Polarimetry of the proton beams at RHIC

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XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS,

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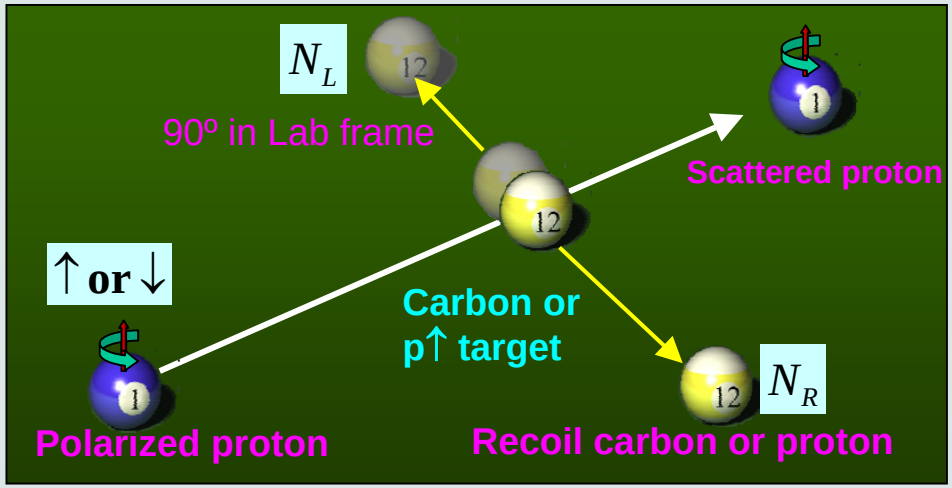
Challenge

1. Absolute polarization measurement with $\Delta P_{beam} / P_{beam} < 0.05$ for experiments.
2. Fast (< 5 min) measurement for accelerator debugging.
3. Ramp and profile measurements.
4. Cover large energy range: 25 – 250 GeV

Solution – CNI !



Elastic scattering in the CNI region

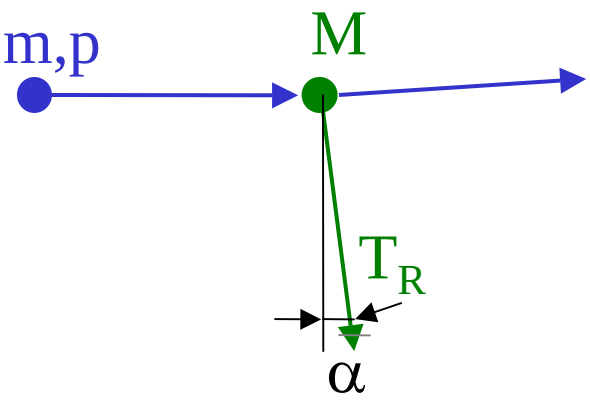
A_N arises mainly from interference between ***EM spin-flip amplitude*** and ***hadronic non spin-flip amplitude*** (CNI = Coulomb – Nuclear Interference)

$$A_N = C_1 \phi_{em}^{flip} Im\phi_{had}^{nonflip} + C_2 \phi_{em}^{nonflip} \phi_{had}^{flip}$$

$\propto (\mu - 1)_p$ Pure CNI $\propto \sqrt{\sigma_{had}^{pp}}$ — Regge poles /Pomeron exchange

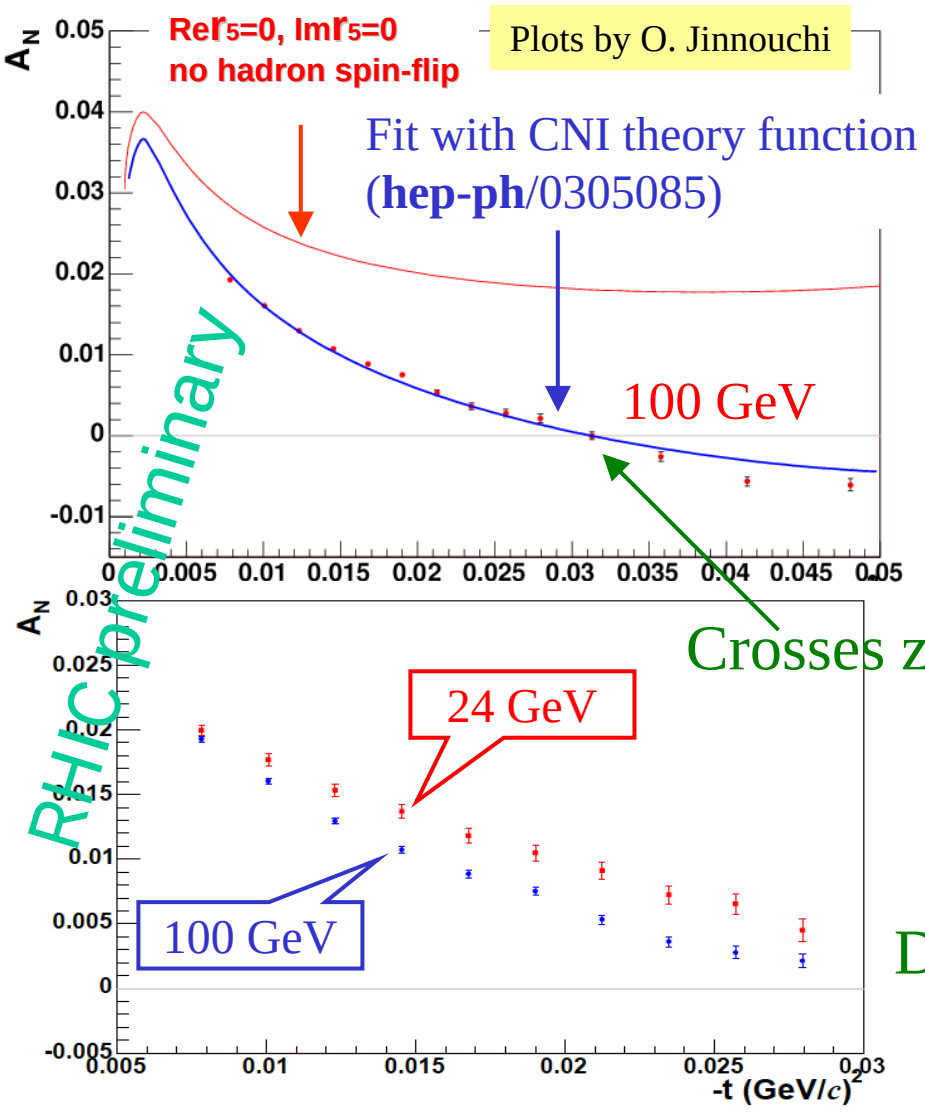
AN is also sensitive probe to hadronic spin flip amplitude

