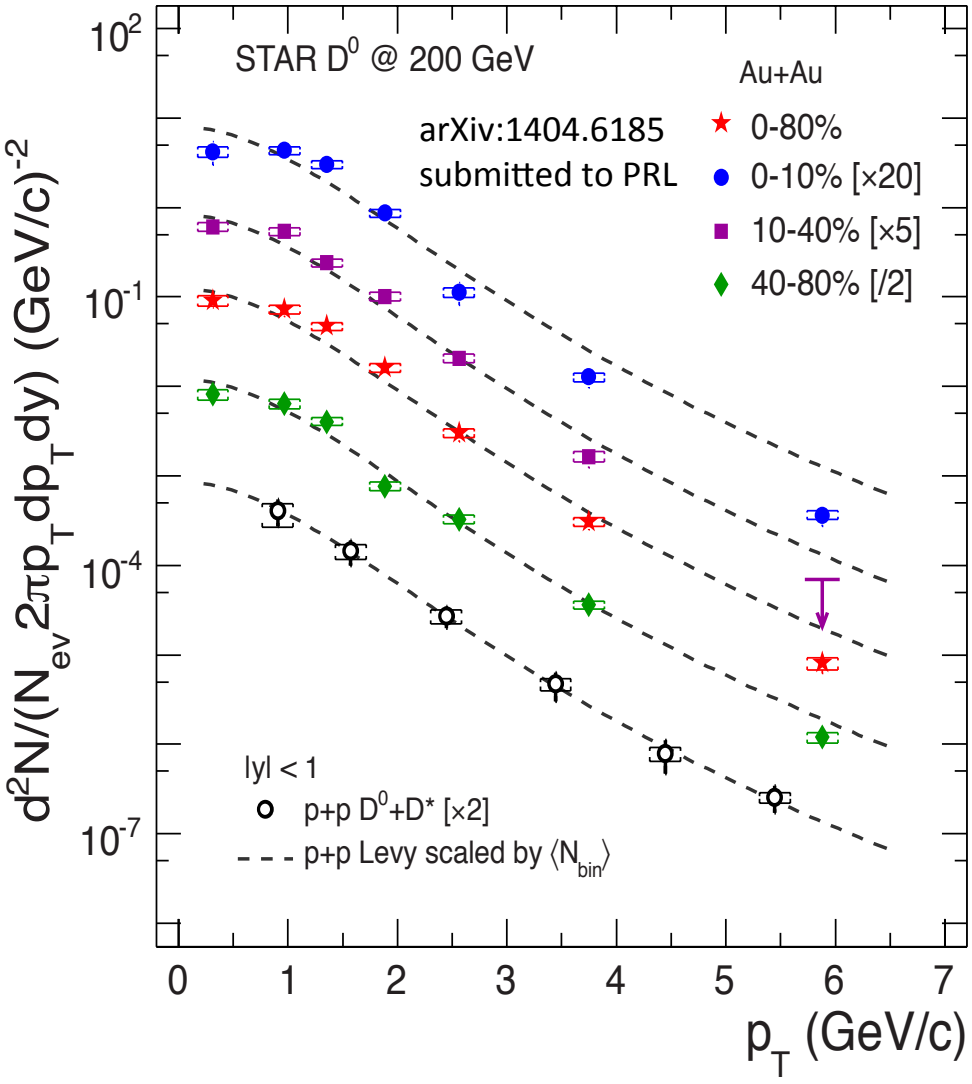


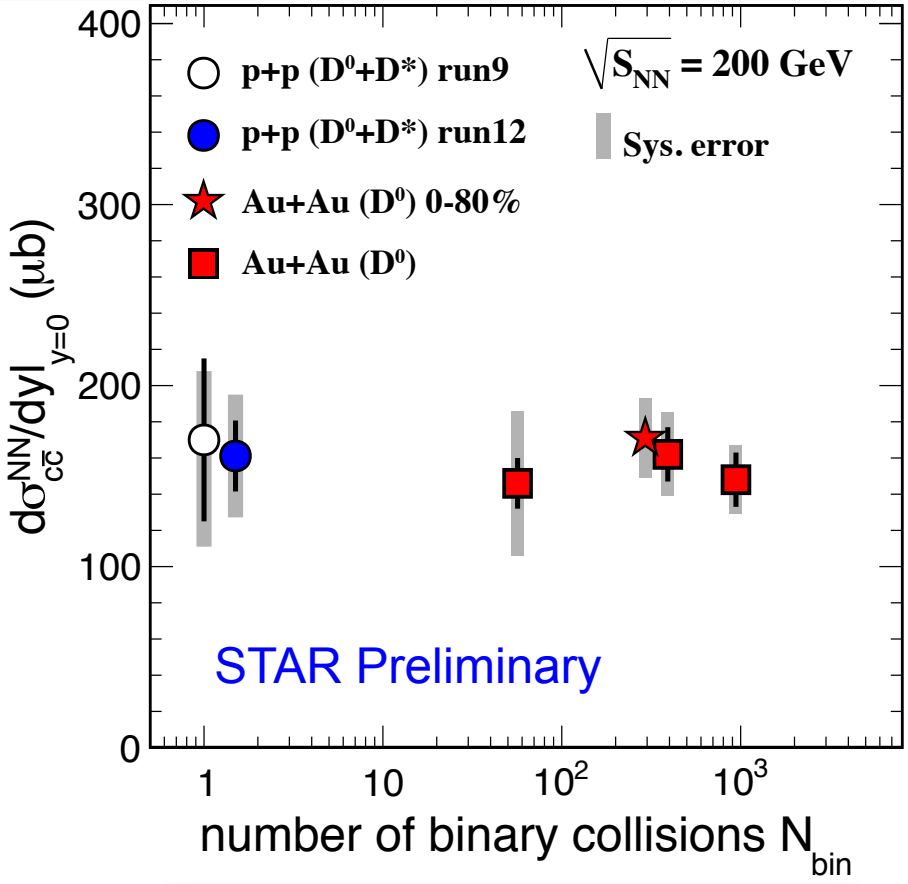




- ★ p+p 200 GeV
  - ★ essential as a baseline for Au+Au
  - ★ consistent with FONLL upper limit
  - ★ new point for pT between 0 and 0.7 GeV/c
    - ★ Levy fit describes data well
- ★ New p+p 500 GeV measurement
  - ★ consistent with FONLL

