Exclusive ϕ electroproduction with CLAS12

Workshop on Vector Quarkonia and Pressure Gauges

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clas
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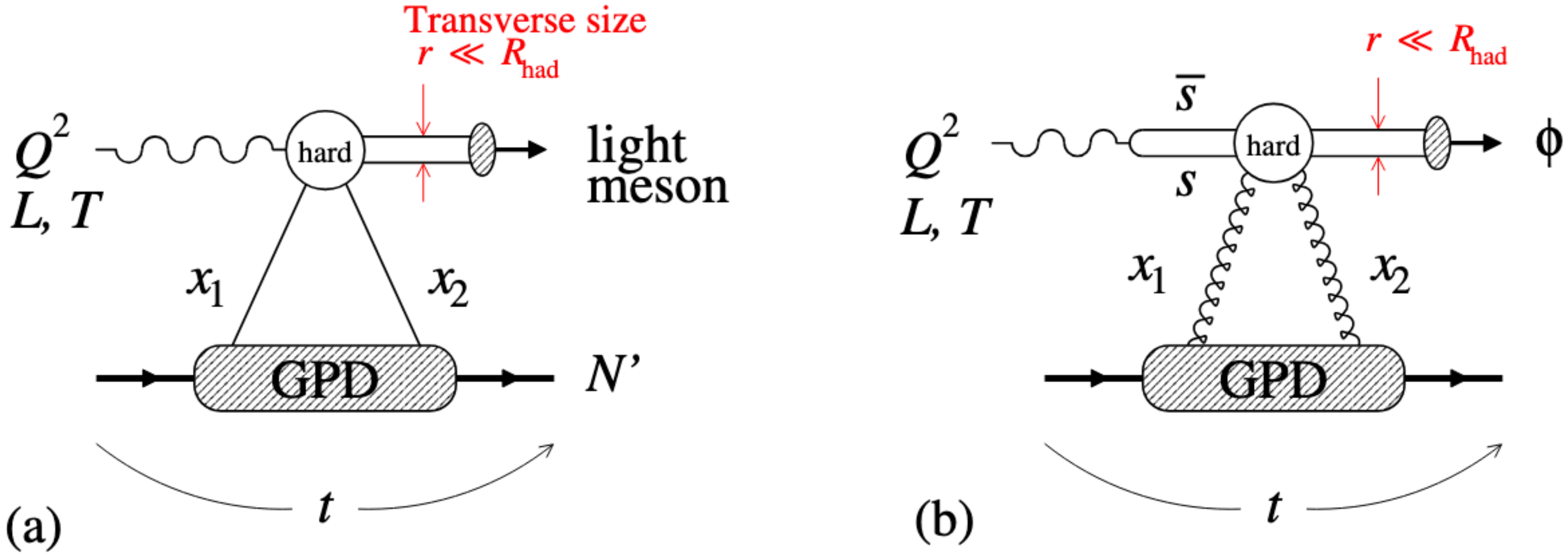
Clean Probe For Gluonic Structure of Nucleon

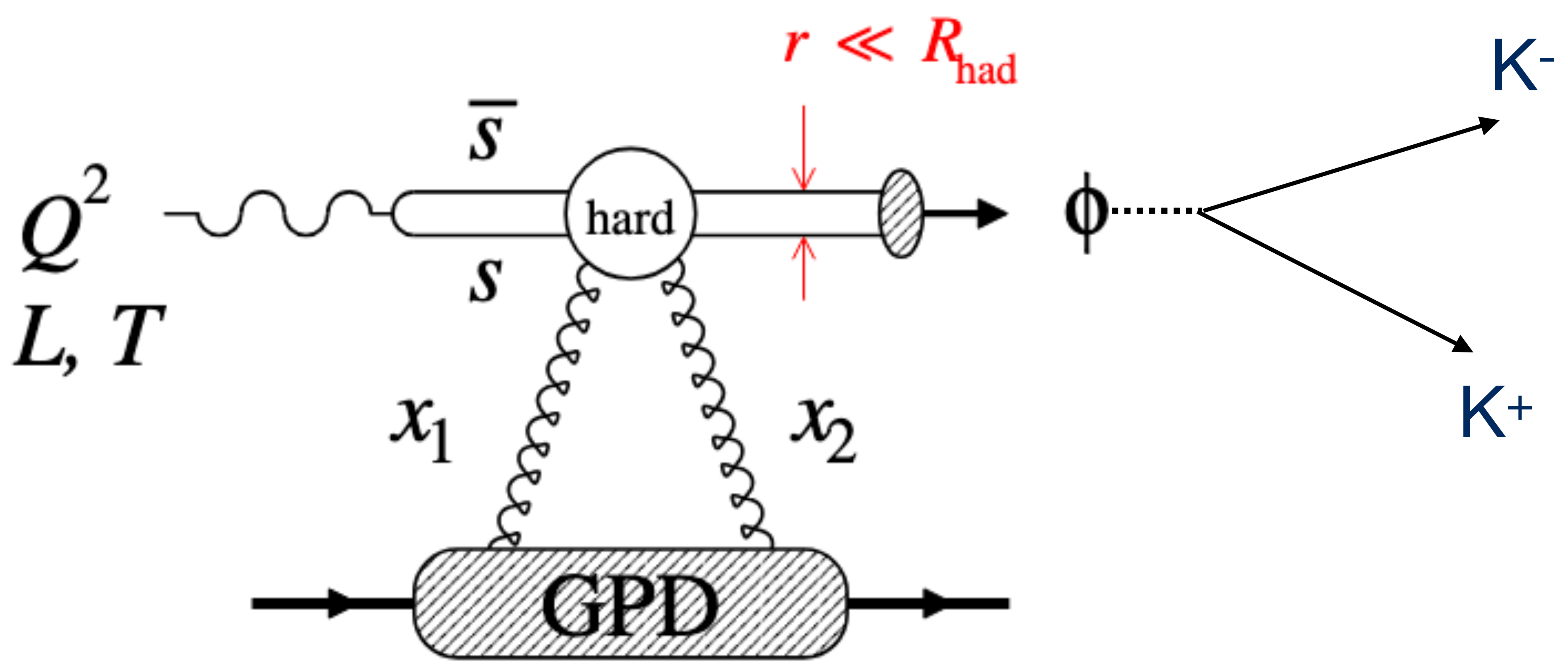
- ϕ meson a **pure $s\bar{s}$ state**, its coupling to light quarks (u,d) is suppressed (by OZI rule)
- Access to the gluon GPD even at low energy due to it's flavor content $s\bar{s}$

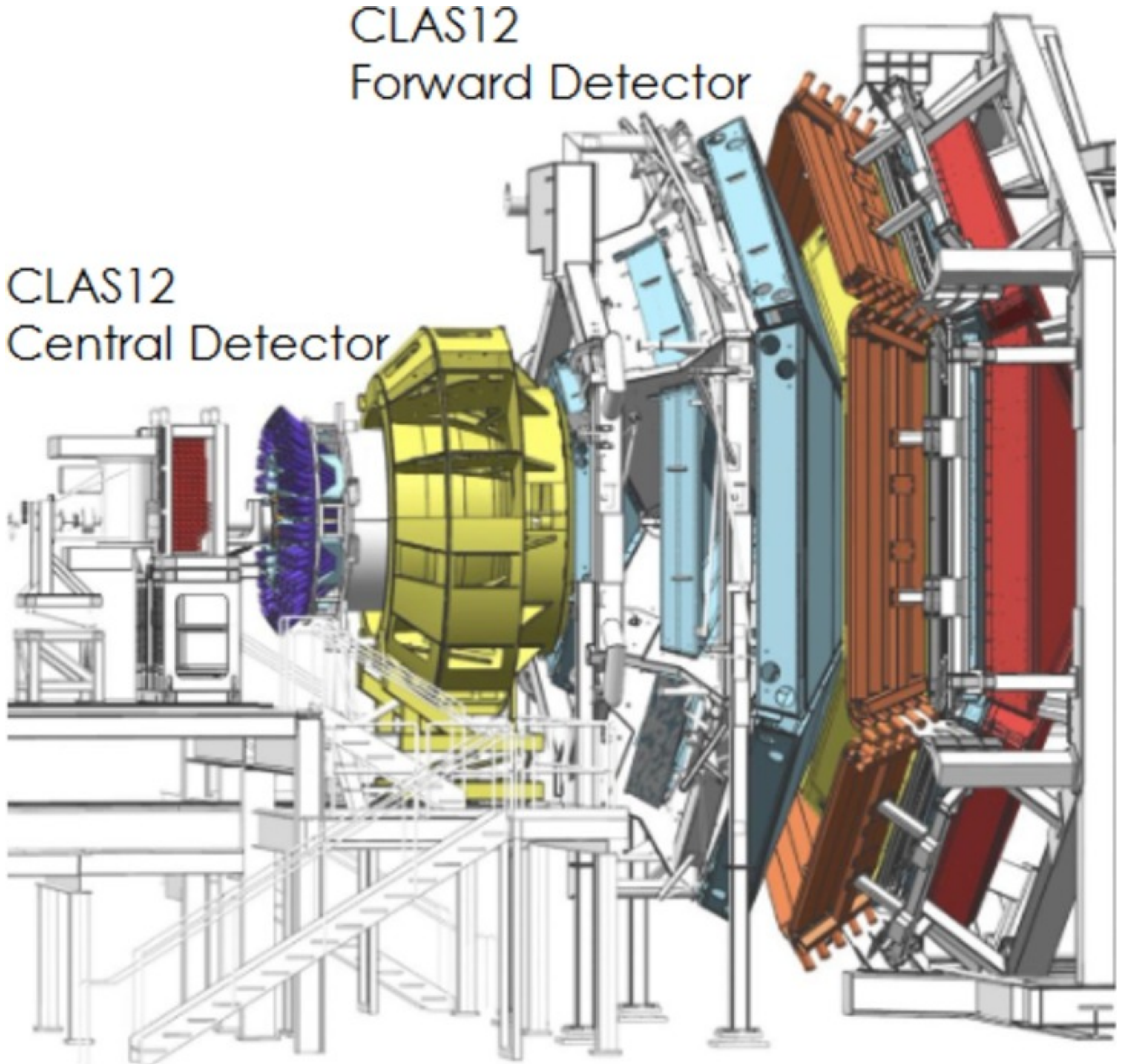


- Q^2 scaling of ϕ production cross section: opens doors to test **QCD factorization** ($\sigma_L \sim 1/Q^6$, $\sigma_L/\sigma_T \sim Q^2$)
- Change of |t|–dependence with Q^2 ➡ **gluonic radius** of the proton
- Search for **near-threshold effects** linked to intrinsic ss̄ pairs

Exclusive ϕ production with proton target

- Beam energy 10.6 GeV dependent production from data sets collection during **2018-19**
- Analysis strategy: select charge decay daughter ep—> e'p'K^+ K^- (branching ratio: ~49.2%)





R. Tyson et al, Comp. Phys. Com., 290, 108783, (2023)

- **Forward Detector (FD)** covers the range of polar angles from 5 to 35 degrees segmented into 6 sectors in azimuthal angle
- **Central Detector (CD)** covers the range of polar angles from 35 to 125 degrees
- Electron selected in only FD while protons and Kaons are selected in both CD and FD

Particle Kinematics (exclusive reaction)

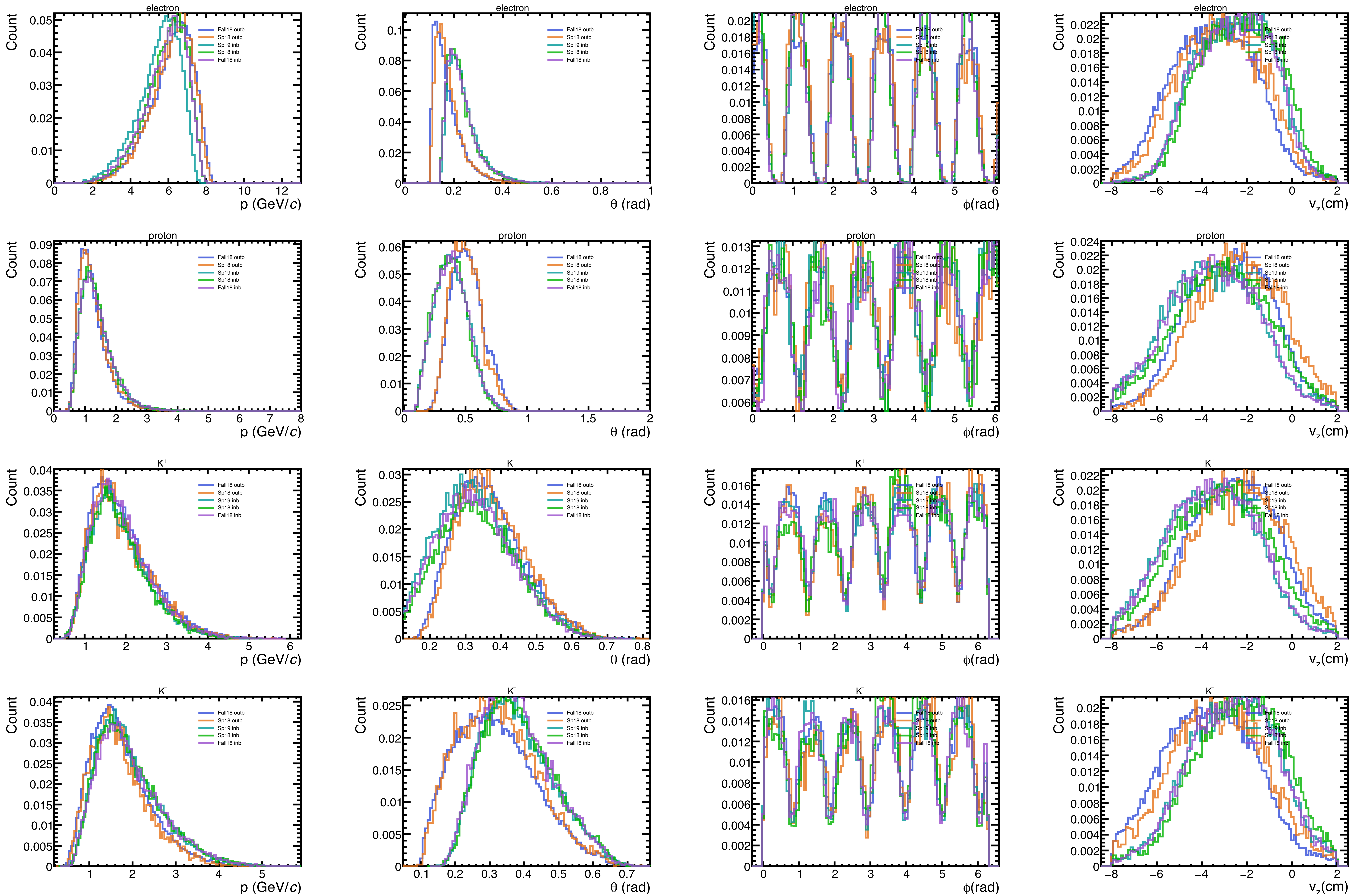
- **Datasets** from Run group A (10.6 & 10.2 GeV beam)
- Torus -1 (inbending) Spring & Fall 2018, and Spring 2019
- Torus+1 (outbending) Spring & Fall 2018

Fall18 outb
Sp18 outb
Sp19 inb
Sp18 inb
Fall18 inb

- Minimum cuts

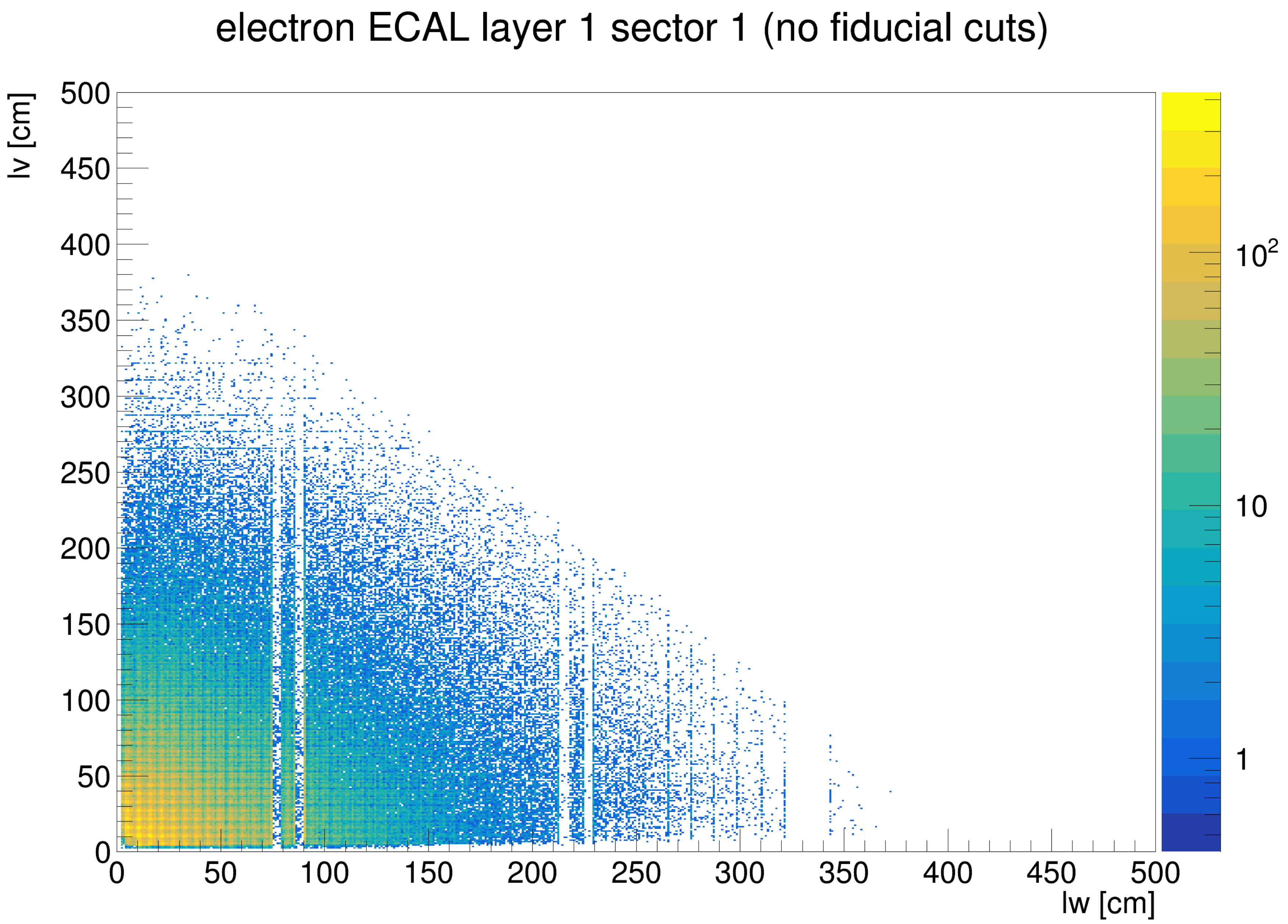
p_e>1.5 GeV in FD
p_p>.4 GeV in FD and CD

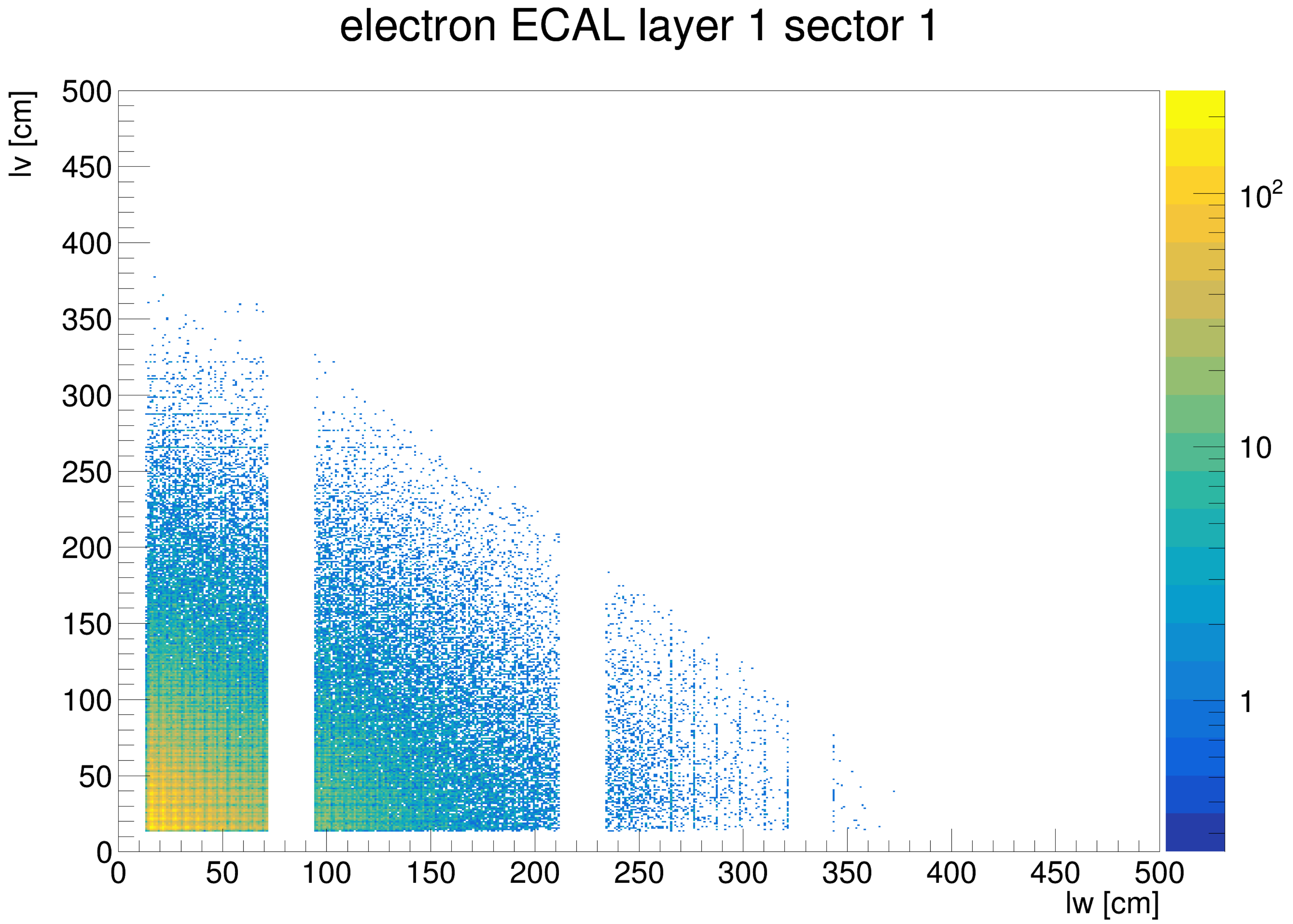
0.2<p_K>7.5 GeV in FD
Vertex for all particles
-8cm < v_z< 2 cm



Fiducial volume for electron and hadrons

- **FD**, and **CD** regions with possible reconstruction inefficiencies are removed.





- In the Calorimeter, the edge cuts (lv, lu, and lw) are applied to remove the inefficient regions (all sectors!) in the $ECAL_{in}$ and $ECAL_{out}$

Fiducial volume for electron and hadrons

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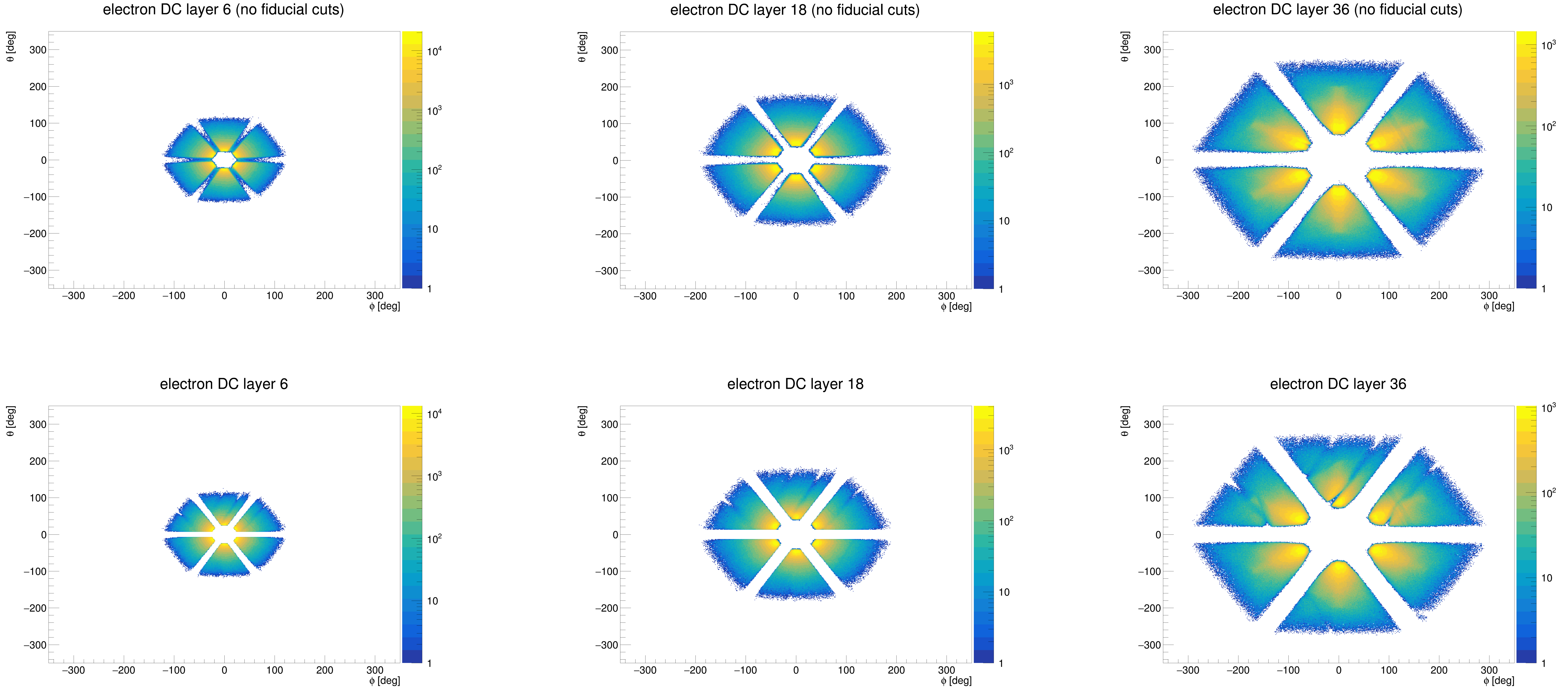

- The inefficient regions in the DC regions for electron protons and Kaons are removed from

- Similarly for Central Vertex Tracker the small regions in layers 1, 3, 5, 7, and 12 are removed

- Sampling fraction cuts for electron, and energy loss corrections for proton are applied.

Exclusivity cuts for further refinements

- Exclusivity variables are prior to phi mass peak cut
- Exclusivity cuts

$E_{miss} \in [-0.0075, 0.32]$ GeV
$P_{Tmiss} < 0.12$ GeV
$Mx^2\,(eK^+K^-)$
$\in [0.64, 1.1664]$ GeV^2
$Mx^2\,(epK^+K^-) < 0.0075$ GeV^2
$Mx^2\,(epK^-) \in [0.08, 0.48]$ GeV^2
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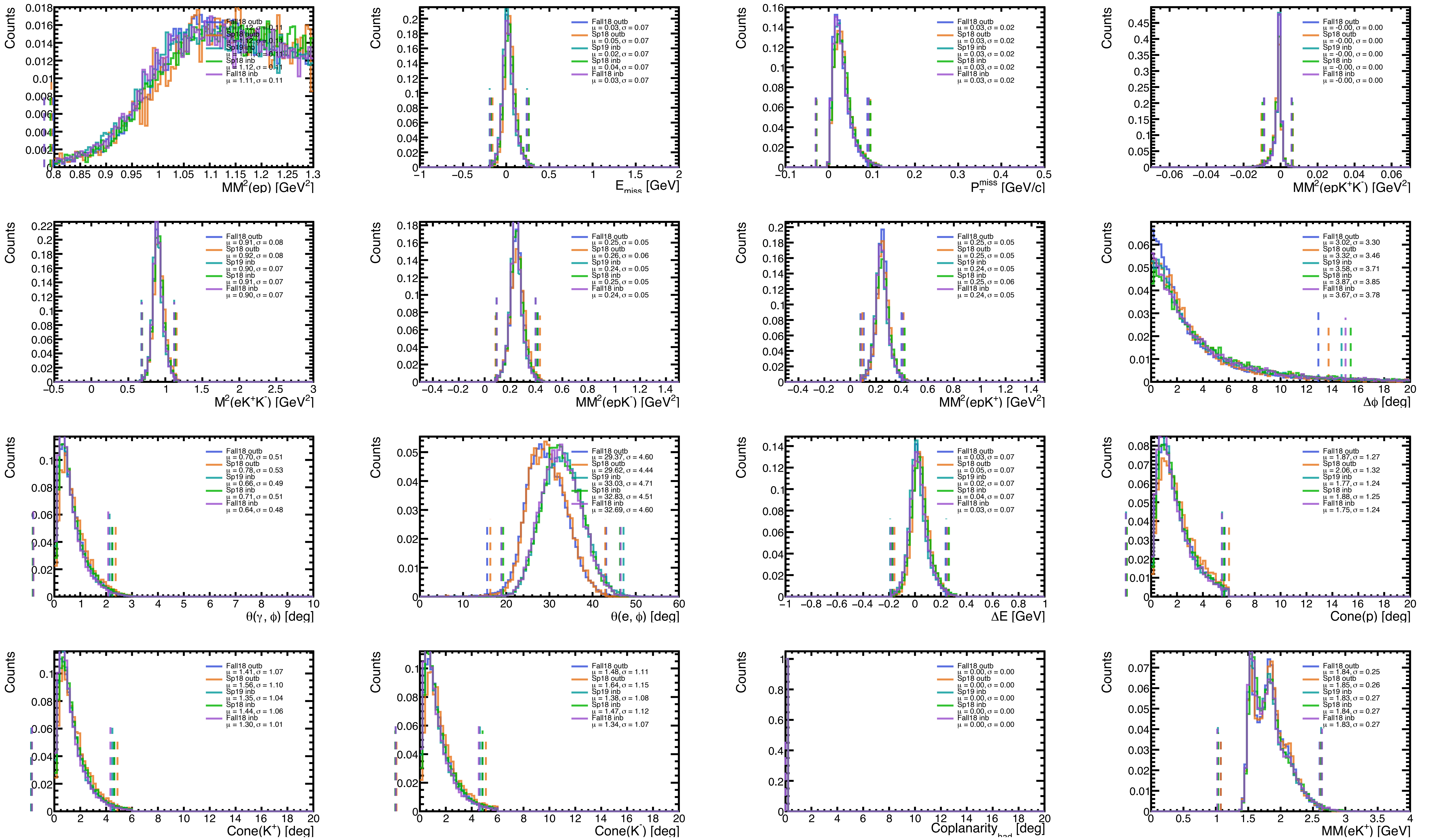
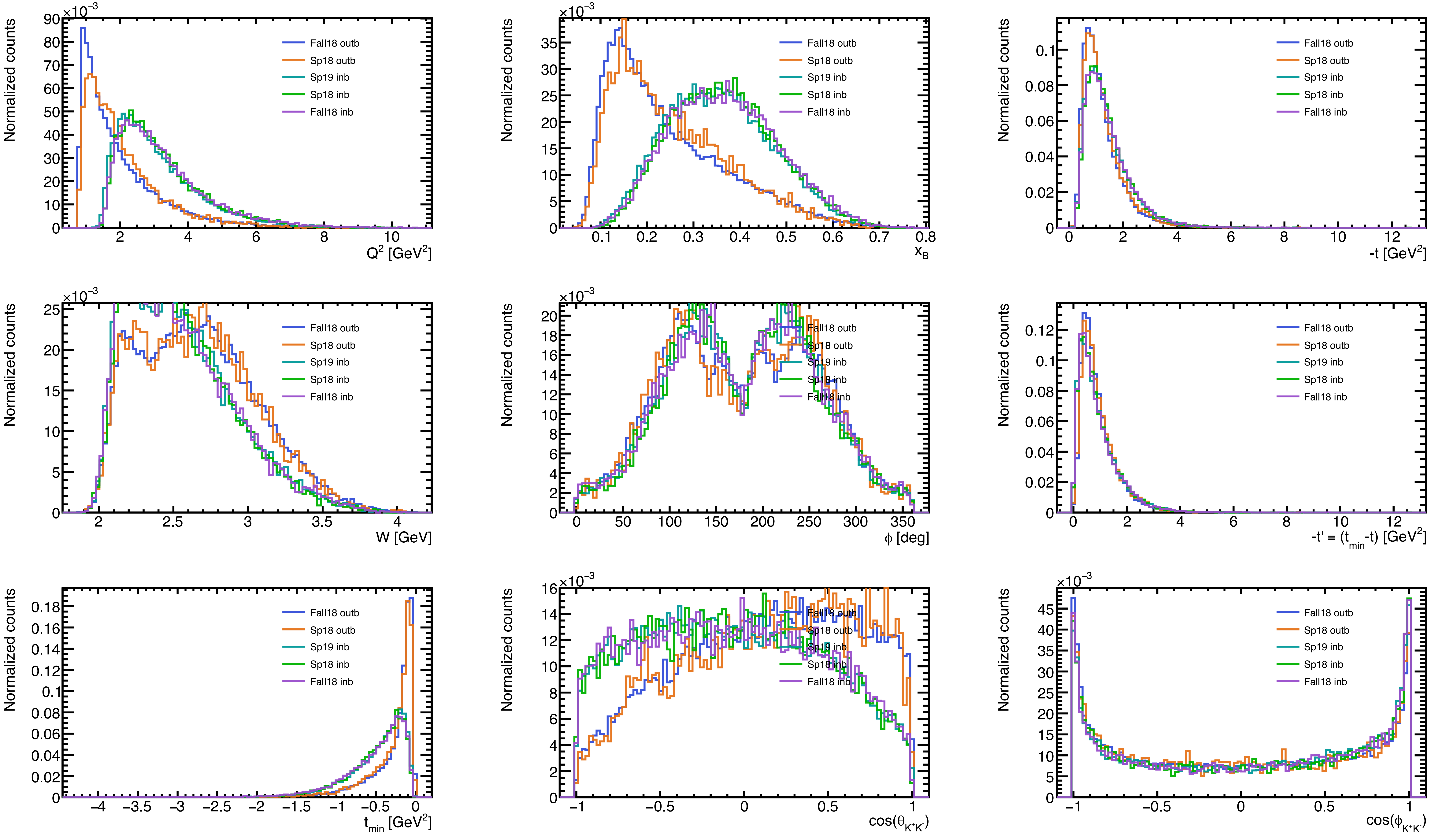
coplanarity < 15 degrees



