

Absolute polarimetry at RHIC

1. How to measure absolute beam polarization?
2. Polarized hydrogen atomic gas jet target system
3. Recoil spectrometer and analysis
4. A_N results from RUN4
5. Beam polarization measurements from RUN5
6. Next step towards the best accuracy

Hiromi Okada (BNL)

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Y. Makdisi, I. Nakagawa, A. Nass, S. Rescia, N. Saito,
E. Stephenson, D. Svirida, T. Wise, A. Zelenski**

How to measure beam polarization ?

$$P_{\text{beam}} = \frac{\varepsilon}{A_N}$$

ε : raw asymmetry

A_N : analyzing power

RHIC Spin Program requires

$$\frac{\Delta P_{\text{beam}}}{P_{\text{beam}}} < 5\%$$

$$\frac{\Delta P_{\text{beam}}}{P_{\text{beam}}} = \frac{\Delta \varepsilon}{\varepsilon} \oplus \frac{\Delta A_N}{A_N}$$

Statistical issue

Our mission
 \Rightarrow achieve 5% measurement

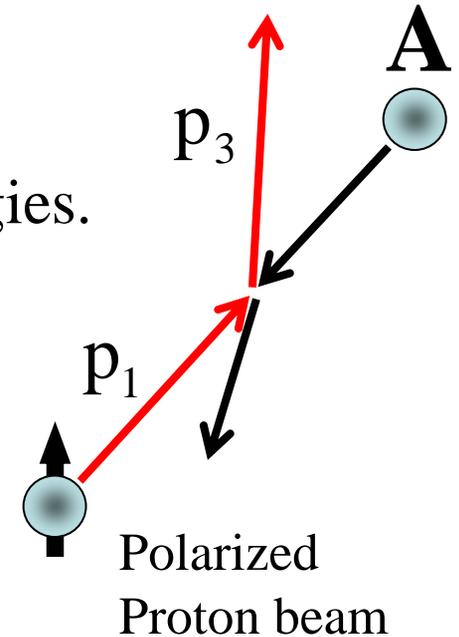
How to choose an ideal interaction for polarimeter ?

- Non-zero A_N
- large cross section
- Common detector set up for different beam energies.
 - Injection 24GeV, flattop 100GeV ~ 250GeV

**Elastic scattering process $p \uparrow A \rightarrow pA$
in very small $-t$ region.**

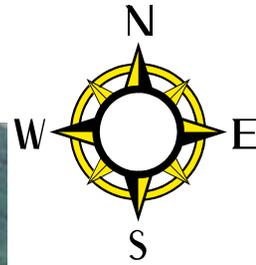
Our case: A is proton or Carbon.

$$t = (p_1 - p_3)^2 < 0$$



- In the region of $-t \sim 10^{-3} (\text{GeV}/c)^2$, coulomb interaction and nuclear interaction become same size
 \Rightarrow **C**oulomb **N**uclear **I**nterference (**CNI**).
- Interfere each other $\rightarrow A_N$ is large from QED Prediction.

RHIC polarimeter complex in BNL



IP12

□ Wednesday 15:40~

□ Y. Makdisi

RHIC

H-Jet polarimeter

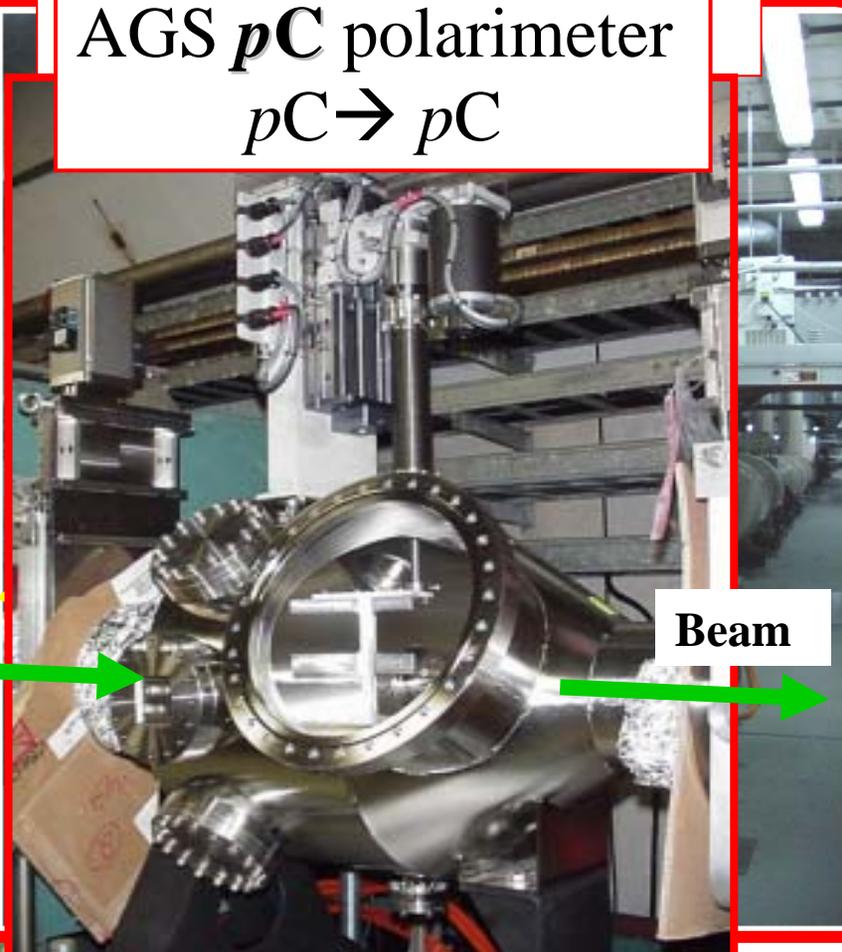
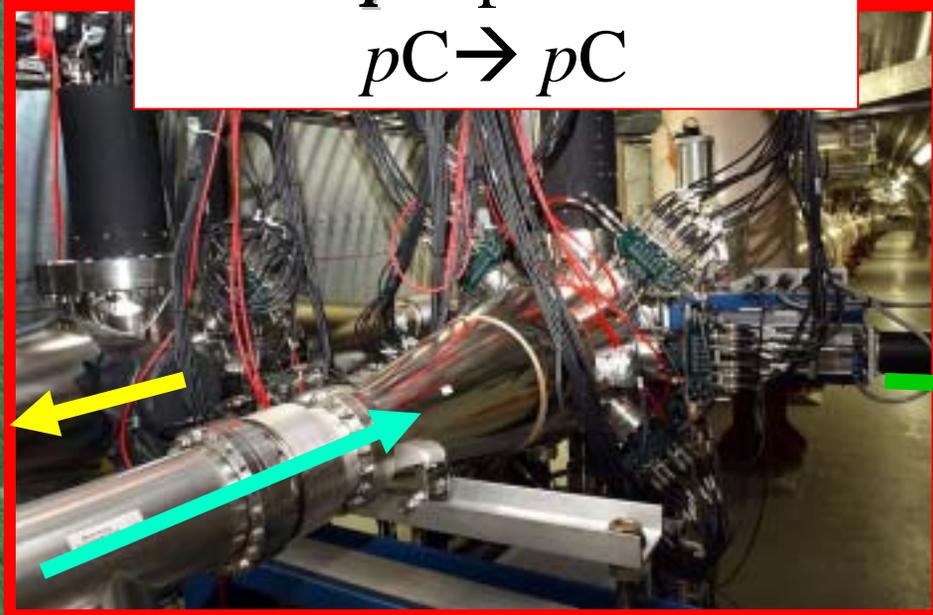
AGS pC polarimeter

$pC \rightarrow pC$

RHIC pC polarimeter

$pC \rightarrow pC$

Beam



Role of two polarimeters at RHIC

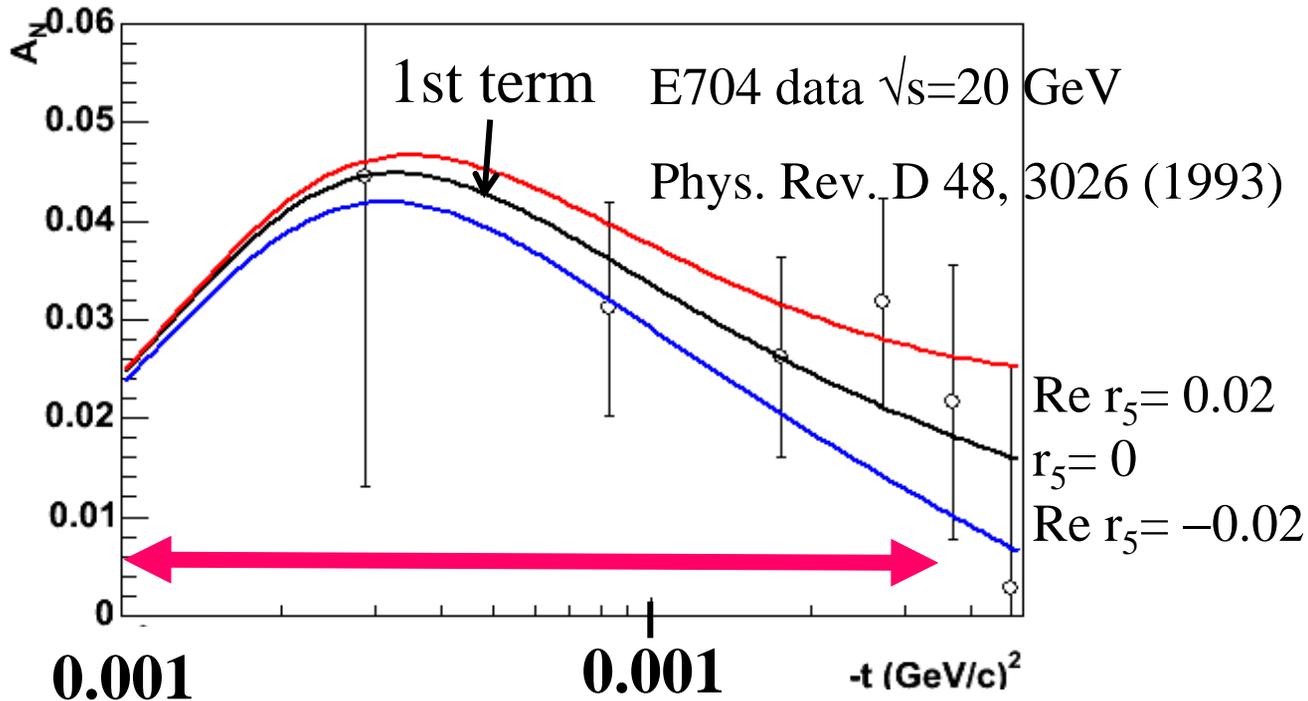
	H-Jet polarimeter	RHIC pC polarimeter
Target	Polarized atomic hydrogen gas jet target	Details of pC pol. are....
Event rate	14 Hz	□ Tuesday 16:00 ~
operation	continuously	□ S. Bazilevsky
A_N	Measured precisely → BRP gives self-calibration	□ B. Morozov
Role	Absolute beam pol. measurement, Calibration for RHIC pC polarimeter	□ Thursday 9:00~ □ I. Nakagawa

Understanding of A_N before 2004

$$A_N \approx \text{Im} \left(\underbrace{\phi_{SF}^{\text{em}} \phi_{NF}^{\text{had}}}_{\text{1st term}} + \underbrace{\phi_{SF}^{\text{had}*} \phi_{NF}^{\text{em}}}_{\text{2nd term}} \right) / \left| \phi_{NF}^{\text{had}} \right|^2$$

The 1st term is expected to be dominant and reach to peak by Schwinger (1946)

- Unpredictable
- Parameterized with r_5

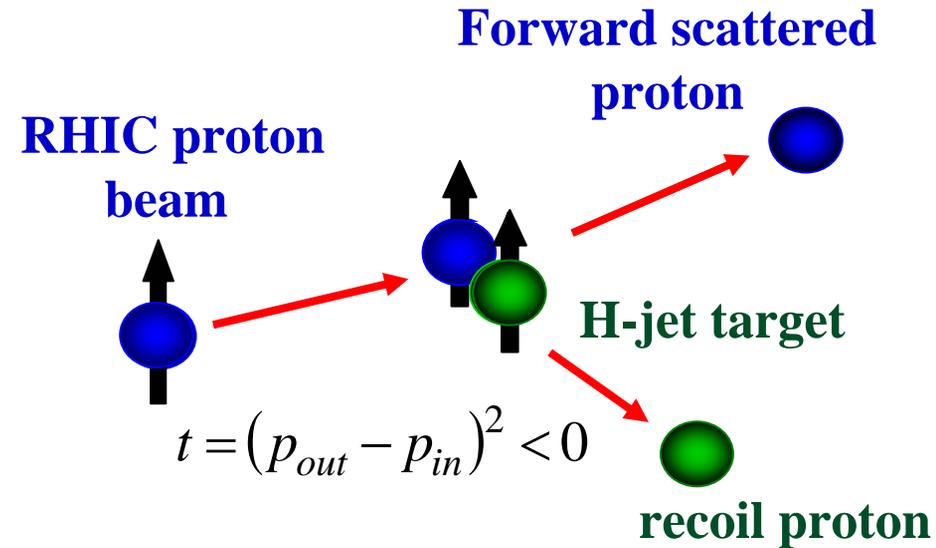


$$\frac{\Delta A_N}{A_N} \gg 0.05$$

Need for precise measurements of A_N in CNI region!!

