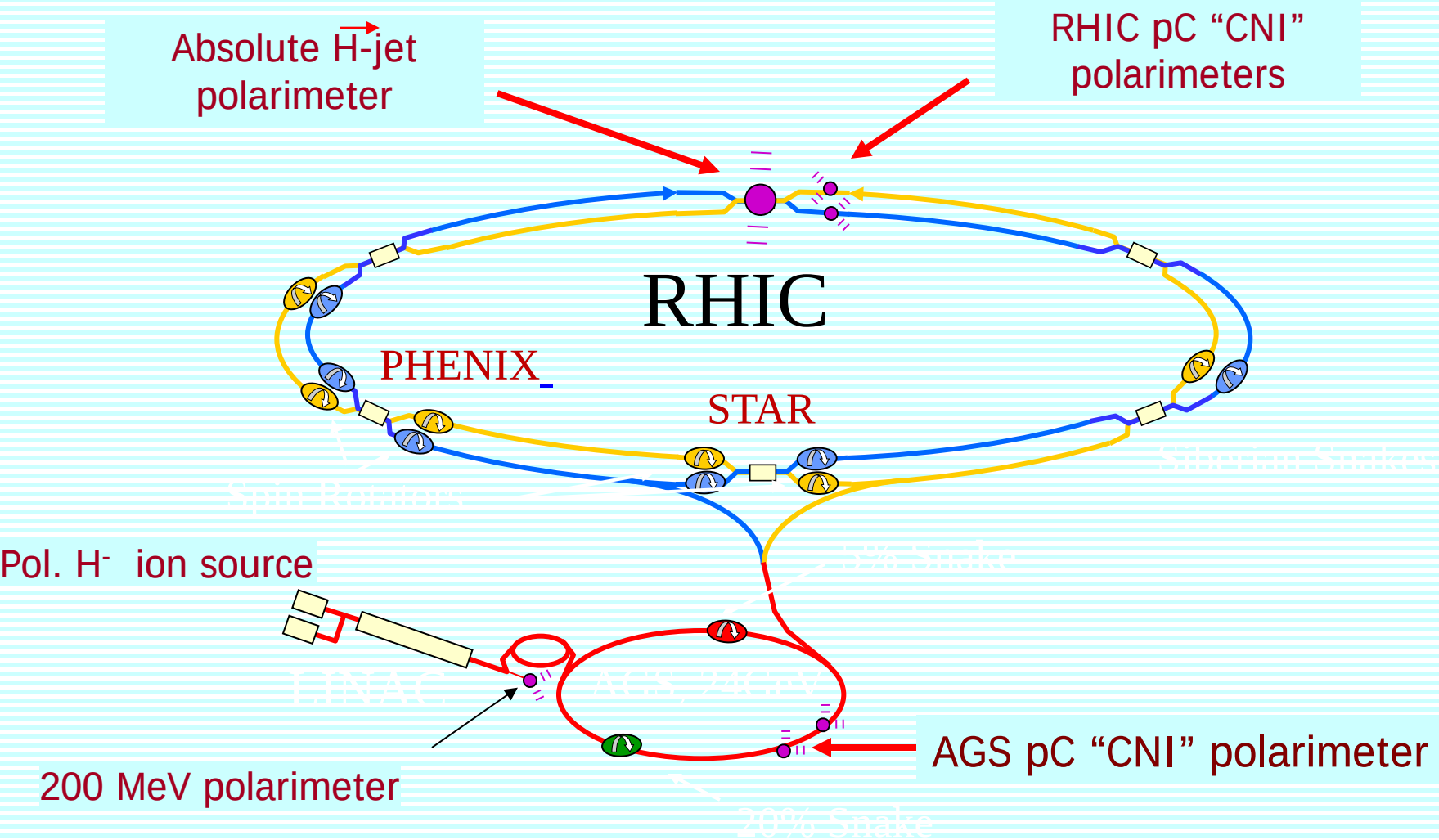
RHIC polarimeter operation.

A.Zelenski, CAD

June 27, 2012

Polarization facilities at RHIC.

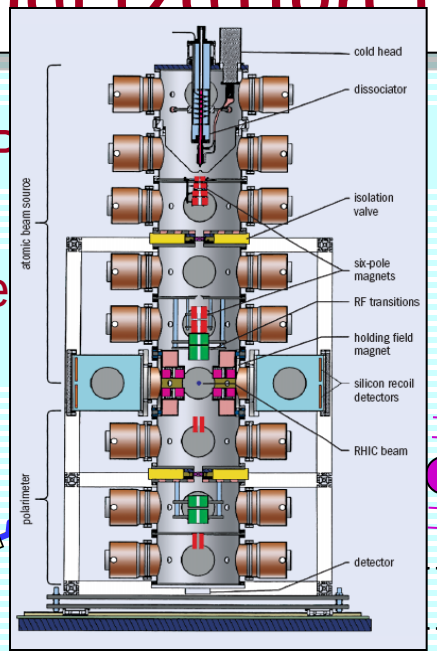
Design goal - 70% Polarization $L_{max} = 1.6 \times 10^{32}\ s^{-1}cm^{-2}$ $\sqrt{s}$ =50-500 GeV



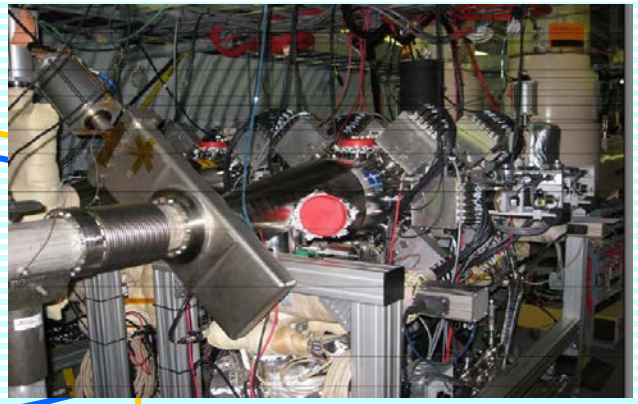
Polarization facilities at RHIC.

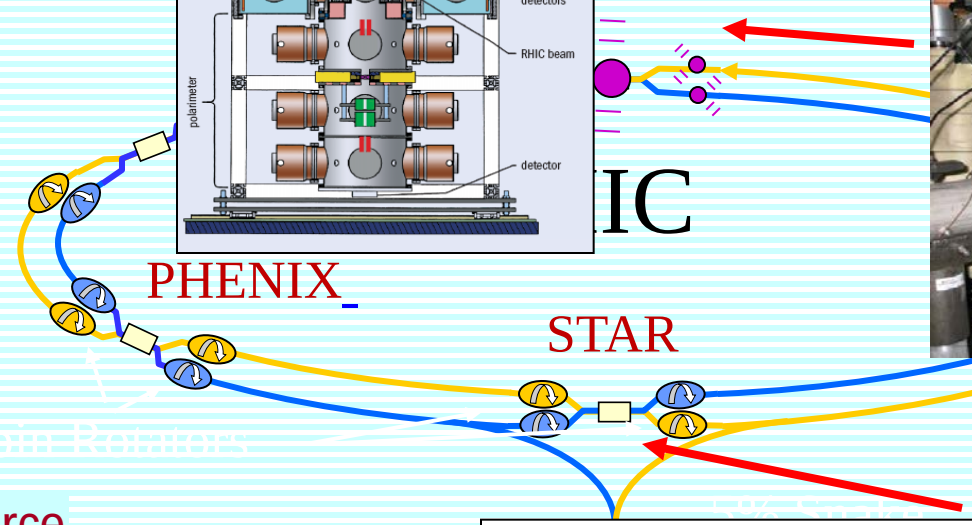
Design goal - 70% P = 1.6×10^{32} $s^{-1}cm^{-2}$ $50 < \sqrt{s} < 500$ GeV

Absolute $\vec{H}$-je polarimeter

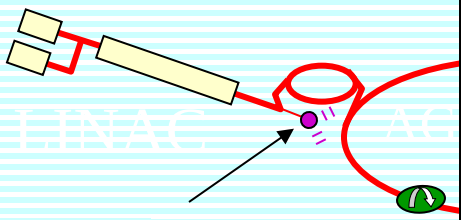


RHIC pC "CNI" polarimeters





Pol. H^- ion source



200 MeV polarimeter

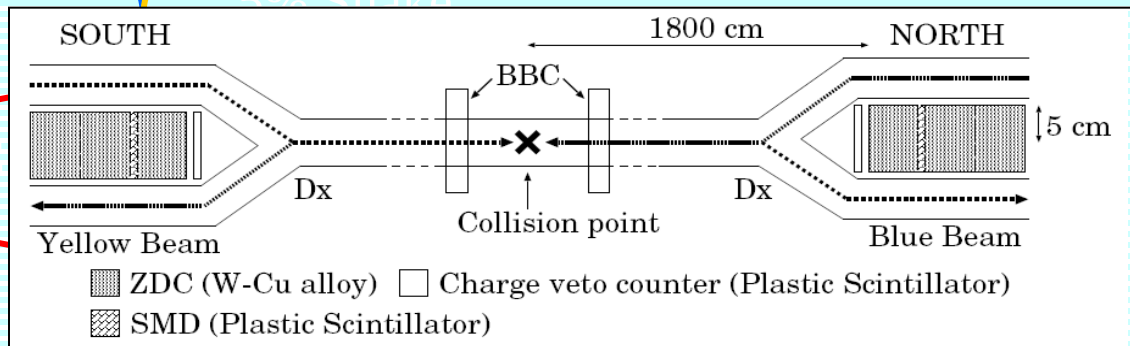


Figure 5.1: A plan view of the experimental setup at PHENIX, not to scale. Shown are the principle components for the leading neutron physics.

Three complimentary pillars of the RHIC polarimetry.

- p-Carbon CNI polarimeter: relative, fast, polarization profiles, bunch-by bunch measurements, polarization decay time.

- Proton-proton H-jet CNI polarimeter: absolute, integral, about 5-7% statistical accuracy in one store.

- Local polarimeters: relative, fast, integral, bunch-by-bunch, polarization decay time.

A_N for Coulomb -Nuclear Interference.

the left – right scattering asymmetry A_N arises from the interference of the spin non-flip amplitude with the spin flip amplitude (Schwinger)

$$A_N = C_1 \,\mathrm{Im}(\phi^{em\,*}_{flip}\,\phi^{had}_{non-flip}) + C_2\,\mathrm{Im}(\phi^{had\,*}_{flip}\,\phi^{had}_{non-flip})$$

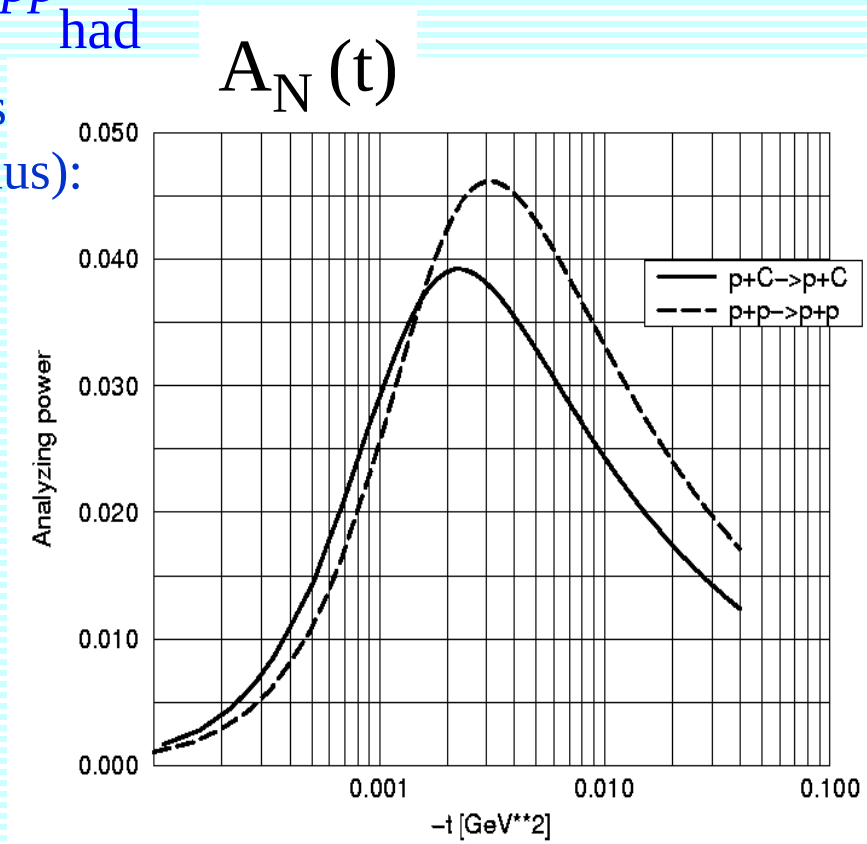
$\propto(\mu-1)_p$ $\propto\sqrt{\sigma^{pp}}_{had}$

in absence of hadronic spin – flip contributions A_N is exactly calculable (Kopeliovich & Lapidus):

$$A_N = \sqrt{\frac{8\pi Z\alpha}{m_p^2\sigma_{tot}^{pA}}}\,\frac{y^{3/2}}{1+y^2}(\mu-1) \qquad y = \frac{\sigma_{tot}^{pA}\,t}{8\pi Z\alpha}$$

