Revised study of global hyperon polarization at NICA/MPD

Elizaveta Nazarova[1]

MPD Cross-PWG Meeting

04.10.2022

[1] Joint Institute of Nuclear Research, Dubna, Russia

NICA

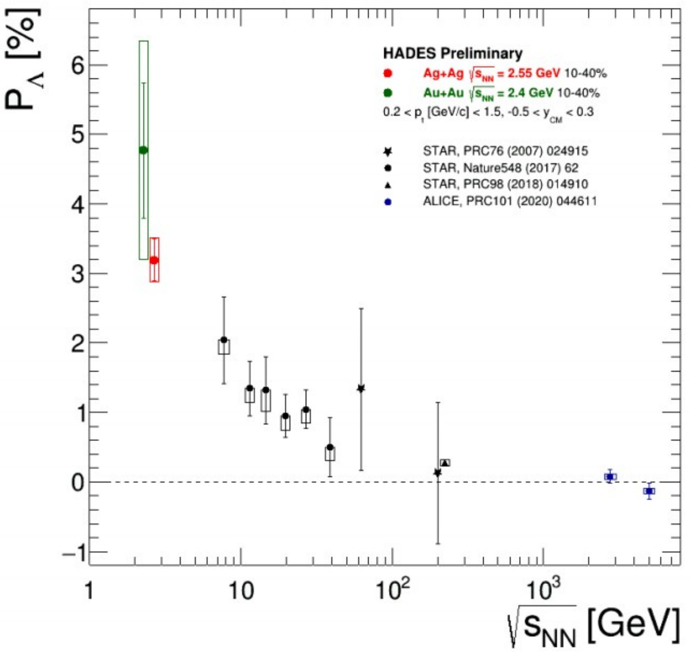
MPD

Outline

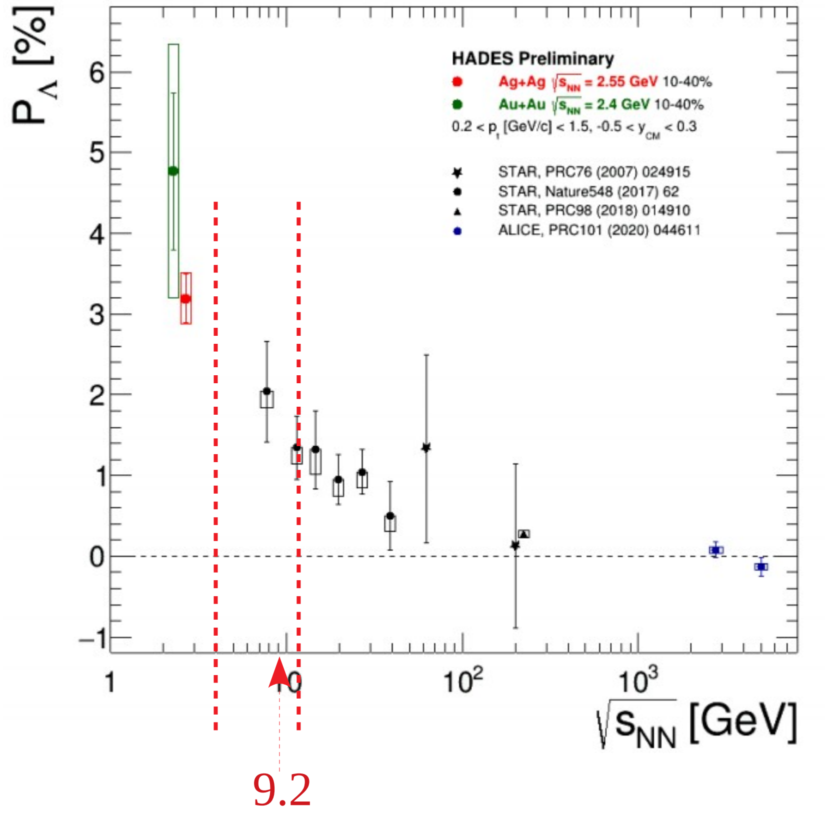
- Review of the analysis
  - Introduction
  - Simulation
  - Analysis technique
  - Revised polarization transfer
- Results with revised polarization transfer
- Conclusions

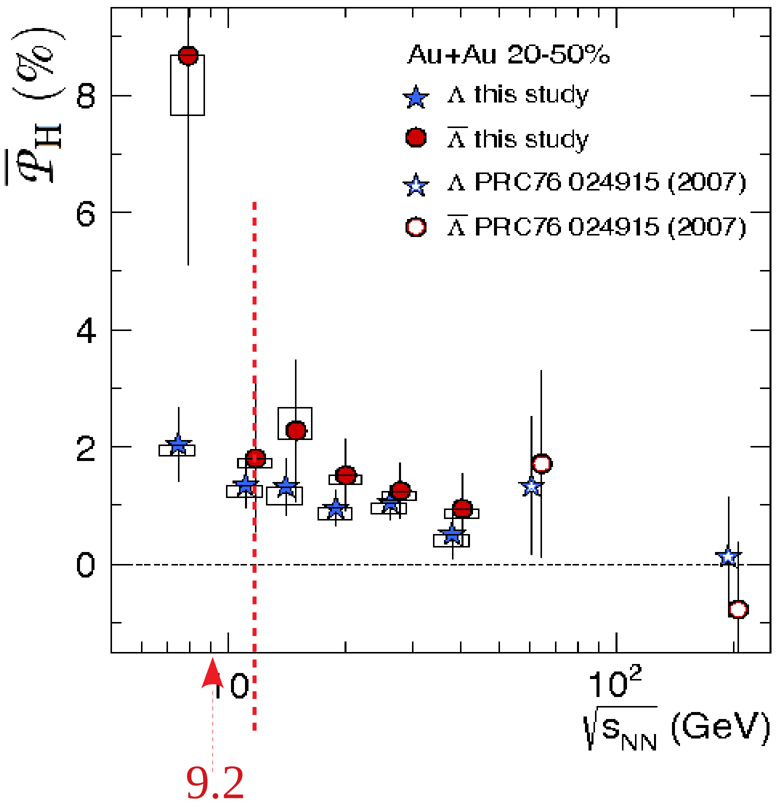
Global polarization of Λ hyperons

- Predicted[1] and observed[2,3] global polarization signals rise as the collision energy is reduced:
  - NICA energy range will provide new insight
- $\Lambda(\bar{\Lambda})$ - splitting of global polarization
- Comparison of models, detailed study of energy and kinematical dependences, improving precision
- Probing the vortical structure with new observables[4,5]



[1] O. Rogachevsky, A. Sorin, O. Teryaev, Phys.Rev. C 82, 054910 (2010)
[2] J. Adam et al. (STAR Collaboration), Phys. Rev. C 98, 014910 (2018)
[3] F. Kornas for the HADES Collaboration, SQM 2021
[4] O. Teryaev and R. Usubov, Phys. Rev. C 92, 014906 (2015)
[5] M. A. Lisa et al., Phys. Rev. C 104, 011901 (2021)





- Motivation (primary): Measurement of $\Lambda(\bar{\Lambda})$ global polarization at NICA/MPD (4 - 11 GeV)

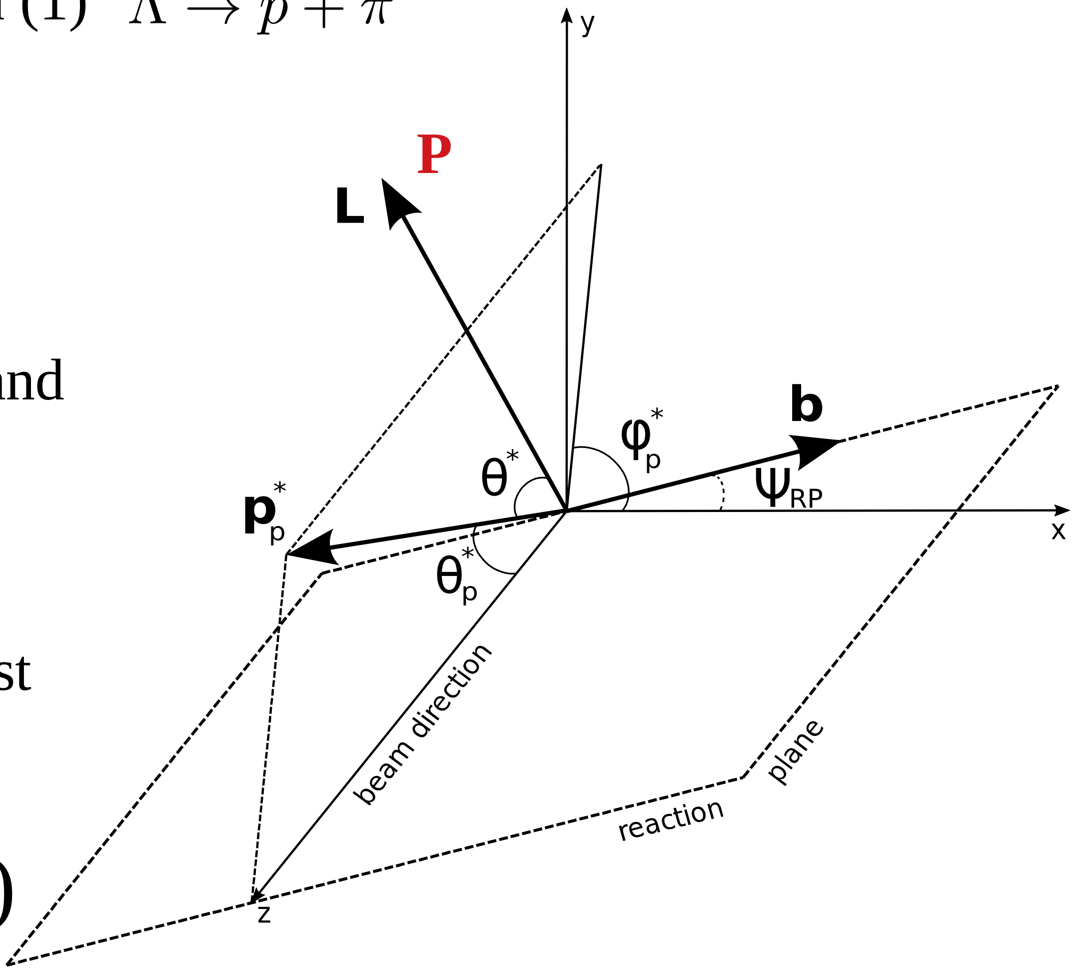
Global polarization of Λ hyperons

- Anisotropic decay for Lambda hyperon (1) $\Lambda \rightarrow p + \pi^-$

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}(1 + \alpha_\mathrm{H}|\vec{P_\mathrm{H}}|\cos\theta^*) \quad (1)$$

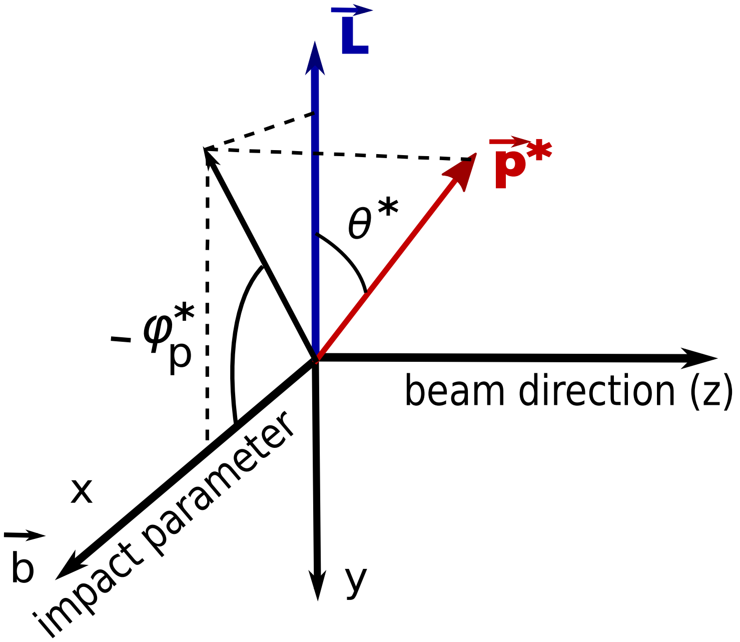
- * — denotes Lambda rest frame
- θ^* — angle between the decay particle and polarization direction
- $\alpha_\Lambda \simeq -\alpha_{\bar{\Lambda}} \simeq 0.732$
- Polarization can be measured using the azimuthal angle of proton in Lambda rest frame φ^* (2)

$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_\mathrm{EP}}\langle\sin(\Psi^1_\mathrm{EP} - \phi^*)\rangle \quad (2)$$



- Obtain invariant mass distribution in bins of $\Delta\phi_p^* = \Psi_{\mathrm{EP}}^1 - \phi_p^*$
  - Net amount of Λ in each bin
  - Distribution of $N_\Lambda(\Delta\phi_p^*)$
- Fit of the distribution[1] to get $\langle\sin(\Delta\phi_p^*)\rangle \rightarrow P_\Lambda$
  - «Event plane» method (p_n — fit parameters)
  - $P_\Lambda = \dfrac{8}{\pi\alpha_\Lambda}\dfrac{p_1}{R_{\mathrm{EP}}^1}$

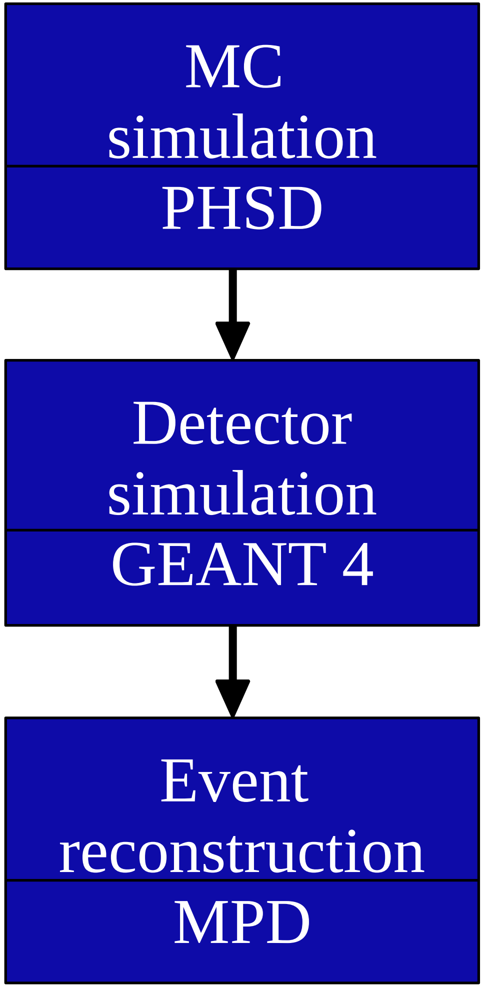
(Following HADES procedure)



$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R_{\mathrm{EP}}^1}\left\langle\sin(\Psi_{\mathrm{EP}}^1 - \phi_p^*)\right\rangle$$

[1] $\dfrac{\mathrm{d}N}{\mathrm{d}\Delta\phi_p^*} = p_0(1 + 2p_1\sin(\Delta\phi_p^*) + 2p_2\cos(\Delta\phi_p^*) + 2p_3\sin(2\Delta\phi_p^*) + 2p_4\cos(2\Delta\phi_p^*) + \ldots)$

Simulation



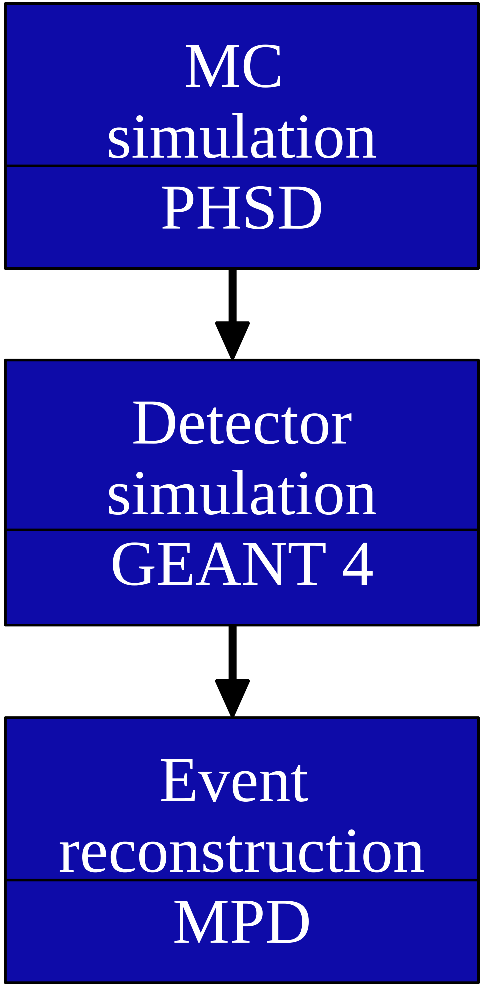
- <u>MC simulation</u> using PHSD model
  - Thermodynamical (Becattini) approach for calculation of thermal vorticity → hyperon polarization ($\mathbf{P} = \{P_x, P_y, P_z\}$)
- <u>Detector simulation</u>
  - Transfer of **P** to MCTracks
  - Transfer of polarization during hyperon decays[1]
  - Anisotropic decay of Λ hyperons (following eq. (1))
- <u>Event reconstruction</u>
  - Centrality calibration - TPC multicplicity
  - Event plane determination (Ψ^1_{EP}, R^1_{EP}) - via FHCal
  - Lambda reconstruction - PID
  - Global polarization extraction - EP method

---

[1] $\Xi^+(\Xi^-)$, Ξ^0, Σ^0 decays

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_H |\vec{P}_H| \cos\theta^*\right) \quad (1)$$

Simulation

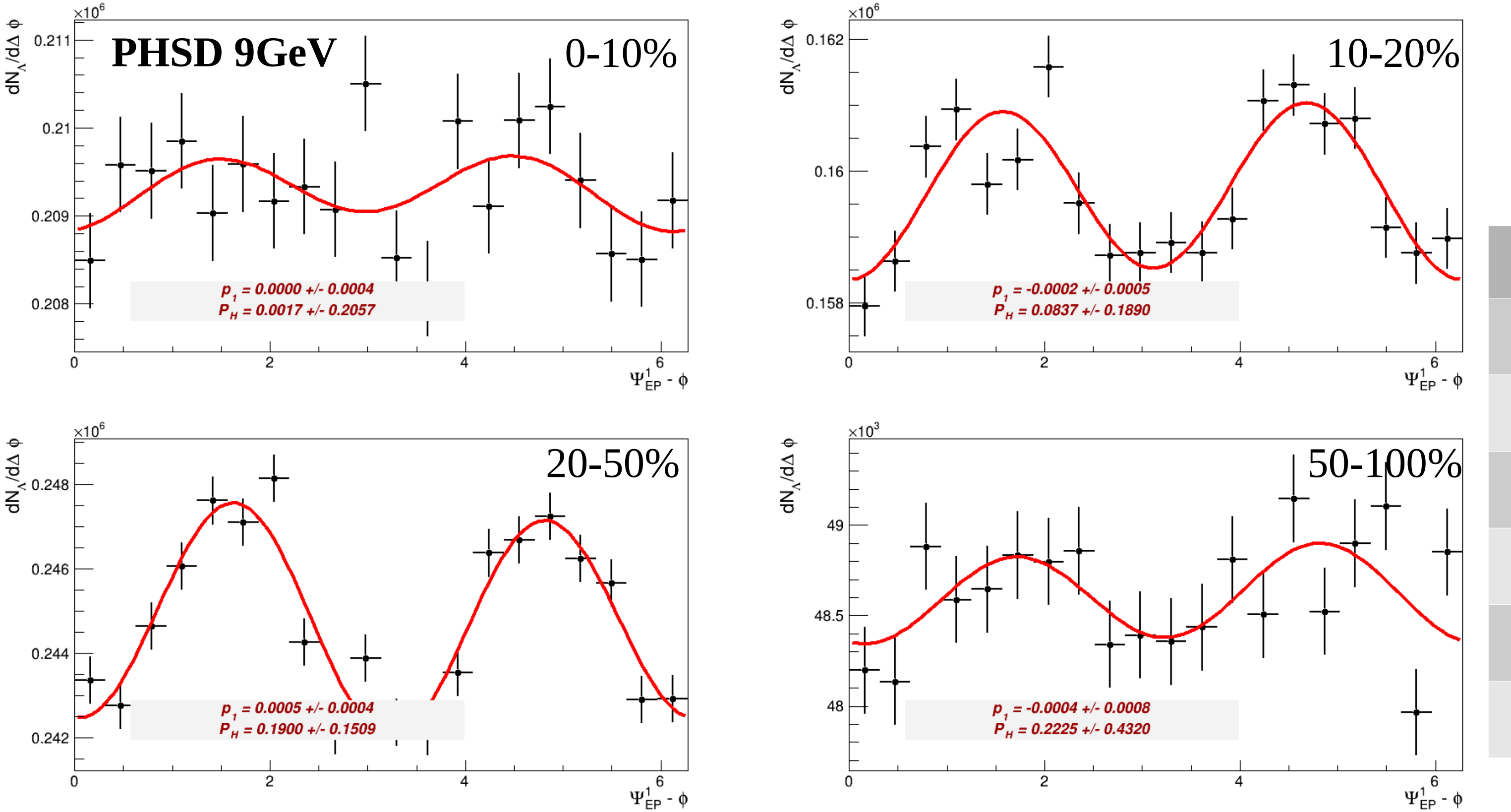


- <u>MC simulation</u> using PHSD model
  - Thermodynamical (Becattini) approach for calculation of thermal vorticity → hyperon polarization ($\mathbf{P} = \{P_x, P_y, P_z\}$)
- <u>Detector simulation</u> — Revised
  - Transfer of **P** to MCTracks
  - Transfer of polarization during hyperon decays[1]
  - Anisotropic decay of Λ hyperons (following eq. (1))
- <u>Event reconstruction</u>
  - Centrality calibration - TPC multicplicity
  - Event plane determination (Ψ^1_{EP}, R^1_{EP}) - via FHCal
  - Lambda reconstruction - PID
  - Global polarization extraction - EP method

[1] $\Xi^+(\Xi^-)$, Ξ^0, Σ^0 decays

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_H |\vec{P}_H| \cos\theta^*\right) \quad (1)$$

Results (prior dataset, 10M events)



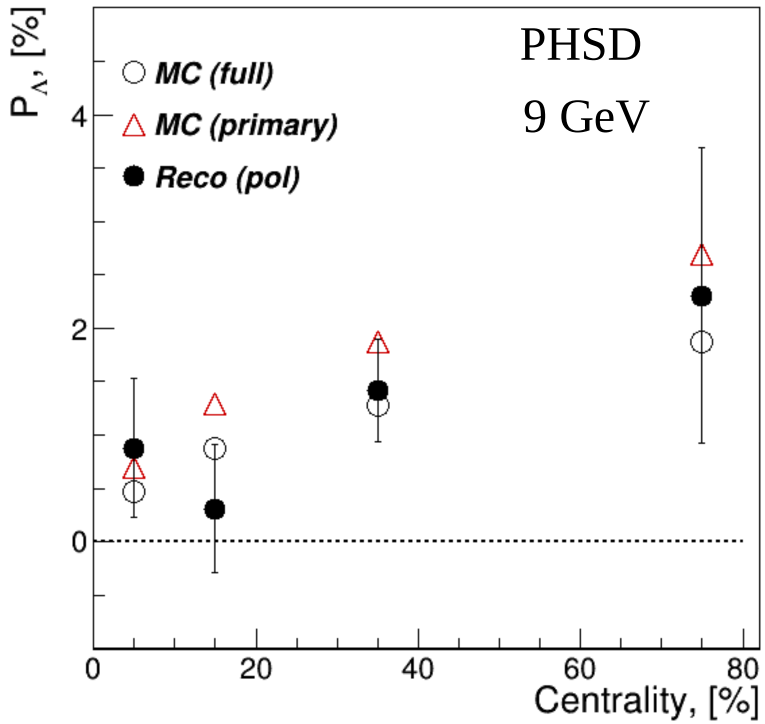
$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda}\frac{p_1}{R^1_{\mathrm{EP}}}$$

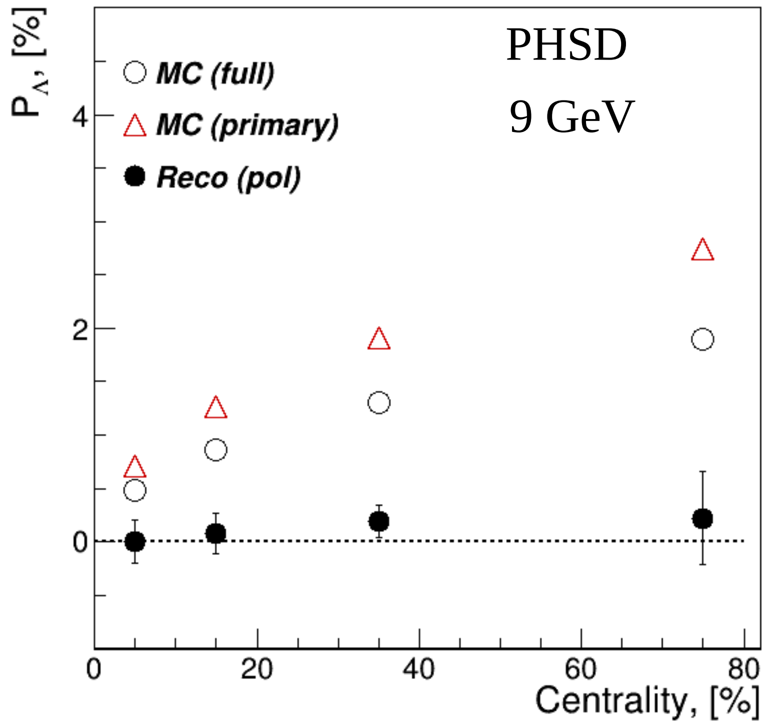
$$\alpha_\Lambda \simeq 0.732$$

	20-50%
N_Λ	$4.9 \cdot 10^6$
p_0	$(2.5 \pm 1.3) \cdot 10^5$
$p_1/10^{-4}$	4.57+/- 3.63
$p_2/10^{-4}$	4.39 +/- 4.61
$p_3/10^{-4}$	-7.62 +/- 3.62
$p_4/10^{-4}$	-51.52 +/- 3.62

$$\frac{\mathrm{d}N}{\mathrm{d}\Delta\phi^*_p} = p_0(1 + 2p_1\sin(\Delta\phi^*_p) + 2p_2\cos(\Delta\phi^*_p) + 2p_3\sin(2\Delta\phi^*_p) + 2p_4\cos(2\Delta\phi^*_p) + ...)$$

