Longitudinal bunch profiles in 2017 *pp* beams as seen by RHIC pC polarimeters

Ana S. Nunes

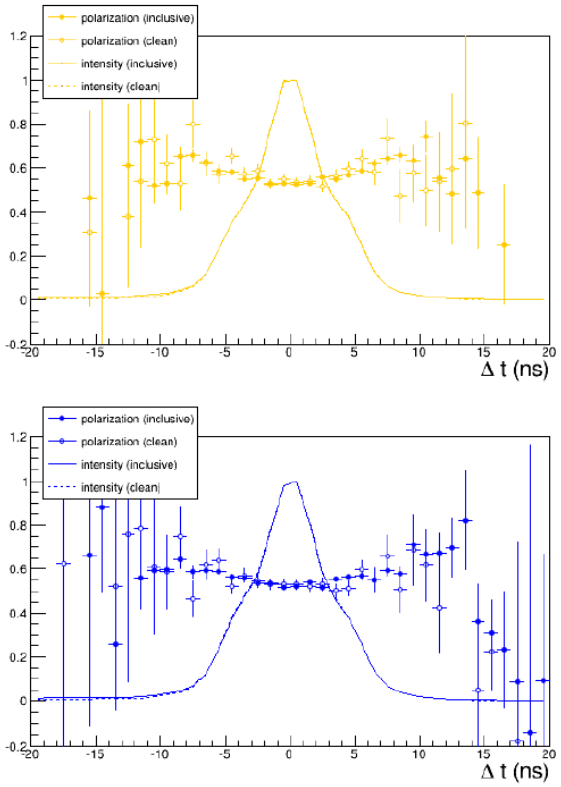
BNL, June 19, 2019

Introduction

- **Transverse bunch profiles** imply **correction factors** to measured polarizations:
  - $\sim \sqrt{1+R_x}\sqrt{1+R_y} \sim (1+R) \simeq 1.15$ for DSA
  - $\sim \sqrt{1+\frac{1}{2}R_x}\sqrt{1+\frac{1}{2}R_y} \sim \left(1+\frac{1}{2}R\right) \simeq 1.07$ for SSA

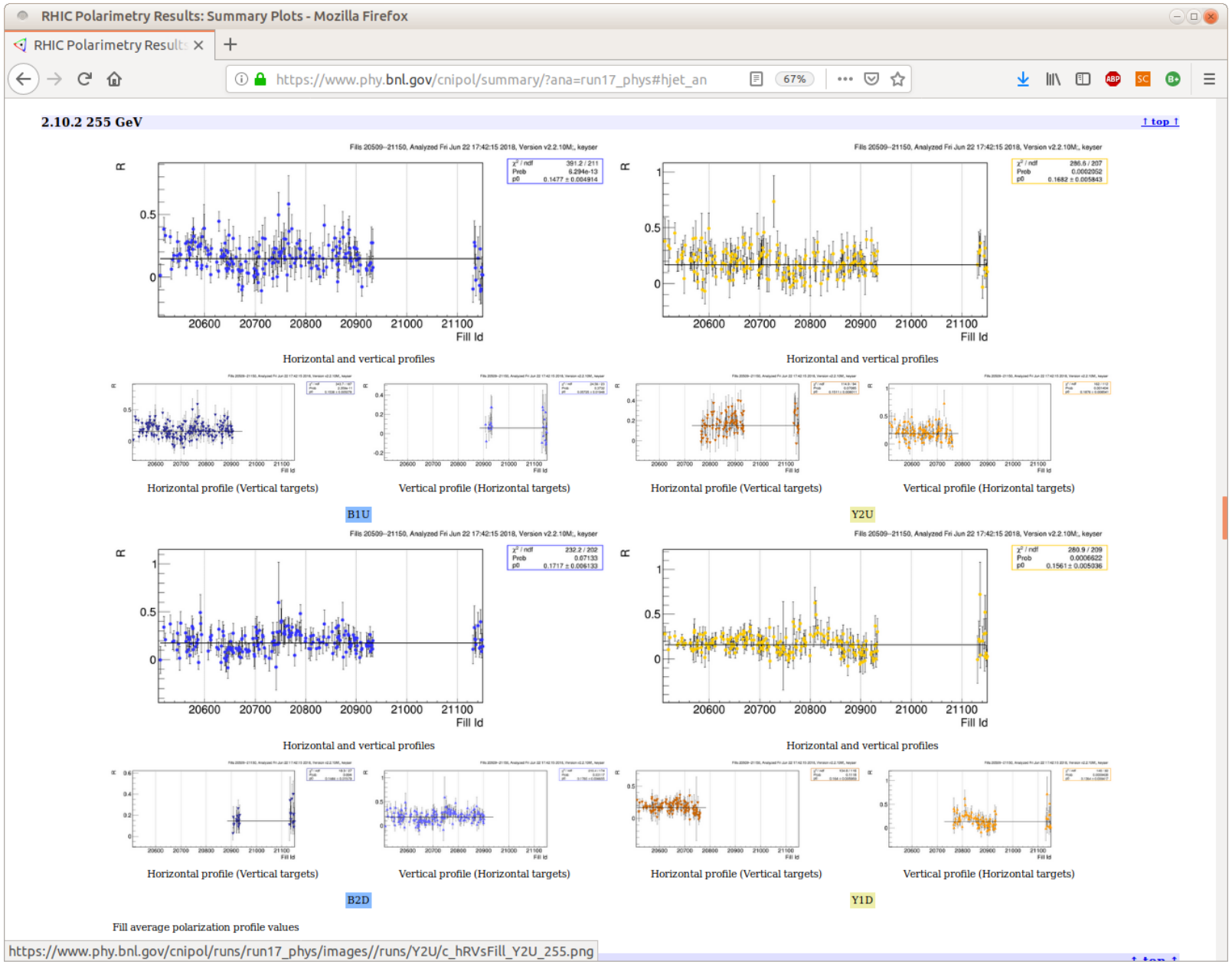
with $$R_{x,y} = \frac{\sigma^2_{I_{x,y}}}{\sigma^2_{P_{x,y}}},\ R = \frac{\sigma^2_I}{\sigma^2_P}$$

- **Longitudinal bunch profiles** seen in the **H-Jet polarimeter**
- pC polarimeters at RHIC are fast and precise (but need normalization using the H-Jet polarimeter)
- How does the longitudinal bunch profile look like in pC polarimeter data?

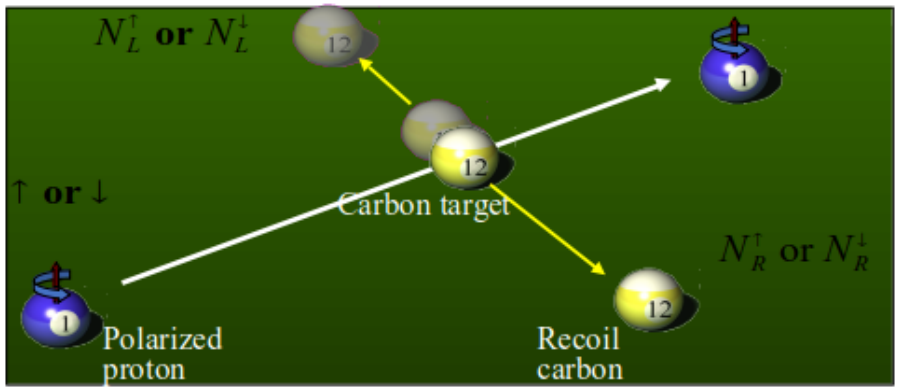


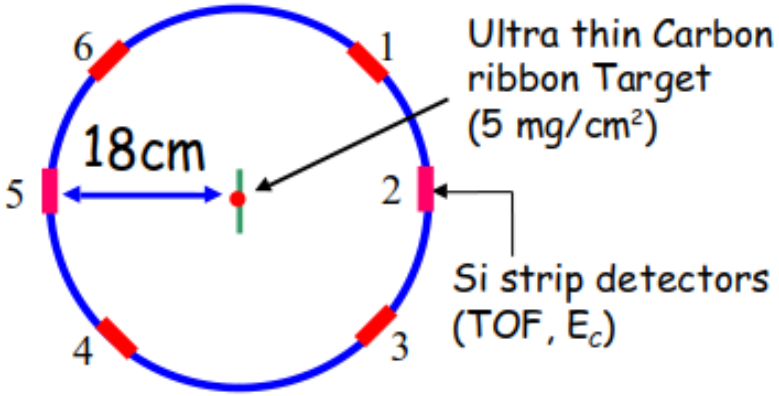
H-Jet data, O. Eyser, 13/Mar/2018, CNI Polarimetry Meeting

Transverse profiles over the year 2017, fill by fill



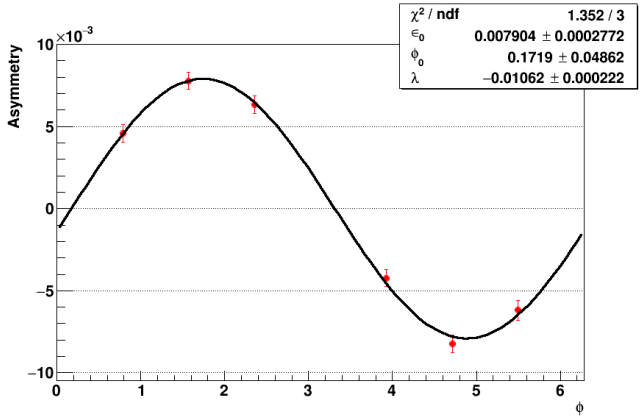
p-Carbon polarimeter





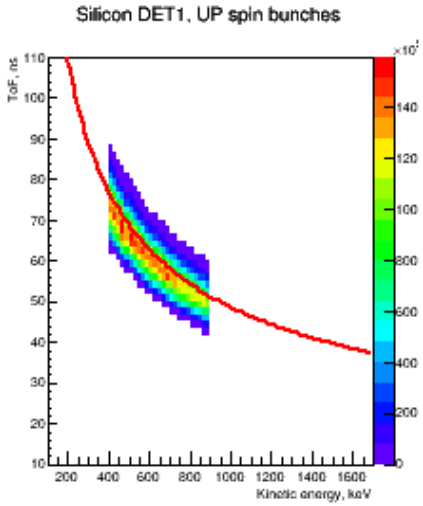
$$P_{beam} = \frac{\epsilon_N}{A_N^{pC}}$$

