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

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How to measure **absolute** beam polarization ?

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

ε: raw asymmetry

A_N: analyzing power

RHIC Spin Program requires

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

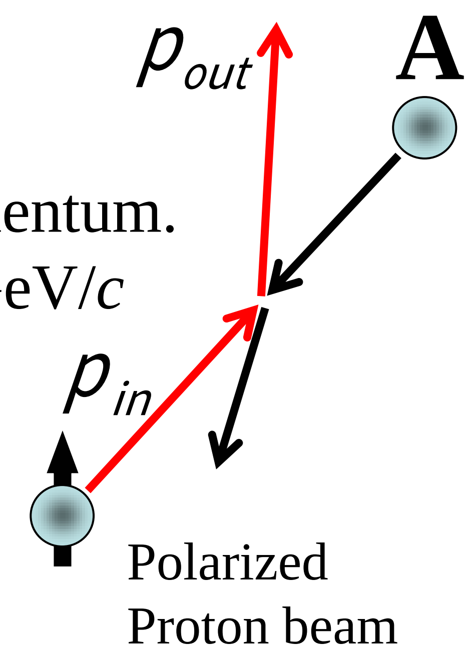
$$\frac{\Delta P_{beam}}{P_{beam}} = \frac{\Delta \varepsilon}{\varepsilon} \oplus \frac{\Delta A_N}{A_N}$$

Statistical issue

Our mission
⇒ 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 momentum.
  - Injection 24GeV/*c*, flattop 100GeV/*c* ~ 250GeV/*c*



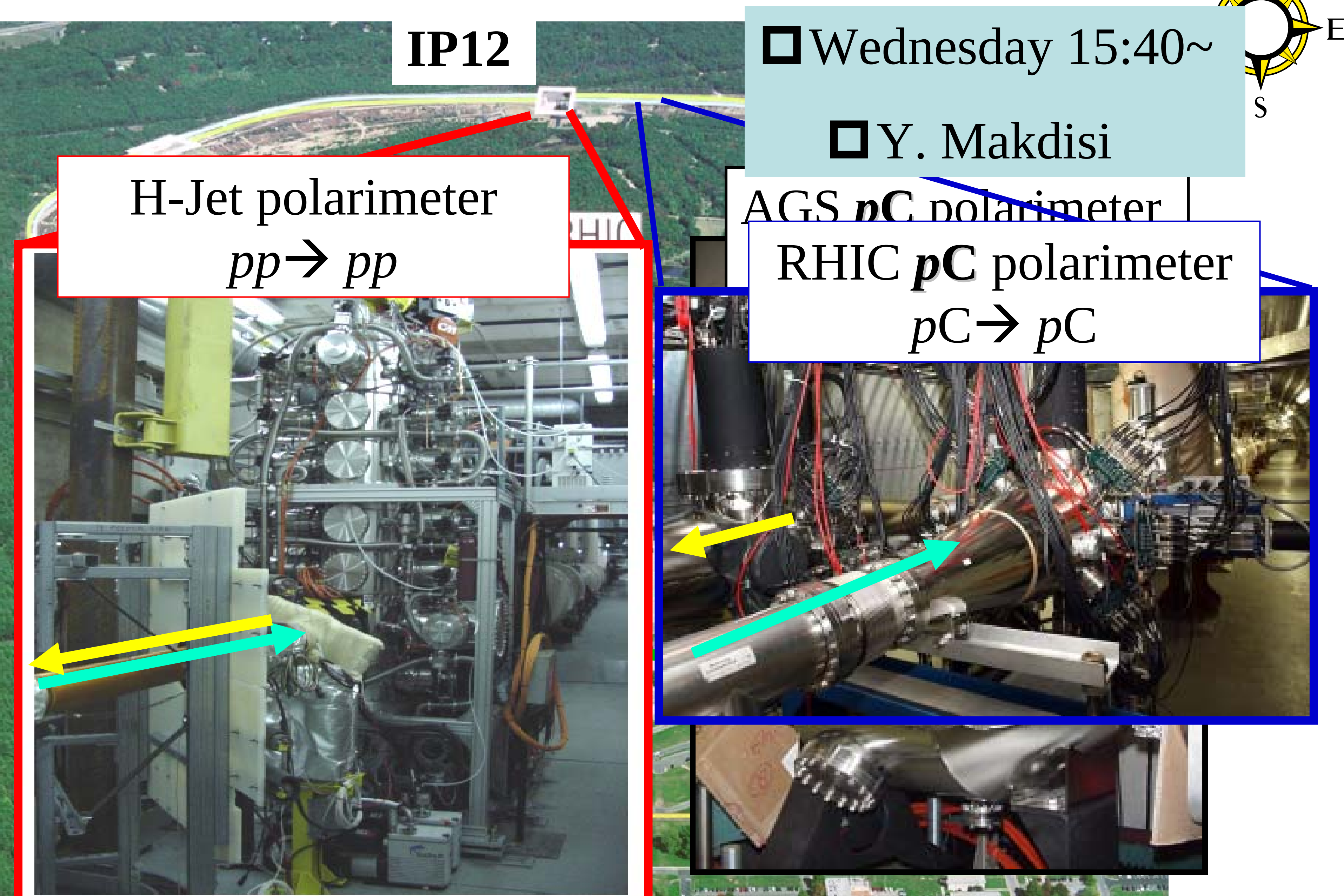
Elastic scattering process $p^{\uparrow}A \rightarrow pA$
in very small -*t* region.
Our case: A is proton or Carbon.

$$t = (p_{out} - p_{in})^2 < 0$$

- In the region of -*t* ~ 10^{-3} (GeV/*c*)^2, coulomb interaction and nuclear interaction become same size and interefere each other $\Rightarrow$ **C**oulomb **N**uclear **I**nterference **(CNI).**

  → A_N is large from QED Prediction.

AGS and RHIC polarimeter complex



Two independent polarimeters in RHIC-ring

	H-Jet polarimeter	RHIC *p*C polarimeter
Target	Polarized atomic hydrogen gas jet target	Ultra thin carbon ribbon
Event rate	14 Hz	2M Hz
operation	continuously	1 minutes every ~2 hours
A_N	Measured precisely → BRP gives P_{target} → self-calibration	Limited accuracy → needs calibration with H-jet polarimeter
Role	Absolute beam pol. measurement, Calibration for RHIC *p*C polarimeter	ONLINE monitor, Fill by Fill beam polarization for experimental groups

Stream of offline analysis

H-jet polarimeter

RHIC *p*C polarimeter

P_{target} from BRP

ε_{target} , ε_{beam}

P_{beam} by H-Jet-polarimeter

A_N of *pp*→ *pp*

1. Confirmation of the system works well.
2. Physics motivation.

Effe

*p*C-

Fill b

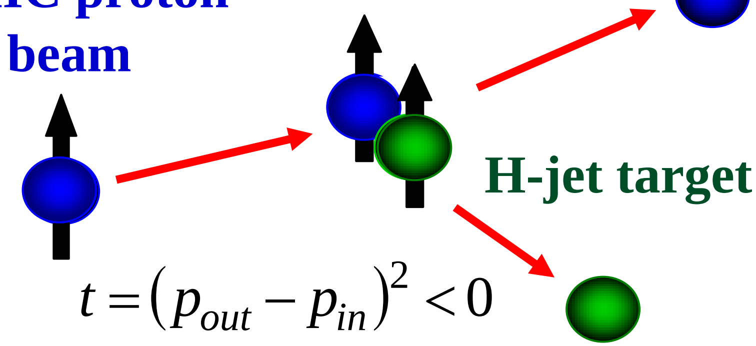
for ex

Details of *p*C pol. are …

- Today 16:00 ~
  - A. Bazilevsky
  - B. Morozov
- Thursday 9:00~
  - I. Nakagawa

Method to get absolute beam polarization

- Beam and target are both proton, A_N should be same.
- P_{target} is measured by BRP precisely.



$$t = (p_{out} - p_{in})^2 < 0$$

$$A_N(t) = -\frac{\varepsilon_{target}}{P_{target}} = \frac{\varepsilon_{beam}}{P_{beam}}$$

$$\Rightarrow \quad P_{beam} = -P_{target}\frac{\varepsilon_{beam}}{\varepsilon_{target}}$$

$$\frac{\Delta P_{beam}}{P_{beam}} \approx \frac{\Delta P_{target}}{P_{target}} < 5\%$$

- **Minimize systematic uncertainty by using the same system !**
- **Confirming A_N is same for every year, we believe our system works properly.**

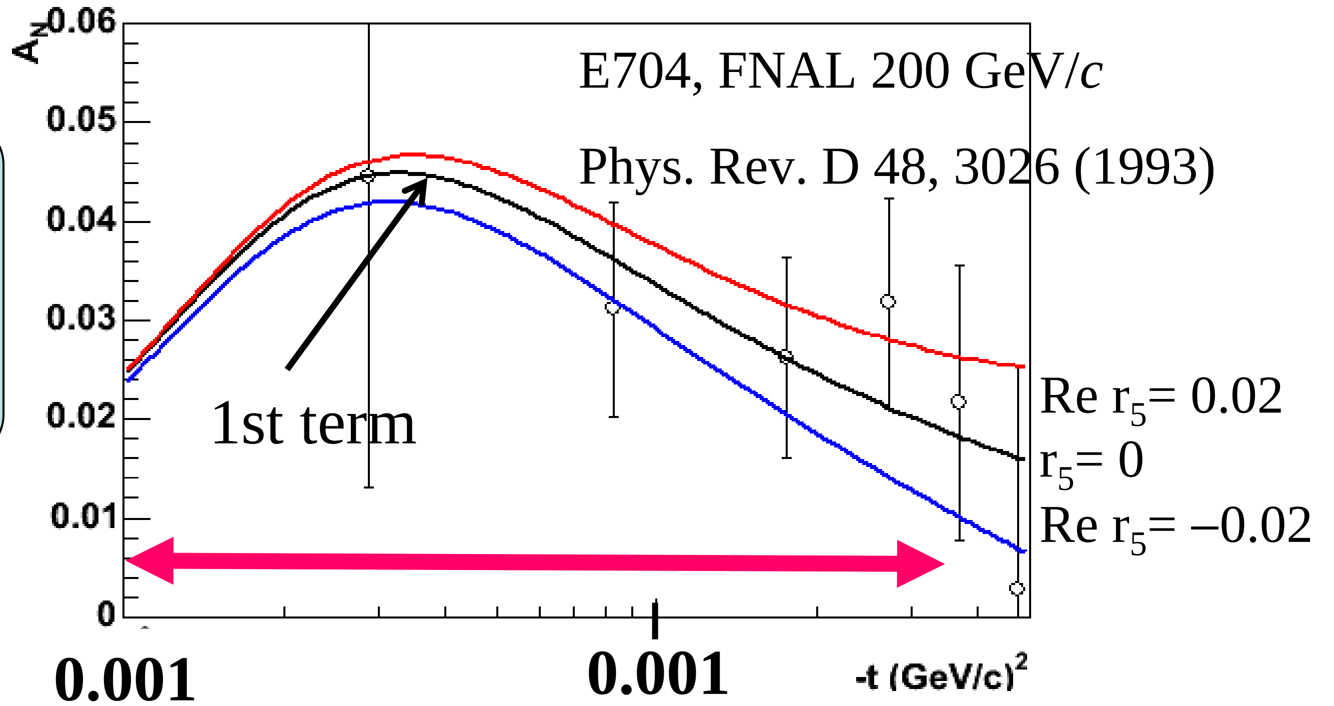
Understanding of A_N before 2004

$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\phi_{NF}^{had} + \phi_{SF}^{had*}\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$

Expect to be dominant and calculable.

