Forward sPHENIX upgrade

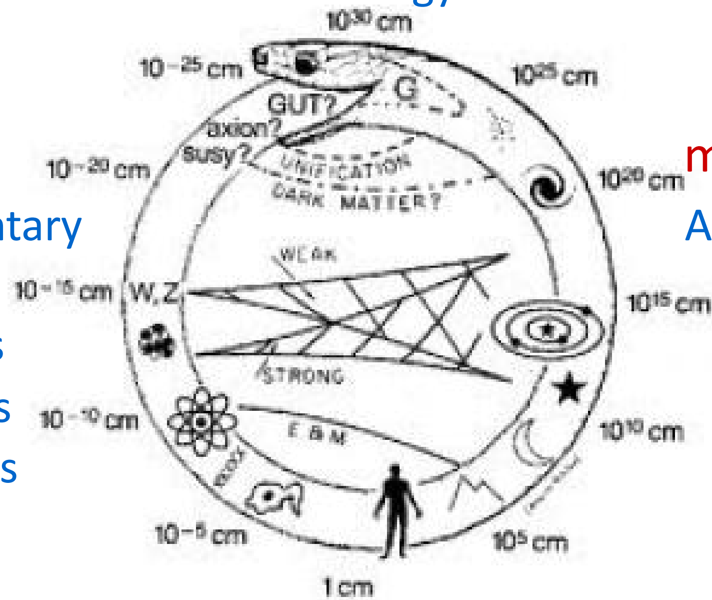
Japan-Korea PHENIX collaboration workshop
at Sungkyunkwan University in Suwon
November 4th, 2013

Yuji Goto (RIKEN)

Hierarchy in Nature

- Glashow’s ouroboros

Cosmology



microscopic

High-energy elementary particle physics

Quark-gluon physics

Hadron physics

Nuclear physics

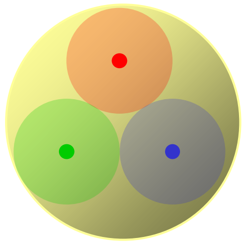
macroscopic

Astrophysics

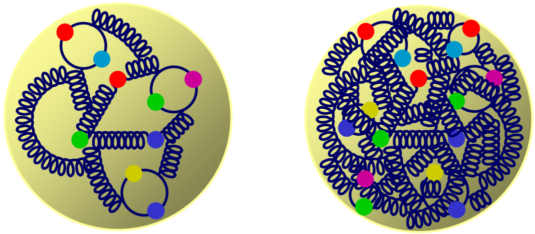
- Quark-gluon physics
  - State and structure of matter
  - Interaction and symmetry (breaking)
- Gap between “quark-gluon” and “hadron”

Nucleon structure

- Constituent-quark model
  - Quarks with the effective mass (caused by the gluon)
  - Explains the magnetic moment of the nucleons
  - But, the quark spin cannot explain the nucleon spin (“spin puzzle”)



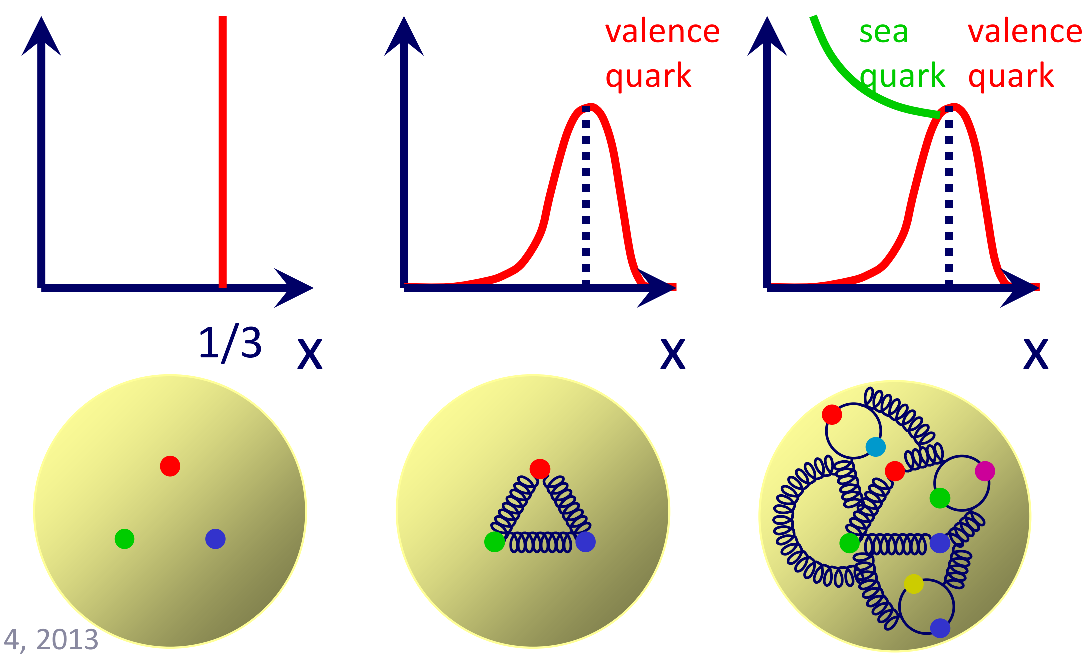
- Quark-gluon model
  - Current quarks and gluon interaction
  - Initial state of high-energy hadron colliders



- Understanding the differences (or gap) of these models
  - Chiral symmetry (breaking)
  - Confinement

Nucleon structure

- Nucleon: the simplest multi-body system for studying dynamics of confined quarks and gluons
- Simple parton picture
  - 1-dimensional picture: in "longitudinal" direction
  - The nucleon consists of incoherent quarks and gluons
  - Described by the parton distribution functions (PDF)



x: Bjorken's x
"longitudinal" momentum fraction (1-dimensional picture)

Origin of the nucleon spin 1/2

- Expected to be explained by the quark spin (from the constituent quark model)
- Experiments
  - CERN-EMC experiment (polarized DIS experiment)
    - Quark-spin contribution

      $\Delta\Sigma = \Delta u + \Delta d + \Delta s = 12 \pm 9(\mathrm{stat}) \pm 14(\mathrm{syst})\%$
    - Combining with neutron and hyperon decay data
    - Total quark spin constitutes a small fraction of the nucleon spin
    - Integration in x = 0 ~ 1 makes uncertainty
  - SLAC/CERN/DESY/JLAB experiments
    - More data to cover wider x region with more precision
- Based on the quark-gluon model

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L$$

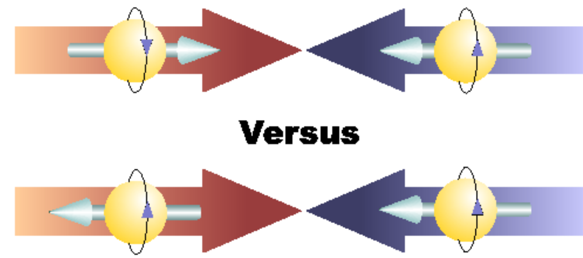
Orbital angular momentum

Gluon spin contribution

Quark spin contribution

Helicity structure of the nucleon

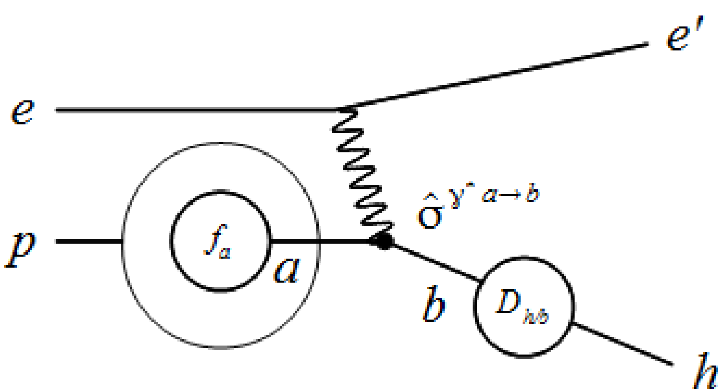
- Longitudinally polarized experiment
  - Polarized in beam or collision direction



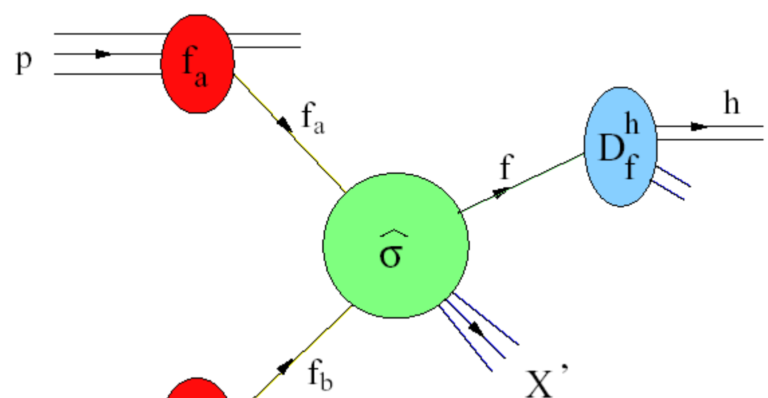
$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}$$

  - $f_a(x)$ or $q(x)$: parton distribution function (PDF)
    - "universal" property of the nucleon – same in all reactions

Deep Inelastic Scattering (DIS)



p+p Collision



unpolarized structure function

$$\boxed{F_2(x) = x \sum_a e_a^2 f_a(x)}$$

$$\Updownarrow$$

polarized structure function

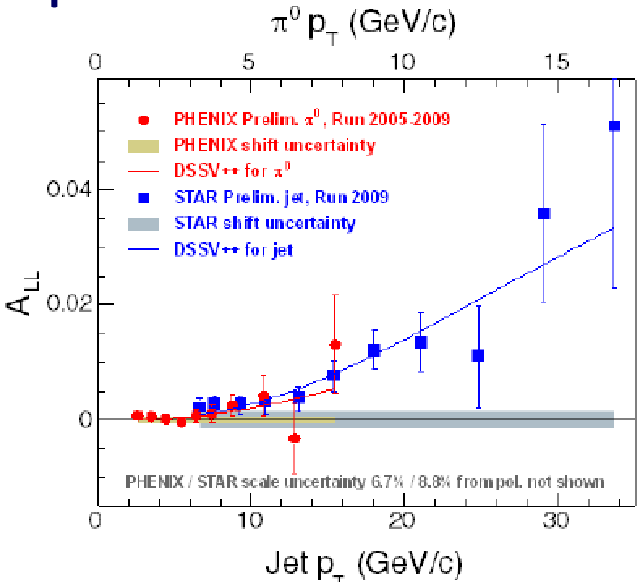
$$\boxed{g_1(x) = \sum_a e_a^2 \Delta f_a(x)}$$

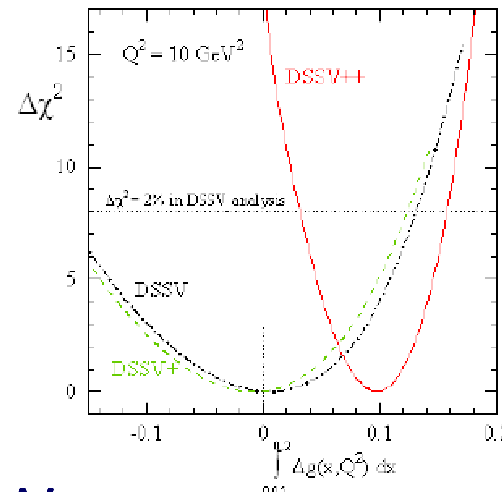
$\Delta f_a(x)$ or $\Delta q(x)$: polarized PDF

Polarized p+p collision at RHIC

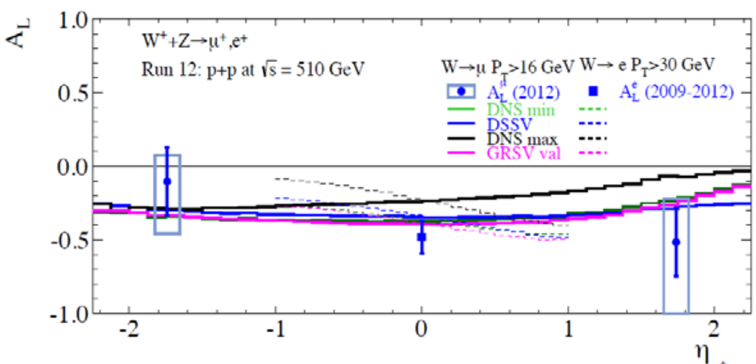
- Gluon polarization

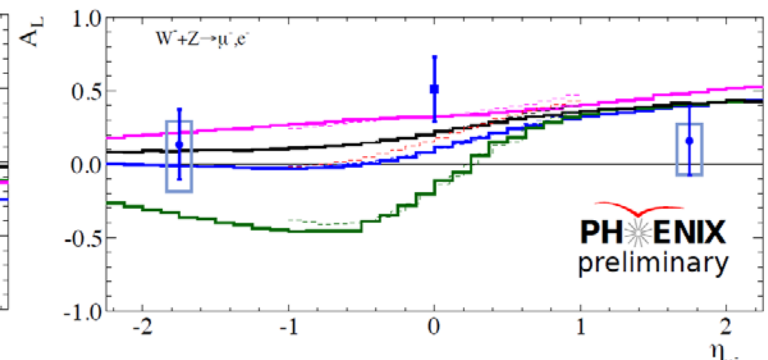
$$\int_{0.05}^{0.2} \Delta g(x)\,dx = 0.1 \pm^{0.06}_{0.07}$$





- Sea quark polarization with W measurement

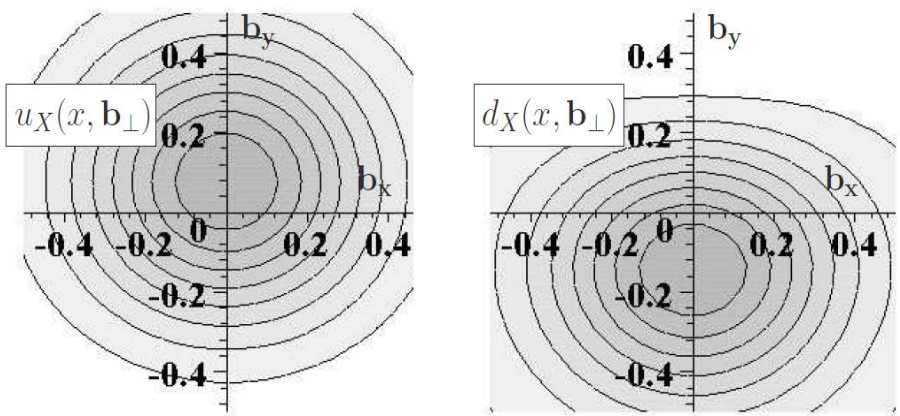




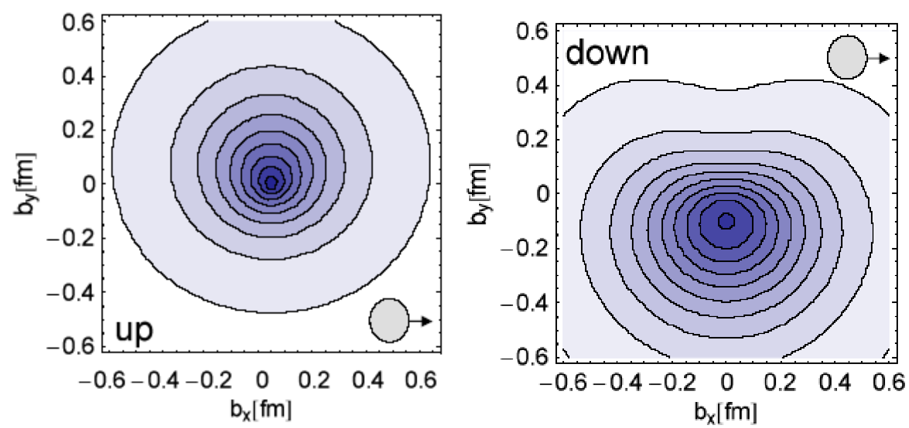
- Next direction: Orbital angular momentum