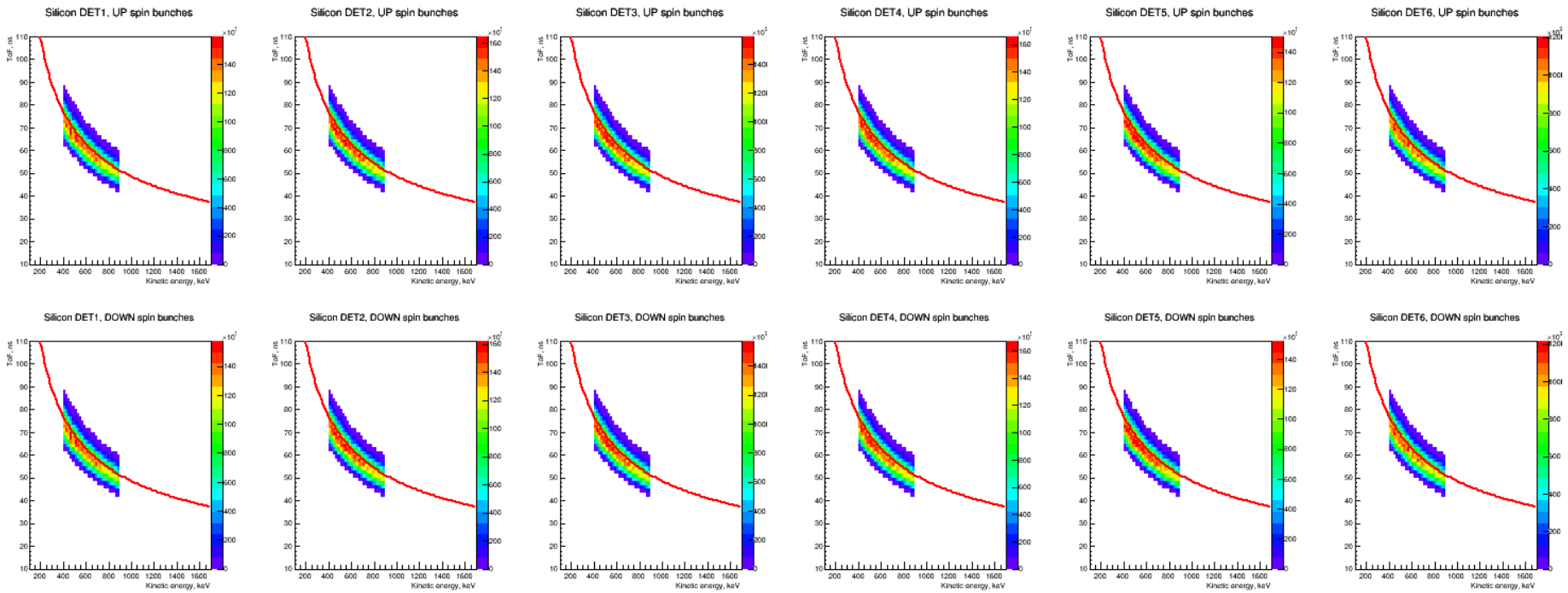
$$\epsilon_N = \frac{N_L - N_R}{N_L + N_R}$$



ToF vs E_{kin} (for 6 Si detectors, 2 spin orientations)

- Input: program CNIPOL output ROOT files
- Used histograms: std/channel<ch>/hTofVsKinEnergyA_ch<ch>_<ss>
  <ch>: channel number (1-72)
  <ss>: spin orientation (up/down)
- Assumed all histograms occupy same locus in (E_{kin}, tof) plane
- Combined channels into corresponding silicon detectors





Input for Δt slices

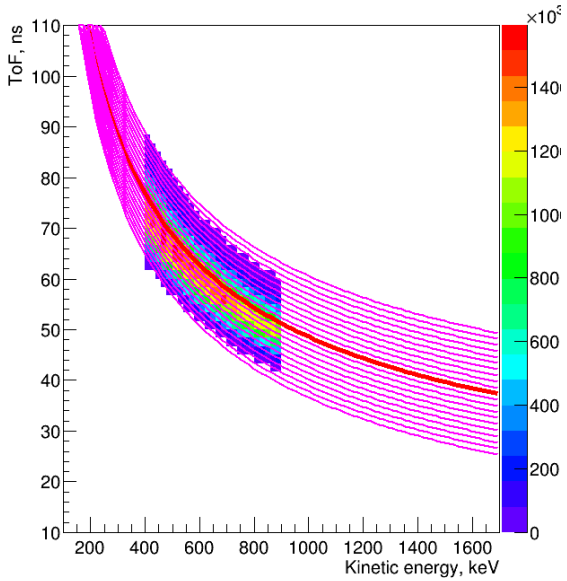
For each bin, used:

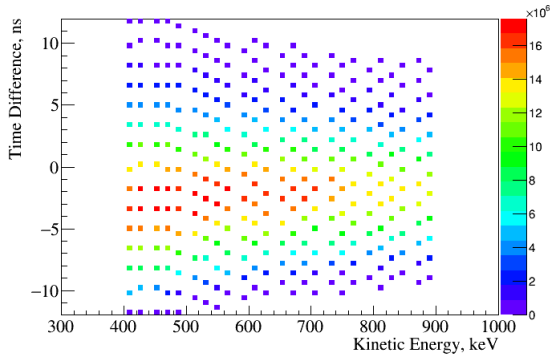
- center of bins of E_{kin}
- (1) center of bins in *tof* and (2) *tof* of the ideal functional form (red line)

$$tof = L\sqrt{\frac{M_C}{2E_{kin}}},$$

  with $L = 19.5$ cm, to get a time difference Δt for each bin

- Δt used to decide to which slice the bin belongs to
- 20 slices of width 1.2 ns used (matching the detectors' time resolution)





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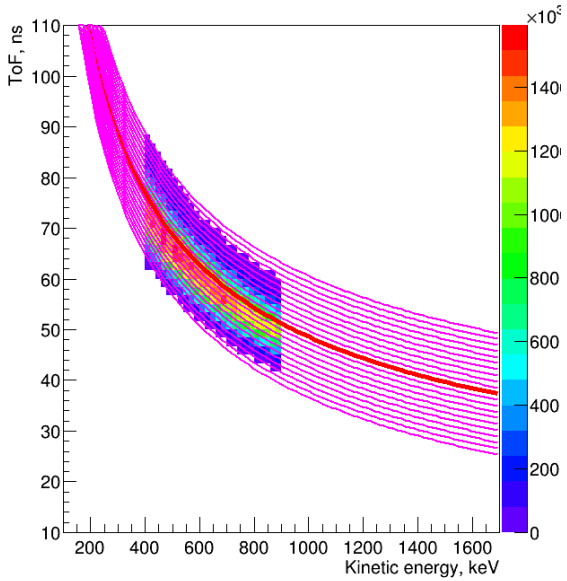
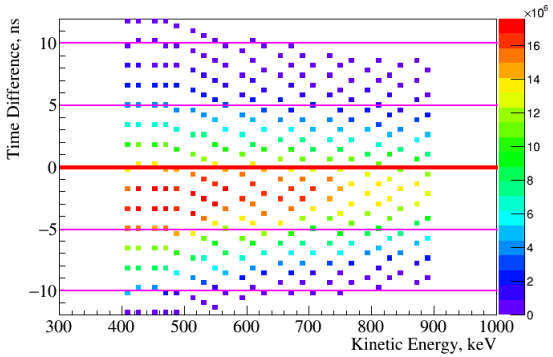
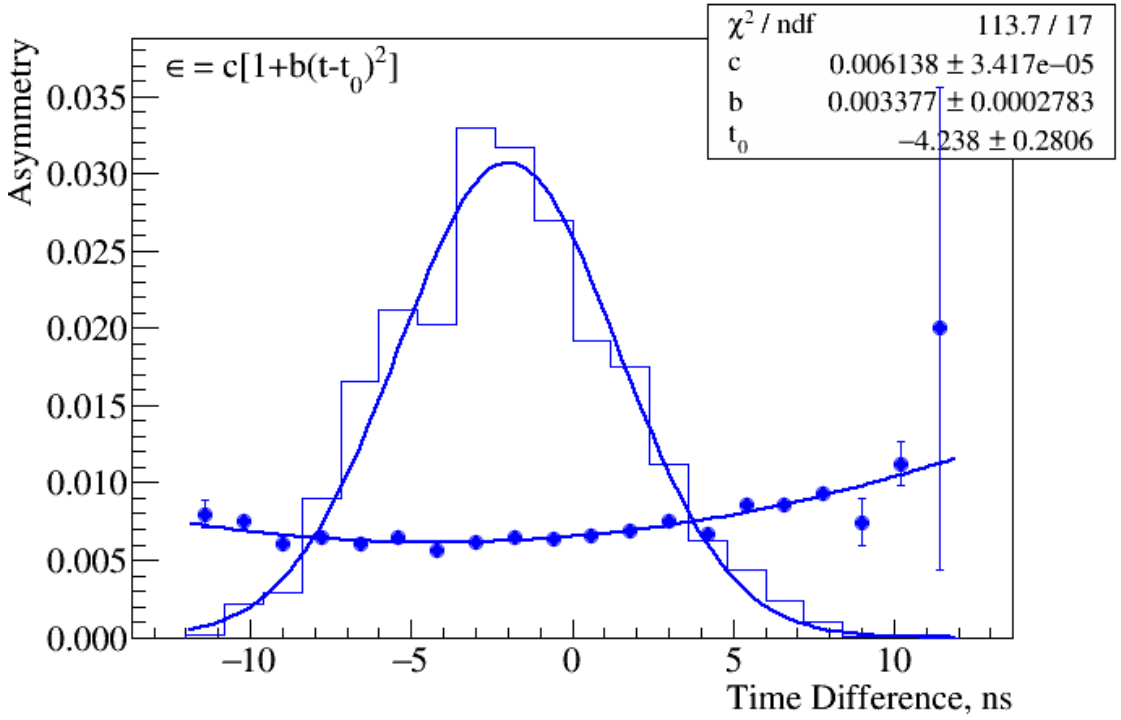




