A. Poblaguev

1. Hjet results from Run16

- ✓ ***Evaluation of molecular hydrogen contribution to systematic errors***
- ✓ ***Spin correlated asymmetry in inelastic background ?***
- ✓ ***Preliminary results for $p^{\uparrow}d$ and $p^{\uparrow}Au$ analyzing power***

Systematic errors due to background

The beam polarization measurement is based on the equality of the analyzing powers $A_N(t)$ for beam a_{beam} and jet a_{jet} asymmetries.
Background generally violates this equality

$$A_N^{(meas)} = \frac{A_N + rA_N^{(jet)}}{1+r}$$

$$P_{beam}^{(meas)} = P_{beam} \times \frac{A_N + rA_N^{(beam)}}{A_N + rA_N^{(jet)}}$$

Where r is fraction of background events and $A_N^{(beam)}$ and $A_N^{(jet)}$ are background analyzing powers for beam and jet asymmetries, respectively.

For most (if not all) backgrounds we may expect $A_N^{(jet)} = 0.$

For the "molecular hydrogen" component in the jet / beam gas $A_N^{(beam)} = A_N$, which results in a factor $1 + r_{mol}$ overestimation of the measured beam polarization.

Based on experimental evaluation of the r_{mol} (10 years ago) the RHIC Spin Group decided to use the jet polarization $92.4 \pm 1.8\%$ instead of $\approx 0.96\%$ measured by Breit-Rabi Polarimeter for atomic component to account the molecular hydrogen admixture of $r_{mol} \approx 3.7\%$.

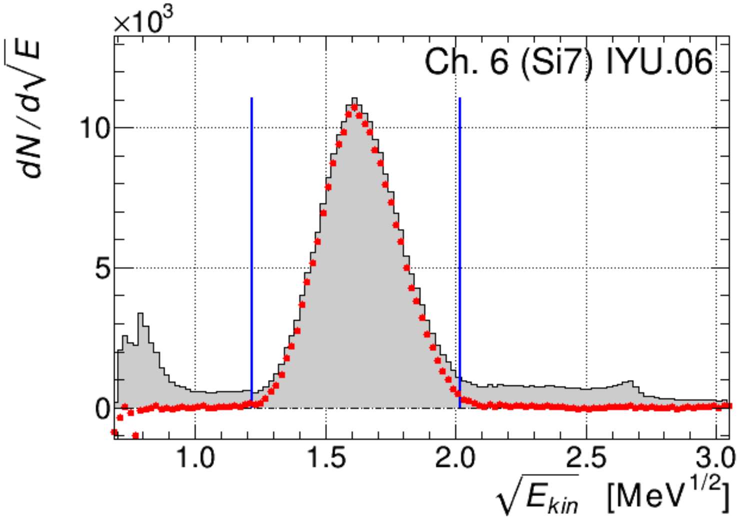
Elastic $A_{beam} + p^{\uparrow}_{target} \rightarrow p_{recoil} + A$ scattering

For elastic scattering: $M_X^2 = (p_b + p_t - p_R)^2 = M_{beam}^2$

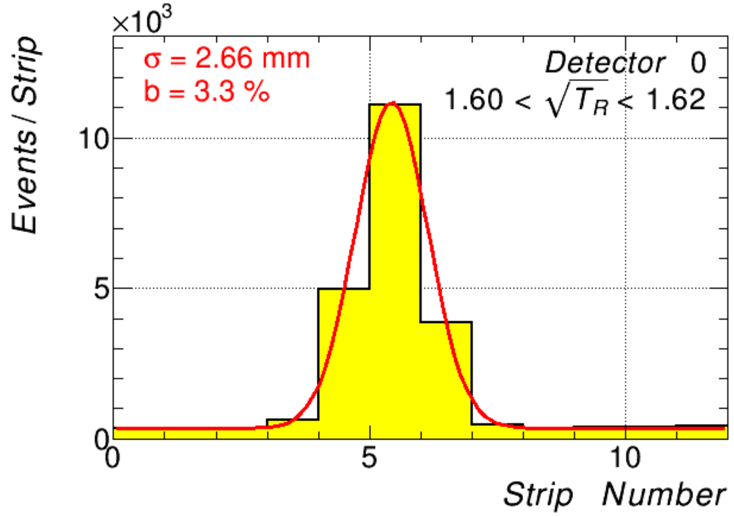
$$z_{str} - z_{jet} = \kappa\sqrt{T_R}, \qquad \kappa = \frac{L}{\sqrt{2m_p}}\sqrt{\frac{E_{beam} + m_p^2/M_{beam}}{E_{beam} - m_p + T_R}} \approx 2\ \mathrm{cm\ MeV^{-1/2}}$$

Two implementations of the dependence:

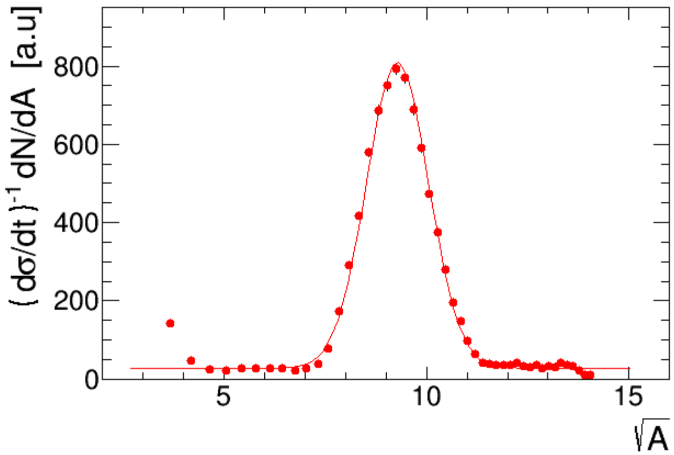
For elastic scattering, energy distribution in a strip is an image of proton distribution in the target



For elastic scattering, number of events distribution distribution in the strips is a histogram of proton distribution in the target

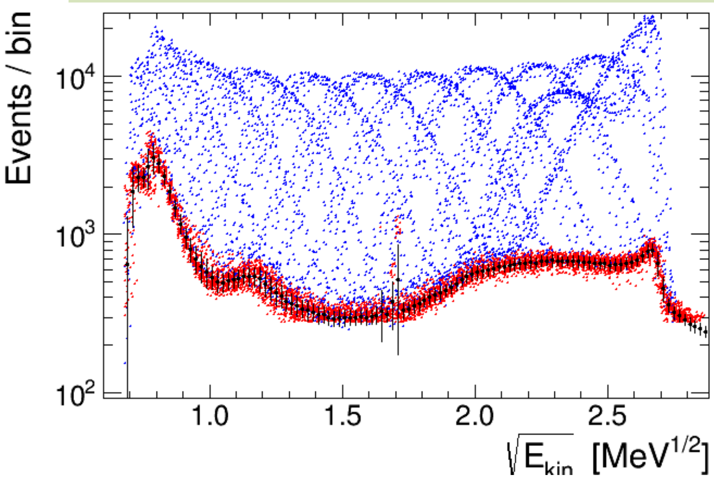


Background

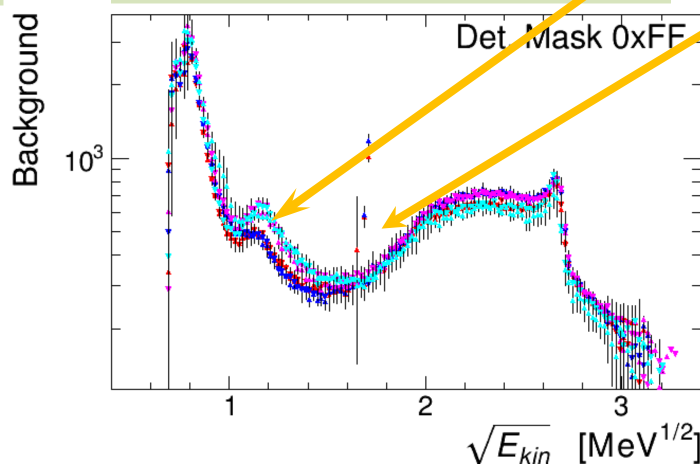


- For all Si strips, the (Gaussian) elastic pp signal is expected to have the same height and width but different position depending on z-coordinate of the strip
- **The molecular hydrogen contribution is expected to be flat and, thus, the same for all strips.**
- **The distributions for inelastic background is expected to be the same for all strips, because the acceptance angle is small and there is no strong correlation between energy and angle.**
- **Selecting events $\pm 4\sigma\ (0.6\ MeV^{1/2})$ outside the elastic peak we can determine the background contribution as a function of energy (amplitude)**

