PHENIX

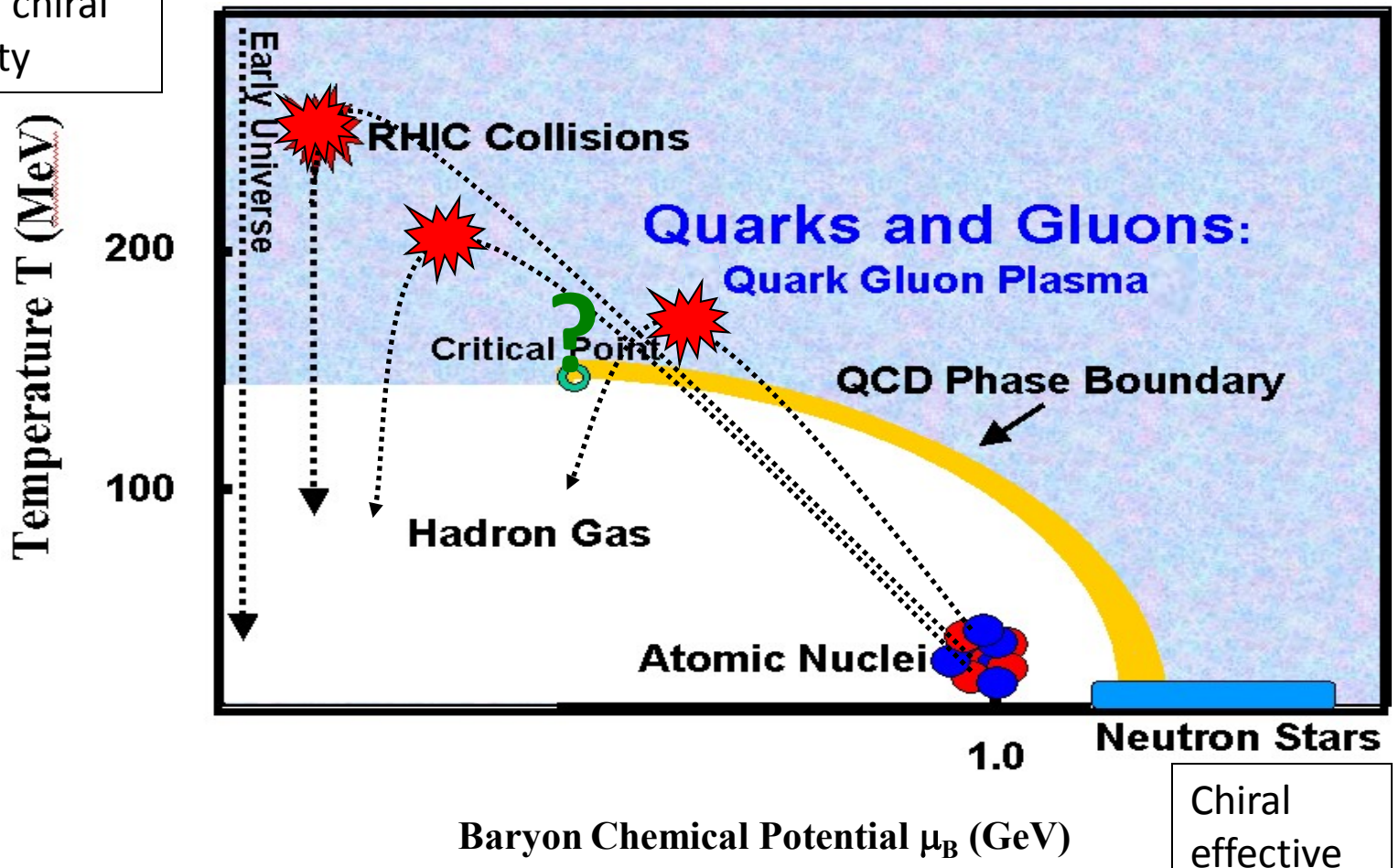
# sPHENIX Participation in the Beam Energy Scan II

## BNL Program Advisory Committee Meeting

## June 12, 2014

# BES Motivation: The CEP

LQCD EoS and behavior of chiral susceptibility




Chiral effective models

- Limited theoretical guidance, need data

# PHENIX and the RHIC BES I

**In the last four years PHENIX has taken Au+Au data at 7 different collision energies**

| RHIC Run | Year | Species | Energy | Ldt sampled |
|---|---|---|---|---|
| Run-10 | 2010 | Au+Au | 7.7 GeV | 260 mbarns-1 |
| Run-14 | 2014 | Au+Au | 14.6 GeV | 2.5 μbarns-1 |
| Run-11 | 2011 | Au+Au | 19.6 GeV | 2.3 μbarns-1 |
| Run-11 | 2011 | Au+Au | 27 GeV | 5.2 μbarns-1 |
| Run-10 | 2010 | Au+Au | 39 GeV | 40 μbarns-1 |
| Run-10 | 2010 | Au+Au | 62.4 GeV | 100 μbarns-1 |
| Run-14 | 2014 | Au+Au | 200 GeV | 2.4 nbarns-1 |

# PHENIX Program in the BES I

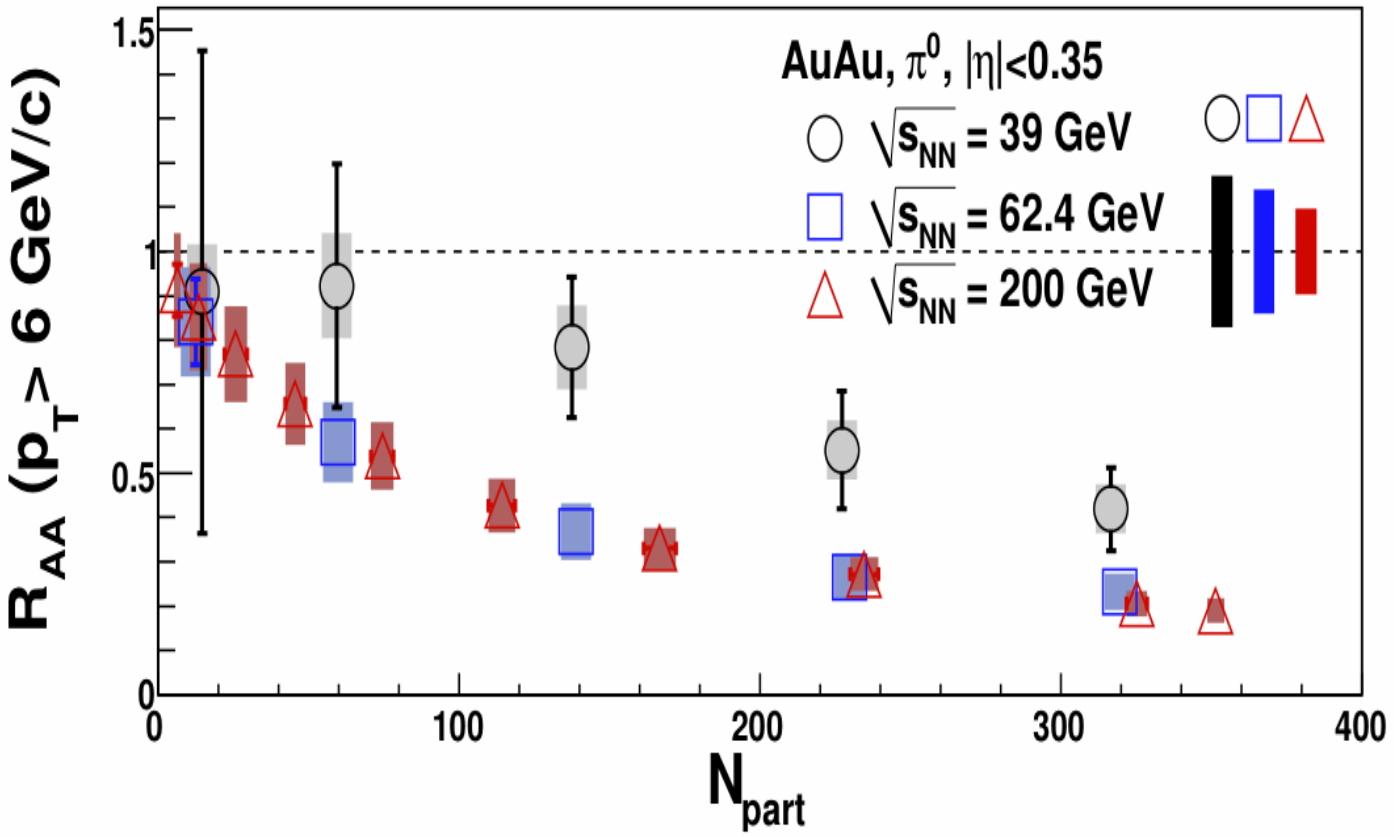
## The RHIC BES Program has been productive for PHENIX

- **Spectra and Nuclear Modification Factors**
- **Global Variables**
- **HBT and Flow**
- **Fluctuations and Analysis of Higher Moments**

