Form factor measurement with process $Z \rightarrow 4l$

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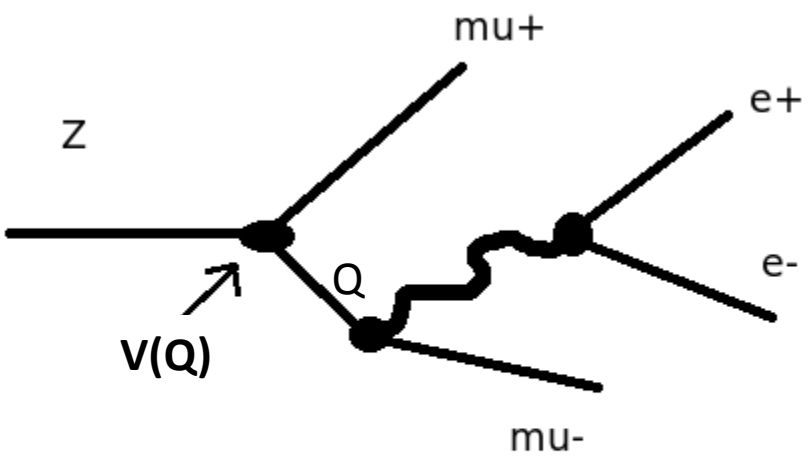
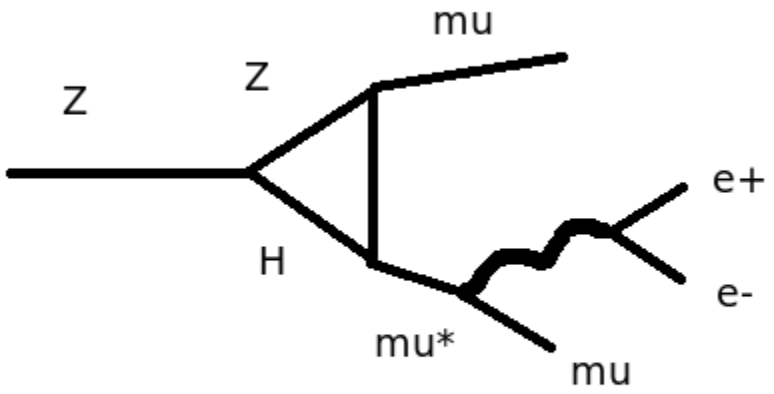
Formfactor measurement with Z→4l



- Z decays to real lepton and virtual one
- Z→ll vertex depends on lepton virtuality Q_{lepton}^2
- This vertex function is called "form factor" V(Q)

V(Q) is sensible to interference effects from New Physics



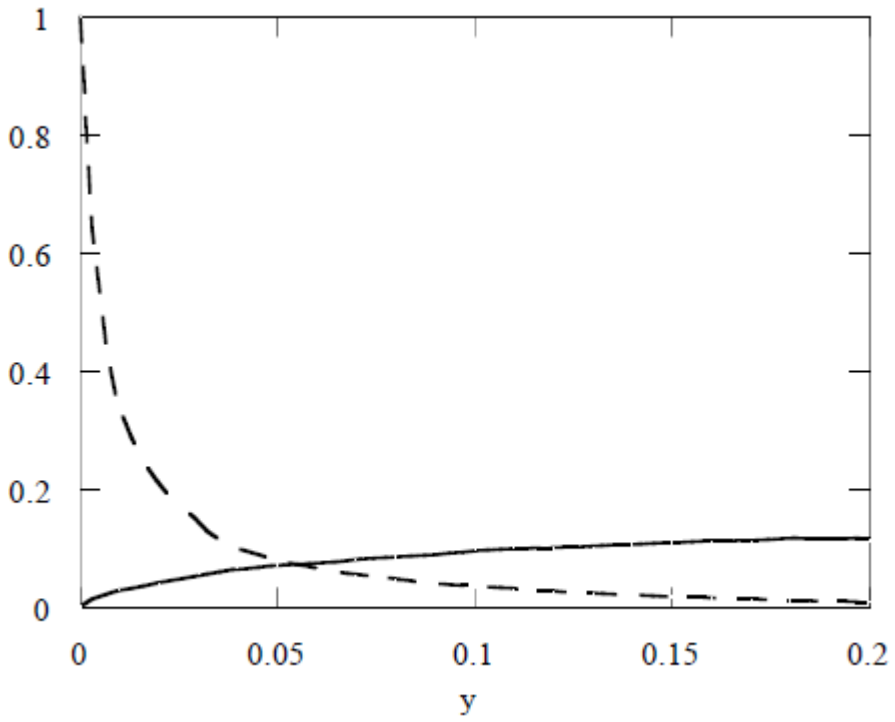
Theory

Effective Lagrangian with CP-violating effects:

$$\mathcal{L}_{\rm CP}(x) = \sum_{\ell} \left[f_{{\rm V}\ell} \bar{\ell}(x) \gamma^{\nu} \ell(x) + f_{{\rm A}\ell} \bar{\ell}(x) \gamma^{\nu} \gamma_5 \ell(x) \right] Z^{\mu}(x) \left[\partial_{\mu} A_{\nu}(x) - \partial_{\nu} A_{\mu}(x) \right] \}$$

Exp/MC ratio $R(y) = \dfrac{\Gamma(\mathrm{Z} \to \ell^+ \ell^- \gamma)}{\Gamma_{\rm SM}(\mathrm{Z} \to \ell^+ \ell^- \gamma)}$

$$\frac{R(y)-1}{\hat{f}^2_{{\rm V}\ell} + \hat{f}^2_{{\rm A}\ell}} = \frac{\Delta\Gamma_{\rm CP}(\hat{f}_{{\rm V}\ell}, \hat{f}_{{\rm A}\ell}; y)}{\Gamma_{\rm SM}(\mathrm{Z} \to \ell^+ \ell^- \gamma)(\hat{\mathrm{f}}^2_{{\rm V}\ell} + \hat{\mathrm{f}}^2_{{\rm A}\ell})}$$



y is a cut parameter
for 2-particles moment sum:

$$\frac{(k_{(1)} + k_{(2)})^2}{m_{\rm Z}^2} \geq y.$$

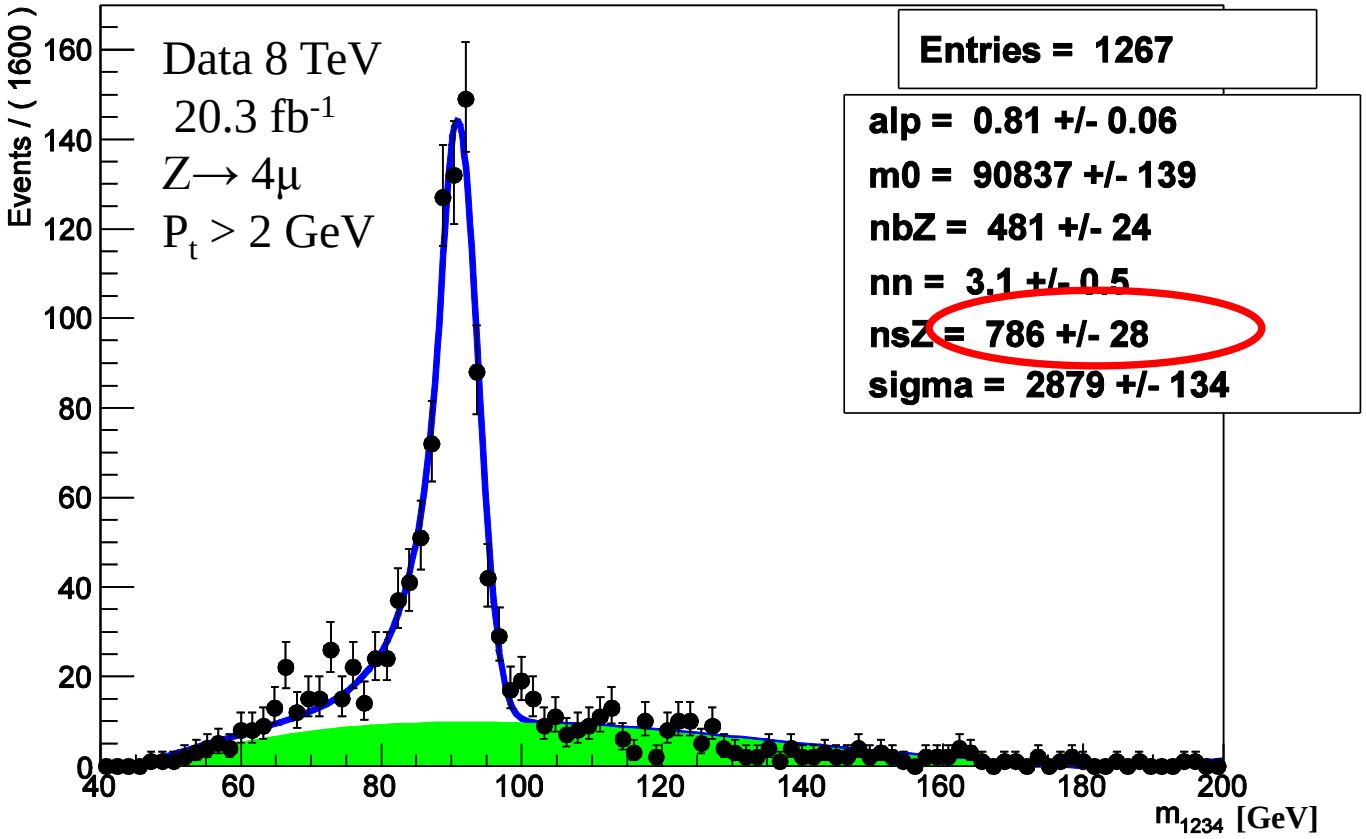
Form factors restrictions:

$$\hat{f}^2_{{\rm V}\mu} + \hat{f}^2_{{\rm A}\mu} < (2.6)^2,$$
$$\hat{f}^2_{{\rm V}\tau} + \hat{f}^2_{{\rm A}\tau} < (2.6)^2.$$

$\hat{f}^2_{{\rm V}\ell} + \hat{f}^2_{{\rm A}\ell} = 1$ will lead to deviations of R(y) from 1 of up to about 10% at y=0.2

D. Bruß, O. Nachtmann, P. Overmann
CP Violation in radiative Z Decays
arXiv:hep-ph/9703216v1

Invariant mass for $Z \rightarrow 4\mu$ in our selections



High statistics is provided by low Pt and no m_{ll} lepton selections

Event selection for 2012 data

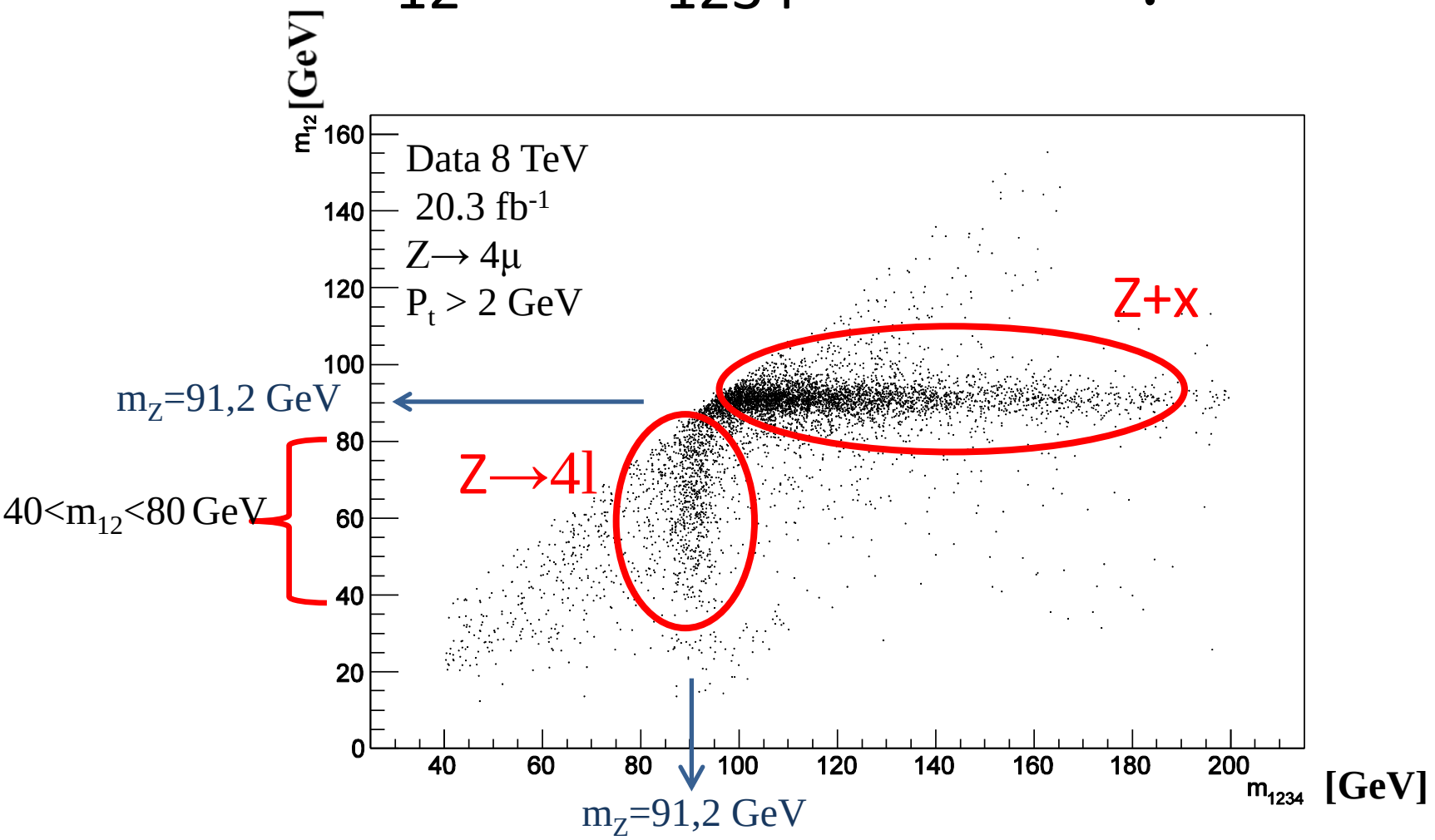
Preselection

- Standart HSG2 cuts without J/ψ veto and m_{ll} cut
- Each lepton is identified as loose (at least)
- P_t > 2 GeV for each lepton and $|\eta|<2.5$ for muons and $|\eta|<2.47$ for electrons

