A study of Initial State Gluon Radiation on the Drell-Yan process in LHC at $\sqrt{s}$ = 13 TeV

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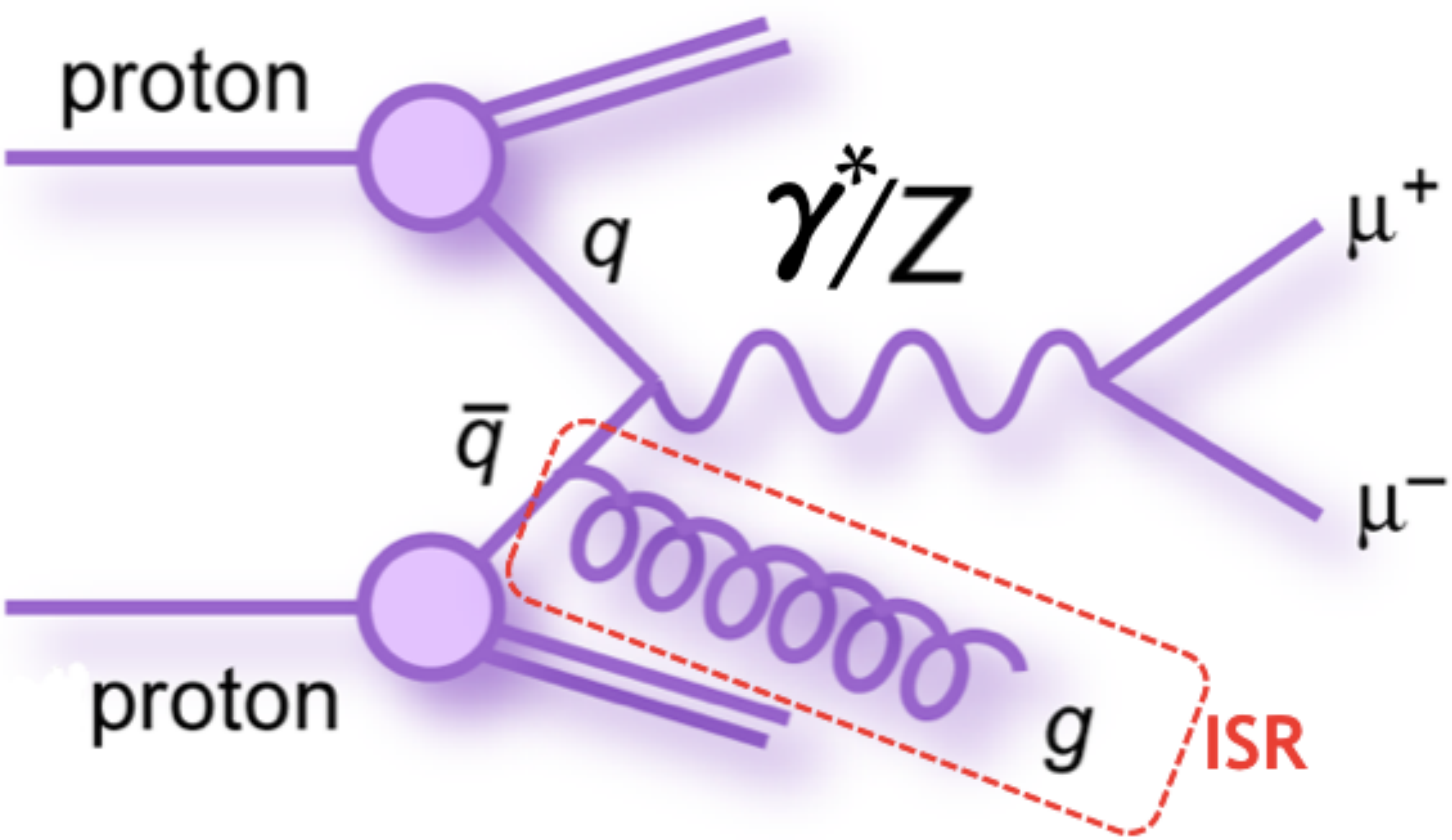
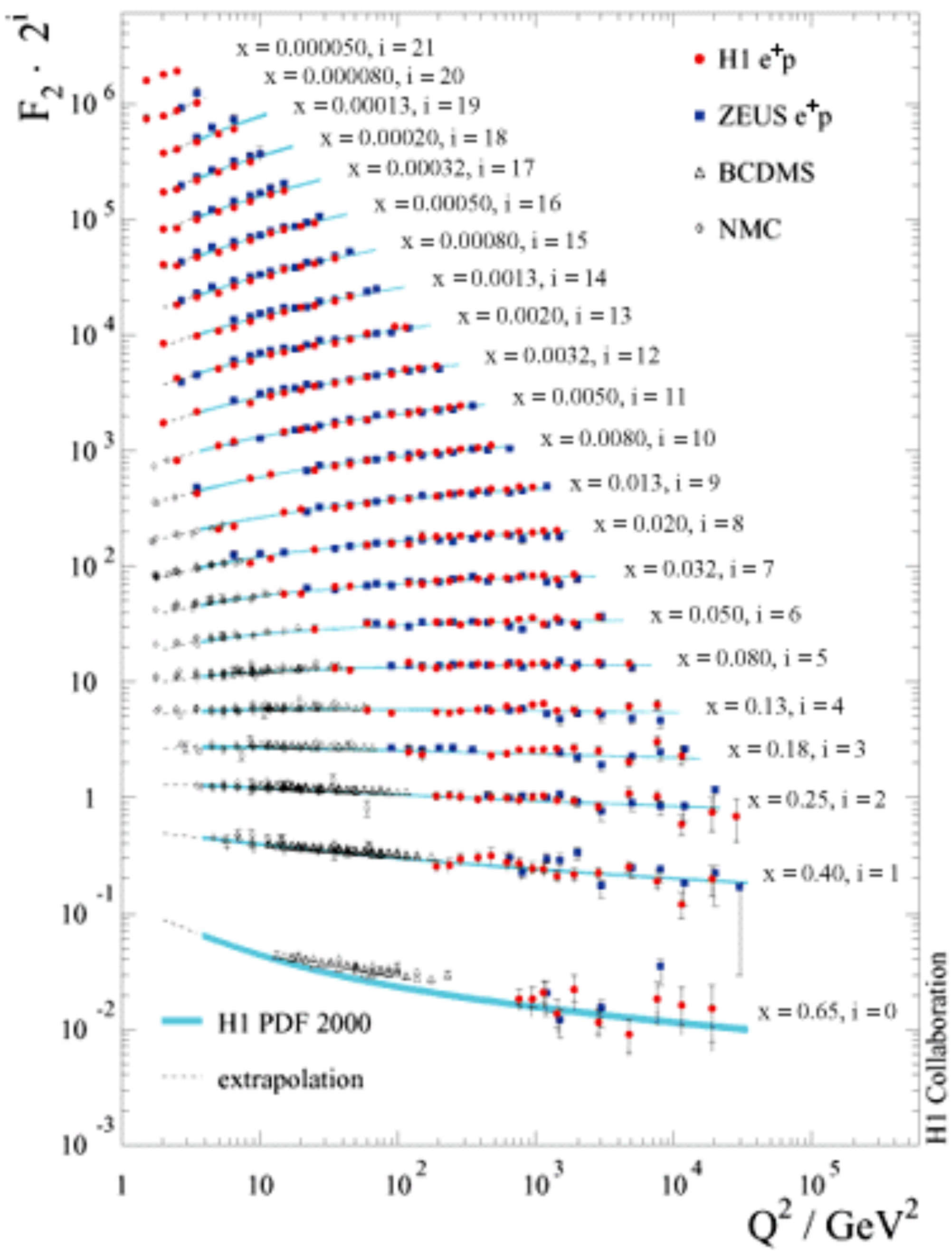
What is ISR?

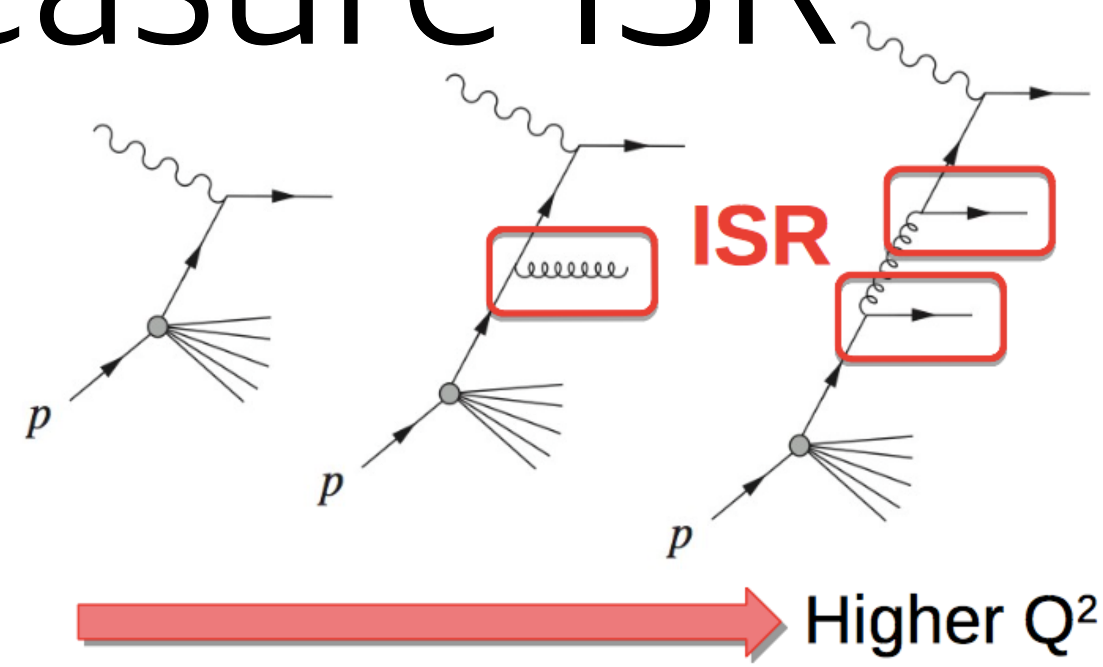


- Radiation from initial state partons
- Especially, we are interested in QCD ISR

How to Measure ISR

- ISR jets from SM are irreducible background to new physics





$$\boxed{dq(x,Q^2)} \over d\ln Q^2$$

$$\frac{dq(x,Q^2)}{d\ln Q^2} = \int_x^1 \frac{dy}{y}\,\alpha_s\left(\frac{Q^2}{\Lambda^2}\right)\boxed{P_{q\to qg}\left(\frac{x}{y},Q^2\right)}\,\boxed{q(y,Q^2)}$$

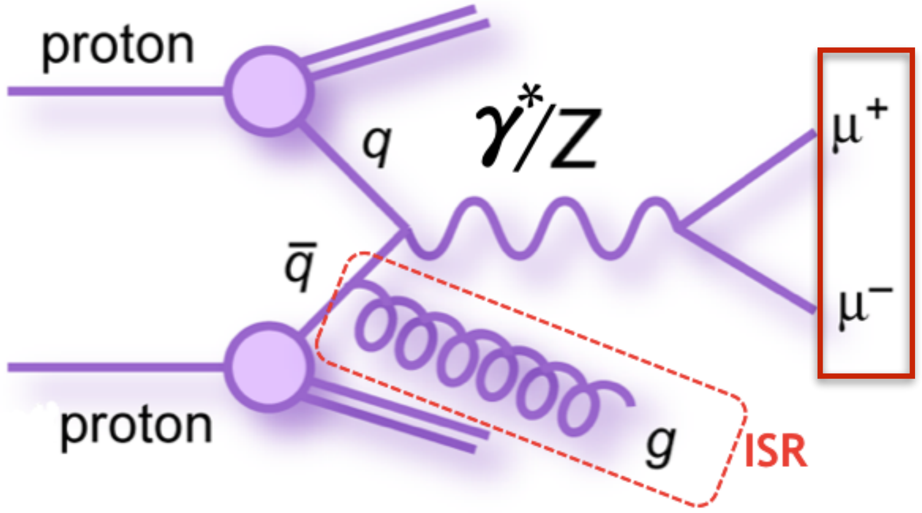
- ISR is controlled by DGLAP evolution equation

- PDF has a logarithmic Q^2 dependence

  - Can we find a way to measure ISR ?

How to Measure ISR

(1) Drell-Yan Process : Only Leptons in the final state



How to Measure ISR

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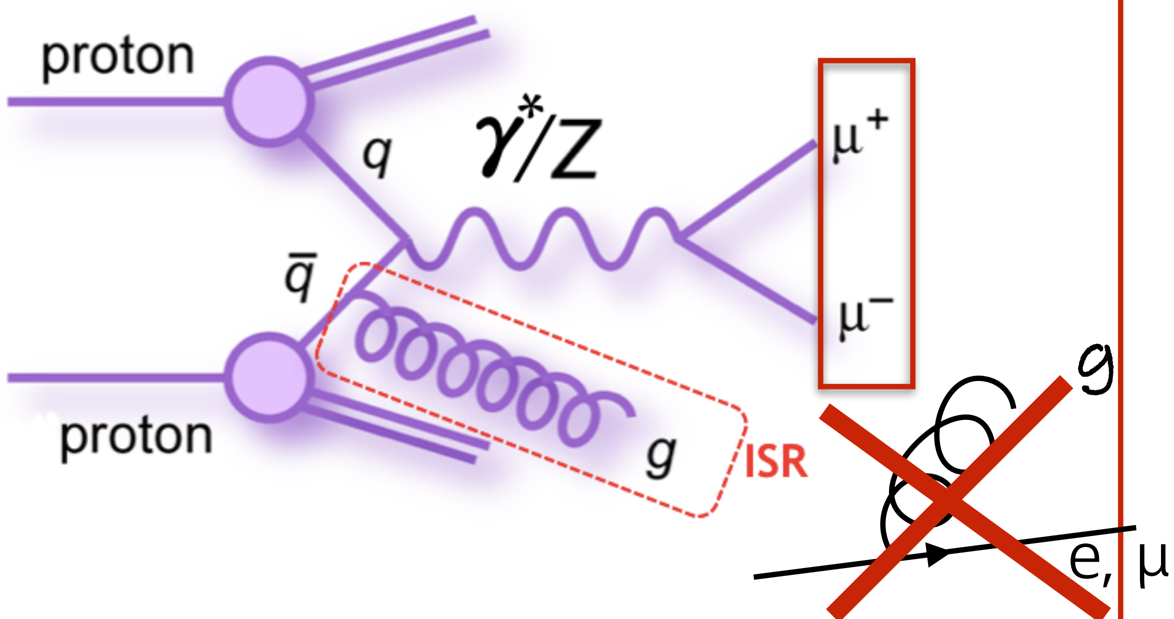
(2) No QCD radiation from the final state



How to Measure ISR

(1) Drell-Yan Process : Only Leptons in the final state

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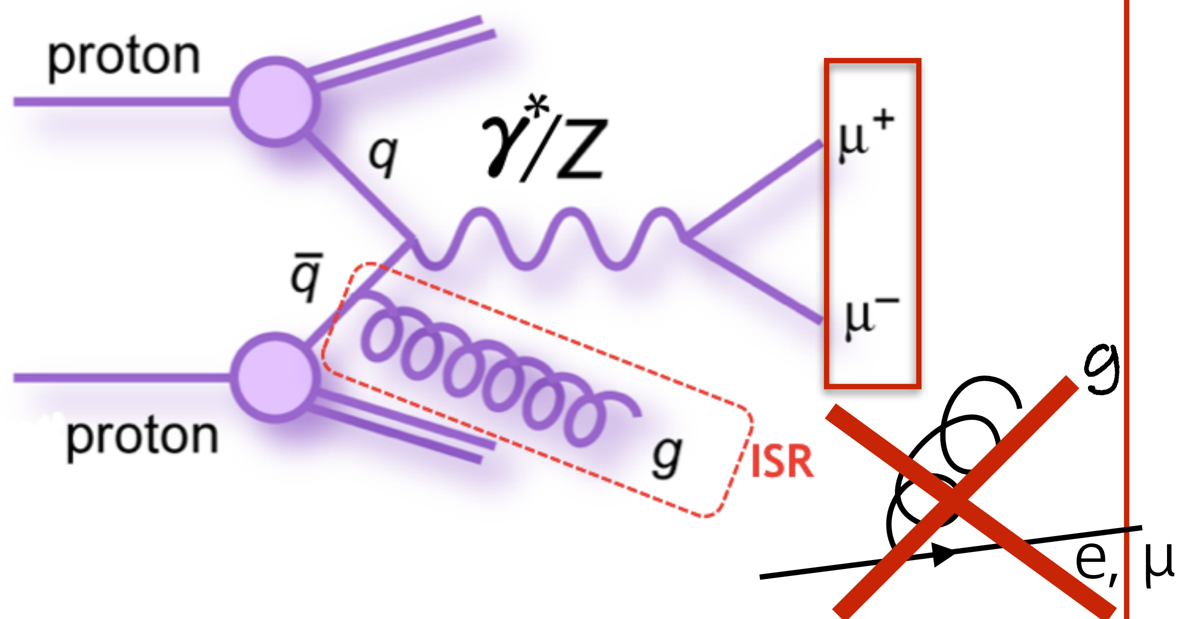
(3) Using $\Sigma\ P_T = 0$ in pp collision

(4) $\Sigma\ [P_T(ll) + P_T(ISR)] = 0$ in DY process

(5) $P_T(ll) = P_T(ISR) \sim$ ISR activity



How to Measure ISR

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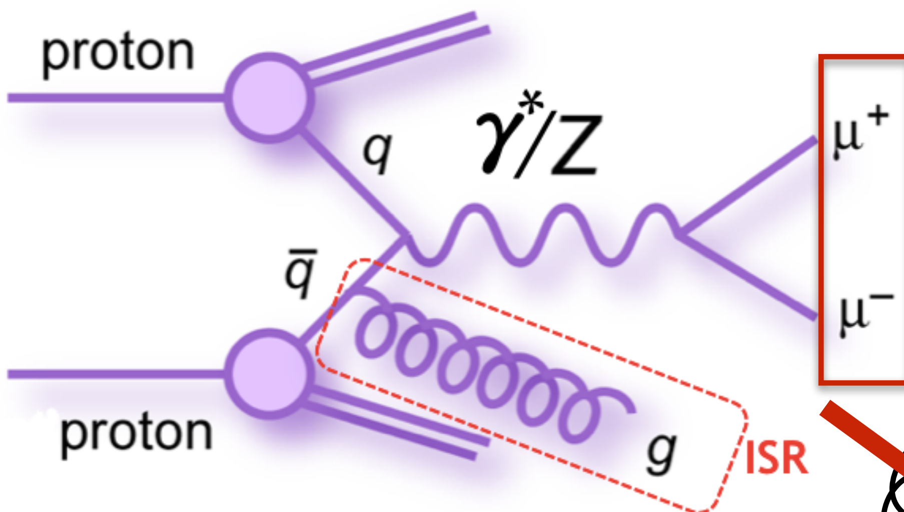
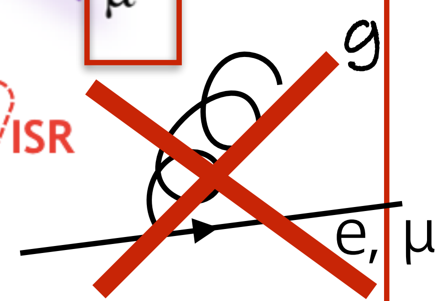
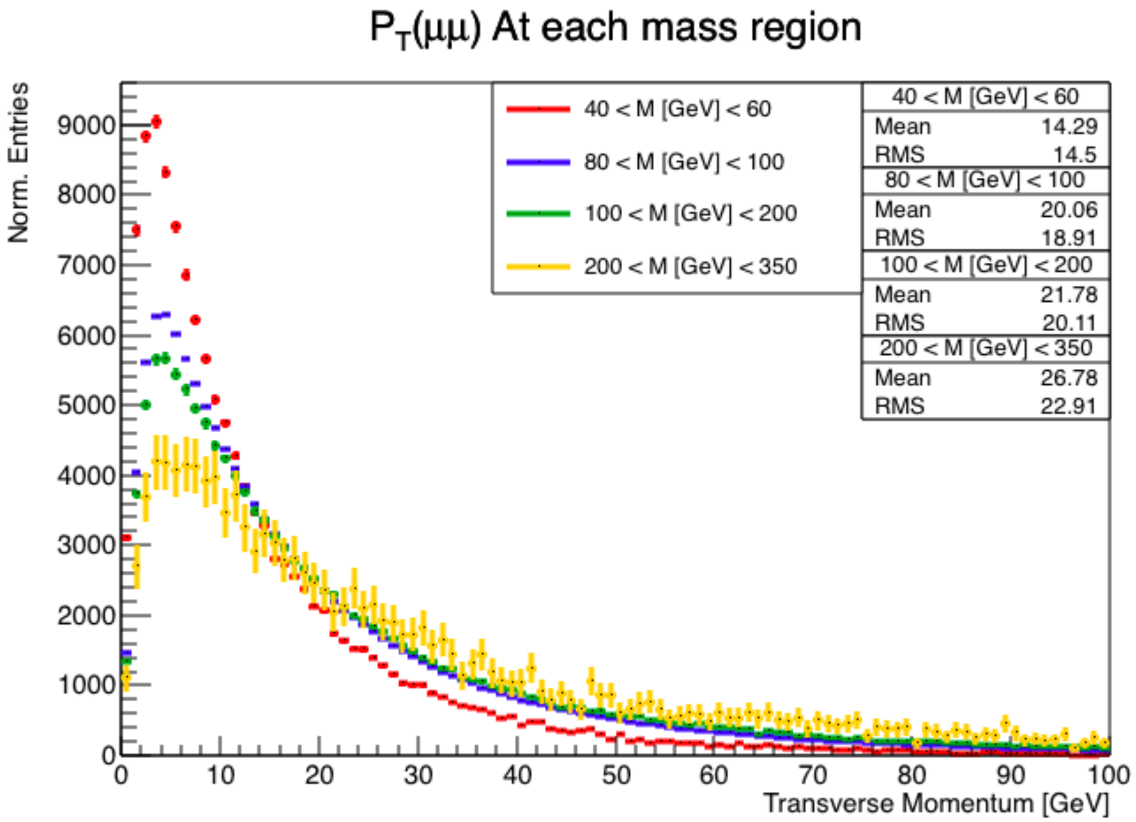


