Exploring gluon polarization in lower-x region

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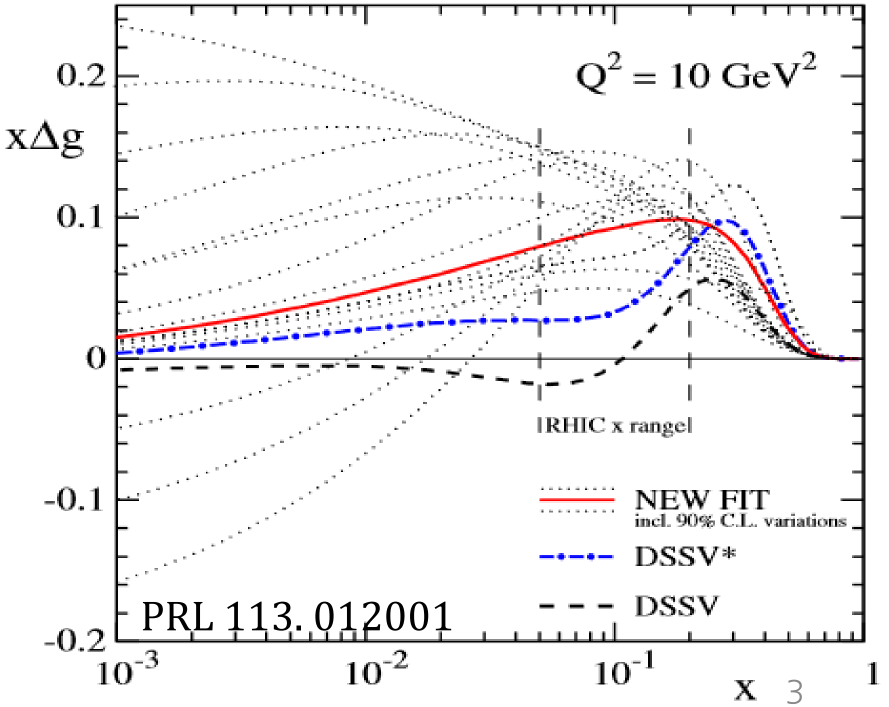
Motivation

- Spin sum rule: $\frac{1}{2} = \int_0^1 dx\, [\frac{1}{2}(\Delta q + \Delta\bar{q}) + \Delta g] + L_q + L_g$
  Quark contribution 25~35% from DIS experiment.

- PP collision provide access to Δg at leading-order through g-g and g-q scattering.

- $A_{LL}^{\pi^0}$ measurement give access to Δg.
  - most of π^0s are from g-g and q-g scattering.
  - large statistics.
  - Clear visible peak

- PHENIX $A_{LL}^{\pi^0}$ (PRD 83, 032001)
  STAR A_{LL}^{Jet} (arXiv:1405.5134)
  at $\sqrt{s} = 200$ GeV.

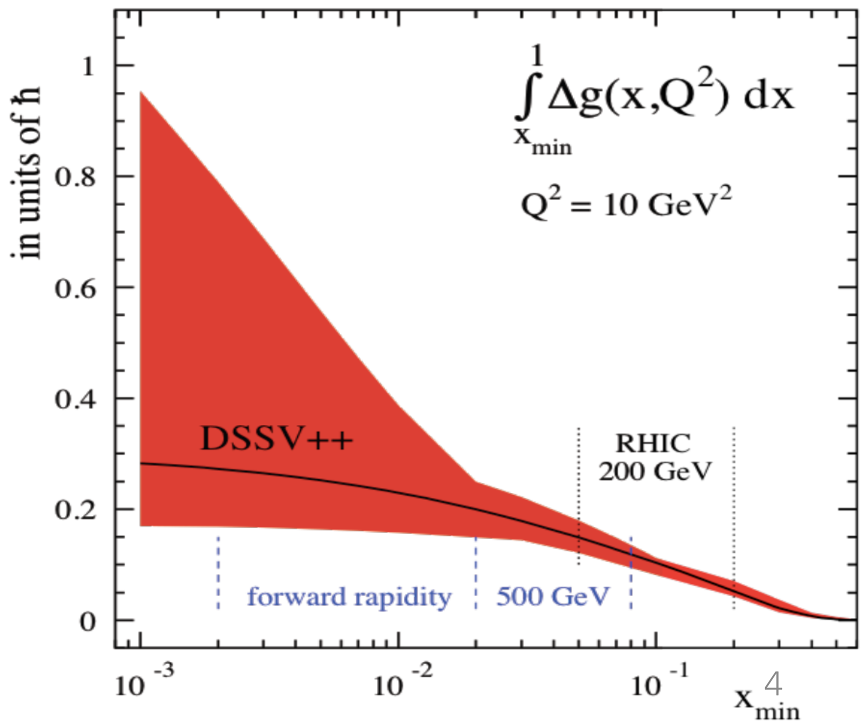


Motivation

- Large uncertainty in low x range.

- To expand sensitivity to low x range,
  1. $A_{LL}^{\pi^0}$ measurement at $\sqrt{s}=510$ GeV.
  2. $A_{LL}^{EM\ Cluster}$ measurement at forward-rapidities.

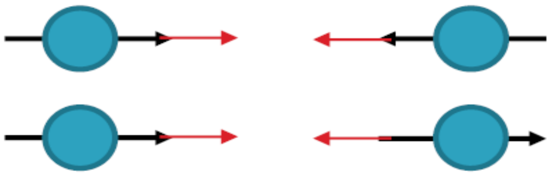
- Coverage
  $A_{LL}^{\pi^0}$ at $\sqrt{s}=200$ GeV : 0.05<x
  $A_{LL}^{\pi^0}$ at $\sqrt{s}=510$ GeV : 0.02<x
  forward $A_{LL}^{EM\ Cluster}$: 0.002<x

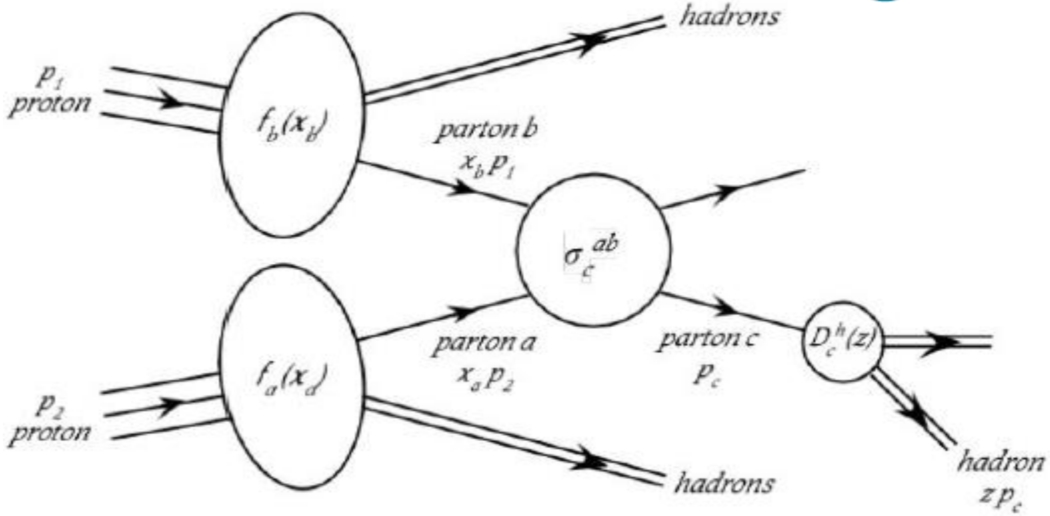


Definition of $A_{LL}^{\pi^0}$ and its interpretation

- $A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$

  $\sigma_{++(+-)}$ from like(unlike) helicity proton collision.





- $\Delta\sigma = \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{ab\to cX} \otimes D_{fc}^{h}$

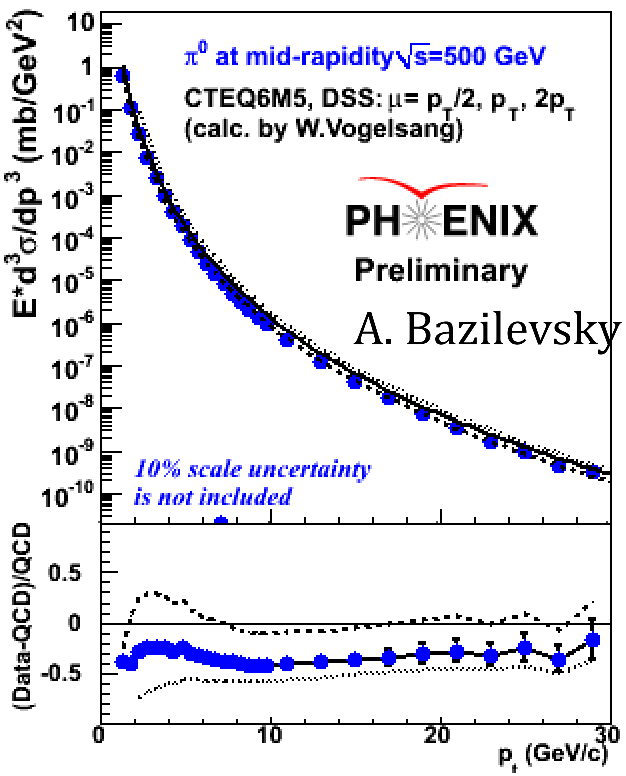
  $d\hat{\sigma}^{ab\to cX}$: pQCD, $D_{fc}^{\pi^0}$: e^+e^- scattering.

Definition of $A_{LL}^{\pi^0}$ and its interpretation

- Validity test of factorization by unpolarized cross-section measurement.

- Theory calculation by factorization explains well experimental data.

- It's safe to use factorization to interpret $A_{LL}^{\pi^0}$.



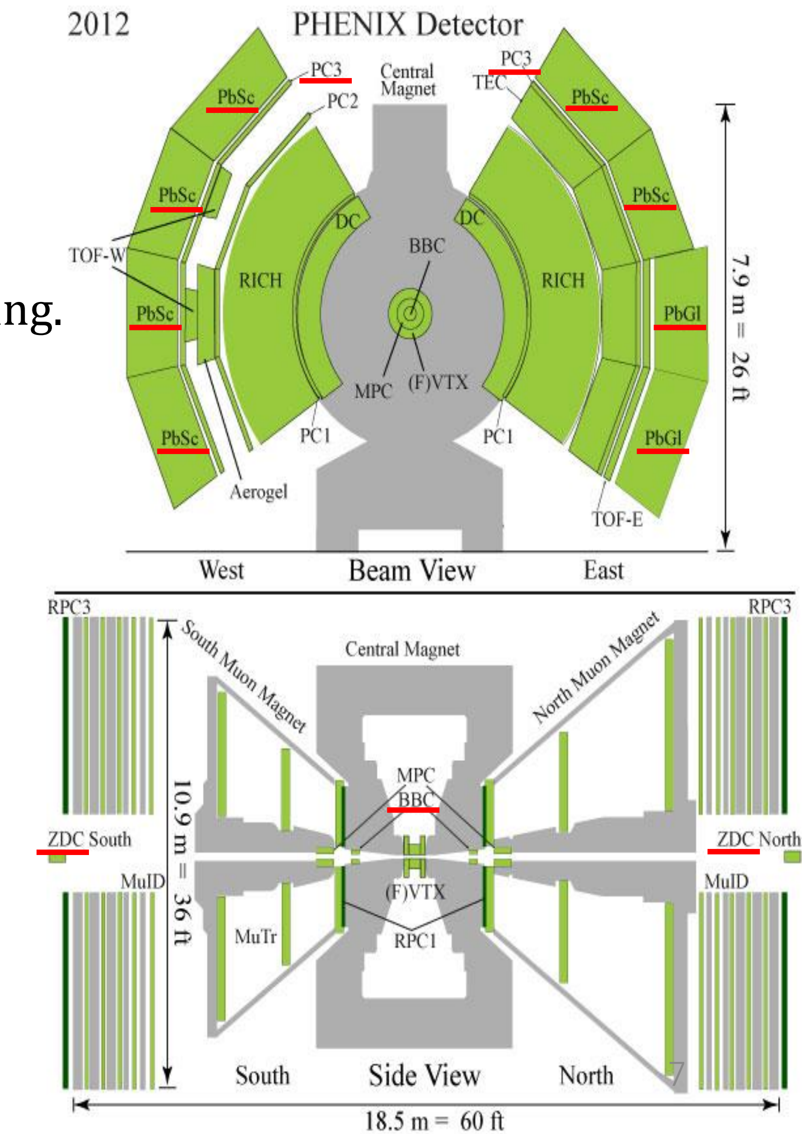
PHENIX Detector Configuration

- EMCal : $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

- ERT : high energy cluster trigger
  Different circuits are used for even and odd crossing.
  → Crossing separated analysis is needed.

- BBC : minbias trigger, primary lumi. detector.
  ZDC : secondary lumi. detector

- PC3 : to reject charged cluster.