Method to get absolute beam polarization

- “Absolute” means that measurements A_N by ourselves, Self-calibration!
- Beam and target are both proton, we can switch the role....



Detect the elastic pp process by measuring recoil proton only!

$$A_N(t) = -\frac{\epsilon_{target}}{P_{target}}, \quad (\langle P_{beam} \rangle = 0)$$

$$A_N(t) = \frac{\epsilon_{beam}}{P_{beam}}, \quad (\langle P_{target} \rangle = 0)$$



$$P_{beam} = -P_{target} \frac{\epsilon_{beam}}{\epsilon_{target}}, \quad \frac{\Delta P_{beam}}{P_{beam}} < 5\%$$

P_{target} is given by Breit-rabi Polarimeter

Minimize errors of $\epsilon_{target} / \epsilon_{beam}$ by using the same system !

Polarized hydrogen atomic gas jet target system (H-jet-target system)

Brief history

April 2002

Atomic Beam Source trajectory calculation completed. Magnets ordered.

January 2002

Wisconsin Univ. and BNL design details.

January 2003

Chambers for Jet ordered.

March 2004

H-jet system installed and completed commissioning run successfully!

Very stable 2005, 2006 long runs!

- Polarization
- Size
- Thickness
- Stability

Very rapid assembly sequence by super professional team!

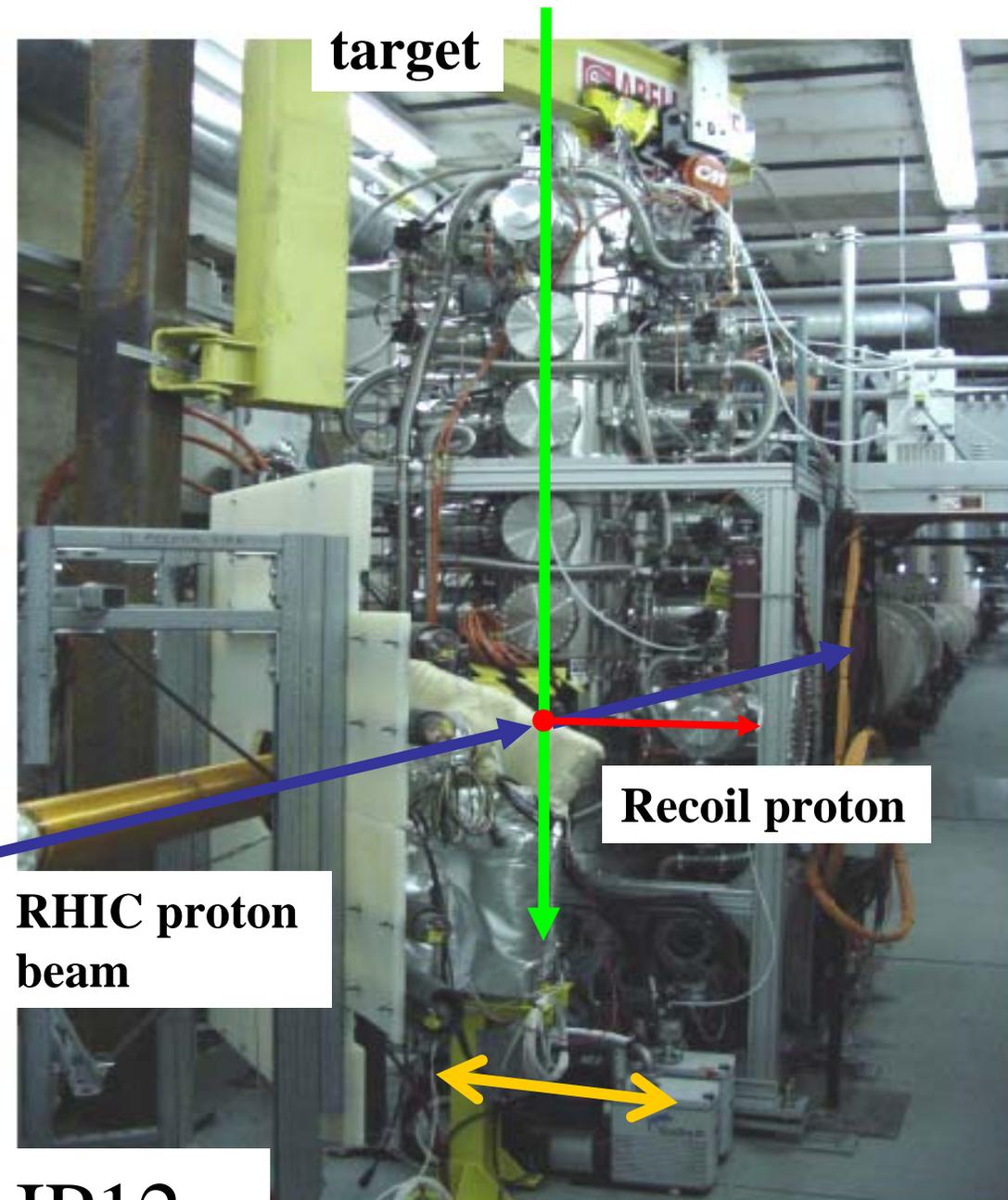
☐ Today 16:00~, Fri. 11:30~

☐ T. Wise

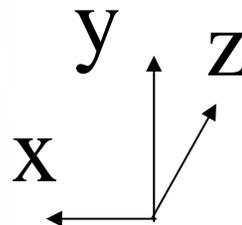
☐ Wednesday 9:00~

☐ W. Haeberli

H-jet-target system

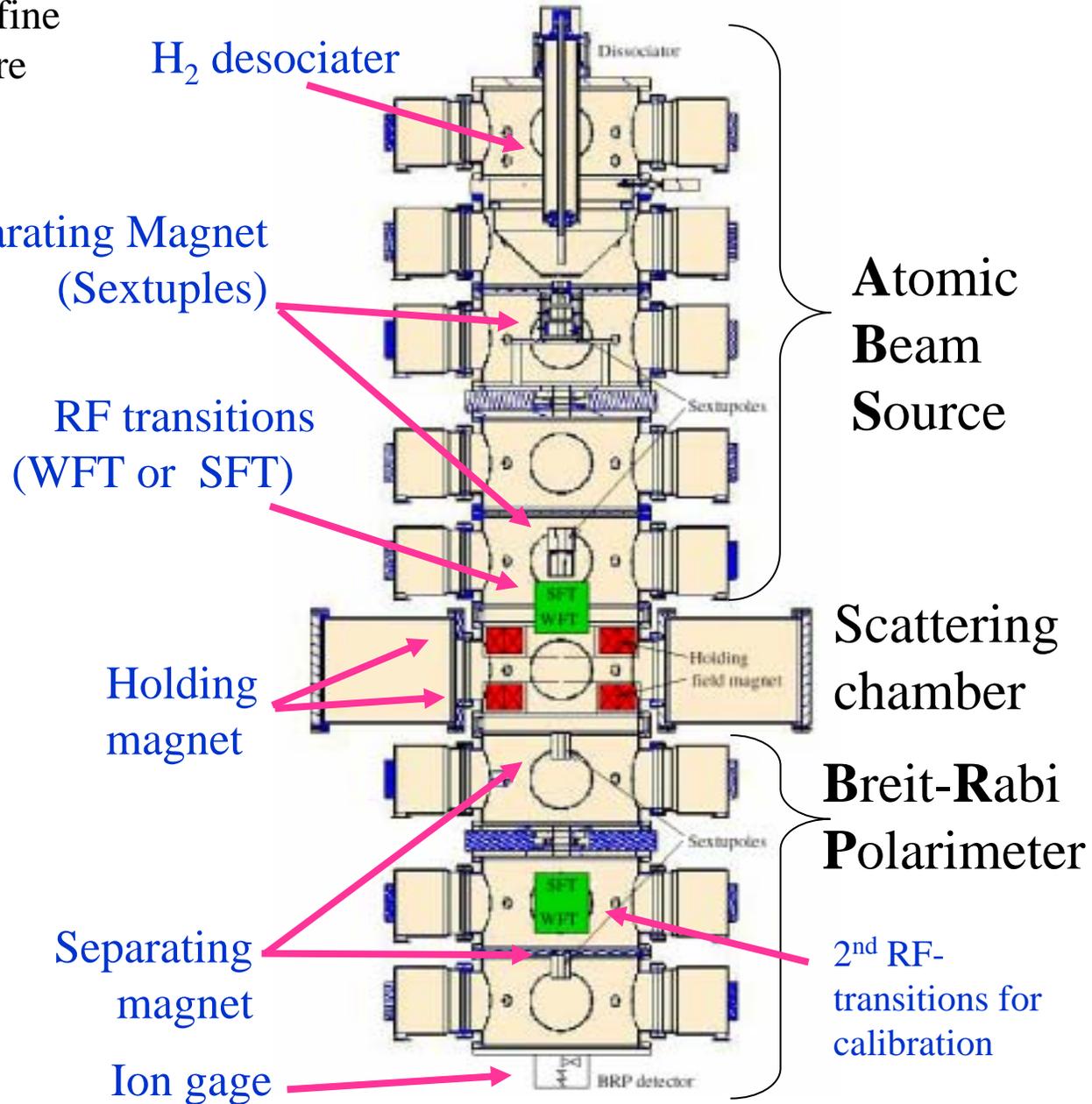
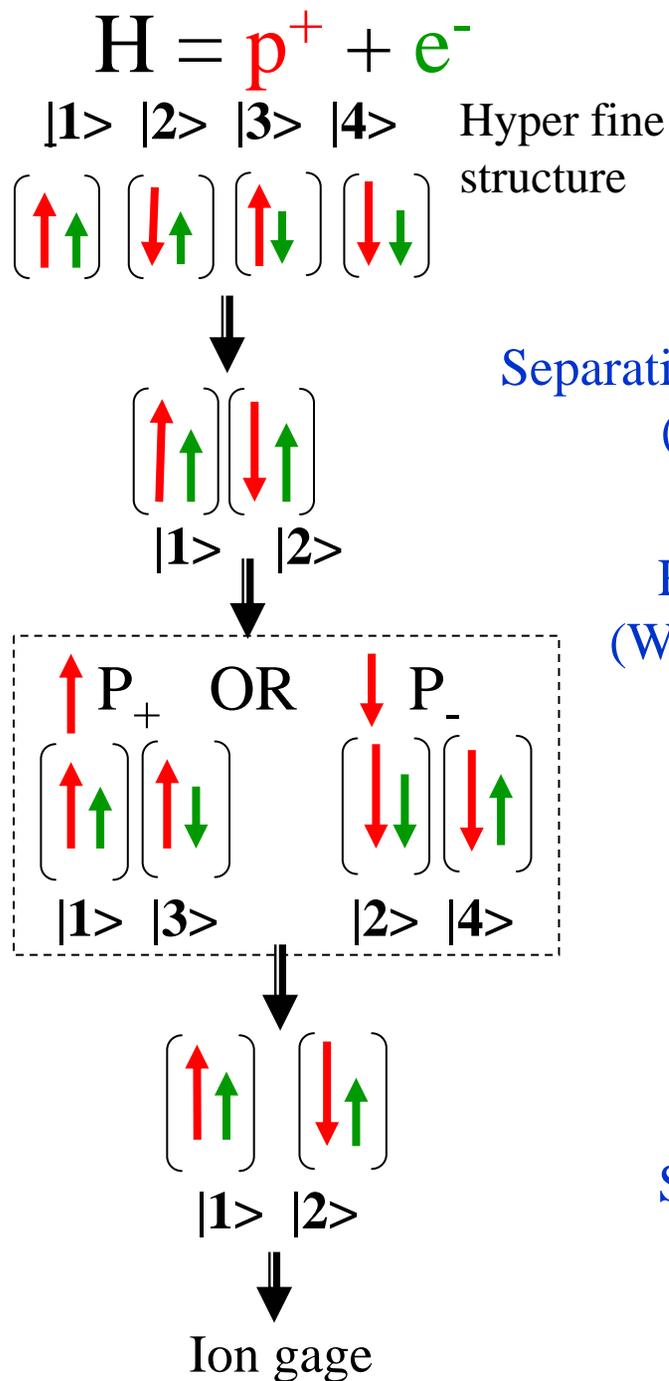


