19. KONFERENCIA
ČESKÝCH A SLOVENSKÝCH FYZIKOV

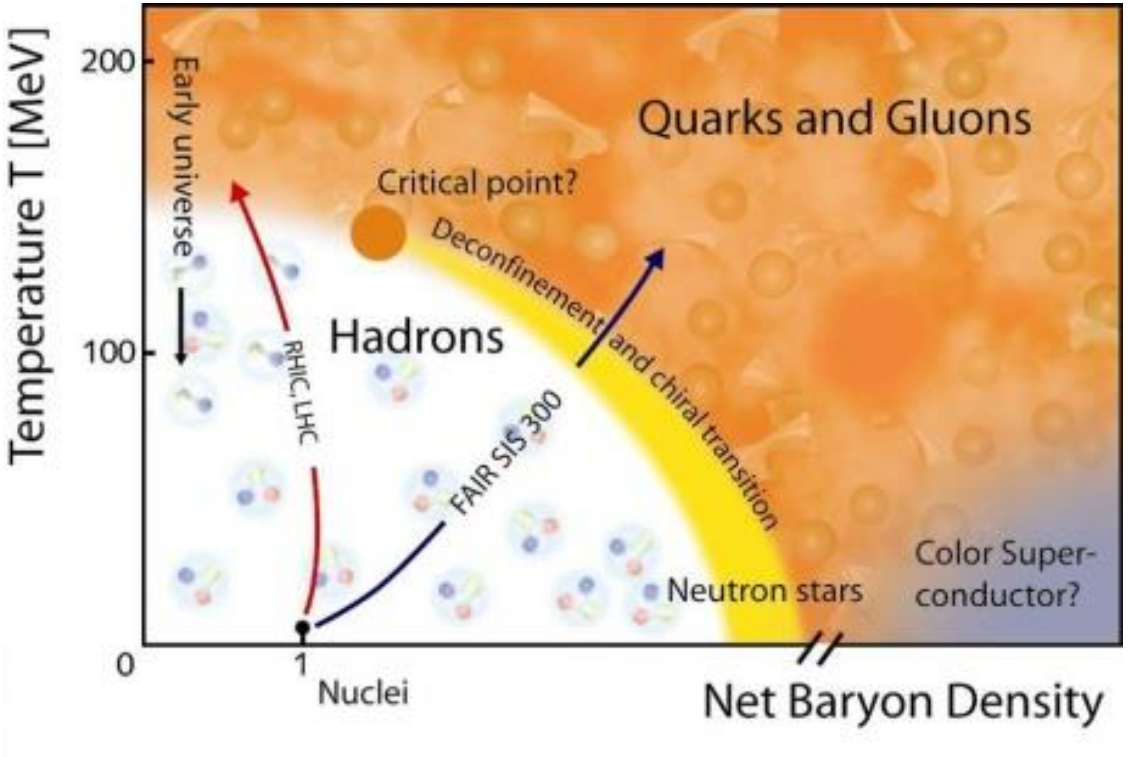
4. – 7. september 2017, Prešov, Slovenská republika
Prešovská univerzita v Prešove, Fakulta prírodných a humanitných vied

Measurement of Λ_c baryon production in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV with the STAR experiment

Miroslav Šimko
for the STAR Collaboration
Nuclear Physics Institute
of the Czech Academy of Sciences

Quark-gluon Plasma (QGP)

Phase diagram of strongly interacting matter



- New state of matter composed of deconfined quarks and gluons
- Expected to exist in neutron stars and in the early Universe

More on QGP in the talk on Wednesday
at 10:00 am by Jana Bielčíková

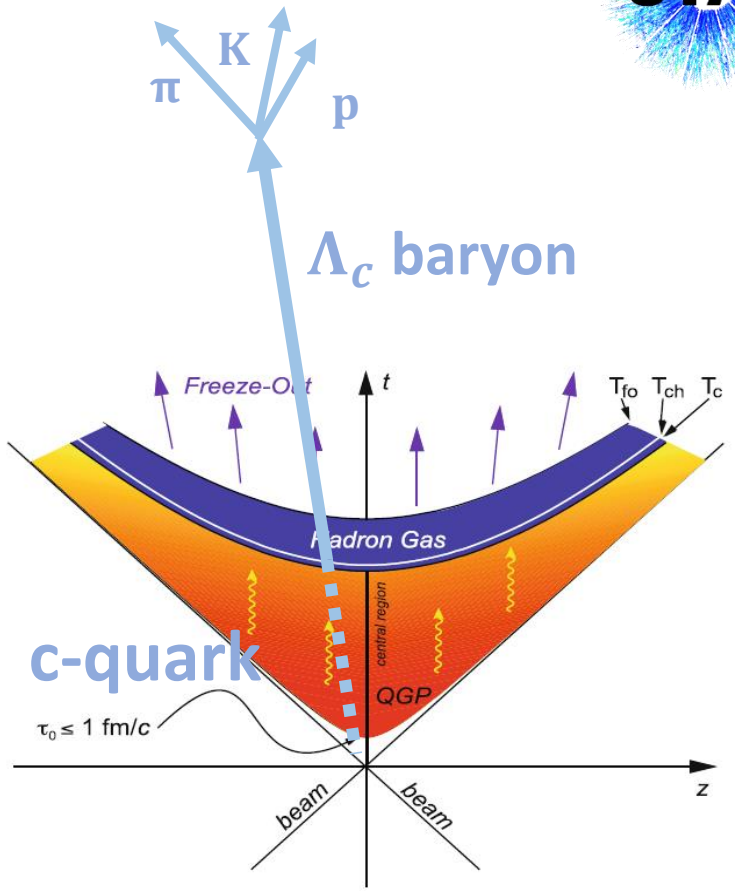
Use charm quarks to probe QGP

- Charm quarks are predominantly produced in hard scatterings during early stages of heavy-ion collision
  - $m_{\mathrm{c}} = 1.28 \pm 0.03\ \mathrm{GeV}/c^2 \gg T_{\mathrm{QGP}}$

    $m_{\mathrm{u}} = 2.2^{+0.6}_{-0.4}\ \mathrm{MeV}/c^2,$
    $m_{\mathrm{d}} = 4.7^{+0.5}_{-0.4}\ \mathrm{MeV}/c^2,$
    $m_{\mathrm{s}} = 98^{+6}_{-4}\ \mathrm{MeV}/c^2$

    [Chin. Phys. C, 40, 100001 (2016) and 2017 update]

- Good probe of the behavior of QGP as charm quarks experience the entire evolution of the medium



