PHENIX detector upgrades for enhanced physics programs

DIS2013 in Marseilles

April 24, 2013

Yuji Goto (RIKEN)

for the PHENIX Collaboration

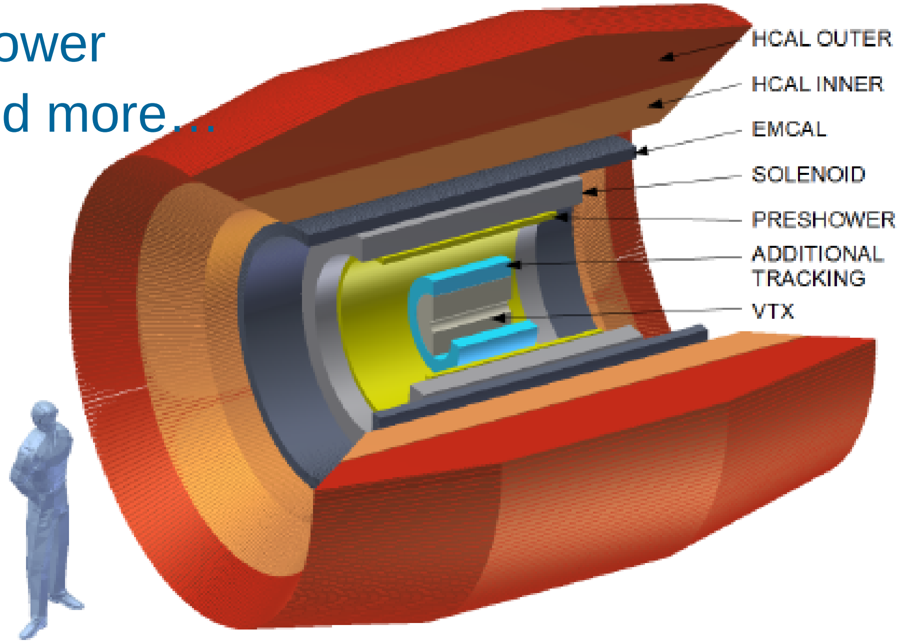
Outline

- Stages of sPHENIX detector upgrades
  - Baseline upgrades
    - Compact jet detector at midrapidity
  - Midrapidity options
  - Forward upgrades
- Detector concept
- Physics
  - Heavy-ion physics
  - Cold nuclear matter physics
  - Spin physics

Stages of PHENIX detector upgrades

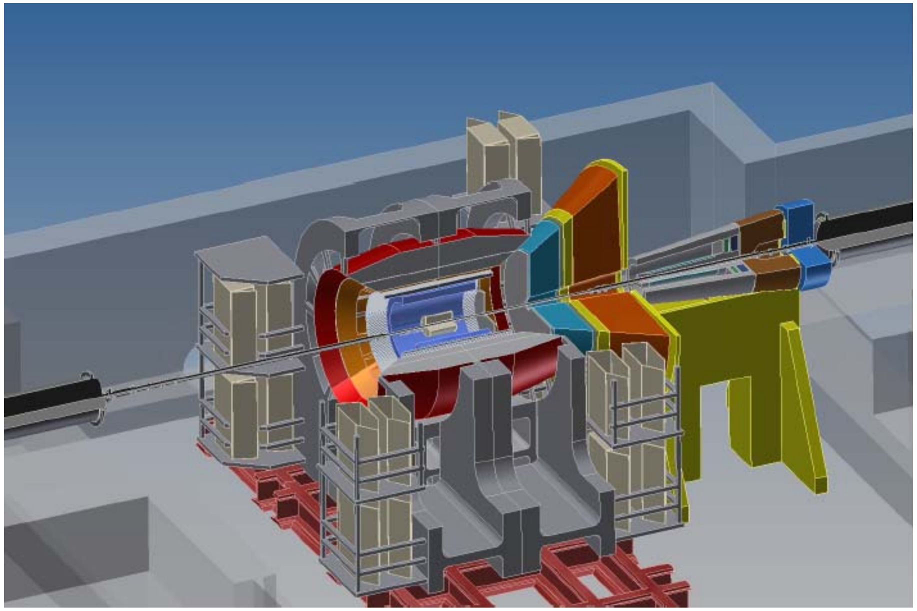
PHENIX

- Long-term enhancement for major physics programs
  - Sustained program with dedicated QCD machine
- (Baseline) “sPHENIX” upgrades
  - Compact jet detector at midrapidity with high-rate capability
  - With recent upgraded RHIC accelerator
  - Precision jet / dijet / γ-jet measurements to understand the nature of the strongly-coupled QGP
- Future option upgrades
  - Midrapidity tracking and preshower
  - Heavy-flavor quarkonia / jet and more…



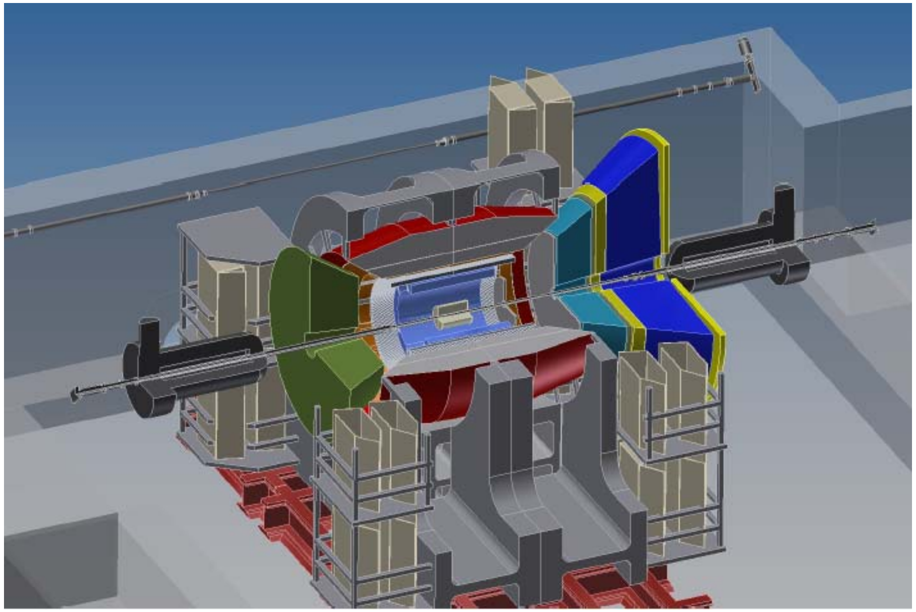
Stages of PHENIX detector upgrades

- Forward "sPHENIX" upgrades
  - Open geometry for wide kinematic coverage of photon / jet / leptons / identified-hadrons
  - For understanding 3-dimensional (transverse-momentum dependent) quark-gluon structure of the nucleon and nuclei
  - Measurement of the nuclear gluon distribution $G_A(x)$ and search for gluon saturation at small-x



Stages of PHENIX detector upgrades

- Towards “ePHENIX” at eRHIC
  - More precision for 3-dimensional quark-gluon structure of the nucleon and nuclei
  - For precision understanding of strongly-coupled QGP by knowing the initial state
  - Detailed ePHENIX talk by Klaus Dehmelt at FEX on Apr.25(AM)
  - EIC talks by Deshpande at Spin/FEX on Apr.23(AM) and Aschenaue, Zhang, Nadel-Turonski, Lamont at FEX on Apr.24(PM) and Apr.25(AM)



sPHENIX upgrades

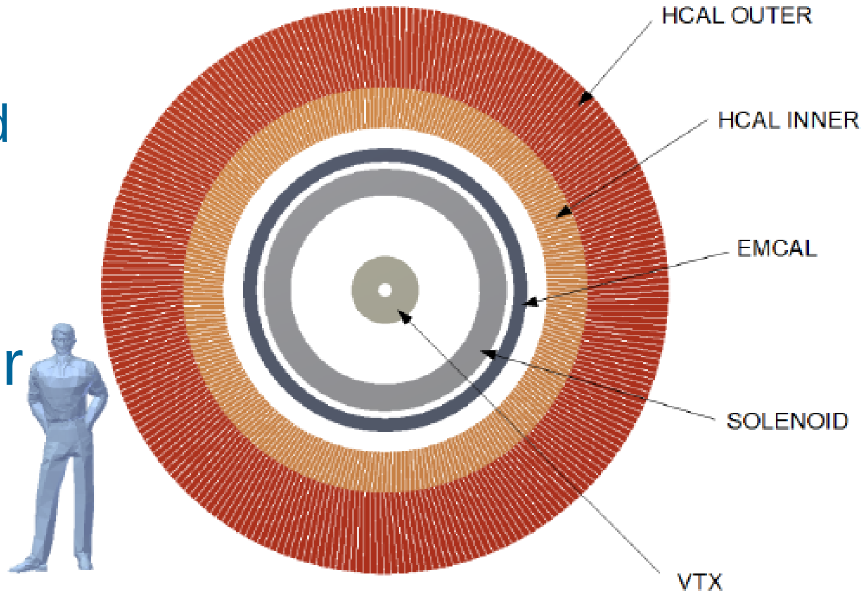
- Design goals for a jet detector
  - Full azimuthal coverage in a fiducial region $|\eta| < 1$
  - 2T solenoid for high resolution tracking in a small volume
  - Electromagnetic and hadronic calorimetry
  - Data acquisition capable of recording >10 kHz
- With recent upgraded RHIC accelerator
  - EBIS for various nuclear species
  - Upgraded luminosity
  - Energy scan
  - Flexibility with dedicated QCD machine
- Requirements
  - Large enough jet rates
  - Distinguishable jets from background fakes