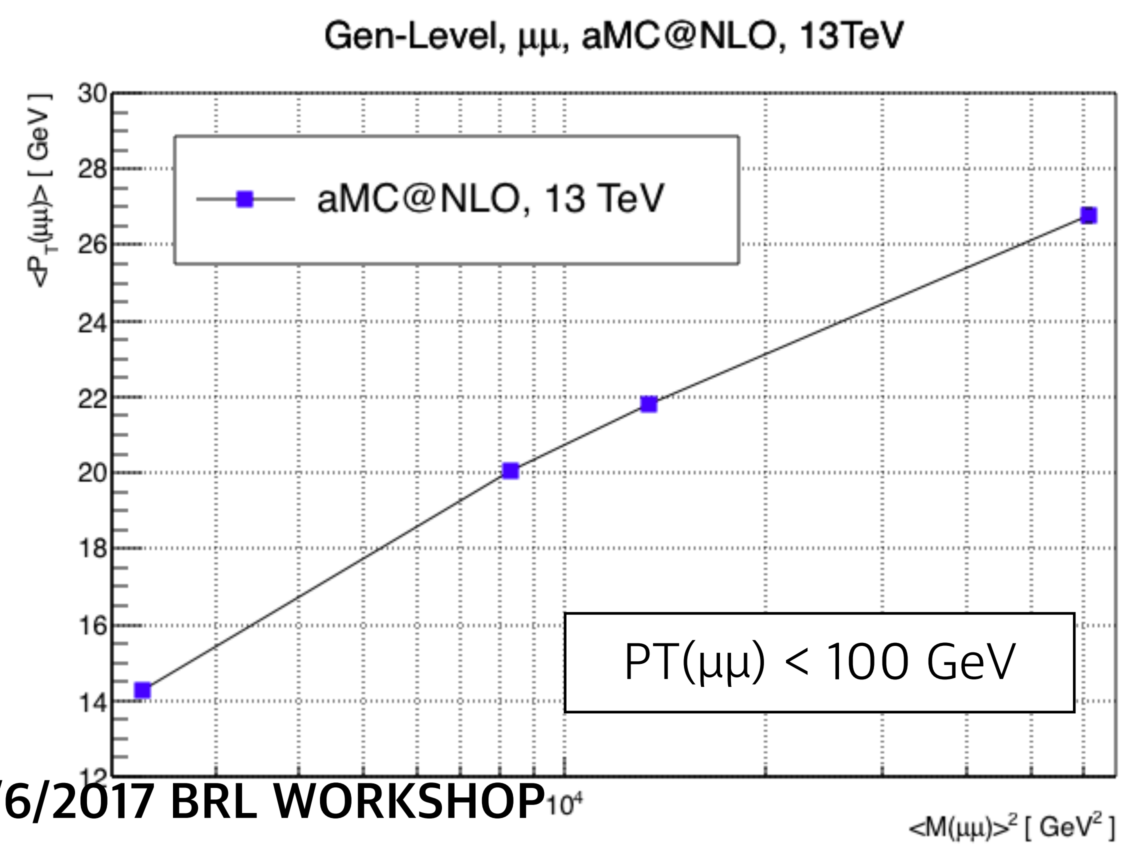


Measure Q^2 dependence of $P_T(ll)$ in DY

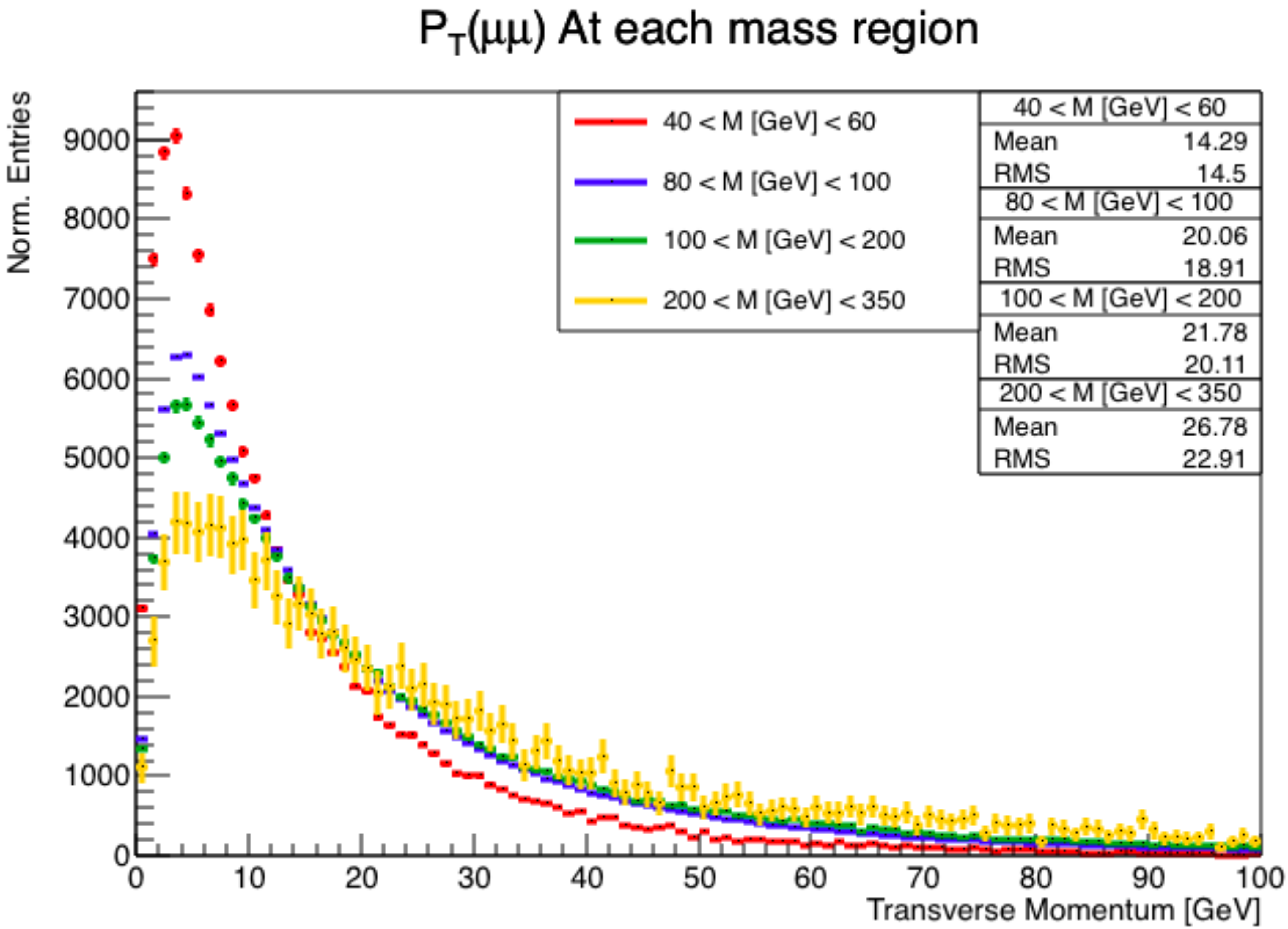
= Measure Q^2 dependence of ISR

How to Analyze ISR



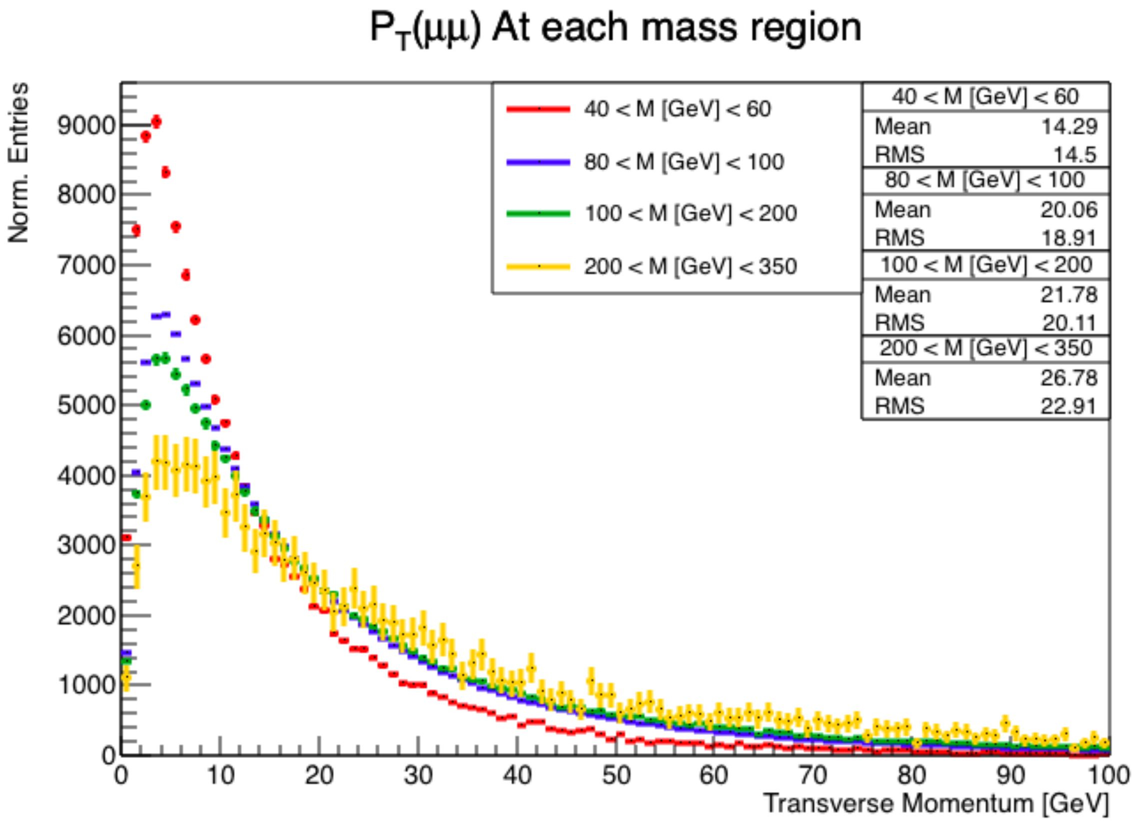


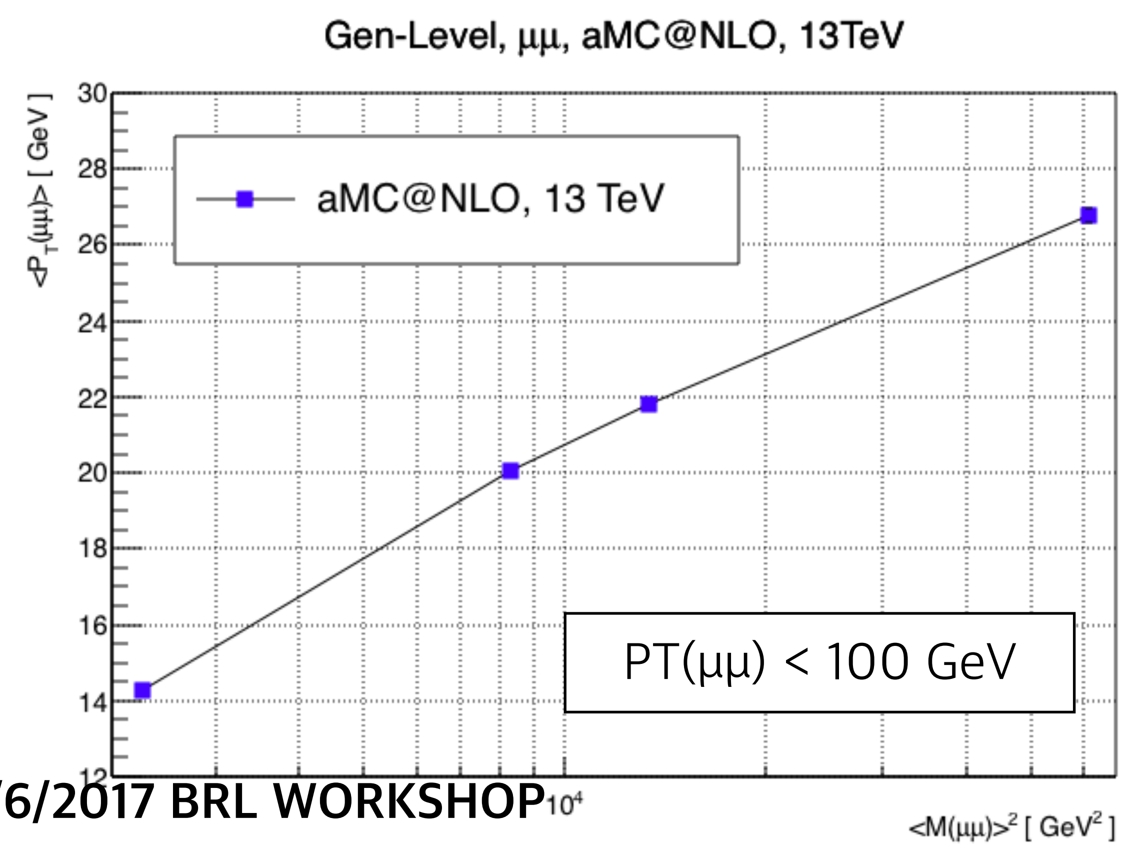
- <PT(ll)> is sensitive to the ISR activity in DY process
- $Q^2 \sim M^2(ll)$ as interaction scale
- In generator level, Pt(ll) – $\log(Q^2)$ shows linear slope.
- Check <PT(ll)> as a function of $Q^2 \sim M(ll)^2$ in data
- Measure the slope to estimate ISR activity at high Q^2 region.



$P_T(\mu\mu)$ At each mass region
Norm. Entries
Transverse Momentum [GeV]
40 < M [GeV] < 60
80 < M [GeV] < 100
100 < M [GeV] < 200
200 < M [GeV] < 350
40 < M [GeV] < 60
Mean 14.29
RMS 14.5
80 < M [GeV] < 100
Mean 20.06
RMS 18.91
100 < M [GeV] < 200
Mean 21.78
RMS 20.11
200 < M [GeV] < 350
Mean 26.78
RMS 22.91

How to Analyze ISR





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Datasets, 2.2/fb 2015

Process	Generator	Parton shower
DY	aMC@NLO	PYTHIA8
	Madgraph	PYTHIA8
	Powheg	PYTHIA8
$t\bar{t}$	Madgraph	PYTHIA8
VV	PYTHIA8	PYTHIA8
WJets	aMC@NLO	PYTHIA8

DoubleMuon / DoubleEG, periodC+D, 2.2/fb 2015

Event Selection

- DiMuon Channel
  - Double Muon Trigger
  - Tight Muon ID
  - 71 mb min. bias xsec

- DiElectron Channel
  - Double Electron Trigger
  - Tight Electron ID
  - 71 mb min. bias xsec

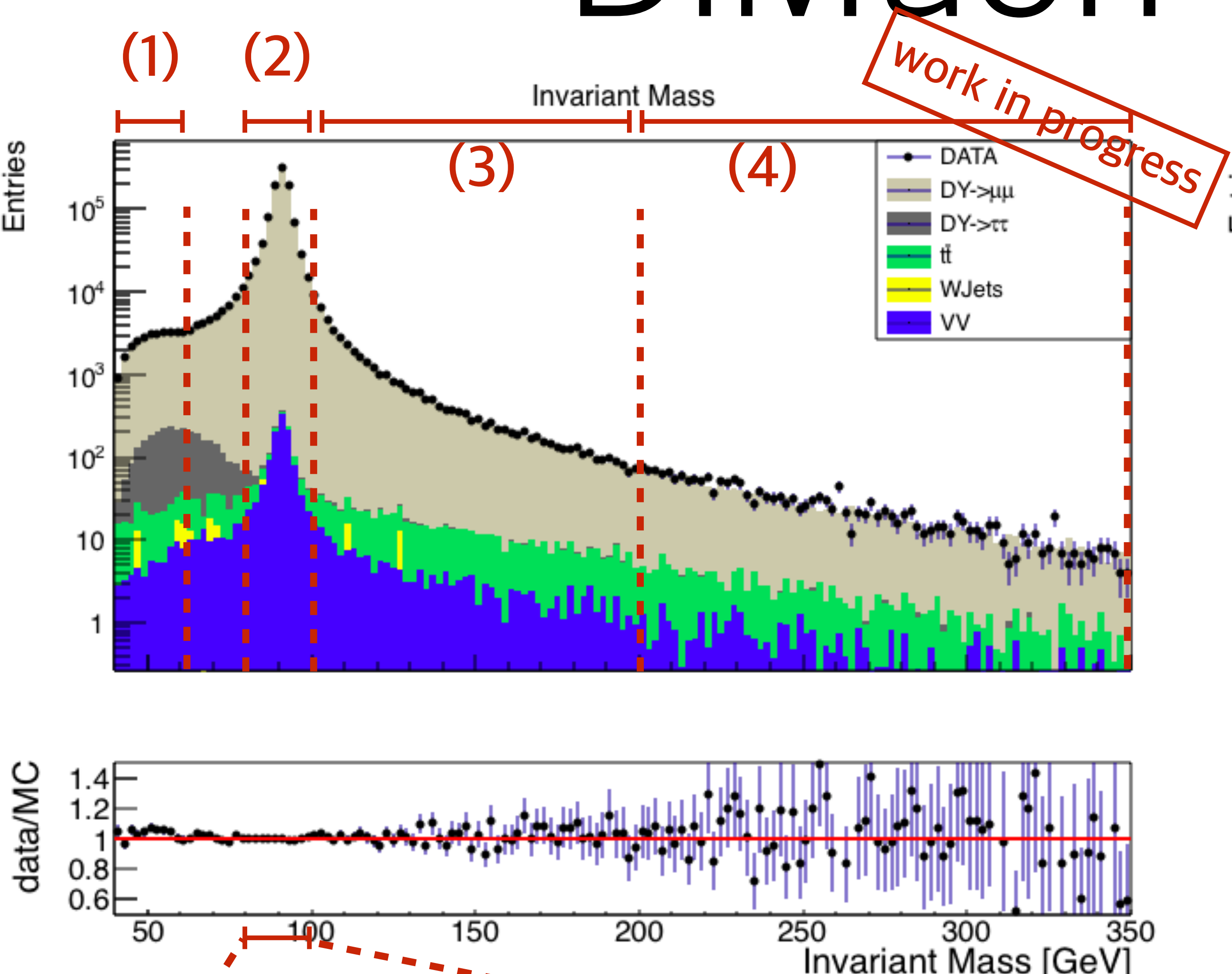
- Object Selection
  - PT > 20 GeV
  - |eta| < 2.4
  - Missing ET < 35 GeV

