Updated polarization transfer at NICA/MPD

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MPD Polarization Meeting
«Vorticity and Polarization in Heavy-Ion Collisions»

26.07.2022

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

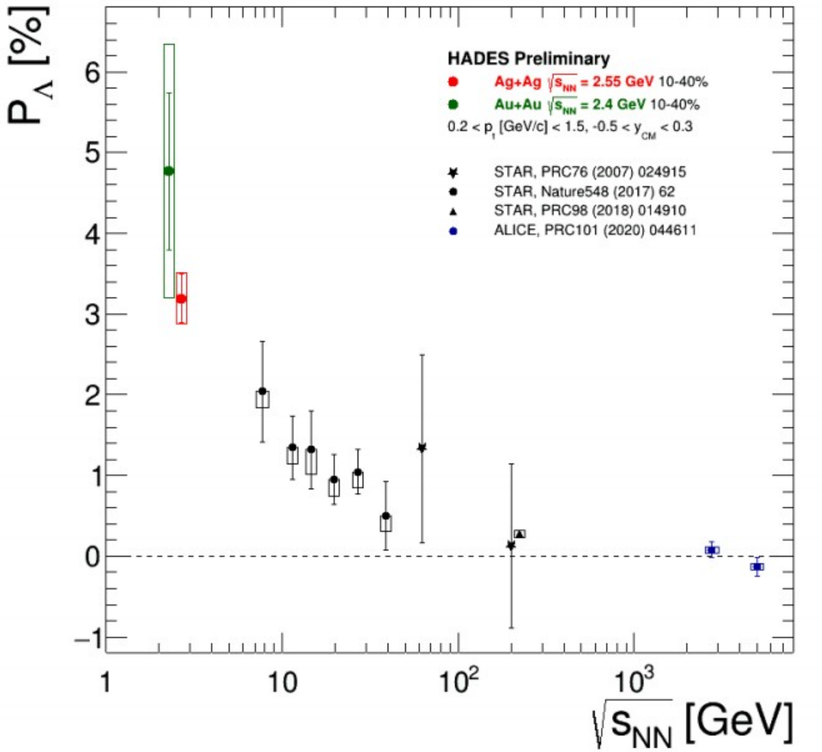
NICA

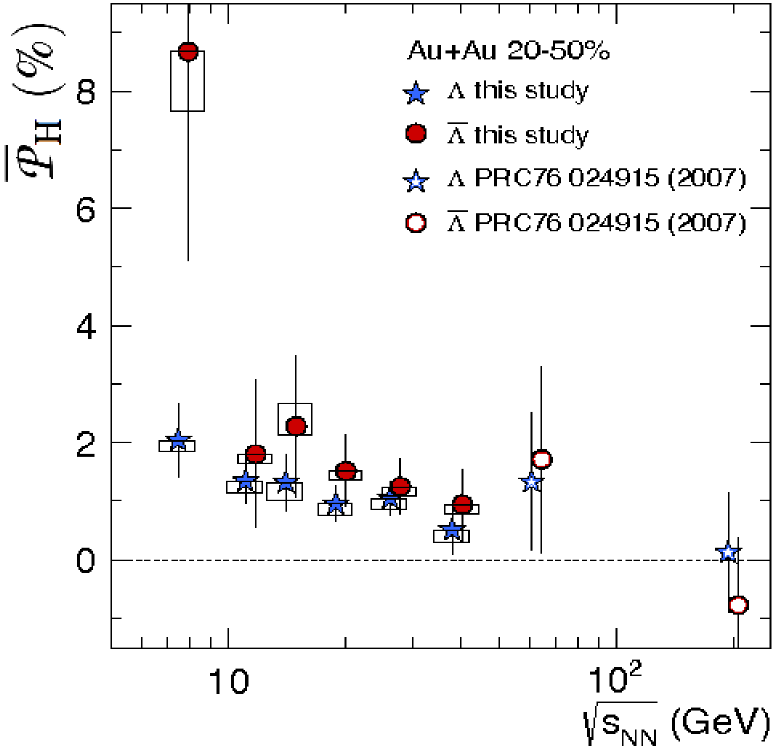
MPD

Outline

- Review of what we had
  - Introduction
  - Simulation
  - Analysis technique
  - Results
- Updated transfer
- Results
- Conclusions

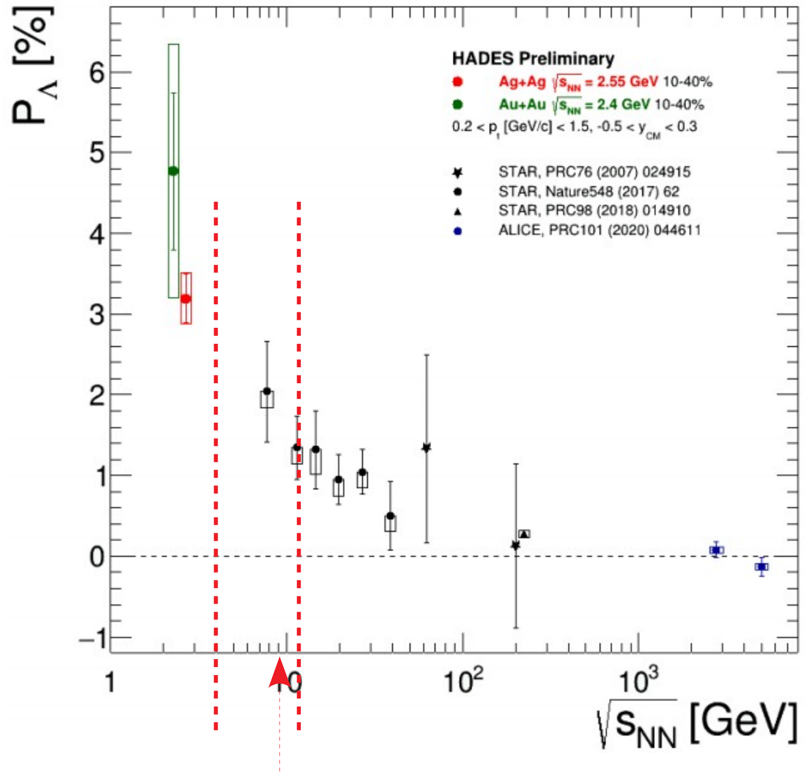
Motivation

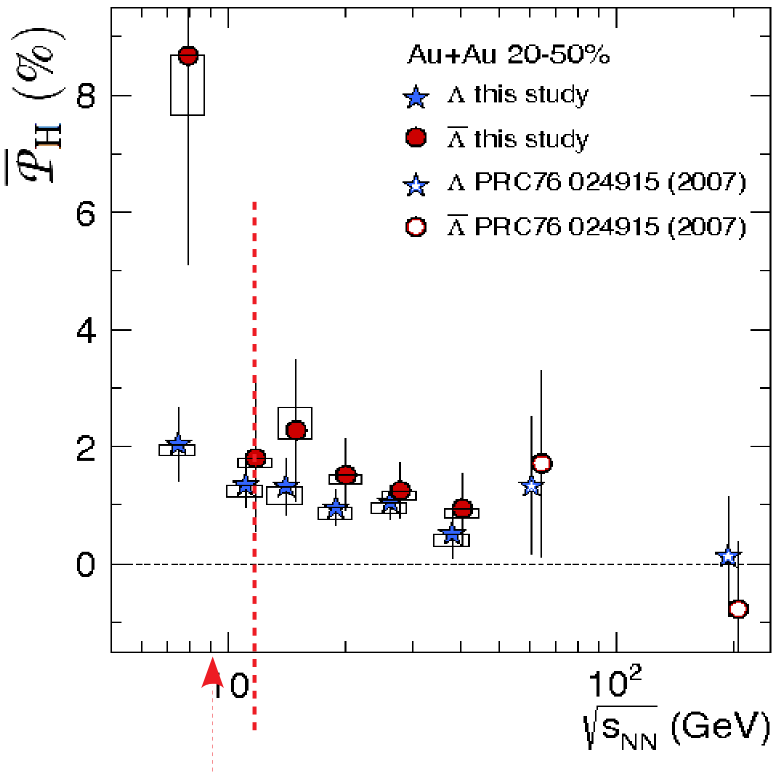




- Measurement of $\Lambda(\bar{\Lambda})$ global polarization at NICA/MPD

Motivation





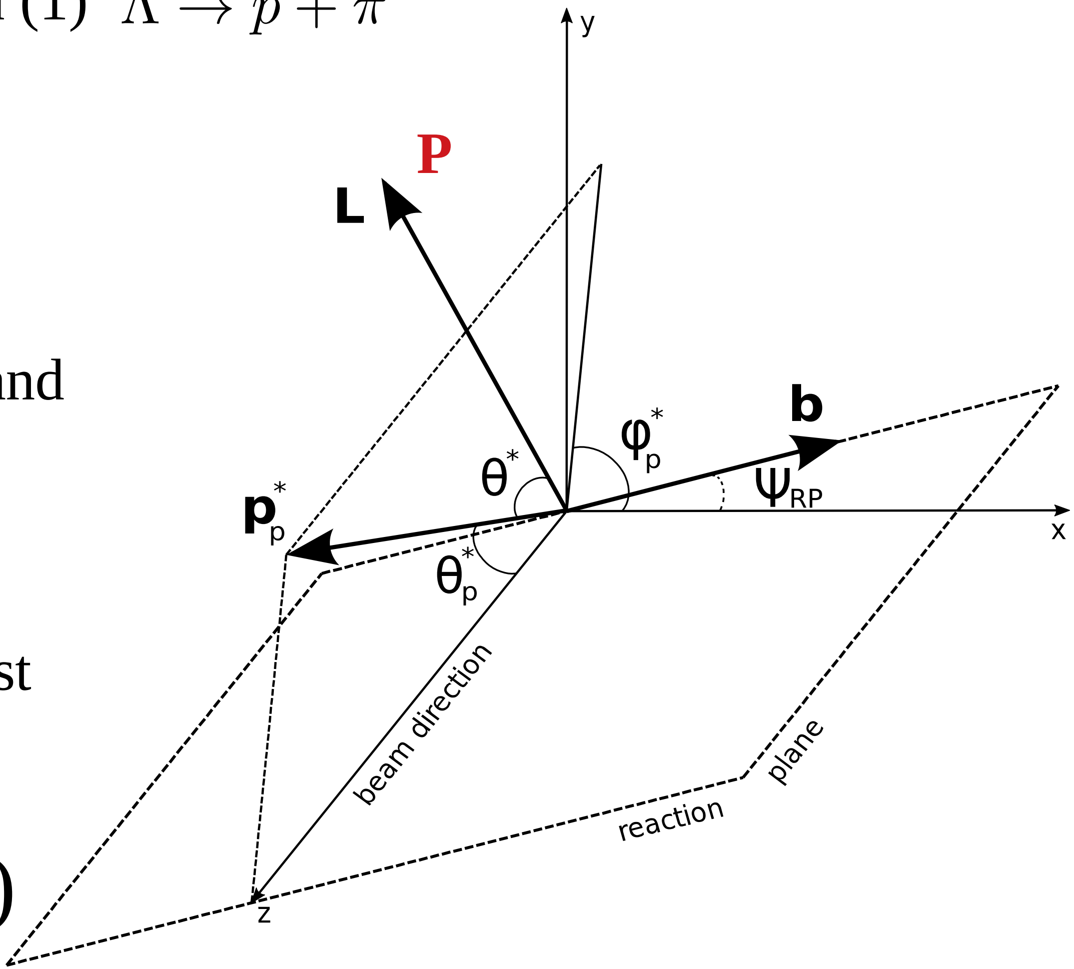
- Measurement of $\Lambda(\bar{\Lambda})$ global polarization at NICA/MPD (4-11 GeV)

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

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

- * — 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)

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

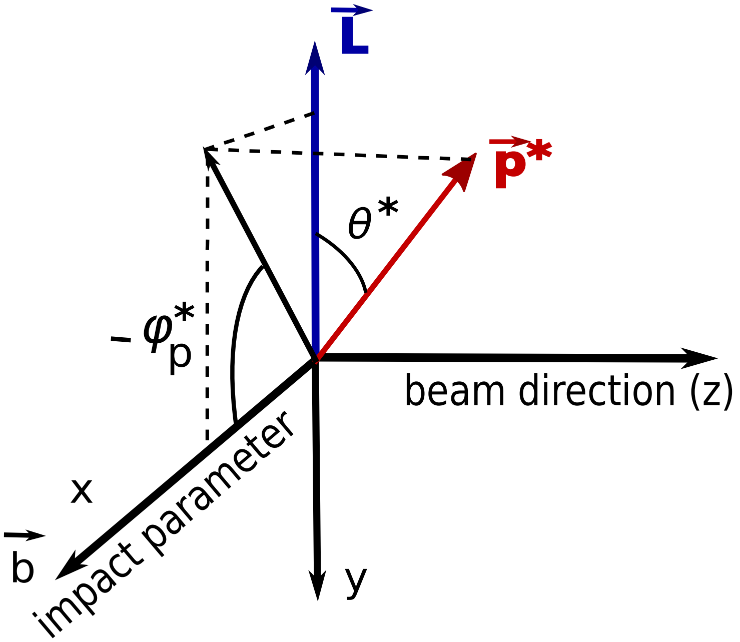


Polarization extraction — EP method

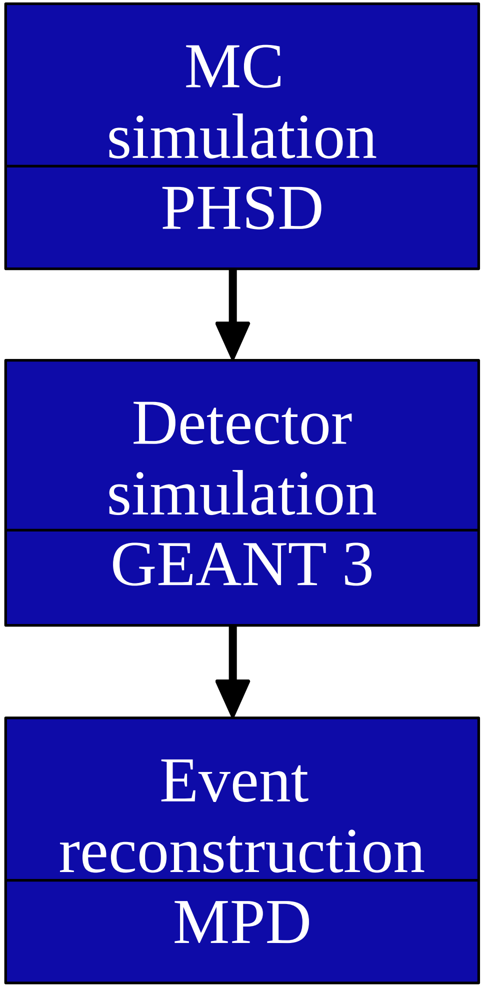
- Obtained invariant mass distribution in bins of $\Delta\phi_p^* = \Psi_{\mathrm{EP}}^1 - \phi_p^*$
  - Net amount of Λ in each bin
  - Distribution of $N_\Lambda(\Delta\phi_p^*)$
- Fit of the distribution[1] to get $\langle \sin(\Delta\phi_p^*) \rangle \to P_\Lambda$
  - «Event plane» method (p_n —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

(Following HADES procedure)

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



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



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

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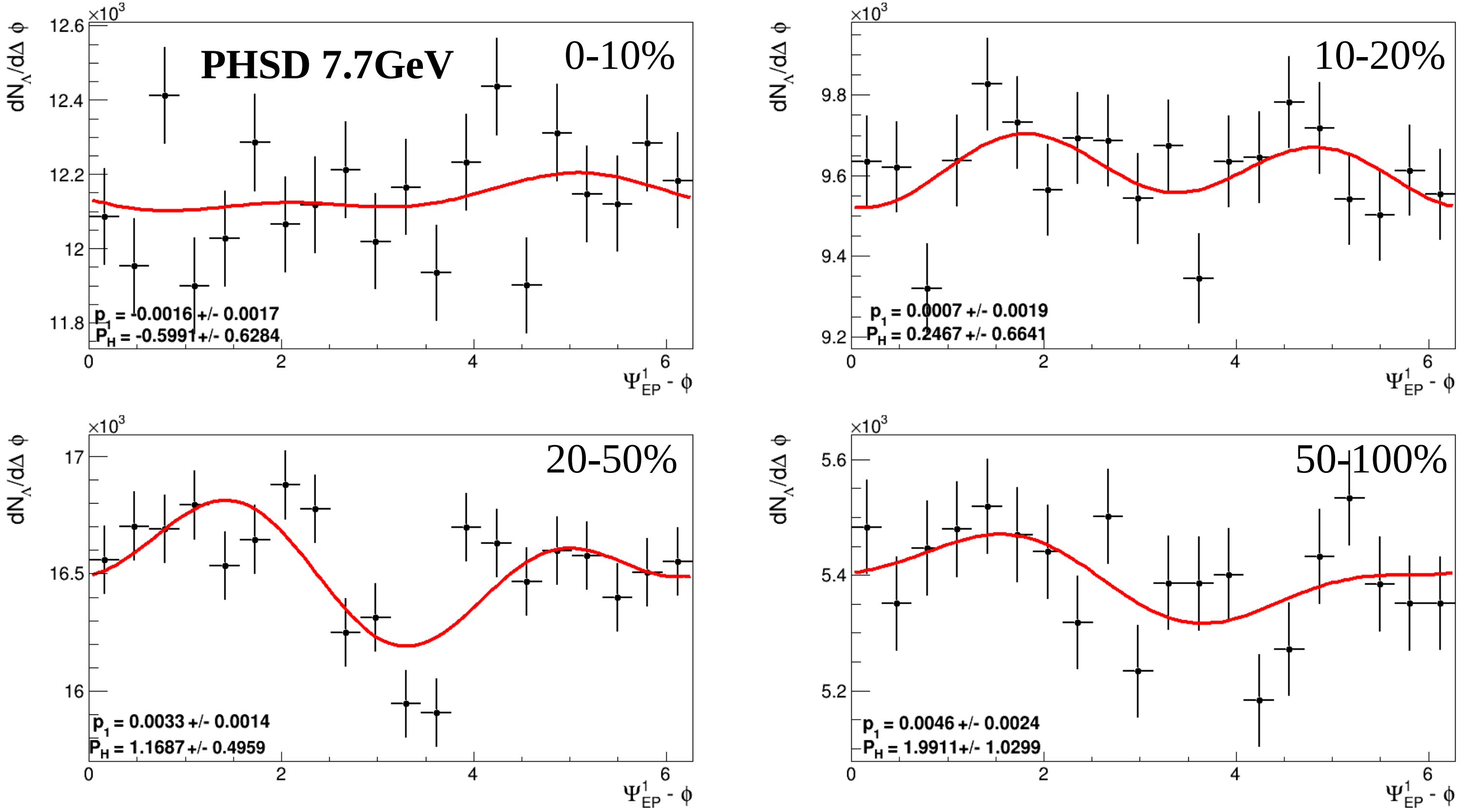
[1] $\Xi^+(\Xi^-)$, Ξ^0, Σ^0 decays

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

Results (1M events)



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

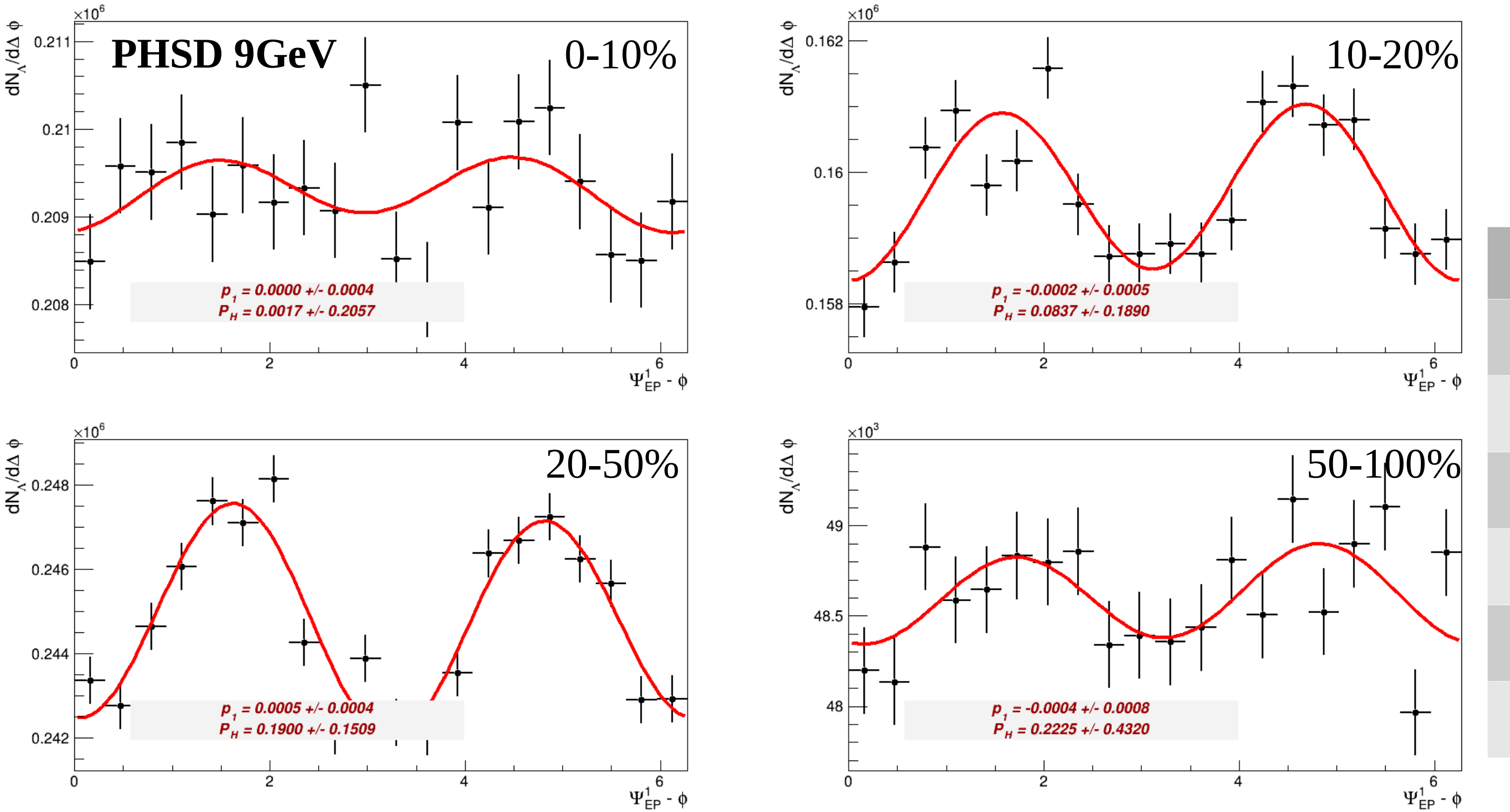
$$\alpha_\Lambda \simeq 0.732$$

	20-50%
N_Λ	$3.3 * 10^5$
p_0	$(1.6 +/- 3.3) * 10^4$
$p_1/10^{-4}$	33.02+/- 14.01
$p_2/10^{-4}$	44.03 +/- 13.93
$p_3/10^{-4}$	-3.26 +/- 13.95
$p_4/10^{-4}$	-52.39 +/- 14.00