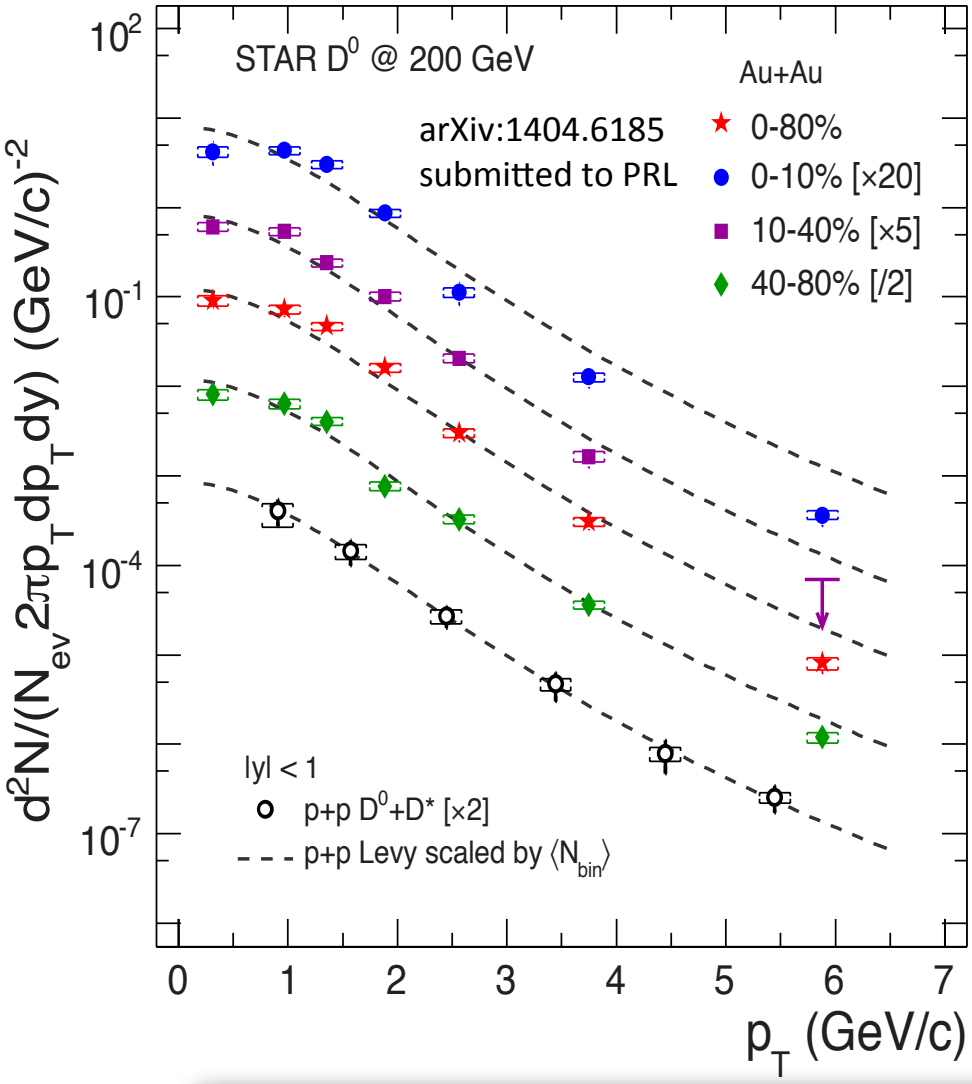
D^0 production in Au+Au

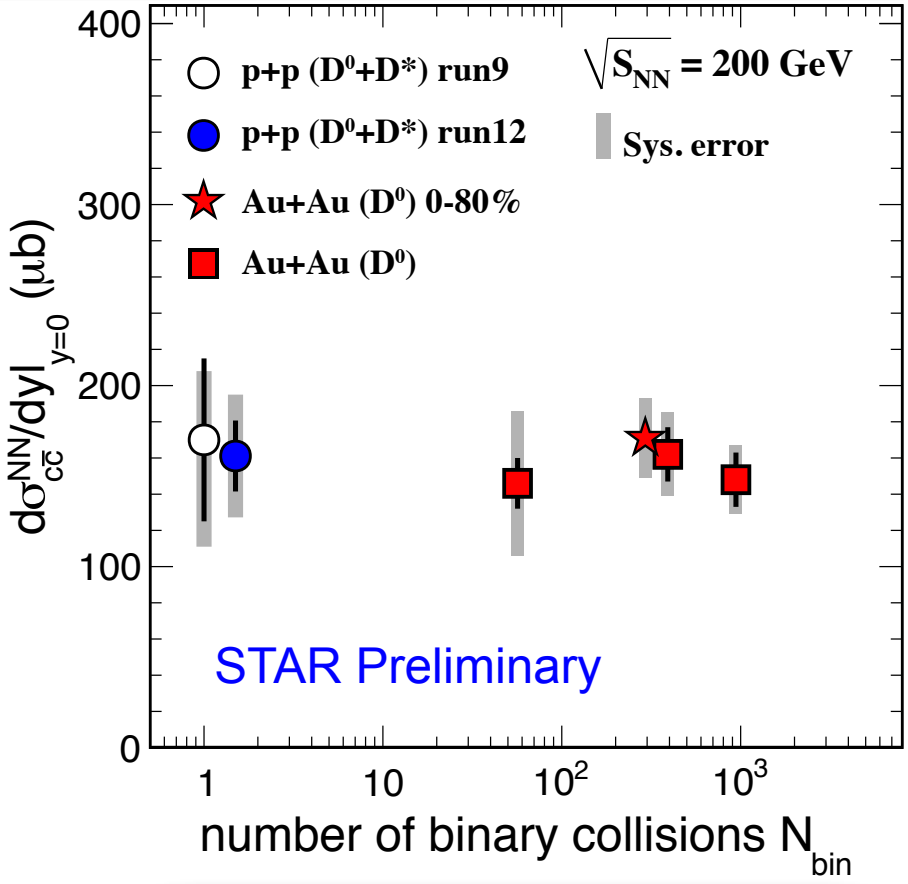




Total cross section scales with the number of binary collisions

D^0 production in Au+Au

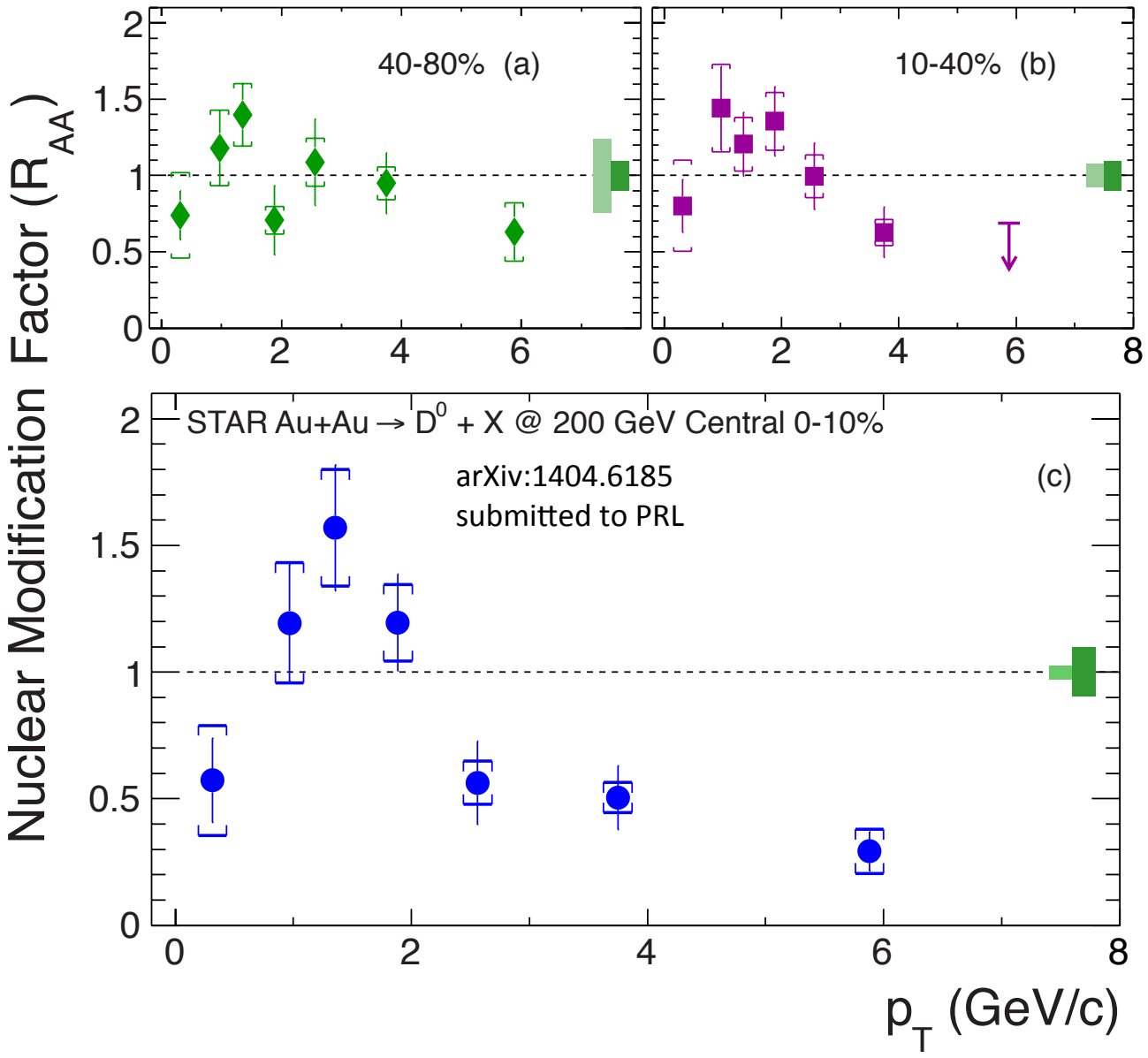




Total cross section scales with the number of binary collisions