PHENIX Longitudinal Spin Runs

Table 1. Summary of PHENIX Longitudinal Spin Runs.

Year	$\sqrt{s}$ (GeV)	L (pb^{-1})	P (%)	FoM (P^4L)
2003	200	3.5×10^{-1}	27	1.9×10^{-3}
2004	200	1.2×10^{-1}	40	3.1×10^{-3}
2005	200	3.4×10^{0}	49	2.0×10^{-1}
2006	200	7.5×10^{0}	57	7.9×10^{-1}
2006	62.4	8.0×10^{-2}	48	4.2×10^{-3}
2009	500	1.0×10^{1}	40	2.6×10^{-1}
2009	200	1.4×10^{1}	57	1.4×10^{0}
2011	500	1.7×10^{1}	48	8.8×10^{-1}
2012	510	3.0×10^{1}	52	2.2×10^{0}
2013	510	1.5×10^{2}	55	1.4×10^{1}

Run13 Spin Patterns

- 2 weeks : p1 ~ p8.
  Remaining weeks : p21 ~ p28

- After middle of Run13, crossing 38, 39, 78, and 79 are filled.

- 16 patterns can be sorted in 4 groups.

SOOSSOO	P1	P4	P5	P8
OSSOOSS	P2	P3	P6	P7
SSOO	P21	P24	P25	P28
OOSS	P22	P23	P26	P27

Table 2.4: Sort of spinpattern

∵ p1 and p5 are symmetric under beam change.
p1 and p4 are symmetric under parity inversion.

- Because of ghost clusters, analysis has been done 4 spin patterns separately.

Analysis Flow

- Low level study
  - EMCal tower-by-tower ToF correction.
  - EMCal warn map generation.
  - EMCal run-by-run energy correction.

- Event selection
  - Trigger requirement on event
    : ERT4x4C&&BBCLL1 : $P_T < 5$GeV, ERT4x4A&&BBCLL1 : $P_T > 5$GeV.
  - Trigger requirement on π^0 : at least one triggered cluster.
  - $|ZVertex_{BBC}| < 30$cm
  - Min. energy requirement > 300 MeV
  - -15ns<ToF<15ns (PbSc), -10ns<ToF<10ns.
  - prob_photon>0.02
  - Charge veto.

Analysis Flow - continue

- A_{LL} calculation.
  - A_{LL}^{Peak} and A_{LL}^{Side} calculation.
  - Background subtraction and $A_{LL}^{\pi^0}$.

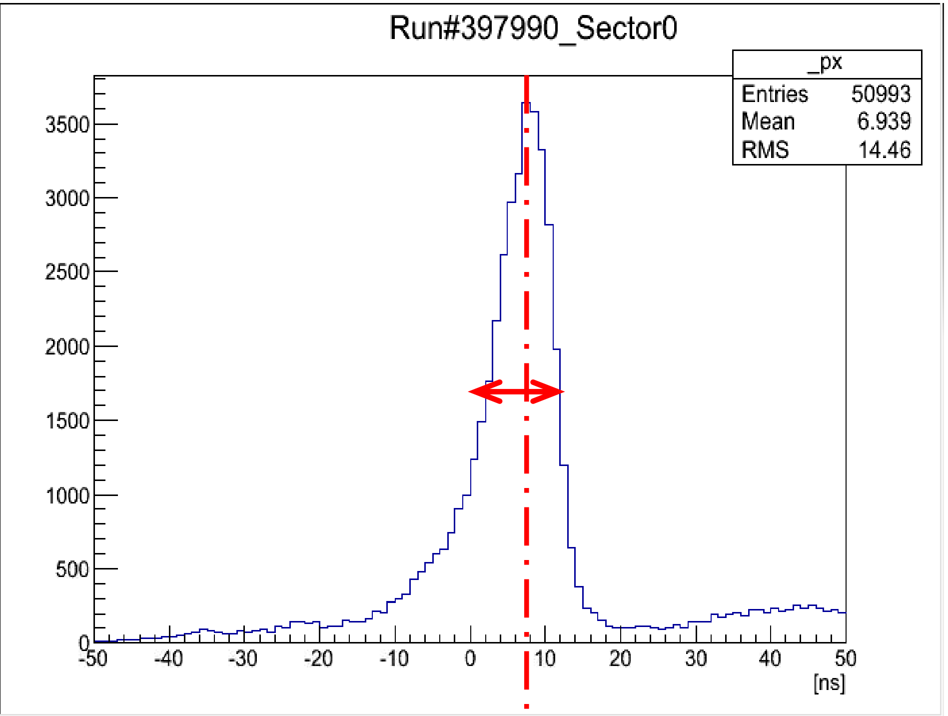
- $A_{LL}^{ZDC/BBC}$ measurement.
  - Check helicity dependence of luminosity detector.
  - Pileup correction
  - Width correction.
  - Spin pattern correlation.

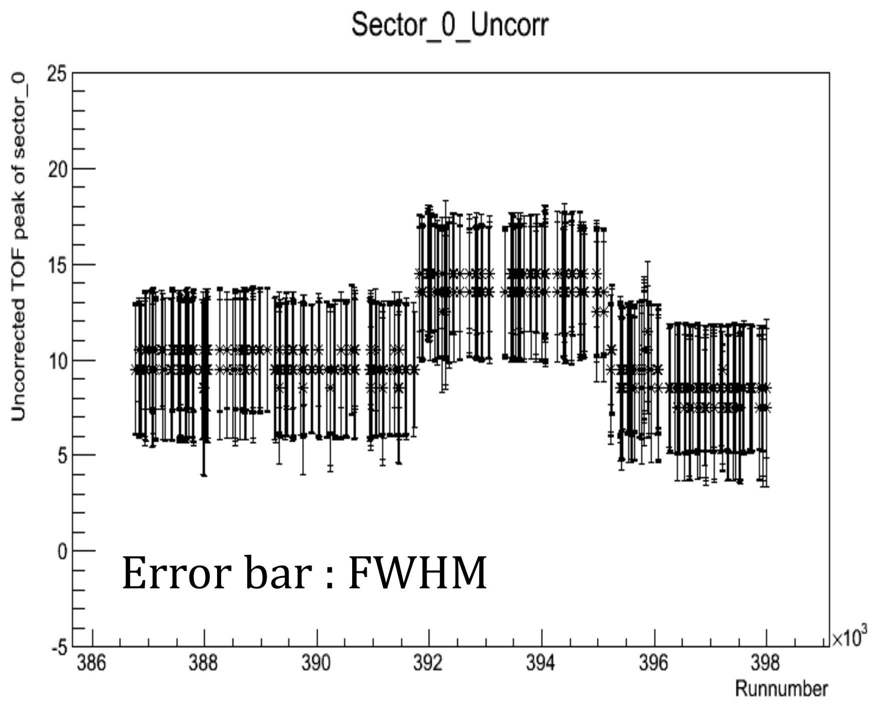
- A_L calculation.

EMCal Tower-by-Tower ToF Correction

- Tower-by-tower ToF shift is observed and the shift depends on time.

- We need to correct it to apply ToF cut.

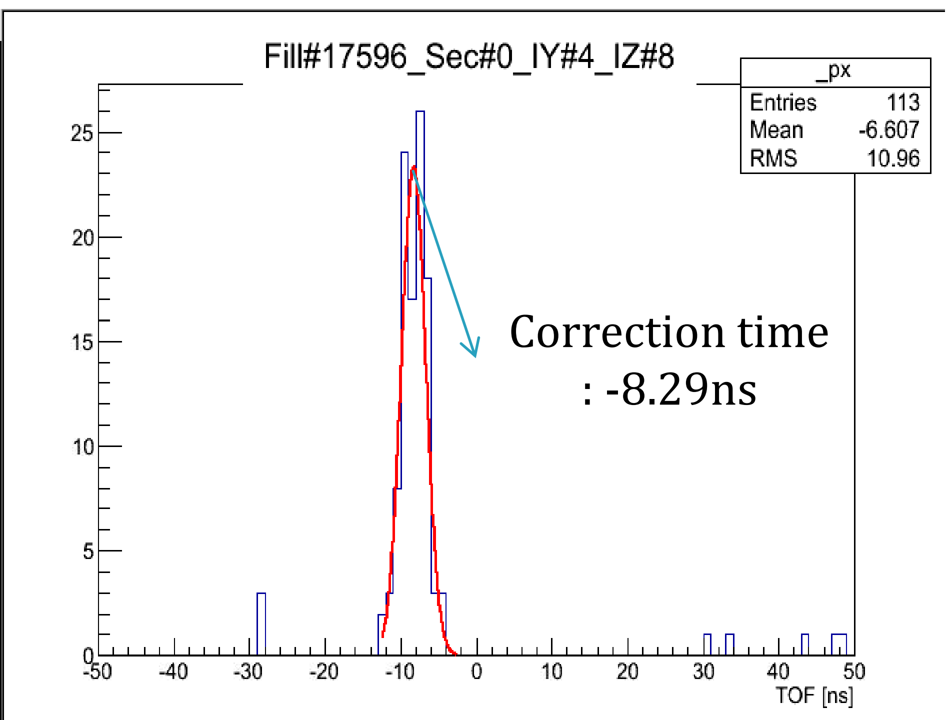


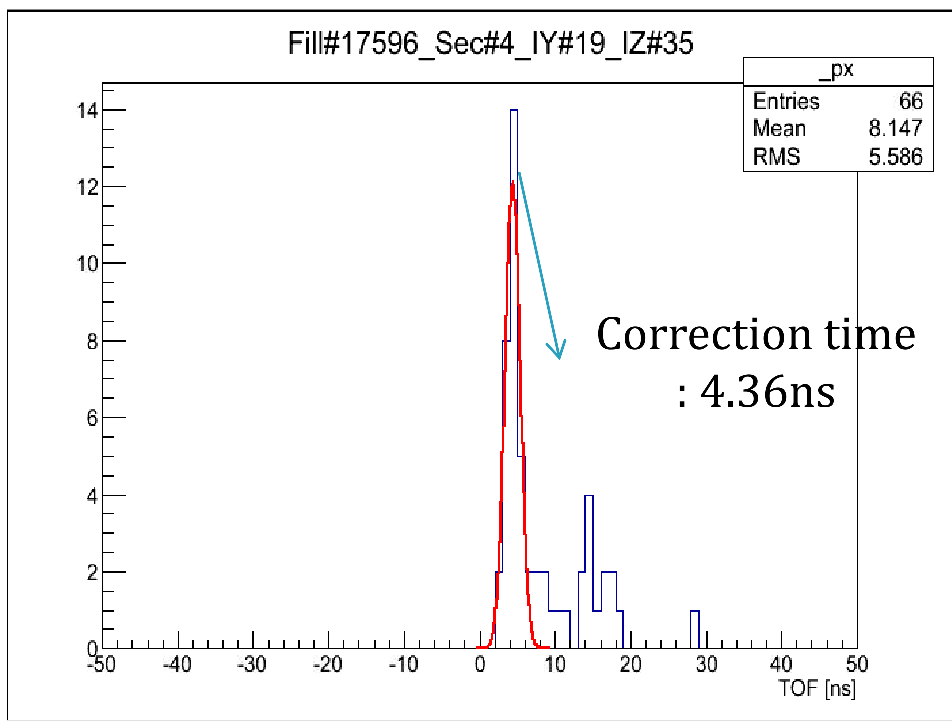


EMCal Tower-by-Tower ToF Correction

- Uncorrected $TOF = EMCal\ TOF(tower) - BBC\ t0$.
  Correted $TOF = EMCal\ TOF(tower) - BBC\ t0 - Correction\ time(tower)$.

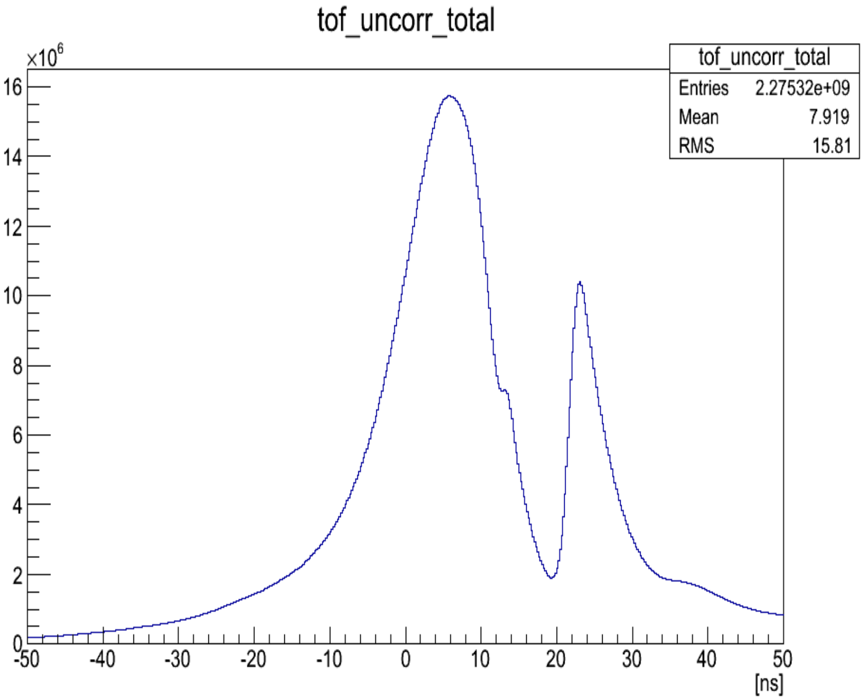
- Correction times : finding peak time of photons. (shower shape cut)
  Fill-by-fill correction : to remove time dependence of the shift.

