Open Heavy Flavor Physics with the sPHENIX MVTX Detector at RHIC

Ming X. Liu

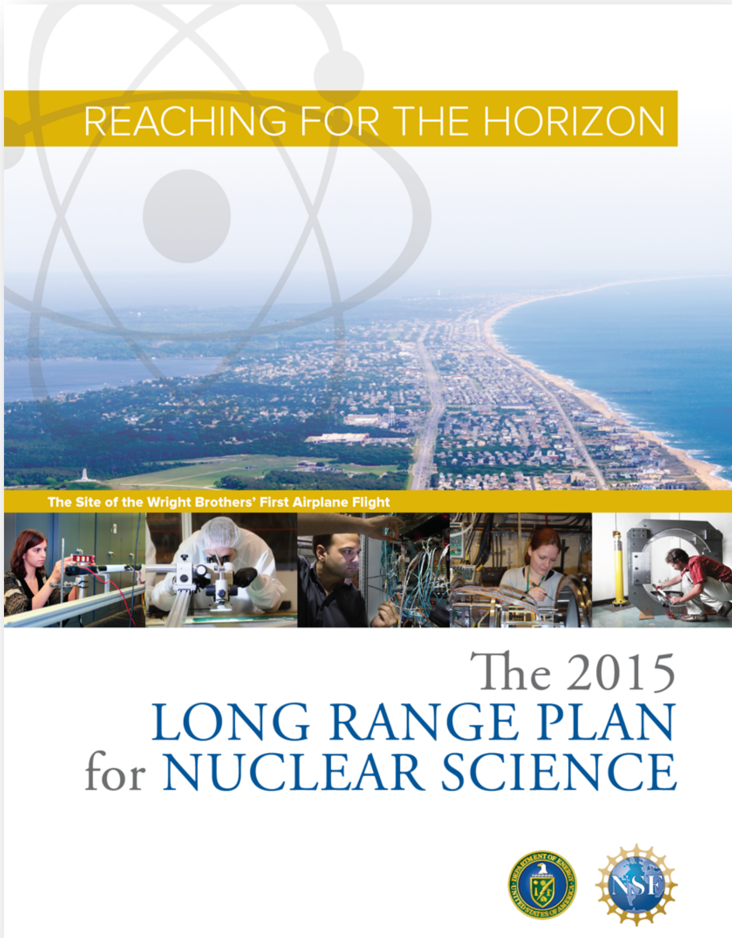
Los Alamos National Laboratory

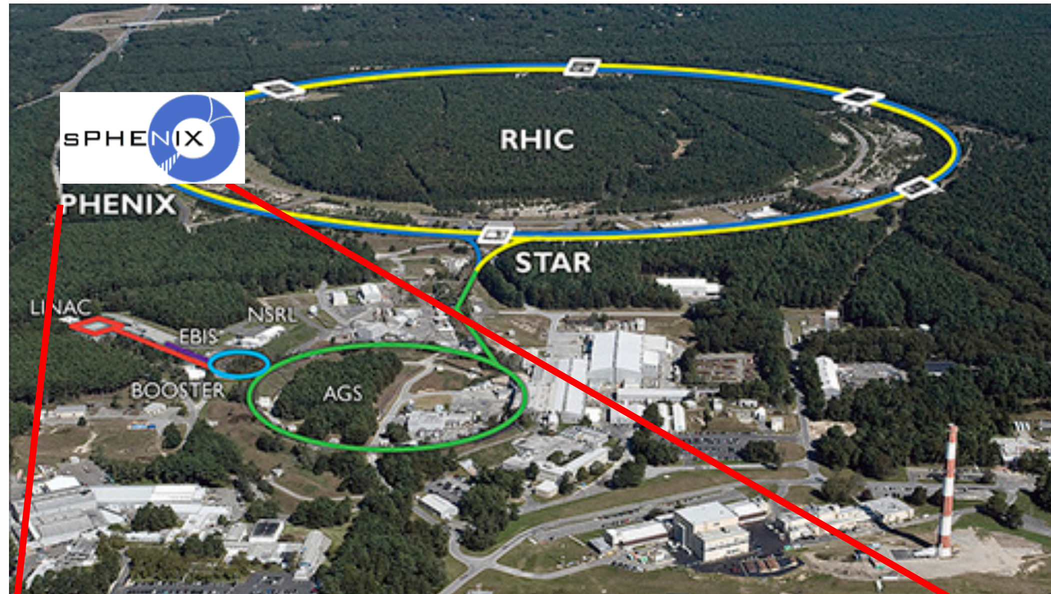
for the sPHENIX Collaboration

Outline

- Science
- MAPS-based VeTex detector (MVTX)
- Physics prospects

The Scientific Mission at RHIC

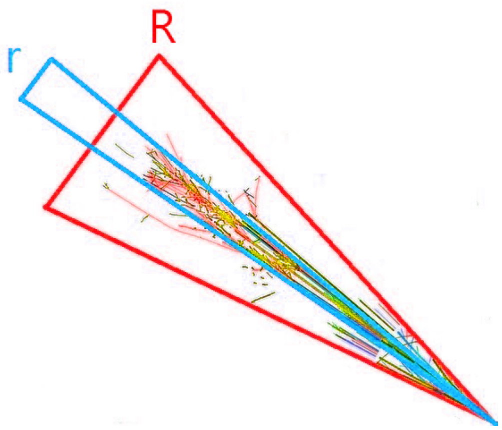




There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

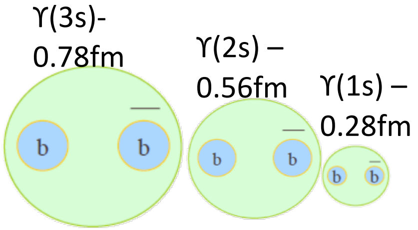
Three Physics Pillars

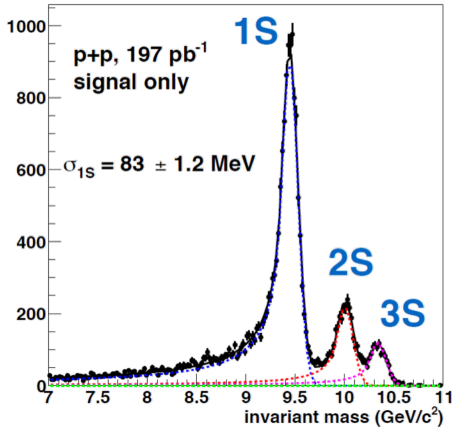
Jet cor. & substructure



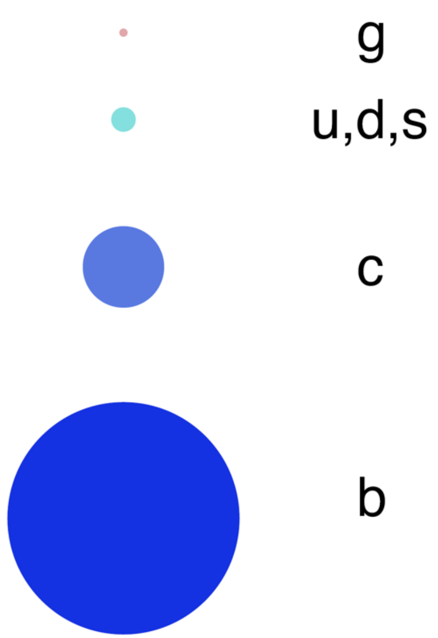
Justin Frantz, Monday
sPHENIX jet physics

Upsilon spectroscopy
Size of the probe





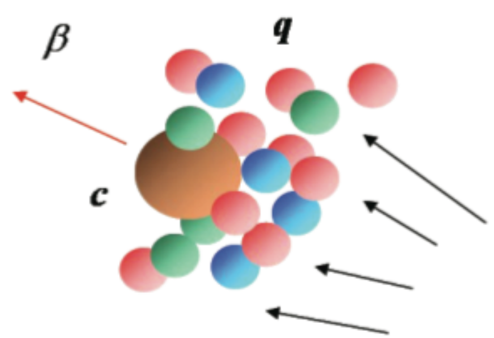
Parton energy loss & cor.
mass dependent

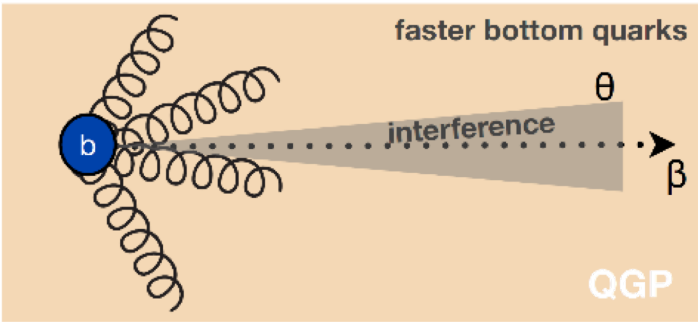


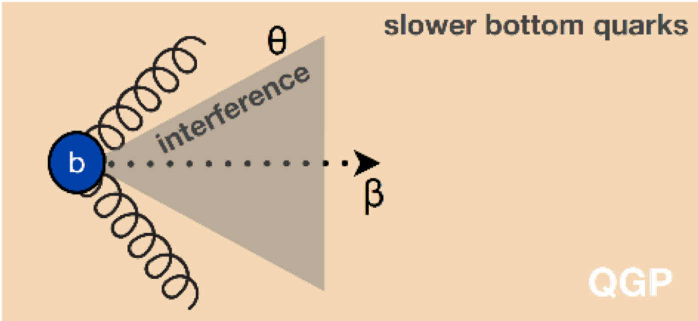
This talk : HF program

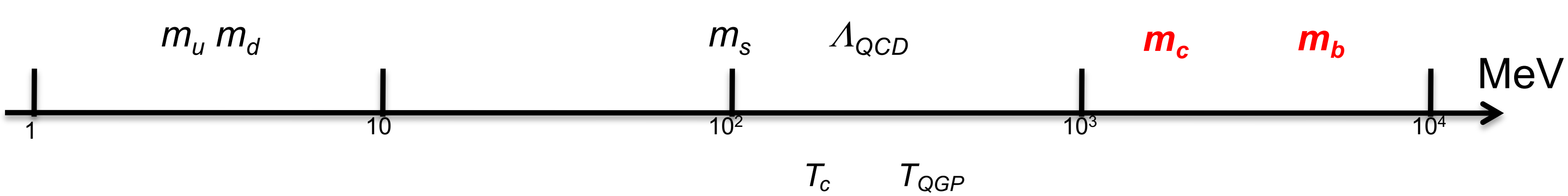
Heavy Quarks - Unique Probe of QGP

- Study mass dependence in
  - Jet quenching and dE/dx
  - Flow – interaction with medium
- Access QGP properties







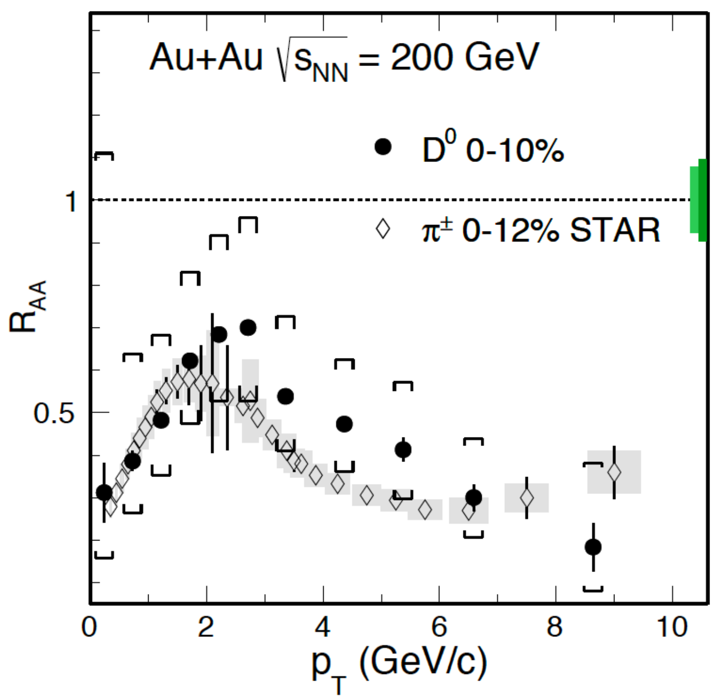


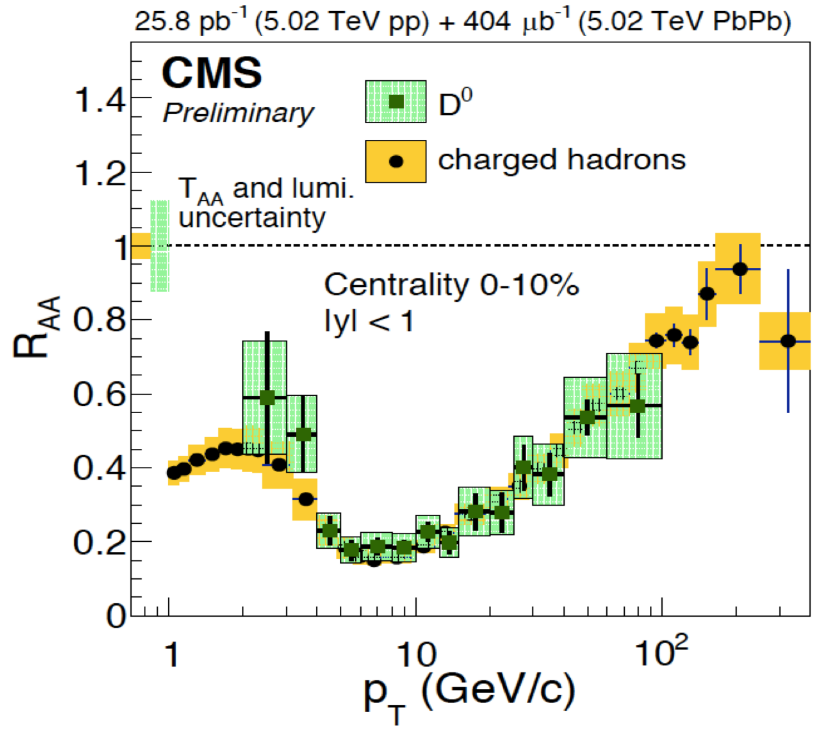
Recent Highlights: Charm R_{AA}

R_{AA} (D-meson) ~ R_{AA} (h) at high p_T ~> 4 GeV/c

- significant suppression of charmed hadron R_{AA} in central A+A collisions
- strong charm-medium interactions
- mass effect expected important at low pT, dead-cone effects etc.