- Unpredictable
- Parameterized with r_5

Spin-orbit interaction from the motion of the neutron magnetic moment in the nuclear-coulomb field (Schwinger 1948)



$$\frac{\Delta A_N}{A_N} >> 5\%$$

Physics motivation: Precise A_N data in CNI region

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!

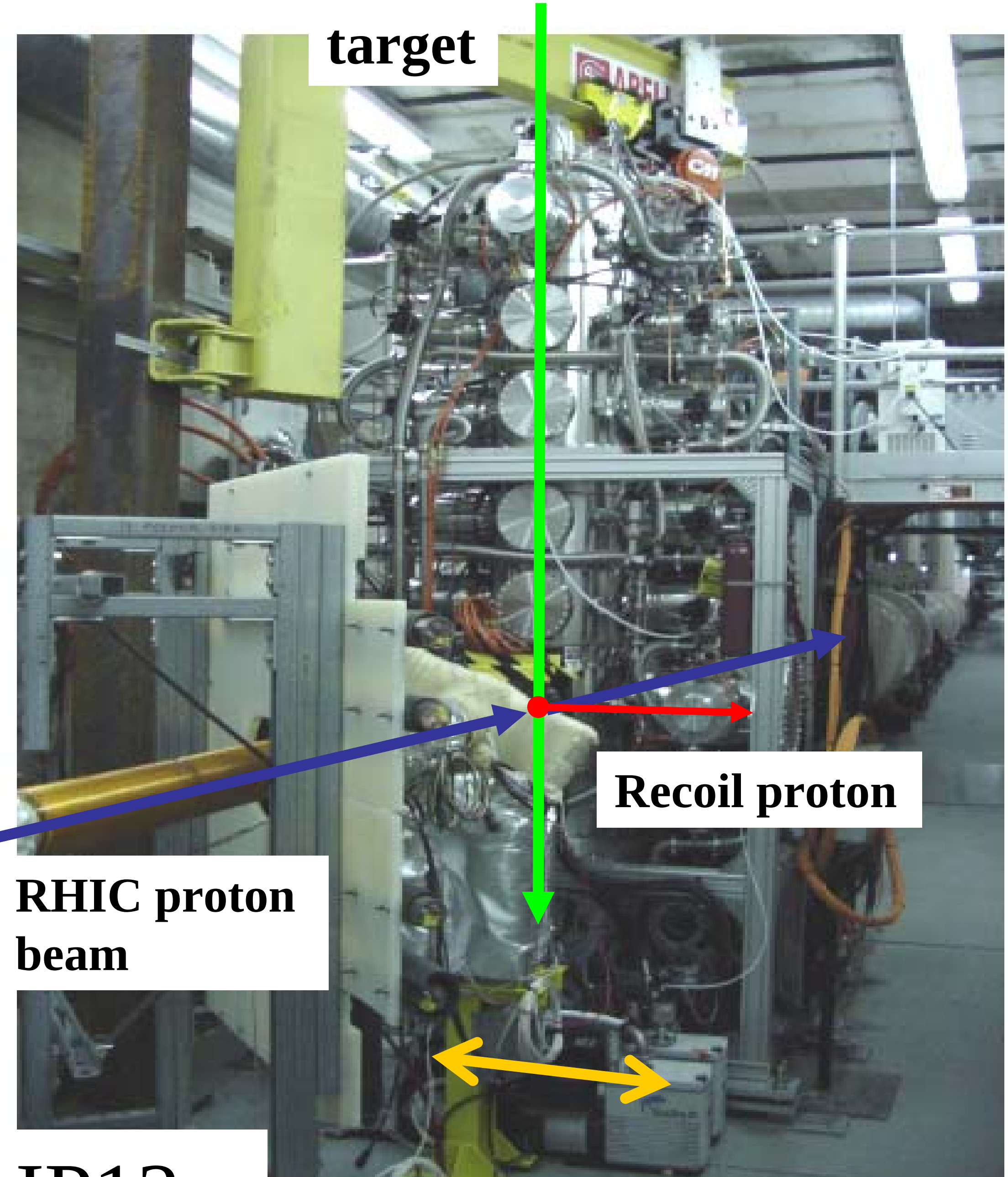
Very stable 2005, 2006 long runs!

- **Polarization**
- **Profile**
- **Thickness**
- **Stability**

Very rapid assembly sequence by super professional team!

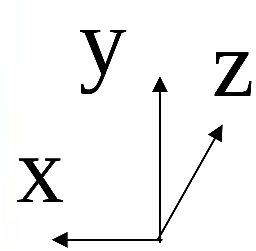
- Fri. 11:30~
  - T. Wise
- Wednesday 9:00~
  - W. Haeberli

