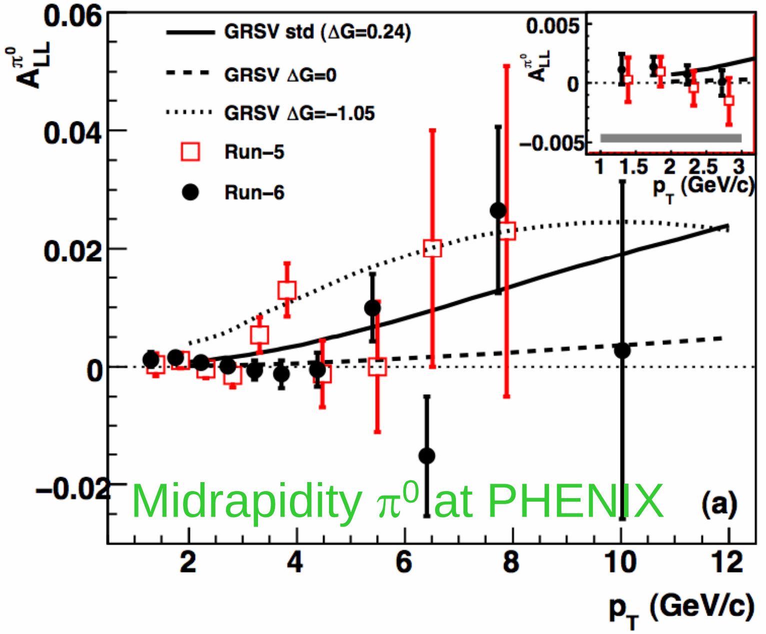
Letter of Intent

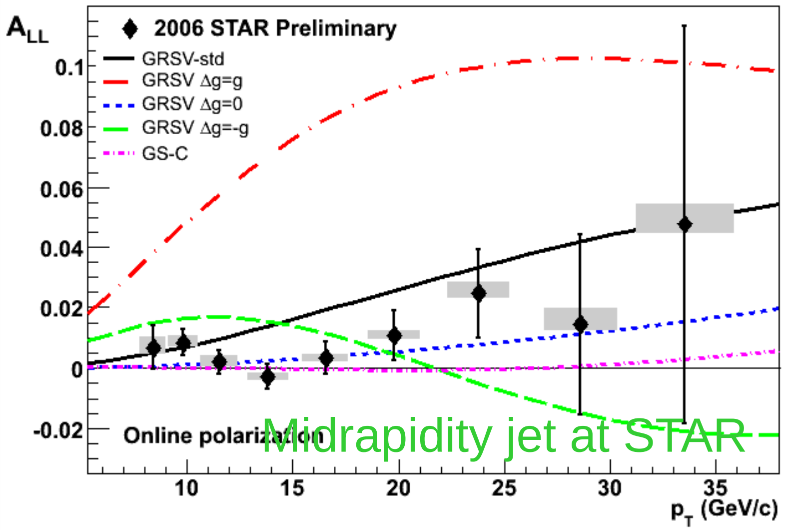
Measurement of Dimuons from Drell-Yan Process with Polarized Proton Beams and an Internal Target at RHIC

PAC meeting at BNL
June 21st, 2010
Yuji Goto (RIKEN/RBRC)

Introduction

- Origin of the proton spin 1/2 - “proton-spin puzzle”
  - Polarized DIS experiments
  - Polarized hadron collision experiments
- Longitudinal-spin asymmetry measurement
  - Helicity structure of the proton
    - Quark-spin contribution
    - Gluon-spin contribution

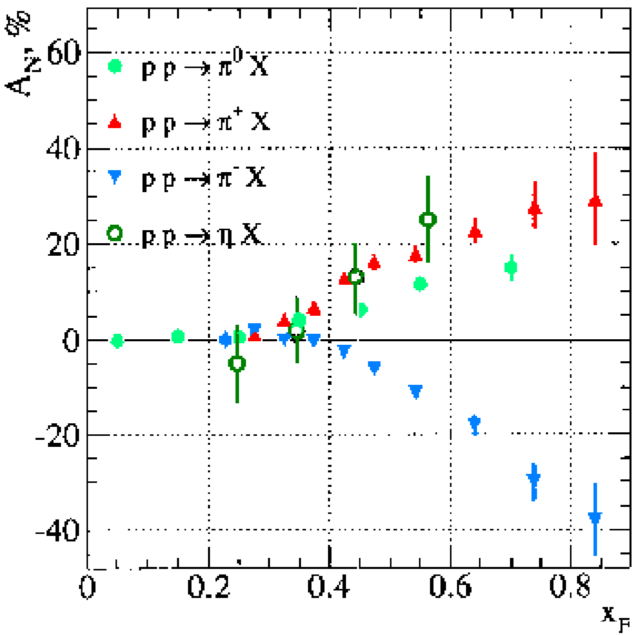




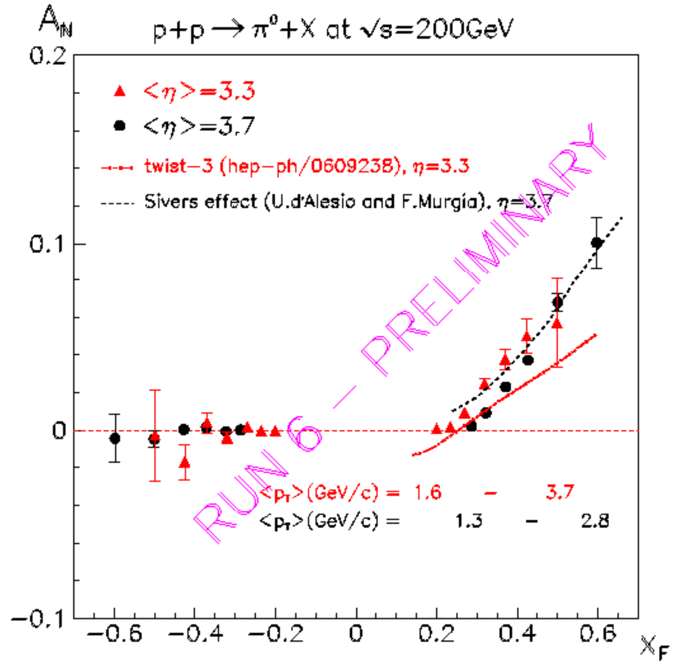
  - Large restriction for the gluon-spin contribution or gluon helicity distribution

Introduction

- Transverse-spin asymmetry measurement



FNAL-E704 √s = 20 GeV



RHIC-STAR √s = 200 GeV

  - Theoretical development to understand the transverse structure of the nucleon
    - Sivers effect, Collins effect, higher-twist effect, …
    - Relation to orbital angular momentum inside the nucleon

Introduction

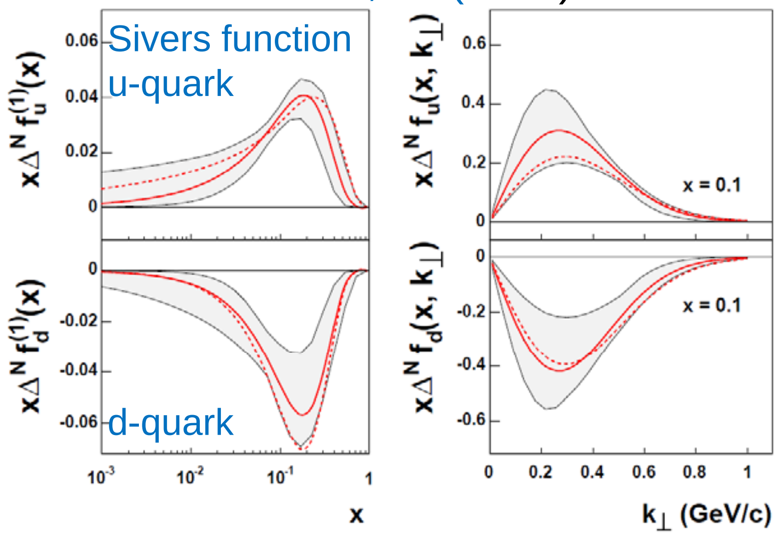
- Transverse structure of the proton
  - Transversity distribution function
    - Correlation between nucleon transverse spin and parton transverse spin
  - TMD distribution functions
    - Sivers function
      - Correlation between nucleon transverse spin and parton transverse momentum (k_T)
    - Boer-Mulders function
      - Correlation between parton transverse spin and parton transverse momentum (k_T)

	unpolarized parton	longitudinally-polarized parton	transversely-polarized parton
unpolarized nucleon	f_1		$h_1^\perp$
longitudinally-polarized nucleon		g_1	$h_{1L}^\perp$
transversely-polarized nucleon	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

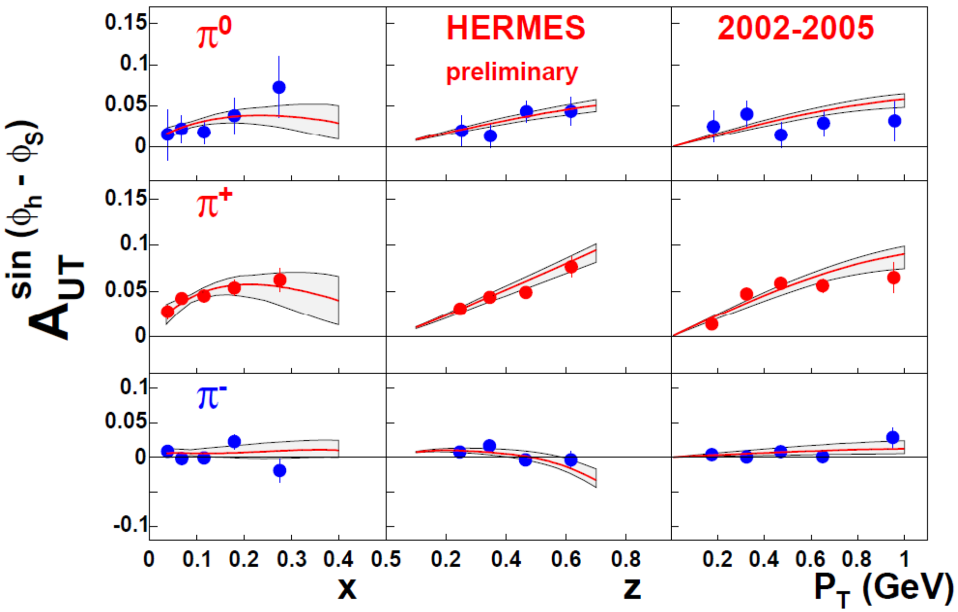
Leading-twist transverse momentum dependent (TMD) distribution functions

