

# RHIC Polarimetry

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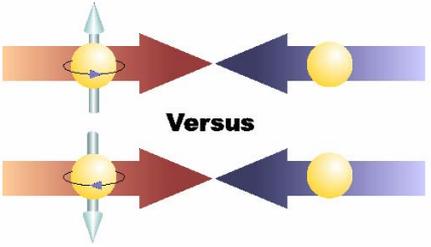
Itaru Nakagawa

*RIKEN/RBRC*

On Behalf of Polarimeter Group

# Polarimetry: Impact of

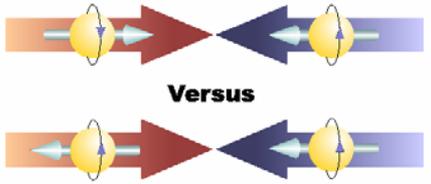
## Single Spin Asymmetries



Physics As

$$A_N = \frac{1}{P_{beam}}$$

## Double Spin Asymmetries

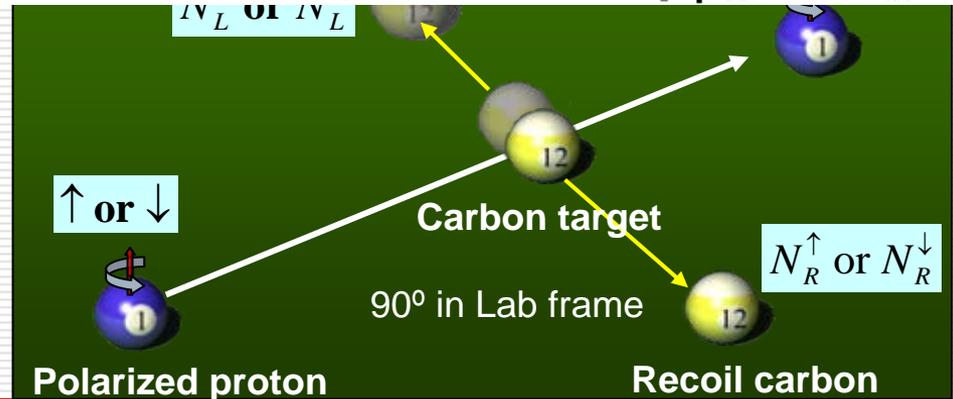
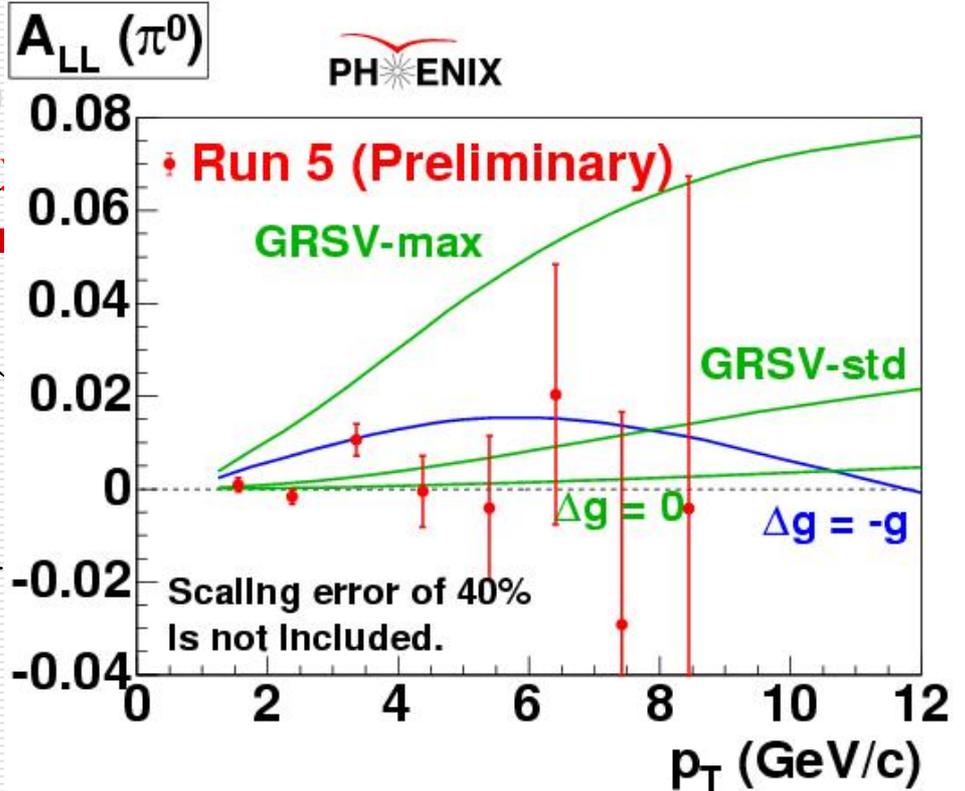


$$A_{LL} = \frac{1}{P_{beam}^2}$$

Polarization measurement  
by Elastic  $\vec{p}p(p\vec{p})/\vec{p}C$

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

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

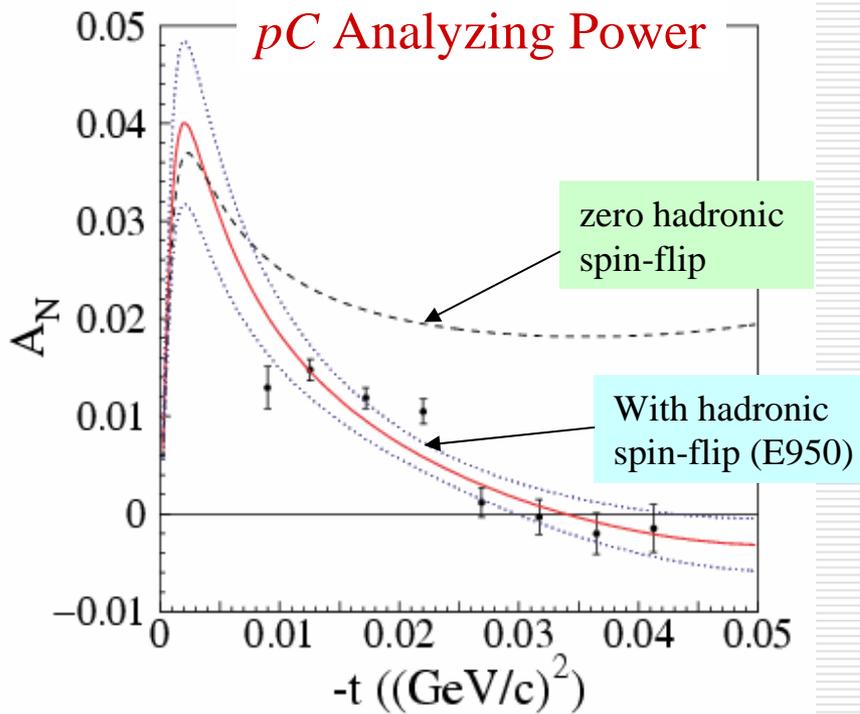


$$t = (p_{out} - p_{in})^2 \approx -2M_C T_{kin} < 0$$

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

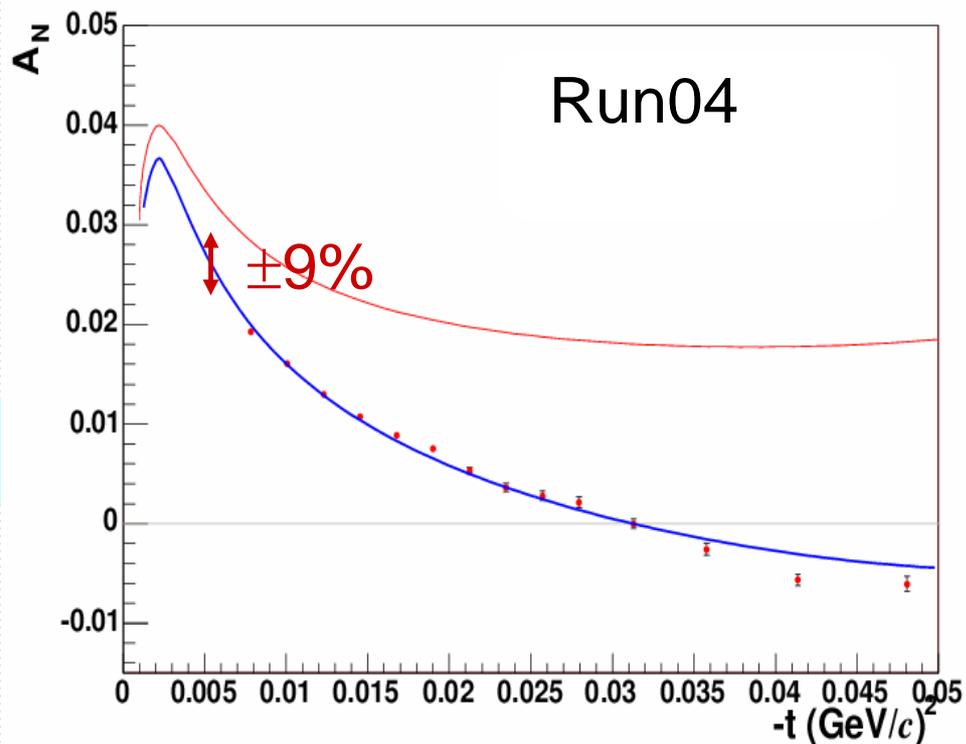
# $A_N$ at Coulomb Nuclear Interference (CNI) Region

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



*Phys.Rev.Lett.,89,052302(2002)*

$E_{beam} = 21.7 \text{ GeV}$

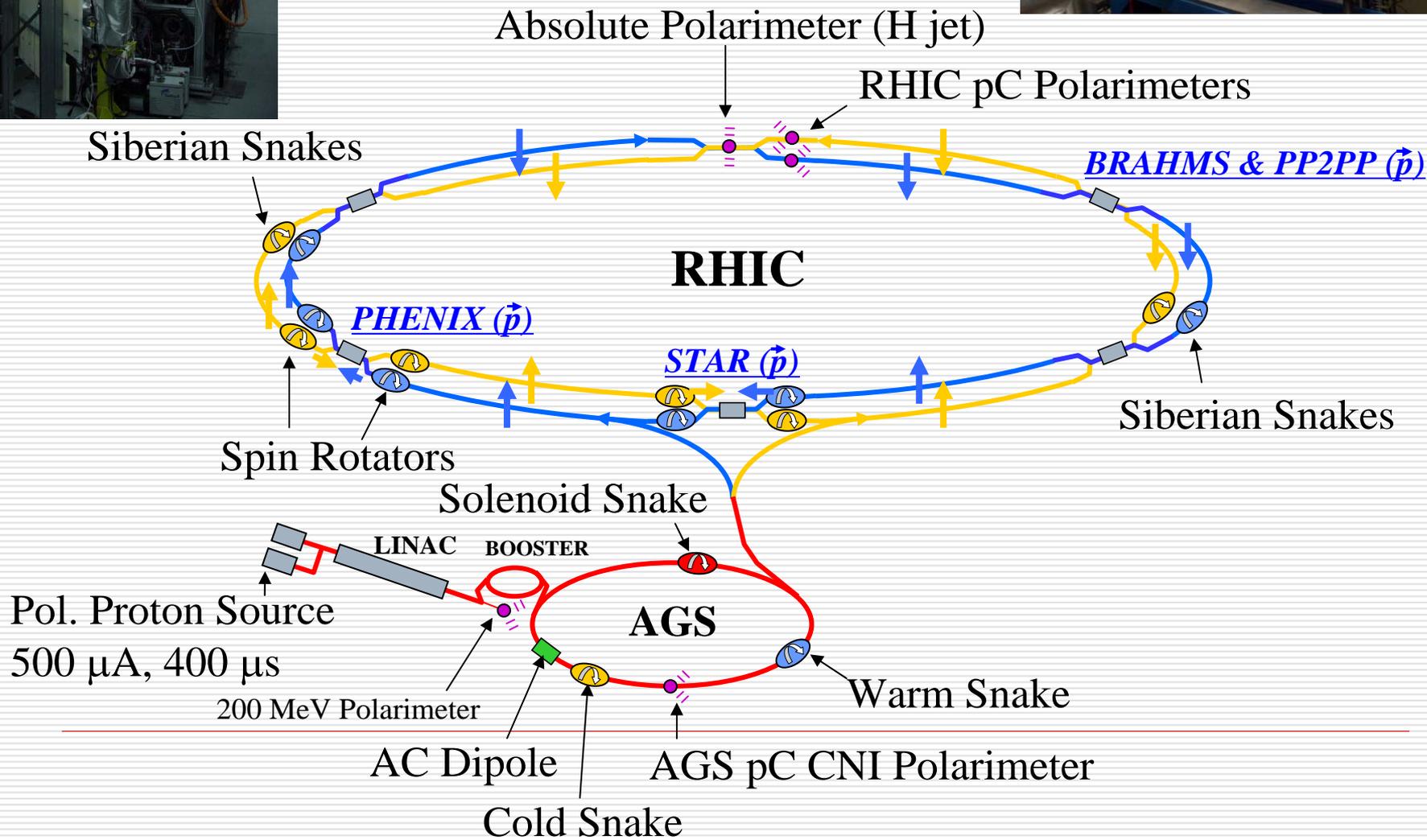
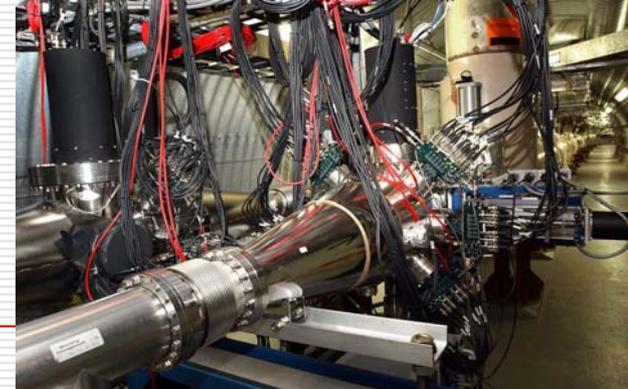


*unpublished*

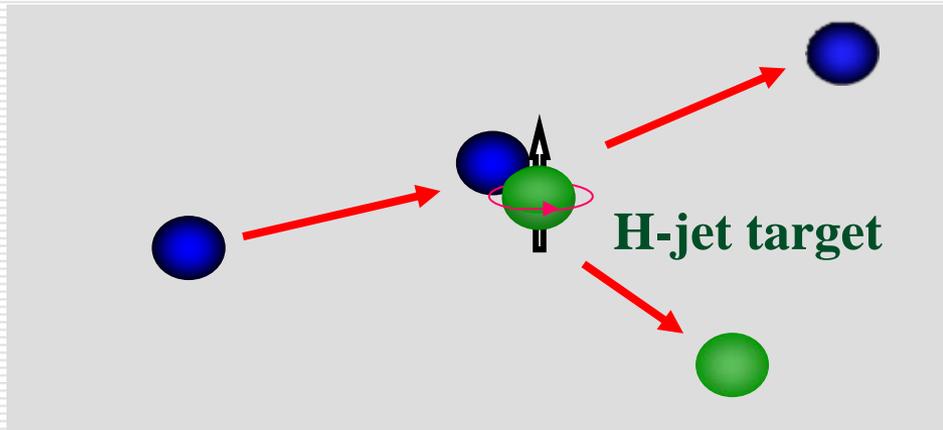
$E_{beam} = 100 \text{ GeV}$



# Polarimeters



# Gas Jet Elastic $\vec{p}\vec{p}$



$$P_{beam} = -\frac{\mathcal{E}_{beam}}{A_N^{beam}(t)} \quad \dots(1)$$

$$P_{target} = \frac{\mathcal{E}_{target}}{A_N^{target}(t)} \quad \dots(2)$$

↑ Breit-Rabi

Because they are both protons:

$$A_N^{\vec{p}\vec{p}} = A_N^{beam}(t) = A_N^{target}(t)$$

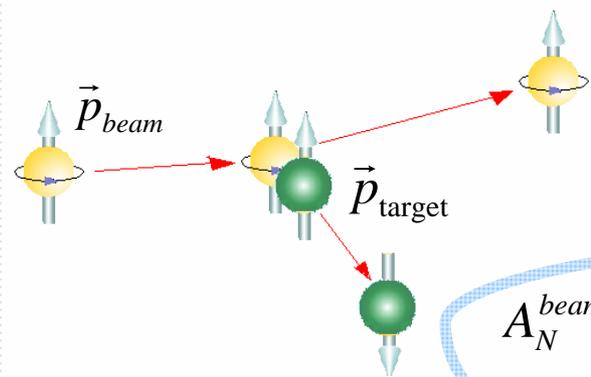


$$P_{beam} = -P_{target} \frac{\mathcal{E}_{beam}}{\mathcal{E}_{target}}$$

# $\vec{p}\vec{p}$ vs. $\vec{p}C$

Elastic pp

Elastic pC



$$A_N^{beam}(t) = A_N^{target}(t)$$

$$P_{beam} = -P_{target} \frac{\epsilon_{beam}}{\epsilon_{target}}$$

**Absolute**

$$A_N^{pC} = \frac{1}{P_{beam}} \epsilon_{pC}$$

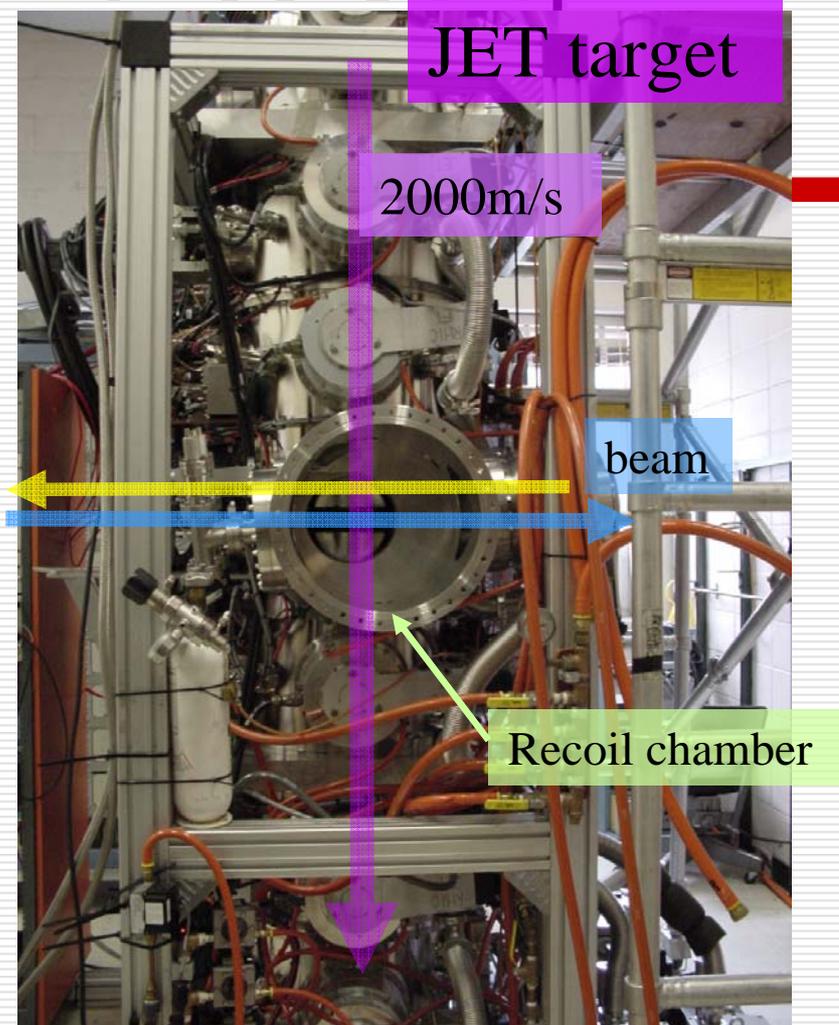
$$P_{beam} = -\frac{1}{A_N^{pC}} \epsilon_{pC}$$

**Relative**

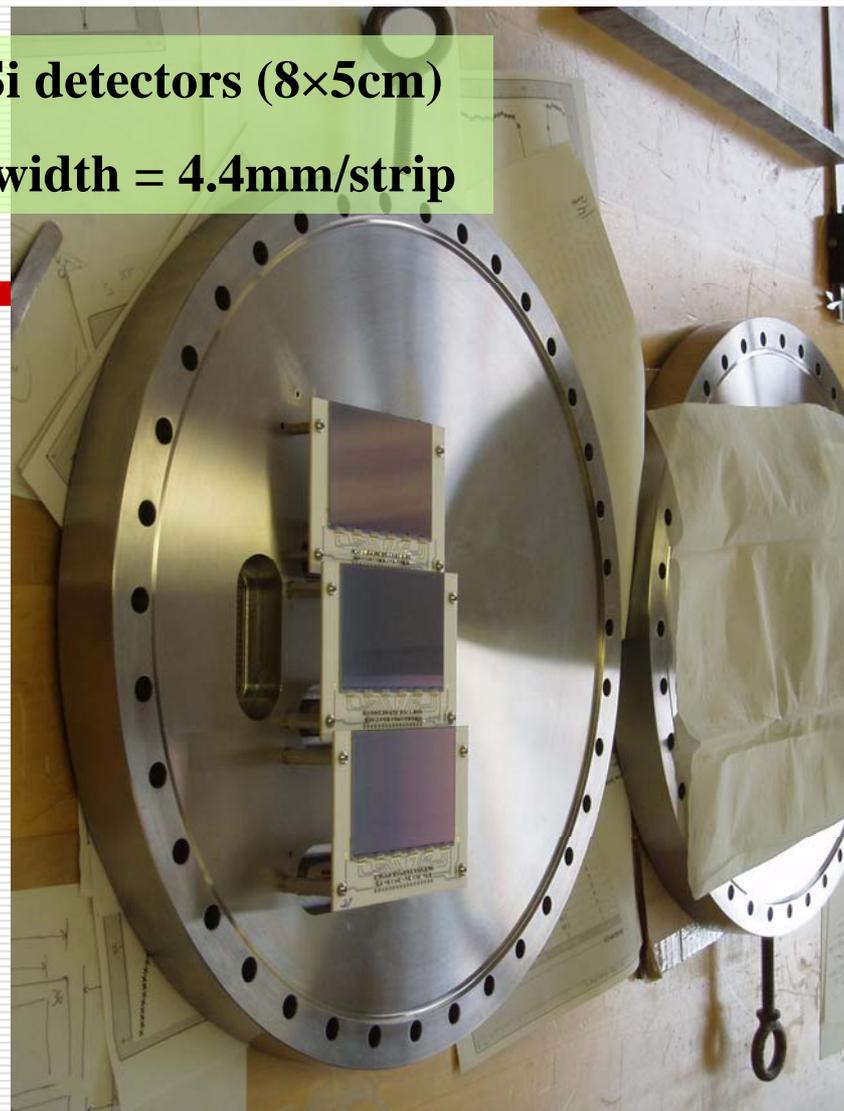
- ☺ Can measure polarization w/o knowing  $A_N$
- ☹ Statistically poor
- ~~2 days to accumulate 5% statistics~~