H-jet-target system

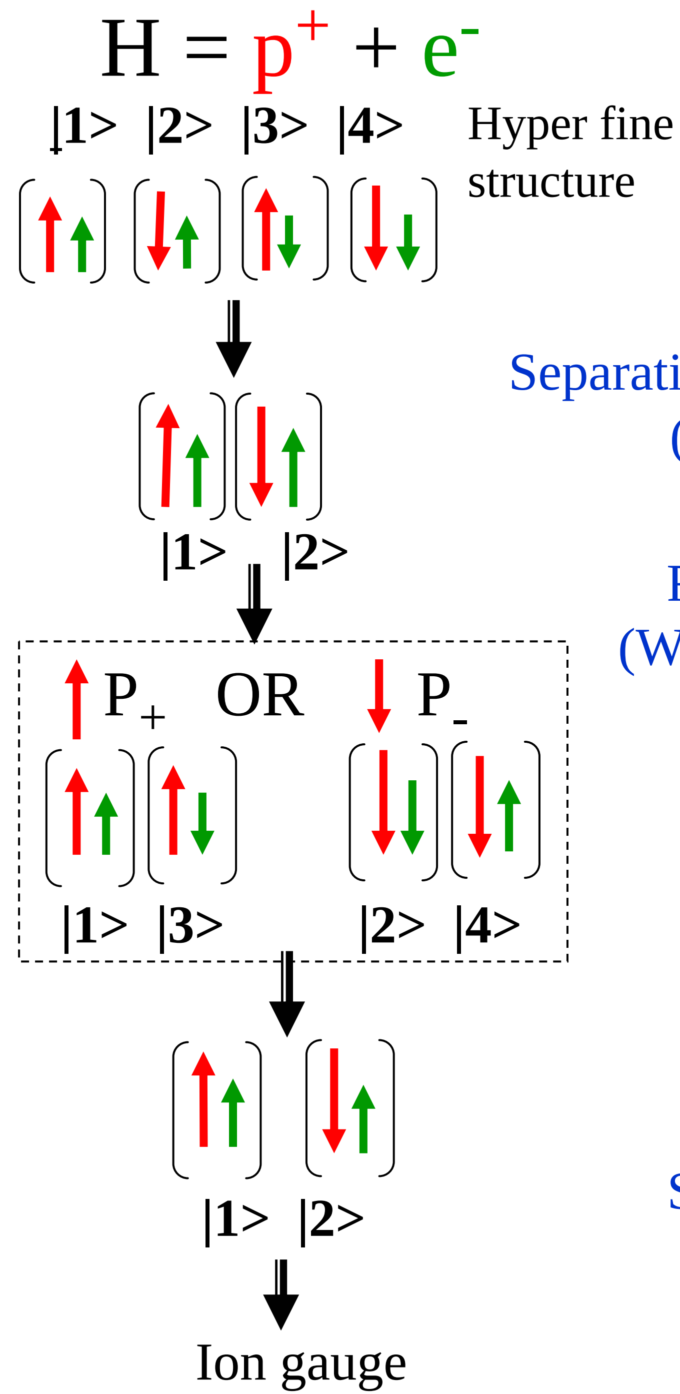


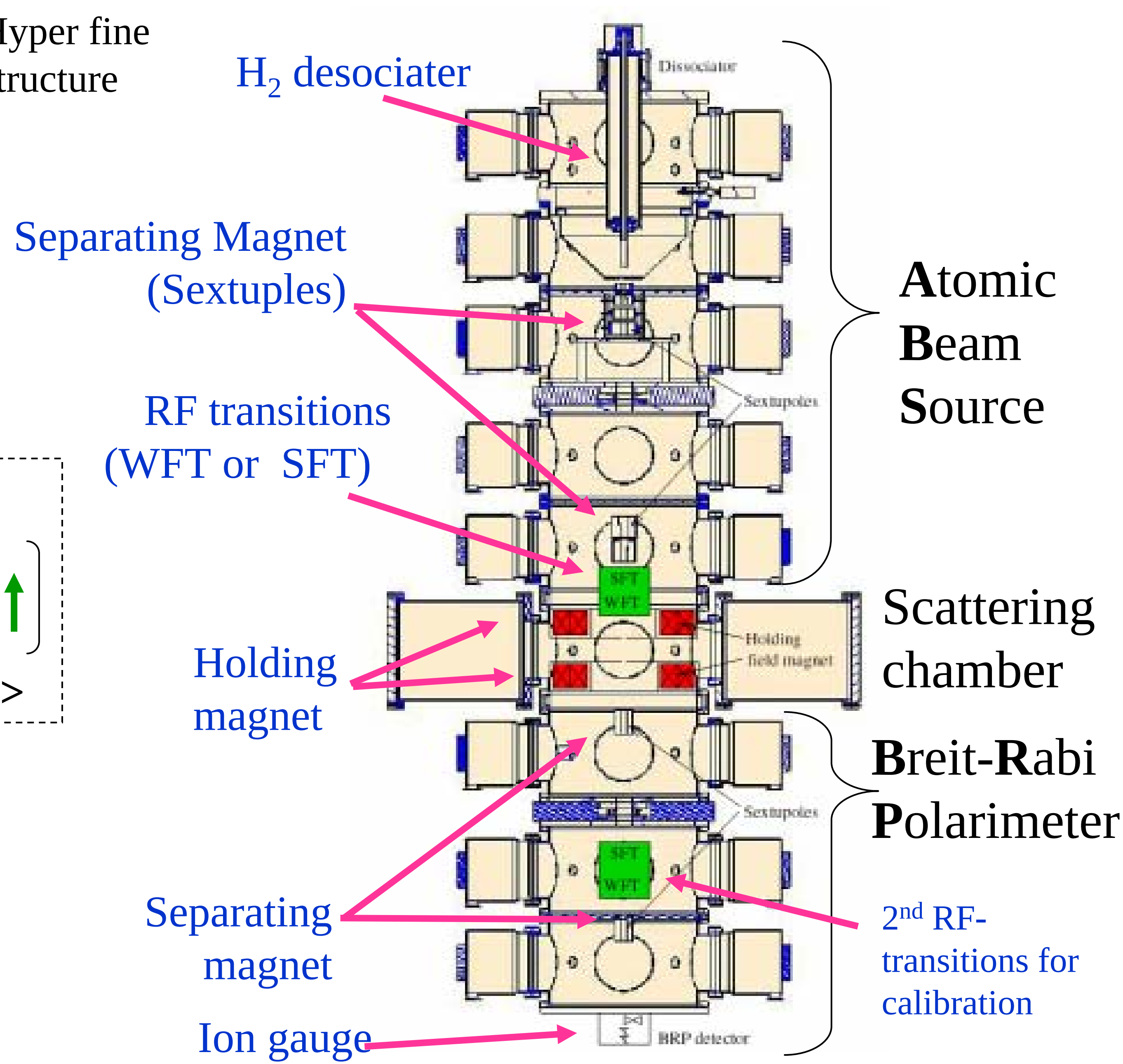
IP12

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

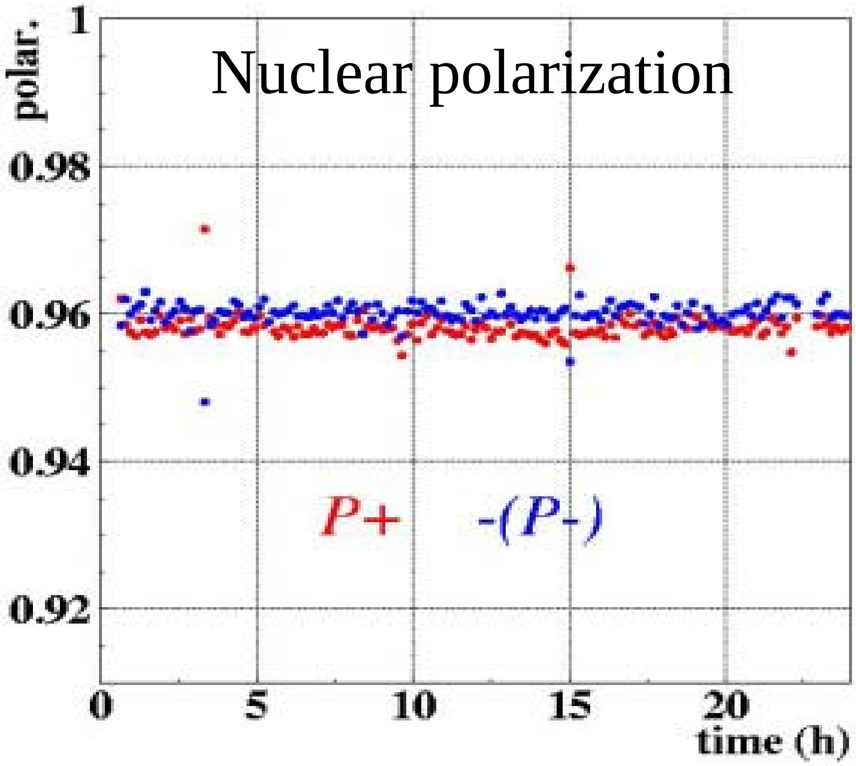


H-jet-target system





Target polarization



1 day

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

Nuclear polarization of the atoms measured by BRP: 95.8% ± 0.1%

Correct H_2, H_2O contamination.
Divide with factor 1.037

$$\mathbf{P_{target} = 92.4\% \pm 1.8\%}$$

Very stable for entire run period !

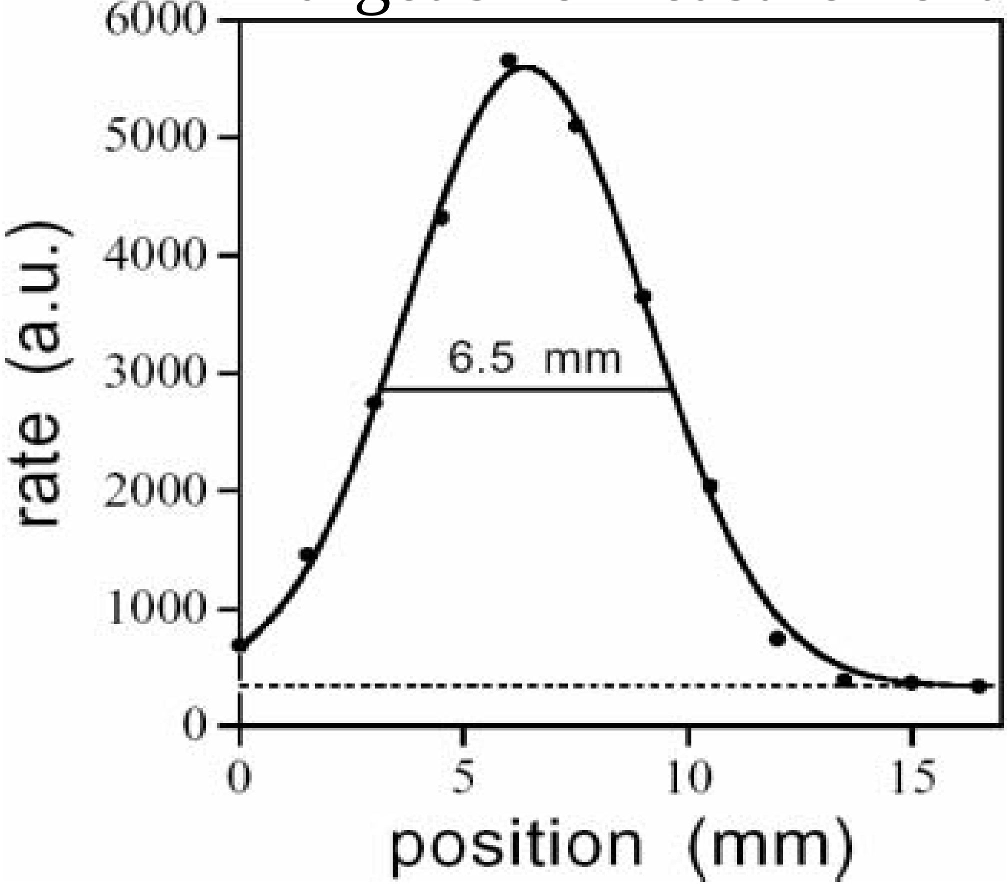
$$\frac{\Delta P_{target}}{P_{target}} = 2\%$$

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/cm^2

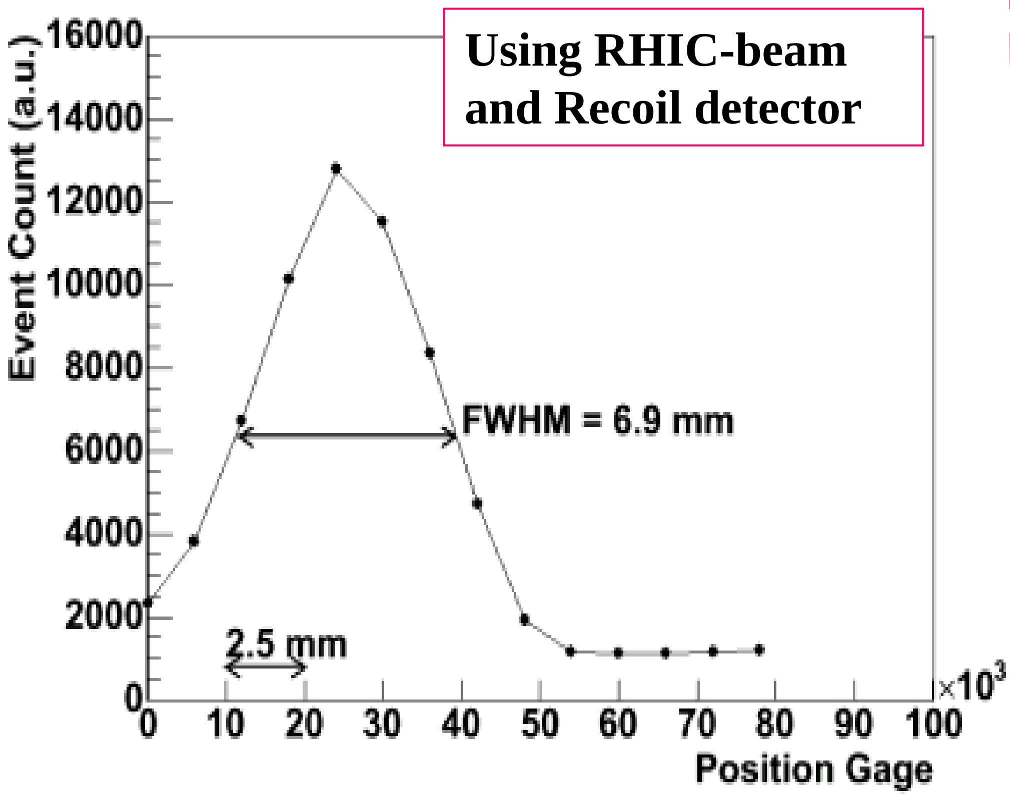
Achieve designed values!

