KY electroproduction with CLAS12

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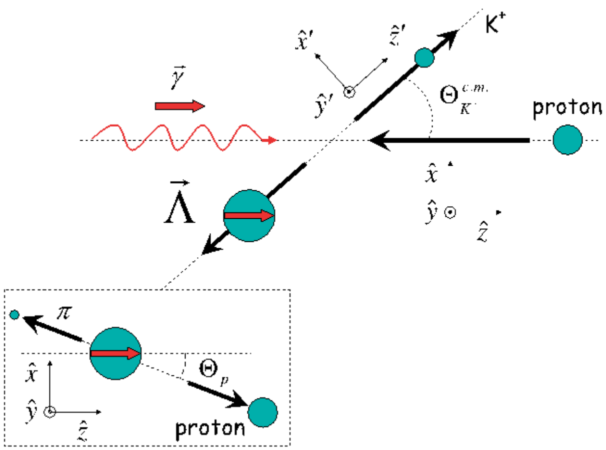
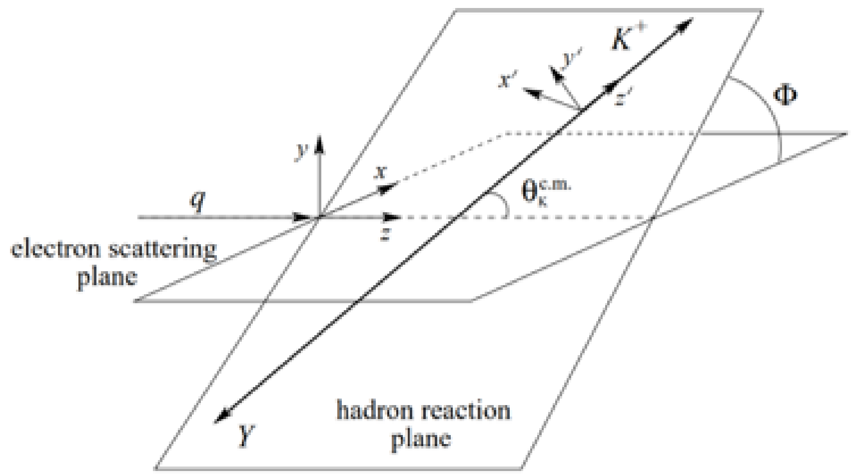
Strong 2020 HaSP School, 12 September 2023

What do we want to measure?

Extraction of Lambda induced polarization in the electroproduction process:

$$ep \rightarrow e'K^+\Lambda \qquad \Lambda \rightarrow p\pi^- \qquad \Gamma^{BR} = 0.64$$





For electroproduction, the reaction kinematics are uniquely defined by the set of four variables (Q^2 , W, cos θ^K_{CM} , Φ), where:

- θ^K_{CM} : kaon production angle in the virtual photon-proton center-of-mass (CM) frame
- Q^2 is the squared four-momentum transfer of the virtual photon
- W is the invariant mass of the intermediate state

$$W = \sqrt{M_p^2 + 2M_p\nu - Q^2} \qquad \nu = E_e - E_{e'}$$

- Φ is is the relative angle between the electron-scattering and the hadron-production planes

What do we want to measure?

Extraction of Lambda induced polarization in the electroproduction process

$$ep \rightarrow e' K^+ \Lambda$$

$K^+\Lambda$ electroproduction cross section

$$\frac{d^5\sigma}{dE_{e'} d\Omega_{e'} d\Omega_K^{CM}} = \Gamma \frac{d^2\sigma_v}{d\Omega_K^{CM}} \quad \text{where} \quad \Gamma = \frac{\alpha}{4\pi} \frac{W}{M_p^2 E_e^2}(W^2 - M_p^2)\left[\frac{1}{Q^2(1-\epsilon)}\right]$$

Where α is the fine-structure constant and ε is the virtual photon polarization parameter given by

$$\epsilon = \left[1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\frac{\theta_{e'}}{2}\right]^{-1}$$

Which in the most general case can be written as:

$$\begin{aligned}\frac{d^2\sigma_v}{d\Omega_K^{CM}} = KS_\alpha S_\beta\Big[&R_T^{\beta\alpha} + \epsilon R_L^{\beta\alpha} + \sqrt{\epsilon(1+\epsilon)}(\,{}^cR_{LT}^{\beta\alpha}\cos\Phi + \,{}^sR_{LT}^{\beta\alpha}\sin\Phi) \\ &+ \epsilon(\,{}^cR_{TT}^{\beta\alpha}\cos 2\Phi + \,{}^sR_{TT}^{\beta\alpha}\sin 2\Phi) \\ &+ h\sqrt{\epsilon(1-\epsilon)}(\,{}^cR_{LT'}^{\beta\alpha}\cos\Phi + \,{}^sR_{LT'}^{\beta\alpha}\sin\Phi) + h\sqrt{1-\epsilon^2}R_{TT'}^{\beta\alpha}\Big].\end{aligned}$$

During this experiment, a longitudinally polarized electron beam was incident upon an unpolarized proton target, producing a polarized recoil hyperon. Summed over both helicities of the incident electron beam the equation simplifies into:

$$\frac{d^2\sigma_v}{d\Omega_K^{CM}} = \sigma_0(1 + P_{x'}^0\hat{S}_{x'} + P_{y'}^0\hat{S}_{y'} + P_{z'}^0\hat{S}_{z'})$$

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$$ep \rightarrow e' K^+ \Lambda$$

$$\frac{d^2\sigma_v}{d\Omega_K^{CM}} = \sigma_0(1 + P^0_{x'}\hat{S}_{x'} + P^0_{y'}\hat{S}_{y'} + P^0_{z'}\hat{S}_{z'})$$

where the $P^0{}_j$ terms (with j = x' , y' , z') are the induced hyperon polarization components with respect to the primed coordinate system. If we express these components in terms of the response functions and we integrate over Φ we obtain

$$\mathcal{P}^0_{x'} = 0,$$
$$\mathcal{P}^0_{y'} = \frac{K}{\sigma_0}\left(R_T^{y'0} + \epsilon R_L^{y'0}\right)$$
$$\mathcal{P}^0_{z'} = 0.$$

We can extract the $P^0{}_j$ terms **from data** and compare them to these formal constraints exploiting the relationship:

$$\frac{dN}{d\cos\theta_p^{RF}} = N_0(1 + \alpha\mathcal{P}_j\cos\theta_p^{RF})$$

α=0.732

Where θ_p^{RF} is the angle between the spin quantization axis and the Λ decay proton in the Yperon rest frame

What do we want to measure?

