Polarized proton in J-PARC

Spin Fest 2015 workshop @ J-PARC

July 23rd, 2015

Yuji Goto (RIKEN/RBRC)

Polarized proton acceleration in J-PARC

- Studied in 2006–2007 and shown at PAC in 2008
  - For possible polarized Drell-Yan experiment at J-PARC

Proposal

Polarized Proton Acceleration at J-PARC

November 30, 2007

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USA: BNL, UIUC, LANL, RBRC
Japan: KEK, Kyoto, RCNP, RIKEN, Rikkyo, Tokyo Tech, TUS, Yamagata

- No progress after 2008
  - Fermilab-E906 (SeaQuest) finally started after 2008
  - Polarized Drell-Yan experiment at Fermilab is under development
    - E1027 with polarized beam
    - E1039 with polarized target

High-energy spin physics

- Spin puzzle

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

Orbital angular momentum

Gluon spin contribution

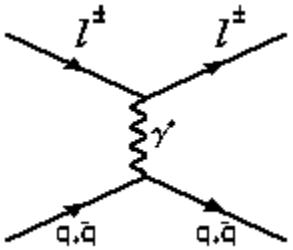
Quark spin contribution

  - Longitudinal-spin physics
    - Helicity structure of the nucleon
      - 1-dimensional
    - Collinear factorization
      - Incoherent scattering of partons at leading order
  - Transverse-spin physics
    - 3-dimensional structure of the nucleon
      - Many-body correlation of partons
      - Parton distribution in transverse direction
        - » Extended/generalized picture of parton distribution
        - » Transverse-momentum dependence (TMD)
        - » Space distribution (tomography)

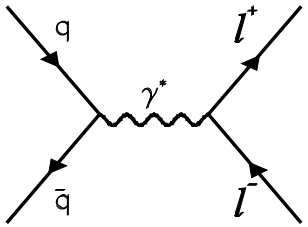
Drell-Yan process

- The simplest process in hadron-hadron reactions

DIS



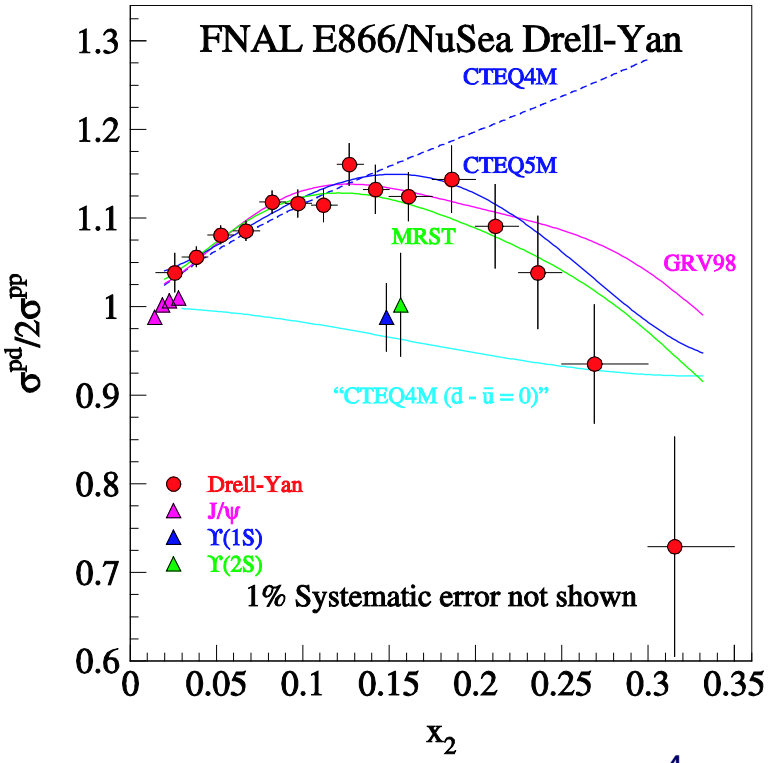
Drell-Yan



  - No QCD final state effect
- Fermilab-E866
  - Unpolarized Drell-Yan experiment with Ebeam = 800 GeV
  - Flavor asymmetry of sea-quark distribution

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

  - x = 0.01 – 0.35 (valence region)



Polarized Drell-Yan experiment

- 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.
- "Non-universality" of Sivers function
  - Sign of Sivers function determined by SSA measurement of DIS and Drell-Yan processes should be opposite each other

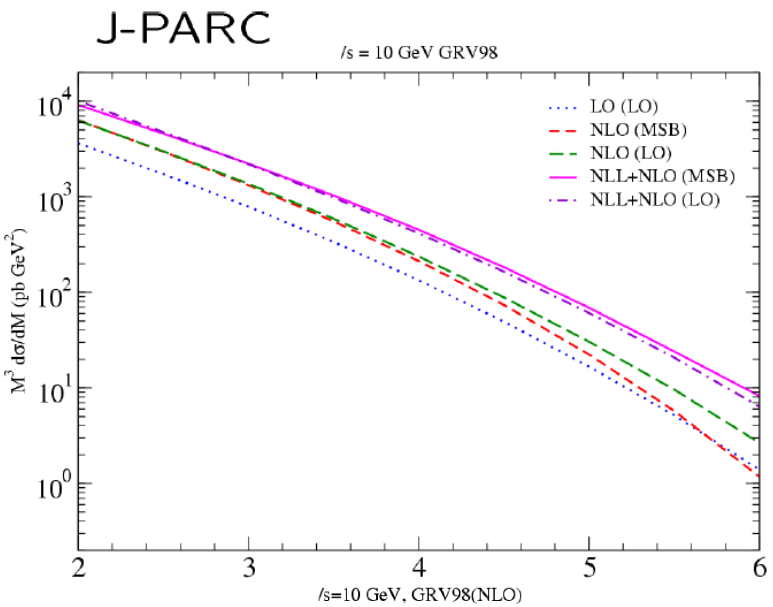
$$f^{Sivers}(x, k_\perp)|_{DY} = -f^{Sivers}(x, k_\perp)|_{DIS}$$

    - final-state interaction with remnant partons in DIS process
    - Initial-state interaction with remnant partons in Drell-Yan process
  - Fundamental QCD prediction
  - Milestone for the field of hadron physics to test the concept of the TMD factorization

