Some pC systematics

polar. mtg.
21.01.15

Principle:

- Two independent measurements same quantity, e.g. X1 & X2, with stat. uncert. σ_{X1}, σ_{X2}
- Distribution of trials: $(X1-X2)/(\sigma_{X1} \oplus \sigma_{X2})$
- Width of distribution: $\approx 1 \Rightarrow$ stat. uncert. accounts for deviations
  $>1 \Rightarrow$ additional systematic deviations

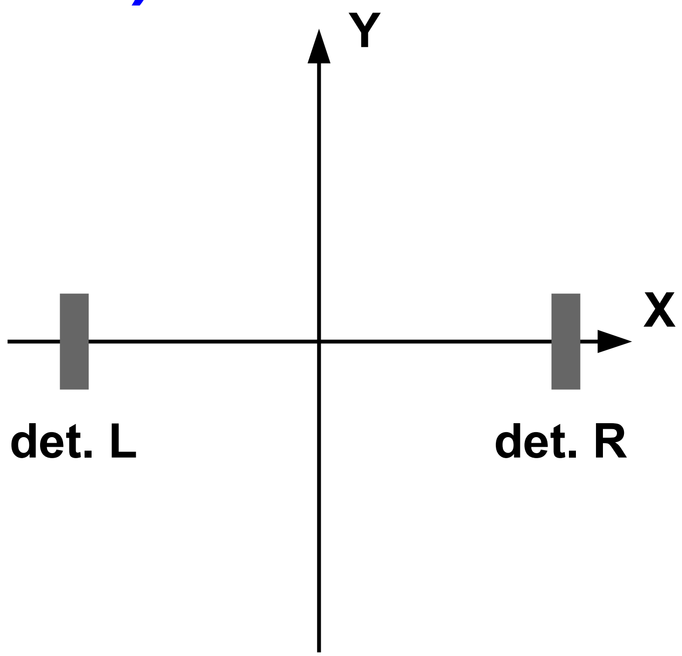
pC polarimeters:

- Square root formula: use 2 (3) pairs detectors for H (V) targets
  - Have 2 (3) measures of lumi asymmetry for H (V) targets
  - For V targets have 2 measures of $\epsilon_Y \propto P_Y$
- Up/Down-stream polarims. (using ϵ vs. ϕ fit for $|\epsilon|$):
  - measurements ~same time, 2 measures of $|\epsilon| \propto |P|$

Also today:

- Definitive measure non-vertical spin component P_x

Square root (cross ratio) formula



- Pair of detectors (L,R), 180° apart: different detector acceptances a_L, a_R
- Exposed to up/down beam spins +,-: different up/down luminosities L_+, L_-
- Beam polarization along Y-axis P_Y: physics asymmetry $\epsilon = A_N P_Y$

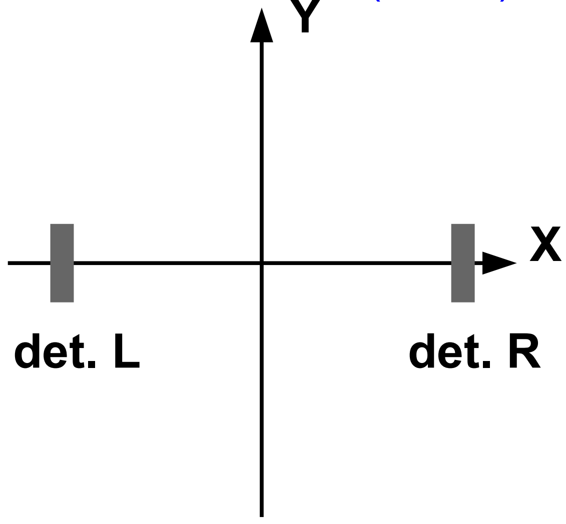
- Measure 4 event counts:

  beam up: $N_{R+} = a_R L_+ (1+\epsilon)$ $N_{L+} = a_L L_+ (1-\epsilon)$

  beam down: $N_{R-} = a_R L_- (1-\epsilon)$ $N_{L-} = a_L L_- (1+\epsilon)$

- Extract 3 asymmetries (& stat. uncert.):
  - physics asym. $\epsilon = A_N P_Y$
  - luminosity asym. $\lambda \equiv (L_+ - L_-)/(L_+ + L_-)$; $(L_-/L_+) = (1-\lambda)/(1+\lambda)$
  - acceptance asym. $\alpha \equiv (a_R - a_L)/(a_R + a_L)$

Square root (cross ratio) formula (contd.)



- 4 event counts: $N_{R+} = a_R L_+(1+\epsilon)$ $N_{L+} = a_L L_+(1-\epsilon)$

  $N_{R-} = a_R L_-(1-\epsilon)$ $N_{L-} = a_L L_-(1+\epsilon)$
- Cross ratio asymmetries:

  e.g. $\epsilon = (\sqrt{N_{R+}N_{L-}} - \sqrt{N_{L+}N_{R-}})/(\sqrt{N_{R+}N_{L-}} + \sqrt{N_{L+}N_{R-}})$

  are exact under some assumptions about N_{R+}, N_{L+} etc.

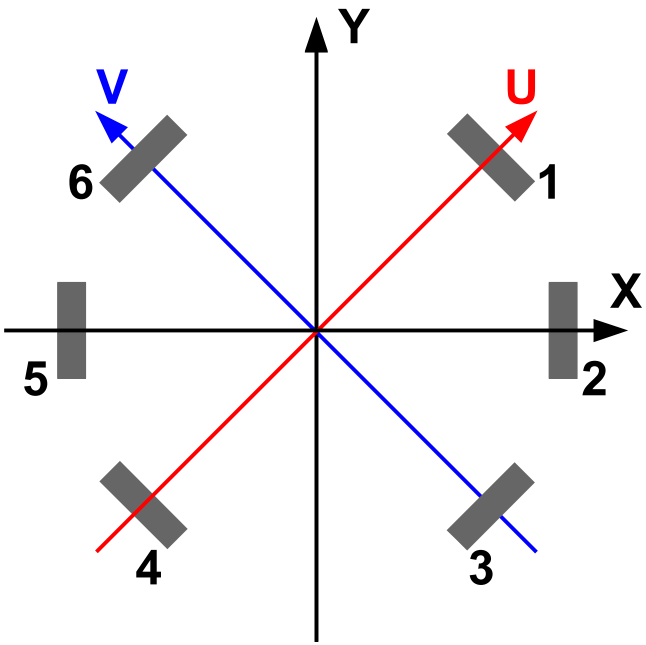
<u>Assumptions:</u>

- Detector acceptances a_L,a_R are same for +/- beam spin states;
  - detector geometry (θ,ϕ) ~fixed
  - +/- spin bunches separated by 100's nanoseconds; fair assumption
- Detectors are 180° apart; ~fixed by scattering chamber design
- +/- bunches same magnitude polarization: $|P_+| = |P_-|$
  - to 1st order: $\epsilon = ½(|P_+|+|P_-|) A_N$ (mean of P magnitudes)
- Detectors have same analyzing power A_N
  - varying calibrations, target ⇒ varying E_{carbon} ranges ⇒ varying A_N
  - to 1st order: $\epsilon = ½(A_{NR}+A_{NL})P$ (mean of detector A_N's)
  - luminosity asym. λ unchanged to 1st order
  - **least certain assumption, test $A_N \propto \epsilon$ with cross checks**

pC polarim.: 3 detector pairs

- 3 180° detector pairs, det.1+4, 2+5, 3+6:
- Measure 3 sets of asymmetries:

$$\epsilon_{25} = A_N P_Y \,,\ \lambda_{25} \,,\ \alpha_{25}$$
$$\epsilon_{14} = A_N P_V \,,\ \lambda_{14} \,,\ \alpha_{14}$$
$$\epsilon_{14} = A_N P_U \,,\ \lambda_{36} \,,\ \alpha_{36}$$

