# RHIC Polarimetry

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For the RHIC Polarimetry Group

RHIC&AGS User's Meeting
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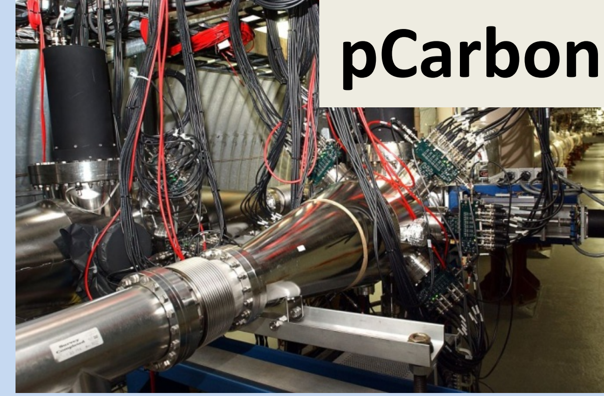
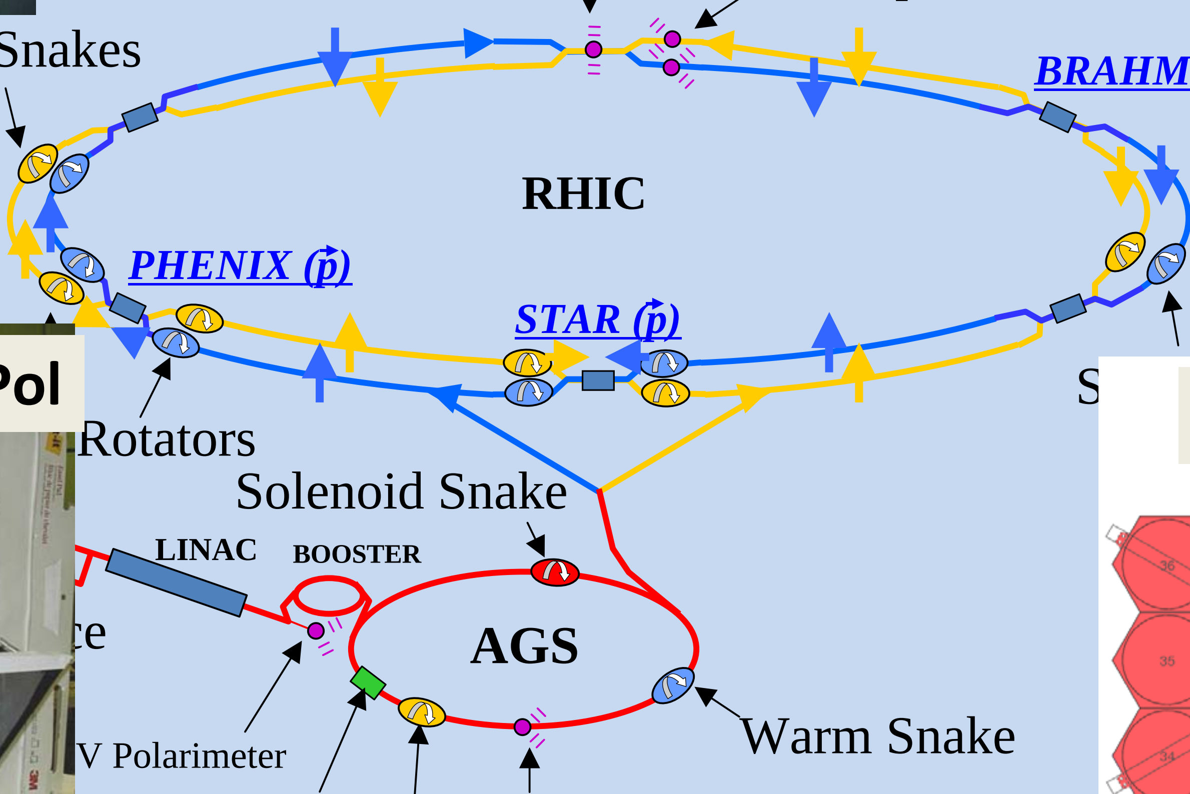
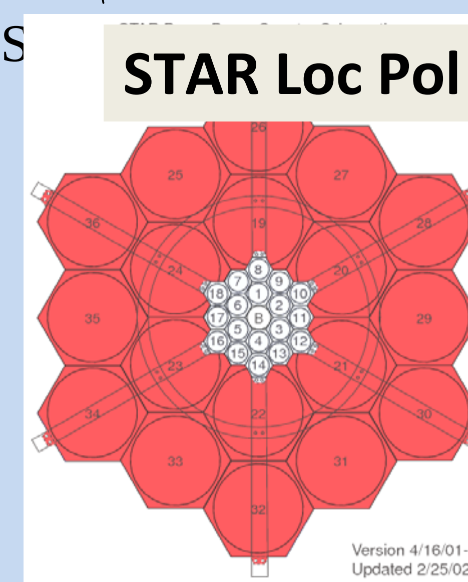
# RHIC and Polarimetry





# Polarization Measurements

## H-Jet

Absolute polarization

## p-Carbon

Polarization profile

Polarization vs time in a fill

Bunch-by-bunch polarizations

Fill-by-fill polarizations

## Local Polarimeters

Monitor spin direction at collision regions
(Confirmation of long. polarization)

Capable to monitor polarization decay vs time in a fill and bunch-by-bunch polarization

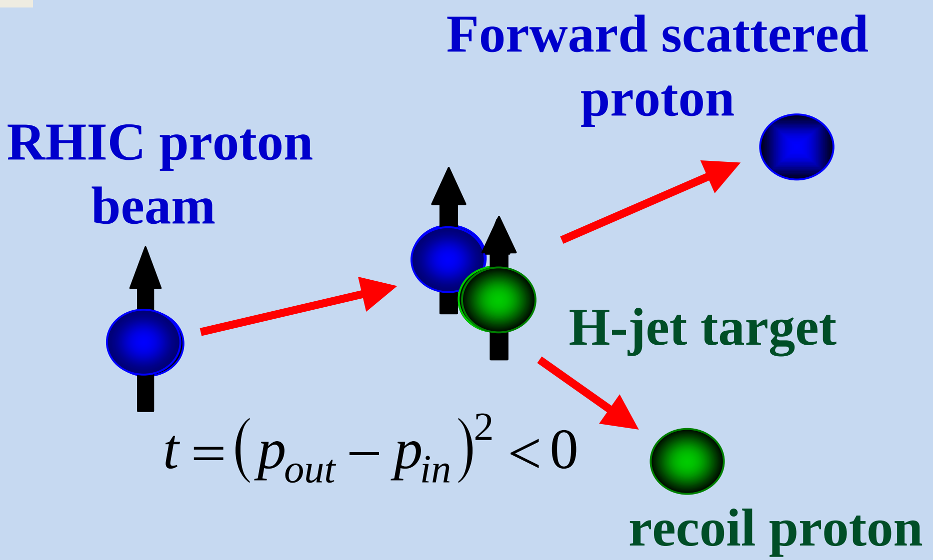
# HJet

Left-right asymmetry in elastic scattering:
Interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

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

Beam and target are both protons

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




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

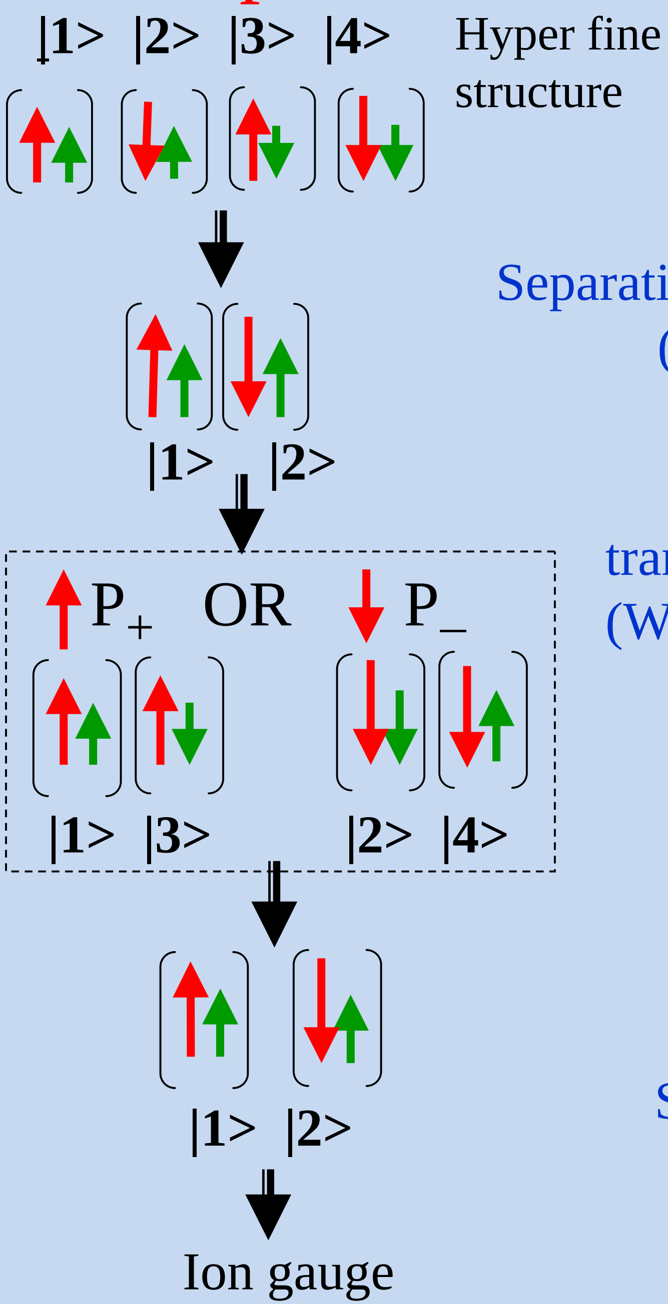
$$P_{beam} = -P_{target}\frac{\varepsilon_{beam}}{\varepsilon_{target}}$$