Advantage at J-PARC

- Systematic analysis of small-cross-section processes with large-yield data accumulation
  - Utilizing high-intensity (polarized) proton beam
  - Poor in collider experiments
  - Drell-Yan / direct photon / heavy-flavor
- Systematic understanding of 3-dimensional structure of the nucleon (and nuclei)
  - Quark-gluon structure based on QCD

Applicability of perturbative QCD



- Cross section
  - pQCD correction can be controlled at J-PARC energy

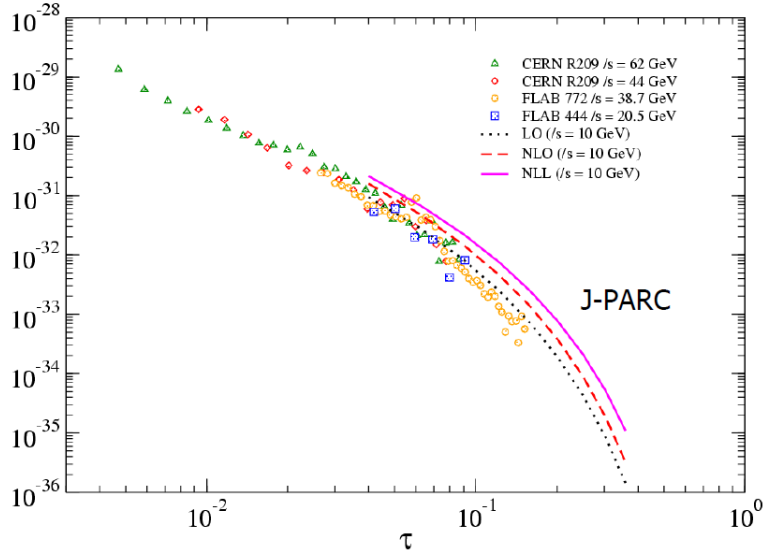
NNLO calculation

Hamberg, van Neerven, Matsuura, Harlander, Kilgore

NLL, NNLL calculation

Yokoya, et al...

Prediction for /s = 10 GeV



with GRV98

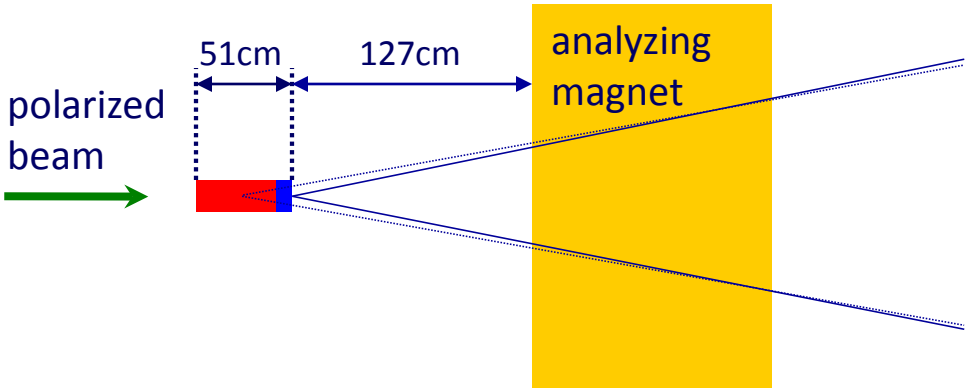
M = 2 ~ 6 GeV

J-PARC proposals & LoI

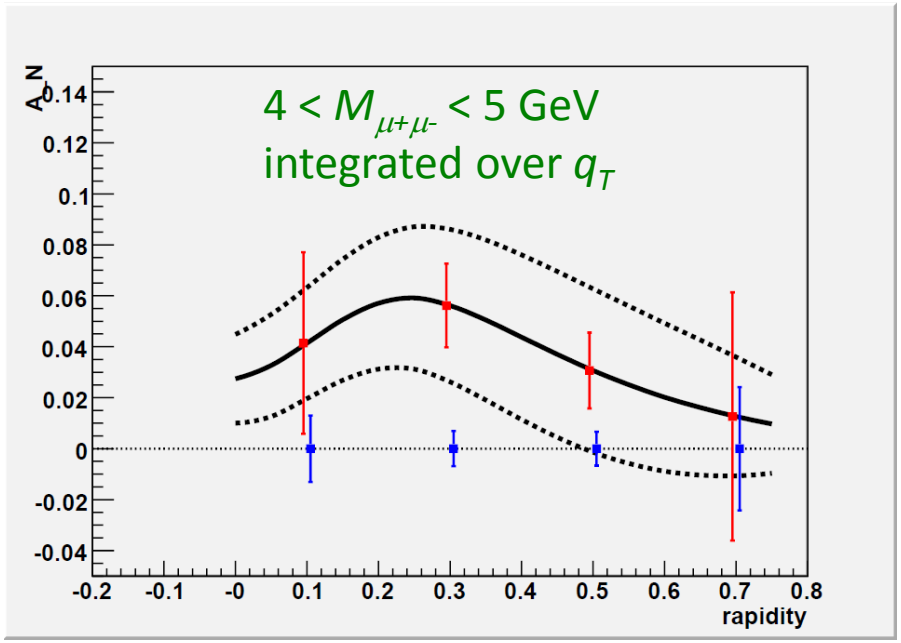
- P04: measurement of high-mass dimuon production at the 50-GeV proton synchrotron
  - spokespersons: Jen-Chieh Peng (UIUC) and Shinya Sawadas (KEK)
  - “deferred”
- P12-LoI: study of parton distribution function of mesons via Drell-Yan process at J-PARC at high-p beamline
  - spokesperson: Seonho Choi (Seoul National University)
- P24: polarized proton acceleration at J-PARC
  - contact persons: Yuji Goto (RIKEN) and Hikaru Sato (KEK)
  - “no decision”

