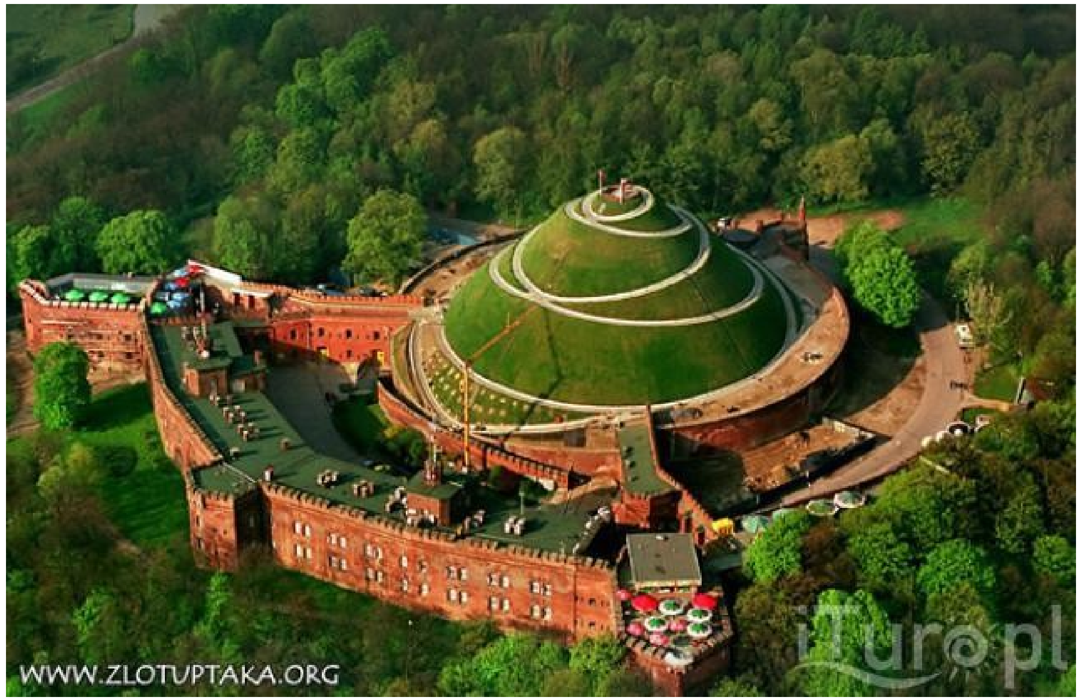
Theoretical Tools for (Hard) Diffraction at LHC



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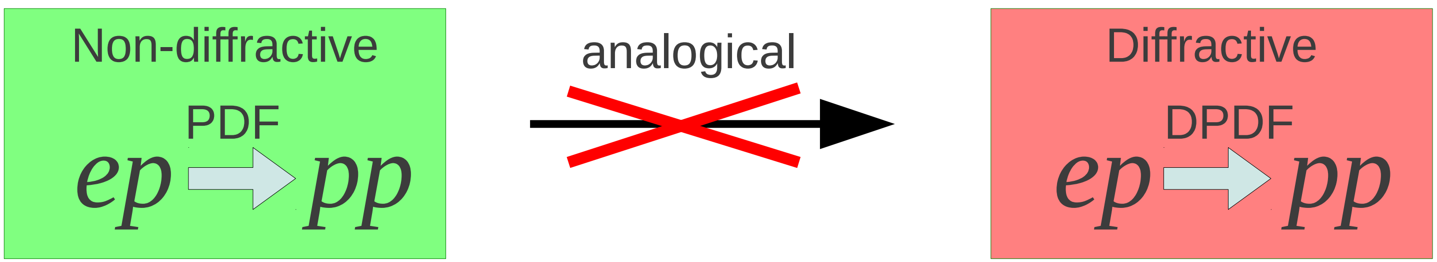
Krakow 2011

Factorisation in Diffraction

- The simple idea of using diffractive PDF from ep (as in non-diffractive case) to predict pp diffractive cross-section does not work (at Tevatron by factor up to 10)



- To calculate the suppression factors for different beam energies and different final state kinematics is a great theoretical challenge
- On the other hand, theoretical predictions based on factorization theorem can be compared with measurements and then used to estimate suppression factors.

Suppression factor for certain process:

$$S^2 = \frac{\sigma(data)}{\sigma(theory)}$$

Based on ep DPDFs

Tests of Diffractive Factorisation

- Diffractive factorisation successfully tested for dijet production and D* production in DIS by H1 and ZEUS
- HERA DPDF fails to predict hadron-hadron diffractive cross sections!

Suppression factor for certain process:

$$S^2 = \frac{\sigma(data)}{\sigma(theory)}$$

Based on ep DPDFs

Tevatron
$S^2 \approx 0.1$

HERA
Incl., dijet in DIS
$S^2 \approx 1$

?

HERA
Dijet in PHO
$S^2 \approx (0.5, 1.0)$

β -dep. factor

LHC
$S^2 \approx 0.03$

HERA
D* in DIS
$S^2 \approx 1$

HERA
D* in PHO
$S^2 \approx (0.7, 1.3)$

?

low statistics
within errors
fact. holds

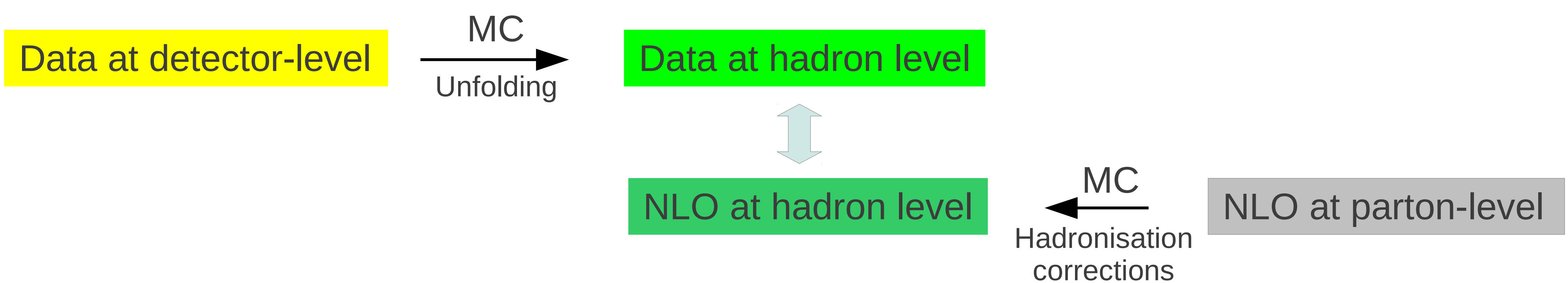
MC and NLO Advantages/Disadvantages (pp at LHC)