Cuts

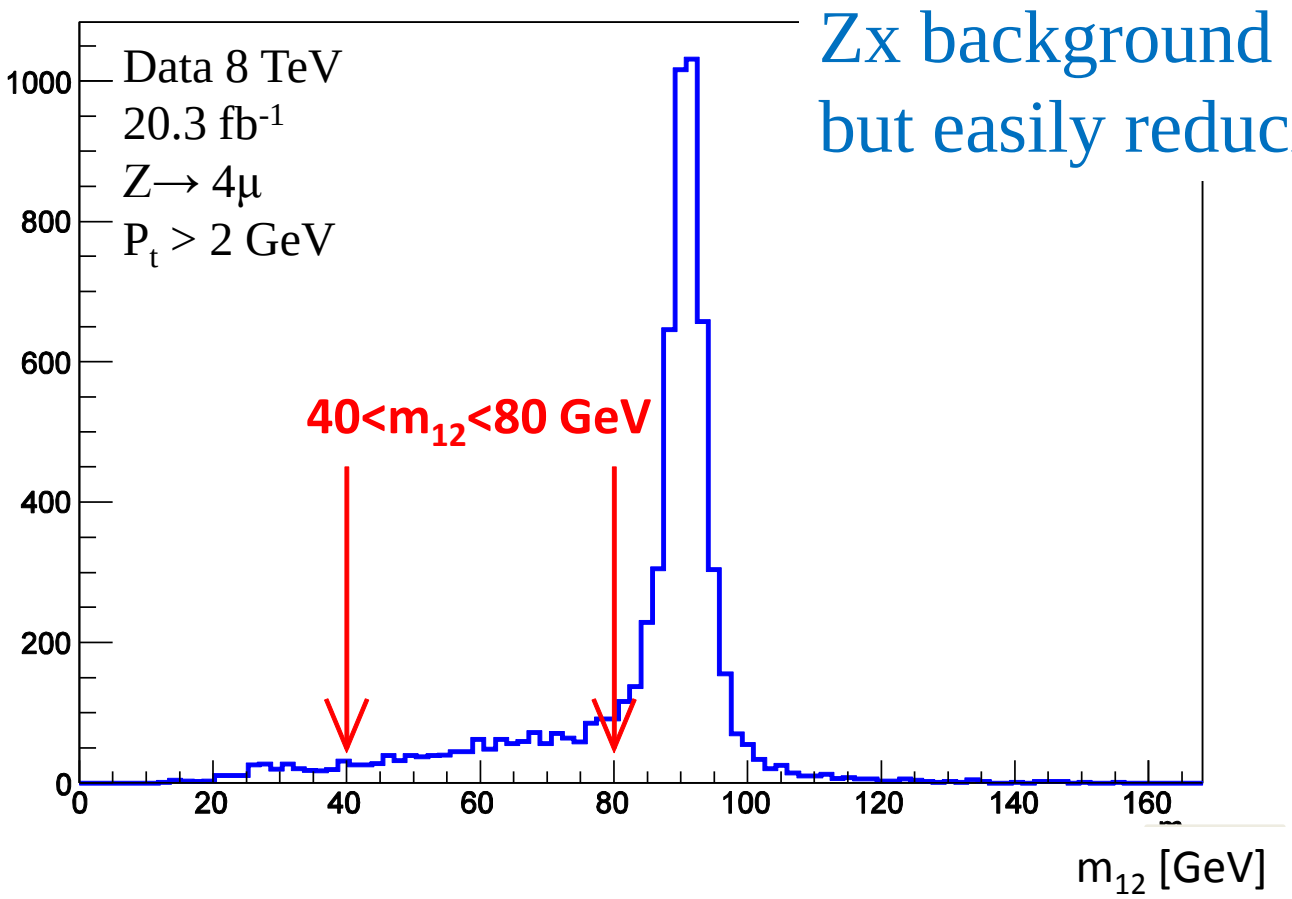
- Track isolation $\sum P_t/P_t < 0.1$
- Calorimeter isolation $\sum E_t/E_t < 0.5$
- Sum of Pt > 60 GeV
- $d_0/\sigma_{d_0} < 5$ for muons
- $40 < m_{12} < 80$ GeV

m_{12} vs m_{1234} for Z→4μ



For this analysis we take only Z→4l region of the plot

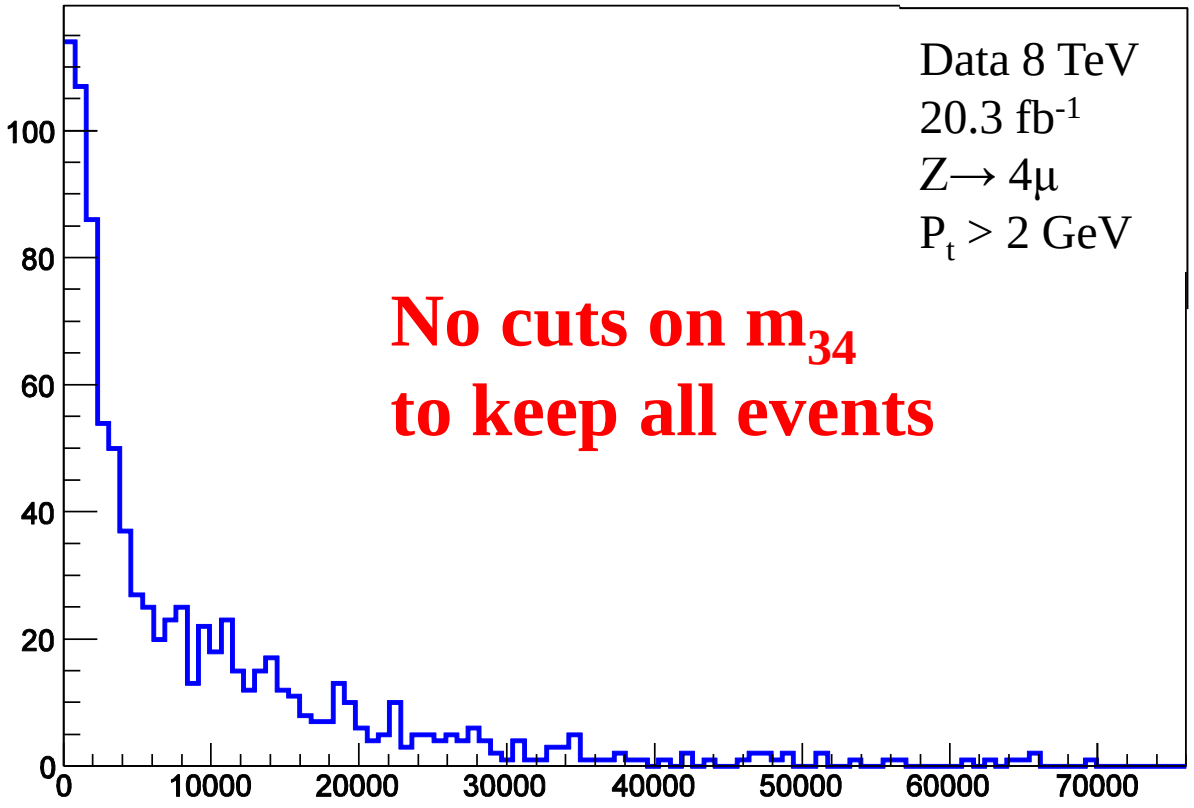
Invariant mass distribution of the leading lepton pair, m_{12}



Zx background is huge, but easily reducible

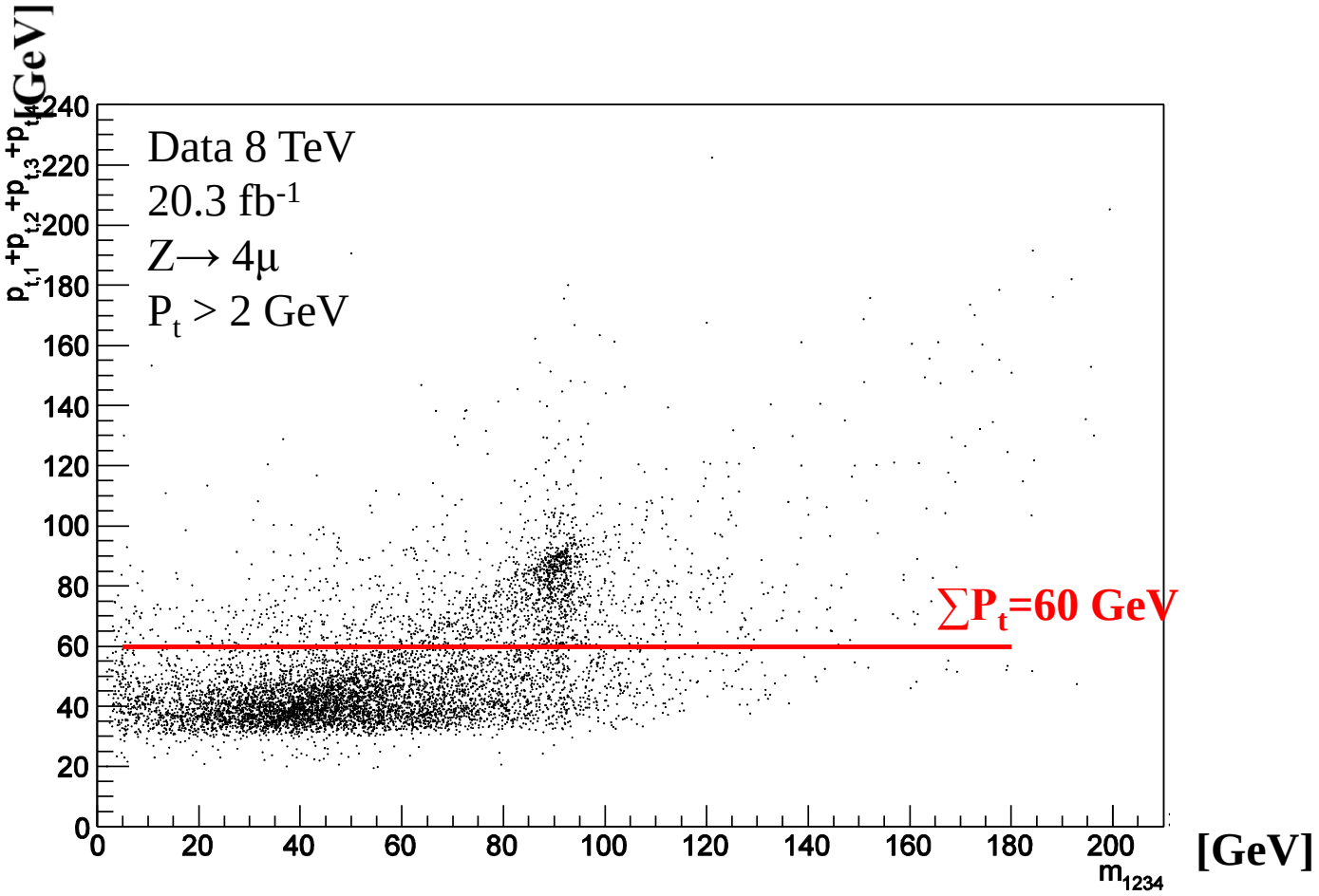
For this analysis we take $40 < m_{12} < 80$ GeV to reduce Zx bkg