Extraction of Lambda induced polarization in the electroproduction process

$$ep \to e' K^+ \Lambda$$

$$\frac{dN}{d\cos\theta_p^{RF}} = N_0(1 + \alpha \mathcal{P}_j \cos\theta_p^{RF})$$

The induced polarization for a given coordinate can be extracted by forming the forward-backward yield asymmetry with respect to cos $\theta^{RF}{}_{p}$ = 0.
Integrating from 0 to 1 (forward) and -1 to 0 (backward), gives the corresponding yields N^+ and N^- as:

$$N^+ = \int_0^1 N_0(1 + \alpha \mathcal{P}_j^0 \cos\theta_p^{RF}) d\cos\theta_p^{RF} = N_0 + N_0 \frac{\alpha \mathcal{P}_j^0}{2}$$

$$N^- = \int_{-1}^0 N_0(1 + \alpha \mathcal{P}_j \cos\theta_p^{RF}) d\cos\theta_p^{RF} = N_0 - N_0 \frac{\alpha \mathcal{P}_j^0}{2}.$$

The forward-backward yield asymmetry with respect to a given axis j, Aj , is then defined as

$$A_j = \frac{N^+ - N^-}{N^+ + N^-} = \frac{\alpha \mathcal{P}_j^0}{2}$$

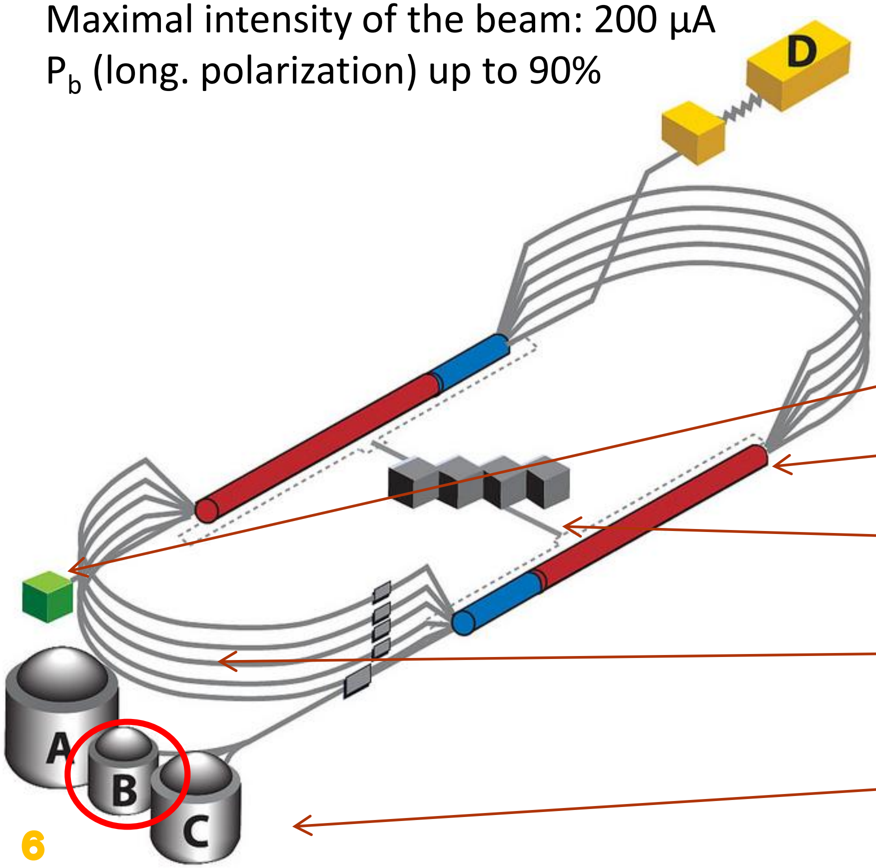
$$\mathcal{P}_j^0 = \frac{2A_j}{\alpha} = \frac{2}{\alpha} \cdot \frac{N^+ - N^-}{N^+ + N^-}$$

INDUCED POLARIZATION

Experimental Setup: CEBAF

Important parameters:

- Injector energy: 45 MeV
- Temporal separation of the bunches 0,7 ns
- 1200 MeV each loop
- Halls A, B, C receive a 11 GeV electron beam, Hall D a 12 GeV electron with a 2 ns time interval
- High work frequency: almost continuum beam
- Maximal intensity of the beam: 200 µA
- P_b (long. polarization) up to 90%



Components:

Injector

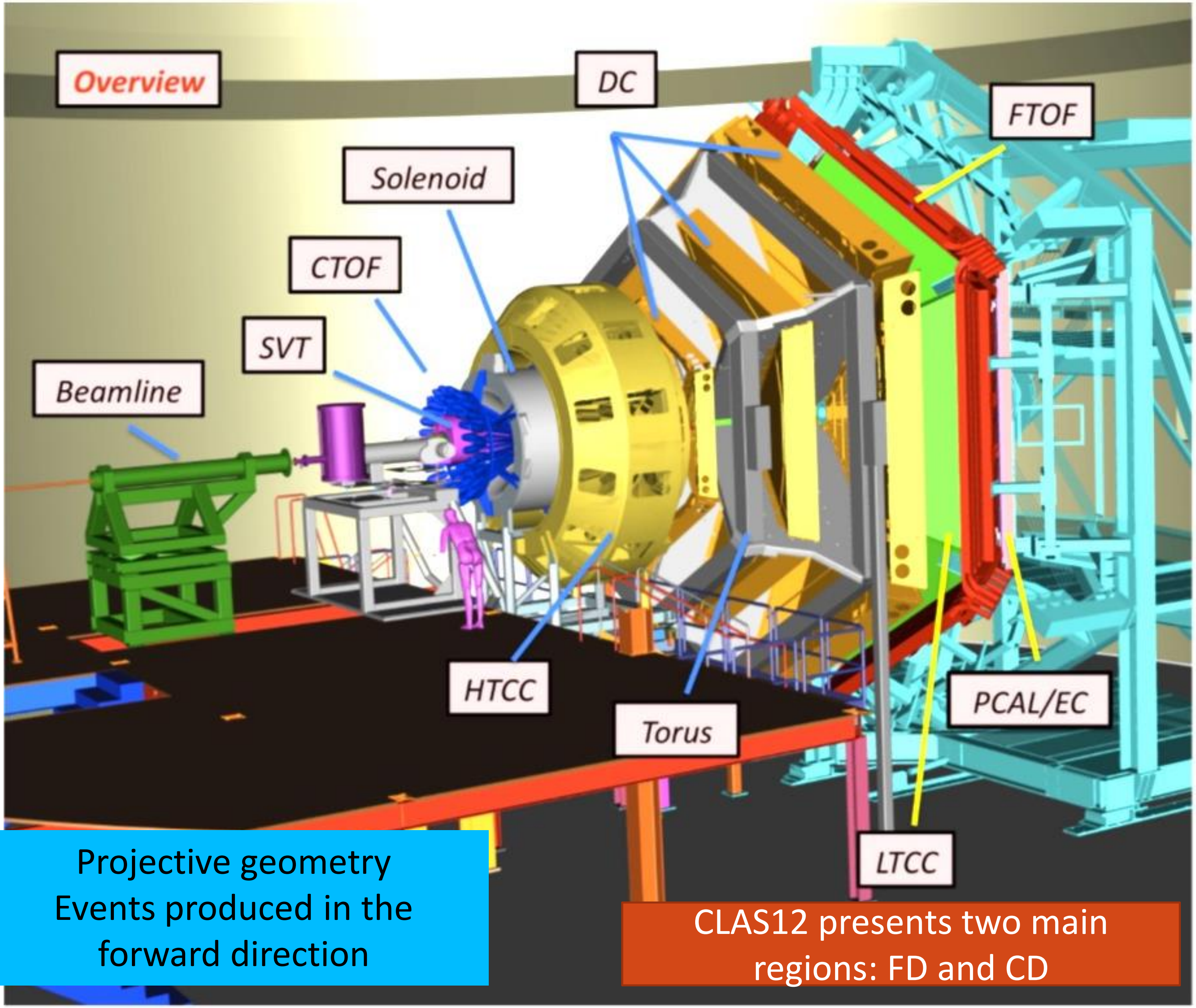
LINAC

Refrigeration plant

Magnets

Experimental Halls

Experimental Setup: CLAS12

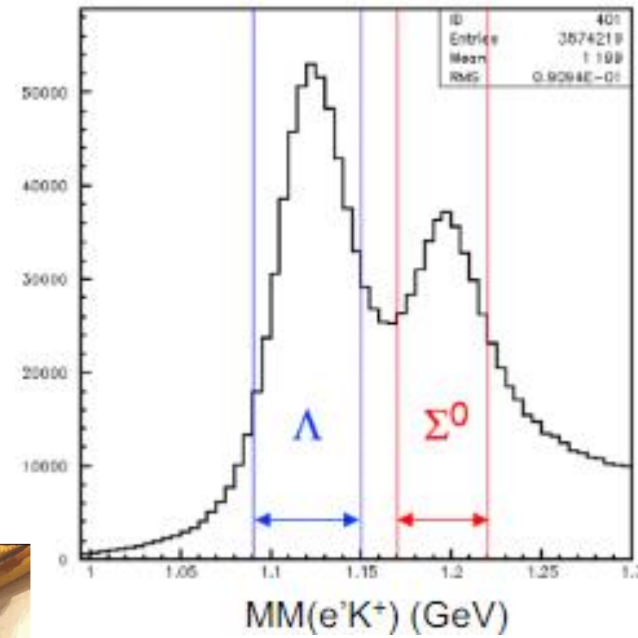


Projective geometry
Events produced in the forward direction

CLAS12 presents two main regions: FD and CD

Two experimental problems to solve

- The peak is very close to the Λ Yperon peak
- The acceptance effects have to be taken into account



CLAS12 can be divided in 2 regions: FORWARD (FD) and CENTRAL (CD)
Events reconstructed in the two regions must be «cleaned» differently

Topologies

The reconstructed final state for the hyperon polarization analysis required the detection of:

- the scattered electron,
- the electroproduced K+,
- the p from the hyperon decay.

The electron was required to be reconstructed in the ECAL. If we consider the FD and the CD separately, then the hadron reconstruction divides into four distinct topologies:

- K+ FORWARD pFORWARD
- K+ CENTRAL pFORWARD
- K+ FORWARD pCENTRAL
- ~~K+ CENTRAL pCENTRAL~~

Procedure employed for the analysis

- For each topology **customized cuts** are applied
- Events are divided according to kinematic variable value, forward and backward helicity
- To count the number of Lambda baryons for each bin a range of interest around the peak is selected
- The procedure is repeated for real data and simulated events
- The polarization is extracted

List of Cuts kFORWARD pFORWARD

- Final state with epK^+ (chi2pid < 5)
- Track status: abs(STATUS) = 2xxx (K,p)
- -0.02 $< MM^2$(epK) $<$ 0.08 GeV^2
- FWD K+: $\Delta T_{meas-calc}$
- FWD p: $\Delta T_{meas-calc}$
- $\frac{sampling\ fraction}{p} >$ mean - 3.5σ
- vertex -10<vz<1 (e^-, K^+)
- time cut, electron: 21 $<$ TOF $<$ 26 ns
- time cut, FWD K+: 20 $<$ TOF $<$ 35 ns
- time cut, FWD proton: 20 $<$ TOF $<$ 55 ns
- W>0
- FWD p, K+: 0.4 $\leq \beta \leq$ 1.1
- FWD p, K+: 0.4 $\leq$ p $\leq p_{beam}$
- π^- contamination removal: E_{ECin}/p $<$ -0.84 $\cdot E_{PCAL}/p_e$ + 0.17
- Fiducial cuts: electron U, V, W
- q != 0