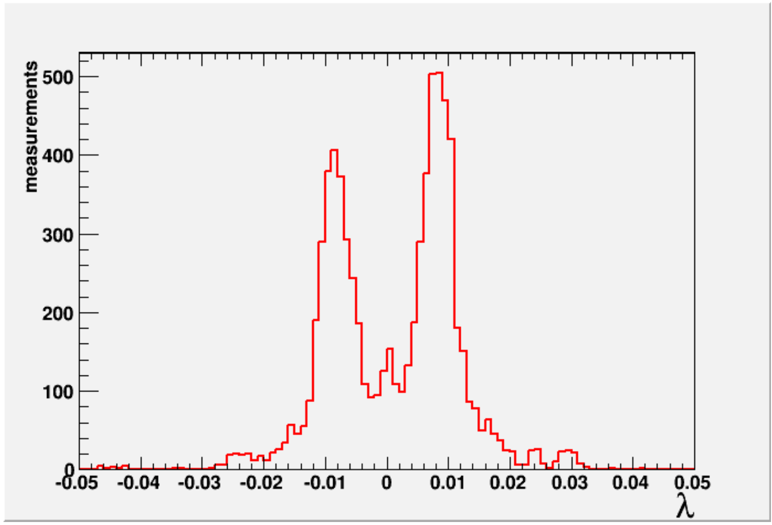


Cross checks:

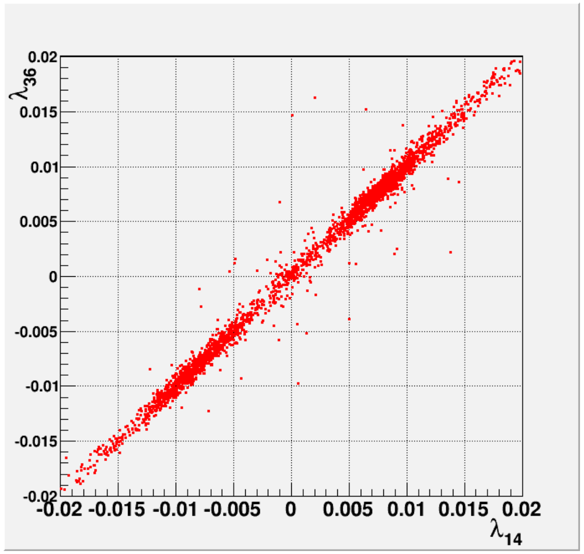
- All detector pairs measure same beam, lumi asym. λ
  compare λ_{14}, λ_{25}, λ_{36} : agree within stat. uncert. (↘ next slide)
- All detector pairs measure same beam, polarization P
  two measures of $\epsilon_Y = A_N P_Y$, using $P_Y = 1/\sqrt{2}(P_V+P_U)$
  - from 90° det. 2+5: $\epsilon_{Y90} = \epsilon_{25}$ (vertical targets only)
  - from 45° det. 1+4, 3+6: $\epsilon_{Y45} = 1/\sqrt{2}(\epsilon_{14}+\epsilon_{36})$
  - compare ϵ_{Y90}, ϵ_{Y45}, check if A_N same all detectors (↘ next-next slide)

Luminosity asymmetries λ

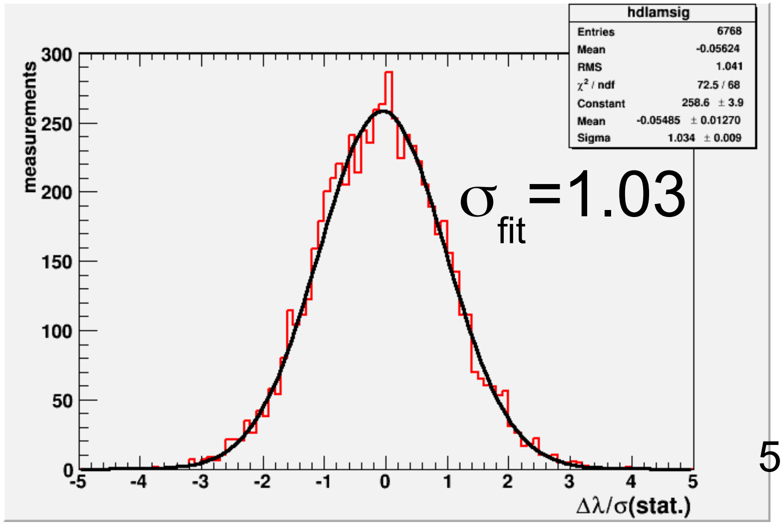
- Lumi asyms. $\lambda \sim$ +/- 1% typically 111 bunches, one extra +/- bunch



- λ from different detector pairs track each other, here e.g. λ_{36} vs. λ_{14}:

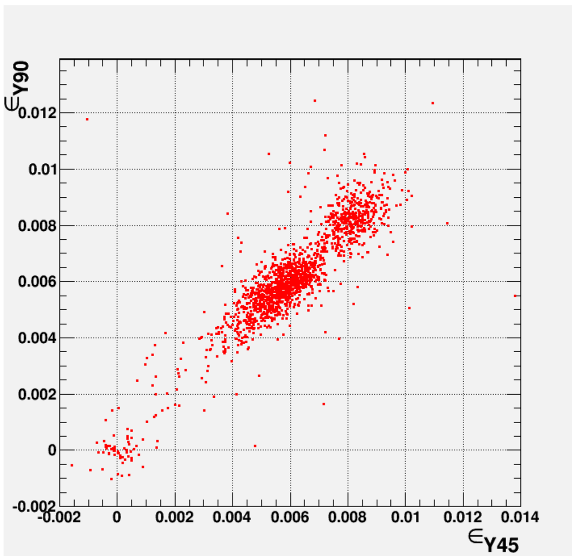


- Plot $(\lambda_A - \lambda_B)/\sigma(\text{stat})$
- Unit gaussian: no significant systematic, square root formula works
- Good measure of λ for experiments?
  - extra slide: λ from WCM bunch currents not as good



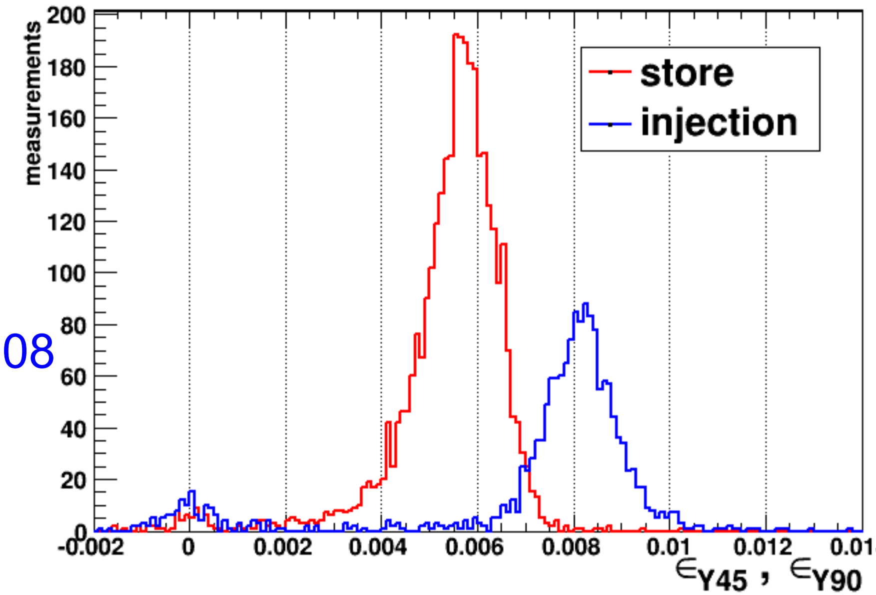
ϵ_Y from 90°, 45° detectors

- Independently measure ϵ_Y with 90°,45° detectors (vertical targets only):
- ϵ_{Y90}, ϵ_{Y45} nicely correlated:



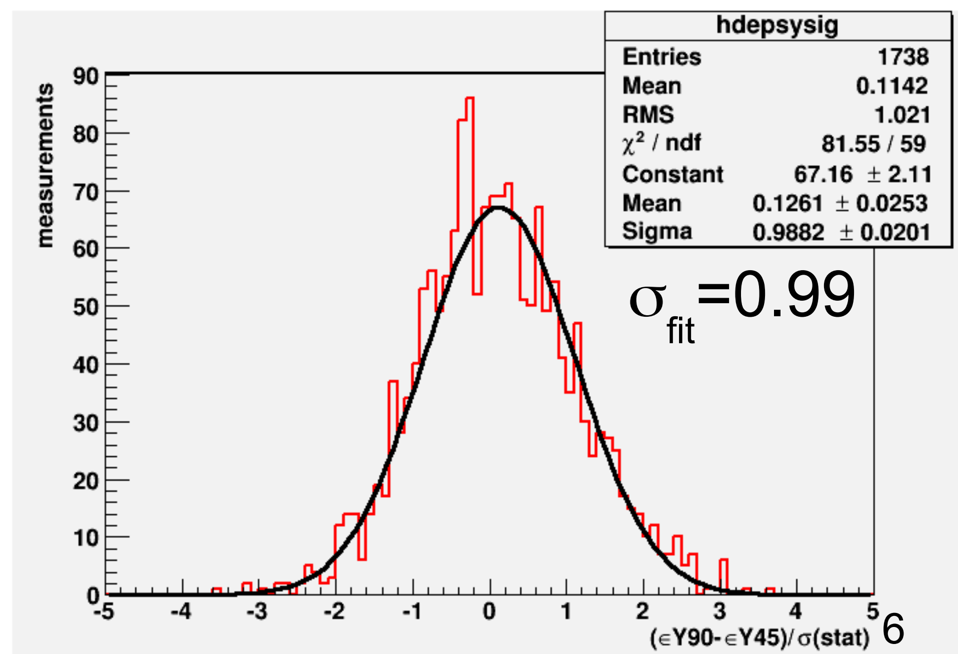
store ϵ_Y~0.006

injection ϵ_Y~0.008



- Distribution $(\epsilon_{Y90}-\epsilon_{Y45})/\sigma(\text{stat})$,

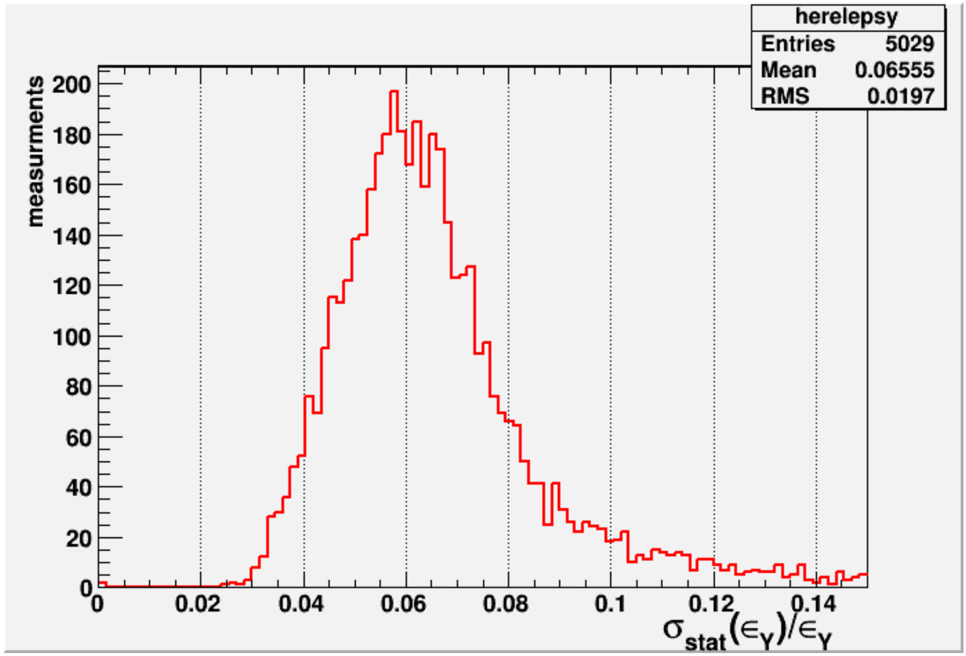
  unit gaussian:
- $\sigma_{fit} = (1 \oplus \sigma_{syst}/\sigma_{stat})$, $\sigma_{syst}(\epsilon_Y) \ll \sigma_{stat}(\epsilon_Y)$
- The variations we see in ϵ_{Y90}, ϵ_{Y45} are statistical, no indication systematic variations



σ_{fit}=0.99

ϵ_Y from 90°, 45° detectors

- $\sigma_{syst}(\epsilon_Y) \ll \sigma_{stat}(\epsilon_Y)$
- Relative stat. uncert. $\sigma_{stat}(\epsilon_Y)/\epsilon_Y \approx 7\%$:
- So $\sigma_{syst}(\epsilon_Y)/\epsilon_Y \ll 7\%$,
  say $\sigma_{syst}(\epsilon_Y)/\epsilon_Y \leq$ 1-2%
- $A_N \propto \epsilon_Y$
- So $\sigma_{syst}(A_N)/A_N \leq$ 1-2%



- **Systematic variations of A_N,**
  between detectors in the same polarimeter, are below the 1-2% level

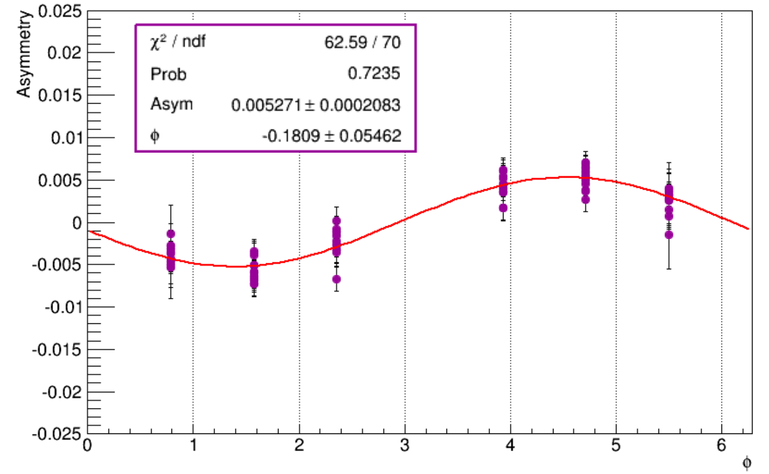
<u>Same conclusion for:</u> (↘ plots extra slide)

- Each polarimeter (B1,Y1,B2,Y2)
- Injection/store
- α-gain not corrected for drifts (!?)

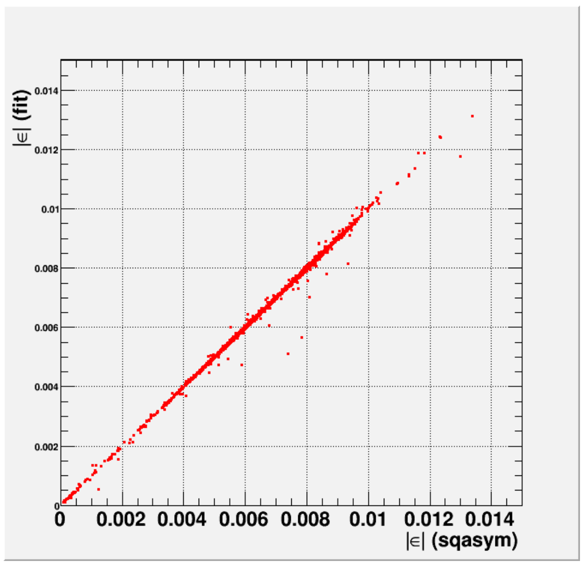
slight aside:

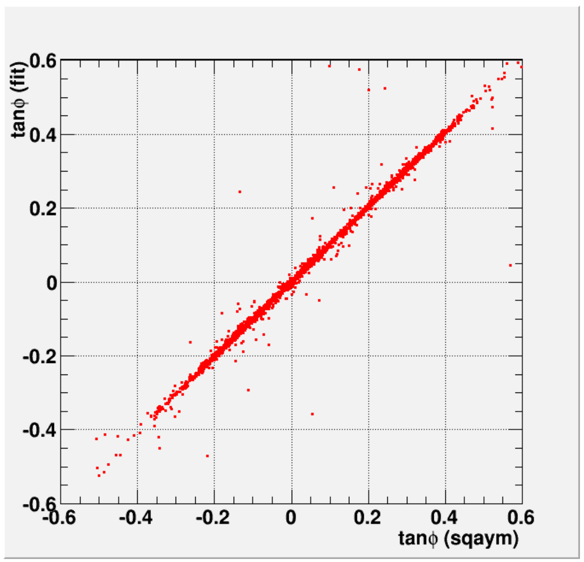
Cross ratio vs. fit asymmetries

- Our default asymmetry (may be) from this fit: per-strip asymmetries using flawed approximation for relative luminosities



- It agrees well with rigorous √ asymmetries, here e.g. $|\epsilon|$ and $\tan\phi = \epsilon_X/\epsilon_Y$:



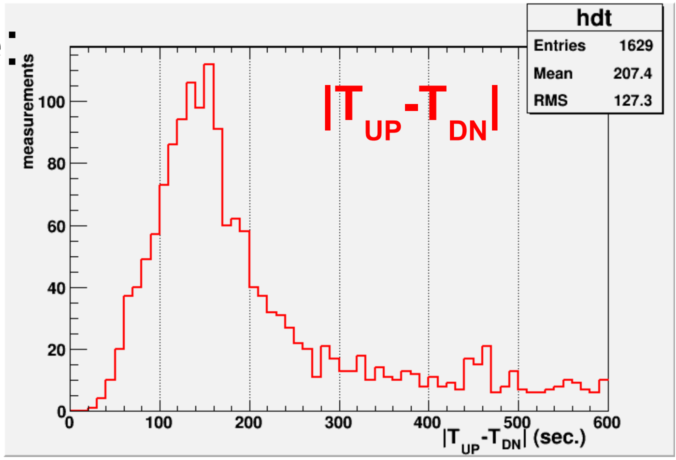


- Also: fit gives ~same stat. uncert. as √ asym.
  deviations (fit - √ asym.) small compared to stat. uncert.

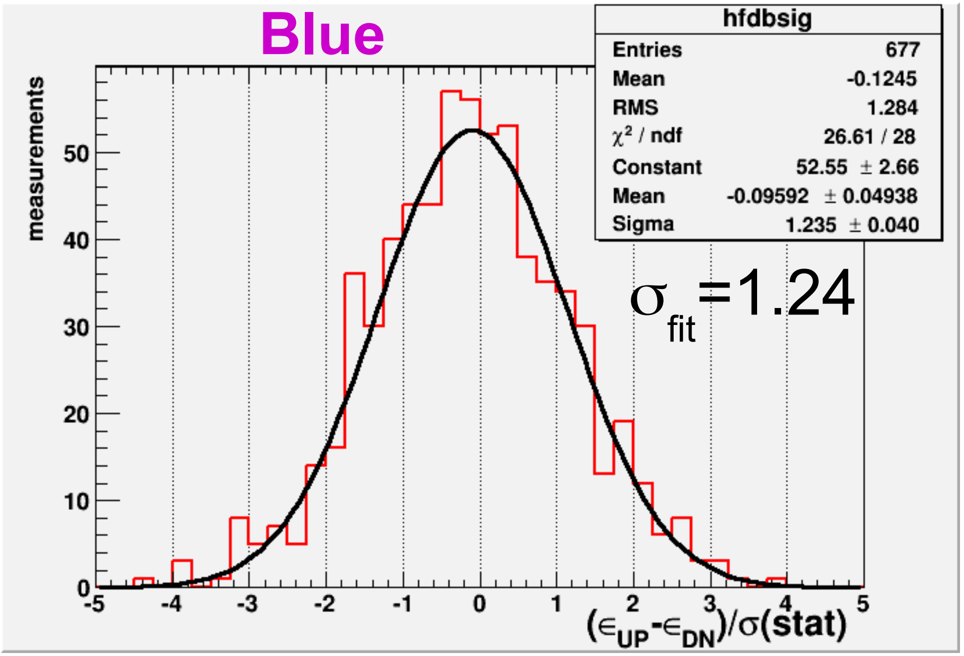
- **Conclusion: fit is adequate, small systematic effects**
  use for further analysis (convenience, we're stuck with it)

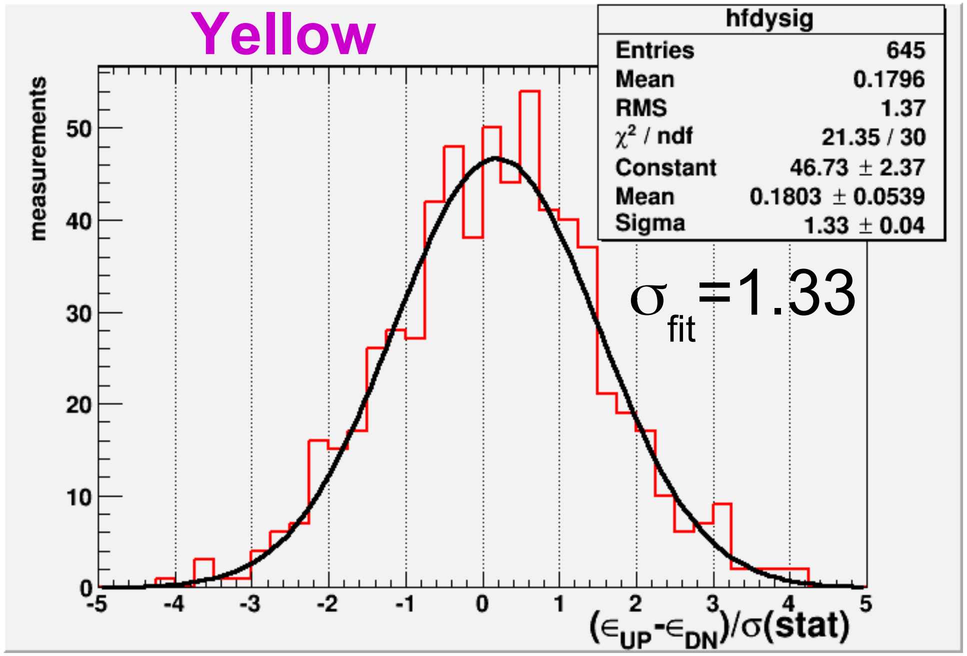
$|\epsilon|$ from U/D polarimeters

- Select Blu or Yel U,D measurements ~same time:
  - typically within 3-4 minutes, select <10 min.
  - beam |P| negligible drop in this time



- Compare U/D differences to stat. uncert. $(|\epsilon_{UP}|-|\epsilon_{DN}|)/\sigma(\text{stat})$:



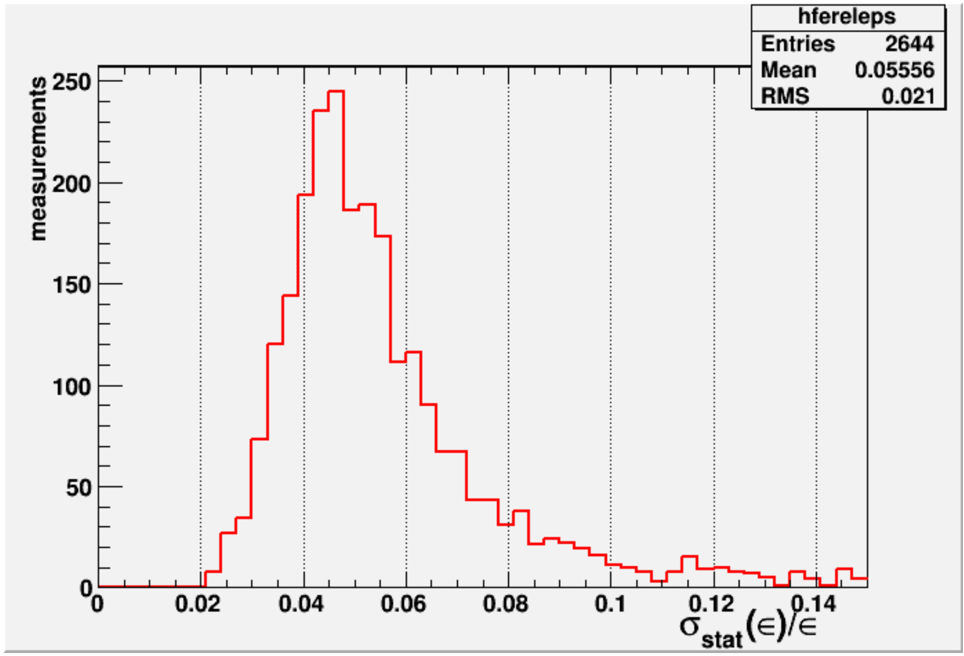


- Distributions significantly wider than unit gaussian: $\sigma_{fit}\sim 1.3$
- $\sigma_{fit} = (1 \oplus \sigma_{syst}/\sigma_{stat})$, $\sigma_{syst}(|\epsilon|)$ comparable to $\sigma_{stat}(|\epsilon|)$

$\sigma_{syst}(|\epsilon|) \sim 0.83 \cdot \sigma_{stat}(|\epsilon|)$

$|\epsilon|$ from U/D polarimeters

- $\sigma_{syst}(\epsilon) \sim 0.83 \cdot \sigma_{stat}(\epsilon)$
- Relative stat. uncert. $\sigma_{stat}(\epsilon)/\epsilon \approx 6\%$:
- So $\sigma_{syst}(\epsilon)/\epsilon \approx 5\%$,
- $A_N \propto \epsilon$
- So $\sigma_{syst}(A_N)/A_N \approx 5\%$



- **Systematic variations of A_N, between between different polarimeters, is about 5%**

<u>Same conclusion for:</u> (↘ plots extra slide)

- ϵ for U/D polarims. from cross asym. 45° det. instead of fit (less statistics since 90° det. not used, less significant conclusion)

Summary ϵ systematics

- Ascribe variations of ϵ as due to variations in A_N

  e.g. variations in E_{carbon} range: miscalibration

  dE/dx loss in targets

- Variations of ϵ in the *same polarimeter* are negligible:

  - miscalibrations different detectors insignificant

  even when we ignore α-calibration drifts!

- Variations of ϵ between *different polarimeters* are ~5%:

  - different polarimeters → different targets

  → different dE/dx loss in targets

  - expected magnitude effect on A_N 5-10%

  (my slides polarim. mtg. 14.07.11)

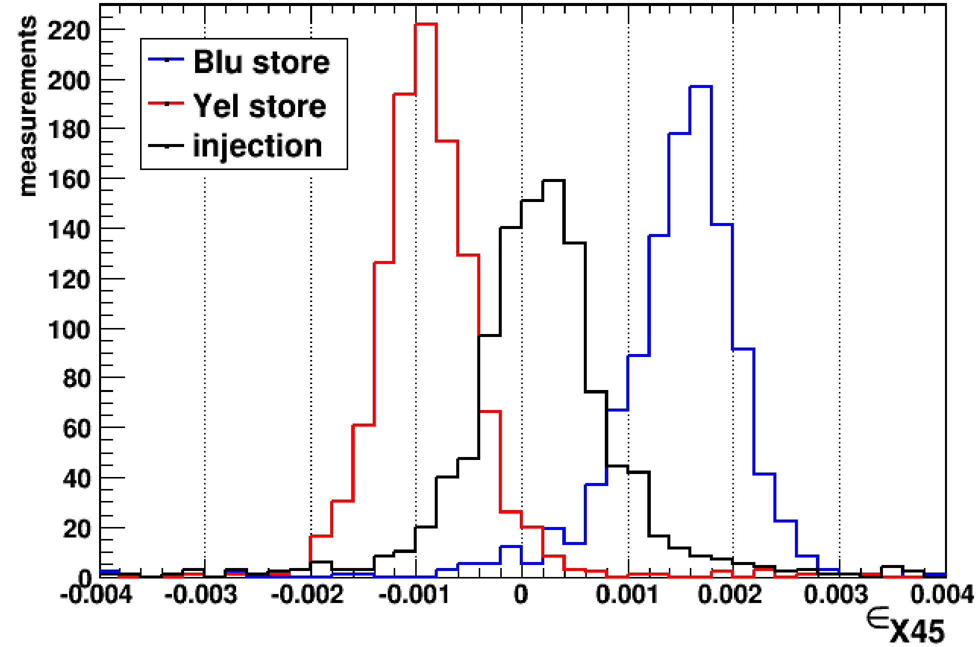
<u>Another lesson:</u>

- Comparing systematic↔statistical fluctuations,

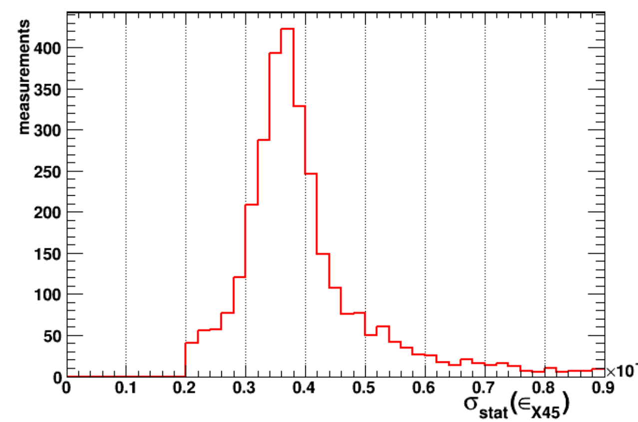
  barely sensitive to systematics

- Increased statistics would enable real systematic studies

ϵ_X from 45° detectors



- 45° detectors: $1/\sqrt{2}(\epsilon_{14}-\epsilon_{36}) = \epsilon_X \propto P_X$
  horizontal component spin vector
- Very clear:
  @ injection $\epsilon_X \sim 0$
  @ store $\epsilon_X > 0$ (Blu), $\epsilon_X < 0$ (Yel)
- In geographical coordinates:
  at store both Blu and Yel spin vectors *tilted toward RHIC ring center*
- Widths ϵ_X distributions ~ ϵ_X stat. uncert.:
  (➘ ‹ › ℓ• ₤d ℒ extra slide)



- So spin tilt @ store ~fixed number,
  $\epsilon_X/\epsilon_Y \Rightarrow$ angle from vertical: Blu ~ +16°
  Yel ~ -9°

Spin vector tilt @ H-jet?

- Clearly measure spin tilt at pC polarimeters
  (~100 from IP12)
- Is there a spin tilt at H-jet (at IP12)?

Implications:

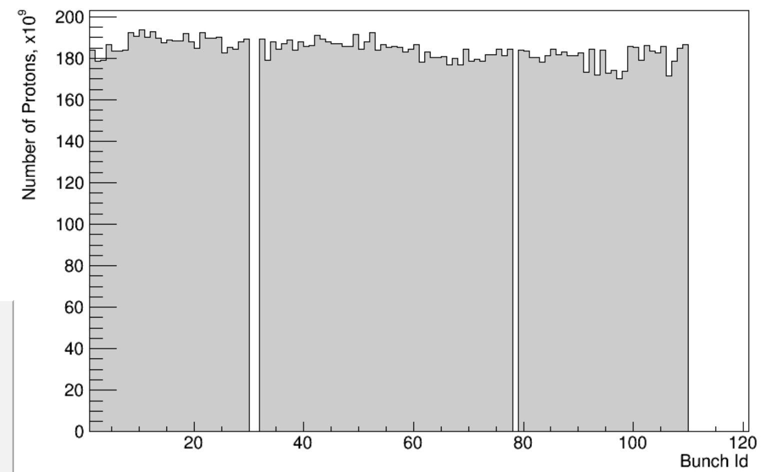
- H-jet measures $\epsilon_Y \propto P_Y$ (only 90° horizontal detectors)
- In pC/H-jet normalization we assume
  H-jet measures magnitude |P|
- Spin tilt at H-jet would give scale shift in |P|,
  e.g. spin tilt 16° $\Rightarrow$ 4% scale shift

Should discuss with RHIC experts...