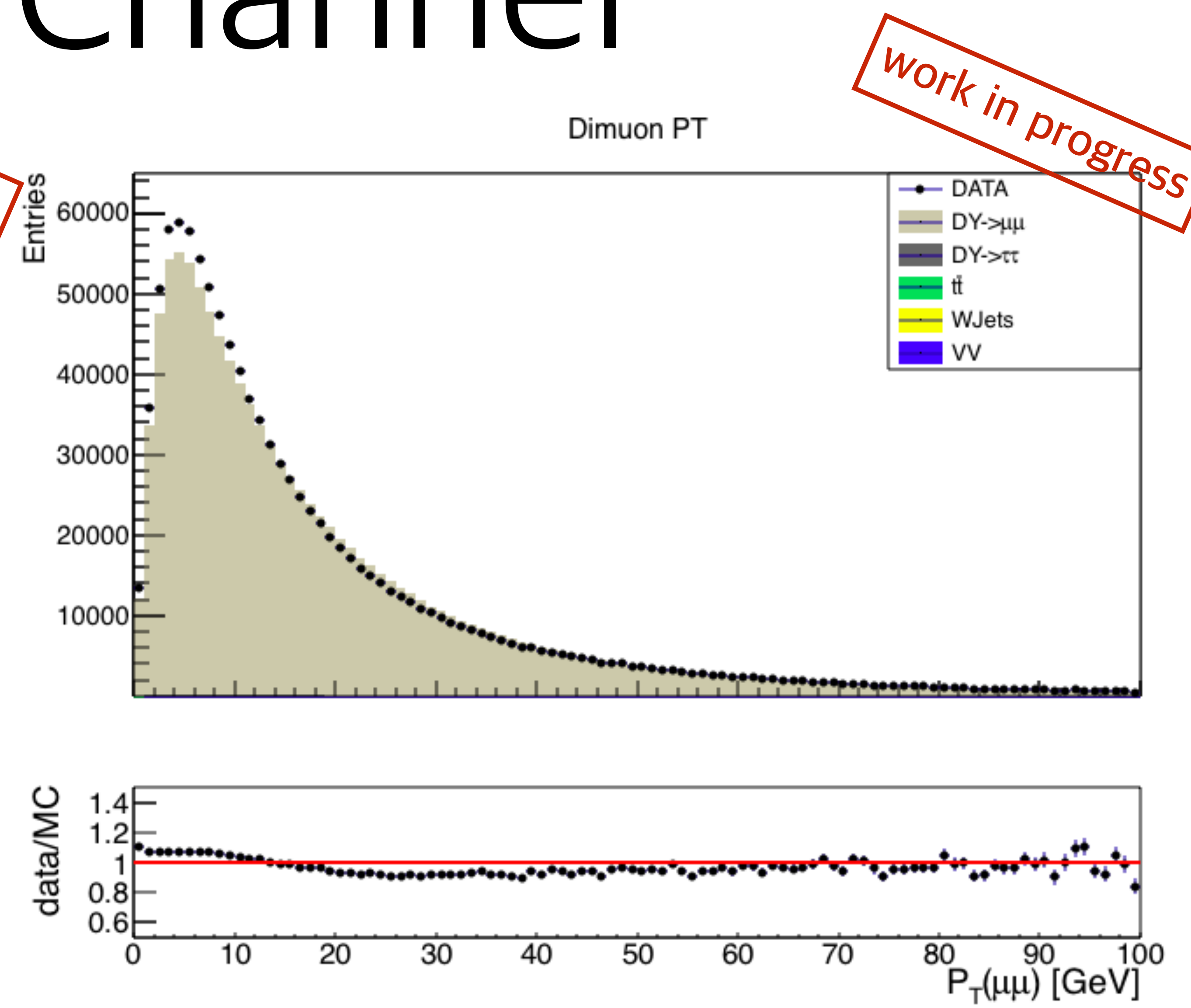
    To reduce the contribution from BKG

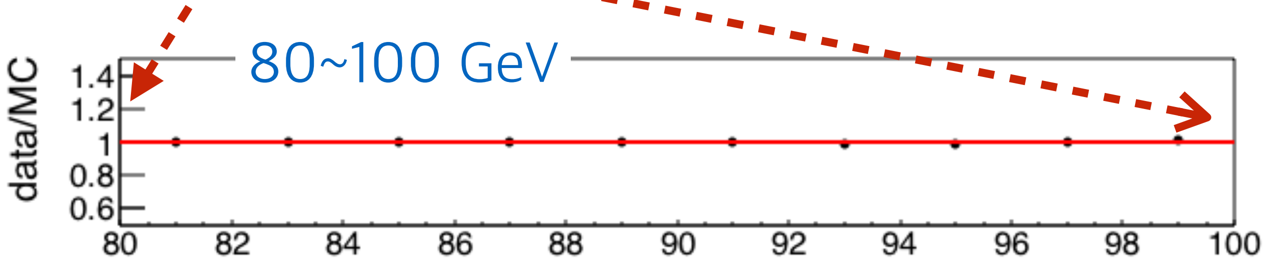
  - PT(ll) < 100 GeV

    To reduce the contribution from hard scattering process

DiMuon Channel



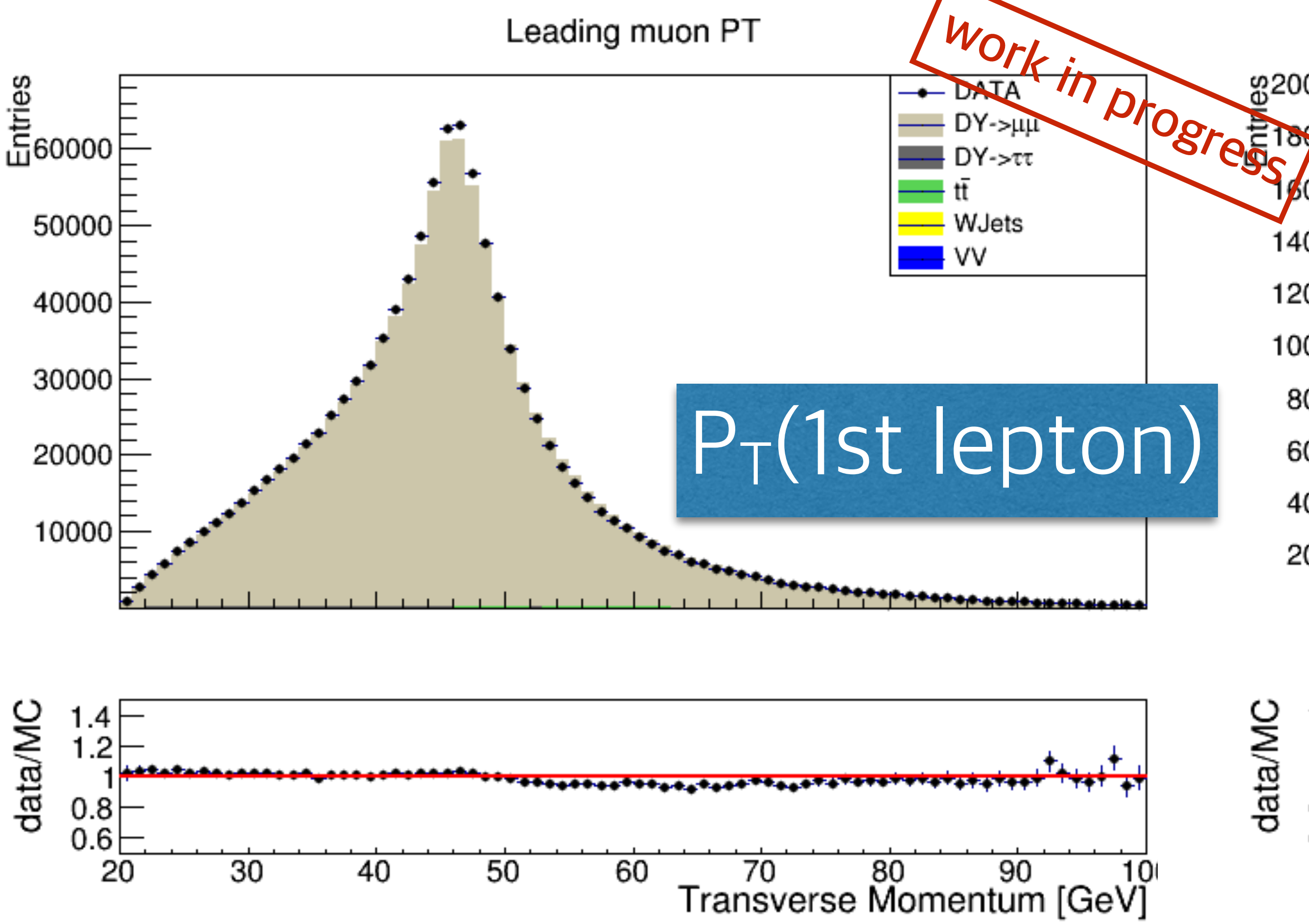


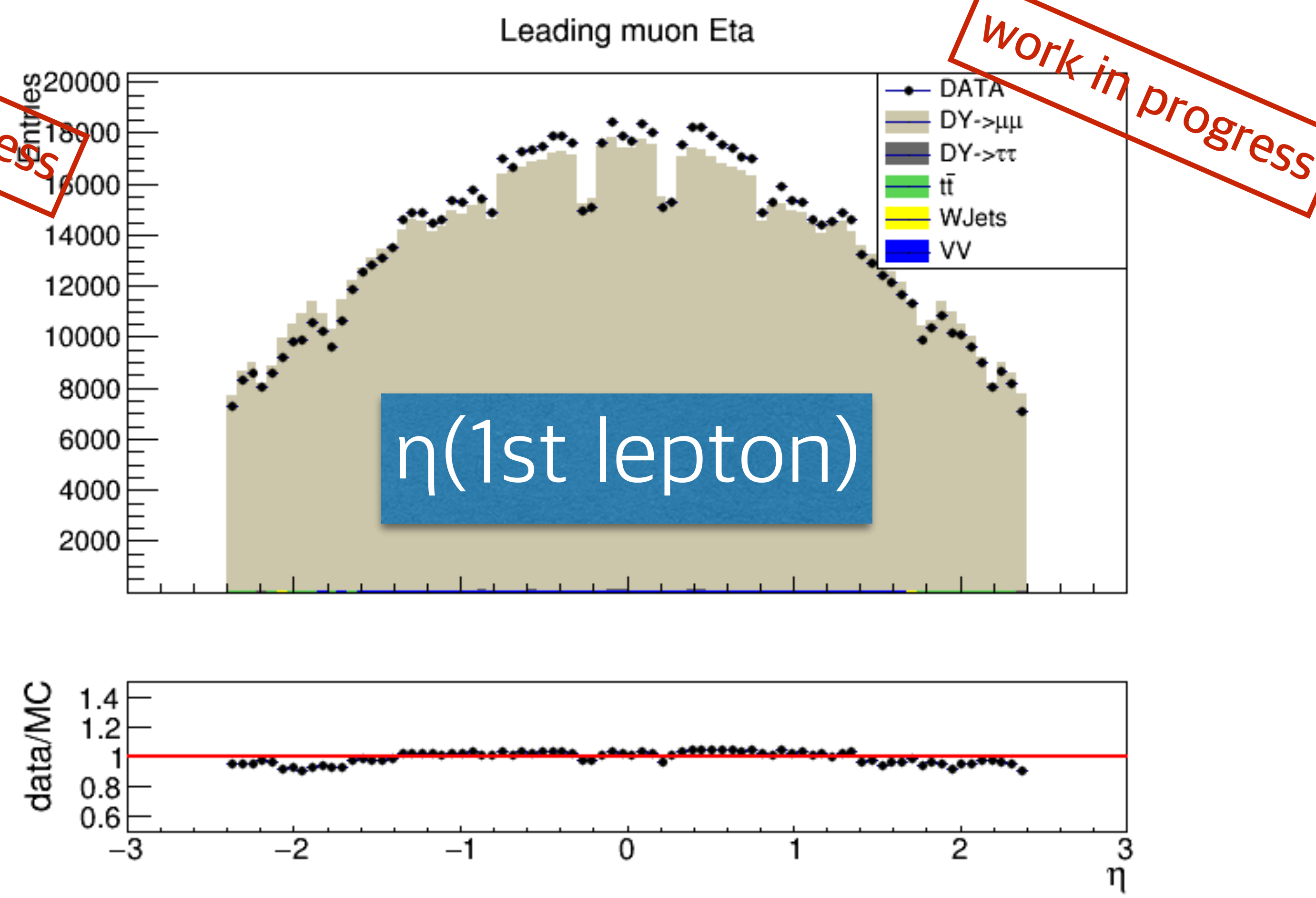


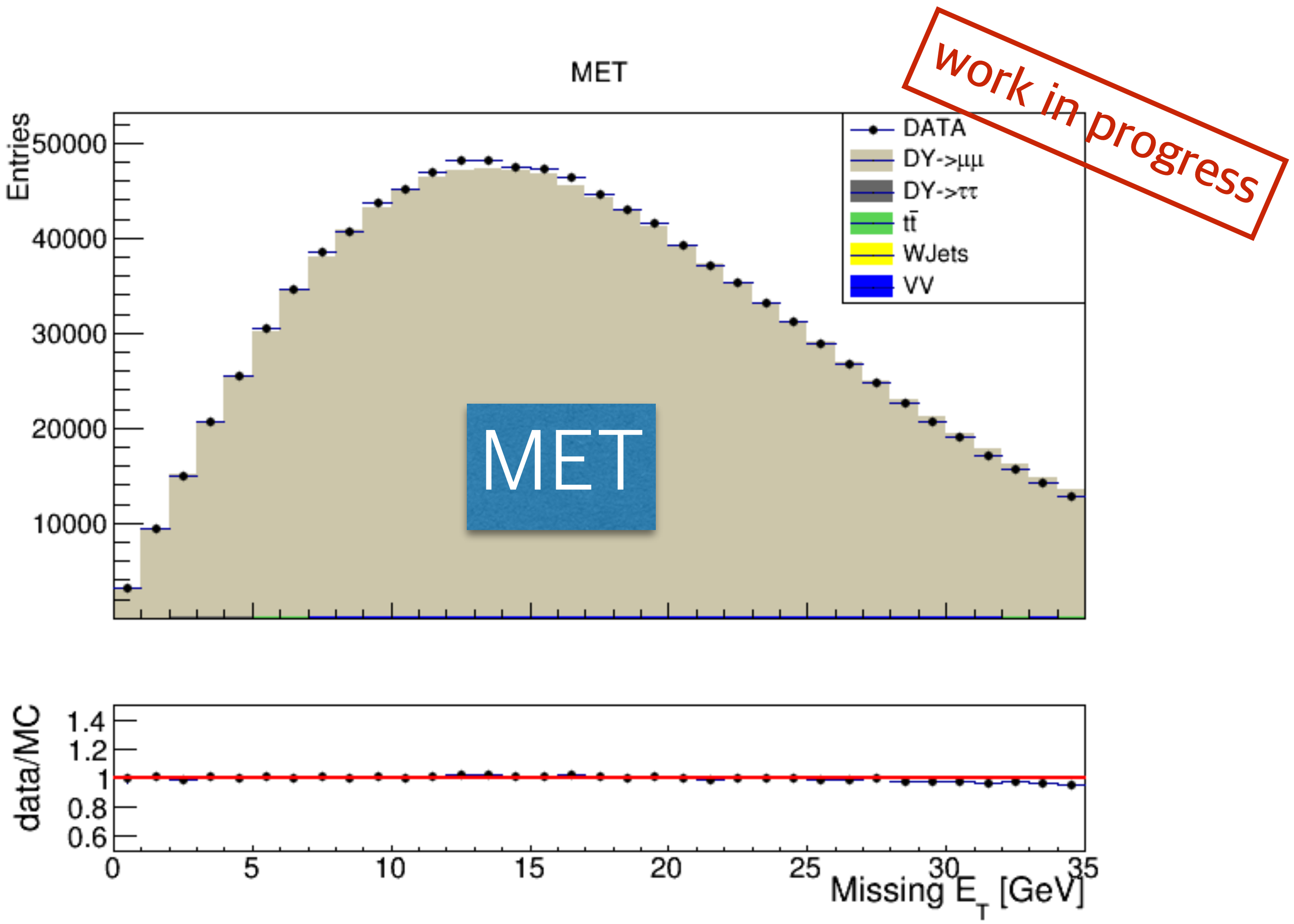
- 4 mass regions, except [60, 80] GeV

-> [40, 60] [80, 100] [100, 200] [200, 350]