Longitudinal profile in pC polarimeters

Fit: $\epsilon = c \cdot [1 + b\,(t - t_0)^2]$



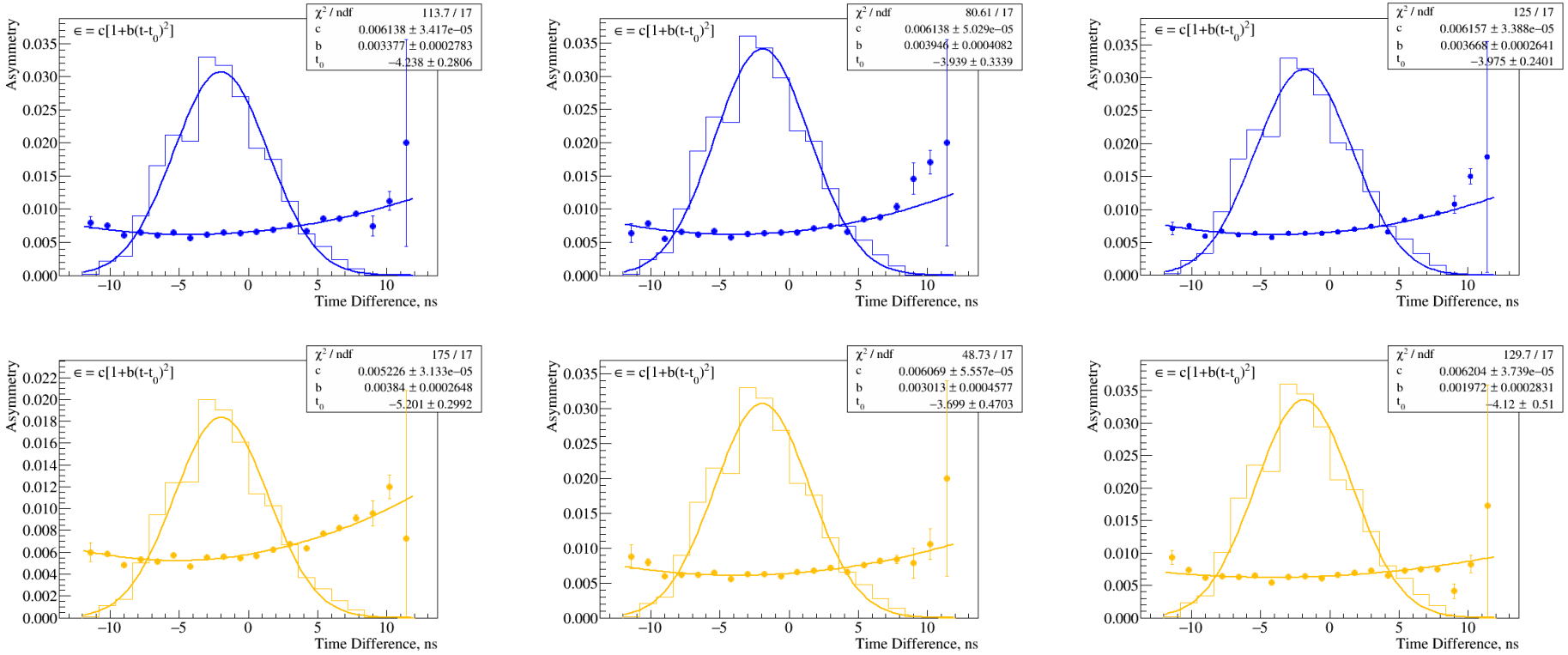
- The plot: (first 2017 BluV) 100 measurements of the pC polarimeters
- Asymmetry obtained using Bill Schmidke's fit function

```
void fit1asym(double nup[6],double ndn[6],double par[],double epar[],double &chi2,int fixpar = 0)
```

- Intensity fitted to gaussian; asymmetries fitted to parabola
- $R_s = \frac{\sigma^2_{I_s}}{\sigma^2_{P_s}} \simeq -2 \cdot b \cdot \sigma^2_{I_s}$. Here: $R_s \sim -0.09 \pm 0.04$ (cf. $R_{x,y} \sim +0.15$)

Longitudinal profile in pC polarimeters along the year

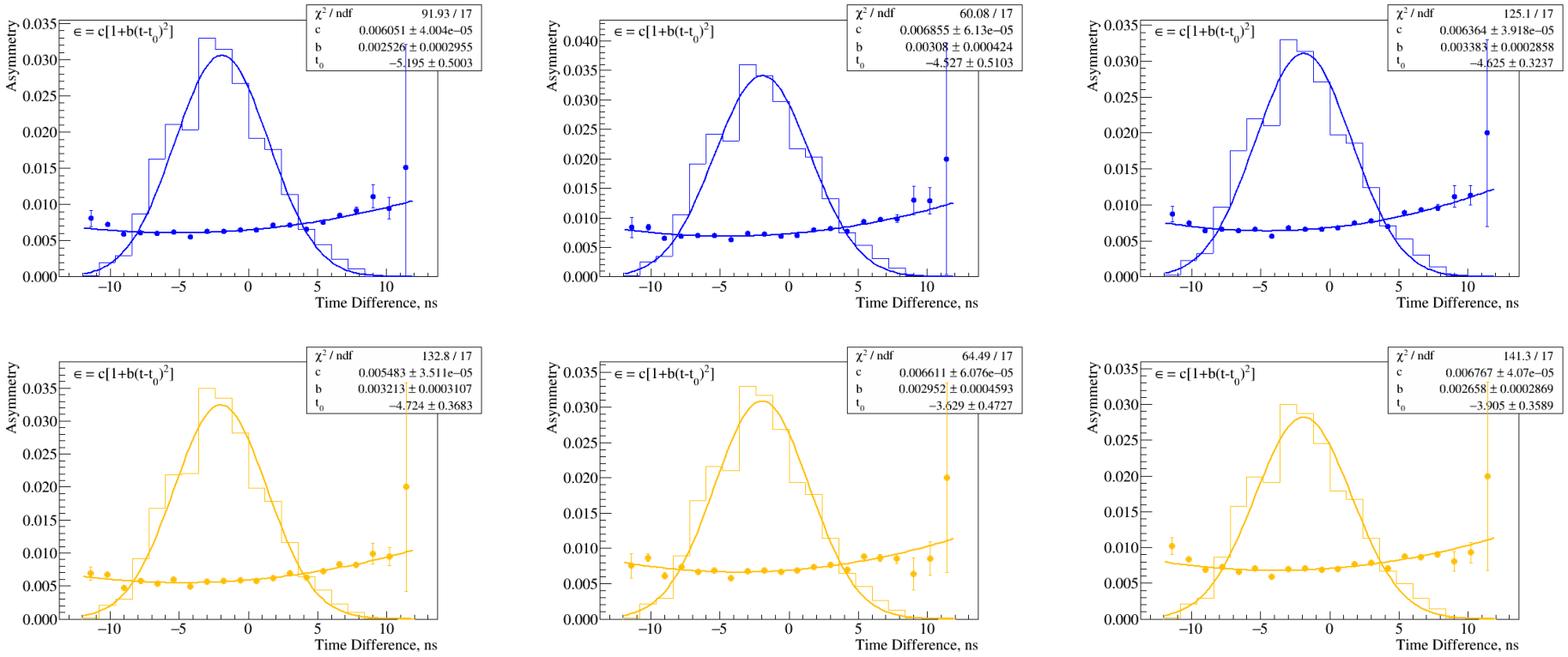
Beginning of year | Middle of year | End of year



- Each plot: 100 measurements at 255 GeV of the pC polarimeters
- Here, only measurements of the vertical carbon targets

Longitudinal profile in pC polarimeters along the year

Beginning of year | Middle of year | End of year



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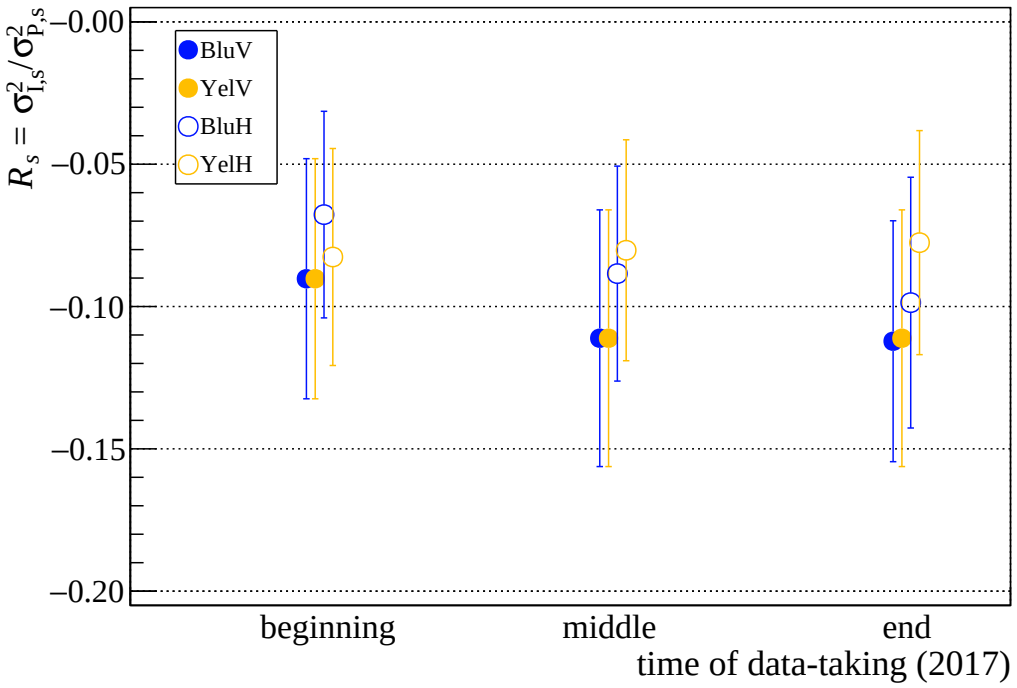
- Here, only measurements of the horizontal carbon targets

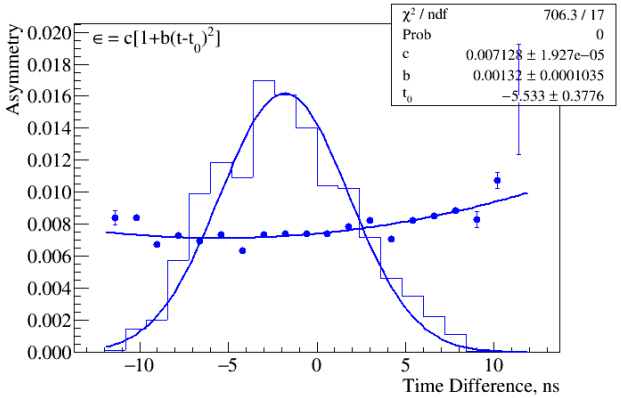
Longitudinal profile in pC polarimeters along the year



- $R_s = \frac{\sigma^2_{I_s}}{\sigma^2_{P_s}} \simeq -2 \cdot b \cdot \sigma^2_{I_s}$
- Each point: 100 measurements at 255 GeV of the pC polarimeters

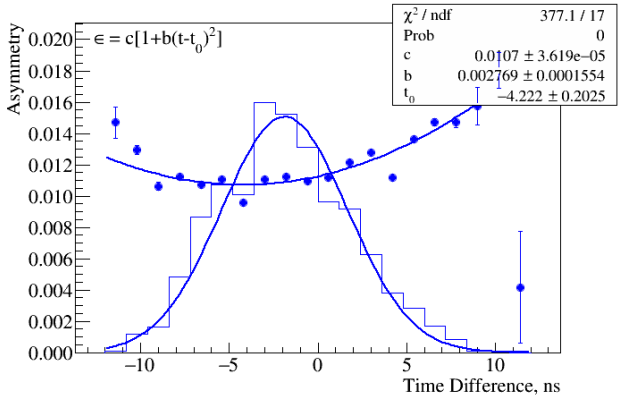
Longitudinal profile in pC polarimeters in 2017