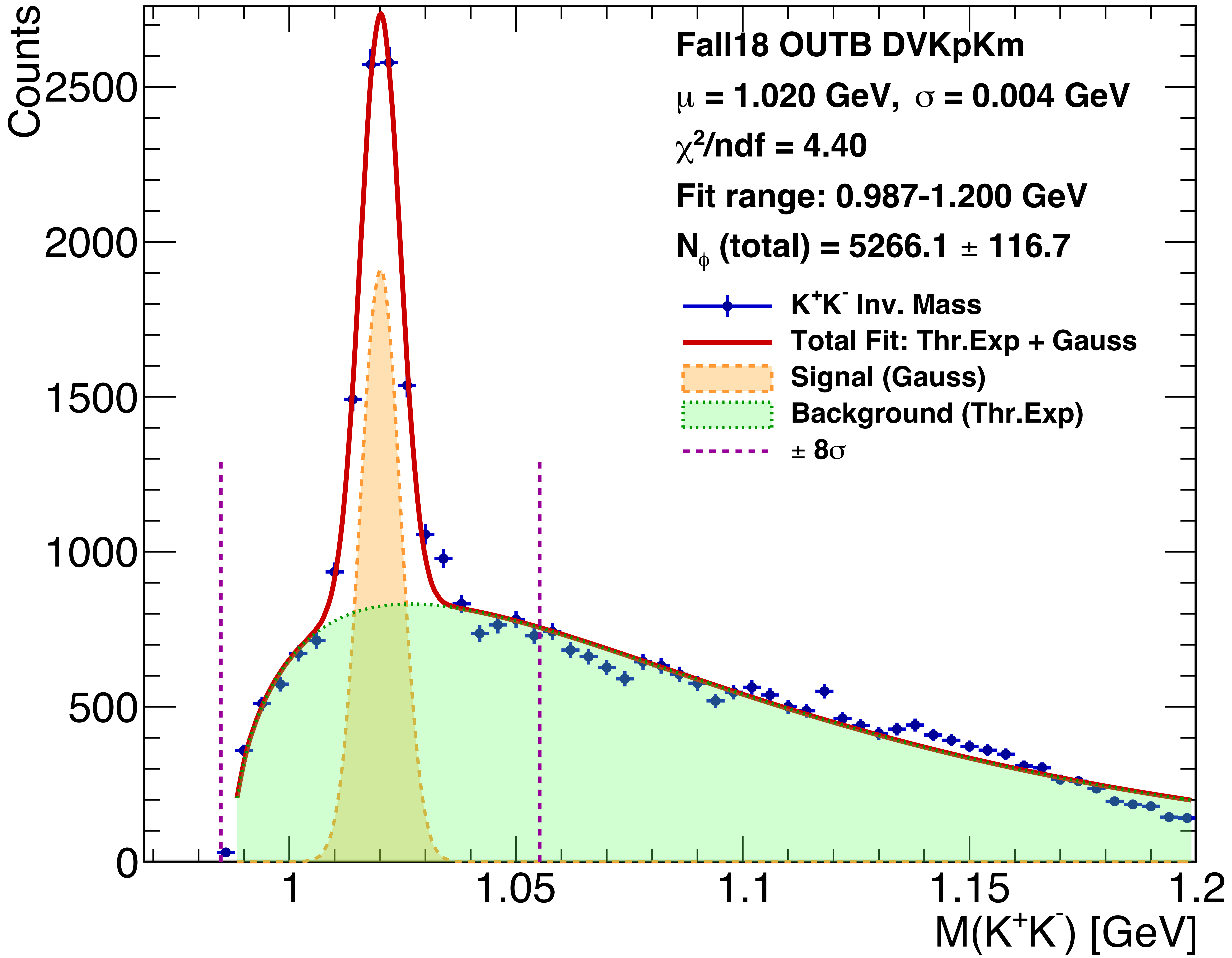
DVEP Kinematic variables

- Energy loss correction for proton and $W > 1.8$ GeV and $Q^2 > 0.2$ GeV^2



K^+K^- Invariant Mass Distributions

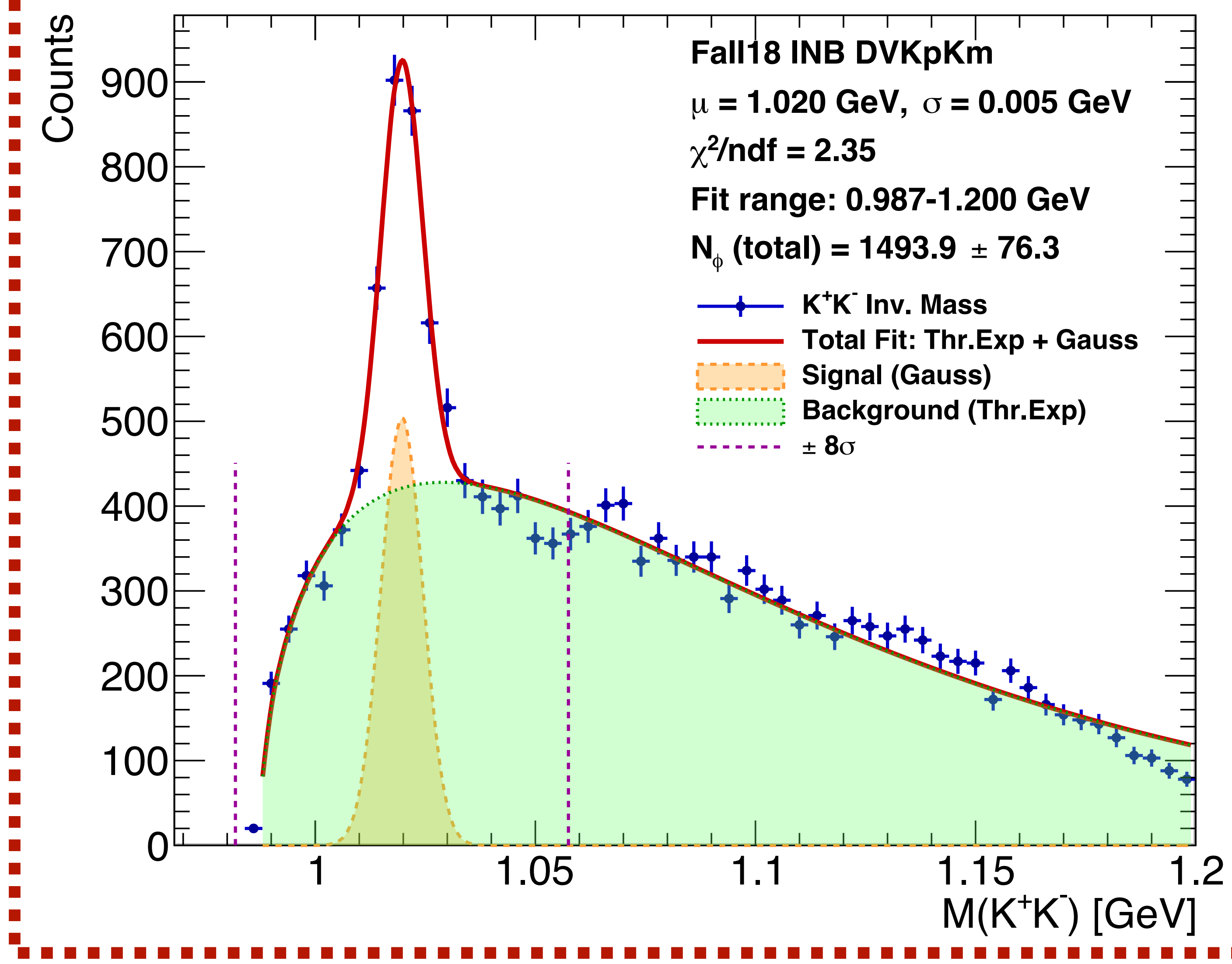
- ϕ candidate counts from the invariant mass peak at ~1.019 GeV of K^+K^-in $ep \to epK^+K^-$
- Signal: Gaussian distribution
- Background: Exponential+polynomial 3rd order
- Extracted yield as integral of the Gaussian function
- Exclusive selection: ~**5200** candidates from fall 2018 outb alone

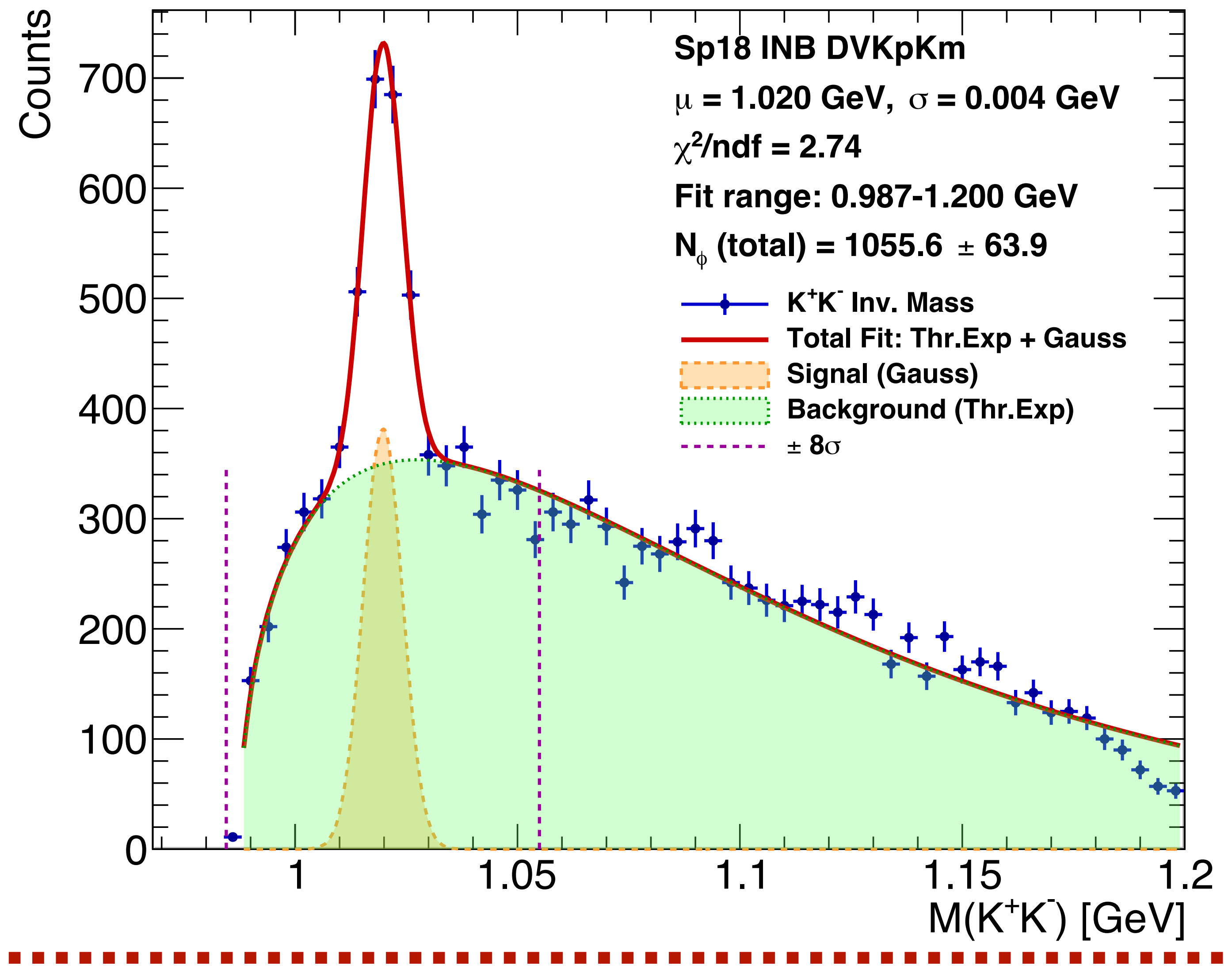


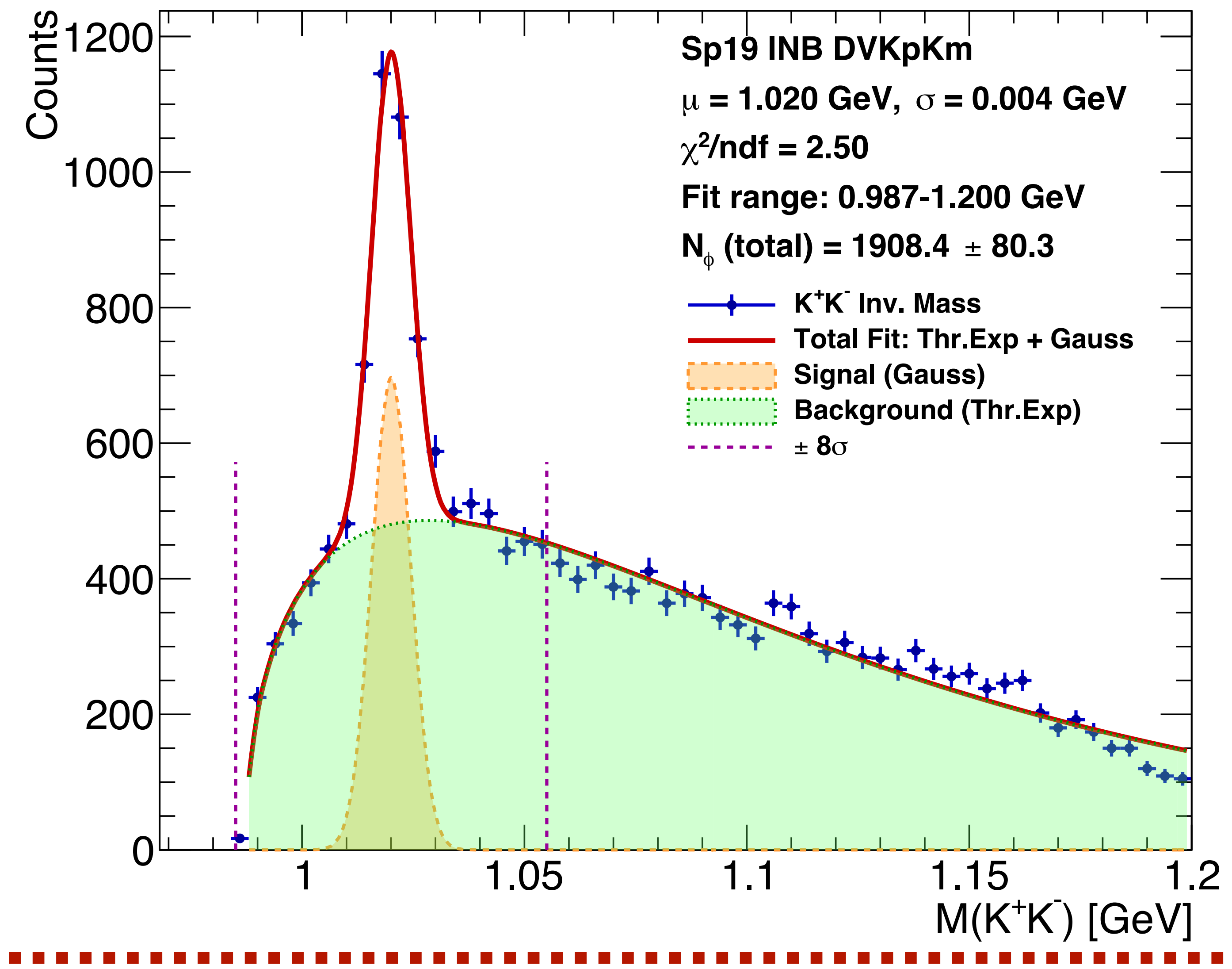
All phi K+K- Invariant Mass all periods of 2018-19 run

- ϕ peak at ~1020 MeV, total ~**10000** candidates from 2018-19 Run group A datasets

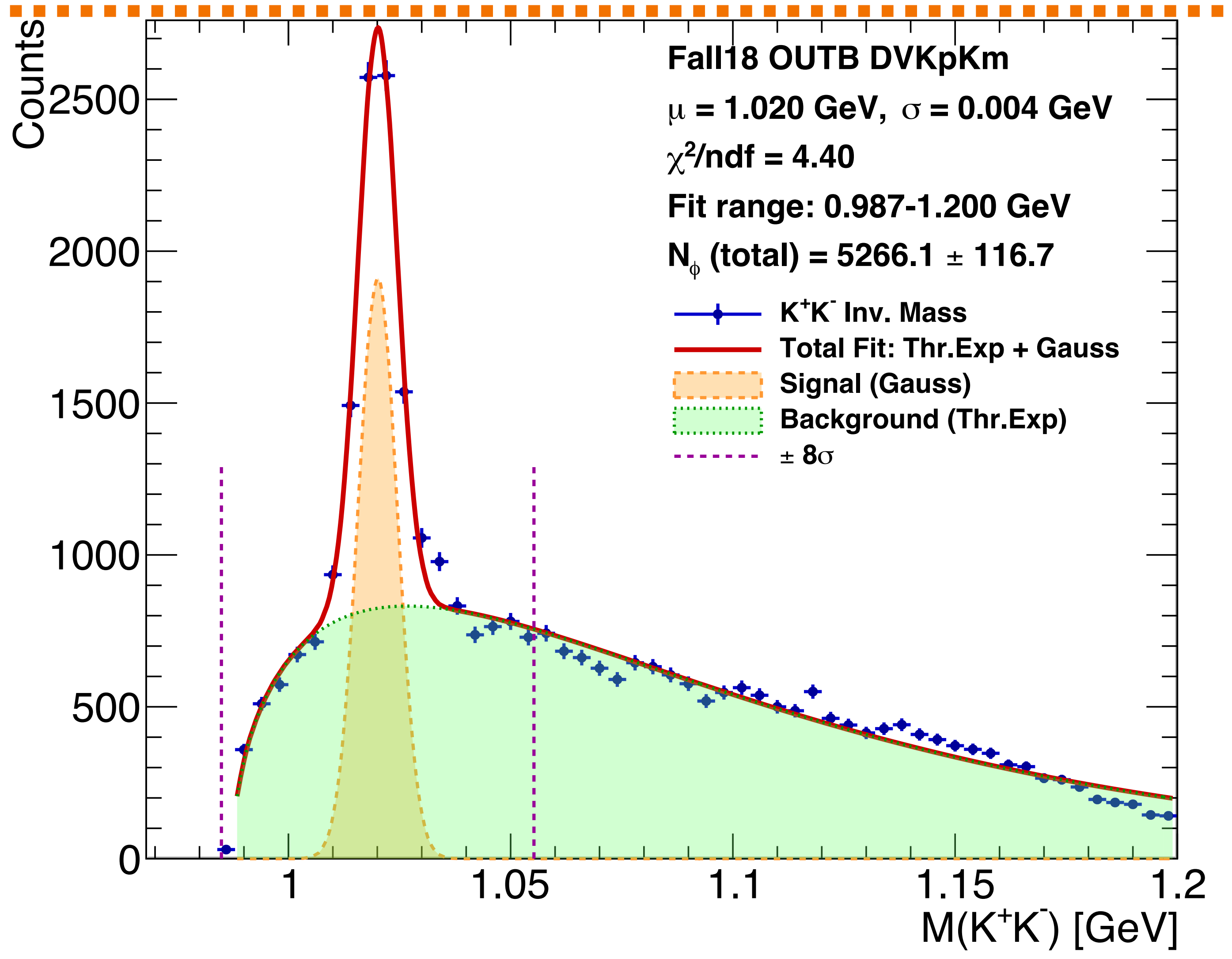
Inb

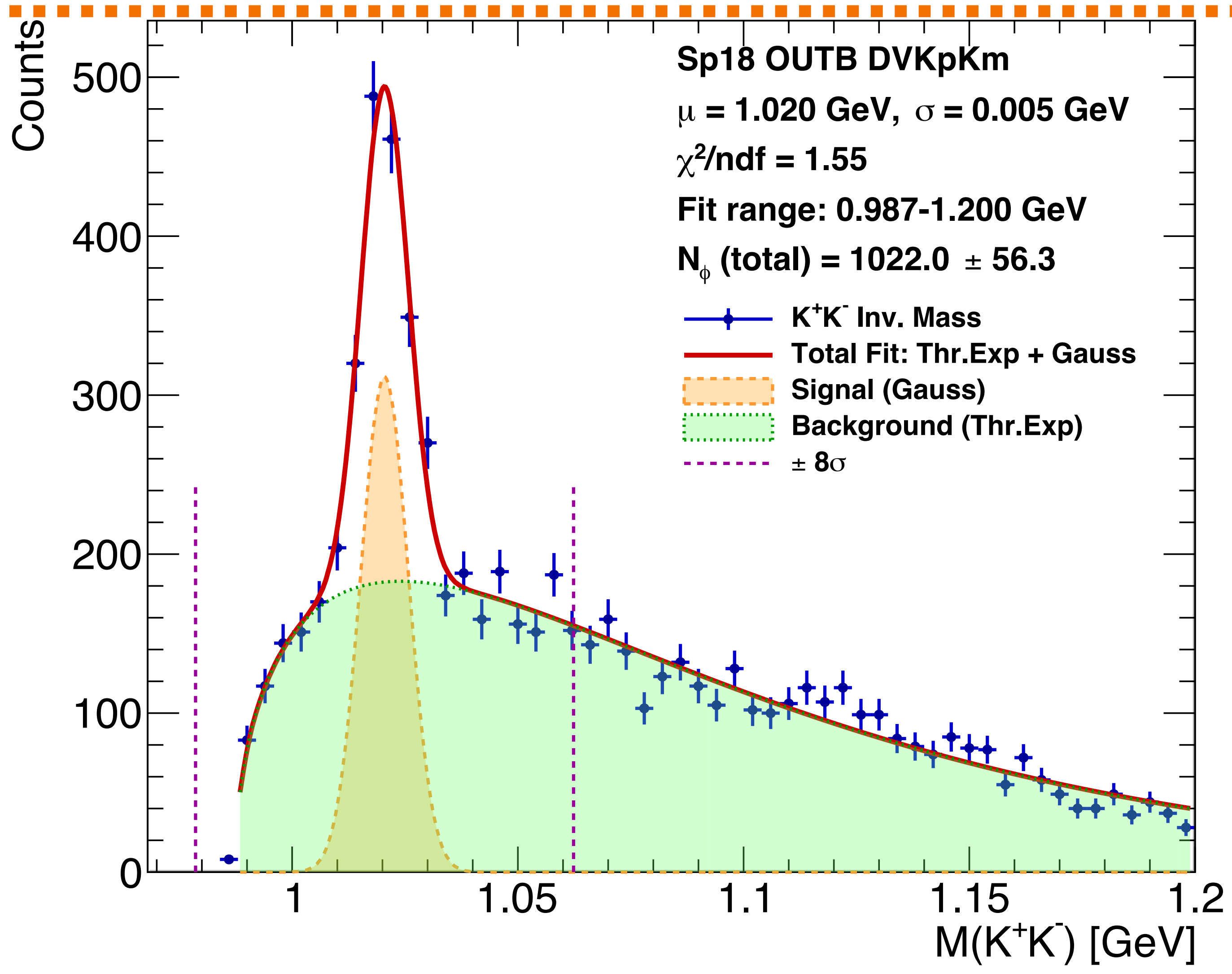






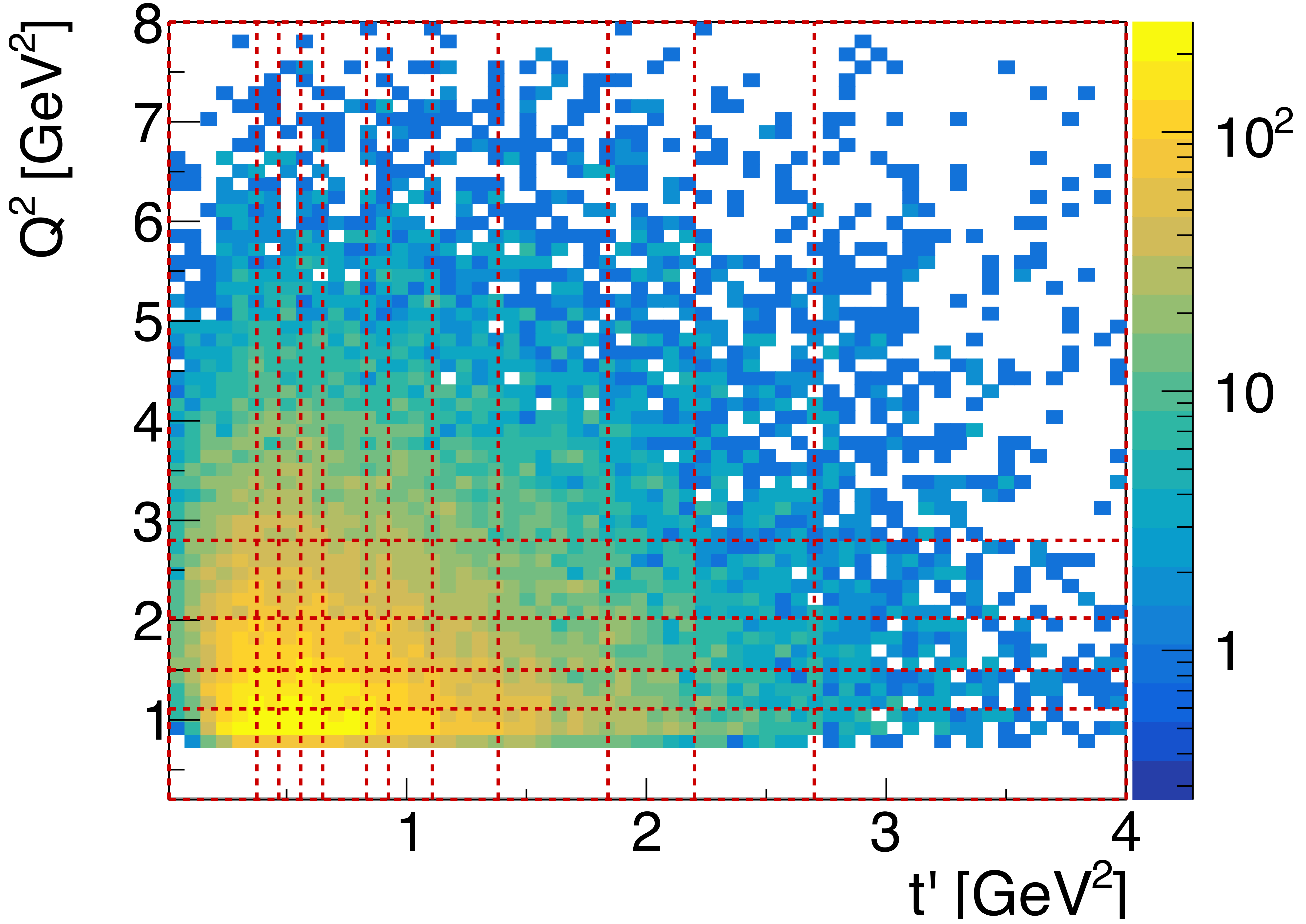
Outb





Extraction of cross-section

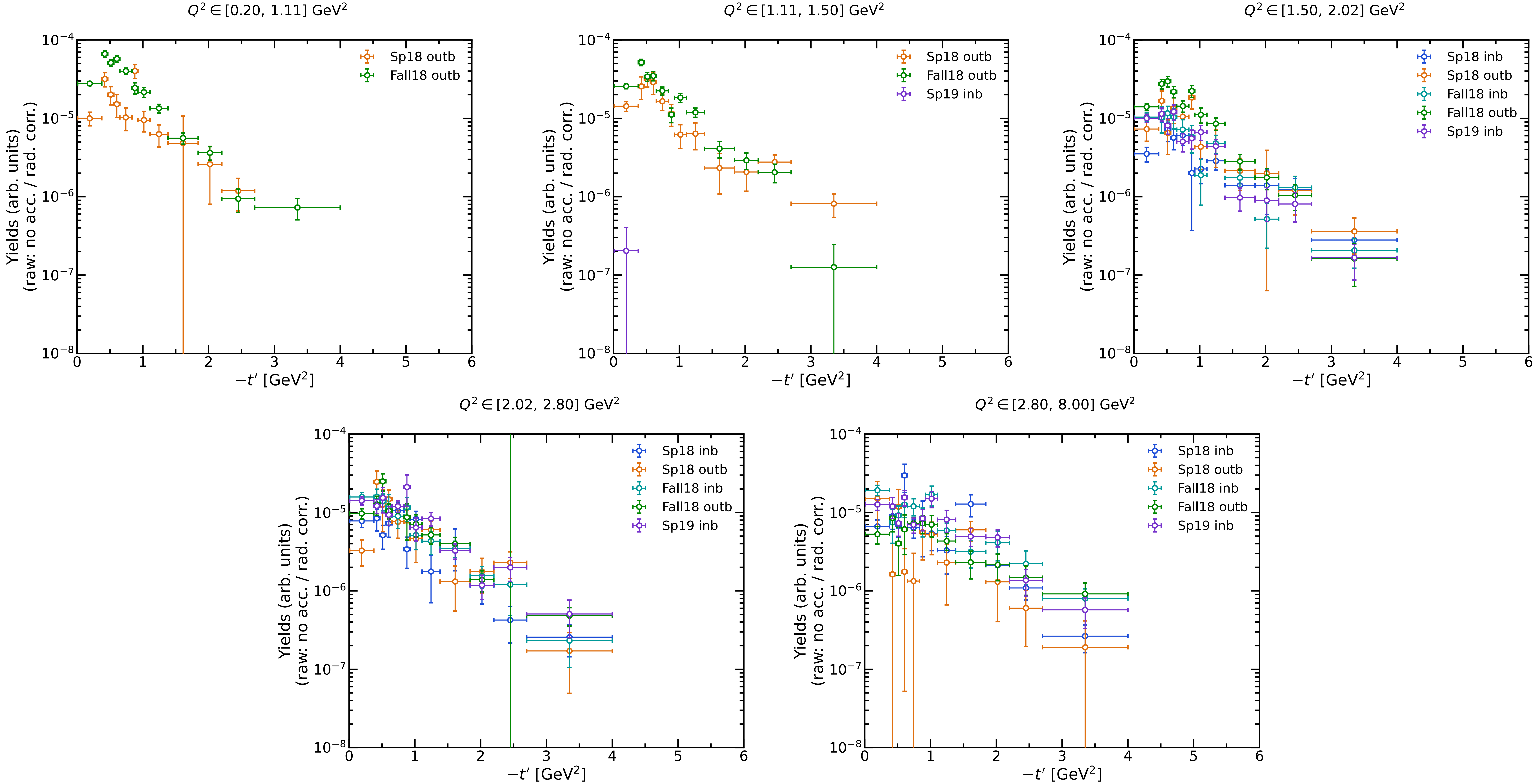
- Divide the sample total sample with equal statistics in each Q^2 and t' bin
- Currently **5** Q^2 and **12** t' bins
- In each -t' bin used a $InvM_{K^+K^-}$ distribution to extract the counts of ϕ



t' bin edge (GeV^2)	[0.01, 0.38]	[0.38, 0.47]	[0.57,0.56]	[0.56,0.65]	[0.65,0.83]	[0.83,0.93]	[0.93,1.11]	[1.11,1.38]	[1.38, 1.84]	[1.84, 2.2]	[2.2, 2.7]	[2.7,4.0]
Q^2 bin edge (GeV^2)	[0.20, 1.11]	[1.11, 1.50]	[1.50, 2.02]	[2.02, 2.80]	[2.80,8.0]							

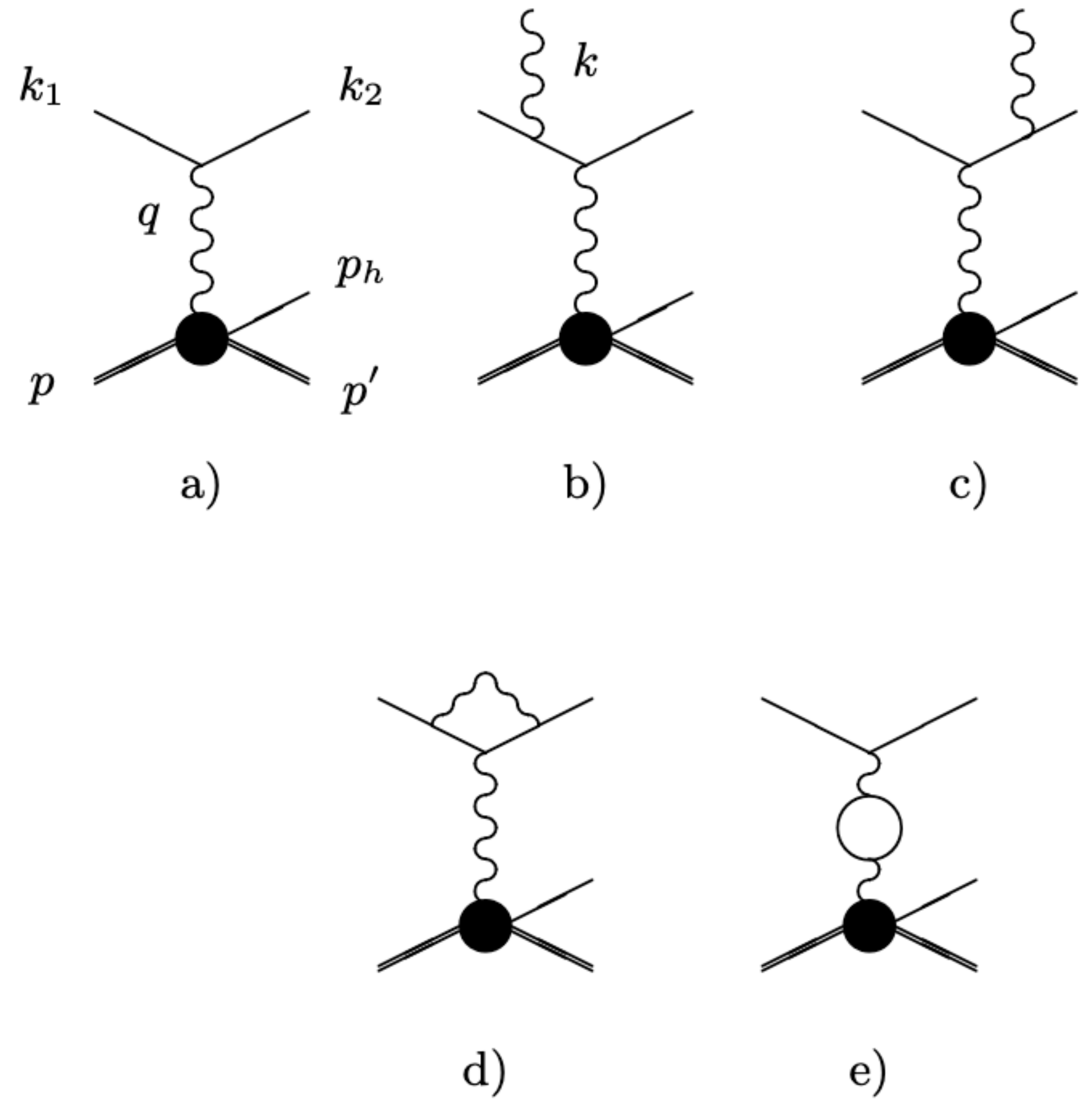
The raw yields

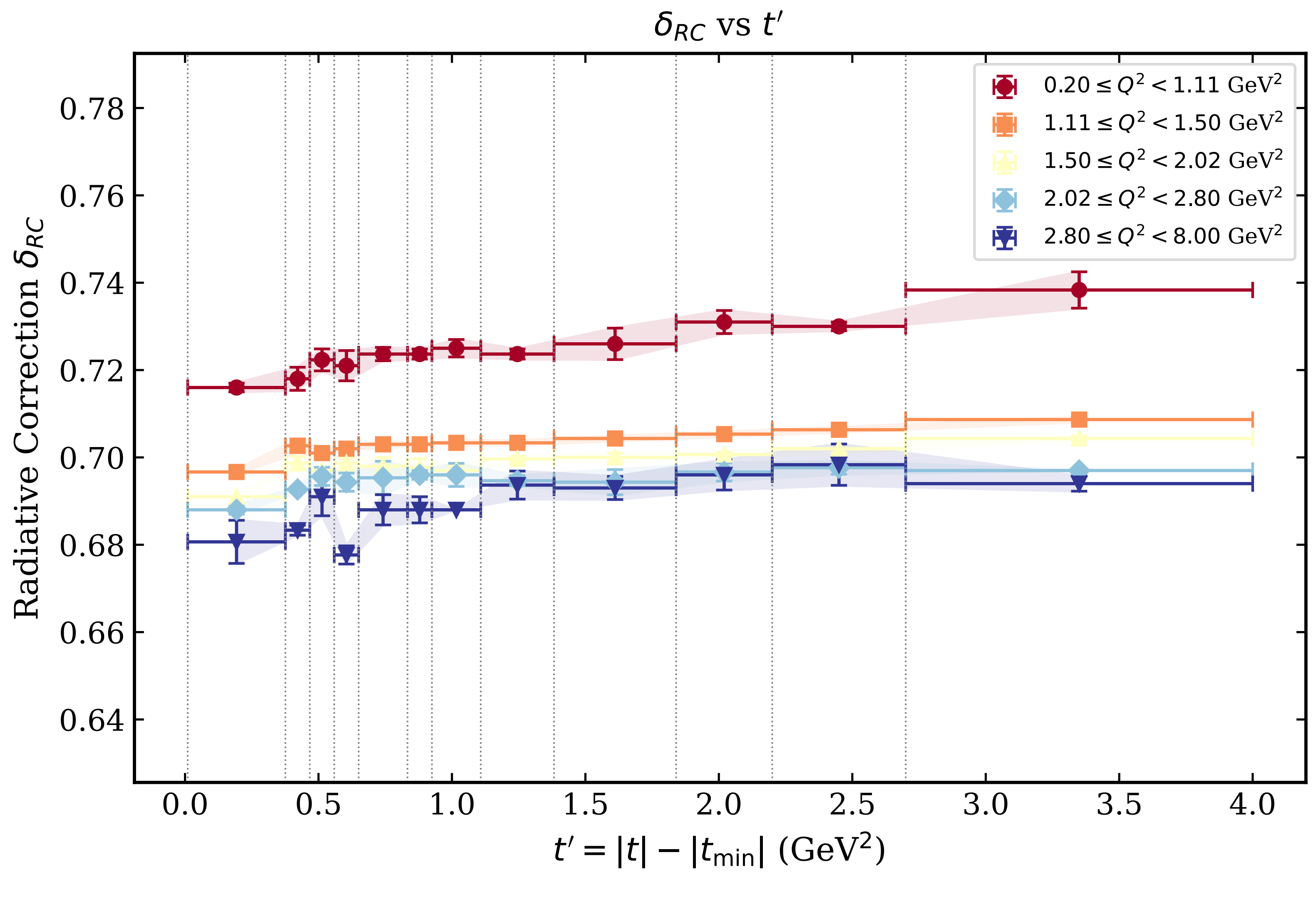
- **Without** the efficiency corrections!