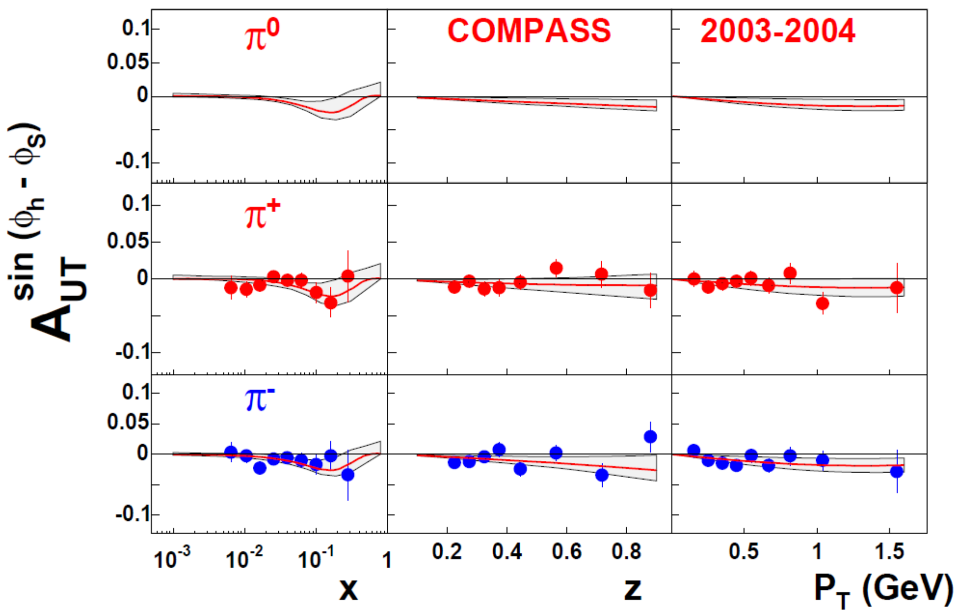
Sivers function

M. Anselmino, et al.
EPJA 39, 89 (2009)



- Single-spin asymmetry (SSA) measurement
  - < 1% level multi-points measurements have been done for SSA of DIS process
    - Valence quark region: x = 0.005 – 0.3
    - (more sensitive in lower-x region)

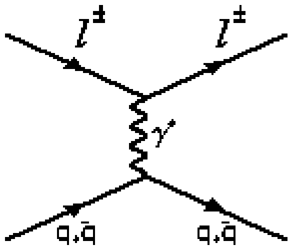




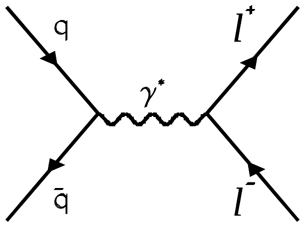
Drell-Yan process

- The simplest process in hadron-hadron reactions

DIS



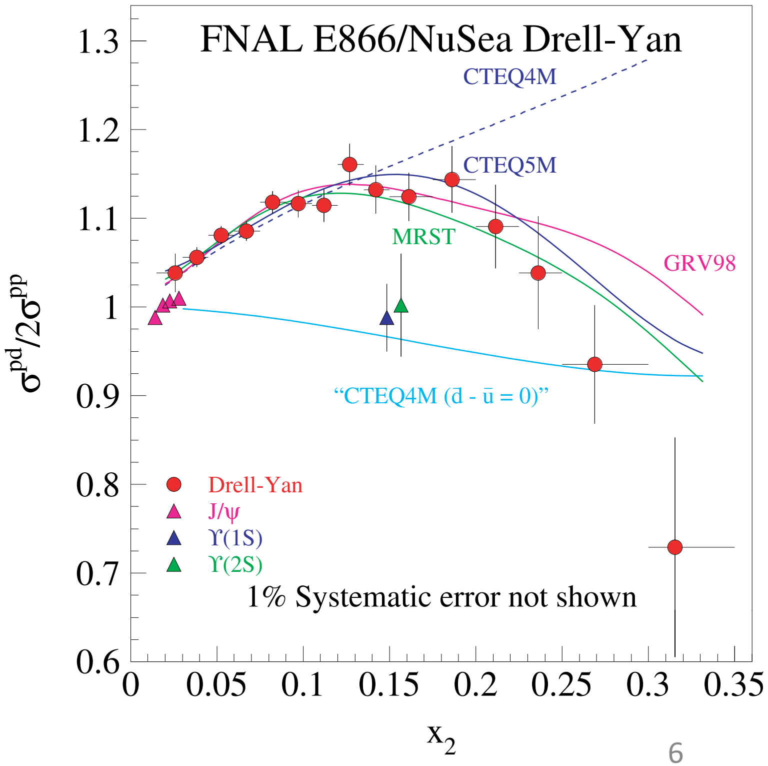
Drell-Yan



  - No QCD final state effect
- FNAL-E866
  - Unpolarized Drell-Yan experiment with E_{beam} = 800 GeV
  - Flavor asymmetry of sea-quark distribution

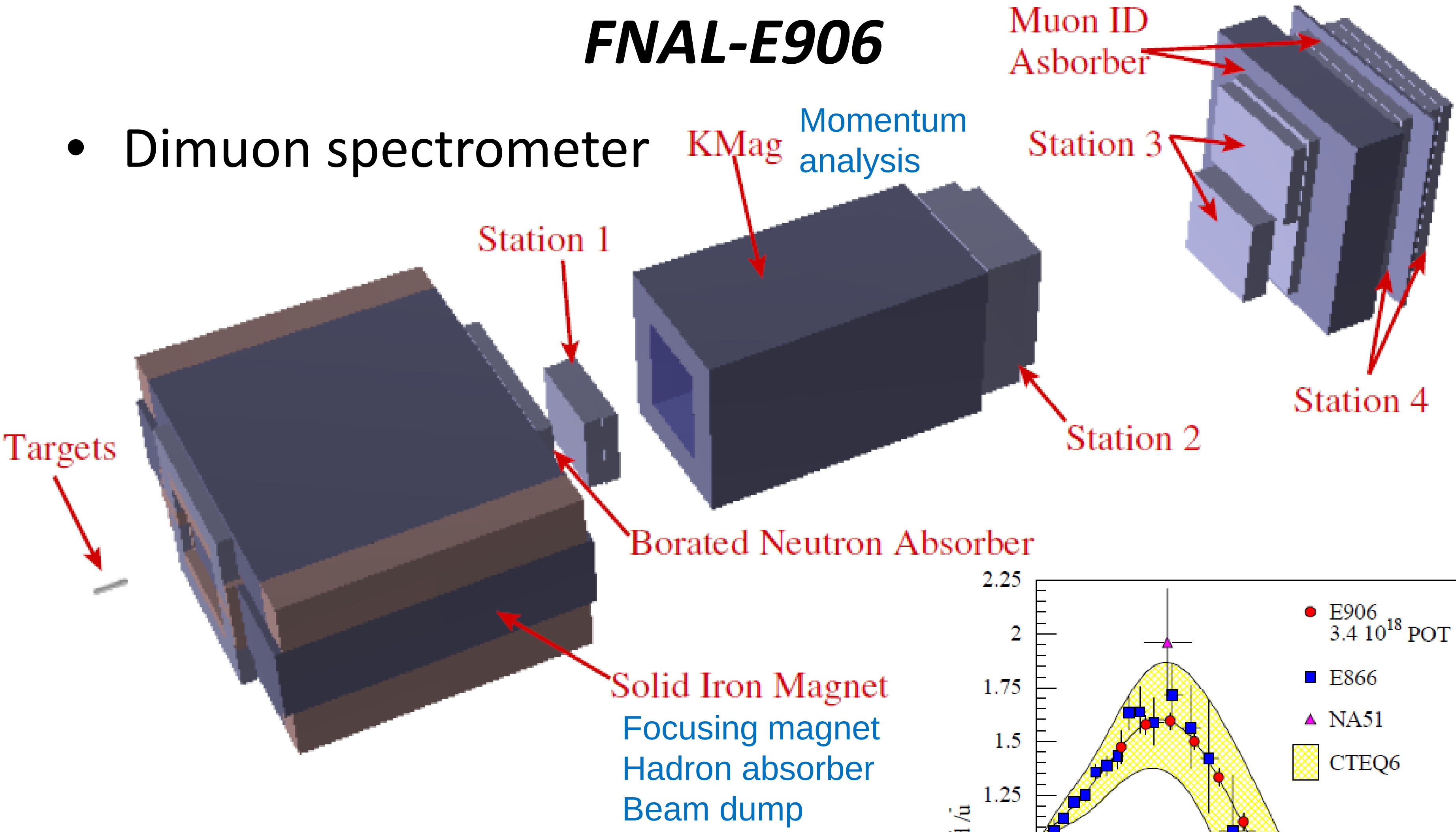
$$\frac{\sigma^{pd}}{2\sigma^{pp}} \sim \frac{1}{2}\left[1+\frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$$

