STANDARD MODEL BACKGROUNDS TO SUSY SEARCHES

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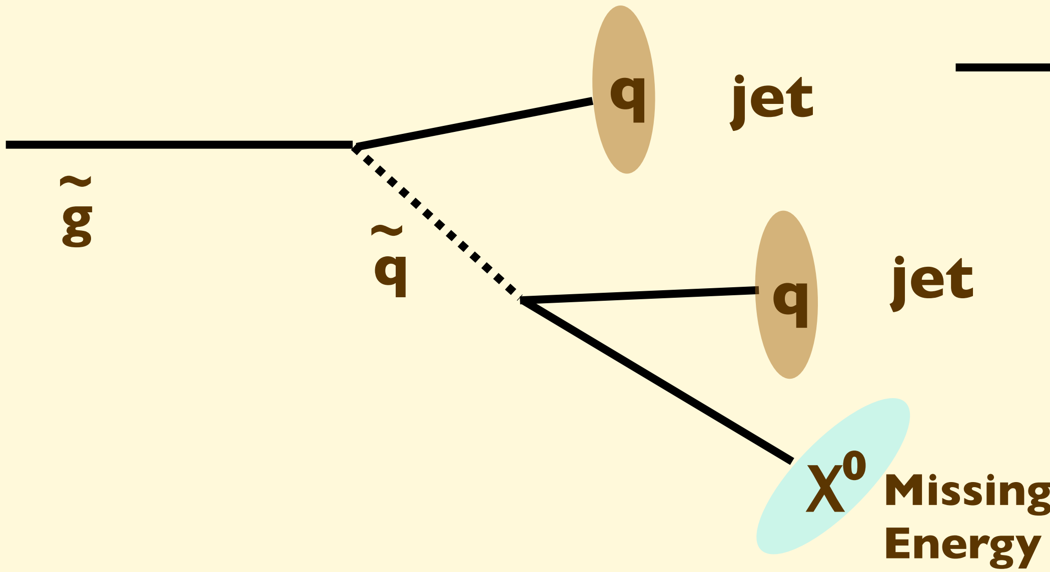
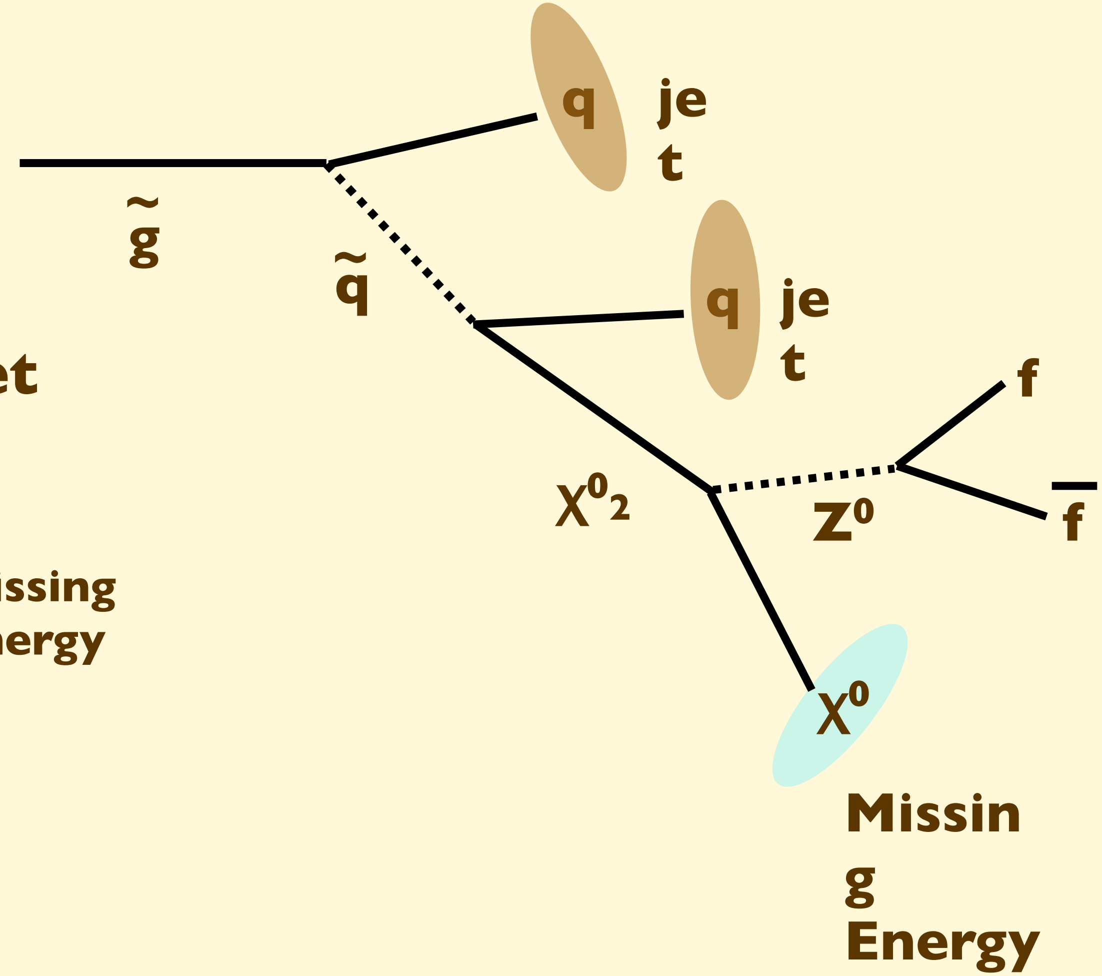
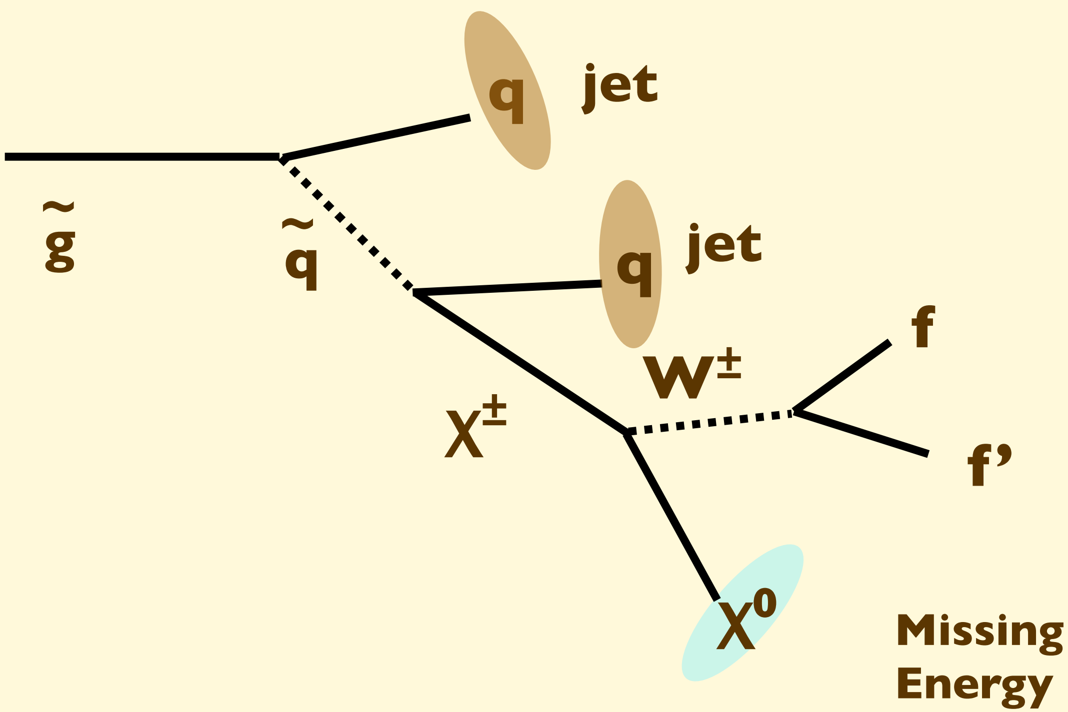
See also talks in SUSY // session, by D'Onofrio & Shamim (Tevatron) and Tytgat, Chiorboli, Yamamoto, De Santo (LHC)