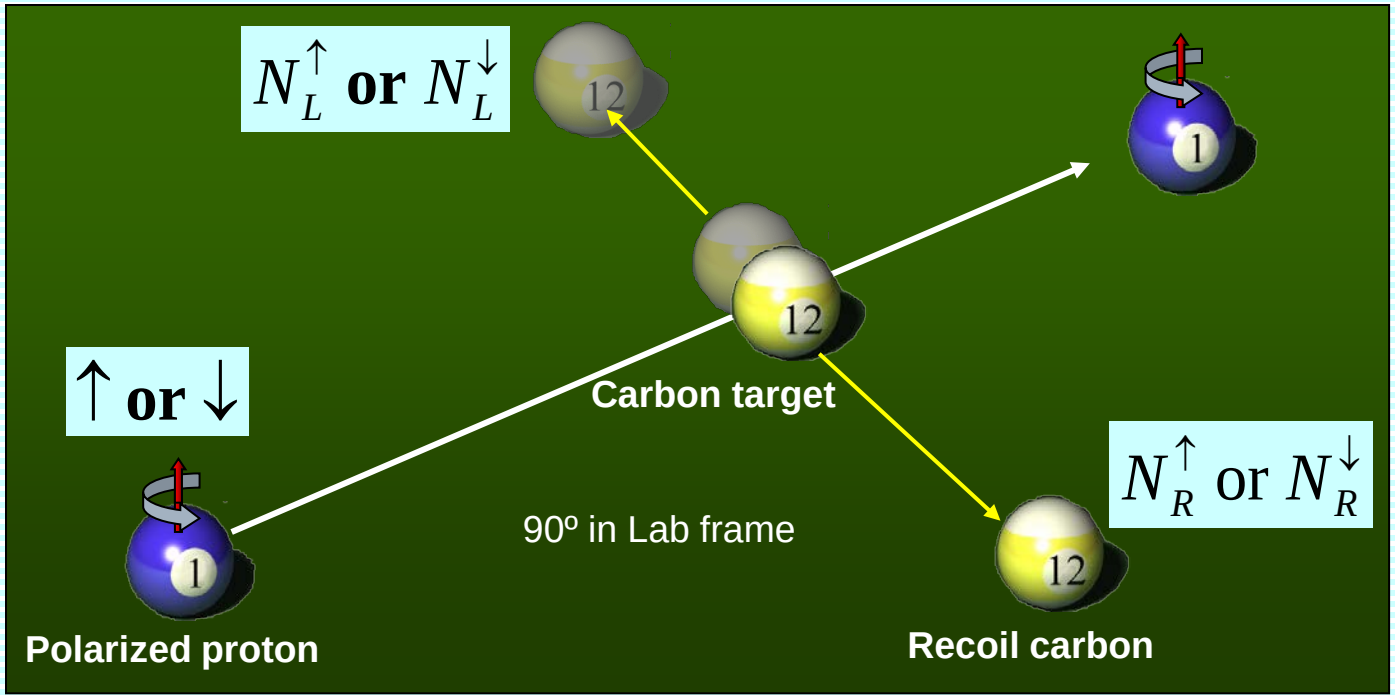
hadronic spin- flip modifies the QED "predictions"

$$\frac{\mu_p-1}{2} \rightarrow \frac{\mu_p-1}{2} - I_5 + \left(\frac{\mu_p-1}{2} I_2\right)$$



p-Carbon Polarimetry at RHIC

$$\vec{p}C \rightarrow \vec{p}C$$



$$t = (p_{out} - p_{in})^2 \approx -2M_C T_{kin} < 0$$

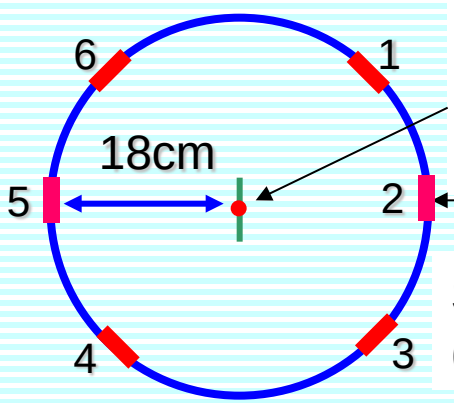
$$0.005 < |t| < 0.05\ (GeV/c)^2$$

The RHIC p-Carbon CNI polarimeter.

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

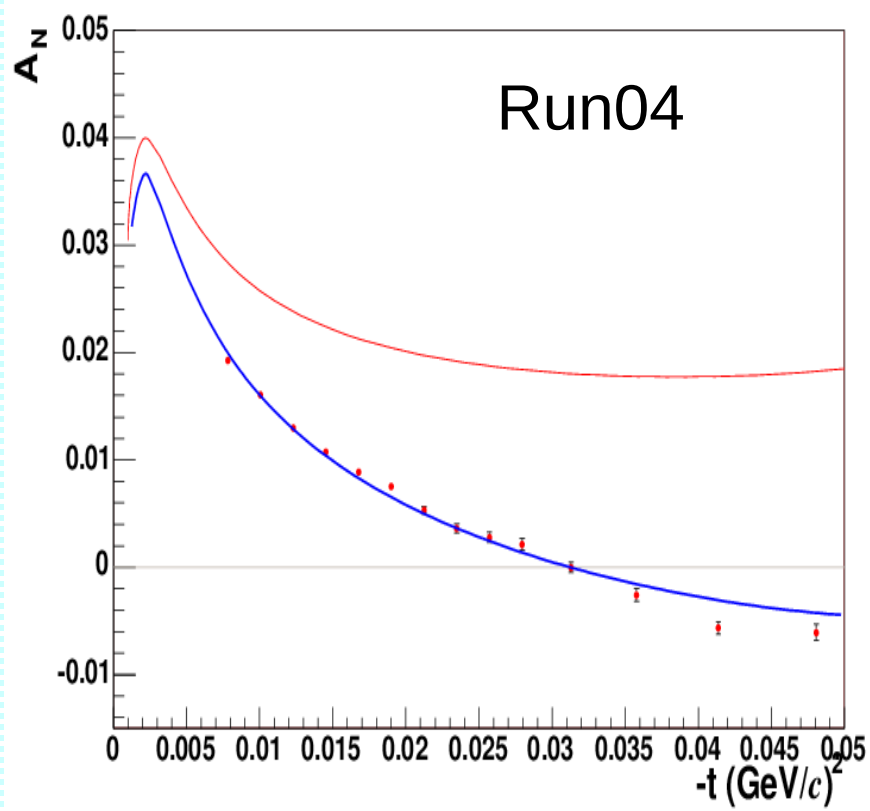
$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

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



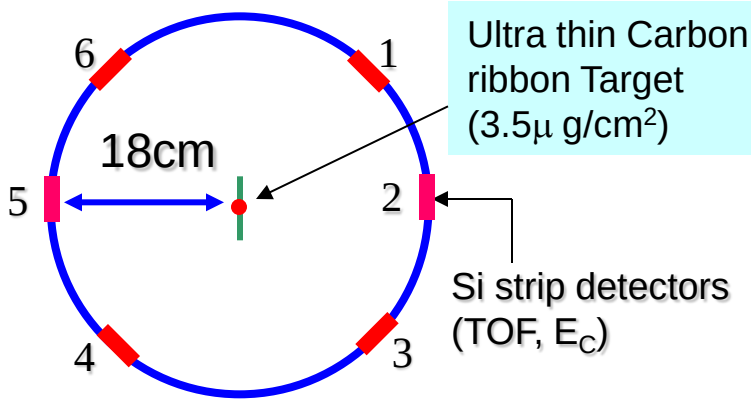
Ultra thin Carbon ribbon Target (5 μg/cm²)

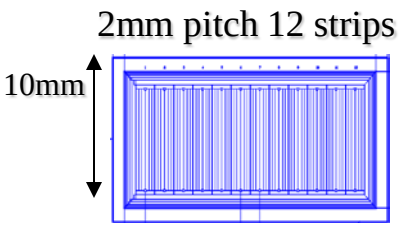
Si strip detectors (TOF, E_C)



E_{beam} = 100 GeV

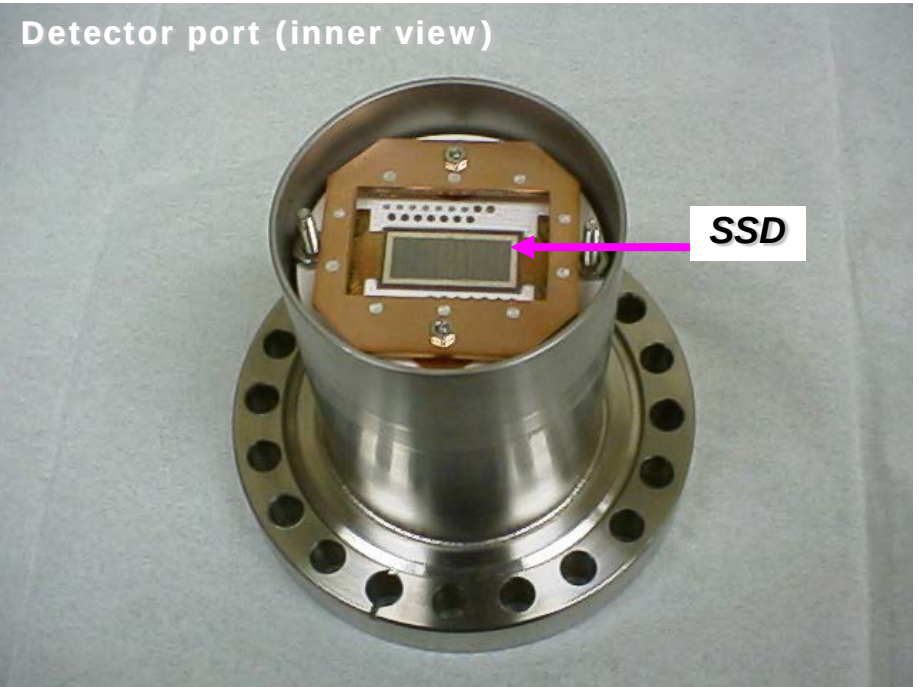
Detector Setup

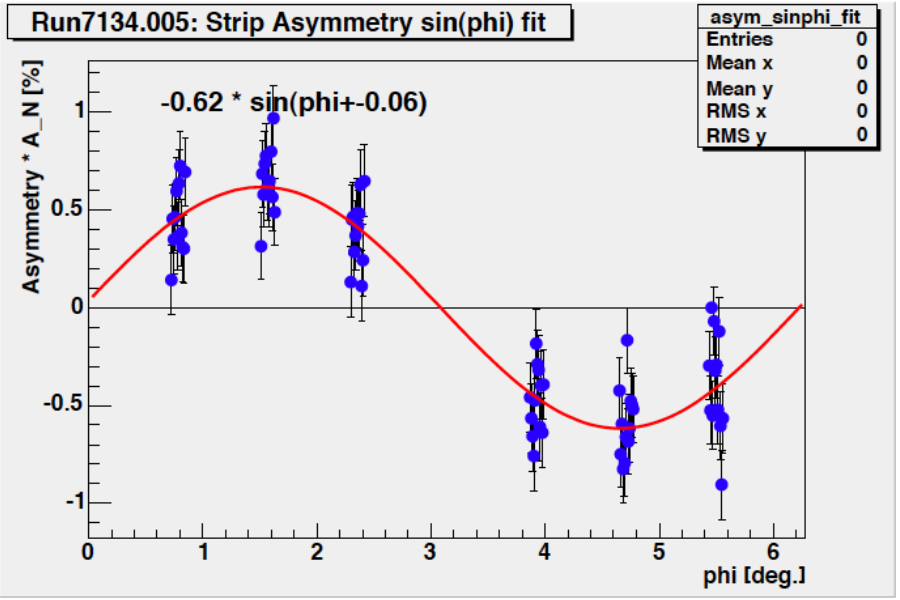




72 strips in total

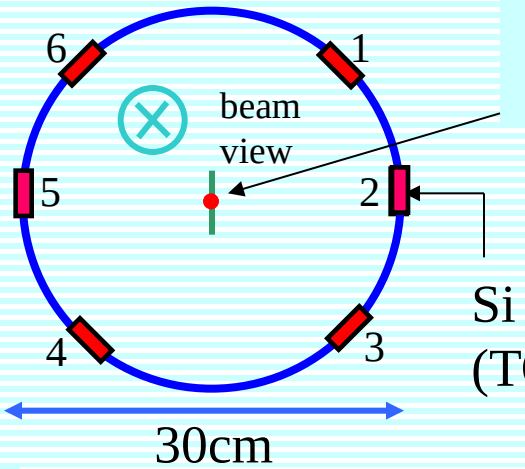
Redundancy
↓
Systematic/Consistency Check





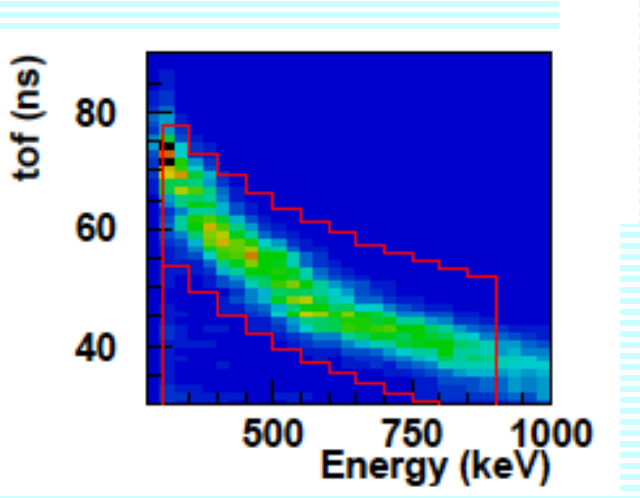
Proton-Carbon CNI polarimeter in RHIC.