Superposition of $\sqrt{E}$ distributions for all Si strips. Points selected for background evaluation are marked red



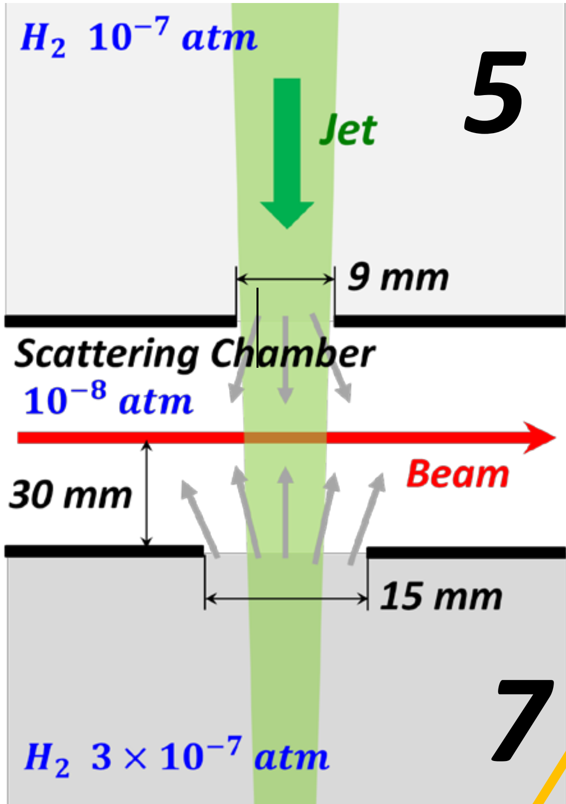
Background distributions determined for each detector separately.



- Beam halo is not the same for inner and outer detectors.
- Some alpha source particles in the data
- Background is slightly detector dependent.

Background should be measured separately for every detector and every beam / jet polarization

Molecular Hydrogen

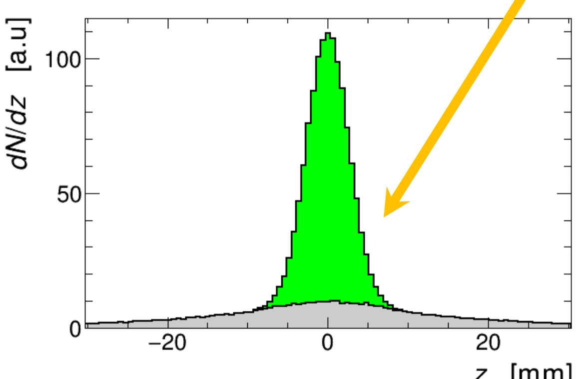


The hydrogen density in the HJET scattering chamber may be approximated as

$$\frac{dN}{dxdz} \propto e^{-\frac{x^2+z^2}{2\sigma^2}} + r_{mol} e^{-\frac{x^2+z^2}{2\sigma_{mol}^2}}$$

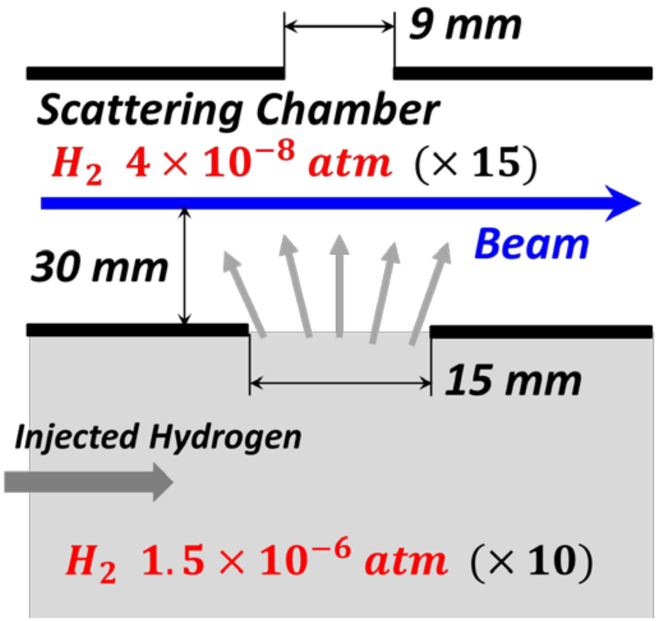
Where first term corresponds to the atomic polarized hydrogen (jet) and the second term describes molecular hydrogen (unpolarized) background.

A simple simulation of the H2 flow gives an estimate $\sigma_{mol} \approx 5\sigma$. Since the H2 scattering on the chamber walls was not accounted, a realistic σ_{mol} is expected to be much larger.



The experimental study with injected hydrogen to the chamber performed in Run16 gave $\sigma_{mol} \approx 30\sigma$. However the flat distribution was corrupted by collimators.

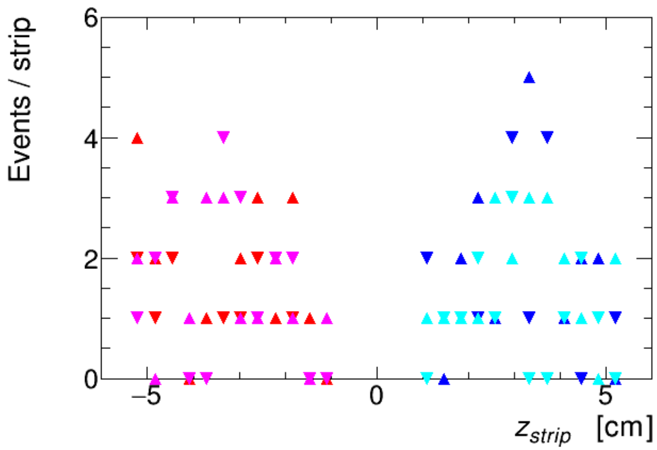
Molecular Hydrogen Profile



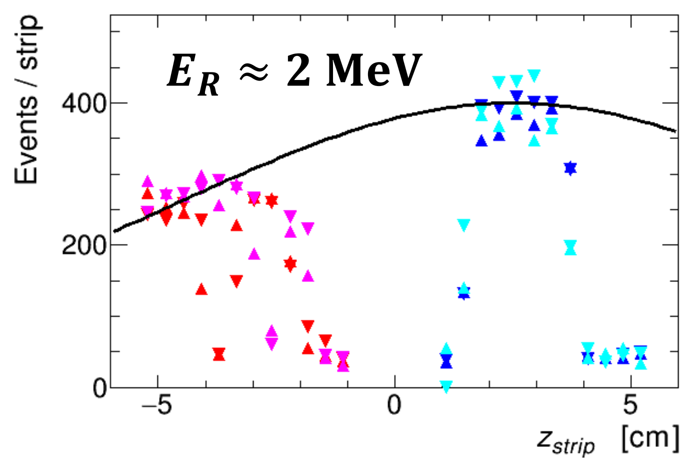
- *1 hour run (APEX) was taken. Single blue beam at injection ($E_{\mathrm{Au}} = 9.8\ \mathrm{GeV/n}$)*
- *To emulate molecular hydrogen distribution in the HJET, hydrogen was injected to the Chamber 7 (while Jet OFF).*
- *Relative fixed energy (consequently fixed scattering angle) rate in Si strips describes the distribution of hydrogen in the HJET*

$$z_{str} - z_{jet} = k\sqrt{E_R}\,, \quad k = 2\ \mathrm{cm/MeV^{1/2}}$$

No injected hydrogen (10 min)

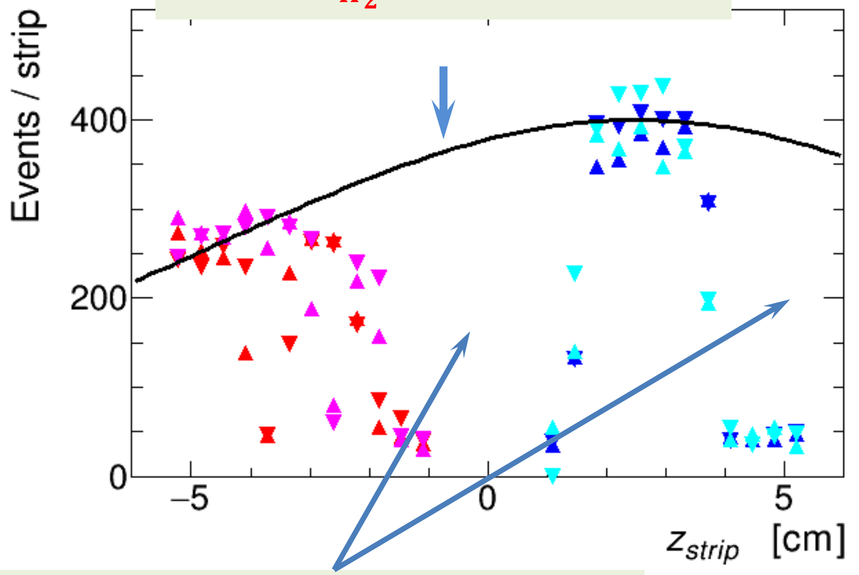


Hydrogen was injected (20 min)