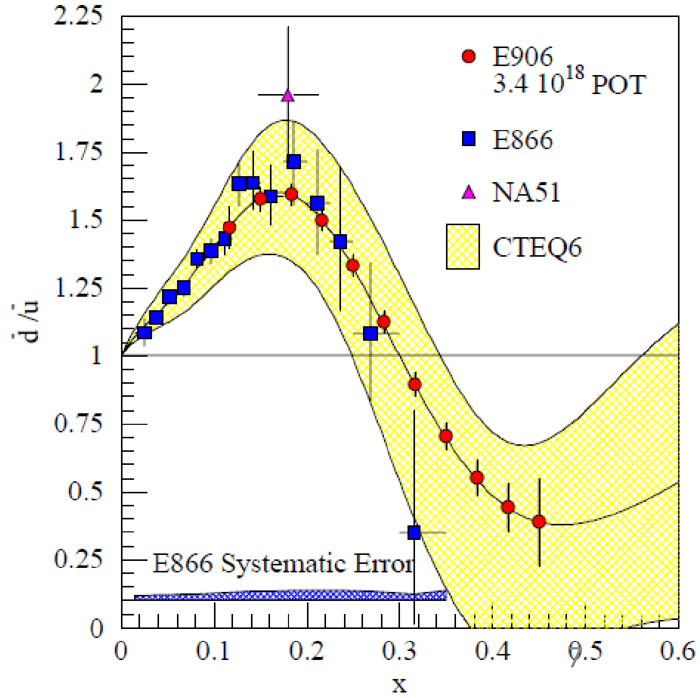
    - x = 0.01 – 0.35 (valence region)
- FNAL-E906
  - Similar experiment with main-injector beam E_{beam} = 120 GeV
    - x = 0.1 – 0.45



FNAL-E906

- Dimuon spectrometer





- Main injector beam E_{beam} = 120 GeV
- Higher-x region: x = 0.1 – 0.45
- Beam time: 2010 – 2013

Polarized Drell-Yan

- 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

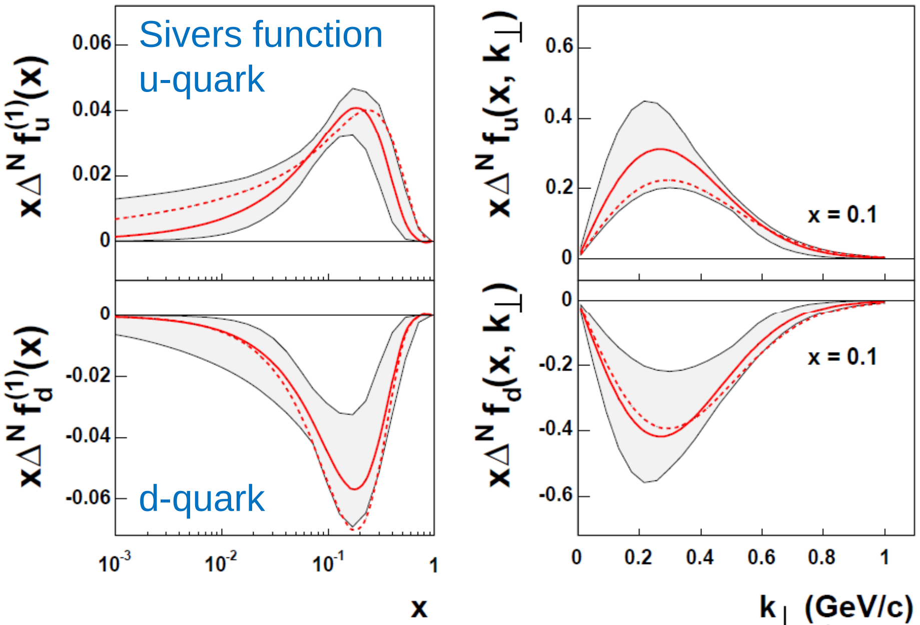
$$f^{Sivers}(x, k_\perp)|_{DY} = -f^{Sivers}(x, k_\perp)|_{DIS}$$

    - 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

Goal of the experiment

- Comparison with DIS data
  - DIS data
    - < 1% level multi-points measurements have already been done for SSA of DIS process
    - 0.005 < x < 0.3
  - Comparable level measurement needs to be done for SSA of Drell-Yan process for comparison
    - Measure not only the sign of the Sivers function but also the shape of the function
- x region
  - Valence quark region: x ~ 0.2
    - Expect to show the largest asymmetry
  - … and explore larger x region

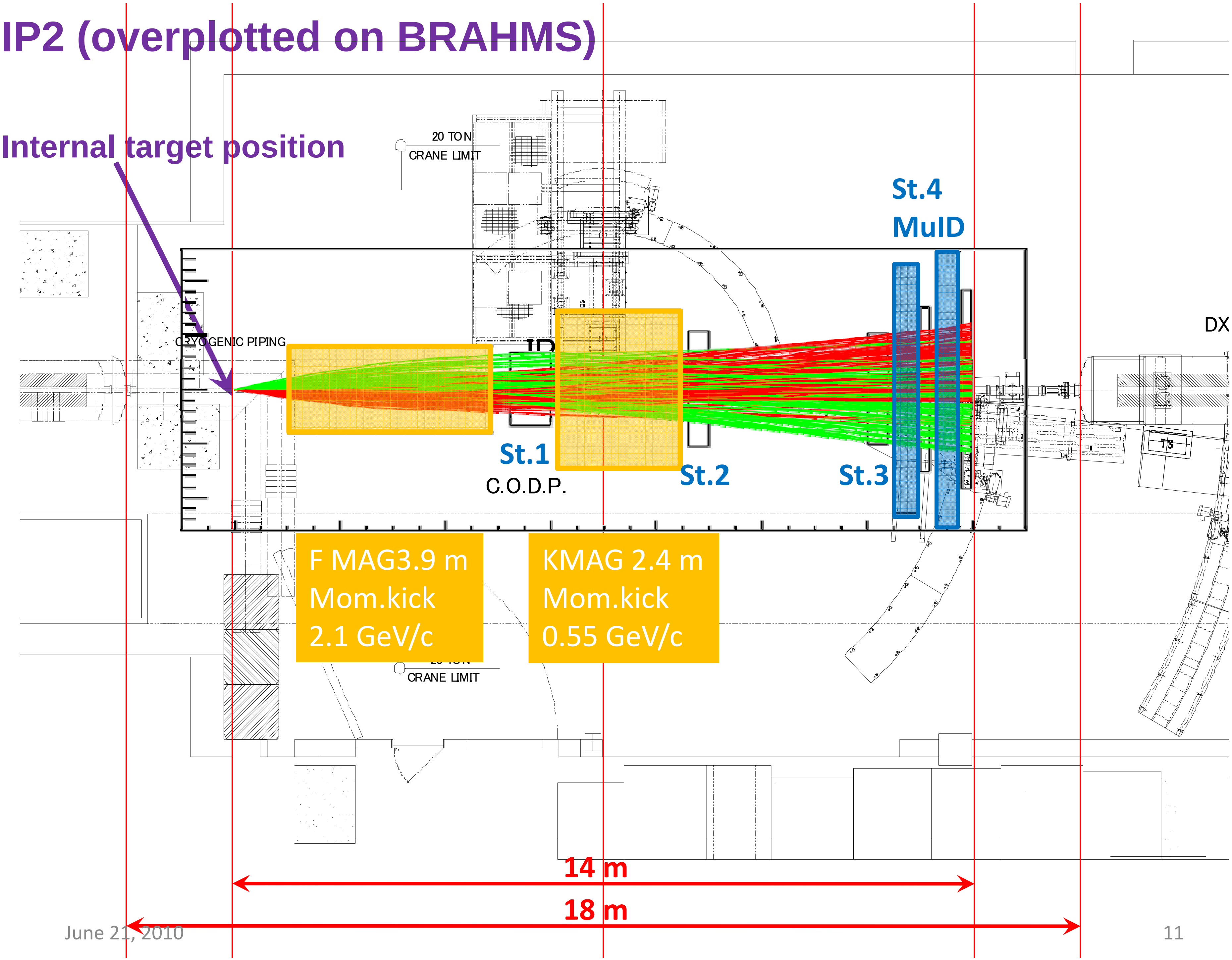
M. Anselmino, et al.
EPJA 39, 89 (2009)