List of Cuts KCENTRAL pFORWARD

- Final state with epK^+ (chi2pid $<$ 5)
- -0.02 $< MM^2$(epK) $<$ 0.08 GeV
- $\frac{sampling\_fraction}{p} >$ mean - 3.5σ
- vertex -10<vz<1 (e^-, K^+)
- Track status: abs(STATUS) $\geq$ 4000 (K)
- time cut, electron: 21 $<$ TOF $<$ 25 ns
- time cut, CTRL K+: 0.2 $<$ TOF $<$ 5 ns
- time cut, FWD proton: 20 $<$ TOF $<$ 50 ns
- W>0
- FWD p: 0.4 $\leq \beta \leq$ 1.1
- FWD p: 0.4 $\leq$ p $\leq p_{beam}$
- CTRL K+: 0.2 $\leq \beta \leq$ 1.1
- CTRL K+: 0.2 $\leq$ p $\leq$ 3
- π^- contamination removal: E_{ECin}/p $<$ -0.84 $\cdot E_{PCAL}/p_e$ + 0.17
- q != 0
- Fiducial Cuts

List of Cuts kFORWARDpCENTRAL

- Final state with epK^+ (chi2pid $<$ 5)
- -0.02 $<$ MM^2(epK) $<$ 0.08 GeV
- $\frac{sampling\ fraction}{p}$ $>$ mean - 3.5σ
- vertex -10$<$vz$<$1 (e^-, K^+)
- Track status: abs(STATUS) $\geq$ 4000 (p)
- time cut, electron: 21 $<$ TOF $<$ 25 ns
- Time cut, FWD K+: 0.2 $<$ TOF $<$ 5 ns
- Time cut, CTRL proton: 20 $<$ TOF $<$ 50 ns
- W$>$0
- FWD K+: $\Delta T_{meas-calc}$
- FWD K+: 0.4 $\leq \beta \leq$ 1.1
- FWD K+: 0.4 $\leq$ p $\leq$ p_{beam}
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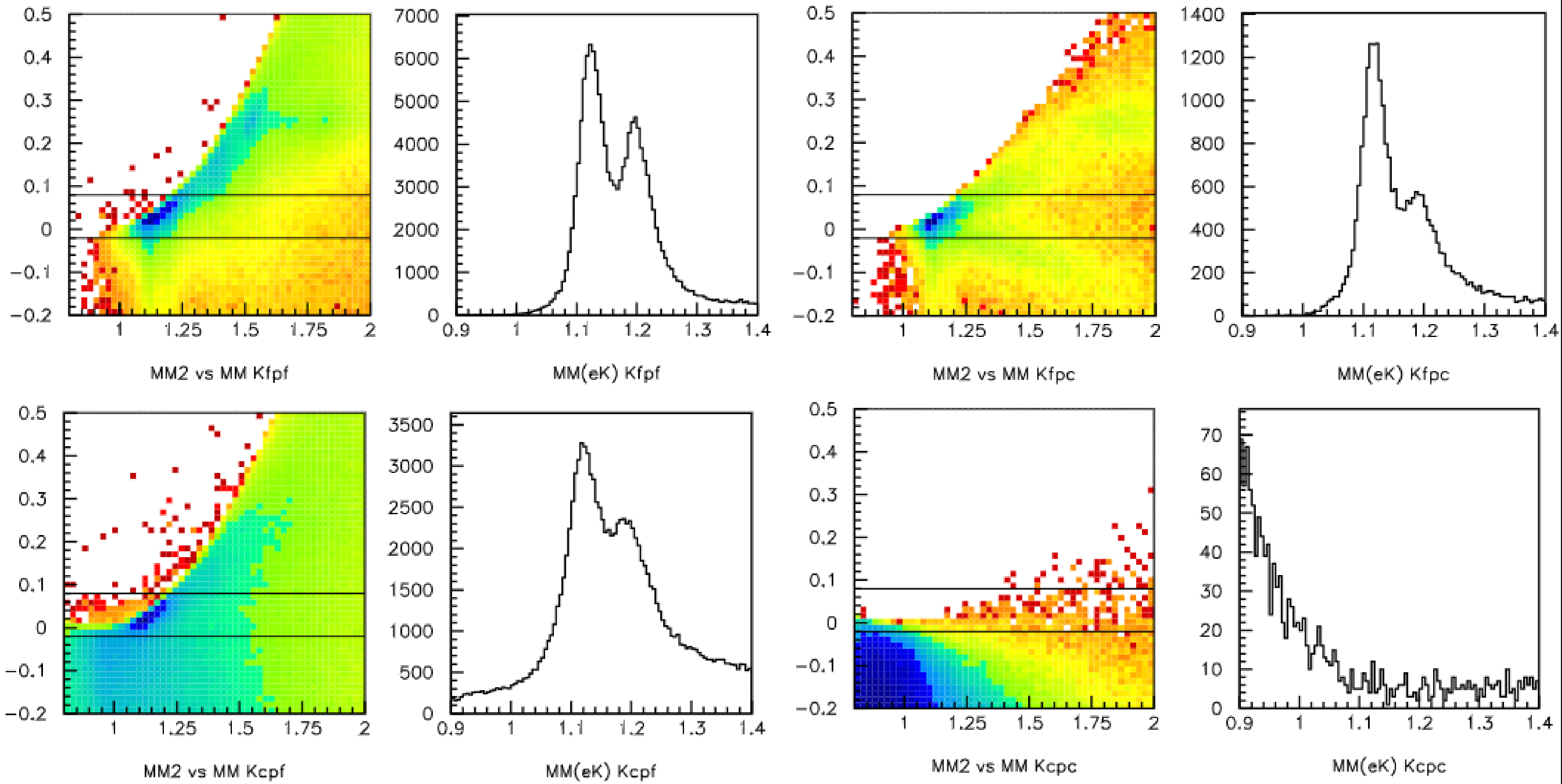
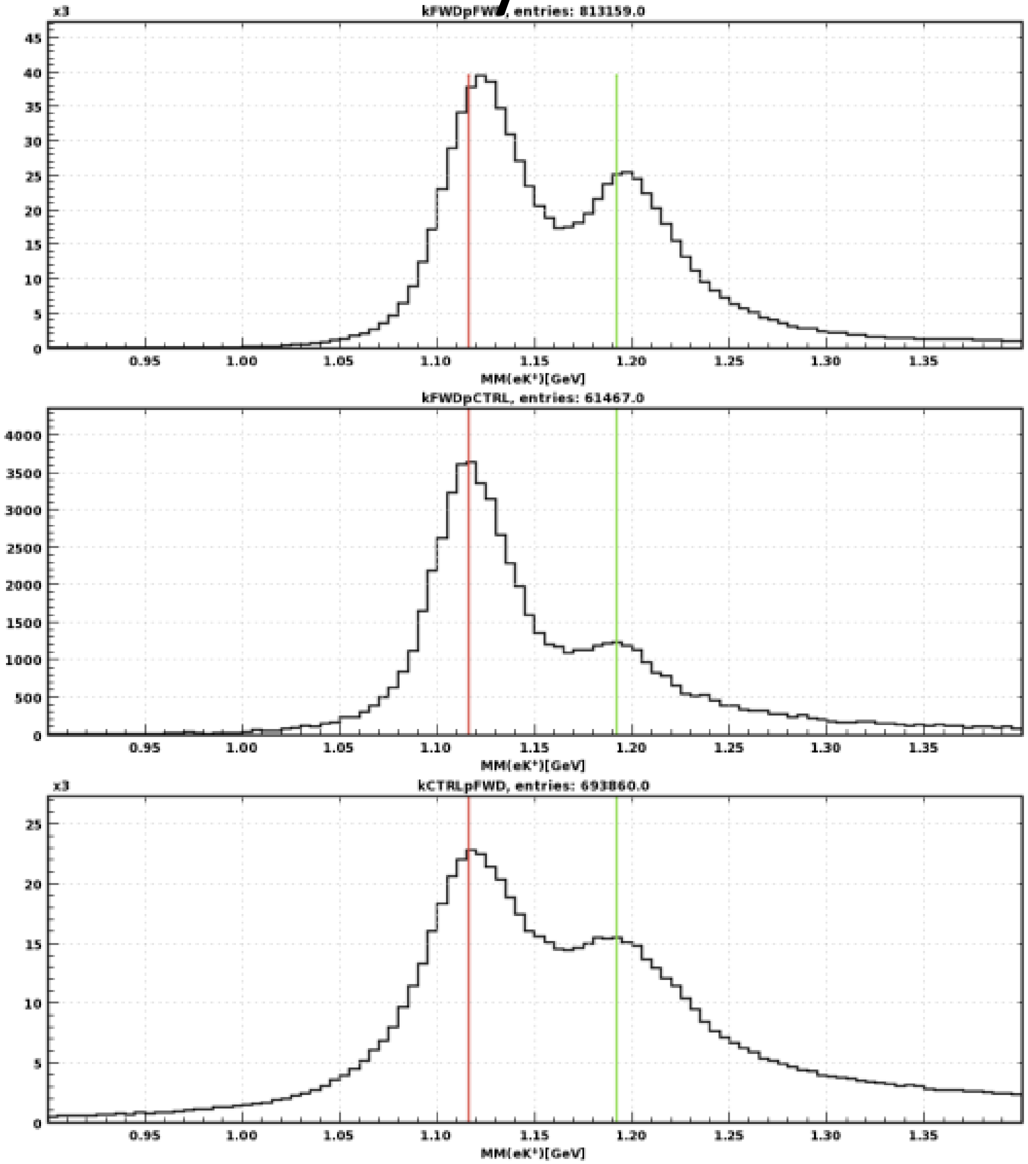
- CTRL p: 0.2 $\leq$ p $\leq$ 3
- π^- contamination removal: E_{ECin}/p $<$ -0.84 $\cdot E_{PCAL}/p_e$ + 0.17
- Fiducial Cuts
- q != 0

