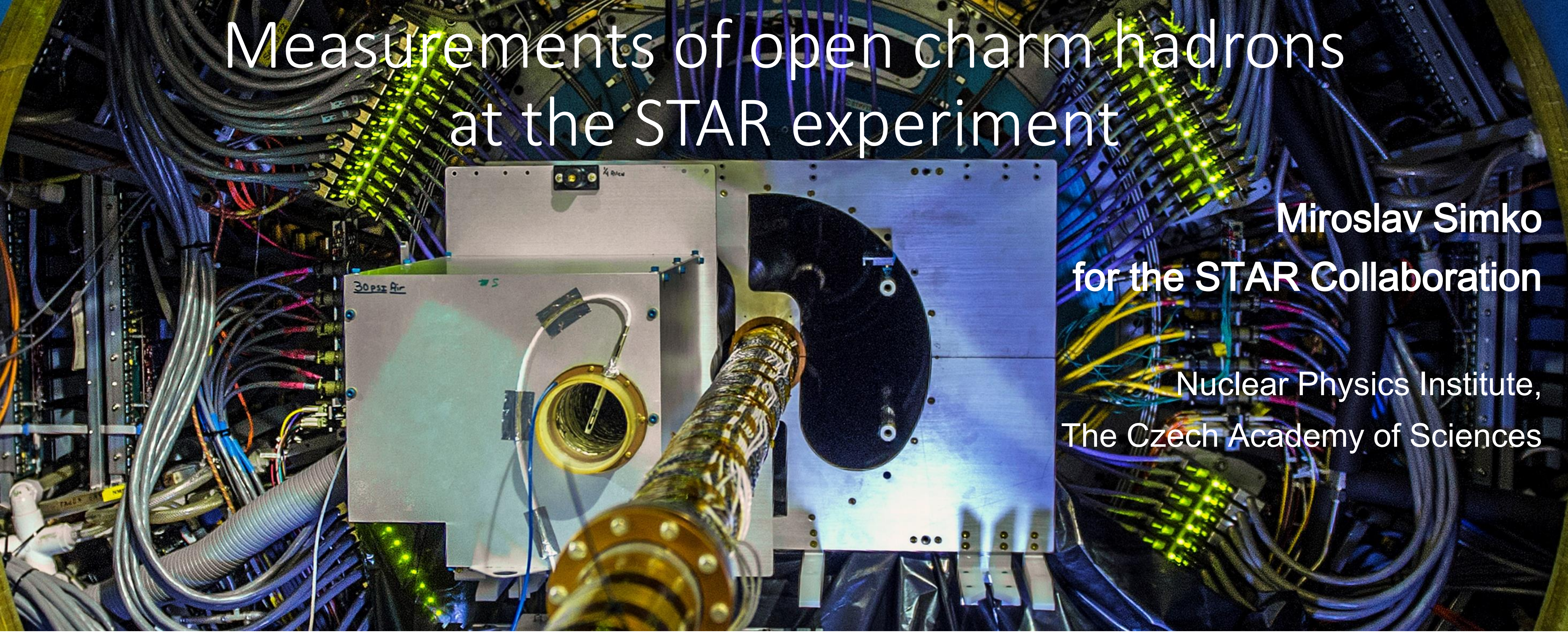

Measurements of open charm hadrons at the STAR experiment

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for the STAR Collaboration

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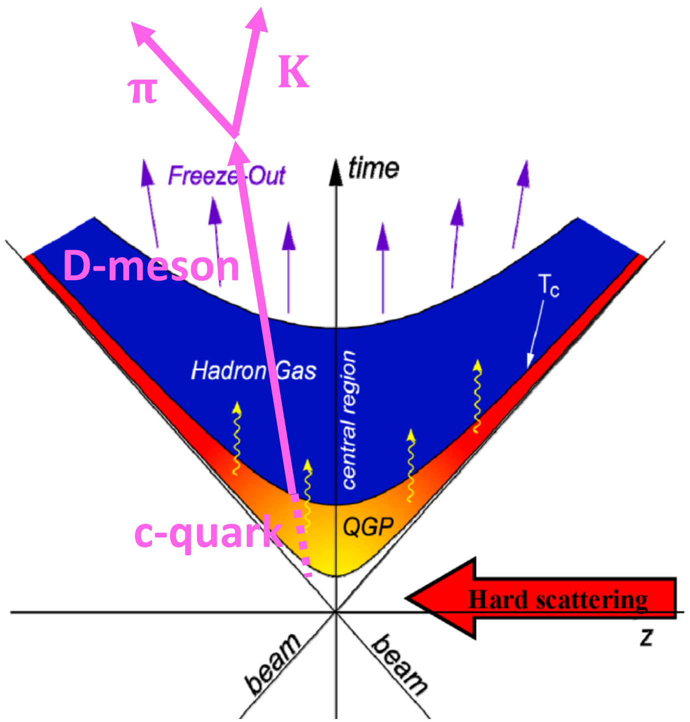
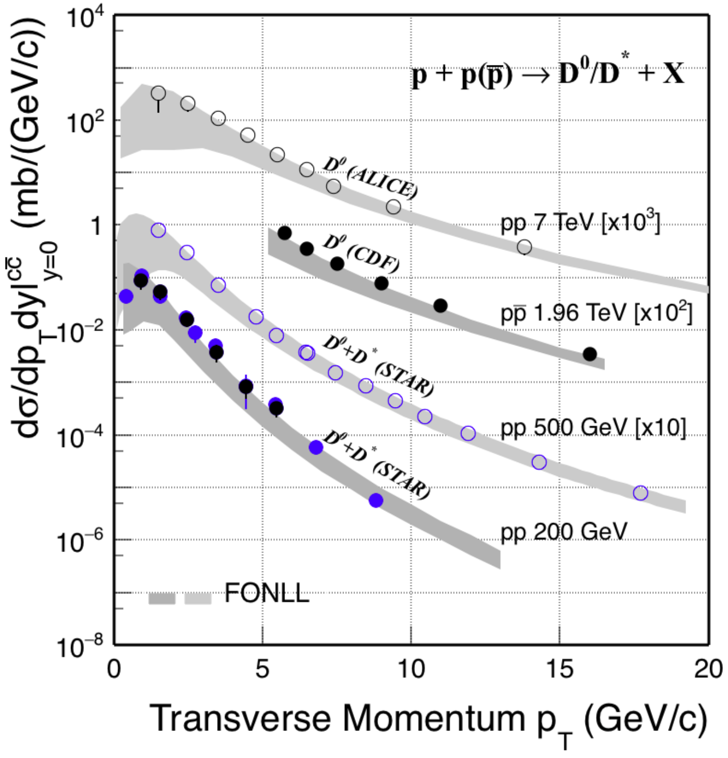
Outline

- Motivation of open charm measurements
- STAR with Heavy Flavor Tracker
- D^0 meson:
  - Nuclear modification factor R_{AA}, D^0 elliptic flow (v_2), comparison to models, diffusion coefficient
- $\mathrm{D_s}$ meson:
  - R_{AA}, $\mathrm{D_s}/\mathrm{D}^0$ ratio, and v_2 of $\mathrm{D_s}$
- Summary

Studying QGP with open charm

- $m_c \gg T_{QGP}, \Lambda_{QCD}$
- Produced in hard scattering during early stages of the collision
- Excellent probe for energy loss mechanisms in the QGP
- p+p collisions described well by FONLL
- New open charm hadrons measurements (D_s) bring more insight into charm hadronization

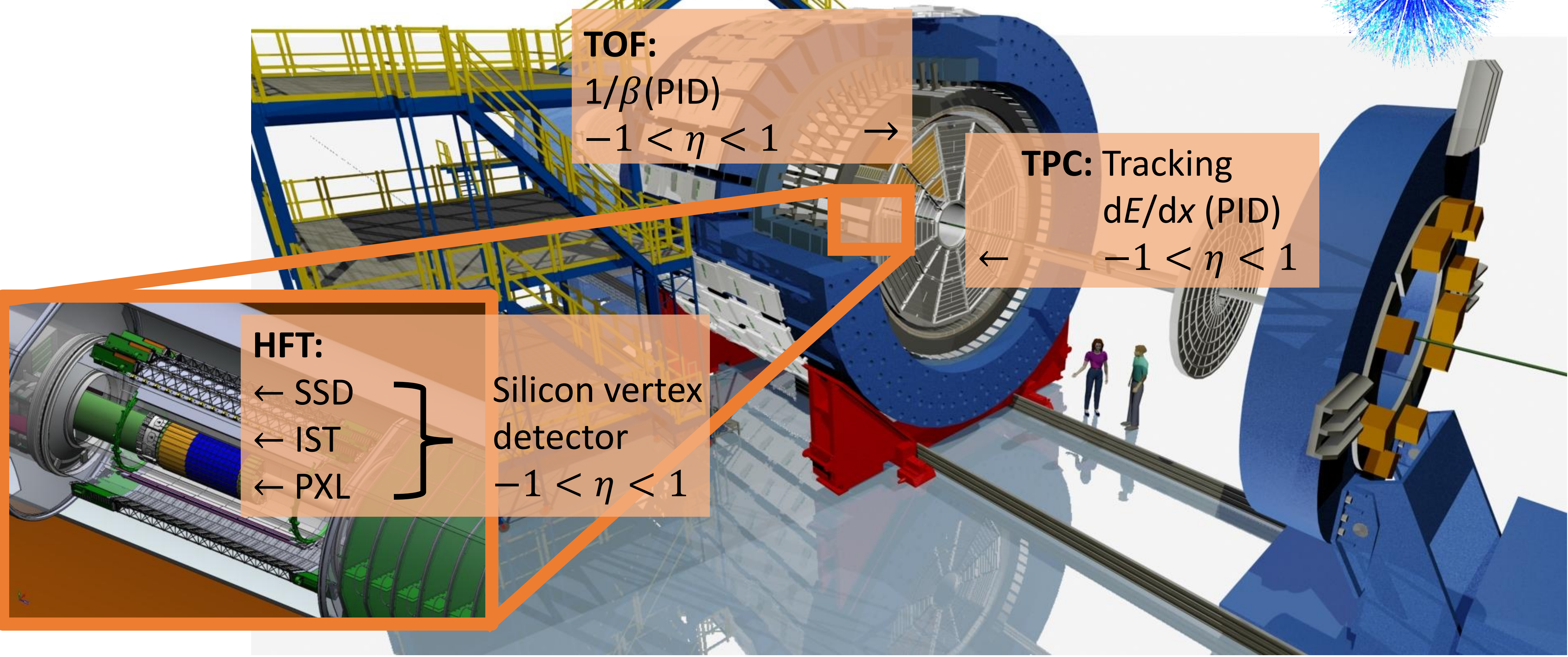




[STAR: PRD 86 (2012) 072013, NPA 931 (2014) 520; CDF: PRL 91 (2003) 241804; ALICE: JHEP01 (2012) 128; FONLL: PRL 95 (2005) 122001]