- Height : 3.5 m
- Weight : 3000 kg
- Entire system moves along x-axis $-10 \sim +10$ mm to adjust RHIC beam position.

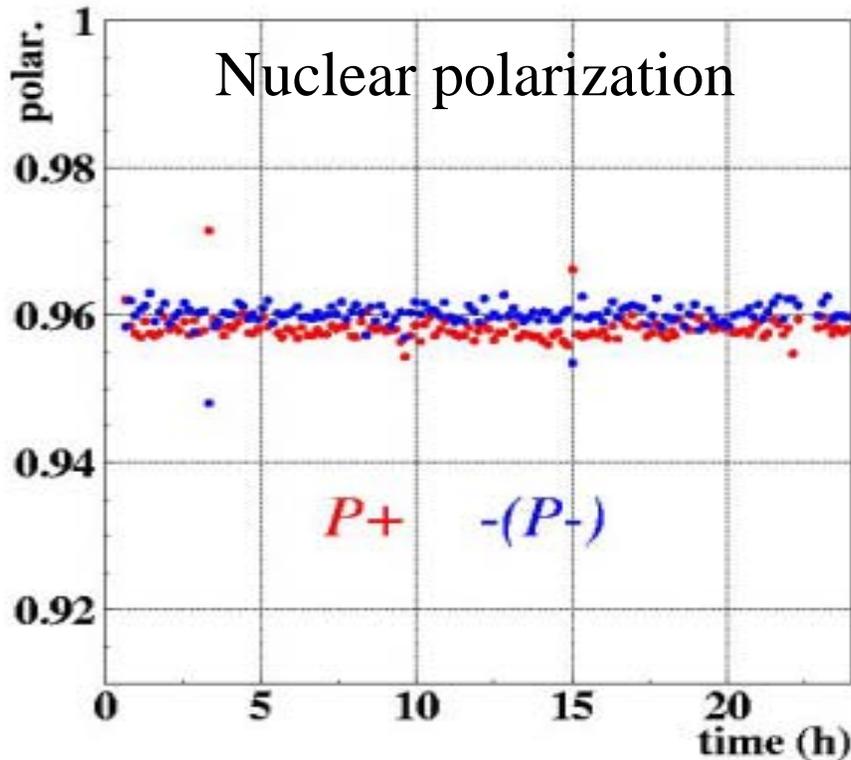


IP12

H-jet-target system



Target polarization



1 day

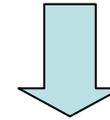
Polarization cycle
(+ / 0 / -) = (500/50/500) seconds

$$\mathbf{P}_{\text{target}} = \mathbf{92.4\% \pm 1.8\%}$$

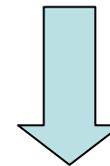
Very stable for entire run period !

$$\frac{\Delta P_{\text{target}}}{P_{\text{target}}} = 2\%$$

Nuclear polarization of the atoms measured by BRP:
 $95.8\% \pm 0.1\%$



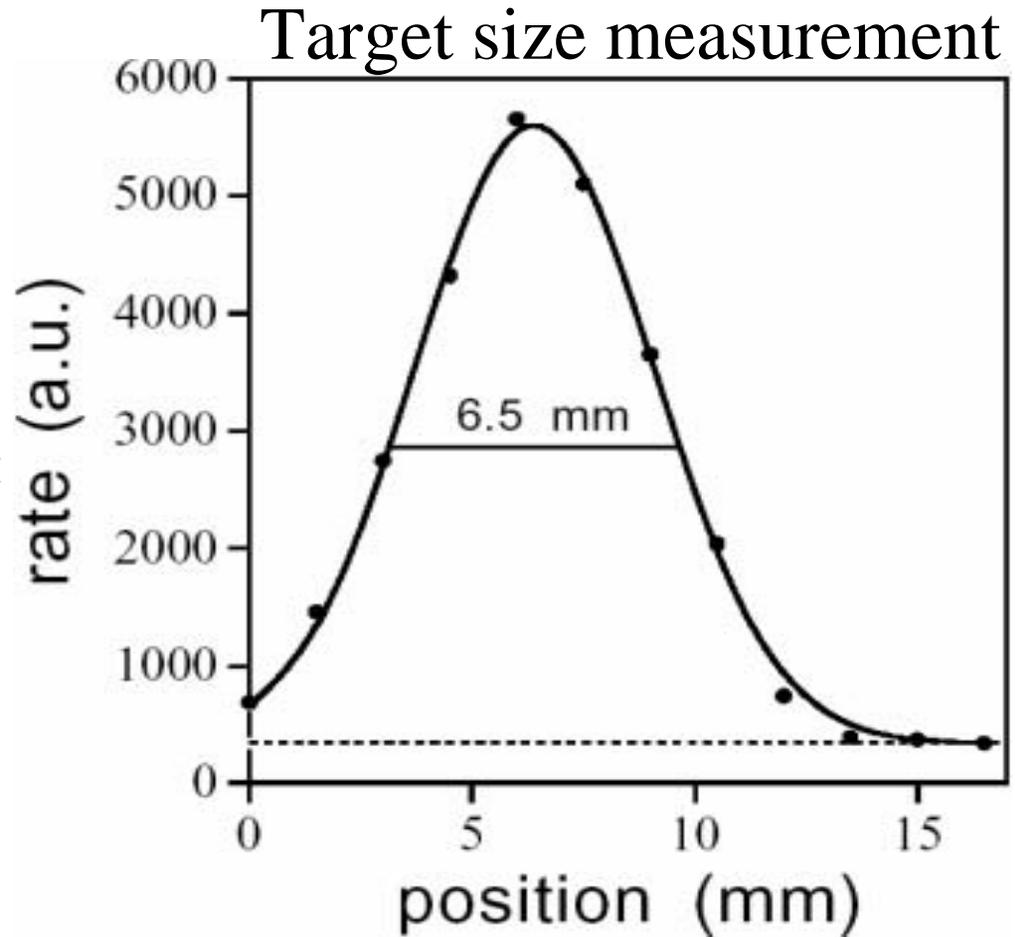
Correct H_2 , H_2O contamination.
Divide with factor 1.037



Performance of H-jet-target system

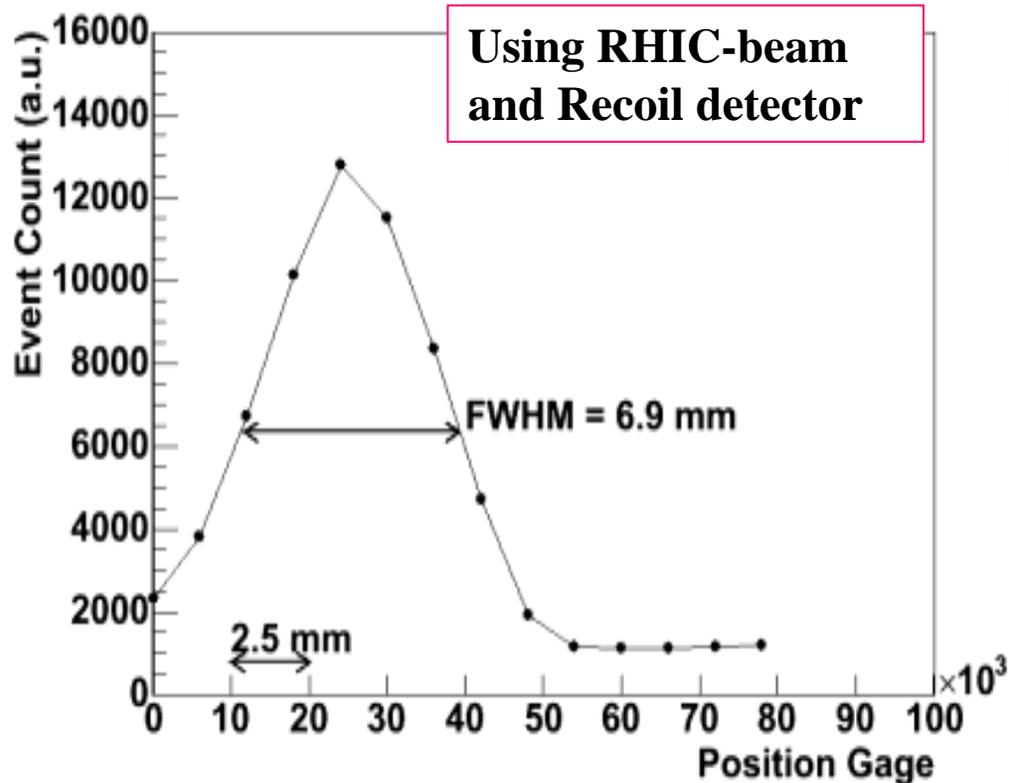
- Target size in collision point
FWHM = 6.5 mm
 - Guarantee required angle
resolution $\Delta\theta < 5$ mrad
- Target thickness along z-axis:
 $(1.3 \pm 0.2) \times 10^{12}$ atoms/cm²

**Achieve designed
values!**

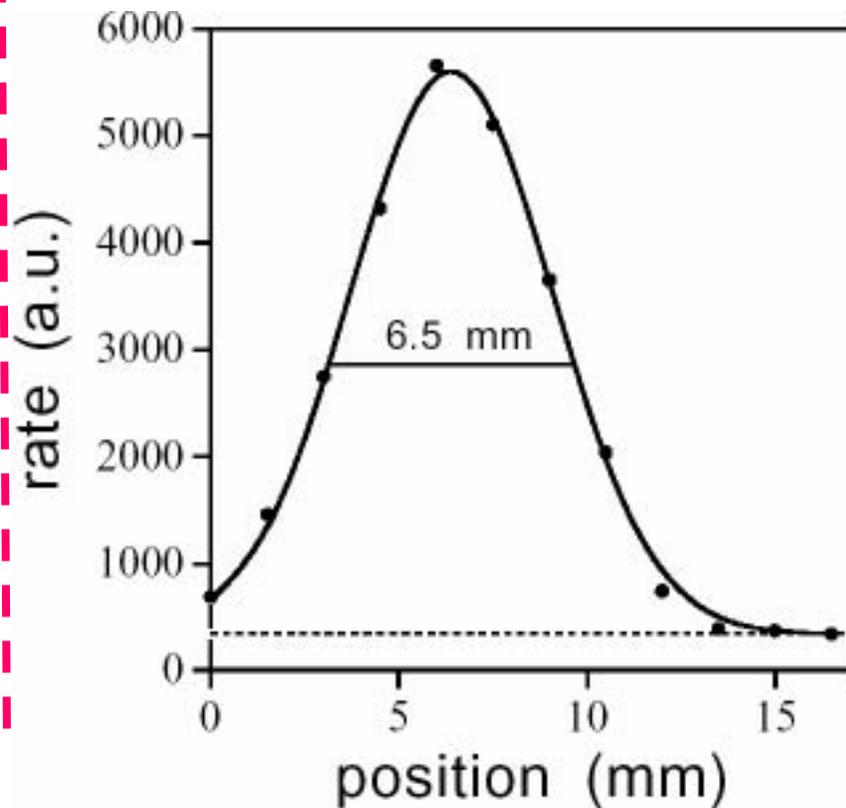


Measurements were done by using 2.0 mm diameter compression tube

Find meeting point and confirm target size using RHIC beam!