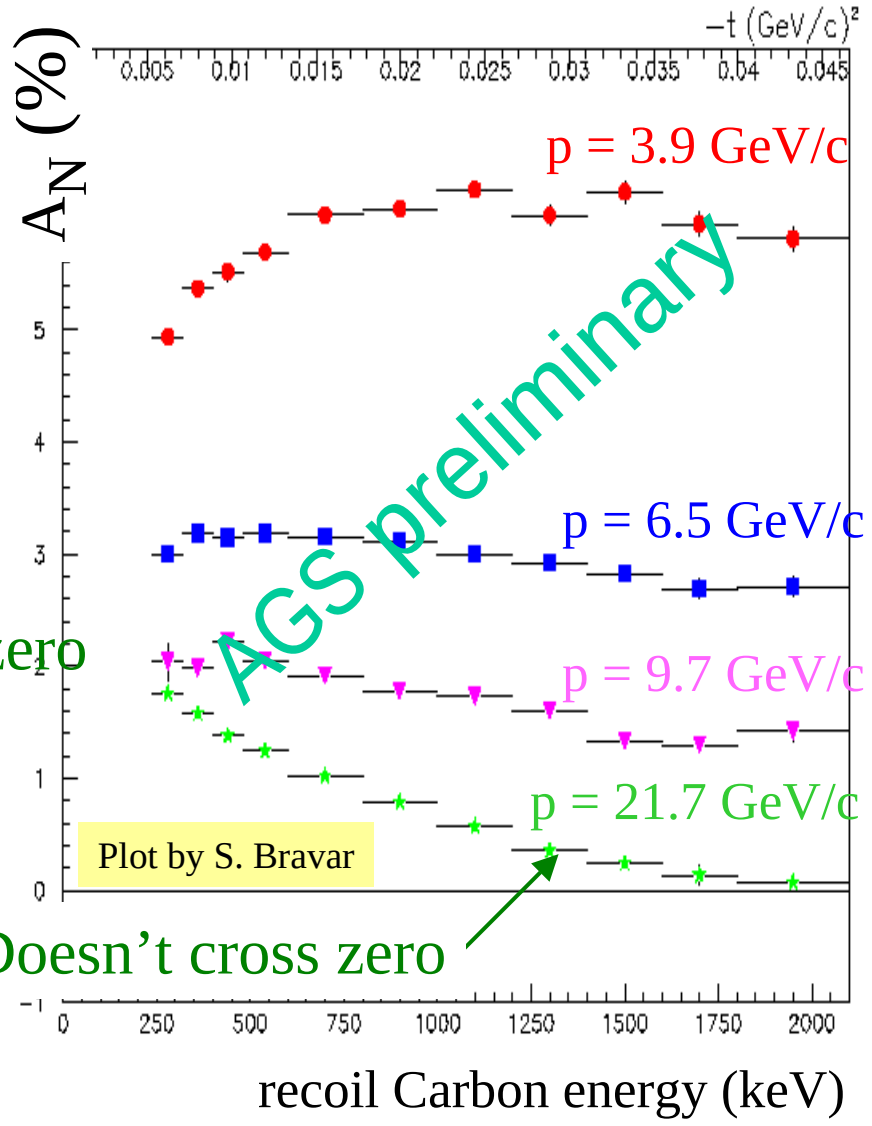
- All kinematics is defined by recoil particle.
- For all RHIC beam energies recoil particle goes at 90°.
- Analyzing power small, but with weak energy dependence.
- Large cross section ⇒ very good figure of merit.
- Need to collect 2-5·10^7 events per measurement.
- Energy of the recoil particle is very small ⇒ target must be extremely thin.



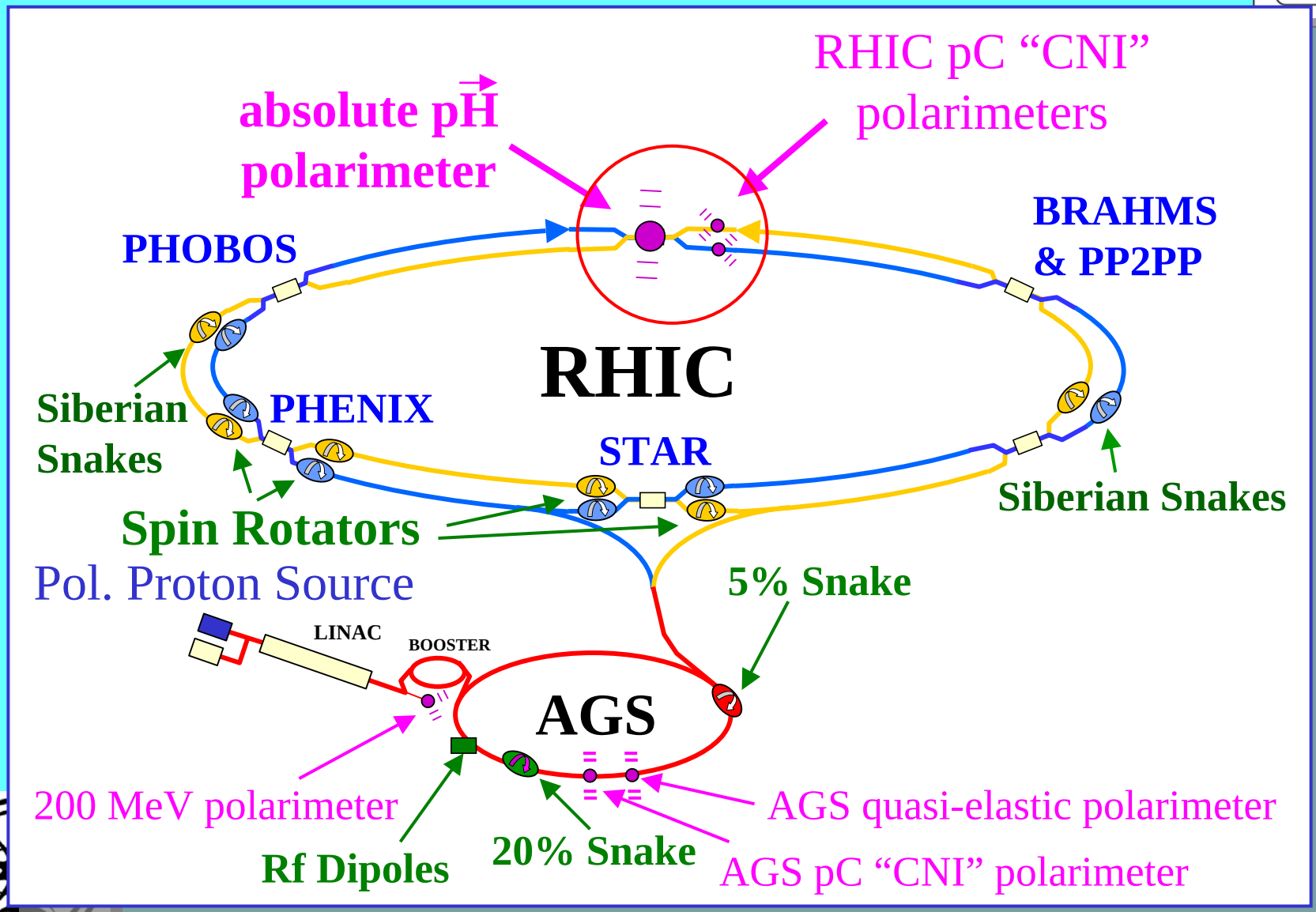
$$\sin\alpha = \frac{\sqrt{p^2 + m^2} + M}{p} \sqrt{\frac{T_R}{T_R + 2M}} \propto \sqrt{\frac{T_R}{2M}}$$

pC: shape is different ! – Calibration required.





