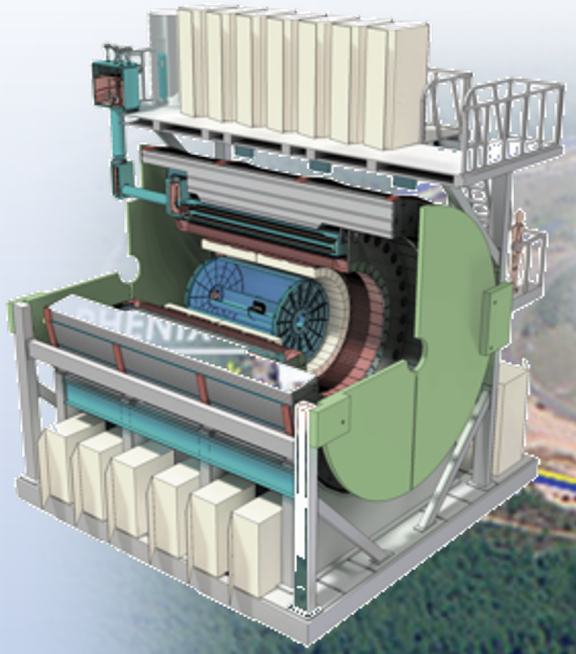


sPHENIX Open Heavy Flavor Physics

Ming Liu
Los Alamos National Lab
for the sPHENIX Collaboration

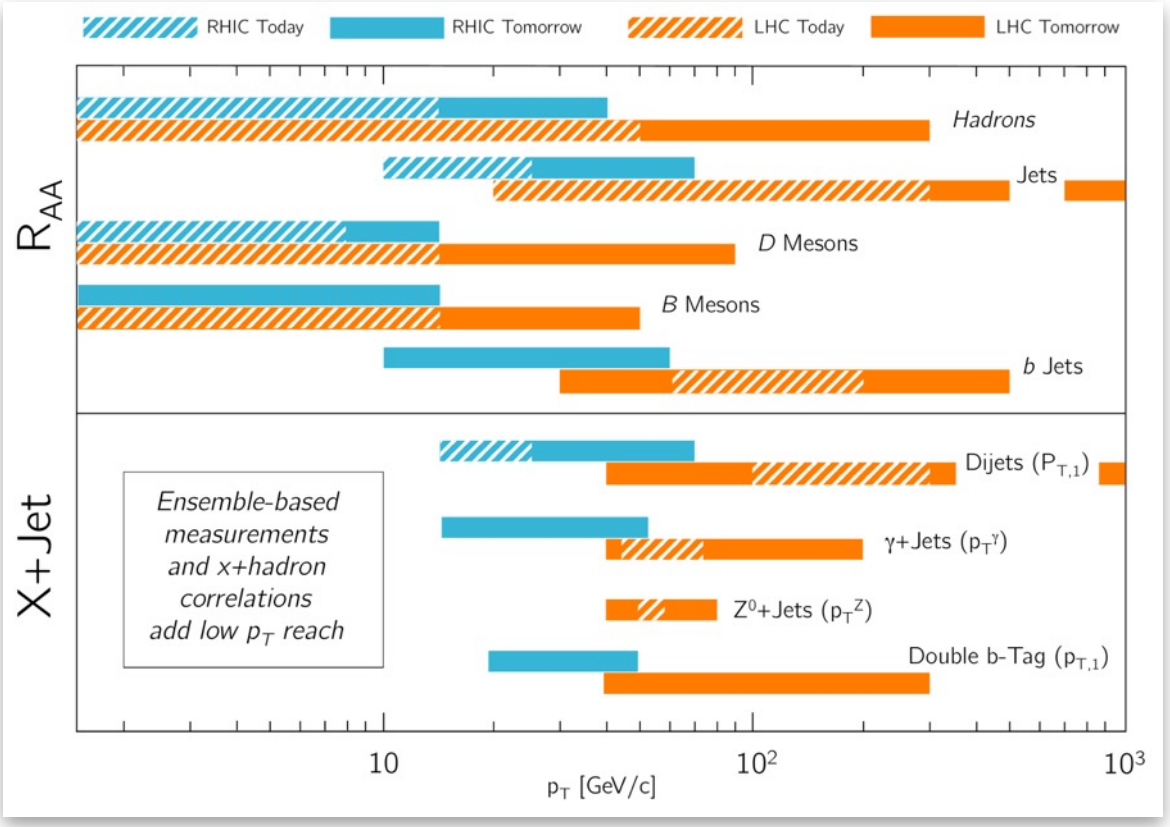
04/20/2021
APS April Meeting (Online)

Probing the "Inner Workings" of QGP with HF

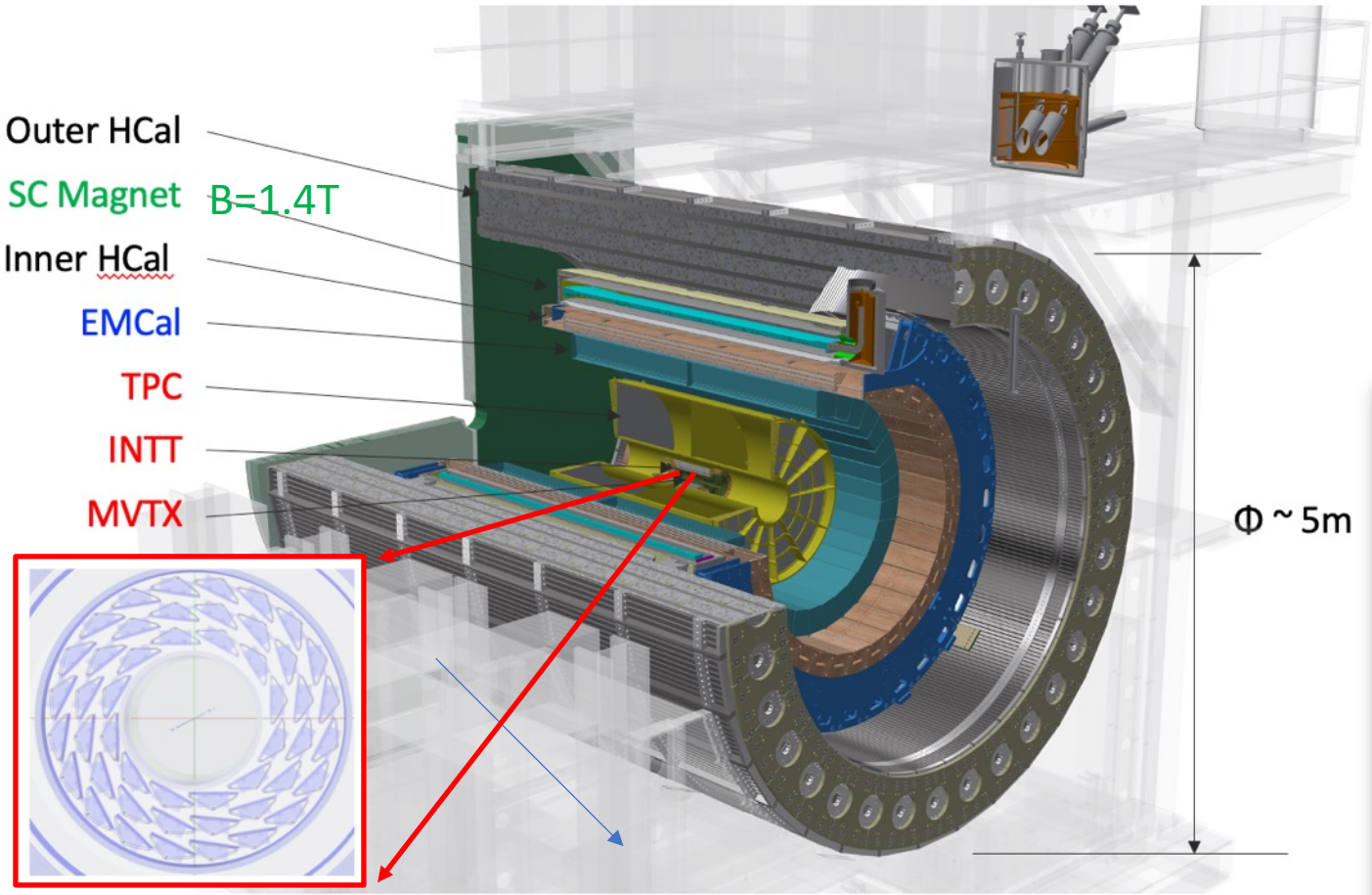
- **Heavy quark energy loss mechanisms in QGP**
  - Radiative vs collisional
  - Mass dependence R_{AA} @transition region, pT ~ M_Q
- **Heavy quark interactions with QGP**
  - HF diffusion coefficient, "flow"
  - QGP properties, RHIC vs LHC
- **CNM to QGP transition**
  - pp, pA and AA, RHIC vs LHC
  - Event multiplicity dependence, onset of QGP?
- **Heavy quark hadronization**
  - Coalescence, non-perturbative QCD at low pT
  - Baryon/Meson ratios
  - Test pQCD at high pT

sPHENIX projections:

Rich set of observables - hadrons and jets



The sPHENIX Experiment



MVTX beam view
R = 2.5 – 4.0 cm

Key capabilities:

- Full azimuth, |eta| < 1.1
- High trigger rate ~15kHz, collect all central AuAu
- EMCal: high pT direct photons
- Inner and outer HCals: jets
- Precision tracking: HF and more
  - 0.2 < pT < 40 GeV

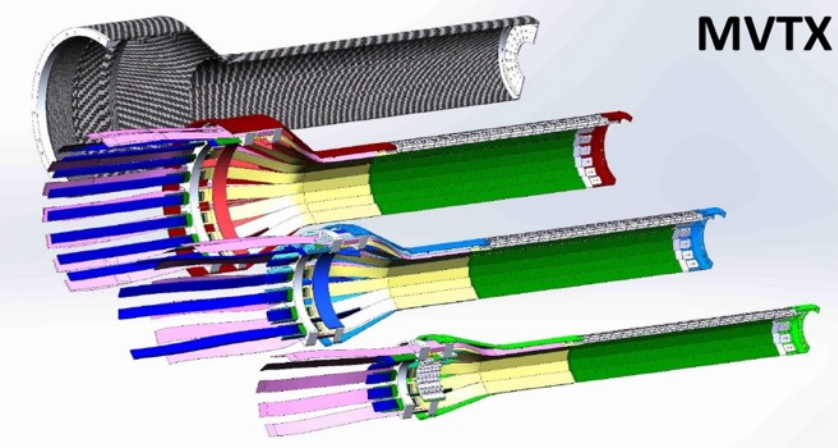
  Trigger-less streaming readout, p+p and pAu

sPHENIX Run Plan

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Open HF Tagging with MVTX Upgrade

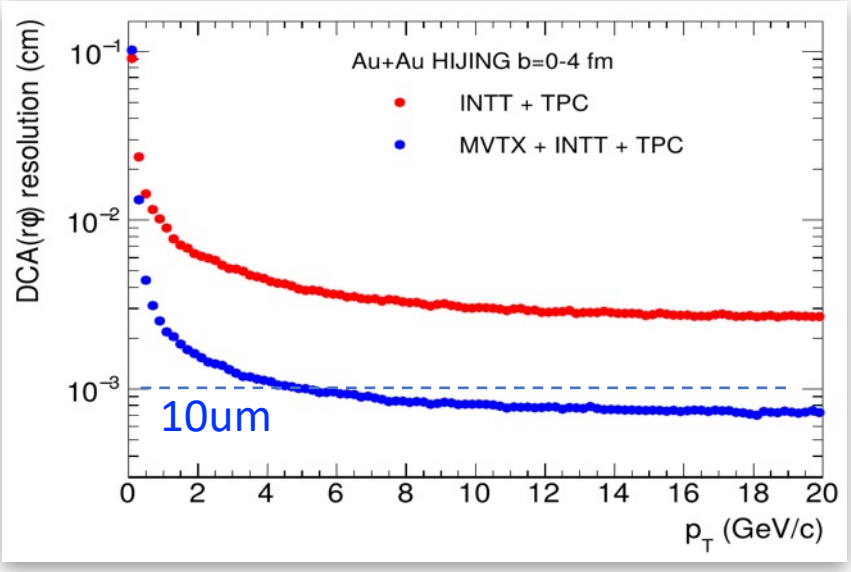
- Monolithic-active-pixel-sensor based VerTeX detector

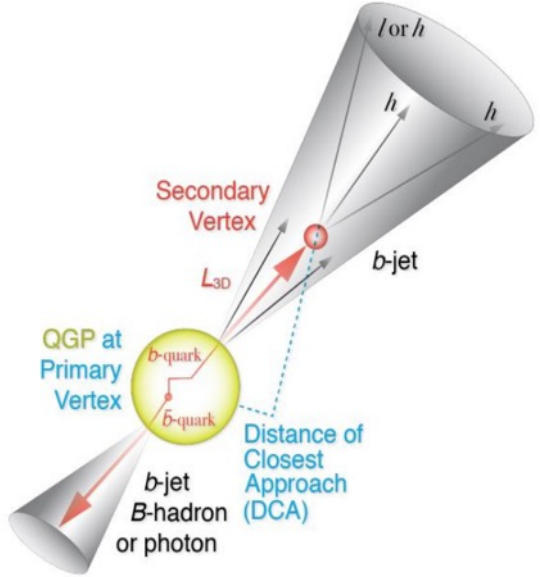


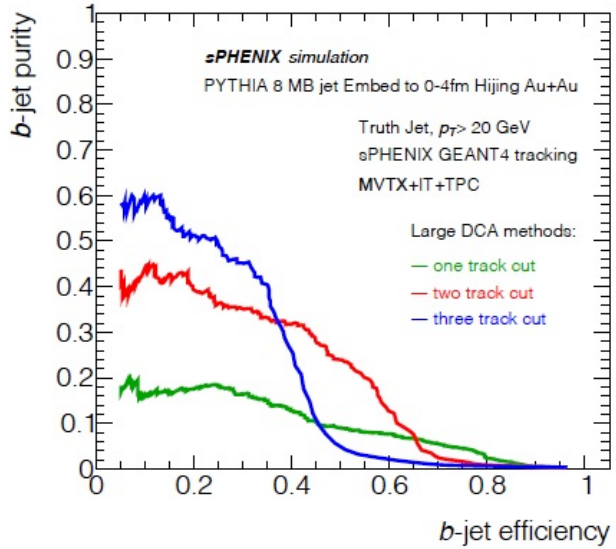
MVTX key parameters: (ALPIDE)