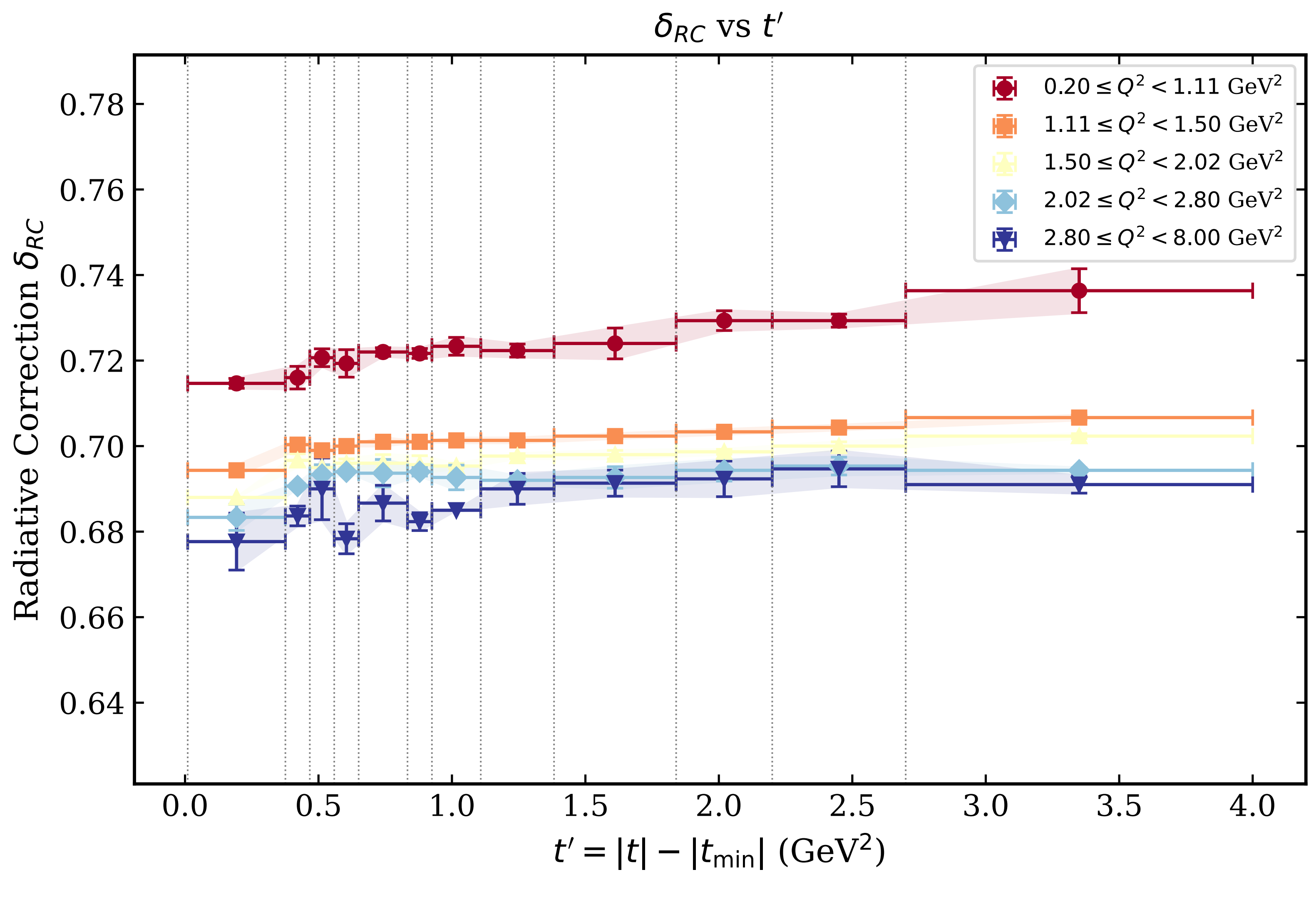
Radiative correction for phi meson production

- Based on the codes by DIFFRAD (I.Akushevich, EPJC8:457-463,1999)
- Inelasticity cut parameter $v_m = 0.02$ (J. Santoro, “Electroproduction of ϕ(1020) mesons)





E_{beam} = 10.20 GeV, $W^2 \in [3.2, 6.2]$ GeV^2

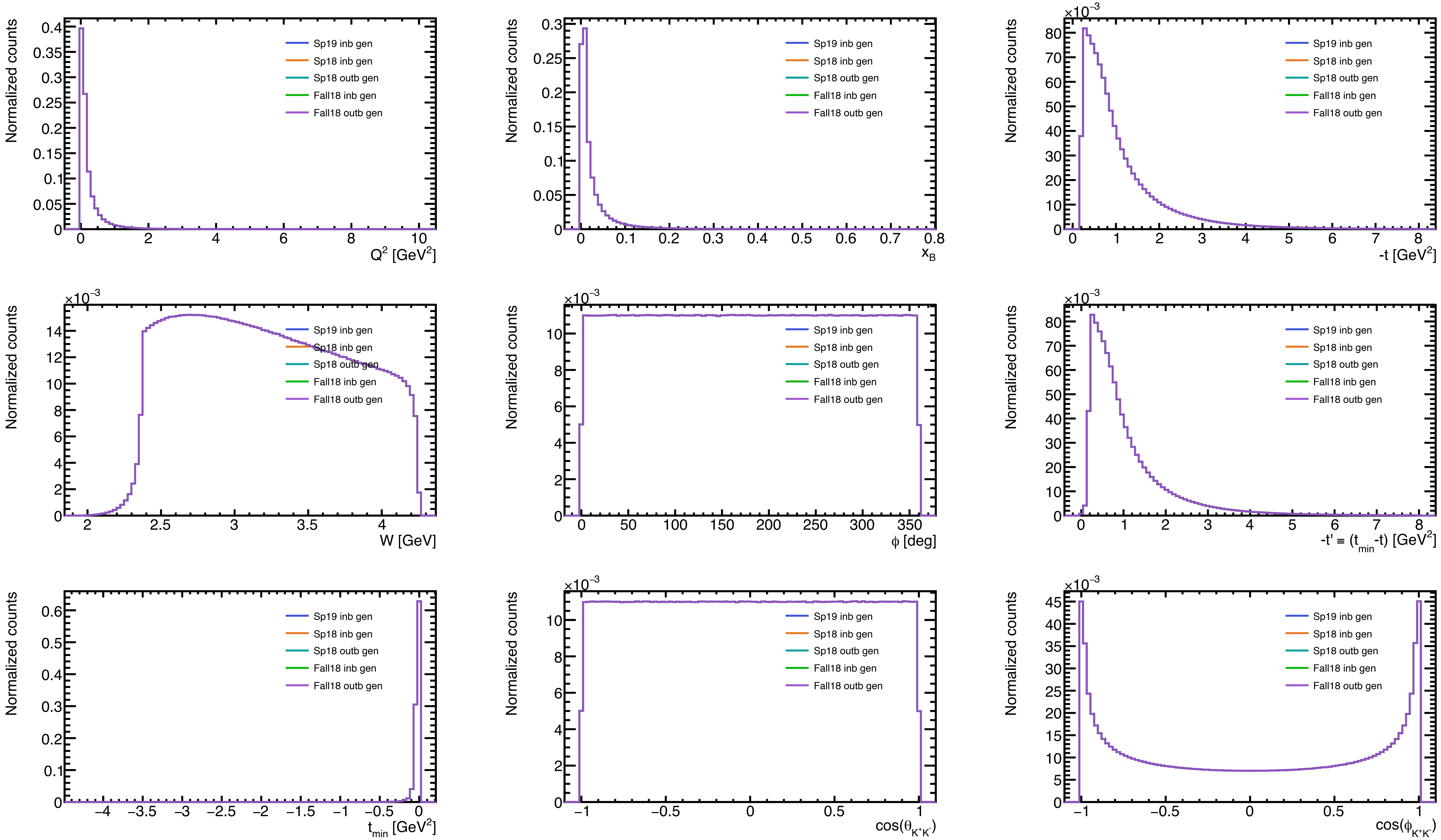


E_{beam} = 10.60 GeV, $W^2 \in [3.2, 6.2]$ GeV^2

- The observed correction is ~30% which is very large! Need further check investigations!

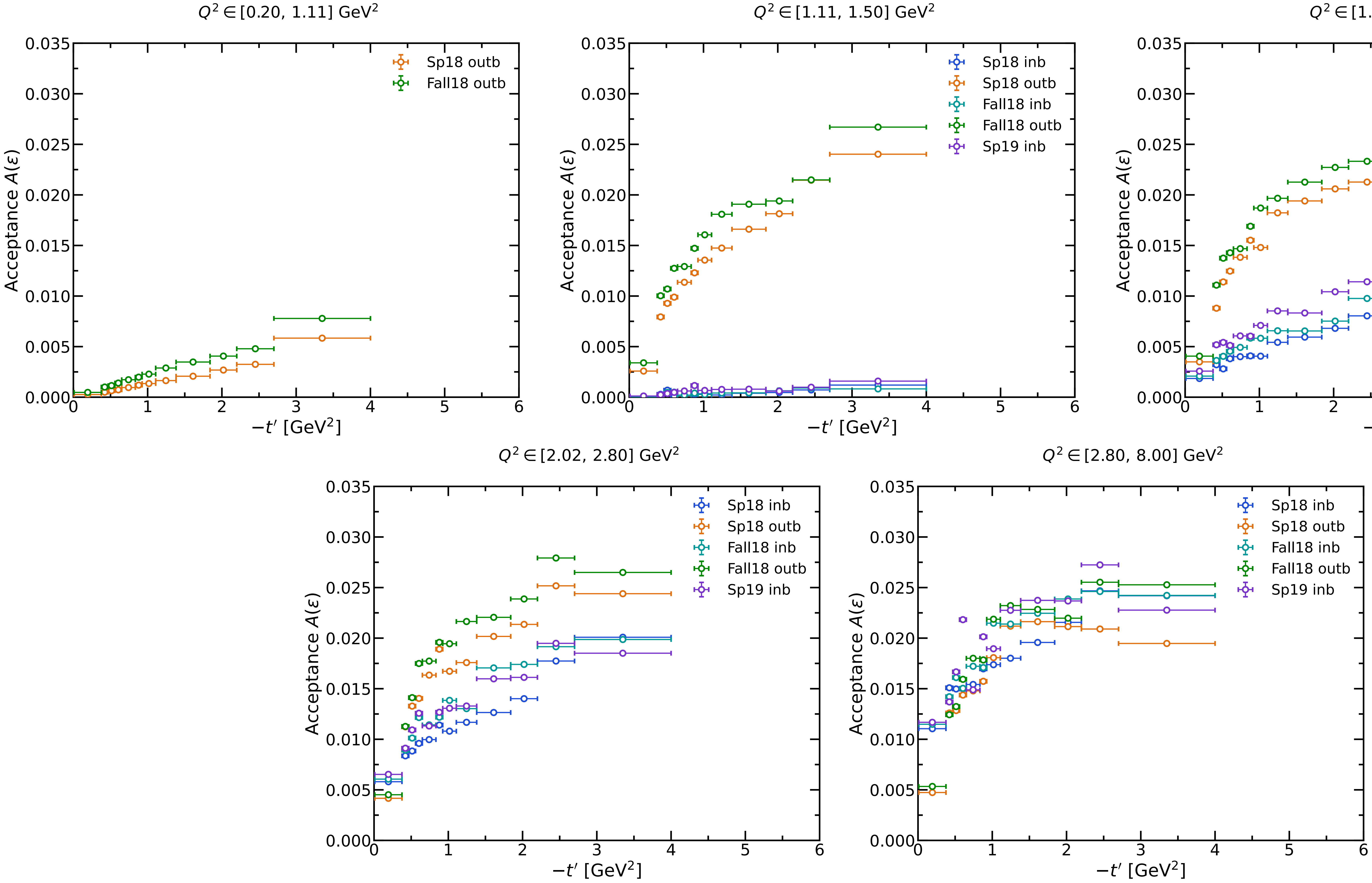
Acceptance Effects within CLAS12

- Simulations based on the Argonne ϕ Event Generator tuned to Clas 6 data and **ϕ event decay in rest mass is considered as isotropic (flat distribution)**



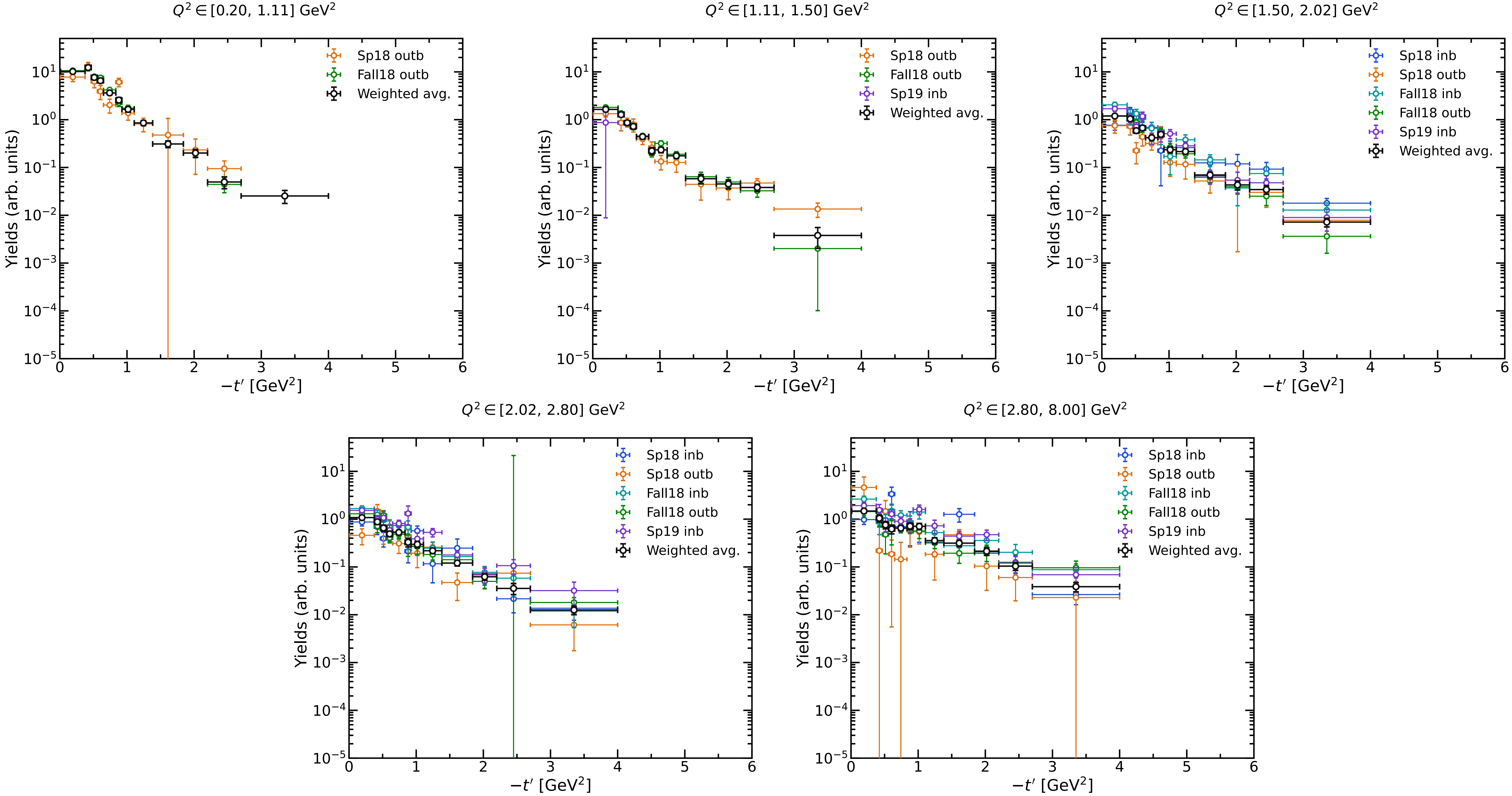
Detector acceptance effects

- **Without** the efficiency for background merging corrections!



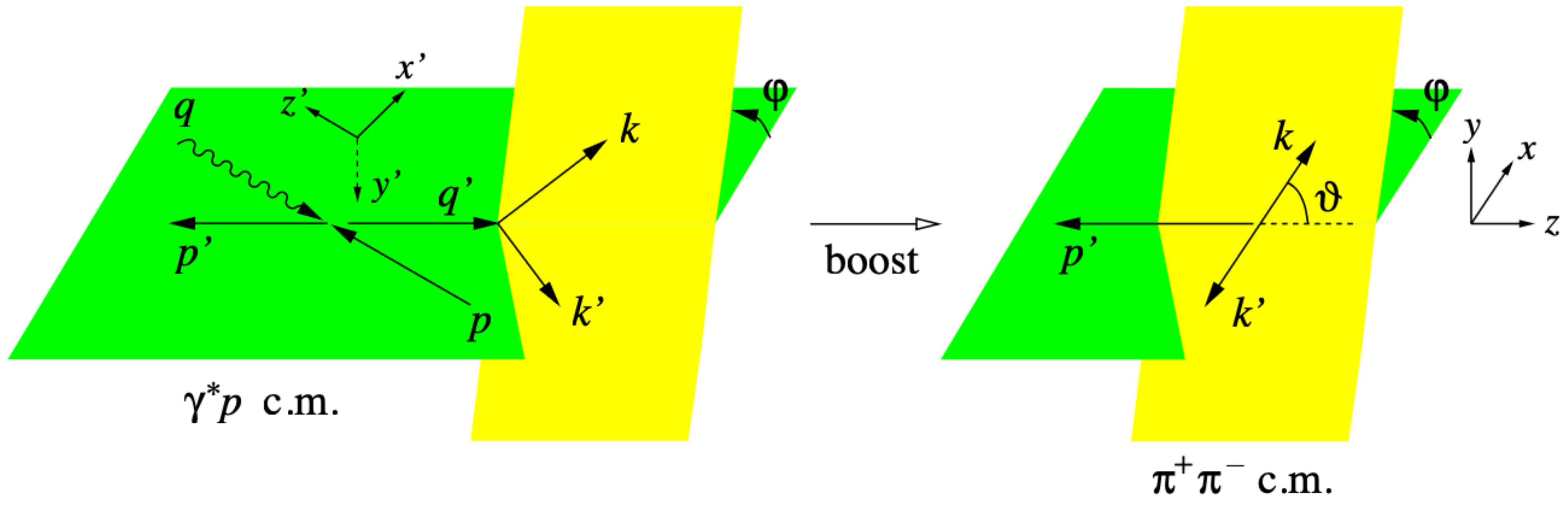
Final reduced cross-sections

- **Without** the efficiency for background merging corrections!



ϕ-decay and acceptance within CLAS 12

- Vector meson with spin 1 possible decay is expected to be a non-flat distribution



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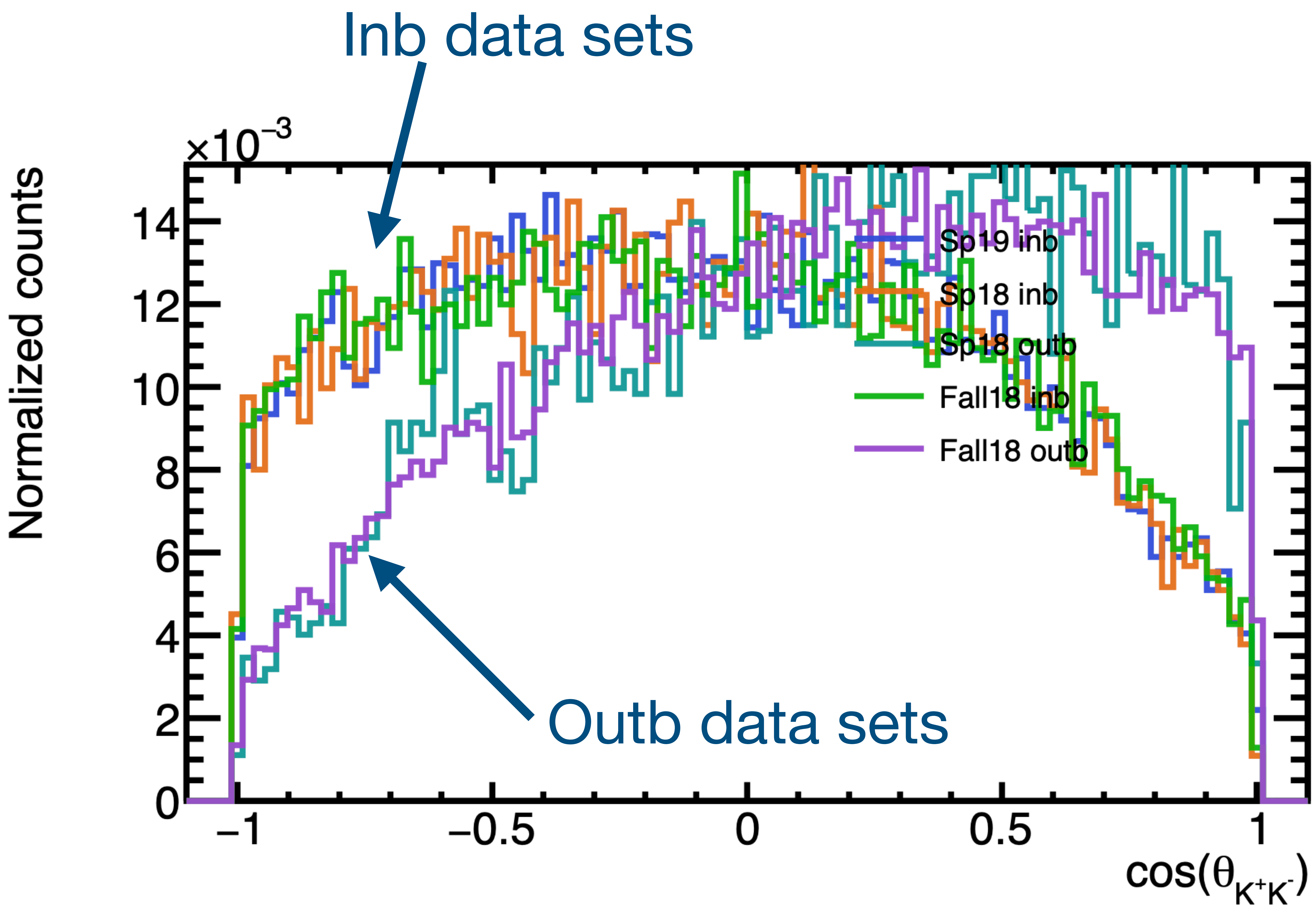
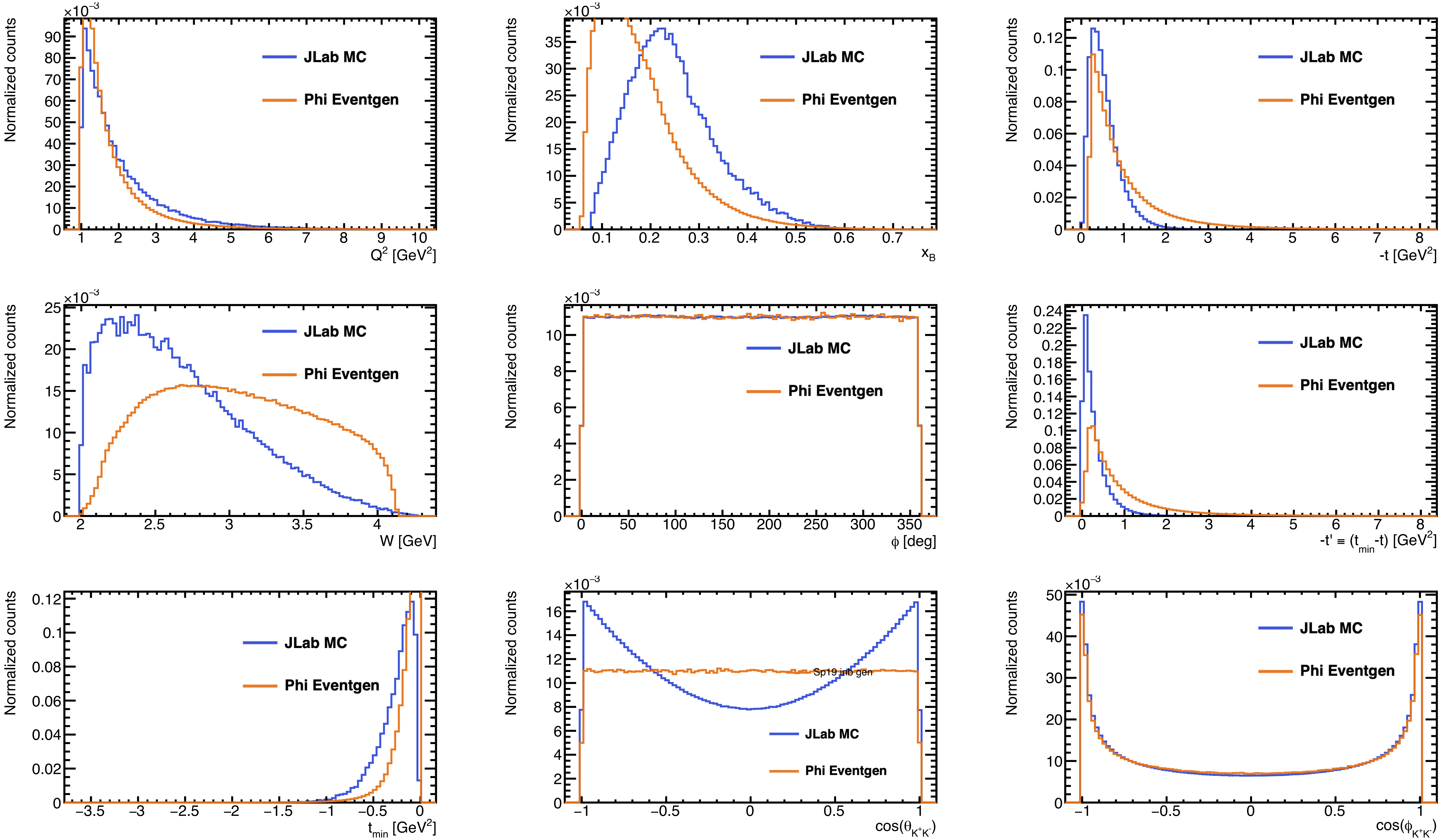


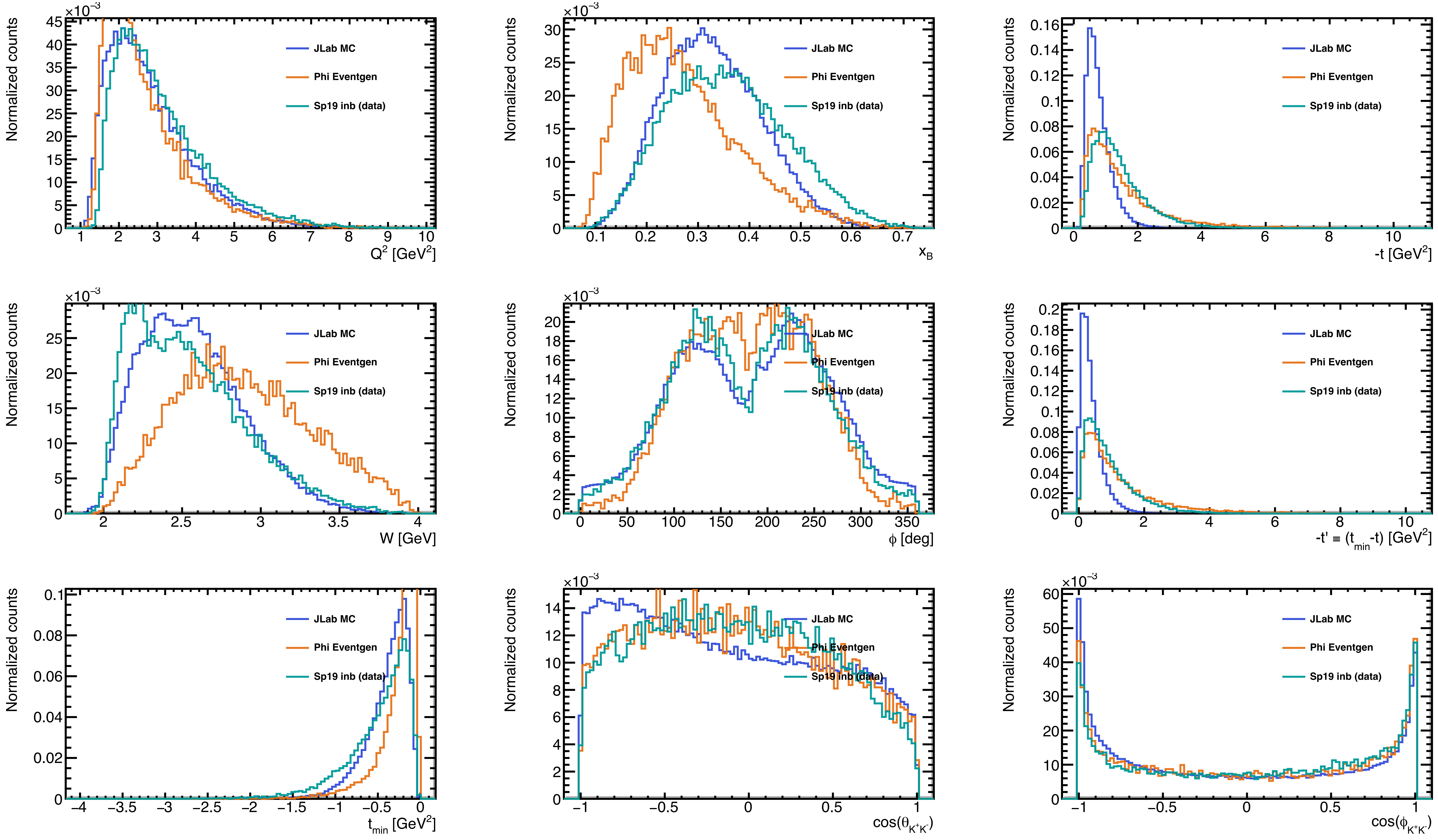
MC can change things drastically (Gen only)

- Two generator Argonne group and **JLab vector meson event generator (JLab MC)** with ρ^0 like decay
- In house **JLab MC** has enhanced longitudinal contribution in the cross-section