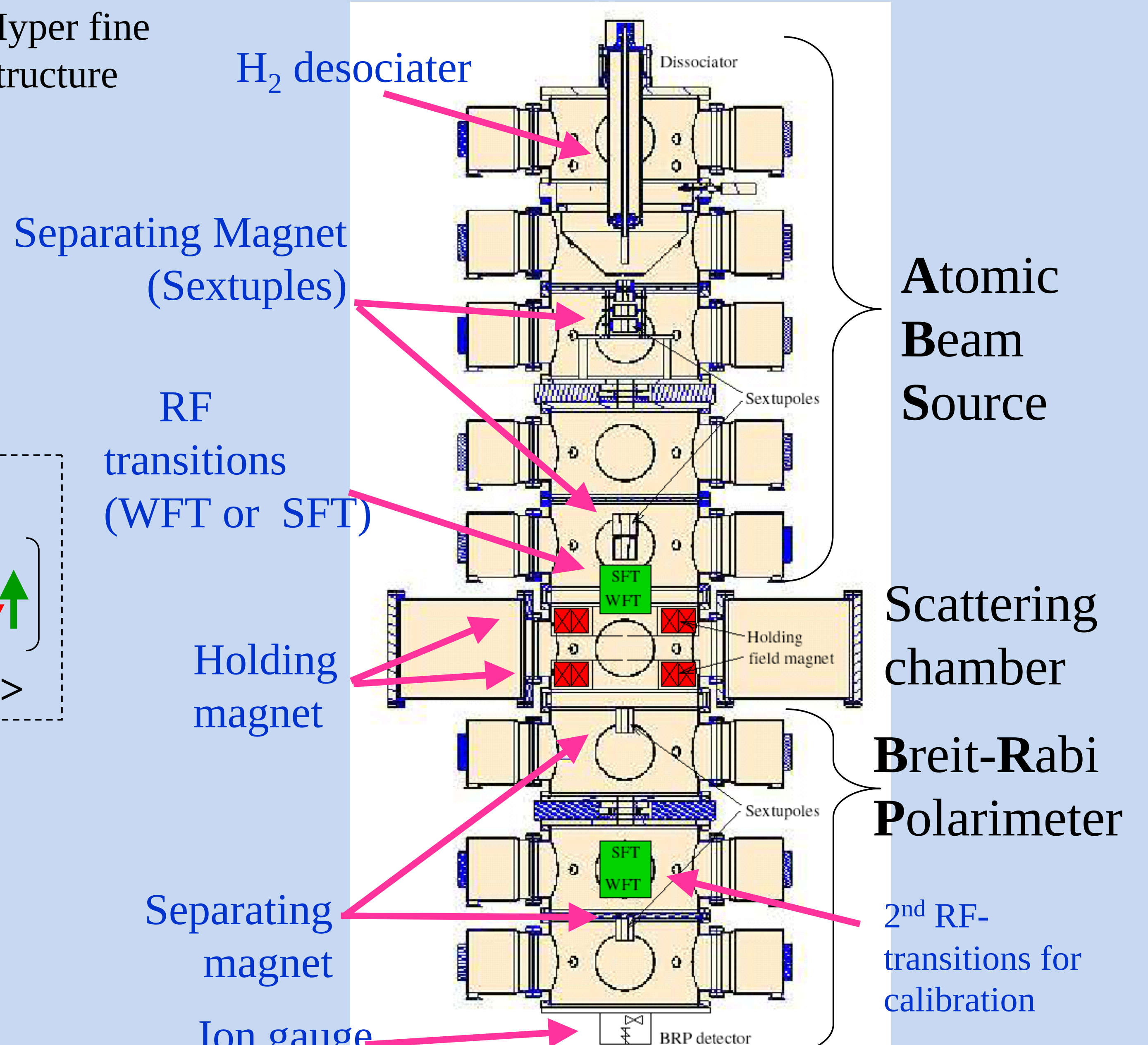
$$\frac{\Delta P_{beam}}{P_{beam}} \approx \frac{\Delta P_{target}}{P_{target}} \oplus \frac{\Delta\varepsilon_{target}}{\varepsilon_{target}} \oplus \frac{\Delta\varepsilon_{beam}}{\varepsilon_{beam}}$$ $<5\%$

$P_{target}$ is provided by Breit Rabi Polarimeter

# HJet target system

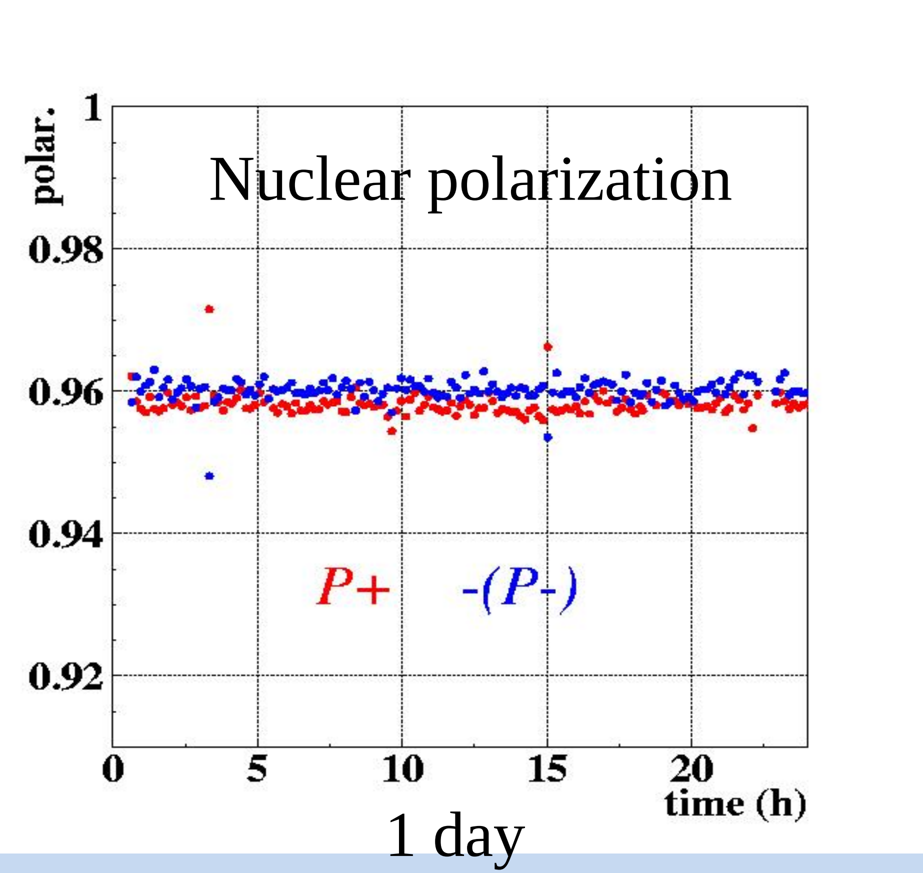
$H = p^{+} + e^{-}$



# HJet: $P_{target}$

Source of normalization for polarization measurements at RHIC




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

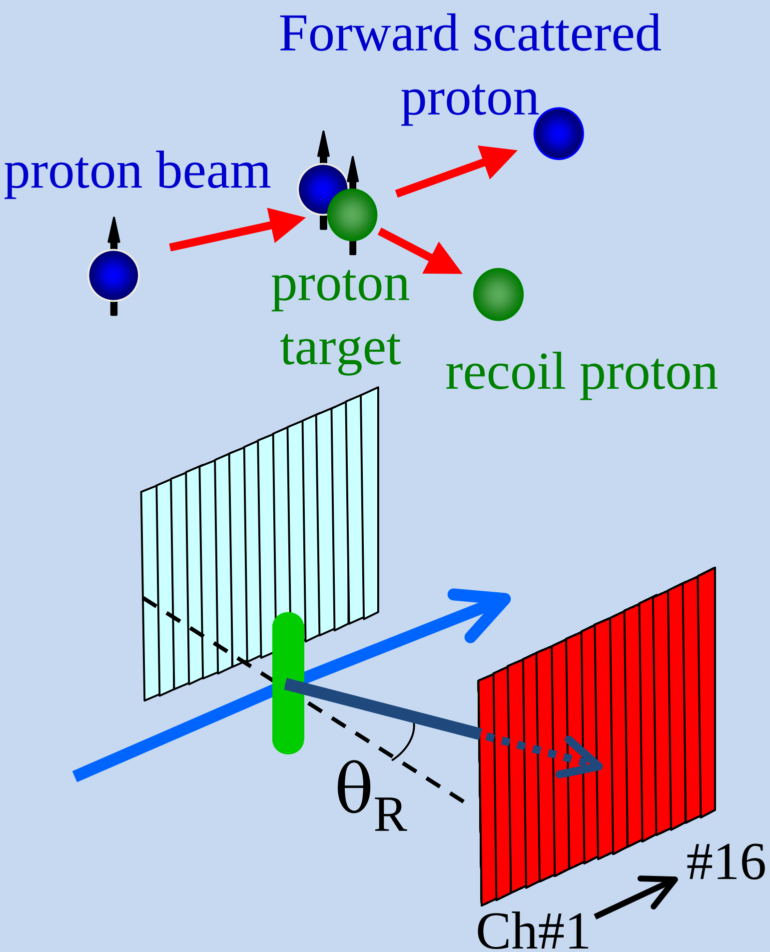
Very stable for entire run period !

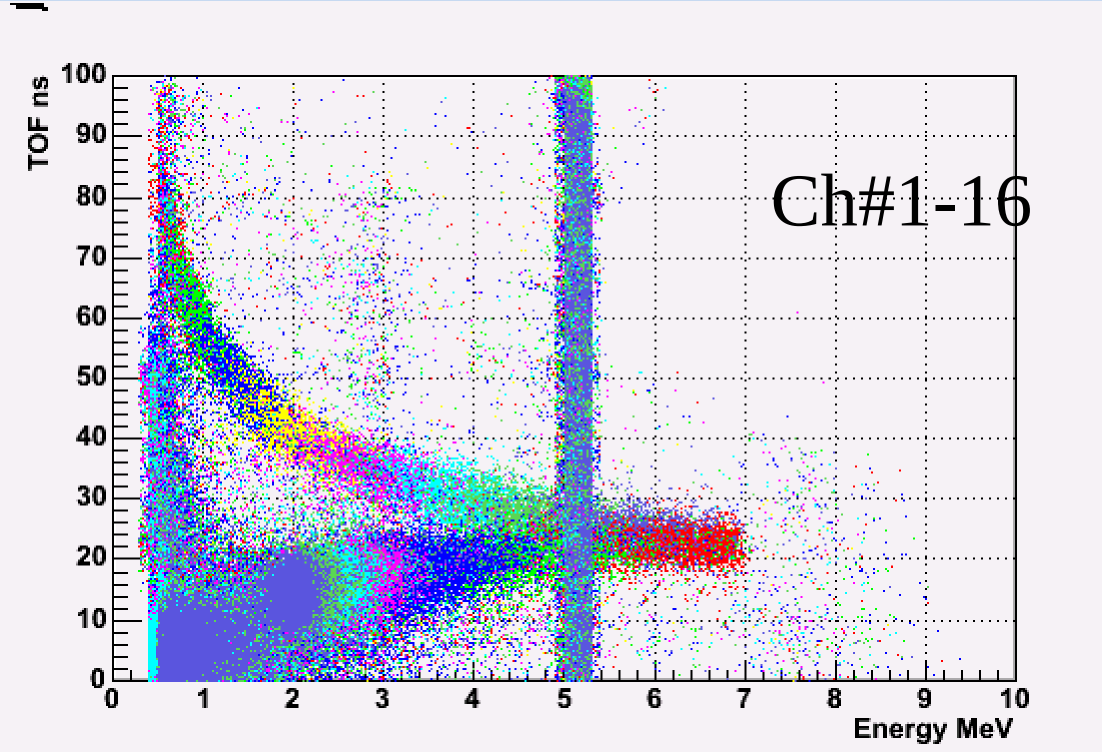
Nuclear polarization of the atoms measured by BRP: 95.8% ± 0.1%

Correct for $H_2$, $H_2O$ contamination.