Results (prior dataset, 1M vs 10M events)





- (left) PHSD @ 9 GeV, ~1M events
- (right) PHSD @ 9 GeV, ~10M events
- Not only the errors decreased, but the value of polarization
- For the full sample, the reconstructed value is consistent with 0

Revised polarization transfer

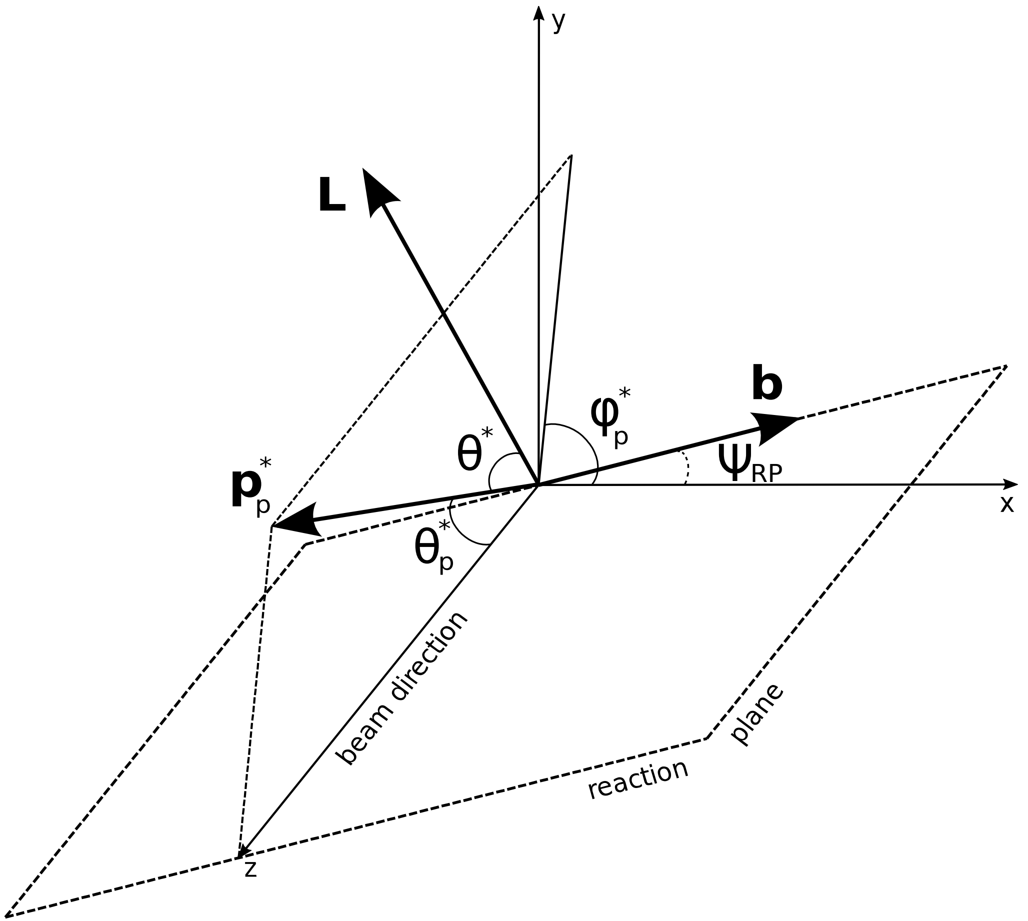
Polarization transfer revised (V. Voronuyk, global_polarization branch) — will be merged with dev branch of mpdroot after all productions for 2nd collaboration paper are done

- Polarization vector **P** = $\{P_x, P_y, P_z\}$ from PHSD model data rotated w.r.t. reaction plane
- Spin direction for hyperons is randomized according to the probability (length of the vector |**P**|)
- For secondary Lambda: spin direction randomized, dependent on the feed-down constant
- Fixed anisotropic decay for anti-Lambda hyperons

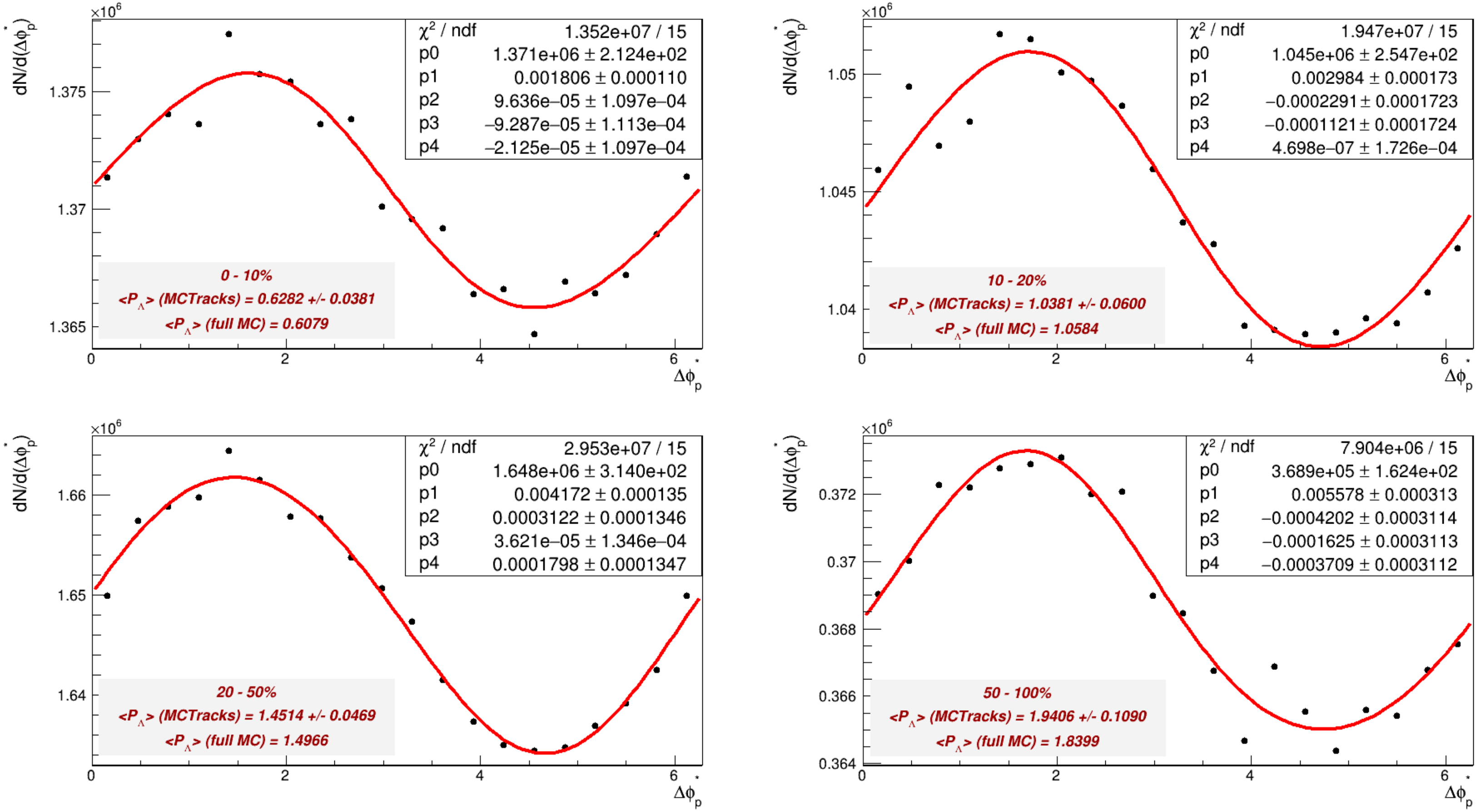
Revised polarization transfer

- Calculate random $\cos\theta^*$ (from (1)) with |P|=1)
- $\alpha_{\bar{\Lambda}} = -\alpha_{\Lambda} = 0.732$
- φ^* - random in [0,2π]
- Construct unitary vector of proton
- Rotate it w.r.t. polarization direction
- Boost to the lab frame

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}(1 + \alpha_{\mathrm{H}}|\vec{P}_{\mathrm{H}}|\cos\theta^*) \quad (1)$$

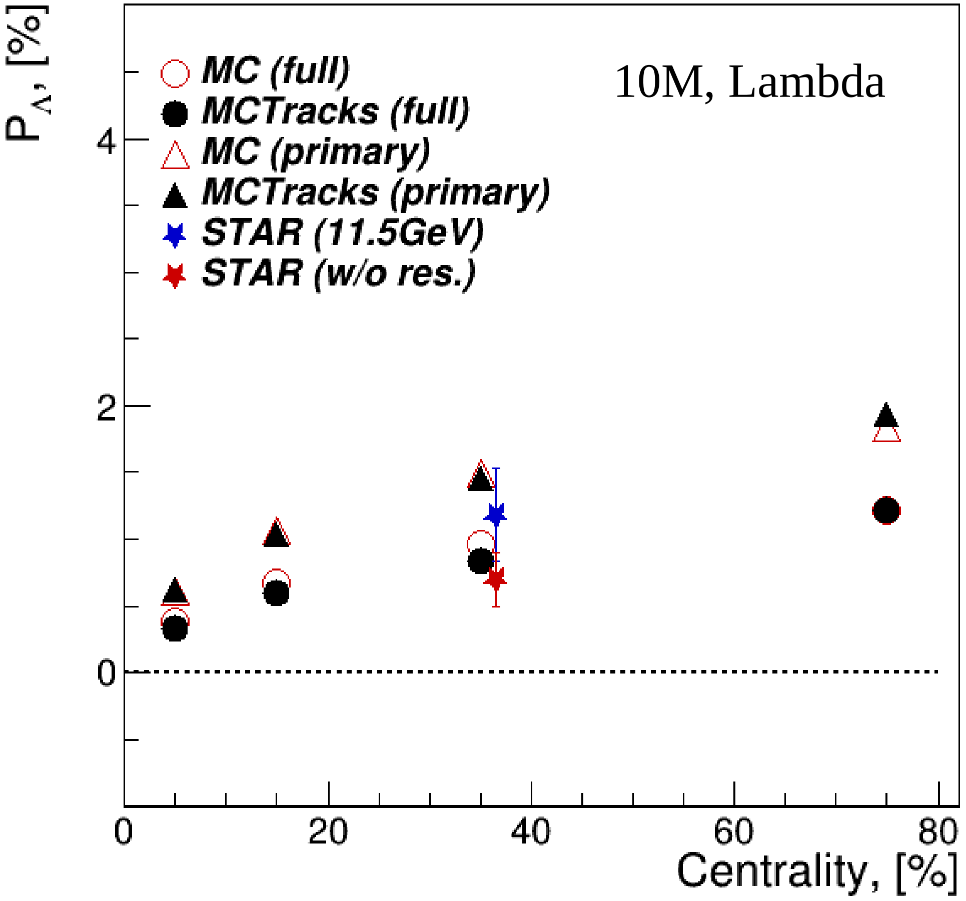


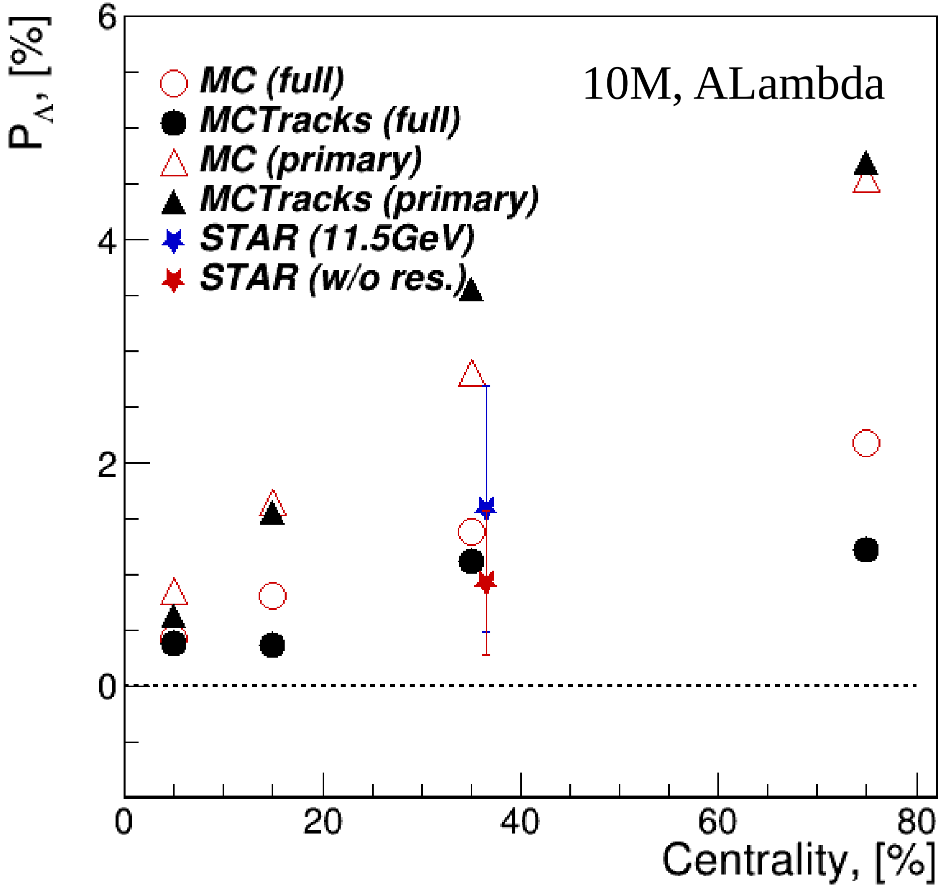
- <u>Testing</u>
  - Using our prior production of 10M events — MCTracks information
  - Using privately produced dataset with the revised transfer — 1M, 2M and 4M events for comparison



- Anisotropy is clearly visible in the angular distribution
- Good agreement between values calculated via fitting procedure and mean polarization

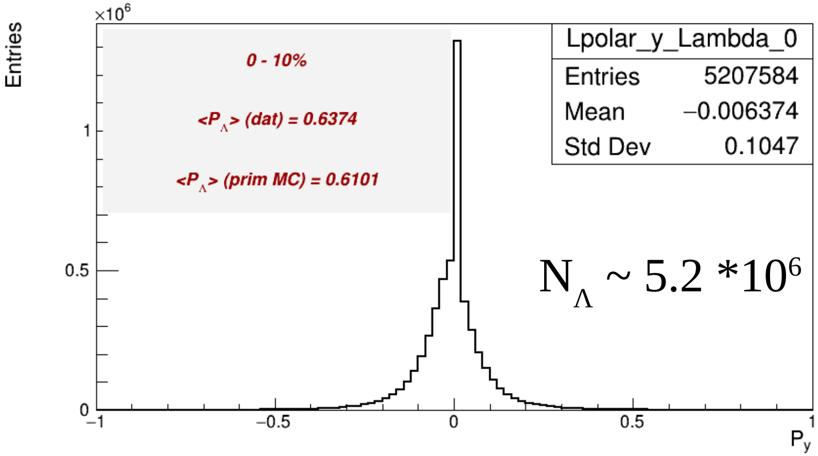
Results: 1. Mean Lambda polarization — prior 10M production

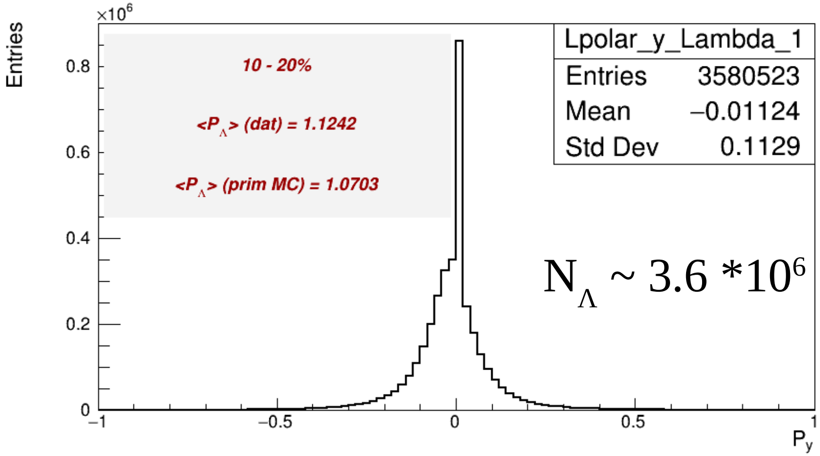


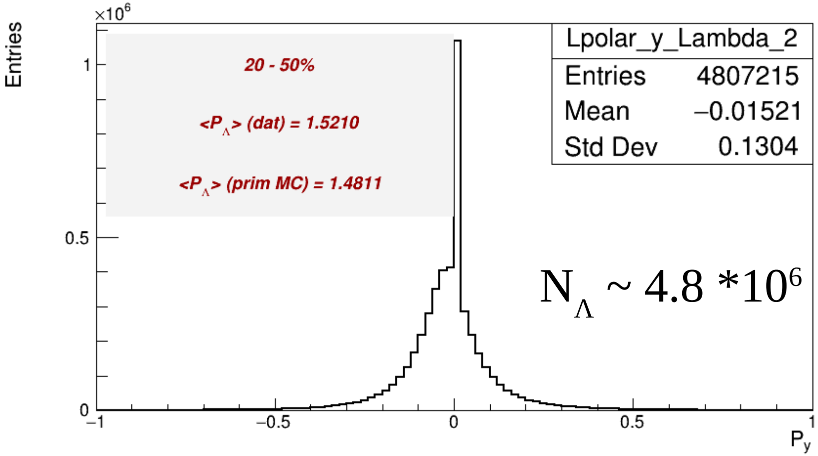


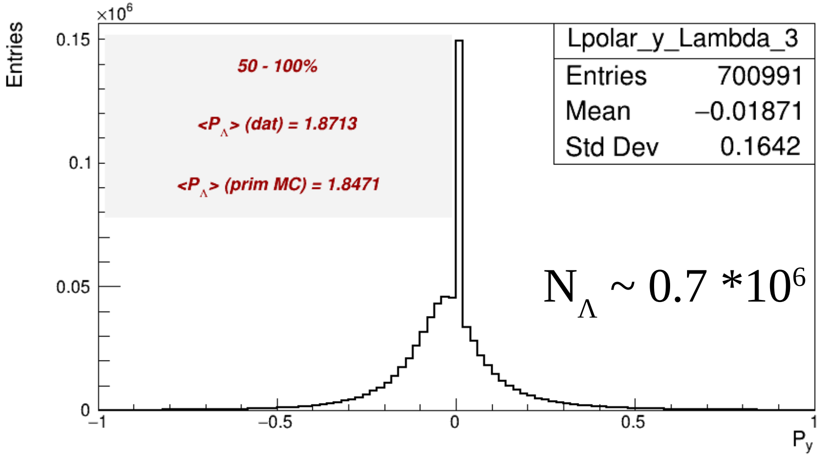
Returning the values of mean global polarization in both cases

Results: 2. Private production — MCTracks (1M, Lambda)



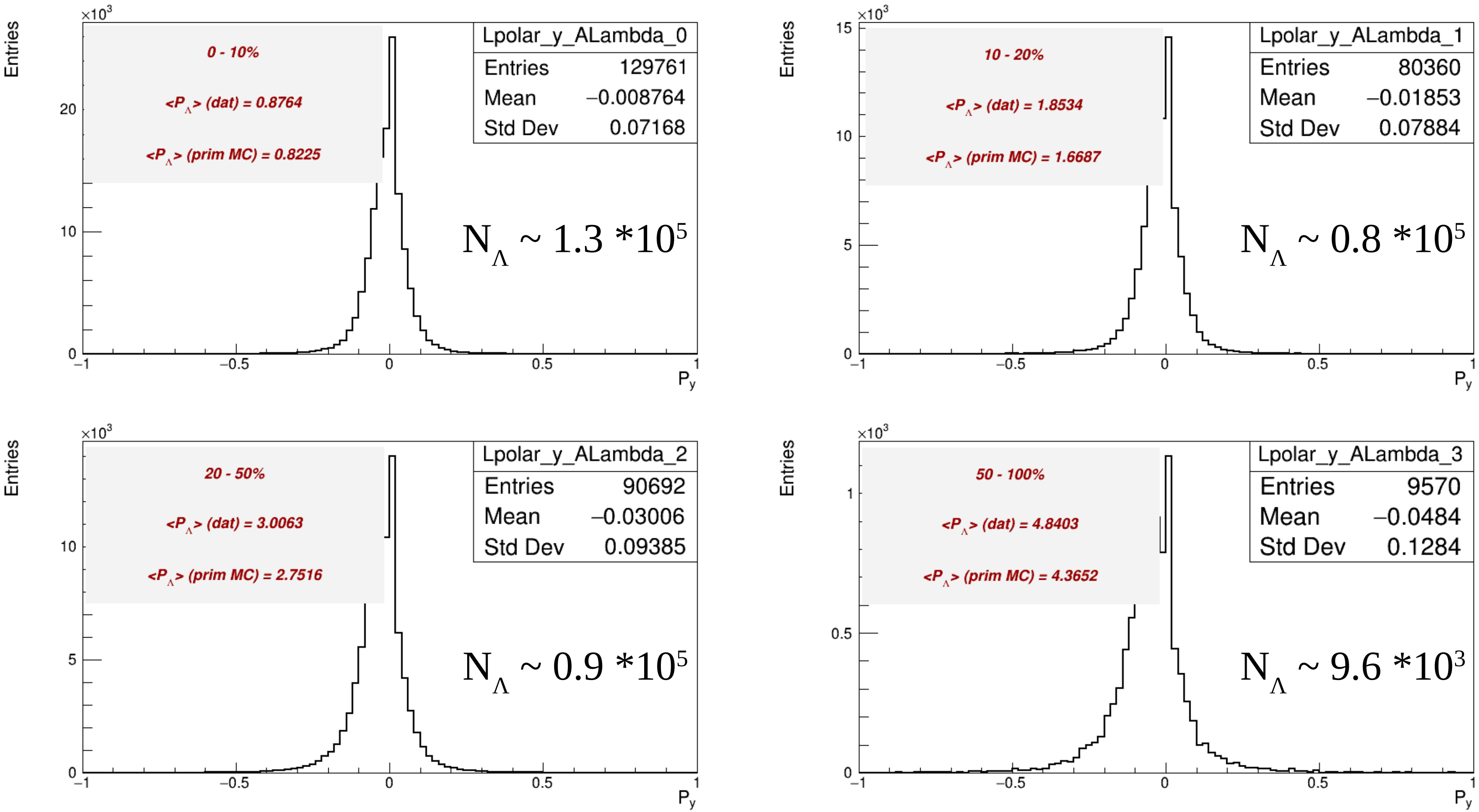




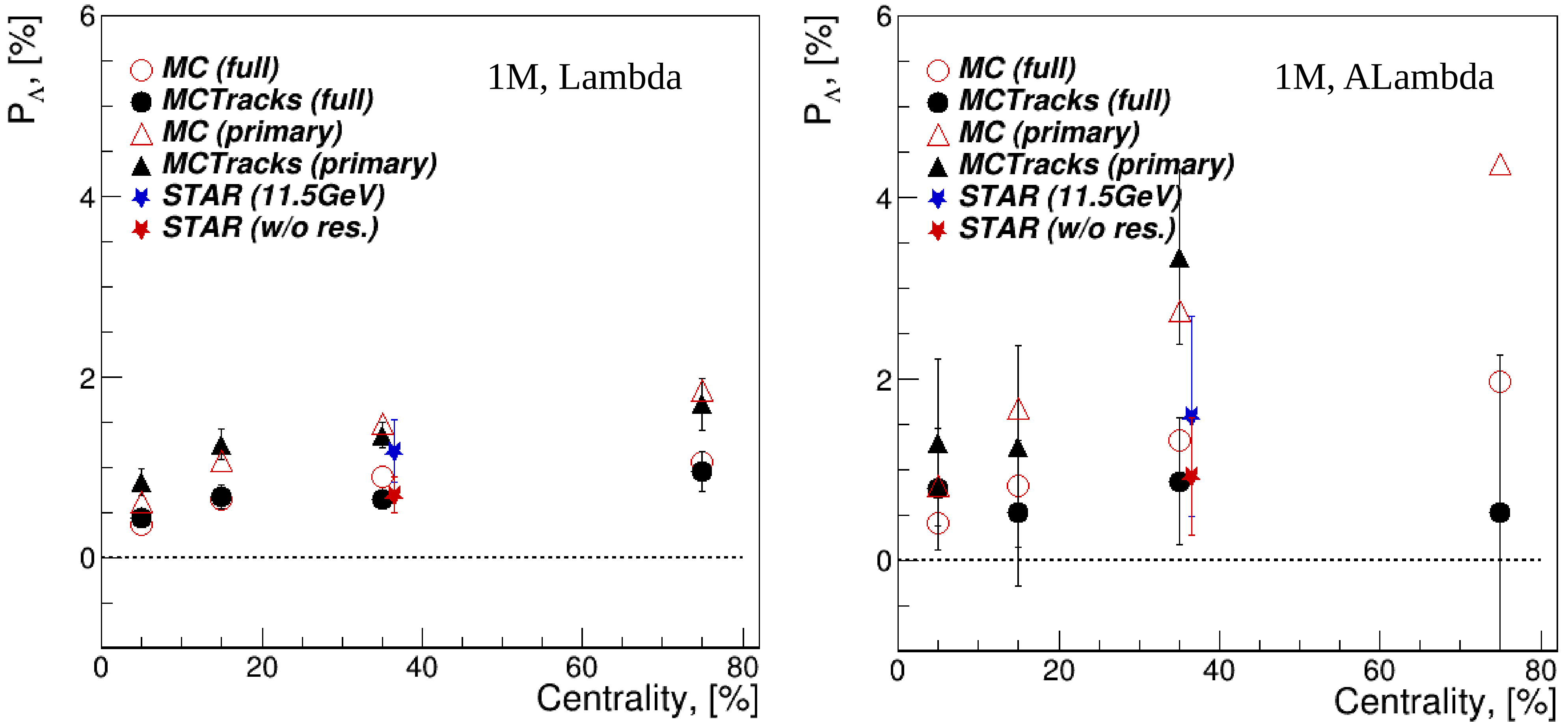


Different centrality selection — still, good agreement (signal of polarization present)

