Drell-Yan実験
- Fermilab-E906/SeaQuest実験
- 偏極Drell-Yan実験の計画

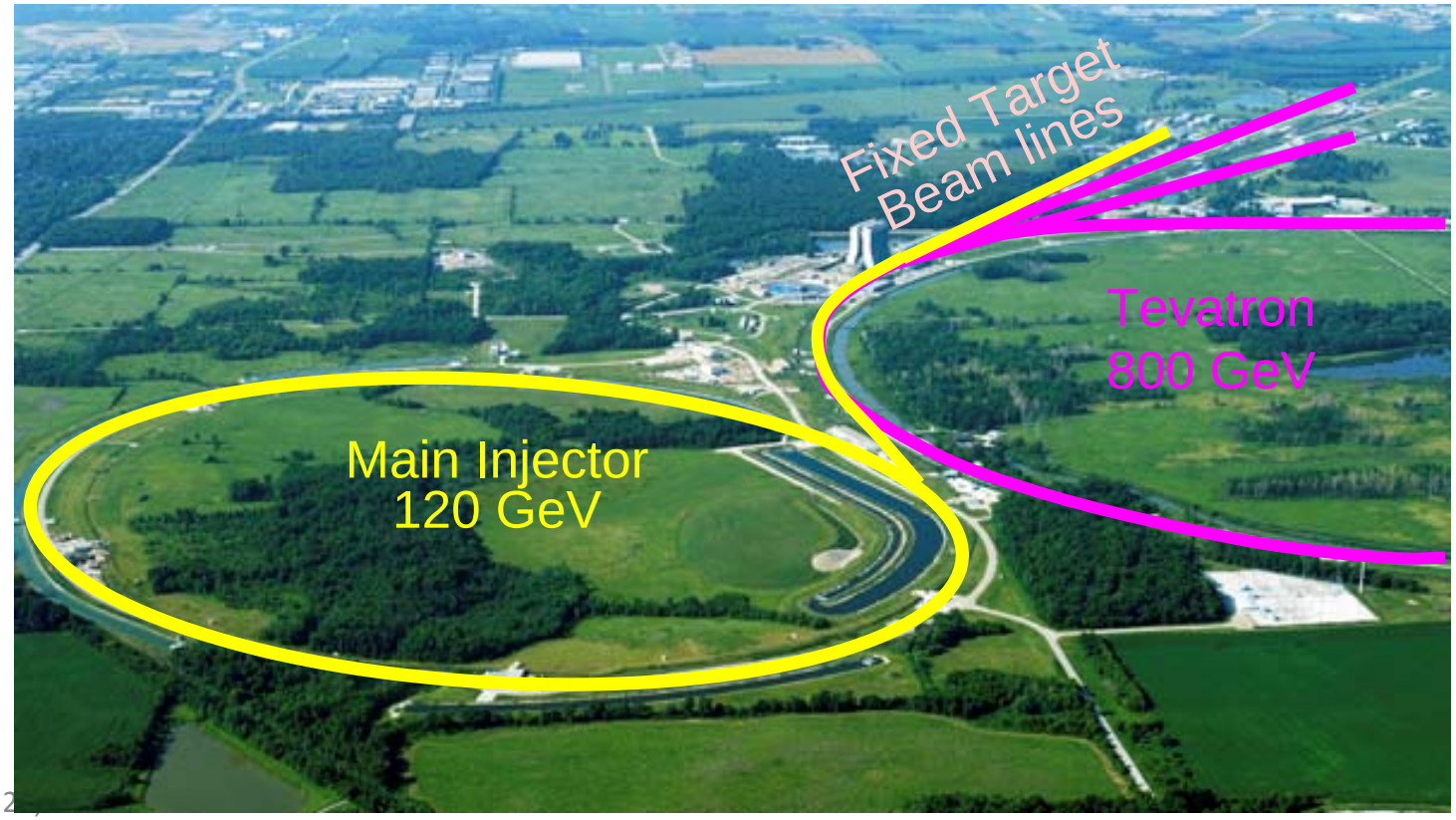
放射線研PHENIXミーティング

2011年1月21日(金)

後藤雄二

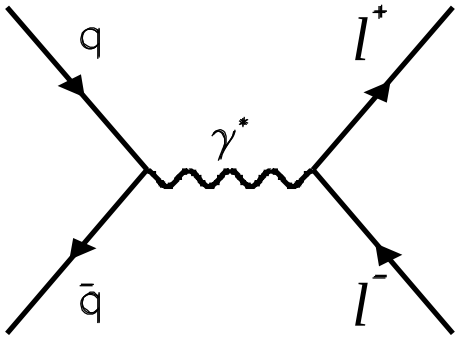
Fermilab-E906/SeaQuest実験

- Drell-Yan過程からのdimuonの測定
  - 物理ランは今春開始
  - 物理の結果はまだない
  - 建設と設置が進行中
  - 3月からビームを用いた調整



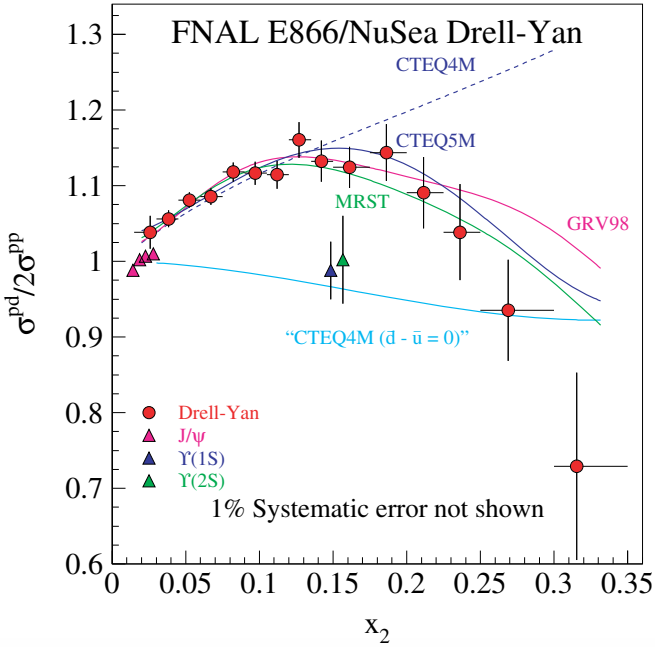
実験の目標

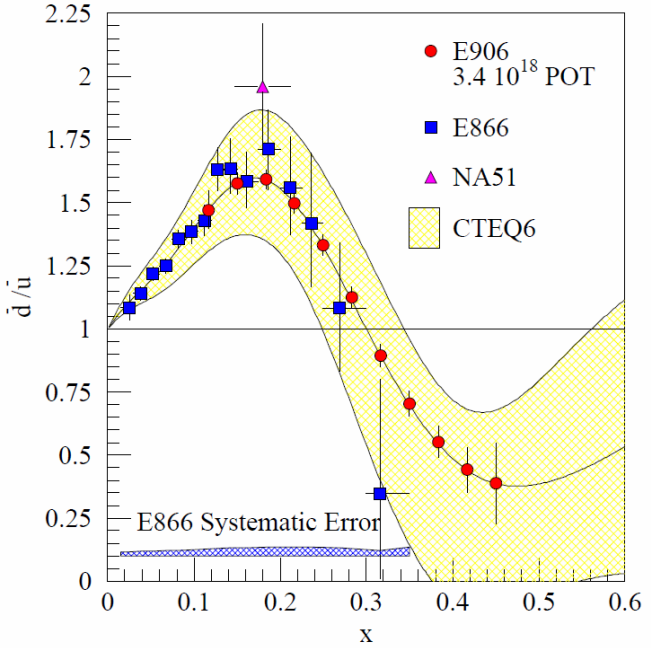
- Drell-Yan過程
  - ハドロン同士の反応において最も単純な過程
    - QCD終状態効果がない
  - ターゲットのsea-quark分布を選択
- 核子構造
    - 水素および重水素標的
  - Sea-quark分布のフレーバー非対称性
  - Boer-Mulders分布関数
    - 核子スピン構造との関連
- 核物質
    - 原子核標的
  - パートンのエネルギー損失
  - EMC効果