3-dimensional nucleon structure

- Nucleon structure beyond the simple parton picture
- Many-body correlation of partons
  - To describe the orbital motion inside the nucleon
- Parton distribution in transverse direction
  - Extended/generalized picture of the parton distribution
  - Transverse-momentum dependence (TMD)
  - Space distribution (tomography)



Phenomenological model
with GPD data



Lattice QCD calculation

Transverse structure of the nucleon

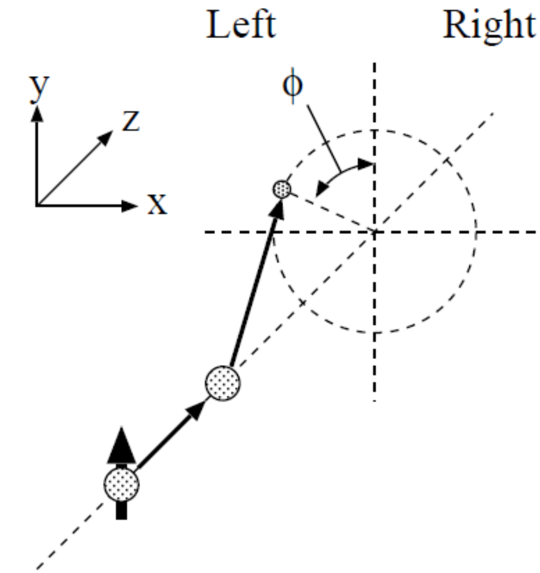
- Single transverse-spin asymmetry

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

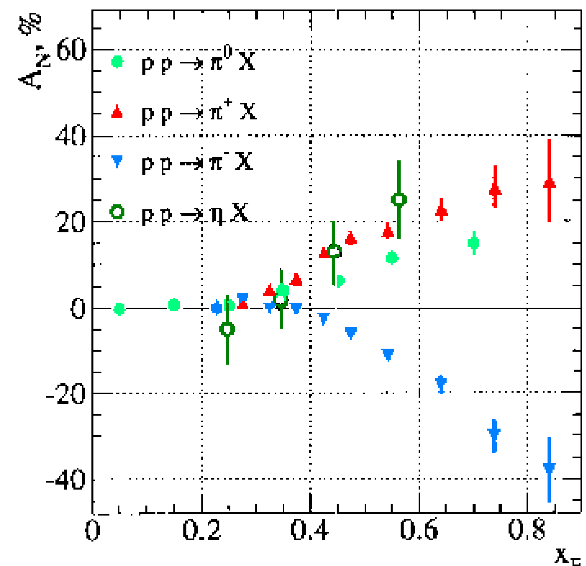
  - Expected to be small in hard scattering at high energies

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

Kane, Pumplin, Repko
PRL 41 1689 (1978)

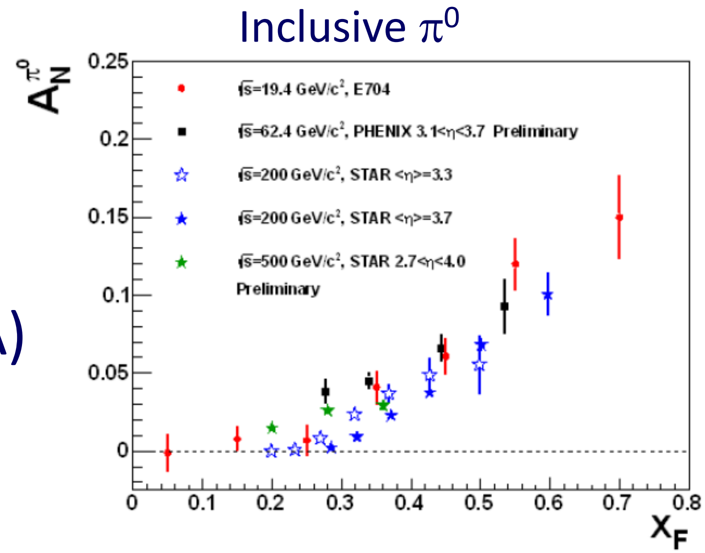


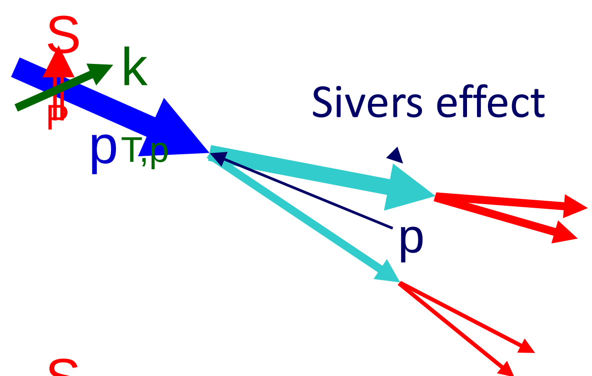
- FNAL-E704
  - Unexpected large asymmetry found in the forward-rapidity region
  - Development of many models based on perturbative QCD

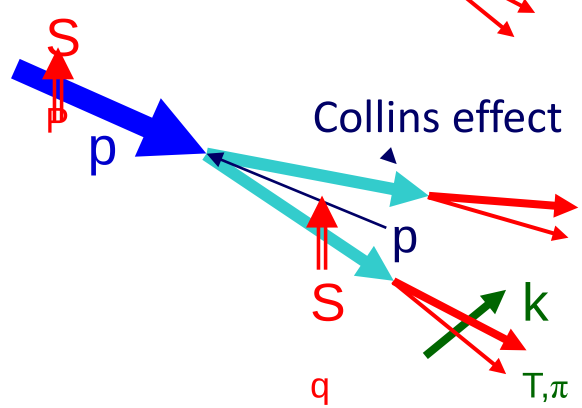


Transverse-spin physics

- For establishment of TMD and higher-twist approach
  - Single transverse-spin asymmetry (SSA) of inclusive hadrons
  - Sivers effect
    - Sivers distribution function (initial state)
  - Collins effect
    - Transversity distribution (initial state)
    - Collins fragmentation function (final state)
  - Higher-twist effect
    - quark-gluon & multi-gluon correlation
- Two milestones
  - non-universality of TMD distribution function
  - sign mismatch of TMD and higher-twist

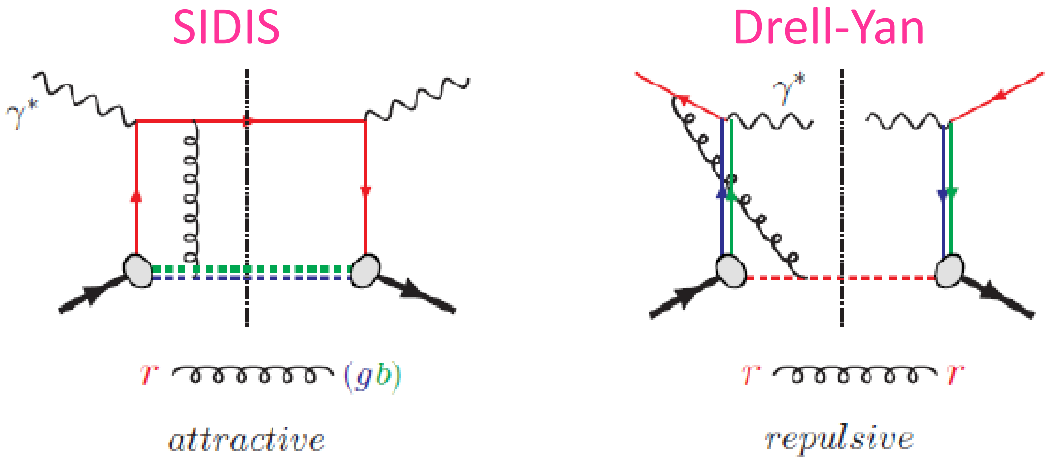






Non-universality of TMD distribution function

- Opposite-sign contribution of TMD distribution function to SSA in semi-Inclusive DIS (SIDIS) process and Drell-Yan process



$$f_{1T}^{\perp q}|_{\mathrm{SIDIS}} = -f_{1T}^{\perp q}|_{\mathrm{DY}}$$

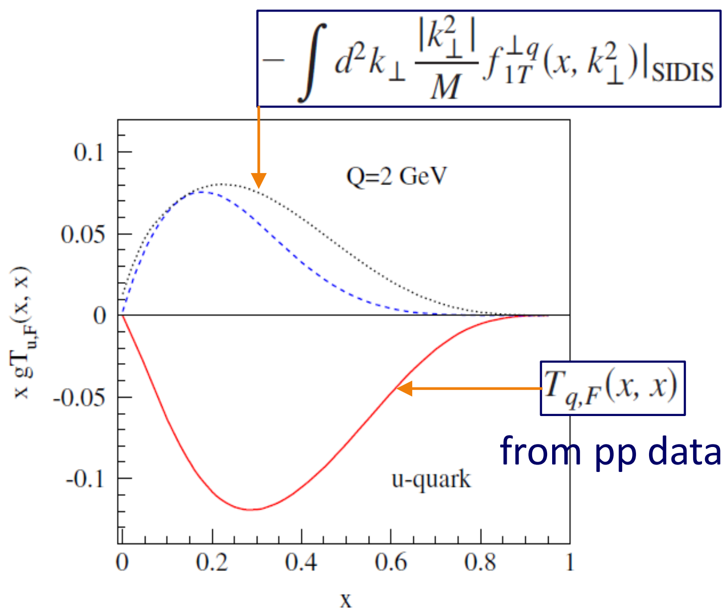
- Fundamental property based on gauge invariance of QCD
- Experimental verification required
  - Understanding in wide kinematic range from fixed target experiments to collider experiments
  - Polarized Drell-Yan experiments
    - COMPASS, SeaQuest, RHIC(, GSI-FAIR, NICA, …)
  - Polarized SIDIS experiments
    - eRHIC

Sign mismatch of TMD and higher-twist

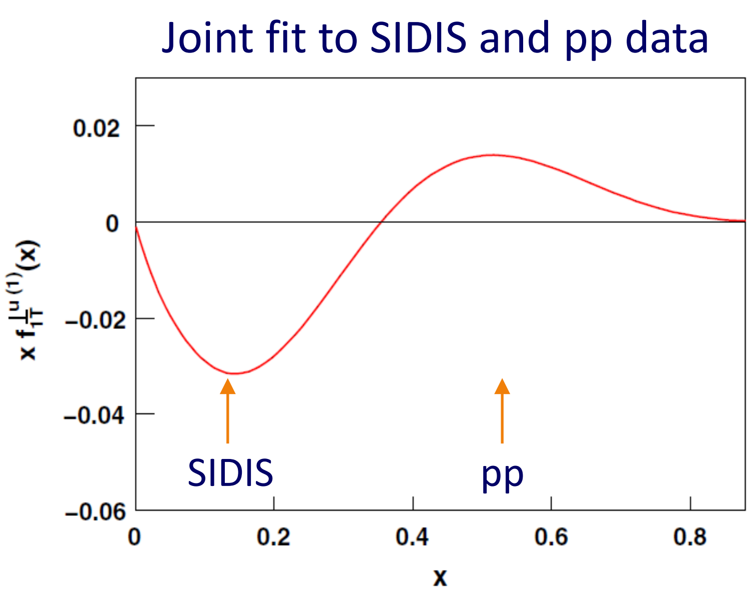
- TMD description at low p_T region, higher-twist description at high p_T region, and consistent description in the middle region

$$T_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp^2|}{M} f_{1T}^{\perp q}(x,k_\perp^2)|_{\text{SIDIS}}$$

- But, sign mismatch of each description obtained from experiments
  - Large contribution from Collins effect in transversely-polarized proton collisions?
  - Polarized SIDIS experiment at high x region?



Kang, Qiu, Vogelsang, Yuan (2011)



Kang, Prokudin (2012)

Present timeline

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	• Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		• Transition to eRHIC

Detector upgrade project of the PHENIX experiment

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
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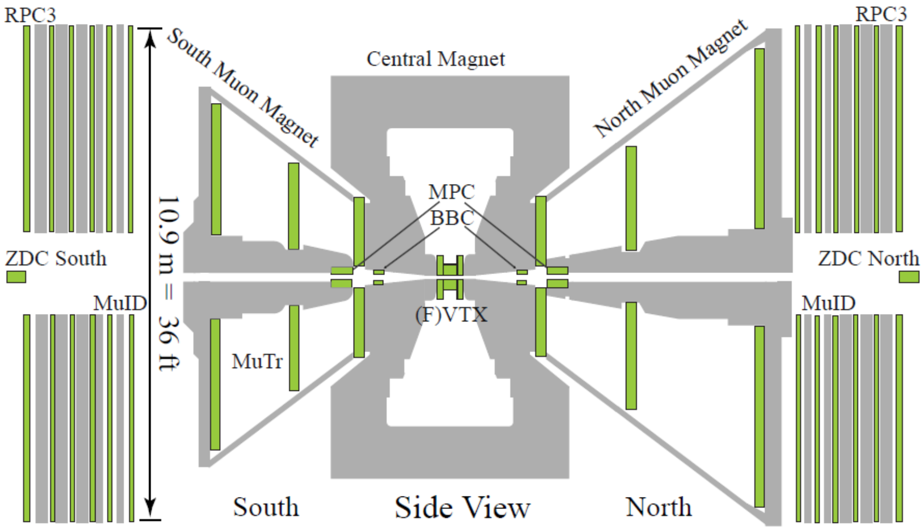
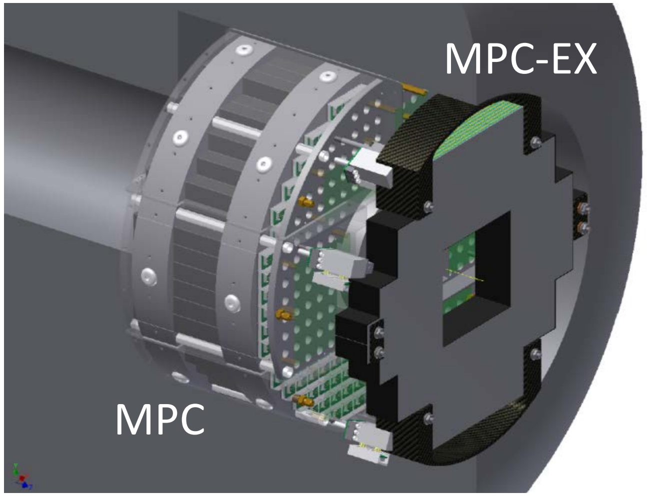
- MPC (Muon Piston Calorimeter)
  - Electromagnetic calorimeter
- MPC-EX
  - Preshower detector
  - Under construction now
  - Commissioning in 2014
  - Experiment in 2015-2016
- $3.1 < \eta < 3.8$
  - Installed in the muon piston