MC

- Event-to-event generation
- ME in LO
- Parton-showers
- Hadronisation implemented
- Used for detector simulation+simulation of hadronisation effects

NLO

- Analytical calculations
- ME in NLO
- Complicated (non-existing) matching of ME with corresponding NLO parton-showers
- Only at parton level
- Used for calculation of cross-sections at parton-level

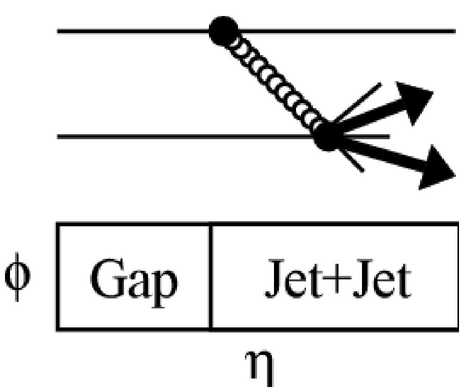


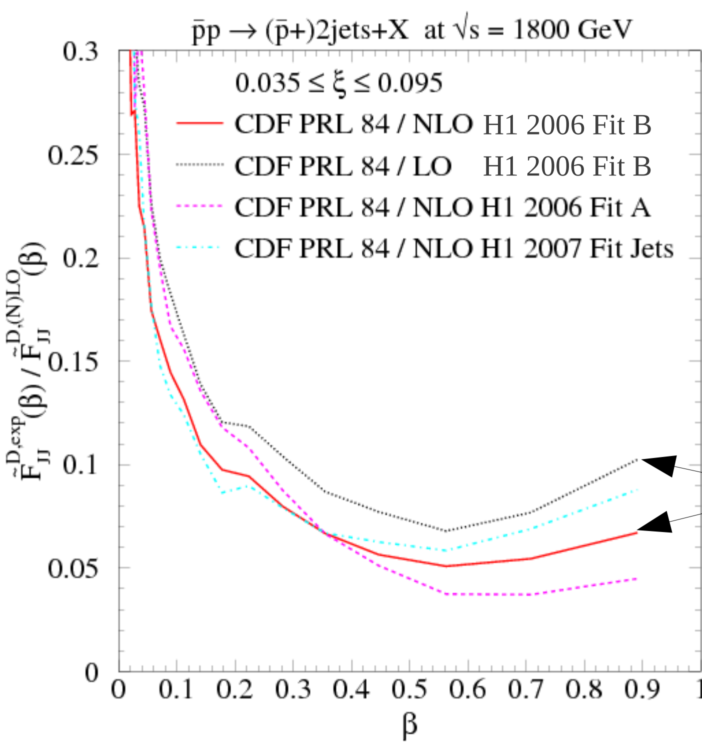
MC@NLO only special processes (H, W, t,... production), not for inclusive QCD processes

Single-Diffractive Dijet Analysis at Tevatron

CDF Collaboration, Phys. Rev. Lett. **84**, 5043 (2000)

- The first NLO calculations for this process performed by M. Klasen (arXiv:0908.2531)
- However the data cross-section was obtained with symmetric E_T jet cuts of 7 GeV
- Asymmetric cuts used only in calculations (7 GeV, 6.6 GeV) → comparison with data problematic





β-dependent suppression factor!

NLO/LO ~ 2

My Goal

- The implementation of NLO calculations for single-diffractive dijet production in pp
- Studies of cuts for jets for NLO calculations
- Comparison of RAPGAP MC and POMWIG for single-diffractive dijet production in pp

NLO Single-Diffractive pp Calculations for ATLAS

- Analysis of low-luminosity ATLAS data in progress. Single-diffractive events selected by rapidity gap method, cuts for first and second jets are different to have proper NLO predictions
- FRIXIONE and NLOJET++ modified for single diffraction by slicing in ξ ($= x_{IP}$) variable and compared each other and with RAPGAP MC without parton-showers

$$\xi = 1 - \frac{E_p'}{E_p}$$

$$z_{IP} = \frac{\sum_{jets} (E + P_z)_i}{2 \xi E_{beam}}$$

Modification of pp NLO for diffraction

Single-diffraction in resolved pomeron model effectively corresponds to collision of:

proton	$E_p = E^{beam}$	$f_p(x, \mu^2)$
+ pomeron	$E_{IP} = \xi E^{beam}$	$f_{IP}(z, \mu^2)$

$$E_{CMS} = \sqrt{\xi} E^0_{CMS} \qquad \eta_{CMS} = -\frac{1}{2} \log \frac{1}{\xi}$$

Slicing in ξ variable (consistent with chosen ξ binning), x-section of A in bin i given by factorization formula

$$\sigma_{A_i} = \sum_j f_{IP/p}^{|t|<|t_0|}(\xi_j) \sigma_{A_i}^{\xi_j} \Delta \xi_j$$

Pomeron flux

NLO is run for each slice j separately

Two NLO QCD programs used:

- NLOJET++ (in C++, Z. Nagy)
- FRIXIONE (in Fortran, S. Frixione, G. Ridolfi)
- **Analysis routines in C++, Fortran respectively**

NLOJET++ 2D $E_T^{jet1,2}$ X-Section

- Total x-section with symmetric cuts negative!