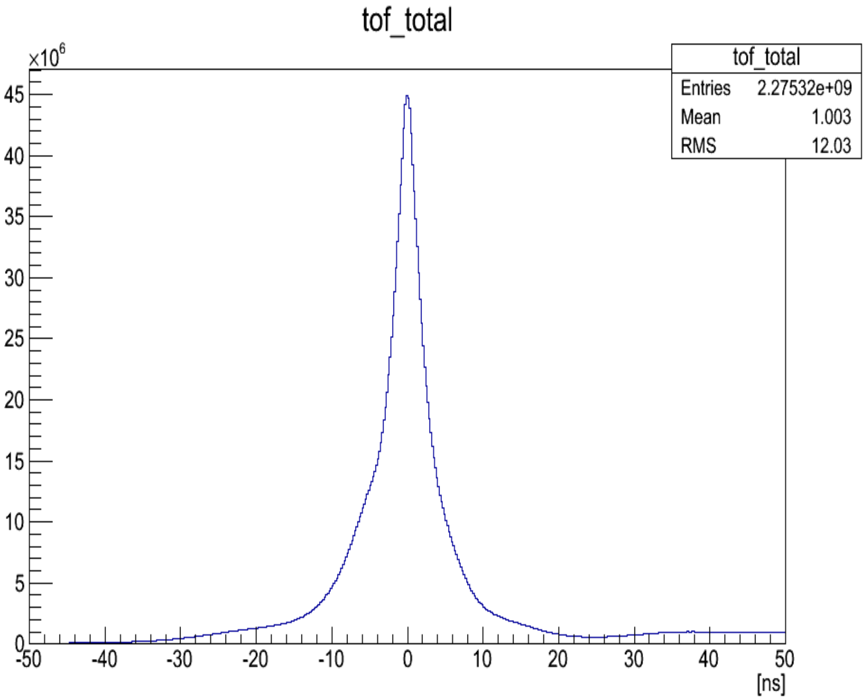




EMCal Tower-by-Tower ToF Correction

- After the correction, EMCal ToF is well corrected for $A_{LL}^{\pi^0}$ analysis.



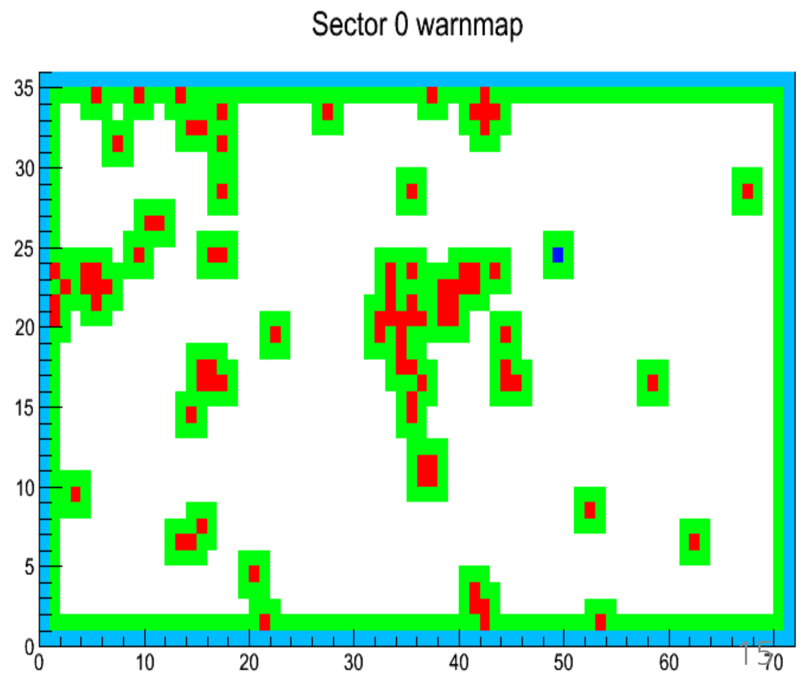


EMCal Warnmap Generation

- Map of hot, dead, uncalibrated, edge of sector, and neighbor of the bad towers.

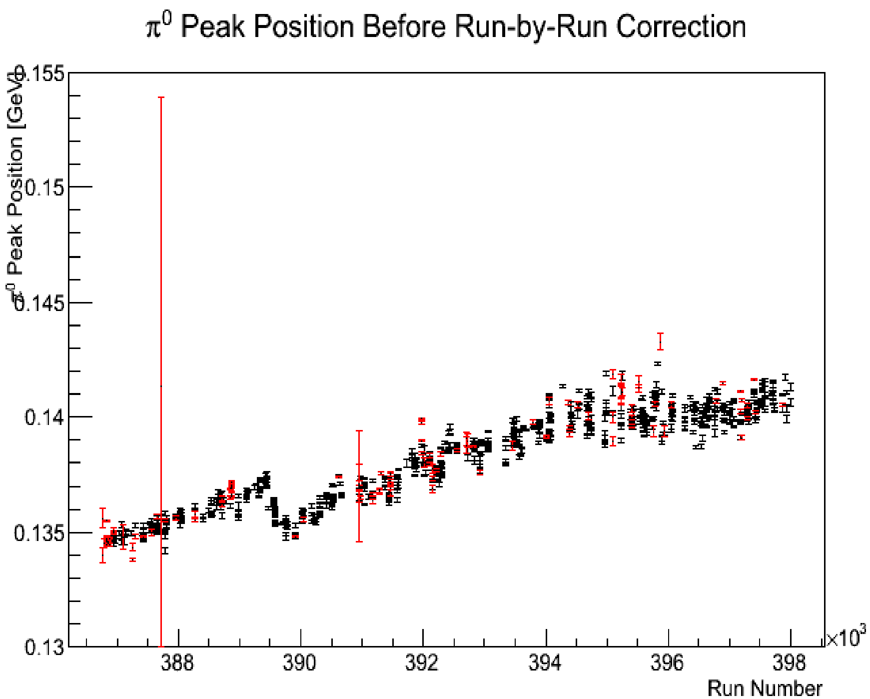
- EM cluster spreads at least 3x3 towers.
  Thus EM hit neighbor tower leaks into the bad towers.

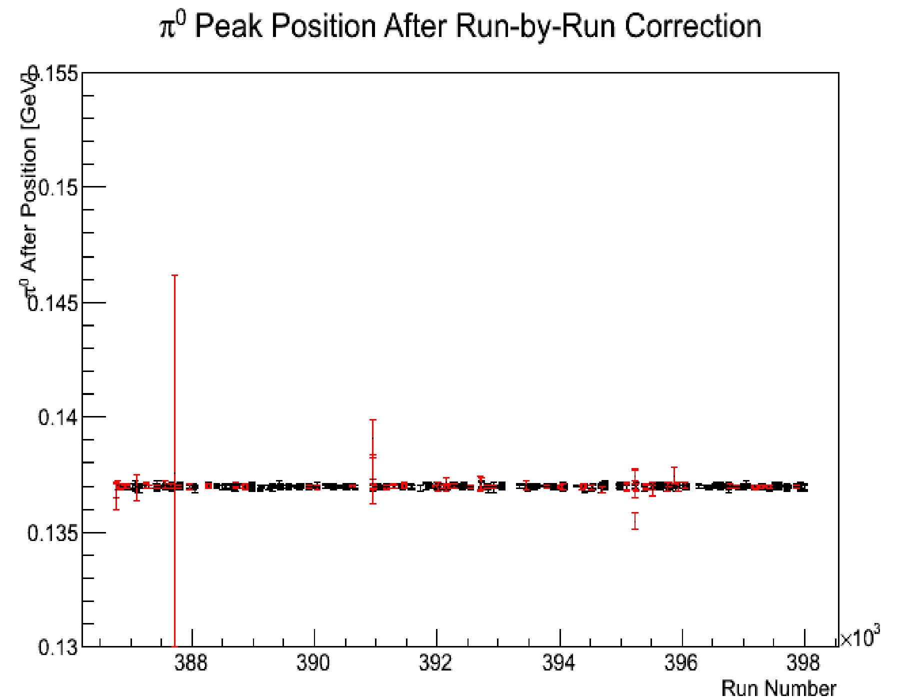
- Additional (non edge tower) 15% of EMCal towers are masked.



EMCal run-by-run Energy calibration

- Run-by-run EMCal gain shift is observed.
- EMCal run-by-run energy calibration has been done by π^0 peak position.
- The calibration has been done run-by-run and sector-by-sector.