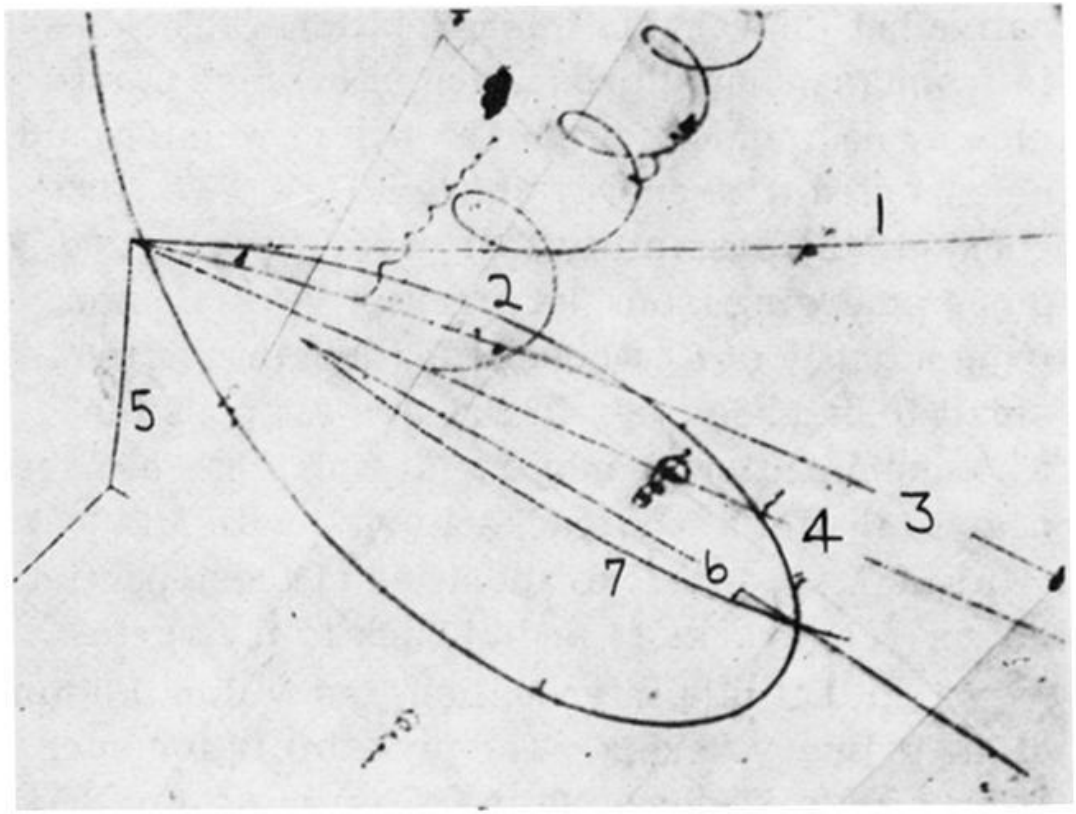
More on charm meson measurements in the talk on Wednesday at 12:15 by Lukáš Kramárik

Λ_c baryon

- Lightest charm baryon
- Valence quarks: u+d+c
- Mass: 2286 MeV/c^2
- $c\tau \sim 60\ \mu\mathrm{m}$

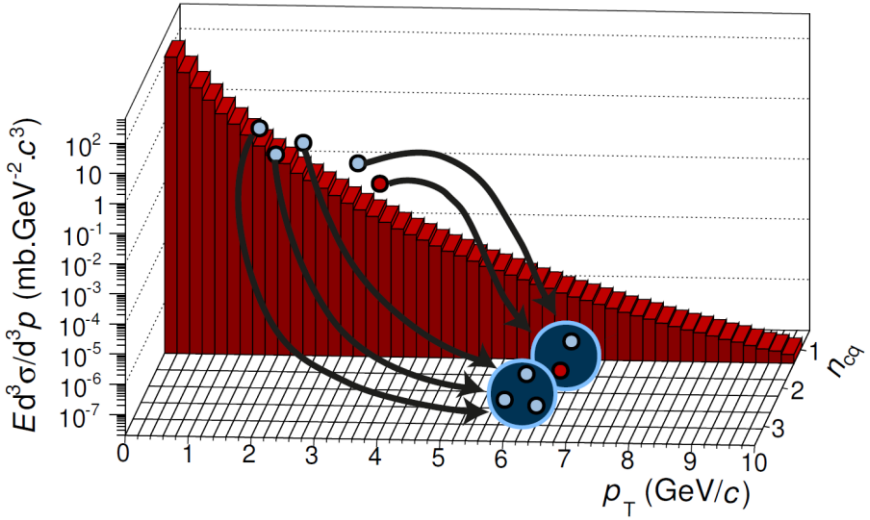
- First observed in 1975 at BNL 7-ft cryogenic bubble chamber, exposed to a neutrino beam

[Cazzioli et al. PRL 34 (1975) 1125]