Invariant mass distribution of the subleading lepton pair, m_{34}



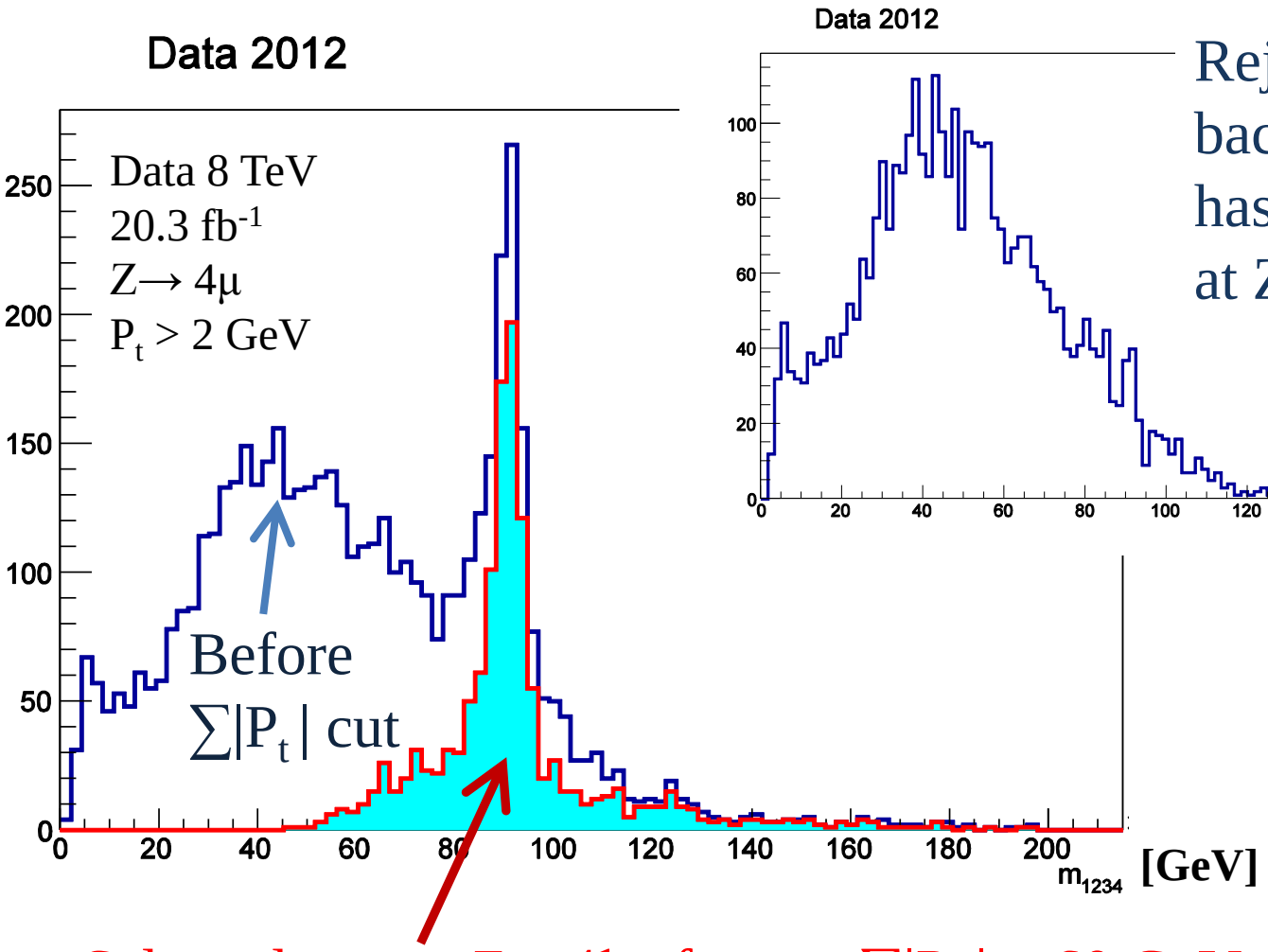
For events selected with all cuts

$\sum|P_t|$ vs m_{1234} for $Z\rightarrow 4\mu$

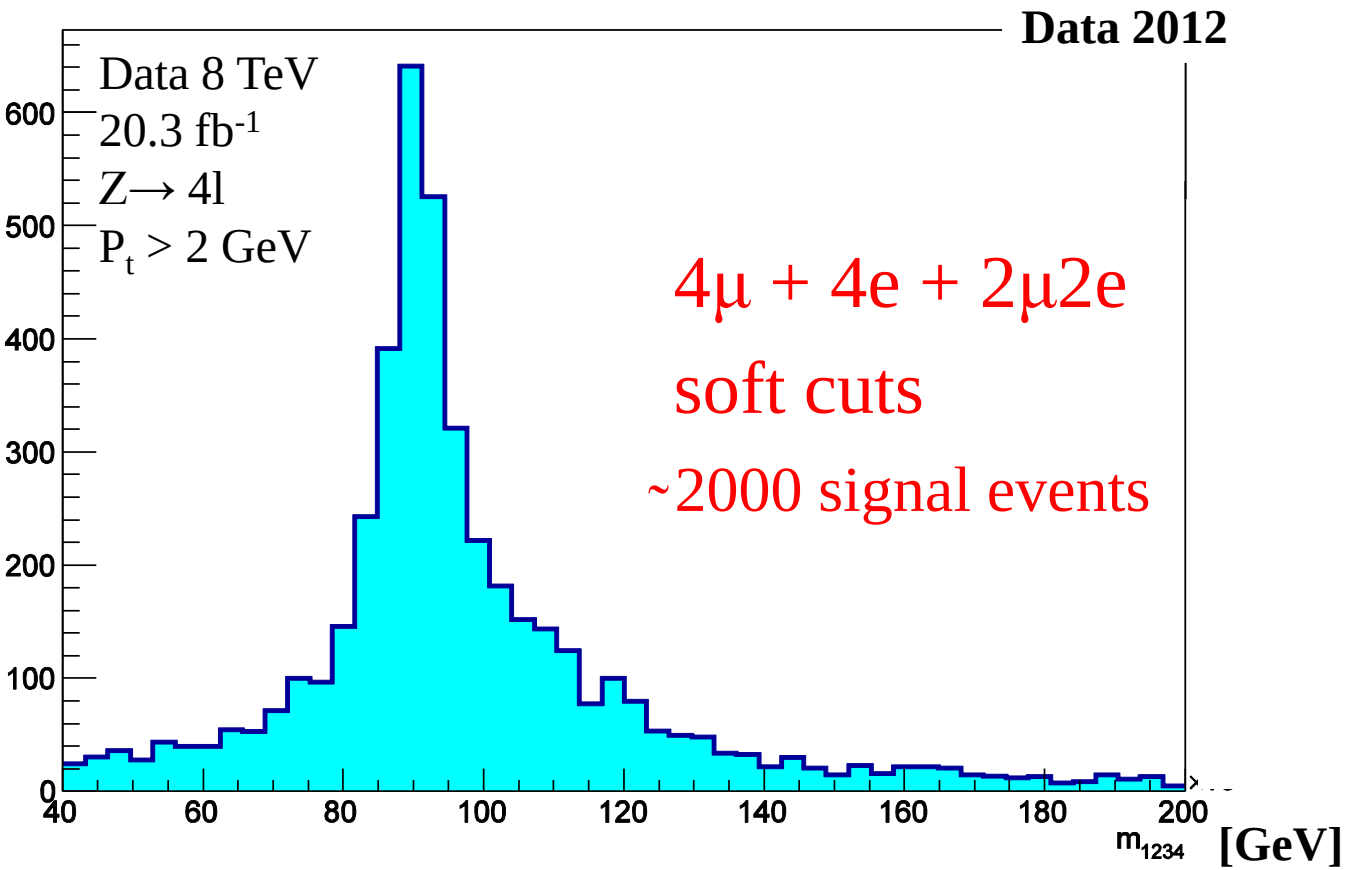


Most of the non Zx bkg has $\sum P_t < 60$ GeV

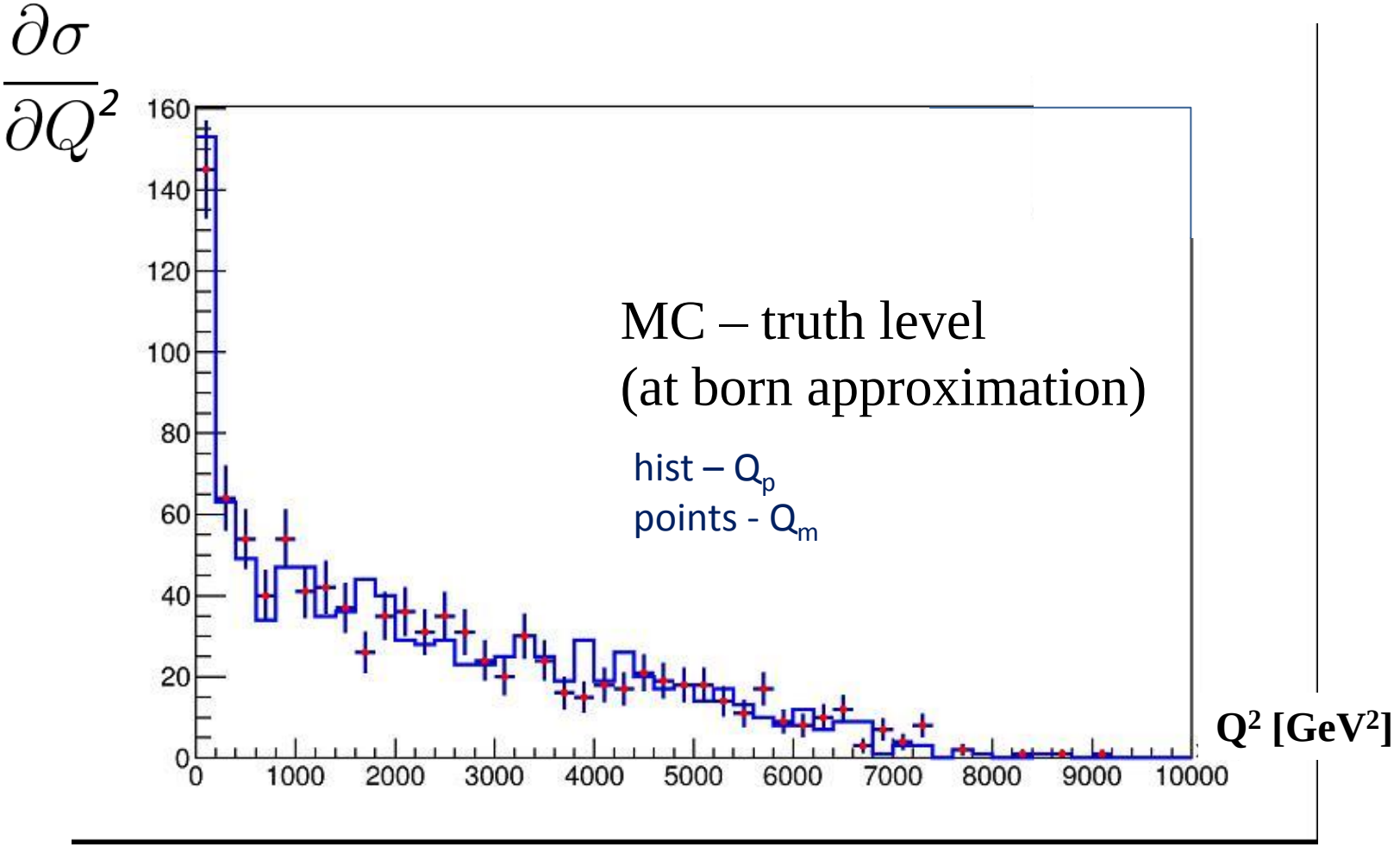
$Z \rightarrow 4\mu$ before and after $\sum|P_t|$ cut



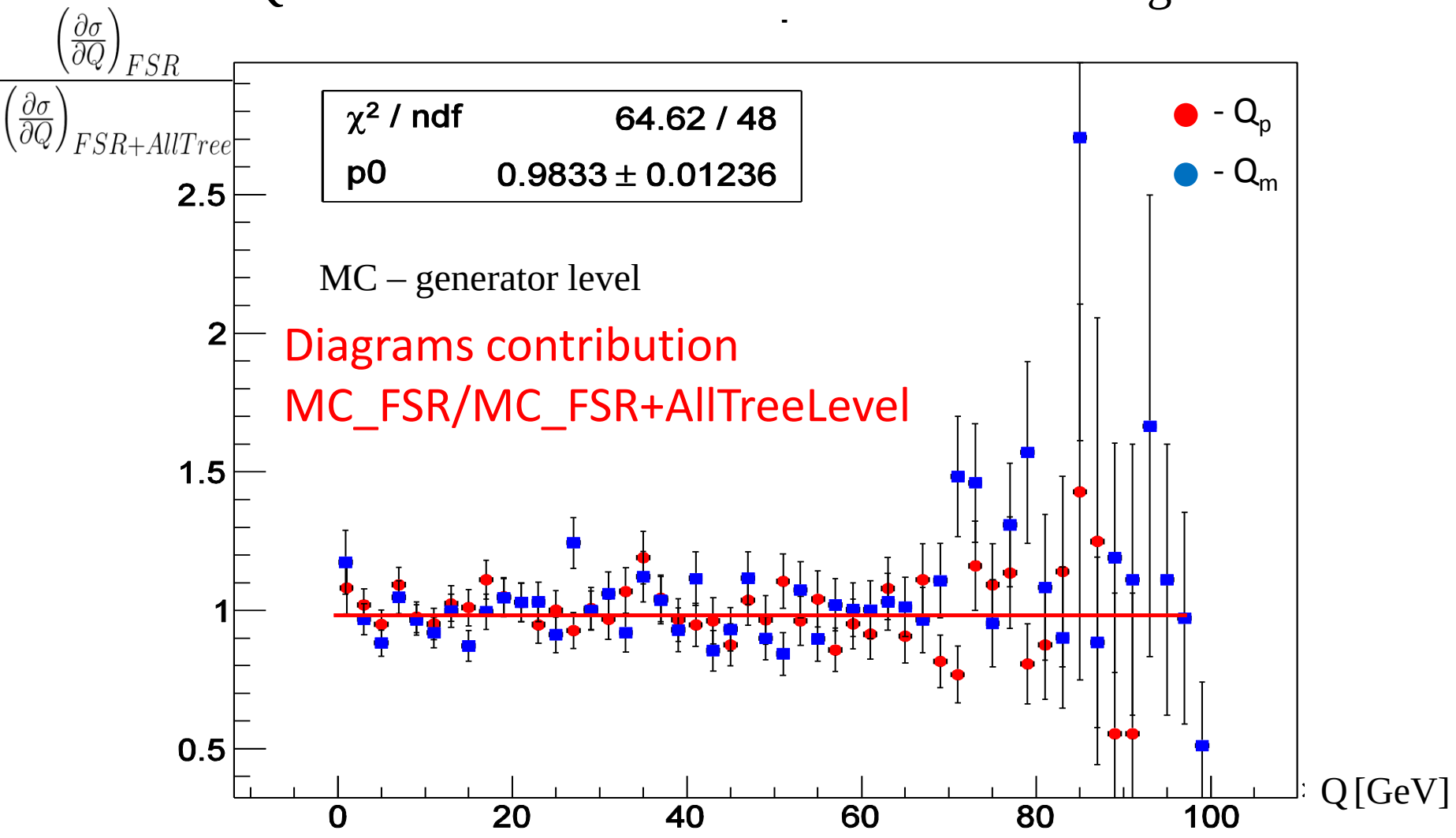
Invariant mass of 4 leptons with soft cuts



Q^2 - distribution for Q_p and Q_m



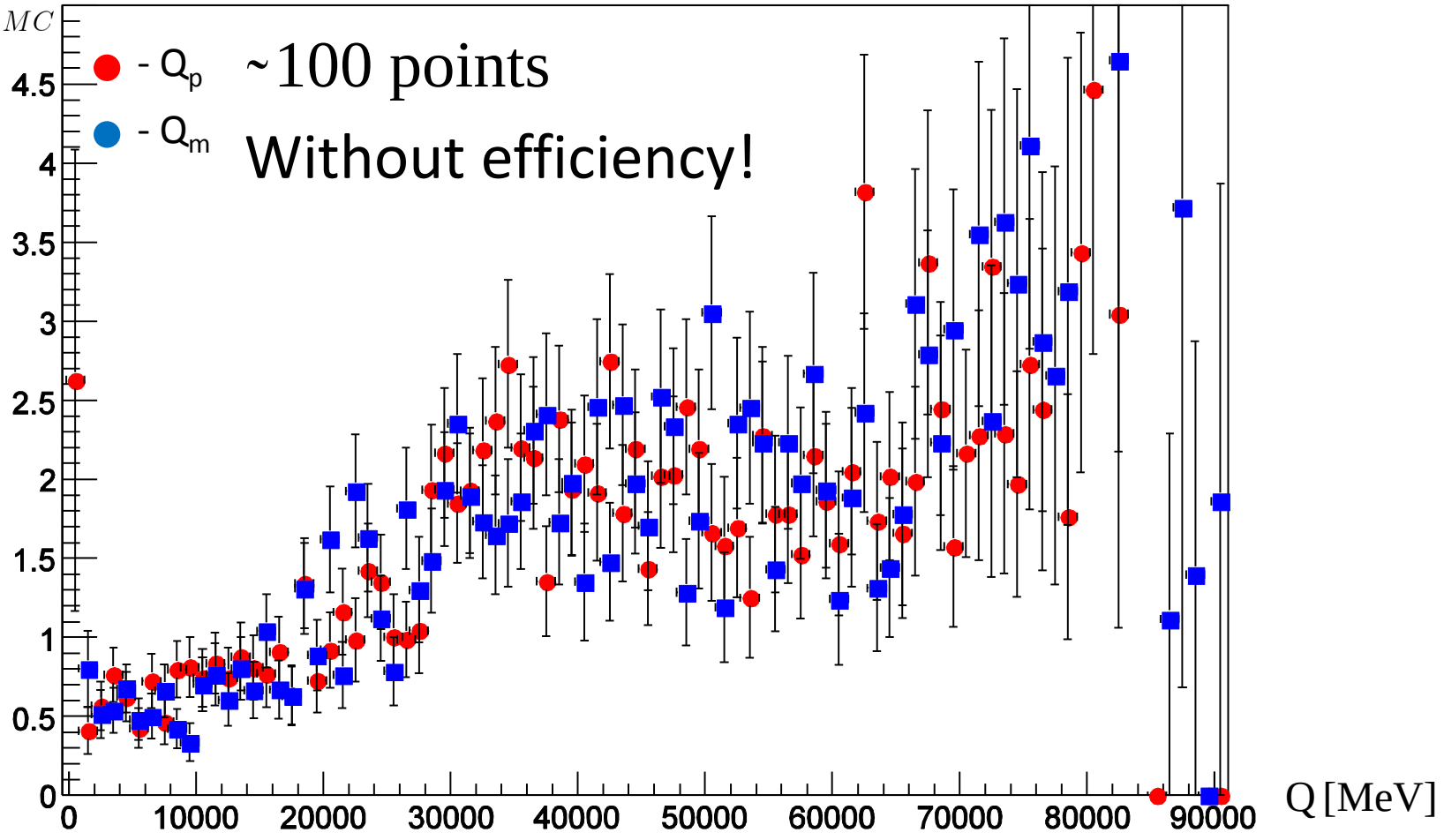
Q – distribution in MC with only FSR diagram divided to Q – distribution in MC with all tree level diagrams