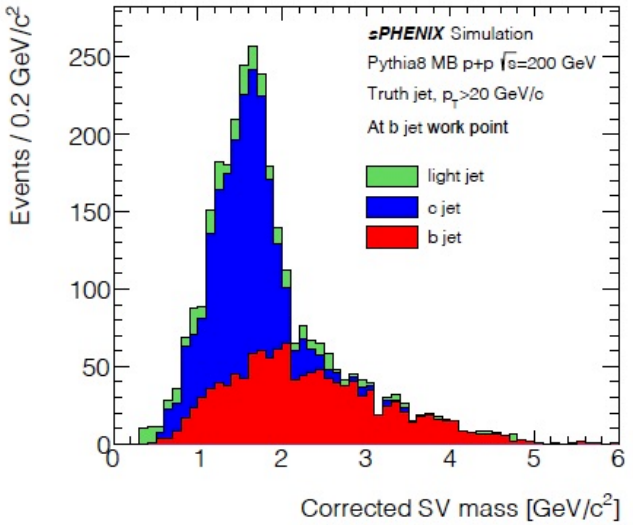
- pixel size: **27um x 29 um**
- ultra-thin stave: **0.35%X_0**
- Integration time: **~5us**

- Multi-tracks w/ large DCA
- 2nd vertex mass
- Exclusive hadron reconstruction





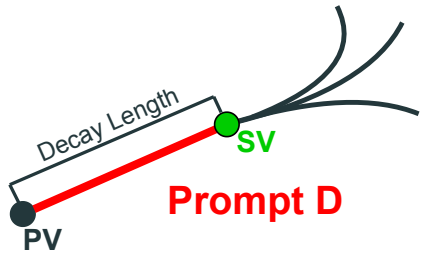


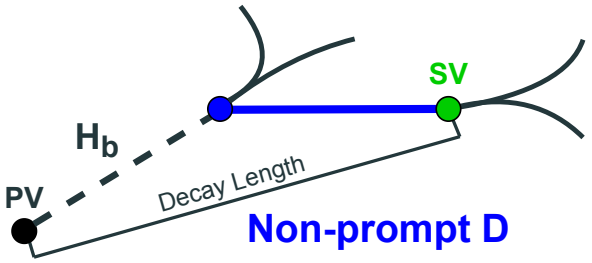


Work in Progress: from Full Monte Carlo Simulations

PYTHIA 8 p+p with full detector GEANT sim + reco

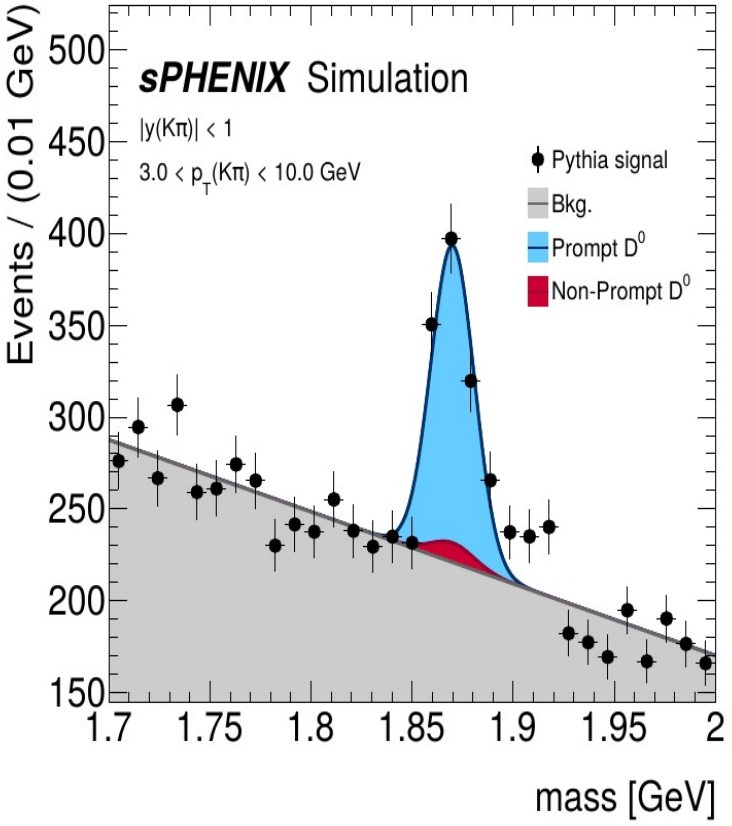
$$p + p \to D^0 + X \to (K^- \pi^+) + X$$

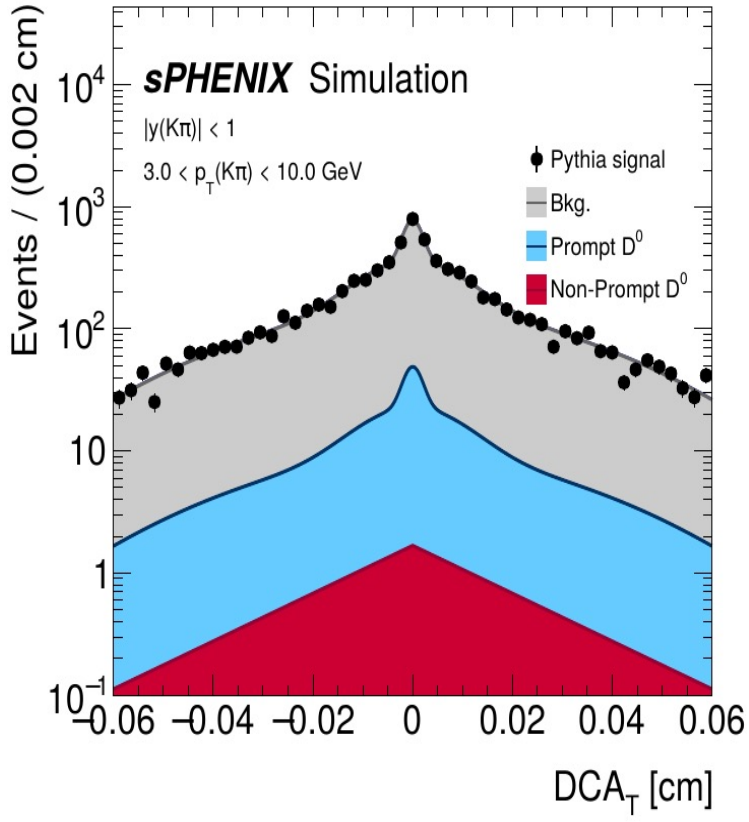




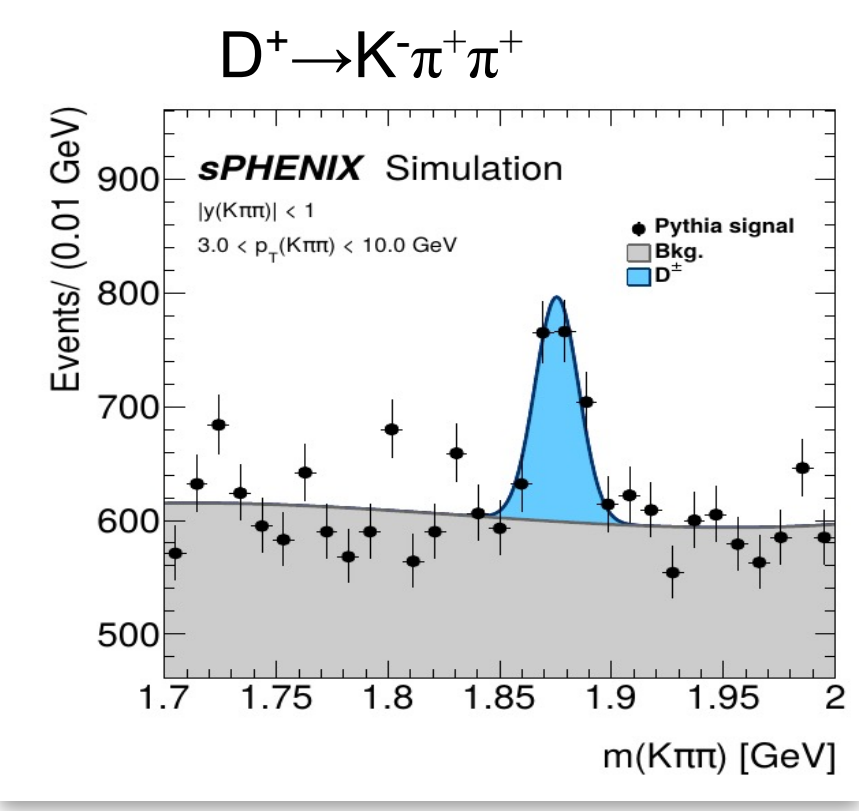
$$p + p \to H_b + X \to (D^0 + X') + X$$

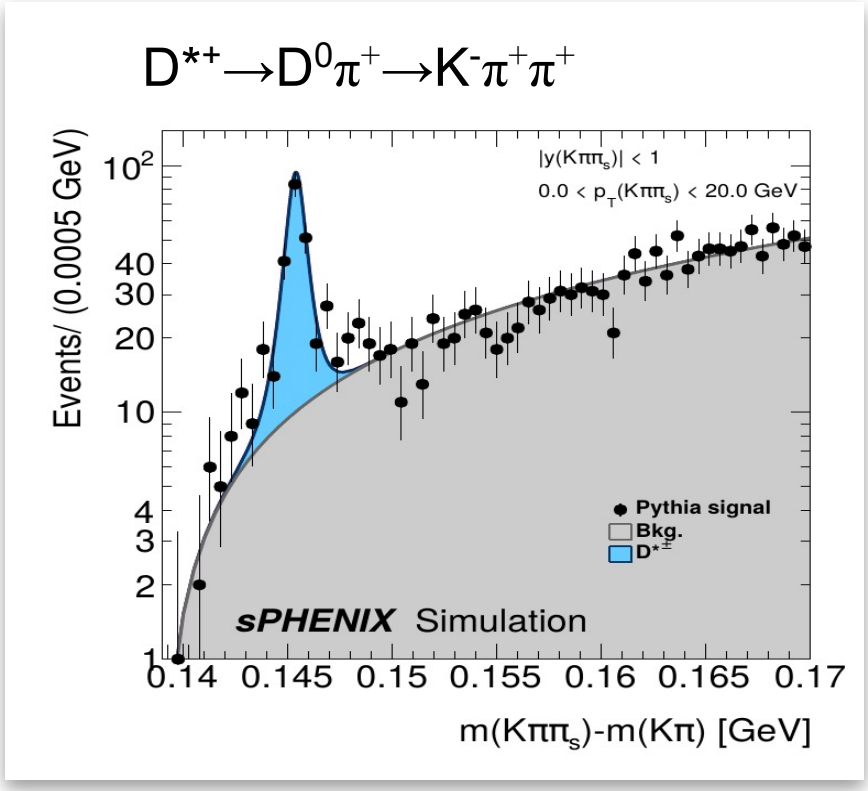
KFParticle package implemented for exclusive HF hadron reconstruction





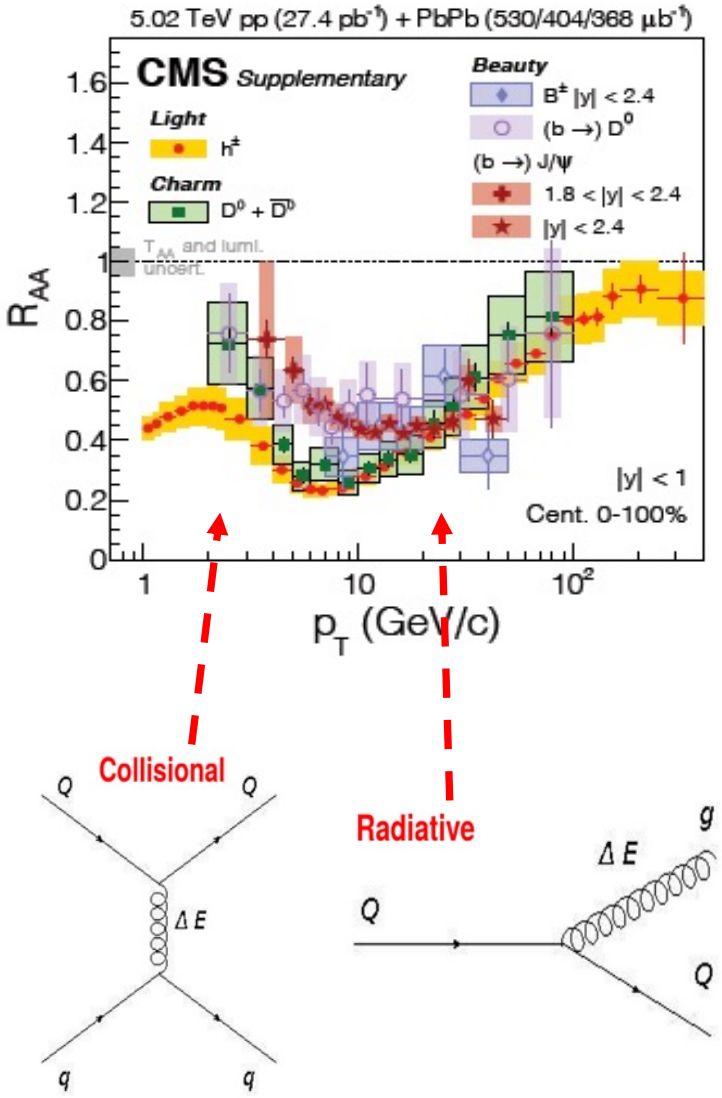
Work in Progress: More from KFParticle Outputs