Gluino final states



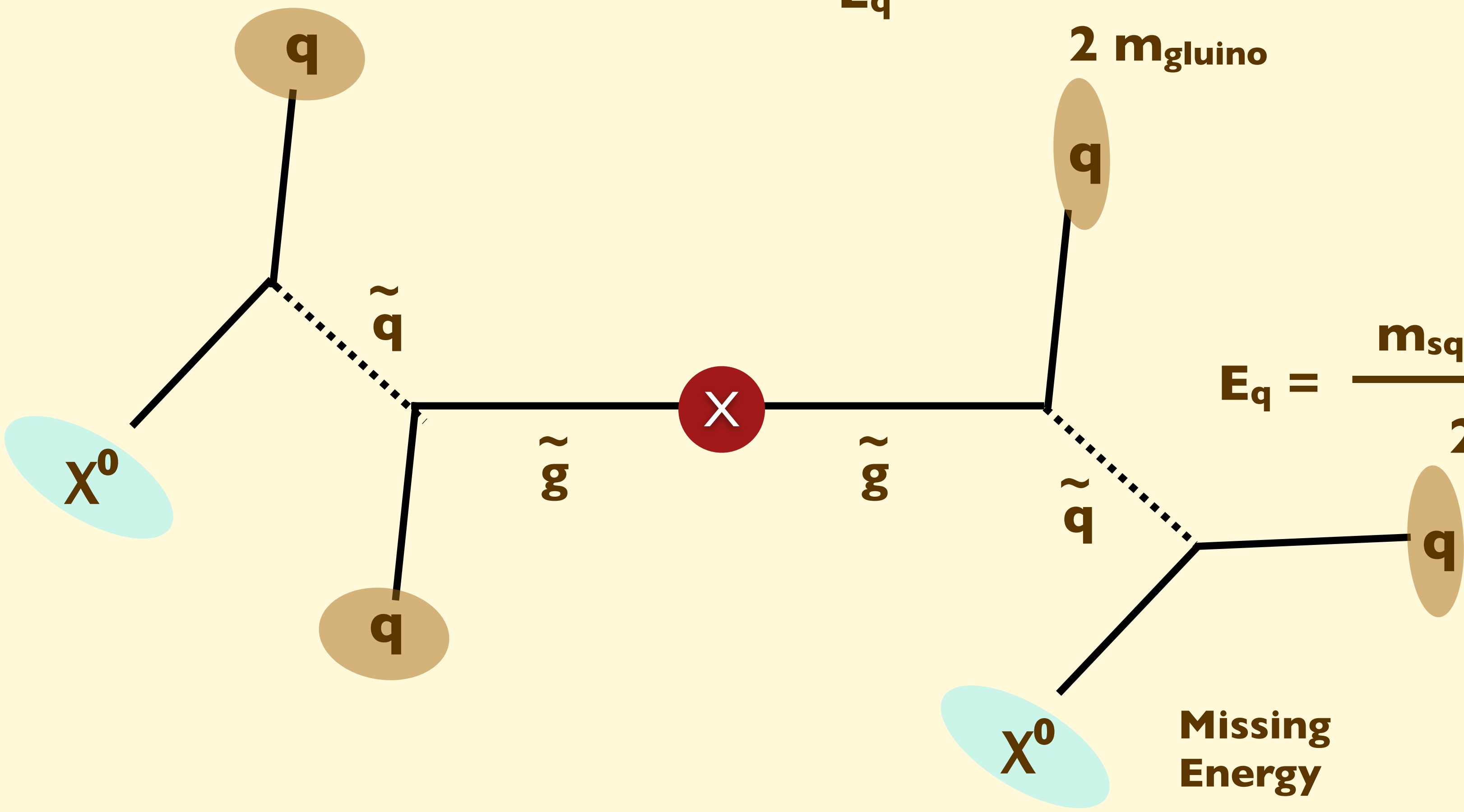




$\tilde{g} \longrightarrow \geq 2$ jet + MET + $\geq 0\ \ell^\pm$

Enhancements of leptons, b quarks, or presence of h^0, are possible in some regions of parameter space

$\tilde{g}\,\tilde{g} \rightarrow$ 4 jet + MET



$$E_q = \frac{m_{gluino}^2 - m_{squark}^2}{2\, m_{gluino}}$$

$$E_q = \frac{m_{squark}^2 - m_{X}^2}{2\, m_{squark}}$$

Typically widely-spaced jets, no significant hierarchies in transverse energies and missing E_T

Typical analysis cuts (ATLAS EXAMPLE):

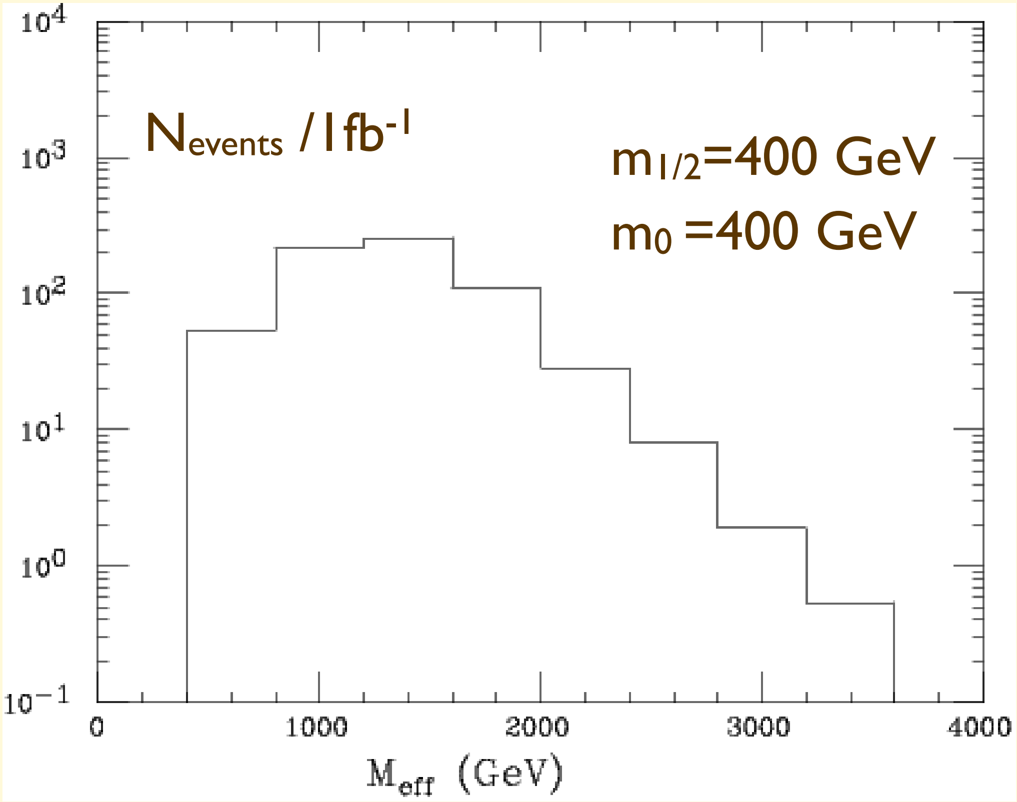
$\geq$4jets, E_T>50 GeV   leading jet E_T>100 GeV

no lepton with E_T>20 GeV

MissET> max(100, 0.2 M_{eff})

M_{eff} = MET + $\sum_{i=1,..,4} E_T^i$

Transverse sphericity > 0.2



SM Backgrounds

Missing energy ⇒ νs ⇒ W/Z production

"Irreducible": individual events cannot be distinguished from the signal

Z+4jets, Z→ νν

"Reducible": individual events feature properties which distinguish them from the signal, but these can only be exploited with limited efficiency

W+3jets, W→ τν, τ→hadrons (jet)

τ jet has low multiplicity, and originates from a displaced vertex, because of τs lifetime

W+4jets, W→ e/μ ν, lepton undetected

e/μ can be detected, but cannot be vetoed with 100% efficiency, else the signal would be killed as well (e /μ may come from π conversions or decays)

tt → W+jets, with W→ leptons as above

In addition to the above, top decays have b's, but these cannot be detected and vetoed with 100% efficiency

“Instrumental”: individual events resemble the signal because of instrumental “effects” (namely detector deficiencies, accidents, or non-collision bgs)