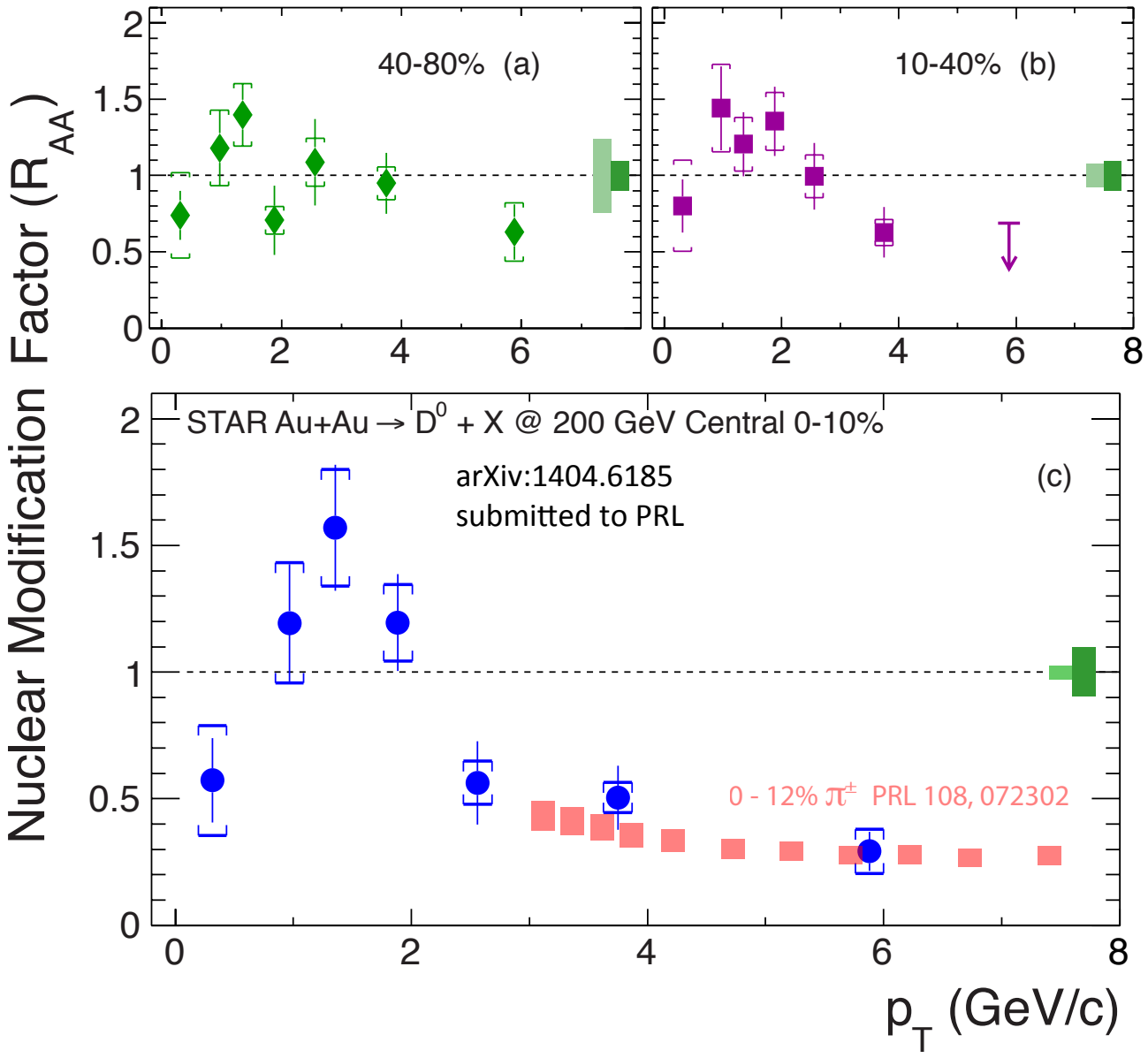
Charm is mostly produced in initial hard processes

D^0 suppression in Au+Au



- ★ p+p baseline from Levy fit to Run 09 data
- ★ strong suppression in central collisions at $p_T > 2$GeV/c
- ★ enhancement at $1 < p_T < 2$ GeV/c