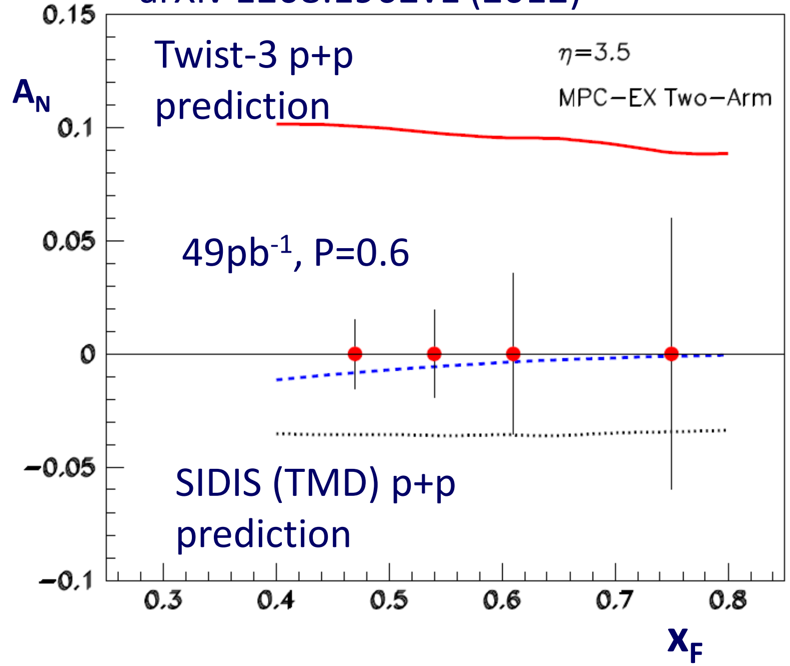


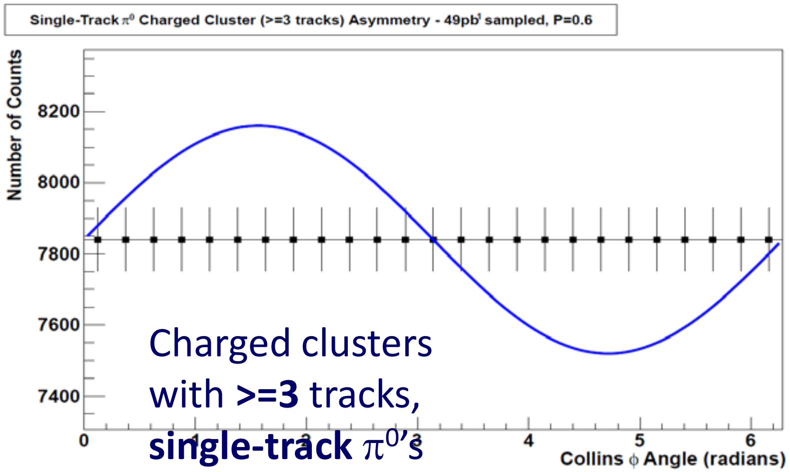
MPC-EX



- 3.1 < η < 3.8
  - Installed in the muon piston
- Direct photon asymmetry
  - To distinguish the Sivers effect and the higher-twist effect
- Collins asymmetry in jets
  - π^0 correlation with jet-like clusters

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





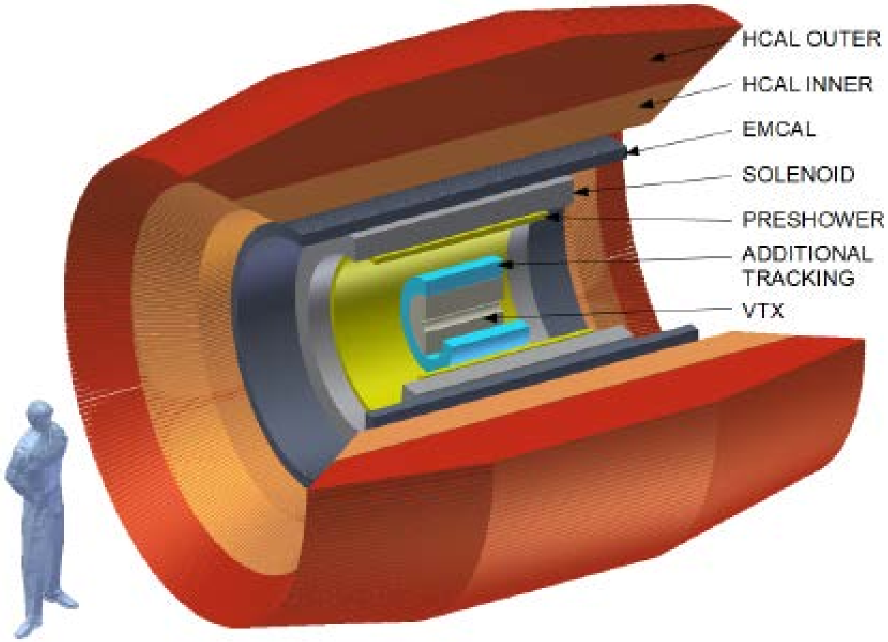
Detector upgrade project in the PHENIX experiment

- sPHENIX
  - Barrel upgrade
  - Forward upgrade
  - Partial installation and commissioning in 2018-2019
  - Completion and experiment in 2021-2022
- ePHENIX at eRHIC
  - Transition to eRHIC in 2023-2024
  - Commissioning and experiment start in 2025

2018-2019	• 5-20 GeV Au+Au (BES-2)	• Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		• Transition to eRHIC

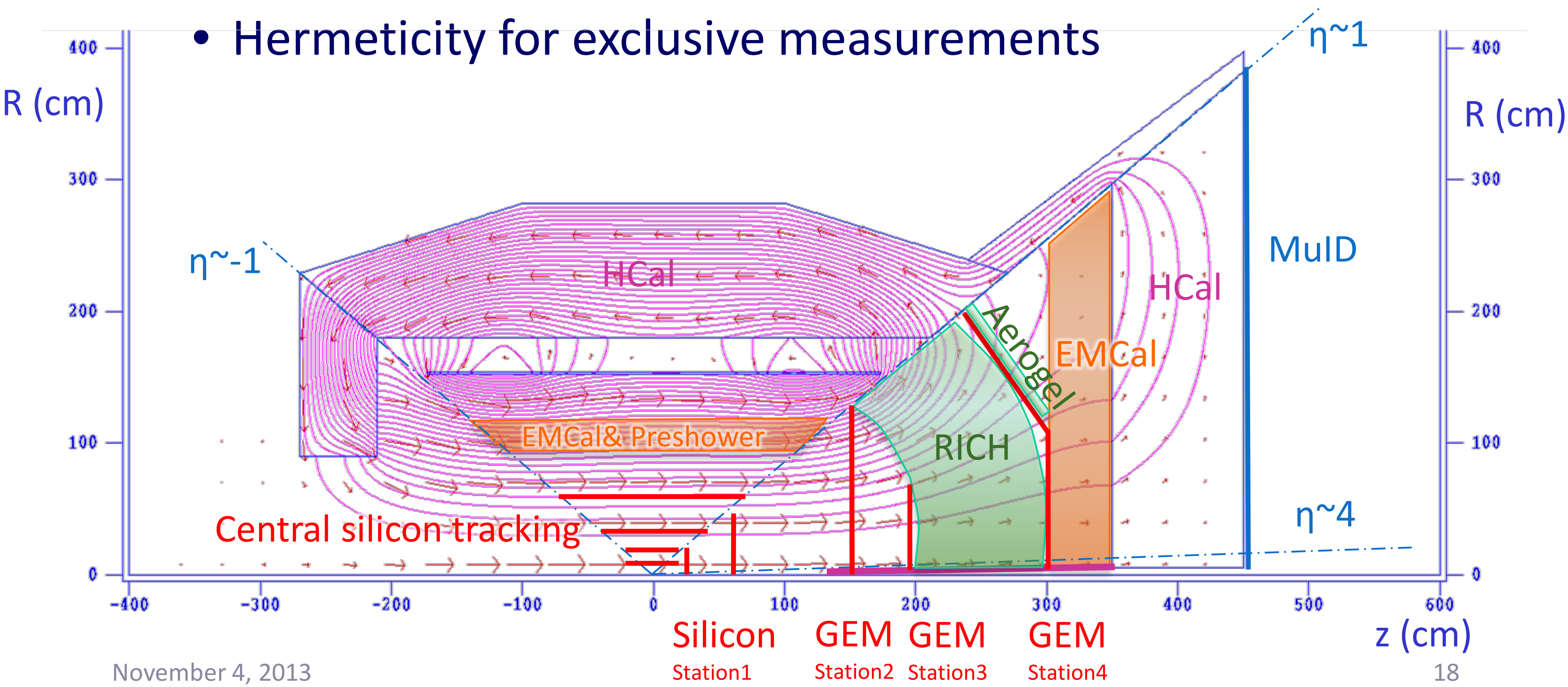
sPHENIX barrel upgrade

- Baseline
  - Compact jet detector
  - Using upgraded RHIC accelerator
  - For precision measurement of jet, dijet, photon-jet correlation to understand the nature of QGP
- Extension
  - Additional tracking layers
  - Preshower detector
  - For heavy-flavor and internal jet structure measurements



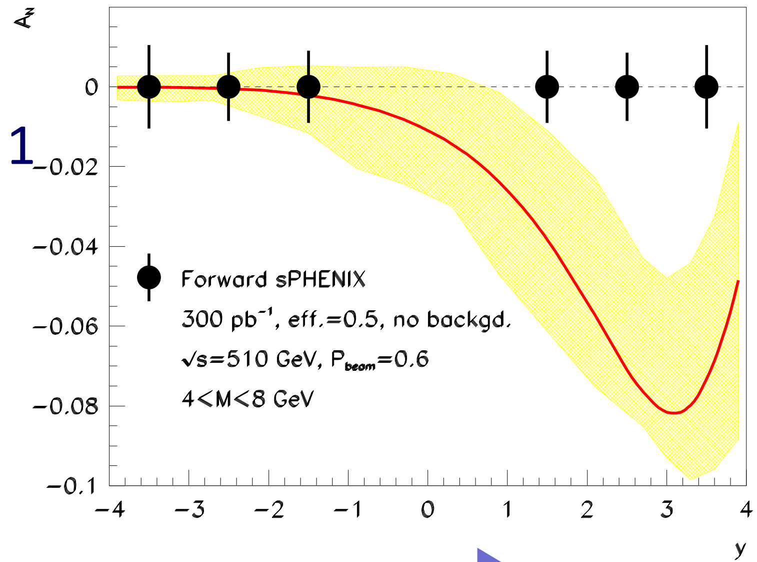
sPHENIX forward upgrade

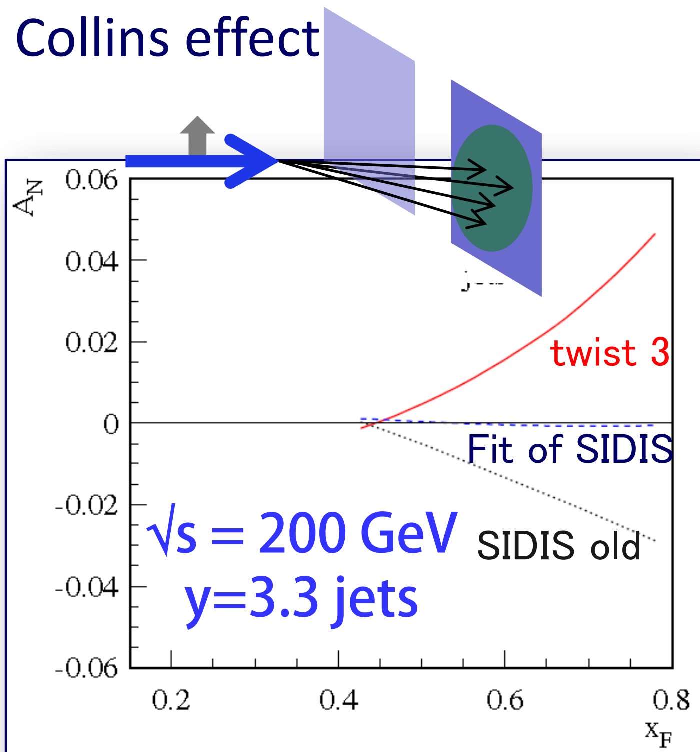
- Open geometry
  - Wide kinematic coverage of photon, jet, leptons and identified hadrons
- Compatible design for eRHIC detector (ePHENIX)
  - Constraint from IR design of eRHIC (|z| < 4.5m)
  - Hermeticity for exclusive measurements

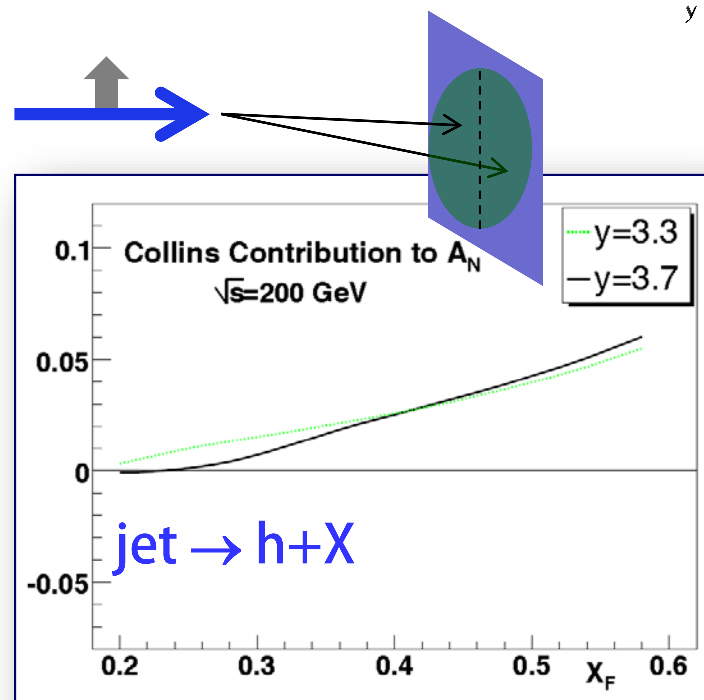


sPHENIX forward upgrade

- Sivers effect in Drell-Yan process
  - Valence quark region at x~0.2 with 1 < η < 4 coverage
- Jet asymmetry
  - Sivers effect or higher-twist effect
- Asymmetry inside of jets
  - Collins effect