Sea-quark分布のフレーバー非対称性

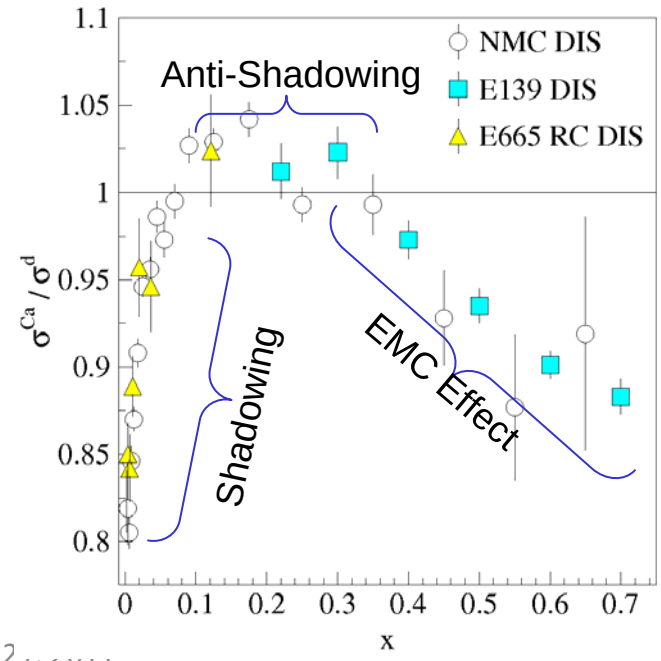
- Fermilab E866/NuSea
  - Sea-quark分布のフレーバー非対称性
  - E_{beam} = 800 GeV $\quad \frac{\sigma^{pd}}{2\sigma^{pp}} \sim \frac{1}{2}\left[1+\frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$
    - x = 0.01 – 0.35 (valence region)
- Fermilab E906/SeaQuest
  - E_{beam} = 120 GeV
    - x = 0.1 – 0.45
- 競合する説明
  - 摂動論的QCD
    - グルーオンの解離
  - 非摂動論的QCDからの寄与
    - 中間子雲模型
    - カイラルクォーク模型

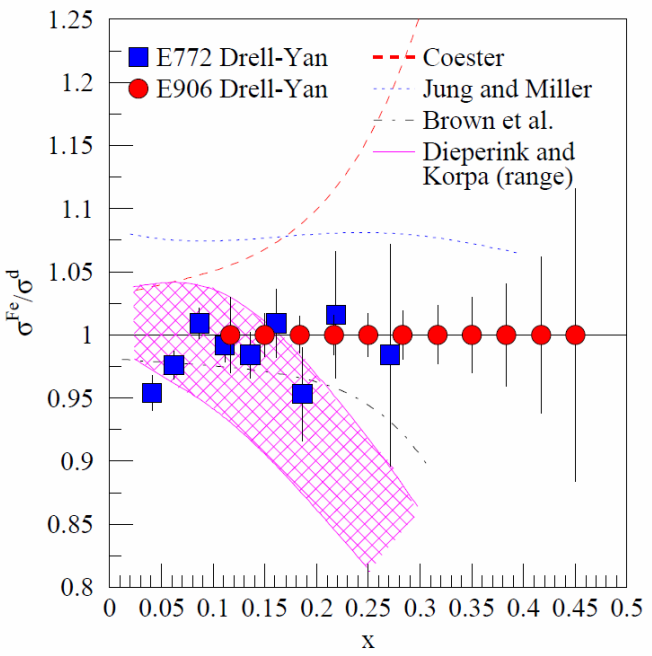




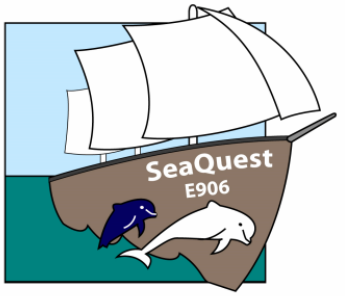
EMC効果

- 1983年、EMC (European Muon Collaboration) がミューオンDIS実験において発見
- 原子核中のパートン分布が核子中の分布に対して修正を受ける
  - 仮想中間子の交換が原子核中のパートン分布に修正を与える
  - 現在あるDrell-Yan過程のデータには、この修正がないことが示唆される





Fermilab E906/SeaQuest Collaboration



Abilene Christian University
- Obiageli Akinbule
- Brandon Bowen
- Mandi Crowder
- Tyler Hague
- Donald Isenhower
- Ben Miller
- Rusty Towell
- Marissa Walker
- Shon Watson
- Ryan Wright

Academia Sinica
- Wen-Chen Chang
- Yen-Chu Chen
- Shiu Shiuan-Hal
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- John Arrington
- Don Geesaman*
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University of Colorado
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- Bryan Dannowitz
- Dan Jumper
- Bryan Kerns
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- Jen-Chieh Peng

KEK
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Ling-Tung University
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Los Alamos National Laboratory
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University of Michigan
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RIKEN
- Yuji Goto
- Atsushi Taketani
- Yoshinori Fukao

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- Ron Gilman
- Ron Ransome
- Elaine Schulte
- Brian Tice
- Ryan Thorpe
- Yawei Zhang

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- Carl Gagliardi
- Robert Tribble

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- S. Miyasaka
- S. Takeuchi

Yamagata University
- Yoshiyuki Miyachi

*Co-Spokespersons

スケジュール

- http://www.fnal.gov/directorate/program_planning/schedule/

2010-2011 Fermilab Accelerator Experiments Schedule

This schedule will be updated regularly, as plans change.

Calendar Year		2010	2011	
Tevatron Collider		CDF	CDF	OPEN
		DZero	DZero	OPEN
Neutrino Program	B	MiniBooNE	MiniBooNE #	
	MI	MINERvA	MINERvA	
		ArgoNeuT		
		MINOS	MINOS	
SY 120	MT	Test Beam	Test Beam	
	MC	OPEN	OPEN	
	NM4	E-906/SeaQuest	E-906/SeaQuest	

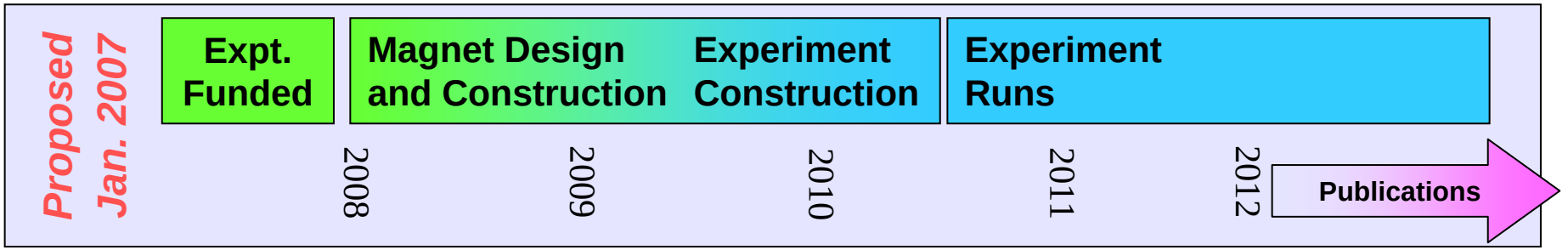
Draft 2010-13 Fermilab Accelerator Experiments' Run Schedule

Typically Revised Annually - This Version from June, 2010

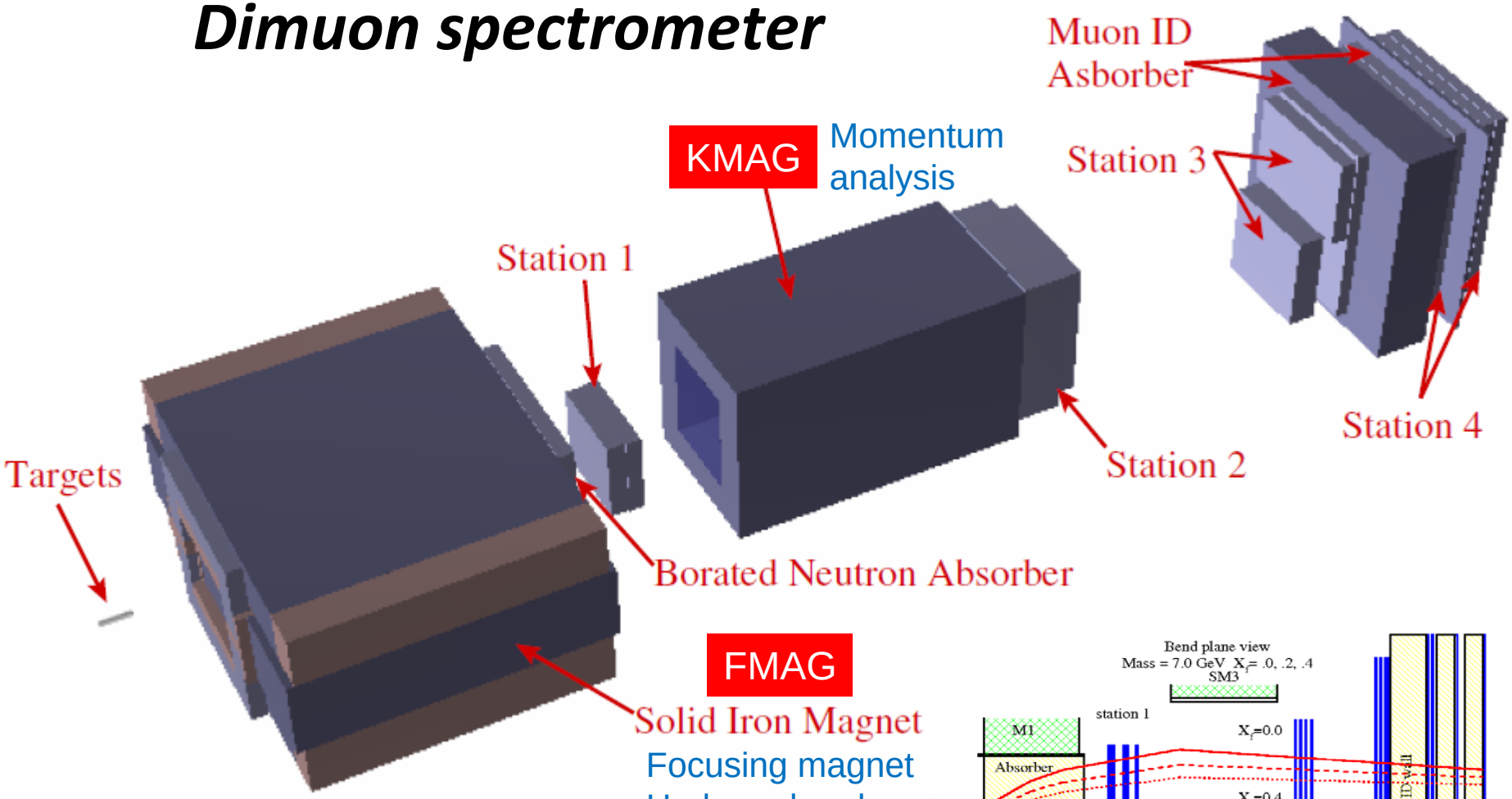
Calendar Year		2010	2011	2012	2013
Tevatron Collider		CDF & DZero	CDF & DZero	OPEN	OPEN
Neutrino Program	B	MiniBooNE	MiniBooNE #		MicroBooNE
	MI	MINOS	MINOS		OPEN
		MINERvA	MINERvA		MINERvA
		ArgoNeuT			
			NOvA		NOvA
SY 120	MT	Test Beam	Test Beam		Test Beam
	MC	OPEN	OPEN		OPEN
	NM4	E-906/SeaQuest	E-906/SeaQuest		E-906/SeaQuest