Vertical carbon targets

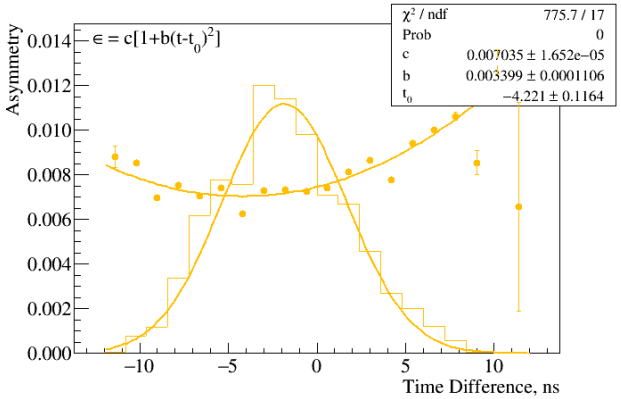


$R_s = -0.105 \pm 0.046$

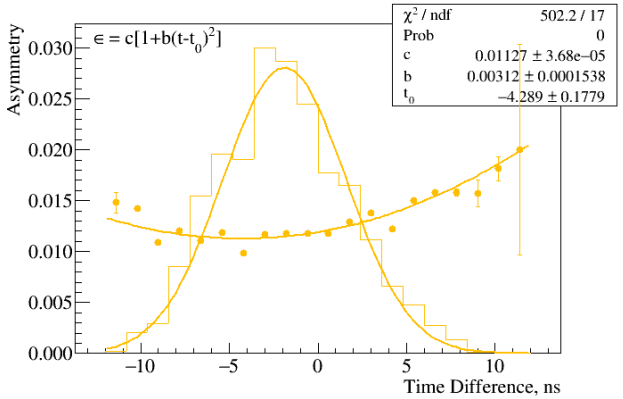
Horizontal carbon targets



$R_s = -0.112 \pm 0.026$



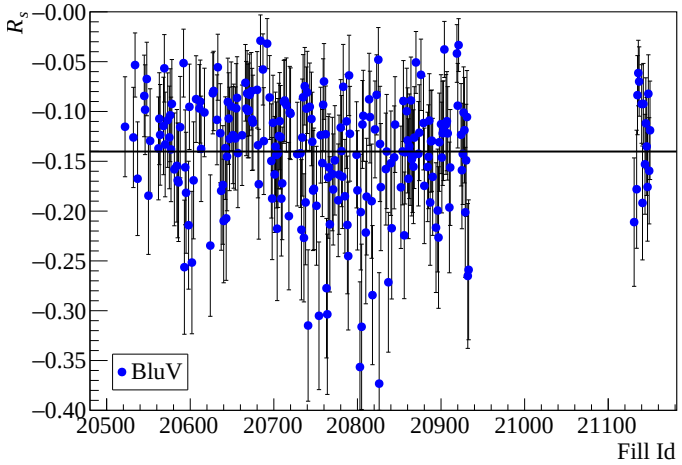
$R_s = -0.105 \pm 0.045$



$R_s = -0.095 \pm 0.042$

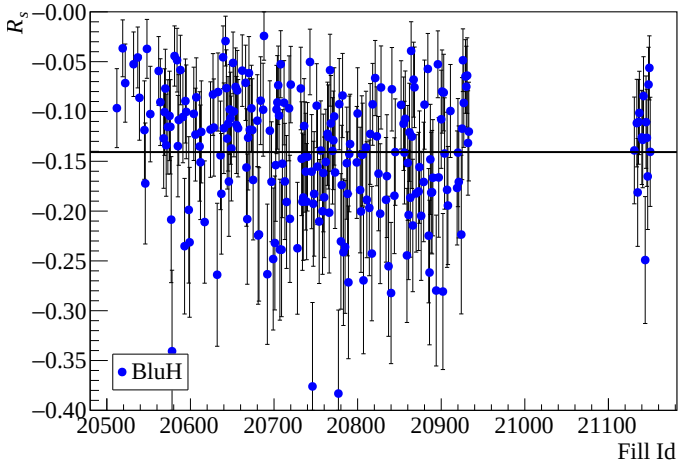
Longitudinal profile in pC polarimeters fill by fill

Vertical carbon targets

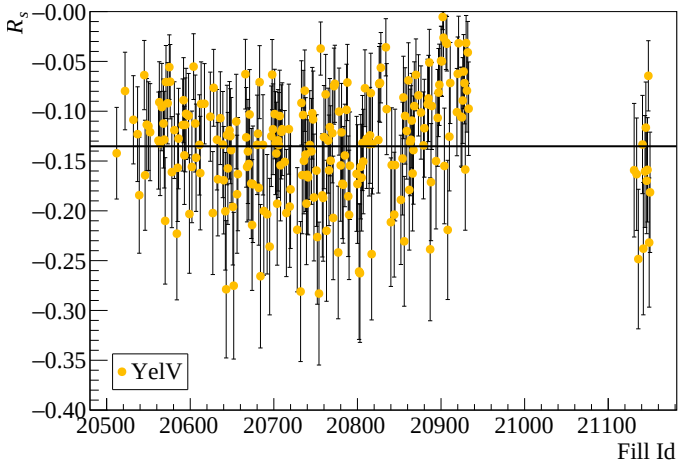


$\langle R_s \rangle = -0.140 \pm 0.004$

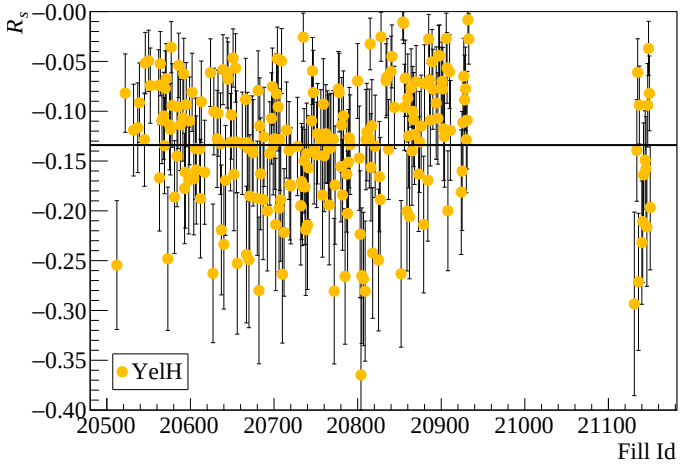
Horizontal carbon targets



$\langle R_s \rangle = -0.141 \pm 0.004$



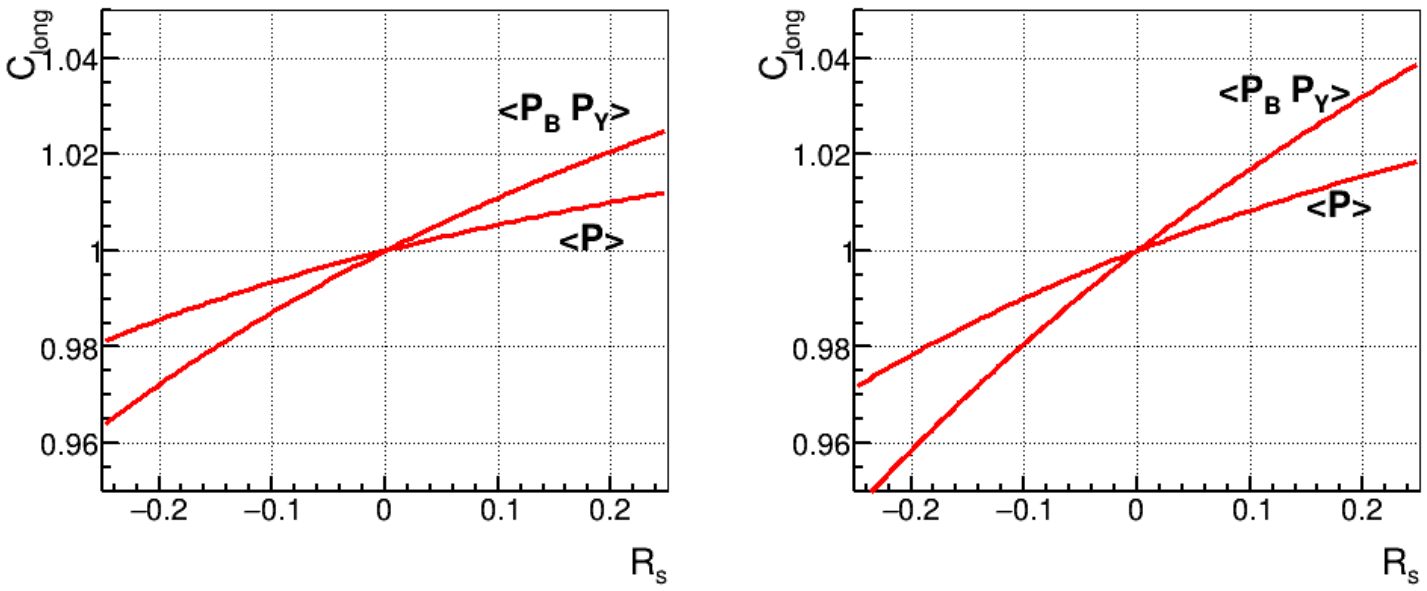
$\langle R_s \rangle = -0.135 \pm 0.006$



$\langle R_s \rangle = -0.134 \pm 0.004$

Impact on polarization (calculations for 2017 conditions)

- Cases with minimal ($\sigma_l = 100$ cm and $\beta^* = 150$ cm) and maximal ($\sigma_l = 120$ cm and $\beta^* = 120$ cm) polarization profile changes
- Extension to negative values valid if $(1 + mR_s) > 0$ and $(1 + nR_s) > 0$



[Alexander Bazilevsky, email 1/May/2019]

- Minimal and maximal corrections:
  - $\langle P_B P_Y \rangle$: $0.978 - 0.985$
  - $\langle P \rangle$: $0.988 - 0.989$

