Tools for Drell-Yan at NNLO

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Drell-Yan at LHC

- neutral current Z production has large σ

  - clear collider signature with l^+l^-

- LHC standard candle

  - detector calibration

  - luminosity monitoring   (Dittmar et. al.)

  - measure EW parameters

  - PDF measurements

DY at NNLO?

- LHC will produce large amount of data
  → small statistical error
  → measurements limited by systematics &
    theoretical error

- Can expect percent level physics

- Need to understand distributions, backgrounds, uncertainties

  – measurements require theory input

  – need higher order calculations

Need for Differential Distributions

- DY at NNLO calculated, but inclusive   (Hamberg, Matsuura, van Neerven)

- differential distributions needed

  - PDF extraction Z rapidity dependent

  - simulate distributions in detector-like scenarios

    > cuts on p_T, rapidity, isolation

- 2006: FEWZ   (Melnikov, Petriello)

  - compute W/Z DY cross sections in hadron colliders

    > Fully Exclusive at LO, NLO, & NNLO in QCD

    > Leptonic decays of W & Z contain full spin correlations

FEWZ
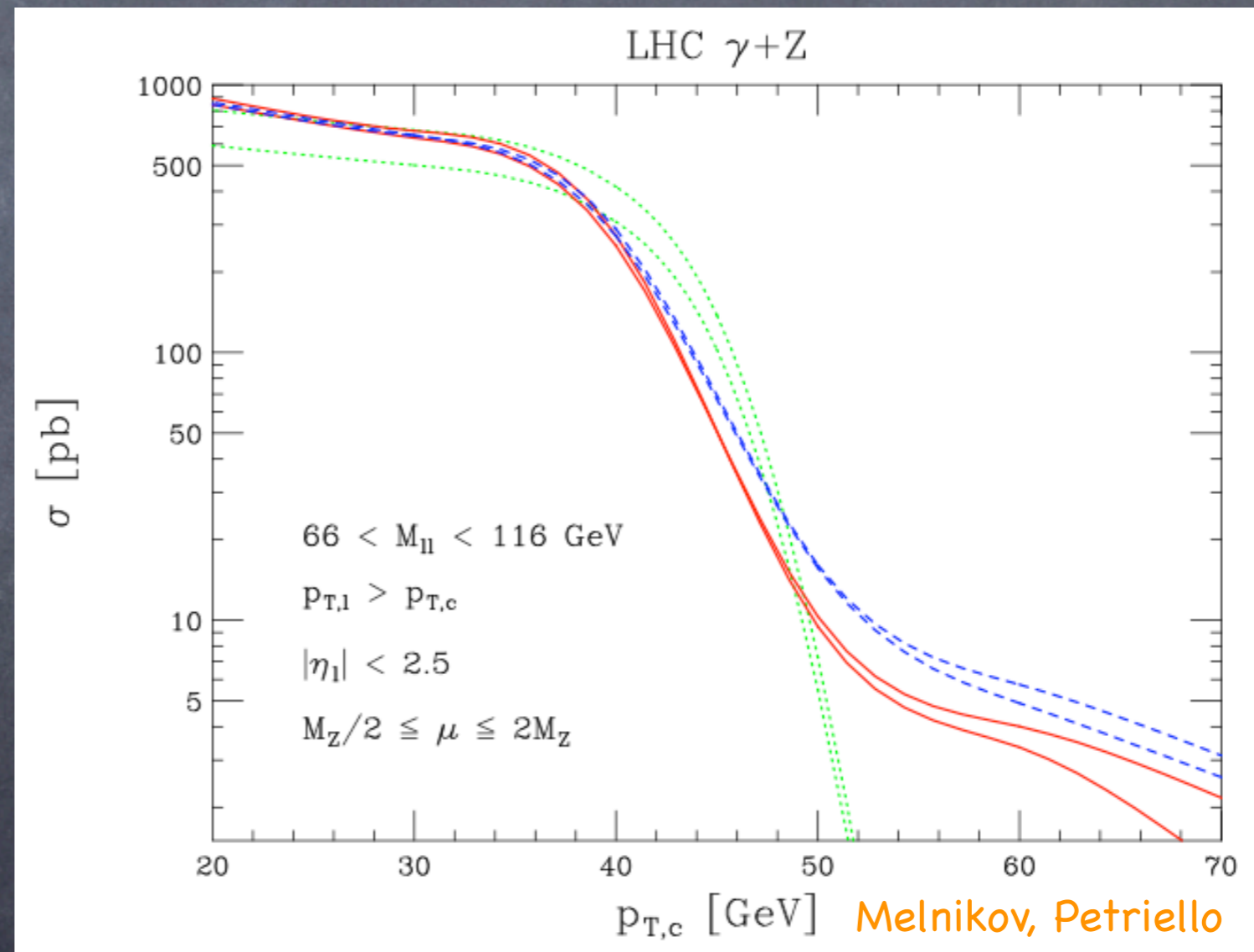
- Fortran based numerical code which allows user to control DY calculation:

  - two executables: FEWZw & FEWZz, for charged and neutral current DY production respectively

  - perturbative order in QCD & CM energy

  - collider type (pp or p$\bar{\text{p}}$)

  - numerical integration parameters (Vegas)

  - PDF set (CTEQ & MRST/MSTW)

  - cuts on leptons

FEWZ

- Example: $\sigma_{Z \to l^+l^-}$(lepton p_T cut)

- clear discrepancy between NLO & NNLO at high p_T cutoff

NNLO: blue

NLO: red

LO: green

LHC $\gamma + Z$

$66 < M_{ll} < 116$ GeV

$p_{T,l} > p_{T,c}$

$|\eta_l| < 2.5$

$M_Z/2 \leq \mu \leq 2M_Z$

σ [pb]

$p_{T,c}$ [GeV]   Melnikov, Petriello

FEWZ

- FEWZ is very useful, but could use improvements

  - can only calculate one number per run

  - lengthy run time for NNLO

  - user must manually hard code cuts

  - some parameters are hard coded (Vegas, EW)

- Changes to some FEWZ parameters require recompiling

- Goal: ease use of FEWZz (neutral current DY) for user

Improved FEWZz

⦿ New features to FEWZz:

- PDF error propagation

- revised input file (set cuts, PDF, jet algorithm, isolation)

- simultaneous generation of predefined histograms

  > histogram parameters set in a histogram input file

- reduced run time for NNLO calculations

Reduced Run Time at NNLO

- Previous version, entire NNLO expression in integrand

  - large expression for Vegas to integrate

- NNLO expression now sensibly split into 'sectors'

  - each sector integrated separately, then combined later

  - some sectors anti-correlate - recombined before integration - improve convergence and lower X^2

  - separate sectors can be evaluated in parallel using multiple processors locally, or by using a batch job system (e.g. Condor)

Input File

- Improved input file → improved user interface

  - set CMS collision energy, μ_F & μ_R scales, collider type, EW parameters (couplings, masses, widths)

  - set Vegas parameters (desired accuracy, evaluation, iterations)

  - set desired cuts: invariant lepton mass
    Z, lepton, & jet - p_T & rapidity (Y, η)
    jet algorithm cone size, ΔR_{algo}
    isolation: lep/lep, lep/jet
    min & max # of jets allowed in event