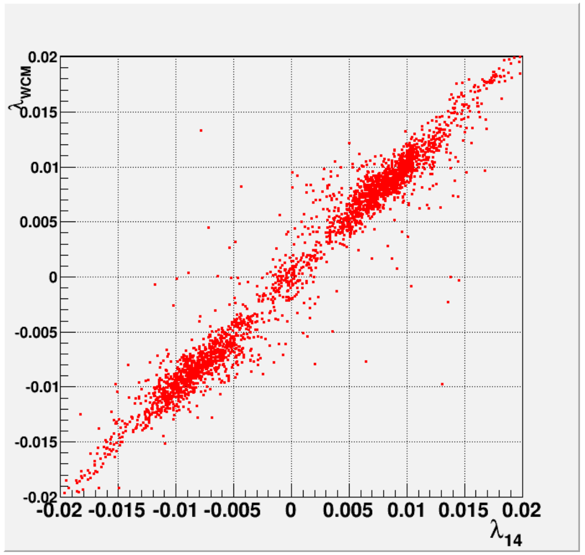
Extras

Luminosity asymmetry from WCM

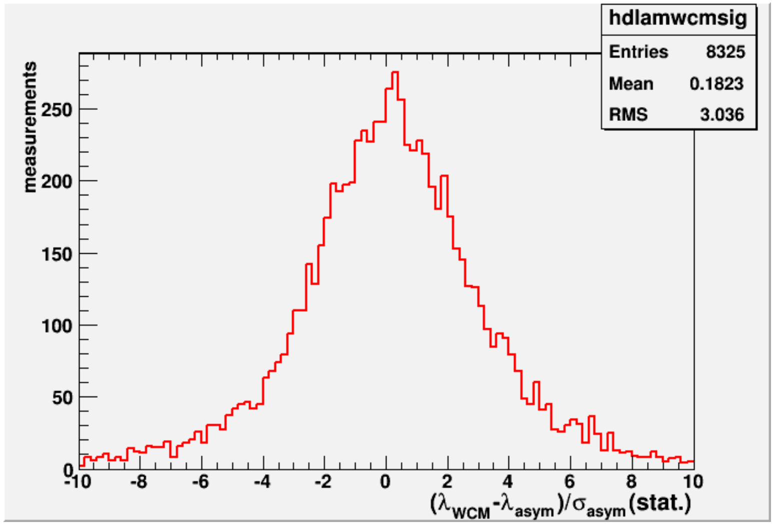
- Bunch currents, sum I_+, I_-
- measure $\lambda_{WCM} = (I_+ - I_-)/(I_+ + I_-)$



- λ_{WCM} correlates nicely with e.g. λ_{14} from det. 14 sqrt asym:

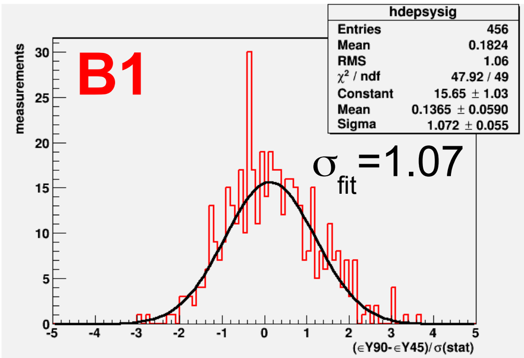


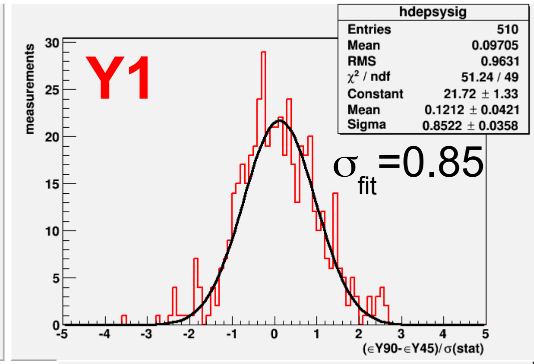
- Distribution $(\lambda_{WCM} - \lambda_{asym})/\sigma_{asym}$(stat):
- RMS ~3: WCM uncertainties much larger than detector stat. uncert.

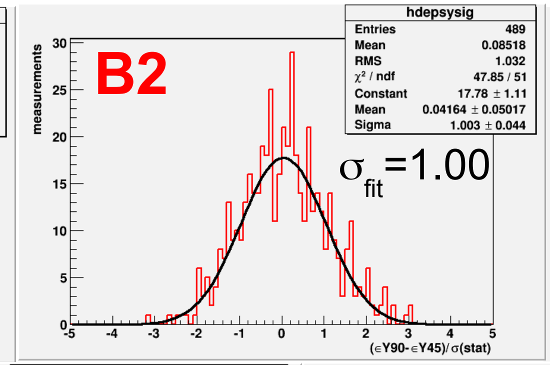


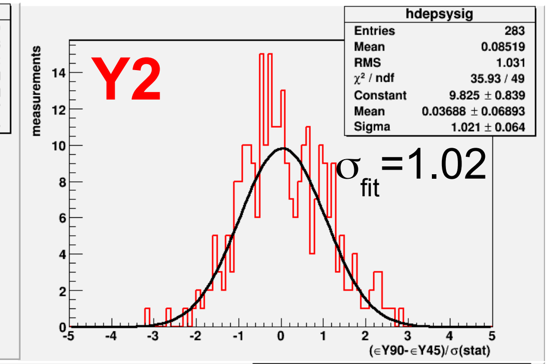
$(\epsilon Y90-\epsilon Y45)/\sigma(stat)$

- 4 polarimeters:

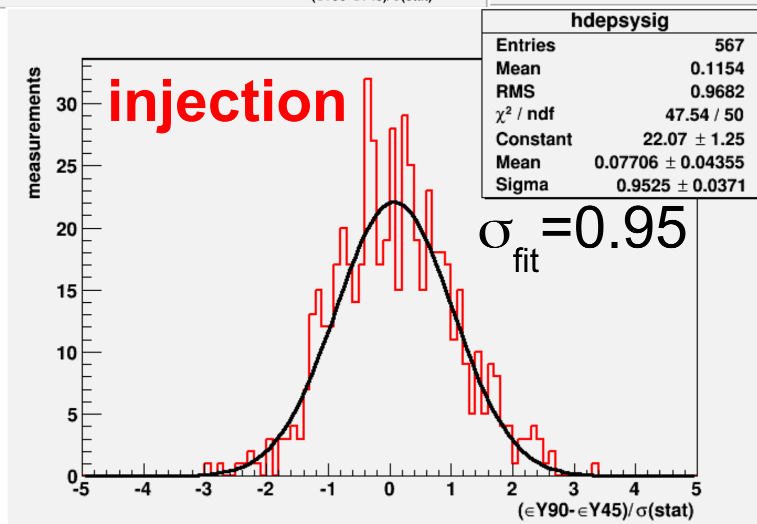


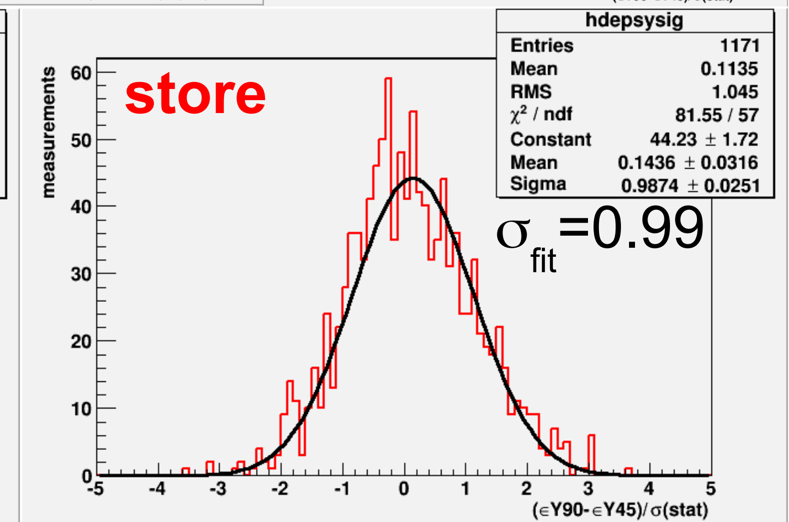




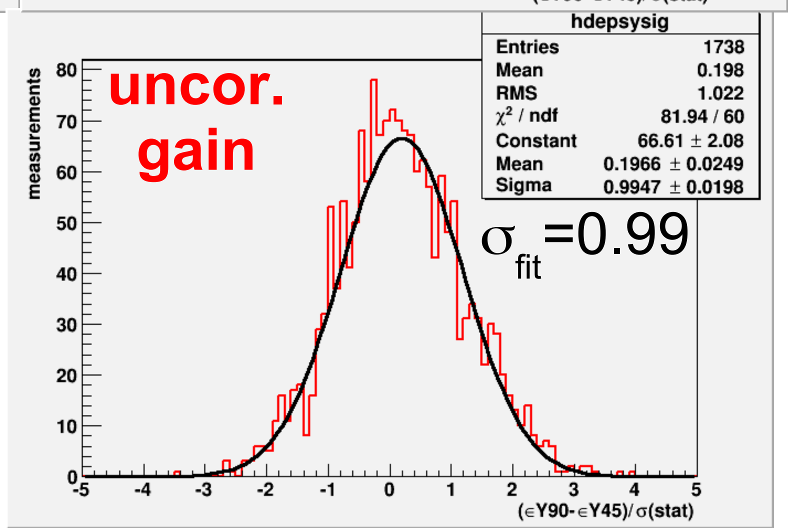


- injection / store:





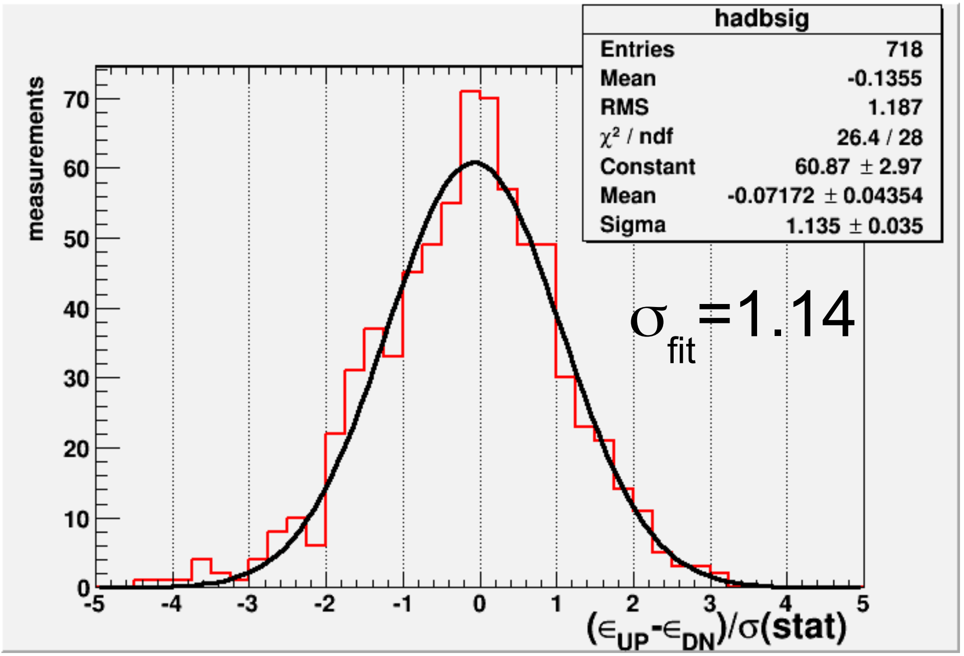
- α-gain not corrected:

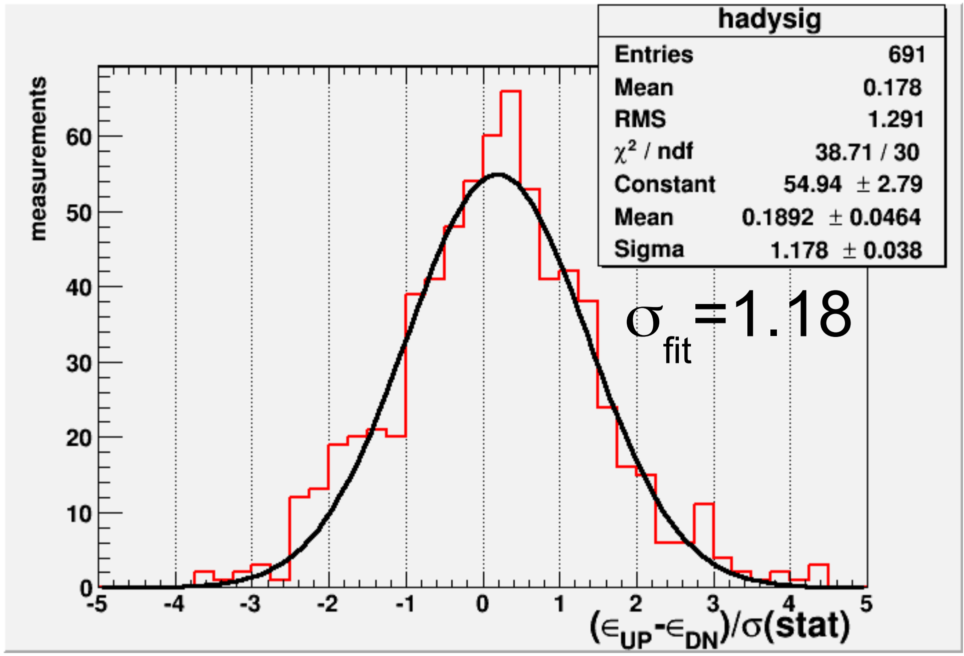


- **In all cases fluctuations**
- **consistent with statistics (RMS~1),**
- **no indication of systematic effects**

$|\epsilon|$ from U/D: 45° det. asym.

- Select Blu or Yel U,D measurements ~same time:
- Instead of ϵ vs. ϕ fit get $|\epsilon|$ from 45° det. cross asym.
  (easier to get. stat. uncert. from only 45° det.)
- Compare U/D differences to stat. uncert. $(|\epsilon_{UP}|-|\epsilon_{DN}|)/\sigma(\text{stat})$:
  (90° det. not used, less statistics, less significant conclusion)



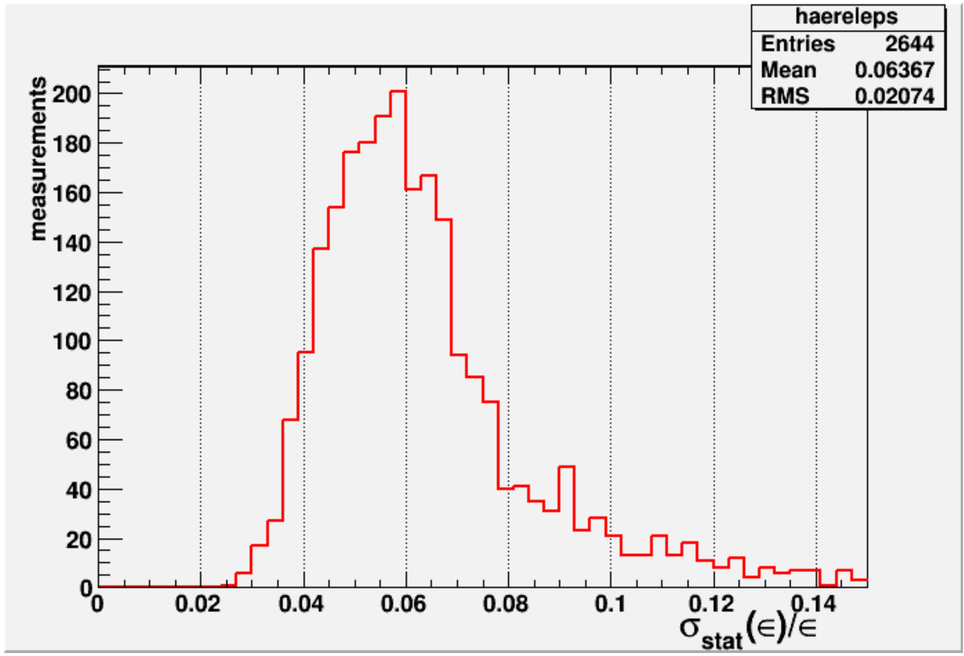


- Distributions significantly wider than unit gaussian: σ_{fit}~1.16
- $\sigma_{fit} = (1 \oplus \sigma_{syst}/\sigma_{stat})$, $\sigma_{syst}(|\epsilon|)$ comparable to $\sigma_{stat}(|\epsilon|)$