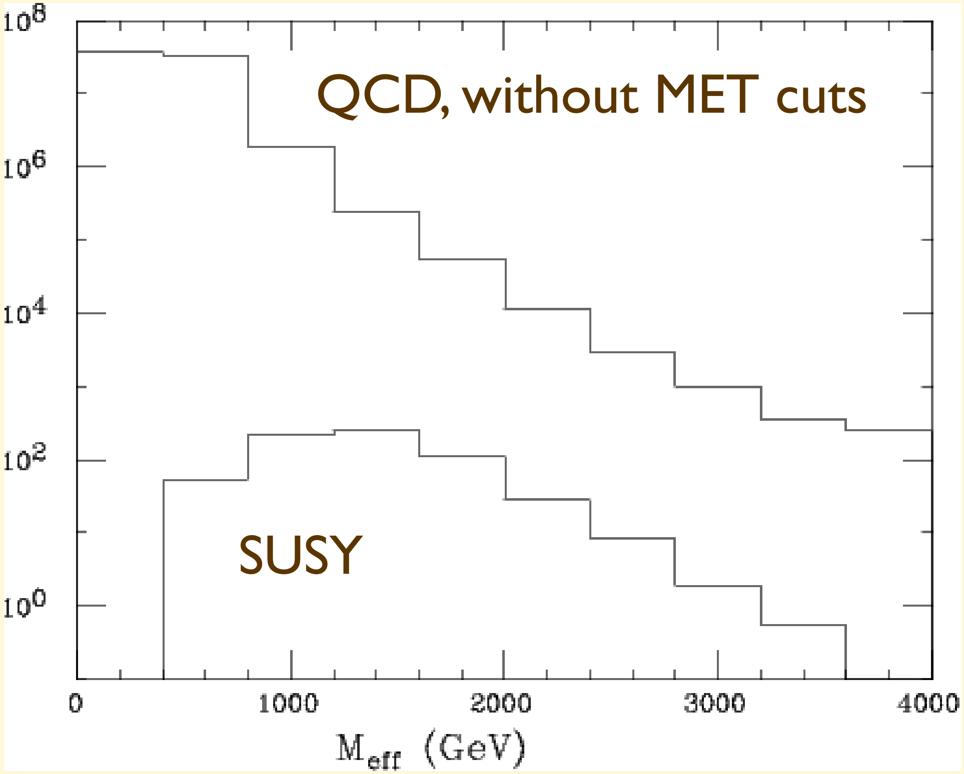
E.g.: Multijets

The missing ET may originate from several sources:

Mismeasurement of the energy of individual jets

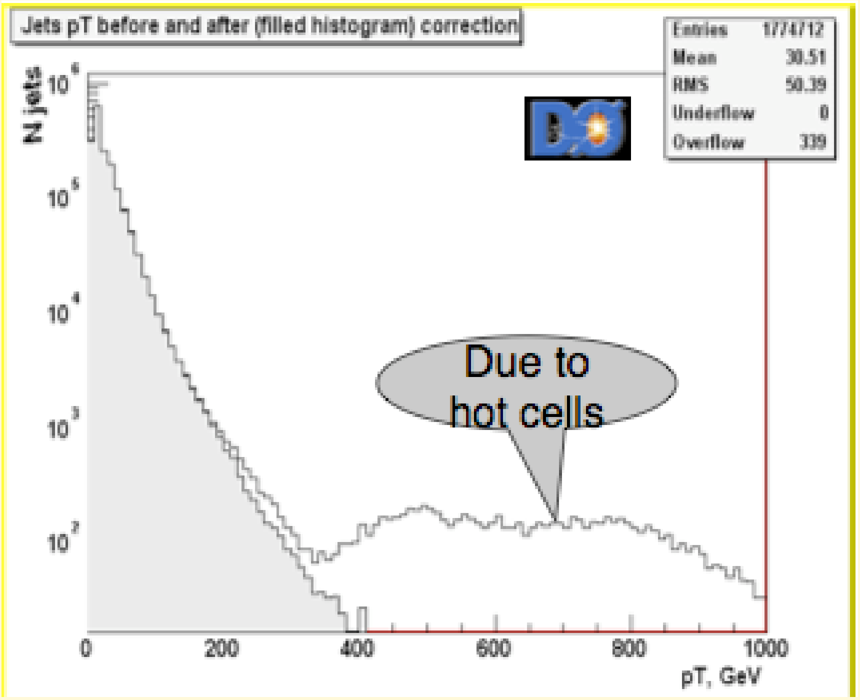
Incomplete coverage in rapidity (forward jets undetected)

Accidental extra deposits of energy (cosmic rays on time, beam backgrounds, , electronic noise, etc.etc.etc.)