RHIC-Spin accelerator complex



CNI polarimeters

- ✓ Fast but relative pC-polarimeter
- ✓ Slow but absolute p-polarized H-jet polarimeter

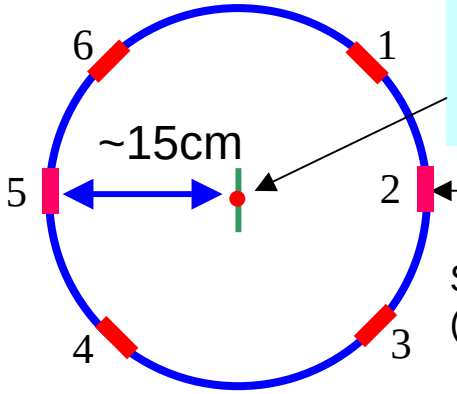
Common:

- Fixed target, 90°-recoil particle kinematics
- Elastic scattering with small momentum transferred – CNI-region
- Si detectors
- α-Calibration
- ToF versus energy recoil particle identification
- WFD based DAQ

Differences:

Polarimeter	pC - relative	$pH_{\uparrow}$ - absolute
Position	In each beam	At IP12
Target	Extremely thin carbon foil	Polarized hydrogen jet
$-t$ T_R	0.007-0.030 $(GeV/c)^2$ 0.3-1.3 MeV	0.0015-0.01 $(GeV/c)^2$ 0.8-5.5 MeV
Recoil angle	Smashed by multiple scattering	Elastic events selection criteria
ToF base ToF time range	~15 cm 10-50 ns	~80 cm 20-80 ns
Counting Rate Measurement time	Up to ~1 MHz 20-200 c	~100 Hz Several fills
Radial polarization	Yes with 45° detectors	No

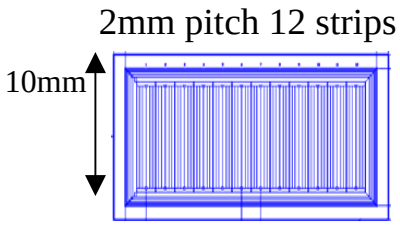
pC polarimeter setup



Ultra thin Carbon ribbon Target (3.5μg/cm²)

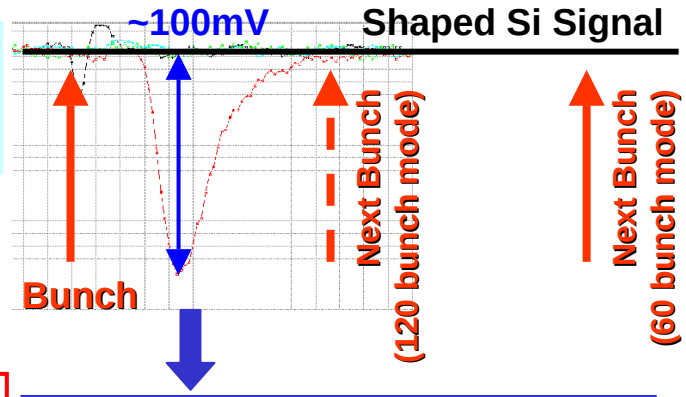
Si strip detectors (TOF, E_C)

Thin dead layer for low energy carbon spectroscopy



p^+ implants ~150 nm depth

72 strips in total



No dead time !

Wave Form Digitizer (WFD)

420 Msamples/sec

- Pulse Height
- TOF
- TMAX
- Bunch ID
- Integral (Q)
- revolution #

online

Select carbons at on-board LUT

- Scaler data
- Asymmetry calculation
- Online results (to experiments)