# Nuclear Modification Factor

PRL109(2012)152301

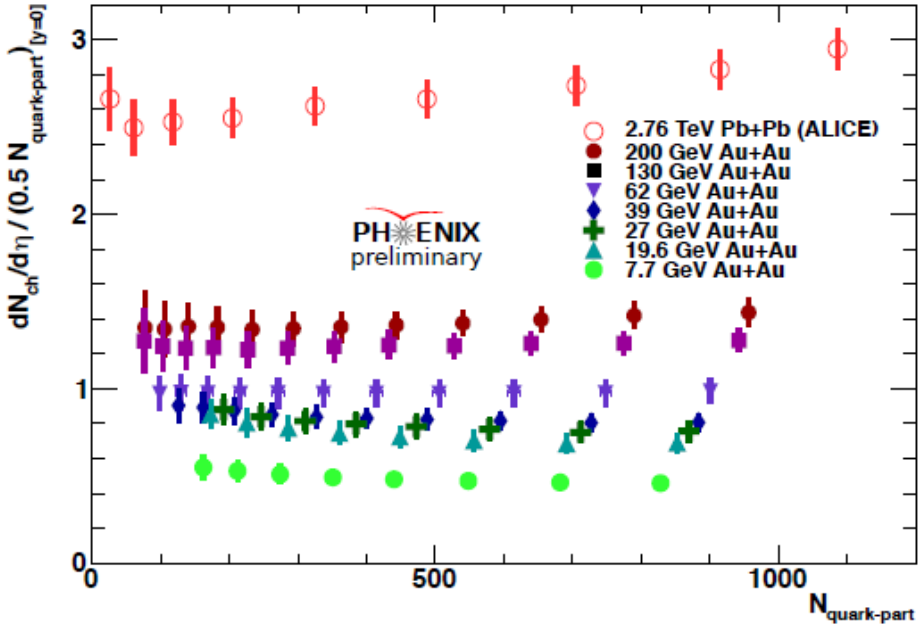
$R_{AA}$ for $\pi^0$

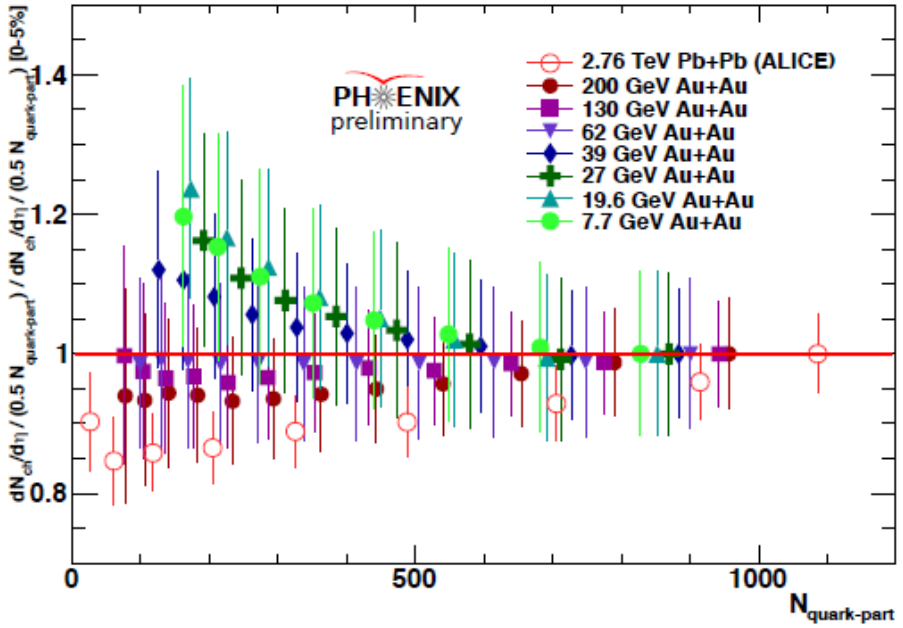



Suppression of $\pi^0$ vs centrality observed down to $\sqrt{s_{NN}}$ = 39 GeV

# Multiplicity (Quark Scaling)

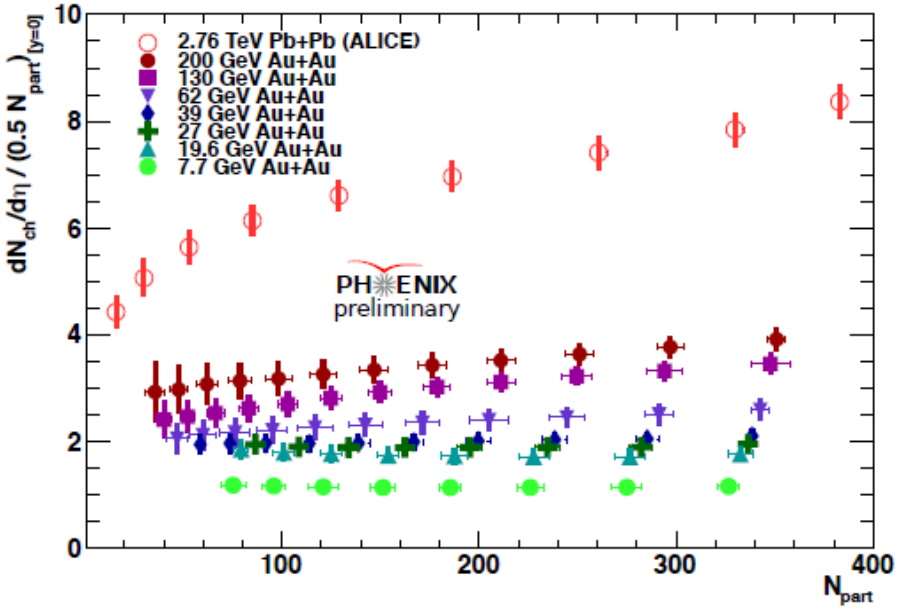
10.1103/PhysRevC.89.044905

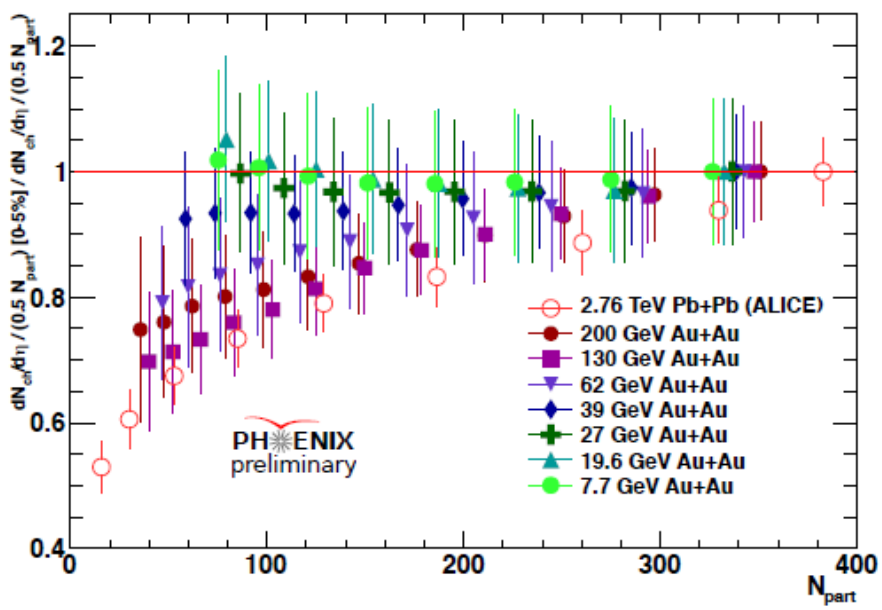



Participant quark scaling works well $\sqrt{s_{NN}}$= 62-200 GeV

# Multiplicity (Nucleon Scaling)



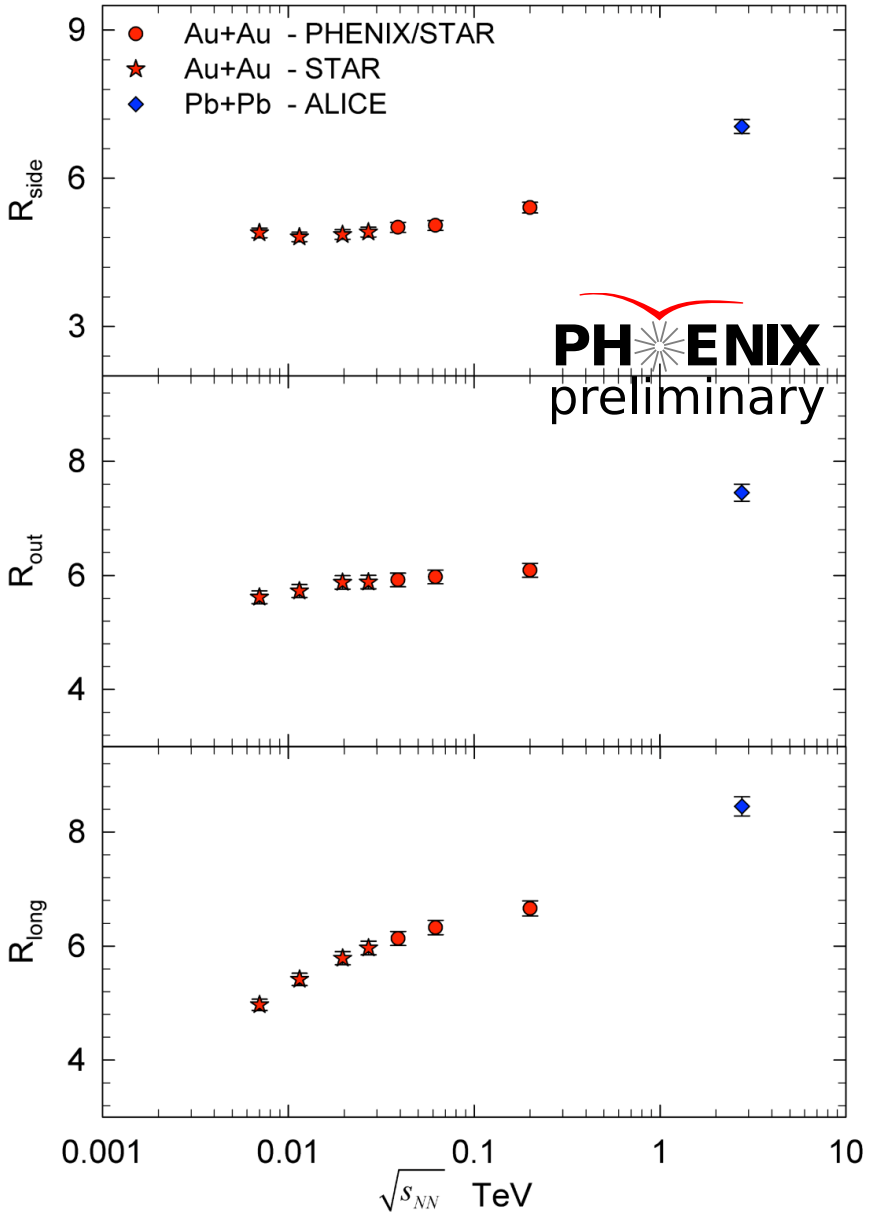




Participant nucleon scaling works well $\sqrt{s_{NN}}$ <= 27 GeV

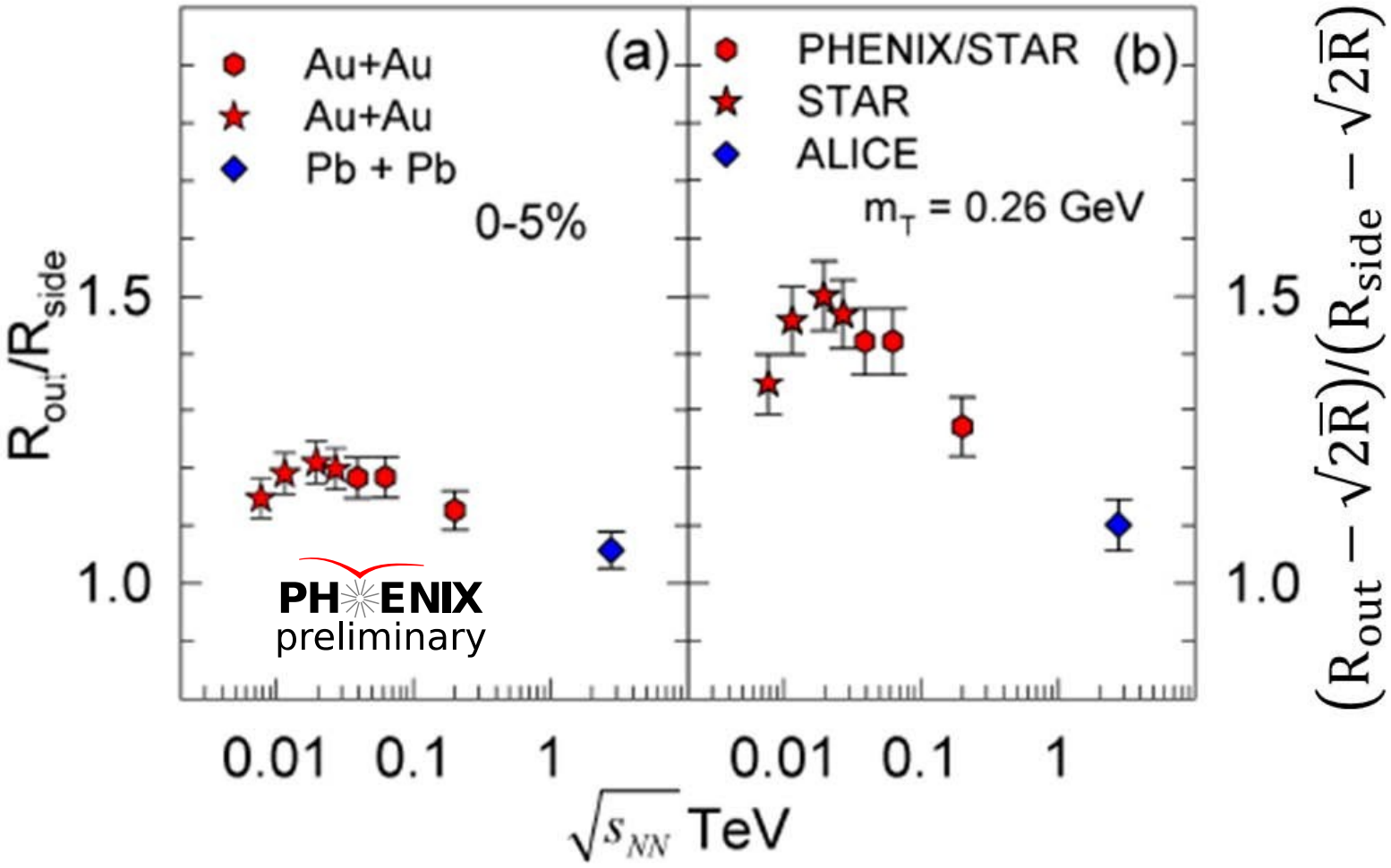
Implications for CEP and associated signatures?

