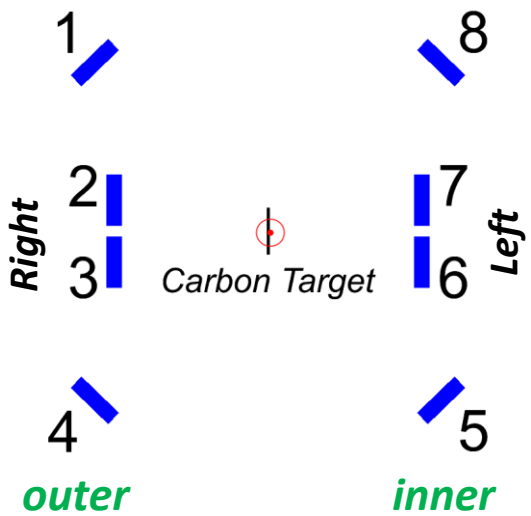
A. Poblaguev

The AGS pCarbon polarimeter. Unsolved problems (Run 2012).

- Rate corrections
- Intensity scans
- Detector 7 (inner slow Hamamatsu) puzzle
- Comments on the square root formula
- Correlated noise

AGS CNI Polarimeter 2012



4 different detector types:

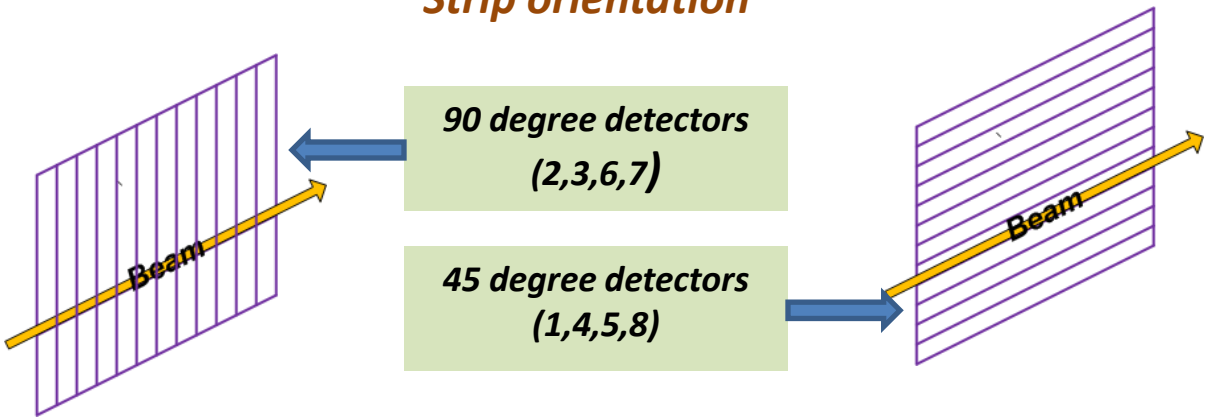
1,8 - Hamamatsu, slow preamplifiers, L = 51 cm

2,7 - BNL 2mm, fast preamplifiers, L = 30 cm

3,6 - BNL 1 mm, fast preamplifiers, L = 30 cm

4,5 - Hamamatsu, fast preamplifiers, L = 51 cm

Strip orientation



Rate corrections in the AGS CNI polarimeter (Run12)

Rate dependence of signal detection efficiency (due to pileup)

$$\varepsilon(r) = e^{-kr} \approx 1-kr$$

results in systematic error of polarization measurements

$$P_{meas.} \approx P_{true} \times (1-kr)$$

Only 1 event per bunch may be acquired.

$$k \approx 1 - \varepsilon_0\rho/2 - \varepsilon_1(1-\rho)$$

where

$\rho \approx 0.5$ **is good/total rate ratio.**

ε_0 **is probability of detection of good signal if two good events coincide.**

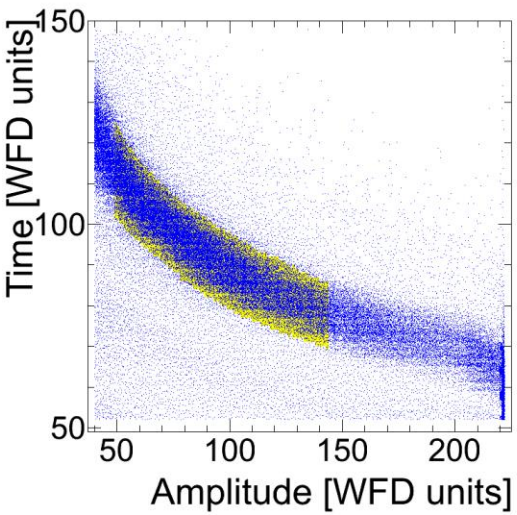
ε_1 **is probability of detection of good event if coincide with background .**

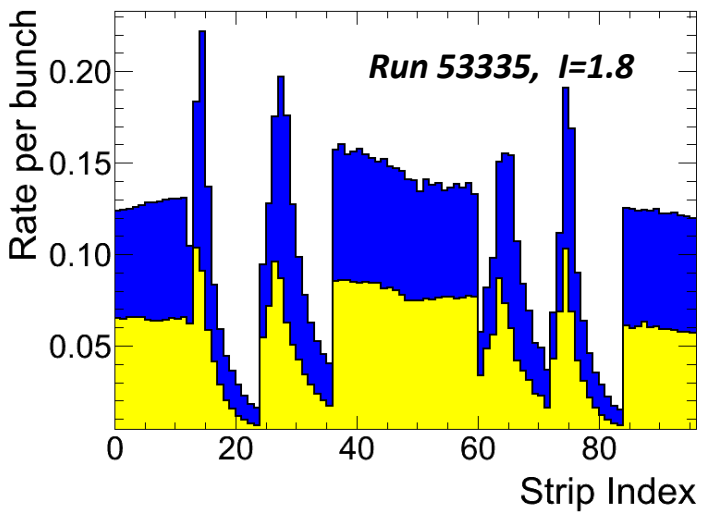
Assuming $\varepsilon_0 = 1$ **and** $\varepsilon_1 = 0$ **we can estimate k ≈ 0.75**

Not a pileup contributions to the ***k are also possible*****.**

(*k* should be determined experimentally)

Online : k=1

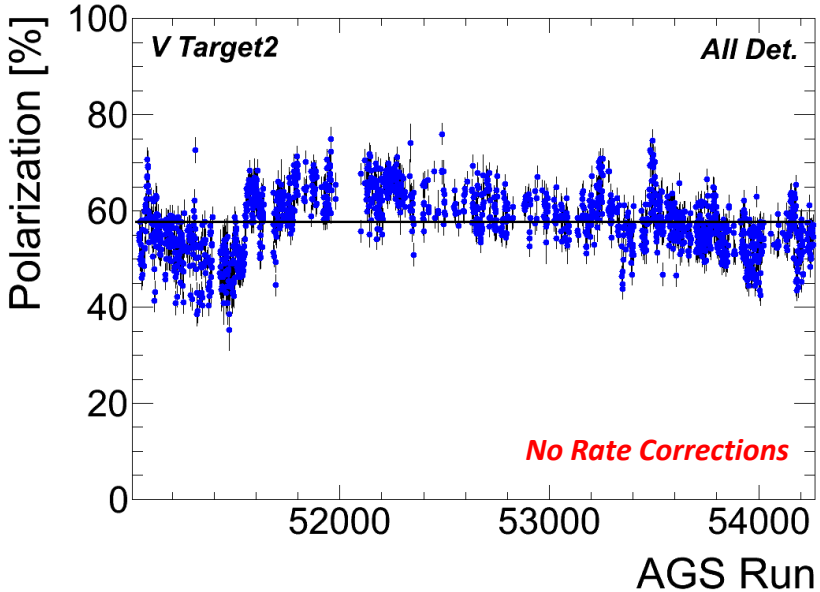


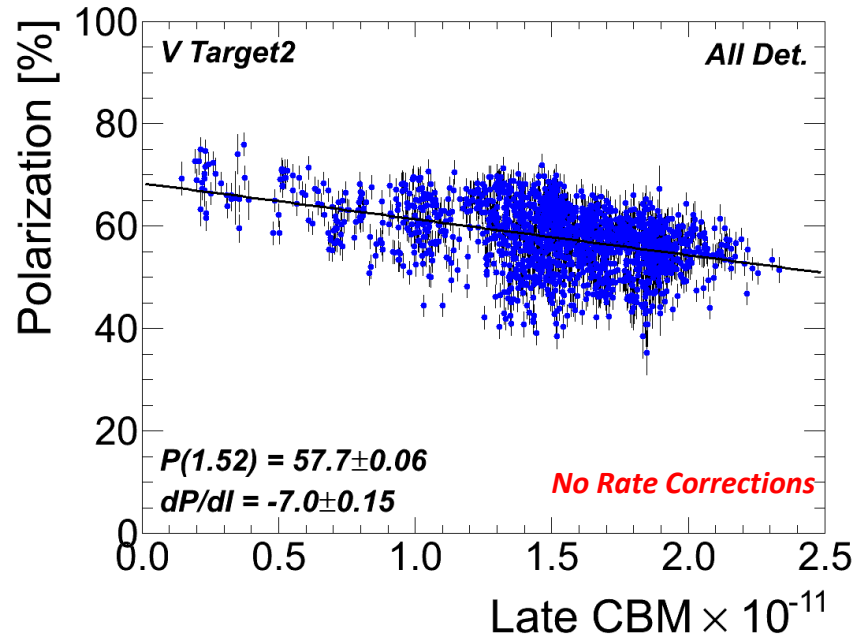


Rate Correction 10-15%
Accurate determination of k is needed

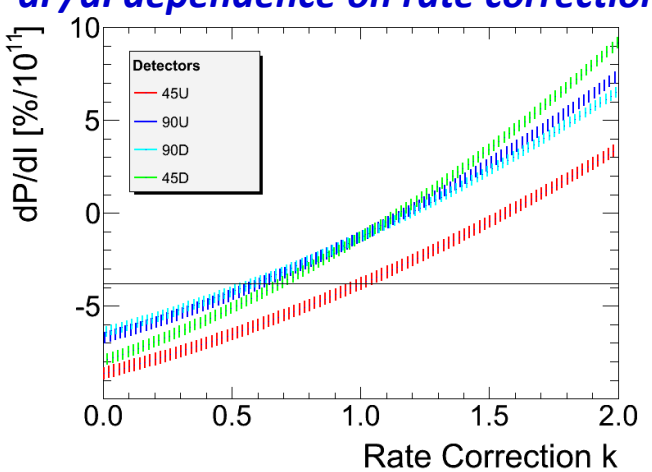
Rate Corrections from the dP/dI study

All polarization measurements with Target V2 in the 2012 Run:



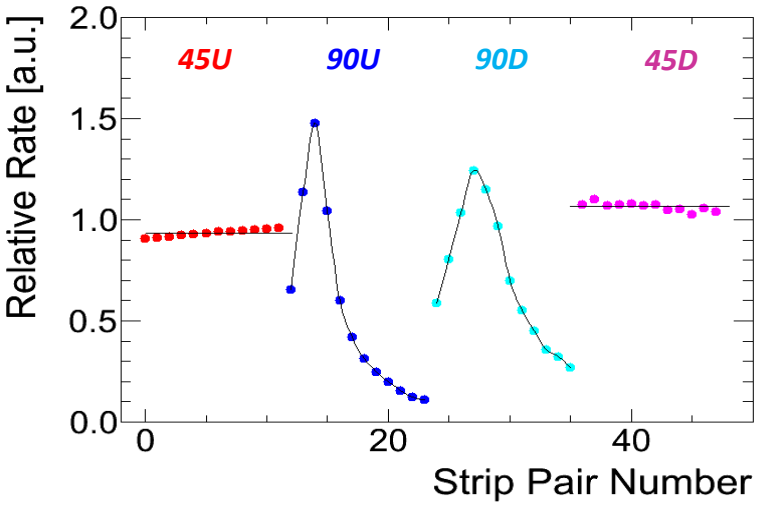


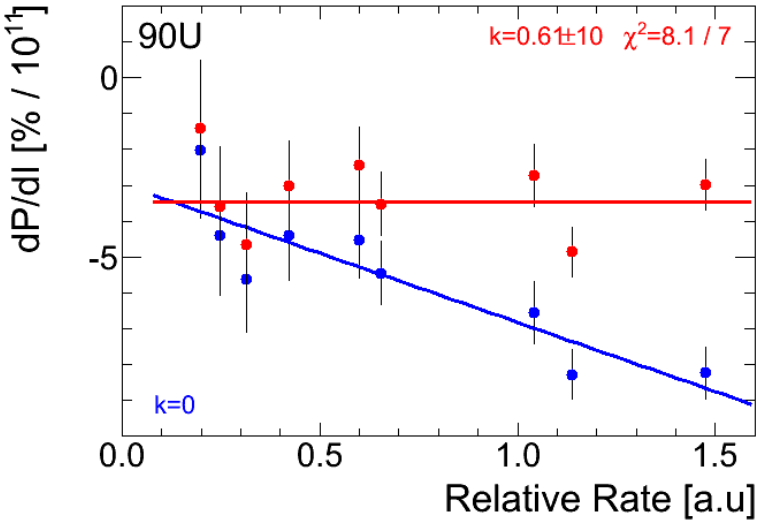
dP/dI dependence on rate correction



- ***Rate correction was calibrated assuming that measured dP/dI was the same for all detectors.***
- ***Rate correction for the 45Up detectors (Hamamatsu, slow) is significantly different from other detectors.***