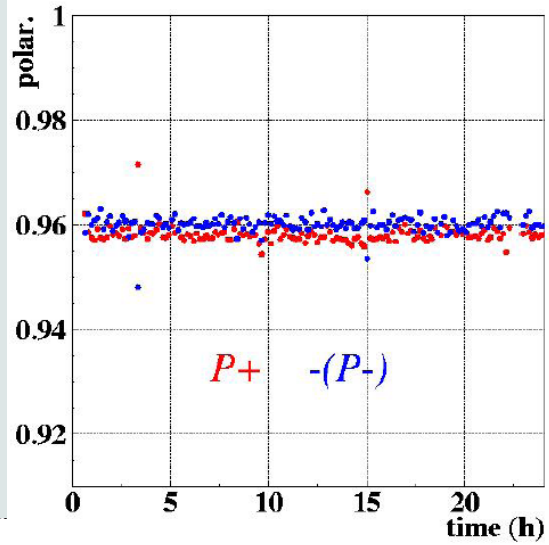
offline

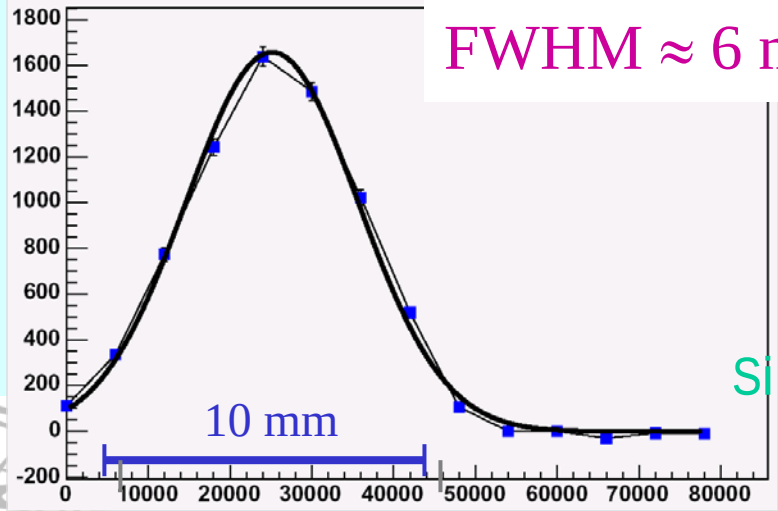
Event by event data

- Stored in on-board memory
- Used for offline detailed study

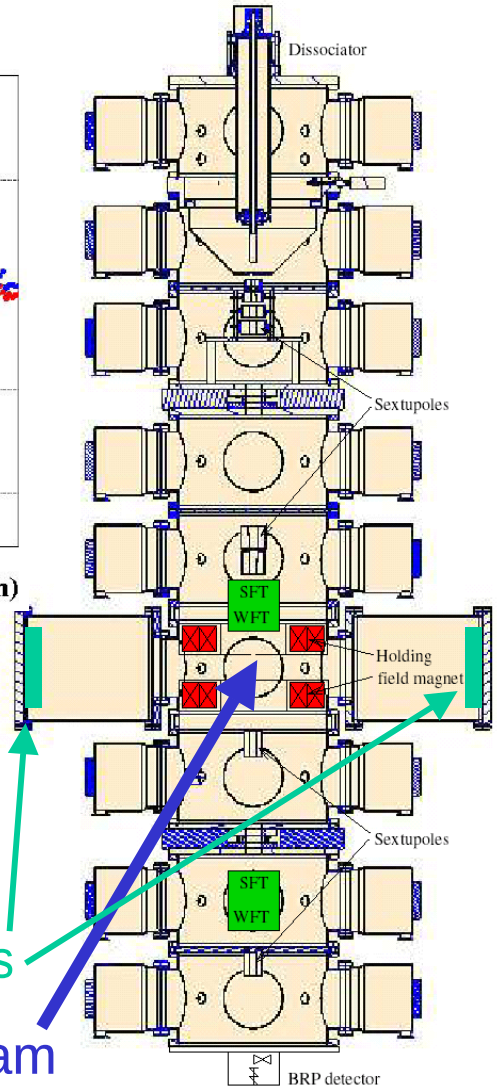
Polarized gas jet target

- ✓ Average intensity 10^{17} atoms/sec.
- ✓ Thickness 10^{12} atoms/cm^2.
- ✓ H_2 background ≈ 3%.
- ✓ $P_{TARGET} \approx 0.924 \pm 0.018$

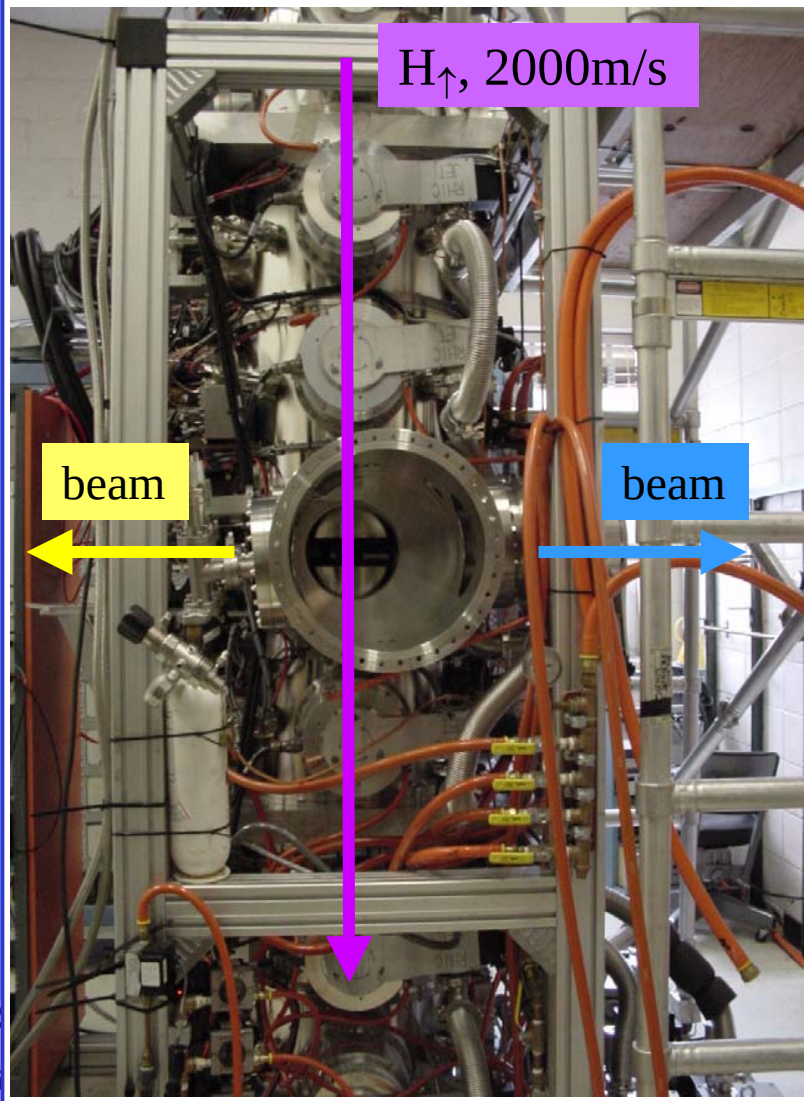




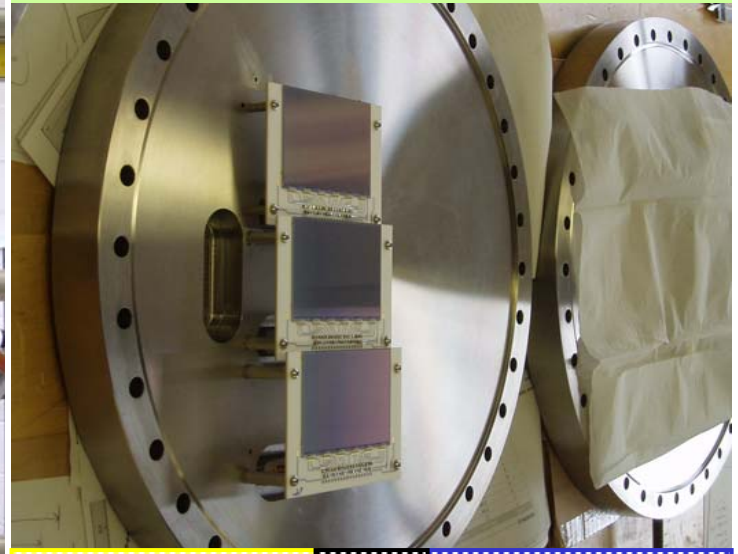
FWHM ≈ 6 mm



Polarized gas jet target (2)