# HBT radii vs. $\sqrt{s_{NN}}$

- PHENIX,STAR,ALICE data
- $m_T$=0.26 GeV interpolations
- $R_{long}$ decreasing with $\sqrt{s_{NN}}$
- $R_{out}$,$R_{long}$ curvature differ from $R_{side}$
- construct ratios and differences

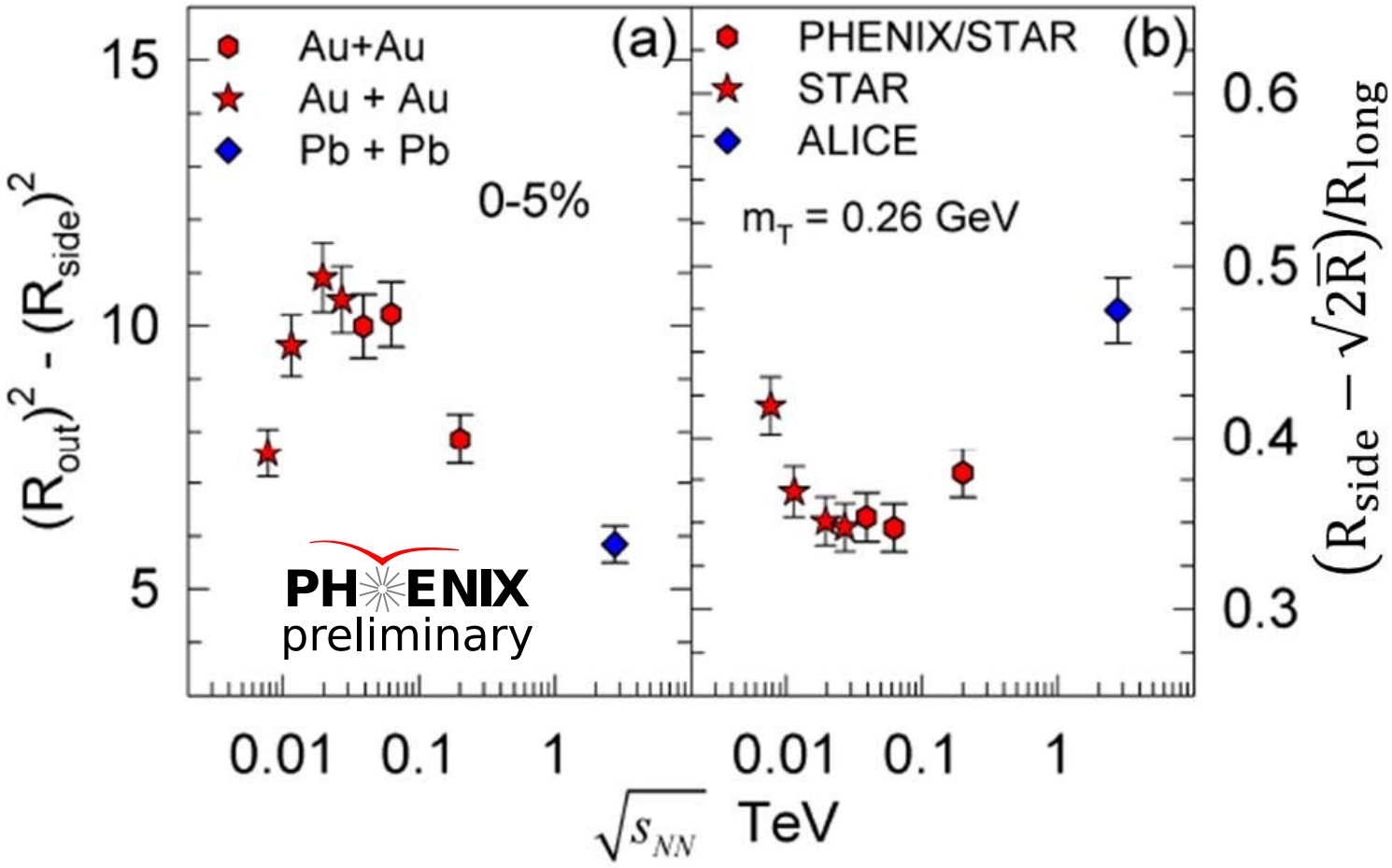


# Measures of emission duration




- Non-monotonicity in $R_{out}/R_{side}$
- Subtract $\sqrt{2}\bar{R}$ to (over) estimate expansion

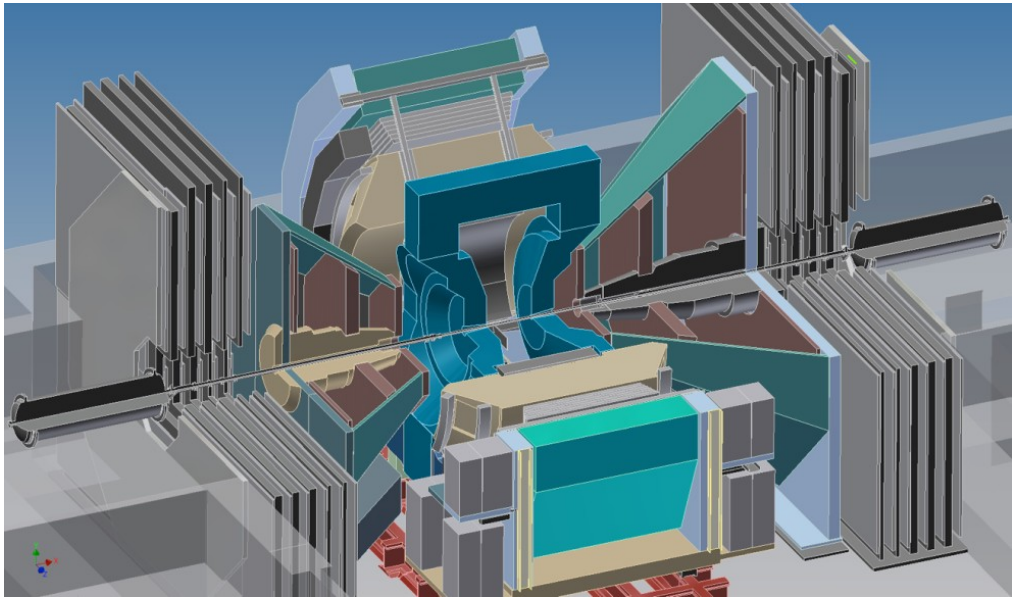
# Emission duration and expansion/lifetime



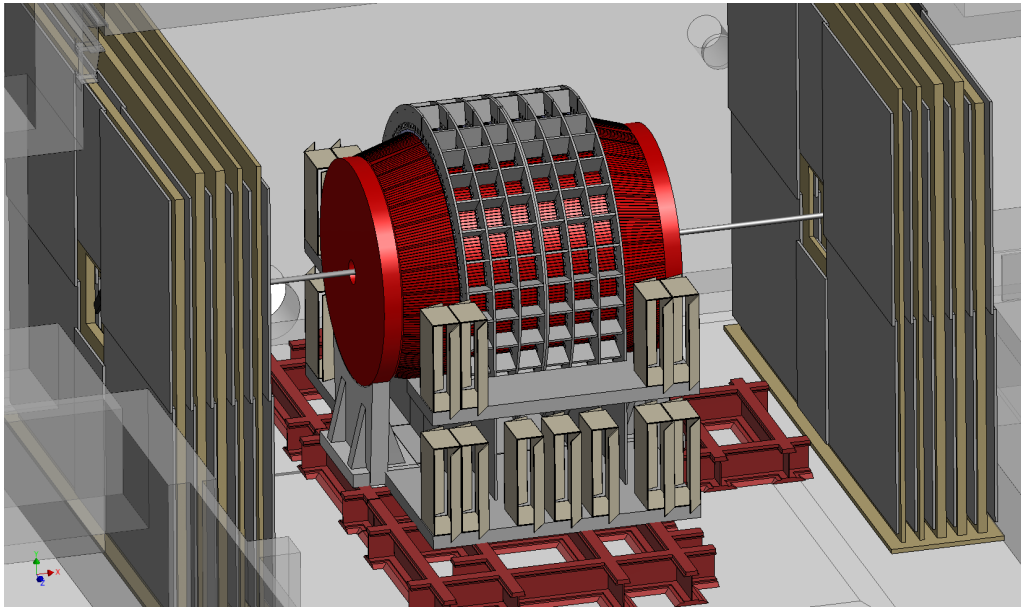

- Non-monotonicity magnified with $(R_{out})^2 - (R_{side})^2$
- $R_{side}/R_{long}$ indicative of expansion/lifetime

**Anticipate a longer emission duration near a first order phase transition**

# PHENIX and sPHENIX



**Available through the end of Run-16 PHENIX 4 arm spectrometer plus the new Muon Piston Calorimeter – Extension preshower detector.**
**$3.1 < |\eta| < 3.8$ for Run-15**

