Charm Production in CC DIS at HERA

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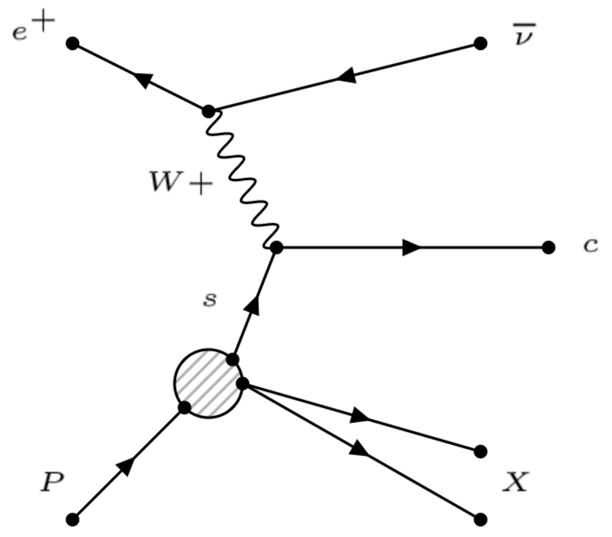
Objectives

- Charm cross section measurement in high-Q^2 charged current (CC) DIS. $\rightarrow$ Constraints on $s(x, Q^2)$



- The same process via d is Cabibbo-suppressed.
- Allows $s(x, Q^2)$ measurement.
- Due to the final state neutrino, a large missing P_T is observed.
- Invariant kinematic variables (x, y, Q^2) defined by using Jacquet-Blondel Method.

$$y_{JB} = \frac{\sum_h (E - p_z)_h}{2E_{e,beam}} \qquad Q^2_{JB} = \frac{p^2_{T,h}}{1 - y_{JB}} \qquad x_{JB} = \frac{Q^2_{JB}}{s y_{JB}}$$

- Complementary measurement (high-Q^2) to the previous analyses by CCFR/NuTeV and ATLAS

$\rightarrow$ CCFR/NuTeV : $\frac{\int_0^1 dx[xs + x\bar{s}]}{\int_0^1 dx[x\bar{u} + x\bar{d}]} = 0.477^{+0.063}_{-0.053}$ $\quad (Q^2 = 1 - 100\ GeV^2)$

$\rightarrow$ ATLAS : $\frac{s + \bar{s}}{\bar{u} + \bar{d}} = 1.13 \pm 0.05$ $\quad (Q^2 = 1.9\ GeV^2, x = 0.023)$

Charm in CC

- Charged current events are always weak interactions.

$$\frac{d^2\sigma_{Born}^{CC,e^{\pm}p}}{dxdQ^2} = (1 \pm P_e)\frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \tilde{\sigma}_{CC}^{e^{\pm}p}$$

- The double-differential cross section is sensitive to different quark densities.

$$\tilde{\sigma}_{CC}^{e^{+}p} = x[\bar{u} + \bar{c} + (1-y)^2(d + \boldsymbol{s})]$$
$$\tilde{\sigma}_{CC}^{e^{-}p} = x[u + c + (1-y)^2(\bar{d} + \bar{\boldsymbol{s}})]$$

- The resulting $c/\bar{c}$ production is tagged and light flavor contribution is suppressed by using the lifetime-tagging method.

DIS Selection

- Trigger
  - FLT 39 || 40 || 41 || 43 || 44 || 60 || 63
  - SLT EXO4
  - TLT EXO2 || EXO6
  - DST 34
- DQ
  - EVTAKE, POLTAKE, MVDTAKE, STTTAKE
- Kinematic
  - $Q^2 > 200\ GeV^2, y < 0.9$
- Charged Current Selection
  - $P_T > 12\ GeV, P'_T > 10\ GeV$
- Tracking Based
  - $|Z_{vtx}| < 30\ cm$
  - $\phi_{cal} - \phi_{trk} < 90$ degrees
  - $N_{trkvtx} > 0.125\ (N_{trk} - 20)$
- PhP rejection
  - $V_{AP}/V_P < 0.25$ if $P_T < 20\ GeV$, $V_{AP}/V_P < 0.35$ else
- NCDIS rejection
  - reject if $P_T < 30\ GeV$ && $E - P_z > 30\ GeV$ ...
- Complete list of DIS selection listed in backup slide.

** $P_T = -P_{T,miss}$
** $P'_T = P_T$ measurement excld. the ones near the beam pipe.

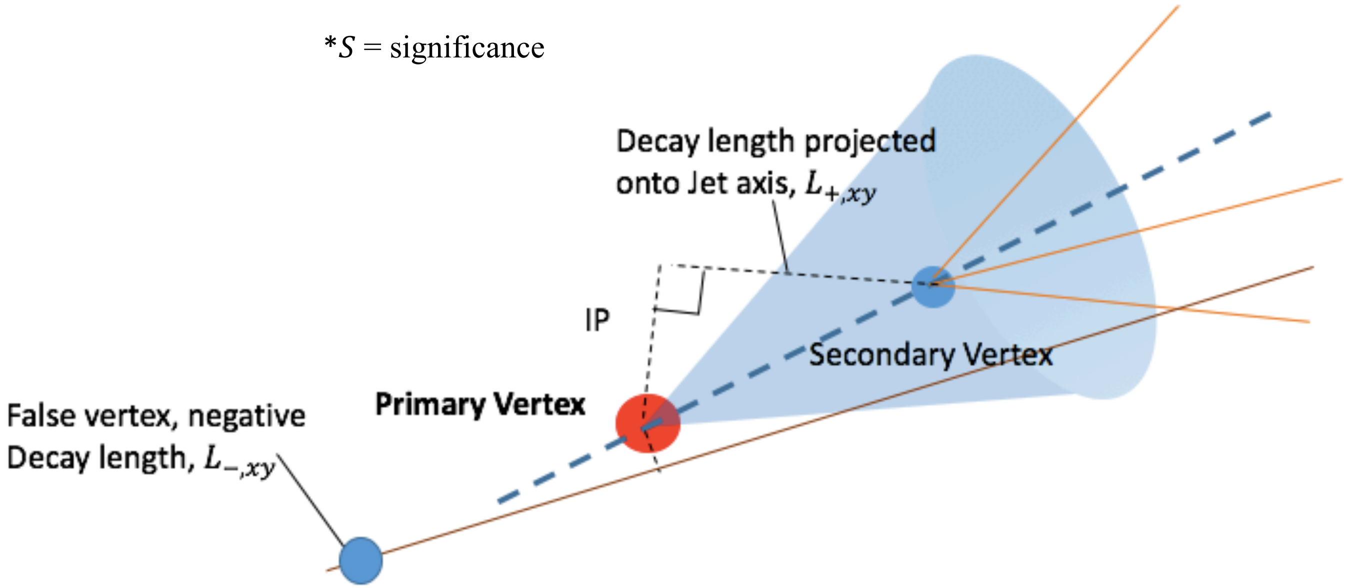
Charm Tagging

Lifetime-tagging Method

- 2D decay length (L_{xy}) projected onto Jet axis.
  - LF → Short-lived, Symmetric decay length.
  - Charm → Long-lived, Asymmetric.
- LF contribution (background) suppressed by mirroring decay length distribution around $L_{xy} = 0$.

  $(M_{L+} - M_{L-}, M_{S+} - M_{S-})$

  *S = significance



Jet Selection	ORANGE : Kt_jet_a
	$E_T^{jet} > 5\ GeV$
	$-2.5 < \eta^{jet} < 2.5$
Track Selection	ZTT tracks $P_T > 0.5\ GeV$
	$(N_{CTD} \geq 3 \mid\mid N_{STT} \geq 1) \&\& N_{MVD} \geq 4$
	Distance to closest jet $R = \sqrt{\Delta\varphi^2 + \Delta\eta^2} < 1$
SecVtx Selection	ORANGE : Vtxsec_type[secvtxID] = 1
	$\chi^2/N_{dof} < 6$
	$\lvert Z_{secvtx} \rvert < 30\ cm$
	Distance to beamspot $\sqrt{\Delta x^2 + \Delta y^2} < 1\ cm$

DATA & Monte Carlo Samples

Data

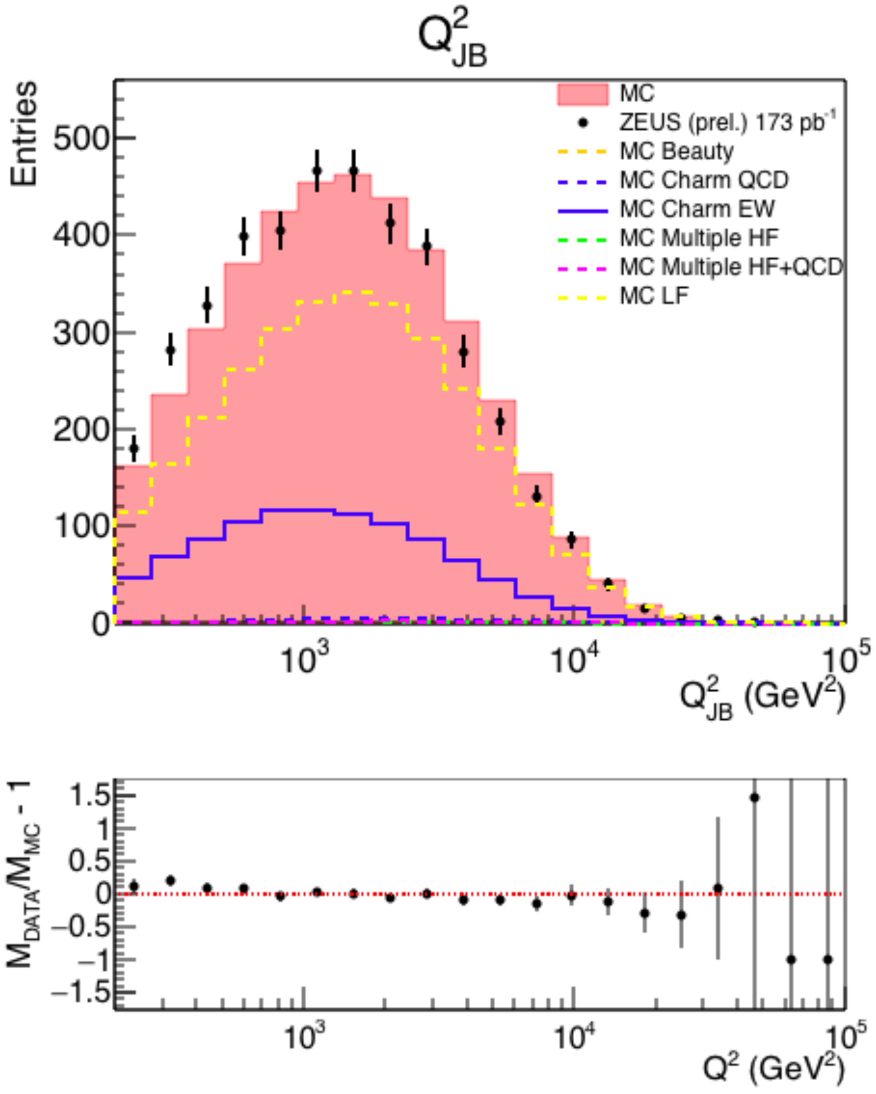
- HERA II
  - $e^{-}p$: $05e, 06e$ w/ $L \cong 185\, pb^{-1}$
  - $e^{+}p$: $0304p, 0607p$ w/ $L \cong 173\, pb^{-1}$

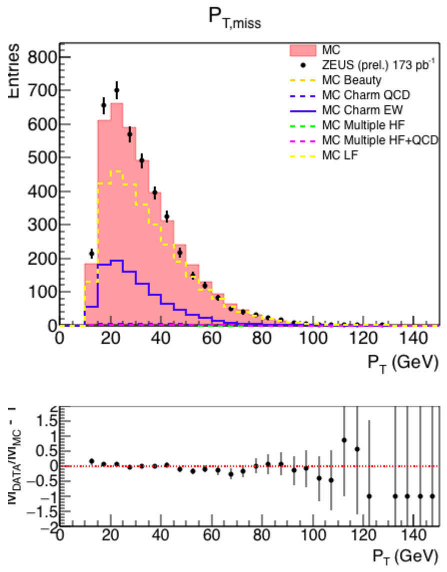
Year	Collision	Integrated Luminosity (pb^{-1})
2003/04	$e^{+}p$	~ 38
2004/05	$e^{-}p$	~ 133
2006	$e^{-}p$	~ 52
2006/07	$e^{+}p$	~ 135

