Future Drell-Yan Experiments at J-PARC and RHIC (internal target)

CERN Workshop on “Studying the hadron structure in Drell-Yan reactions”

April 27th, 2010

Yuji Goto (RIKEN/RBRC)

Outline of this talk

- J-PARC proposals
  - Unpolarized experiment
  - Polarized experiment with a polarized beam
- Ideas at RHIC
  - (Collider)
  - Fixed-target experiment

J-PARC proposals

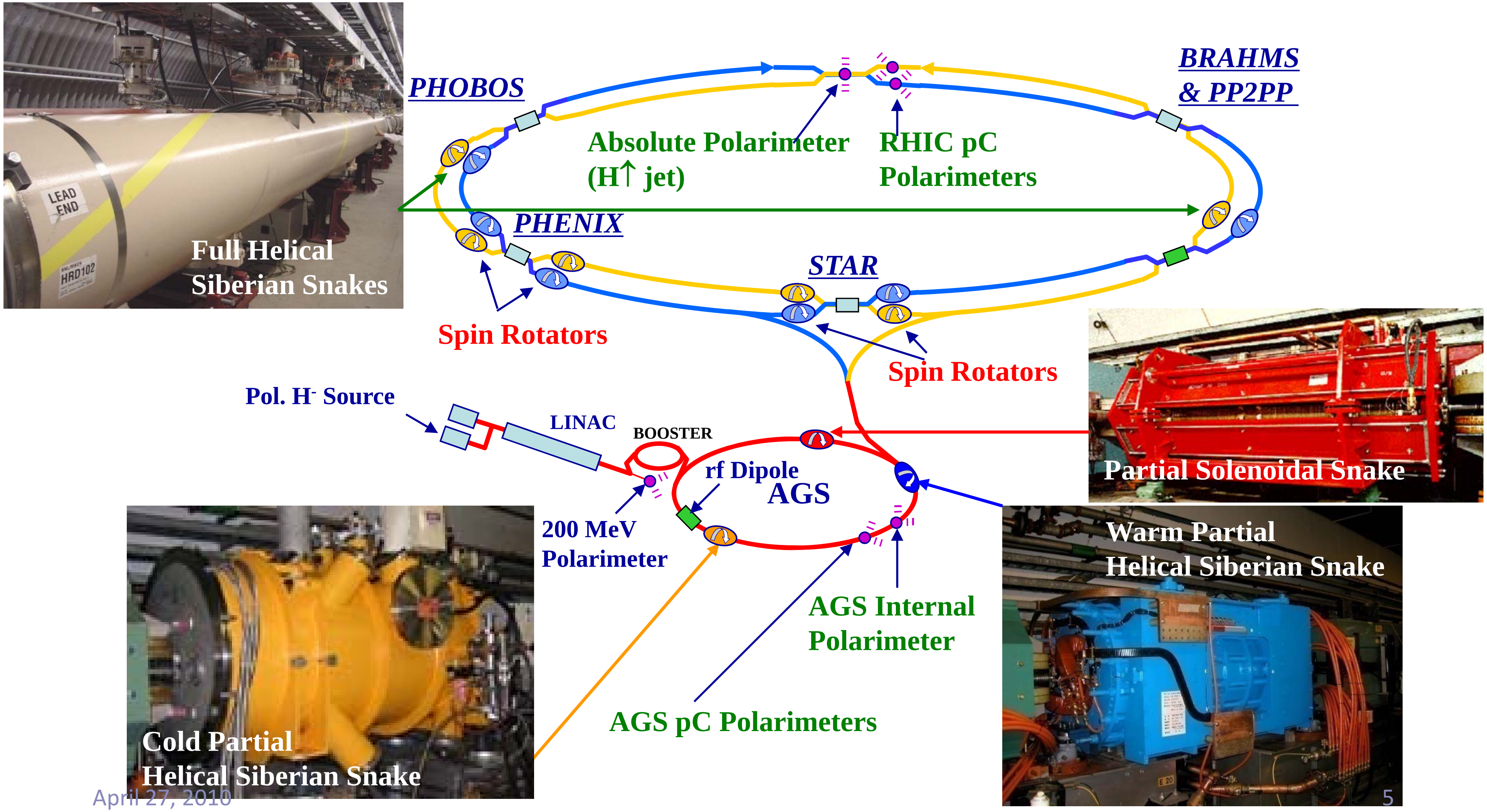
- P04: measurement of high-mass dimuon production at the 50-GeV proton synchrotron
  - spokespersons: Jen-Chieh Peng (UIUC) and Shinya Sawadas (KEK)
  - collaboration: Abilene Christian Univ., ANL, Duke Univ., KEK, UIUC, LANL, Pusan National Univ., RIKEN, Seoul National Univ., TokyoTech, Tokyo Univ. of Science, Yamagata Univ.
  - including polarized physics program, but not discussed
  - “deferred”
- P24: polarized proton acceleration at J-PARC
  - contact persons: Yuji Goto (RIKEN) and Hikaru Sato (KEK)
  - collaboration: ANL, BNL, UIUC, KEK, Kyoto Univ., LANL, RCNP, RIKEN, RBRC, Rikkyo Univ., TokyoTech, Tokyo Univ. of Science, Yamagata Univ.
  - polarized Drell-Yan included as a physics case
  - “no decision”
- Next proposal for the polarized physics program
  - not submitted yet

Polarized proton acceleration

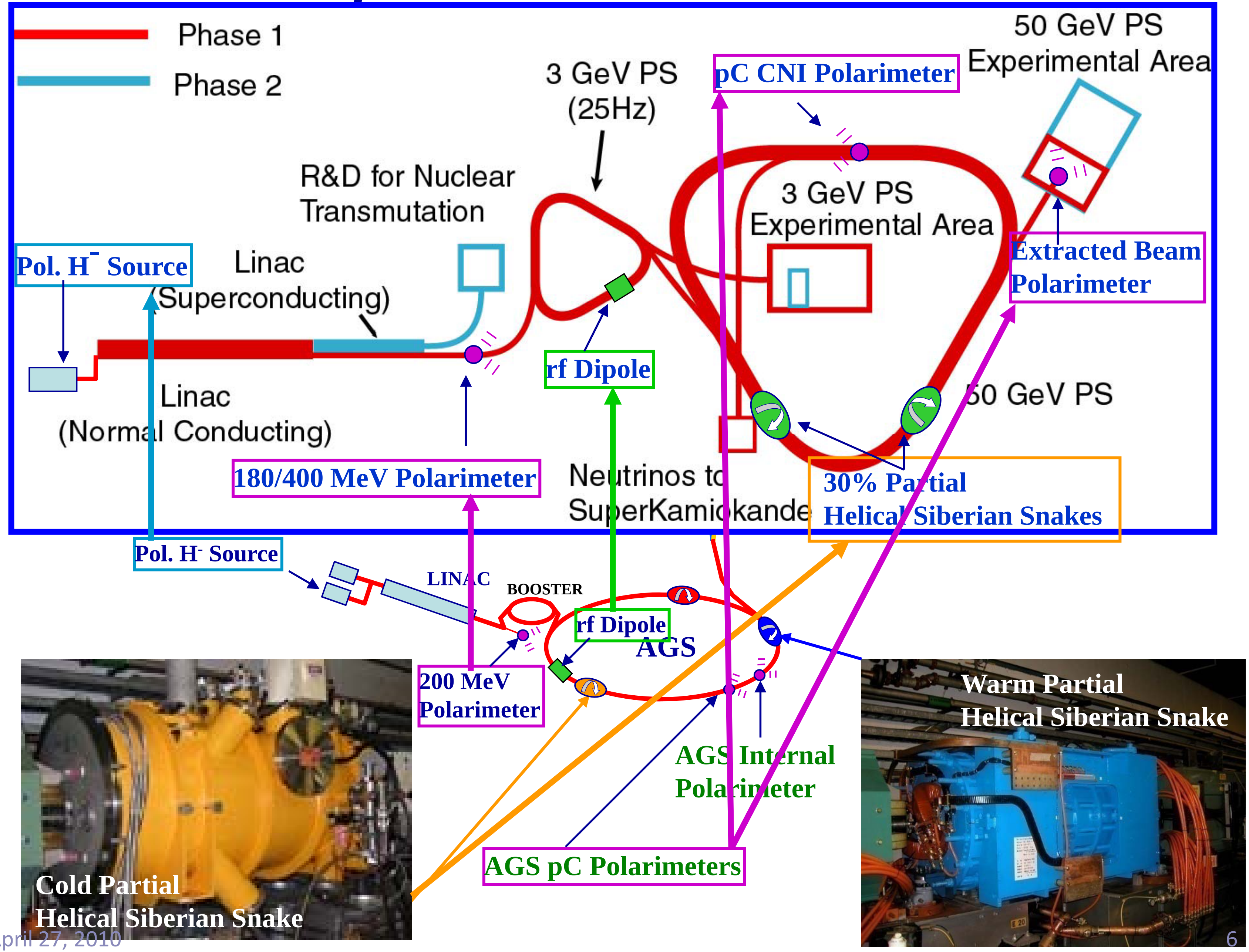
- How to keep the polarization given by the polarized proton source
  - depolarizing resonance
    - imperfection resonance
      - magnet errors and misalignments
    - intrinsic resonance
      - vertical focusing field
  - weaken the resonance
    - fast tune jump
    - harmonic orbit correction
  - intensify the resonance and flip the spin
    - rf dipole
    - snake magnet
- How to monitor the polarization
  - polarimeters

Polarized proton acceleration at AGS/RHIC

- Proposed scheme for the polarized proton acceleration at J-PARC is based on the successful experience of accelerating polarized protons to 25 GeV at BNL AGS

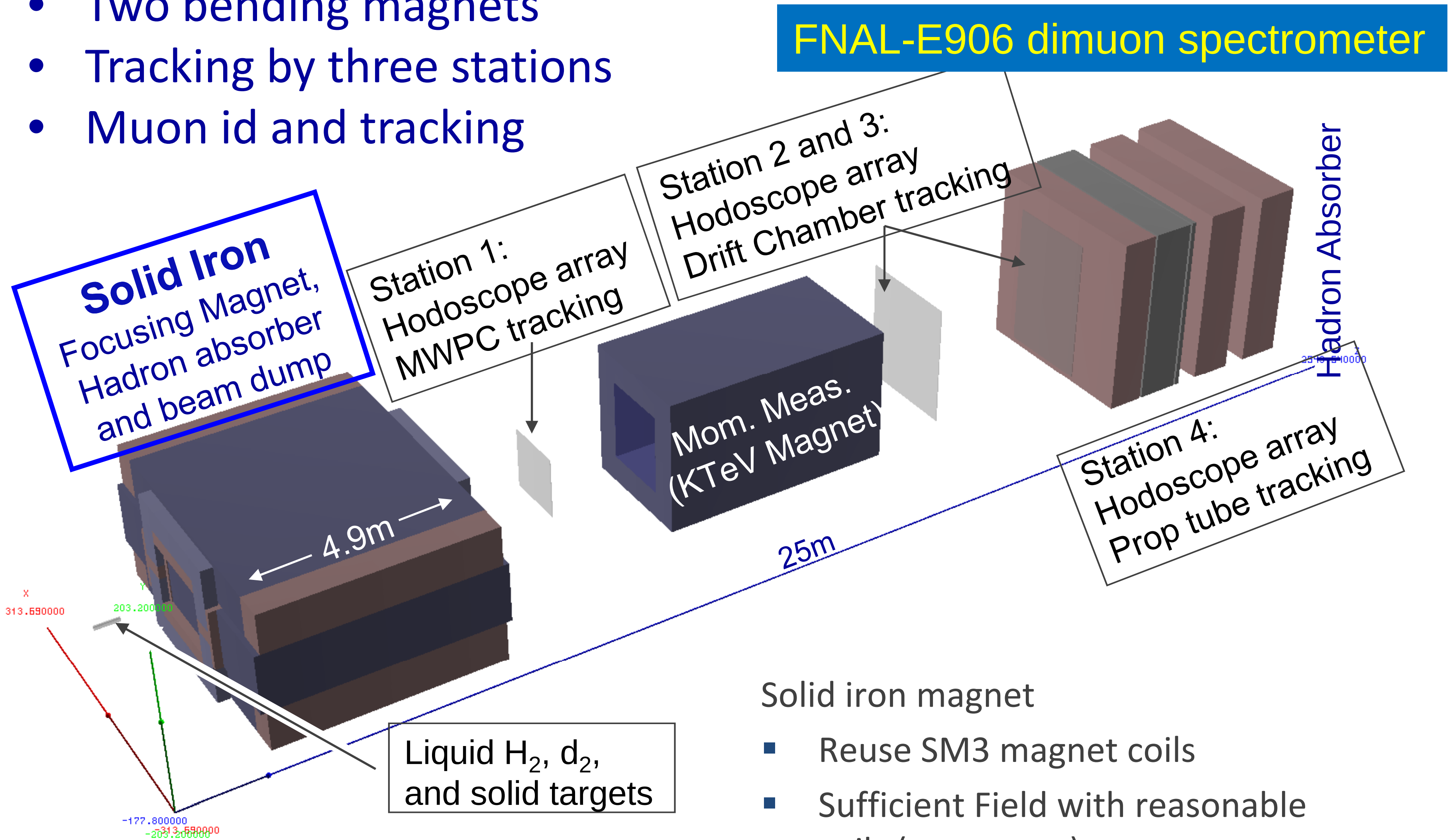


Polarized proton acceleration at J-PARC



Dimuon experiment at J-PARC

- Based on the Fermilab spectrometer
- Two bending magnets
- Tracking by three stations
- Muon id and tracking