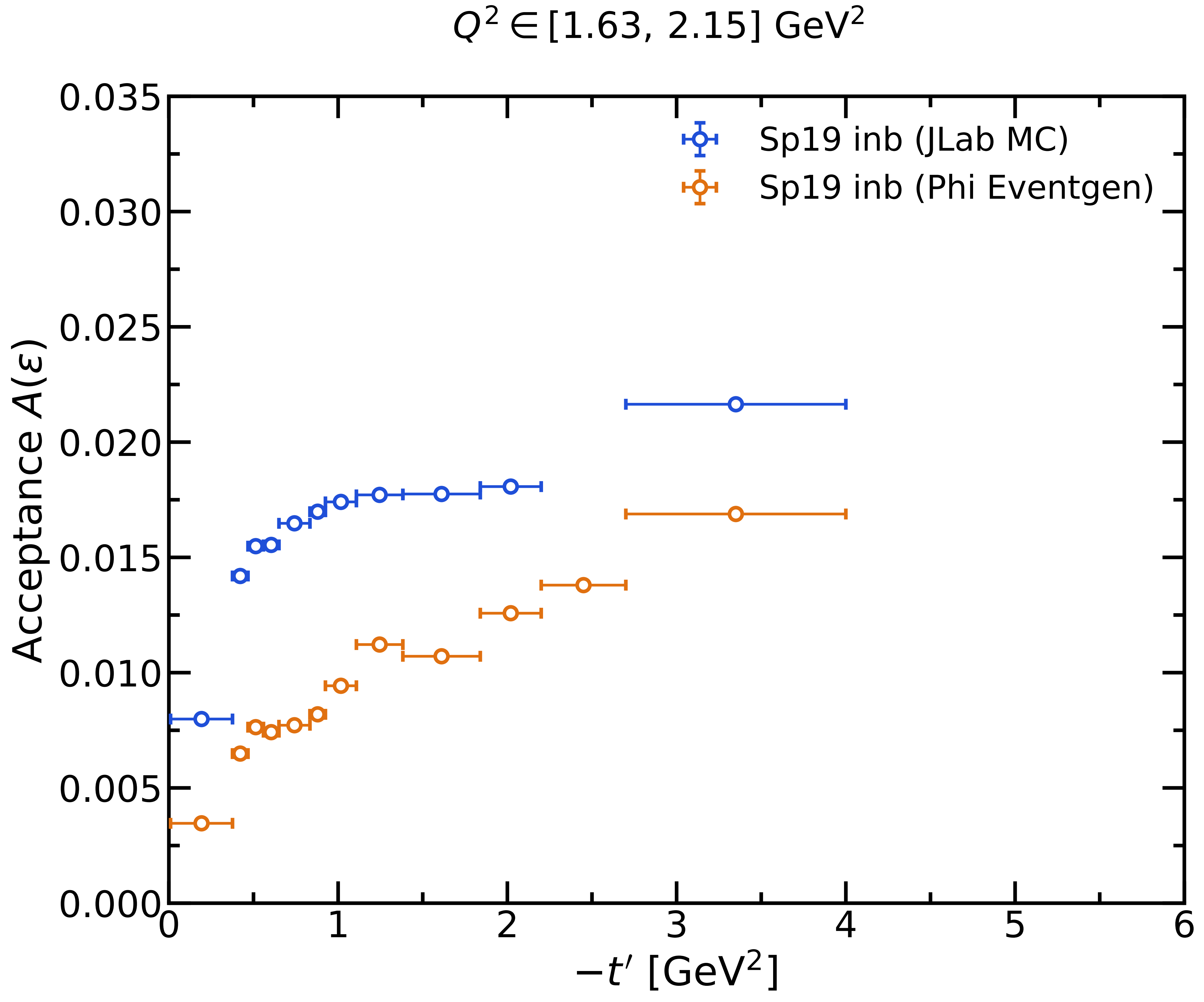


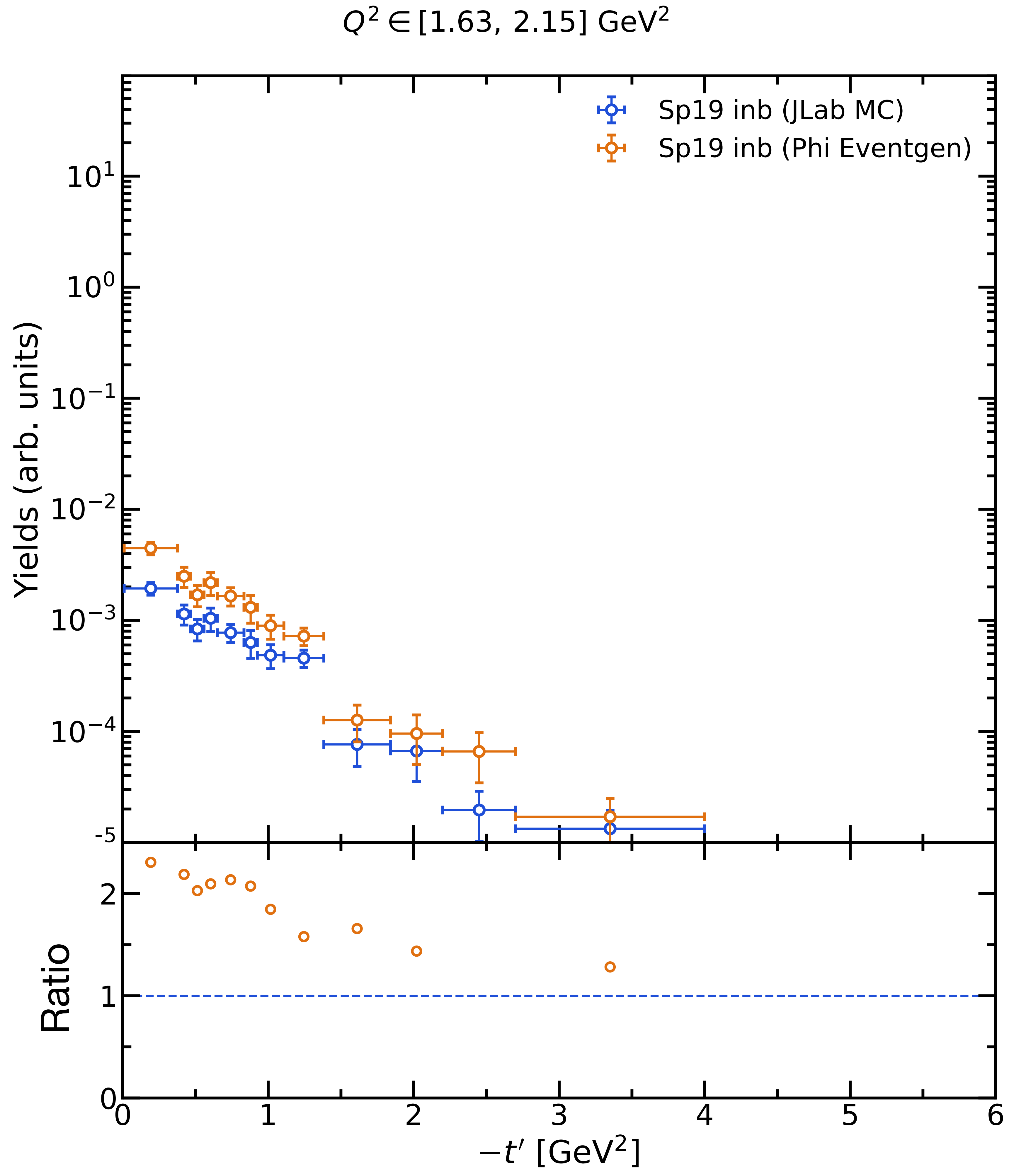
MC can change things drastically (Reconstruction GEMC)

- While the reconstructed events have similar decay angle from both MC



Impact on the acceptance



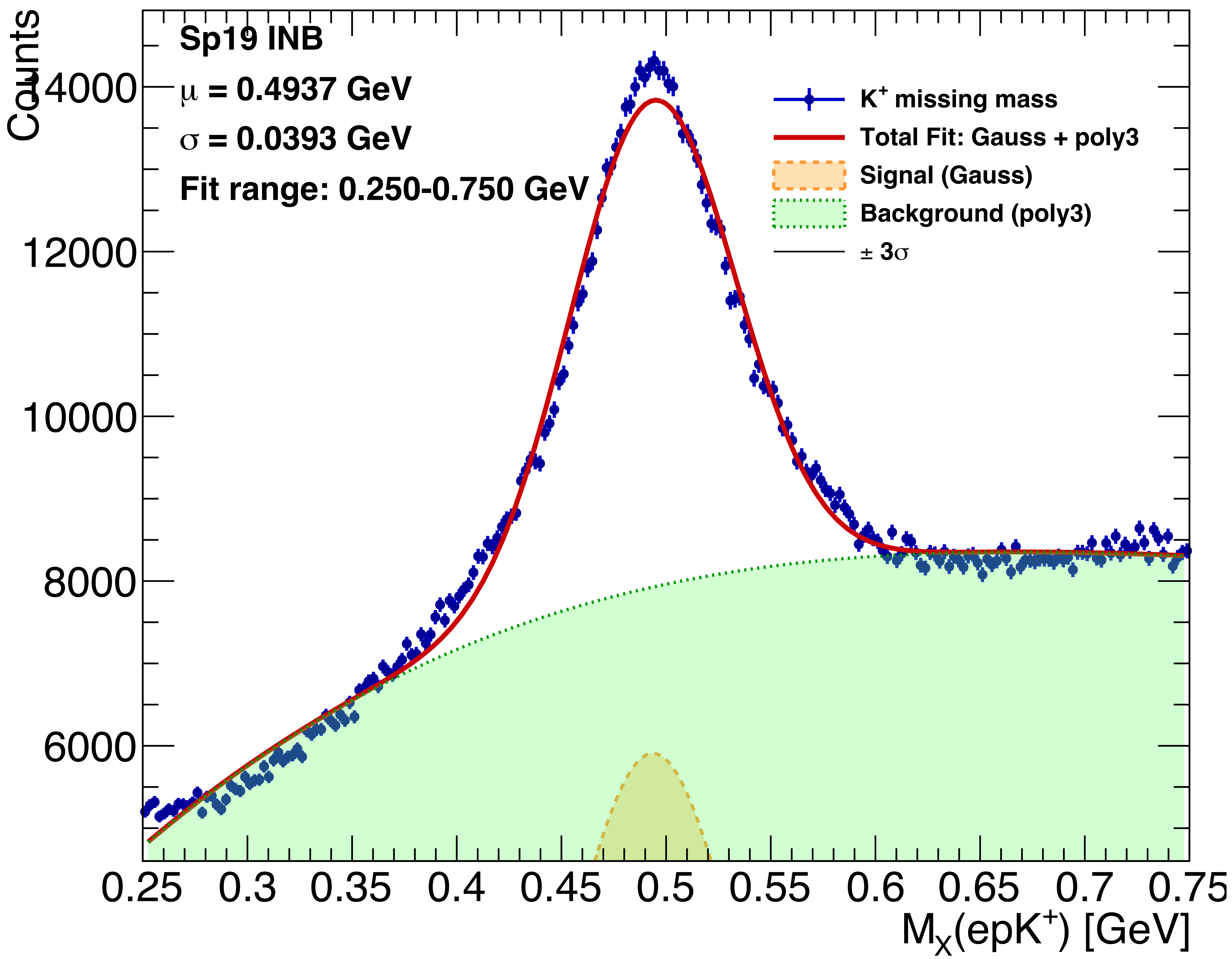


The appropriate SDMEs in the generator is crucial for acceptance corrections for low statistics analysis!

Missing mass analysis

- Reconstruct the missing K⁻ peak at ~493 MeV: +- 3*sigma cut around the the peak

K⁻ peak for $ep \rightarrow epK^{+}(K^{-})$



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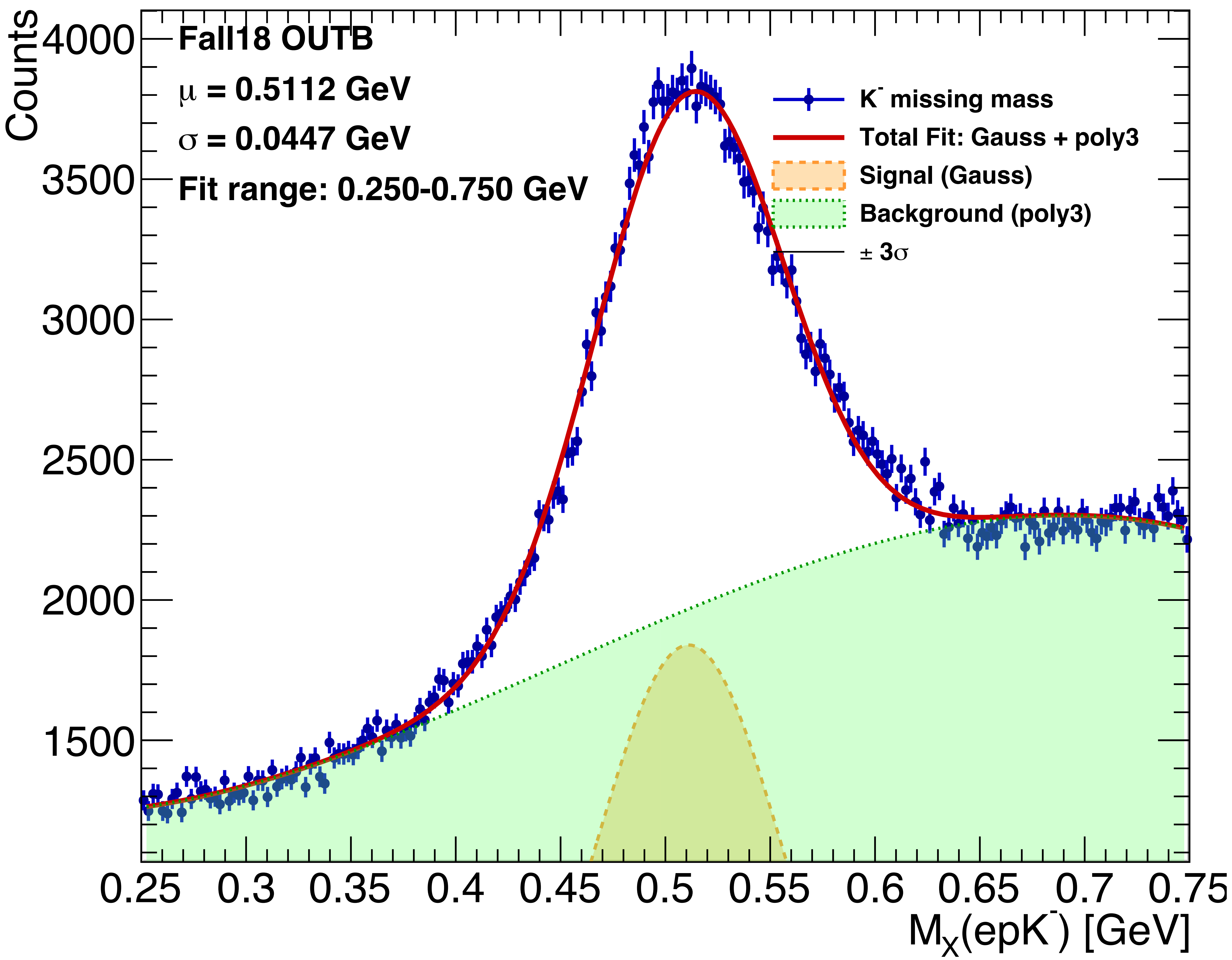
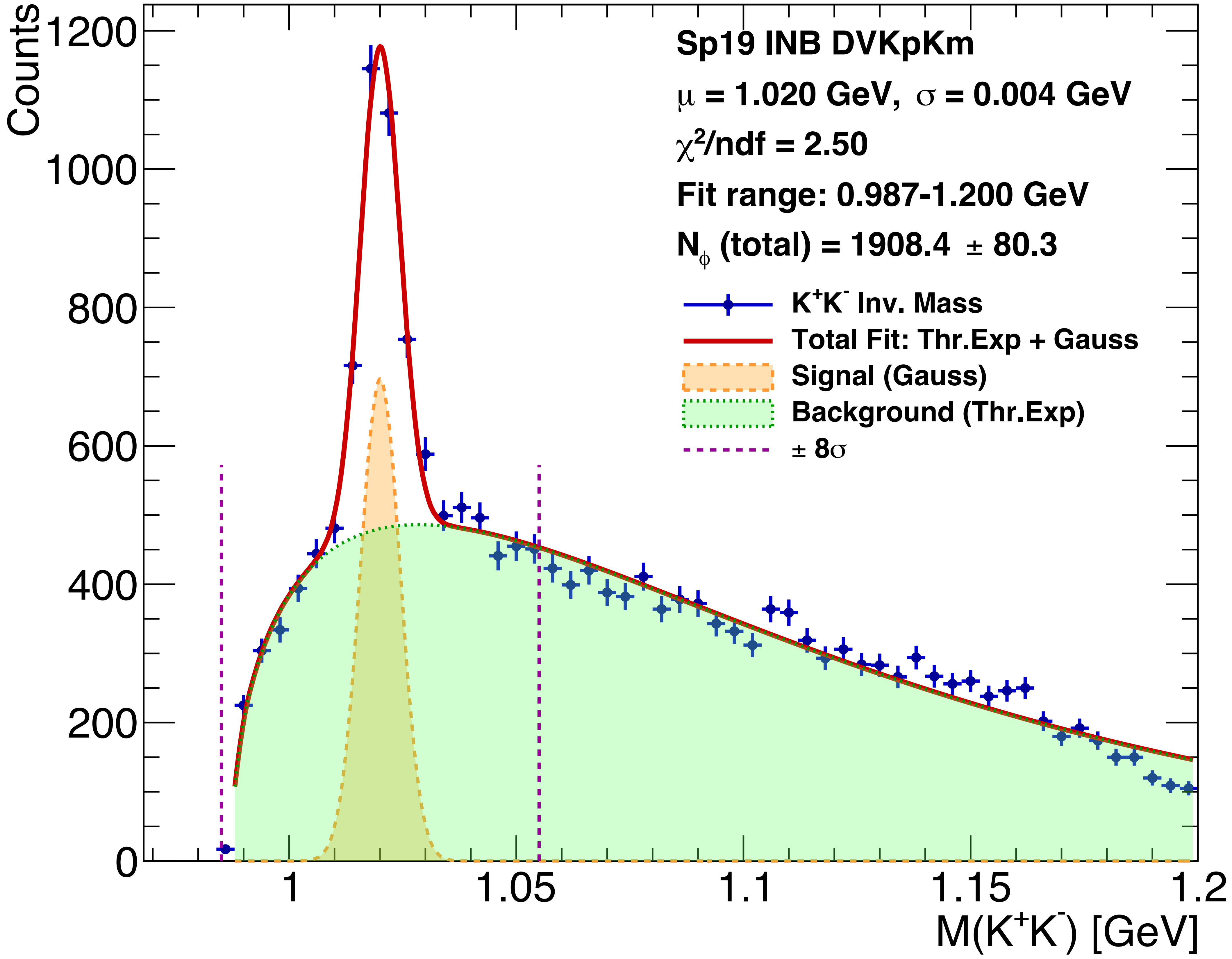


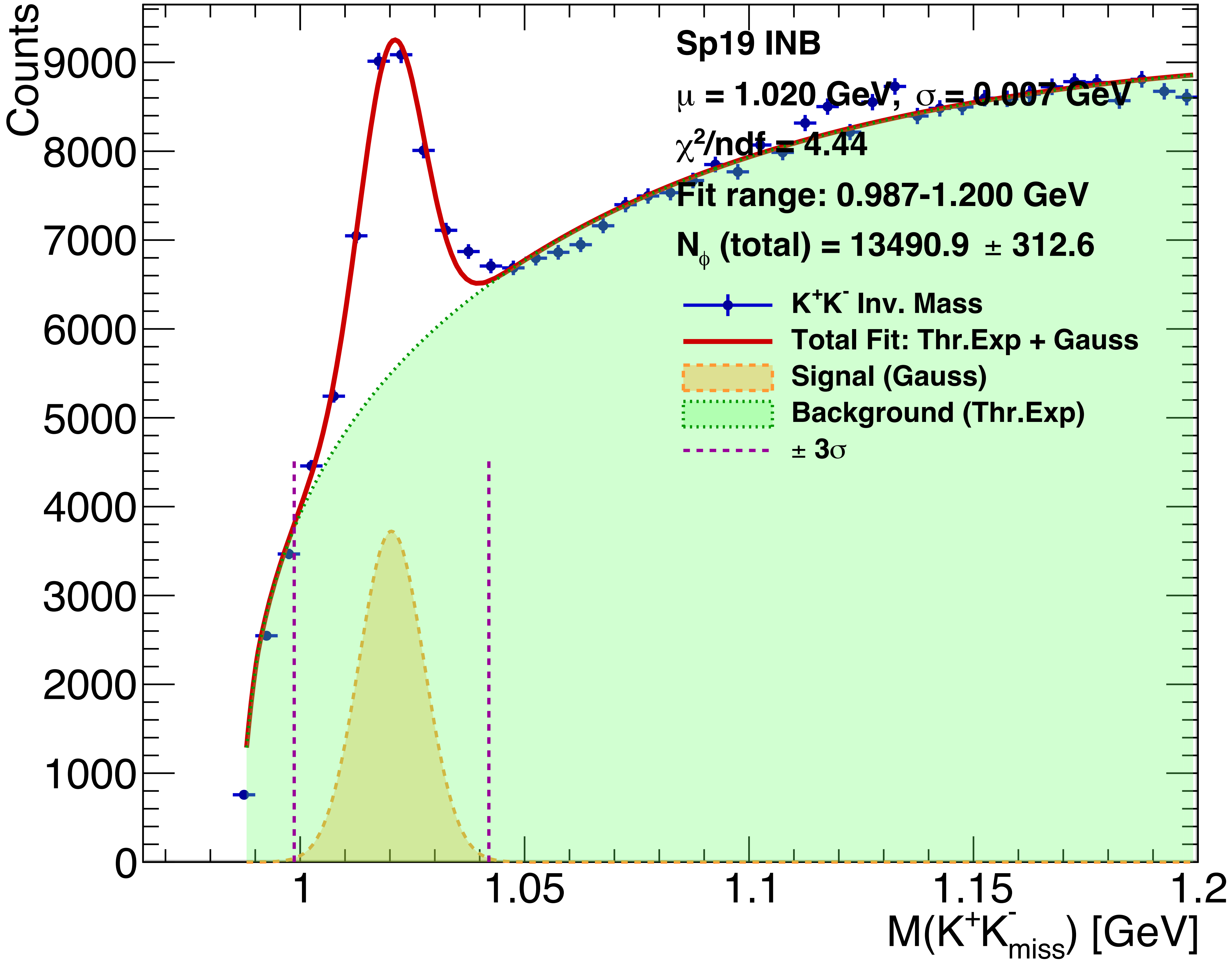
Missing Mass vs Exclusive topology

- Enhanced statistics ~7-8 fold in the missing mass analysis.
- Larger background!

1908 ϕ candidates



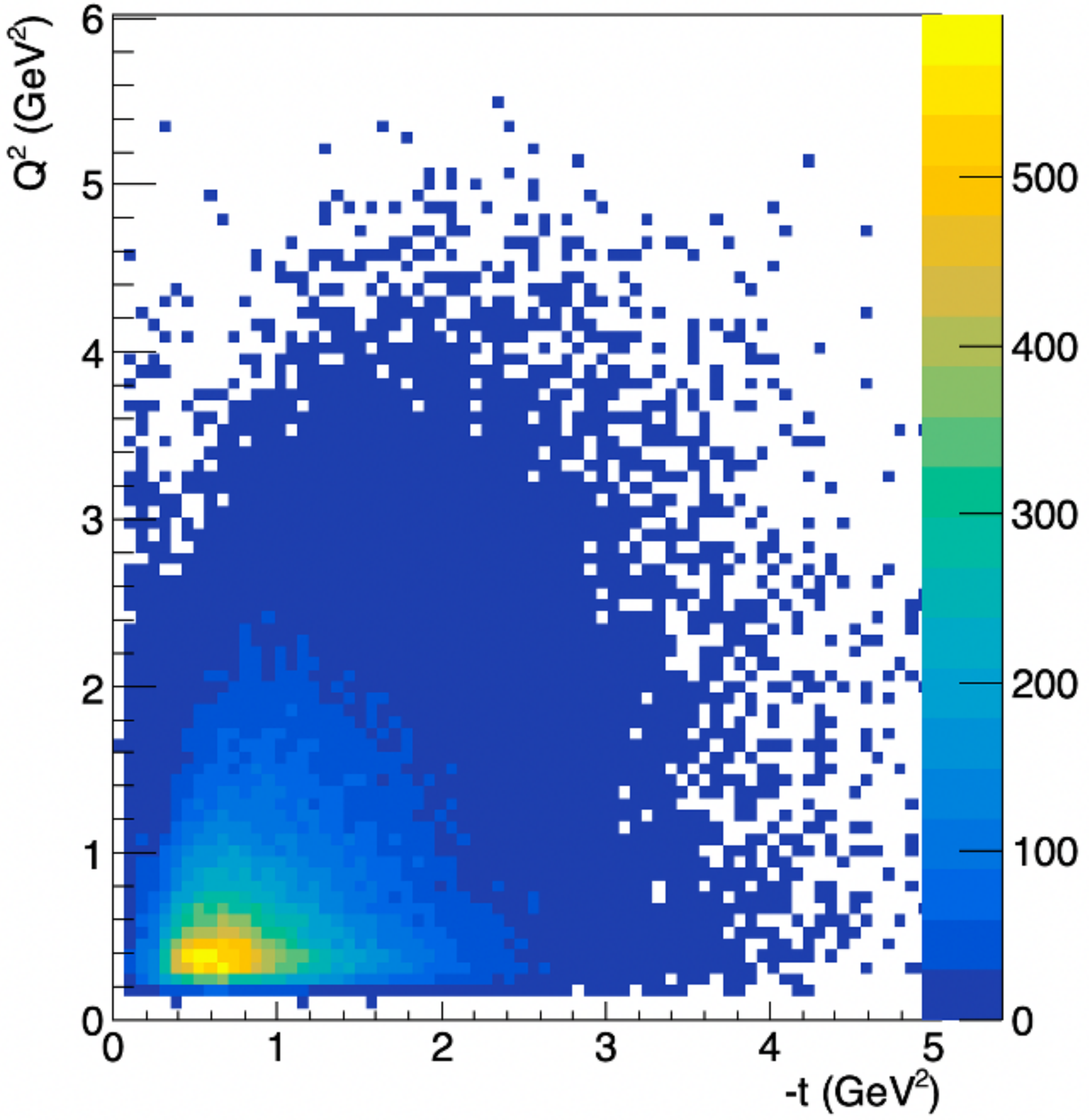
13490 ϕ candidates



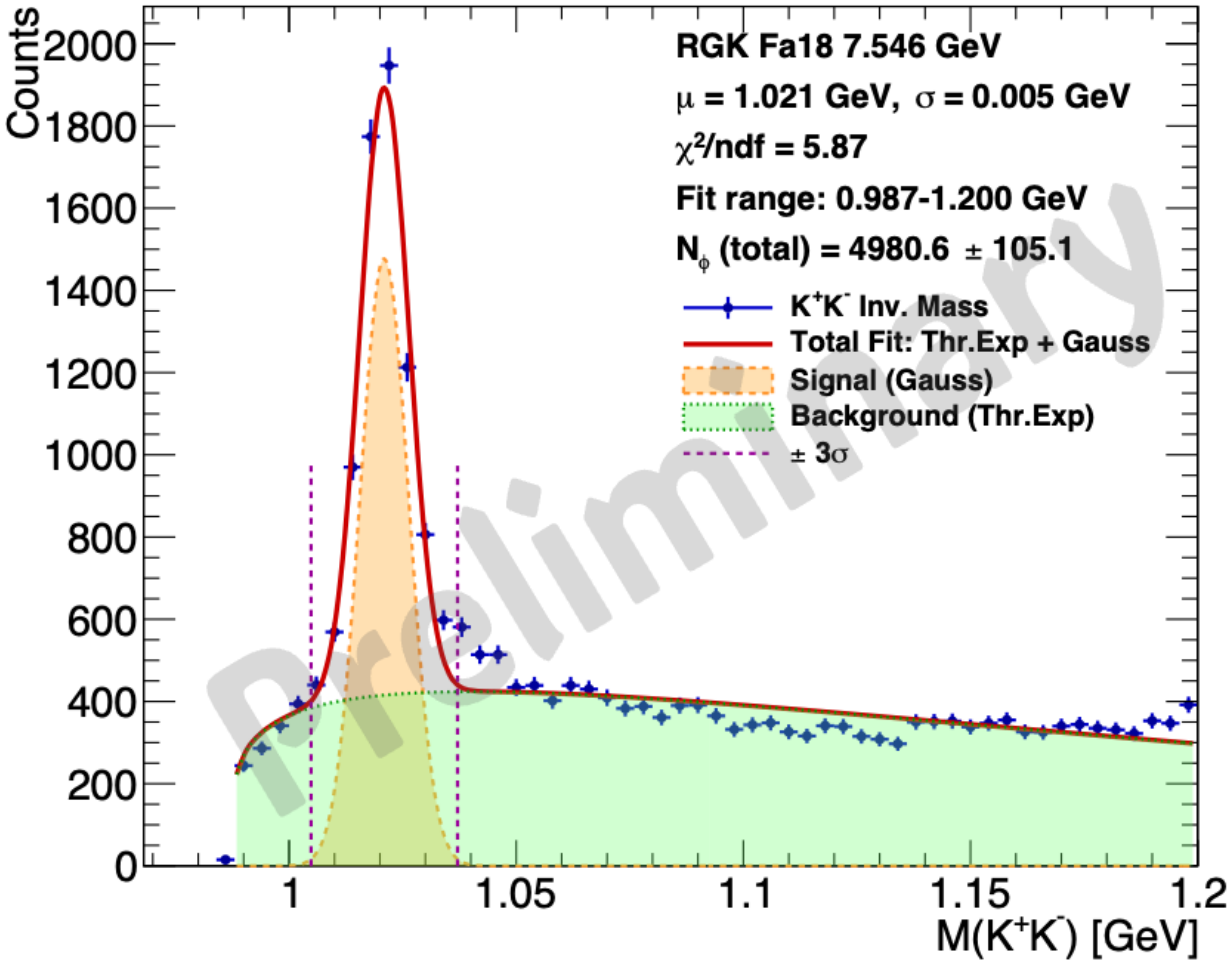
Sneak peak: RGK Fall 2018 Outbending (pass2)

- Charge Decay Channel : ep → e'p'ϕ → e'p'K^+K^- (Exclusive Topology)
- **Exp. data**: RGK, beam energy 7.546 GeV ~ 4980 ϕ candidates with full exclusive topology (135 runs)

Q^2 vs –t Distribution

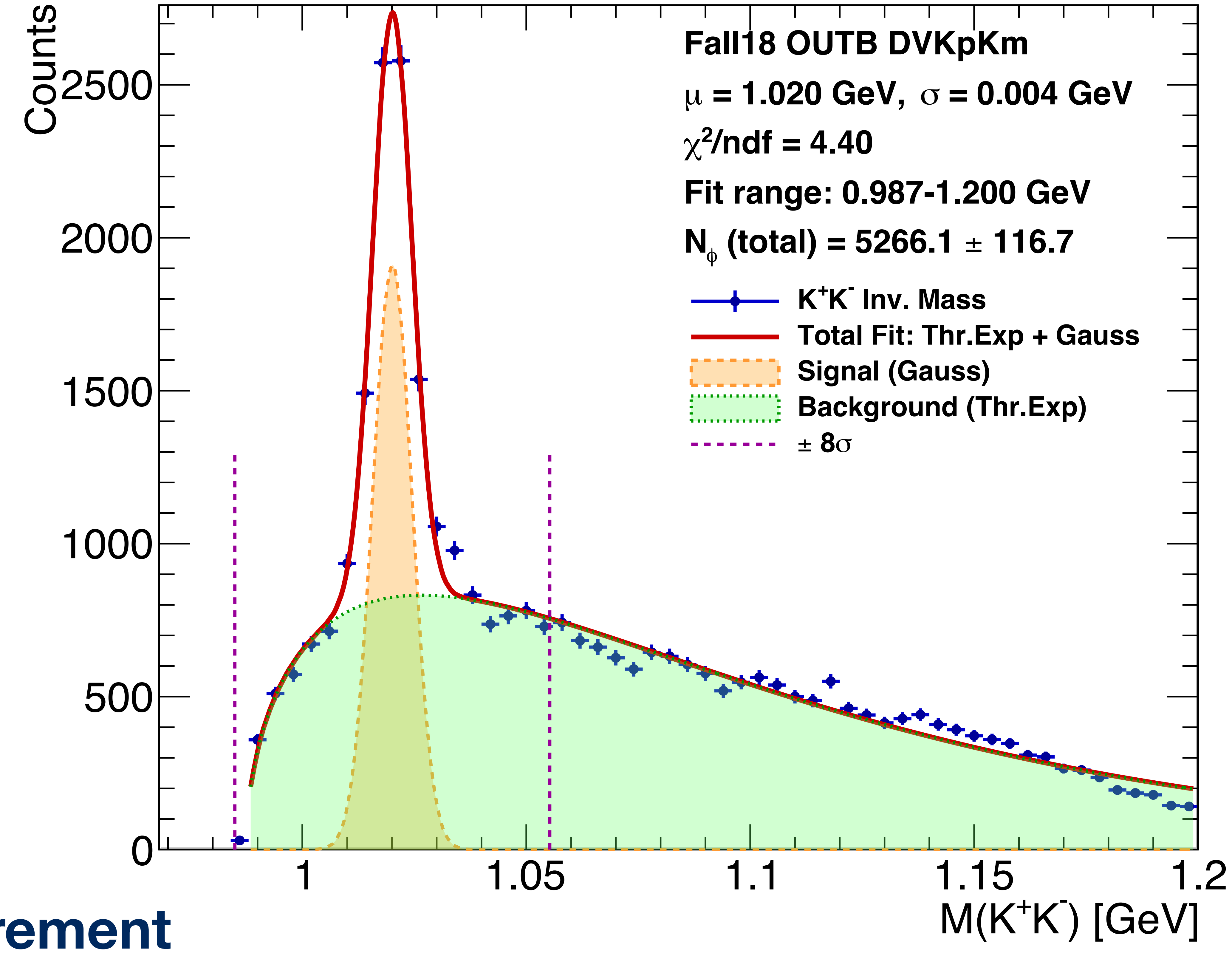


ϕ- Inv mass Distribution



Summary

- So far
  - First look at the exclusive ϕ meson production combining all data set from RGA 10.6-10.2 GeV
  - Established missing mass analysis to enhance the statistics
- Next steps
  - Development of realistic **event generator with SDMEs**
  - Systematics on **acceptance** and efficiency corrections!
  - **More** data from different energies at **6.4, 6,5, 7.5, 8.4 GeV**!
- We need
  - **Theoretical calculations for better interpretation the measurement**



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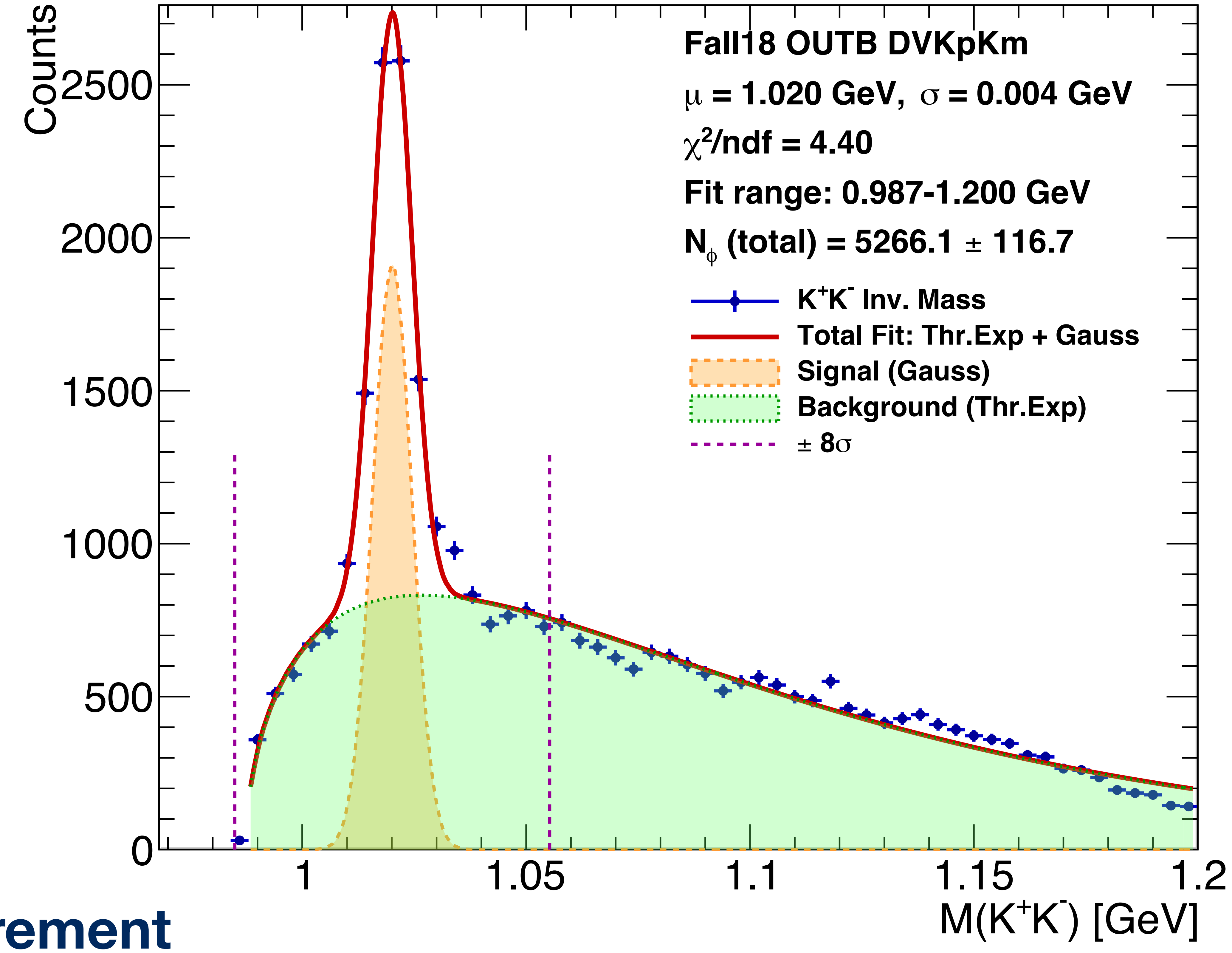

Thank you for your attention!