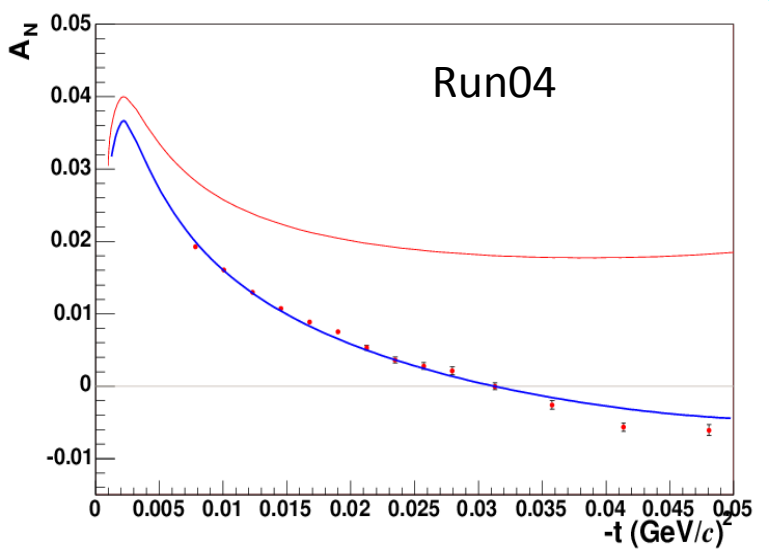
RHIC x 2 rings



Ultra thin Carbon ribbon Target ($3.5\mu g/cm^2$,$10\mu m$)

Si strip detectors (TOF, E_C)





unpublished

E_{beam} = 100 GeV

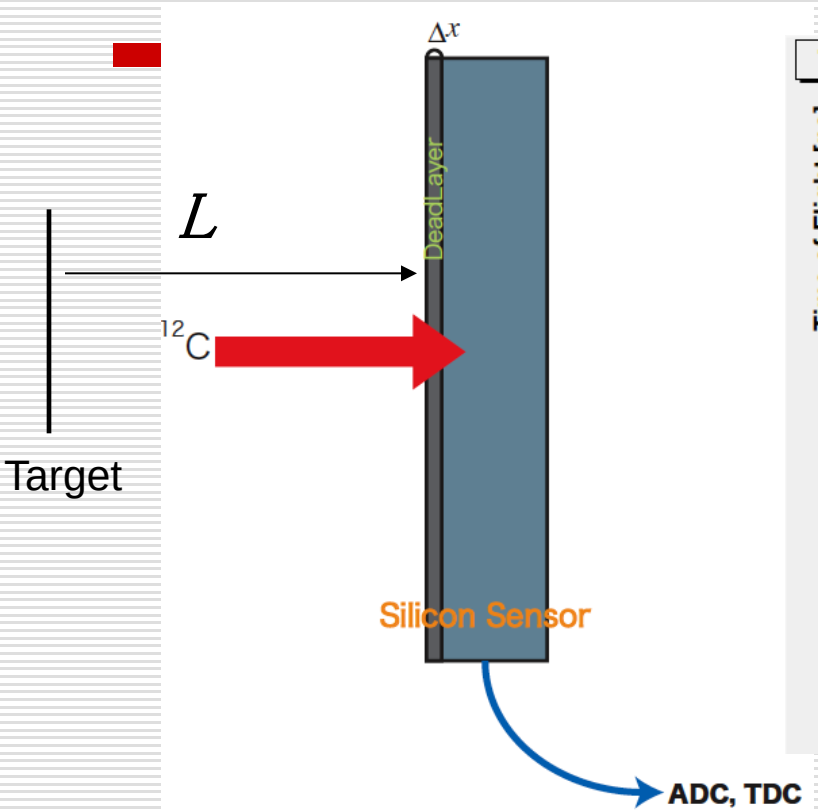
- Measuring the recoil carbons from
- Carbon identification by kinematics cut (banana cut)

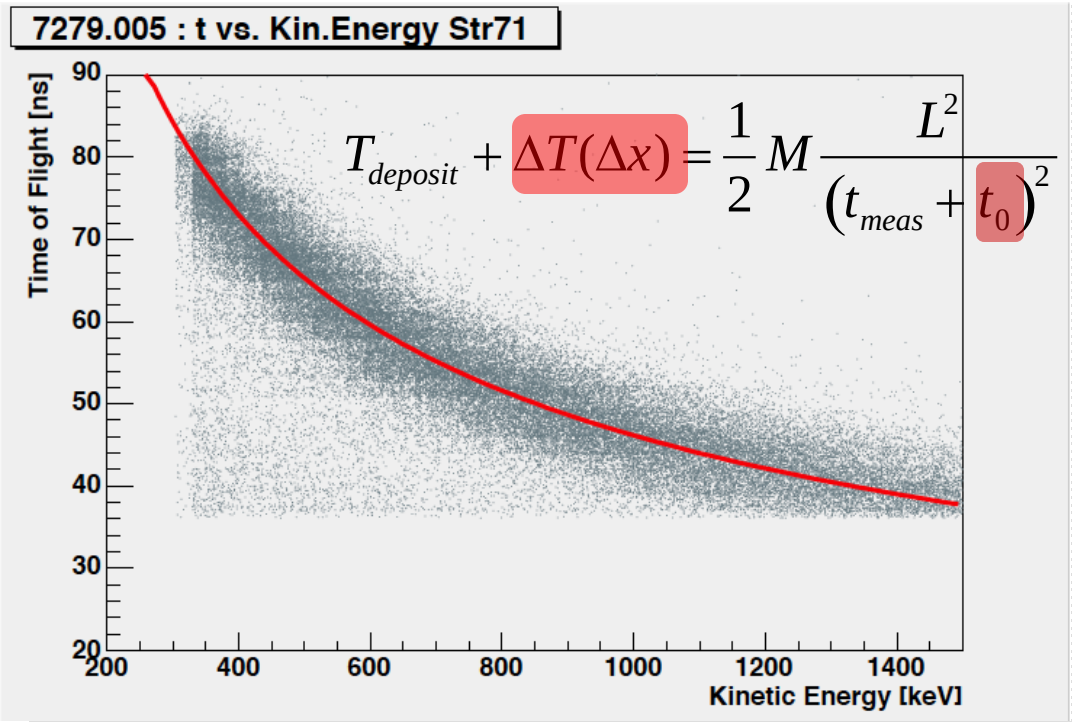
$$p^{\uparrow}C \rightarrow p^{\uparrow}C$$

$$P_B = \frac{\varepsilon_{LR}}{A_N}, \quad \varepsilon_{LR} = \frac{N_L - N_R}{N_L + N_R}$$

$\mathbf{A_N \approx 0.015}$ originates from anomalous magnetic moment of p

Energy Correction





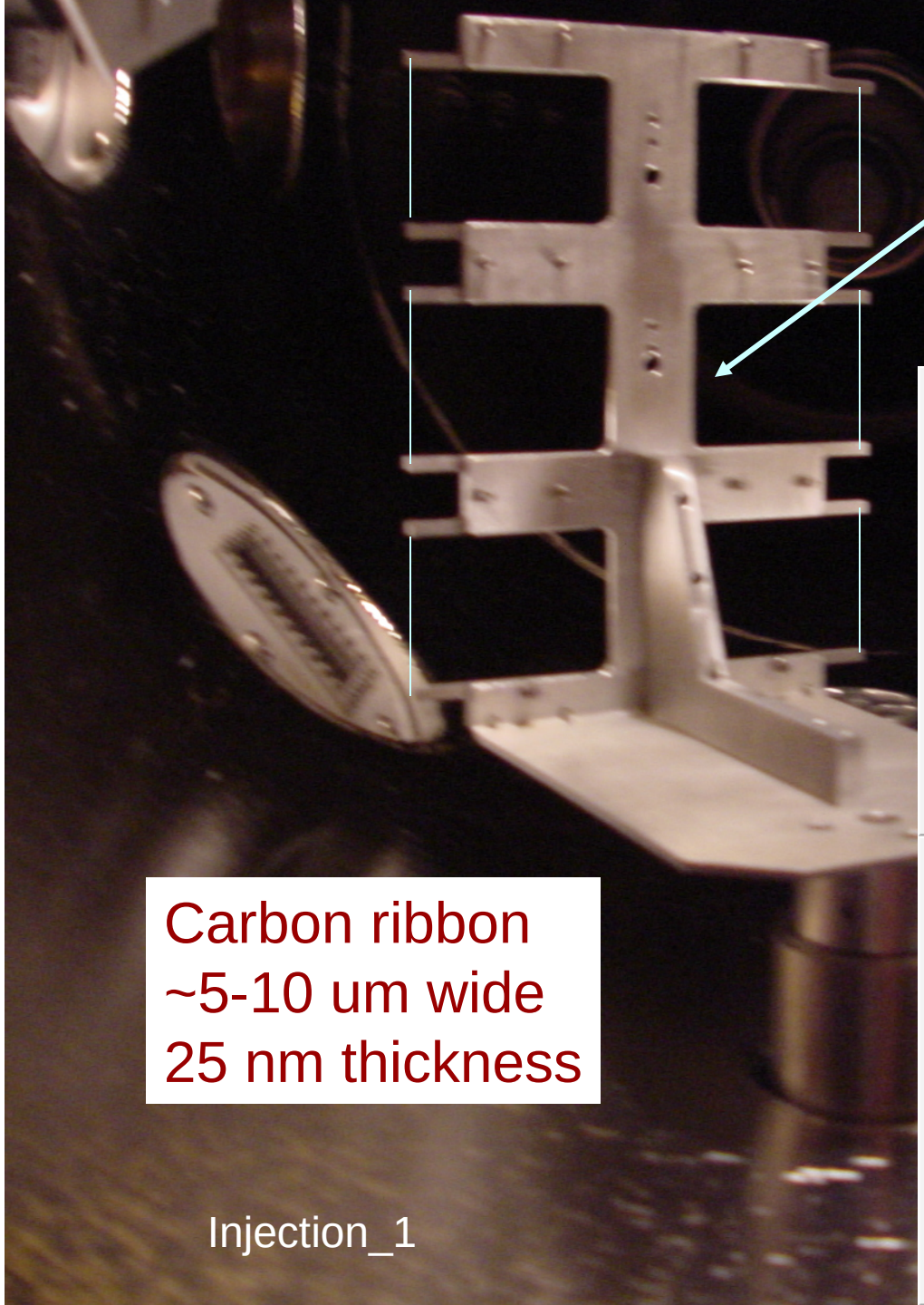
$$T = T_{deposit} + \Delta T(\Delta x)$$

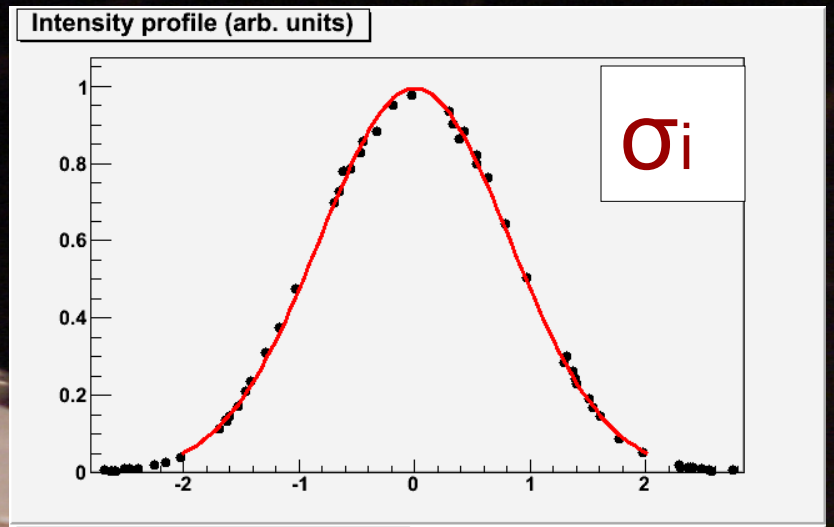
(adc×C_α) (effective deadlayer)