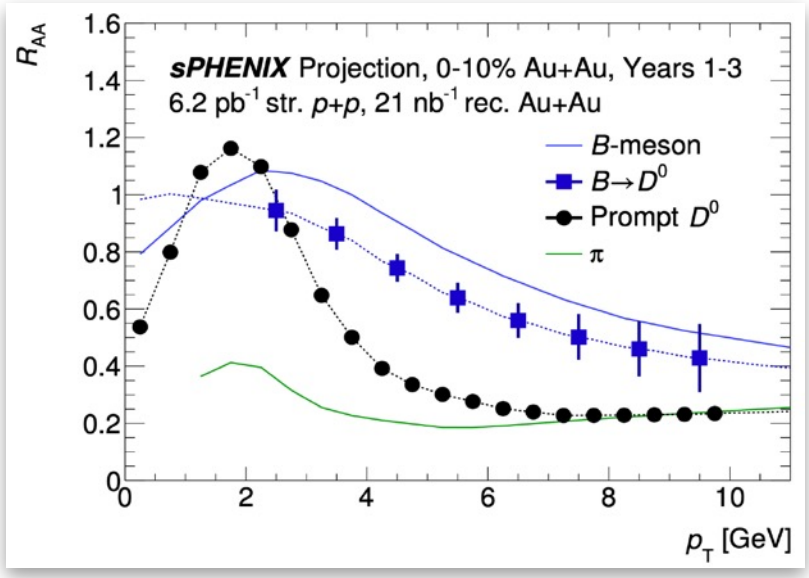


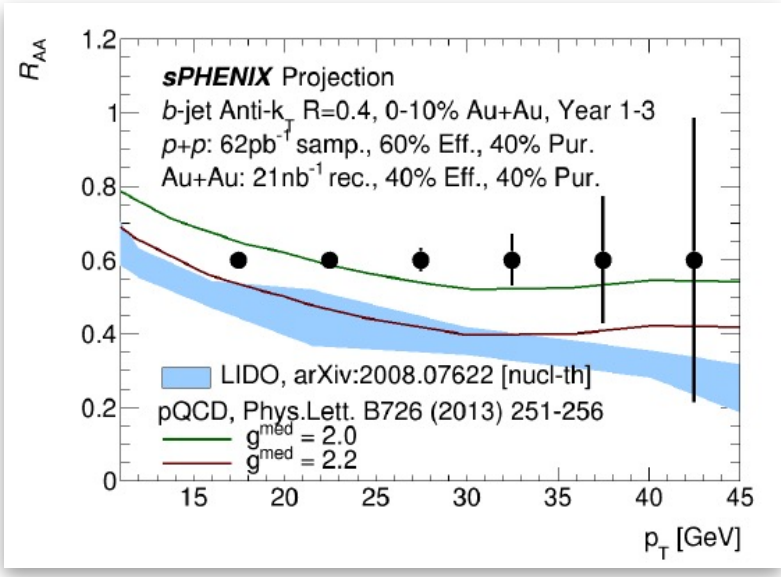


For D*, pT ~> 1.5GeV, with soft pion pT > 0.2GeV

Precision HF Hadron and b-Jet R_{AA}







Many factors affect the HF hadron production:

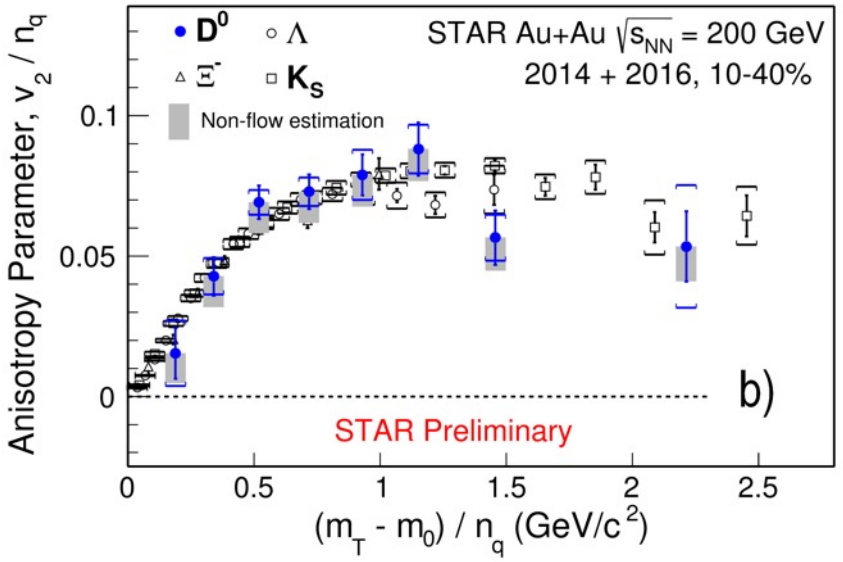
- Heavy quark energy loss in QGP: mass, pT dependence
- Heavy quark diffusion in QGP
- Heavy quark hadronization in QGP

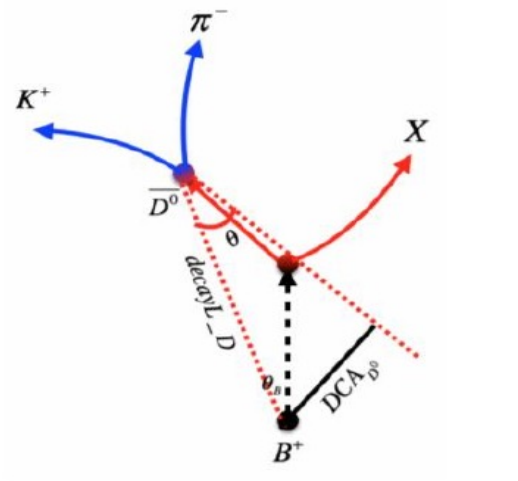
Also other observables:

- di-b-jet, modification of HF jet structures etc.

Precision “Flow” Measurements of B-hadron and b-Jets

STAR: D^0 v2 m_T scaling observed





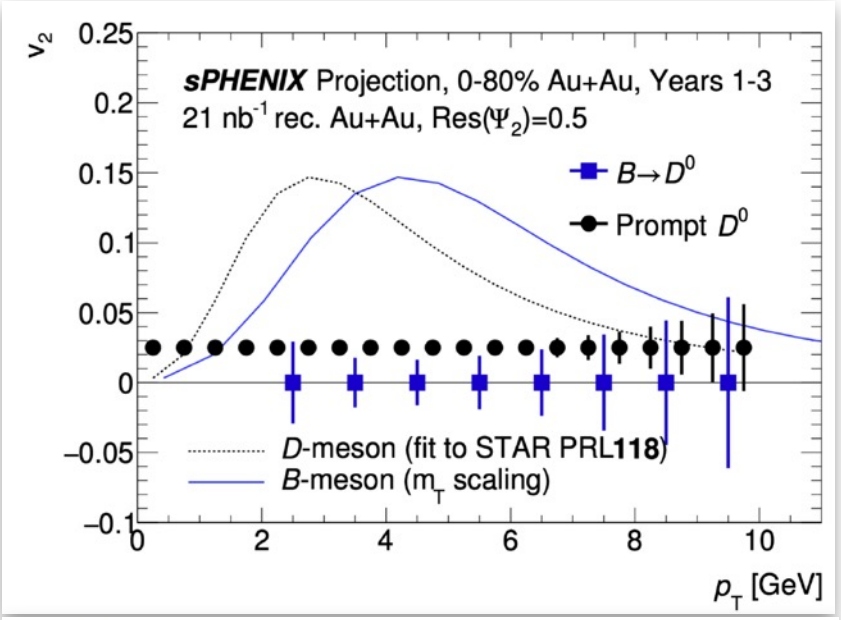
$B \rightarrow \overline{D^0} + X$ (B.R. 60%)

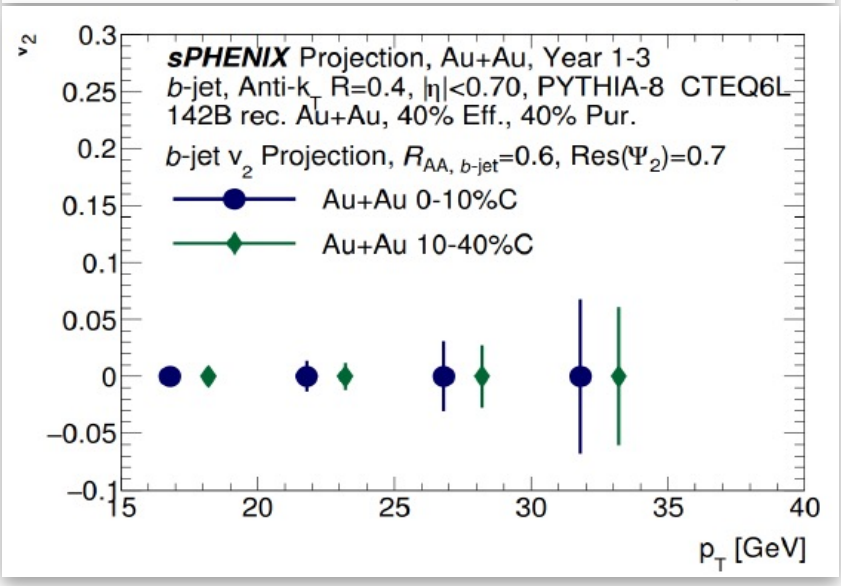
Many factors affect the HF hadron production:

- Heavy quark energy loss in QGP
- Heavy b-quark diffusion in QGP
- Heavy quark hadronization in QGP

b-jet flow, pQCD:

- Energy loss induced v2?



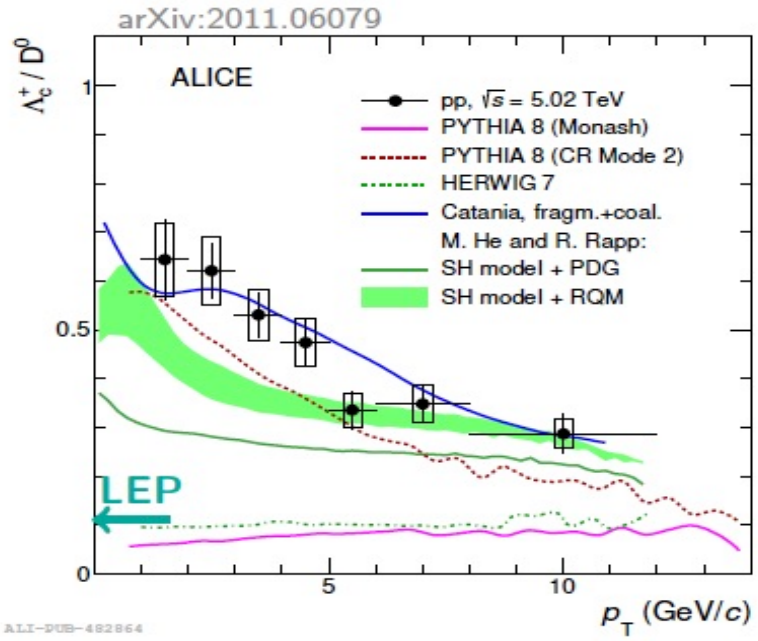


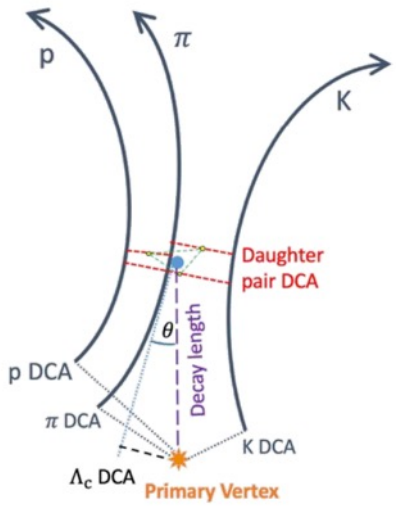
From Quarks to Hadrons in QGP

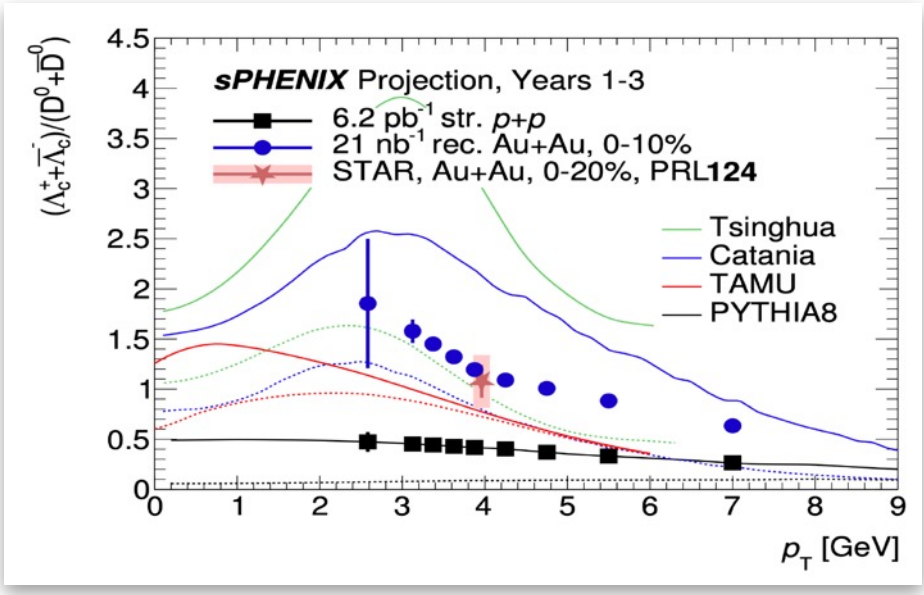
- Critical to understand the hadronization process

