Quarkonium in sPHENIX

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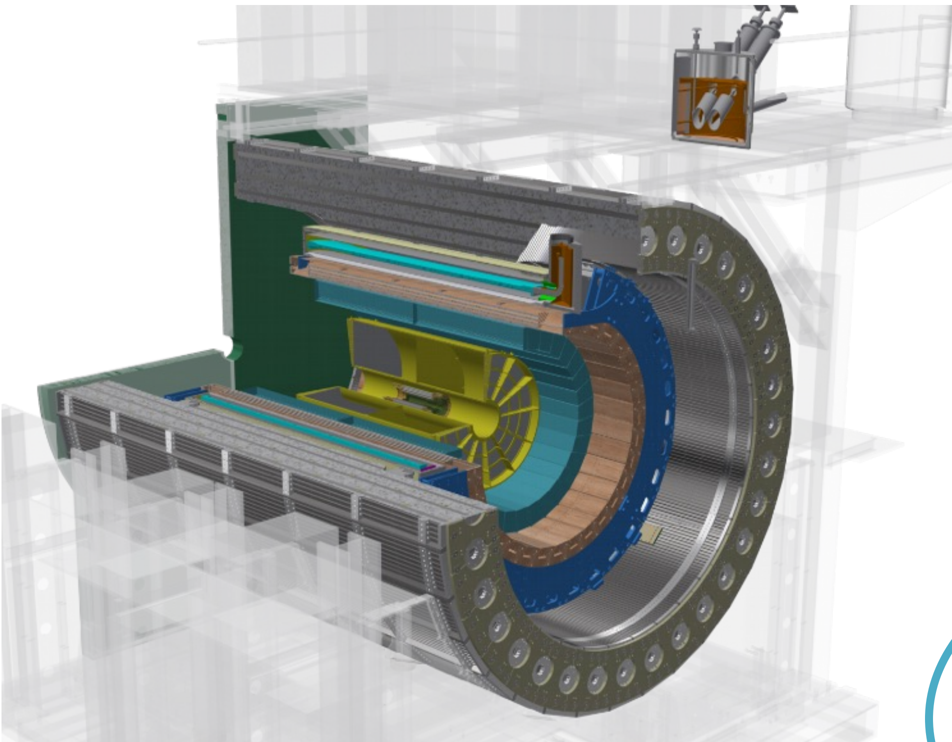
sPHENIX Physics Program

sPHENIX goal is to probe the QGP near 1-2 T_c and over a broad ranges of scales in the region of strongest coupling



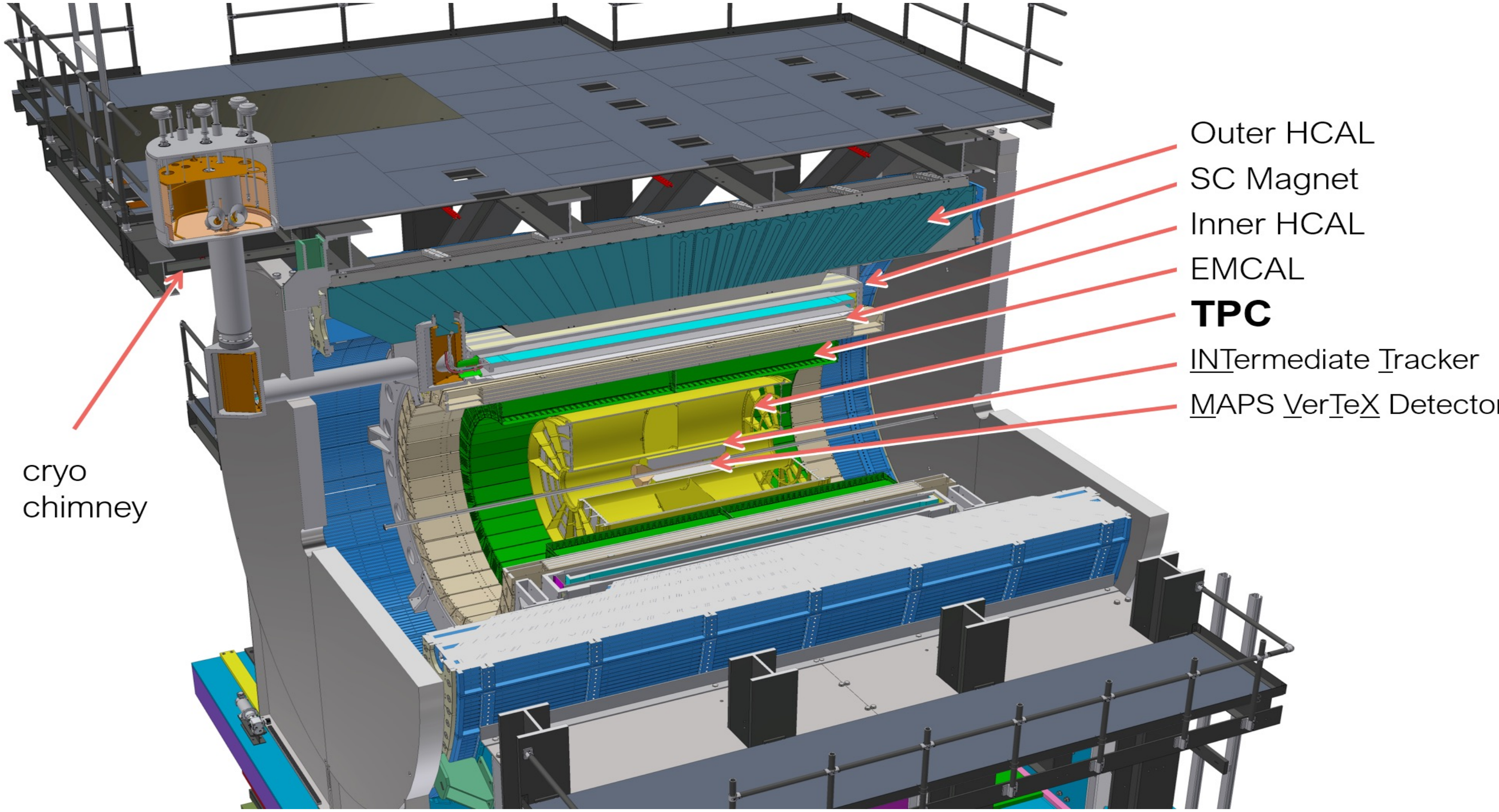
- Jet inclusive spectra
- γ-jet correlations
- Heavy flavor jets &hadrons
- Separated Υ(1S), Υ(2S), Υ(3S) suppression

