Open Charm Hadron Production via Hadronic Decays at STAR

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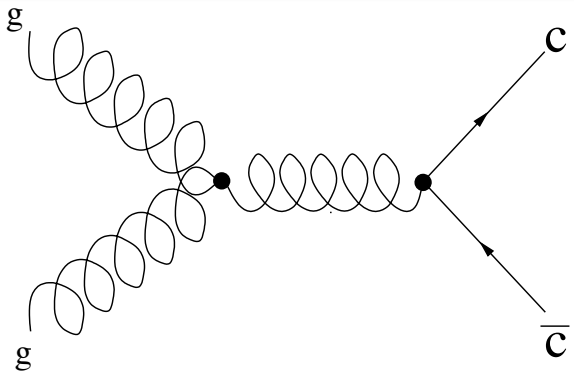
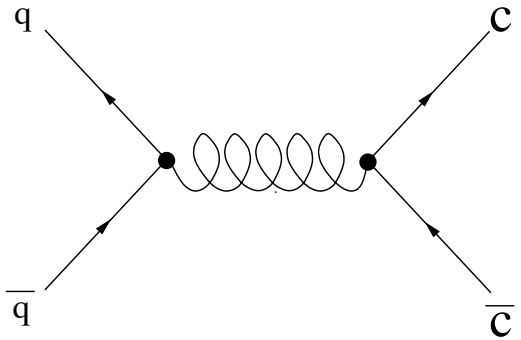
for the STAR collaboration

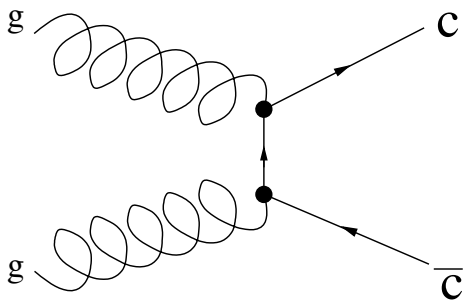
Outline

1. Motivation
2. STAR detector and analysis
3. D^0 in Au+Au 200 GeV collisions
4. D^0 and D* in p+p 500 GeV collisions
5. Summary

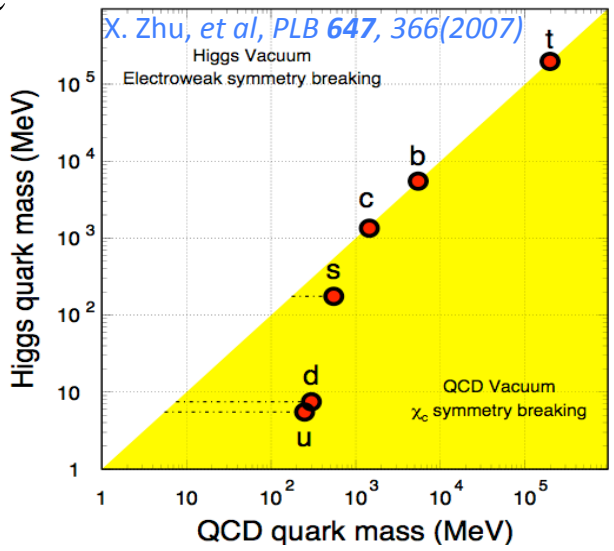
Why to study heavy quarks

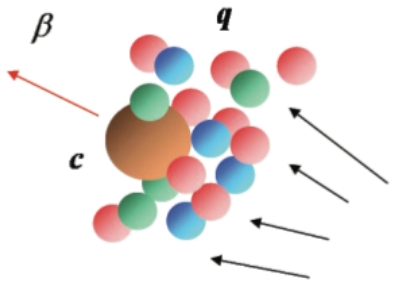




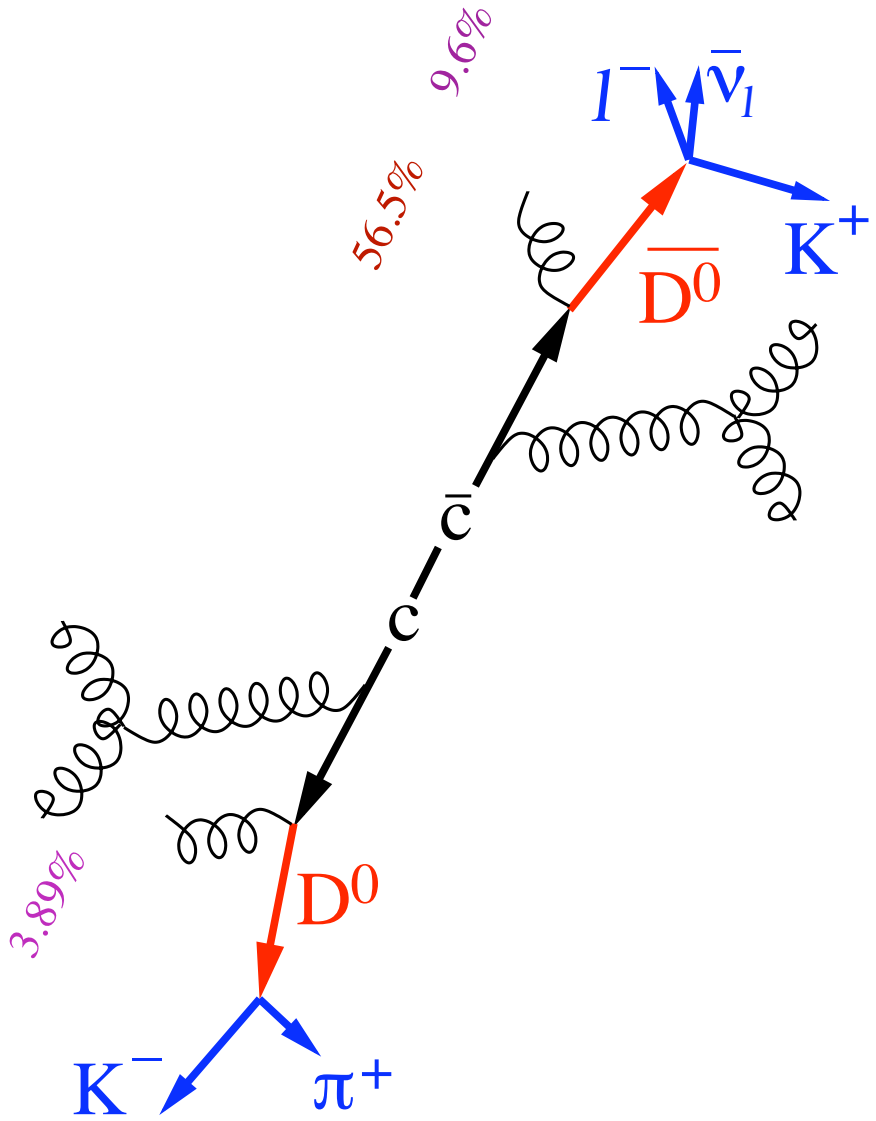


- Produced in initial hard partonic collisions (described well by pQCD) => $\sigma_{(c\bar{c})}$ should follow number-of-binary-scaling
- Heavy quark mass is believed to be external to QCD (=> stay heavy even in QGP)
- Reveal critical features of the medium



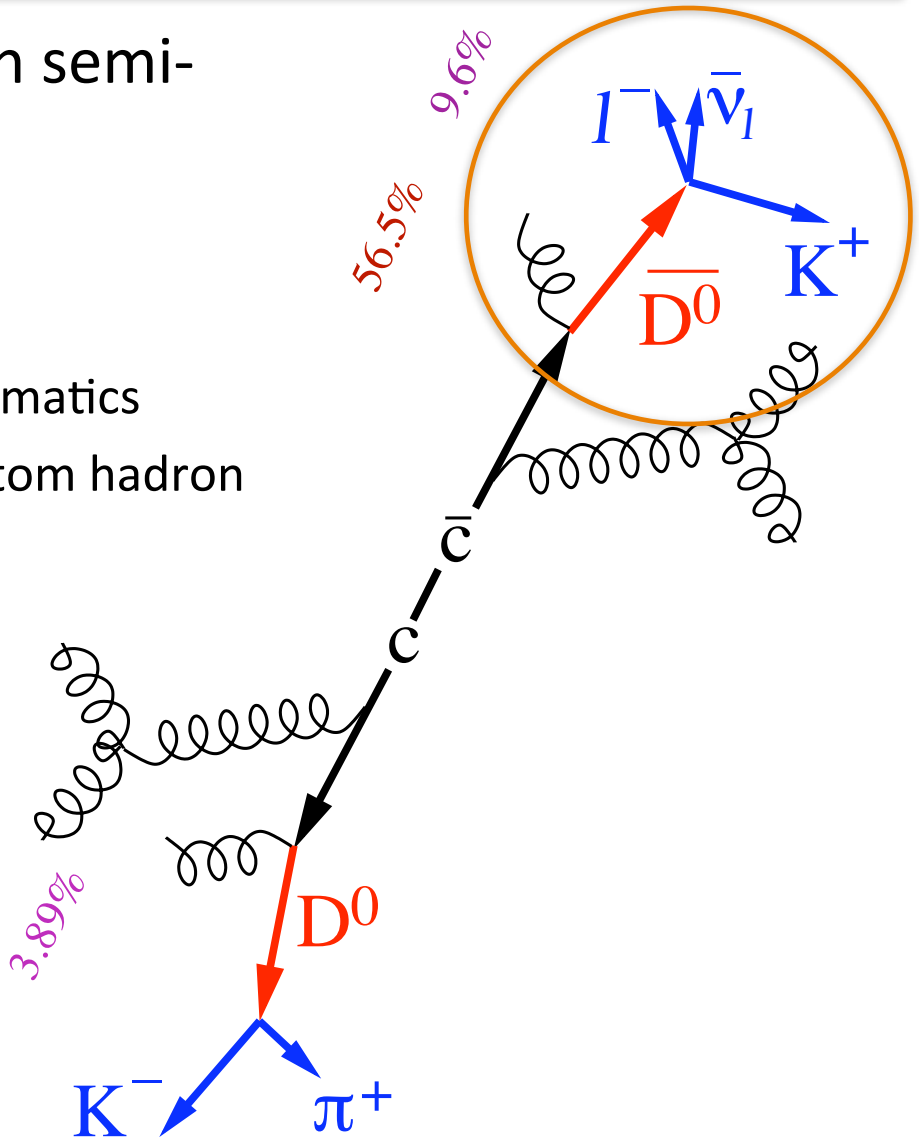


How to Measure Charm Quarks



How to Measure Charm Quarks

- ★ Indirect measurements through semi-leptonic decay
  - ★ can be triggered easily (high p_T)
  - ★ higher B.R.
  - ★ indirect access to the heavy quark kinematics
  - ★ contribution from both charm and bottom hadron decays



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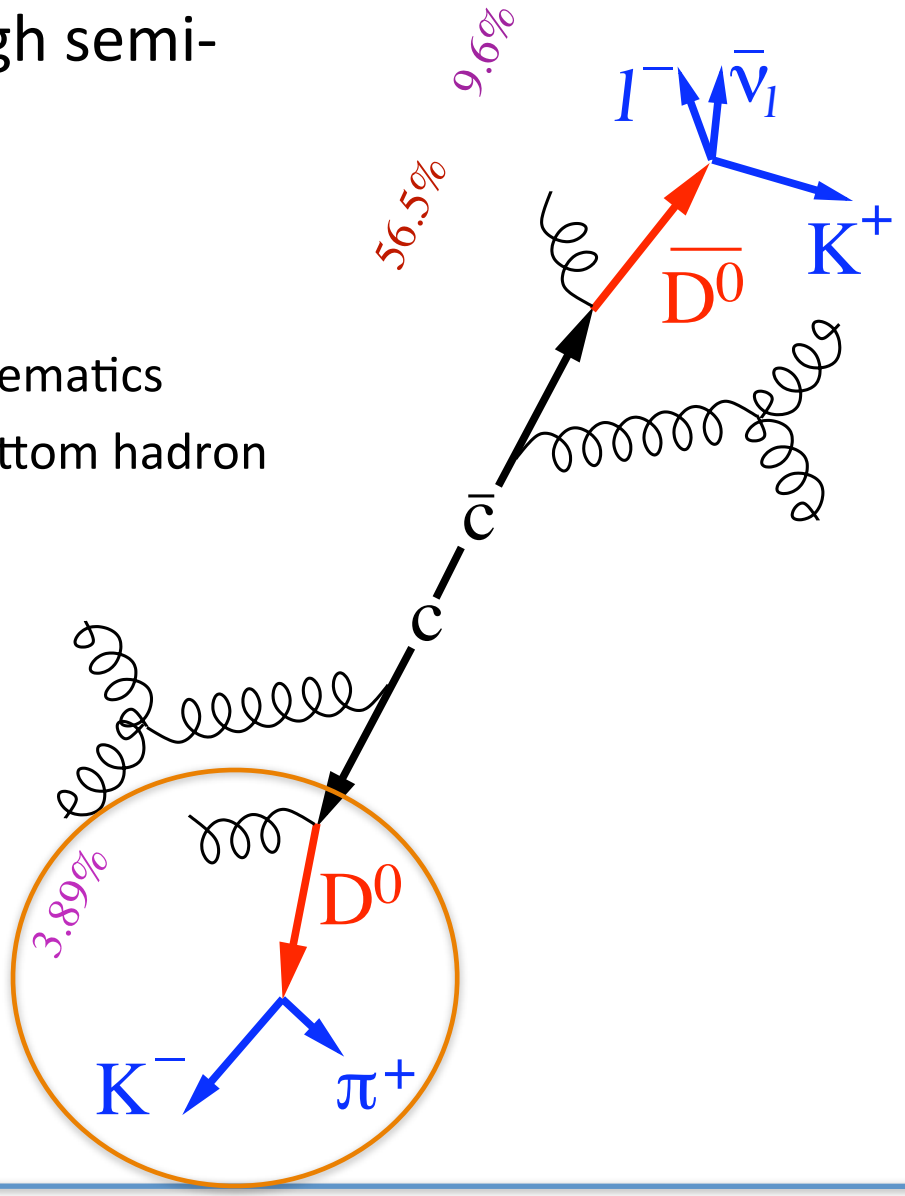
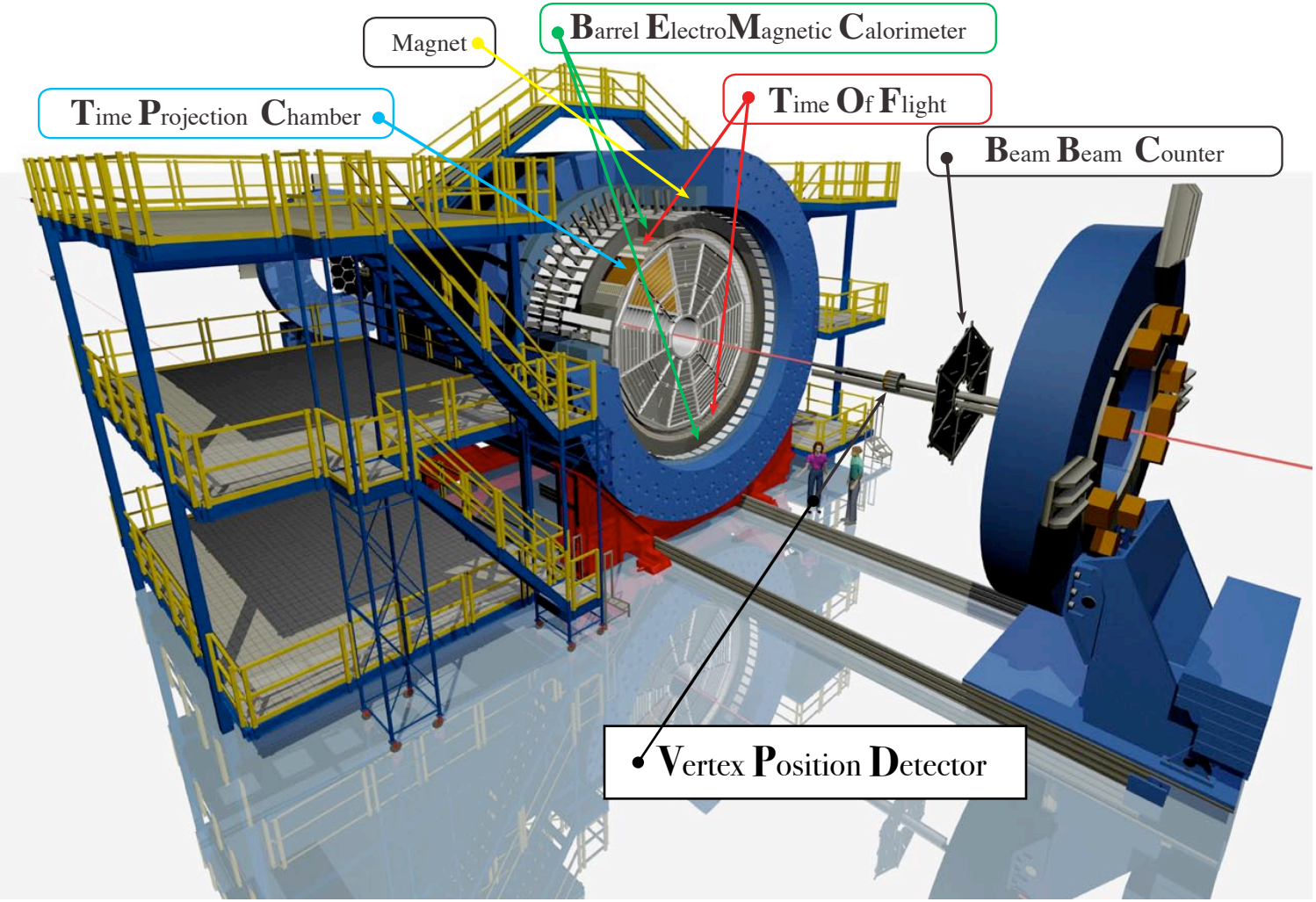
  - ★ contribution from both charm and bottom hadron decays
- ★ Direct reconstruction
  - ★ direct access to heavy quark kinematics
  - ★ difficult to trigger (high energy trigger only for correlation measurements)
  - ★ smaller Branching Ratio (B.R.)
  - ★ large combinatorial background (need handle on decay vertex)