Experimental site and apparatus

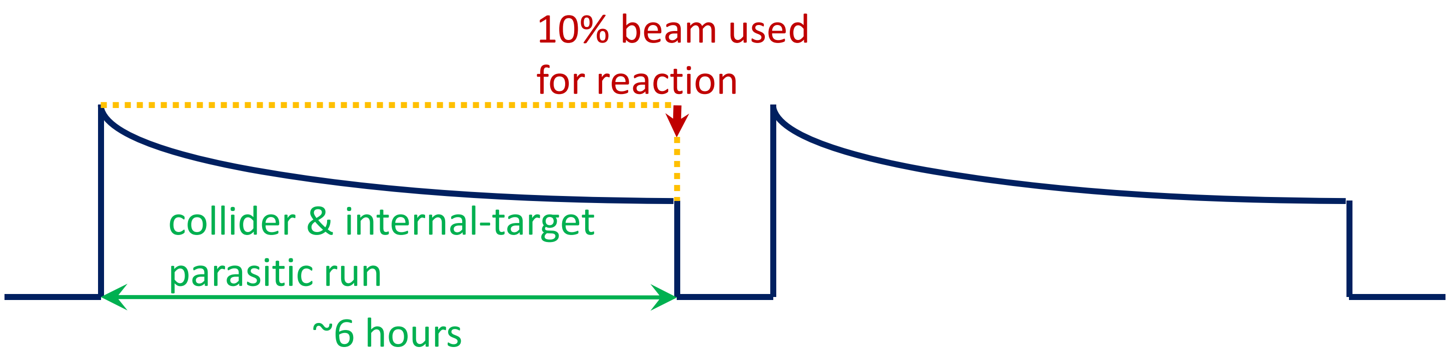
- IP2 configuration shown in the next slide
  - Detector components from FNAL-E906 apparatus
  - Limited z-length at IP2
    - E906: total z-length ~25m
    - IP2: available z-length ~14m
  - 1^{st} magnet
    - Z-size should be shortened
    - We will be able to make a similar magnet to E906 FMag with the second long coil pack of SM3 magnet (originally for E605) and E866-SM12 magnet iron
    - A hole for the beam pipe necessary
      - Inside the hole, the magnetic field is shielded
  - 2^{nd} magnet
    - Shorter magnet should be found
    - e.g. Jolly Green Giant (JGG) magnet used by E907 (originally planned to be used by E906) may be available
    - Magnetic shield necessary around the beam pipe
  - Momentum resolution would be a few times worse than that of E906 due to about a half-long lever arm of the momentum analysis
    - Momentum resolution (geometric estimation) $\Delta p/p = 6 \times 10^{-4} \times p$ (GeV/c)

IP2 (overplotted on BRAHMS)



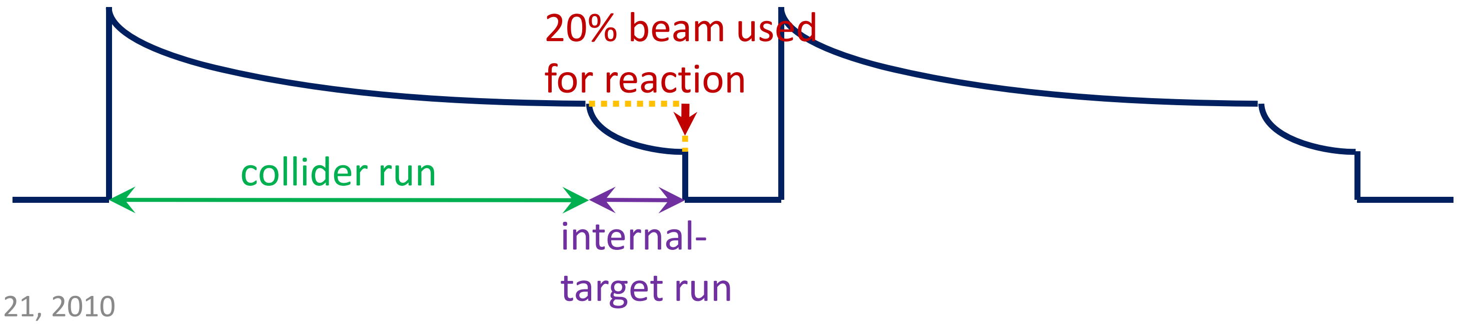
Beam time request

- Phase-1: parasitic beam time – Option-1
  - Beam intensity $2 \times 10^{11} \times 10\text{MHz} = 2 \times 10^{18}/\text{s}$
  - Cluster-jet or pellet target 10^{15}atoms/cm^2
    - 50 times thinner than RHIC CNI carbon target
  - Luminosity $2 \times 10^{33}/\text{cm}^2/\text{s}$
  - $10{,}000\text{pb}^{-1}$ with $5 \times 10^6\text{s}$
    - 8 weeks, or 3 years (10 weeks × 3) with efficiency and live time
  - Hadronic reaction rate $2 \times 10^{33} \times 50\text{mb} = 10^8/\text{sec} = 100\text{MHz}$
    - 10% beams are used by hadronic reactions in ~6 hours
  - Beam lifetime
    - $2 \times 10^{11} \times 100\text{bunch} / 10^8 = 2 \times 10^5\text{s}$ from hadronic reactions
    - $5 \times 10^4\text{s}$ = ~15 hours from small-angle scatterings (by D. Trbojevic)
    - from energy loss?



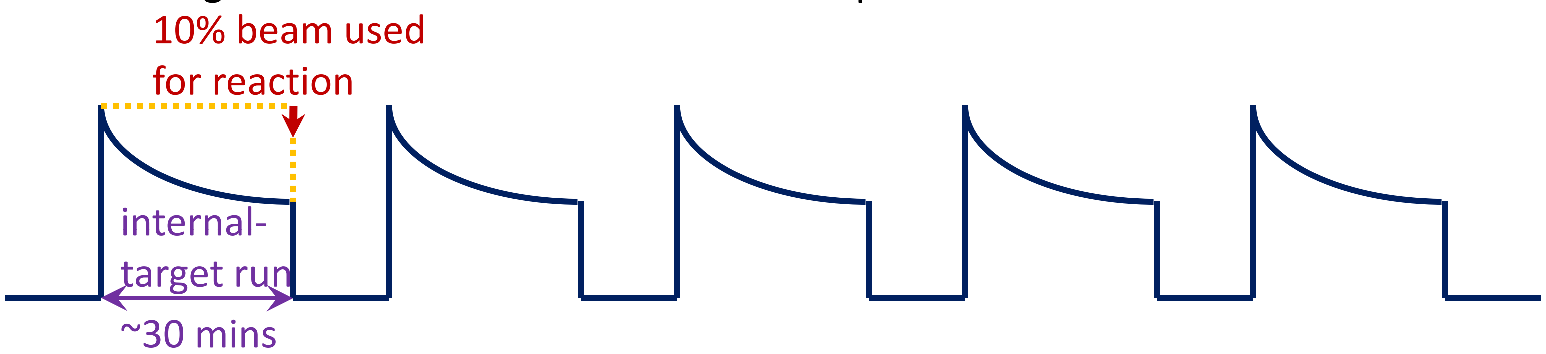
Beam time request

- Phase-1: parasitic beam time – Option-2 (beam dump mode)
  - Beam time at the end of every fill after stopping collider experiments and dumping one beam
  - Beam intensity assuming $10^{11} \times 10$MHz = 10^{18}/s
  - Target with ~10^{17}atoms/cm^2 thickness (if available)
    - Comparable thickness with RHIC CNI carbon target
  - Luminosity 10^{35}/cm^2/s
  - Hadronic reaction rate $10^{35} \times 50$mb = 5×10^9/s = 5GHz
    - 20% beams are assumed to be used = 40 pb^{-1}
    - In ~ 1,000s depending on how fast the beam dumps?
  - We request 250 fills to accumulate 10,000 pb^{-1}
    - 8 weeks, or 3 years (10 weeks $\times$ 3) with efficiency and live time?



Beam time request

- Phase-2: dedicated beam time
  - Beam intensity $2 \times 10^{11} \times 15\text{MHz} = 3 \times 10^{18}$/s, 1.5 times more number of bunches as assumed at eRHIC
  - Pellet or solid target $10^{16}/\text{cm}^2$
    - 5 times thinner than RHIC CNI carbon target
  - Luminosity $3 \times 10^{34}/\text{cm}^2/\text{s}$
  - 30,000pb^{-1} with 10^6s
    - 2 weeks, or 8 weeks with efficiency and live time
  - Hadronic reaction rate $3 \times 10^{34} \times 50\text{mb} = 1.5 \times 10^9/\text{s} = 1.5\text{GHz}$
    - 10% beams are used by hadronic reactions in ~30 minutes
  - Beam lifetime
    - $2 \times 10^{11} \times 150\text{bunch} / 1.5 \times 10^9 = 2 \times 10^4$s from hadronic reactions
    - 5×10^3s = ~1.5 hours from small-angle scatterings (by D. Trbojevic)
    - from energy loss ?
  - Even higher luminosity possible, if target with ~10^{17}atoms/cm^2 thickness available (beam dump mode)
    - e.g. 20% beams are used in a shorter period

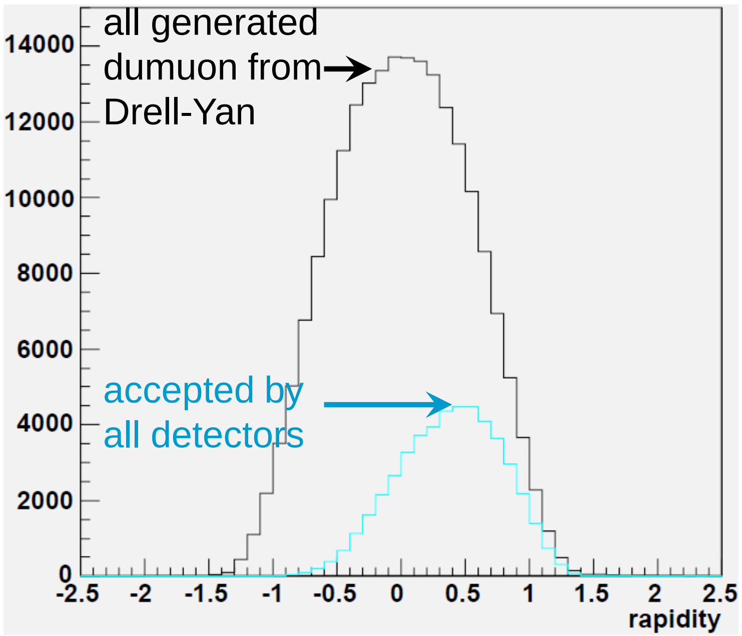


Requirement for the accelerator

- Appropriate beam lifetime and low background
  - Affected by beam blow-up (small-angle scattering, beam energy loss at the target, …)
  - low background for collider experiments (in phase-1)
- Compensation for dipole magnets in the experimental apparatus
  - both beams need to be restored on axis in two colliding-beam operation
- Higher beam intensity at phase-2
  - 1.5-times more number of bunches (assumed at eRHIC)
  - Otherwise, 1.5-times longer beam time is required
- Radiation issues
  - Beam loss/dump requirement?
- Experimental site issues
  - Magnet, civil engineering works, …