  - define desired PDF and related parameters
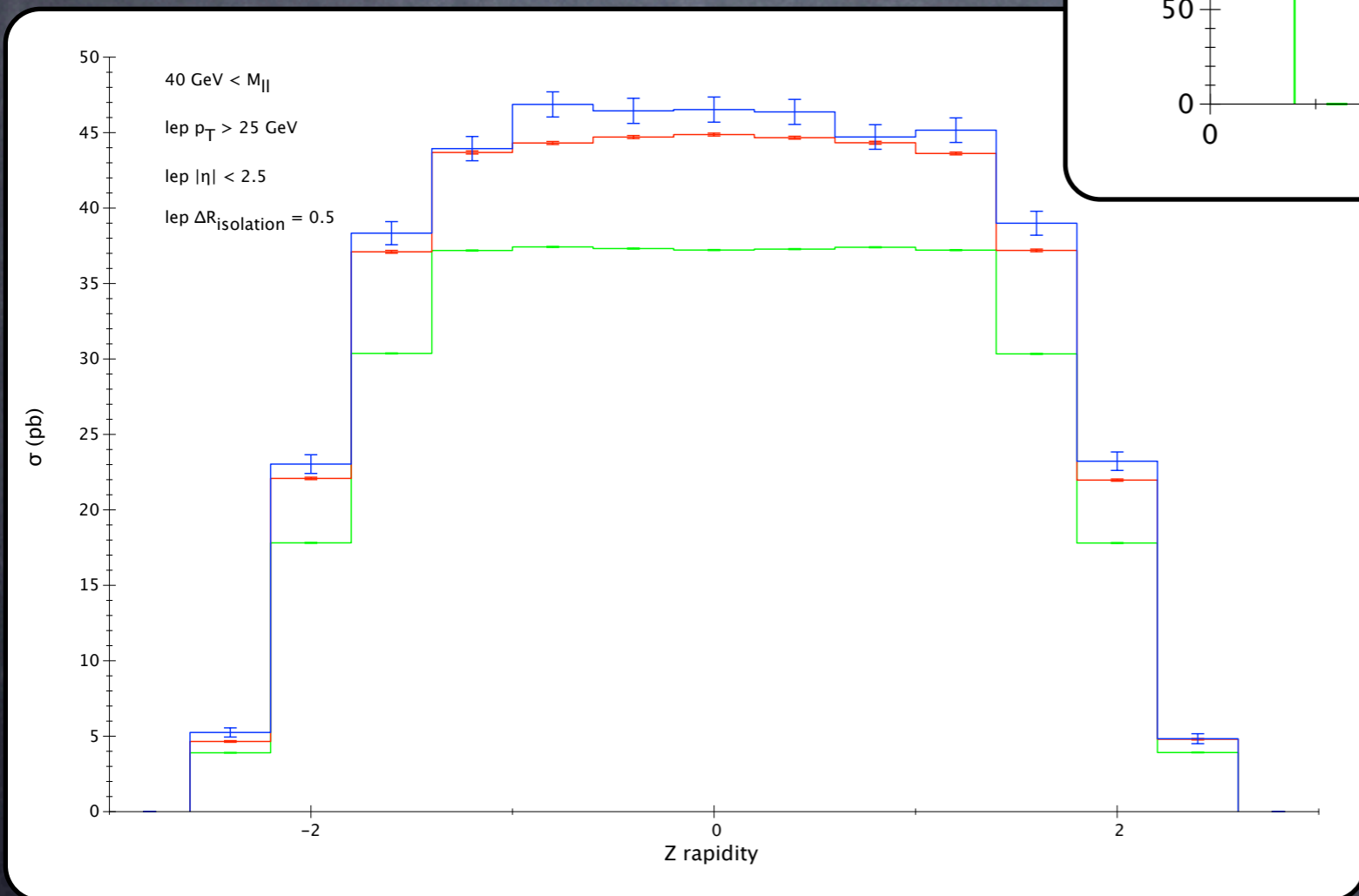