-> Too many events that immigrate from Z mass region

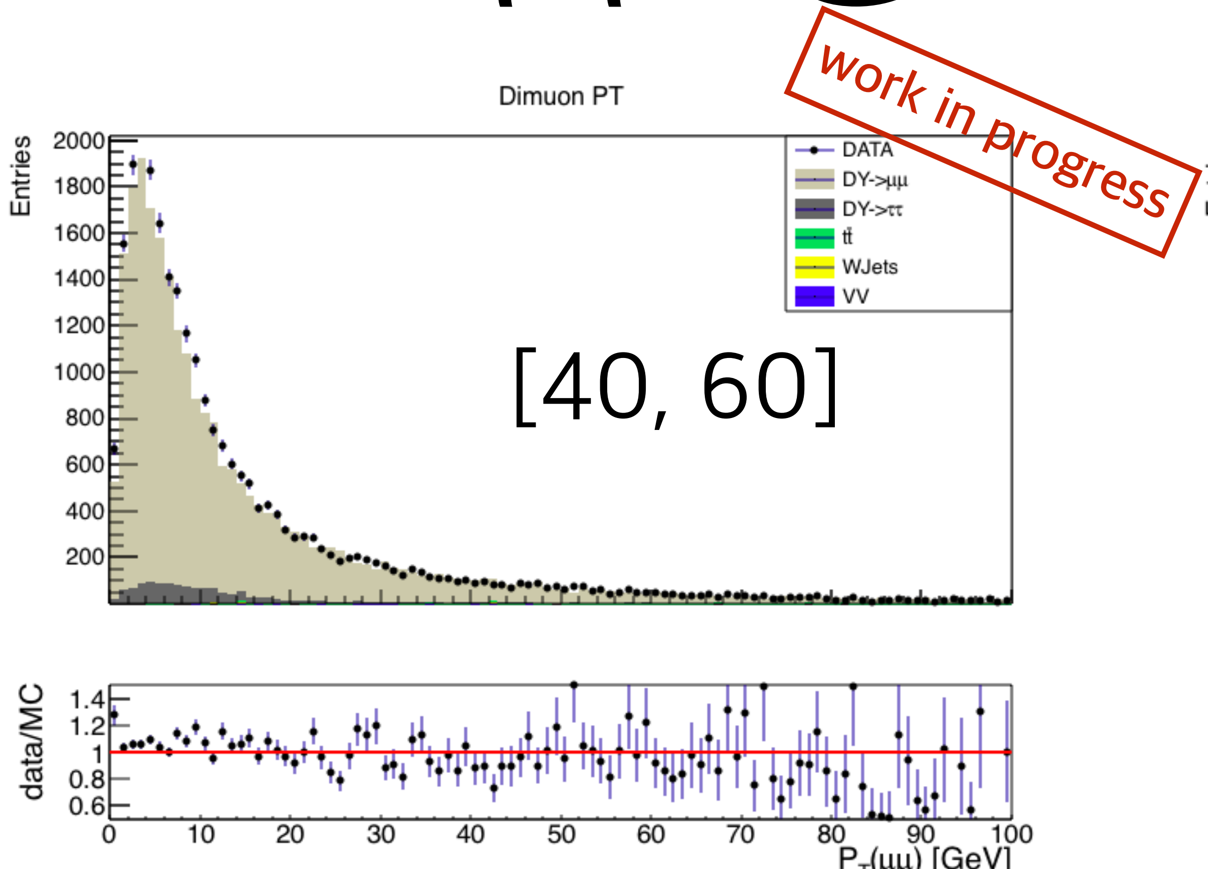


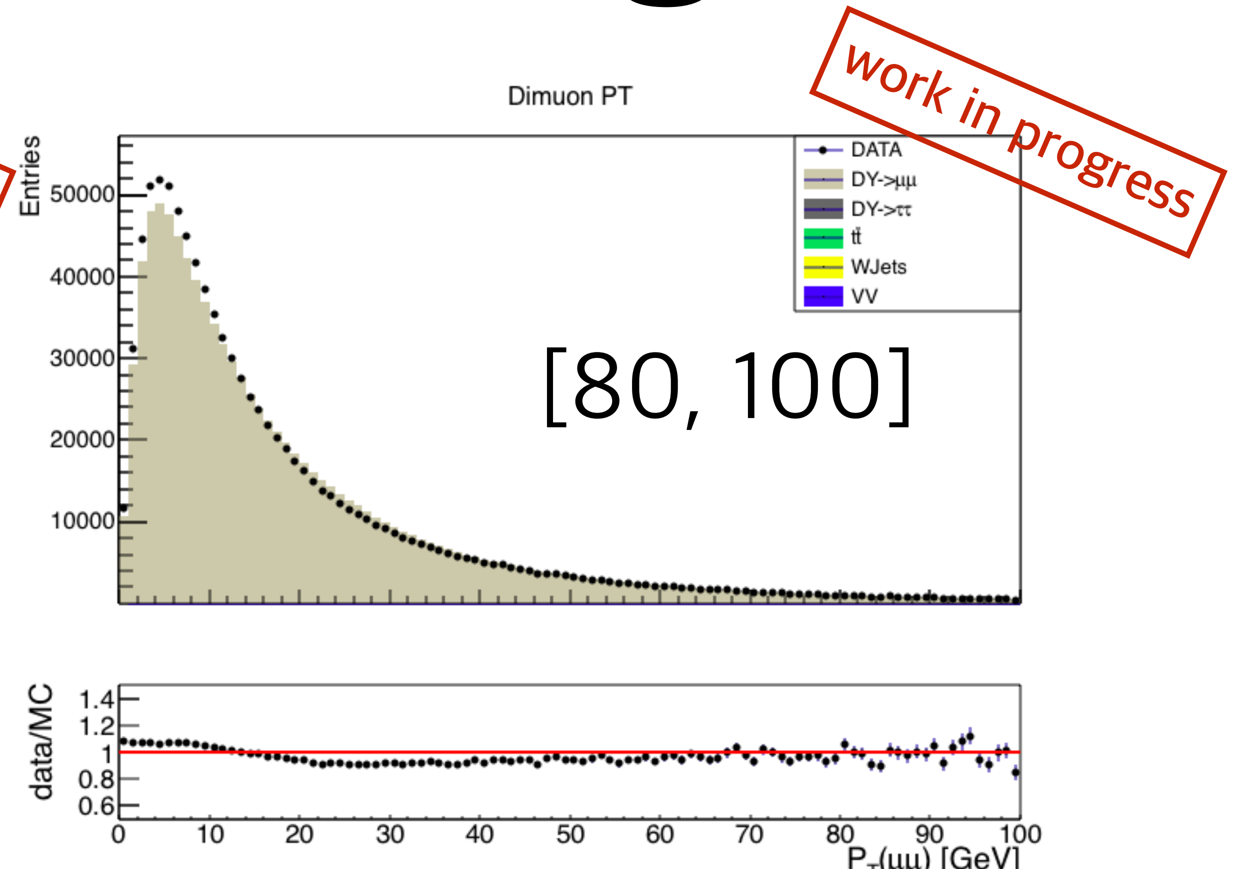


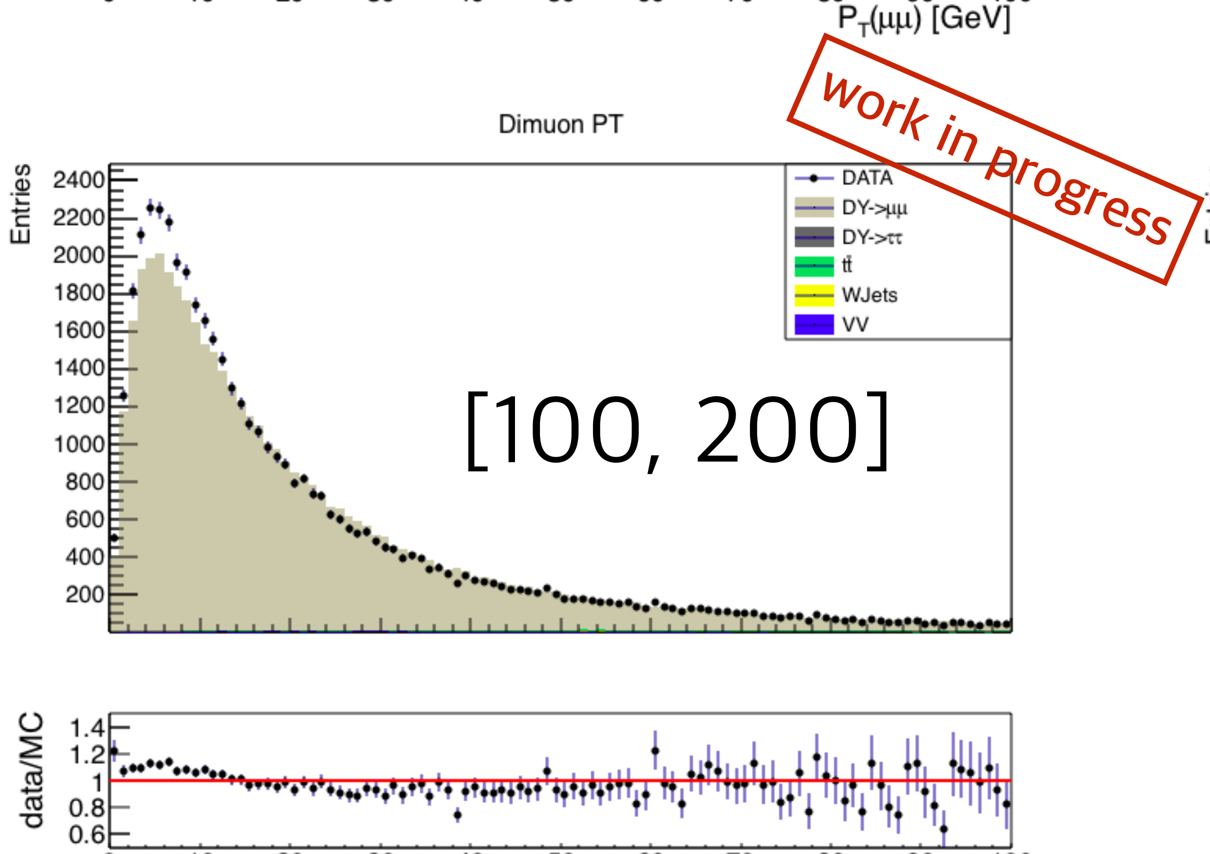


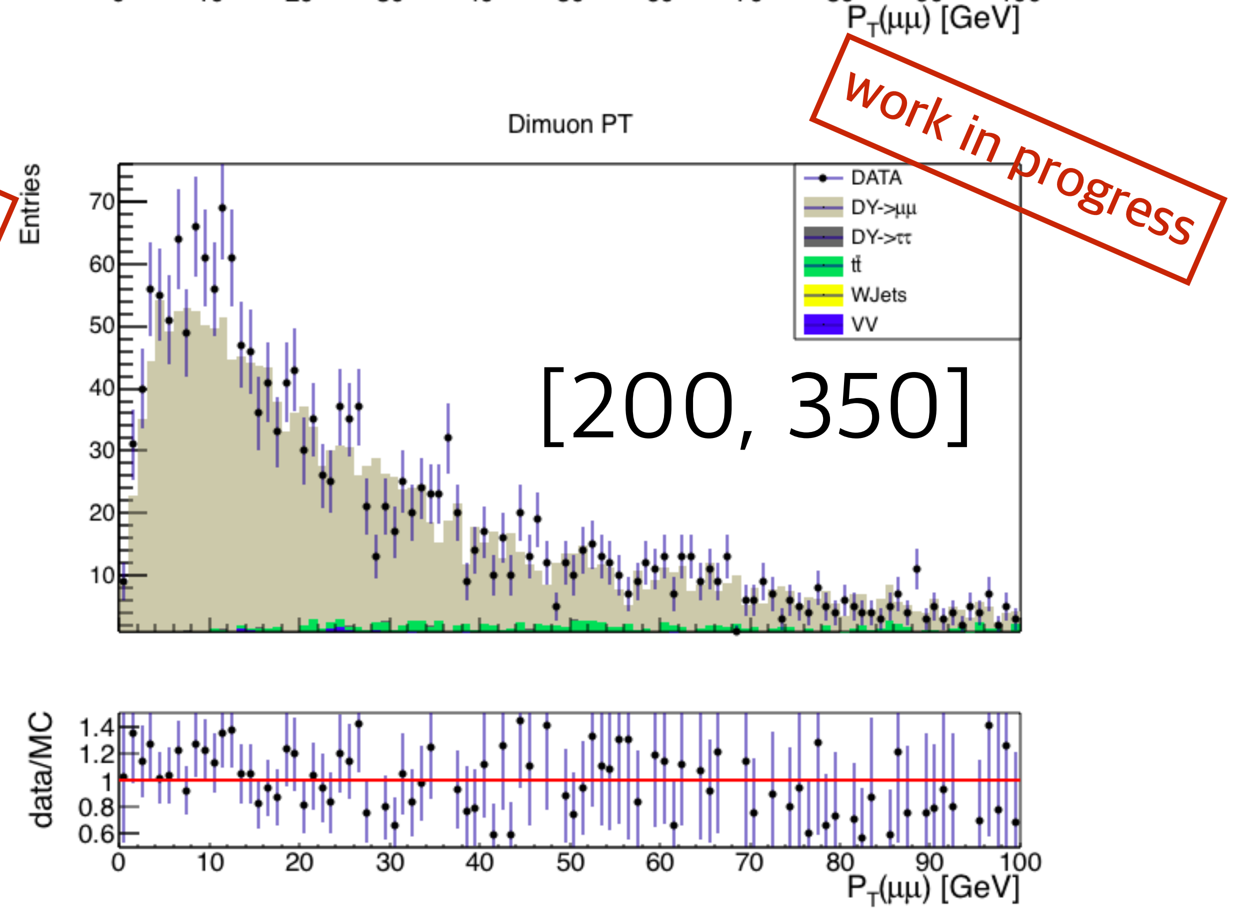
MC agrees with data well !