**$P_{target}$ = 92.4% ± 1.8%**

# HJet: Identification of Elastic Events

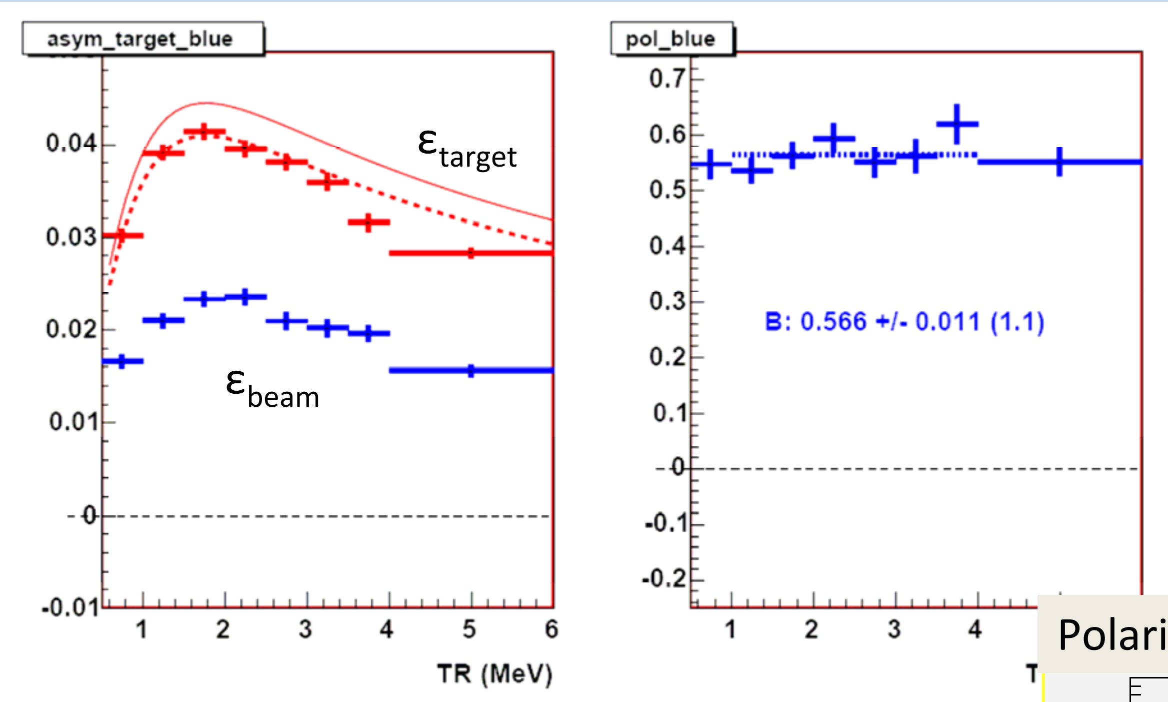


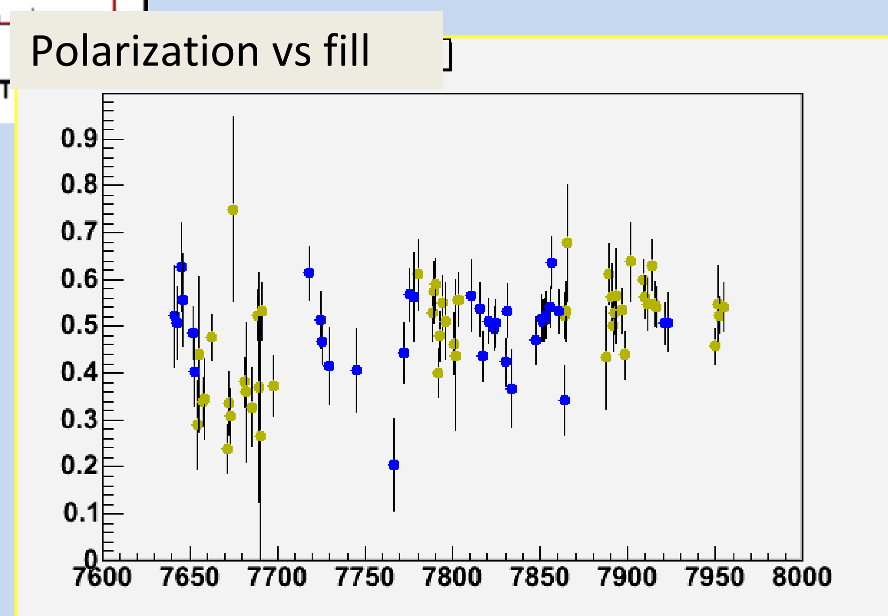

Array of Si detectors measures $T_R$ & **ToF** of recoil proton.
Channel # corresponds to recoil angle $\theta_R$.
Correlations ($T_R$ & ToF ) and ($T_R$ & $\theta_R$ ) → the elastic process

# HJet:

## Example from Run6



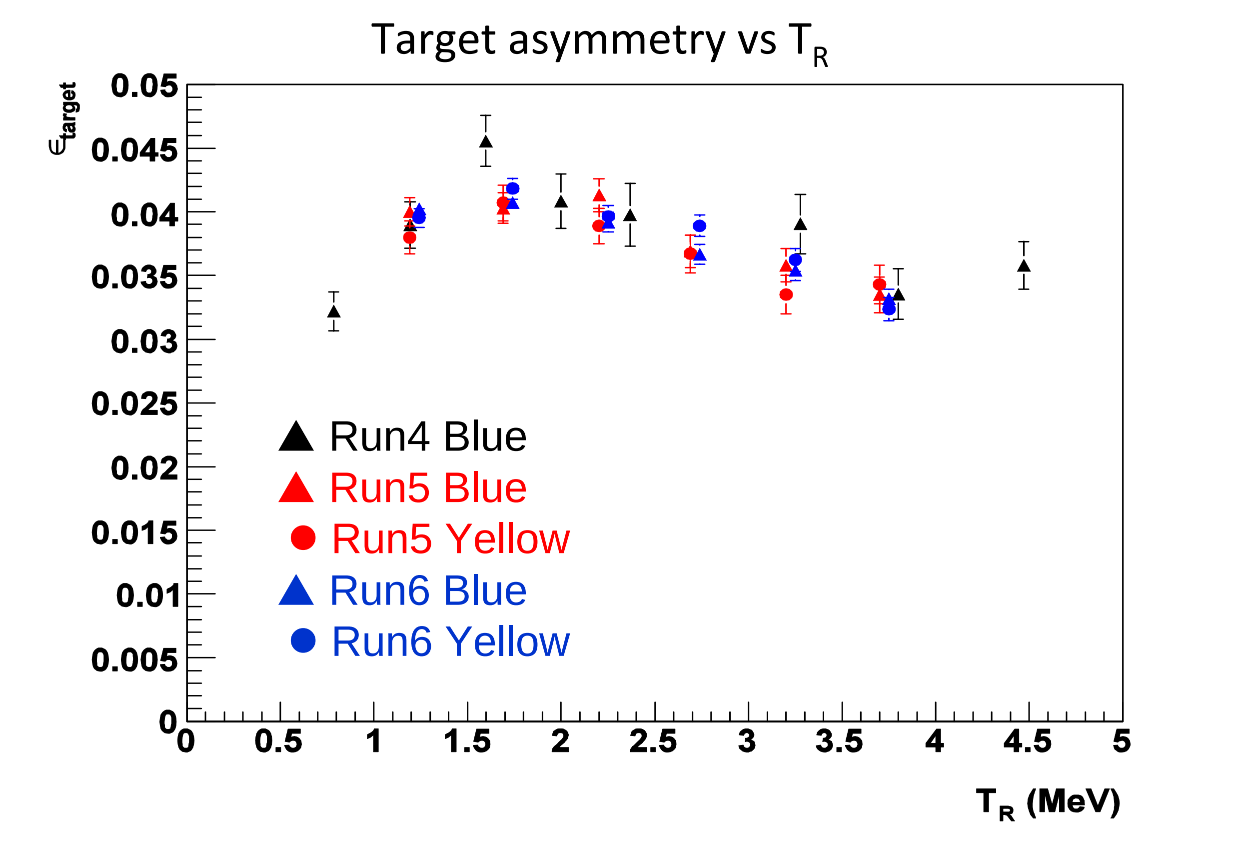

$$\frac{P_{beam}}{P_{\text{target}}} = \frac{\varepsilon_{beam}}{\varepsilon_{\text{target}}}$$




Measures average over beam profile polarization with fill-by-fill stat. uncertainty ~10%

Data accumulated for a few fills provide normalization for pC polarimeter with uncertainty <5%

# HJet



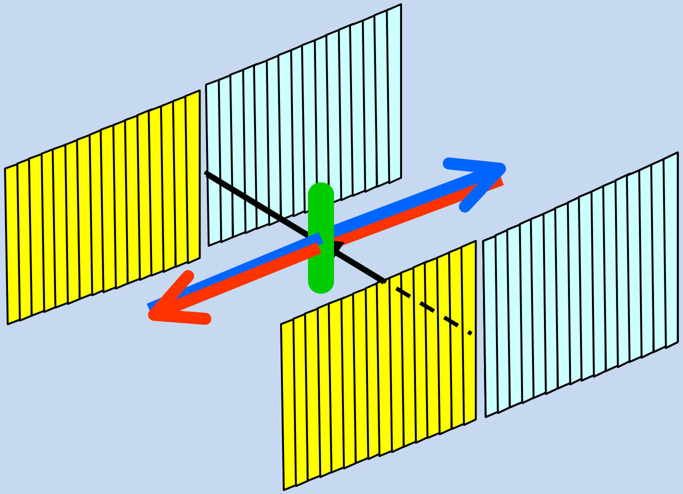

Agreement within stat. errors

HJet performance is very stable through the Years

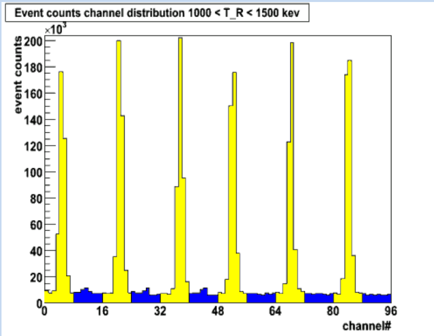
Background is small and doesn't change from Year to Year, for Blue and Yellow (within 2-3%)

⇒ Beam polarization is measured reliably by HJet

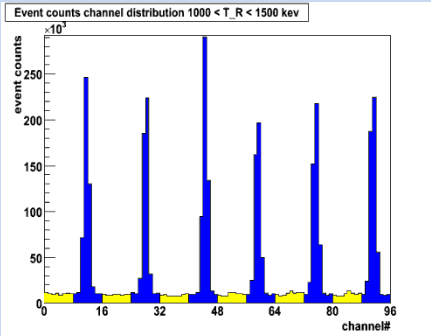
# Hjet: Two Beam Mode



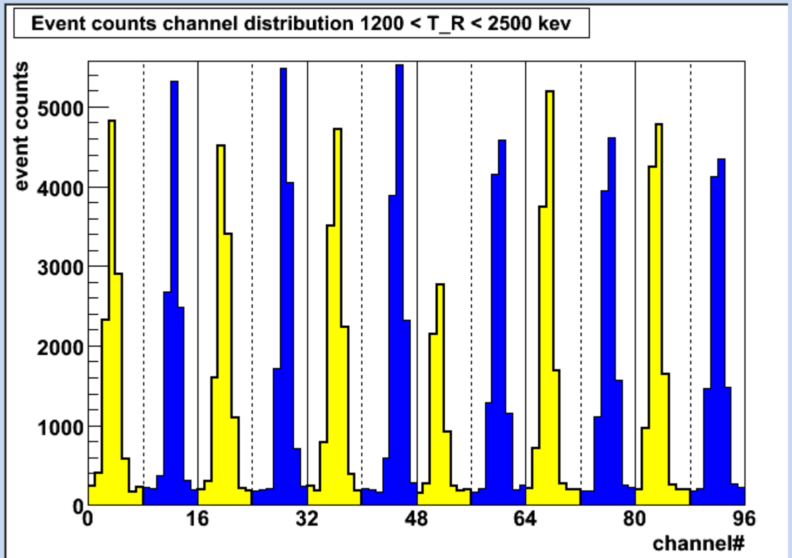
Yellow beam on target




Blue beam on target




Both beams on target

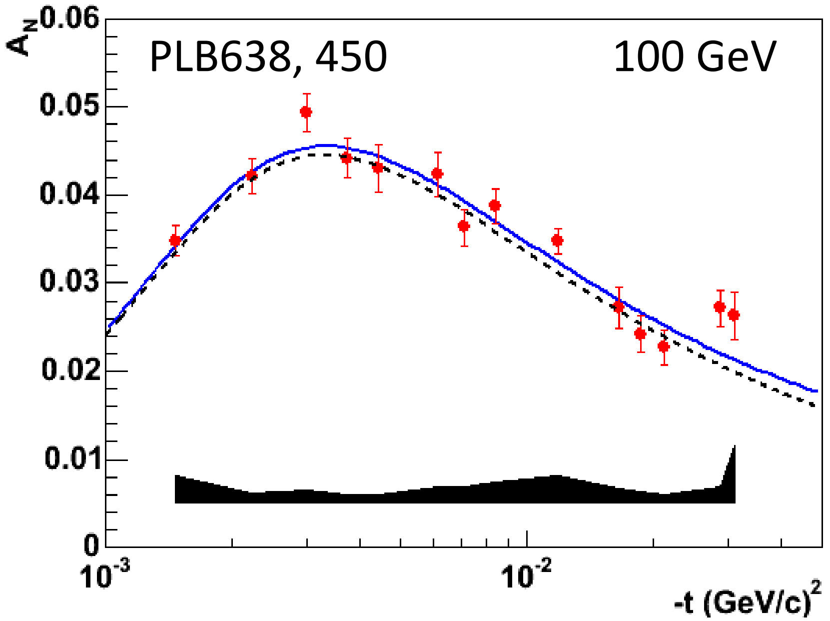



Successfully tested in Run8

- ✓ Background level is the same as in single beam mode
- ✓ Will allow to monitor both beam polarizations by HJet simultaneously in all fills