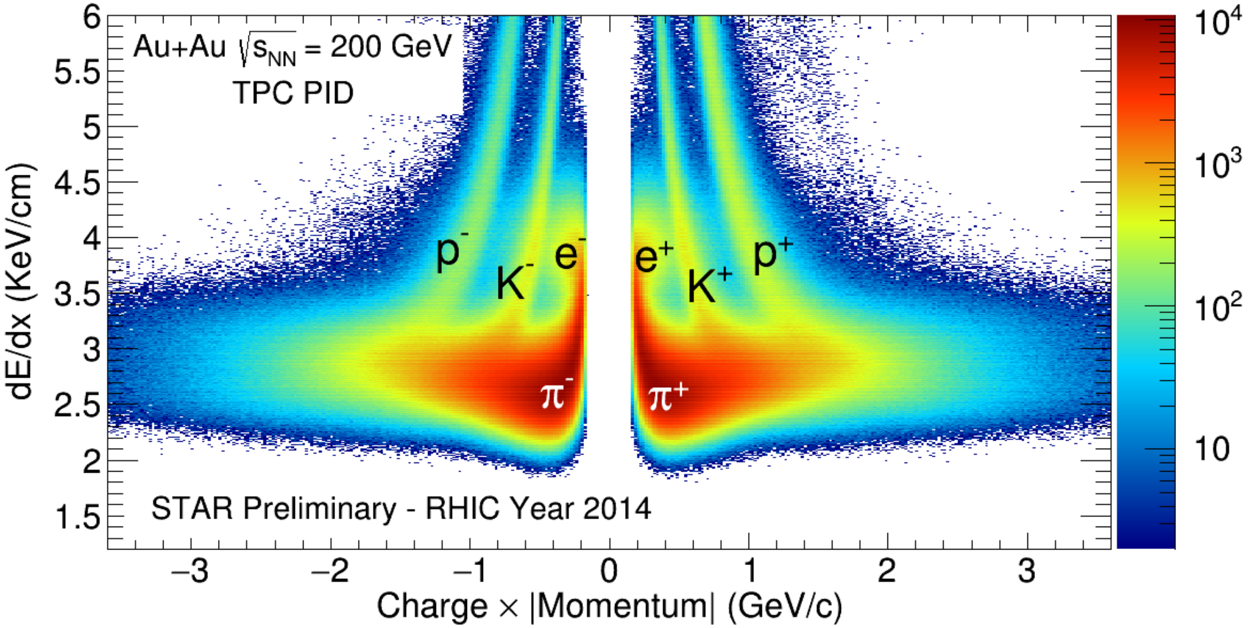
STAR detector

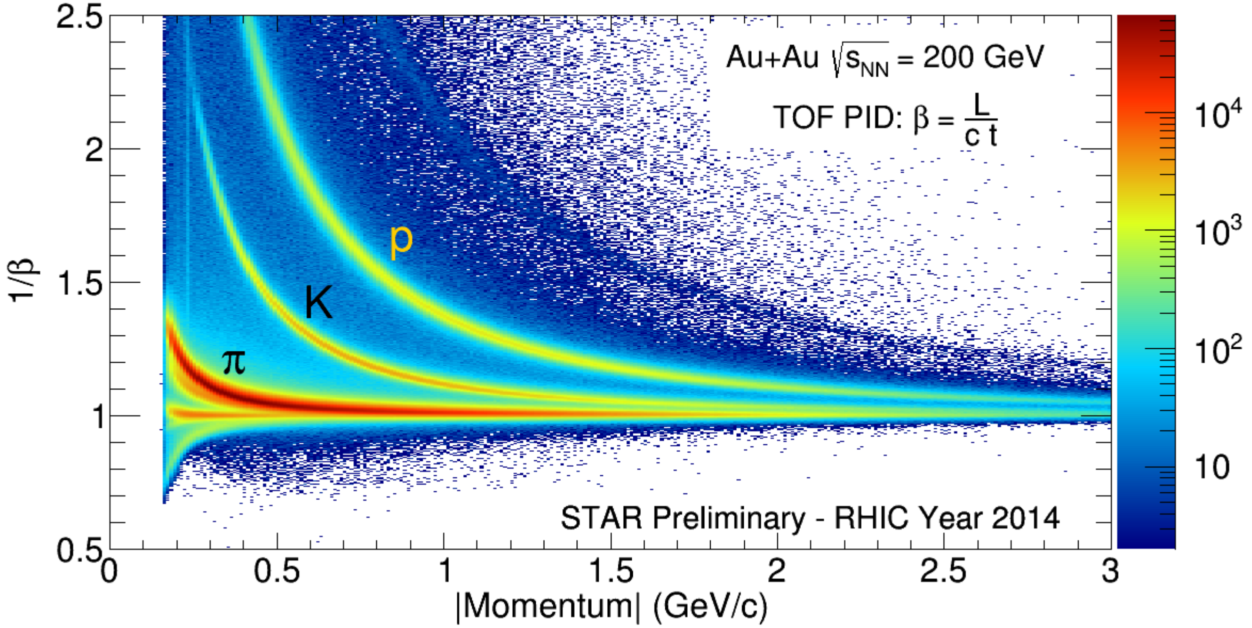
2π acceptance in azimuth



Particle Identification in TPC and TOF

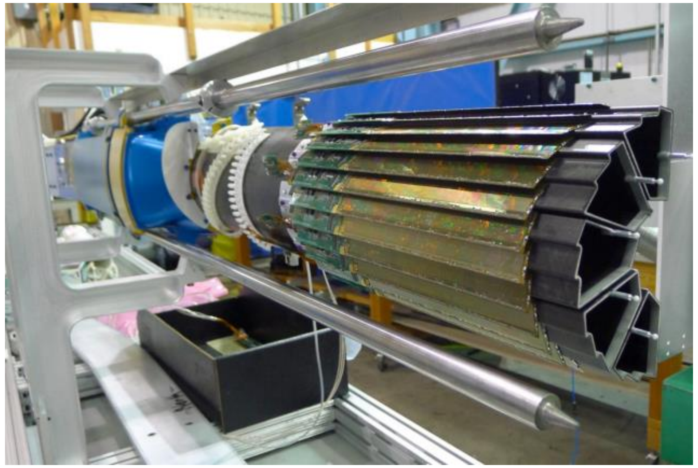
- Clear separation for long-lived hadrons
- $D^0(\overline{D^0}) \rightarrow \pi^{\pm}K^{\mp}$
- $D_s^{\pm} \rightarrow \pi^{\pm}\phi(1020) \rightarrow \pi^{\pm}K^{\mp}K^{\pm}$
- $D^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}K^{\mp}$

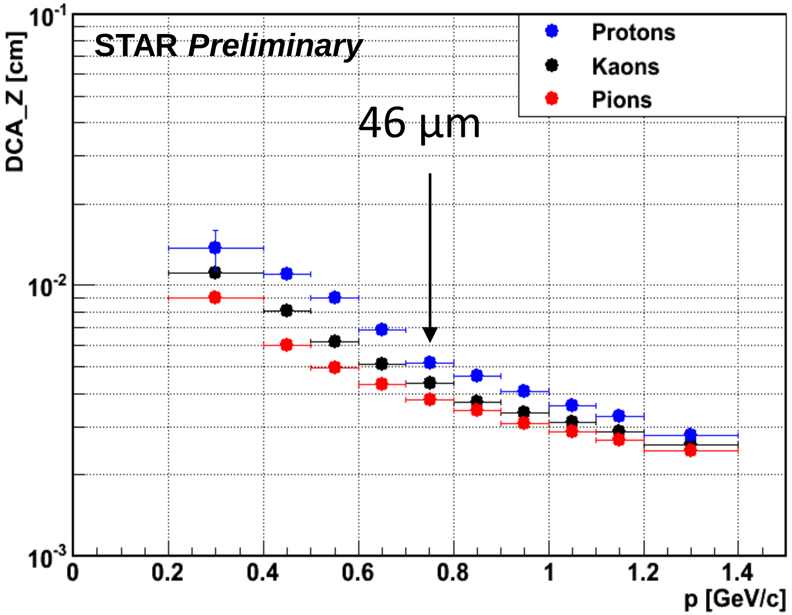


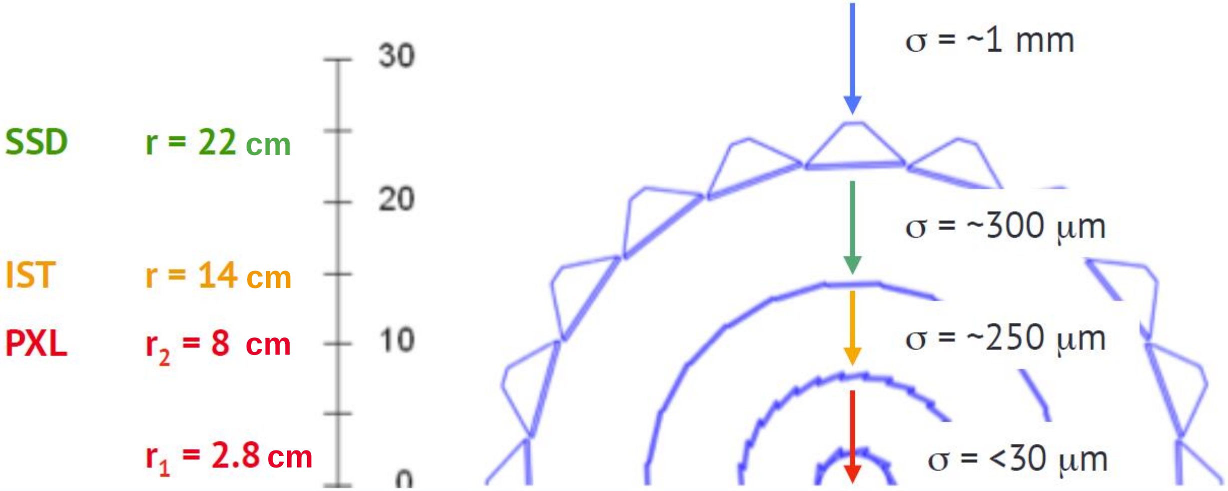


STAR Heavy Flavor Tracker

- The Pixel detector: First MAPS technology in a collider experiment
- Pointing resolution: $\sim$30 μm at high p_T (exceeds the requirement of 55 μm for 750 MeV/c kaons)
- Radiation length 0.4 % X_0 for the 1st layer of pixel
- Recorded $\sim$ 3.2 B good Au+Au events in 2014 and 2016
- 750 M events shown in this talk