STAR: arXiv:1812.10224

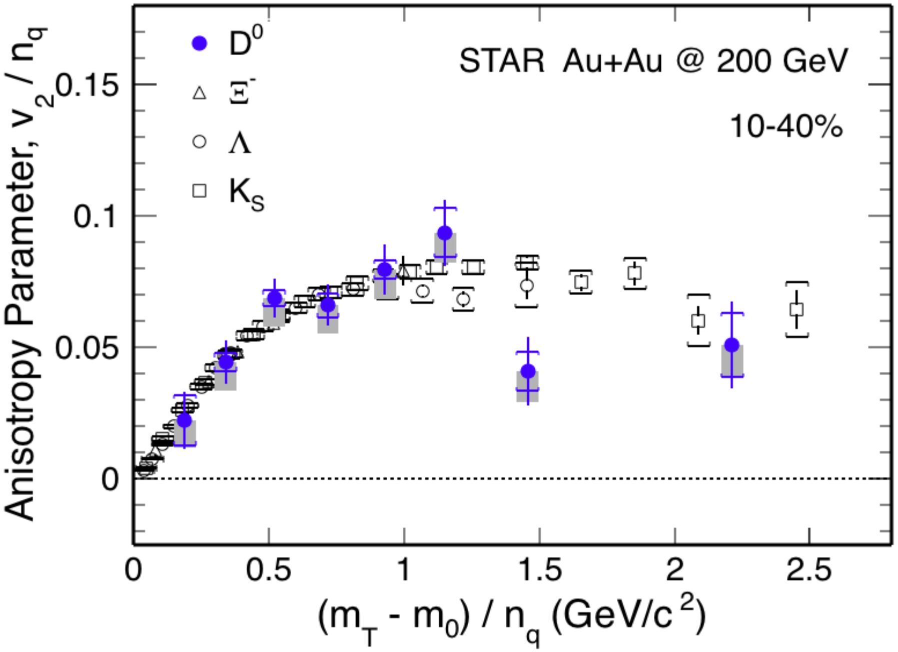


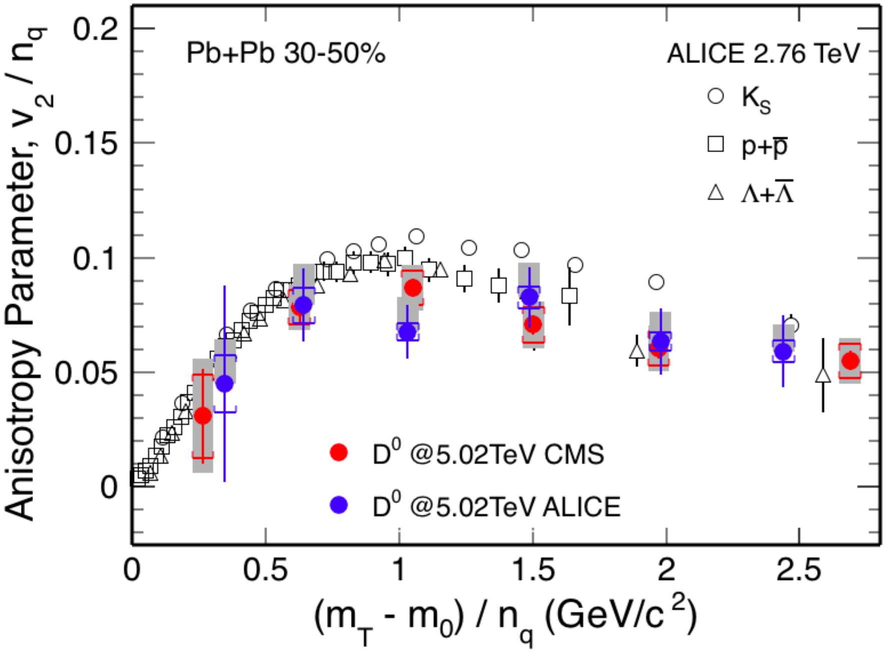


Recent Highlights: Charm V_2

v2 of D^0 follows the same trend as light hadrons

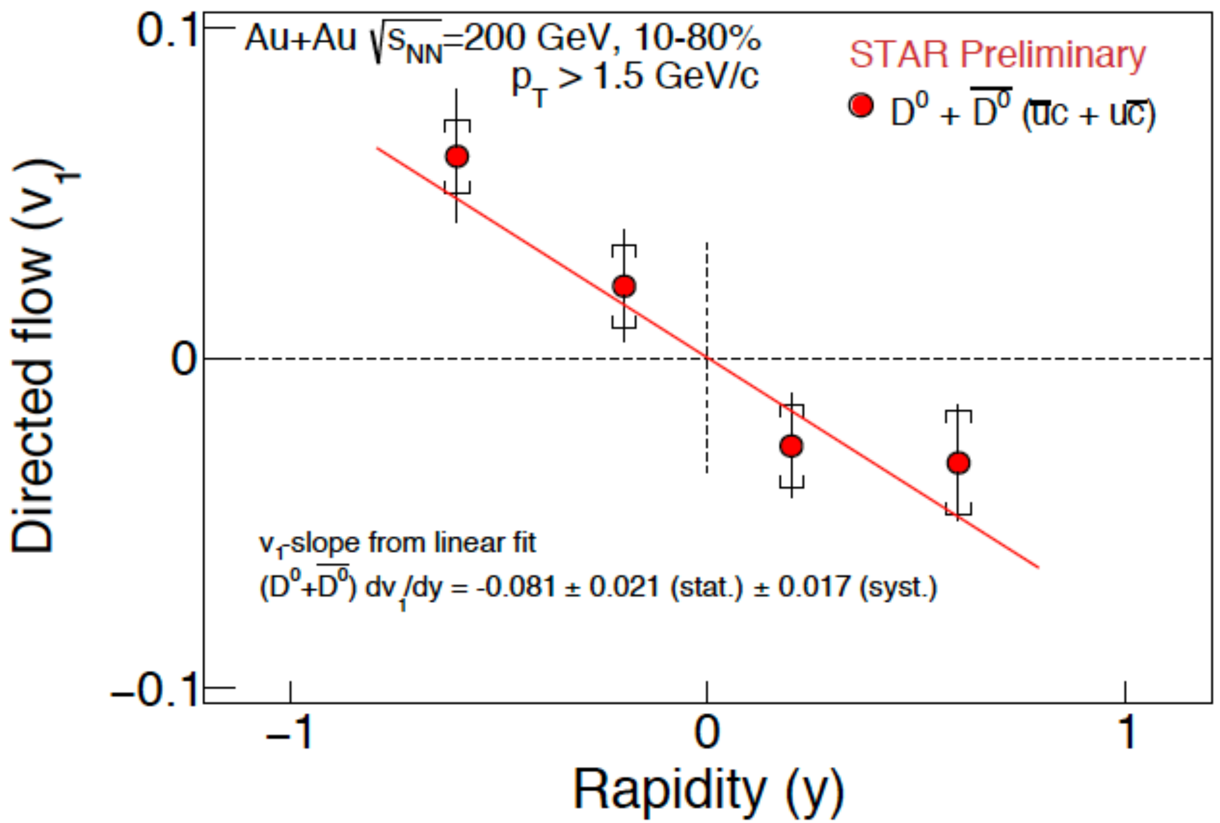
- *Charm quarks flow the same as light quarks*
- *Strong coupling to medium at low pT*



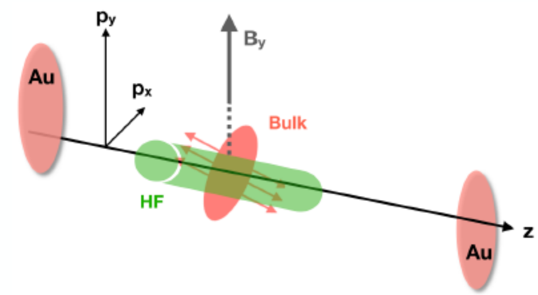


sPHENIX

Direct Flow of Charm Observed at RHIC



Singha, WWND19

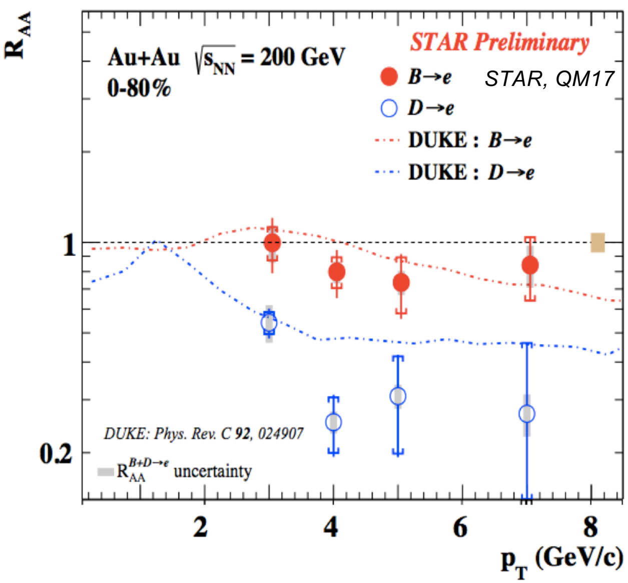


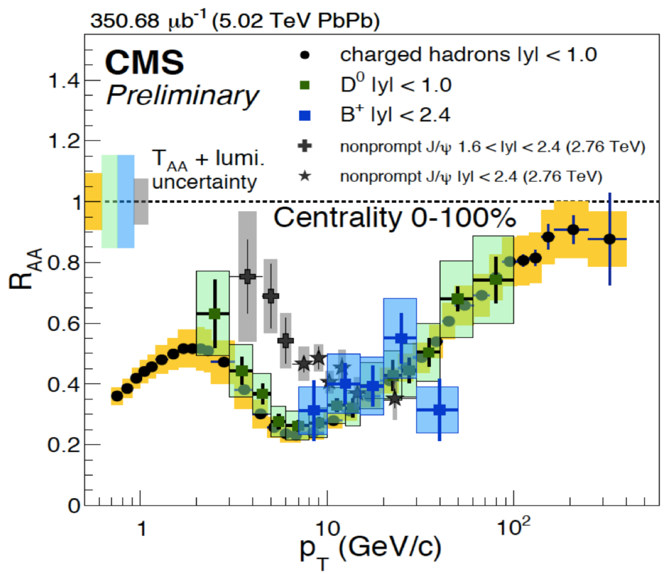
- First evidence of non-zero D^0 v_1

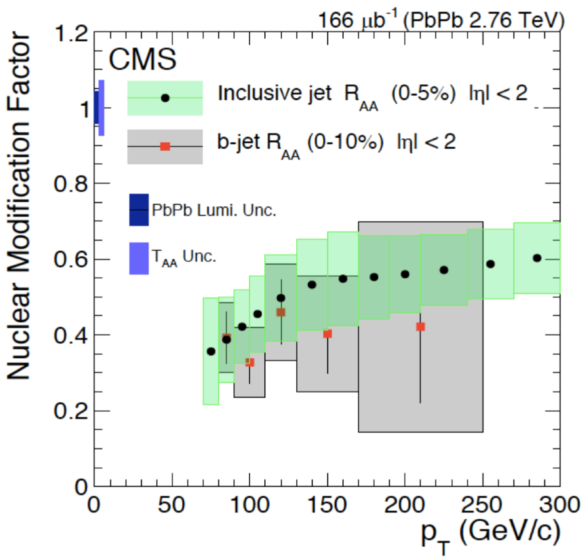
Recent Highlights: Beauty?