Q^2 distribution for Z→4l process is saturated by FSR diagrams at 2% level

Q distribution for Data-2012 divided to MC-truth level Comphep (4μ + 4e + 2e2μ)

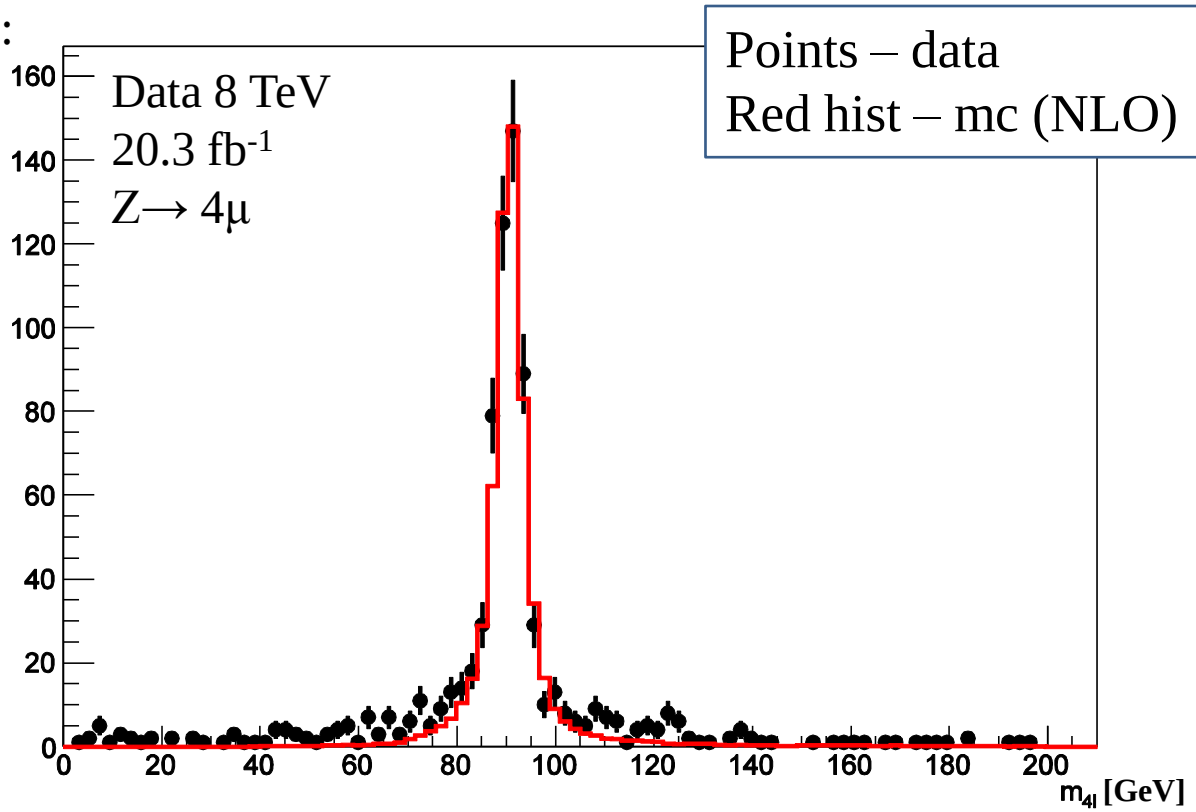
$$F(Q) = \frac{\left(\frac{\partial\sigma}{\partial Q}\right)_{Data}}{\left(\frac{\partial\sigma}{\partial Q}\right)_{MC}}$$



$Z \rightarrow 4\mu$ comparison with full MC

Event Selection for Data and MC:

- Track isol $\sum P_t/P_t < 0.1$
- Calo isol $\sum E_t/E_t < 0.5$
- four leptons with $P_t > 3$ GeV
- Sum of Pt > 70 GeV
- $m_{12} < 80$ GeV

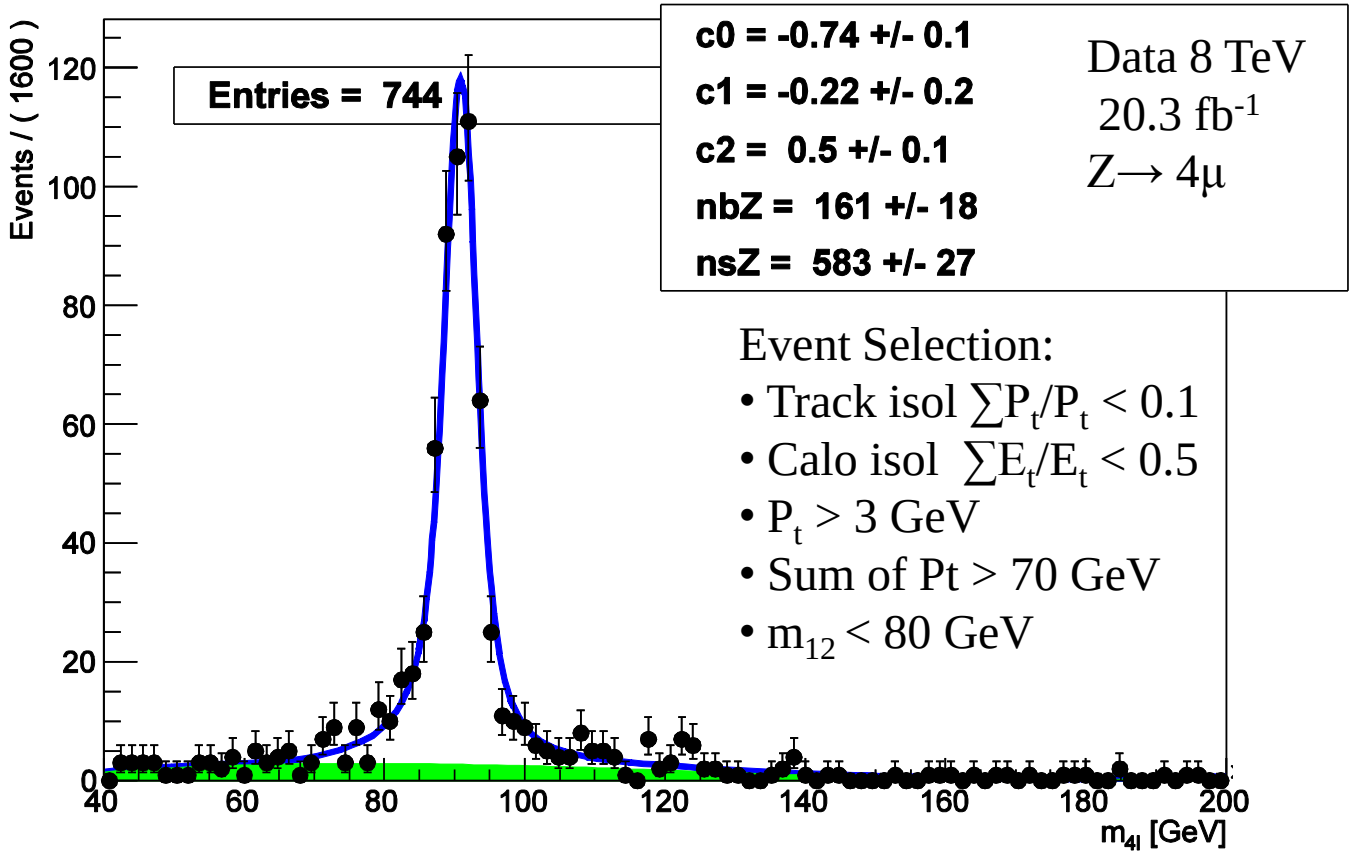


Powheg generator cuts

- $m_{ll} > 0.25$ GeV
- four leptons with $P_t > 3$ GeV,
- $m_{4l} > 40$ GeV

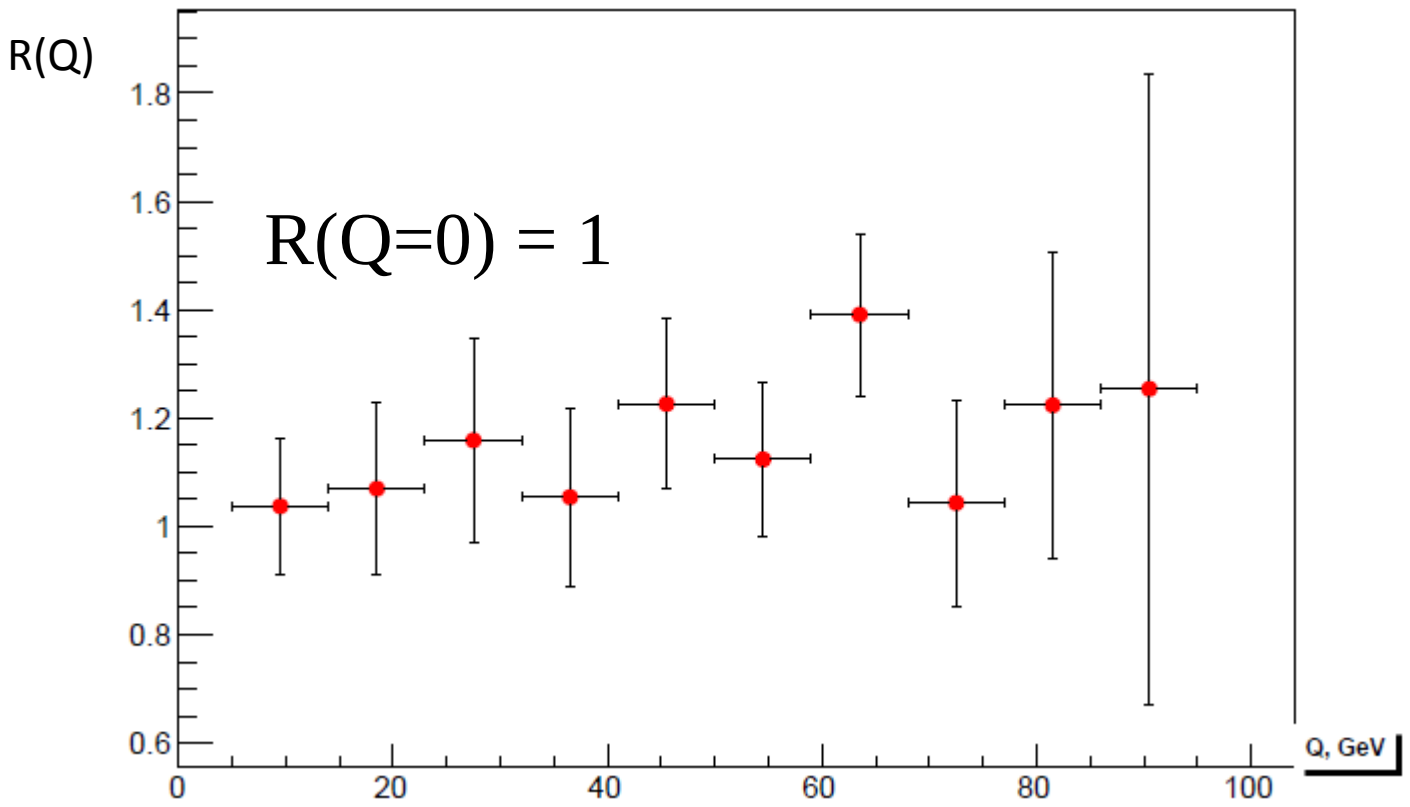
mc12_8TeV.147225.PowhegPythia8_AU2CT10_ZZ_4mu_mll025_4lpt3_m4l40.merge.NTUP_SMWZ.e1750_s1581_s1586_r3658_r3549_p1328