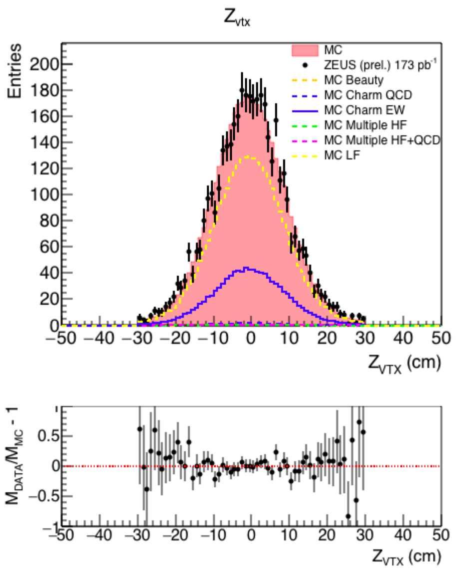
MC

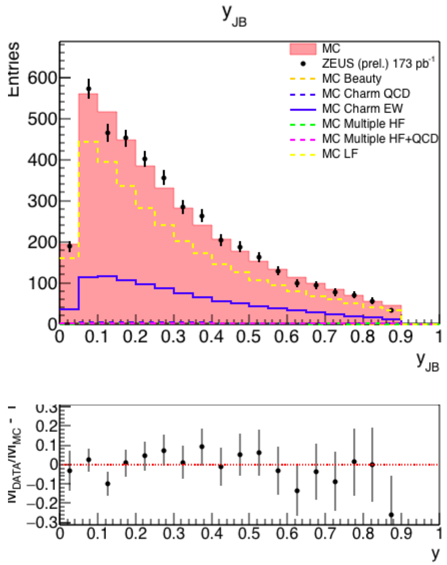
- DIS
  - Inclusive CCDIS MC num07t3.1: Amadeus 2006a, DJANGOH 1.6, ARIADNE 4.12, CTEQ-5D.
- Background
  - Inclusive NCDIS MC: DJANGOH 1.6, ARIADNE 4.12, CTEQ-5D
  - PhP MC: HERWIG, resolved & direct

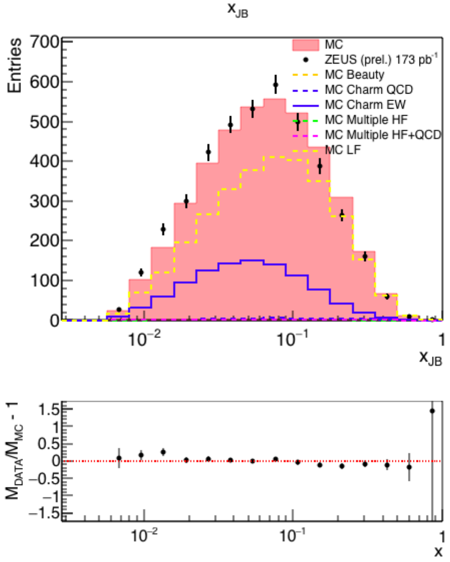
Control Plots – Event (e^+p)







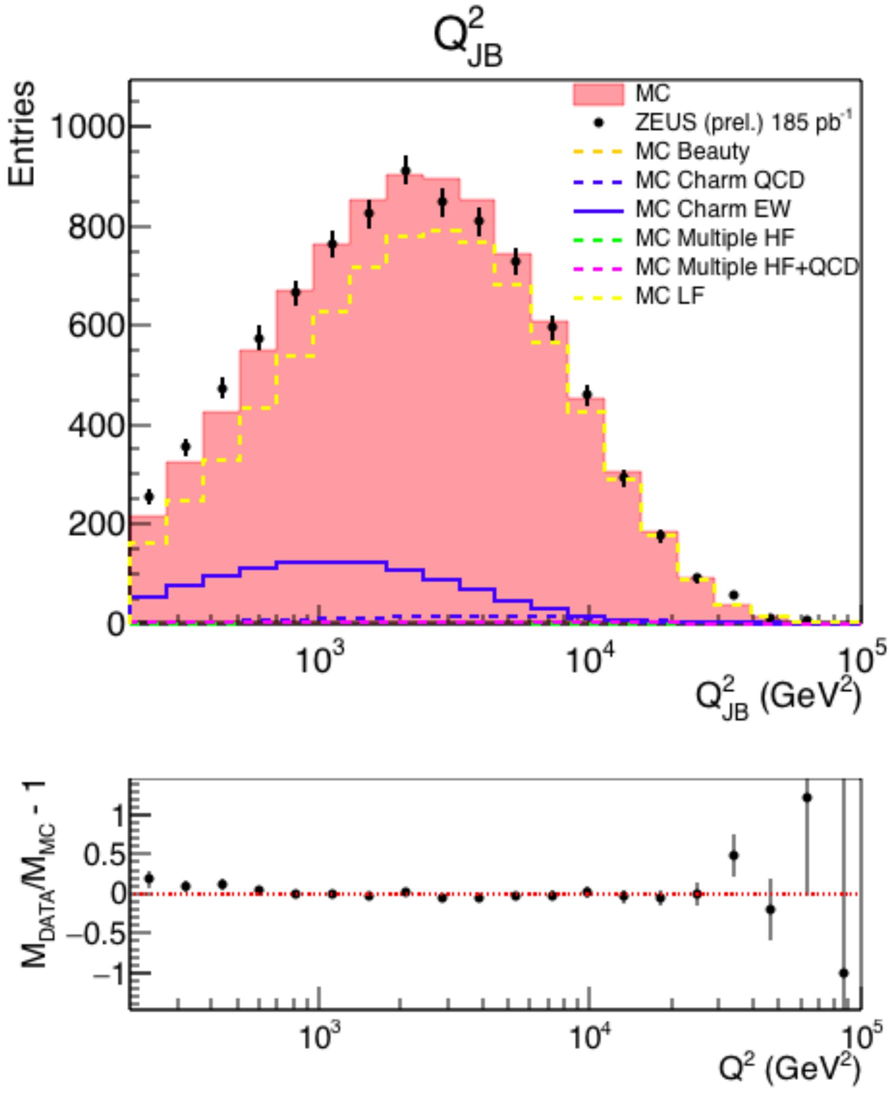


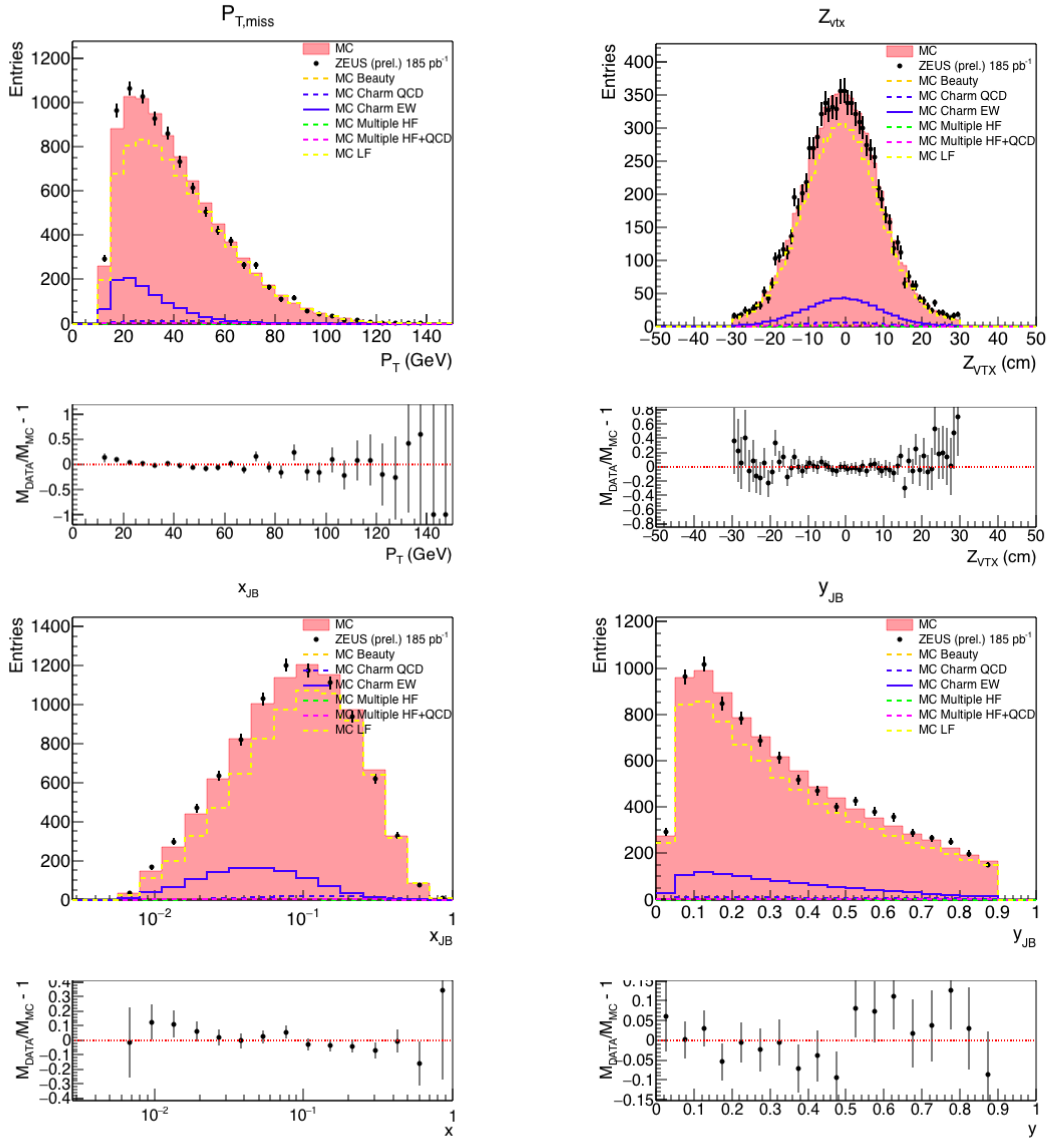


Legend Info

- Charm EW
  - Charm from $W\ s/d \to c$. This is the signal of interest.
- LF
  - Light-flavor contribution.
  - Major source of background.
- Charm QCD
  - Charm from $g \to c\bar{c}$. Background
- Beauty
  - b quark in CC.
  - Background
- Multiple HF(+ QCD)
  - $c + b\ (+\ \bar{c})$. Partly signal. Currently not sensitive to this.

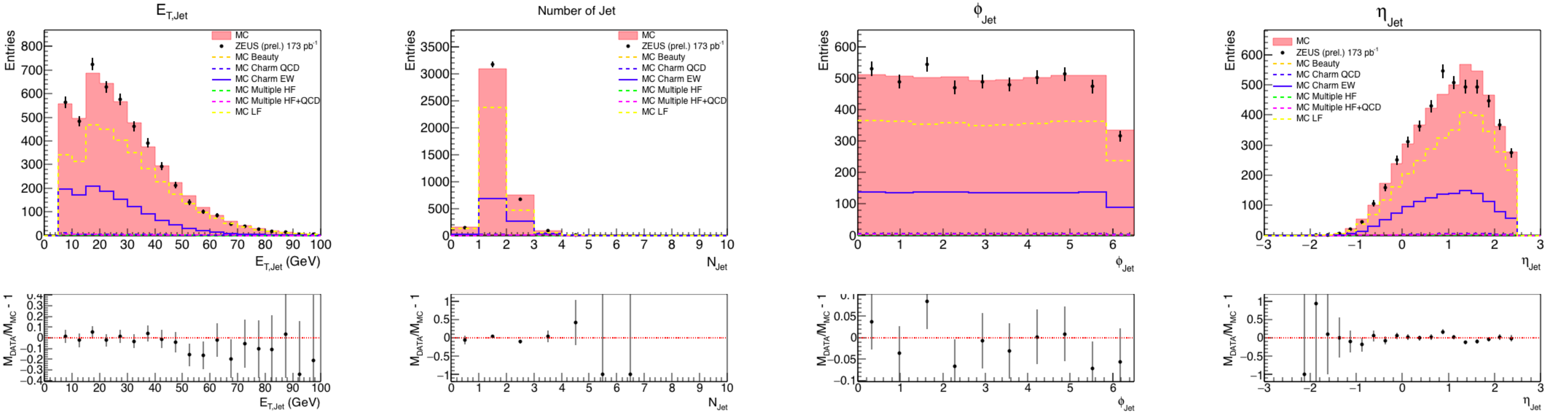
Control Plots – Event (e^-p)