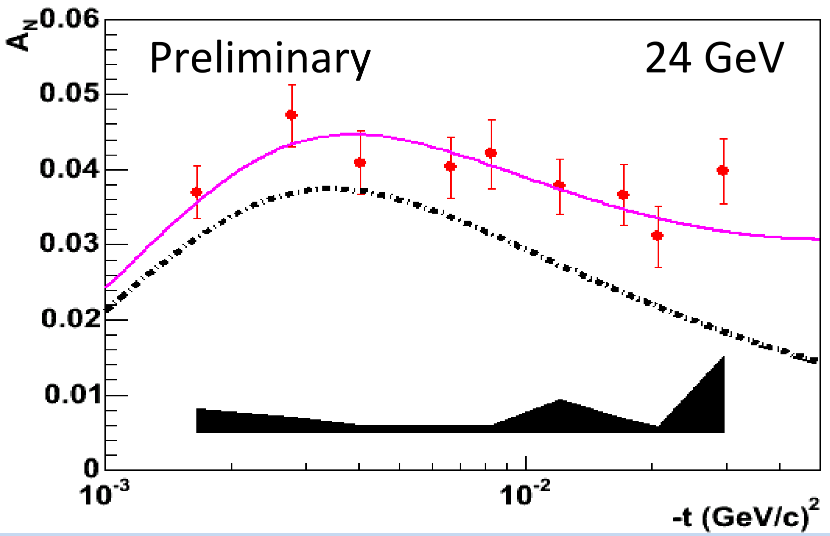
# HJet: $A_N$ in pp

$$A_N^{pp} = \frac{\varepsilon_{\text{target}}}{P_{\text{target}}}$$




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

100 GeV: calculations with no hadronic spin flip amplitude contribution are consistent with data




24 GeV: calculations with no hadronic spin flip amplitude contribution are not consistent with data

$A_N$ almost constant vs beam energy → Reliable polarimetry in wide range of beam energies

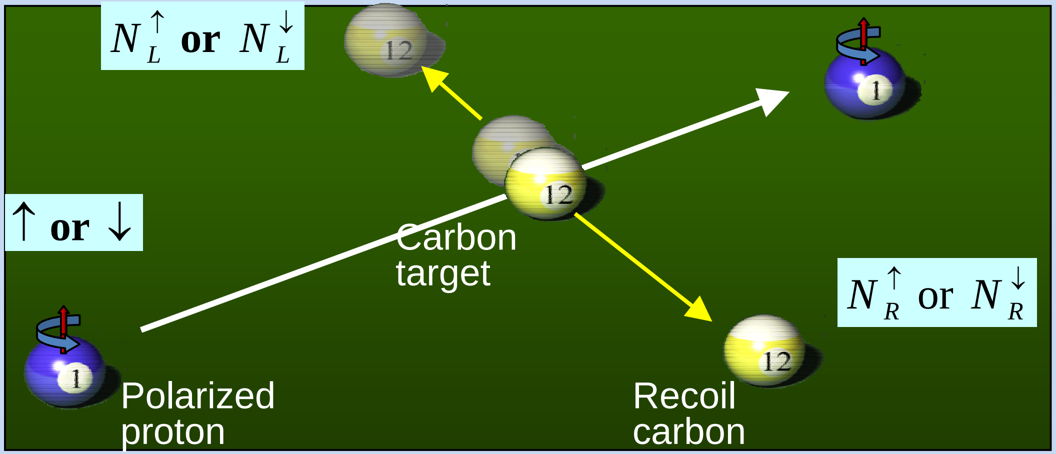
More data to come:
24 GeV: take more data in Run9/10
31 GeV: finalize analysis of data from Run6
250 GeV: take data in Run9/10

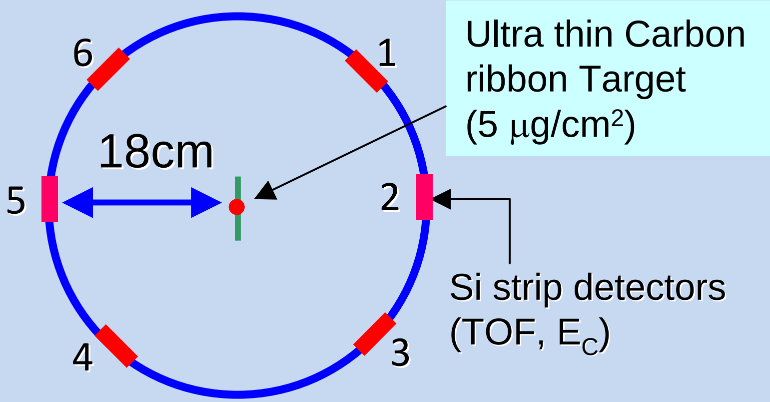
# pC:

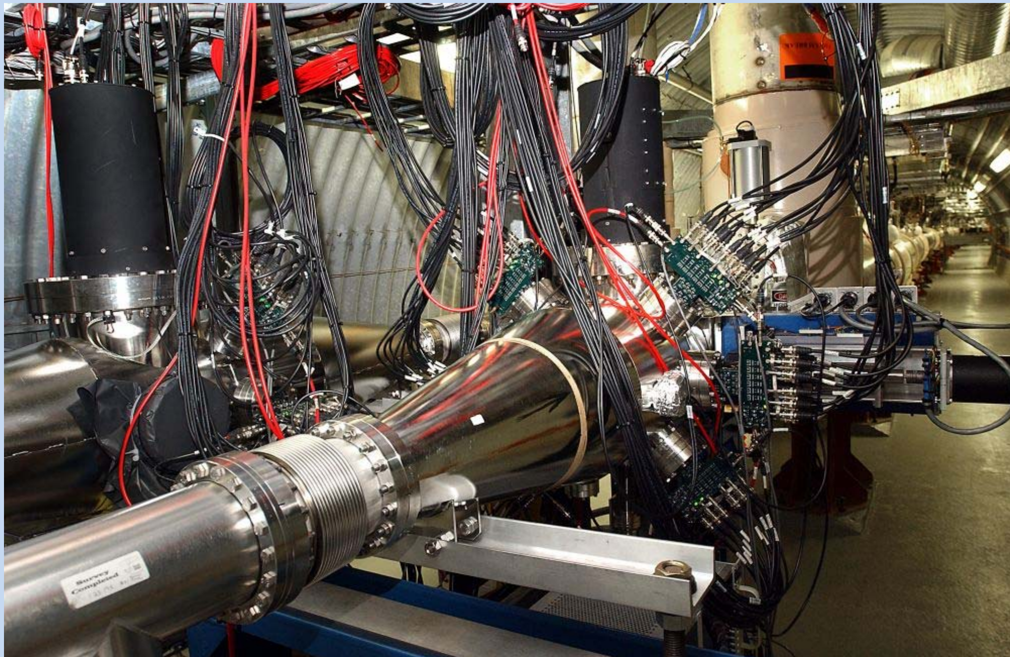
Left-right asymmetry in elastic scattering: Interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$



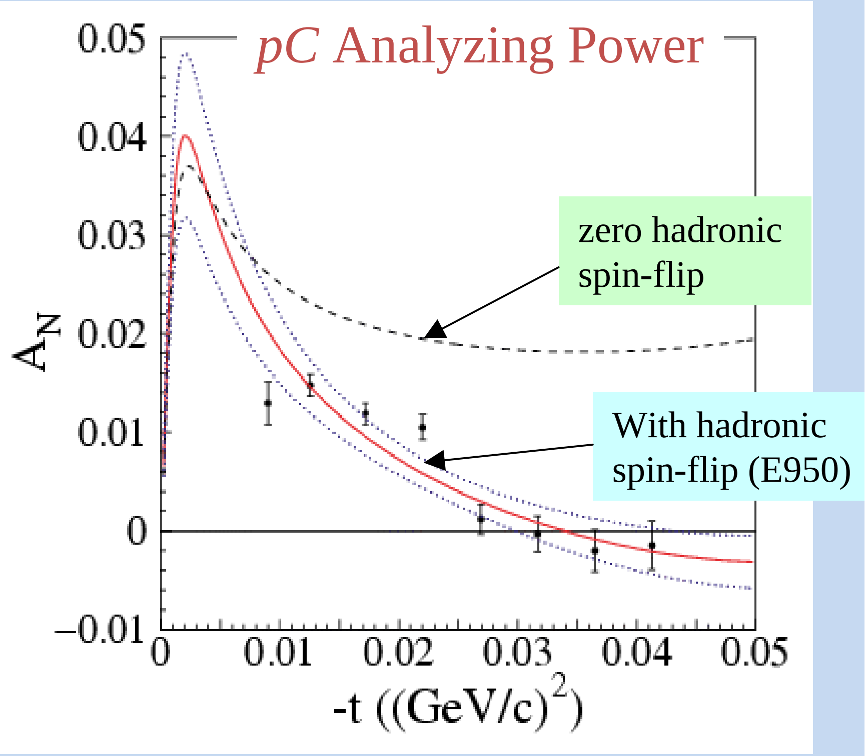



# pC: $A_N$

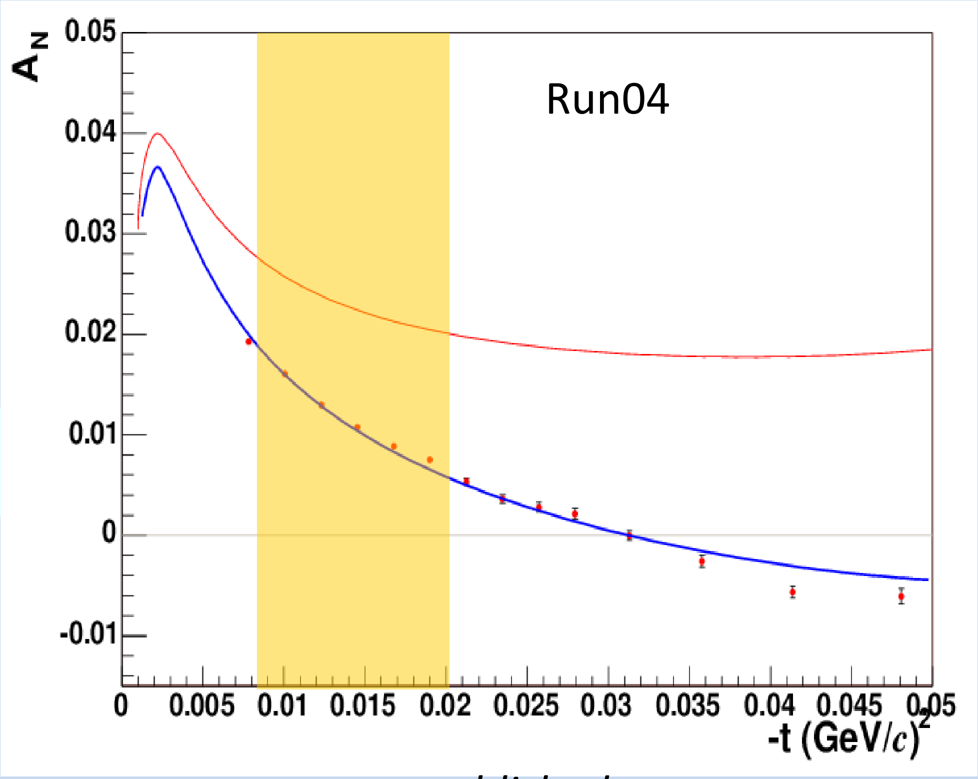
Elastic scattering: interference between electromagnetic and hadronic amplitudes in the Coulumb-Nuclear Interference (CNI) region

$$A_N \approx C_1 \phi_{flip}^{em\,*} \phi_{non-flip}^{had} + C_2 \phi_{non-flip}^{em\,*} \phi_{flip}^{had}$$