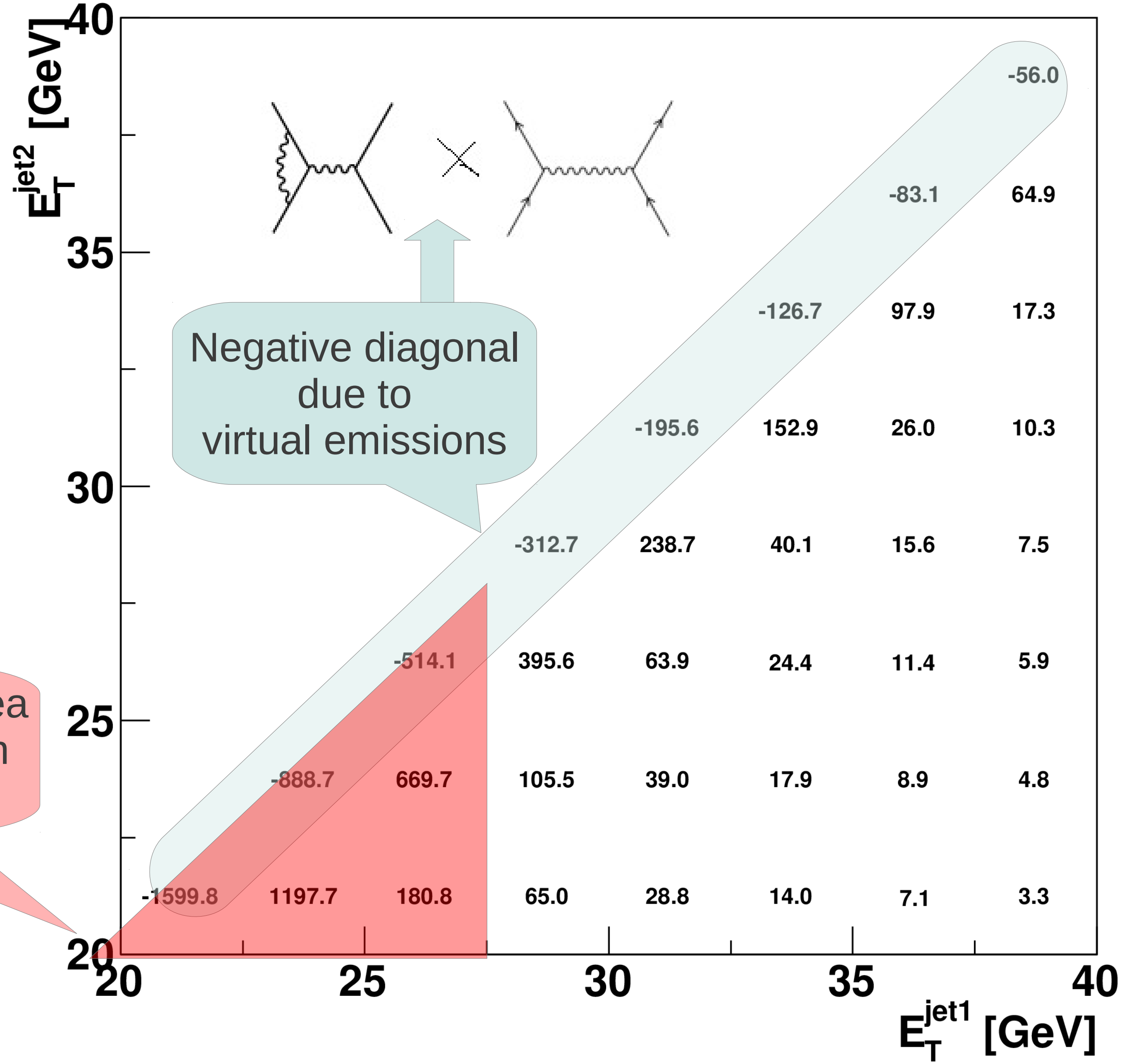
Single-diffraction
Leading proton goes to positive z direction

$$E_T^{jet1,2} > 20\,\mathrm{GeV}$$
$$-5 < \eta^{jet1,2} < 3$$
$$\xi < 0.03$$
$$|t| < 1\,\mathrm{GeV}^2$$

Anti-kT jet alg – R=0.6

Cuts proposed by Birmingham ATLAS group

Cutting this dangerous area makes the total x-section positive



NLOJET++ - Safe $E_T^{jets,cut}$ Difference?

- E_T^{jet1} must have typical exponential shape

Anti-kT R=0.6
$E_T^{jet1,cut}=26\,\text{GeV}$

Anti-kT R=0.4
$E_T^{jet1,cut}=28\,\text{GeV}$

- Jet algorithm absorbs infrared divergences
  Small R → Divergences remain unabsorbed

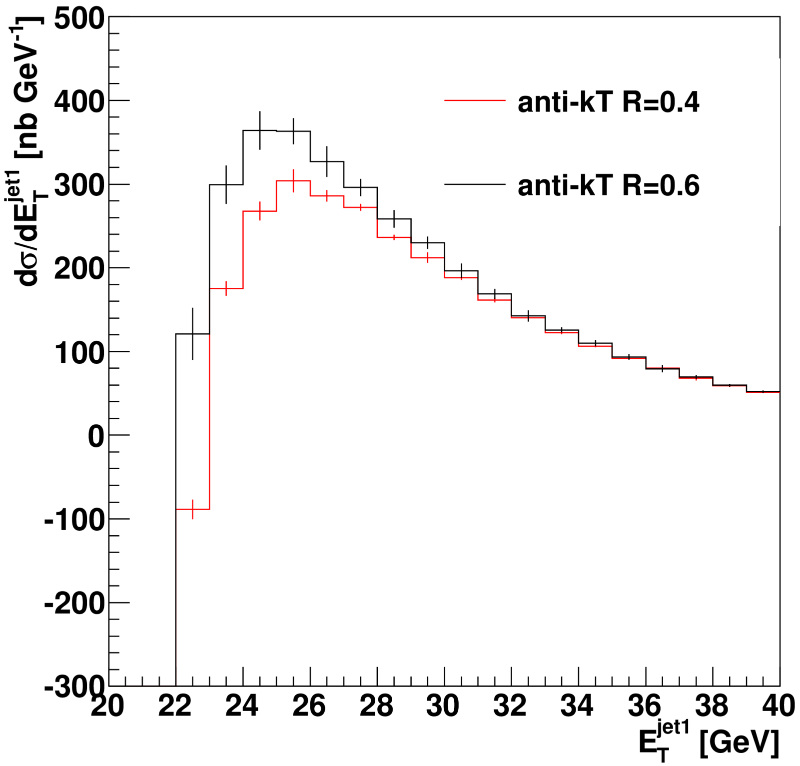
Cuts as before:

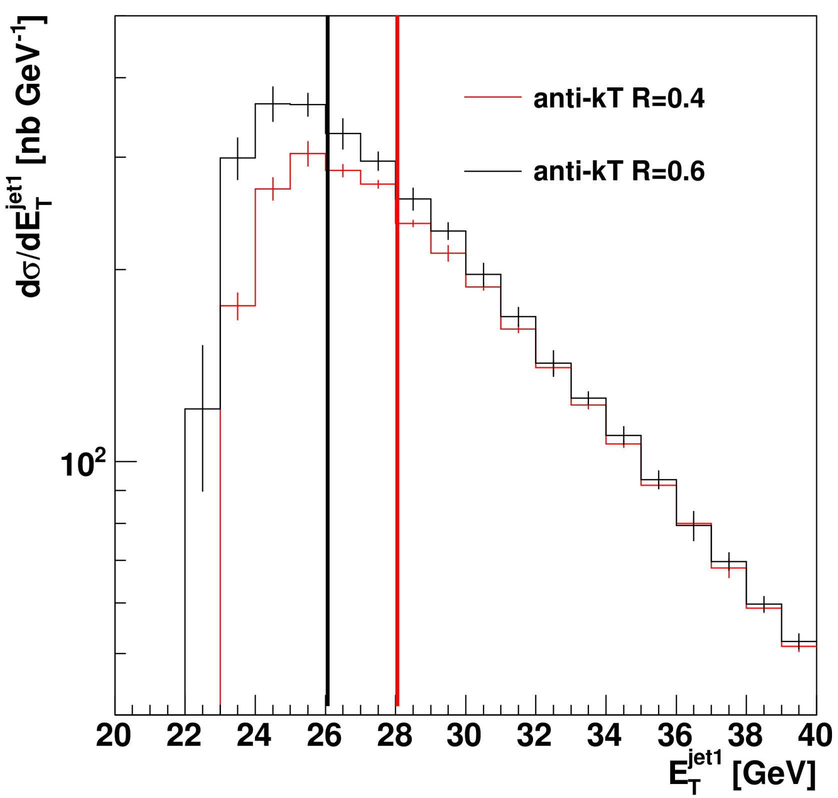
$E_T^{jet1,2}>20\,\text{GeV}$

$-5<\eta^{jet1,2}<3$

$\xi<0.03$

$|t|<1\,\text{GeV}^2$

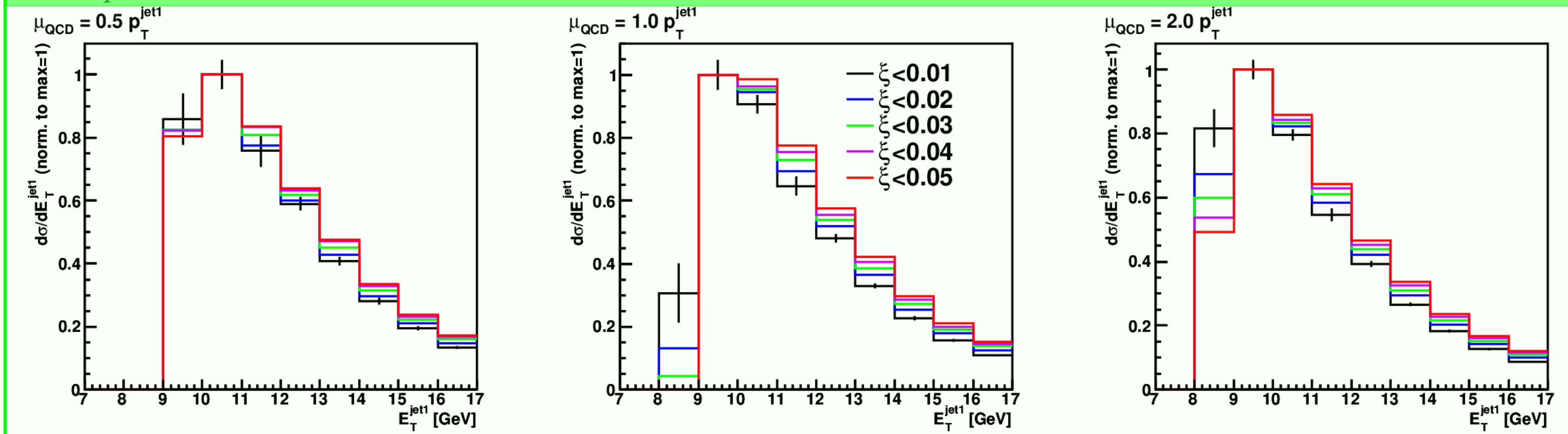




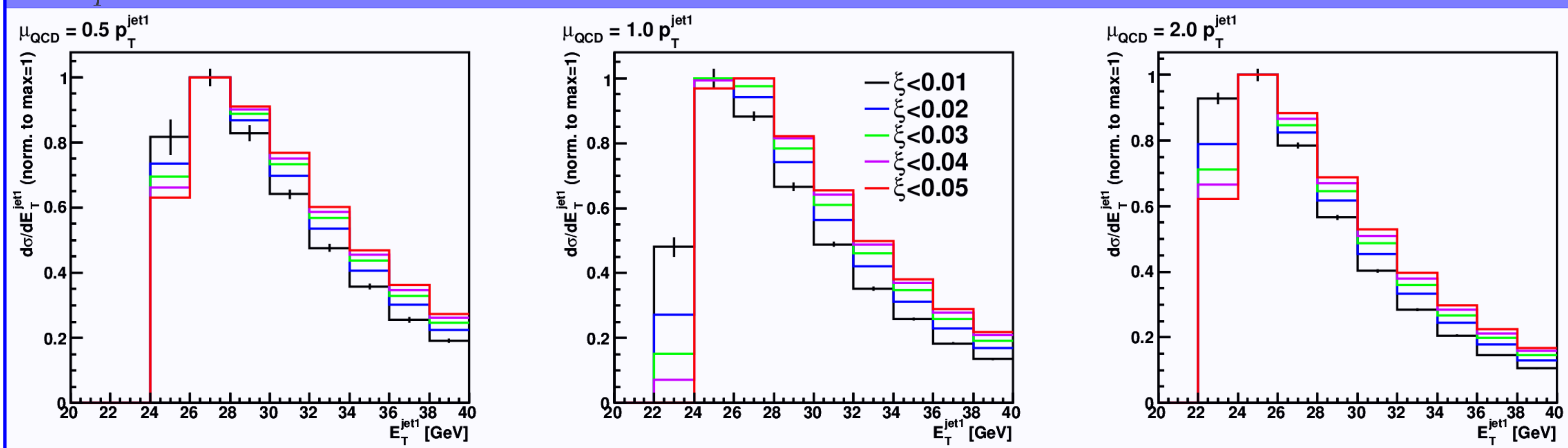
NLOJET++ ξ and Scale Dependence of $E_T^{\mathrm{jets,cut}}$

- The larger the hard QCD scale → Smaller coupling → better-converging perturbative series
- Larger ξ requires a little bit larger E_T^{jets} cut difference

$E_T^{\mathrm{jet1,2}} > 7\,\mathrm{GeV}$ anti-kT R=0.4, other cuts as before



$E_T^{\mathrm{jet1,2}} > 20\,\mathrm{GeV}$ anti-kT R=0.4, other cuts as before



NLOJET++

- Even with “Safe” Jet Cuts Some Distributions Unphysical (similar in FRIXIONE)

Cuts:

$E_T^{jet1} > 30\,\mathrm{GeV}$

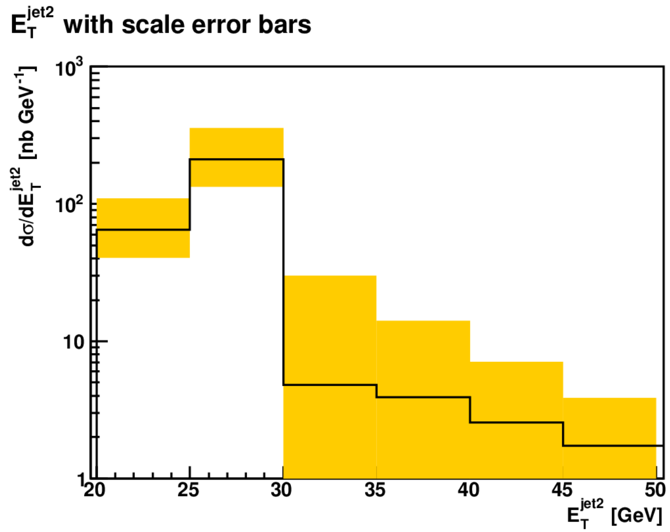
$E_T^{jet2} > 20\,\mathrm{GeV}$

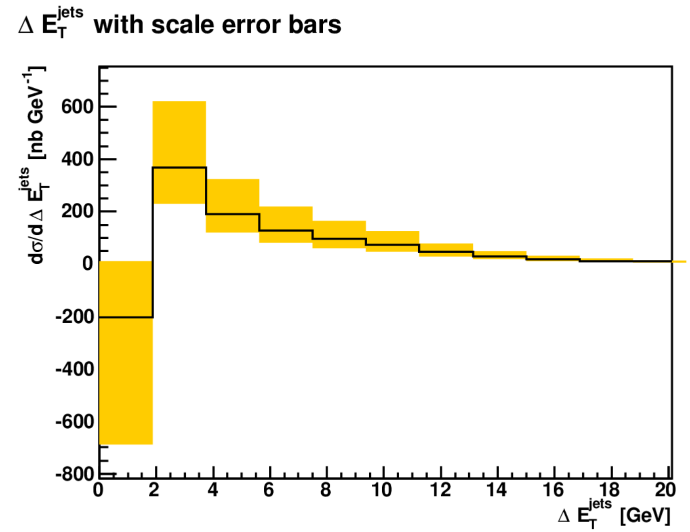
$-5 < \eta^{jet1,2} < 3$

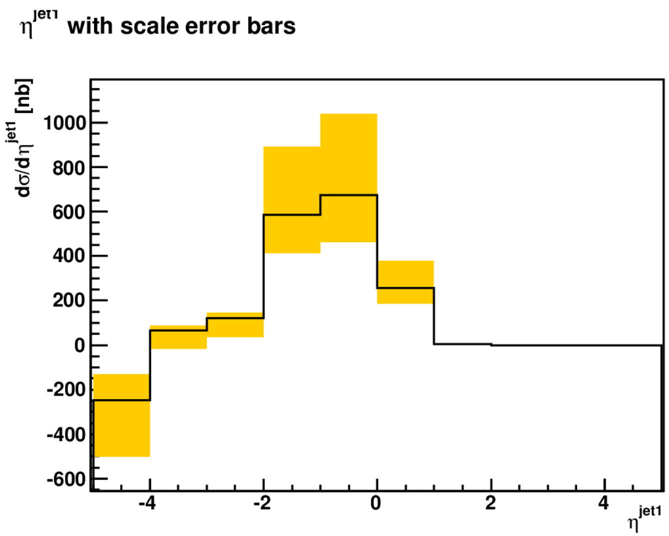
$\xi < 0.03$

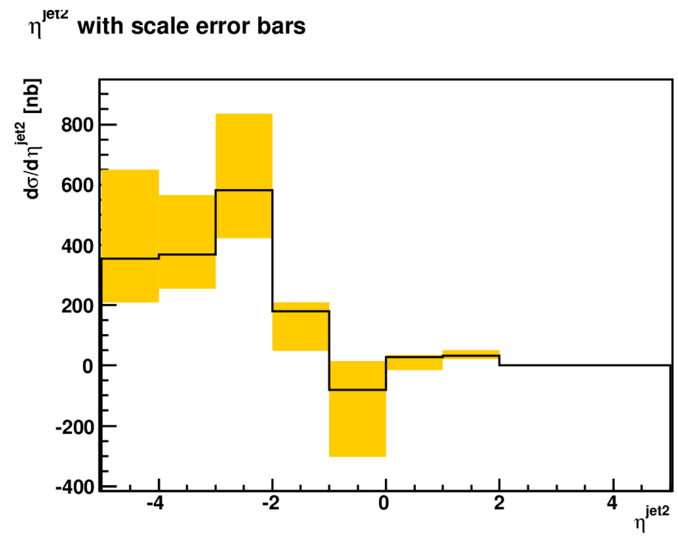
$|t| < 1\,\mathrm{GeV}^2$

anti-kT R=0.6



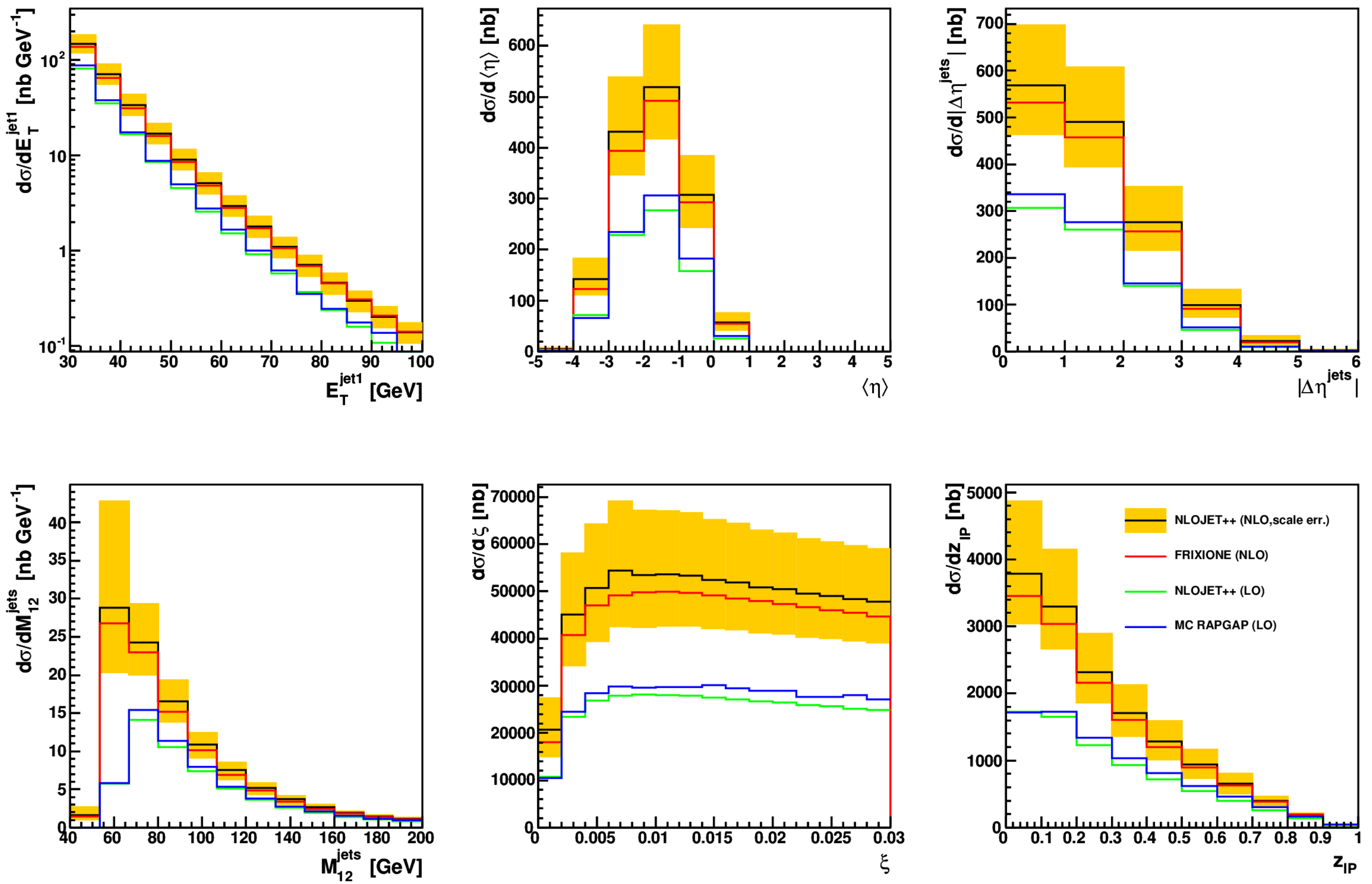






NLOJET++ vs FRIXIONE vs RAPGAP