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



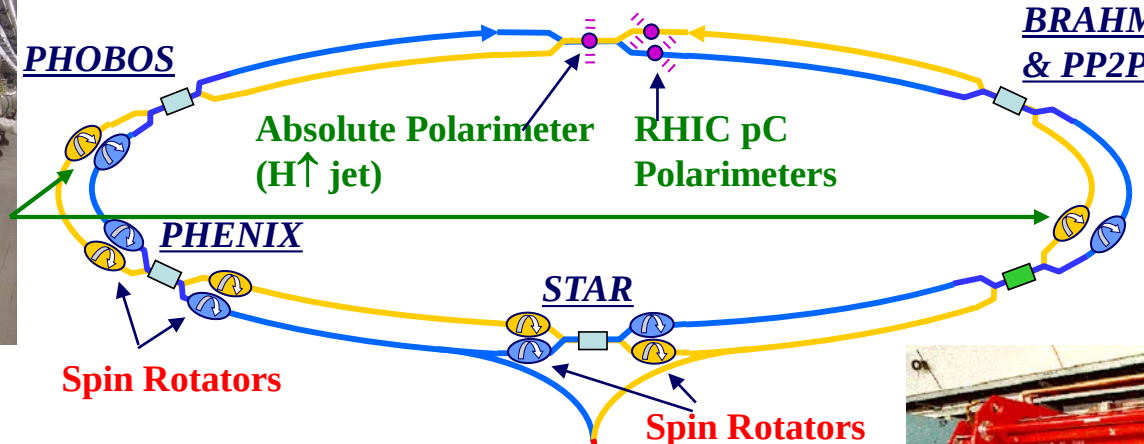
Polarized proton acceleration

- 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

Full Helical Siberian Snakes

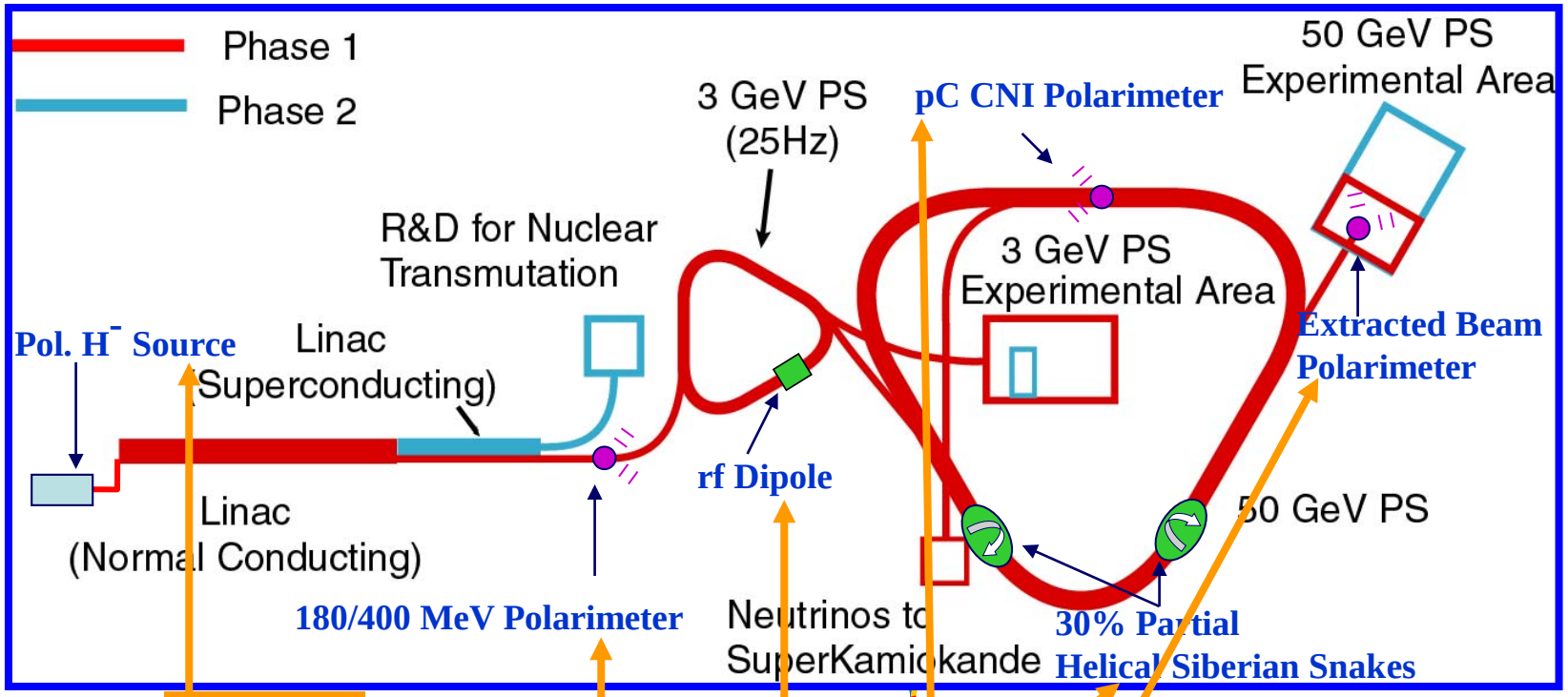


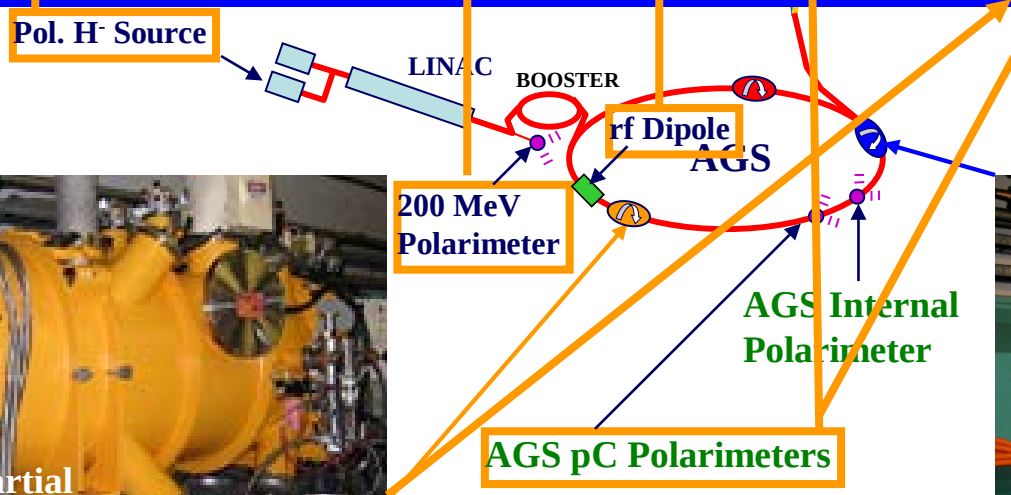

Partial Solenoidal Snake


Cold Partial Helical Siberian Snake


Warm Partial Helical Siberian Snake

Polarized proton acceleration at J-PARC





Modes of operation

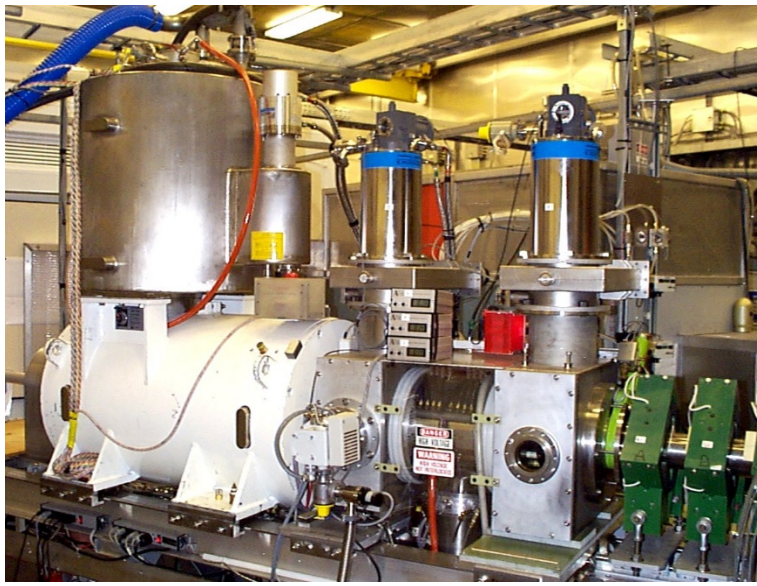
- Operation mode of the J-PARC MR should be:
  - 50 GeV maximum energy
  - 10^{12} proton/spill (~10^{36}cm^{-2}s^{-1} luminosity with a ~5% interation target)
    - 8 bunches
    - 2×10^{11} proton/bunch at RCS
  - 0.5 s spill length (working assumption)
  - 80% polarization