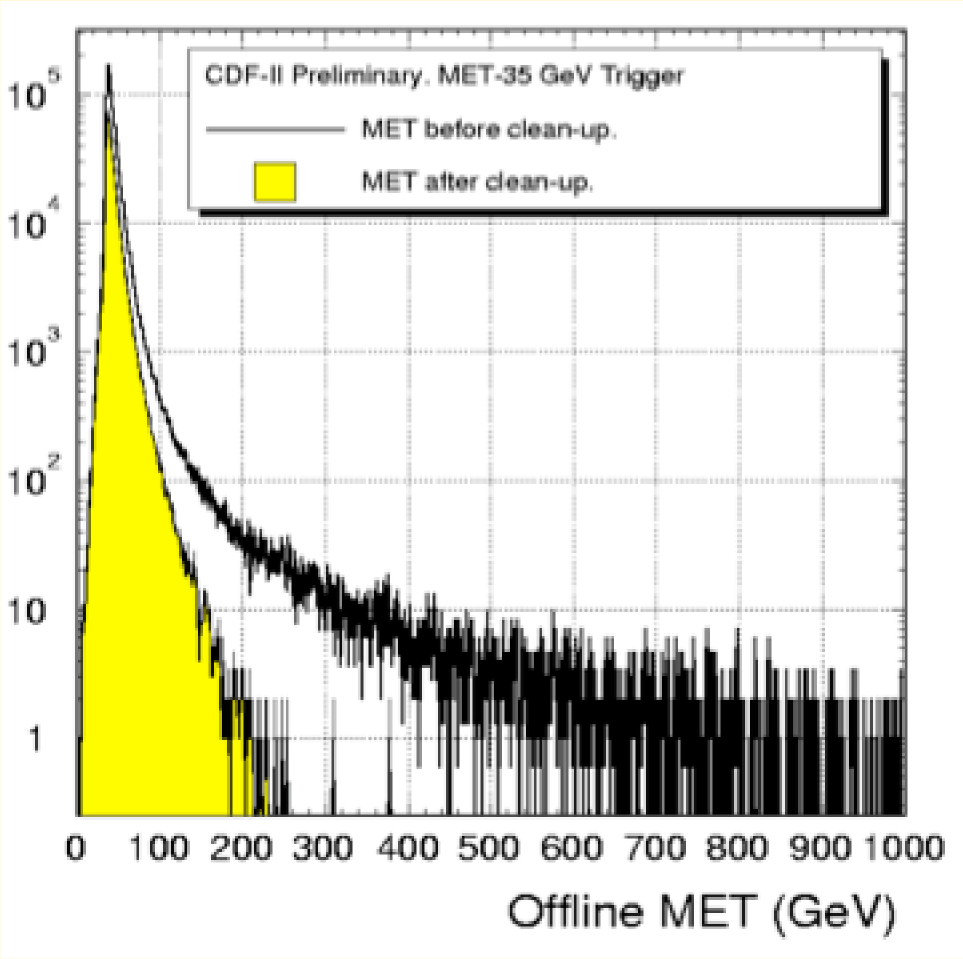
It is sufficient that these effects leave a permille fraction of the QCD rate for the signal to be washed away!

Examples from the Tevatron's experience



Detector occasional glitches ("hot-towers")

Non-collision bg's (beam-gas, cosmics, etc)



The prediction of each of these backgrounds, both physics and detector ones, and of possible additional ones, should be entirely based on the data themselves

Each search strategy should contain the definition of control samples and control observables to be used for

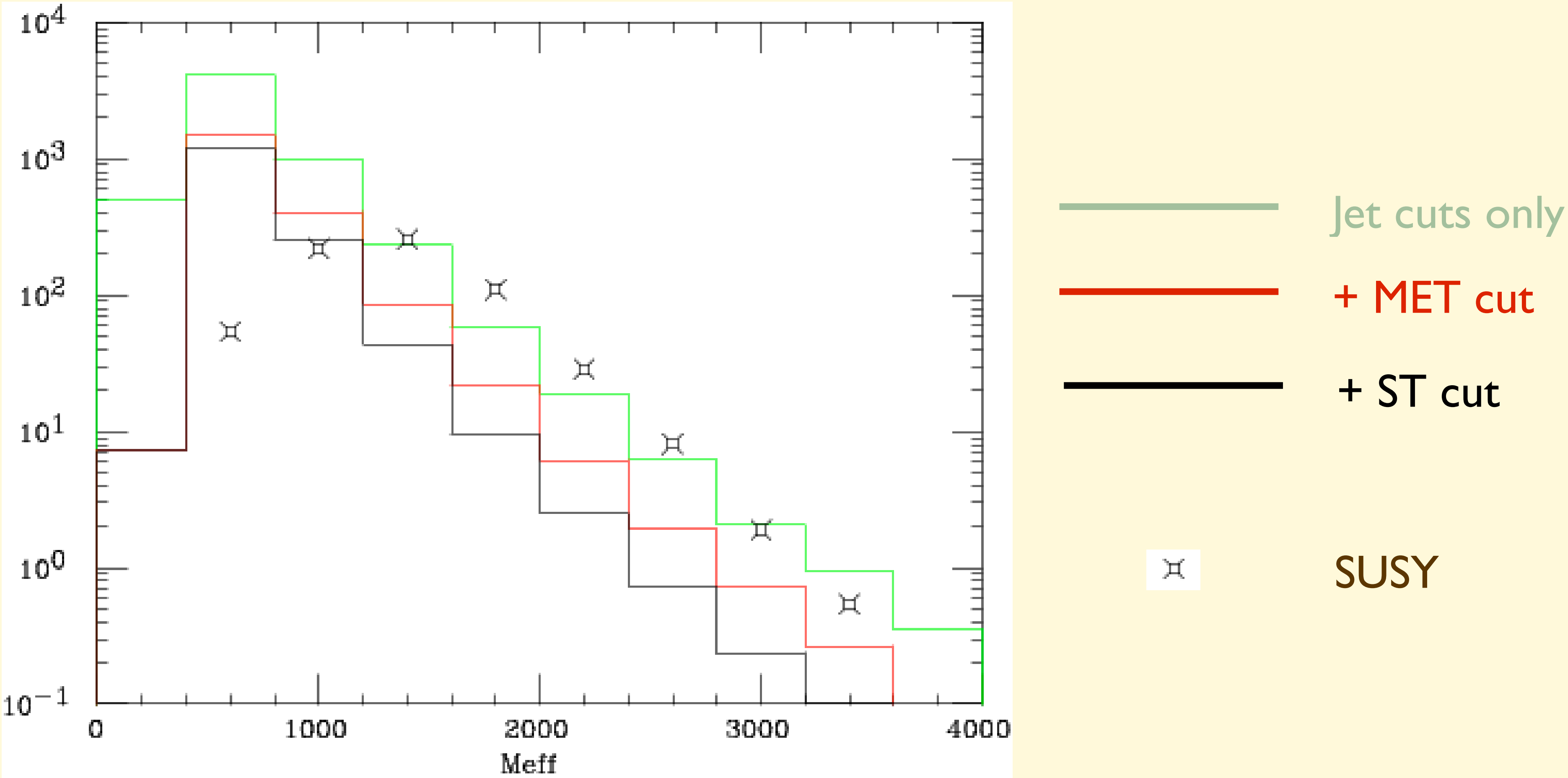
- ★ the direct determination of the backgrounds (e.g. by extrapolation of sidebands)
- ★ the validation of the MC tools,

and the proof that extrapolation is legitimate

Role of theoretical predictions:

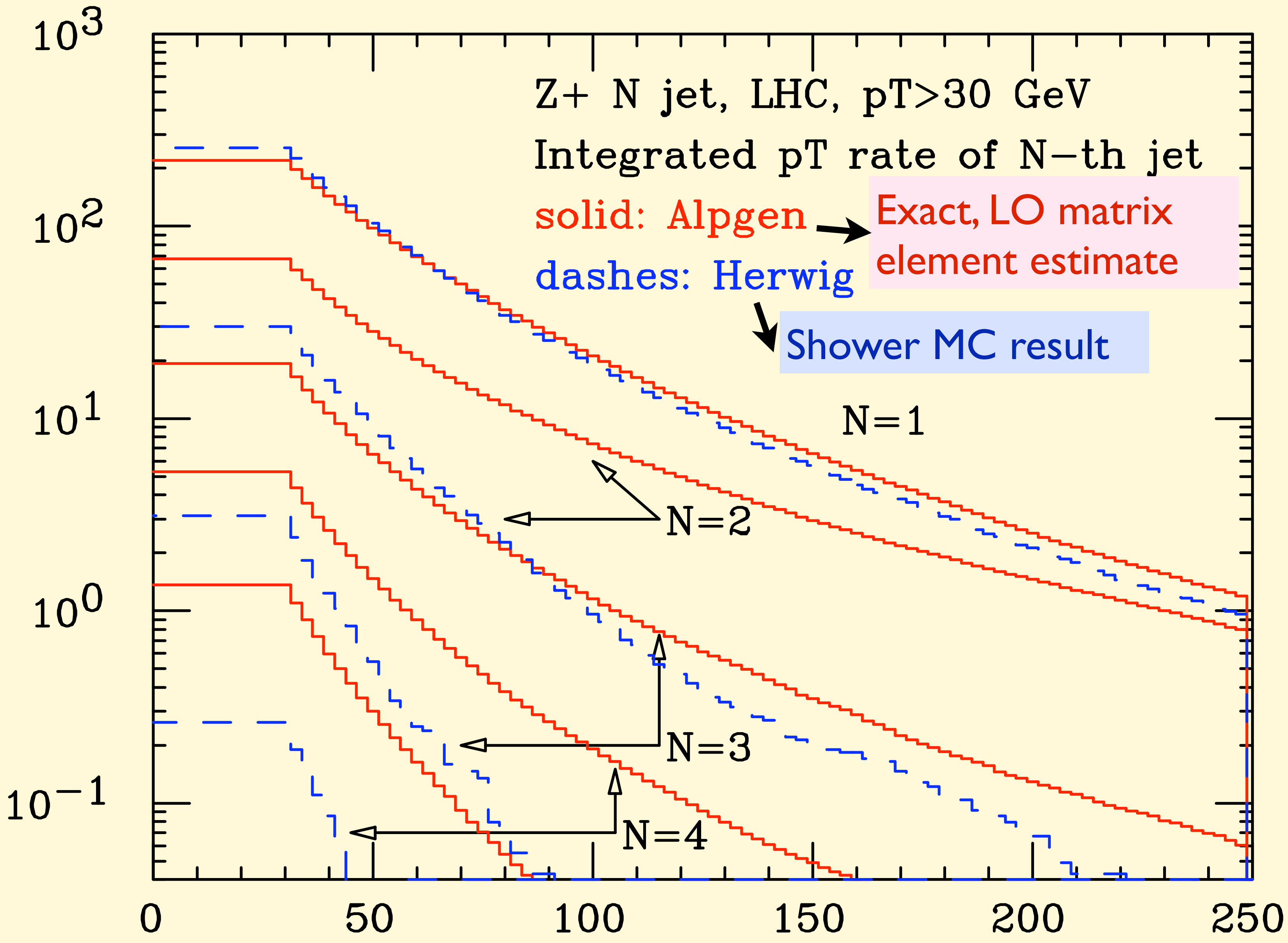
- **accurate absolute predictions for inclusive quantities:**
  - E.g. W/Z total cross sections ⇒ luminosity determination, PDF measurements
  - E.g. Higgs and other new particles cross sections ⇒ extract couplings, BRs
  - ⇨ **require N(N)LO for reduced scale dependence**
- **complete description of final states**
  - complete description of SM processes with, e.g. ,
    - large jet multiplicities
    - associated production of multiple EW and QCD objects (t,b,g,H,W,...)
  - Goal is not first-principle predictability, but good agrement with data after tuning
  - ⇨ **require full MC generators, flexibility in the input param's for accurate tuning**

Z(→νν) + jets



10^4
10^3
10^2
10^1
10^0
10^-1
0
1000
2000
3000
4000
Meff
Jet cuts only
+ MET cut
+ ST cut
SUSY

N.B. Reliability/systematics of MC tools: Shower MC vs Matrix element results



Normalizing the bg rate using data ...