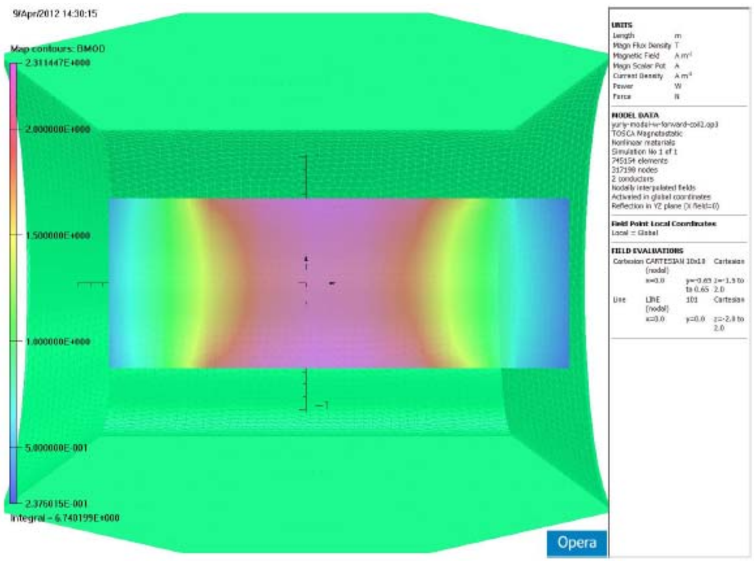
Expected counts within $|\eta| < 1$ in a 20 week run at 200 GeV

	Au+Au (central 20%)	$p+p$	d+Au
$> 20\,\text{GeV}$	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
$> 30\,\text{GeV}$	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
$> 40\,\text{GeV}$	10^5 jets	10^4 jets	10^5 jets
$> 50\,\text{GeV}$	10^4 jets	10^3 jets	10^4 jets

sPHENIX upgrades

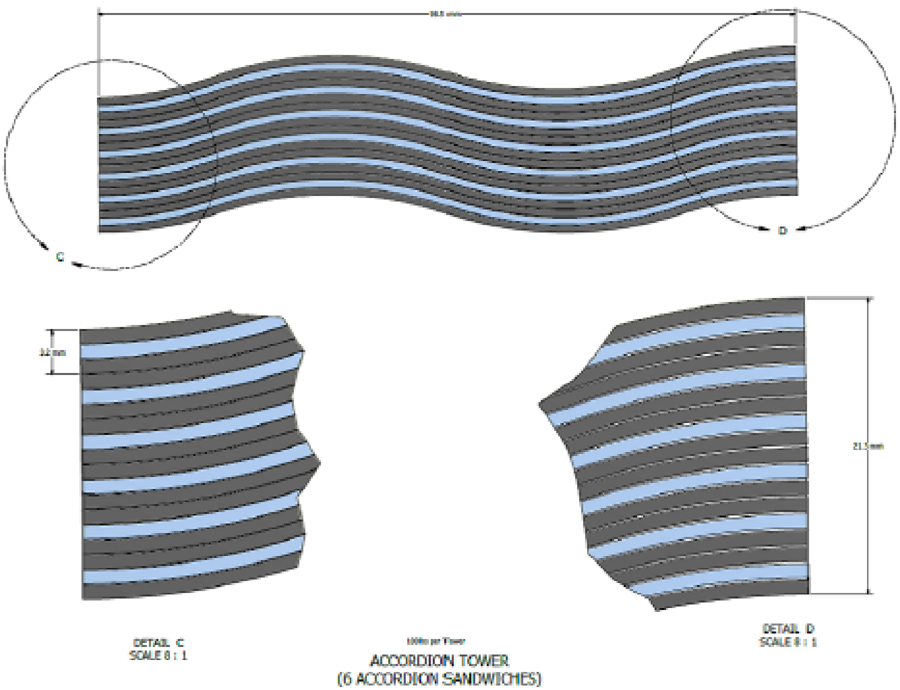
- Magnetic solenoid
  - 2 T superconducting solenoid
  - 70 cm inner radius
  - Less than 1 X_0
- Electromagnetic calorimeter
  - Accordion tungsten-fiber calorimeter
  - $\Delta\eta$ x $\Delta\phi \sim$ 0.03 x 0.03
  - $\sigma_E / E \sim 15\% / \sqrt{E}$
- Hadronic calorimeter
  - Steel-scintillator calorimeter
  - $\Delta\eta$ x $\Delta\phi \sim$ 0.1 x 0.1
  - $\sigma_E / E \sim 100\% / \sqrt{E}$
  - Flux return yoke for the solenoid



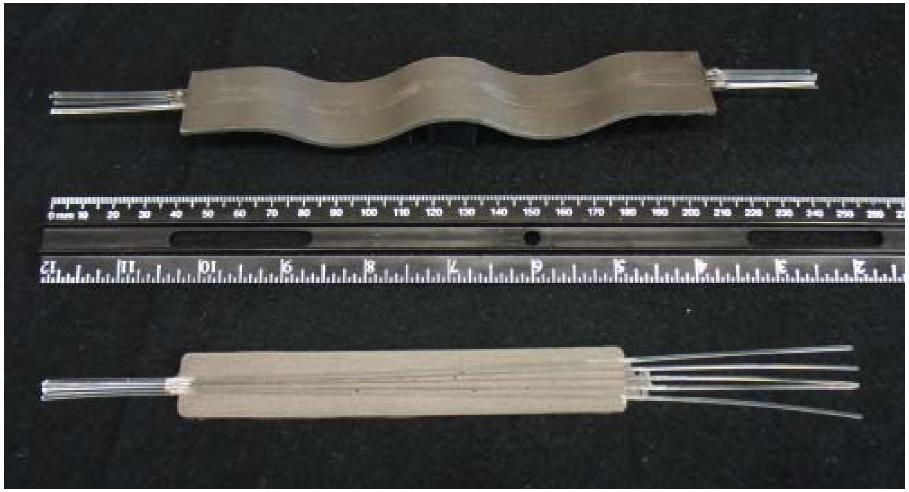


Electromagnetic calorimeter

- Accordion tungsten scintillating-fiber calorimeter
  - compact
- Silicon photomultiplier (SiPM) readout
  - small, high gain, no high voltage required, work in a magnetic field



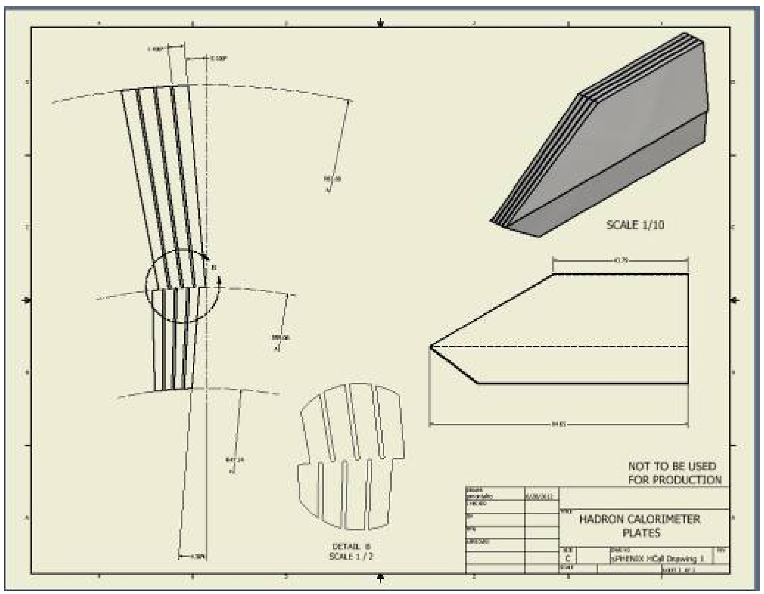
Accordion tower
= 6 accordion sandwiches