Exclusivity cuts

- Proton in CD and Kaons in FD (less stat)
- Exclusivity variables are prior to phi mass peak cut
- Exclusivity cuts

$E_{miss} \in [-0.0075, 0.32]$ GeV
$P_{Tmiss} < 0.12$ GeV
$Mx^2 (eK^+K^-) \in [0.64, 1.1664]$ GeV^2
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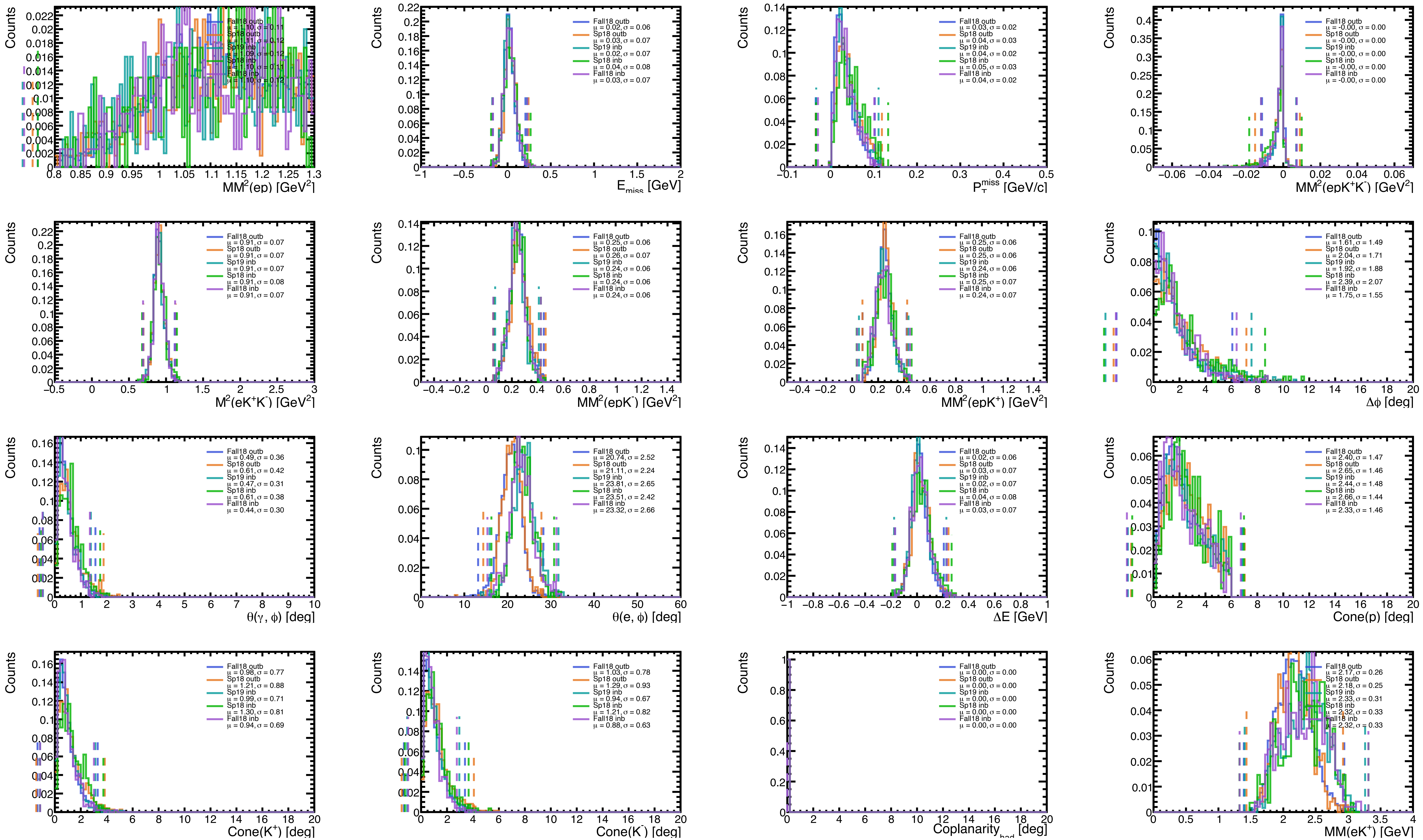


Venturing into Angular Distributions

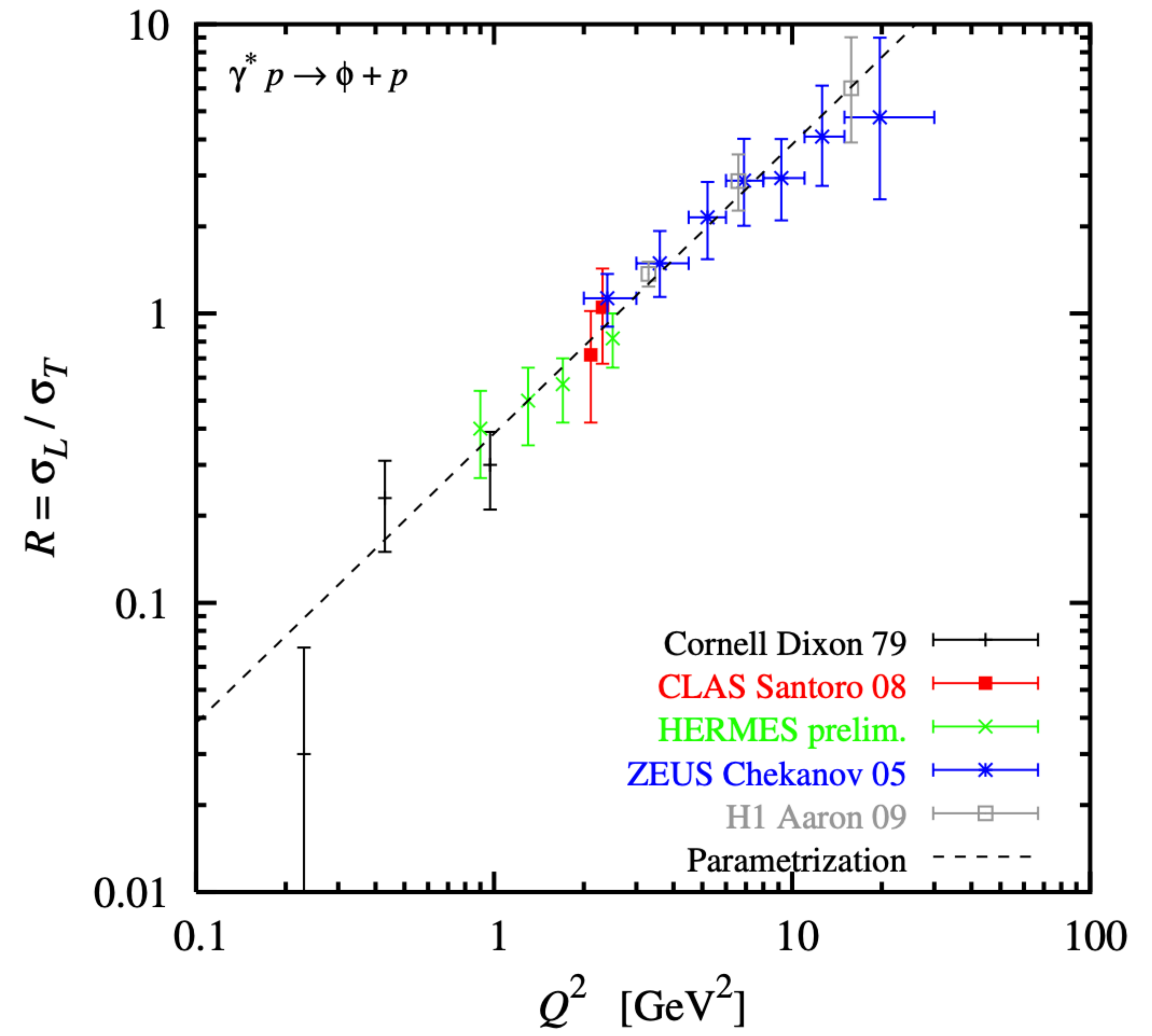
- It works at a single energy because **R** comes entirely from the shape of the K^+K^- helicity-frame $\cos\theta_H$ distributions

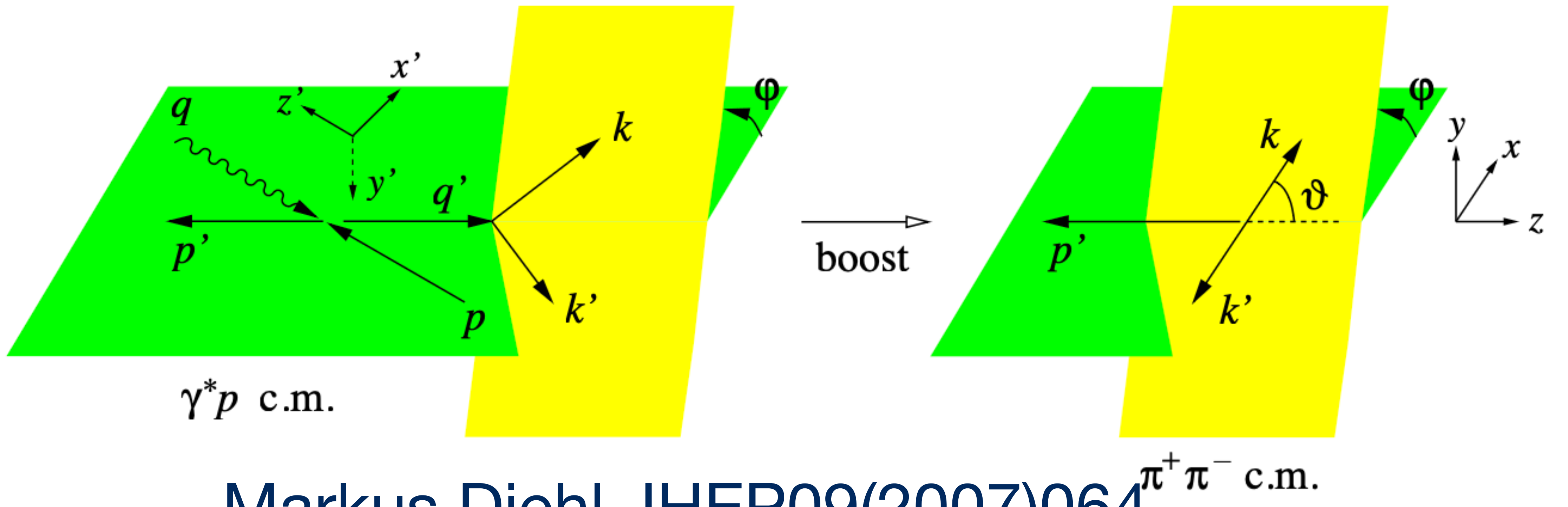
$$W(\cos\theta_H) = \frac{3}{4}\left[(1 - r^{04}_{00}) + (3r^{04}_{00} - 1)\cos^2\theta_H\right]$$

- The fit to this shape gives $\mathbf{r^{04}_{00}}$ with no reference to beam energy at all

$$R = \frac{r^{04}_{00}}{\varepsilon(1 - r^{04}_{00})}$$

- The **ε** is the tunable parameter to the beam energy— it is simply the kinematic value at the mean **y** and **Q²** of the bin





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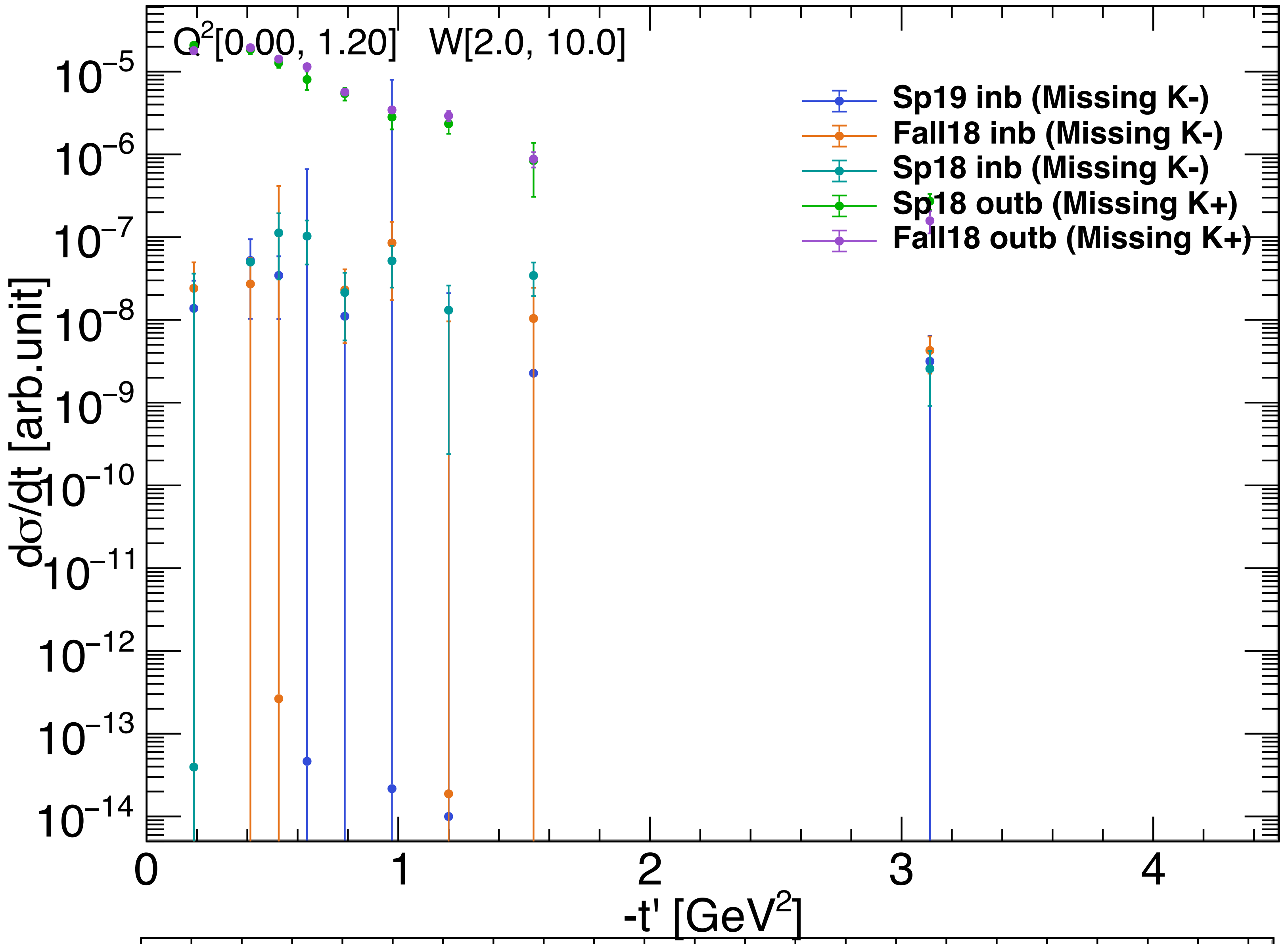
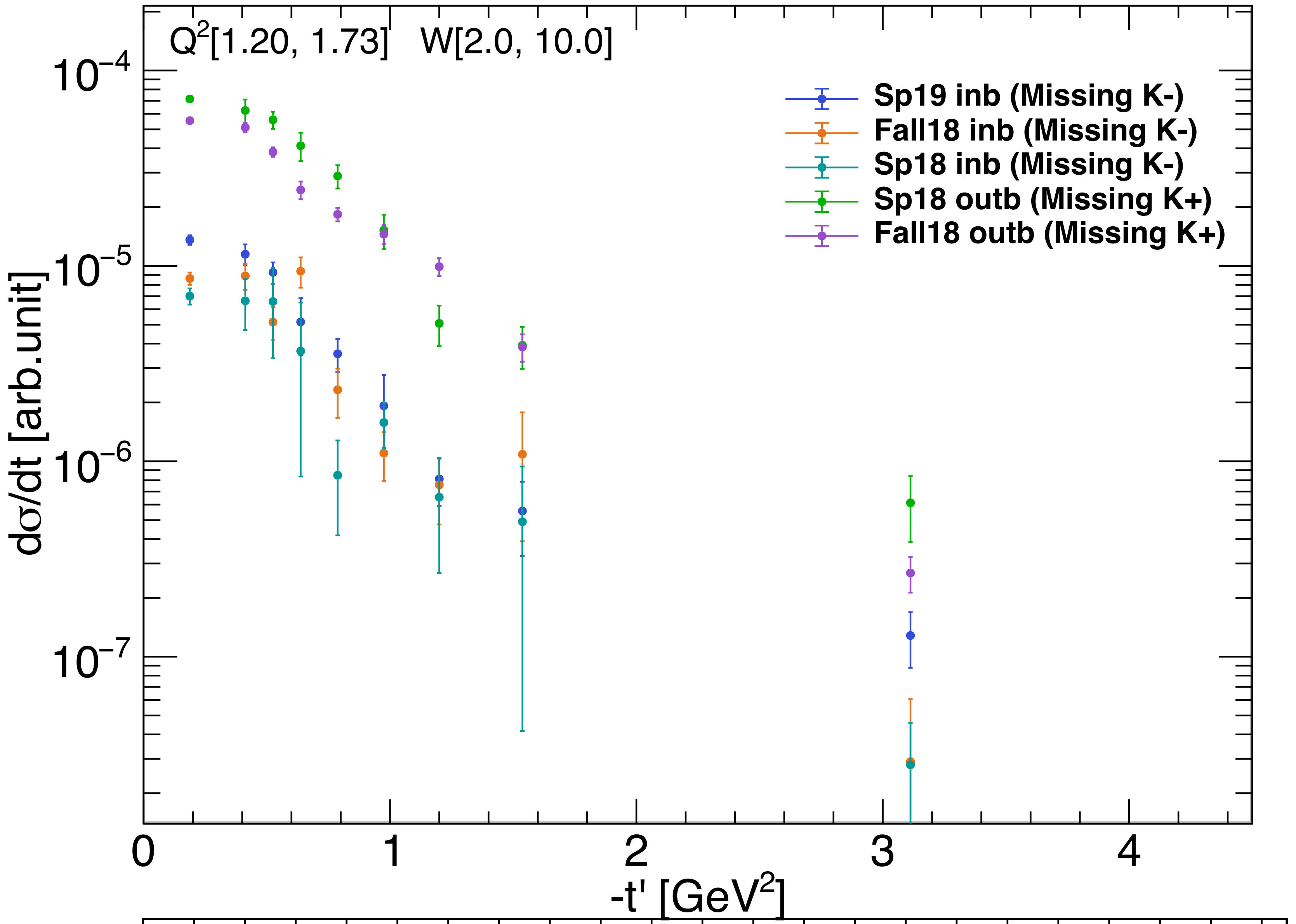
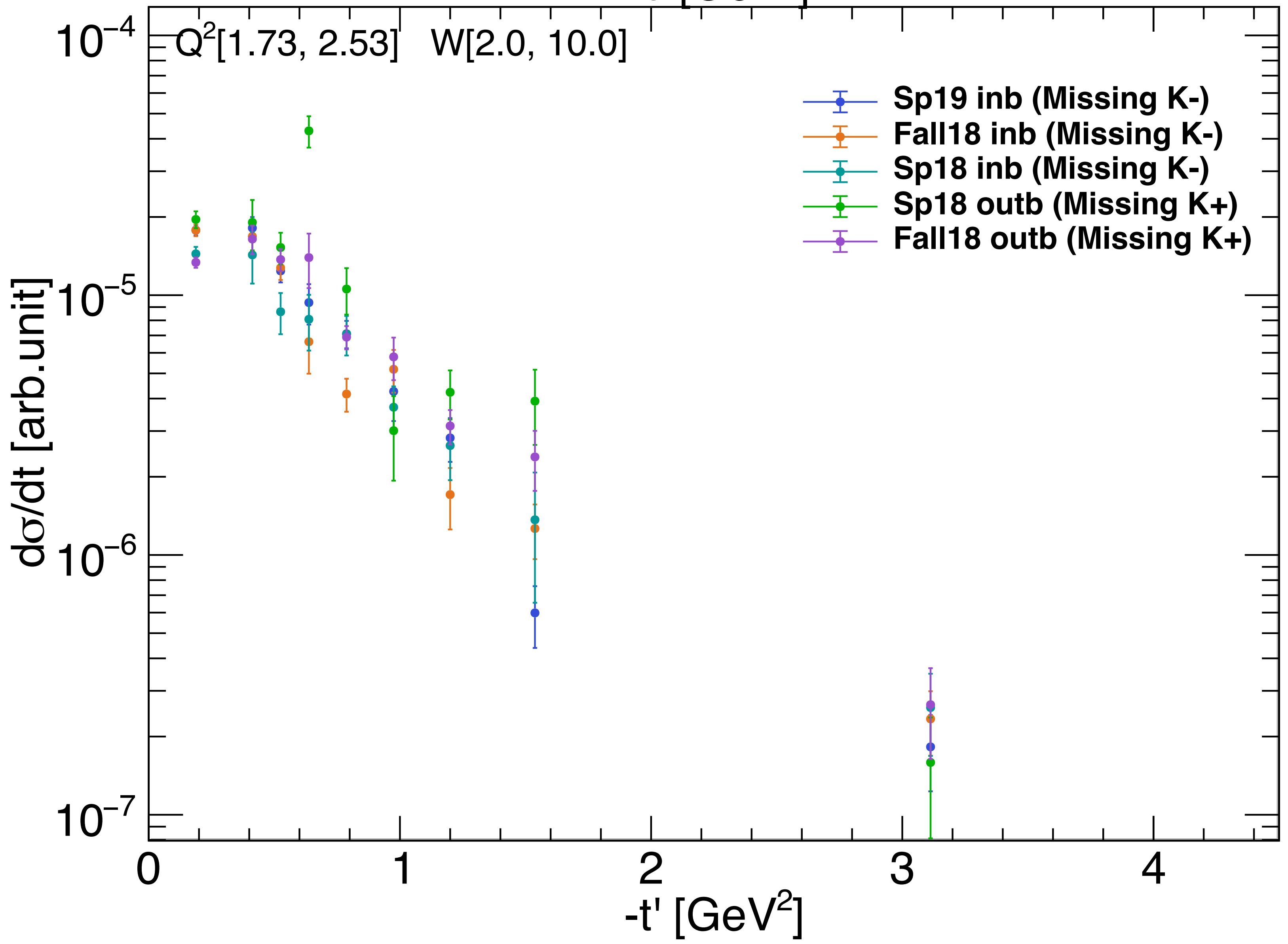
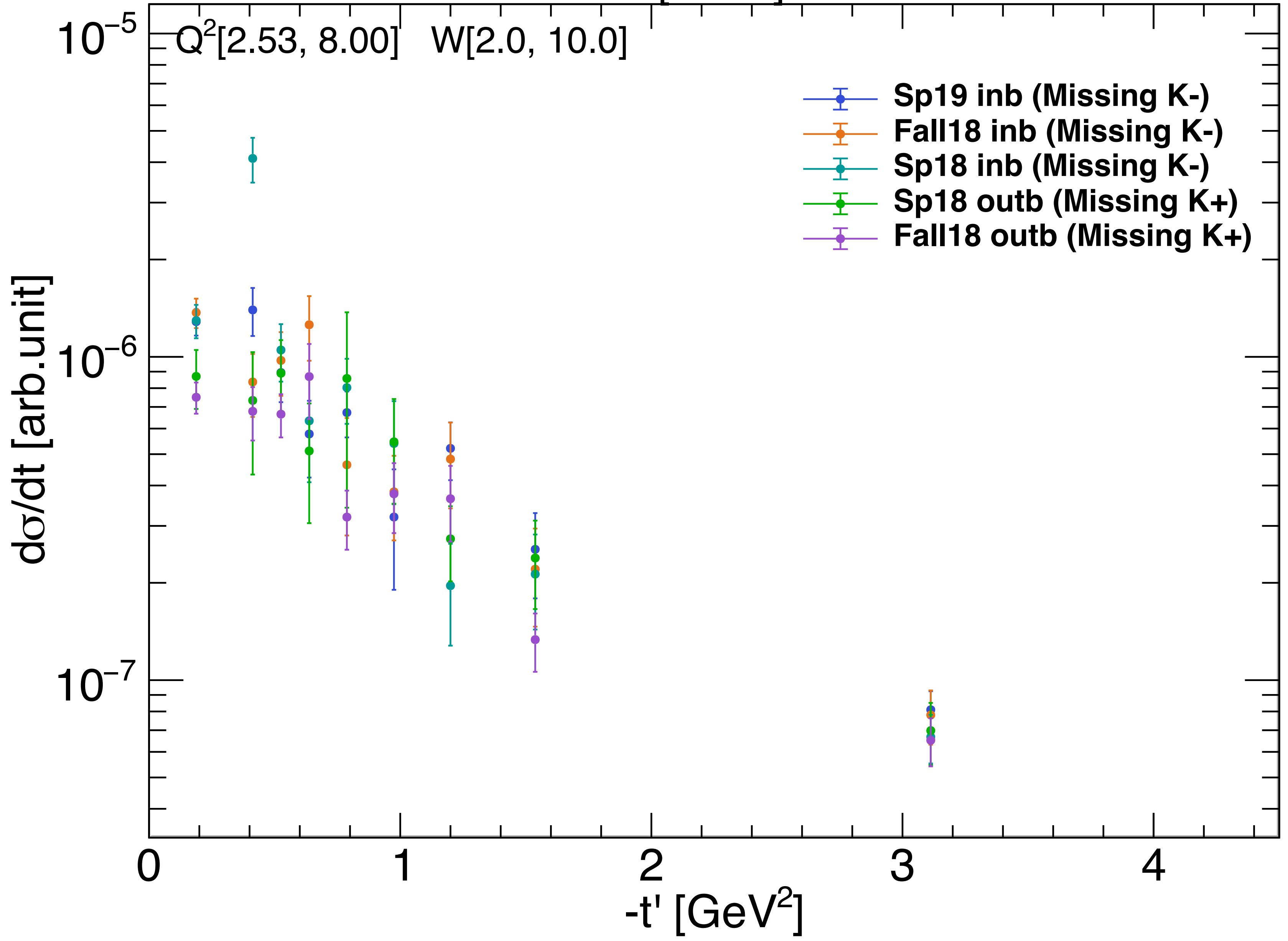
Full statistics for all runs: momentum and QADB corrections









Gluon radius extraction

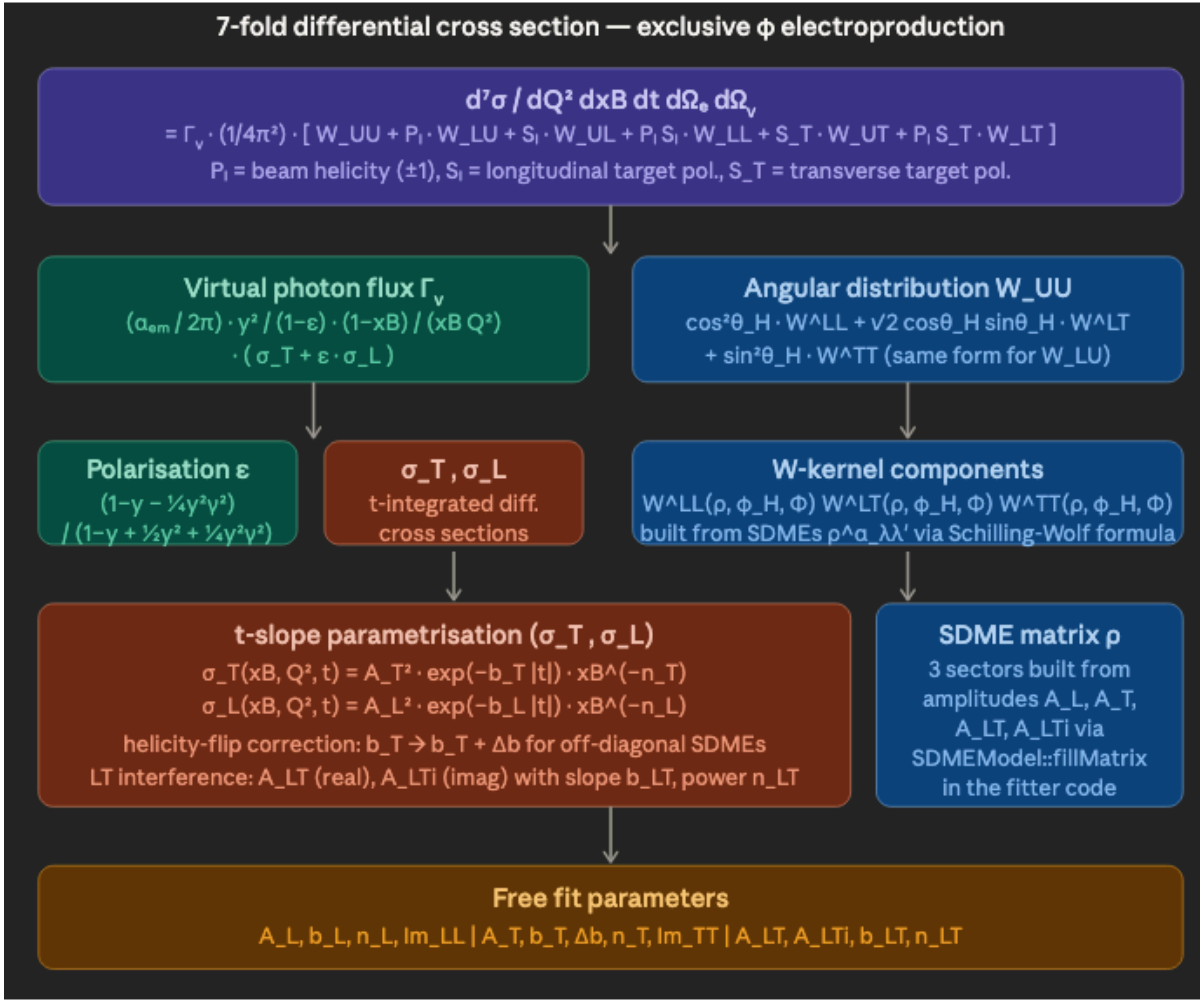
- Based on the PAC39 we can extract the gluon radius by assuming a dipole like behavior of the X

$$\text{Fit function } \frac{d\sigma}{dt} = \frac{\sigma_0}{\left(1 + \frac{|t|}{m_g^2}\right)^4}$$

- Extract the mean gluon radius via the dipole mass: $m_g^2 = \frac{8}{\langle b^2 \rangle_g} - |t_{\text{min}}|$

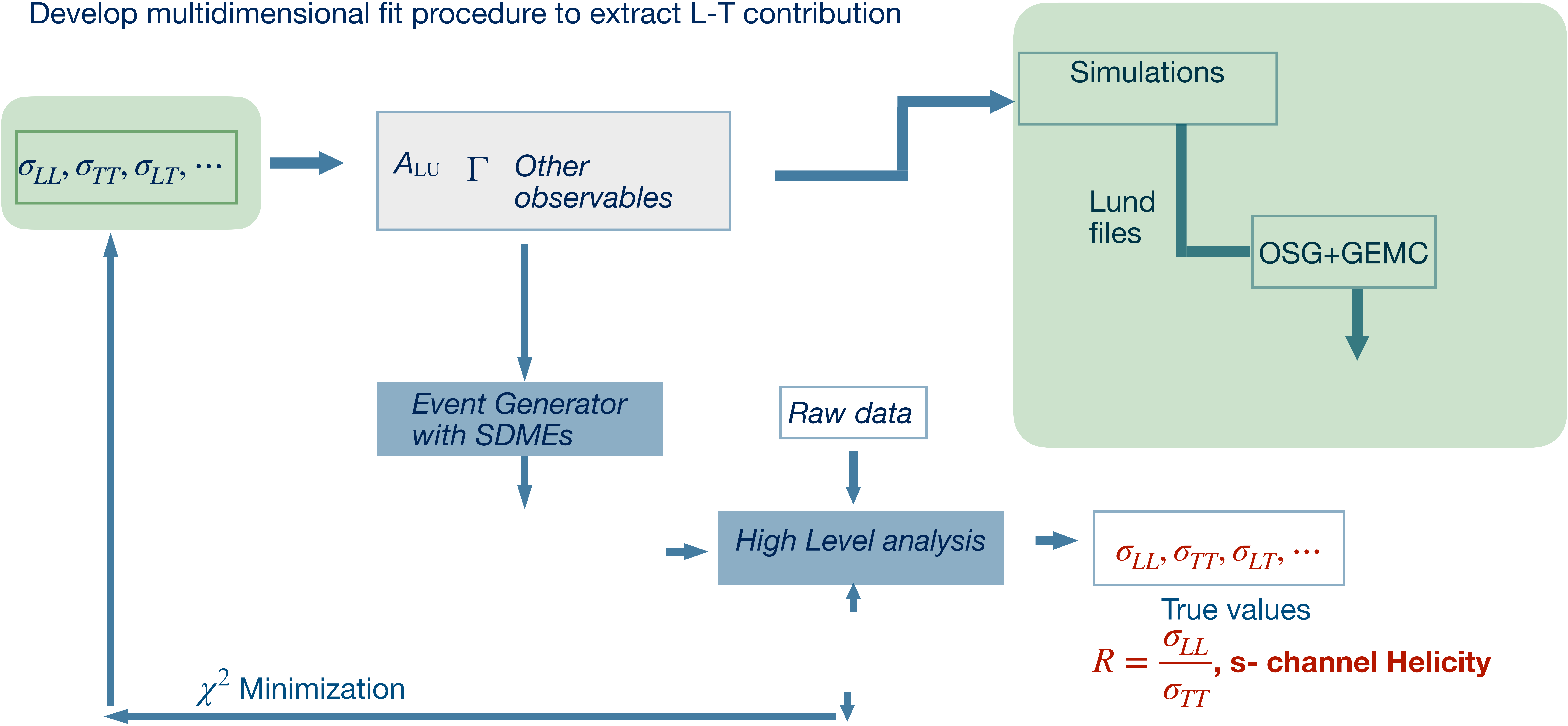
- Mean gluon radius as $\langle b^2 \rangle_g = \frac{8}{m_g^2 + |t_{\text{min}}|} \times (0.1973\ \text{fm})^2$ for different mean xB values

The way we can compute directly the R



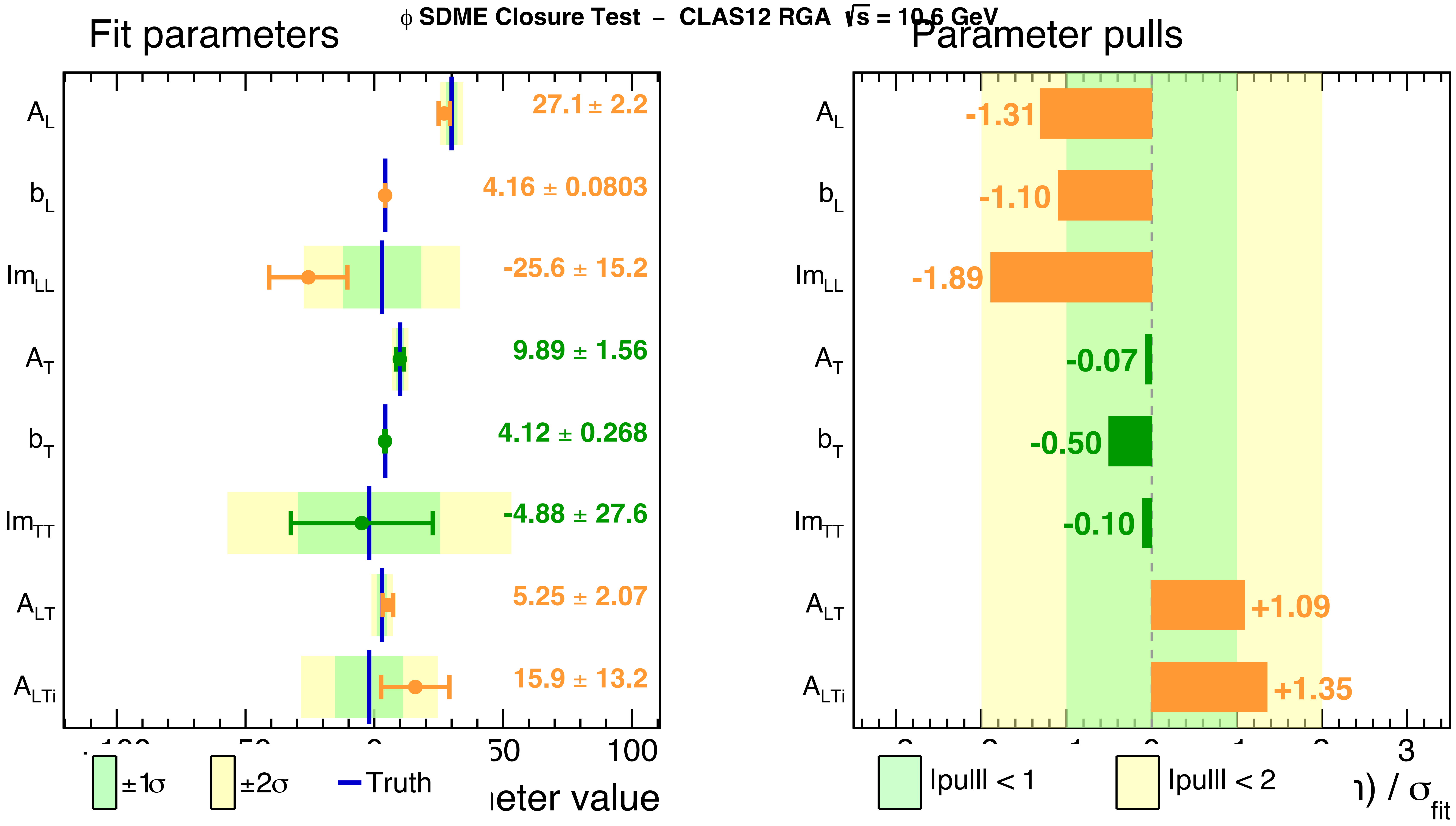
Plan to tackle the MC situation

- Develop multidimensional fit procedure to extract L-T contribution



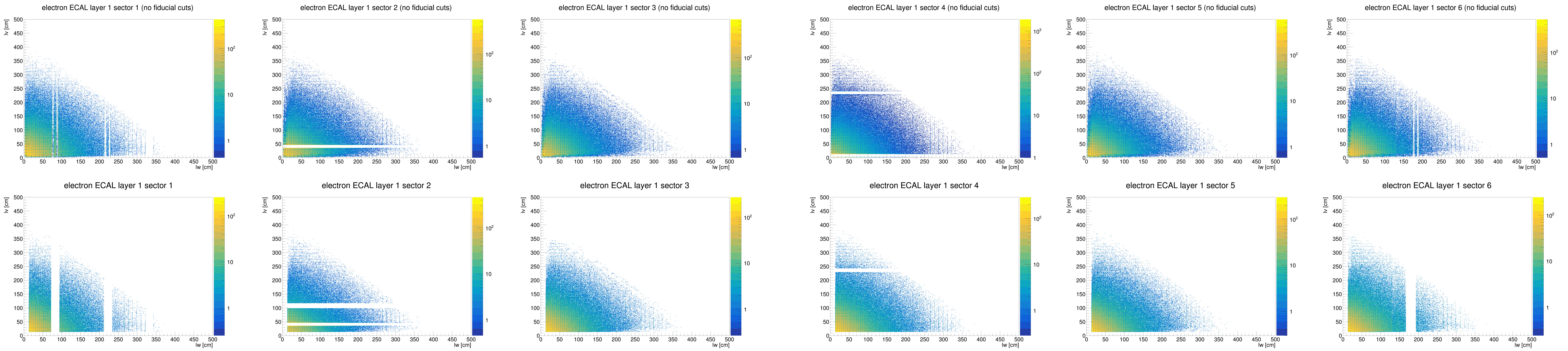
Closure test for fitting procedure

- Take the generated cross-section with parameters +5 % smearing and expect the fits to return the similar parameters —> **Closure test passed!**



Fiducial volume for electron and hadrons

- FT, **FD**, and CVT regions with possible reconstruction inefficiencies are removed.