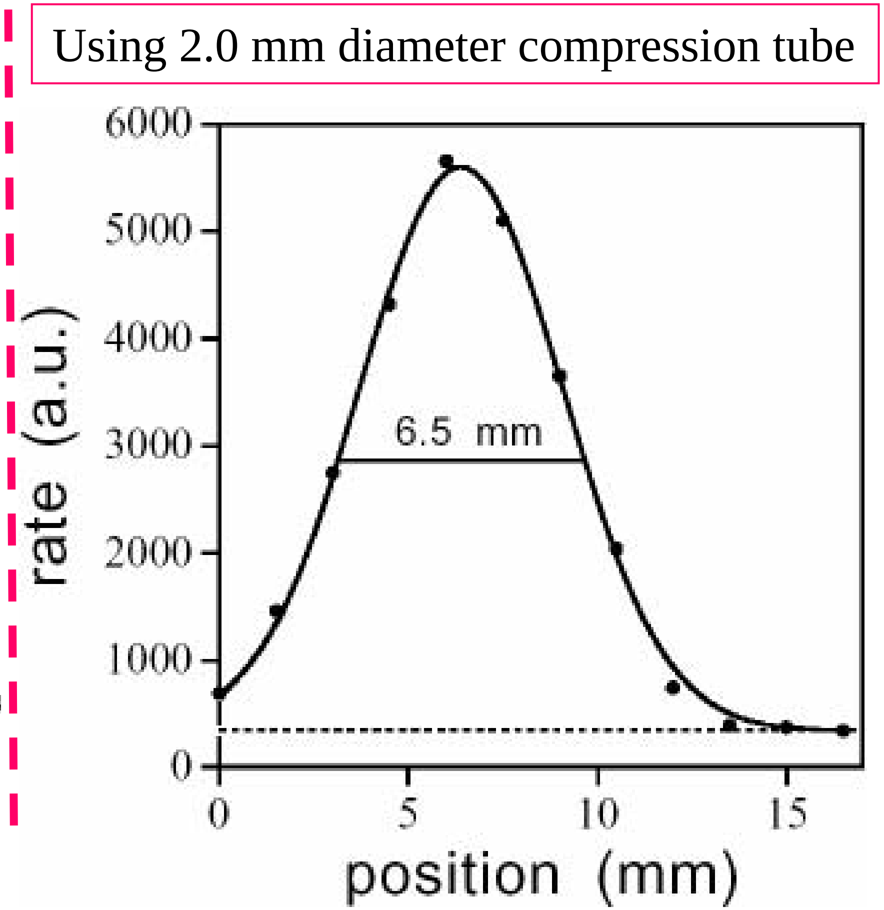
Target size measurement



Measurements were done by using 2.0 mm diameter compression tube

Find meeting point and confirm target size using RHIC beam!





- Fix RHIC proton beam position (diameter σ ~1mm).
- Move entire system for every 1.5 mm step.
- Find collision point.

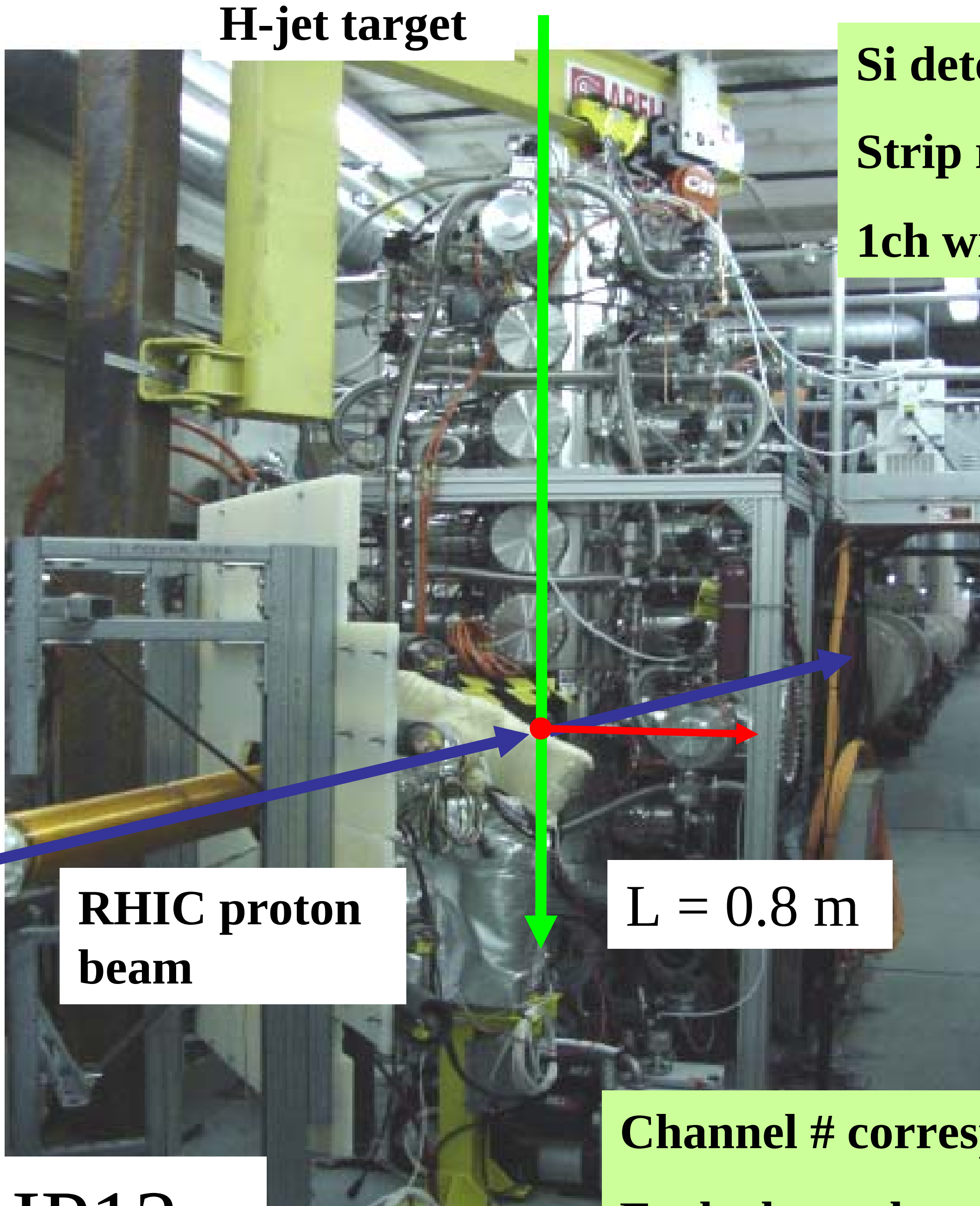
Consistent measurement !

Recoil spectrometer set up

Analysis

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

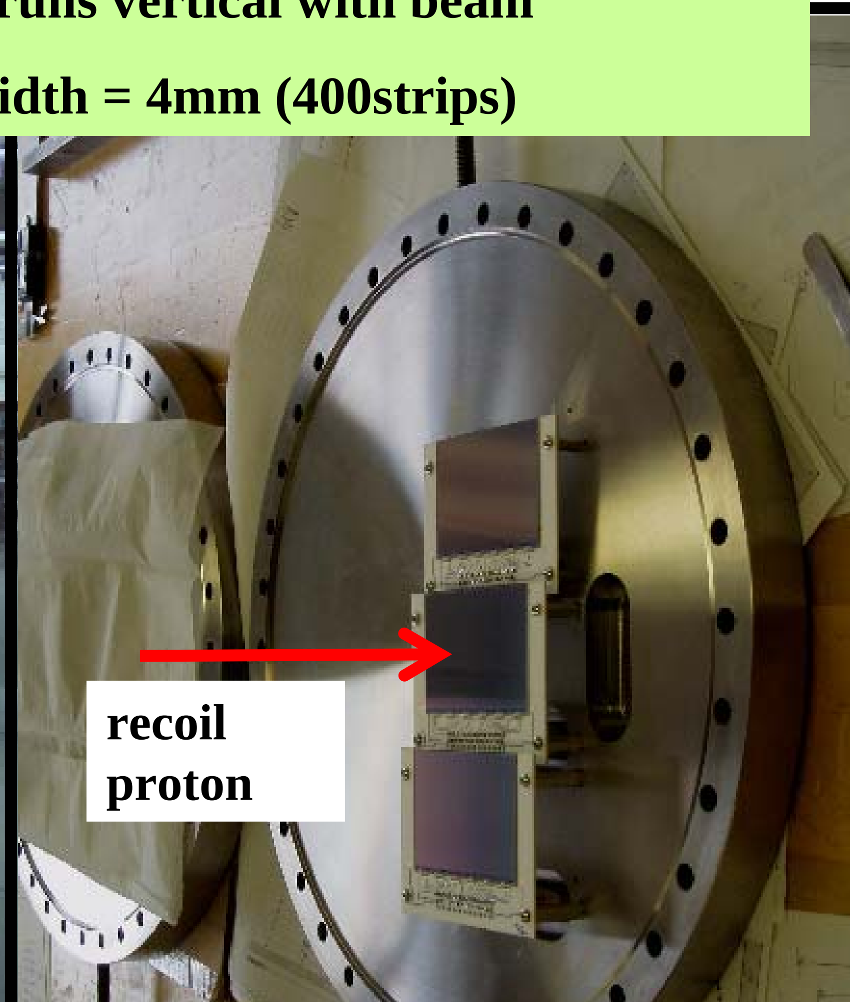
Raw asymmetry



Si detectors (8cm × 5cm)×3× L-R sides

Strip runs vertical with beam

1ch width = 4mm (400strips)