In this talk

sPHENIX Concept

- Uniform Acceptance $|\eta|<1$ $\Delta\phi=2\pi$
- Superconducting magnet enabling high resolution tracking
- Compact electromagnetic calorimeter to allow fine segmentation at a small radius
- High data acquisition rate capability
- Hadronic calorimeter doubling as flux return

sPHENIX Detector



$-1.1 < \eta < 1.1$
2π azimuthal coverage

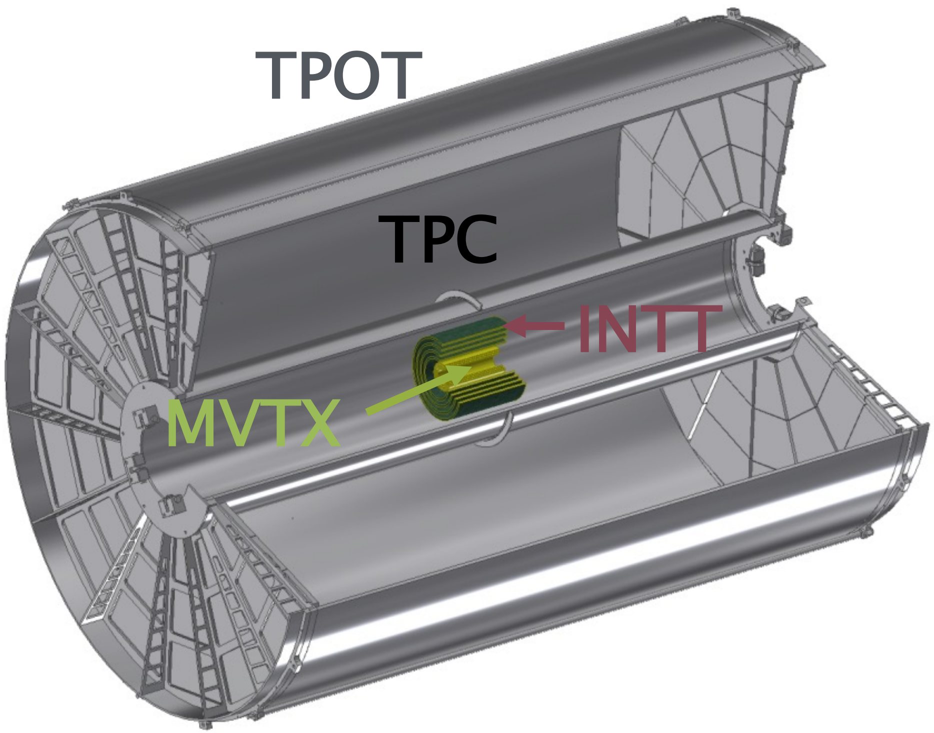
15 kHz MB trigger

Solenoidal magnetic field
B = 1.4 T

sPHENIX Tracking Detectors

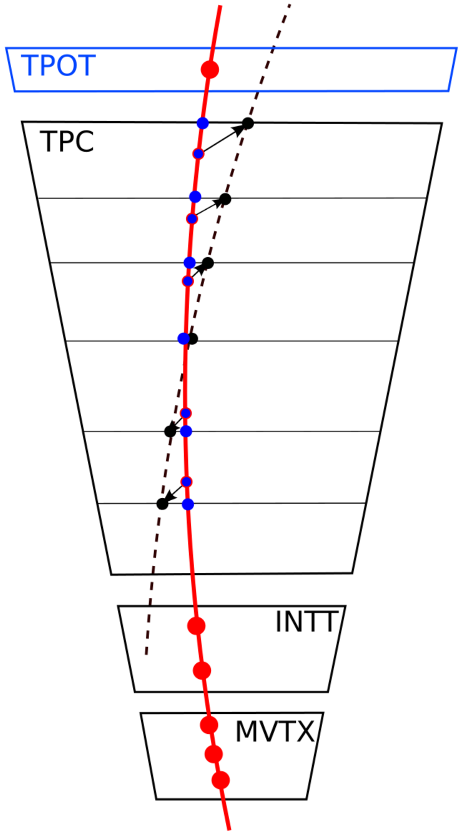
Tracking currently consists of 4 sub-detectors; Pixel Vertex Detector (MVTX), Intermediate Silicon Tracker (INTT), Time Projection Chamber (TPC) and Time Projection Outer Tracker (TPOT)

- **MVTX** - precise track vertex
- **INTT** - timing & pattern recognition
- **TPC** - momentum measurement
- **TPOT** - calibration



sPHENIX Momentum Reconstruction

- TPC
  - Compact - 48 layers (30-78cm radius)
  - Gateless, continuous readout
  - Quad GEM electron multiplier + chevron readout pads
  - R-ϕ resolution ~ 150 μm
  - Δp/p~1% at 5 GeV/c
- TPOT
  - Uses micromegas for detection
  - Allows calibration of beam-induced space charge distortions



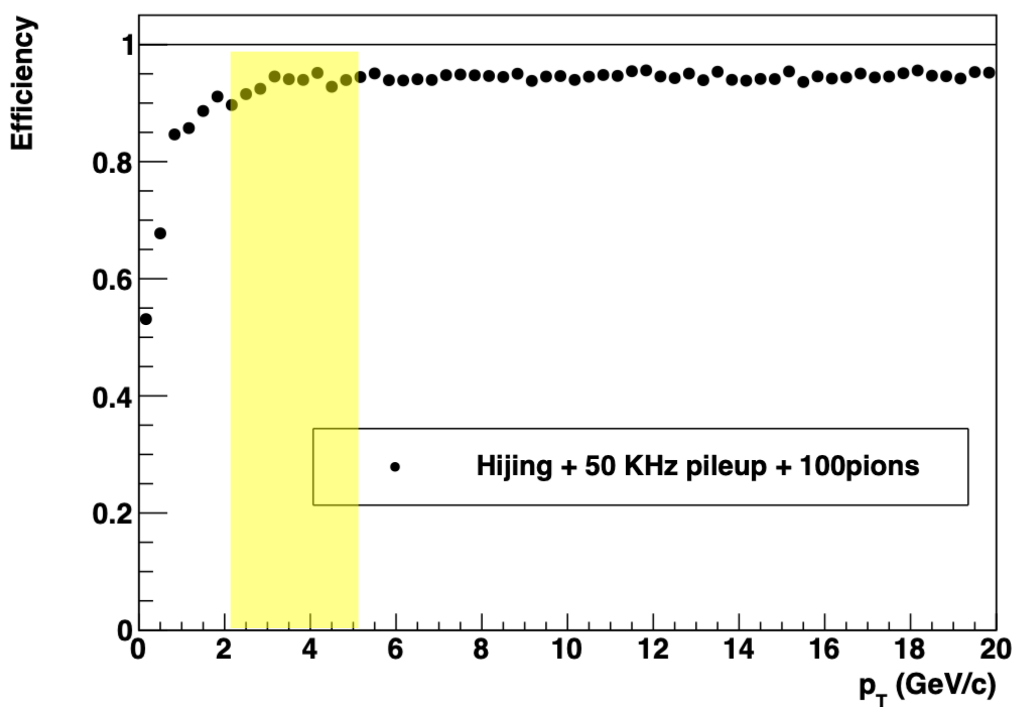
⇨ momentum resolution of 100 MeV or better even in central collisions

sPHENIX Tracking

- Track finding in the TPC and silicon detectors is done separately.
- Track stubs are matched in η, ϕ, position at the beam-line.
- Multiple matches are resolved later, using fit quality
- The reconstruction software goal: reconstruct Au+Au event in 10 seconds per event, including all calibrations.
- We have adopted the ACTS tracking package and final track fitting is done using ACTS Kalman Filter

sPHENIX Tracking Performance

- Simulated performance for minimum bias Hijing events with 50 KHz pileup rate + embedded 100 pions embedded 100 pions.