$\sigma_{syst}(\epsilon) \sim 0.59 \cdot \sigma_{stat}(\epsilon)$

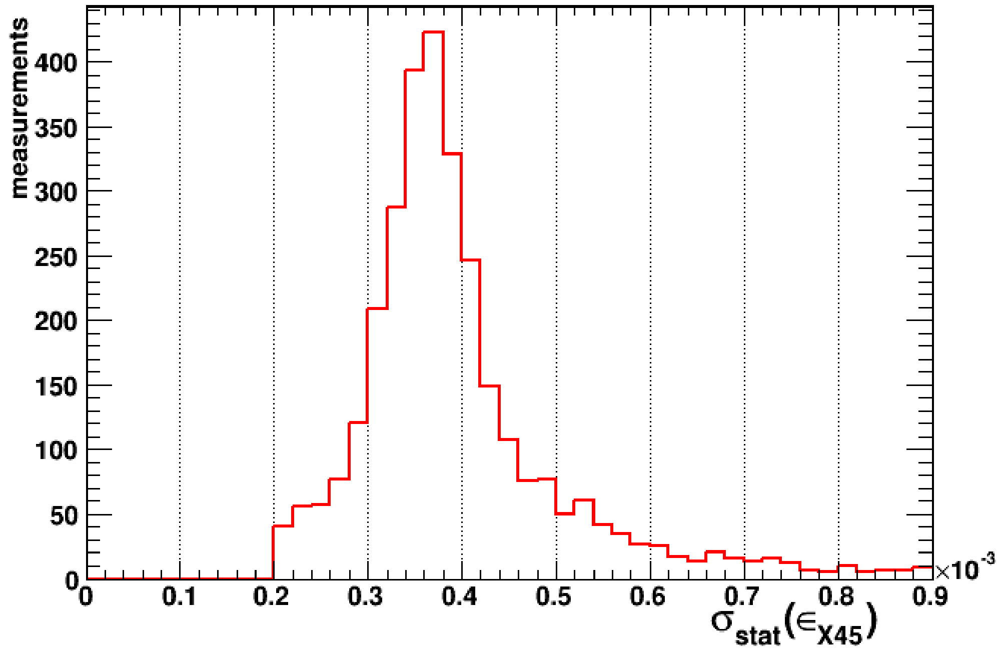
$|\epsilon|$ from U/D: 45° det. asym.

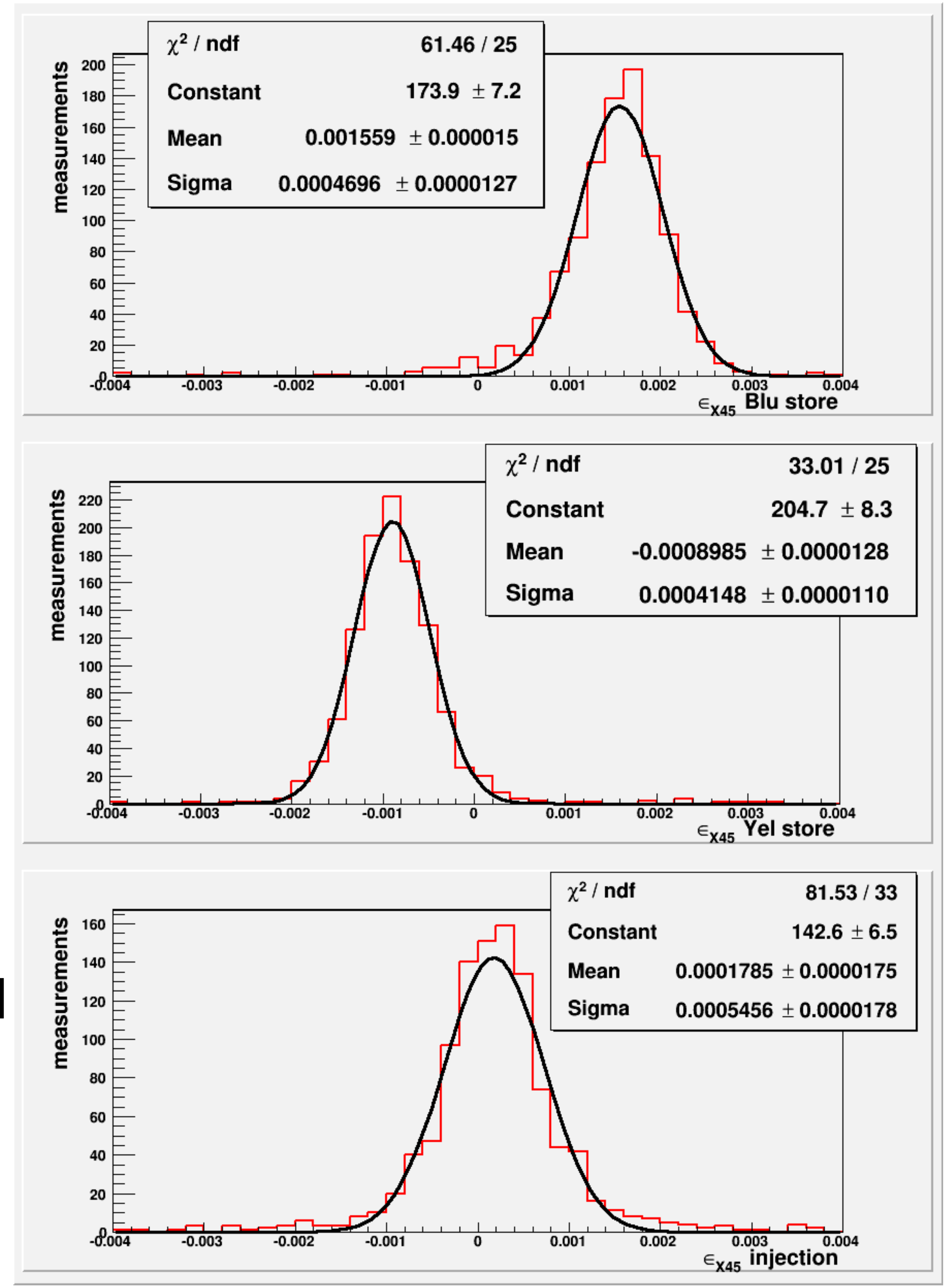
- $\sigma_{syst}(\epsilon_Y) \sim 0.59 \cdot \sigma_{stat}(\epsilon_Y)$
- Relative stat. uncert. $\sigma_{stat}(\epsilon)/\epsilon \approx 6.4\%$:
- So $\sigma_{syst}(\epsilon)/\epsilon \approx 4\%$,
- $A_N \propto \epsilon$
- So $\sigma_{syst}(A_N)/A_N \approx 4\%$



- **Systematic variations of A_N, between between different polarimeters, is about 4%**

RMS ϵ_X





- Widths of ϵ_X distributions 4-5×10^{-4}
- Stat. uncert. ~4×10^{-4}
- Widths of ϵ_X distributions dominated by stat. fluctuations