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

Results (10M events)

MPD



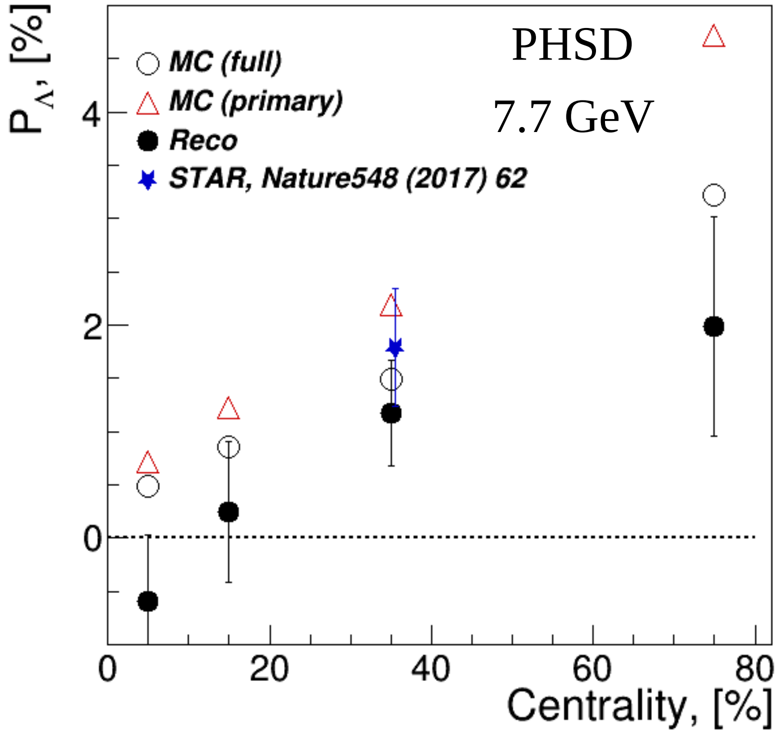
$$P_\Lambda = \frac{8}{\pi \alpha_\Lambda} \frac{p_1}{R^1_{\mathrm{EP}}}$$

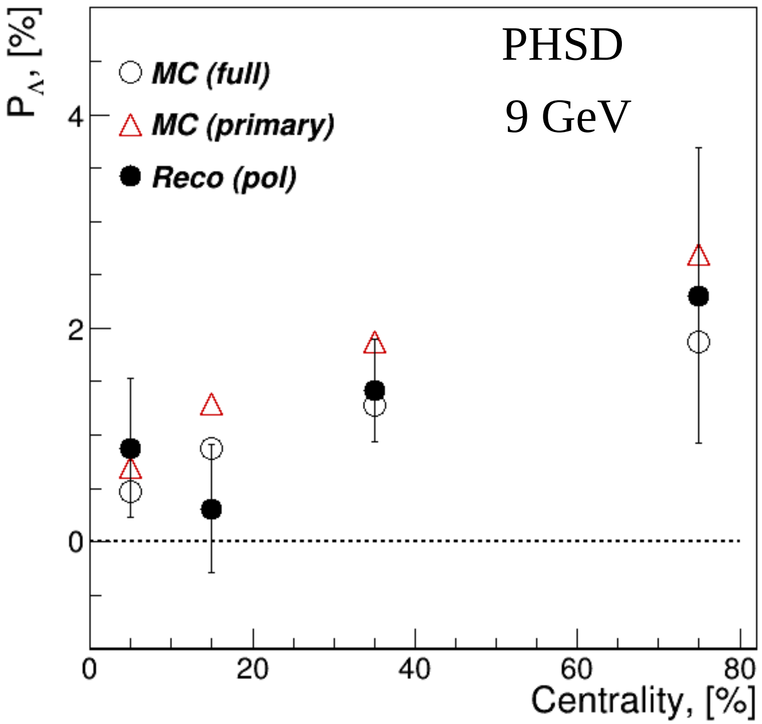
$$\alpha_\Lambda \simeq 0.732$$

	20-50%
N_Λ	$4.9 * 10^6$
p_0	$(2.5 +/- 1.3) * 10^5$
$p_1/10^{-4}$	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

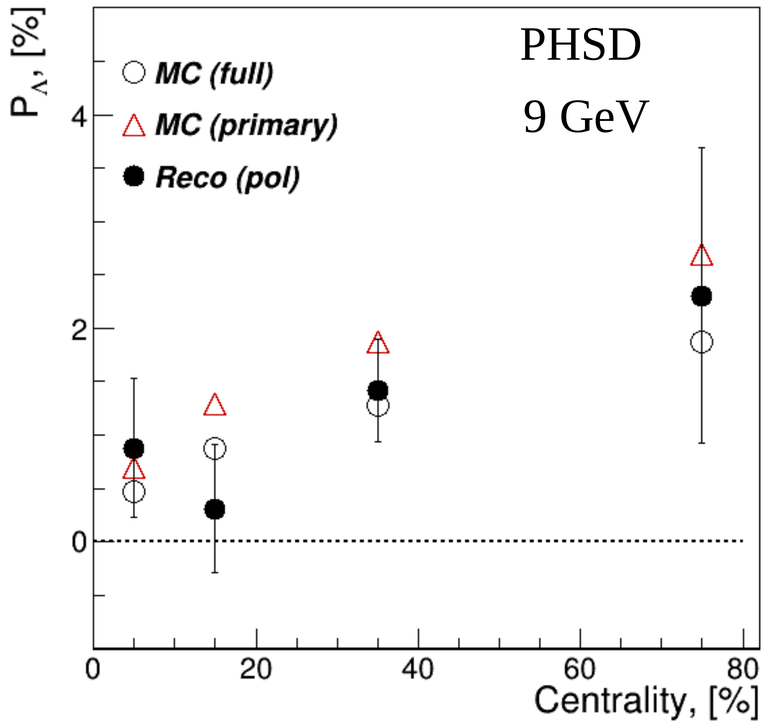
$$\frac{\mathrm{d}N}{\mathrm{d}\Delta\phi^*_p} = p_0(1 + 2p_1 \sin(\Delta\phi^*_p) + 2p_2 \cos(\Delta\phi^*_p) + 2p_3 \sin(2\Delta\phi^*_p) + 2p_4 \cos(2\Delta\phi^*_p) + \ldots)$$

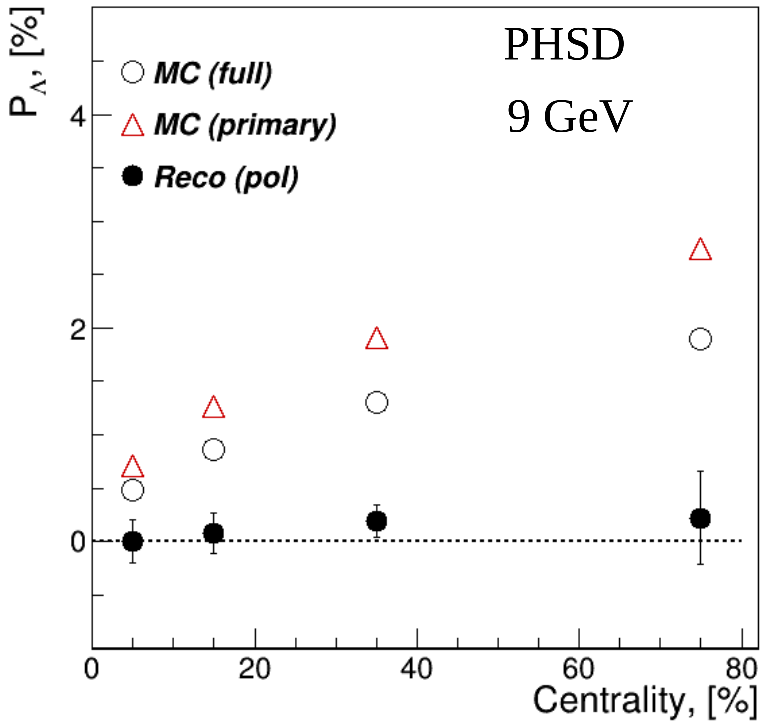
Results





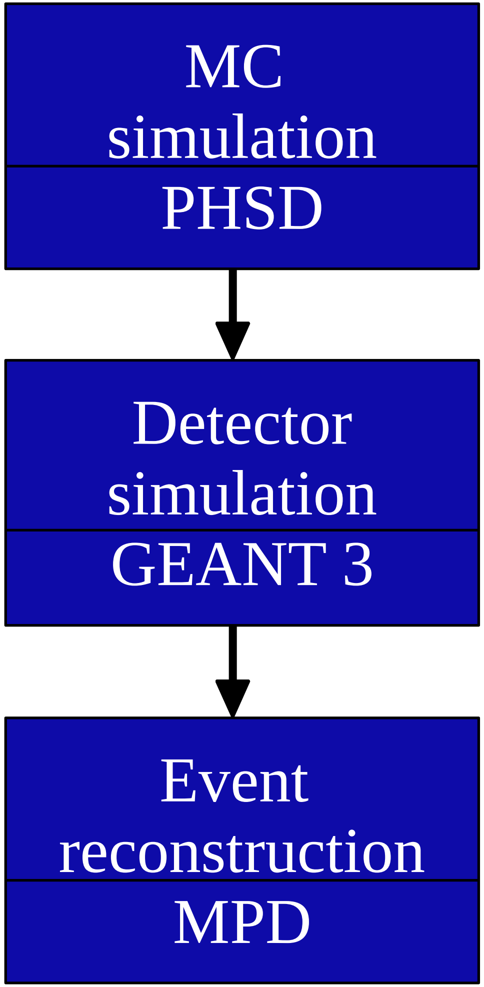
- (left) Previous result (PHSD ~1M events, @ 7.7 GeV)
- (right) New result with ~1M events, PHSD @ 9 GeV
- The results seem similar, but ...





- (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

Simulation



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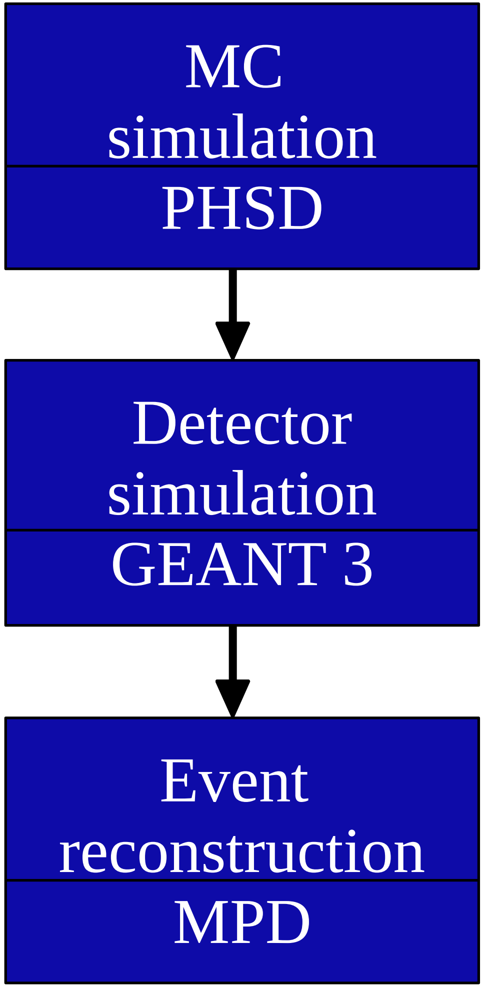
$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_\mathrm{H}|\vec{P}_\mathrm{H}|\cos\theta^*\right) \quad (1)$$

Simulation



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[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 of polarization transfer

- Anisotropic decay for Lambda hyperon: $\Lambda \to p + \pi^-$

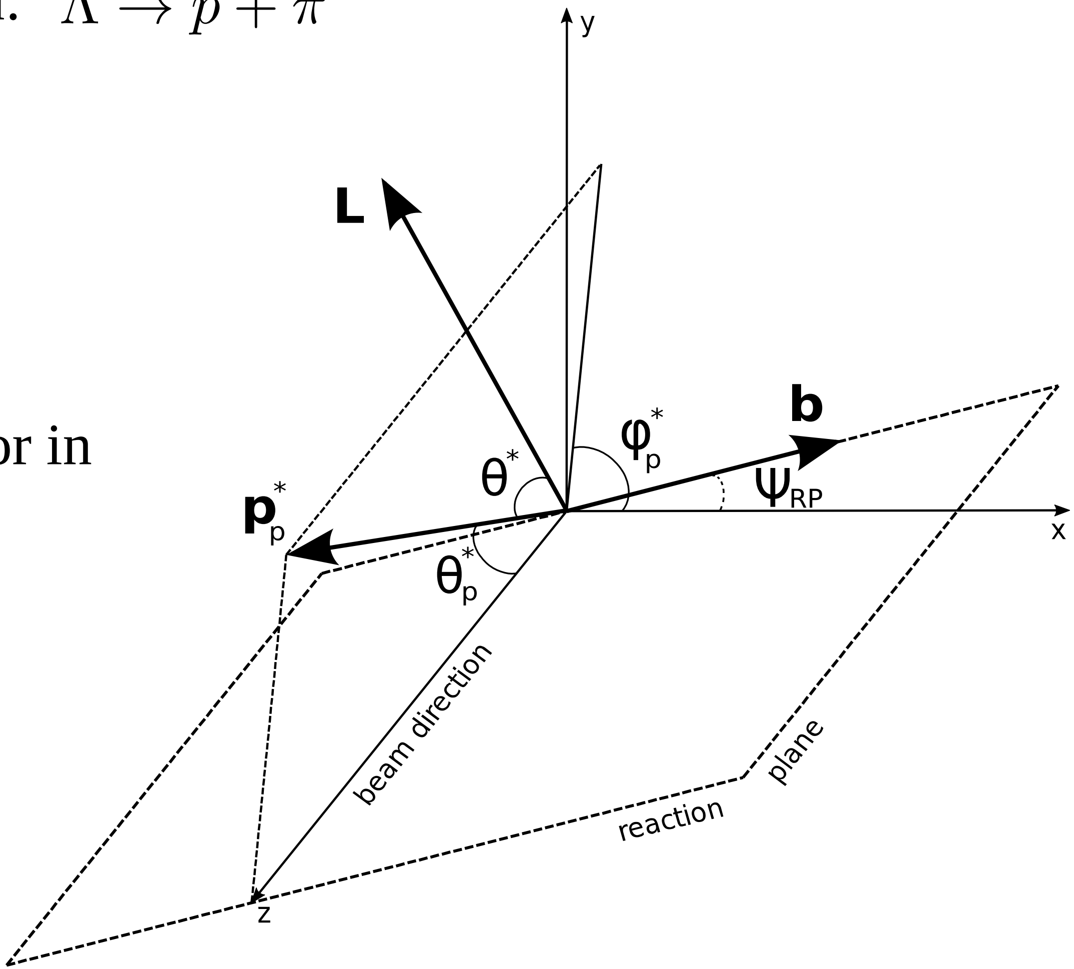
$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}(1 + \alpha_H |\vec{P}_H| \cos\theta^*) \quad (1)$$

- * — denotes Lambda rest frame

$\alpha_\Lambda = -\alpha_{\bar{\Lambda}} \simeq 0.732$

$|\vec{P}_H|$ — the length of the polarization vector in Lambda rest frame

- Calculate random $\cos\theta^*$ (from (*))
- φ^* - random in [0,2π]
- Complicated rotations back and forth to Lambda and lab frames
- Boost to the lab frame



MPD

Polarization transfer redone (V. Voronuyk):

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

(1)
```
if (fPsiRP != 0.) pol.RotateZ(fPsiRP);
```

(2)
```
Float_t xxx = frandom->Rndm();
if (xxx > 1. / 2. * (1. + weight_pol)) {
        pol *= -1.;
        part->SetWeight(-1.*weight_pol);
} else {
        part->SetWeight(weight_pol);
}
part->SetPolarisation(pol);
```

Updated polarization transfer

Polarization transfer redone (V. Voronuyk):

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

(3)

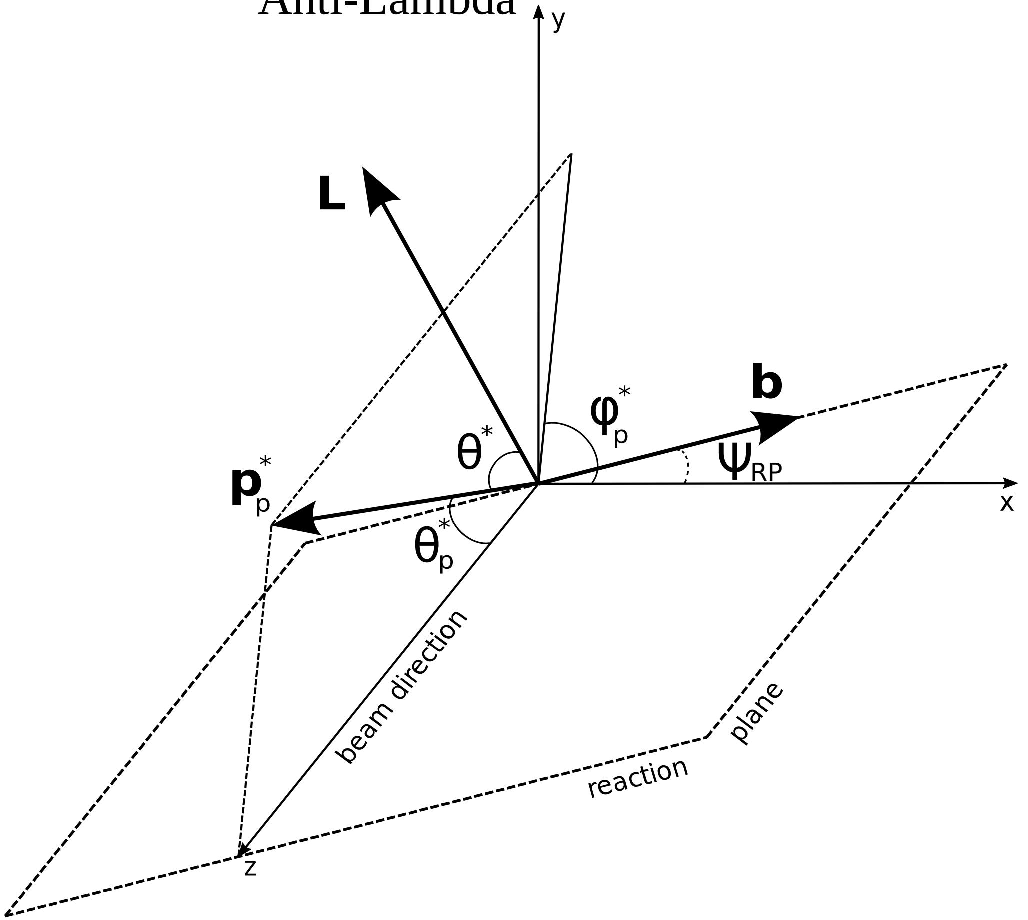
```
Float_t xxx = gRandom->Rndm();
if (TMath::Abs(moth->GetPdgCode())
== 3212) {
      if (xxx > 1. / 3.) {
            polar *= -1.0;
      }
} else if (TMath::Abs(moth-
>GetPdgCode()) == 3312) {
      if (xxx < 0.927) {
            polar *= -1.0;
      }
} else if (TMath::Abs(moth-
>GetPdgCode()) == 3322) {
      if (xxx < 0.900) {
            polar *= -1.0;
      }
}
```