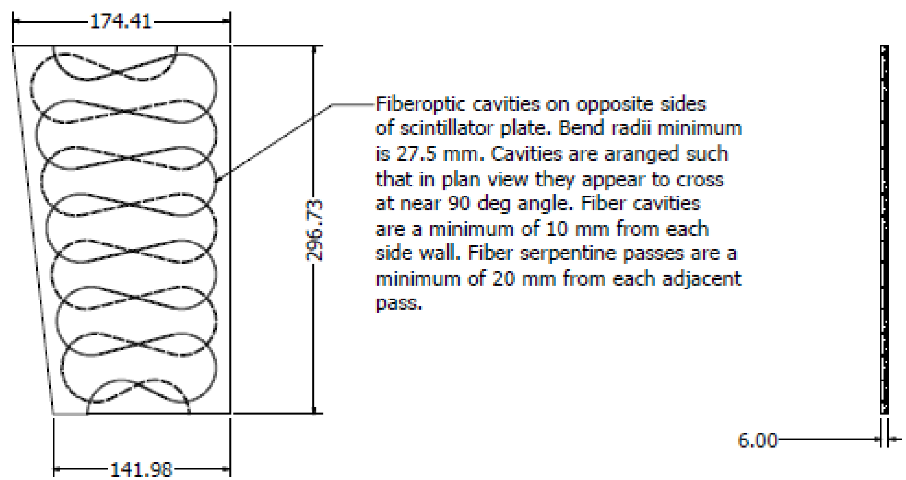
Scintillating fiber in tungsten powder epoxy polymer

Hadronic calorimeter

- Steel-scintillator calorimeter
  - ~1 λ_{int} EMC + ~5 λ_{int} HC
  - Wavelength shifting fiber embedded in scintillator for light collection
  - Flux return for magnetic field



Fin structure of inner & outer segments oriented at an angle of ±5 degree



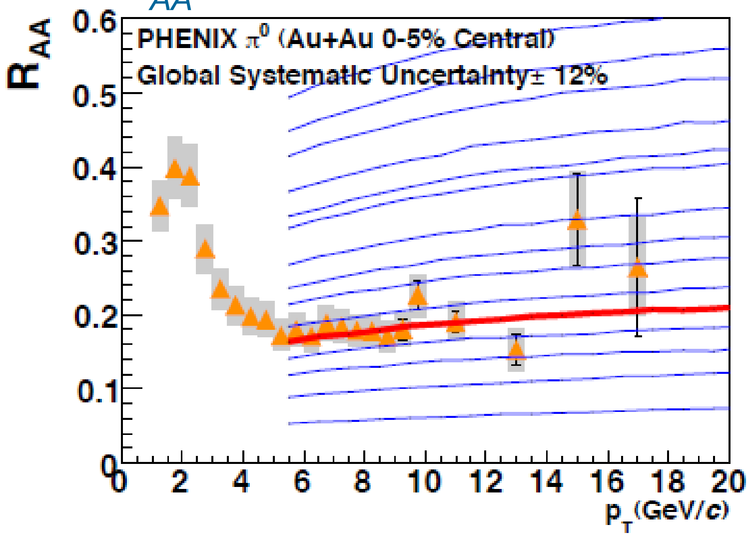
Scintillator tile with a wavelength shifting fiber along a serpentine path

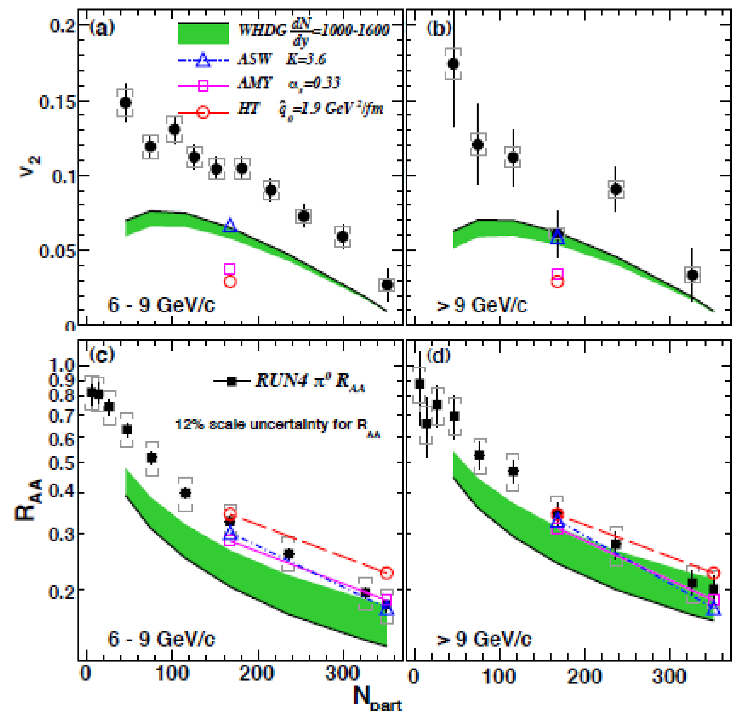
Physics of sPHENIX

- Current jet-probe measurements
  - Nuclear modification factor (R_{AA})
    - Suppression of single hadron yields compared to expectations from *p+p* collisions
    - Jet quenching: significant loss of energy for partons traversing the QGP
  - Azimuthal anisotropy of hadron production with respect to the reaction plane (v_2)
    - Weakly-coupled radiative energy loss model cannot explain the azimuthal anisotropy

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2N^{A+A}/dp_T d\eta}{d^2N_{inel}^{p+p}/dp_T d\eta}$$