- R_{AA} (B->e) > RAA (D->e, h) @low p_T
- B^+ & b-jet ~ light hadrons & charm @high p_T

Highly desired: precision measurements of B @ p_T ~< 50GeV



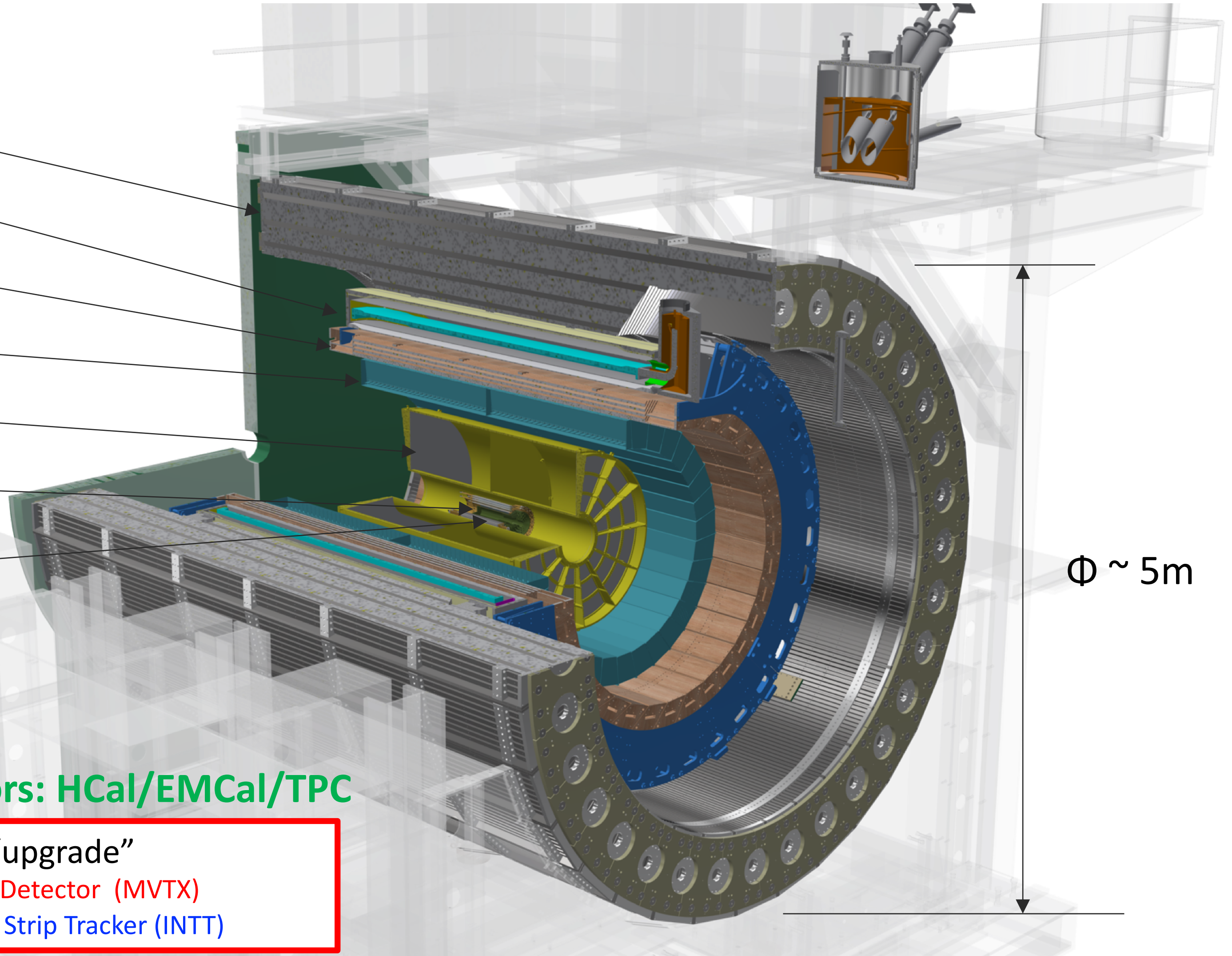




The sPHENIX Detectors

J. Frantz & A.Bazilevsky

Outer HCal
SC Magnet
Inner HCal
EMCal
TPC
INTT
MVTX



15 kHz trigger
>10 GB/s data

Baseline detectors: HCal/EMCal/TPC

Parallel Activities "upgrade"

- MAPS-based Vertex Detector (MVTX)
- Intermediate Silicon Strip Tracker (INTT)

sPHENIX MVTX Detector Design

Adapts ALICE Upgrade ITS/IB design, modifiied to fit sPHENIX environment:

-Sensors:

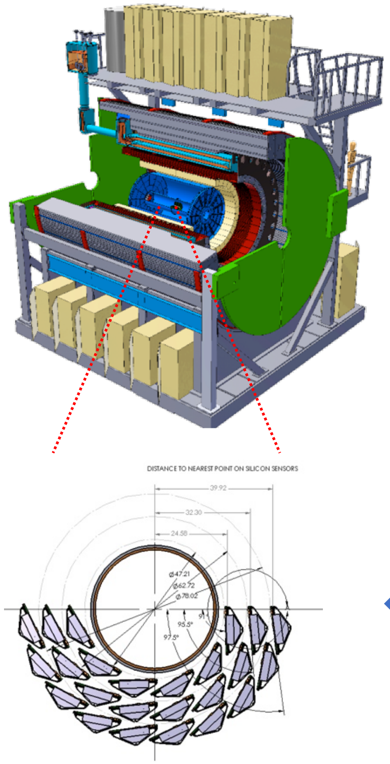
Use ALICE ALPIDE sensors and the identical ITS/IB design of the active part

-Readout:

A hybrid design using ALICE frontend Readout Unit(RU) and ATLAS upgrade backend PCIe based FELIX boards for sPHENIX

-Mechanics:

Modified mechanical frame design for sPHENIX

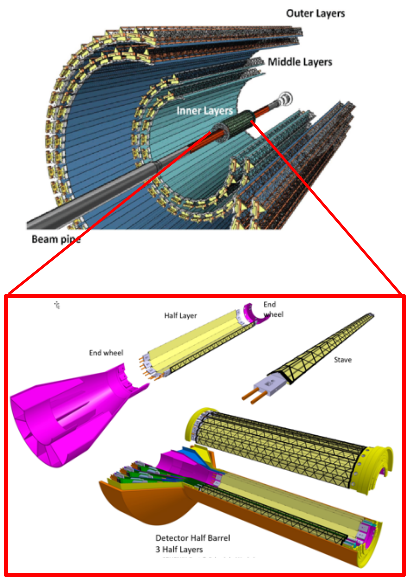


Modified MVTX detector layout for sPEHINX

Adapt ITS/IB design
- Min. Risks
- Max. Phys.

R = 2.5/3.5/4 cm
Z = 27 cm

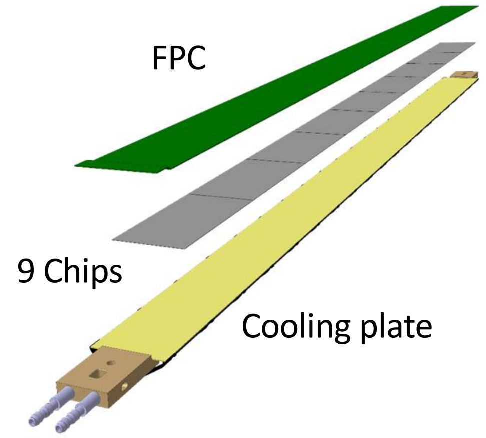
ALICE ITS Upgrade:
Inner Barrel Tracker



Monolithic-Active-Pixel-Sensors (MAPS)

The next Generation State of the Art Pixel Tracker

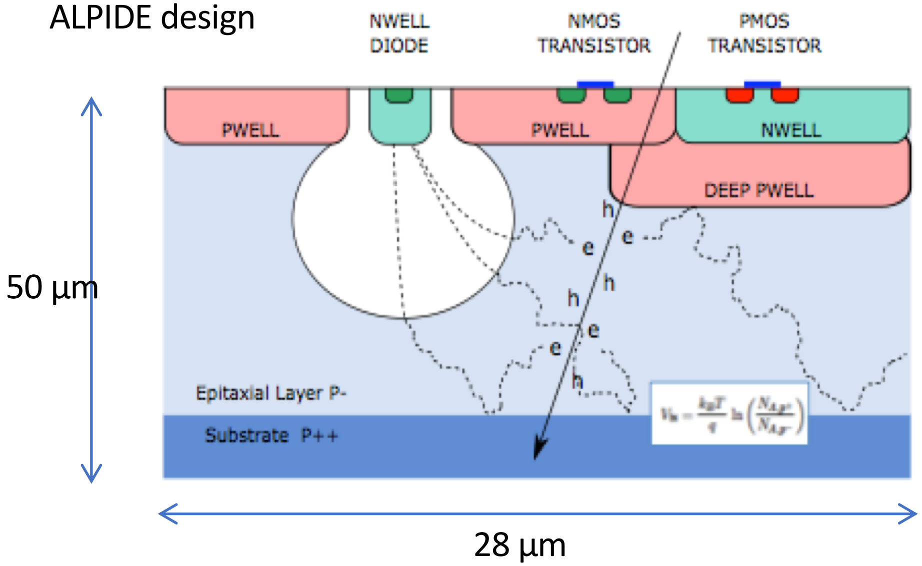
- Advantages of ALICE MAPS/ALPIDE:
  - Very fine pitch (27x29 µm)
  - High efficiency (>99%) and low noise ($<10^{-6}$)
  - Fast readout, ~5 µS
  - Ultra-thin/low mass, 50µm (~0.3% X_0)
  - On-pixel digitization, low power dissipation



A 9-chip MAPS stave, 1.5 x 27cm^2

An ideal detector for QGP b-jet physics!

ALPIDE design



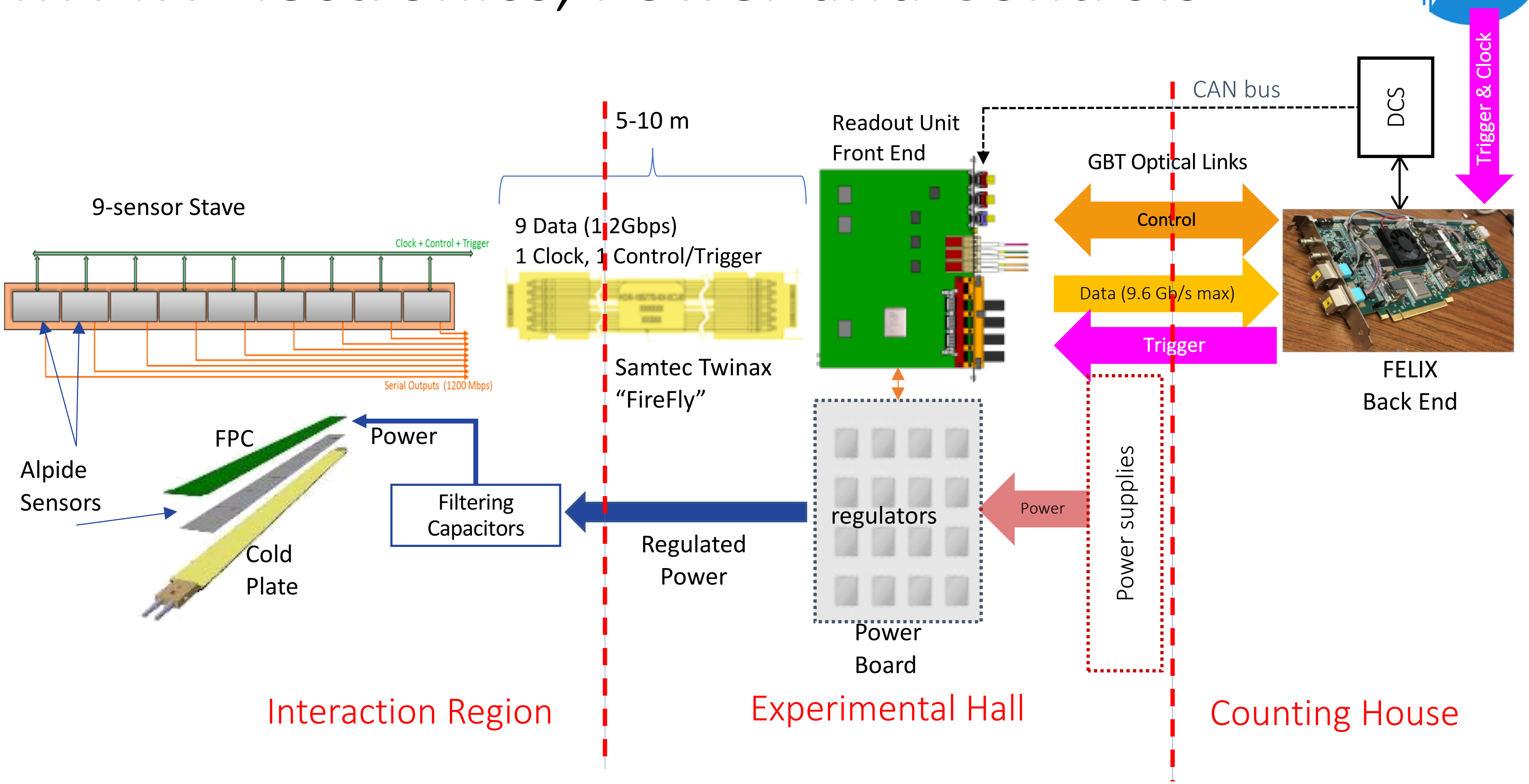
Tower Jazz 0.18 µm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

substrate: $N_A \sim 10^{18}$
epitaxial layer: $N_A \sim 10^{13}$
deep p-well: $N_A \sim 10^{16}$

MVTX Electronics, Power and Controls

sPHENIX



Sensor-Stave (9 ALPIDE chips) | **Front End**-Readout Unit | **Back End**-FELIX

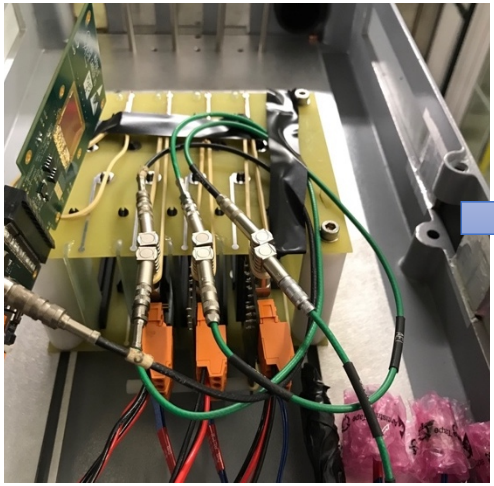
(------- ALICE/ITS Hardware --------) **(-- ATLAS Hardware --)**