- ☹ Need to normalize  $A_N$  by  $\vec{p}\vec{p}$
- ☺ Statistically abundant
- 2% statistical precision can be achieved in 20 seconds

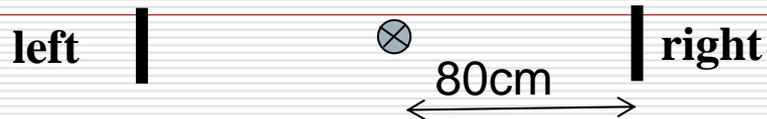
# Run05 Setup



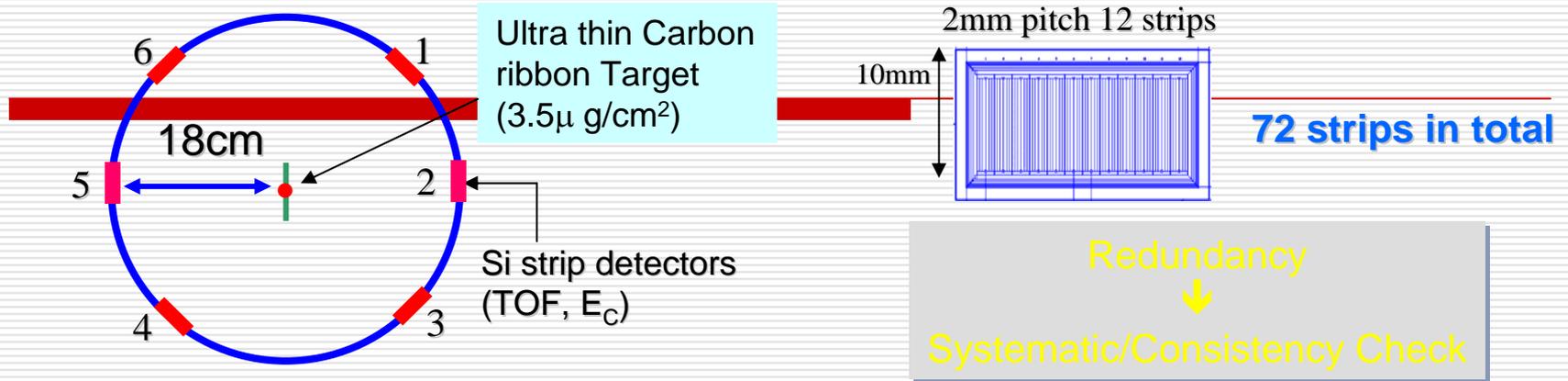
Si detectors (8×5cm)  
width = 4.4mm/strip



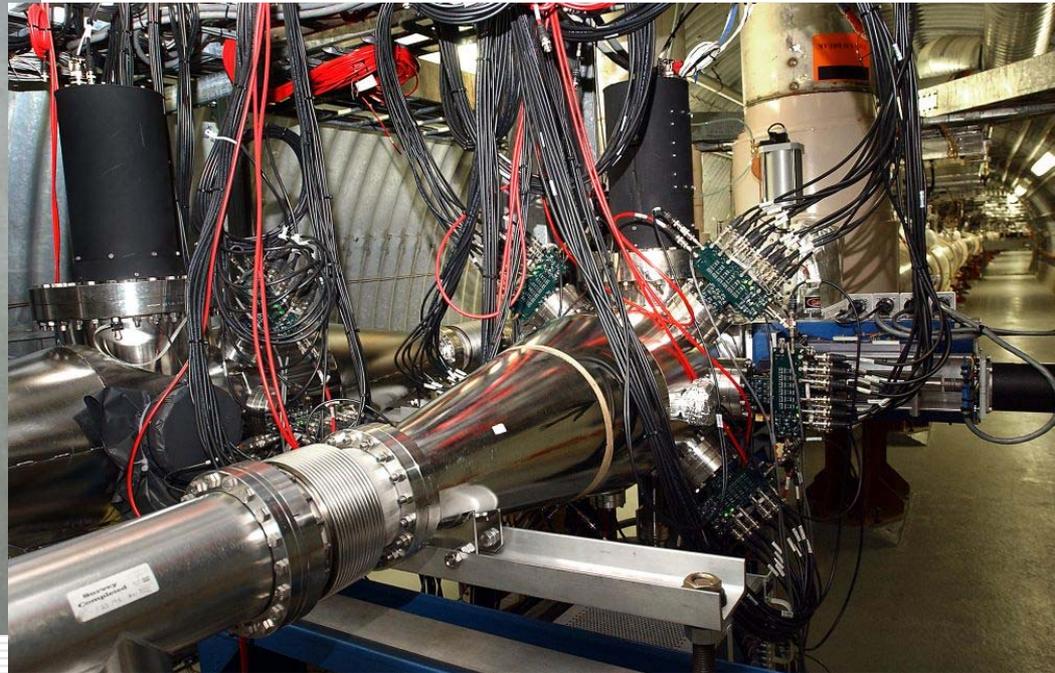
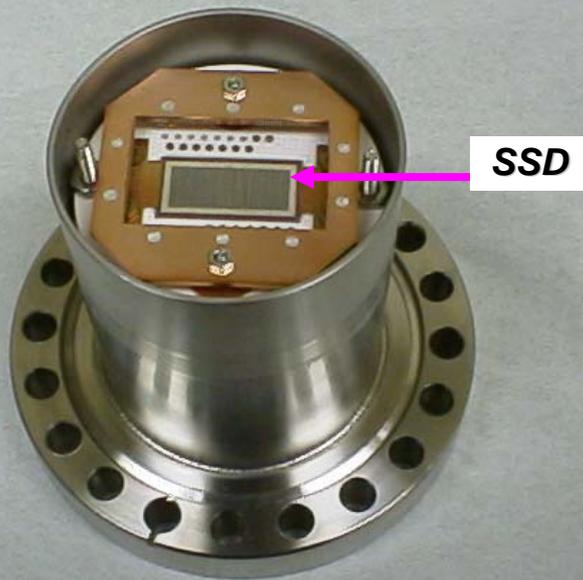
Left-right pairs



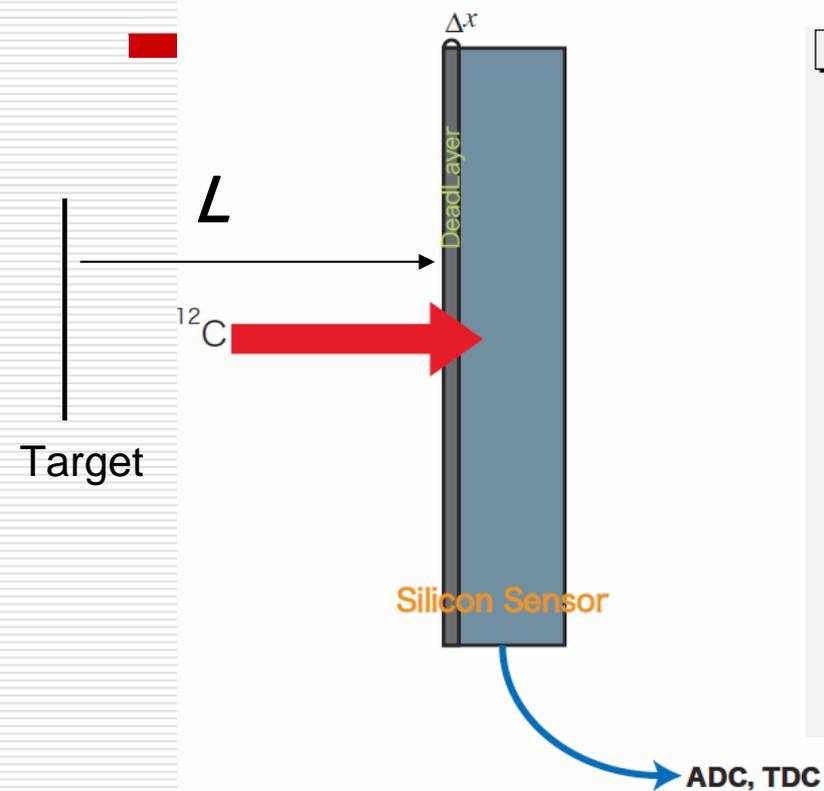
# pC Polarimeter Setup



Detector port (inner view)



# Energy Correction

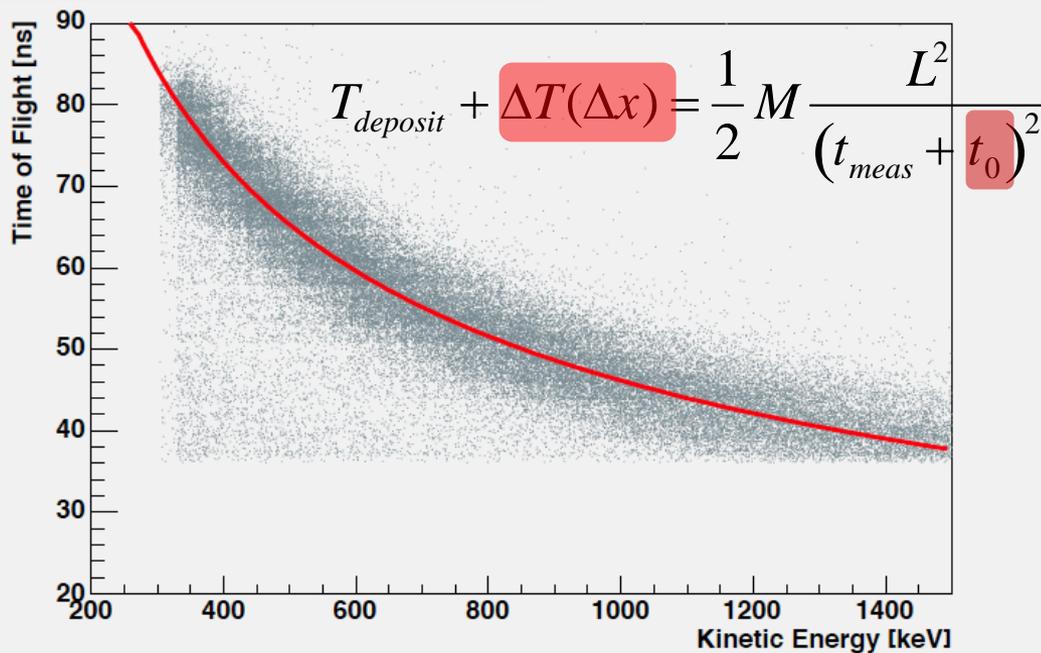


$$T = T_{deposit} + \Delta T(\Delta x)$$

(adc $\times$ C $_v$ ) (effective deadlayer)

~ 30%

7279.005 : t vs. Kin.Energy Str71

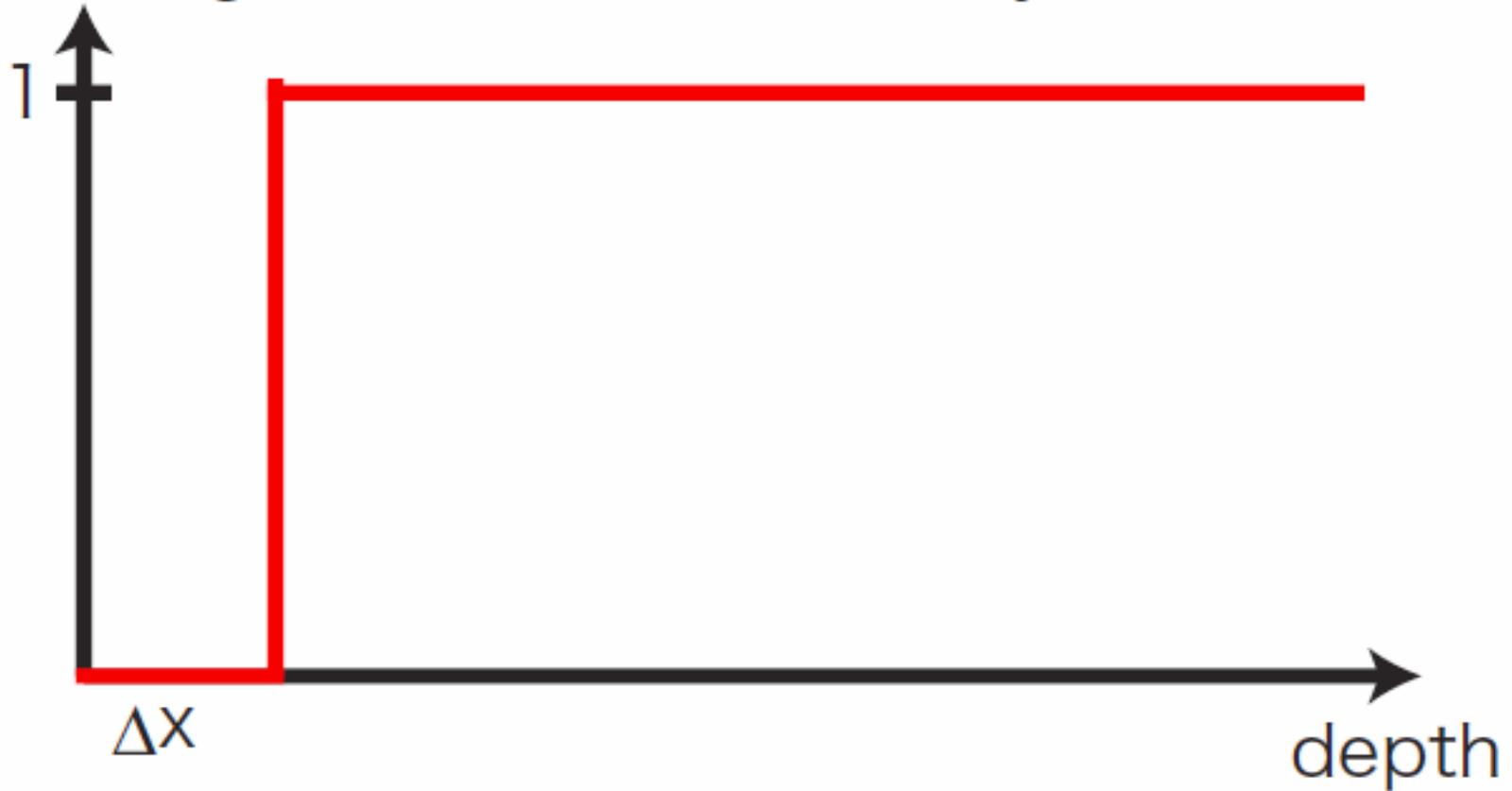


$(t_0, \Delta x) \rightarrow$  Kinematic Fit

# Effective DeadLayer

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Charge Collection Efficiency

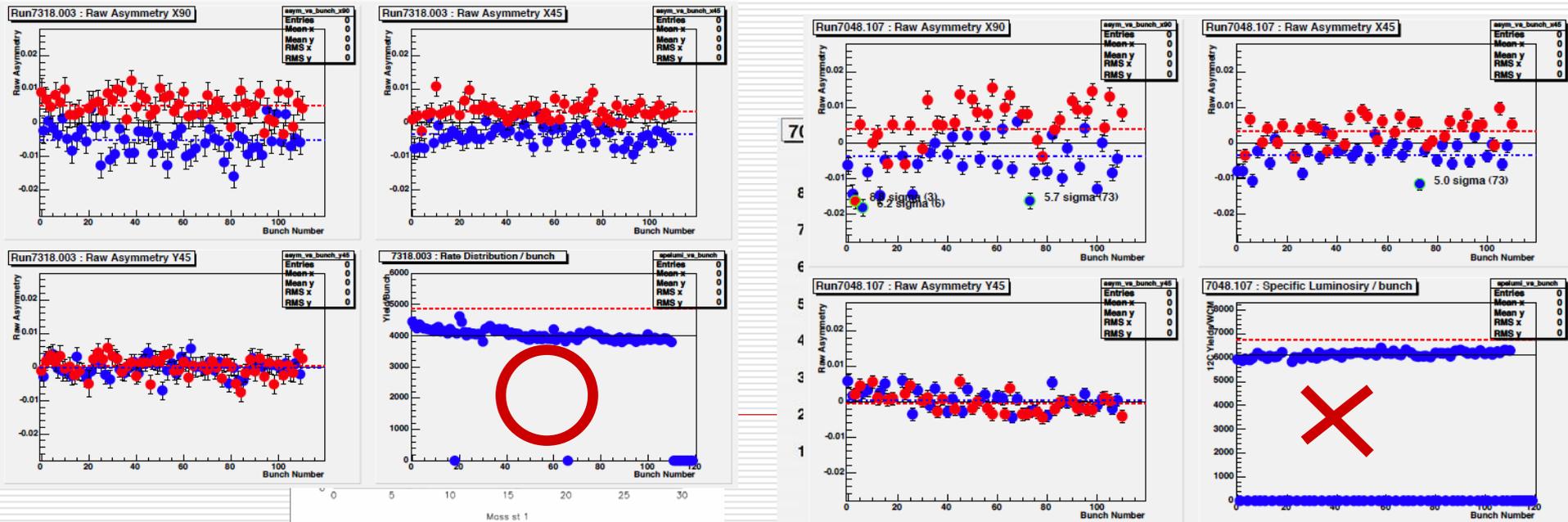


# QA

## Software Anomaly Checker

- Checked all strips (reasonable dead-layer, good invariant mass)
- Bunch by bunch asymmetry consistency

## Longitudinal target position

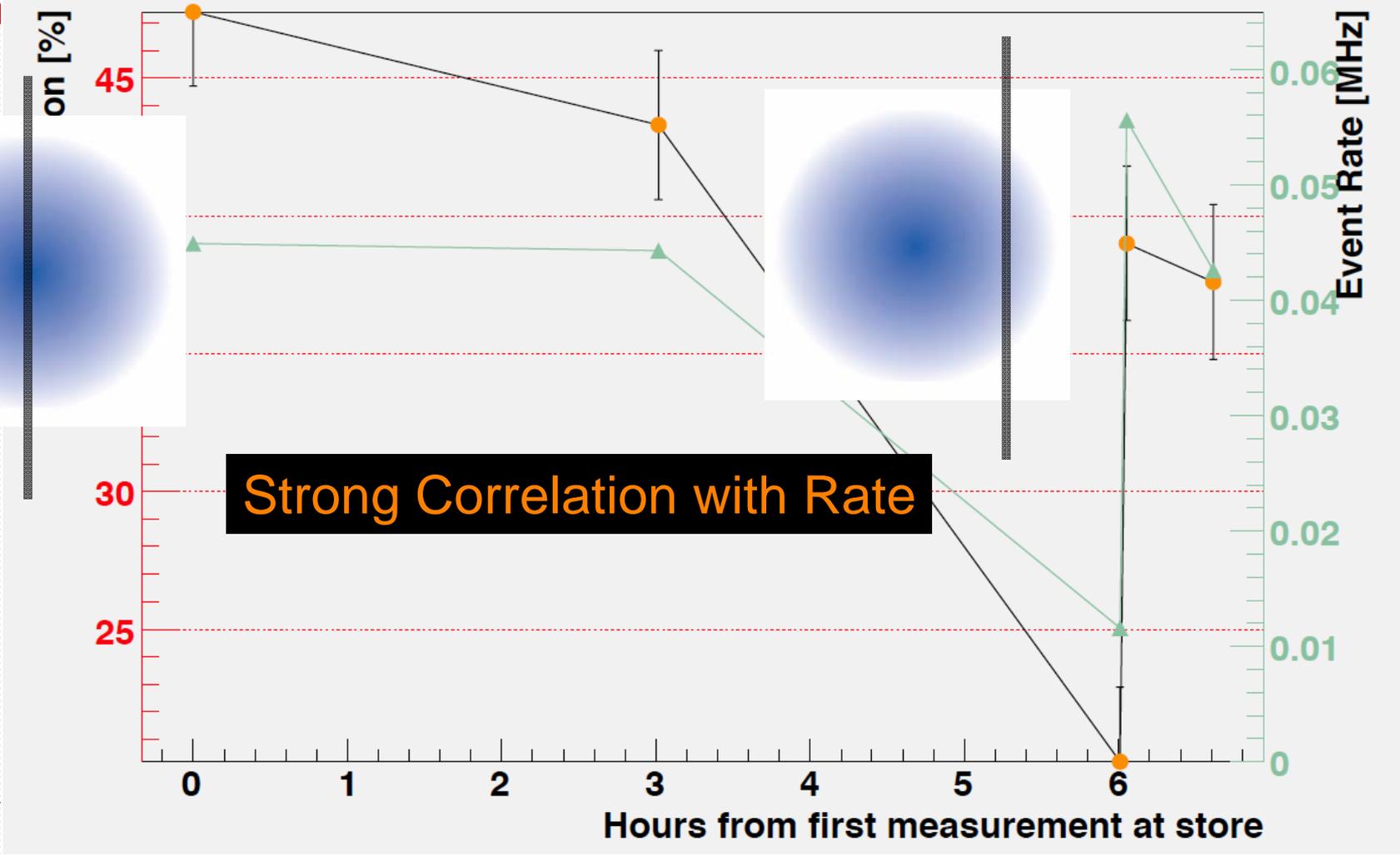


# Polarization Profiles

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# Consistency within Fill

Fill# 7237 (Yellow)