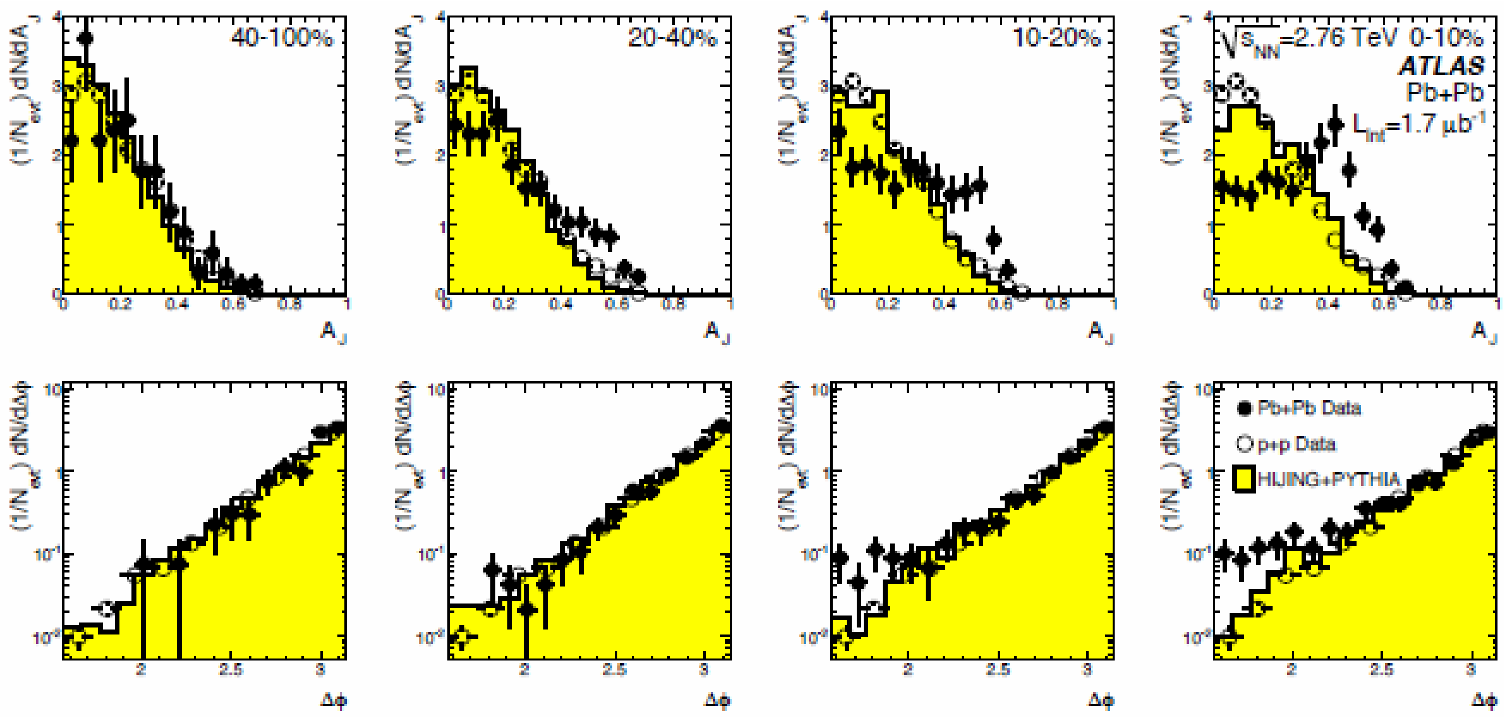
PHENIX π^0 R_{AA}





Physics of sPHENIX

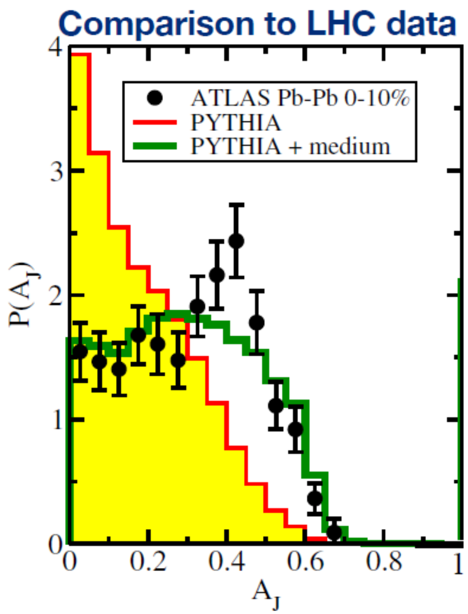
- New data from LHC
  - Fully reconstructed jets
  - Dijet asymmetry $A_J = (E_1 - E_2) / (E_1 + E_2) \rightarrow$ energy loss for jets
  - Unmodified $\Delta\phi$ distribution $\rightarrow$ no broadening in traversing the matter

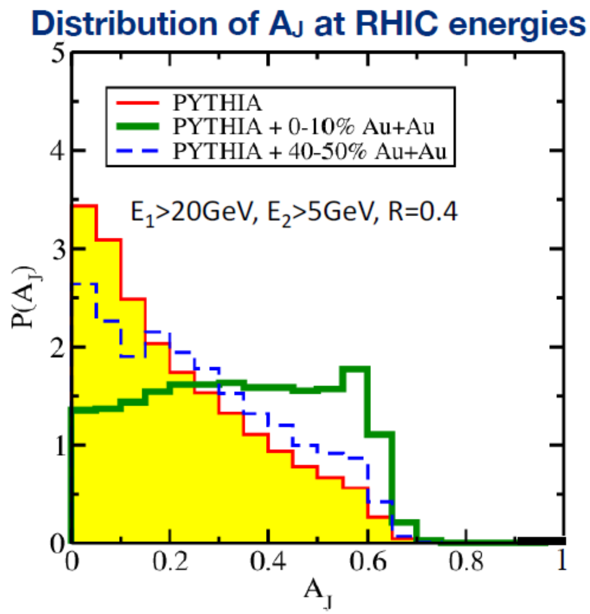


  - Direct photon + jet correlations
    - Cleaner handle on the expected jet p_T

Physics of sPHENIX

- Importance of fully reconstructed jets
  - Precision jet / dijet / γ-jet measurements to understand the nature of the strongly-coupled QGP
  - Significant extension of kinematic range
  - Jet modification



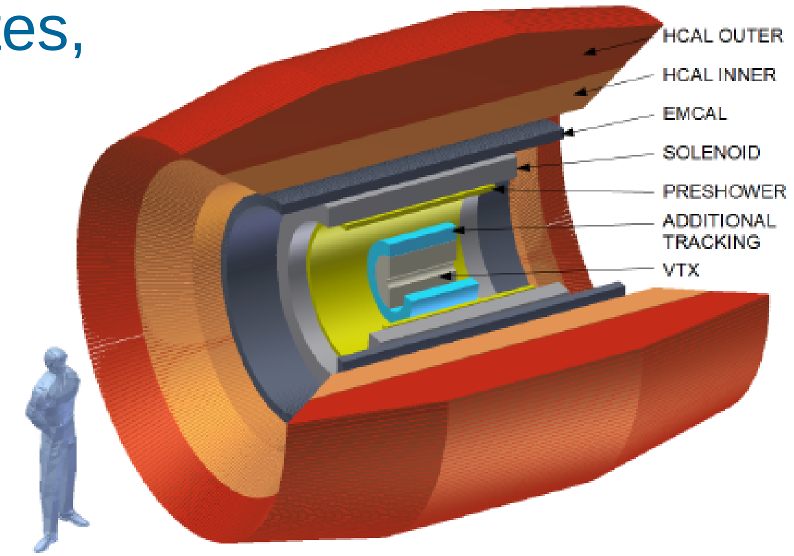


G.-Y.Qin and B.Muller PRL106, 162302 (2011)

- Temperature dependence
  - > 300 MeV at RHIC and > 420 MeV at LHC
- More flexible study at RHIC
  - With different energies and nuclear species

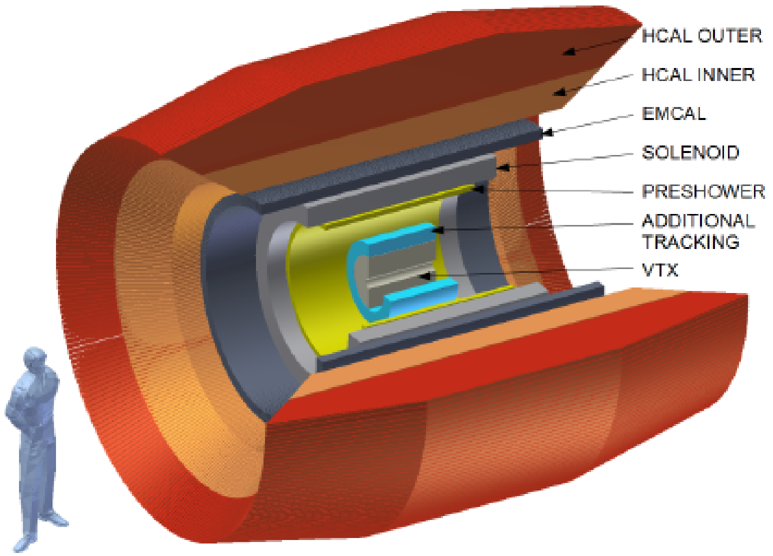
Future option upgrades

- Additional charged-particle tracking
  - Improved tracking in the magnetic field (15–65 cm radii) for high resolution momentum measurement
    - Existing 4 layers of VTX
      - $\Delta p/p \sim 0.1 + 0.02 \times p$ [GeV/c]
    - Additional silicon layers at 40 cm & 60 cm radii
      - $\Delta p/p \sim 0.007 + 0.0015 \times p$ [GeV/c]
  - For good separation of ϒ states, ϒ(1s)/ϒ(2s)/ϒ(3s)