Rate Corrections from comparison of 90 degree strips

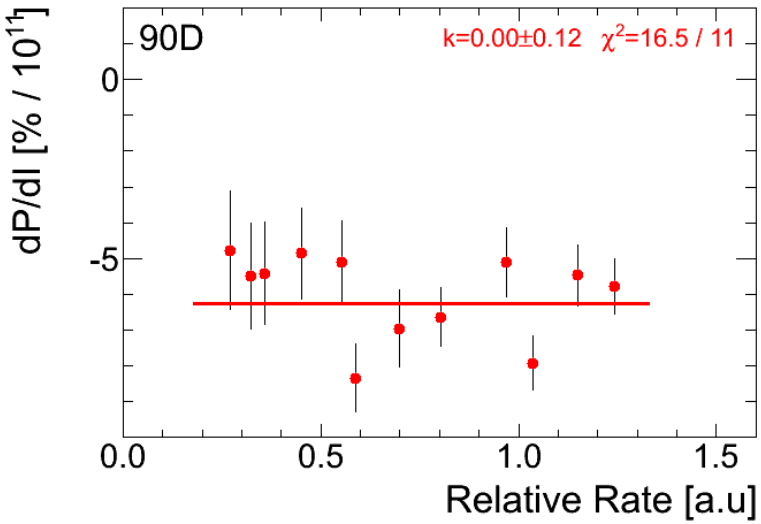




A puzzle:

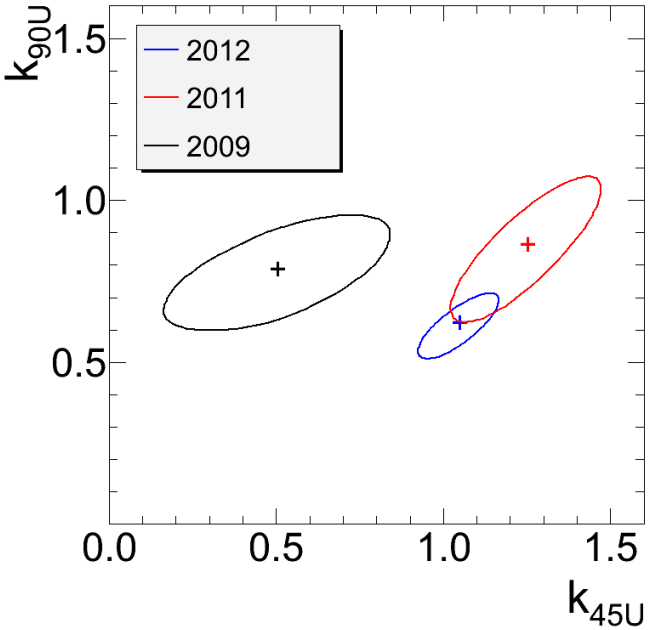
- *A method works well for **90U** detectors*
- *Wrong result for **90D** + not good χ^2*
- *In 2011 all 90 degree detectors were the same, 2 mm BNL, and results were consistent*
- *In 2012 we used 1 mm detectors in **90D**.*

The result for 90U detectors is consistent with other methods.

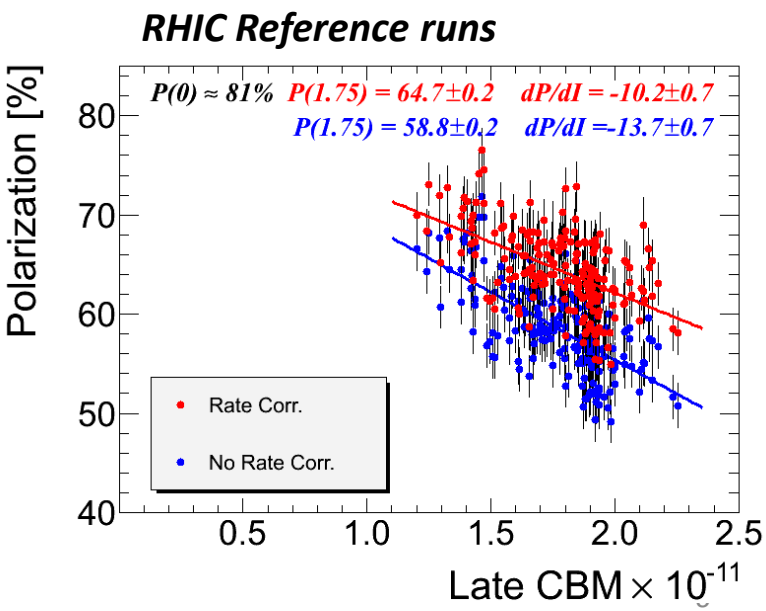


Rate Corrections. dP/dI data fit.

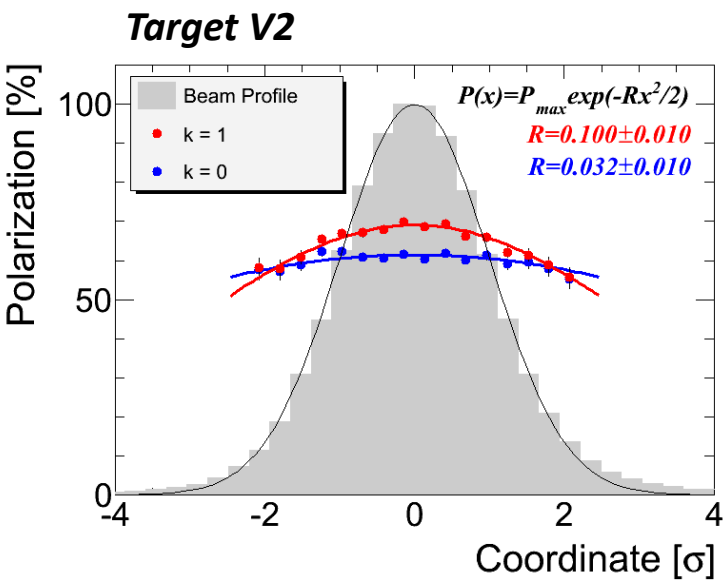
- Much better accuracy in 2012 is mainly due to higher rate and, thus, more sensitivity to the corrections.
- 2012 and 2011 results are consistent.
- In 2009, other detector type was used in 45U

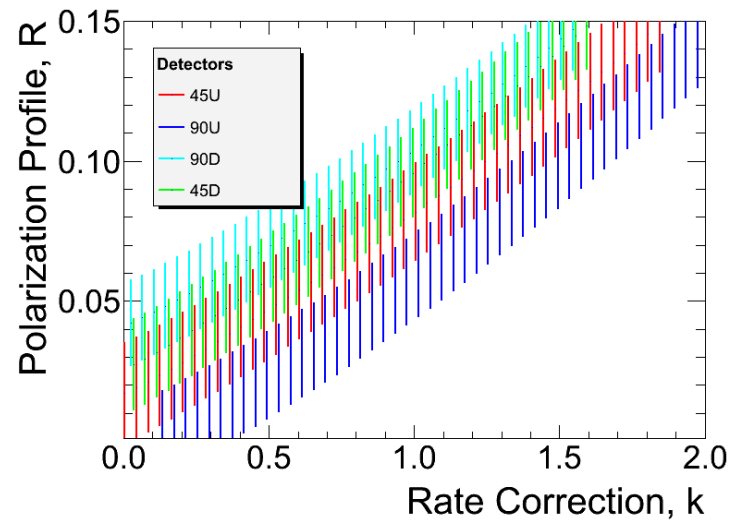


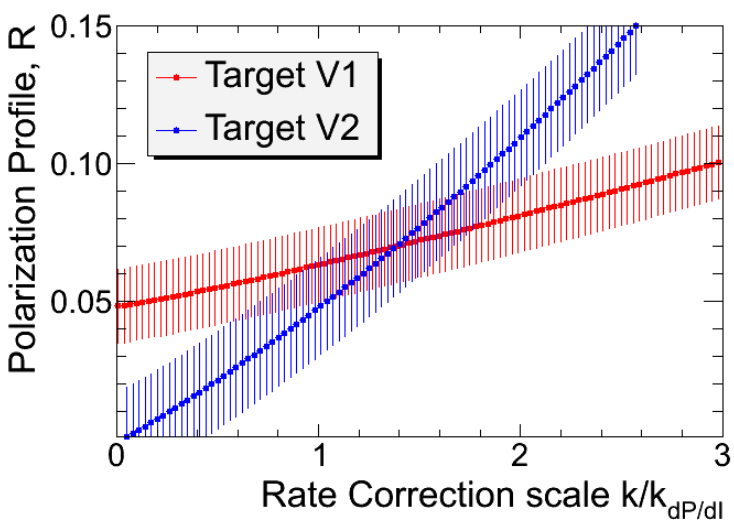
Detector	k	
45U	1.00 ± 0.12	Hamamatsu, slow
90U	0.61 ± 0.10	BNL, 2mm
90D	0.57 ± 0.14	BNL, 1mm
45D	0.69 ± 0.10	Hamamatsu, fast



Rate Corrections from Profile Measurement



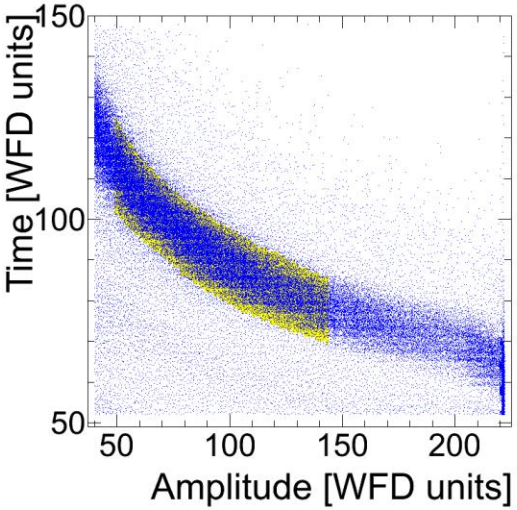




Combined Fit (dP/dI + R)

Detector	k	
45U	0.96 ± 0.11	Hamamatsu, slow
90U	0.59 ± 0.10	BNL, 2mm
90D	0.49 ± 0.13	BNL, 1mm
45D	0.58 ± 0.10	Hamamatsu, fast

Alternative Method of Estimation of Rate corrections



Probability that detected event is "good"

$$\rho = r_{\text{good}}/r$$

$$\rho = \rho_0(1 - ar)$$

A pileup probability of any event detection

Detection efficiency:

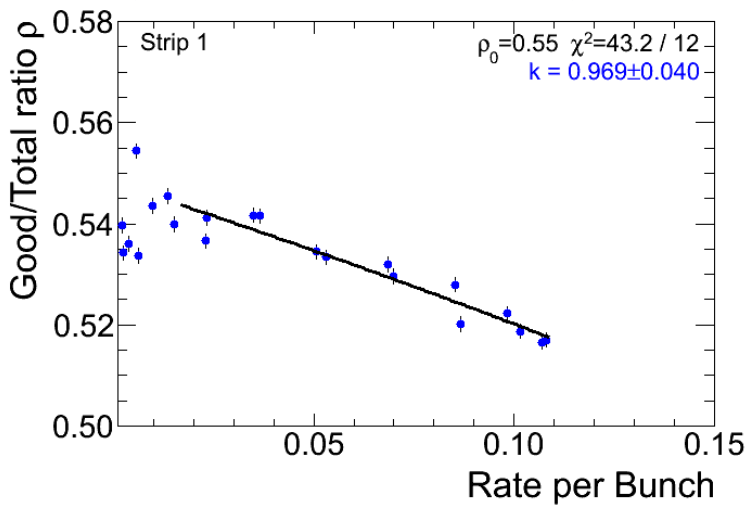
$$\varepsilon(r) = \frac{1 - e^{-r}}{r} \times (1 - ar) \approx 1 - kr$$

$$k = 0.5 + a$$

Advantage:

- *A single sweep target run provides acceptable statistical accuracy.*
- *Rate correction parameter may be measured for each strip separately.*

Single Run Measurement (sweep)



Known problems:

- *Wrong results at low intensities*
- *Results are target dependent for 45deg. detectors*
- *For inner 45 degree detectors the value of k is 20% larger than for outer*
- *For 45D detectors the result is strip dependent*

First results:
(estimates of systematic errors are shown in parentheses)

Detector	k (V2)	k (V1)
45U	1.14 (0.05)	0.93 (0.10)
90U	0.65 (0.04)	0.63 (0.04)
90D	0.66 (0.04)	0.64 (0.04)
45D	0.92 (0.05)	0.72 (0.05)

More work is needed to verify the method

Rate Correction Summary

- Rate Correction calibration failed for 1 mm BNL detectors
- Full Run 12 data is required to calibrate rate corrections.
- Alternative method of calibration is promising, but more work is needed
- In spite of some puzzles, the rate correction parameterization is self consistent.