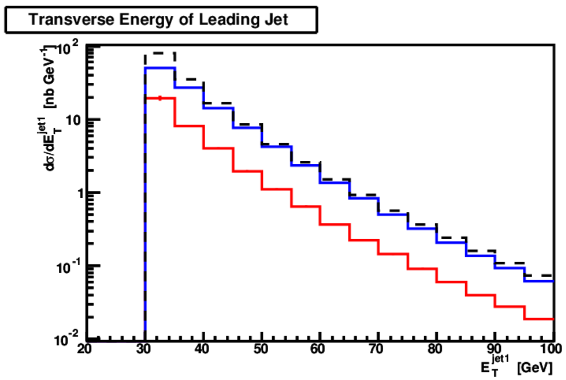
- RAPGAP at parton-level without showers
- Normalization difference 7 % (NLOJET++ vs FRIXIONE)

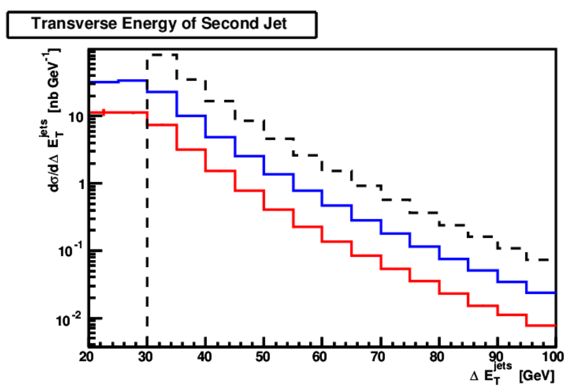


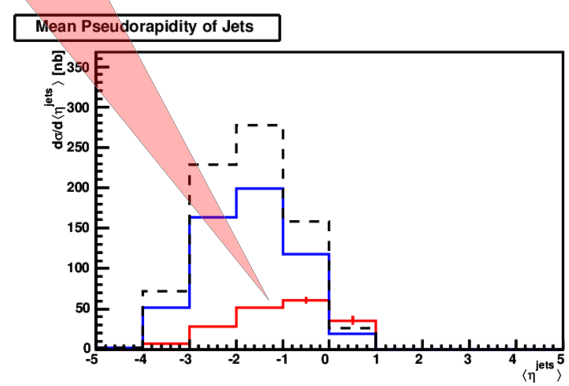
Comparison of MCs

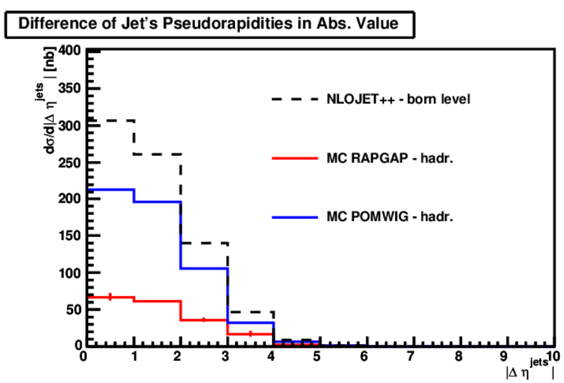
- POMWIG vs RAPGAP at hadron-level with parton-showers
- NLOJET++ in LO at parton-level