The STAR Detector

Solenoidal **T**racker **A**t **R**HIC : $-1 < \eta < 1, 0 < \phi < 2\pi$



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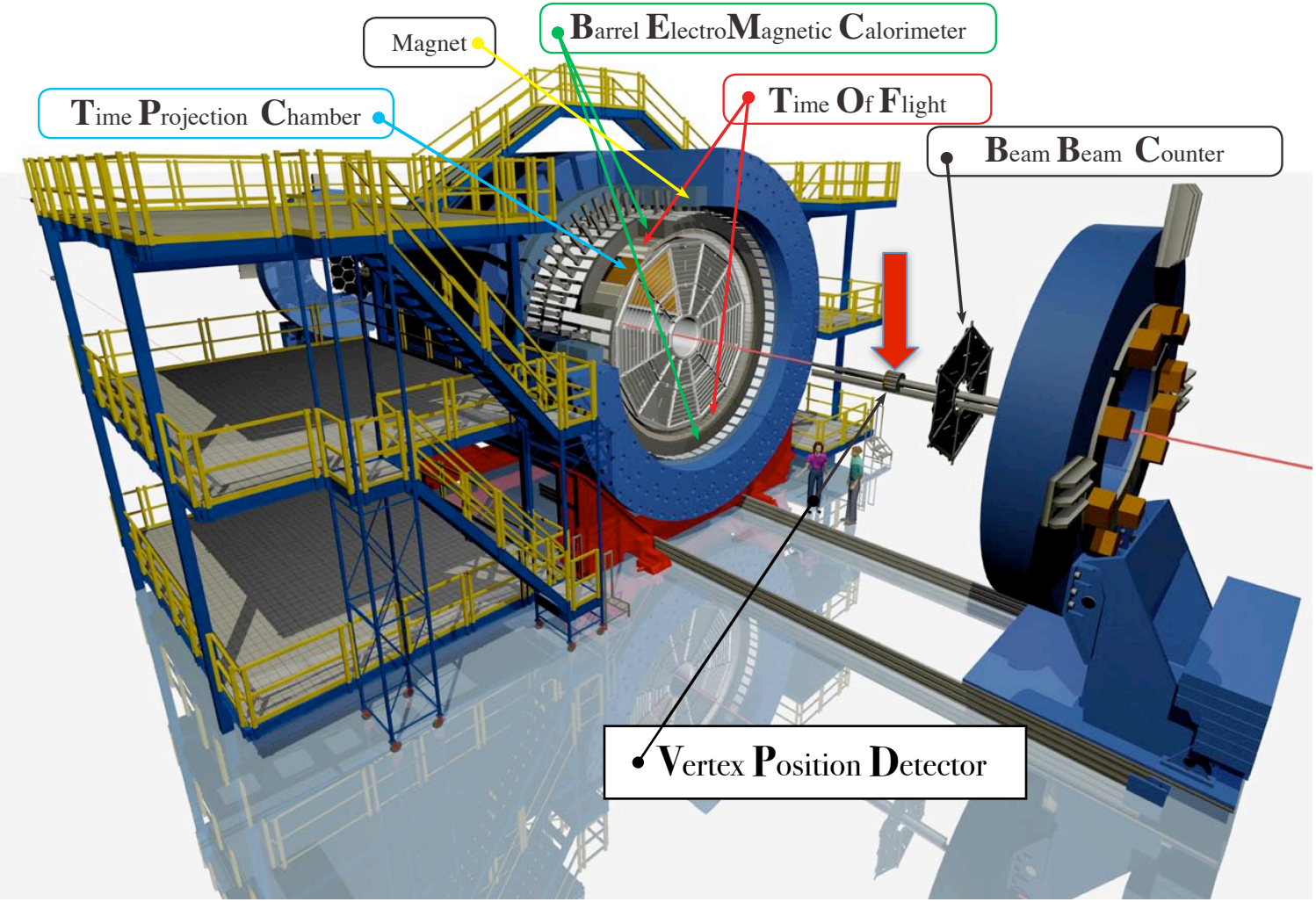

★ **VPD: minimum bias trigger**

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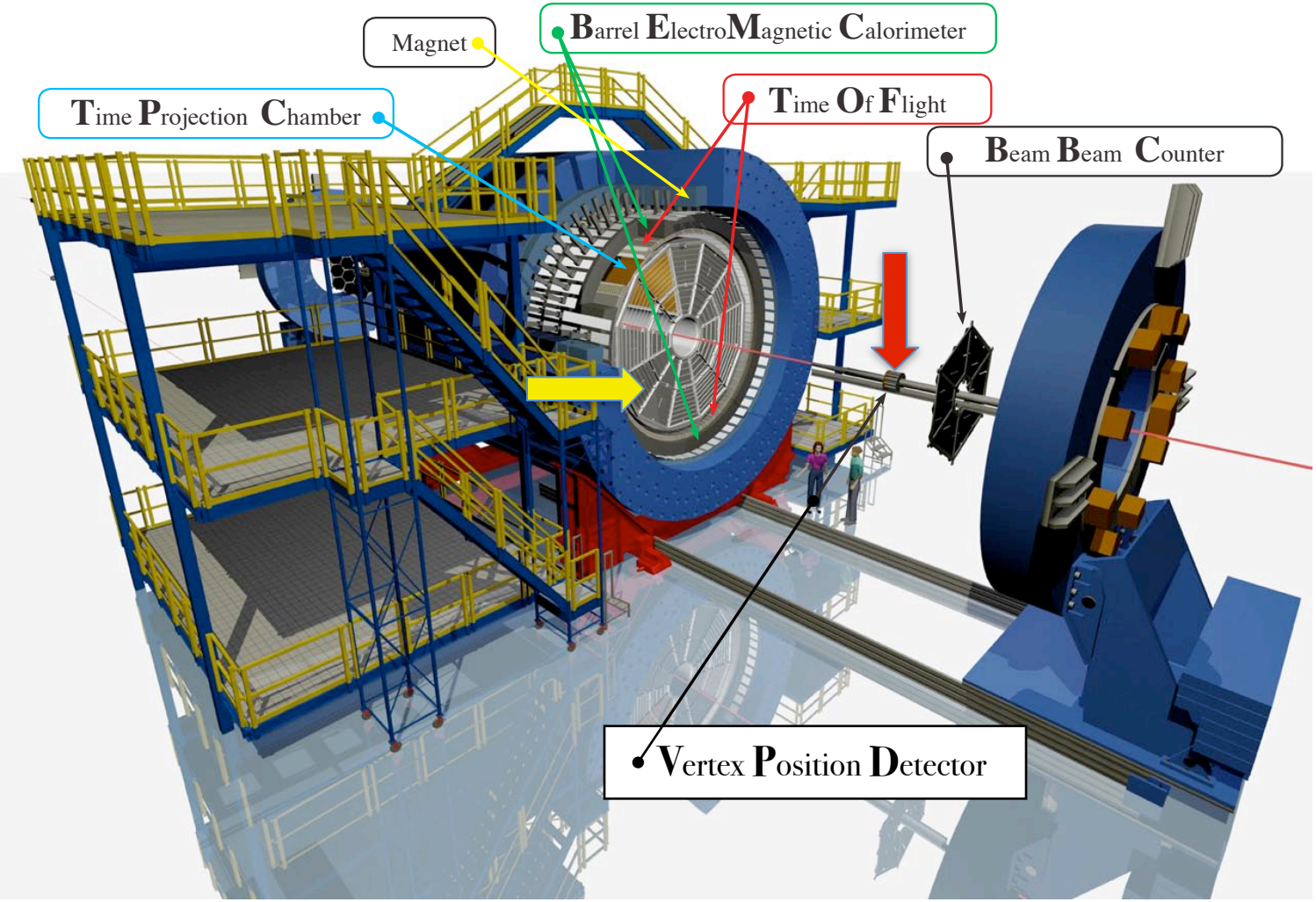

- ★ **VPD: minimum bias trigger**
- ★ **TPC: PID, tracking**

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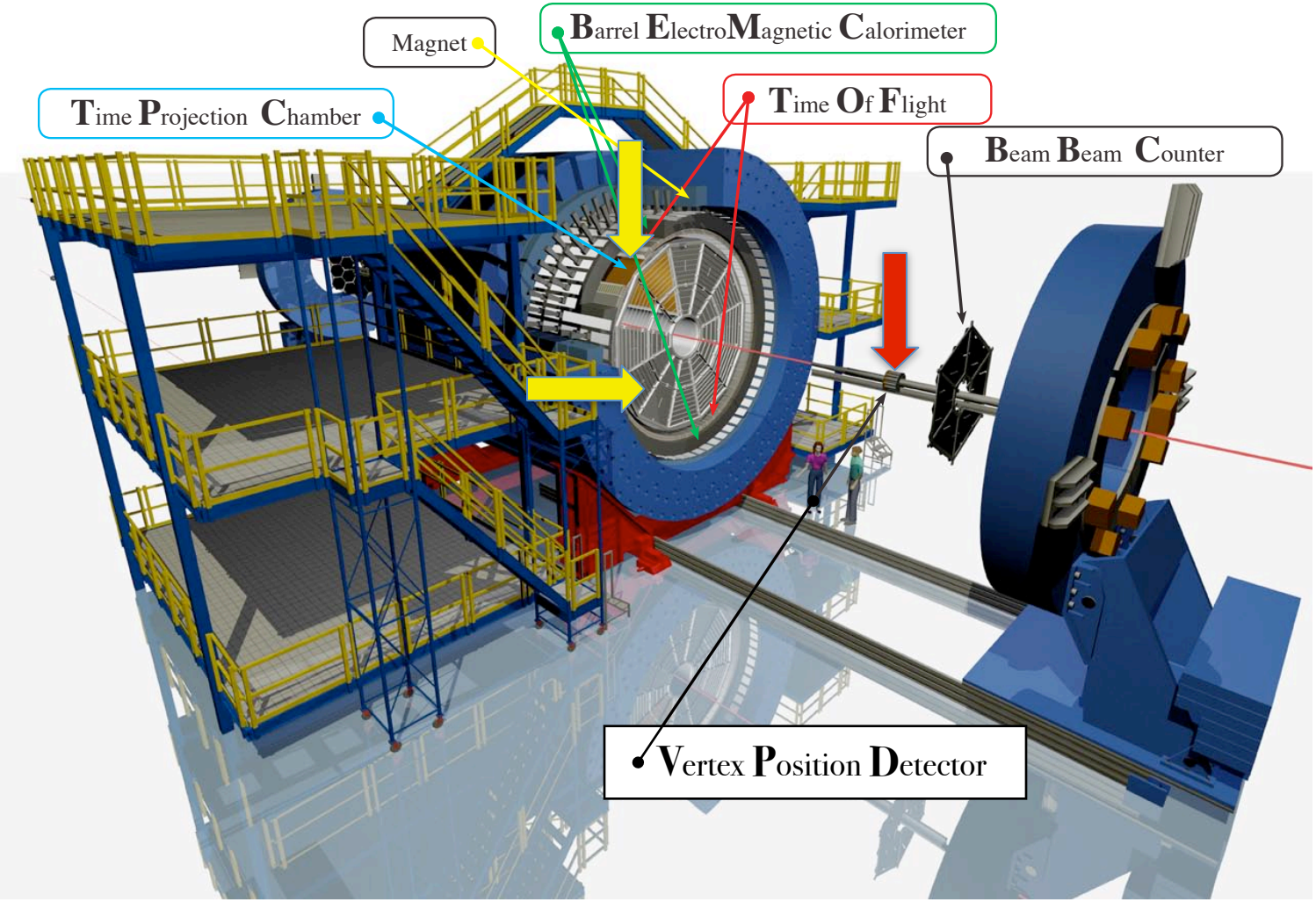

- ★ **VPD: minimum bias trigger**
- ★ **TPC: PID, tracking**
- ★ **TOF: PID** (time resolution 110 ps in p+p, 100 ps in Au+Au)

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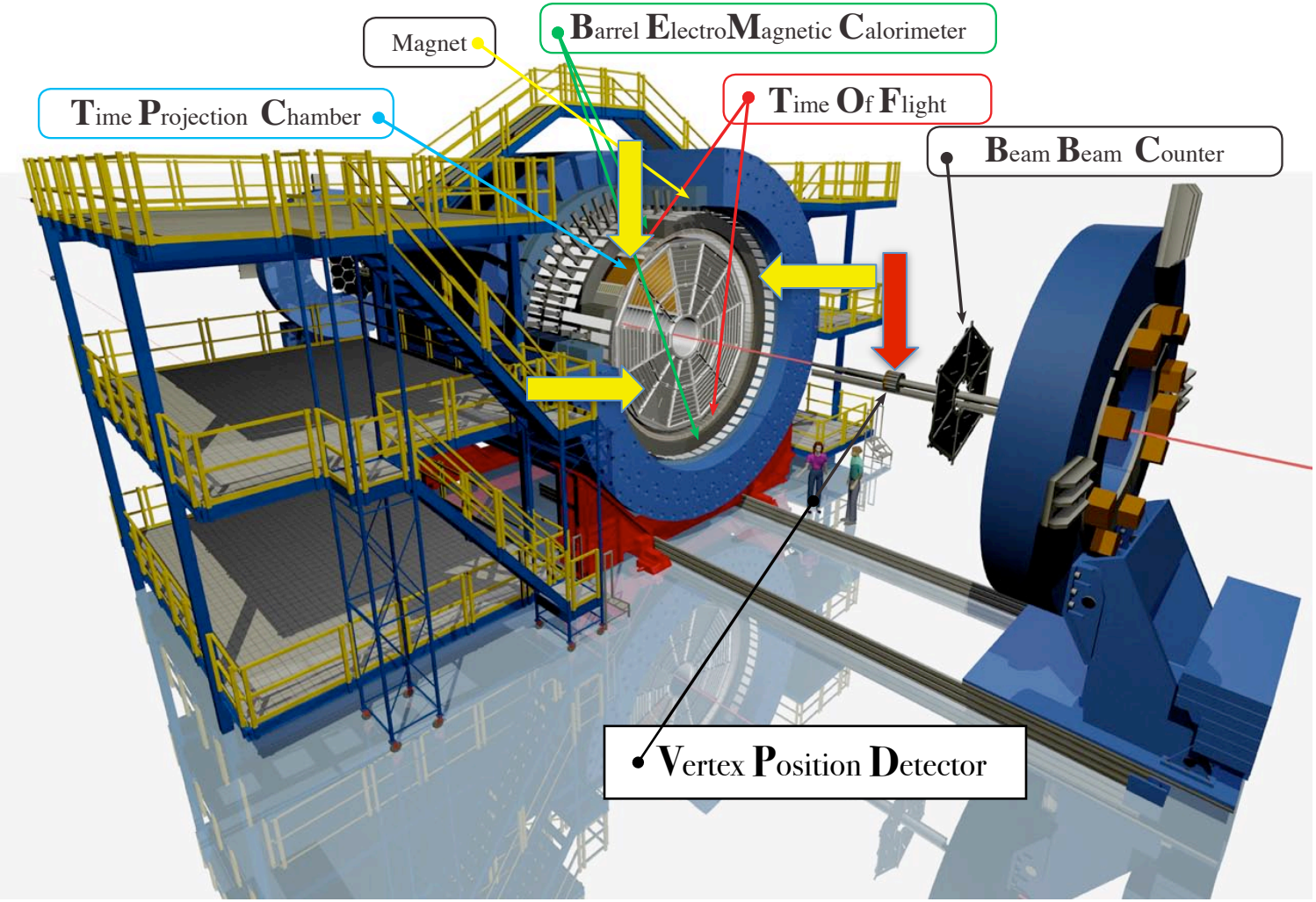
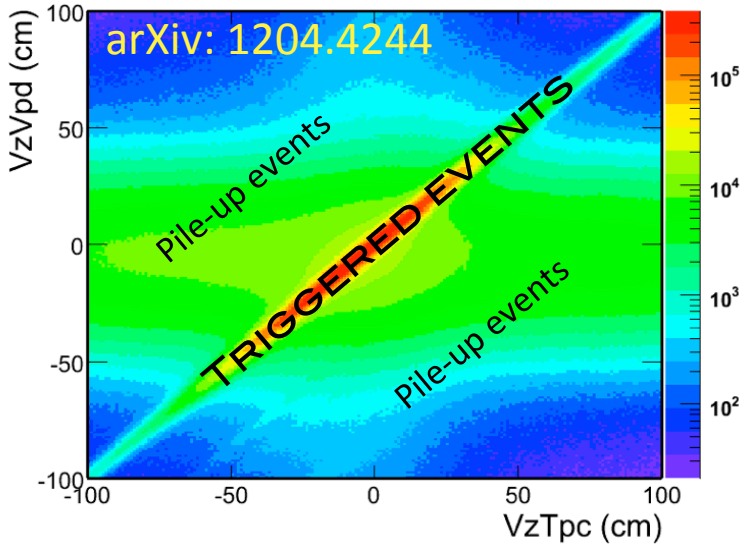
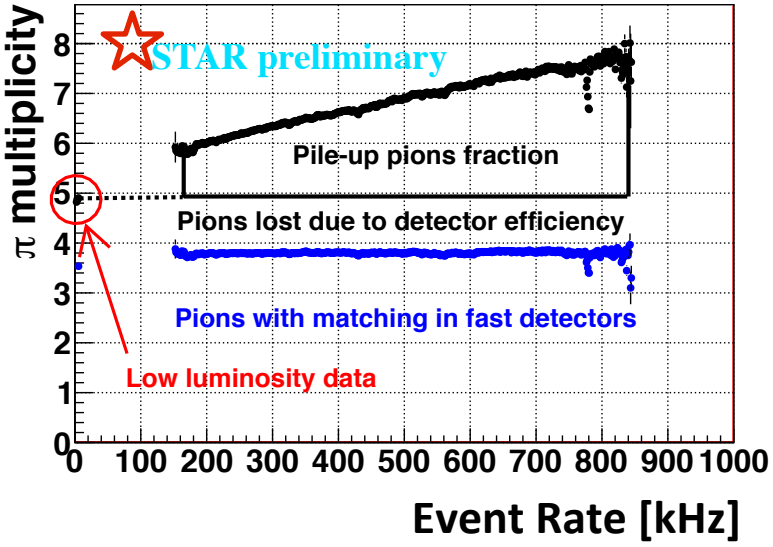


- ★ **VPD: minimum bias trigger**
- ★ **TPC: PID, tracking**
- ★ **TOF: PID (time resolution 110 ps in p+p, 100 ps in Au+Au)**
- ★ **BEMC: remove pile-up tracks**