Z→4μ fit with shape from MC



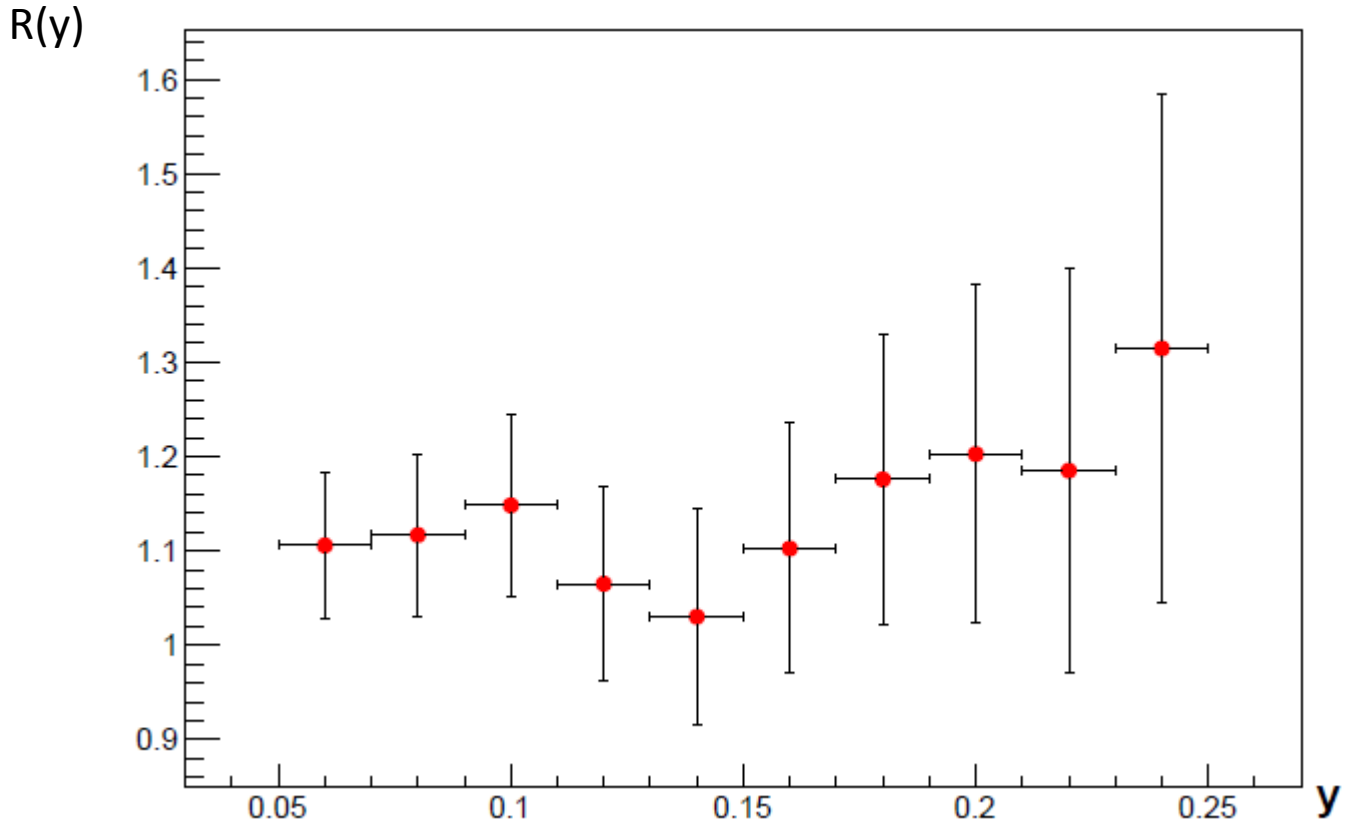
To estimate number of signal and background events the fit was provided in each Q-bin. Signal shape was taken from Powheg full MC and background shape was fitted with Chebyshev polynoms.

Z→4μ fit with shape from MC



Powheg MC is multiplied by factor 1.32 taken from Powheg/Comphep cross sections comparison at truth level

$Z \rightarrow 4\mu$ fit with shape from MC



Powheg MC is multiplied by factor 1.32 taken from Powheg/Comphep Cross sections comparison at truth level

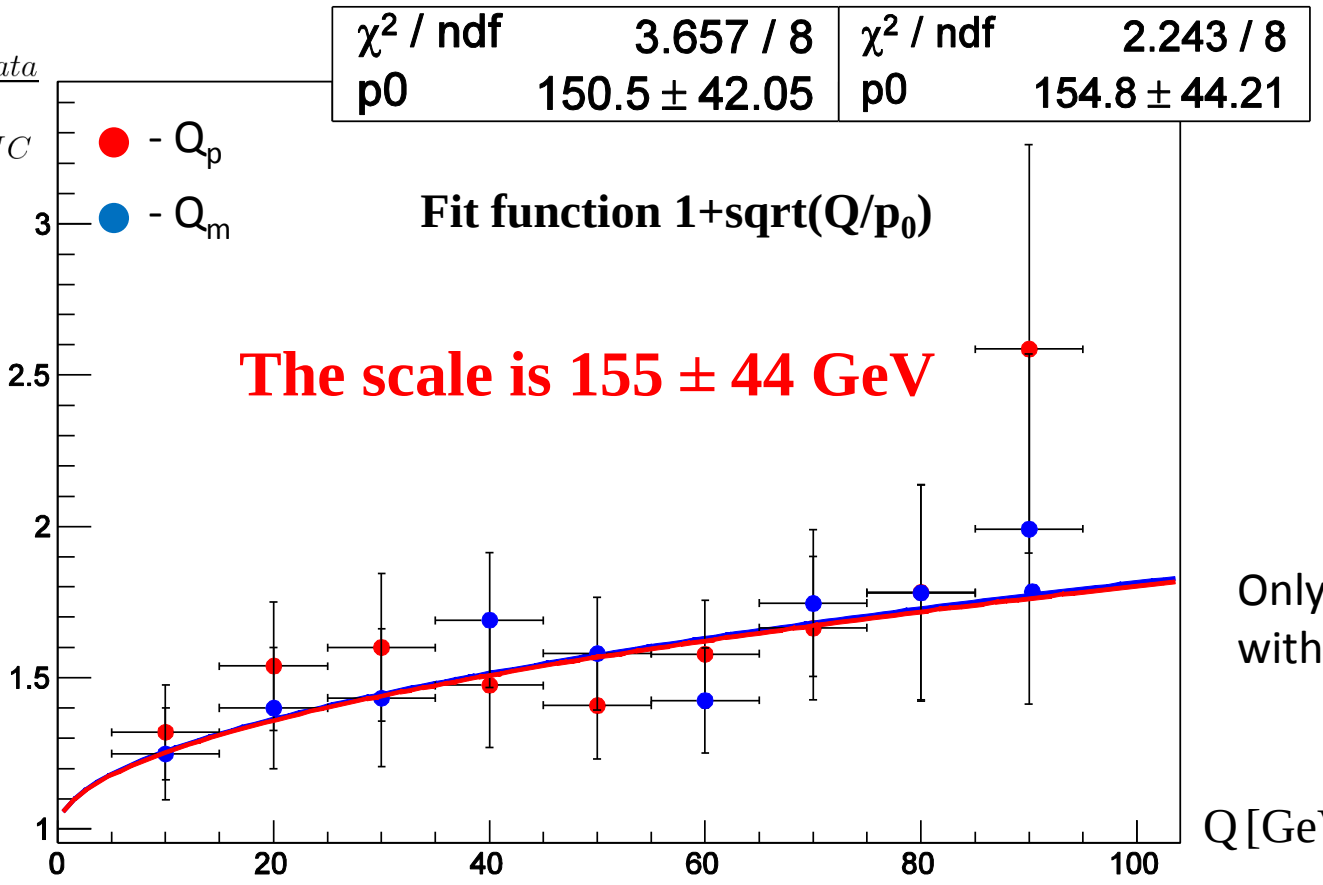
Conclusions

- We report $Z \rightarrow 4l$ soft selections resulting in high statistics
- It allows to measure $Z \rightarrow 2l$ vertex dependence on the Q_{lepton}^2 (or cross section dependence on Q_{lepton}^2)
- $Z \rightarrow 2l$ vertex dependence on the Q_{lepton}^2 is sensible to interference with New Physics
- To measure $Z \rightarrow 2l$ vertex dependence on the Q_{lepton}^2 one needs:
  - $Z \rightarrow 4l$ MC with low $P_t > 2$ GeV
  - Recommendations for μ/e with low $P_t > 2$ GeV
- First look at $Z \rightarrow 4\mu$ gives $f_V^2 + f_A^2$ about 0.5

Back ups

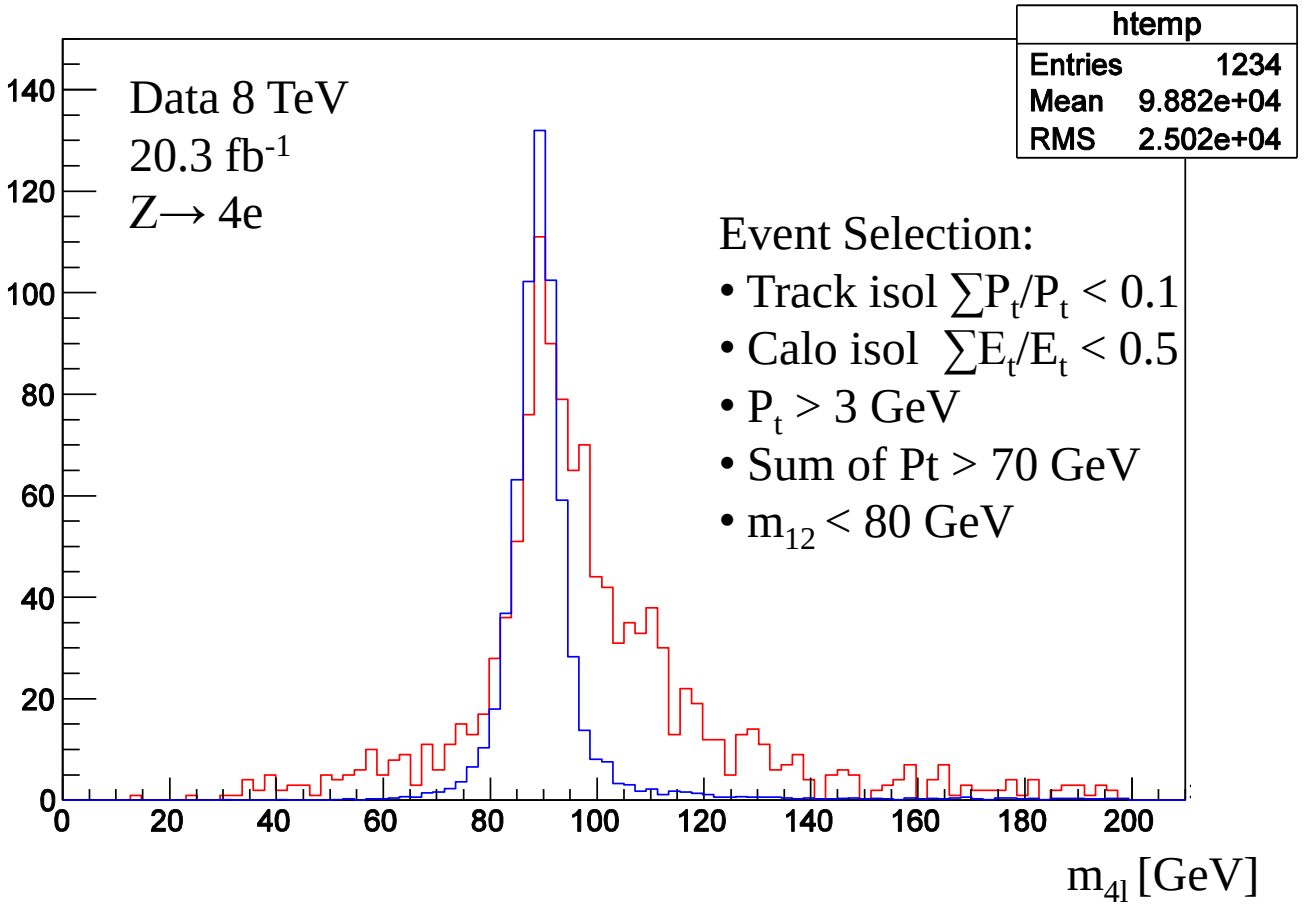
Z→4μ form factor measurement – first look

$$F(Q) = \frac{\left(\frac{\partial\sigma}{\partial Q}\right)_{Data}}{\left(\frac{\partial\sigma}{\partial Q}\right)_{MC}}$$