D^0 suppression in Au+Au



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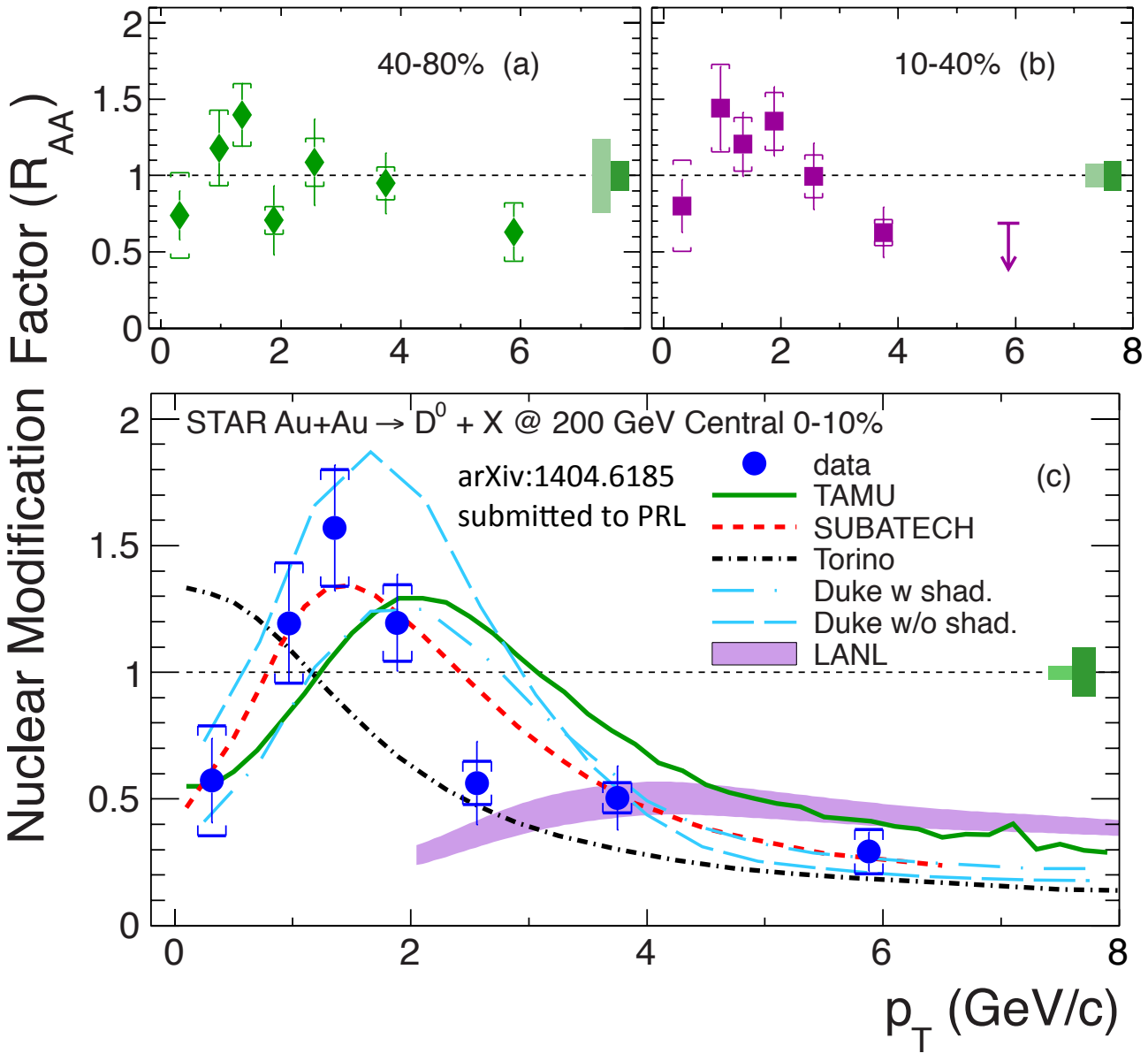
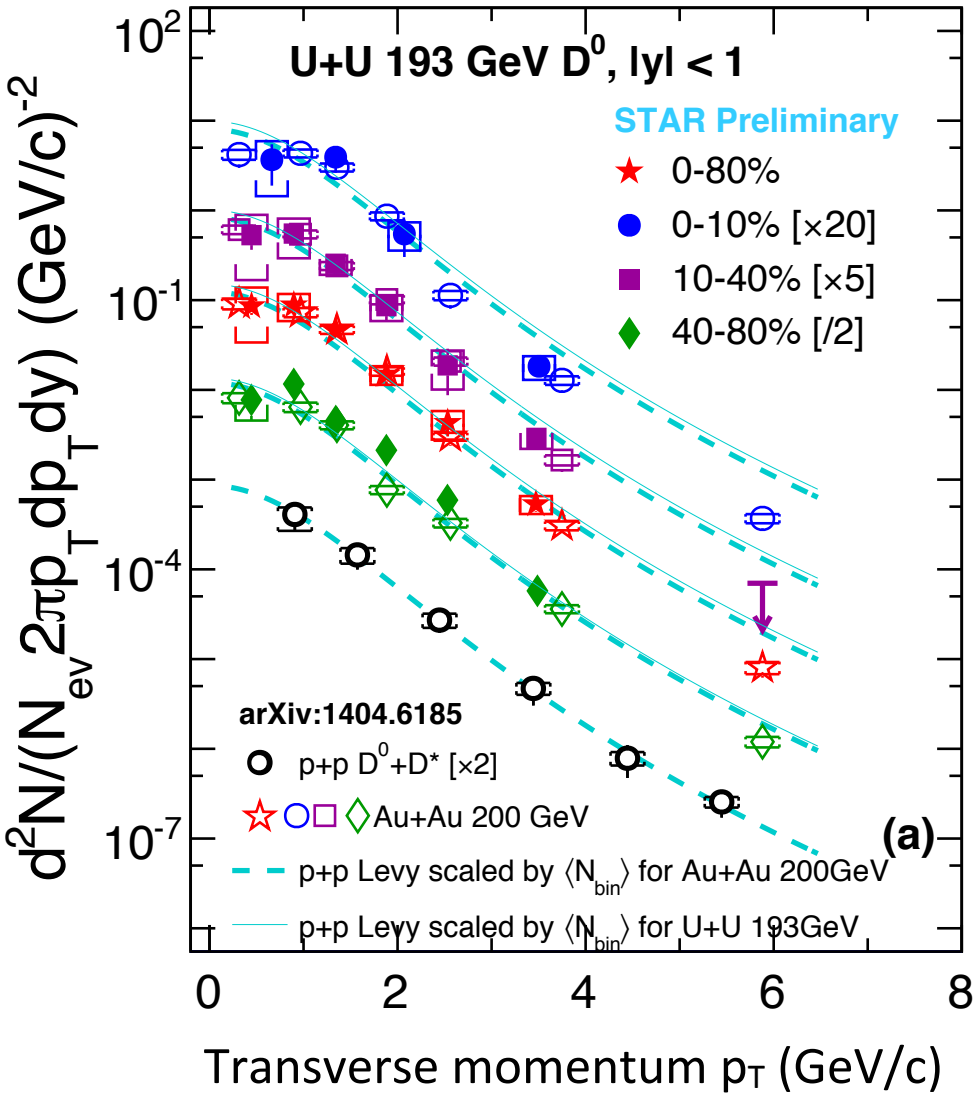
D^0 suppression in Au+Au



- ★ p+p baseline from Levy fit to Run 09 data
- ★ strong suppression in central collisions at $p_T > 2$GeV/c
- ★ like the suppression of pions
- ★ enhancement at $1 < p_T < 2$ GeV/c
- ★ Understanding from models
- ★ The enhancement is predicted by models that include charm-light quark coalescence
- ★ The suppression is consistent with strong charm-medium interaction
- ★ Cold Nuclear Matter effects might be important