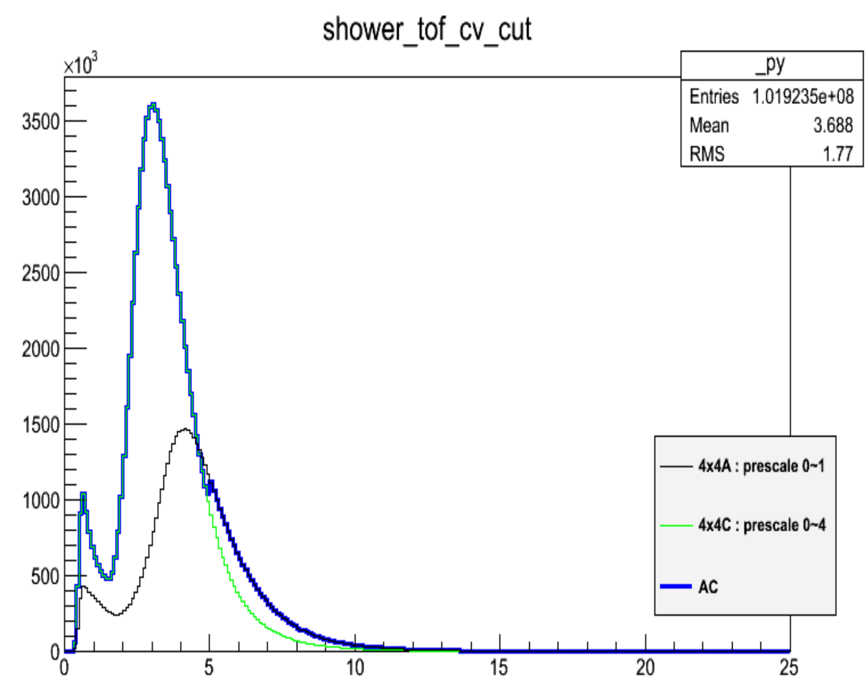


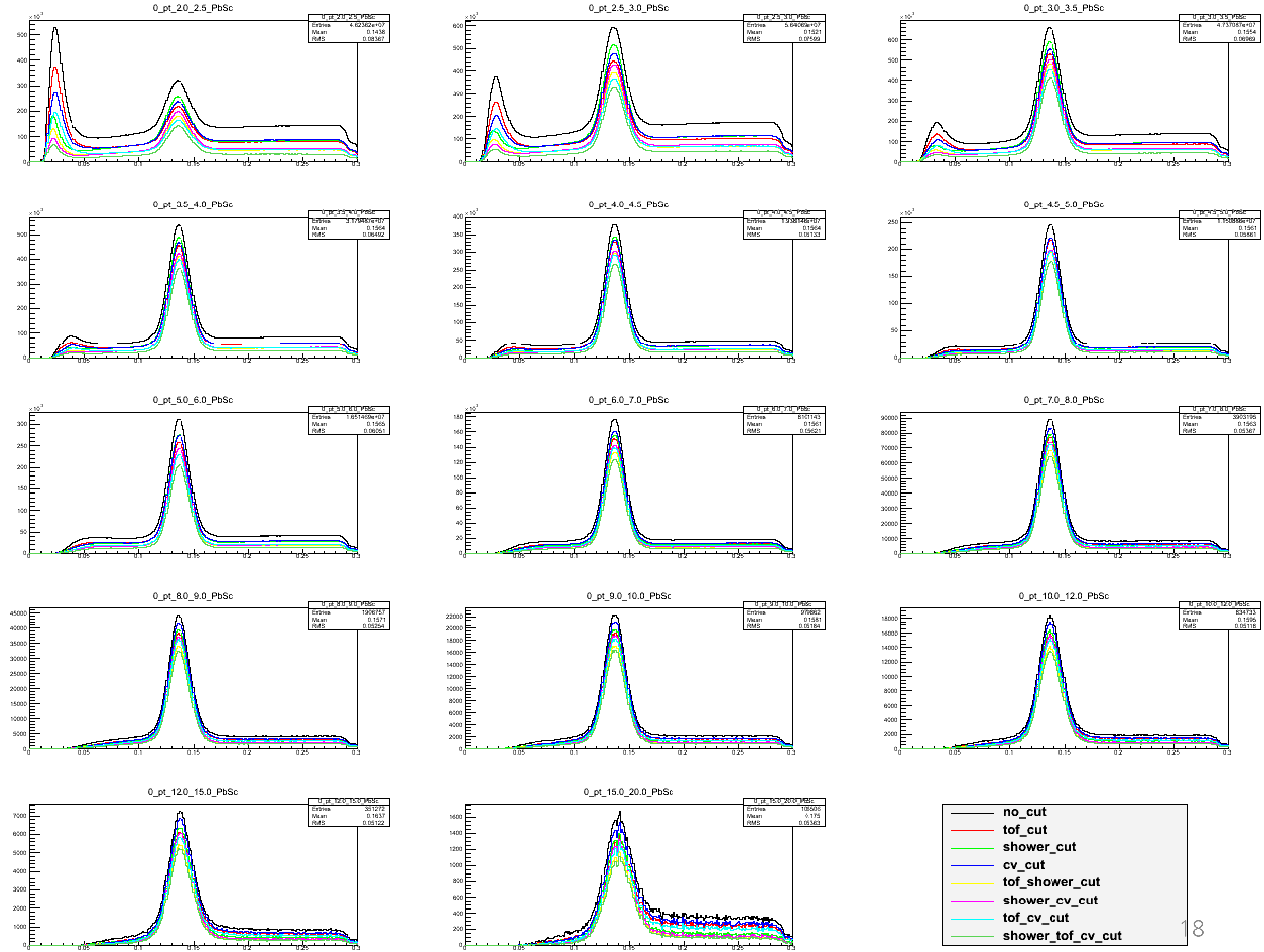


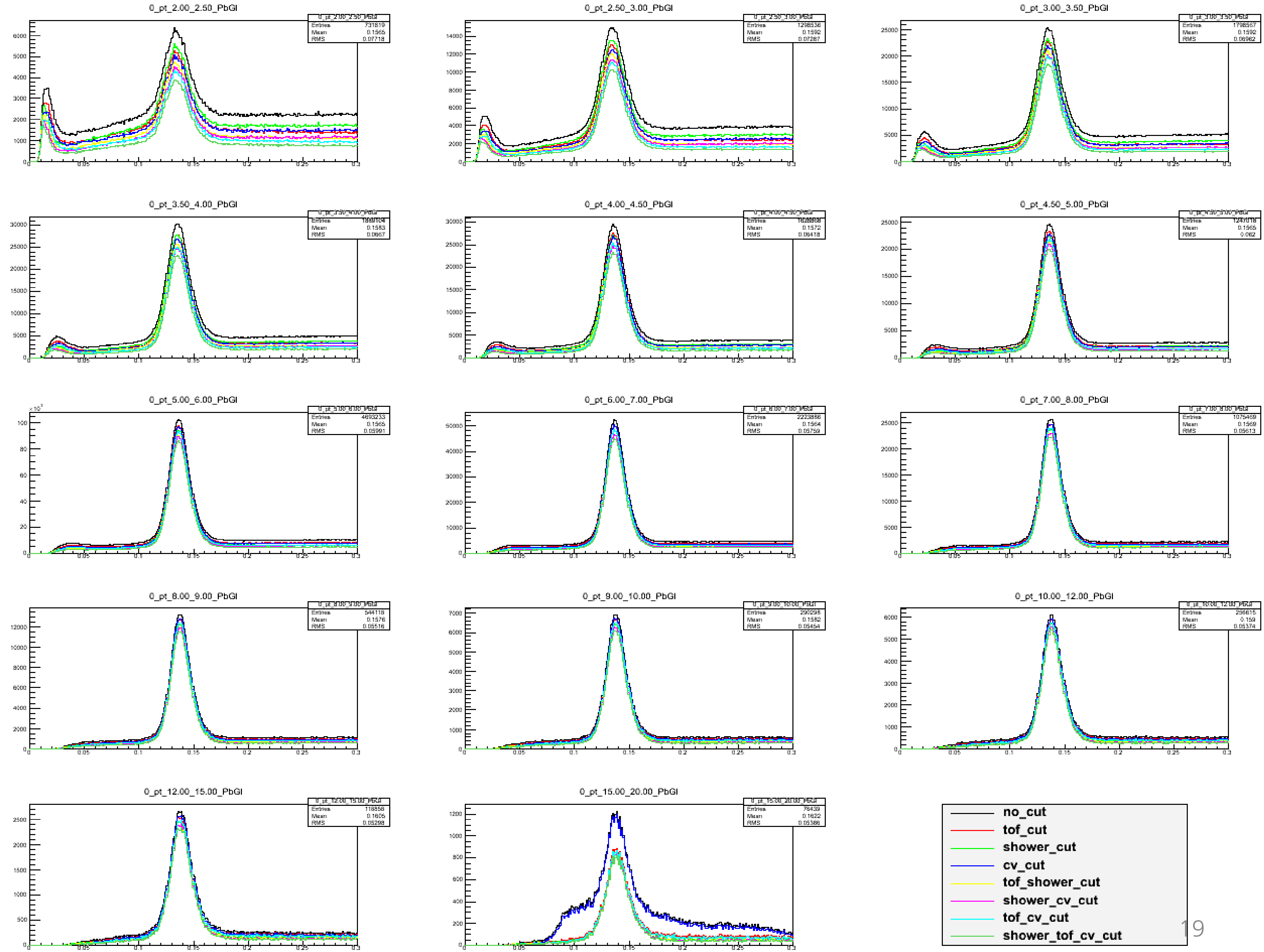
Trigger Requirement

- For $P_T < 5GeV$, 4x4C
  For $P_T > 5GeV$, 4x4A.

- Trigger bit is required for at least one cluster to assure same trigger bias.
  $p + p \rightarrow \pi^0 + X$ and π^0 triggers ERT.
  $p + p \rightarrow \pi^0 + C + X$ and C triggers ERT. (×)
  ∵ second π^0 is from different bias.




0_pt_2.0_2.5_PbSc
0_pt_2.5_3.0_PbSc
0_pt_3.0_3.5_PbSc
0_pt_3.5_4.0_PbSc
0_pt_4.0_4.5_PbSc
0_pt_4.5_5.0_PbSc
0_pt_5.0_6.0_PbSc
0_pt_6.0_7.0_PbSc
0_pt_7.0_8.0_PbSc
0_pt_8.0_9.0_PbSc
0_pt_9.0_10.0_PbSc
0_pt_10.0_12.0_PbSc
0_pt_12.0_15.0_PbSc
0_pt_15.0_20.0_PbSc
no_cut
tof_cut
shower_cut
cv_cut
tof_shower_cut
shower_cv_cut
tof_cv_cut
shower_tof_cv_cut


0_pt_2.00_2.50_PbGl
0_pt_2.50_3.00_PbGl
0_pt_3.00_3.50_PbGl
0_pt_3.50_4.00_PbGl
0_pt_4.00_4.50_PbGl
0_pt_4.50_5.00_PbGl
0_pt_5.00_6.00_PbGl
0_pt_6.00_7.00_PbGl
0_pt_7.00_8.00_PbGl
0_pt_8.00_9.00_PbGl
0_pt_9.00_10.00_PbGl
0_pt_10.00_12.00_PbGl
0_pt_12.00_15.00_PbGl
0_pt_15.00_20.00_PbGl
no_cut
tof_cut
shower_cut
cv_cut
tof_shower_cut
shower_cv_cut
tof_cv_cut
shower_tof_cv_cut

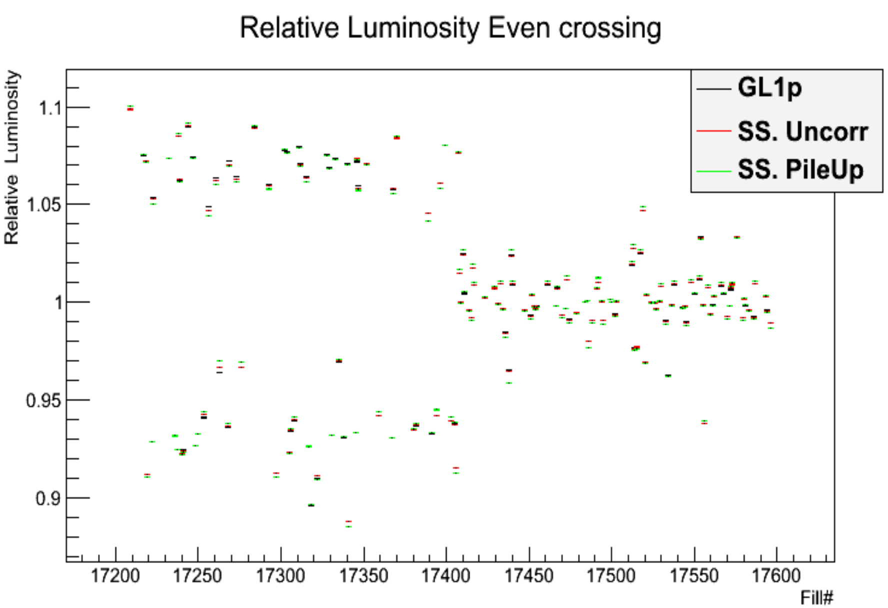
Fill-by-Fill A_{LL} Calculation

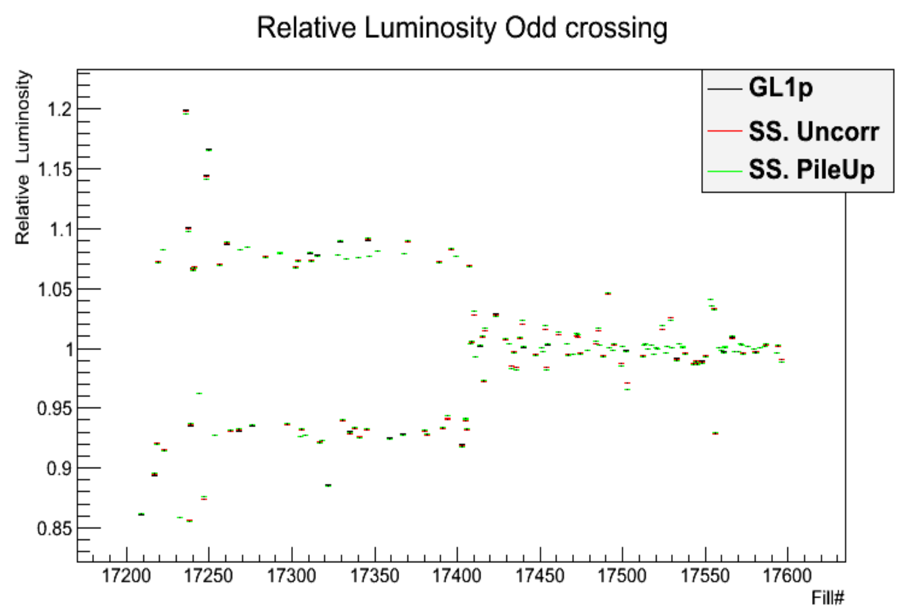
- $A^{Peak(Side)}{}_{LL} = \frac{1}{P_B P_Y} \frac{N^{Peak(Side)}{}_{++} - R N^{Peak(Side)}{}_{+-}}{N^{Peak(Side)}{}_{++} + R N^{Peak(Side)}{}_{+-}}$,

  $R = \frac{\sum N^{BBC}_{++}}{\sum N^{BBC}_{+-}}$. (pileup corrected, prescale+1 down)

- N^{Peak} : events $0.112GeV < M_{\gamma\gamma} < 0.162GeV$

  N^{Side} : events $0.047GeV < M_{\gamma\gamma} < 0.097GeV$ or $0.177GeV < M_{\gamma\gamma} < 0.227GeV$

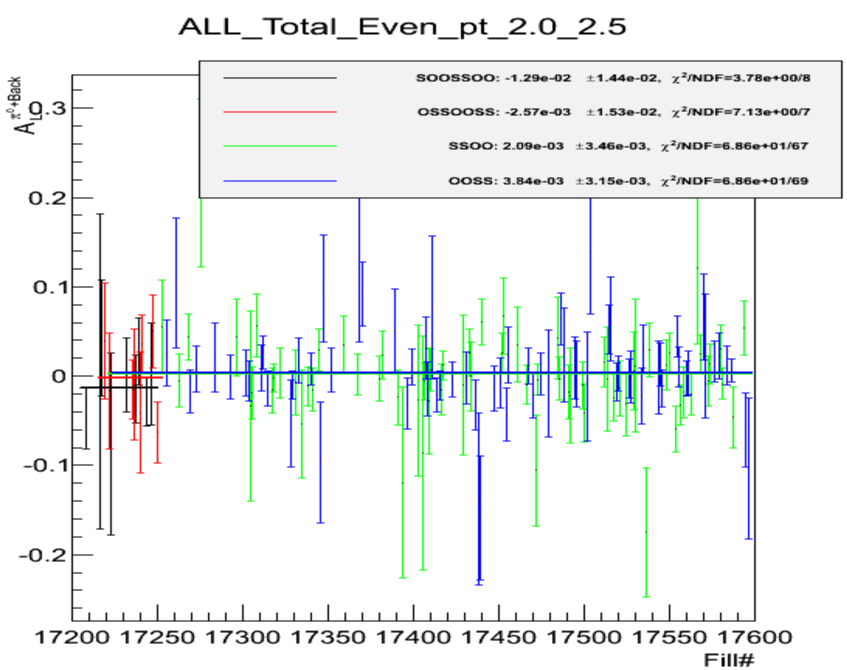




Obtaining Run13 A_{LL}

- Constant fit to get Run13 A_{LL}.