Experimental sensitivities

- PYTHIA simulation
  - $\sqrt{s}$ = 22 GeV (E_{lab} = 250 GeV)
  - luminosity assumption 10,000 pb^{-1}
    - ~ 10 times larger luminosity necessary than that of the collider experiments
    - because of ~10 times smaller cross section × acceptance (in the same mass region)
  - 4.5 GeV < $M_{\mu\mu}$ < 8 GeV
  - acceptance for Drell-Yan dimuon signal is studied

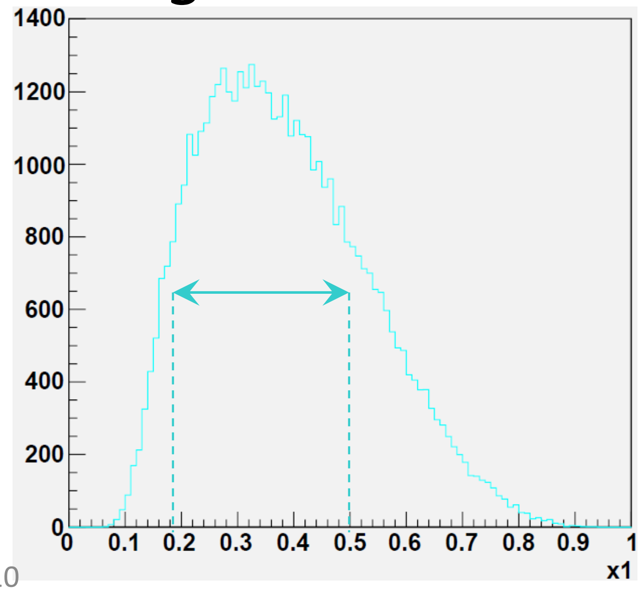


Experimental sensitivities

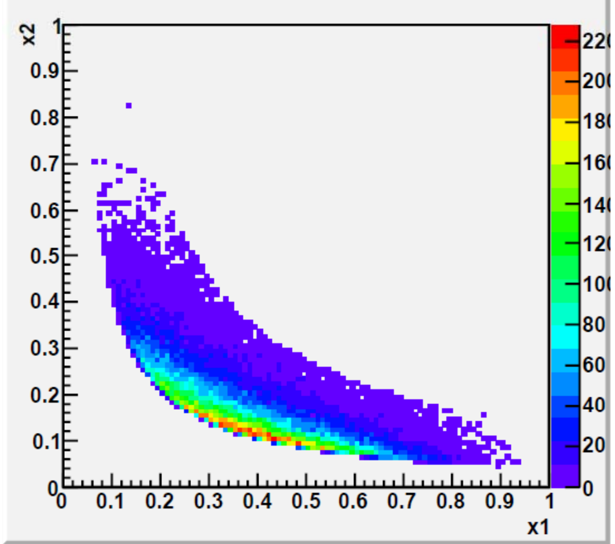
- About 50K events for 10,000pb^{-1} luminosity

	Mass (GeV/c^2)			Total
Rapidity	45 – 50	50 – 60	60 – 80	45 – 80
-0.4 – 0	3.1 K	3.1 K	1.4 K	7.6 K
0 – 0.4	6.2 K	6.1 K	3.0 K	15.3 K
0.4 – 0.8	7.6 K	6.4 K	2.3 K	16.3 K
0.8 – 1.2	4.4 K	2.5 K	0.4 K	7.3 K

- *x-coverage: 0.2 < x < 0.5*



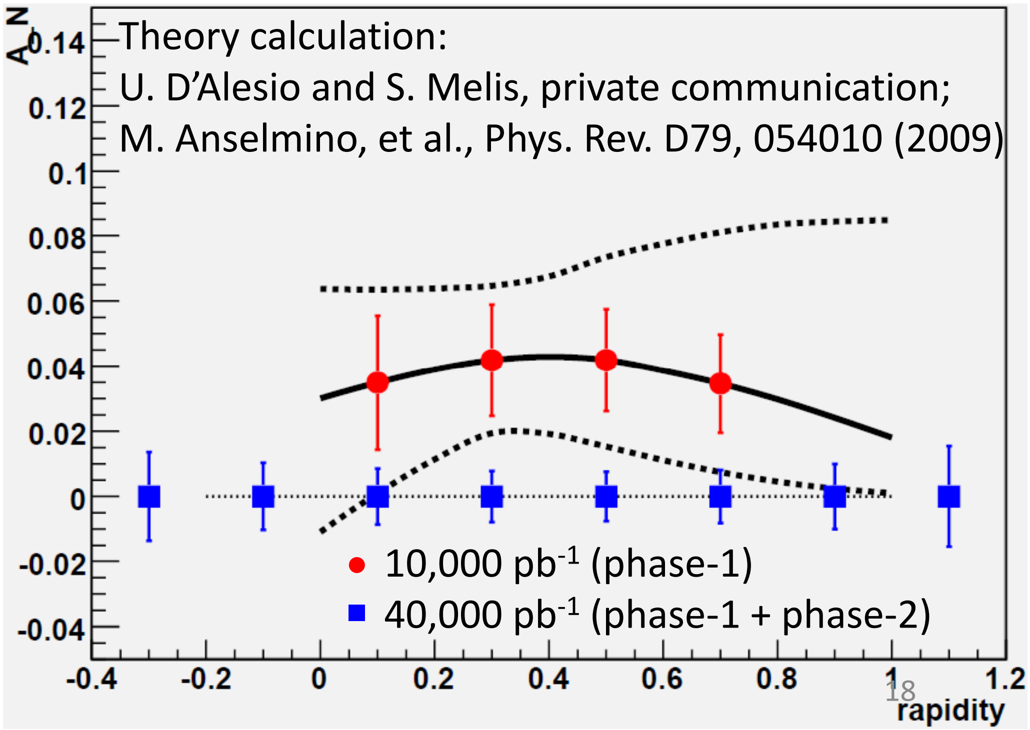
x_1: x of beam proton (polarized)
x_2: x of target proton



Experimental sensitivities

- Phase-1 (parasitic operation)
  - $L = 2 \times 10^{33}\ cm^{-2}s^{-1}$
  - 10,000 pb^{-1} with 5×10^6 s ~ 8 weeks, or 3 years (10 weeks $\times$ 3) of beam time by considering efficiency and live time
- Phase-2 (dedicated operation)
  - $L = 3 \times 10^{34}\ cm^{-2}s^{-1}$
  - 30,000 pb^{-1} with 10^6 s ~ 2 weeks, or 8 weeks of beam time by considering efficiency and live time

Measure not only the sign of the Sivers function but also the shape of the funcion

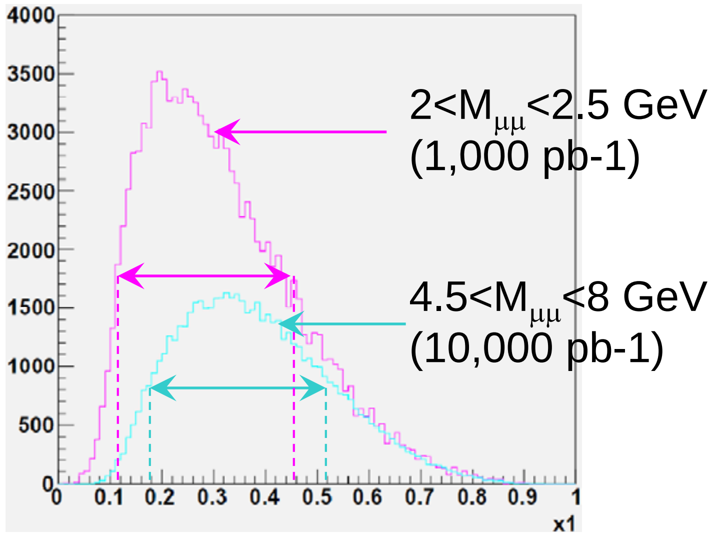


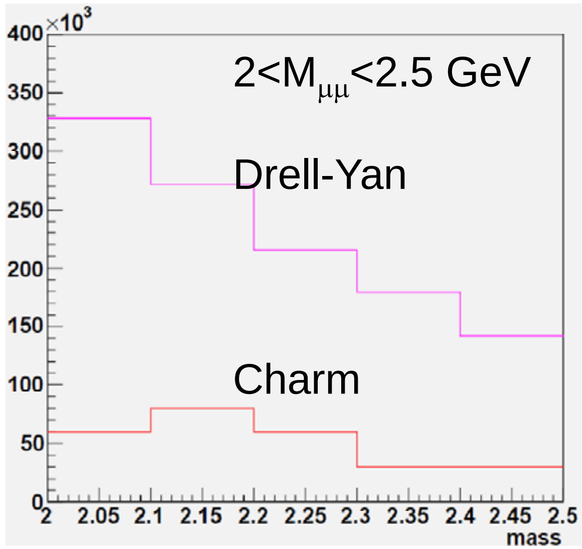
Cost and schedule

- Cost
  - Experimental apparatus
    - FNAL magnet (reassembled or modified) or other existing magnet at BNL
    - FNAL-E906 apparatus (modification) and new/existing apparatus
    - $3M - $5M?
  - Internal target
    - e.g. PANDA pellet target: $1.5M R&D, infrastructure + $1.5M construction
  - Accelerator & experimental hall (IP2)
    - the most uncertain part
- Schedule
  - 2010-2013 FNAL-E906 beam time
  - 2011-13 accelerator R&D, internal target R&D + construction
  - 2014 experimental setup & commissioning at RHIC
  - 2015-2017 phase-1: parasitic experiment (10 weeks × 3 years)
  - 2018 phase-2: dedicated experiment (8 weeks)