- **Hadron production strongly affected by the QCD environment**
  - Non-perturbative process important at low pT, coalescence etc.
  - Strong multiplicity dependence observed in p+p, pA and AA … @RHIC and LHC
  - Breakdown of pQCD factorization at low pT
- **High precision measurements of HF meson and baryons in sPHENIX**

Clear pT dependence observed: e+e- vs pp



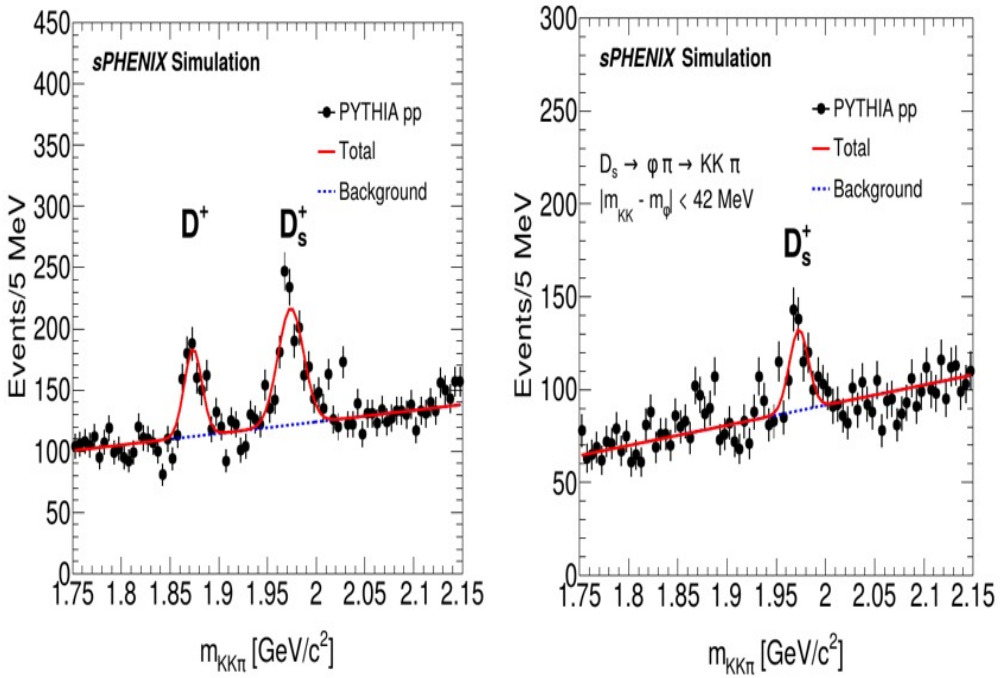




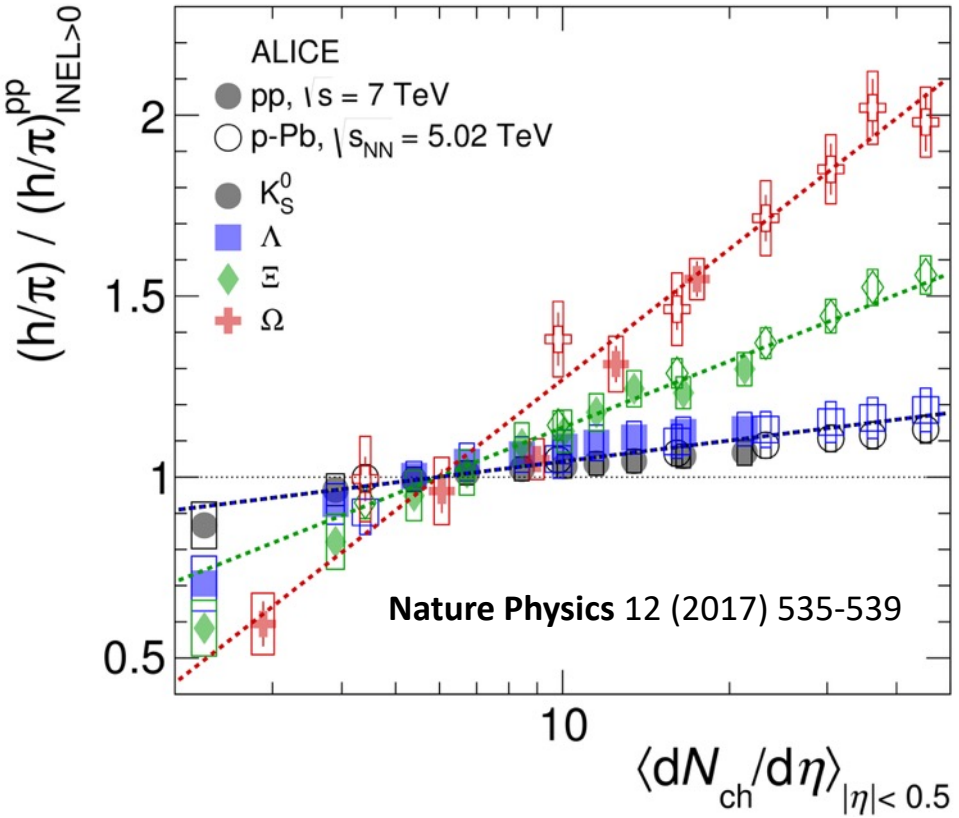
From Quarks to Hadrons (Cont.)

- More exclusive HF hadrons – $D^{+/-}$, Ds, Bs yields etc.
- Event multiplicity dependence

w/ True MC information $D \rightarrow K^+K^-\pi^+$

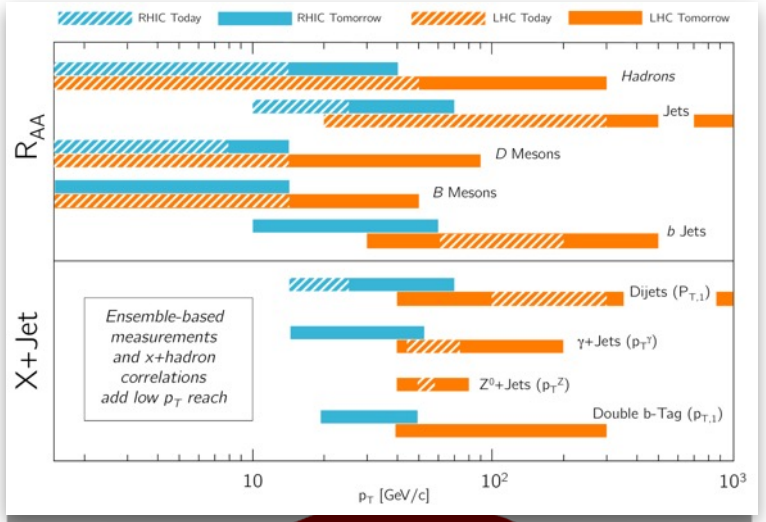


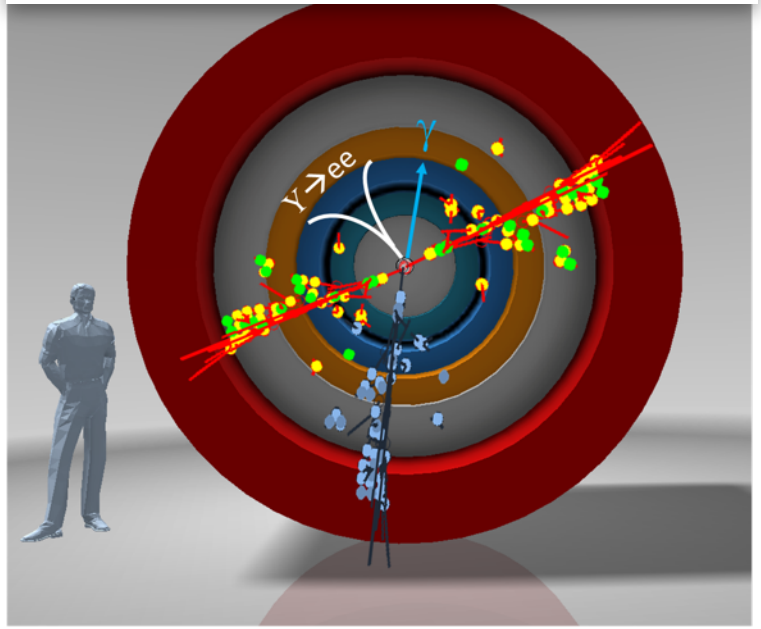
Strangeness enhancement in high multiplicity pp



Summary and Outlook

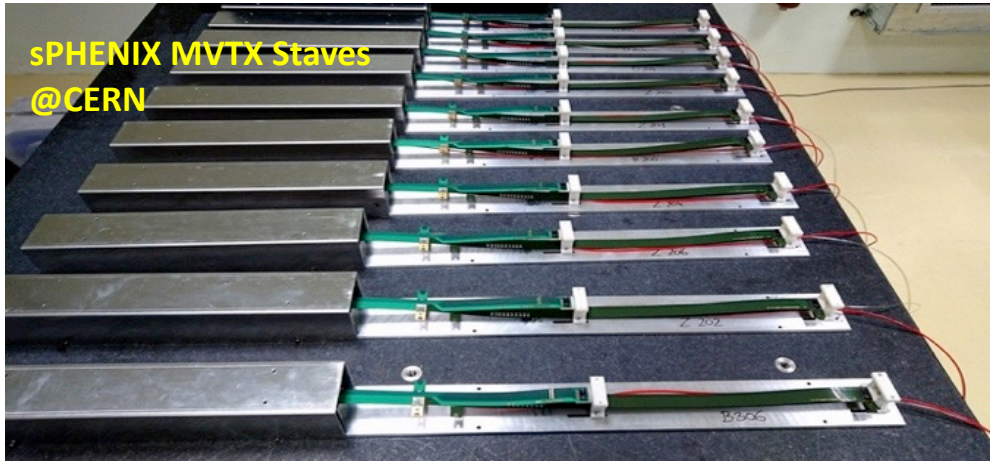
- **Great HF physics opportunity at RHIC**
  - High precision measurements of HF over a wide pT range, to study “inner workings of QGP”
    - Heavy quark energy loss mechanisims
    - HF diffusion coefficients
    - Jet structure modification in QGP
    - Heavy quark hadronization and QCD
  - Complimentary to LHC
- **sPHENIX day-1 physics in early 2023**
  - Detectors ready by 2022
- **Other physics not covered here**
  - Jets and QGP
  - Upsilons and QGP
  - Spin and cold QCD