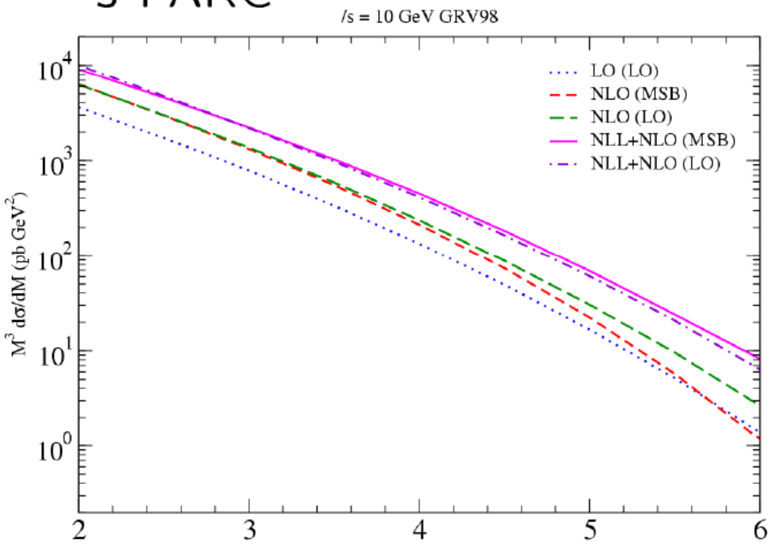
Solid iron magnet

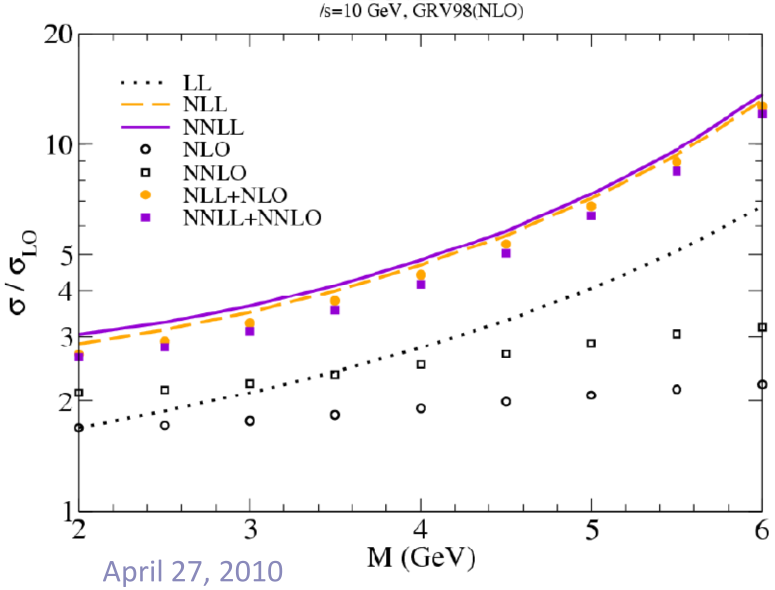
- Reuse SM3 magnet coils
- Sufficient Field with reasonable coils (amp-turns)
- Beam dumped within magnet

pQCD studies of Drell-Yan cross section

- pQCD correction can be controlled at J-PARC energy

J-PARC





NNLO calculation

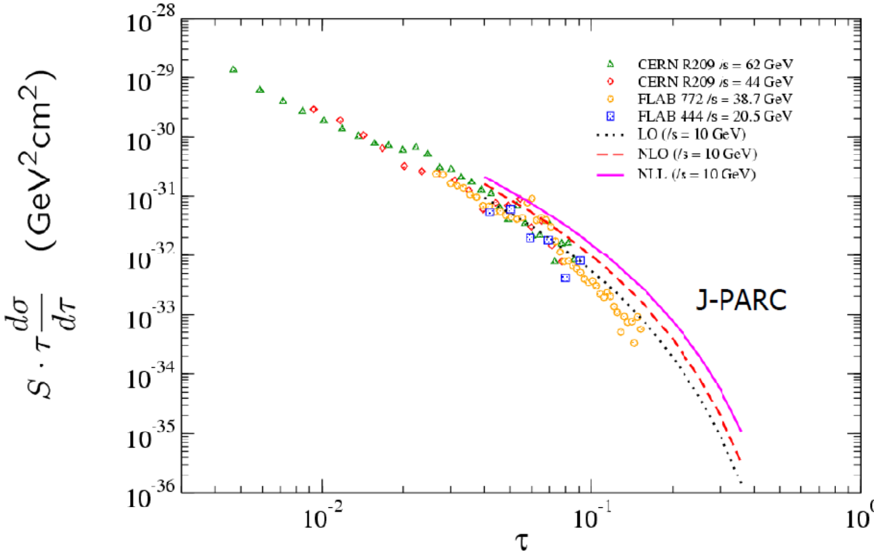
Hamberg, van Neerven, Matsuura, Harlander, Kilgore

NLL, NNLL calculation

Yokoya, et al...

by Hiroshi Yokoya

Prediction for /s = 10 GeV

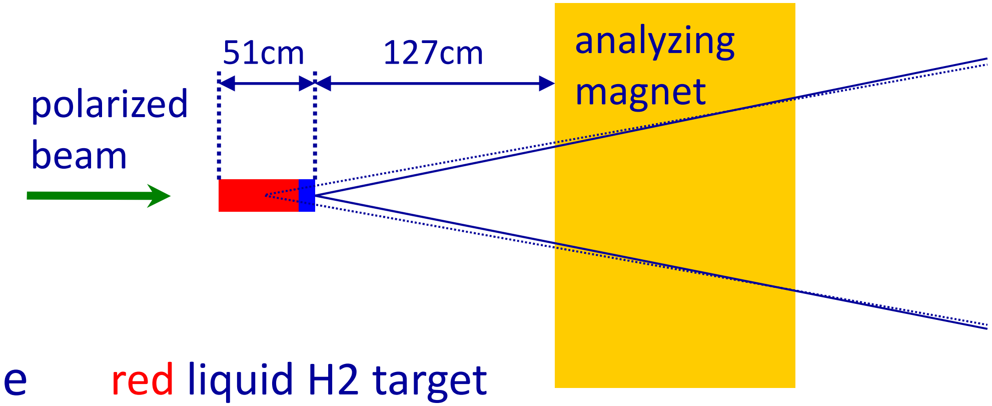


with GRV98

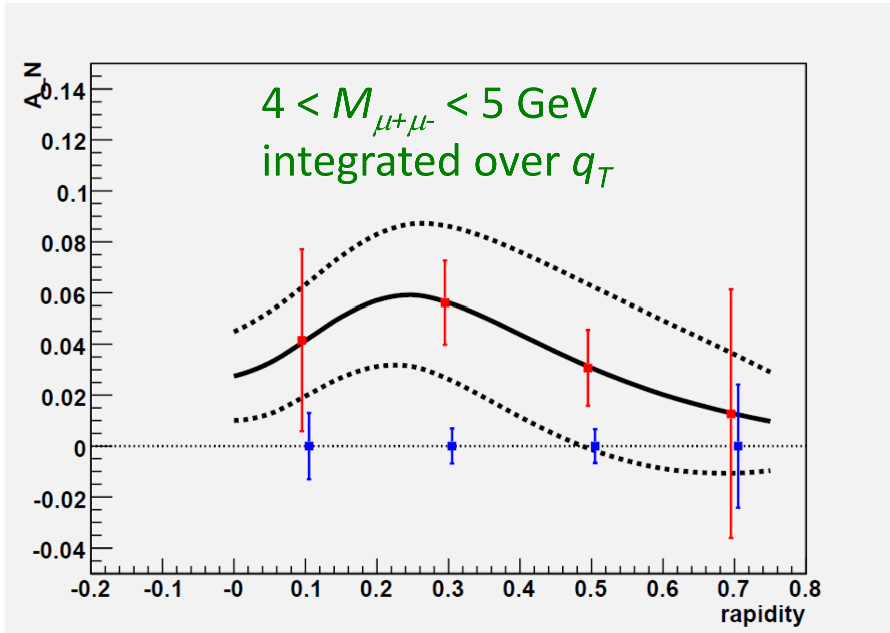
M = 2 ~ 6 GeV

Polarized Drell-Yan experiment at J-PARC

- Single transverse-spin asymmetry
  - Sivers effect measurement
- Experimental condition
  - higher beam intensity is possible for unpolarized liquid H_2 target, or nuclear target
    - 5×10^{12} ppp = $2.5\times10^{12}\times2$sec in 1pulse (5sec) possible?
  - PYTHIA simulation
    - 75% polarization beam
    - 120 days, beam on target 5×10^{17} (with 50% duty factor)
    - ~5% liquid H_2 target
      - 10000 fb^{-1} luminosity
    - ~20% nuclear target
      - 40000 fb^{-1} luminosity
    - mass 4 – 5 GeV/c^2



red liquid H2 target
blue nuclear target



Theory calculation by Ji, Qiu, Vogelsang and Yuan based on Sivers function fit of HERMES data (Vogelsang and Yuan: PRD 72, 054028 (2005))

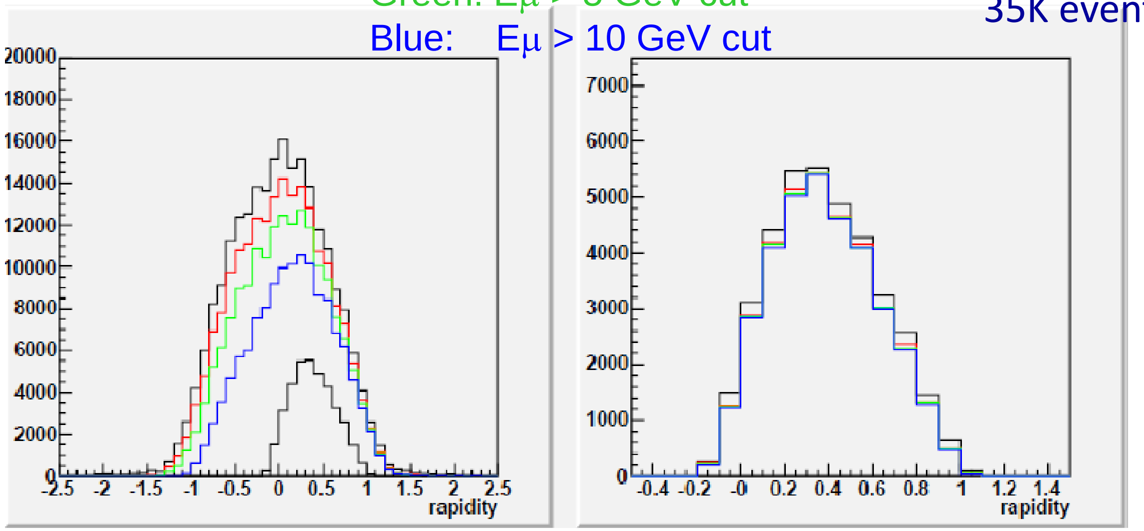
J-PARC and/or RHIC

- J-PARC
  - Advantage
    - High intensity = high luminosity
  - Disadvantage
    - Smaller cross section (at the same invariant mass)
  - Uncertainties
    - Availability of 50 GeV beam
    - Polarized proton beam?
- RHIC
  - Advantage
    - Polarized proton beam available
    - Larger cross section (at the same invariant mass)
  - Disadvantage
    - Luminosity?
  - Collider or fixed-target (internal-target) experiment

Fixed-target experiment

- Simple PYTHIA simulation for a fixed target experiement
  - $\sqrt{s}$ = 22 GeV (E_{lab} = 250 GeV)
  - Angle & E_μ cut only
    - $0.03 < \theta < 0.1$
    - $E_\mu > 2, 5, 10$ GeV
    - (no magnetic field, no detector acceptance)
  - luminosity assumption 10,000 pb^{-1}
    - ~ 10 times larger luminosity necessary than collider experiments
    - because of ~10 times smaller cross section × acceptance
  - $M_{\mu\mu}$ = 4.5 ~ 8 GeV

Red: Eμ > 2 GeV cut
Green: Eμ > 5 GeV cut
Blue: Eμ > 10 GeV cut



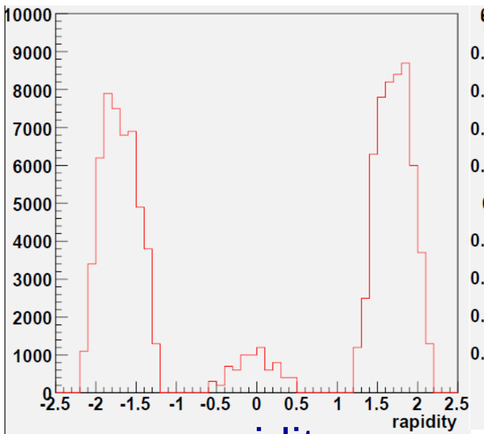
35K events total with 10-GeV cut

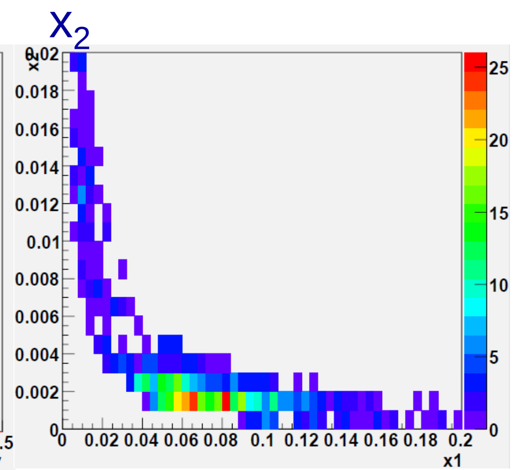
rapidity	#event
−0.4, 0.0	1K
0.0, 0.4	17K
0.4, 0.8	14K
0.8, 1.2	2K

Collider vs fixed-target

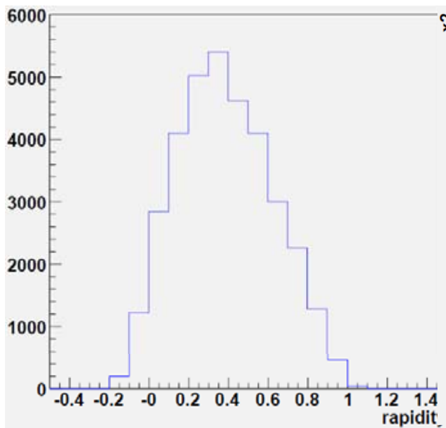
- x_1 & x_2 coverage
  - PHENIX muon arm
    - Single arm: x_1 = 0.05 – 0.1 (x_2 = 0.001 – 0.002)
      - Very sensitive x-region of SIDIS data
    - Back-to-back: small x_1 & x_2
  - Fixed-target experiment
    - x_1 = 0.25 – 0.4 (x_2 = 0.1 – 0.2)
      - Can explore higher-x region with better sensitivity

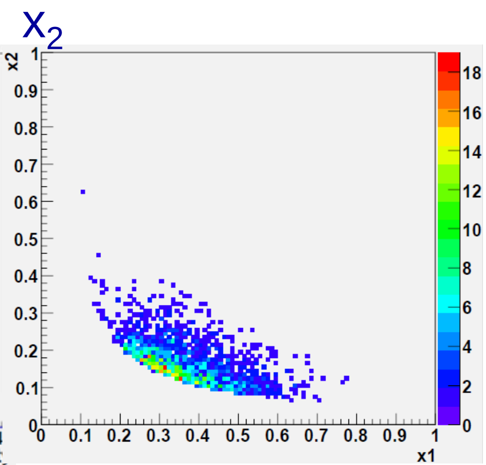
PHENIX muon arm





Fixed-target experiment
(angle & E_μ cut only)