Interpretation of the measurement

Molecular hydrogen profile:
$\sigma_{H_2} \approx 7.5\ cm$



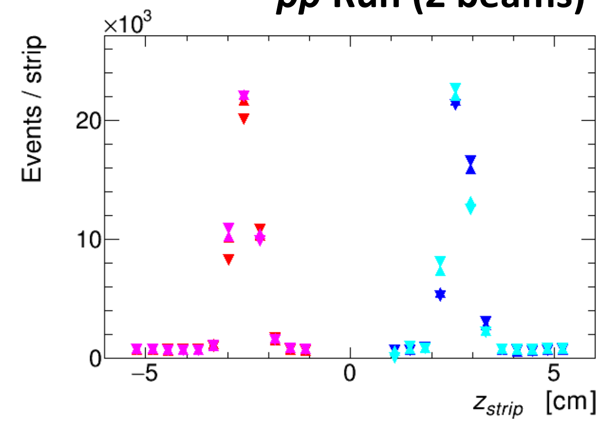
Si strips are partially screened by the RF shield and collimators

Recoil proton energy:

$$\sqrt{E_R} = 1.4 \pm 0.1\ \ MeV^{1/2}$$

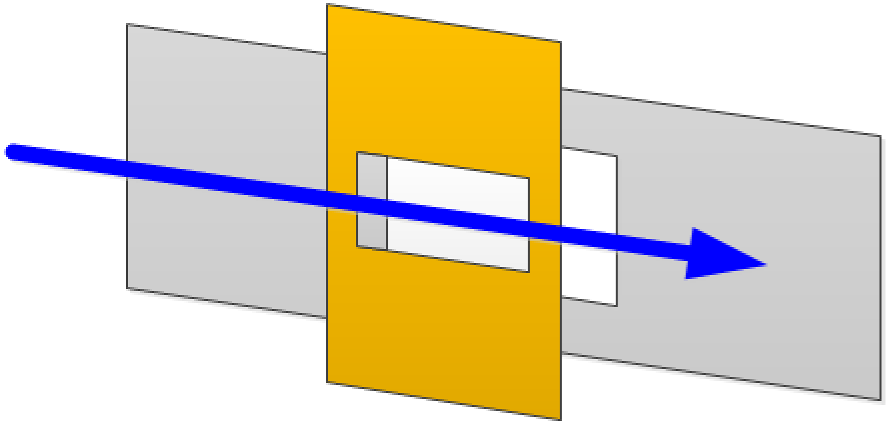
Strips are partially screened by the RF shielding and collimators

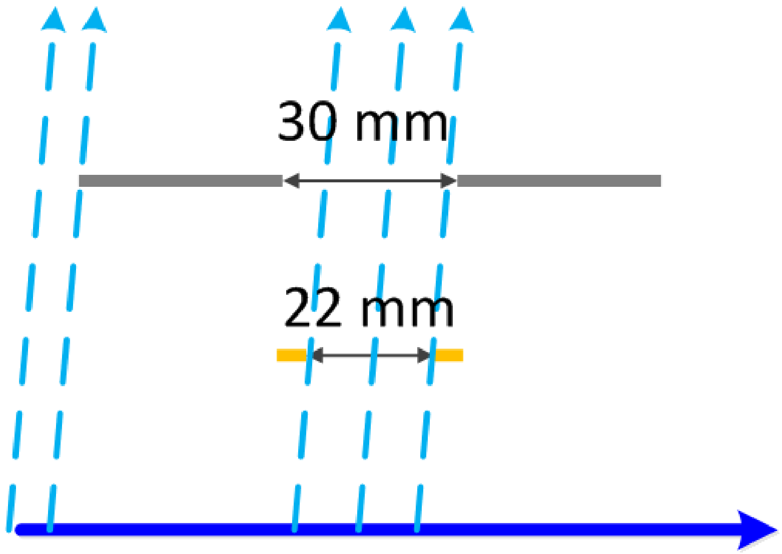
***pp* Run (2 beams)**



Good News: *molecular hydrogen distribution is flat*.
Bad News: *The flatness is corrupted by collimators.*
It is likely that molecular hydrogen was underestimated in the previous Run15 analysis. More study is needed.
Do we really need collimators ?

Do we need collimators in HJET ?





Collimators allows us to suppress recoil protons form opposite beam scattering on molecular hydrogen cloud

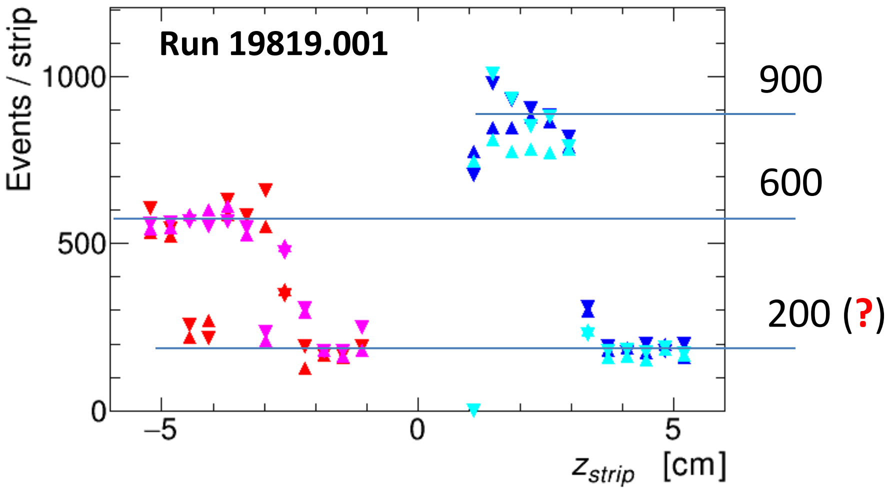
- These events do not affect the polarization measurements (if there is no polarization correlation in simulatneous ("colliding") yellow and blue bunches.
- These events does not change background statistics significantly.

Collimators makes background subtraction more difficult.