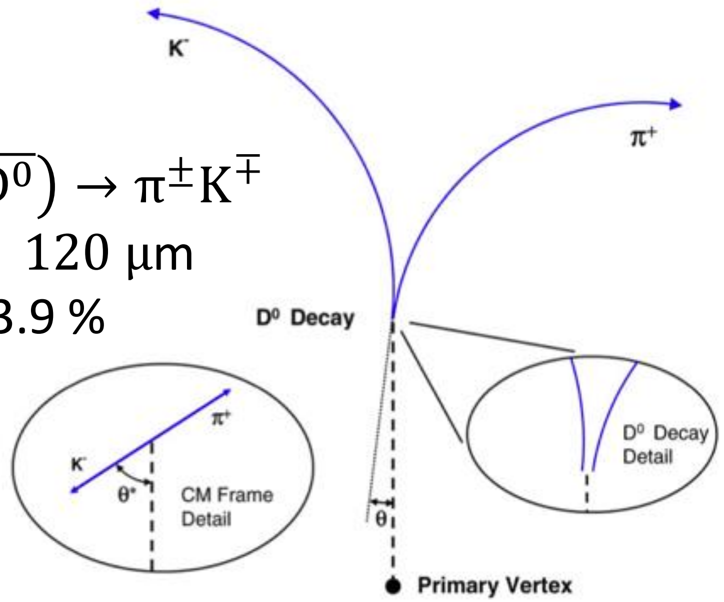
Topological reconstruction

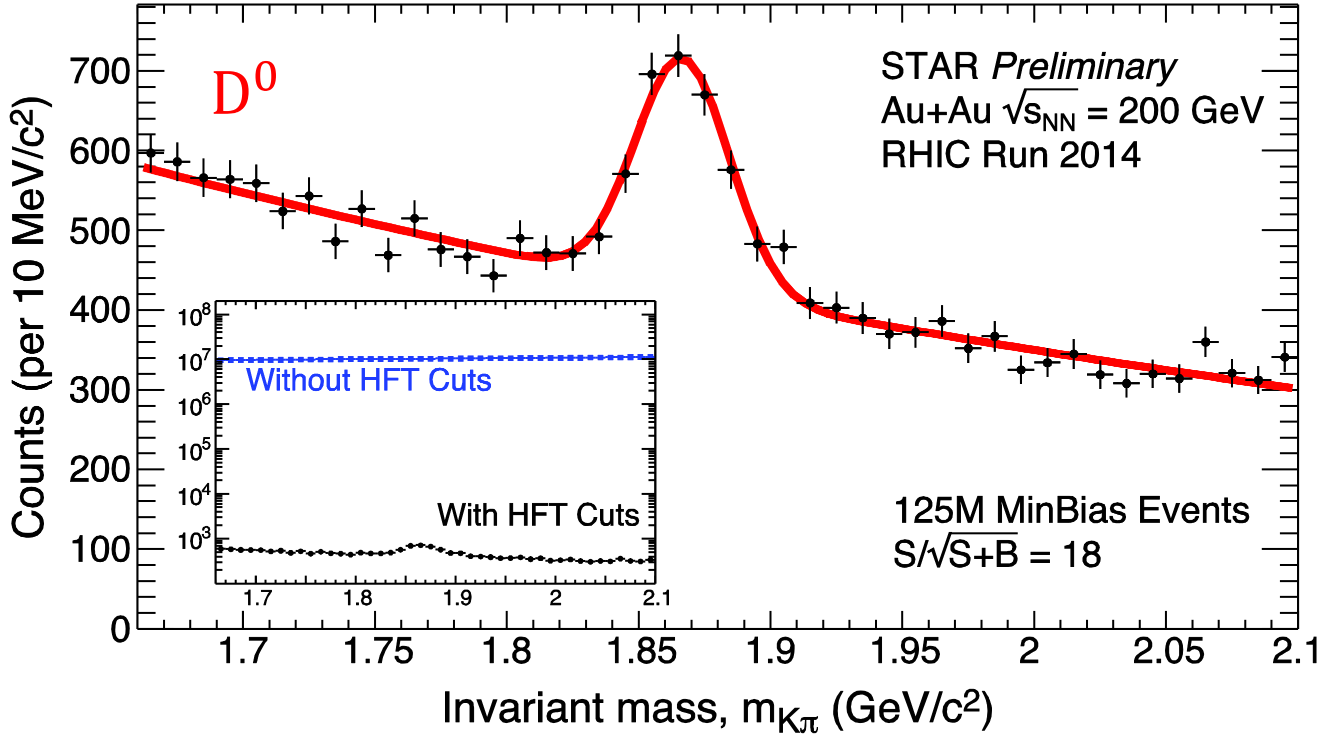
- Combinatorial background suppressed by 4 orders of magnitude
- Highly improved signal-to-background ratio

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

$c\tau = 120\ \mu m$

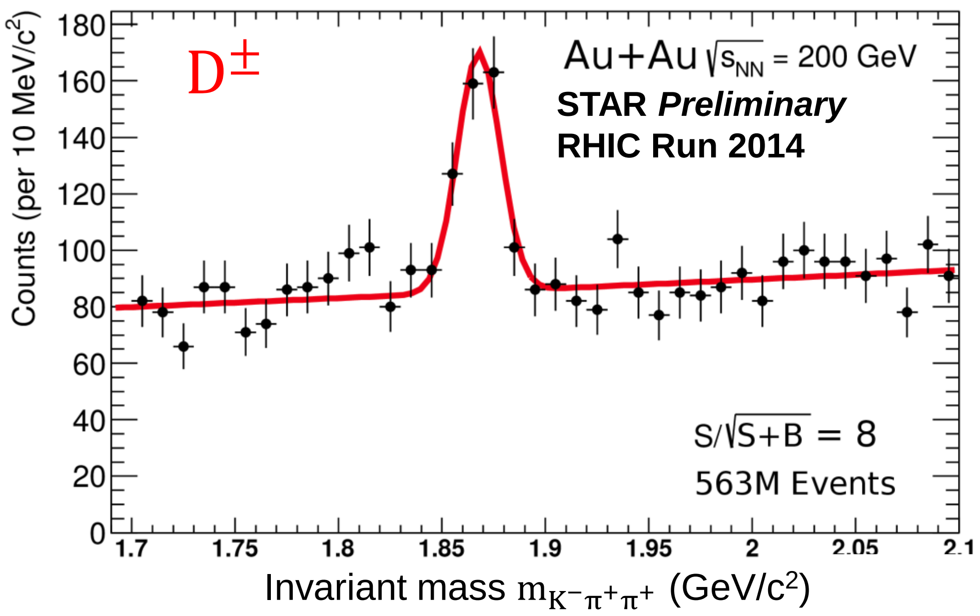
B.R. 3.9 %

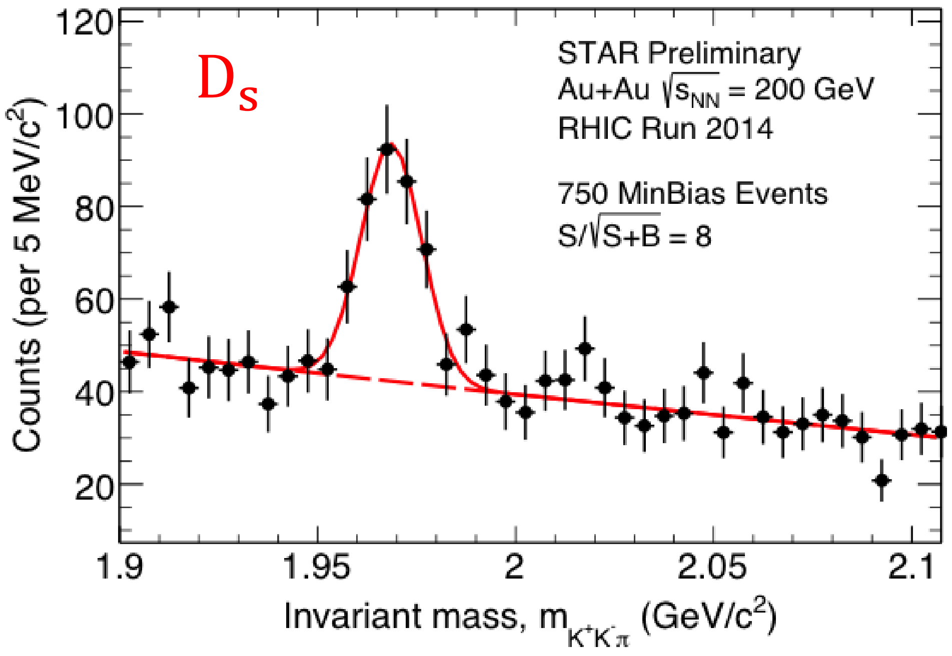




Three body decays

- $D^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}K^{\mp}$ $c\tau = 312\ \mu m$ B.R. 9.46 %
- $D_s^{\pm} \rightarrow \pi^{\pm}\phi(1020) \rightarrow \pi^{\pm}K^{\pm}K^{\mp}$ $c\tau = 150\ \mu m$ B.R. 2.32 %