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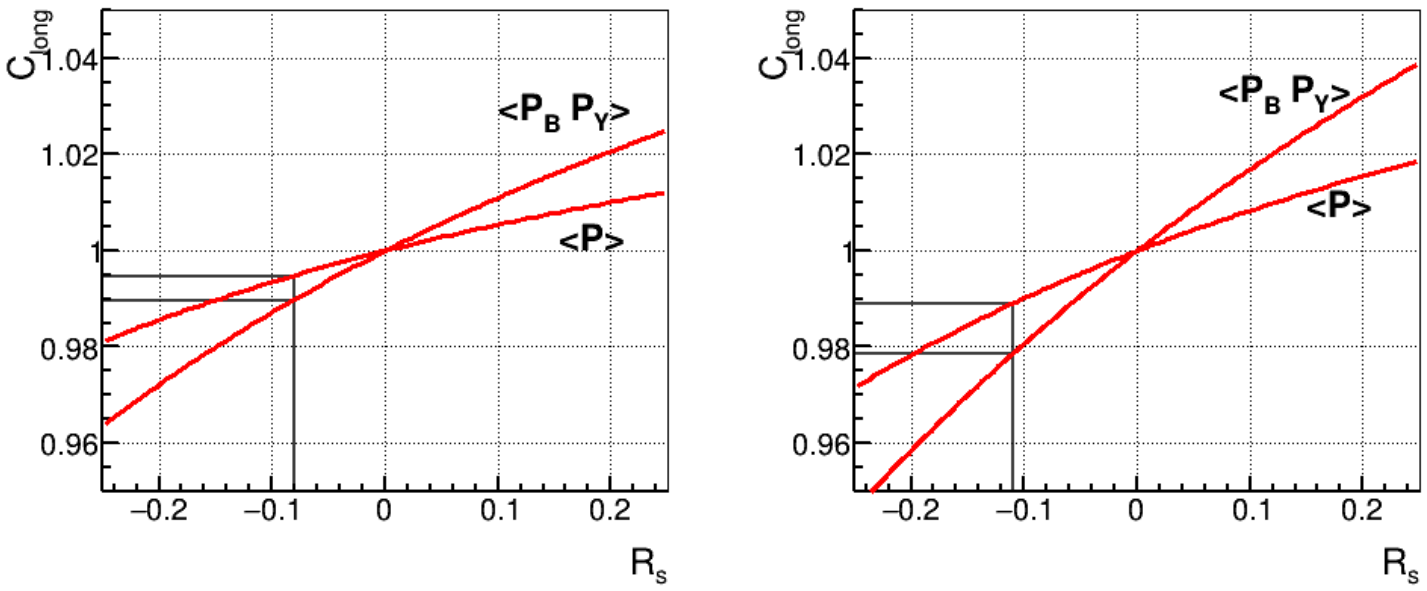

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  - $\langle P_B P_Y \rangle$: 0.978 – 0.985
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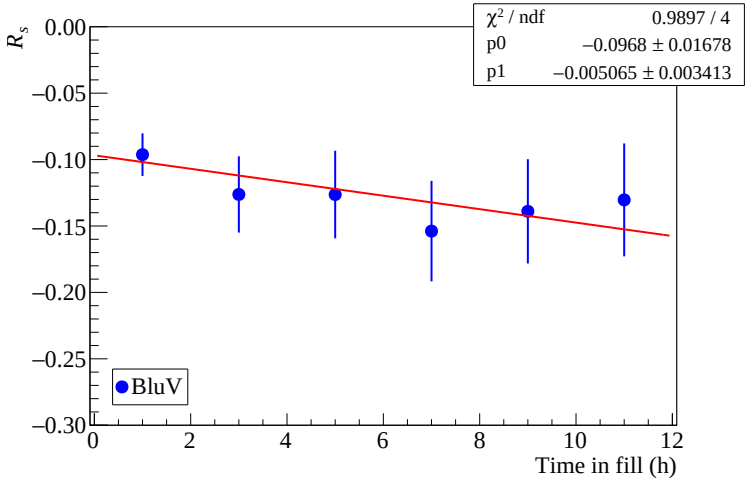
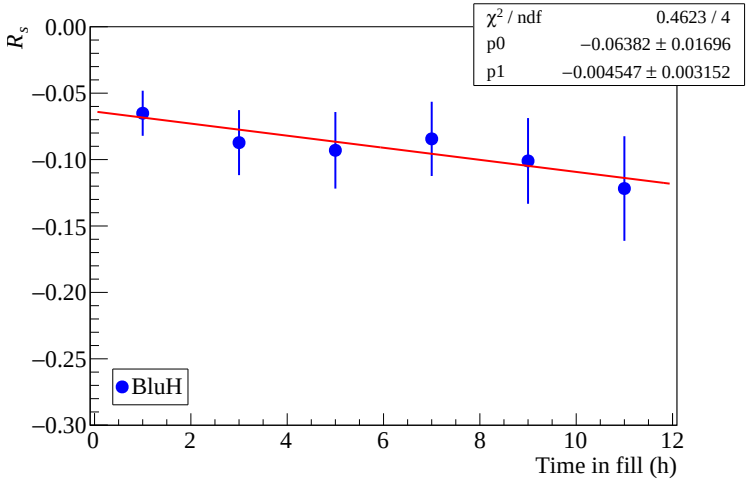
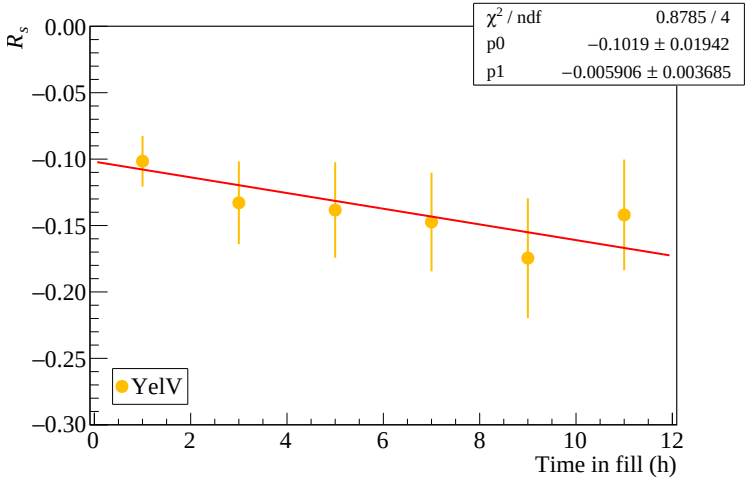
R_s throughout the fill

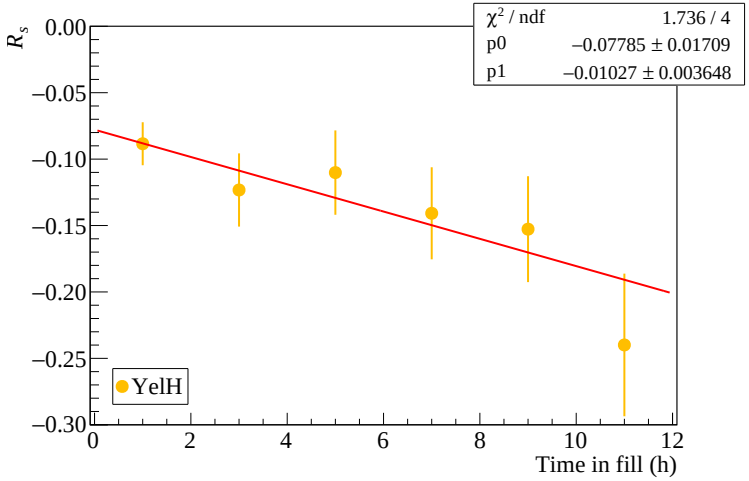
Vertical carbon targets



Horizontal carbon targets







Summary

- **Longitudinal bunch profile** studied for 2017 *pp* pC polarimeter data
- **Top-opening parabola shape** of bunch polarization profile observed
- Result consistent with observation in H-jet polarimeter, and more **precise**
- Effect **consistently present throughout the year**
- **Limited impact** correction factors for polarization (1-2%), of **opposite sign** with respect to the ones due to the transverse bunch polarization profile
- **R_s increases (in absolute value) along the fill**
- Is R_s the same in the interaction regions? It is assumed it is.
- If the profile is a result of a beam-beam effect, it may be more pronounced in the EIC

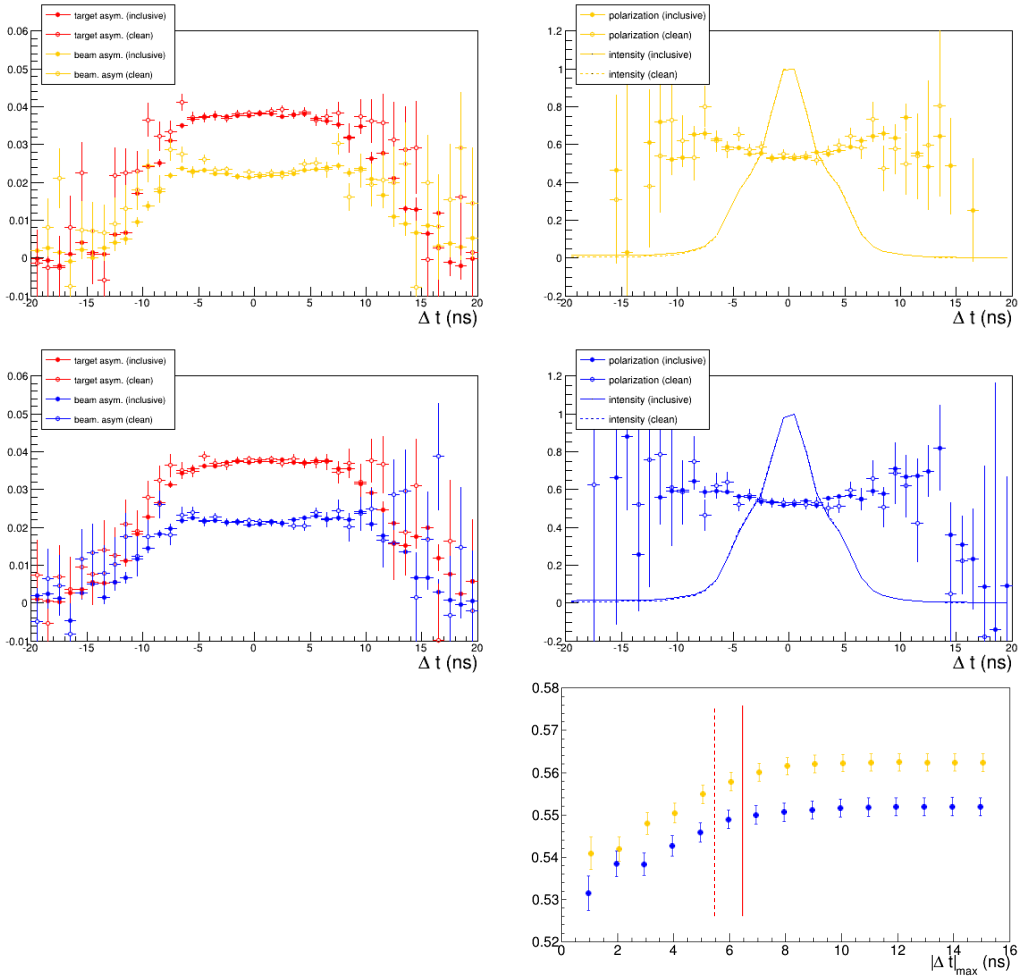
- To do: $dP/dt(t_{fill}, I_{bunch}, I_{partner\ bunch}, \epsilon)$