Normalization of the Molecular Hydrogen background

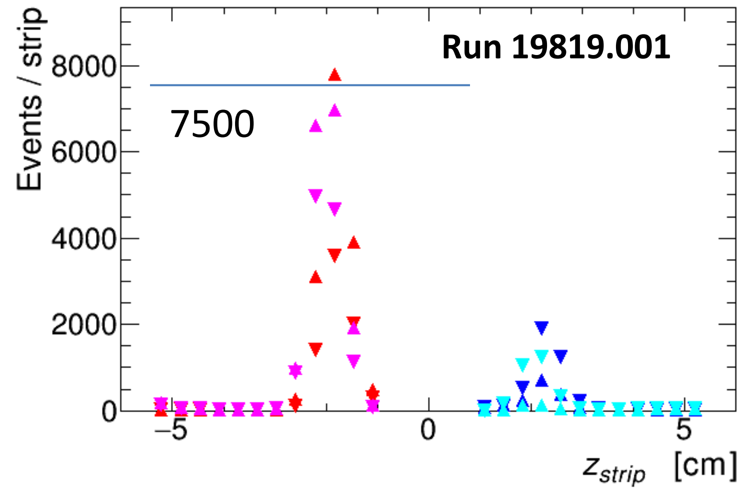
Injected Hydrogen Run

Au 9.8 GeV, $1.0 < \sqrt{T_R} < 1.2$



Regular dAu Run

Au 9.8 GeV, $1.0 < \sqrt{T_R} < 1.2$



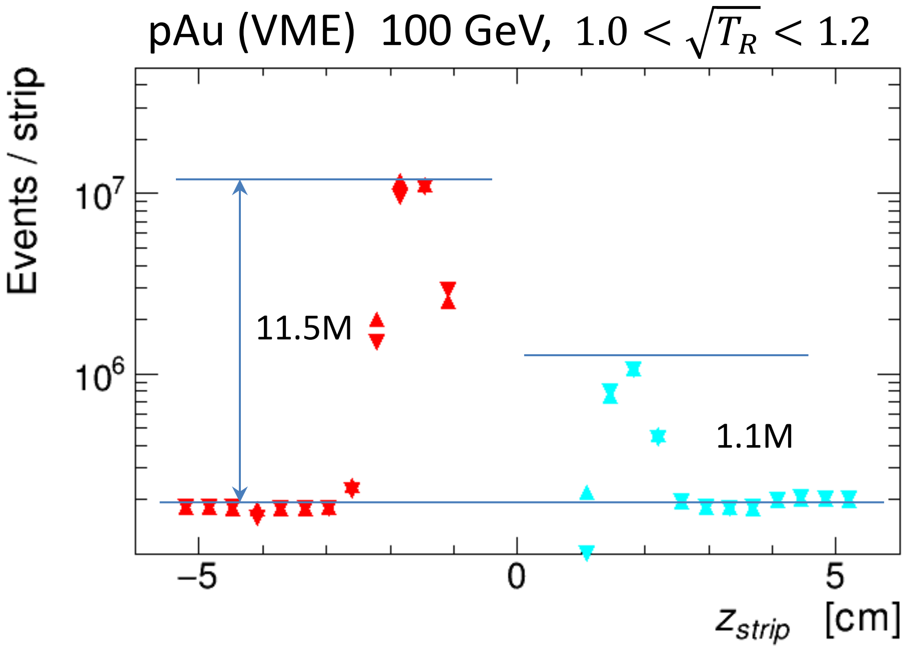
	19819.001	20040.002
Meas. Time (s)	1350	1682
WCM	$163 - 189$	$51 - 58$
Peak rate (a.u.)	900	7500
Pressure Ch. 6	5.0×10^{-8}	3.2×10^{-9}
Pressure Ch. 7	1.7×10^{-6}	1.7×10^{-7}

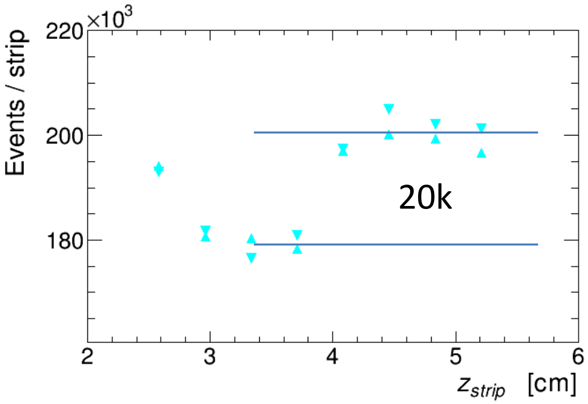
$$f_{Bgr}^{(peak)} = 0.4 \pm 0.1\ \%$$

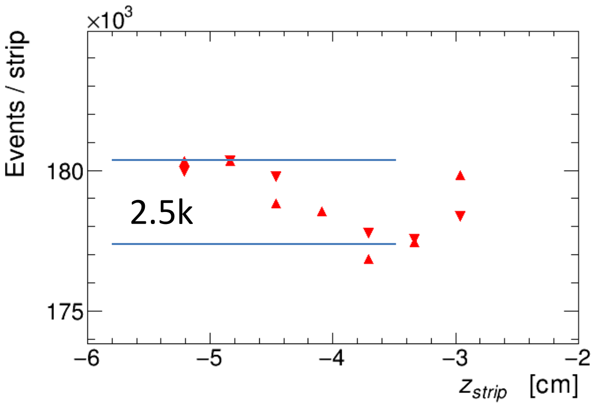
$$f_{Bgr}^{(int)} = 0.9 \pm 0.3\ \%$$

Gaussian shape of elastic signal is accounted.

An alternative estimate of the Molecular Hydrogen background





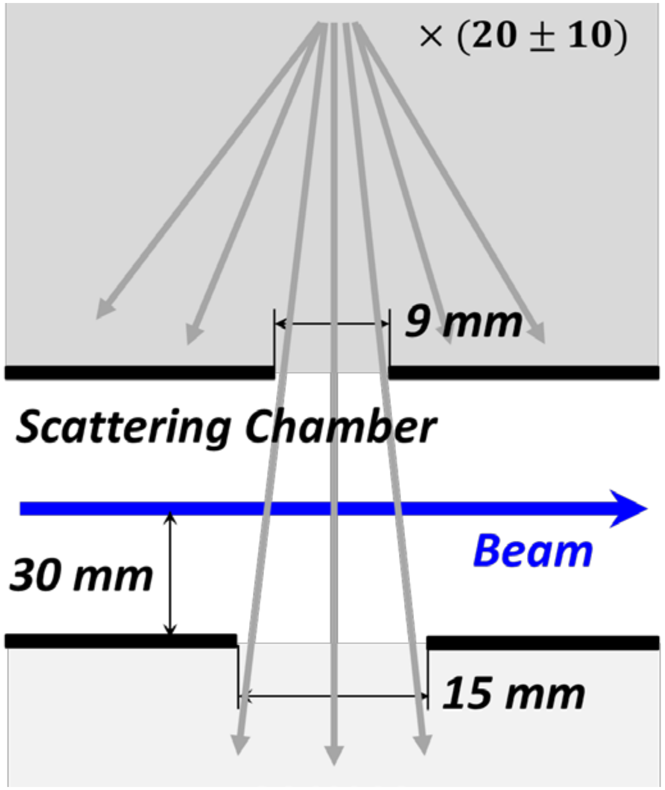


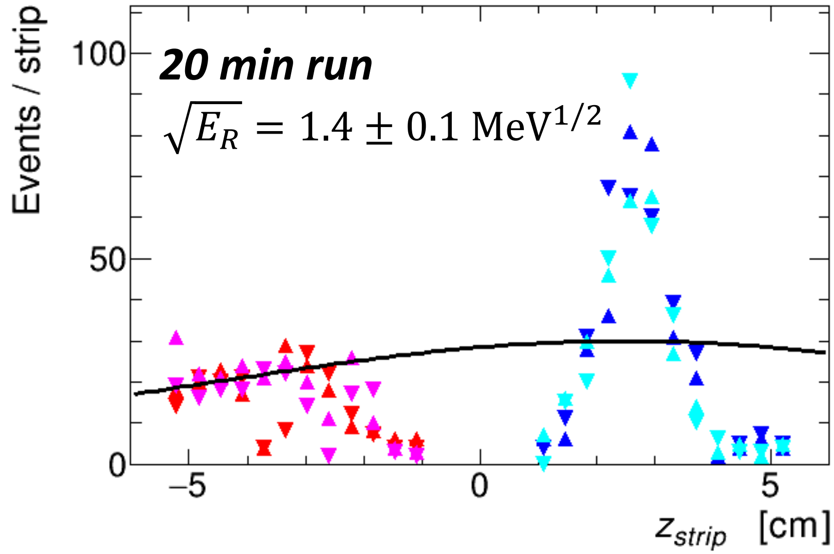
$$f_{Bgr}^{peak} = \frac{20 \times 10^3}{(11.5 - 0.2) \times 10^6} \times \frac{9}{4} \approx 0.4\ \%$$

$$f_{Bgr}^{peak} = \frac{2.5 \times 10^3}{(1.1 - 0.2) \times 10^6} \times \frac{9}{4} \approx 0.6\ \%$$

Assuming that endpoint rate increase is associated with the flat background, we confirm the previous estimate

Molecular Hydrogen from dissociator





- The "molecular hydrogen Jet" is visible.
- Corrections to measured beam polarization can not be eliminated by the background subtraction.
- The fraction of the background was estimated as:

$$f_{Bgr}^{(peak)} = 0.3 \pm 0.1\ \%$$

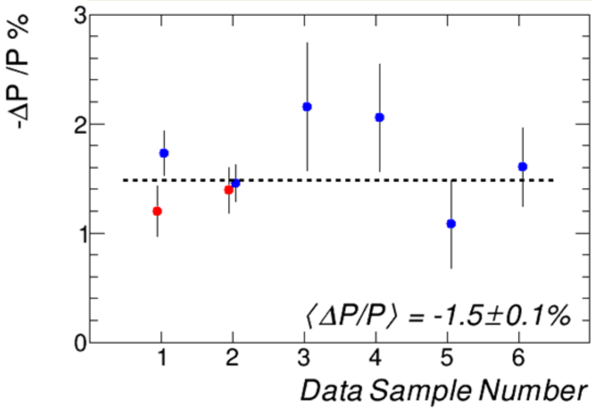
Molecular Background Summary

Estimated fraction of hydrogen atom bounded in molecules:

	Peak fraction	Integral fraction	Subtracted
Flat bgr.	0.4 ± 0.1 %	0.9 ± 0.3 %	$\mathbf{0.3 \pm 0.1}$ %
Jet bgr.	0.3 ± 0.1 %	0.4 ± 0.2 %	–
Total:	0.7 ± 0.2 %	1.3 ± 0.4 %	$\mathbf{1.5 \pm 0.1}$ %

Experimental evaluation

Energy range 0.75 - 7.0 MeV



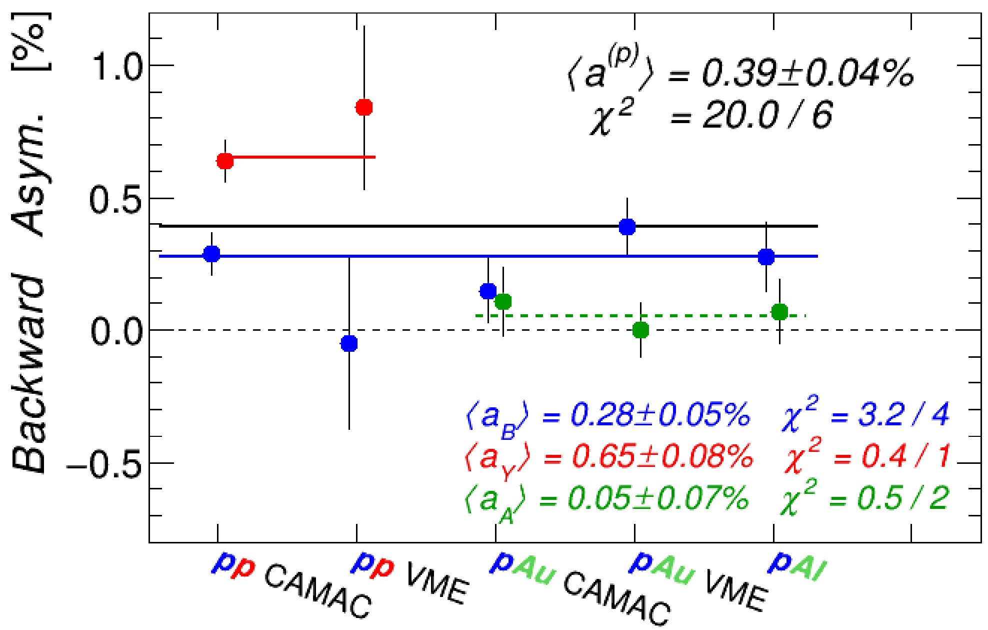
- Potentially, molecular hydrogen background may be evaluated with a sub-percent accuracy from the data.
- Specified errors are very rough estimates only.
- Molecular hydrogen background (even flat part) is subtracted only partially due to collimators.
- There is a clear discrepancy between estimated correction due to background subtraction and experimentally measured value.
- **Does inelastic background beam spin correlated ?**

Data samples:

1. 18920-18926 pp, CAMAC
2. 18950-18953 pp, VME
3. 19060-19069 pAu, CAMAC
4. 19094-19099 pAu, VME
5. 19125-19134 pAu, VME
6. 19237-19248 pAl, VME

Spin correlated asymmetry in backward detectors

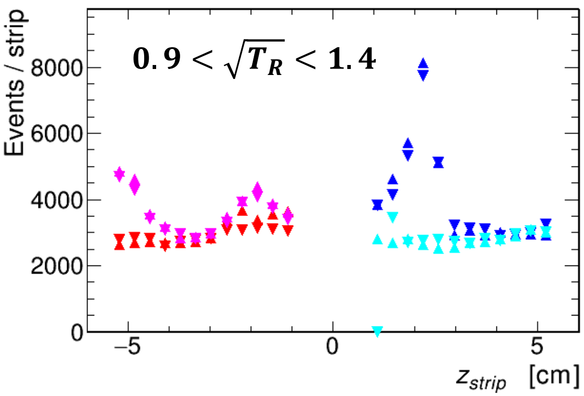
- We can select bunches with blue or yellow beam only in HJET
- In backward detectors (e.g. yellow detectors for blue beam) we can measure asymmetry correlated with the beam polarization.
- "Missing mass cut " is dropped for such a study.

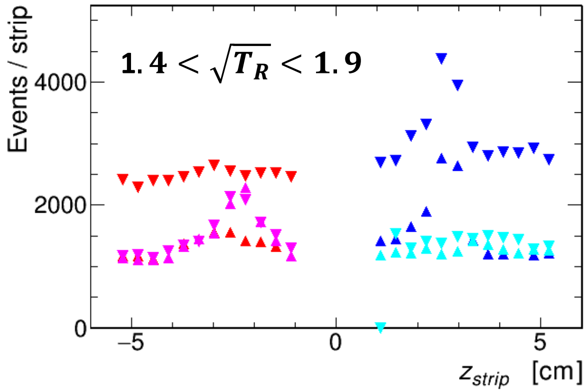


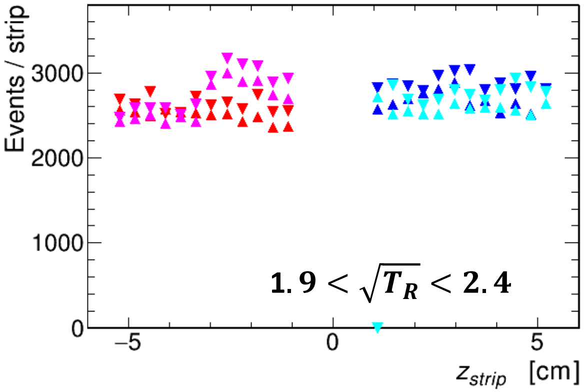
- There is a clear beam spin correlated asymmetry for background events in backward detectors
- The source of asymmetry is not proved yet.
- ***More study is needed.***

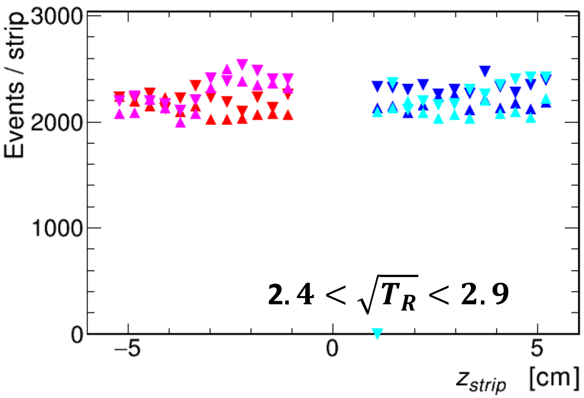
Non-uniformity of inelastic background

RHIC Fills 20004-20024, dAu 9.8 GeV, ***Empty Target Runs***









- Flat distributions were expected
- Strong non-flatness for inner blue and outer yellow detectors at $0.9 < \sqrt{T_R} < 1.9$
- Up/down asymmetry in inner detectors ($1.4 < \sqrt{T_R} < 1.9$)
- In outer yellow detectors, the issue is observed at $1.9 < \sqrt{T_R} < 2.9$

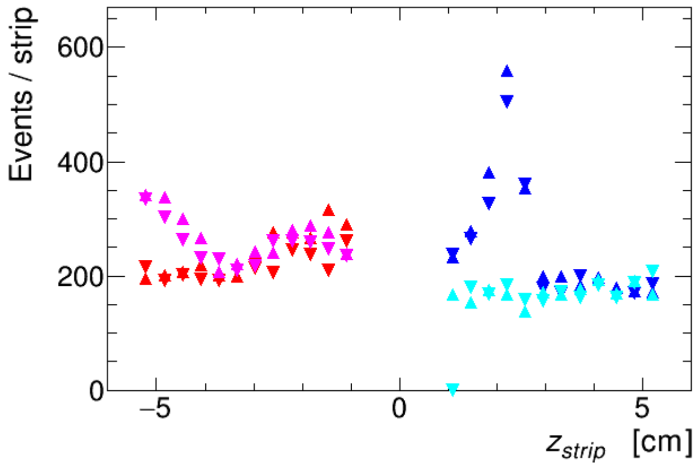
✓ Background subtraction might not work properly for inner blue and yellow detectors

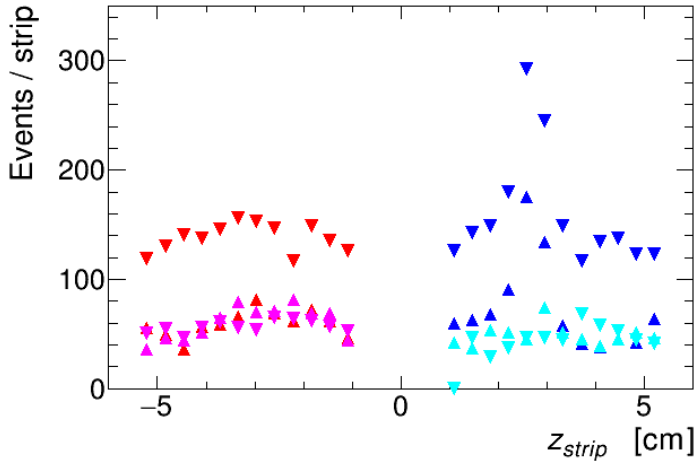
✓ Symmetry measurements might be affected.