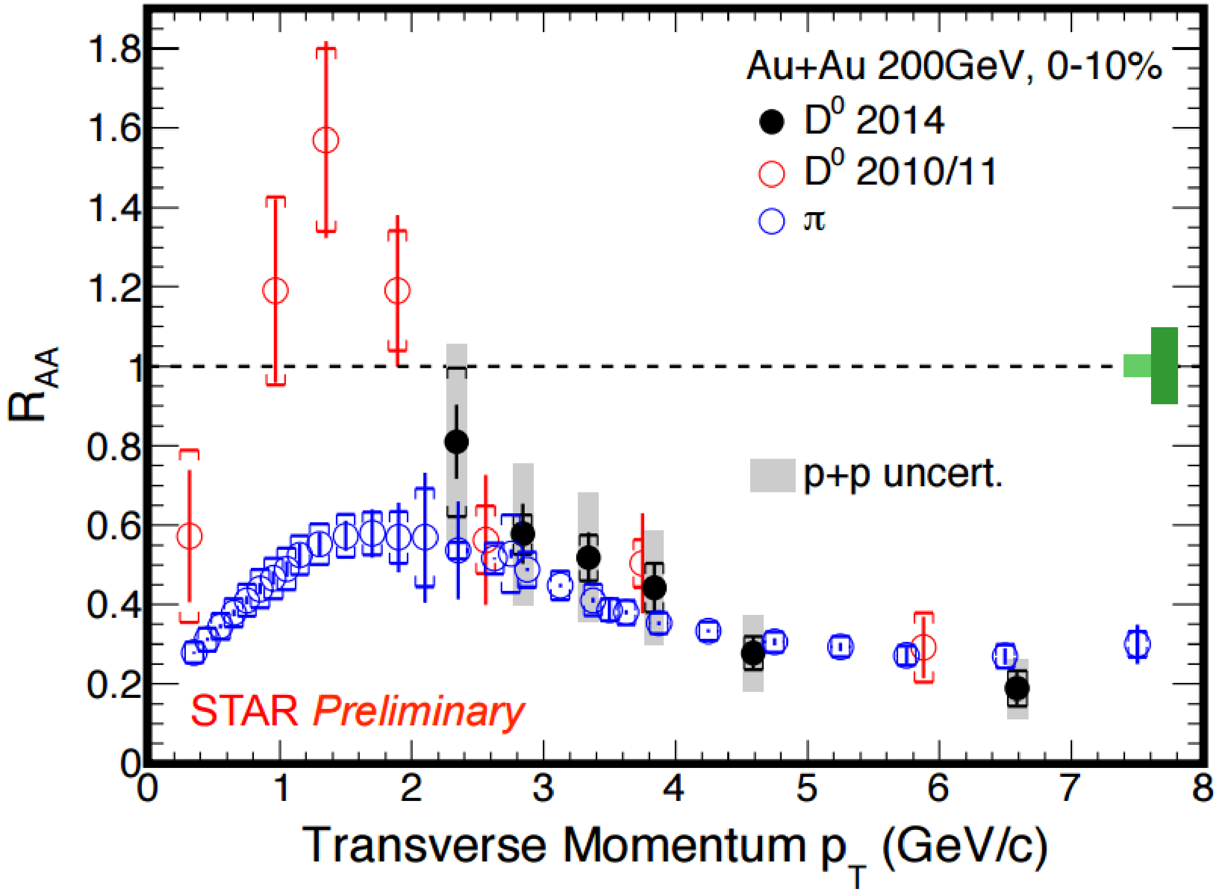




R_{AA} of D^0

$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle \times dN_{pp}/dp_T}$$

- Yield at high p_T greatly suppressed
  - Improved precision with the new measurement
- D^0 shows similar suppression to light mesons at high p_T



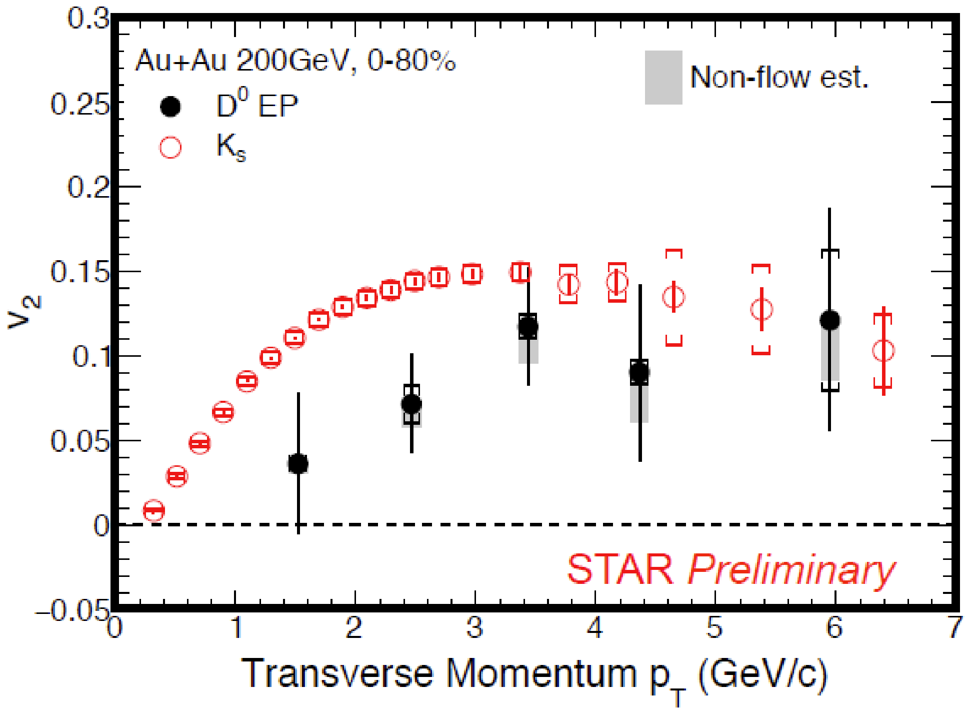
[STAR: PRL 113 (2014) 142301
PLB 655 (2007) 104]

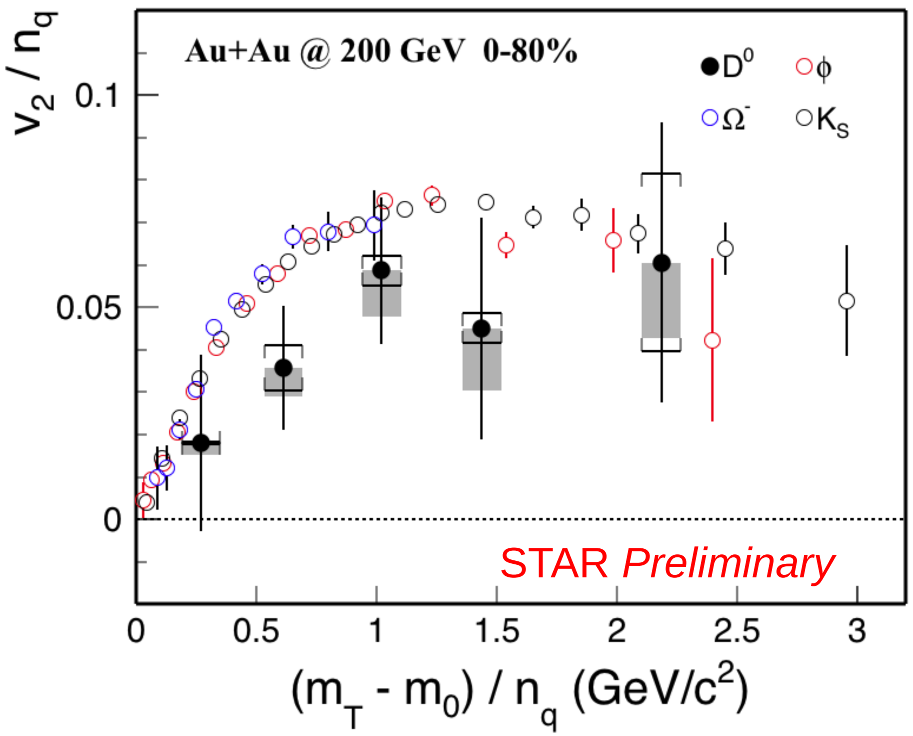
D^0 azimuthal anisotropy v_2

$$\frac{dN}{d\phi} = N_0\left(1 + \sum_n 2v_n \cos[n(\varphi - \psi_n)]\right)$$

- Significantly above zero for p_T > 2 GeV/c

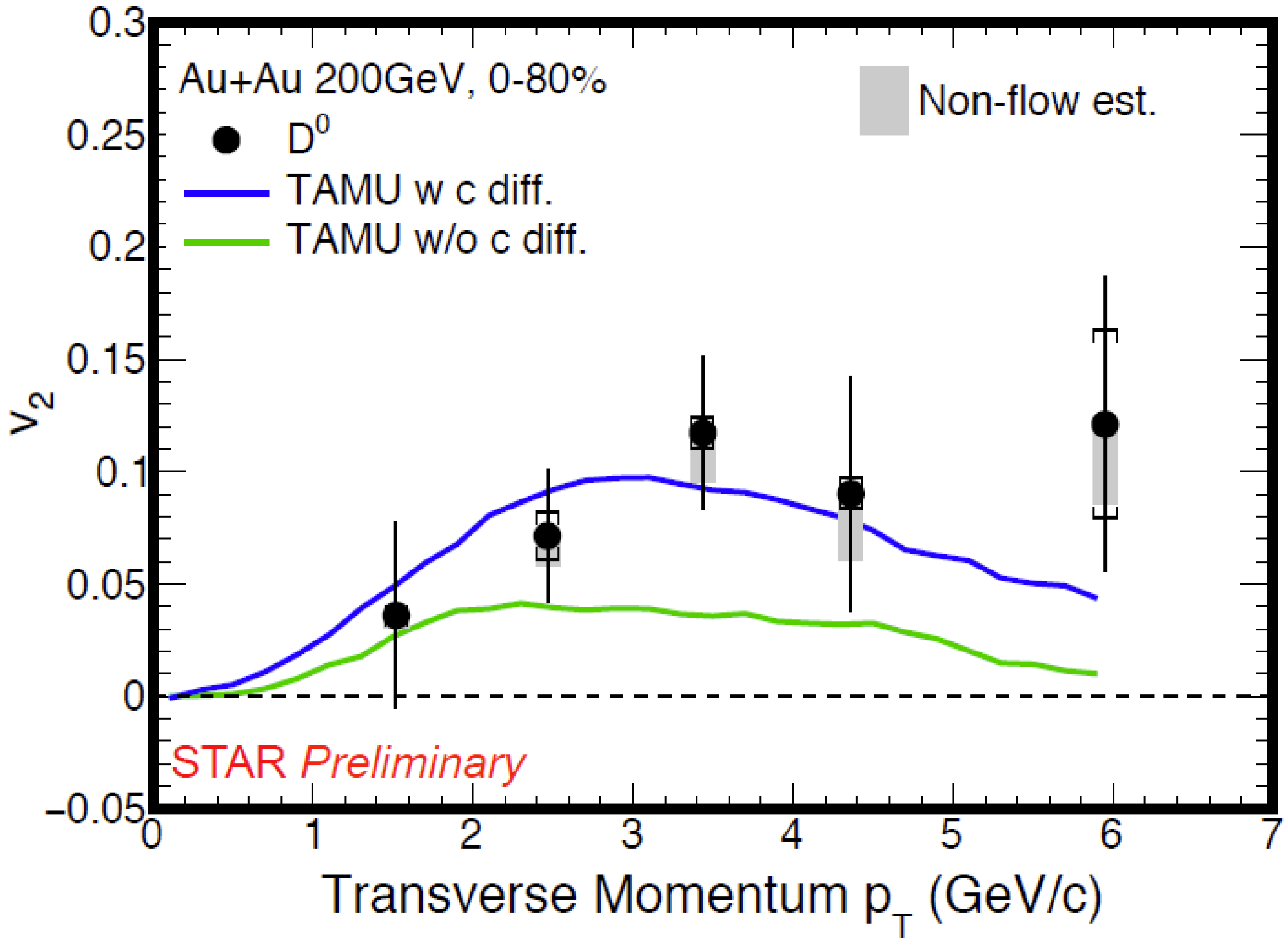
- $m_T^2 = m^2 + p_T^2$
- v_2 is slightly below lighter hadrons
  - Higher statistics will enable a comparison in finer centrality bins