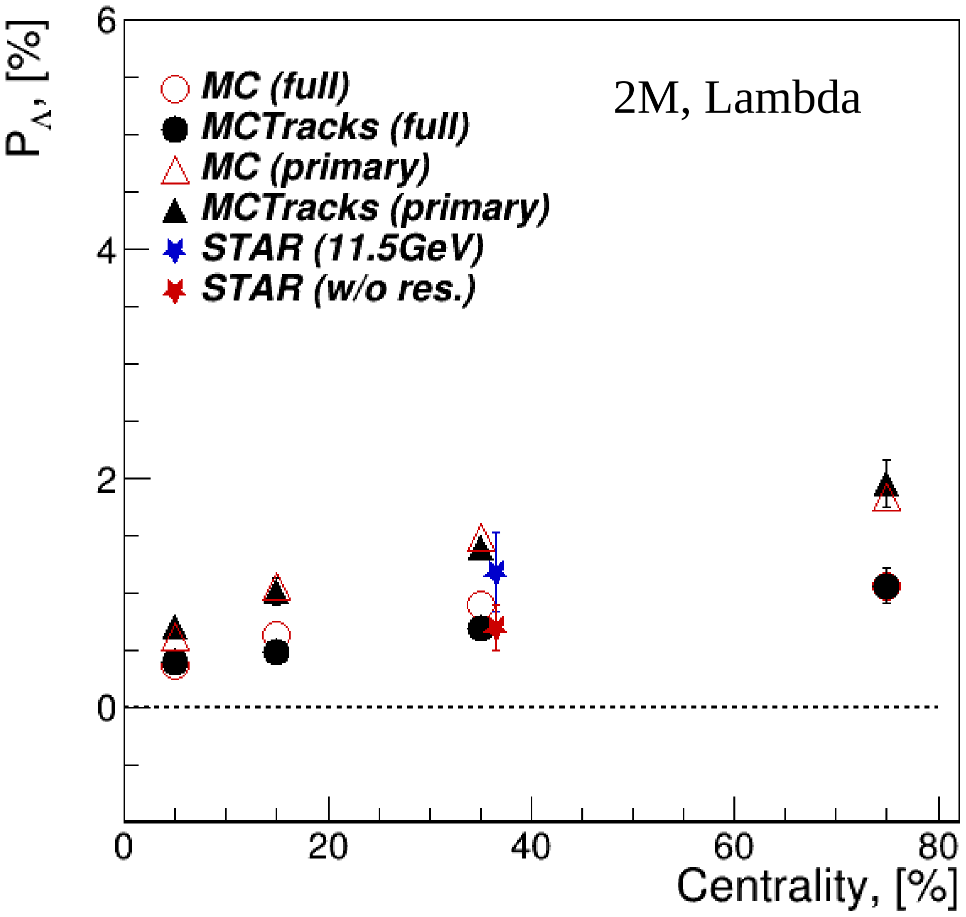
Results: 2. Private production — MCTracks (1M, ALambda)

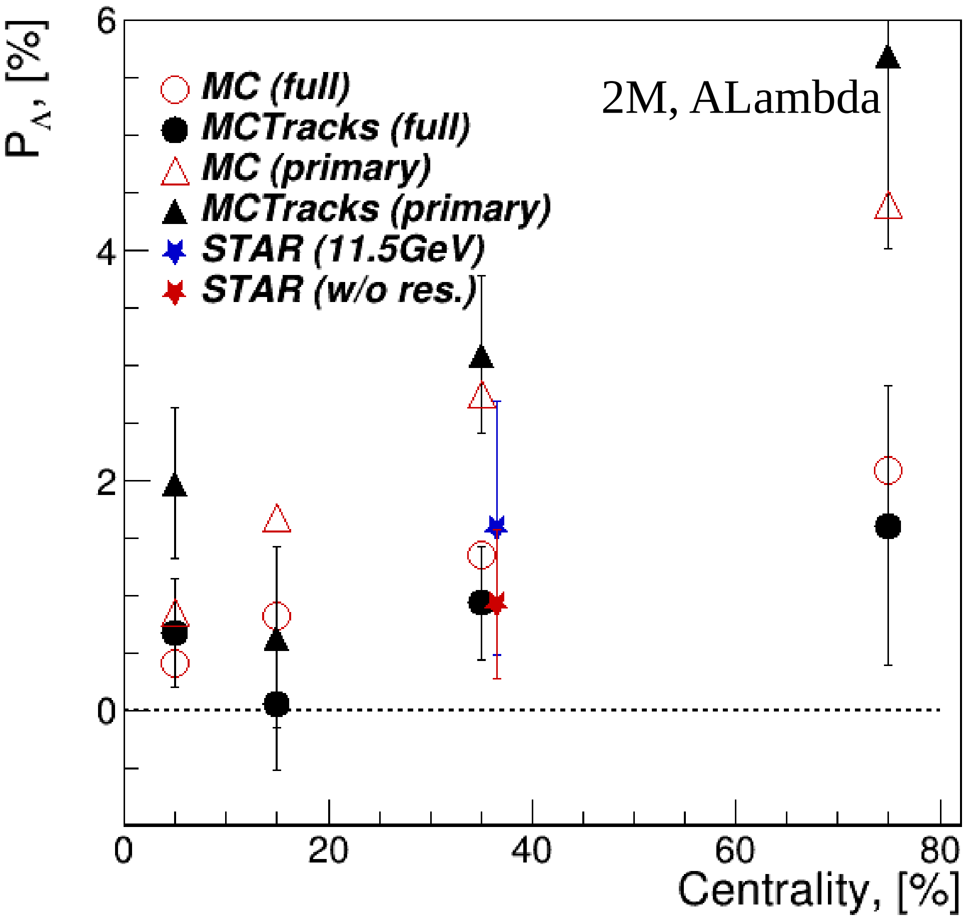


Different centrality selection — still, good agreement (signal of polarization present)



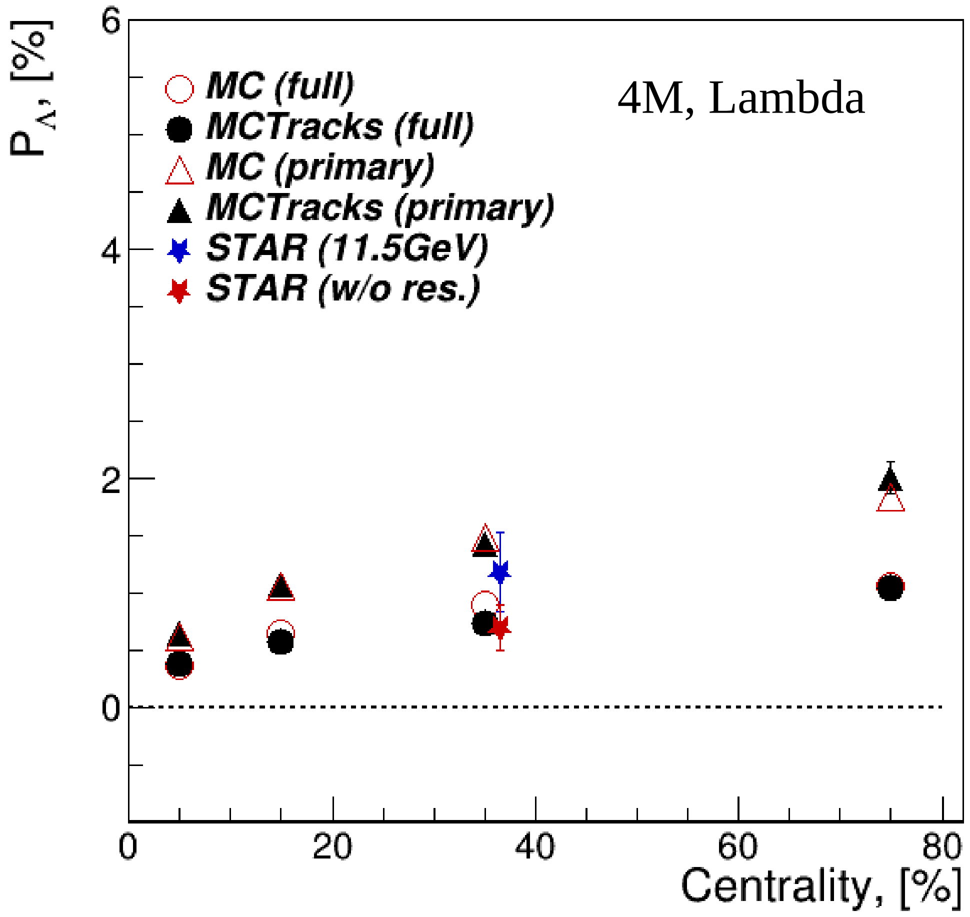
Good agreement for Lambda, for Anti-Lambda statistics is much smaller — larger uncertainty

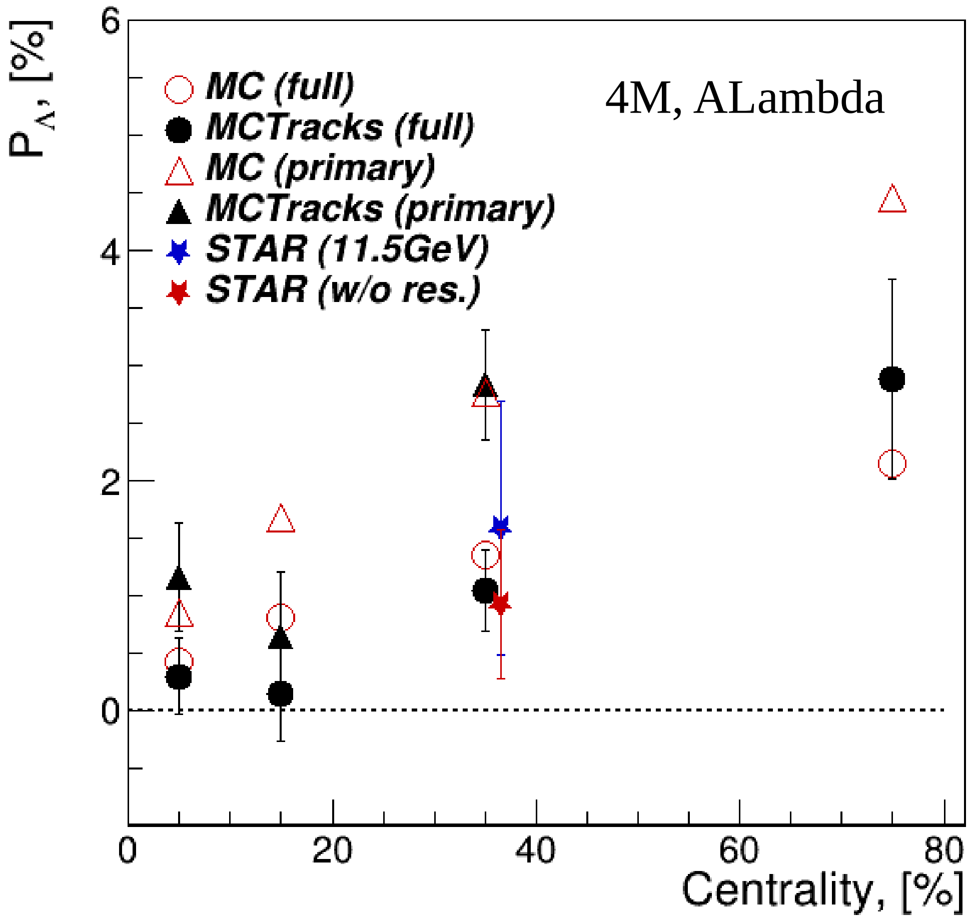




Good agreement for Lambda, for Anti-Lambda statistics is much smaller — larger uncertainty

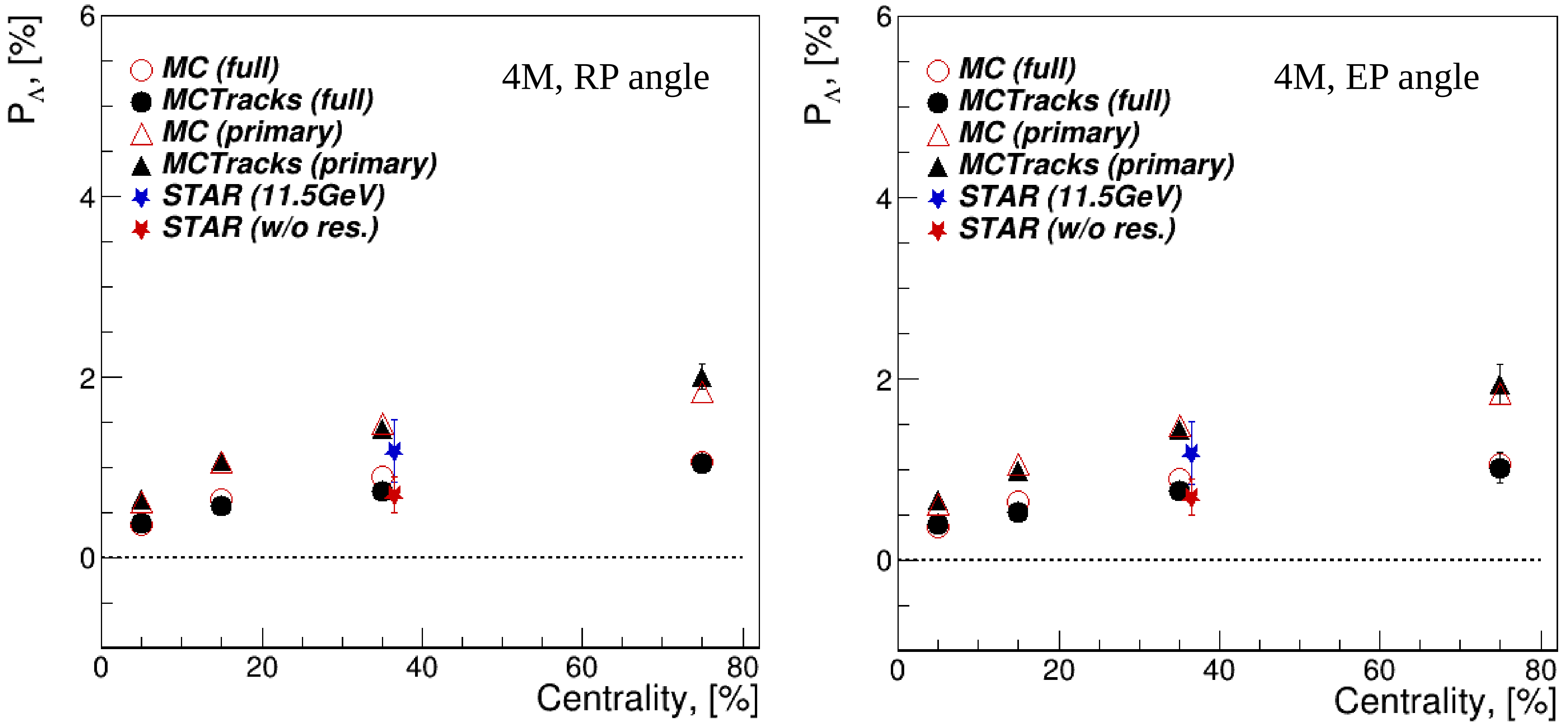
Results: 2. Private production — MCTracks, Mean polarization





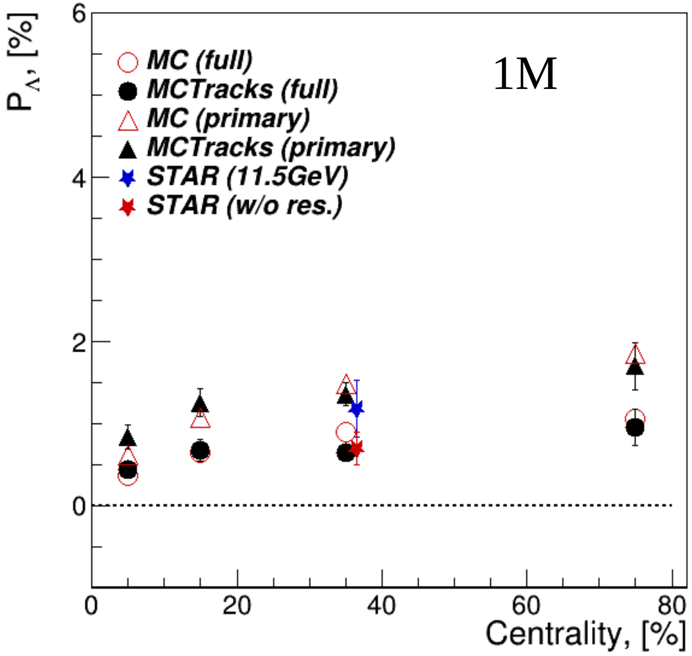
Good agreement for Lambda, for Anti-Lambda statistics is much smaller — larger uncertainty

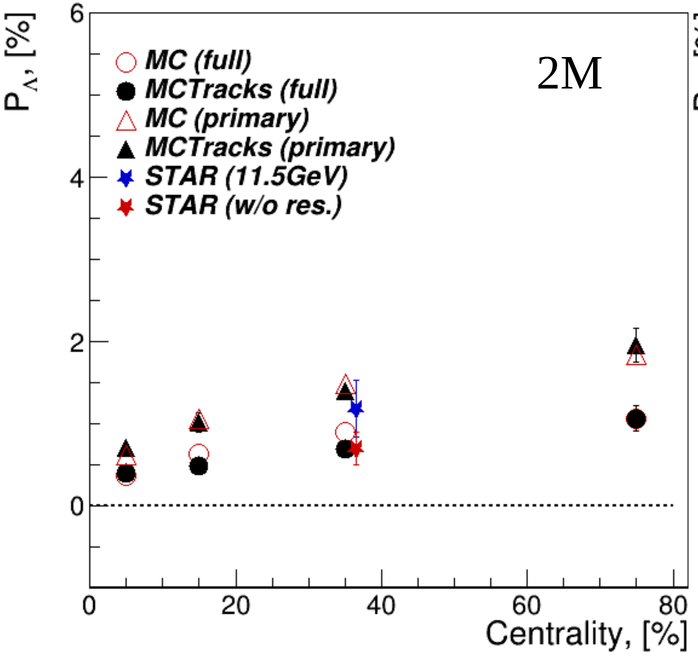
Results: 2. Private production — MCTracks, Mean polarization

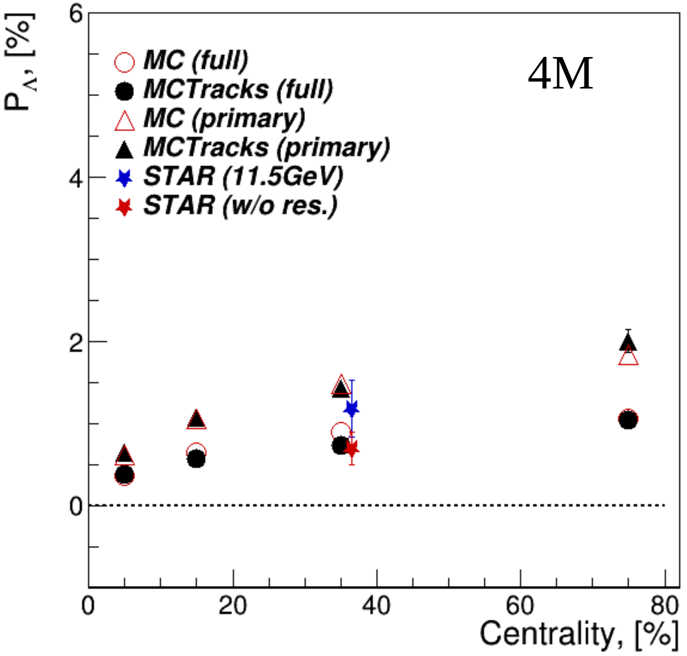


Using EP angle and its resolution instead of RP angle gives consistent results

Results: 2. Private production — MCTracks, Lambda

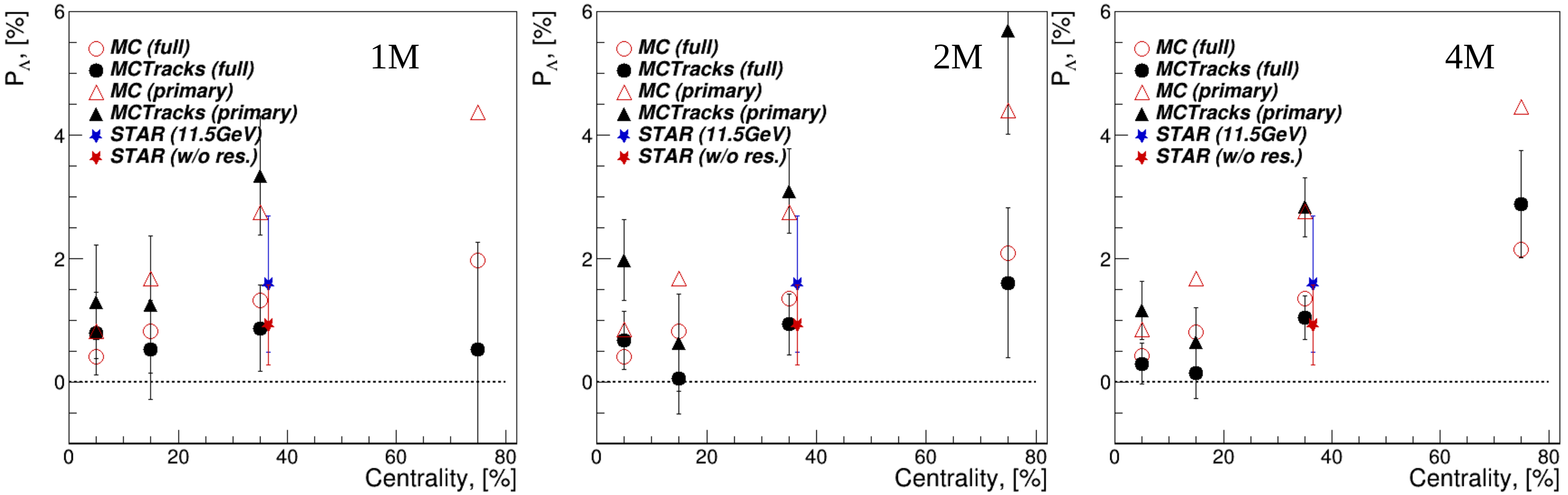






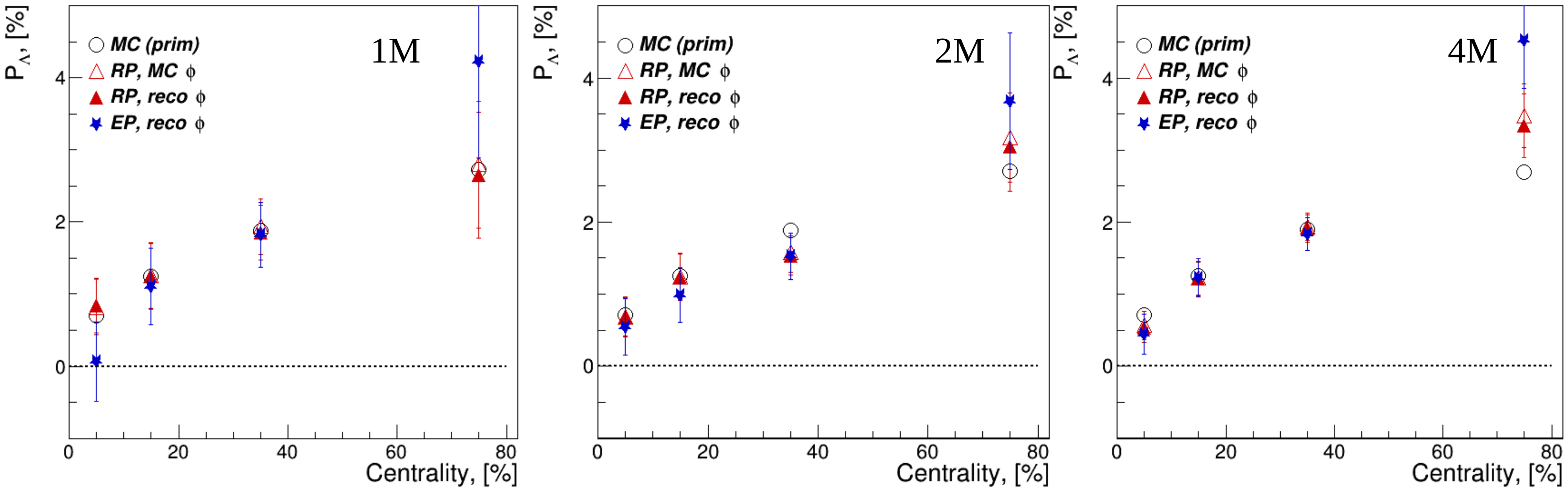
- In 20-50% region persists slight underestimation for full Lambda
- Summary: results are consistent and in good agreement