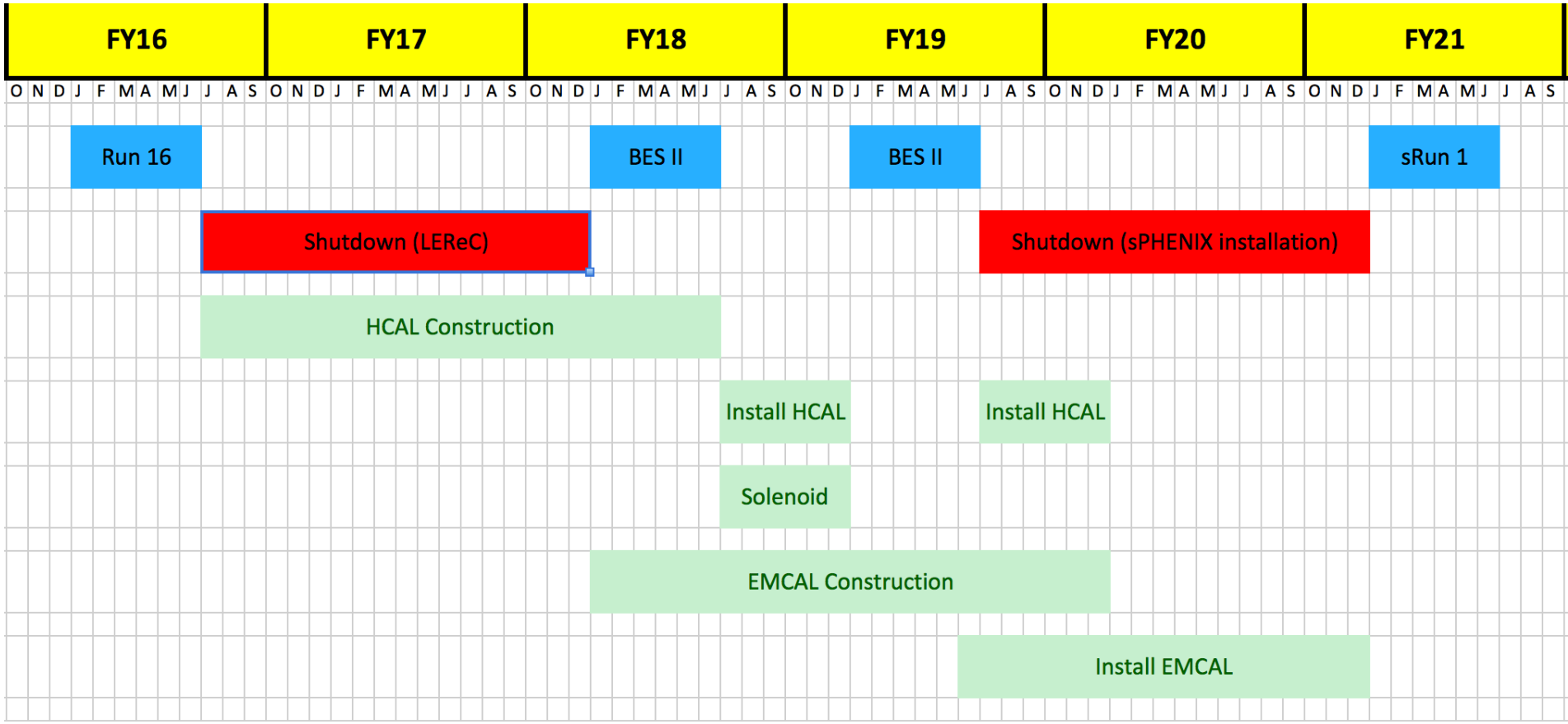


**Available for the RHIC run in 2021 sPHENIX detector including SC-solenoid, HCal, EMCal and 6 layers of Si tracking.**

# PHENIX to sPHENIX Transition 2016-2021

- **Final PHENIX run is RHIC Run-16 ending July 2016**
- **The 18 month period Jul 2016-Jan 2018 will be used for decommissioning and removal of the PHENIX detector followed by the installation of initial components of sPHENIX especially infrastructure**
- **1st BESII running period in 2018 has NO planned sPHENIX participation**
- **Six month shutdown period Jul 2018 - Jan 2019 for installation of SC-solenoid plus outer HCal/flux return**
  - **A partial installation of the EMCal and VTX would allow sPHENIX participation in the 2019 BESII run beyond a system test.**
- **An 18 month period Jul 2019-Jan 2021 to complete sPHENIX installation and prepare for the RHIC 2021 run**

# sPHENIX schedule

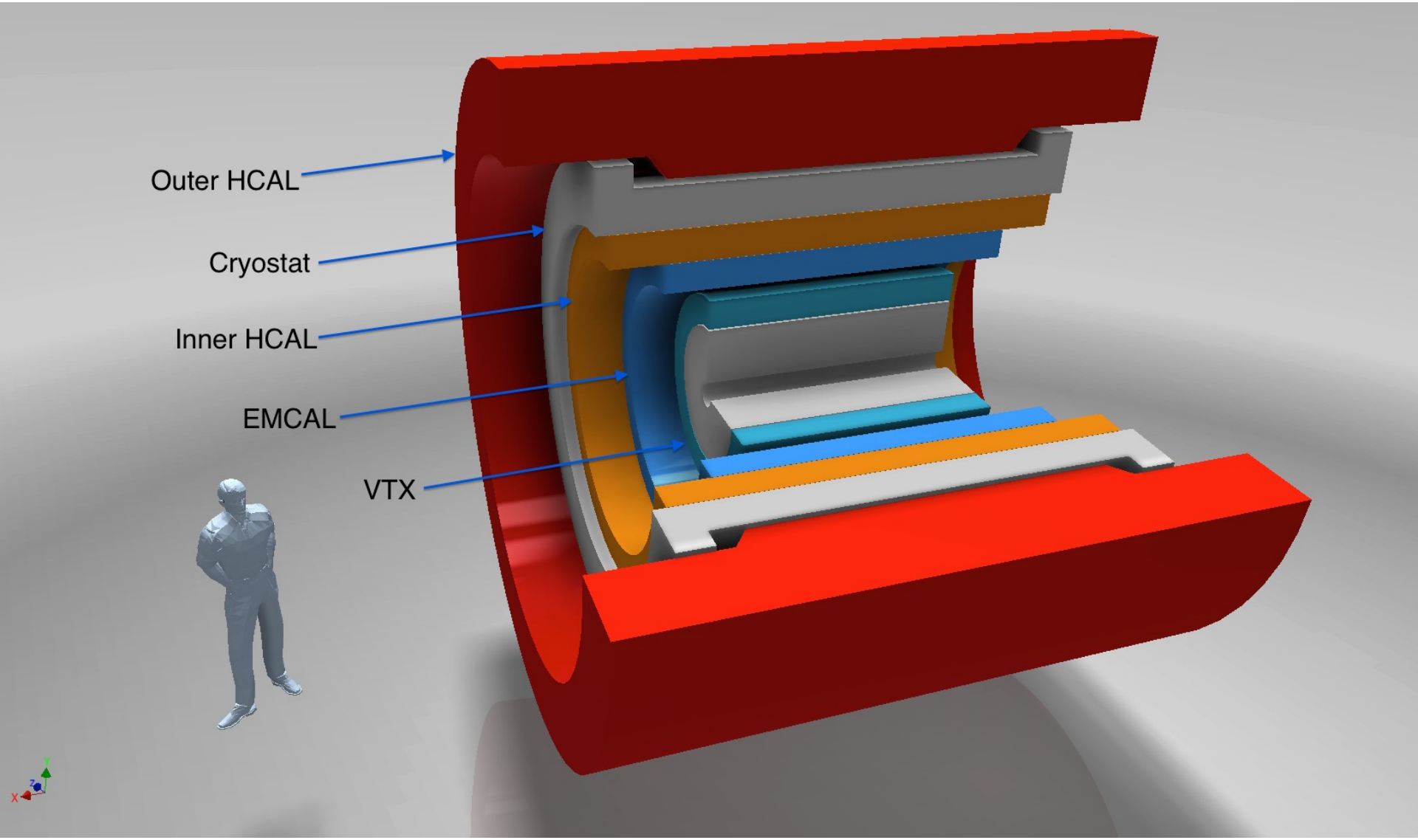



**Desirable to have whole HCal installed prior to 2019 Run**

# PHENIX Decommissioning Steps 2016-17


| | Est. Duration |
|---|---|
| • Area preparation and beam pipe disassembly, removal and storage | 1 mo |
| – VTX/FVTX removal and storage | |
| • East Carriage removal and disposition | 2 mo |
| • Muon Magnet South removal and disposition | 2 mo |
| • Central magnet removal and disposition | 2 mo |
| • West carriage removal and disposition | 2 mo |
| • Muon Magnet North removal and disposition | 2 mo |
| • Removals of all remaining extraneous infrastructure: | |
| – Obsolete piping, cables, fibers, & MuID planes not captured by the Muon steel | 2 mo |

# sPHENIX



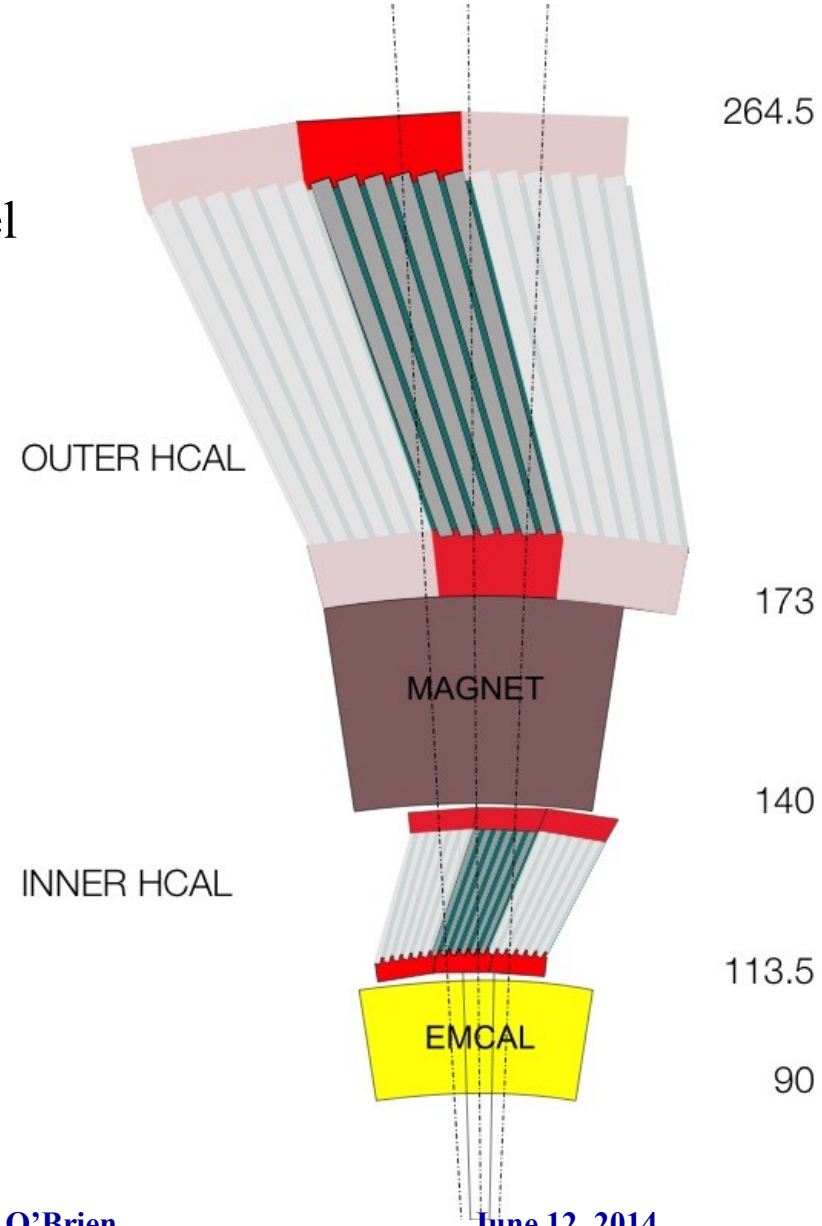
# sPHENIX Solenoid


- Will use the BaBar SC Solenoid
- 1.5 T central field
- Cryostat 140 cm < r < 173 cm
- 384 cm length covers -1 < η <1
- Considerable additional equipment also available
  - Power supplies, dump resistor, quench protection
  - Valve box
  - Cryogenic paraphernalia
- Manufactured by Ansaldo 1997, still in excellent condition
- Transfer of ownership to BNL approved by DOE