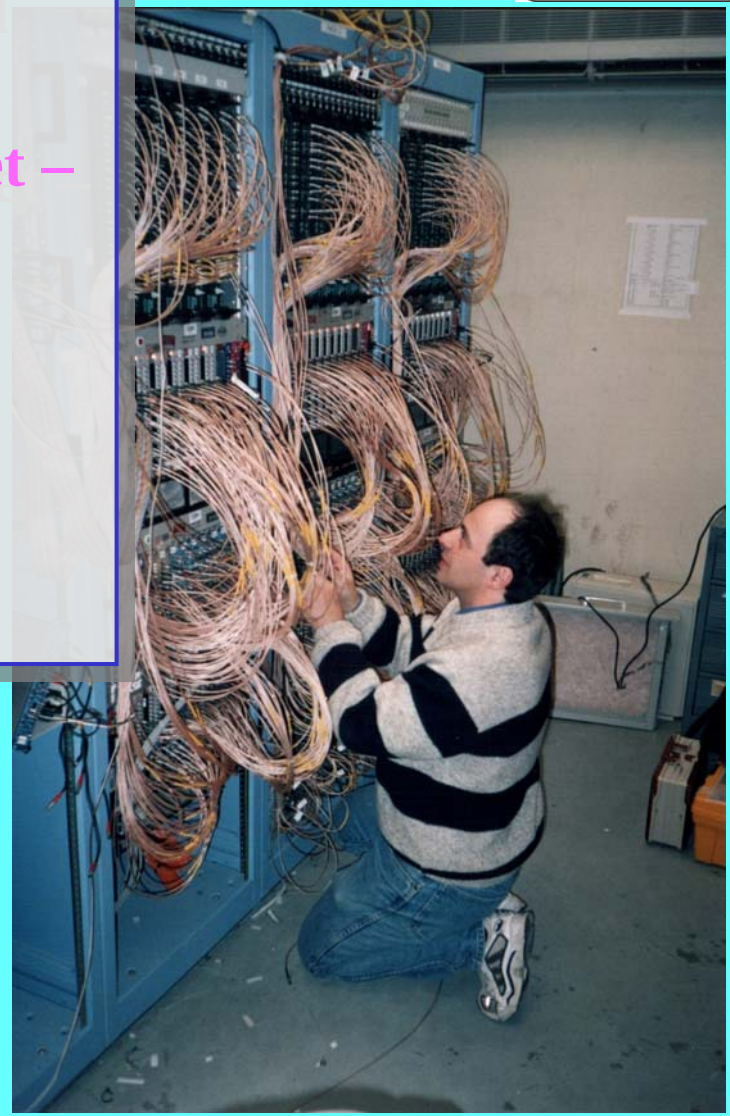
- Si detectors 8 x 5 cm^2
- 1ch width = 4mm (40 strips)
- Vertical strips



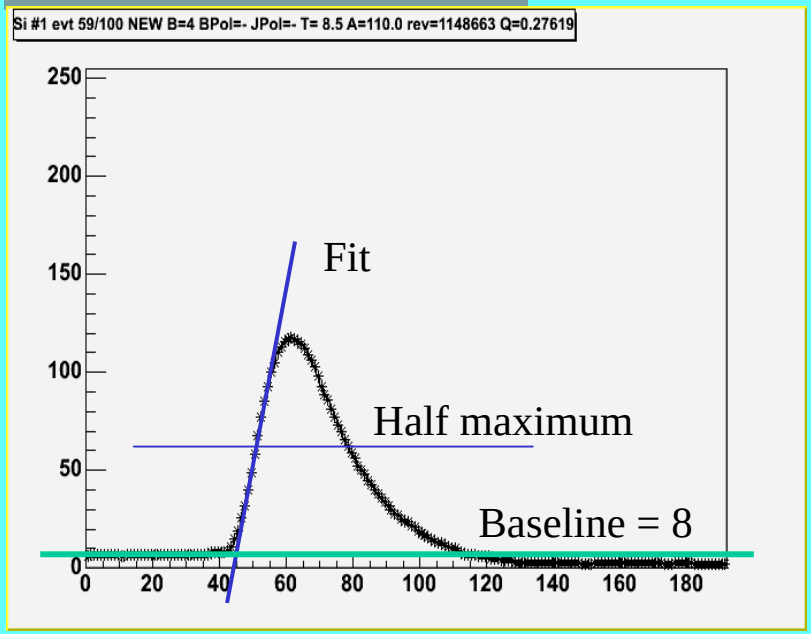
Ch # 1-8 “yellow”	unused	Ch # 9-16 “blue”

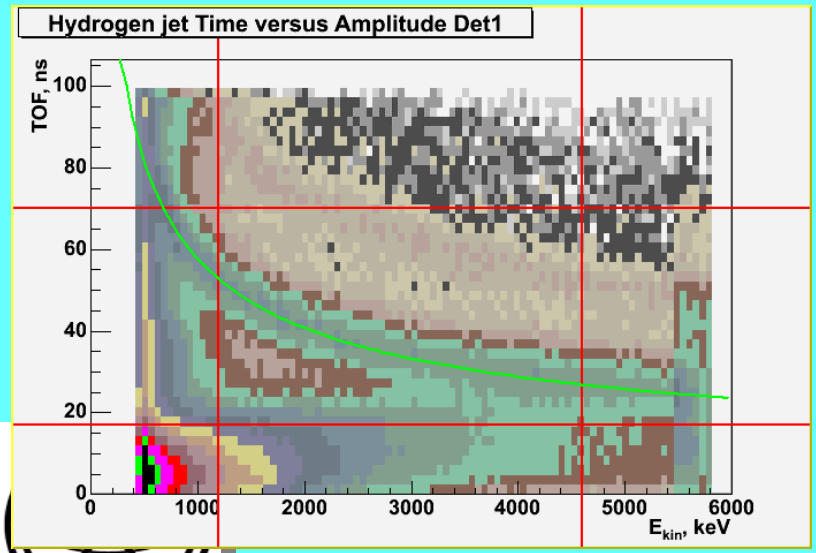
Improvements 2006

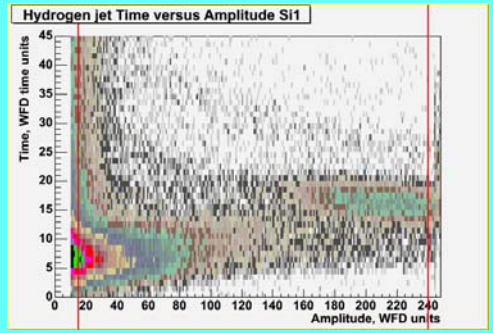
- ✓ **Independent BLUE, YELLOW and Hjet DAQ hardware.**
- ✓ **New WFD firmware version for Hjet – long waveforms without internal analysis**
- ✓ **New Hjet online monitor.**
- ✓ **Scanning profile in each pC measurement**

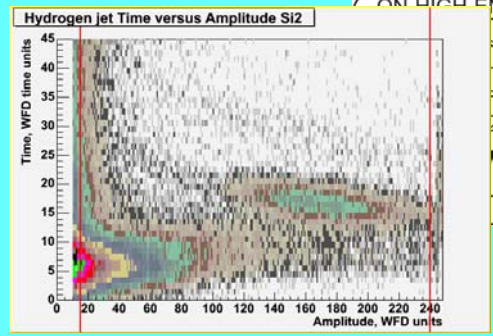


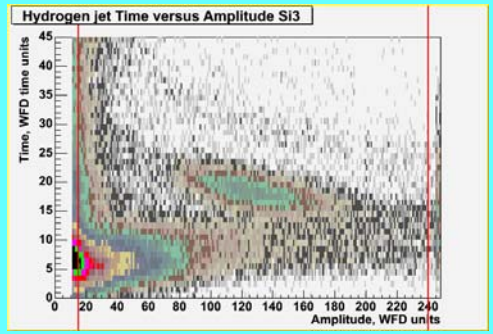
New Hjet DAQ

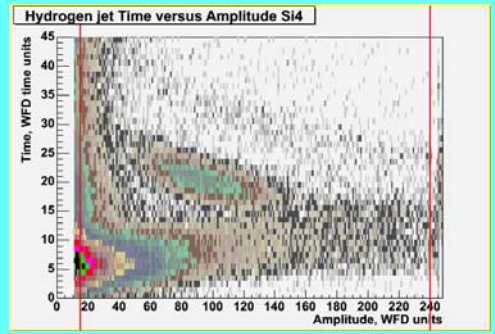

Si #1 evt 59/100 NEW B=4 BPol=- JPol=- T= 8.5 A=110.0 rev=1148663 Q=0.27619
Fit
Half maximum
Baseline = 8