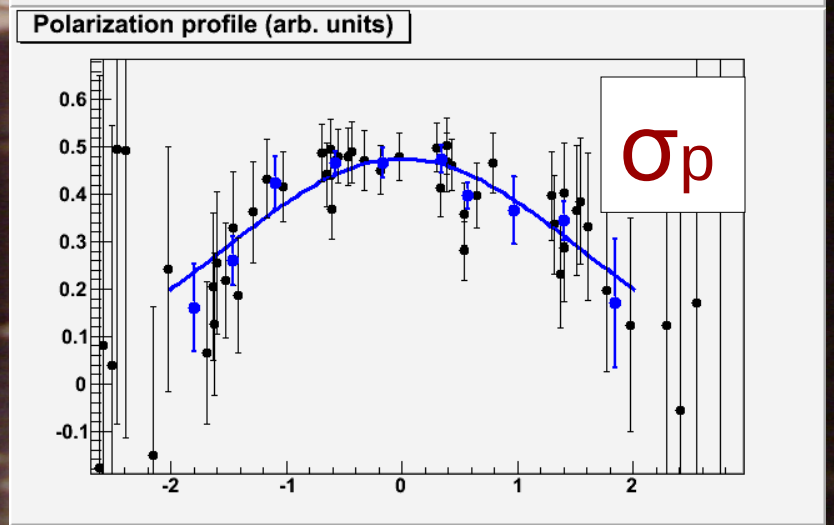
$(t_0, \Delta x)$ ➔ Kinematic Fit

~ 30%

The target ladder



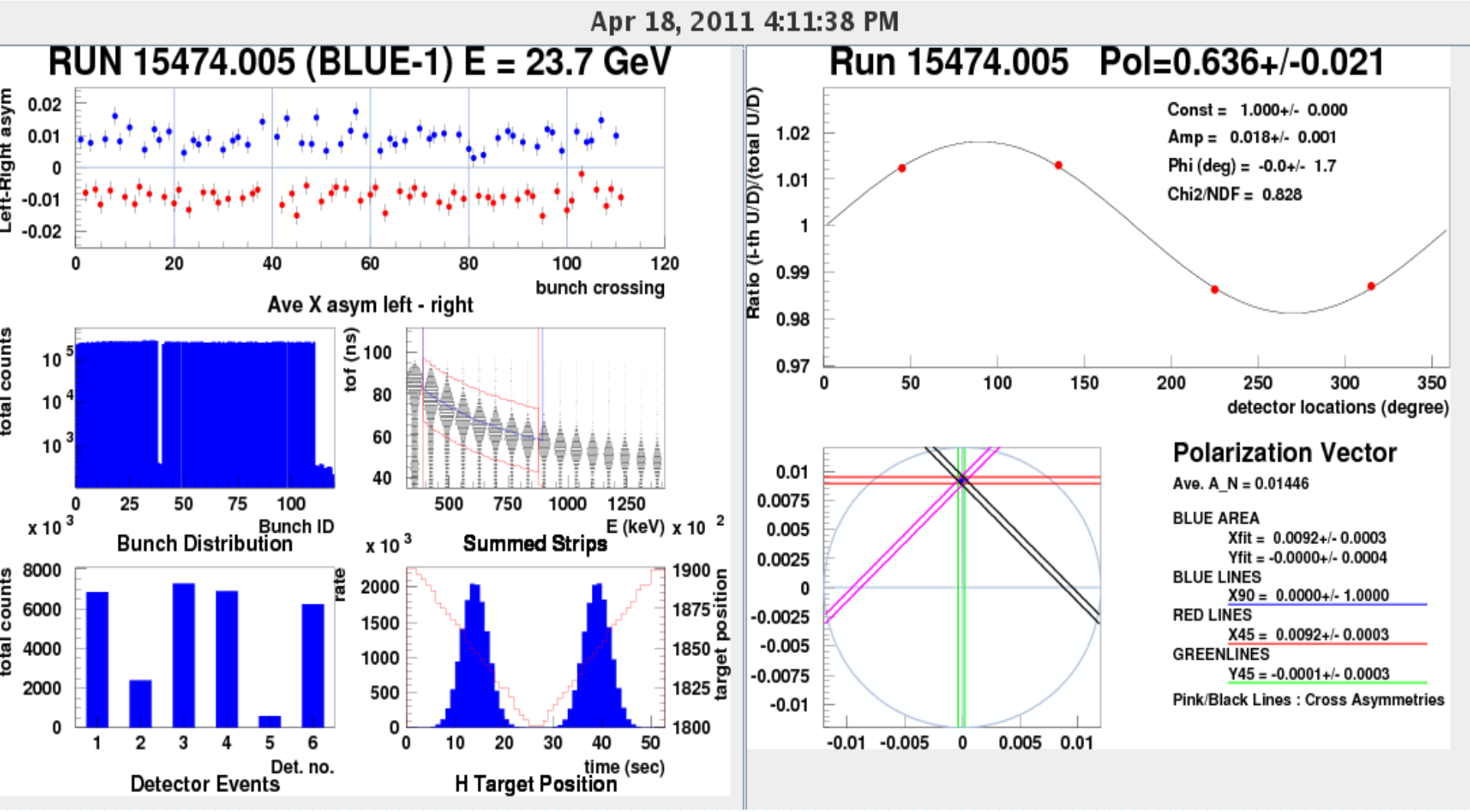




Carbon ribbon
~5-10 um wide
25 nm thickness

Injection_1

April 18, 2011, Blue1, H6



Polarization Profiles

- Polarization loss from intrinsic resonances: polarization lost at edge of beam → polarization profile.
- Impact of polarization profile on beam polarization at collisions:

$$P(x,x',y,y') = P_0 e^{-\frac{x^2+x'^2}{2\sigma_{x,P}^2}} e^{-\frac{y^2+y'^2}{2\sigma_{y,P}^2}}; \quad I(x,x',y,y') = I_0 e^{-\frac{x^2+x'^2}{2\sigma_{x,I}^2}} e^{-\frac{y^2+y'^2}{2\sigma_{y,I}^2}}; \quad R_H = \frac{\sigma_{x,I}^2}{\sigma_{x,P}^2}; \quad R_V = \frac{\sigma_{y,I}^2}{\sigma_{y,P}^2}$$

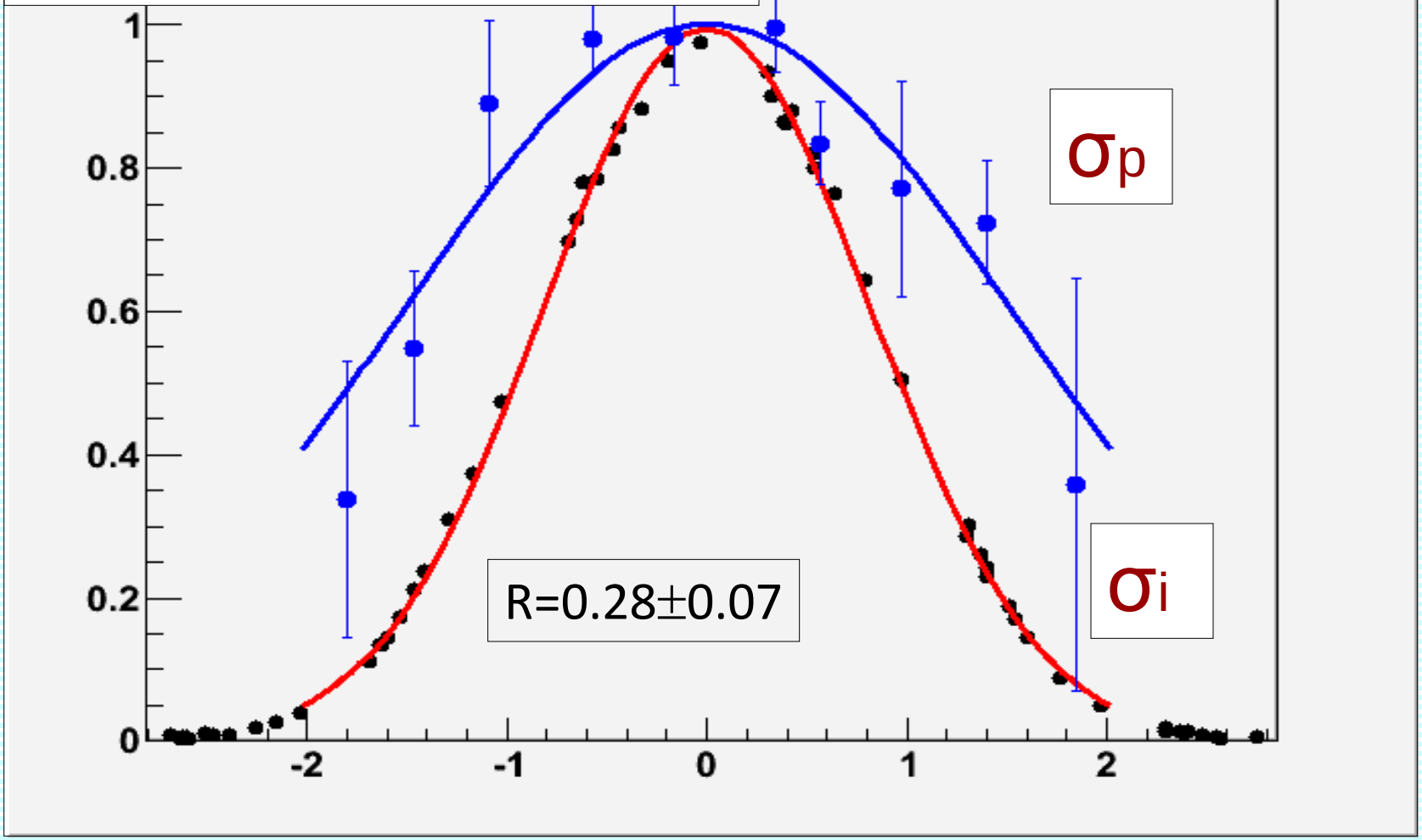
$$\langle P \rangle = P_0 \frac{1}{(1+R_H)(1+R_V)}; \quad P_{coll.} = P_0 \frac{1}{\sqrt{1+\frac{1}{2}R_H}\sqrt{1+R_H}\sqrt{1+\frac{1}{2}R_V}\sqrt{1+R_V}} = \langle P \rangle \frac{\sqrt{1+R_H}\sqrt{1+R_V}}{\sqrt{1+\frac{1}{2}R_H}\sqrt{1+\frac{1}{2}R_V}}$$

For $R_H \approx R_V$ and small: $P_0 = \langle P \rangle (1+\langle R \rangle)^2$;

$P_{coll.} = \langle P \rangle (1+\frac{1}{2}\langle R \rangle)$

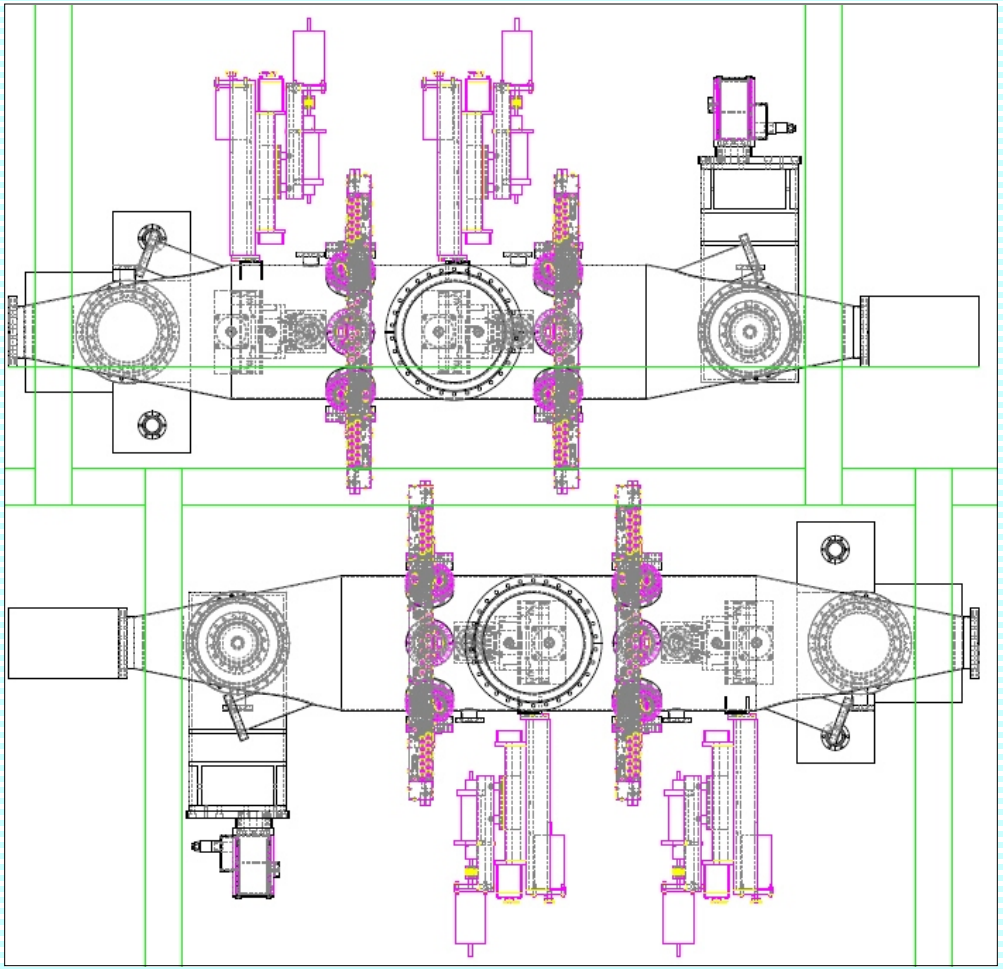
Pol. Profile: 250 GeV in Run-2009

Intensity and polarization profiles:

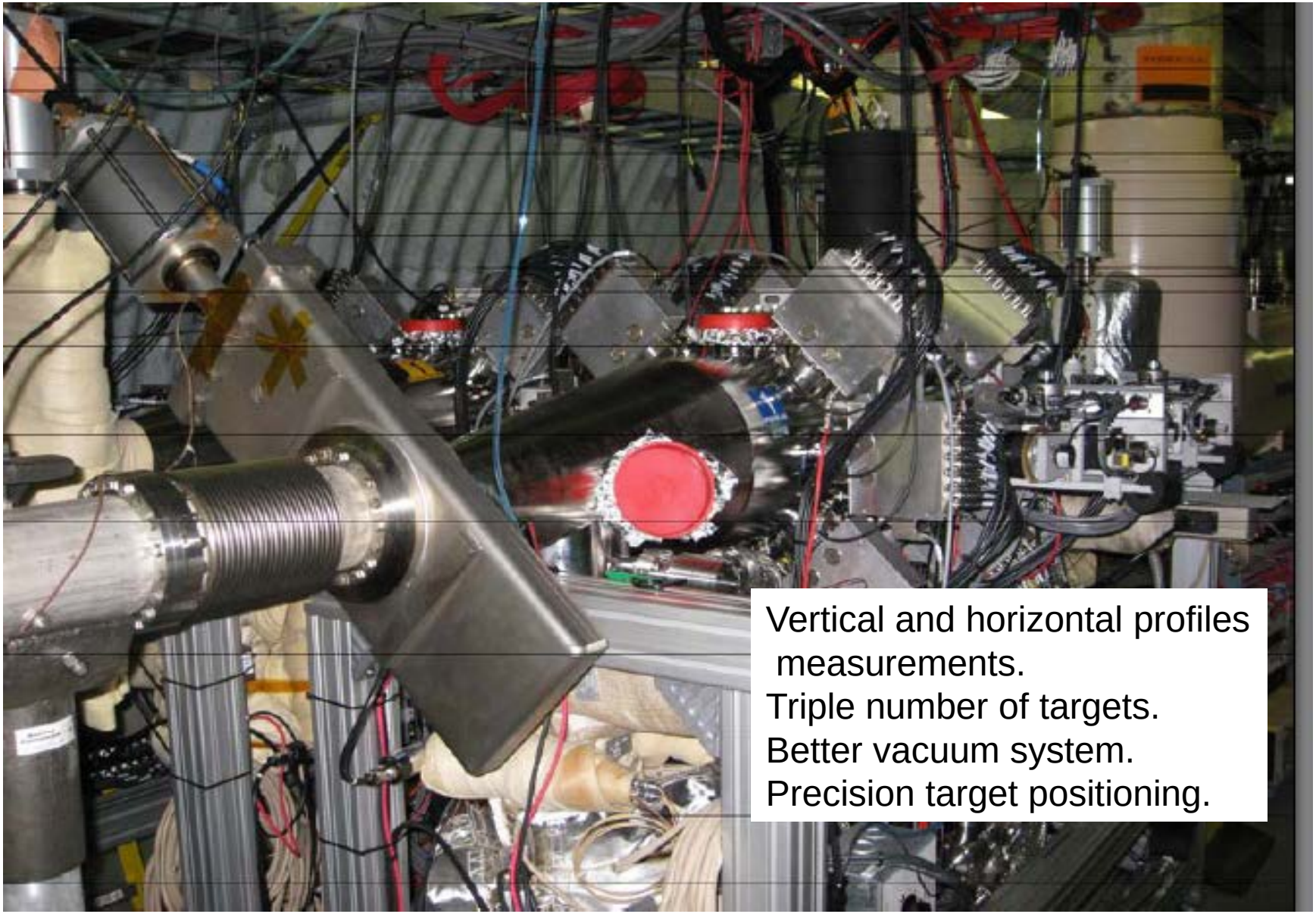


P-Carbon polarimeter upgrade for Run-2009

- Two polarimeters in each ring.
- Routine polarization profile measurements in both-vertical and horizontal planes.
- Beam intensity profile (emittance) measurements.
- Doubled number of Carbon-strip targets.
- New detectors development.



