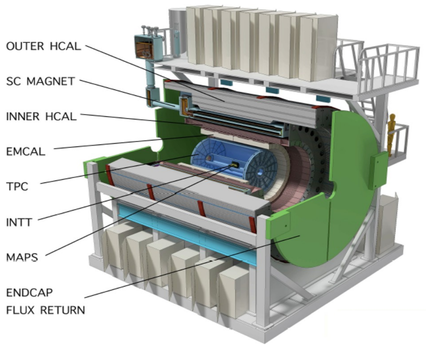
The SPHENIX experiment at RHIC



Marzia Rosati
Iowa State University
on behalf of sPHENIX Collaboration

Virtual Presentation, Wednesday Sept 22
LXXI International conference NUCLEUS – 2021

sPHENIX

Outline

- sPHENIX science mission and core physics program
- sPHENIX detector and beam use proposal
- Projected results and construction update

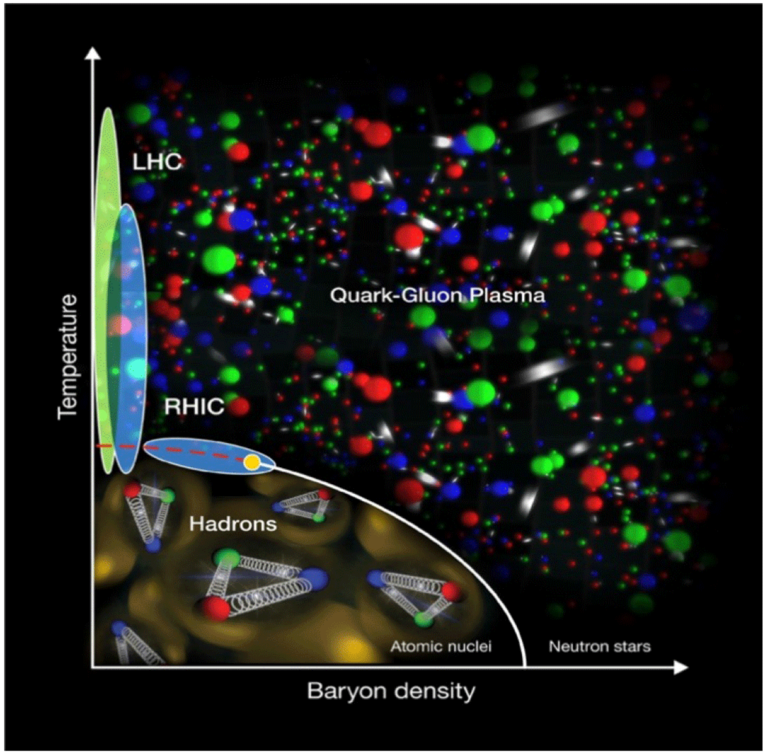
QCD Phase Diagram

- QCD Lagrangian

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + igf^{abc}A^b_\mu A^c_\nu$$

gluon self interactions

asymptotic freedom | confinement

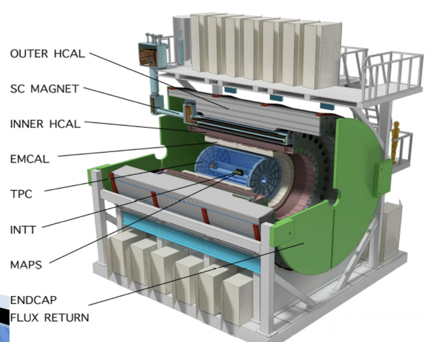


- At high temperature or density hadronic matter deconfines into the Quark-Gluon Plasma (QGP), and understanding the nature and characteristic of the QGP is the goal of heavy ion physics experiments at RHIC &LHC

sPHENIX Science Mission

- The goals of heavy-ion experiments at RHIC and the LHC as a result of the 2015 Long Range Plan for Nuclear Science are two-fold :
  1. To map the QCD phase diagram with experiments planned at RHIC
  2. To probe the inner workings of quark-gluon plasma (QGP) by resolving its properties at shorter and shorter length scales

sPHENIX Science Mission



- The goals of heavy-ion experiments at RHIC and the LHC as a result of the 2015 Long Range Plan for Nuclear Science are two-fold :
  1. To map the QCD phase diagram with experiments planned at RHIC
  2. To probe the inner workings of quark-gluon plasma (QGP) by resolving its properties at shorter and shorter length scales
- The sPHENIX detector is a state-of-the-art jet detector under construction at BNL to elucidate properties of the QGP at shorter and shorter length scales

sPHENIX Collaboration

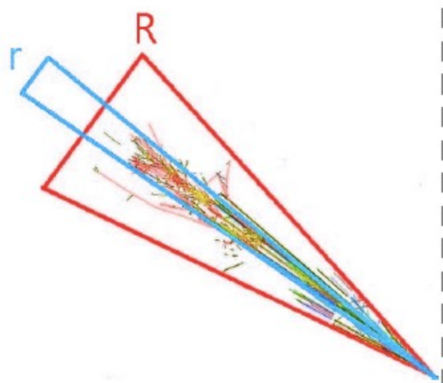
- Officially formed in 2016
- More than 320 members from 84 institutions in 14 countries as of 2021

Members from around the world gathered around a common science goal

sPHENIX Core Physics Program

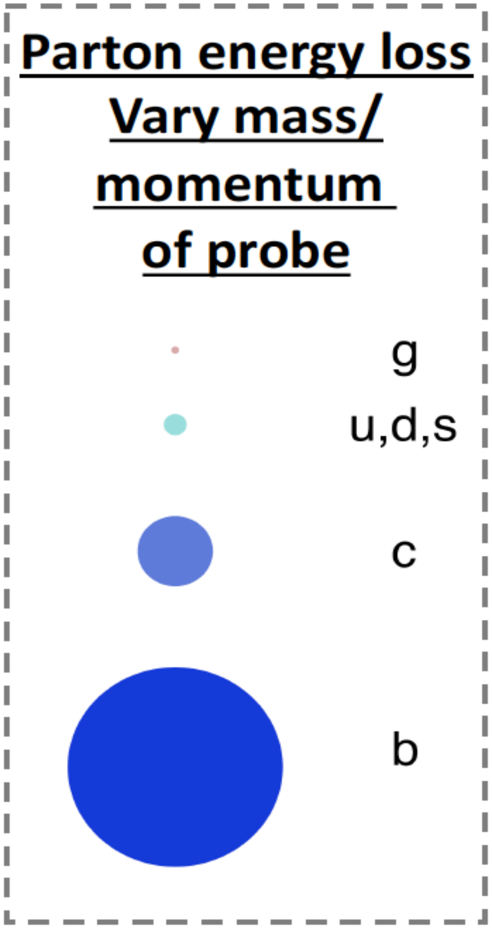
Jet correlation & substructure

Vary momentum/ angular size of probe



- Guided by the science mission, sPHENIX aims to : probe the QGP in different ways :
  - Vary probe's momentum and angular scale

sPHENIX Core Physics Program

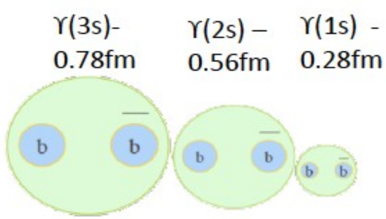


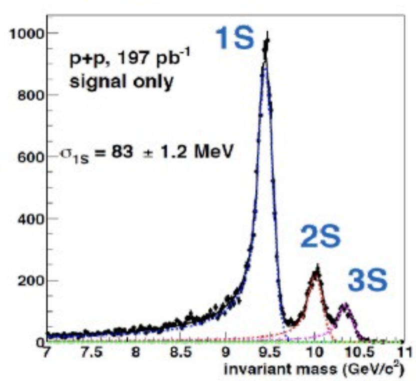
- Guided by the science mission, sPHENIX aims to : probe the QGP in different ways :
  - Vary probe's momentum and angular scale
  - Vary probe's mass and momentum