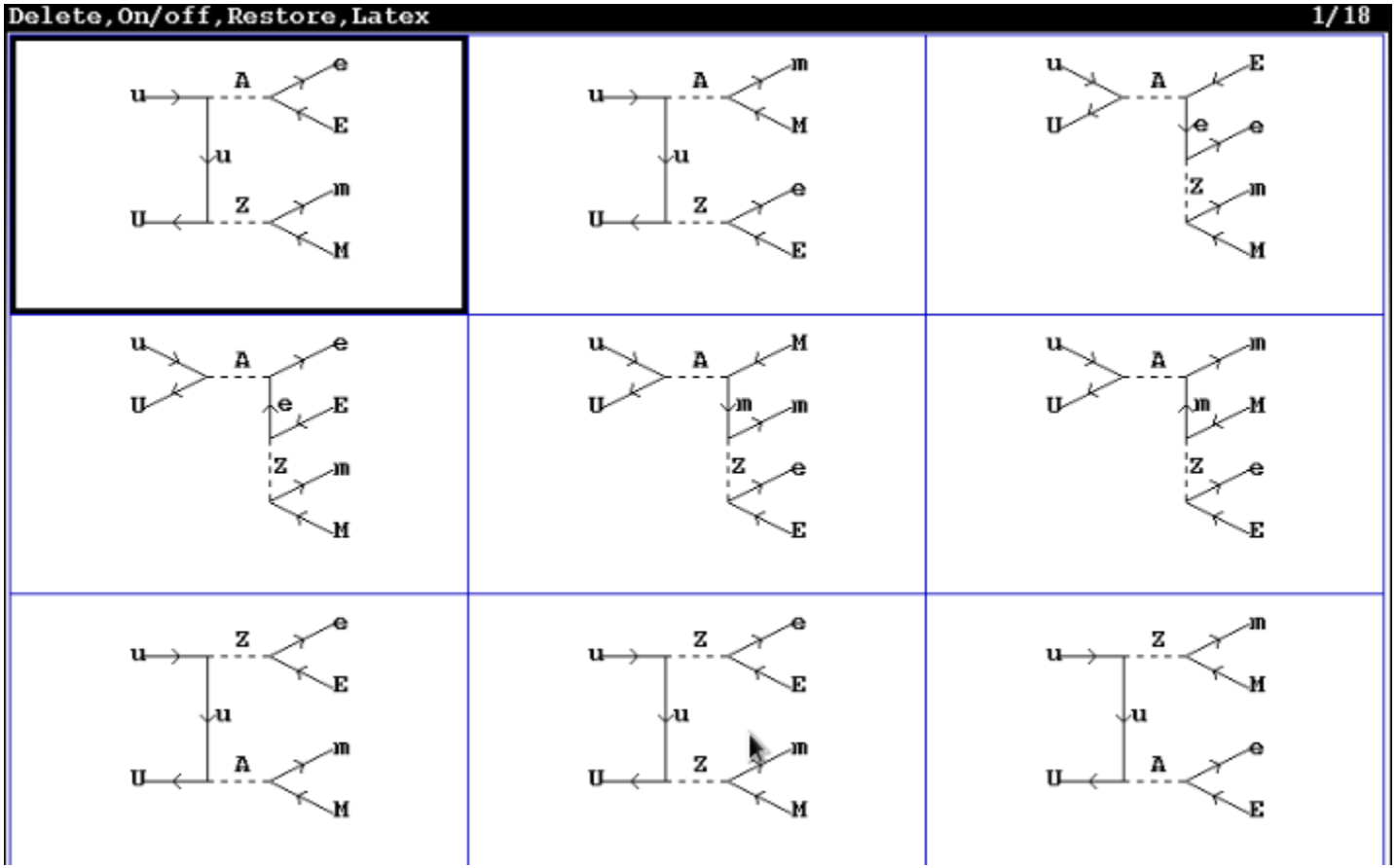


Only muons with $P_t > 3$ GeV

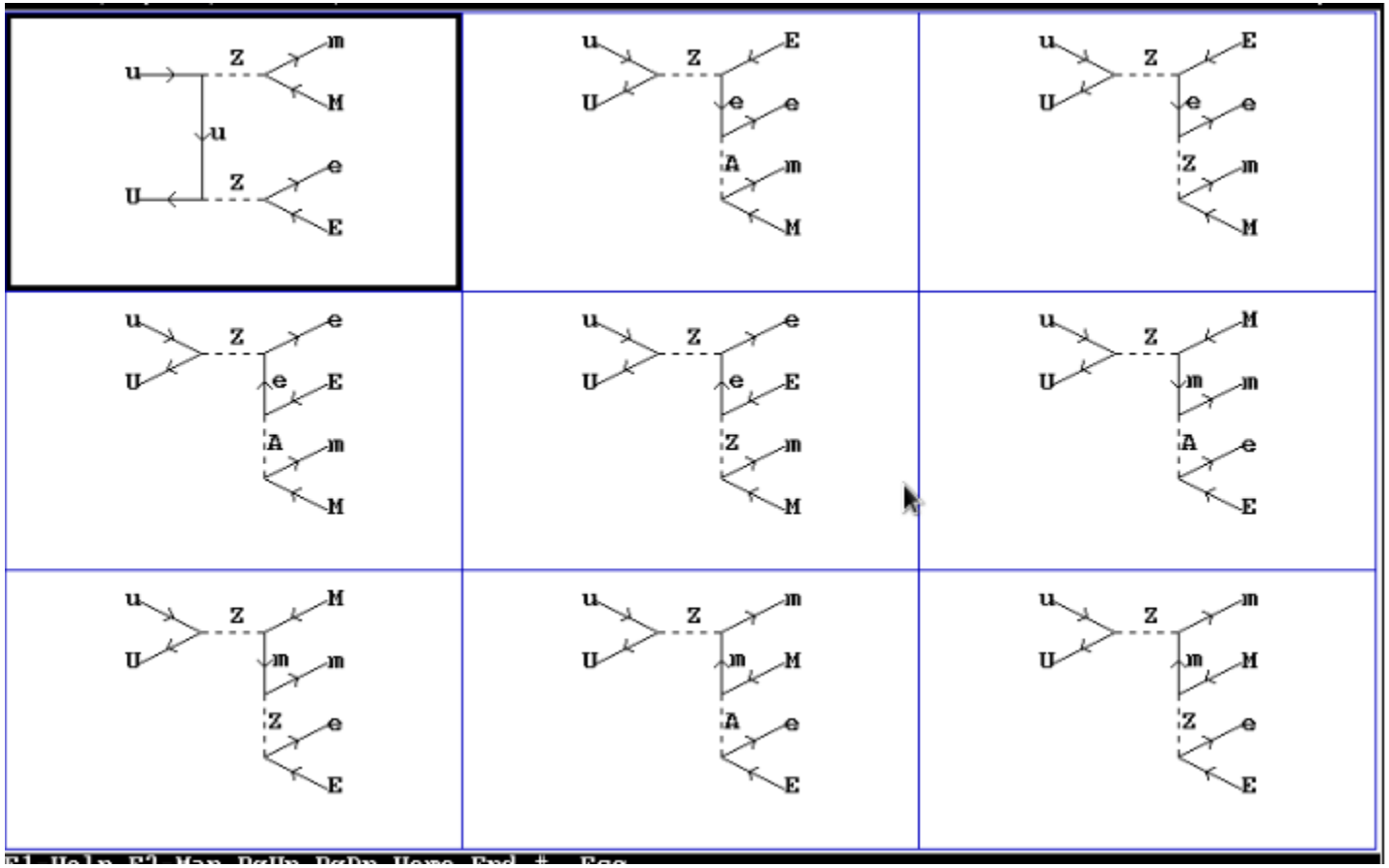
Z→4e comparison with full MC



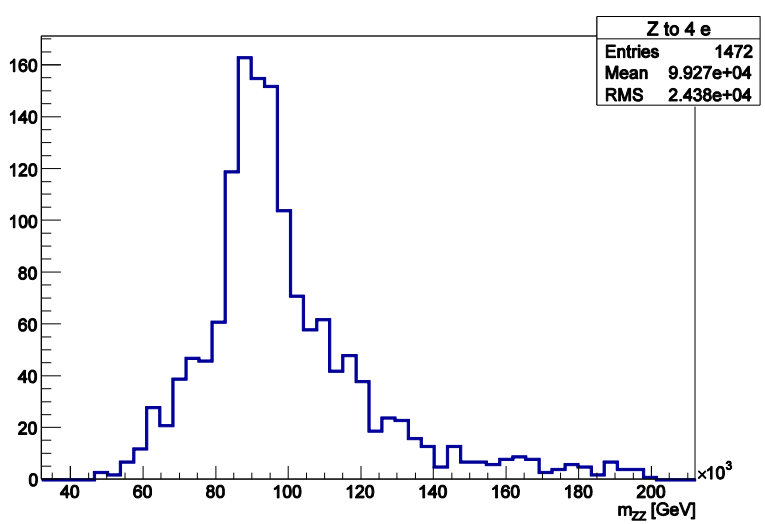
Tree level diagrams - 1

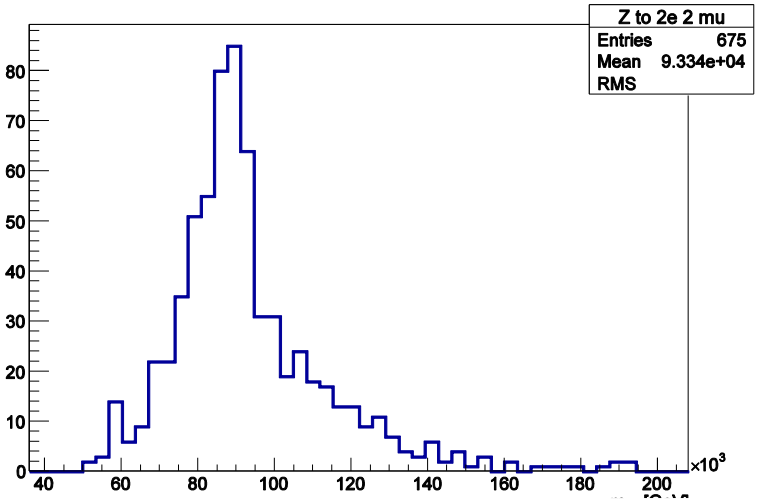


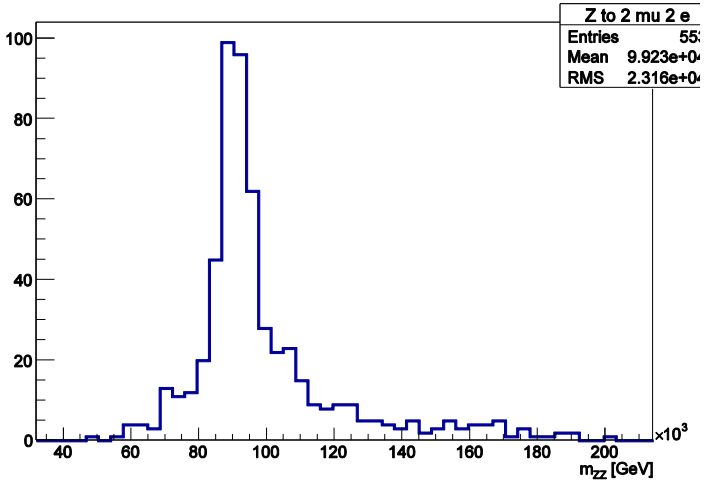
Tree level diagrams - 2

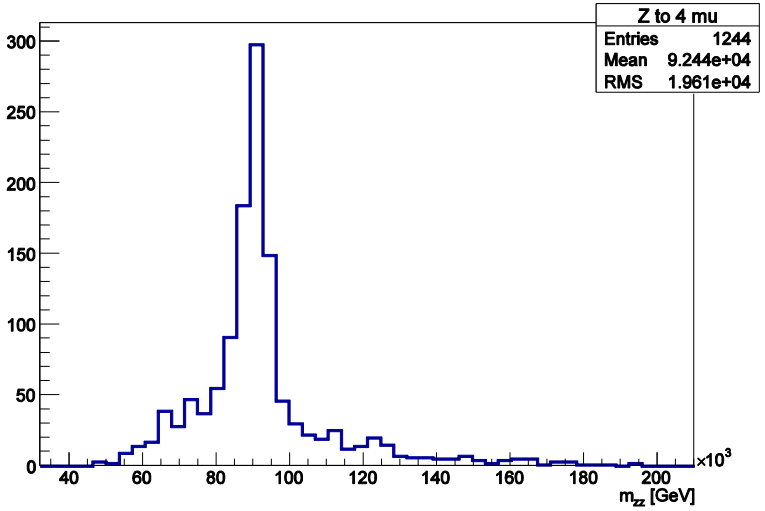


Invariant mass for 4 leptons

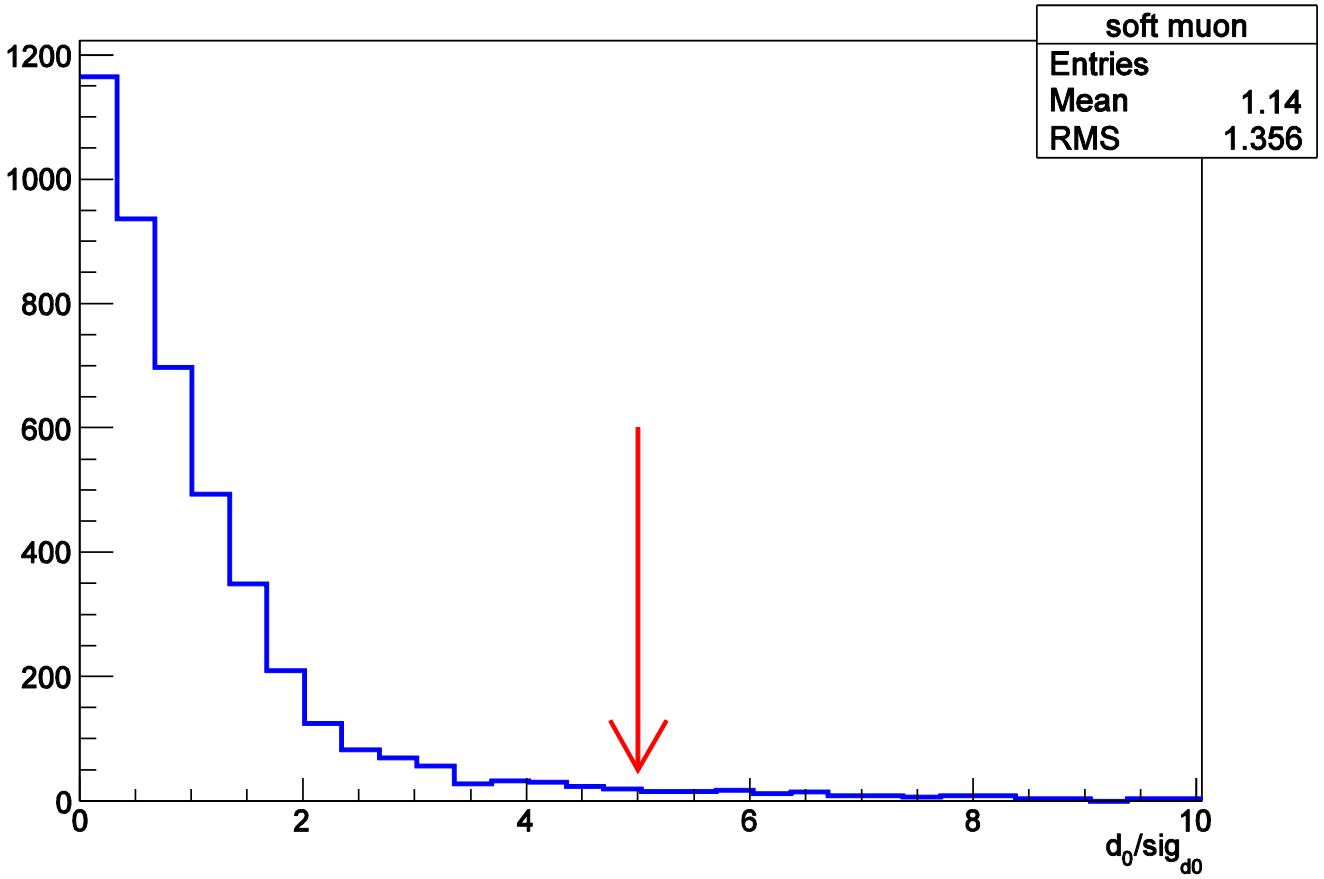




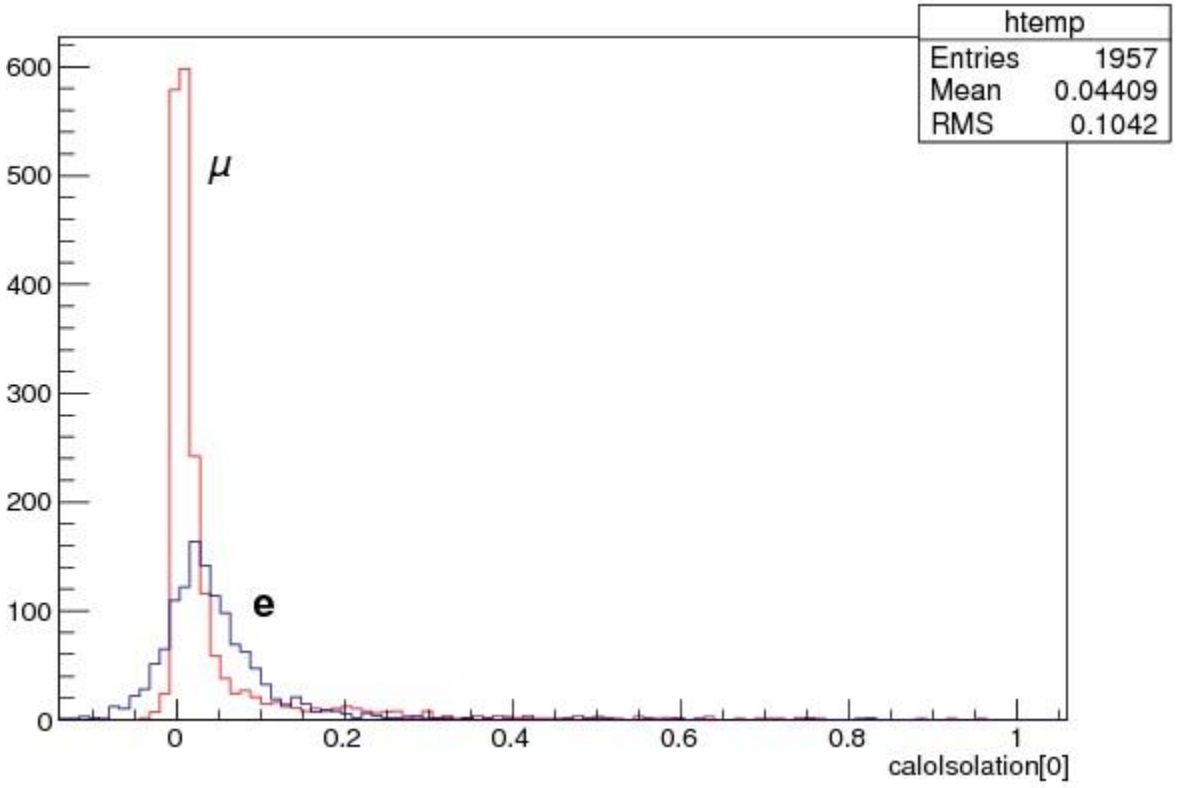




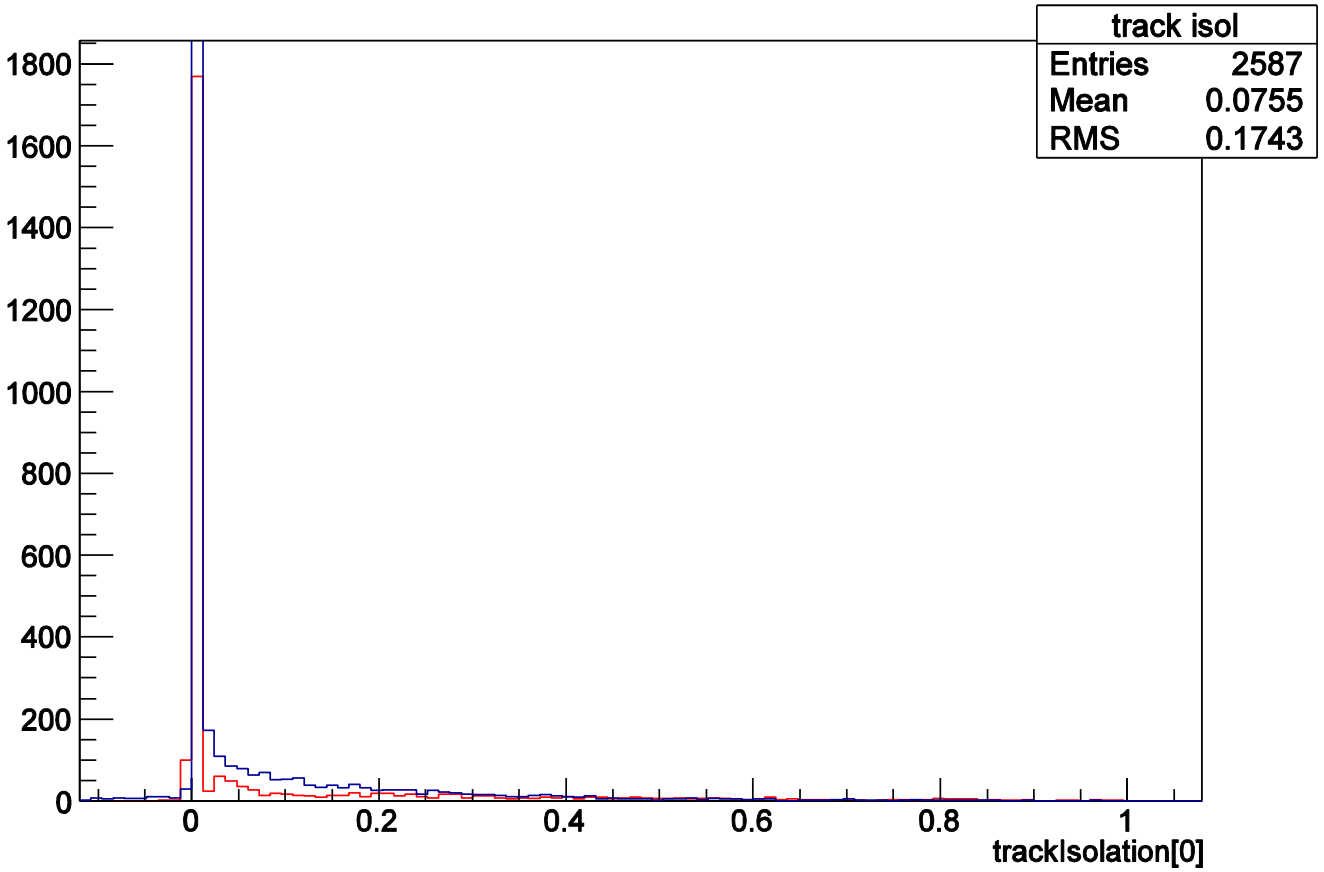
d_0/σ_{d_0} for soft muon (3)