Events Selection – Example of Cut: MM2(eKp) vs. MM(eK)



Pass1 skim21 MM(eK) final datasets, induced polarization analysis



K FORWARD
P FORWARD

K FORWARD
P CENTRAL

K CENTRAL
P FORWARD

Example: Bin in Q^2, comparison of DATA and REC events

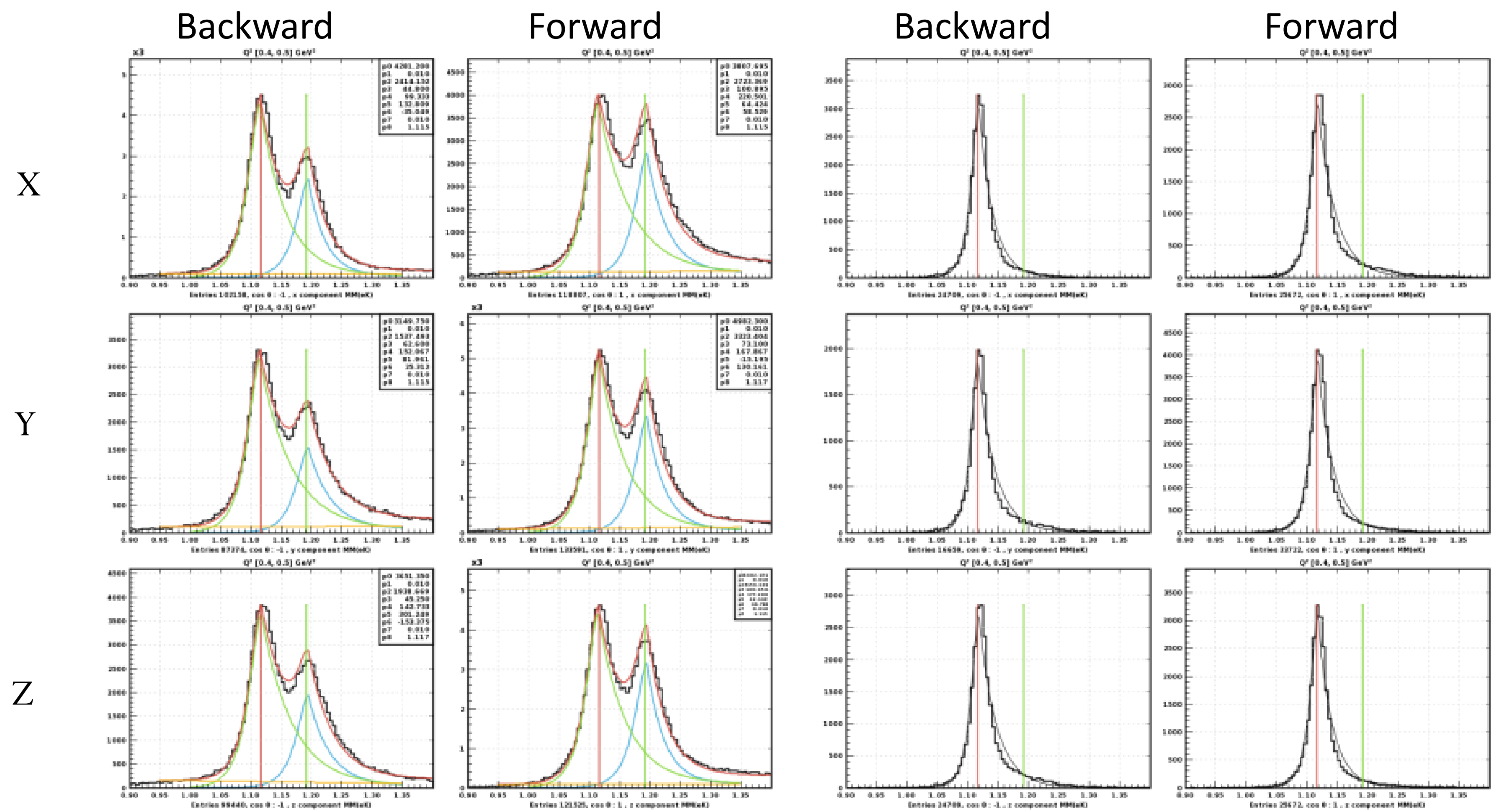


Figure: Left: DATA. Right: REC.

Acceptance correction – 6.5 GeV, primed system (x1, y1, z1)

To get the acceptance correction the number of Λ events for each bin of direction (FWD and BCK), component (x,y,z) and kinematic variable (Q^2, W, $\cos\theta^*_K$) is extracted. This procedure is repeated for the MC events and for the REC events. The factor N_{acc} is obtained from the ratio between $\frac{N_{REC}}{N_{MC}} = N_{acc}$.

$$\frac{N^+ - N^-}{N^+ + N^-} \rightarrow \frac{\frac{N^+}{N^+_{acc}} - \frac{N^-}{N^-_{acc}}}{\frac{N^+}{N^+_{acc}} + \frac{N^-}{N^-_{acc}}}$$

The event selection procedure is applied to DATA and REC events using the same code. Yields employed in this presentation are obtained using the Λ mass range (1.07-1.15 GeV) and the Σ one (1.15-1.23 GeV) - both DATA and REC.

Dataset Definition

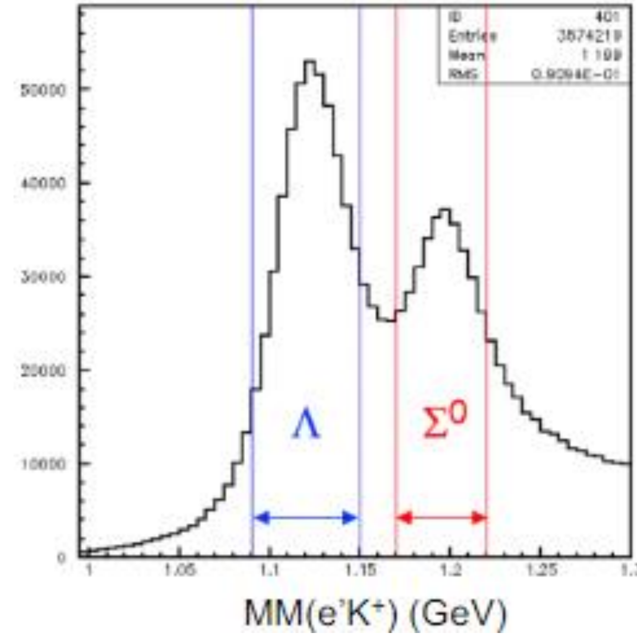
DATA: data without correction (black) $\frac{N^+ - N^-}{N^+ + N^-} = \frac{\nu_Y \alpha P_Y}{2}$ $\nu_Y = 1$, $\alpha = 0.732$

REC: simulations, reconstructed, REC::Particle bank (blue)

$$\frac{N^+_{REC} - N^-_{REC}}{N^+_{REC} + N^-_{REC}} = \frac{\nu_Y \alpha P_Y}{2}$$

MC: simulations, generated, MC::Particle (red)