sPHENIX Core Physics Program

Upsilon spectroscopy

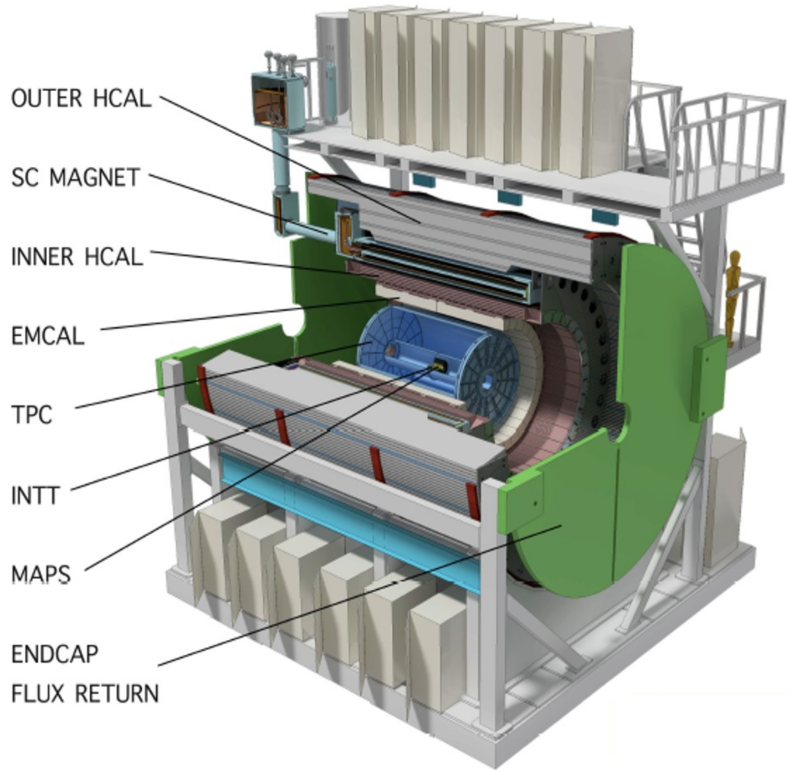
Vary size
of the probe





- Guided by the science mission, sPHENIX aims to : probe the QGP in different ways :
  - Vary probe's momentum and angular scale
  - Vary probe's mass and momentum
  - Vary probe's size

sPHENIX Detector Overview



Calorimetry

- Outer Hadronic Calorimeter (oHCAL)
- Inner Hadronic Calorimeter (iHCAL)
- Electromagnetic Calorimeter (EMCAL)

Magnet

- 1.4T superconducting solenoid used by the BaBar experiment

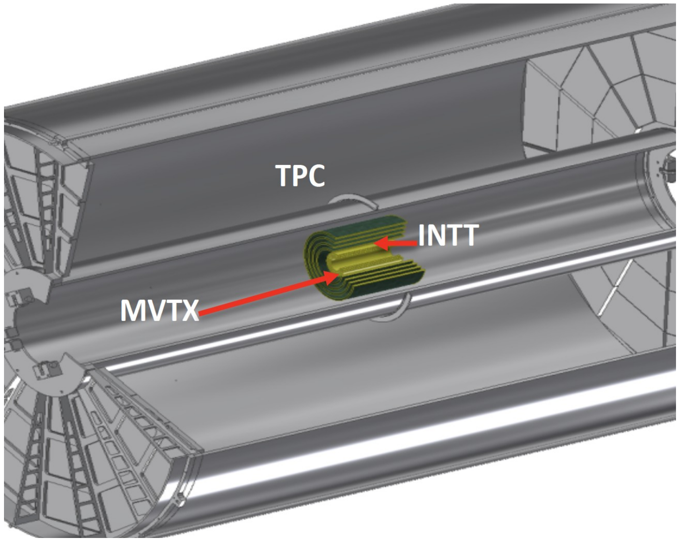
Tracking

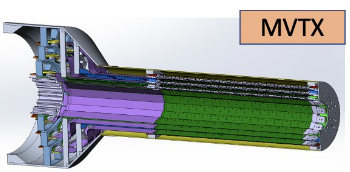
- Time Projection Chamber (TPC)
- Intermediate Silicon Tracker (INTT)
- MAPS-based Vertex Tracker (MVTX)

Performance

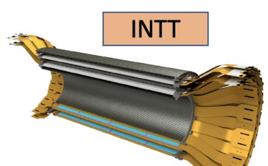
- **High data rate :** read out rate of 15 kHz for all subdetectors
- **Acceptance :** hermetic coverage over full azimuth & pseudorapidity $|\eta| \leq 1.1$ for the tracking & calorimeter systems

sPHENIX Tracking System

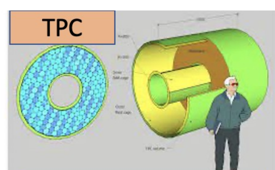




2.3 cm < r < 3.9 cm



6 cm < r < 12 cm



20 cm < r < 78 cm

MVTX : *high resolution vertexing*

- 3 layers of Monolithic Active Pixel Sensors based on ALICE ITS-II
- Nearest to the collision point, spatial resolution of 5 μm for tracks with $p_T > 1$ GeV

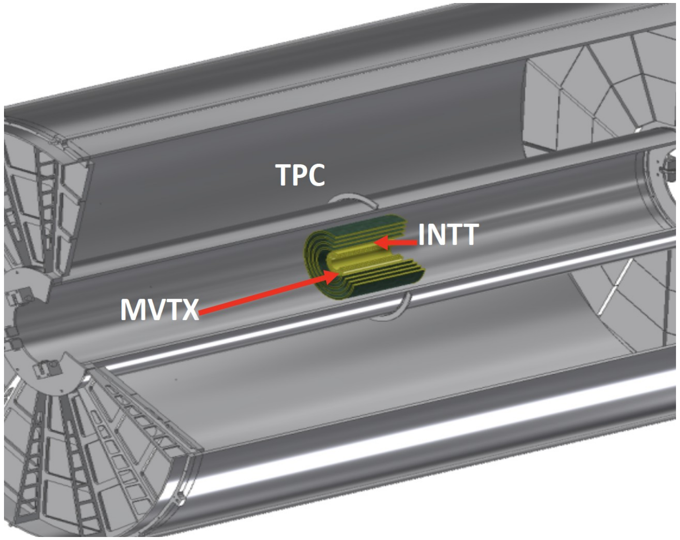
INTT : *pileup event separation*

- Silicon strip detector surrounding the MVTX
- Associates fully reconstructed tracks with the event that produced them

TPC : *momentum measurement*

- Compact (r = 80 cm) & main tracking element filled with Ne-CF_4 gas mixture
- Ungated, with GEM-based read out, spatial resolution of $< 200\ \mu m$

sPHENIX Tracking System



Open heavy flavor measurement

The MVTX higher resolution, read out rate, and larger acceptance compared to previous RHIC detectors will enable a state-of-the art open heavy flavor program at RHIC