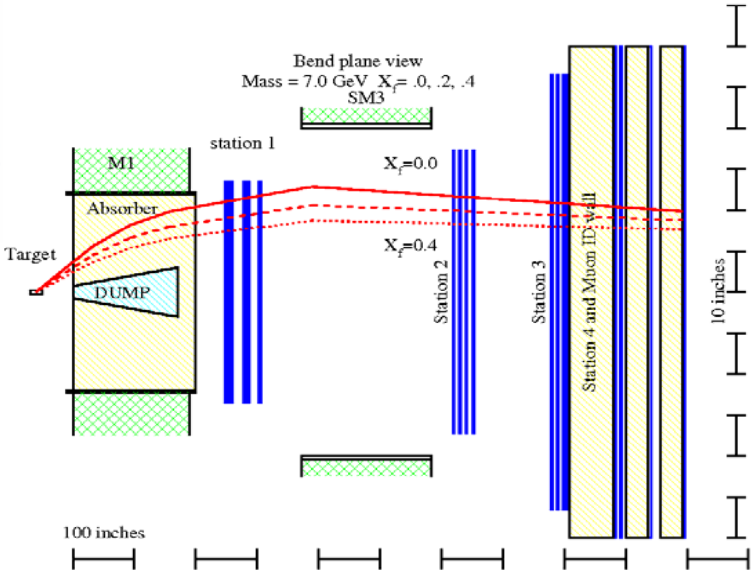
Fermilab E906/SeaQuest timeline

- 2001年: Fermilab PACにより採択
- 2007年: DOE nuclear physicsから資金を得る
- 2008年-2009年: Fermilab所長によるステージ2採択およびFermilabとE906 collaborationの間でMoU (Memorandum of Understanding)が交わされる
- 2009年-2010年: 実験装置の建設および設置
- 2011年3月: ビームを用いた実験調整開始
- 2011年-2013年: 物理データ集積

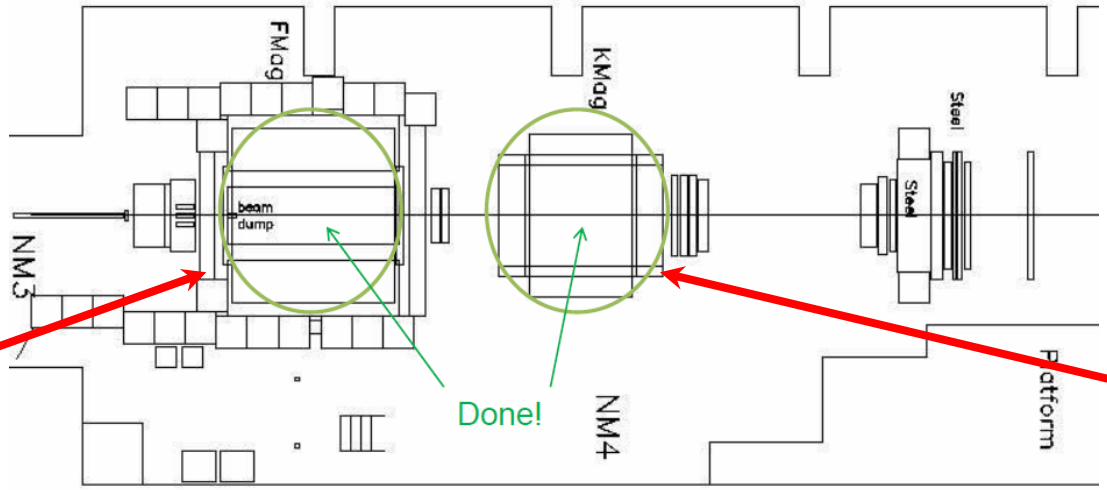


Dimuon spectrometer





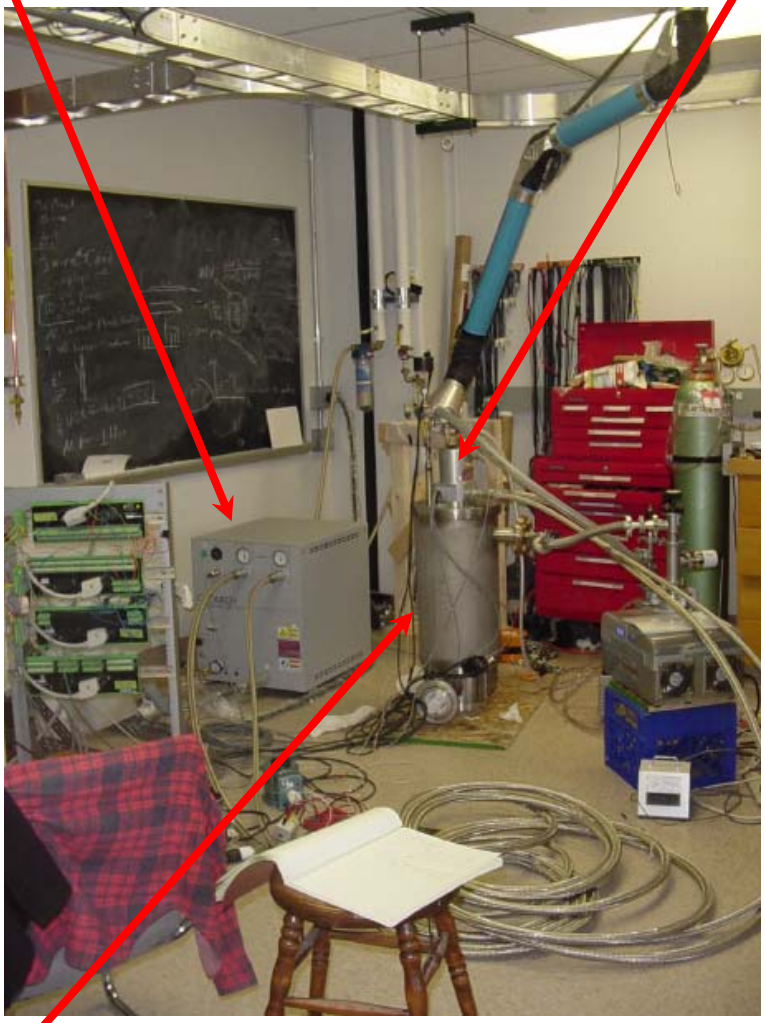
NM4 hall (ex KTeV hall) & magnets



FMAG

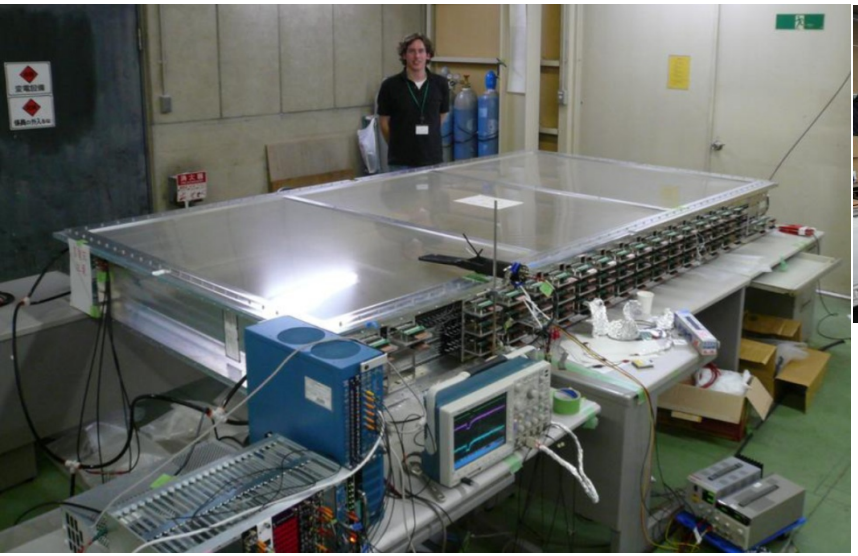
KMAG

水素/重水素標的


Cryocooler compressor
Cryocooler coolhead
Condenser
Vacuum vessel
Target test flask