MVTX R&D Highlights

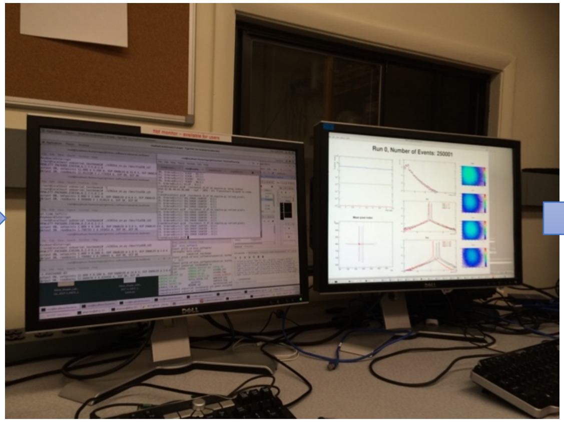
2018 test beam @Fermilab

Feb-July 2018 FermiLab Test beam facility, test of each sPHENIX detector subsystem

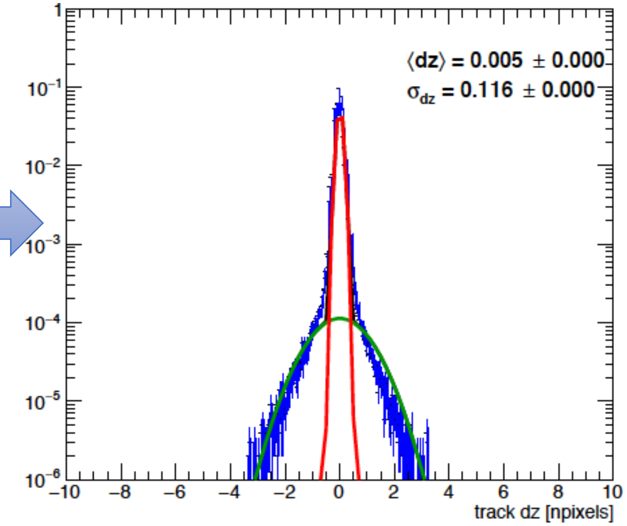
4x MVTX sensor in beam



sPHENIX DAQ

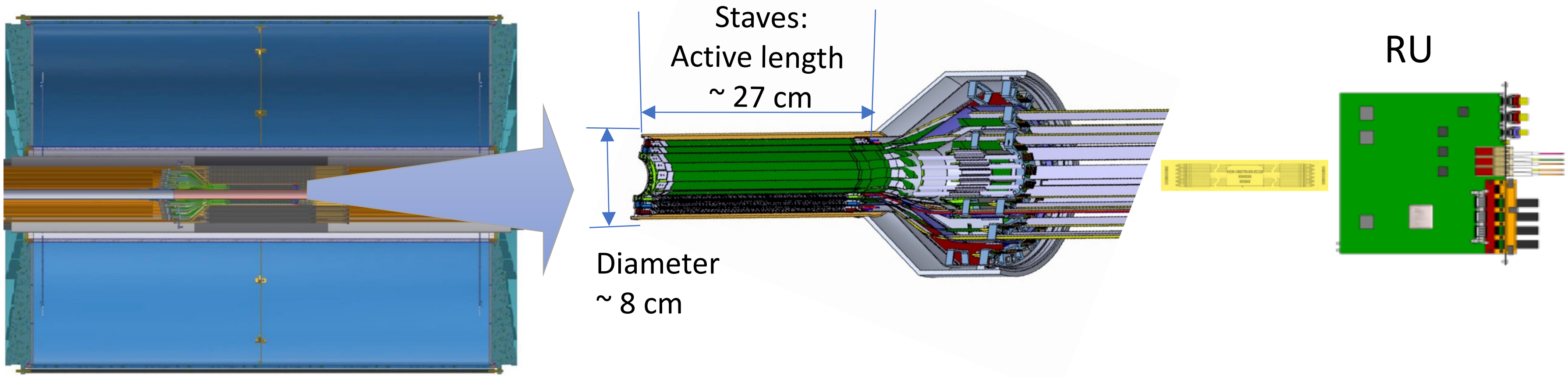


MVTX Hit Spatial Resolution: < 5 um

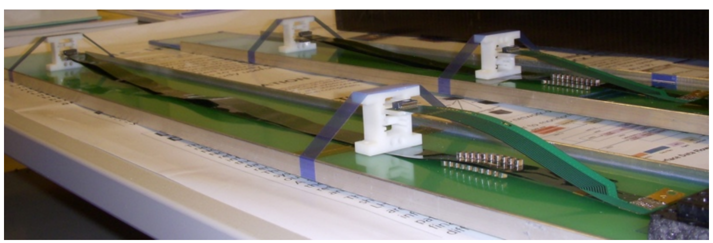


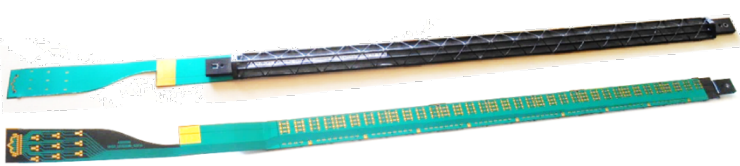
MVTX Status

- Stave & RU production: starts soon following ALICE ITS production at CERN
  - 84 Staves: 3-layer + spares (full inner 2-layer + 20%); 60 RUs: 48 + 25% spares
- Back-end DAQ: sPHENIX production of ATLAS FELIX cards at BNL
- Mechanical system design in progress; Installation in 2022, day-1 physics 2023

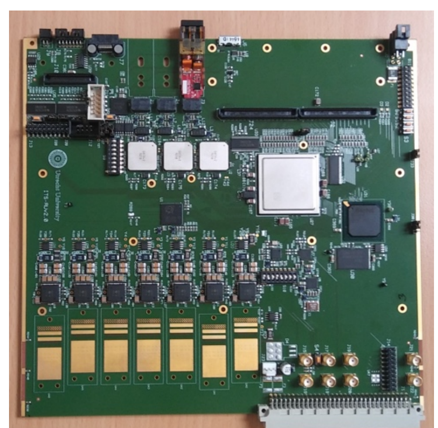


Sensor tested with sPHENIX extension

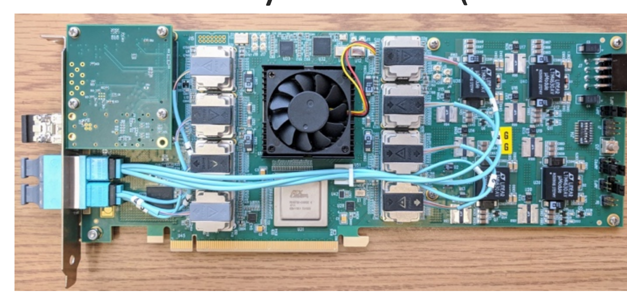




Readout Unit v2

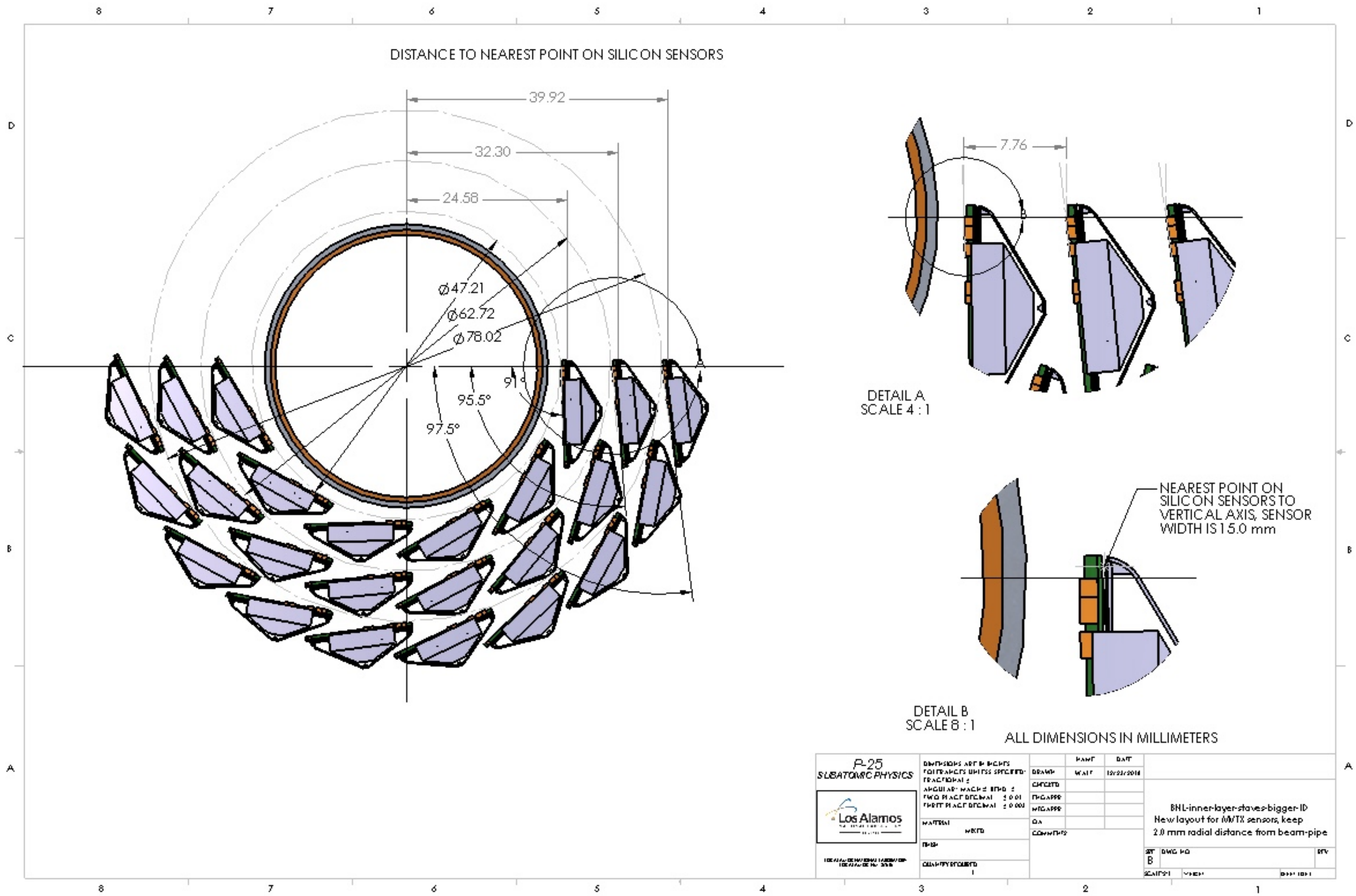


Data Assembly Module (FELIX v2)



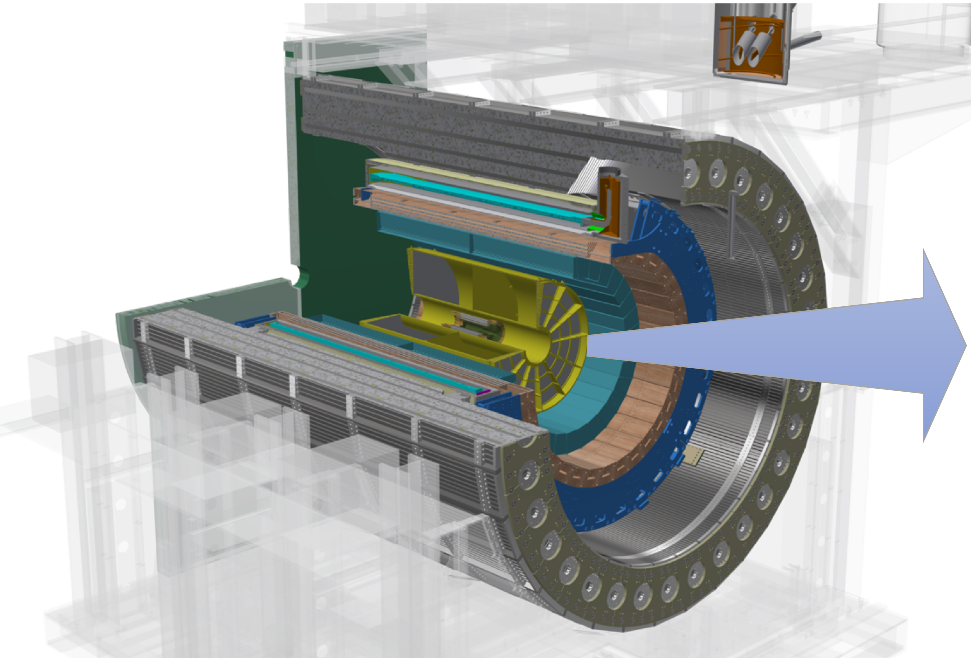
In close coordination with R&D and production for ALICE/ATLAS Phase-I upgrade