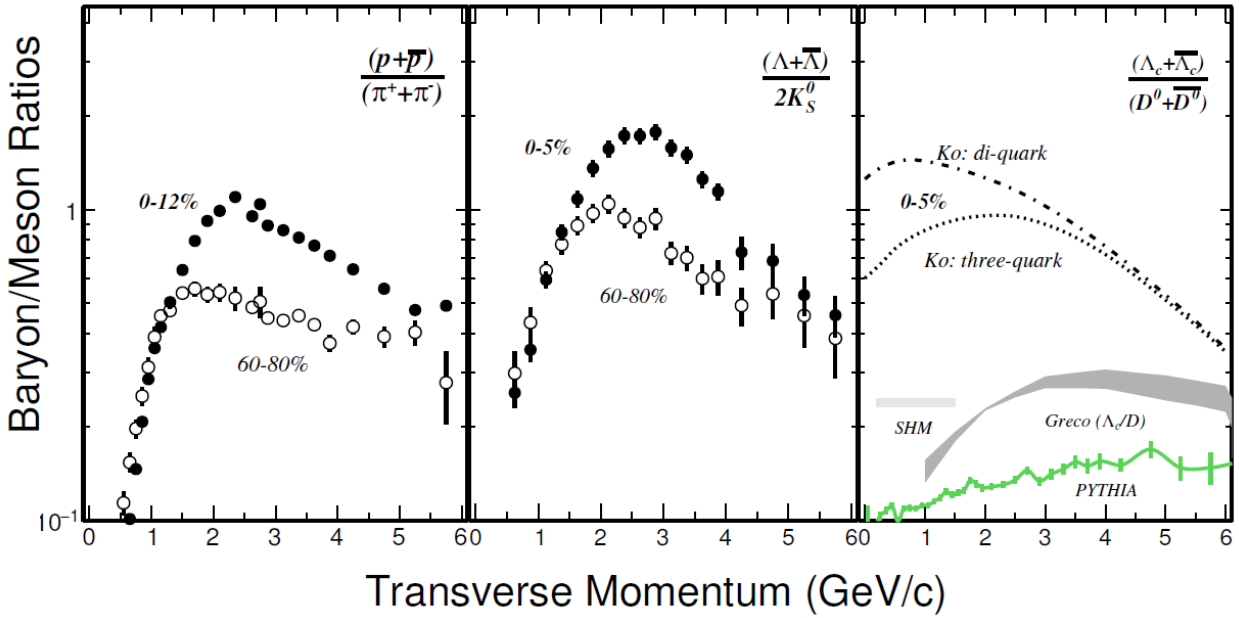


Quark coalescence

- Enhancement of baryon-to-meson ratios for light hadrons have been observed in Au+Au collisions compared to that in p+p collisions
- Hadronization mechanisms:
  - Fragmentation: one parton fragments into hadron(s)
  - Coalescence: multiple quarks cluster together to form a hadron
- Coalescence hadronization process is expected to occur in heavy-ion collisions, as compared to only fragmentation hadronization in elementary collisions
- Measurement of Λ_c/D^0 ratio will provide new insights into whether charm quarks also participate in coalescence hadronization

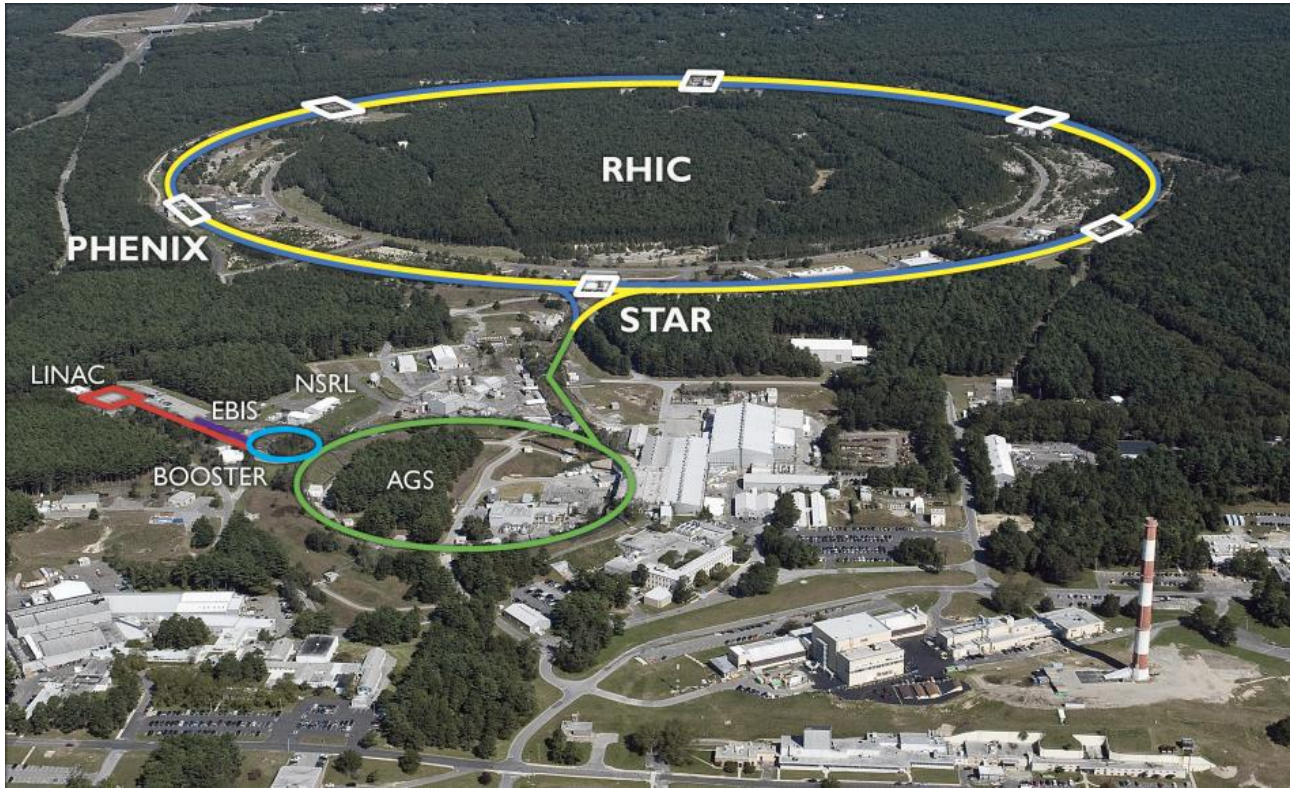


[STAR: PRL 108 (2012) 072301]
[Theory:
SHM: PLB 659 (2008) 149];
Greco: PRD 90 (2014) 054018;
Ko: PRL 100 (2008) 222301]



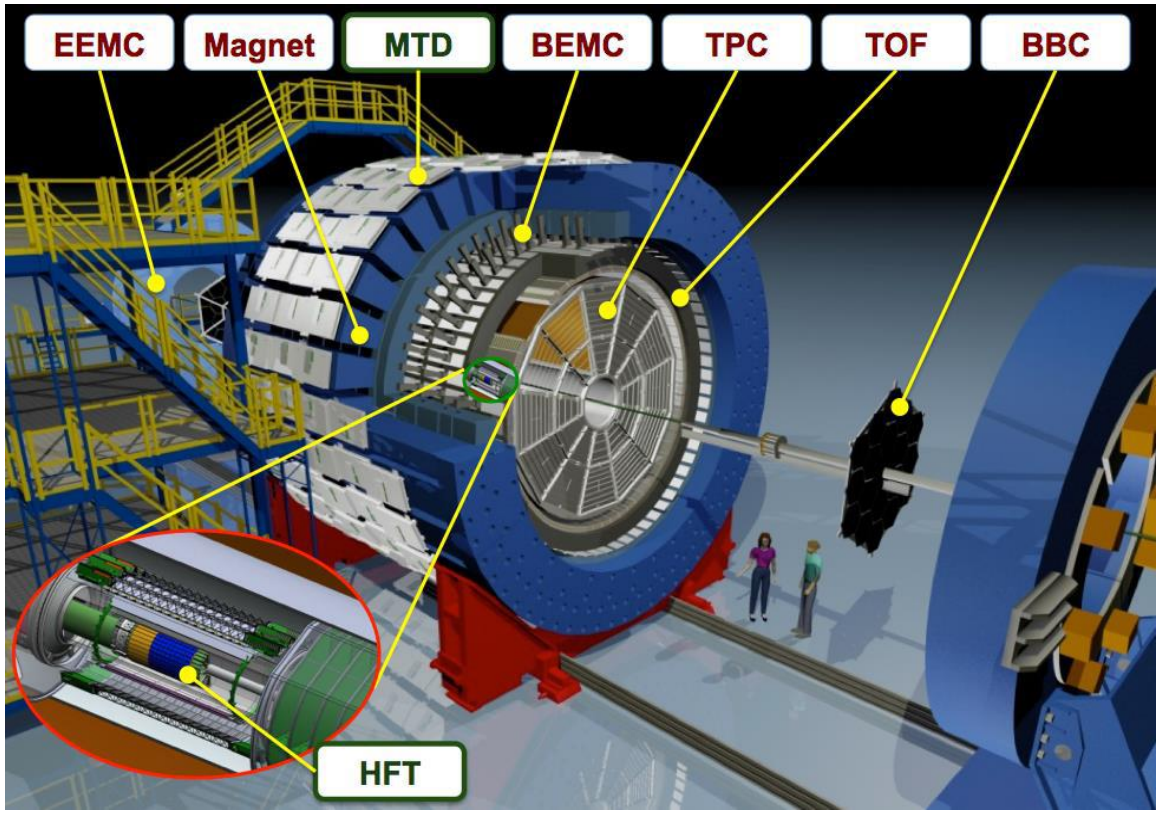
The Relativistic Heavy-Ion Collider at Brookhaven National Laboratory