Event Selection and Hadron Identification





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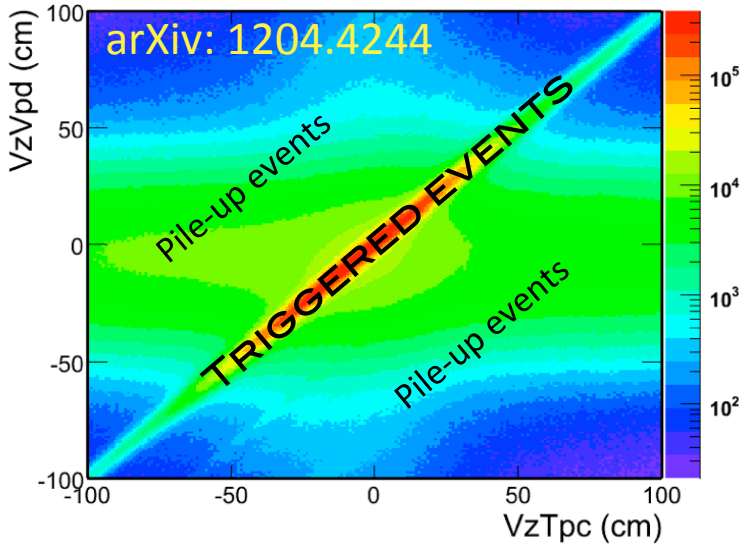
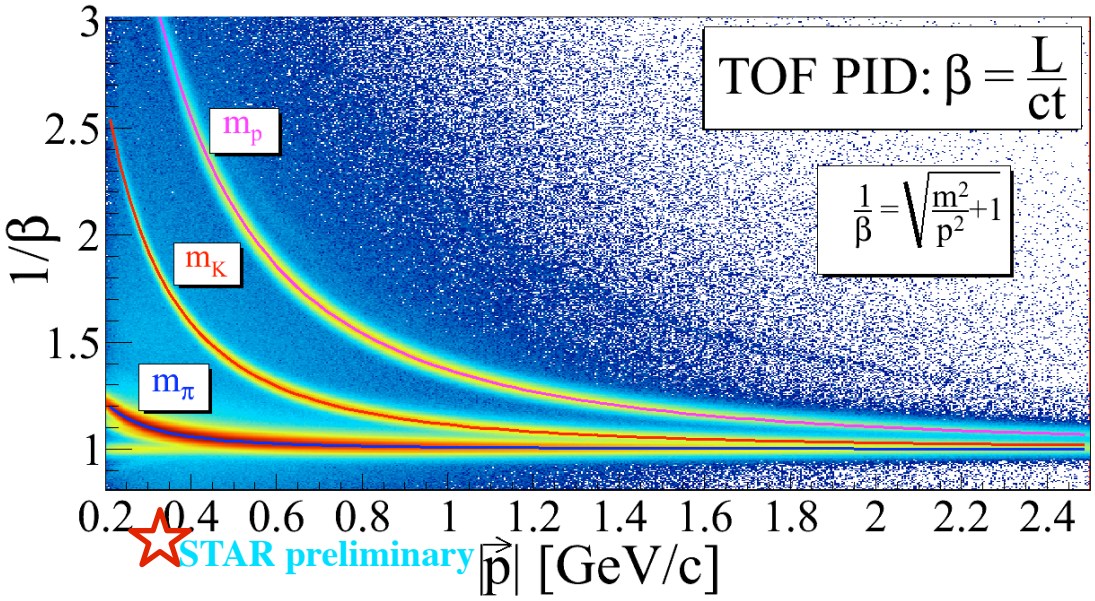
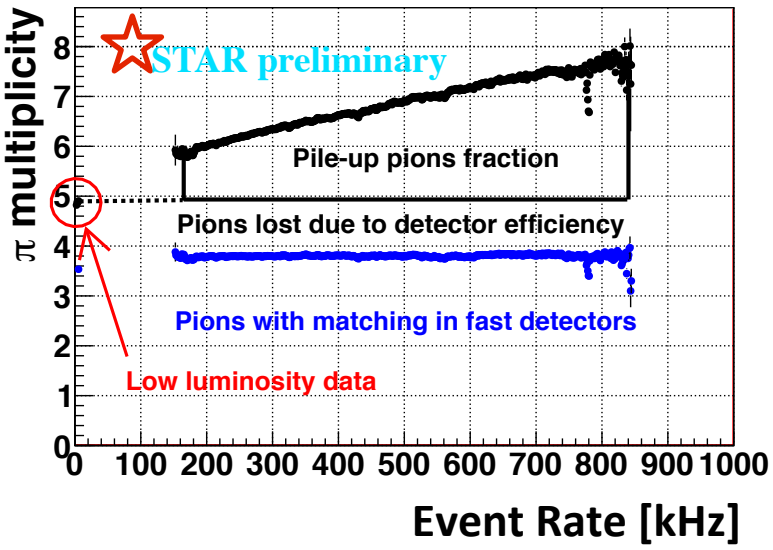
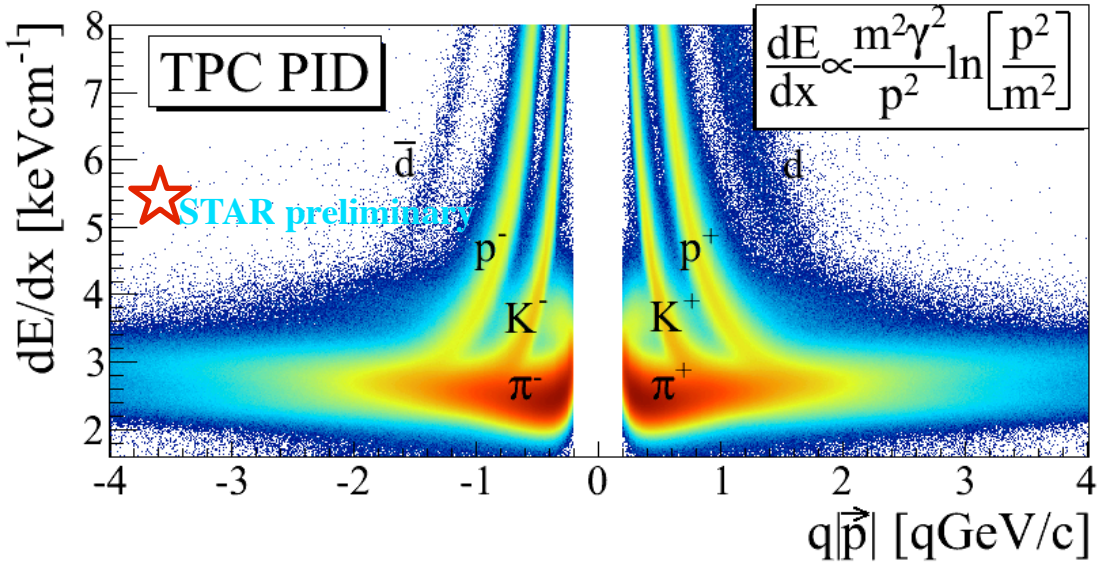
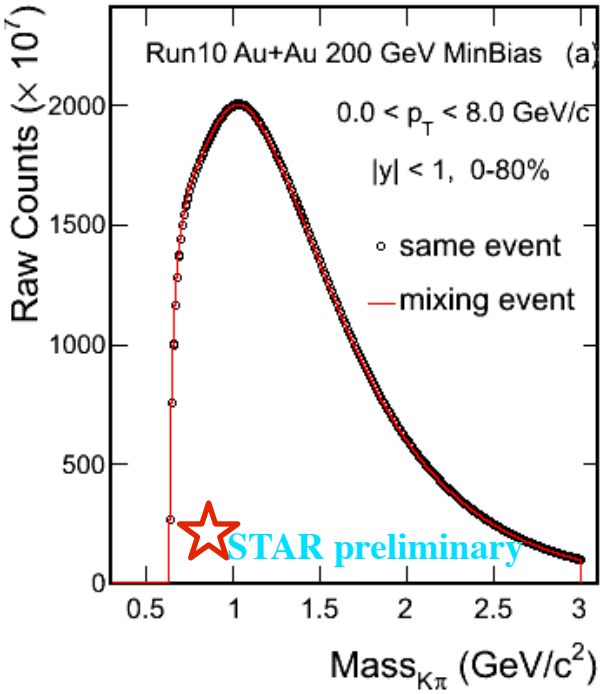


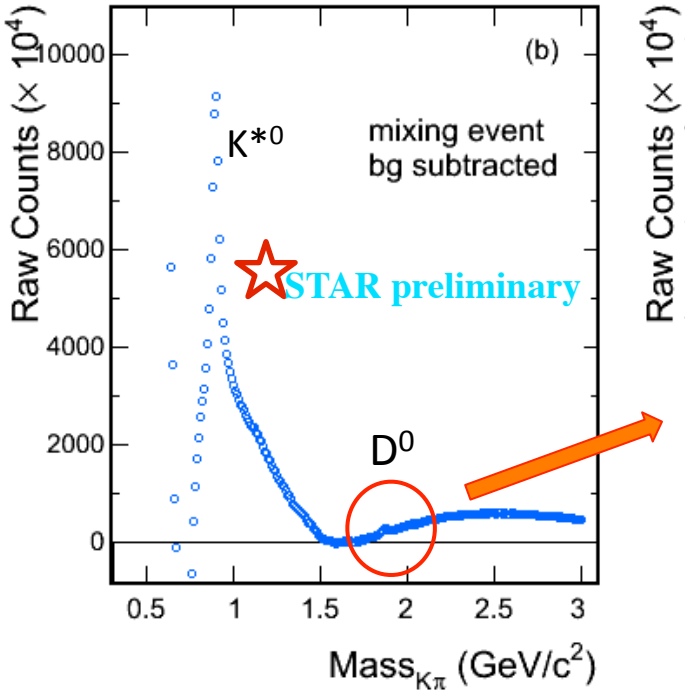


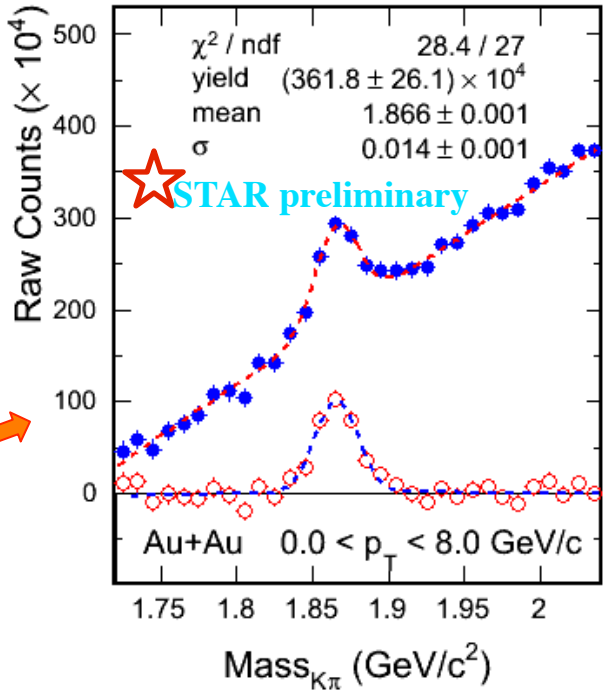




D^0 in Au+Au 200 GeV (Run 10 & 11)







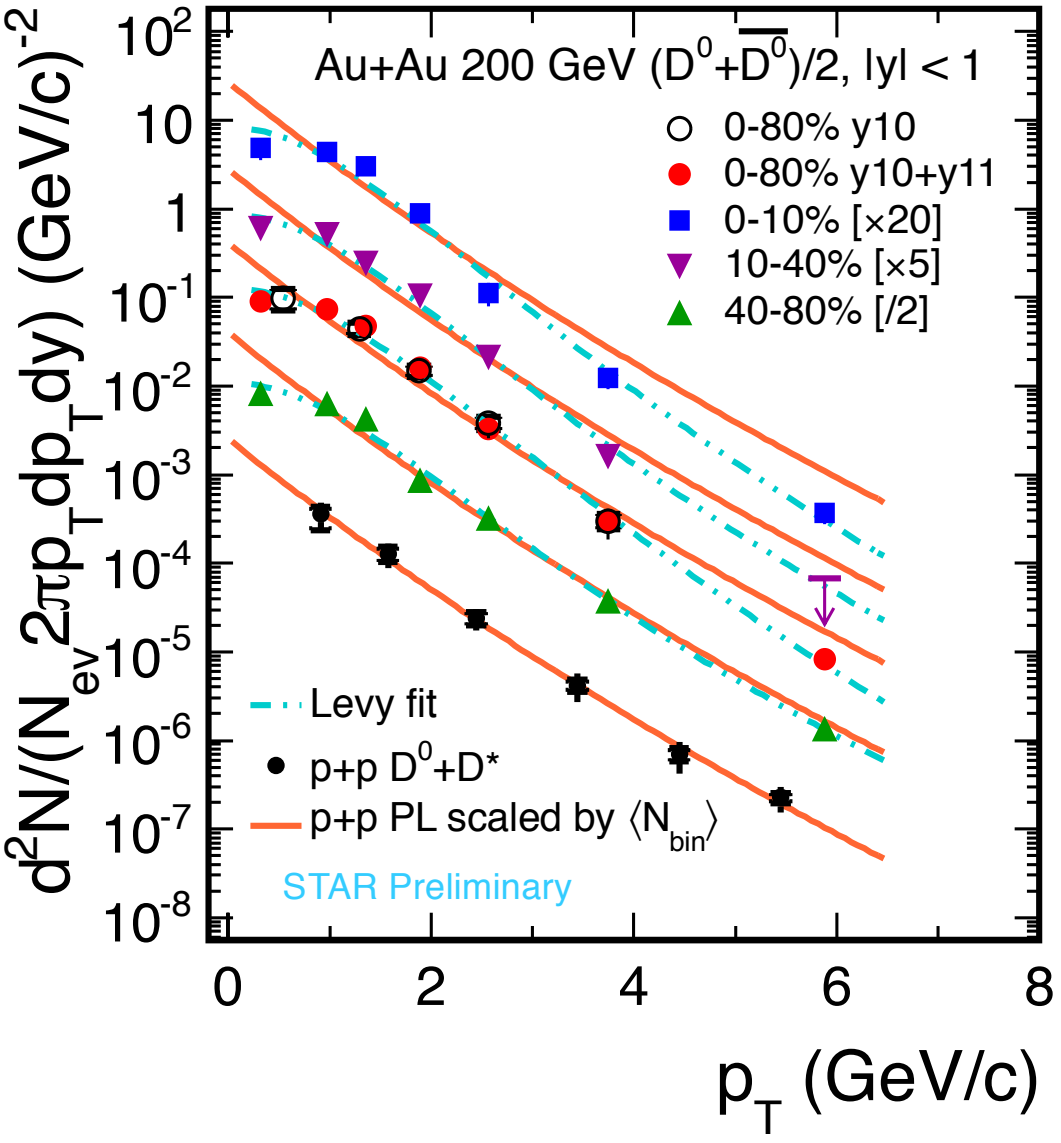
S/√(S+B) ~ 14; Mass = 1866 ± 1 MeV/c^2 (PDG: 1864.5 ± 0.4 MeV/c^2)

split into 7 p_T and 3 centrality bins

fit by Lévy function

$$\frac{1}{2\pi p_T}\frac{\mathrm{d}^2N}{\mathrm{d}p_T\mathrm{d}y} = \frac{\mathrm{d}N}{\mathrm{d}y}\frac{(n-1)(n-2)}{2\pi nC[nC+m_0(n-2)]}\left(1+\frac{\sqrt{p_T^2+m_0^2}-m_0}{nC}\right)^{-n}$$

D^0 Au+Au 200 GeV Invariant Yield Spectra & R_{AA}



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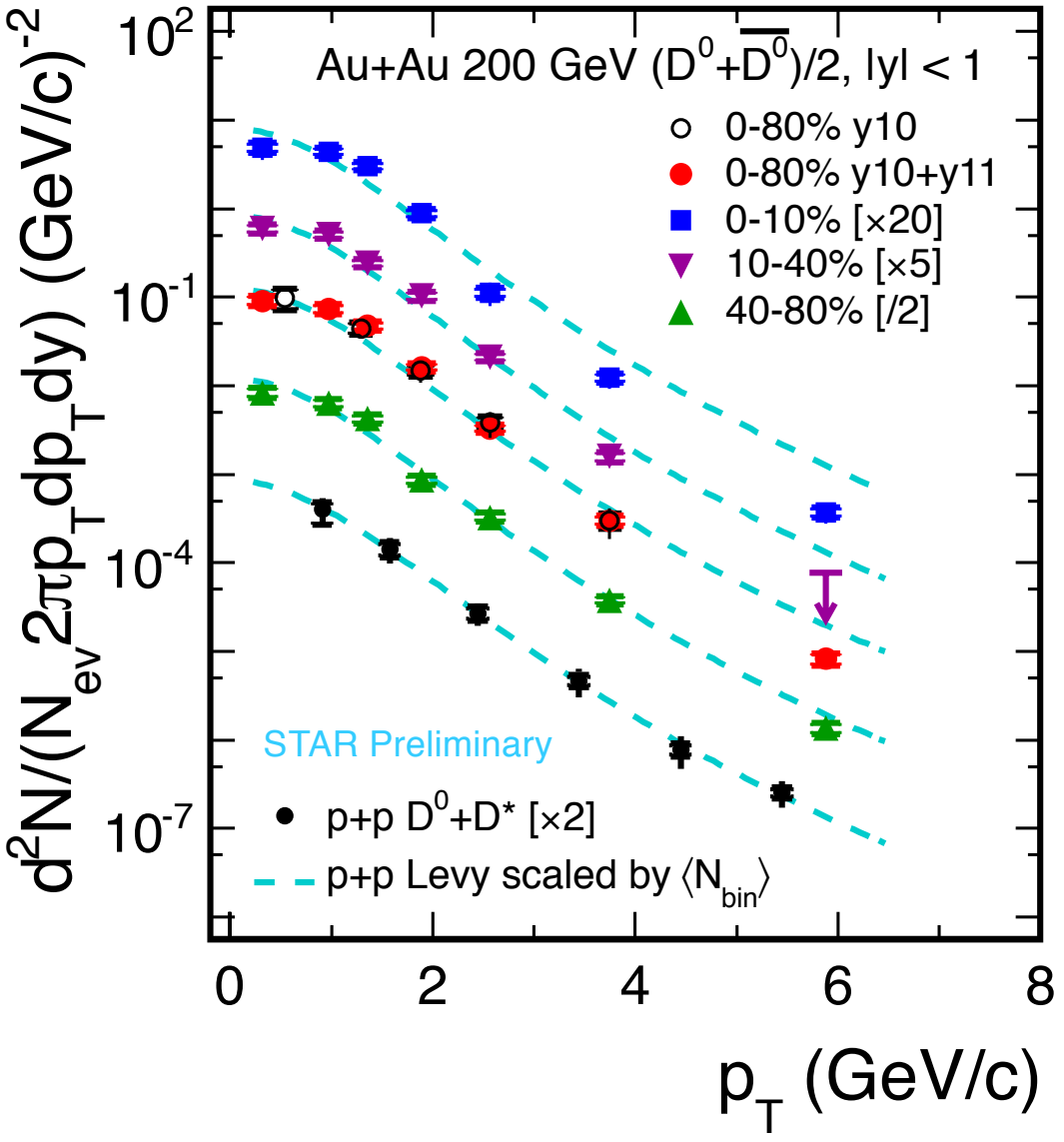