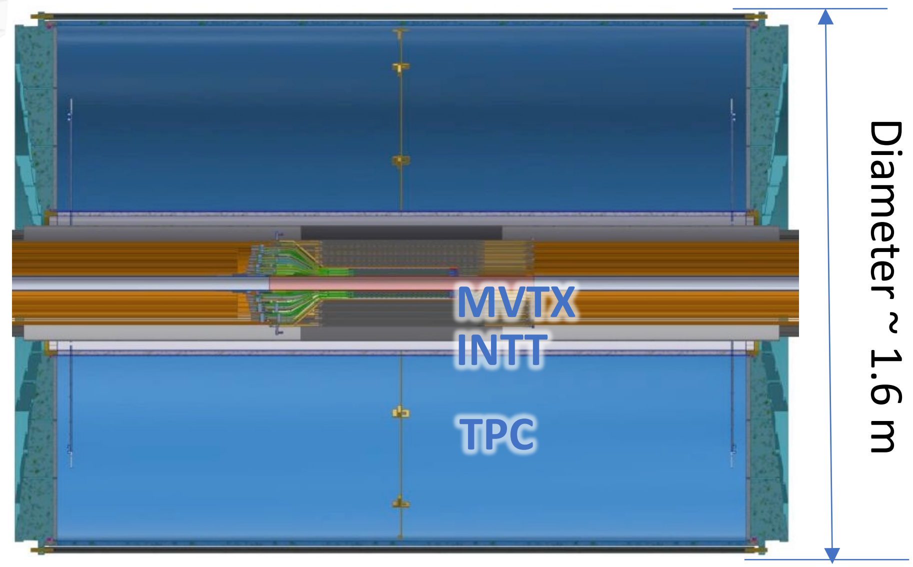
New MVTX Stave Configuration



sPHENIX Tracking Detectors

See also calorimeters – Justin Frantz





Inner tracker: |eta|<1

- **MVTX**: MAPS pixel sensors (3-layer)
  - Modified ALICE ITS IB staves
    Precision vertexing R_MVTX: 2.5 ~ 4.0 cm
- **INTT**: strip silicon sensors (2-layer)
  - Pattern recognition, timing

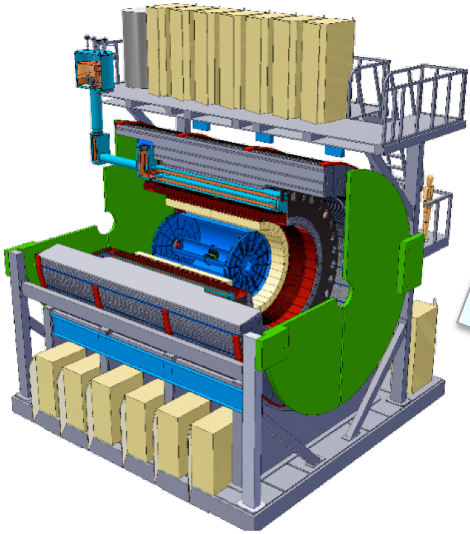
R_INTT: 8 ~ 12 cm (TBD)

Outer tracker: |eta|<1

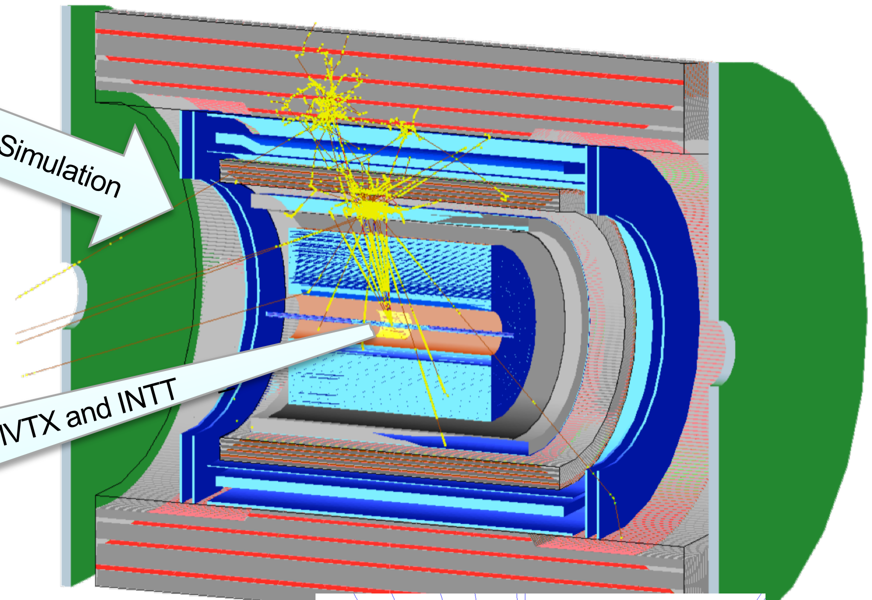
- **TPC**: gateless and continuous readout
  - Provide momentum measurement
- $\delta p/p < 2\%$ for p_T<10 GeV/c

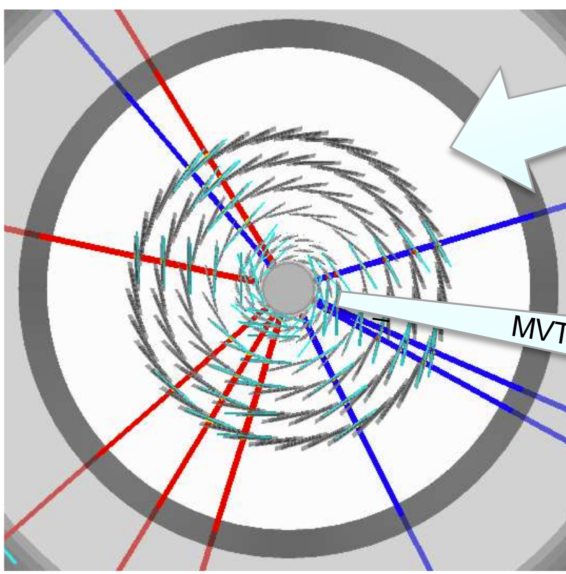
R_TPC: 30 ~ 78 cm

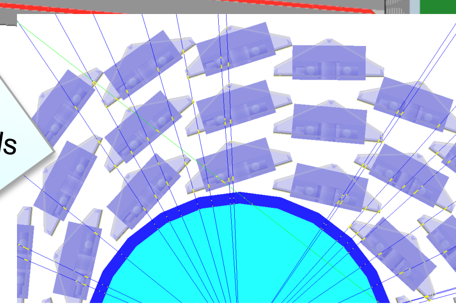
Simulation for *b*-jet and *B*-meson



sPHENIX Geant4 display of p_T=30 GeV/c B^+-hadron





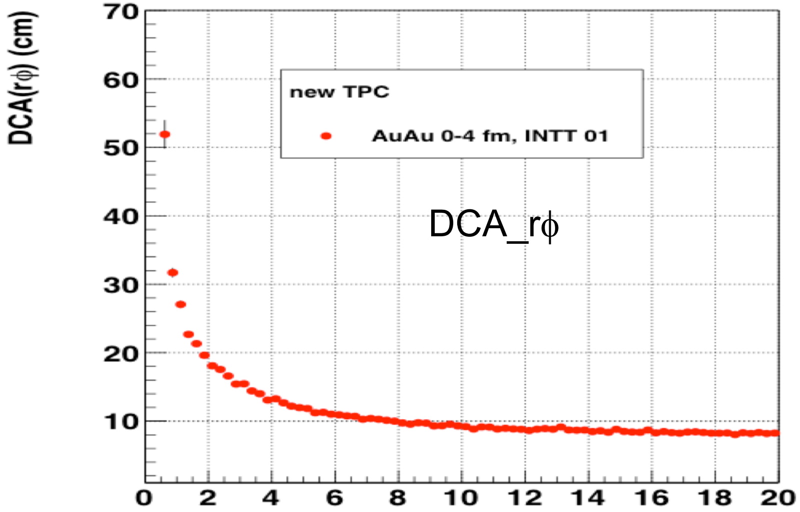


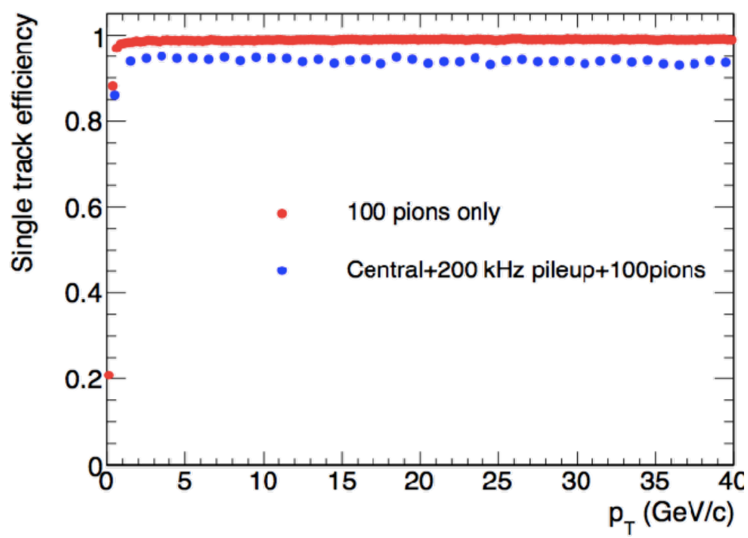
MVTX sensors

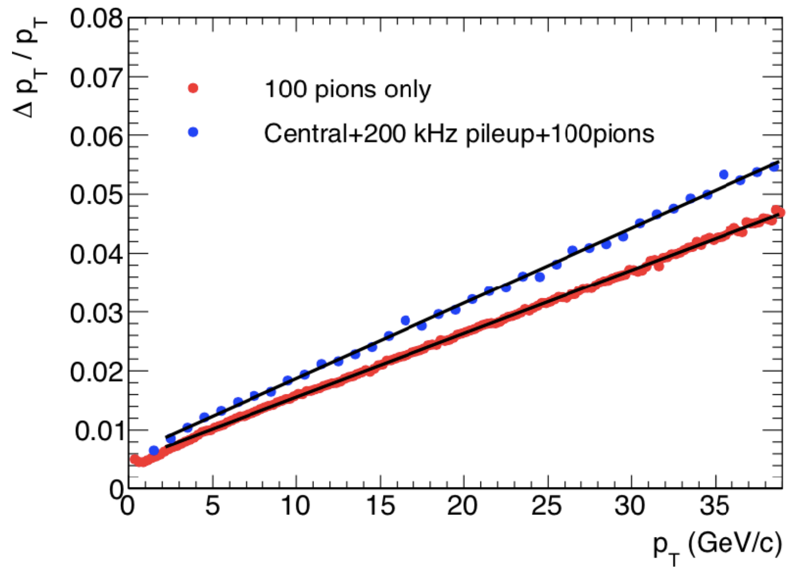
New INTT design: 2-layer (was 4)

Tracking Performance

- MVTX geometry modeled and digitized according to ALICE ITS/IB
- Cluster resolution: ~5 µm
- DCA_{2D}, DCA_z<30 µm down to 1 GeV/c
- Robust tracking at top projected RHIC collision rate







Open Charm & Beauty Production

Hadron	Abundance	cτ (μm)
D^0	61%	123
D^+	24%	312
D_s	8%	150
Λ_c	6%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

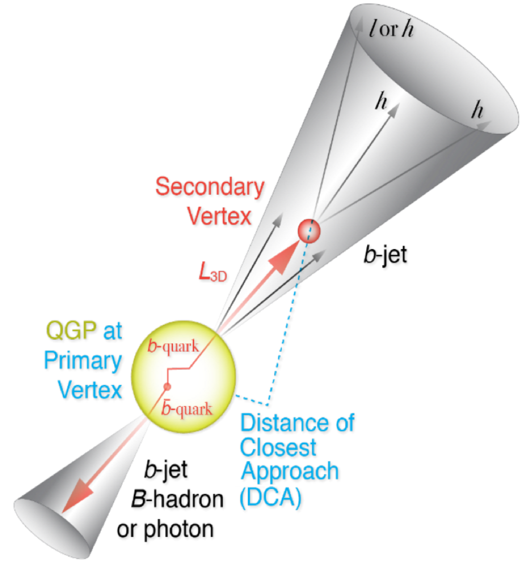
b-tagged jet and cor. p_T>15 GeV

$B \rightarrow \overline{D}^0 + X$ 60%

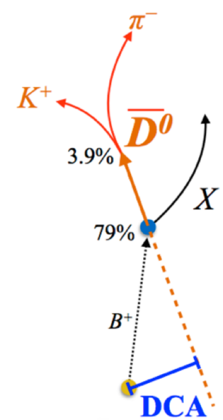
$B^+ \rightarrow \overline{D}^0 \pi^+$ 0.5%

p_T<15 GeV

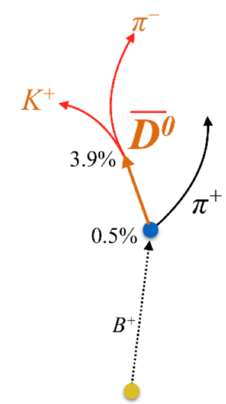
Exploring $B \rightarrow J/\psi + X$ and more