Fixed-target experiment

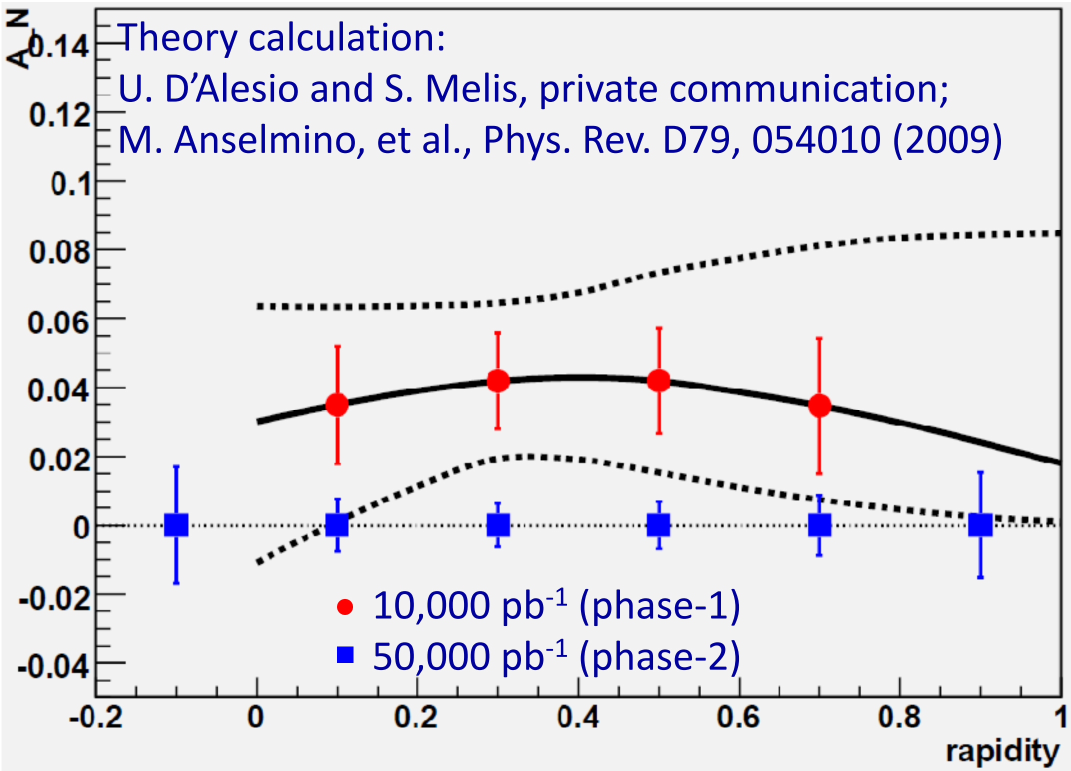
- Phase-1: parasitic experiment (with other collider experiments)
  - Beam intensity $2\times10^{11}\times10$MHz = 2×10^{18}/sec
  - Cluster or pellet target $10^{15}/cm^2$
    - 50 times thinner than RHIC CNI carbon target
  - Luminosity $2\times10^{33}/cm^2/sec$
  - 10,000pb^{-1} with 5×10^6sec
    - 8 weeks, or 3 years (10 weeks $\times$ 3) with efficiency and live time
  - Reaction rate $2\times10^{33}\times50$mb = 10^8/sec = 100MHz
  - Beam lifetime $2\times10^{11}\times100$bunch / 10^8 = 2×10^5sec (at longest)
    - More factor to make the lifetime shorter, but expected to be still long enough

Fixed-target experiment

- Phase-2: dedicated experiment
  - Beam intensity $2\times10^{11}\times30\text{MHz} = 6\times10^{18}$/sec
  - Cluster, pellet or solid target $10^{16}/\text{cm}^2$
    - 5 times thinner than RHIC CNI carbon target
  - Luminosity $6\times10^{34}/\text{cm}^2/\text{sec}$
  - 10,000pb^{-1} with 2×10^5sec
    - 3 days, or 2 weeks with efficiency and live time
  - Or 50,000pb^{-1} with 10^6sec
    - 2 weeks, or 8 weeks with efficiency and live time
  - Reaction rate $6\times10^{34}\times50\text{mb} = 3\times10^9/\text{sec} = 3\text{GHz}$
  - Beam lifetime $2\times10^{11}\times300\text{bunch} / 3\times10^9 = 2\times10^4\text{sec} \sim$ 6hours
    - More factor to make the lifetime shorter
    - Special short-interval operation necessary

Physics

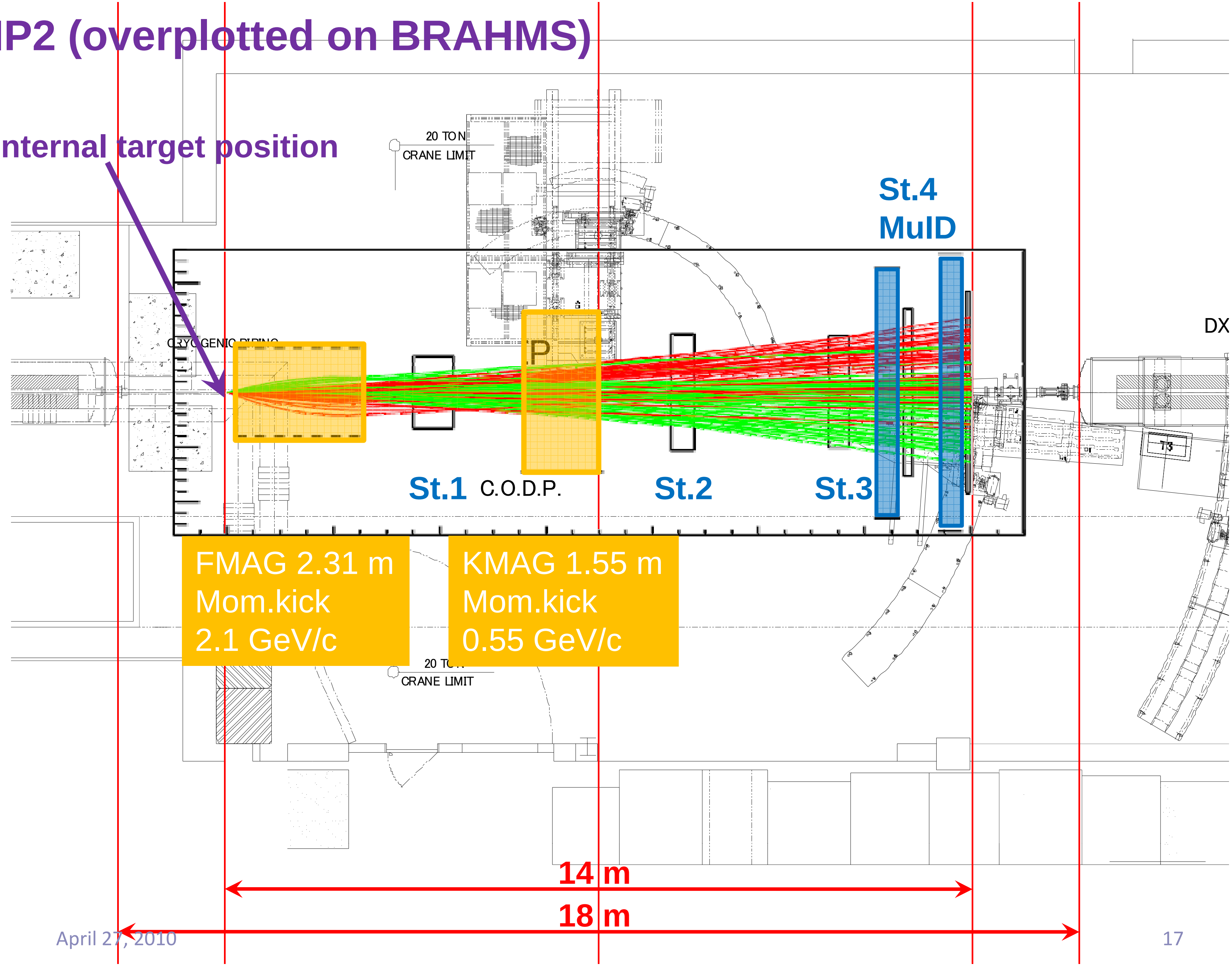
- Experimental sensitivity
  - Phase-1 (parasitic operation)
    - L = 2×10^{33} $cm^{-2}s^{-1}$
    - 10,000 pb-1 with 5×10^{6} s ~ 8 weeks (1 year), or 3 years of beam time by considering efficiency and live time
  - Phase-2 (dedicated operation)
    - L = 6×10^{34} $cm^{-2}s^{-1}$
    - 50,000 pb-1 with 10^{6} s ~ 2 weeks, or 8 weeks (1 year) of beam time by considering efficiency and live time



Issues for the fixed-target experiment

- Requirement for target thickness
  - In phase-1 (parasitic operation), 10^{15} /cm^2 thickness is necessary to achieve $L = 2\times10^{33}$ cm^{-2}s^{-1}
    - Pellet target (~10^{15} /cm^2) or cluster-jet target (up to 8×10^{14}/cm^2 ?) is necessary
    - If it is not achieved, the internal-target experiment would not be competitive against collider experiments
    - In collider experiments, $L = 2(\text{or } 3)\times10^{32}$ is expected and cross section ($\times$ acceptance) is >10 times larger
  - In phase-2 (dedicated operation), 10-times larger thickness, 10^{16} /cm^2 is expected
- Requirement for accelerator
  - Compensation of dipole magnets in the experimental apparatus (in two colliding-beam operation)
  - Size of the experimental site and possible target-position (with proper beam operation)
  - Reaction rate (peak rate) and beam lifetime
  - Radiation issues
    - Beam loss/dump requirement

IP2 (overplotted on BRAHMS)



Summary

- Polarized Drell-Yan experiment
  - The simplest process in hadron-hadron reaction
  - But, not yet done because of technical difficulties so far
  - At present it has become feasible, finally
- J-PARC proposal
  - Not accepted yet
    - Waiting for FNAL-E906 result for unpolarized measurements
  - 50 GeV beam necessary, polarized-beam necessary
- RHIC
  - Collider experiment
  - Fixed-target (internal-target) experiment
  - Both feasible

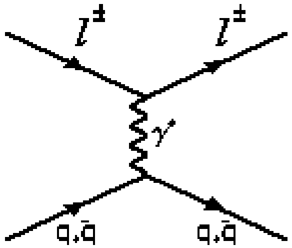
Backup slides

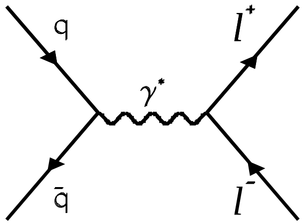
Outline of this talk

- Physics motivations of polarized Drell-Yan experiments
- J-PARC proposals
  - Unpolarized experiment
  - Polarized experiment with a polarized beam
- Ideas at RHIC
  - Collider
  - Fixed-target experiment
- Other possibility

Drell-Yan experiment

- The simplest process in hadron-hadron reactions

DIS 

Drell-Yan 

  - No QCD final state effect

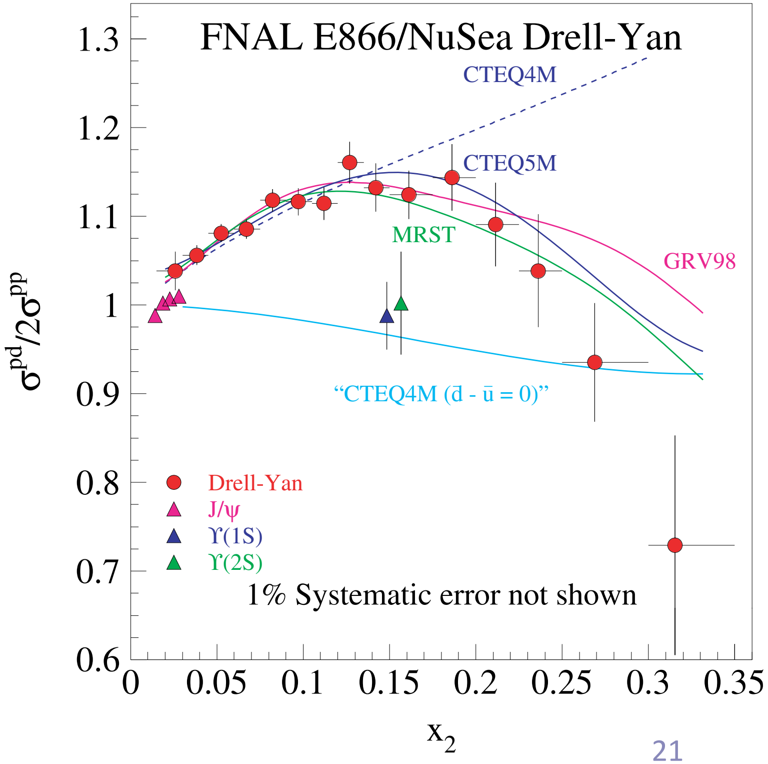
- Fermilab E866
  - Flavor asymmetry of sea-quark distribution

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \sim \frac{1}{2}\left[1+\frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$$

with CTEQ5M

$$\int_{0.015}^{0.35} dx[\bar{d}(x)-\bar{u}(x)] = 0.0803 \pm 0.011$$

$$\int_{0}^{1} dx[\bar{d}(x)-\bar{u}(x)] = 0.118 \pm 0.012$$



Drell-Yan experiment

- Flavor asymmetry of sea-quark distribution
  - Possible origins
    - meson-cloud model
      - virtual meson-baryon state
    - chiral quark model
    - instanton model
    - chiral quark soliton model

$$p \rightarrow p\pi^0, n\pi^+, \Delta\pi$$

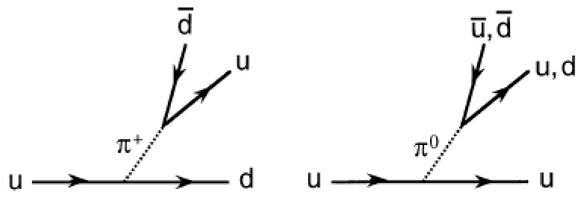


Fig. 17. Valence *u* quark splitting.

  - π^+ in the proton as an origin of anti-d quark
    - pseudo-scaler meson should have orbital angular momentum in the proton…
- Polarized Drell-Yan experiment
  - Not yet done!
  - Many new inputs for remaining proton-spin puzzle
    - flavor asymmetry of the sea-quark polarization
    - transversity distribution
    - transverse-momentum dependent (TMD) distributions
      - Sivers function, Boer-Mulders function, etc.