Polarimeter upgrade for Run 2009



Vertical and horizontal profiles measurements.
Triple number of targets.
Better vacuum system.
Precision target positioning.

P_0 –maximum polarization, P_{coll}-polarization for colliding beams.

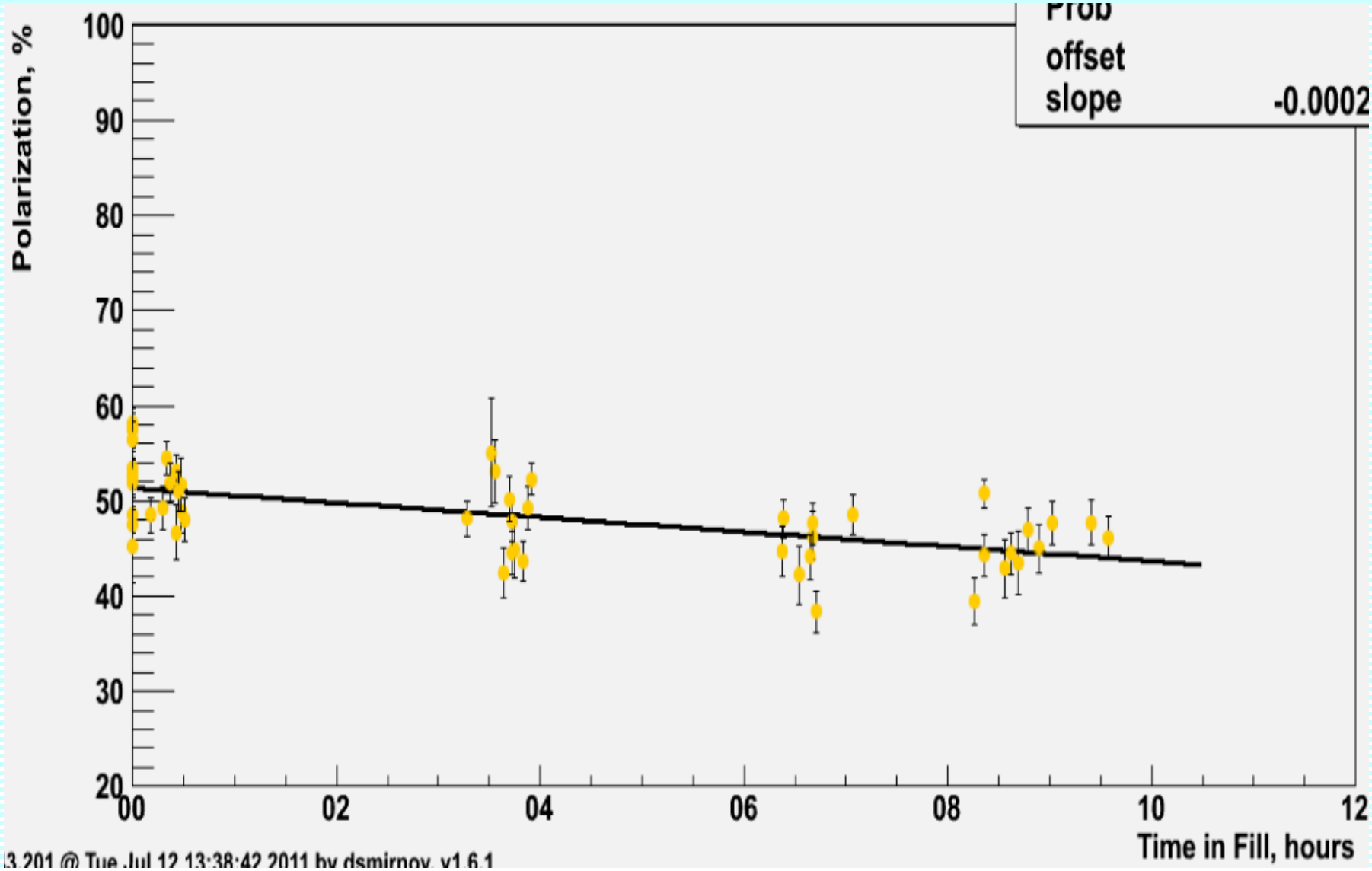
	24 GeV		100 GeV		255 GeV	
	B	Y	B	Y	B	Y
<P> Hjet			61.1	57.0	51.7	53.7
R	0.05	0.06	0.09	0.09	0.15	0.15
P_0			72%	67%	68%	67%
P_{coll}			64%	60%	55%	56 %

About 3-5% errors, mostly systematic on all above numbers.

AGS - $P_0 \sim 68.4\% \times 1.055 = 72\%$

Blue- X 0.98=71%
Yellow- X 0.96=69%

Polarization decay during the store.
Yellow ring, Vert.target, 0.72+/-0.18%/hr



Measurements with p-Carbon CNI polarimeter.

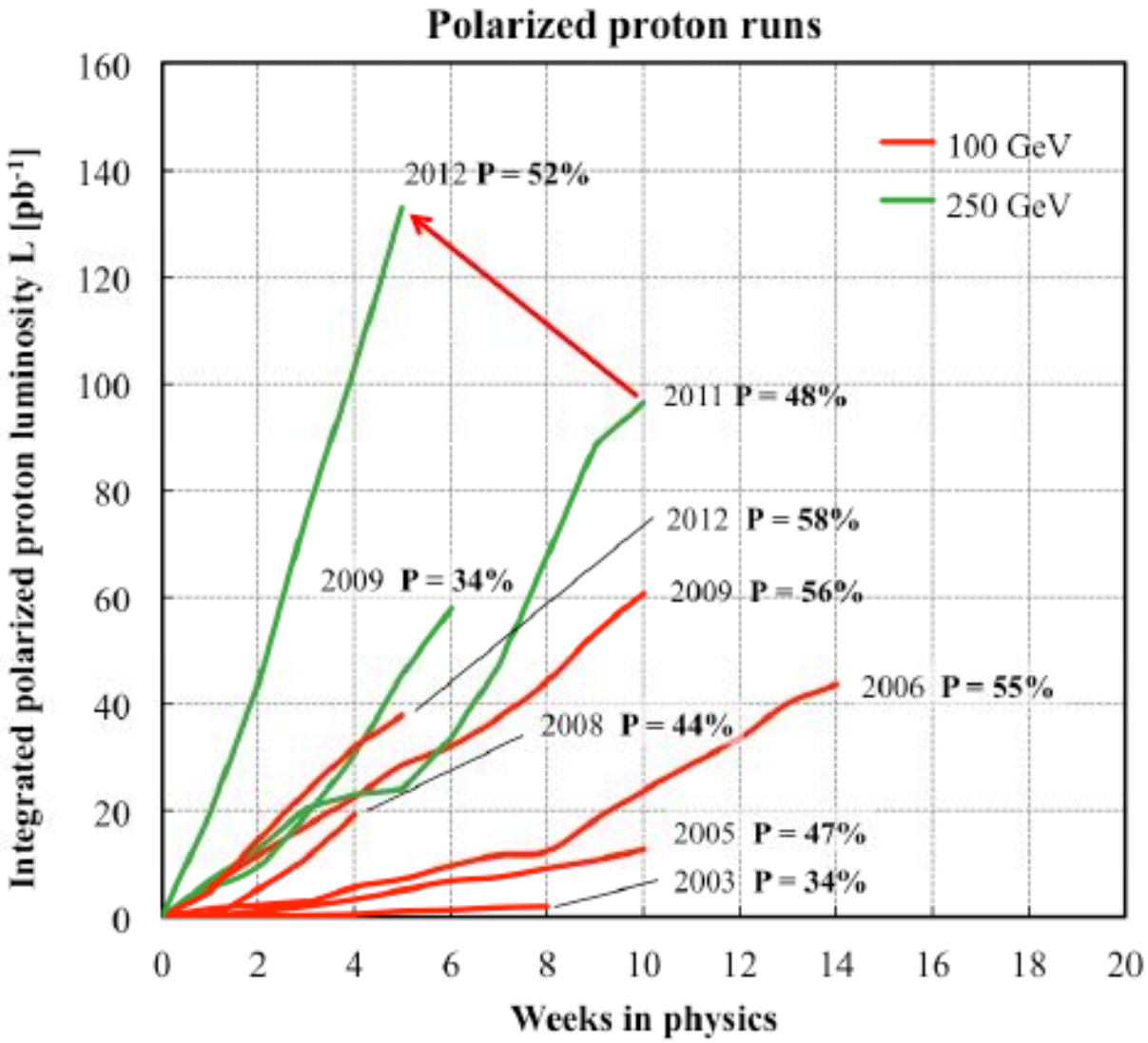
- Polarization, polarization profile measurements in the scanning mode.
- Polarization losses during acceleration and store.
- Polarization decay during store.
- Beam intensity profile (emttance) including bunch-by-bunch.
- Emittance measurements cross-calibrations.
- Emittance measurements on the ramp.

Polarimeters operation in Run-2012

- Higher beam (bunch) intensity, small emittances (higher beam density) and shorter bunch length were obtained this year as a result of numerous upgrades.
- All of above beam properties improvements affected the polarimeter operation (noise level and target lifetime).
- In Run-2011 one set of targets (48 targets was used for entire run). In Run-2012 we replaced targets twice (144 targets).

Break_42_1:07

RHIC polarized protons – luminosity and polarization



At 255 GeV in 2012

L_{avg} = 105x10^{30}cm^{-2}s^{-1}

P_{avg} = 52%

L_{avg} +15% relative to 2011

P_{avg} +8% relative to 2011

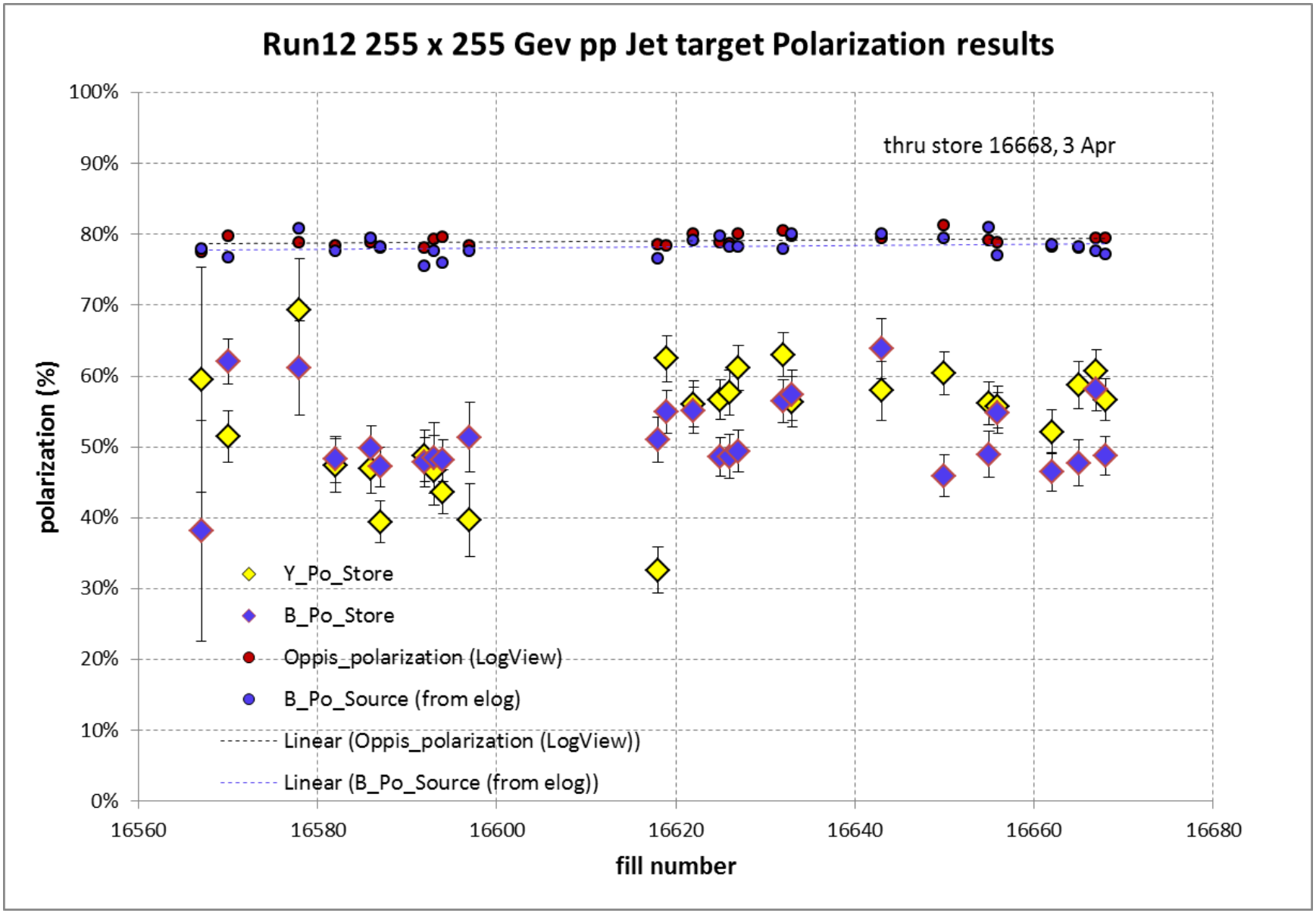
$FOM = LP^2$

(single spin experiments)