[STAR:PRC 77 (2008) 54901
PRL 116 (2016) 62301]

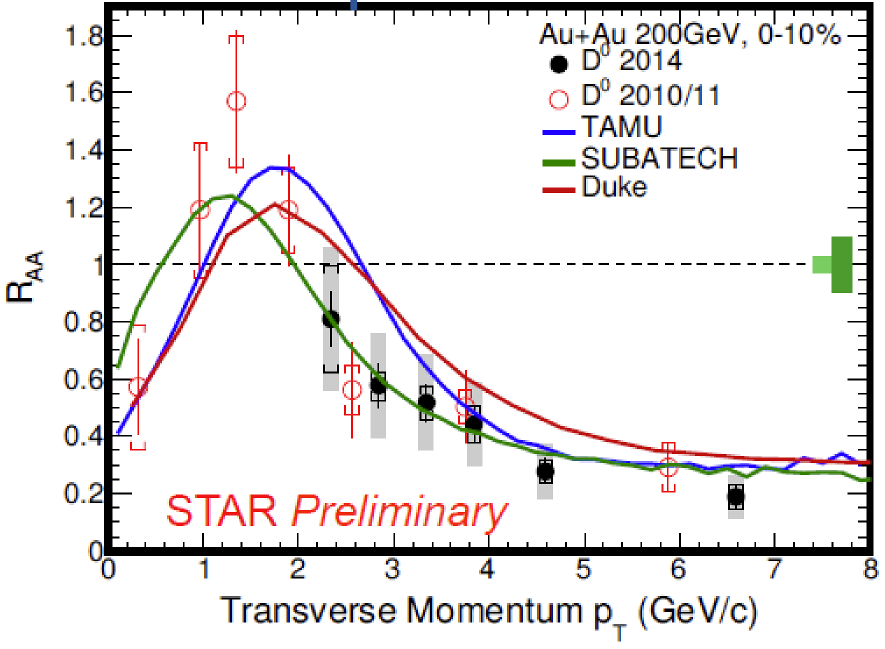
Charm quark diffusion

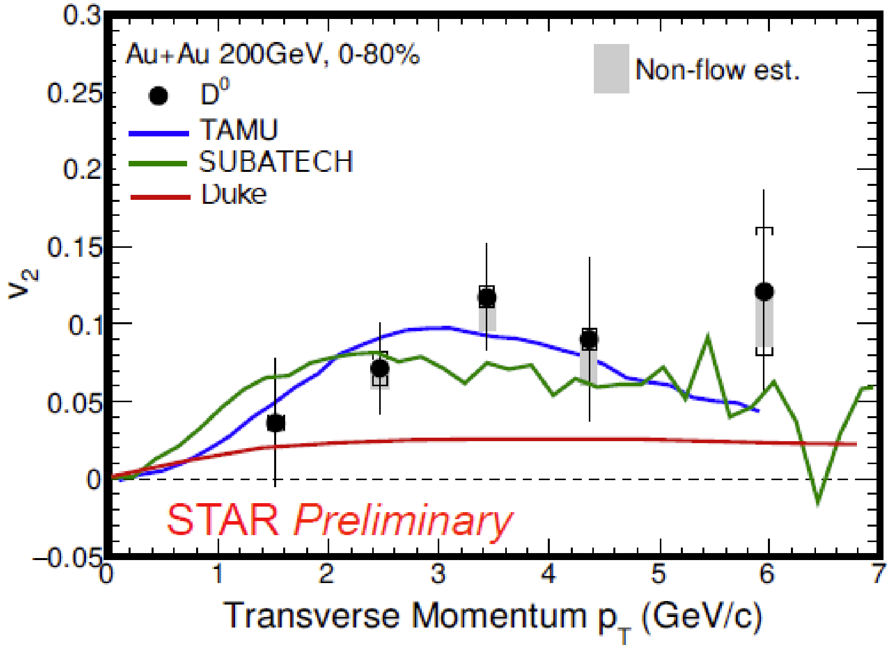


[Theory: Eur. Phys. J. C (2016) 76: 107 & private comm.]

- TAMU: non-perturbative T-matrix approach
- The model with charm diffusion in the medium is favored by data

Comparison to models with charm diffusion

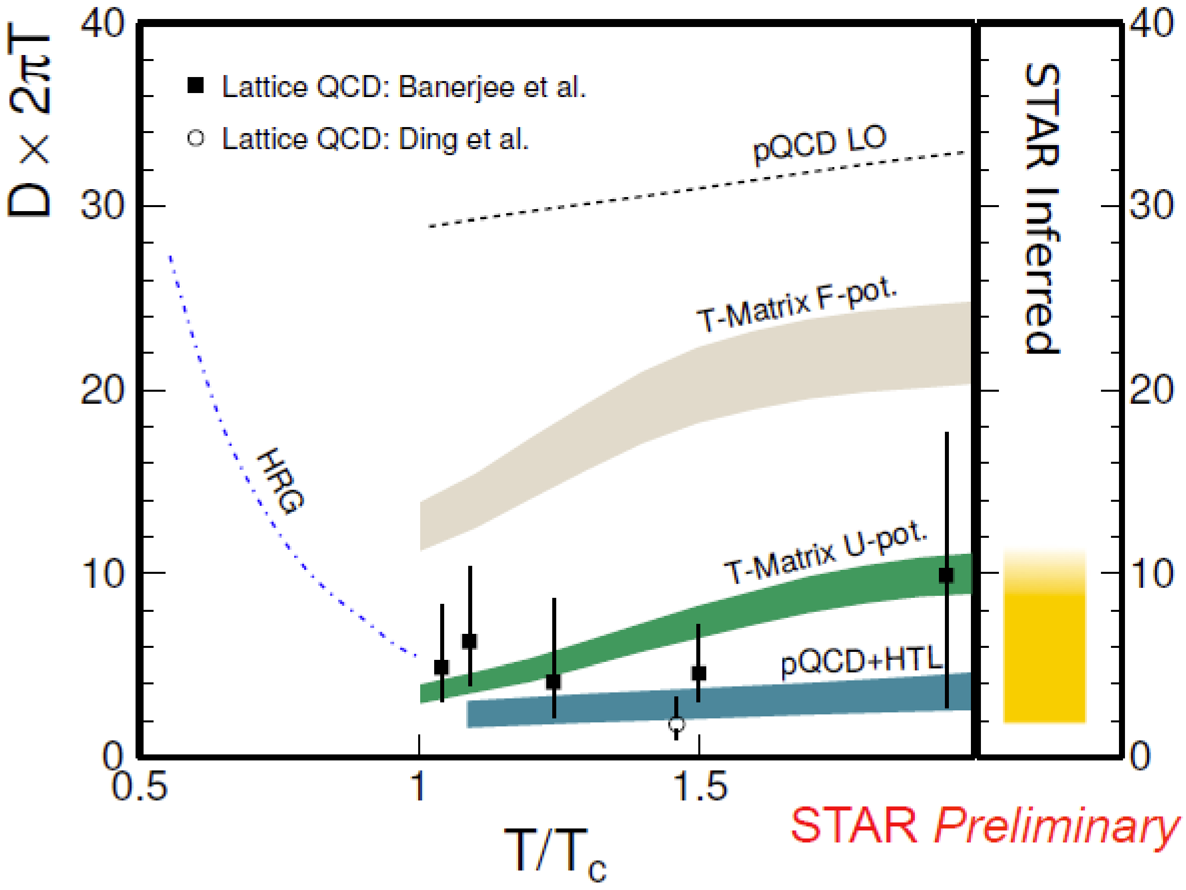




- Models can describe the data
- TAMU: non-perturbative T-matrix approach:
  - $(2\pi T)D = 2 - \sim 10$
- SUBATECH: pQCD + hard thermal loops for resummation:
  - $(2\pi T)D = 2 - 4$
- Duke: Langevin simulation with transport properties tuned to LHC data:
  - $(2\pi T)D = 7$

[Theory:
TAMU: Eur. Phys. J. C (2016) 76: 107 & private comm.;
SUBATECH: PRC 91(2015) 054902 & private comm.;
Duke: PRC 92(2015) 024907 & private comm.]
[STAR 2010/11: PRL 113 (2014) 142301]

Diffusion coefficient $(2\pi T)D$



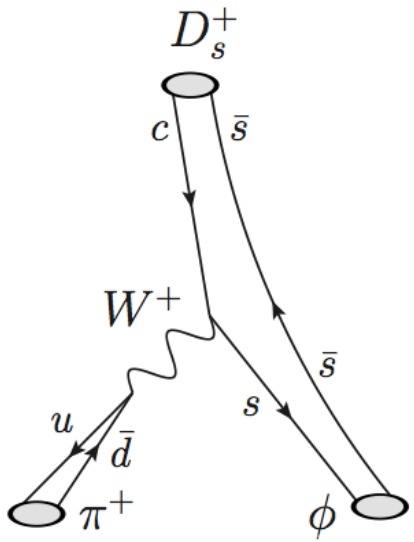
- The STAR data can be described by model calculations
  with charm quark diffusion coefficient