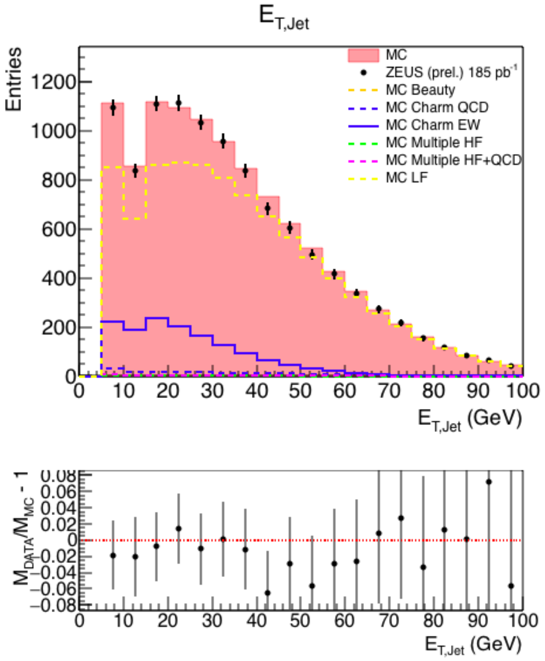
Control Plots – Jet ($e^{+}p$)

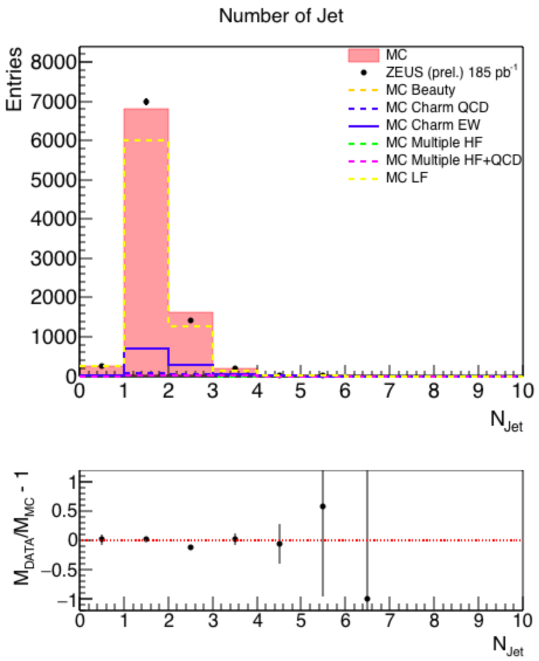
- Small peak around $\eta \sim 1$, mostly coming from 0304p. (backup slide)
- Otherwise, good agreement between Data and MC.

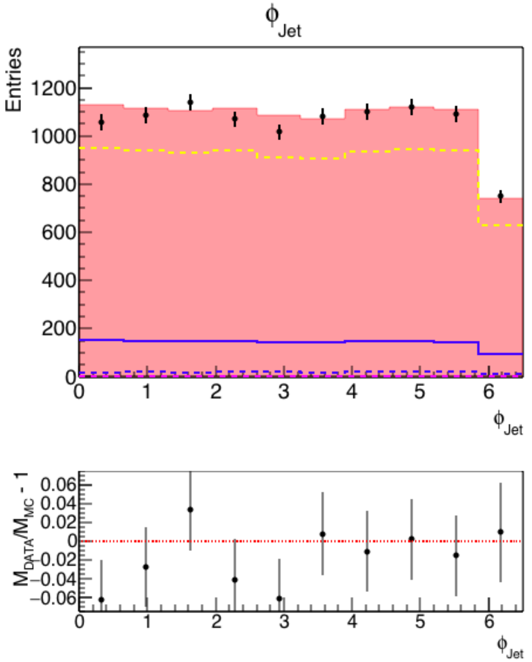


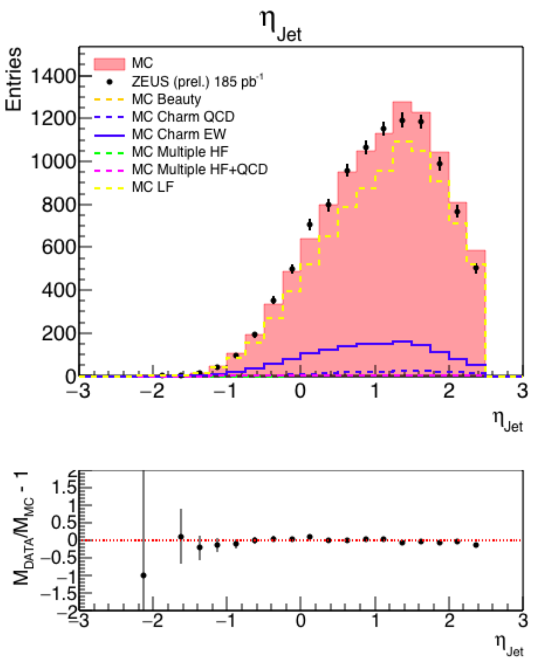
Control Plots – Jet ($e^{-}p$)

- Better agreement between MC and Data.



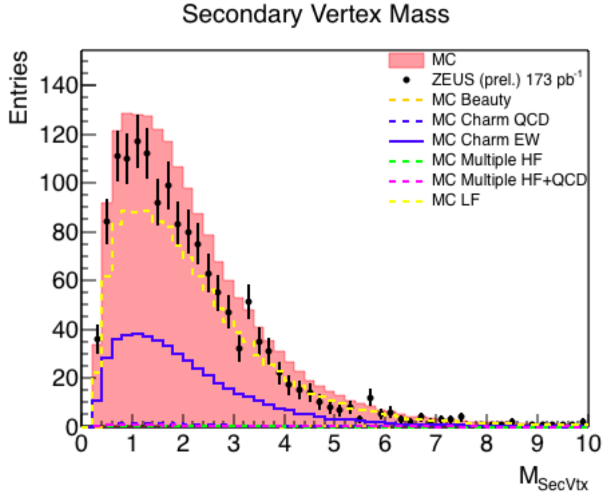


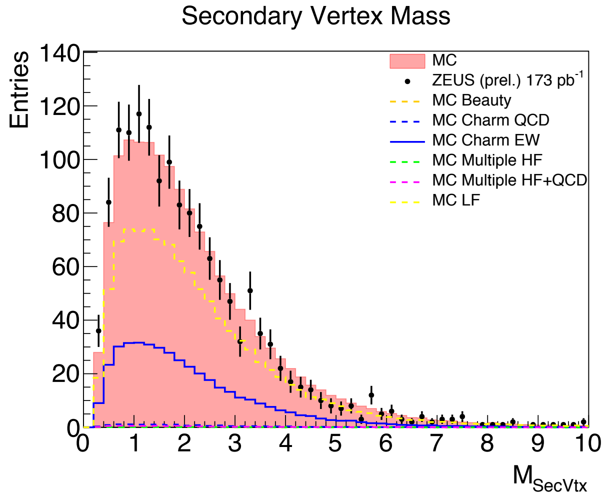


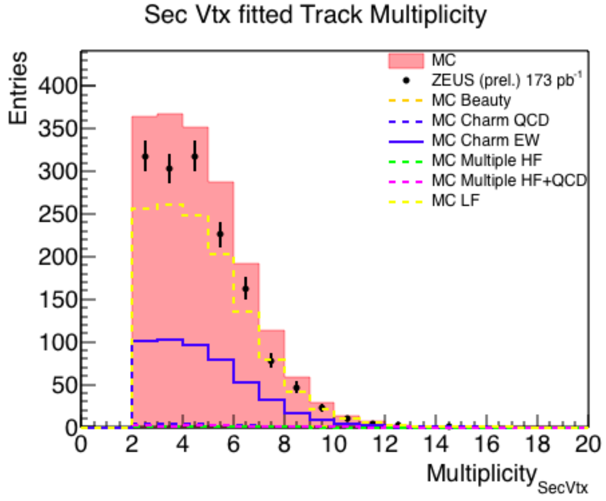


Secondary Vertex Scaling

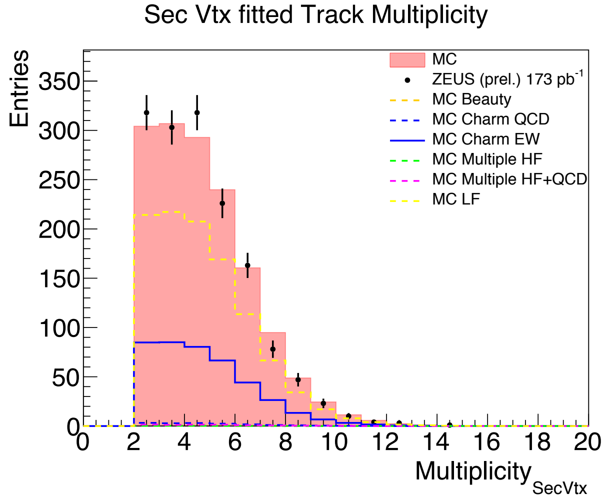
(0607p)