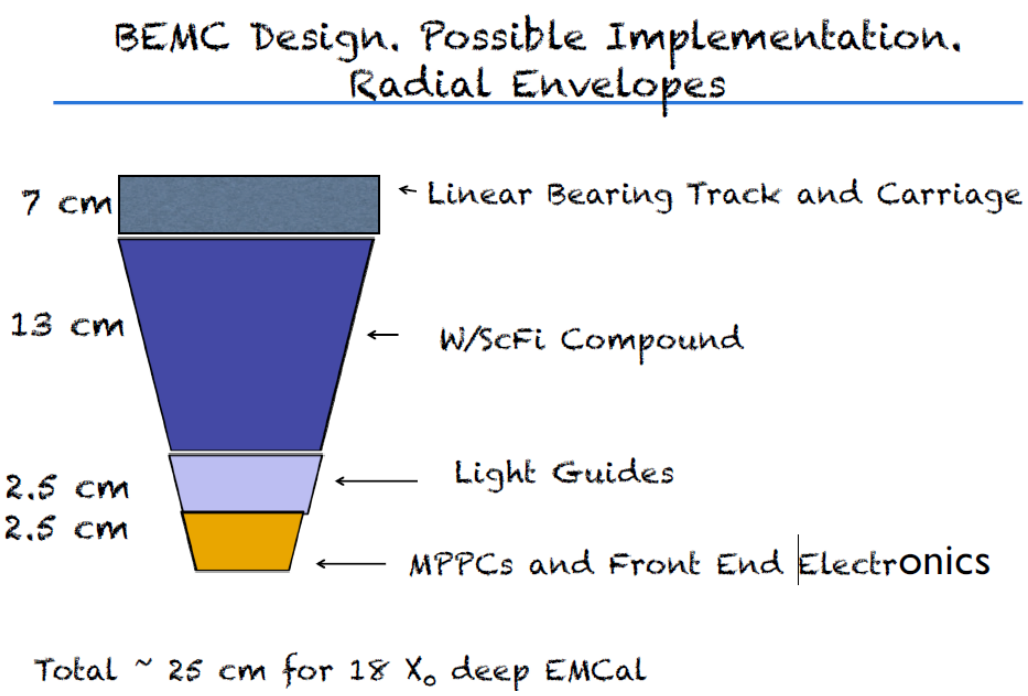
# sPHENIX Calorimetry

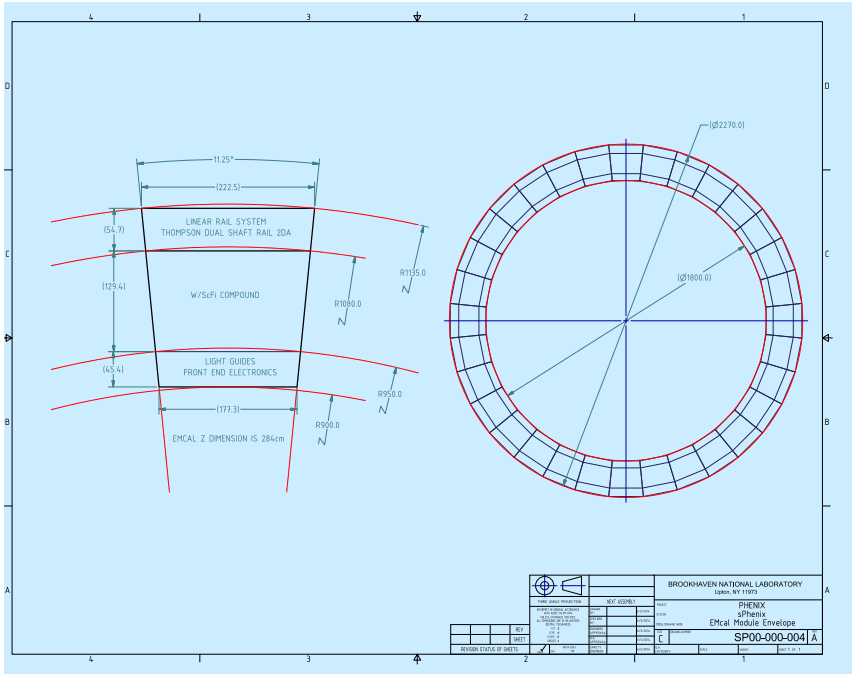
- **EMCAL** Tungsten-scintillating fiber
- **HCAL Outer** (steel)/**Inner** (stainless steel or brass) and scintillating tiles with wavelength shifting fiber
- **Readout** Solid state photodetectors (SiPMs)

- **Outer HCAL ≈4$\lambda_I$**
- **Magnet ≈1$X_0$**
- **Inner HCAL ≈1$\lambda_I$**
- **EMCAL ≈18$X_0$≈1$\lambda_I$**



# sPHENIX EMCal Concept



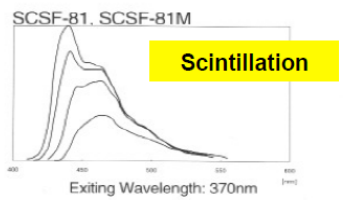

**Tungsten Spacal EMCal**

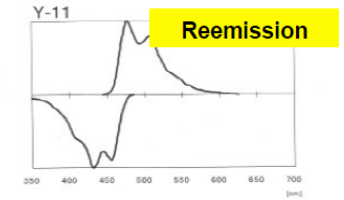
- **18 $X_0$**
- **Segmentation $\Delta\eta$ x $\Delta\phi$ = 0.024 x 0.024**
- **256 x 96 channels**
- **Sampling fraction ~ 2%**
- **$R_M$ ≈ 2.3 cm cell size**
- **Resolution ~ 12%/√E**

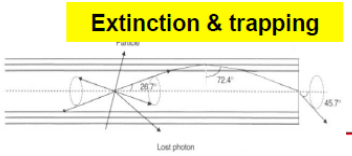
# sPHENIX Hadron Calorimeter Plans

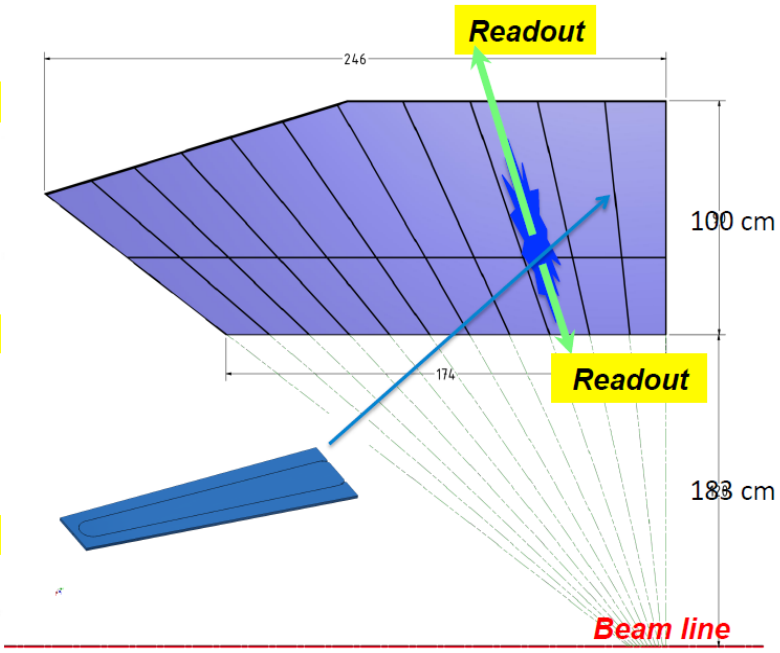
- HCal divided into two longitudinal sections
  - Inner $1\lambda_I$ made of brass or stainless steel
  - Outer $4\lambda_I$ made of steel and doubling as the magnetic flux return
- Absorber plates oriented parallel to the beamline with gaps for scintillator tiles embedded with WLS fibers
- Fibers coupled to Silicon Photomultipliers
- 64x24 readout channels
- $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- Single particle res. ~75%/√E

Extruded polystyrene tiles (7-9 mm) with WLS fibers embedded into machined grooves