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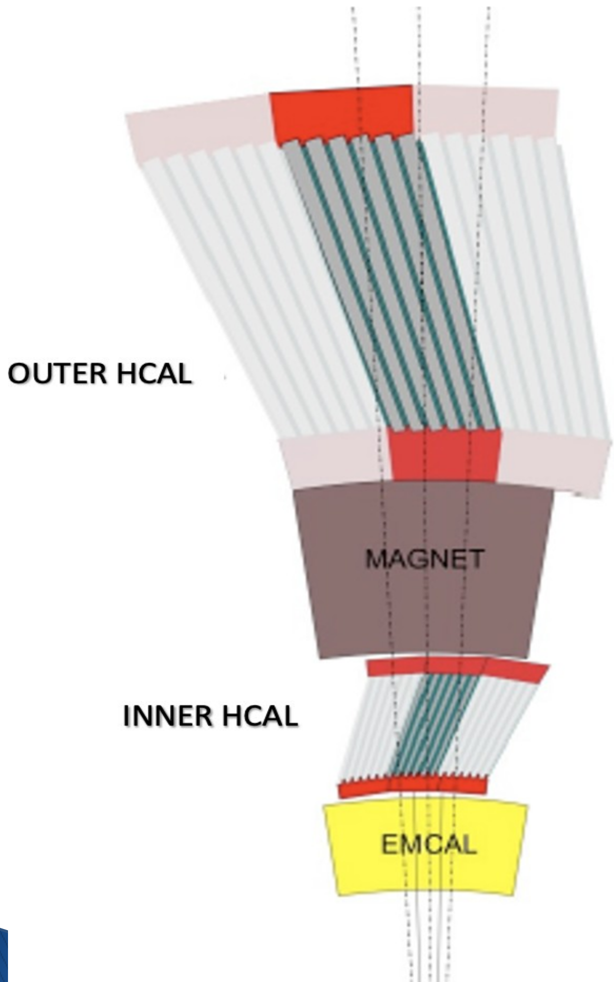
sPHENIX Calorimeter System



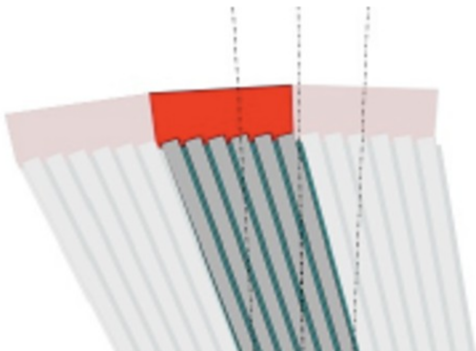
Hadronic calorimetry

- First at RHIC (at mid-rapidity)
- Plastic scintillating tiles + tilted steel plates with embedded WLS fibers (oHCAL) ; scintillating tiles + Al plates for the iHCAL
- Overall tile segmentation of $\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$

Electromagnetic calorimetry

- Scintillating fibers in tungsten and epoxy
- High segmentation for HI collisions : $\Delta\eta \times \Delta\varphi \approx 0.025 \times 0.025$
- Good energy resolution : $\sigma_E/E < 15\%/\sqrt{E}$

sPHENIX Calorimeter System



Jet measurement

- The large hadronic calorimeter acceptance (full azimuth & pseudorapidity $|\eta| \le 1.1$) enables unbiased selection (& triggering in p+p) for jets
- Improves jet resolution & extends the range for high p_T single hadron measurements

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sPHENIX 3-Year Run Plan

sPHENIX Beam Use Proposal (BUP) sPH-TRG-2020-001, August 31, 2020.

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\| < 10$ cm	Samp. Lum. $\|z\| < 10$ 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} [5kHz] 4.5(6.2) pb^{-1} [10%-str]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5kHz] 0.02 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}

Year 1 (2023) :

- Commissioning high multiplicity Au+Au run
- Measurement of standard Au+Au candles at RHIC

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Year 2 (2024) :

- Commissioning p+p
- $p^{\uparrow}$+$p^{\uparrow}$, $p^{\uparrow}$+Au : HI reference set and cold QCD

sPHENIX 3-Year Run Plan

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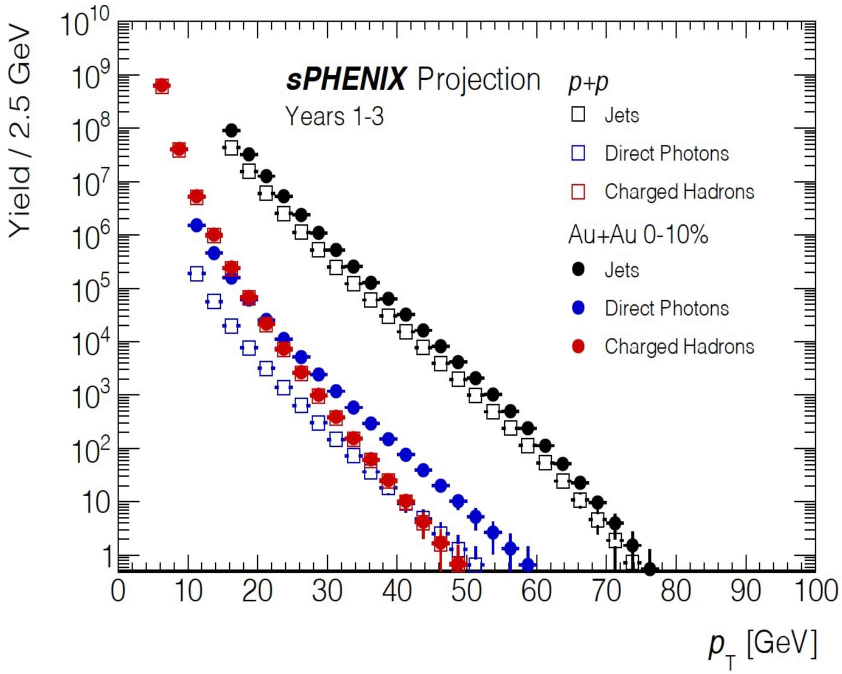
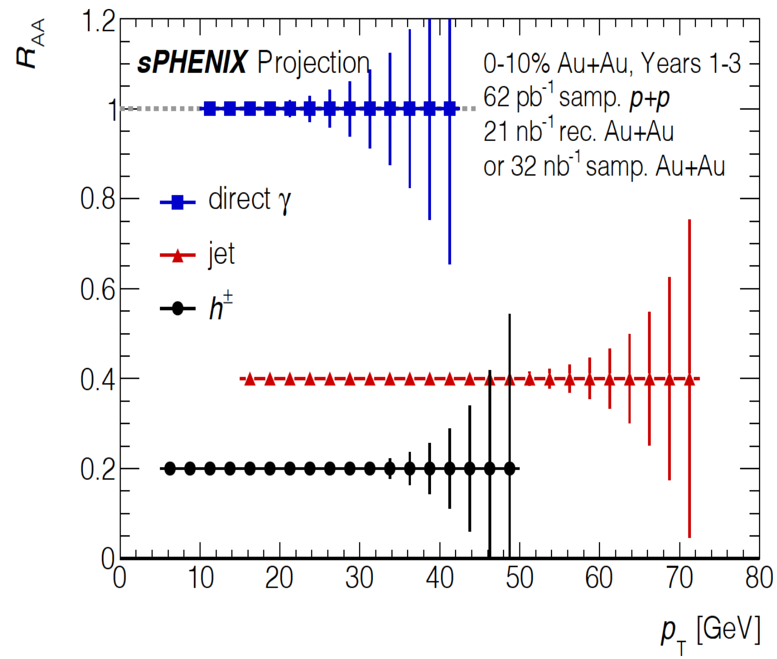
Year 3 (2025) :

- Very large Au+Au heavy-ion set for jet and heavy flavor physics
- 141 B events recorded in total

sPHENIX Probes : Jets and Photons





- Projected total yields for jets, photons and charged hadrons in 0-10% Au+Au events and p+p events