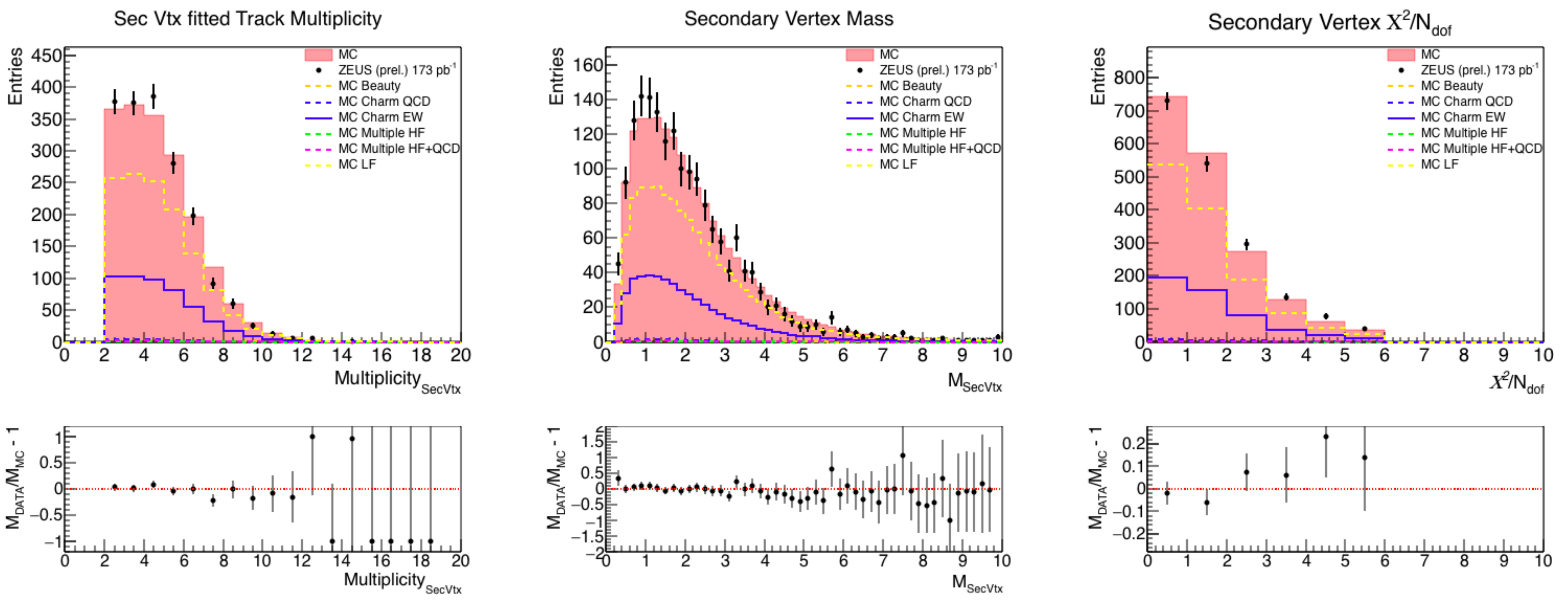
MC scaling factor
$= 0.834$



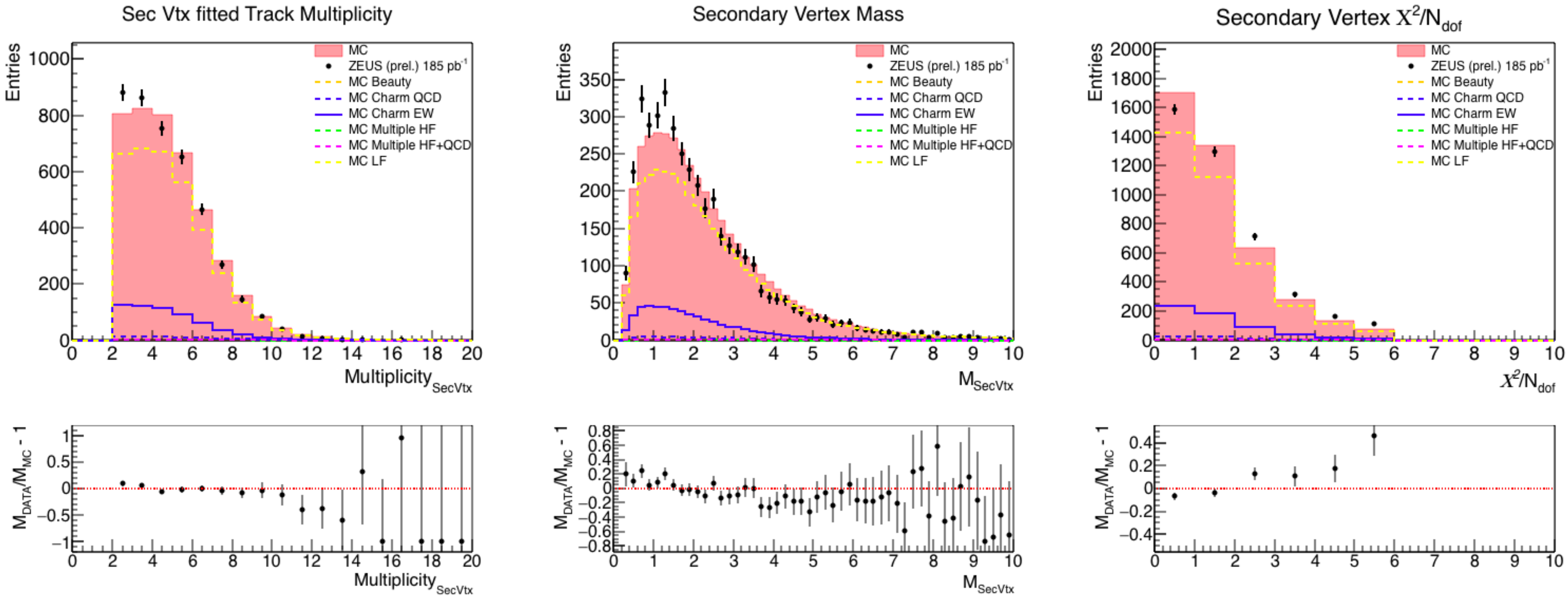
- Due to its higher tracking efficiency, MC overestimates trackings & secondary vertices.
- A secondary scaling applied to MC to match Data.

$$
\begin{aligned}
N^{DATA}_{SecVtx}/N^{MC}_{SecVtx} &= 0.686\ \ (0304p)\\
&= 0.802\ \ (05e)\\
&= 0.810\ \ (06e)\\
&= 0.834\ \ (0607p)
\end{aligned}
$$

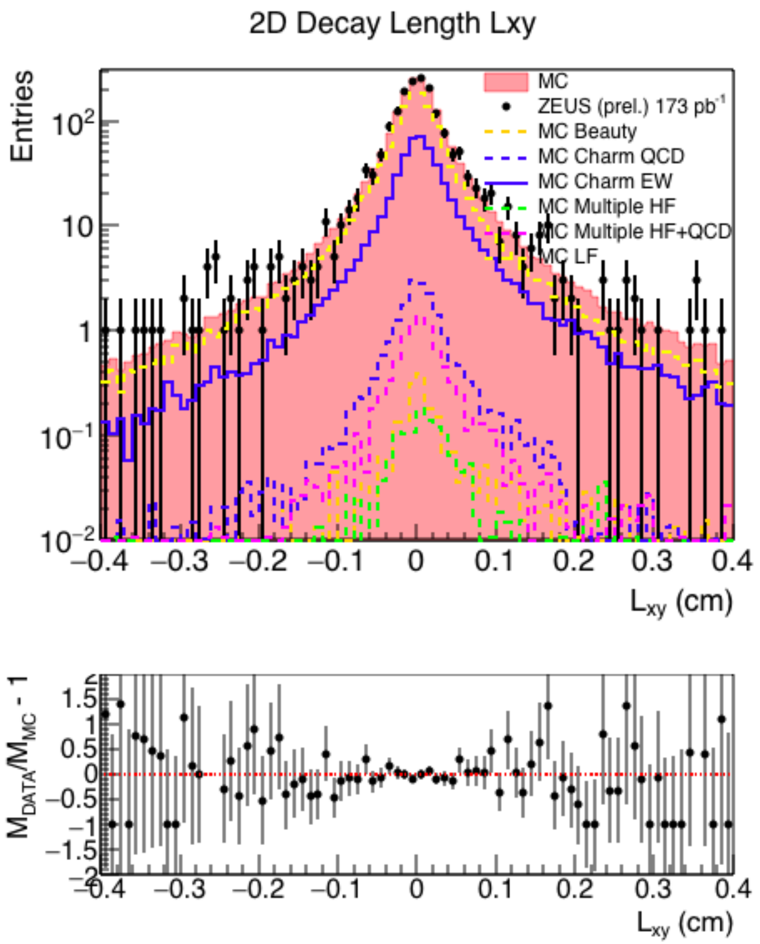
Control Plots – Secondary Vertex (e^+p)

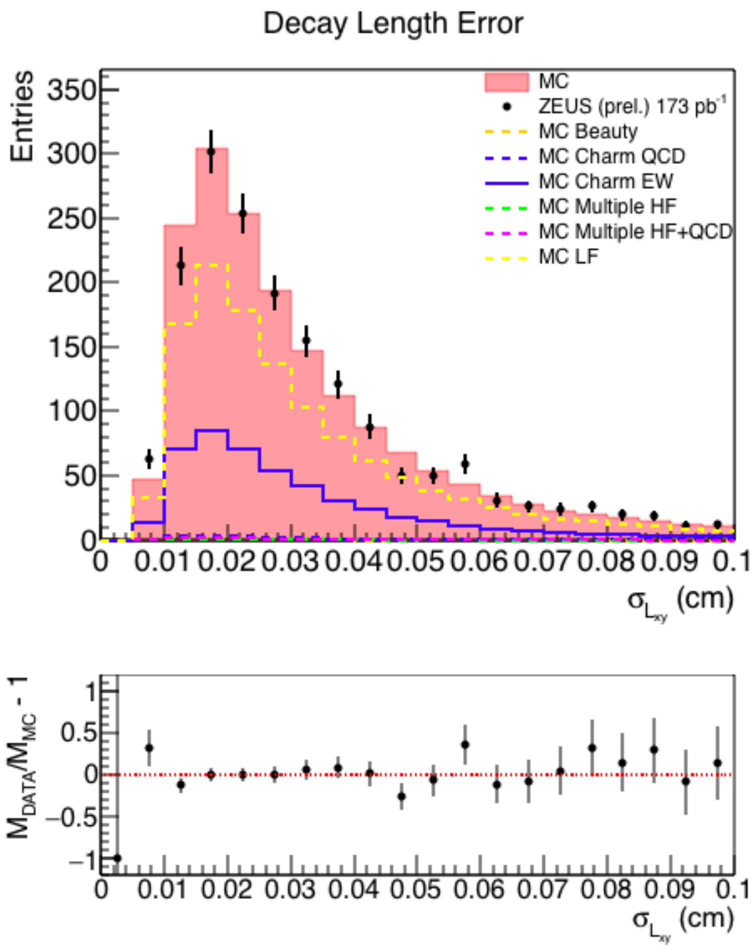


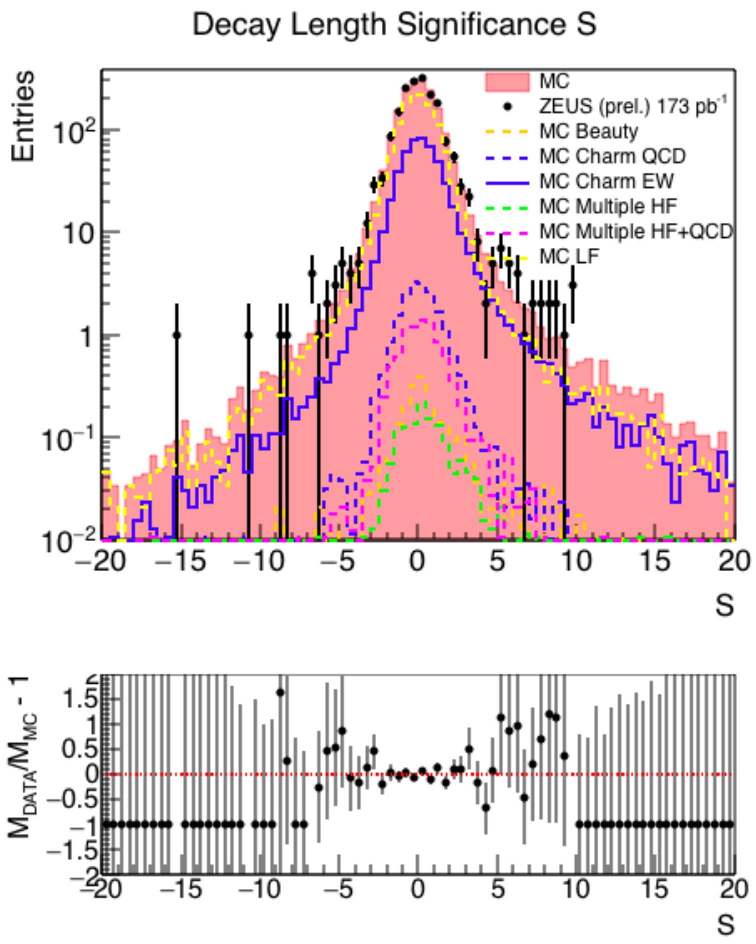
Control Plots – Secondary Vertex ($e^{-}p$)



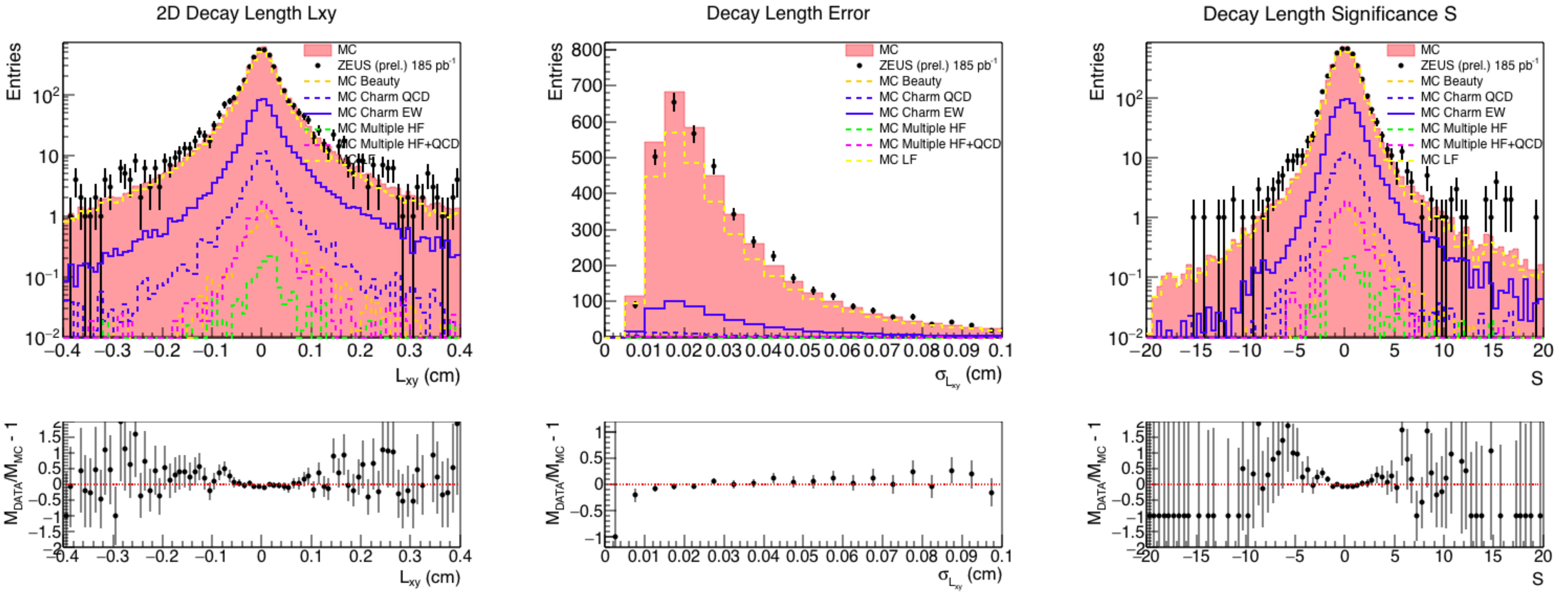
Decay Length Plots (e^+p)