Channel # corresponds to recoil angle θ_R

Each channel measures kinetic energy T_R and *TOF*

IP12

Read out electronics

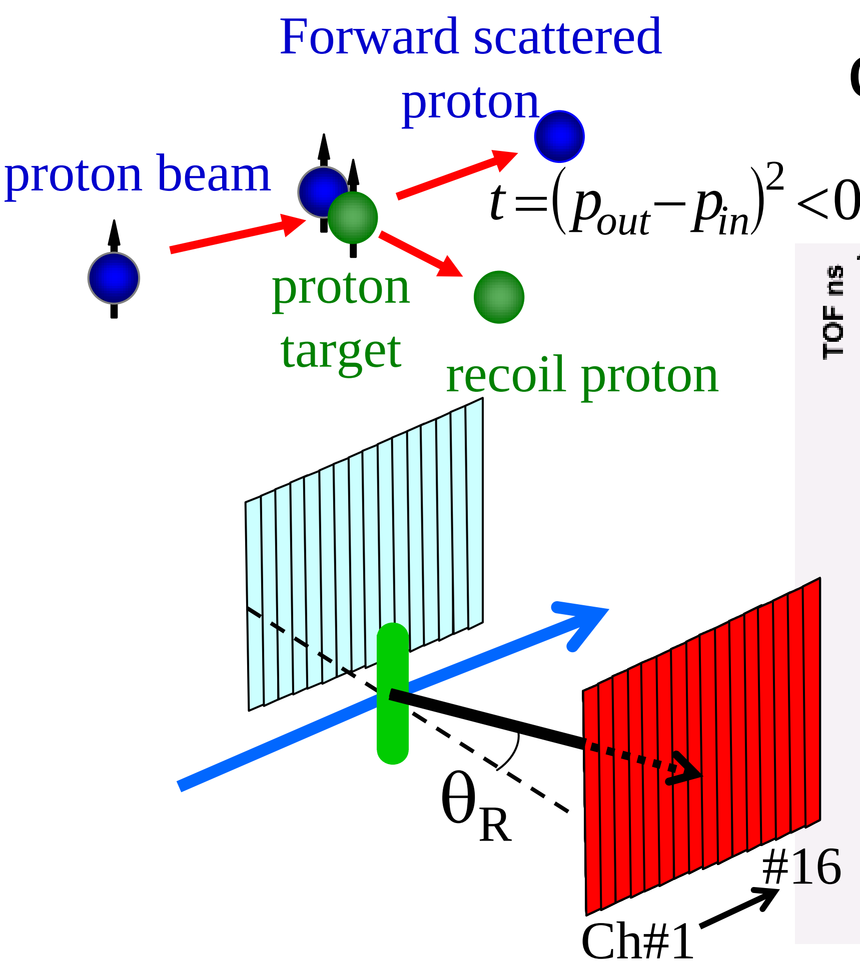
RHIC-ring、IP12
Recoil spectrometer

3 left-right pairs Si detectors

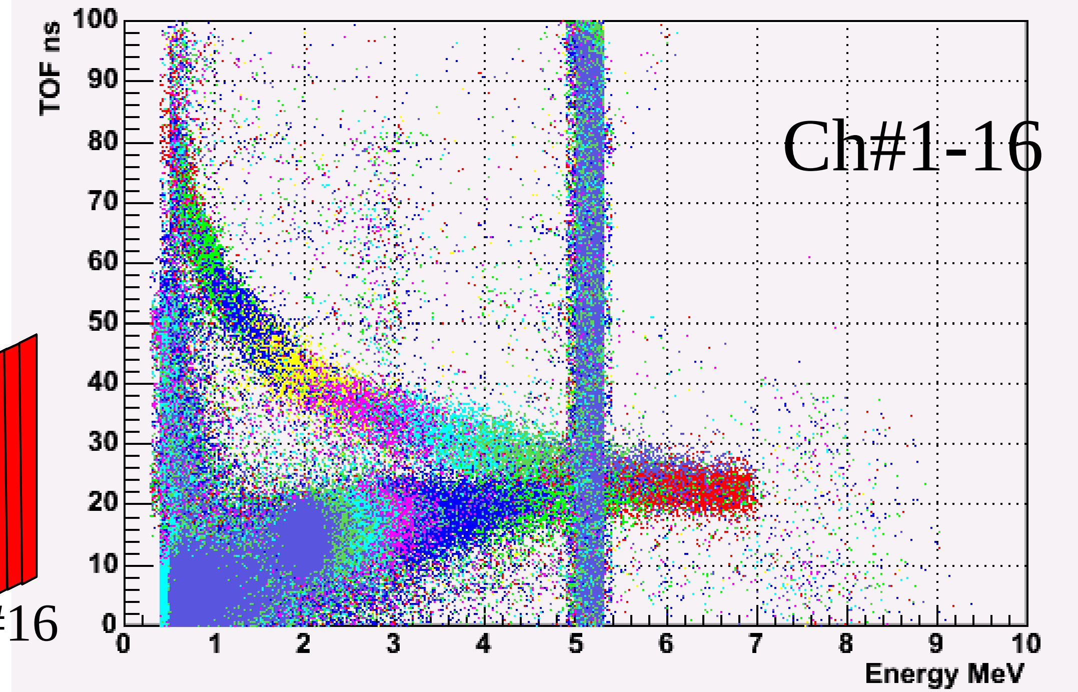
- 96 read-out channels
- 96 charge-sensitive preamplifiers

55 m twisted pair cables (category 5)

What we measure by recoil spectrometer ?



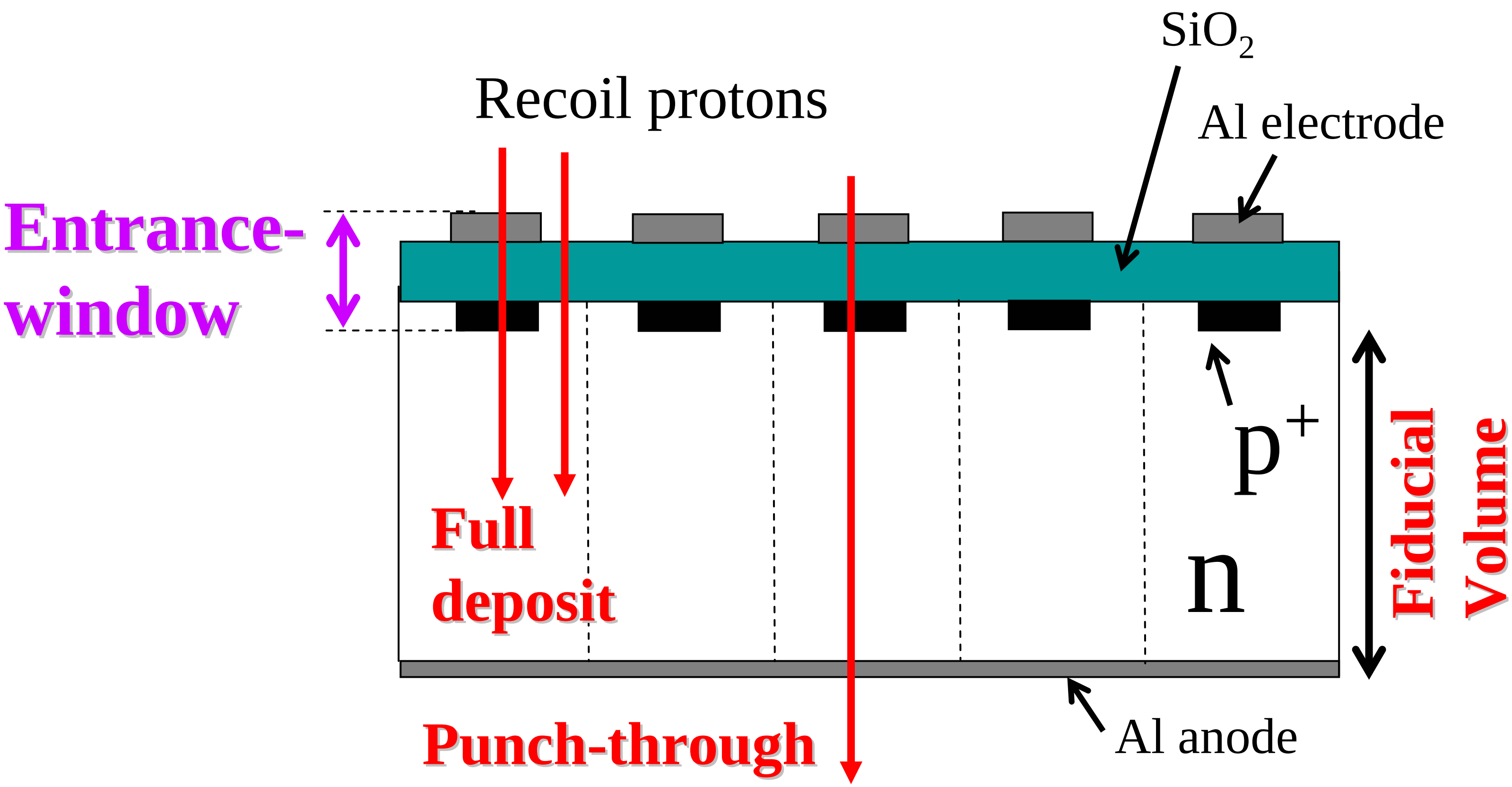
$$ch\# \propto \theta_R \;,\; \theta_R \text{ big} \Rightarrow T_R \text{ big}$$
$$\Rightarrow \text{fast protons}$$