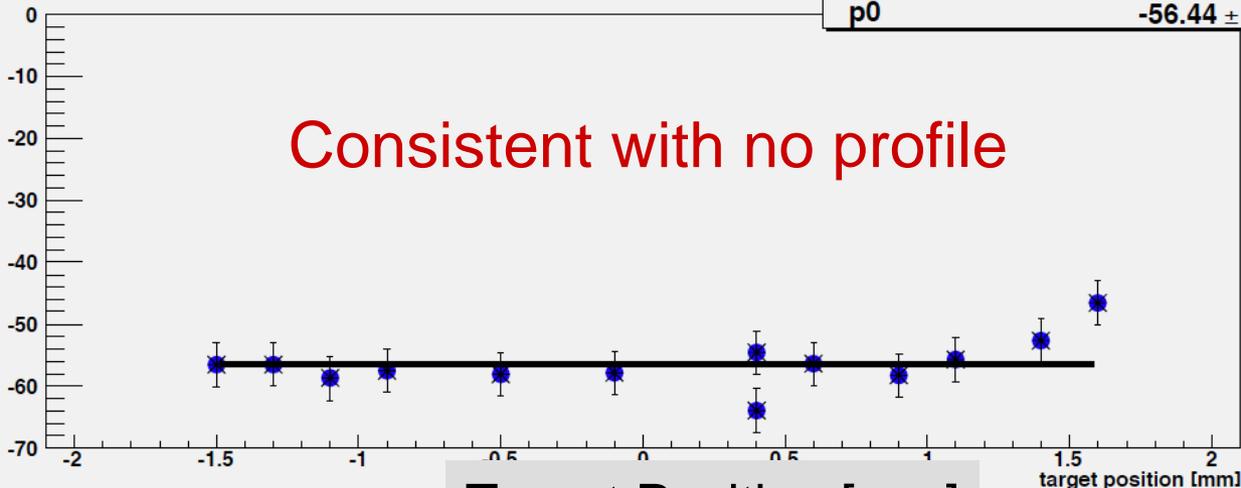


**Strong Correlation with Rate**

# Blue Polarization Profile

Blue - Fill7151

Polarization[%]



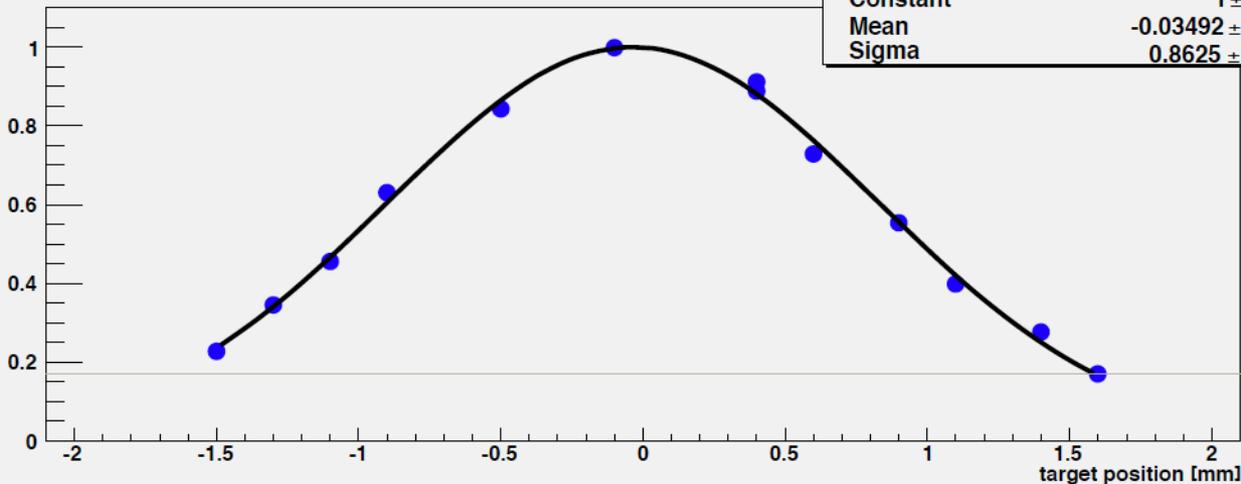
$\chi^2 / \text{ndf}$  14.47 / 12  
p0  $-56.44 \pm 0.9786$

28 / 10  
1.547  
0.2447  
0.7668

Target Position [mm]

Blue - Fill7151

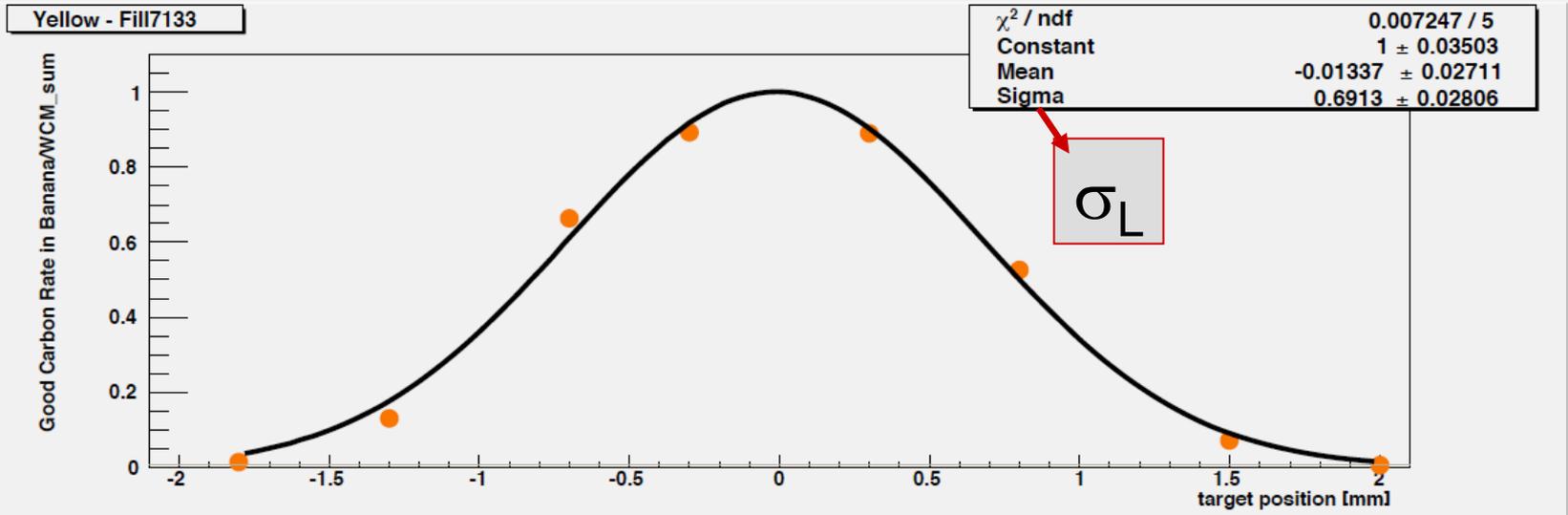
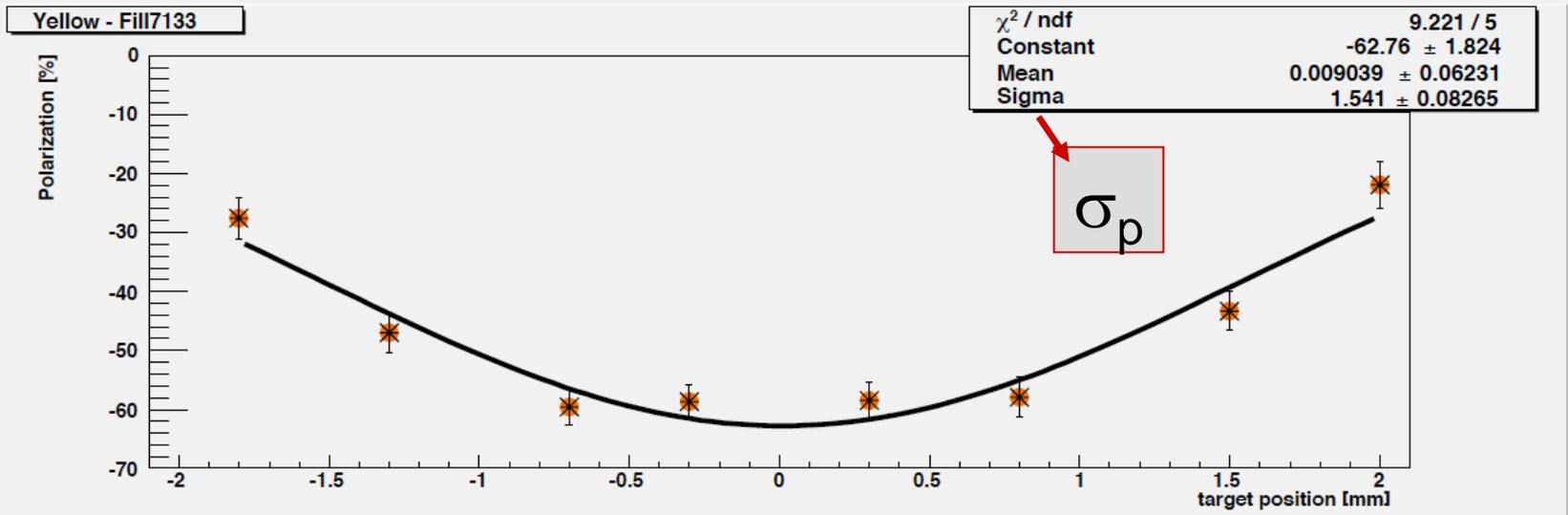
Rate



$\chi^2 / \text{ndf}$  0.004697 / 10  
Constant 1  $\pm 0.01341$   
Mean  $-0.03492 \pm 0.01154$   
Sigma  $0.8625 \pm 0.01298$

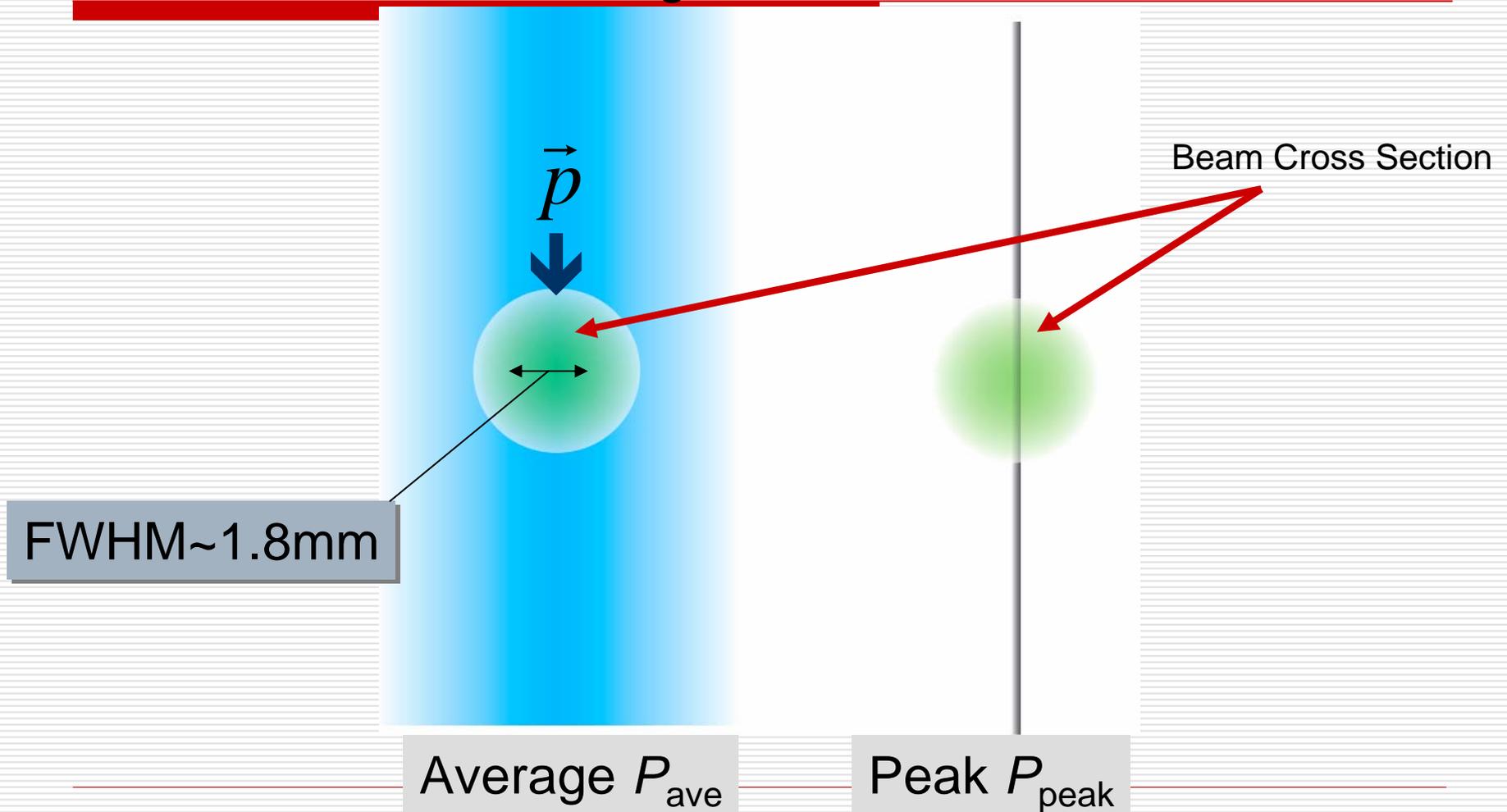
97 / 10  
0.01341  
0.01154  
0.01298

# Yellow Polarization Profile



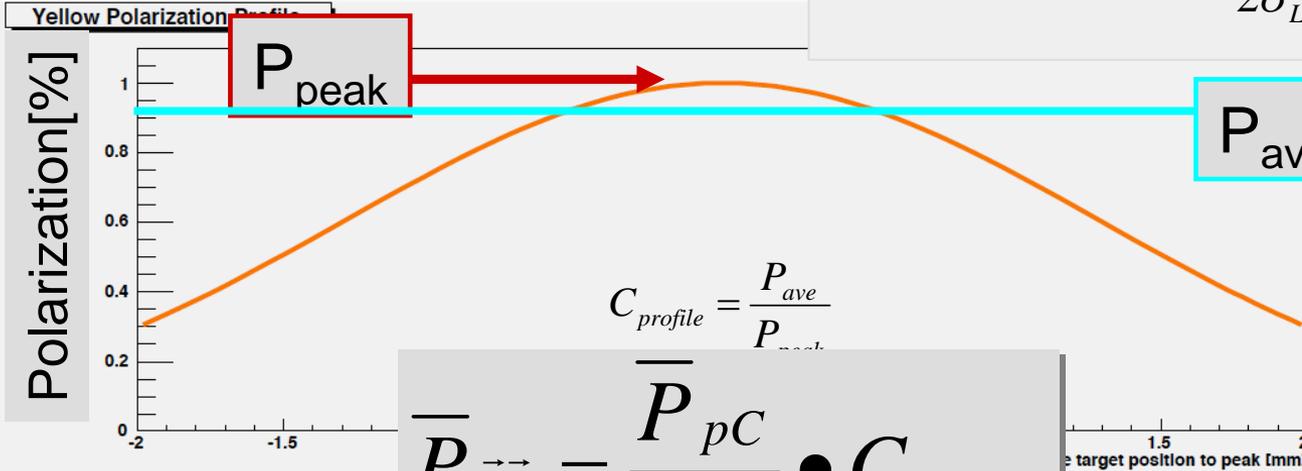
# Hydrogen Gas Jet and Carbon Wire Targets

Gas Jet Target      Carbon Wire Target



# Peak -> Average Polarization

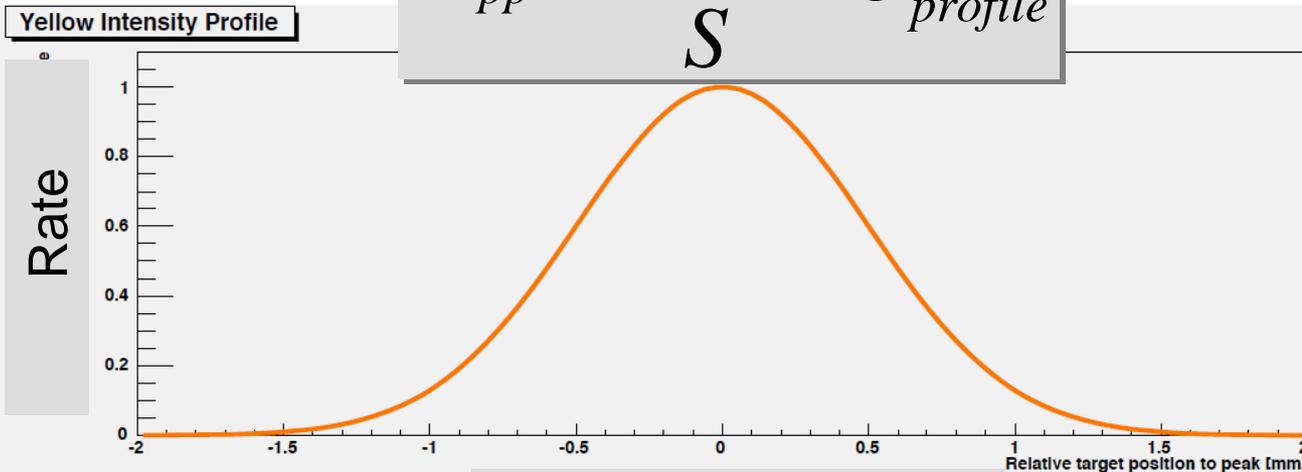
$$P_{ave} = \frac{P_{peak} \int \exp(-\frac{x^2}{2\sigma_P^2}) \exp(-\frac{x^2}{2\sigma_L^2}) dx}{\int \exp(-\frac{x^2}{2\sigma_L^2}) dx} = \frac{P_{peak}}{\sqrt{1 + \left(\frac{\sigma_L}{\sigma_P}\right)^2}}$$



$$C_{profile} = \frac{P_{ave}}{P_{peak}}$$

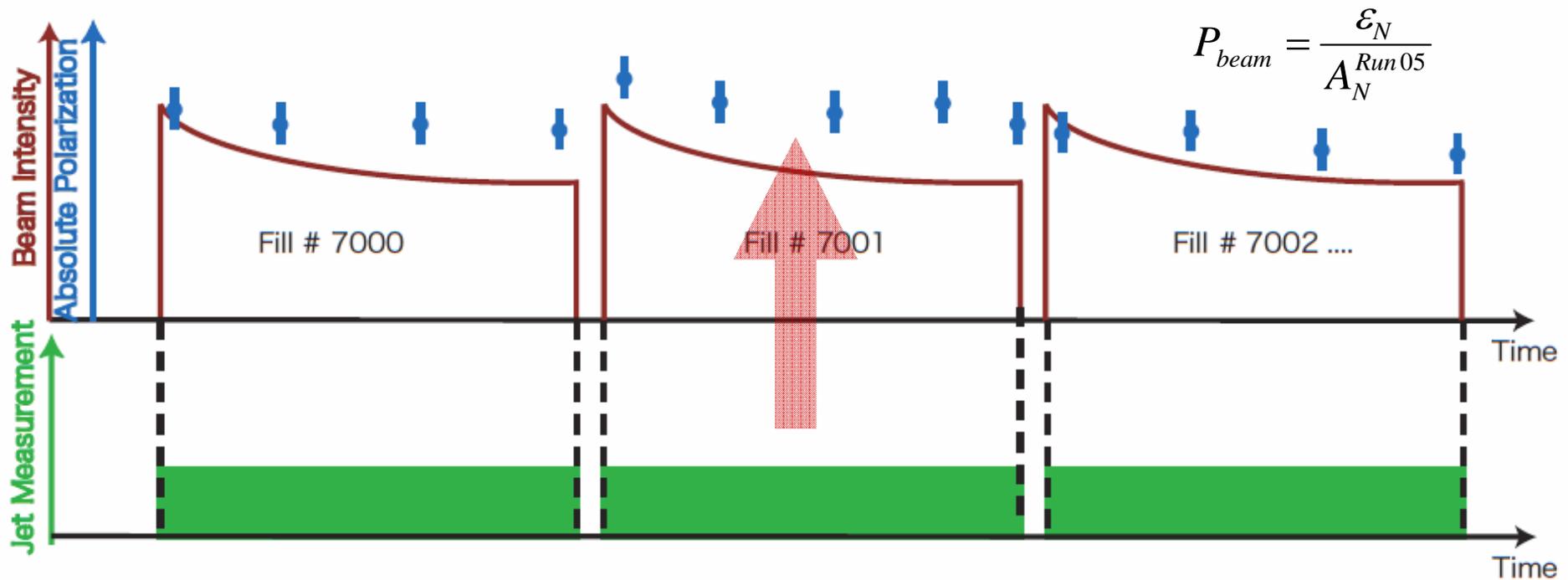
$$\bar{P}_{\vec{p}\vec{p}} = \frac{\bar{P}_{pC}}{S} \bullet C_{profile}$$

$$\frac{\sigma_L}{\sigma_P} = 0.38$$

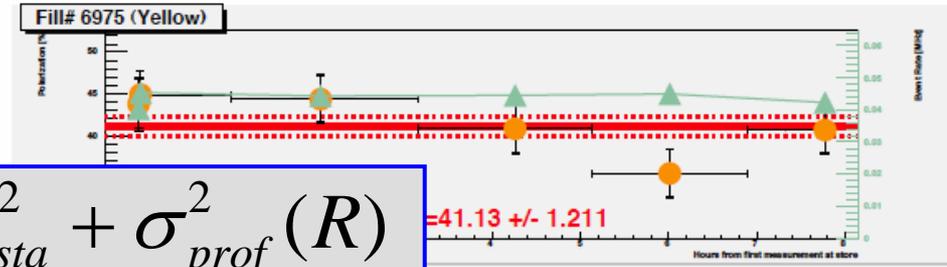
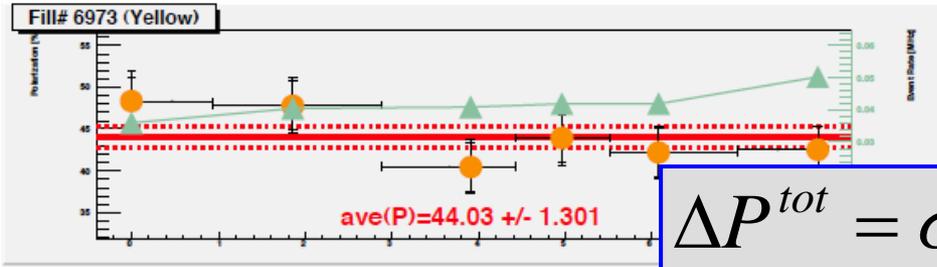