Polarized Drell-Yan experiment

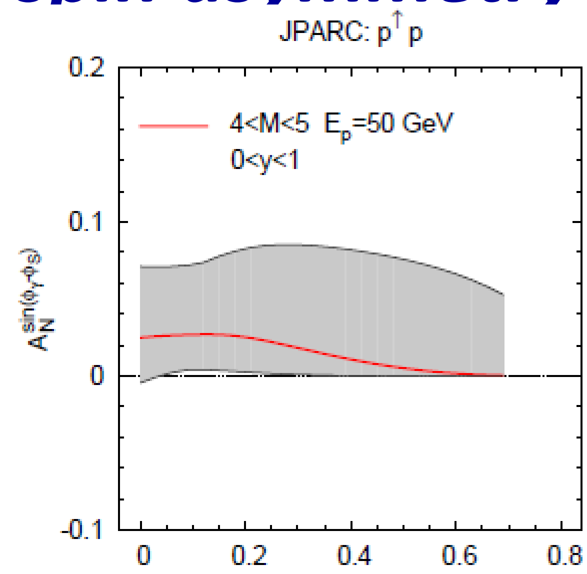
- Single transverse-spin asymmetry
  - Sivers function measurement
  - Transversity ⊗ Boer-Mulders function

$$\sigma_{TU} \propto f_{1T}^{\perp} f_1 + \sin 2\phi h_1 h_1^{\perp} + \sin 2\phi h_{1T}^{\perp} h_1^{\perp}$$

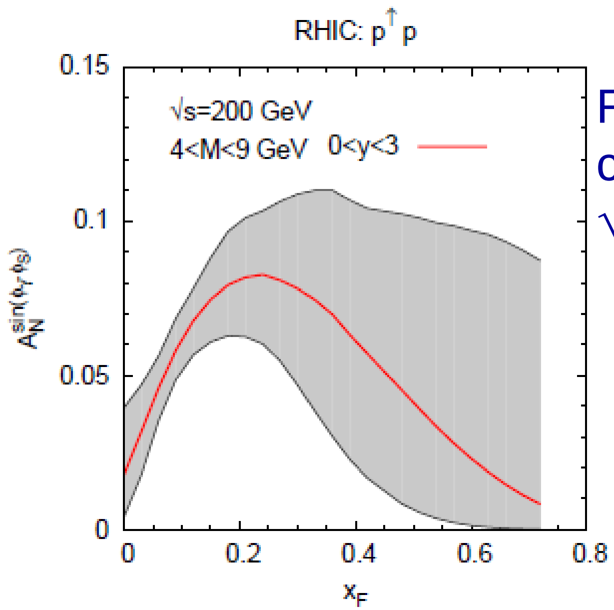
- Double transverse-spin asymmetry
  - Transversity (quark ⊗ antiquark for p+p collisions)
- Double helicity asymmtry
  - Flavor asymmetry of quark polarization
- Other physics
  - Parity violation asymmetry?

Single transverse-spin asymmetry

- Sivers effect
  - Spin-correlated transverse momentum distribution of an parton in the proton (Sivers distribution function)
  - Related to the orbital angular momentum in the proton (and the shape of the proton)
    - Multi-dimensional structure of the proton
  - Initial-state or final-state interaction with remnant partons



J-PARC
50-GeV
polarized beam
√s ~ 10 GeV

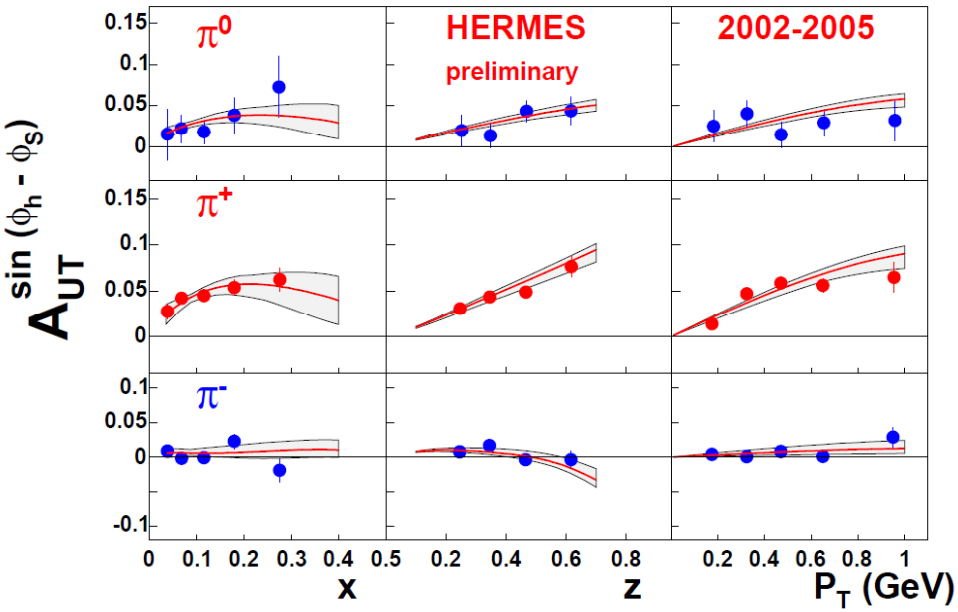


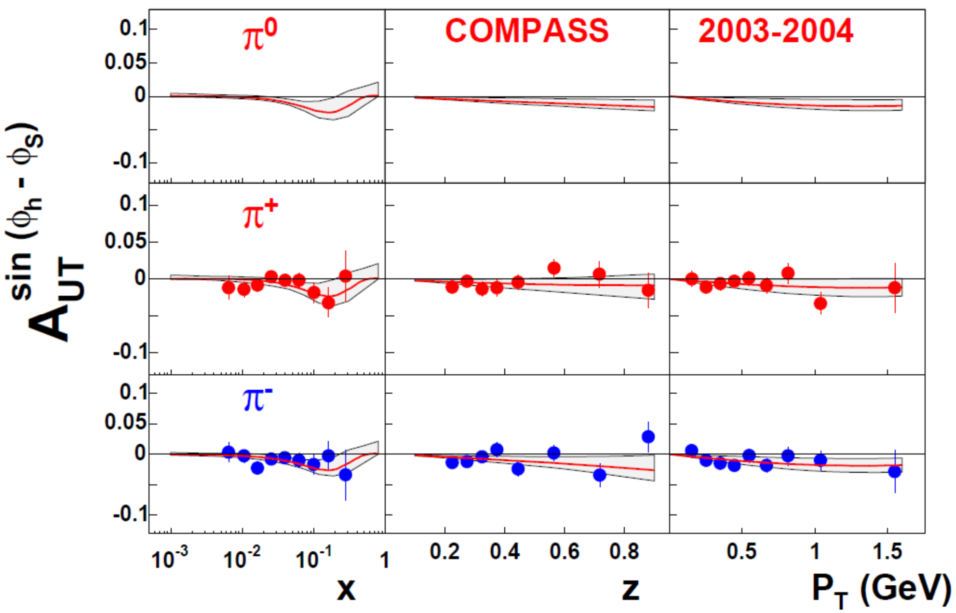
RHIC
collider
√s = 200 GeV

Anselmino, et al., PRD79, 054010 (2009)

Sivers function measurement

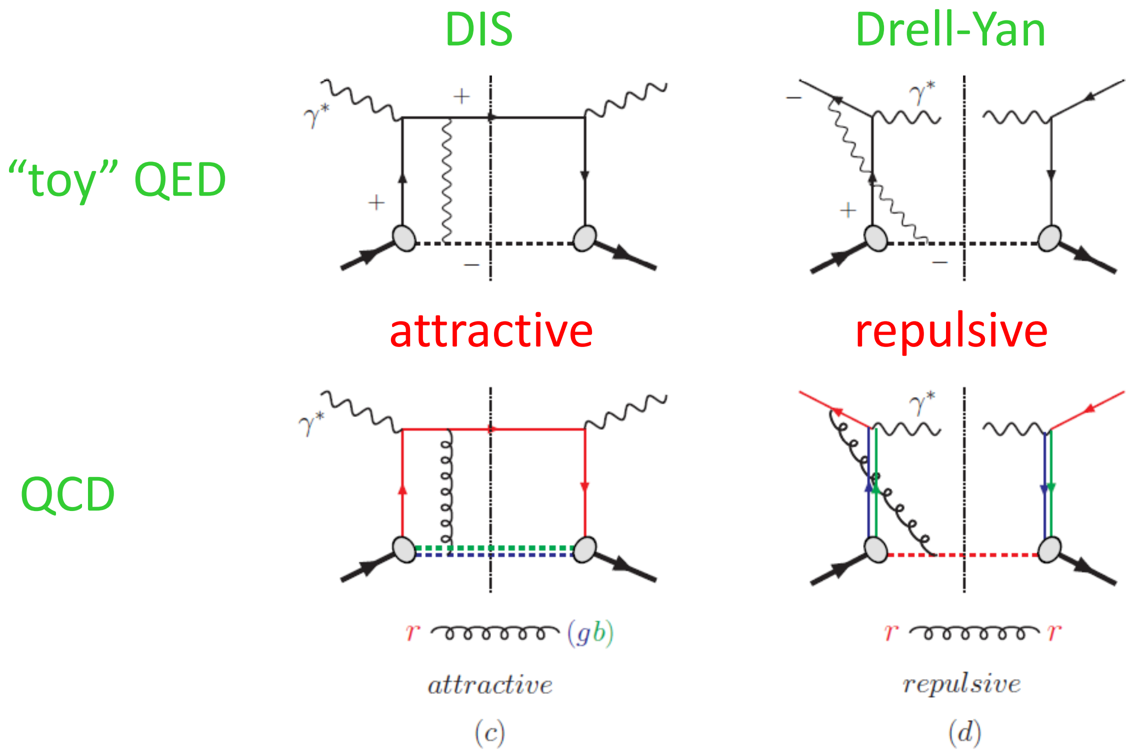
- Sign of Sivers function determined by single transverse-spin (SSA) measurement of DIS and Drell-Yan processes
  - Should be opposite each other
    - Initial-state interaction or final-state interaction with remnant partons
- < 1% level multi-points measurements have already been
- done for SSA of DIS process
  - x = 0.005 – 0.3 (more sensitive in lower-x region)
- comparable level measurement needs to be done for SSA of Drell-Yan process for comparison





Sivers function measurement

- Sign of Sivers function determined by single transverse-spin (SSA) measurement of DIS and Drell-Yan processes
  - Should be opposite each other
    - Initial-state interaction or final-state interaction with remnant partons
  - Test of TMD factorization
  - Explanation by Vogelsang and Yuan…
    - From "Transverse-Spin Drell-Yan Physics at RHIC," Les Bland, et al., May 1, 2007



Sivers function measurement

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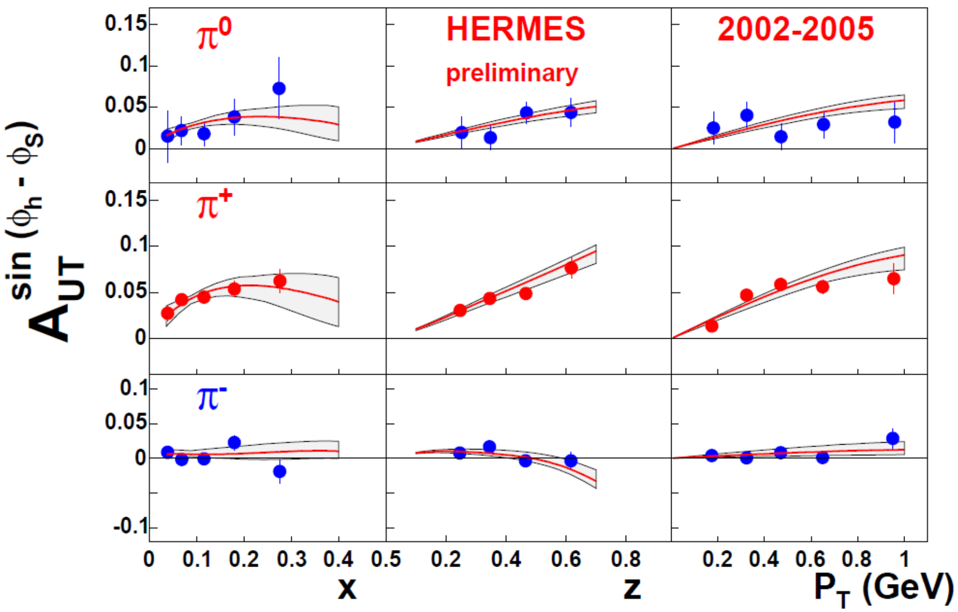
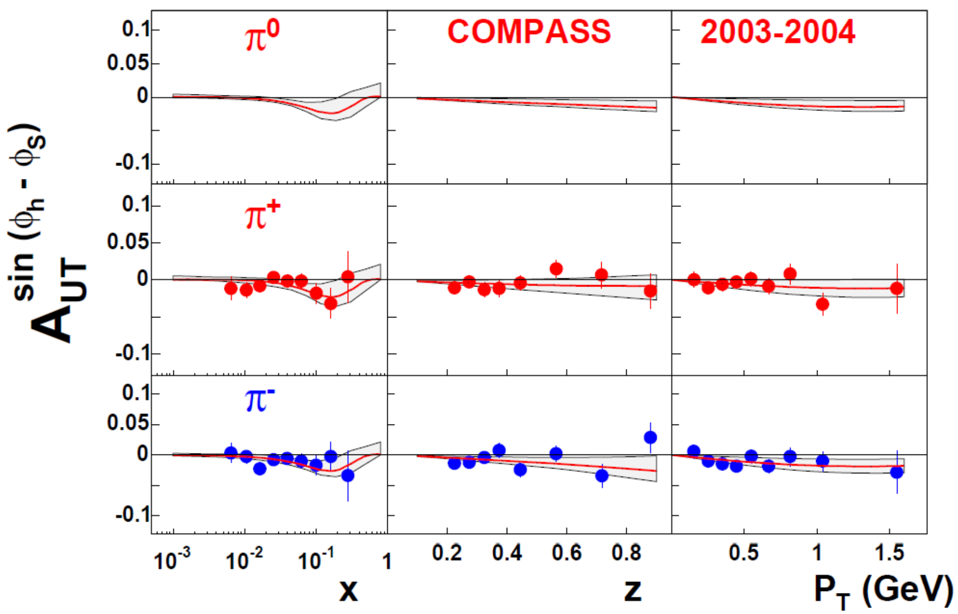