Using 2.0 mm diameter compression tube



- Fix RHIC proton beam position (diameter $\sigma \sim 1\text{mm}$).
- Move entire system for every 1.5 mm step
- Find meeting point !

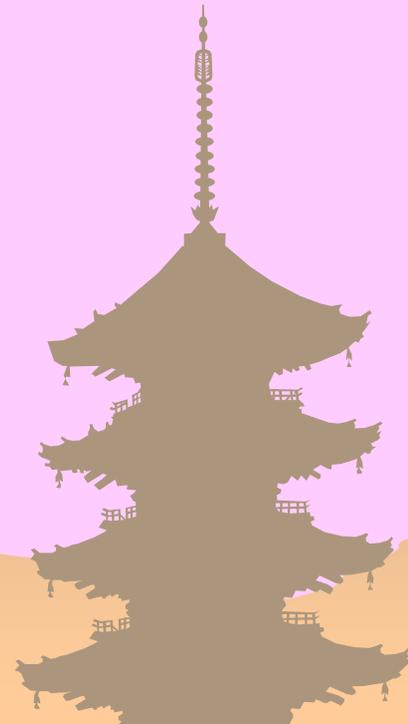
Consistent measurement !

Recoil spectrometer set up

Analysis

1. Recoil proton kinetic energy correction
2. Elastic event selection

Raw asymmetry

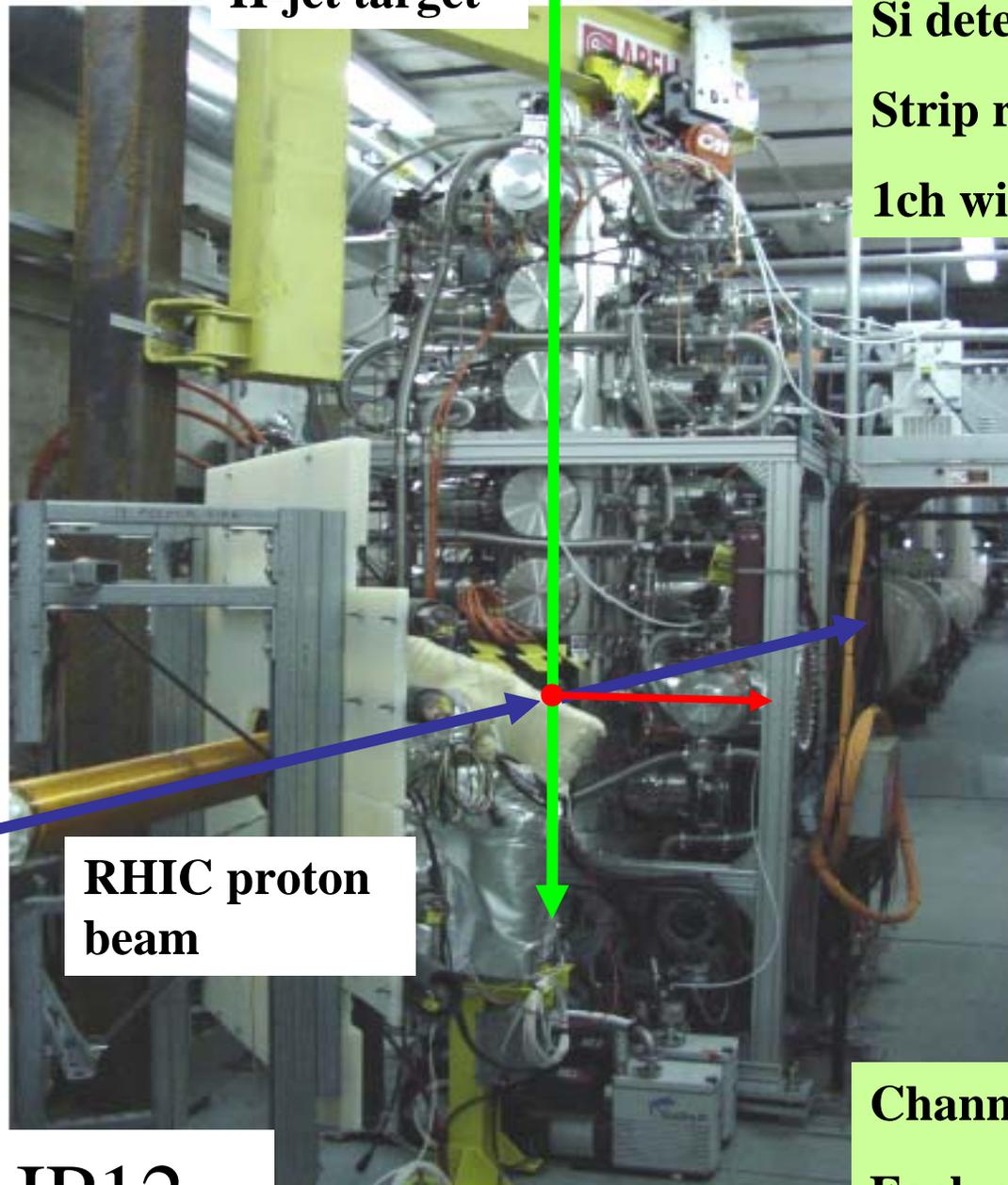


H-jet target

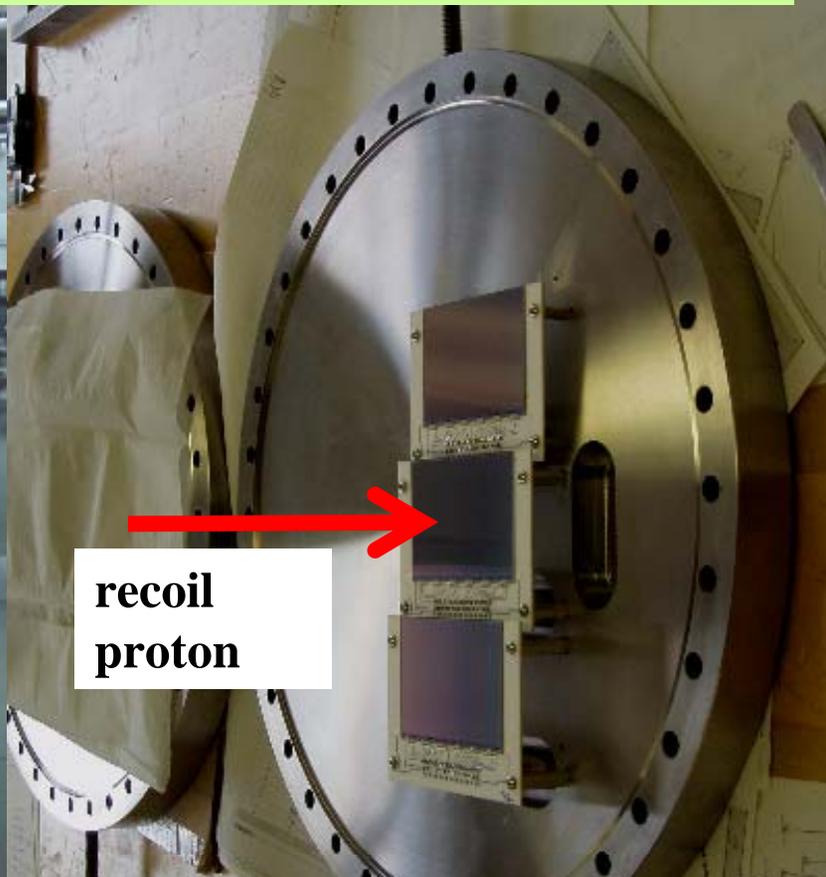
Si detectors (8cm * 5cm)*3* L-R sides

Strip runs vertical with beam

1ch width = 4mm (400strips)