Station 3 ドリフトチェンバー

- 日本で建設
- 航空便で日本からFermilabへ輸送



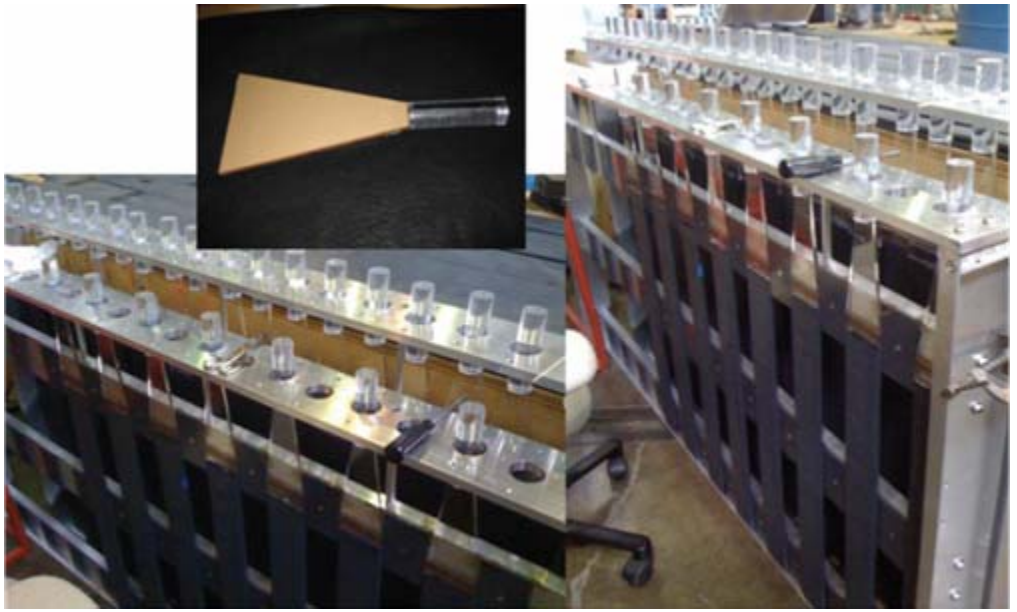
2010.7.2 RIKEN

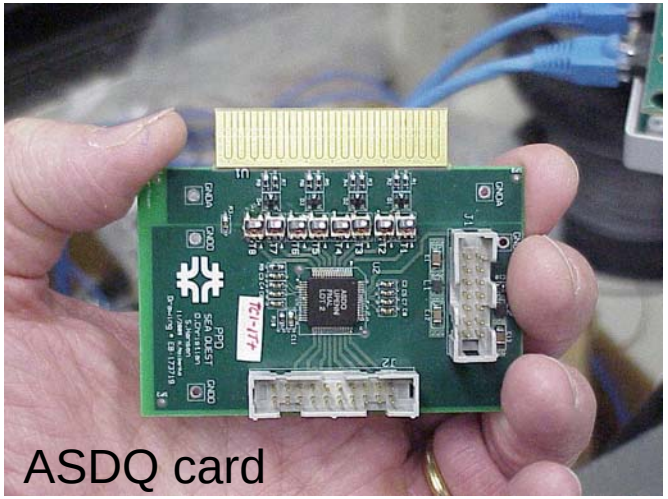
2010.7.20 Fermilab

飛跡検出器、エレキ

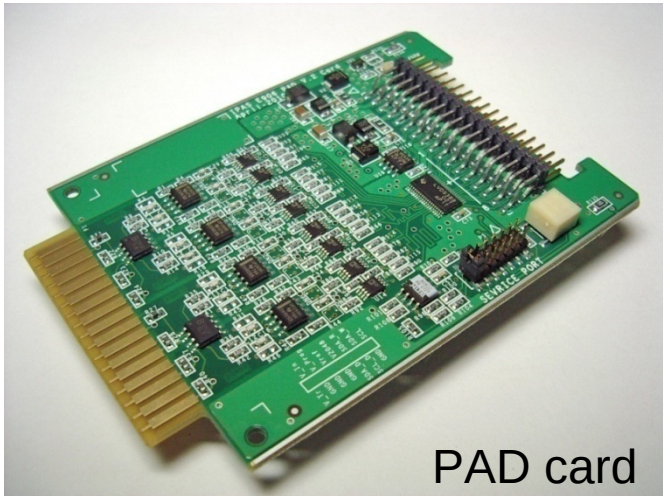
Station 4 proportional tubes

Hodoscopes for dimuon trigger

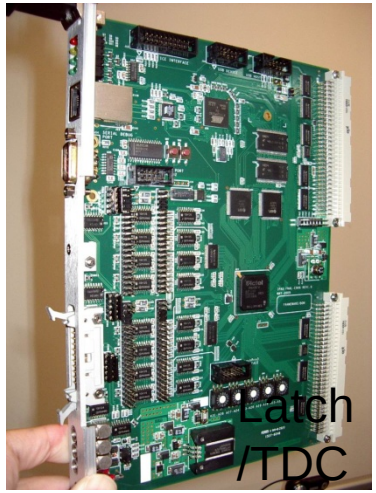




ASDQ card



PAD card



Latch /TDC

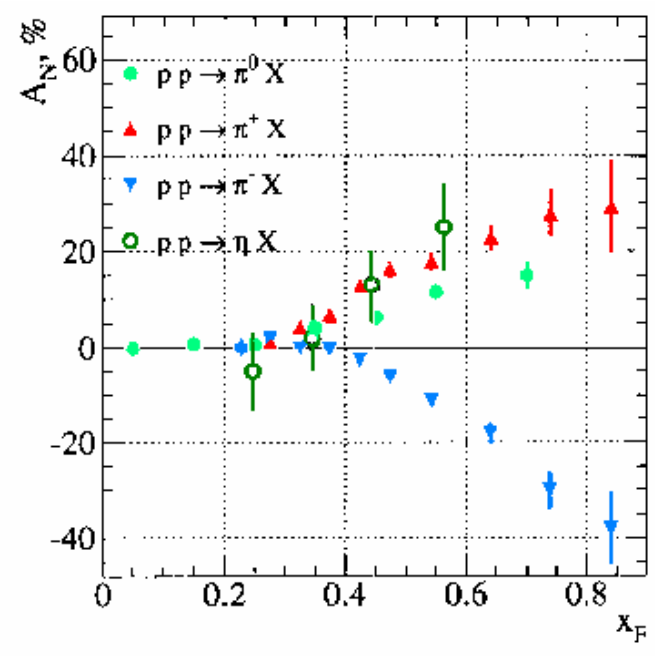
Readout electronics

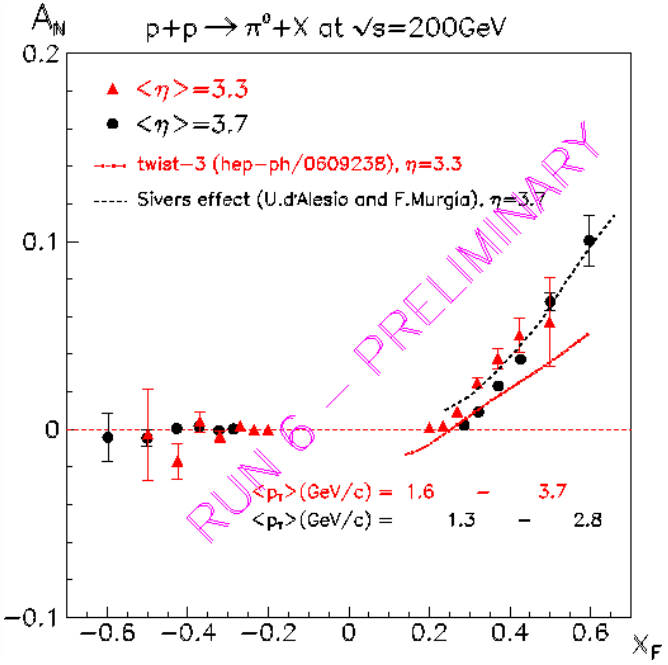
ここまでのまとめ

- Fermilab-E906/SeaQuest実験
  - Drell-Yan過程からのdimuon測定
    - 核子構造
      - Sea-quark分布のフレーバー非対称性
      - Boer-Mulders分布関数
    - 核物質
      - EMC効果
      - パートンのエネルギー損失
- 立ち上げの現状
  - 建設と設置が進行中
    - ビームライン、電磁石、飛跡検出器、ガス、エレキ、トリガー、DAQ
    - Station 3ドリフトチェンバーを日本で建設、2010年7月に航空便でFermilabへ輸送
  - 2011年3月からビームを用いた調整
    - ビームの理解、検出器ゲイン・タイミング、トリガータイミング・レート・マトリクス、位置合わせ、DAQ、データ解析
  - 今春物理データ収集を開始、2013年まで2年間集積