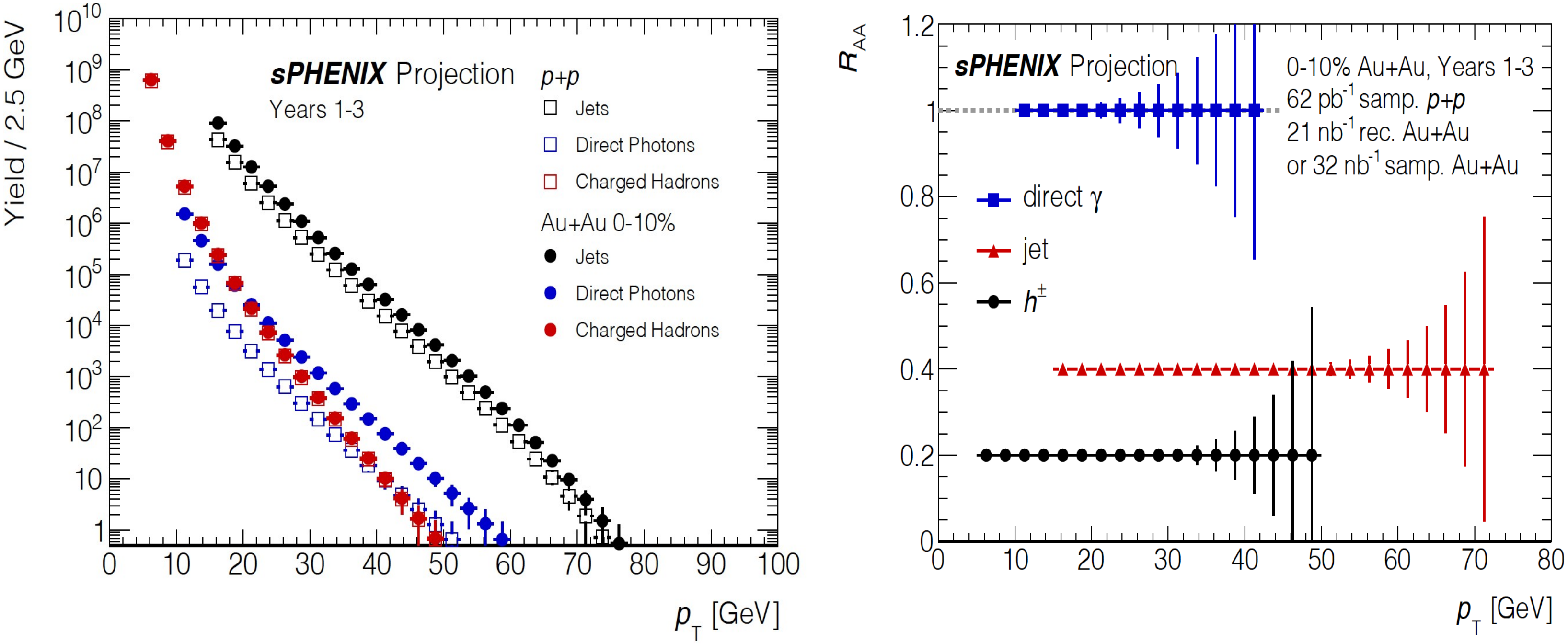
- Projected nuclear modification factor R_{AA}

Yields in A+A

$$R_{AA} = \frac{1}{N_{\rm coll}} \frac{\frac{dN_{AA}}{dp_T}}{\frac{dN_{pp}}{dp_T}}$$

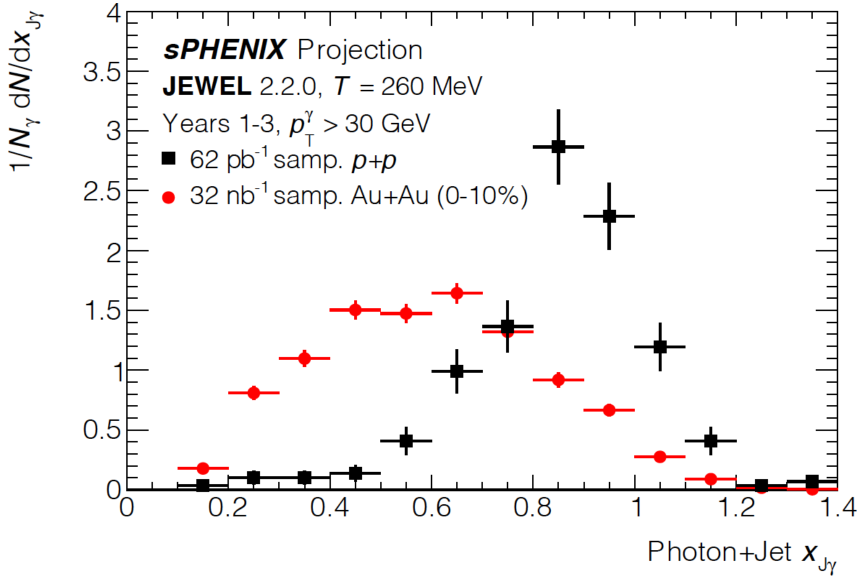
pp reference

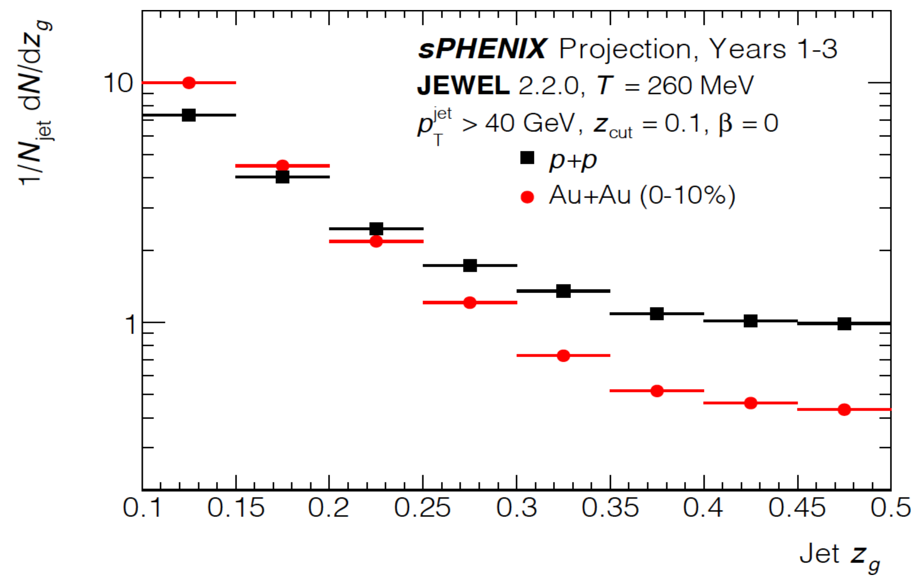
sPHENIX Probes : Jets and Photons



- 2023-2025 data taking will have kinematic reach out to ≈ 70 GeV for jets and ≈ 50 GeV for hadrons and photons
- The kinematic reach will resolve varying theoretical prediction for R_{AA} at higher p_T

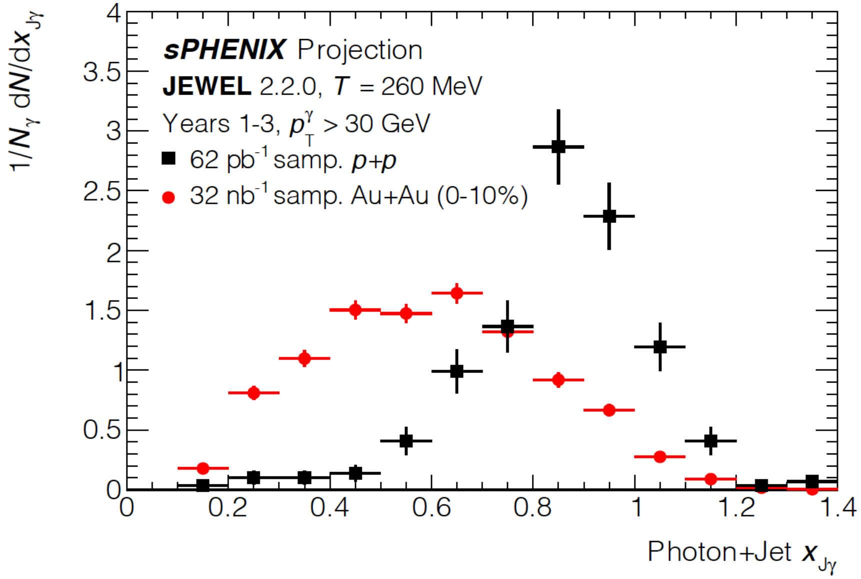
sPHENIX Probes : Jet Correlations and Substructure