$$\frac{N^+_{MC} - N^-_{MC}}{N^+_{MC} + N^-_{MC}} = \frac{\nu_Y \alpha P_Y}{2}$$

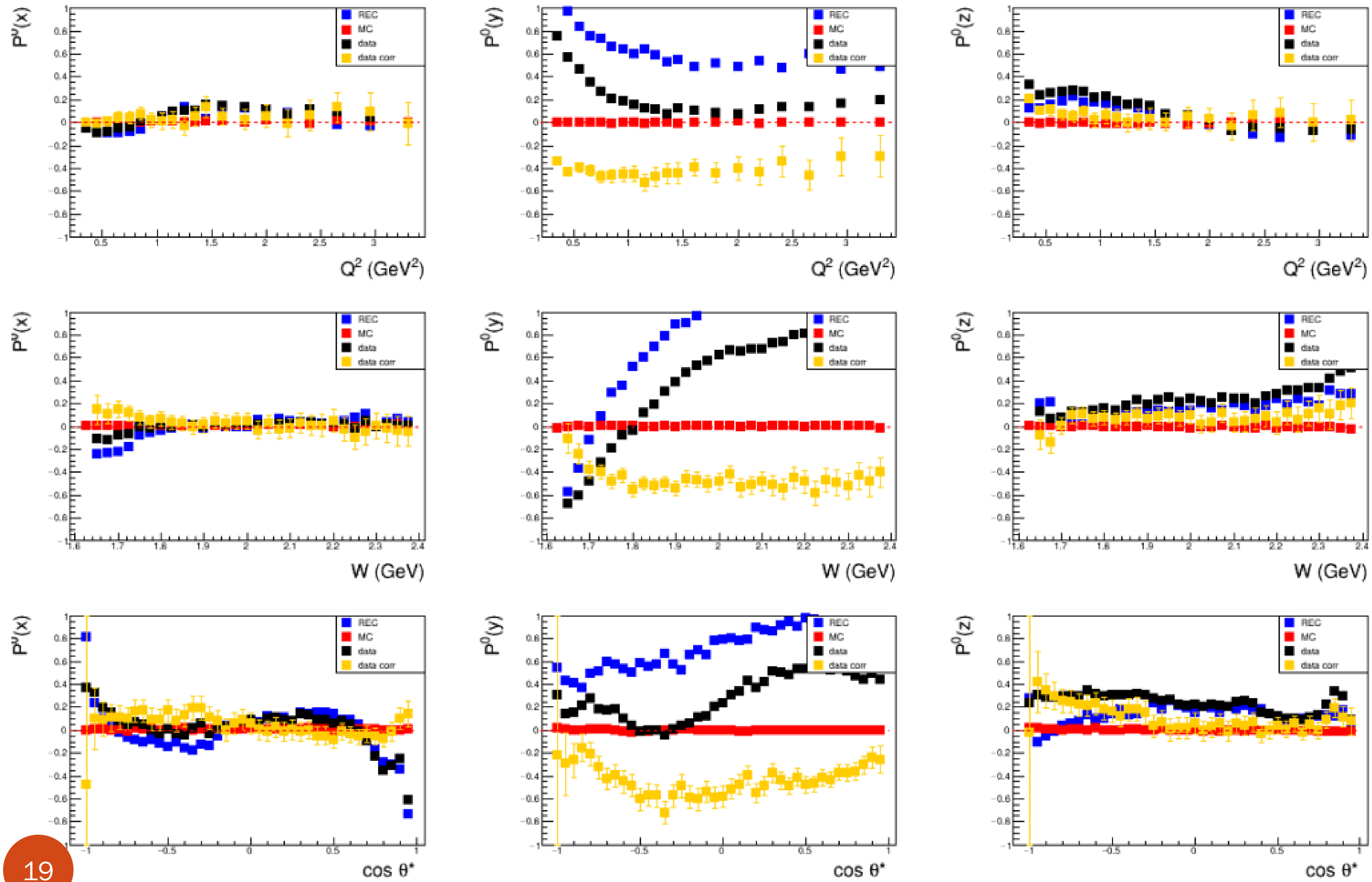


DATA CORR: data with acceptance correction applied (gold)

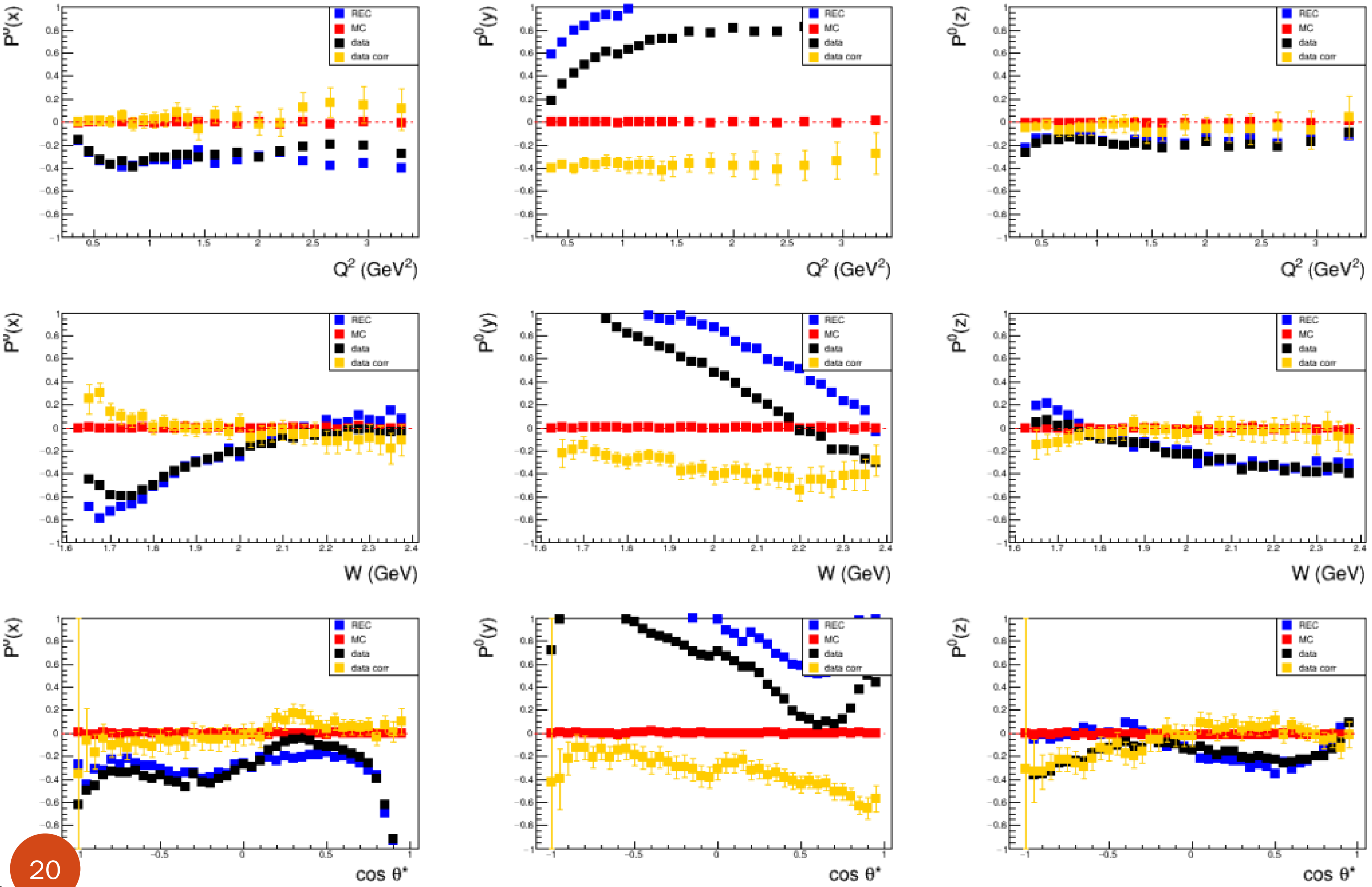
$$\frac{N_{REC}}{N_{MC}} = N_{acc} \quad \frac{\frac{N^+}{N^+_{acc}} - \frac{N^-}{N^-_{acc}}}{\frac{N^+}{N^+_{acc}} + \frac{N^-}{N^-_{acc}}} = \frac{\nu_Y \alpha P_Y}{2}$$