- Dedicated facility to study the Quark-Gluon Plasma and proton spin
- Capable of colliding a variety of nuclei as well as polarized protons
- 3.9 km circumference
- Maximum center-of-mass energy: $\sqrt{s_{\mathrm{NN}}}$= 200 GeV for Au+Au, $\sqrt{s}$= 510 GeV for p+p



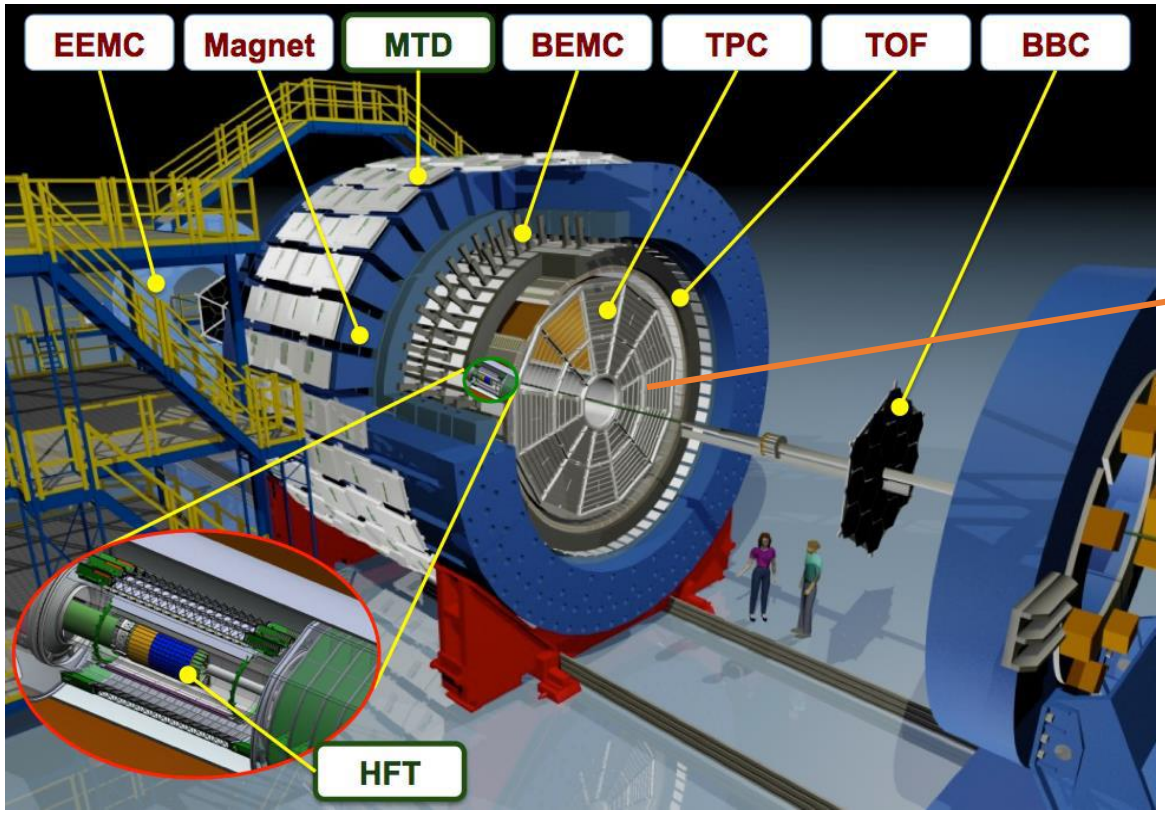
The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
- Excellent tracking and identification of charged particles with full azimuthal coverage at midrapidity
- Mostly inside of a 0.5T solenoid magnet



The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
- Excellent tracking and identification of charged particles with full azimuthal coverage at midrapidity
- Mostly inside of a 0.5T solenoid magnet