D^0 in U+U collisions

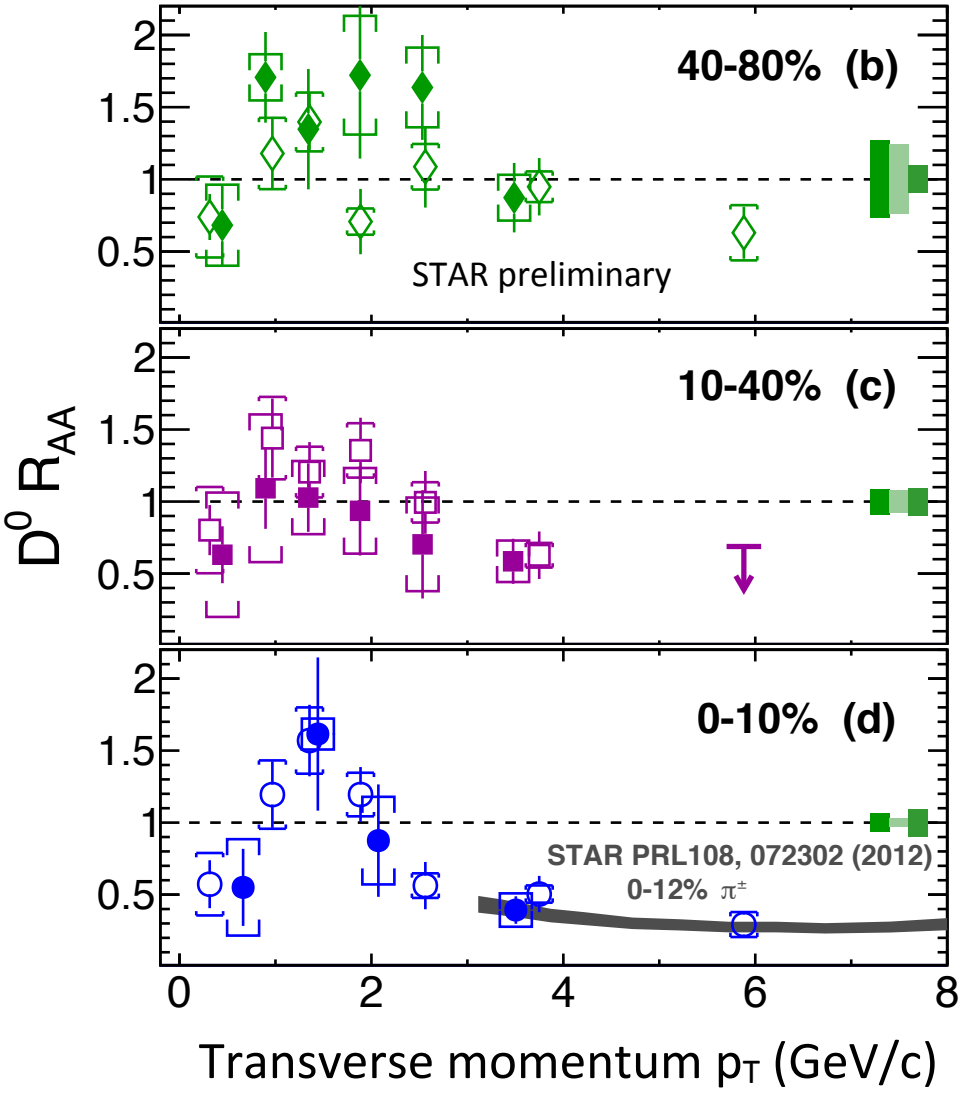


U+U collisions reach ~20% higher Bjorken energy density than Au+Au

PRC 84 054907

open symbols: Au+Au closed symbols: U+U

D^0 in U+U collisions



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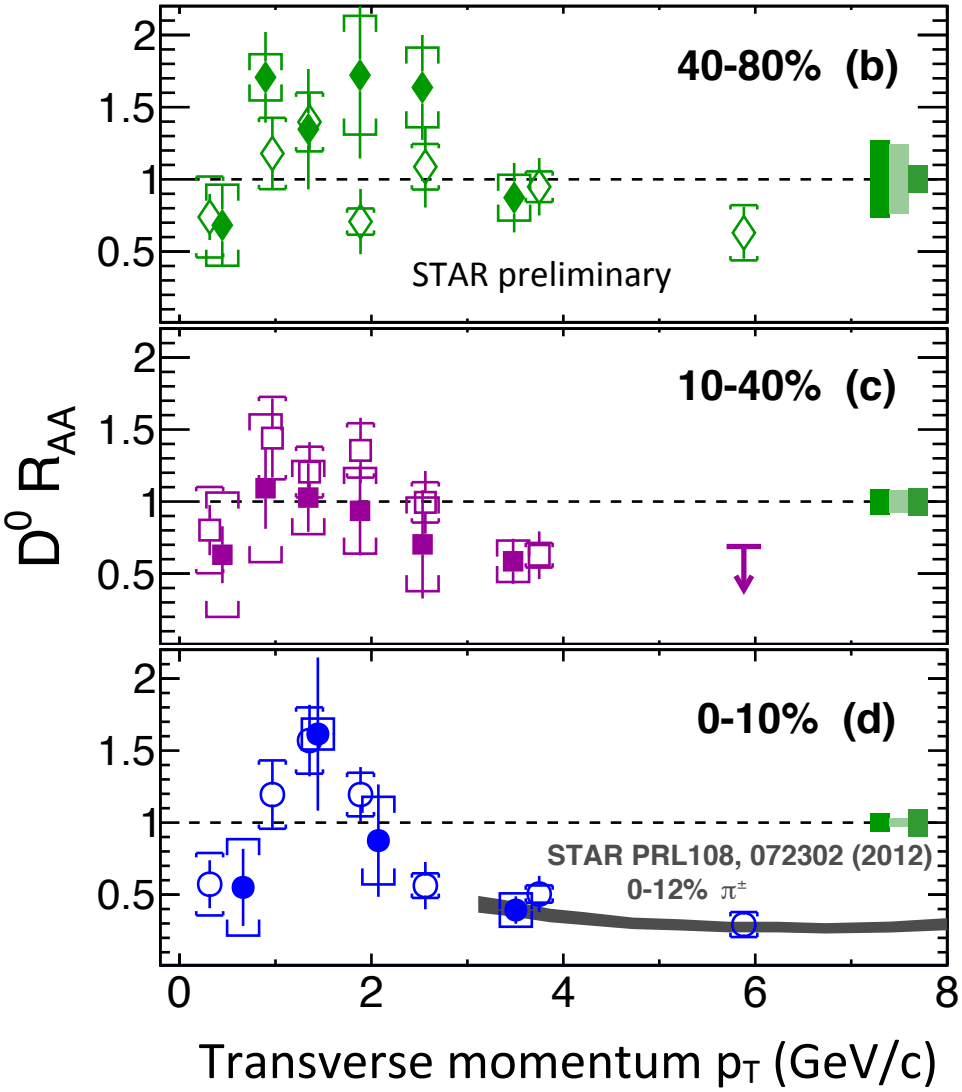