Results: 2. Private production — MCTracks, ALambda



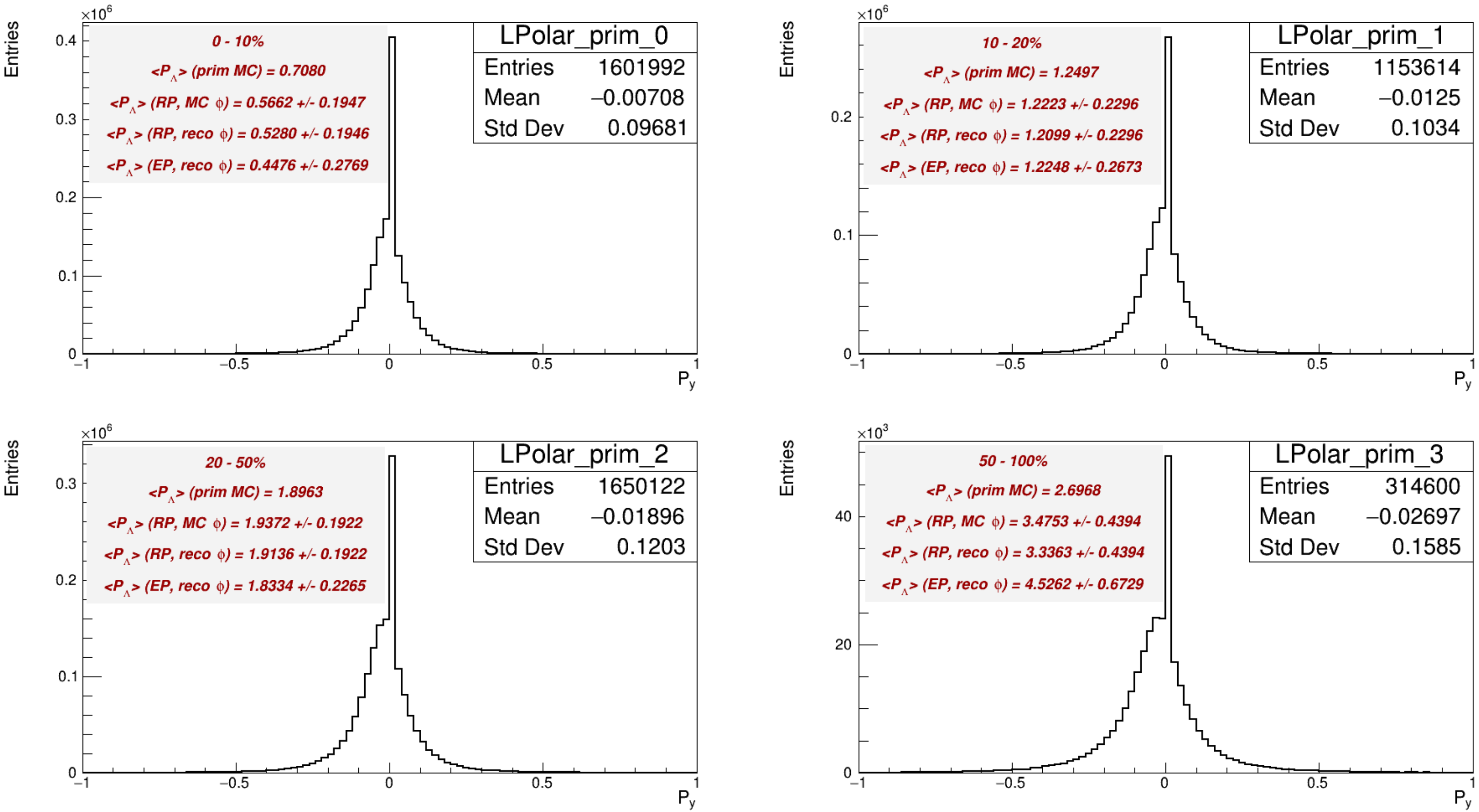
- For Anti-Lambda statistics is much smaller — larger uncertainty
- Signal of polarization is now present
- Even for MCTracks, only for 0-10% and 20-50% centrality results are in good agreement
- Summary: in the full sample (15M events) we might get a result in reco polarization, albeit with rather large uncertainties

Results: 3. Private production — MC Reco Lambda (primary)



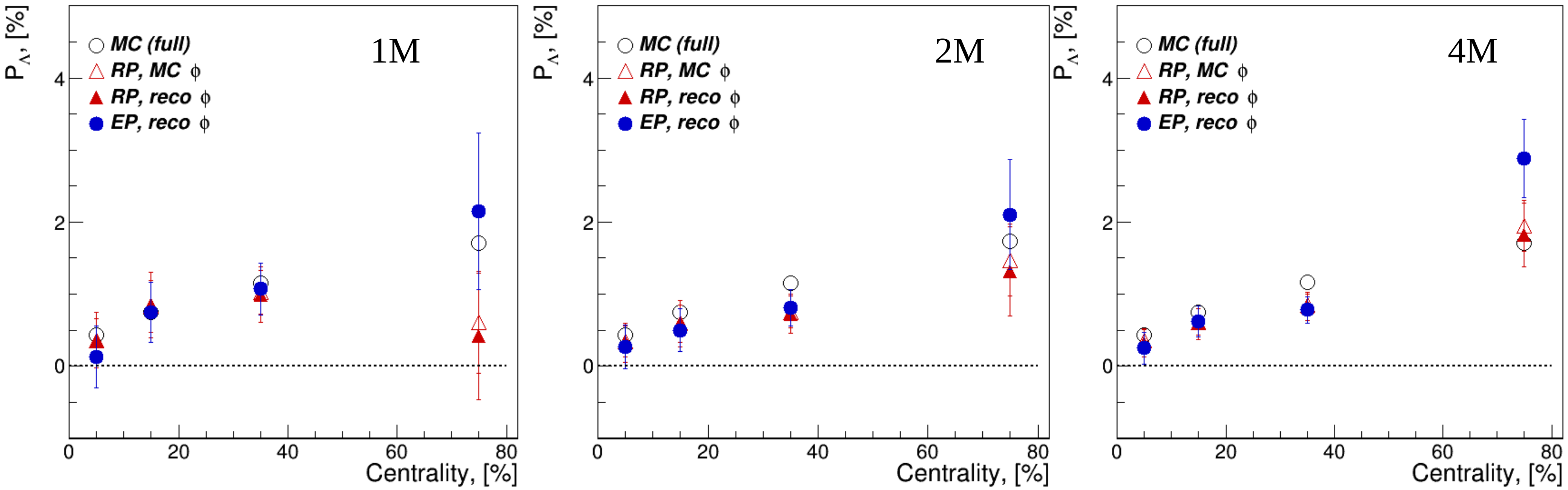
- Fitting of angular distributions for «true» Lambda from Reco
- Using exact angle (MC φ), reconstructed angle (reco φ) - with RP angle
- Using reconstructed angle (reco φ) - with EP angle and its resolution
- Summary: consistent results between all, except for 50-100% centrality region — smaller statistics and resolution

Results: 3. Private production — MC Reco Lambda (prim, 4M)



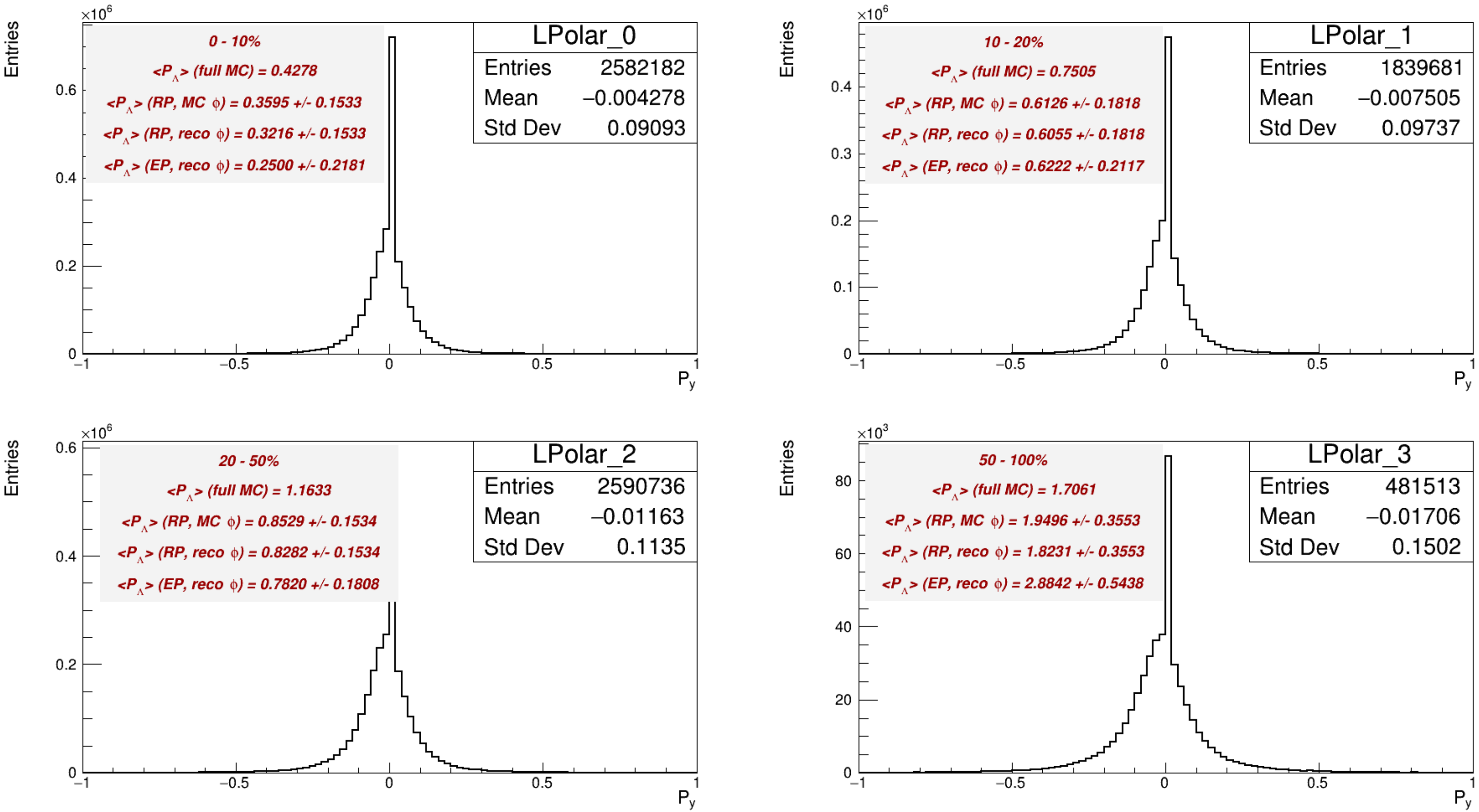
Rather good agreement

Results: 3. Private production — MC Reco Lambda (full)



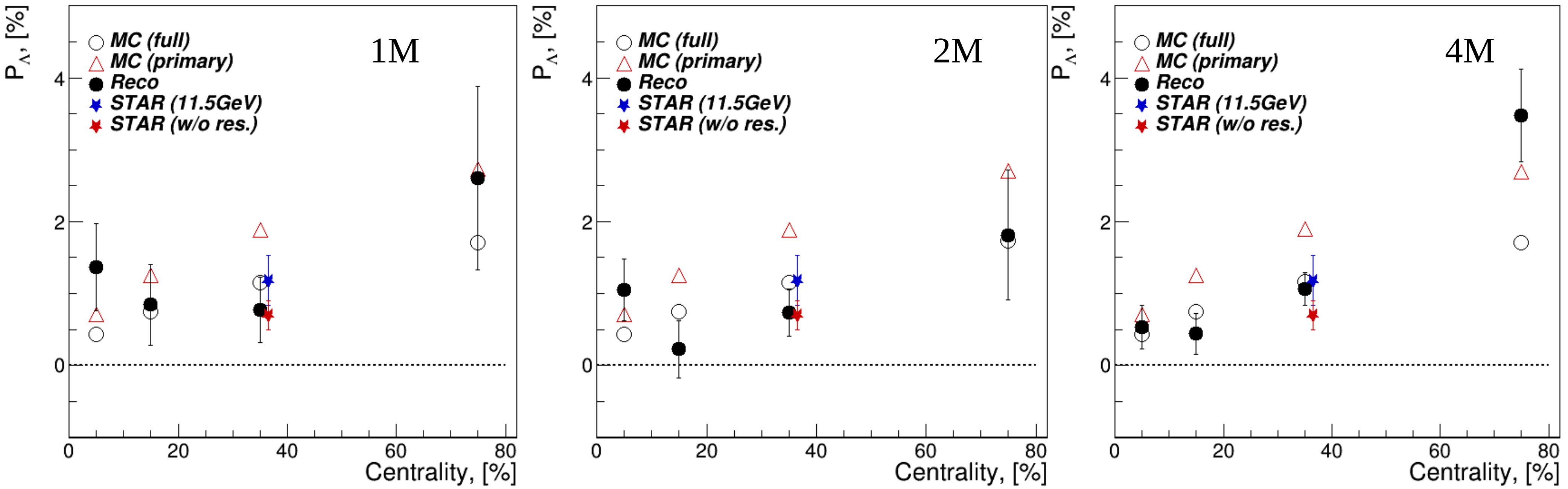
- Fitting of angular distributions for «true» Lambda from Reco
- Using exact angle (MC φ), reconstructed angle (reco φ) - with RP angle
- Using reconstructed angle (reco φ) - with EP angle and its resolution
- Summary: consistent results between all, except for 50-100% centrality region — smaller statistics and resolution

Results: 3. Private production — MC Reco Lambda (full, 4M)



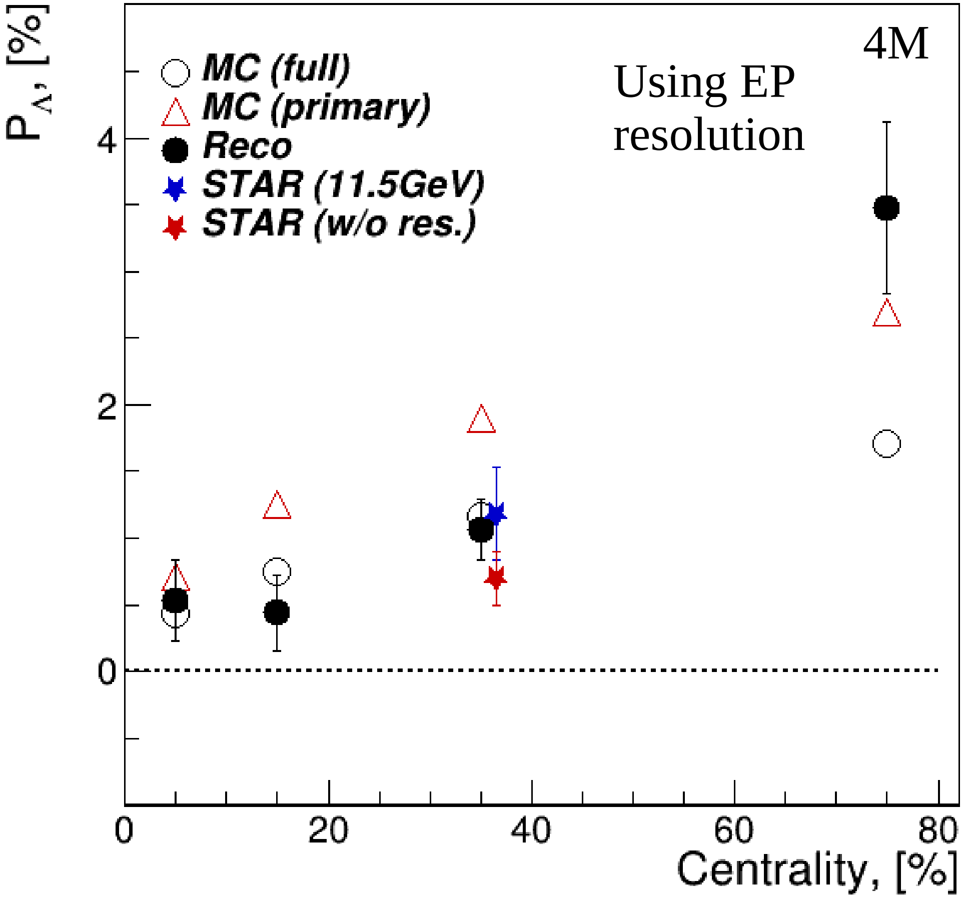
Rather good agreement

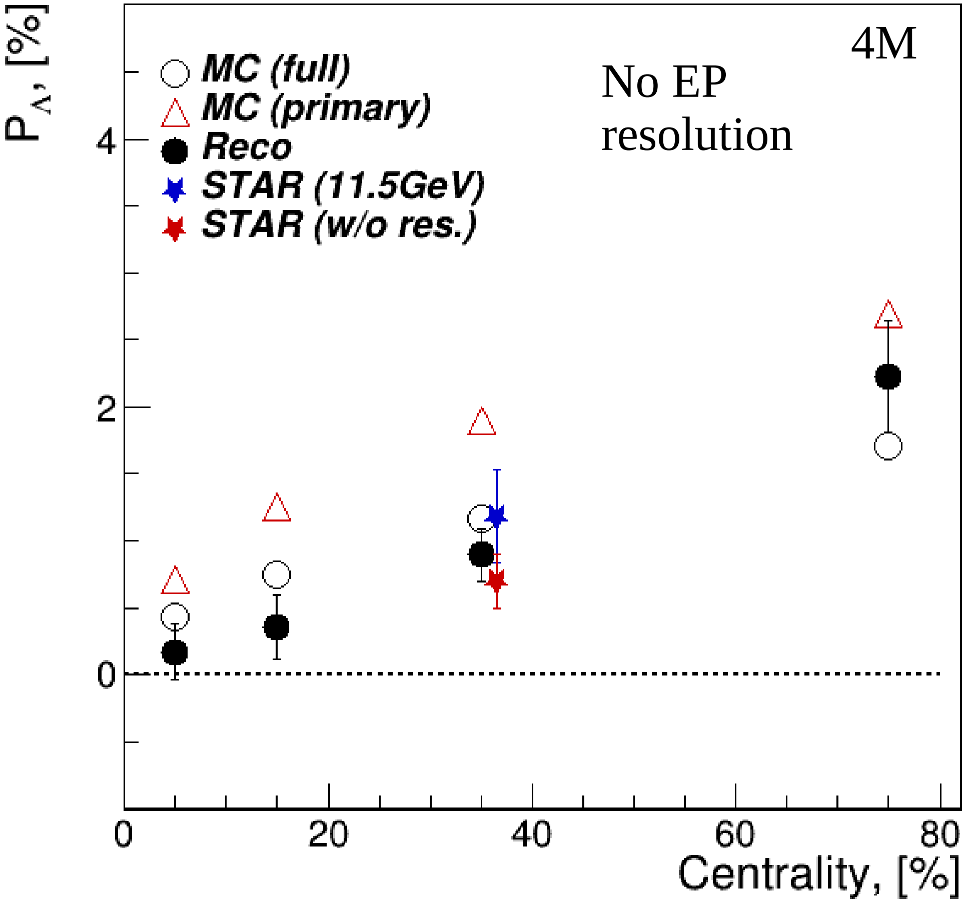
Results: 3. Private production — Reco Lambda



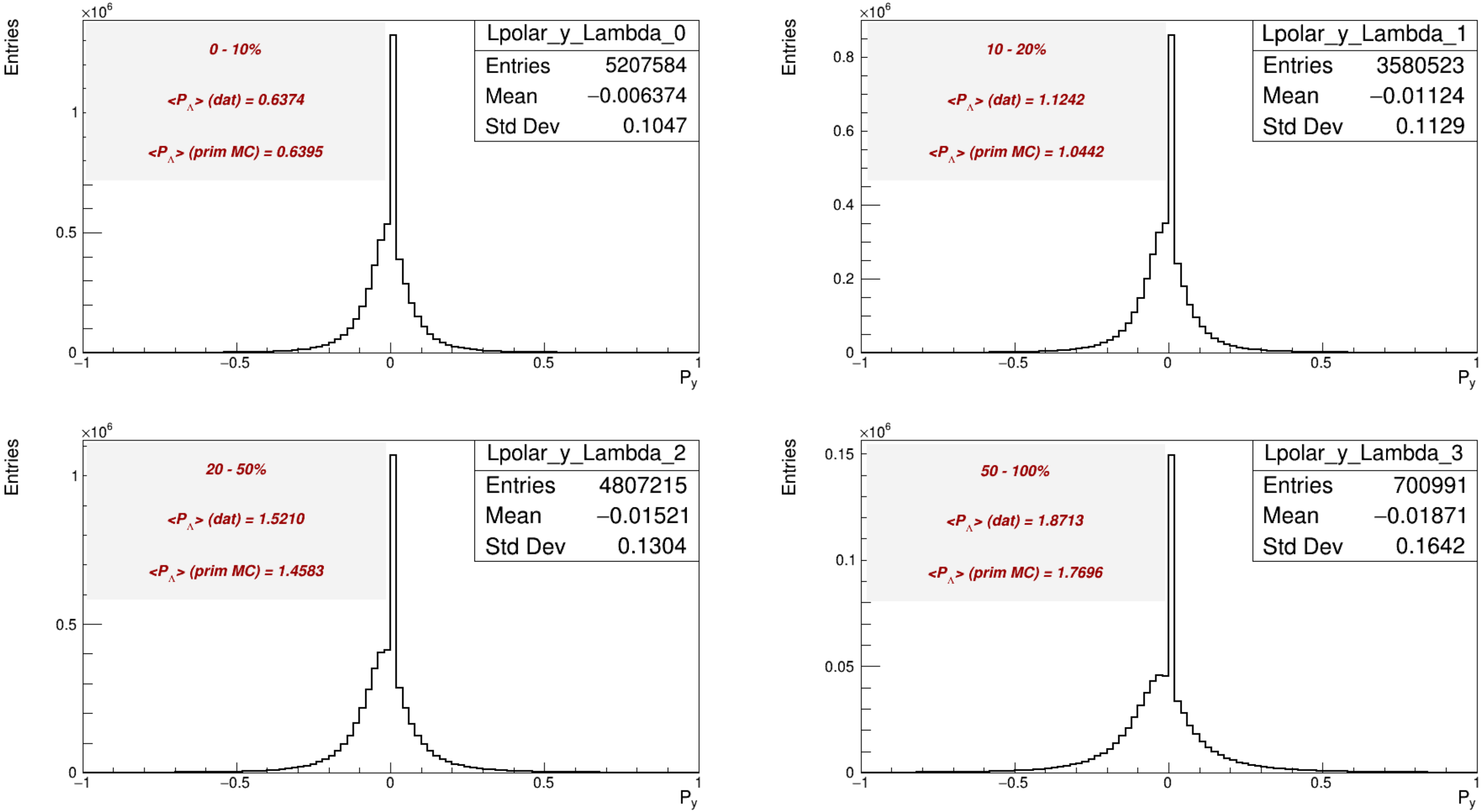
- 4M events give rather small uncertainties and agreement with MC values
- 50-100% centrality region: lowest statistics, smallest EP resolution
- Reconstruction may be improved (either current one by varying parameters or introducing event-mixing technique)
- Summary: results are consistent for the start of the new official production → Request 30

Results: 3. Private production — Reco Lambda (resolution effect)



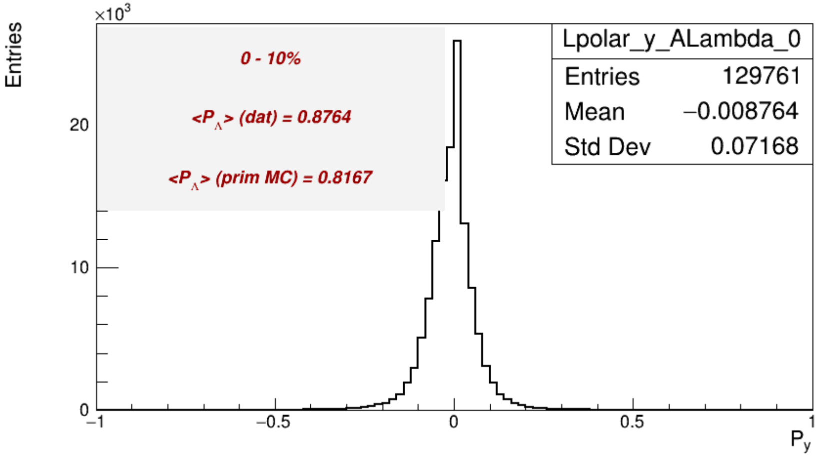


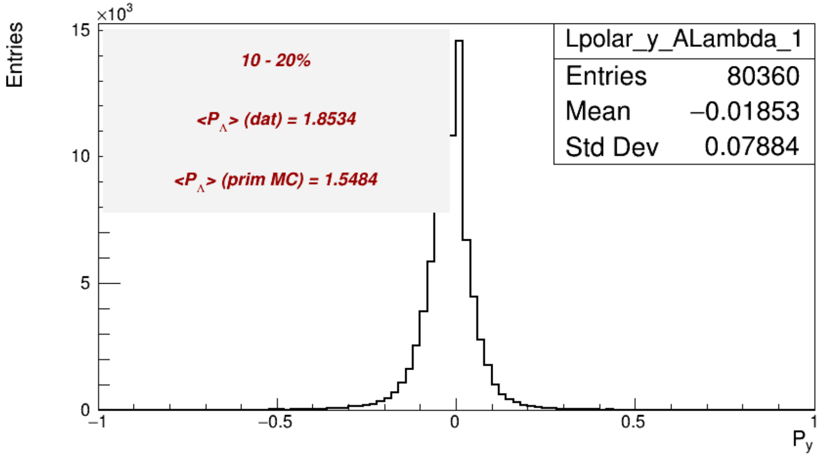
Results: Official production (Request 30, QA stage) - Lambda