Introduction

- Transverse-spin asymmetry measurement





FNAL-E704 $\sqrt{s}$ = 20 GeV RHIC-STAR $\sqrt{s}$ = 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)

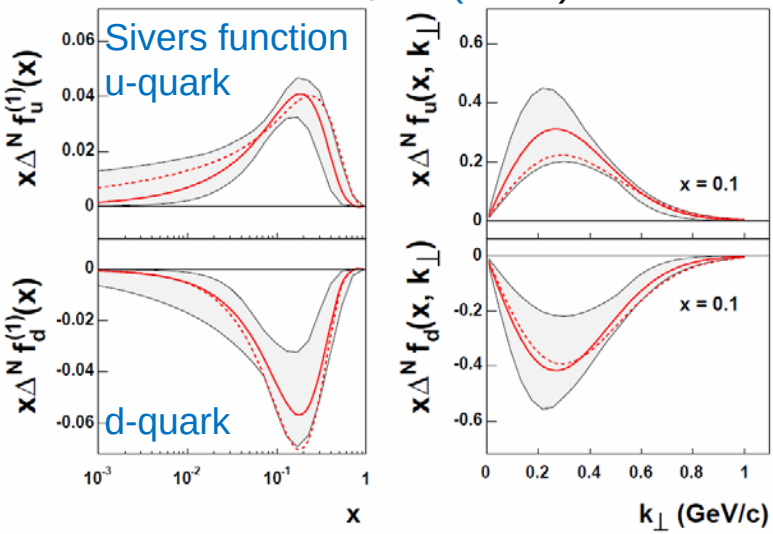
	unpolarized parton	longitudinally-polarized parton	transversely-polarized parton
unpolarized nucleon	f_1		$h_1^\perp$
longitudinally-polarized nucleon		g_1	$h_{1L}^\perp$
transversely-polarized nucleon	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

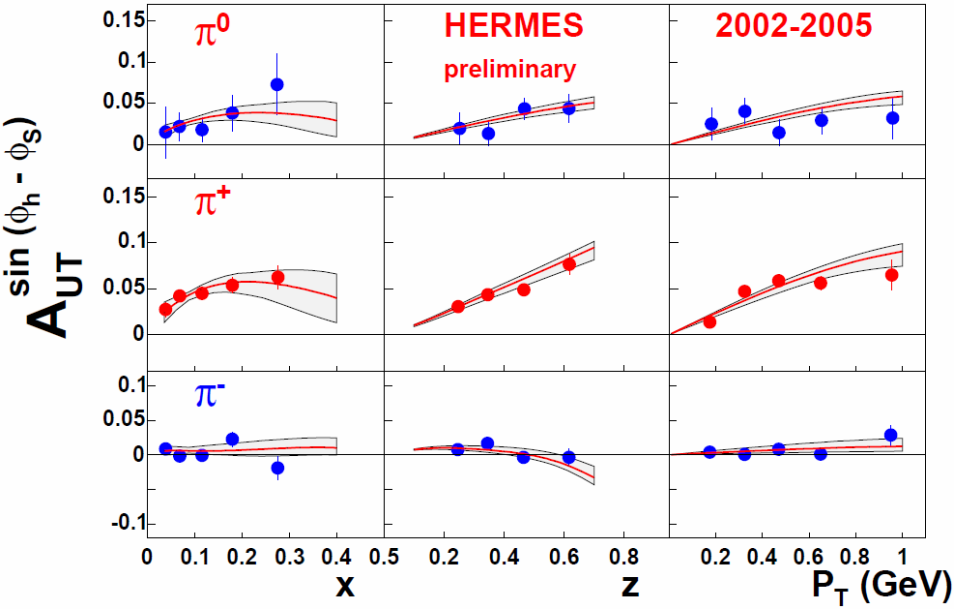
Leading-twist transverse momentum dependent (TMD) distribution functions

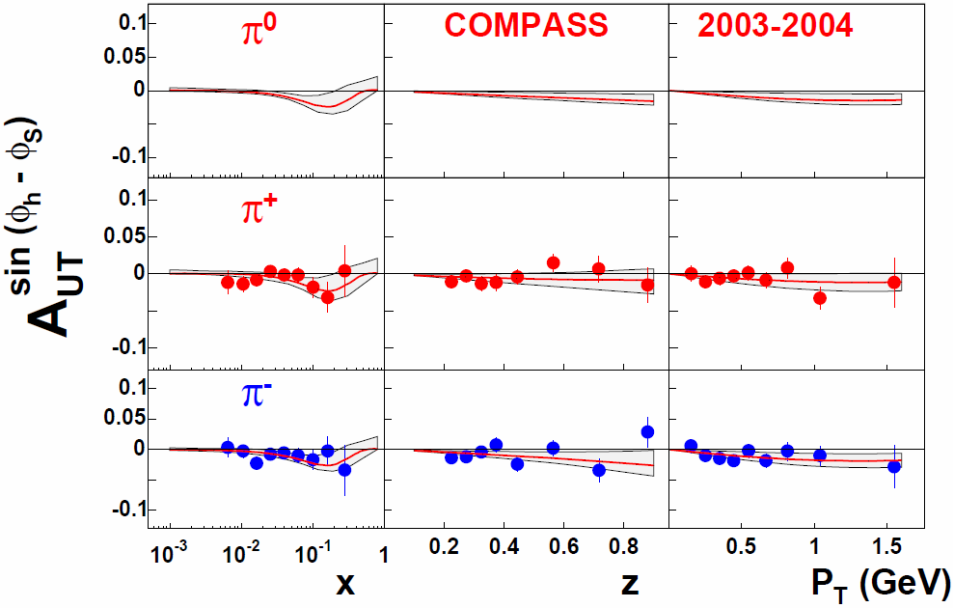
Sivers function

- 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)

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







Single transverse-spin asymmetry

- Sivers function
  - Correlation between nucleon transverse spin and parton transverse momentum (Sivers distribution function)
  - Related to the orbital angular momentum in the proton (and the shape of the proton)
- "Non-universality" of Sivers function
  - Sign of Sivers function determined by SSA measurement of DIS and Drell-Yan processes should be opposite each other

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

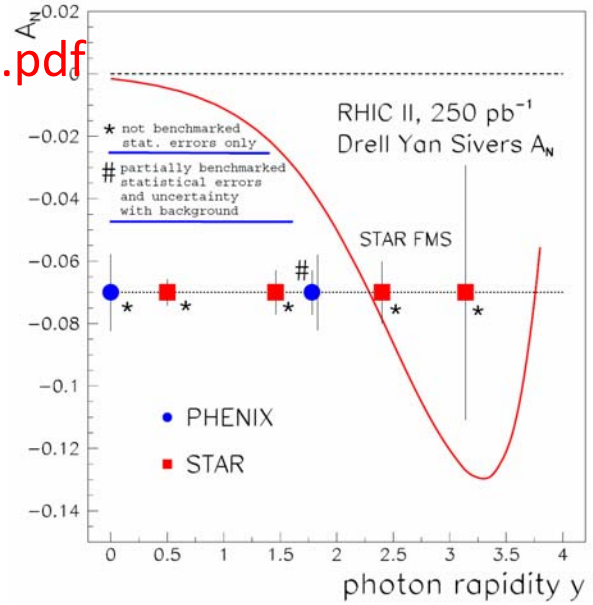
    - final-state interaction with remnant partons in DIS process
    - Initial-state interaction with remnant partons in Drell-Yan process
  - Fundamental QCD prediction
  - One of the next milestones for the field of hadron physics

Future polarized Drell-Yan 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} $cm^{-2}s^{-1}$

Polarized Drell-Yan experiments at RHIC

- "Transverse-Spin Drell-Yan Physics at RHIC"
  - http://spin.riken.bnl.gov/rsc/write-up/dy_final.pdf
  - Les Bland, et al., May 1, 2007
  - $\sqrt{s}$ = 200 GeV
  - PHENIX muon arm
  - STAR FMS (Forward Muon Spectrometer)



- Discussions at PHENIX and STAR underway in their decadal plan discussion with their upgrade plan
- Two new Letter-of-Intent submitted to BNL PAC
  - Collider experiment dedicated to the polarized Drell-Yan experiment
    - "Feasibility Test of Large Rapidity Drell-Yan Production at RHIC"
  - Fixed-target experiment
    - "Measurement of Dimuons from Drell-Yan Process with Polarized Proton Beams and an Internal Target at RHIC"

Collider experiment LoI

- http://www.bnl.gov/npp/docs/pac0610/Crawford_LoI.100524.v1.pdf

Letter Of Intent

Feasibility Test of Large Rapidity Drell Yan Production at RHIC

E.C.Aschenauer, A. Bazilevsky, L.C. Bland, A. Gordon, Y. Makdisi, A. Ogawa, P. Pile, T.G. Throwe
Brookhaven National Laboratory, Upton, NY

H.J. Crawford, J.M. Engelage, E.G. Judd, C.W. Perkins
University of. California, Berkeley/Space Sciences Laboratory, Berkeley, CA