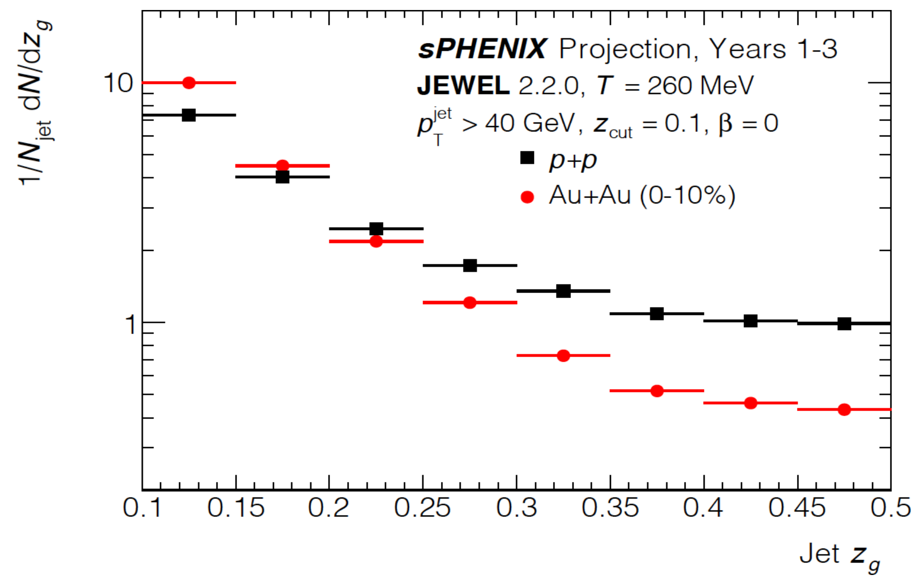




- Statistical projections for the jet-to-photon p_T balance for photons with p_T > 30 GeV
- subjet splitting fraction for jets with p_T > 40 GeV

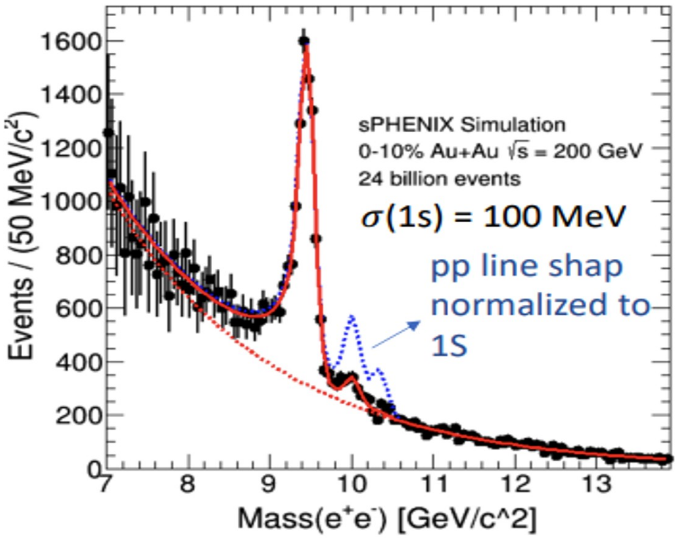
sPHENIX Probes : Jet Correlations and Substructure

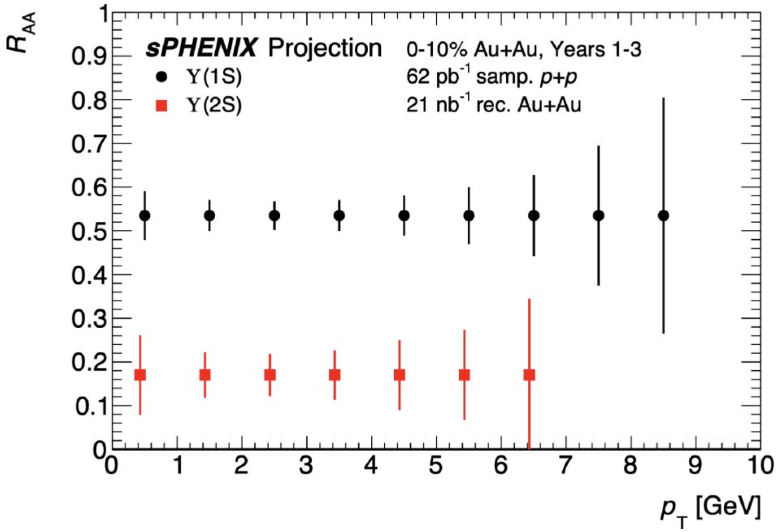




- Large sample of physics objects (above a p_T threshold) will enable the study of jet internal structure and photon+jet correlations
- The large data set allows for highly differential high p_T observables

sPHENIX Probes : Upsilon Spectroscopy

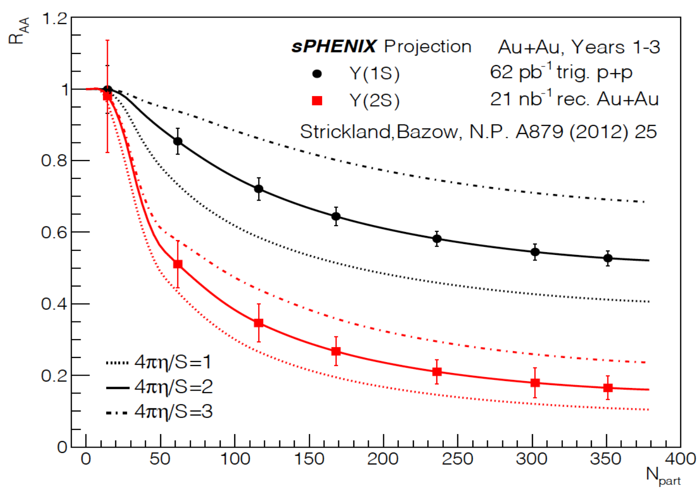


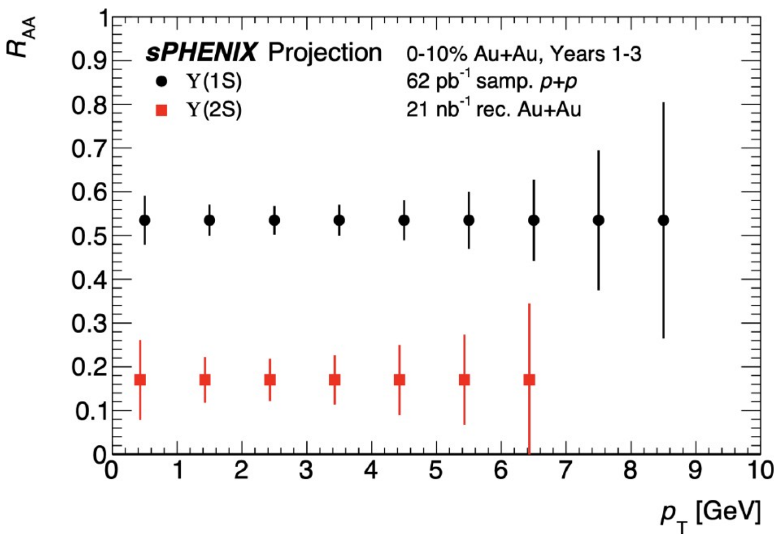


- Dielectron Invariant Mass

- Projected statistical uncertainties for the R_{AA} of the $\Upsilon(1S)$ and $\Upsilon(2S)$ states as a function of p_T