Y decay electrons region: efficiency ~94%

sPHENIX Tracking Performance

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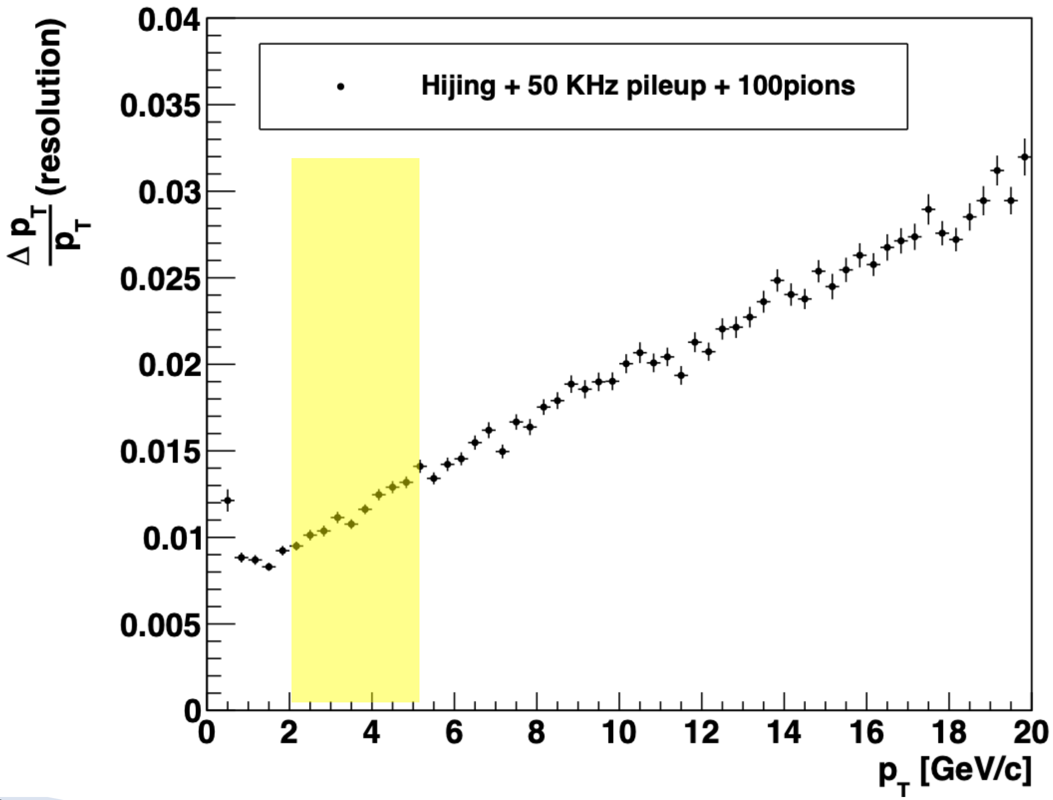
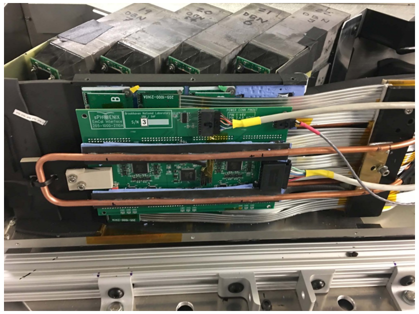


Y decay electrons region: resolution ~1.2%

Electromagnetic Calorimeter



- Tungsten-scintillating fiber sampling calorimeter. 18 X_0, 1 λ
- $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- Read out by silicon photomultipliers
- 2D projective geometry
- Small Moliere Radius, short radiation length

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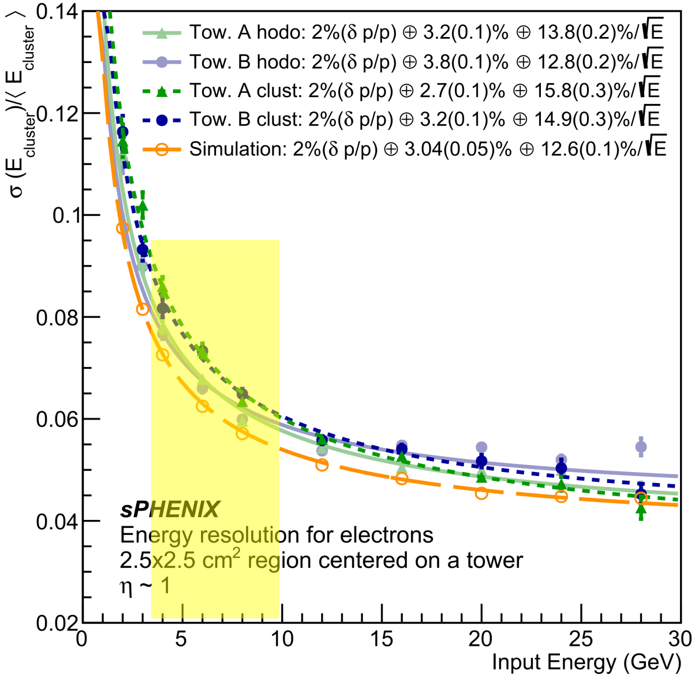
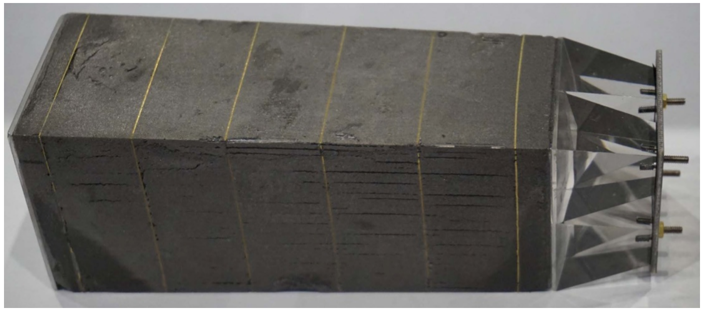
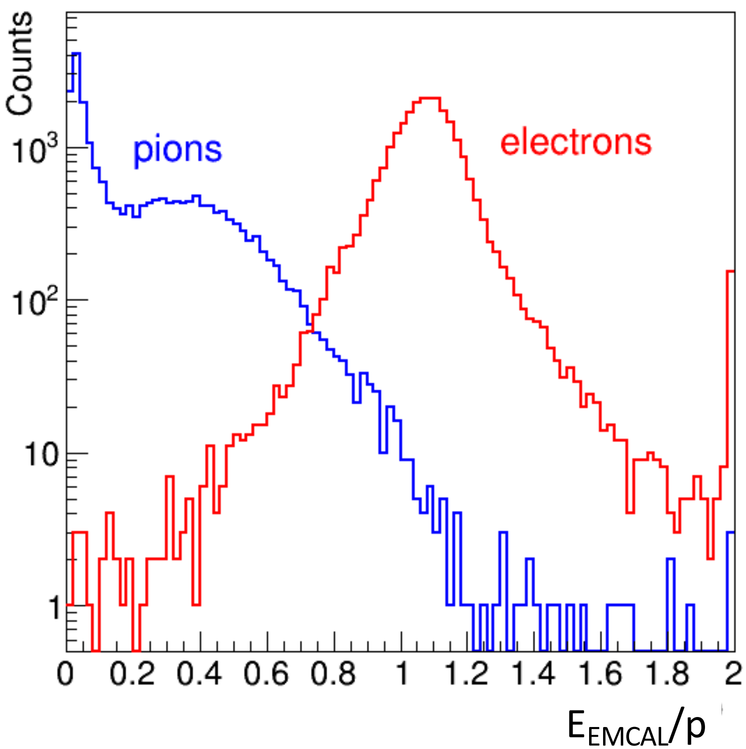