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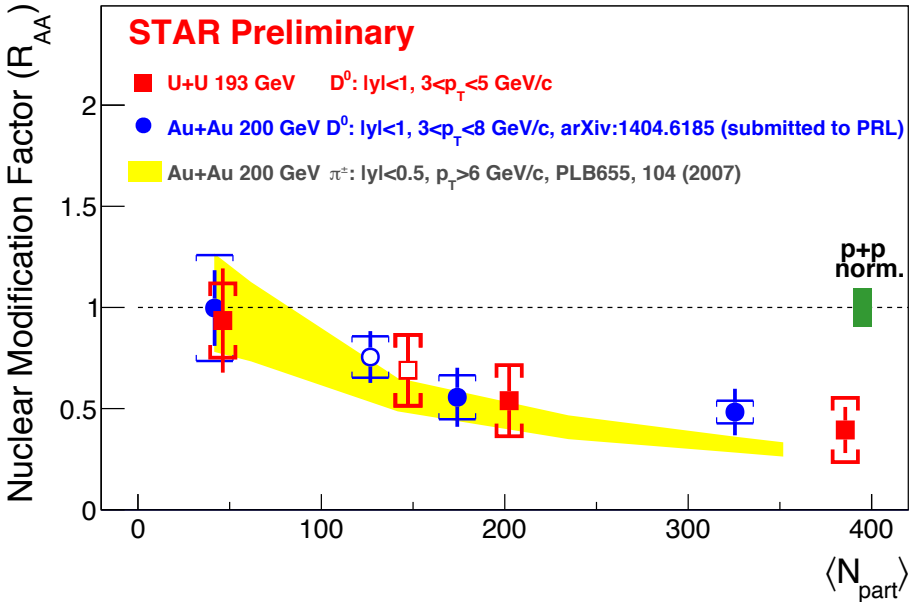

★ Trend in Au+Au continued in U+U

★ increasing suppression for $p_T > 3$ GeV/c with N_{part}

Non-photonic Electrons (NPE) Measurements

$$Y_{\mathrm{NPE}} = \zeta Y_{e^-} - \frac{Y_\gamma}{\epsilon_\gamma}$$

Y_{NPE} : Yield of Non-photonic electrons

ζ : Purity of inclusive electrons

Y_{e^-} : Yield of inclusive electrons

Y_γ : Yield of the photonic electrons

ϵ_γ : Efficiency of photonic electrons reconstruction

main sources of photonic electrons:

$\pi^0 \to \gamma + e^+ + e^-$ $\eta \to \gamma + e^+ + e^-$ $\gamma \to e^+ + e^-$

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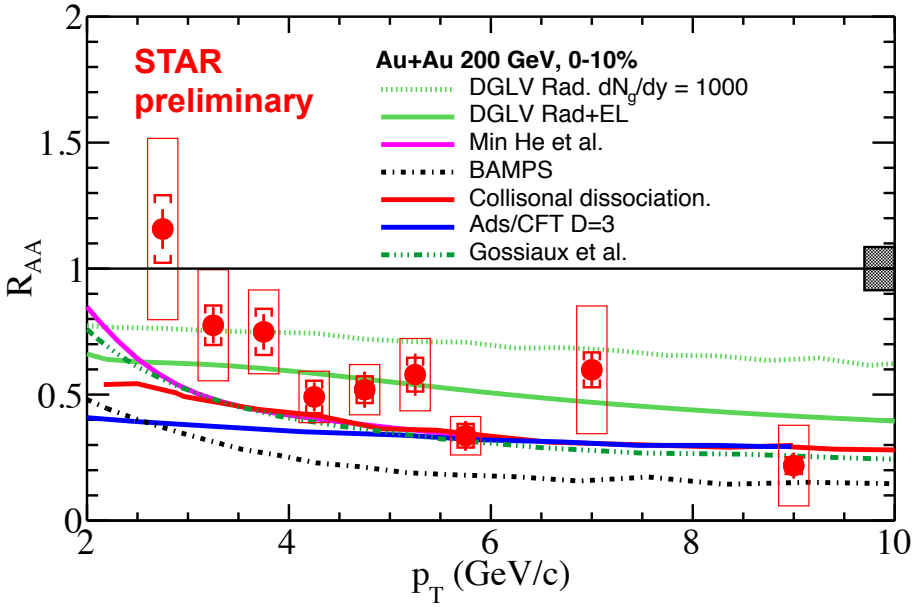
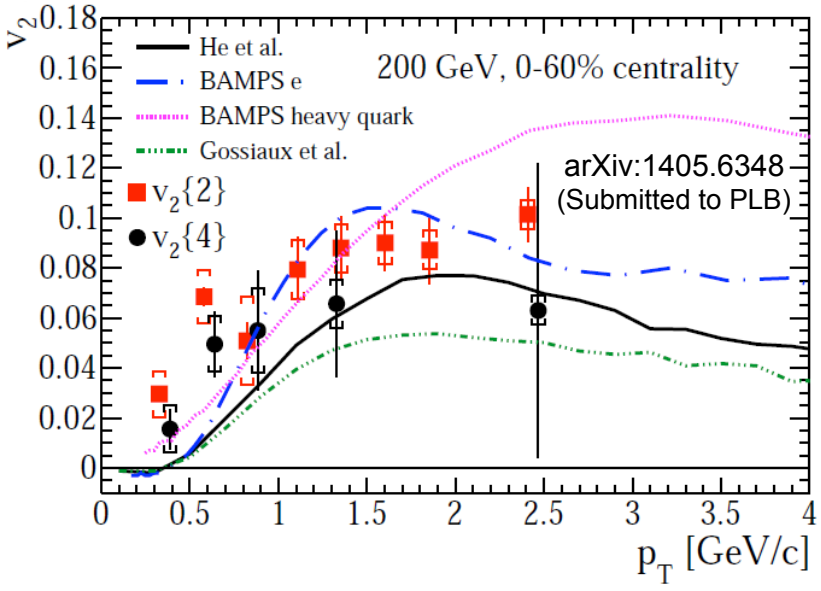
secondary contributions: ρ, ω, Φ Dalitz decays, Drell-Yan, Charmonia