New polarization transfer

- Then calculate random cosθ* (from (1)) with |P|=1)
- φ* - random in [0,2π]
- Construct unitary vector of proton
- Rotate it w.r.t. polarization direction
- Boost to the lab frame

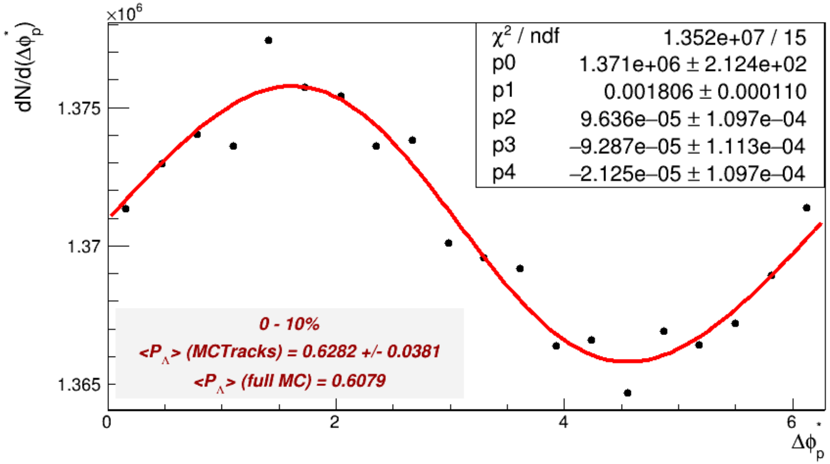
$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{1}{2}(1+\alpha_{\mathrm{H}}|\vec{P}_{\mathrm{H}}|\cos\theta^*) \quad (1)$$

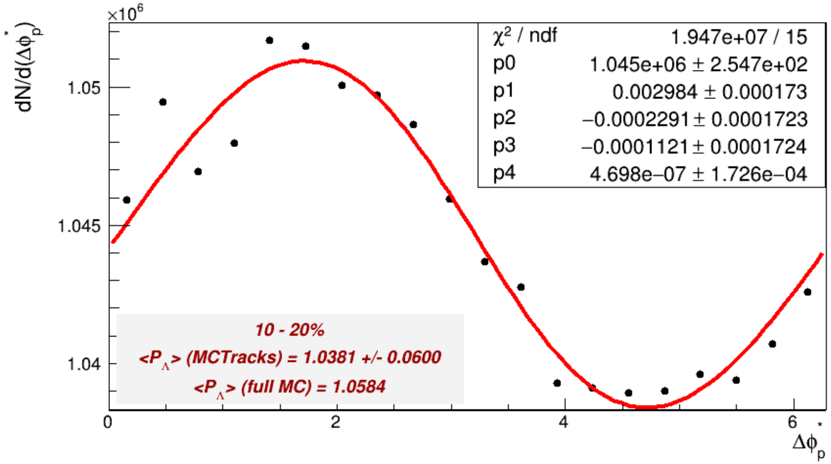
+ introduced anisotropic decay for Anti-Lambda

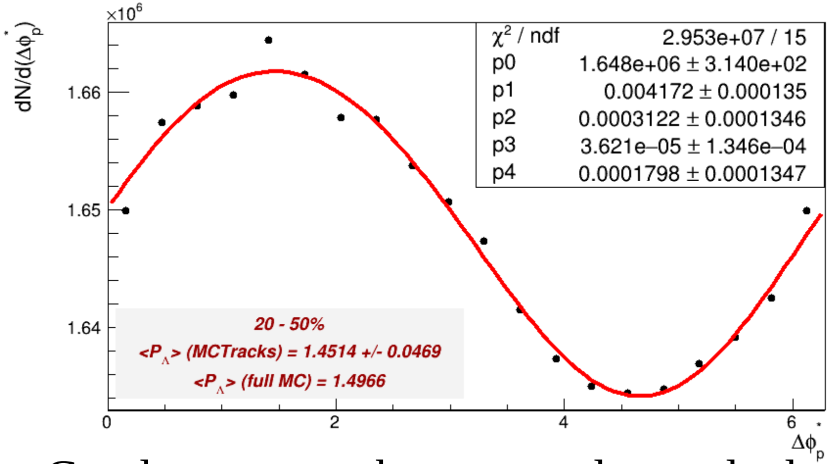


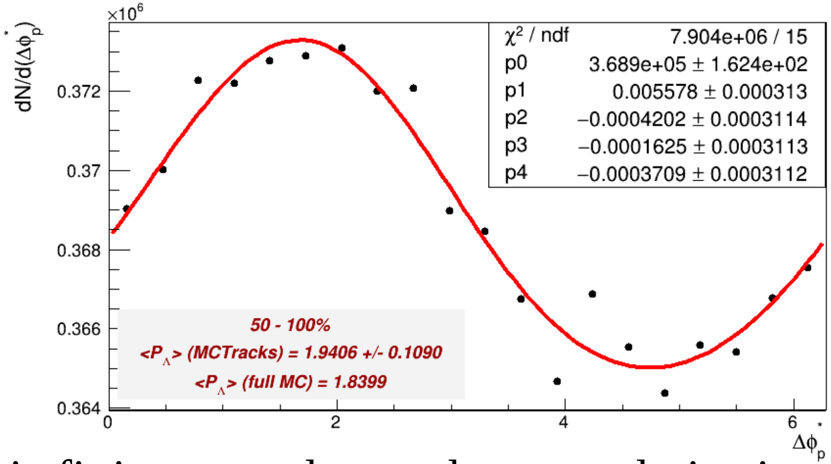
- Testing
  - Using our production of 10M events — MCTracks information
  - Using privately produced dataset with the updated transfer — 1M and 2M for comparison

1. Primary Lambda — 10M production



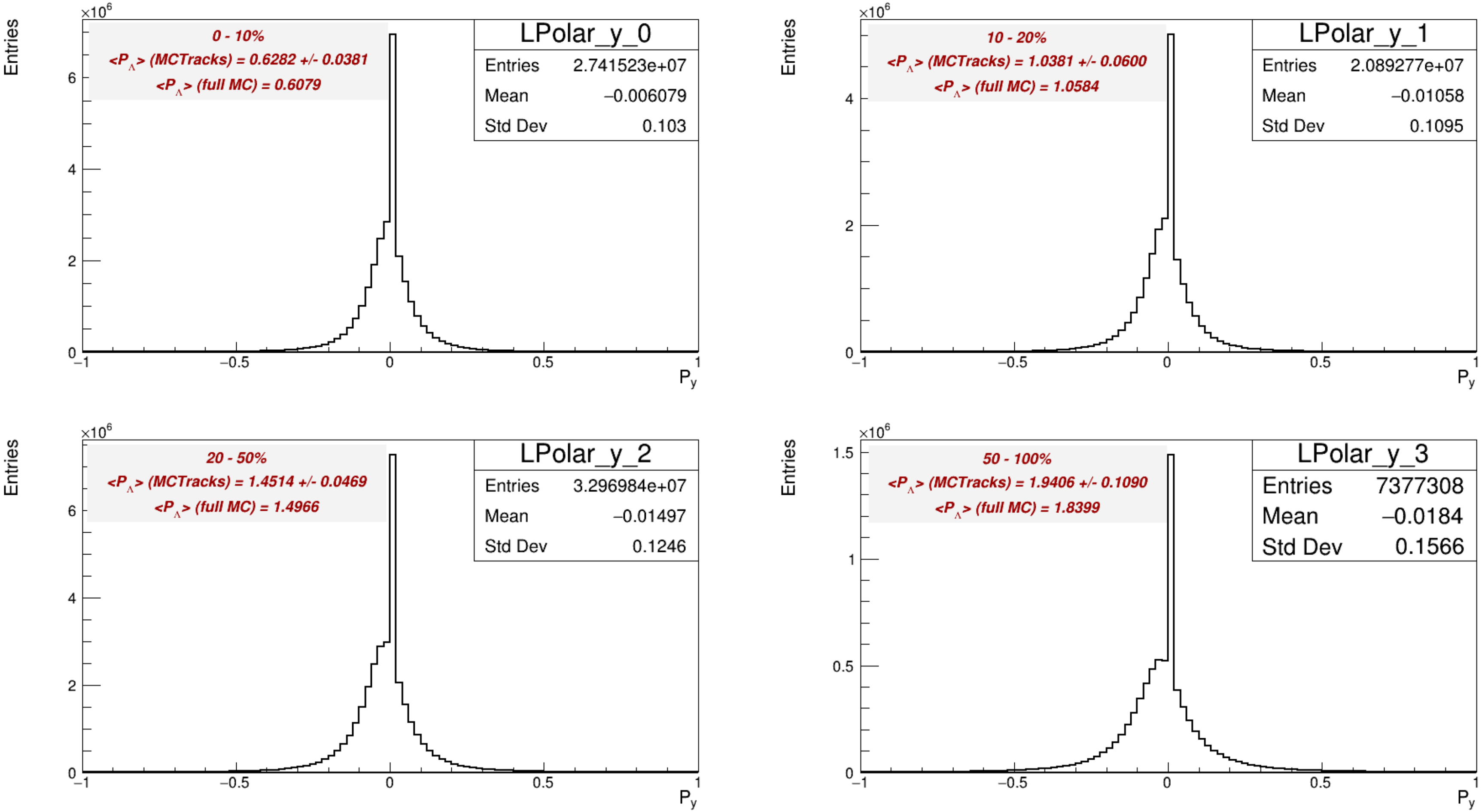






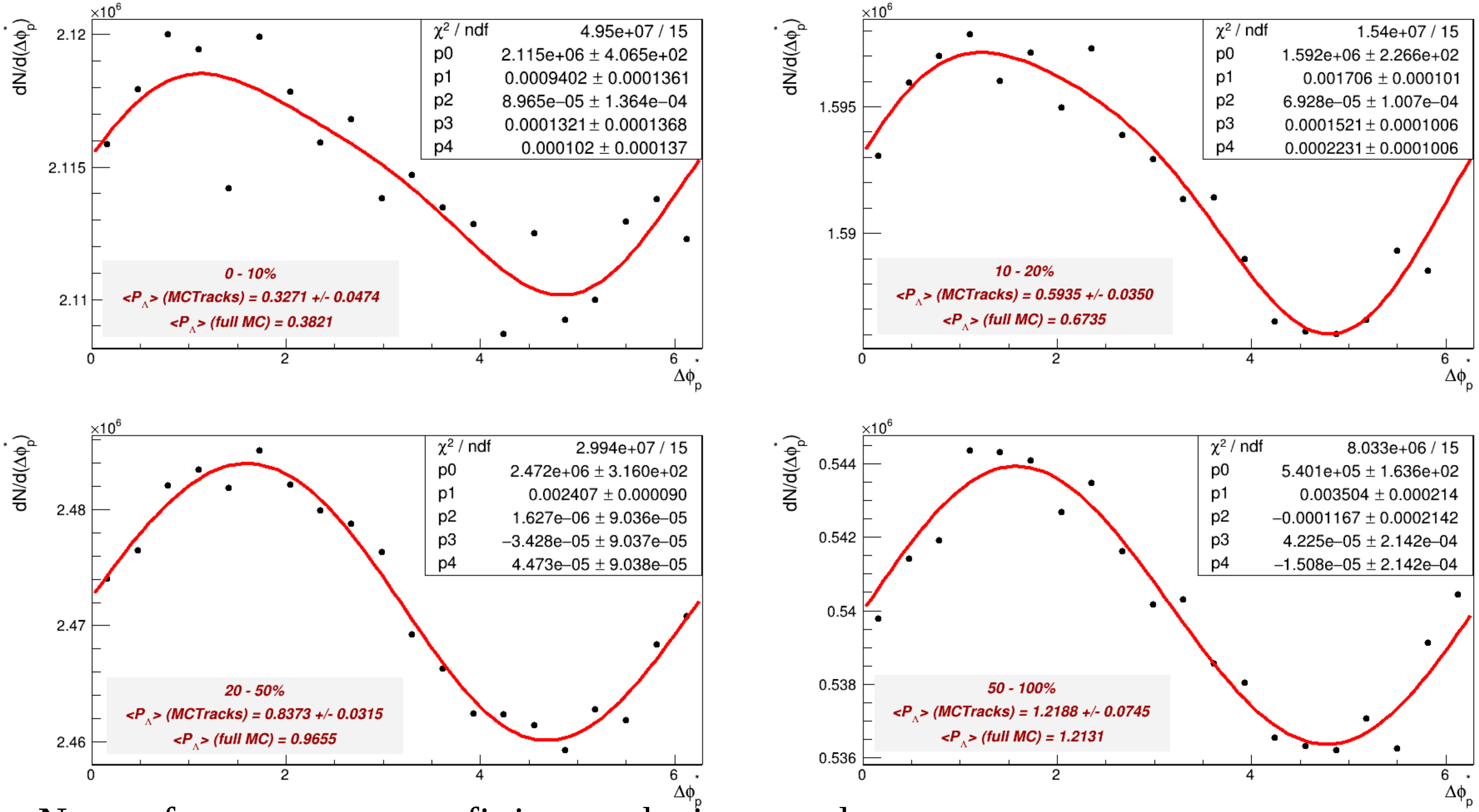
Good agreement between values calculated via fitting procedure and mean polarization

1. Primary Lambda — 10M production



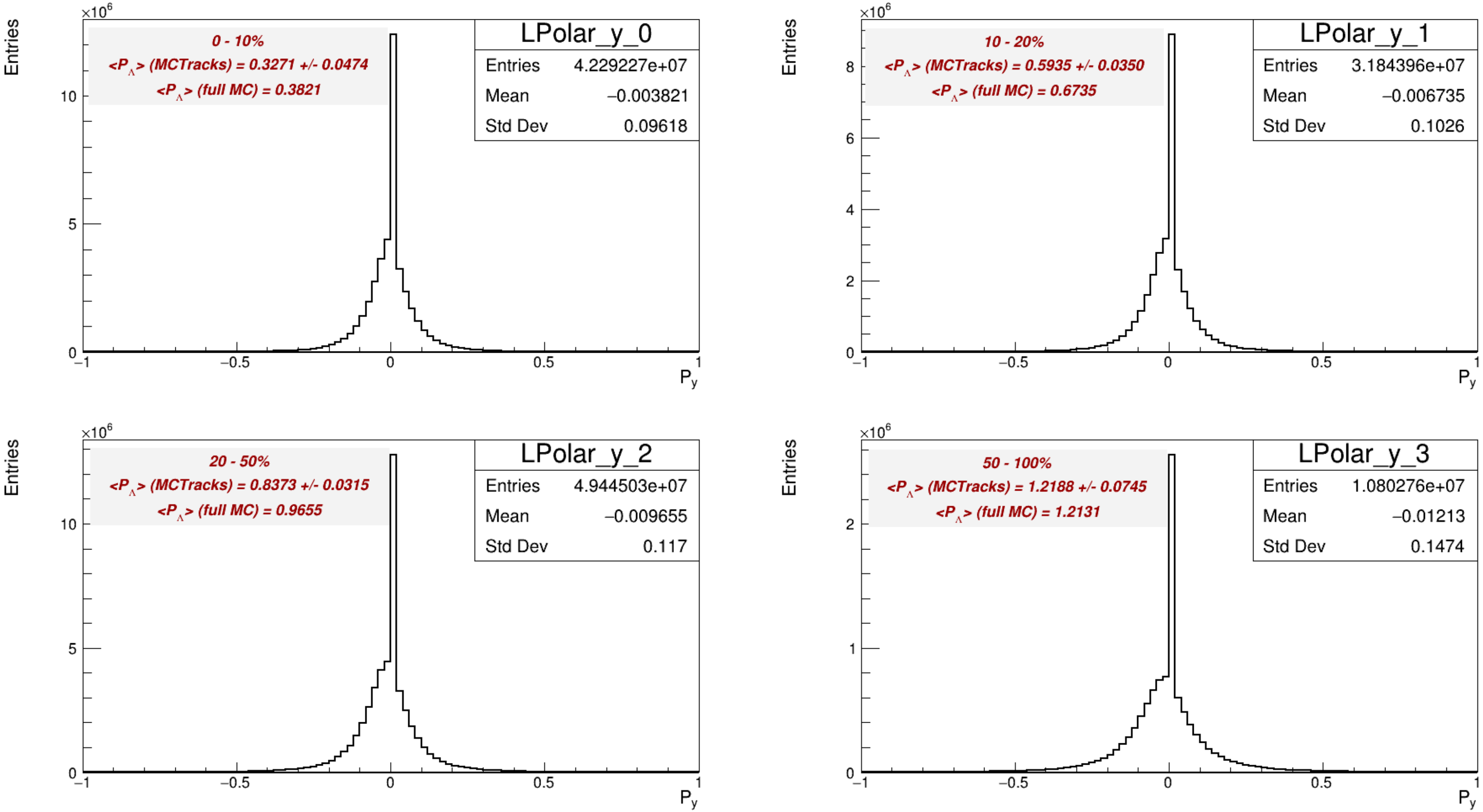
Good agreement between values calculated via fitting procedure and mean polarization

1. Full Lambda — 10M production



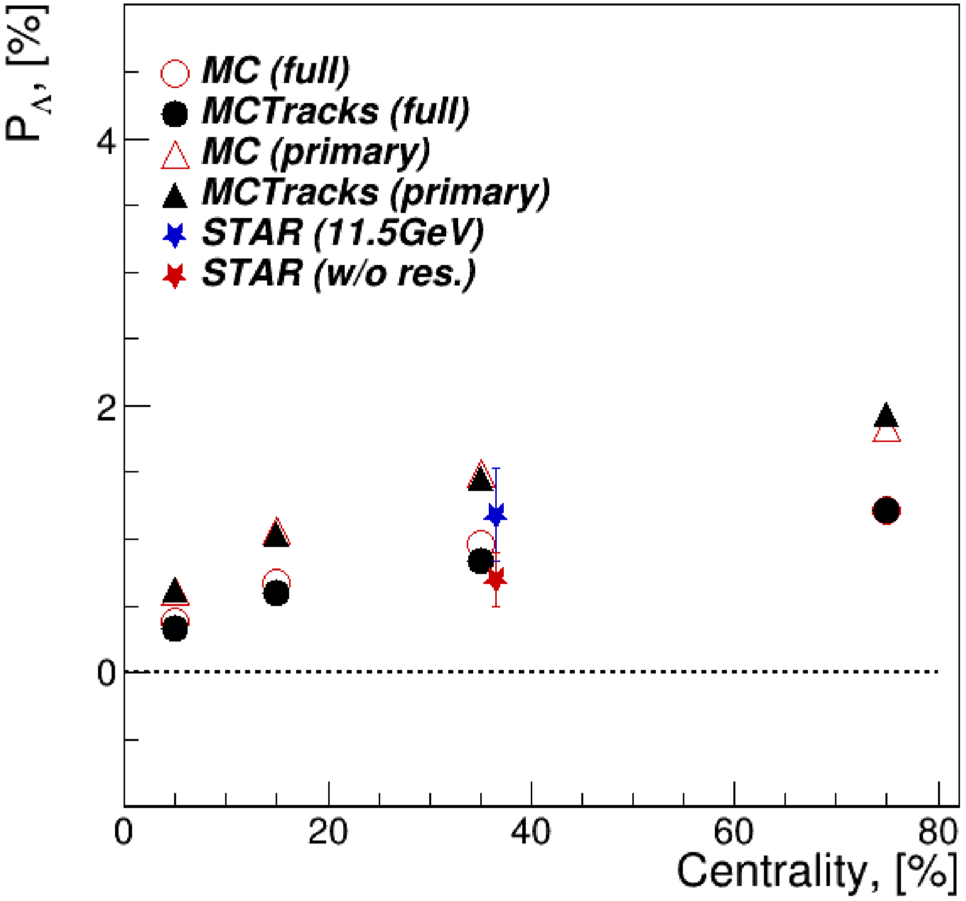
Not perfect agreement — fitting can be improved