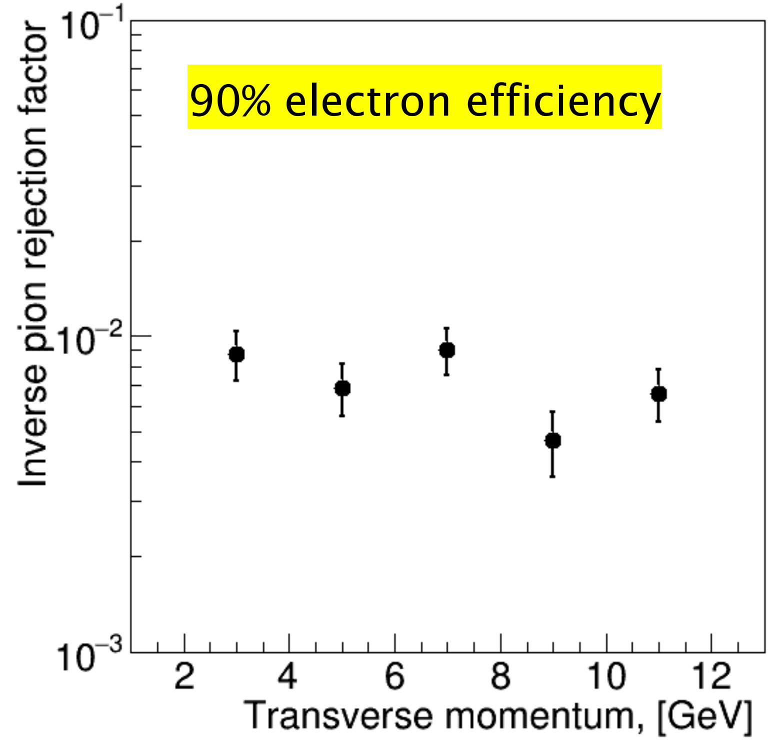


EMCAL block equipped with light guides and SiPMs

Electron/Pion Separation in EmCal

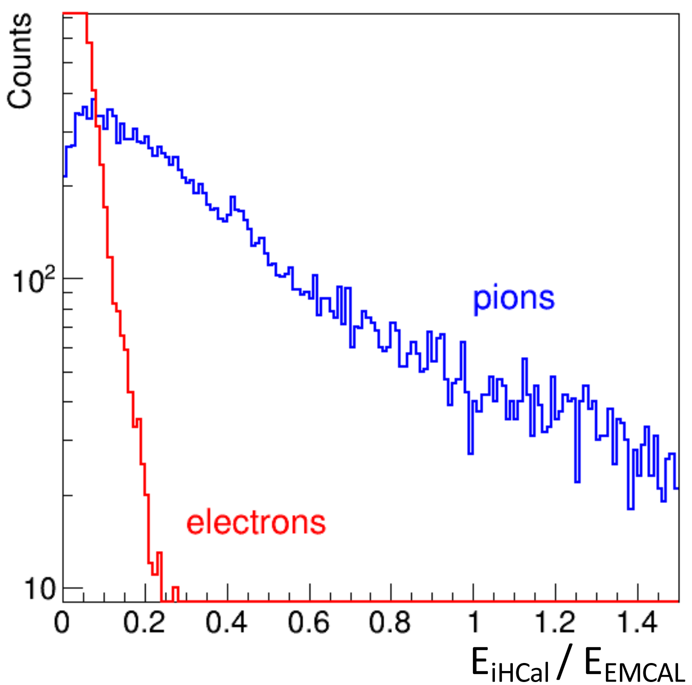
- Electrons/pions embedded in Min. Bias Au+Au Hijing events
- Electrons deposit most of the energy in EmCal (red) while pions (blue) only start showering in the inner HCal

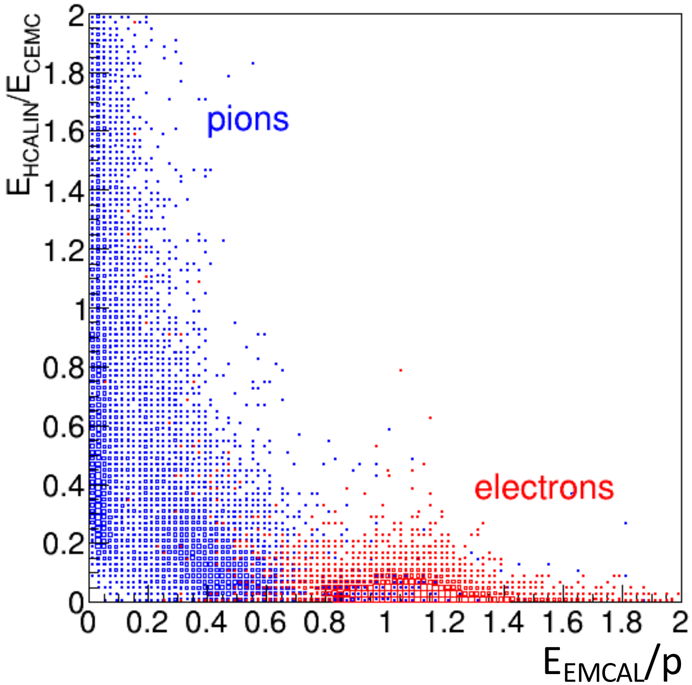




Electron/Pion Separation in iHCal

- Electrons deposit most of the energy in EmCal and little deposited in iHCal (red) while pions (blue) start to shower in the iHCal