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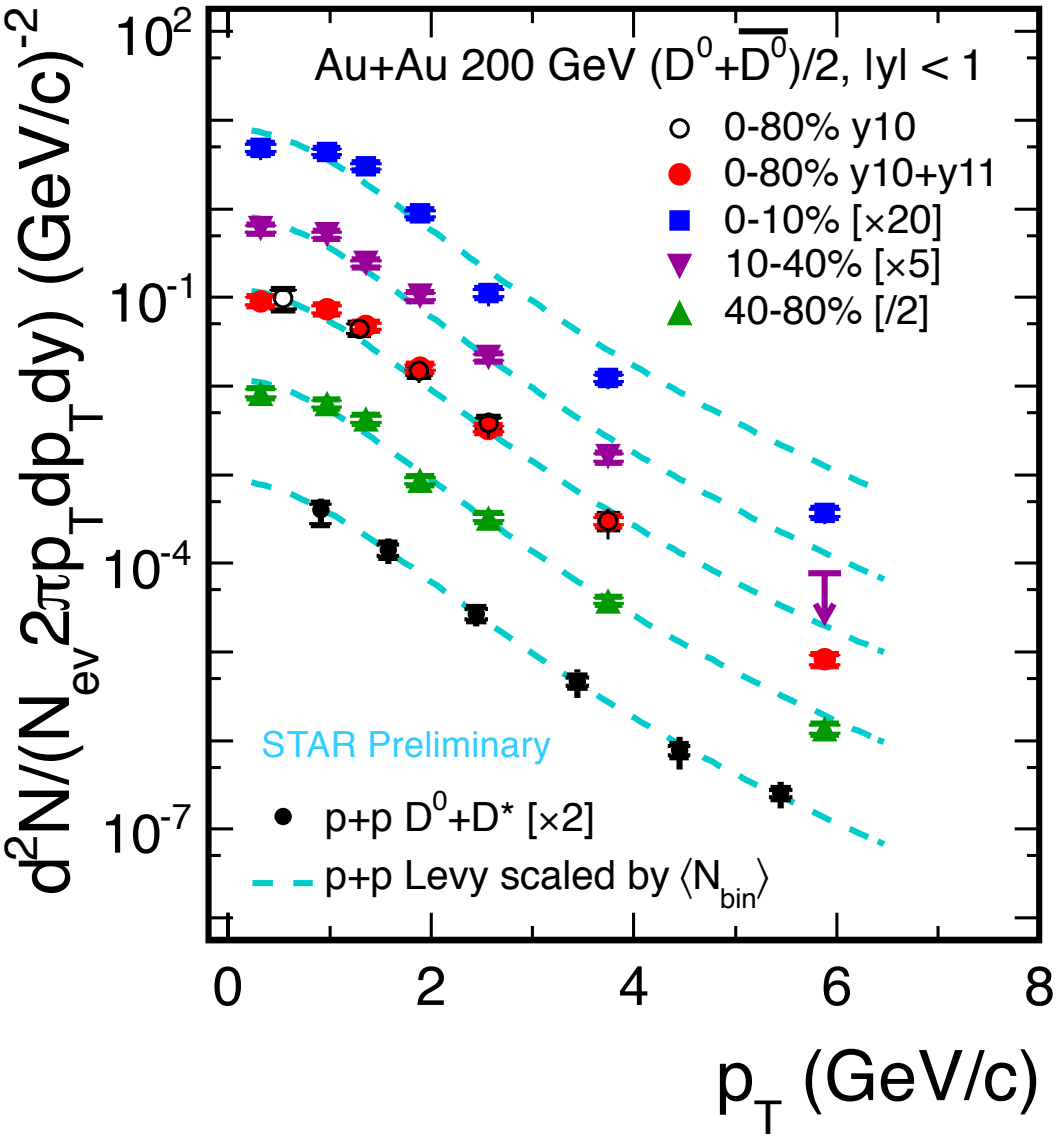

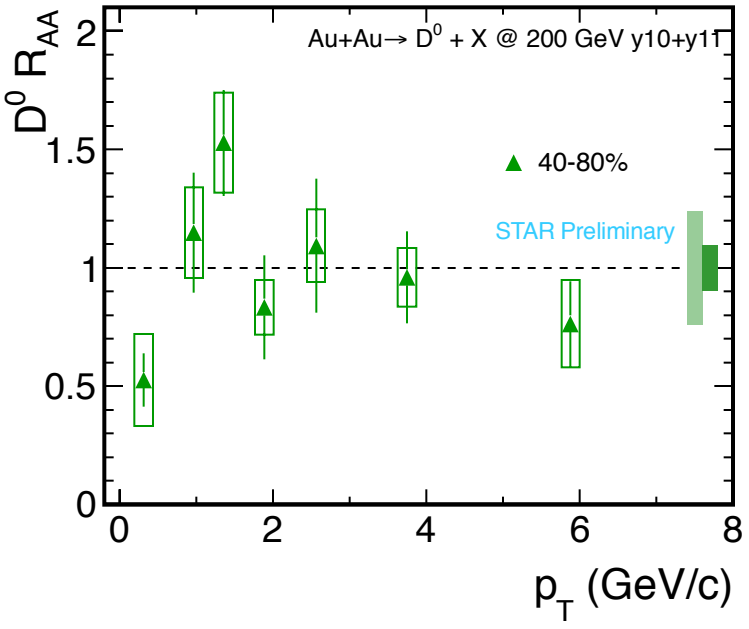

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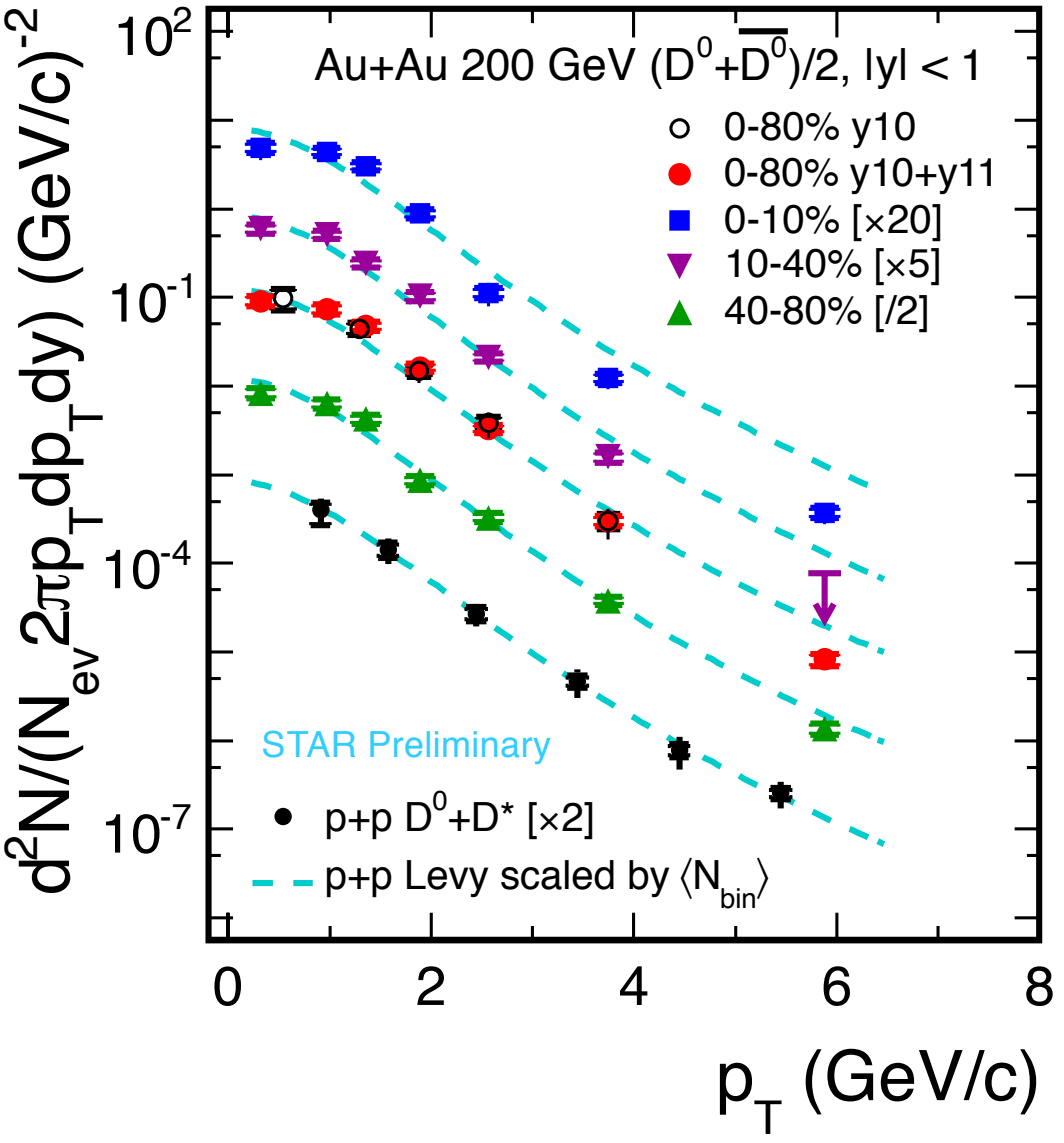

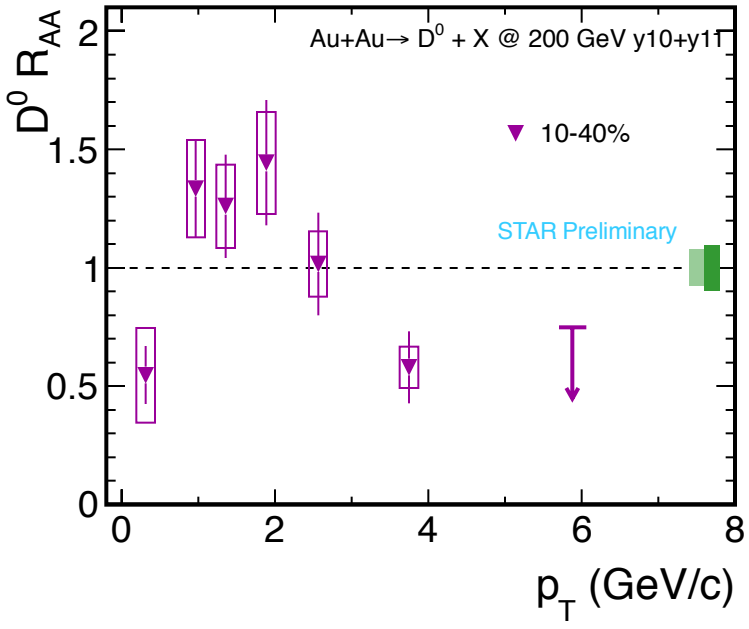

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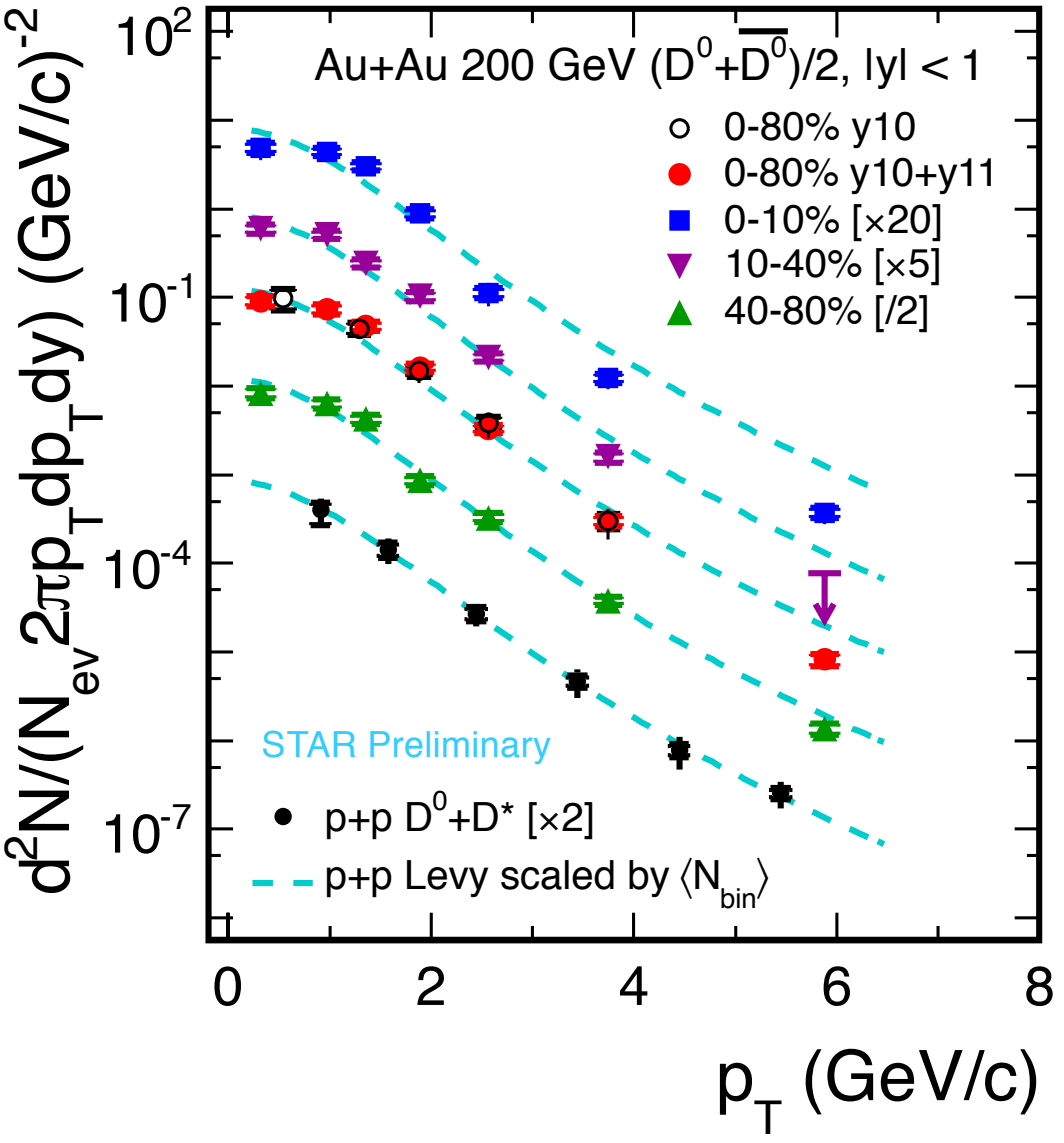

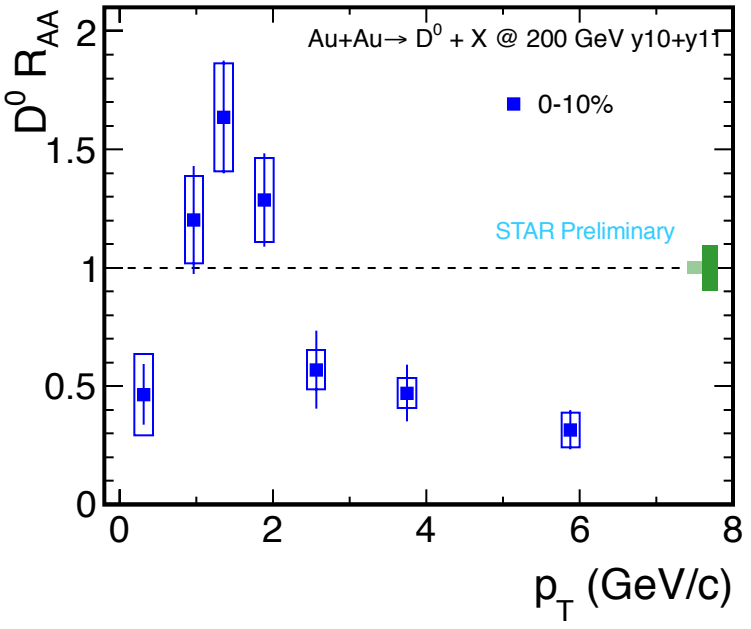

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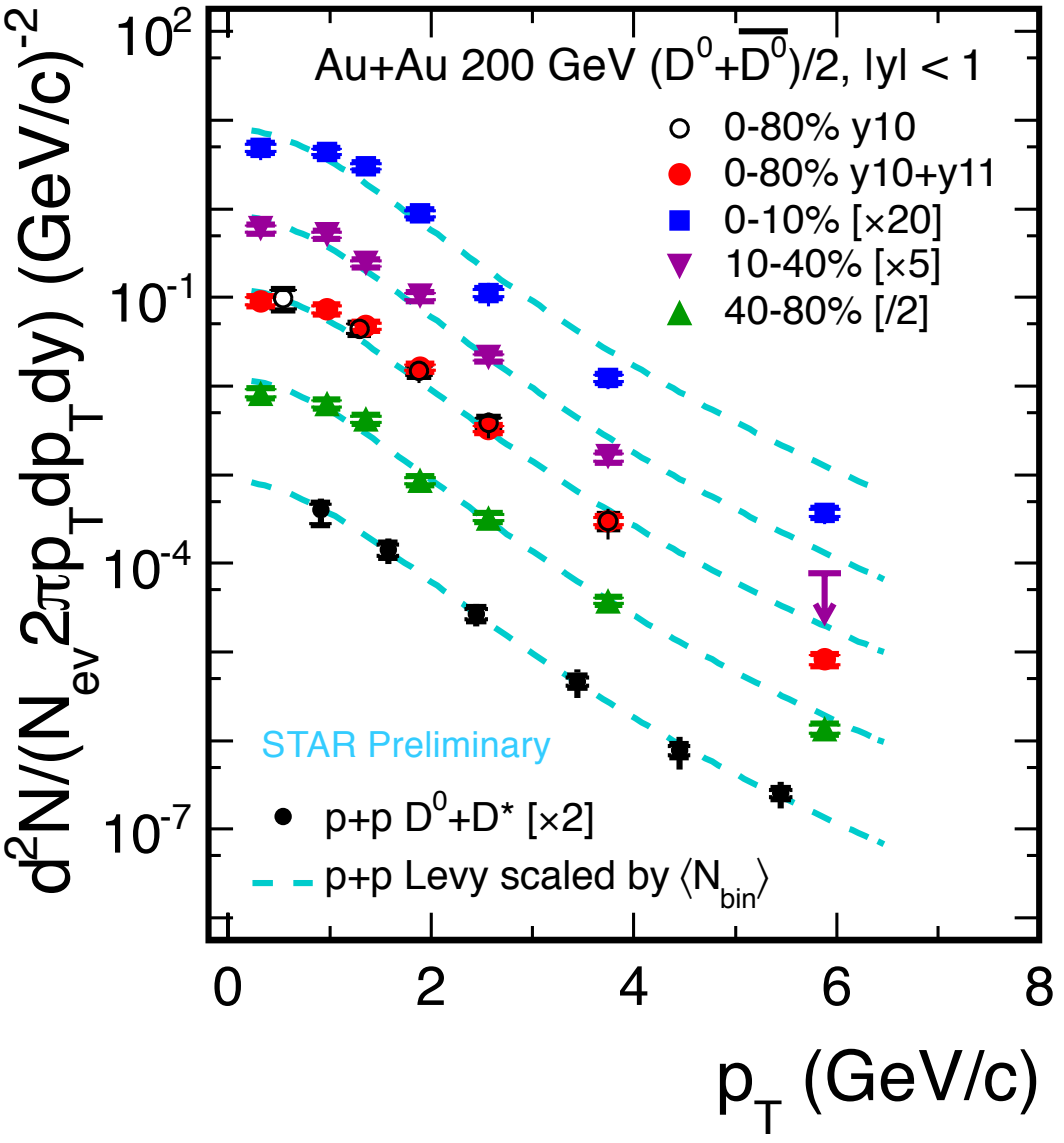