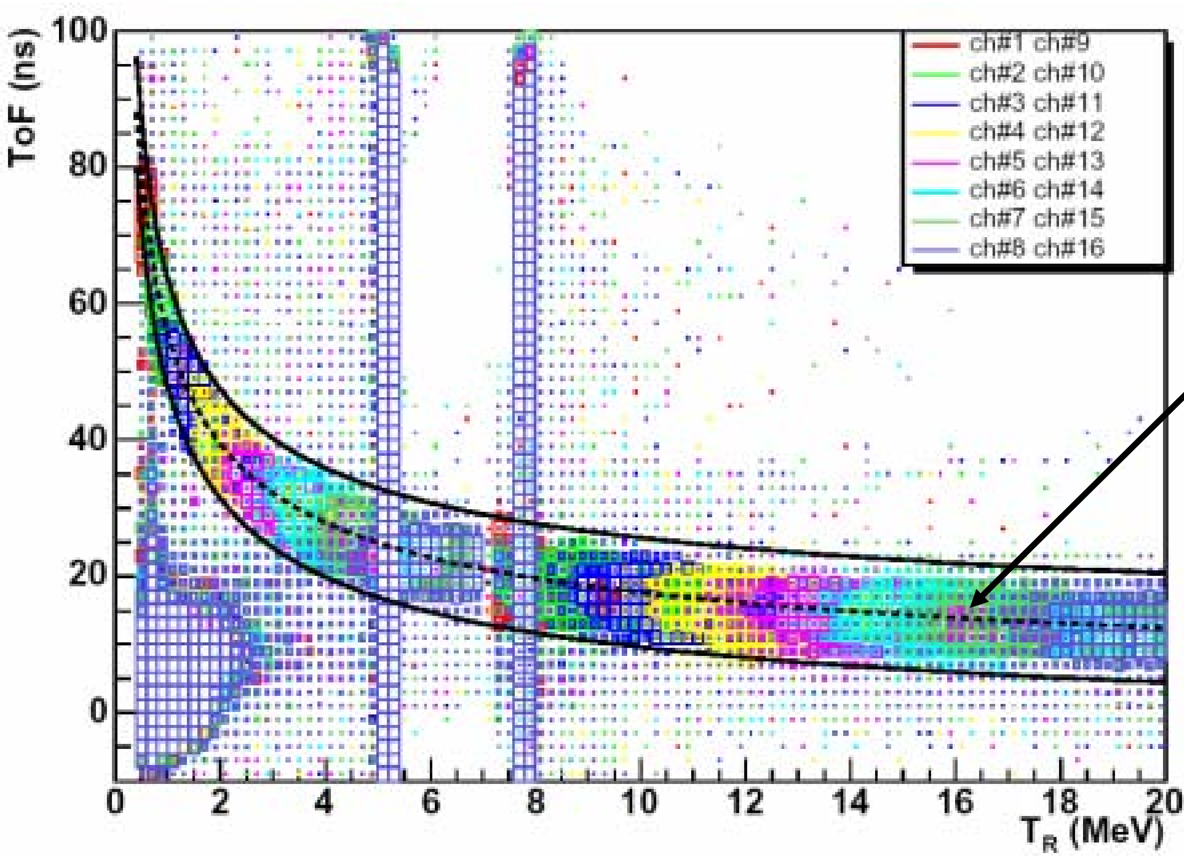
Array of Si detectors measures **T_R** **&** ***ToF*** of recoil particles.
Channel # corresponds to recoil angle θ_R.
2 correlations (T_R & *ToF*) and (T_R & θ_R) → the elastic process

Recoil proton kinetic energy corrections

- ✓ Measured deposit energy ≠ kinetic energy T_R
- ✓ 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



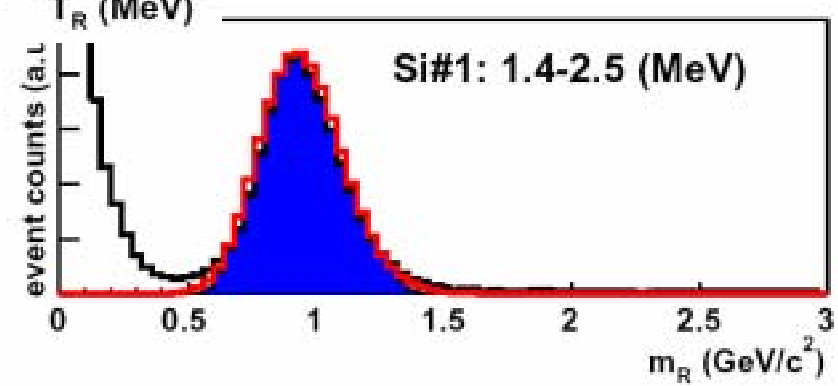
$$ToF_{cal.} \approx L\sqrt{\frac{m_p}{2T_R}}$$

Recoil protons :

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

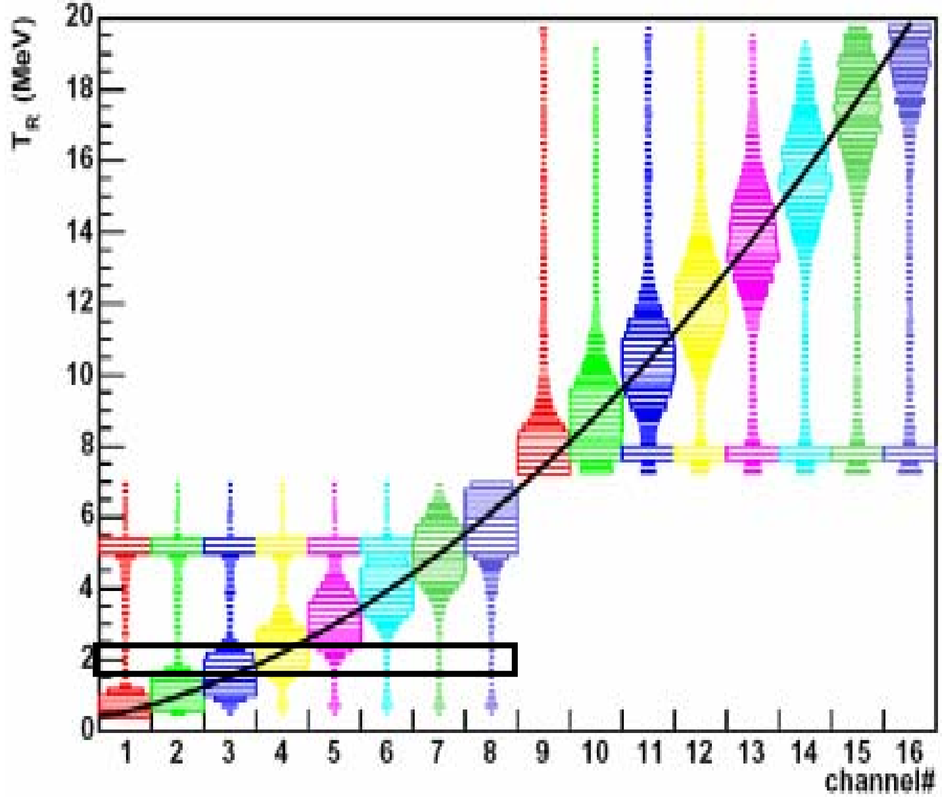
Blue area: $(ToF \pm 8)$ nsec

Red line:expected spectrum from ToF and T_R resolutions

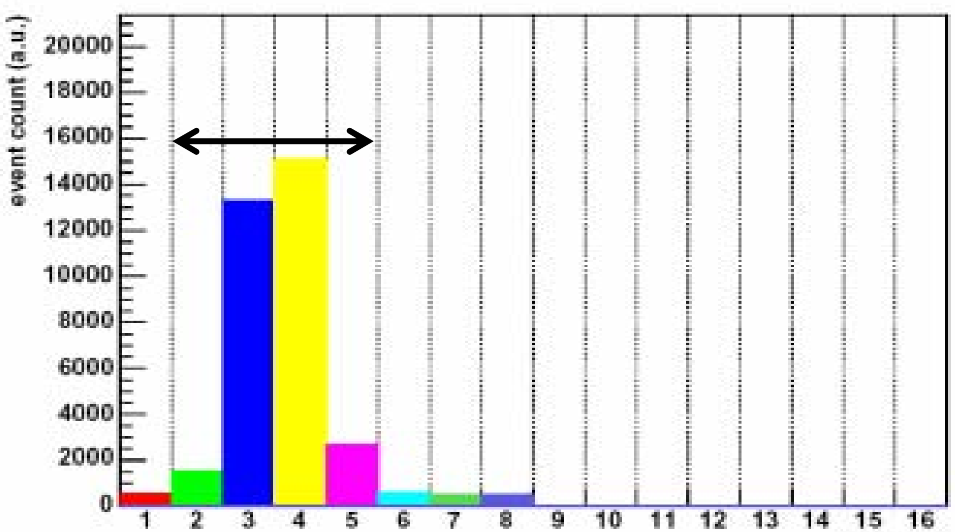


Elastic event selection
(2) Forward scattered proton identification

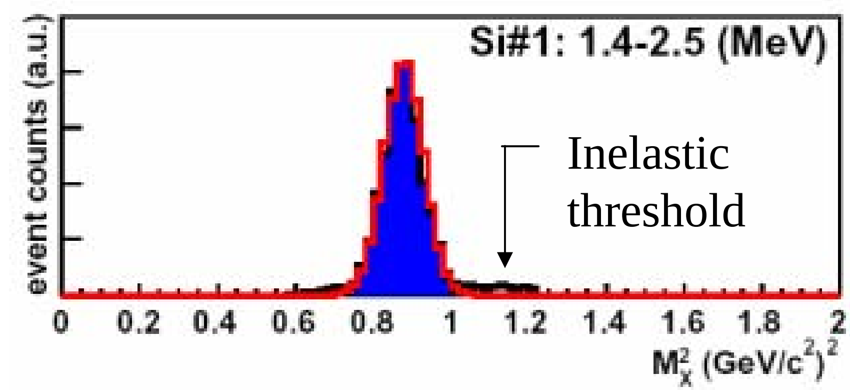
$$T_R \approx 2m_p \sin\theta_R{}^2 \propto (ch\#)^2$$



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
- ε_{target} : Based on H-Jet target polarization sign.
  (sign changes every 6 minutes)
- ε_{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)