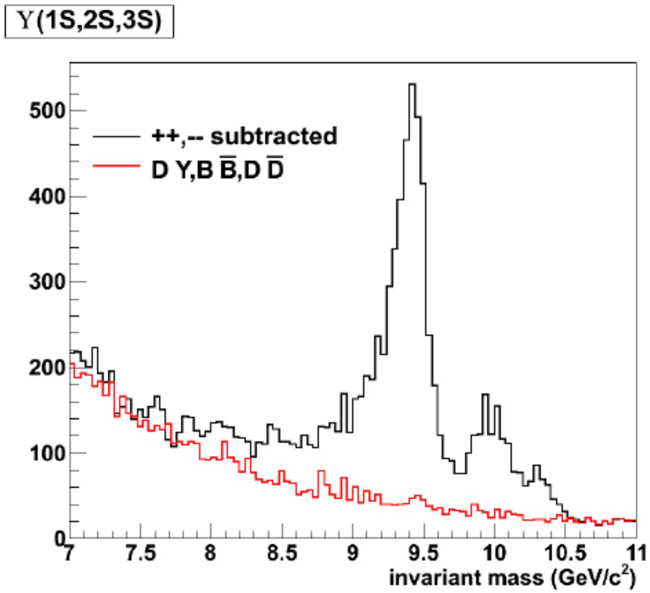
Future option upgrades

- Preshower detector with fine segmentation
  - Improved reach of γ/π^0 separation
    - Good separation of single photon from $\pi^0 \rightarrow \gamma\gamma$ up to 10 GeV with electromagnetic calorimeter of $\Delta\eta$ x $\Delta\phi$ = 0.024 x 0.024
    - Improved separation up to 50 GeV with tungsten + silicon layer of $\Delta\eta$ x $\Delta\phi$ = 0.0005 x 0.1
  - Improved electron identification
    - For good separation of ϒ states



Physics of sPHENIX

- Quarkonia spectroscopy of Υ states
  - J/ψ suppression stronger at RHIC than at LHC
  - For competing Υ measurement at RHIC at different energies with more flexibility (energies / nuclear species)
- Charm / beauty jets
- Extending π^0 R_{AA}
  - up to 10 GeV → 50 GeV
- High-*z* jet fragmentation functions
- Low and intermediate mass dileptons



Yield of different Υ states in one year at RHIC

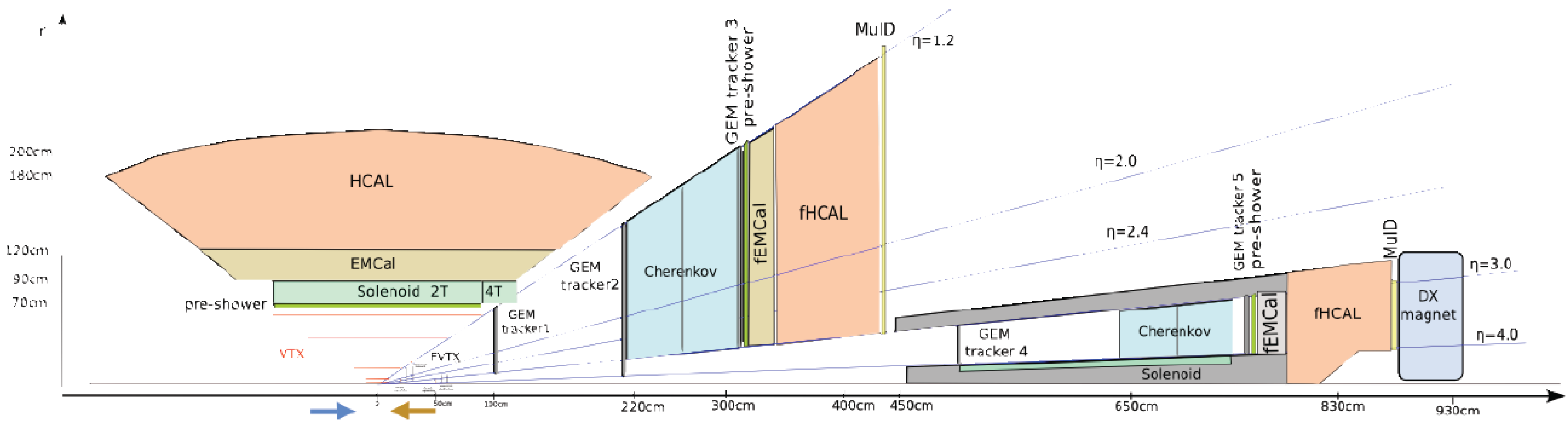
Species	$\int$ L dt	Events	$\langle N_{coll} \rangle$	Υ(1S)	Υ(2S)	Υ(3S)	Υ(1S+2S+3S)
$p+p$	18 pb^{-1}	756 B	1	805	202	106	1113
Au+Au (MB)		50 B	240.4	12794	3217	1687	17698
Au+Au (0–10%)		5 B	962	5121	1288	675	7084

Forward sPHENIX upgrades

- A straw man layout of a possible detector
  - Charged-particle tracking - GEM
  - Particle identification - RICH
  - Electromagnetic calorimeter
  - Hadronic calorimeter

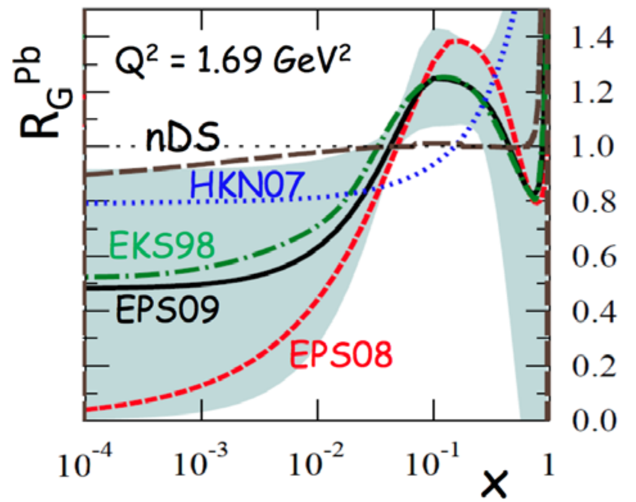
Forward spectrometer
$1.2 < \eta < 3$

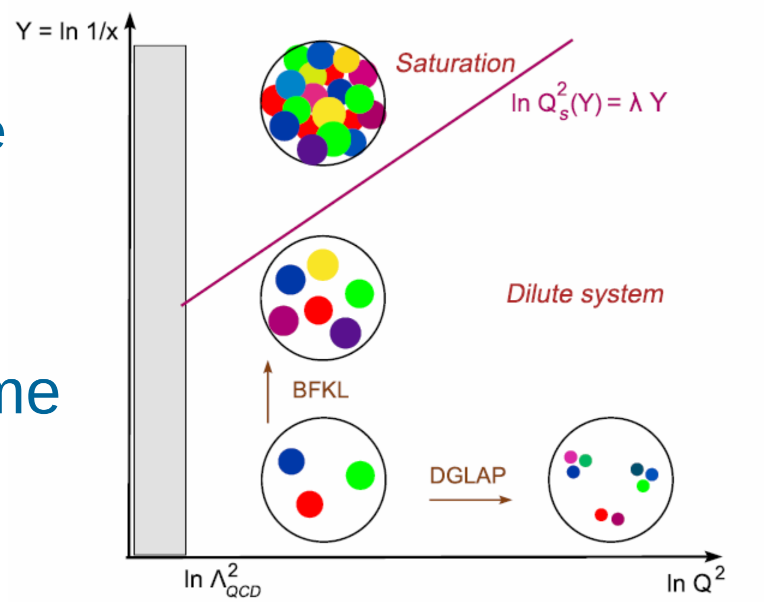
Very forward spectrometer
$3 < \eta < 4$



CNM physics of forward sPHENIX

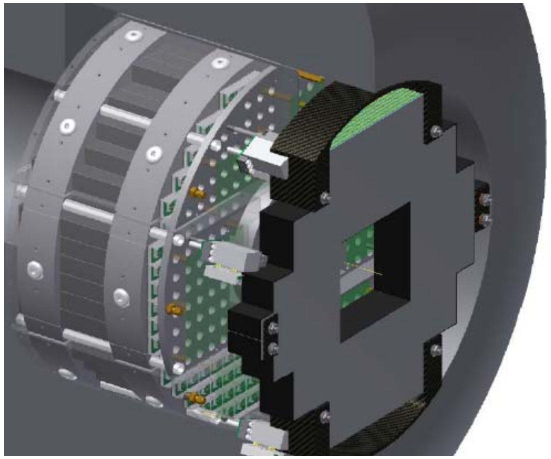
- Cold Nuclear Matter (CNM) effects
- Measurement of the nuclear gluon distribution $G_A(x)$
  - To know Initial state of heavy-ion collisions
  - Precision understanding of strongly-coupled QGP
- Search for gluon saturation, or suppression of $G_A(x)$ at small-x and verify CGC (color glass condensation) framework
  - CGC: effective field theory to describe the saturated gluon
- Energy loss of partons and p_T broadening
- Hadronization mechanisms and time scales