- Estimated accuracy of the rate correction parameterization is

$$\delta k \approx 0.1$$

which corresponds to systematic error of polarization measurement

$$\delta P \approx 1\% \text{ (absolute)}$$

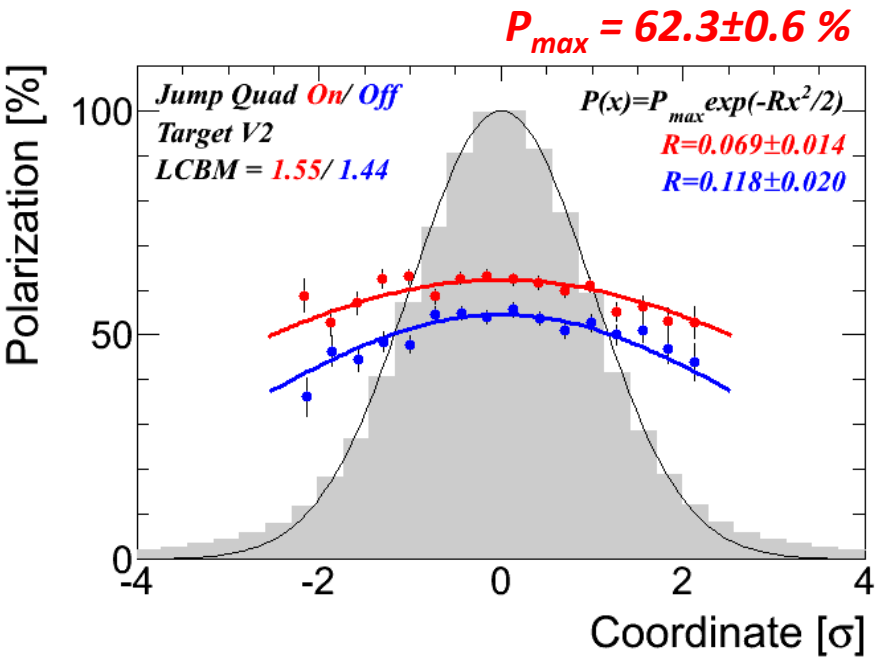
at RHIC injection intensity (I=1.8) and
systematic error of profile measurement

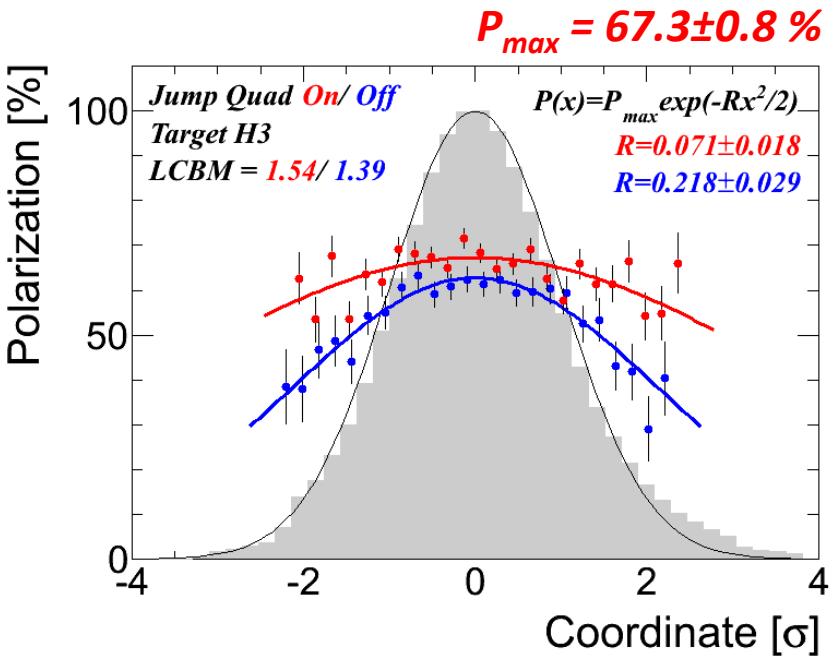
$$\delta R \approx 0.005$$

The *dP/dI* calibration was used in the next slides:

Detector	k	
45U	1.00 ± 0.12	Hamamatsu, slow
90U	0.61 ± 0.10	BNL, 2mm
90D	0.57 ± 0.14	BNL, 1mm
45D	0.69 ± 0.10	Hamamatsu, fast

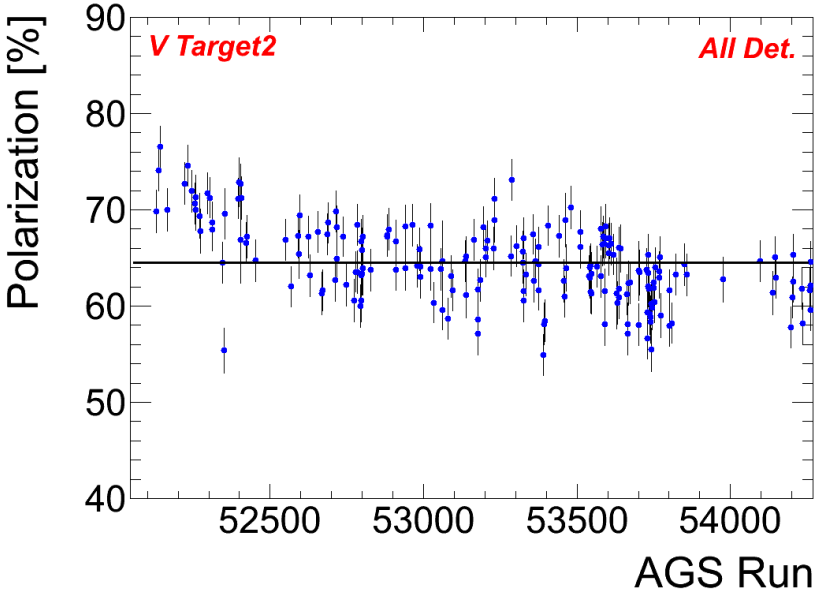
Tests of the Jump Quads

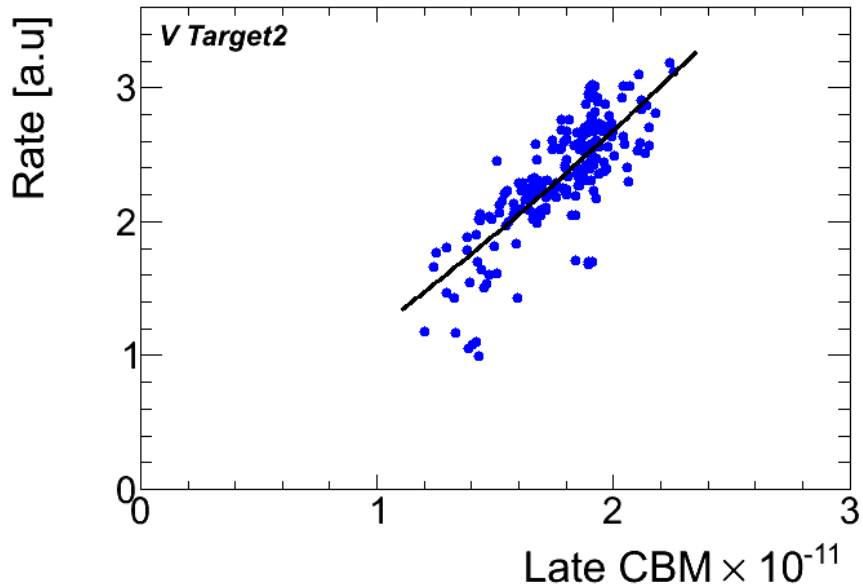


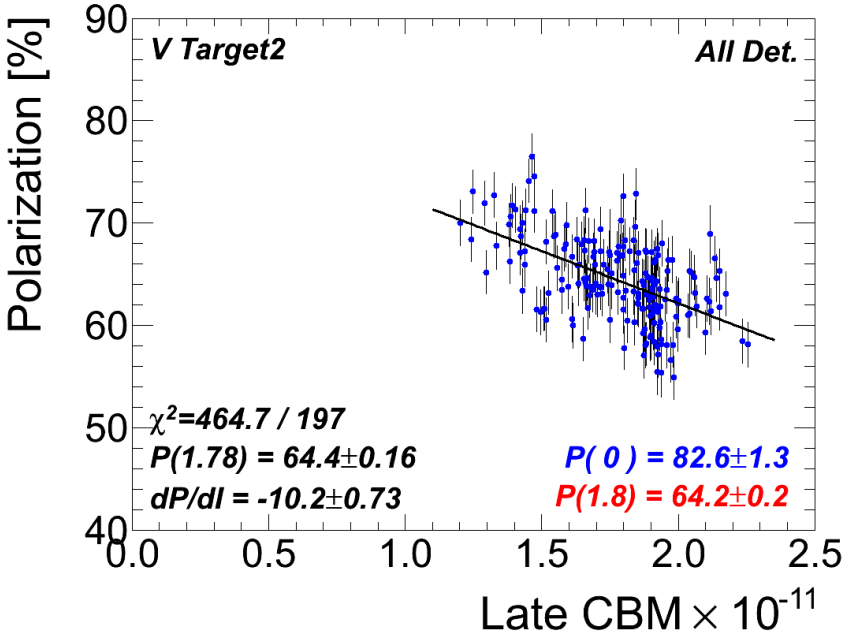


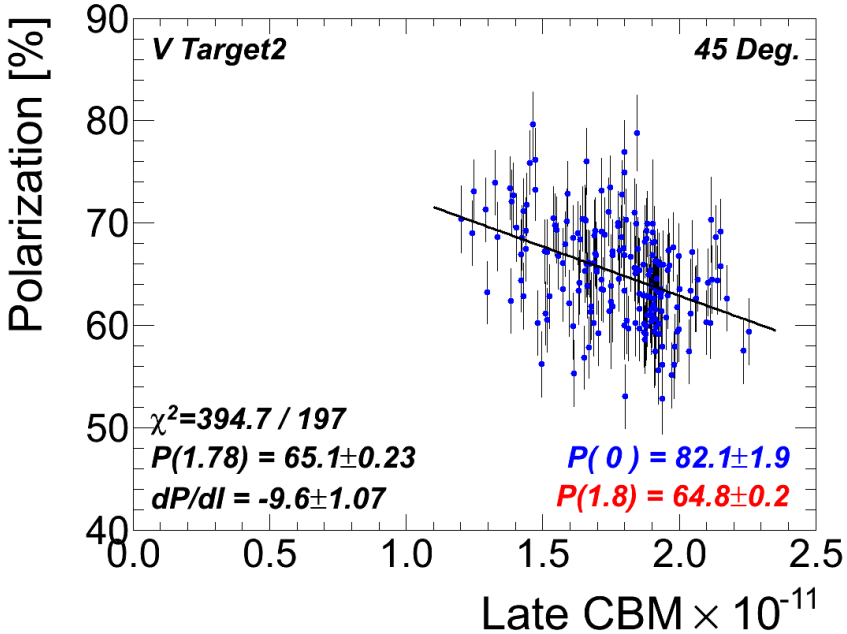
- ***After applying rate corrections, the measured polarization profile R is consistent with RHIC injection measurements.***
- ***Horizontal Target gives larger polarization.***