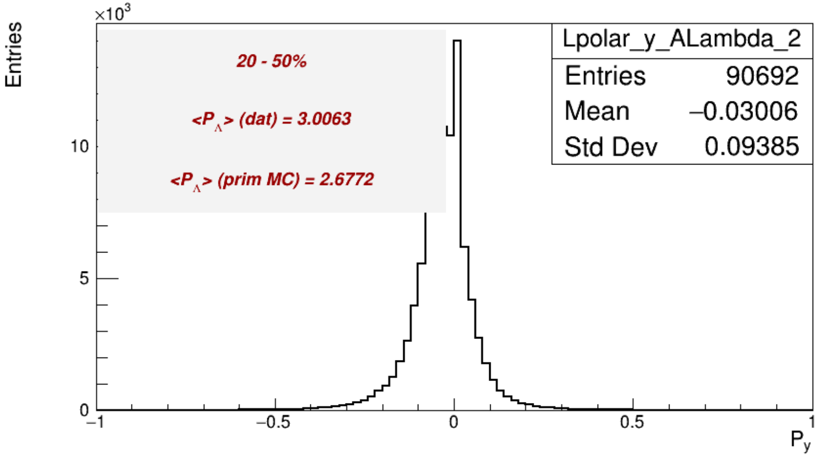


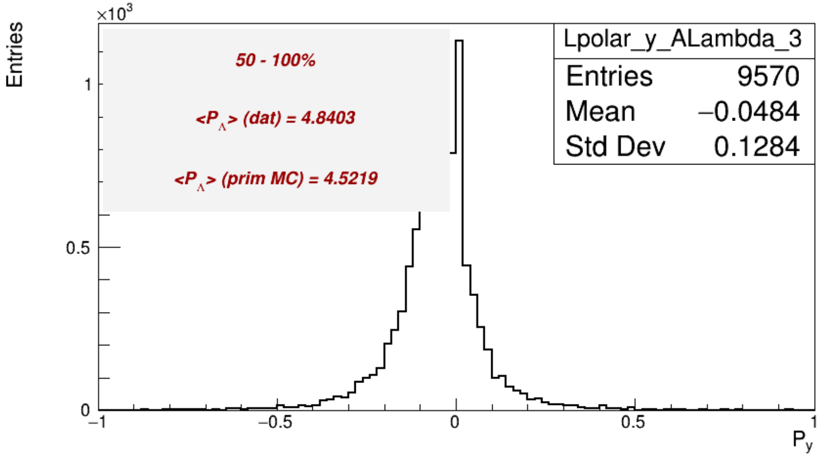
Preliminary (~175k events out of 1M for QA are ready)

Results: Official production (Request 30, QA stage) - ALambda

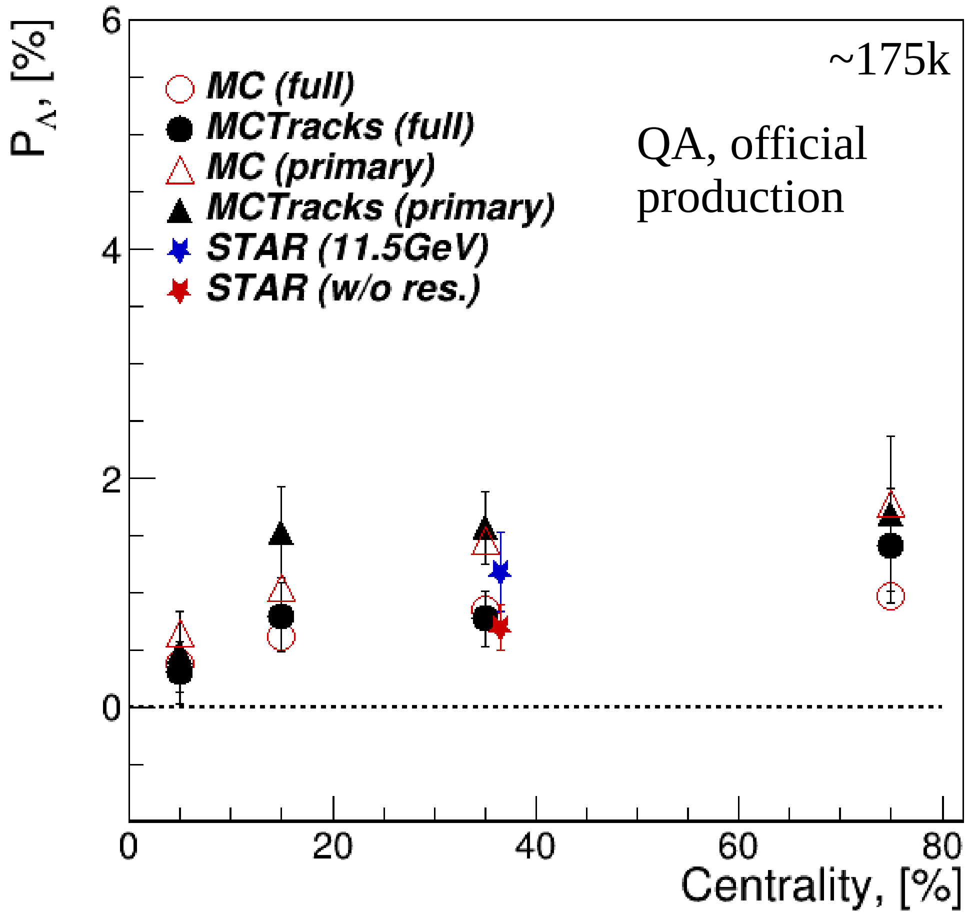


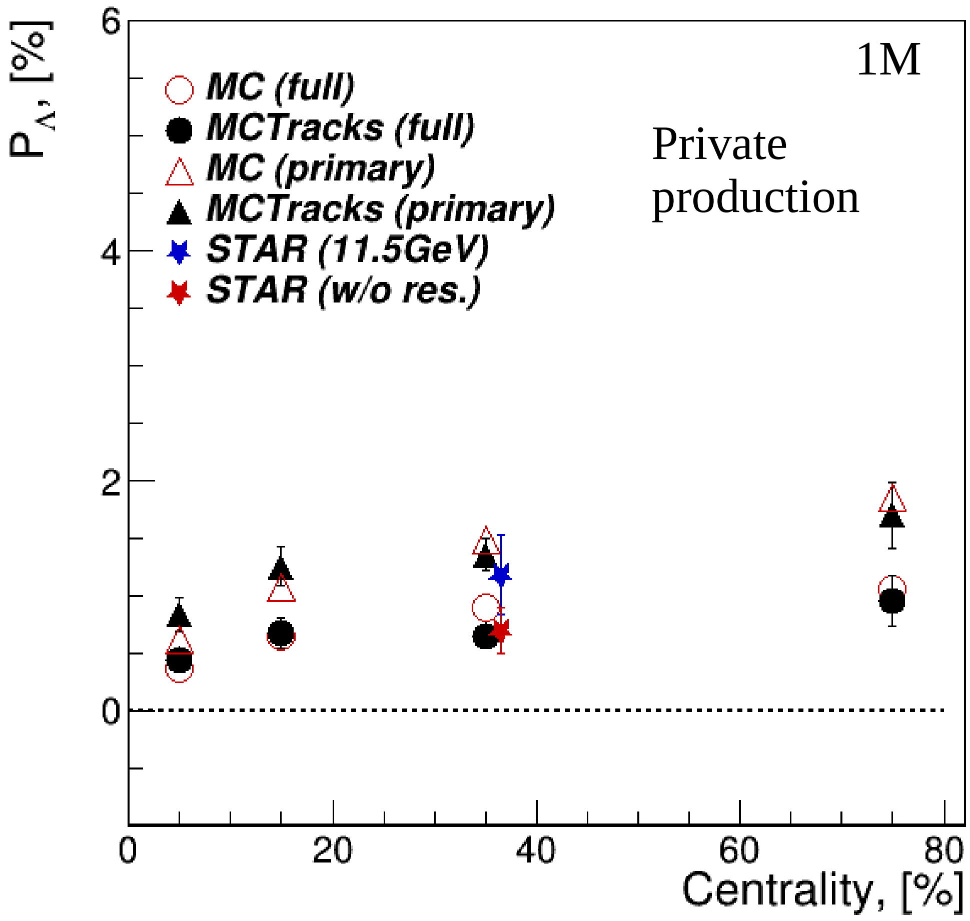






Preliminary (~175k events out of 1M for QA are ready)





Preliminary (~175k events out of 1M for QA are ready)

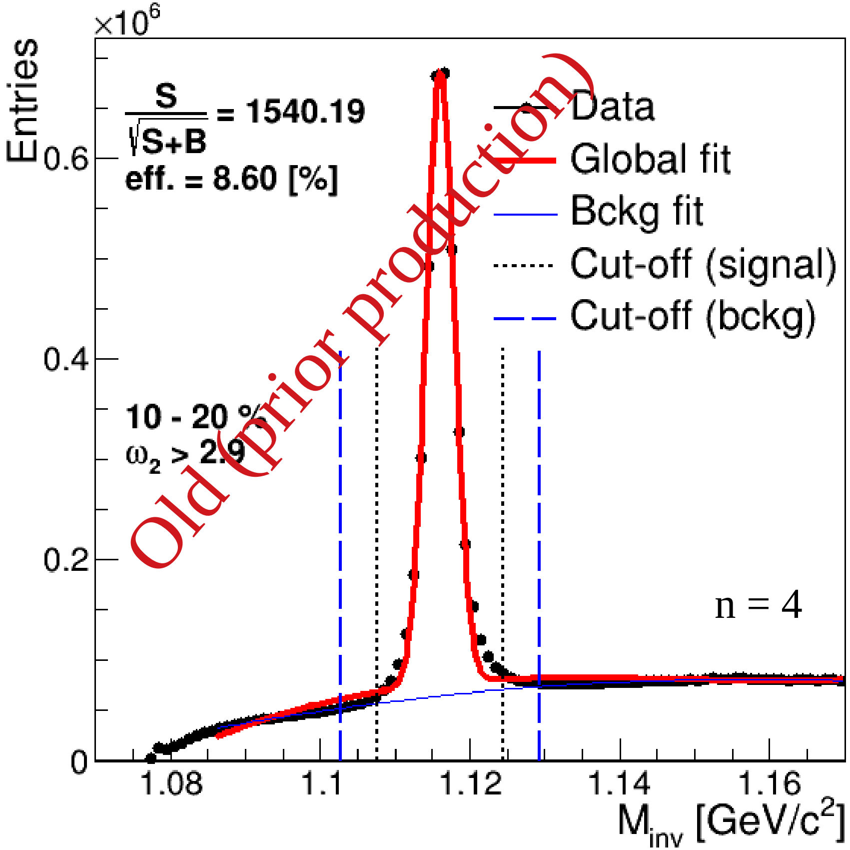
Conclusions

- Revised polarization transfer
  - rotation w.r.t. reaction plane
  - Primary hyperons: spin direction randomized according to the probability (|**P**|)
  - Secondary Lambda: spin direction randomized dependent on the feed-down constant
- Tests on private production (1M, 2M and 4M events)
  - (Λ) MCTracks & MC Reco: results are consistent and in good agreement
  - (Λ) Reco: except 50-100% cent., results are in good agreement with MC values
  - ($\bar{\Lambda}$) MCTracks: in 0-10% & 20-50% cent. results are in good agreement, need larger statisctics for accurate Reco analysis
- New official production (Request 30)
  - QA stage, waiting for full statistics (preliminary test shows no problems)

The End

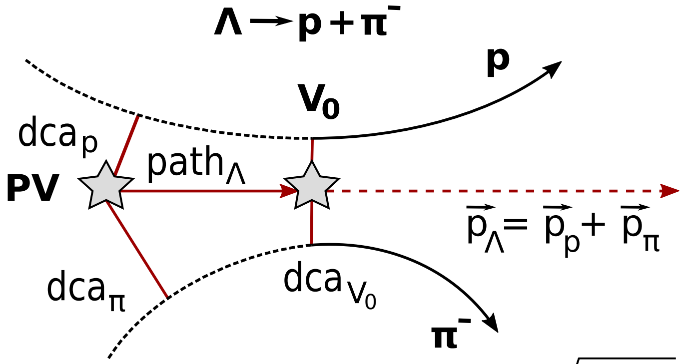
Thank you for your attention!

Back Up



Fitting procedure:

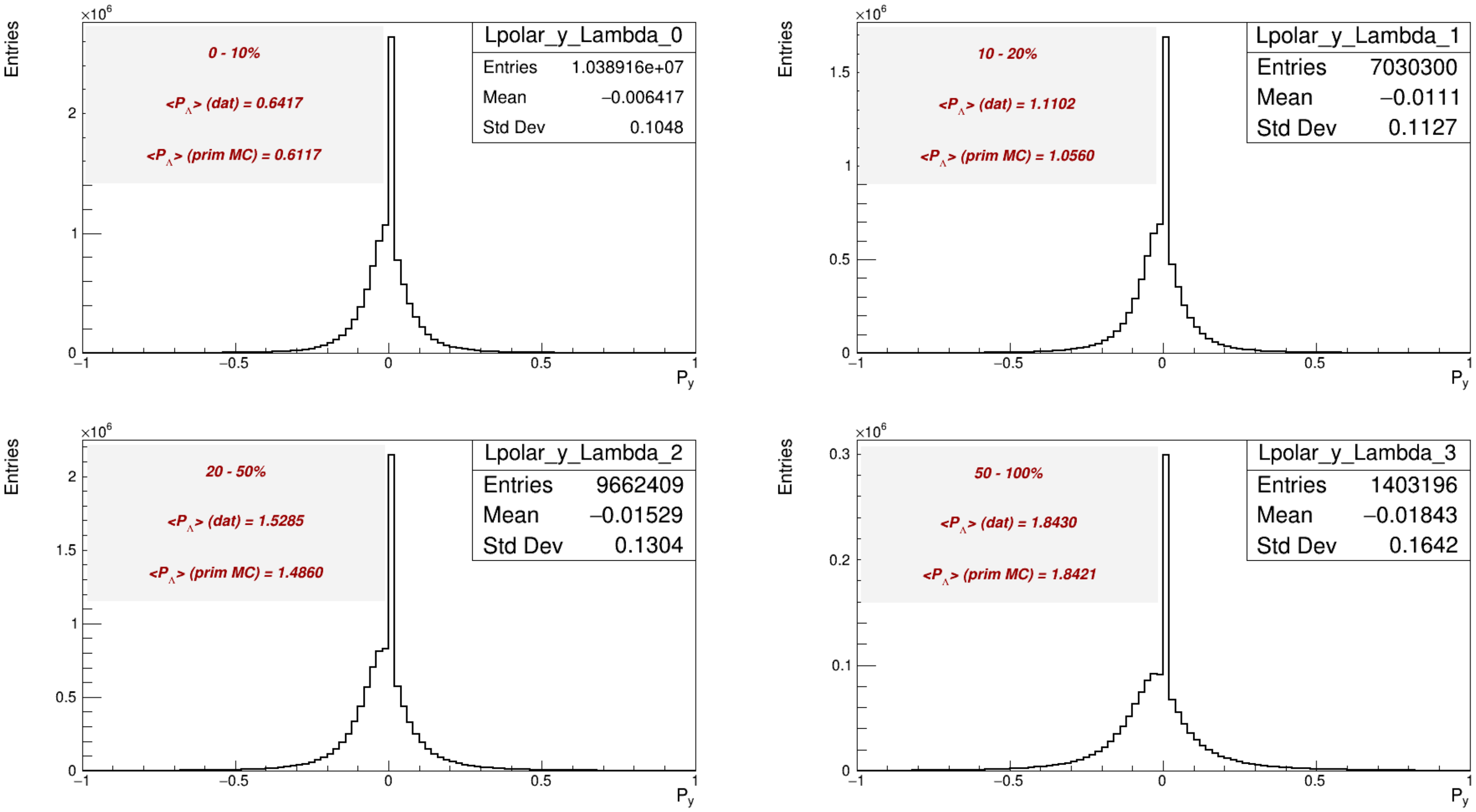
- Global fit (Gauss + Legendre polynomials) → get cut-off region for bckg fit
- Background fit in sidebands ($\pm$ 7σ)
- Cut-off: $\langle M_\Lambda \rangle \pm n^*\sigma$
- ω_2 cut based on maximum significance (for each centrality bin)



$$\omega_2 = \ln \frac{\sqrt{\chi^2_\pi \chi^2_p}}{\chi^2_\Lambda + \chi^2_{V_0}}$$

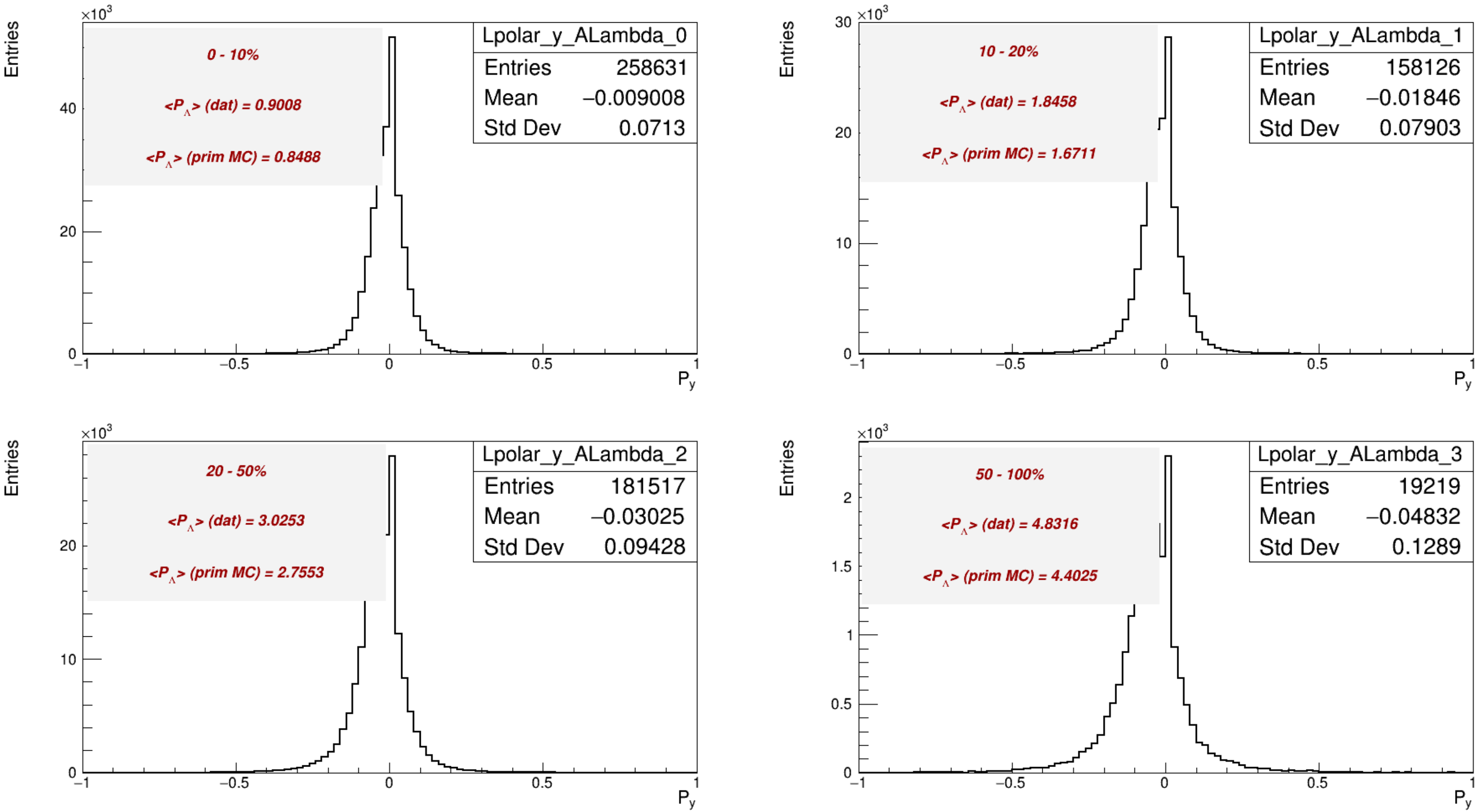
$$f(x) = p_0 \exp\left(\frac{(-0.5(x-p_1))^2}{p_2^2}\right) + p_3(L_0 + p_4 L_1 + p_5 L_2 + p_6 L_3 + p_7 L_4)$$

1. Compare MCTracks with data — 2M (Lambda)



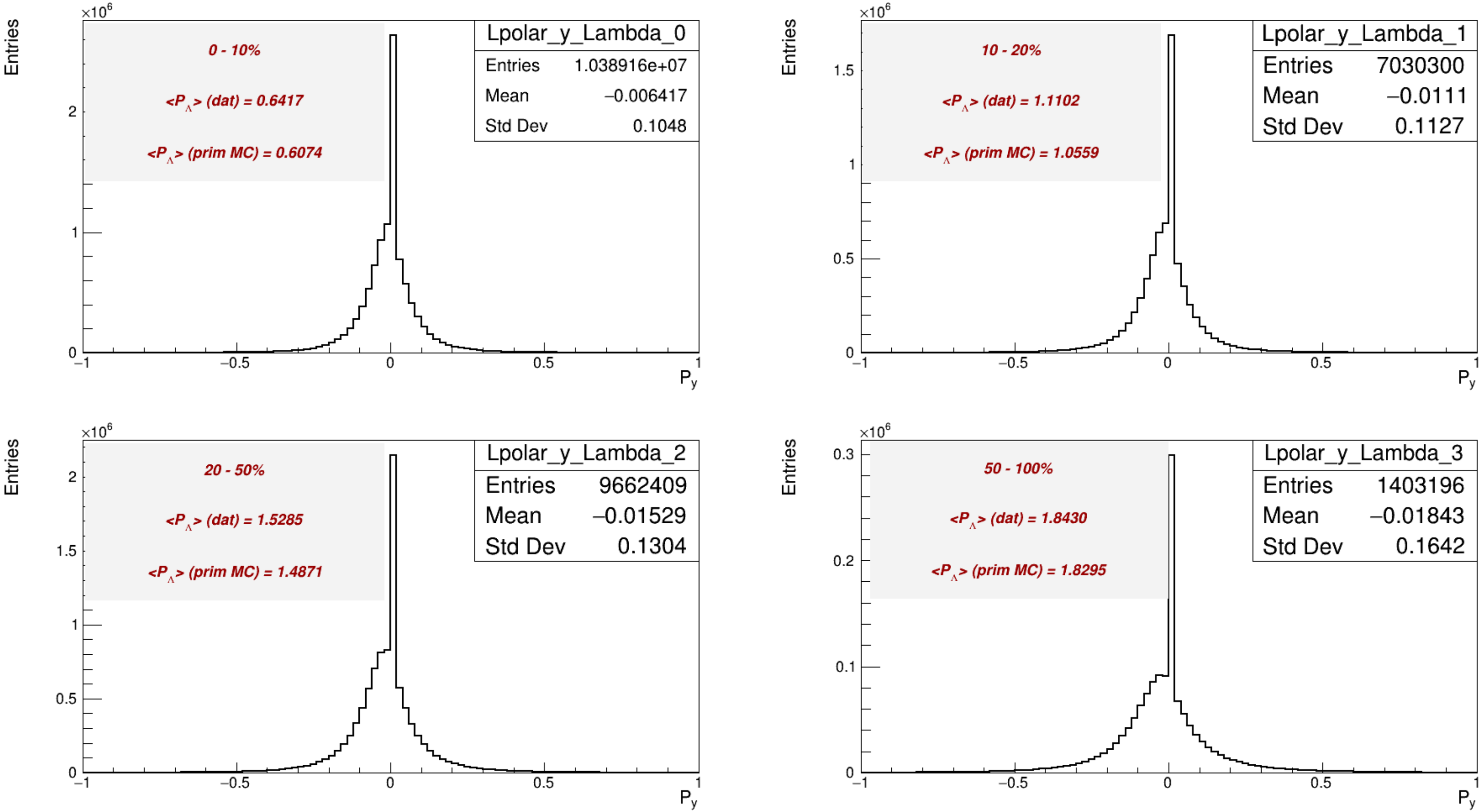
Different centrality selection — still, good agreement