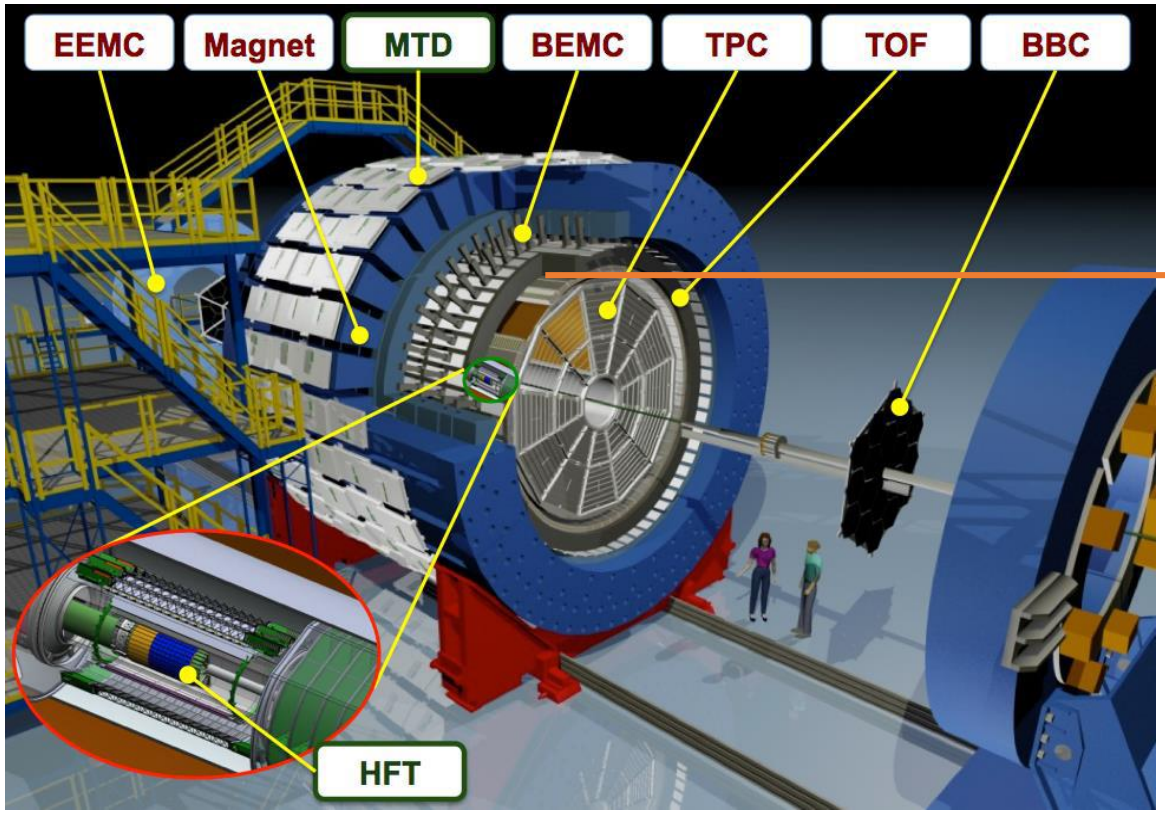


Time-Projection Chamber (TPC)

- Large-volume gaseous detector
- Tracking and particle identification via energy-loss measurement

The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
- Excellent tracking and identification of charged particles with full azimuthal coverage at midrapidity
- Mostly inside of a 0.5T solenoid magnet

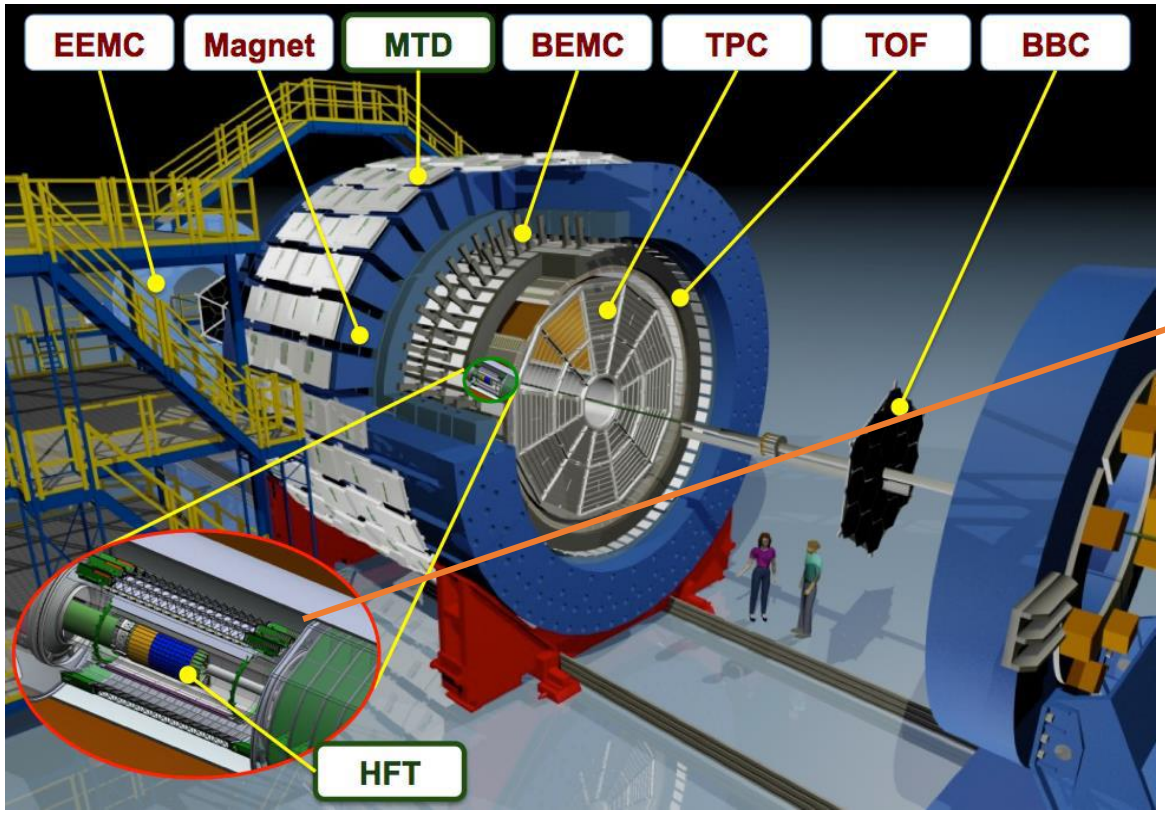


Time-Of-Flight detector (TOF)

- MRPC
- Particle identification via measurement of the time of flight

The Solenoidal Tracker at RHIC (STAR)

- Multipurpose particle detector
- Excellent tracking and identification of charged particles with full azimuthal coverage at midrapidity
- Mostly inside of a 0.5T solenoid magnet