Excluded PCAL cuts for electron

Edge cuts (all sectors): lw: 0.0–13.5, lv: 0.0–13.5cm
Sector 1: lw: 72–94.5cm, 211.5–234cm
Sector 2: lv: 99–117.5cm
Sector 3: lv: 346.5–378cm
Sector 4: lv: 0–13.5cm, 229.5–243cm
Sector 6: lw: 166.5–193.5cm

Similarly for EC_{in}

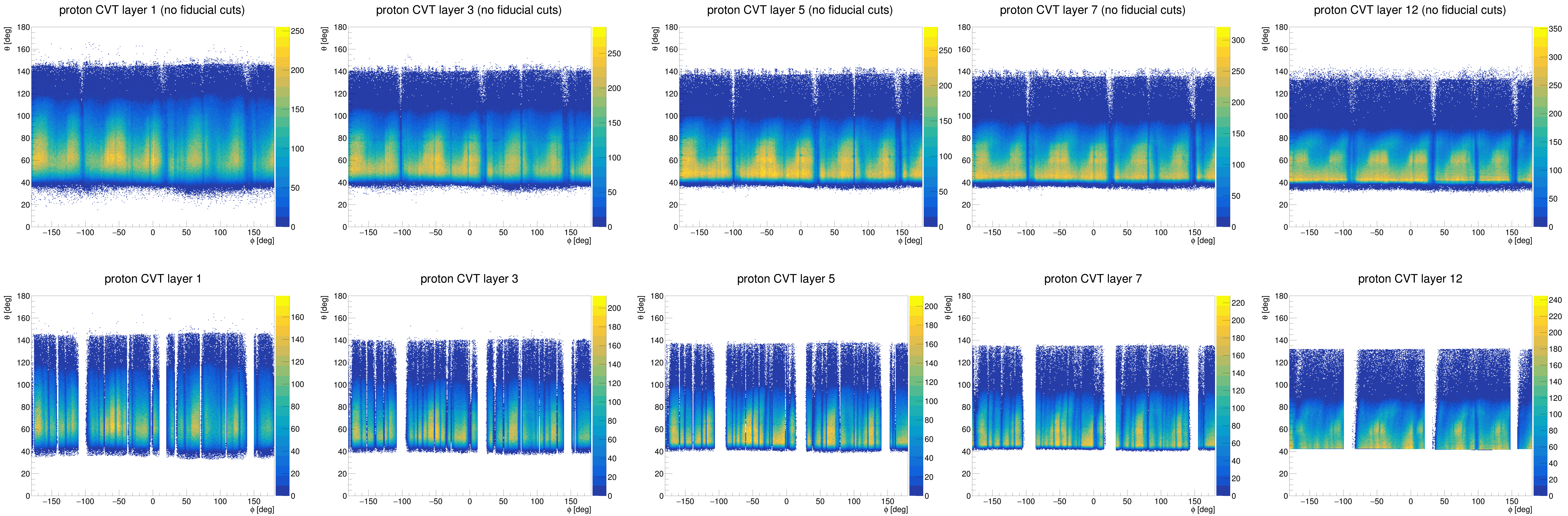
Sector 1 lv: 67.5cm —94.5cm
Sector 4 lw: 0.0cm — 23.5cm
Sector 5 lv: 0.0cm —23.5cm
Sector 6 lv: 0.0cm —23.5cm

Similarly for EC_{out}

Sector 1 lv: 0.0cm → 40.5cm
Sector 5 lw: 193.5cm → 216.0cm

Fiducial volume for electron and hadrons

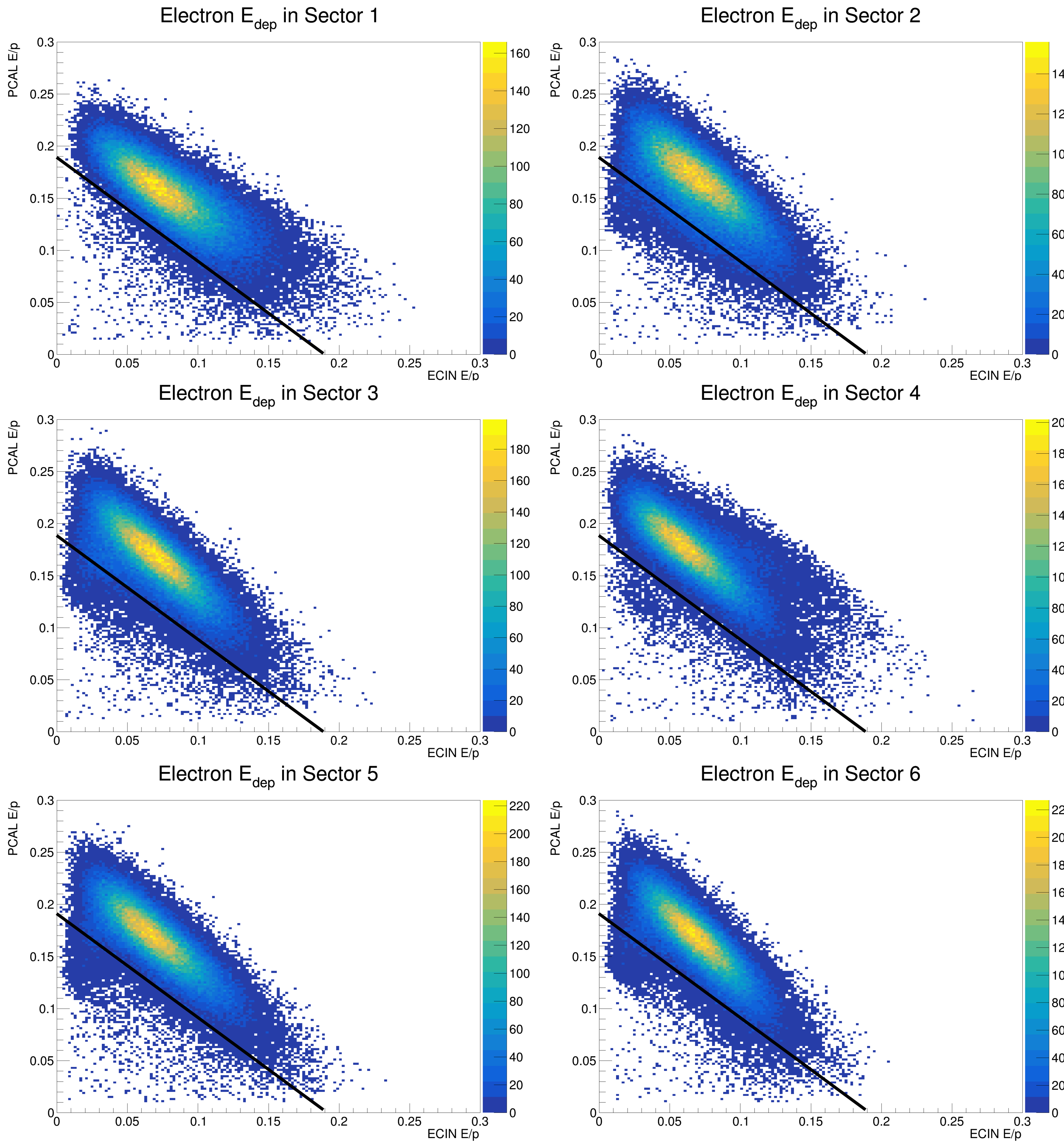
- FT, FD, and **CVT** regions with possible reconstruction inefficiencies are removed.

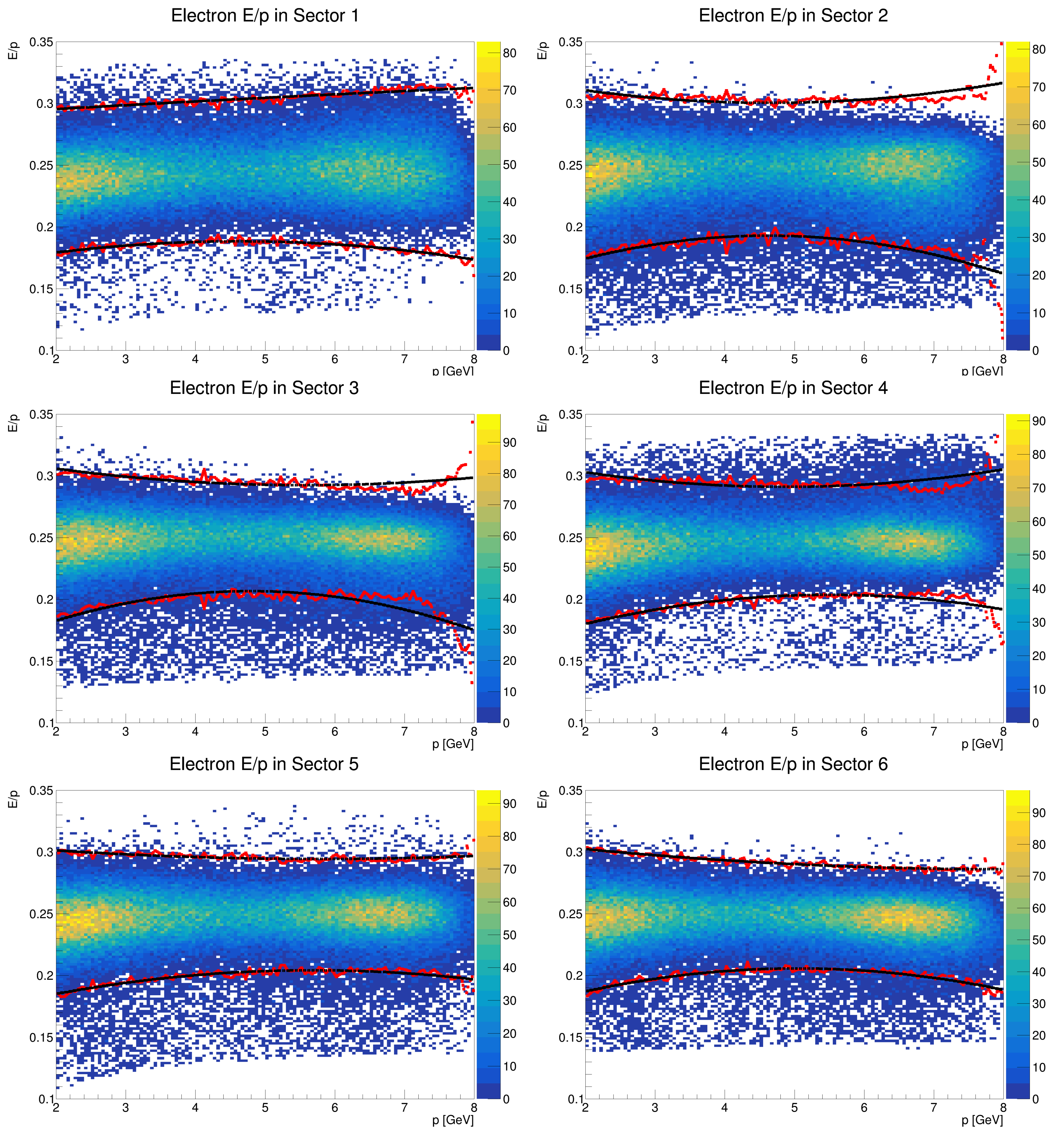


- CVT regions for chi²/NDF is non-flat below the edge variable **Fiducial cuts for the layer 1, 3, 5, 7, and 12)**
- **Sampling fraction cuts for electron, and energy loss corrections for proton are applied.**
- **QADB cuts to select the good run/events**

Electron sampling fraction (spring 2018 inb)

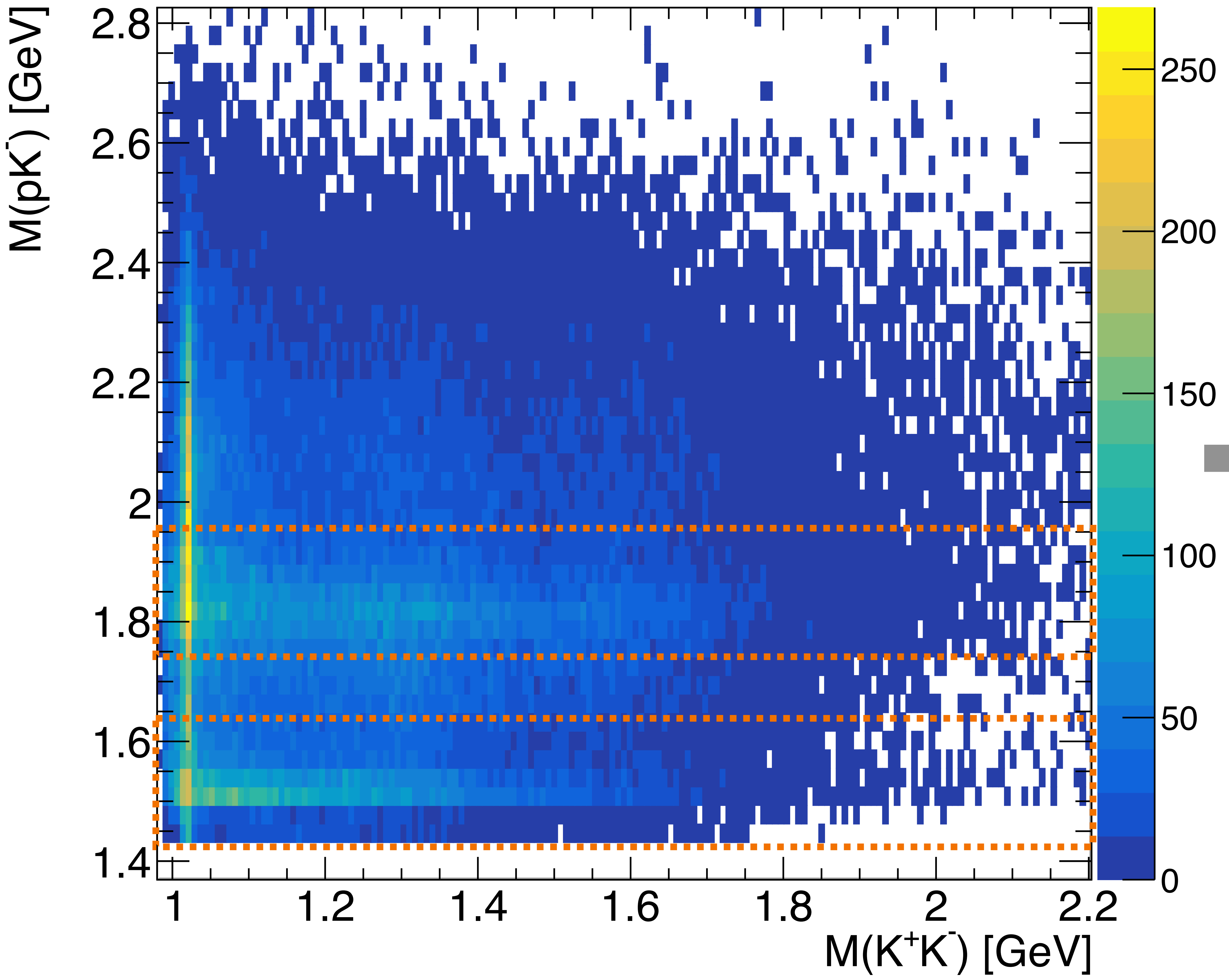
- To reduce the contamination in the electron sample we enforce +- 3 sigma cuts on E/P distributions and PCAL E/p vs ECin E/p diagonals cuts to separate possible pi- contaminations

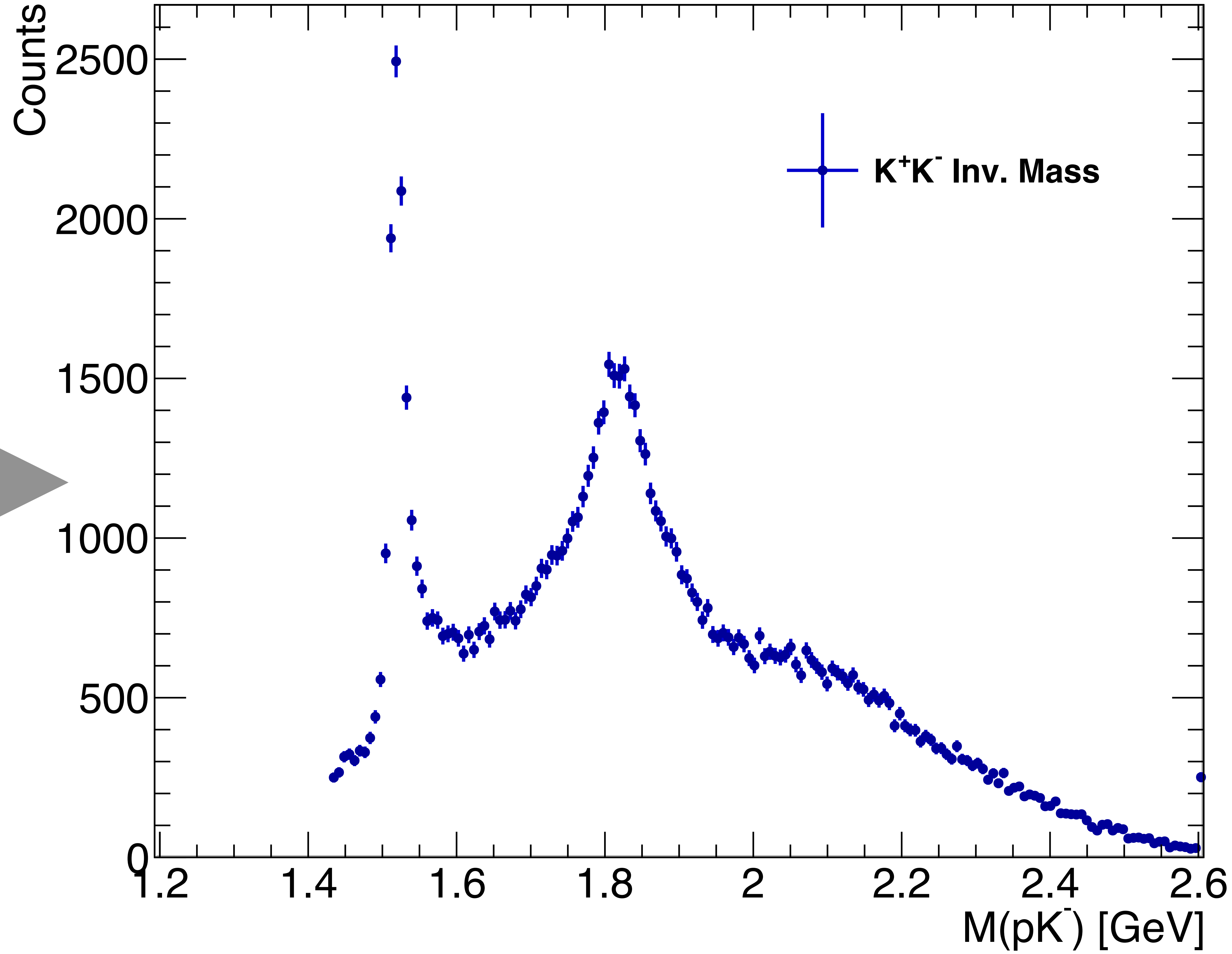




Background under the signal

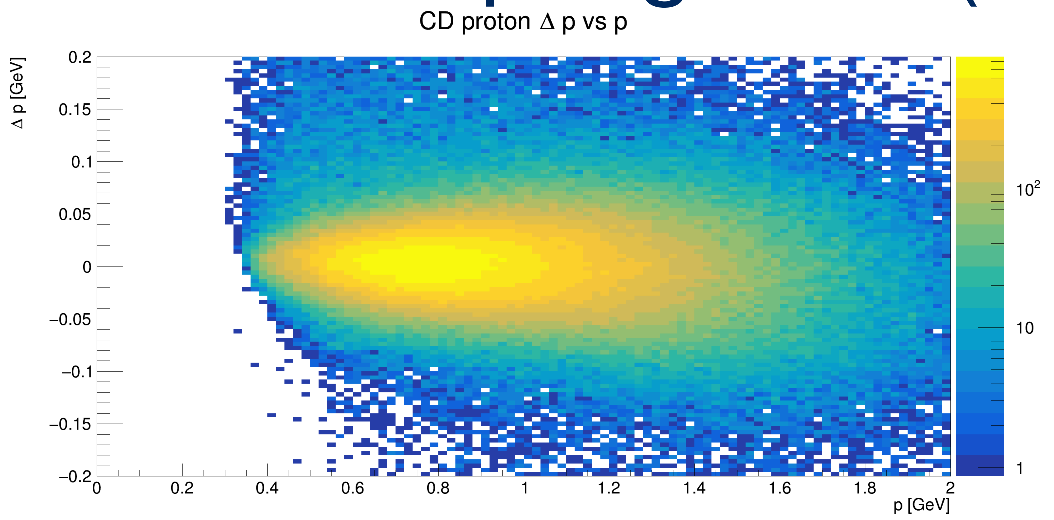
- Production of $\Lambda^*(1520,1830)$ can lead to contamination in the phi DVMP channel





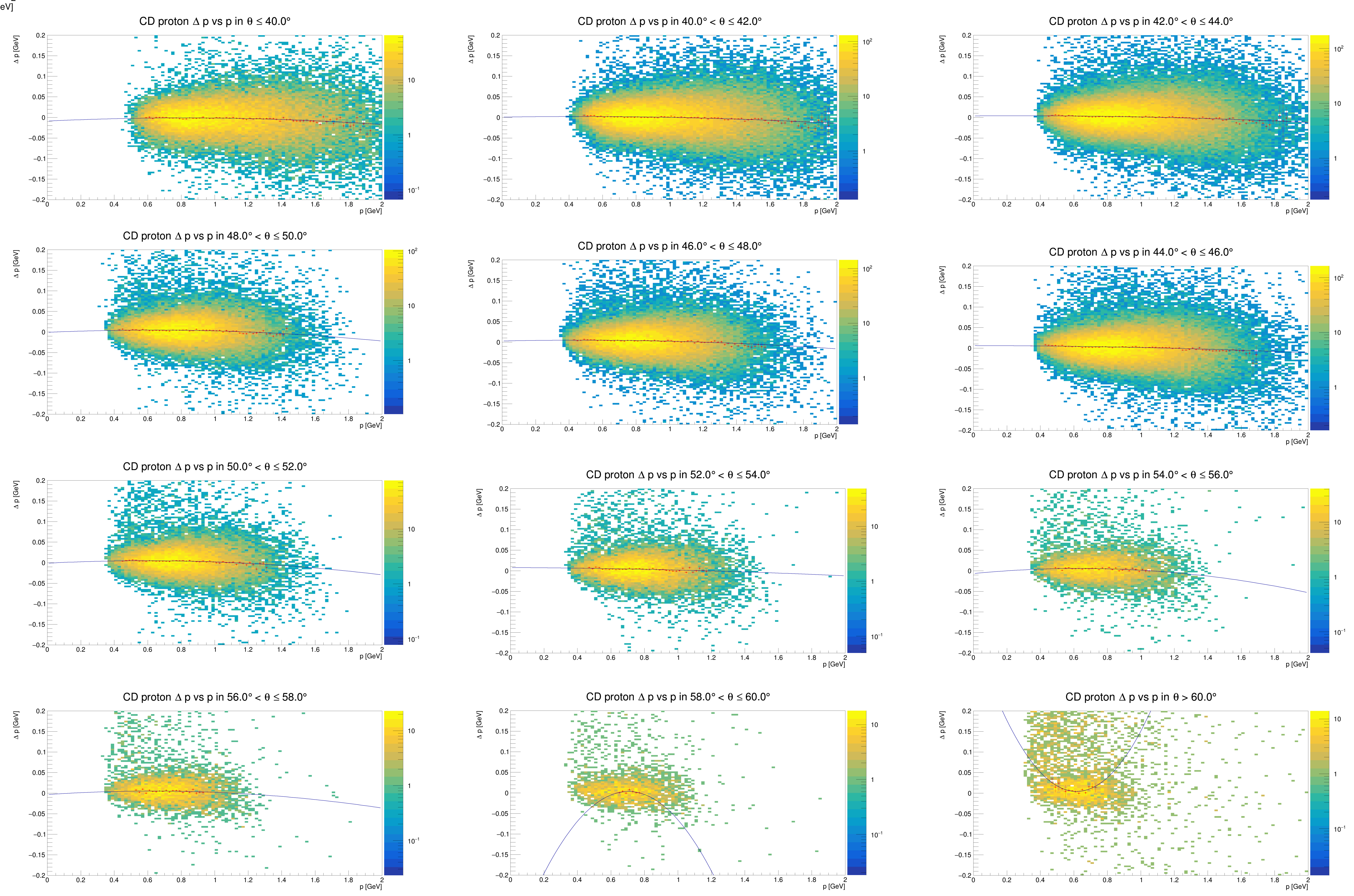
Energy loss corrections RGA (spring 2018 inb)

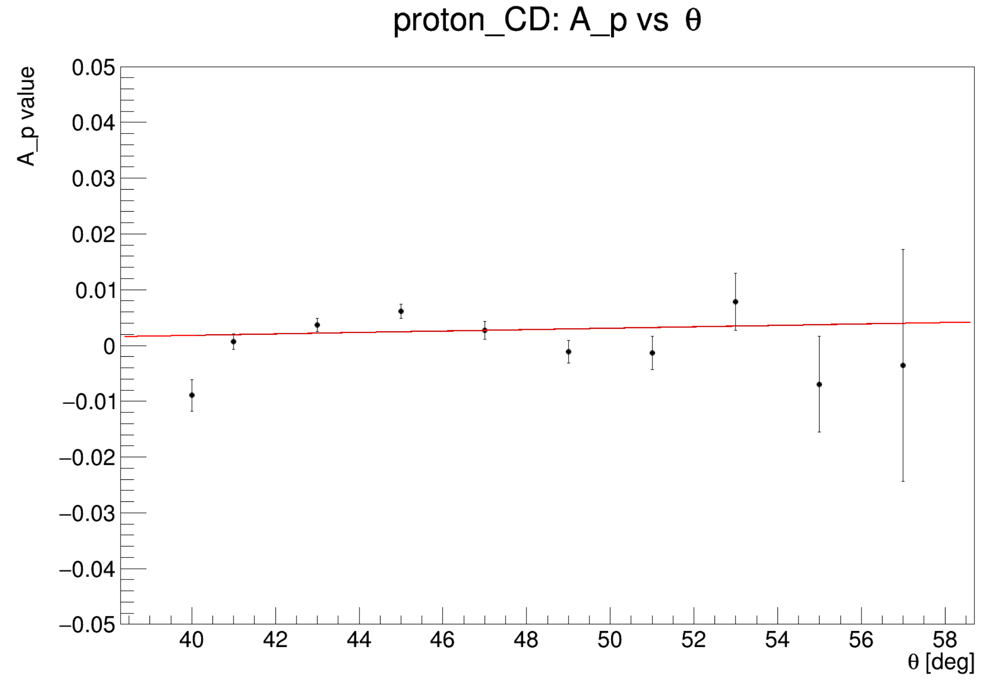
- Here spring 2018 (Fall 2018, spring 2019 T. Hayward see slides:)

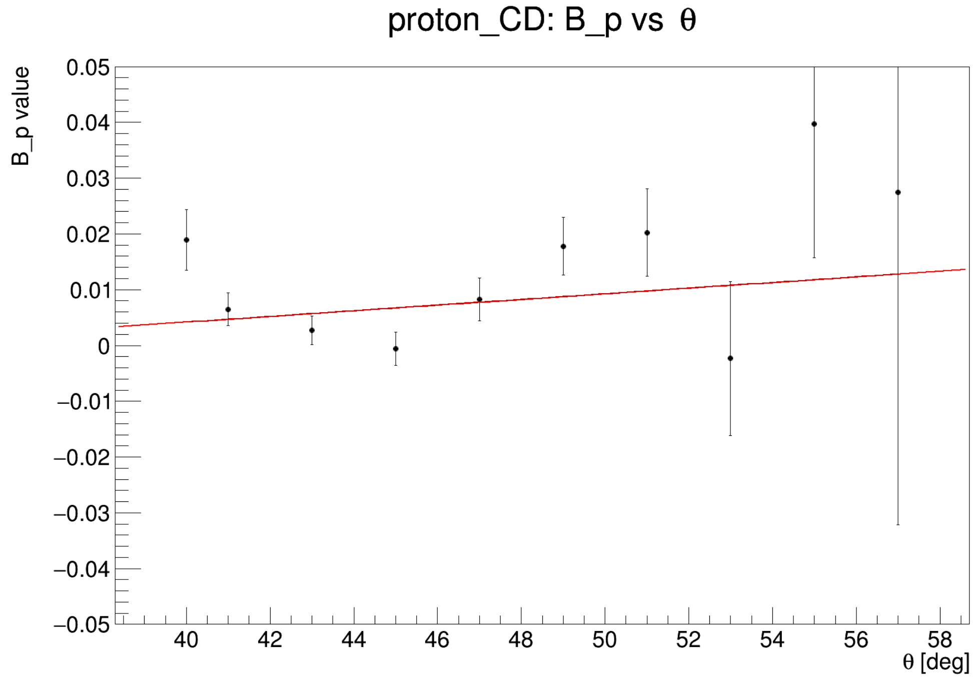


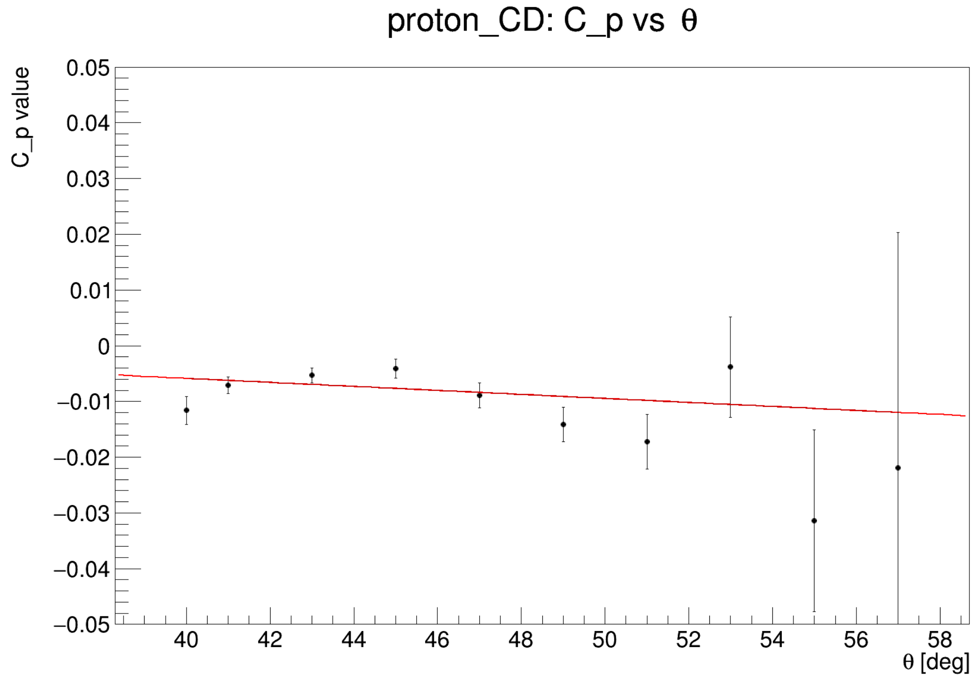
$$\Delta p = A + B \cdot p + C \cdot p^2$$