1. Full Lambda — 10M production

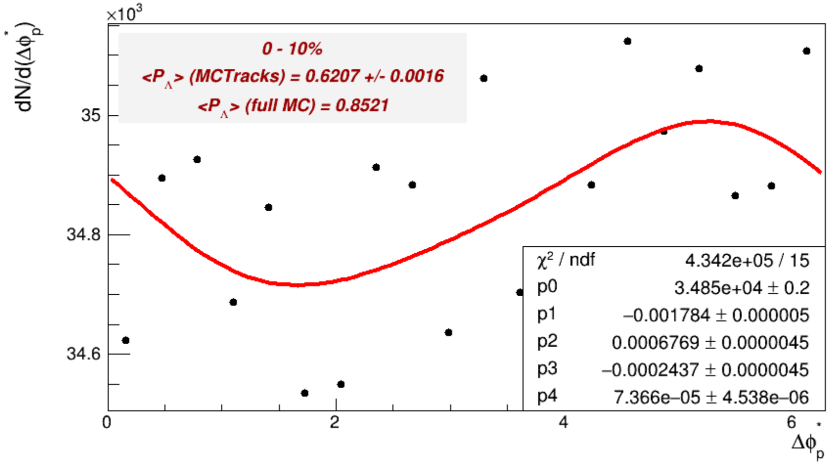


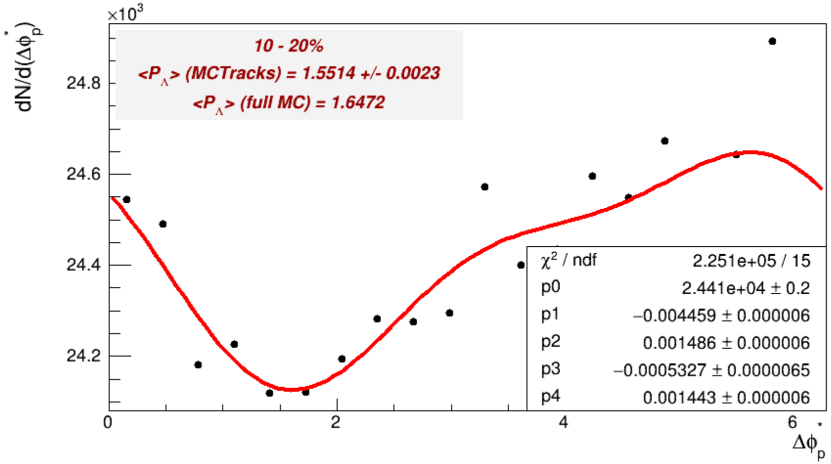
Not perfect agreement — fitting can be improved

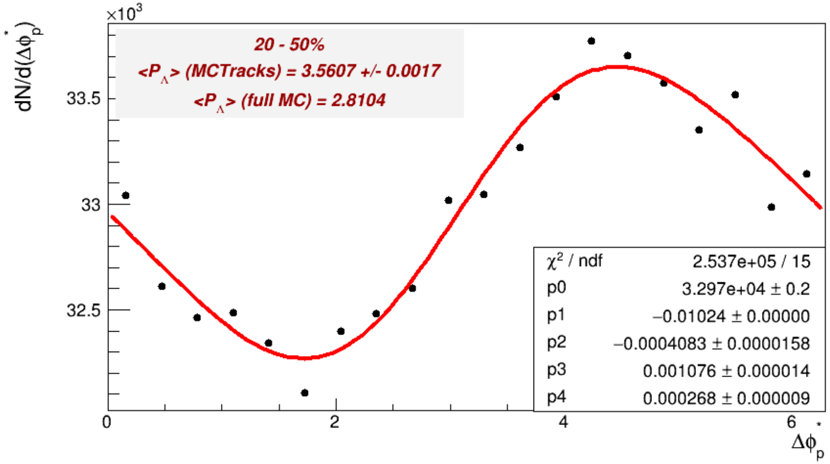
1. Mean Lambda polarization — 10M production

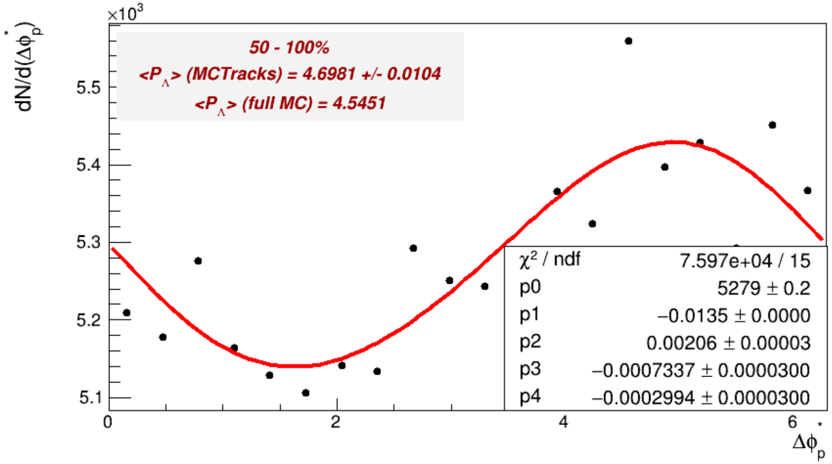


Returning the values of mean global polarization in both cases

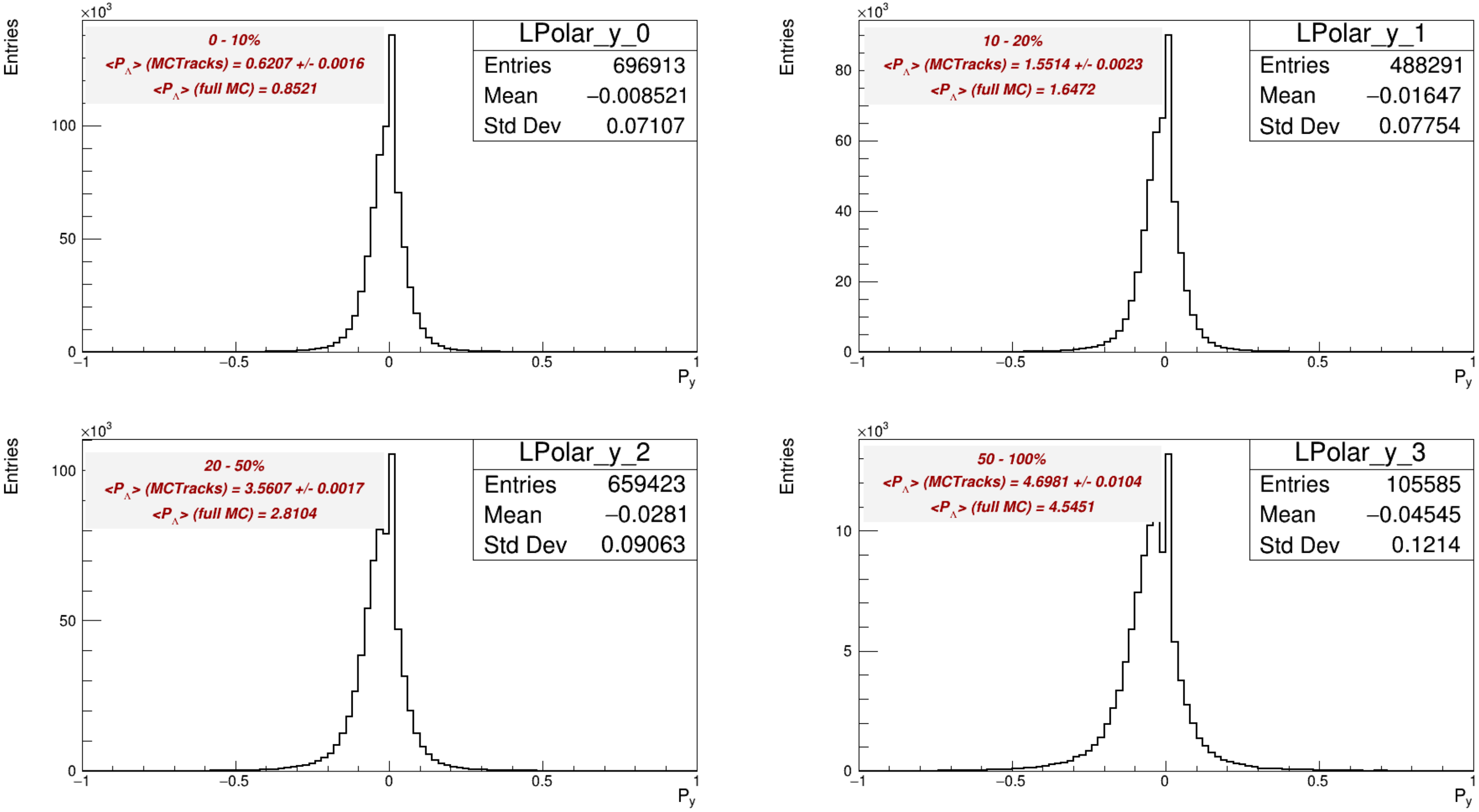

0 - 10%
<PΛ> (MCTracks) = 0.6207 +/- 0.0016
<PΛ> (full MC) = 0.8521
χ2 / ndf 4.342e+05 / 15
p0 3.485e+04 ± 0.2
p1 −0.001784 ± 0.000005
p2 0.0006769 ± 0.0000045
p3 −0.0002437 ± 0.0000045
p4 7.366e−05 ± 4.538e−06
dN/d(Δφp*)
Δφp*
×10^3


10 - 20%
<PΛ> (MCTracks) = 1.5514 +/- 0.0023
<PΛ> (full MC) = 1.6472
χ2 / ndf 2.251e+05 / 15
p0 2.441e+04 ± 0.2
p1 −0.004459 ± 0.000006
p2 0.001486 ± 0.000006
p3 −0.0005327 ± 0.0000065
p4 0.001443 ± 0.000006
dN/d(Δφp*)
Δφp*
×10^3

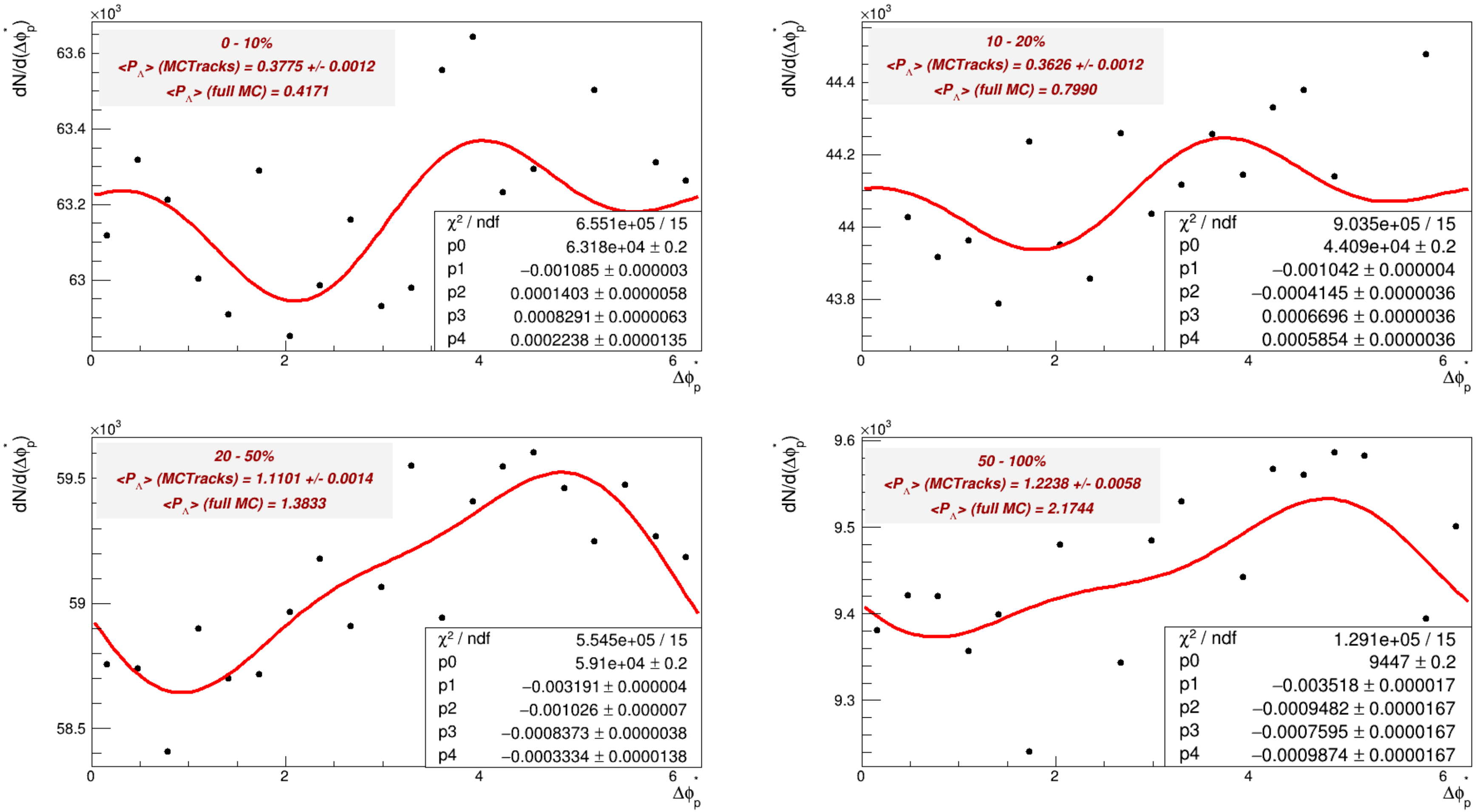

20 - 50%
<PΛ> (MCTracks) = 3.5607 +/- 0.0017
<PΛ> (full MC) = 2.8104
χ2 / ndf 2.537e+05 / 15
p0 3.297e+04 ± 0.2
p1 −0.01024 ± 0.00000
p2 −0.0004083 ± 0.0000158
p3 0.001076 ± 0.000014
p4 0.000268 ± 0.000009
dN/d(Δφp*)
Δφp*
×10^3


50 - 100%
<PΛ> (MCTracks) = 4.6981 +/- 0.0104
<PΛ> (full MC) = 4.5451
χ2 / ndf 7.597e+04 / 15
p0 5279 ± 0.2
p1 −0.0135 ± 0.0000
p2 0.00206 ± 0.00003
p3 −0.0007337 ± 0.0000300
p4 −0.0002994 ± 0.0000300
dN/d(Δφp*)
Δφp*
×10^3