$B \rightarrow \overline{D}^0 + X$

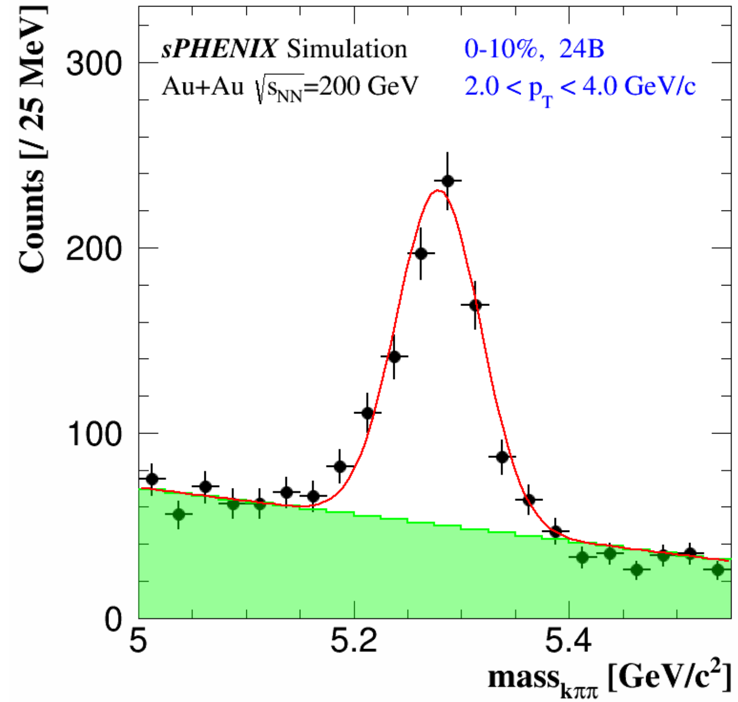


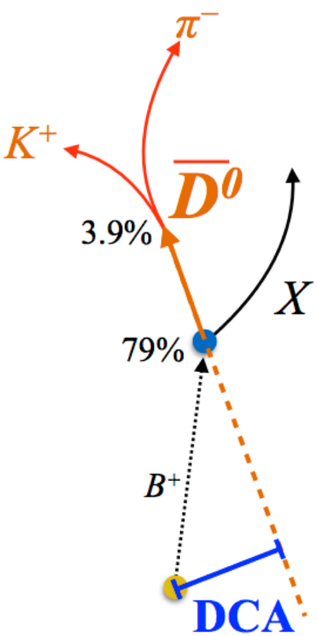
$B^+ \rightarrow \overline{D}^0 \pi^+$

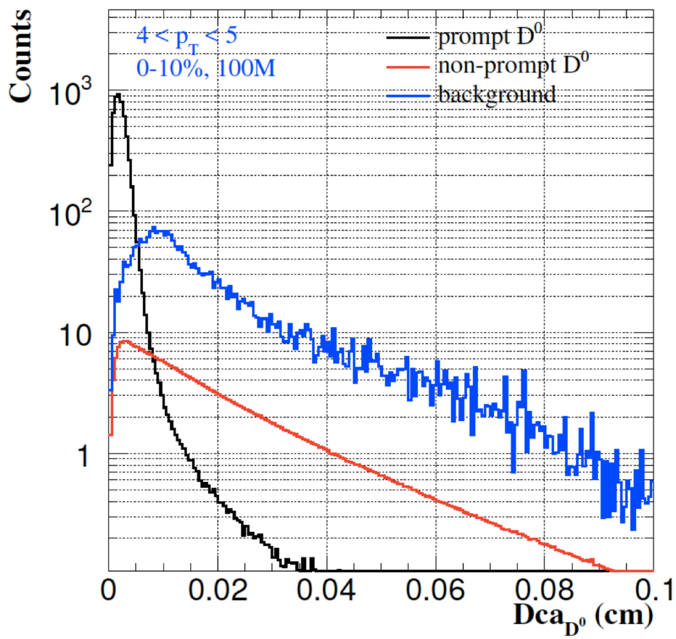


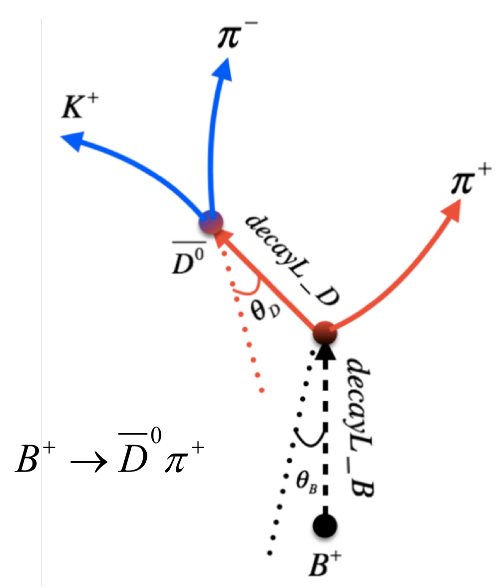
B-hadron Tagging

- Impact parameter (DCA) method to tag non-prompt D^0 from B-meson decays
- Inclusive and exclusive channels possible







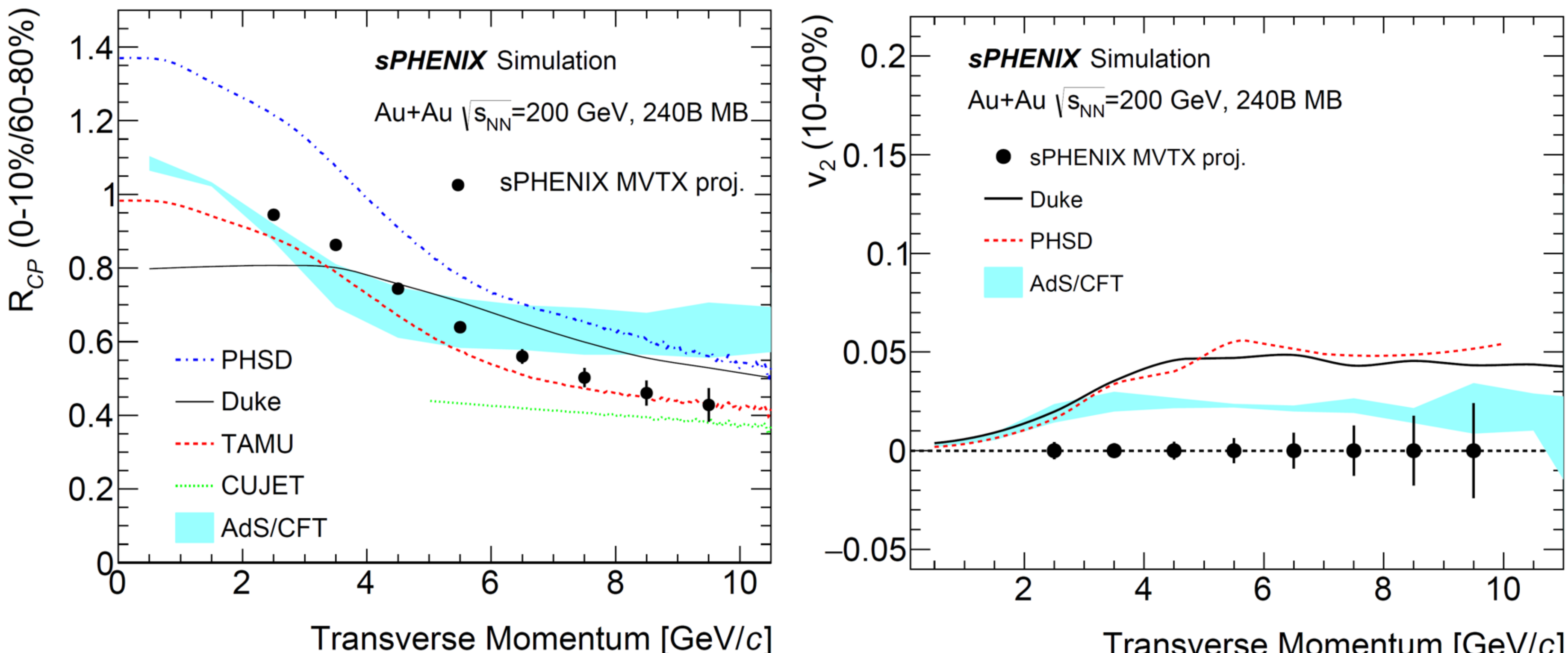


B-meson Projections

- High precision non-prompt-*D* suppression and flow at RHIC
- Determine the bottom quark collectivity
  → clean access to D_{HQ} at RHIC energy

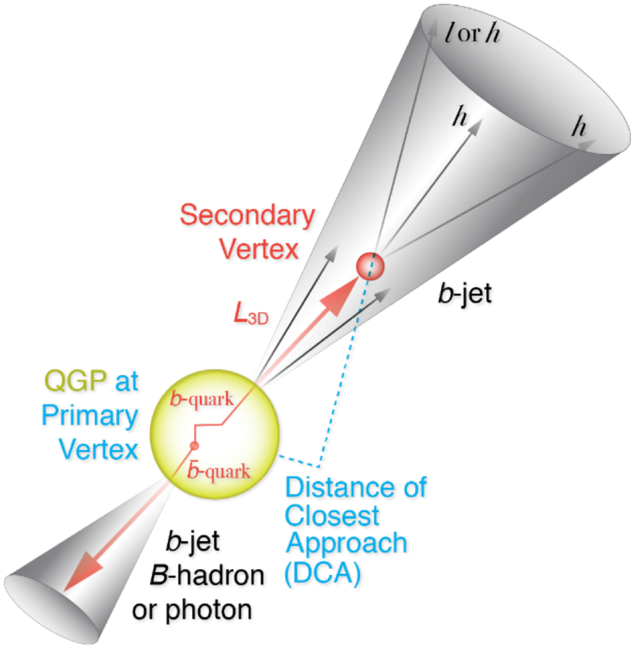
MVTX Proposal

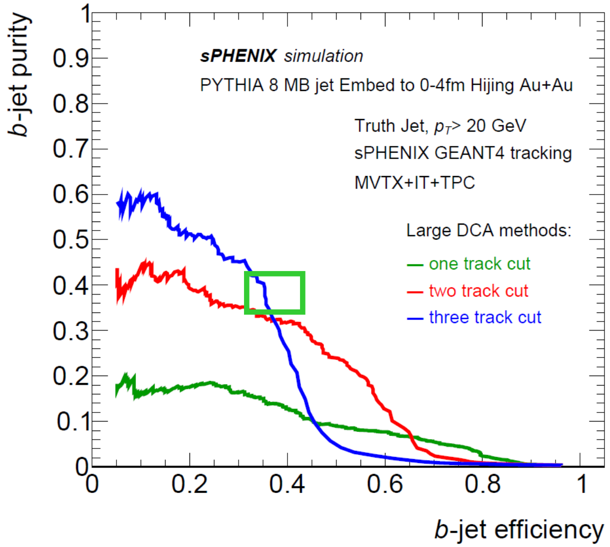
A+A: non-prompt *D*-meson and predictions for sPHENIX