Target Position [mm]

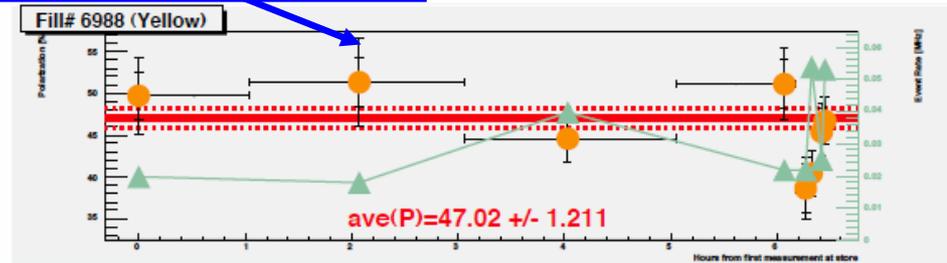
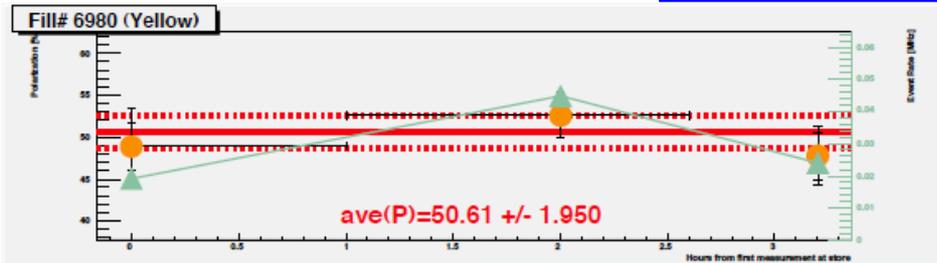
# Normalization with $\vec{p}\vec{p}$ jet



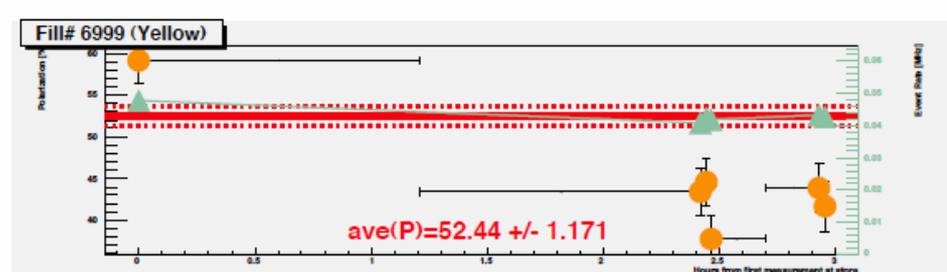
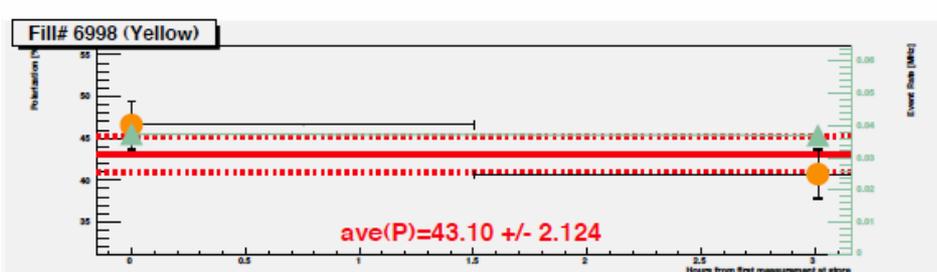
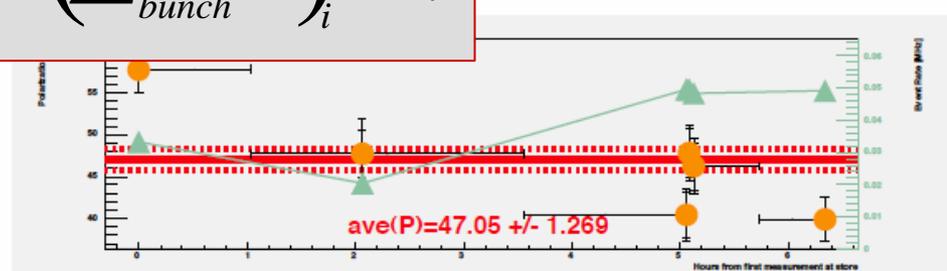
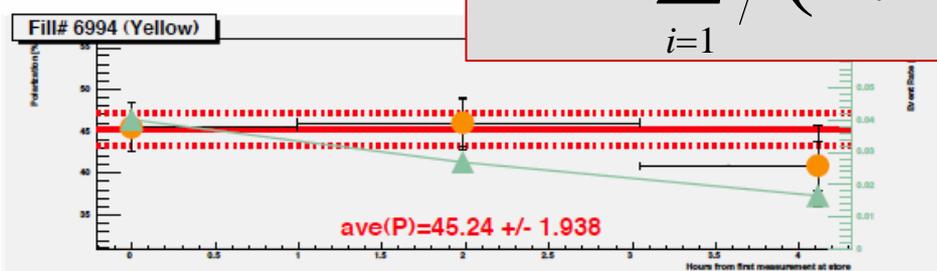
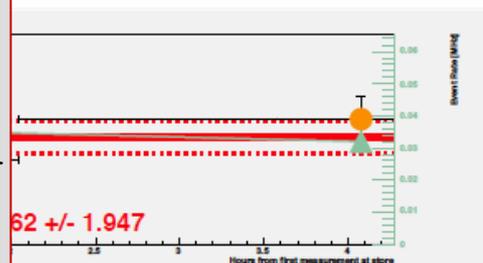
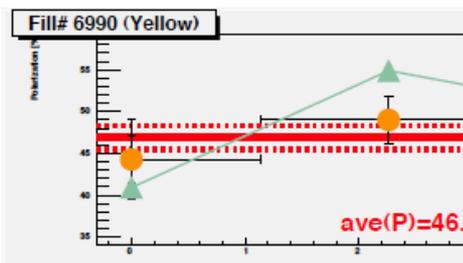
$$S = \frac{\overline{P}_{beam}^{pC}}{\overline{P}_{beam}^{\vec{p}\vec{p}}} = \frac{A_N^{Run5}(t)}{A_N^{Run4}(t)}$$



$$\Delta P^{tot} = \sigma_{sta}^2 + \sigma_{prof}^2 (R)$$



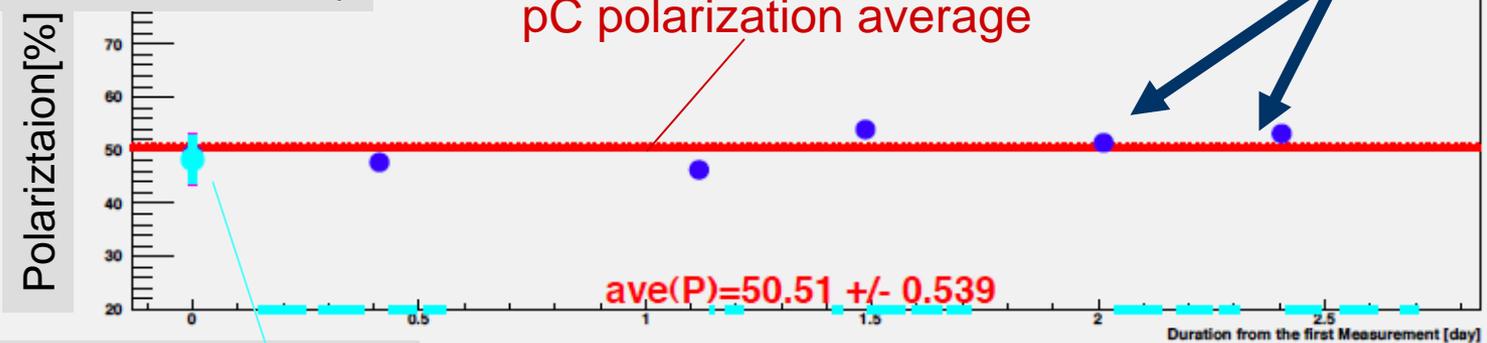
$$P_{fill} = \frac{\sum_{i=1}^n P_i / (\Delta P_i^{tot})^2 \cdot \left( \sum_{bunch} WCM \right)_i \cdot dt_i}{\sum_{i=1}^n 1 / (\Delta P_i^{tot})^2 \cdot \left( \sum_{bunch} WCM \right)_i \cdot dt_i}$$



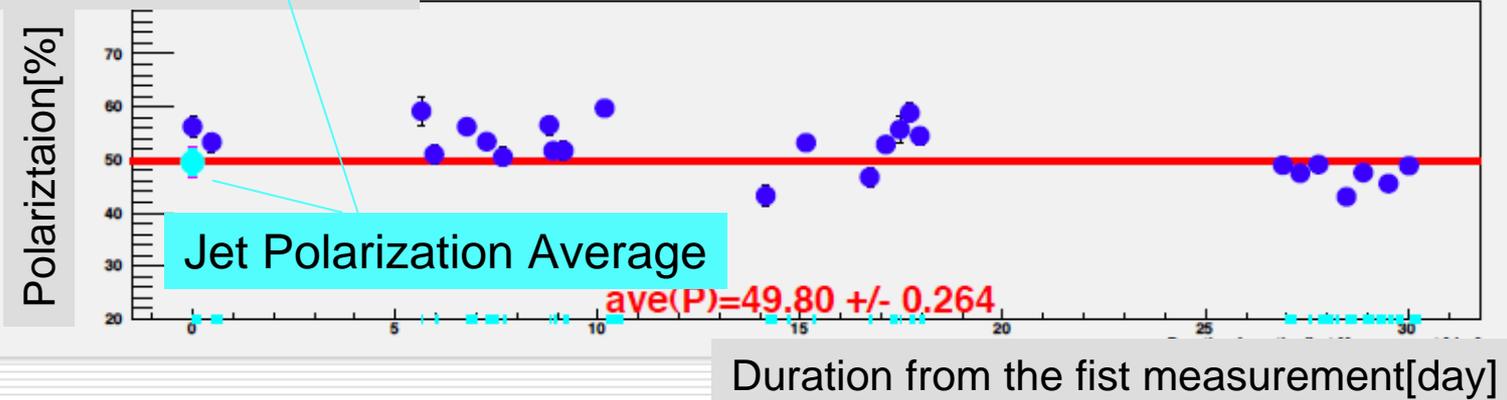
# Comparison between pC vs. Jet (Blue)

$$\overline{P}_{pC}^{fill}$$

(60 Bunch Mode)

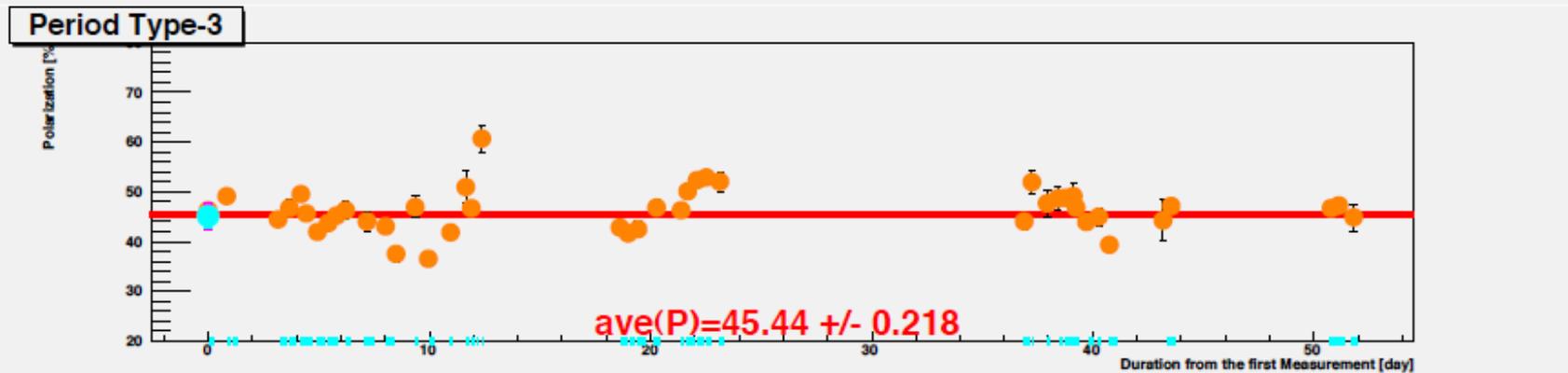
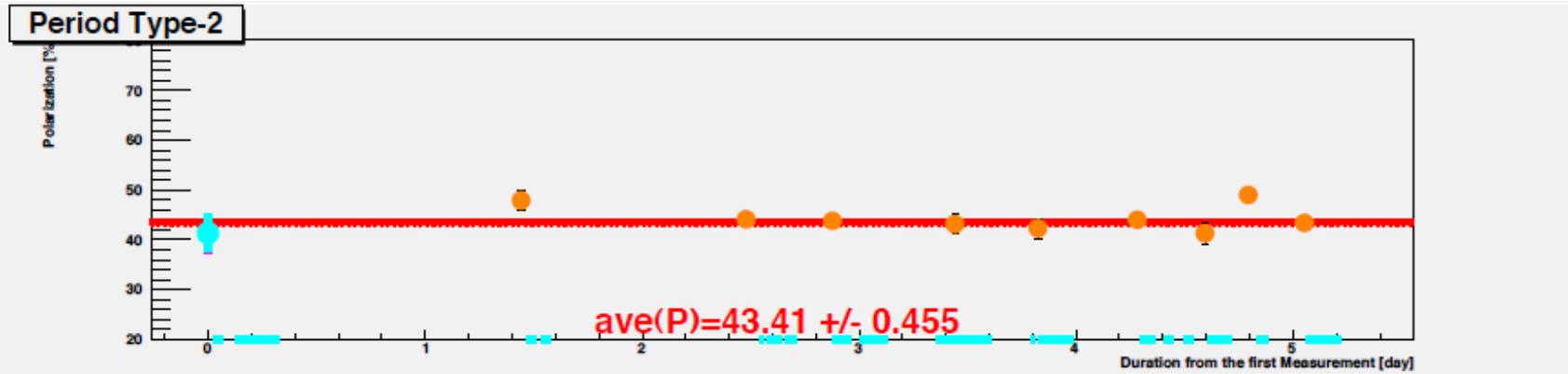


(120 Bunch Mode)



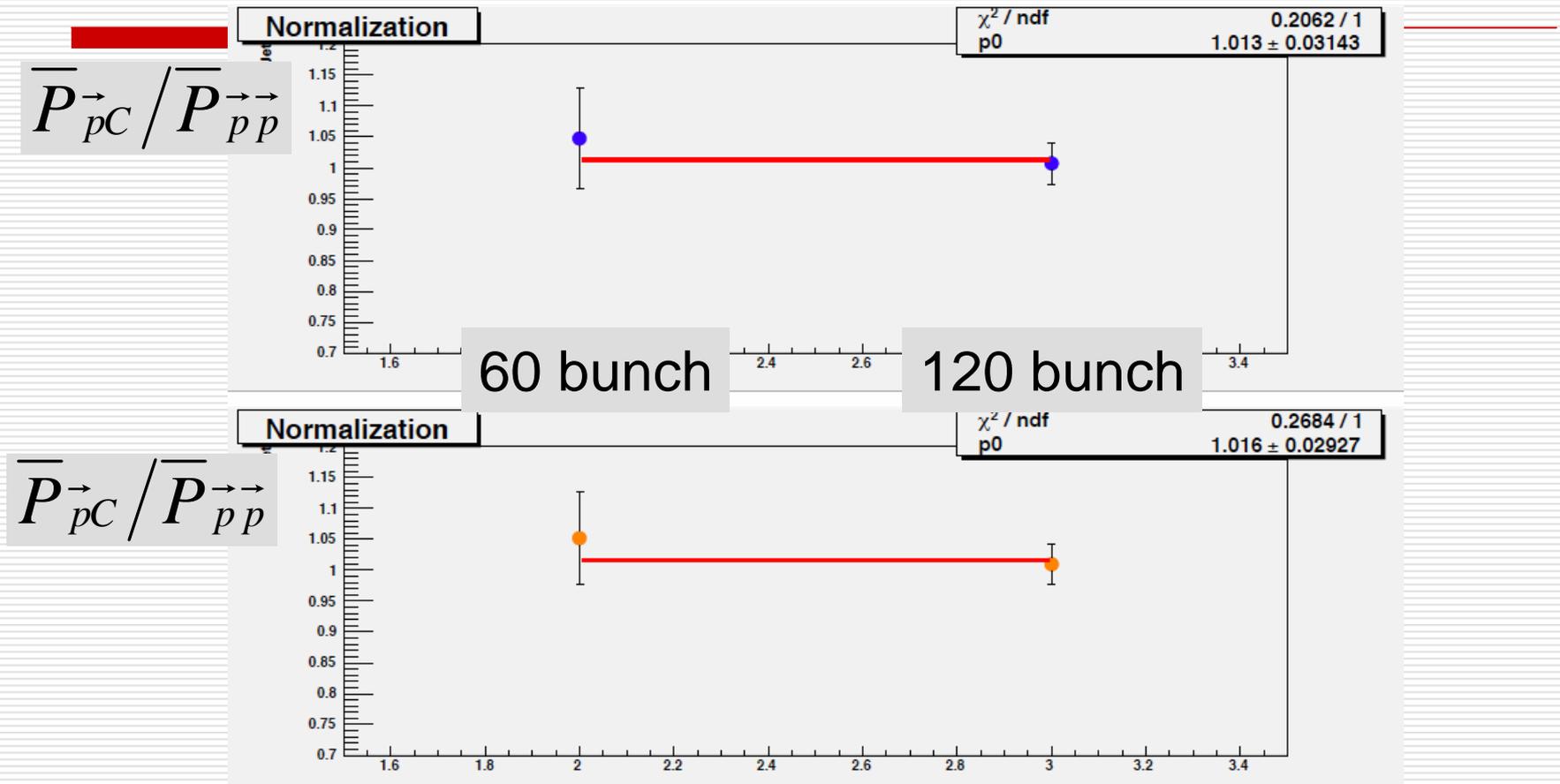
- Compared Average polarizations measured by pC and Jet.
- They are consistent within 1%.

# pC vs. Jet (Yellow)



pC Average polarization are scaled by 0.93. It accounts for profile correction to covert from peak to average polarization. As a consequence, pC and jet polarizations agree within 1%.

# Jet Normalization



Normalization factors are estimated by averaging over two periods. Blue and yellow obtained normalizations of 1~2%.

# Jet Normalization Summary

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$$A_N^{Run05} = A_N^{Run04} \cdot \left( S \pm \Delta\sigma_{sta} \pm \sigma_{sys}^{jet} \pm \Delta_{prof} \right)$$

□ Blue

$$A_N^{Run05} = A_N^{Run04} \cdot \left( 1.01 \pm 0.03 \pm 0.02 + 0.04 \right)$$

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$$\Delta A_N = 5.9\%$$

□ Yellow

$$A_N^{Run05} = A_N^{Run04} \cdot \left( 1.02 \pm 0.03 \pm 0.02 \pm 0.05 \right)$$

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$$\Delta A_N = 6.2\%$$

$S \sim 1 \rightarrow$  Consistent with Run04

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$S \sim S \rightarrow$  Consistent Blue & Yellow Polarimeters

# Systematic Error Summary

	$\Delta P_{fill}/P_{fill}$	
	Blue	Yellow
Global $\Delta A_N^{gl}$	5.9	6.2
$\Delta P_{fill}^{sta}$	$\Delta P_{fill}^{sta}$	$\Delta P_{fill}^{sta}$
Energy Correction $\sigma_{dl}$	1.5	1.7
$\Delta C_{prof}$	4.3	5.7
$\sigma_{prof}(R)$	0.0	$\sigma_{prof}(R)$

$$\Delta P_{fill}^{tot} / P_{fill} = \Delta A_N \pm \Delta P_{sta} \pm \sigma_{dl} \pm \Delta C_{prof} \pm \sigma_{prof}(R)$$

~6%

Subject to be vanished with combining fills.