Single transverse-spin asymmetry

- Sivers function measurement
- Transversity ⊗ Boer-Mulders function measurement

by Stefano Melis

$$\frac{\Delta d\sigma^{\text{Sivers}}}{d^4q\,d\Omega_{cs}} \propto \underbrace{\Delta^N f_{a/A\uparrow}\left(\frac{q_0+q_L}{\sqrt{s}}\right)}_{\text{Sivers}} f_{b/B}\left(\frac{q_0-q_L}{\sqrt{s}}\right)$$
$$\times \frac{q_T}{M_{Siv}}\Big\{\underbrace{(1+\cos^2\theta_{cs})\sin(\phi_{S_A}-\phi_\gamma)}_{\text{analogous of the }\lambda\text{ like term in unp. DY}} + O(q_T/M)\Big\}$$

$$\frac{\Delta d\sigma^{h_1-BM}}{d^4q\,d\Omega_{cs}} \propto \underbrace{h_1\left(\frac{q_0+q_L}{\sqrt{s}}\right)\Delta f_{b^\uparrow/B}\left(\frac{q_0-q_L}{\sqrt{s}}\right)}_{\text{transversity}\,\times\,\text{Boer-Mulders}}$$
$$\times \frac{q_T}{M_{BM}}\Big\{\sin^2\theta_{cs}\cos 2\phi_{cs}\sin(\phi_{S_A}-\phi_\gamma)$$
$$\underbrace{-\sin^2\theta_{cs}\sin 2\phi_{cs}\cos(\phi_{S_A}-\phi_\gamma) + O(q_T^2/M^2)\Big\}}_{\text{same role of }\nu\text{ like term in unp. DY}}$$

Polarized and unpolarized Drell-Yan experiment

- A_{TT} measurement
  - $h_1(x)$: transversity
    - quark ⊗ antiquark in p+p collisions

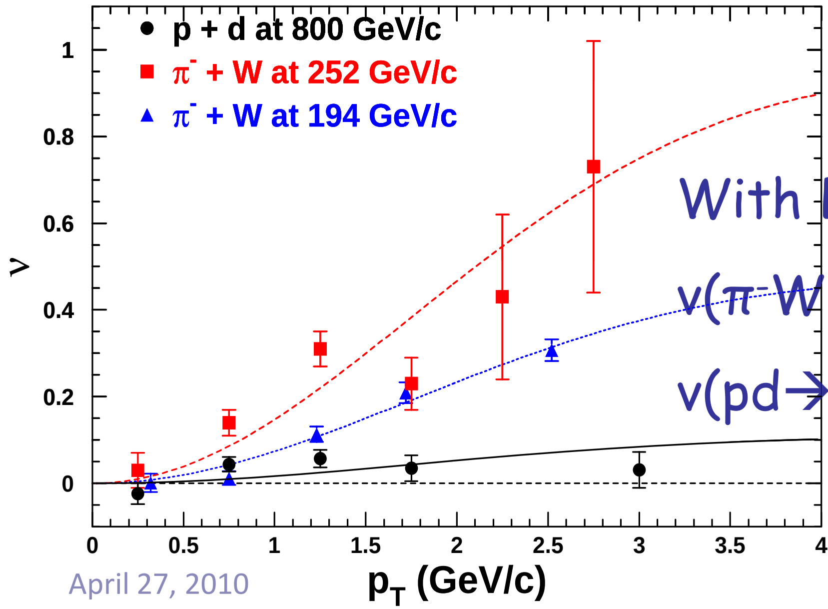
$$A_{TT} = \hat{a}_{TT} \cdot \frac{\sum_q e_q^2 (\bar{h}_{1q}(x_1) h_{1q}(x_2) + (1 \leftrightarrow 2))}{\sum_q e_q^2 (\bar{f}_{1q}(x_1) f_{1q}(x_2) + (1 \leftrightarrow 2))}$$

$$\hat{a}_{TT} = \frac{\sin^2\theta \cos(2\phi - \phi_{S_1} - \phi_{S_2})}{1 + \cos^2\theta}$$

- Unpolarized measurement
  - angular distribution of unpolarized Drell-Yan
  - Boer-Mulders function
    - violation of the Lam-Tung relation

$$\left(\frac{1}{\sigma}\right)\left(\frac{d\sigma}{d\Omega}\right) = \left[\frac{3}{4\pi}\right]\left[1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi\right]$$

$$\nu \neq 0, 1 - \lambda \neq 2\nu$$



With Boer-Mulders function $h_1^{\perp}$:

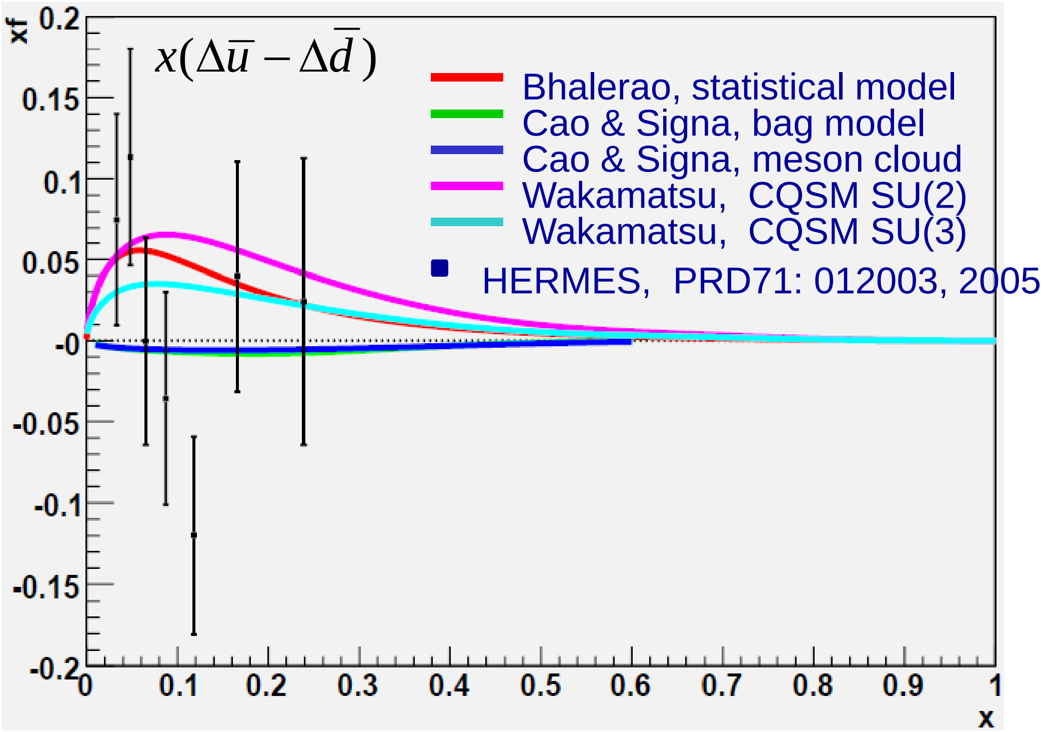
$\nu(\pi^- W \rightarrow \mu^+\mu^- X)$ ~ valence $h_1^{\perp}(\pi)$ * valence $h_1^{\perp}(p)$

$\nu(pd \rightarrow \mu^+\mu^- X)$ ~ valence $h_1^{\perp}(p)$ * sea $h_1^{\perp}(p)$

L.Y. Zhu, J.C. Peng, P. Reimer et al.
hep-ex/0609005

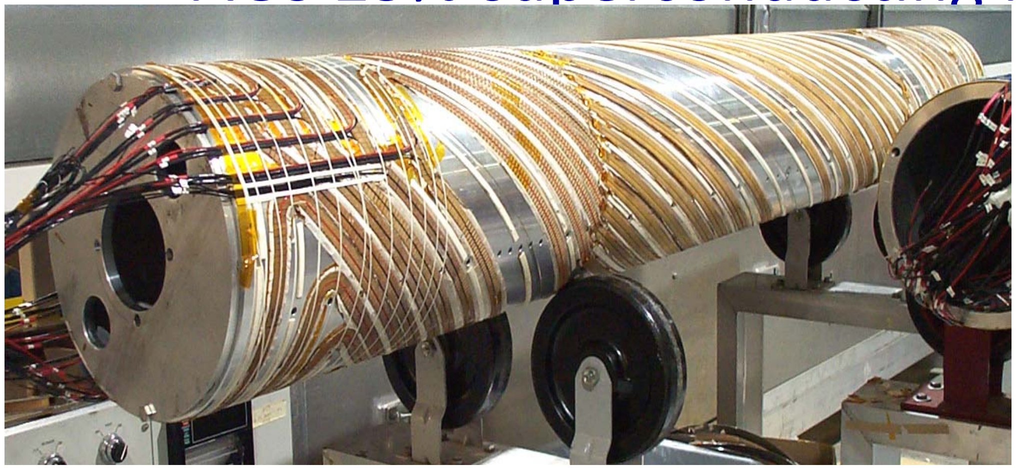
Polarized Drell-Yan experiment

- Longitudinally-polarized measurement
  - A_{LL} measurement
  - flavor asymmetry of sea-quark polarization
    - SIDIS data from HERMES, and new COMPASS data available
    - W data from RHIC will be available in the near future
    - Polarized Drell-Yan data will be able to cover higher-x region



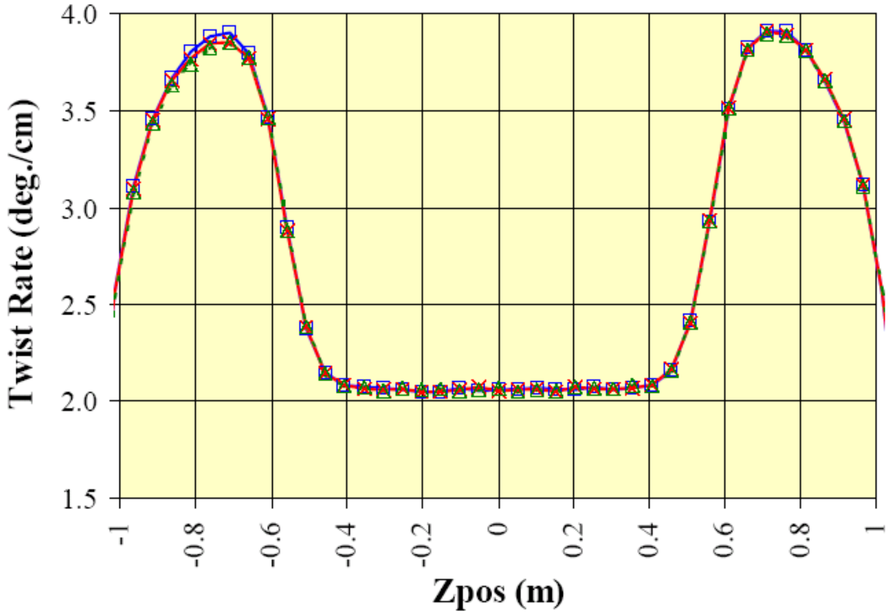
Accelerating polarized protons in the MR