A. Derevshchikov, N. Minaev, D. Morozov, L.V. Nogach
Institute for High Energy Physics, Protvino, Russia

G. Igo, S. Trentalange
University of California, Los Angeles, Los Angeles, CA

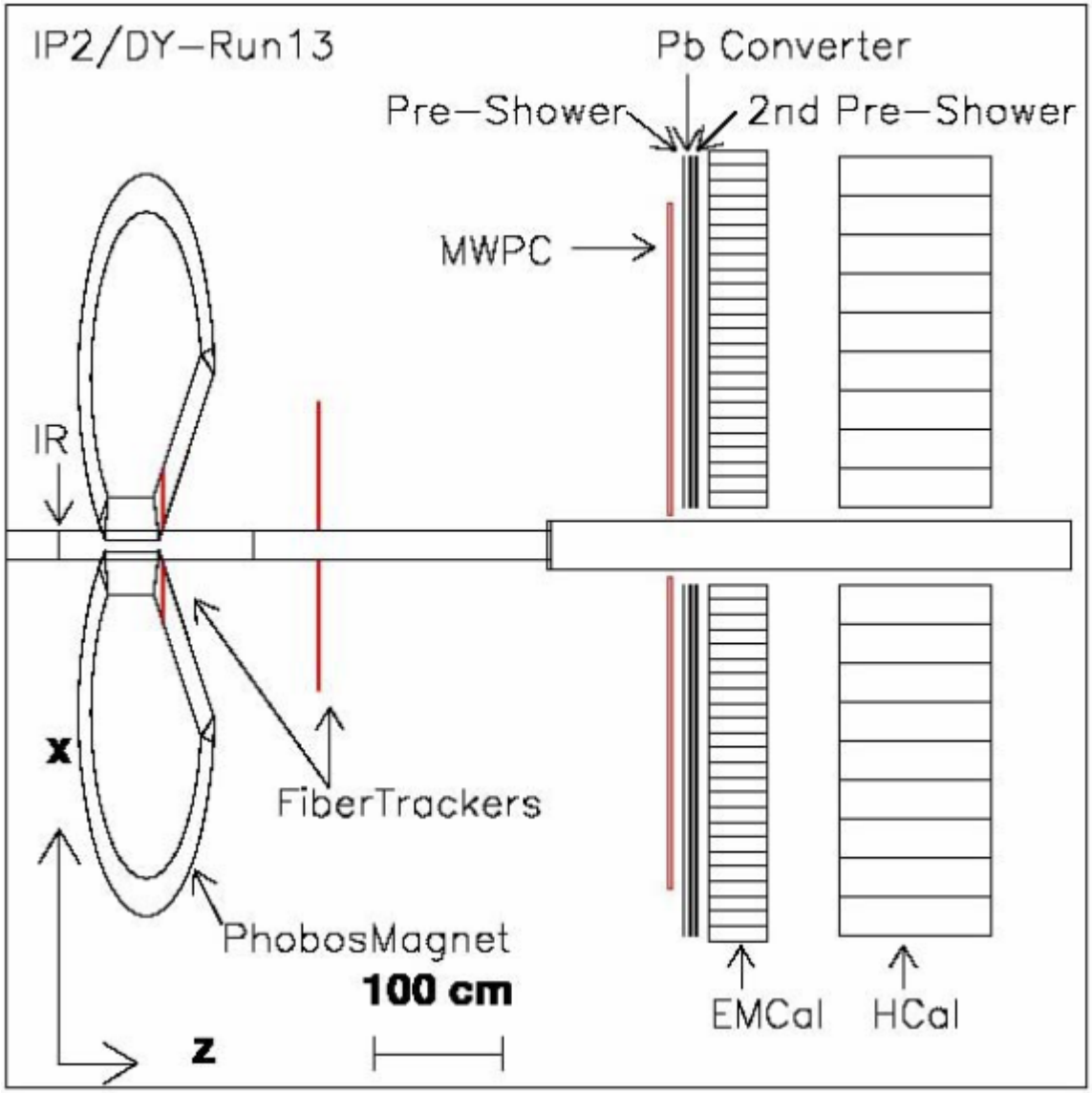
M. Grosse Perdekamp, A. Vossen
University of Illinois, Urbana-Champaign, IL