sPHENIX Probes : Upsilon Spectroscopy

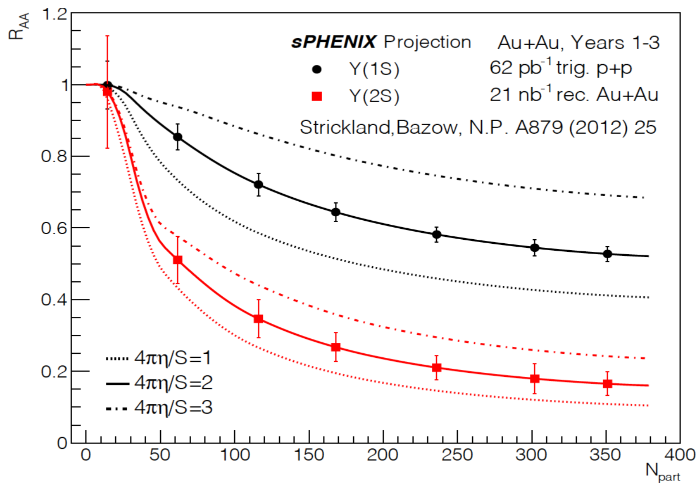


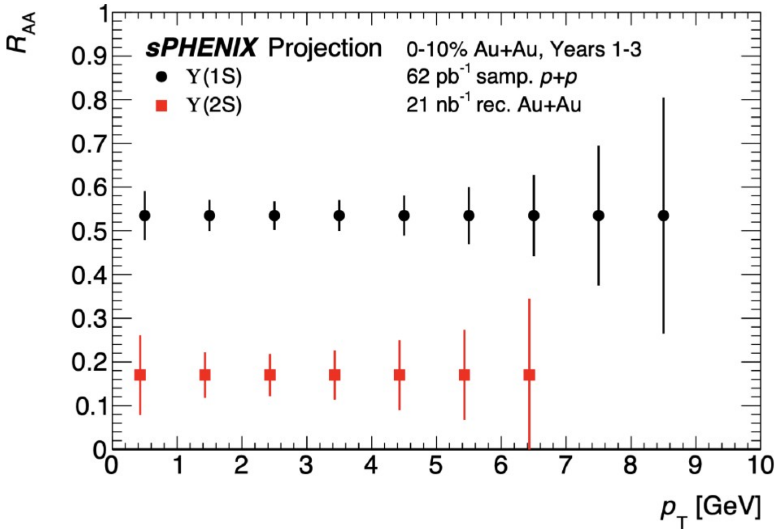


- Projected statistical uncertainties for the R_{AA} of the Υ(1S) and Υ(2S) states as a function of N_{part}

- Projected statistical uncertainties for the R_{AA} of the Υ(1S) and Υ(2S) states as a function of p_T

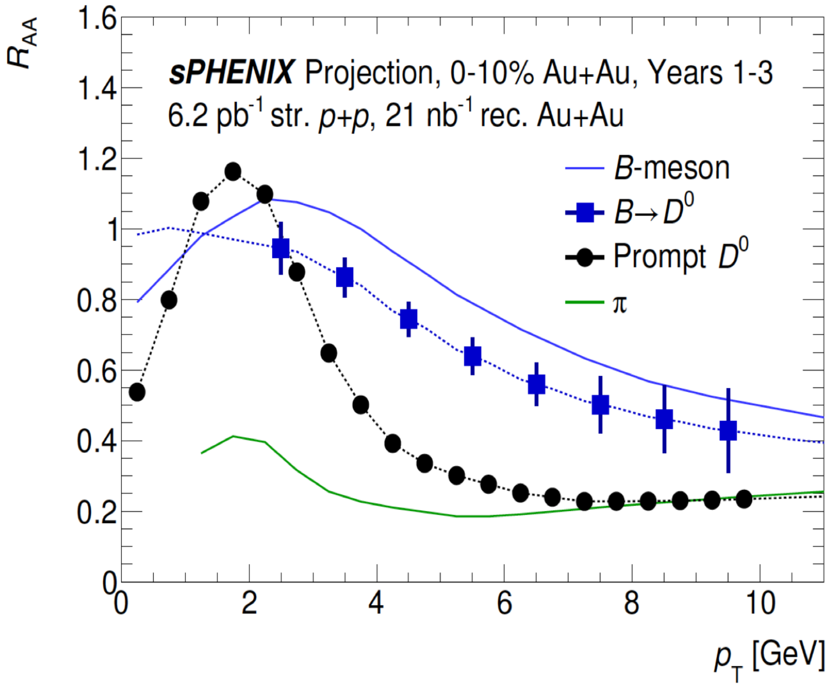
sPHENIX Probes : Upsilon Spectroscopy

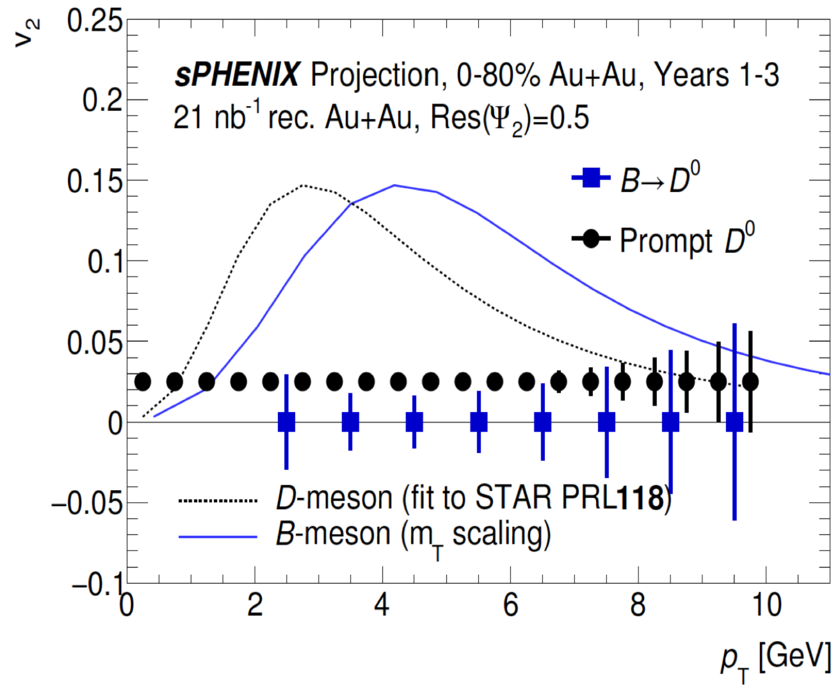




- Clear separation of Υ states allows for comparison between RHIC and LHC measurements
- Crucial measurement, since the temperature profiles from hydrodynamic calculations show important differences with collision energy