- Spin pattern and crossing separated fitting has been done.
  ∵ Spin pattern : ghost cluster.
  Crossing : ERT property.



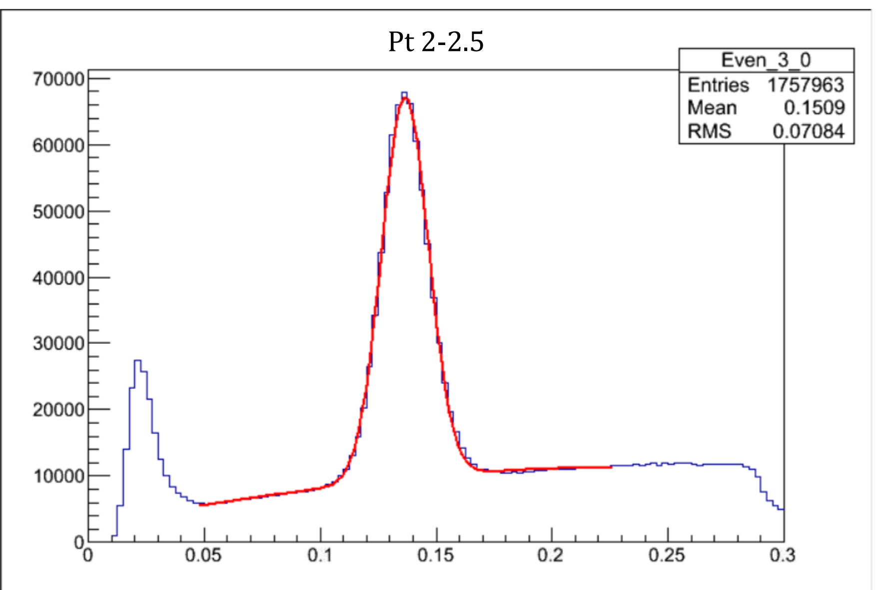
Subtracting Background Contribution

- $A_{LL}^{\pi^0} = \frac{A_{LL}^{Peak} - rA_{LL}^{Side.}}{1-r}$, Where r is background fraction in peak region.

  BG subtraction : spinpattern and crossing separated.

- To get r, gaus+pol3 fitting has been done.

  Then, $r = \frac{\int_{0.112}^{0.162} pol3}{\int_{0.112}^{0.162} Gaus+pol3}$.



Pt bin	fraction.(%)
2-2.5	20.9777
2.5-3	15.6042
3-3.5	12.5159
3.5-4	10.9631
4-4.5	9.76821
4.5-5	9.73248
5-6	10.9942
6-7	9.73907
7-8	9.46908
8-9	9.75697
9-10	7.9014
10-12	6.72958
12-15	8.28725
15-20	9.1639

$A_{LL}^{ZDC/BBC}$ measurement

- $R = \frac{\sum N_{++}^{BBC}}{\sum N_{+-}^{BBC}}$

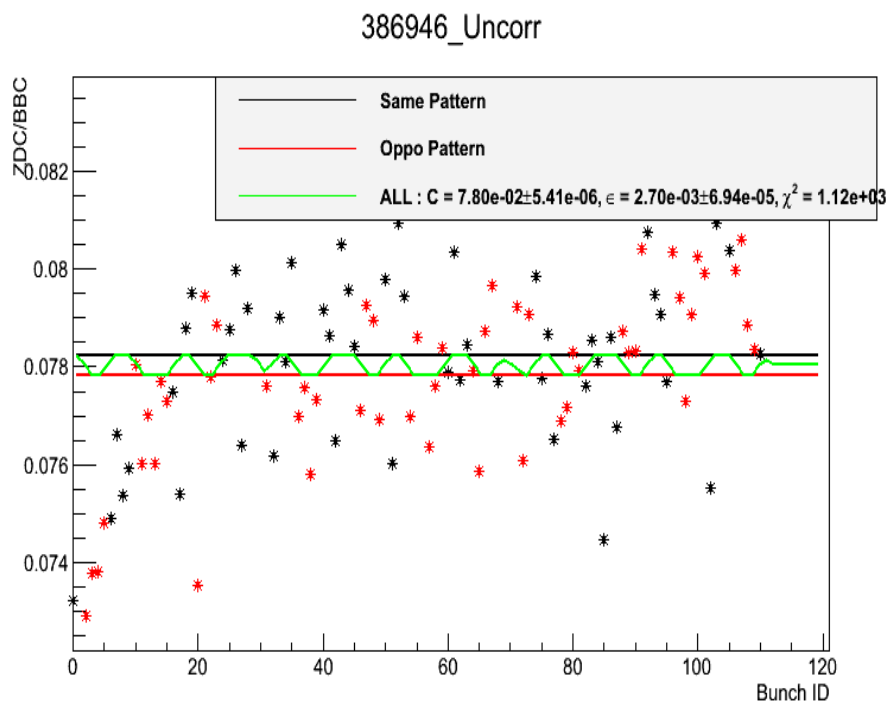
- Need to check helicity dependence of luminosity detector.
  → Need to measure A_{LL} of luminosity detector, BBC30.
  → Secondary luminosity detector is needed, ZDC30.
  BBC30 for luminosity, ZDC30 for event count. (vice versa.)
  → $A_{LL}^{ZDC/BBC}$

- $A_{LL}^{ZDC/BBC}$ and its uncertainty are source of systematic uncertainty of any A_{LL}.

$A_{LL}^{ZDC/BBC}$ measurement

- $r(i) = c \times [1 + \epsilon_{LL} \times Pattern_{Blue} \times Pattern_{Yellow}]$, where $r(i) = \frac{ZDC\ 30(i)}{BBC\ 30(i)}$

$\rightarrow Single\ run\ A_{LL}^{ZDC/BBC} = \frac{\varepsilon_{LL}}{P_B P_Y}$,

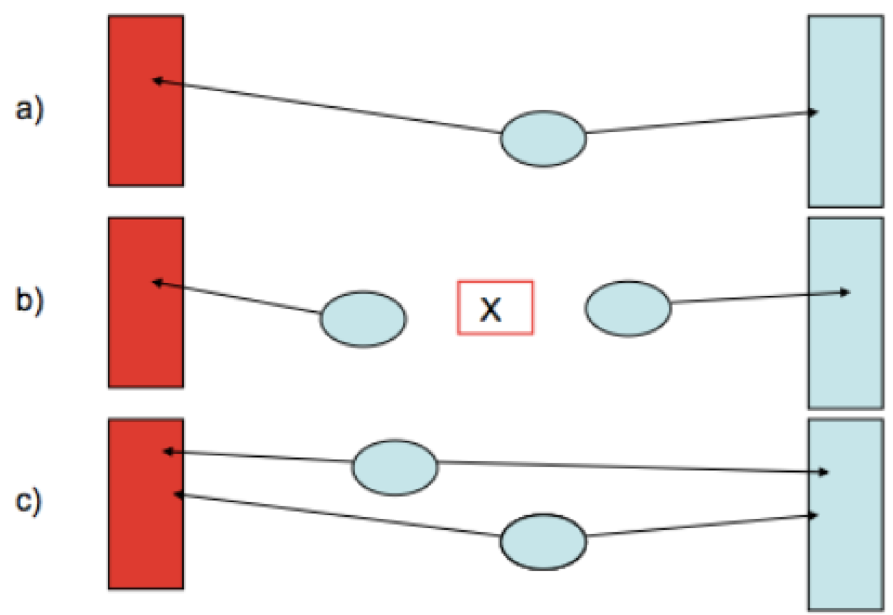


Pileup Correction

- Luminosity can be miscounted by multiple or single-side collision.

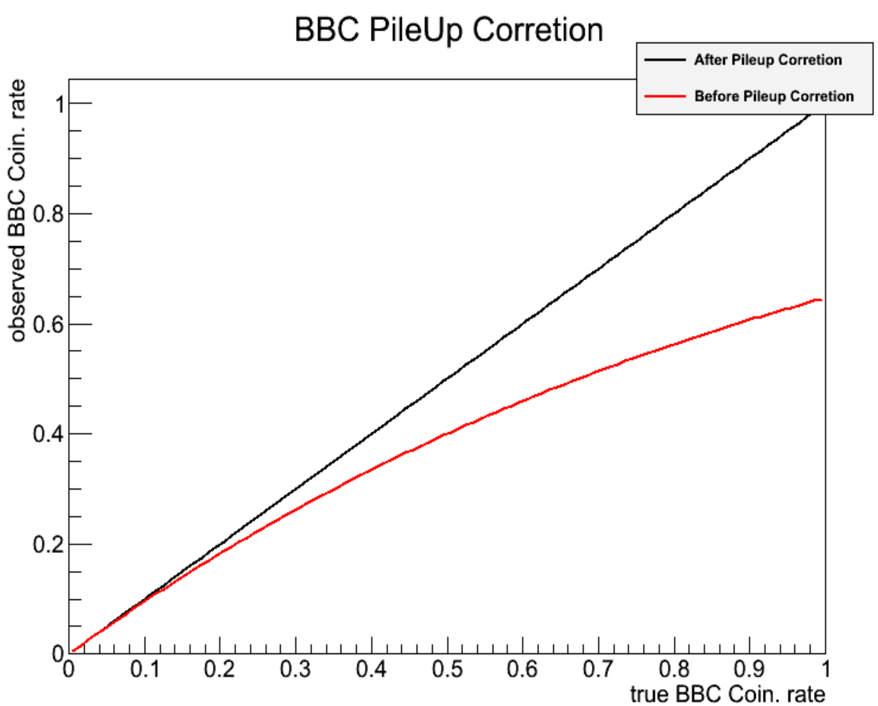
- $observed\ rate = 1 - e^{-true\ rate(1+k_n)} - e^{-true\ rate(1+k_s)} + e^{-true\ rate(1+k_n+k_s)}$
  where,
  $k_{n(s)} = \frac{\epsilon_{n(s)}}{\epsilon_{ns}}$
  ϵ_0 : no hit on both side detector.
  ϵ_n : exclusive hit on north side detector.
  ϵ_s : exclusive hit on south side detector.
  ϵ_{ns} : coin. hit on south side detector.

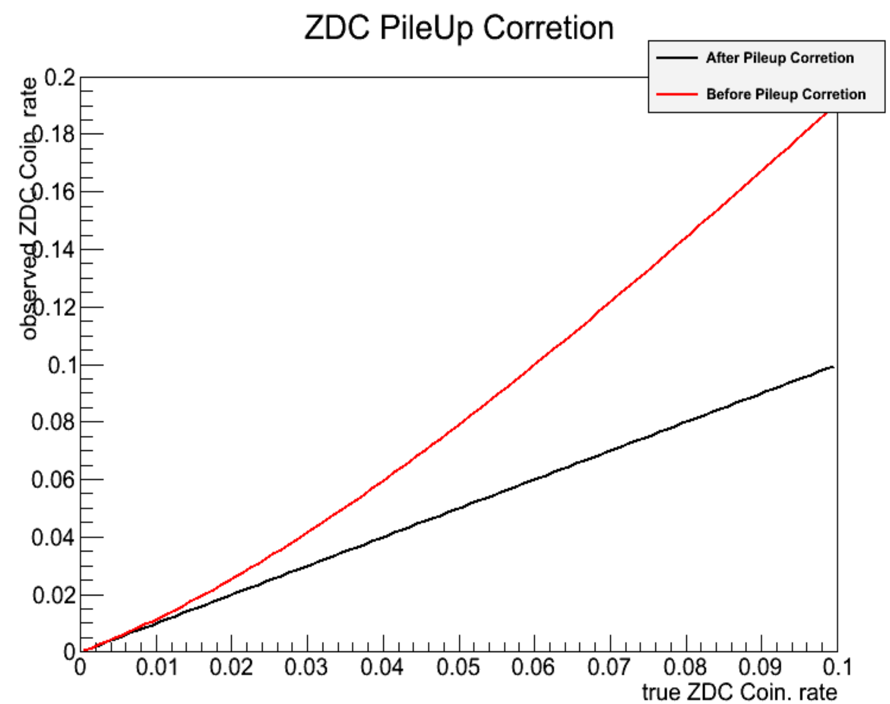
- k_n^{BBC}: 0.2256
  k_s^{BBC} : 0.2256
  k_n^{ZDC} : 3.838
  k_s^{ZDC} : 4.037



Pileup Correction

- $observed\ rate = 1 - e^{-true\ rate(1+k_n)} - e^{-true\ rate(1+k_s)} + e^{-true\ rate(1+k_n+k_s)}$
- BBC : undercount dominant at high rate.
  ZDC : overcount dominant at high rate.