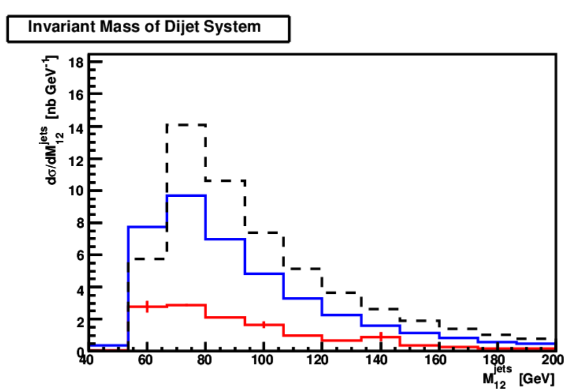
RAPGAP shifted to positive rapidities

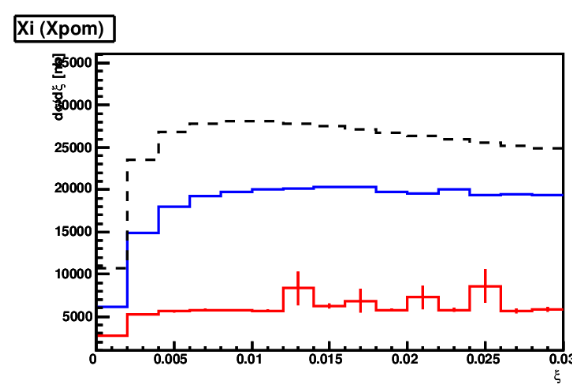


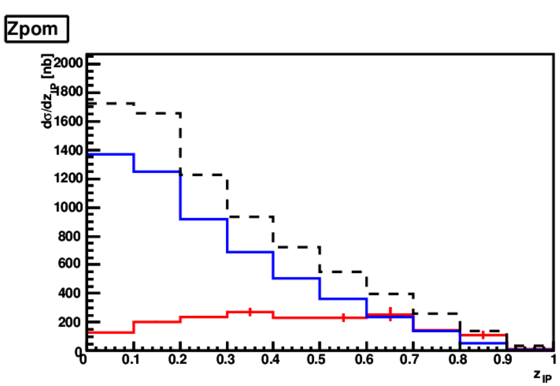






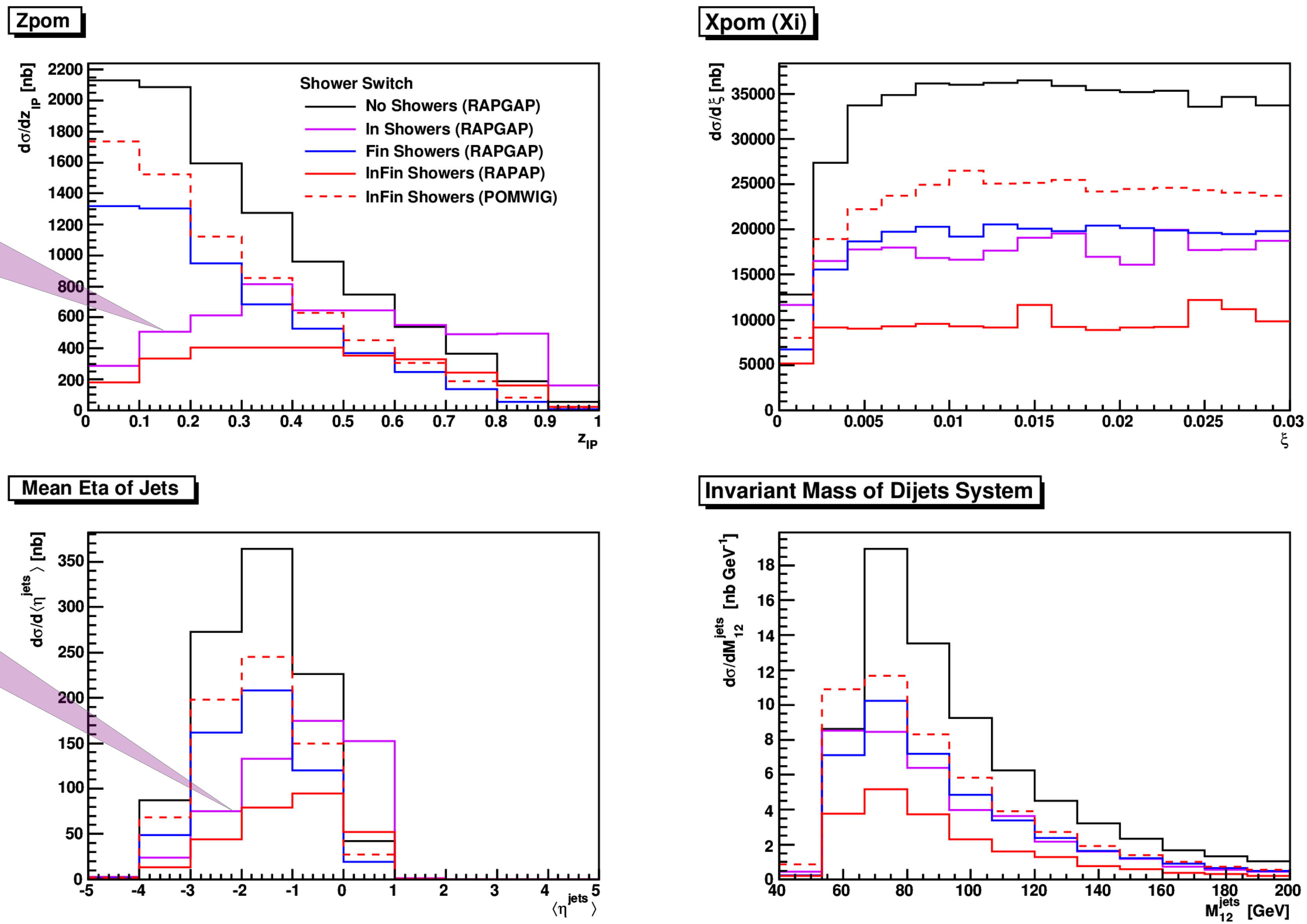






Why is RAPGAP so Different?