# Run04 & Run05 Systematic Errors

	Run04 (Yellow)	Run05(Yellow)
Total	16.6 %	6.2%

- Jet Normalization 8.5% → 3.6%
- Dead-Layer 9.8% → negligible
  - Ran Jet for both Blue and Yellow Beam
  - Various Modifications in ADC vs. ToF fitting
- Online/Offline 9.3% → 0%
  - Full event mode analysis
- Polarization Profile 0 % → 5%
  - Strong Profile in Run05

# Conclusion

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- ❑ Beam polarizations for Run05 at RHIC are precisely measured.
  - ❑ Achieved 6% precision of the polarization measurement (factor 2 ~ 3 smaller than Run04).
  - ❑ Uncertainties are dominated by the polarization profile error for Run05.
-

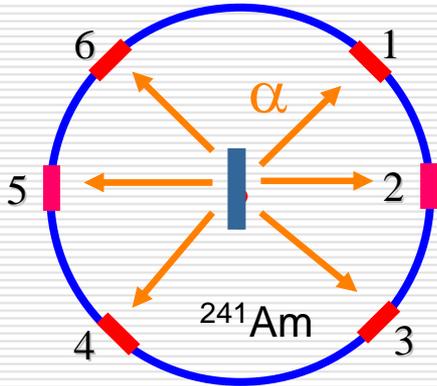
# Backup Slides

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# Systematic Uncertainties for Fill Average Polarization

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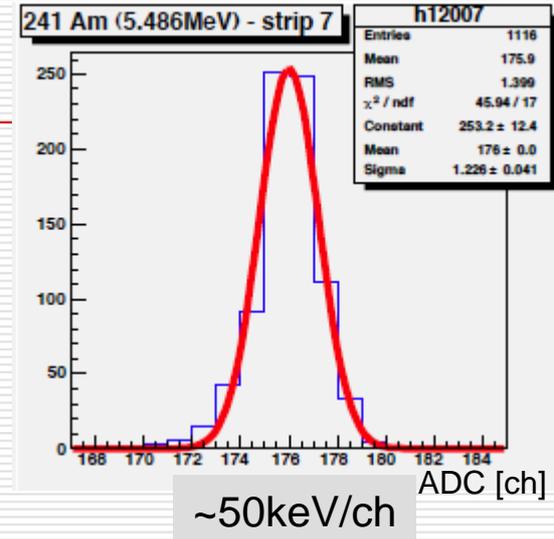
# Energy Calibration



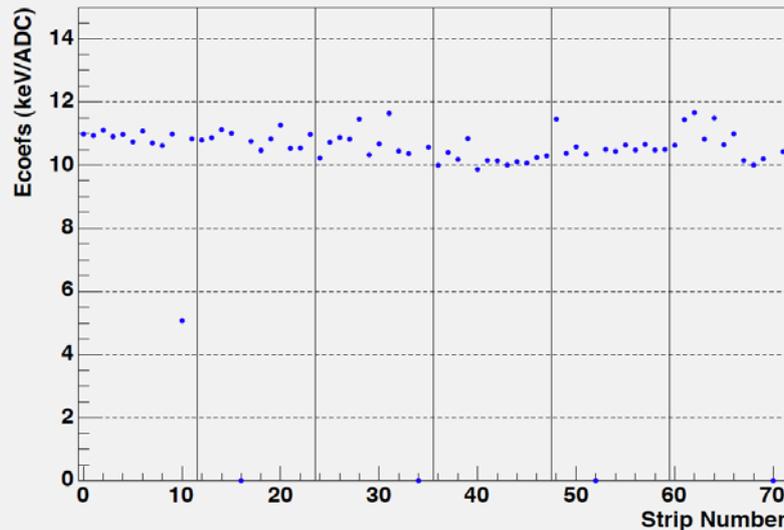
5.486 MeV (85%)  
5.443 MeV (12%)

$$E_{\alpha}$$

Fitting Error < 0.01%

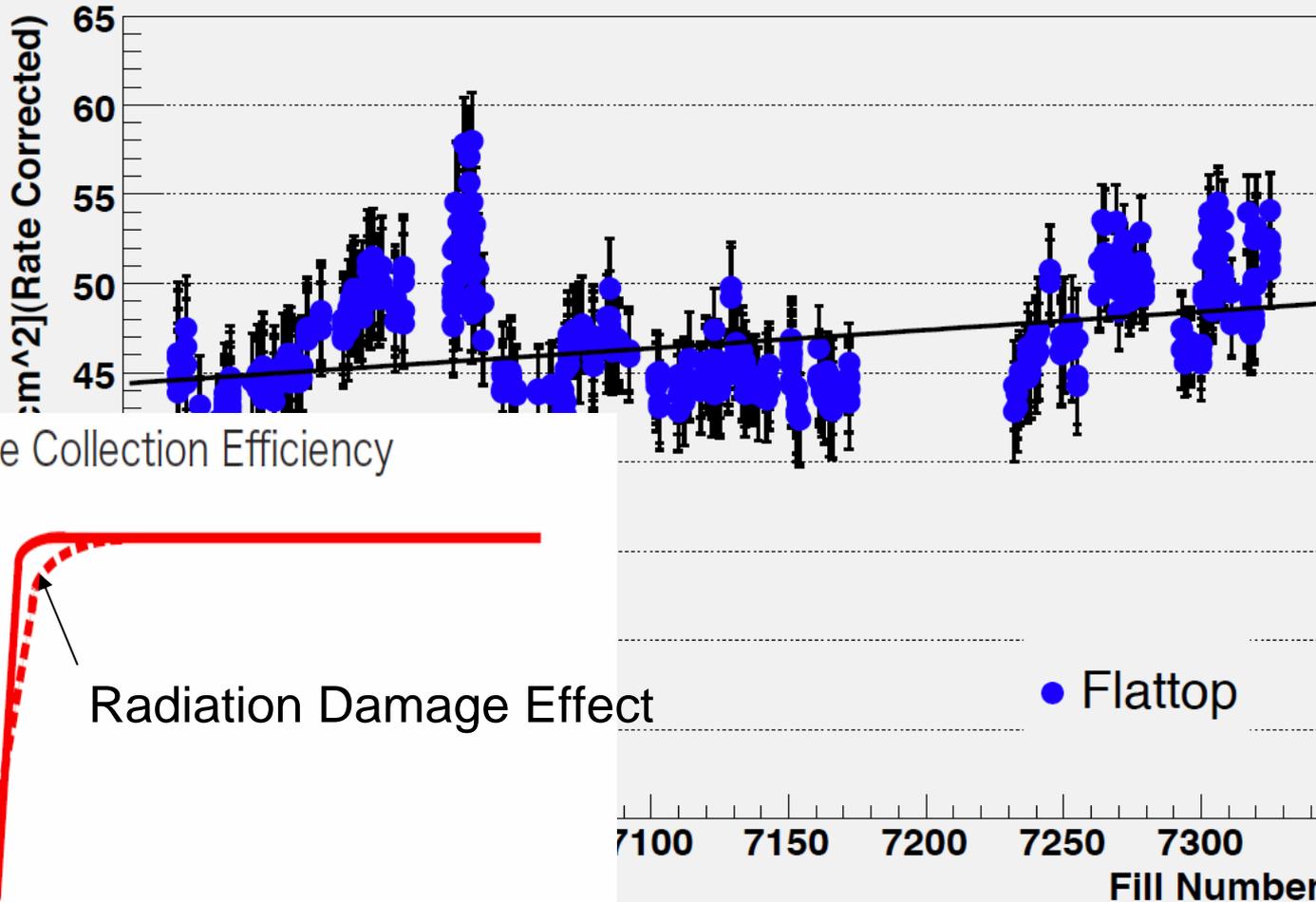


(0213.003) Am calibration Result

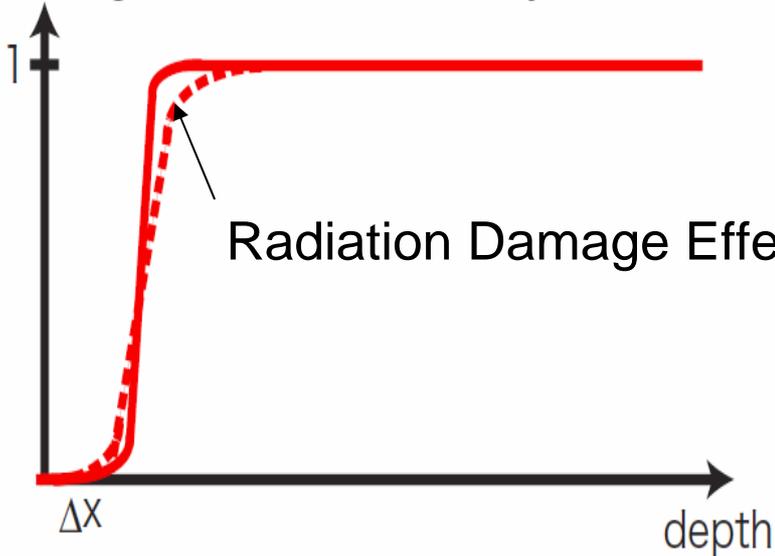


# Energy Correction History (blue)

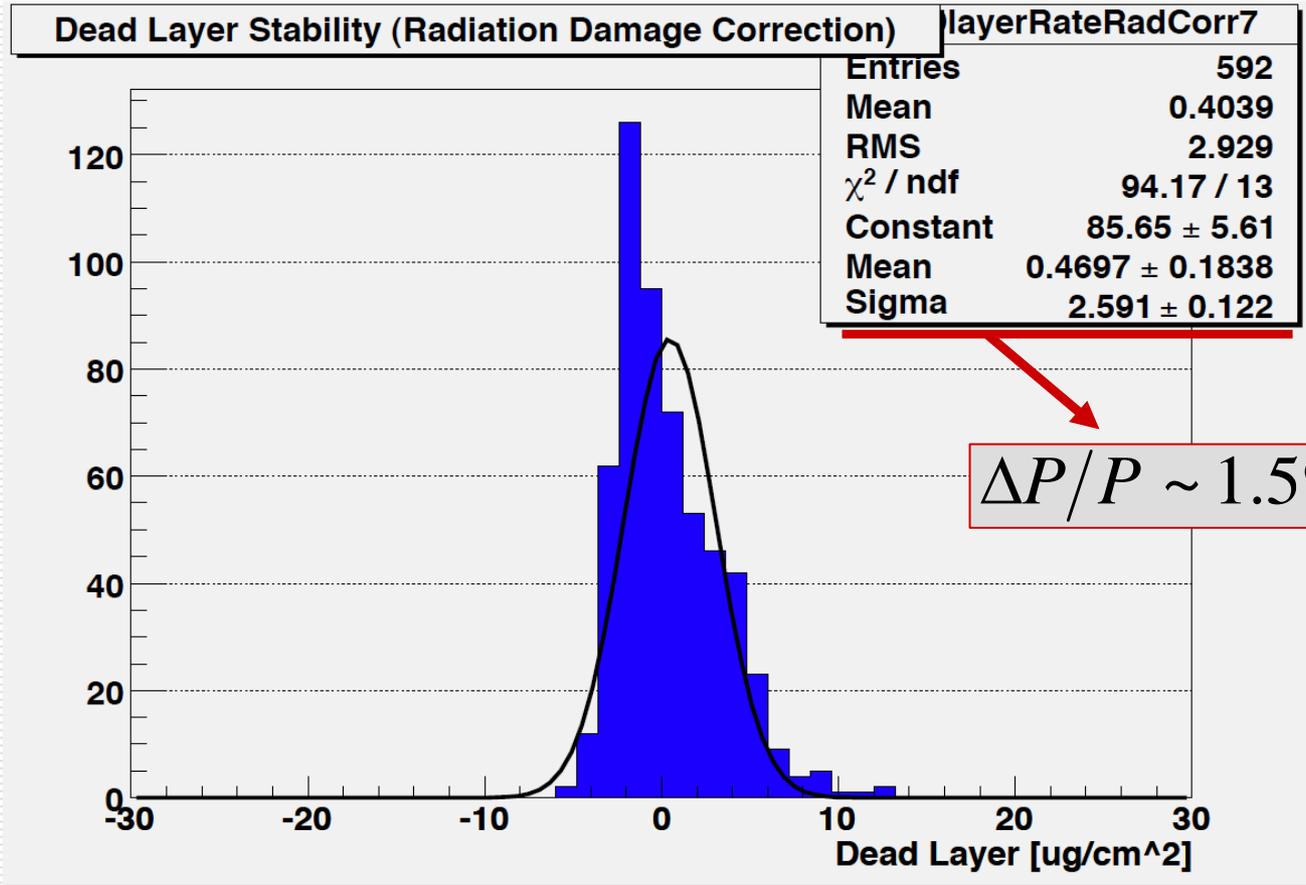
DeadLayer History (Blue)



Charge Collection Efficiency



# Energy Correction Projection (Blue)

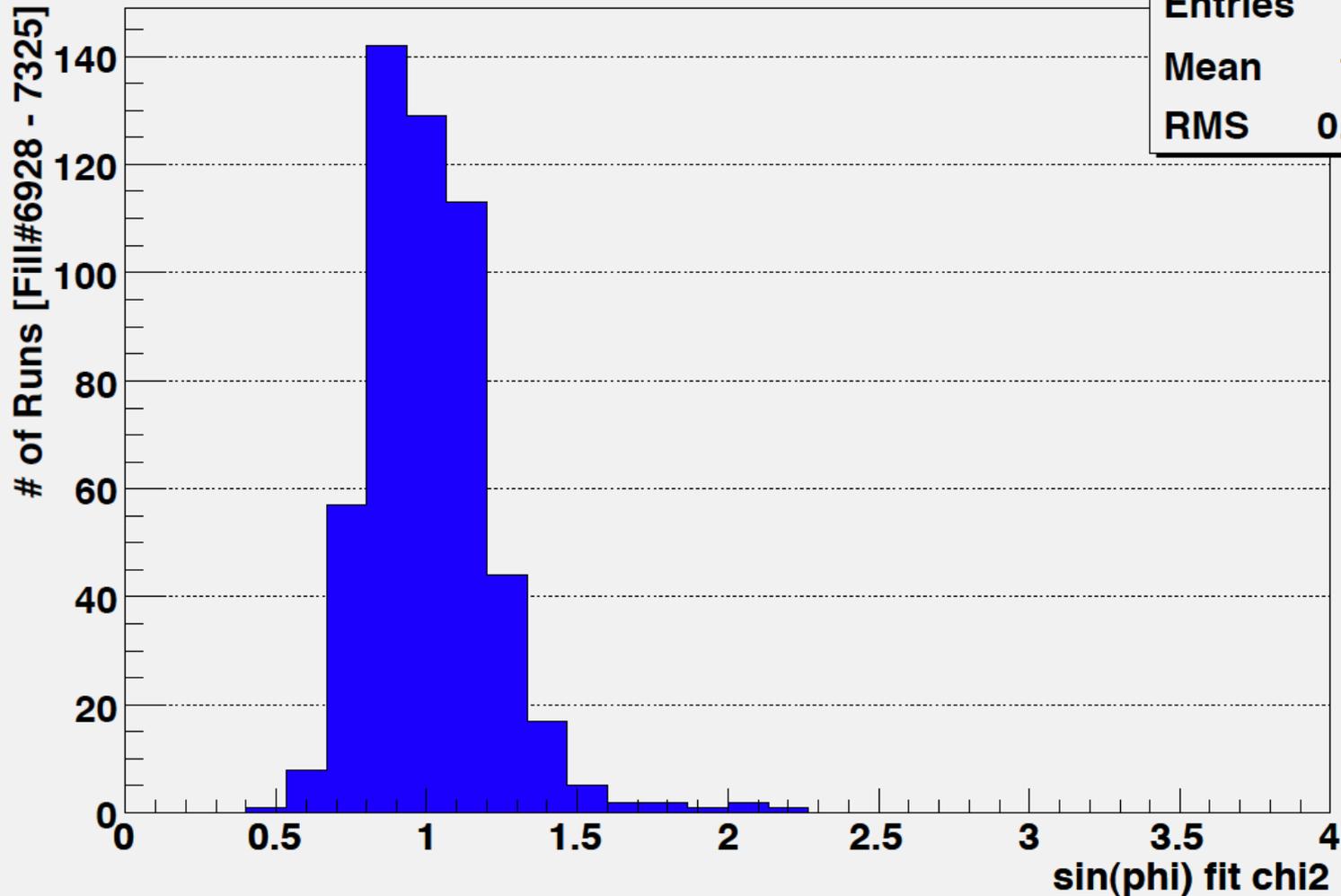


# Sin(phi) fit chi2 (blue)

chi2 distribution of P\*sin(phi) fit

**sfitchi2**

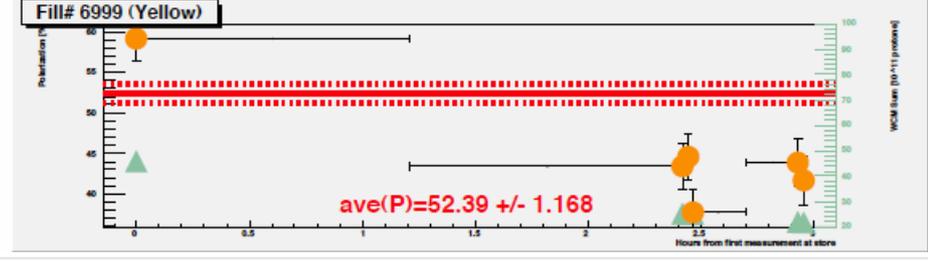
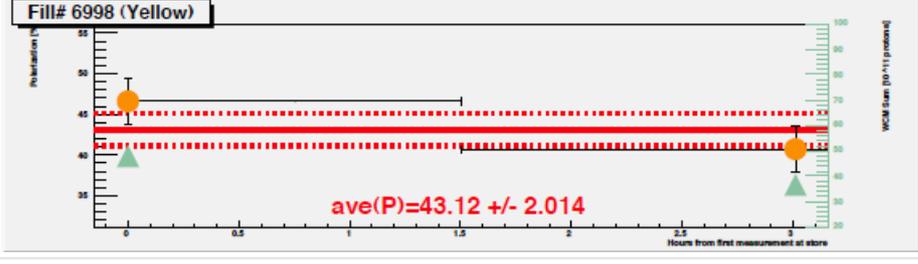
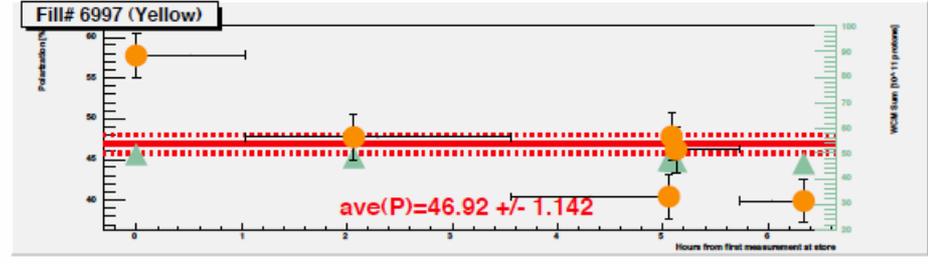
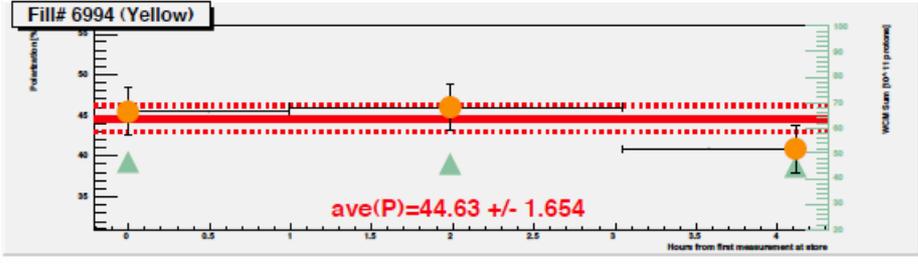
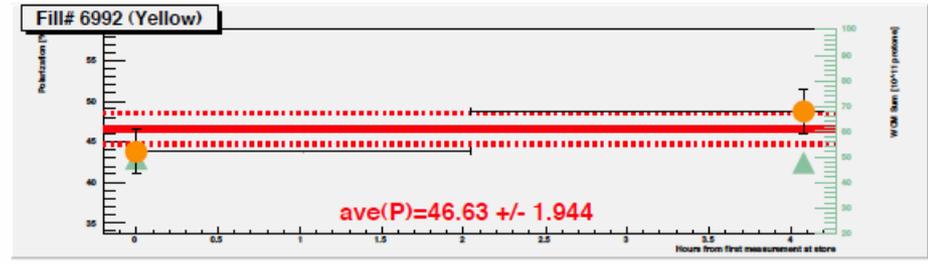
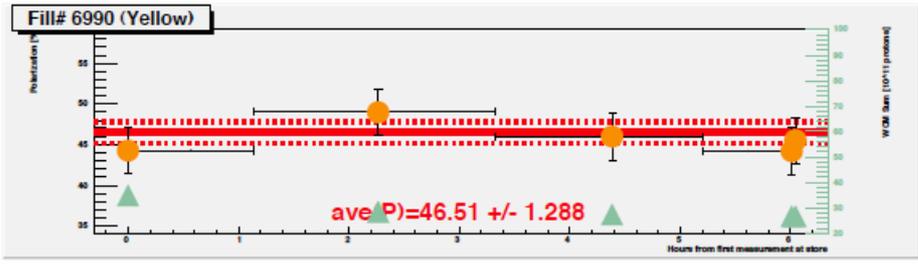
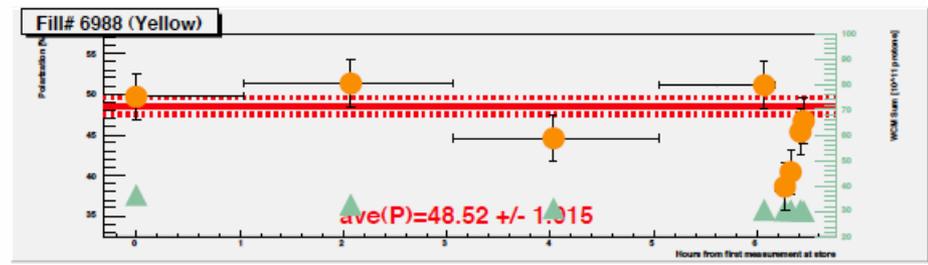
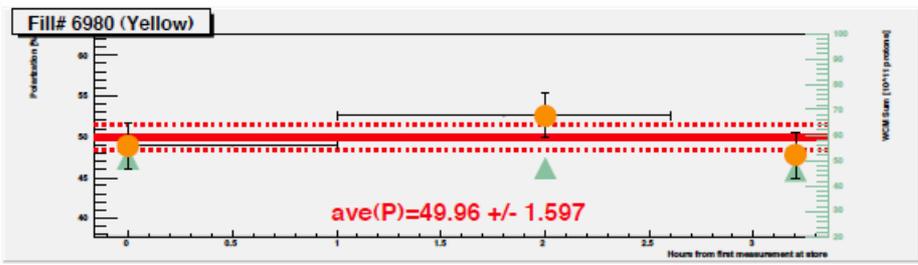
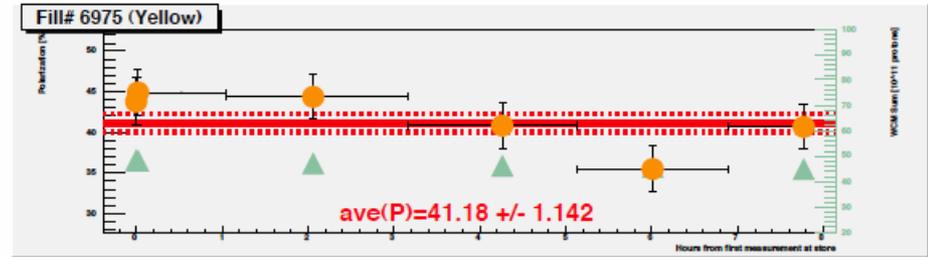
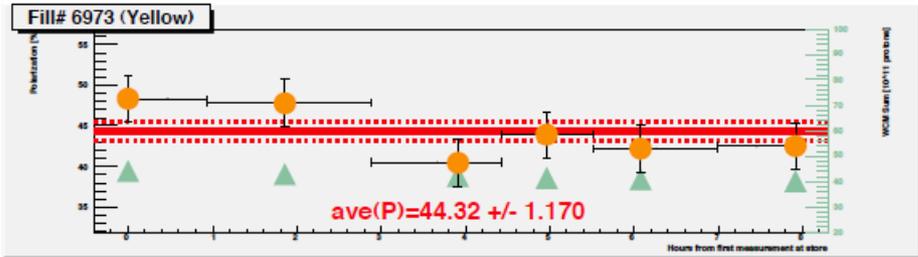
Entries	524
Mean	1.009
RMS	0.2128