✓ **Is this a collimator related issue ?**

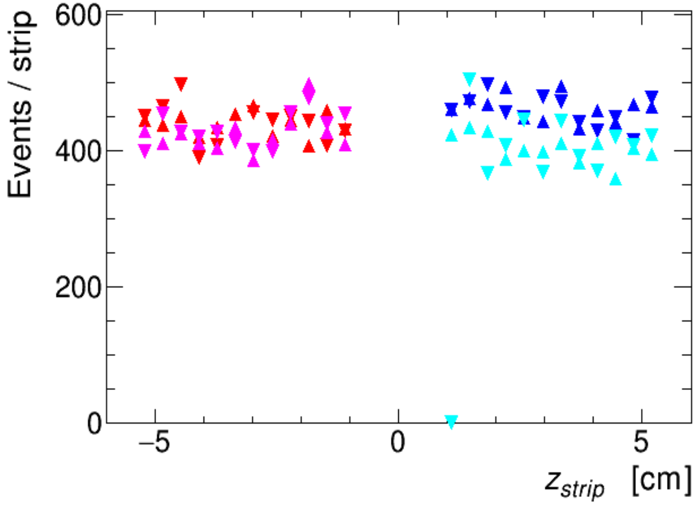
The source of an issue: Blue or Yellow beam

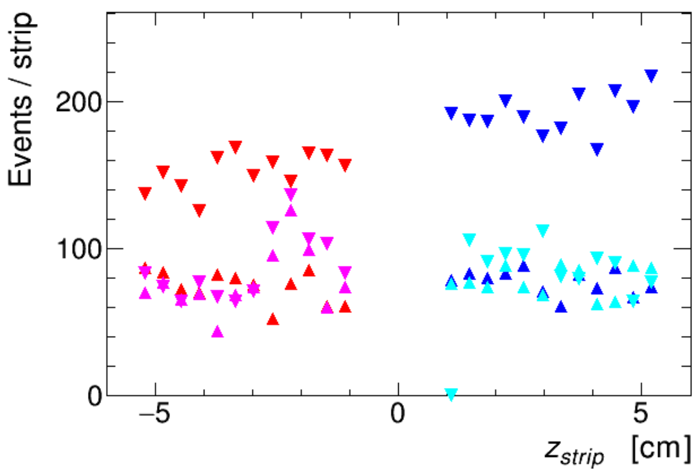
Yellow Beam (Au) only:





Blue Beam (d) only:

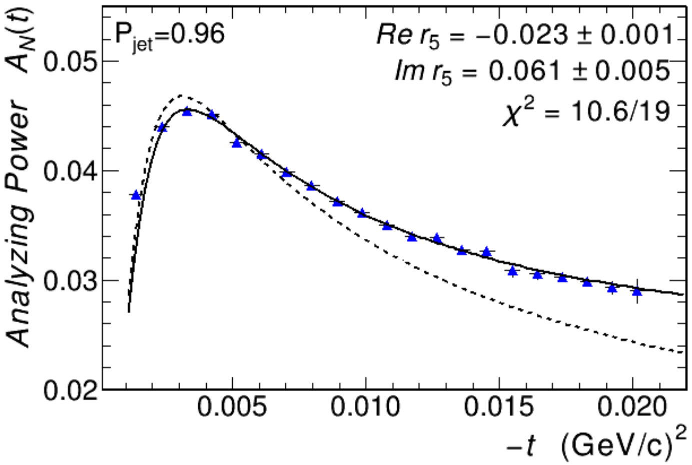


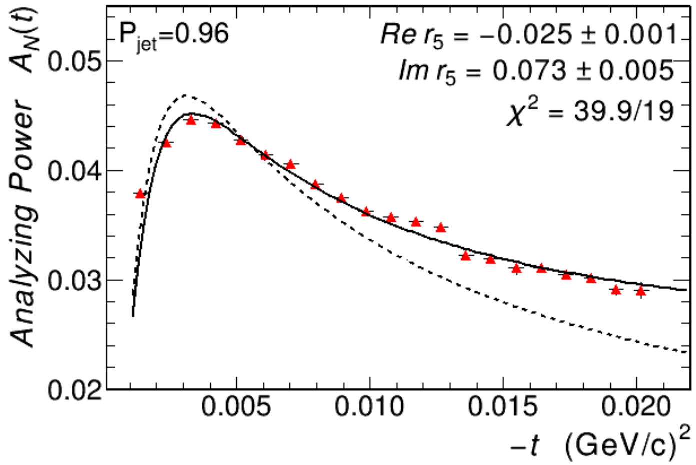


How data is affected: pp $A_N(t)$ fit

Phys. Lett. B638 (2006) 450: $\mathrm{Re}\, r_5 = -0.0008 \pm 0.0091, \ \mathrm{Im}\, r_5 = -0.015 \pm 0.029$

Run 2015, *pp*, CAMAC:





"Non-correlated " errors are show, which gives about factor 2 reduction compared to "correlated" errors in the published results.

$$A_N(t) = \frac{[\kappa(1-\rho\delta_C) - 2(\mathrm{Im}\, r_5 - \delta_C \mathrm{Re}\, r_5)]\frac{t_c}{t} - 2\mathrm{Re}\, r_5 + 2\rho \mathrm{Im}\, r_5}{f(t_c/t)} = a(r_5)\ \frac{t_c/t - b(r_5)}{f(t_c/t)}$$

$a \approx \kappa - 2\mathrm{Im}\, r_5, \qquad \kappa = 1.91$

$b \approx 2\mathrm{Re}\, r_5 \ / a$

$$\Delta P_{jet} \rightarrow \begin{cases} \Delta\mathrm{Im}\, r_5 = (\kappa/2 - \mathrm{Im}\, r_5)\, \Delta P/P \approx \Delta P \\ \Delta\mathrm{Re}\, r_5 = \mathrm{Re}\, r_5\ \Delta P/P \ \approx \Delta \mathrm{P} \times \mathrm{Re}\, r_5 \end{cases}$$

Preliminary estimates for hadronic spin-flip amplitude

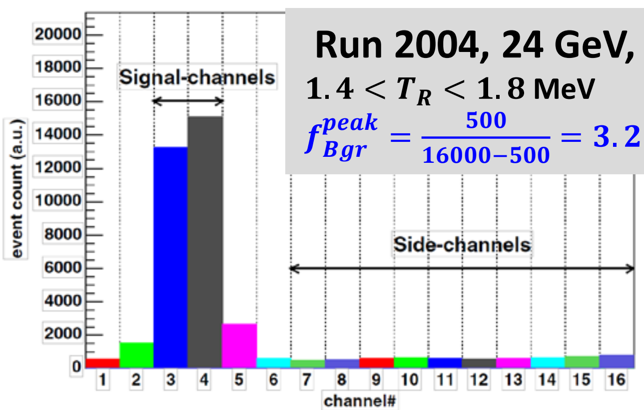
$p^{\uparrow}p, \quad 100\ GeV$ $\quad$ $P_{jet} = 0.96$

			$\mathrm{Re}\, r_5$	$\mathrm{Im}\, r_5$
CAMAC	pp	Blue	-0.023 ± 0.001	0.061 ± 0.005
CAMAC	pp	Yellow	-0.025 ± 0.001	0.073 ± 0.005
VME	pp	Blue	-0.023 ± 0.003	0.074 ± 0.016
VME	pp	Yellow	-0.030 ± 0.003	0.096 ± 0.016
CAMAC	pAu	Blue	-0.034 ± 0.002	0.131 ± 0.010
VME	pAu	Blue	-0.033 ± 0.002	0.135 ± 0.008
VME	pAl	Blue	-0.037 ± 0.002	0.128 ± 0.009

- **Results are in a clear disagreement with a 2006 publication**
- **Statistical errors, are about factor 3 better than in published data.**
- **The effective Jet polarization should be reduced at minimum by 1% which will result in reduction of $\mathrm{Im}\, r_5$ by about ~ 0.010.**
- **The discrepancy between pp and pA data clearly indicates that improper subtracted background strongly affect the results of measurement.**
- **It is worth to continue the analysis of the hadronic spin-flip amplitude.**
  - **To study systematic errors**
  - **To obtain new publishable result**

Do we need collimators in HJET ?