NPE in 200 GeV Au+Au collisions

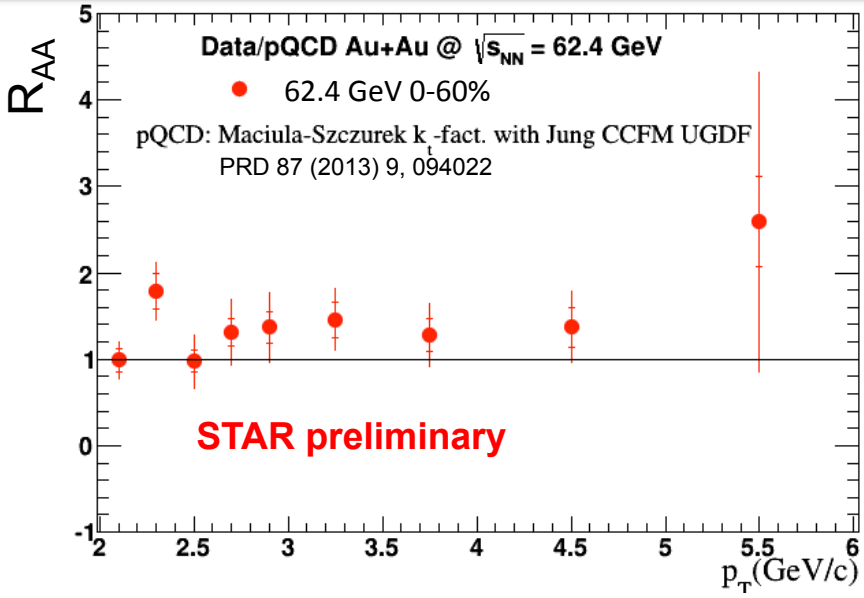


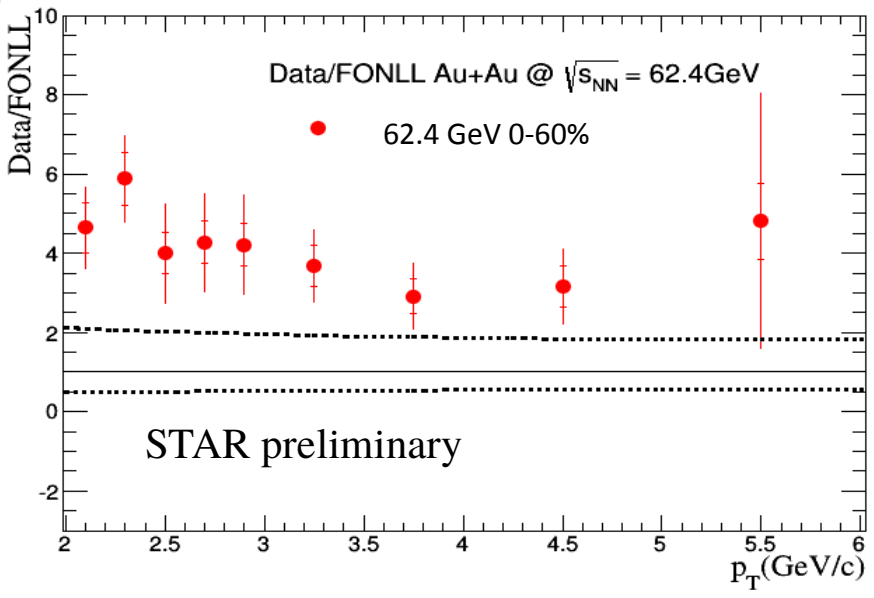


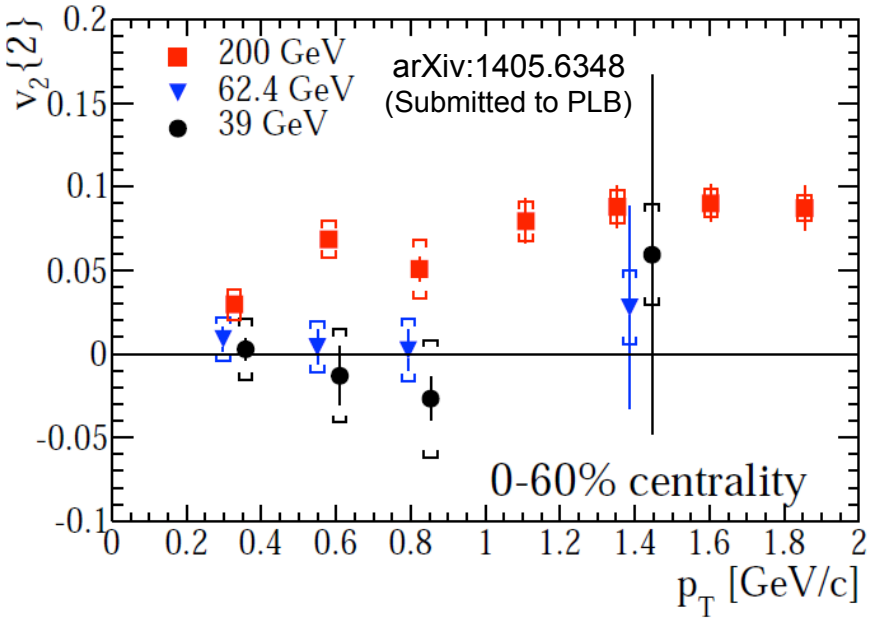
- ★ Suppression
  - ★ significant suppression of NPE in central collisions at $p_T > 4$ GeV/c
  - ★ similar to that of D^0 and light hadrons
  - ★ radiative energy loss alone not enough to explain the suppression
    - ➡ consistency with SUBATECH model for D^0 R_{AA}

- ★ Anisotropy (v_2)
  - ★ Substantial elliptic flow of NPE is seen in 200 GeV Au+Au collisions

NPE in 39 and 62.4 GeV Au+Au collisions







- ★ Suppression
  - ★ no sign of suppression of NPE in 62.4 GeV Au+Au collisions for $2 < p_T < 6$ GeV/c
  - ★ note: pQCD-scaled p+p reference
- ★ Anisotropy (v_2)
  - ★ NPE in 39 and 62.4 GeV Au+Au collisions consistent with no flow at $p_T < 1$ GeV/c

Summary

- ★ Charm pair production x-section in p+p collisions is consistent with pQCD predictions
- ★ Total D^0 x-section follows N_{bin} scaling confirming that **charm is produced in initial hard processes**
- ★ D^0 enhancement around 1.5 GeV/c suggests **charm-light quark coalescence**
- ★ Strong suppression of D^0 production above 3 GeV/c in central Au+Au collisions indicates **strong charm-medium interaction**
- ★ U+U measurements show similar suppression pattern to Au+Au
- ★ Non-photonic electrons in Au+Au at 62.4 GeV not suppressed and have elliptic flow consistent with zero, contrary to 200 GeV