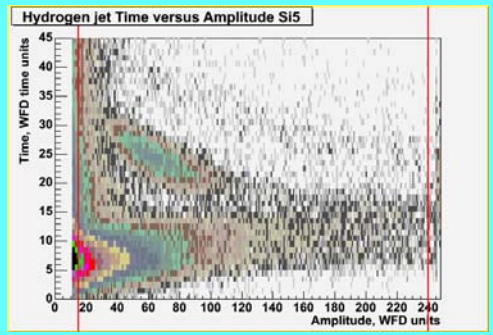

Hydrogen jet Time versus Amplitude Det1
TOF, ns
E_kin, keV

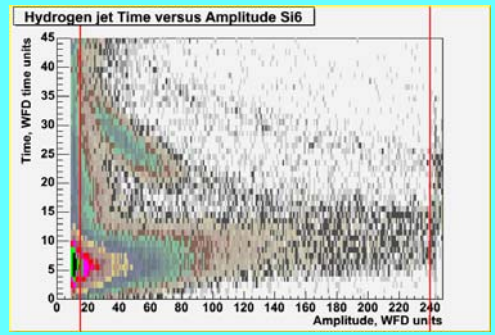

Hydrogen jet Time versus Amplitude Si1
Time, WFD time units
Amplitude, WFD units

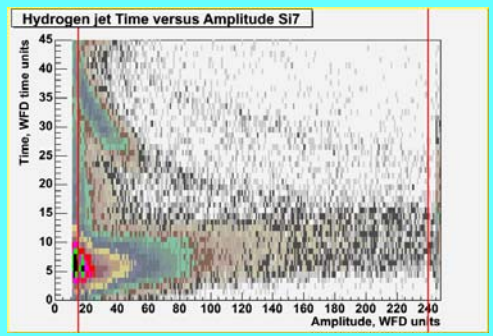

Hydrogen jet Time versus Amplitude Si2
Time, WFD time units
Amplitude, WFD units

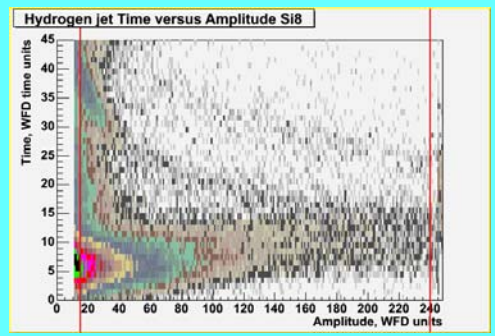

Hydrogen jet Time versus Amplitude Si3
Time, WFD time units
Amplitude, WFD units


Hydrogen jet Time versus Amplitude Si4
Time, WFD time units
Amplitude, WFD units

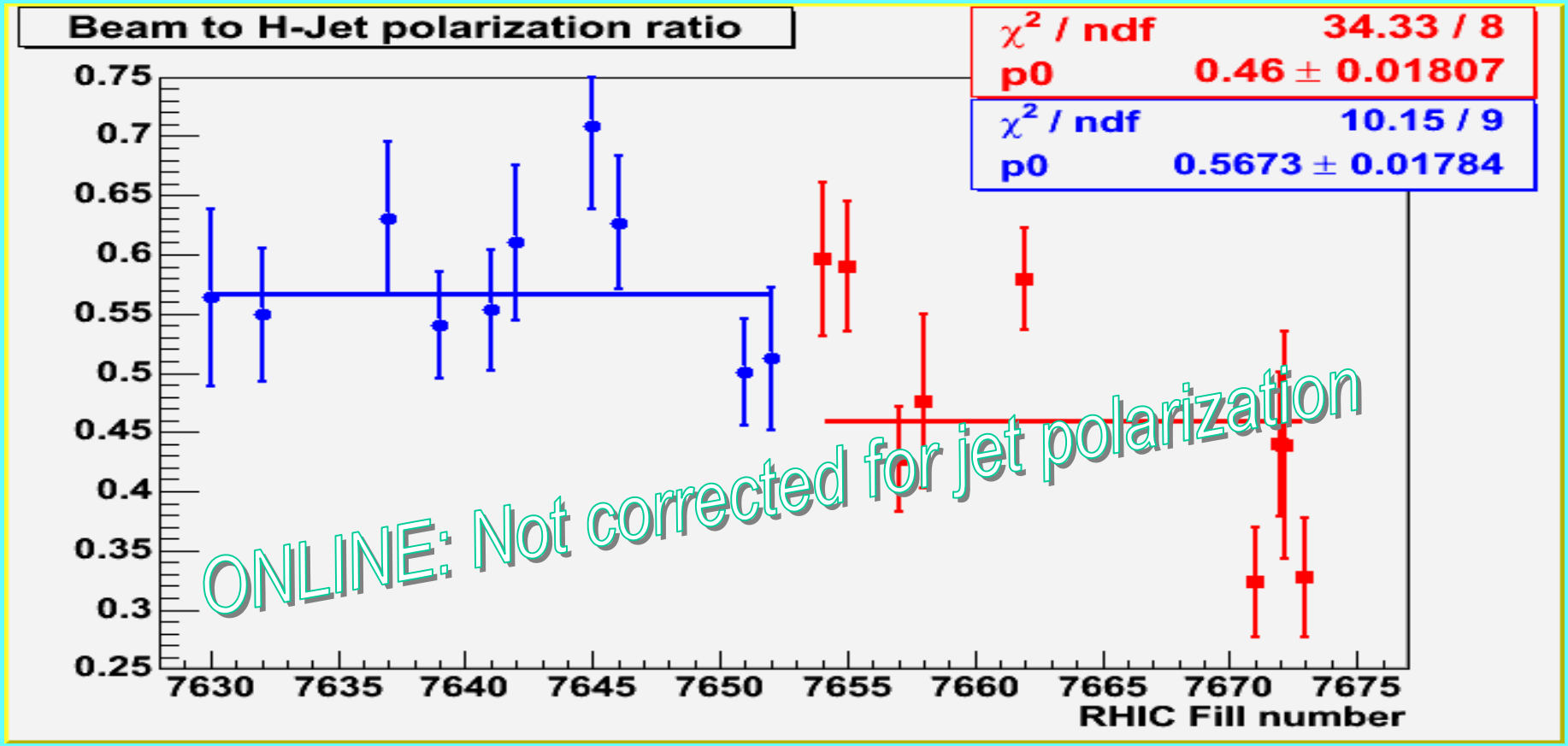

Hydrogen jet Time versus Amplitude Si5
Time, WFD time units
Amplitude, WFD units


Hydrogen jet Time versus Amplitude Si6
Time, WFD time units
Amplitude, WFD units


Hydrogen jet Time versus Amplitude Si7
Time, WFD time units
Amplitude, WFD units

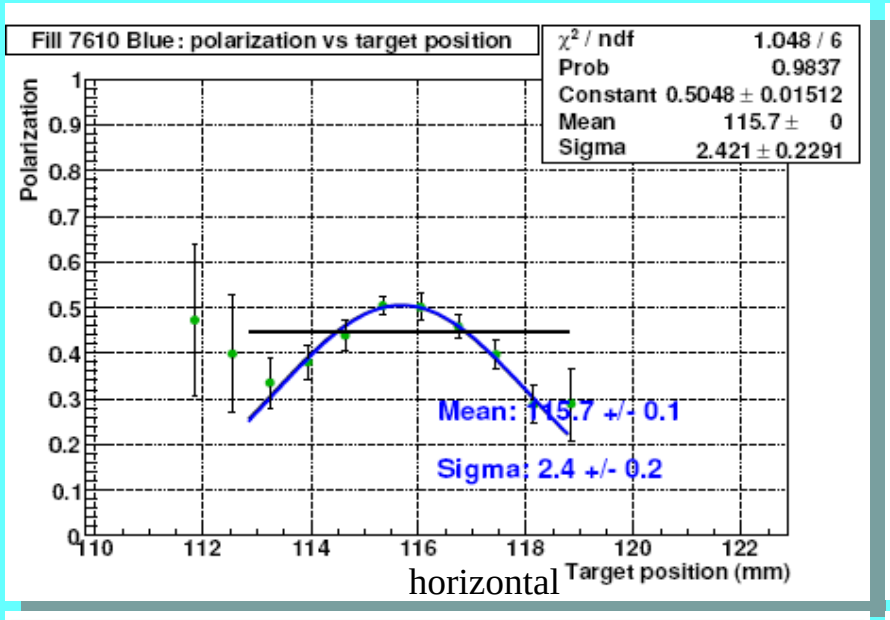

Hydrogen jet Time versus Amplitude Si8
Time, WFD time units
Amplitude, WFD units

Hjet: 10% absolute measurement in one store

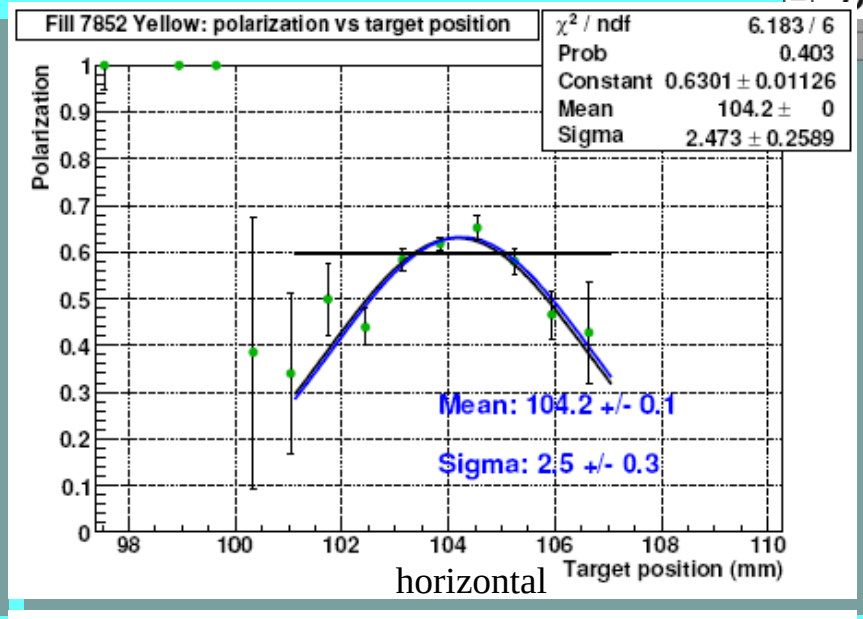


Polarization profile - examples