BACKUP

Longitudinal profiles in the H-Jet polarimeter

7

Bunch Profile



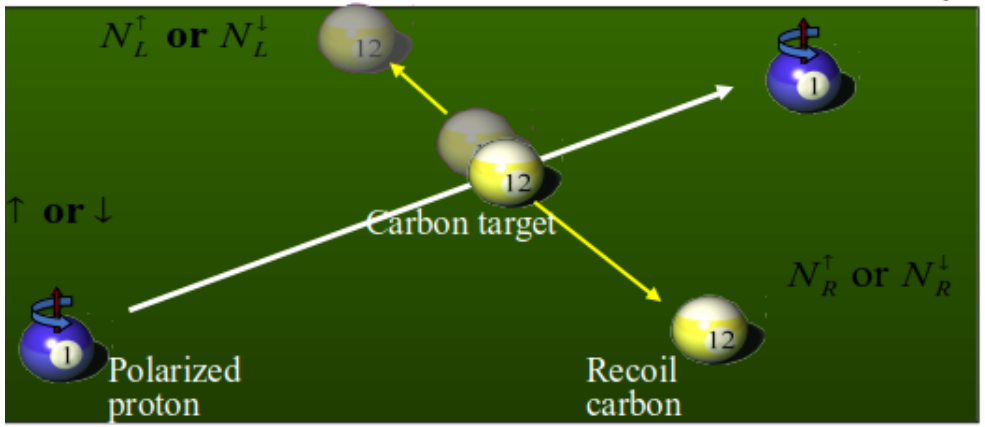
- Small differences between inclusive and clean asymmetries
- Consistent beam polarization measurement
- Longitudinal polarization profile (target asymmetry flat)
- Wider time of flight window for polarization determination, 6.0 ns
- Include longitudinal profile in luminosity weighting?

$$1.5 < T_R < 7.0 \text{ MeV}$$
$$|\Delta t| < 6.0 \text{ ns}$$
$$|\Delta m_{miss}| < 60 \text{ MeV/c}^2$$

H-Jet data, O. Eyser, 13/Mar/2018, CNI Polarimetry Meeting

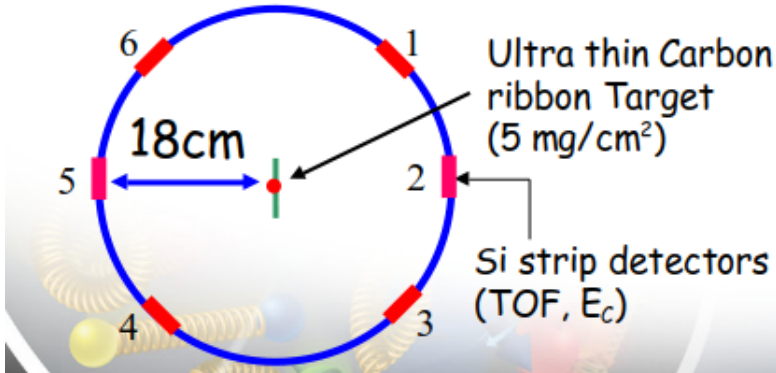
P-Carbon Polarimeter:

Left-right asymmetry in elastic scattering due to spin-orbit interaction:
interaction between (electric or strong) field of Carbon and magnetic moment associated with the spin of the proton



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

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



Target Scan mode (20-30 sec per measurement)

Stat. precision 2-3%

Polarization profile, both vertical and horizontal

Normalized to H-Jet measurements over many fills (with precision <3%)

5 RHIC Polarimeter Meeting E.C. Aschenauer

Transverse longitudinal profile

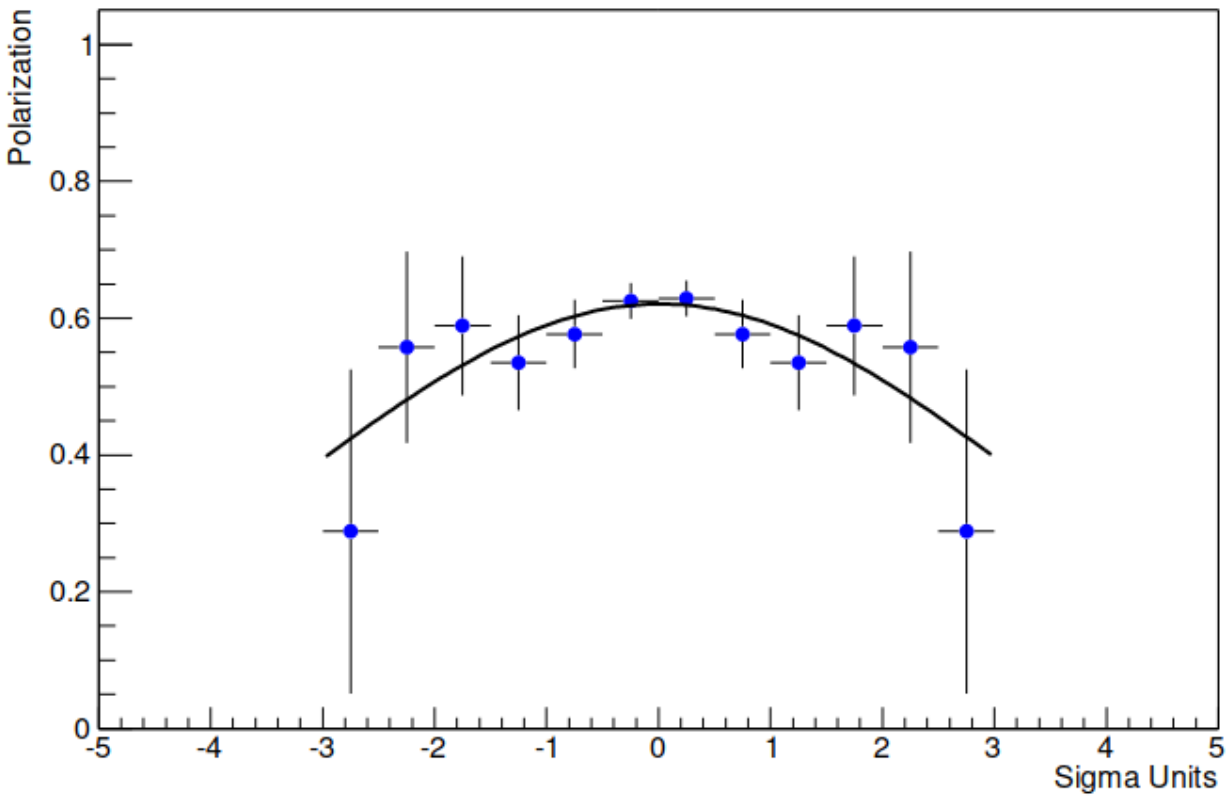


Figure 2: The polarization profile from a single measurement at store. The horizontal axis is in unit of beam size sigma.

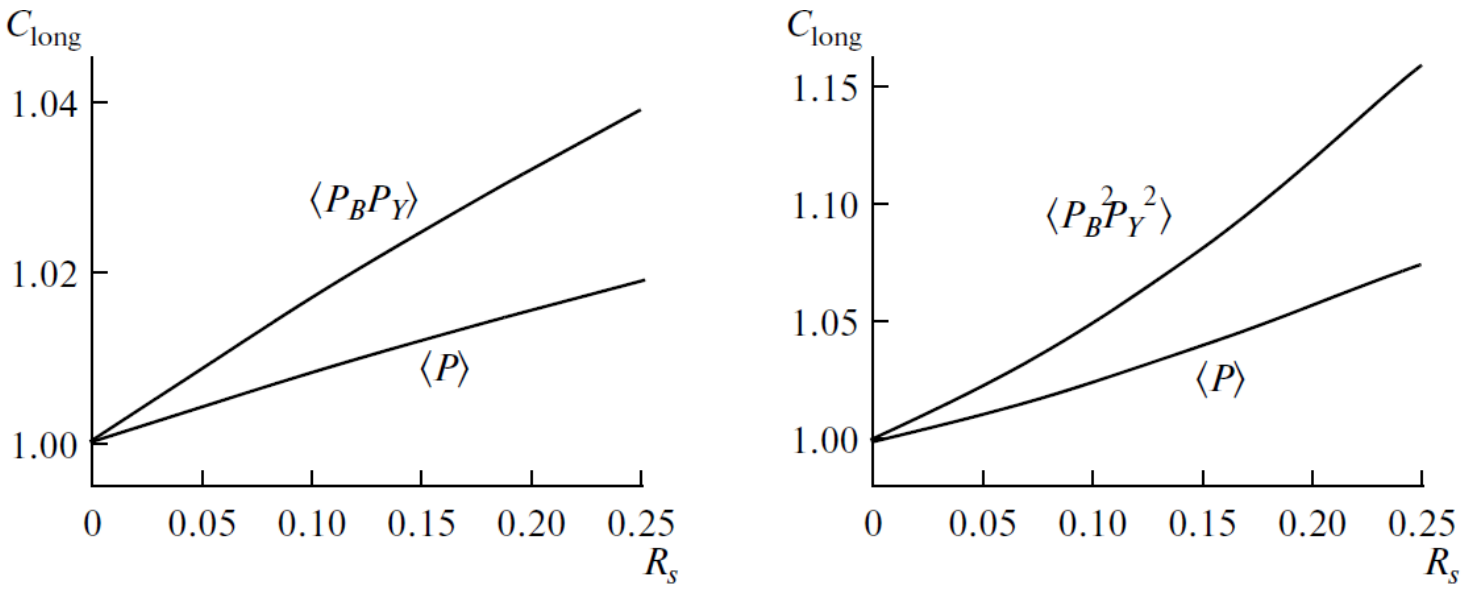
[H. Huang *et al.*, 6th International Particle Accelerator Conference, 2015, doi:10.18429/JACoW-IPAC2015-MOPTY011]

Longitudinal profile in pC polarimeters along the year

- Parabola and gaussian width parameters and $R_s \simeq -2 \cdot b \cdot \sigma_l^2$

	b (ns^{-2})	σ_l (ns)	R_s
BluV-Begin	$0.00337661 \pm 0.00027832$	3.65548 ± 0.189717	-0.0902403 ± 0.0421795
YelV-Begin	$0.00394597 \pm 0.00040819$	3.75263 ± 0.185067	-0.1111360 ± 0.0450926
BluH-Begin	$0.00252648 \pm 0.00029551$	3.66052 ± 0.188514	-0.0677066 ± 0.0362902
YelH-Begin	$0.00337661 \pm 0.00027832$	3.65548 ± 0.189717	-0.0902403 ± 0.0421795
BluV-Middle	$0.00394597 \pm 0.00040819$	3.75263 ± 0.185067	-0.1111360 ± 0.0450926
YelV-Middle	$0.00394597 \pm 0.00040819$	3.75263 ± 0.185067	-0.1111360 ± 0.0450926
BluH-Middle	$0.00308027 \pm 0.00042403$	3.78879 ± 0.174465	-0.0884340 ± 0.0377633
YelH-Middle	$0.00301280 \pm 0.00045772$	3.69123 ± 0.189538	-0.0820997 ± 0.0400472
BluV-End	$0.00377530 \pm 0.00026194$	3.85474 ± 0.175304	-0.1121950 ± 0.0423196
YelV-End	$0.00321347 \pm 0.00031074$	3.58507 ± 0.177412	-0.0826036 ± 0.0381171
BluH-End	$0.00338301 \pm 0.00028584$	3.81804 ± 0.193669	-0.0986311 ± 0.0440482
YelH-End	$0.00265838 \pm 0.00028693$	3.81928 ± 0.195132	-0.0775552 ± 0.0393545
Average	0.00331 ± 0.00009	3.72 ± 0.05	-0.09 ± 0.01

Impact on polarization and figure of merit



Correction due to longitudinal polarization profile for the polarization (left), and for the figure of merit (right) in single (lower curves) and double (upper curves) spin measurements for the RHIC setup in polarized proton run with 250 GeV beams in 2011.