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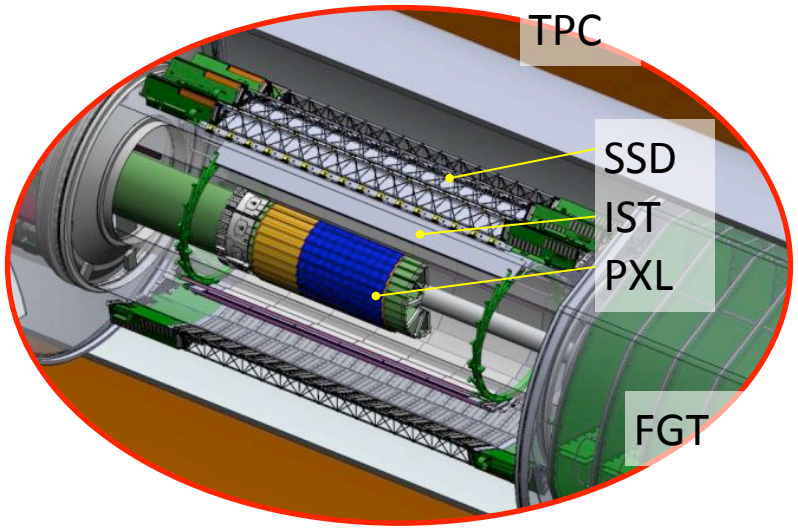
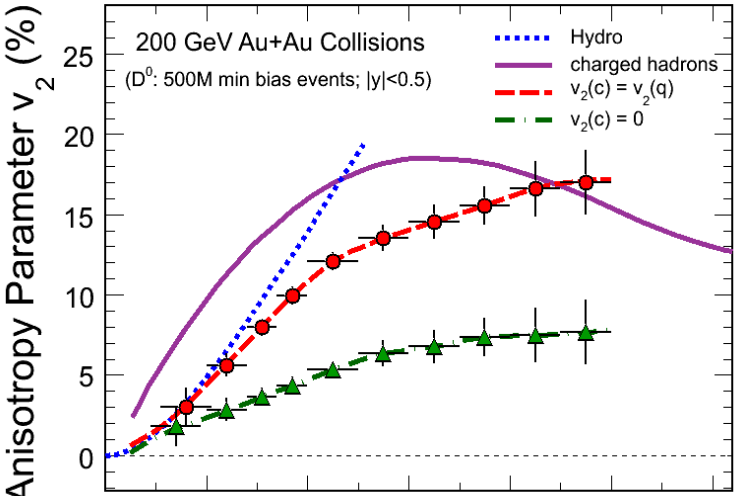
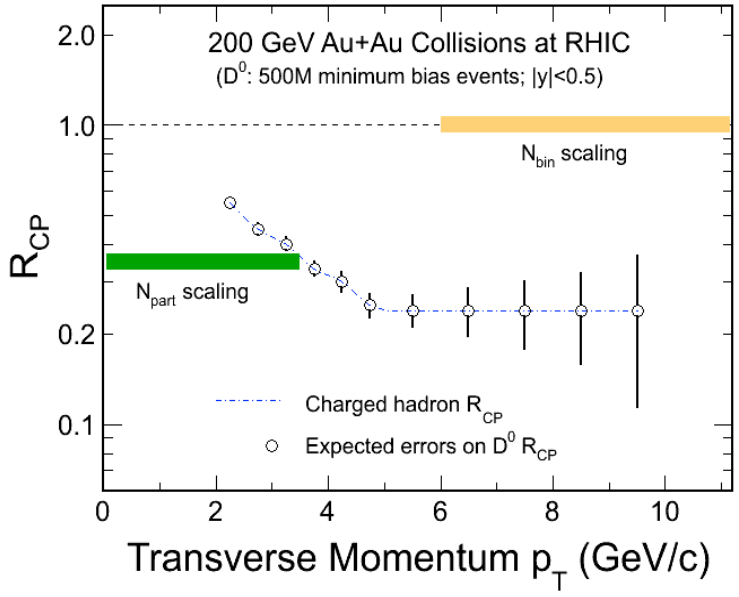
Stay tuned for new great results with HFT and MTD

Thank you

Heavy Flavor Tracker







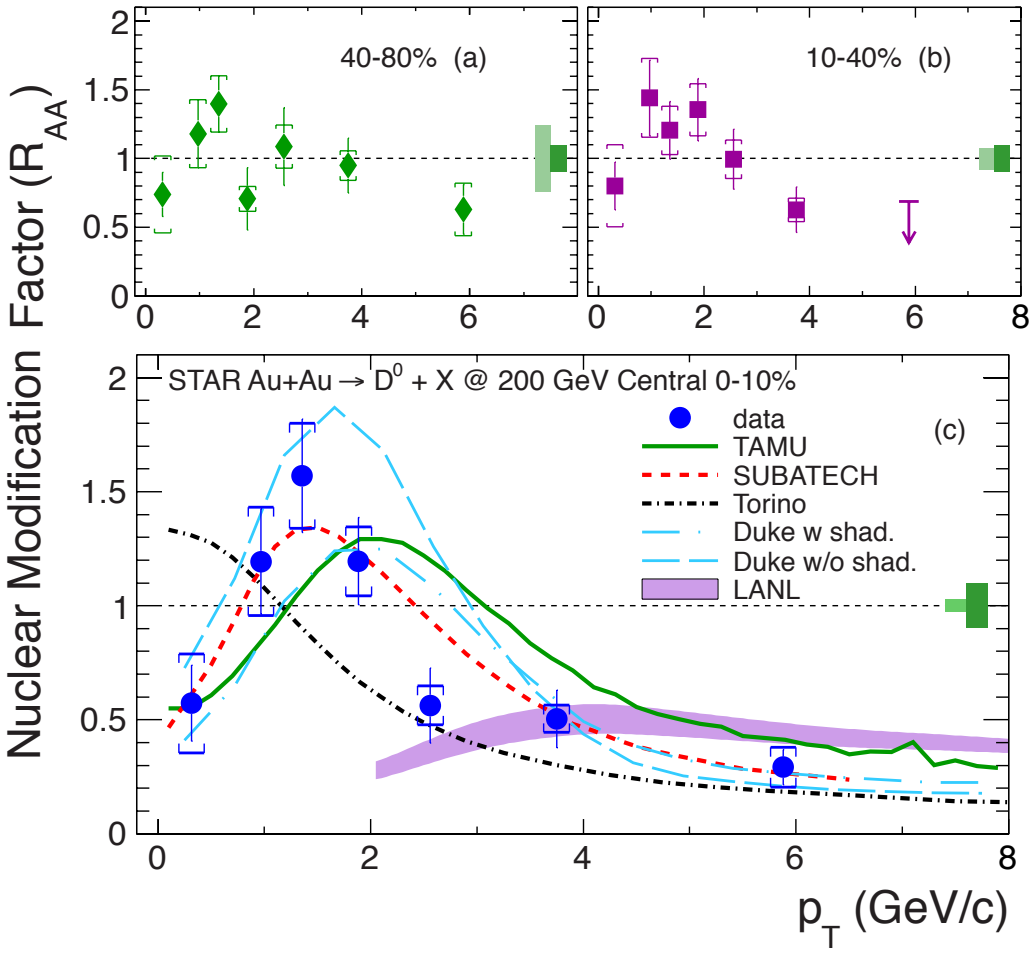
STAR Heavy Flavor Tracker Project.

- ✓ Reconstruct secondary vertex.
- ✓ Dramatically improve the precision of measurements.
- ✓ Address physics related to heavy flavor.

v_2 : thermalization

R_{CP}: charm quark energy loss mechanism.

Models For R_{AA}



	TAMU	SUBTECH	Torino	Duke	LANL
HQ prod.	LO	FNOLL	NLO	LO	LO
QGP-Hydro.	ideal	ideal	viscous	viscous	ideal
HQ eLoss	coll.	coll. +rad.	coll +rad.	coll +rad.	diss. +rad.
Coalescence	Yes	Yes	No	Yes	No
Cronin effect	Yes	Yes	No	No	Yes
Shadowing	No	No	Yes	Yes/No	Yes

★ Understanding from models

★ The enhancement is predicted by models that include charm-light quark coalescence

★ The suppression is consistent with strong charm-medium interaction

★ Cold Nuclear Matter effects might be important