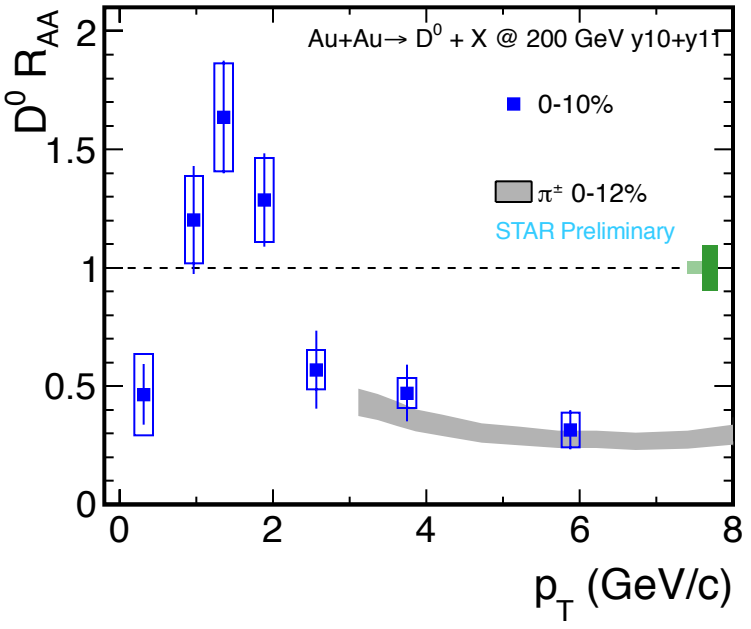

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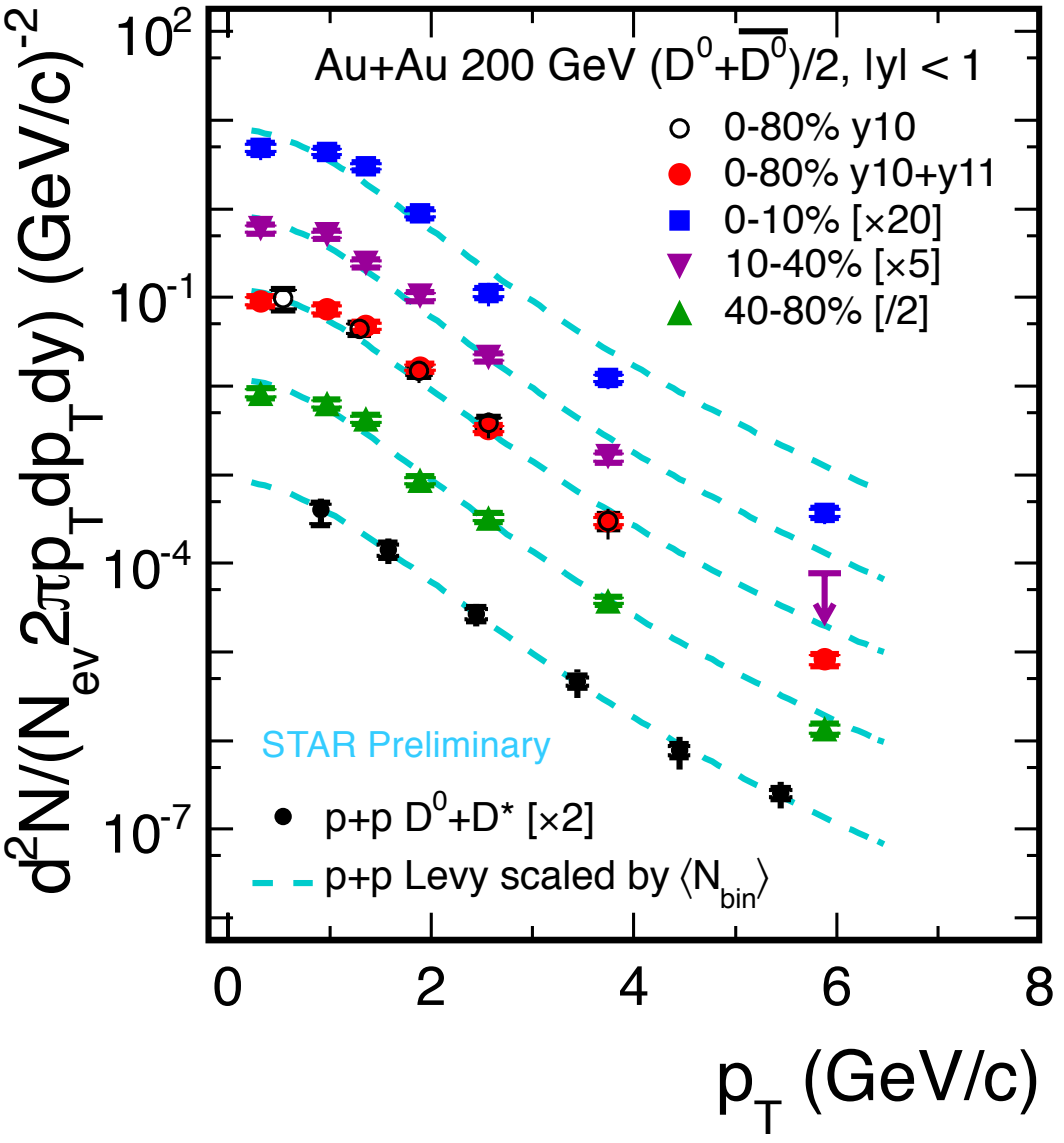

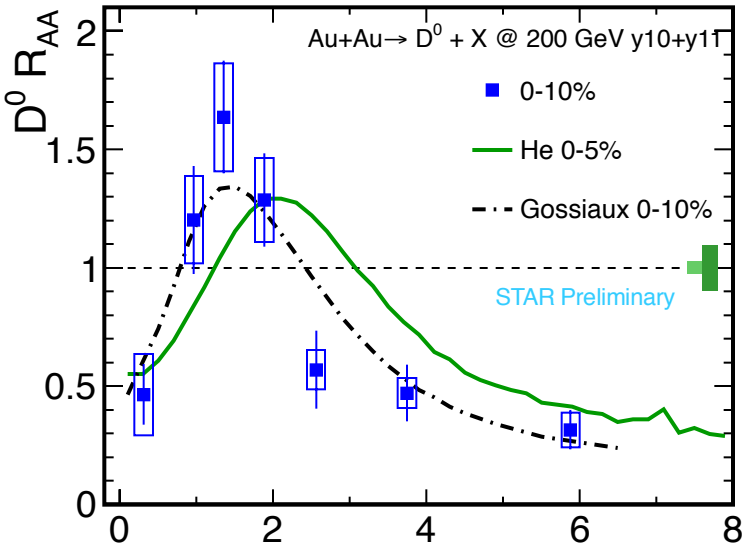

He: arXiv:1204.4442
Focker-Planck
Resonance
recombination

Gossiaux: arXiv:1207.5445
Boltzmann
pQCD with running coupling

- ★ Suppression at high pT in central and mid-central collisions
- ★ Enhancement at intermediate pT.

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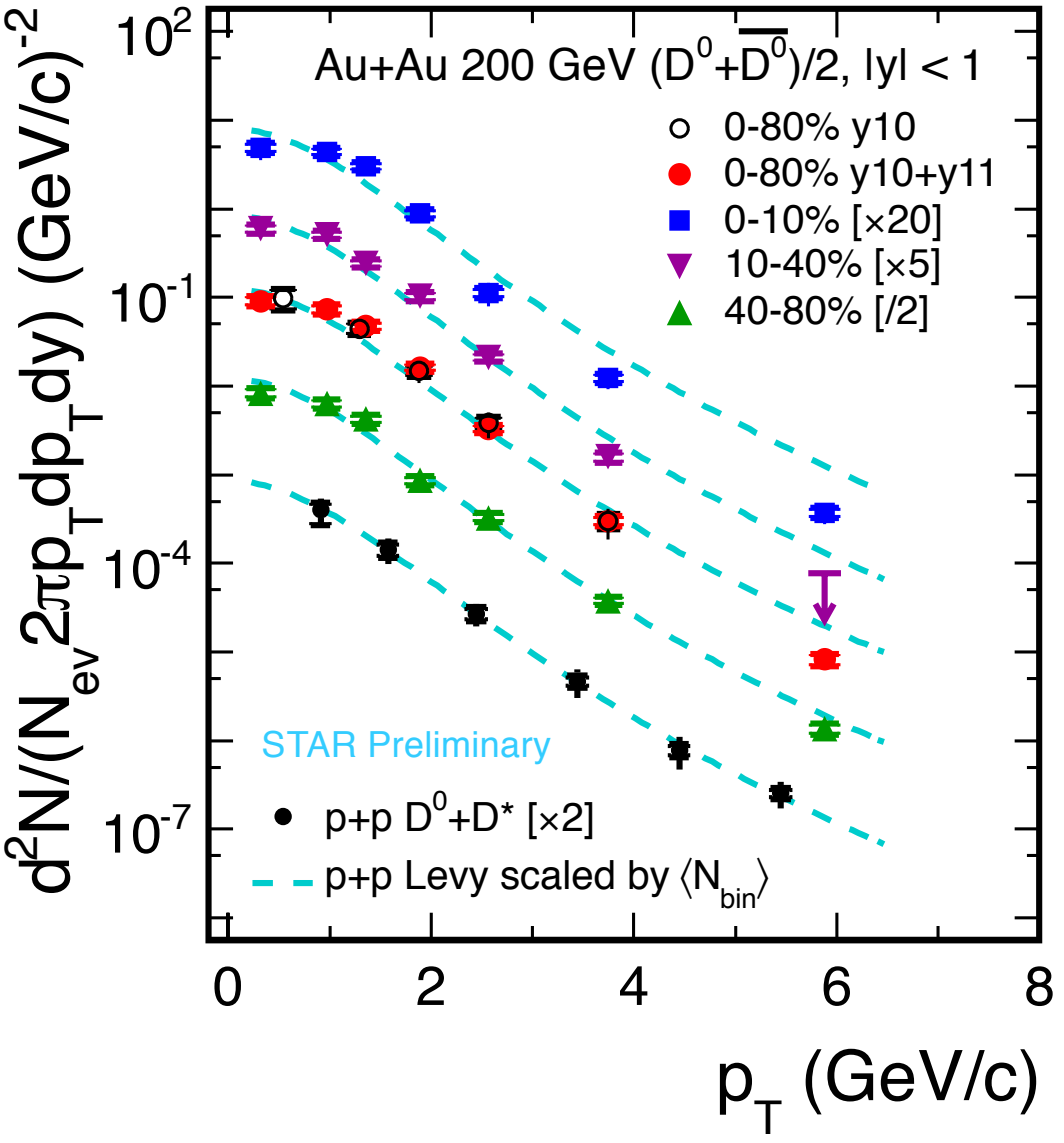