$$(2\pi T)D = 2 - {\sim}10$$

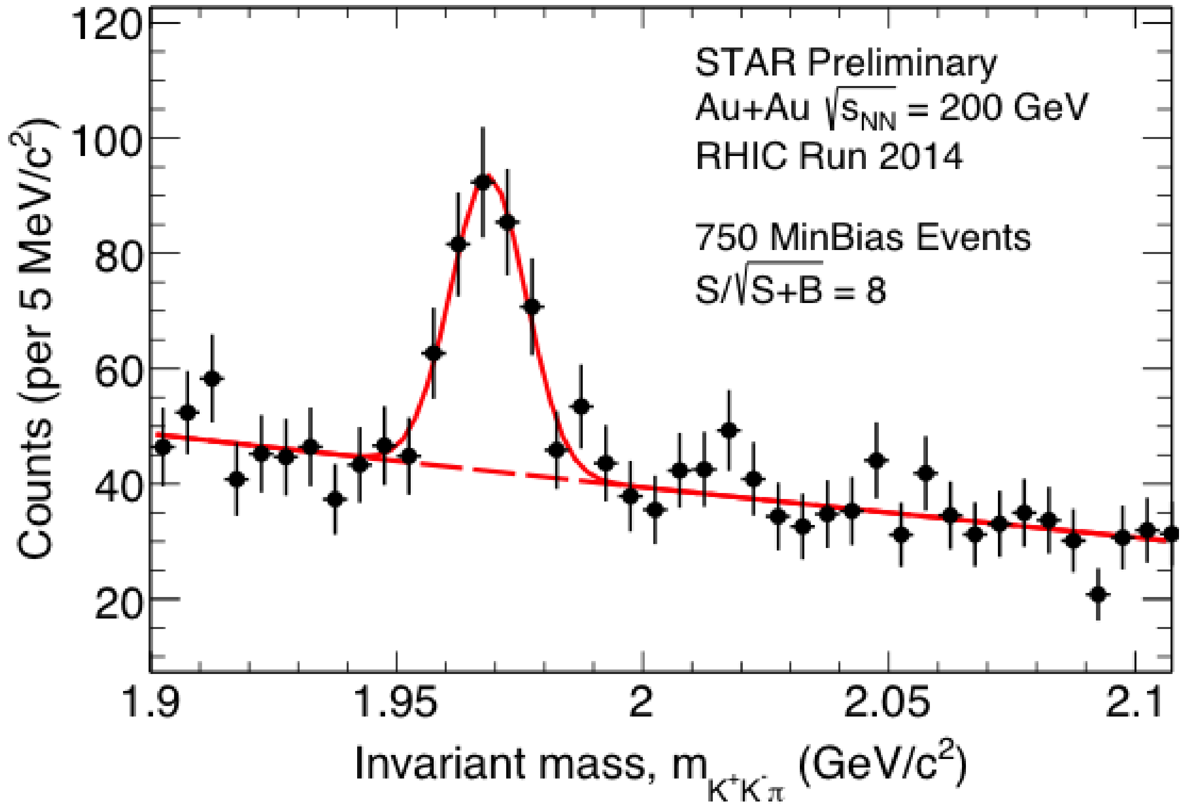
- This range matches the lattice QCD calculation

$\mathrm{D_s}$ reconstruction

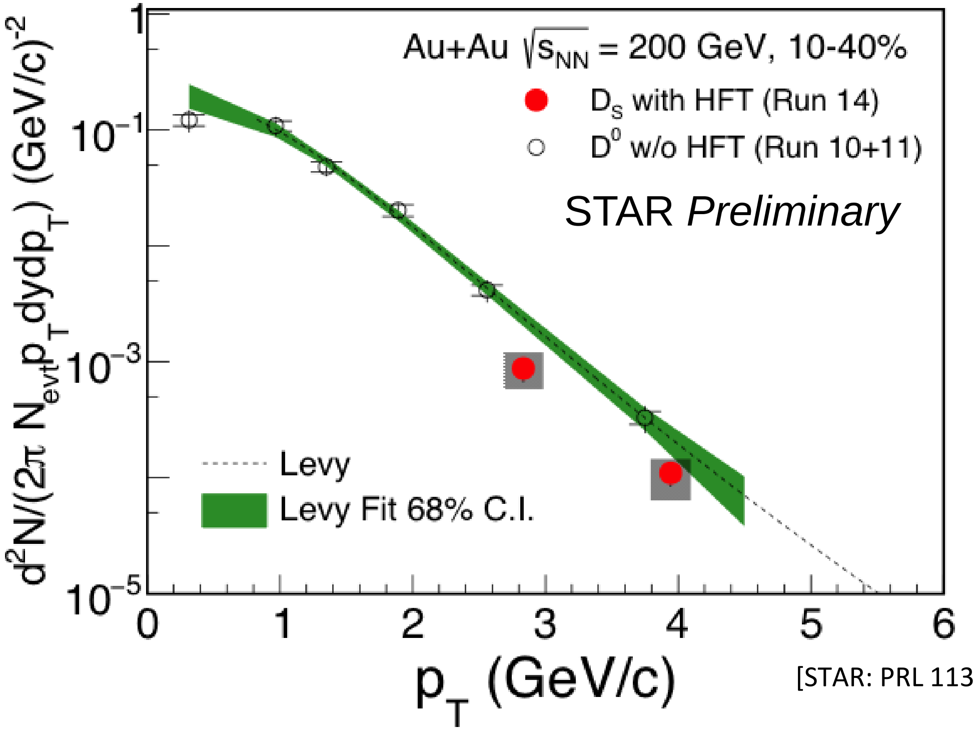
- $\mathrm{D_s^{\pm}} \rightarrow \pi^{\pm}\phi(1020) \rightarrow \pi^{\pm}\mathrm{K}^{\pm}\mathrm{K}^{\mp}$
- $c\tau = 150\ \mu\mathrm{m}$
- B.R. 2.32 %
- Mass 1968.47 MeV/c^2
- First measurement of $\mathrm{D_s}$ at RHIC



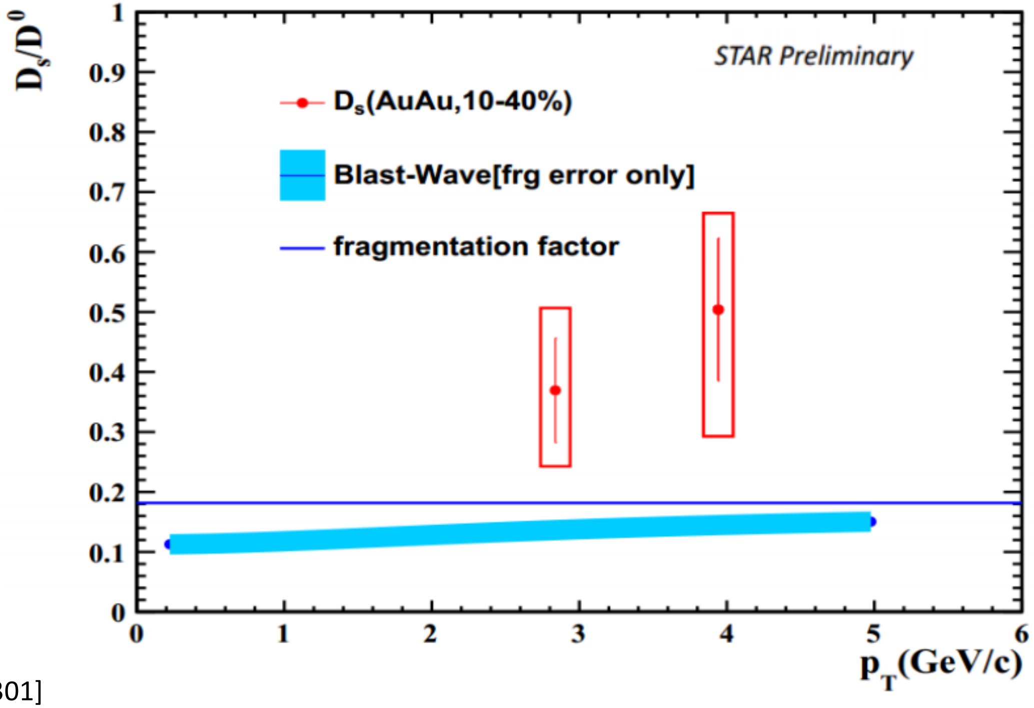
Courtesy, Peter Filip



D_s yield and D_s/D_0 ratio

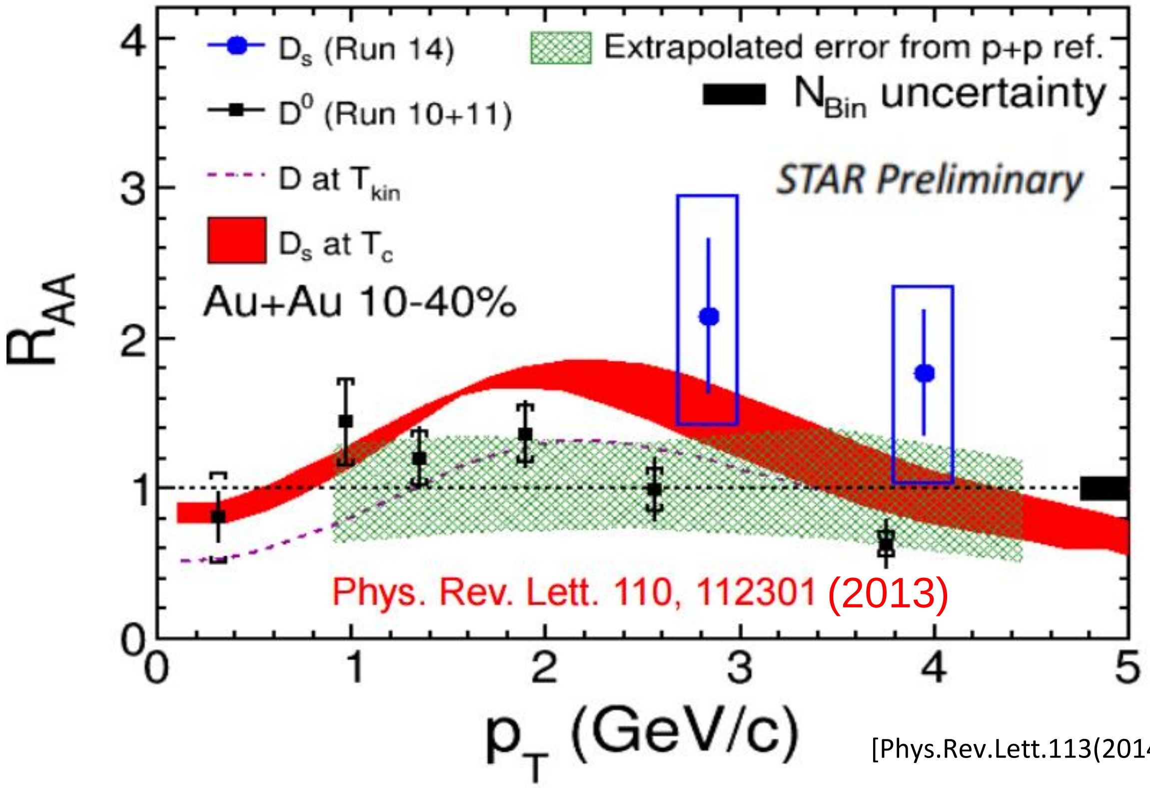


[STAR: PRL 113 (2014) 142301]



- Fragmentation factor from charm to D_s is 0.9 ± 0.1 [H1 Collaboration, Eur.Phys.J.C38(2005)447] [ZEUS Collaboration, Eur.Phys.J.C44(2005)351]
- Hint of D_s enhancement compared to D^0