$P_T(\mu\mu)$@4 mass regions

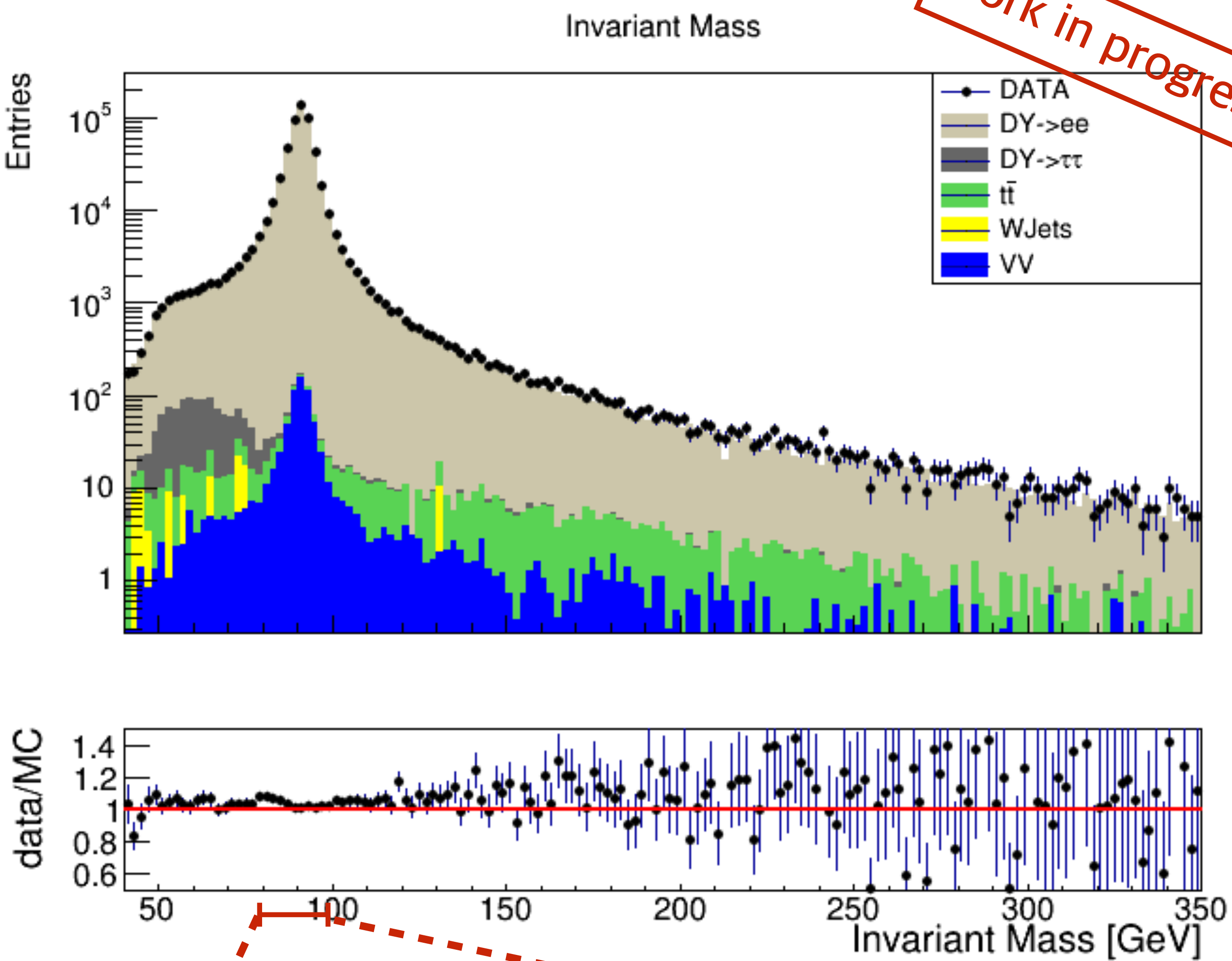


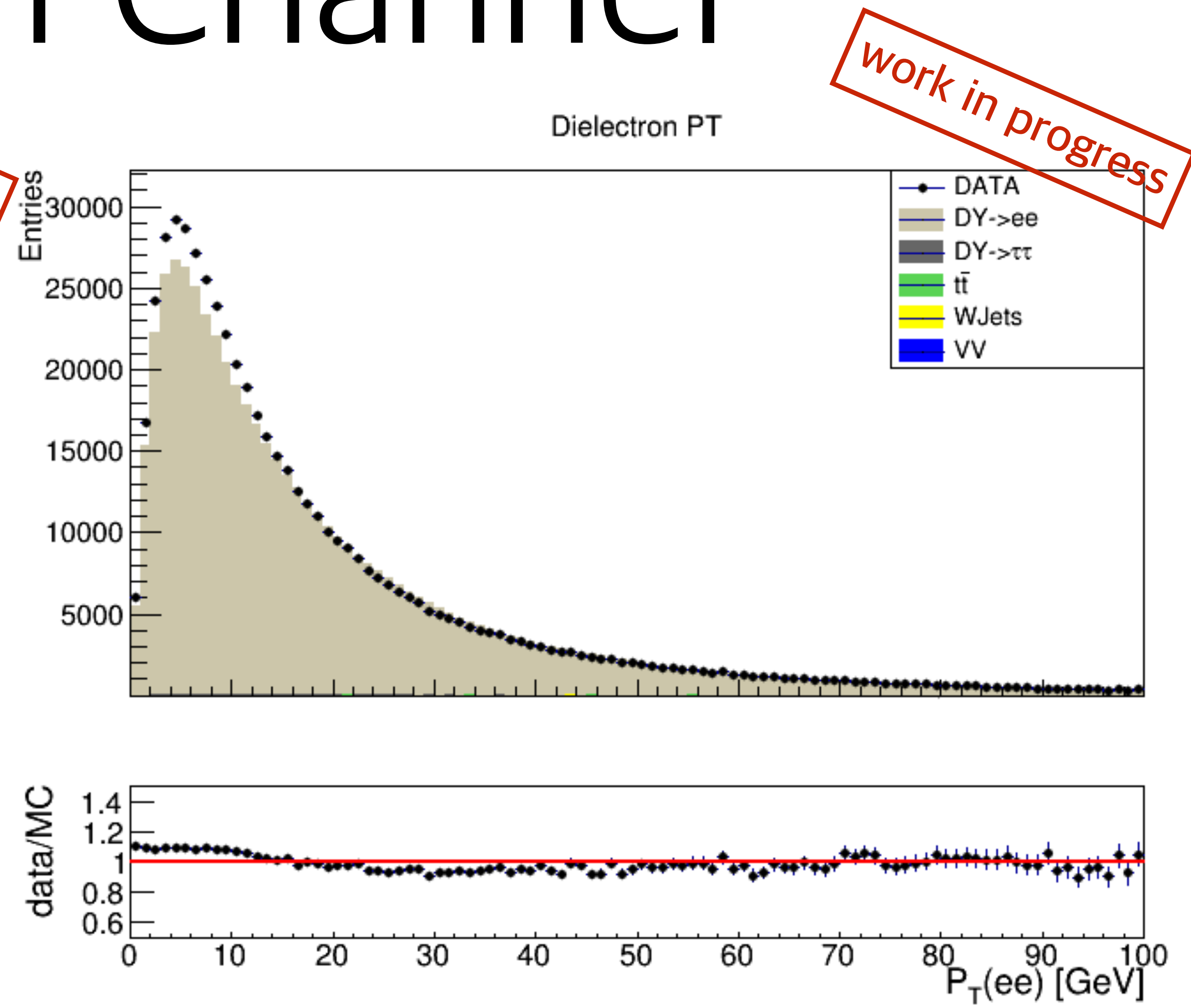


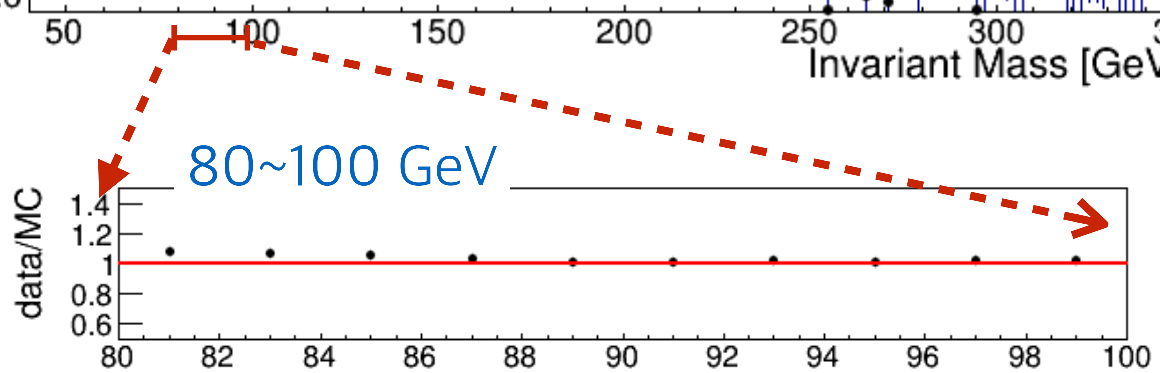


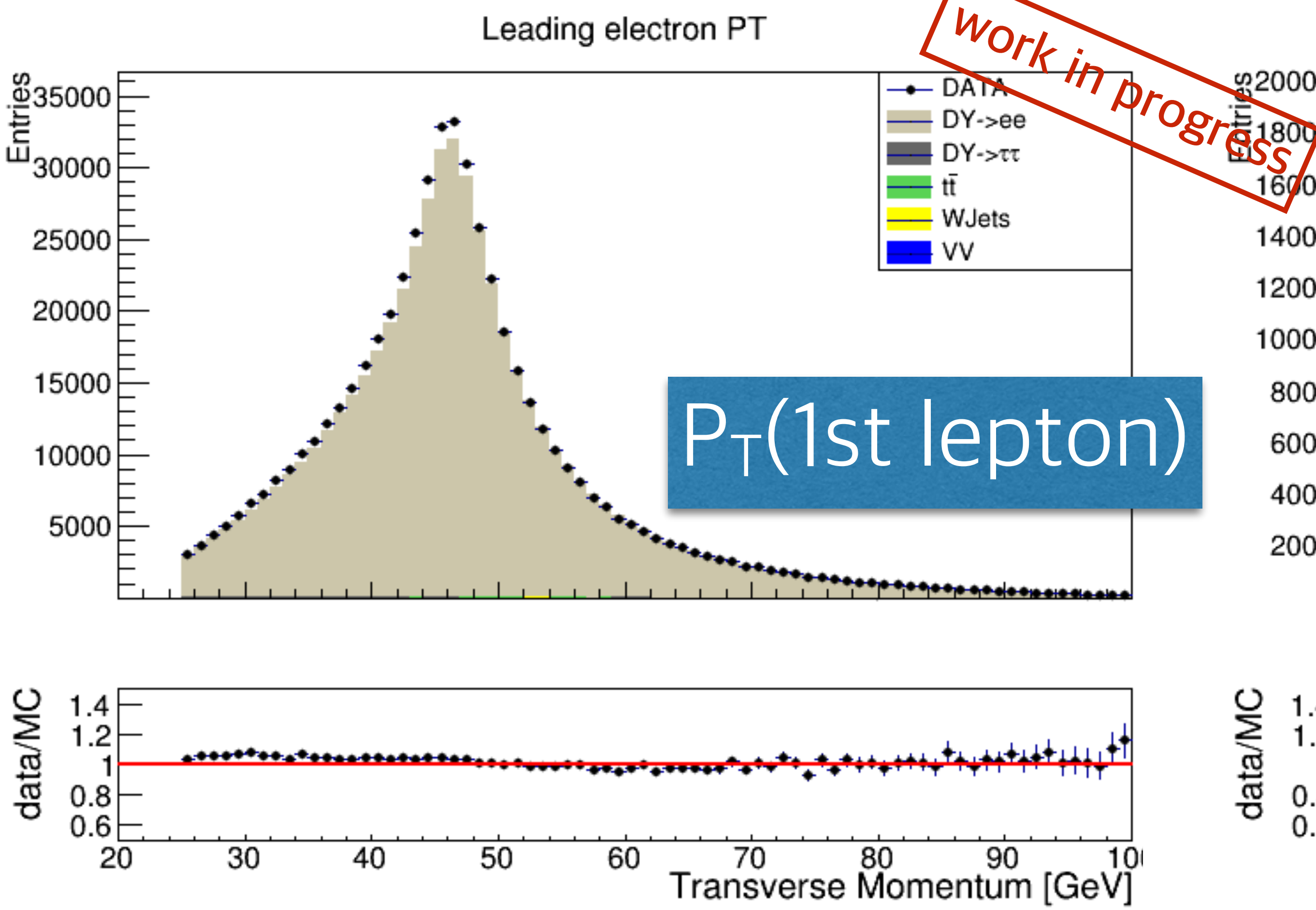


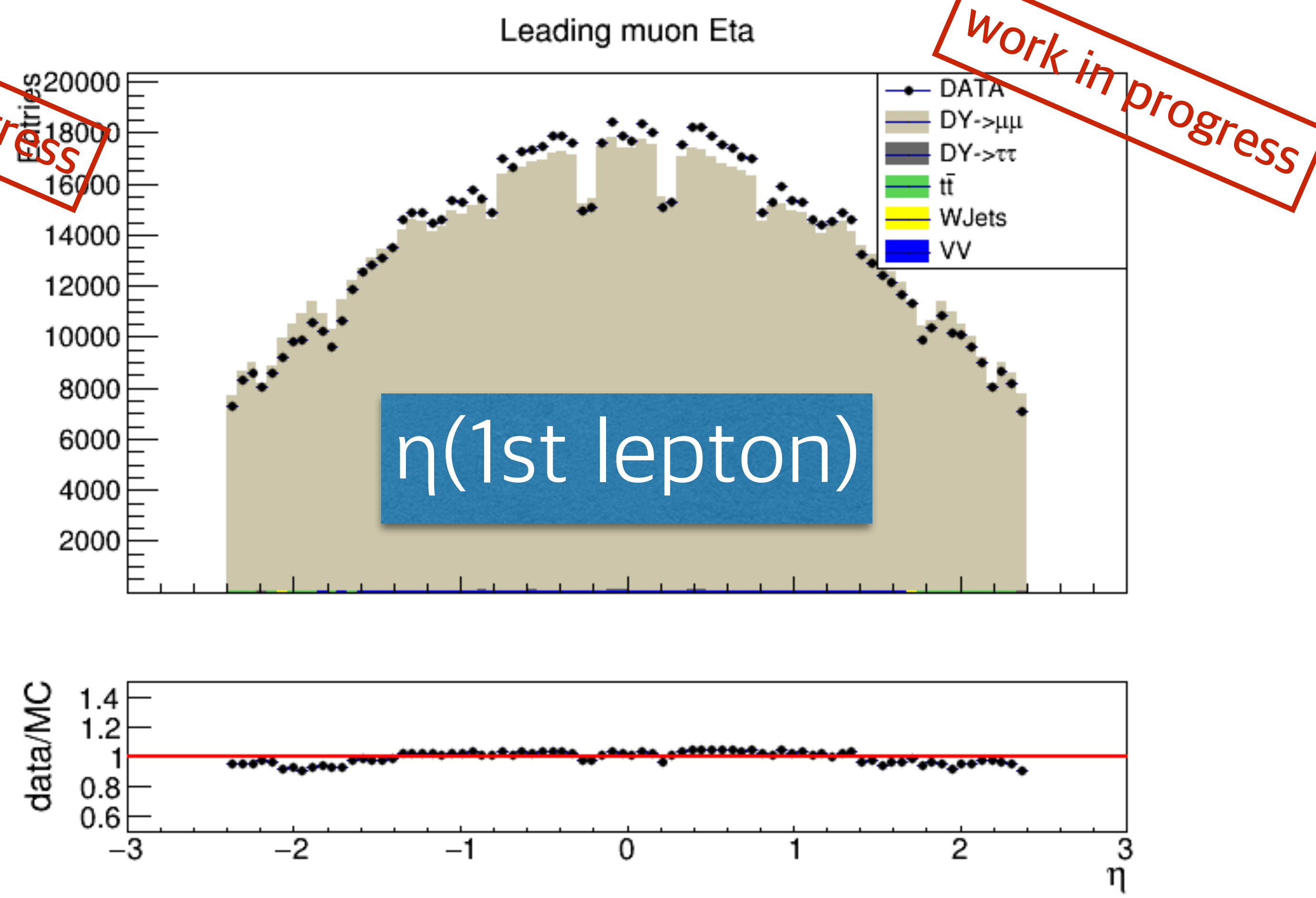
DiElectron Channel

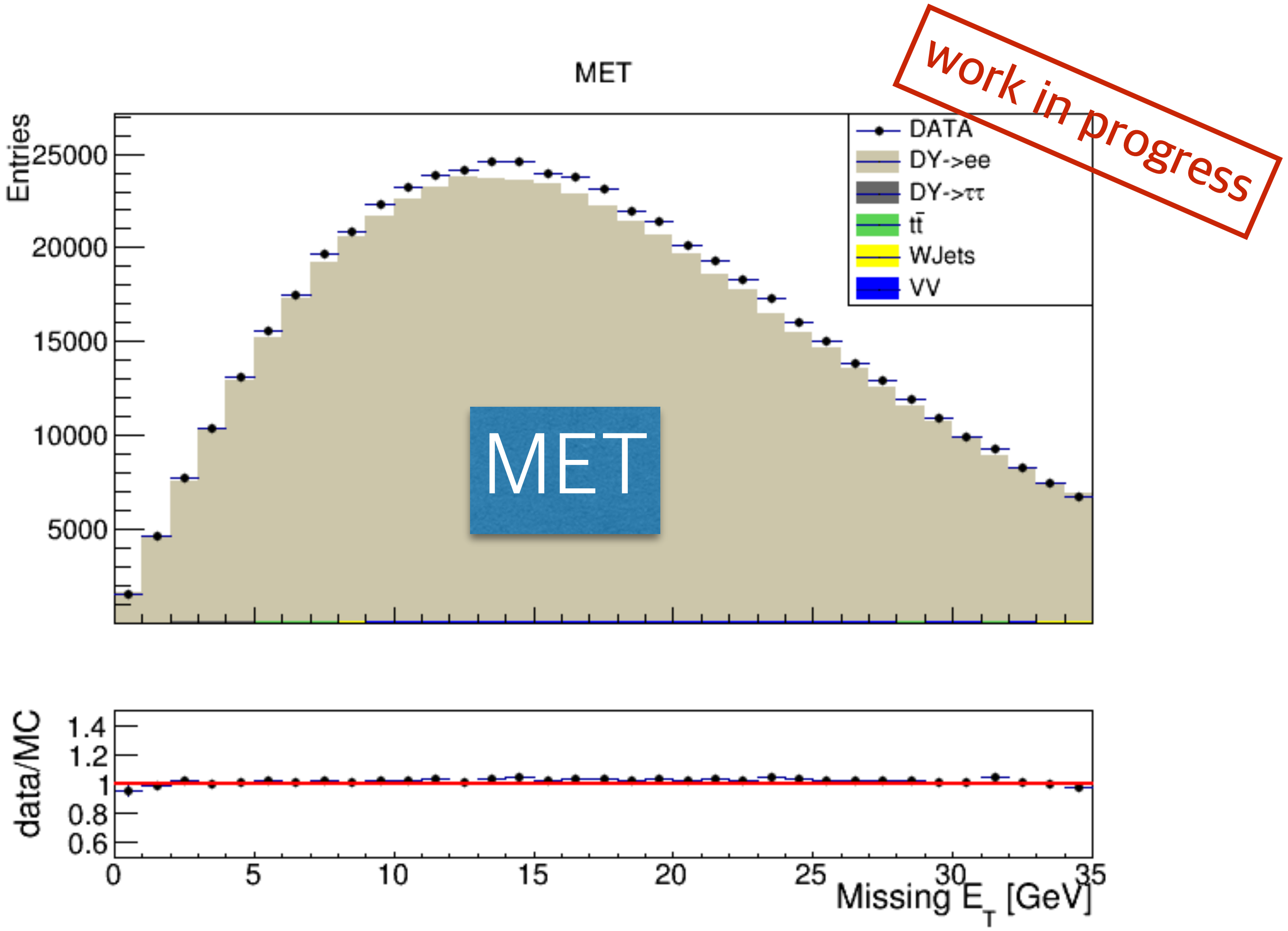






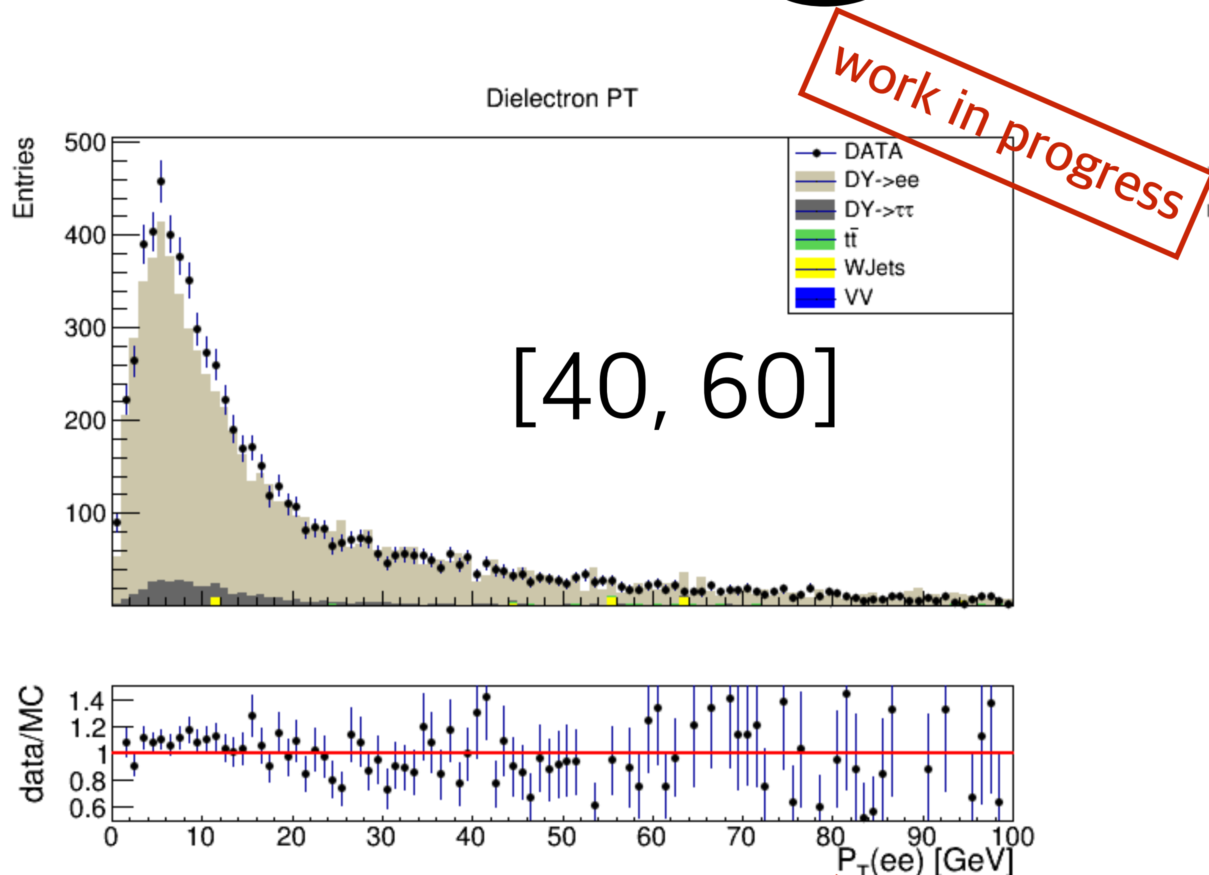


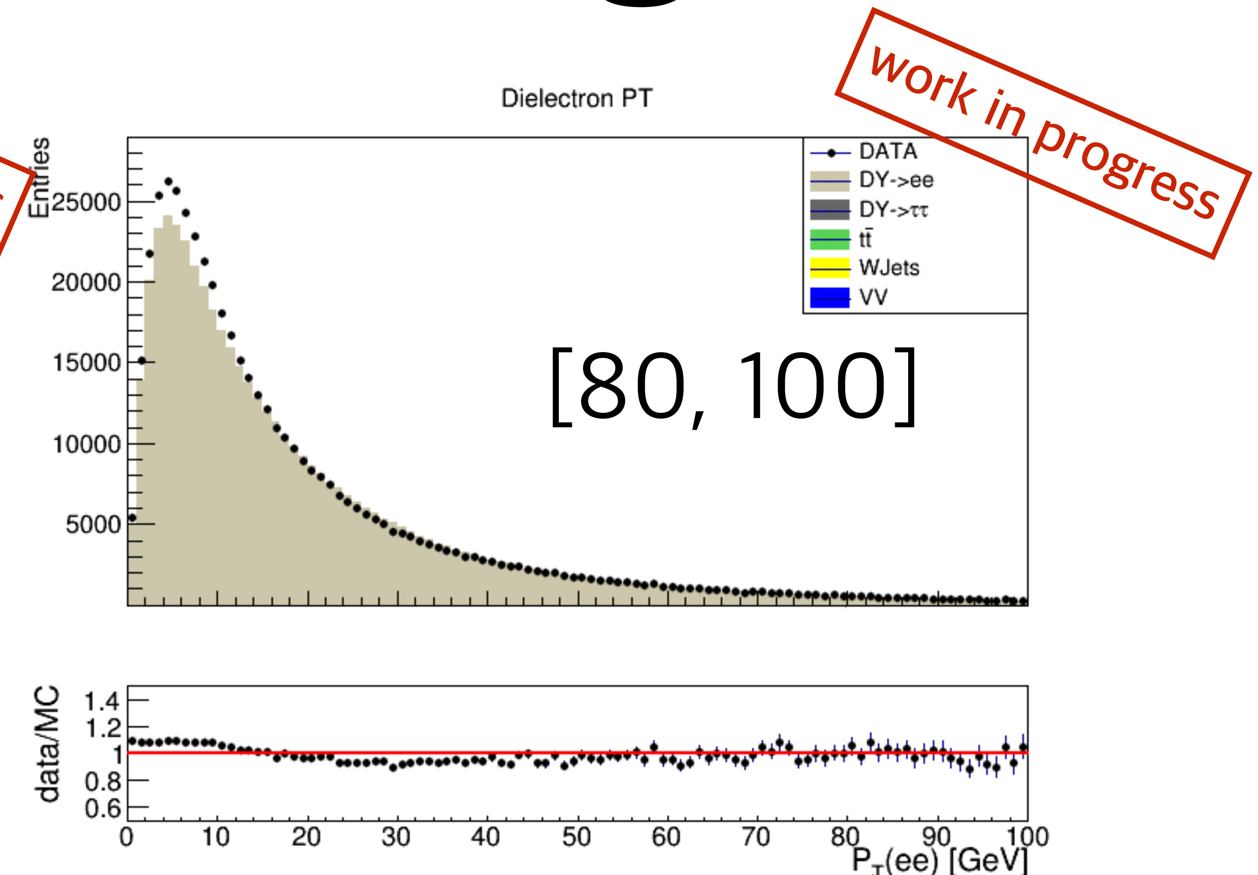


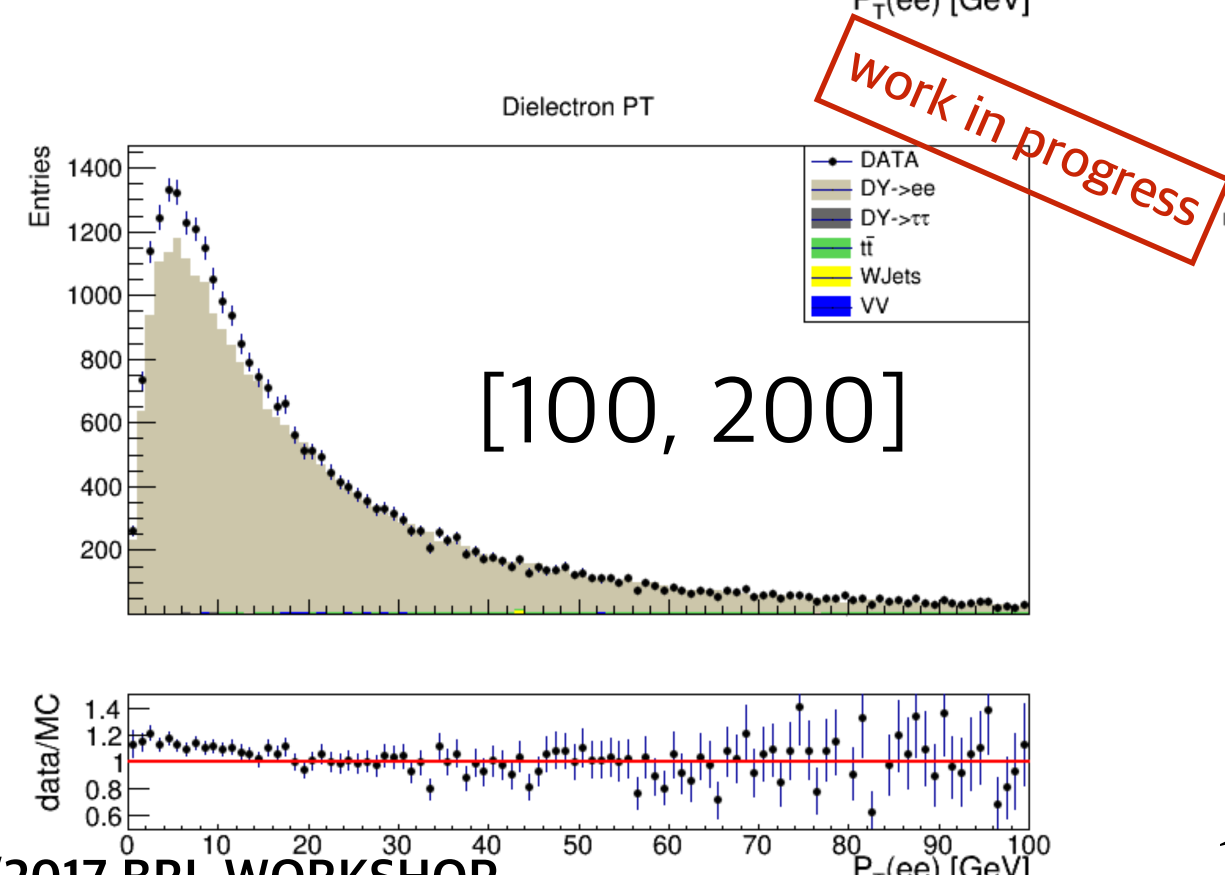


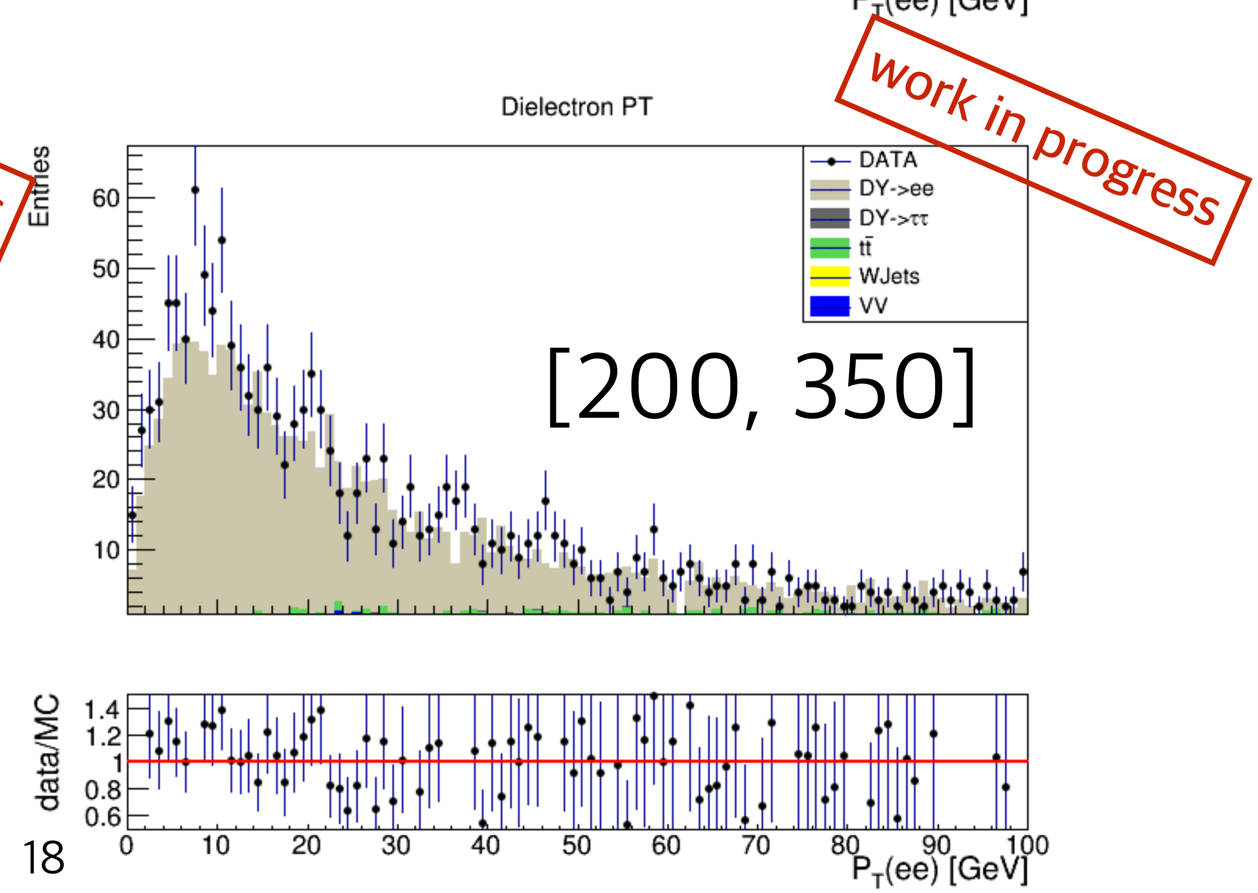
MC agrees with data well !