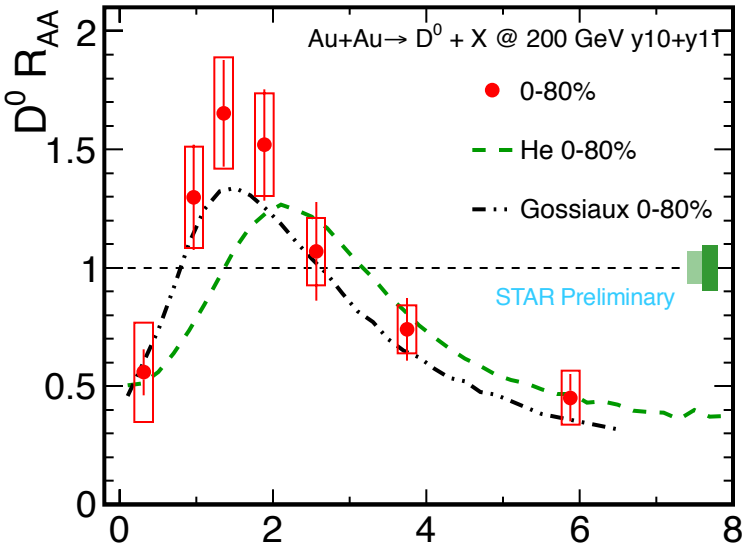

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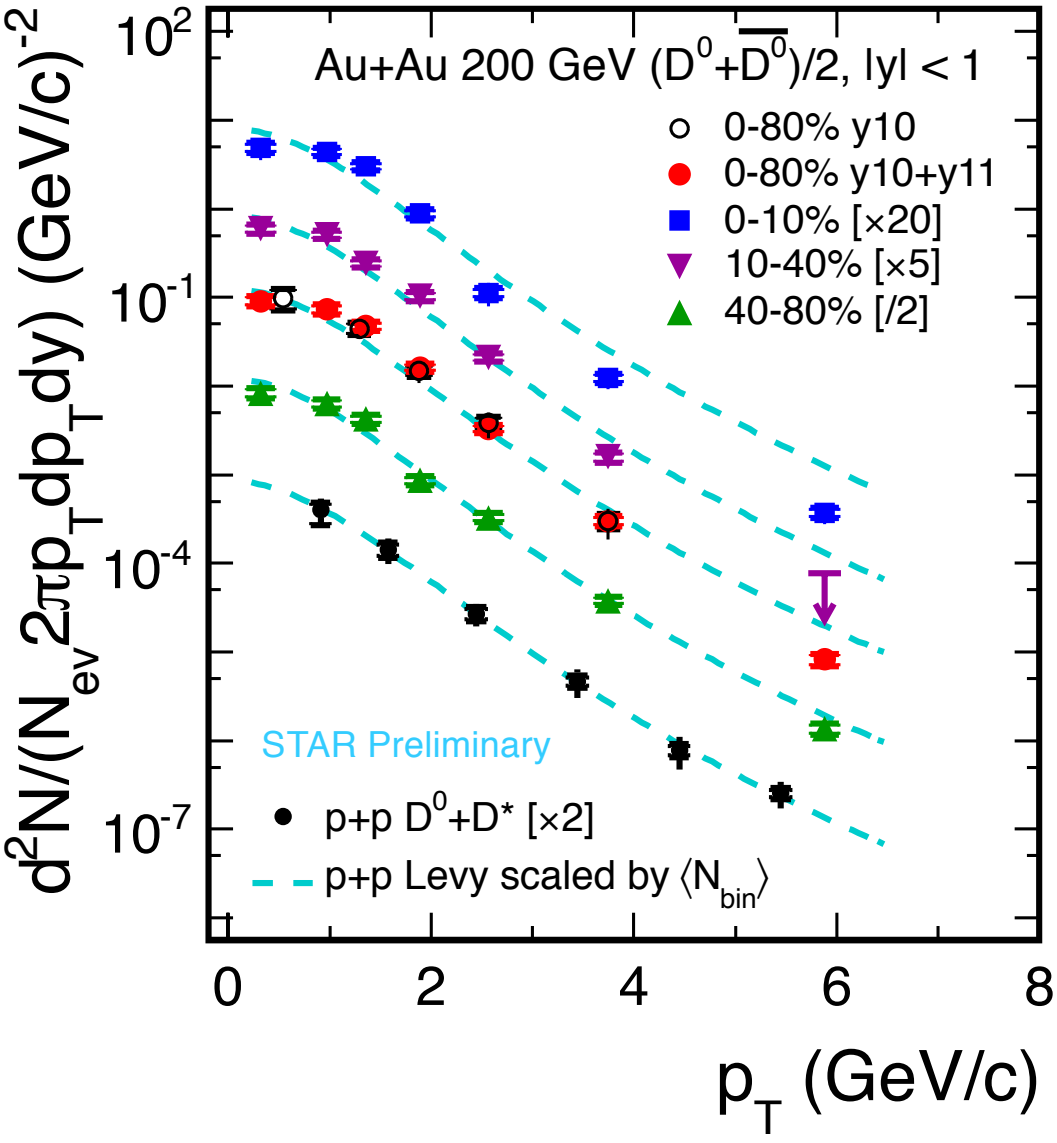
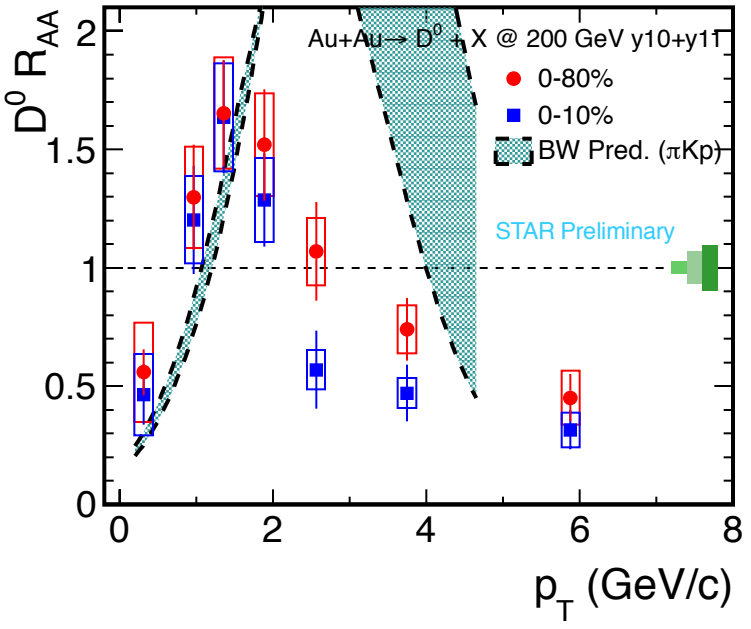
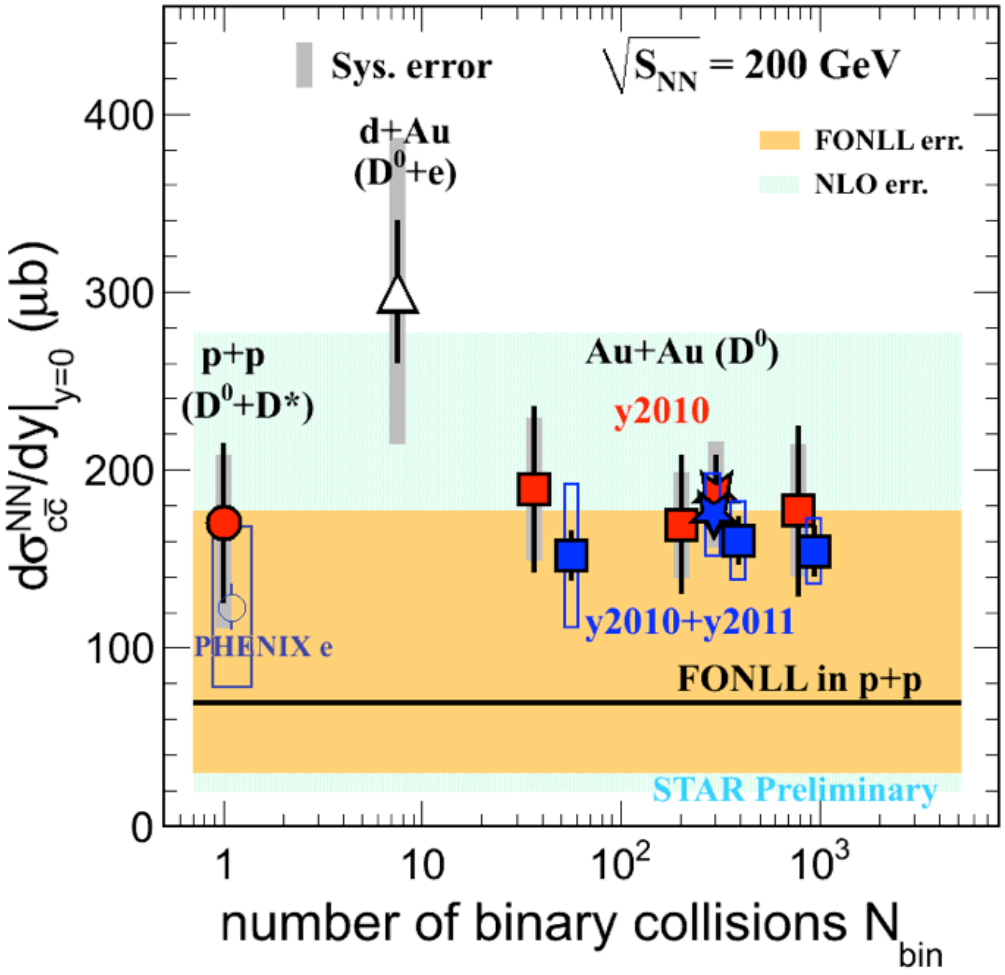
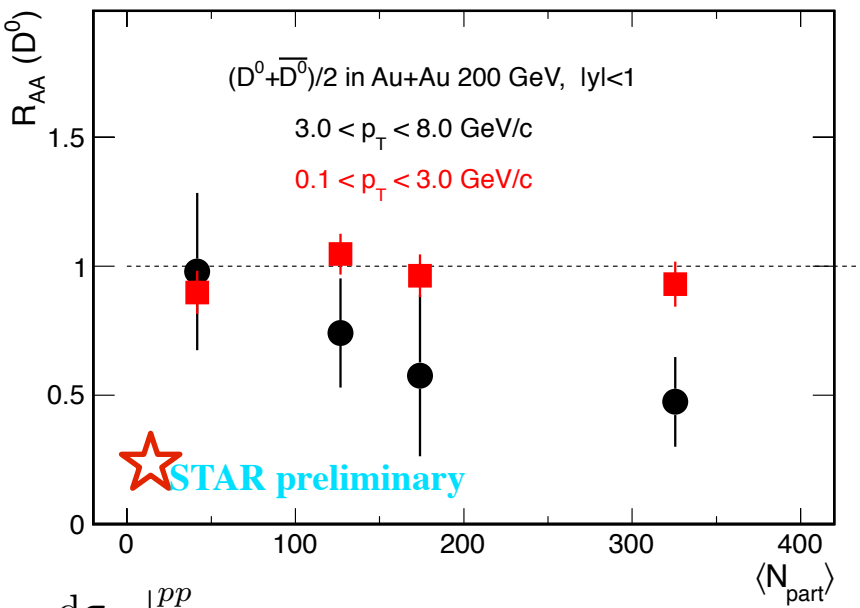




- ★ Suppression at high pT in central and mid-central collisions
- ★ Enhancement at intermediate pT.
- ★ D^0 freeze out earlier than light hadron and/or does not have much radial flow as light quarks

Number-of-binary-collisions Scaling





$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{y=0}^{pp} = 170 \pm 45(\text{stat.})^{+38}_{-59}(\text{sys.})\ \mu\text{b}$$

$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{y=0}^{AuAu} = 175 \pm 13(\text{stat.}) \pm 23(\text{sys.})\ \mu\text{b}$$

Charm cross section follows number of binary collisions scaling =>
Charm quark produced at early stage of collisions.

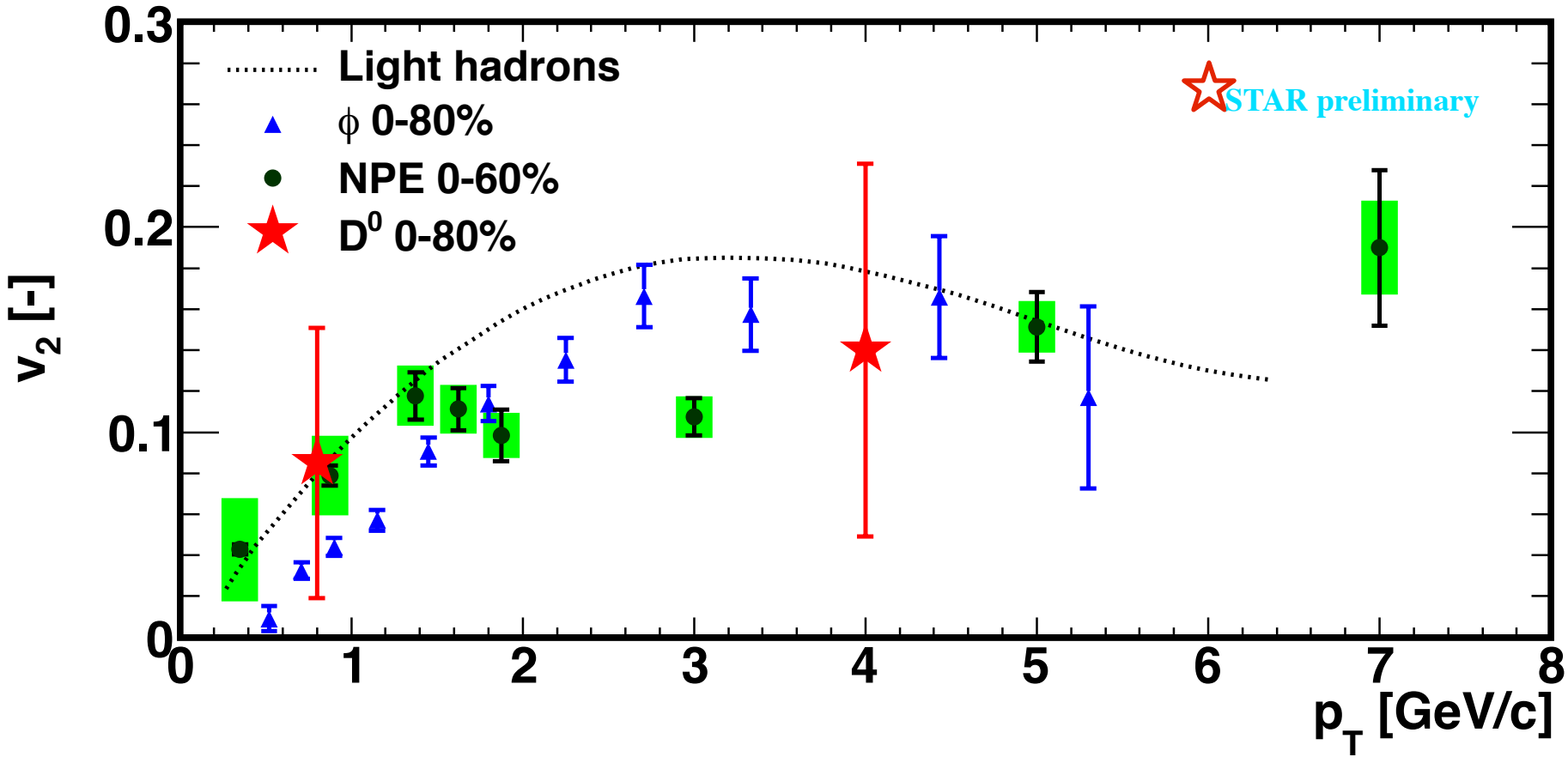
[1] FONLL: M. Cacciari, PRL 95 (2005) 122001.
[2] NLO: R. Vogt, Eur.Phys.J.ST 155 (2008) 213
[3] PHENIX e: A. Adare, et al., PRL 97 (2006) 252002.

D^0 Au+Au 200 GeV Elliptic Flow

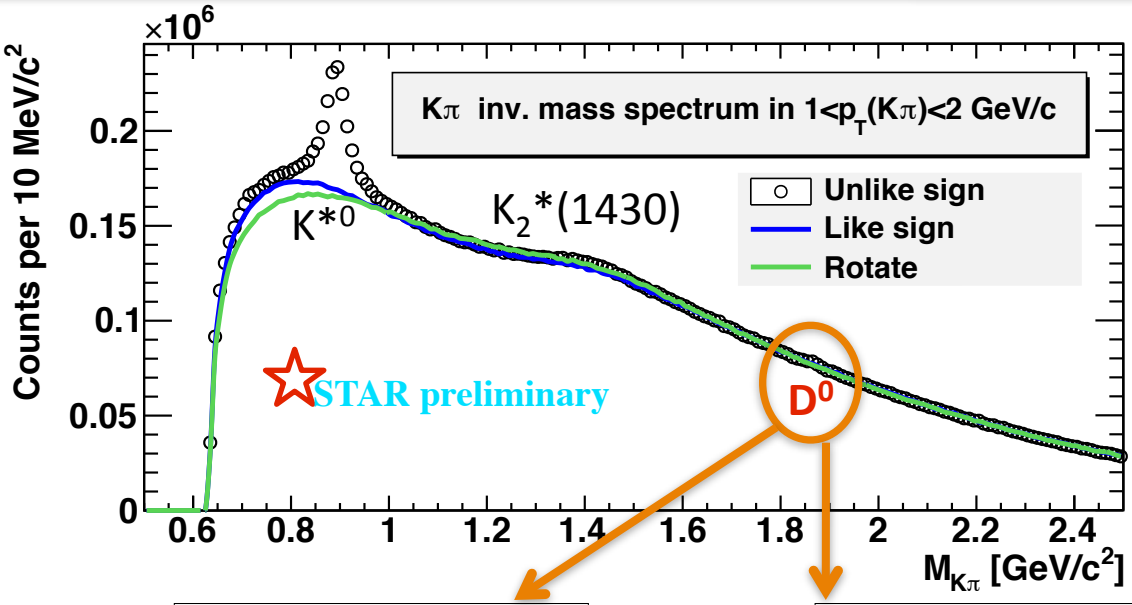
$$E\frac{\mathrm{d}^3N}{\mathrm{d}\mathbf{p}^3} = \frac{1}{N_{\mathrm{ev}}}\frac{\mathrm{d}^2N}{p_T\mathrm{d}p_T\mathrm{d}y}\left(1+2\sum_{n=1}^{\infty}v_n\cos[n(\phi-\Psi_{\mathrm{RP}})]\right)$$

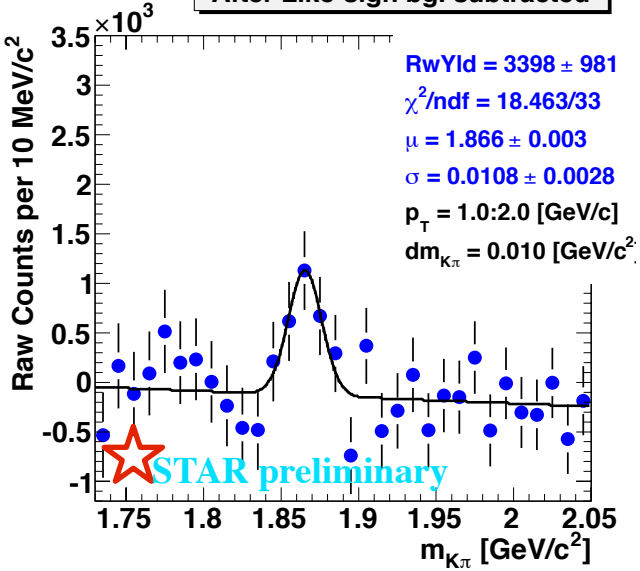
$$v_n(p_T,y) = \langle\cos[n(\phi-\Psi_{\mathrm{RP}})]\rangle$$

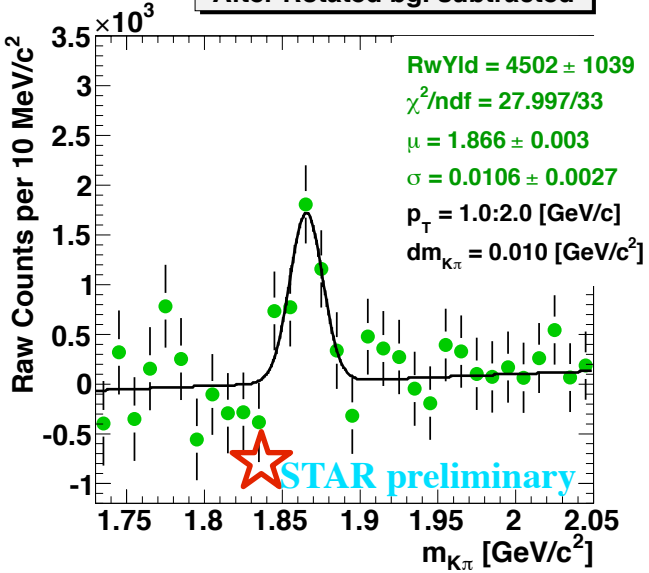
Charm flow: Daniel Kikola, poster 216
J/ψ flow: Barbara Trzeciak, Parallel 1D
NPE flow: Mustafa Mustafa, Parallel 7A