- Because of initial-state parton showers

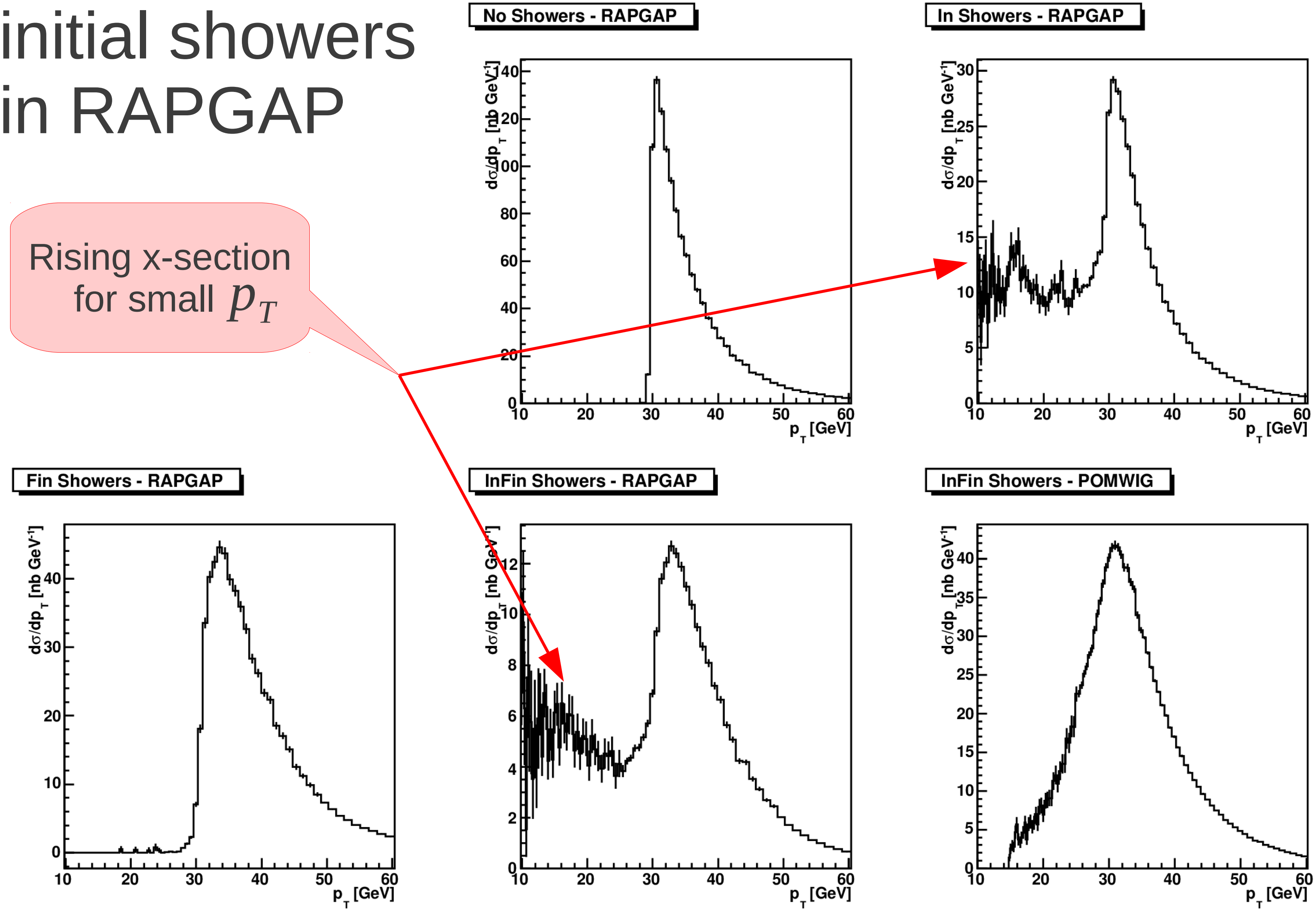


RAPGAP In-showers lower

RAPGAP In-showers shifted

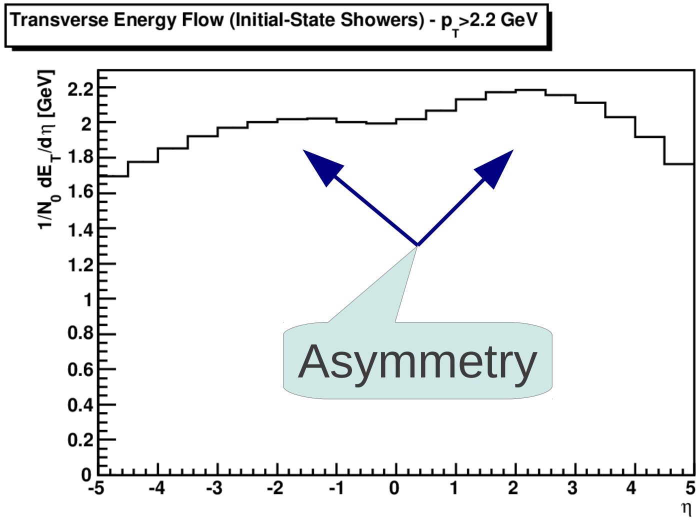
p_T of The Hard Subprocess

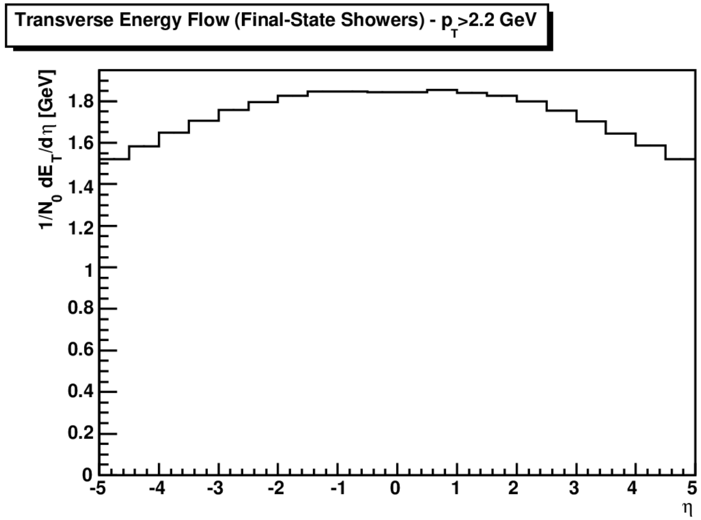
- Strange behavior for distribution containing initial showers in RAPGAP

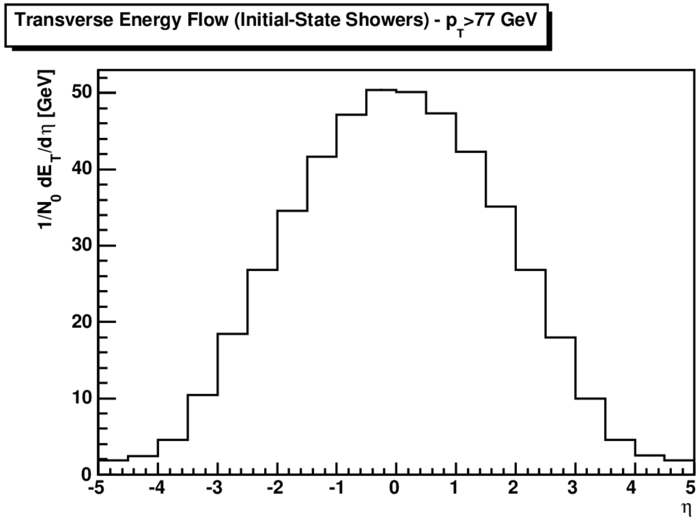


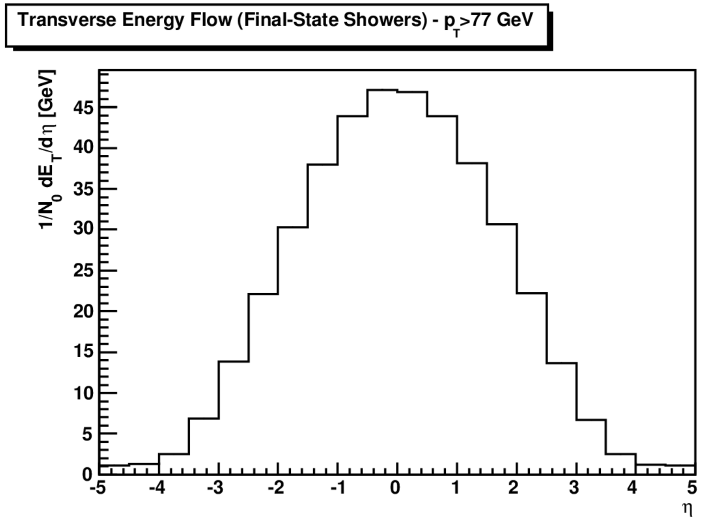
Energy Flow for Non-Diffractive pp RAPGAP

- Unphysical asymmetry in eta observed
- Without cuts on jets









Conclusions

- NLOJET++ and FRIXIONE NLO QCD programs implemented and studied for single-diffractive pp interaction 3.5+3.5 TeV
- Comparison of RAPGAP and POMWIG done
- Bug in RAPGAP? (Hannes Jung contacted)