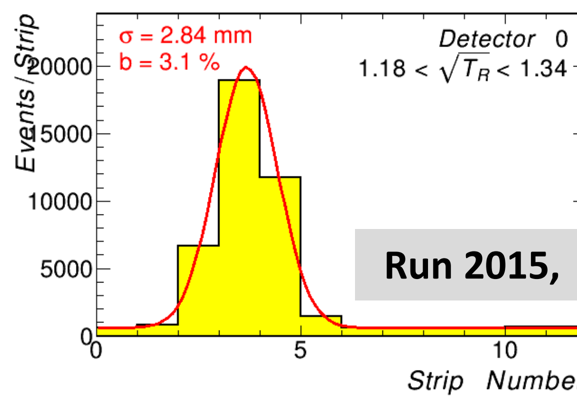
- **In my understanding**, the collimators were installed to suppress some background from opposite beam
  - This portion of background is very small
  - It is effectively “non-polarized” background
- Collimators gave significant non-uniformity of background distributions
  - The uniformity is currently the main source of uncorrected systematic errors.



Run 2004, 24 GeV,

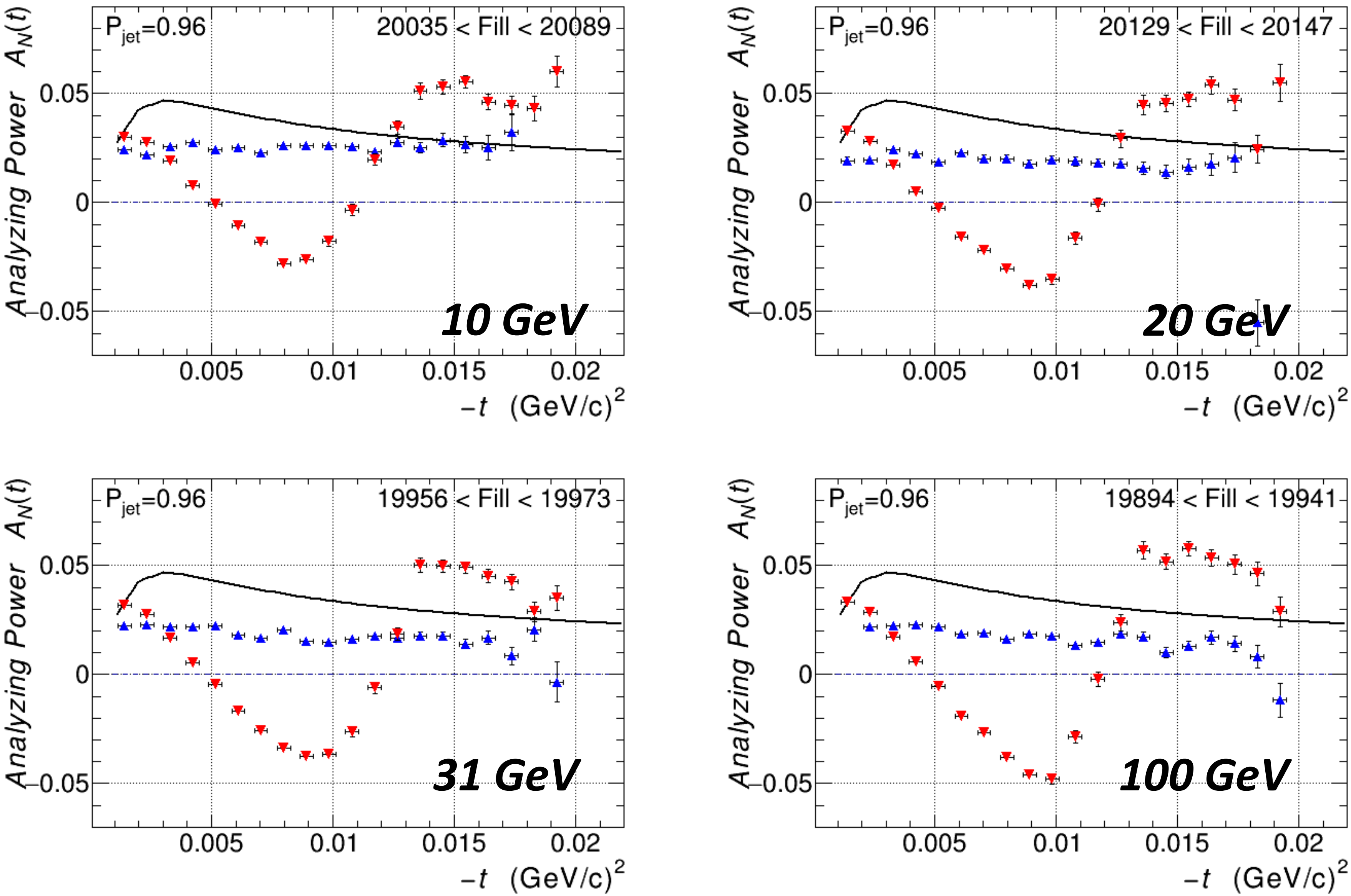
$\mathbf{1.4 < T_R < 1.8}$ **MeV**

$f_{Bgr}^{peak} = \frac{500}{16000-500} = 3.2\%$



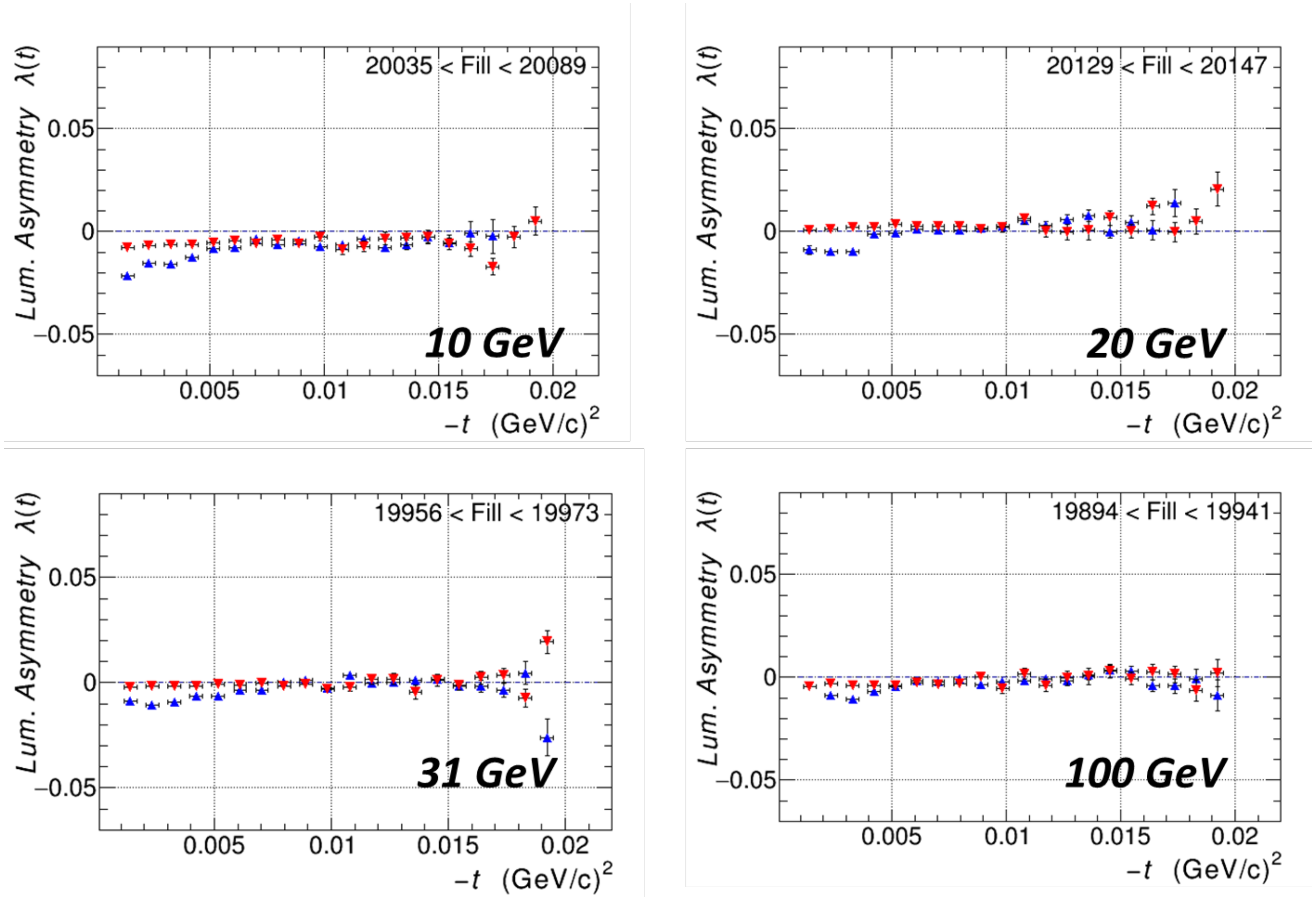
Run 2015, 100 GeV

HJET. PRELIMINARY results for $p^{\uparrow}d$ and $p^{\uparrow}\mathrm{Au}$ analyzing power (Run 2016)



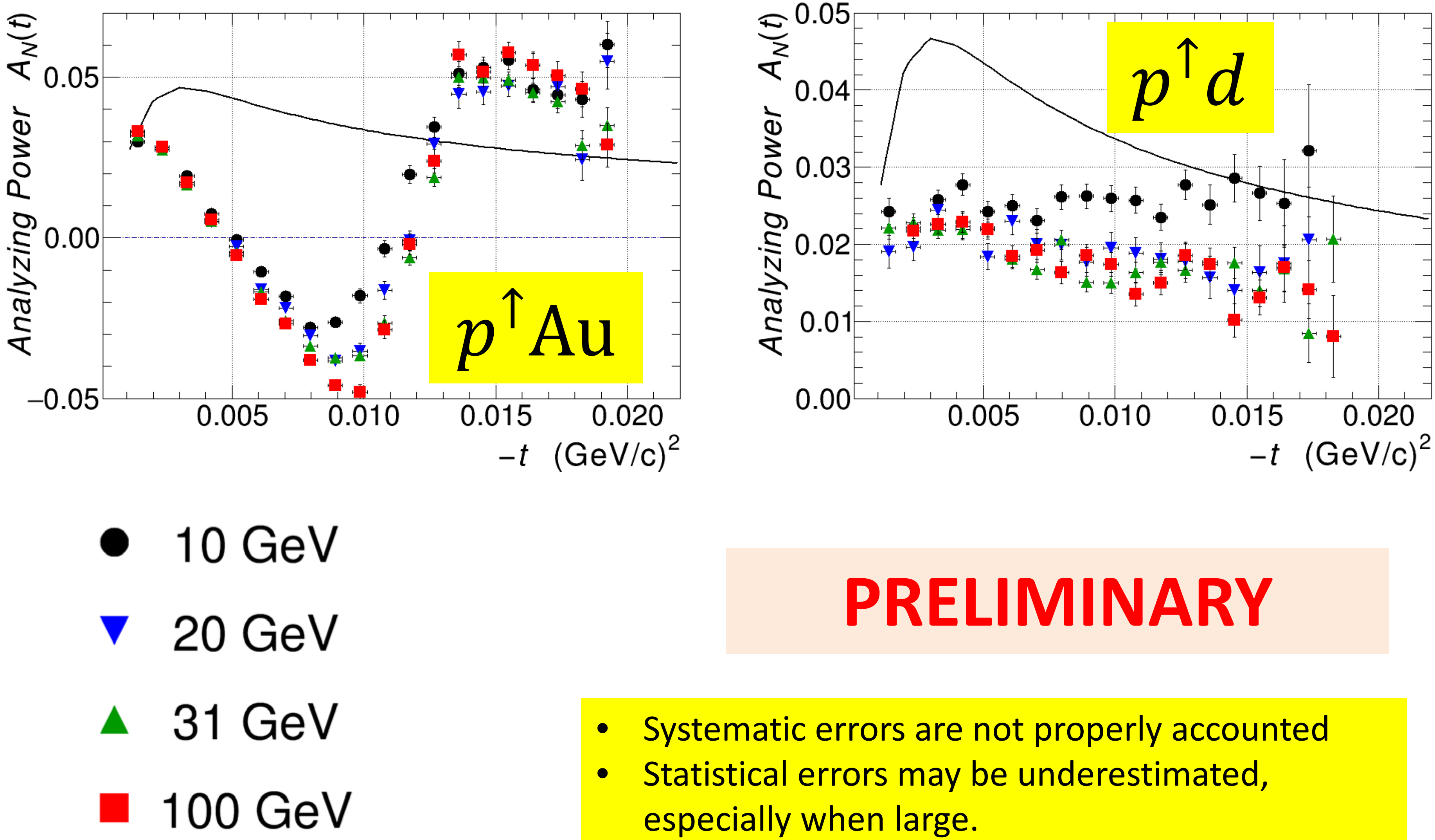
*Solid black line is a theoretical prediction for $p^{\uparrow}p$ (with no spin-flip amplitude, $r_5 = 0$)

Luminosity (intensity) asymmetry $p^{\uparrow}d$ and $p^{\uparrow}\mathrm{Au}$ measurements



- The $\lambda(t)$ has to be t independent