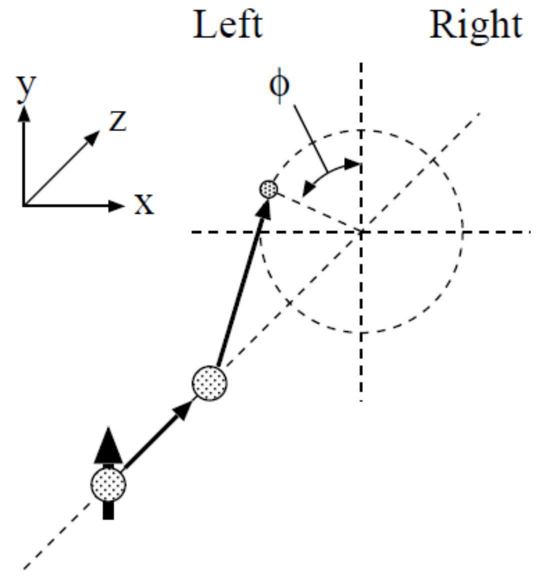
CNM physics of forward sPHENIX

- Current measurements
  - J/ψ and hadron-hadron correlations over a broad range of rapidity
    - Sensitive to extended range of x
  - Open heavy-flavor and a first look at Drell-Yan
    - With FVTX installed in 2012
    - Comparison data to J/ψ



- MPC + MPC-EX upgrade (2014–)
  - Electromagnetic calorimeter + preshower
  - $3.1 < \eta < 3.8$ in the muon piston
  - Prompt-γ
- Forward sPHENIX
  - Quarkonia, vertex-tagged open heavy-flavor, inclusive hadrons and fully-reconstructed jets, jet-jet correlations, and Drell-Yan
    - Much more extended kinematic reach
    - Smaller statistical and systematic uncertainties
    - Different energies and nuclear species

Spin physics of forward sPHENIX



- Single transverse-spin asymmetry

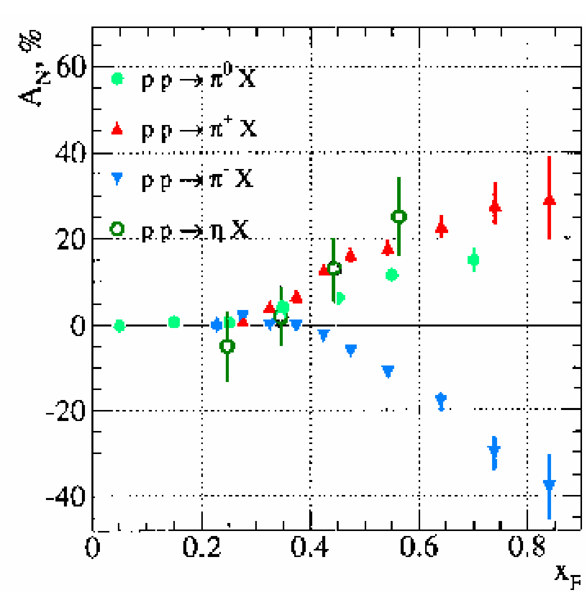
$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

  - Expected to be small in hard scattering at high energies

$$A_N \approx \frac{m_q \alpha_S}{p_T} \approx 0.001$$

Kane, Pumplin, Repko
PRL 41 1689 (1978)

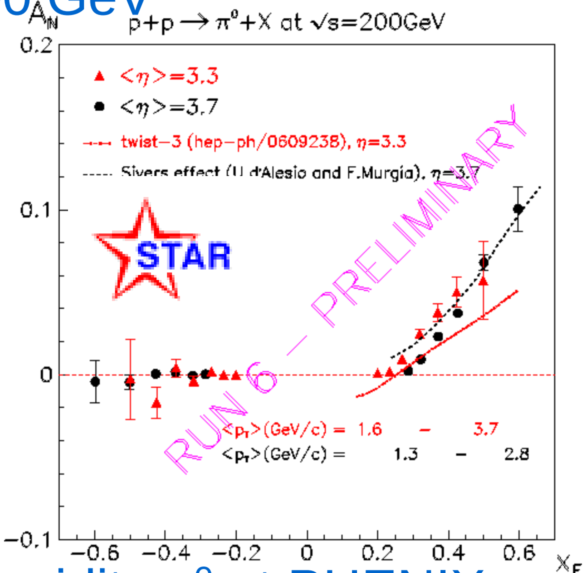
- FNAL-E704
  - Unexpected large asymmetry found in the forward-rapidity region
  - Development of many models based on perturbative QCD



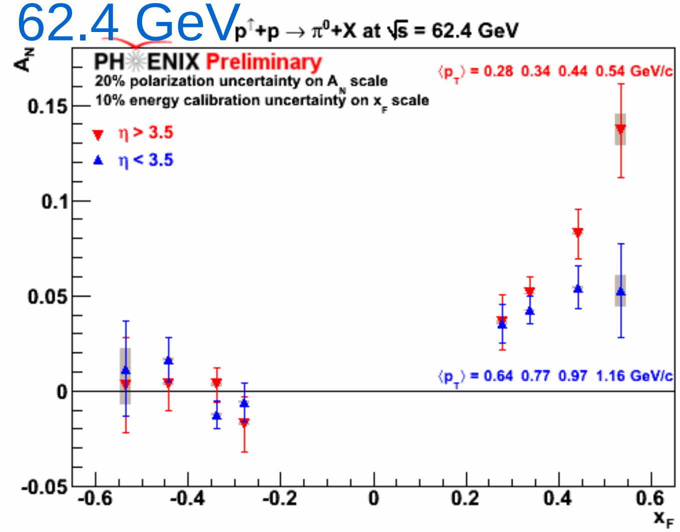
$x_F = 2p_L/\sqrt{s}$ (Feynman's x)

Transverse-spin physics

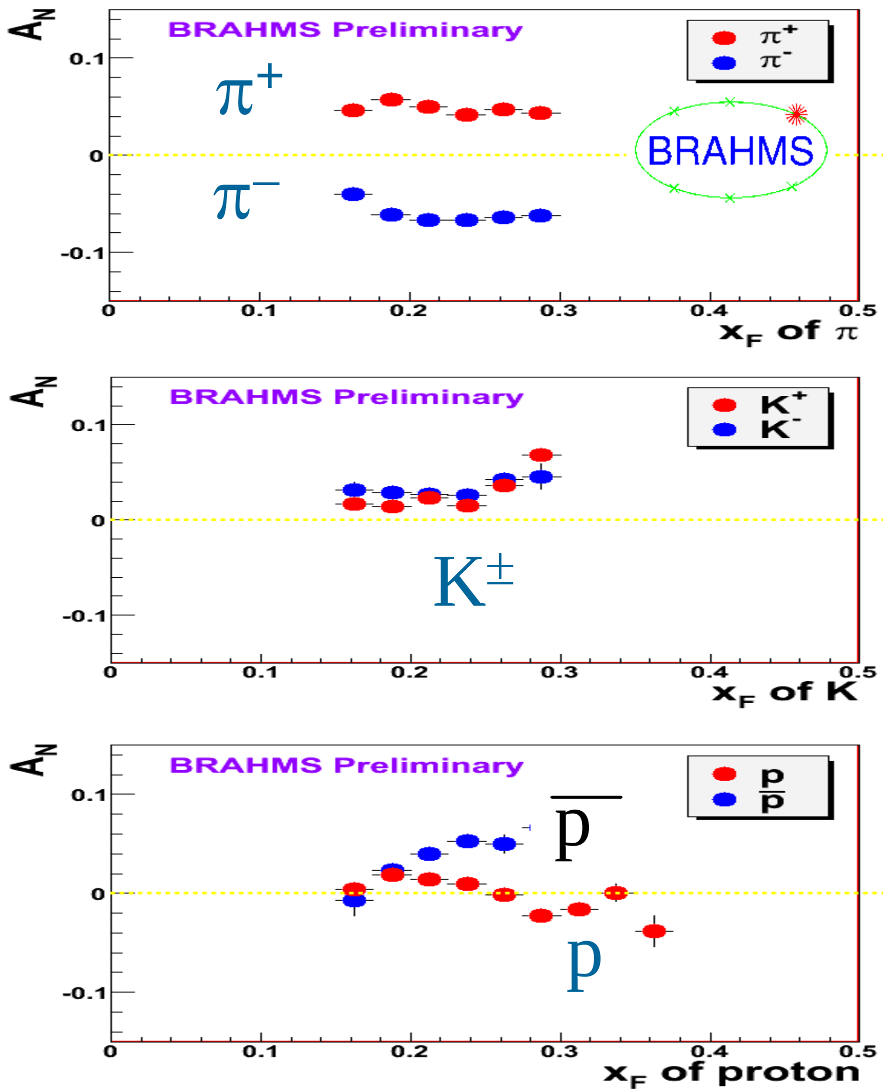
Forward rapidity π^0 at STAR
at $\sqrt{s}$ = 200 GeV