1. Compare MCTracks with data — 2M (ALambda)



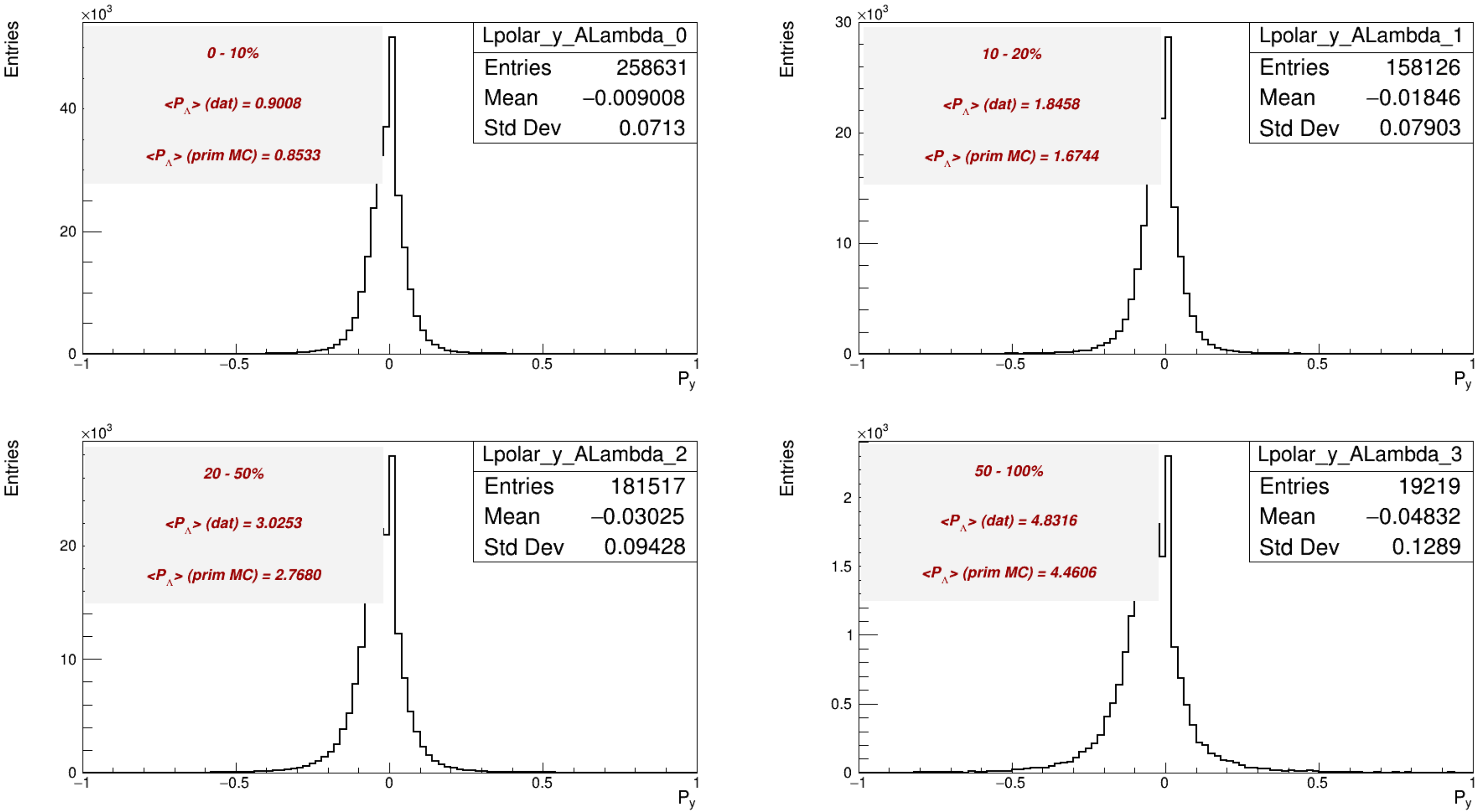
Different centrality selection — still, good agreement

1. Compare MCTracks with data — 4M (Lambda)



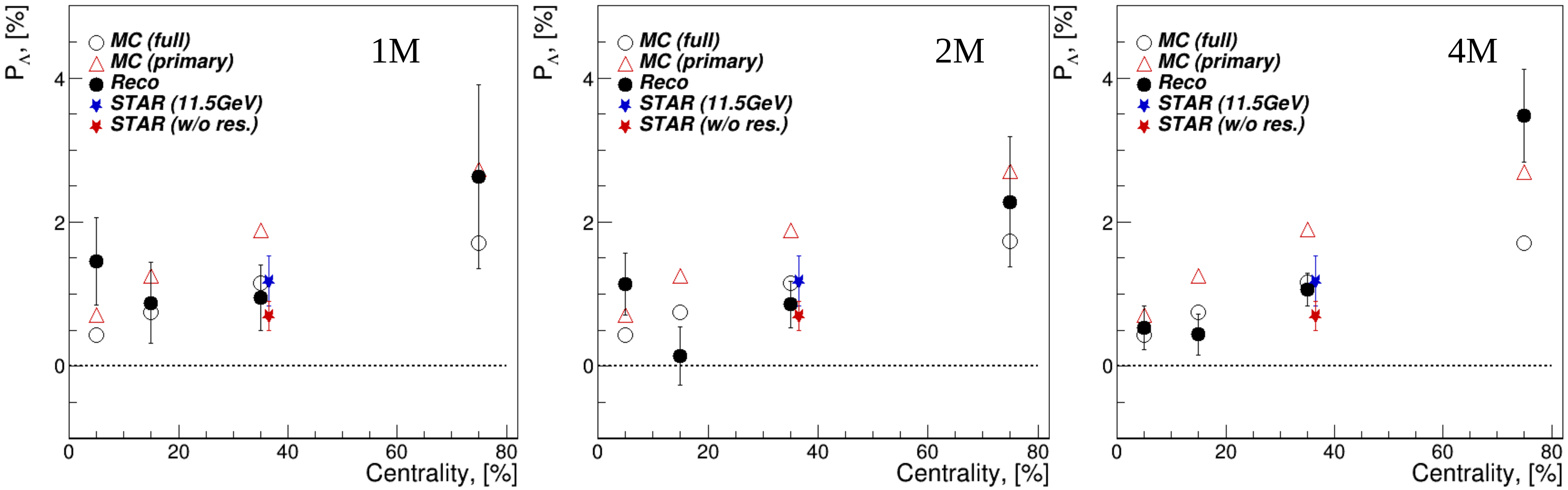
Different centrality selection — still, good agreement

1. Compare MCTracks with data — 4M (ALambda)

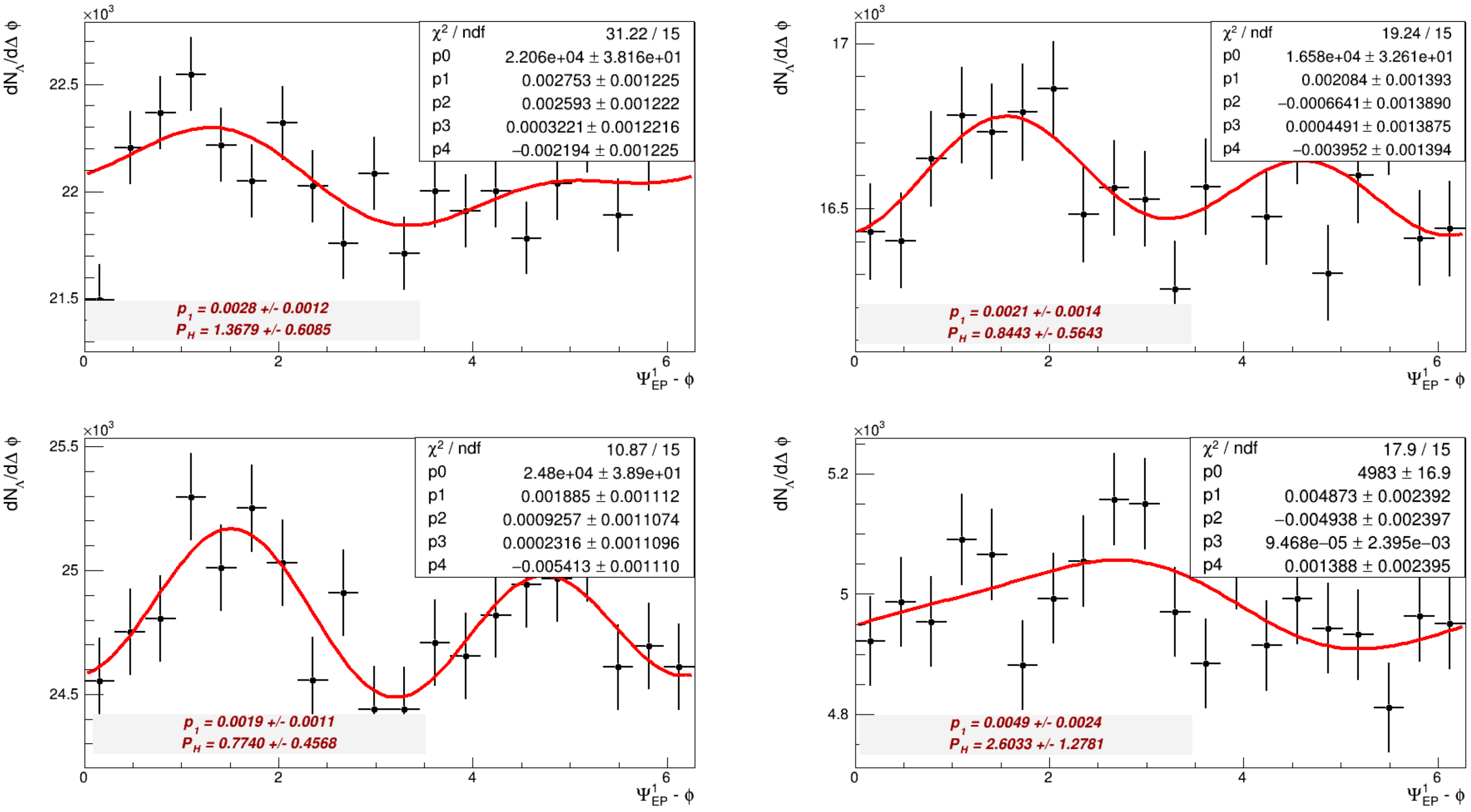


Different centrality selection — still, good agreement

2. Mean polarization — Reco Lambda (1M vs 2M vs 4M) - 8sigma

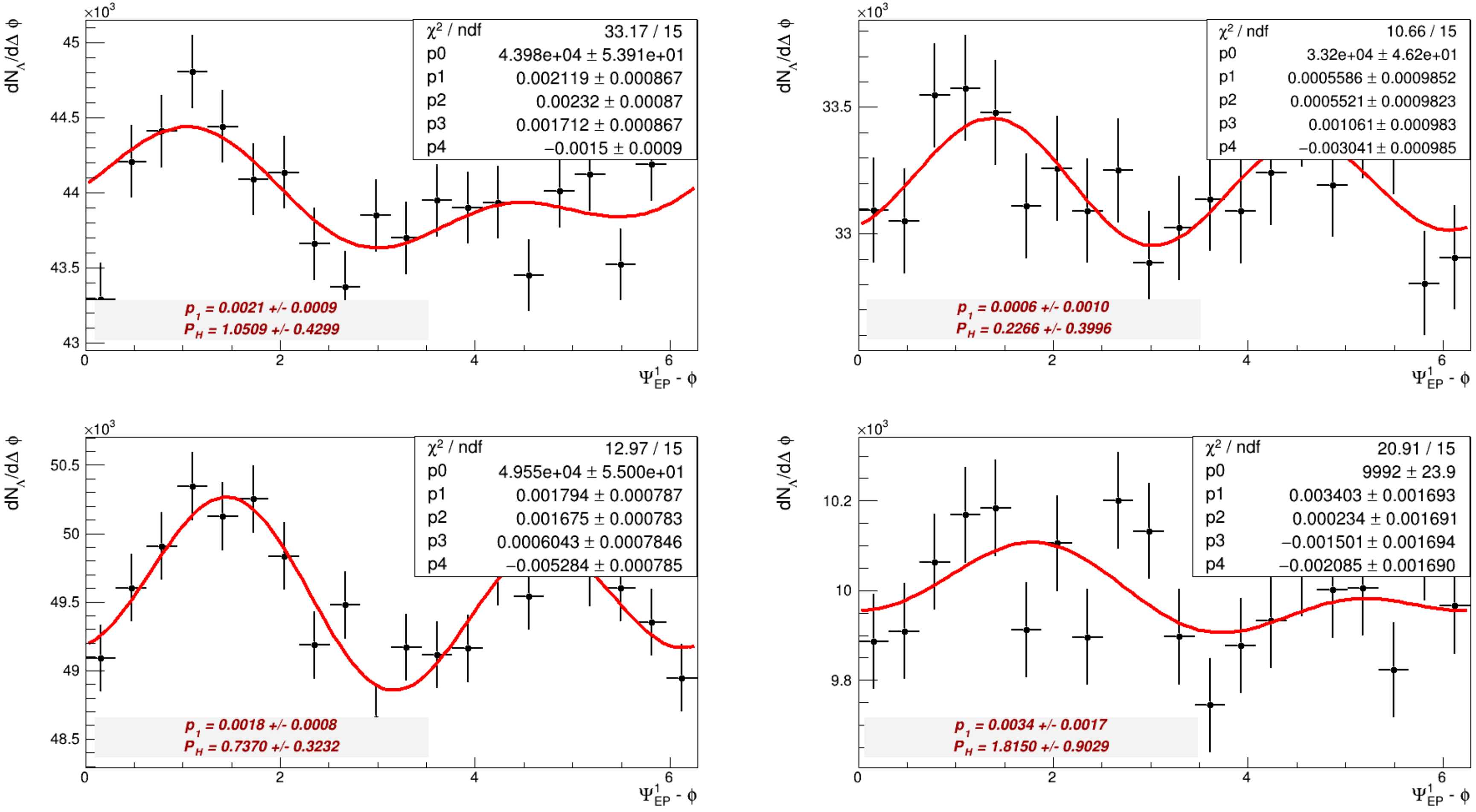


- Reconstruction may be improved (either current one by varying parameters or introducing event-mixing technique)
- e.g.: changing the range of background fit from 7sigma to 8sigma away from the peak region

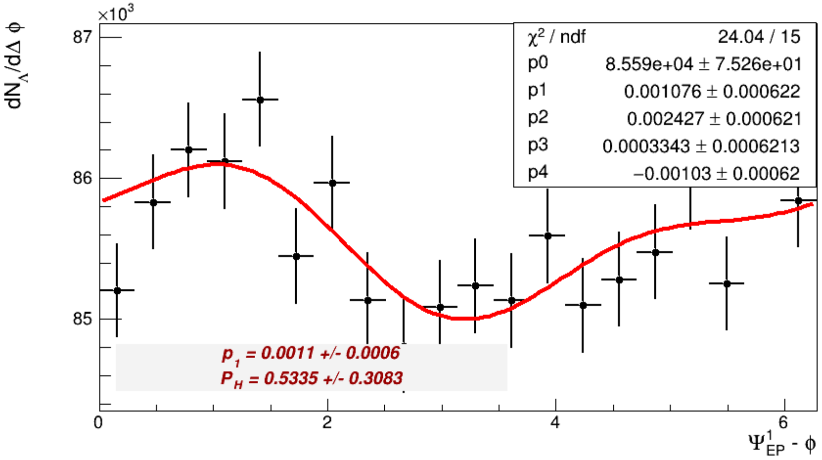


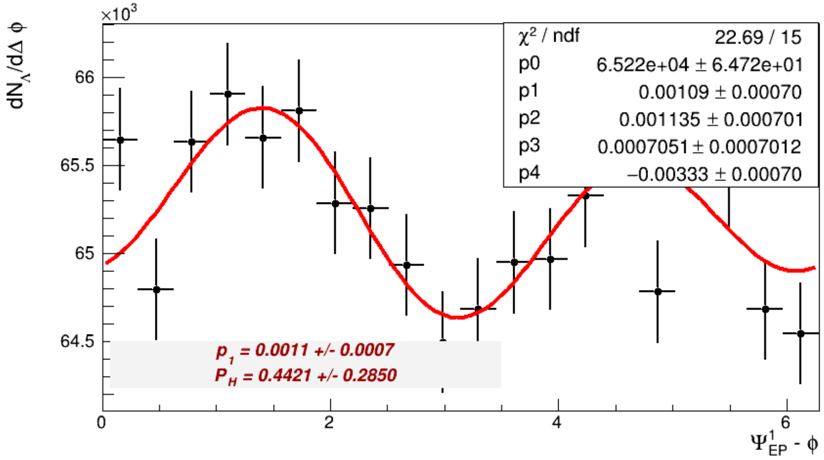
$\times10^3$
$dN_\Lambda/d\Delta\phi$
Ψ^1_{EP} - ϕ
χ2 / ndf 31.22 / 15
p0 2.206e+04 ± 3.816e+01
p1 0.002753 ± 0.001225
p2 0.002593 ± 0.001222
p3 0.0003221 ± 0.0012216
p4 −0.002194 ± 0.001225
p_1 = 0.0028 +/- 0.0012
P_H = 1.3679 +/- 0.6085
χ2 / ndf 19.24 / 15
p0 1.658e+04 ± 3.261e+01
p1 0.002084 ± 0.001393
p2 −0.0006641 ± 0.0013890
p3 0.0004491 ± 0.0013875
p4 −0.003952 ± 0.001394
p_1 = 0.0021 +/- 0.0014
P_H = 0.8443 +/- 0.5643
χ2 / ndf 10.87 / 15
p0 2.48e+04 ± 3.89e+01
p1 0.001885 ± 0.001112
p2 0.0009257 ± 0.0011074
p3 0.0002316 ± 0.0011096
p4 −0.005413 ± 0.001110
p_1 = 0.0019 +/- 0.0011
P_H = 0.7740 +/- 0.4568
χ2 / ndf 17.9 / 15
p0 4983 ± 16.9
p1 0.004873 ± 0.002392
p2 −0.004938 ± 0.002397
p3 9.468e−05 ± 2.395e−03
p4 0.001388 ± 0.002395
p_1 = 0.0049 +/- 0.0024
P_H = 2.6033 +/- 1.2781

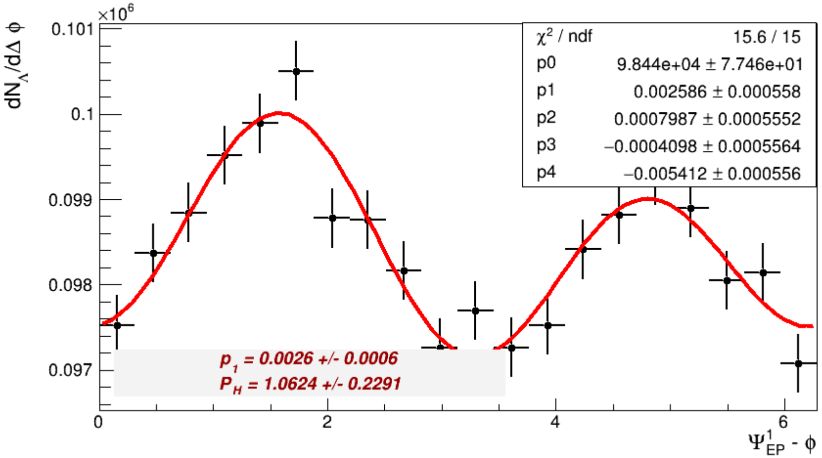
2. Fitting Reco Lambda (2M)