2012 RHIC Reference Runs

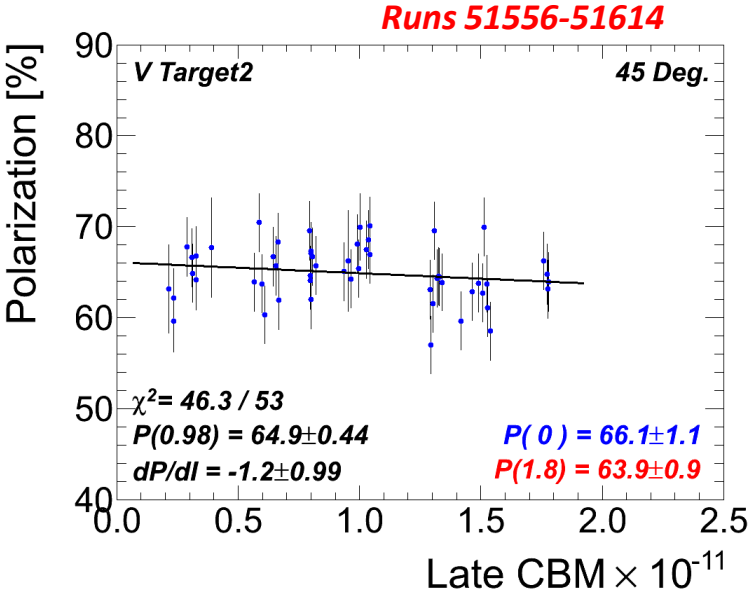


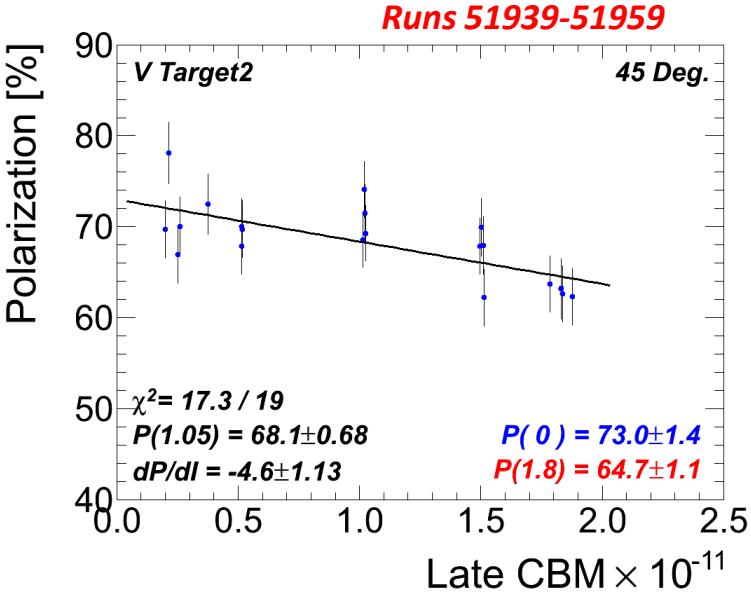


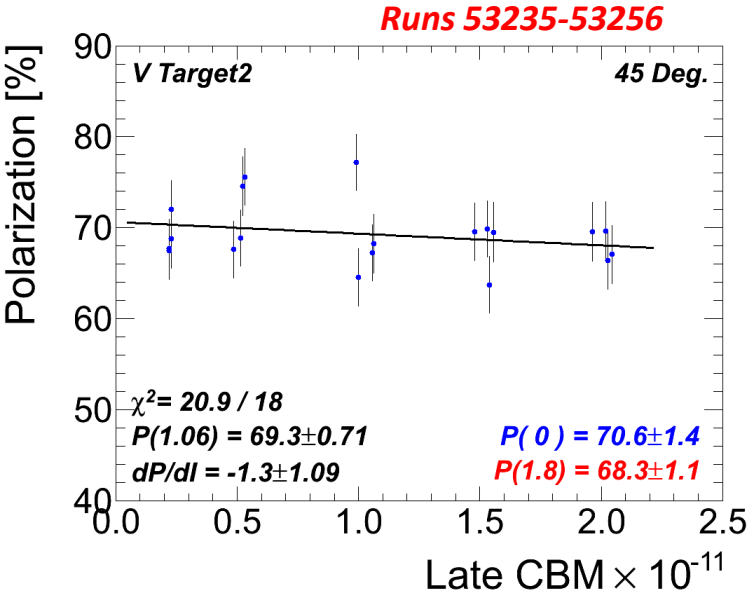


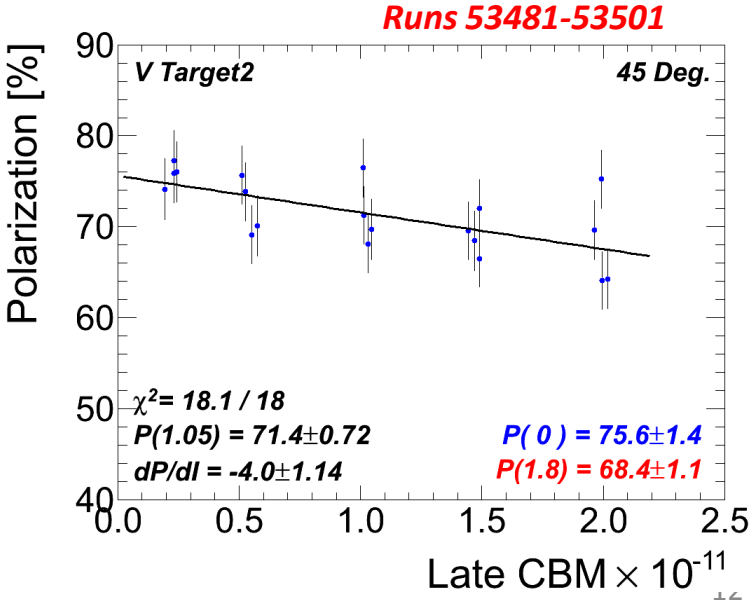


Intensity Scans (Target V2)









Intensity Scans Summary

45 degree detectors only

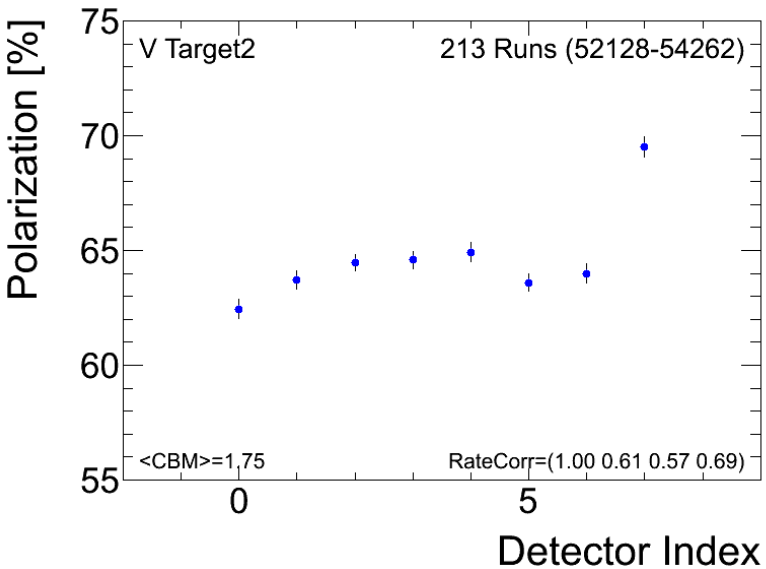
Target	Rel. Thickness†	Rate‡	Runs	dP/dI	P(0)	P(1.8)
V2	1	1.57	RHIC Ref.	-9.6 ± 1.1	81.1 ± 1.9	64.8 ± 0.2
V2*	~0.5	0.66	51556-51614	-1.2 ± 1.0	66.1 ± 1.1	63.9 ± 0.9
V2*	~0.5	0.85	51939-51959	-4.6 ± 1.1	73.0 ± 1.4	64.7 ± 1.1
V2	1	1.63	53235-23256	-1.3 ± 1.1	70.6 ± 1.4	68.3 ± 1.1
V2	1	1.77	53481-53501	-4.0 ± 1.1	75.6 ± 1.4	68.4 ± 1.1
V3	~0.3 (?)	0.53	52569-52590	-4.9 ± 1.2	76.7 ± 1.5	67.8 ± 1.2
V4	0.99	0.94	52068-52097	-4.6 ± 1.1	76.2 ± 1.7	67.9 ± 0.8
H1	0.44	0.46	52599-52604	-5.4 ± 1.1	79.2 ± 1.4	69.4 ± 0.9
H3	0.62	0.66	53481-53507	-5.8 ± 0.8	81.3 ± 1.1	70.8 ± 0.8

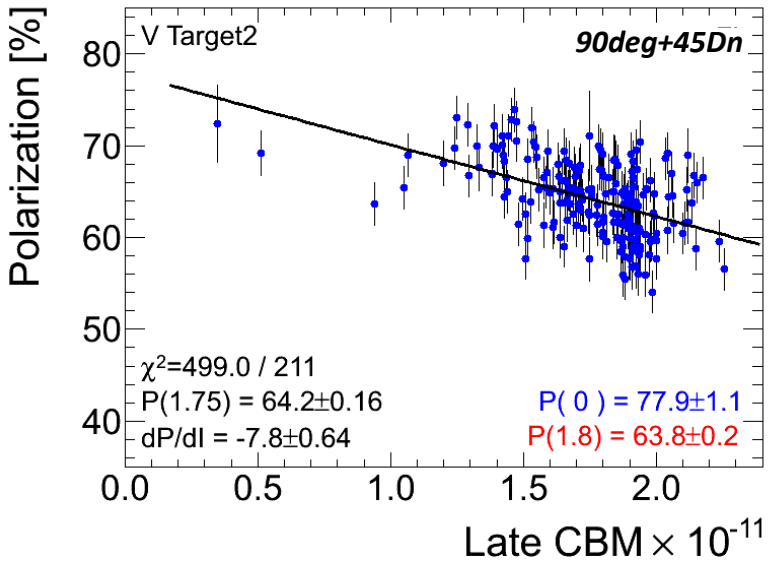
V2* - this 125 µm target was used before AGS Run 51981 (Jan. 24, 2012). New target **V2** was installed on Feb.3 (run 52102)

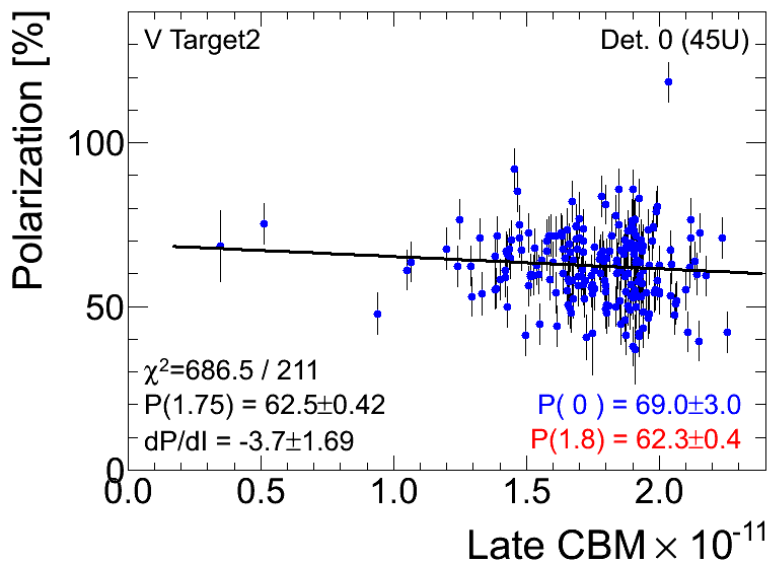
Rel. Thickness† was experimentally estimated (sweep target profile measurements) as a value proportional to *Emittance × Rate / Intensity.*
Rate‡ is number of millions of events in 45 degree detectors per spill at beam intensity of 1.8×10^{11}.

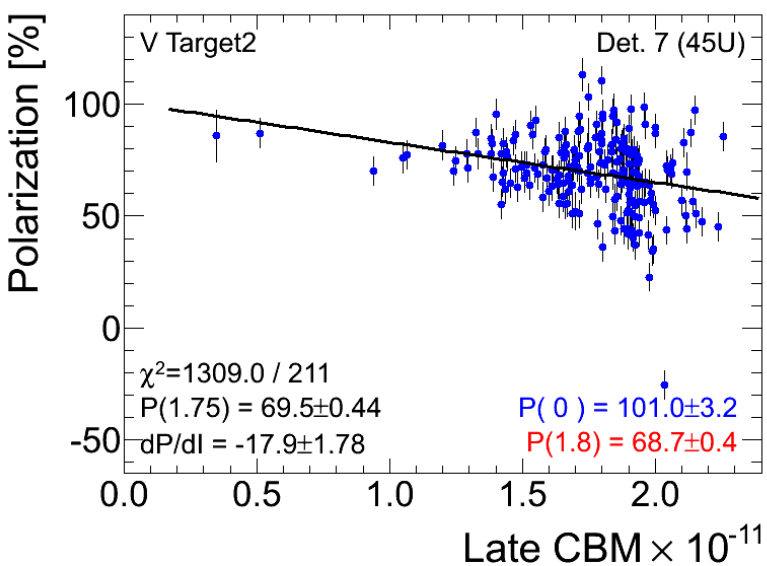
Results are NOT well consistent,
It is unlikely that it may attributed to the rate corrections.