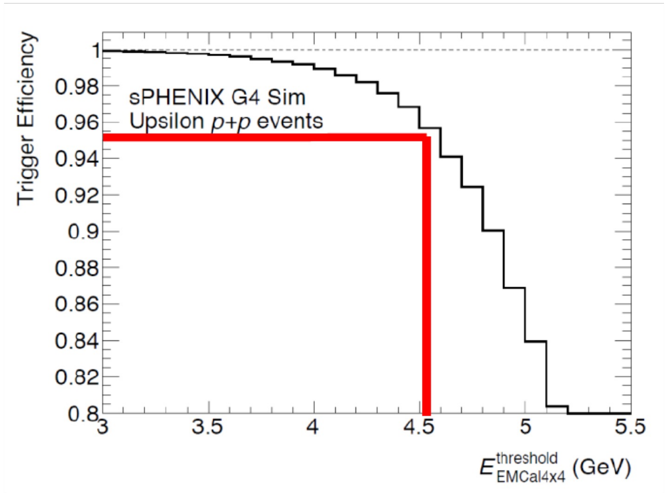


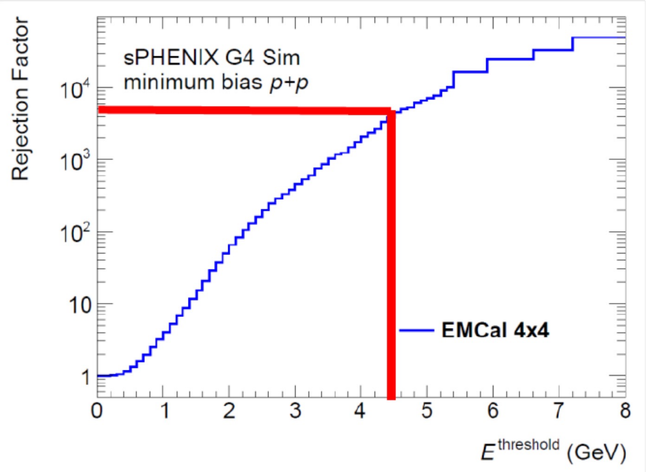
- iHCal provides good rejection power, but overlaps with E/p rejection in EMCal, sophisticated multi-variable analysis study ongoing

Trigger strategy

- The sPHENIX DAQ will record data at 15 KHZ.
  - Au+Au data will be recorded using minimum bias triggers.
  - p+p and p+Au data will be recorded using level 1 triggers.
    - The Υ trigger will be an EMCal trigger based on the energy of the electrons and also pair invariant mass cut.

- Single cluster trigger efficiency and rejection in p+p simulations.





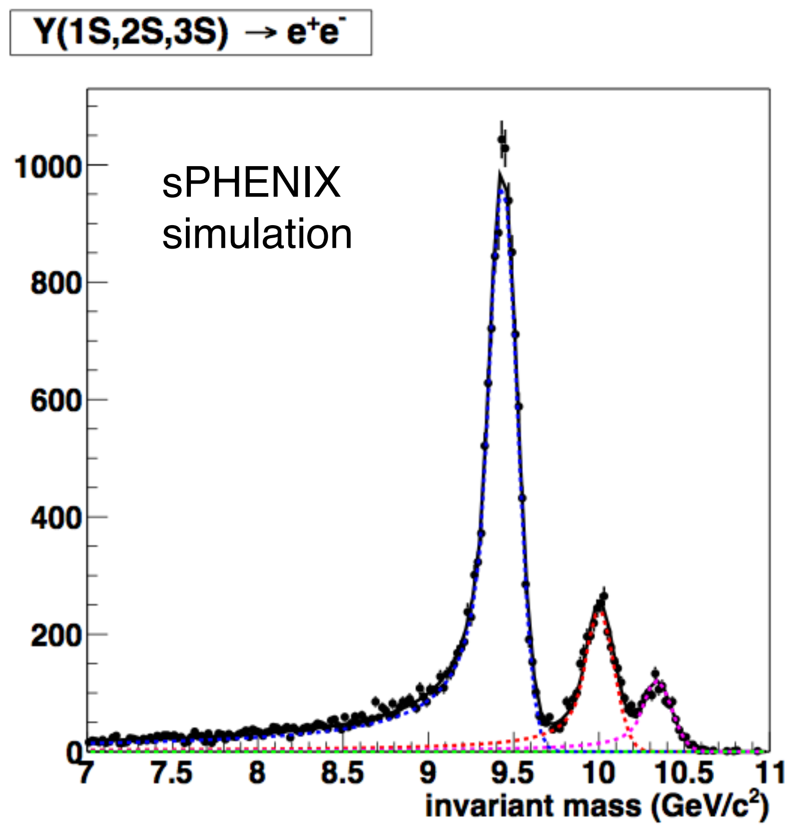
Upsilon Observables

- The observable we plan to measure Υ(1S), Υ(2S), Υ(3S) R_{AA} as a function of collision centrality and p_T.

- Signal statistical precision that translates directly into Υ(1S), Υ(2S), Υ(3S) R_{AA} and depends on
  - ✓PID efficiency
  - ✓Tracking efficiency and momentum resolution
  - ✓Combinatorial and Correlated Backgrounds (semileptonic decays of b,c hadrons and Drell Yan)

Υ Measurement in p+p Collisions

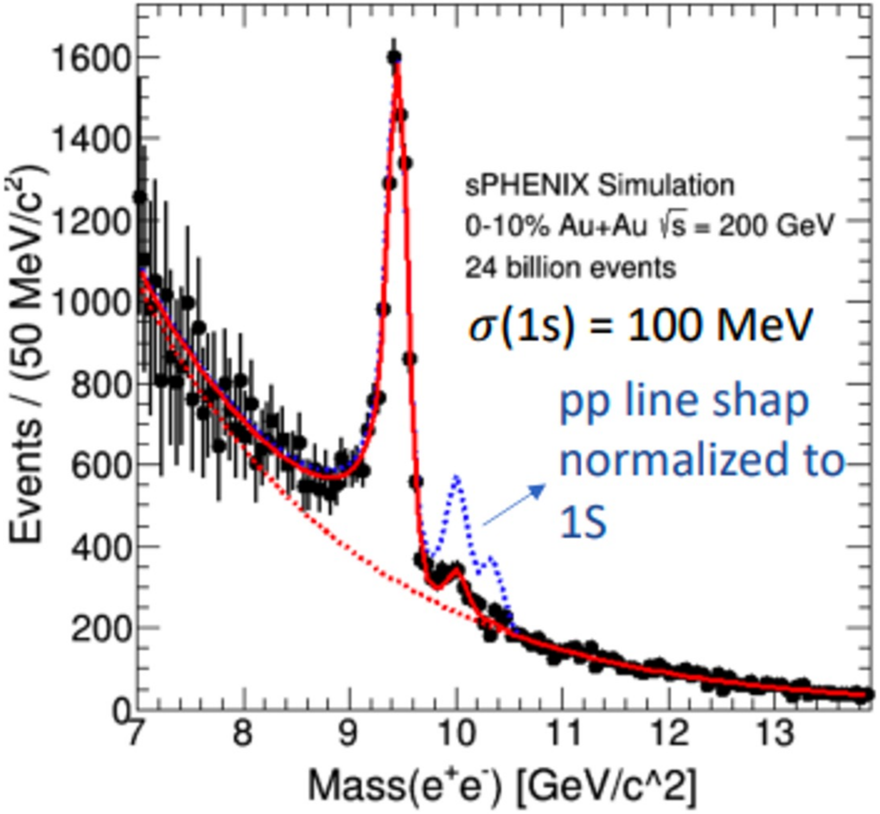
- Opposite sign e^+e^- invariant mass, signal only