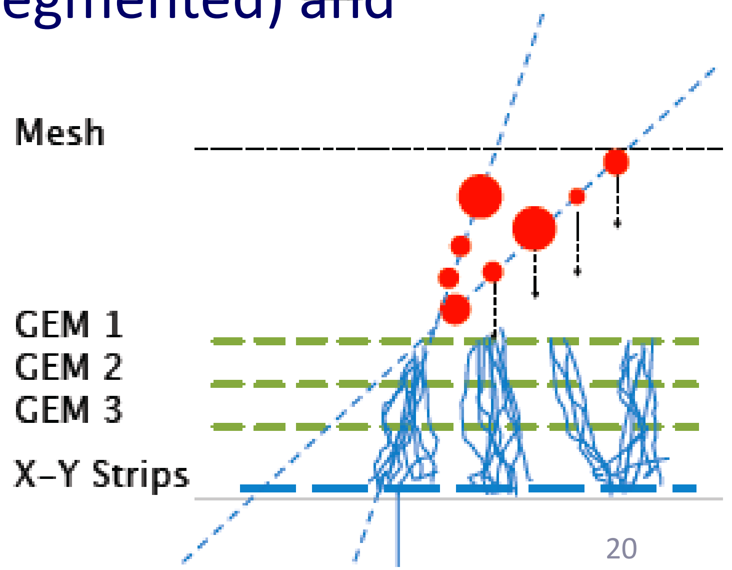






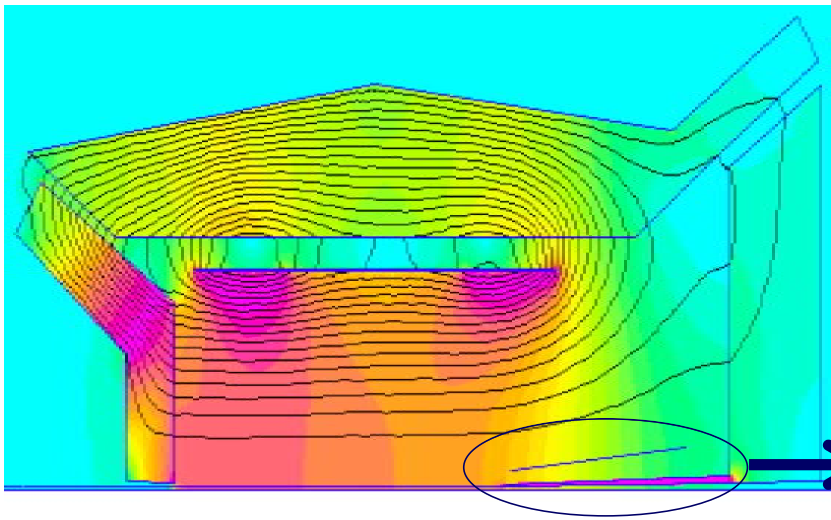
Tracking

- Design parameters
  - Charge sign reconstruction to high momentum
    - dp/p~0.004p for 3-σ charge sign reconstruction at p~60 GeV
    - Needed for both jets and Drell-Yan
  - Enough momentum resolution to use RICH
    - dp/p~0.004p for reasonable ring separation between particle species
  - Constrain J/ψ peak leakage for Drell-Yan
- Current plan
  - 2 new layers of silicon (finely φ segmented) and "rotated" FVTX layers
  - 3 GEM layers

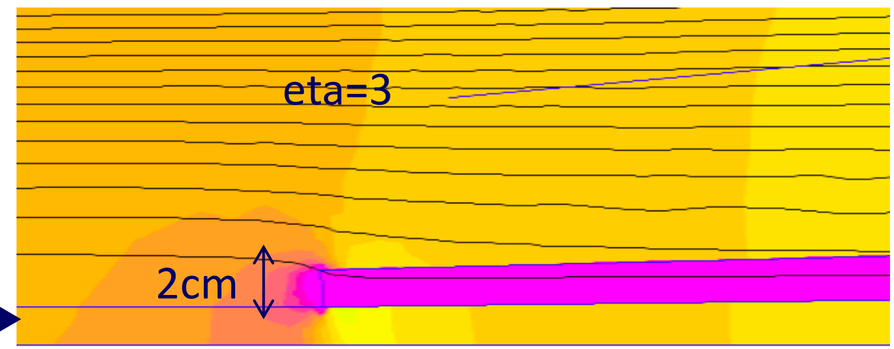


Magnet

- Magnetic field without causing too much stress or background
  - The most challenging part of the forward sPHENIX design



Hiperco-50 (49%Co+49%Fe alloy) passive field shaper provides a boost in the field strength at high eta



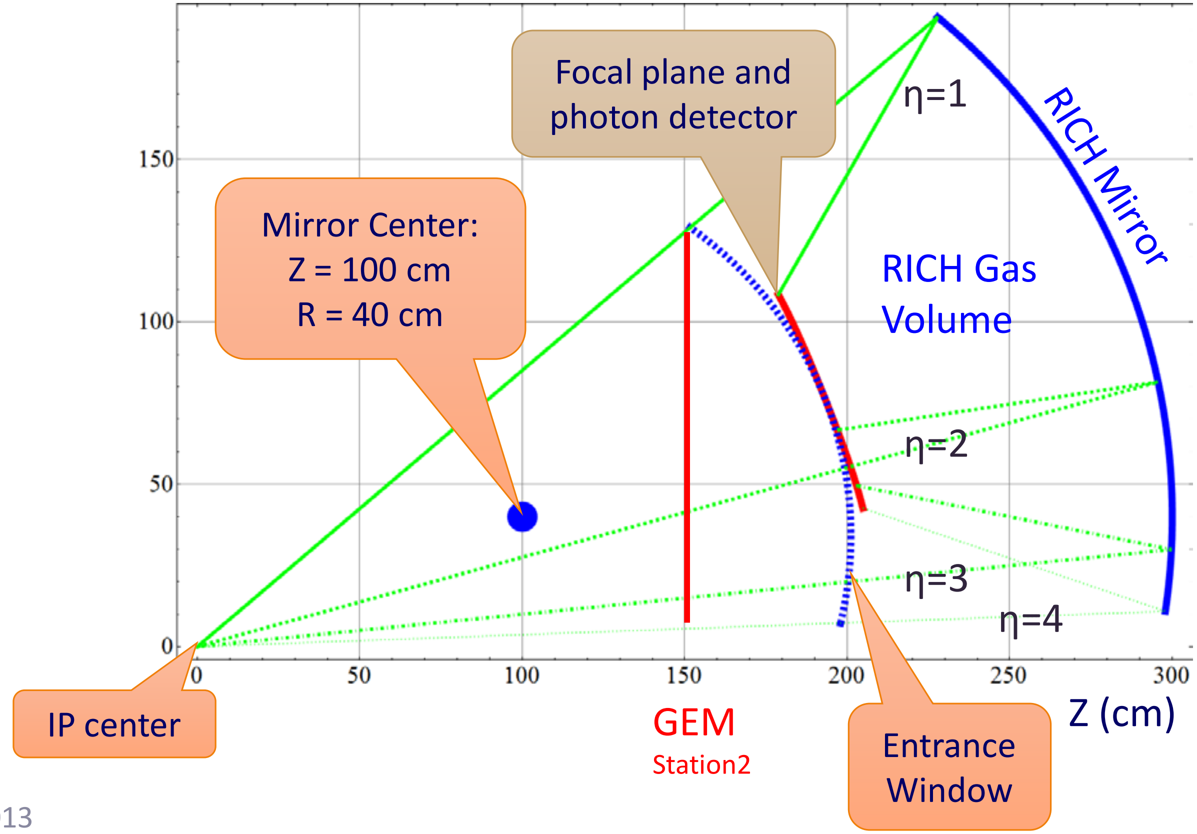
- Passive field shaper + BaBar magnet
  - HCal as a return yoke
  - Passive field shaper surrounding the beam pipe e.g. made by Hiperco-50 (49% Co + 49% Fe alloy) with high magnetic saturation
  - We can achieve the necessary resolution over a large range in pseudo-rapidity

Calorimetry

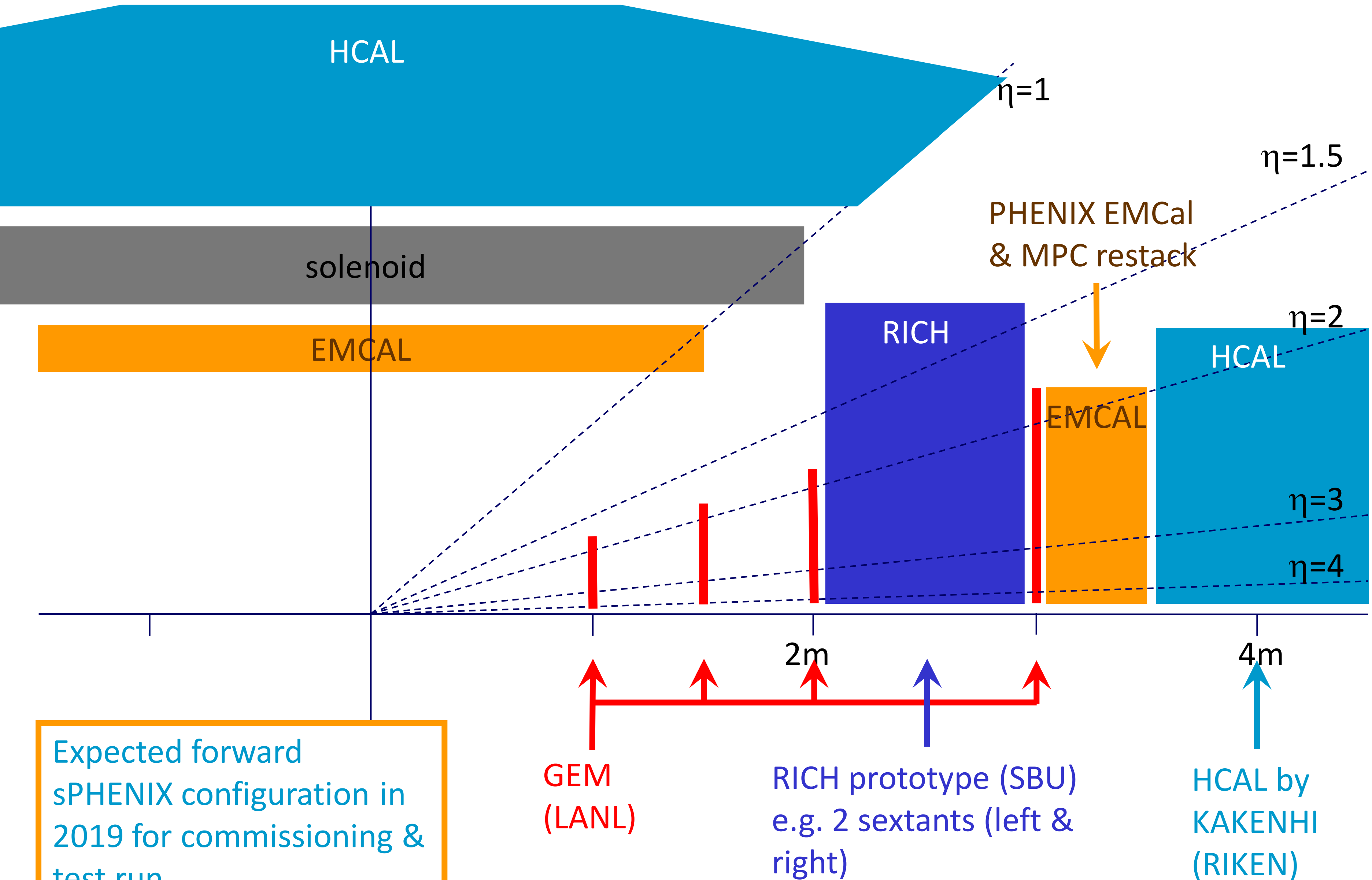
- Design parameters
  - Aid in background rejection for Drell-Yan of e^+e^- channel
  - Reasonable energy resolution for jets and EM particles
  - A+A needs fine segmentation, especially at high η
- Current plan
  - EMCal: restack of the current PHENIX EMCal and MPC with SiPM readout
  - HCal: required resolution is likely not very high
  - Pre-shower?: a simple GEM tracker in front of absorber (W, Pb)

Particle-ID - RICH

- Design parameters
  - Hadron-ID: π/K/p separation above a few GeV/c and to a high momentum ~70 GeV/c
  - Drell-Yan particle-ID
    - Electrons/positrons need sufficient e/π separation
    - Muons need sufficient shielding and identification