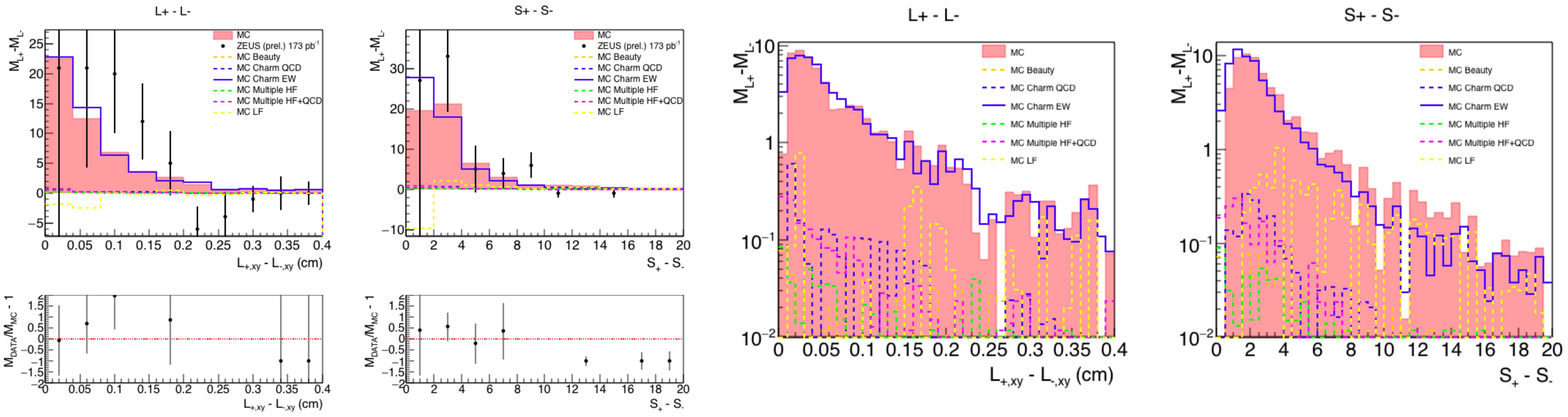


Decay Length Plots ($e^{-}p$)

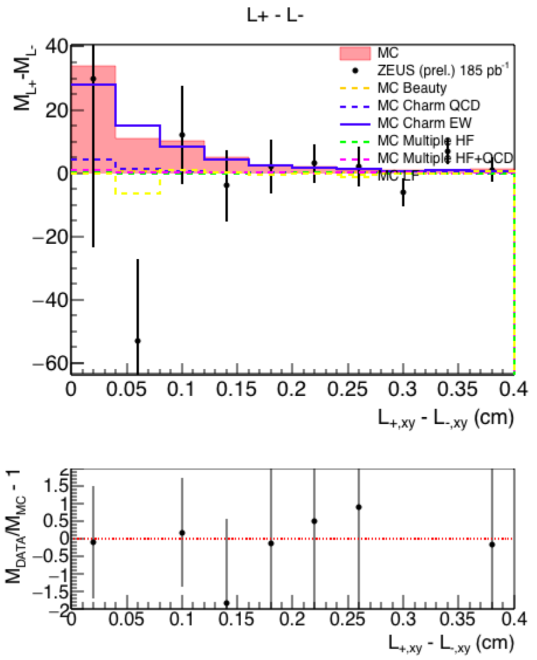


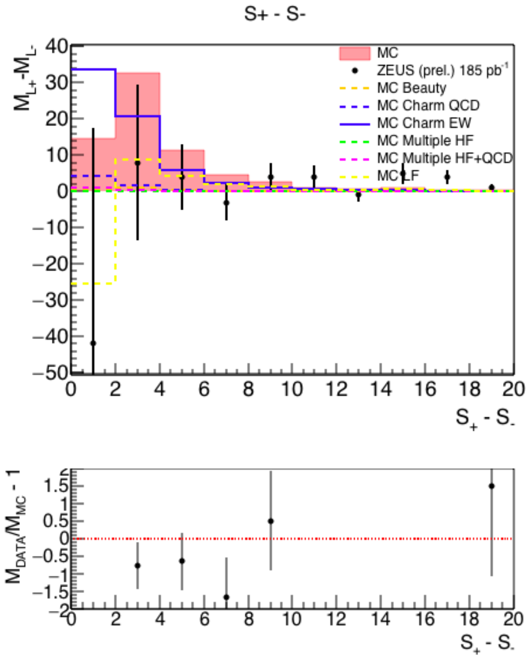
Mirrored Decay Length (e^+p)

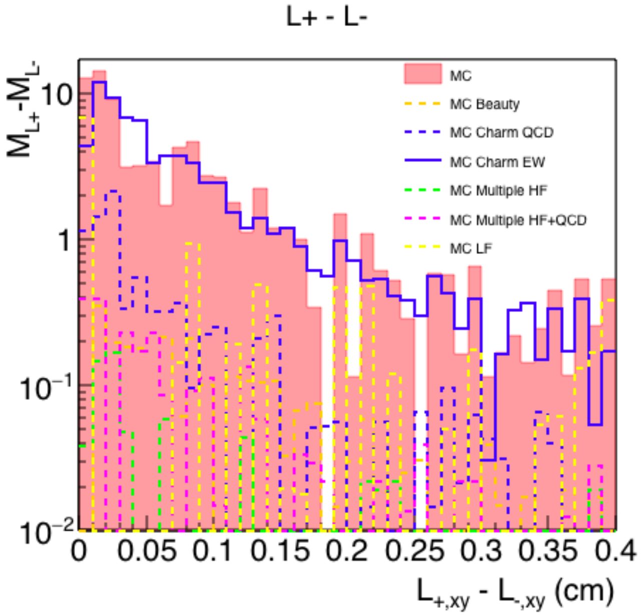
- Charm signal observed with LF contribution (Background) suppressed.
- Statistics ~70 is split into 2 bins in Q^2 to unfold single-differential cross section $\left(\frac{d\sigma}{dQ^2}\right)$.

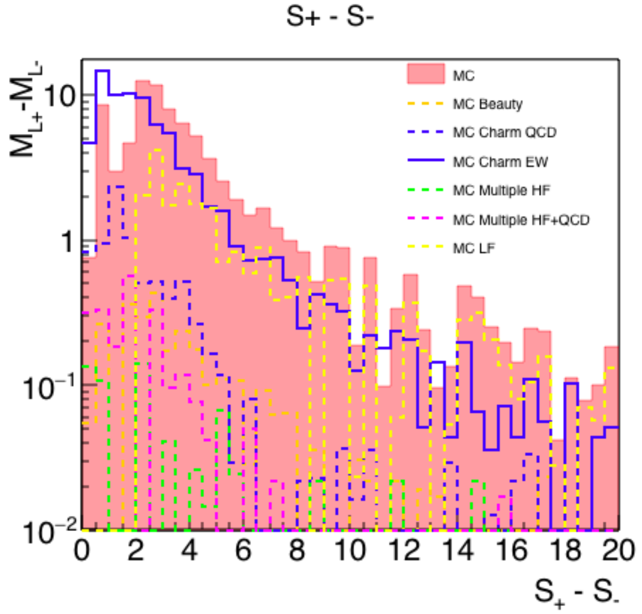


Mirrored Decay Length ($e^{-}p$)





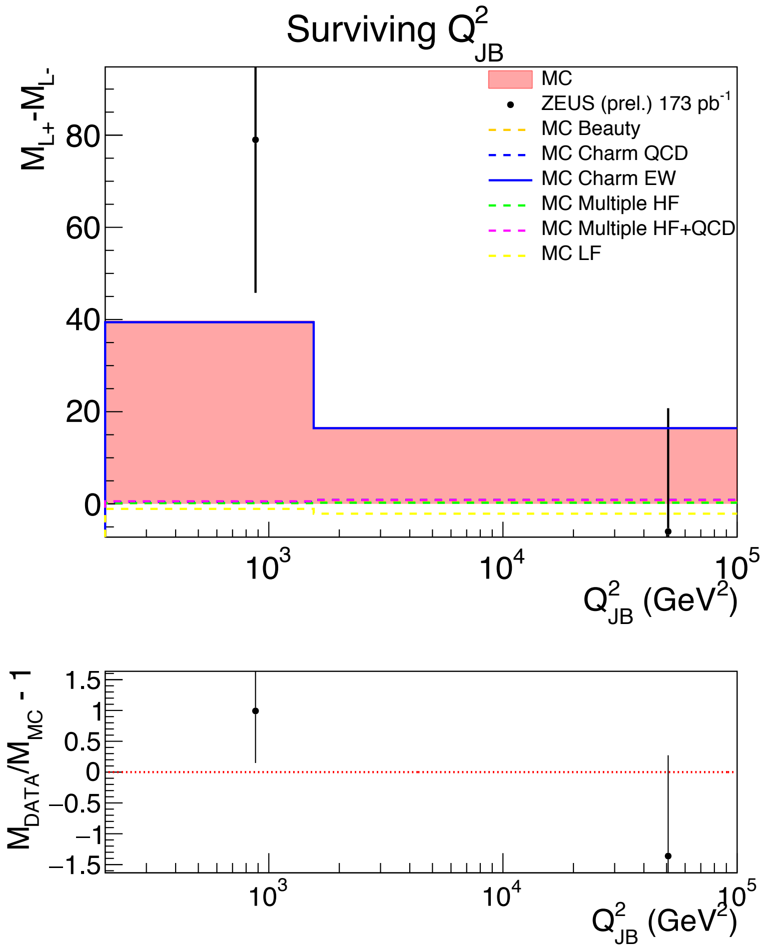




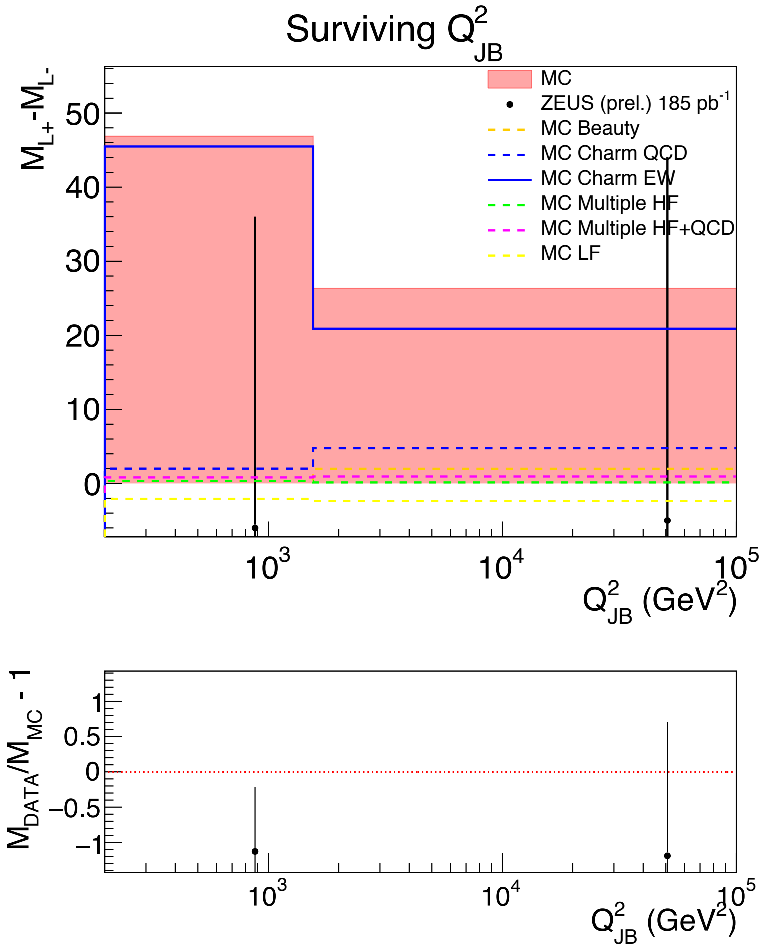
Kinematics after mirroring

- The bin separation point was determined at $Q^2_{JB} = 1554.9\ GeV^2$

e^+p



e^-p



Cross Section Unfolding

$$\left(\frac{d\sigma^{EWc}}{dQ^2}\right)_i = \frac{N_i^{EWc}}{L\,\Delta Q^2}$$

$$\left(\frac{d\sigma^{EWc}}{dQ^2}\right)_i = \frac{N_{meas,i}^{EWc}}{A_i\,L\,\Delta Q^2}$$