P_T(ee)@4 mass regions

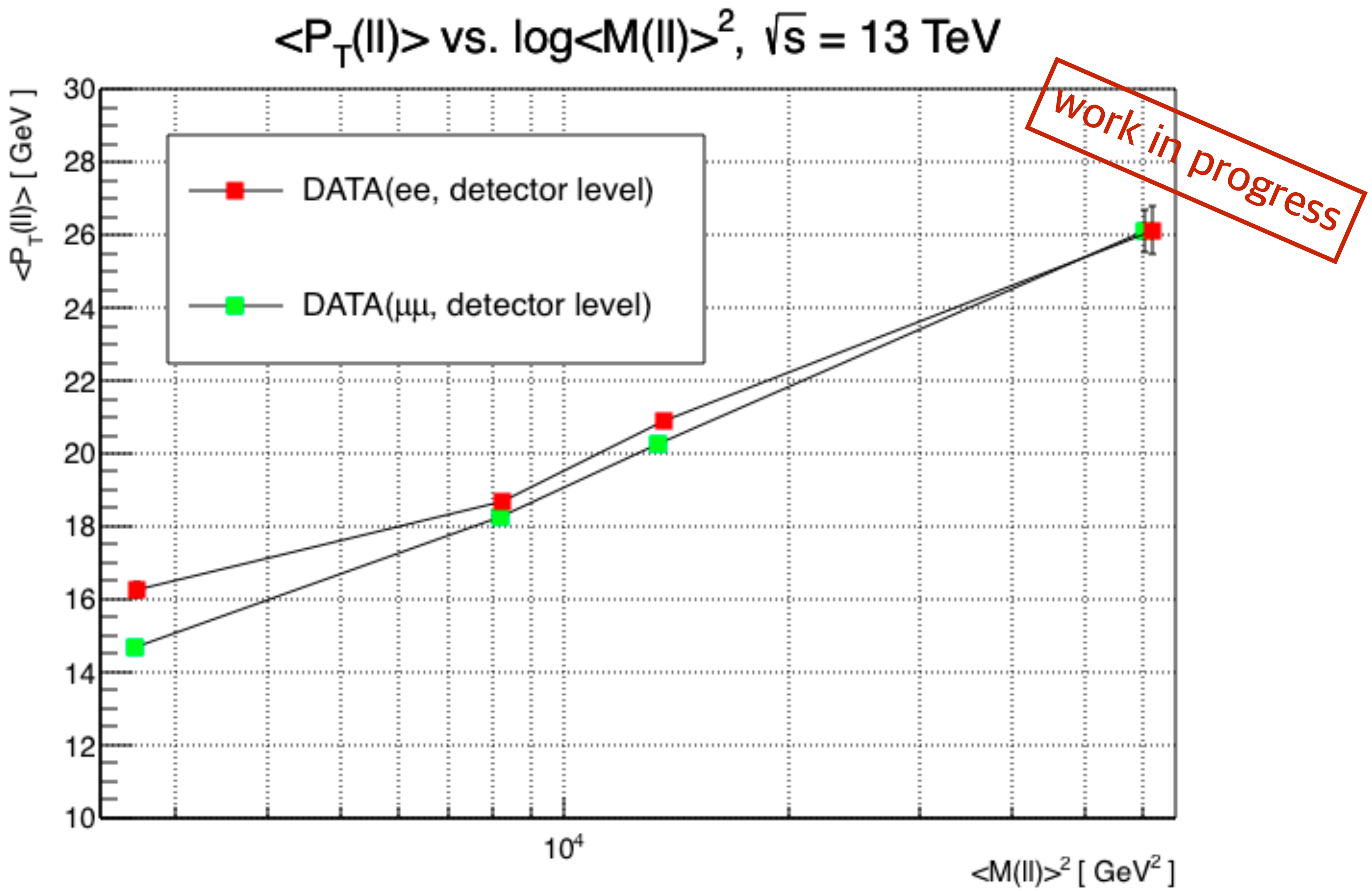








$<PT(ll)>_{detector}$ vs $<M(ll)>^2_{detector}$



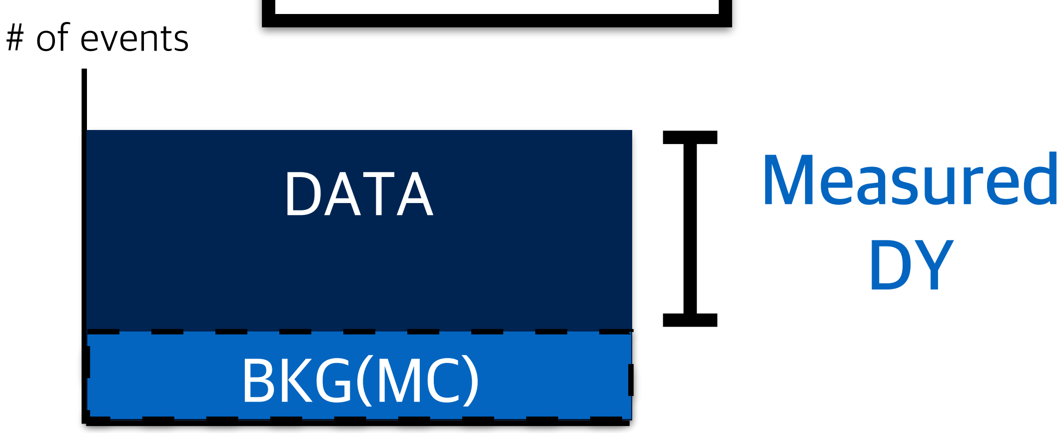
Unfolding using correction factor

<PT(ll)>data

<PT(ll)>data-bkg

<PT(ll)>gen, pre-FSR

BKG subtraction

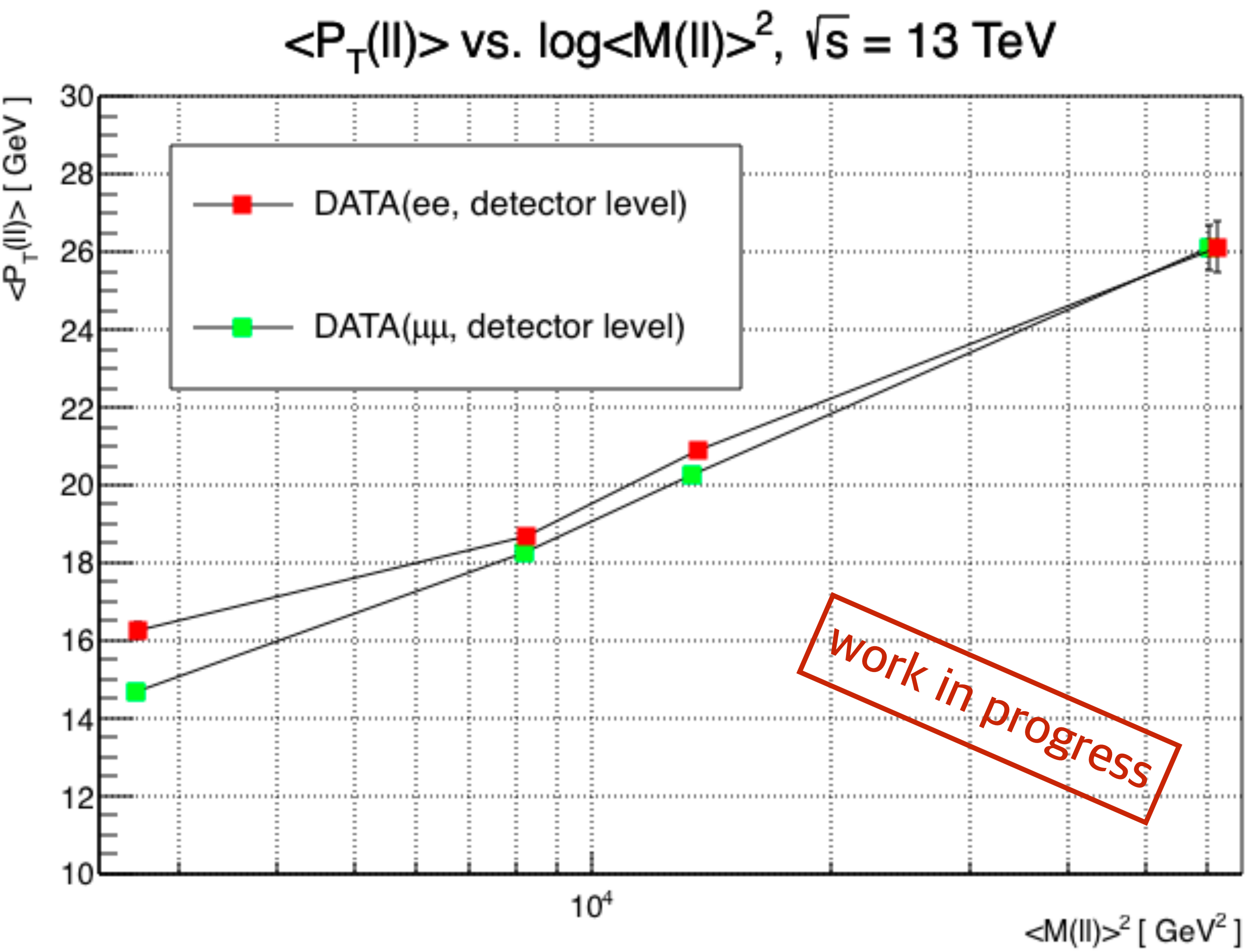


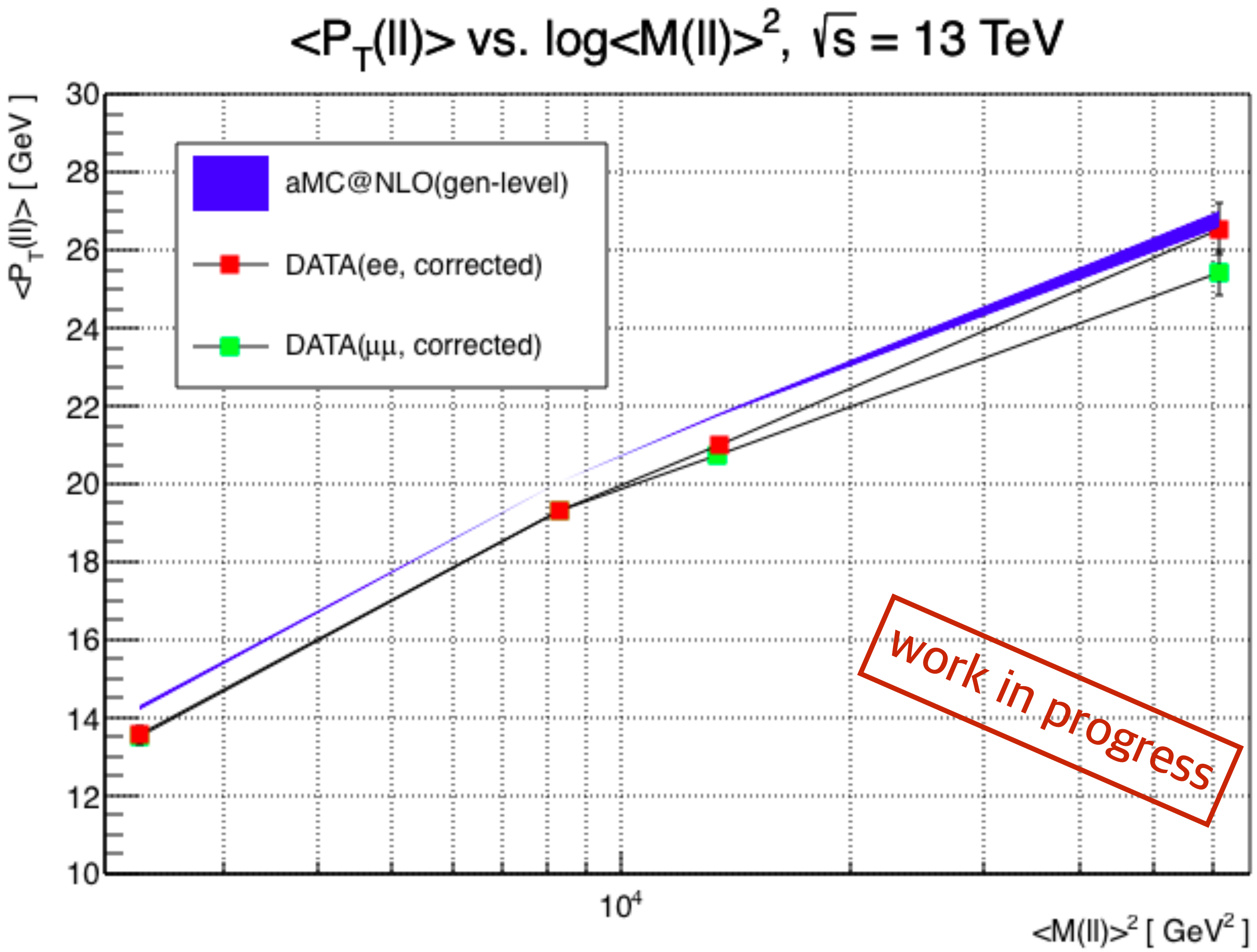
Multiply R

$$R = \frac{\langle PT \rangle_{gen\_DY(MC,\ preFSR)}}{\langle PT \rangle_{reco\_DY(MC)}}$$

- Same process is done for <M(ll)>

<PT(ll)> vs <M(ll)>^{2}





Unfolding

Systematic Uncertainty

	N_{bkg}	R
LeptonID	✓	✓
Lepton Energy/Momentum	✓	✓
QED-FSR		✓
PDF		✓
BKG Normalization	✓	
MC generator [POWEHG]		✓
JER	✓	✓
JES	✓	✓
Pileup	✓	✓
Λ_{QCD}		✓

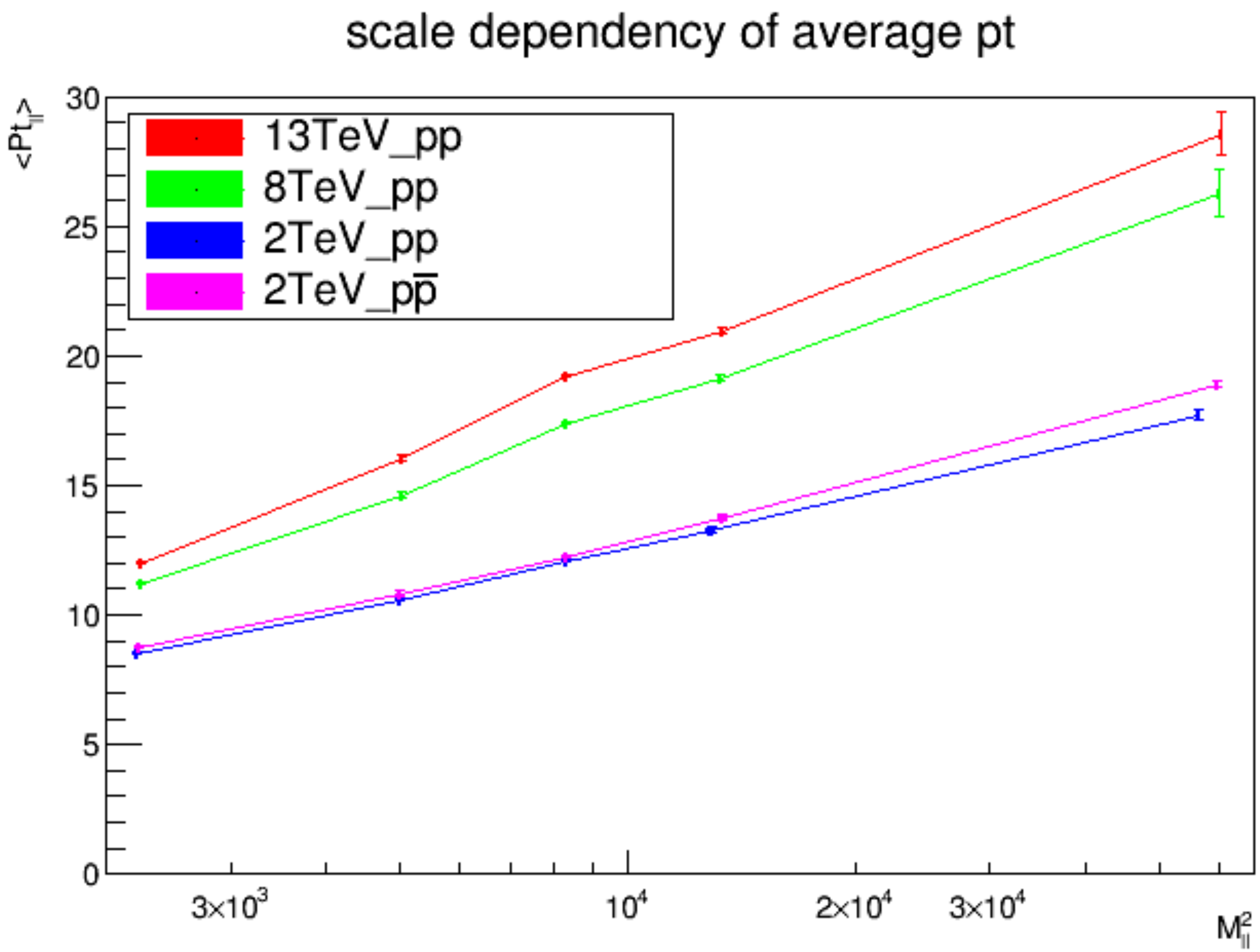
Each factor affects BKG subtraction(N_{bkg})& unfolding(R)

PT(ll) Uncertainty

work in progress

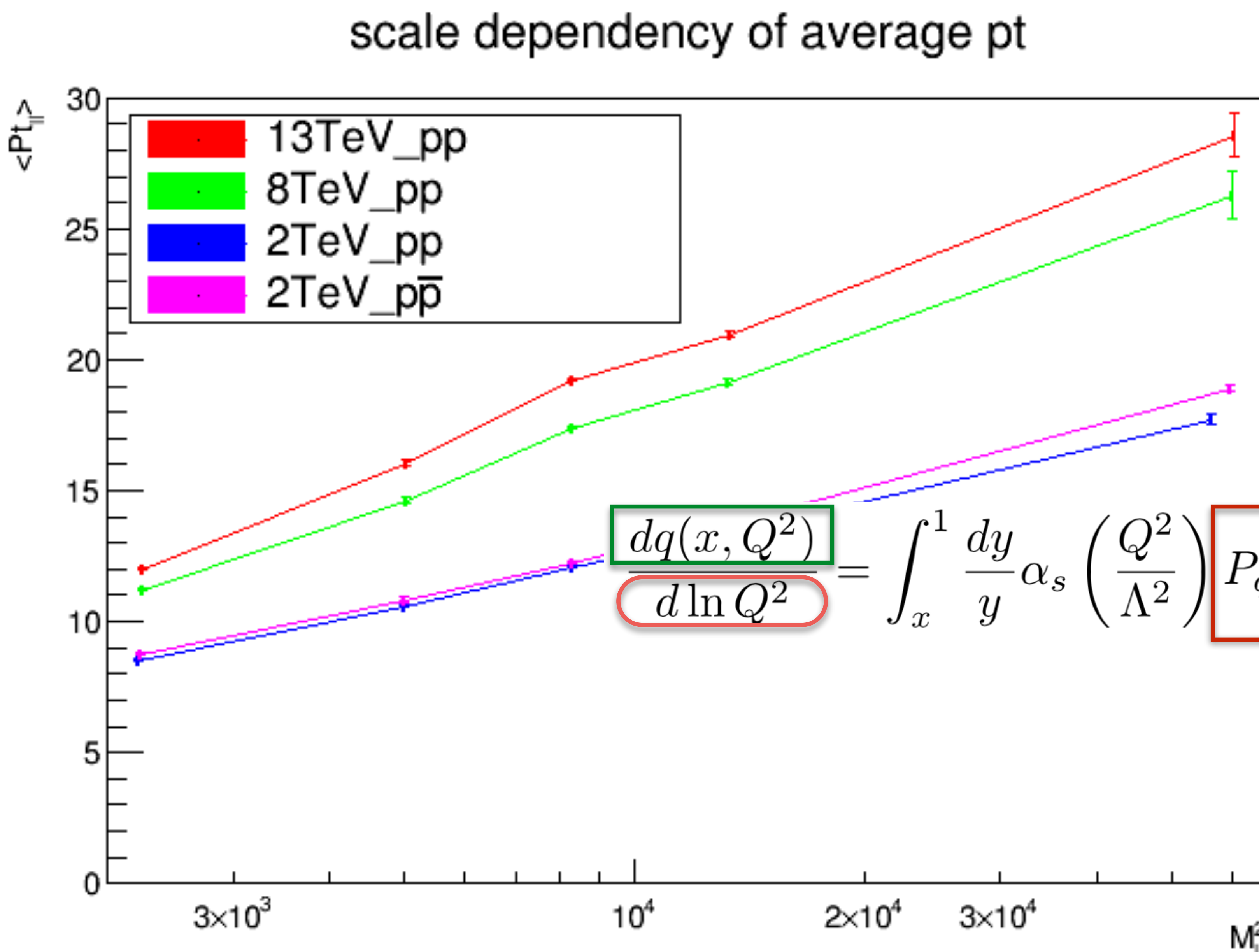
		40-60	80-100	100-200	200-350
Muon	Statistical	0.77%	0.10%	0.45%	2.19%
	ID+ISO	0.13%	0.07%	0.06%	0.04%
	pileup	0.06%	0.02%	0.05%	0.14%
	Trigger	0.09%	0.01%	0.03%	0.10%
	BKG norm.	0.12%	0.00%	0.11%	0.47%
	JetEnergy	0.36%	0.36%	0.44%	1.44%
Electron	Staticstical	1.02%	0.12%	0.50%	2.35%
	Reco+ID	0.53%	0.51%	0.42%	0.44%
	PileUp	0.03%	0.01%	0.06%	0.03%
	Trigger	0.06%	0.00%	0.03%	0.06%
	BKG norm.	0.12%	0.00%	0.09%	0.40%
	JetEnergy	0.46%	0.34%	0.45%	0.93%

ISR activity @ different √ s



- Different slope & intercept for different center of mass energy

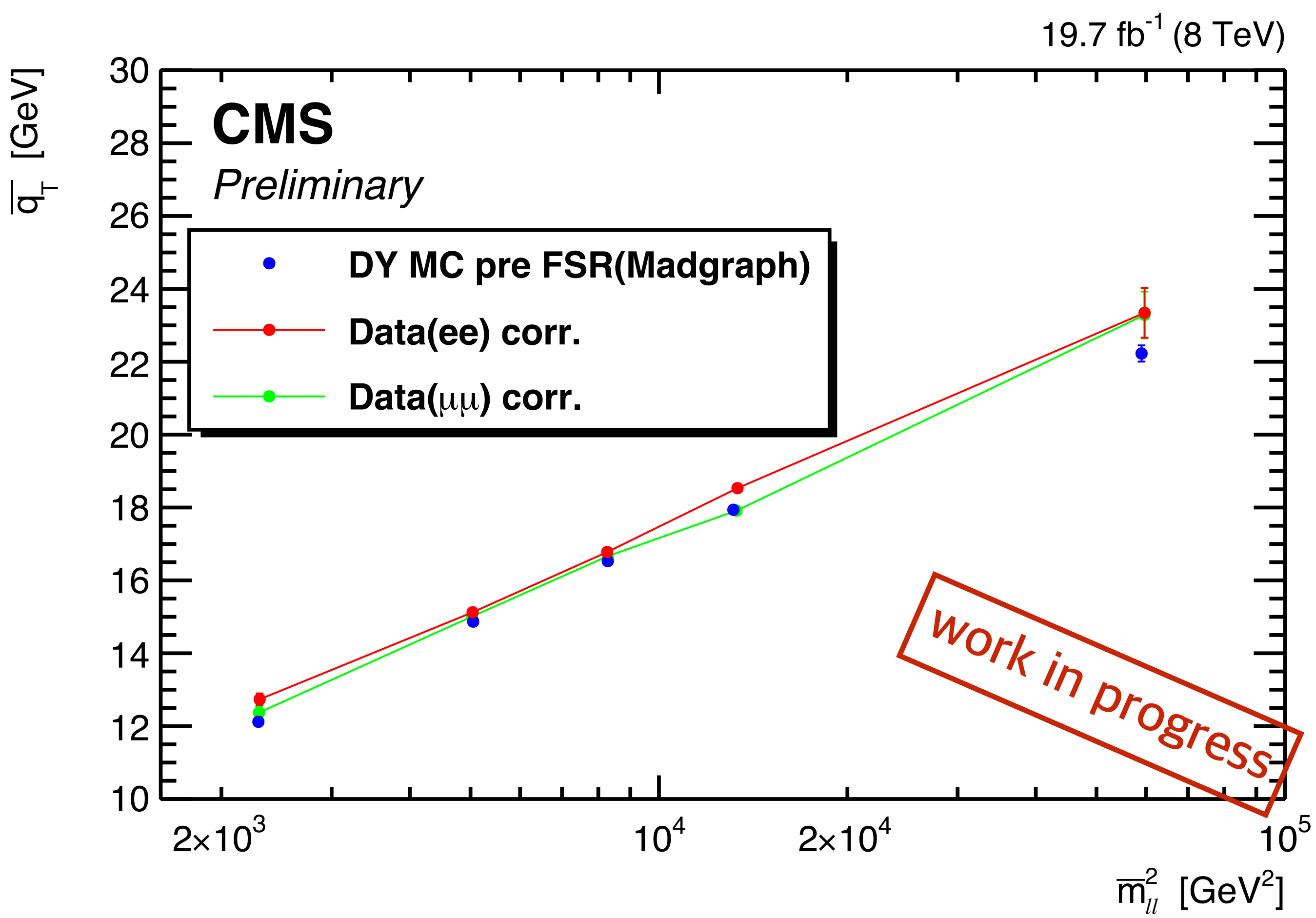
ISR activity @ different √ s

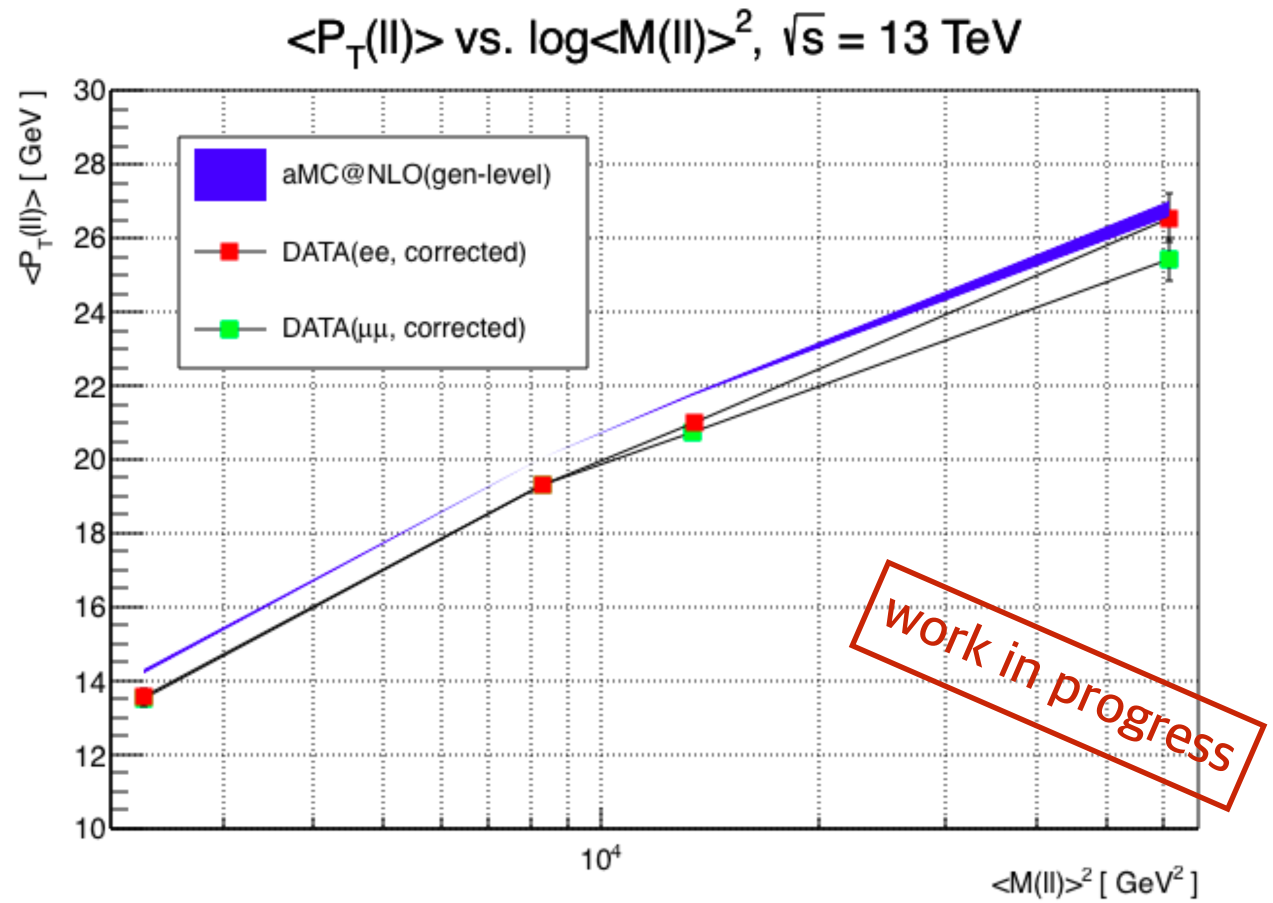


$$\frac{\boxed{dq(x,Q^2)}}{d\ln Q^2} = \int_x^1 \frac{dy}{y}\alpha_s\left(\frac{Q^2}{\Lambda^2}\right)\boxed{P_{q\to qg}\left(\frac{x}{y},Q^2\right)}\boxed{q(y,Q^2)}$$