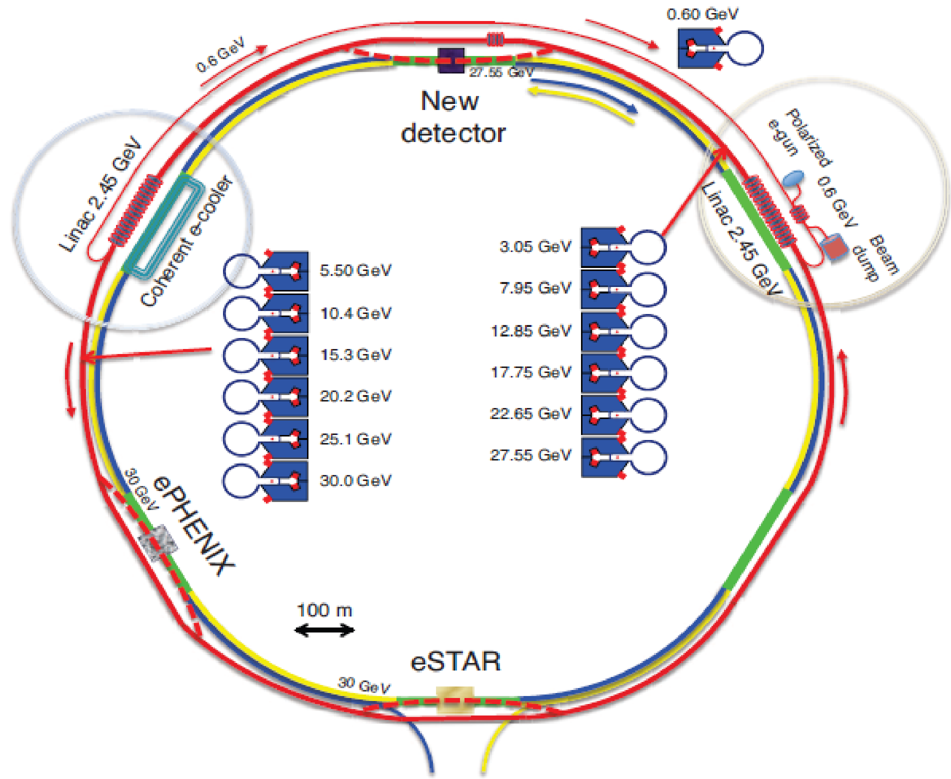
Possible 1st-stage configuration

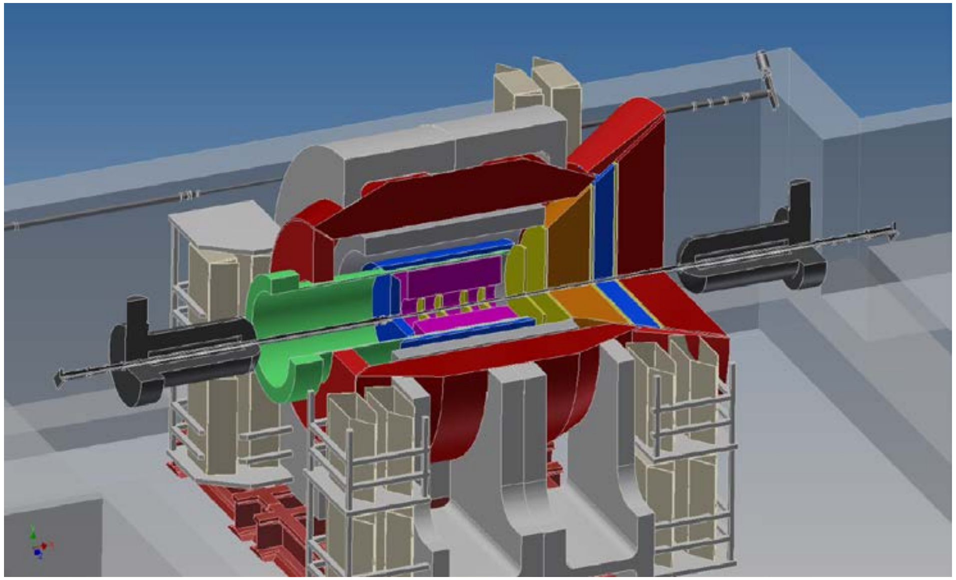


Expected forward sPHENIX configuration in 2019 for commissioning & test run

ePHENIX

- 1^{st} stage eRHIC detector
  - 5GeV-10GeV electron beam
  - 10^{33} $cm^{-2}s^{-1}$ luminosity
- Inclusive DIS
  - Helicity distribution of quarks and gluons
- Semi-inclusive DIS
  - TMD & higher-twist
- Exclusive & diffractive measurements
  - GPD measurement by DVCS (Deeply Virtual Compton Scattering) and HEMP (Hard Exclusive Meson Production) measurement
  - Transverse space distribution inside the nucleon
  - tomography





Summary

- The forward sPHENIX upgrades will give us great opportunities for studying the nucleon spin structure toward understanding of the extended 3-dimensional nucleon structure (and cold nuclear matter)
  - Sivers asymmetry in Drell-Yan process
  - Jet asymmetry measurements
  - (Search for gluon saturation)
- Two milestones with sPHENIX forward upgrade
  - Sign change of the TMD distribution function
    - Polarized Drell-Yan experiment at RHIC and polarized SIDIS experiment at eRHIC
  - Sign mismatch of TMD and higher-twist
    - Distinguish Sivers/higher-twist and Collins/transversity
- Detector design and studies are ongoing with physics requirements
  - Detector configuration
  - Evolution to ePHENIX toward electron-proton collisions at eRHIC

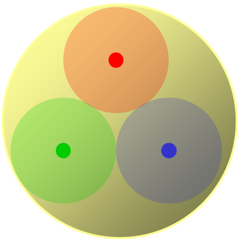
Backup Slides

Outline

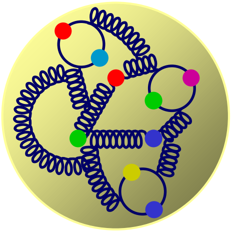
- Introduction
  - Nucleon (spin) structure
- Forward sPHENIX upgrades
- Design
- Physics
  - 3-dimensional nucleon structure
  - Cold nuclear matter
- Evolution to ePHENIX

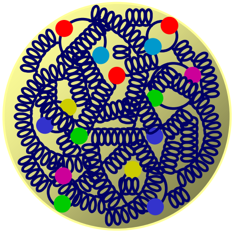
Nucleon structure

- Constituent-quark picture
  - Magnetic moment of the nucleons explained
  - Deeply-inelastic scattering (DIS) experiments have measured quark-spin contribution to the nucleon spin to be about 30%
  - “Spin Puzzle”



- Quark-gluon picture
  - DIS experiments measure current quarks instead of constituent quarks
  - Gluon interaction and Nucleon structure with gluons necessary
  - Initial state of high-energy hadron collision experiments





- Understanding gap of hierarchy in nature between these pictures
  - Chiral symmetry breaking
  - Confinement

"Spin Puzzle" to 3-dim picture of the nucleon

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L$$

Orbital angular momentum

Gluon spin contribution

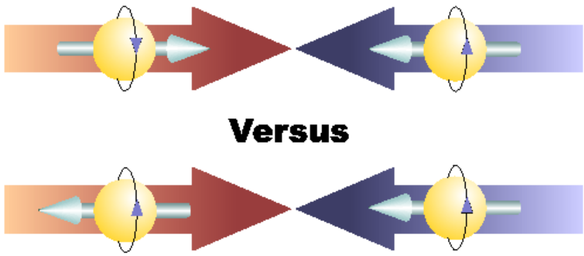
Quark spin contribution

- Longitudinally polarized proton collision at RHIC
  - Helicity distribution of gluons
  - Helicity distribution of sea-quarks with W boson measurement
- Toward understanding of the "Spin Puzzle" with extended picture of the nucleon structure
  - 3-dimensional description of the nucleon structure
    - Quantum many-body correlation of quarks and gluons
    - Transverse quark-gluon distribution inside the nucleon
  - TMD (Transverse-Momentum Dependence) factorization and collinear higher-twist factorization
    - Transverse-momentum distribution inside the nucleon
  - GPD (Generalized Parton Distribution)
    - Space distribution, tomography
  - Understanding angular motion inside the nucleon

Nucleon structure and parton reaction

- Precision measurement of PDFs
  - Helicity structure of the nucleon

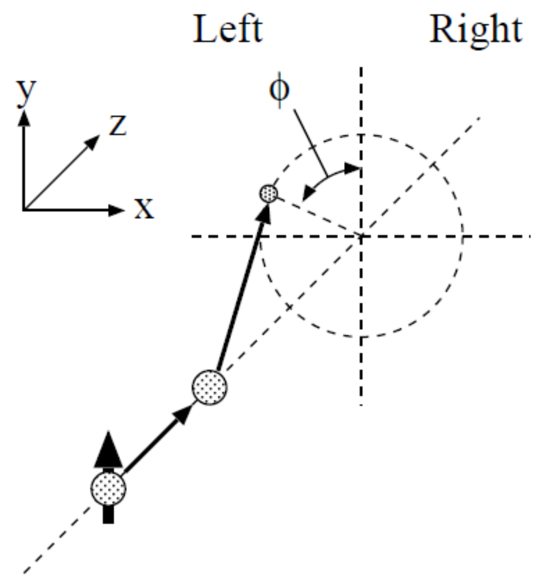
$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}$$



- Transverse-spin phenomena

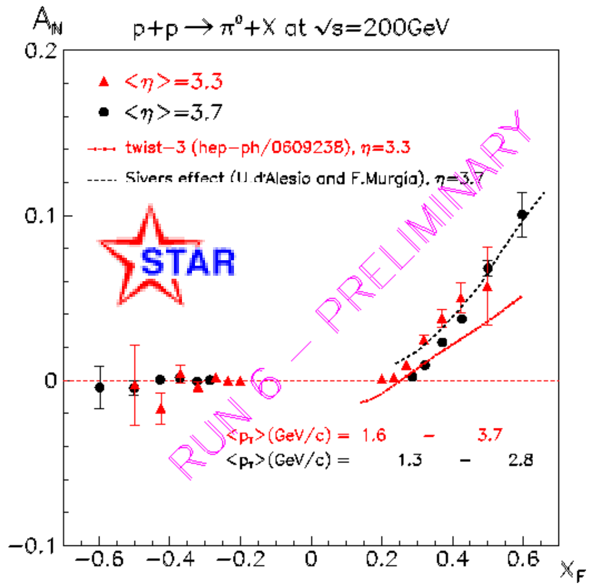
$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

  - Many-body correlation of partons
  - TMD (transverse-momentum dependent) factorization
    - Transverse structure of the nucleon
  - Higher-twist effect on collinear factorization
    - Parton reaction

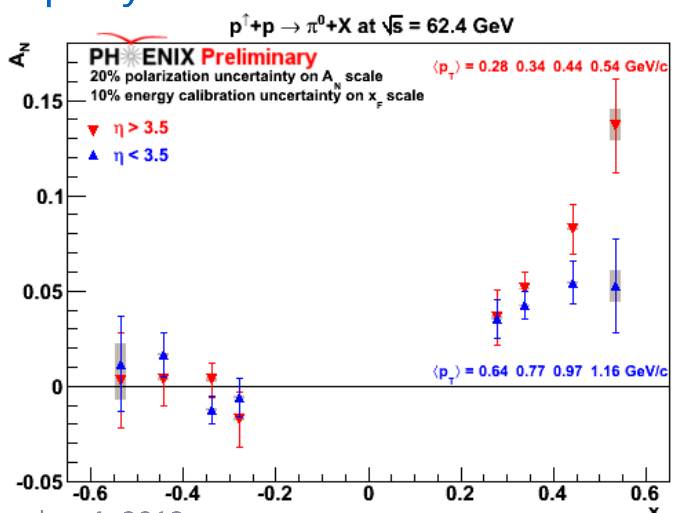


Transverse spin asymmetries at RHIC

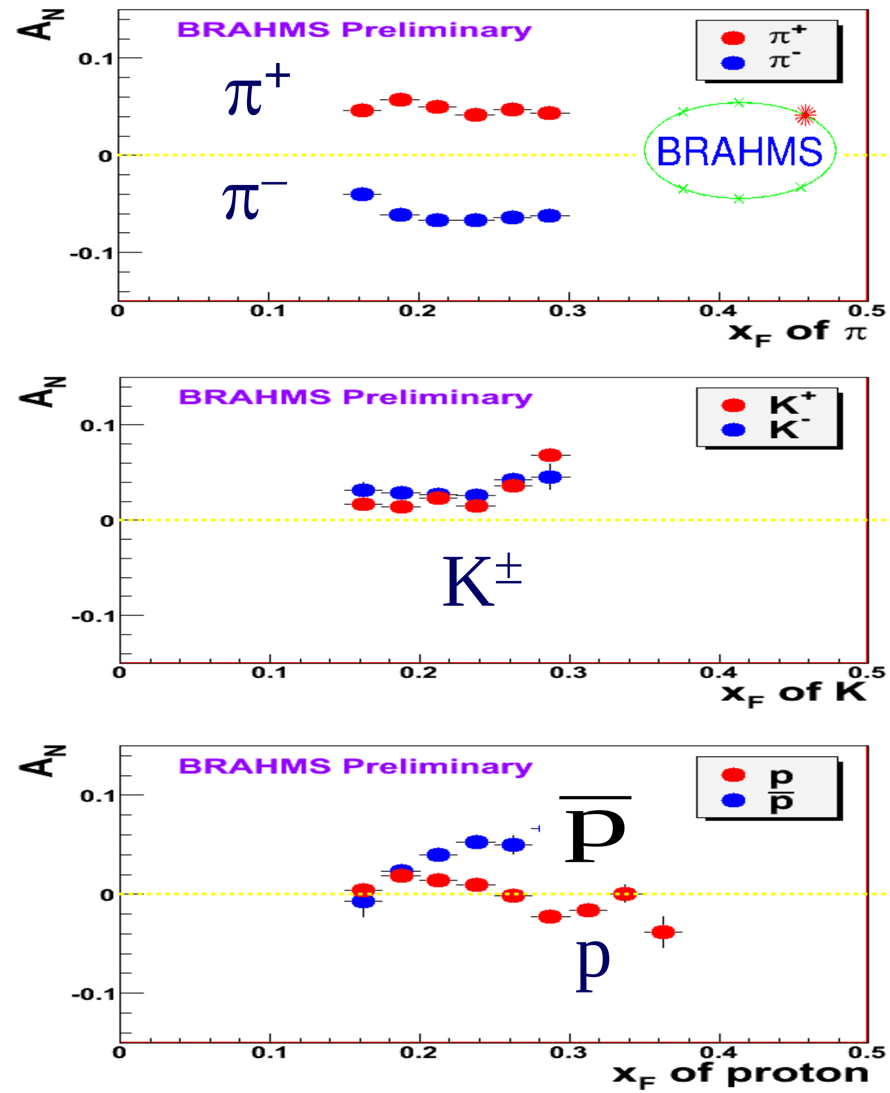
Forward rapidity π^0 at STAR at $\sqrt{s}$ = 200 GeV



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

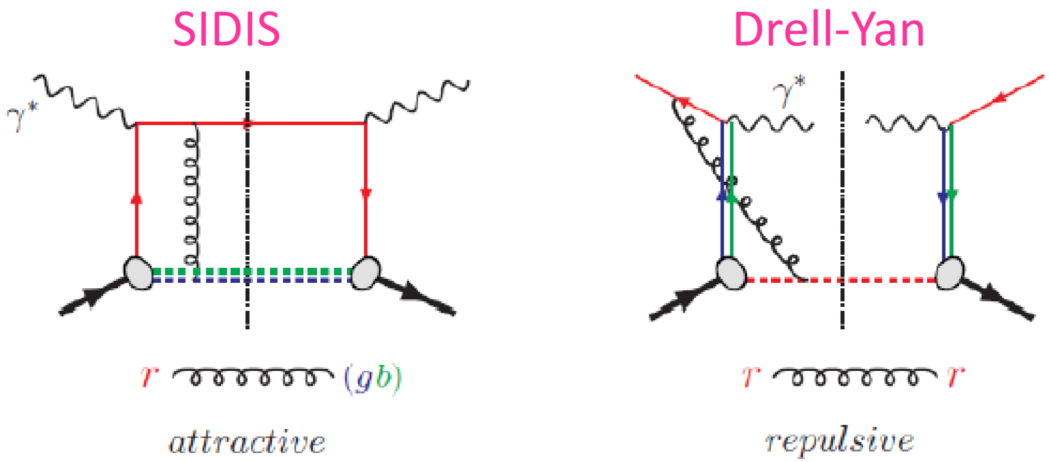


Forward identified particles at BRAHMS



TMD non-universality

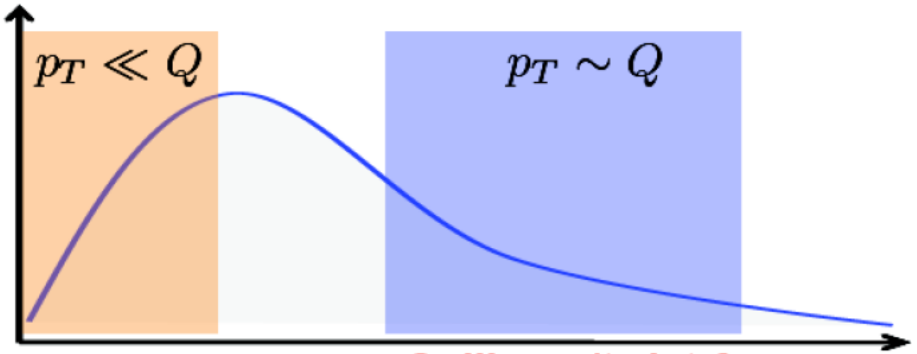
- Opposite-sign contribution to the transverse-spin asymmetries in the semi-inclusive DIS process and the Drell-Yan process
- Fundamental QCD prediction based on gauge invariance
- Verification is an important milestone for the field of hadron physics
- Competitive program in fixed target experiments and in collider experiments