*Phys.Rev.Lett.,89,052302(2002)*

$E_{beam}$ = 21.7GeV




*unpublished*

$E_{beam}$ = 100 GeV

# pC: goals/strategy

Polarization measurements for experiments

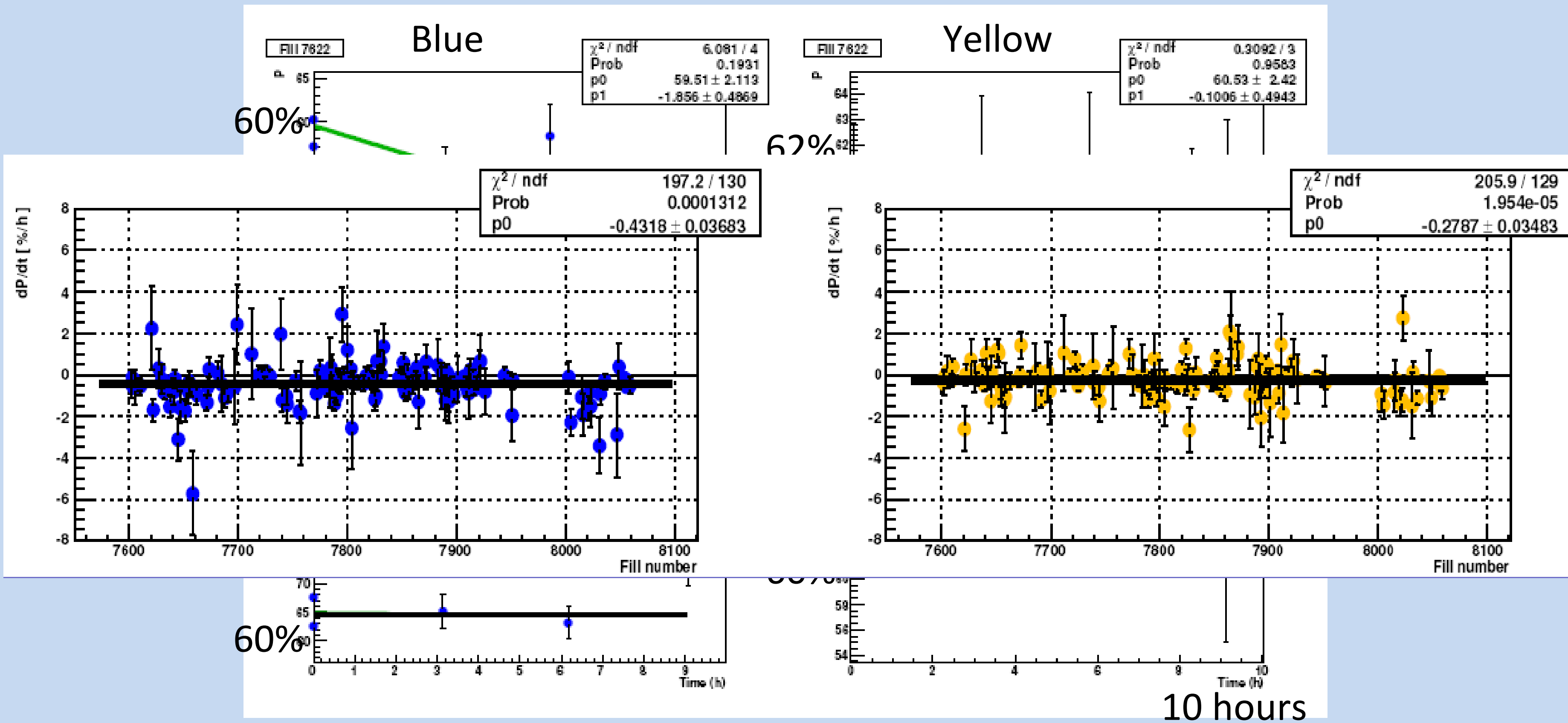
- Target Scan mode
  - Provides polarization at beam center, polarization profile, average polarization over profile
- 20-30 sec per measurement
  - For stat. precision 2-3%
- 4-5 measurements per fill, per ring
  - Controls polarization decay vs time in a fill
- Polarization profile, both vertical and horizontal
- Normalized to HJet measurements over many fills
  - Knowledge on polarization profile in one transverse direction is required
- Fill-by-fill polarization
  - Knowledge on polarization profile in both transverse directions is required

Feedback for accelerator experts

- Beam emittance measurements, bunch-by-bunch
- Polarization
- Polarization profile, both vertical and horizontal
- Polarization at injection (and polarization loss in transfer)
- Polarization on the ramp (and polarization loss during ramp)

# pC: polarization in a fill

Example from Run6

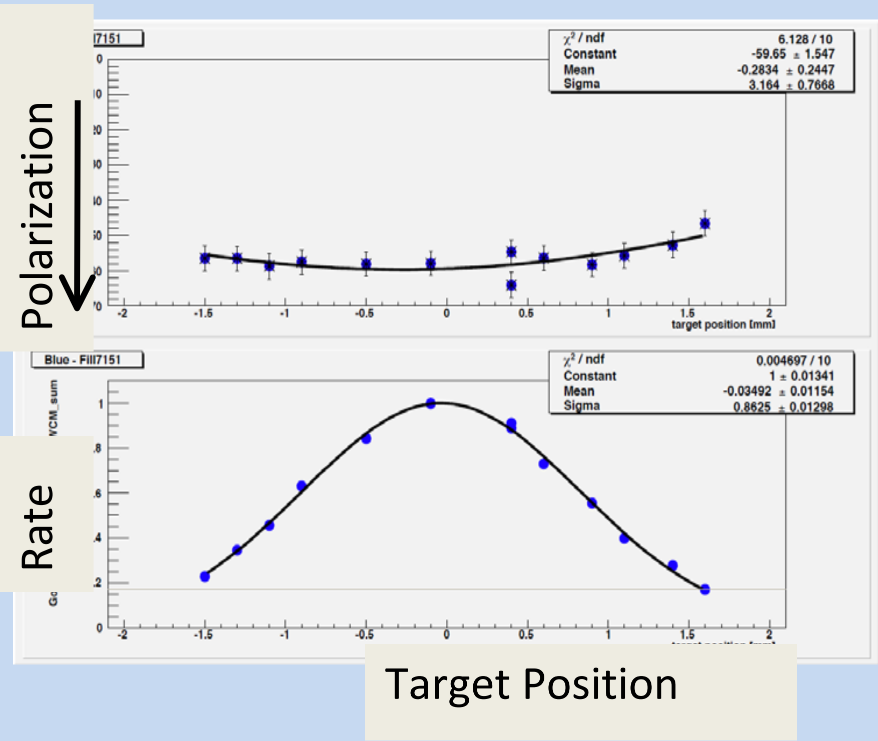


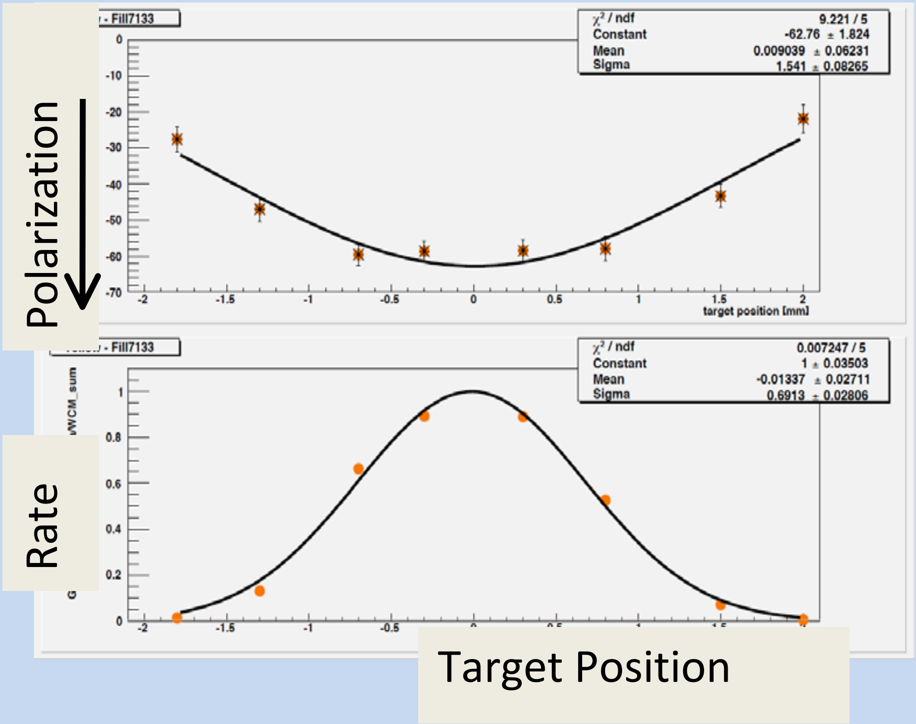

Some fills may show polarization decay vs time

Run6: average polarization drop during a fill 0.3-0.4% per hour

# pC: Polarization Profile

Examples of pC measurements in Run5

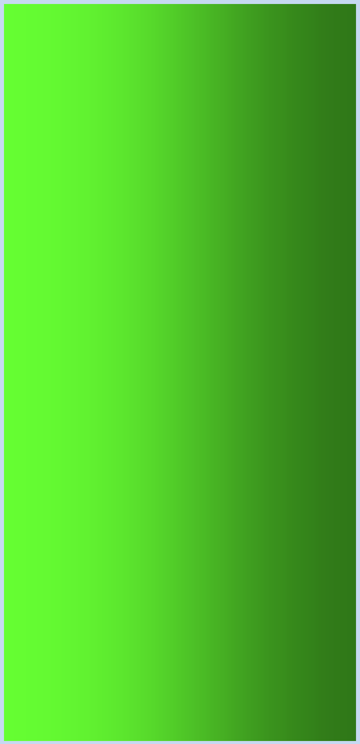


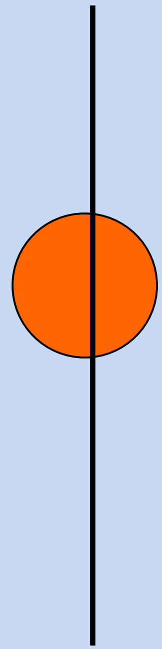

Beam polarization profile is different for different beams, different fills $\Rightarrow$
Correction for **average polarization** depends on beam/fill

# Average Polarization

H-Jet

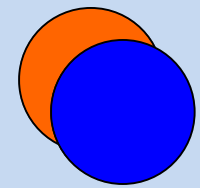


pC



$x$=$x_0$

Collider Experiments



$$\langle P \rangle = \frac{\int P(x,y) I(x,y) dxdy}{\int I(x,y) dxdy}$$

$$\langle P \rangle = \frac{\int P(x0,y) I(x0,y) dy}{\int I(x0,y) dy}$$

$$\langle P \rangle = \frac{\int P(x,y) I_1(x,y) I_2(x,y) dxdy}{\int I_1(x,y) I_2(x,y) dxdy}$$