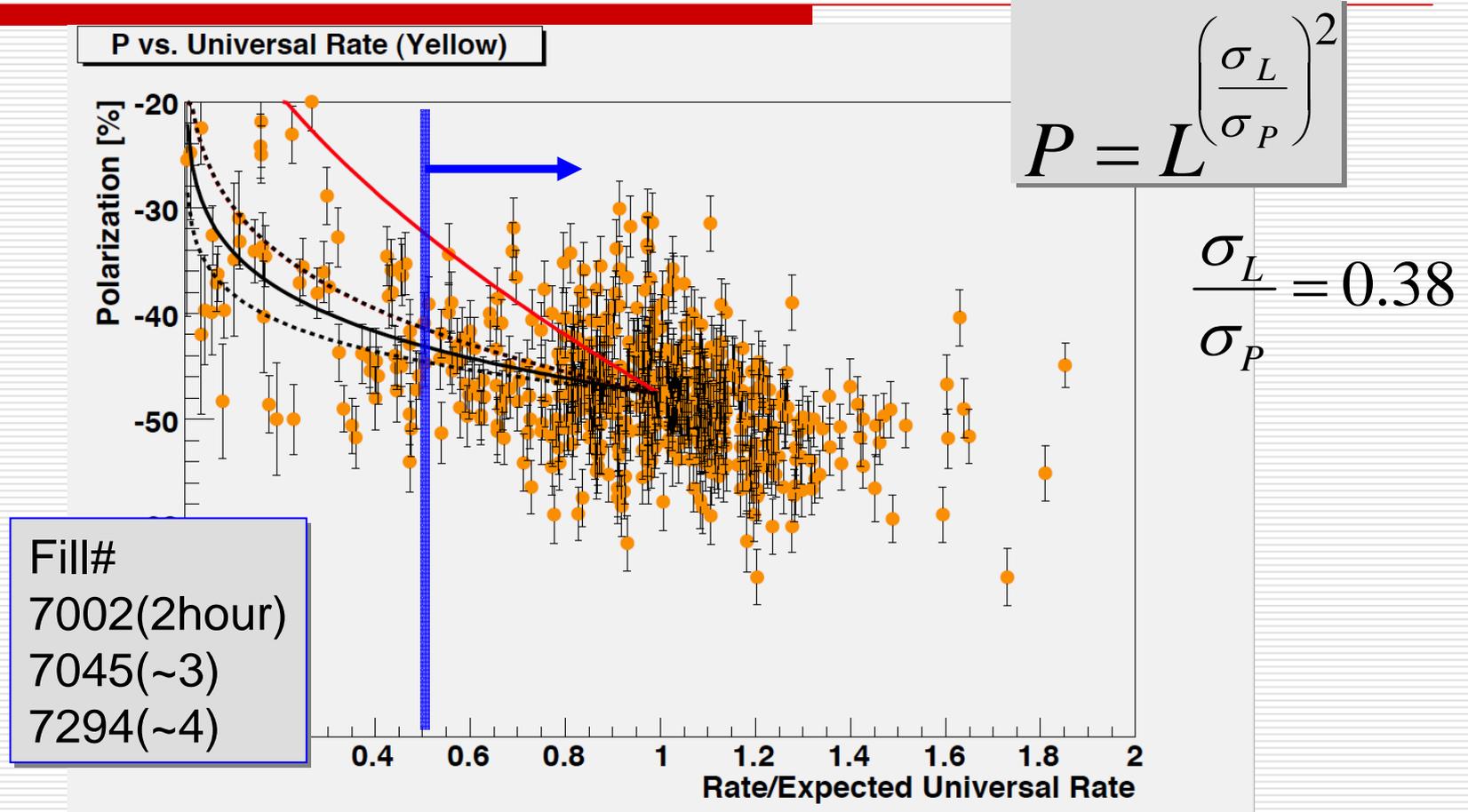
# Fill By Fill Summary

	$\Delta P_{fill}/P_{fill}$	
	Blue	Yellow
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$\Delta P_{fill}^{sta}$	$\Delta P_{fill}^{sta}$	$\Delta P_{fill}^{sta}$
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$\Delta C_{prof}$	4.3	5.7
$\sigma_{prof}(R)$	0.0	$\sigma_{prof}(R)$

$$\Delta P_{fill}^{tot} / P_{fill} = \Delta P_{sta} \pm \sigma_{dl} \pm \Delta C_{prof} \pm \sigma_{prof}(R)$$

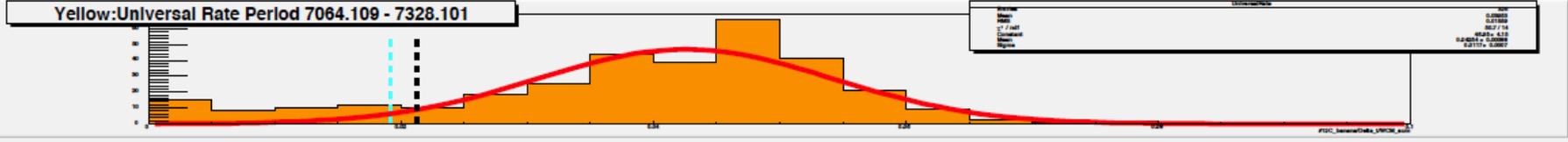
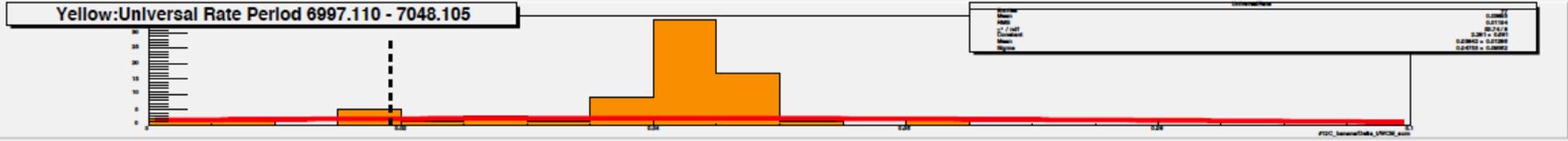
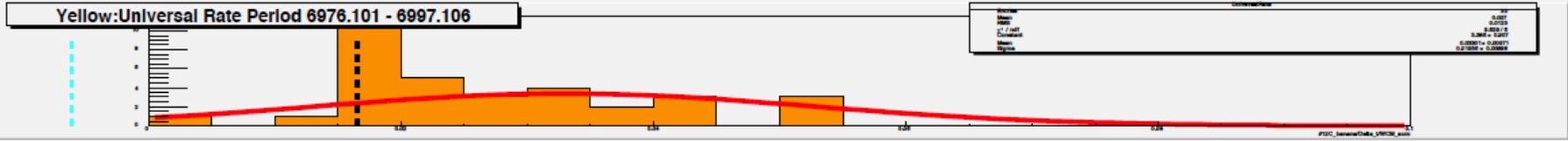


# Universal Rate vs. Polarization (Yellow)

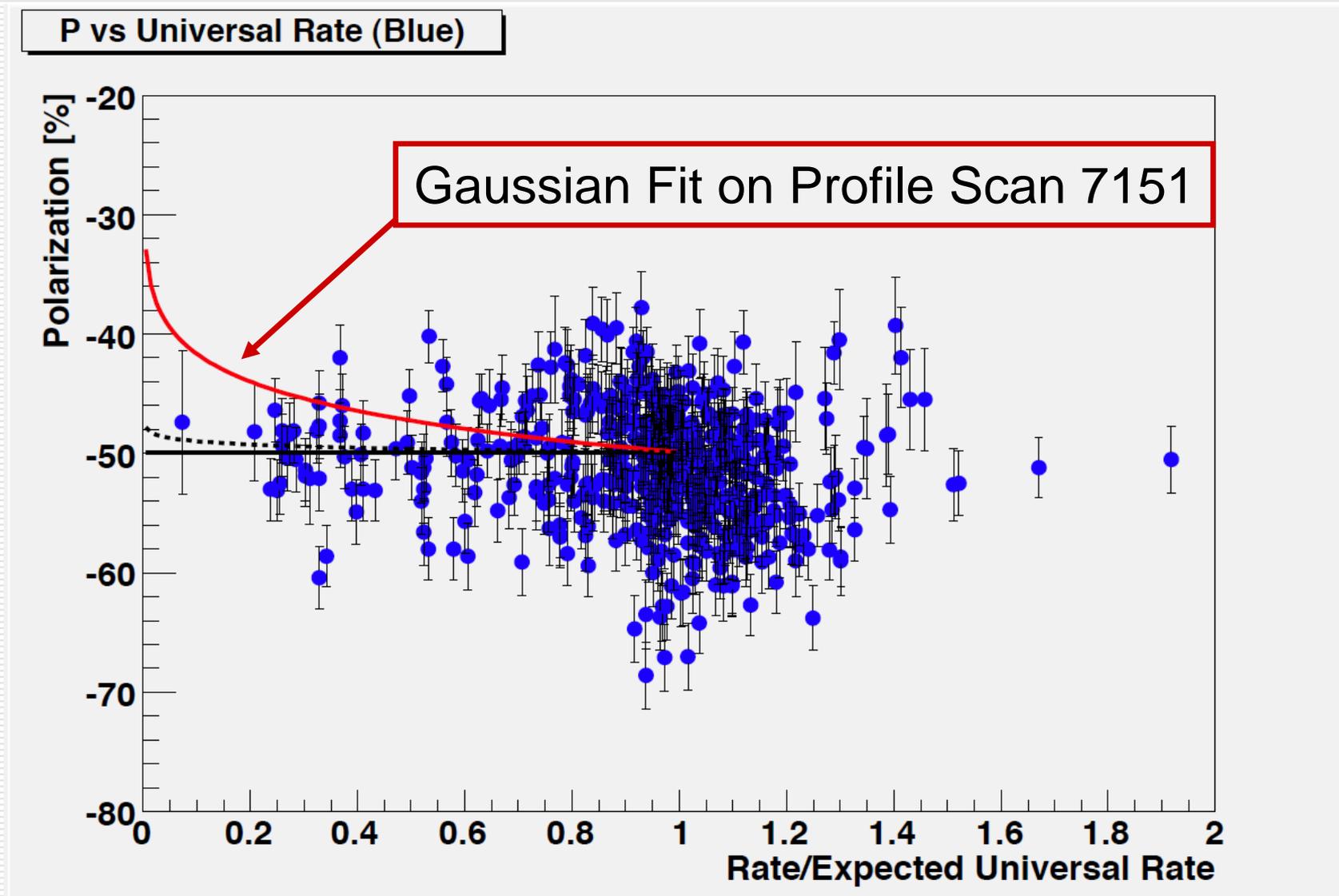


Reject Data Universal Rate < 0.5

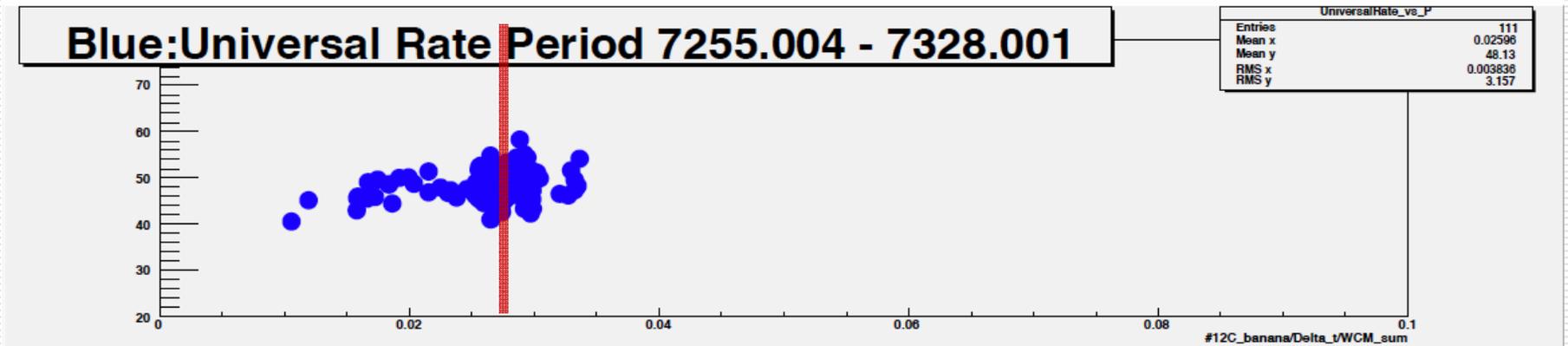
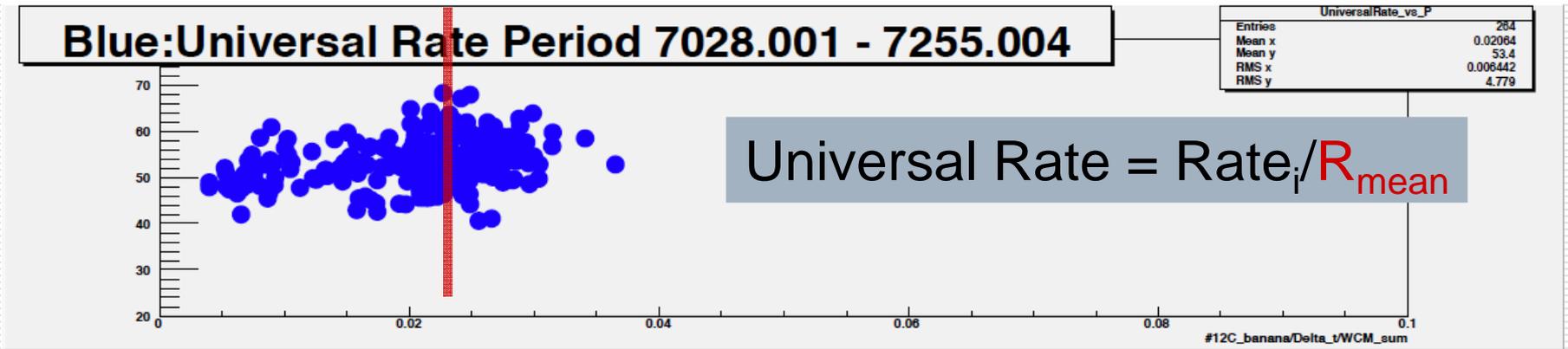
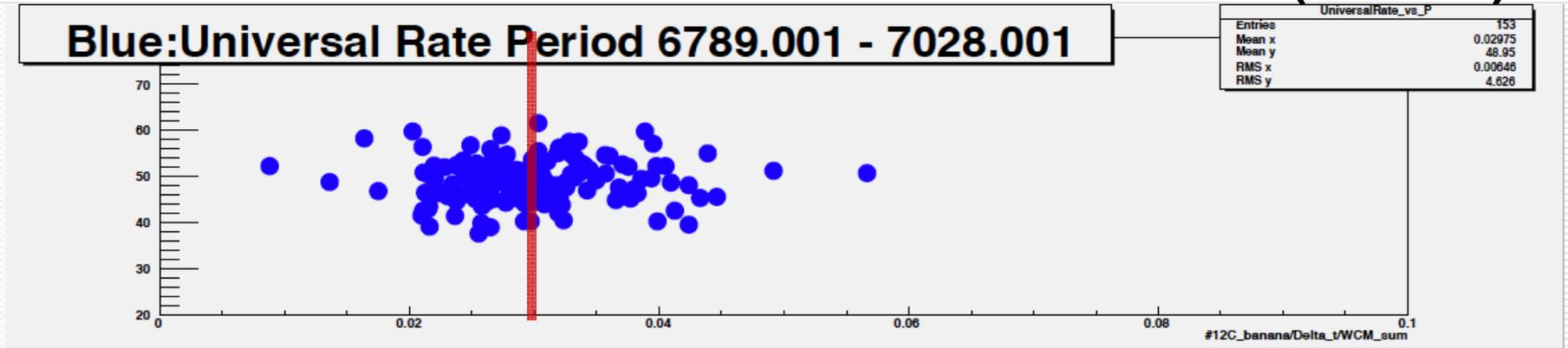
# Rate Distribution for given target (Yellow)



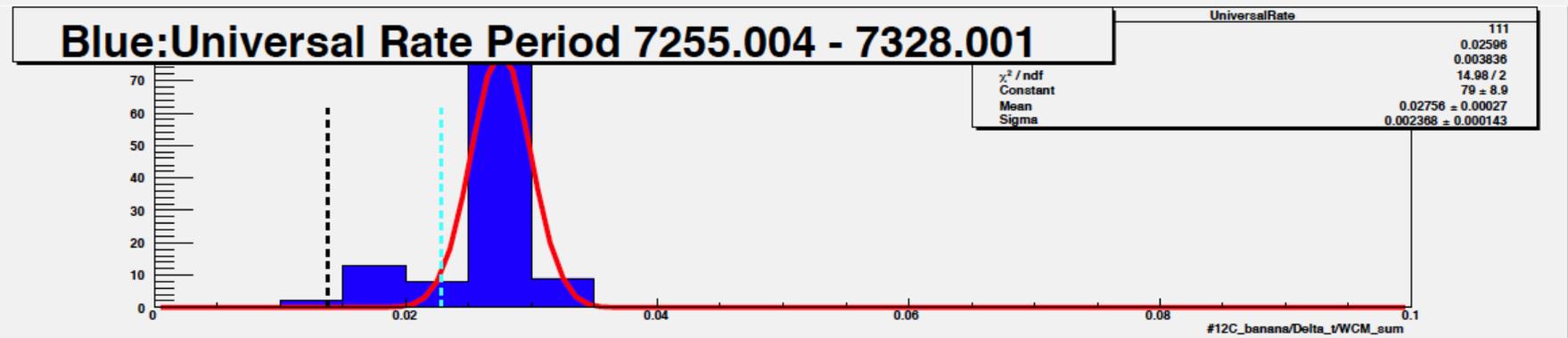
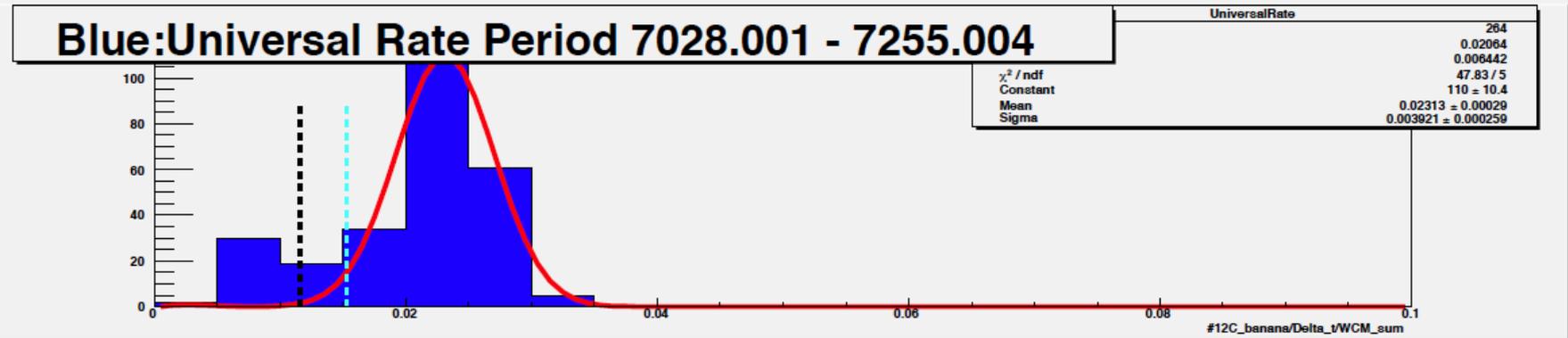
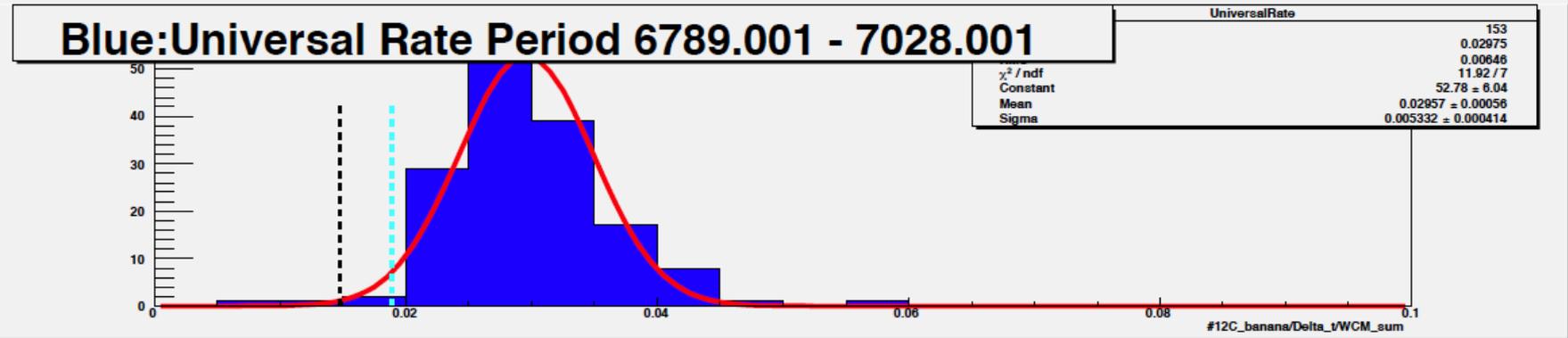
# Universal Rate vs Polarization (Blue)