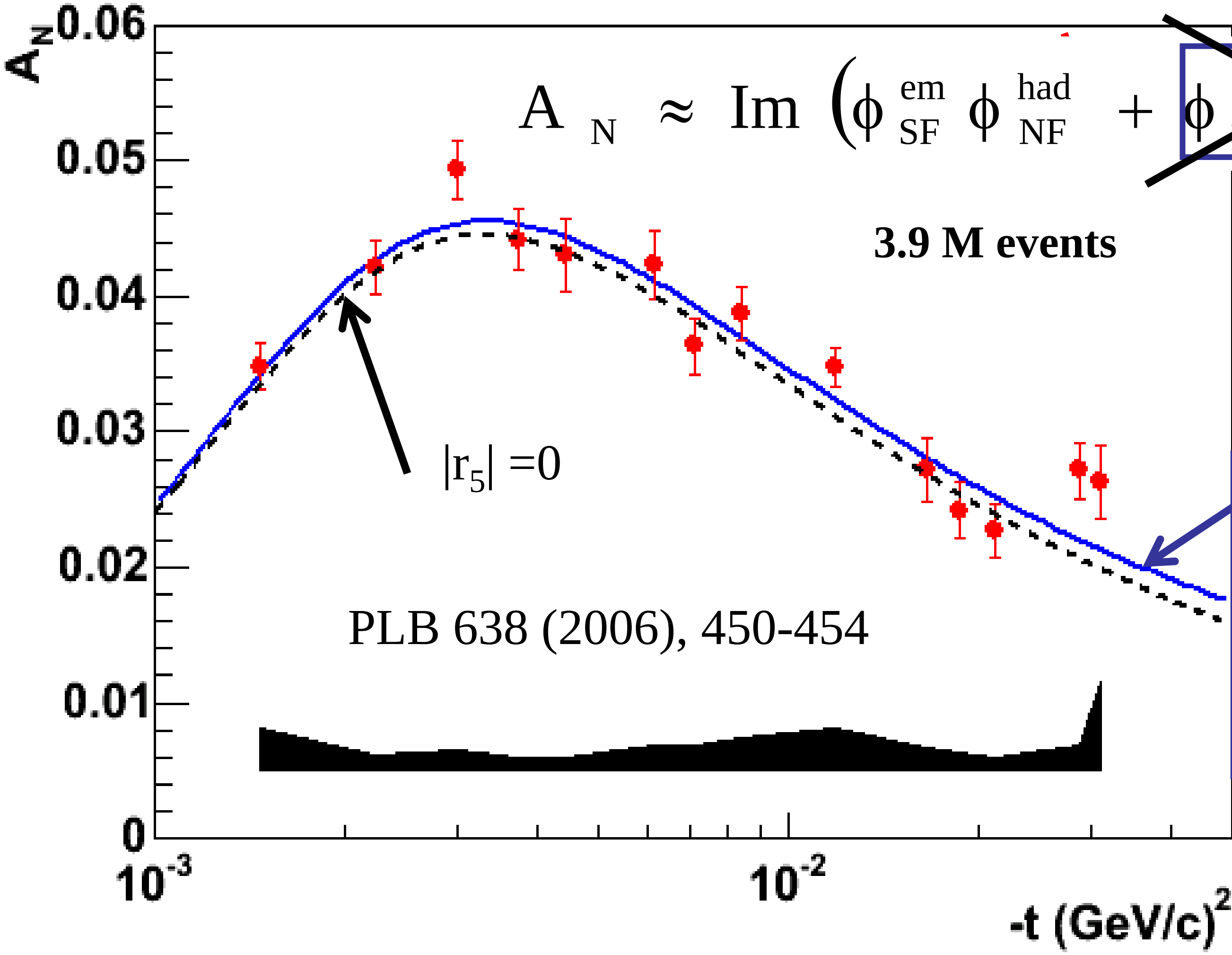
$$\varepsilon = \frac{\sqrt{N_{\uparrow}^{L}}\sqrt{N_{\downarrow}^{R}} - \sqrt{N_{\downarrow}^{L}}\sqrt{N_{\uparrow}^{R}}}{\sqrt{N_{\uparrow}^{L}}\sqrt{N_{\downarrow}^{R}} + \sqrt{N_{\downarrow}^{L}}\sqrt{N_{\uparrow}^{R}}}$$

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

A_N from RUN4

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

$$A_N \approx \mathrm{Im}\left(\phi_{SF}^{em}\,\phi_{NF}^{had} + \phi_{SF}^{had\,*}\,\phi_{NF}^{em}\right) \Big/ \left|\phi_{NF}^{had}\right|^2$$



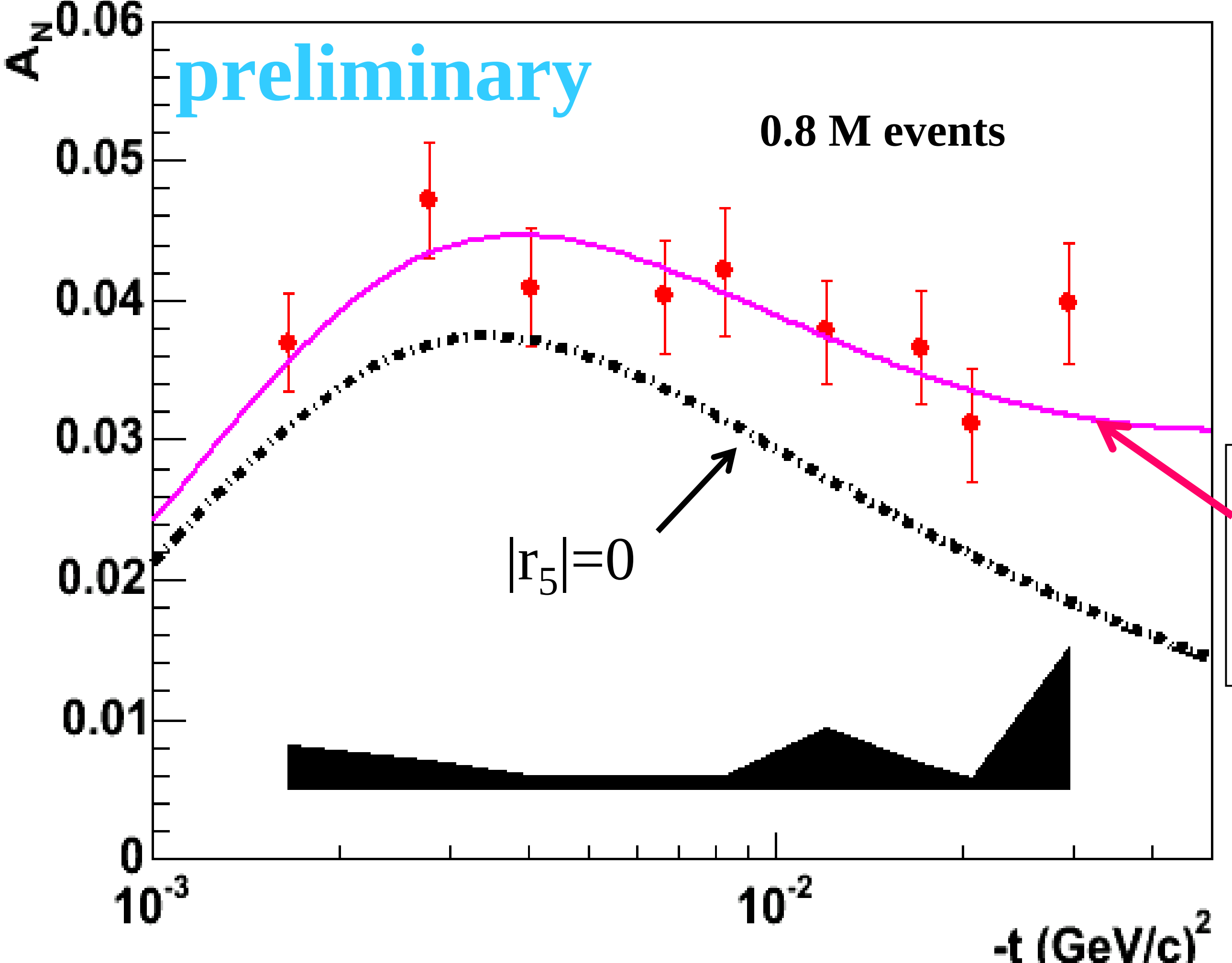
Unpredictable
Parameterized with r_5

Set r_5 as free parameter:
→ χ^2/ndf = 11.1/12
→ $|r_5|$ is consistent with zero!

- Errors on the data points are statistics only.
- Components of systematic errors
  - Acceptance asymmetry
  - Background correction
  - Elastic event selection

- Compare measured A_N and expected curve with $|r_5| = 0$ → χ^2/ndf = 13.4/14.
- Tool itself has a beautiful A_N and described from first principle QED explanation at 100 GeV/*c*.

A_N and r_5 results at 24 GeV/*c*



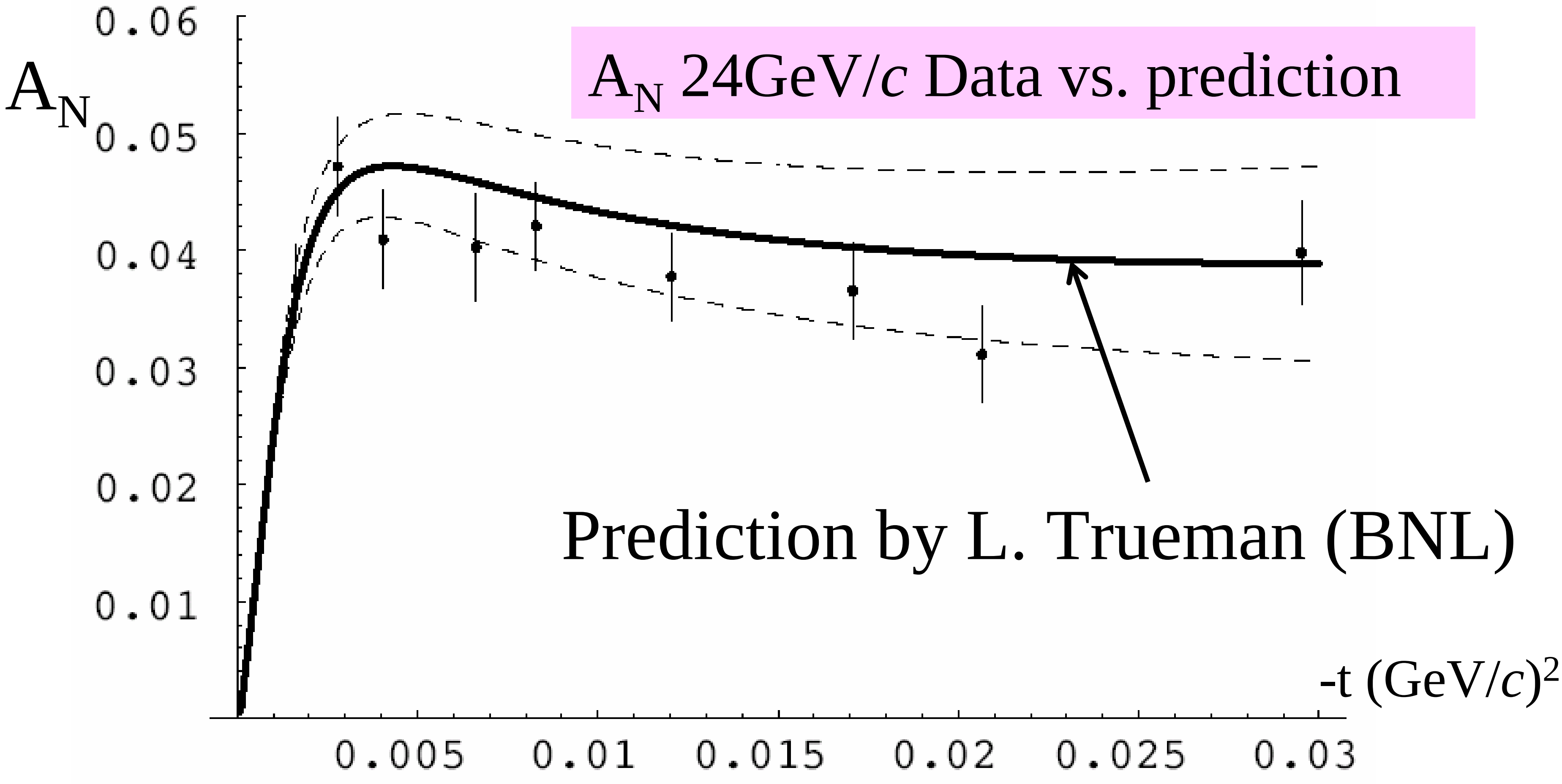
Set r_5 as free parameter
→ Im r_5 = –0.108 ± 0.074
→ Re r_5 = –0.006 ± 0.031
→ χ^2/ndf = 2.87/7

- Compare measured A_N and expected curve with |r5| =0 → $\chi2$/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*.