$P(x,y)$ – polarization profile, $I(x,y)$ – intensity profile

# Average Polarization

$$P(x) = P_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_P^2}\right) \qquad I(x) = I_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right) \qquad R = \frac{\sigma_I^2}{\sigma_P^2}$$

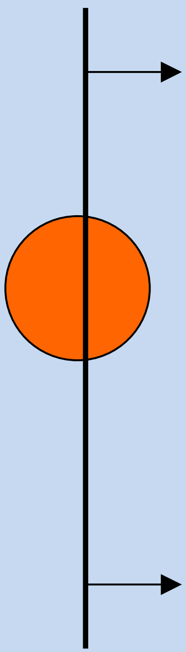
| | | |
|---|---|---|
| H-Jet | $\langle P \rangle = \frac{\int P(x,y) I(x,y) dx}{\int I(x,y) dxdy} = \frac{P_{\max}}{\sqrt{1+R_X}}$ | |
| pC | $\langle P \rangle = P_{\max}$ | If target positioned at beam peak intensity/polarization |
| Collider Experiment | $\langle P \rangle = \frac{\int P(x,y) I_1(x,y) I_2(x,y) dxdy}{\int I_1(x,y) I_2(x,y) dxdy} \approx P_{\max} \frac{\sqrt{1+\frac{1}{2}R_Y}}{\sqrt{1+\frac{1}{2}R_X}}$ | If $\sigma_{I1} = \sigma_{I2} = \sigma_I$ |

Corrections due to polarization profiles are different when normalizing pC to H-Jet and when propagating pC measurements to experiments

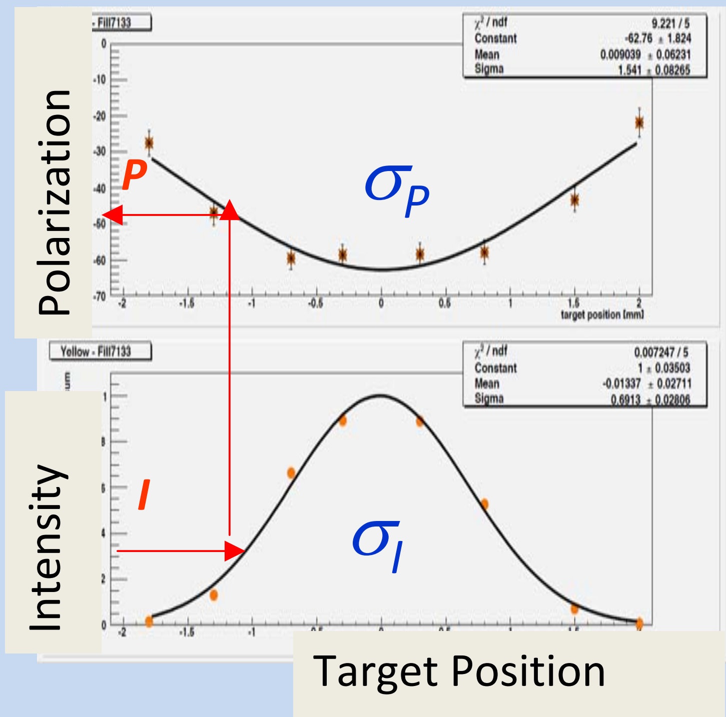
Polarization profile in both trans. directions (X,Y) required

# pC: Polarization Profile

pC



Scan C target over the beam cross:




1. Directly measure $\sigma_I$ and $\sigma_P$:

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

2. Obtain R directly from the $P(I)$ fit:

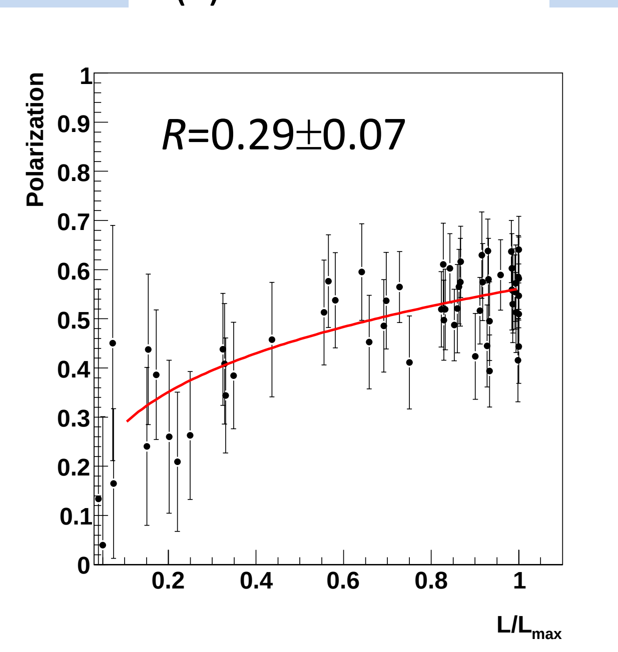
$$\left.\begin{aligned} P(x) &= P_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_P^2}\right) \\ I(x) &= I_{\max} \cdot \exp\left(-\frac{x^2}{2\sigma_I^2}\right) \end{aligned}\right\} \quad P = P_{\max} \cdot \left(\frac{I}{I_{\max}}\right)^R$$