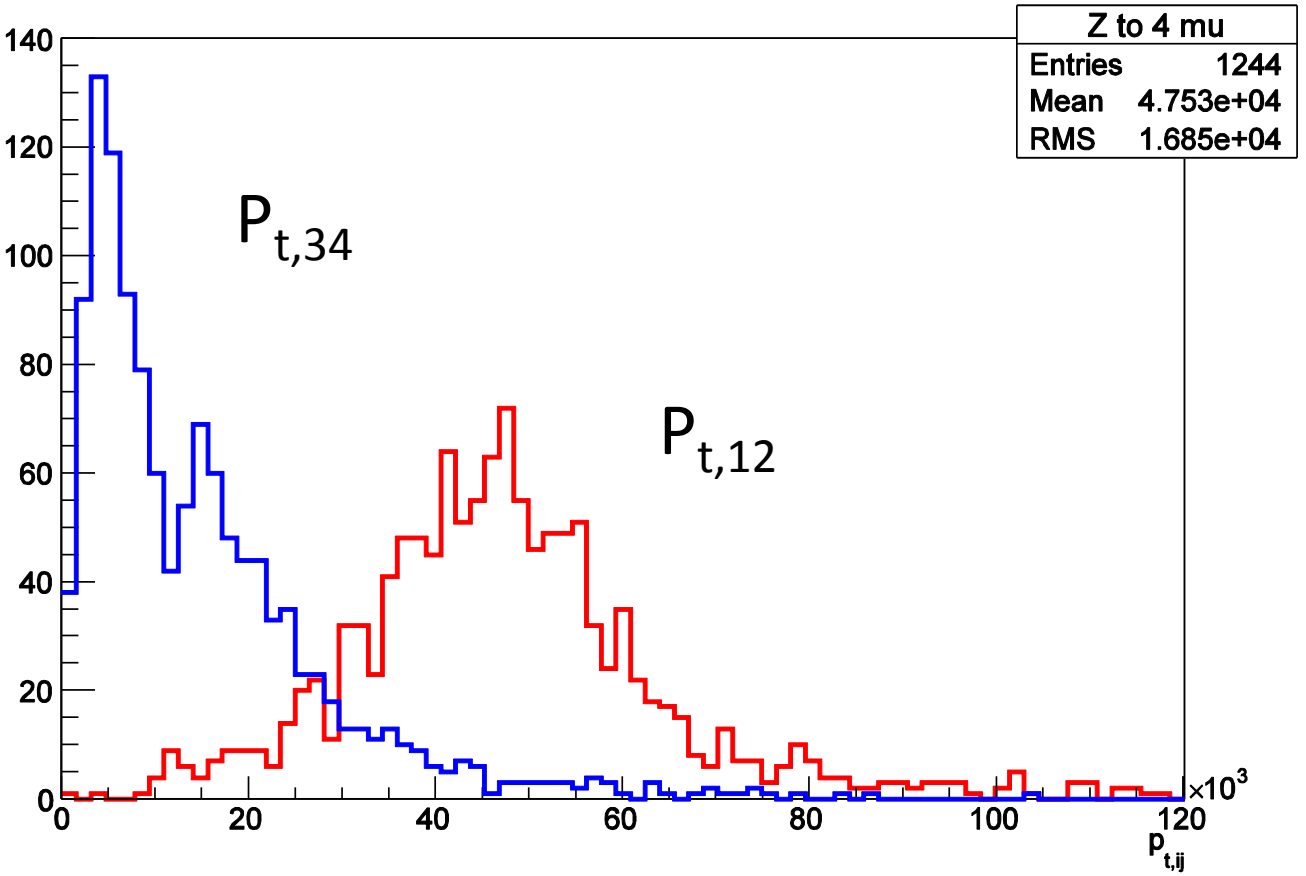
Calorimeter isolation

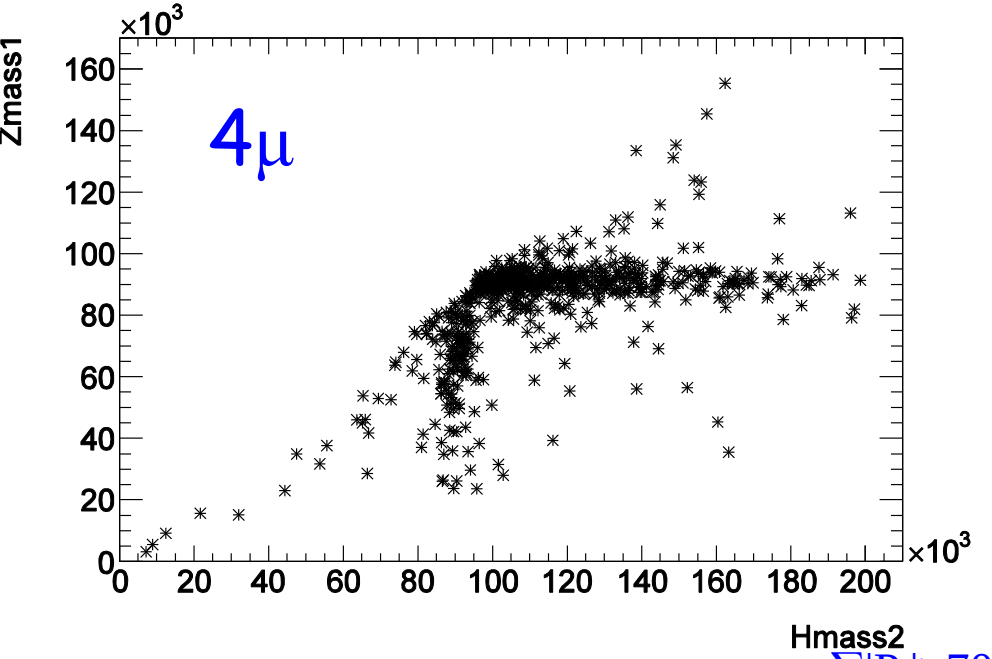


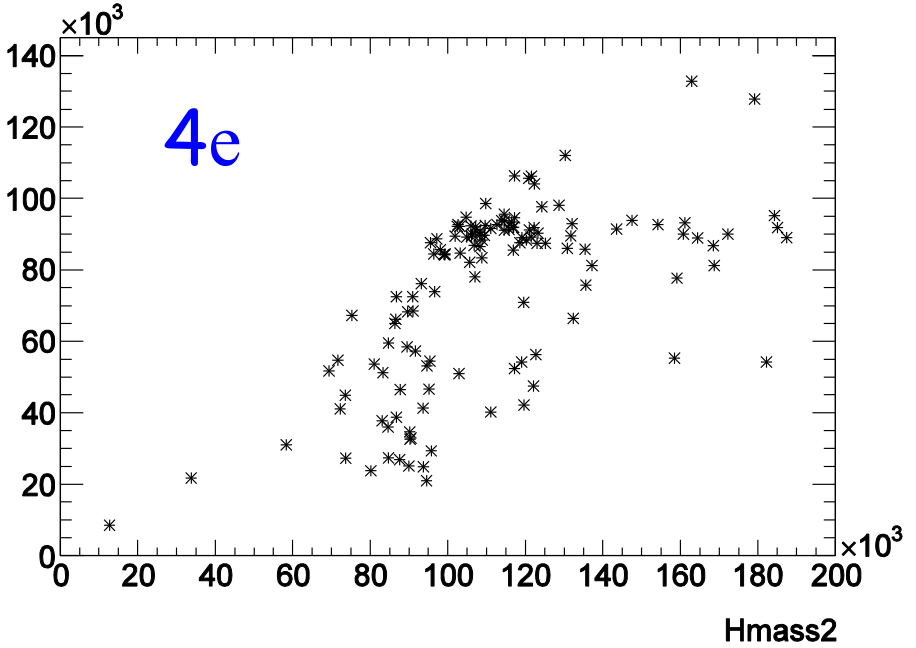
Track isolation



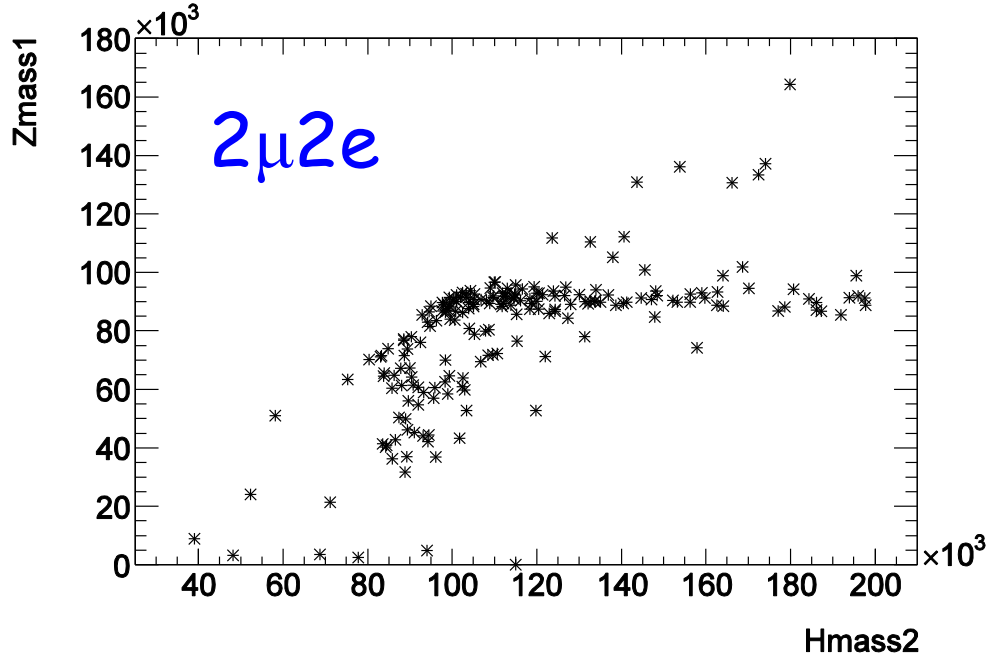
Transverse momentum distribution

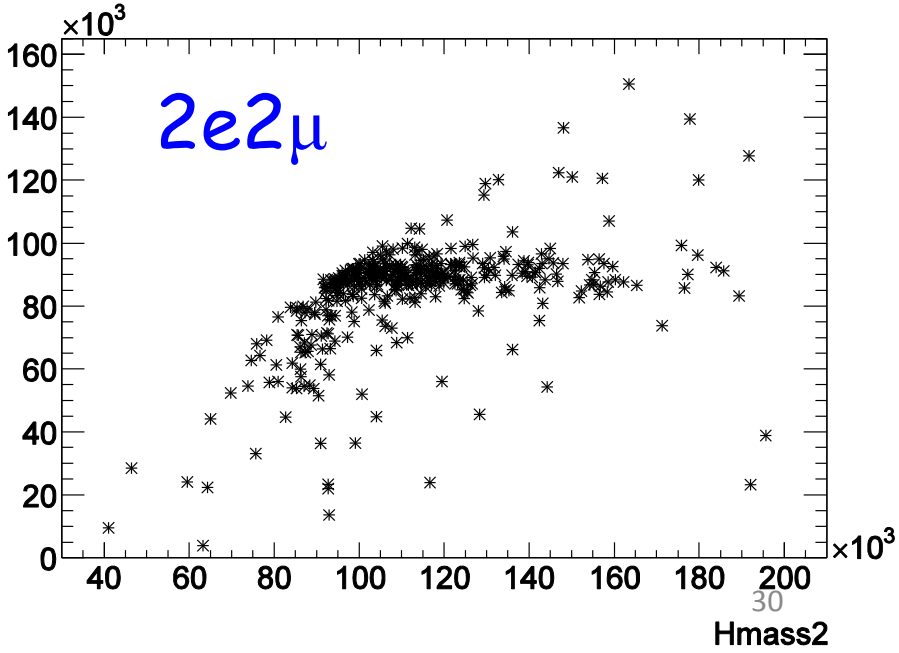



4μ
Zmass1
Hmass2
×10³

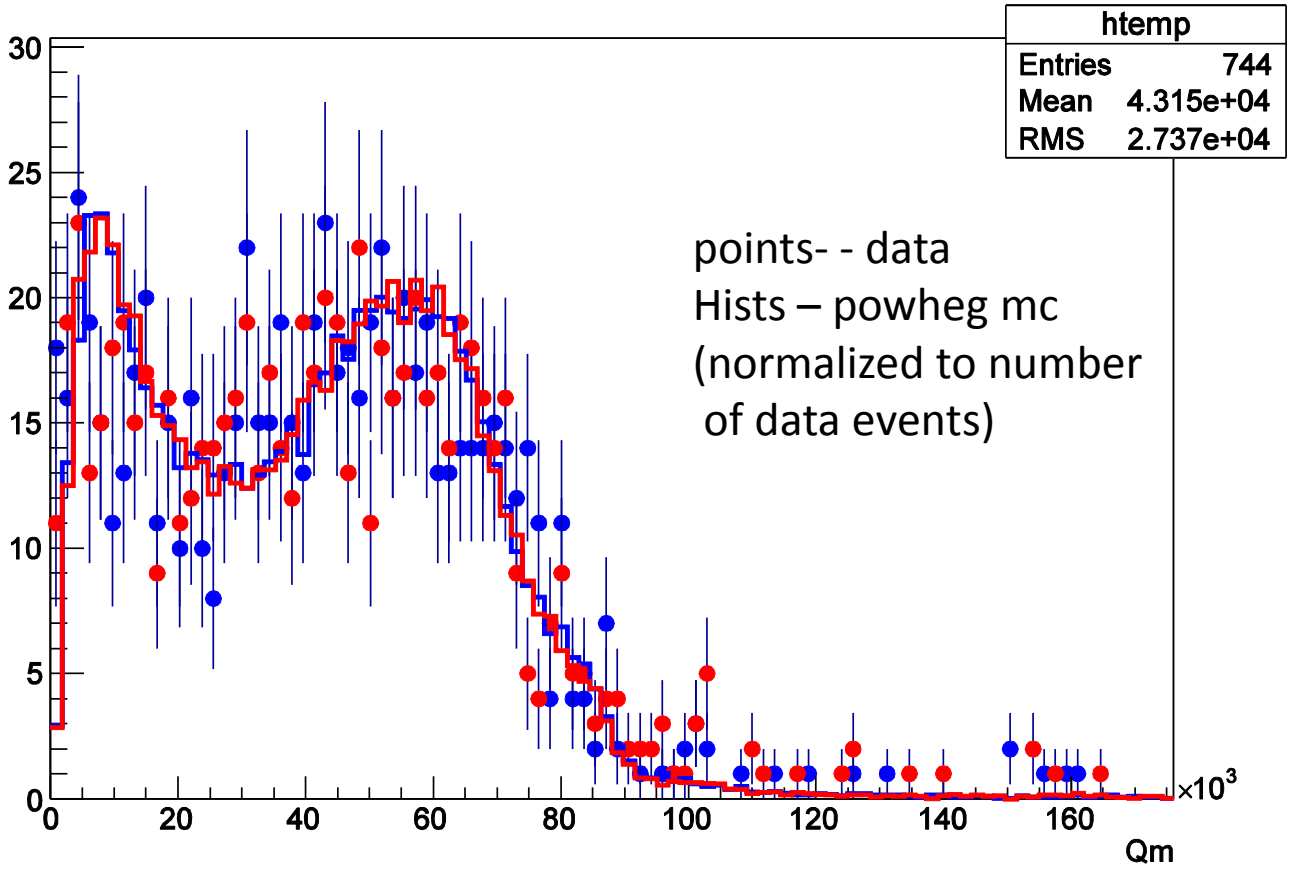

4e
Hmass2
×10³

$\sum|P_t|>70$ ГэВ

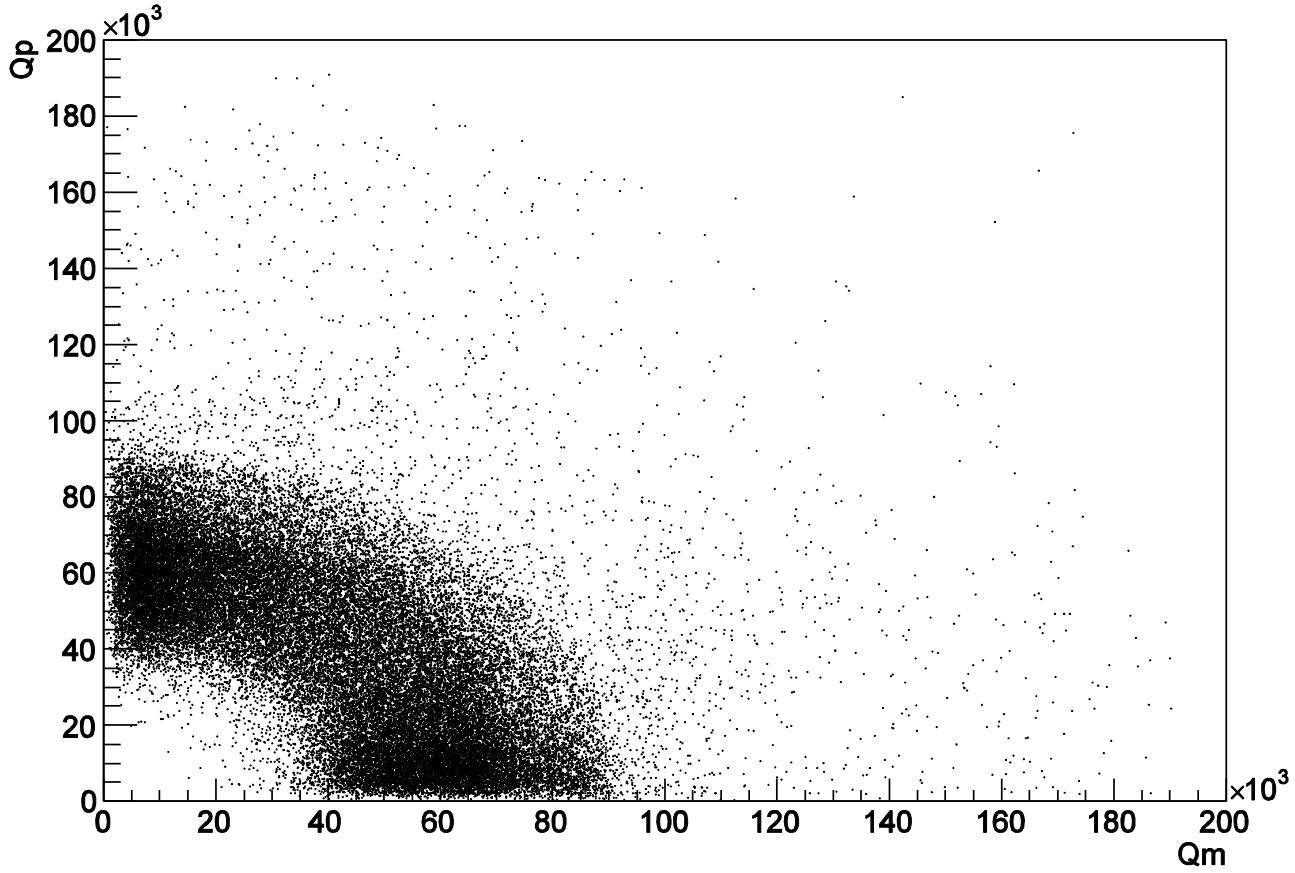

2μ2e
Zmass1
Hmass2
×10³


2e2μ
Hmass2
×10³