Contribution to theoretical understanding of A_N

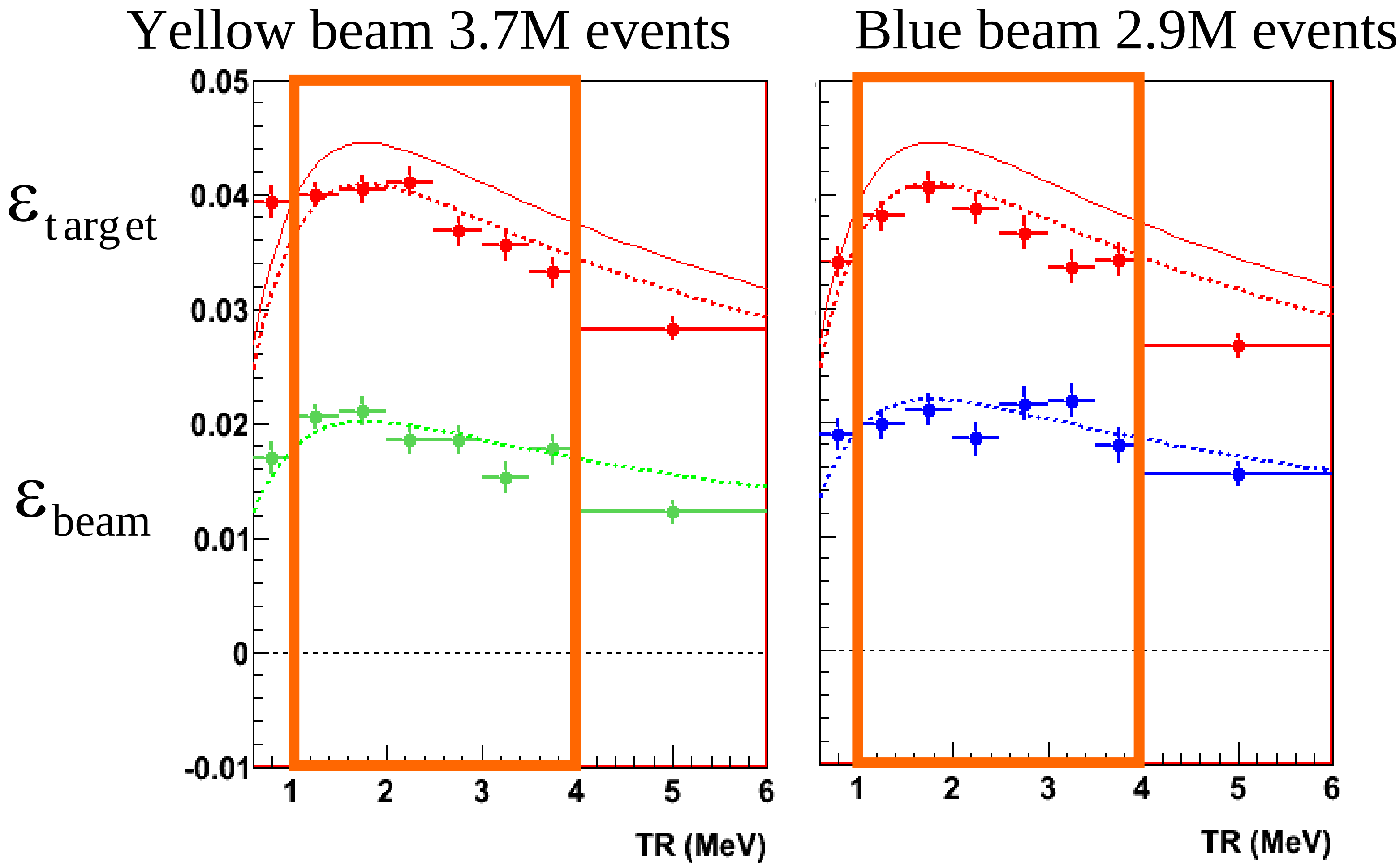
Input: A_N^{pC} at 24GeV/*c*, 100GeV/*c*
A_N^{pp} at 100GeV/*c*

Prediction:
A_N at 24GeV/*c*



Beam polarization results from RUN5

Raw asymmetries from RUN5



$$P_{beam} = \frac{\varepsilon_{beam}}{\varepsilon_{target}} P_{target}$$

Run5 statistics Yellow: 5.3 M events

Blue: 4.2 M events

Source of systematic uncertainty

Total systematic uncertainty : 2.9%

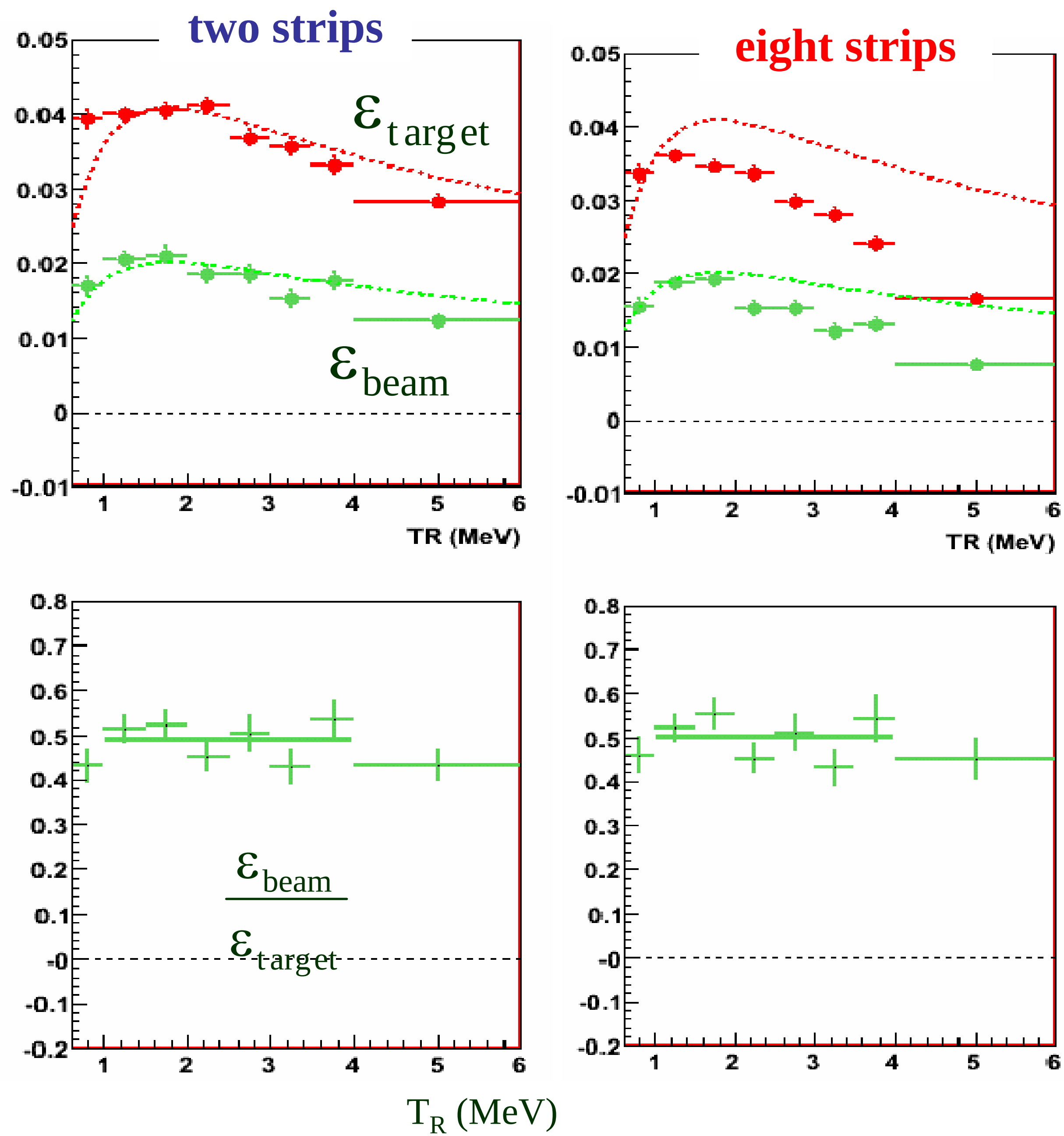
- Background effect: 2.1 %

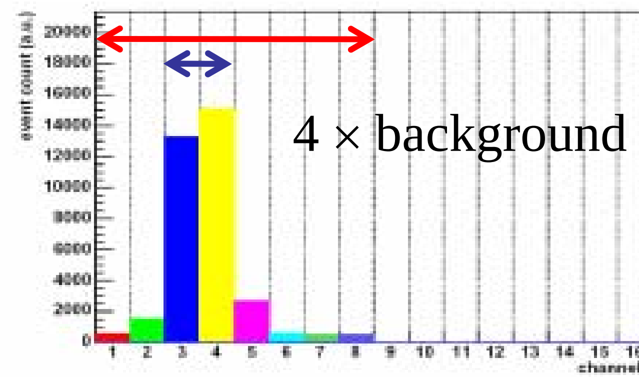
→ Next slide

- Unpolarized fraction of Jet-target: 2.0 %

→ H_2, H_2O contamination

Upper limit of systematic uncertainty from background effects





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

ε_{beam} / ε_{target} is only weakly affected!

Systematic uncertainty from background effects

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

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 unpolarized fraction of H-Jet target.
  - Currently 2%
  - Improvement is ongoing…..

Sunrise at Montauk

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

courierhttp://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 study the contribution of gluons to the proton spin. But how the degree of polarization of the beam known? 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 des gluons dans le spin du proton. Mais comment déterminer le degré de

impliq

opant

Thank you!

Labor

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