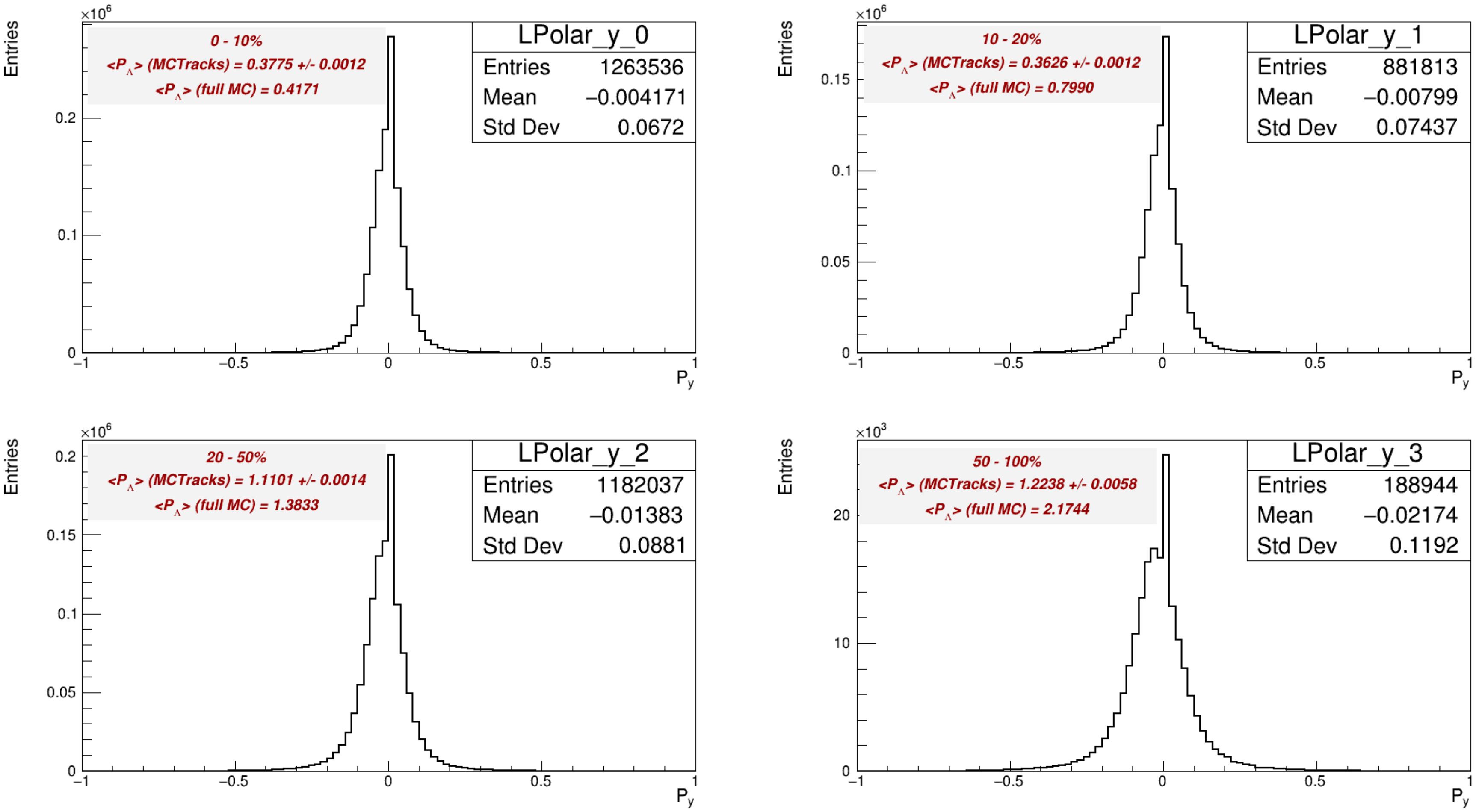
1. Primary ALambda — 10M production



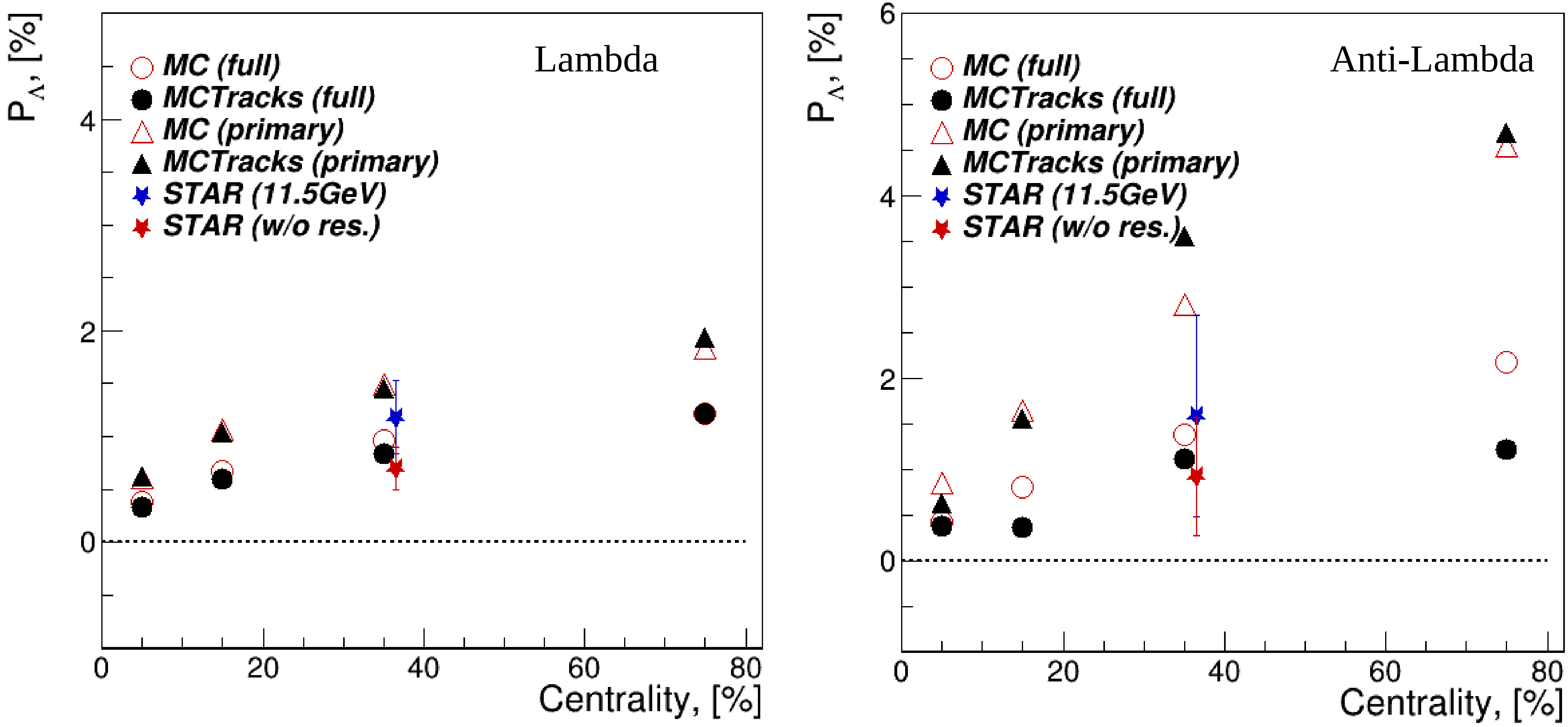
1. Full ALambda — 10M production



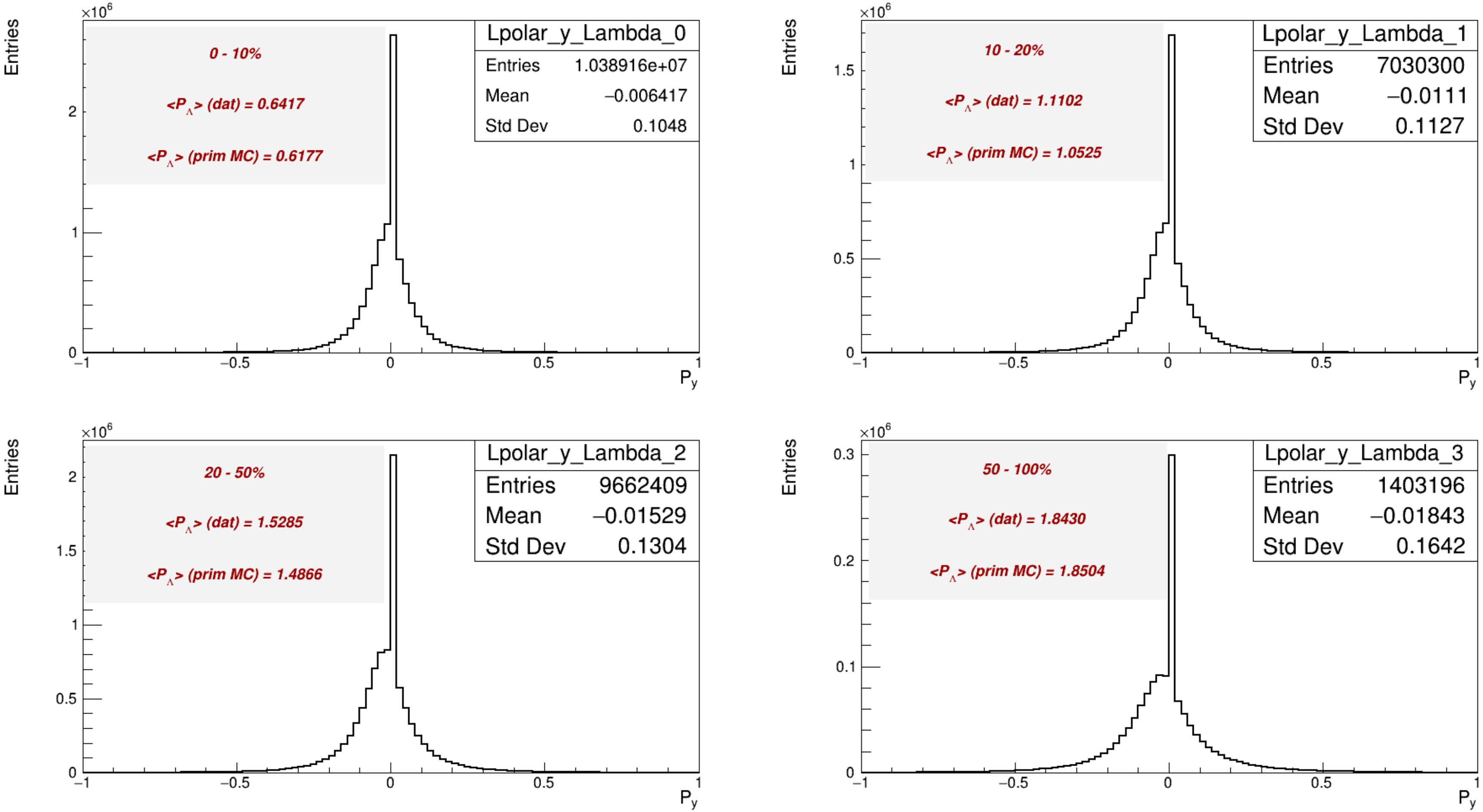
1. Full ALambda — 10M production



1. Mean global polarization — 10M production



2. Compare MCTracks with data — 2M private production



Different centrality selection — still, good agreement

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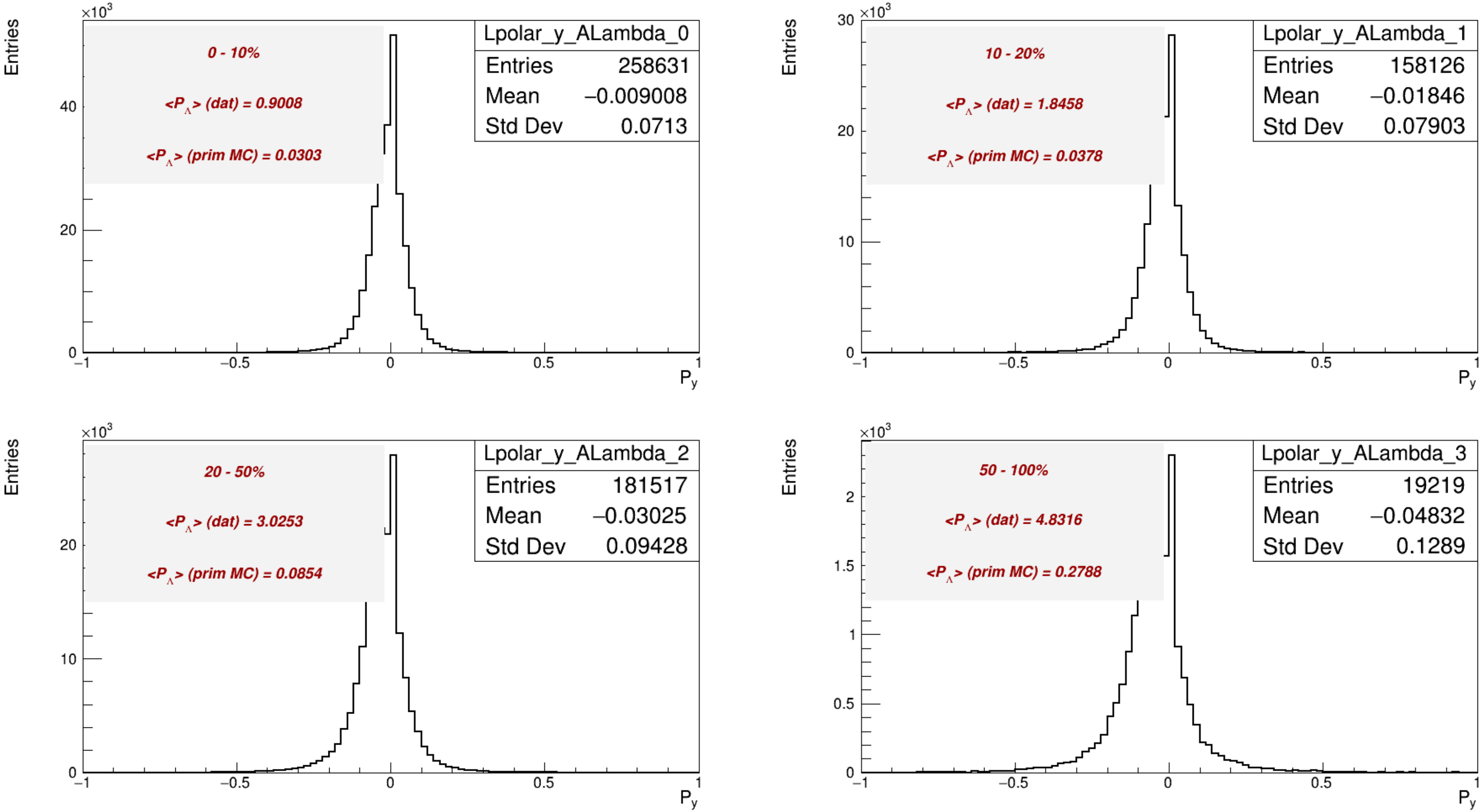
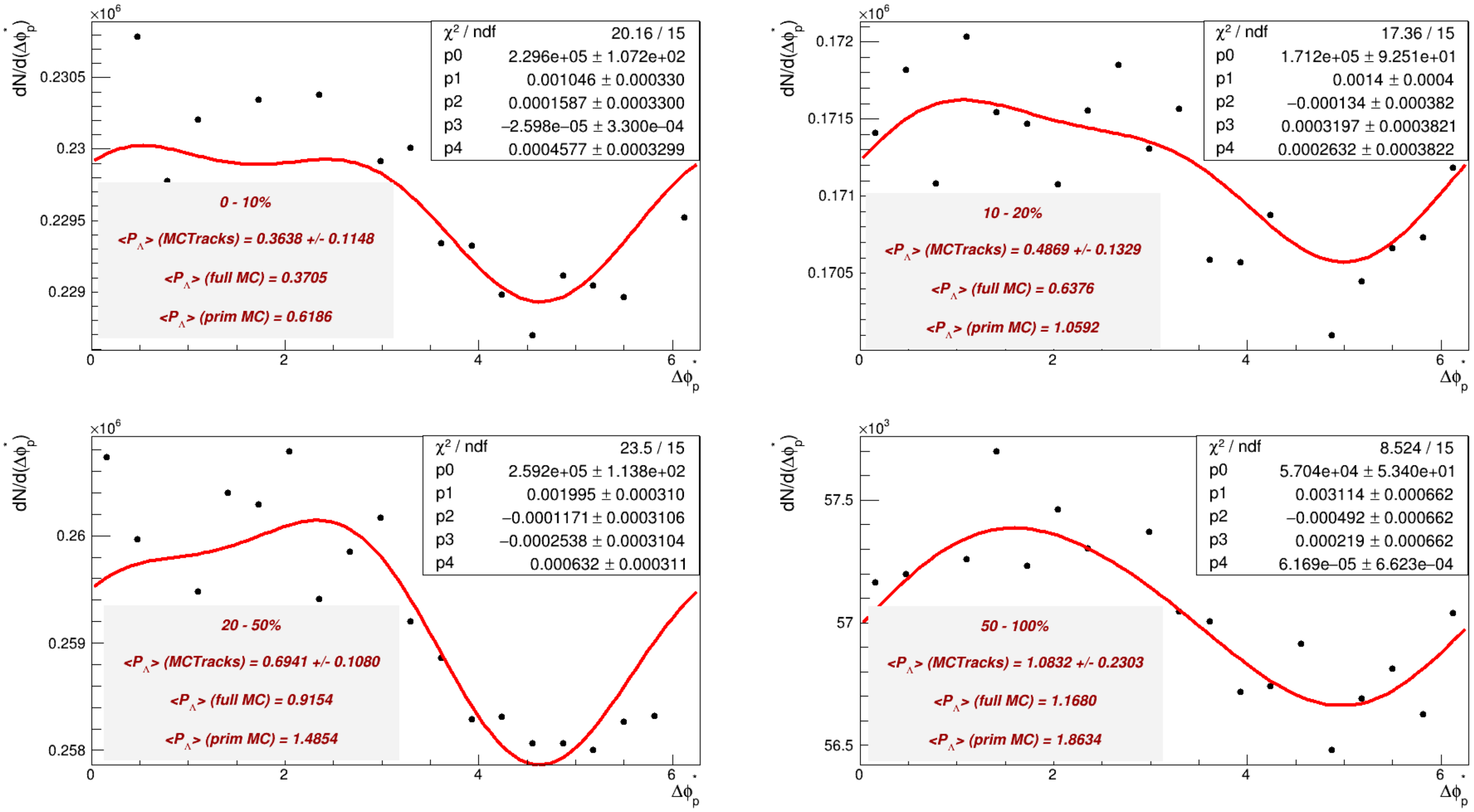


Something goes wrong in the simulation — needs to be checked for ALambda

2. Full Lambda — 1M private production (MCTracks)



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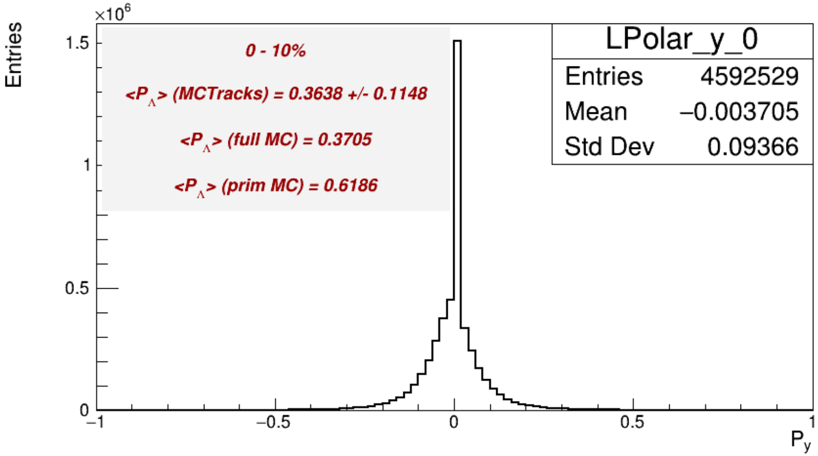
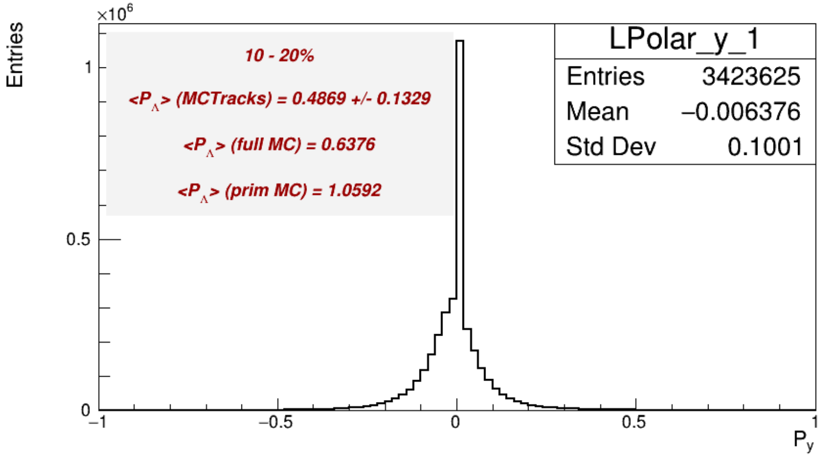
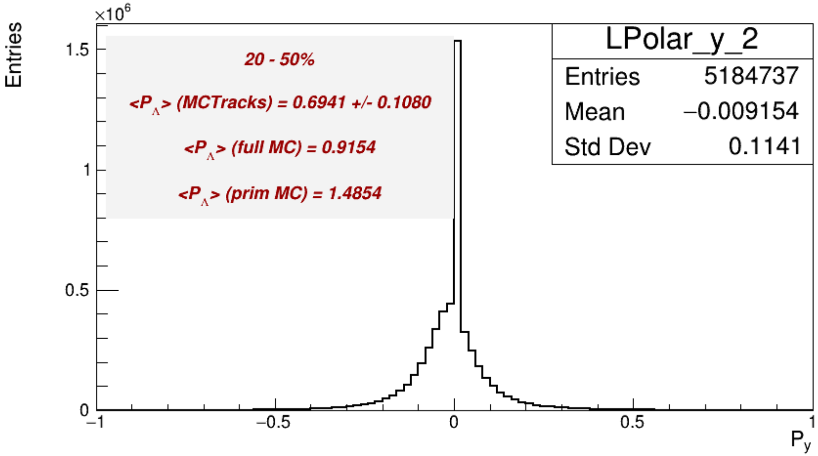
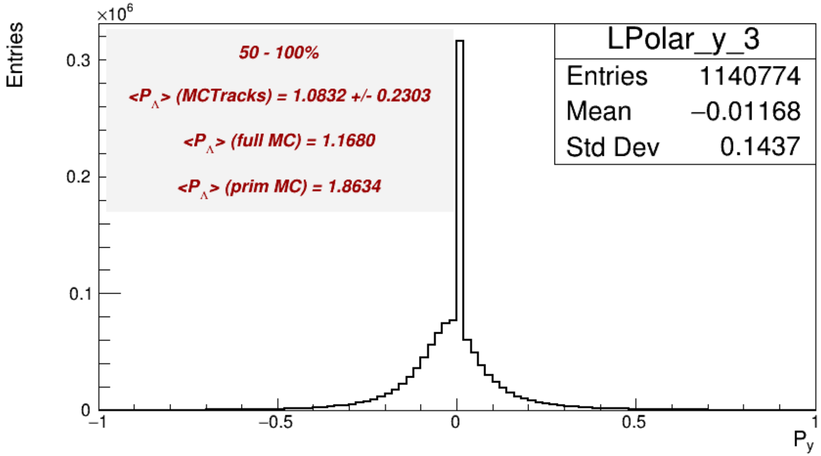
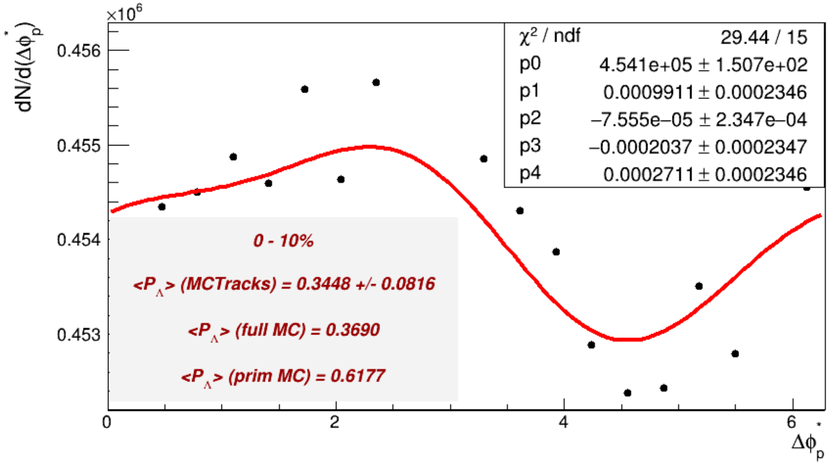