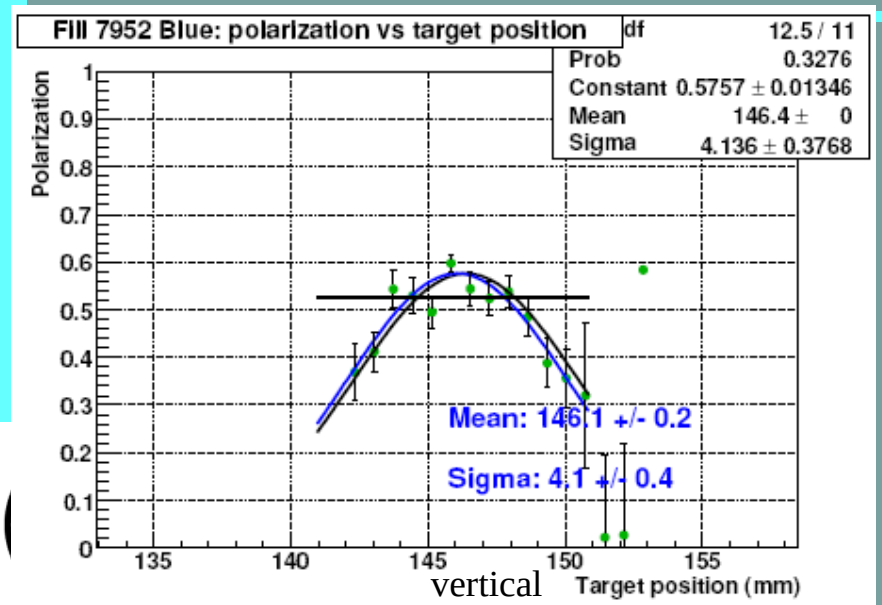
Figures by C. Camacho



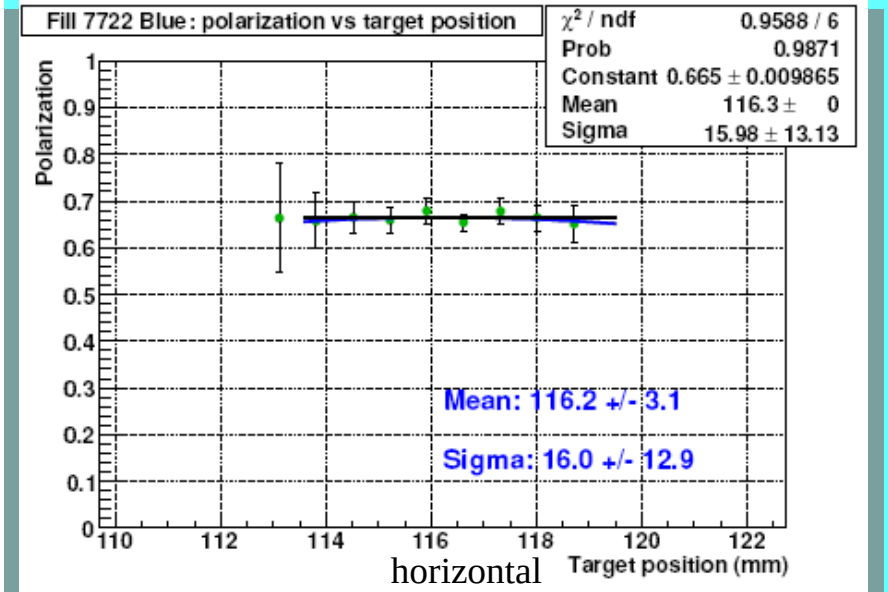
horizontal



horizontal



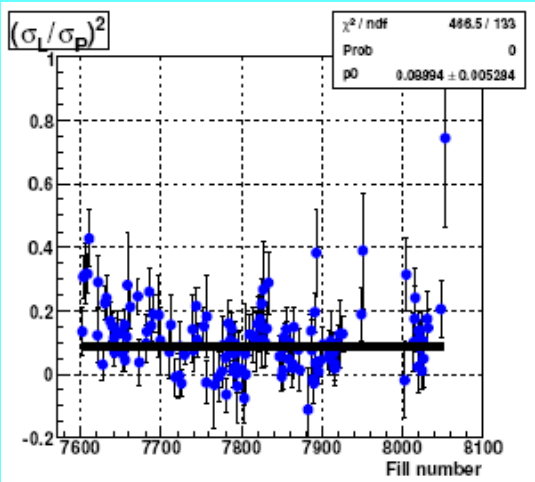
vertical

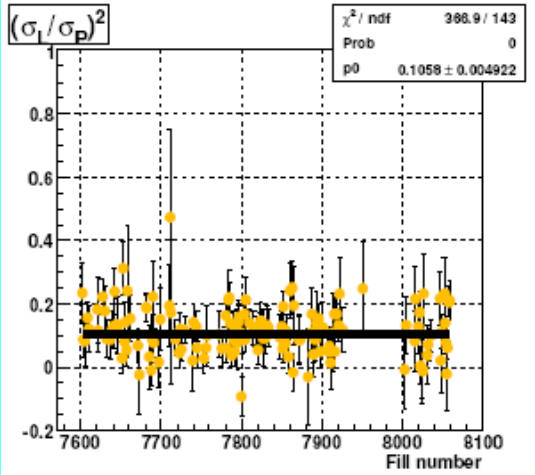


horizontal

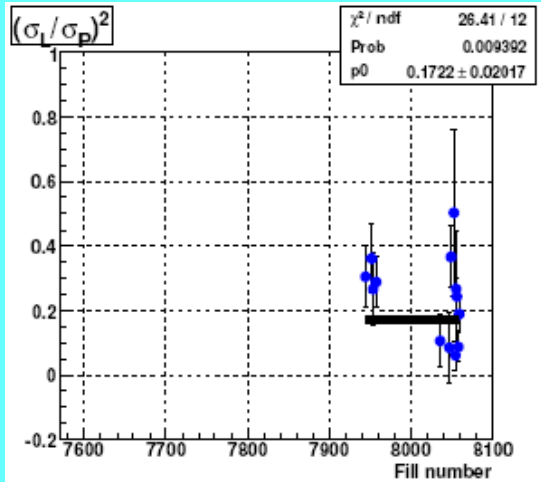
Polarization profile - discussion (data 2006)

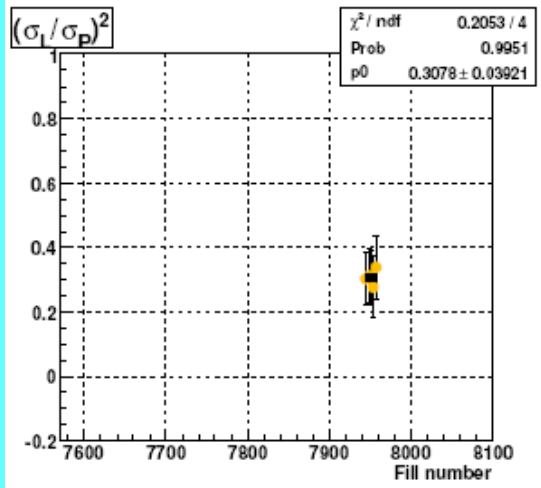
horizontal





vertical





- **Observed in both rings, both vertical and horizontal**
- **Different from fill to fill**
- **Both Hjet and pC (in horizontal scan mode) measure polarization averaged over intensity – no correction needed**
- **Experiments see polarization averaged over luminosity – a product of the beams intensities. => Can produce a systematic shift of the polarization.**
- **Correction for experiments (fill by fill ?): $+\frac{1}{2}(\sigma_L/\sigma_P)^2$ ~ 0-7%**

Figures by C. Camacho

Roadmap to absolute polarization

A JET target polarization P_{target} (Breit-Rabi polarimeter) $\Rightarrow$ **$\sigma \approx 2\%$.**

B A_N for elastic *pp* in CNI region: $A_N = - 1 / P_{target}\, \varepsilon_N'$.