  - 10π mm·mrad normalized 95% emittance and 0.3 eVs longitudinal emittance

High-intensity polarized H^- source

- OPPIS parameters required:
  - 0.16 mA peak H^- ion current in 500 μsec pulse
    - 5×10^{11} H^- ion/pulse
  - 50Hz repetition rate
  - 1.0π mm·mrad normalized emittance
  - 35 keV beam energy
  - 85% polarization

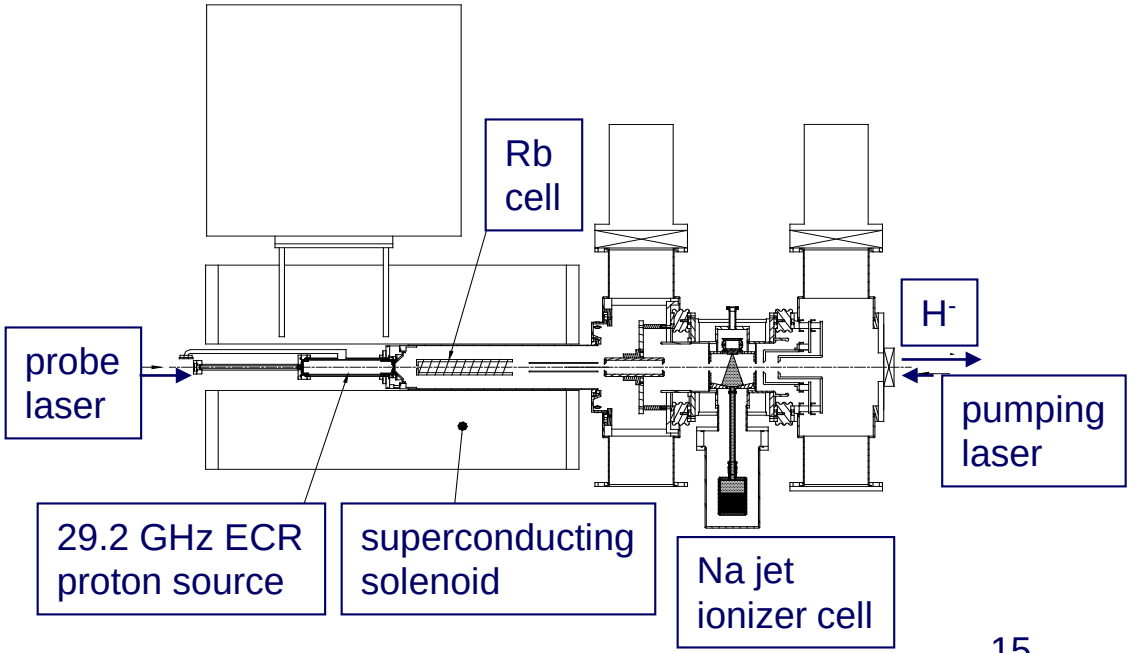
High-intensity polarized H^- source

- RHIC OPPIS
  - built at KEK and upgraded at TRIUMF
  - 0.5-1.0 mA (max. 1.6 mA) H^- ion current in 400 μsec pulse
    - $1.2\text{-}2.4\times10^{12}$ H^- ion/pulse
  - 7 Hz max. repetition rate
    - 1 Hz routine repetition rate
  - 82-85% polarization



Issues

- where to locate the polarized H^- source
- how to merge the polarized beam to the existing beam line (may require RFQ)
- maintenance of the laser system