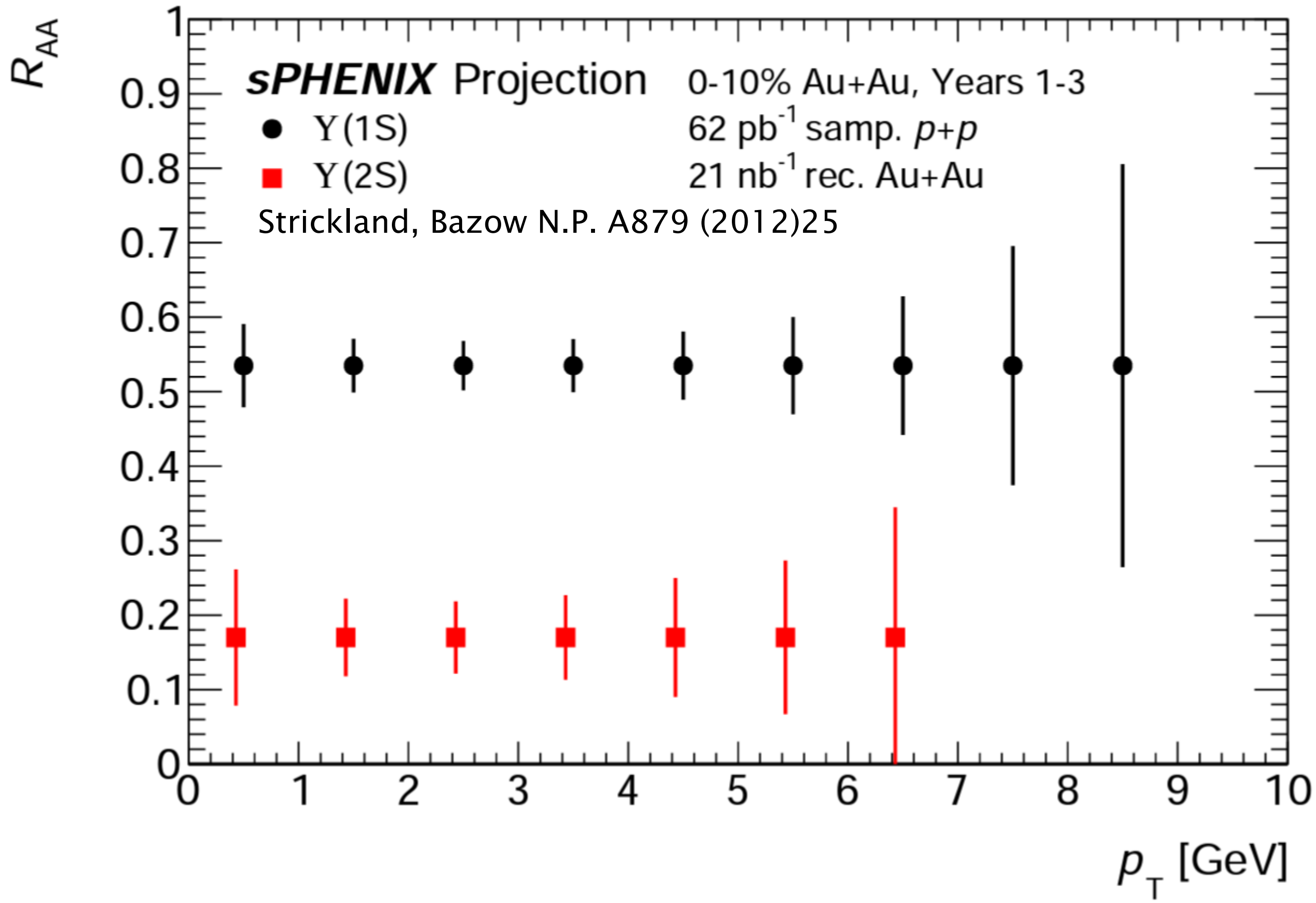
Υ Measurement in AuAu Collisions

Simulated mass spectrum in 0-10% central Au+Au collisions.

- Before like-sign background subtraction.
- Suppression taken from Strickland & Bazow N.P. A879 (2012)25.