RHIC proton beam



recoil proton

Channel # corresponds to recoil angle

Each channel measures Energy and TOF

IP12

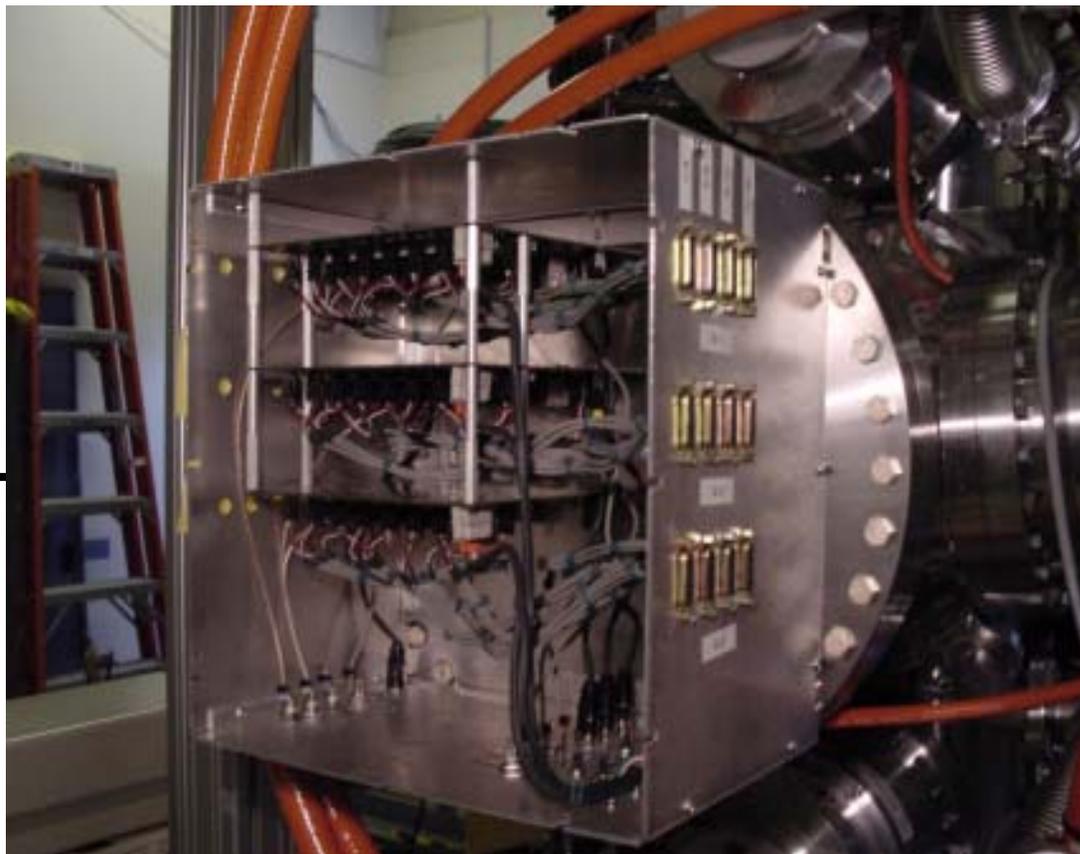
Read out electronics

RHIC-ring, IP12
Recoil spectrometer

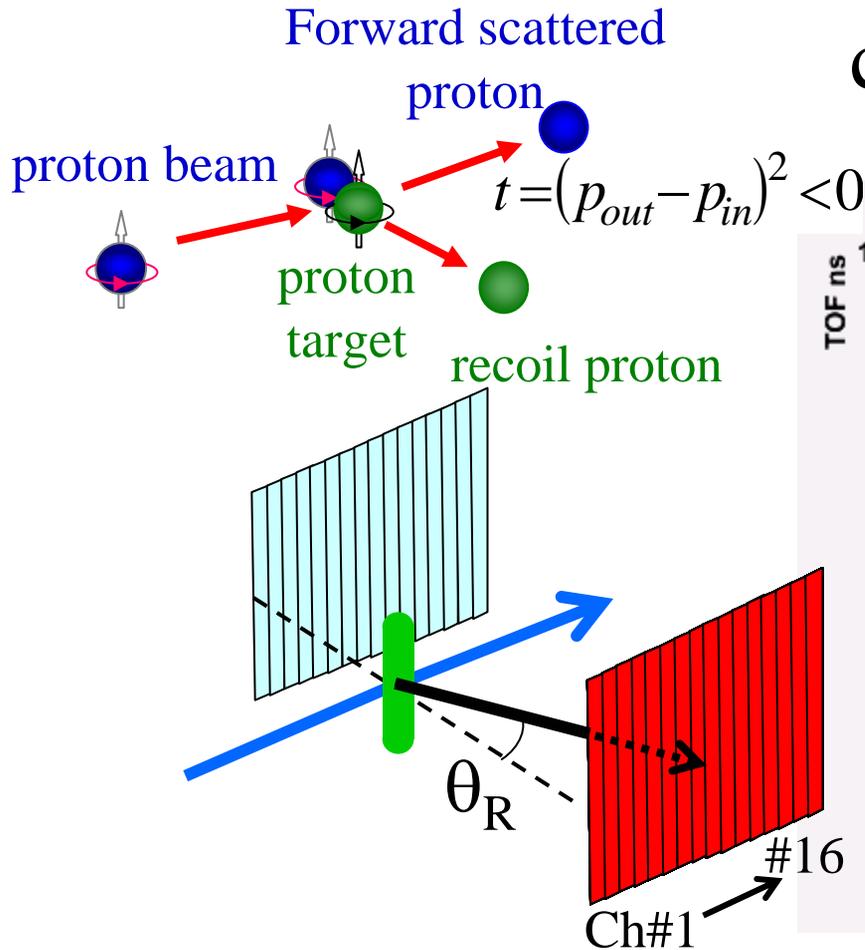
3 left-right pairs Si detectors

- 96 read-out channels
- 96 charge-sensitive preamplifiers

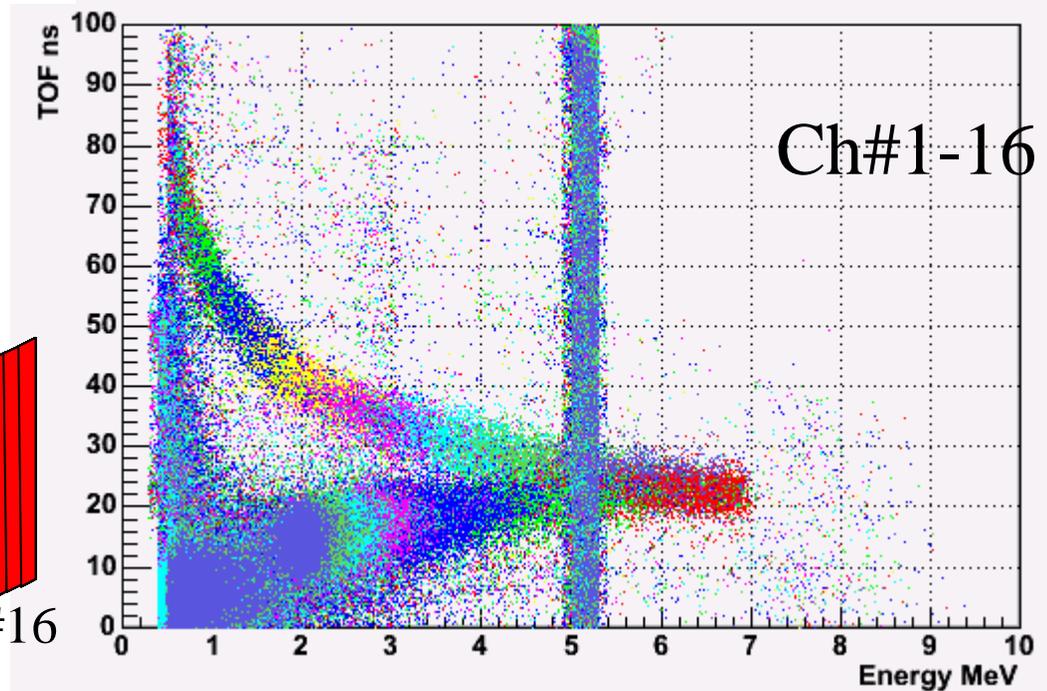
55 m twisted pair
cables (category 5)



What we measure by recoil spectrometer ?



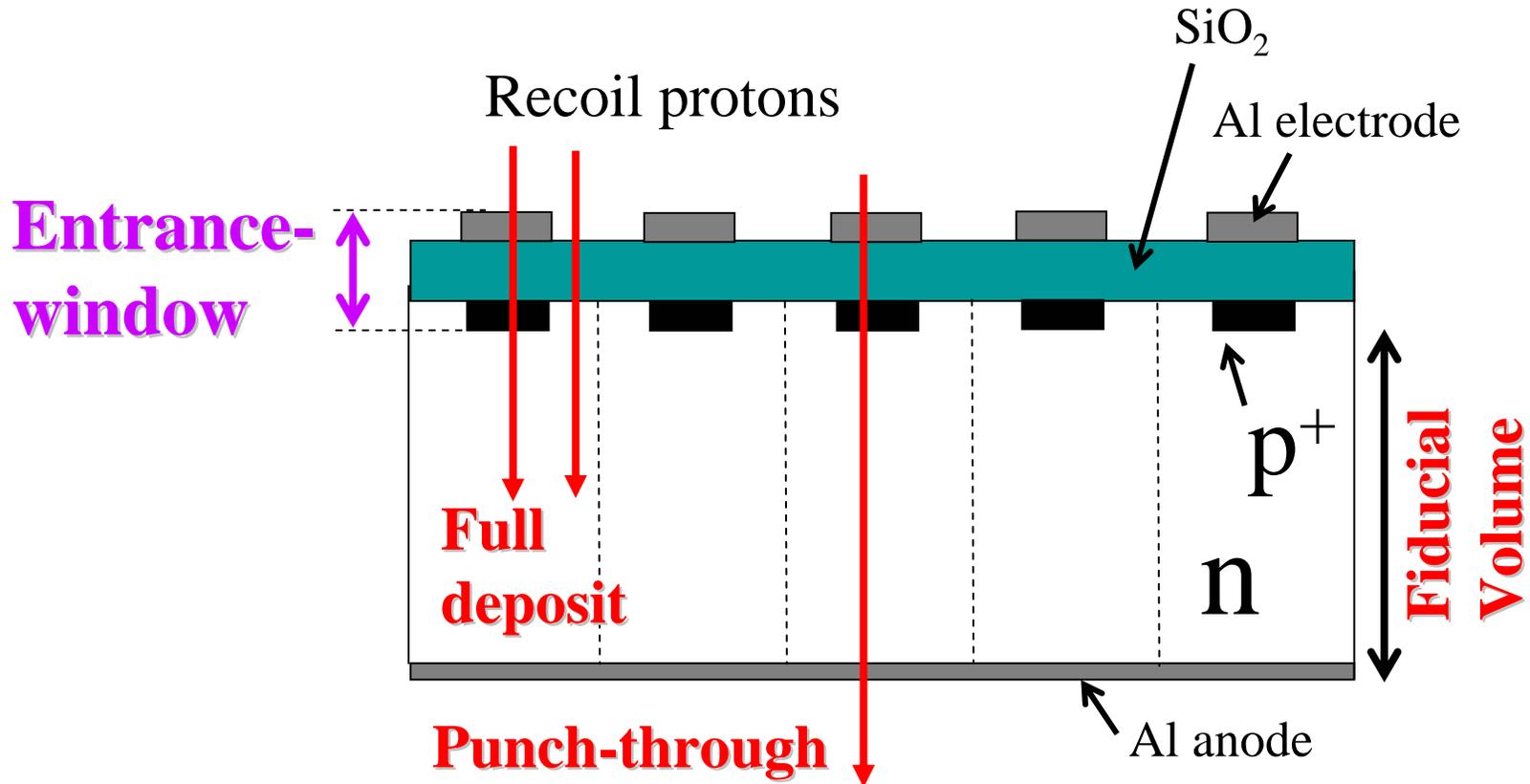
$ch\# \propto \theta_R$, θ_R big $\Rightarrow T_R$ big
 \Rightarrow fast protons



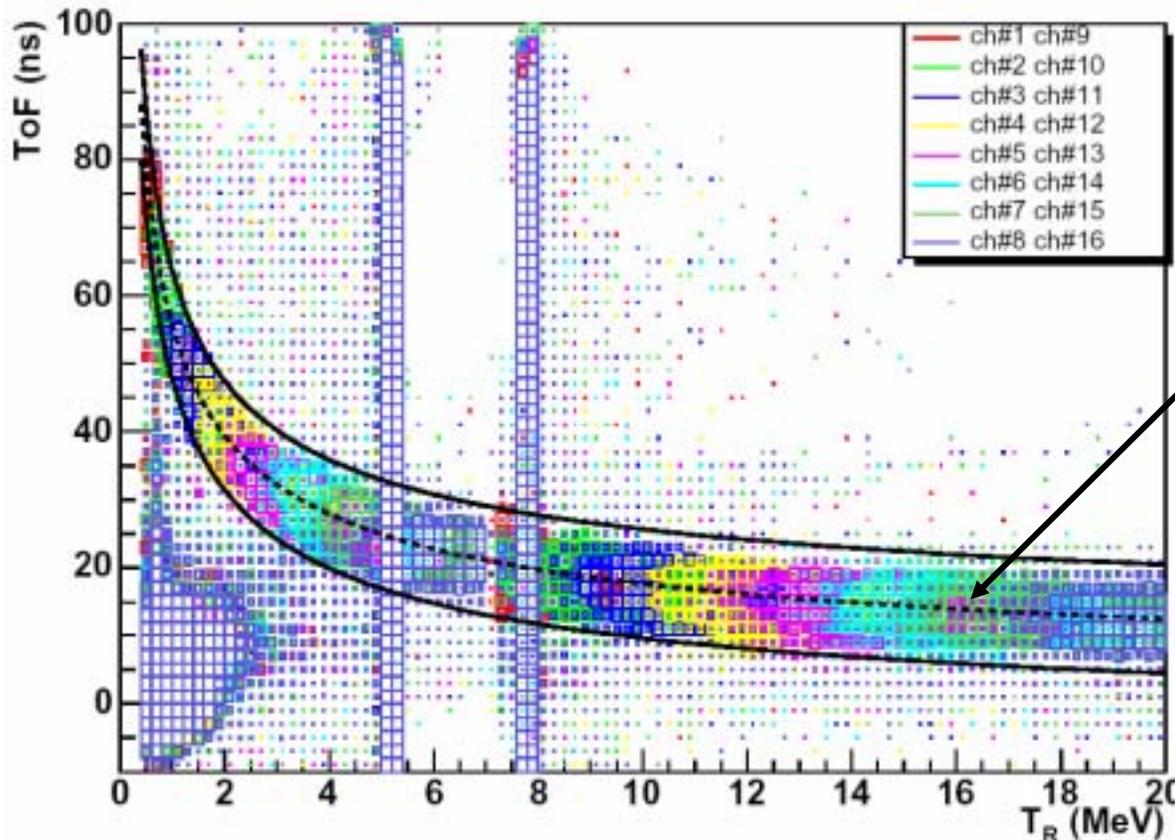
Array of Si detectors measures T_R & **tof** of recoil particles.
Channel # corresponds to recoil angle θ_R .
2 correlations (T_R & **tof**) and (T_R & θ_R) \rightarrow the elastic process

Recoil proton kinetic energy corrections

- ✓ Energy loss correction in the entrance-window for low energy recoil protons: $T_R < 1$ MeV.
- ✓ Punch through correction for high energy recoil protons: $T_R > 7$ MeV.