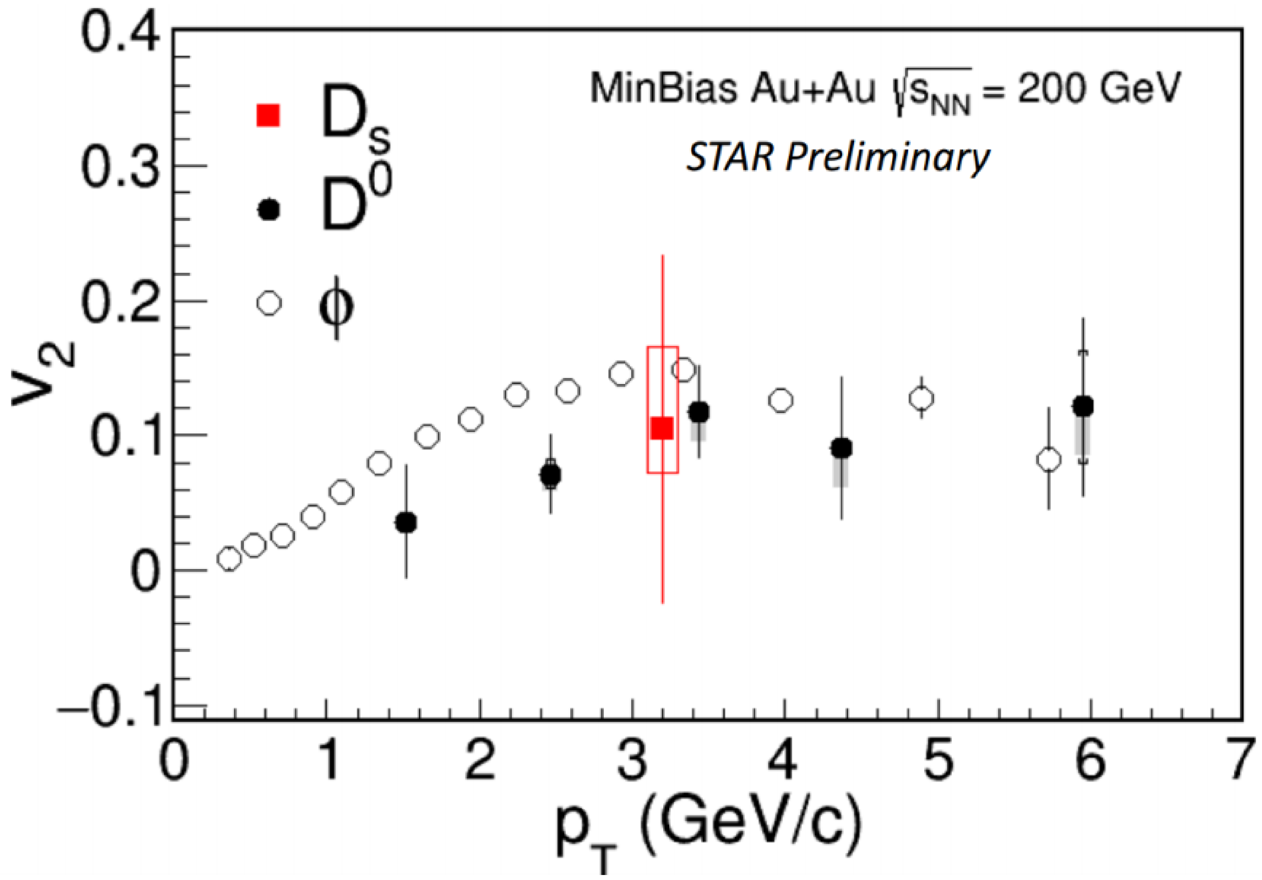
R_{AA} compared to a model calculation



[Phys.Rev.Lett.113(2014) 142301]

- p+p reference obtained from the charm cross-section measured by STAR scaled by $c \rightarrow D_s$ fragmentation factor
  [H1 Collaboration, Eur.Phys.J.C38(2005)447]
  [ZEUS Collaboration, Eur.Phys.J.C44(2005)351]
- Consistent with the model calculations within uncertainties
- Hint of D_s enhancement

$\mathrm{D_s}$ azimuthal anisotropy v_2



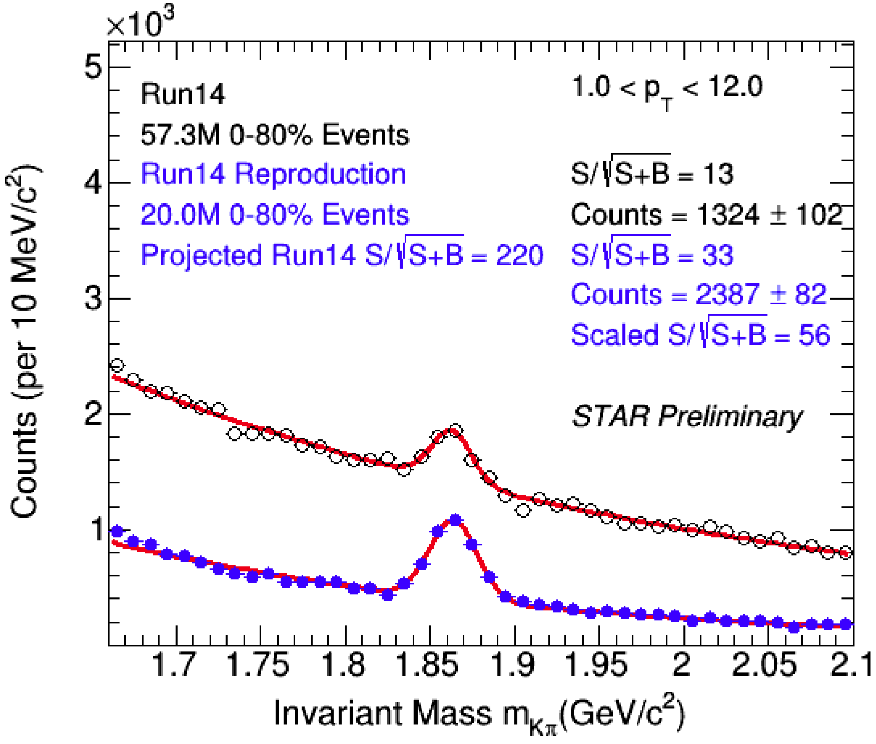
- First measurement of $\mathrm{D_s}$ v_2 at RHIC
- Integrated p_T
- Hint of finite v_2
- Consistent with $\mathrm{D^0}$ v_2

Summary

- HFT–Pixel: First implementation of the MAPS technology in a collider experiment
- STAR HFT delivers first physics results on charmed hadrons
  - First implementation of topological reconstruction for charmed hadrons at RHIC
- First measurement of D^0 v_2 at RHIC
  - Charm quarks flow with the medium
  - The measurements of R_{AA} and v_2 together constrain the models and thus predict the value of $(2\pi T)D$
- First measurement of $\mathrm{D_s}$ at RHIC
  - Hint of enhancement compared to p+p collisions and non-zero v_2

Outlook

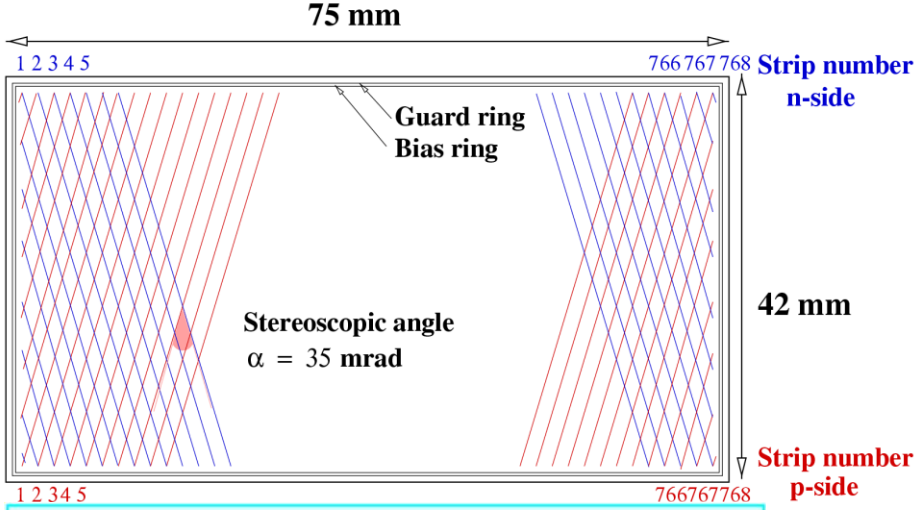
- ~3.2 B good MB events recorded for Au+Au collisions in 2014 and 2016 with the HFT (compared to 750 M shown in this presentation)
- With improved reconstruction software 2–4 times improved significance for D^0 in 2014 data
- Reference p+p and p+Au data recorded in 2015
- Data analyses of Λ_c and $D^{\pm}$ are in progress

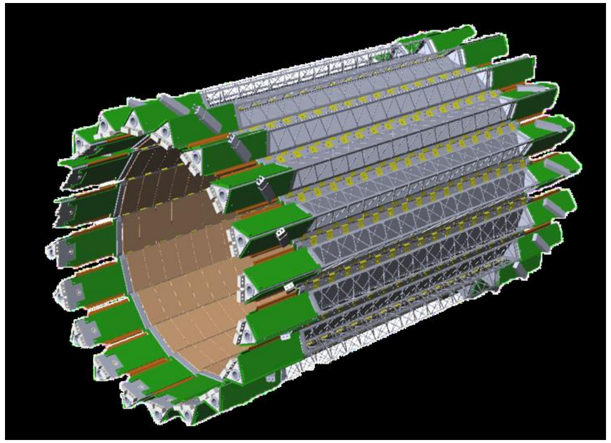


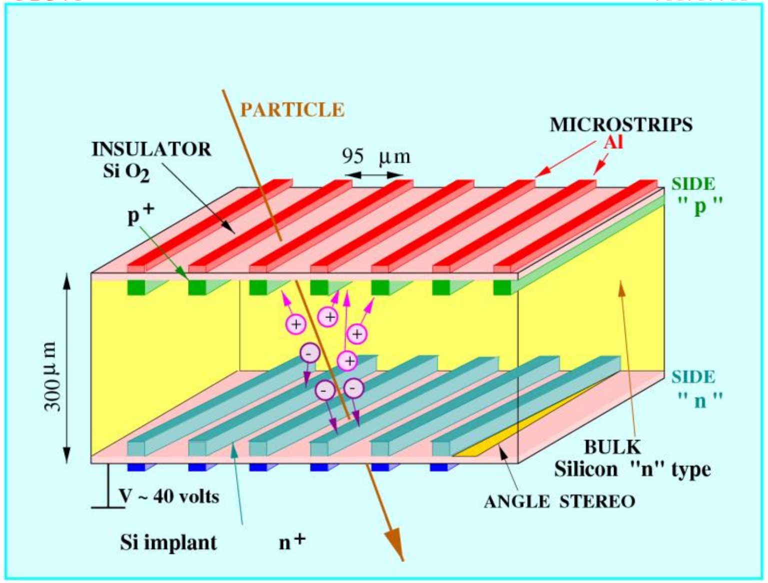
Thank you for your attention

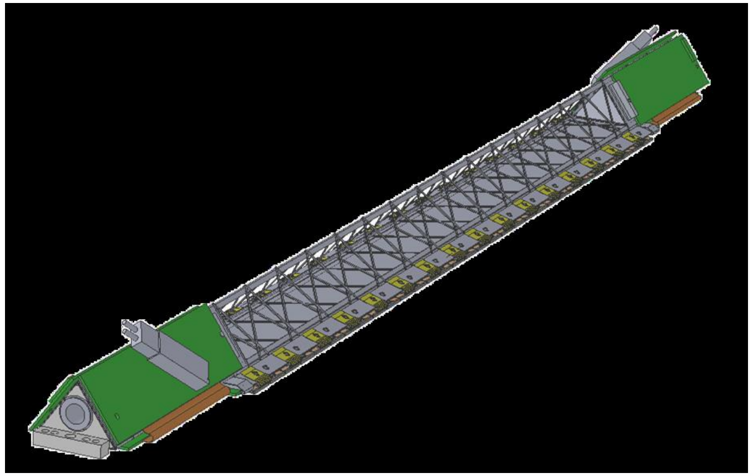
Backup

Silicon Strip Detector (SSD)