2012 RHIC Reference Runs. Det. 7 puzzle.









Intensity Scans Summary (45U pexcluded)

45Dn (Hamamatsu, fast)

Target	Rel. Thickness†	Rate‡	Runs	dP/dI	P(0)	P(1.8)
V2	1	1.57	RHIC Ref.	-6.3 ± 1.1	75.9 ± 2.0	64.5 ± 0.3
V2*	~0.5	0.66	51556-51614	-1.6 ± 1.3	66.7 ± 1.4	63.8 ± 1.2
V2*	~0.5	0.85	51939-51959	-4.4 ± 1.5	71.4 ± 1.8	63.4 ± 1.5
V2	1	1.63	53235-53256	-3.5 ± 1.4	71.4 ± 1.8	65.1 ± 1.4
V2	1	1.77	53481-53501	-1.6 ± 1.5	72.6 ± 1.8	69.6 ± 1.5
V3	~0.3 (?)	0.53	52569-52590	-4.3 ± 1.7	75.6 ± 1.5	67.8 ± 1.2
V4	0.99	0.94	52068-52097	-6.8 ± 1.5	77.0 ± 2.2	64.8 ± 1.0
H1	0.44	0.46	52599-52604	-4.7 ± 1.5	78.1 ± 1.9	69.5 ± 1.3
H3	0.62	0.66	53481-53507	-4.9 ± 0.8	79.8 ± 1.4	70.9 ± 1.1

The consistency of results is a bit better. ("Not good" results are highlighted)

One can think that:

- ***Horizontal targets give a few percent higher polarization (already observed in 2011)***
- ***Rate corrections should be increased (? In 2011 rate correction was almost factor 2 larger)***

Square Root Formula

Systematic errors of the polarization measurement may be strongly suppressed if 2 left-right symmetric detectors are used and proton spin is flipping during the mesurements

$$\begin{cases} N_R^+ = N_0(1+a)(1+\epsilon)(1+\lambda) \\ N_R^- = N_0(1-a)(1+\epsilon)(1-\lambda) \\ N_L^+ = N_0(1-a)(1-\epsilon)(1+\lambda) \\ N_L^- = N_0(1+a)(1-\epsilon)(1-\lambda) \end{cases}$$

Exact solution →

$$a = \frac{\sqrt{N_R^+ N_L^-} - \sqrt{N_L^+ N_R^-}}{\sqrt{N_R^+ N_L^-} + \sqrt{N_L^+ N_R^-}}$$

a – physical asymmetry
ε – acceptance asymmetry
λ – luminosity asymmetry

Square root formula is <u>absolutely</u> valid as long there is no correlation between ***a, ε,*** and ***λ.***
(and if we neglect statistical errors in measured number of events)

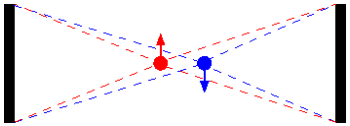
Possible correlation between asymmetries

$$\begin{cases} N_R^+ \propto (1+a+\delta_{LR}+\delta_\pm)(1+\epsilon+\delta_\epsilon)(1+\lambda) \\ N_R^- \propto (1-a-\delta_{LR}+\delta_\pm)(1+\epsilon-\delta_\epsilon)(1-\lambda) \\ N_L^+ \propto (1-a+\delta_{LR}-\delta_\pm)(1-\epsilon-\delta_\epsilon)(1+\lambda) \\ N_L^- \propto (1+a-\delta_{LR}-\delta_\pm)(1-\epsilon+\delta_\epsilon)(1-\lambda) \end{cases}$$

$$\begin{aligned} a_{\text{meas.}} &= a + \delta_\epsilon \\ \epsilon_{\text{meas.}} &= \epsilon + \delta_\pm - \cancel{a\delta_{LR}} \\ \lambda_{\text{meas.}} &= \lambda + \delta_{LR} - \cancel{a\delta_\pm} - \cancel{\epsilon\delta_\epsilon} \end{aligned}$$

δ_ε - acceptance asymmetry dependence on beam polarity.

Possible source: a shift between averaged beam/target positions for positive and negative polarities.



δ_{LR} – left right asymmetry of the analyzing power due to inaccurate calibration etc.

$\delta_\pm$ - analyzing power dependence on beam polarity.

(here added for completeness)

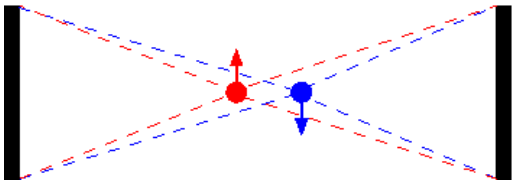
Since λ must be the same for all detectors, the monitoring of λ allows us to estimate possible variations of δ_{LR}

δ_ε - acceptance asymmetry dependence on beam polarity

Vertical target:

x-coordinate is defined by the target position.

We may expect $\delta_\varepsilon \approx 0$.



Horizontal Target:

x-coordinate is defined by beam position.

If $|x_+ - x_-| > 100\ \mu m$, a percent correction to the measured polarization is possible.

Could δ_ε give an explanation of the discrepancy between vertical and horizontal target results ?

$\delta_\pm$ - analyzing power dependence on beam polarity.

For a pair of Si detectors we can measure (determine) 4 averaged analyzing powers:

$$\begin{cases} a_R^+ = a + \delta_{LR} + \delta_\pm + \delta_n \\ a_R^- = a + \delta_{LR} - \delta_\pm - \delta_n \\ a_L^+ = a - \delta_{LR} + \delta_\pm - \delta_n \\ a_L^- = a - \delta_{LR} - \delta_\pm + \delta_n \end{cases}$$

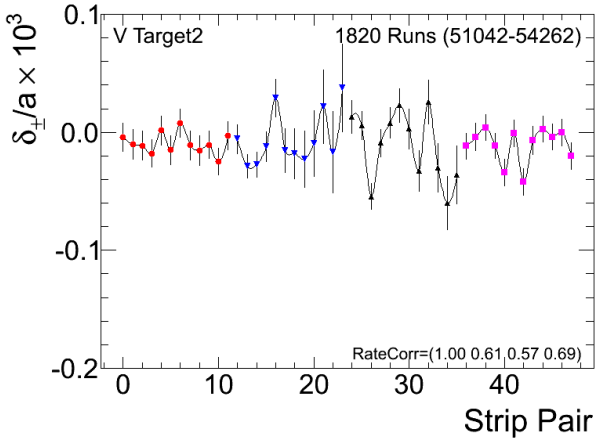
$$\begin{aligned} 4\delta_\pm &= a_R^+ - a_R^- + a_L^+ - a_L^- \\ 4\delta_n &= a_R^+ - a_R^- - a_L^+ + a_L^- \end{aligned}$$

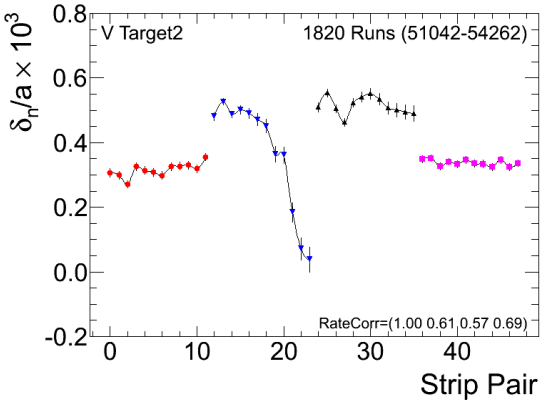
An estimate of the $\delta_\pm + \delta_n$:

$$a^\pm = \frac{\int A_N(t) N_\pm(t) dt}{\int N_\pm(t) dt}$$

$$N_\pm(t) = N_0(t) \times (1 \pm A_N(t) P)$$

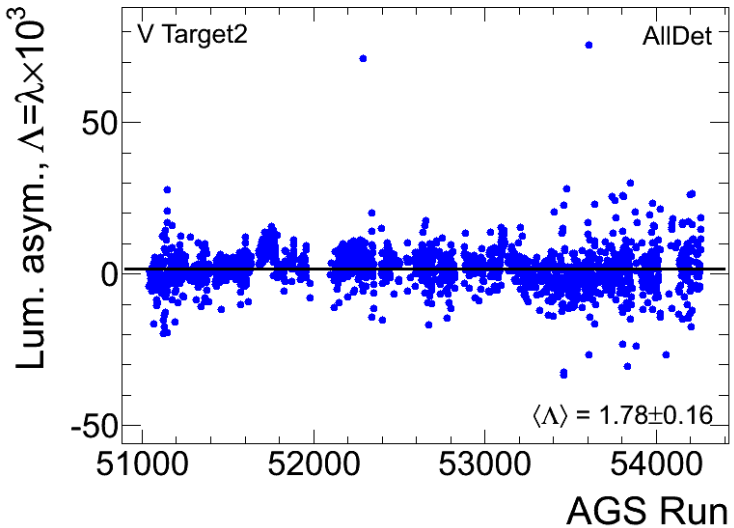
$$\delta_\pm + \delta_n = \frac{a^+ - a^-}{a^+ + a^-} = P \frac{\langle A_N^2 \rangle - \langle A_N \rangle^2}{\langle A_N \rangle}$$

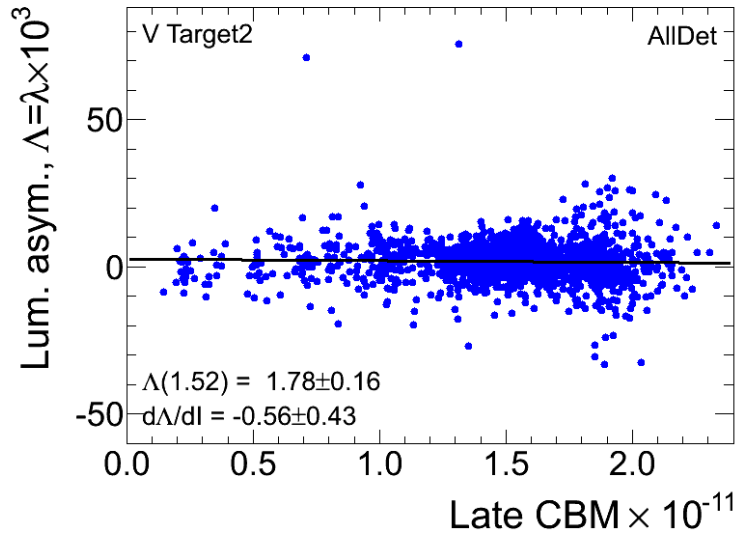


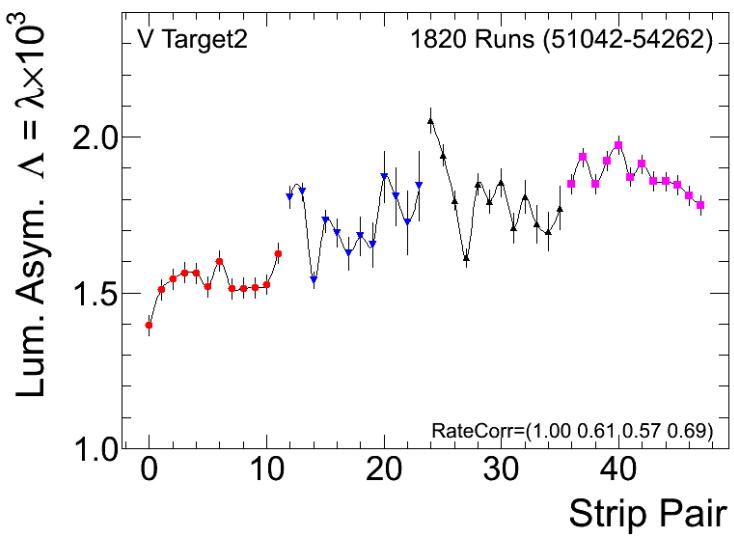


$|\delta_\pm/a| < 10^{-4}$ is very small and contributes only to the acceptance asymmetry. We may disregard this term.