Elastic event selection (1) recoil proton identification



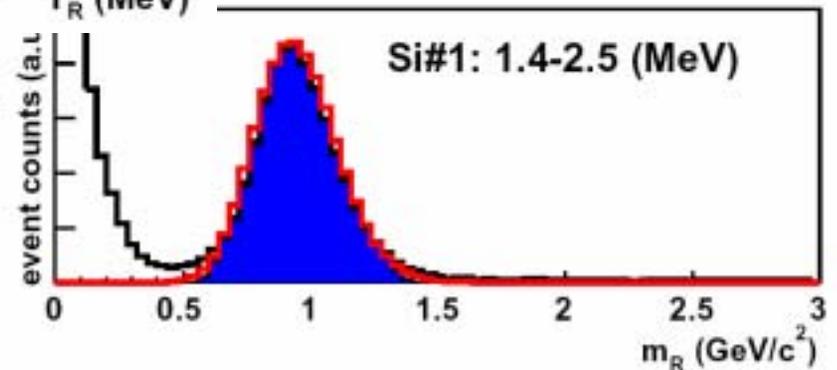
$$ToF_{cal.} \approx L \sqrt{\frac{m_p}{2T_R}}$$

Recoil protons :

$$|ToF_{cal.} - ToF| < 8 \text{ nsec}$$

Blue area: $(ToF \pm 8)$ nsec

Red line: expected spectrum
from ToF and T_R resolutions

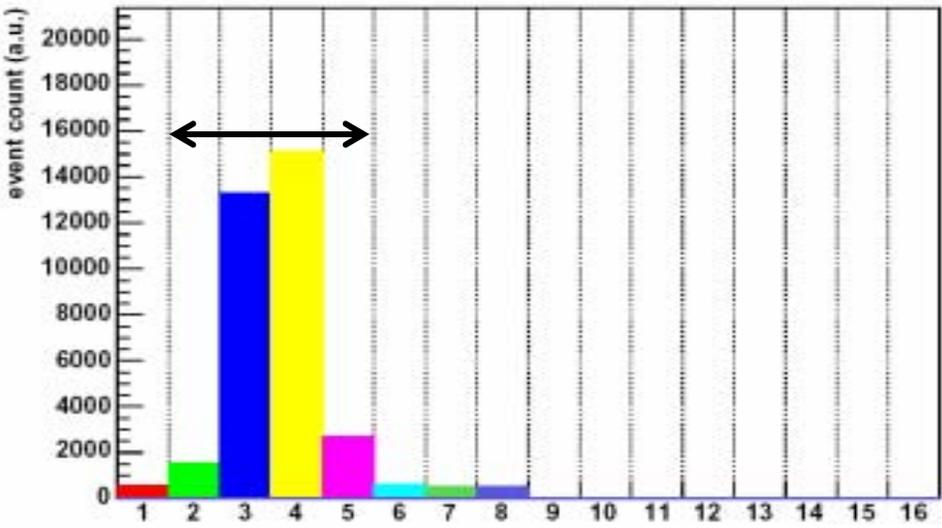
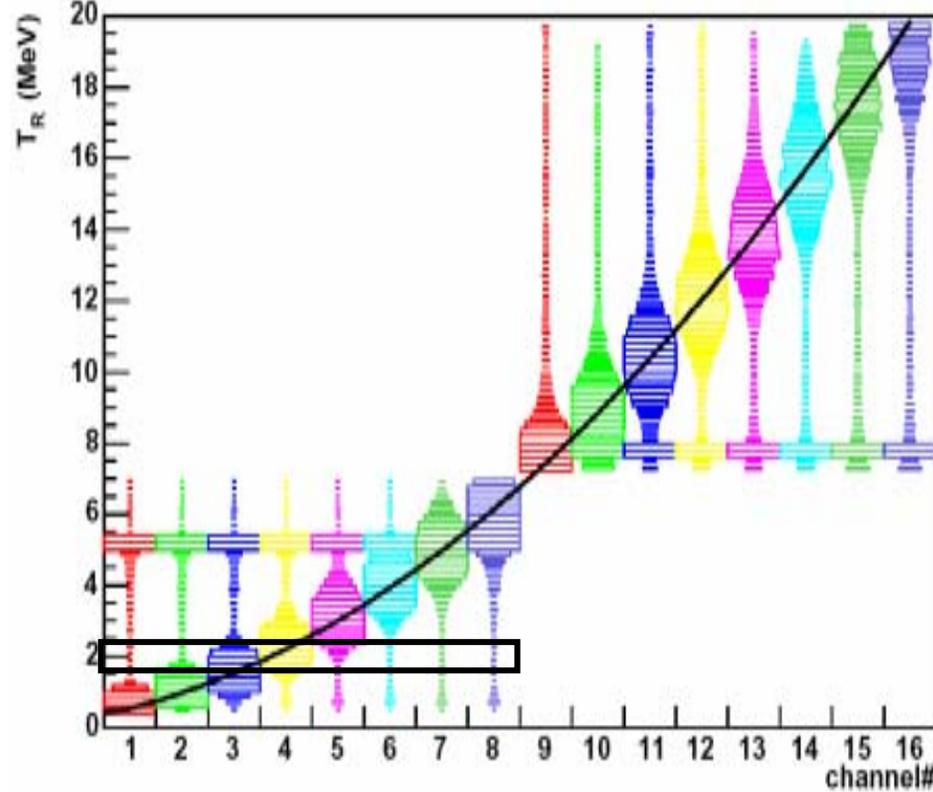


Elastic event selection

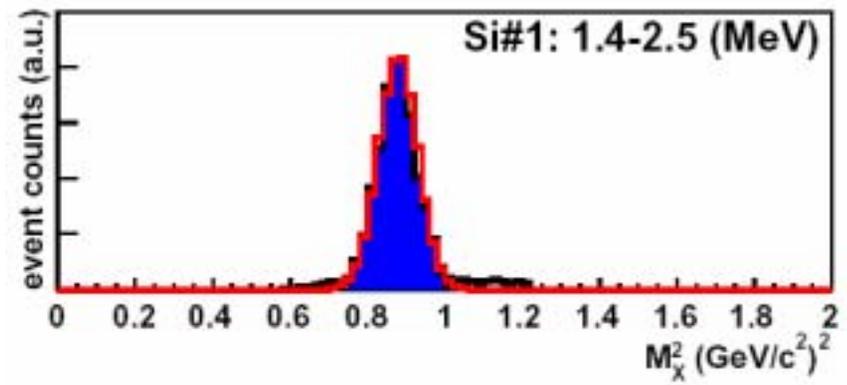
(2) Forward scattered proton identification

$$T_R \approx 2m_p \sin^2 \theta_R \propto (\text{ch\#})^2$$

Select proper 3 ~4 channels for each T_R bin.



Channel#



Blue area: "selected" channels

Red line: Expected spectrum from T_R and θ_R resolutions

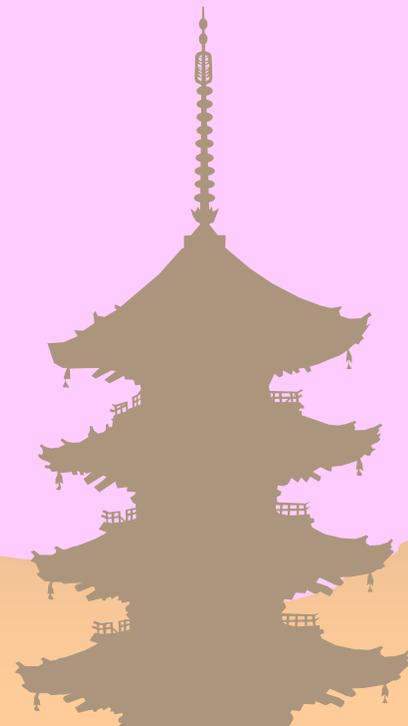
Raw-asymmetry calculation of selected elastic events

- Calculation is done using square-root formula
- $\varepsilon_{\text{target}}$: Based on H-Jet target polarization sign.
(sign changes every 6 minutes)
- $\varepsilon_{\text{beam}}$: Based on beam polarization sign.
(sign changes every bunch)
- Sort with $-t$ ($=2m_p T_R$)
- Apply background correction, R_{BG} : 2~3%
(can vary RHIC-beam condition)