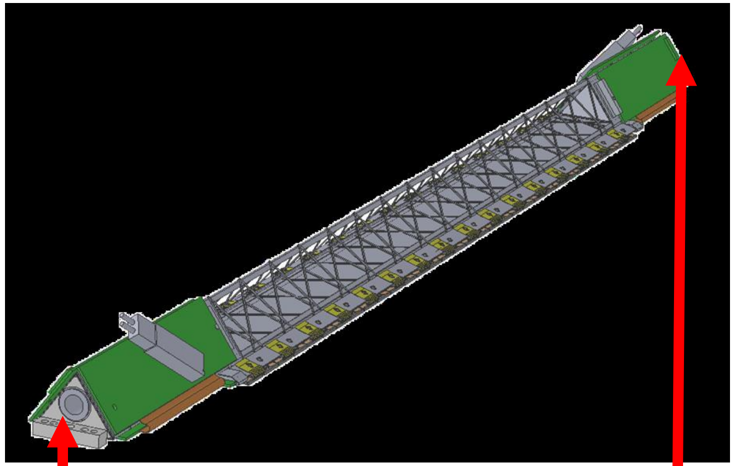




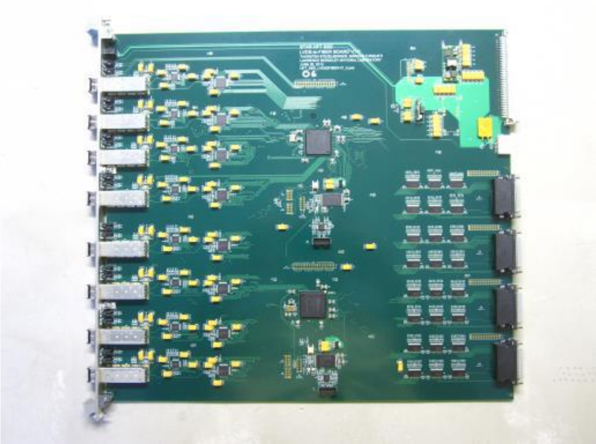
SSD radius	22 cm
SSD length	106 cm
$\|\eta\|$ coverage	< 1.2
Number of ladders	20
Number of wafers per ladder	16
Total number of wafers	320
Number of strips per wafer side	768
Number of sides per wafer	2
Total number of channels	491520
Silicon wafer size	75 × 42 mm
Silicon wafer sensitive size	73 × 40 mm
Silicon thickness	300 µm
Strip pitch	95 µm
Stereo angle	35 mrad
R-ϕ resolution	20 µm
Z resolution	740 µm

SSD readout refurbishment

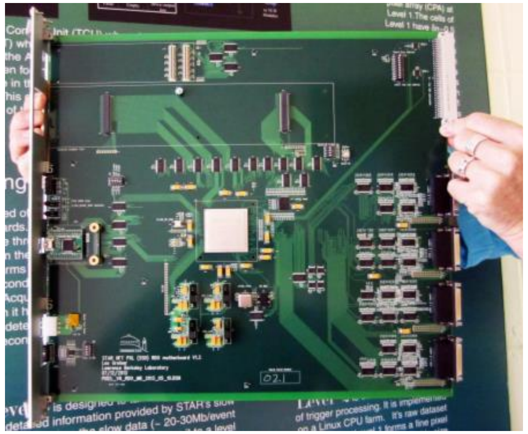
- Upgrade from 200 Hz to 1 kHz
- New
  - 40 ladder cards on detector
  - 5 RDO cards
  - 5 Fiber-to-LVDS boards



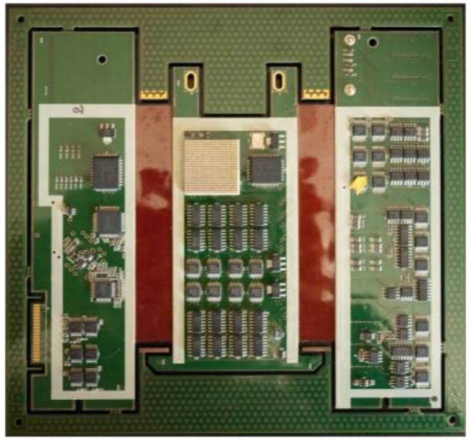
Fiber-to-LVDS



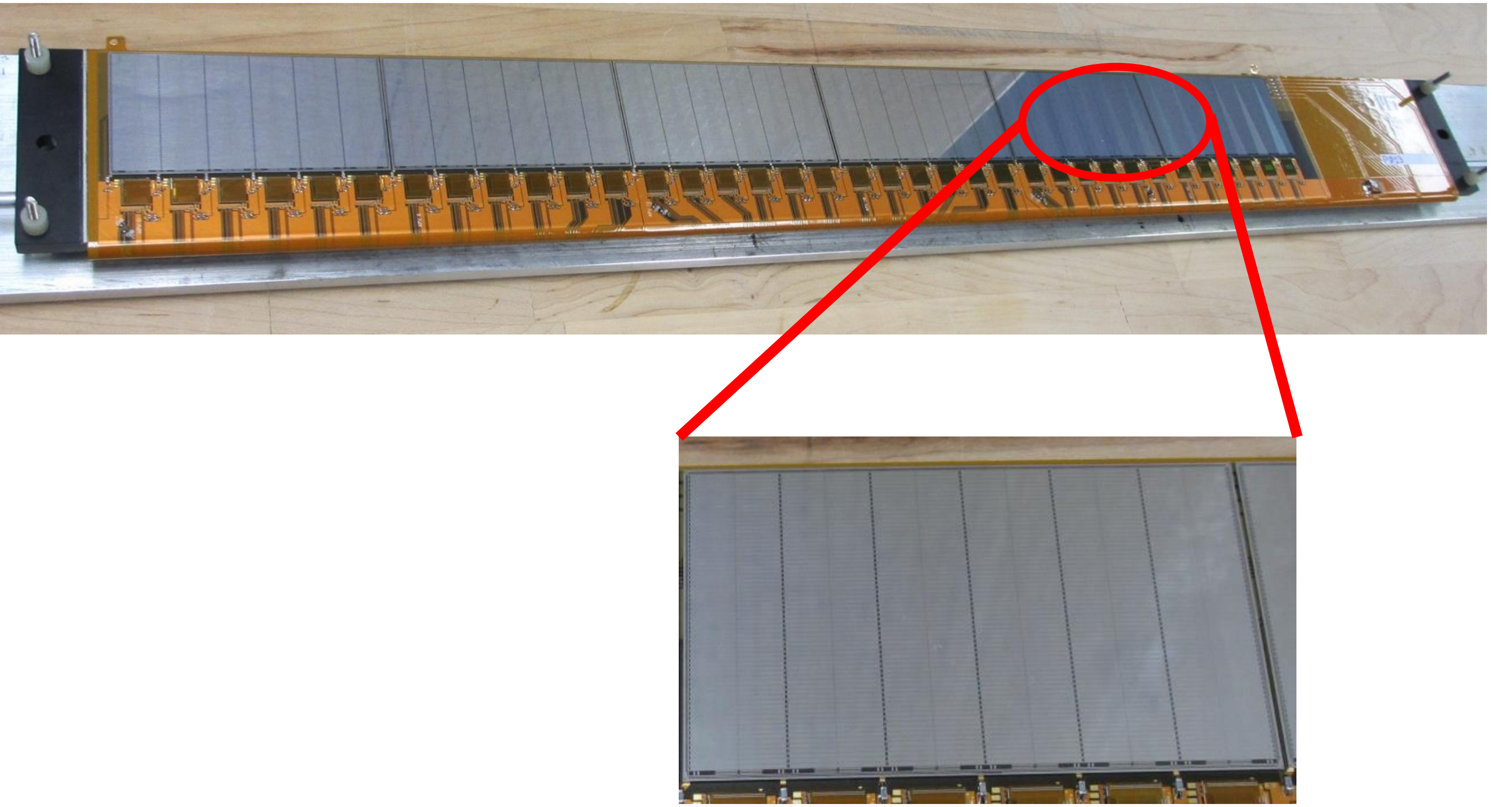
RDO board – adapted from PXL



Ladder cards



Intermediate Silicon Tracker (IST)



Radius	14 cm
Length	50 cm
ϕ-Coverage	2π
|η|-Coverage	≤1.2
Number of ladders	24
Number of hybrids	24
Number of sensors	144
Number of readout chips	864
Number of channels	110592
R-ϕ resolution	172 μm
Z resolution	1811 μm
Z pad size	6000 μm
R-ϕ pad size	600 μm

Pixel detector (PXL)

DCA pointing resolution	$(12 \oplus 24\ \text{GeV}/p_T c)$
Radii	Layer 1 at 2.8 cm Layer 2 at 8 cm
Pixel size	$20.7\ \mu\text{m} \times 20.7\ \mu\text{m}$
Hit resolution	$3.7\ \mu\text{m}$
Position stability	6 μm RMS (20 μm envelope)
Radiation length	Layer 1: $X/X_0 < 0.4\%$ Layer 2: $X/X_0 < 0.5\%$
Number of pixels	$\sim$ 356 M
Integration time (affects pileup)	185.6 ms
Radiation environment	20 – 90 kRad/year 2×10^{11} to 10^{12} 1 MeV n eq/cm^2
Installation time	$\sim$ 1 day