Precise target positioning is NOT necessary

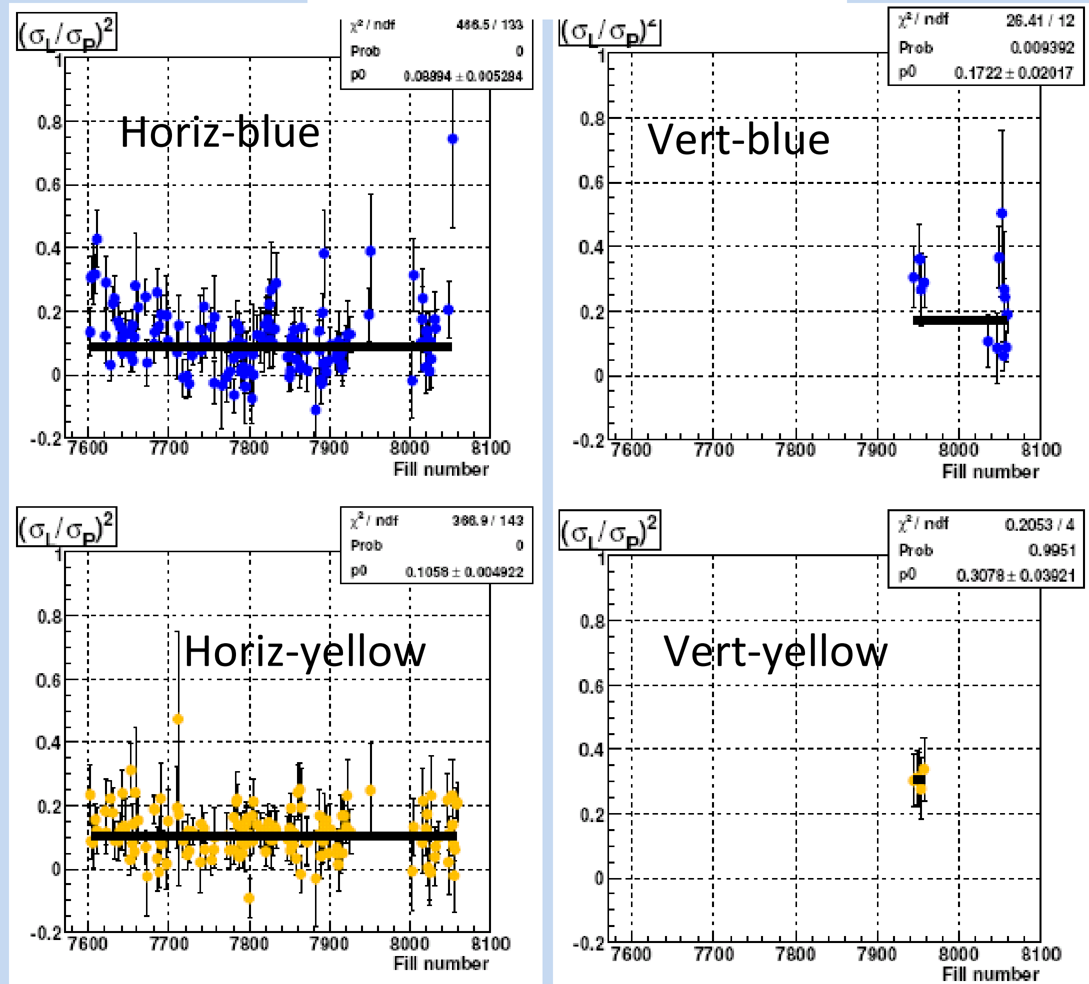
# pC: Polarization Profile

$$P = P_{\max} \cdot \left( \frac{I}{I_{\max}} \right)^R$$

*P*(*L*) in one fill



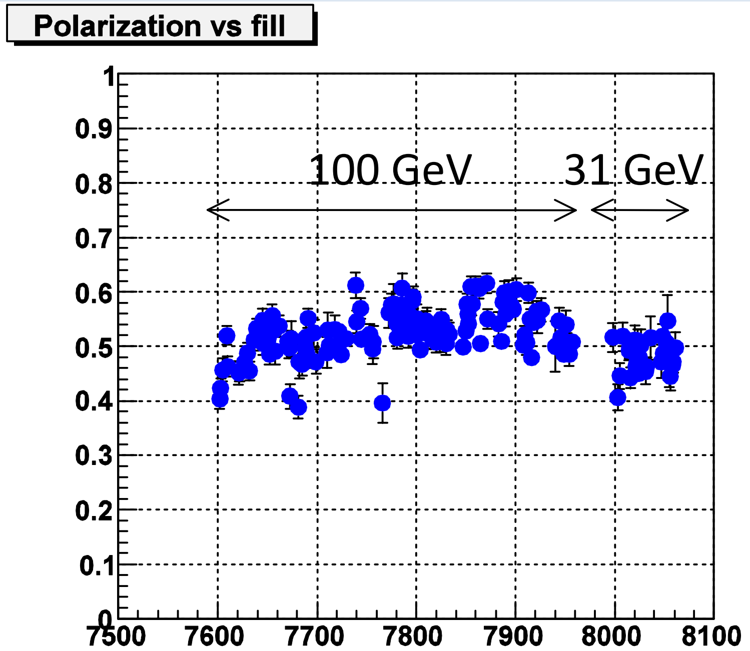

Run6 data: R vs fill

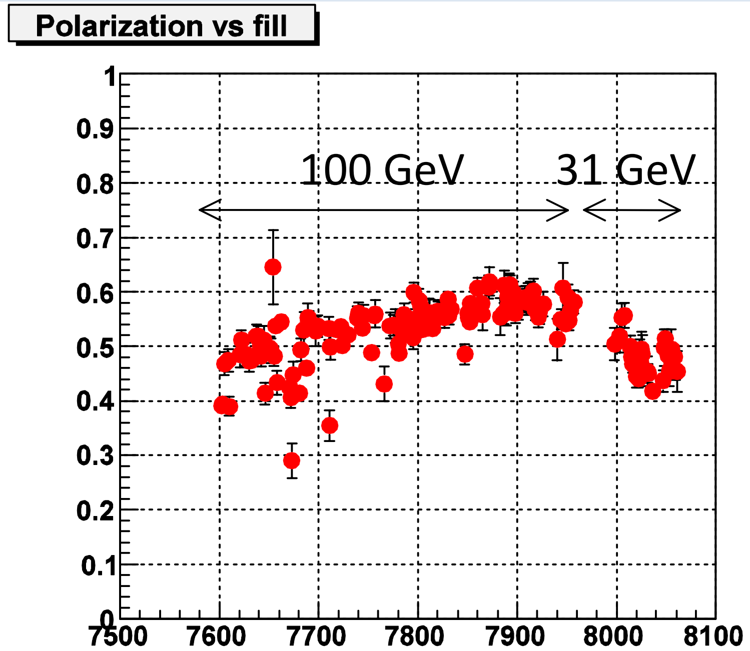



*R* ~ 0.1–0.3 ⇒ 5–15% different polarization seen by HJet and by experiments

# pC: Polarization vs Fill

Run6 results



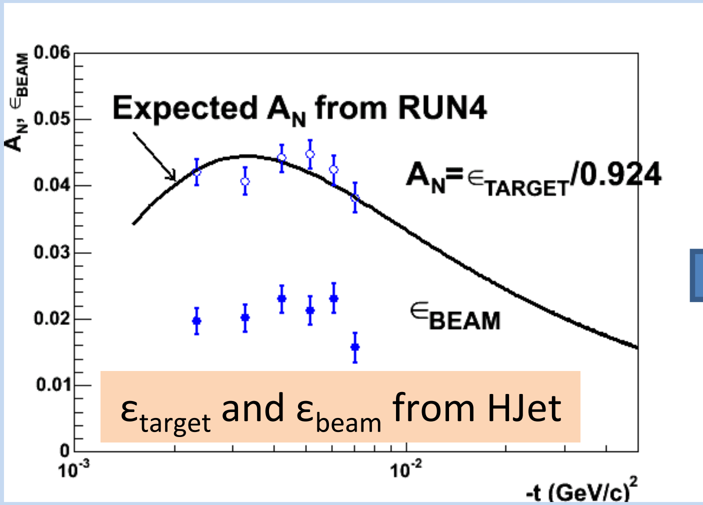

- ✓ Normalized to Hjet
- ✓ Corrected for polarization profile

$$\frac{\delta P_B}{P_B} = 4.7\% \qquad \frac{\delta P_Y}{P_Y} = 4.8\%$$

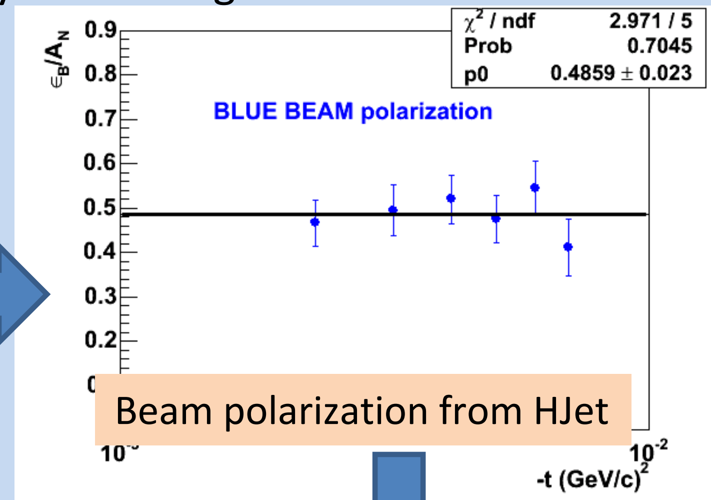
$$\frac{\delta (P_B P_Y)}{P_B P_Y} = 8.3\%$$

# Hjet+pC: Run8 Analysis

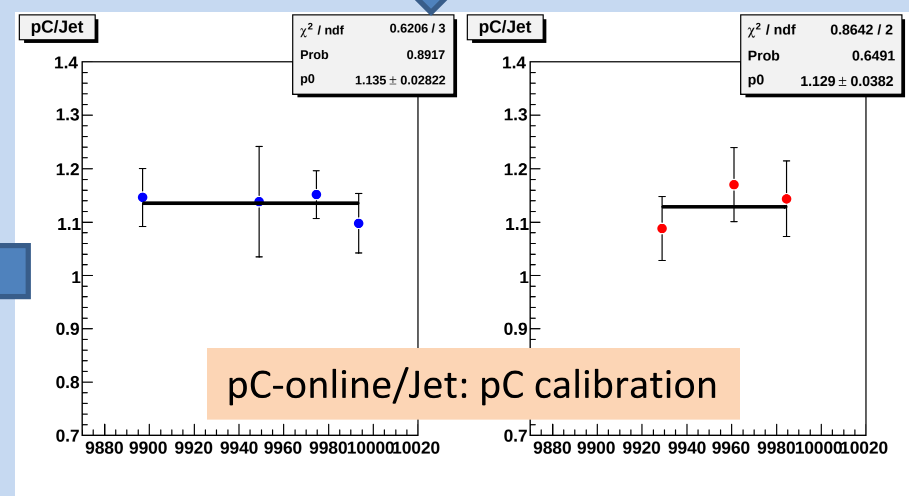
Fast (~online) analysis – during the run



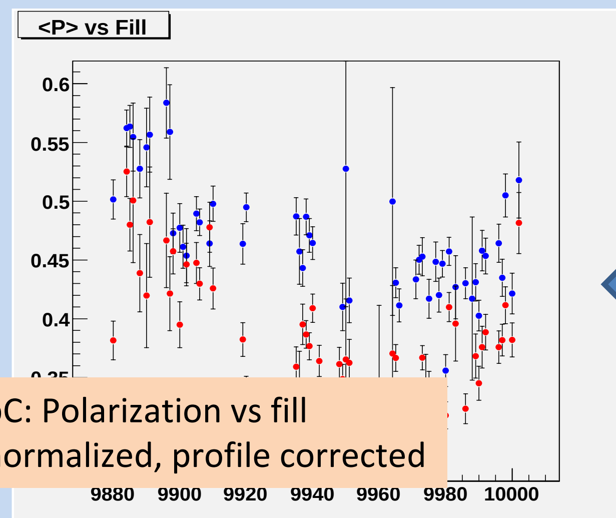

$\varepsilon_{target}$ and $\varepsilon_{beam}$ from HJet




Beam polarization from HJet




pC-online/Jet: pC calibration




pC: Polarization vs fill normalized, profile corrected

**Offline analysis is almost completed and results will be released soon**

# pC: Upgrade

## Detector upgrade

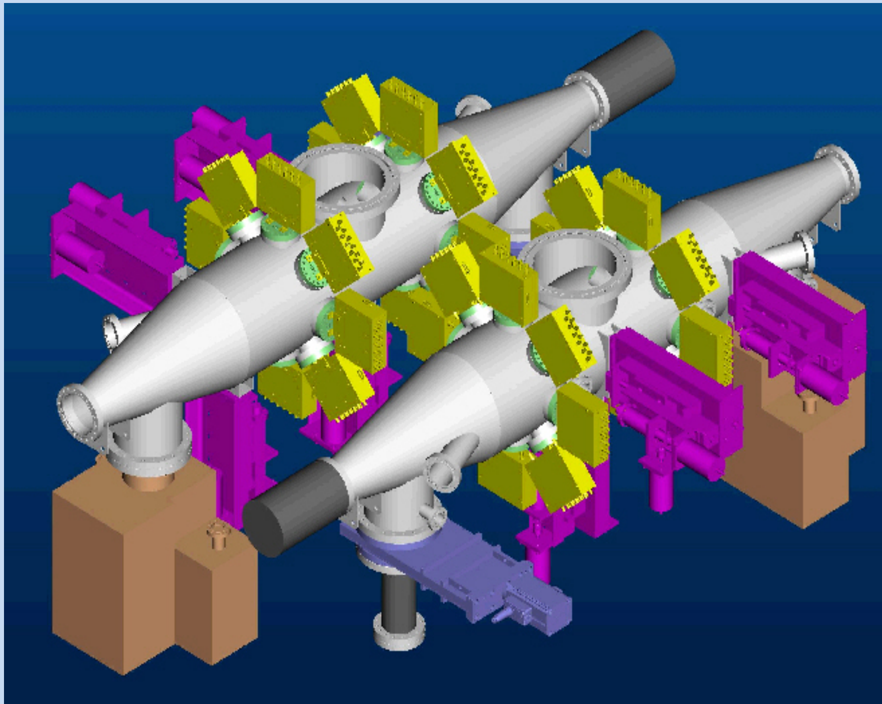
- Photo-diode instead of Si strips

## Target upgrade

- Possibility of using nano-tubes under investigation

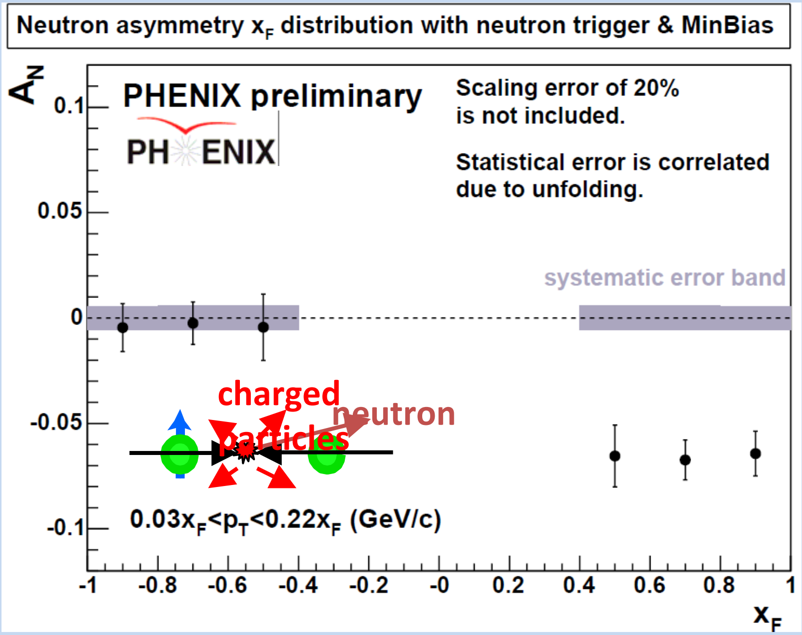
## pC vacuum chamber upgrade

- Two polarimeter setups per ring
- Double number of targets (to avoid a need to open chamber to install new targets during the run)
- Reduce the time required for successive measurements  of horiz.  and vert. profiles
- Allows installation and testing  new detectors for higher rate capabilities



# PHENIX Local Polarimeter

Utilizes spin dependence of very forward neutron production (PLB650, 325):




ZDC (energy) + SMD (position)