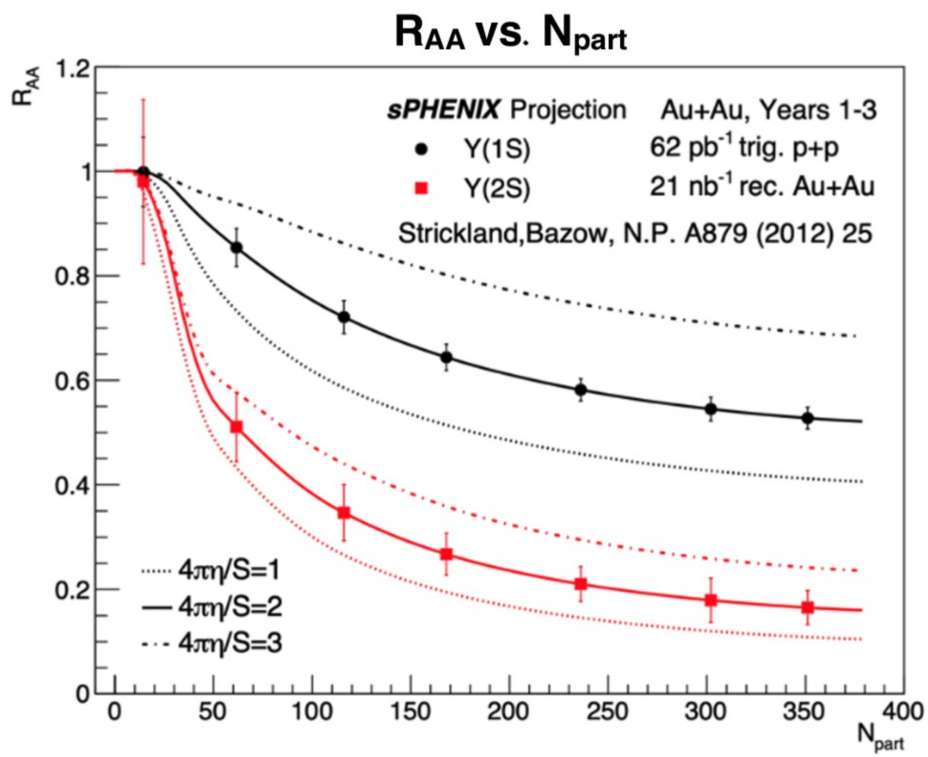


Upsilon R_{AuAu} vs p_T



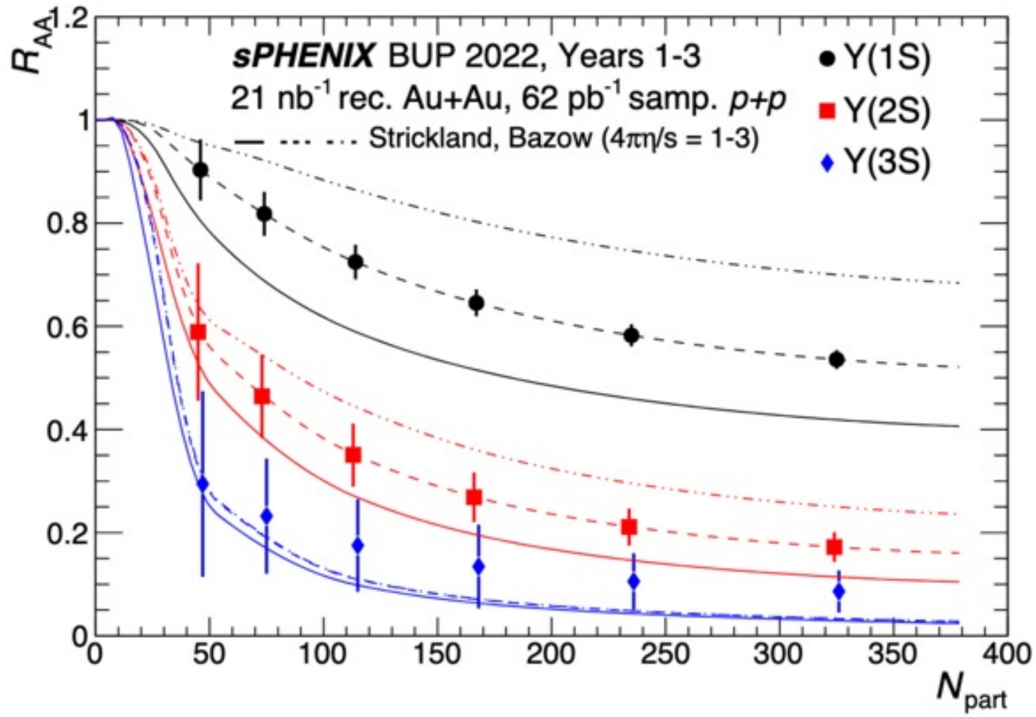
Upsilon R_{AuAu} vs centrality

- Using expected luminosity from Au+Au runs in 2023 and 2025 and p+p run in 2024.
- In the Strickland-Bazow model the Υ(3S) state is so heavily suppressed that it is weaker than the estimated Drell Yan background.



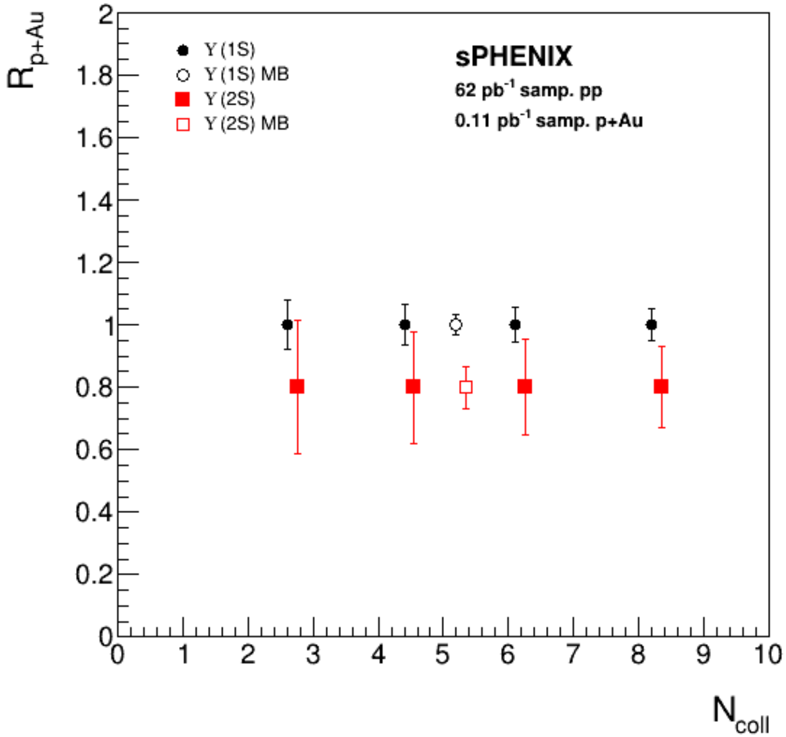
Upsilon R_{AuAu} vs centrality

Recently observed by CMS Υ(3S) suppression < theory prediction: $R_{AA}(3S)/R_{AA}(2S) \sim 0.5$ at the LHC, we can project an observable yield for Υ(3S)



Upsilon R_{pAu} vs centrality

- This measurement serves as a baseline for the Au+Au measurement.
- The modification of the Υ yields in p+Au collisions is a measure of cold nuclear matter effects, not well constrained theoretically.



CNM effects include:

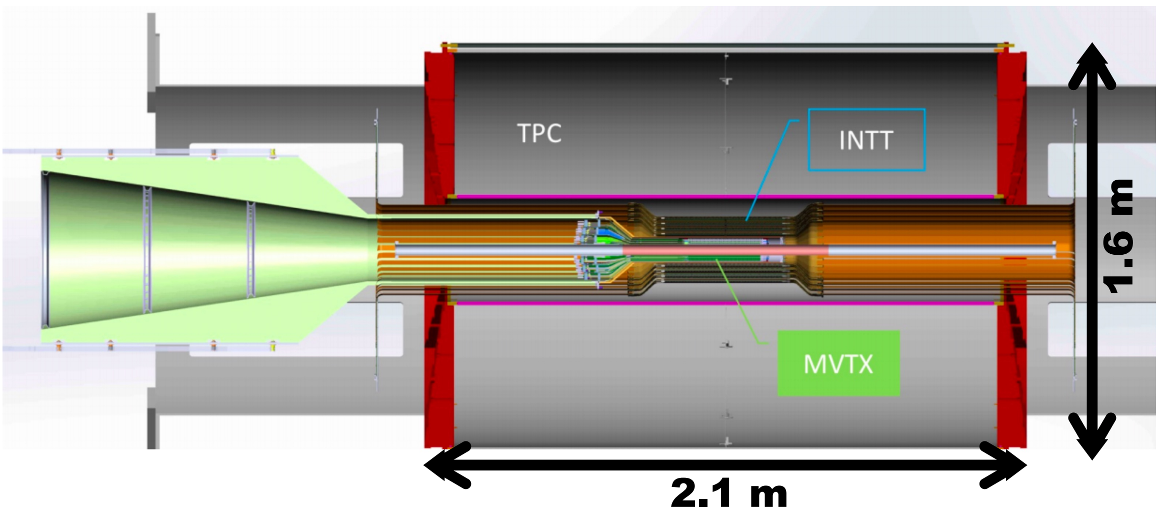
- Gluon shadowing (nPDF's), CGC.
- Initial state parton energy loss
- Nuclear "absorption" i.e. collisions with target nucleons.