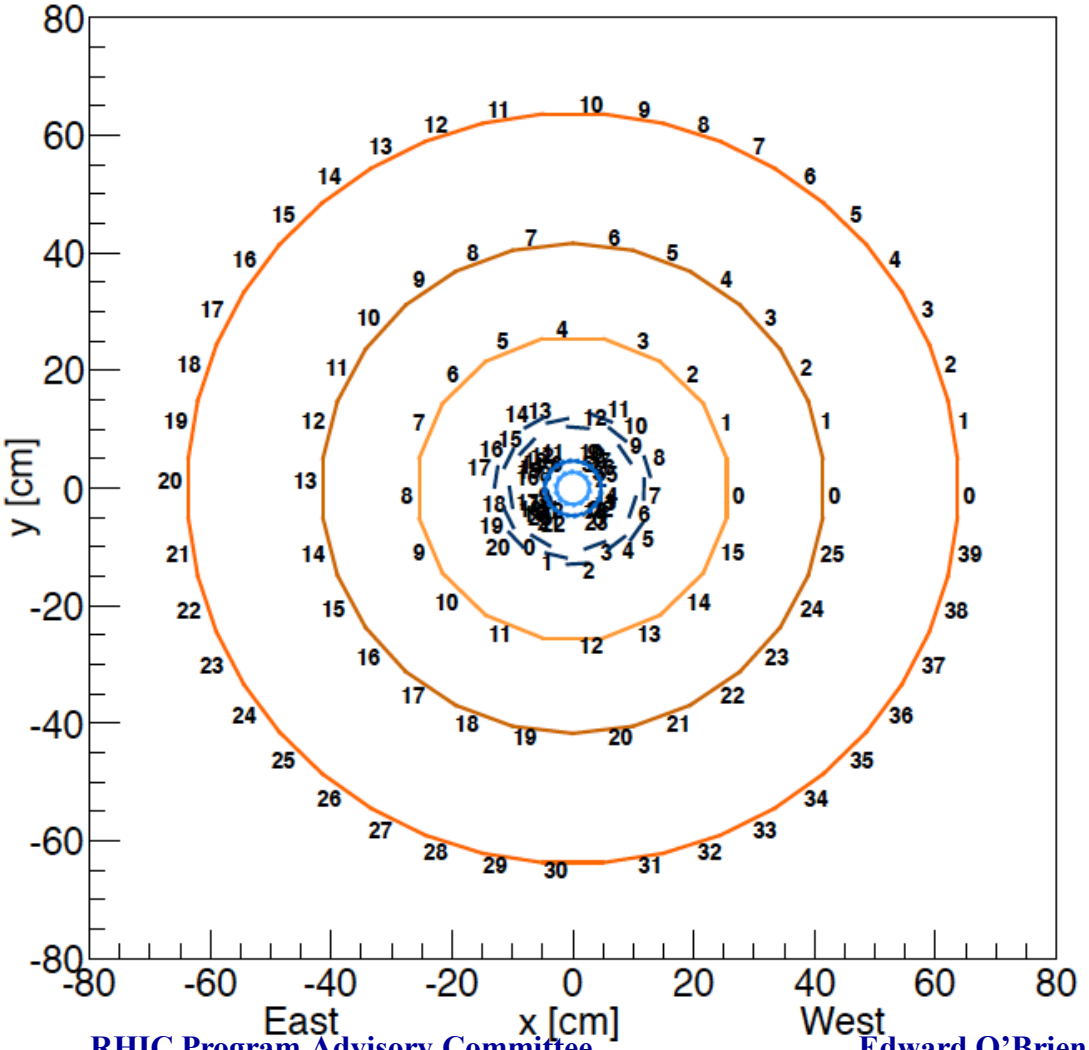



# sPHENIX Silicon Tracking

## sPHENIX will re-use the existing VTX and add 3 additional outer Si strip layers

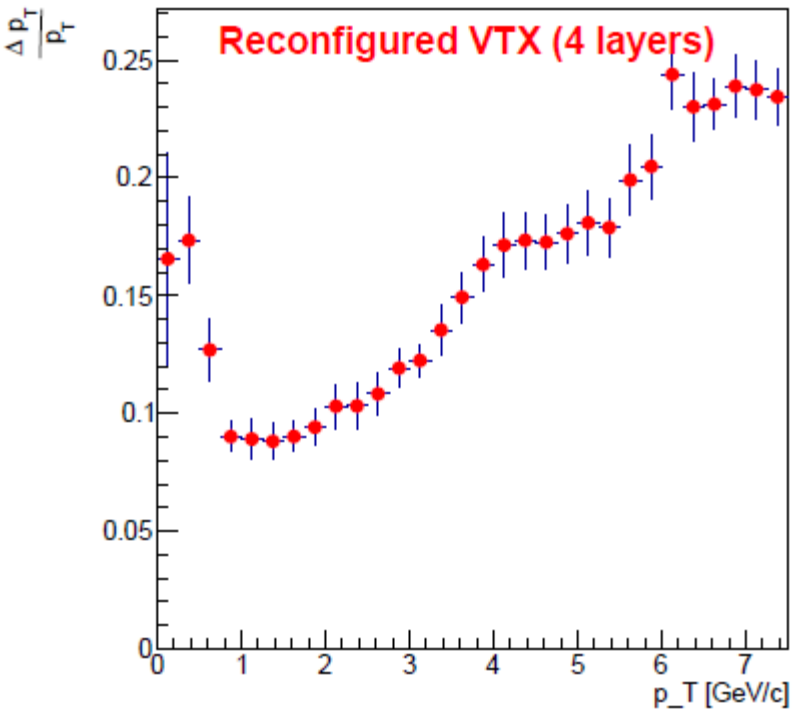
**For complete coverage in ϕ layer B0 moved slightly out and layer B1 moved slightly in**




| Layer | Radius (cm) | Ladders |
|---|---|---|
| 0 | 2.710 | 14 |
| 1 | 4.630 | 24 |
| 2 | 11.765 | 21 |
| 3 | 25.46 | 16 |
| 4 | 41.38 | 26 |
| 5 | 63.66 | 40 |

# Momentum Resolution of Si Tracking

Existing 4 layers at Current Radii




sPHENIX 6-Layer VTX

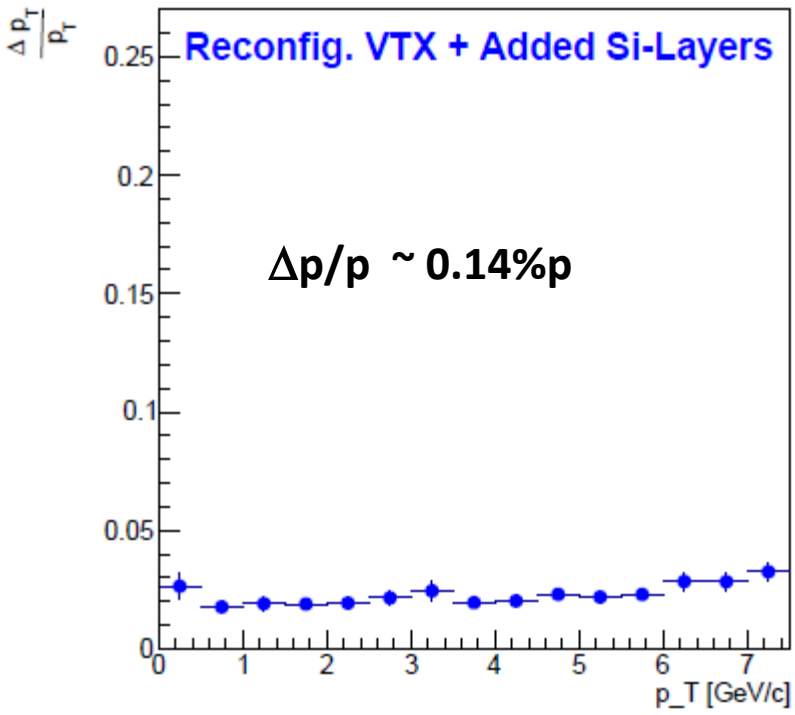



**Figure 2.1:** (left) GEANT-4 simulation of the momentum resolution achievable with the reconfigured VTX (assuming four layers) in the 1.5 T solenoidal field of sPHENIX. (right) GEANT4 simulation with the reconfigured VTX and additional outer strip layers.

# Projected RHIC Luminosity Rates 2019 BESII

**Table 4.1:** A summary of the projected RHIC luminosity and the projected PHENIX event rate for BES II. The PHENIX event rate is quoted as millions of events per day for good events that can be used for analysis within $|z_{vertex}| < 30$ cm and includes the PHENIX and RHIC duty factor. The PHENIX event rates for collision energies not covered in Run-10 are obtained from an exponential fit to the rates from the Run-10 data sets.

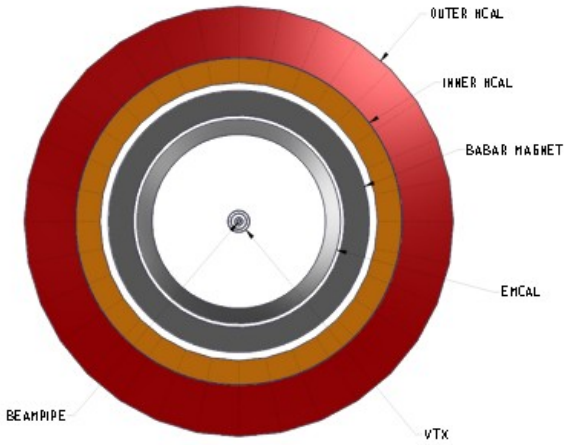
| | Run-10 | | Run-19 projection | | |
|---|---|---|---|---|---|
| $\sqrt{s_{NN}}$ | rate | $\langle\mathcal{L}\rangle$ | rate | $\langle\mathcal{L}\rangle$ | gain |
| GeV | Mevt/day | $cm^{-2}s^{-1}$ | Mevt/day | $cm^{-2}s^{-1}$ | factor |
| 19.6 | 0.95 | $4.0 \times 10^{25}$ | 24 | $1.0 \times 10^{27}$ | 25 |
| 15.0 | 0.35 | | 3.8 | $2.6 \times 10^{26}$ | 11 |
| 13.0 | 0.26 | | 2.2 | $1.7 \times 10^{26}$ | 8 |
| 11.5 | 0.17 | $1.6 \times 10^{25}$ | 1.0 | $9.1 \times 10^{25}$ | 6 |
| 9.0 | 0.10 | | 0.4 | $1.2 \times 10^{25}$ | 4 |
| 7.7 | 0.041 | $1.3 \times 10^{24}$ | 0.13 | $4.0 \times 10^{24}$ | 3 |
| 5.0 | 0.023 | | 0.05 | $4.3 \times 10^{23}$ | 2 |

# Potential Physics Program in the BES II

- Global Variables
- Spectra and Nuclear Modification Factors
- HBT and Flow
- Chiral Magnetic Effect
- Fluctuations and Analysis of Higher Moments
- Commissioning and Physics Opportunities at 200 GeV

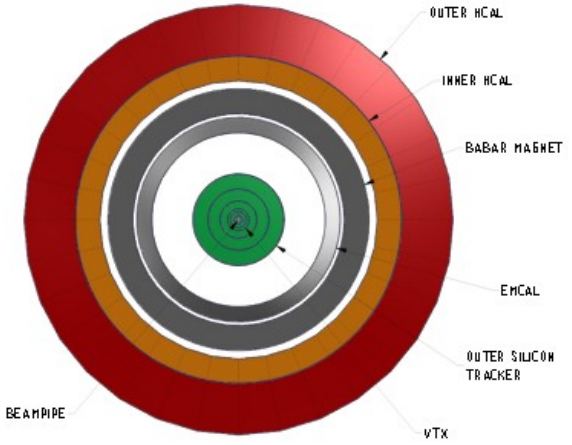
**Many members of the PHENIX collaboration have a strong interest in the BES II physics program**

# The BES II WP Described 3 Detector Options

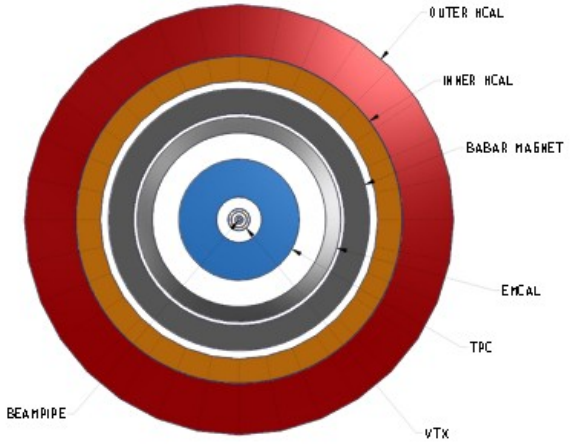



**sPHENIX w/ 4 layer VTX**

**sPHENIX w/ 6 Layer VTX**




**sPHENIX w/ 4 Layer VTX & TPC**



# sPHENIX Physics Program BESII WP

**Physics topics accessible with sPHENIX in the BESII including an estimate for the minimum number of events necessary to make a statistically significant measurement in the 10% most central bin for Au+Au $\sqrt{s_{NN}}$ = 19.6 GeV**

| Physics Analysis | Nevt (x$10^6$) | Required Detectors |
|---|---|---|
| Charged Particle Multiplicity | 5 | VTX and/or TPC |
| Multiplicity Fluctuations | 5 | VTX and/or TPC |
| Charged Particle pT Spectra | 10 | VTX and/or TPC |
| pT Fluctuations | 10 | VTX and/or TPC |
| Moments of Net Charge | 10 | VTX and/or TPC |
| Charged Particle Flow | 10 | VTX and/or TPC |
| Charged Particle Rcp | 30 | VTX and/or TPC |
| Di-hadron Correlations | 50 | VTX and/or TPC |
| Chiral Magnetic Effect | 10 | VTX and/or TPC |
| Transverse Energy | 5 | EMCal |
| Neutral Pion Spectra | 10 | EMCal |
| Neutral Pion Rcp | 30 | EMCal |
| Identified Particle Spectra | 10 | TPC |
| Identified Particle Ratios | 10 | TPC |
| Identified Particle Flow | 30 | TPC |
| Identified Particle HBT | 50 | TPC |
| Moments of Net Protons | 100 | TPC |
| Particle Ratio Fluctuations (K/pion…) | 100 | TPC |

# BESII Physics Program with Baseline sPHENIX in 2019

**Physics topics accessible with sPHENIX in the BESII including an estimate for the minimum number of events necessary to make a statistically significant measurement in the 10% most central bin for Au+Au $\sqrt{s_{NN}}$ = 19.6 GeV**

| Physics Analysis | Nevt (x$10^6$) | Required Detectors |
|---|---|---|
| Charged Particle Multiplicity | 5 | VTX and/or TPC |
| Multiplicity Fluctuations | 5 | VTX and/or TPC |
| Charged Particle pT Spectra | 10 | VTX and/or TPC |
| pT Fluctuations | 10 | VTX and/or TPC |
| Moments of Net Charge | 10 | VTX and/or TPC |
| Charged Particle Flow | 10 | VTX and/or TPC |
| Charged Particle Rcp | 30 | VTX and/or TPC |
| Di-hadron Correlations | 50 | VTX and/or TPC |
| Chiral Magnetic Effect | 10 | VTX and/or TPC |
| Transverse Energy | 5 | EMCal |
| Neutral Pion Spectra | 10 | EMCal |
| Neutral Pion Rcp | 30 | EMCal |
| Identified Particle Spectra | 10 | TPC |
| Identified Particle Ratios | 10 | TPC |
| Identified Particle Flow | 30 | TPC |
| Identified Particle HBT | 50 | TPC |
| Moments of Net Protons | 100 | TPC |
| Particle Ratio Fluctuations (K/pion…) | 100 | TPC |