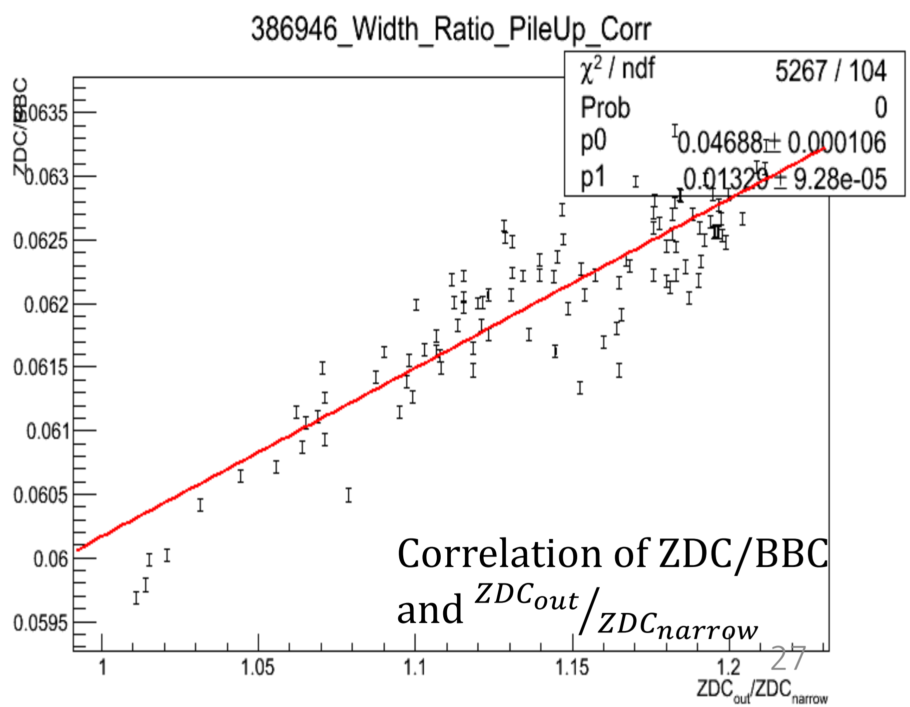


Width Correction

- ZDC misses scaler counts because of poor resolution.
  For narrow vertex width, undercount dominant.
  For wide vertex width, “the scaler count missing” become weak.
  => ZDC/BBC ratio depends on the vertex width.

- To parametrize ZDC vertex width,
  $ZDC_{out} = ZDC_{wide} - ZDC_{narrow}$.
  ZDC vertex width ~ ${}^{ZDC_{out}}/_{ZDC_{narrow}}$

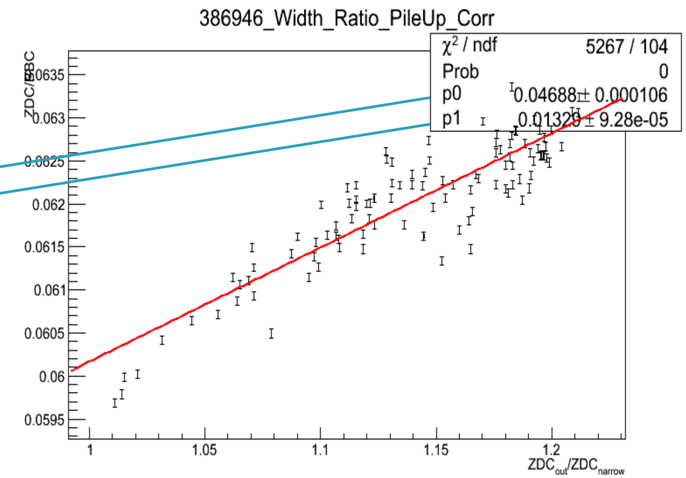
- Clear correlation between ZDC/BBC and ${}^{ZDC_{out}}/_{ZDC_{narrow}}$.

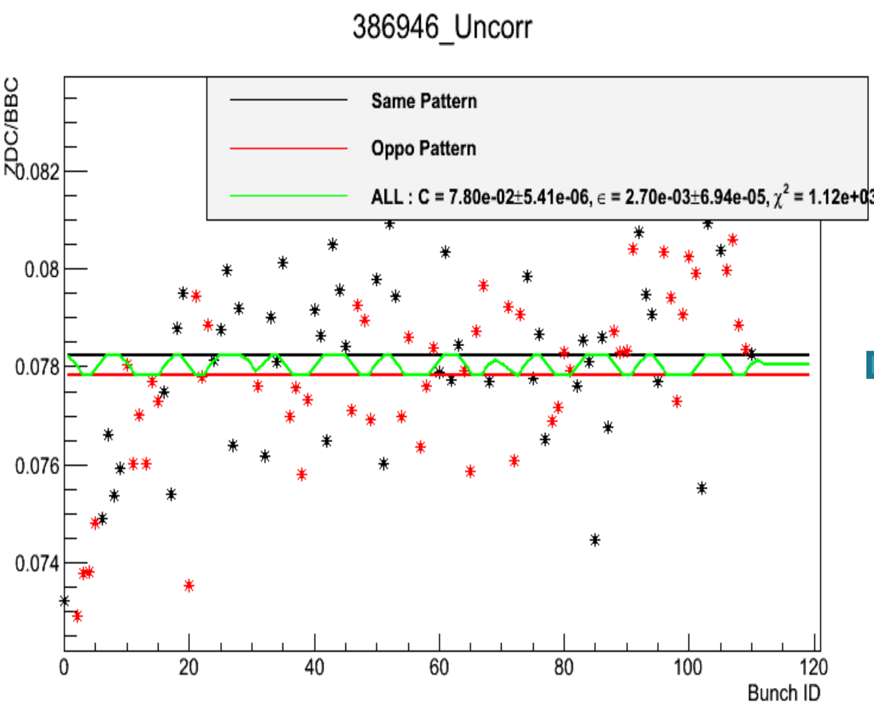


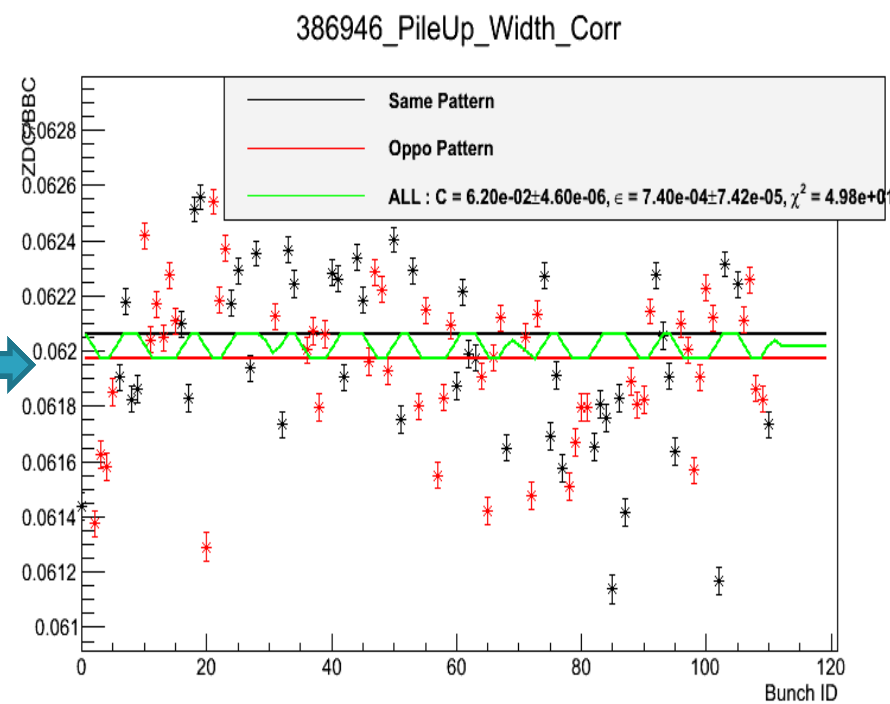
Correlation of ZDC/BBC and ${}^{ZDC_{out}}/_{ZDC_{narrow}}$

Width Correction

- $(ZDC/_{BBC})' = ZDC/_{BBC} * \dfrac{\langle ZDC/_{BBC} \rangle}{p0 + p1 * ZDC_{out}/_{ZDC_{narrow}}}$





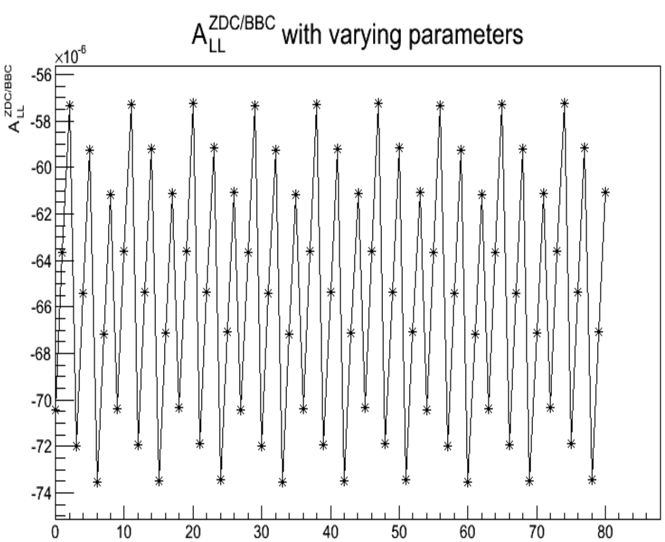


$A_{LL}^{ZDC/BBC}$ measurement - Result

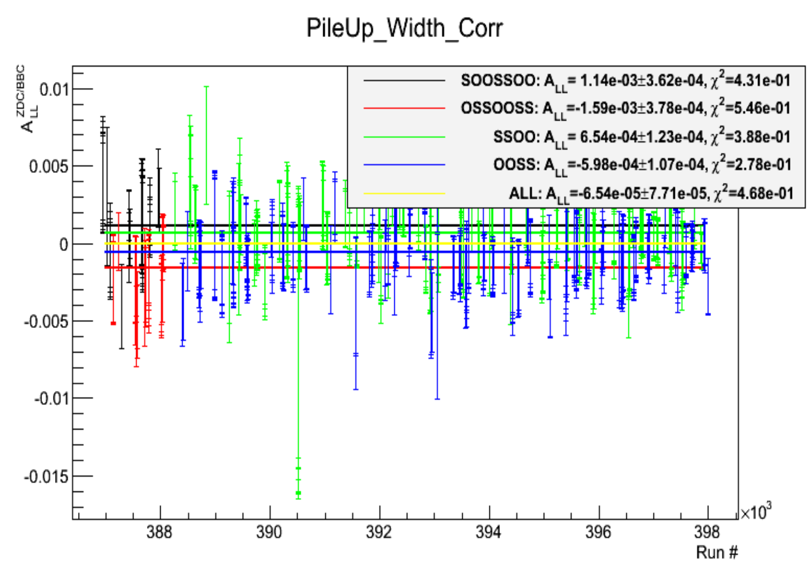
- $A_{LL}^{ZDC/BBC} = -6.5380 \times 10^{-5} \pm 7.7110 \times 10^{-5}(stat.) \pm 7.9559 \times 10^{-4}(pattern) \pm 8.1354 \times 10^{-6}(correction.)$

- $\delta A_{LL}^{ZDC/BBC}(stat.) = \sqrt{\chi^2_{reduced}} \times fitting\ uncertainty.$

- $\delta A_{LL}^{ZDC/BBC}(corection.)$ from varying correction parameters.



1.627×10^{-5}

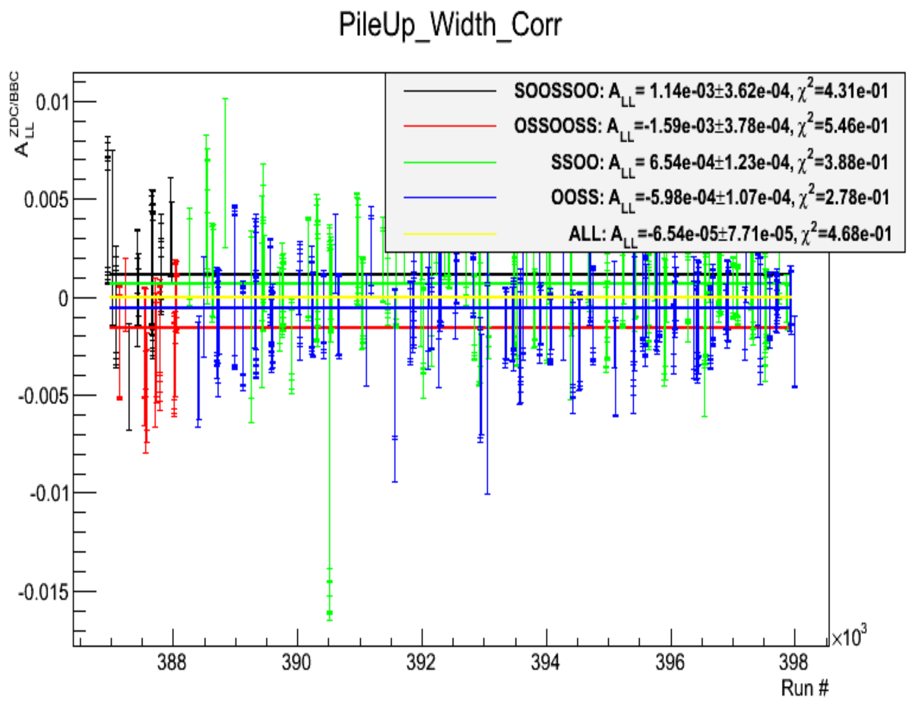


$A_{LL}^{ZDC/BBC}$ measurement - Result

- Weighted average of absolute value of deviation.