CD Proton

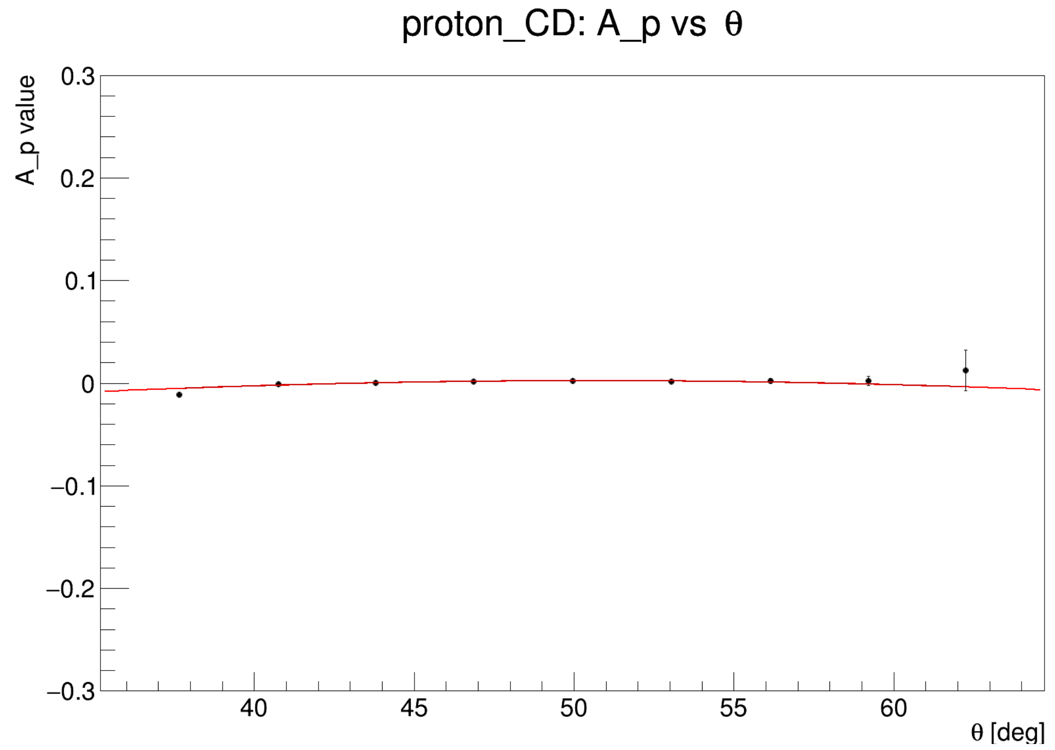


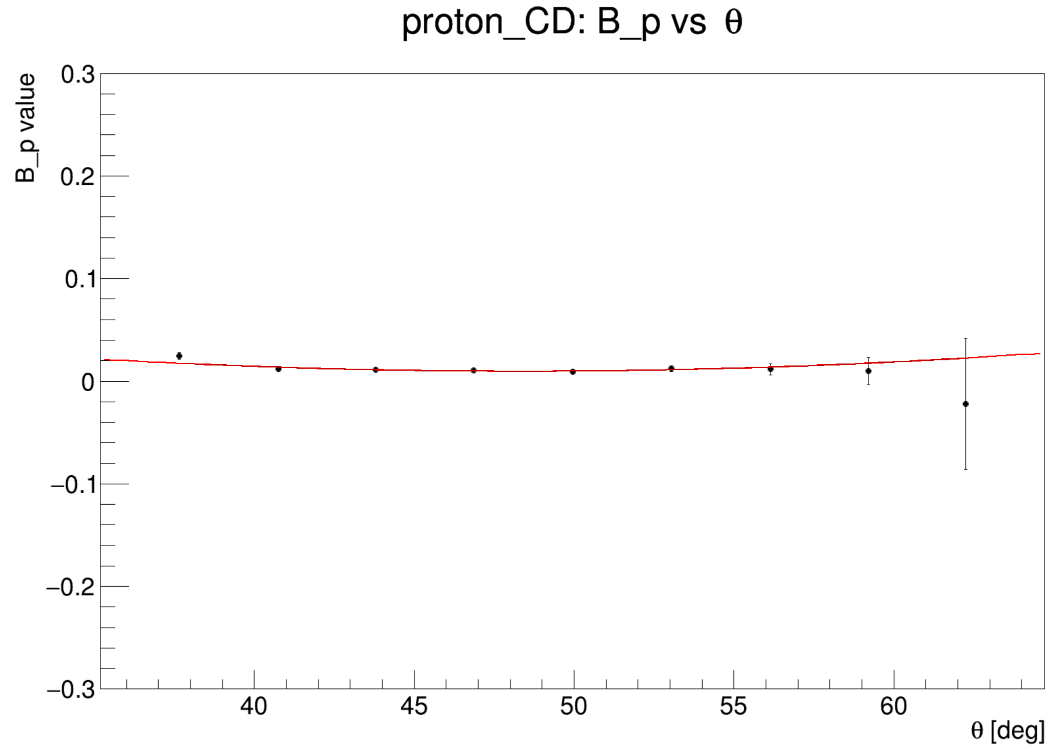


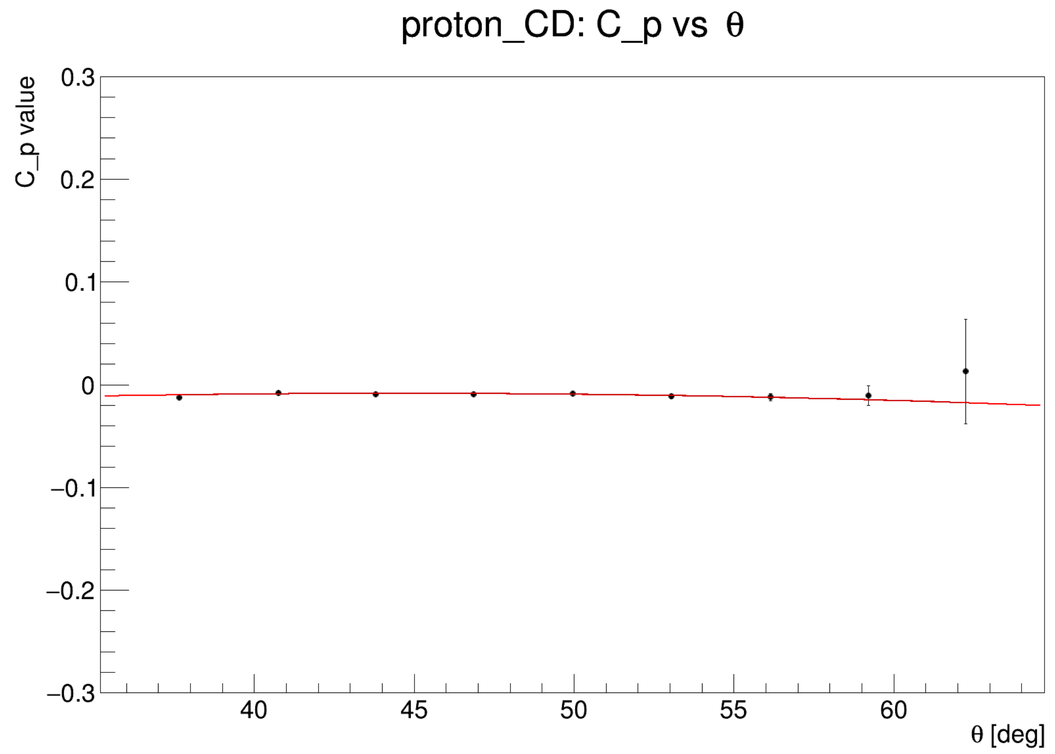




Benchmark: Fall2018_inb proton energy loss correction



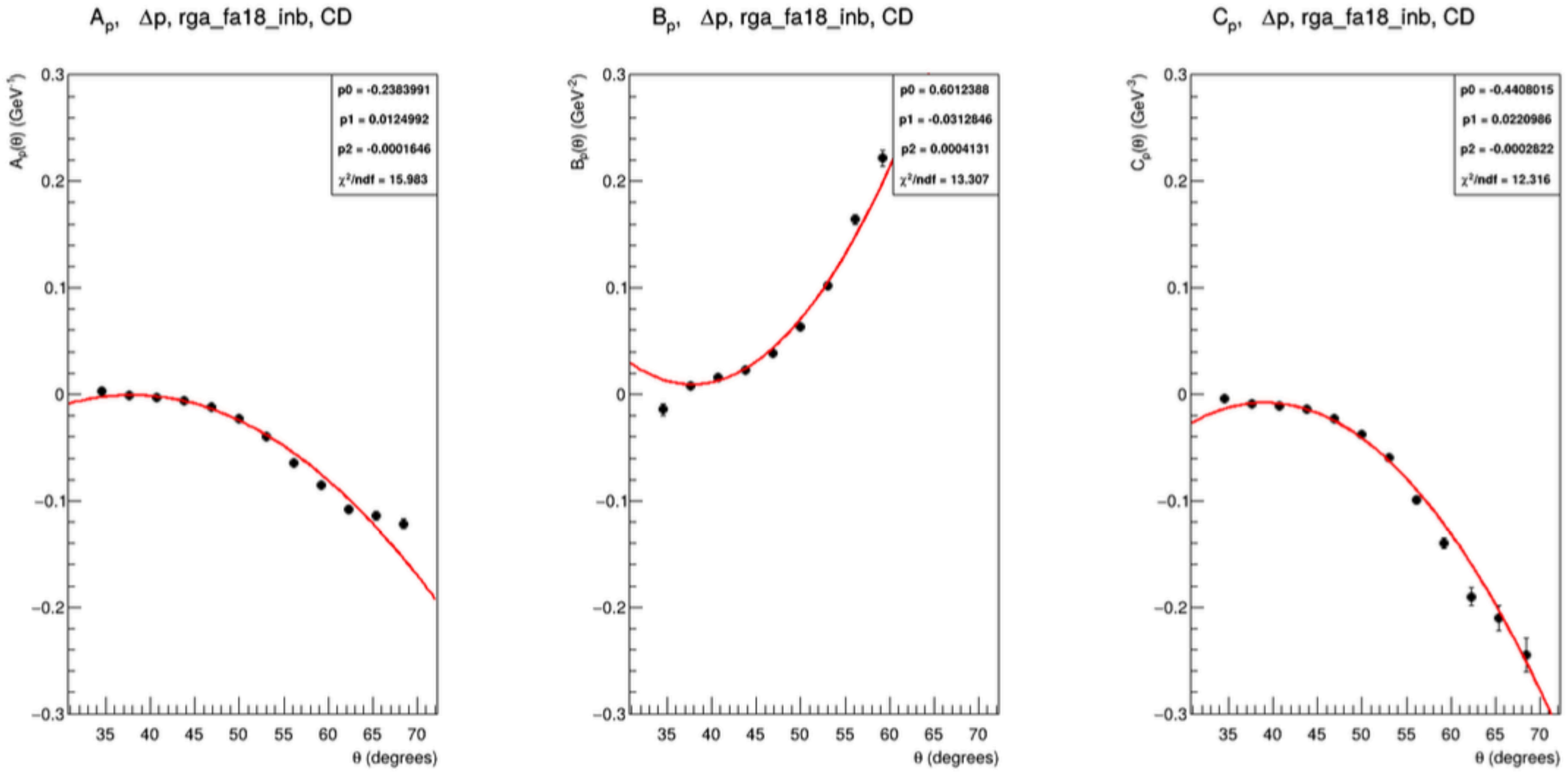




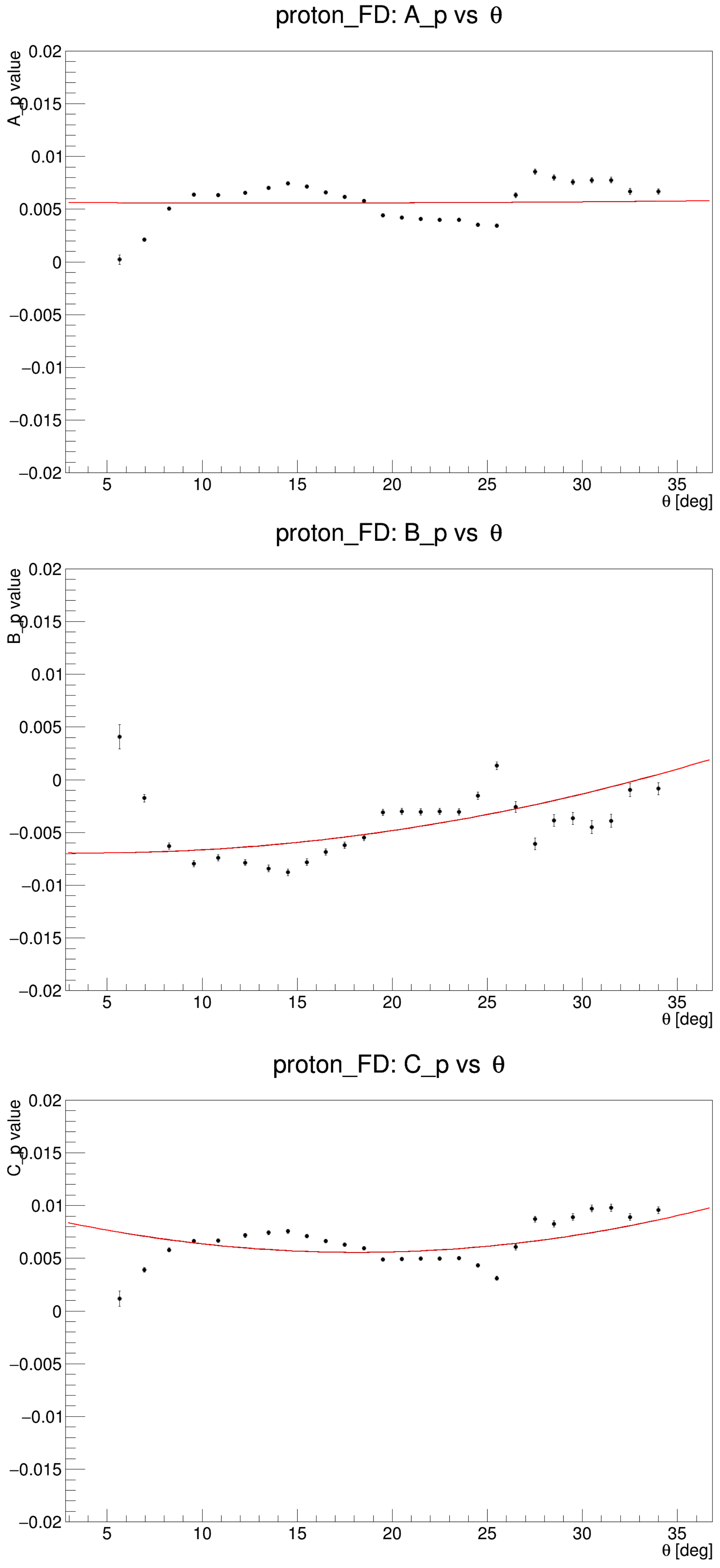
CD

From Timothy

$$p \to p + A_p^{\mathrm{CD}}(\theta) + B_p^{\mathrm{CD}}(\theta)p + C_p^{\mathrm{CD}}(\theta)p^2$$



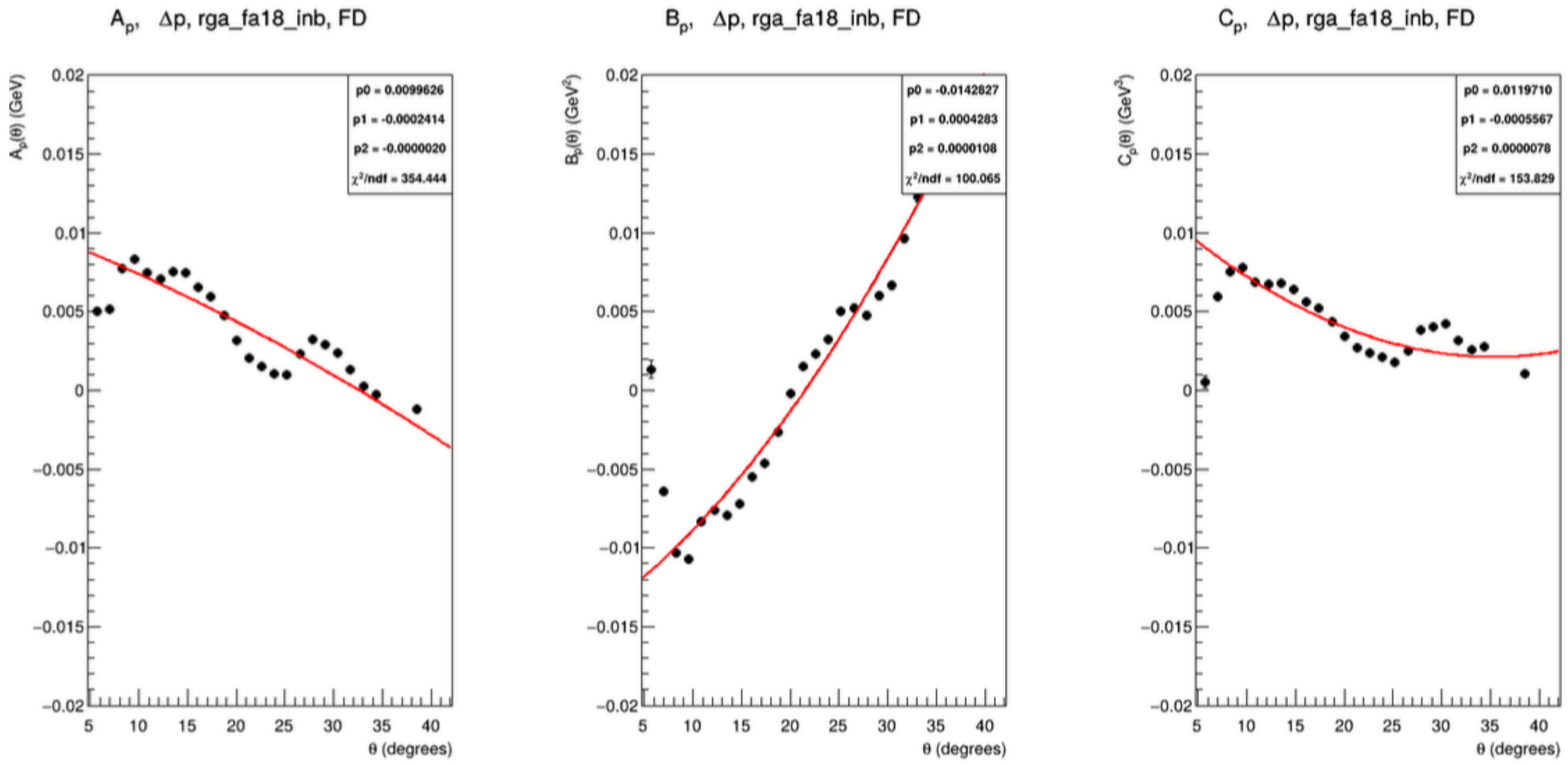
Benchmark: Fall2018_inb proton energy loss correction



FD

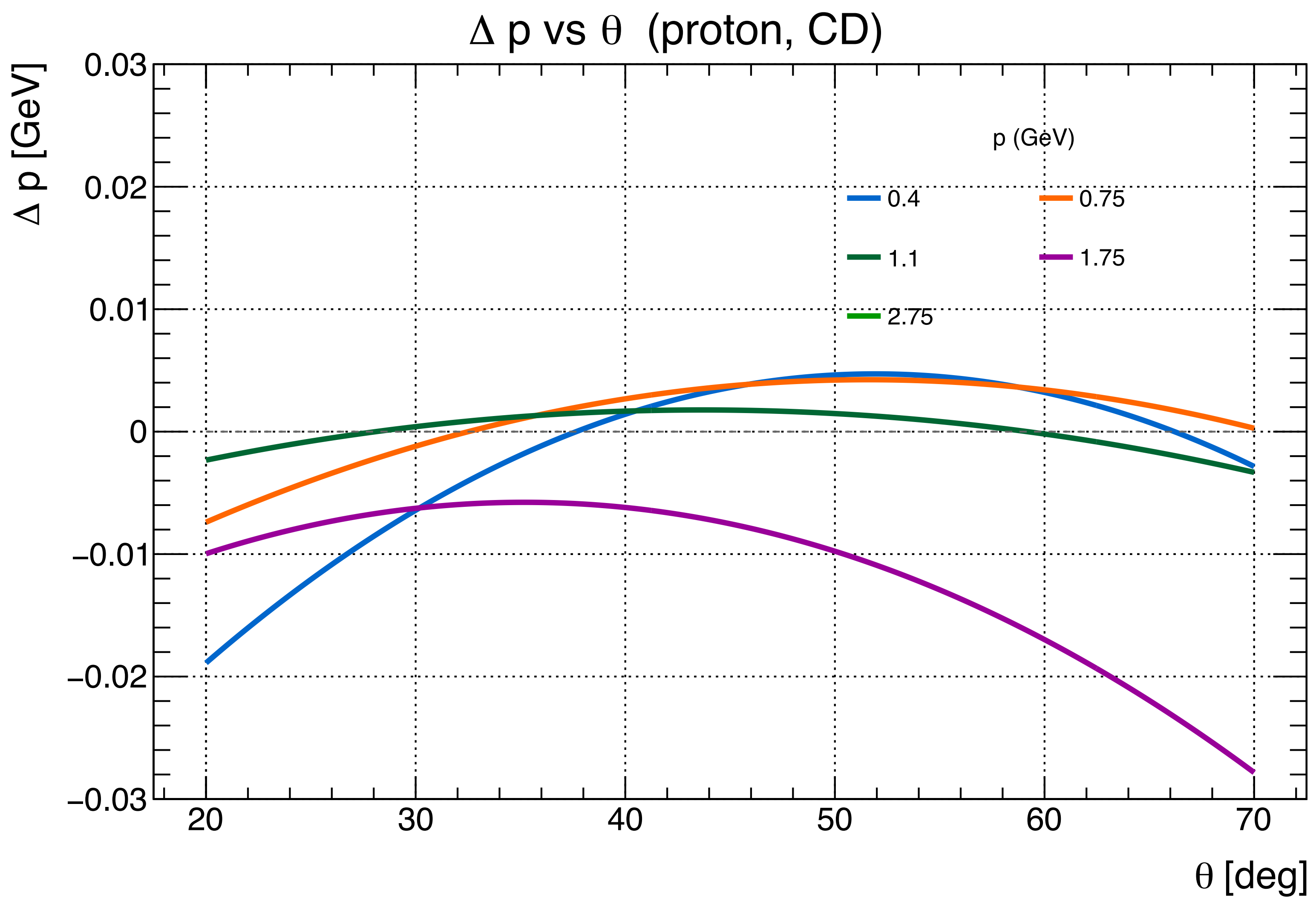
From Timothy

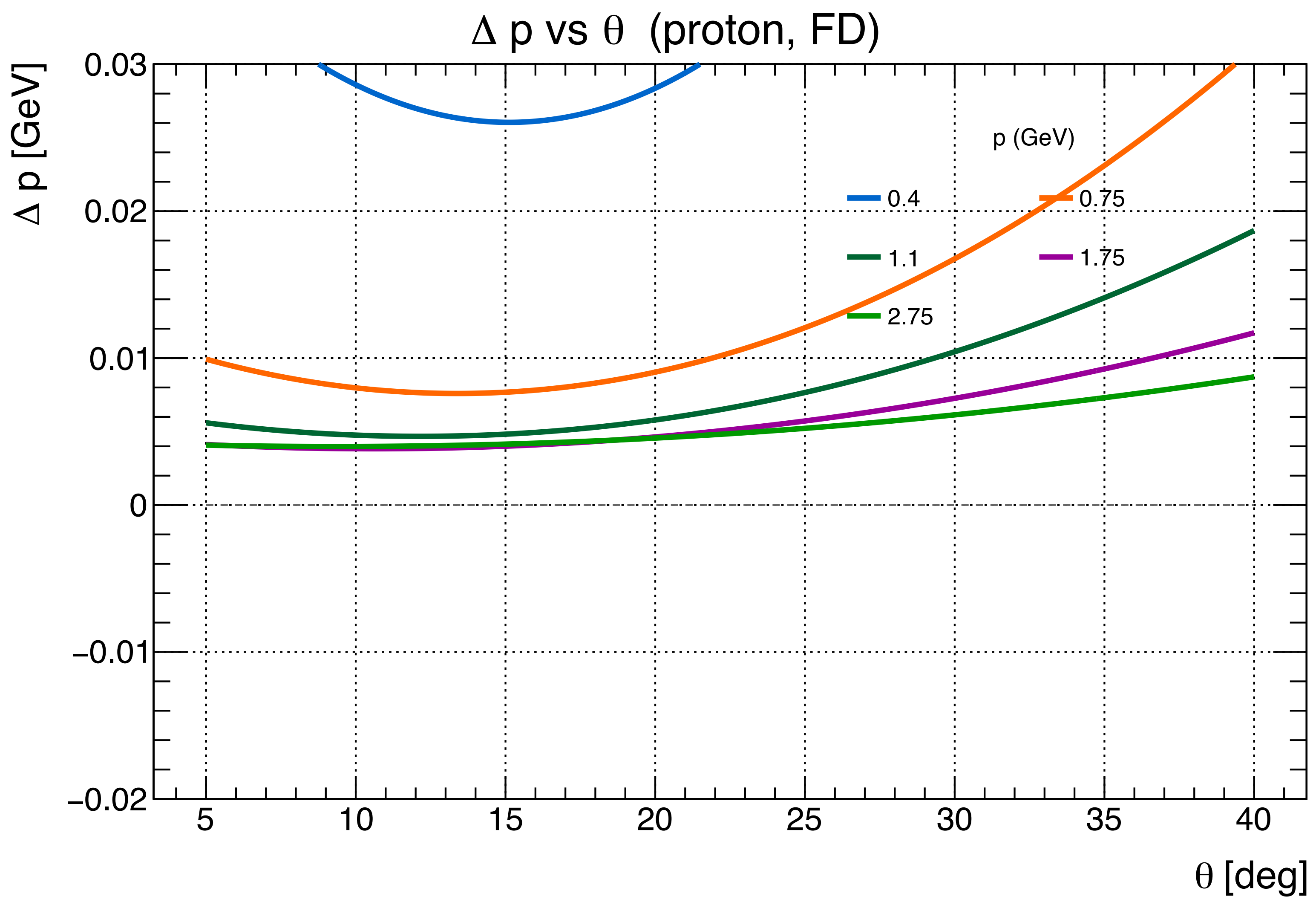
$$p \to p + A_p^{\mathrm{FD}}(\theta) + B_p^{\mathrm{FD}}(\theta)/p + C_p^{\mathrm{FD}}(\theta)/p^2$$



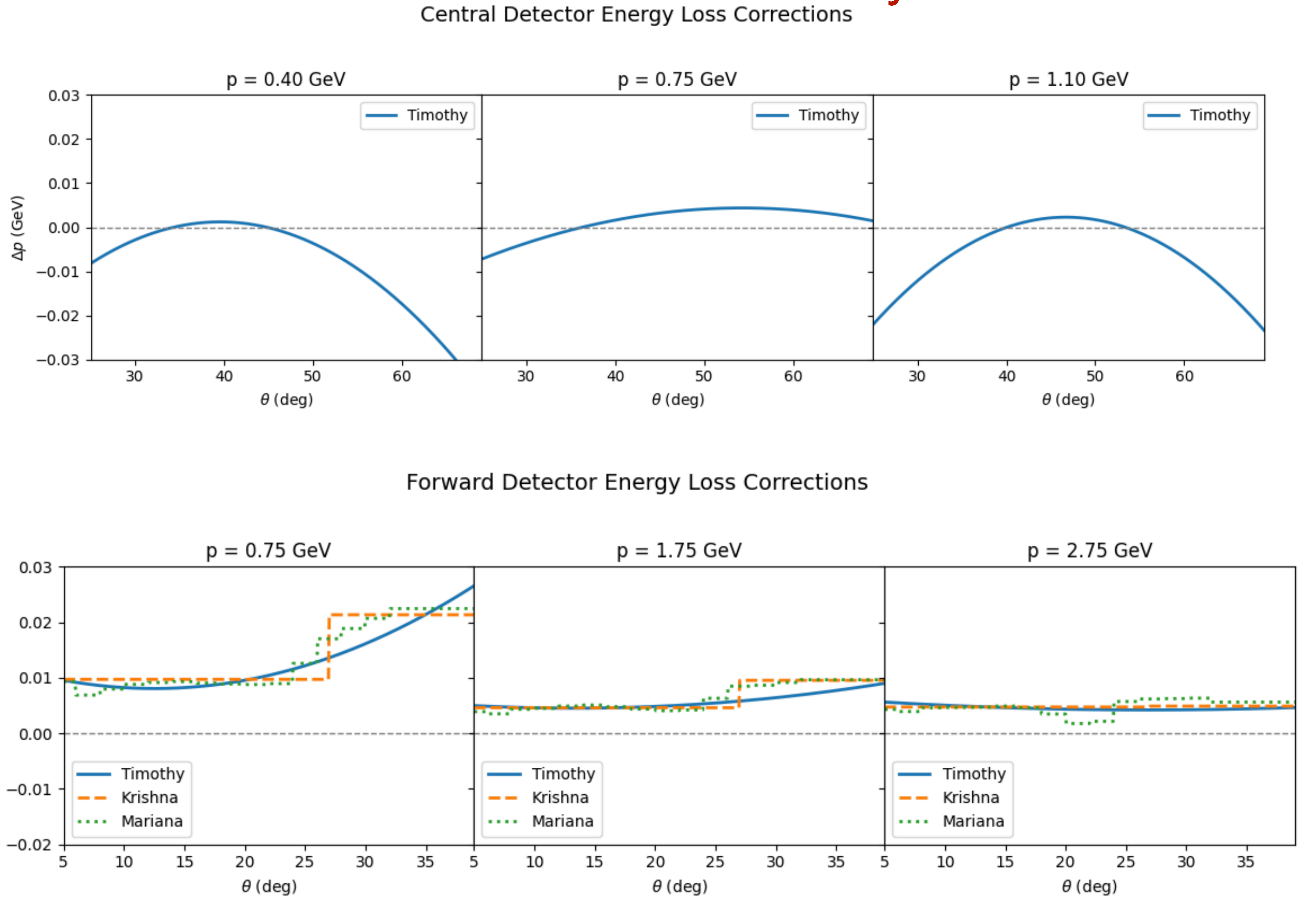
Corrections as function of theta (inb fall 2018)

- Final corrections for different momenta



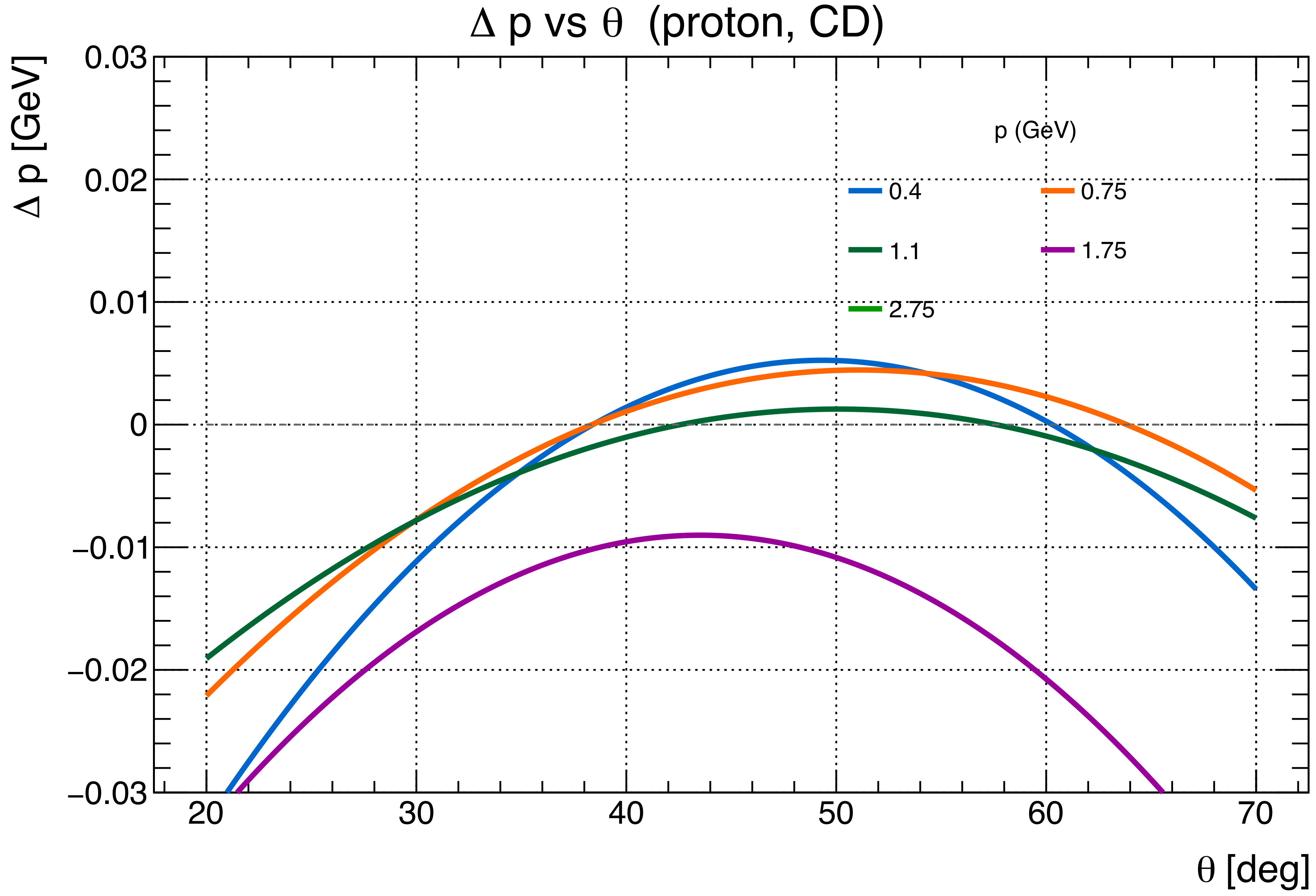


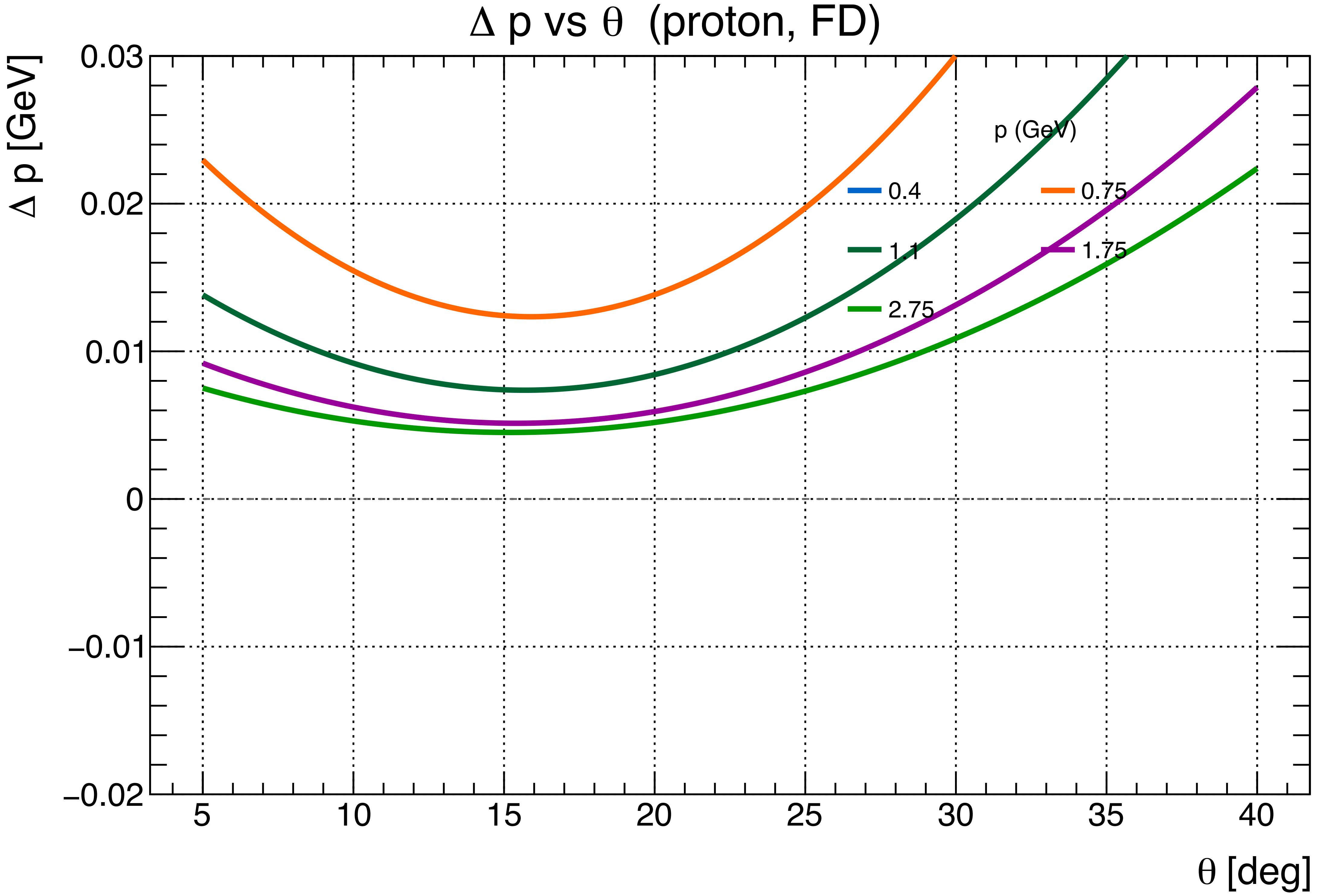
From Timothy



Corrections as function of theta (inb sp2018)