# sPHENIX Run Request for 2019

- **22 weeks of cyro operations translated into 19 weeks of physics running**
- **Collisions with energy steps spanning range of interest for CEP and where the Low Energy RHIC Electron Cooling is effective.**
- **sPHENIX is a new detector so "re-taking" data at 19.6 GeV will be very useful**
- **Dedicating ~ 15% of the 2019 run to sPHENIX commissioning/calibration at √s = 200 GeV will be tremendously beneficial to the preparation of the detector for the 2021 RHIC run**

| Species | $\sqrt{s_{NN}}$ (GeV) | $\mu_B$ (MeV) | Run Time (Days) | Events(M) $\lvert z_{vtx}\rvert < 10$cm | Events(M) $\lvert z_{vtx}\rvert < 30$cm | Events(M) $\lvert z_{vtx}\rvert < 1$ m |
|---|---|---|---|---|---|---|
| Au+Au | 11.5 | 315 | 45 | 15 | 45 | 112.5 |
| | 13.0 | 281 | 23 | 17 | 50 | 125 |
| | 9.0 | 376 | 41 | 6 | 17 | 42.5 |
| | 19.6 | 205 | 4 | 33 | 100 | 2500 |
| | 200 | 20 | 10 | 1200 | 3600 | 9000 |
| p+p | 200 | | 10 | 1.2 $pb^{-1}$ | 3.6 $pb^{-1}$ | 9 $pb^{-1}$ |

# Benefit of a Short 200 GeV Au+Au & p+p Run in 2019

**Provide an invaluable data set with a partially instrumented sPHENIX detector that will enable us a head start in preparing for the 2021 data set with the completed sPHENIX detector**

- **Calibrating the jet energy scale in the sPHENIX detector (p+p)**
- **Understanding the HI event underlying the jet signal (Au+Au)**
- **Developing analysis techniques for the full jet measurement and direct photon measurement. (Both)**

# Fluctuations in (s)PHENIX

- Sensitive to correlation length, ξ [LQCD]

Variance : $\sigma^2 = \langle(\Delta\mathcal{N})^2\rangle \sim \xi^2$ $[\chi^{(2)}/\chi^{(1)}]$

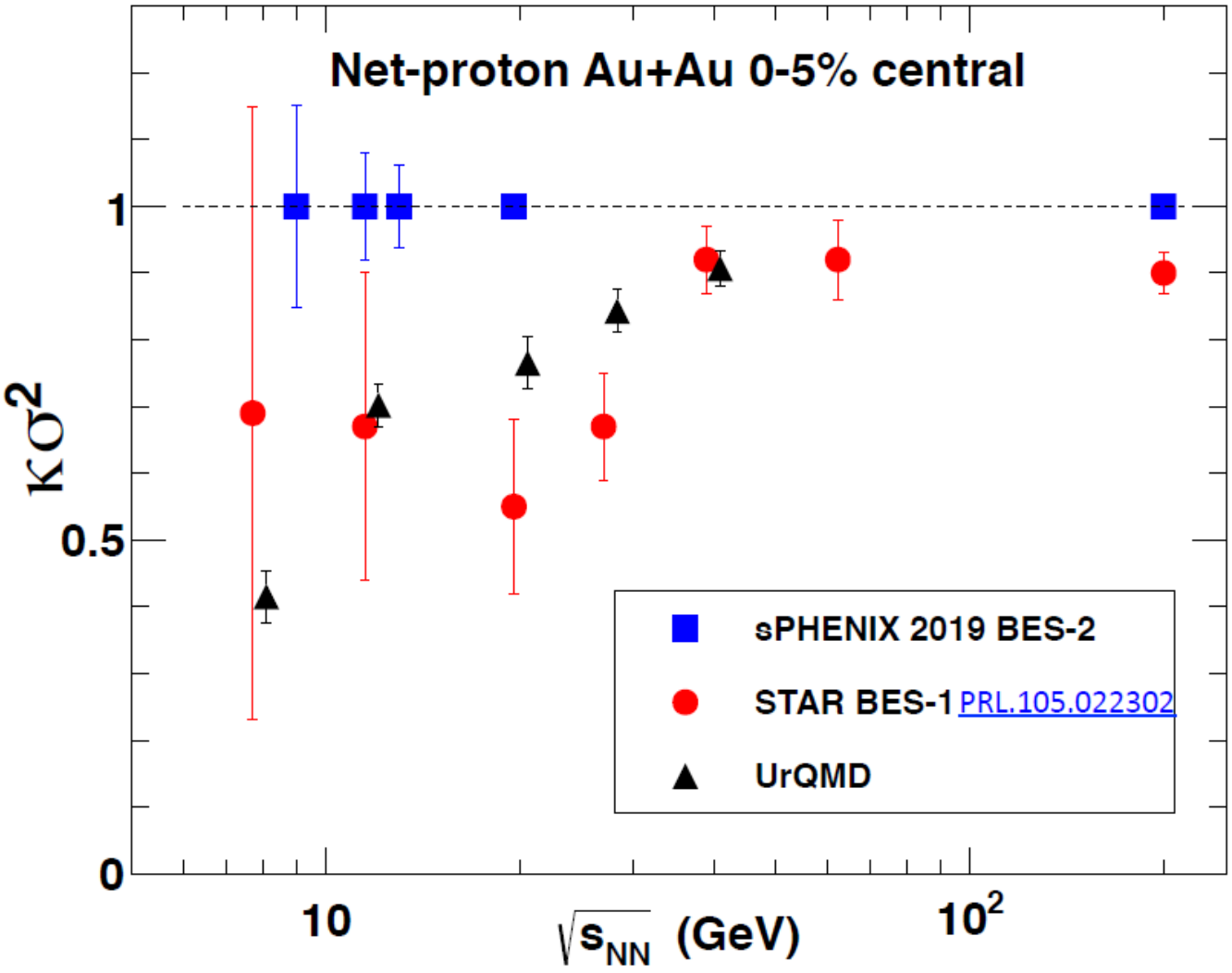
Skewness: $S\sigma = \langle(\Delta\mathcal{N})^3\rangle/\sigma^2 \sim \xi^{5.5}$ $[\chi^{(3)}/\chi^{(2)}]$

Kurtosis: $K\sigma^2 = \langle(\Delta\mathcal{N})^4\rangle/\sigma^2\text{-}3\sigma^2 \sim \xi^9$ $[\chi^{(4)}/\chi^{(2)}]$

- Quark susc., $\chi$, LQCD calculate directly (μ=0)
  - for μ>0, higher order terms needed

# BES II (Stretch) Projection
# N.B. : Requires Proton ID

http://www.phenix.bnl.gov/plans.html - BES2 Whitepaper



# Conclusion

- **RHIC BES I produced interesting results from PHENIX, a number of which call for further investigation in the $\sqrt{s_{NN}}$ = 10-20 GeV range.**
- **PHENIX will get decommissioned at the end of Run-16. Plans for sPHENIX construction and installation are underway.**
- **We plan to have sPHENIX partially installed prior to the start of the RHIC 2019 run which is the second year of the BES II.**
  - **At a minimum sPHENIX would like to use the 2019 run for an early start to commissioning of available detector components.**
- **A stretch goal for 2019 is to have sufficient components of sPHENIX installed and available that the detector can contribute to the physics measurements of the BES II.**
- **The collaboration has a strong interest in the physics of the BES II and is enthusiastic about contributing to the measurements.**

PHENIX

# Back Up

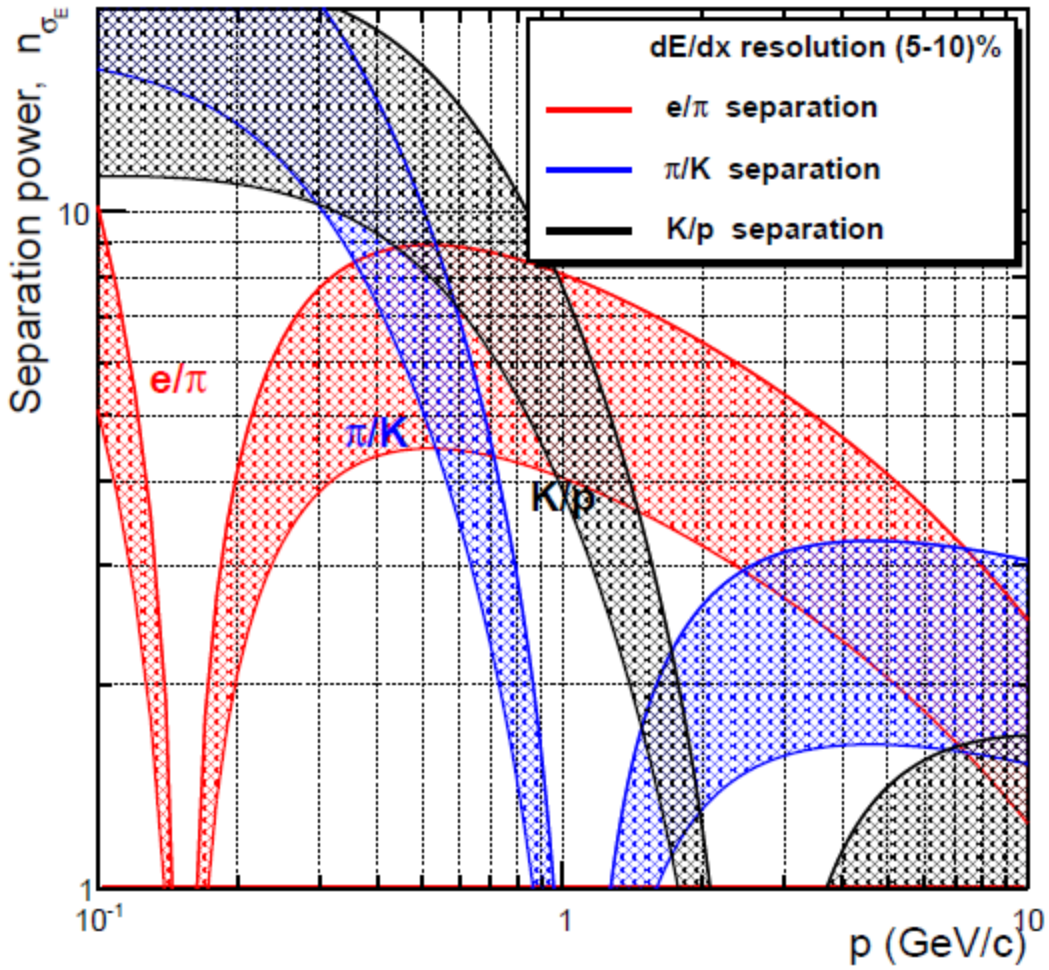



**Figure 2.5:** Particle identification capabilities of the $dE/dx$ technique. The bands correspond to 5–10% resolution in the measurement of the charge for a fully reconstructed track.