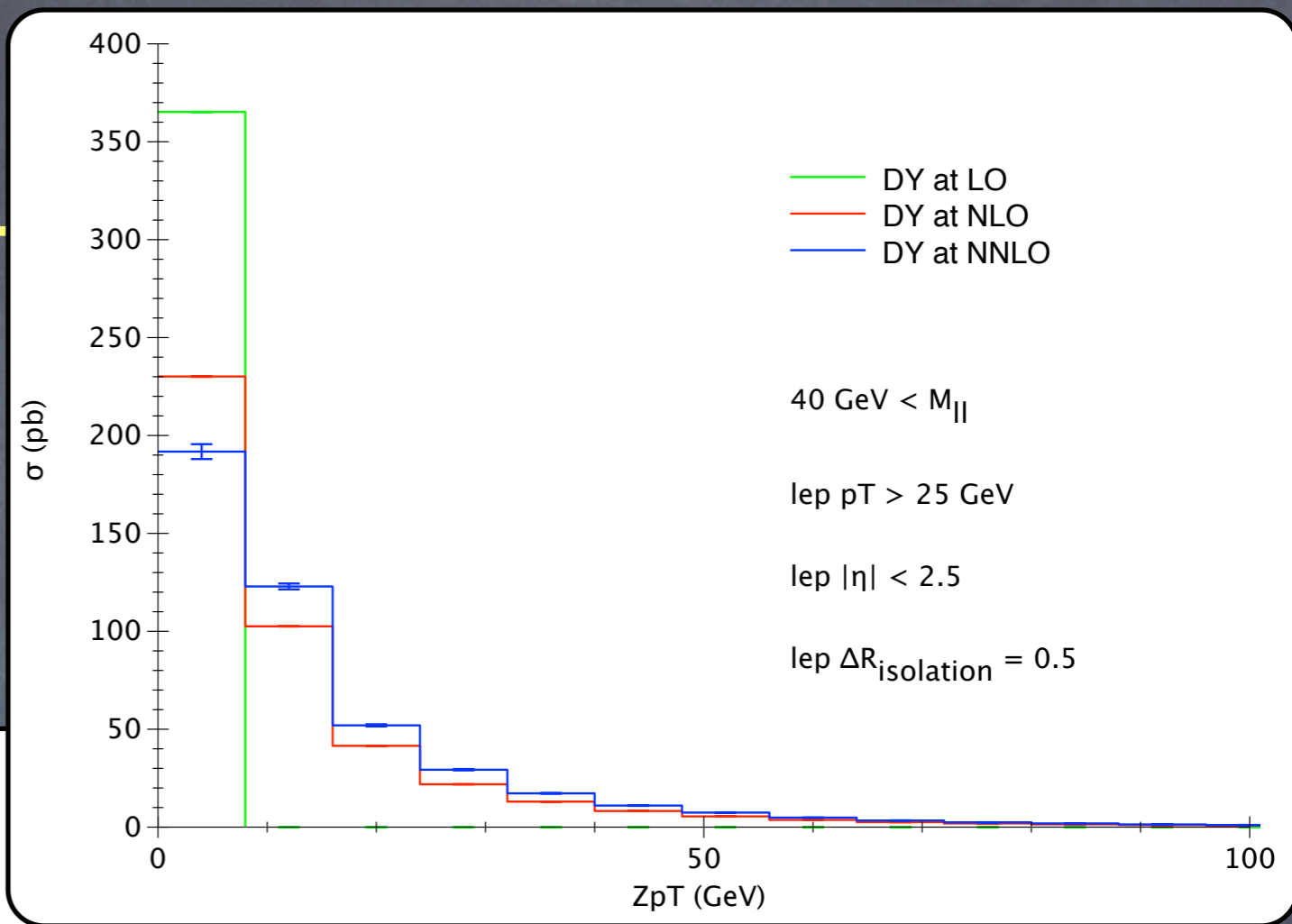