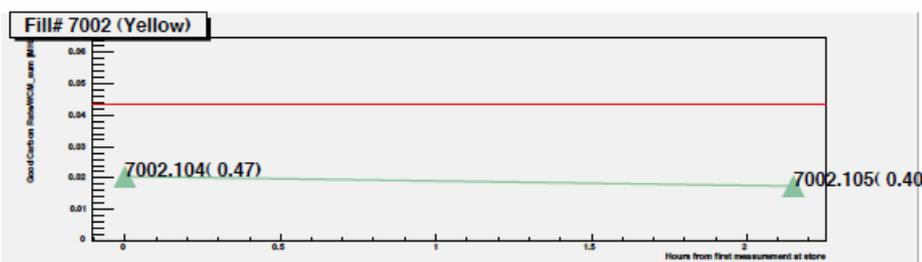
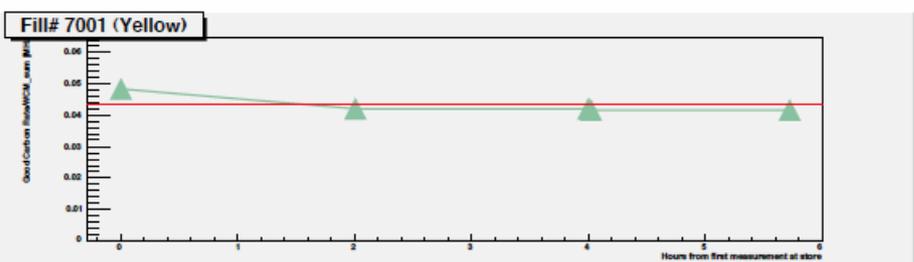
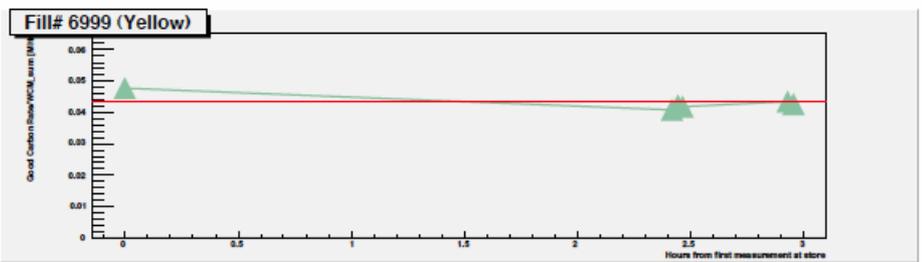
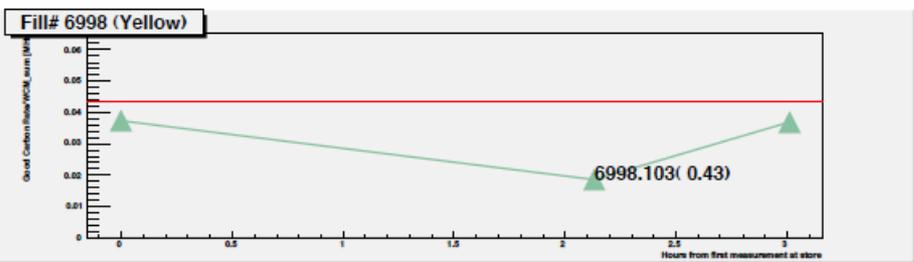
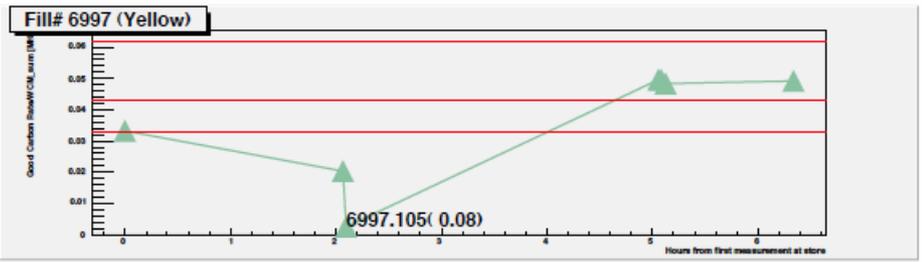
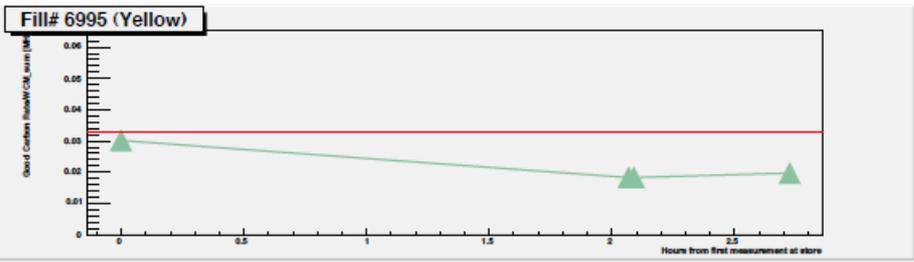
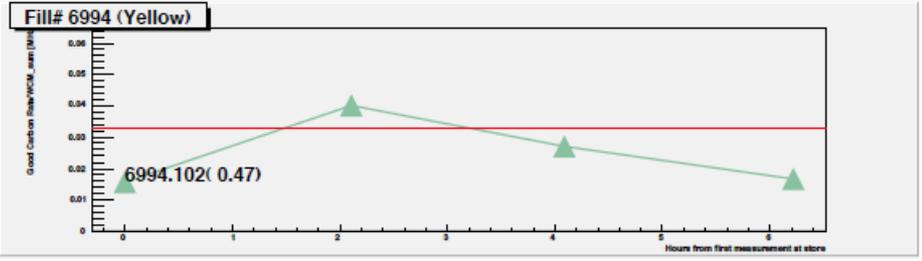
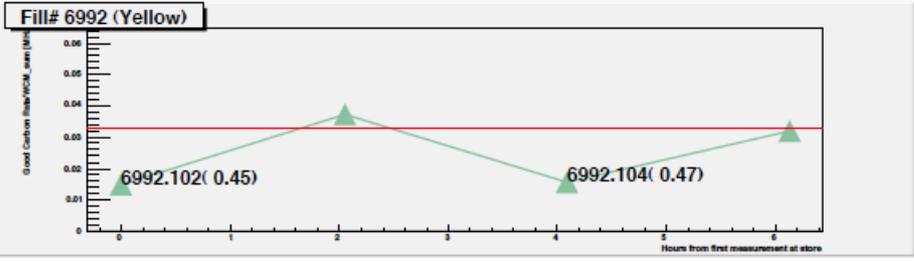
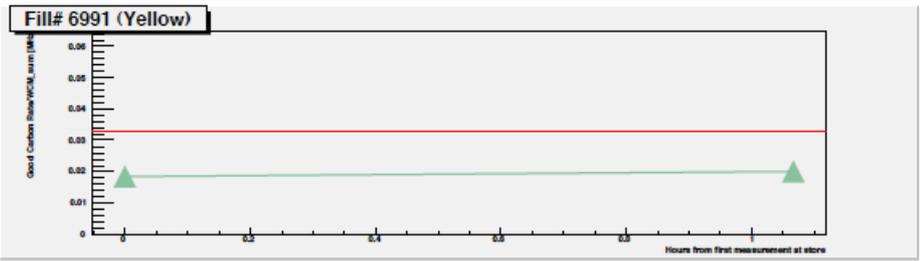
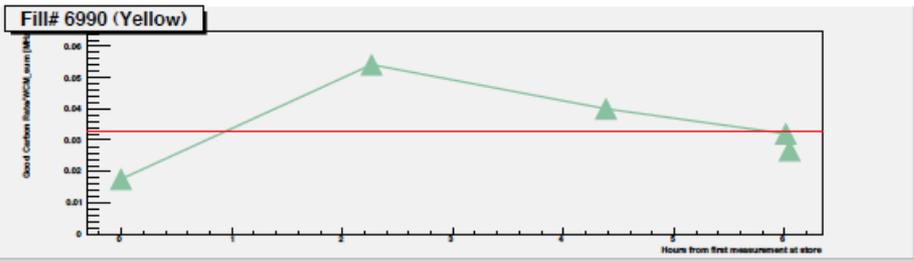


# Rate vs. Polarization Correlation (Blue)



# Rate Distribution for given target (blue)





# Rate vs Polarization Profile

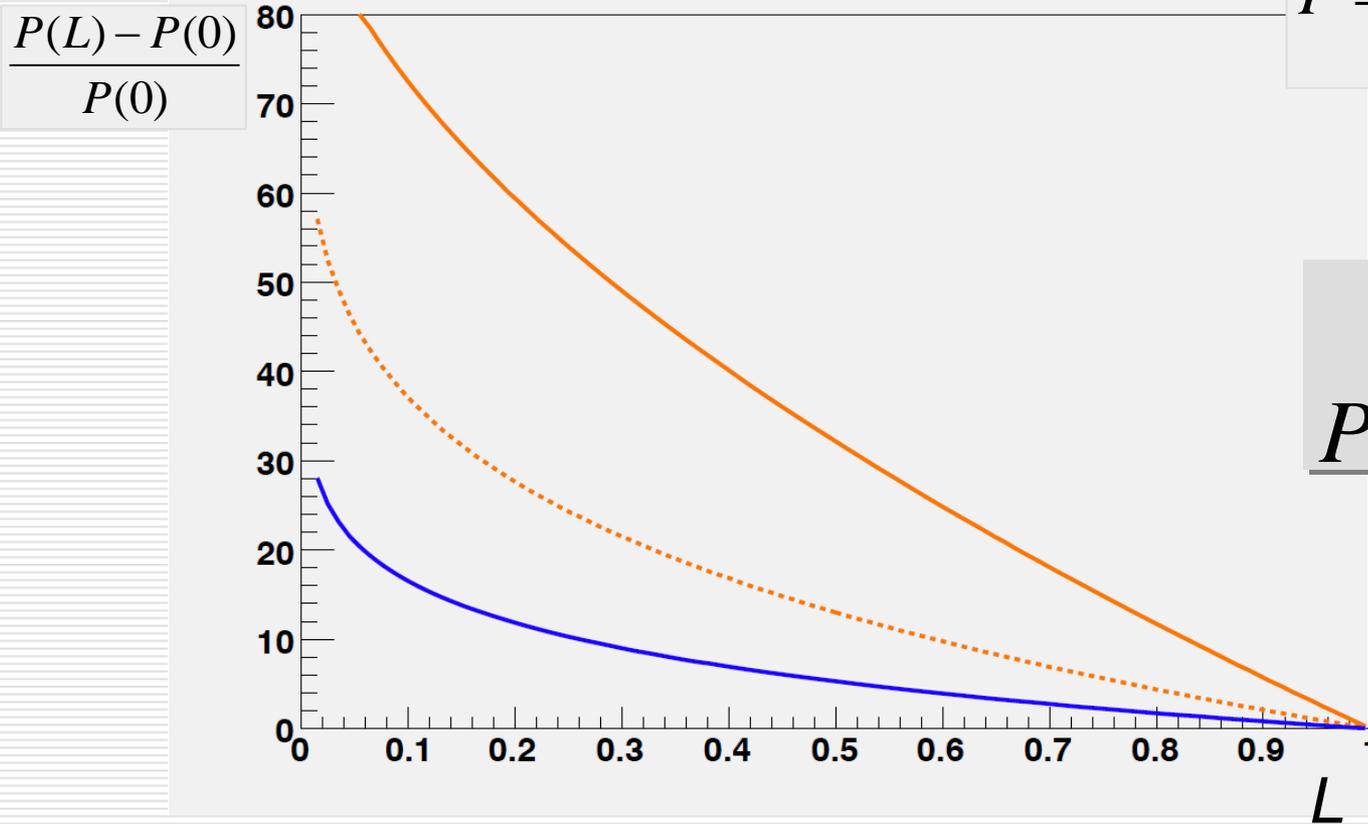
$$L = \exp\left(-\frac{x^2}{2\sigma_L^2}\right)$$

$$P = \exp\left(-\frac{x^2}{2\sigma_P^2}\right)$$



$$P = L \left(\frac{\sigma_L}{\sigma_P}\right)^2$$

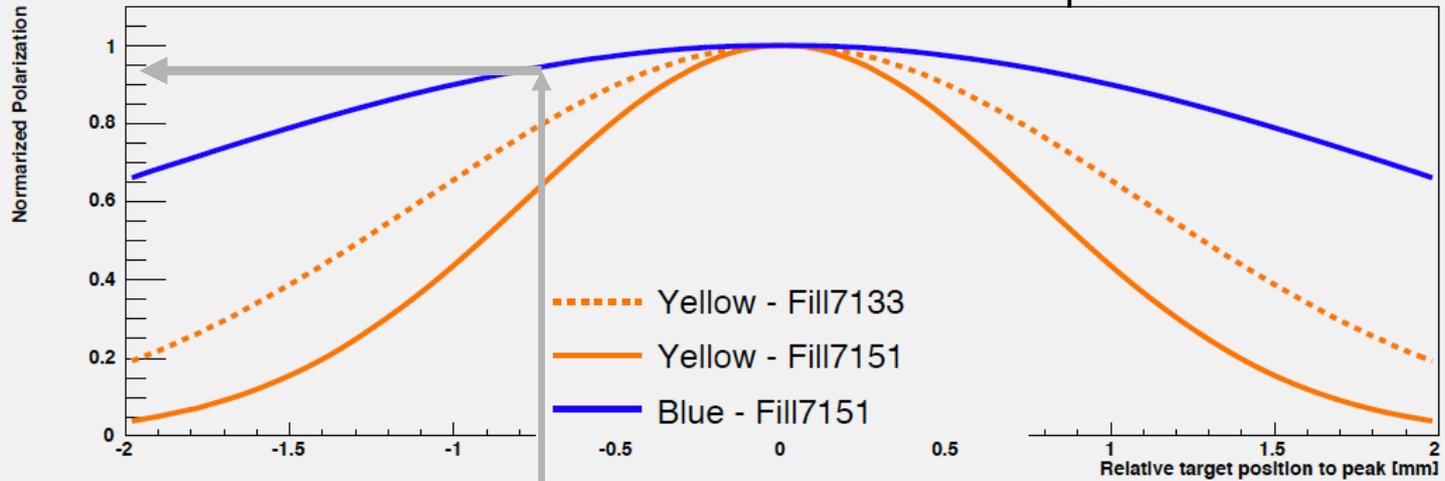
Rate vs. Polarization drop from center (relative)



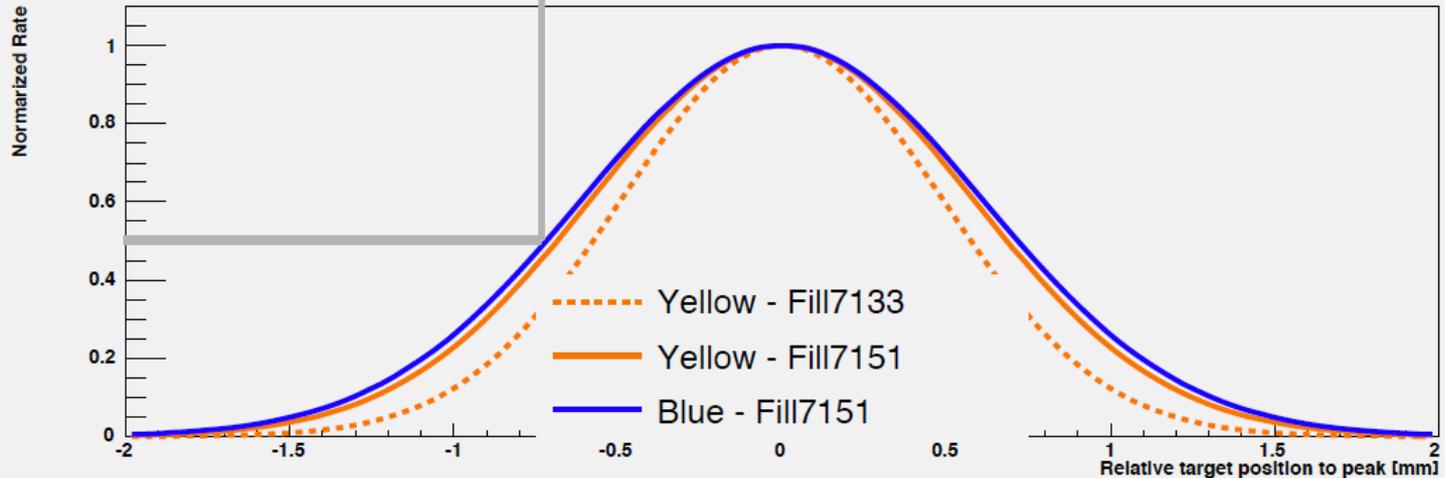
# Three Polarization Profiles

Rate  $\rightarrow x_{pos} \rightarrow$  Polarization

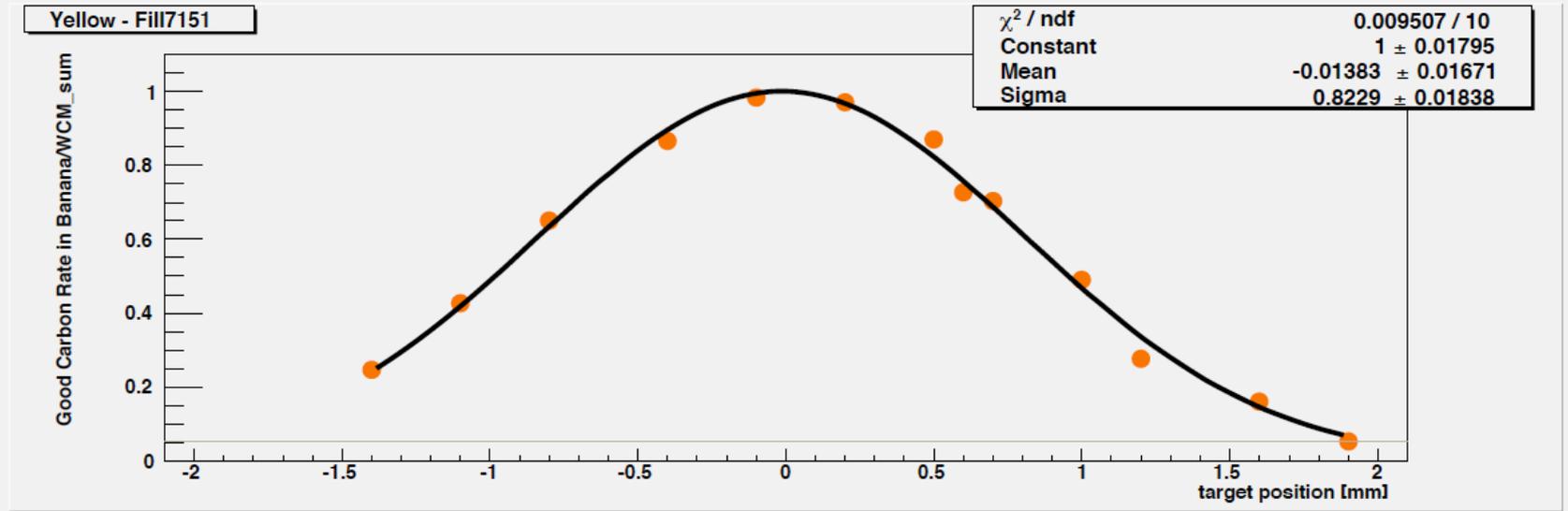
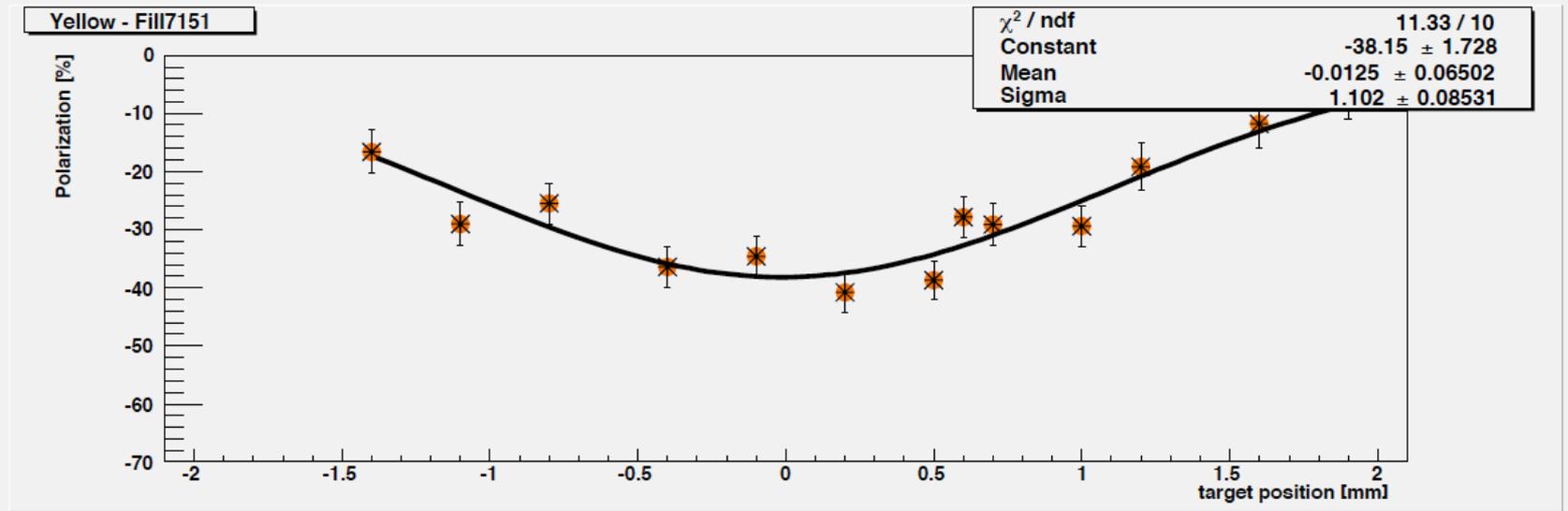
Polarization Profile