$FOM = LP^4$

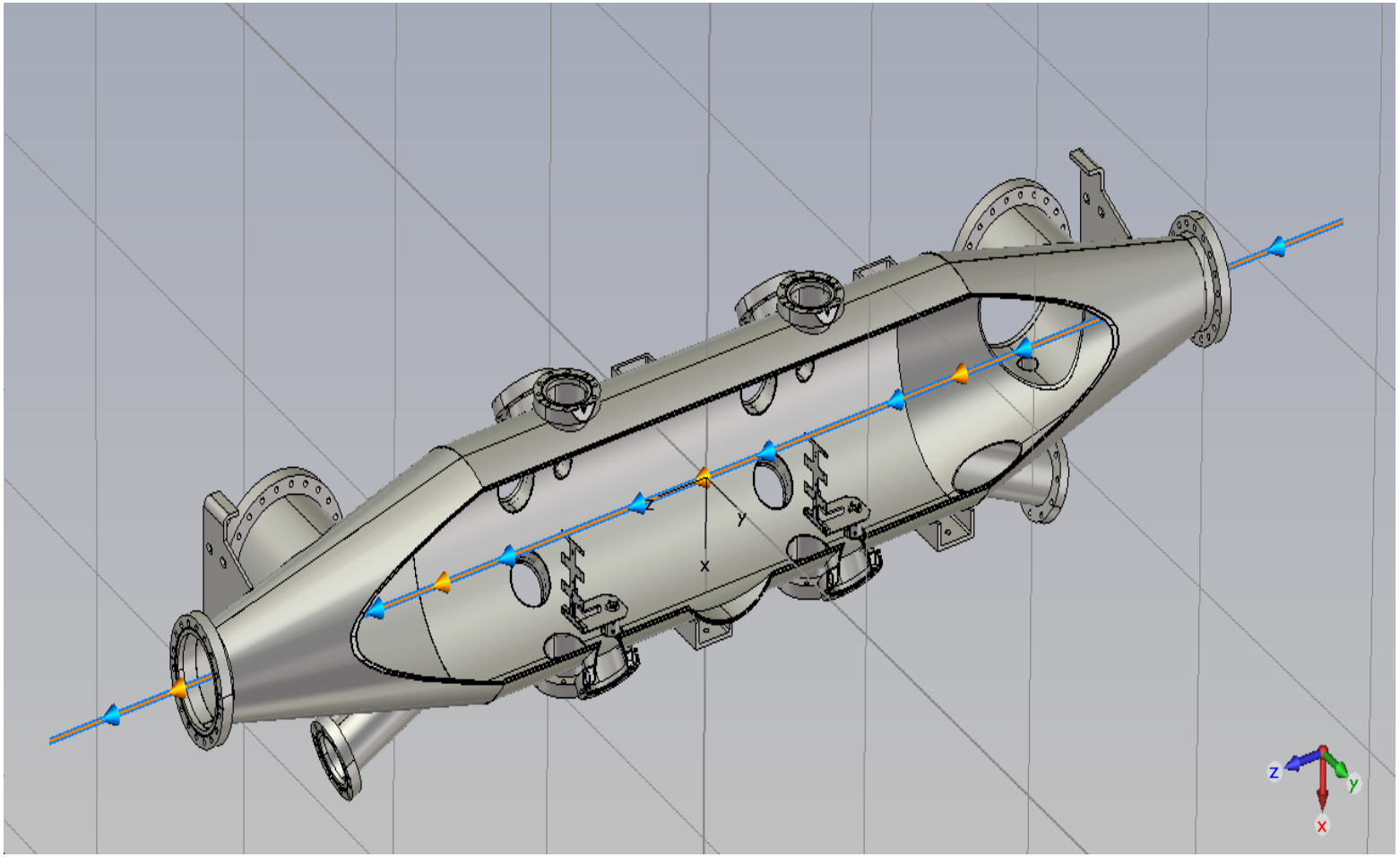
(double spin experiments)

Wolfram Fischer

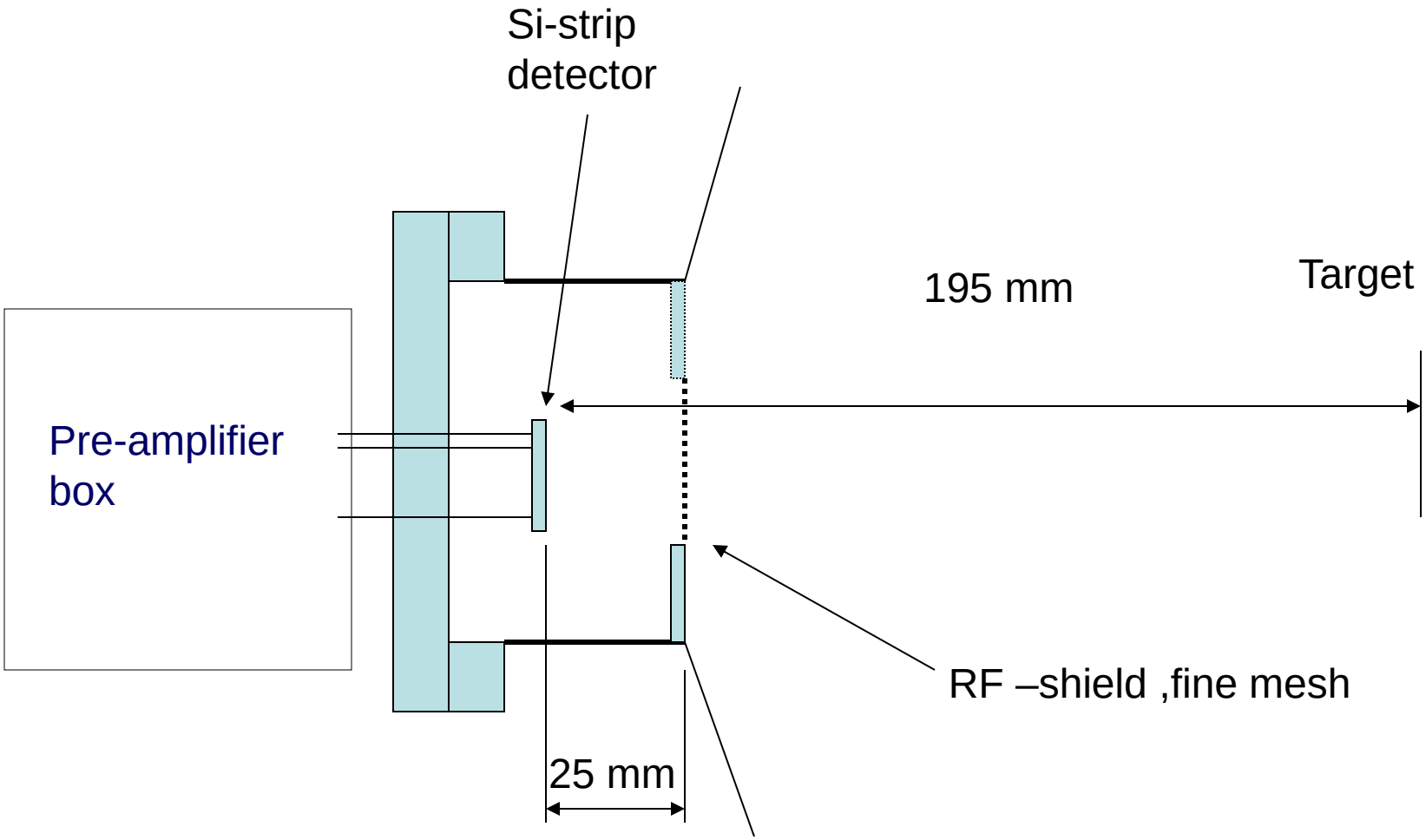


Blue weighted average = 51.4% ± 0.6%, 35% below source pol
Yellow weighted average = 53.7% ± 0.7%, 32% below source pol

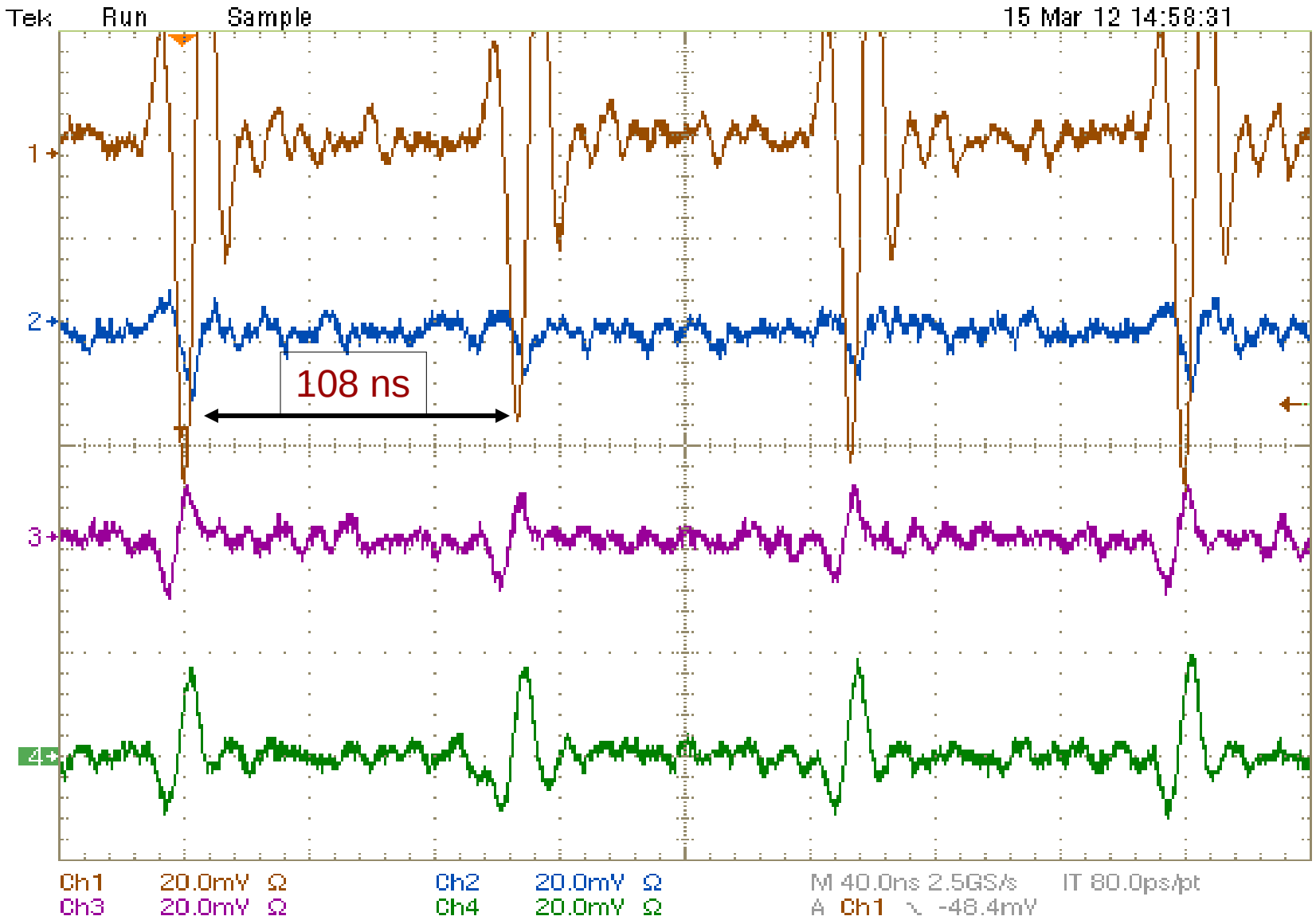
CNI polarimeter as RF cavity



Si-strip detector and RF shield configuration.



Run-12, March 15, 255 GeV, Y2, #1, 2,3,6



Run-12, Yellow-1, #4,5,6, 100GeV. Beam induced noise is strongly depended on bunch length (197 MHz cavity operation).

- C
  F

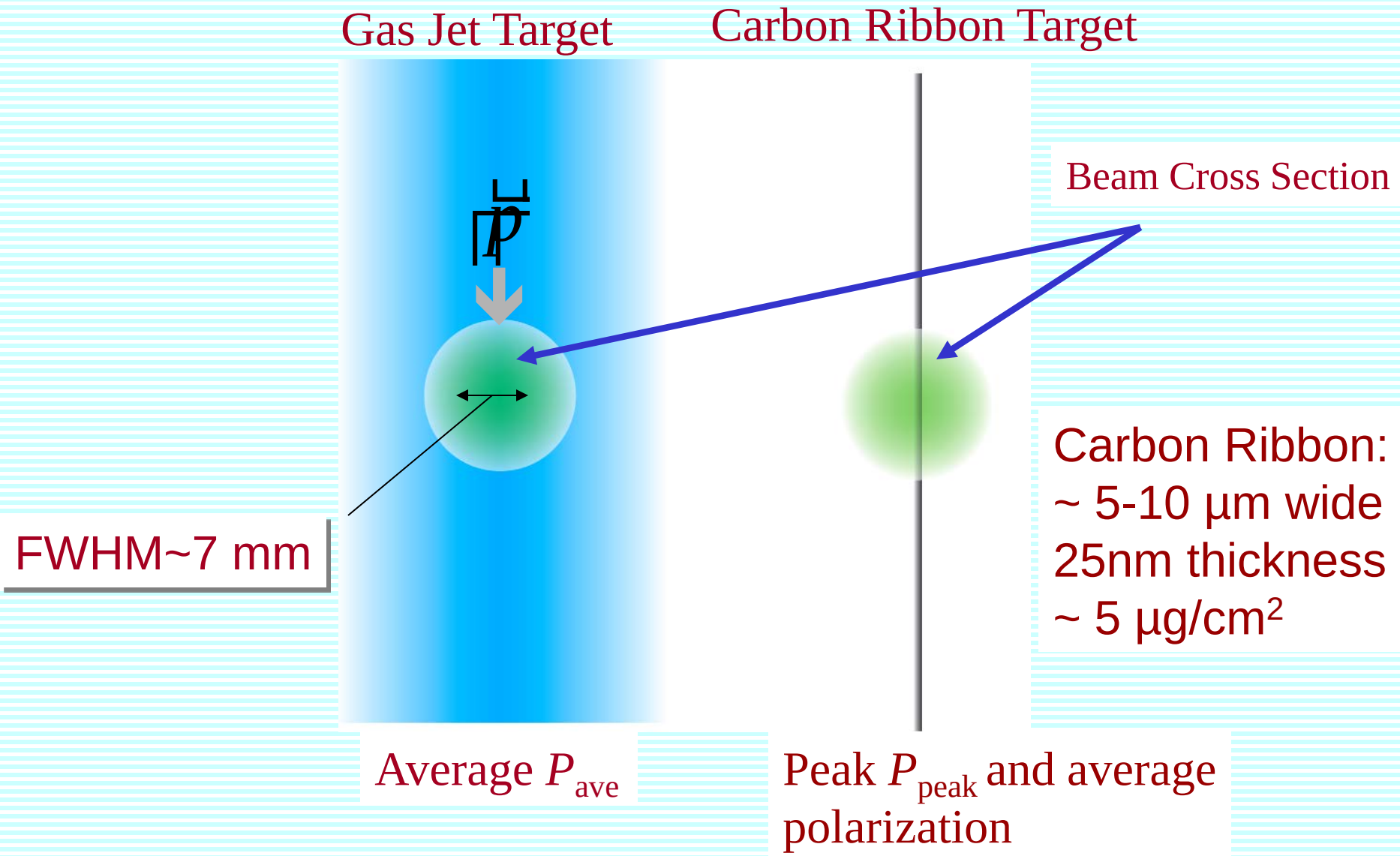
“Noise” in p-Carbon CNI polarimeters.