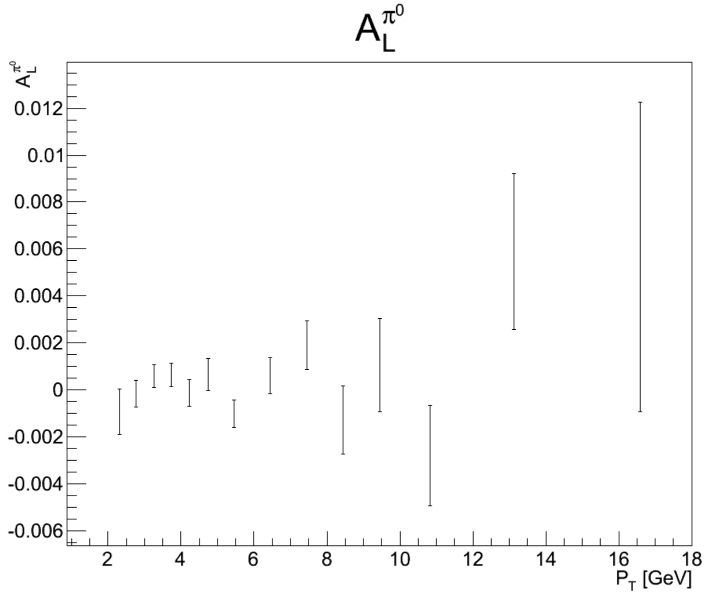
$$\delta A_{LL}^{ZDC/BBC}(pattern) = \frac{\sum w_i |A_{LL}(pattern) - A_{LL}|}{\sum w_i}, \text{ where } w_i = 1/\delta A_{LL}(pattern, stat.)$$
$$= 7.956 \times 10^{-4}$$

- $\delta A_{LL}^{\pi^0}(RelLumi) = 8.020 \times 10^{-4}$



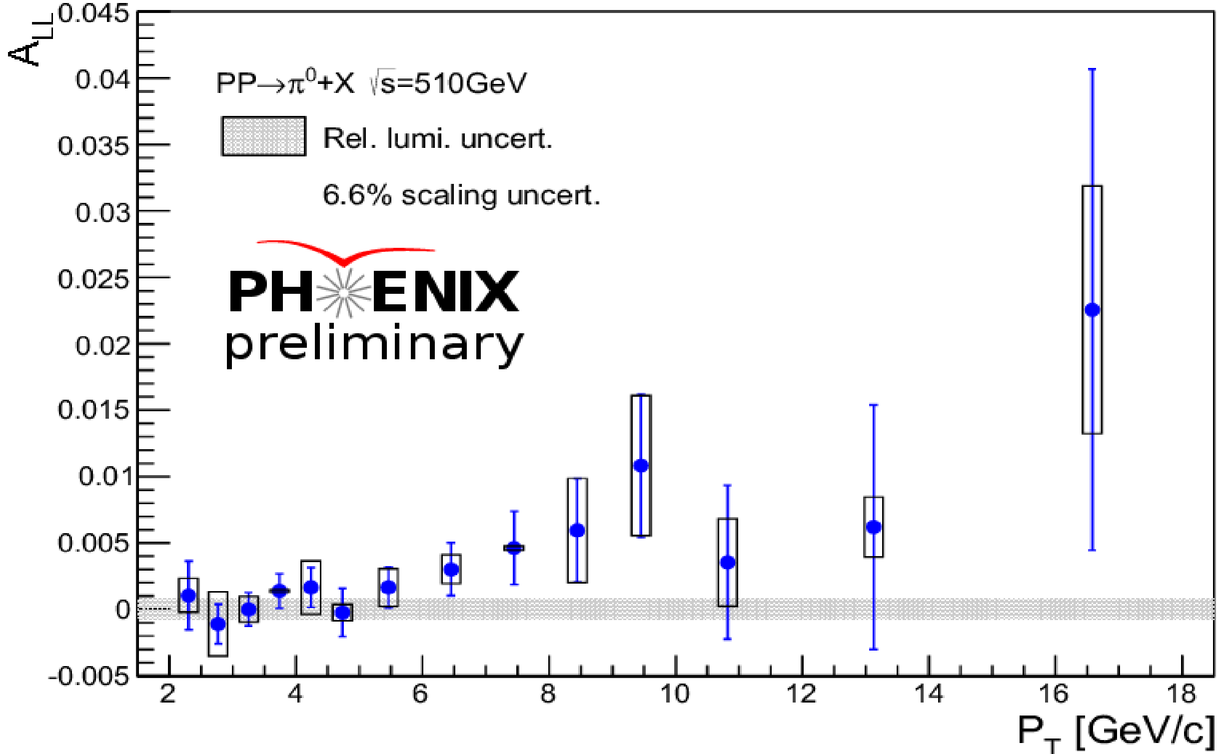
$A_L^{\pi^0}$ measurement

- Parity invariant strong interaction should gives zero $A_L^{\pi^0}$. Good tool of testing validity of the analysis.



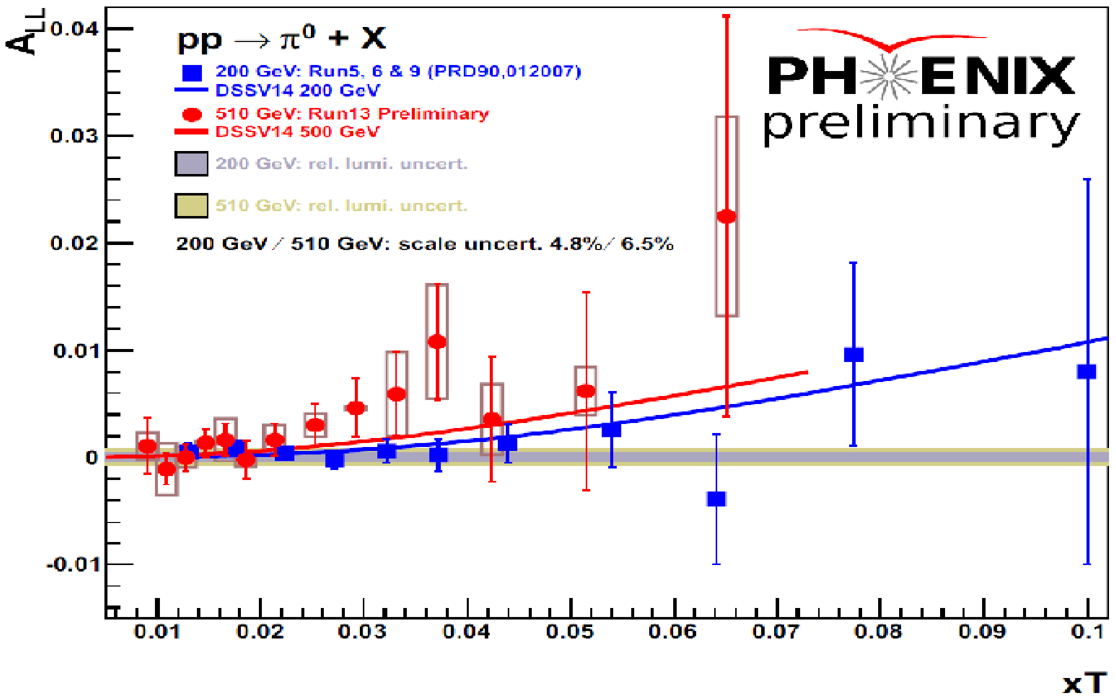
- Measured $A_L^{\pi^0}$ show zero asymmetry within uncertainty.

Preliminary Result



- Non-zero A_{LL} is measured.
- Confirmed by 3 analyzers.

Preliminary Result



- 510GeV A_{LL} approaches two times smaller x_T.
  → Significant contribution on global analysis expected.

- 510 GeV A_{LL} is larger. : Q^2 evolution?

Outlook

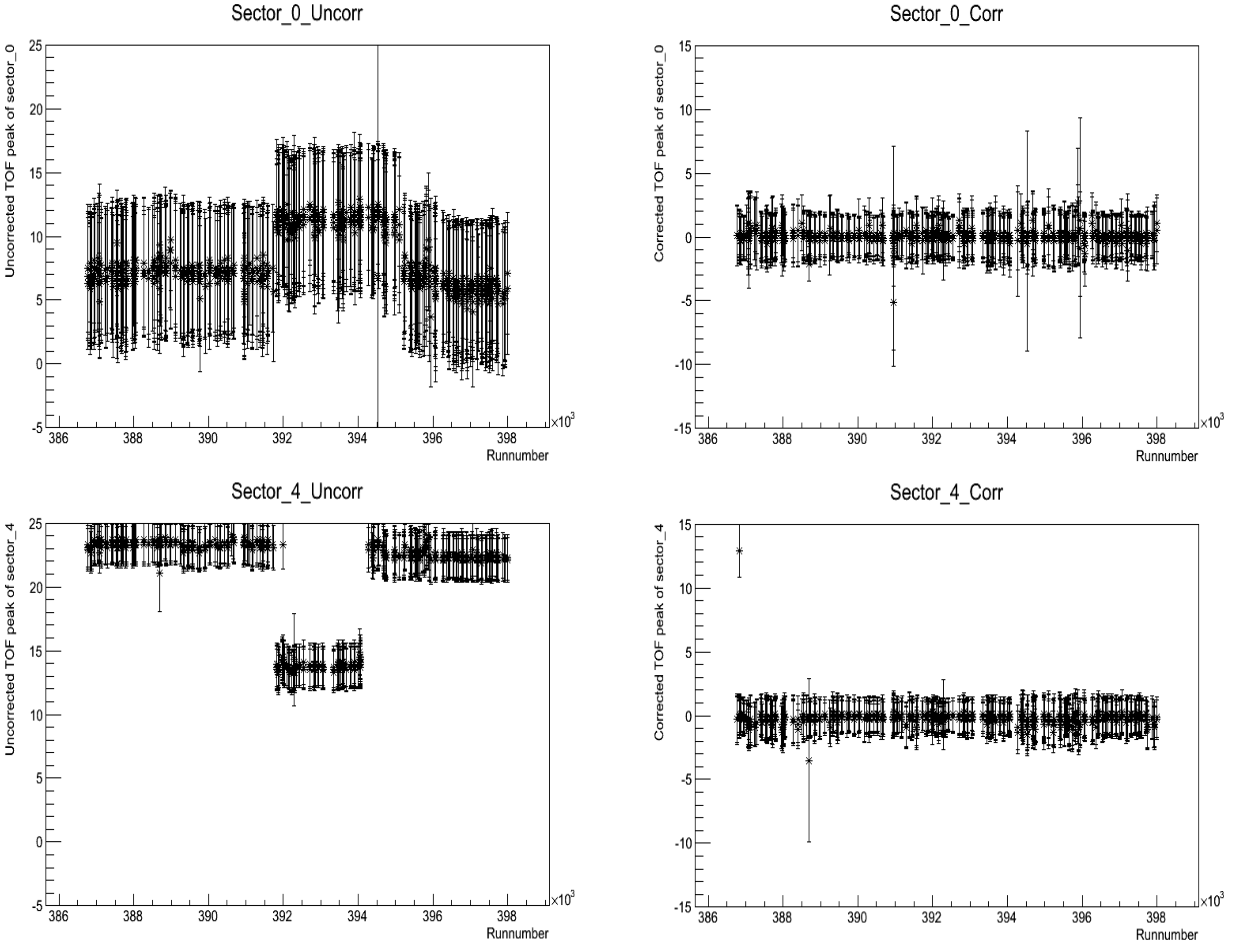
- Current uncertainty estimation : very conservative.
  → Uncertainty could be reduced in final result.
    - Prescale effect : stat. uncertainty ↓.
    - Using ERT4x4B : stat. uncertainty at high P_T ↓.
    - Residual rate correction : spin pattern correlated $A_{LL}^{ZDC/BBC}$ ↓.

- Removing analysis dependent P_T correlated syst. : urgent!