δ_{LR} – left right asymmetry of the analyzing power







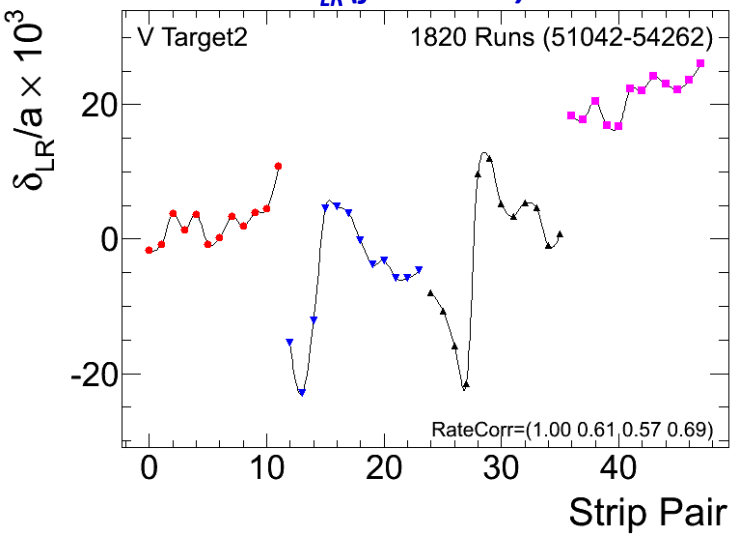
$$\lambda_{\mathrm{meas}} = \lambda + \delta_{\mathrm{LR}}$$

λ is the same for any strip pair.
We can evaluate δ_{LR}.

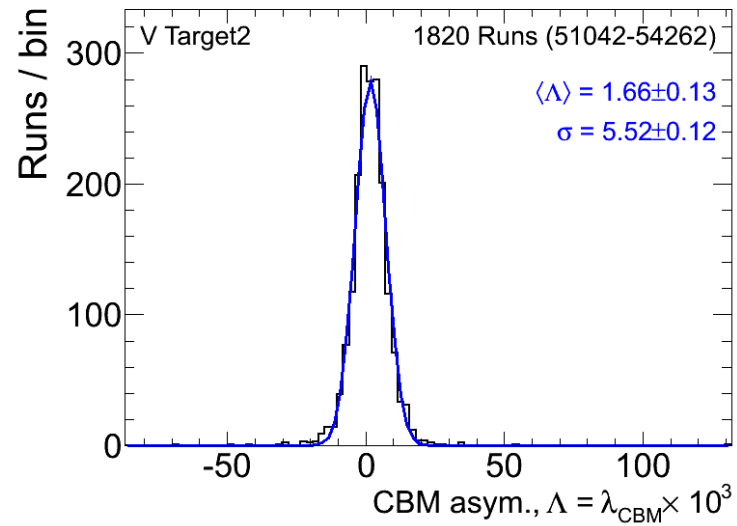
δ_{LR} should be compared with *$a \approx 10^{-2}$*

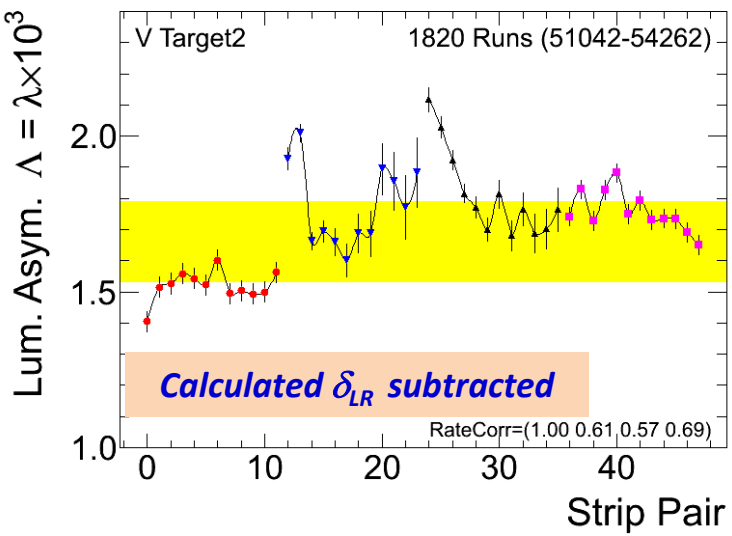
δ_{LR} – left right asymmetry of the analyzing power

Calculated δ_{LR} (from data)



Lum. asymmetry from the CBM.





- ***Variations of λ indicate uncontrolled errors in determination of the analayzing power.***
- ***There is a clear discrepancy between fast (36-47) and slow (0-11) 45 degree detectors.***
- ***CBM measurements do not allow us to resolve this discrepancy.***
- ***We observe a systematic luminosity asymmetry ~ few×10^{-3}***

Multiple (non-symmetric) detector case

$$a_i = \langle A_N(t)\rangle_i \sin\theta_i$$

λ is the same for allstrips

G_i is detector acceptance

$$\begin{cases} N_i^+ = (1 + a_i P) G_i (1 + \lambda) \\ N_i^- = (1 - a_i P) G_i (1 - \lambda) \end{cases}$$

For ***n*** detectors, there are ***2n*** equations and ***n+2*** unknown values. To find ***P, λ, G_i*** we should minimize the

$$\chi^2 = \sum_{i,\pm} \frac{\left(N_i^\pm - (1 \pm a_i P) G_i (1 \pm \lambda)\right)^2}{N_i^\pm}$$

<u>Iteration method:</u>

0. *P=0. λ=0*
1. $G_i = \sqrt{\frac{N_i^+ N_i^-}{(1 - a_i^2 P^2)(1 - \lambda^2)}} \approx \sqrt{N_i^+ N_i^-} \times \left(1 + \mathcal{O}(10^{-4})\right)$
2. Minimize χ^2 with fixed G_i. (Find P and λ)
3. Goto 1.

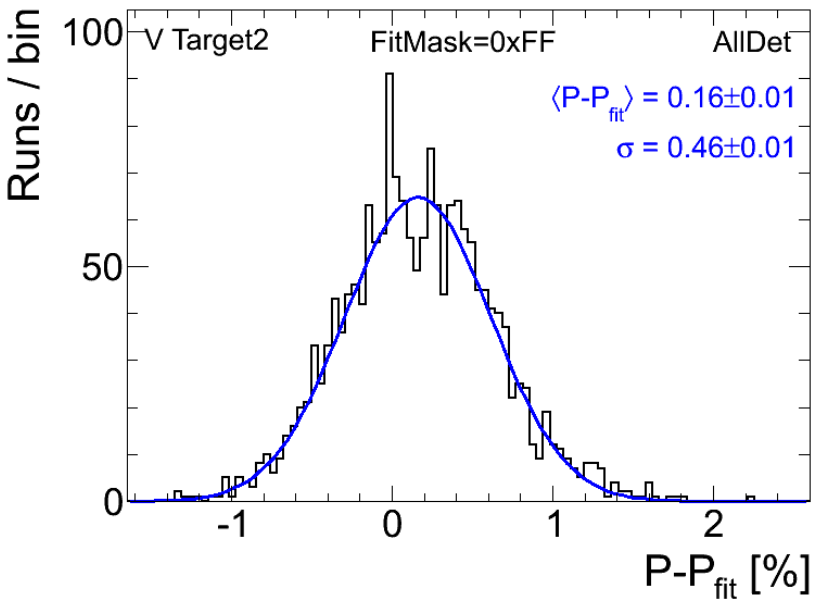
The method works well in the case of asymmetric detectors. For example, 90 degree detectors in one side and 45 degree in other side

We can determine λ using all detectors and then study every detector separately. Also, we can get λ from non-polarimeter data, e.g. from CBM.

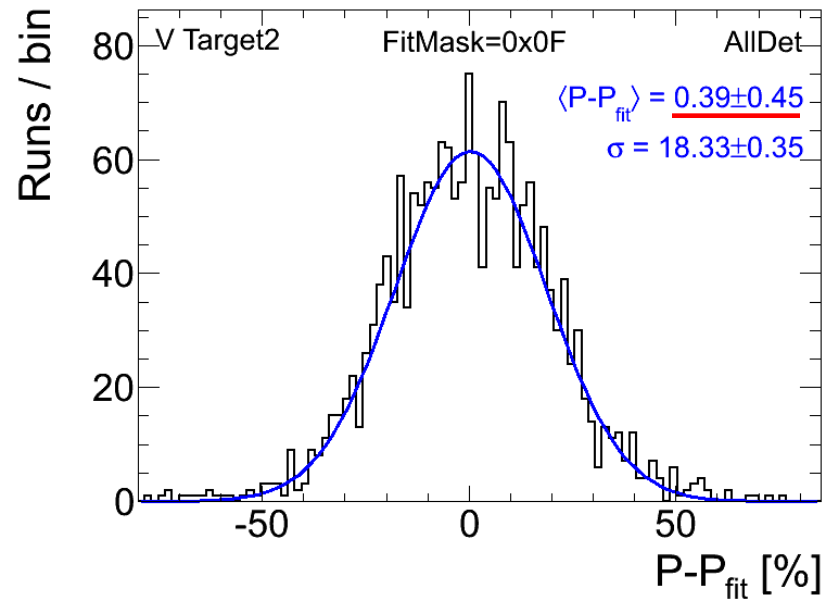
The method might be helpful for the RHIC polarimeter !

Fit vs Square Root Formula

All detectors in Fit



Right side detectors only in Fit



δ_{LR}

Statistical accuracy of the polarization measurement ≈2% (single run)

- For symmetric detectors, actual difference between the Fit and the Square Root Formula is accounting of calculated δ_{LR}, which does not affect polarization measurements.
- The Fit works well in asymmetric case.
- The Fit provide a better control on the results of measurements.
- Polarization angle φ and beam position (x,y) could be easily entered to the Fit.

An estimate of sigma for the right side only fit

$$\sigma_P/P \propto \frac{\sqrt{N}}{N(\sin\theta_R - \sin\theta_L)}$$

$$\sigma_{0x0F} \approx 2\% \frac{\sqrt{2}(\sin 90^\circ - \sin -90^\circ)}{\sin 90^\circ - \sin 45^\circ} \approx 19\%$$

Evaluation of the systematic errors in the Fit

$$\tilde{a}_i = a_i(1+\varepsilon_i)$$

$\tilde{a}, \tilde{P}, \tilde{\lambda}$ are true values of a, P, and λ

No acceptance asymmetry

$$\delta P = P_{\text{fit}} - \tilde{P} = \tilde{P}\frac{\sum_i N_i a_i^2 \varepsilon_i \sin^2\theta_i}{\sum_i N_i a_i^2 \sin^2\theta_i}$$

$$\delta\lambda = \lambda_{\text{fit}} - \tilde{\lambda} = \tilde{P}\frac{\sum_i N_i a_i \varepsilon_i \sin\theta_i}{\sum_i N_i}$$

$$\delta P_k = \tilde{P}\left(\varepsilon_k - \frac{\delta P}{\tilde{P}} - \frac{\delta\lambda}{\tilde{P} a_k \sin\theta_k}\right)$$

$$\delta a_k = -a_k\left(\varepsilon_k - \frac{\delta P}{\tilde{P}} - \frac{\delta\lambda}{\tilde{P} a_k \sin\theta_k}\right)$$