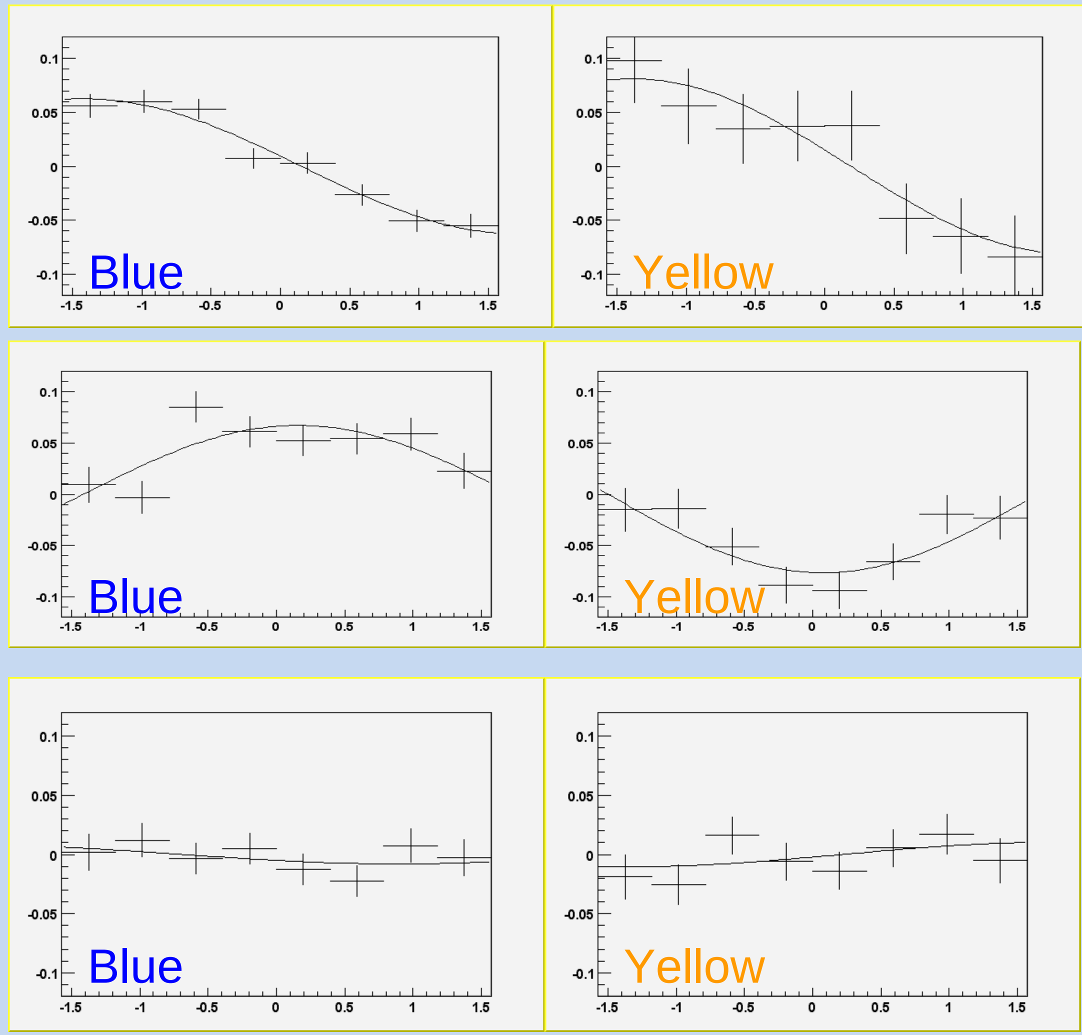
# PHENIX Local Polarimeter

Asymmetry vs $\phi$

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Current Reversed
Radial polarization

Spin Rotators ON
Correct Current !
Longitudinal polarization!

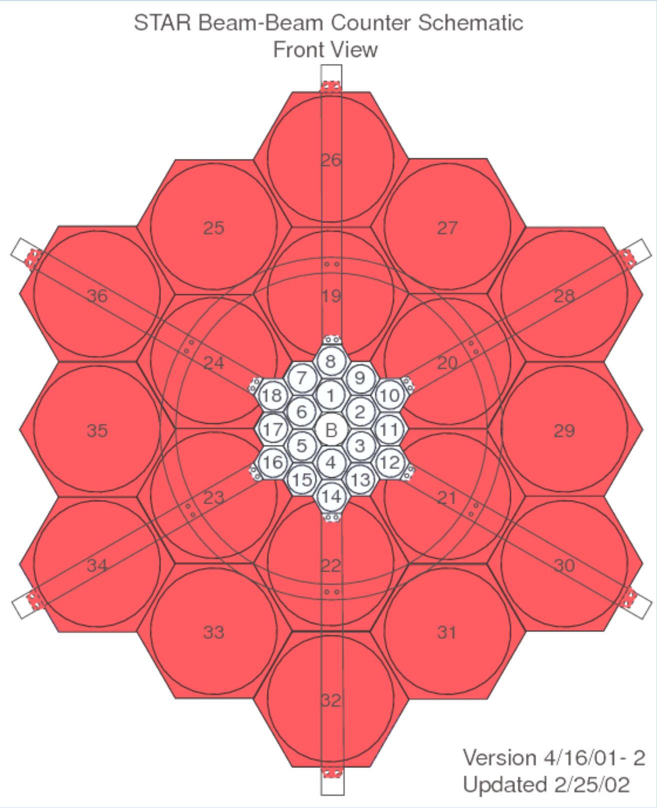



Monitors spin direction in PHENIX collision region

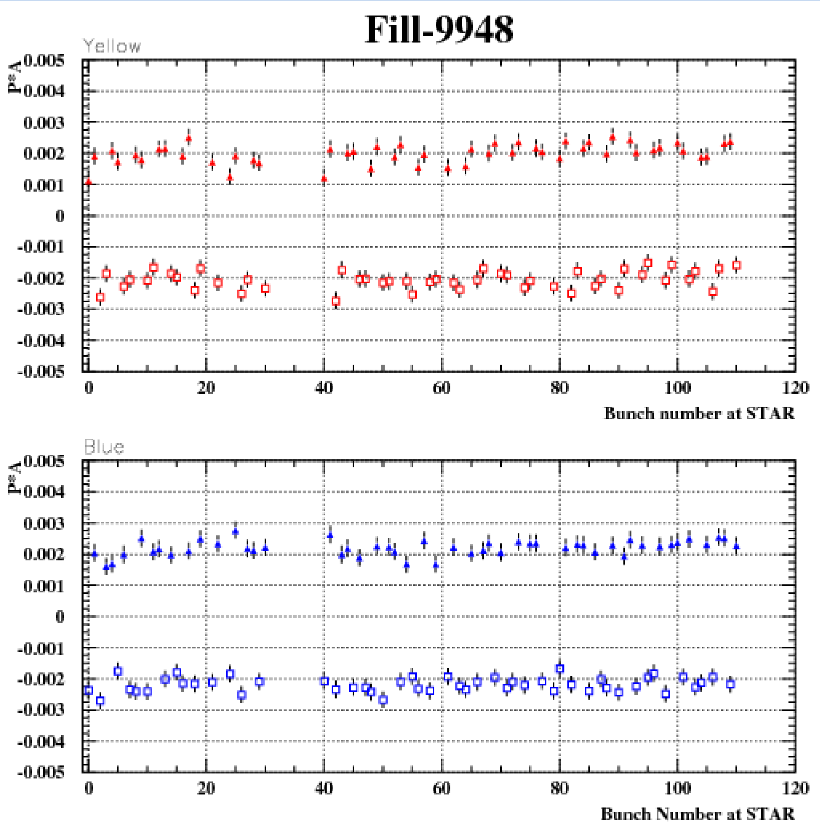
# STAR Local Polarimeter

Utilizes spin dependence of hadron production at high $x_F$:

$3.3<|\eta|<5.0$ (small tiles only)




Bunch-by-bunch (relative) polarization




Monitors spin direction in STAR collision region

Capable to precisely monitor polarization vs time in a fill, and bunch-by-bunch

# Summary

## RHIC Polarimetry consists of several independent subsystems

<u>Hjet:</u>

- Absolute polarization measurements
- Absolute normalization for other RHIC Polarimeters

<u>pC:</u>

- Separate for blue and yellow beams
- Normalization from HJet
- Polarization vs time in a fill
- Polarization profile
- Fill-by-fill polarizations for experiments

<u>PHENIX and STAR Local Polarimeters:</u>

- Monitor spin direction (through trans. spin component) at collision
- Polarization vs time in a fill (for trans. pol. beams)
- Polarization vs bunch (for trans. pol. beams)

## Reliably provides RHIC beam polarizations

With relative uncertainty better than 5%

## Continuously developing

Detector and target system upgrade to deal with high beam intensities, and to improve efficiency and reliability

# RHIC CNI Polarimetry Group: a factory of CNI Polarimetrer experts

Each Run (Year) new students/postdocs are involved in the data monitoring and data analysis. They

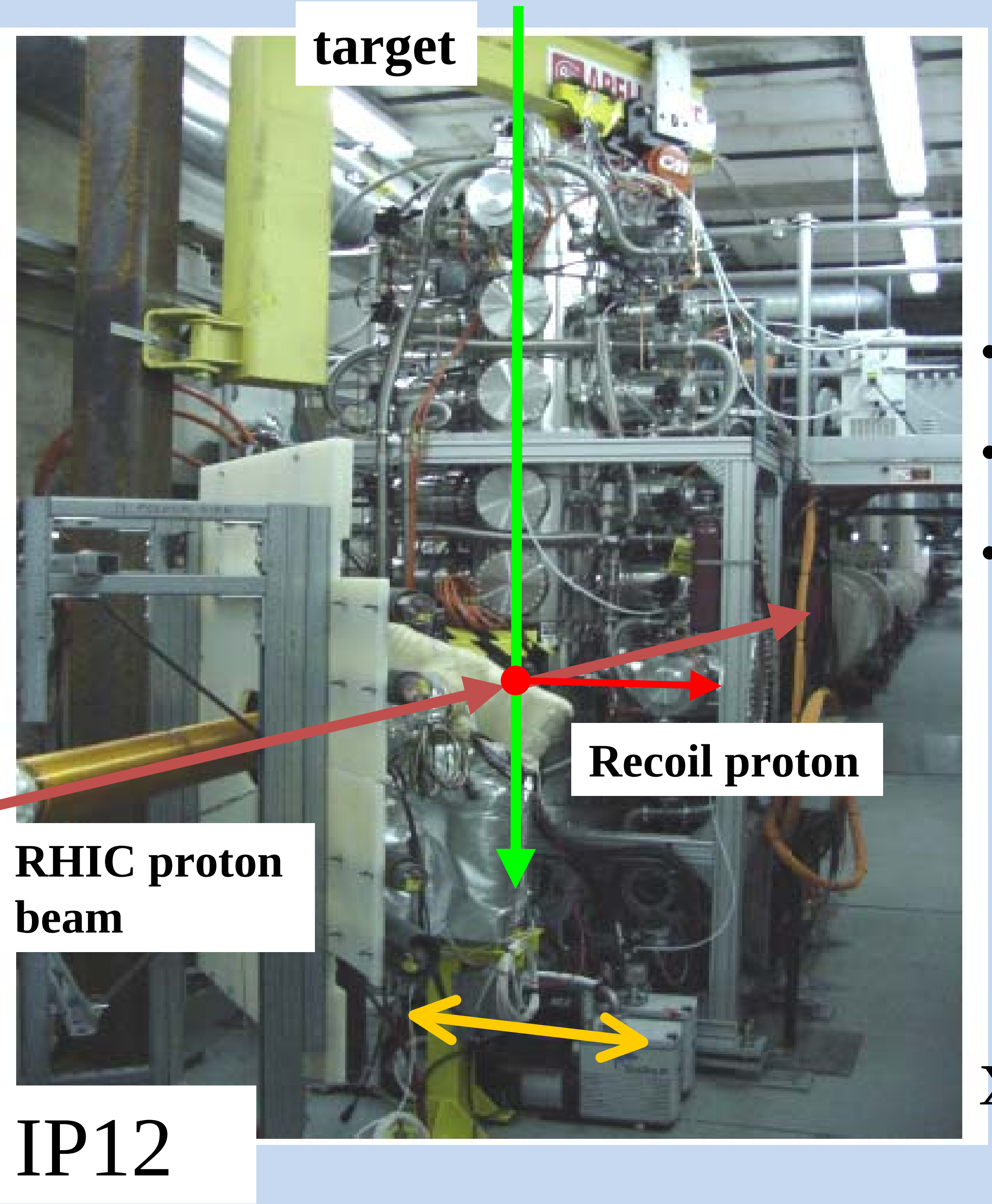
- Learn
- Contribute
- Leave (to use newly gained expertise in other projects)

A call for new volunteers to work on Run9/10 etc.

- Please come, learn, become an expert, contribute
- New challenges every Run/Year
- Physics is coming out (with more statistics, reduced systematics, different energies)

# Backups

# H-jet system




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