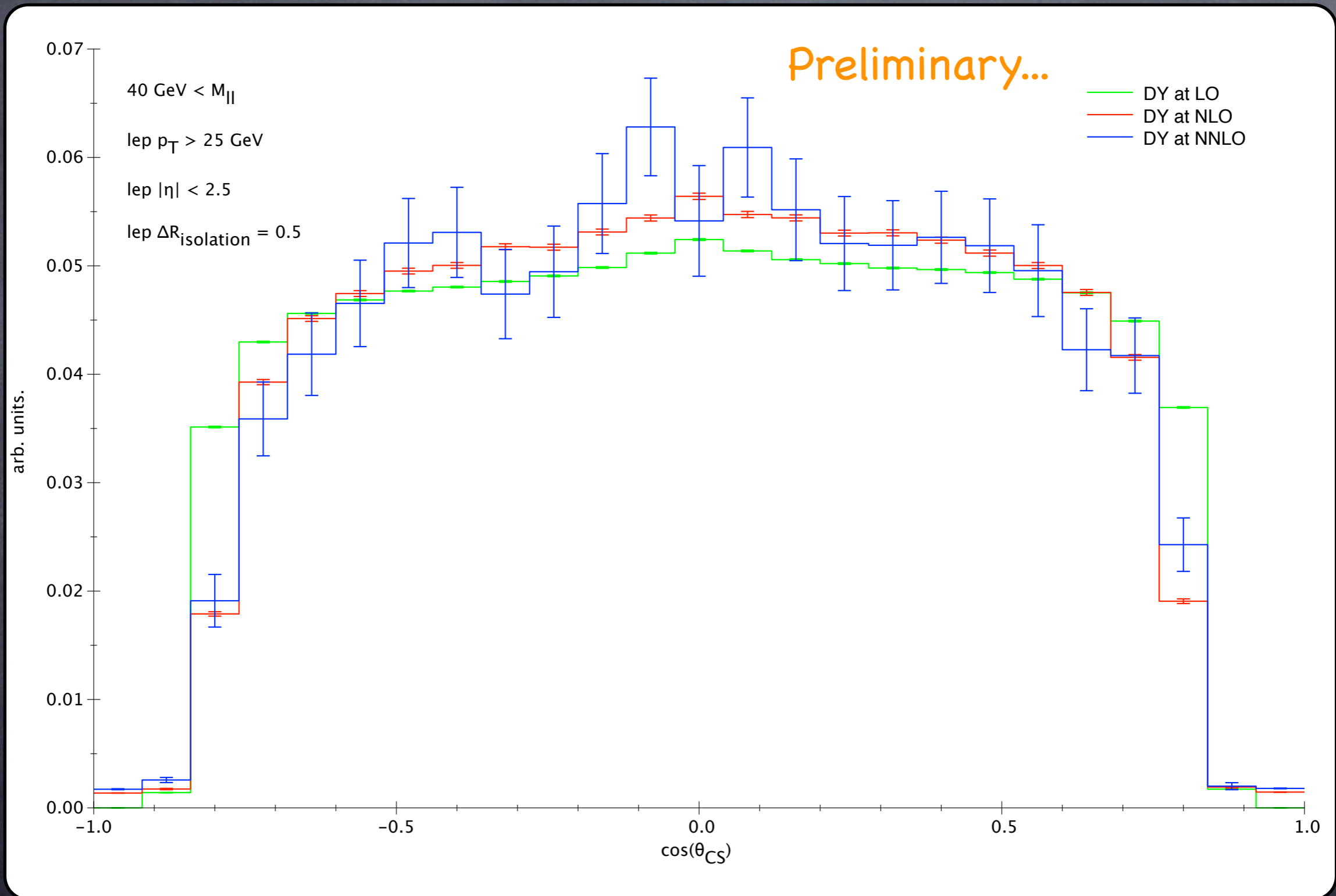- These parameters no longer hard coded