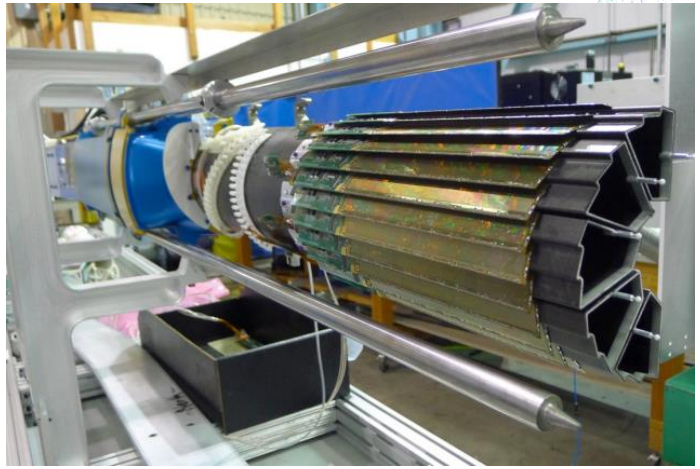


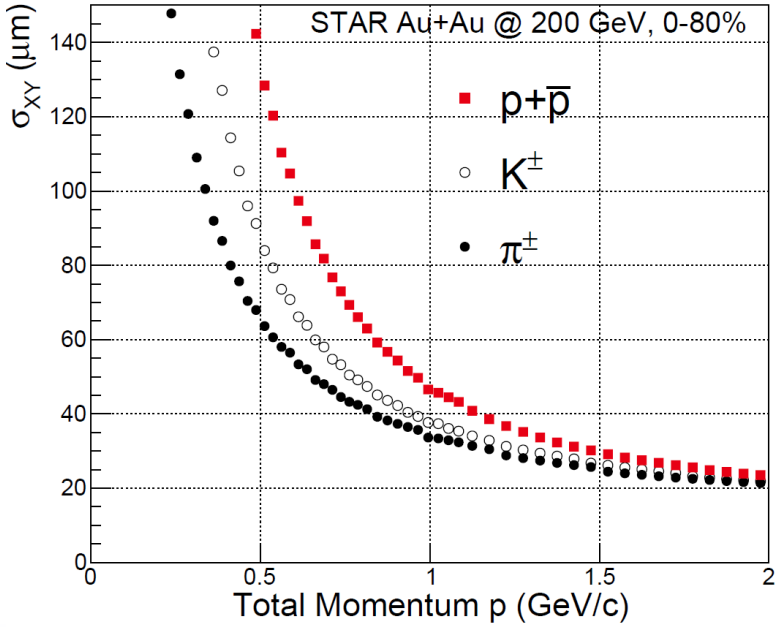
Heavy Flavor Tracker (HFT)

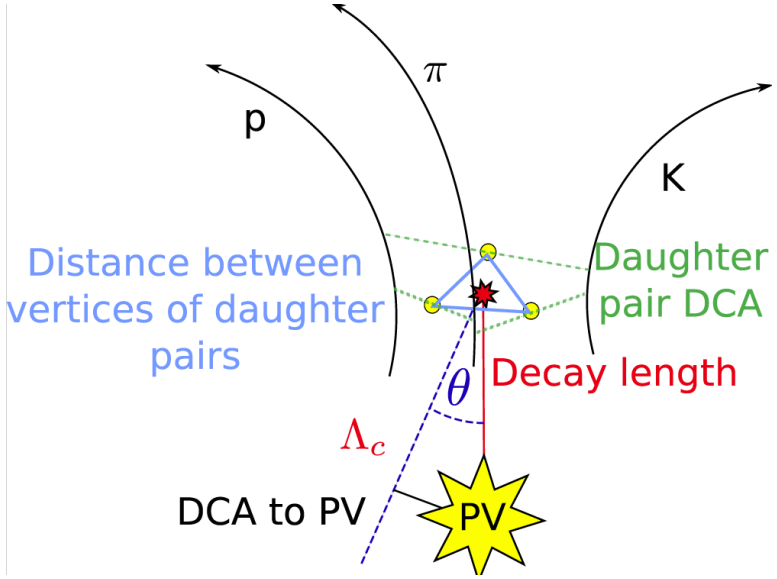
- Installed in 2014 – 2016
- 4 layers of silicon detectors
- Precise vertexing detector

STAR Heavy Flavor Tracker

- The Pixel detector: the first MAPS technology in a collider experiment
- Pointing resolution: ~20 μm at high p_T (exceeds the requirement of 55 μm for 750 MeV/c kaons)
- Recorded $\sim 9 \times 10^8$ good Au+Au events in 2014. Results shown in this presentation are based on this data-sample





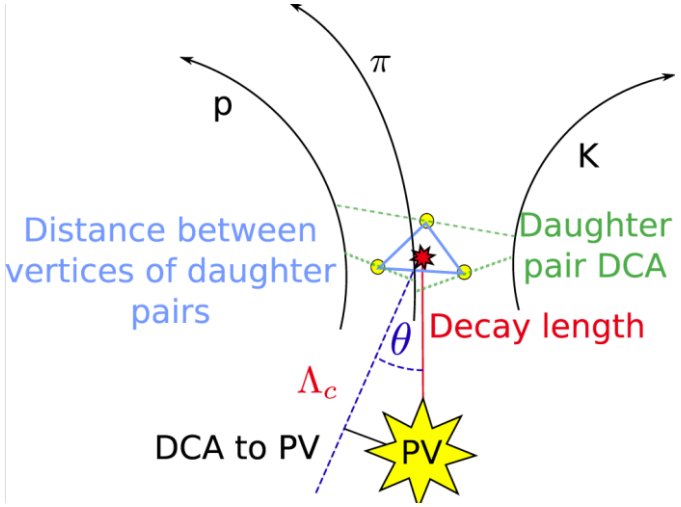


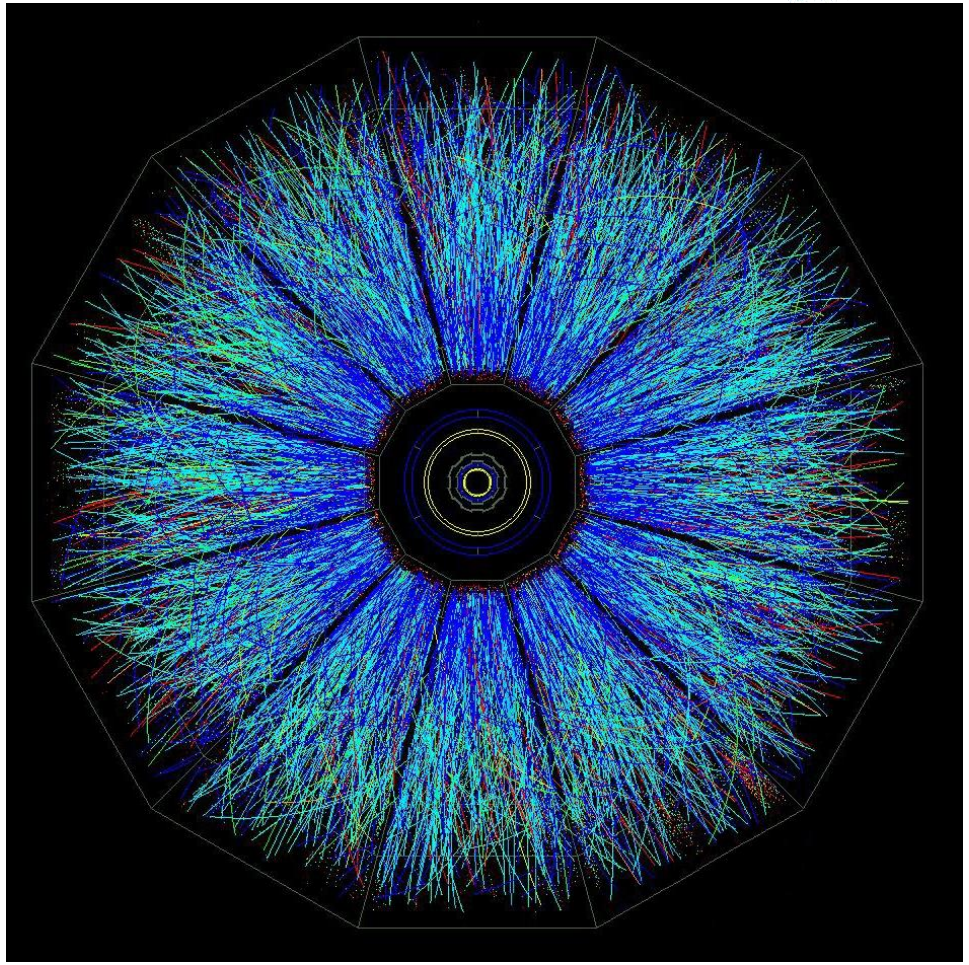
[STAR: PRL 118 (2017) 212301]