Q - distribution for Q_p and Q_m



Q_p vs Q_m for Powheg MC



MC Samples

- Powheg

mc12_8TeV.147225.PowhegPythia8_AU2CT10_ZZ_4mu_mll025_4lpt3_m4l40

M_ll > 0.25 GeV

m_4l > 40 GeV

pT > 3 GeV

- Comphep

Private sample Z →4 μ at truth level

M_ll > 0.5 GeV

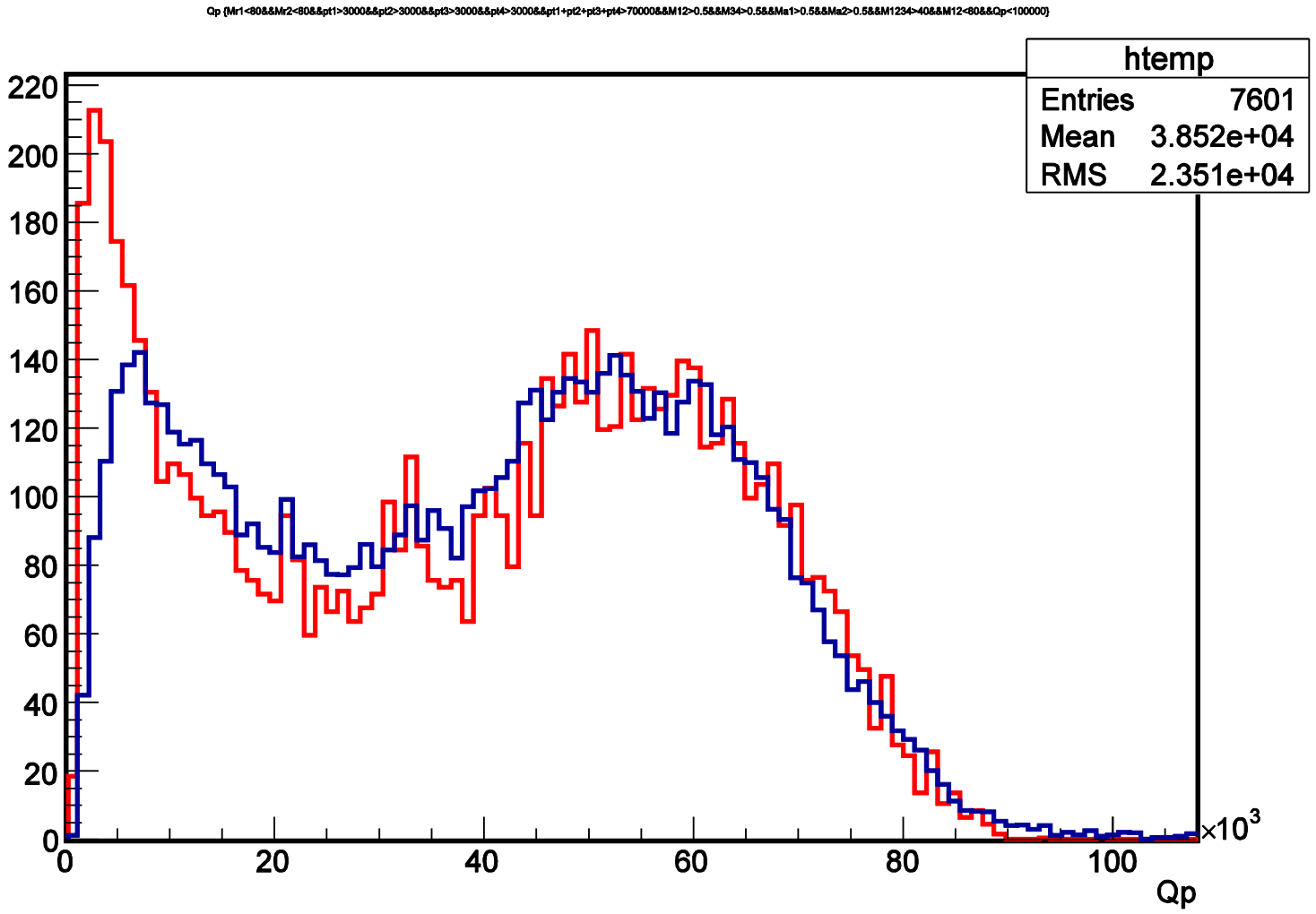
- Sherpa

Mc12_8TeV.189608.Sherpa_CT10_llll_ZZ_MassiveSB

M_ee>0.1 GeV

pT > 5 GeV for two leading leptons

PowhegPythia/ComphepPythia comparison



Powheg/Comphep comparison