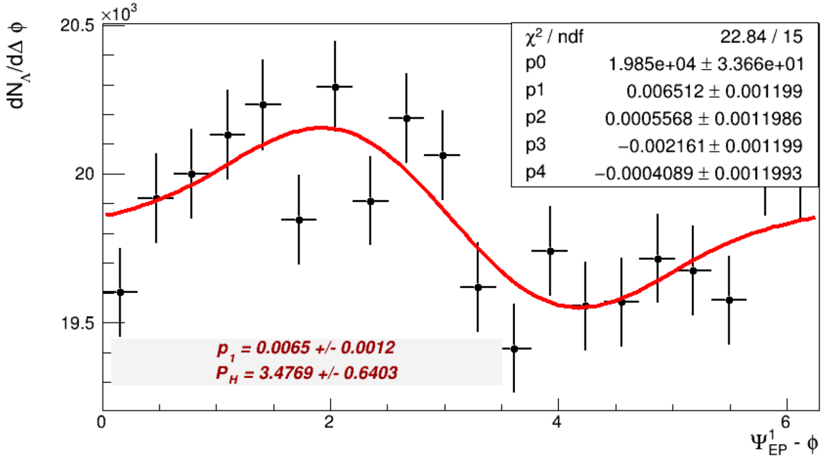


2. Fitting Reco Lambda (4M)

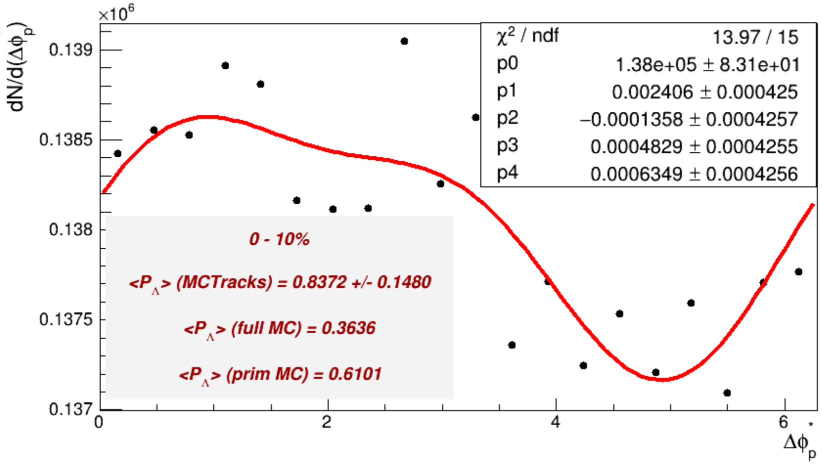


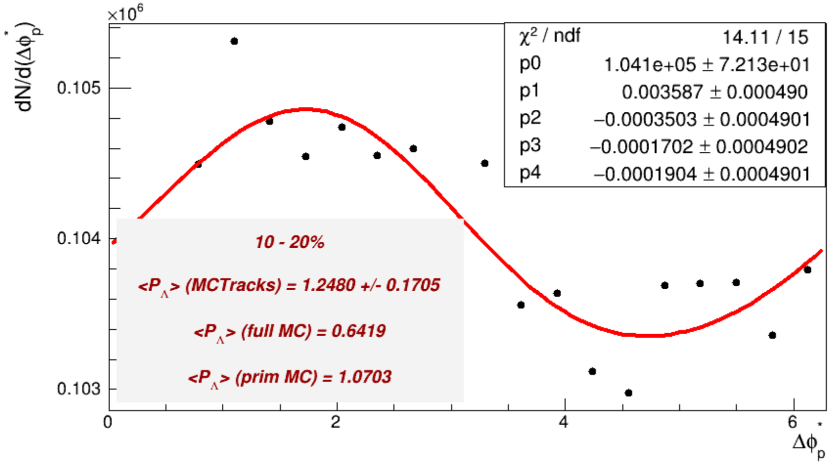


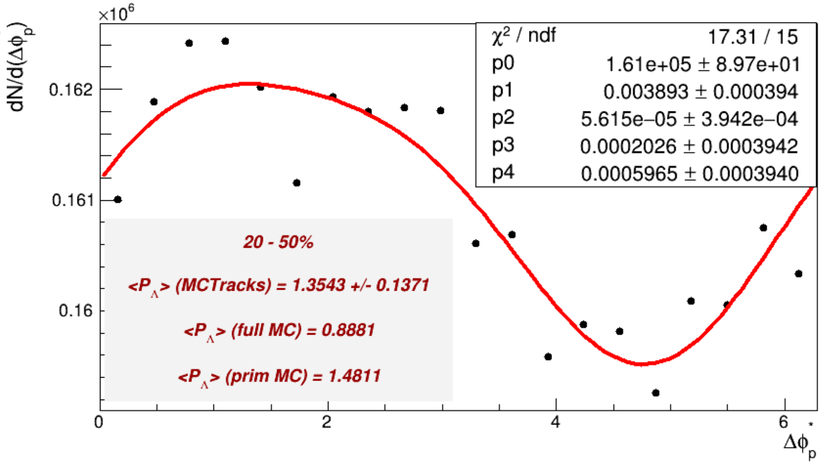


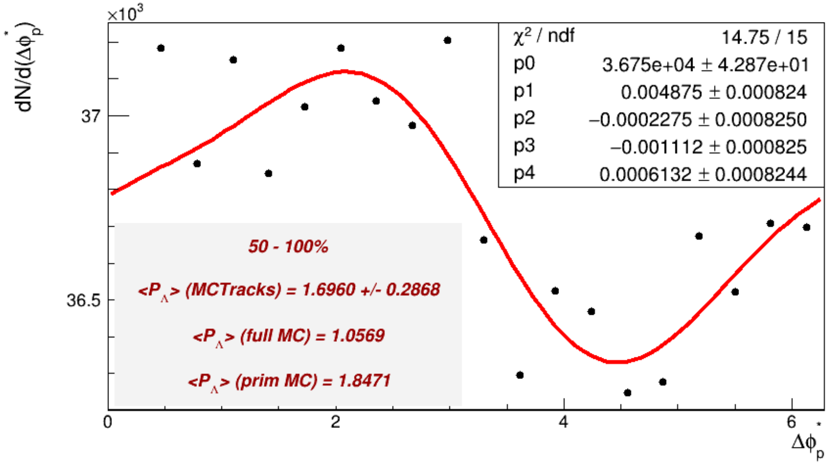


1. Primary Lambda — 1M (MCTracks)

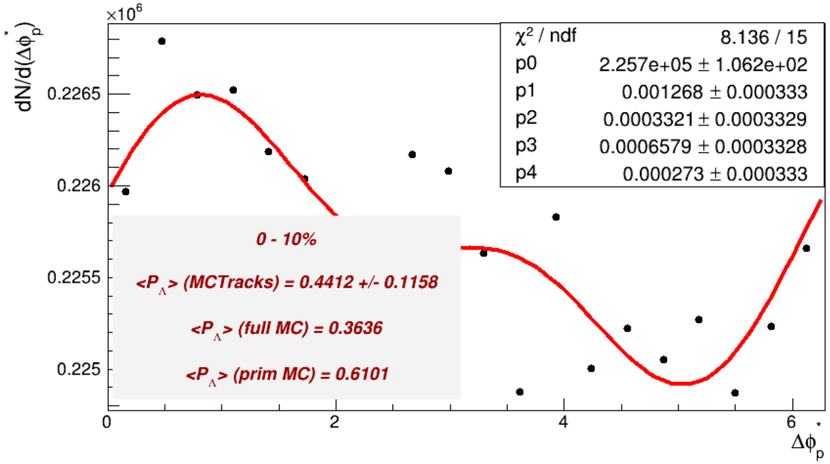


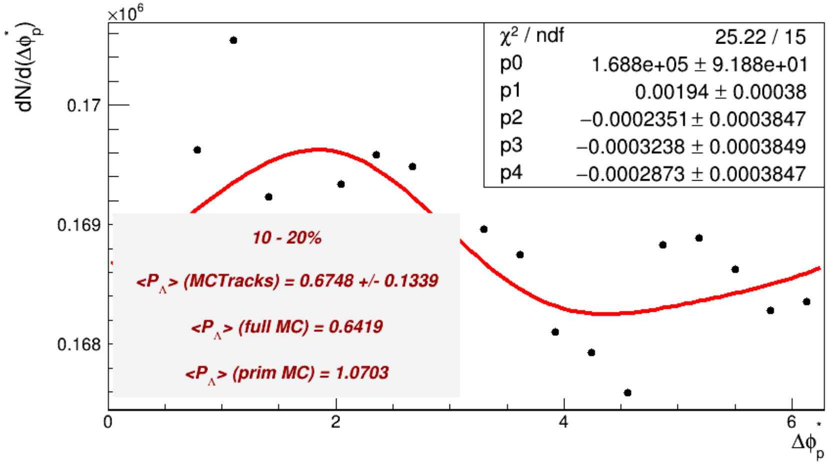


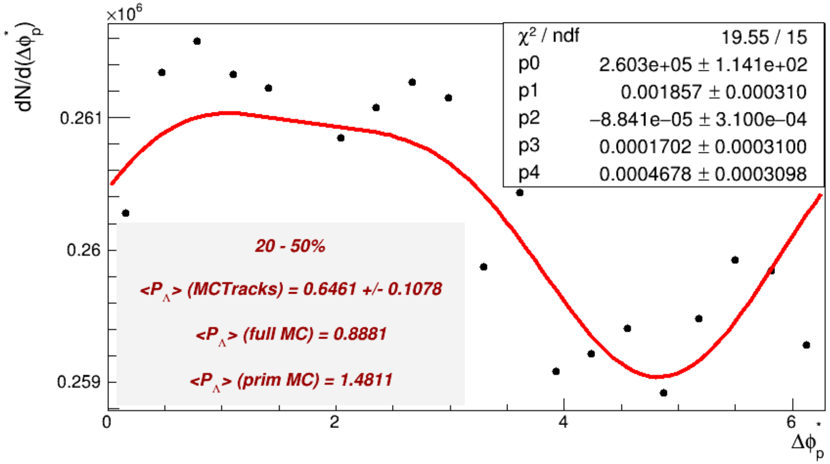


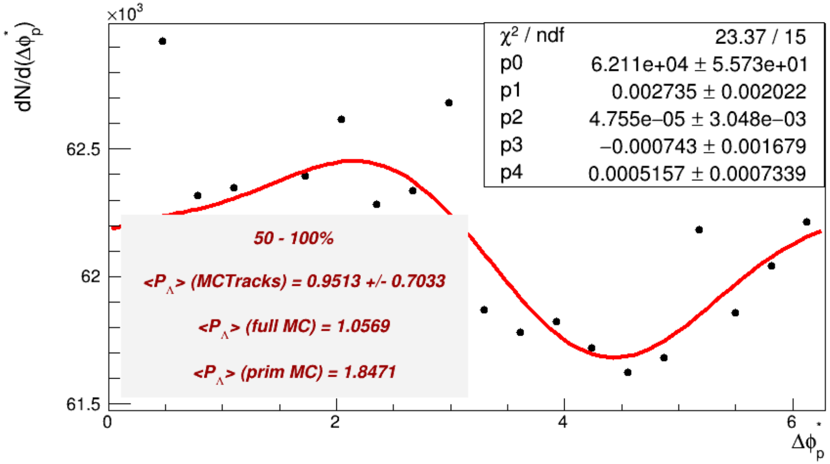


1. Full Lambda — 1M (MCTracks)

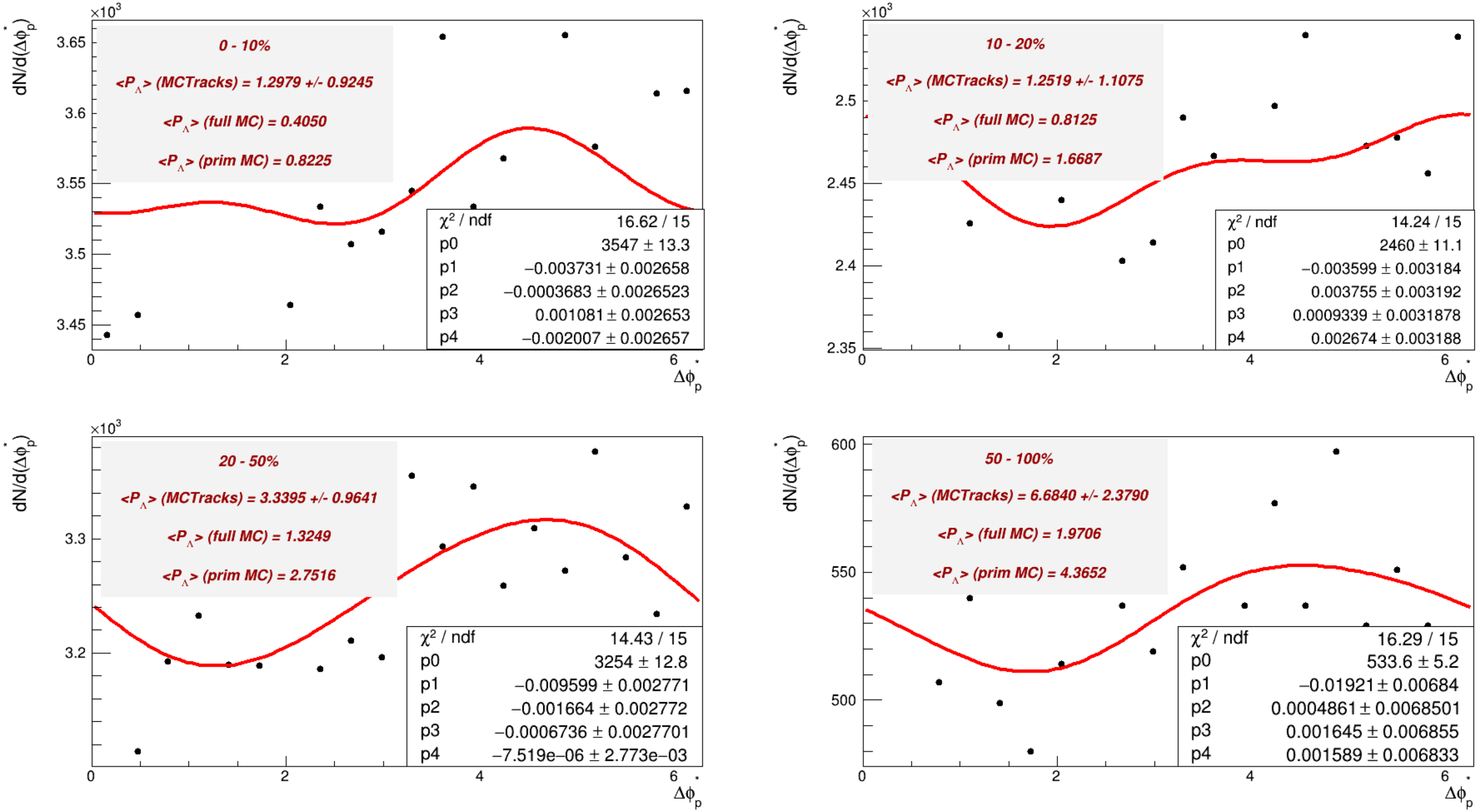




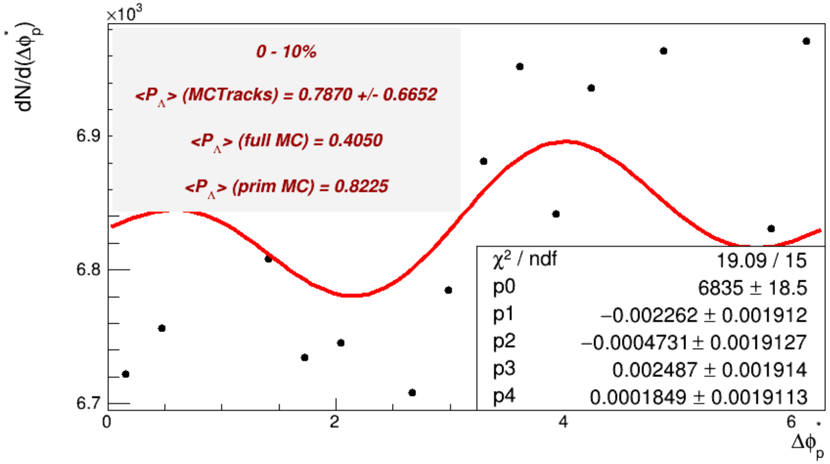


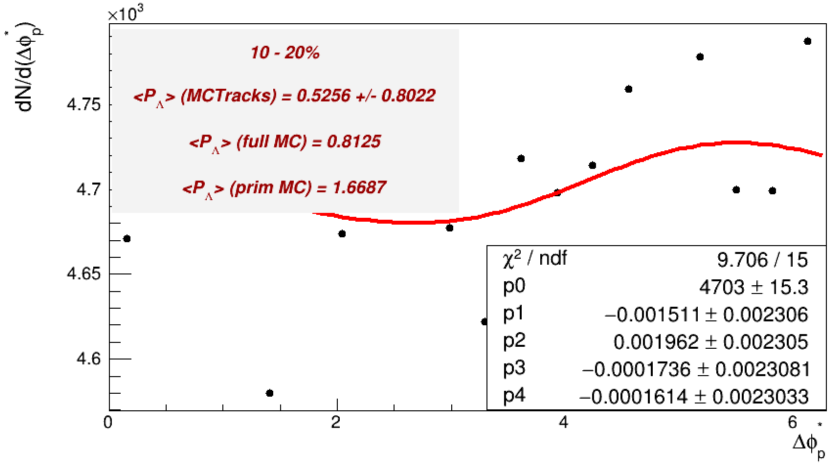


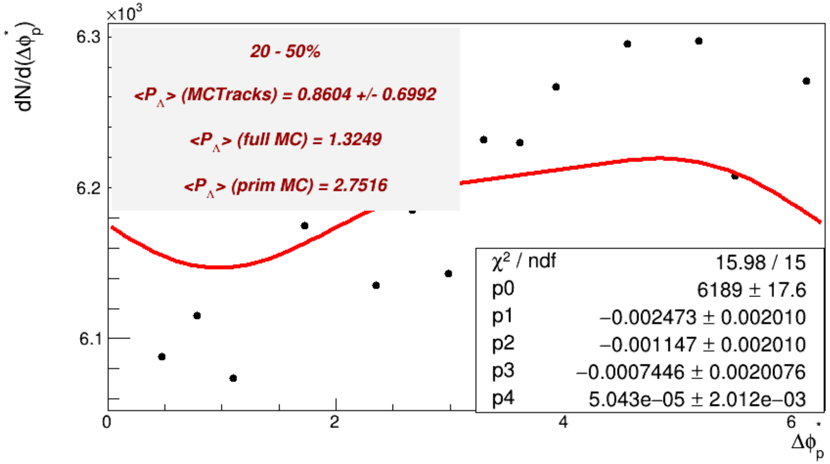
1. Primary ALambda — 1M (MCTracks)

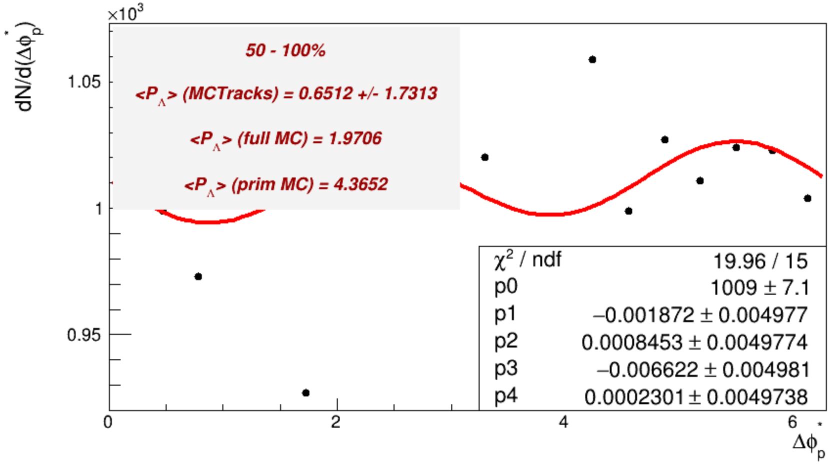


1. Full ALambda — 1M (MCTracks)

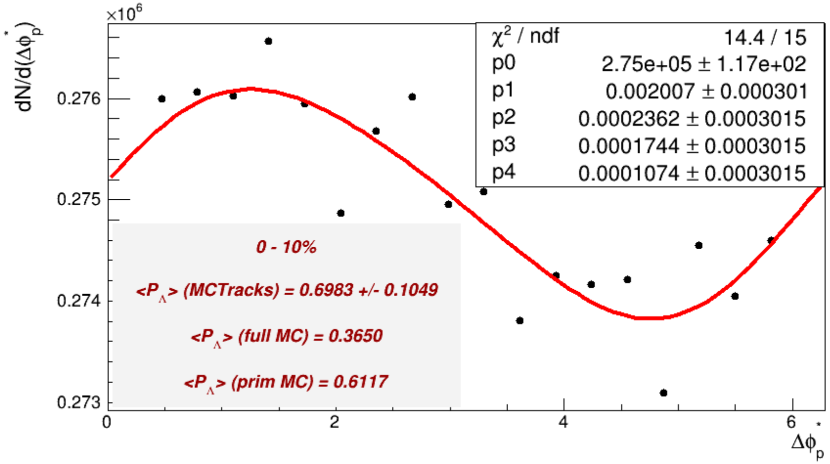


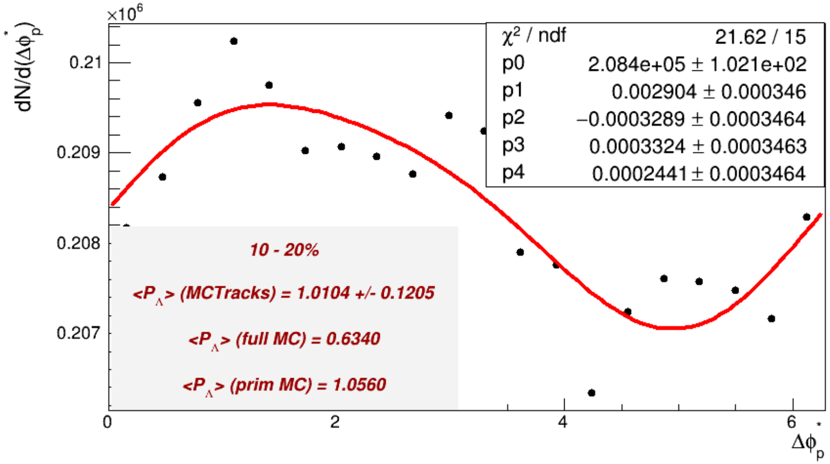


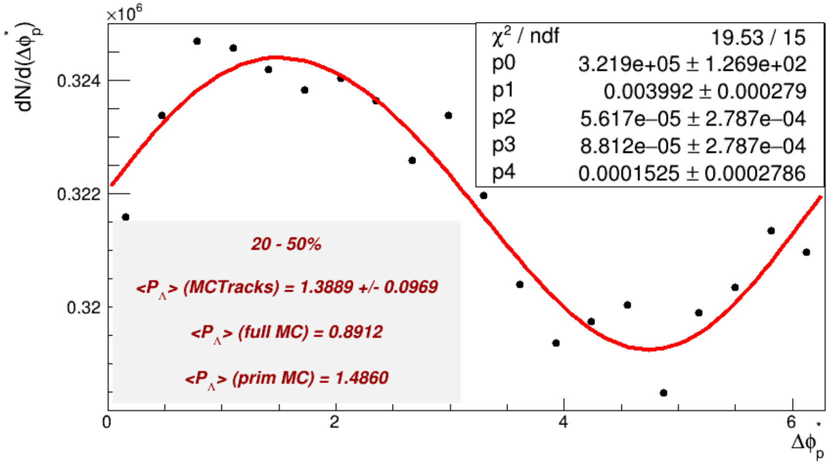


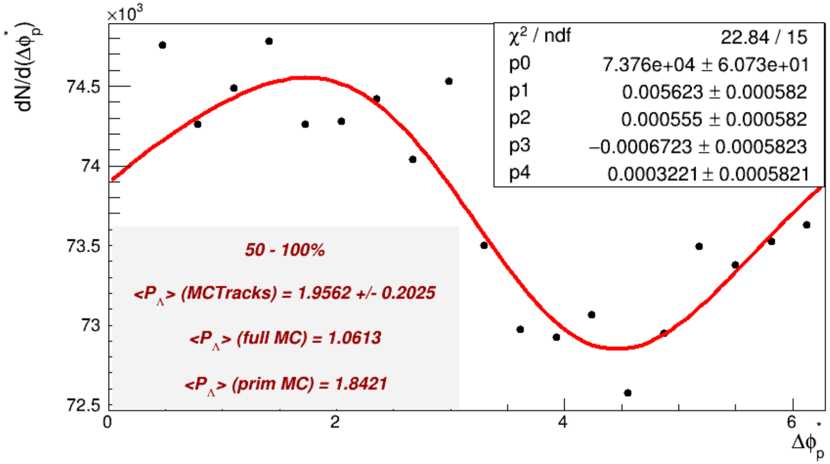


1. Primary Lambda — 2M (MCTracks)

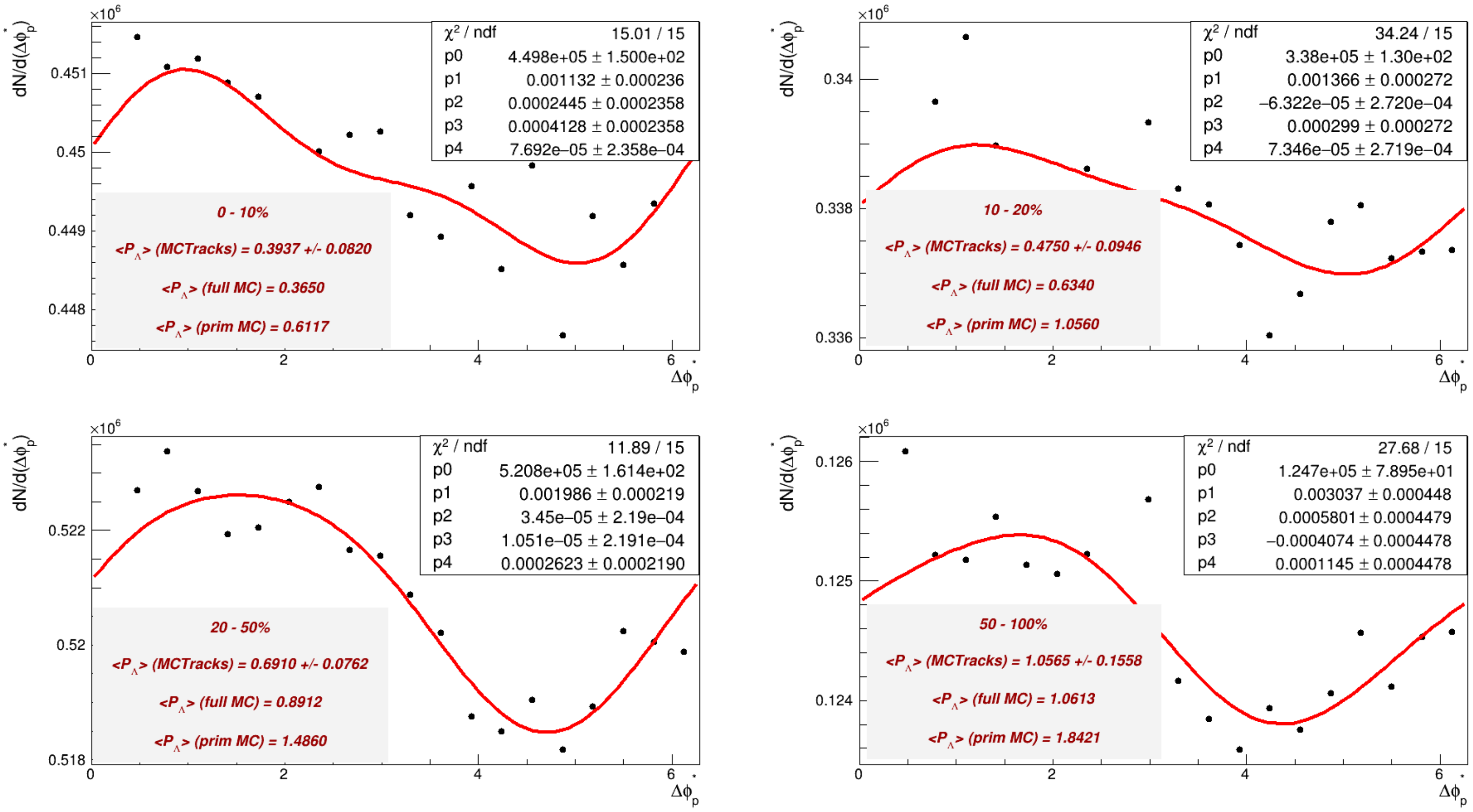




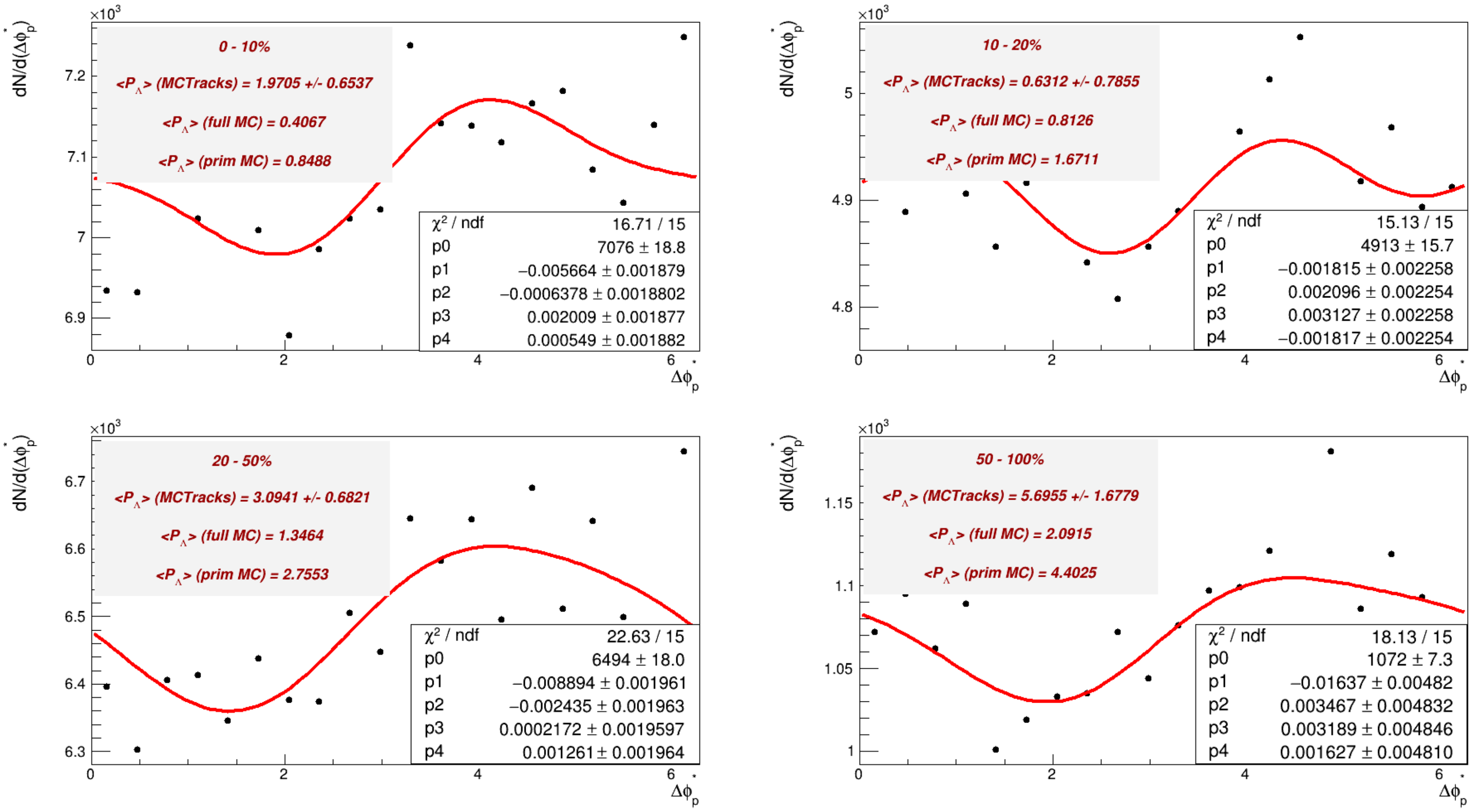




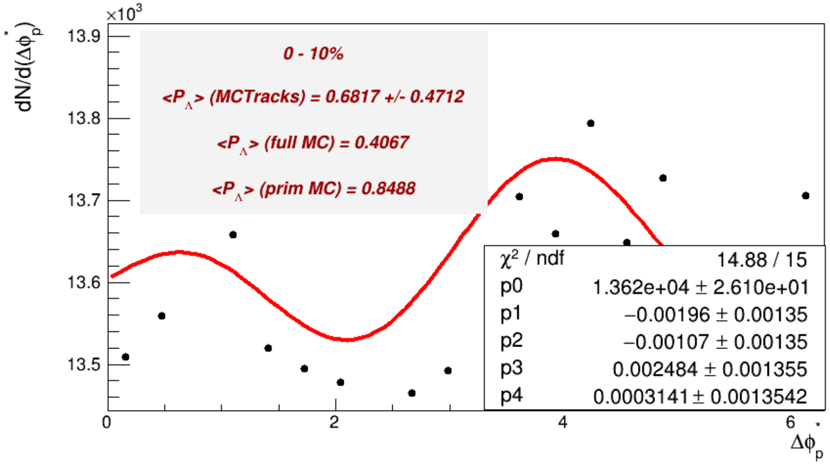
1. Full Lambda — 2M (MCTracks)