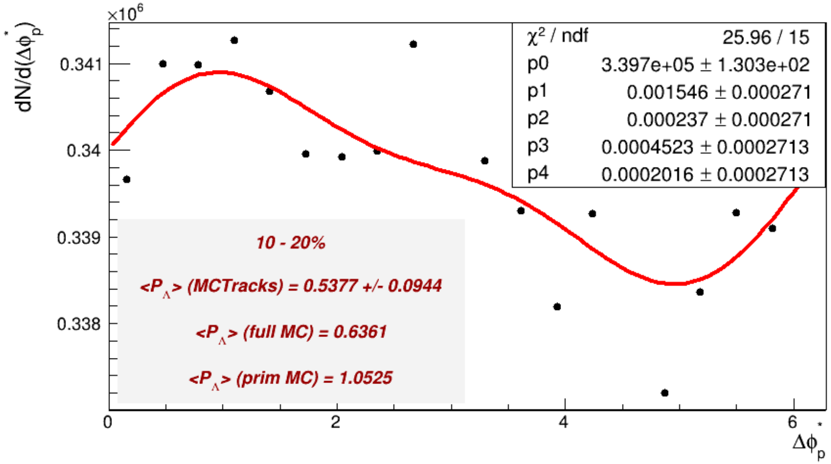


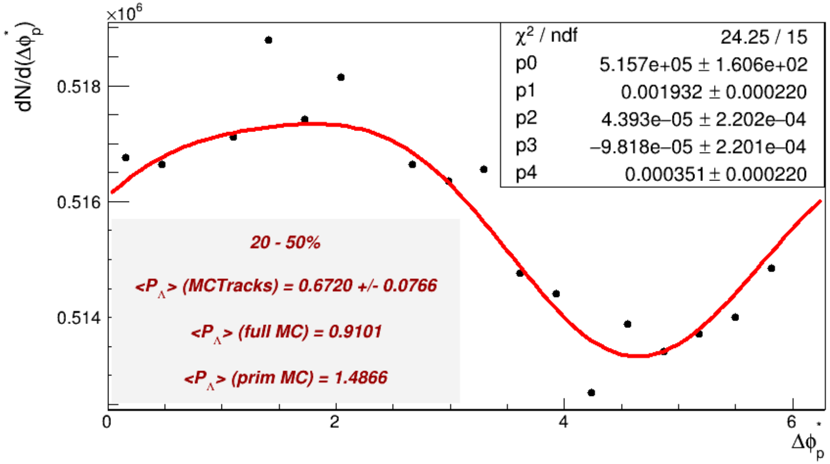


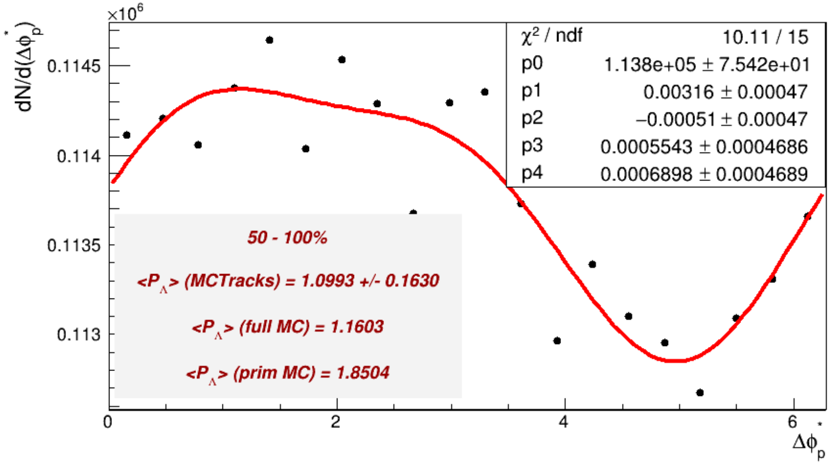


2. Full Lambda — 2M private production (MCTracks)

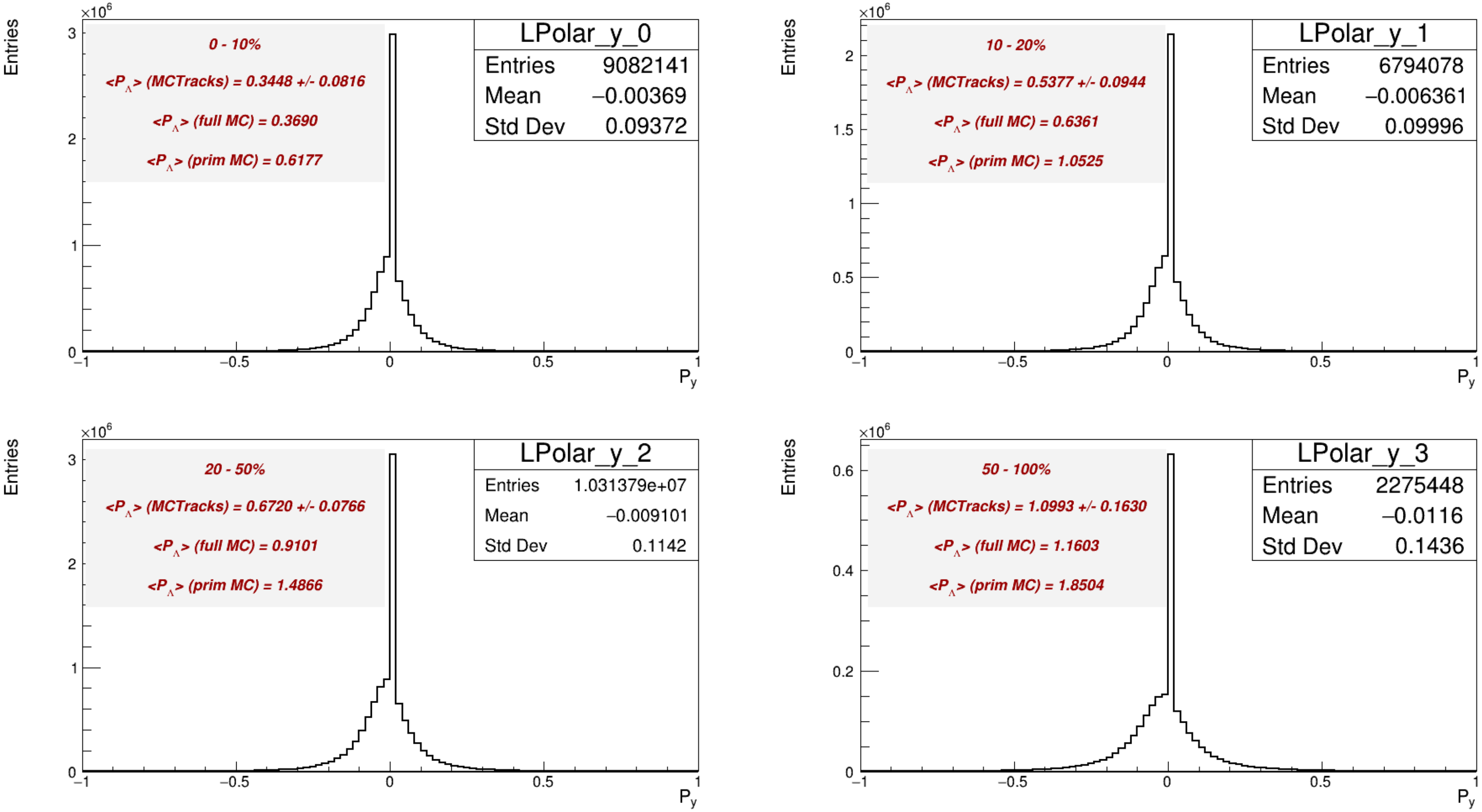




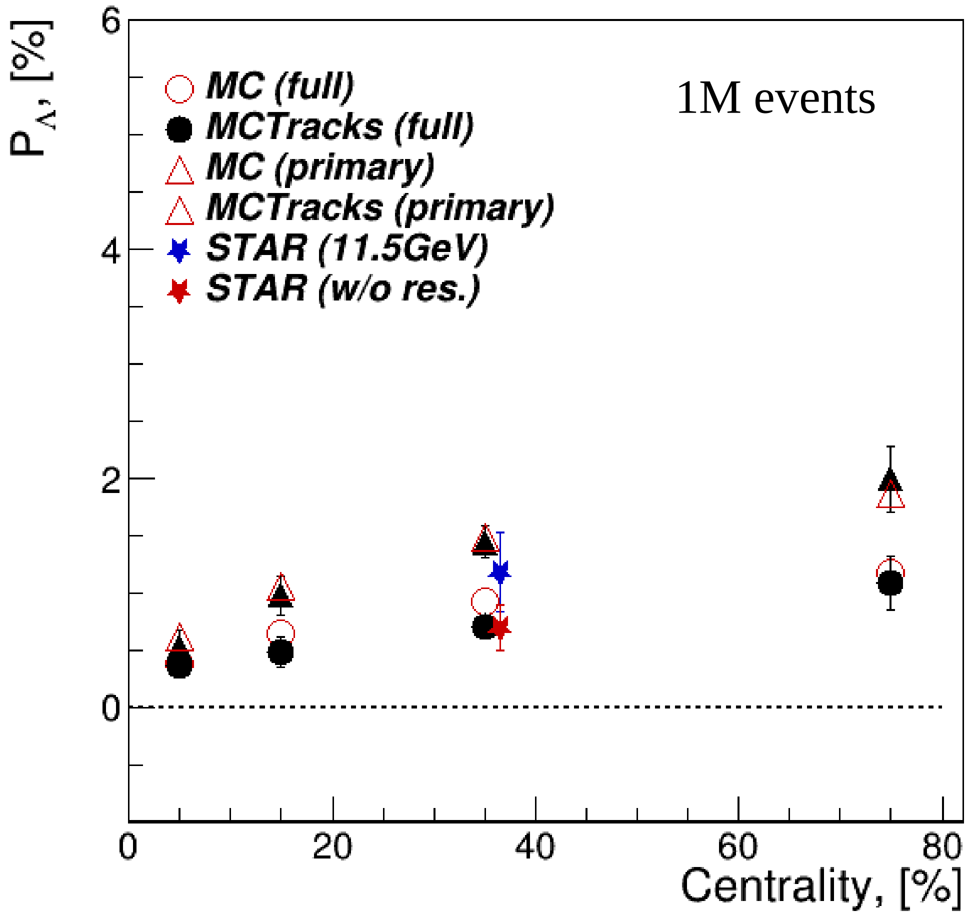


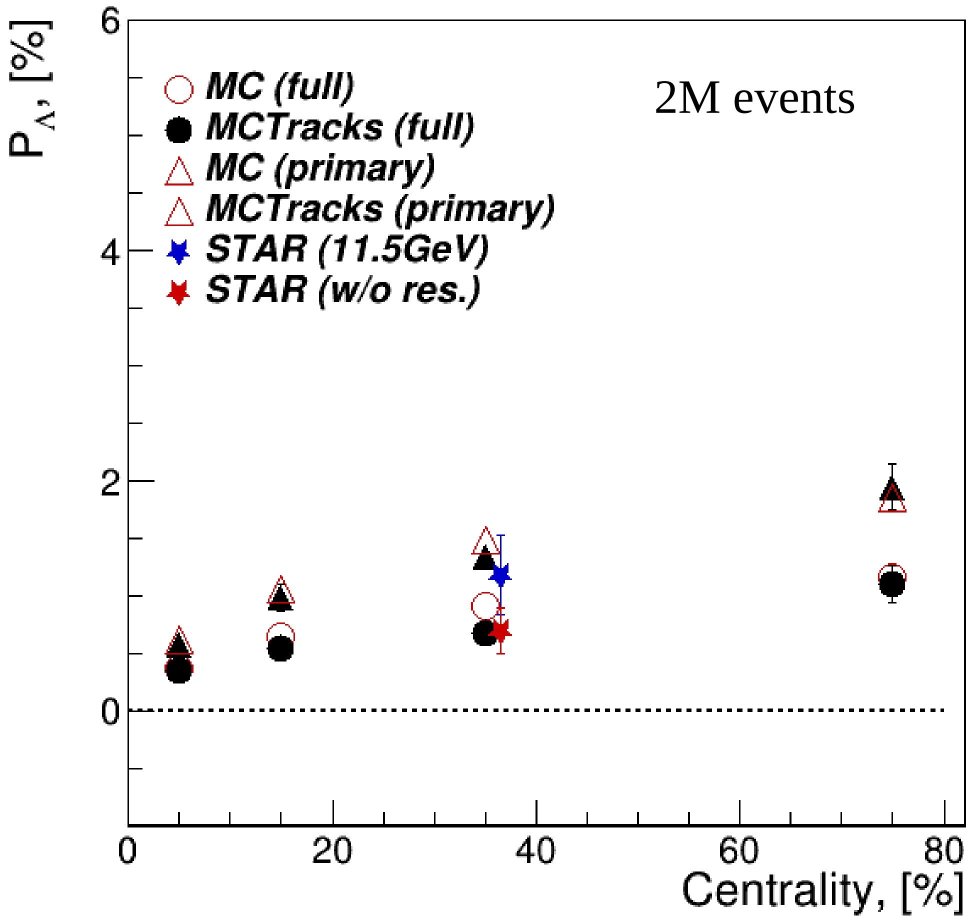


2. Full Lambda — 2M private production (MCTracks)

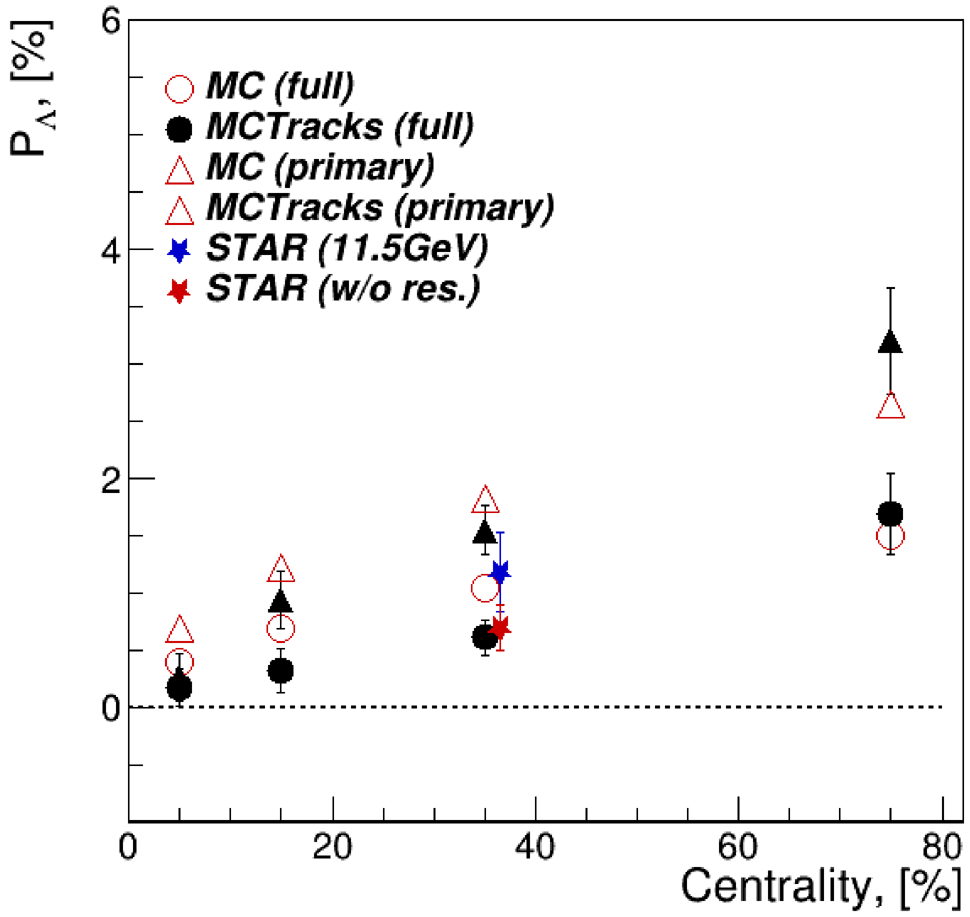


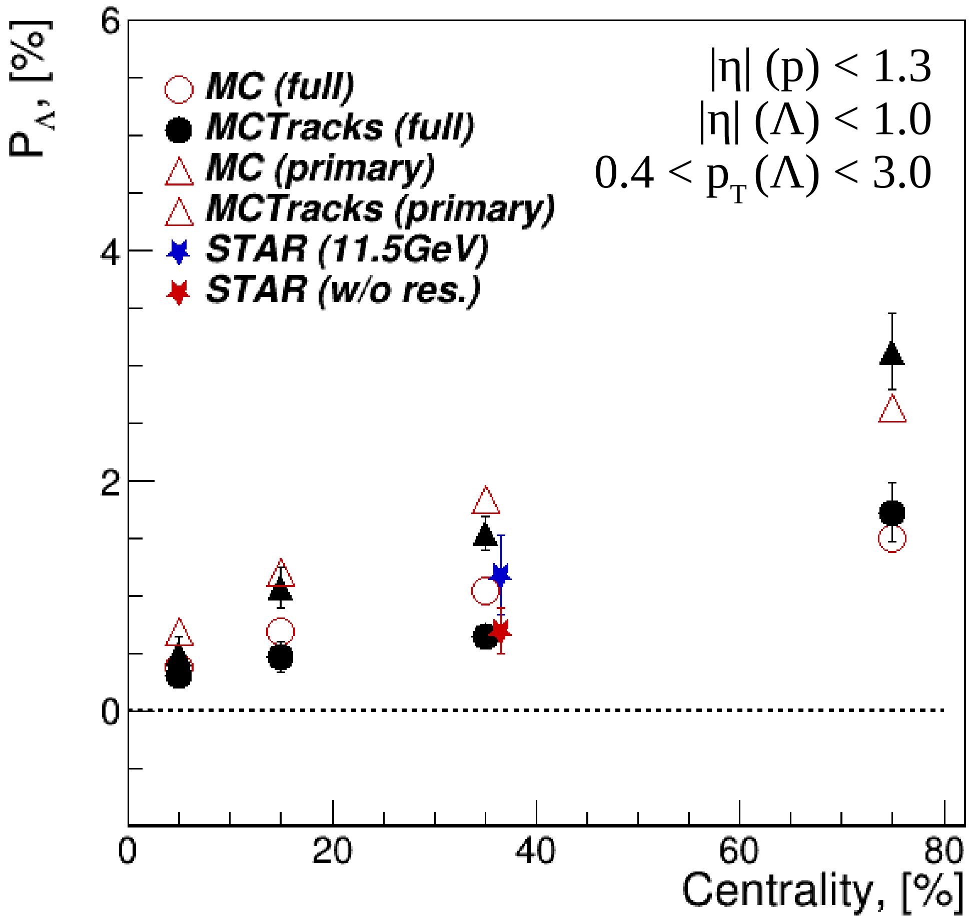
1. Mean Lambda polarization — 1M vs 2M

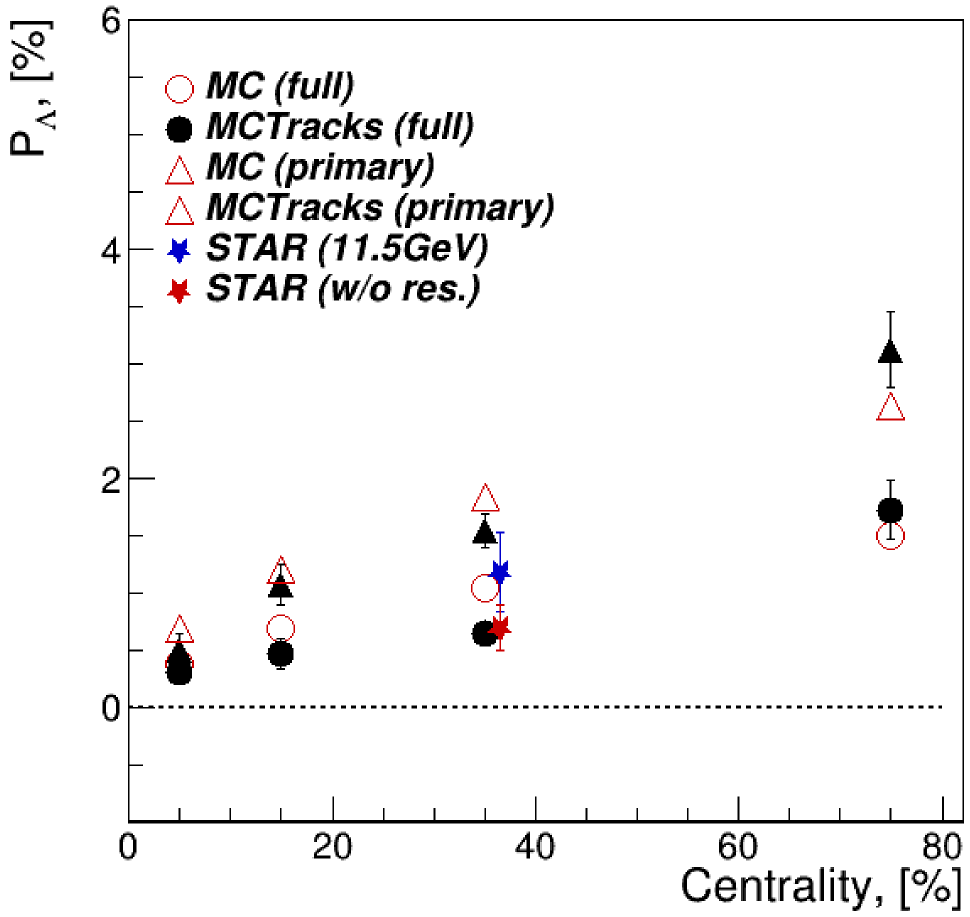


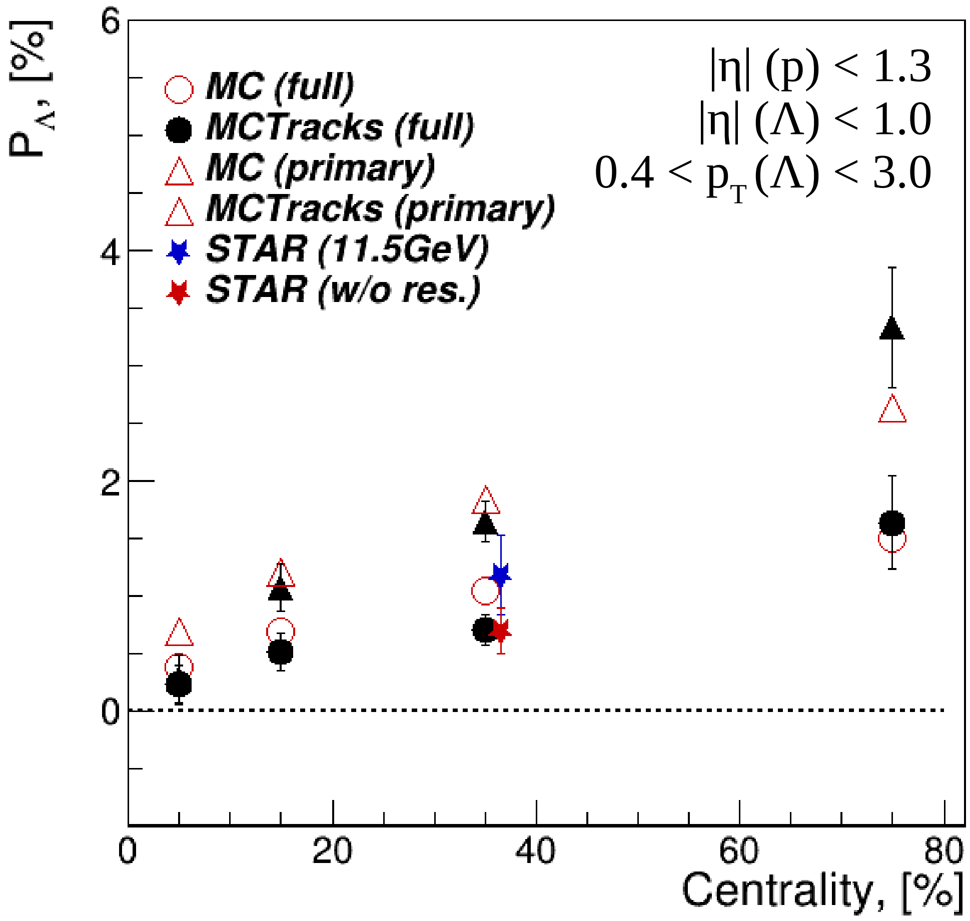


1. Mean Lambda polarization — 1M vs 2M (with cuts)

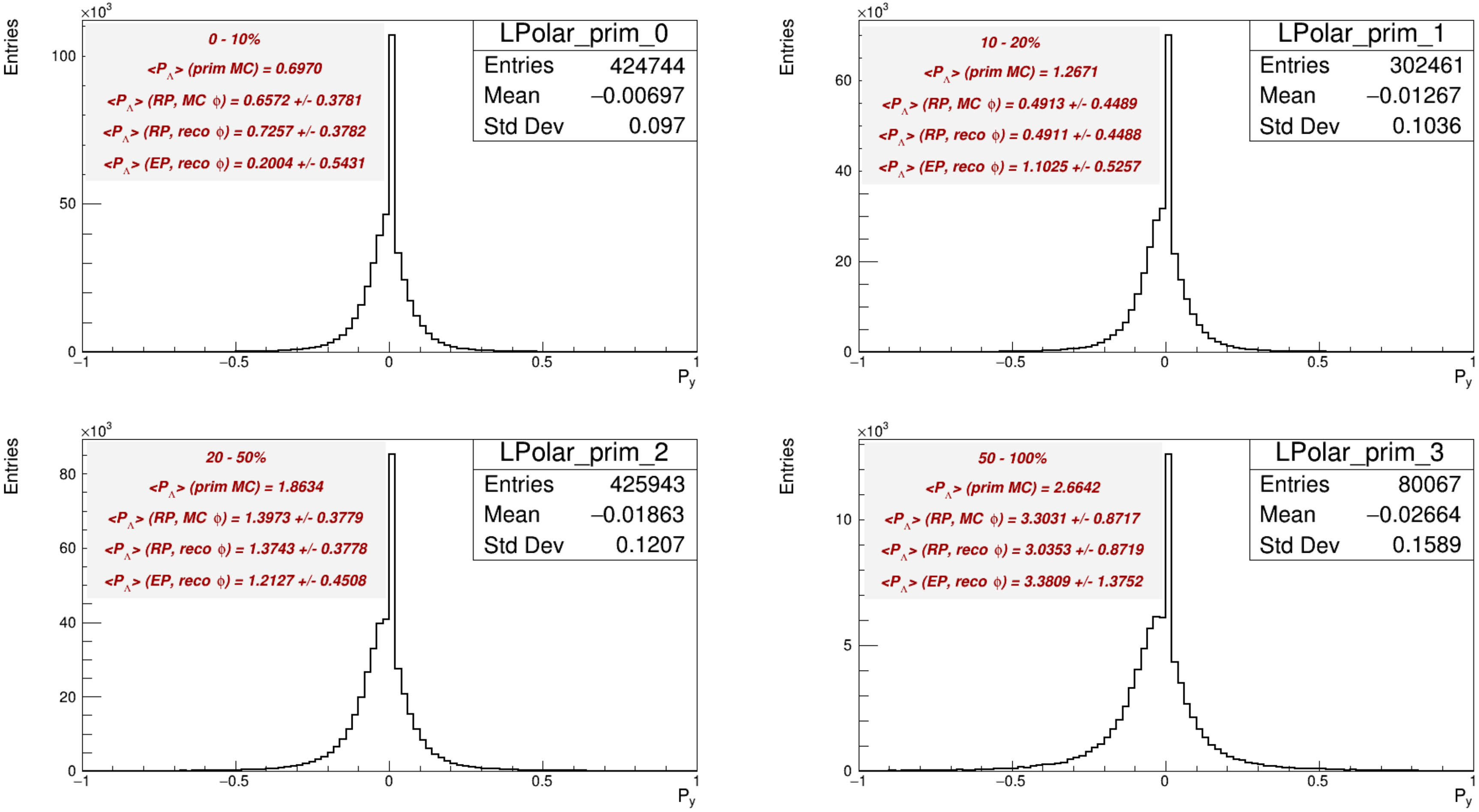




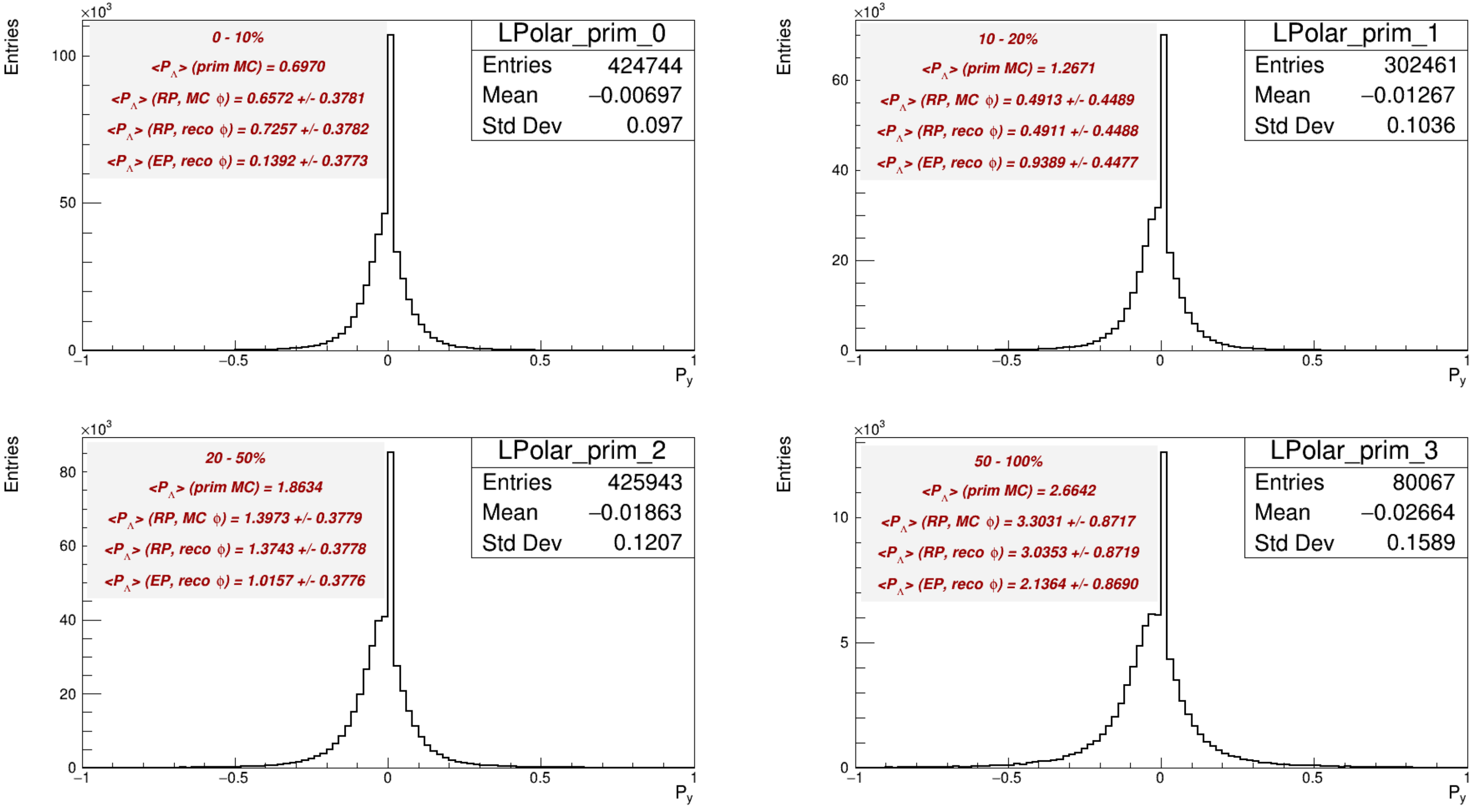