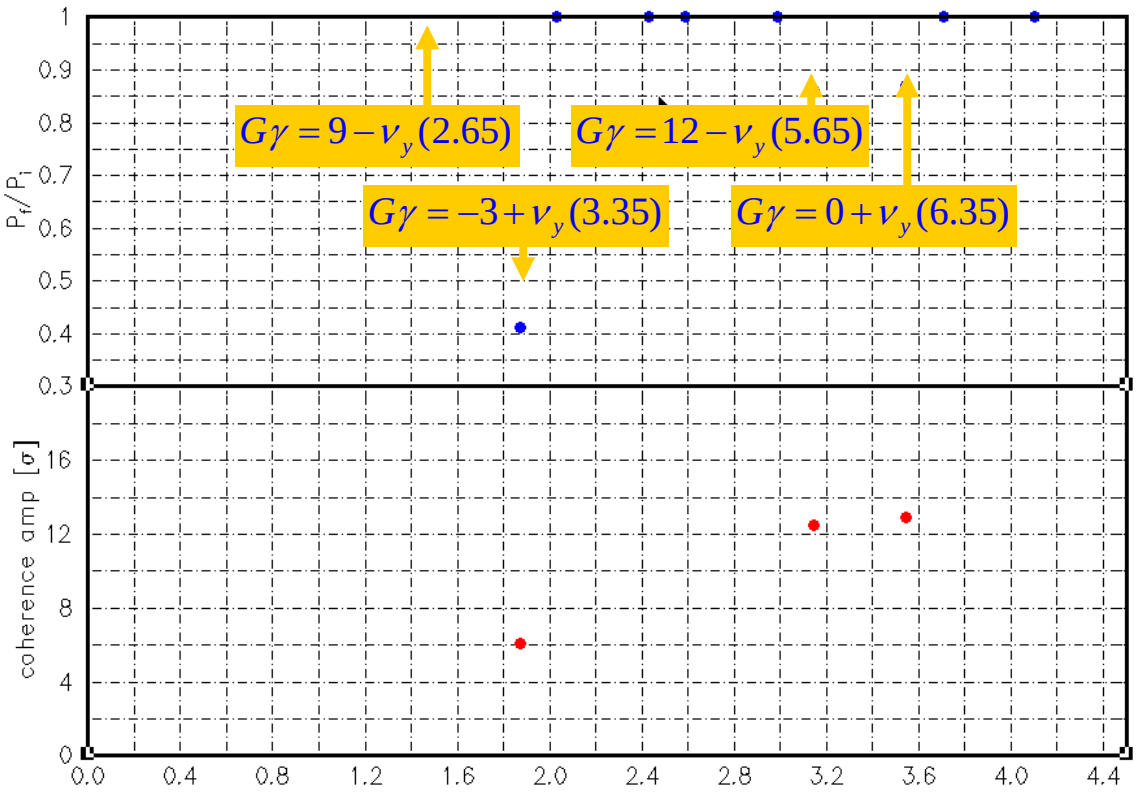


From source to RCS

- Polarimeter
  - at the end of the linac
  - proton-Carbon inclusive polarimeter similar to that at BNL
- Stripping foil
  - 300-500 $\mu g/cm^2$ stripping foil for injection to RCS
  - need to be replaced by 100 $\mu g/cm^2$ foil to have better dp/p

Accelerating polarized protons in the RCS

- Kinetic energy from 0.18 GeV to 3 GeV
  - Gγ = 2.2 ~ 7.5
  - betatron tune ν_y = 6.35



by Mei Bai (BNL)

Accelerating polarized protons in the RCS

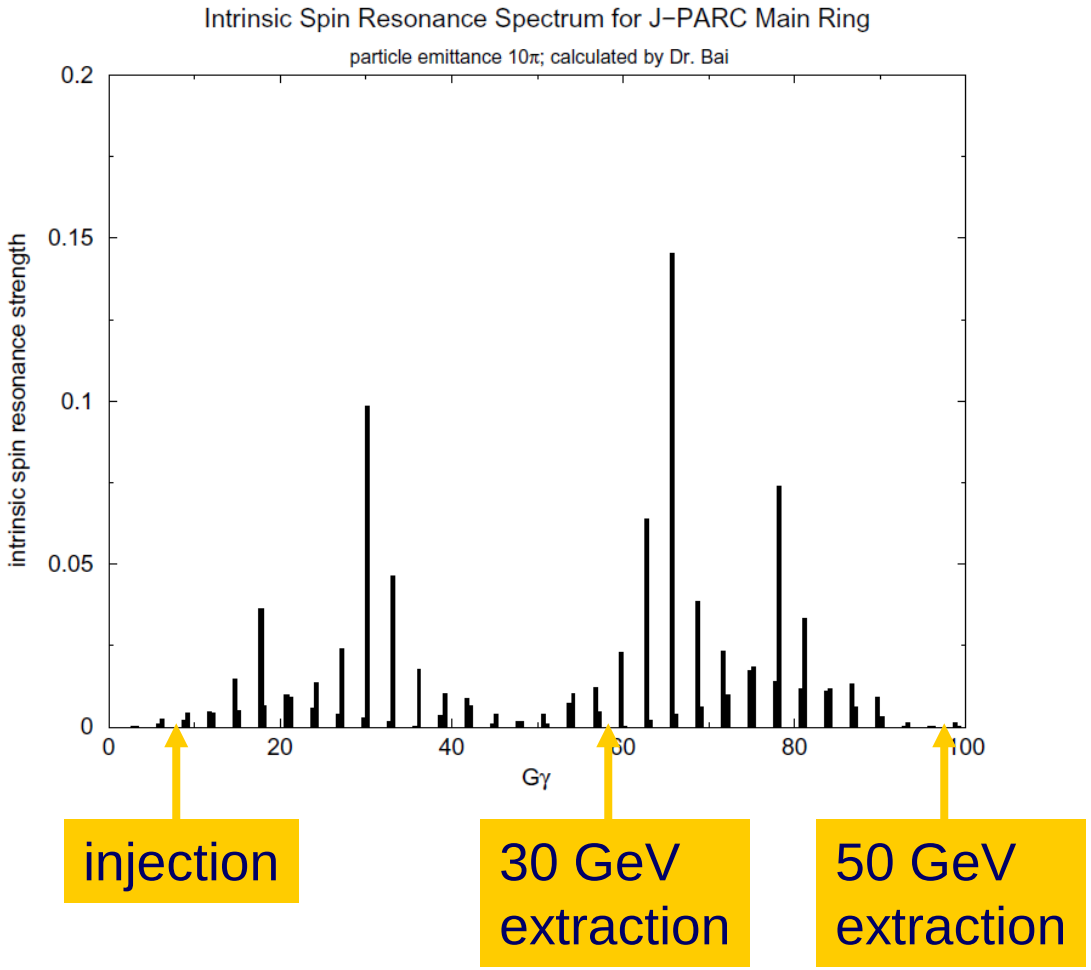
- 5 imperfection resonances
  - $G\gamma$ = 3, 4, 5, 6, 7
  - corrected by harmonic orbit correction
- 4 intrinsic resonances
  - betatron tune ν_y = 6.35
  - $G\gamma$ = 2.65 (9-ν_y), 3.35 (-3+ν_y), 5.65 (12-ν_y), 6.35 (0+ν_y)
  - first small resonance is corrected by fast tune jump
  - latter three strong resonances are completely (> 99%) spin-flipped by a rf dipole
    - 20 Gm vertical rf dipole
    - smaller size of beam (comparing to 7cm painting beam) required: operational issue