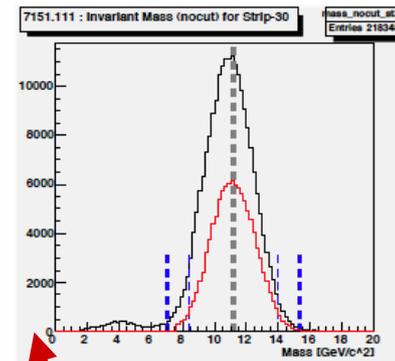
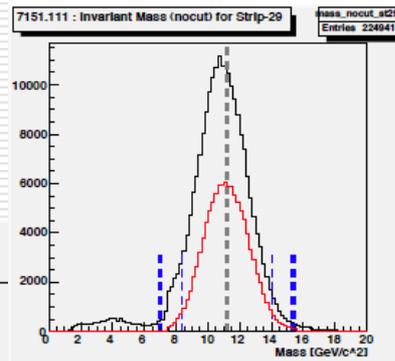
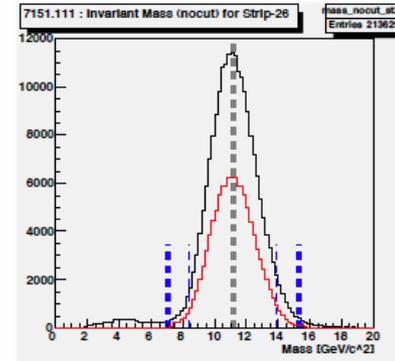
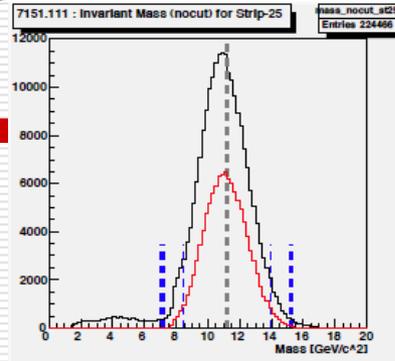
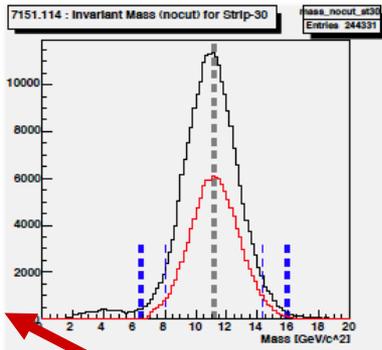
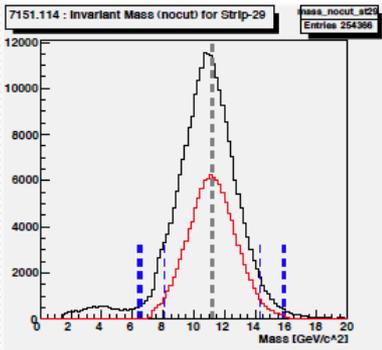
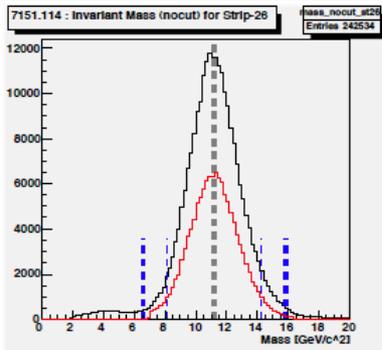
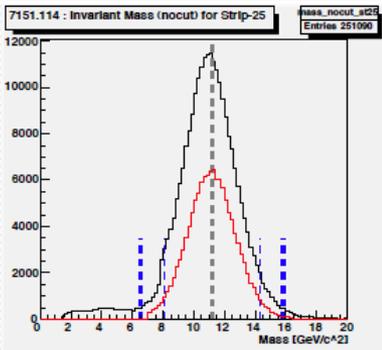
Intensity Profile



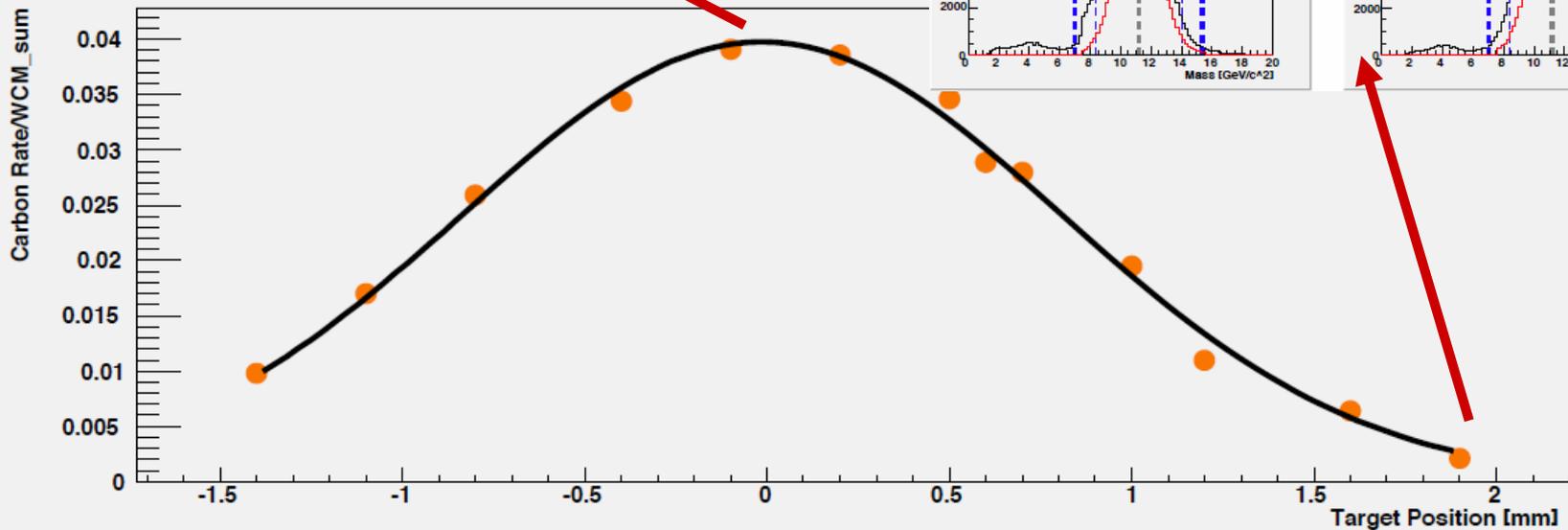
# Yellow 7151



# Edge of Profile



Graph



# 3 Profile Data Sets from Run05

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7133.106 ~ 7133.115

7151.107 ~ 7151.119

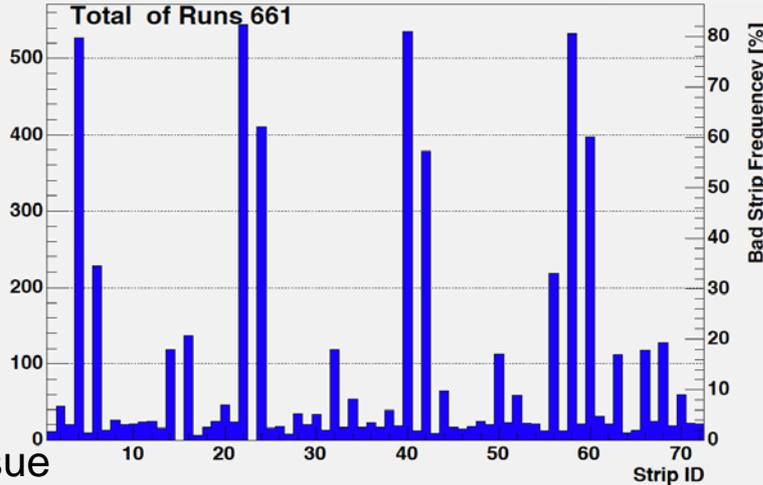
7151.007 ~ 7151.019

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# Problematic Strip Statistics

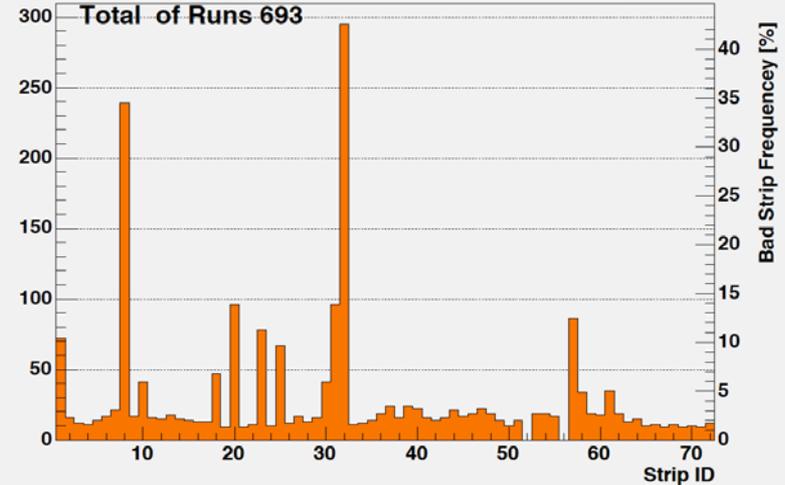
Bad Strip Statistics

BadStripStatistics31  
Entries 5869



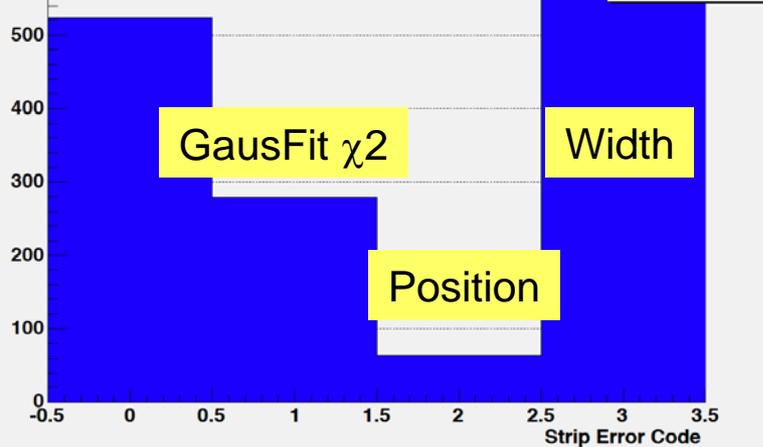
Bad Strip Statistics

BadStripStatistics32  
Entries 2080



Strip Error Code

StripErrCode25  
Entries 2512  
Mean 1.469  
RMS 1.331



Strip Error Code

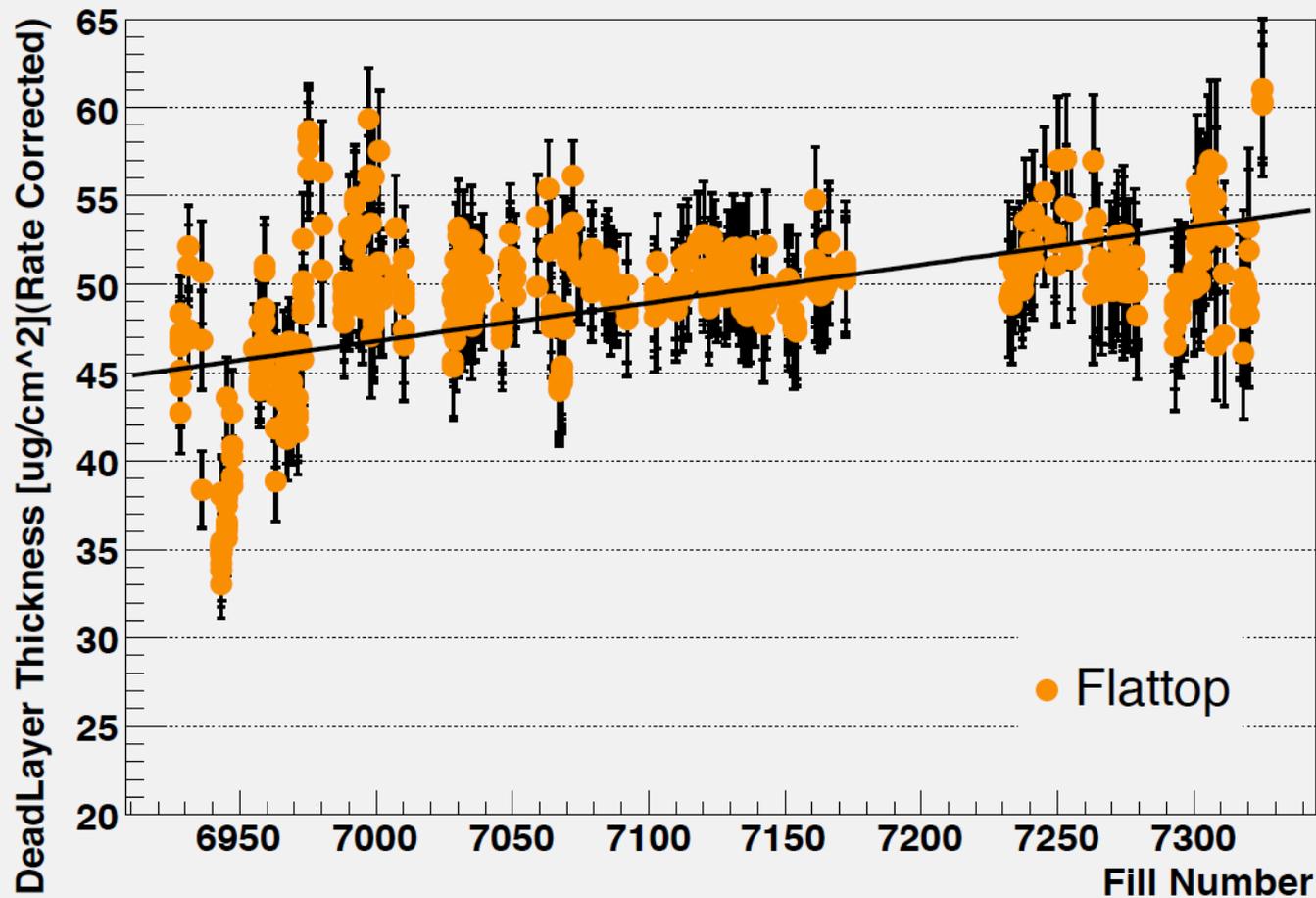
StripErrCode26  
Entries 2500  
Mean 0.4587  
RMS 1.003



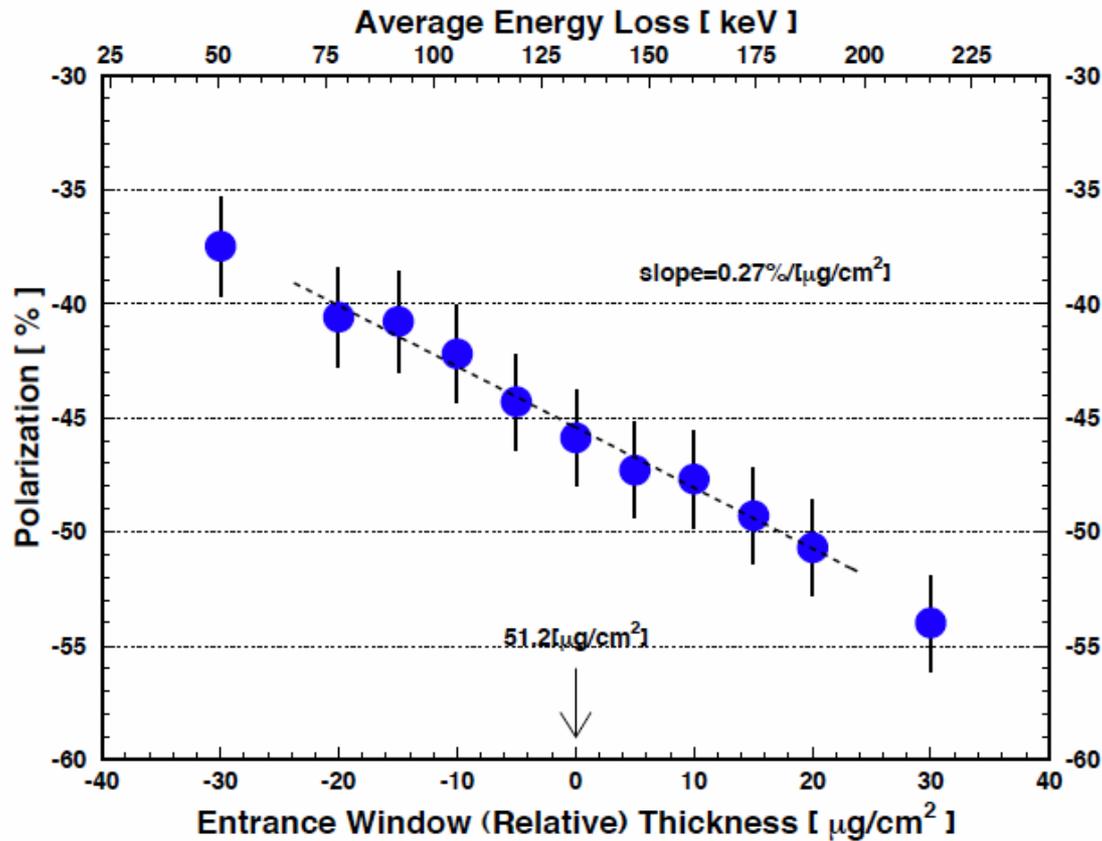
WFD issue

# Energy Correction History (Yellow)

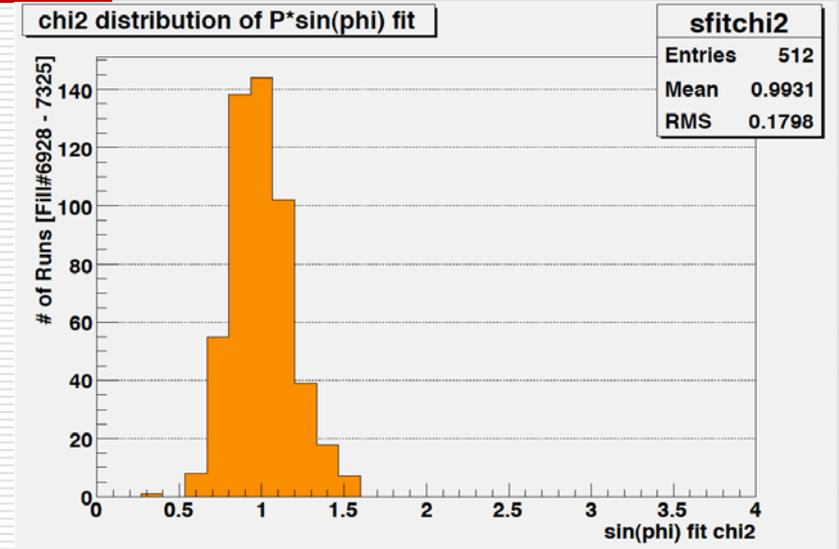
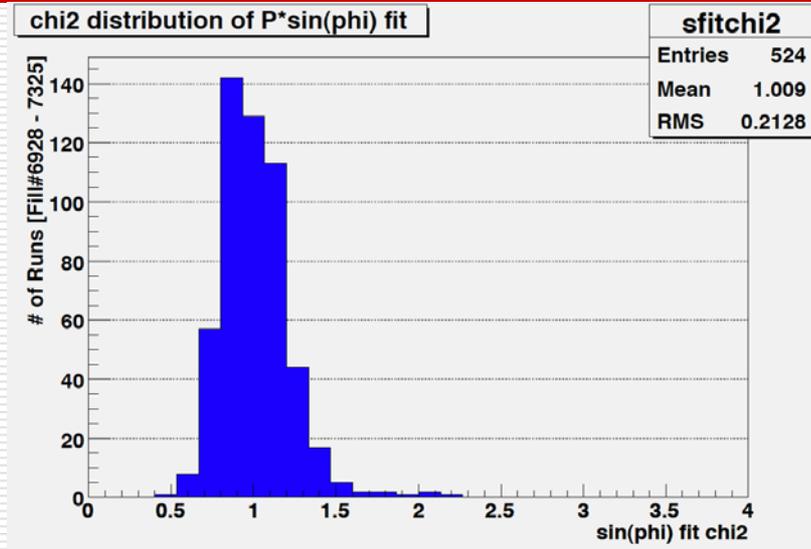
DeadLayer History (Yellow)



# DeadLayer vs. Pol Dependence (Blue)



# Strip by Strip Consistency



- $\chi^2$  Distribution of  $\sin(\phi)$  fit
- Well Distributed around 1
- Evidence of Consistent Polarization Measurements by individual strips