[Bazilevsky, A. & Fischer, W. Phys. Part. Nuclei (2014) 45: 257. https://doi.org/10.1134/S1063779614010134]

Impact on polarization and figure of merit

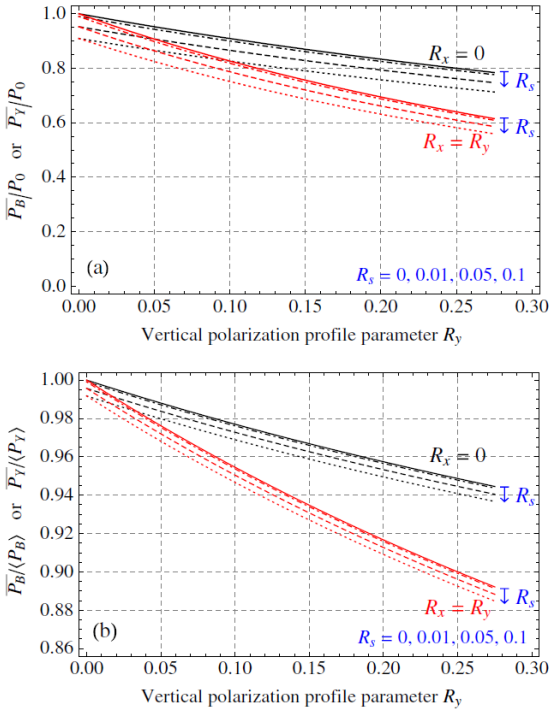


FIG. 1. (a) Relative reduction of the average polarization, $\overline{P_B}/P_0$ or $\overline{P_Y}/P_0$, as a function of the vertical profile parameter R_y. (b) Ratio of the polarization measured by a polarimeter to the average polarization in single spin colliding beam experiments, $\overline{P_B}/\langle P_B\rangle$ or $\overline{P_Y}/\langle P_Y\rangle$. The cases $R_x = 0$ and $R_x = R_y$ are shown for $R_s = 0, 0.01, 0.05, 0.1$ each.

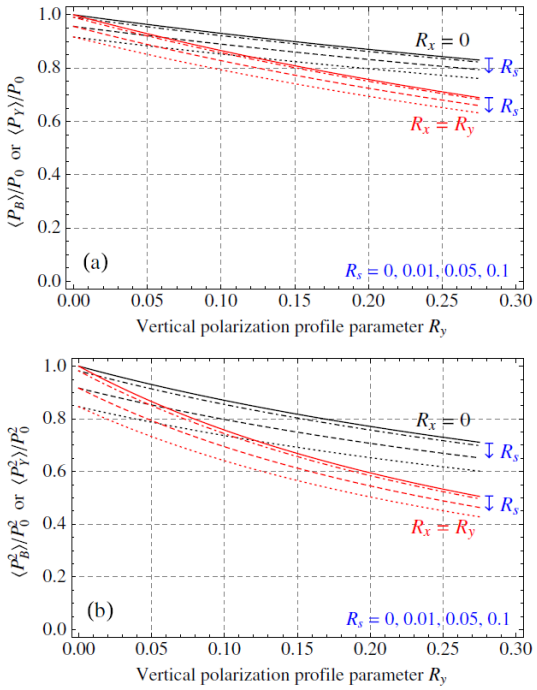


FIG. 2. For single spin colliding beam experiments (a) relative reduction of the average polarization $\langle P_B\rangle/P_0$ or $\langle P_Y\rangle/P_0$, and (b) relative reduction of the figure of merit $\langle P_B^2\rangle/P_0^2$ or $\langle P_Y^2\rangle/P_0^2$, as a function of the vertical profile parameter R_y. The cases $R_x = 0$ and $R_x = R_y$ are shown for $R_s = 0, 0.01, 0.05, 0.1$ each.

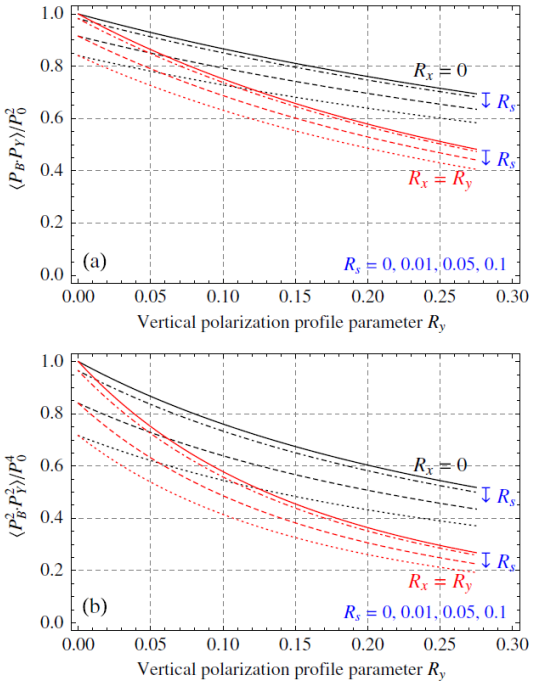
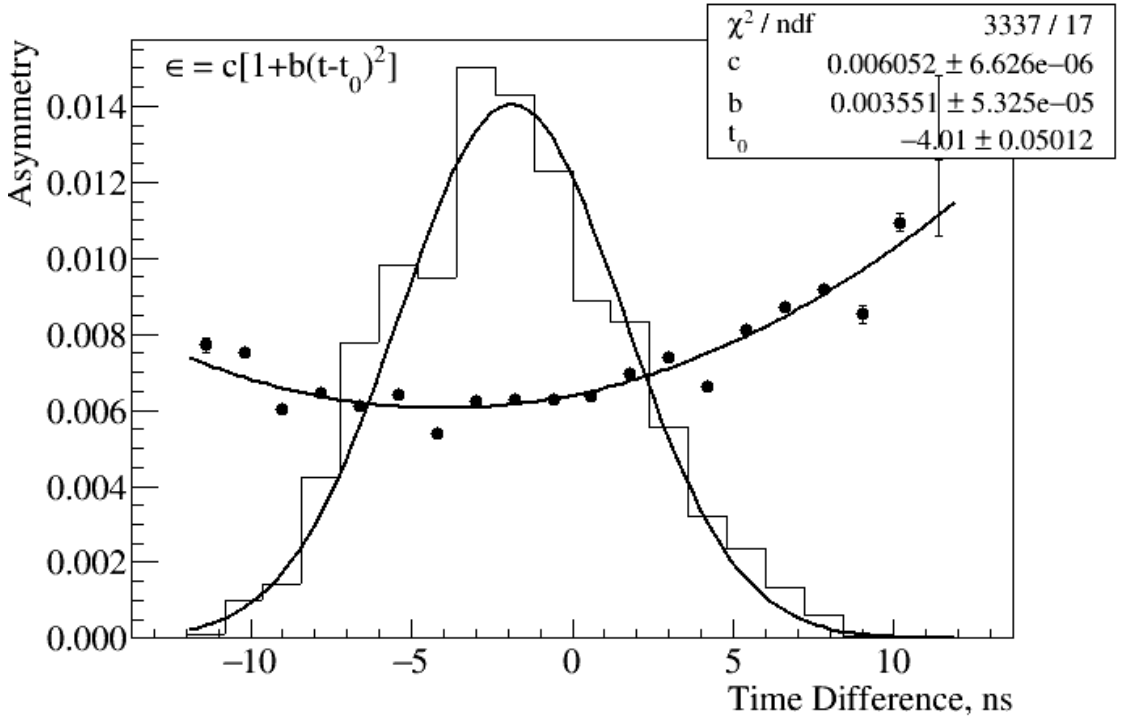


FIG. 3. For double spin colliding beam experiments (a) relative reduction of the average polarization function $\langle P_B \cdot P_Y\rangle/P_0^2$, and (b) relative reduction of the figure of merit $\langle P_B^2 \cdot P_Y^2\rangle/P_0^4$, as a function of the vertical profile parameter R_y. Assuming the same polarization profiles in both beams the cases $R_x = 0$ and $R_x = R_y$ are shown for $R_s = 0, 0.01, 0.05, 0.1$ each.