- Strong Noise is a new feature in Run-12.
- Noise depends on bunch intensity, bunch length and shape (197 MHz cavity voltage).
- The worst noise was observed for shorter bunches with Booster scraping at injection energy 24 GeV.
- Noise is quite different in different detectors (and strips).

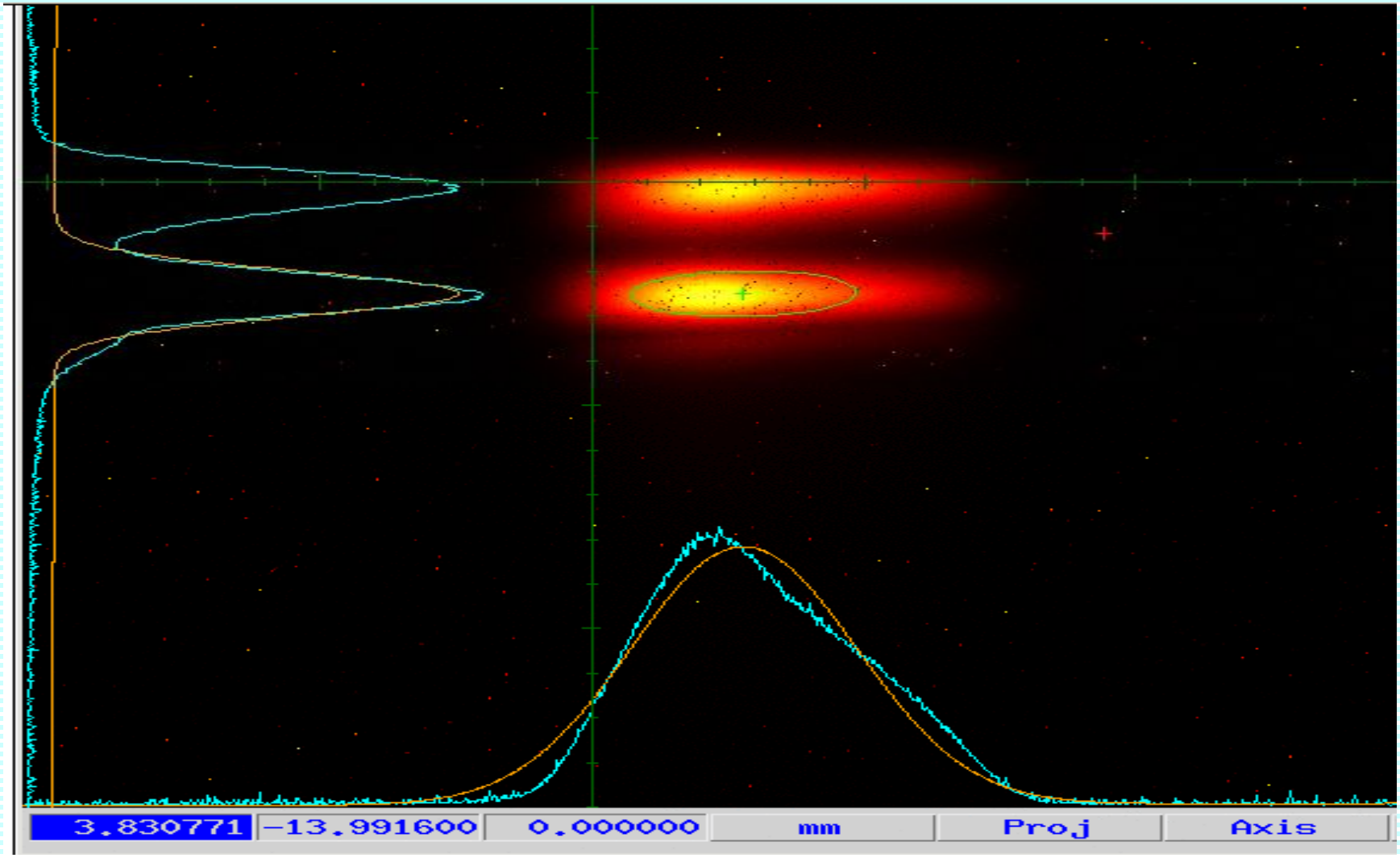
- Two types of “noise” were identified:
- Beam induced pick-up to detectors inside the polarimeter chamber
- RF field penetration outside of chambers and coupling to pre-amplifiers, which do not have proper shielding.

- “Noise” in detectors was very closely reproduced at the test-bench. Observation at the test-bench were successfully used in the operational polarimeter.

Hydrogen Gas Jet and Carbon Ribbon Targets.

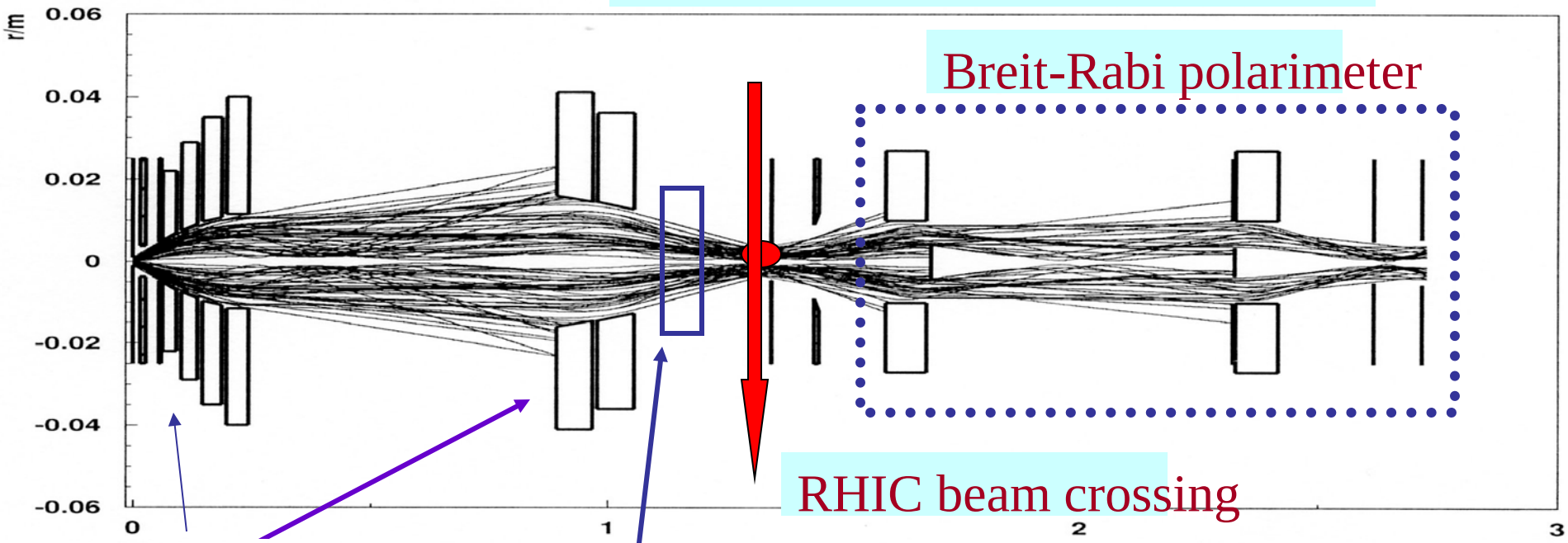


H-jet as a luminescence beam intensity monitor.



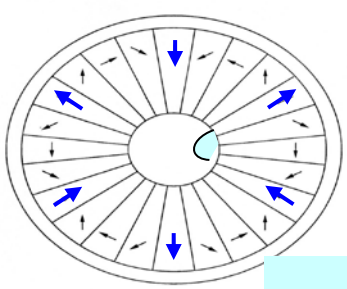
Spin filtering technique. Atomic Beam Sources.

Hydrogen atoms with electron polarization: m_J=+1/2 trajectories.



Breit-Rabi polarimeter

RHIC beam crossing



RF transition, polarization transfer from electrons to protons

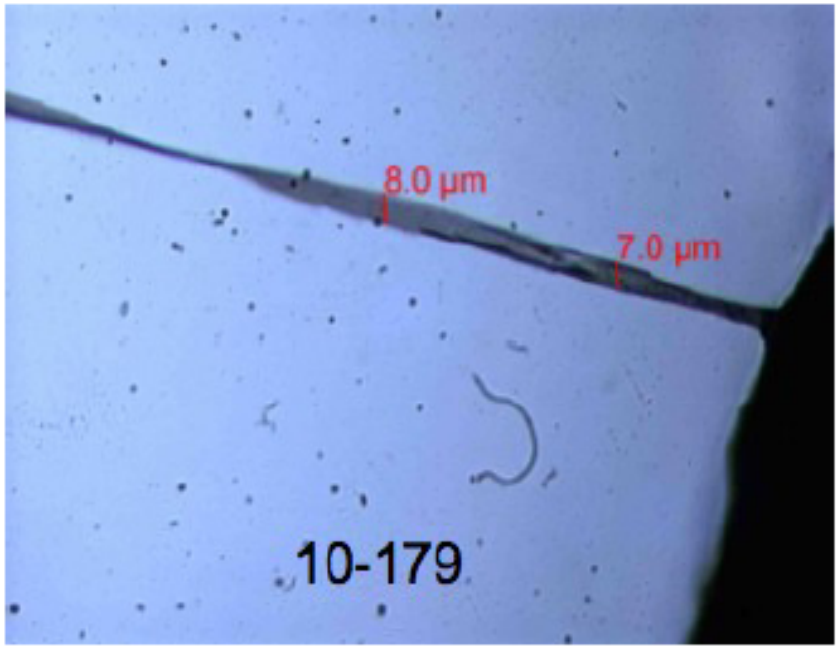
permanent magnet sextupole - 1.7 T
gradient 5.7 T/cm

Electron magnetic moment is 659 times Larger than proton : μ_e / μ_P ~659.
Focusing strength: ~ (dB/dr)× μ_e

Target strip orientation

- But in reality we have little control over θ

- Example of twisted ribbon from Dannie's slides:
- Length scale of twists ≈ 150 μ
- A few crossings of θ=0° divergence across beam 0.5-1 mm



- Loose ribbons swaying in the breeze: orientation ill-defined

- Perhaps consider alternatives to ribbon geometry

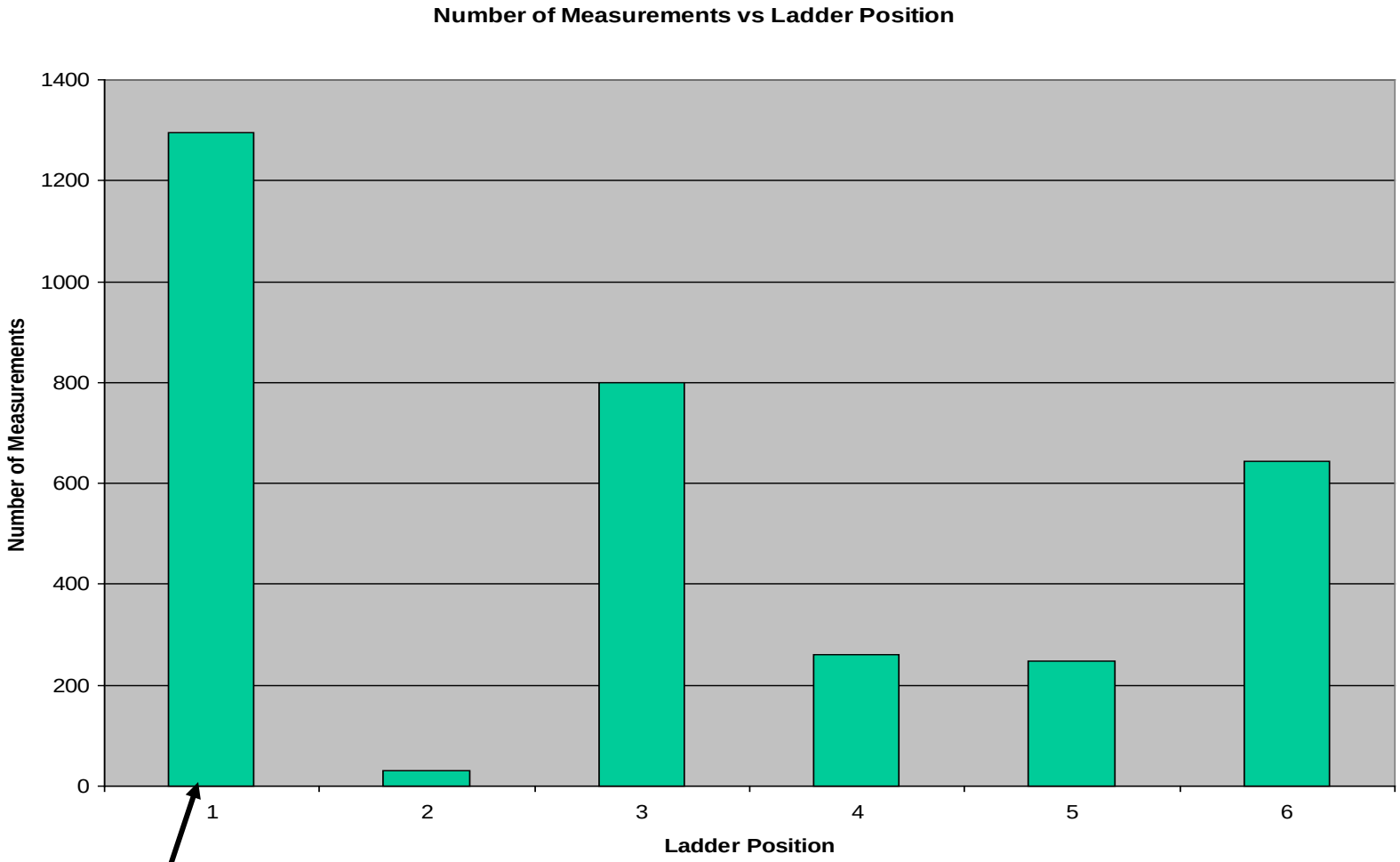
Target usage in Run 2011, 250 GeV

Approximate number of sweep measurements performed with each target

	1		2		3		4		5		6		All	
	H	V	H	V	H	V	H	V	H	V	H	V	H	V
Blue-1 Upstream	81	297	1	1	333	6	74	0	61	0	224	0	777	304
Yellow-1 Downstream	249	16	4	4	56	15	98	7	113	1	65	1	585	44
Blue-2 Downstream	175	49	3	4	41	118	1	75	6	19	1	219	227	484
Yellow-2 Upstream	74	355	6	8	52	178	1	5	41	8	17	116	191	670

Target usage history at 250 GeV

Targets lifetime in Run-2011



Total # of measurements
With eight #1 targets.