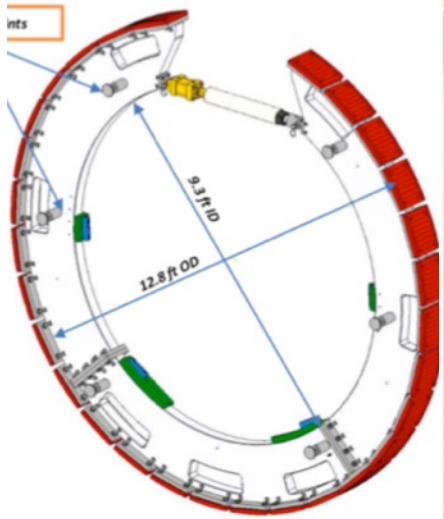
Backup slides/plots

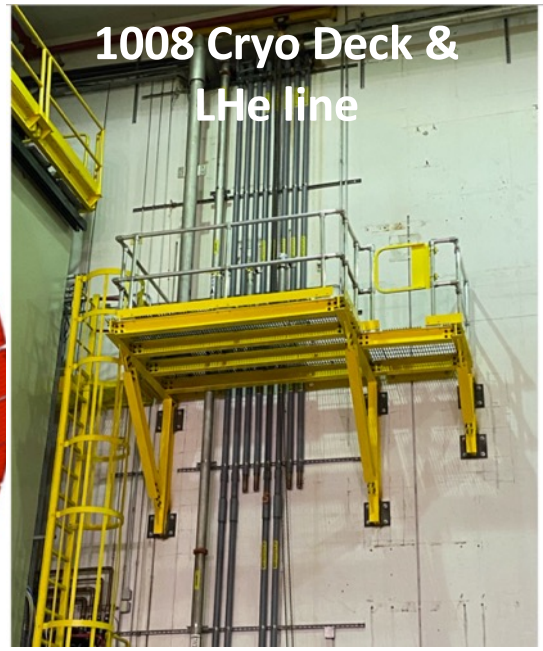
sPHENIX Detector Construction Photos



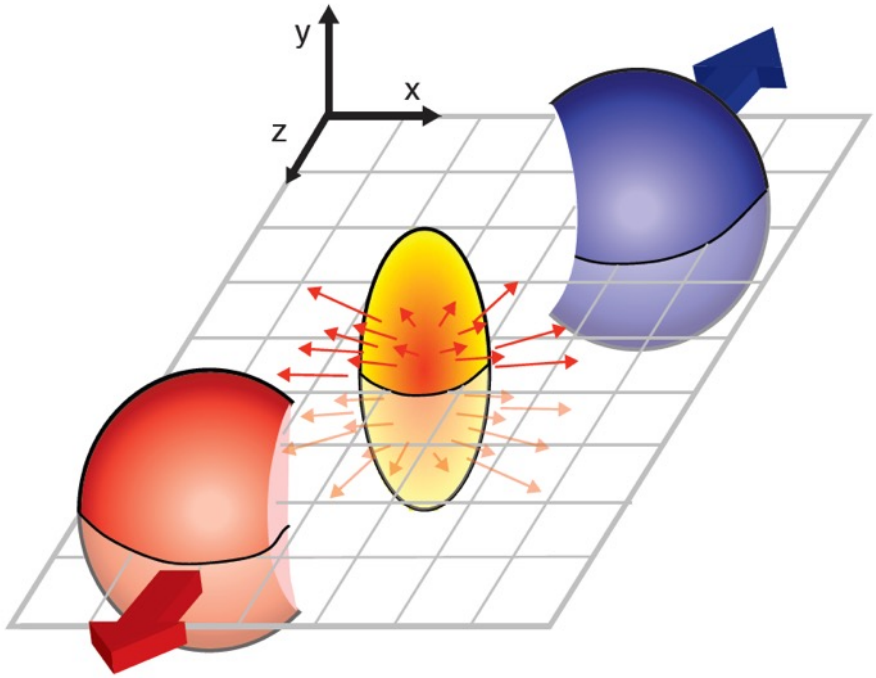
sPHENIX in Progress: 1008 I&F in Photos

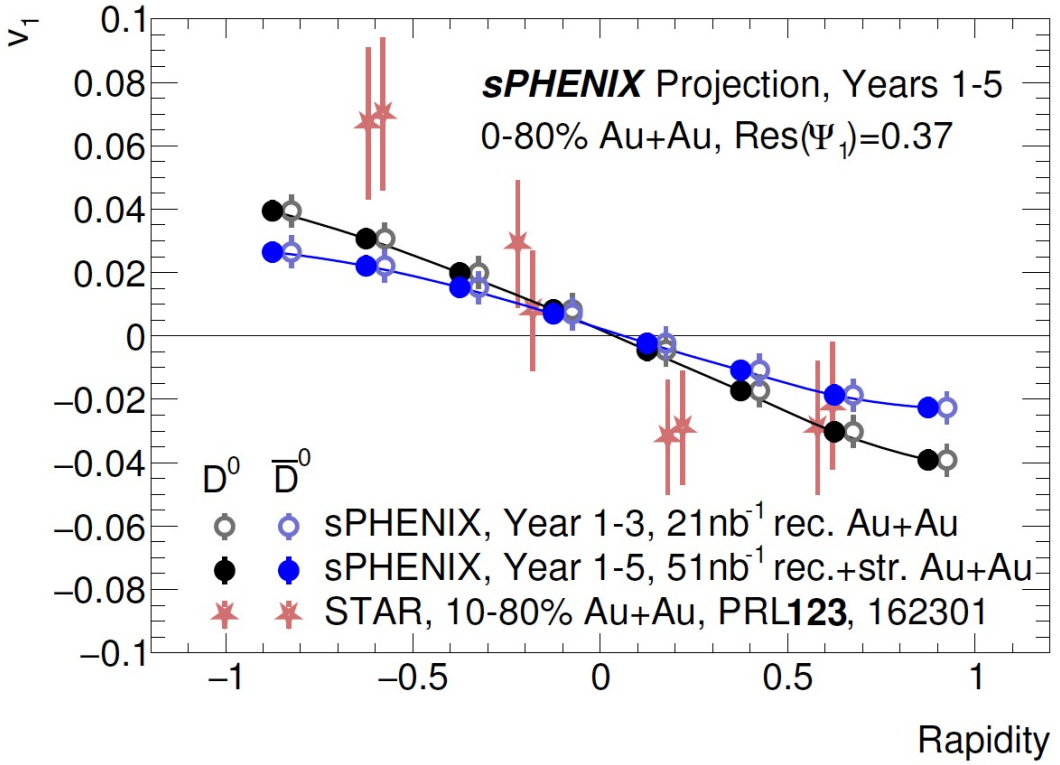
Large Support Rings





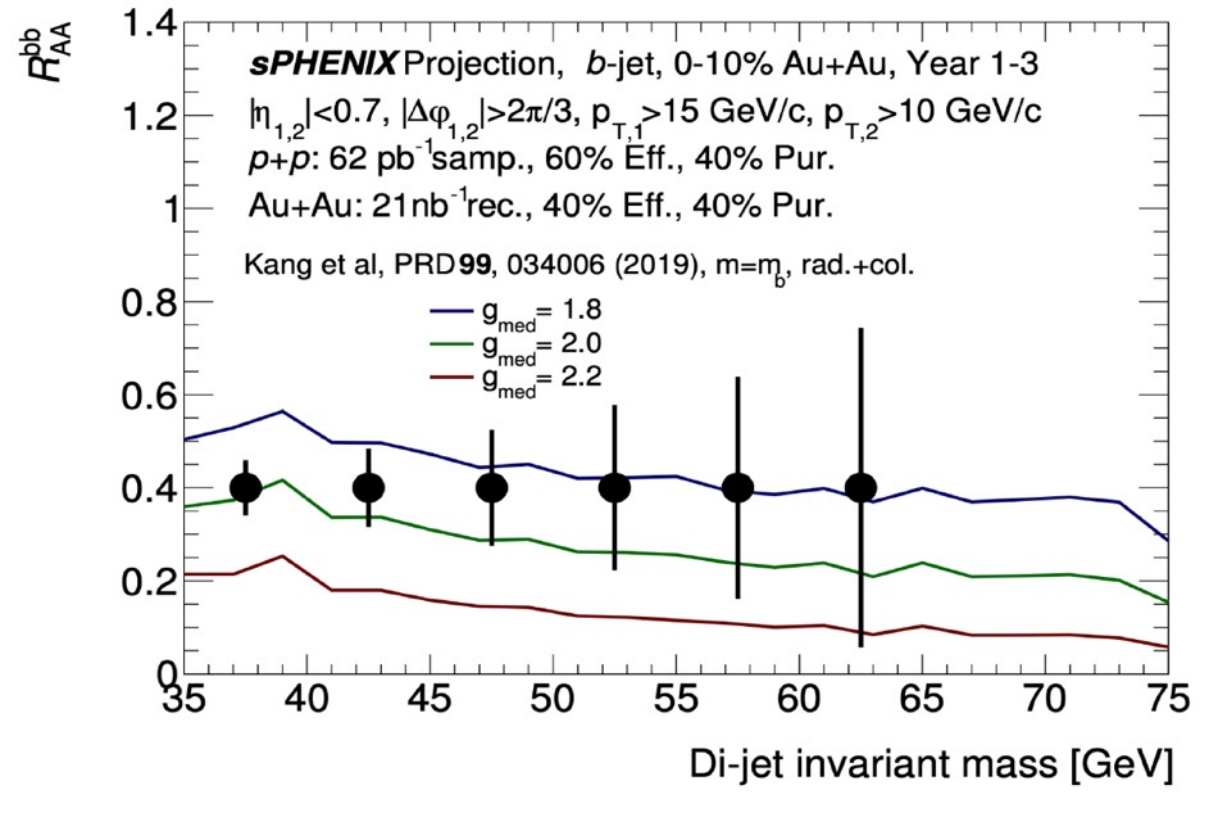
Probe Initial Magnetic Field in HI collisions

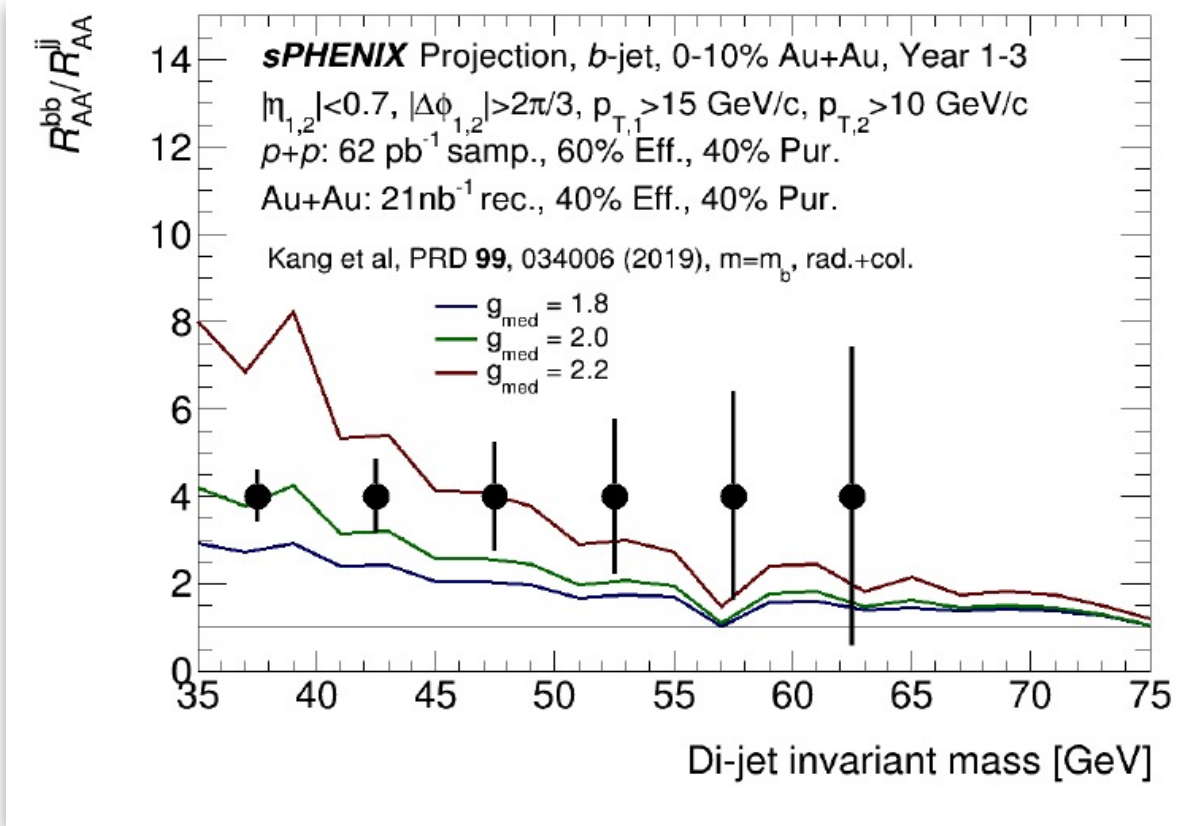




Di-b-Jets in QGP

Kang, Reiten, Vitev, Yoon, PRD 99, 034006 (2019)