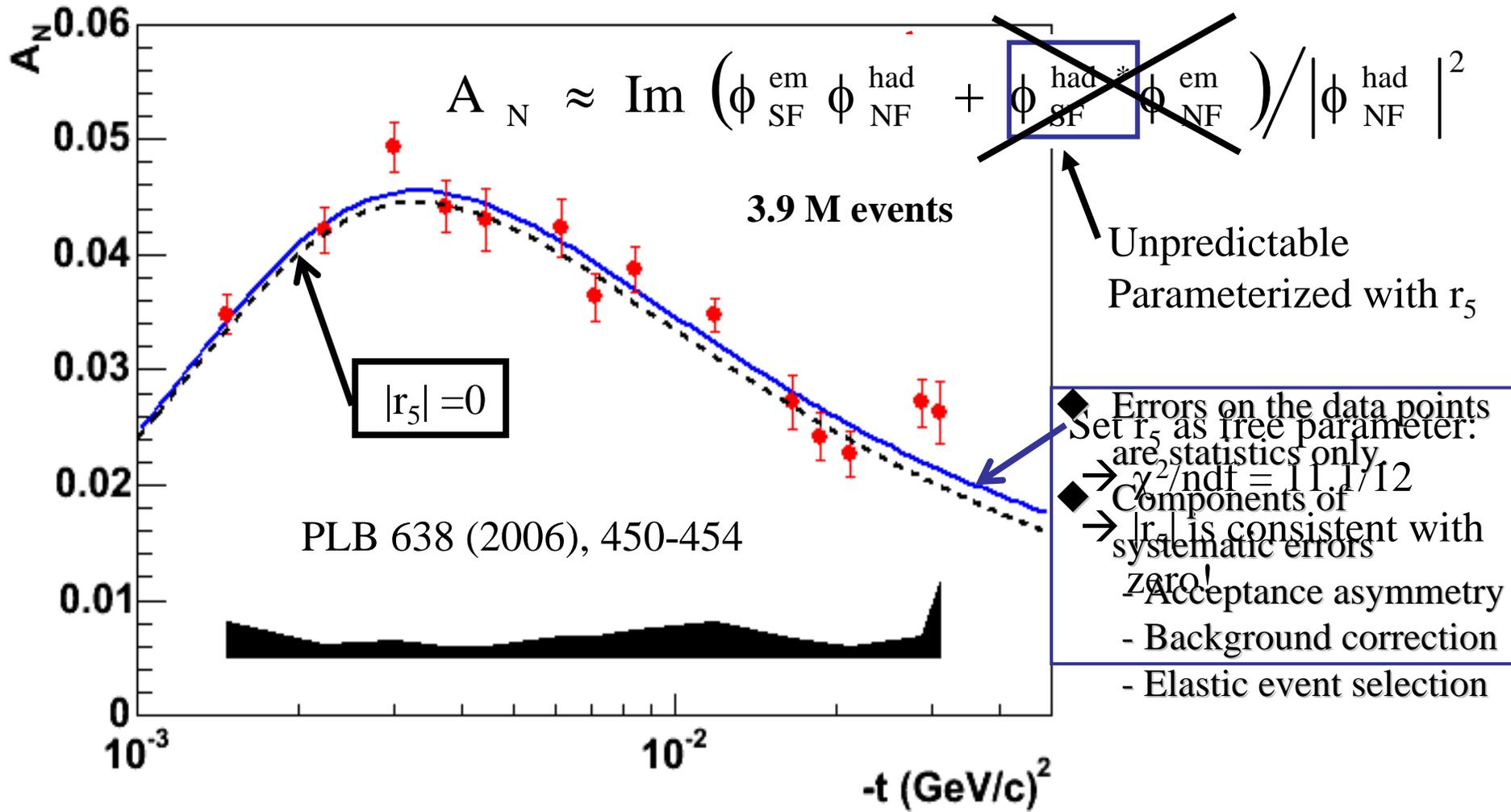
$$\varepsilon = \frac{\sqrt{N_{\uparrow}^{\text{L}}} \sqrt{N_{\downarrow}^{\text{R}}} - \sqrt{N_{\downarrow}^{\text{L}}} \sqrt{N_{\uparrow}^{\text{R}}}}{\sqrt{N_{\uparrow}^{\text{L}}} \sqrt{N_{\downarrow}^{\text{R}}} + \sqrt{N_{\downarrow}^{\text{L}}} \sqrt{N_{\uparrow}^{\text{R}}}}$$

$$A_N = \frac{\varepsilon_{\text{target}}}{P_{\text{target}}} \frac{1}{1 - R_{\text{BG}}}$$

A_N from RUN4

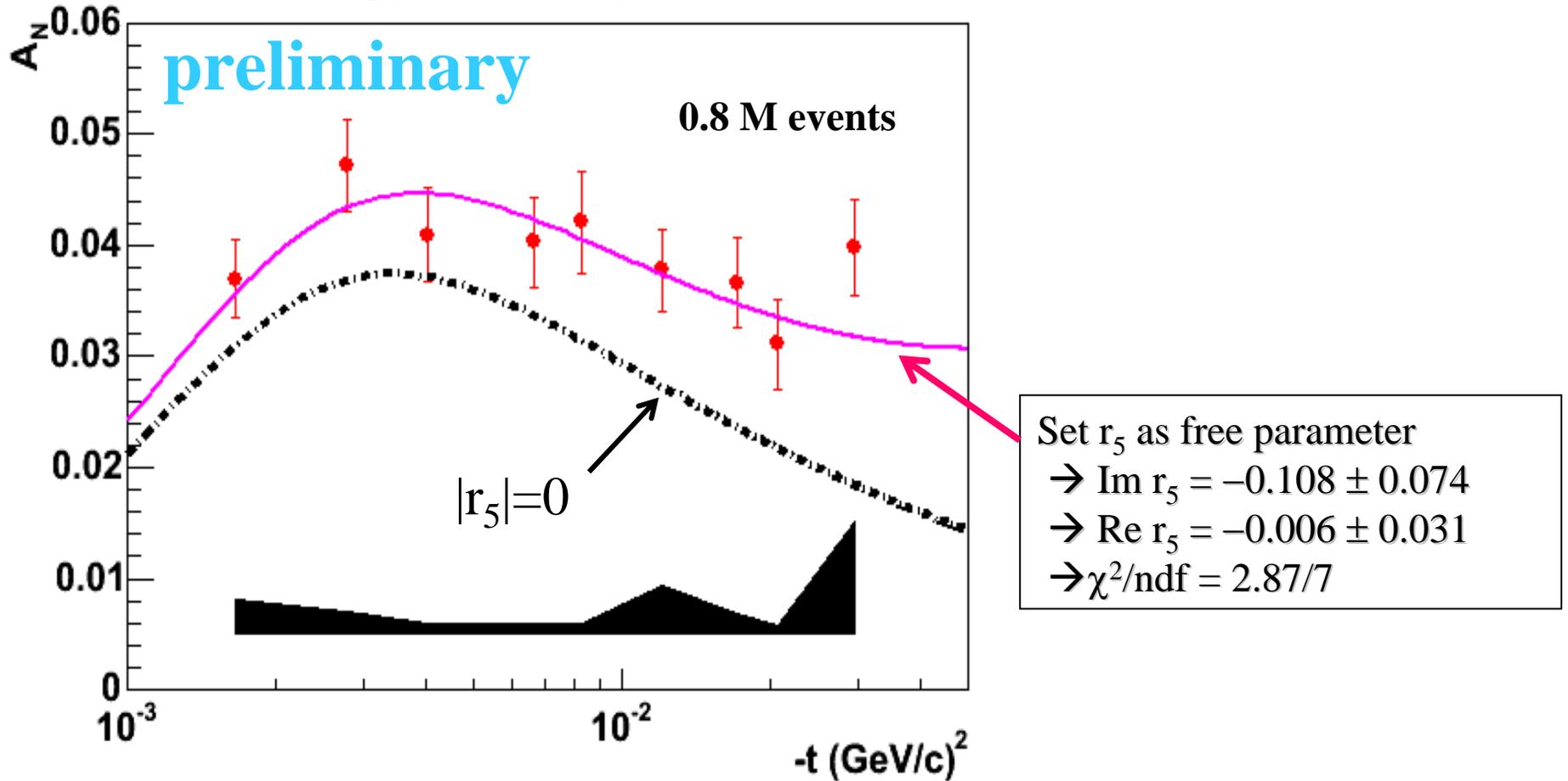


Results of A_N in the CNI region @ 100 GeV/c



- Compare measured A_N and expected curve with $|r_5| = 0 \rightarrow \chi^2/\text{ndf} = 13.4/14$.
- Tool itself has a beautiful SSA and described from first principle QED explanation at 100 GeV/c.

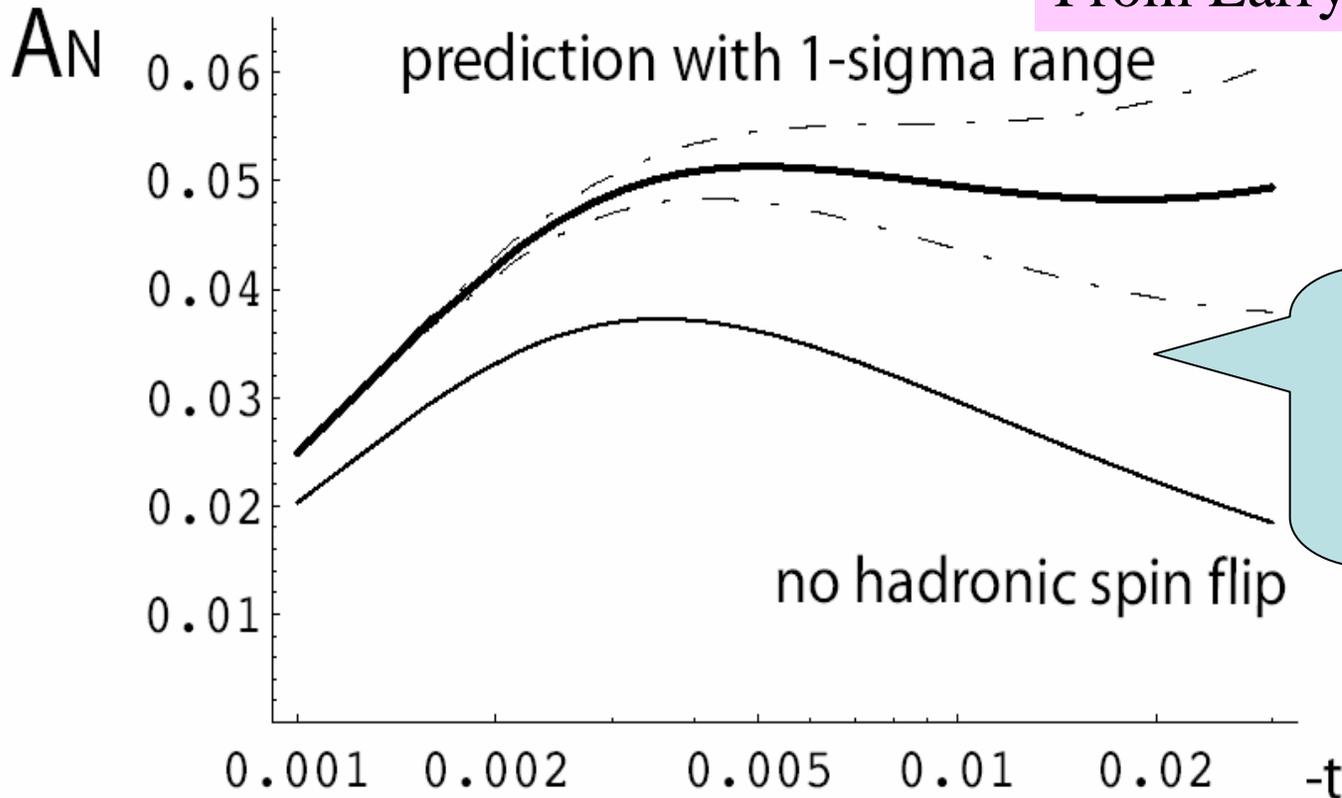
A_N and r_5 results at 24 GeV/c



- ◆ r_5 is not zero at 24 GeV/c ! $\chi^2/\text{ndf} = 35.5/9$
- ◆ r_5 has \sqrt{s} dependence ? → Not improbable; theoretical prediction using A_N^{pC} @24GeV/c, 100GeV/c and A_N @100GeV/c.