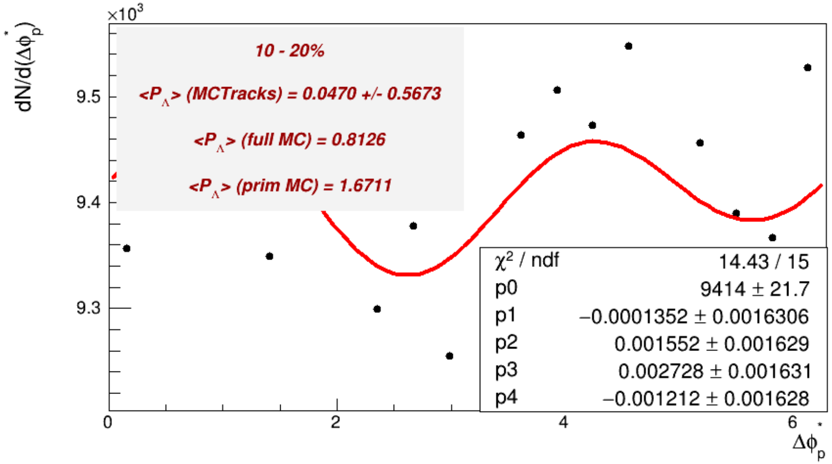


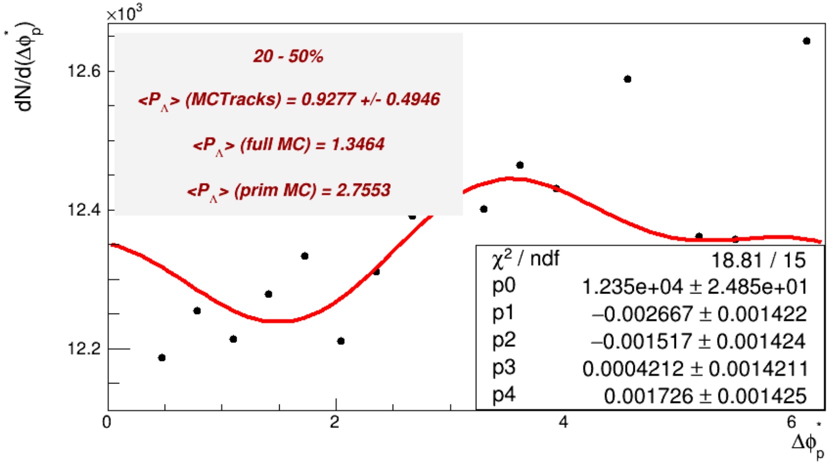
1. Primary ALambda — 2M (MCTracks)

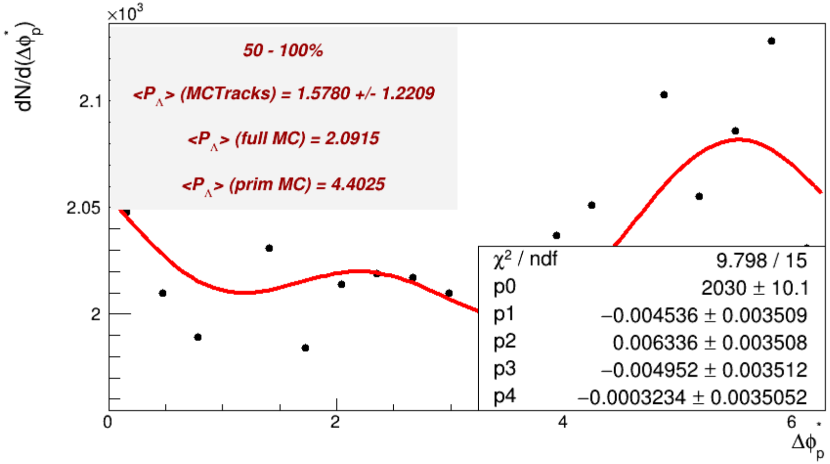


1. Full ALambda — 2M (MCTracks)

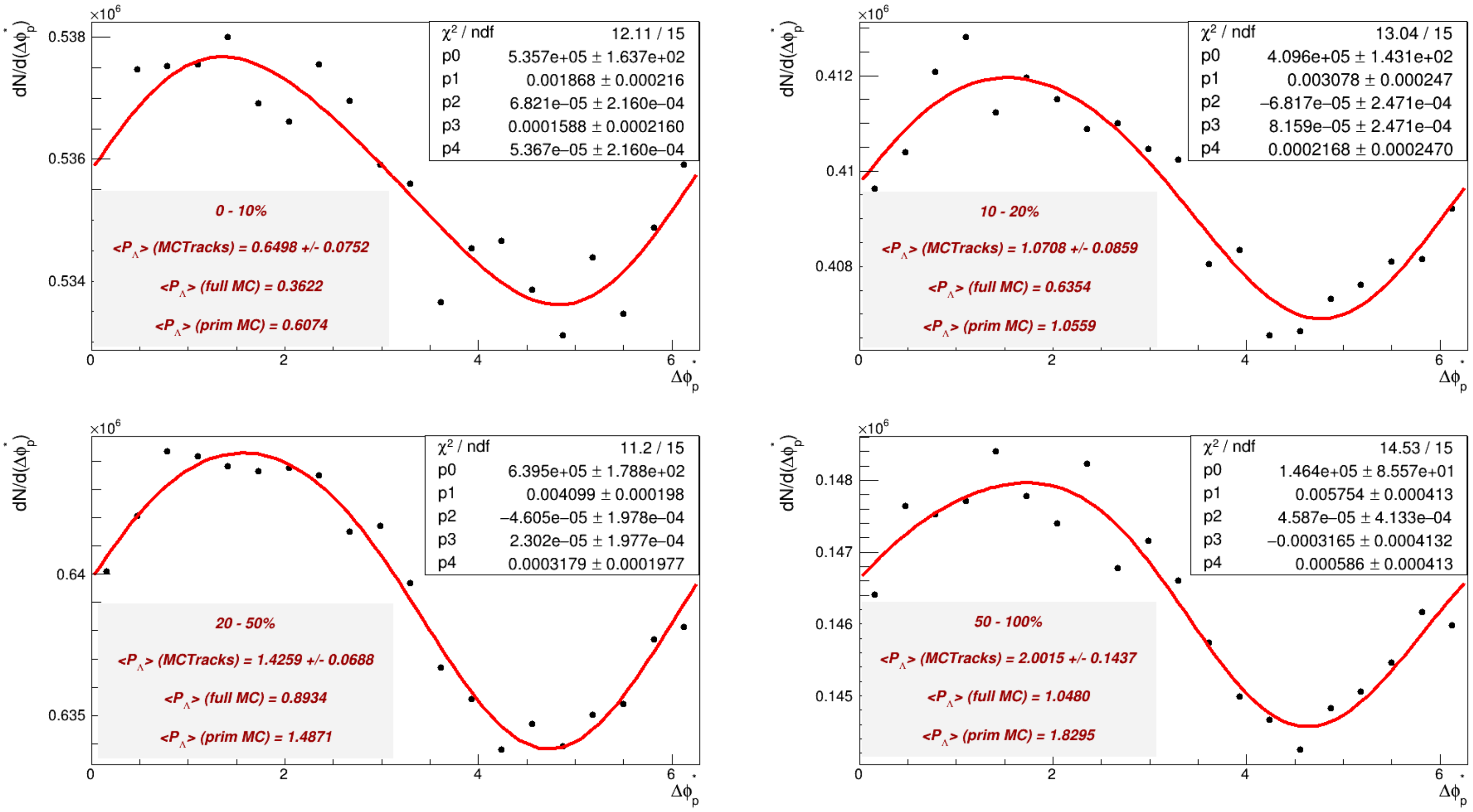




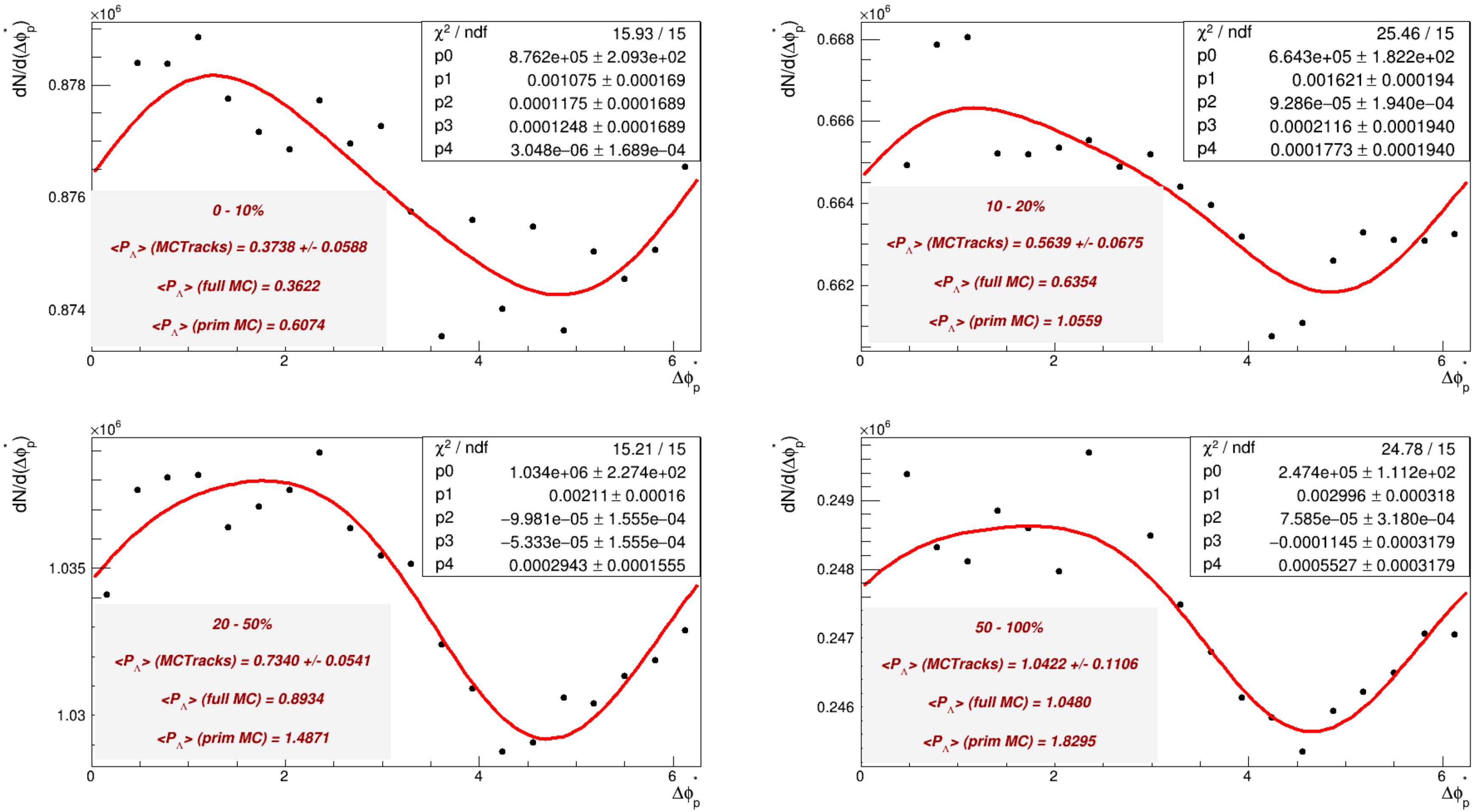




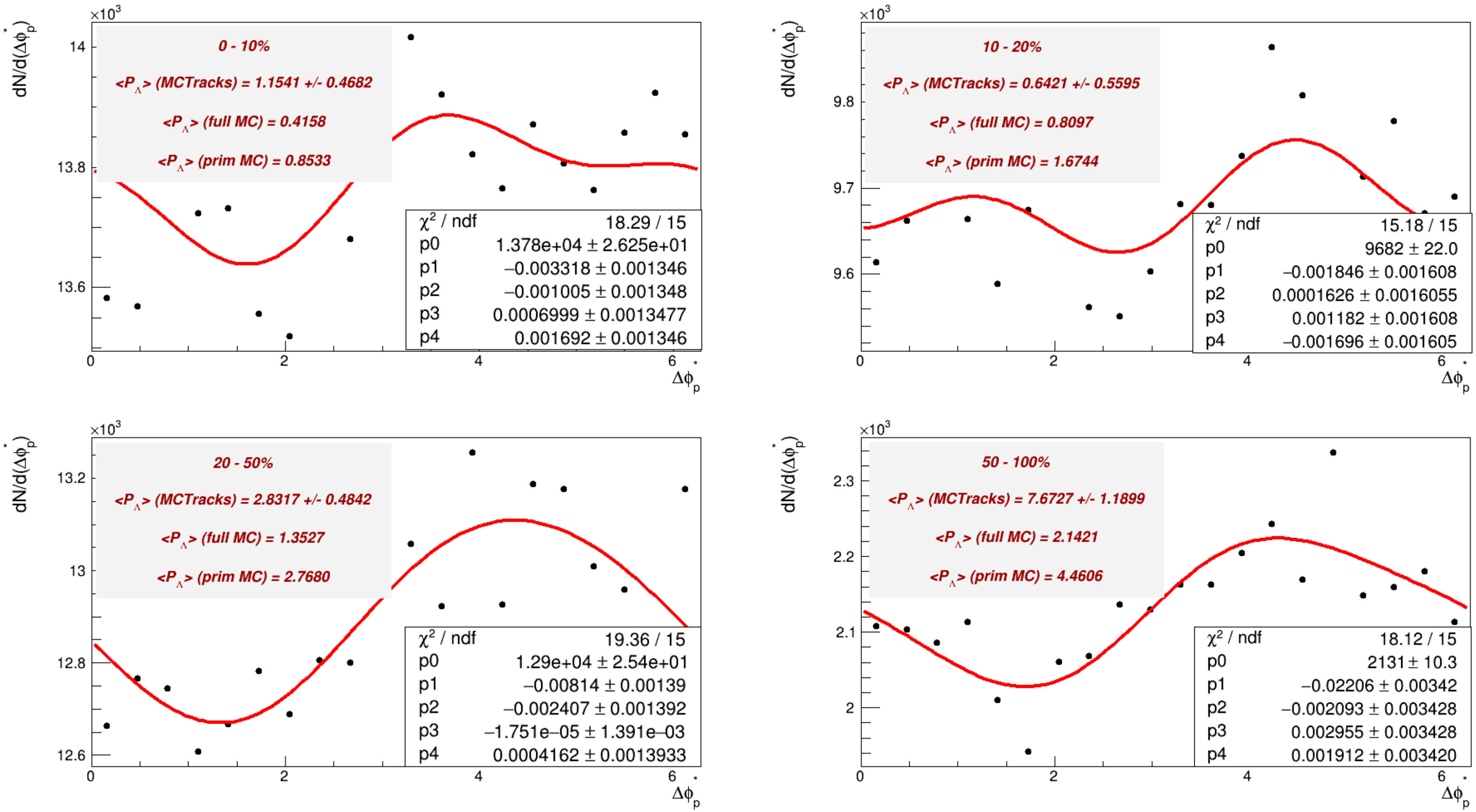
1. Primary Lambda — 4M (MCTracks)



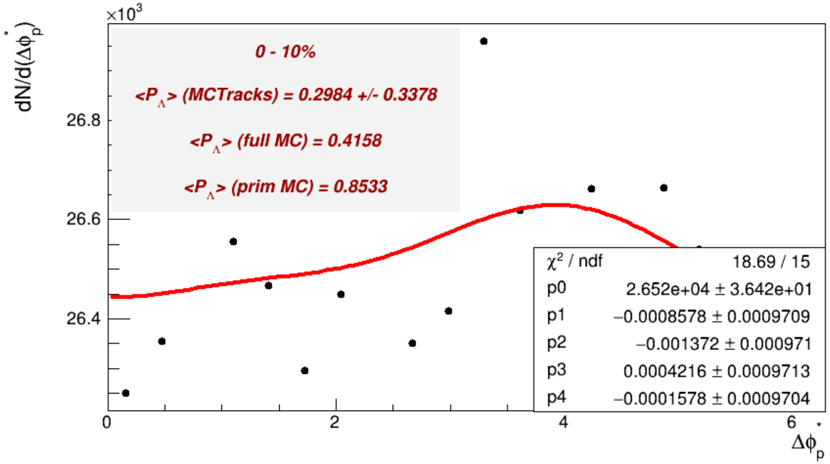
1. Full Lambda — 4M (MCTracks)

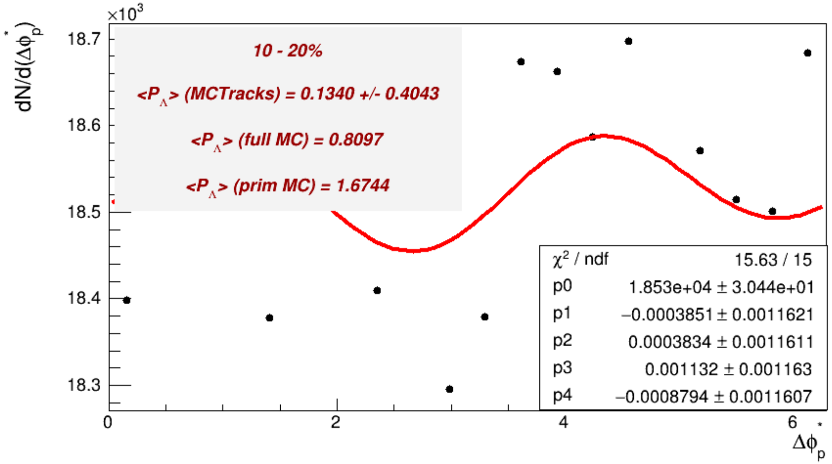


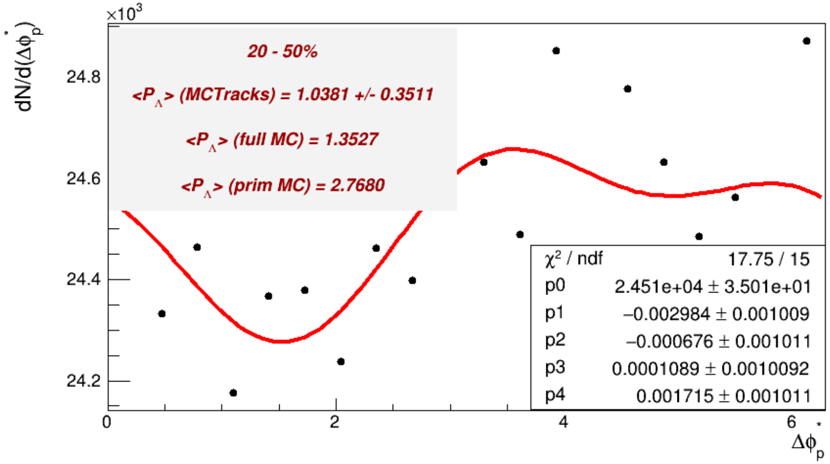
1. Primary ALambda — 4M (MCTracks)

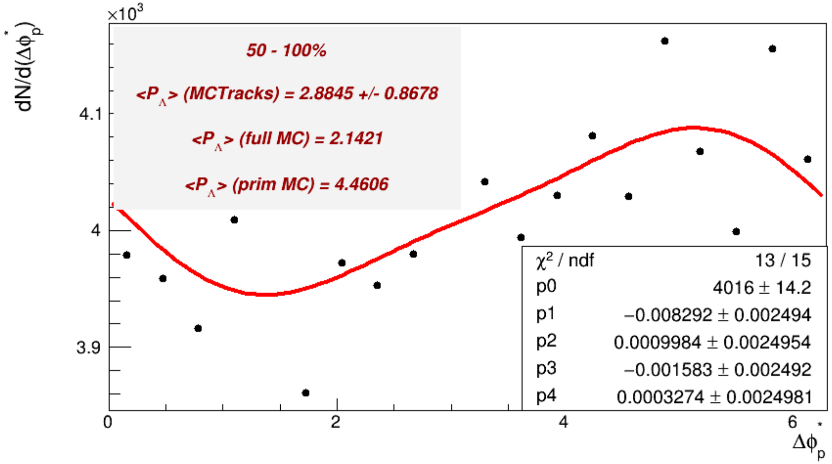


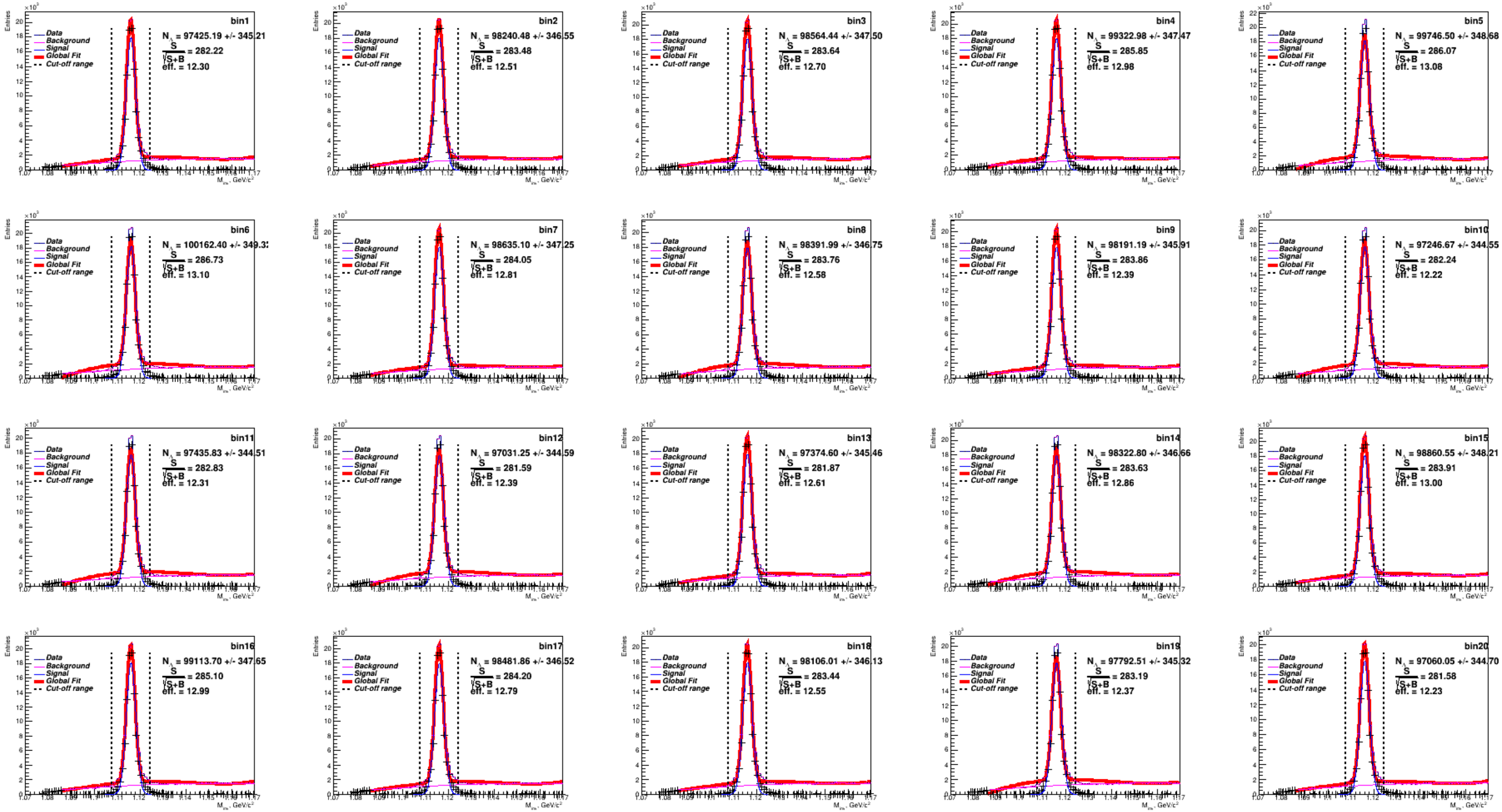
1. Full ALambda — 4M (MCTracks)











Entries
Data
Background
Signal
Global Fit
Cut-off range
bin1
N = 97425.19 +/- 345.21
S/√S+B = 282.22
eff. = 12.30
bin2
N = 98240.48 +/- 346.55
S/√S+B = 283.48
eff. = 12.51
bin3
N = 98564.44 +/- 347.50
S/√S+B = 283.64
eff. = 12.70
bin4
N = 99322.98 +/- 347.47
S/√S+B = 285.85
eff. = 12.98
bin5
N = 99746.50 +/- 348.68
S/√S+B = 286.07
eff. = 13.08
bin6
N = 100162.40 +/-
S/√S+B = 286.73
eff. = 13.10
bin7
N = 98635.10 +/- 347.25
S/√S+B = 284.05
eff. = 12.81
bin8
N = 98391.99 +/- 346.75
S/√S+B = 283.76
eff. = 12.58
bin9
N = 98191.19 +/- 345.91
S/√S+B = 283.86
eff. = 12.39
bin10
N = 97246.67 +/- 344.55
S/√S+B = 282.24
eff. = 12.22
bin11
N = 97435.83 +/- 344.51
S/√S+B = 282.83
eff. = 12.31
bin12
N = 97031.25 +/- 344.59
S/√S+B = 281.59
eff. = 12.39
bin13
N = 97374.60 +/- 345.46
S/√S+B = 281.87
eff. = 12.61
bin14
N = 98322.80 +/- 346.66
S/√S+B = 283.63
eff. = 12.86
bin15
N = 98860.55 +/- 348.21
S/√S+B = 283.91
eff. = 13.00
bin16
N = 99113.70 +/- 347.65
S/√S+B = 285.10
eff. = 12.99
bin17
N = 98481.86 +/- 346.52
S/√S+B = 284.20
eff. = 12.79
bin18
N = 98106.01 +/- 346.13
S/√S+B = 283.44
eff. = 12.55
bin19
N = 97792.51 +/- 345.32
S/√S+B = 283.19
eff. = 12.37
bin20
N = 97060.05 +/- 344.70
S/√S+B = 281.58
eff. = 12.23

2. Fitting of the reconstructed Alambda (20-50%)