Use Z->ee + multijets, apply same cuts as MET analysis but replace MET with ET(e^+e^-)

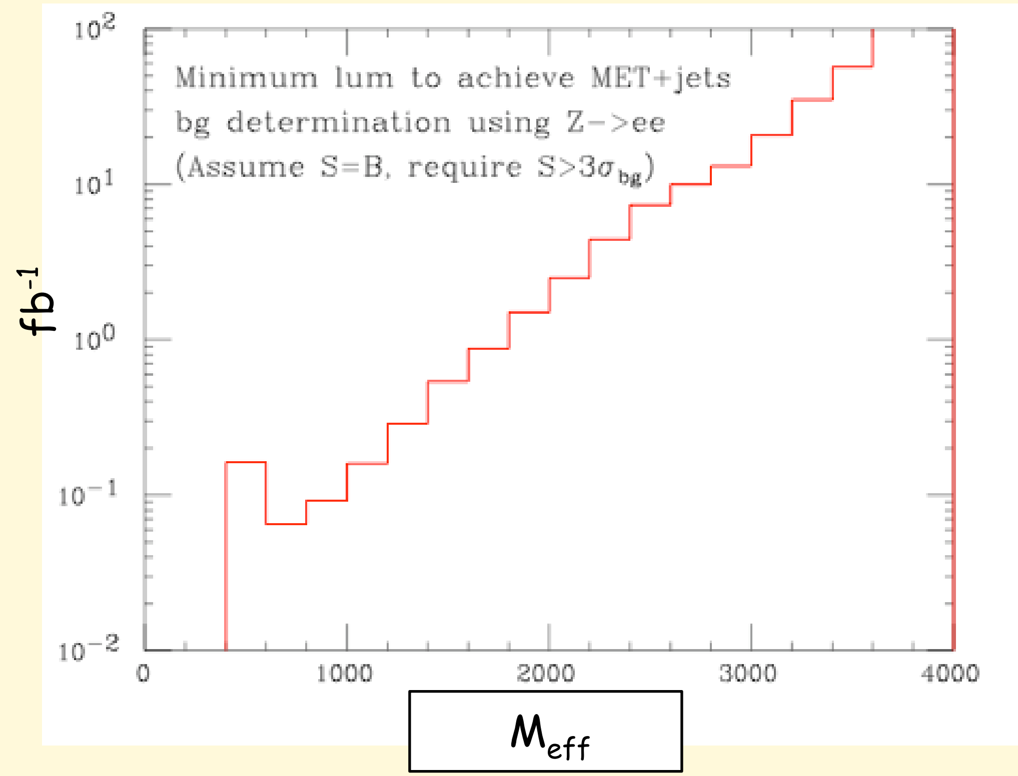
Extract $Z\to\nu\nu$ bg using, bin-by-bin:
$(Z\to\nu\nu) = (Z\to ee)\ B(Z\to\nu\nu)/B(Z\to ee)$

Assume that the SUSY signal is of the same size as the bg, and evaluate the luminosity required to determine the Z->nunu bg with an accuracy such that:

$$N_{susy} > 3\ \sigma$$

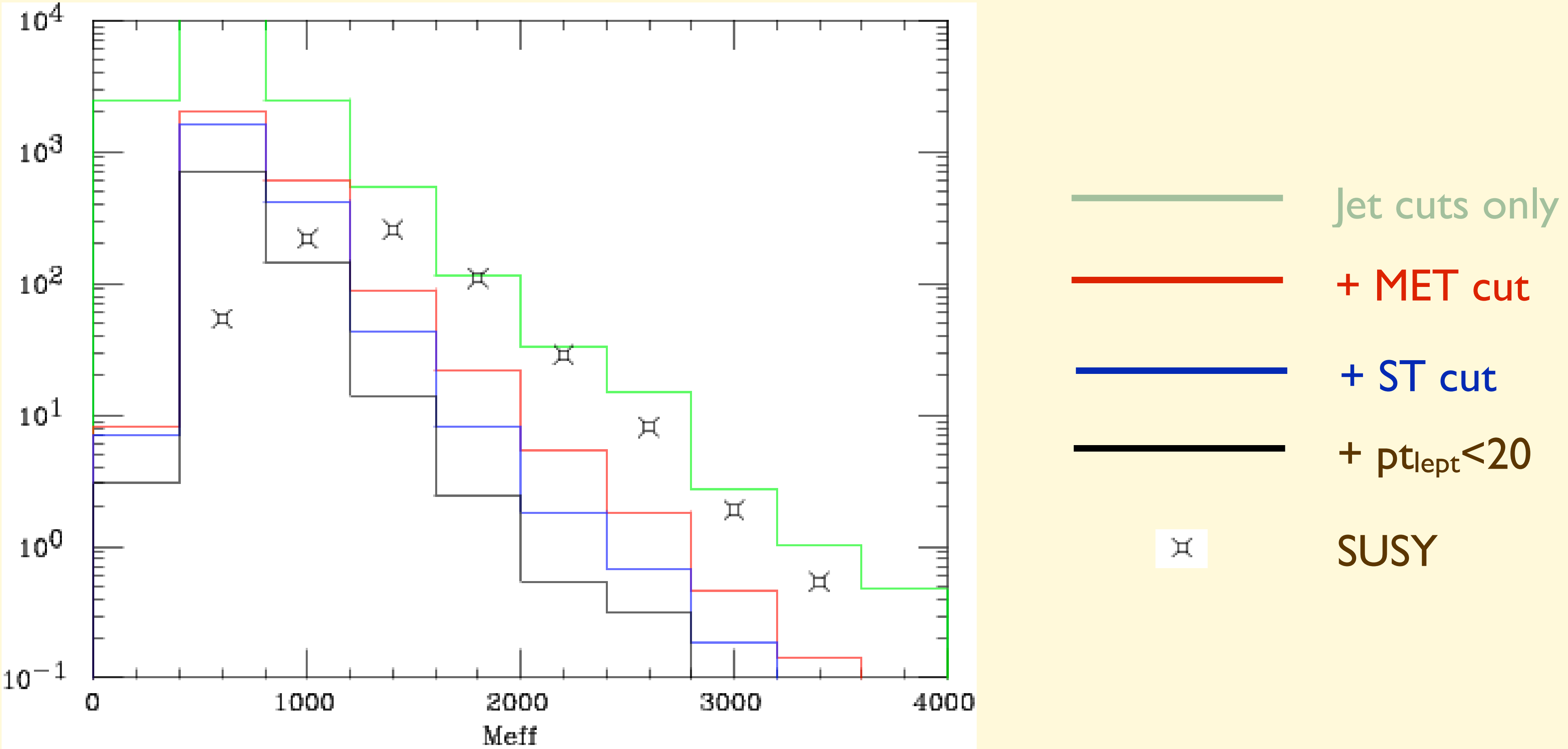
where

$$\sigma=\sqrt{[\ N(Z\to ee)\ ]} * B(Z\to\nu\nu)/B(Z\to ee)$$



=> few hundred pb^{-1} are required. They are sufficient if we believe in the MC shape (and only need to fix the overall normalization). More is needed if we want to keep the search completely MC independent