To-do list

- Low-mass region study
  - 2 – 2.5 GeV
  - Larger yield
  - covering lower x region
    - 0.1 < x < 0.45
  - With lower magnetic field?
  - Charm background < 20% (PYTHIA)
- Geometry optimization
  - Opposite polarity of two magnets
    - May be better for restoring beams on axis
  - Aperture study of the magnets
    - For inventory check of BNL magnets
- GEANT simulation
  - Background rate study
    - From the beam pipe?
    - Effect for the DX magnet?
    - Peak rate?
- Internal target study





Author list

- Academia Sinica
  - W.C. Chang
- ANL
  - D.F. Geesaman, P.E. Reimer, J. Rubin
- UC Riverside
  - K.N. Barish
- UIUC
  - M. Groose Perdekamp, J.-C. Peng
- KEK, Japan
  - N. Saito, S. Sawada
- LANL
  - M.L. Brooks, X. Jiang, G.L. Kunde, M.J. Leitch, M.X. Liu, P.L. McGaughey
- RIKEN/RBRC
  - Y. Fukao, Y. Goto, I. Nakagawa, K. Okada, R. Seidl, A. Taketani
- Seoul National Univ.
  - K. Tanida
- Stony Brook Univ.
  - A. Deshpande
- Tokyo Tech.
  - K. Nakano, T.-A. Shibata
- Yamagata Univ.
  - N. Doshita, T. Iwata, K. Kondo, Y. Miyachi

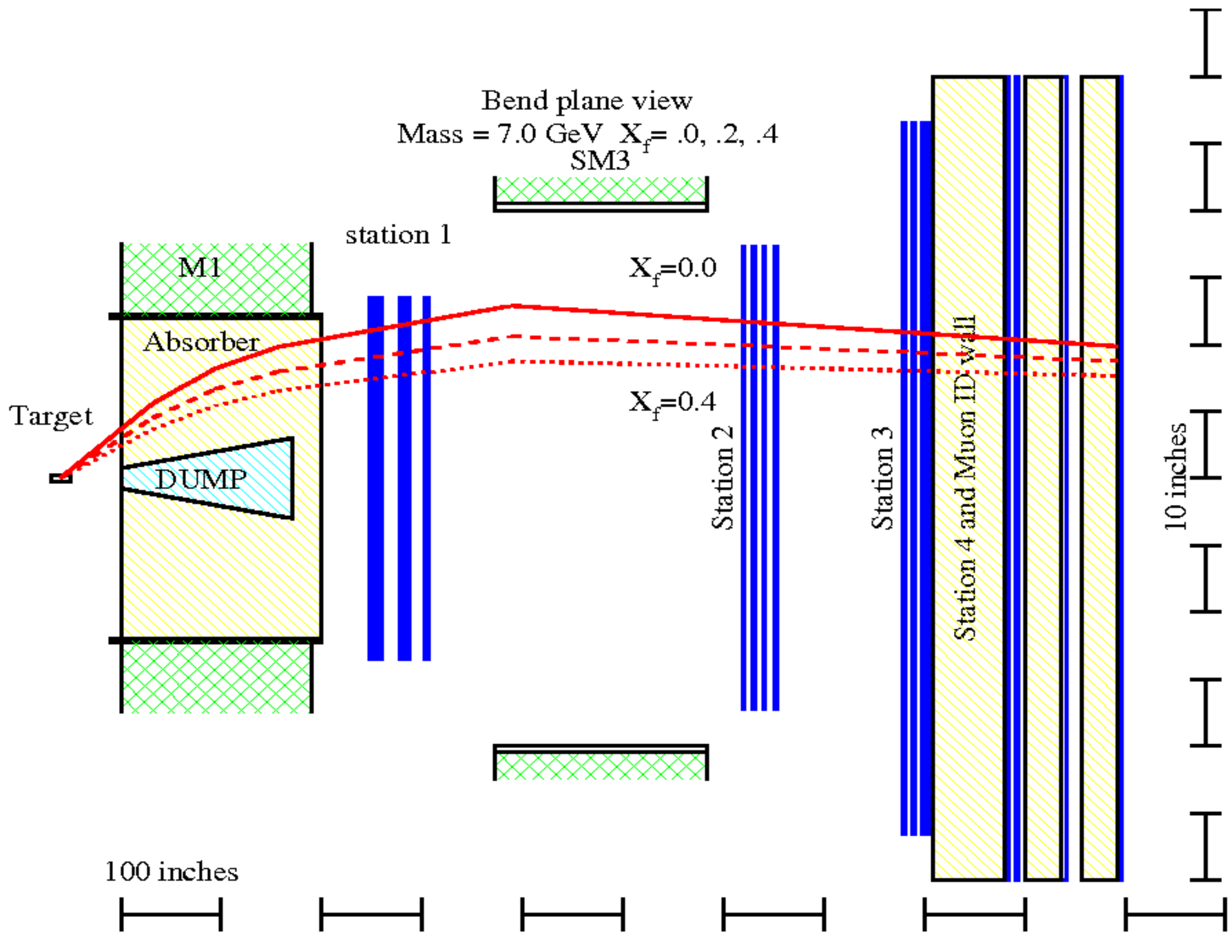
Summary

- Internal-target polarized Drell-Yan experiment
  - 250 GeV transversely polarized proton beam, $\sqrt{s}$ = 22 GeV
  - Dimuon spectrometer based on FNAL-E906 spectrometer
- Sivers function measurement in the valence-quark region from the SSA of Drell-Yan process
  - Test of the QCD prediction “Sivers function in the Drell-Yan process has an opposite sign to that in the DIS process”
  - Milestone for the field of hadron physics
- Layout of the experiment and results of some initial studies of the expected sensitivities were shown
  - Experimental at IP2 area
  - Beam time request for two phases
    - phase-1 (parasitic beam time) + phase-2 (dedicated beam time)
  - With cluster-jet target or pellet target
- Measurement not only the sign of the Sivers function, but also the shape of the function feasible

Backup Slides

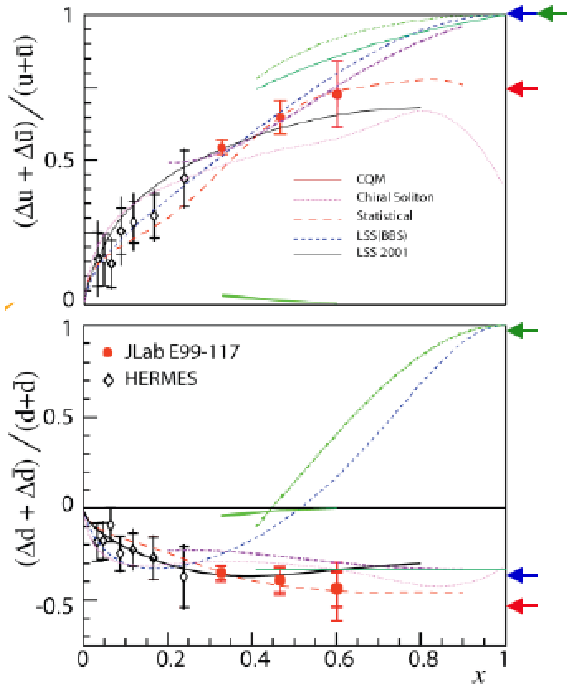
FNAL-E906

- Dimuon spectrometer



Goal of the experiment

- x region
  - Explore larger x region



model	Δu/u	Δd/d
helicity retention	1	1
stat. parton model	0.75	-0.5
rel. const. quark model	1	-1/3

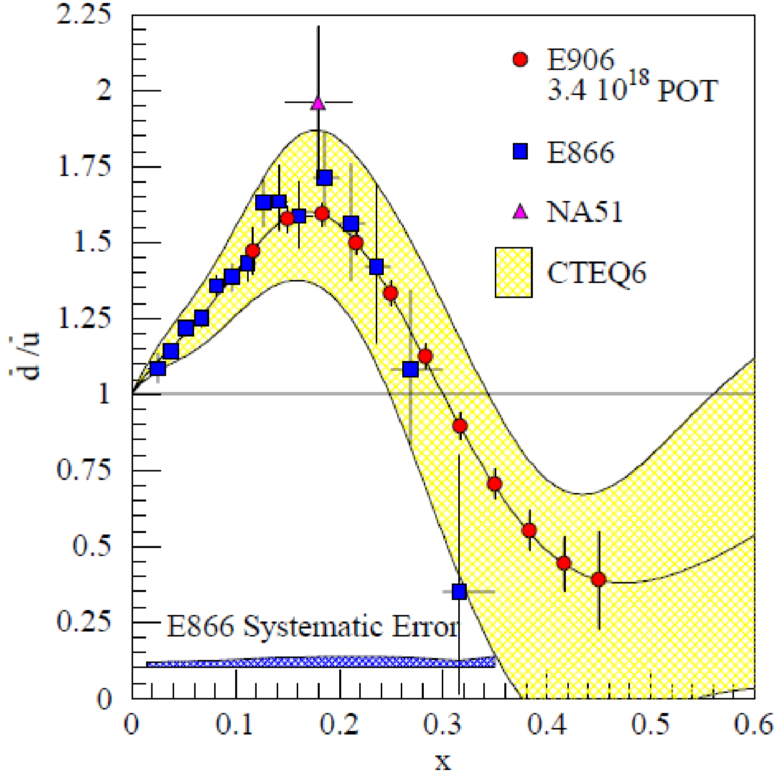
Farrar, Jackson; Brodsky, Schmidt; Brodsky, Burkardt, Schmidt; Avakian et al.