Histogram Input File

- ⦿ Histograms in FEWZz are predefined

  - – lepton pair invariant mass
    Z, lep & jet: pT & rapidity
    ΔR separation: lep/lep, lep/jet, & jet/jet
    Collins-Soper related moments (A_i) and angles

- ⦿ Parameters (for individual histograms) set
  in histogram input file:

  - – lower edge of histogram
    higher edge
    # of bins
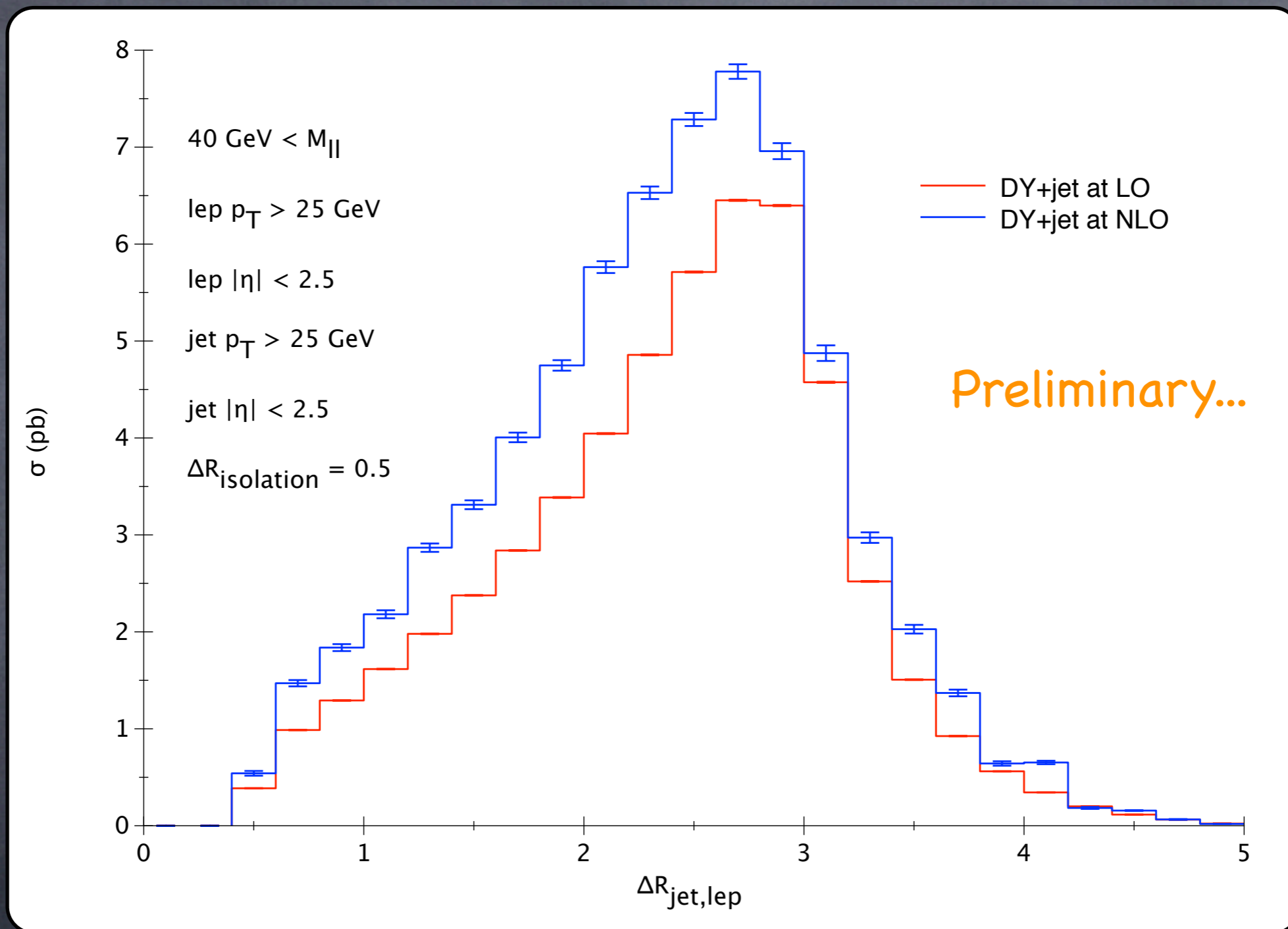   T/F to write histogram to output file

FEWZz at Work

Preliminary...

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Preliminary...

40 GeV < M_{ll}

lep p_T > 25 GeV

lep $|\eta|$ < 2.5

lep $\Delta R_{isolation}$ = 0.5

DY at LO
DY at NLO
DY at NNLO

arb. units.

$\cos(\theta_{CS})$

More Distributions

Conclusions

- Drell-Yan is still a very important process at the LHC
  - need higher order calculations
    - → NNLO QCD corrections to DY
  - need differential distributions at NNLO

- FEWZ is an excellent tool to study higher order effects, through NNLO QCD, on DY at the differential level

- Updated version of FEWZz to be released soon, with many improvements to usability & functionality
  - EW corrections to come in the near future

- Encourage you to download and try FEWZz, especially when new version released (http://www.hep.wisc.edu/~frankjp/FEWZ.html)