MC (full)
MCTracks (full)
MC (primary)
MCTracks (primary)
STAR (11.5GeV)
STAR (w/o res.)
P_Λ, [%]
Centrality, [%]


MC (full)
MCTracks (full)
MC (primary)
MCTracks (primary)
STAR (11.5GeV)
STAR (w/o res.)
$|\eta|$ (p) < 1.3
$|\eta|$ (Λ) < 1.0
$0.4 < p_T (\Lambda) < 3.0$
P_Λ, [%]
Centrality, [%]

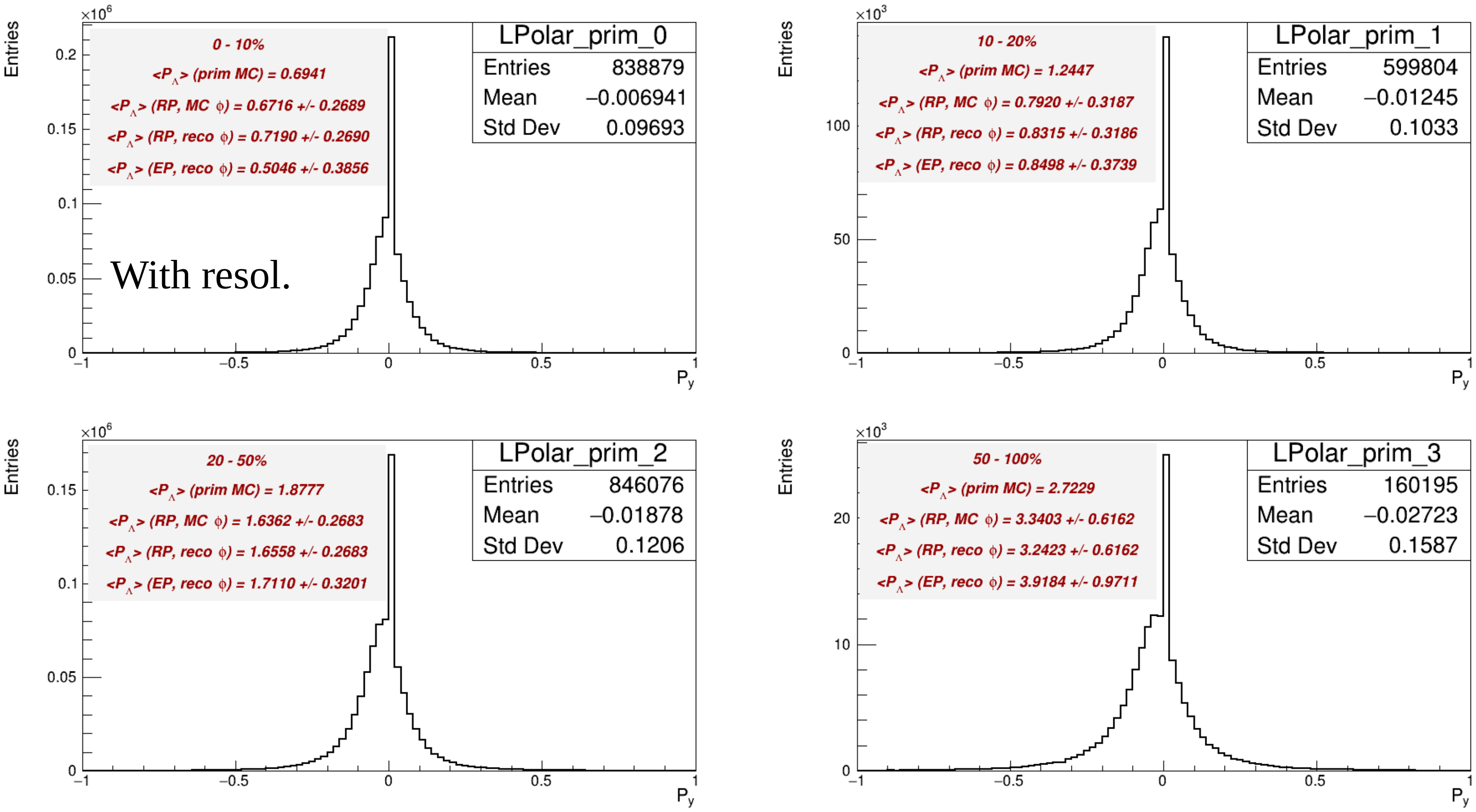
2. Primary Lambda — 1M private production (MC-Reco)



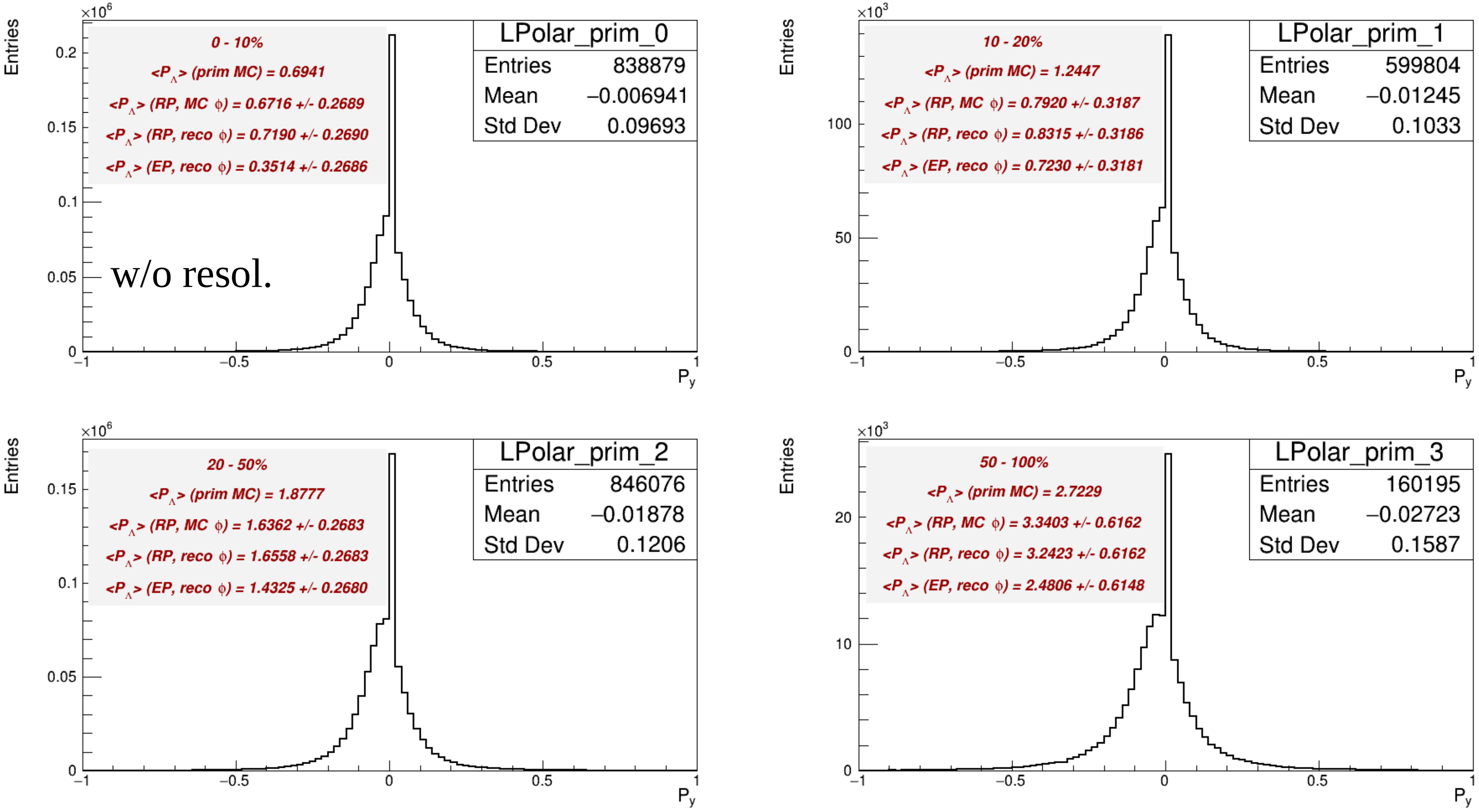
2. Primary Lambda — 1M private production (MC-Reco)



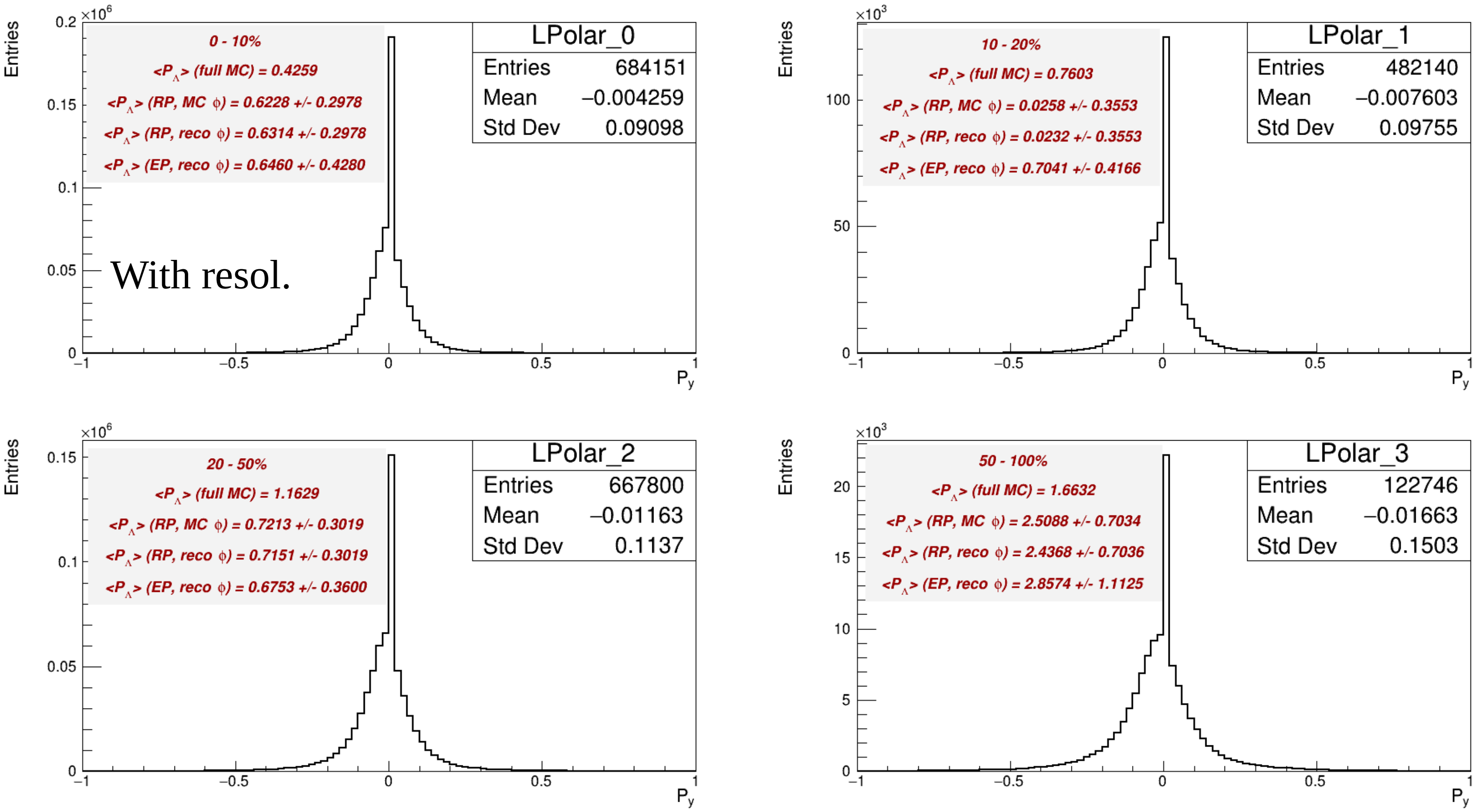
2. Primary Lambda — 2M private production (MC-Reco)



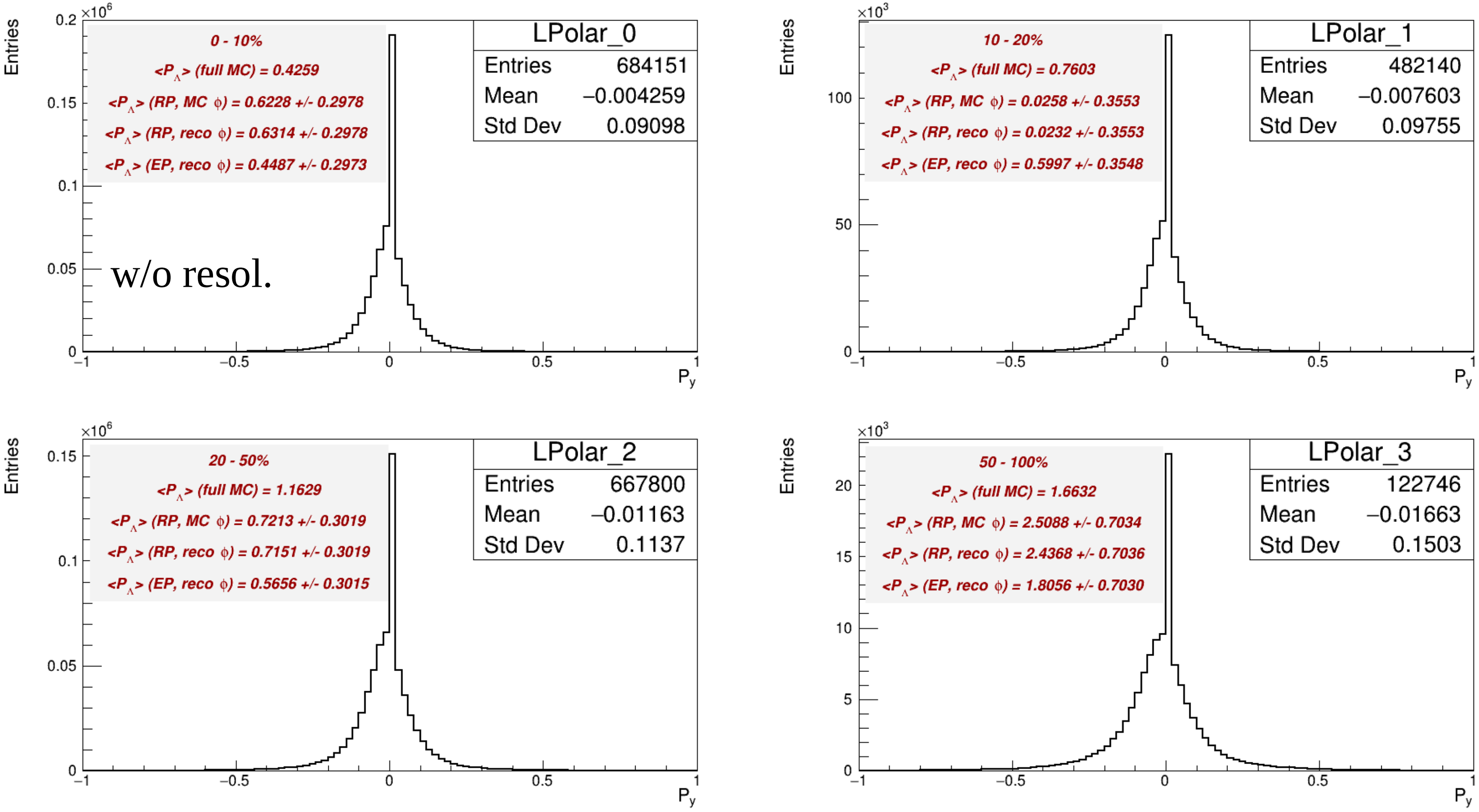
2. Primary Lambda — 2M private production (MC-Reco)