- AGS 25% superconducting helical snake



helical dipole coil

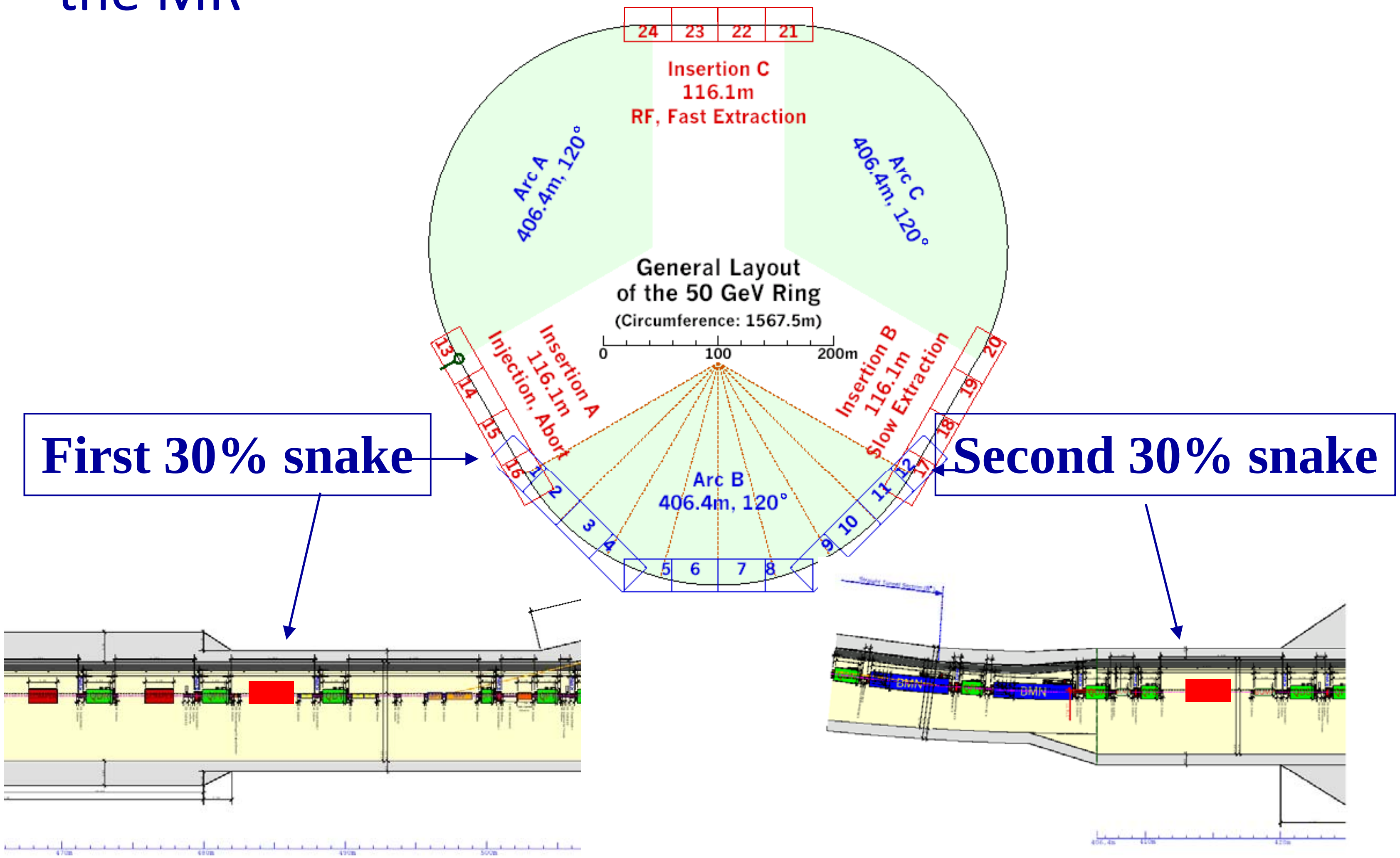
correction solenoid and dipoles



measured twist angle 2 deg/cm in the middle ~4 deg/cm at ends

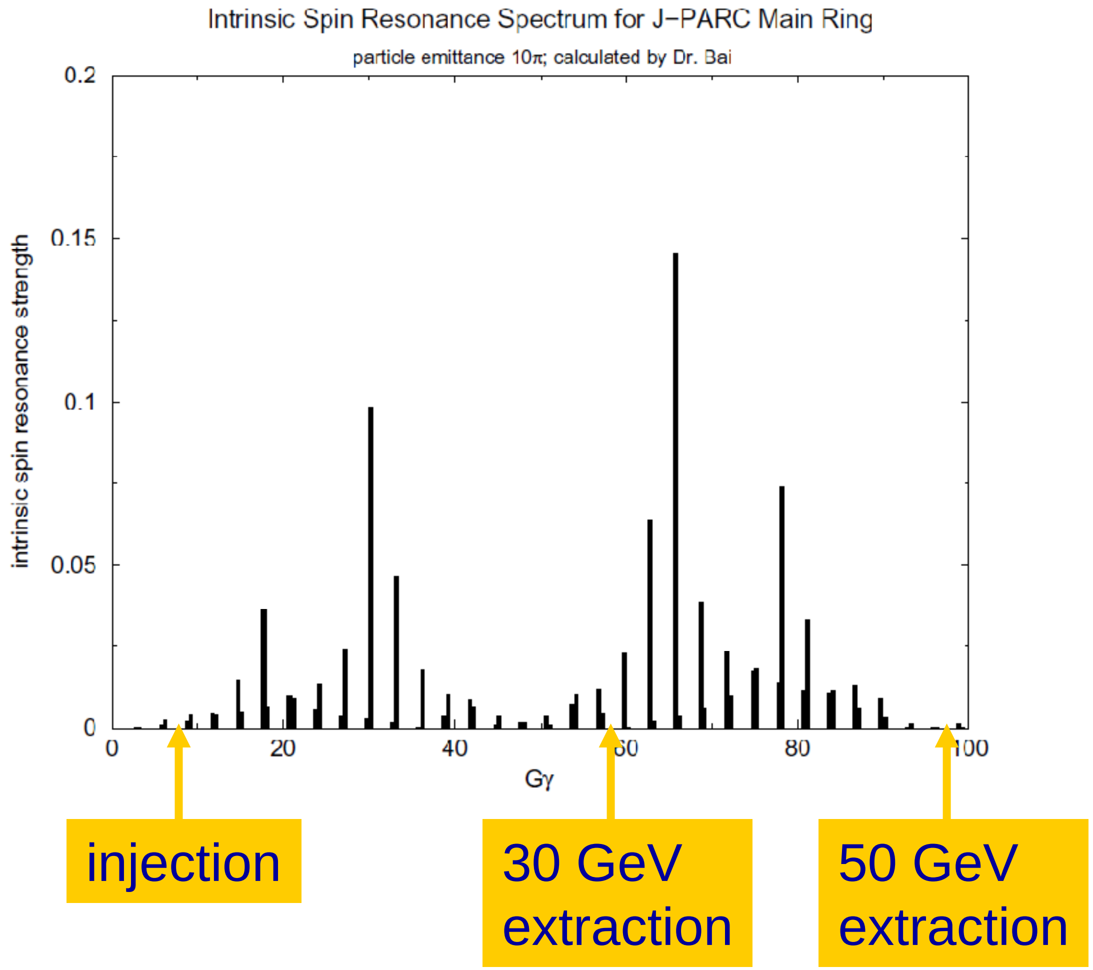
Accelerating polarized protons in the MR

- Possible location of partial helical snake magnets in the MR



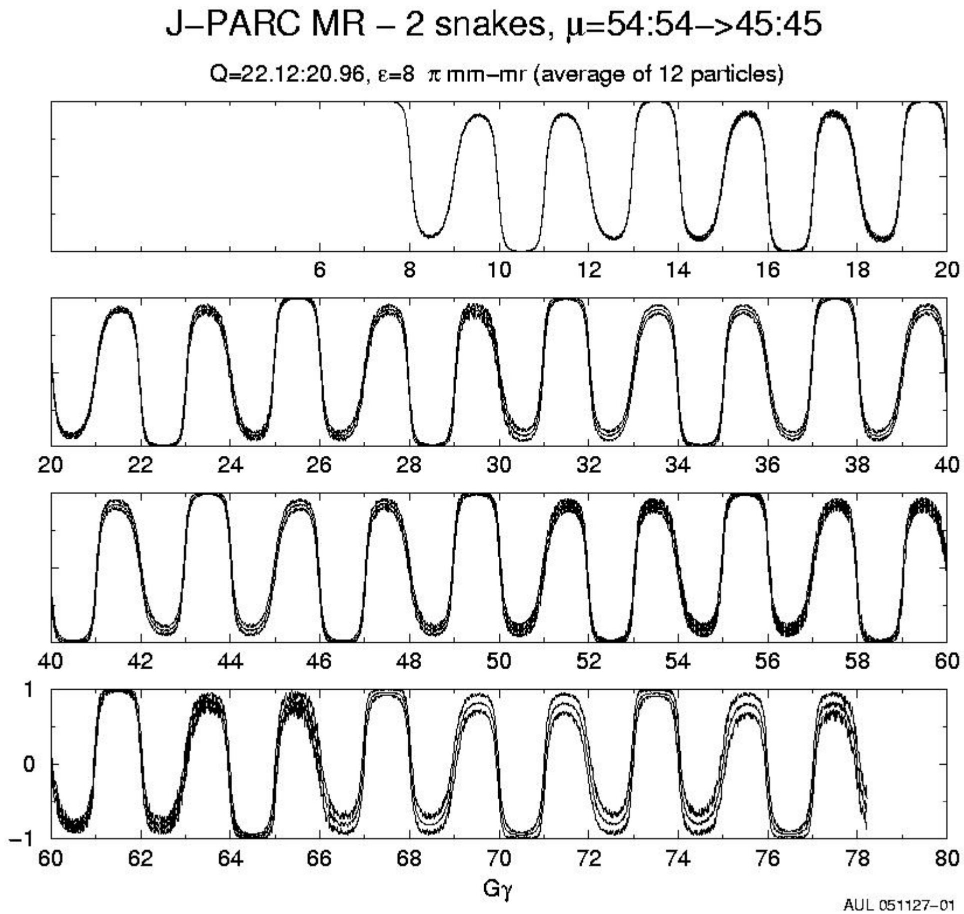
Accelerating polarized protons in the MR

- Kinetic energy from 3 GeV to 50 GeV
  - $G\gamma$ = 7.5 ~ 97.5
  - betatron tune ν_x = 22.339, ν_y = 20.270



Accelerating polarized protons in the MR

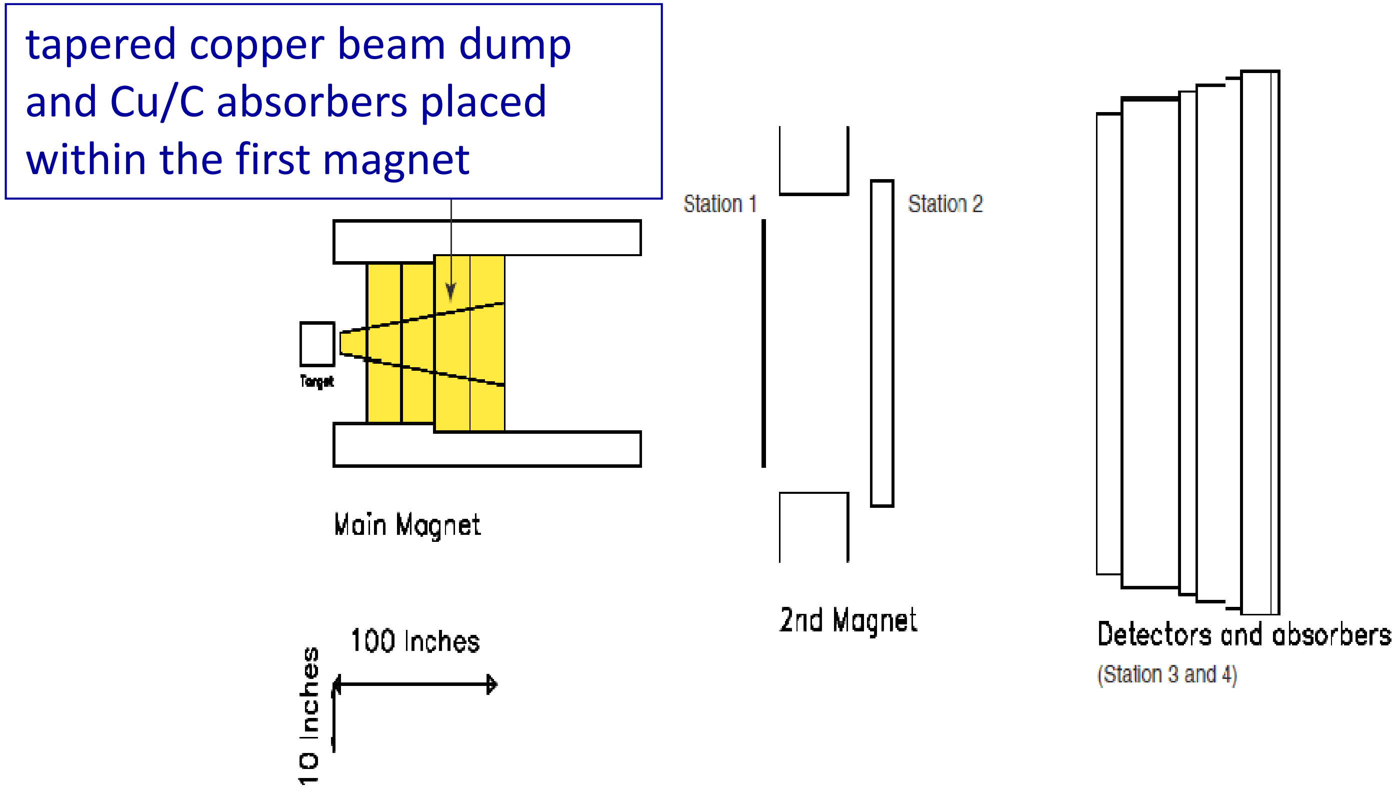
- Spin tracking
  - $\nu_x = 22.128$, $\nu_y = 20.960$
  - average of 12 particles on an ellipse of 8π mm mrad



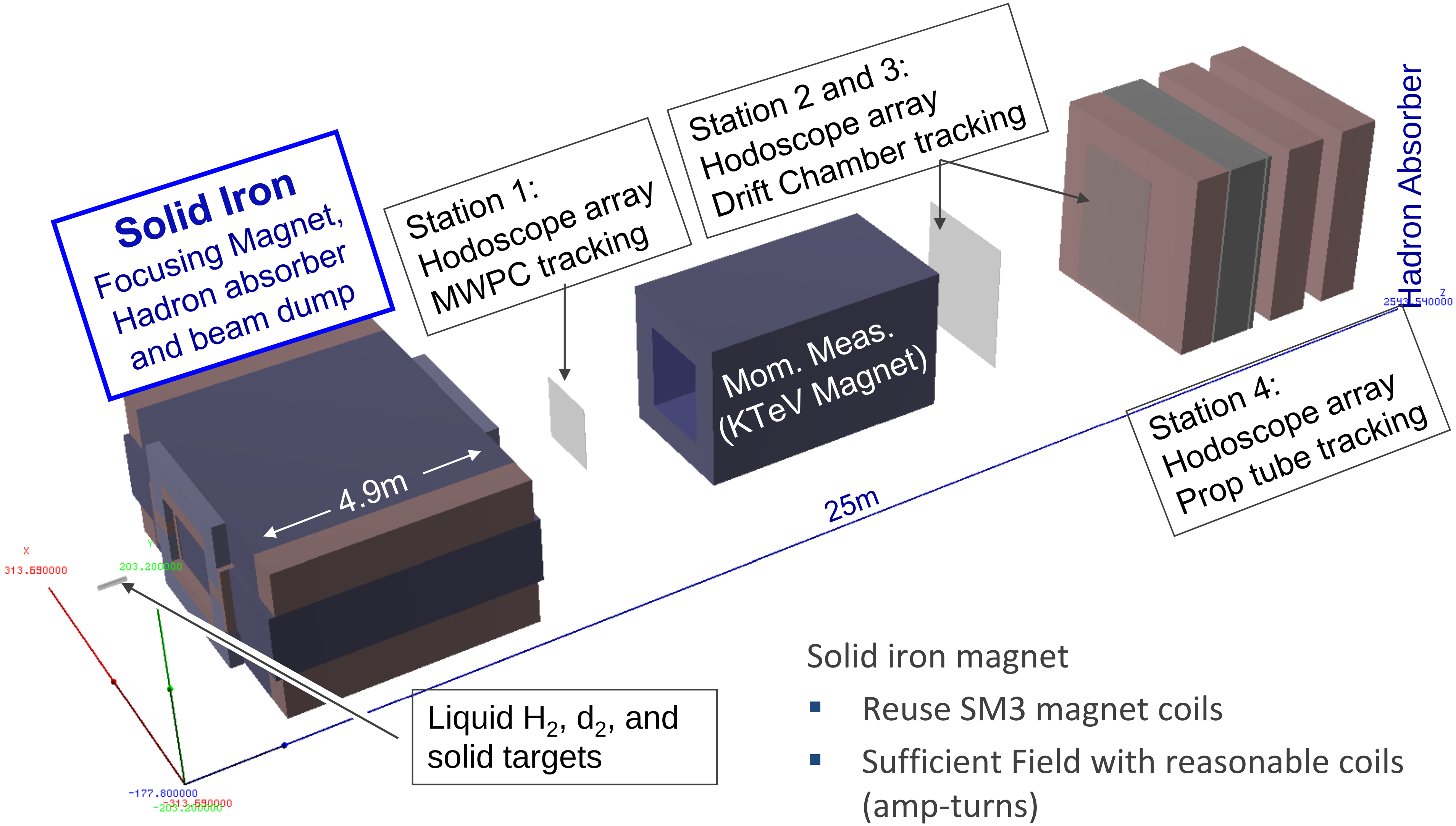
by A.U. Luccio (BNL)

Dimuon experiment at J-PARC (P04)

- based on the Fermilab spectrometer for 800 GeV
- length to be reduced but the aperture to be increased
- two bending magnets with p_T kick of 2.5 GeV/c and 0.5 GeV/c
- tracking by three stations of MWPC and drift chambers
- muon id and tracking