Forward rapidity π^0 at PHENIX
at $\sqrt{s}$ = 62.4 GeV



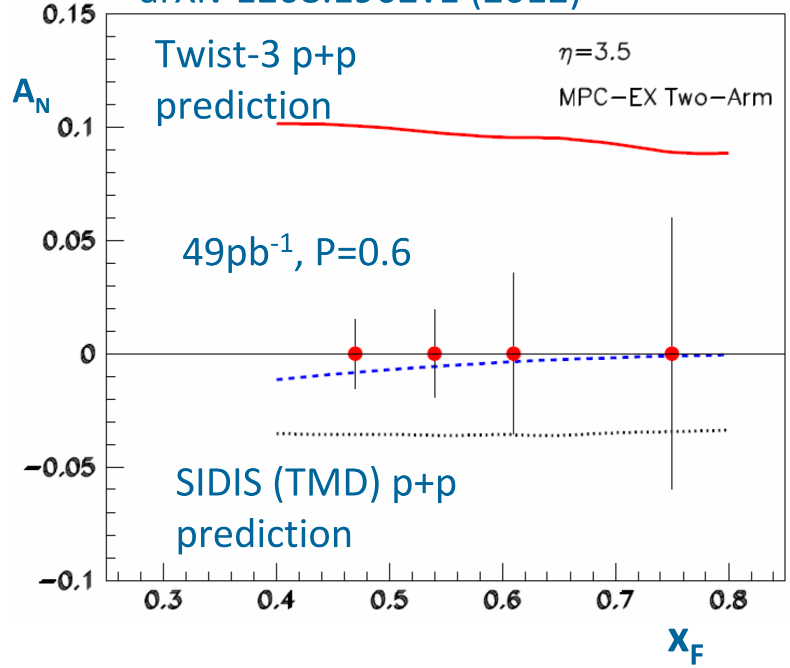
Forward identified particles
at BRAHMS

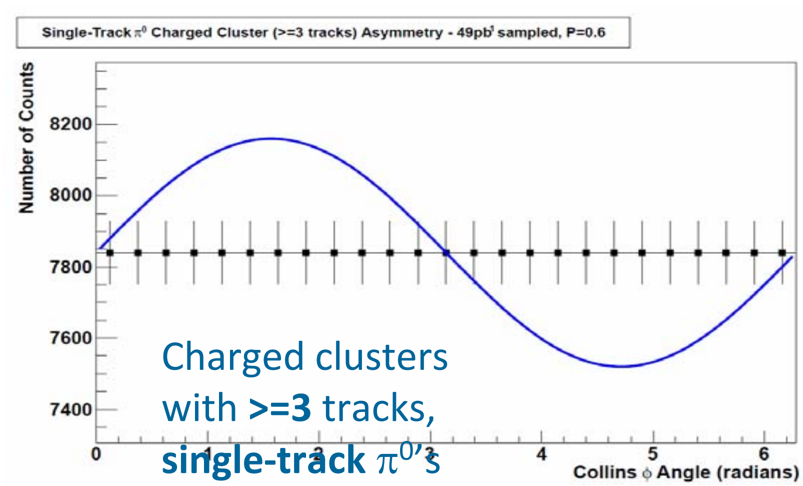


Transverse-spin physics

- Perturbative-QCD models
  - Sivers effect
    - Sivers distribution (initial state)
  - Collins effect
    - Transversity distribution (initial state) + Collins fragmentation (final state)
  - Higher-twist effect
- MPC-EX (2014–)
  - Prompt photon asymmetry
    - To distinguish Sivers effect and higher-twist effect
  - Collins asymmetry in jet
    - π^0 correlations with jet-like clusters

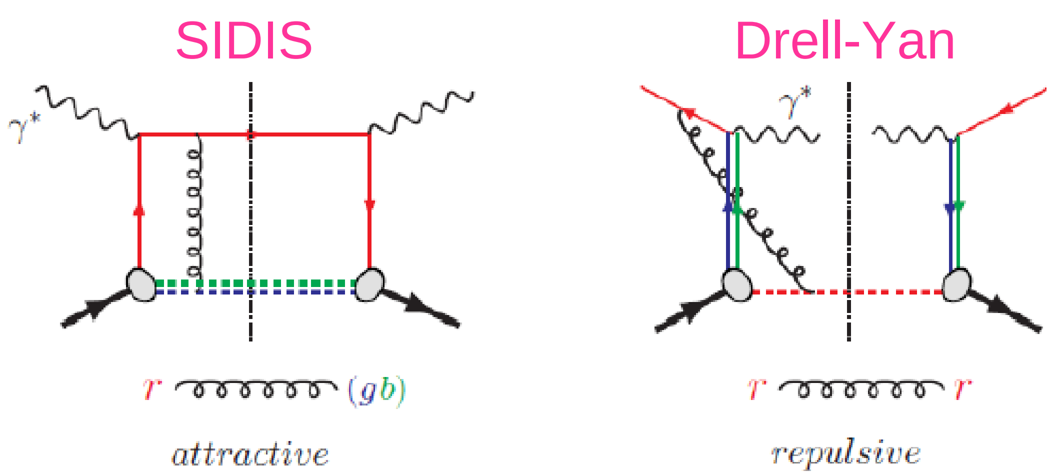
Phys Rev. D 83 094001 (2011)
arXiv 1208.1962v1 (2012)



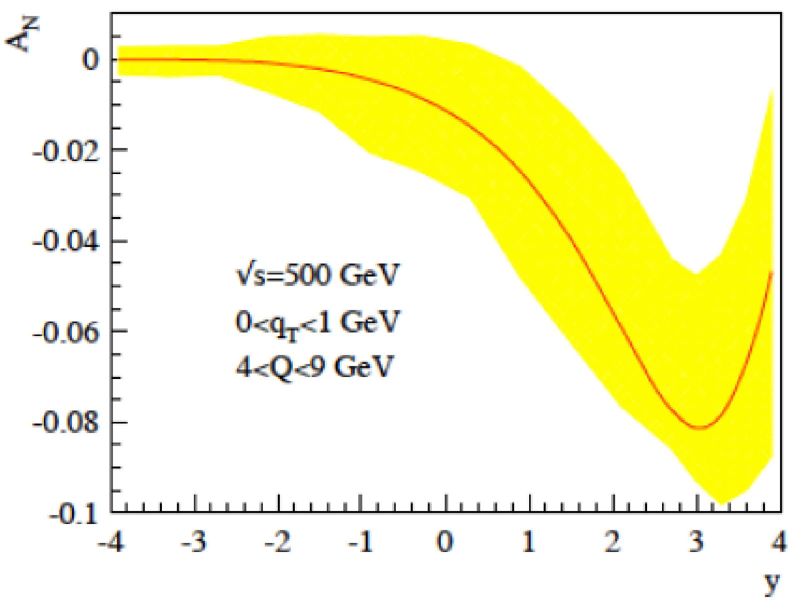


Spin physics of forward sPHENIX

- Transverse-momentum dependent (TMD) phenomena in nucleon structure
  - Sivers effect in Drell-Yan process
    - Comparison of Sivers function measured by polarized semi-inclusive DIS process
    - Competitive program in the world for establishment of the TMD framework