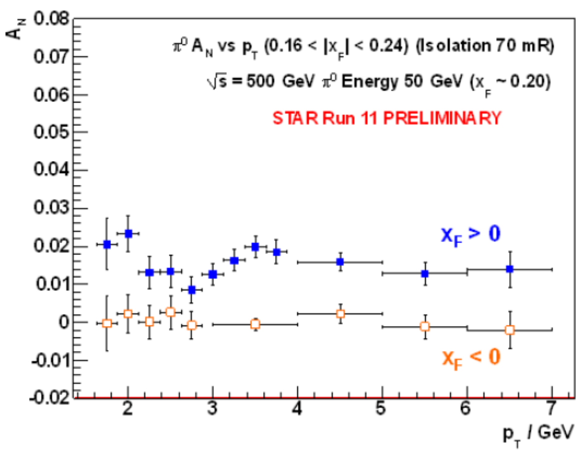
$$f^{Sivers}(x, k_T)|_{SIDIS} = -f^{Sivers}(x, k_T)|_{DY}$$

TMD and higher twist

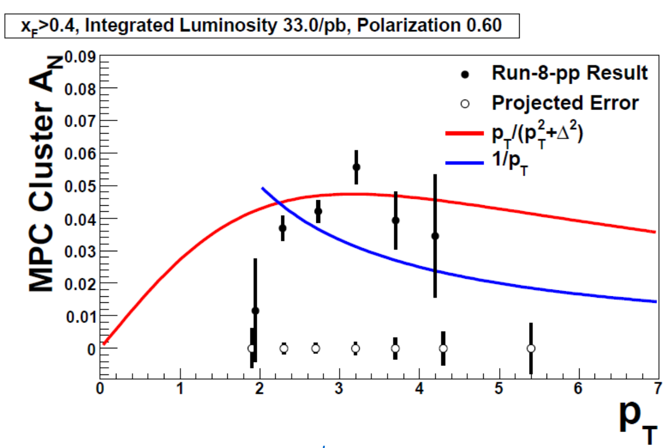
- p_T distribution
  - Small pT: described by the TMD factorization
  - Large pT: described by the collinear higher-twist factorization
  - Intermediate pT: identity in TMD and higher-twist



- Need more statistics
  - To find $1/p_T$ at high p_T



STAR $\sqrt{s}$ = 500 GeV



PHENIX $\sqrt{s}$ = 200 GeV

TMD and higher twist

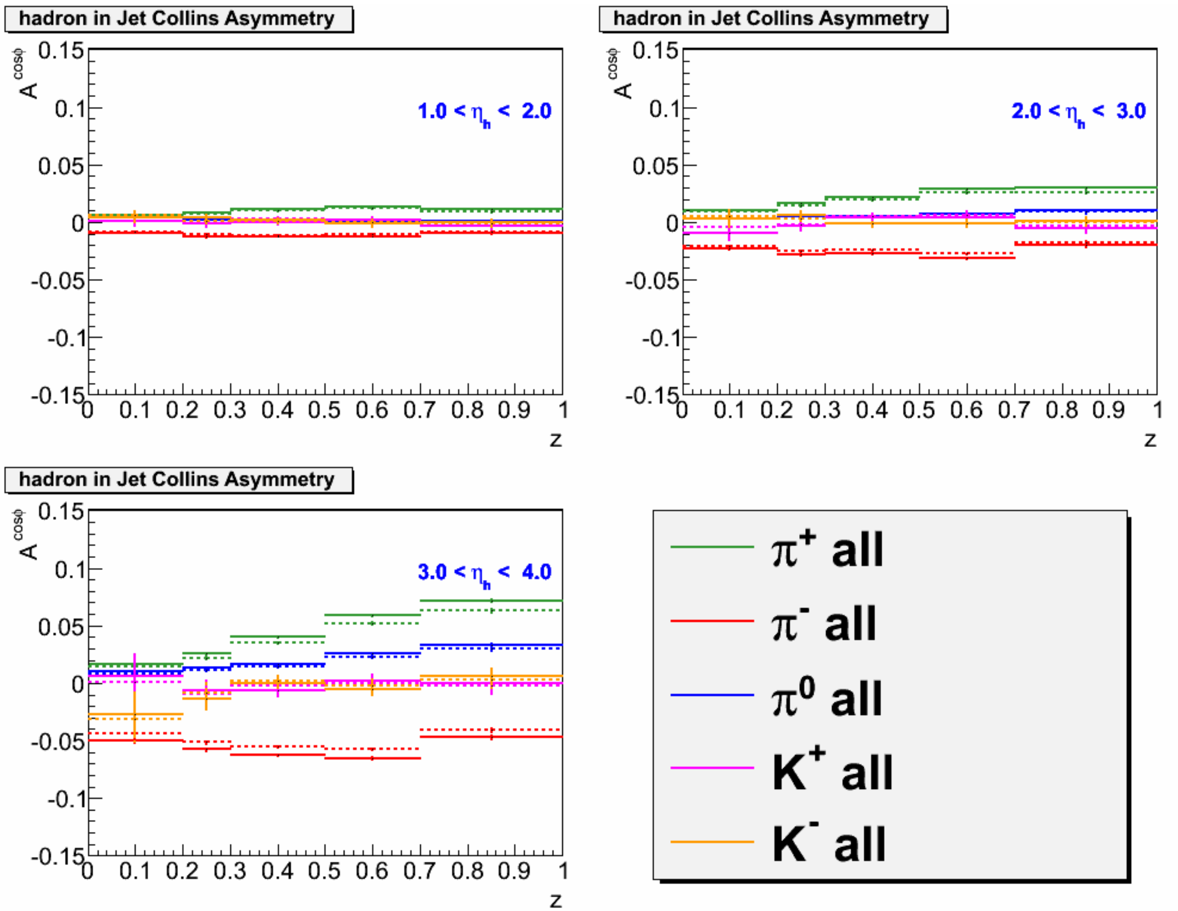
- At small p_T
  - Described by the TMD (Transverse Momentum Dependent) factorization framework
  - Sivers mechanism
    - Correlation between the transverse spin of the nucleon and intrinsic p_T of partons in the initial state
  - Collins mechanism
    - Correlation between the transverse spin of the parton and p_T of hadrons in the final state
- At large p_T
  - Described by the collinear factorization framework
  - Higher twist effect
    - Spin-dependent p_T components generated through quark-gluon and multi-gluon correlations
- At intermediate p_T
  - Identity of the Sivers mechanism and the higher twist effect

Collins effect and transversity

- Azimuthal anisotropy in the distribution of hadrons in final-state jets
- Transversity measurement with single identified hadrons (Collins fragmentation function) or with identified hadron pairs (interference fragmentation function)
  - Determination of the tensor charge of the nucleon
  - Test of the Lattice QCD prediction

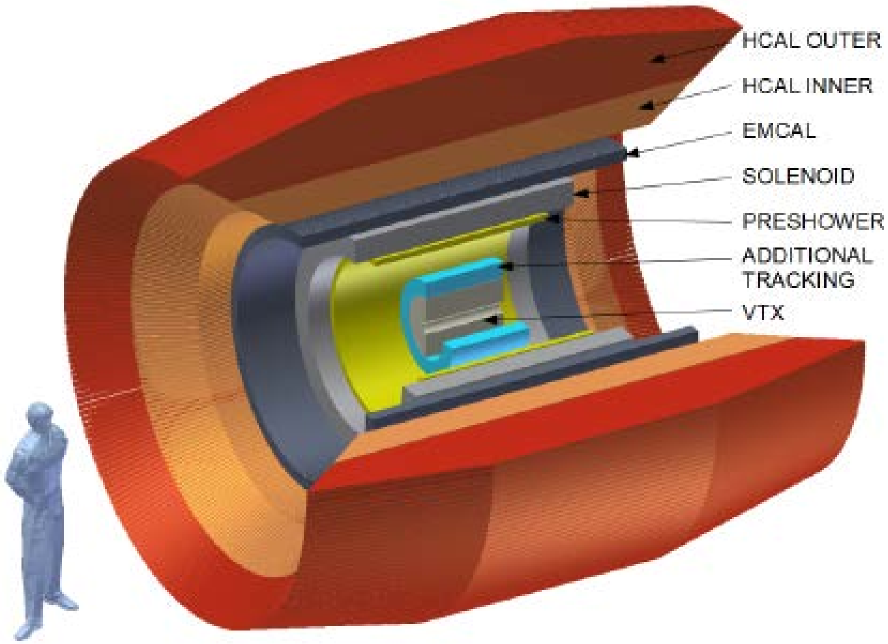
Transverse spin asymmetries at forward sPHENIX

- Collins asymmetry inside the jet
  - TppMC simulation
    - Collins/Sivers functions from Torino
    - Transversity from Soffer bound
    - $p_T > 1$ GeV/c
  - From Ralf Seidl



Stages of PHENIX detector upgrades

- Barrel sPHENIX upgrades
  - Compact jet detector at midrapidity with high-rate capability
  - Precision jet / dijet / photon-jet measurement to understand the nature of the strongly coupled QGP
  - Future options to add tracking and preshower for heavy-flavor quarkonia and internal jet structure measurements



Stages of PHENIX detector upgrades

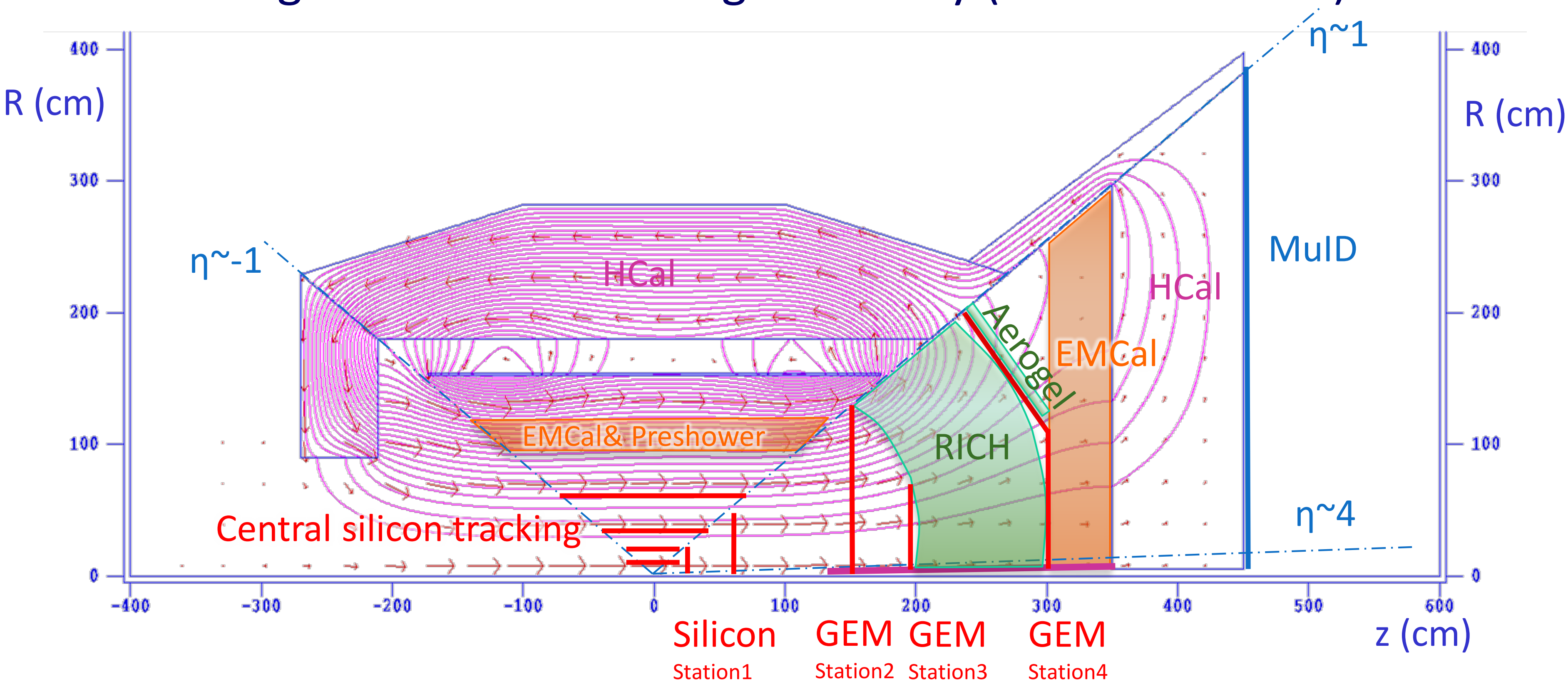
- Forward sPHENIX upgrades
  - Open geometry for wide kinematic coverage of photon / jet / leptons / identified-hadrons
  - Understanding 3-dimensional (TMD) quark-gluon structure of the nucleon and nuclei
  - Measurement of the nuclear gluon distribution and search for gluon saturation at small-x
- Evolution to ePHENIX at eRHIC
  - 3-dimensional space structure (tomography) of the nucleon and nuclei
  - Precision understanding of strongly-coupled QGP by knowing the initial state

Forward sPHENIX design

- Compatible design for eRHIC
  - Constraint from IR design
    - focusing and bending magnets for the electron-ion collision
    - 4.5 m from IP available in z direction
  - Hermeticity for exclusive measurements
- Magnet discussion
  - Piston
  - Dipole
  - Toroid
  - Solenoid extension
- Detector configuration
  - Charged-particle tracking (e.g. GEM)
  - Particle identification (e.g. RICH)
  - EM and hadron calorimeters
  - Vertex detector? (silicon or GEM?)
  - (Roman pot detector for exclusive measurements at eRHIC)
- More discussion by Joe Seele this afternoon

Forward sPHENIX design

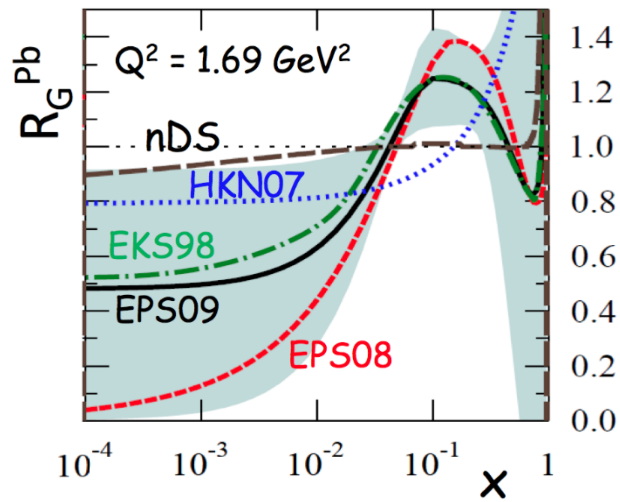
- Forward field shaper
  - Passive piston
  - Total flux much enough?
  - High resolution tracking necessary (silicon detector)