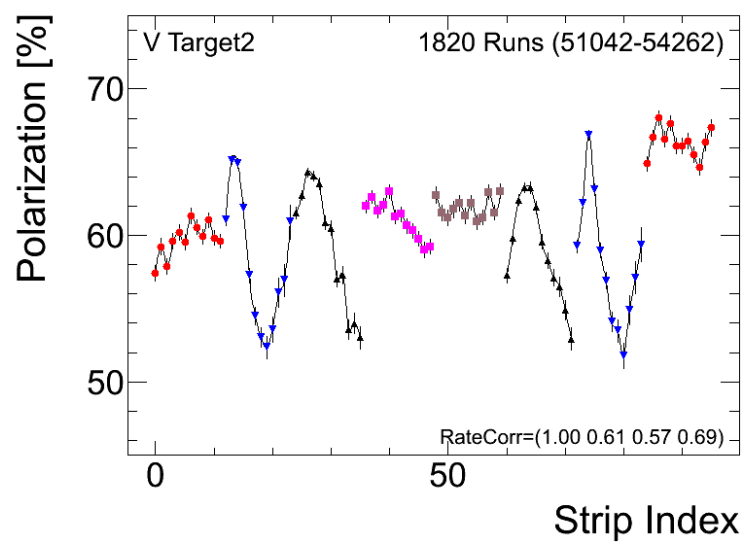
In the Fit we can evaluate values of εk up to 2 constaints:

$$\varepsilon_i \rightarrow \varepsilon_i + \delta\varepsilon$$

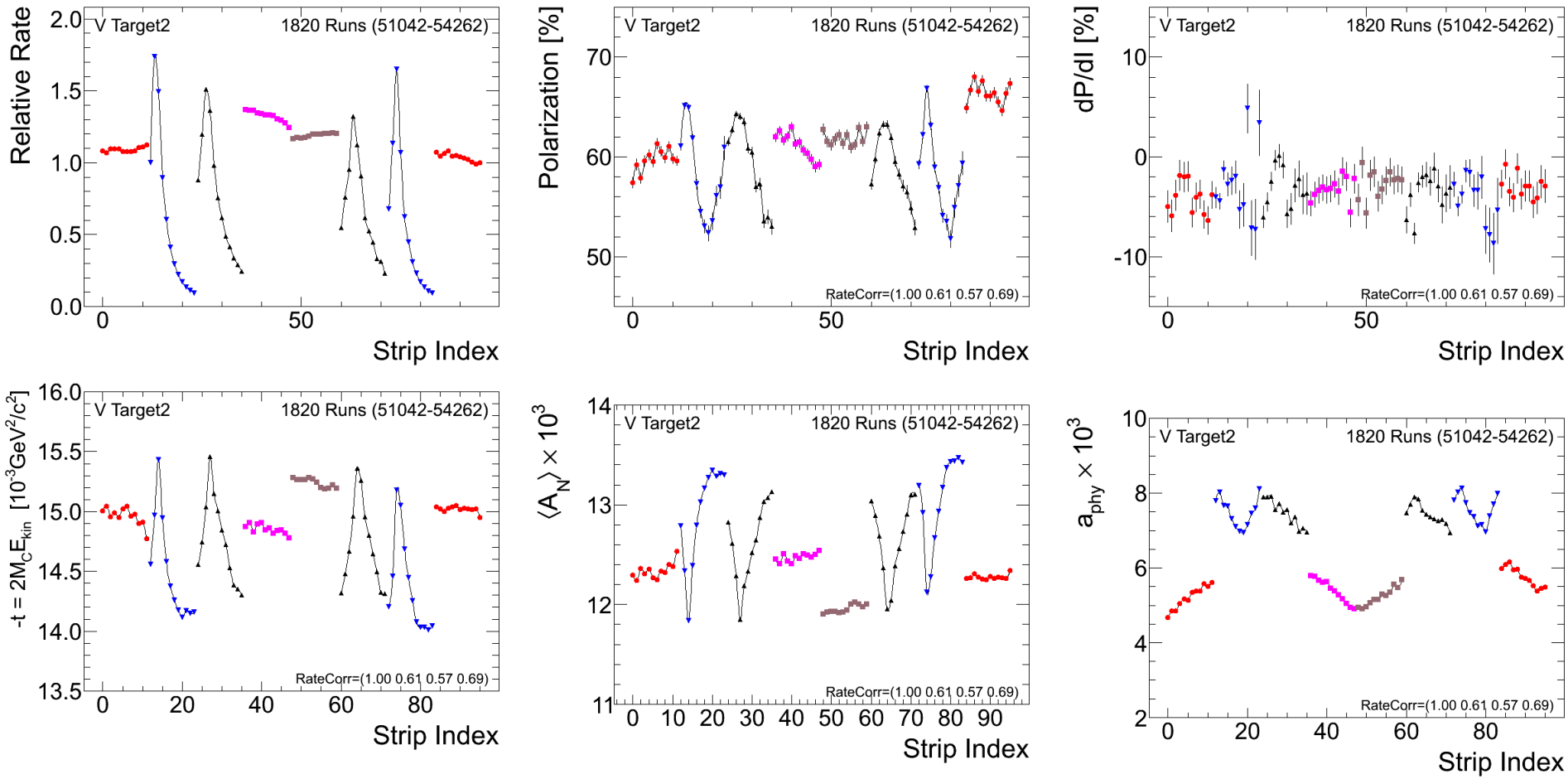
$$\langle\varepsilon_{\text{Right Side}}\rangle = \langle\varepsilon_{\text{Left Side}}\rangle$$

Only first constraint remains if luminosity asymmetry λ can be determined externally.

(Wall Current Monitor (CBM) measurements is a candidate which has to be studied)



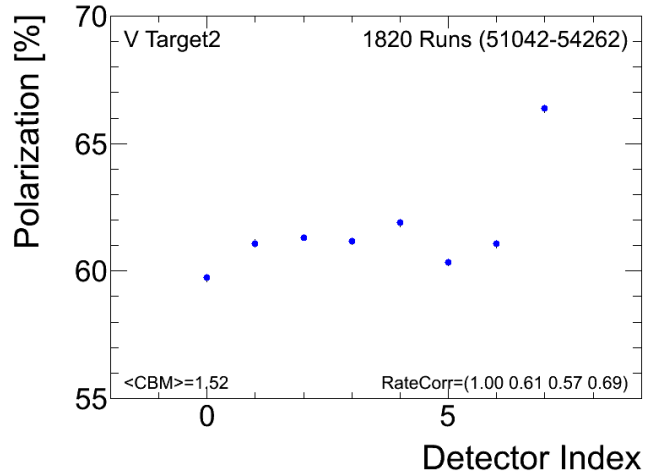
Strip Comparison. Run 2012.

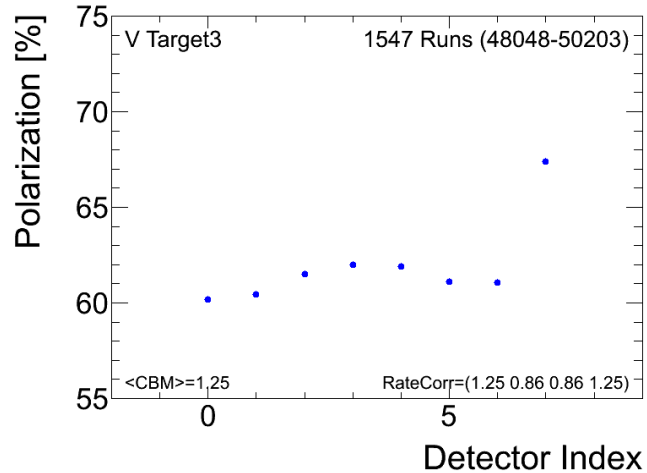


- No good understanding for 90 degree detectors.
  a_{phy} is not correlated with calculated A_N
- For fast Hamamatsu (45D): $A_N(L) \neq A_N(R)$ but $P(L)=P(R)$
- For slow Hamamatsu (45U): $A_N(L)=A_N(R)$ but $P(L) \neq P(R)$

Single detector polarization. Run12 vs Run11.

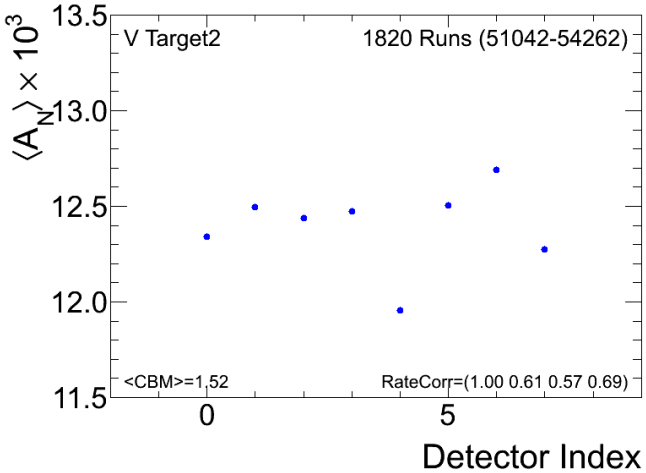
Run 2012

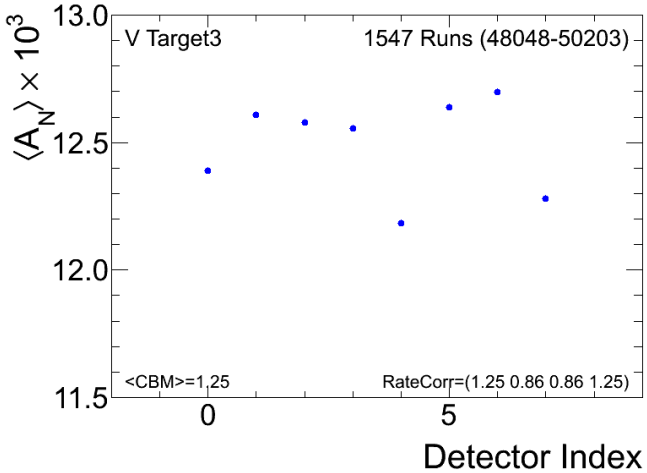




Run 2011

Run 2012



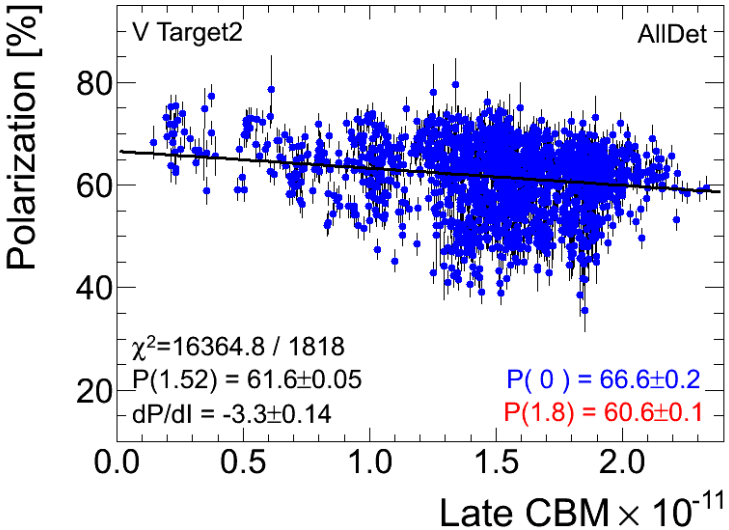


Run 2011

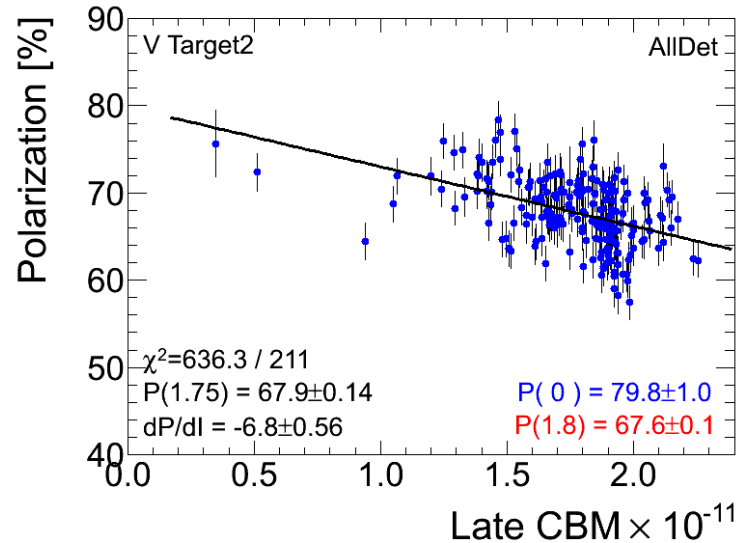
- ***The similar problem existed in Run 2011 (but there was no problem with dP/dI)***
- ***The effect can not be attributed to the error in measured value of analyzing power***
- ***Measured analyzing powers in the fast Hamamatsu detectors are different, but there is no difference in measured polarization.***

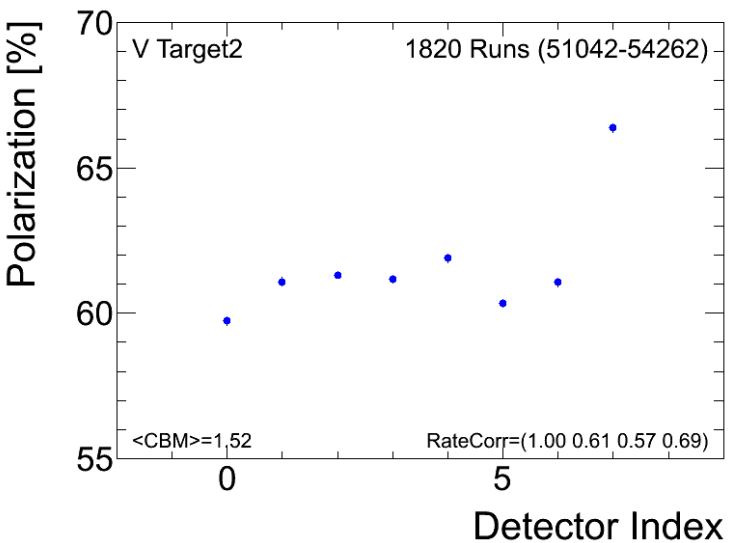
A more detailed look in Run12.