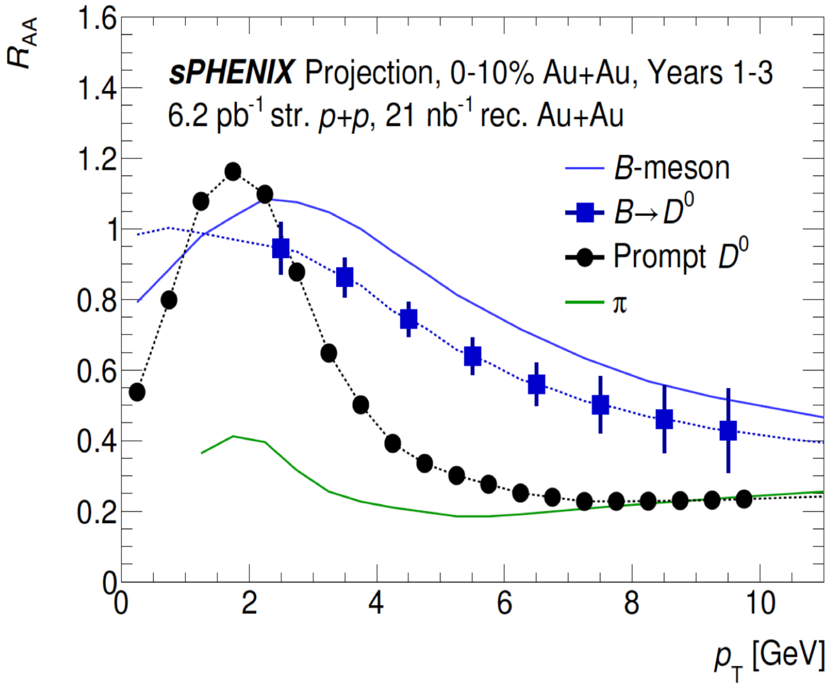
sPHENIX Probes : Open Heavy Flavor

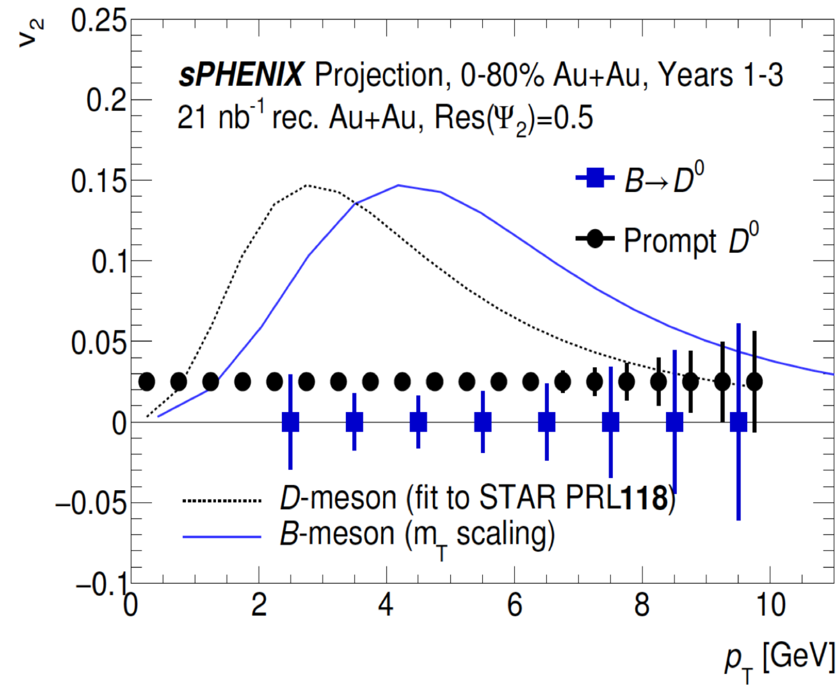




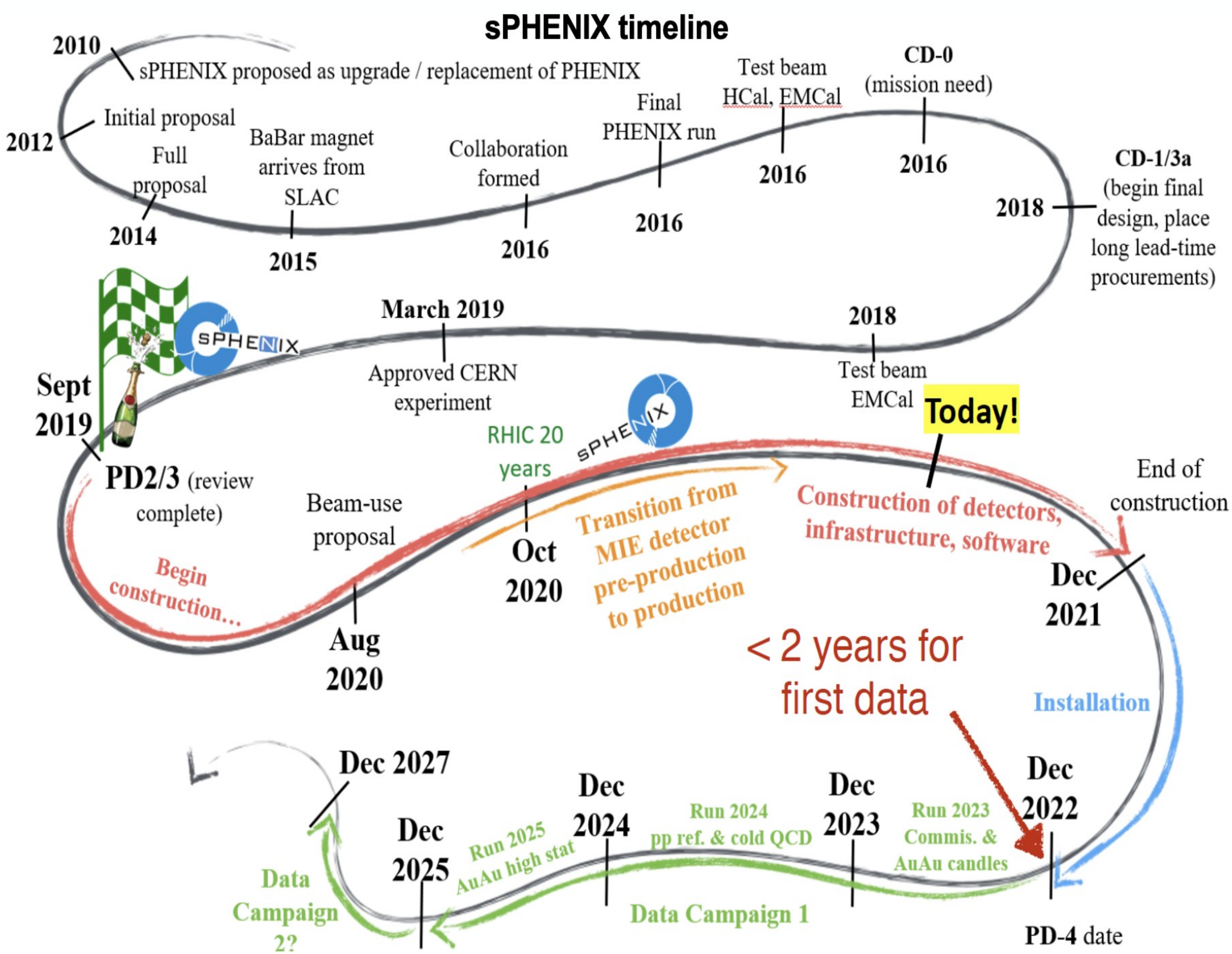
- Projected statistical uncertainties for R_{AA} of non-prompt and prompt Do as a function of p_T in 0-10% central Au+Au collision
- Projected statistical uncertainties for v_2 of non-prompt and prompt Do as a function of p_T in 0-10% central Au+Au collision

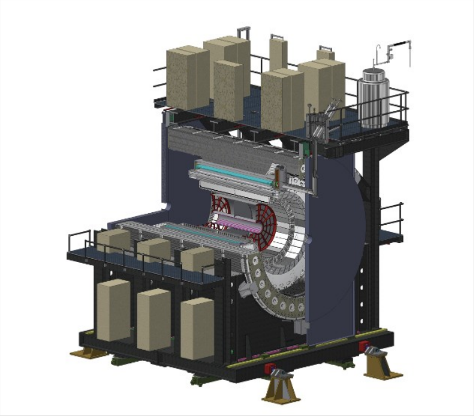
sPHENIX Probes : Open Heavy Flavor





- Large data rate will provide high precision measurement and will allow for studies of mass-dependent energy loss and collectivity in the quark-gluon plasma


sPHENIX timeline
2010
sPHENIX proposed as upgrade / replacement of PHENIX
2012
Initial proposal
Full proposal
2014
BaBar magnet arrives from SLAC
2015
Collaboration formed
2016
Final PHENIX run
2016
Test beam HCal, EMCal
2016
CD-0 (mission need)
2016
2018
CD-1/3a (begin final design, place long lead-time procurements)
2018
Test beam EMCal
March 2019
Approved CERN experiment
Sept 2019
PD2/3 (review complete)
Begin construction…
Beam-use proposal
Aug 2020
RHIC 20 years
Oct 2020
Transition from MIE detector pre-production to production
Today!
Construction of detectors, infrastructure, software
End of construction
Dec 2021
< 2 years for first data
Installation
Dec 2022
PD-4 date
Run 2023 Commis. & AuAu candles
Dec 2023
Run 2024 pp ref. & cold QCD
Dec 2024
Data Campaign 1
Run 2025 AuAu high stat
Dec 2025
Dec 2027
Data Campaign 2?