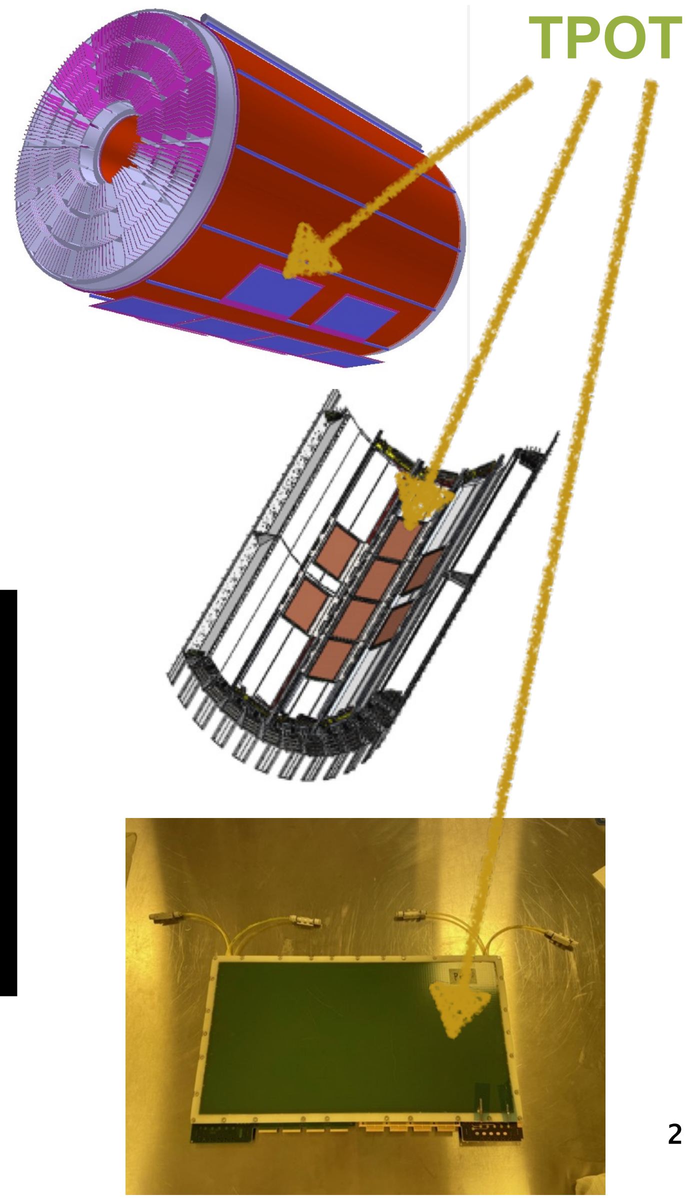
Summary

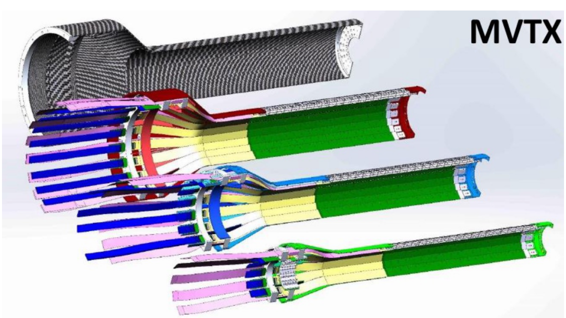
- The goal is for sPHENIX to provide precise measurements of the Υ(1S) and Υ(2S) invariant yields in Au+Au, p+Au and p+p collisions.
- If suppression is smaller than predicted, as at the LHC, we will be able to make the first measurement of the Υ(3S) yield at RHIC
- These measurements will be complementary to measurements by the LHC experiments at higher collision energies.
  - Different initial temperatures.
  - Different underlying bottom production cross sections.
- We are in the process of optimizing the reconstruction and electron identification analysis tools needed for this measurement.
- We will be ready for first beam in February!

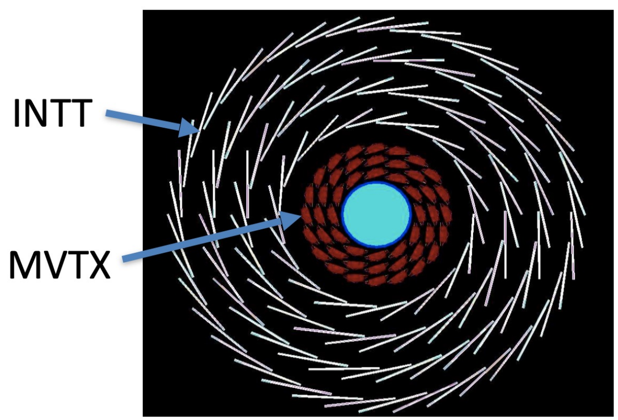
Backup

Tracking System





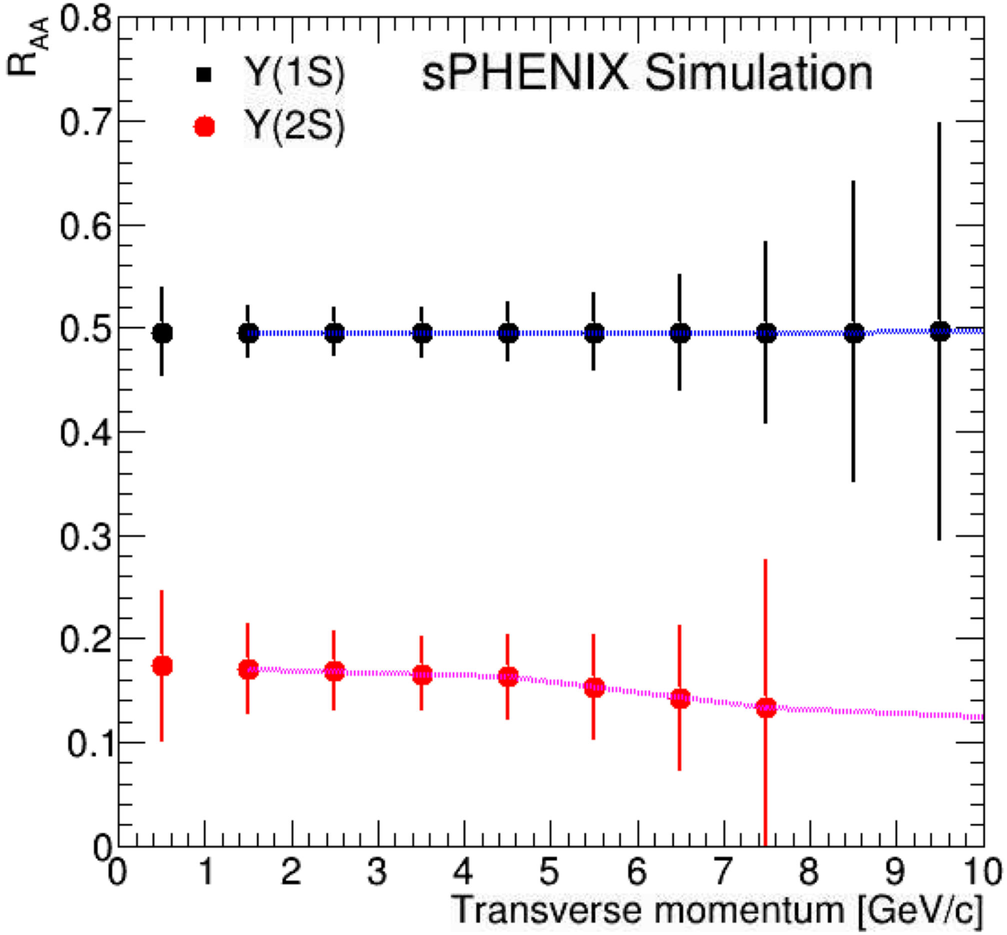




- Tracking system: MVTX + INTT + TPC + TPOT

Other Theory Comparison

See X. Yao, B. Mueller, arXiv:1811.09644



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. $\lvert z\rvert < 10$ 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} [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}

2023: Commissioning high multiplicity Au+Au run

2024: Commissioning p+p
p +p , p +Au : HI reference set and cold QCD

2025: Very large Au+Au heavy-ion set for jet and heavy flavor physics
141 B events recorded in total