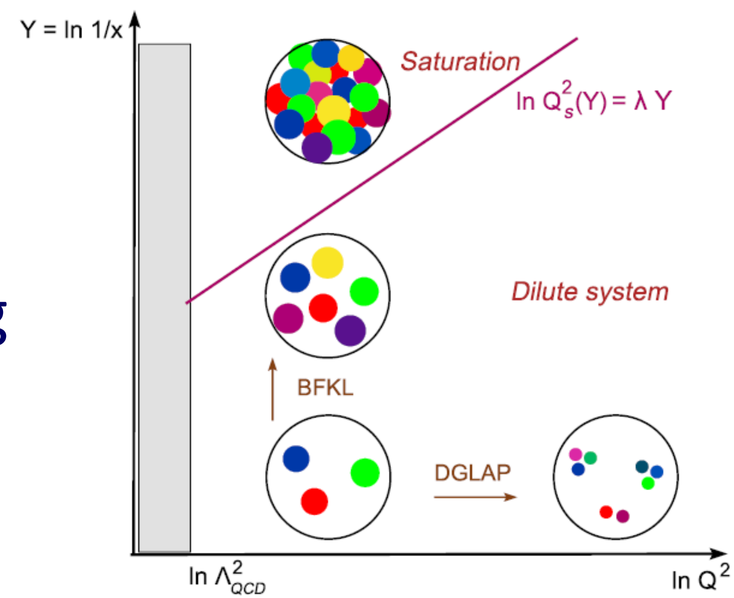


From Jin Huang

Cold Nuclear Matter (CNM) physics

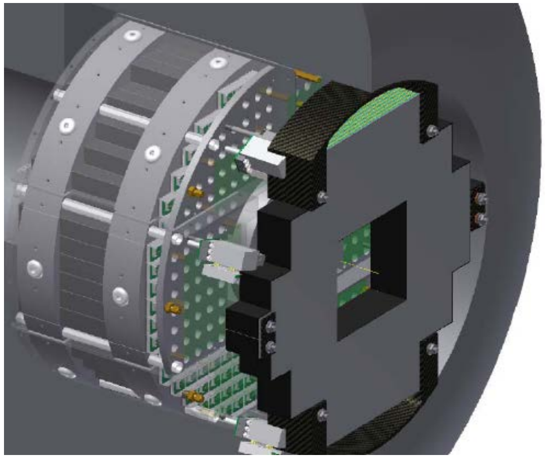
- Measurement of the nuclear gluon distribution $G_A(x)$
  - To know initial state of heavy-ion collisions
  - precision understanding of strongly-coupled QGP
- Search for gluon saturation, or suppression of $G_A(x)$ at small-x and verify CGC (color glass condensation) framework
  - CGC: effective field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





CNM physics at PHENIX

- 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 –)
  - More details by John Lajoie this afternoon
  - Electromagnetic calorimeter + preshower
  - $3.1 < \eta < 3.8$ in the muon piston
  - Prompt-photon



CNM physics at forward sPHENIX

- Quarkonia
- Vertex-tagged open heavy-flavor
- Inclusive hadrons
- Fully-reconstructed jets
- jet-jet correlations
- Drell-Yan
  - Much more extended kinematic reach
  - Smaller statistical and systematic uncertainties
  - Different energies and nuclear species

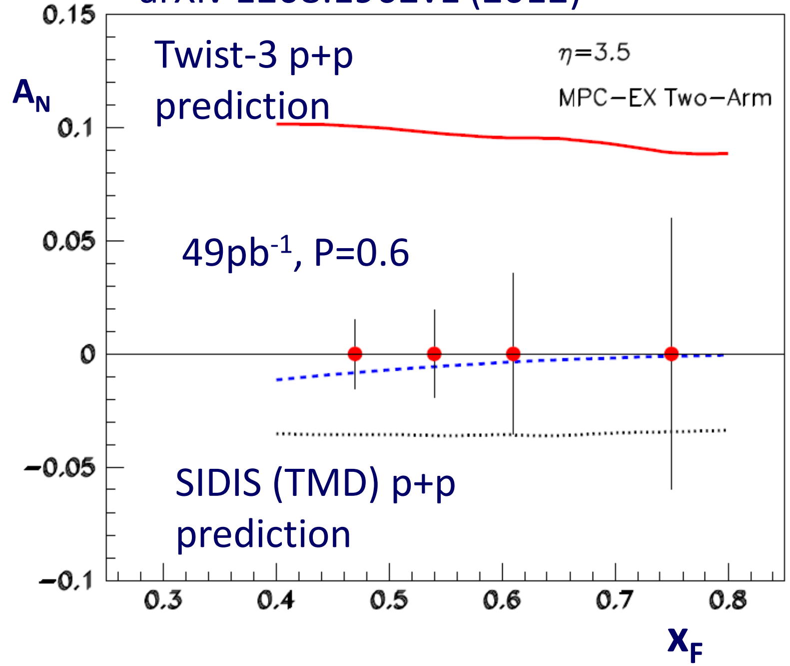
TMD evolution

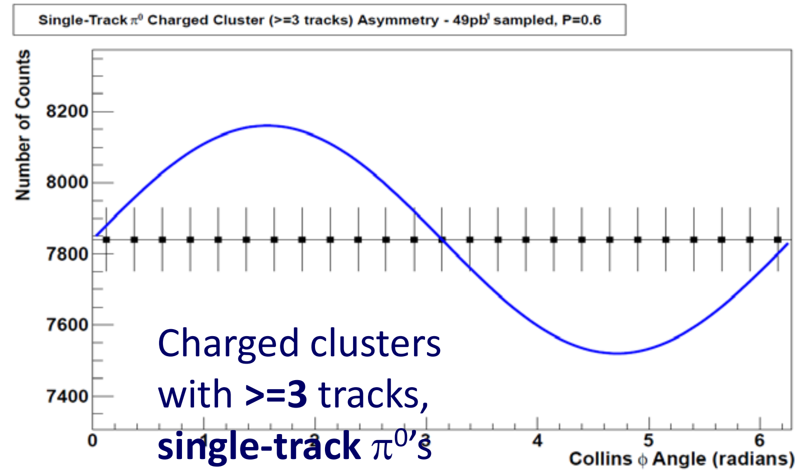
- Recent theoretical progress in the derivation of the evolution equation for TMD parton distribution and fragmentation functions
- Comparison of the asymmetries at fixed-target energies and collider energies for test of the TMD evolution
- QCD analysis of TMD observables to be possible

Transverse spin asymmetries at PHENIX

- MPC-EX (2014 –)
- Prompt photon asymmetry
  - To distinguish the Sivers effect and the hither-twist effect
- Collins asymmetry in jets
  - π^0 correlations with jet-like clusters

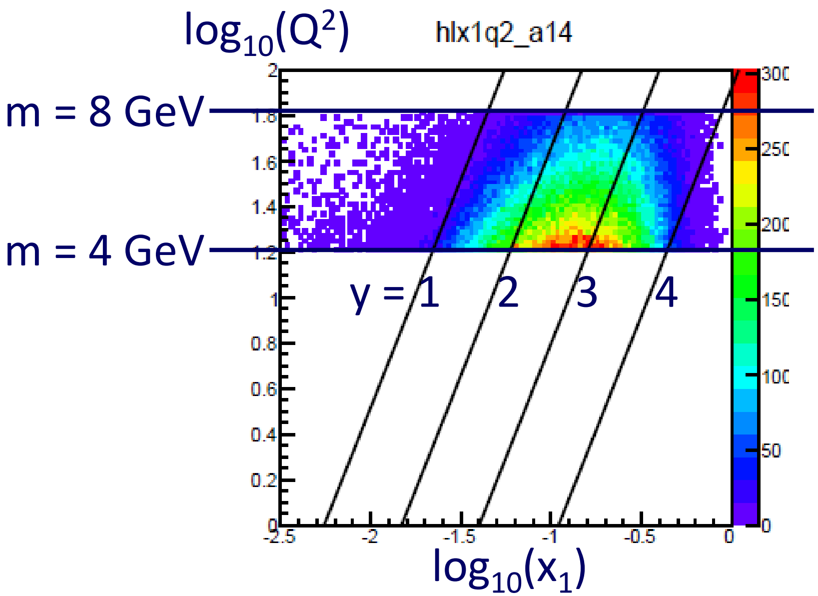
Phys Rev. D 83 094001 (2011)
arXiv 1208.1962v1 (2012)

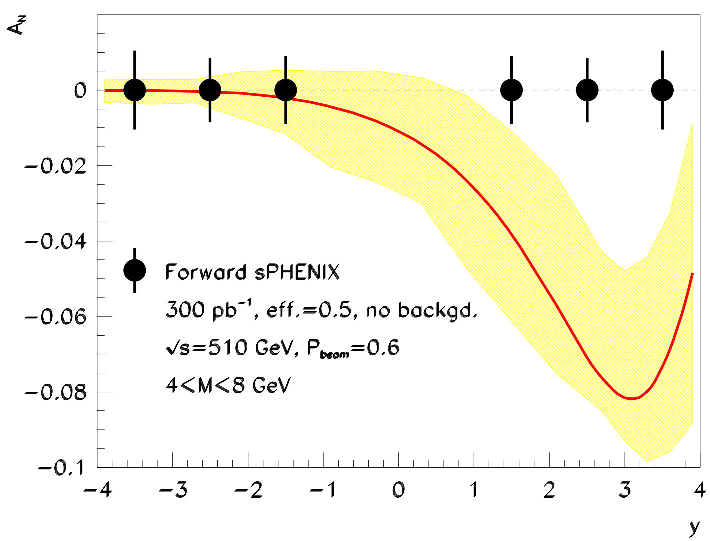




Transverse spin asymmetries at forward sPHENIX

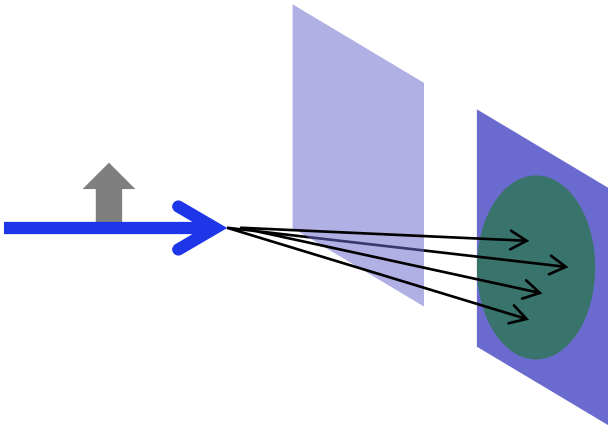
- Sivers effect in Drell-Yan process
  - $\sqrt{s}$ = 500 GeV
  - $1 < \eta < 4$
  - 4 GeV < mass < 8 GeV
    - cover the valence-quark region around $x_{Bj} = 0.2$
    - comparison with SIDIS measurements
    - large asymmetry
    - $3 < \eta < 4$ is important to explore higher x_{Bj} region

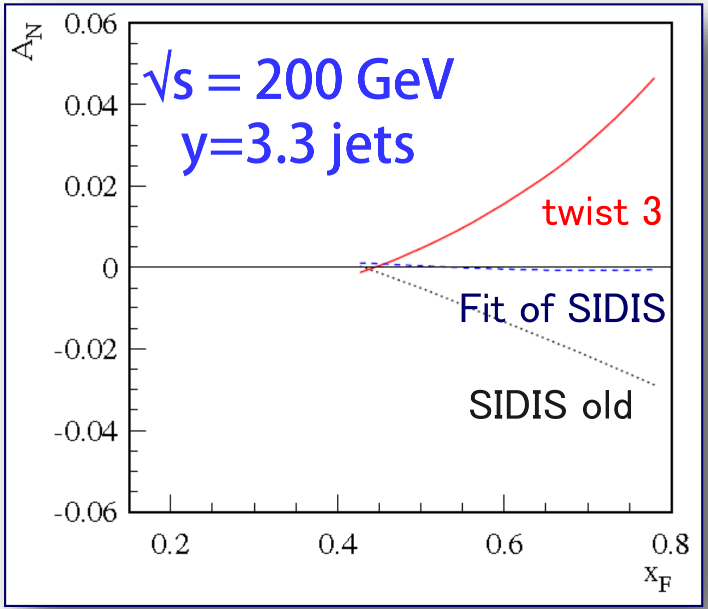




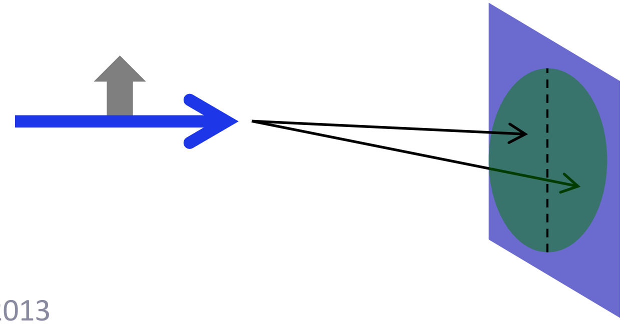
Transverse spin asymmetries at forward sPHENIX

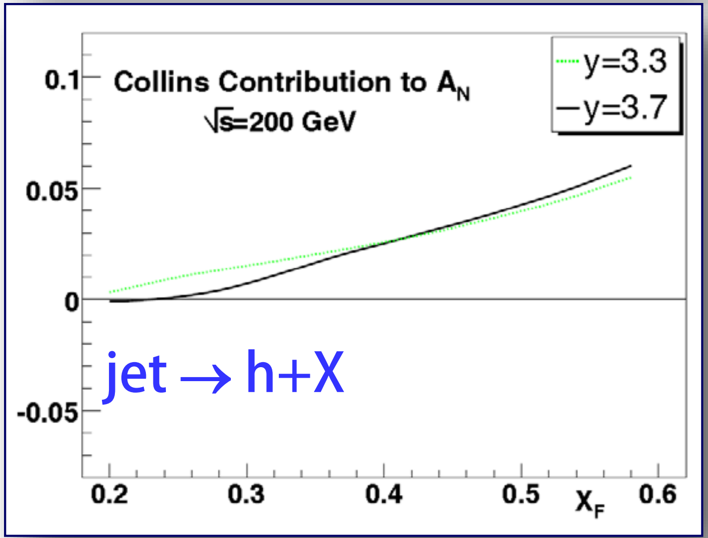
- Jet asymmetry measurement
  - Sivers or higher-twist effect





- Asymmetry inside the jet
  - Collins function
  - Interference fragmentation function





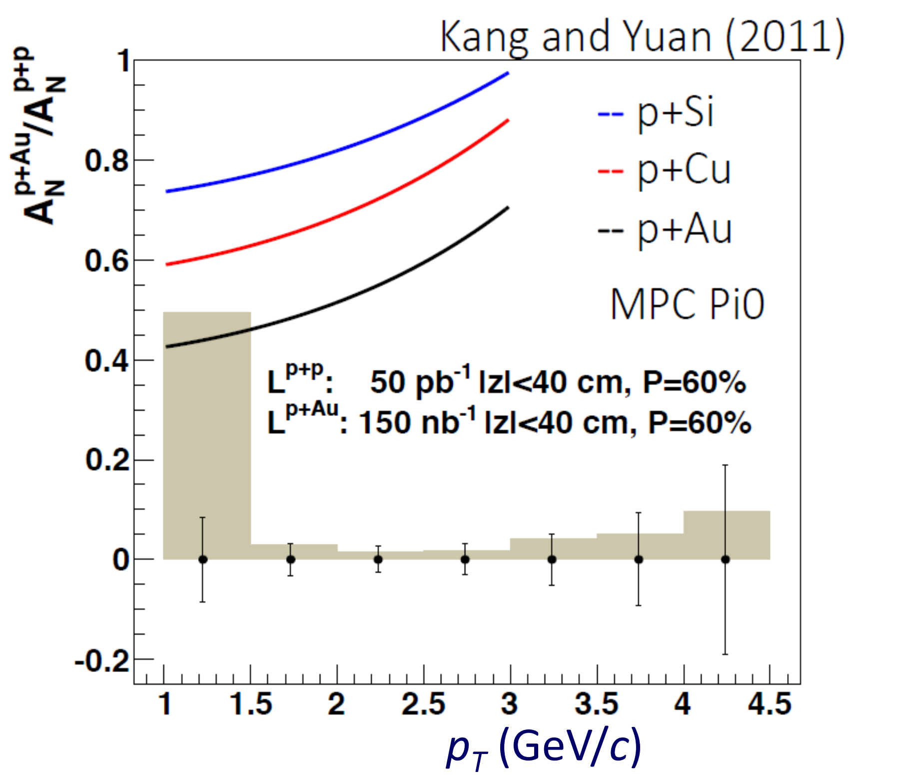
Transverse spin asymmetries at forward sPHENIX

- Polarized-proton nuclei collision for saturation study
  - Link between CNM and spin physics
  - 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).