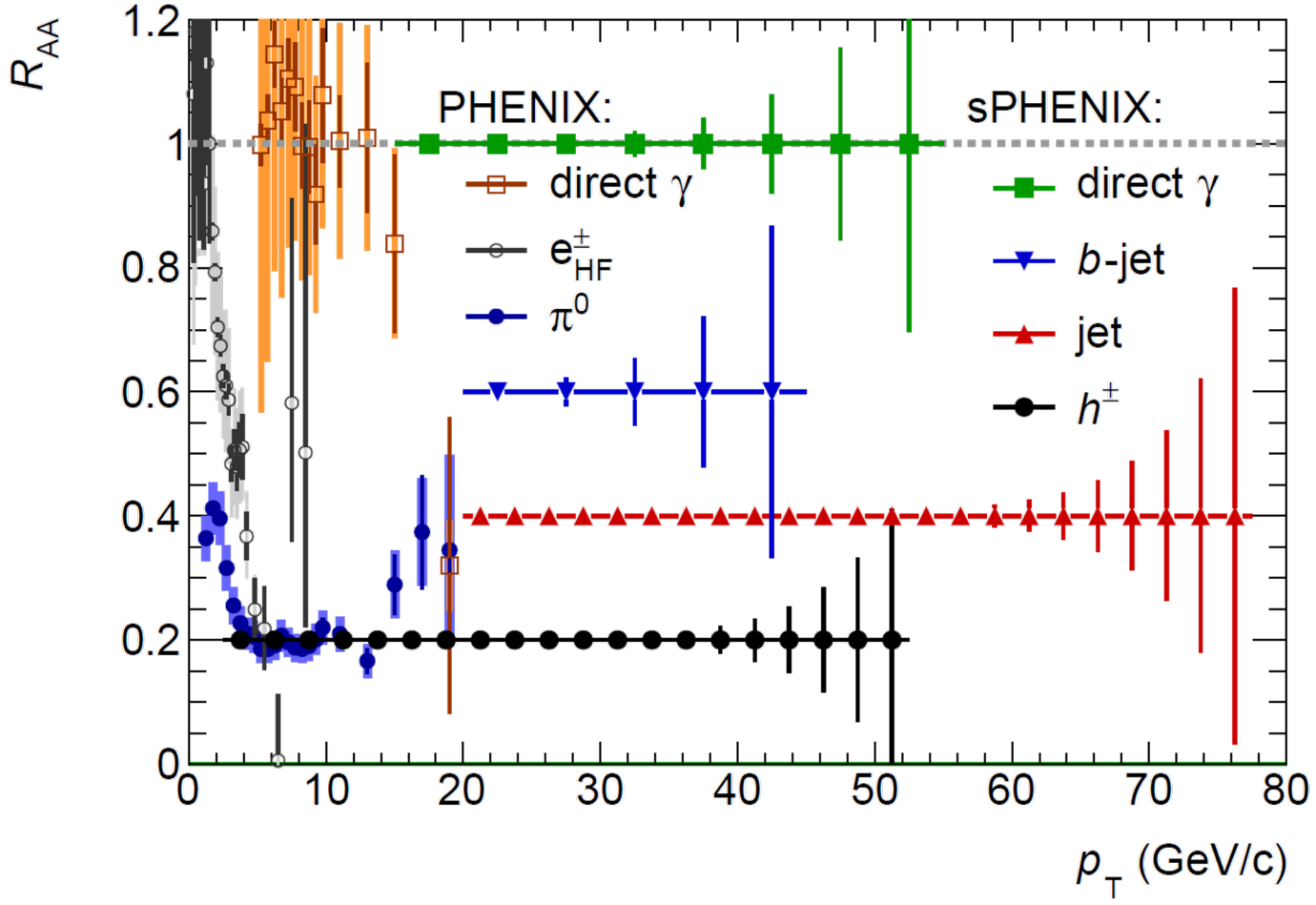




- Sensitive to Jet coupling to QGP

A Broad Physics Program with Hadrons and Jets

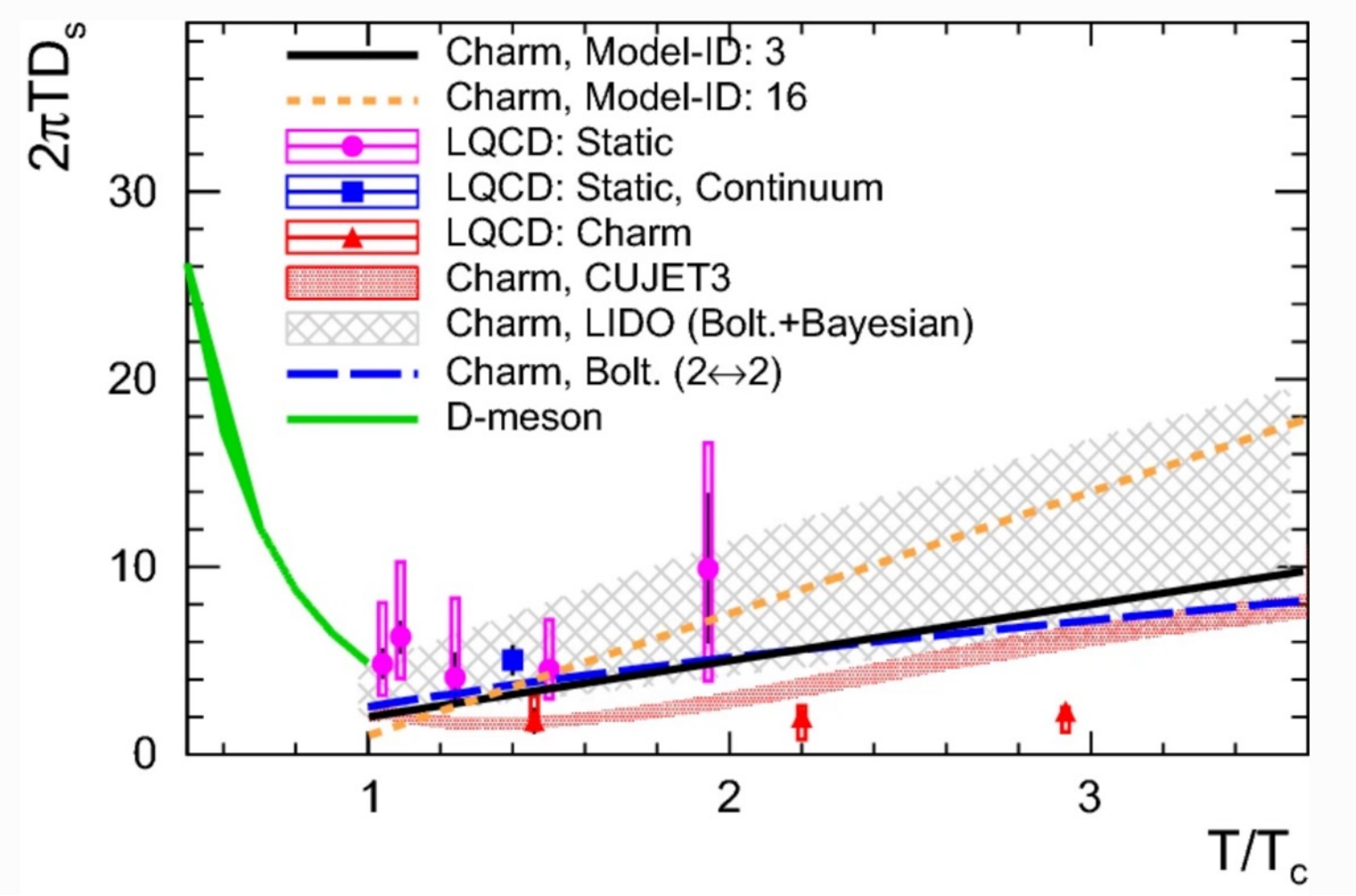
Parton Mass and Flavor Dependence of Jet Suppression and more



HQ Diffusion in QGP

- Model calculations

Shuang Li and Jinfeng Liao, Eur. Phys. J. C (2020) 80: 671



Classical Brownian motion:

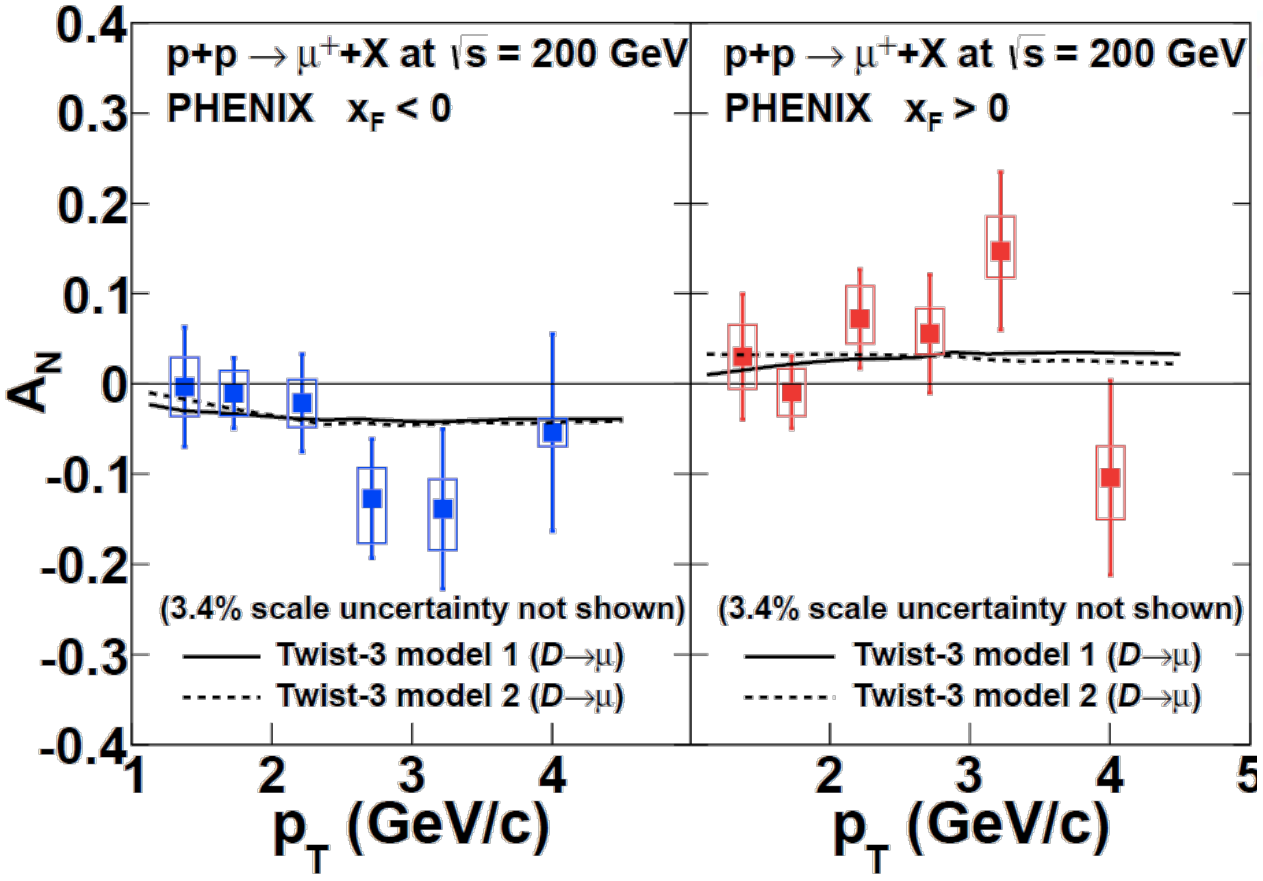
$$\sigma_x^2 = 2Dt$$

$$D \propto \frac{k_B T}{\eta}$$

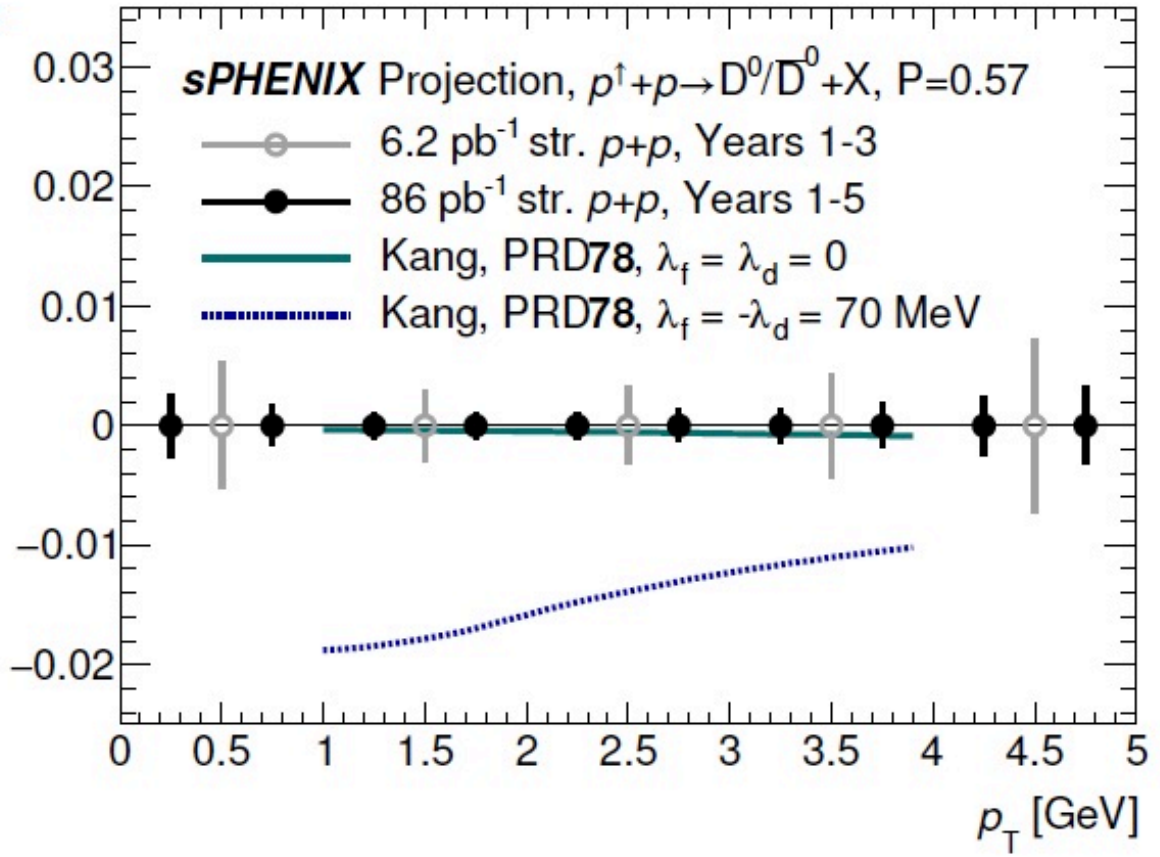
Probe Gluon TMD with D^0

Charm is unique probe of gluon TMD
D^0 A_N→ Tri-gluon correlation functions

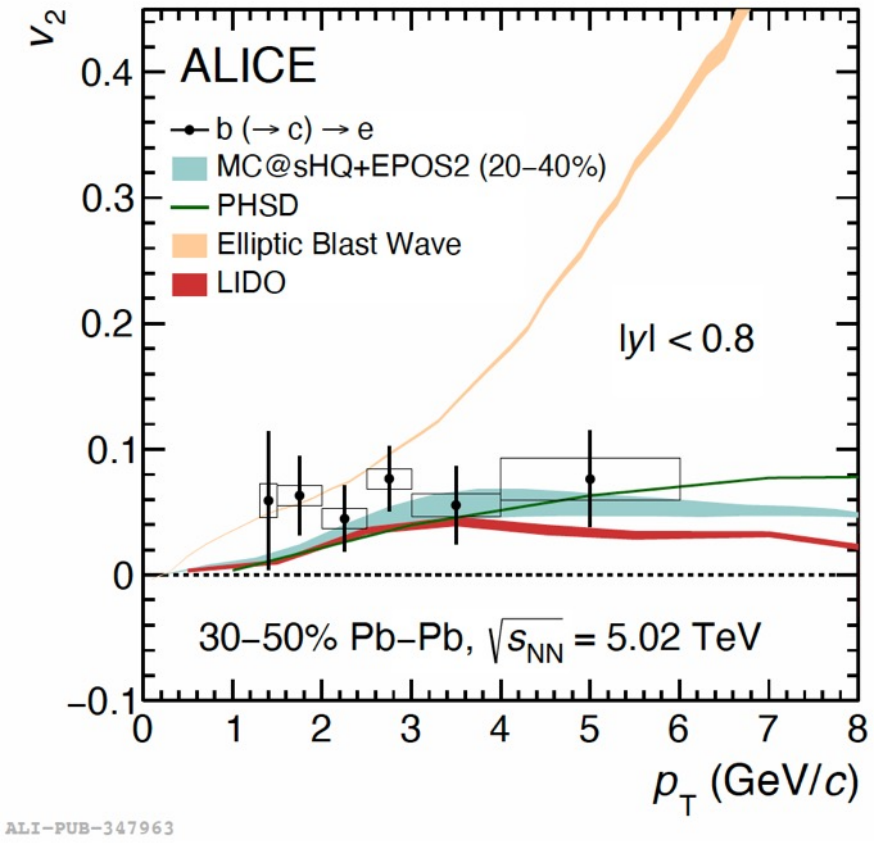
PHENIX, DOI:10.1103/PhysRevD.95.112001

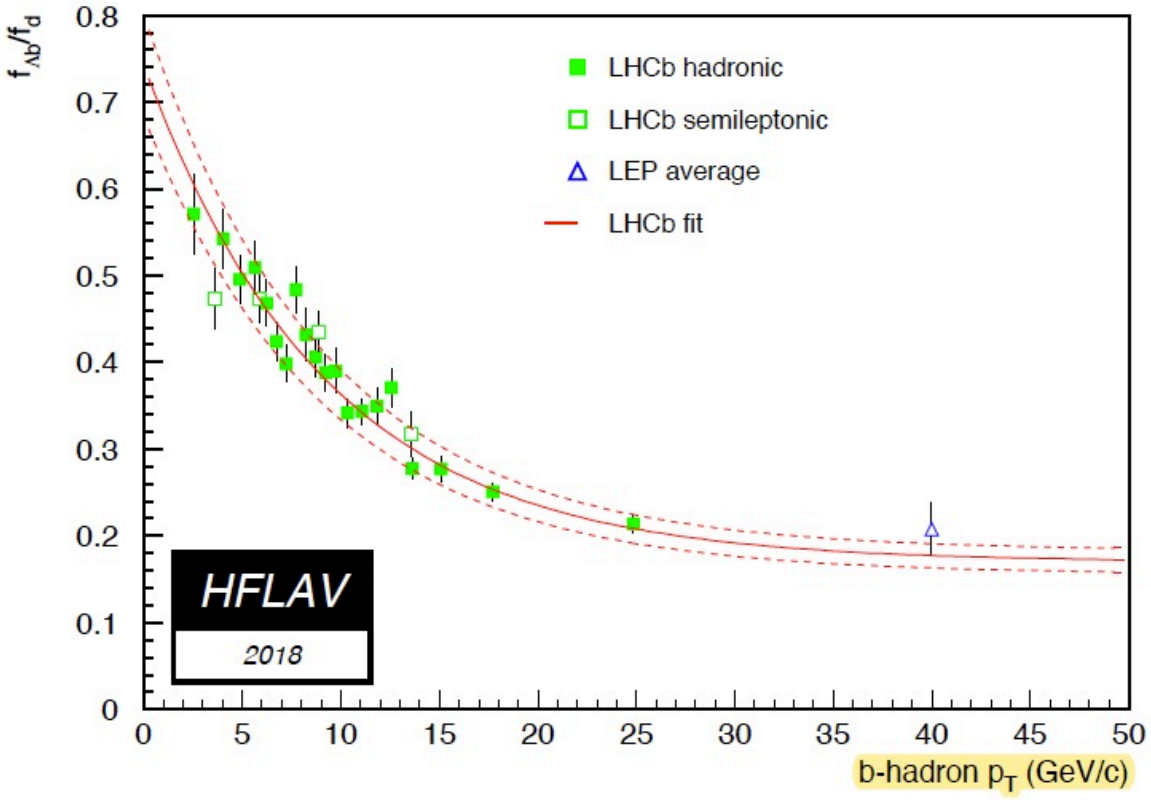


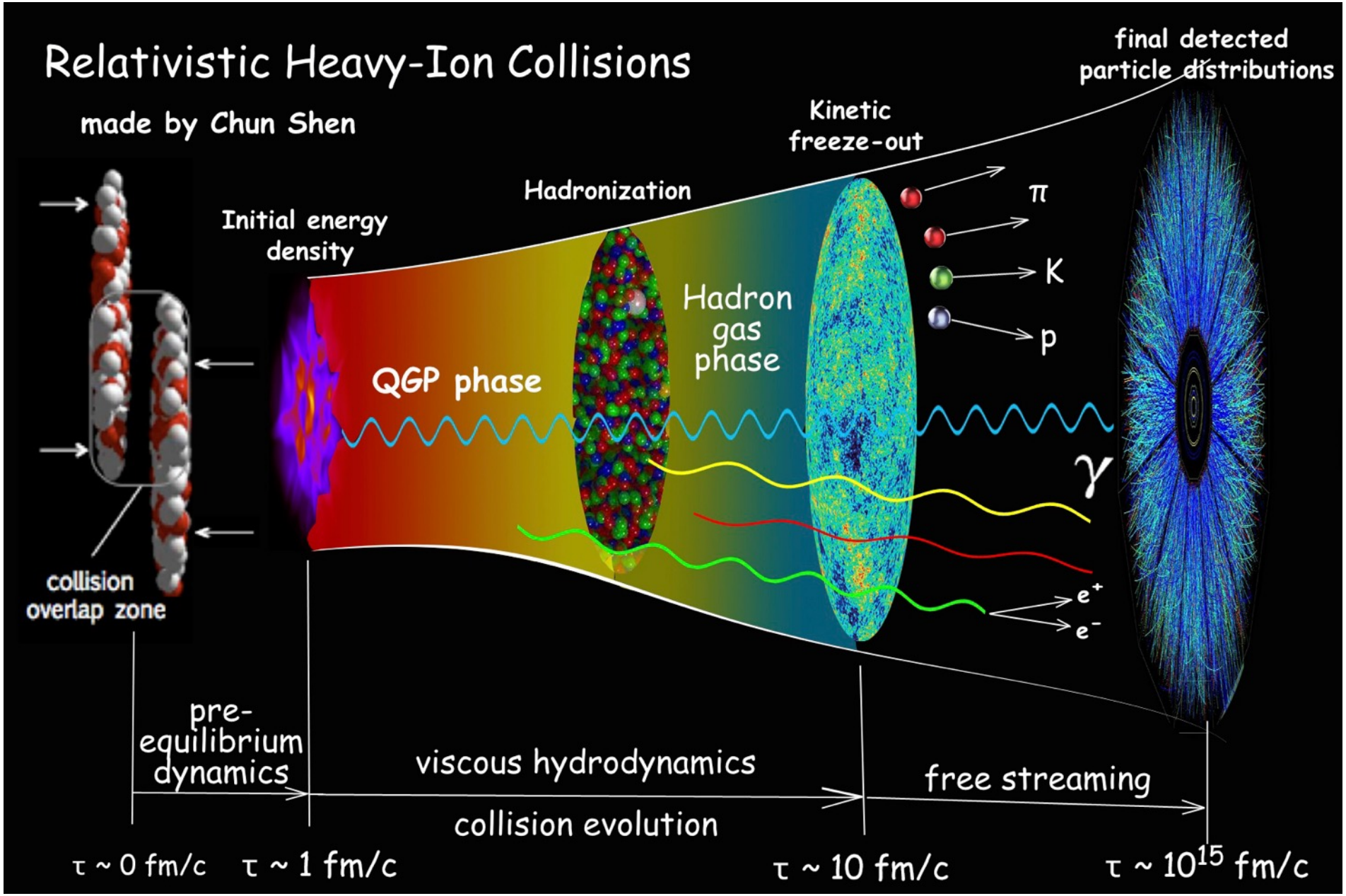
sPHENIX projection



Heavy Quark Hadronization

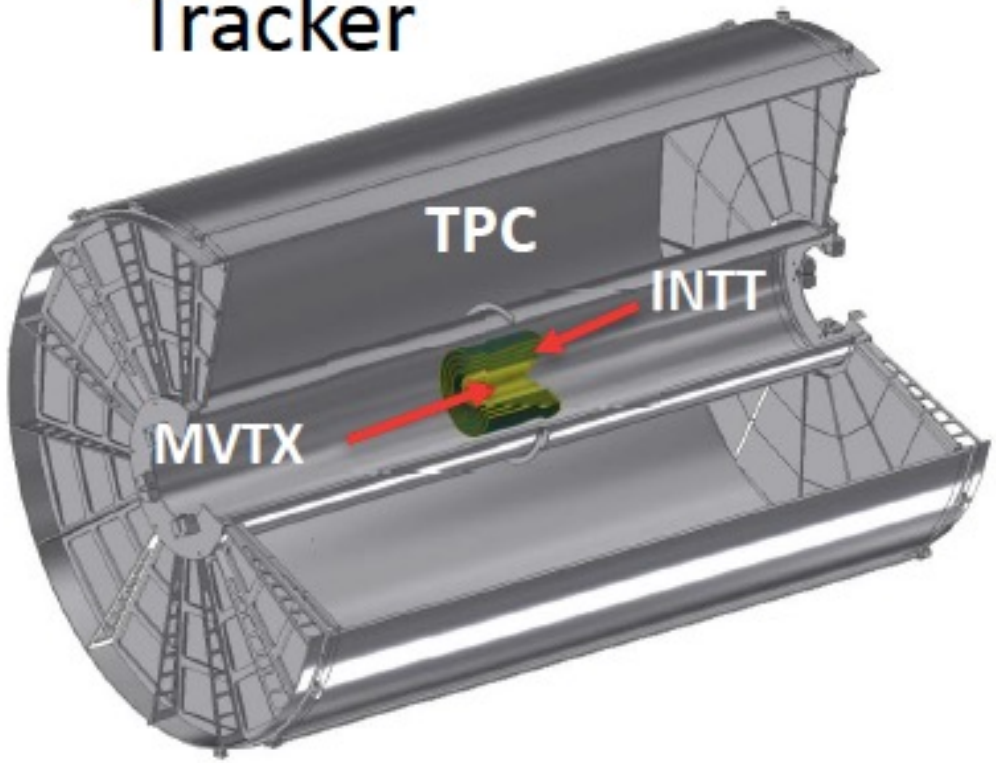





Relativistic Heavy-Ion Collisions
made by Chun Shen
final detected particle distributions
Kinetic freeze-out
Hadronization
Initial energy density
Hadron gas phase
QGP phase
π
K
p
γ
e+
e-
collision overlap zone
pre-equilibrium dynamics
viscous hydrodynamics
free streaming
collision evolution
τ ~ 0 fm/c
τ ~ 1 fm/c
τ ~ 10 fm/c
τ ~ 10^15 fm/c

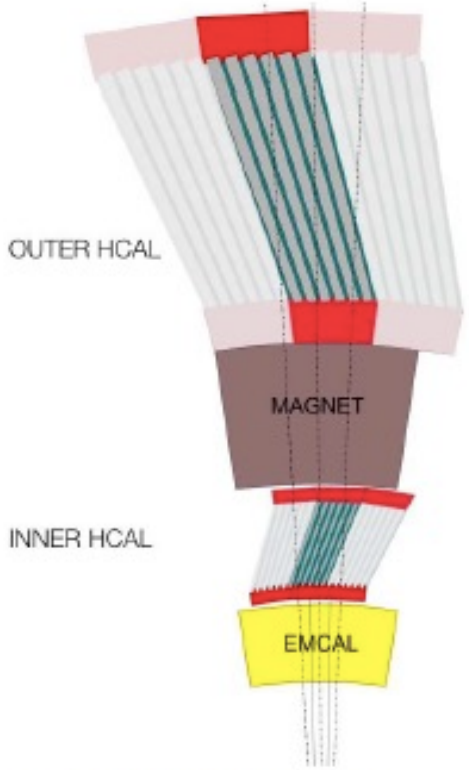
sPHENIX Detector Sub-Systems

Tracker



Continuous readout TPC
Si strip intermediate tracker
3-layer MAPS-based μ vertex

Calorimeter stack



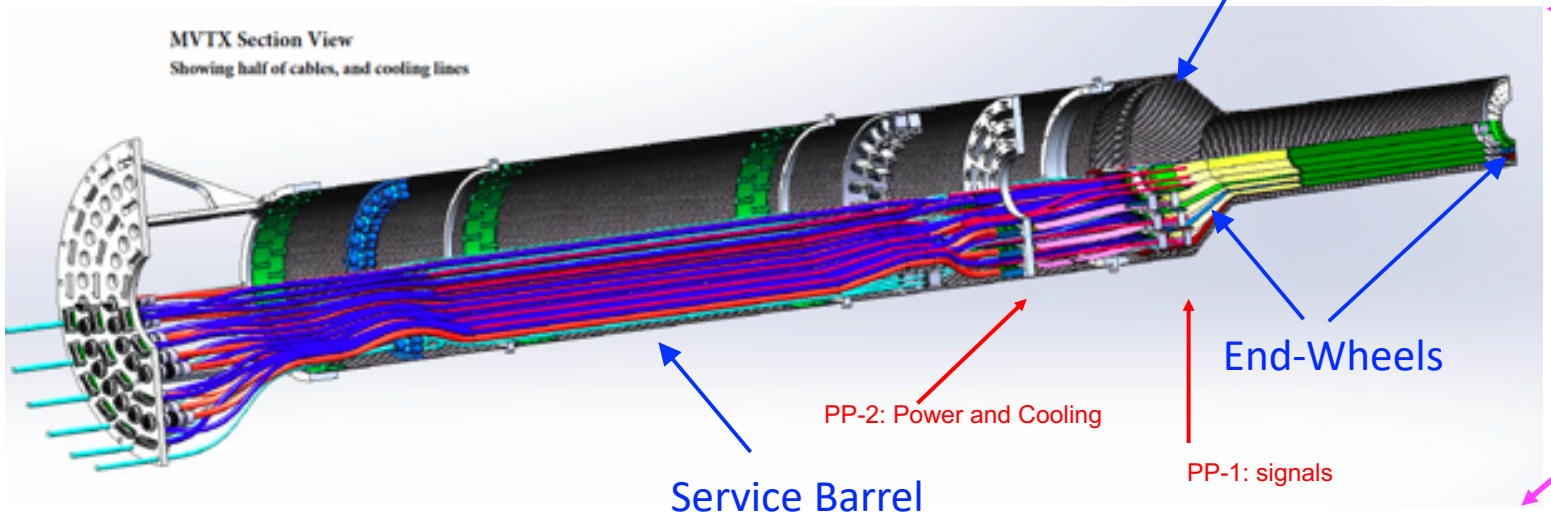
Tungsten/SciFi EMCal
Steel/plastic scintillator HCAL
SiPM readout