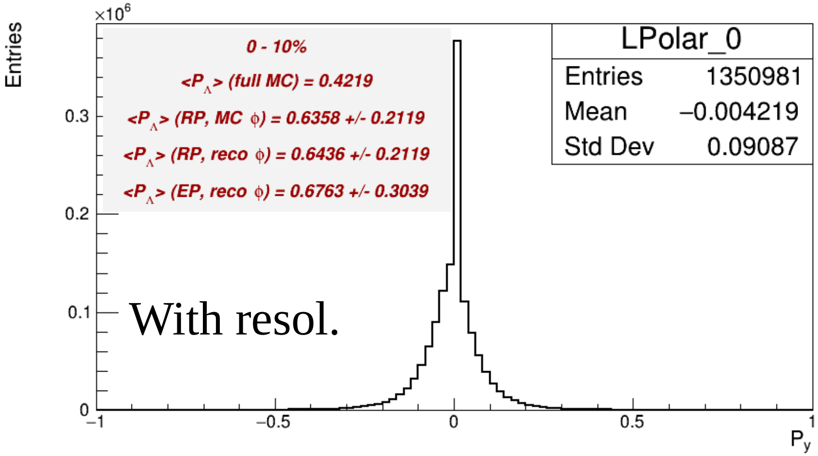
2. Full Lambda — 1M private production (MC-Reco)

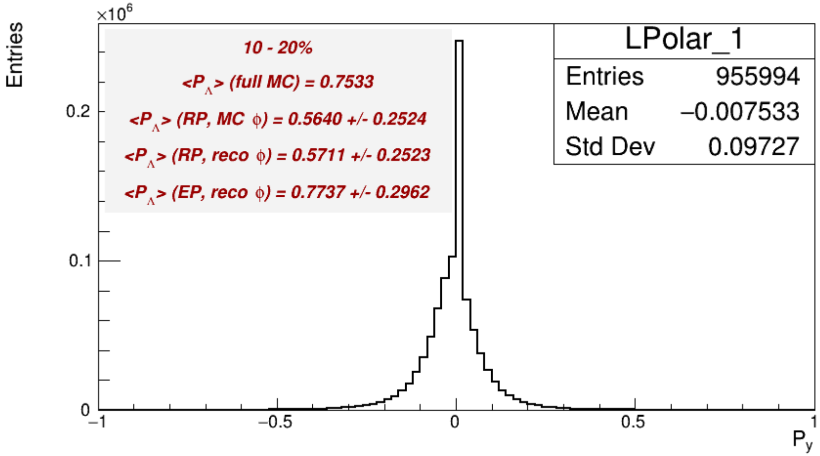


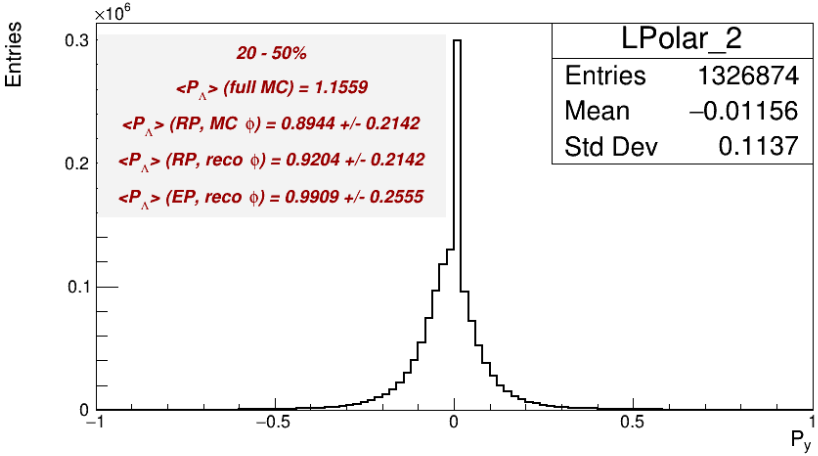
2. Full Lambda — 1M private production (MC-Reco)

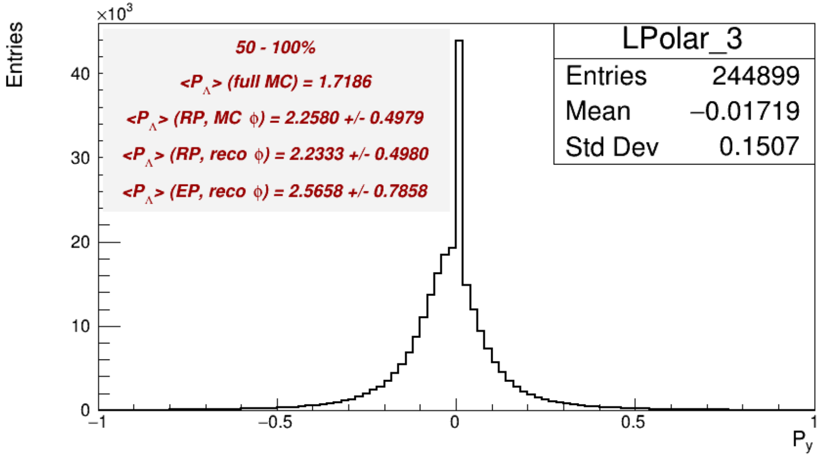


2. Full Lambda — 2M private production (MC-Reco)

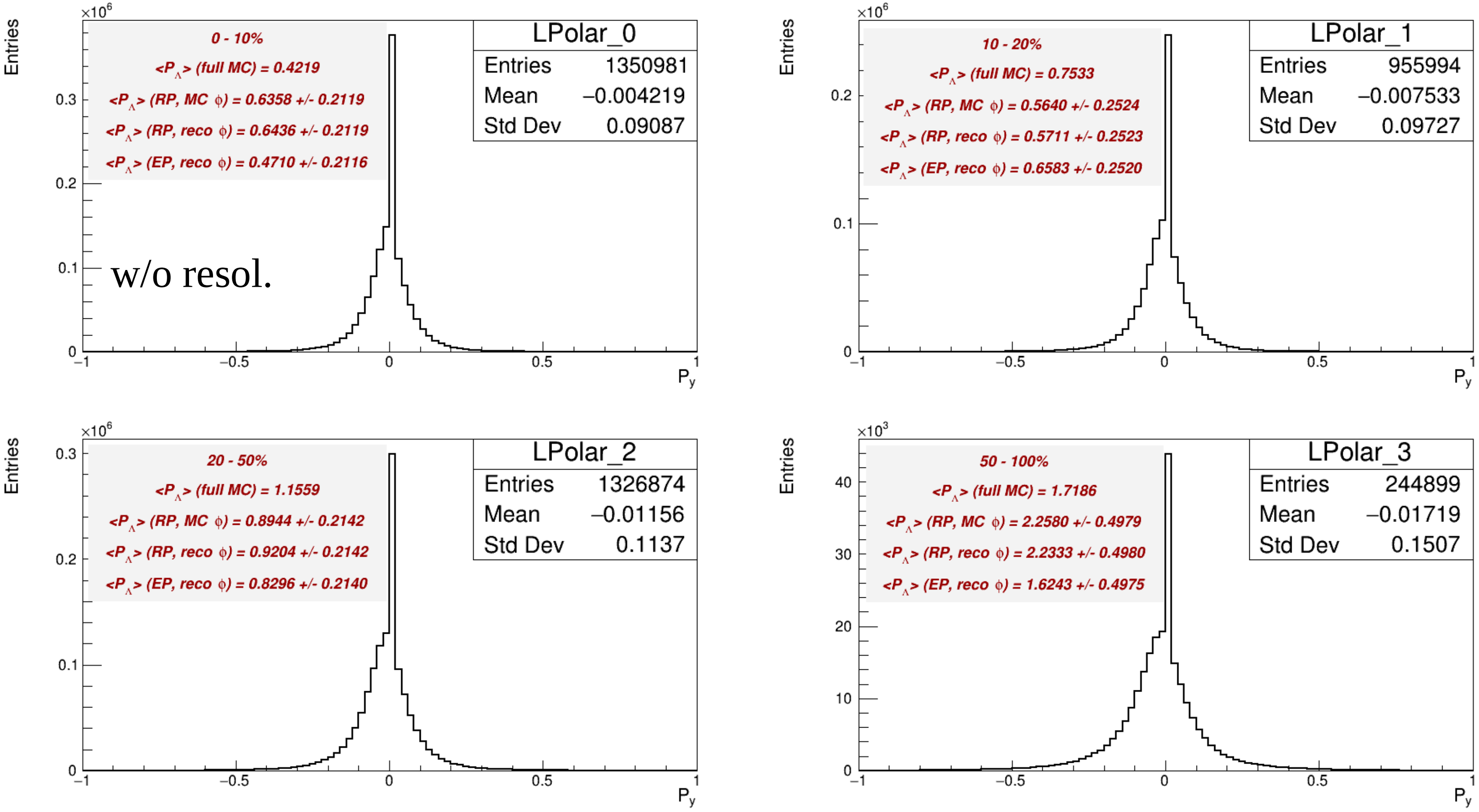




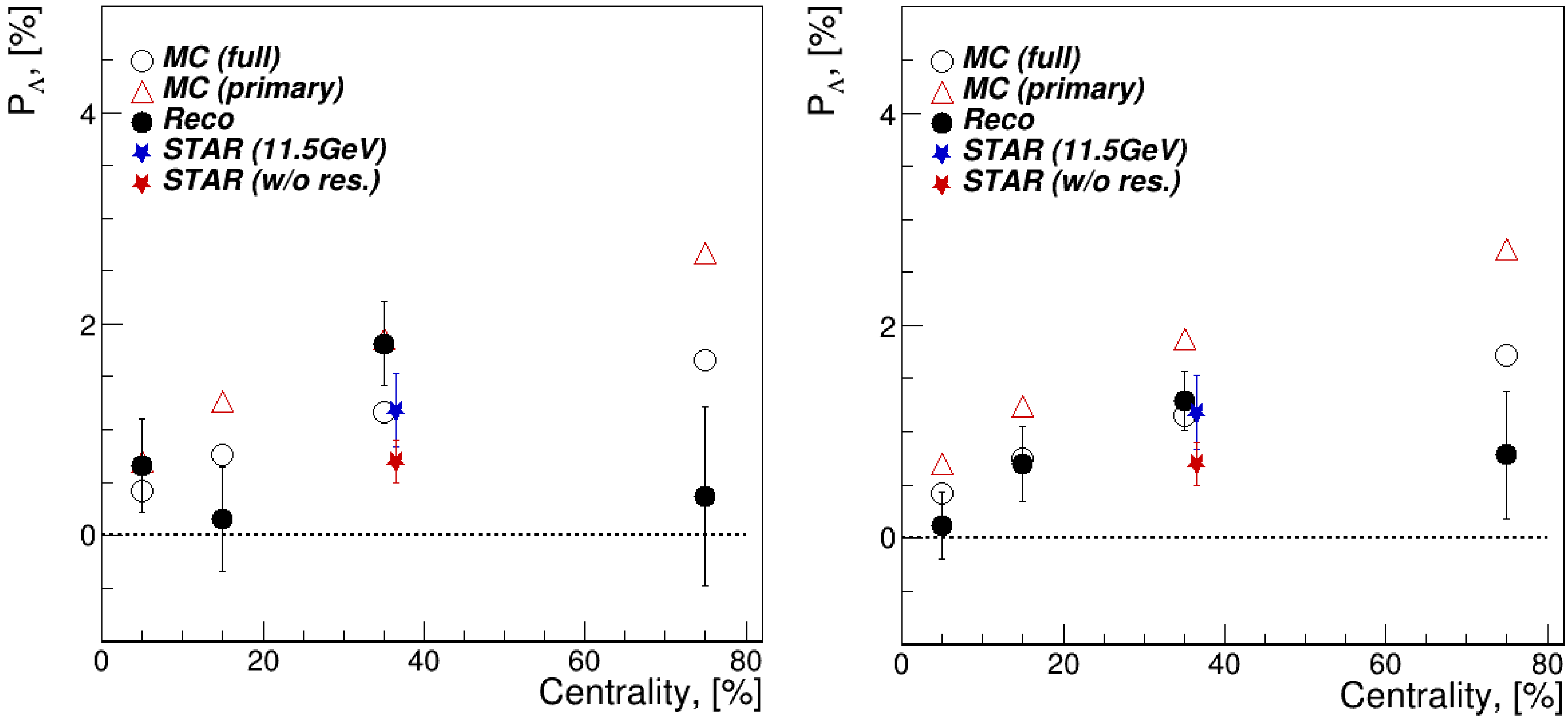




2. Full Lambda — 2M private production (MC-Reco)



2. Mean Reco Lambda polarization — 1M vs 2M

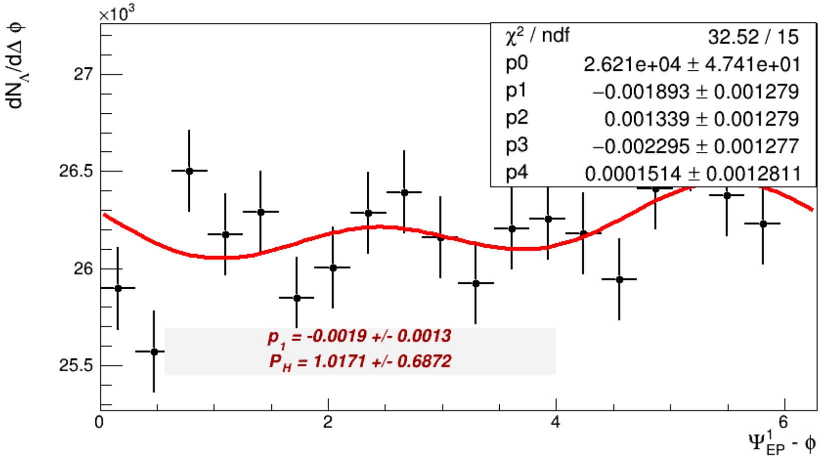


Conclusions

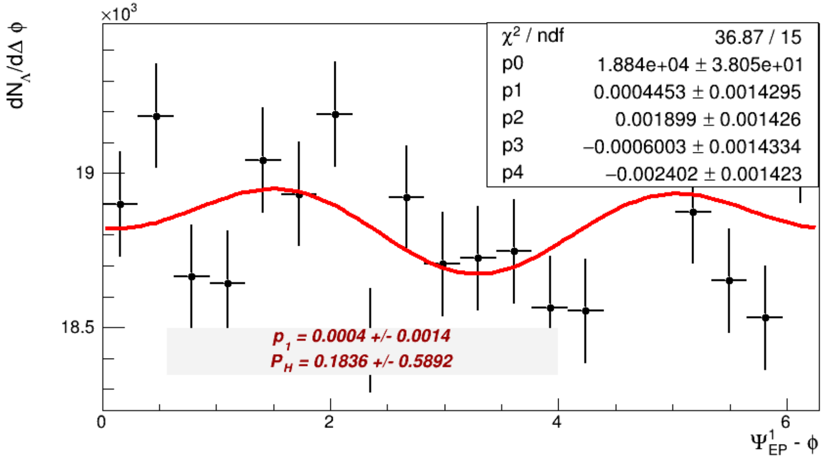
- Updated polarization transfer
  - rotation w.r.t. reaction plane
  - Spin direction randomized according to the probability
- Tests for Lambda on private 2M events production are successful
  - MCTracks: show similar results to the tests on 10M events
  - Reco: tests manage to extract polarization values
- Anisotropic decay for Anti-Lambda
  - Workes in MCTracks test on the official 10M events sample
  - Implementation in mpdroot needs to be tested
- New production?

The End

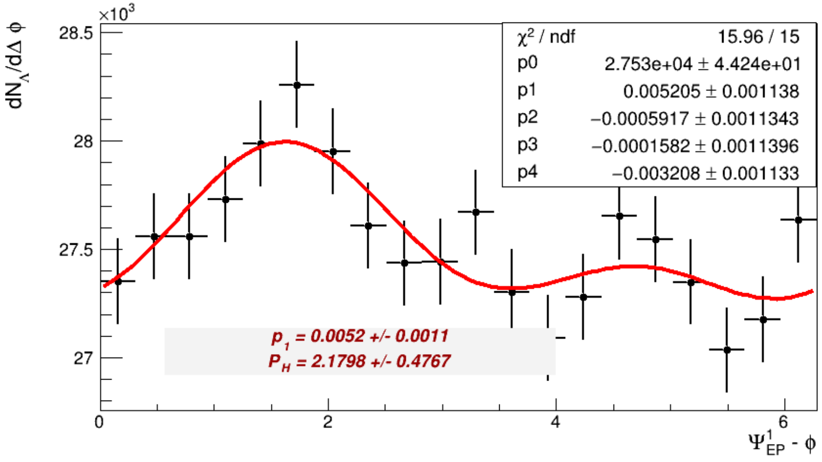
Thank you for your attention!



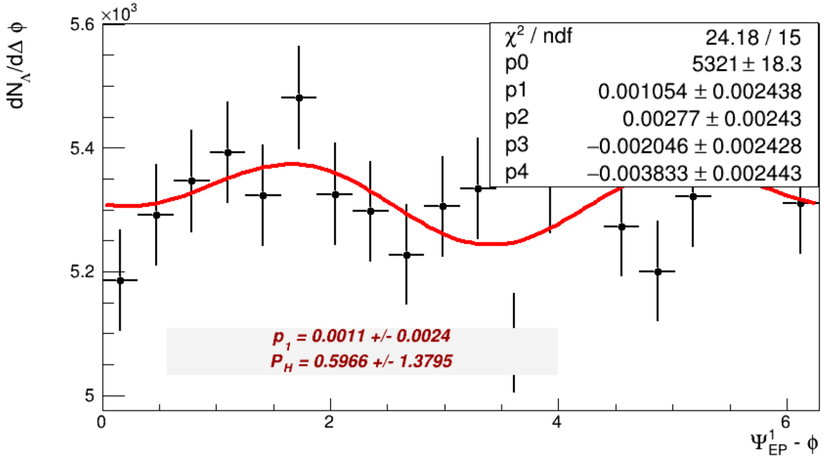
χ^2 / ndf 32.52 / 15
p0 2.621e+04 ± 4.741e+01
p1 −0.001893 ± 0.001279
p2 0.001339 ± 0.001279
p3 −0.002295 ± 0.001277
p4 0.0001514 ± 0.0012811
p_1 = -0.0019 +/- 0.0013
P_H = 1.0171 +/- 0.6872
$dN_\Lambda/d\Delta\phi$
$\Psi^1_{EP} - \phi$



χ^2 / ndf 36.87 / 15
p0 1.884e+04 ± 3.805e+01
p1 0.0004453 ± 0.0014295
p2 0.001899 ± 0.001426
p3 −0.0006003 ± 0.0014334
p4 −0.002402 ± 0.001423
p_1 = 0.0004 +/- 0.0014
P_H = 0.1836 +/- 0.5892
$dN_\Lambda/d\Delta\phi$
$\Psi^1_{EP} - \phi$



χ^2 / ndf 15.96 / 15
p0 2.753e+04 ± 4.424e+01
p1 0.005205 ± 0.001138
p2 −0.0005917 ± 0.0011343
p3 −0.0001582 ± 0.0011396
p4 −0.003208 ± 0.001133
p_1 = 0.0052 +/- 0.0011
P_H = 2.1798 +/- 0.4767
$dN_\Lambda/d\Delta\phi$
$\Psi^1_{EP} - \phi$



χ^2 / ndf 24.18 / 15
p0 5321 ± 18.3
p1 0.001054 ± 0.002438
p2 0.00277 ± 0.00243
p3 −0.002046 ± 0.002428
p4 −0.003833 ± 0.002443
p_1 = 0.0011 +/- 0.0024
P_H = 0.5966 +/- 1.3795
$dN_\Lambda/d\Delta\phi$
$\Psi^1_{EP} - \phi$

2. Full Lambda — 2M private production (Reco)