if $N^+_{MC} \equiv N^-_{MC} \Rightarrow \frac{\frac{N^+}{N^+_{REC}} - \frac{N^-}{N^-_{REC}}}{\frac{N^+}{N^+_{REC}} + \frac{N^-}{N^-_{REC}}} = \frac{\nu_Y \alpha P_Y}{2} \Rightarrow P_Y \gtreqless 0 \Leftrightarrow \frac{N^+}{N^+_{REC}} - \frac{N^-}{N^-_{REC}} \gtreqless 0 \Leftrightarrow N^+ \gtreqless \frac{N^+_{REC} N^-}{N^-_{REC}}$

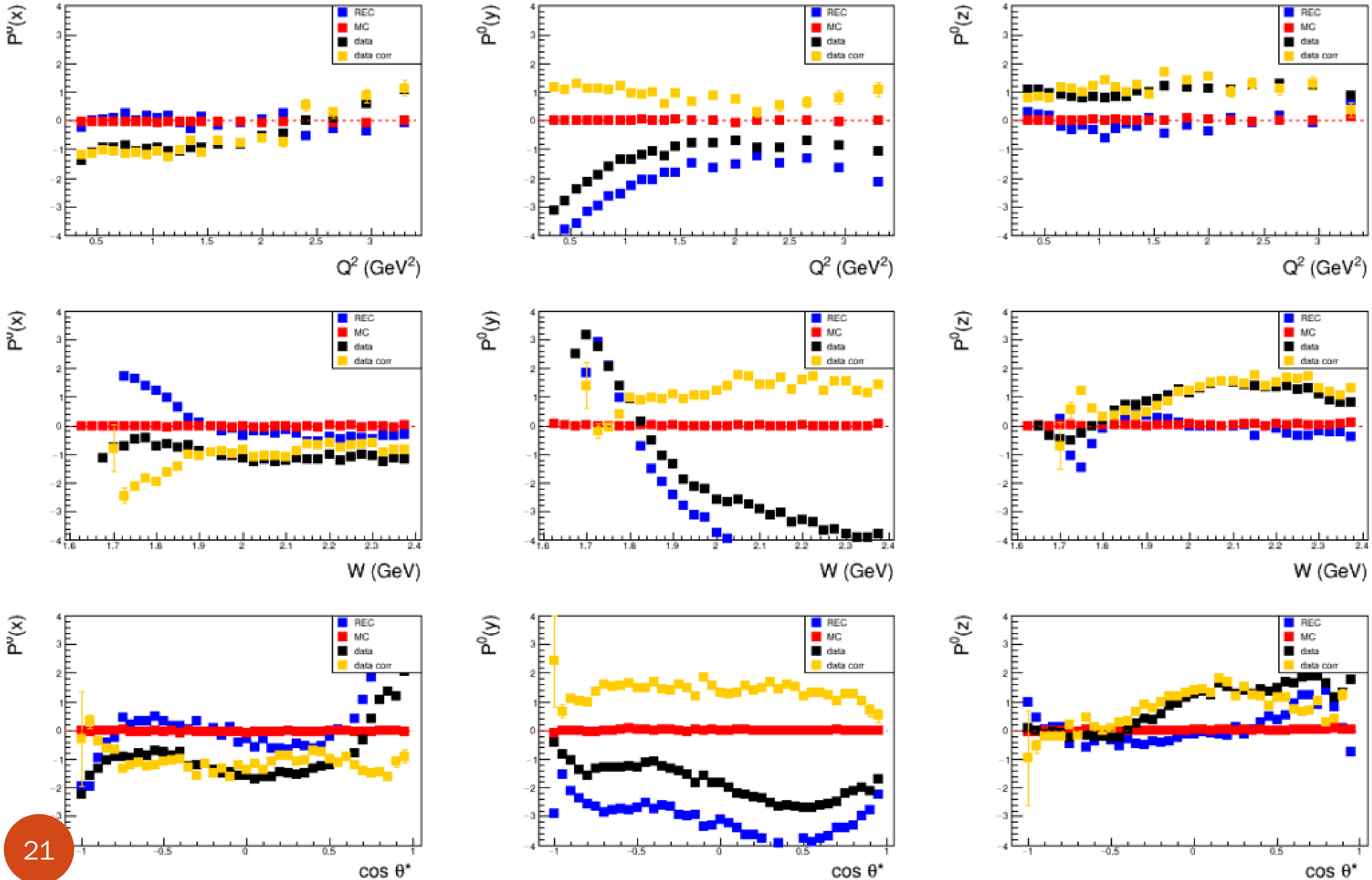
Λ induced polarization components, $P^0(x',y',z')$



Λ induced polarization components, $P^0(x,y,z)$



Σ induced polarization components, $P^0(x',y',z')$



Σ induced polarization components, $P^0(x,y,z)$