Bourrely, Buccella, Soffer

Isgur, Thomas, Close

conclusions so far: ?

$\Delta d/d \rightarrow 1$ a long shot …



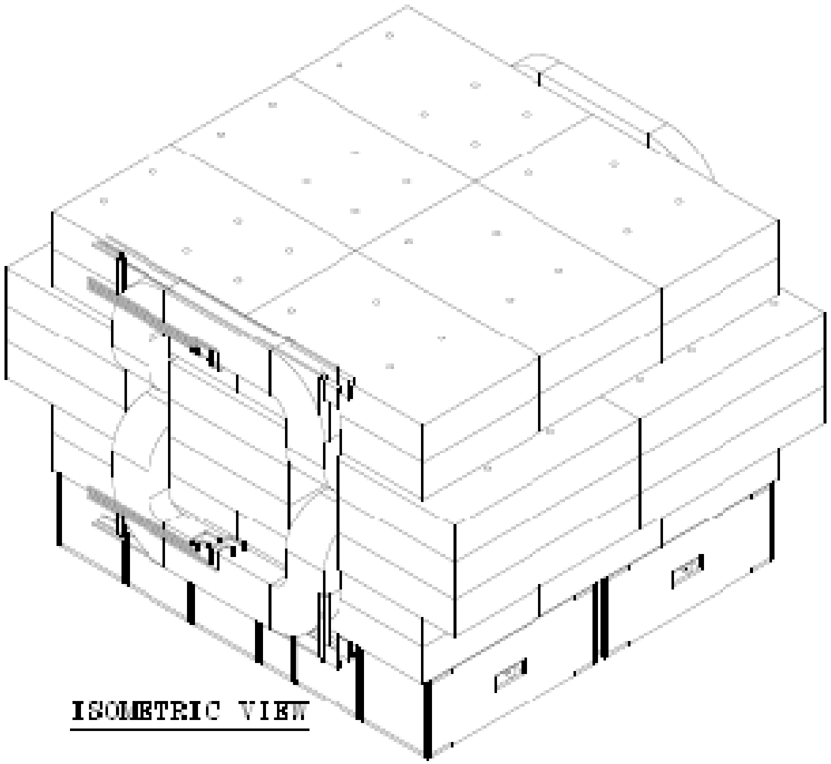
Experimental site and apparatus

- IP2 configuration shown in the next slide
  - Detector components from FNAL-E906 apparatus
    - E906: total z-length ~25m
    - IP2: available z-length ~14m
  - Z-length of th 1st magnet is shortened
    - Because of limited z-length at IP2

	Z-up (inch)	Z-down (inch)	Z-dim (inch)	H-dim/2 (inch)	V-dim/2 (inch)	Mom-kick (GeV/c)
1st magnet	40	193	153	31.5	25.5	2.1
Station1	206	236	30	26	26	0
2nd magnet	241	334	93	57	40	0.55
Station2	339	354	15	41.5	53	0
Station3	473	488	15	40	64	0
Concrete	493	511	18	90	100	0
Station4-1	512	519	7	60	72	0
Concrete	524	542	18	100	100	0
Station4-2	543	550	7	72	72	0

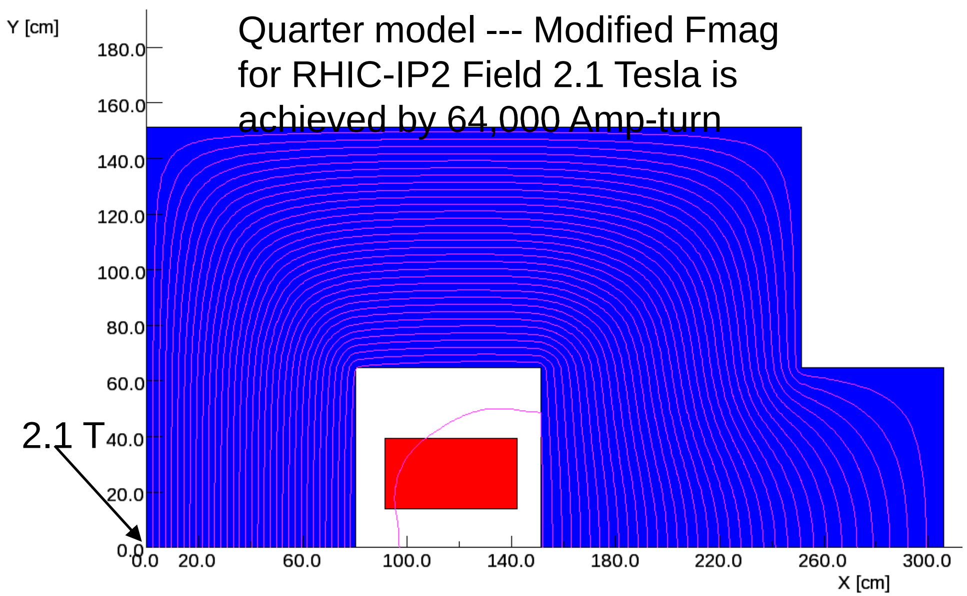
1st magnet

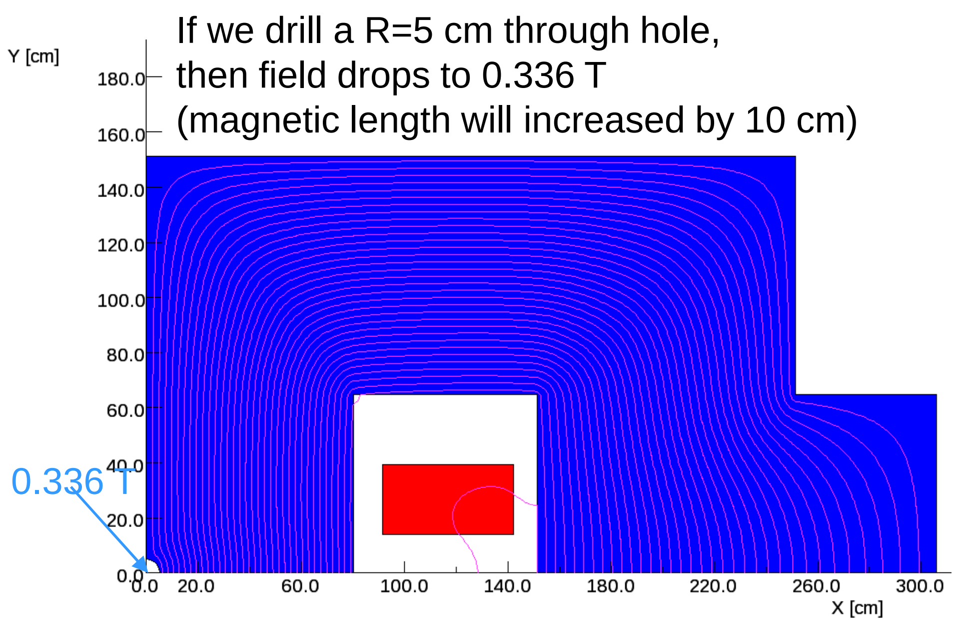
- E906-FMag
  - Under construction
    - Made with the first long coil pack of SM3 magnet (originally for E605) and iron blocks from SM12 magnet (E866)
  - Z-size = 4.7m



1st magnet

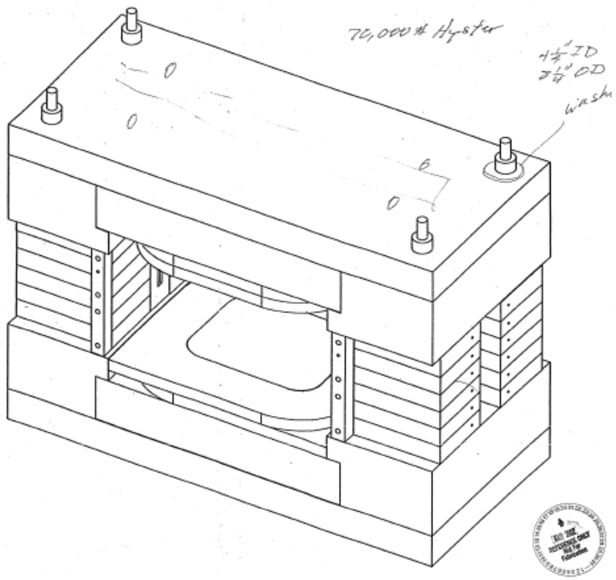
- IP2-FMag
  - Z-size = 3.9m
  - A hole for the beam pipe necessary
    - Inside the hole, the magnetic field is shielded
    - Remaining magnetic field on the beam line (by Wuzheng Meng, Yousef Makdisi and Phil Pile)
      - For the remaining magnetic field, beams are restored on axis





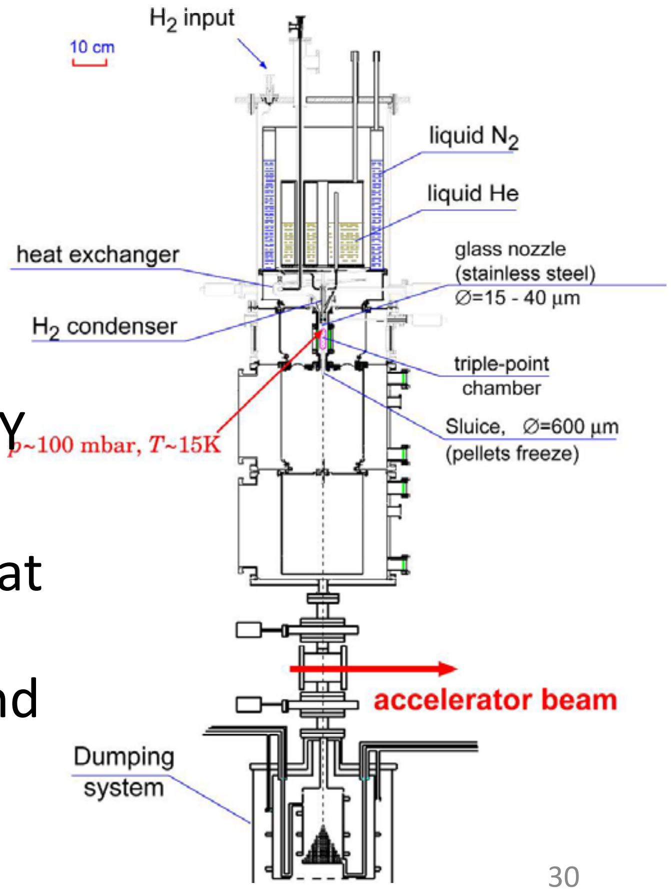
2nd magnet

- E906-KMag
  - KTeV magnet
- IP2-KMag
  - e.g. Jolly Green Giant (JGG) magnet used by E907 exp.