- Final corrections for different momenta

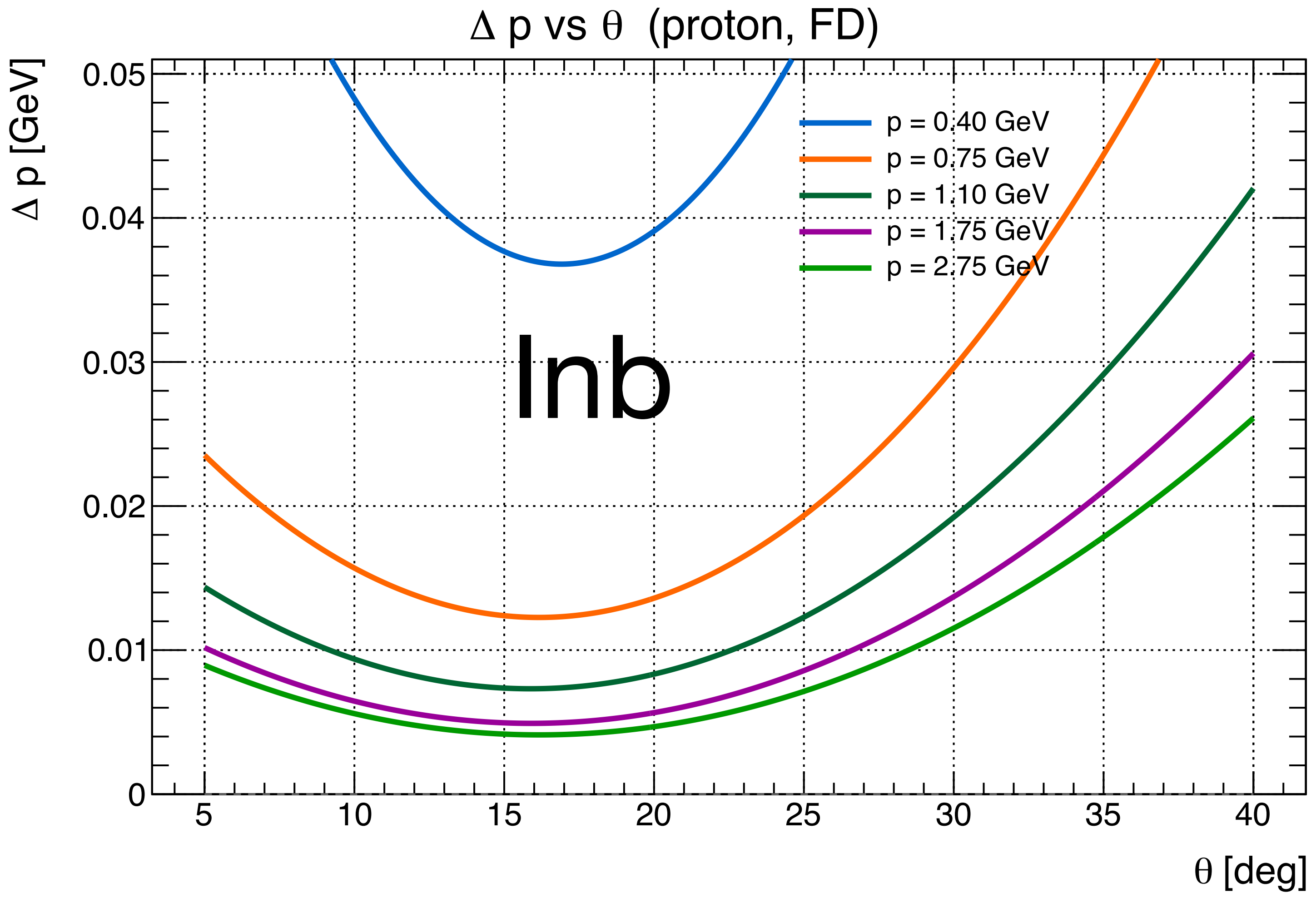


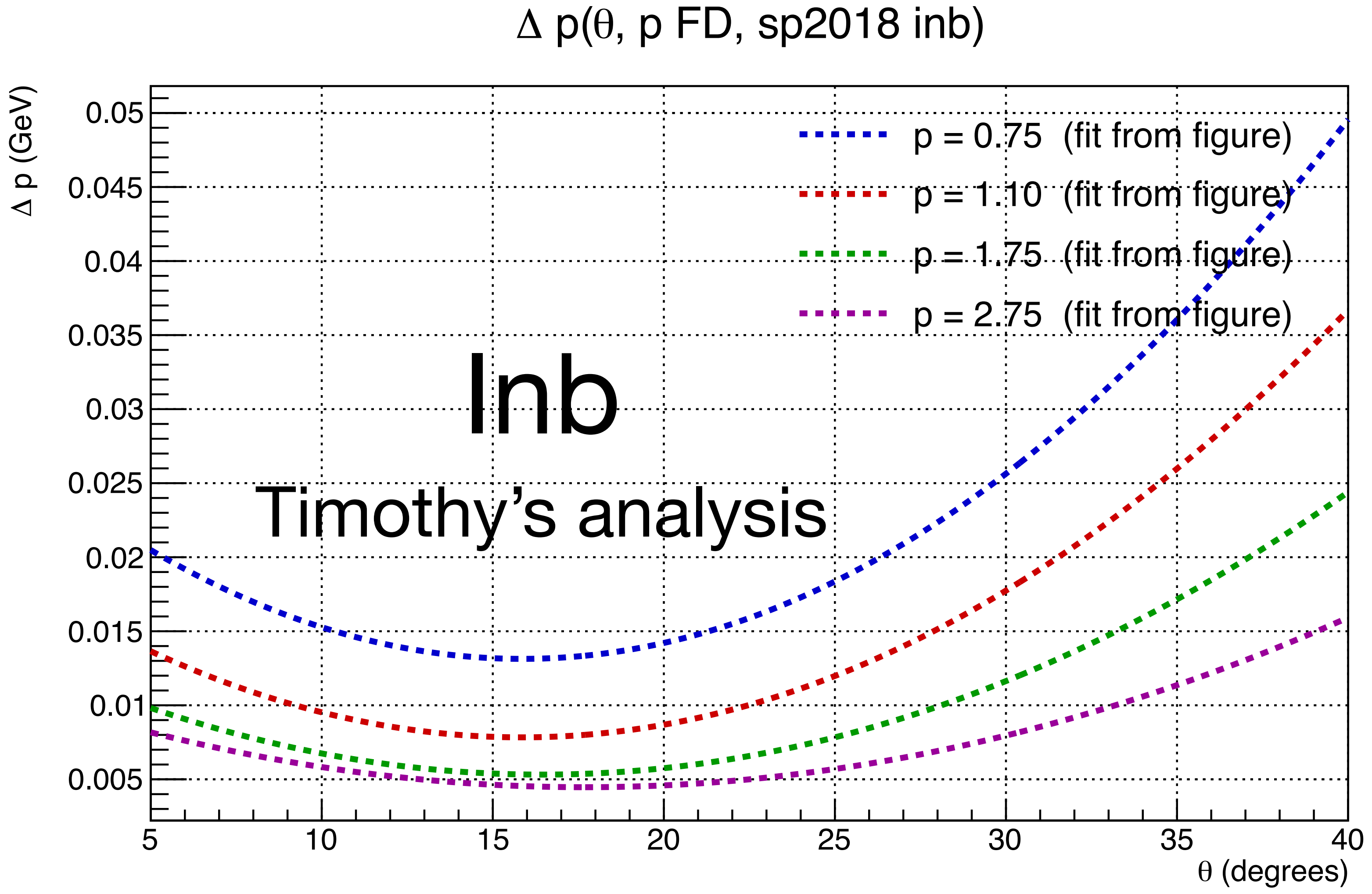


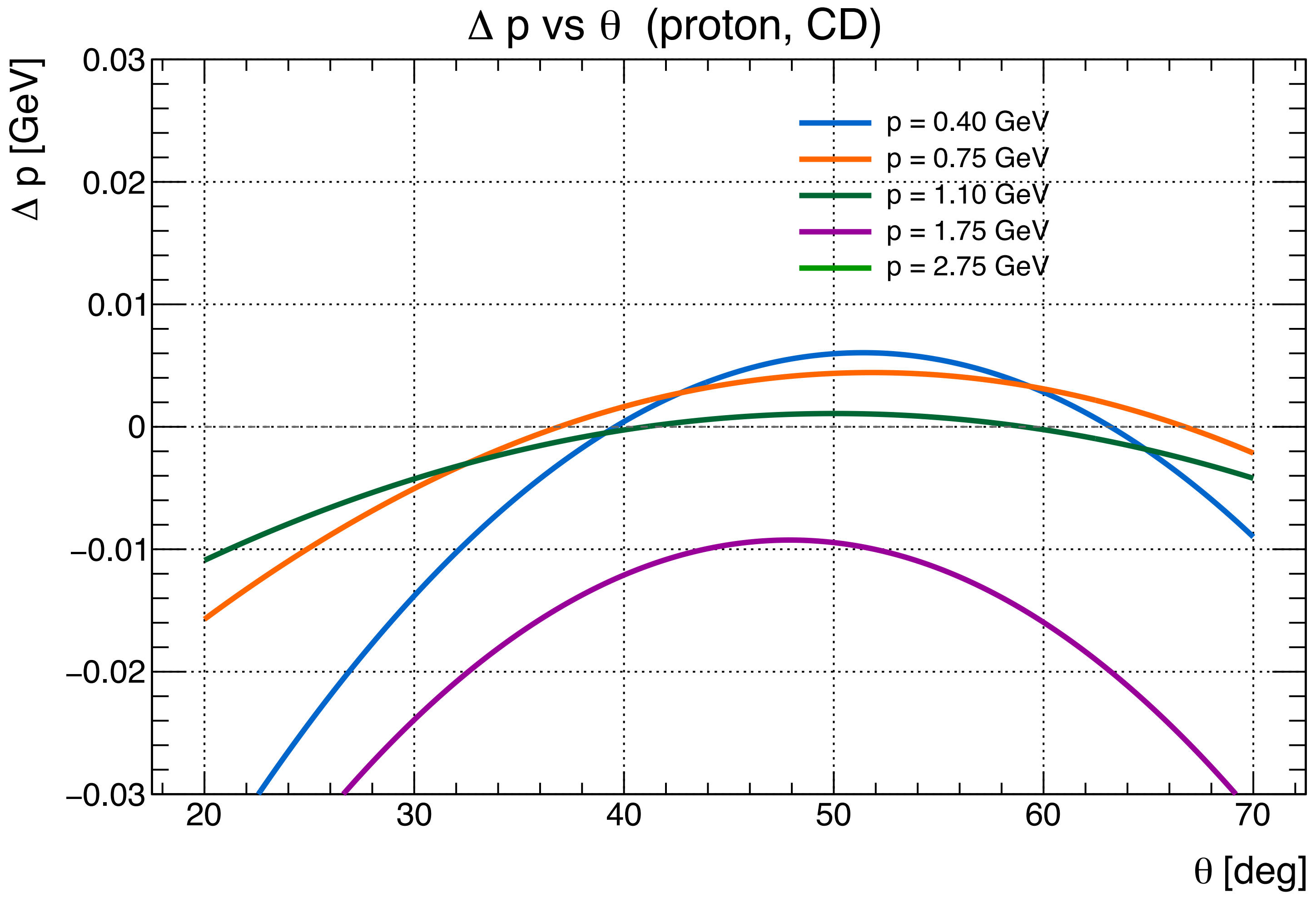
Corrections as function of theta (inb and outb sp2018)

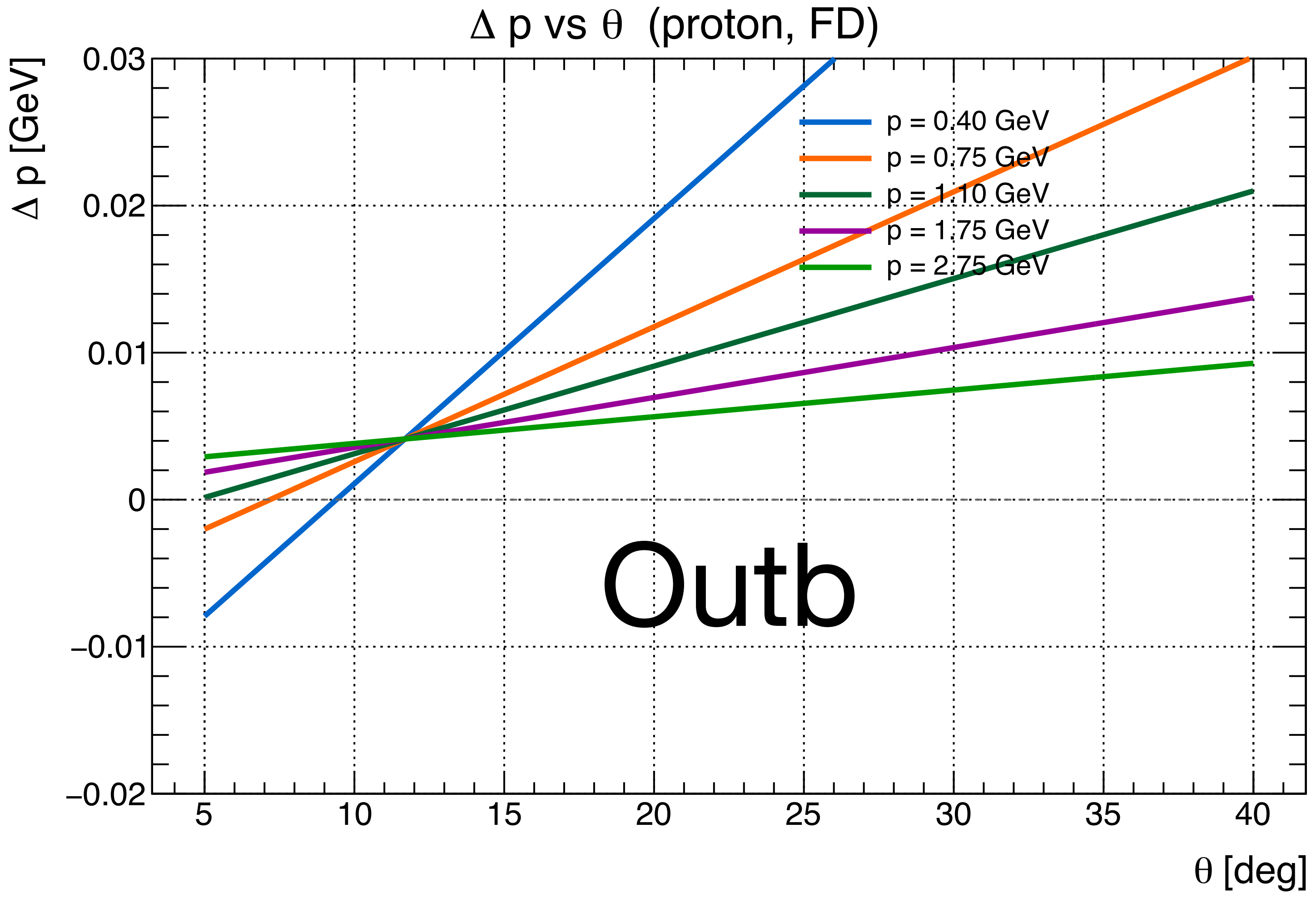
- Final corrections for different momenta

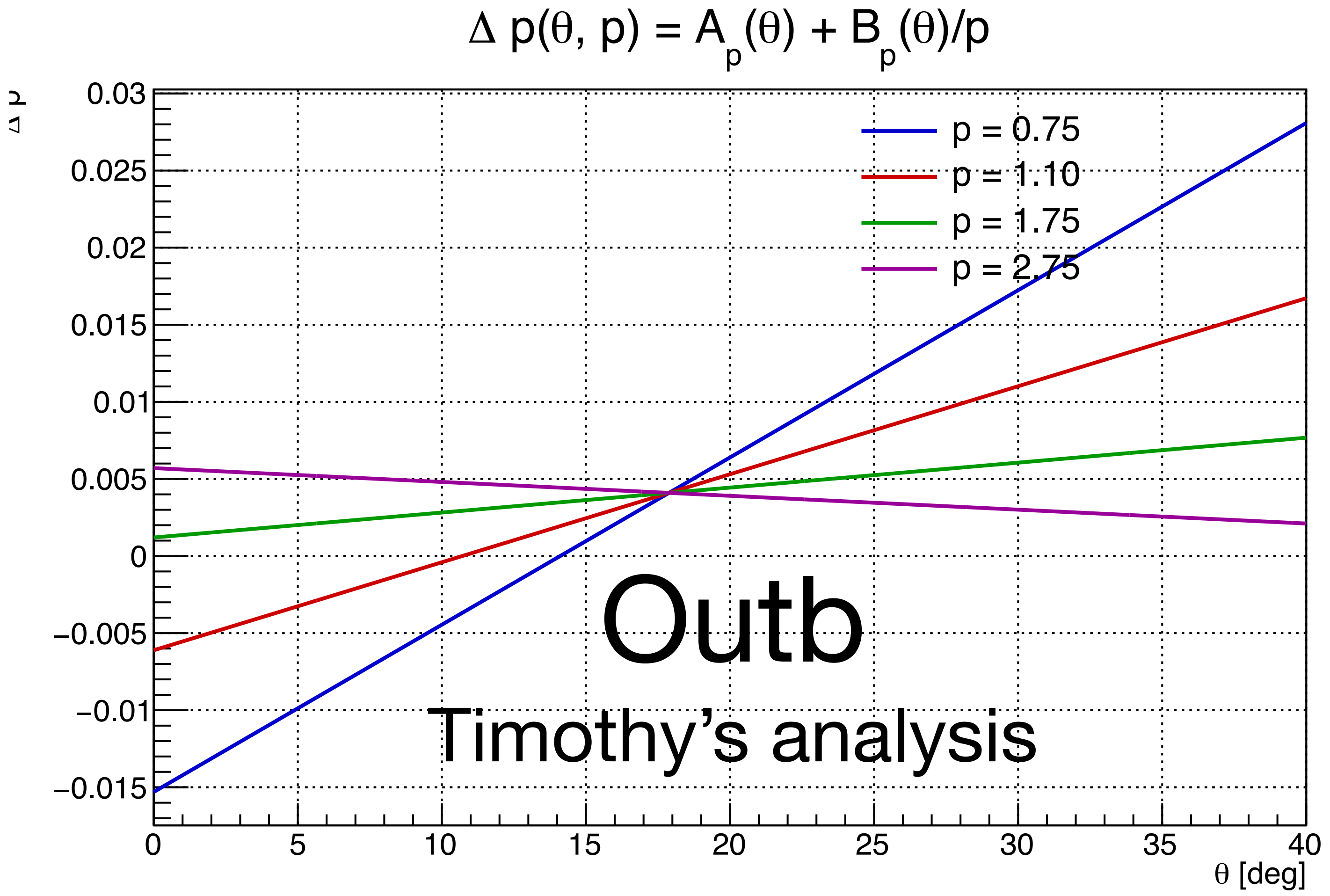
Inb

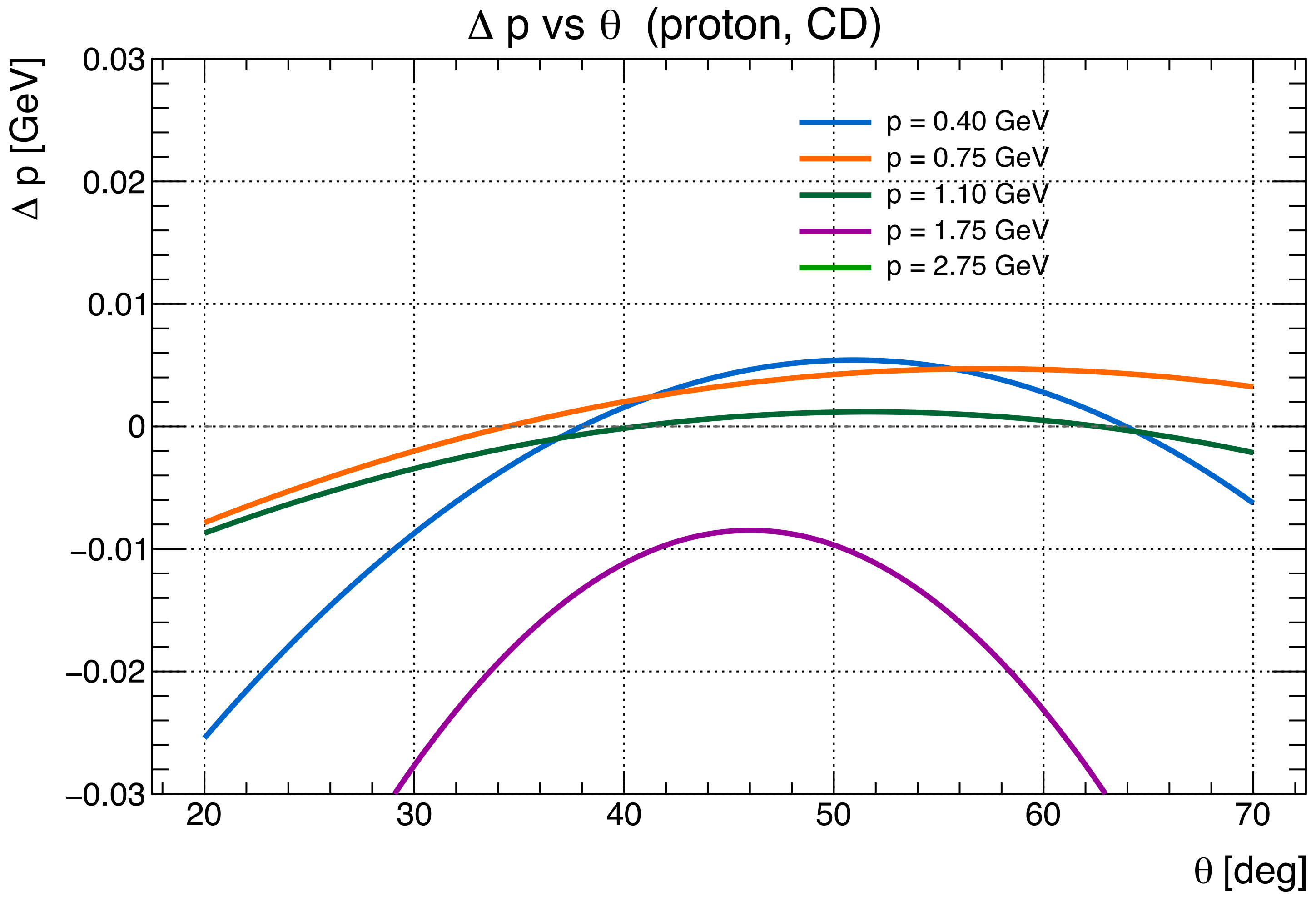








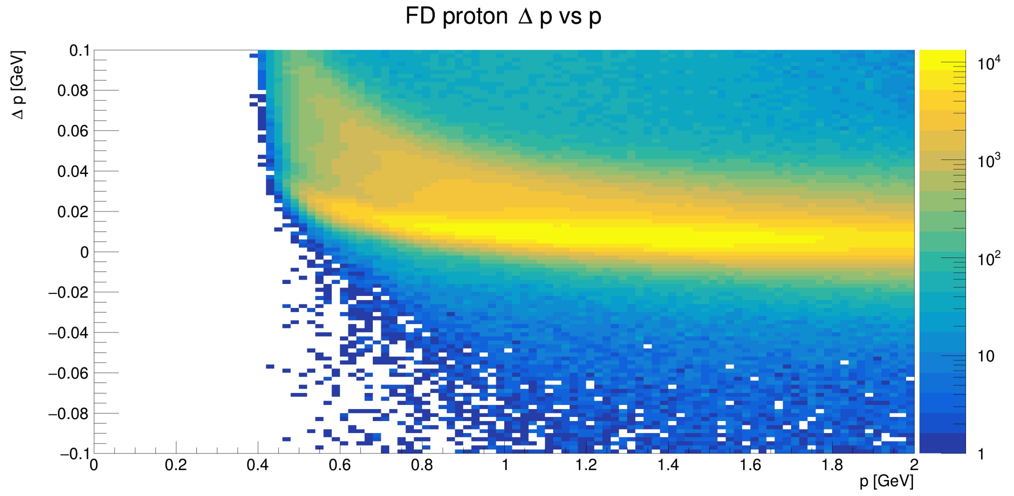


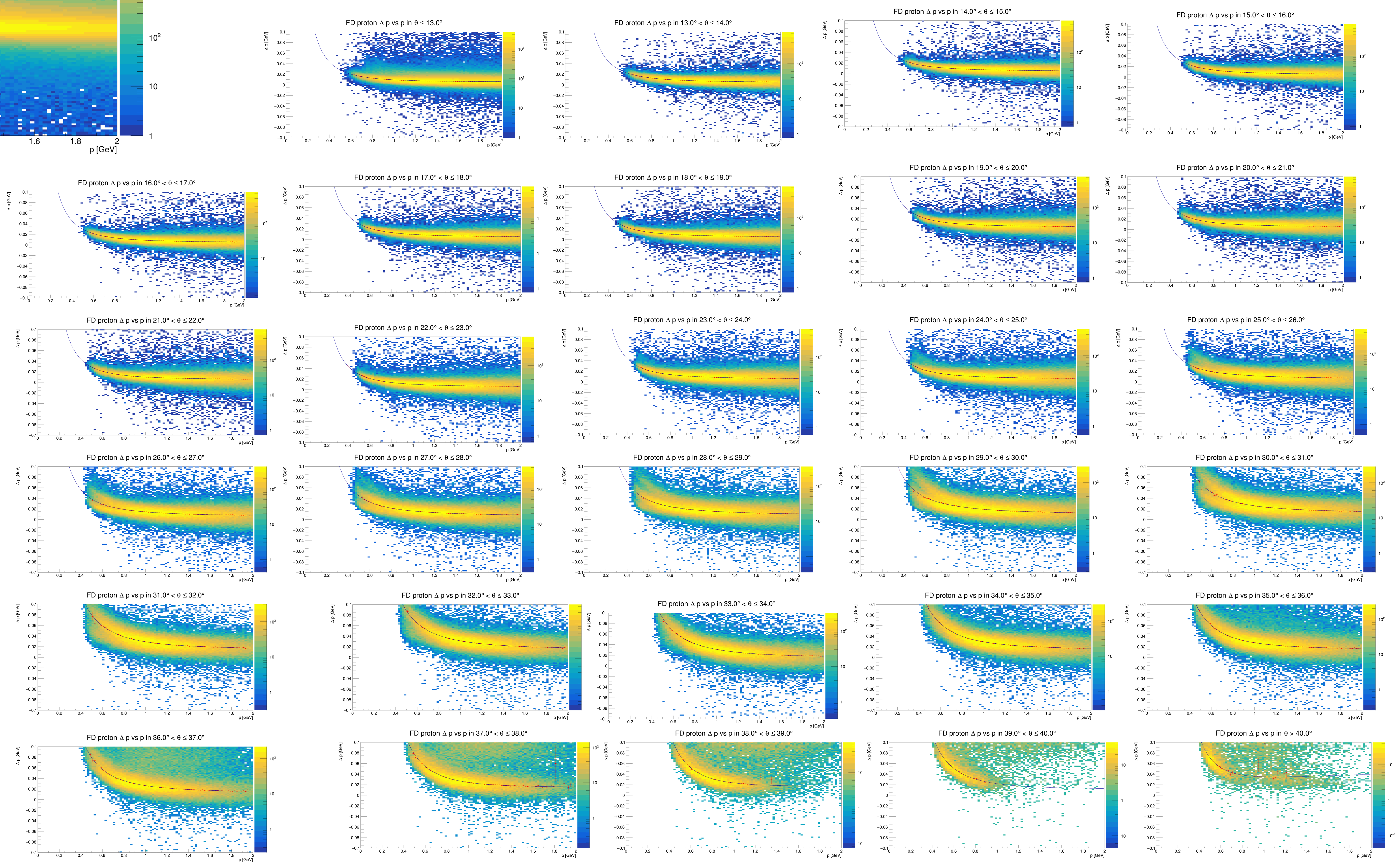


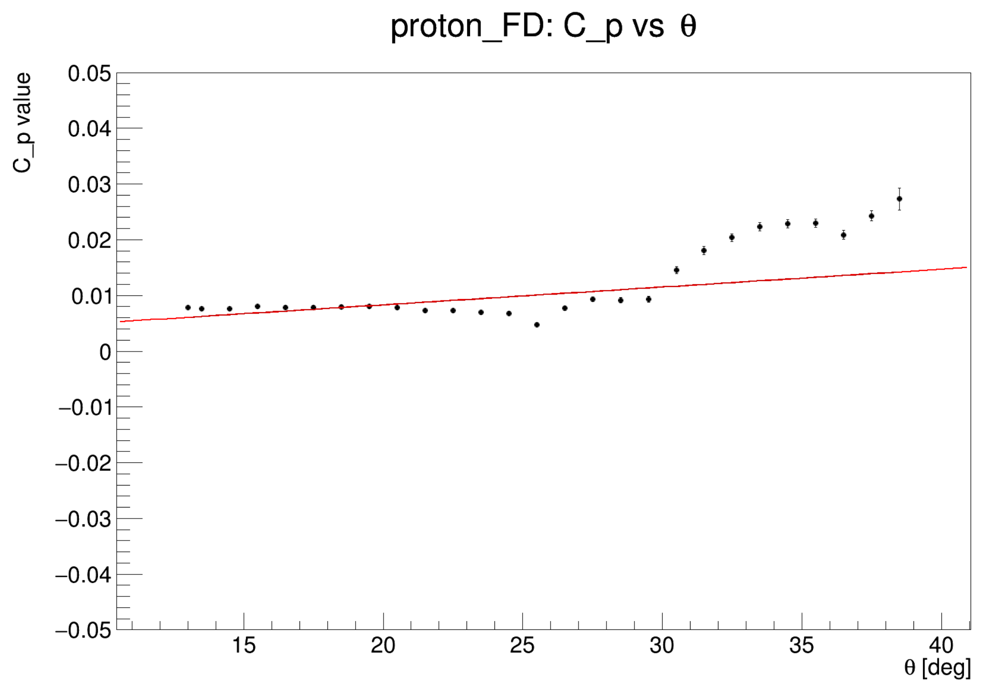
Energy Loss Correction: RGA Spring2018 inb

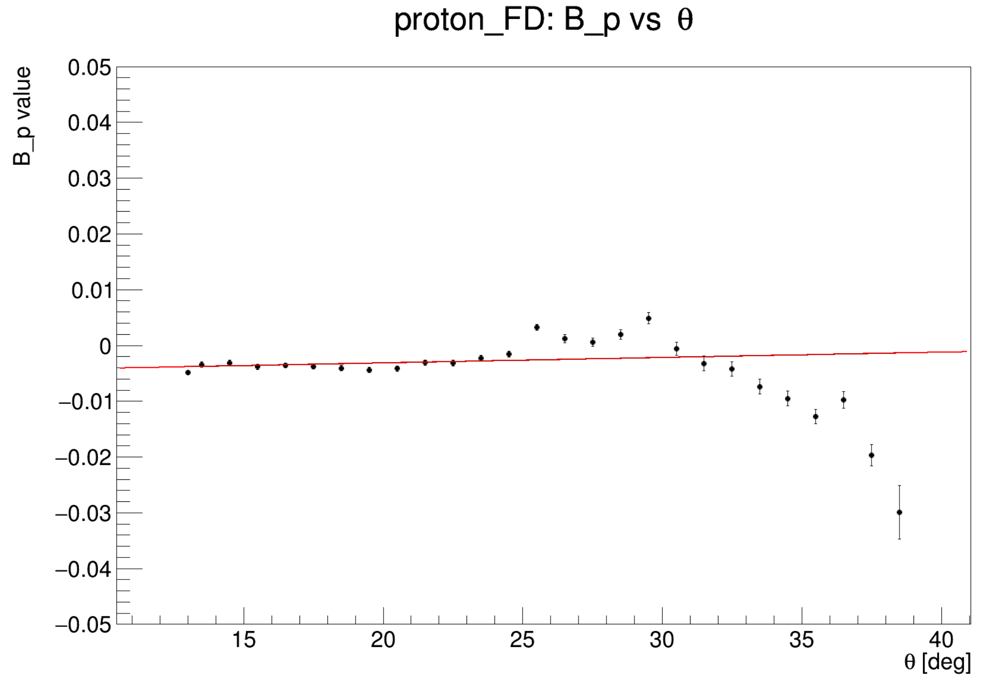
FD Proton

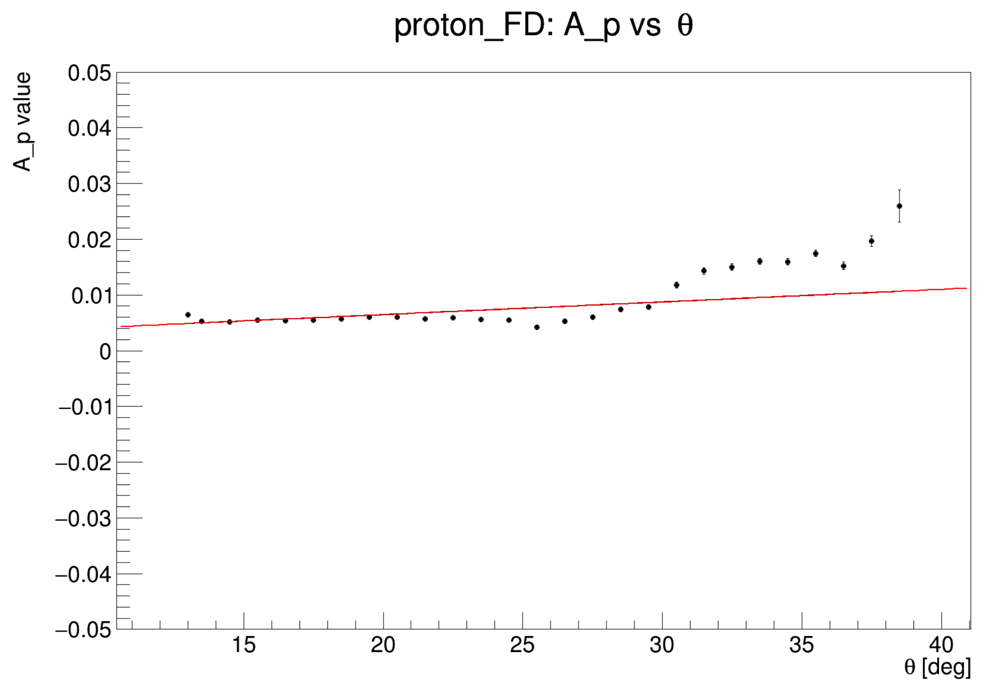
$$\Delta p = A + B/p + C/p^2$$











Energy Loss Correction: RGA Spring2018 inb

CD Proton

$$\Delta p = A + B \cdot p + C \cdot p^2$$