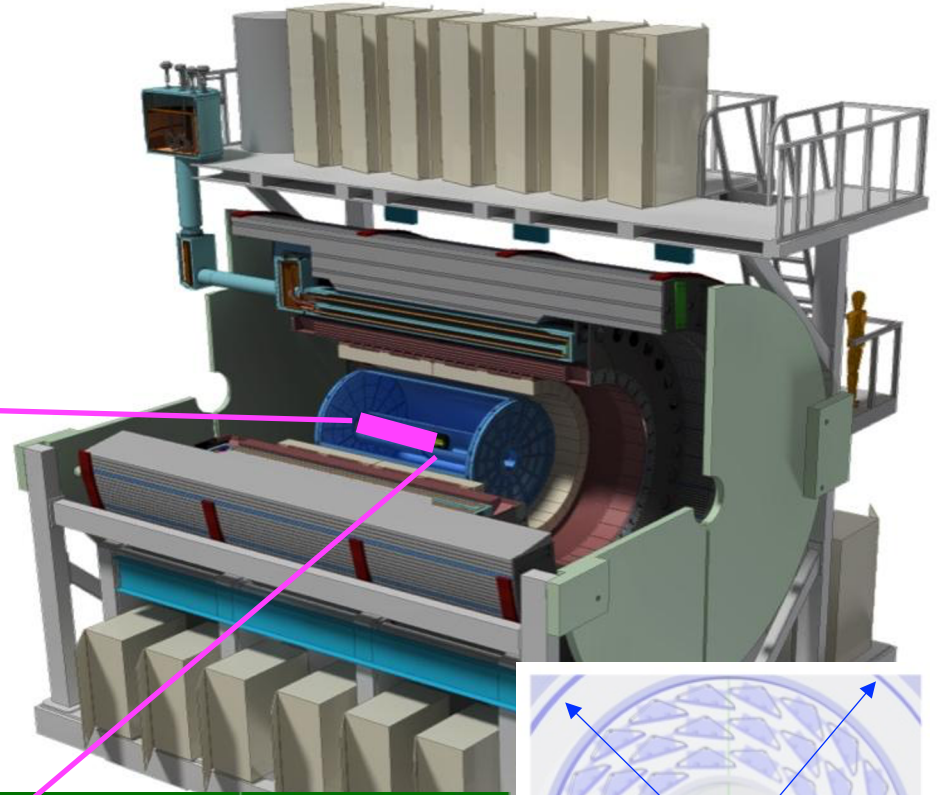
MVTX Detector

Excellent track DCA resolutions in pp, pAu and AuAu

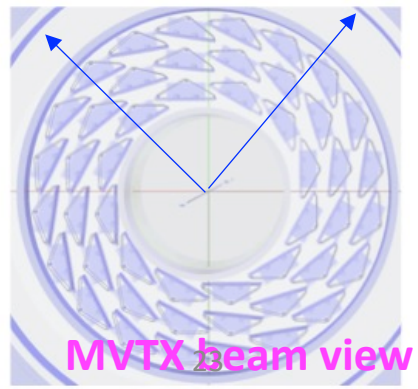
3-layer sensor barrel:

- pixel size: 27 x 29 um
- stave thickness: 0.35%X_0
- Timing resolution: 5us
- 48 staves, 27.1cm long



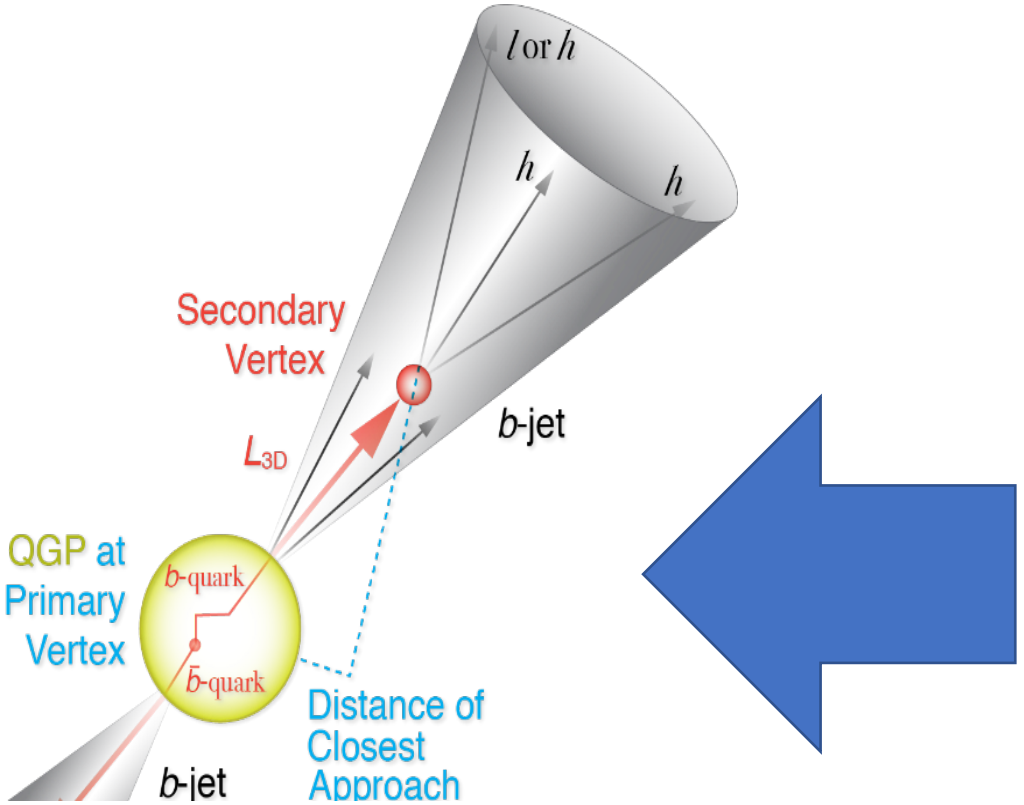


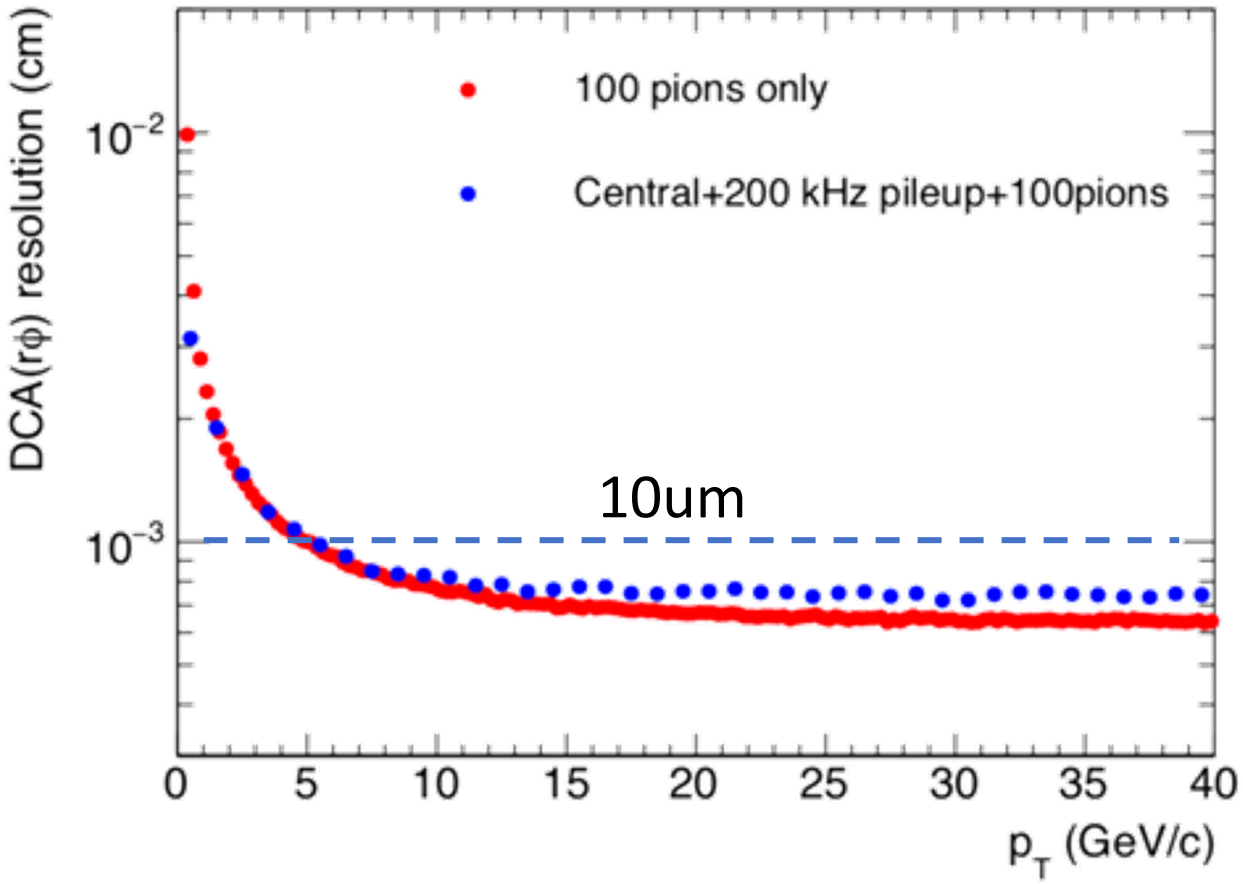
	R_min (mm)
Layer 0	24.61
Layer 1	31.98
Layer 2	39.93



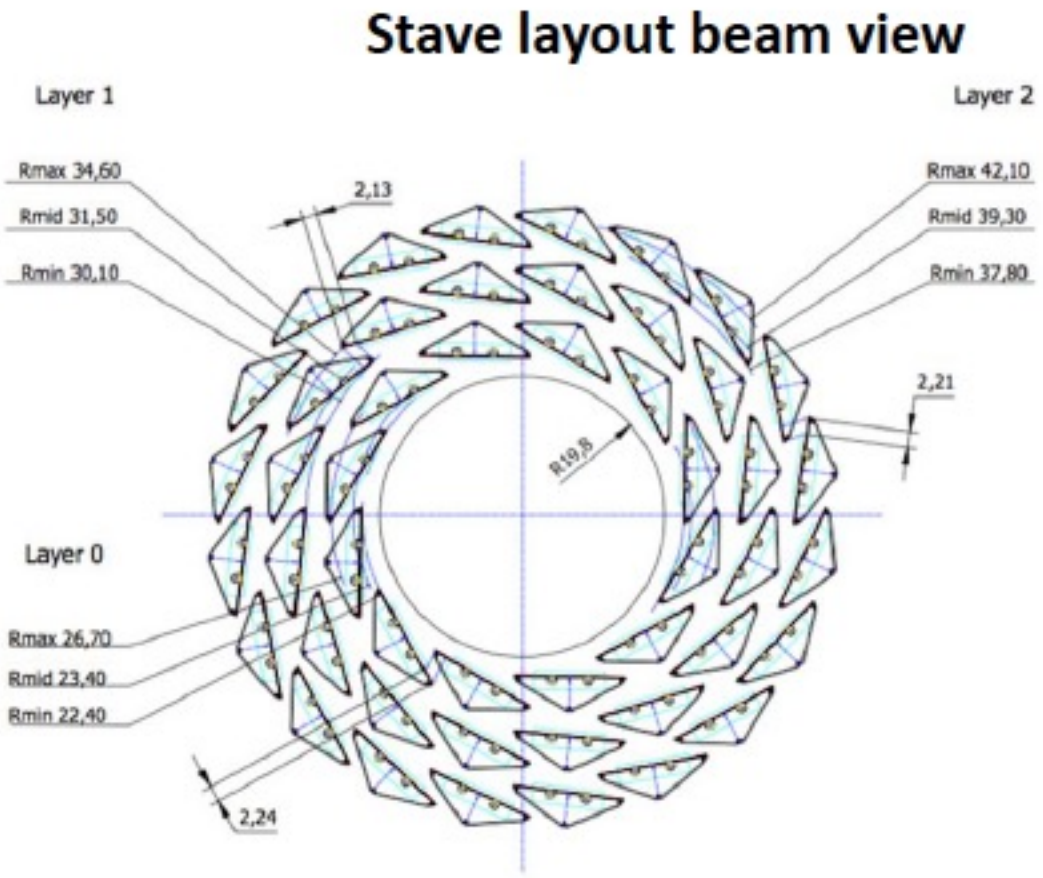
Precision Vertex and Open HF Observables

- Precision vertex tracker + high rate capability
  → Precision open charm and bottom over wide scales





Monolithic-Active-Pixel-Sensor based Precision Vertex Detector
-- for Open Heavy Quark Measurements



MVTX based on copy of ALICE staves with support structure modified for sPHENIX