$$\left(\frac{d\sigma^{EWc}}{dQ^2}\right)_i = \frac{\sum C_{ij} M_{meas,j}^{EWc}}{A_i\,\Delta Q^2} = \frac{\sum C_{ij}\left(M_{meas,j} - M_{meas,j}^{bg}\right)}{A_i\,L\,\Delta Q^2}$$

$$\sigma_{vis}^{EWc} = \frac{\sum_i \sum_j C_{ij}\left(M_{meas,j} - M_{meas,j}^{bg}\right)}{A\,L}$$

$$\sigma_{tot}^{EWc} = C_{ext}\,\sigma_{vis}^{EWc}$$

- The single differential EW charm cross section in bin *i* is given.
- Acceptance A_i accounts for the efficiency of trigger selection, the particle identification method and the detector;
  $$A_i = N_{meas,i}^{EWc} / N_i^{EWc}$$
- Correlation matrix C_{ij} relates the number of true events in bin i, $N_{meas,i}^{EWc}$ with the number of reconstructed events in bin j, $M_{meas,j}^{EWc}$. Also, background is subtracted from signal to estimate $M_{meas,j}^{EWc}$.
- The visible cross section within the given kinematic region ($Q^2 > 200\ GeV^2, y < 0.9, E_T^{jet} > 5\ GeV, |\eta^{jet}| < 2.5$) is given by;
  $$A = \sum N_{meas,i}^{EWc} \,/\, \sum N_j^{EWc}$$
- The total cross section is then extrapolated via C_{ext};

Bin-by-bin Correction

- Good agreement between True and Reconstructed Q^2
- With large bin-widths used in this analysis, only use the diagonal elements of the correlation matrix.

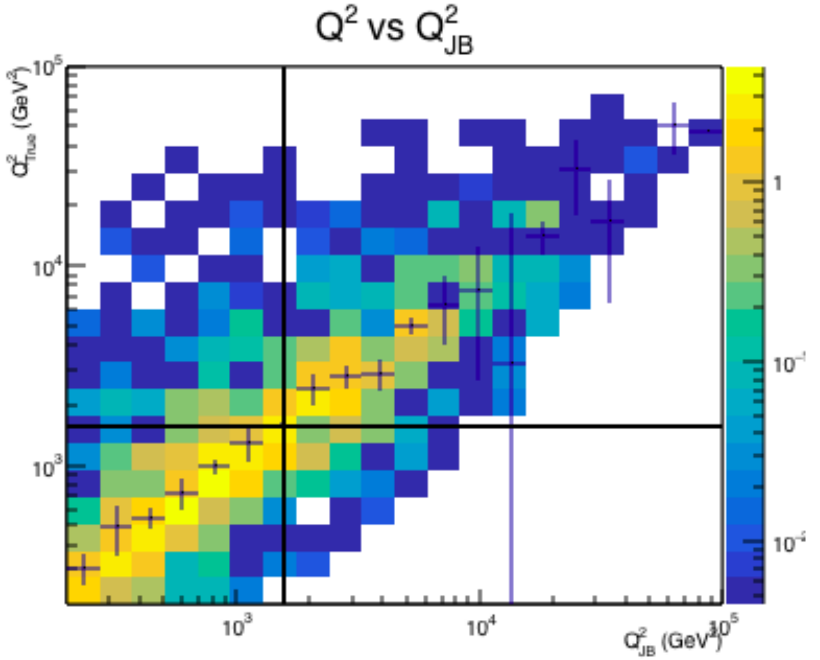
$$N_i = \sum_j C_{ij} M_j$$

$$N_i \cong C_{ii} M_i$$

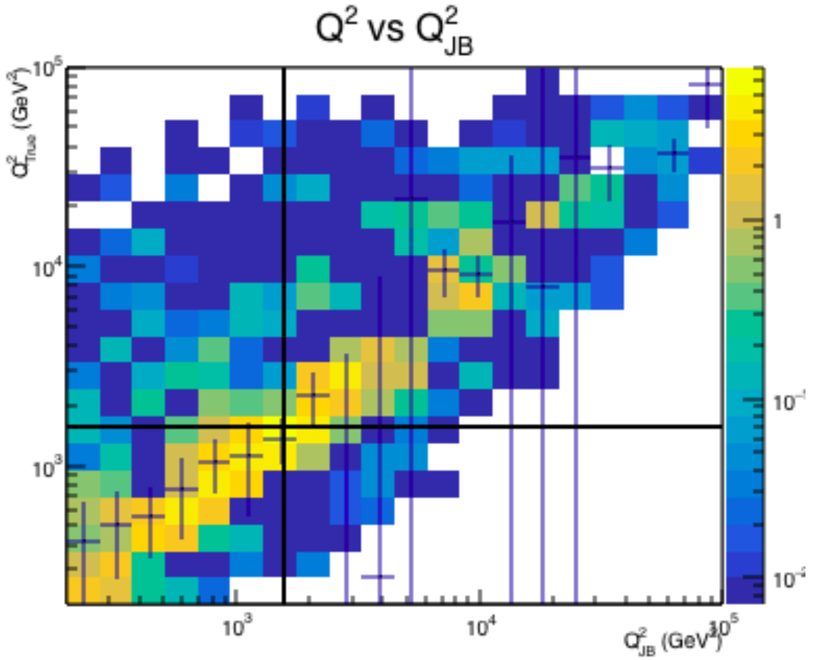
$N_i = true\ number\ of\ entries\ in\ bin\ i$
$M_i = reconstructed\ number\ of\ entries\ in\ bin\ i$
$C_{ij} = correlation\ matrix\ element\ for\ bin\ i,j$
$C_{ii} = diagonal\ matrix\ for\ bin\ i$

Collision	C_{11}	C_{22}
e^+p	0.99	1.01
e^-p	0.98	1.02

e^+p

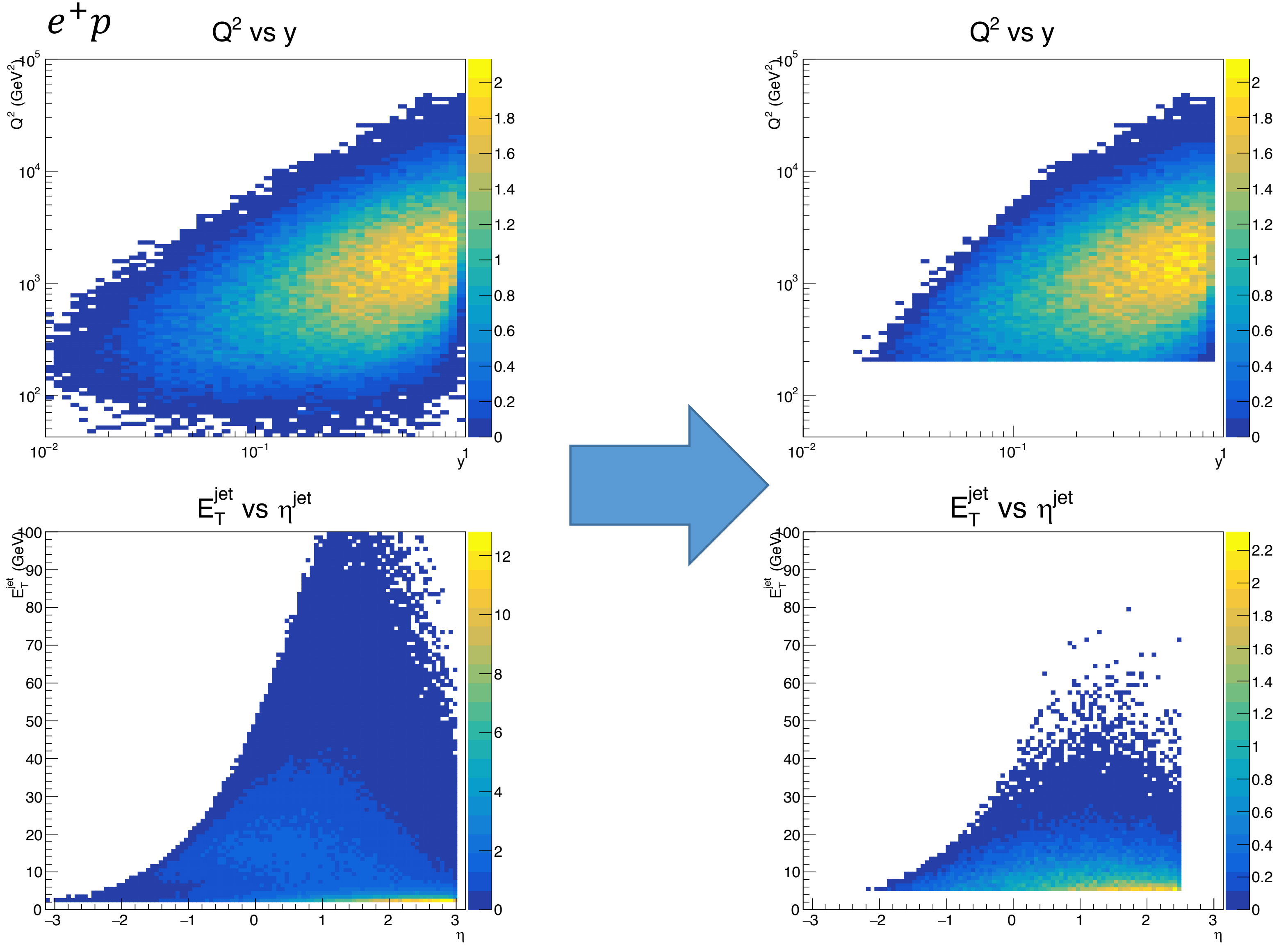


e^-p



Extrapolation Factor

e^+p



- From left to right, a kinematic phase region is defined to optimize detector resolution.

$$Q^2 > 200\ GeV^2$$
$$y < 0.9$$
$$E_T^{jet} > 5\ GeV$$
$$|\eta^{jet}| < 2.5$$

- Extrapolation factor is taken from the ratio;

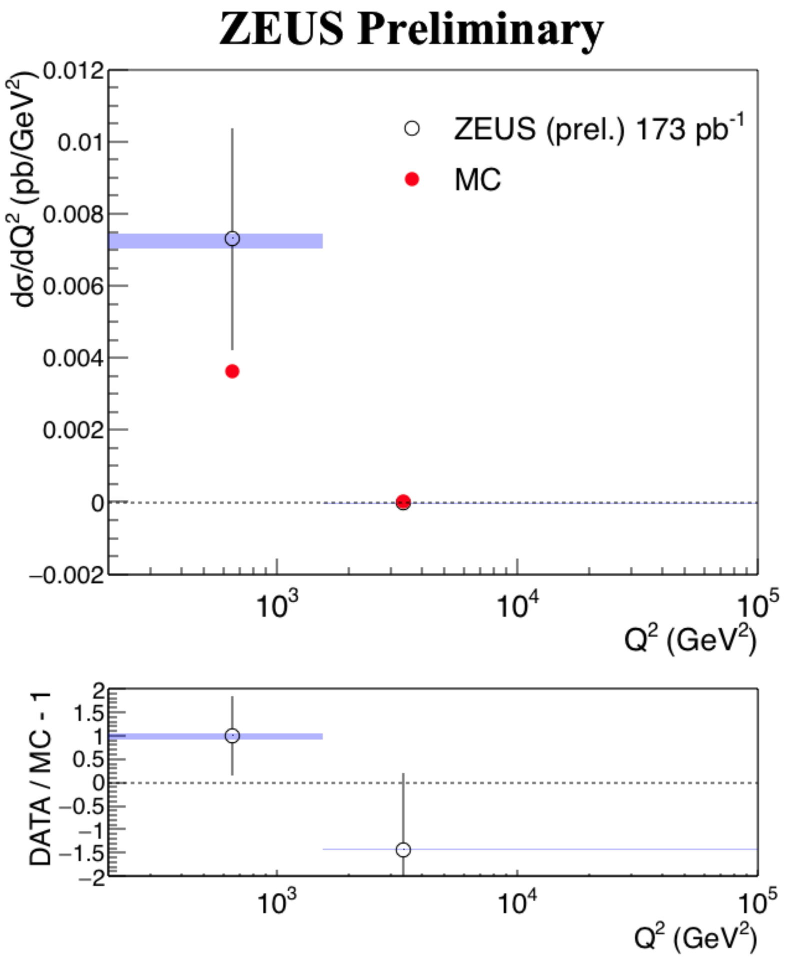
$$C_{ext} = N_{gen}^{full} / N_{gen}^{kin}$$