Topological reconstruction of Λ_c with the HFT

- $\Lambda_c^{\pm} \rightarrow p^{\pm}K^{\mp}\pi^{\pm}$ $\quad c\tau \sim 60\ \mu m,$ $\quad$ BR = 5 %
- Experimentally challenging to measure in heavy-ion collisions

- HFT used for reconstruction of secondary vertices with high precision
- Usage of machine learning methods to optimize topological cuts
- Combinatorial background is greatly suppressed

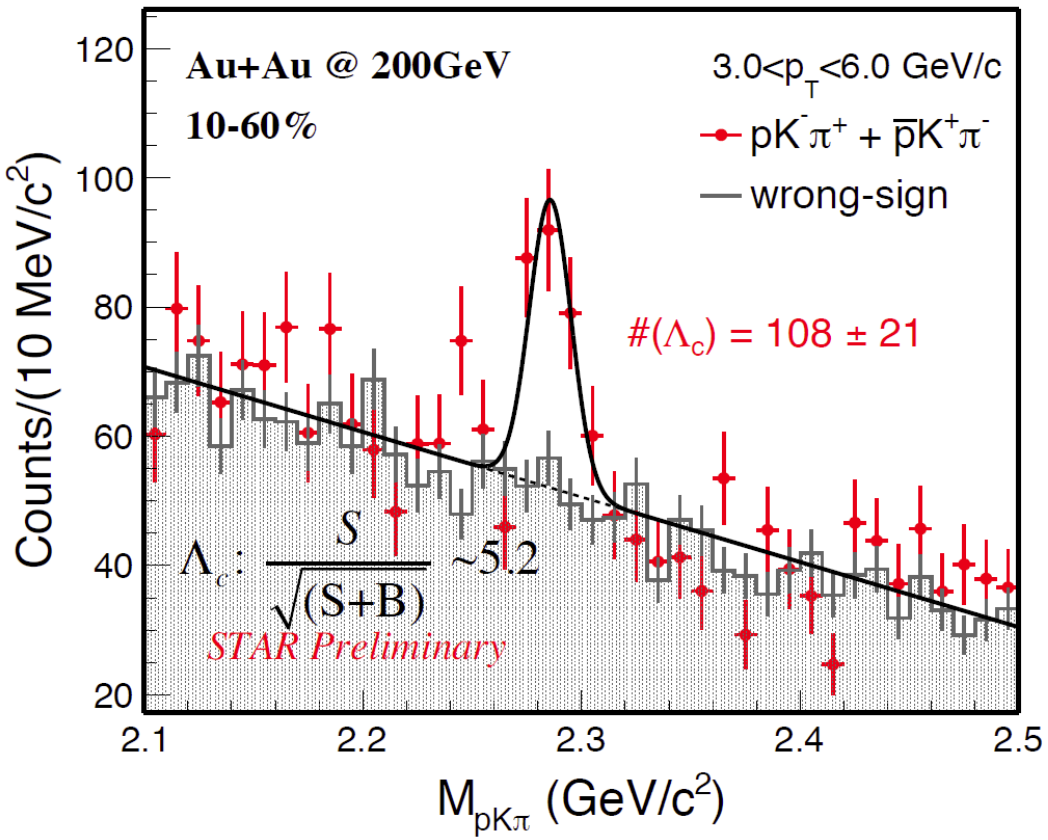




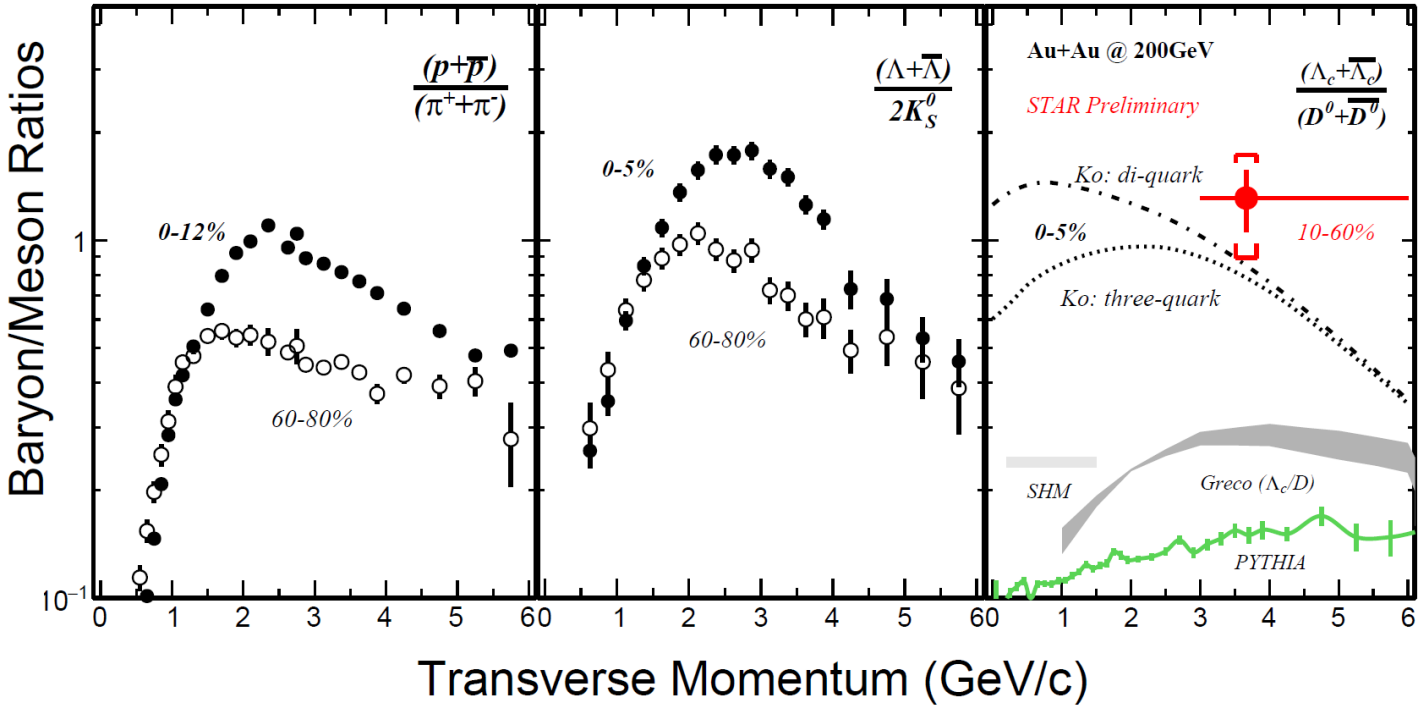
p+K+π invariant mass spectrum

- First measurement of Λ_c baryons in heavy-ion collisions

- Measured for
  - Centrality: 10 – 60 %
  - p_T: 3 – 6 GeV/c
- Significance: $\frac{S}{\sqrt{S+B}} \sim 5.2$
- Background estimation: p+K+π triplets with incorrect combinations of charge signs



Λ_c/D^0 yield ratio



[STAR: PRL 108 (2012) 072301]
[Theory:
SHM: PLB 659 (2008) 149];
Greco: PRD 90 (2014) 054018;
Ko: PRL 100 (2008) 222301]

- Clear enhancement observed compared to the fragmentation scenario predicted by PYTHIA
- Compatible with baryon-to-meson ratios of light hadrons