# Ye Old HBT formulae

- Formerly used to understand dynamics

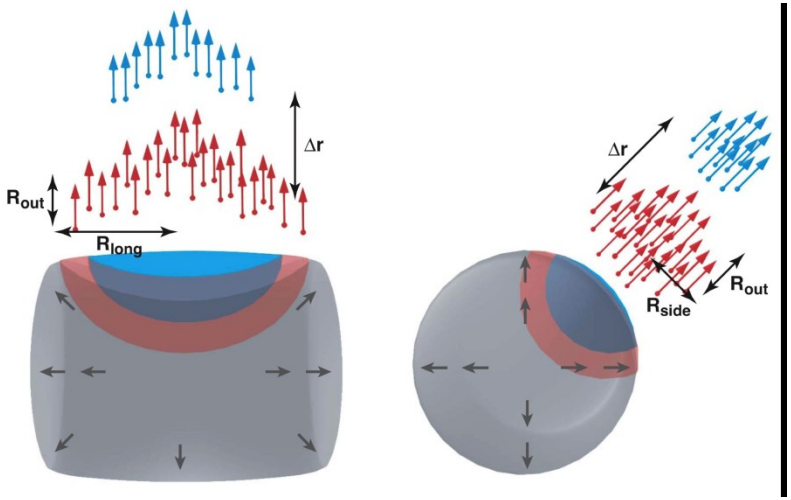
  before era of multi-stage models, assumptions too restrictive

Chapman, Scotto, Heinz, PRL.74.4400 (95)

$$R_{side}^2 = \frac{R_{geo}^2}{1+\frac{m_T}{T}\beta_T^2}$$

$$R_{out}^2 = \frac{R_{geo}^2}{1+\frac{m_T}{T}\beta_T^2} + \beta_T^2(\Delta\tau)^2$$

$$R_{long}^2 \approx \frac{T}{m_T}\tau^2$$




$$R_i = a + \frac{b}{\sqrt{m_T}}$$

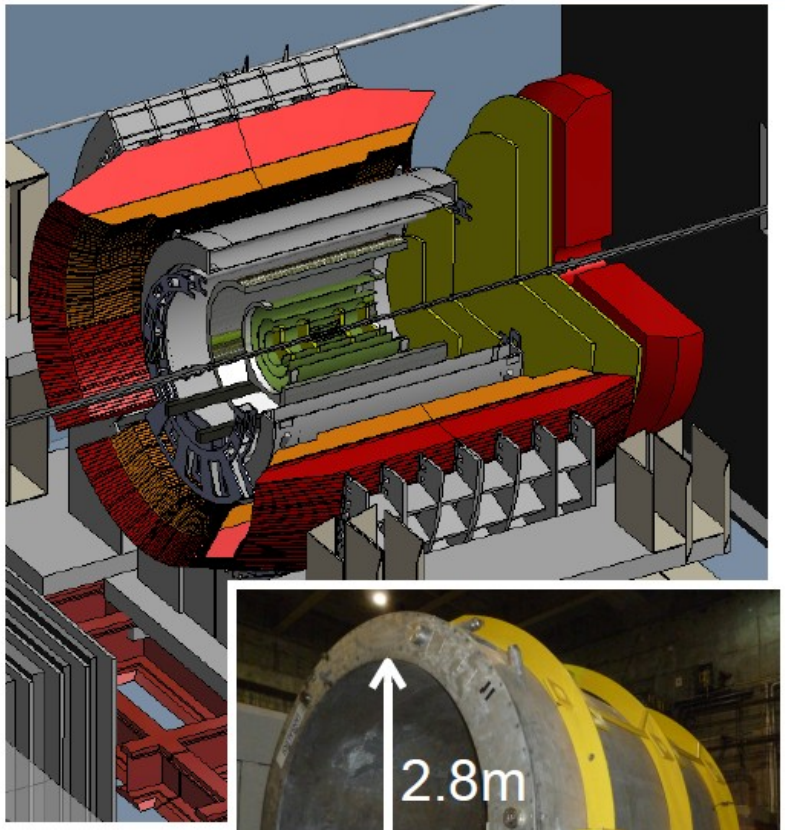
empirical fit just as effective

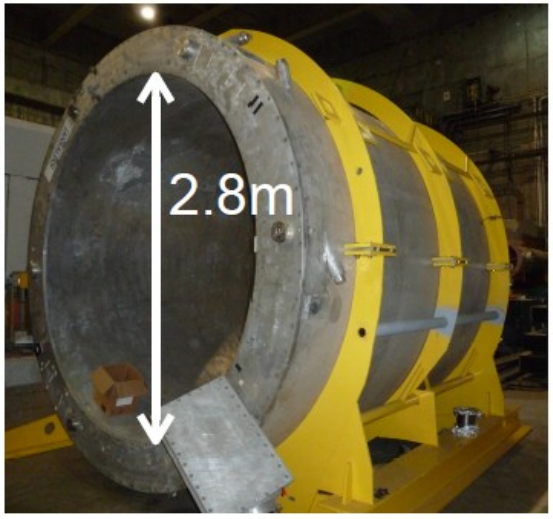
Makhlin, Sinyukov, ZPC.39.69 (88) ($R^2_{out}$-$R^2_{side}$) sensitive to emission duration

Anticipate extended emission duration with 1st order transition

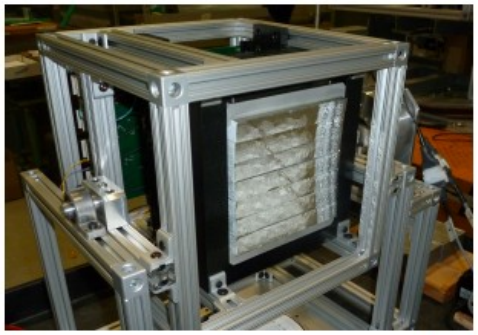
PHENIX

# sPHENIX: Technology and Design





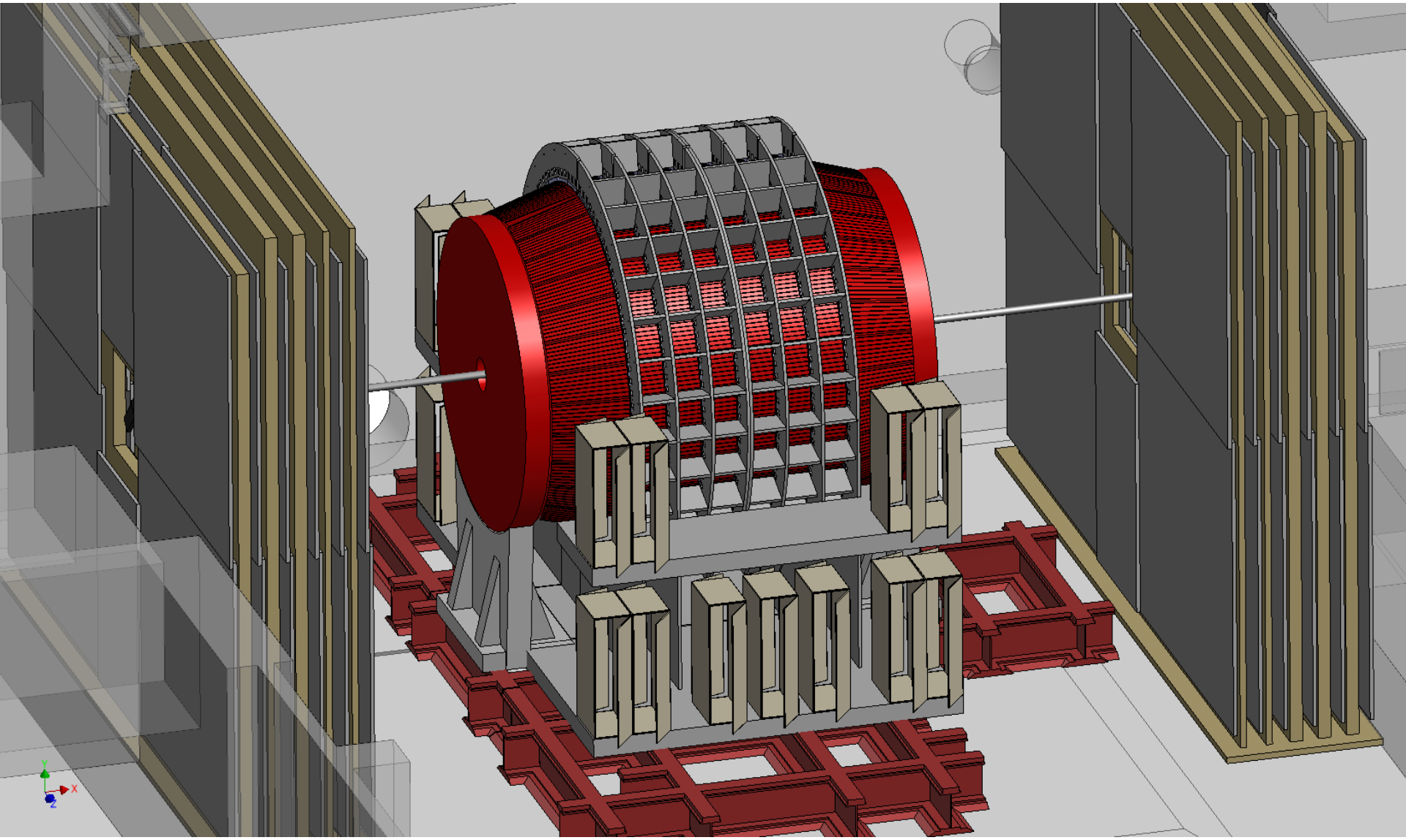

Recently acquired BaBar solenoid – shipping this summer to BNL



Prototype tungsten/scintillator EMCal with SiPMs and fully digital readout electronics

Prototype of steel/scintillator HCal with novel geometry – same RO electronics as EMCal

PHENIX



# sPHENIX Physics Program BESII WP

**Table 3.1:** A summary of physics topics potentially accessible with the PHENIX detector (depending on the configuration) for the BES II program including an estimate of the minimum number of events necessary to make a statistically significant measurement in the 10% most central bin for Au+Au at $\sqrt{s_{NN}} = 19$ GeV.

| Physics Analysis | $N_{evt}$ ($\times 10^6$) | Required Detectors |
|---|---|---|
| Charged Particle Multiplicity | 5 | VTX and/or TPC |
| Multiplicity Fluctuations | 5 | VTX and/or TPC |
| Charged Particle $p_T$ Spectra | 10 | VTX and/or TPC |
| $p_T$ Fluctuations | 10 | VTX and/or TPC |
| Moments of Net Charge | 10 | VTX and/or TPC |
| Charged Particle Flow | 10 | VTX and/or TPC |
| Charged Particle $R_{CP}$ | 30 | VTX and/or TPC |
| Di-hadron Correlations | 50 | VTX and/or TPC |
| Chiral Magnetic Effect | 10 | VTX and/or TPC |
| Transverse Energy | 5 | EMCal |
| Neutral Pion Spectra | 10 | EMCal |
| Neutral Pion $R_{CP}$ | 30 | EMCal |
| Identified Particle Spectra | 10 | TPC |
| Identified Particle Ratios | 10 | TPC |
| Identified Particle Flow | 30 | TPC |
| Identified Particle HBT | 50 | TPC |
| Moments of Net Protons | 100 | TPC |
| Particle Ratio Fluctuations ($K/\pi$,$\overline{p}/p$) | 100 | TPC |