D^0 and D* Signal in p+p 500 GeV







minimum bias L^{-1}=1.53 nb^{-1}

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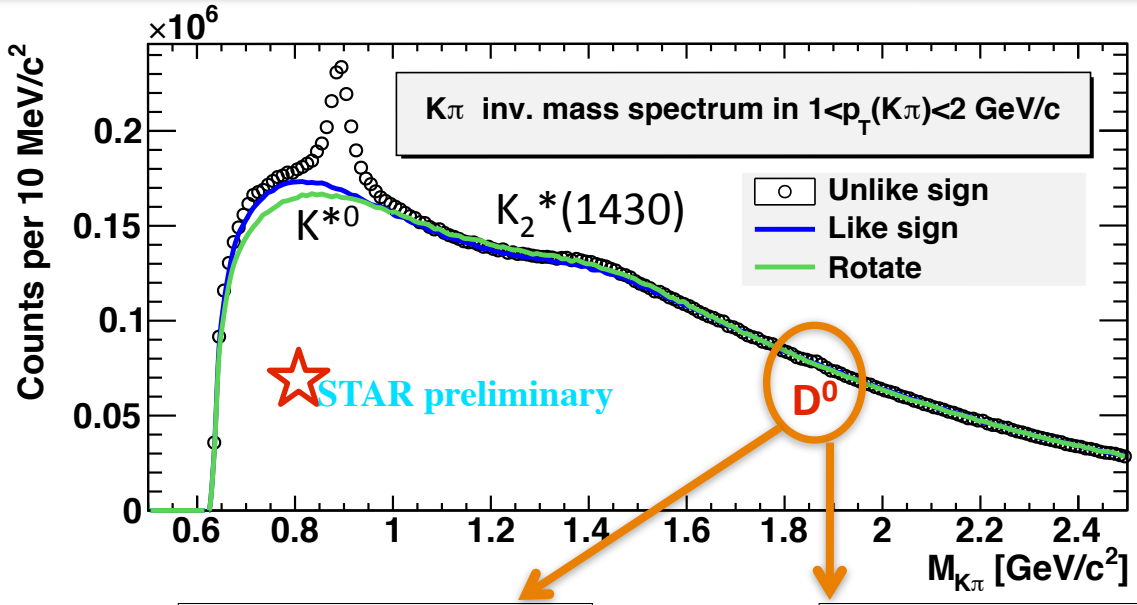
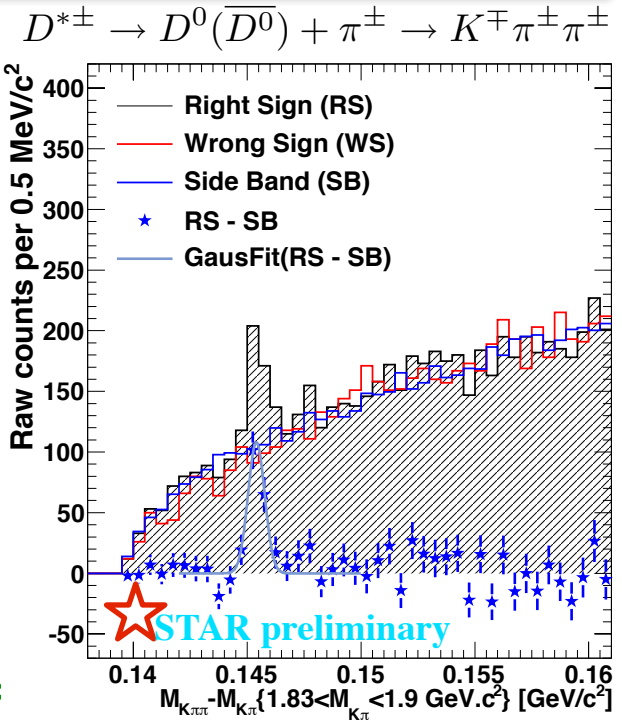
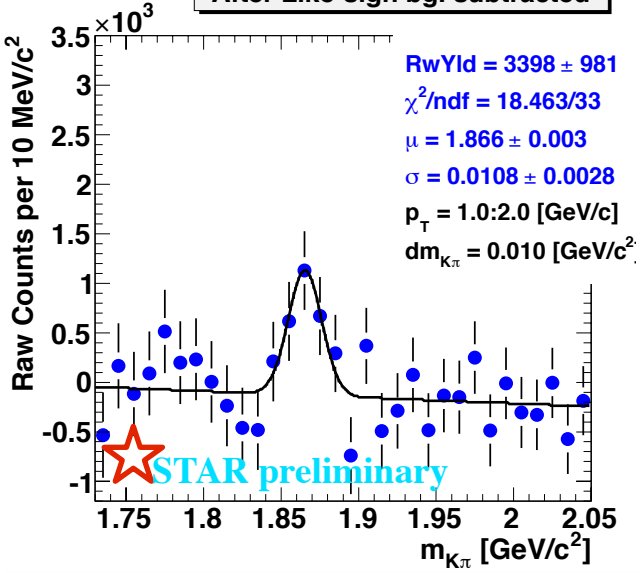
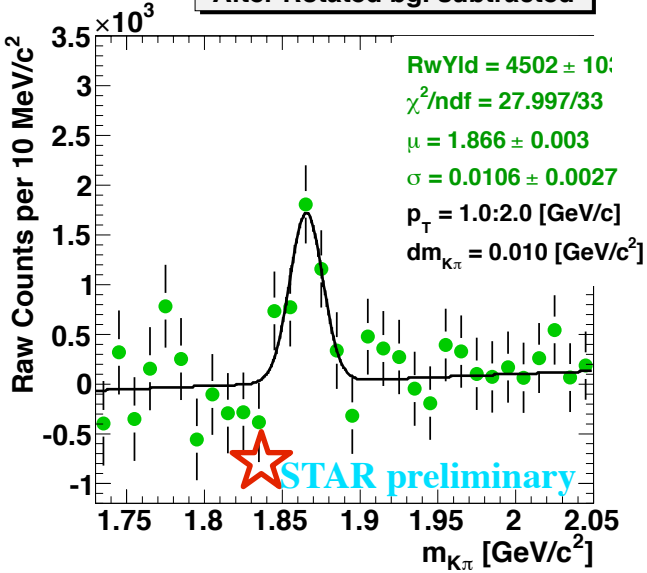




After Like-sign bg. subtracted



After Rotated bg. subtracted



right sign : $1.83<M(K\pi)<1.9$ GeV/c^2

wrong sign : $K^-\pi^+\pi^- + K^+\pi^-\pi^+$

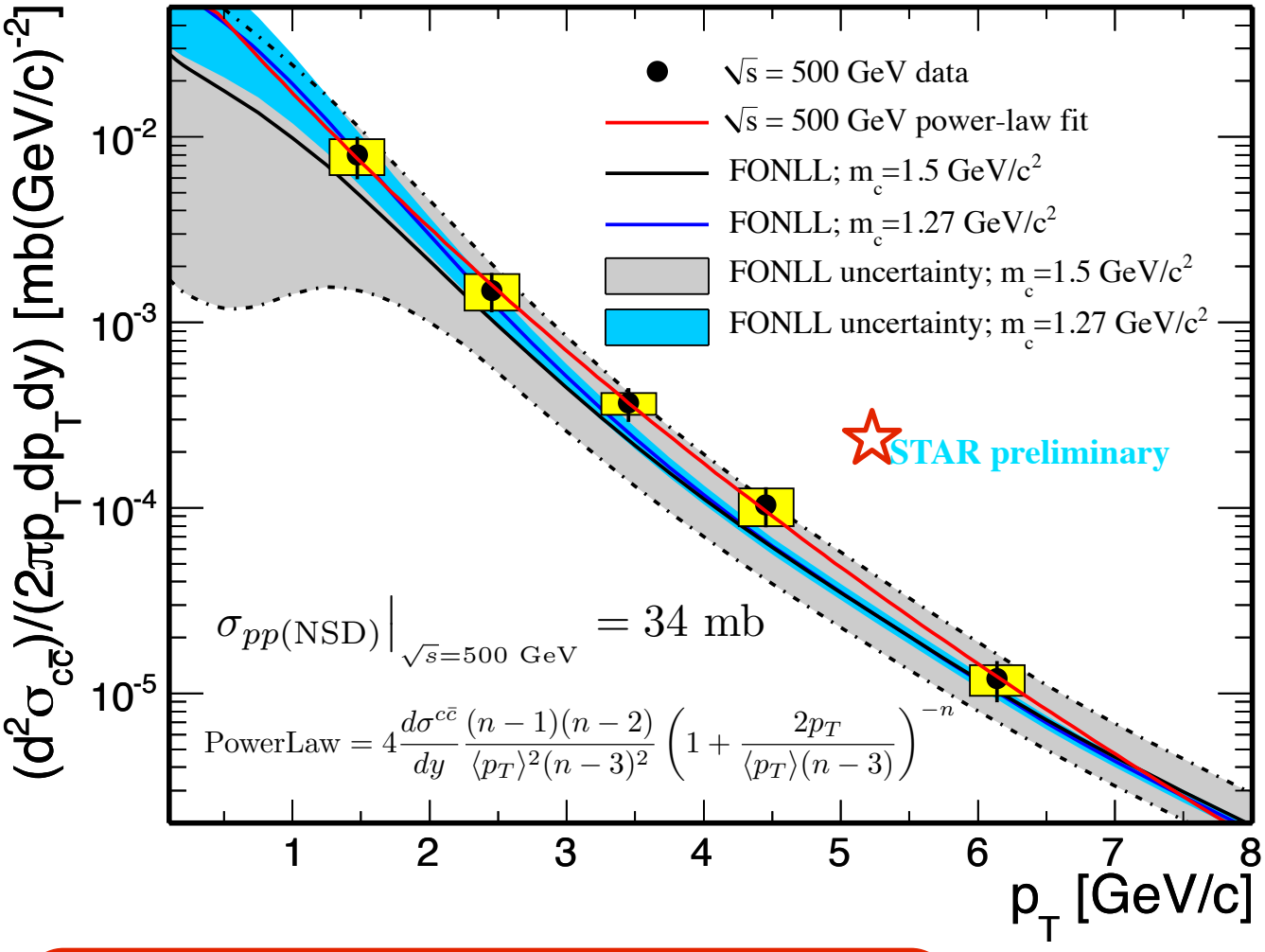
side band : $1.7<M(K\pi)<1.8$ + $+1.92<M(K\pi)<2$ GeV/c^2

minimum bias L^{-1}=1.53 nb^{-1}

Different methods reproduce combinatorial background.

Consistent results from two background methods.

D^0 and D^* p_T Spectra in p+p 500 GeV



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

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

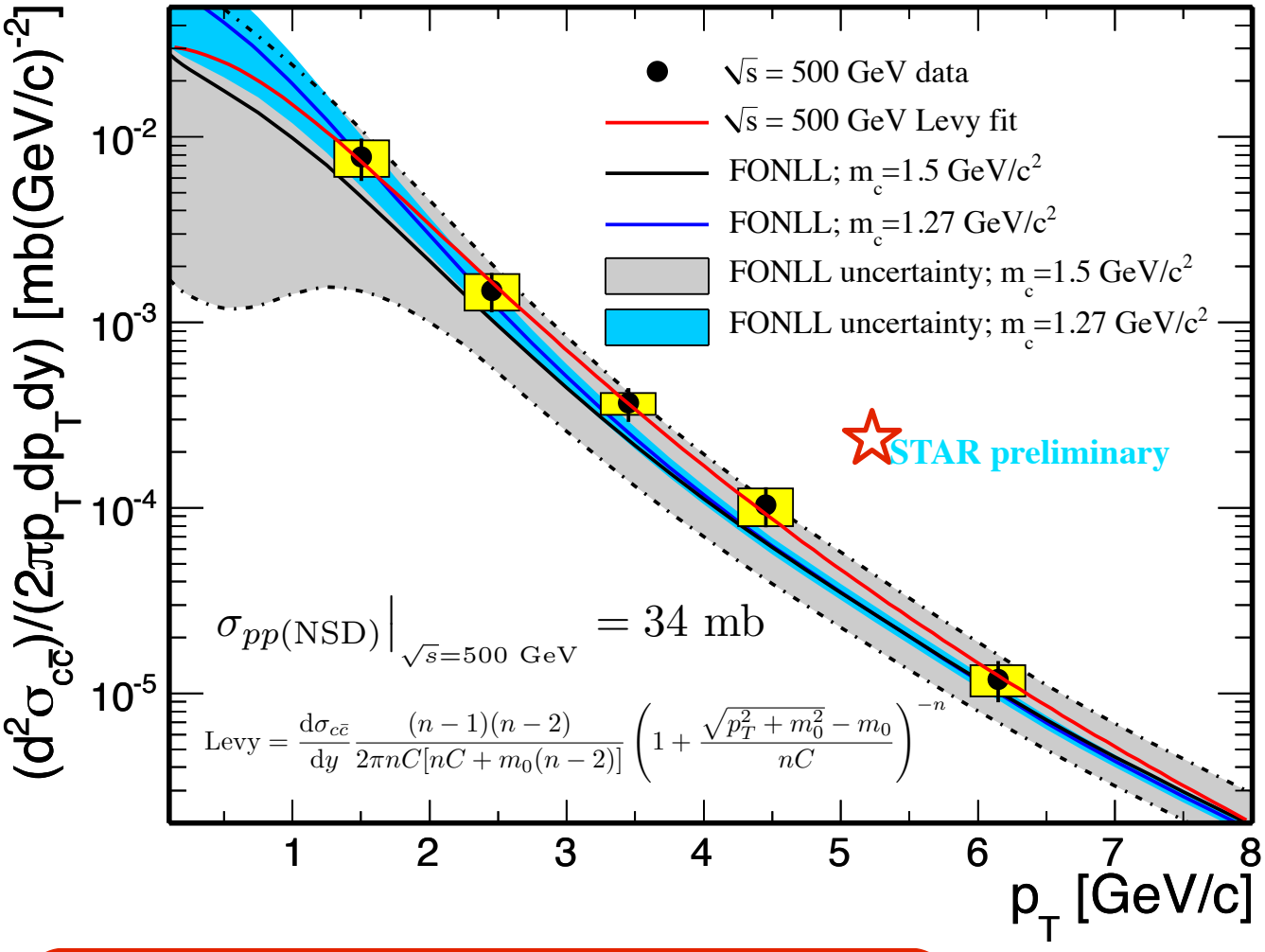
[1] C. Amsler et al. (Particle Data Group), PLB 667 (2008) 1.

[2] FONLL calculation: Ramona Vogt
$\mu_F = \mu_R = m_c$, $|y| < 1$

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

$$\left.\frac{\mathrm{d}\sigma_{c\bar{c}}}{\mathrm{d}y}\right|_{y=0} = \left.\frac{\mathrm{d}N_{c\bar{c}}}{\mathrm{d}y}\right|_{y=0} \sigma_{pp(NSD)}$$

D^0 and D^* p_T Spectra in p+p 500 GeV



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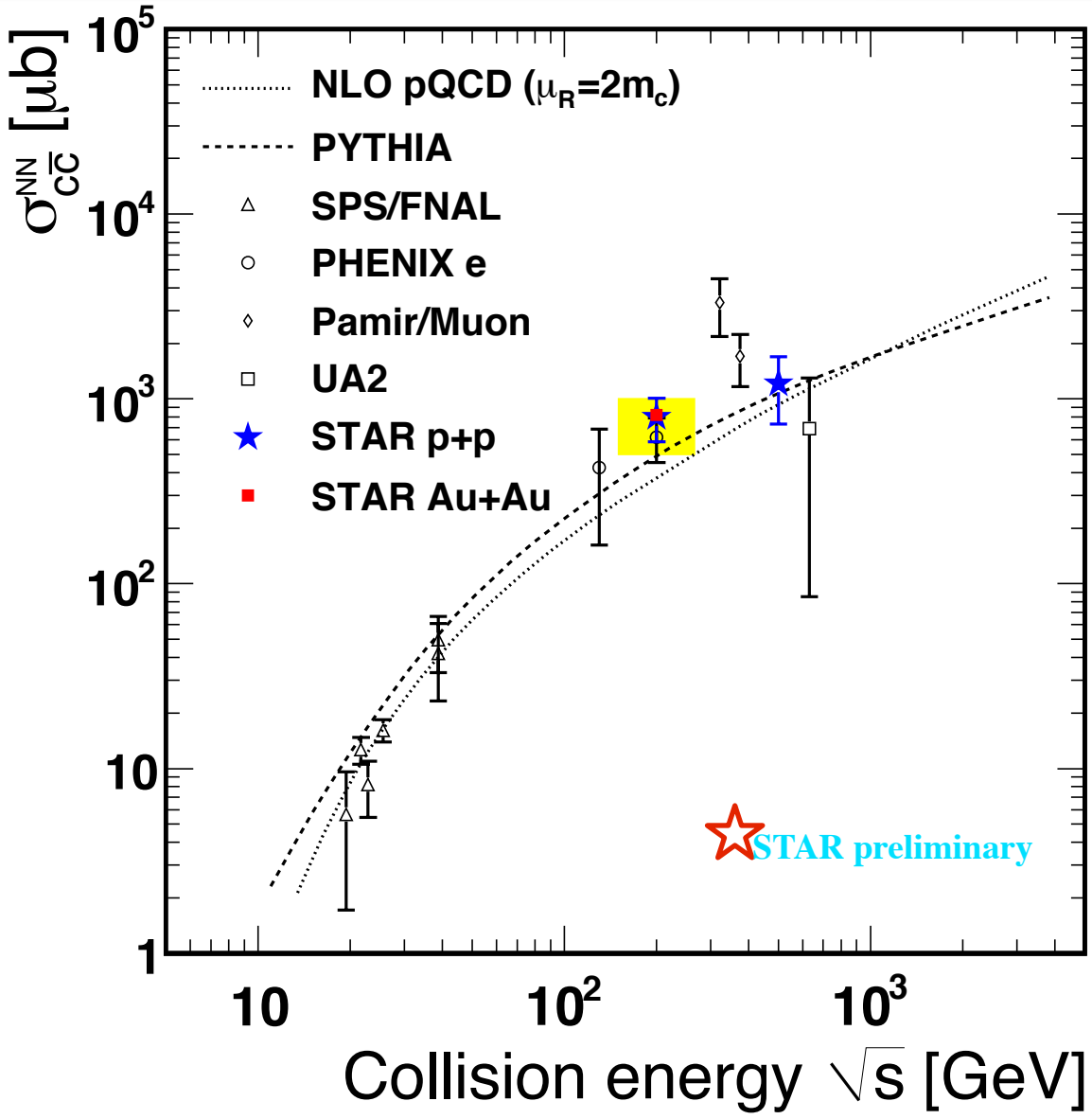
[1] C. Amsler et al. (Particle Data Group), PLB 667 (2008) 1.