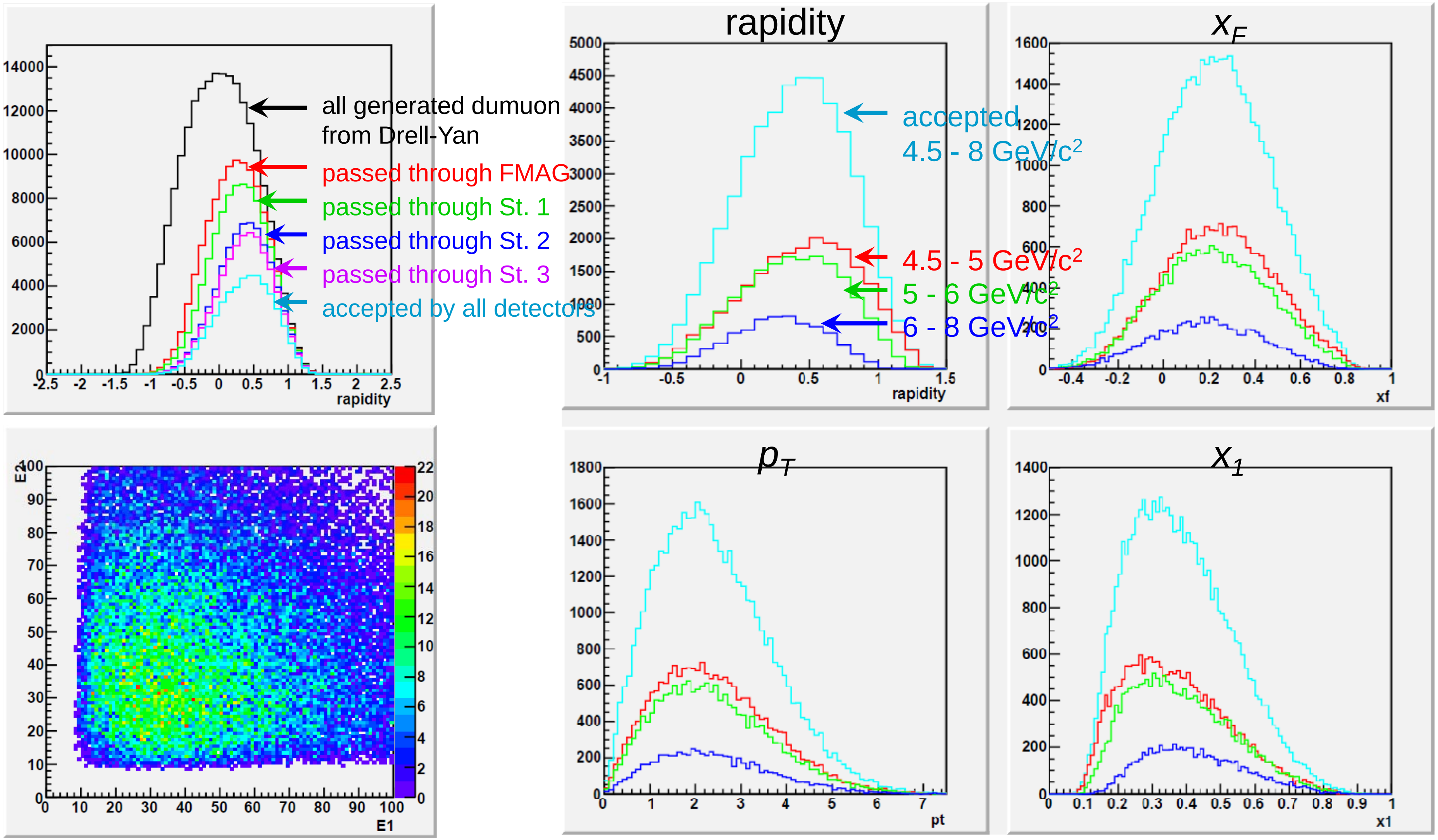


Internal target

- Cluster-jet target
  - H_2, D_2, N_2, CH_4, Ne, Ar, Kr, Xe, …
  - $10^{14} – 10^{15}$ atoms/cm^2
  - Prototype of the PANDA target is operational at the Univ. of Muenster with a thickness of 8×10^{14} atoms/cm^2
- Pellet target
  - H_2, D_2, N_2, Ne, Ar, Kr, Xe, …
  - $10^{15} – 10^{16}$ atoms/cm^2
  - First-generation target was developed in Uppsala and is in use with the WASA@COSY experiment
  - Prototype of the PANDA target is available at Juelich which has been developed in collaboration with Moscow groups (ITEP and MPEI)



Experimental sensitivities



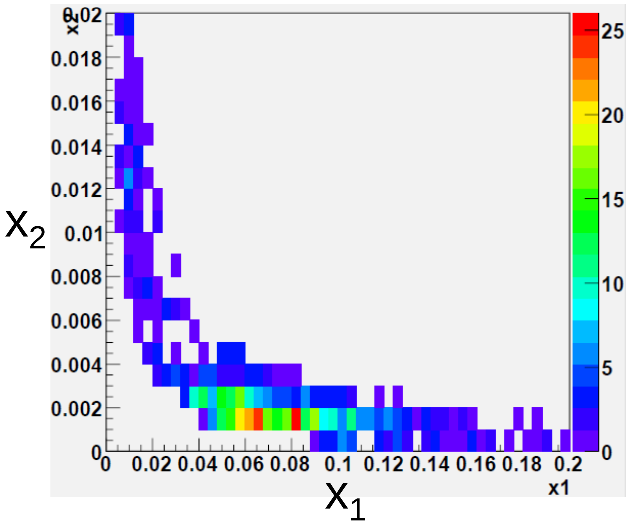
Comparison with other experiments

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} $cm^{-2}s^{-1}$
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 = 0.2 – 0.5	2×10^{33} $cm^{-2}s^{-1}$
RHIC Internal Target phase-2	$p\uparrow$ + p	250 GeV $\sqrt{s}$ = 22 GeV	x1 = 0.2 – 0.5	3×10^{34} $cm^{-2}s^{-1}$

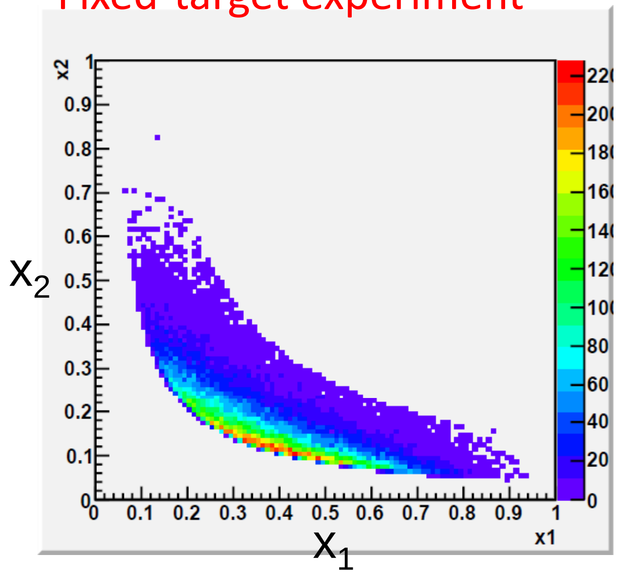
Collider vs fixed-target

- x_1 & x_2 coverage
  - Collider experiment with PHENIX muon arm (simple PYTHIA simulation)
    - $\sqrt{s}$ = 500 GeV
    - Angle & E_μ cut only
      - $1.2 < |\eta| < 2.2$ ($0.22 < |\theta| < 0.59$), $E_\mu > 2, 5, 10$ GeV
      - (no magnetic field, no detector acceptance)
    - luminosity assumption 1,000 pb^{-1}
    - $M_{\mu\mu} = 4.5 \sim 8$ GeV
    - Single arm: $x_1 = 0.05 – 0.1$ ($x_2 = 0.001 – 0.002$)
      - Very sensitive x-region of SIDIS data
  - Fixed-target experiment
    - $x_1 = 0.2 – 0.5$ ($x_2 = 0.1 – 0.2$)
      - Can explore higher-x region with better sensitivity

PHENIX muon arm (angle & E_μ cut only)



Fixed-target experiment



Charm/bottom background

- In collider energies, there is non-negligible background from open beauty production
- In fixed-target energies, background from charm & bottom production is negligible