Issues

- where to locate the rf dipole
- design of the rf dipole
- beam monitor system to cover a wide dynamic range between high-intensity unpolarized beam (4×10^{13}/bunch) and polarized beam (1.5×10^{11}/bunch)
- position monitor necessary to calculate the magnetic field error and correct it by the harmonic orbit correction)
- spin tracking to be done

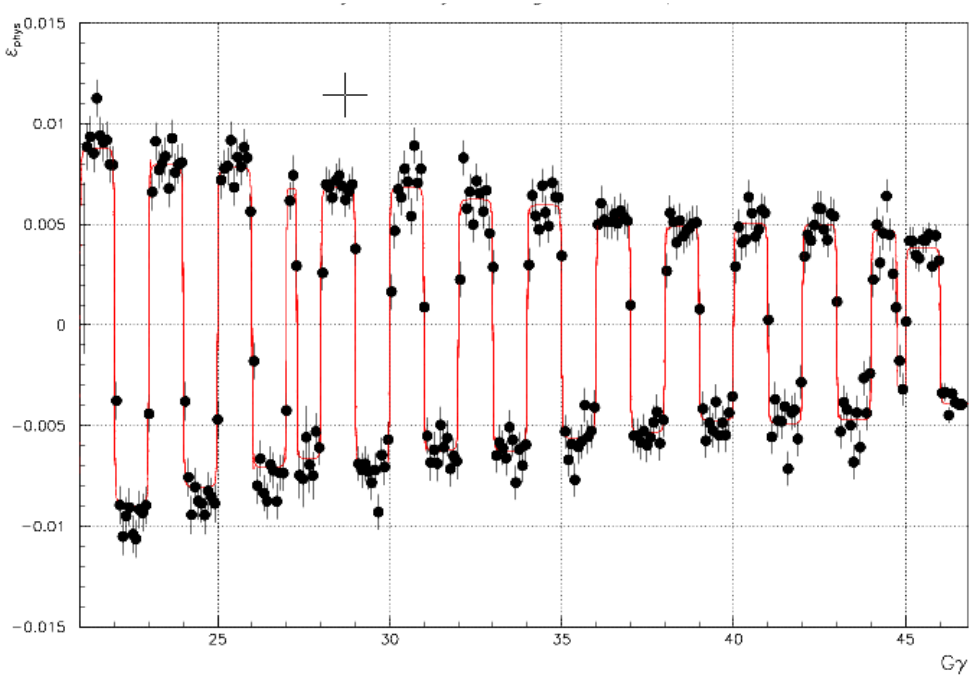
Accelerating polarized protons in the MR

- Kinetic energy from 3 GeV to 50 GeV
  - $G\gamma = 7.5 \sim 97.5$
  - betatron tune $\nu_x = 22.339$, $\nu_y = 20.270$



Accelerating polarized protons in the MR

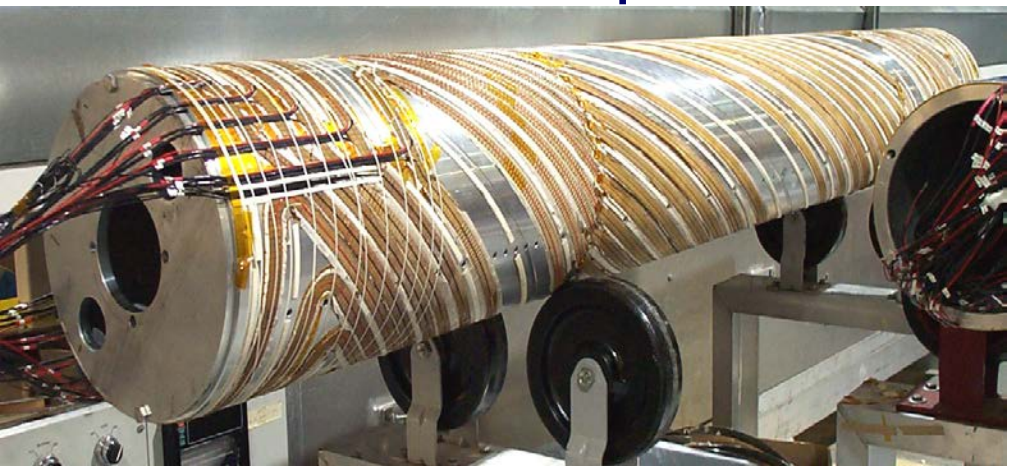
- Two superconducting 30% partial helical Siberian snakes separated by 120 degree installed in two of the three straight sections:
  - avoid all vertical depolarizing resonances
- Two quadrupole doublets
  - to compensate perturbation of the lattice by the snakes at low energies



full spin flip at all imperfection and strong intrinsic resonances using partial Siberian snake and rf dipole at AGS

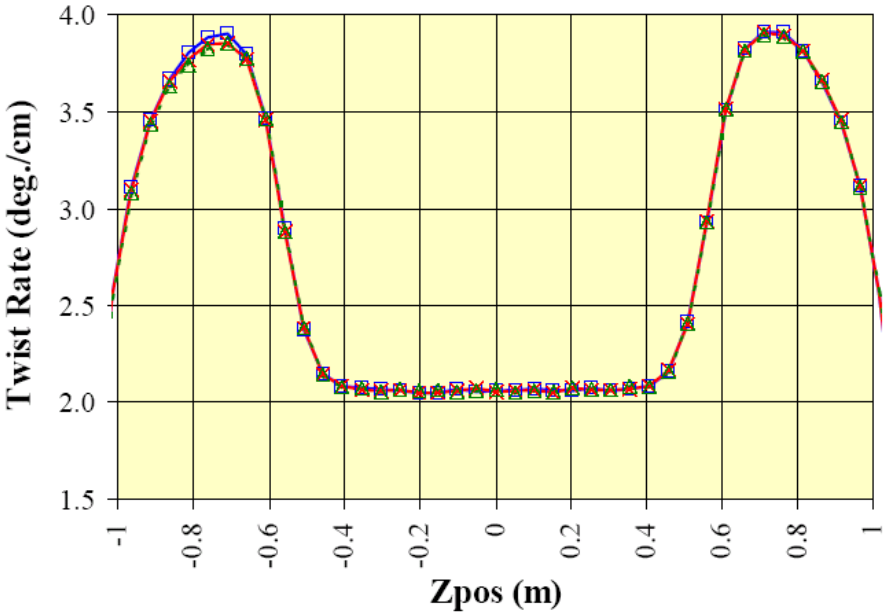
Accelerating polarized protons in the MR