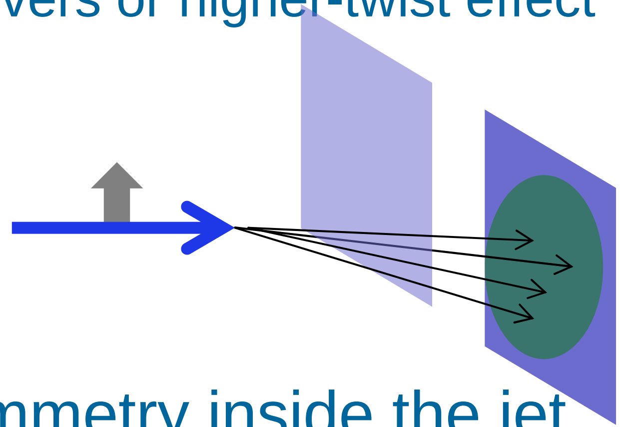


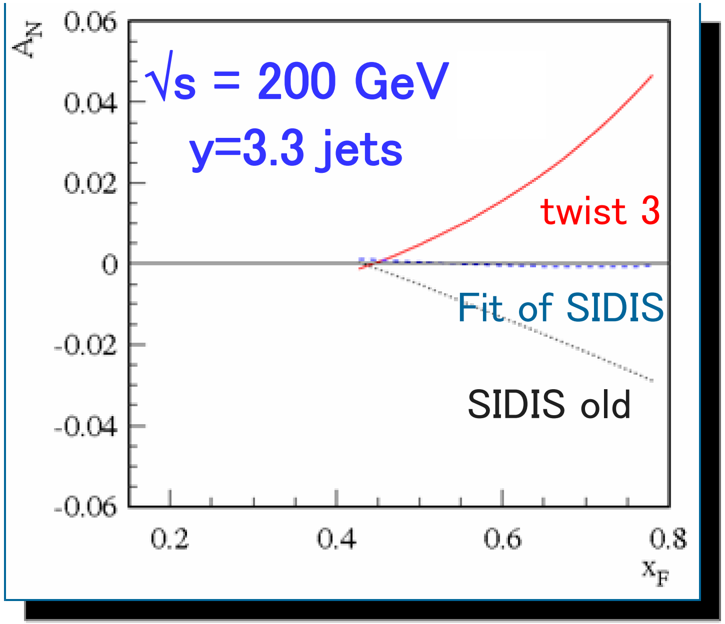
$$f^{Sivers}(x, k_T)|_{SIDIS} = -f^{Sivers}(x, k_T)|_{DY}$$



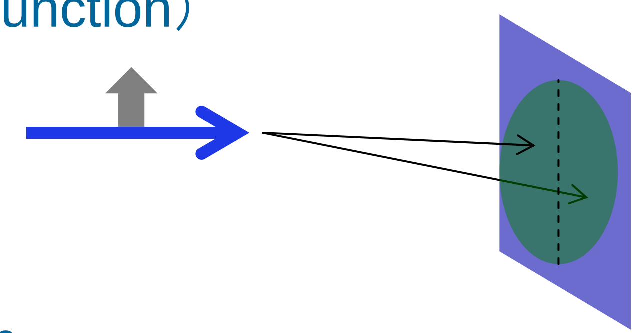
Spin physics of forward sPHENIX

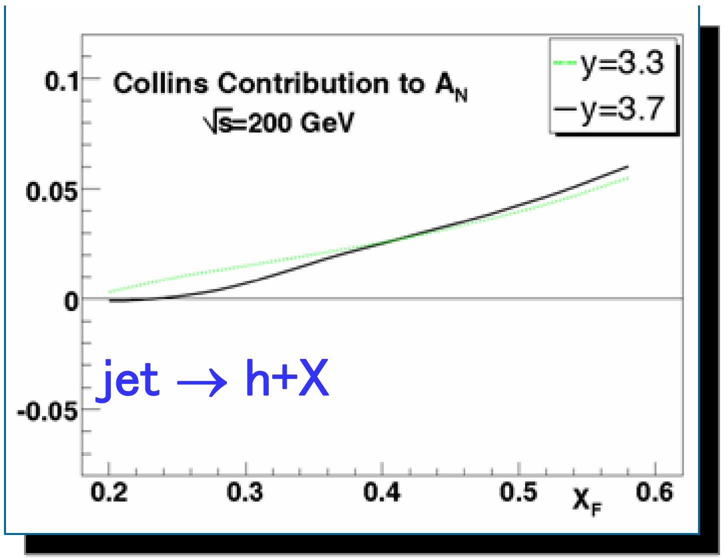
- TMD phenomena in nucleon structure
  - Jet asymmetry measurement
    - Sivers or higher-twist effect





  - Asymmetry inside the jet
    - Collins function (Collins effect)
    - IFF (Interference Fragmentation Function)

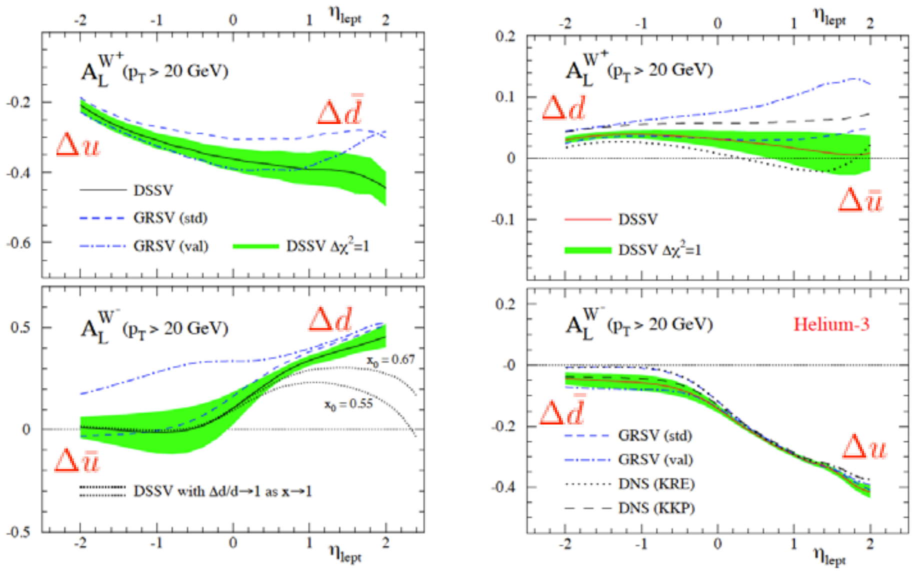




Spin physics of forward sPHENIX

PHENIX

- Sustained study of precision PDF measurements
  - Gluon helicity distribution
  - Quark and anti-quark helicity distributions in W-production
- Polarized neutron with polarized Helium-3 beam
- Polarized-proton nuclei collision for saturation study
  - Link between CNM and Spin
  - Transverse single-spin asymmetries in polarized p+A collisions are sensitive to the saturation scale in the nucleus



$$\frac{A_N^{pA\to hX}}{A_N^{pp\to hX}} \underset{p_T^h << Q_s^2}{\approx} \frac{Q_{s,p}^2}{Q_{s,A}^2} f(p_T^h)$$

$$\frac{A_N^{pA\to hX}}{A_N^{pp\to hX}} \underset{p_T^h >> Q_s^2}{\approx} 1$$

Z.-B.Kan and F.Yuan PRD84, 034019 (2011).

Physics of forward sPHENIX

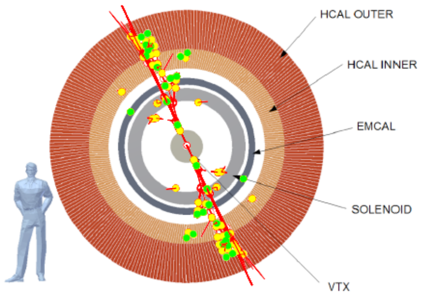
- Forward heavy-ion physics
  - Pioneered by PHOBOS and BRAHMS
  - Direct photons can give information about the expansion of the medium
  - Correlation measurements can test models of longitudinal expansion
  - Extended jet / dijet / γ-jet coverage to study jet energy loss in the medium
  - How far forward the measurements will be able to be made?

Summary

- sPHENIX upgrade proposal was submitted to DOE
  - For precision jet / dijet / γ-jet measurements to understand the nature of the strongly-coupled QGP
  - More information in arXiv:1207.6378
- Future options
  - Midrapidity tracking and preshower
- Forward sPHENIX upgrades
  - Cold nuclear matter effects
  - Spin physics
  - Towards the ePHENIX at eRHIC
- For long-term enhancement for major physics programs

An Upgrade Proposal from the PHENIX Collaboration

July 1, 2012
Updated March 22, 2013



Backup slides…

Transverse-spin physics

- Perturbative-QCD models
  - Sivers effect
    - Sivers distribution (initial state)
  - Collins effect
    - Transversity distribution (initial state) + Collins fragmentation (final state)
  - Higher-twist effect
- Many-body correlation of quarks and gluons
  - Sivers effect on TMD (transverse-momentum dependent) factorization
    - Transverse structure of the nucleon
    - Spin-orbit correlation
      - LS force inside the nucleon
  - Higher-twist effect on collinear factorization
    - Parton reaction