FNAL-E906 dimuon spectrometer

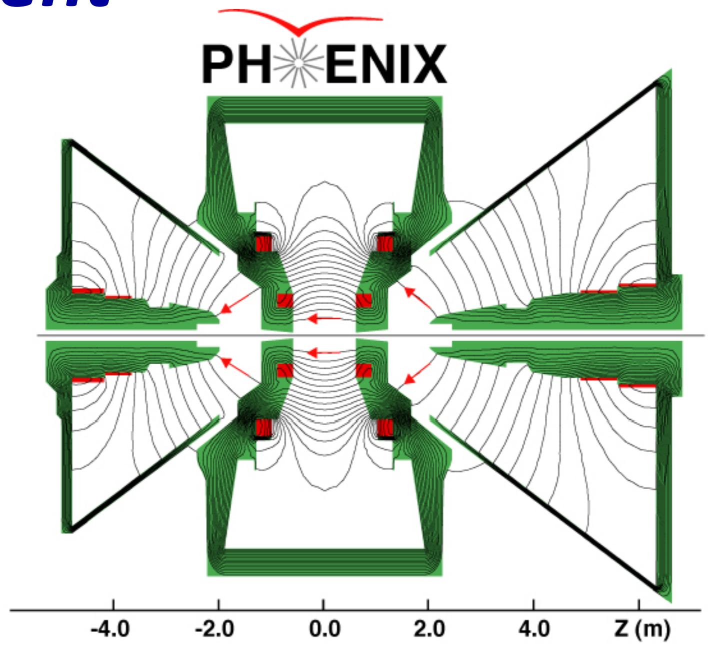


Solid iron magnet

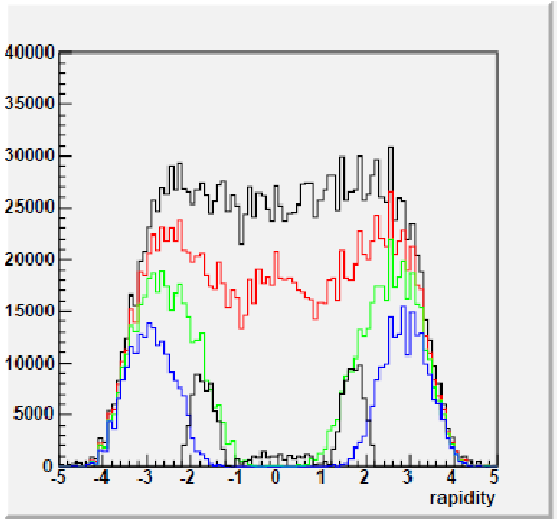
- Reuse SM3 magnet coils
- Sufficient Field with reasonable coils (amp-turns)
- Beam dumped within magnet

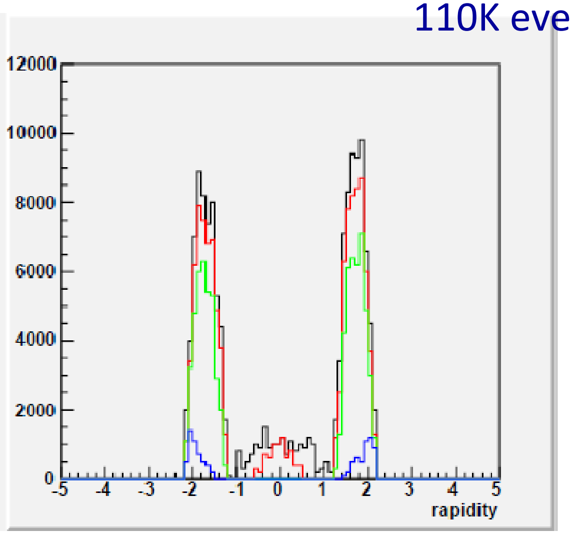
Collider experiment

- Very simple PYTHIA simulation for PHENIX muon arm
  - $\sqrt{s}$ = 500 GeV
  - Angle & E_μ cut only
    - 1.2 < |η| < 2.2 (0.22 < |θ| < 0.59)
    - E_μ > 2, 5, 10 GeV
    - (no magnetic field, no detector acceptance)
  - RHIC-II luminosity assumption 1,000 pb^{-1}
  - $M_{\mu\mu}$ = 4.5 ~ 8 GeV



Magnetic field lines for the two Central Magnet coils in combined (++) mode



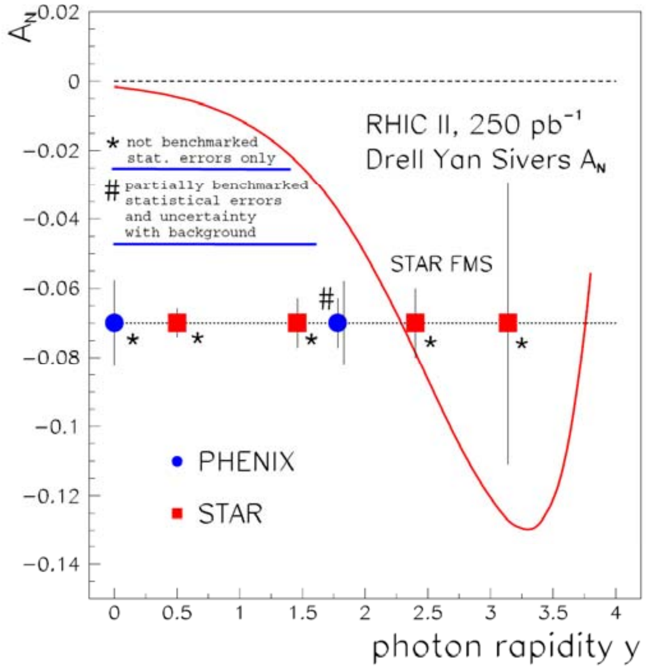


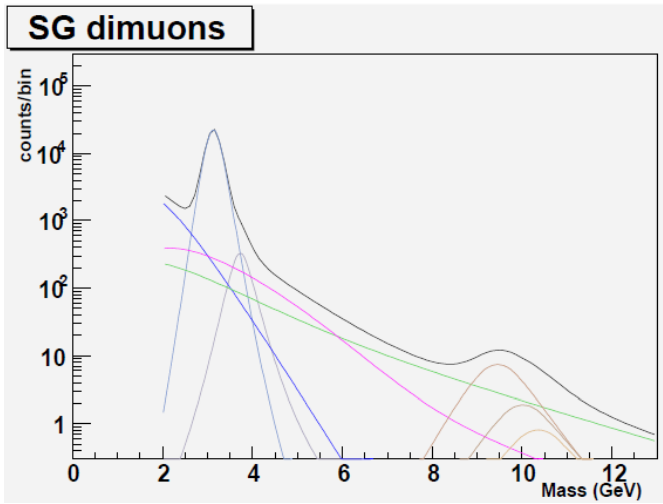
110K events total with 2-GeV cut

rapidity	#event
−2.4, −2.0	5K
−2.0, −1.6	28K
−1.6, −1.2	17K
−0.4, 0.0	3K
0.0, 0.4	3K
1.2, 1.6	18K
1.6, 2.0	31K
2.0, 2.4	5K

Collider experiment

- "Transverse-Spin Drell-Yan Physics at RHIC"
  - Les Bland, et al., May 1, 2007
  - √s = 200 GeV
  - PHENIX muon arm
  - STAR FMS (Forward Muon Spectrometer)
  - Large background from b-quark
  - √s = 500 GeV may be better…
    - Higher luminosity and larger cross section

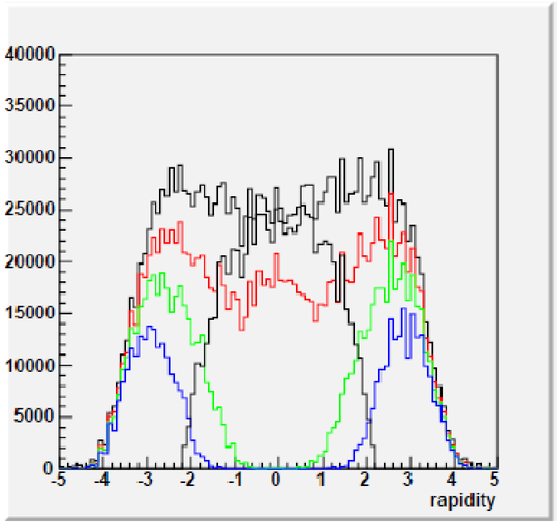


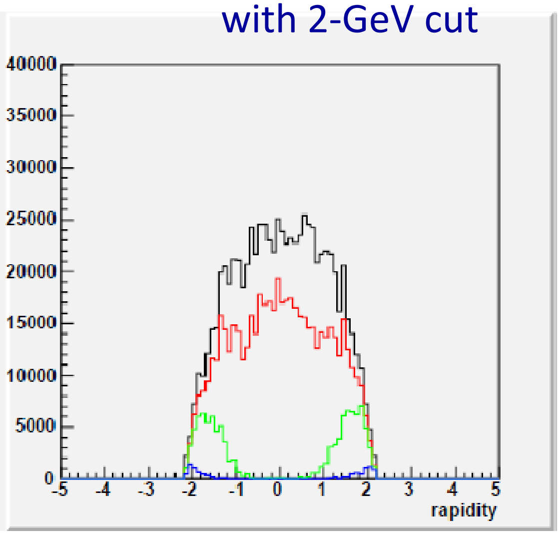


Collider experiment

- Very simple PYTHIA simulation for a dedicated collider experiment
  - $\sqrt{s}$ = 500 GeV
  - Angle & E_μ cut only
    - $|\eta| < 2.2$
    - $E_\mu > 2, 5, 10$ GeV
    - (no magnetic field, no detector acceptance)
  - RHIC-II luminosity assumption 1,000 pb^{-1}
  - $M_{\mu\mu} = 4.5 \sim 8$ GeV

550K events total with 2-GeV cut

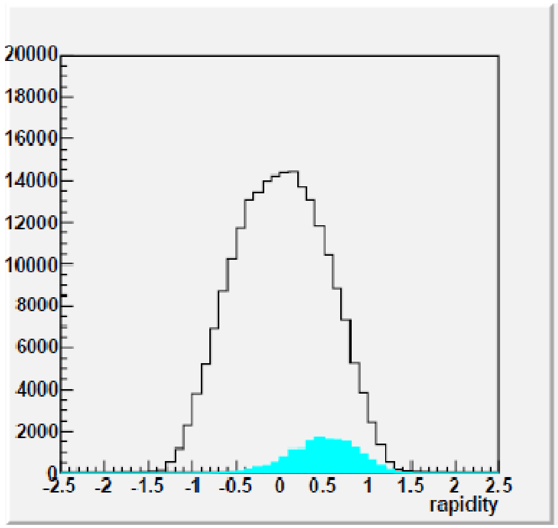


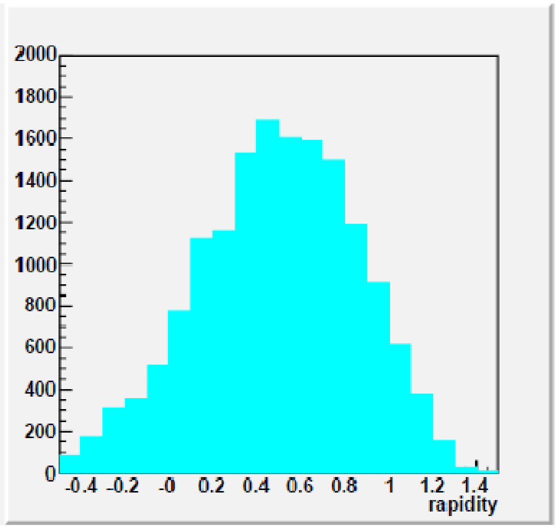


rapidity	#event
−2.4, −2.0	5K
−2.0, −1.6	32K
−1.6, −1.2	53K
−1.2, −0.8	53K
−0.8, −0.4	60K
−0.4, 0.0	70K
0.0, 0.4	68K
0.4, 0.8	60K
0.8, 1.2	55K
1.2, 1.6	54K
1.6, 2.0	36K
2.0, 2.4	5K

Fixed-target experiment

- PYTHIA simulation with FNAL-E906 geometry
  - $\sqrt{s}$ = 22 GeV (E_{lab} = 250 GeV)
  - luminosity assumption 10,000 pb^{-1}
  - $M_{\mu\mu}$ = 4.5 ~ 8 GeV
  - Magnetic field and detector location should be tuned to optimize the acceptance, and fit to available experimental hall