- AGS 25% superconducting helical snake



helical dipole coil

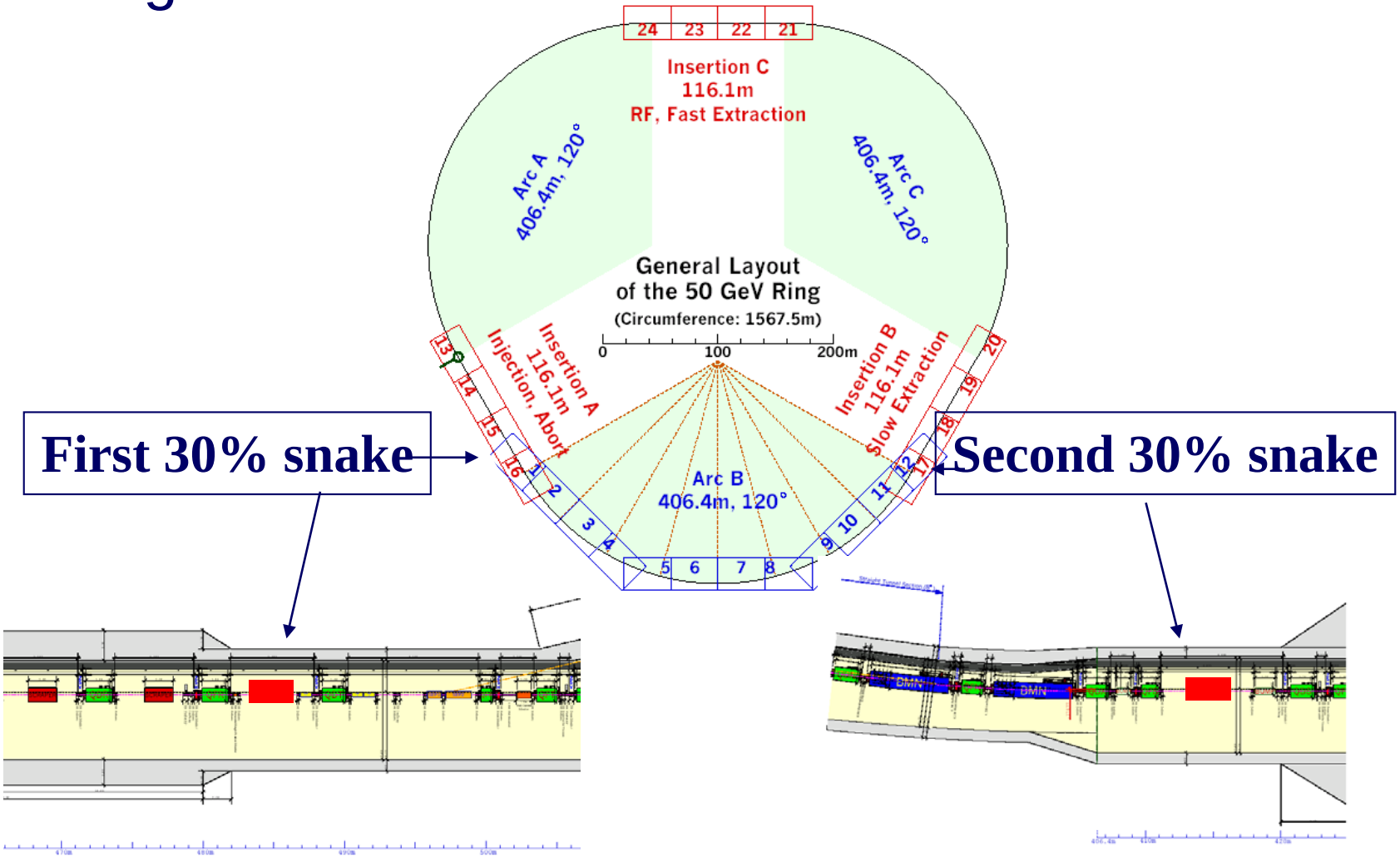
correction solenoid and dipoles



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

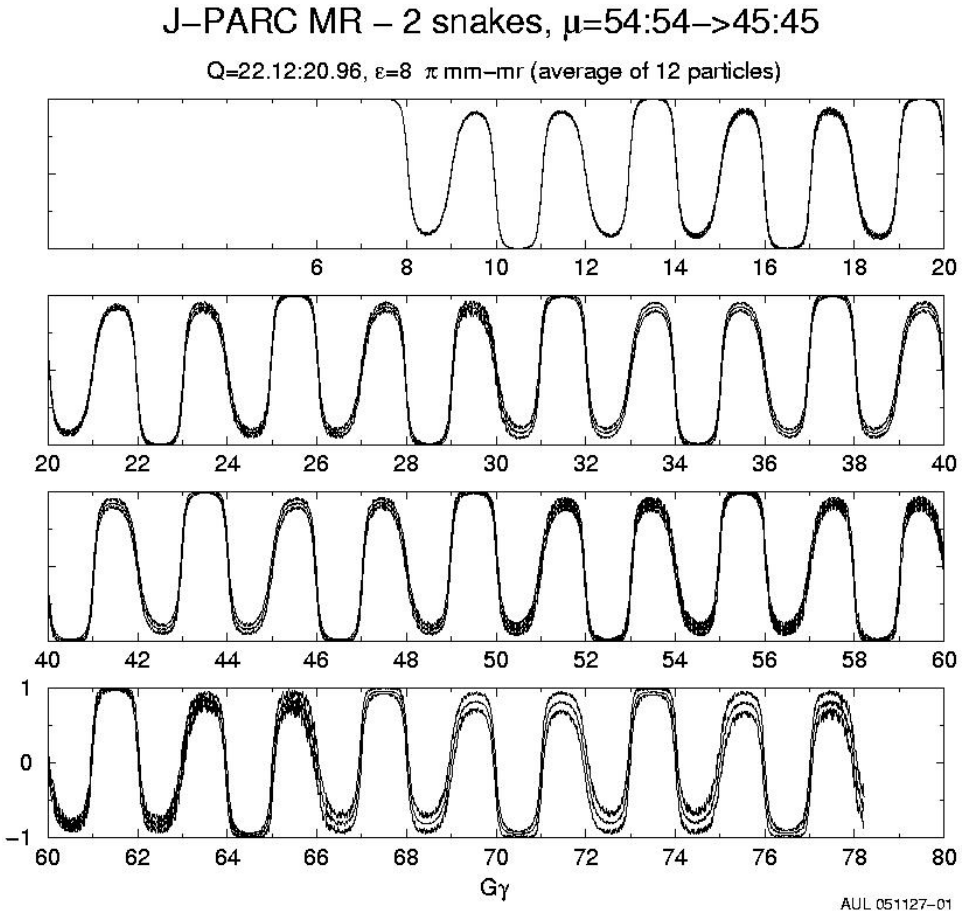
Accelerating polarized protons in the MR