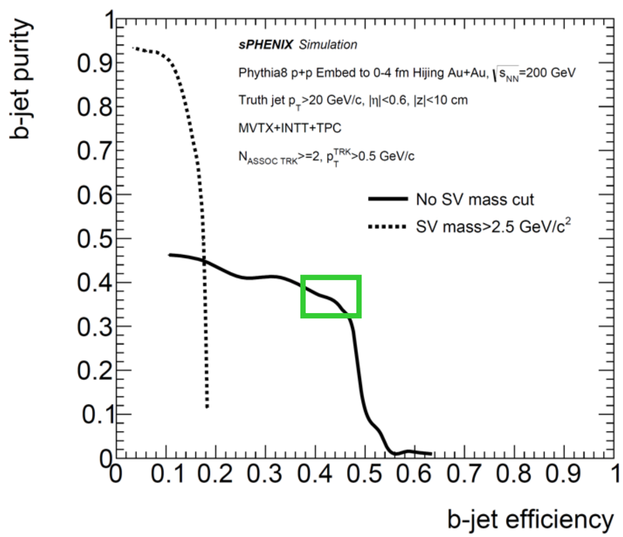


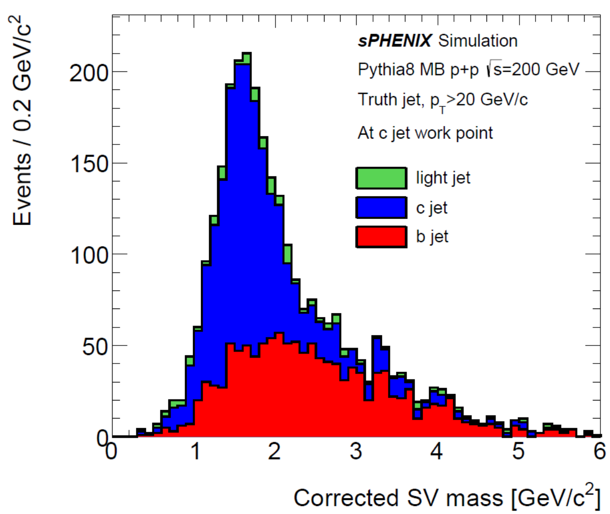
B-jet Tagging

- Multi-tracks w/ large DCA
- 2nd vertex mass reco'd







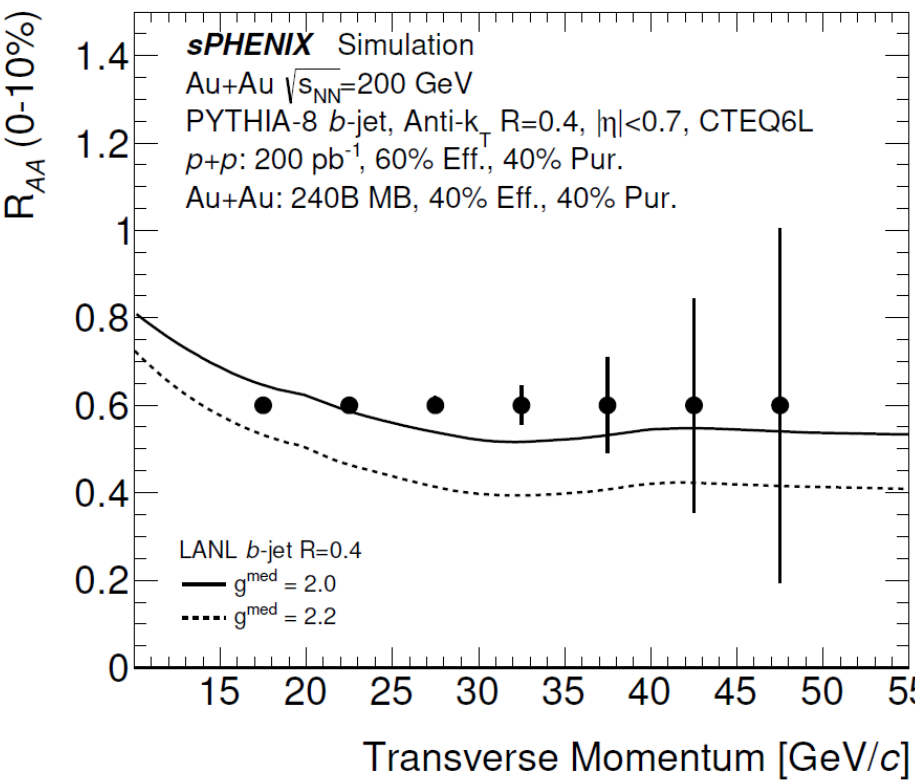


b-jet Projections

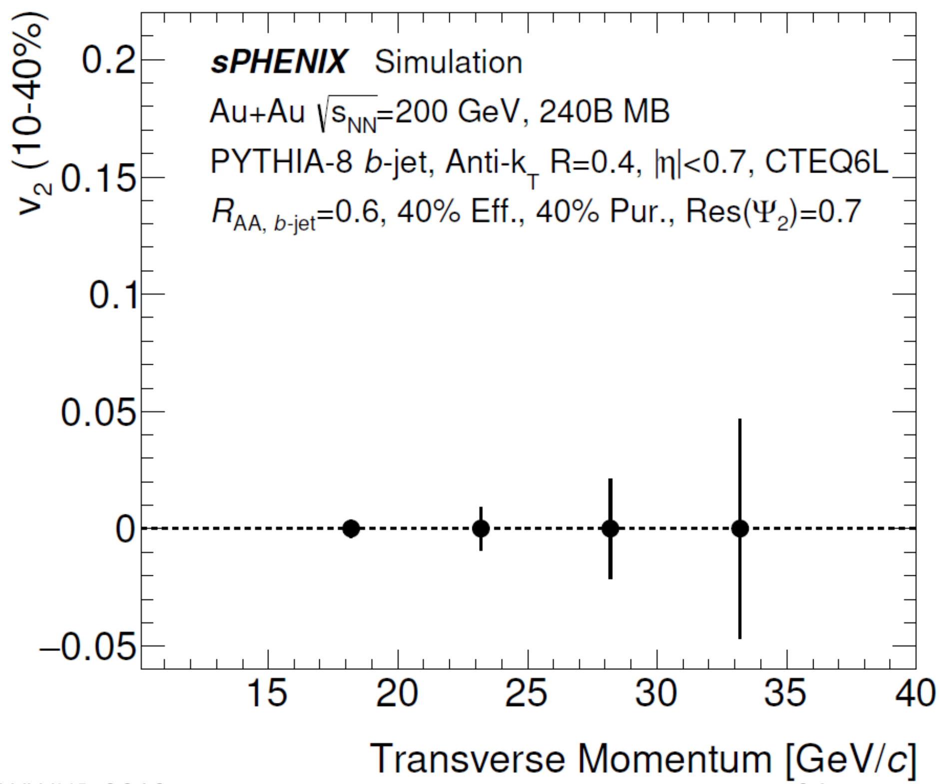
- High precision inclusive b-jet suppression and v_2 at RHIC
- Strong constraints on energy loss models in QGP

[MVTX Proposal](#)

A+A: Inclusive b-jet R_{AA}



Inclusive b-jet v_2

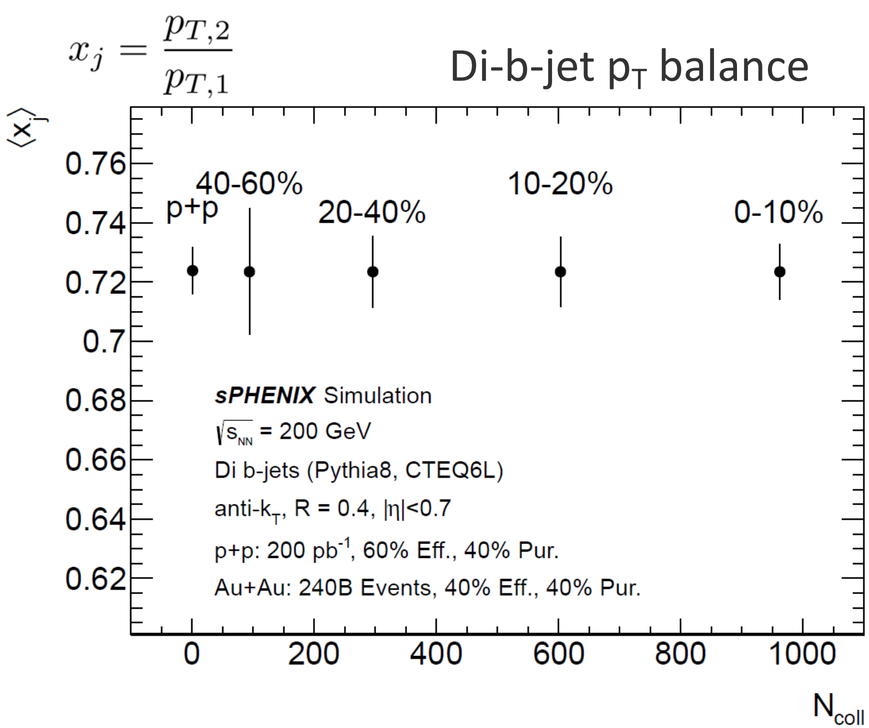


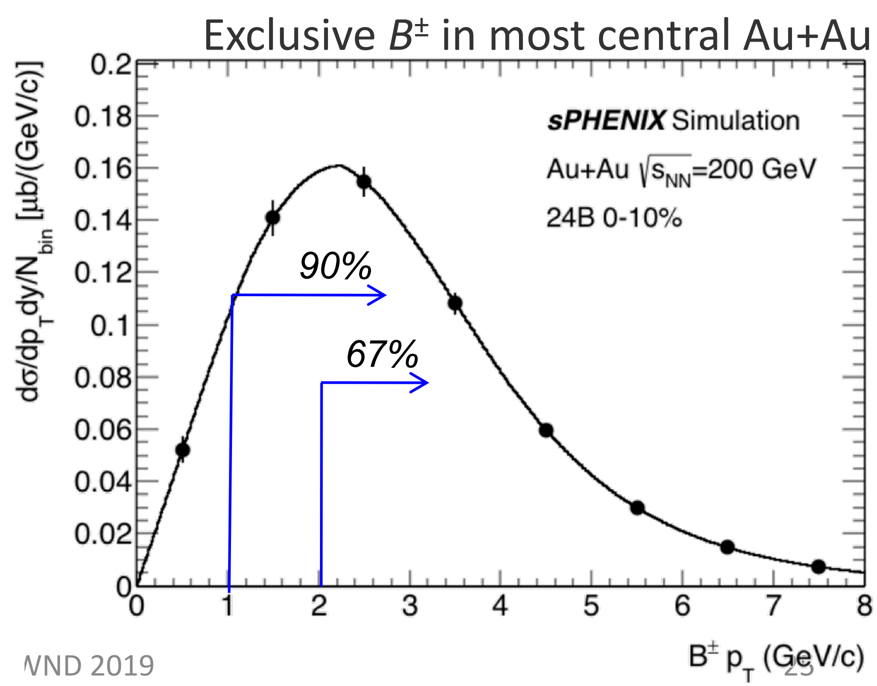
A Broad HF Physics Program

- HF di-jet/hadron correlations, HF jet substructures
- HF baryons, chemistry and hadronization
- Total *b*-cross section for Upsilon baseline reference

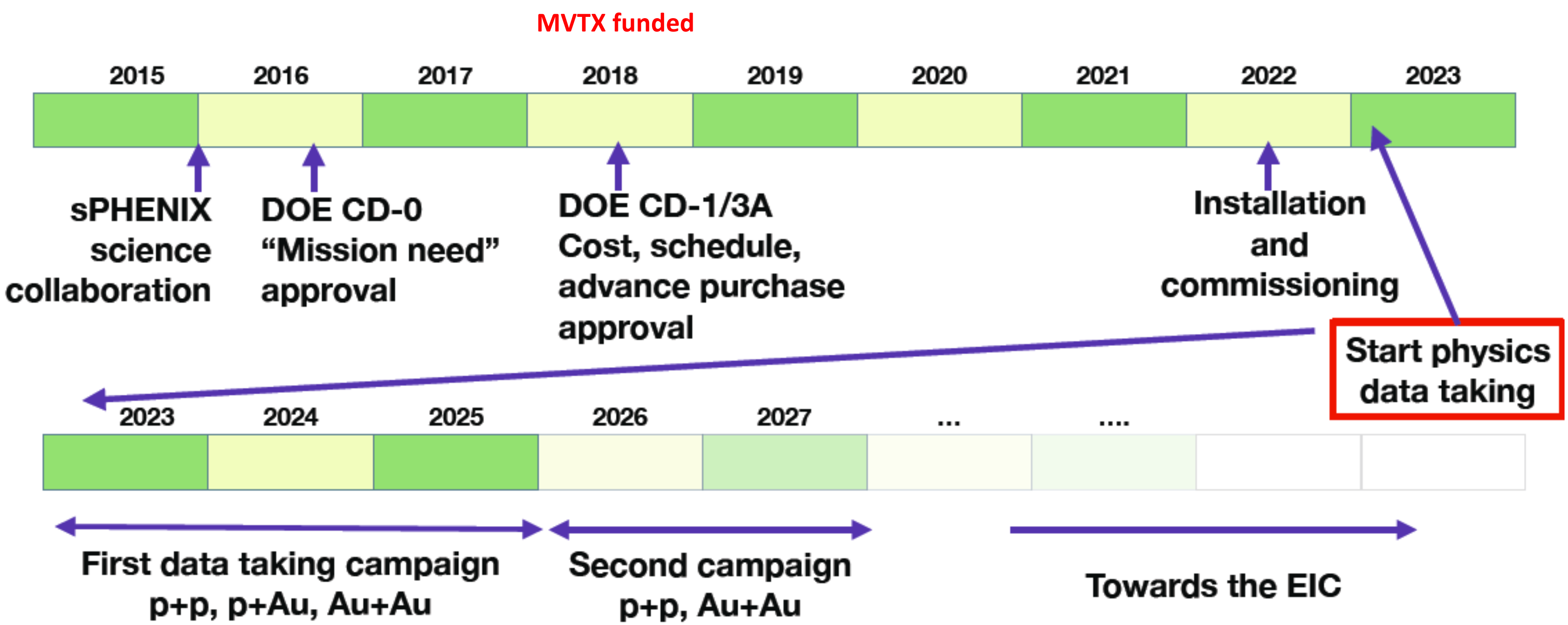
A great opportunity for new ideas and new measurements

[MVTX Proposal](#)





sPHENIX Status and Plan



A Rapidly Growing Collaboration

sPHENIX

The sPHENIX collaboration – formed December 2015

More than 70 institutions currently, significant growth since formation

Augustana University
Banaras Hindu University
Baruch College, CUNY
Brookhaven National Laboratory
China Institute for Atomic Energy
CEA Saclay
Central China Normal University
Chonbuk National University
Columbia University
Eötvös University
Florida State University
Fudan University
Georgia State University
Howard University
Hungarian sPHENIX Consortium
Insititut de physique nucléaire d'Orsay
Institute for High Energy Physics, Protvino
Institute of Nuclear Research, Russian Academy of Sciences, Moscow
Institute of Physics, University of Tsukuba
Institute of Modern Physics, China
Iowa State University
Japan Atomic Energy Agency
Charles University (CUNI), Prague
Czech Technical University in Prague (CTU)
Korea University
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Lehigh University
Los Alamos National Laboratory
Massachusetts Institute of Technology
Muhlenberg College
Nara Women's University
National Research Centre "Kurchatov Institute"
National Research Nuclear University "MEPhI"
New Mexico State UniversityOak Ridge National Laboratory
Ohio University
Peking University
Petersburg Nuclear Physics Institute
Purdue University
Rice University
RIKEN
RIKEN BNL Research Center
Rikkyo University
Rutgers University
Saint-Petersburg Polytechnic University
Shanghai Institute for Applied Physics
Stony Brook University
Sun Yat Sen University
Temple University
Tokyo Institute of Technology
Tsinghua University
Universidad Técnica Federico Santa María
University of California, Berkeley
University of California, Los Angeles
University of California, Riverside
University of Colorado, Boulder
University of Debrecen
University of Houston
University of Illinois, Urbana-Champaign
University of Jammu
University of Maryland
University of Michigan
University of New Mexico
University of Tennessee, Knoxville
University of Texas, Austin
University of Tokyo
University of Science and Technology, China
Vanderbilt University
Wayne State University
Weizmann Institute
Yale University
Yonsei University

2016 2017 2018

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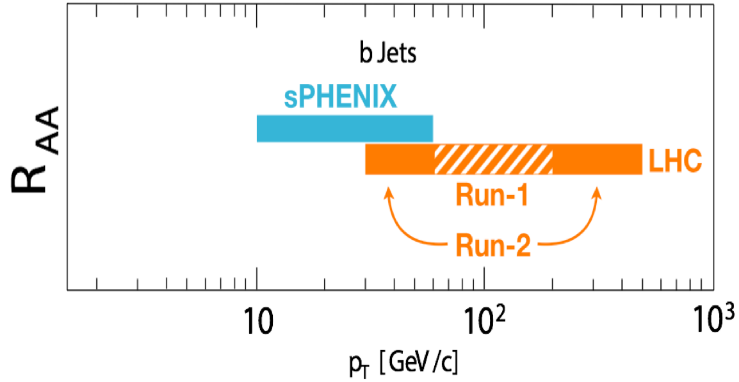
Summary and Outlook