- Ko model (0-5%), including coalescence of thermalized charm quarks, is consistent with the data for both di-quark + 1 quark, and three-quark scenarios

Summary

- The first measurement of Λ_c baryons in heavy-ion collisions
- Enhancement of the Λ_c/D^0 ratio – indication of charm quark coalescence

- In 2016, STAR recorded about twice more Au+Au events compared to 2014
- Stay tuned!

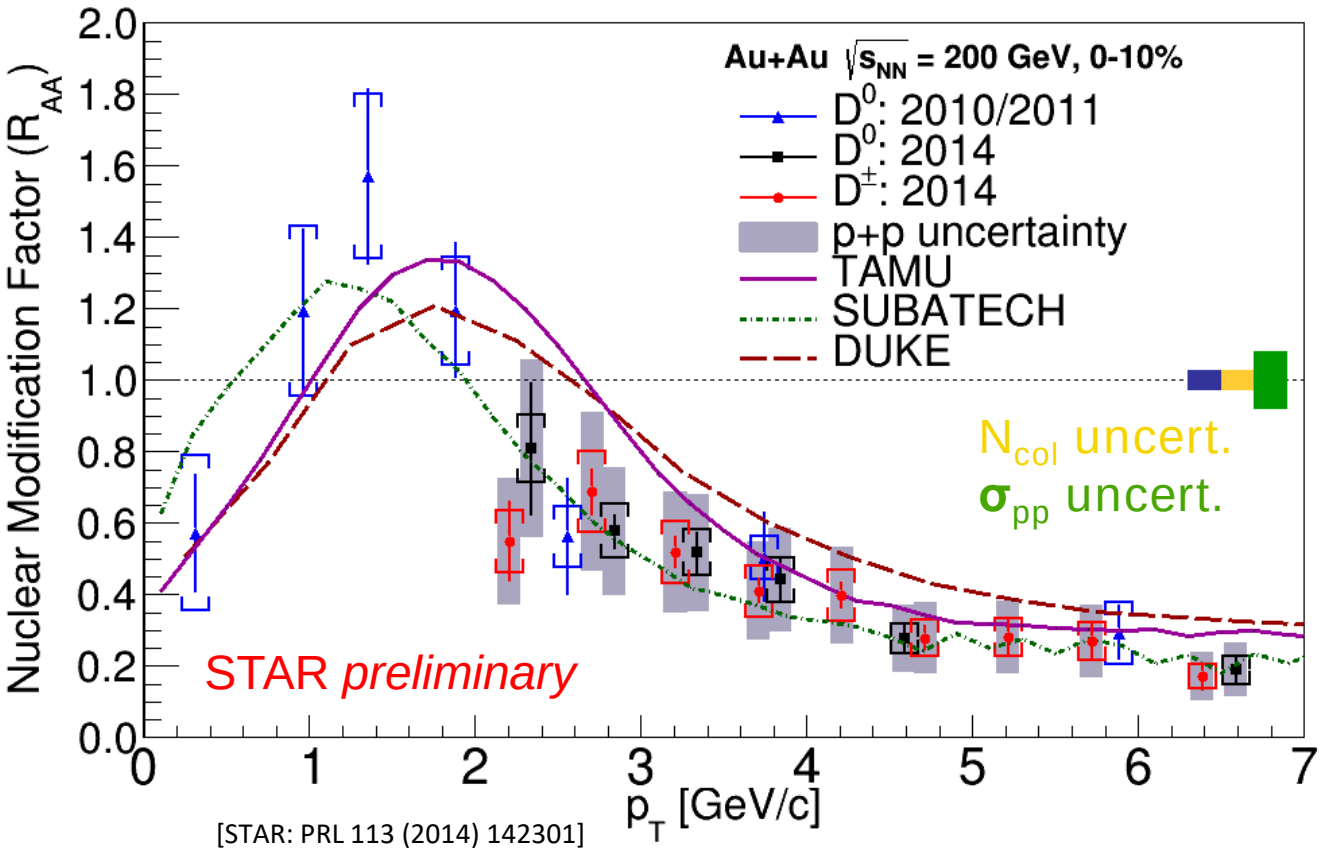
Thank you for your attention

Backup

Nuclear modification factor R_{AA} of D^0 and $D^{\pm}$

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

- Yield at $p_T > 2.5$ GeV/c is greatly suppressed
  - Improved precision with the HFT
  - Results from D^0 and $D^{\pm}$ are consistent
- Models with strong charm-medium interactions describe the data



[STAR: PRL 113 (2014) 142301]
[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]

Pixel detector (PXL)

Radii	Layer 1 at 2.8 cm Layer 2 at 8 cm
Pixel size	$20.7\ \mu\mathrm{m} \times 20.7\ \mu\mathrm{m}$
Hit resolution	$3.7\ \mu\mathrm{m}$
Position stability	$6\ \mu\mathrm{m}$ RMS ($20\ \mu\mathrm{m}$ 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