C $P_{beam} = 1 / A_N\, \varepsilon_N''$.

(B & C) can be combined in a single measurement (much less sensitivity to background etc):

$P_{beam} / P_{target} = - \varepsilon_N' / \varepsilon_N''$ $\Rightarrow$ **$\sigma_{stat} = 3\text{-}4\%$** in 2 weeks (both rings)

D CALIBRATION: A_N^{pC} for *pC* CNI polarimeter in covered kinematical range: $A_N^{pC} = 1 / P_{beam}\, \varepsilon_N'''$.

(B & C & D) measured simultaneously with several insertions of carbon target $\Rightarrow$ **$\sigma_{stat}(pC) \approx 0\%$** - very large statistics.

E BEAM POLARIZATION: $P_{beam} = 1 / A_N^{pC}\, \varepsilon_N''''$ to experiments $\Rightarrow$ **$\sigma(A_N^{pC}) < 1\text{-}2\%$** if jet is run continuously.

$$\frac{\Delta P_{beam}}{P_{beam}} = \left(\frac{\Delta P_{target}}{P_{target}}\right) \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pp} \oplus \left(\frac{\Delta A_N}{A_N}\right)_{pC} \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pC} \oplus \left(\frac{\Delta P}{P}\right)_{prof} \approx 5\%$$

2% 3-4% 1-2% 0% 2%