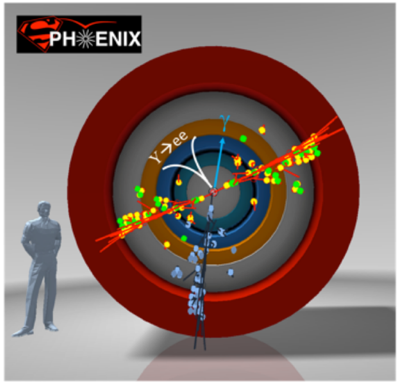
- sPHENIX is the next generation flagship heavy ion physics experiment in the US (NSAC LRP2015)
  - Jets & Upsilons
  - B hadron and b-jet physics enabled by MVTX
- MVTX will complete QGP heavy flavor physics at RHIC
  - Unambiguous determination of key parameters of QGP through precision study of open HF productions
- MVTX on track for day-1 physics in 2023
  - Production begins now
  - Strong community support, ALICE, ATLAS, LANL, BNL *et al*

Complement & extend current and future RHIC and LHC QGP programs

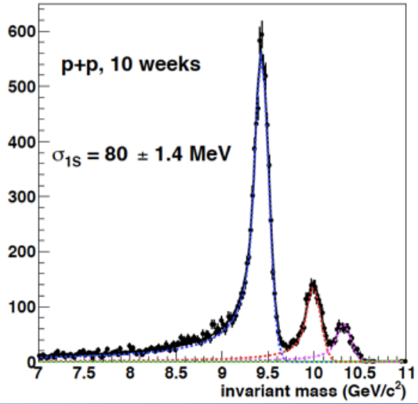


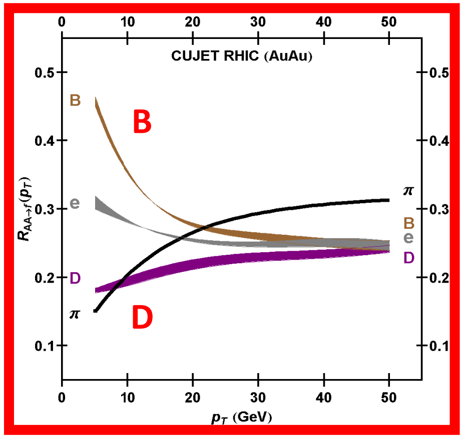
sPHENIX Three Physics Pillars

Jets



Upsilons





backup

sPHENIX

From June 2017
RHIC Users' Meeting talk
by
BNL ALD Berndt Mueller

sPHENIX $\sqrt{s_{NN}}$ = 200 GeV tentative run plan

Year	Species	Goals
2022*	Au+Au	Commissioning Single jet, di-jet, photon-tagged jet, b-tagged jet spectra D-jet asymmetry IUpsilon spectra
2023	p+p p+Au	Reference data for modification of jets, di-jets, b-tagged jets Jet A_{LL} Reference data for cold nuclear matter effects
2024	Au+Au	Direct photon measurement Study of flavor dependence of jet observables Modification of jet fragmentation functions, jet splitting functions, other complex jet observables
2025	p+p	High statistics data for Upsilon modifications High statistics data for jet A_{LL}
2026	Au+Au	High statistics data for b-tagged jets and photon-tagged jets High statistics data for jet fragmentation functions, jet splitting functions, other complex jet observables High statistics data for high p_T direct photons High statistics data for Upsilon modifications, including Υ(3S) Collective flow of b-quarks (B hadron elliptic flow)

campaign 1

campaign 2

*operations start now planned for 2023

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

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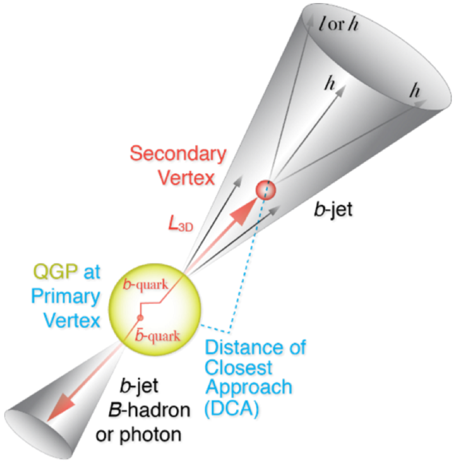
Evolving

RHIC Multi-Year Plan: sPHENIX 2023-2027+

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
2023 ~~2022~~	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
2023	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
2023	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
2024	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
2025	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
2026	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

- Precision vertexing for B-tagging:
  - Tracking resolution better than 50um @pT=1GeV
  - High multiplicity HI collisions
  - Low multiplicity but high rate p+p collisions
  - High efficiency and high purity

B hadrons/pT<15GeV: *O*(1M)
b-jets/pT>15GeV: *O*(100K)

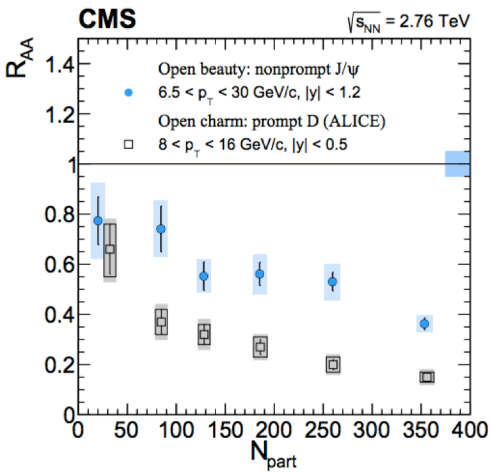


Recent Achievements on Bottom

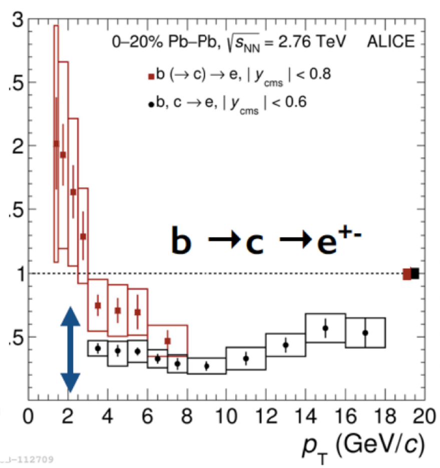
LHC 2.76 TeV

RHIC 200 GeV

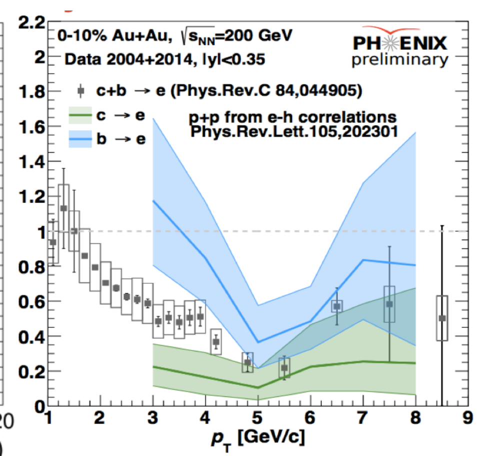
$R_{AA}(J/\psi_B) > R_{AA}(D)$

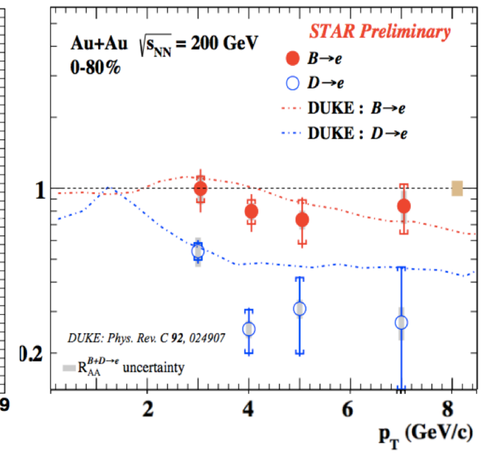


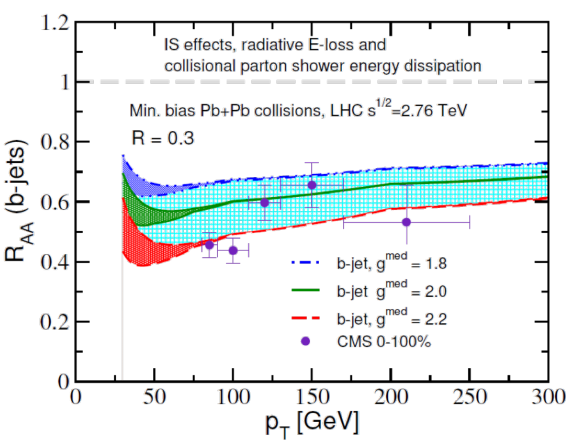
$R_{AA}(e_B) > R_{AA}(e_{D+B})$

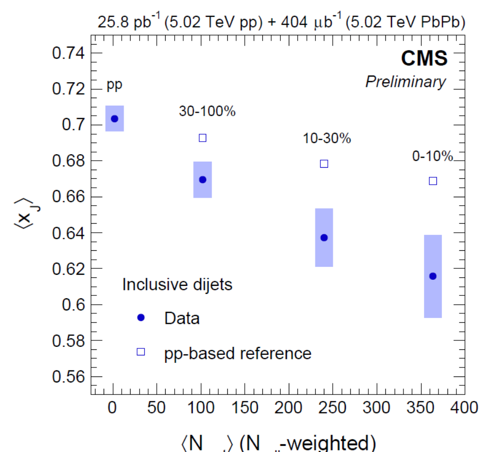


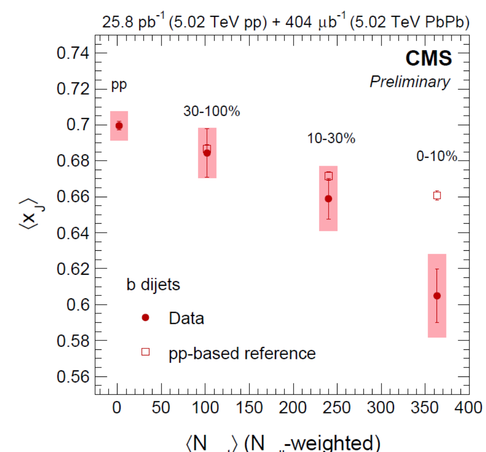
$R_{AA}(e_B) > R_{AA}(e_D)$





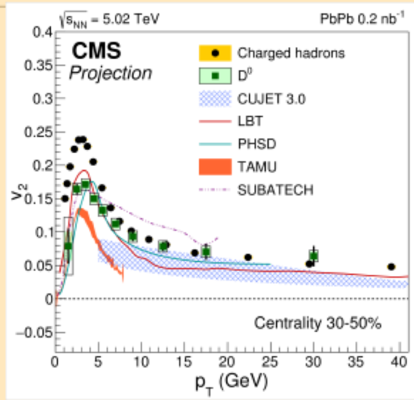




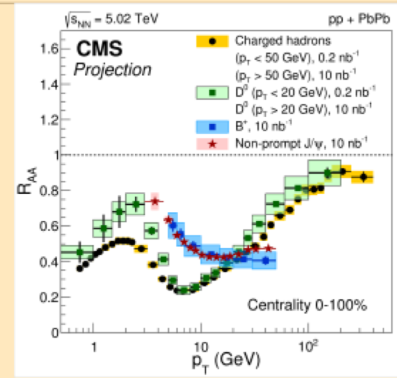


sPHENIX vs LHC Projections

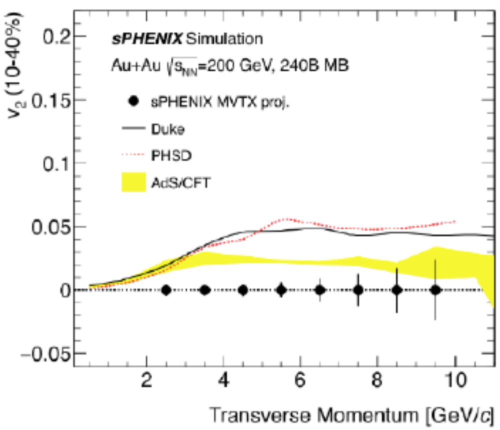
Elliptic flow measures *c* and *b* quark thermalization in medium



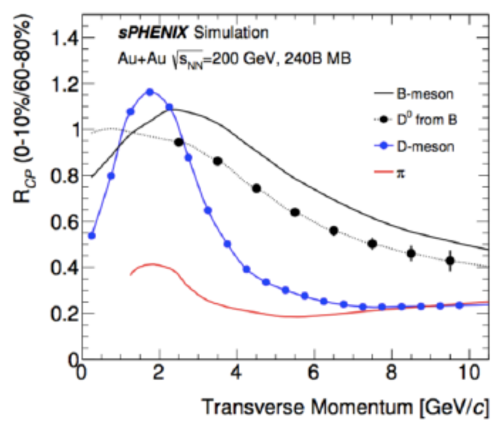
CMS projections for Run III+IV



Open heavy flavor suppression probes flavor dependence of energy loss



sPHENIX projections



sPHENIX vs ALICE Specifications

	ALICE (Run3)	sPHENIX
Pb+Pb / Au+Au	100 kHz (50kHz)	200 kHz
p+p	400 kHz (200kHz)	13 MHz
“Trigger”	C.R. (>50 kHz)	15 kHz

Event size, dN/dη: sPHENIX = 1/3 ALICE (pp), 1/5 ALICE(AA)