Carbon strip targets
(5-10 um wide, 25 nm thickness).

- In Run 9 and Run 11, one set (48 targets) was used for whole Run.
- In Run 12, targets were replaced twice. (March 14, April 11)

- Target production.
- *Conductive paint. Evaporation. Unknown.*
- Beam intensity ~ same
- Beam size is smaller ~ 10-20%.
- *Power density 1.2-1.5 times higher.*
- Bunch length is somewhat shorter- 4.5 ns to 3.5ns.
- Vacuum after target replacement is worse: $5*10^{-10}$ to $1*10^{-8}$ torr.

Targets properties.

- There was an assumption, that carbon-strip targets are conductive and conductive glue had been used to attach carbon strips to the frame.

- The recent measurements showed that new targets , made by carbon evaporation by electron beam (likely amorphous carbon) are not conductive (> 100 MOhm).
- The targets which were exposed by the beam and survived in the Run-11 are conductive (< 1 MOhm).

- Perhaps, target heating during beam exposure to give rise to carbon graphitization. This can make target conductive (change the electrostatic interaction) and perhaps also stronger to withstand the tensile force from electrostatic interaction with the proton beam.

Targets. Summary.

- In Run 9 and Run 11, one set (48 targets) was used for whole Run.
- In Run 12, targets were replaced twice. (March 14, April 11).

- We expect further RHIC beam intensity increase and shorter bunch length in Run 13.
- Additional studies and development are required to operate Carbon polarimeter in Run 13.
- It is necessary to setup test facility for tensile target strength measurements.
- Then we can try to select targets within some specs strength.
- The strength (perhaps) can be increased by:
- Processing improvements (substrate, baking, etc…).
- Study of RF-glow discharge on the target strength.

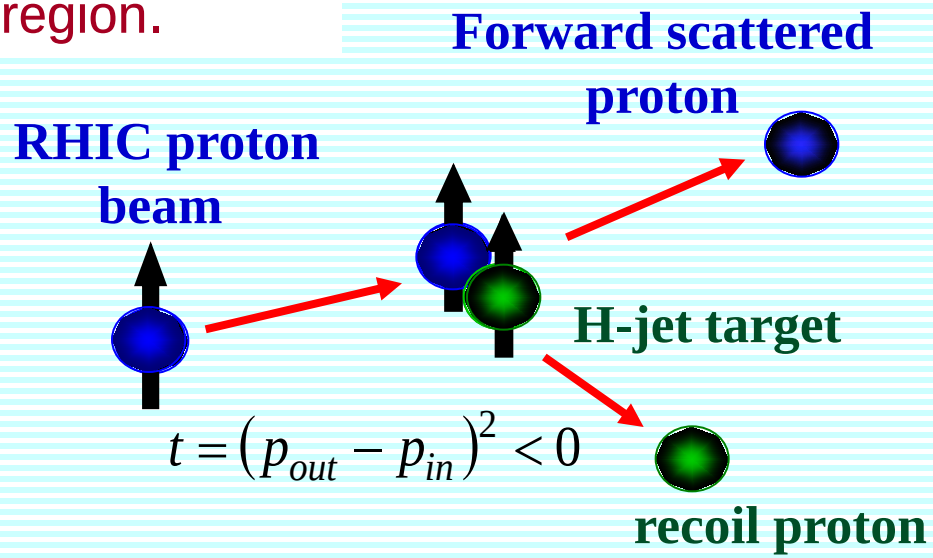
- Nanotubes, or graphene –like targets?

Backup slides.

H-Jet polarimeter.

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

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



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

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

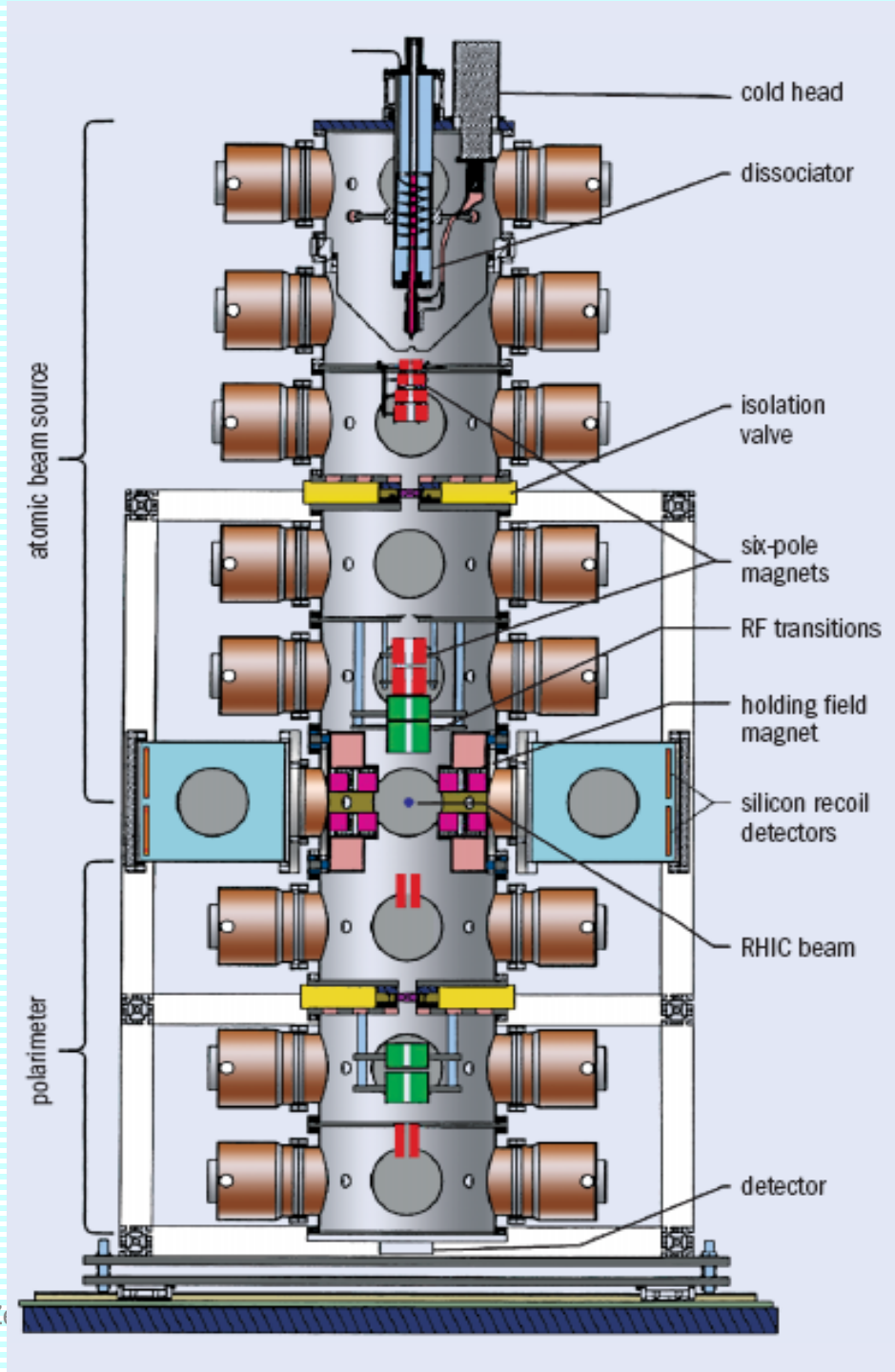
$$\frac{\Delta P_{\text{beam}}}{P_{\text{beam}}} \approx \frac{\Delta P_{\text{target}}}{P_{\text{target}}} \oplus \frac{\Delta \varepsilon_{\text{target}}}{\varepsilon_{\text{target}}} \oplus \frac{\Delta \varepsilon_{\text{beam}}}{\varepsilon_{\text{beam}}}$$

<5%

P_{target} is measured by Breit- Rabi Polarimeter

H-jet polarimeter.

- The H-jet polarimeter includes three major parts: polarized Atomic Beam source (ABS), scattering chamber, and Breit-Rabi polarimeter.
- The polarimeter axis is vertical and the recoil protons are detected in the horizontal plane.
- The common vacuum system is assembled from nine identical vacuum chambers, which provide nine stages of differential pumping.
- The system building block is a cylindrical vacuum chamber 50 cm in diameter and of 32 cm length with the four 20 cm (8.0”) ID pumping ports.



H-jet is an ideal polarimeter !

- High (~4.5%) analyzing power in a wide energy range (23-250 GeV).
- High event rate due to high intensity (~100 mA) circulated beam current in the storage ring (~6% statistical accuracy in one 8hrs. long fill). High polarized H-jet density in RHIC ABS.
- Non-destructive.
- No scattering for recoil protons.
- Clean elastic scattering event identification.
- Direct calibration with Breit-Rabi polarimeter.
- Most of the false asymmetries are cancelled out in the ratio:

$$P_{beam} = (1/A)\,\text{Beam}_{asym} / \text{Target}_{asym}$$

Problem.
Polarization dilution by H_2, H_2O and other residual gases.
Largest source of systematic error.

“Noise” in p-Carbon CNI polarimeters.

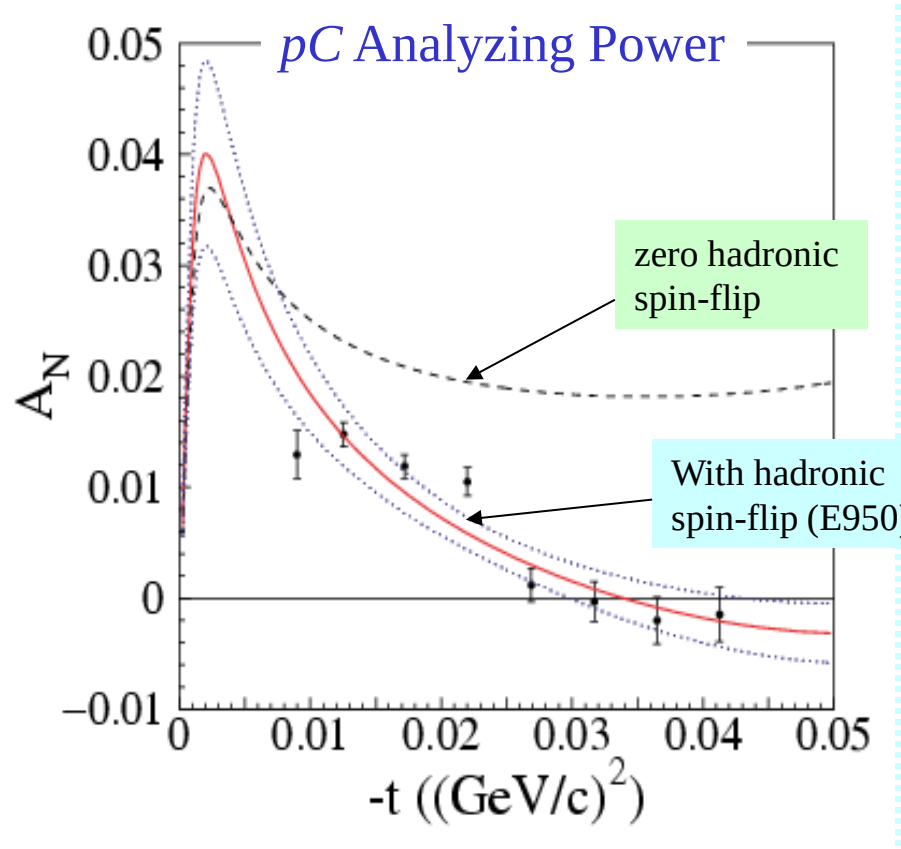
- Strong Noise is a new feature in Run-12.
- Noise depends on bunch intensity, bunch shape (197 MHz cavity voltage).
- The worst noise was observed for shorter bunches with Booster scraping at injection energy 24 GeV.
- Noise is quite different in different detectors (and strips).
- Noise is depended on target ladder position.
- Noise in Yellow polarimeter depends on Yellow stochastic cooling cavity state.
- M.Brennan discovered coupling between Yellow-1 and Yellow-2 polarimeter signals.

- Very likely, similar problems on smaller scale could be contamination for polarization measurements in the previous Runs too, and contributed to the errors and inconsistencies in the polarization measurements with different detectors and polarimeters.
- “Noise” in detectors was very closely reproduced at the test-bench. Observation at the test-bench were successfully used in the operational polarimeter.

P-Carbon: A_N

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

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



E_{beam} = 21.7GeV

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