Summary

- Preliminary $A_{LL}^{\pi^0}$ at $\sqrt{s} = 510$ GeV measurement has been done and released.
- $A_{LL}^{\pi^0}$ at $\sqrt{s} = 510$ GeV : two-times smaller x_T, larger A_{LL}.
- Pushing for final result and publication!

BackUp



Sector_0_Uncorr
Uncorrected TOF peak of sector_0
Runnumber
×10³
Sector_0_Corr
Corrected TOF peak of sector_0
Runnumber
×10³
Sector_4_Uncorr
Uncorrected TOF peak of sector_4
Runnumber
×10³
Sector_4_Corr
Corrected TOF peak of sector_4
Runnumber
×10³

EMCal Warnmap Generation – finding hot towers

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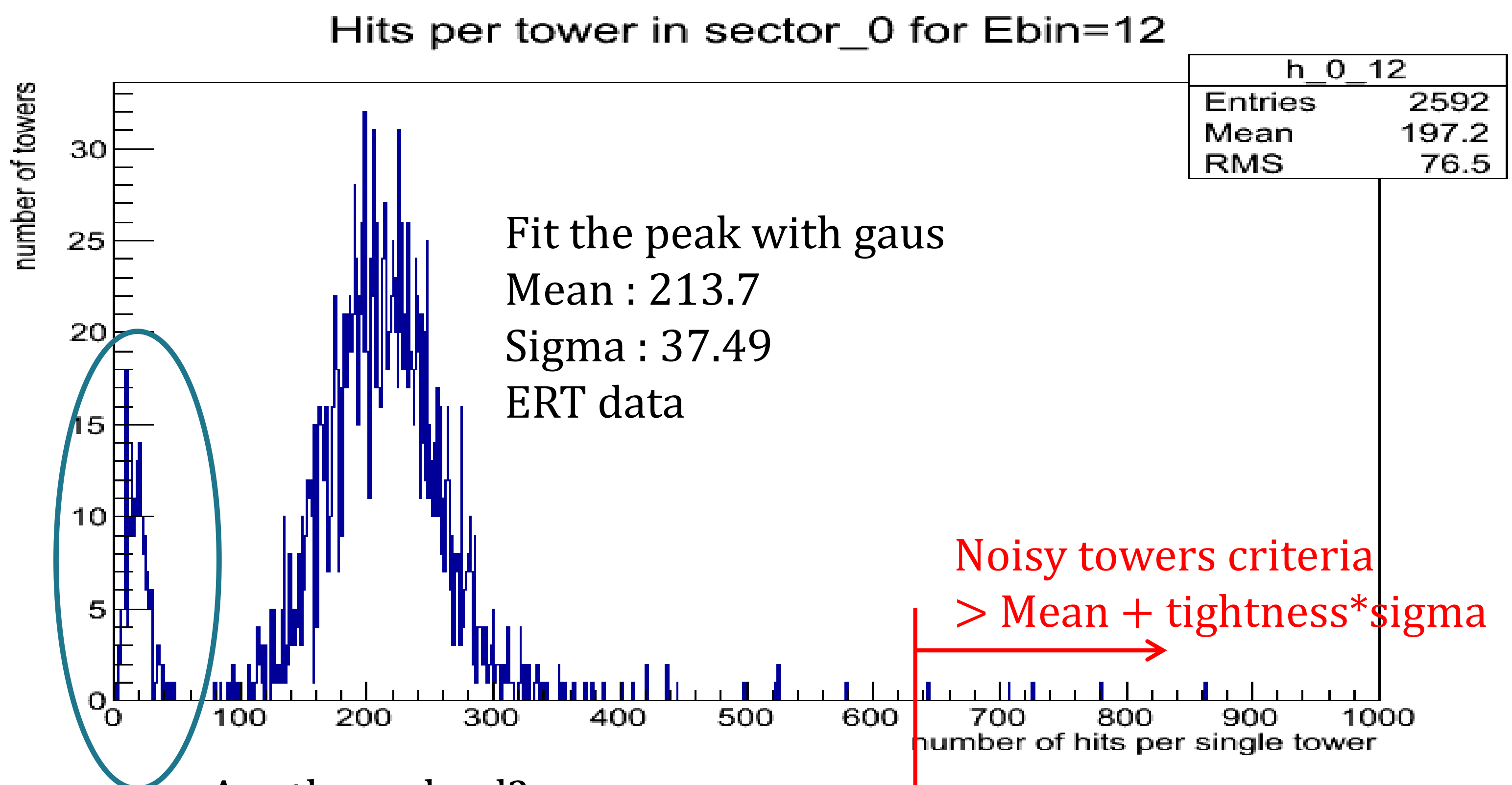
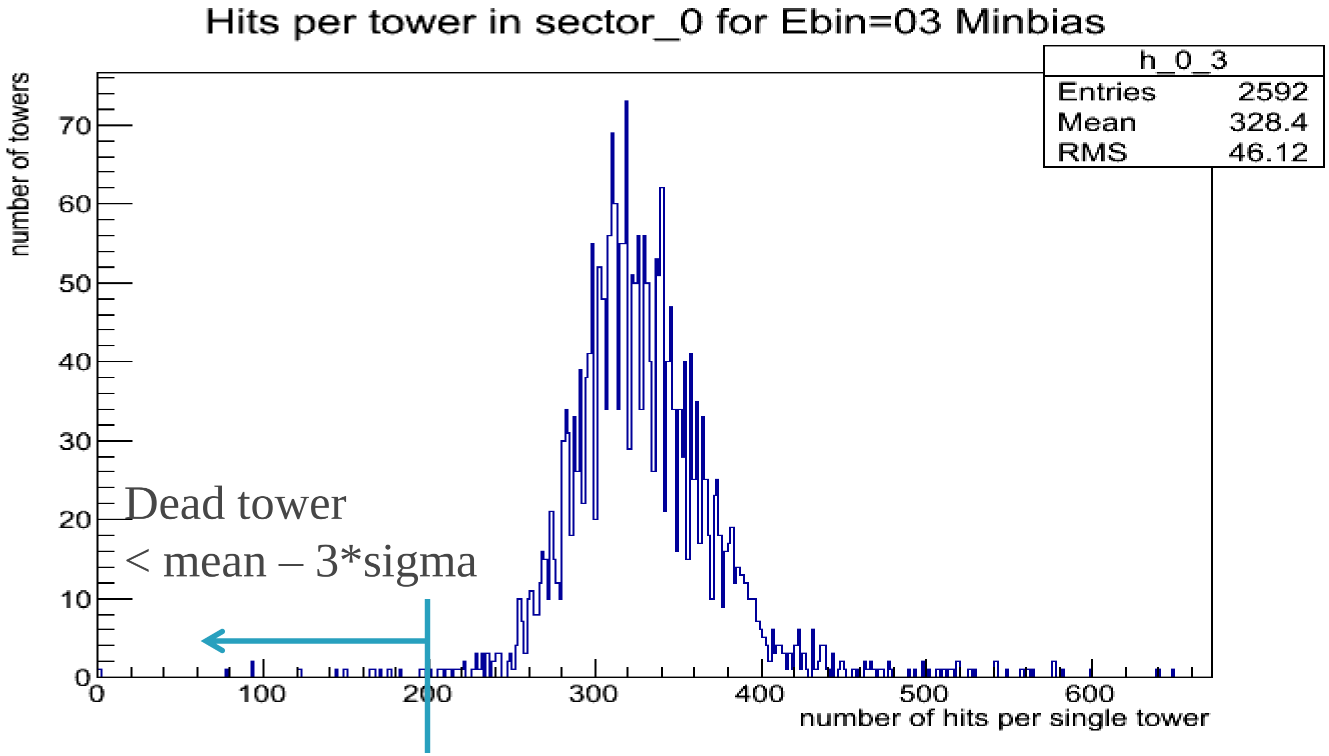


Are those dead?
It contains not only dead towers but also normal towers which ERT triggers are dead.

EMCal Warnmap Generation – finding dead towers

- ERT broken towers are still useful for π^0 reconstruction.
- ERT independent trigger is needed. – minbias.



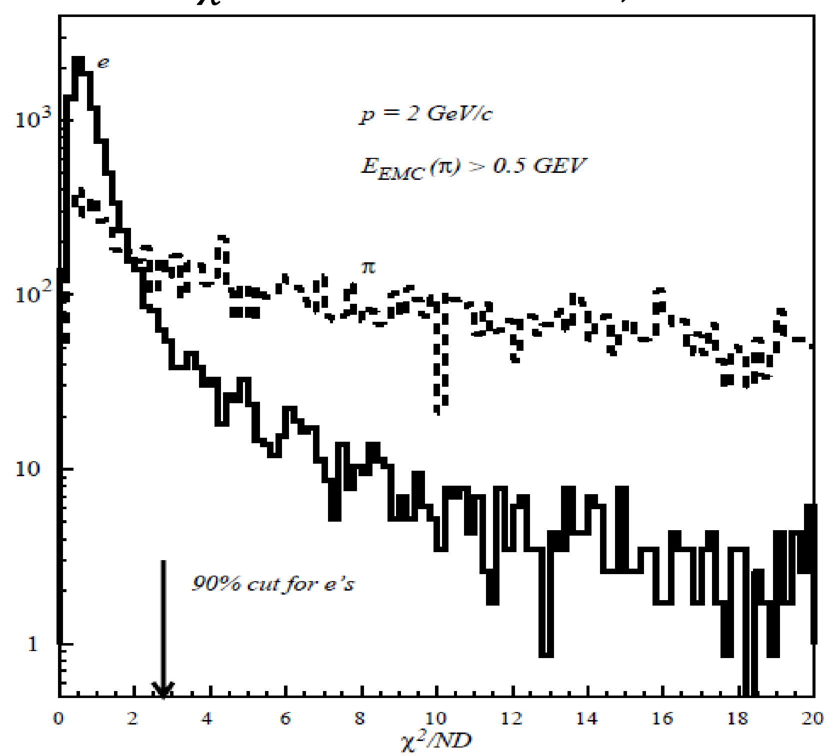
Shower shape Cuts

- To reduce background from hadronic event.

- Compare measured shower shape with shower of electron beam by calculating
$\chi^2 = \sum_i (E_i^{elec} - E_i^{meas})^2 / \sigma_i^2$

- Conventional 2% cut is applied.
(= Level of killing 2% of real EM)

χ^2 distribution of e^-, π



ToF Cuts

- -15ns<ToF<15ns for PbSc, -10ns<ToF<10ns for PbGl.
- To reduce background from ghost cluster.
- Ghost cluster : cluster from previous bunch crossing.
  Cluster in EMCal can remain up to 3 bunch crossing.
  → Source of background.
- Ghost cluster can make different background for different spin patterns.
  → Systematic difference of A_{LL} of different spin pattern has been observed.
- Ghost cluster can't associate BBC T0 and wider ToF distribution.
  Thus ghost cluster can be rejected by ToF cuts.
- Pattern separated analysis has been done.

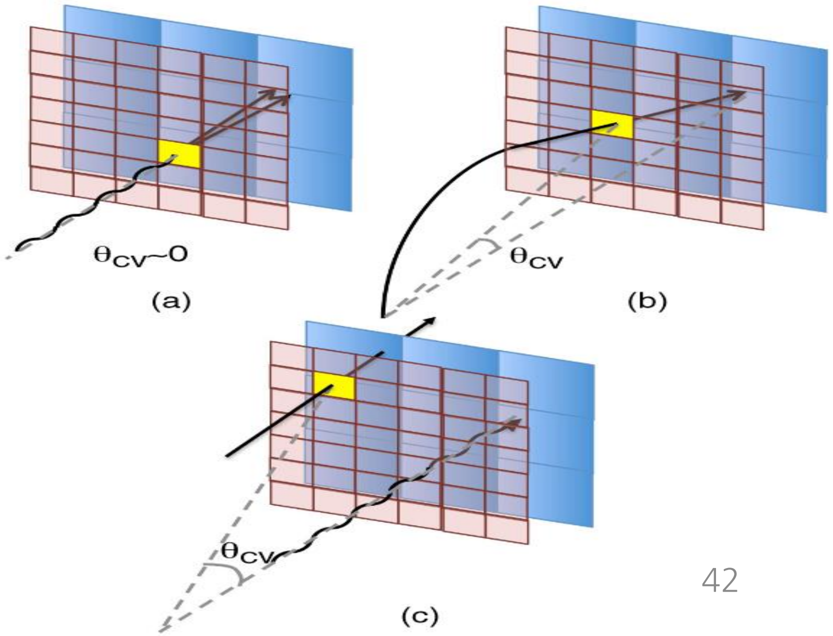
Charge Veto Cuts

- To reject charged hadrons.

- (a) : photons that convert outside of the magnetic field prior to the EMCal, and have very small θ_{cv}

  (b) : charged hadrons that bend in the magnetic field, and so have moderate sized θ_{cv}.

  (c) : photons that do not convert, and are randomly associated with a different particle's PC3 hit.



EMCal run-by-run Energy calibration

- Moderate θ_{cv} region is cut.
- Cut parameters are optimized by maximizing FoM.