- Different slope & intercept for different center of mass energy

8TeV / 13TeV





- ISR studies @8TeV & @13TeV are ongoing.
- 2 TeV study using CDF data

Summary & Plan

- In the first look, logarithmic Q^2 dependence of PT(ll) is shown in data @ 13TeV.
- Estimation of systematic uncertainties is on the way.
- Aim to publish results @ 8TeV this year

Thank you :)

backup

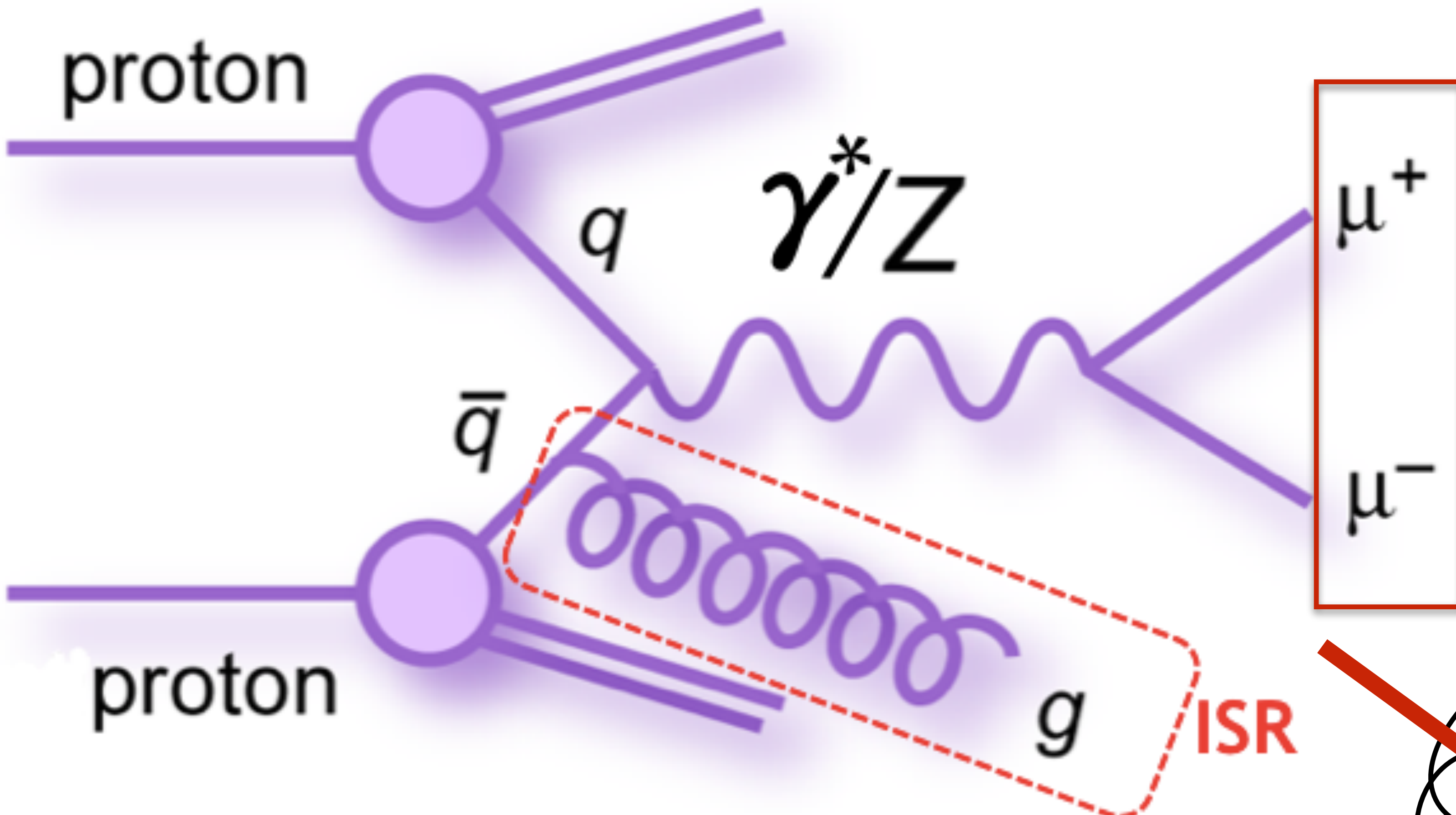
Systematics μμ

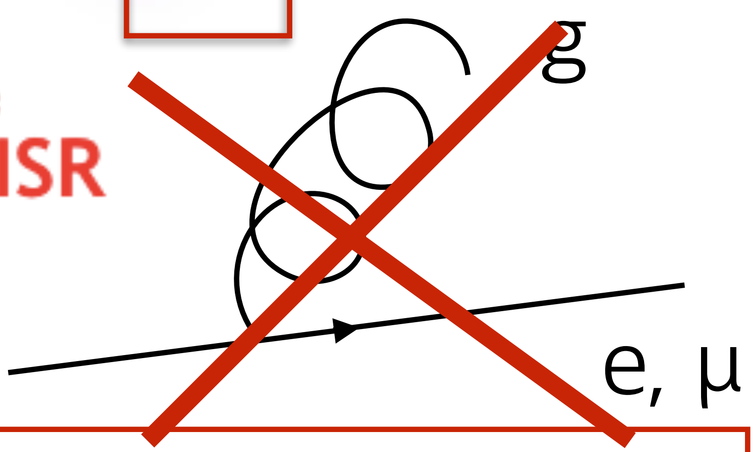
	<PT(ll)>				<M(ll)>			
	40-60	80-100	100-200	200-350	40-60	80-100	100-200	200-350
MuonID	0.07%	0.06%	0.06%	0.04%	0.00%	0.00%	0.01%	0.00%
MuonISO	0.11%	0.03%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%
Pileup	0.03%	0.02%	0.05%	0.23%	0.00%	0.00%	0.00%	0.02%
JER	0.14%	0.25%	0.27%	0.69%	0.00%	0.00%	0.01%	0.10%
JES	0.33%	0.35%	0.46%	1.22%	0.00%	0.00%	0.03%	0.12%

Systematics ee

	<PT(ll)>				<M(ll)>			
	40-60	80-100	100-200	200-350	40-60	80-100	100-200	200-350
Pileup	0,01%	0.01%	0.07%	0.01%	0.00%	0.00%	0.00%	0.03%
JER	0.13%	0.31%	0.31%	1.00%	0.03%	0.00%	0.02%	0.01%
JES	0.09%	0.25%	0.30%	0.22%	0.02%	0.00%	0.00%	0.03%

How to Measure ISR





(1) Drell-Yan Process : Only Leptons in the final state

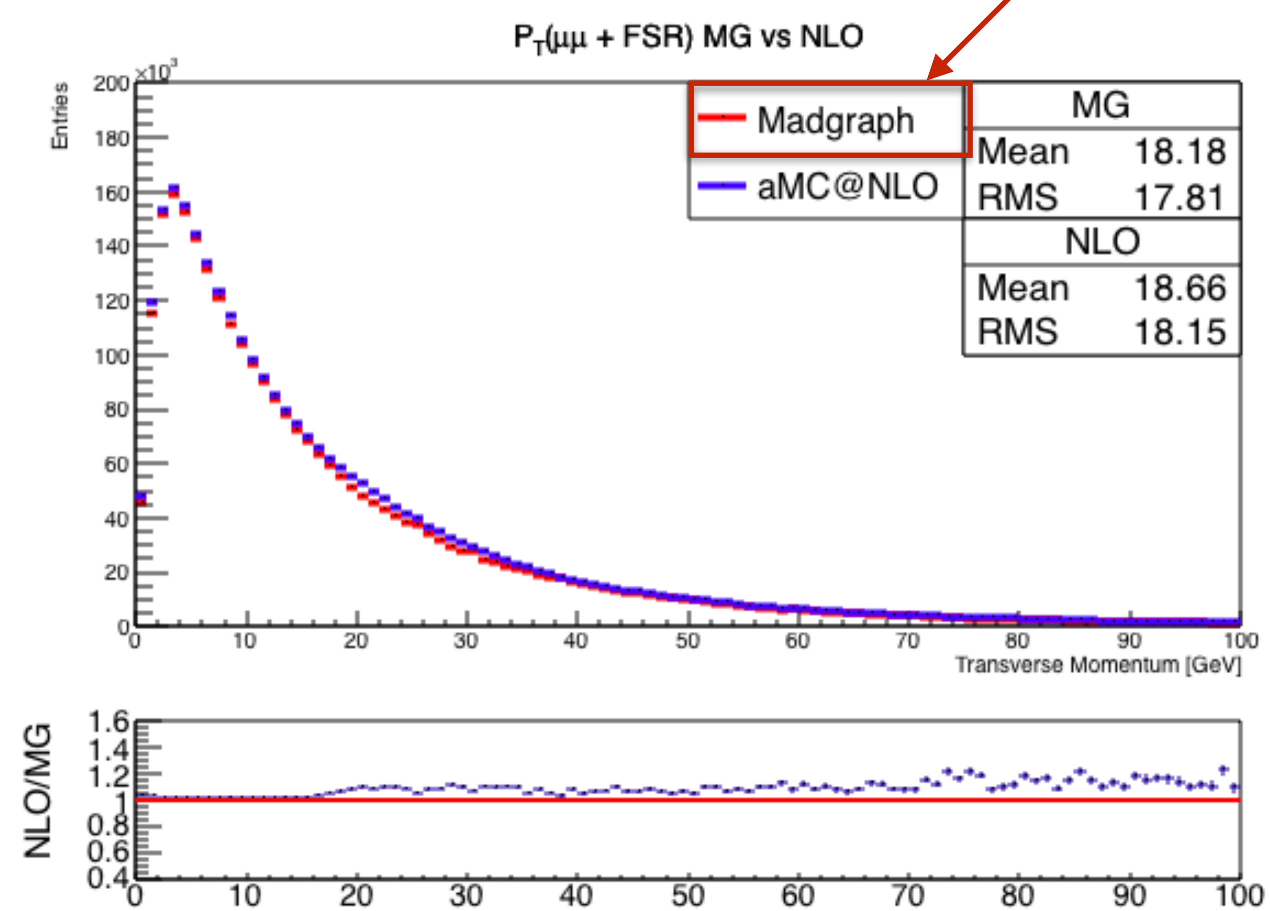
(2) No QCD FSR in DY process -> PT(ll) is sensitive to ISR activity

(3) Study PT(ll) in DY for different Q^2 scales

Gen-Level Study

- Check the effect of
  - LO vs NLO
  - QED FSR
  - Flavour of lepton (ee vs. mumu)
  - PT(ll) cuts

DY + 4jets



- difference at high PT(ll) region

-> Hard scattering region

Gen-Level Study

- Check the effect of
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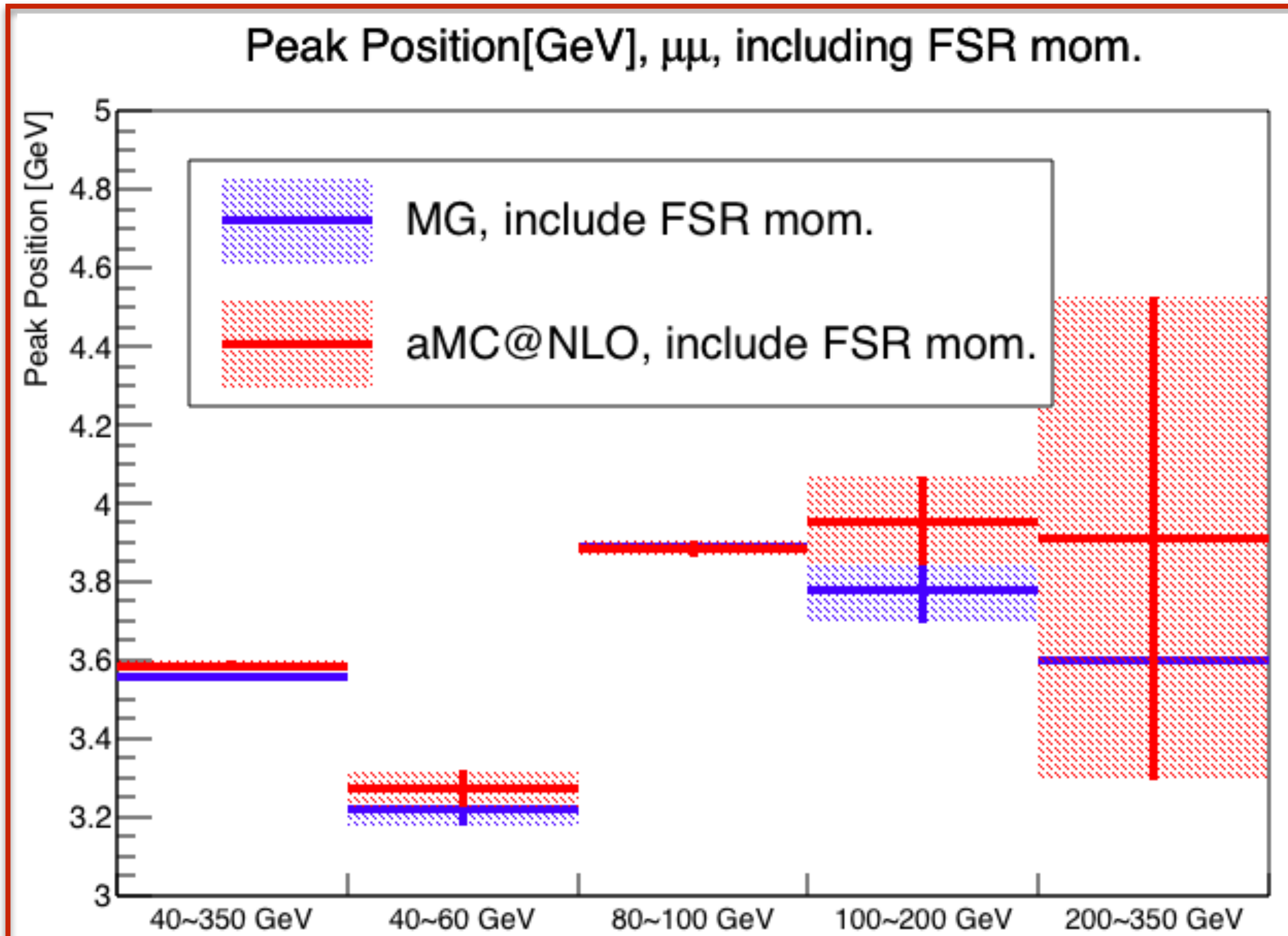
  - Flavour of lepton

    (ee vs. mumu)
  - PT(ll) cuts



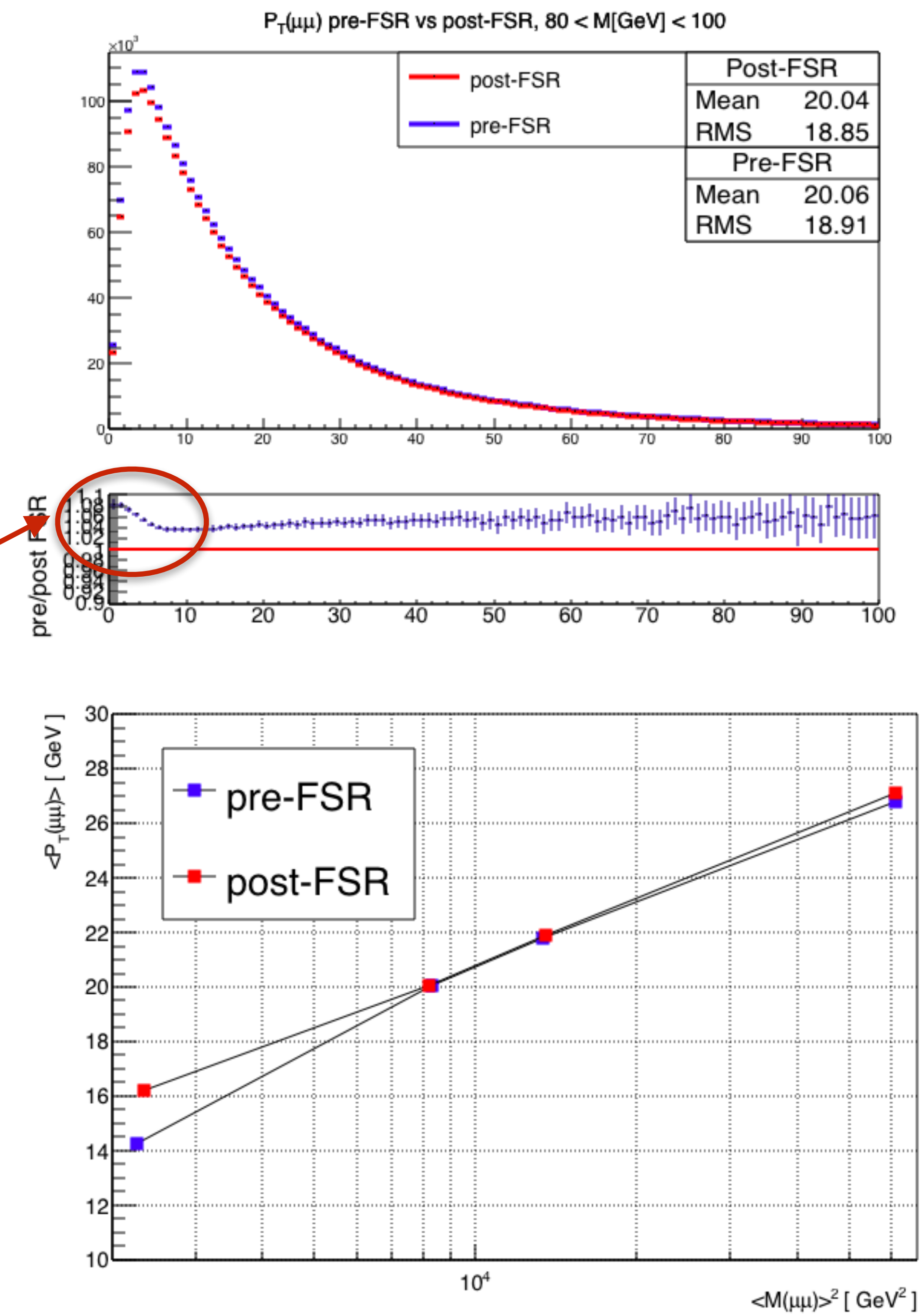
No significant difference of peak positiion

Gen-Level Study

- Check the effect of
  - LO vs NLO
  - QED FSR
  - Flavour of lepton
    (ee vs. mumu)
  - PT(ll) cuts