M.X. Liu
Los Alamos National Laboratory, Los Alamos, NM

H. Avakian
Thomas Jefferson National Accelerator Facility, Newport News, VA

24 May 2010

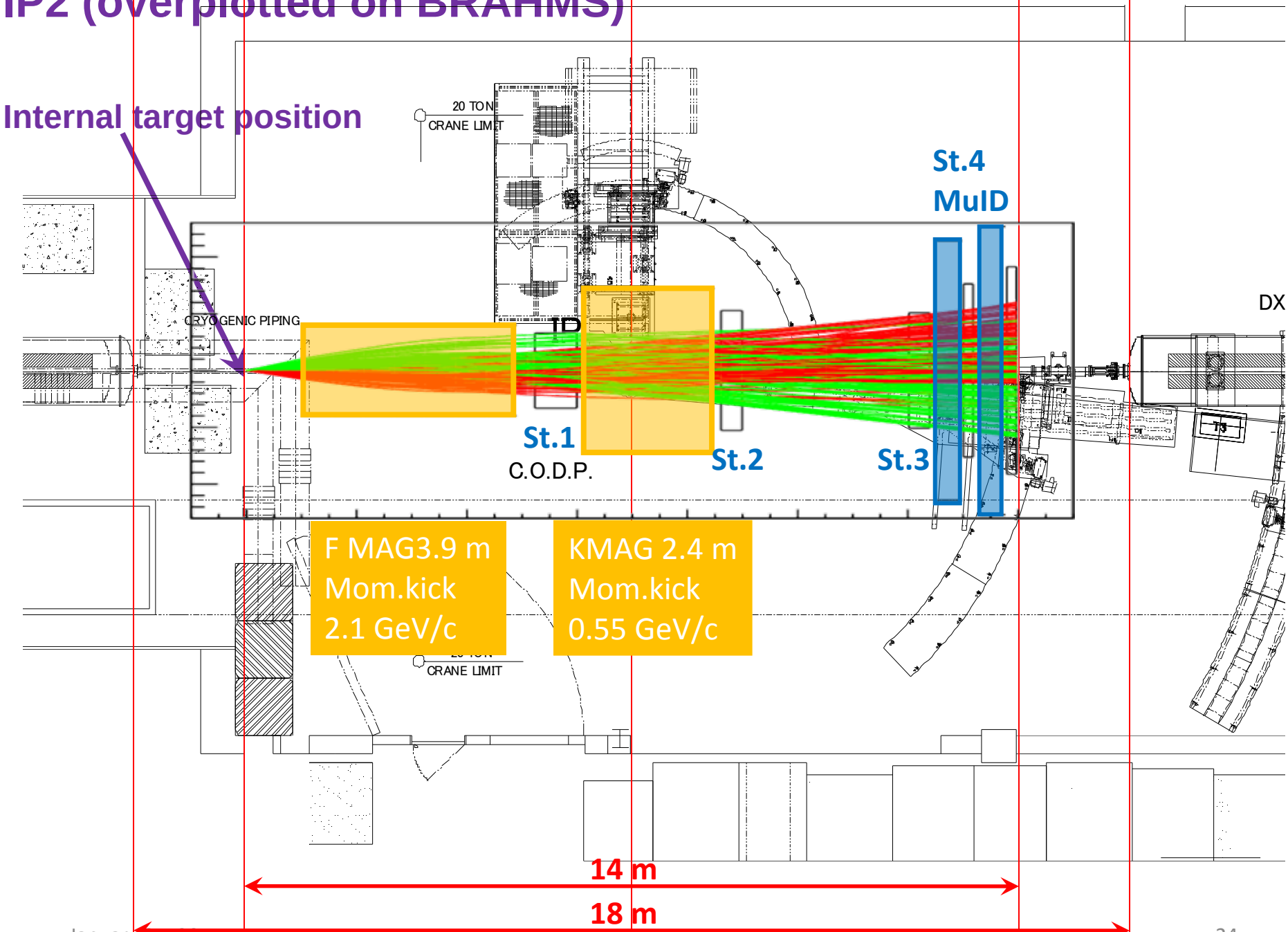
Collider experiment LoI



Fixed-target experiment LoI

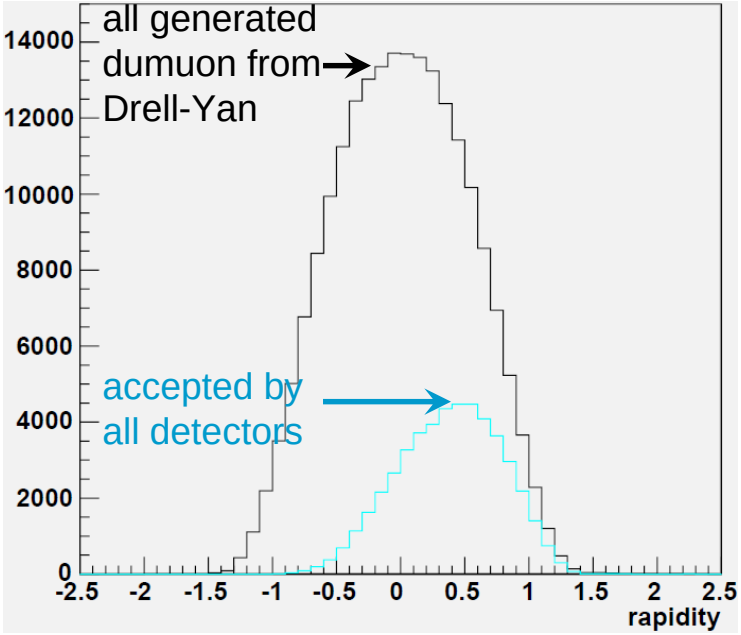
- Measurement of Dimuons from Drell-Yan Process with Polarized Proton Beams and an Internal Target at RHIC
  - http://www.bnl.gov/npp/docs/pac0610/Goto_rhic-drell-yan.pdf
  - Academia Sinica (Taiwan): W.C. Chang
  - ANL (USA): D.F. Geesaman, P.E. Reimer, J. Rubin
  - UC Riverside (USA): K.N. Barish
  - UIUC (USA): M. Groose Perdekamp, J.-C. Peng
  - KEK (Japan): N. Saito, S. Sawada
  - LANL (USA): M.L. Brooks, X. Jiang, G.L. Kunde, M.J. Leitch, M.X. Liu, P.L. McGaughey
  - RIKEN/RBRC (Japan/USA): Y. Fukao, Y. Goto, I. Nakagawa, K. Okada, R. Seidl, A. Taketani
  - Seoul National Univ. (Korea): K. Tanida
  - Stony Brook Univ. (USA): A. Deshpande
  - Tokyo Tech. (Japan): K. Nakano, T.-A. Shibata
  - Yamagata Univ. (Japan): N. Doshita, T. Iwata, K. Kondo, Y. Miyachi

IP2 (overplotted on BRAHMS)



Experimental sensitivities

- PYTHIA simulation
  - $\sqrt{s}$ = 22 GeV (E_{lab} = 250 GeV)
  - luminosity assumption 10,000 pb^{-1}
    - Phase-1 (parasitic operation) 10,000 pb^{-1}
    - Phase-2 (dedicated operation) 30,000 pb^{-1}
  - 4.5 GeV < $M_{\mu\mu}$ < 8 GeV
  - acceptance for Drell-Yan dimuon signal is studied



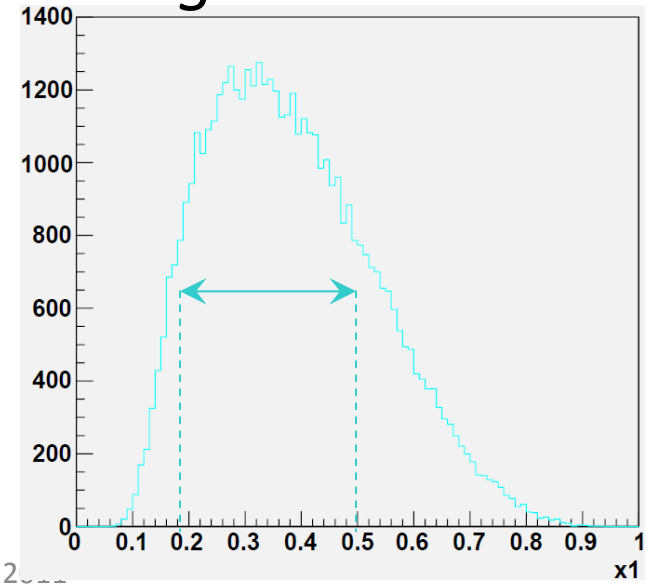
Experimental sensitivities

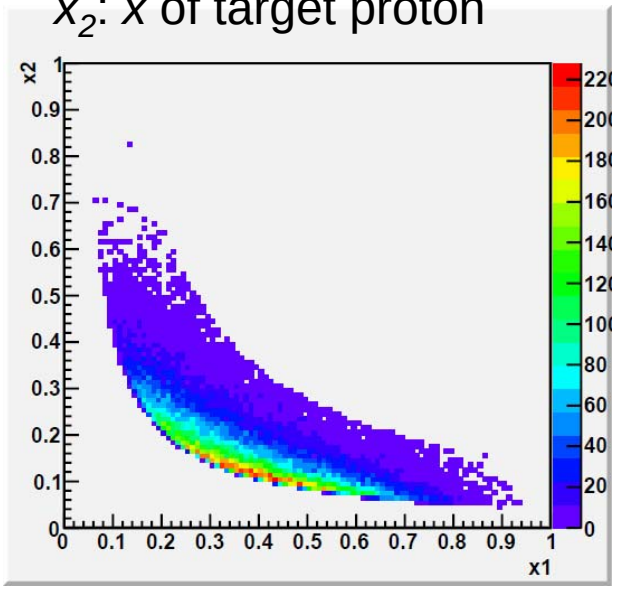
- About 50K events for 10,000pb^{-1} luminosity

	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

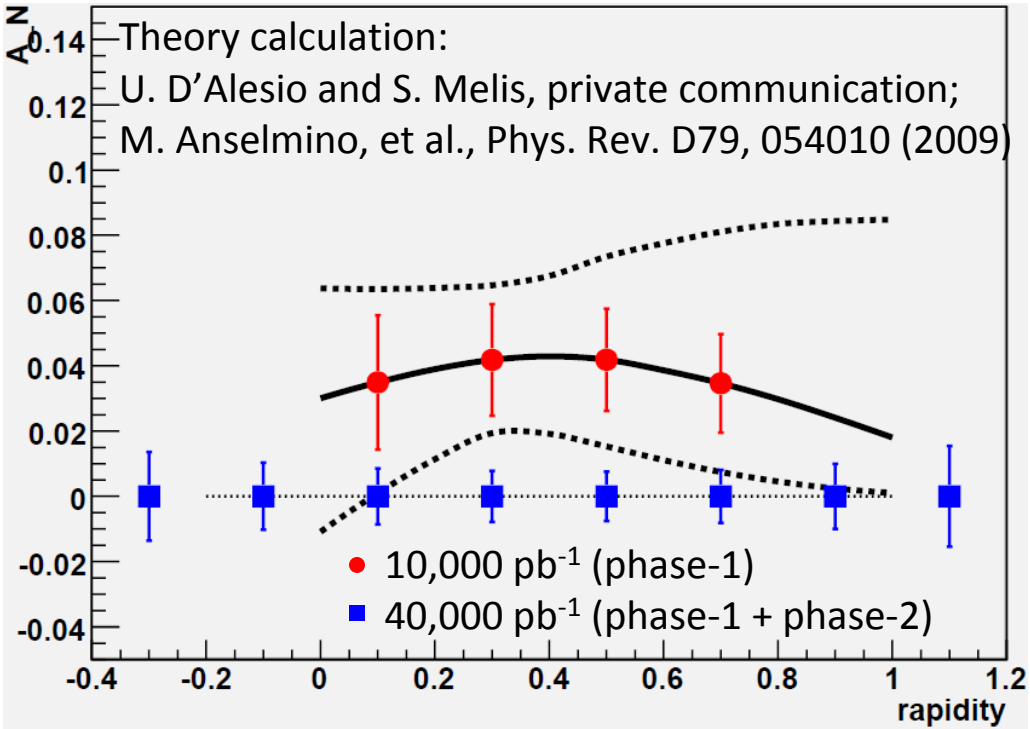




Experimental sensitivities

- 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 × 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