Theoretical prediction and data points of 24 GeV/c A_N

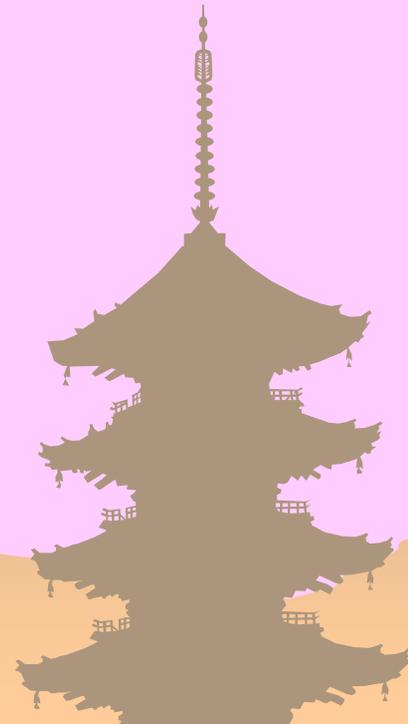
From Larry Trueman (BNL)



A_N^{pC} @ 24GeV/c, 100GeV/c \rightarrow Pomeron

A_N @ 100GeV/c \rightarrow ω , ρ

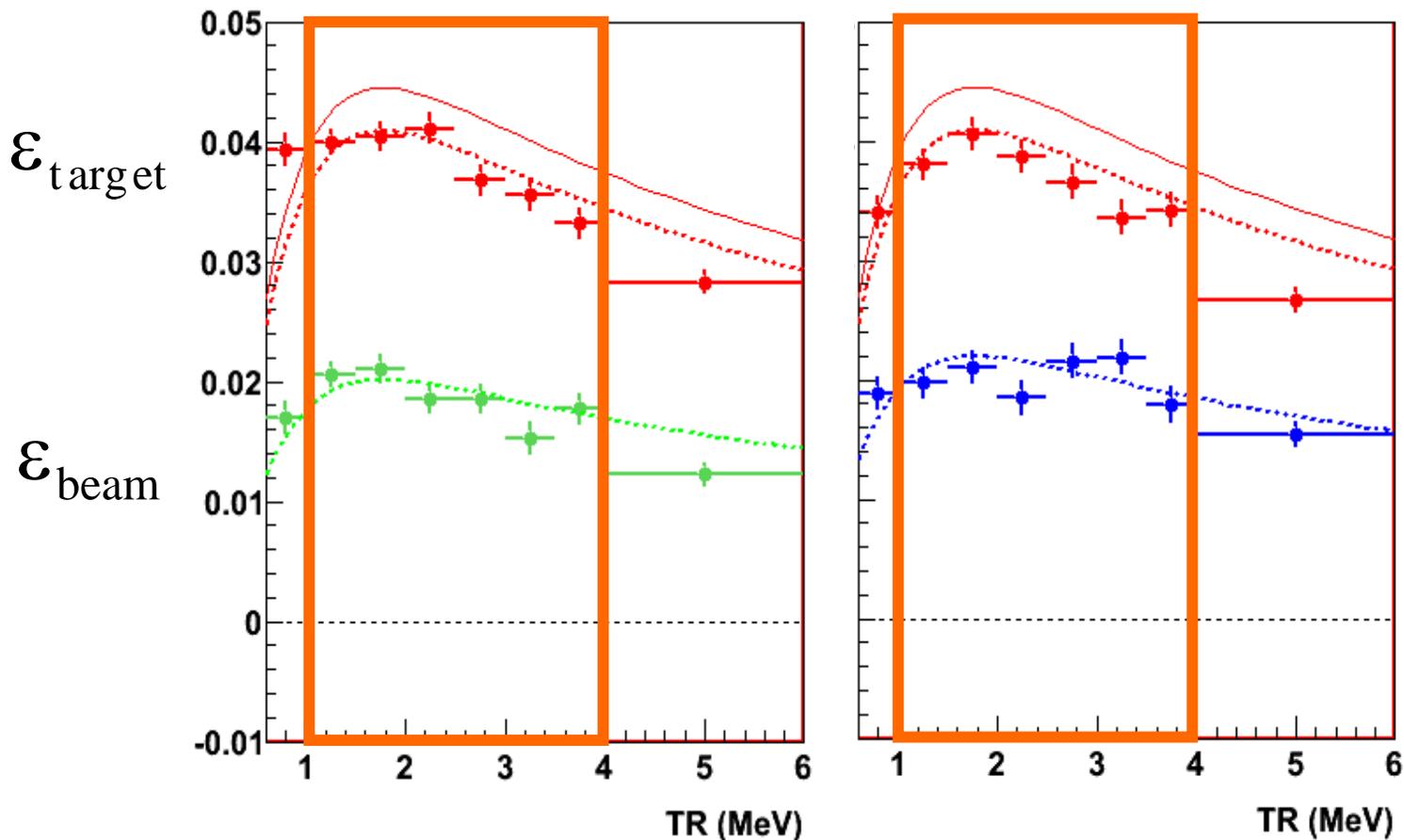
Beam polarization results from RUN5



Raw asymmetries from RUN5

Yellow beam 3.7M events

Blue beam 2.9M events



$$P_{\text{beam}} = \frac{\epsilon_{\text{beam}}}{\epsilon_{\text{target}}} P_{\text{target}}$$

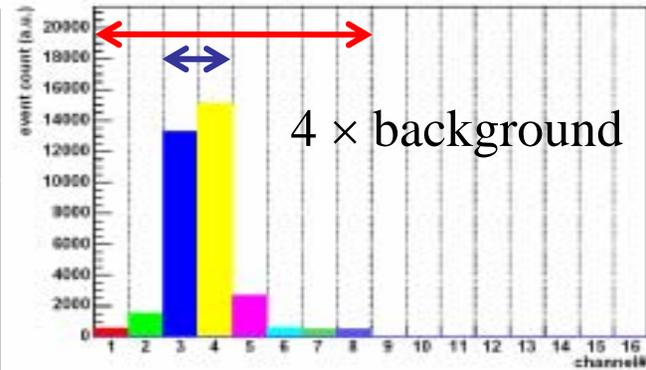
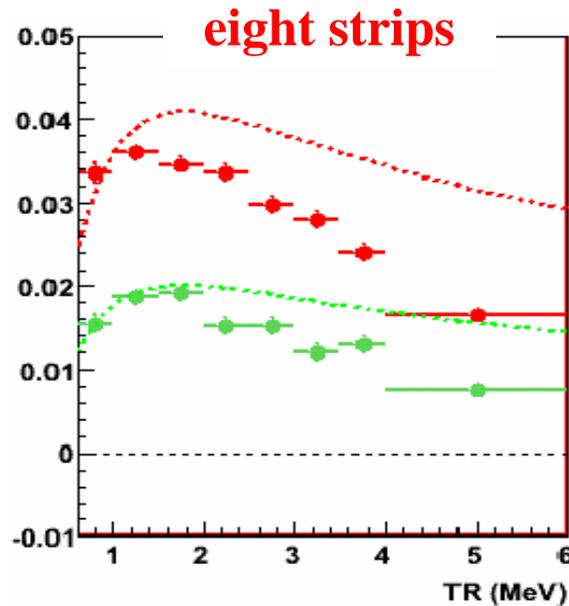
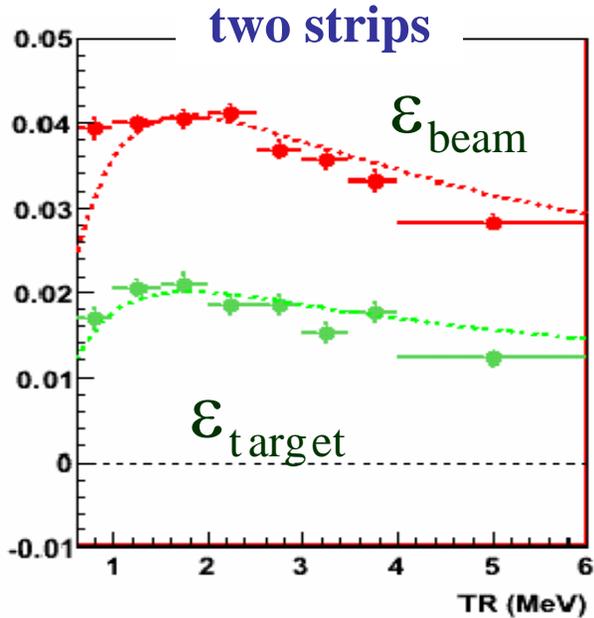
Run5 statistics Yellow: 5.3 M events

Blue: 4.2 M events

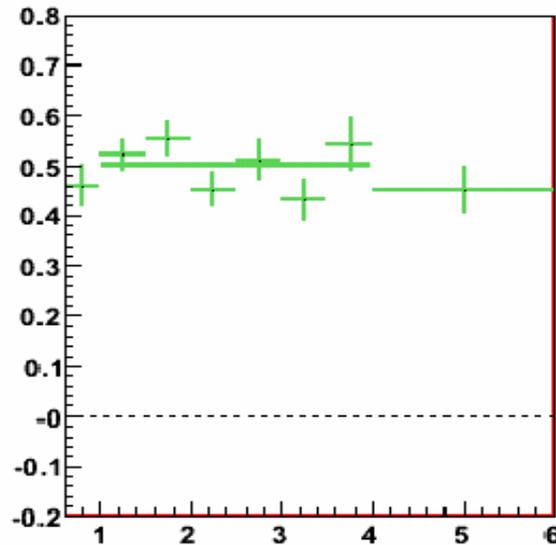
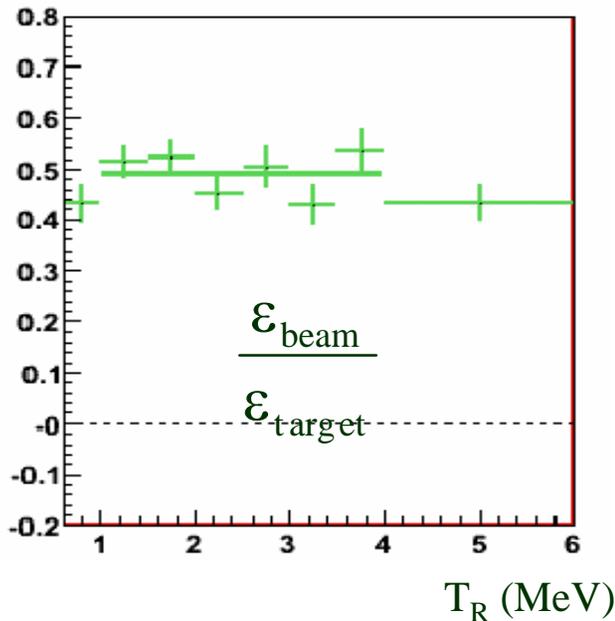
Source of systematic uncertainty

- Total systematic uncertainty : 2.9%
- Background effect: 2.1 %
→ Next slide
 - Unpolarized fraction of Jet-target: 2.0 %
→ H₂, H₂O contamination

Upper limit of systematic uncertainty from background effects



ϵ_{target} , ϵ_{beam} reflect an increase in background.



$\epsilon_{\text{beam}} / \epsilon_{\text{target}}$ is only weakly affected!

Systematic uncertainty from background effects

$$\frac{\Delta P_{\text{beam}}^{\text{BG}}}{P_{\text{beam}}} = 2.1\%$$

RUN5 Absolute beam polarization at RHIC

P(target) = 92.4% ± 1.8%

	stat.	sys.
P(blue beam) = 49.3% ± 1.5% ± 1.4%		
P(yellow beam) = 44.3% ± 1.3% ± 1.3%		

Achieve goal !!

$$\frac{\Delta P(\text{beam})}{P(\text{beam})} = 4.2\%$$

Next step towards the best accuracy

- More data in RUN6 !
 - Yellow: ?? M events, Blue ?? M events
 - Expected statistical uncertainty is ??
- Remaining systematic uncertainty is unpo-sized fraction of H-Jet target.
 - Currently 2%
 - Improvement is ongoing.....



Please Give me numbers !

Pol' H-Jet on CERN COURIER Oct. 2005!

[courierhttp://www.cerncourier.com/main/article/45/8/15](http://www.cerncourier.com/main/article/45/8/15)

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Polarized Protons

H-jet measures beam polarization at RHIC

The RHIC accelerator collides 100 GeV polarized protons head to head to study the contribution of gluons to the proton spin. But how do you know the degree of polarization of the beam? Willy Haeberli explains.

Résumé

Jet de H pour mesurer la polarisation du faisceau au RHIC

L'ensemble d'accélérateurs RHIC de Brookhaven produit des collisions frontales entre des protons polarisés de 100 GeV afin d'étudier le rôle de gluons dans le spin du proton. Mais comment déterminer le degré de

Thank you!

spin-polarized protons to high energies and enables the study of collisions between polarized protons with centre-of-mass energies up to 500 GeV.