$$C_{ext} = 1.45$$

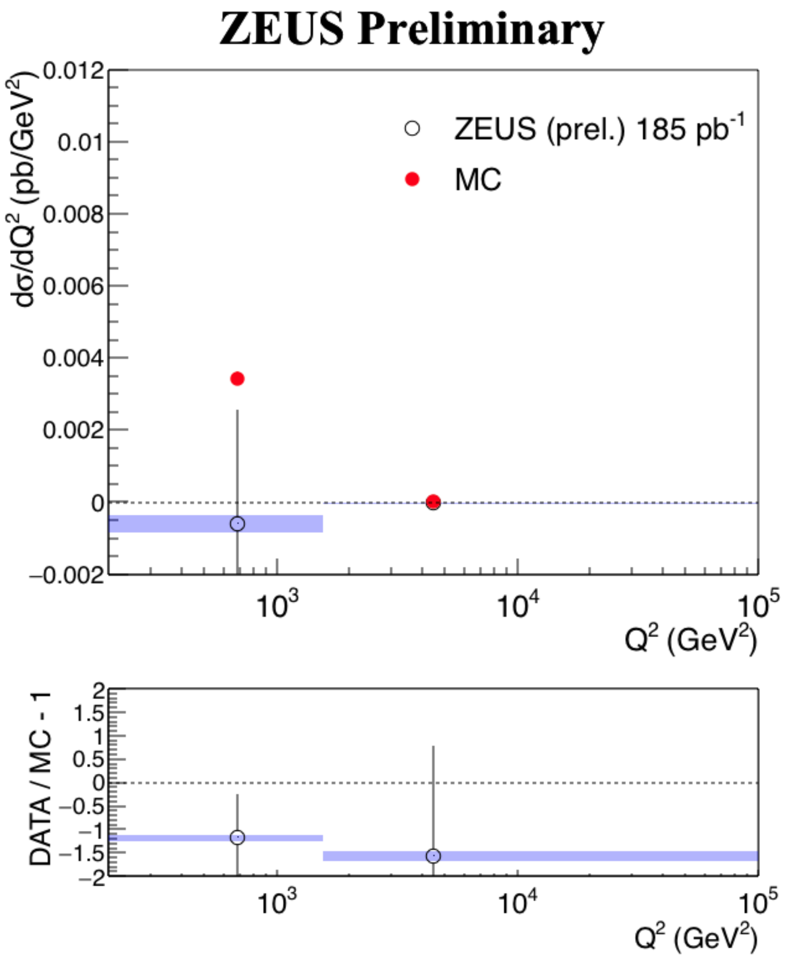
For both $e^{\pm}p$

Results

$e^{+}p$



$e^{-}p$



$$\sigma_{vis}^{EWc} = 11.1 \pm 6.6(stat)^{+0.33}_{-0.56}(syst)\ pb$$

$$\sigma_{tot}^{EWc} = 16.1 \pm 9.5(stat)^{+0.48}_{-0.80}(syst)\ pb$$

$$\sigma_{vis}^{EWc} = -2.4 \pm 7.9(stat)^{+0.49}_{-0.56}(syst)\ pb$$

$$\sigma_{tot}^{EWc} = -3.5 \pm 11.6(stat)^{+0.71}_{-0.81}(syst)\ pb$$

Systematic Uncertainty

Source	Nominal Value	Variation	e^+p δ_i (%)	e^-p δ_i (%)
DIS				
P_T	12 GeV	13 GeV	1.2	-14.7
		11 GeV	-4.0	$+16.1$
Z_{vtx}	30 cm	35 cm	~ 0	~ 0
		25 cm	1.7	-12.7
Calorimeter				
E_T^{jet}	5 GeV	$+3\%$	~ 0	-0.7
		-3%	1.0	-0.7
LF Background		$\pm 30\%$	~ 0	± 12
Tracking Efficiency			$\pm 0.9\%$	
Luminosity			$\pm 2\%$	
Sum (exclud. Luminosity)			$+2\%$	$+20\%$
			-4%	-23%

δ_1 DIS Selection

- Criteria associated with more than 1% uncertainty is listed.

δ_2 Calorimeter

- Due to imperfect calibration of hadronic calorimeter (HAC). Uncertainty in E_T^{jet} is known to be $\pm 3\%$. The reconstructed E_T^{jet} cut was varied 3% for MC events.

δ_3 LF Background

- Asymmetry in LF decay length due to long-lived LF particles.

δ_4 Tracking Efficiency

- Tracking efficiency is overestimated in MC. A dedicated study shows that this causes uncertainty in charm cross section by $\pm 0.9\%$. No dedicated study is conducted in this analyses.

δ_5 Luminosity

- Uncertainty in ZEUS luminosity measurement. Known to be $\pm 2\%$.

Summary

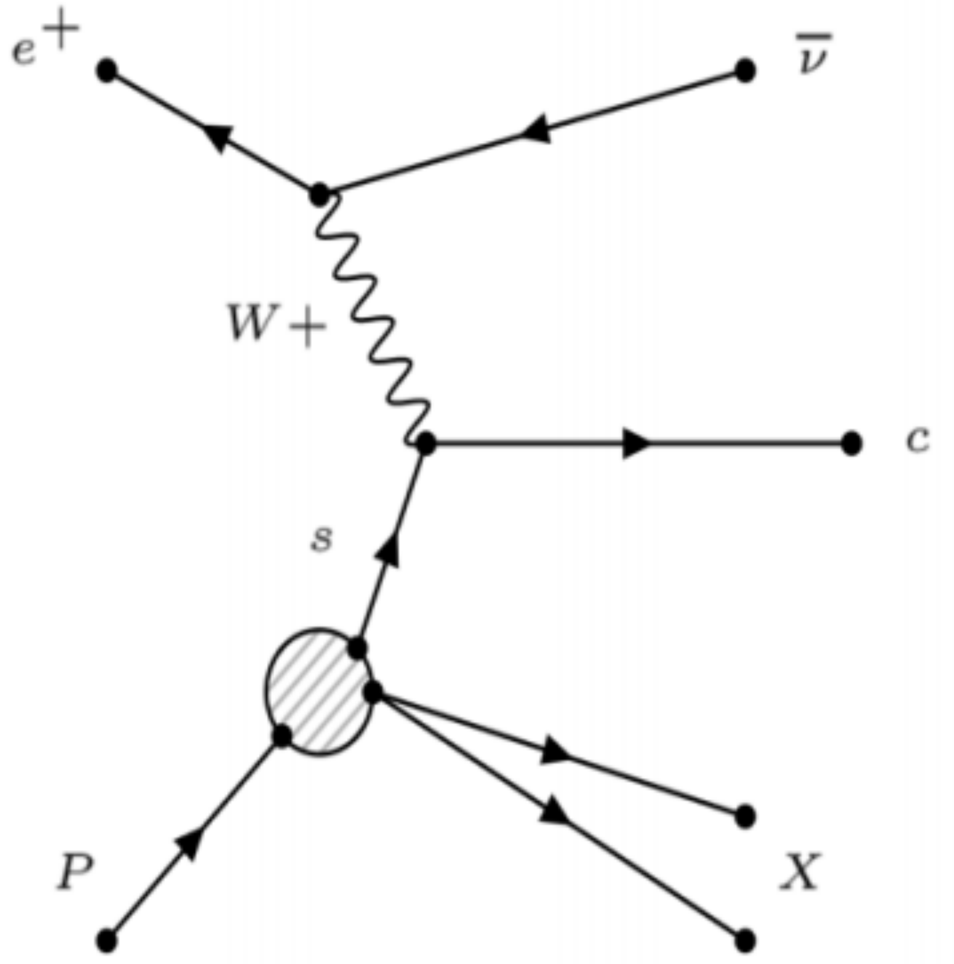
- Measurement of charm cross sections in a kinematic region ($Q^2 > 200\ GeV^2, y < 0.9, E_T^{jet} > 5\ GeV, |\eta^{jet}| < 2.5$) has been performed and total cross sections have been extrapolated with the ZEUS detector with HERA II data.

- Reasonable agreement with MC, given a large statistical uncertainty.

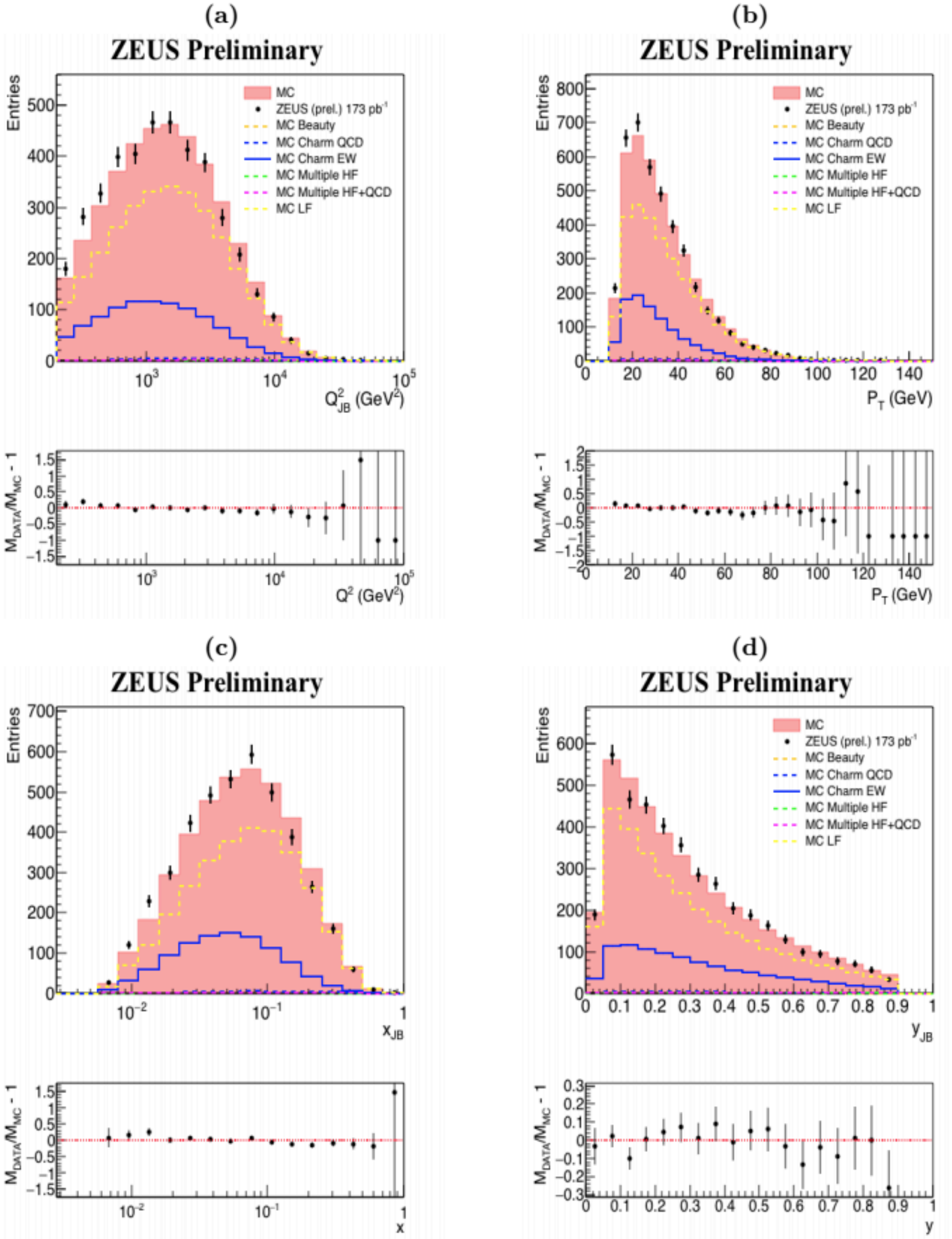
Requested for Preliminary

Q^2 range (GeV^2)	$\frac{d\sigma}{dQ^2}$ (10^{-3} pb GeV^{-2})				
	e^+p				
200–1554.9	8.3	±3.5	(stat.)	$^{+0.17}_{-0.31}$	(sys.)
1554.9–100000	-0.013	±0.050	(stat.)	$^{+0.00054}_{-0.00018}$	(sys.)
	e^-p				
200–1554.9	-0.71	±3.7	(stat.)	$^{+0.28}_{-0.28}$	(sys.)
1554.9–100000	-0.016	±0.066	(stat.)	$^{+0.0025}_{-0.0030}$	(sys.)