- Possible location of partial helical snake magnets in the MR



Accelerating polarized protons in the MR

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



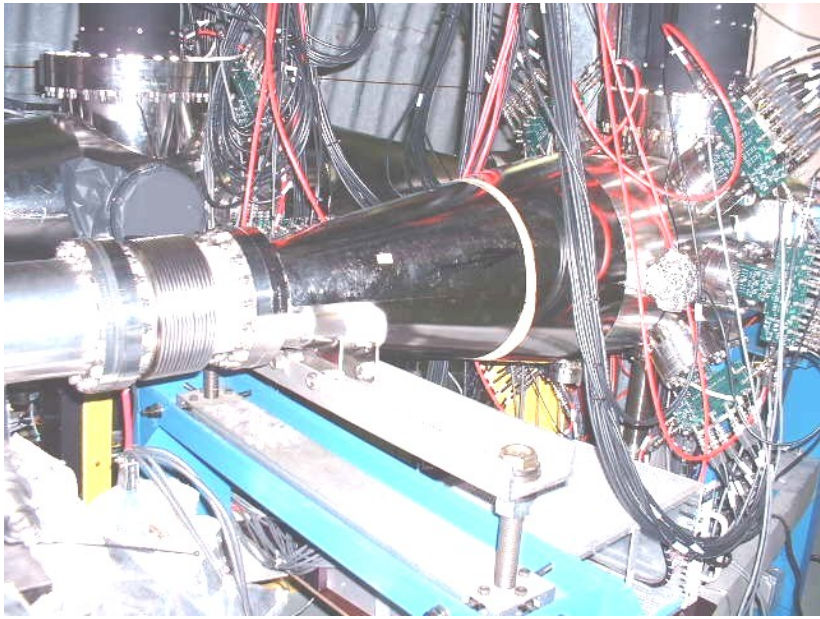
by A.U. Luccio (BNL)

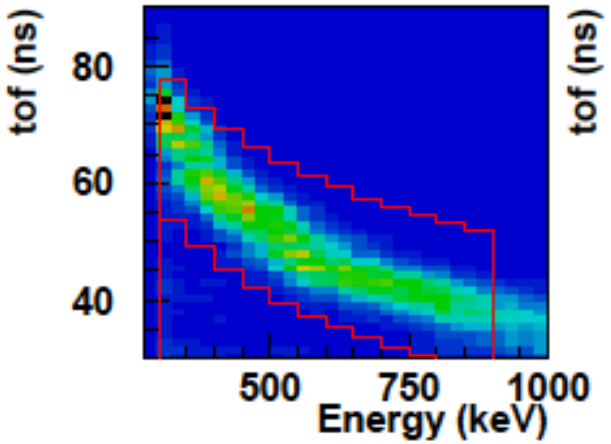
Primary beam extraction

- No serious issues
- Issues
  - operational issues
    - tune change for the extraction
    - vertical bend of the beam line
  - beam profile monitor system for the stability of beam intensity, position, and spot size to provide a systematical control of the experimental data quality
  - spin rotator magnet necessary to manipulate a direction of beam polarization

Proton-carbon elastic-scattering polarimeter

- Requirements
  - known analyzing power A_N
  - small systematic error
  - quick measurement (~1 min)
- AGS/RHIC pC CNI polarimeter
  - elastic scattering in the coulomb-nuclear interference region
  - micro-ribbon carbon target in the circulating beam
  - detecting recoil carbon nucleus
    - arrival time from time-zero to Si sensors





WFD image provided by K. Kurita (Rikkyo)

Proton-carbon elastic-scattering polarimeter

- Proton-carbon CNI polarimeter at J-PARC
  - no time-zero information
  - coincidence measurement between the recoiled carbons and the forward going protons with the extracted beam
  - economical solution which provides a quick turn-around to optimize machine parameters to achieve maximum polarization

Absolute polarimeter

- Proton-proton and proton-carbon elastic scattering at 31.2 GeV of the RHIC beam
  - measured analyzing power data at 31.2 GeV of the RHIC beam
  - available for calibration of absolute polarimeter of the main ring (gas jet) and/or extracted beam (solid target)

Cost for polarized proton acceleration

- Rough estimation based on the cost at BNL
  - 200 million yen high-intensity polarized H^- source
    - OPPIS / RFQ / polarimeter
  - 50 million yen from source to RCS
    - proton-carbon inclusive polarimeter / stripping foil upgrade
  - 100 million yen acceleration at RCS
    - rf dipole magnet / beam monitor system upgrade
  - 500 million yen acceleration at MR
    - two superconducting 30% partial helical Siberian snakes / two quadrupole doublets
  - 250 million yen primary beam extraction
    - beam profile monitor system / spin rotators
  - 100 million yen proton-carbon CNI polarimeter
  - 100 – 300 million yen absolute polarimeter
    - gas jet in the main ring and/or solid target with the extracted beam
- Total 1,300 – 1,500 million yen

Summary

- We want to understand the spin puzzle and transverse-spin phenomena, and establish 3-dimensional structure of the nucleon.
- At hadron-beam facility, polarized Drell-Yan experiment will give essential new information.
- At J-PARC, systematic analysis of small-cross-section processes with large-yield data accumulation is possible by utilizing high intensity (polarized) proton beam.
- Polarized proton beam acceleration at J-PARC seems technically possible, and polarized target R&D is ongoing.
- New idea of exclusive dimuon measurement (to be shown in the next session) will be developed more with polarized beam and target at J-PARC.