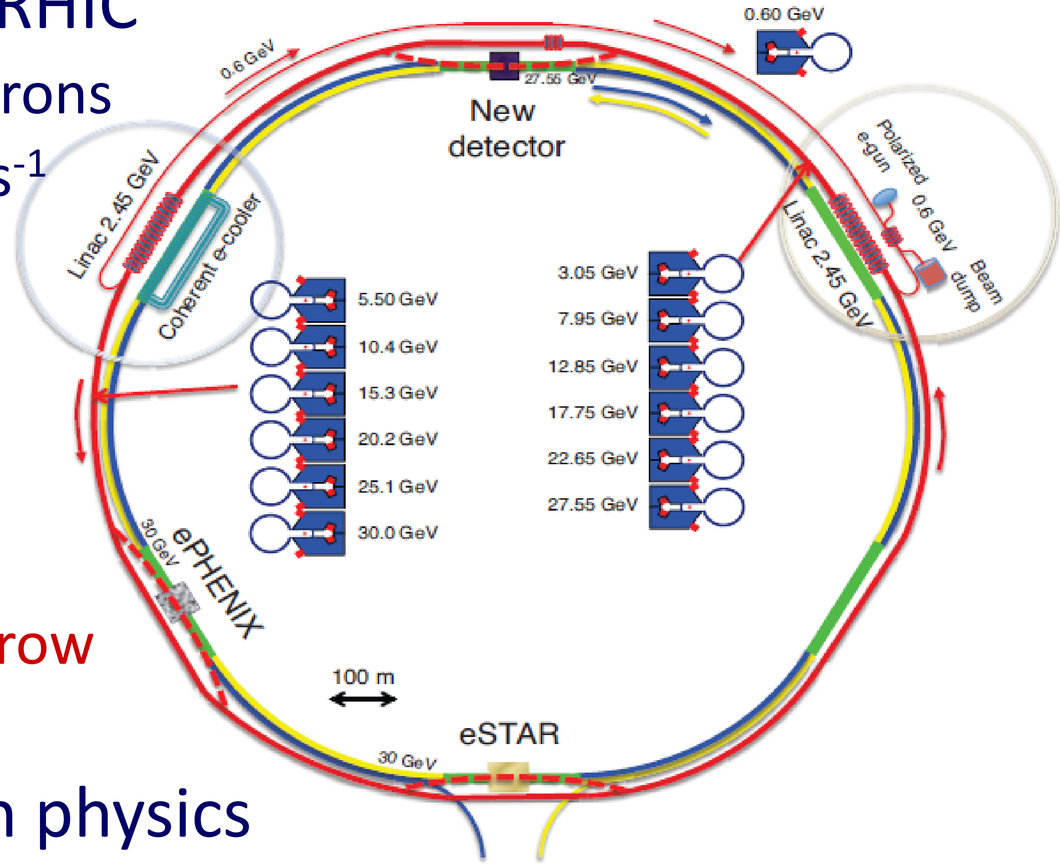


Summary

- Toward understanding of the extended 3-dimensional nucleon structure
- Two milestones with sPHENIX forward upgrade
  - Sign change of the TMD distribution function
    - Polarized Drell-Yan experiment at RHIC and polarized SIDIS experiment at eRHIC
    - From fixed-target experiments to collider experiments
  - Sign mismatch of TMD and higher-twist
    - Distinguish Sivers/higher-twist and Collins/transversity
    - Measurement of jet and direct photon
- Towards electron-proton collisions at eRHIC & ePHENIX
- Understanding of nuclei in quark-gluon picture with pA/eA collisions in addition
  - Understanding of cold nuclear matter
  - Initial state of QGP in high-energy nuclear collisions

Evolution to ePHENIX

- Stage-1 detector of eRHIC
  - 5 GeV – 10 GeV electrons
  - Luminosity 10^{33} $cm^{-2}s^{-1}$

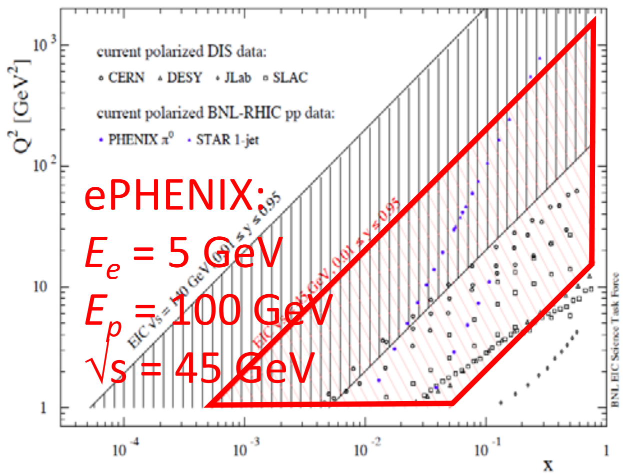


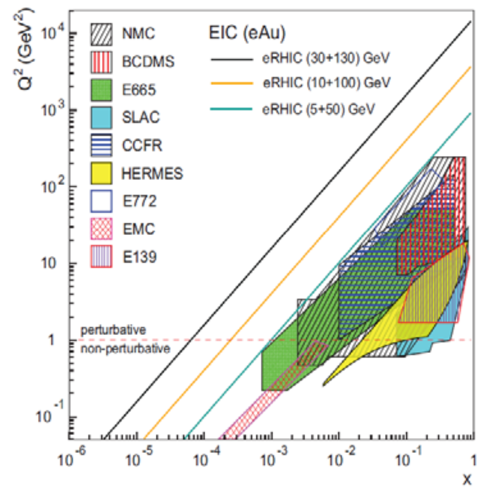
More details on eRHIC given by Abhay Deshpande tomorrow

- CNM physics and spin physics
  - 3-dimensional space structure of nucleon and nuclei
  - Precision understanding of strongly-coupled QGP by knowing the initial state

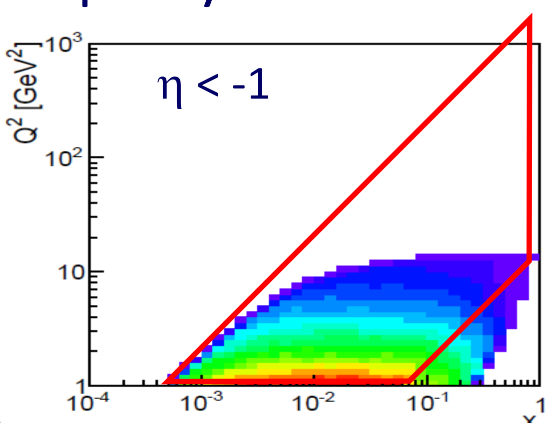
Evolution to ePHENIX

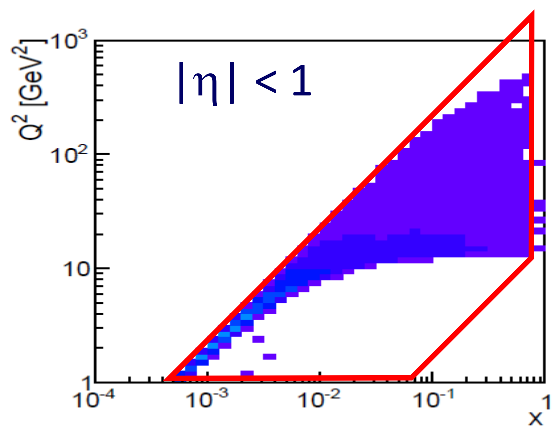
- Inclusive DIS
  - Gluon and sea-quark helicity distributions





  - Scattered electron detection at backward rapidity and midrapidity





Evolution to ePHENIX

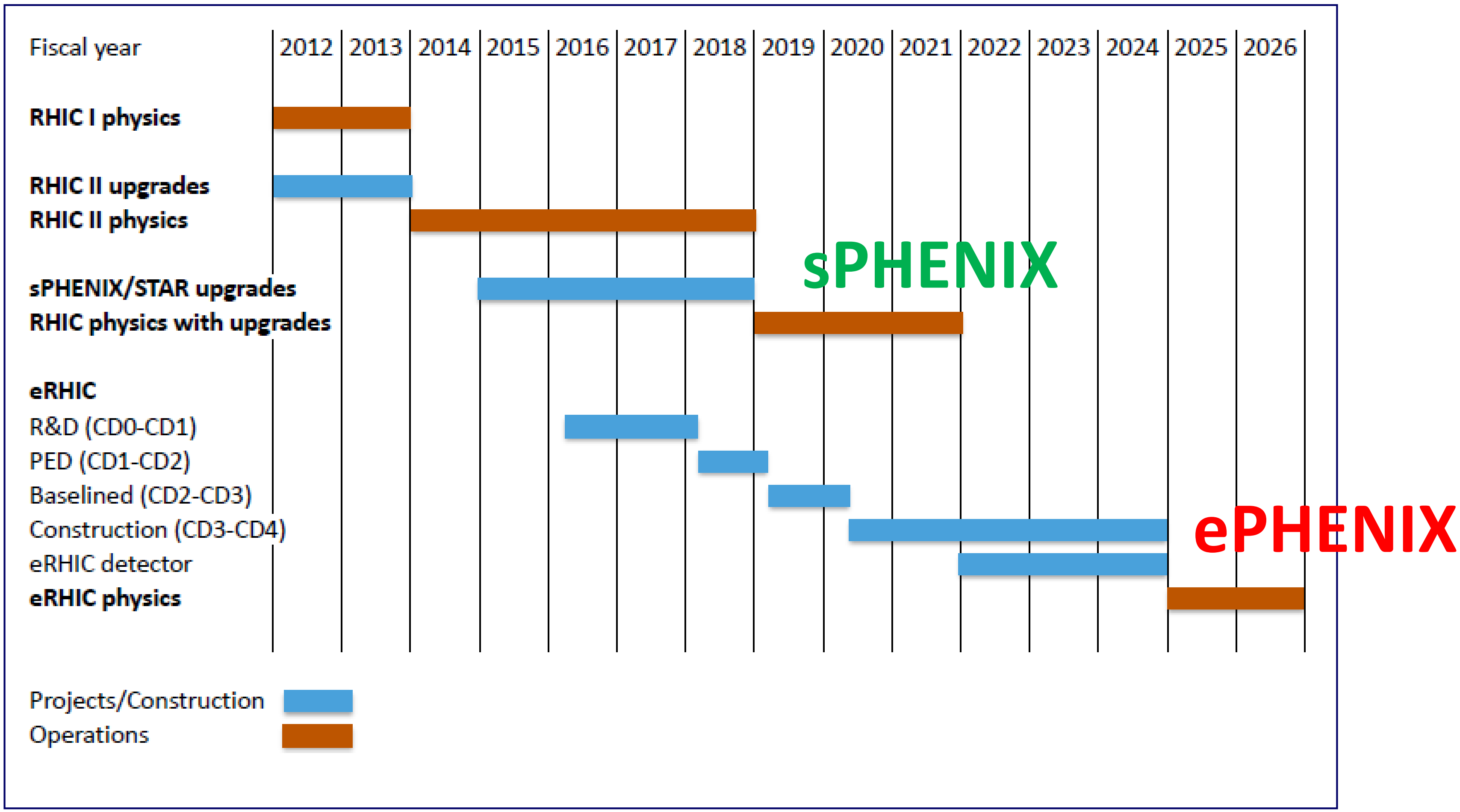
- Semi-inclusive DIS
  - Quark and gluon TMD measurements
  - Tag pions and kaons
  - Extract Δs
- Exclusive and diffractive channels
  - DVCS (Deeply Virtual Compton Scattering) and HEMP (Hard Exclusive Meson Production)
    - With a limited luminosity at stage-1 eRHIC
- More discussion to be performed in the ePHENIX LoI session (by Kieran/Jin/Itaru) Friday morning

Requirements for the detector design

- Sivers effect in Drell-Yan process
  - Open heavy-flavor background
    - Vertex detector
  - Light-hadron background
    - For e^+e^- measurement
      - Calorimeter and tracking
      - Additional e/π separation
    - For $\mu^+\mu^-$ measurement?
- Jet asymmetry measurements
  - Calorimeter and tracking
  - Particle-ID
- ePHENIX
  - Scattered electron detection
    - Backward rapidity and midrapidity
  - Particle-ID
    - Midrapidity and forward rapidity
  - Roman-pot detector to tag scattered proton

Timeline

- Forward sPHENIX
  - RHIC physics (polarized p+p / p+A / d+A) not on the table



Summary

- The forward sPHENIX upgrades will give us great opportunities for studying the nucleon spin structure and cold nuclear matter
  - Sivers asymmetry in Drell-Yan process
  - Jet asymmetry measurements
  - Search for gluon saturation
- Detector design and studies are ongoing with physics requirements
  - Detector configuration
  - Magnet discussion
  - Evolution to ePHENIX
- It is important to perform physics not only at eRHIC but also at RHIC with polarized p+p / p+A / d+A