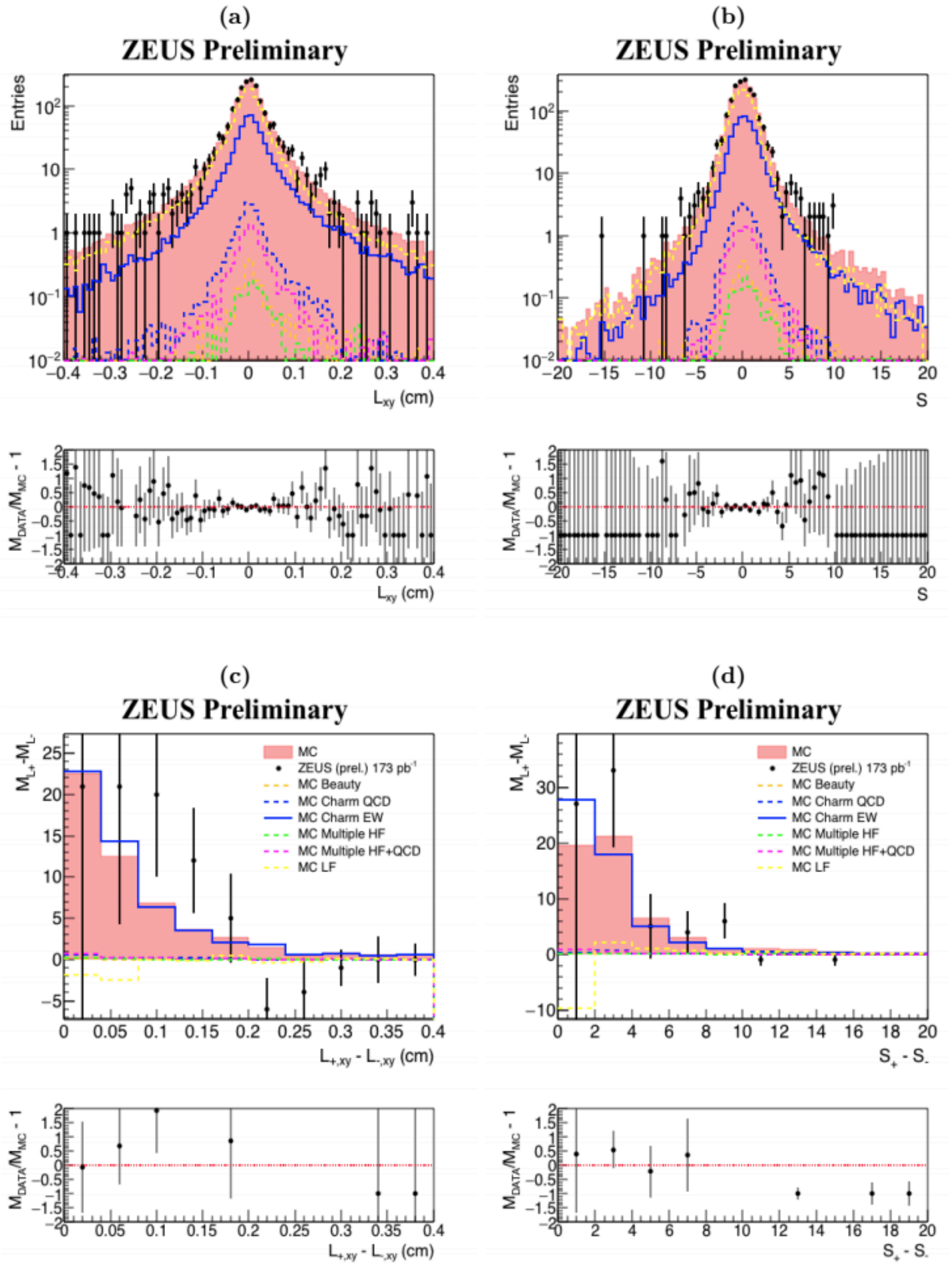
Requested for Preliminary



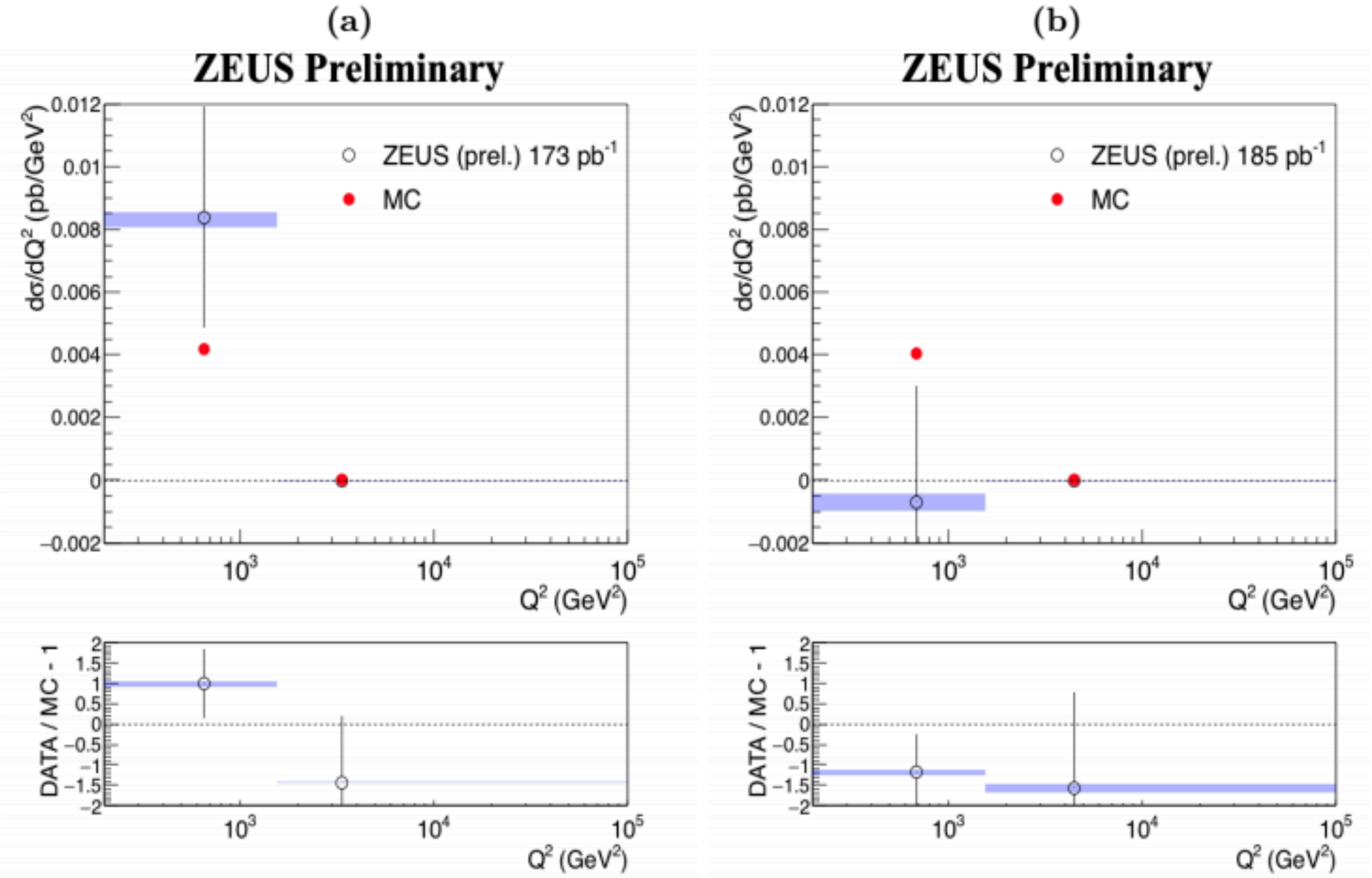
Requested for Preliminary



Requested for Preliminary



Requested for Preliminary



Thank You!

Backup Slides

Event Selection Summary

General Selection	
Trigger	FLT 60 || 63 || 39 || 40 || 41 || 43 || 44 SLT EXO 4 TLT EXO 2 || EXO 6 DST 34
DQ	EVTAKE, POLTAKE, MVDTAKE, STTTAKE
Pt	Pt > 12 GeV P't > 10 GeV
Kinematic	Q2 > 200 GeV2 y < 0.9
Tracking Based Selection	
Vertex	|Zvtx| < 30 cm
ϕcal - ϕtrk	dϕ < 90 degree
Beam Gas Trk	Ntrkvtx > 0.125 * (Ntrk - 20)

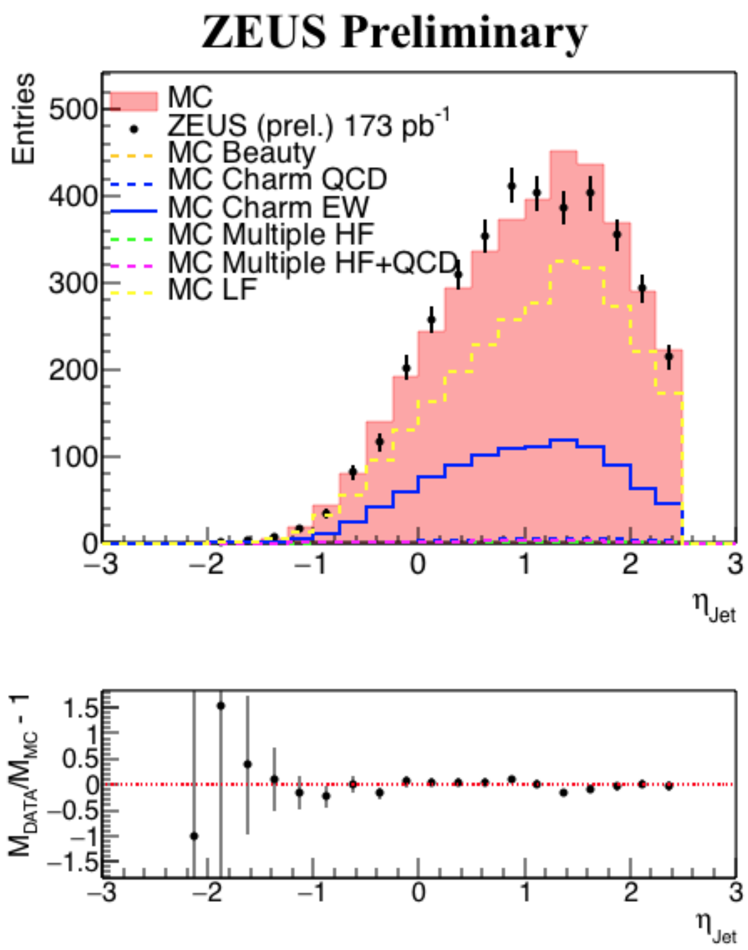
Calorimeter Based Selection	
Timing	Consistent with ep interaction
PhP, Beam Gas	VapVp < 0.25 if (Pt < 20 GeV) VapVp < 0.35 else
Cosmics	Reject if: Ncell < 40 or (BAC/BRMU cosmic muon) or E_RCAL > 2 GeV and f_RHAC > 0.5 or E_BCAL > 2 GeV and f_BHAC > 0.85 or f_BHAC1 > 0.7 or f_BHAC2 > 0.4 or E_FCAL > 2 GeV and f_FHAC < 0.10 or f_FHAC > 0.85 or f_FHAC1 > 0.7 or f_FHAC2 > -.6
Halo Muon	Reject if: MaxEtCell_nr <= 16384 and RCAL asosE > 0.3 GeV (FCAL) or Tsu_halo > 0 (TSUBAME in BCAL) or (BAC/BRMU halo muon)
NC DIS	Reject if: PT < 30 GeV&& E-Pz > 30 GeV && E_e > 4 GeV && E_in < 5 GeV && (Ptrk/Ee > 0.25 for 15 < θe < 164 or Ete > 2 GeV for θe > 164)

yellow – Varies between run periods
-STTTAKE = 0 for 05e data
-FLT 63 active after run 54115

green – Only applied on data
-Timing cut only on data

η peak

$0607p$



$0304p$