Summary

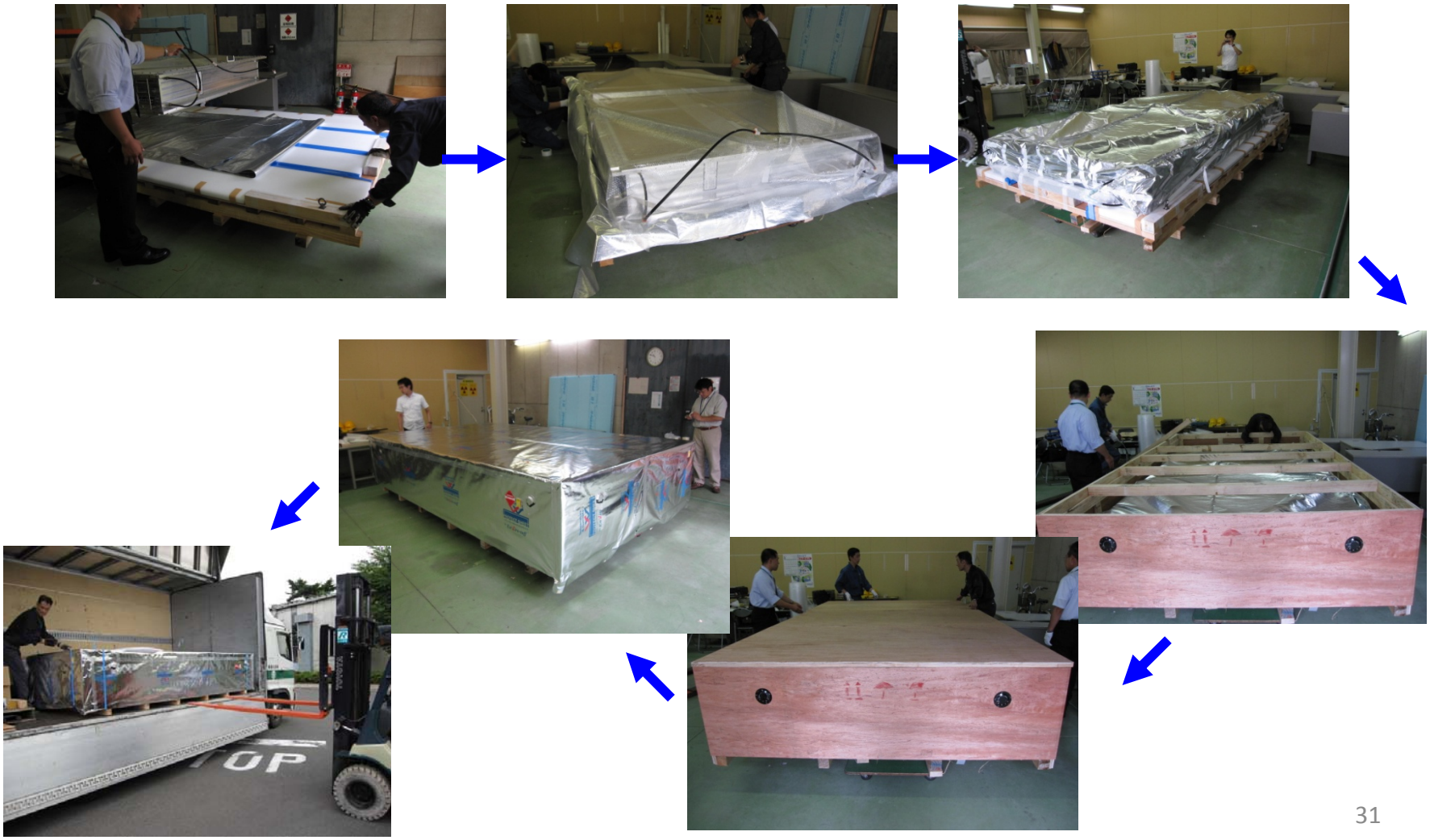
- Polarized Drell-Yan measurement
  - The simplest process in hadron-hadron reaction
  - But, not yet done because of technical difficulties so far
- Sivers function measurement in the valence-quark region from the SSA of Drell-Yan process
  - Test of the QCD prediction “Sivers function in the Drell-Yan process has an opposite sign to that in the DIS process”
  - Milestone for the field of hadron physics
- RHIC
  - Existing collider experiments (PHENIX/STAR)
  - Two new LoI’s – collider exp. and fixed-target exp.
  - Internal-target polarized Drell-Yan experiment at RHIC
    - 250 GeV transversely polarized proton beam, $\sqrt{s}$ = 22 GeV
    - Dimuon spectrometer based on FNAL-E906 spectrometer
- Measurement not only the sign of the Sivers function, but also the shape of the function feasible

Backup slides

Shipping St.3+ Chamber from Japan to Fermilab

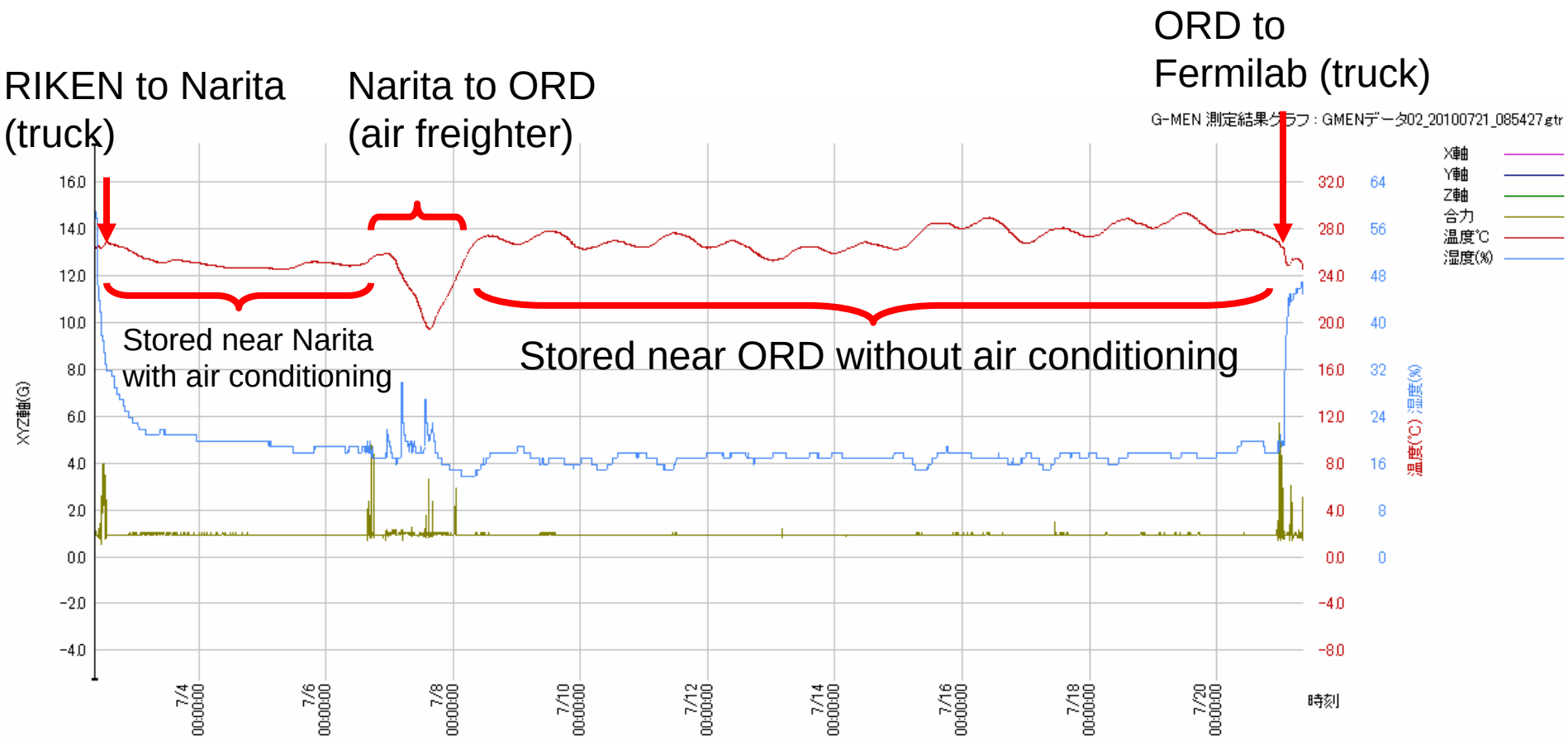
- Concerns
  - Heat expansion of the metal parts
    - Requirement on the specification document: 10 deg. to 40 deg. in celcius.
    - The package was covered by “PROTECT SHEET” to prevent heat and humidity indide.
  - Gas expansion due to pressure drop in the air
    - May cause breaking of the window sheets.
    - Inner volume of the chamber can be ventilated through the gas inlets/outlets.
  - Shock
    - The chamber was laid down on a flat base with shock-absorbing forms.
    - “Shock wathch” and “Tilt watch” were on the surface of the package to warn workers to handle it carefully.
      - Threshhold of the “Shock watch” was 80G/50msec (Morimatsu L-47).

Shipping document (RIKEN, July 2, 2010)



Shipping document (Fermilab, July 20, 2010)

Shipping: Result



- No wire breaking, no damage on the windows.
- Temperature: stable, 19.6 (in aircraft) – 29.4 (near ORD) deg. (C)
- Humidity: low around 20%. Spikes in the aircraft may be due to gas flows caused by pressure change.
- Shocks: 4.080G on the way from RIKEN to Narita, 4.821G at Narita, 5.770G at O'Hare. Acceleration was detected mainly for the vertical direction.

Status

Component	Projected Ready	Comments/Issues
Beam Line	Early to Mid July ????	
Target	When needed -Aug	
Magnets	Mid June	
Sta 1 DC	October	
Hodo 1 and 2	1 July	Support Structure, Cabling, Electronics
Sta 2 DC	Ready	Cabling, Electronics
Absorber wall	Mid June	Needed before Support Structure for 3 and 4
Sta 3 DC – Lower, New	Ready, Early July	Support Structure, Cabling, Electronics
Sta 3 and 4 Scin	Early July	Support Structure, Electronics
Prop Tubes	Early July	Support Structure, Cabling, Electronics
Gas System		Pre mix in July as fall back
Preamps	?????????	
TDC's	??????????	
Latches	August	
Trigger	1 July	Calibration triggers
Scalers		Not a major effort, but need organizing
DAQ	?????	

Fermilab E906/SeaQuest timeline

- Commissioning with beam from October 2010
  - Understand Beam
  - Check detector gains and thresholds with minimum ionizing particles
  - Set detector timing
  - Set trigger timing
  - Measure rates in a systematic way – multiple KMAG fields
  - Take data to align spectrometer – KMAG magnet on and magnet off
  - Take data to study trigger matrices
  - Exercise DAQ and analysis chain
- Phsics run will start in 2010 for 2-year data collection until 2013