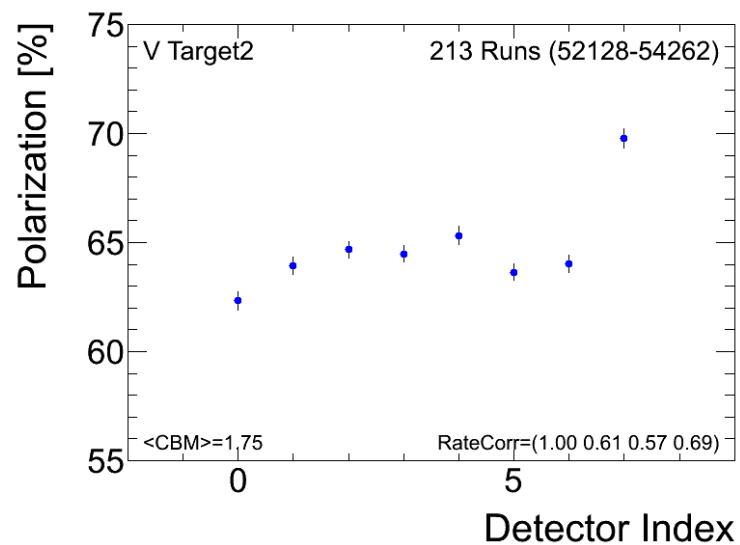
All V2 data



RHIC Ref. Runs

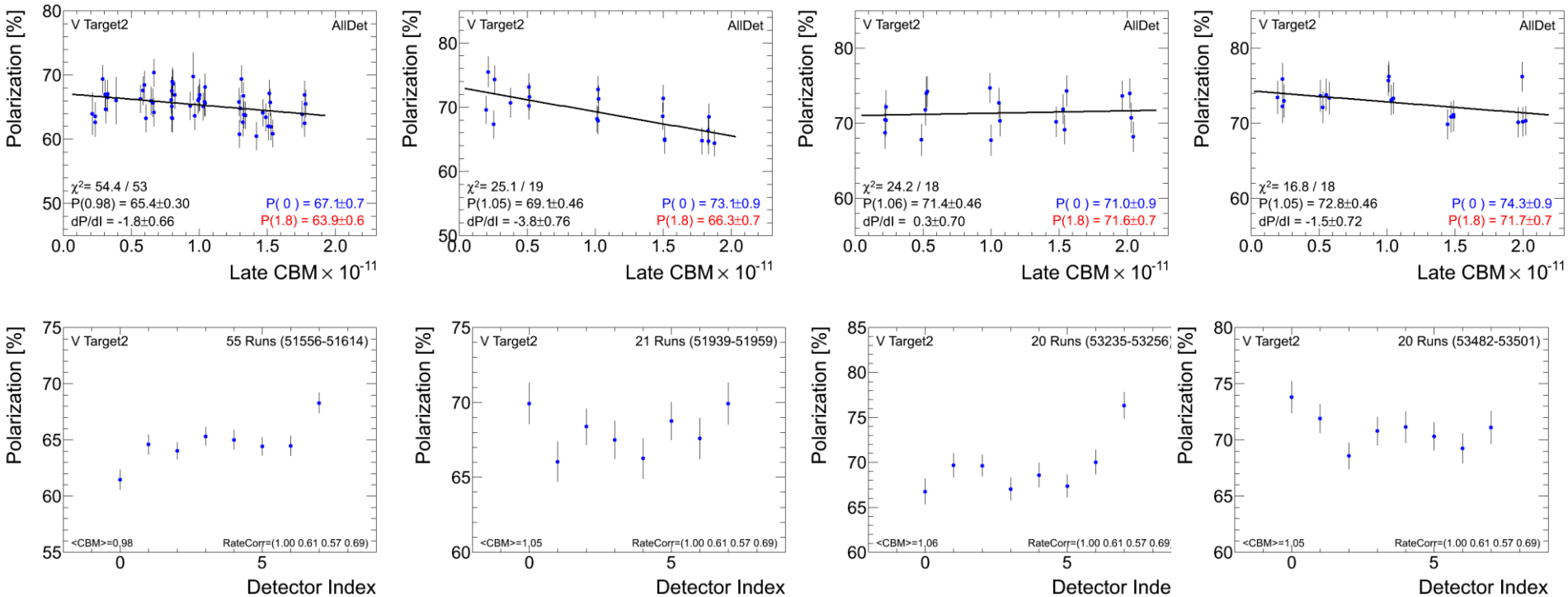






Intensity scans in Run 12

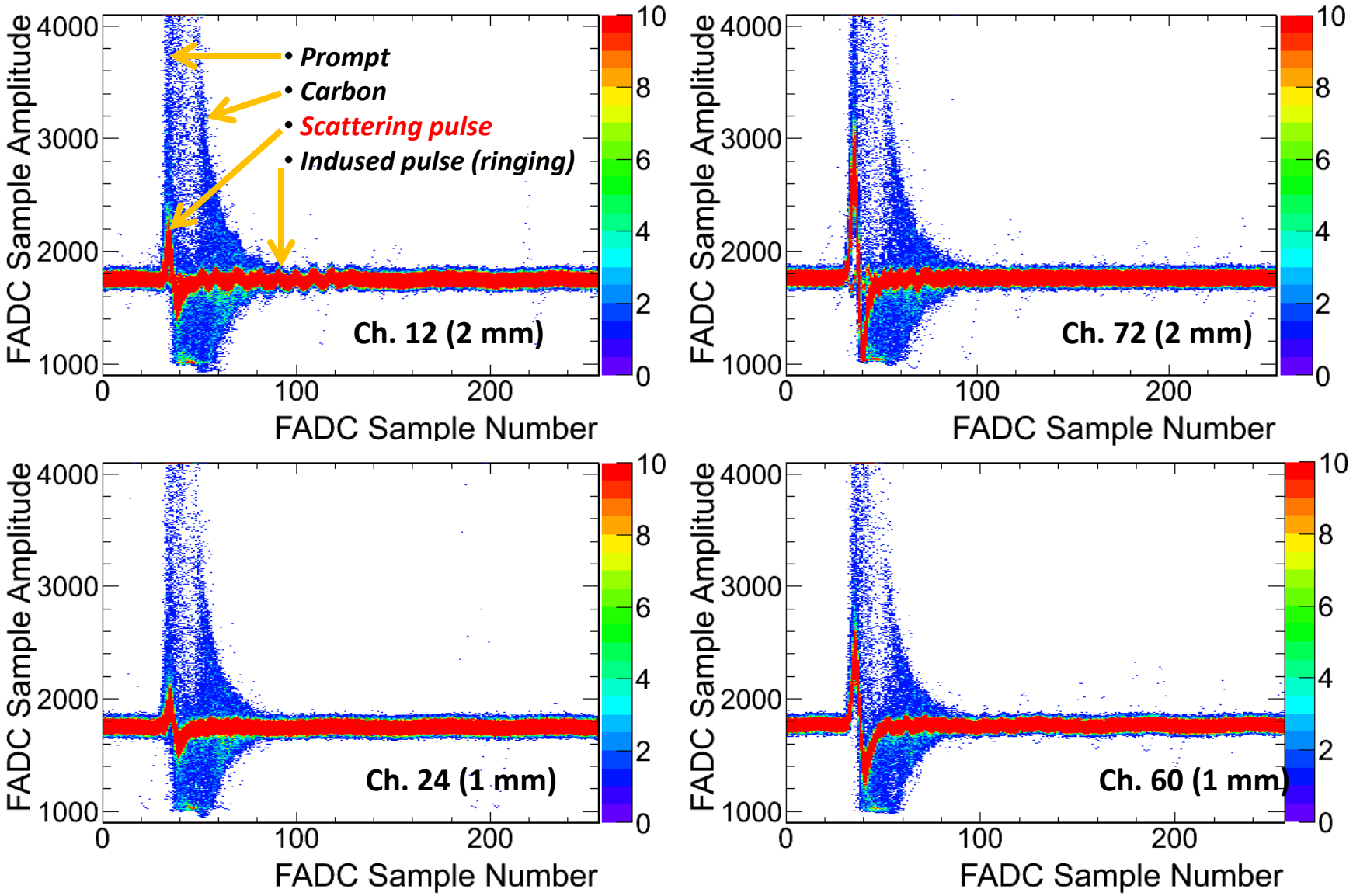
Runs 51556-51614 | **Runs 51939-51959** | **Runs 53235-53256** | **Runs 53482-53501**



Sometimes detector 7 problem gone !?
Is it Rate dependent ?

"Scattering Pulse". BNL detectors. LateCBM=1.7

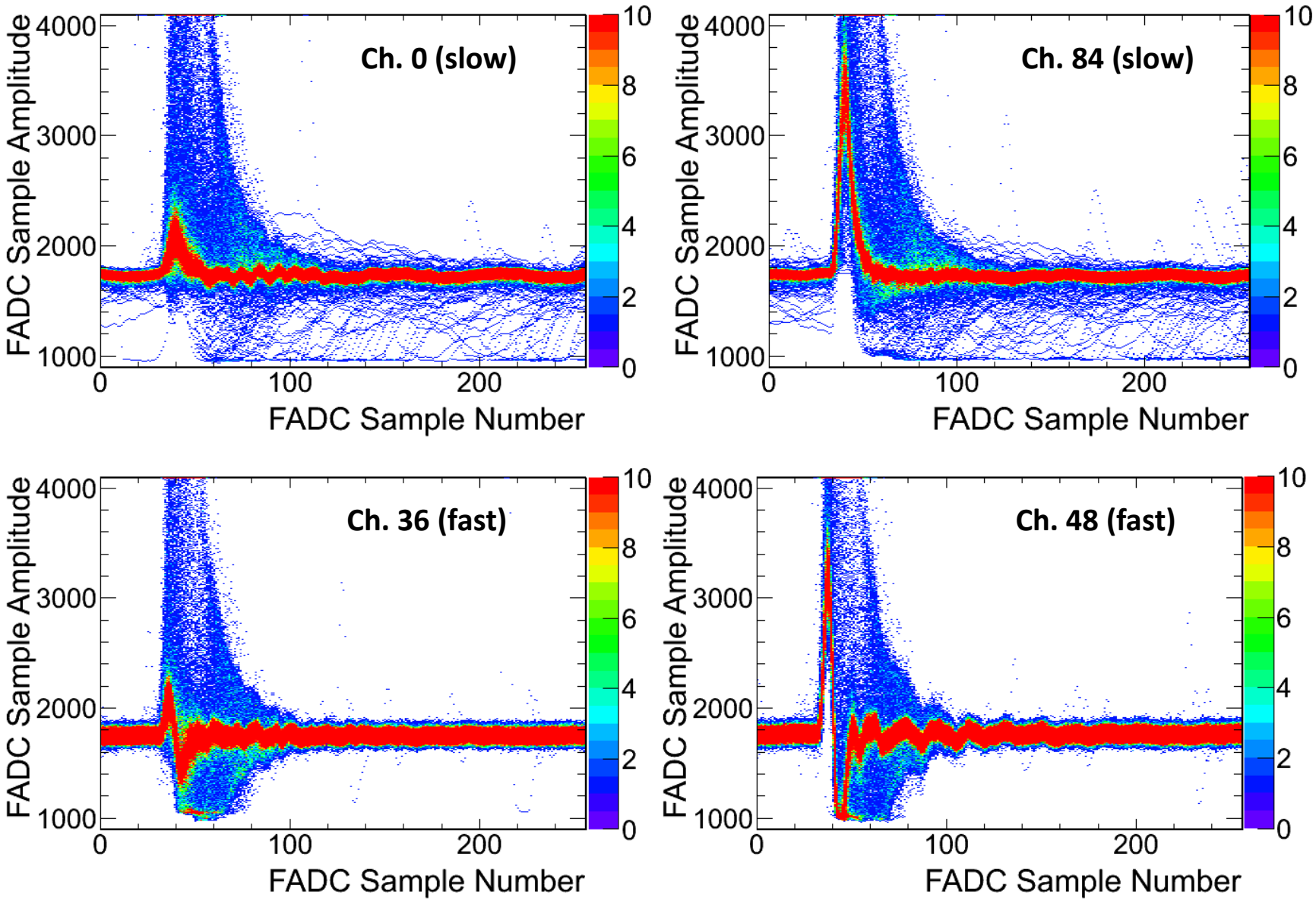
Outer detectors



Inner detectors

"Scattering Pulse". Hamamatsu det. LateCBM=1.7

Outer detectors



Inner detectors

Summary

- ***Our understanding of the accuracy of the polarization measurements is still at few percent level.***
- ***There are many questions which need to be answered***
- ***Some of them were discussed***