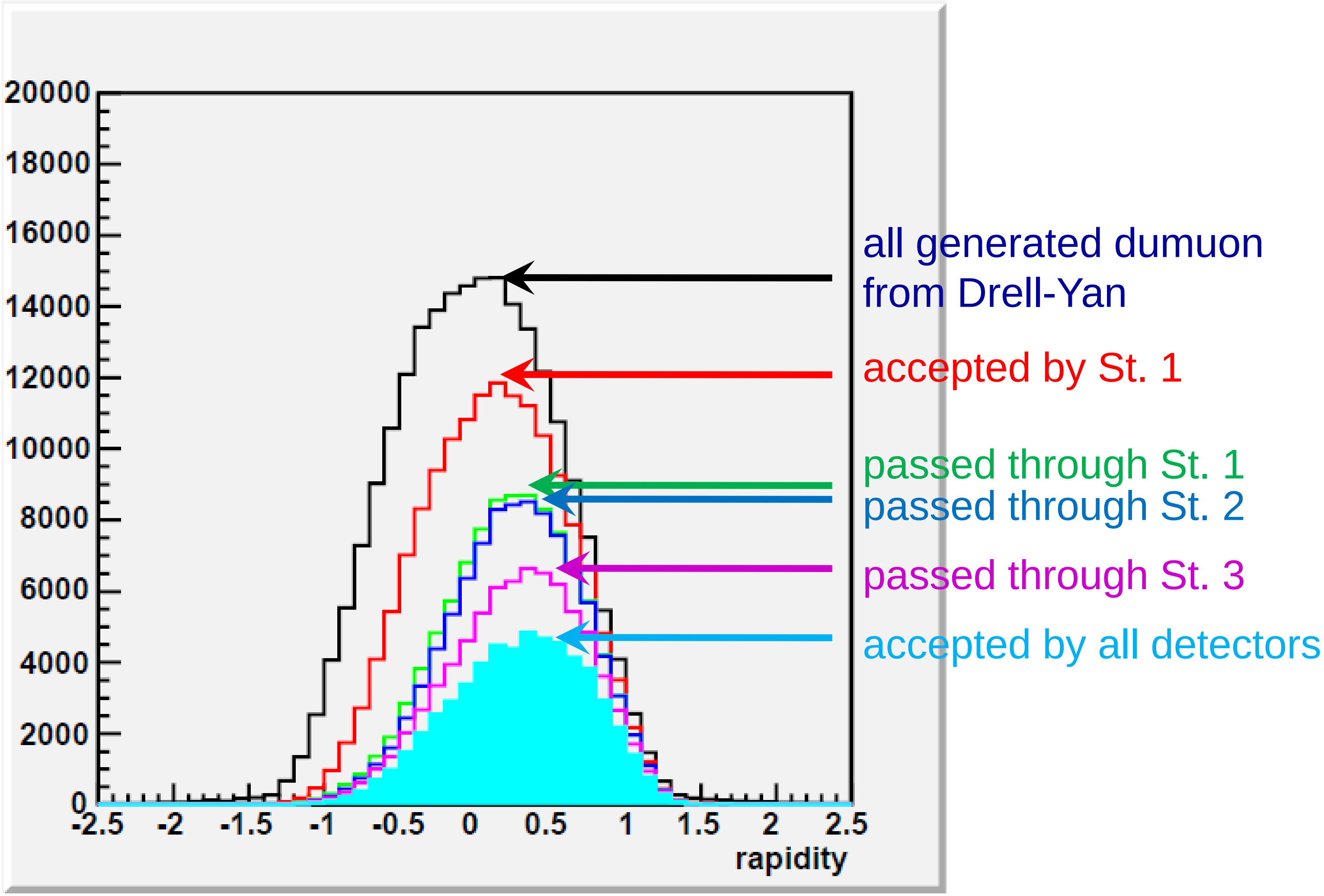
16K events total

rapidity	#event
−0.4, 0.0	1K
0.0, 0.4	5K
0.4, 0.8	6K
0.8, 1.2	3K

PYTHIA simulation with IP2 configuration

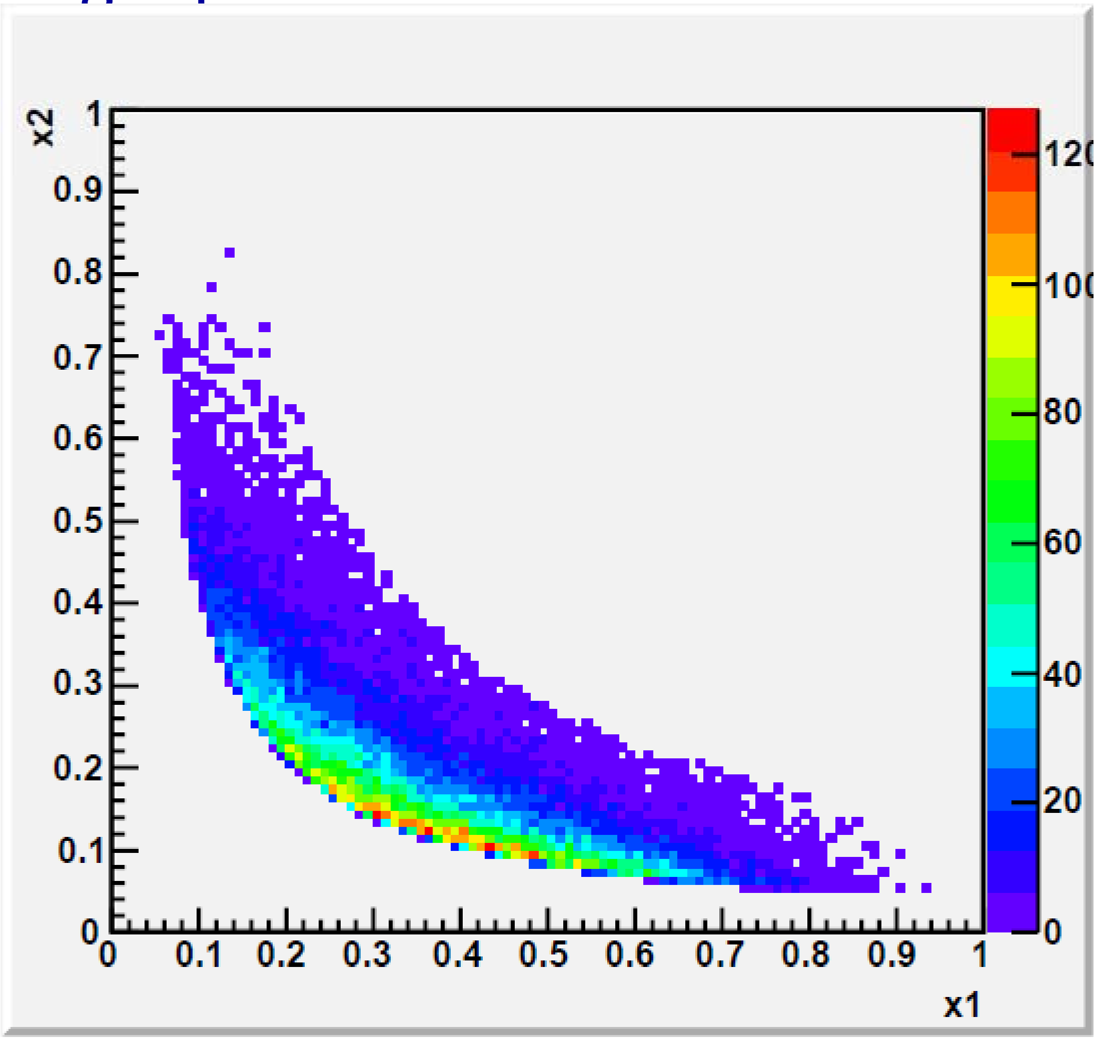
- IP2 configuration shown in the next slide
  - detector components from FNAL-E906 apparatus
    - E906: total z-length ~25 m
    - IP2: available z-lengh ~14 m
  - z-length of FMAG (1^{st} magnet) is shortened
    - because of limited z-length at IP2
- PYTHIA simulation
  - just acceptance for Drell-Yan dimuon signal is studied
  - momentum resolution needs to be studied
  - background rate needs to be studied
- Beam needs to be restored on axis
  - after passing through two bending magnets
  - both beams needs to be restored in parasitic operation

Drell-Yan dimuon rapidity



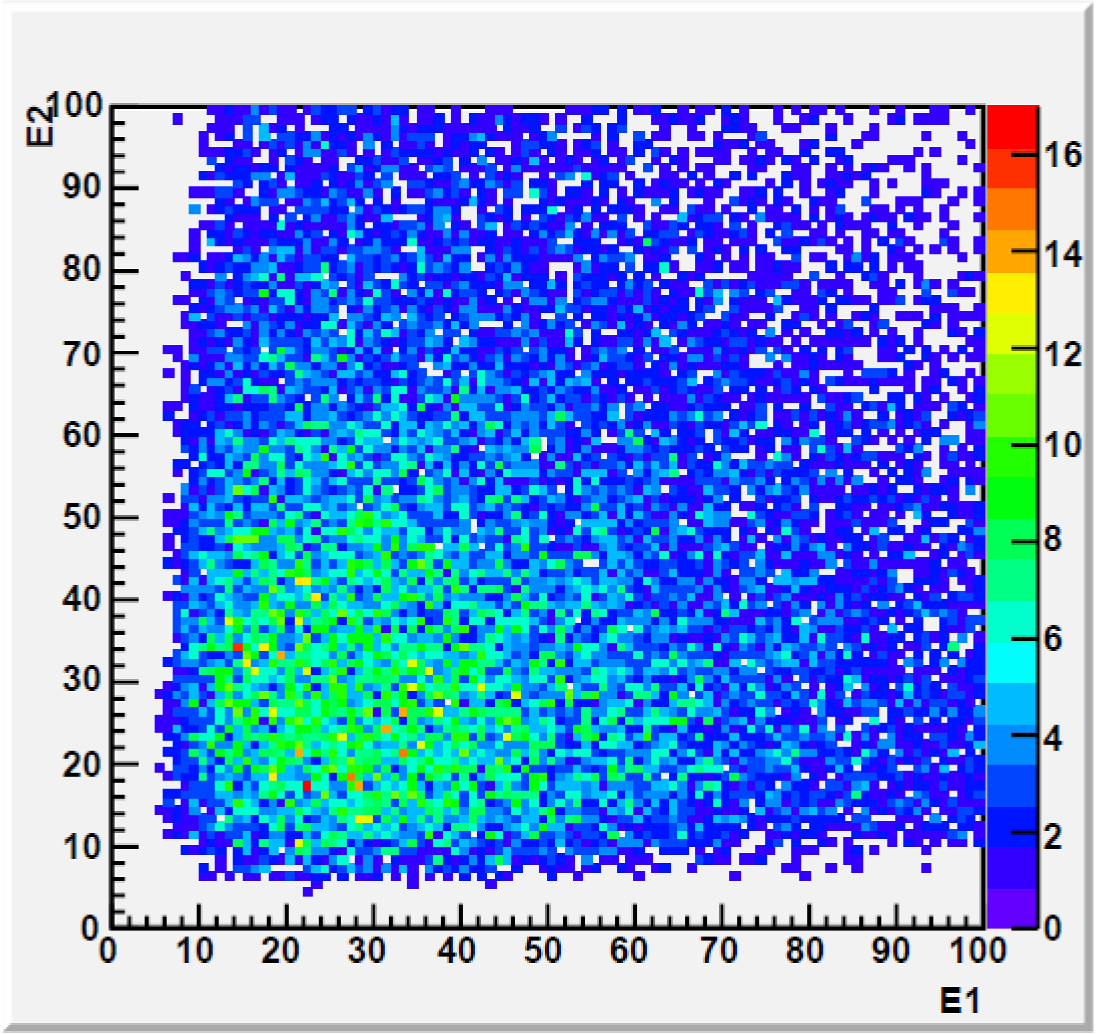
Drell-Yan x_1 vs x_2 (accepted events)

- x_1: x of beam proton (polarized)
- x_2: x of target proton



Drell-Yan E_1 vs E_2 (accepted events)

- E_1, E_2: energy of dimuons
  - energy cut shown at 5 – 10 GeV



Fixed-target experiment

- Internal target
  - Storage cell target (polarized)
    - H_2, D_2, ^3He
    - 10^{14} / cm^2
    - HERMES

Double-spin experiment possible
Low density = low luminosity
Issue to be used in the RHIC ring

  - Cluster jet target
    - H_2, D_2, N_2, CH_4, Ne, Ar, Kr, Xe, …
    - $10^{14} – 10^{15}$ / cm^2
    - CELSIUS (Uppsala), FNAL-E835, Muenster, COSY, GSI, …

High luminosity
Only single-spin experiment possible

  - Pellet target
    - H_2, D_2, N_2, Ne, Ar, Kr, Xe, …
    - $10^{15} – 10^{16}$ / cm^2
    - CELSIUS (Uppsala), COSY, GSI, …

experiment	particles	energy	x1 or x2	luminosity
COMPASS	$\pi\pm + p\uparrow$	160 GeV $\sqrt{s}$ = 17.4 GeV	x2 = 0.2 – 0.3	2×10^{33} $cm^{-2}s^{-1}$
COMPASS (low mass)	$\pi\pm + p\uparrow$	160 GeV $\sqrt{s}$ = 17.4 GeV	x2 ~ 0.05	2×10^{33} $cm^{-2}s^{-1}$
PAX	$p\uparrow$ + pbar	collider $\sqrt{s}$ = 14 GeV	x1 = 0.1 – 0.9	2×10^{30} $cm^{-2}s^{-1}$
PANDA (low mass)	pbar + $p\uparrow$	15 GeV $\sqrt{s}$ = 5.5 GeV	x2 = 0.2 – 0.4	2×10^{32} $cm^{-2}s^{-1}$
J-PARC	$p\uparrow + p$	50 GeV $\sqrt{s}$ = 10 GeV	x1 = 0.5 – 0.9	10^{35} $cm^{-2}s^{-1}$
NICA	$p\uparrow + p$	collider $\sqrt{s}$ = 20 GeV	x1 = 0.1 – 0.8	10^{30} $cm^{-2}s^{-1}$
SPASCHARM (low mass)	$p + p\uparrow$	60 GeV $\sqrt{s}$ = 11 GeV	x2 = 0.05 – 0.2	
SPASCHARM (low mass)	$\pi\pm + p\uparrow$	34 GeV $\sqrt{s}$ = 8 GeV	x2 = 0.1 – 0.3	
RHIC PHENIX Muon	$p\uparrow + p$	collider $\sqrt{s}$ = 500 GeV	x1 = 0.05 – 0.1	2×10^{32} $cm^{-2}s^{-1}$
RHIC Internal Target phase-1	$p\uparrow + p$	250 GeV $\sqrt{s}$ = 22 GeV	x1 = 0.25 – 0.4	2×10^{33} $cm^{-2}s^{-1}$
RHIC Internal Target phase-2	$p\uparrow + p$	250 GeV $\sqrt{s}$ = 22 GeV	x1 = 0.25 – 0.4	6×10^{34} $cm^{-2}s^{-1}$

Key issues

- Requirement for target thickness
  - In phase-1 (parasitic operation), 10^{15} /cm^2 thickness is necessary to achieve L = 2×10^{33} cm^{-2}s^{-1}
    - Pellet target (~10^{15} /cm^2) or cluster-jet target (up to 8×10^{14}/cm^2 ?) is necessary
    - If it is not achieved, the internal-target experiment would not be competitive against collider experiments
    - In collider experiments, L = 2(or 3)$\times10^{32}$ is expected and cross section ($\times$ acceptance) is >10 times larger
  - In phase-2 (dedicated operation), 10-times larger thickness, 10^{16} /cm^2 is expected
- Requirement for accelerator
  - Compensation of dipole magnets in the experimental apparatus (in two colliding-beam operation)
  - Size of the experimental site and possible target-position (with proper beam operation)

Accelerator issues

- Experimental dipole magnets
  - Beam axis restoration (one beam on target, the other beam displaced)
- Size of the experimental site and possible target-position (with proper beam operation)
  - IP2 (BRAHMS) area?
- Reaction rate (peak rate) and beam lifetime
- Radiation issues
  - Beam loss/dump requirement

Summary

- Polarized Drell-Yan experiment
  - The simplest process in hadron-hadron reaction
  - But, not yet done because of technical difficulties so far
  - At present it has become feasible, finally
- J-PARC proposal
  - Not accepted yet
    - Waiting for FNAL-E906 result for unpolarized measurements
  - 50 GeV beam necessary, polarized-beam necessary
- RHIC
  - Collider experiment
  - Fixed-target (internal-target) experiment
  - Both feasible
- Other possibility
  - FNAL $\pi^{\pm}$/antiproton beam with a polarized target
    - Similar to the COMPASS Drell-Yan experiment