[2] FONLL calculation: Ramona Vogt
$\mu_F = \mu_R = m_c$, $|y| < 1$

$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{y=0}^{\sqrt{s}=500\mathrm{GeV}} = 174 \pm 55(\mathrm{stat.}) \pm 47(\mathrm{sys.})\ \mu\mathrm{b}$$

$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{y=0} = \left.\frac{dN_{c\bar{c}}}{dy}\right|_{y=0} \sigma_{pp(NSD)}$$

Total Charm Cross Section



$$\sigma_{c\bar{c}} = F \left. \frac{\mathrm{d}N_{c\bar{c}}}{\mathrm{d}y} \right|_{y=0}$$

$$F \equiv \text{mid } y \rightarrow \text{full } y$$

500 GeV, F = 5.6

$$\sigma_{c\bar{c}} = 1215 \pm 482(\text{stat.}) \pm 409(\text{sys.})\ \mu\text{b}$$

200 GeV, F = 4.7

$$\sigma_{c\bar{c}} = 797 \pm 210(\text{stat.}) \,^{+208}_{-295}(\text{sys.})\ \mu\text{b}$$

Summary

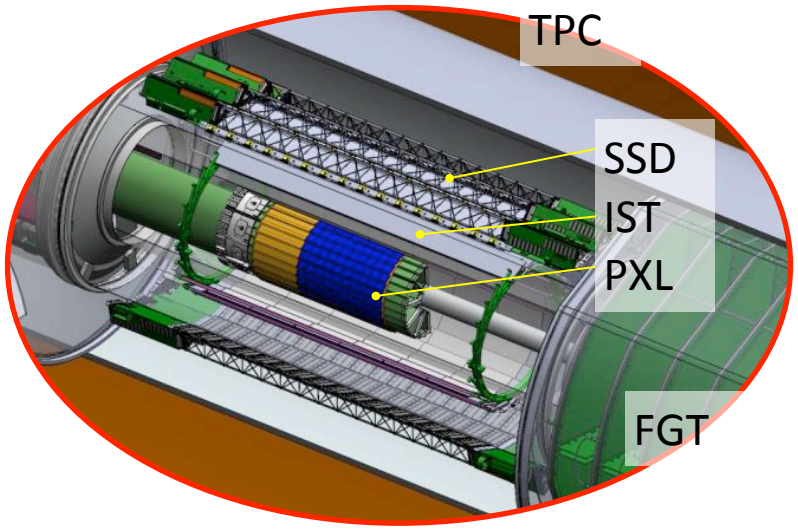
- ★ D^0 and D* are measured in p+p 200 GeV up to 6 GeV/c and in p+p 500 GeV up to 6 GeV/c
  - ➡ $\mathrm{d}^2\sigma^{c\bar{c}}/p_T\mathrm{d}p_T\mathrm{d}y$ consistent with FONLL upper limit.
- ★ D^0 are measured in Au+Au 200 GeV up to 6 GeV/c for 3 centrality bins.
  - ➡ Charm cross sections at mid-rapidity follow number of binary collisions scaling
  - ➡ Strong suppression above 2.2 GeV/c in central collisions, consistent with resonance recombination model
- ★ D^0 observation might indicate non-zero v_2, consistency with quark coalescence models
- ★ Further improvement with Heavy Flavor Tracker

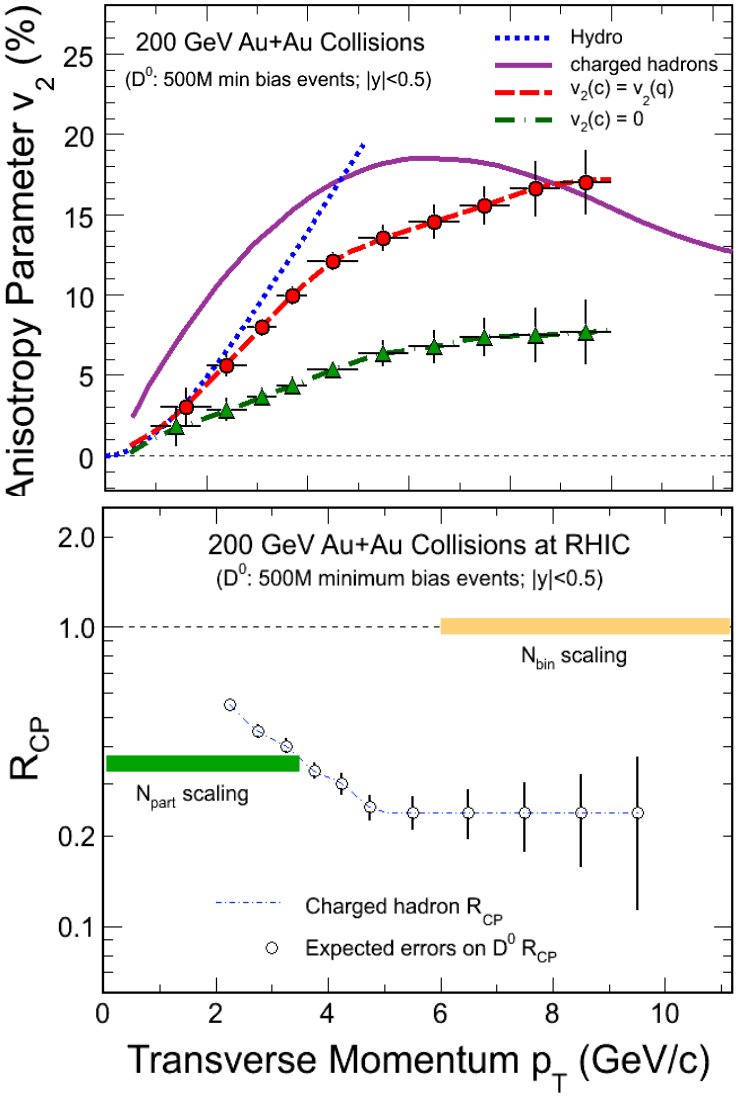

We the People
of the United States, in Order to form a more perfect Union, establish Justice,
insure domestic Tranquility, provide for the common defence, promote the general Welfare, and secure the Blessings of Liberty to ourselves
and our Posterity, do ordain and establish this Constitution for the United States of America.
Article. I.
Section. 1. All legislative Powers herein granted shall be vested in a Congress of the United States, which shall consist of a Senate and House
of Representatives.
Section. 2. The House of Representatives shall be composed of Members chosen every second Year by the People of the several States, and the Electors
in each State shall have the Qualifications requisite for Electors of the most numerous Branch of the State Legislature.
No Person shall be a Representative who shall not have attained to the Age of twenty five Years, and been seven Years a Citizen of the United States,
and who shall not, when elected, be an Inhabitant of that State in which he shall be chosen.
Representatives and direct Taxes shall be apportioned among the several States which may be included within this Union, according to their respective
Numbers, which shall be determined by adding to the whole Number of free Persons, including those bound to Service for a Term of Years, and excluding Indians
not taxed, three fifths of all other Persons. The actual Enumeration shall be made within three Years after the first Meeting of the Congress of the United States,
and within every subsequent Term of ten Years, in such Manner as they shall by Law direct. The Number of Representatives shall not exceed one for every
thirty Thousand, but each State shall have at least one Representative; and until such enumeration shall be made, the State of New Hampshire shall be
entitled to chuse three, Massachusetts eight, Rhode-Island and Providence Plantations one, Connecticut five, New-York six, New Jersey four, Pennsylvania
eight, Delaware one, Maryland six, Virginia ten, North Carolina five, South Carolina five, and Georgia three.
When vacancies happen in the Representation from any State, the Executive Authority thereof shall issue Writs of Election to fill such Vacancies.
The House of Representatives shall chuse their Speaker and other Officers; and shall have the sole Power of Impeachment.
Section. 3. The Senate of the United States shall be composed of two Senators from each State, chosen by the Legislature thereof, for six Years; and each
Senator shall have one Vote.
Immediately after they shall be assembled in Consequence of the first Election, they shall be divided as equally as may be into three Classes. The Seats
of the Senators of the first Class shall be vacated at the Expiration of the second Year, of the second Class at the Expiration of the fourth Year, and of the third
Class at the Expiration of the sixth Year, so that one third may be chosen every second Year; and if Vacancies happen by Resignation, or otherwise, during the
Recess of the Legislature of any State, the Executive thereof may make temporary Appointments until the next Meeting of the Legislature, which shall then fill
such Vacancies.
No Person shall be a Senator who shall not have attained to the Age of thirty Years, and been nine Years a Citizen of the United States, and who shall
not, when elected, be an Inhabitant of that State for which he shall be chosen.
The Vice President of the United States shall be President of the Senate, but shall have no Vote, unless they be equally divided.
The Senate shall chuse their other Officers, and also a President pro tempore, in the Absence of the Vice President, or when he shall exercise the Office of
President of the United States.
The Senate shall have the sole Power to try all Impeachments. When sitting for that Purpose, they shall be on Oath or Affirmation. When the President
of the United States is tried, the Chief Justice shall preside: And no Person shall be convicted without the Concurrence of two thirds of the Members present.
Judgment in Cases of Impeachment shall not extend further than to removal from Office, and disqualification to hold and enjoy any Office of Honor,
Trust or Profit under the United States: but the Party convicted shall nevertheless be liable and subject to Indictment, Trial, Judgment and Punishment,
according to Law.
Section. 4. The Times, Places and Manner of holding Elections for Senators and Representatives, shall be prescribed in each State by the Legislature
thereof; but the Congress may at any time by Law make or alter such Regulations, except as to the Places of chusing Senators.
The Congress shall assemble at least once in every Year, and such Meeting shall be on the first Monday in December, unless they shall by Law
appoint a different Day.
Section. 5. Each House shall be the Judge of the Elections, Returns and Qualifications of its own Members, and a Majority of each shall constitute a
Quorum to do Business; but a smaller Number may adjourn from day to day, and may be authorized to compel the Attendance of absent Members, in
such Manner, and under such Penalties as each House may provide.
Each House may determine the Rules of its Proceedings, punish its Members for disorderly Behaviour, and, with the Concurrence of two thirds, expel a
Member.
Each House shall keep a Journal of its Proceedings, and from time to time publish the same, excepting such Parts as may in their Judgment require
Secrecy; and the Yeas and Nays of the Members of either House on any question shall, at the Desire of one fifth of those Present, be entered on the Journal.
Neither House, during the Session of Congress, shall, without the Consent of the other, adjourn for more than three Days, nor to any other Place
than that in which the two Houses shall be sitting.
Section. 6. The Senators and Representatives shall receive a Compensation for their Services, to be ascertained by Law, and paid out of the Treasury of
the United States. They shall in all Cases, except Treason, Felony and Breach of the Peace, be privileged from Arrest during their Attendance at the
Session of their respective Houses, and in going to and returning from the same; and for any Speech or Debate in either House, they shall not be questioned in
any other Place.
No Senator or Representative shall, during the Time for which he was elected, be appointed to any civil Office under the Authority of the United States,
which shall have been created, or the Emoluments whereof shall have been encreased during such time; and no Person holding any Office under the United
States, shall be a Member of either House during his Continuance in Office.
Section. 7. All Bills for raising Revenue shall originate in the House of Representatives; but the Senate may propose or concur with Amendments as on other Bills.
Every Bill which shall have passed the House of Representatives and the Senate, shall, before it become a Law, be presented to the President of the

Thank you

Backup Slides

Heavy Flavor Tracker





STAR Heavy Flavor Tracker Project.

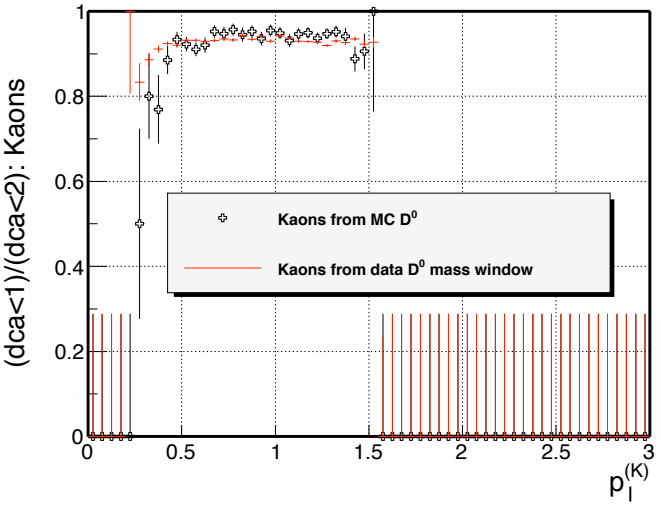
- ✓ Reconstruct secondary vertex.
- ✓ Dramatically improve the precision of measurements.
- ✓ Address physics related to heavy flavor.

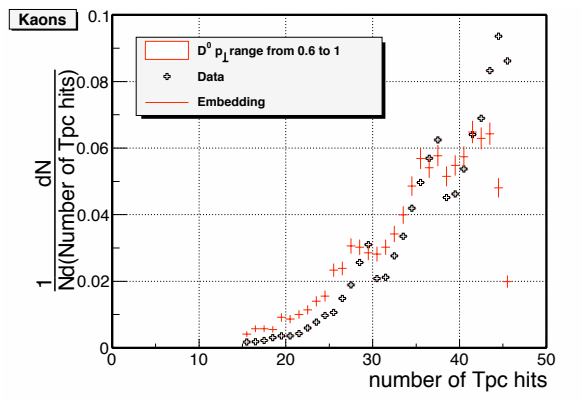
v_2 : thermalization

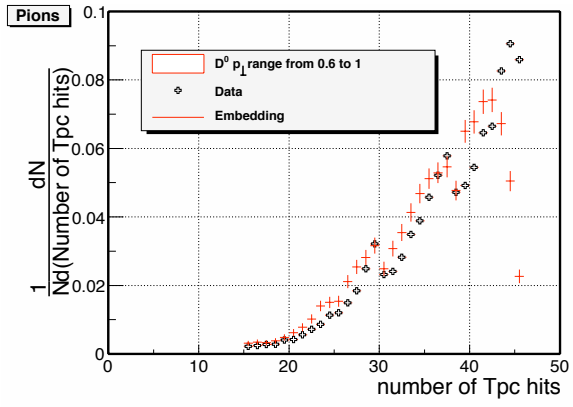
R_{CP}: charm quark energy loss mechanism.

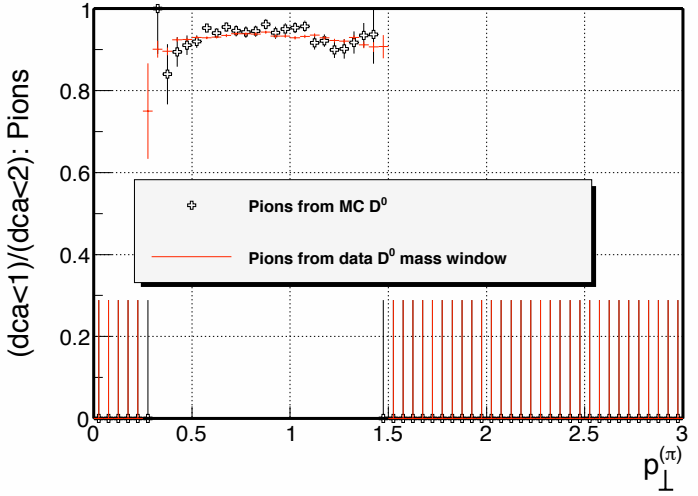
Systematic error study

1) Raw Counts – Difference between methods
2) nFitPoints - difference between MC(nFitPts>25)/MC(nFitPts>15) and Data(nFitPts>25)/Data(nFitPts>15)
3) DCA - difference between MC(dca<1)/MC(dca<2) and Data(dca<1)/Data(dca<2)

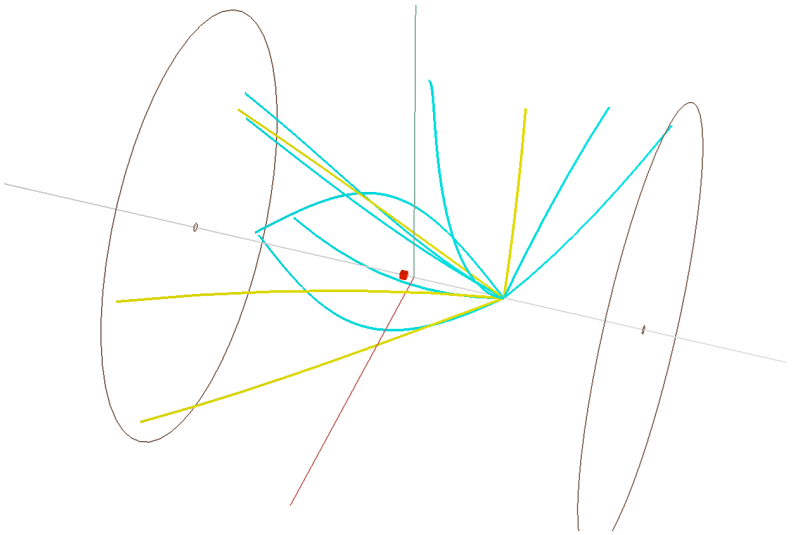


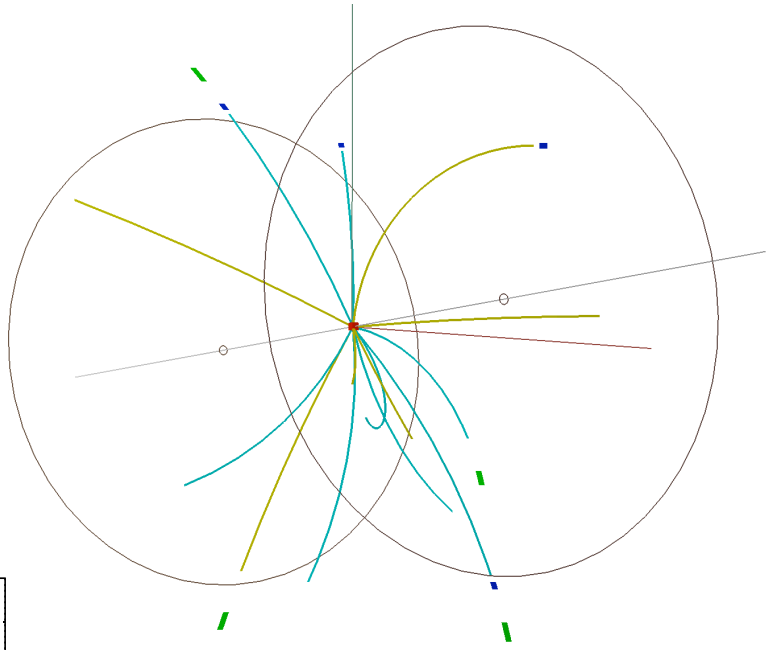


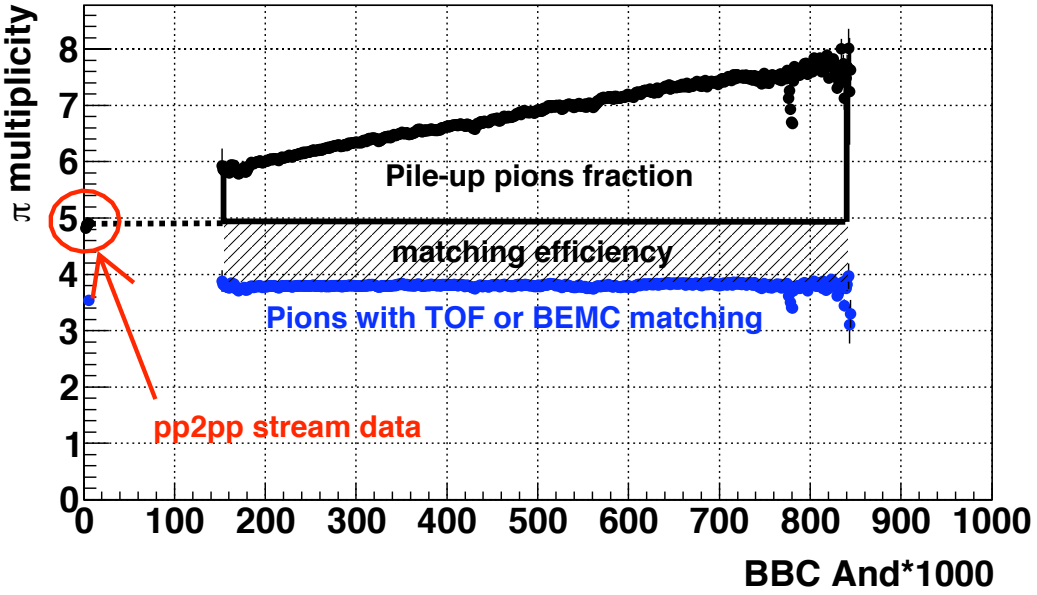




Pile-up removal







- pp collisions peak luminosity $L_{peak} = 5*10^{31}\ cm^{-2}s^{-1}$ in year 2009.
- EventRate = $L_{peak}*\sigma^{NSD}(30\ mb) = 1.5$ MHz
- TPC readout ~ 80 μs => TPC sees tracks from 120 collisions. Pile-ups are removed by
  - |VpdVz - TpcVz| < 6cm cut
  - TPC PPV reconstruction algorithm