[Fischer, W. & Bazilevsky, A. Phys. Rev. Spec. Top. (2012) 15: 041001. https://doi.org/10.1103/PhysRevSTAB.15.041001]

Longitudinal profile in pC polarimeters

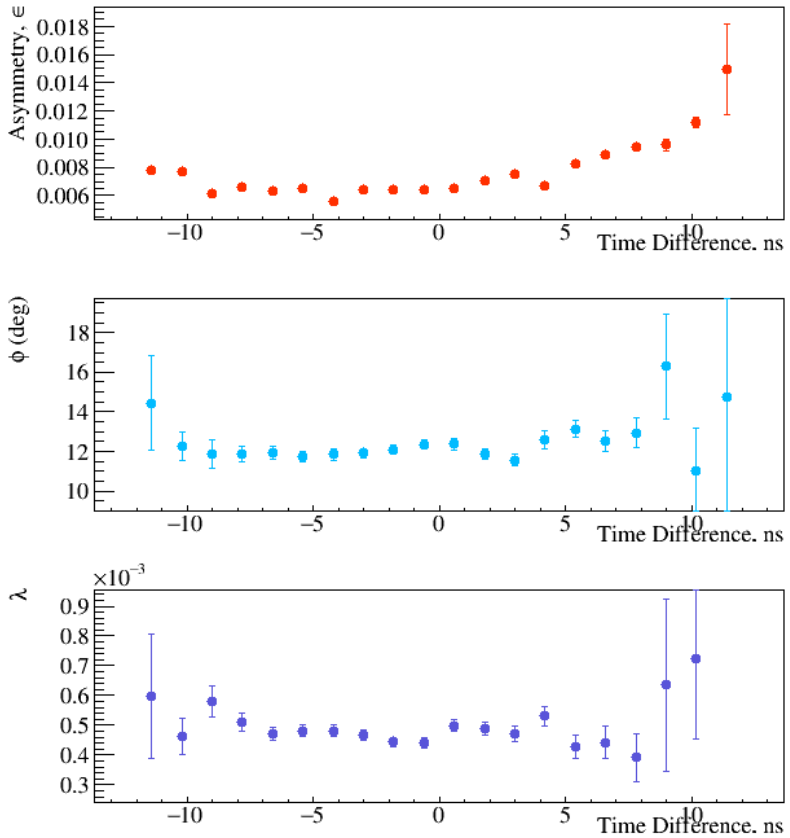


- The plot corresponds to all the 2017 measurements of the pC polarimeters
- Asymmetry obtained using Bill Schmidke's fit function

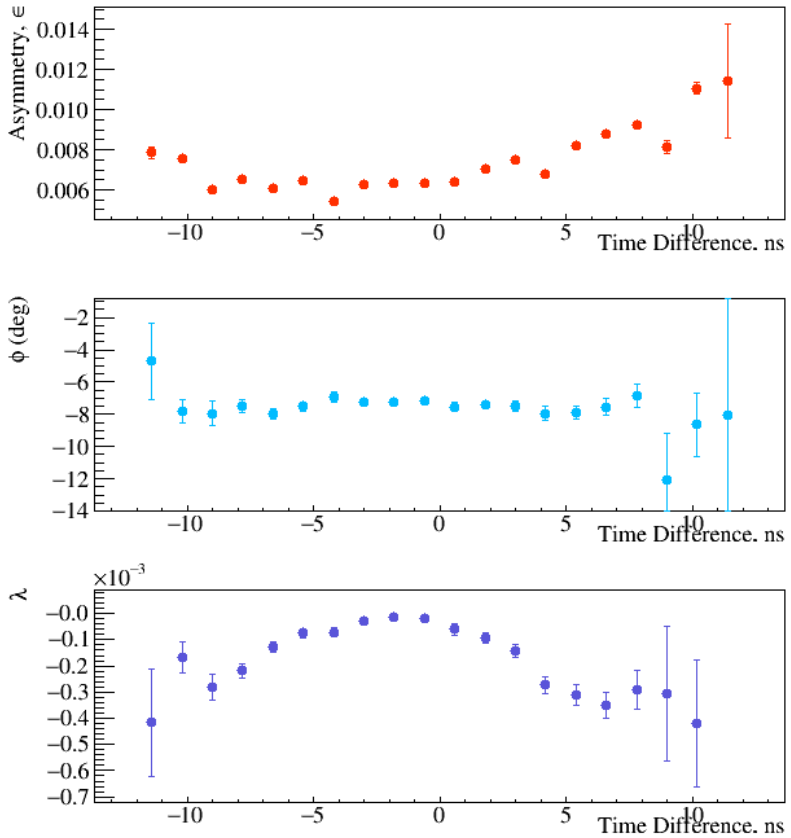
```
void fit1asym(double nup[6],double ndn[6],double par[],double epar[],double &chi2,int fixpar = 0)
```

- Intensity (counts) profile fitted to gaussian; polarization profile fitted to parabola
- $R_s = \frac{\sigma^2_{I_s}}{\sigma^2_{P_s}} \simeq -2 \cdot b \cdot \sigma^2_{I_s}$. Here: $R_s \sim -0.102 \pm 0.046$ (cf. $R_{x,y} \sim +0.15$)

Fit parameters: asymmetry, ϕ, λ



all 2017 **Blue beam** data

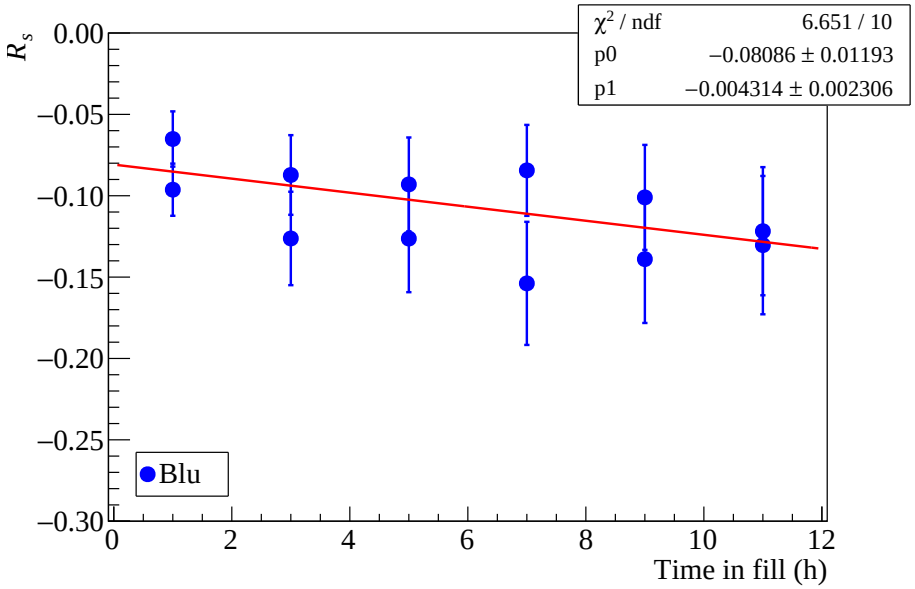


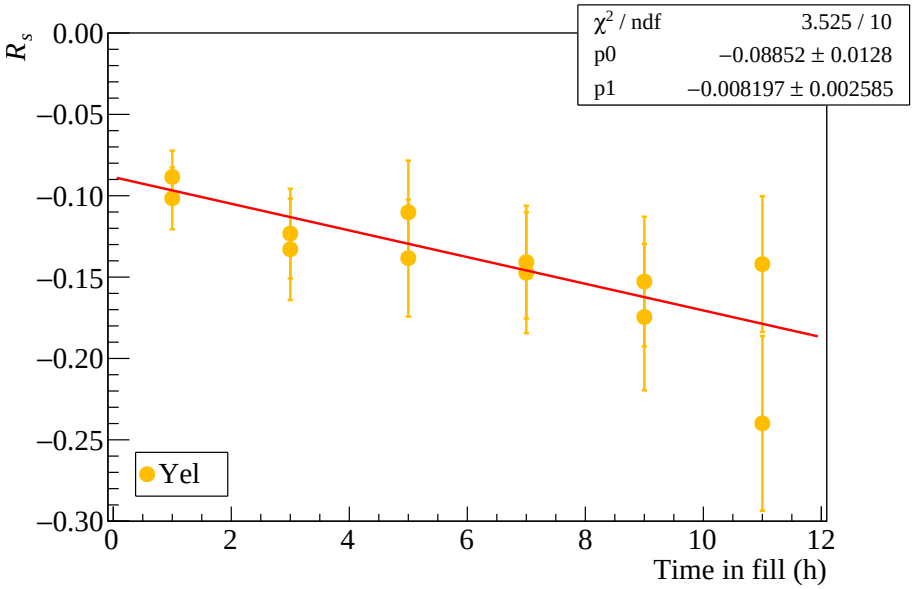
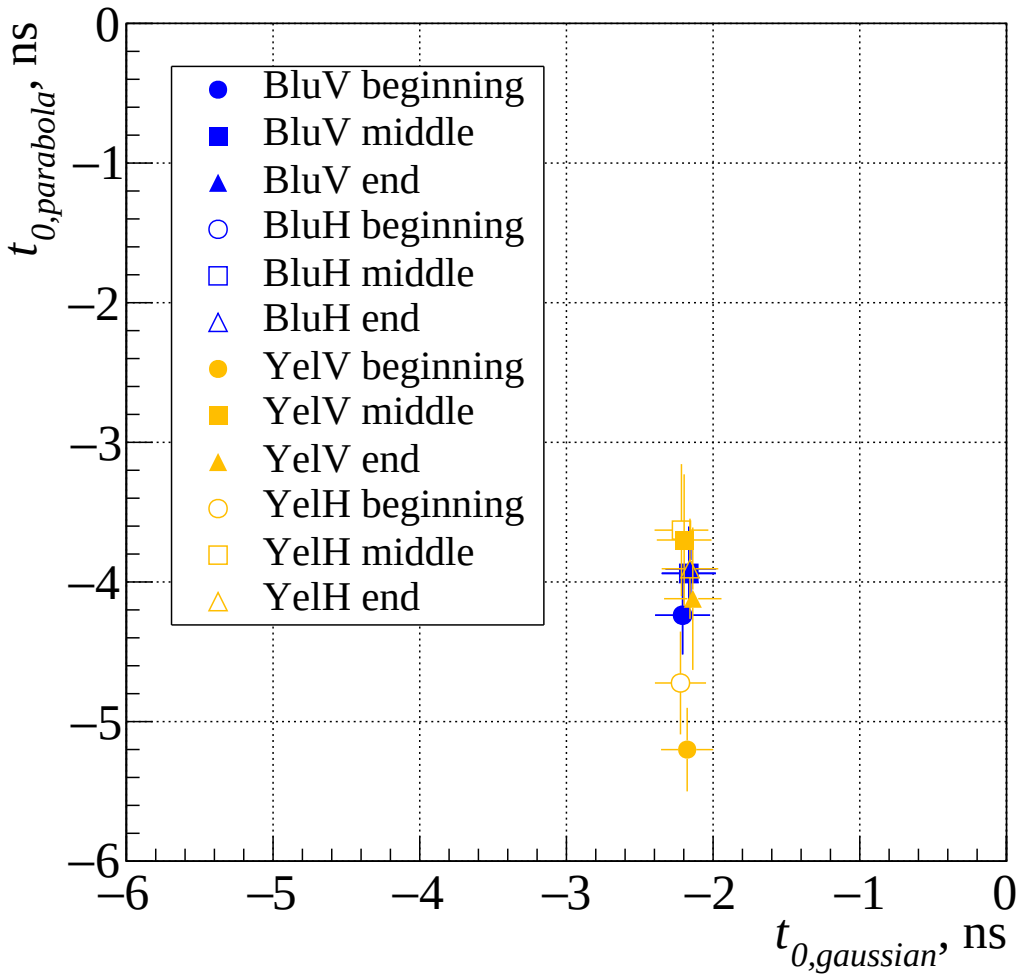
all 2017 **Yellow beam** data

- Parameters obtained using Bill Schmidke's fit function

```
void fit1asym(double nup[6],double ndn[6],double par[],double epar[],double &chi2,int fixpar = 0)
```

R_s throughout the fill





Centroids t_0 of gaussians and parabolas