Pre-FSR :
low PT(ll) region
contribution↑

->low PT(ll) events
immigrate from
low mass region



Gen-Level Study

- Check the effect of
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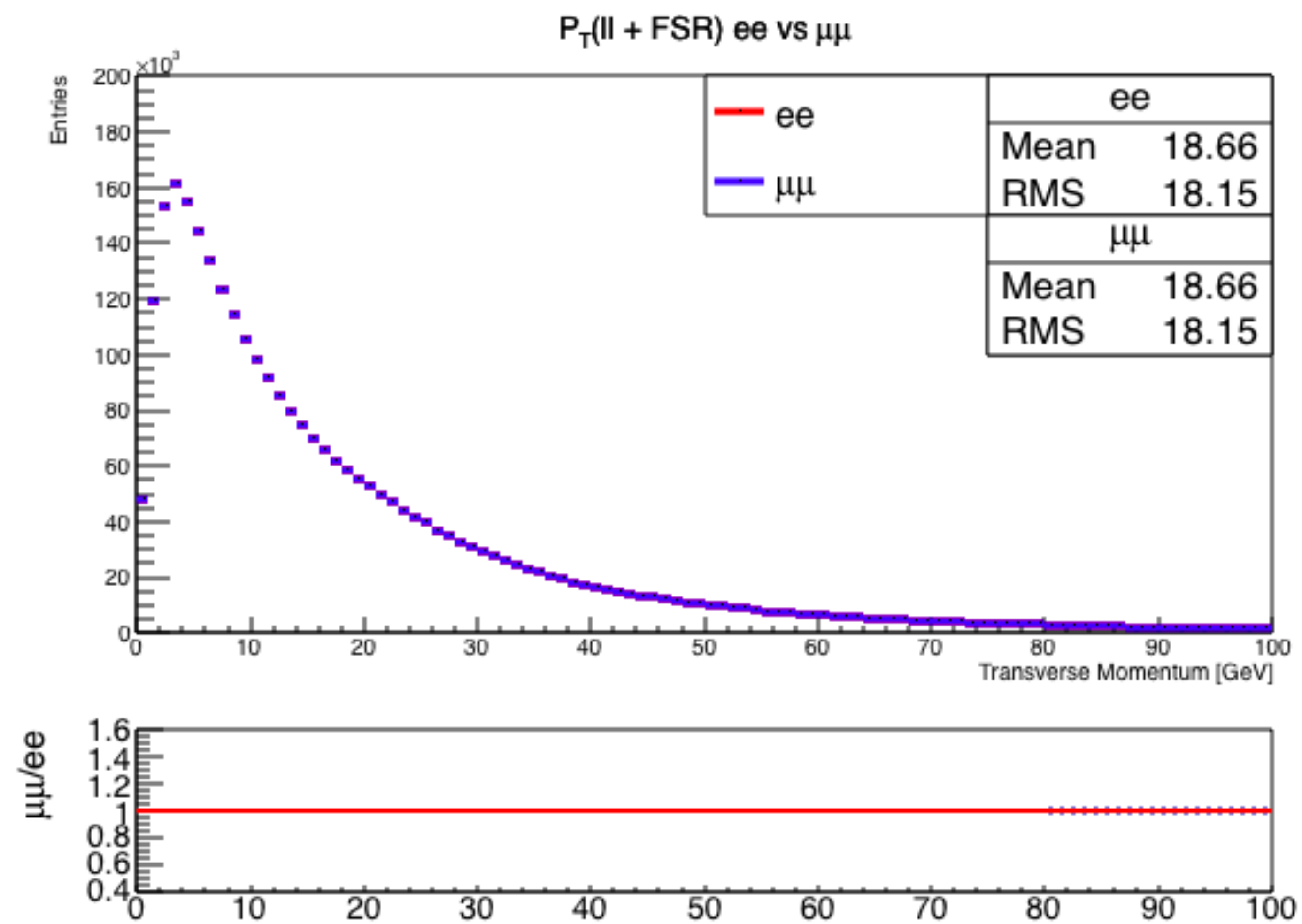
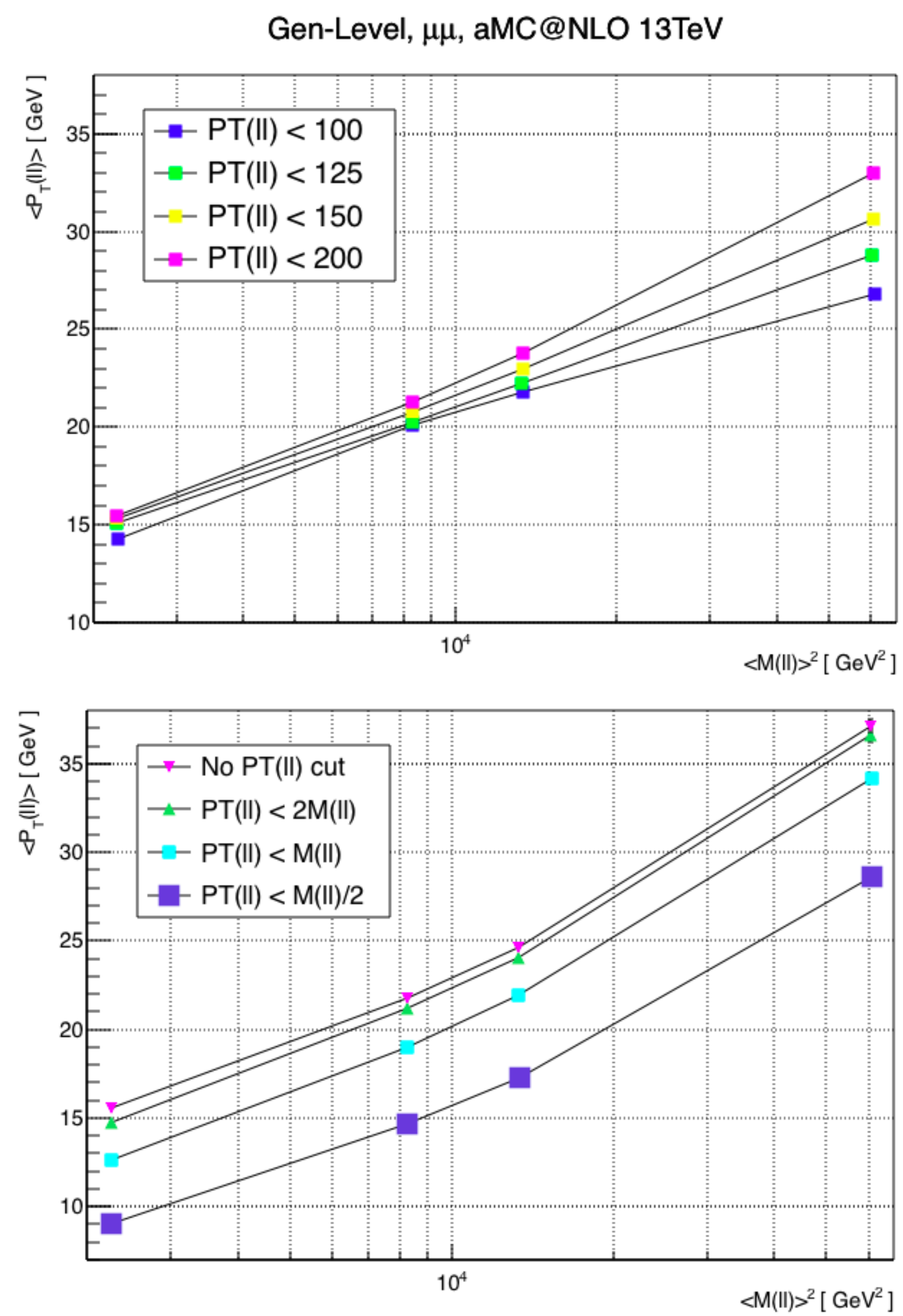


Distribution at generator level
-> independent of lepton flavour

Gen-Level Study

- Check the effect of
  - LO vs NLO
  - QED FSR
  - Flavour of lepton

    (ee vs. mumu)
  - PT(ll) cuts



To reduce the contribution from hard scatterings

Datasets

NAME	DATASET
DY_aMC@NLO	/DYJetsToLL_M-10to50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /DYJetsToLL_M-50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12_ext4-v1/MINIAODSIM
DY_Madgraph	/DYJetsToLL_M-5to50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /DYJetsToLL_M-50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM
DY_powheg	/DYToEE_NNPDF30_13TeV-powheg-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /ZToMuMu_NNPDF30_13TeV-powheg_M_50_120/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /ZToMuMu_NNPDF30_13TeV-powheg_M_120_200/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /ZToMuMu_NNPDF30_13TeV-powheg_M_200_400/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM
$t\bar{t}$	/TTJets_TuneCUETP8M1_13TeV-madgraphMLM-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM
VV	/ZZ_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /WZ_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM /WW_TuneCUETP8M1_13TeV-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM
WJets	/WJetsToLNu_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8/RunIIFall15MiniAODv2-PU25nsData2015v1_76X_mcRun2_asymptotic_v12-v1/MINIAODSIM

DoubleMuon / DoubleEG, periodC+D, 2.2/fb 2015

How to Measure ISR

(1) Drell-Yan Process : Only Leptons in the final state

(2) No QCD radiation from the final state

(3) Using Σ PT = 0 in pp collision

(4) Σ [PT(ll) + PT(ISR)] = 0 in DY process

(5) PT(ll) = PT(ISR) ~ ISR activity

Measure Q^2 dependence of PT(ll) in DY

= Measure Q^2 dependence of ISR

Systematic Uncertainty

- **μμ**
  - ✓ MuonID
  - ✓ MuonISO
  - ✓ JER
  - ✓ JES
  - ✓ Pile-up
  - ⍻ MC generator(POWEHG)
  - ⍻ **Normalization**
  - ⍻ **QED-FSR**
  - ⍻ **Muon momentum(Rochester Corr.)**
  - ⍻ **PDF**
  - ⍻ **Λ_{QCD}**

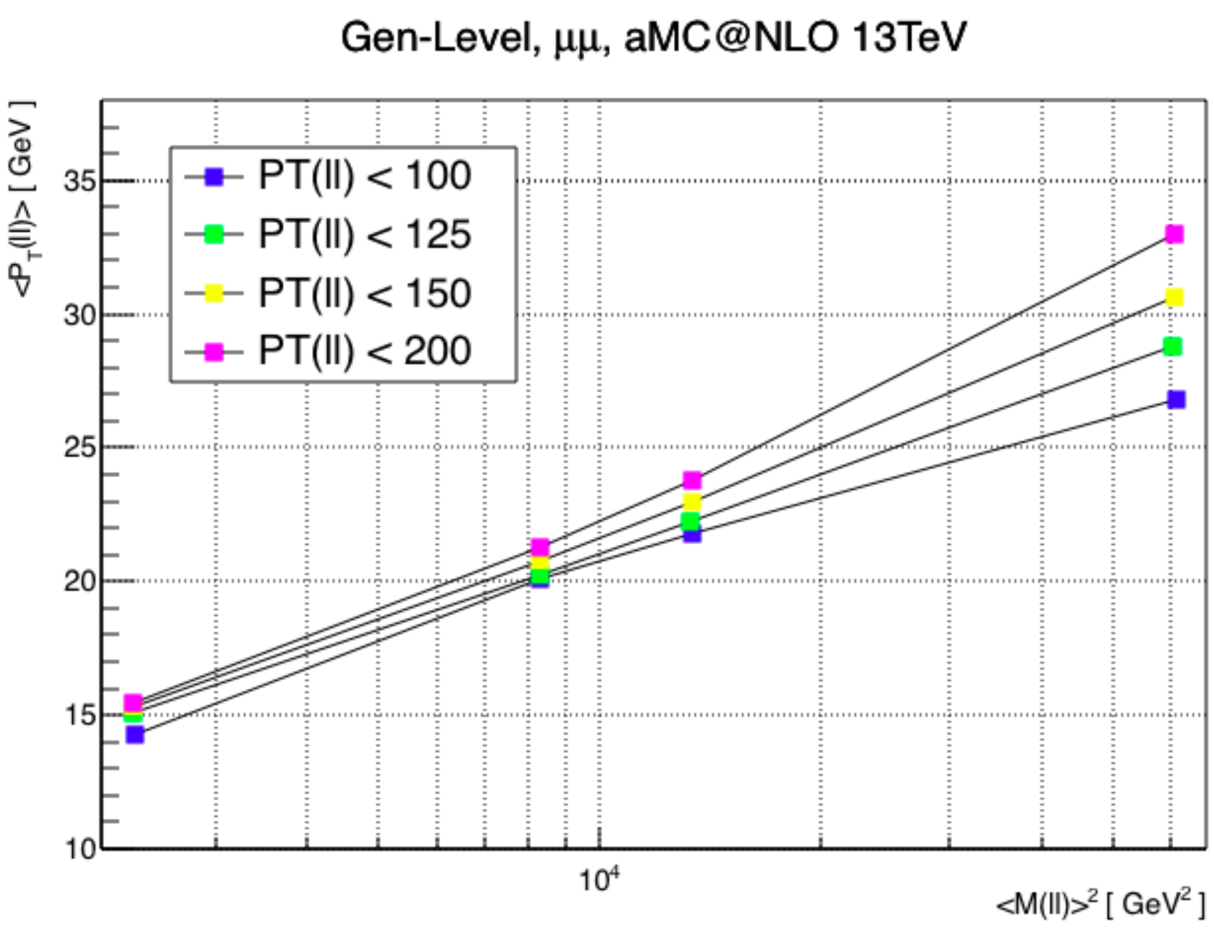
- **ee**
  - ⍻ Electron ID
  - ⍻ Electron Reco
  - ✓ JER
  - ✓ JES
  - ✓ Pile-up
  - ⍻ MC generator(POWEHG)
  - ⍻ **Normalization**
  - ⍻ **QED-FSR**
  - ⍻ **Electron Energy Res/Scale**
  - ⍻ **Electron Energy regression correction**
  - ⍻ **PDF**
  - ⍻ **Λ_{QCD}**

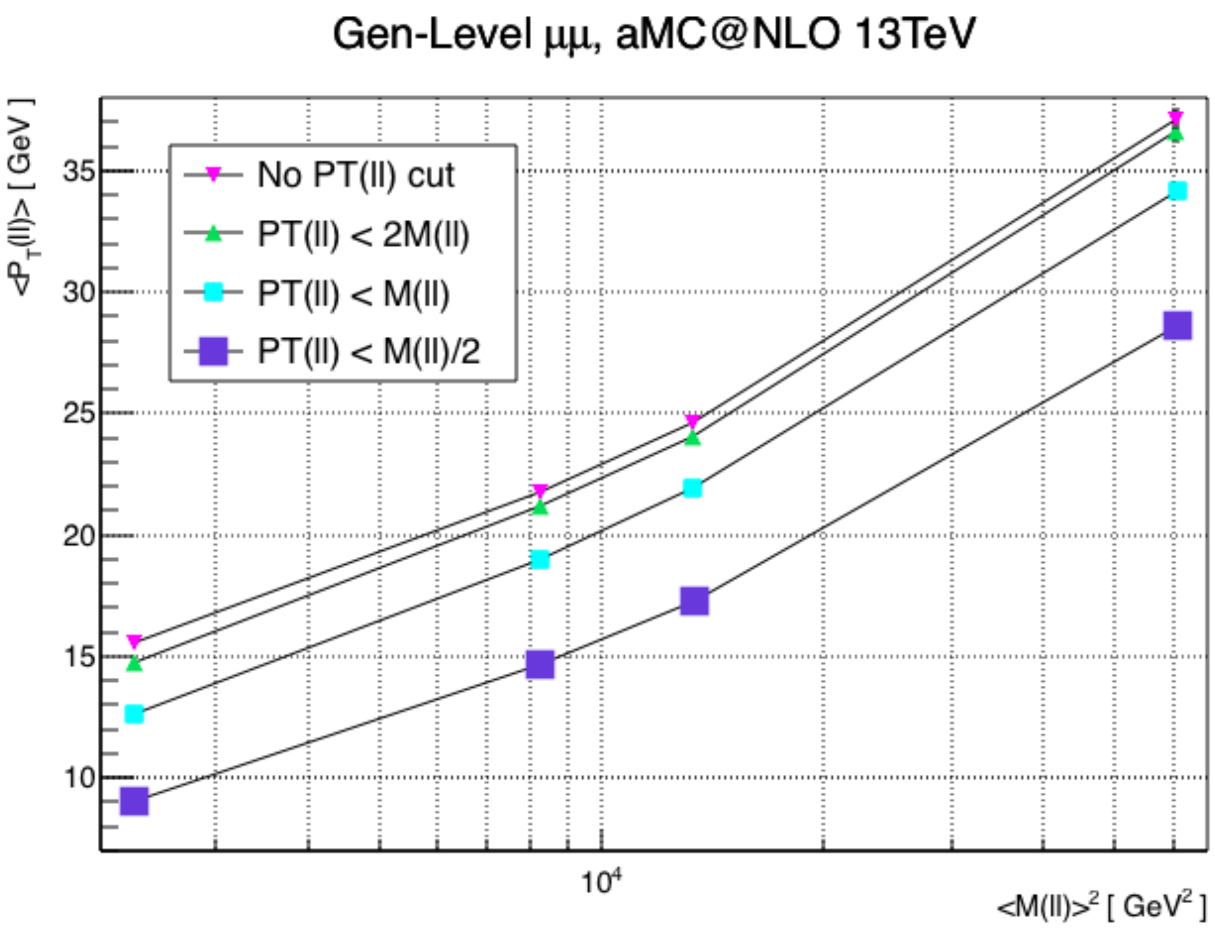
PHOTOS [https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuidePhotosInterface]

$<PT(ll)>_{corrected\_data}$, $<M(ll)>_{corrected\_data}$

	$<PT(ll)>$		$<M(ll)>$	
	DiMuon	DiElectron	DiMuon	DiElectron
40-60	13.5517	13.5534	48.3418	48.2495
80-100	19.2973	19.3073	91.0468	91.0091
100-200	20.7432	21.016	115.786	116.101
200-350	25.4343	26.5406	246.981	246.878

Gen-Level Study





- Linear slope when PT(ll) < 100 GeV
- By measuring the slope
  - Provide property for QCD gluon radiation

Event Selection

- DiMuon Channel

- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_v

- Tight ISO cut

[https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideMuonIdRun2#Muon_Isolation]

- IdSF, IsoSF, TriggerSF, Rochester Corr.

- 71 mb min. bias xsec

- DiElectron Channel

-HLT_Ele17_Ele12_CaloIdL_TrackIdL_IsoVL_DZ_v (prescaled)
- IdSF, RecoSF, TriggerSF, EGMRegression, EGMSmear

- 71 mb min. bias xsec

- Object Selection
  - Tight PDG lepton ID
  - PT > 20 GeV
  - |eta| < 2.4
  - Missing ET < 35 GeV
  - PT(ll) < 100 GeV

Same cut with 8TeV analysis

Systematic Uncertainty

- **μμ**
  - ✓ MuonID
  - ✓ MuonISO
  - ✓ JER
  - ✓ JES
  - ✓ Pile-up
  - ✓ MC generator(POWEHG)
  - ✓Normalization
  - ✓ QED-FSR
  - ✓Muon momentum(Rochester Corr.)
  - ✓ PDF
  - ✓ Λ_{QCD}

PHOTOS [https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuidePhotosInterface]

- **ee**
  - ✓ Electron ID
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  - ✓ Pile-up
  - ✓ MC generator(POWEHG)
  - ✓ Normalization
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  - ✓ Electron Energy Res/Scale
  - ✓ Electron Energy regression correction
  - ✓ PDF
  - ✓ Λ_{QCD}

  lumi

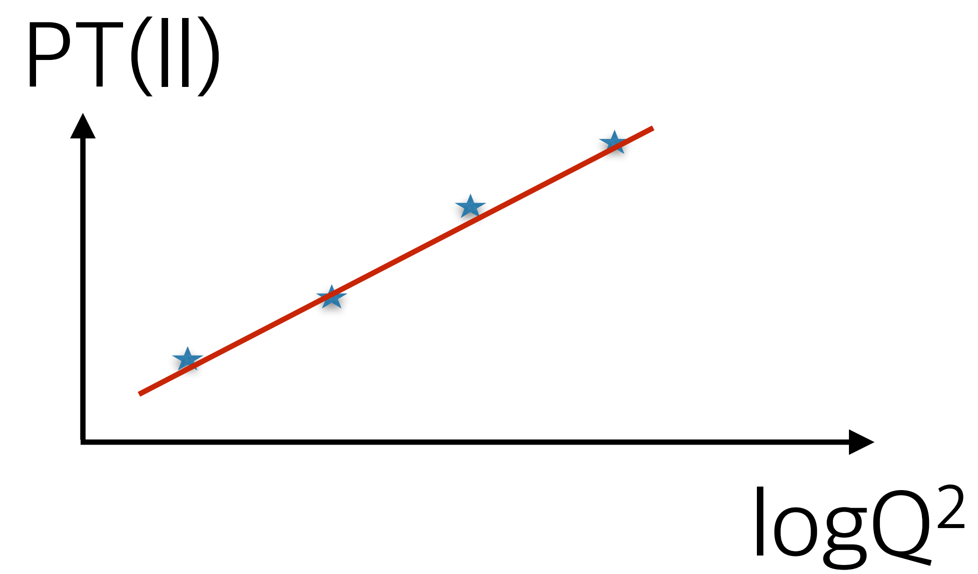
ISR PT(ll) cut study at 13TeV

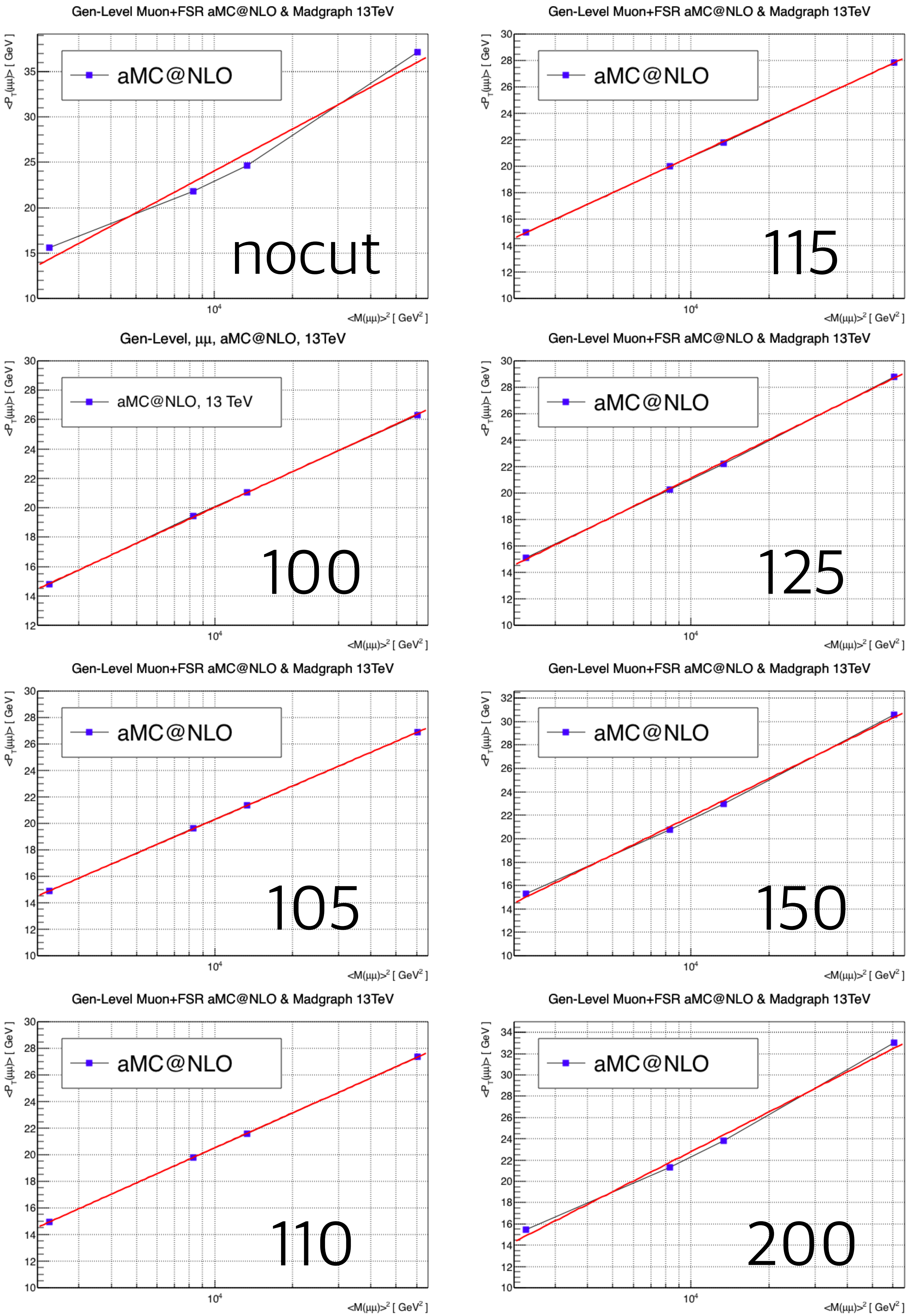
Junho Choi

- Check χ2 of linear fitting y = a+b*logx
- y = PT(ll), x = $Q^2 \sim M^2$

$$\chi^2 \equiv \sum_{i=1}^{n} \frac{(x_i - x_{ti})^2}{\sigma_i^2}$$

- Set all $\sigma_i = 1$





PT(ll) cut	χ2
no cut	5.56924
100	0.0095735
105	0.00154798
110	0.000535367
115	0.0061295
125	0.0459331
150	0.269304
200	1.08025
M/2	4.71732
M	4.5647
2*M	5.05241

PT(ll) < 100 seems not bad