- Improperly subtracted background is expected to be the main source of discrepancy at low t.
- If so, then $P_{jet}\Delta A_N(t) = \Delta\lambda(t)/2$ and measured analyzing power may be easily corrected.

$A_N(t)$ dependence on beam energy



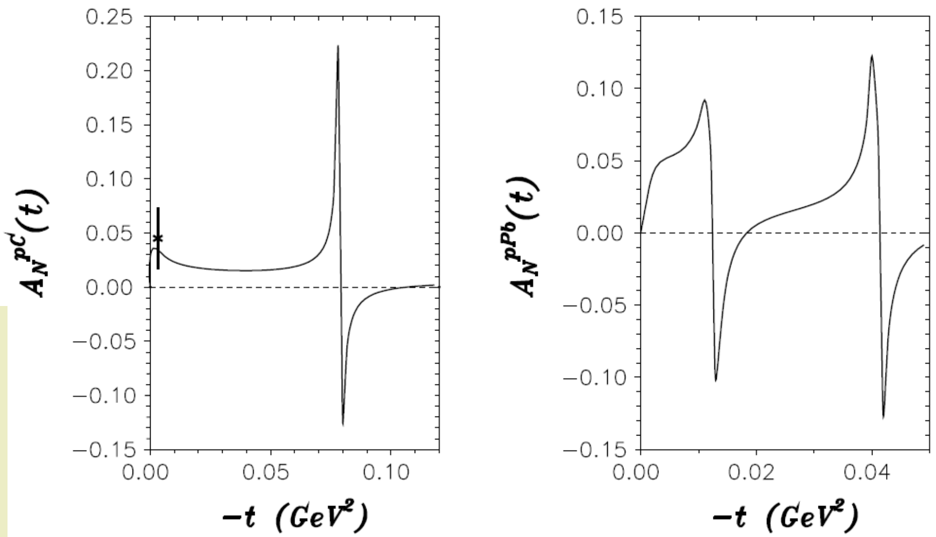
PRELIMINARY

- Systematic errors are not properly accounted
- Statistical errors may be underestimated, especially when large.

Are results interesting for theory ?

The $A_N(t)$ is sensitive to parameterization of hadronic amplitudes, form-factors, Coulomb phase.

Example 1. arXiv:hep-ph/9801414 (**1998**)
Predictions for pC and pPb. Almost no experimental entries. Not a good consistency with measured $p\mathrm{C}$, $p\mathrm{Al}$, and $p\mathrm{Au}$.



Example 2. arXiv:1512.05130 (**2015**)
Dependence of $A_N(t)$ on proton beam energy. Results are qualitatively similar to the pAu data (e.g. the dip dipendence on beam energy). The difference in t-scale may be related to the diffractive minimum dependence on beam energy.