Detector Construction Update

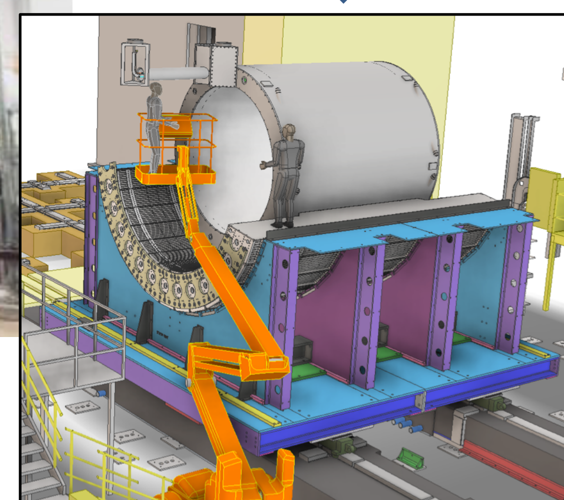
sPHENIX Construction : OHCal

Last week progress:
- Sectors 1-13 are installed
- Next we install the Magnet.

Significant contribution of Uniplast company producing Hadronic Calorimeter Scintillating Tiles

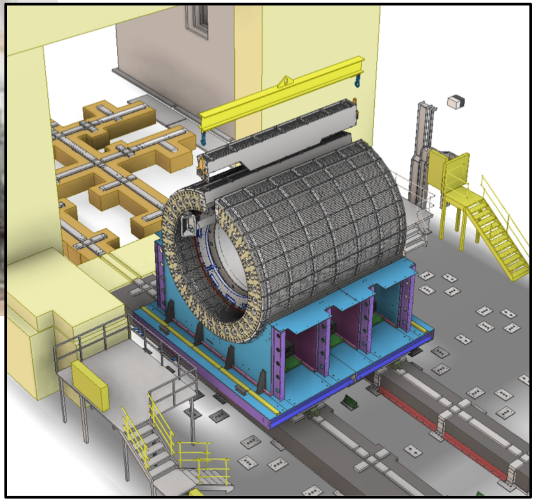
sPHENIX Construction: Magnet

Installation on the carriage/cradle in the upcoming weeks



sPHENIX Construction: Magnet

Then oHCal barrel around the magnet will be completed



sPHENIX Construction : iHCal

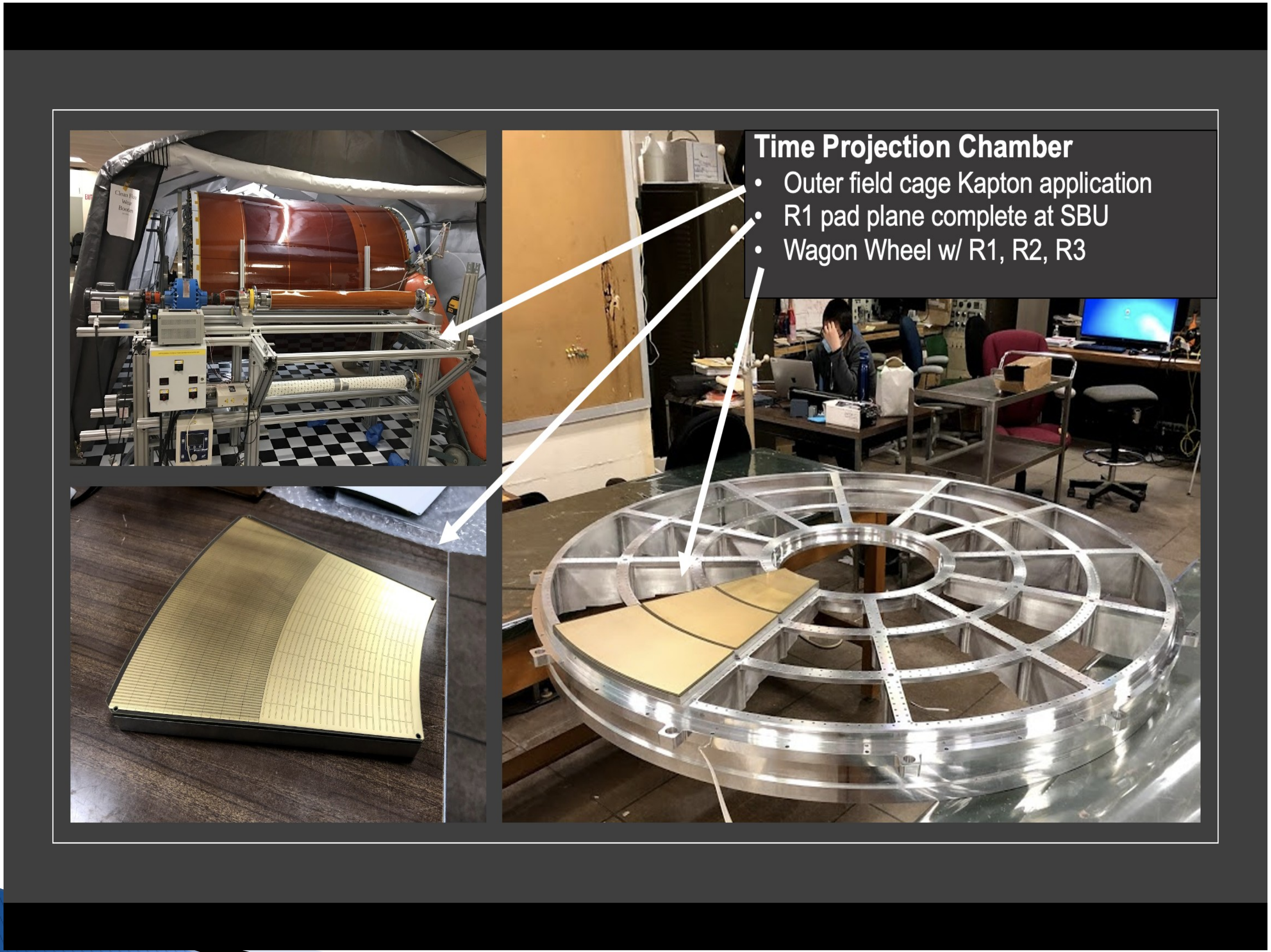
- iHCal sectors at TSI in Ames Iowa
- Last 8 Sectors ship to BNL this week, tiles already at BNL

sPHENIX Construction: EMCAL

Assembly at BNL is ongoing and over 50% complete

Testing is ongoing

sPHENIX Construction: TPC



sPHENIX:
Construction complete by end of the year

1st sPHENIX component Installed in sPHENIX Hall, 5/27/21

Then commissioning starts!

Summary

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  - High rate, large acceptance, precision tracking and dedicated EM and hadronic calorimeter systems

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  - Jet correlations & substructure, open heavy flavor, Y spectroscopy, at unprecedented kinematic range at RHIC

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- sPHENIX aims to meet science mission goal of :
  - Probing the microscopic nature of the quark-gluon plasma

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  - Probing the microscopic nature of the quark-gluon plasma

First data taking begins in 2 years!