W(→lν) +4 jets



10^4
10^3
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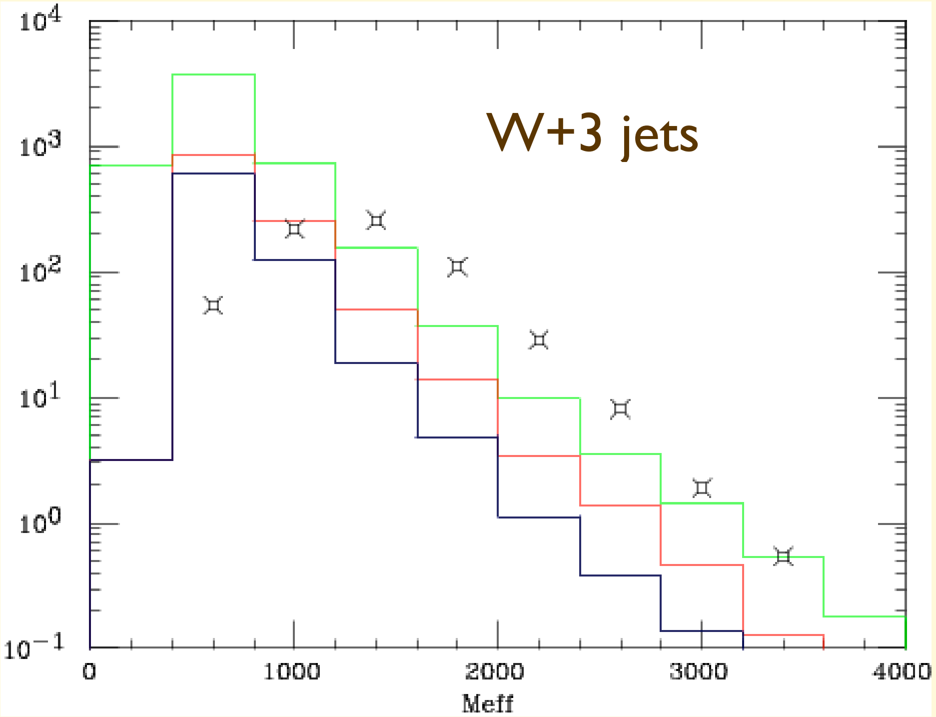
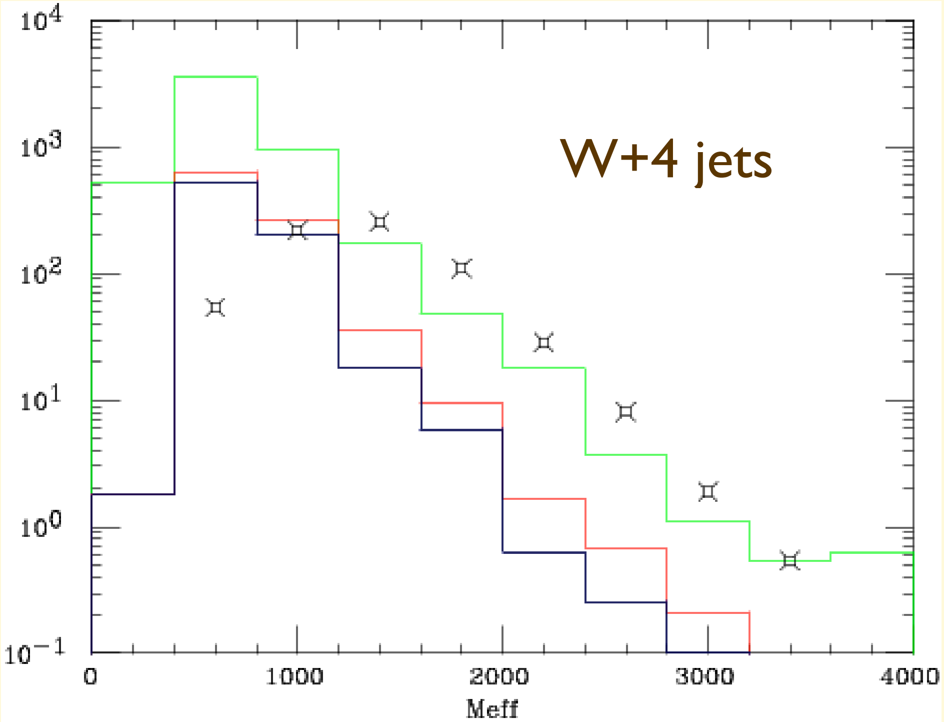
10^1
10^0
10^-1
0
1000
2000
3000
4000
Meff
Jet cuts only
+ MET cut
+ ST cut
+ pt_lept<20
SUSY

W(→tau-jet ν) + jets





Jet cuts only

+ MET cut

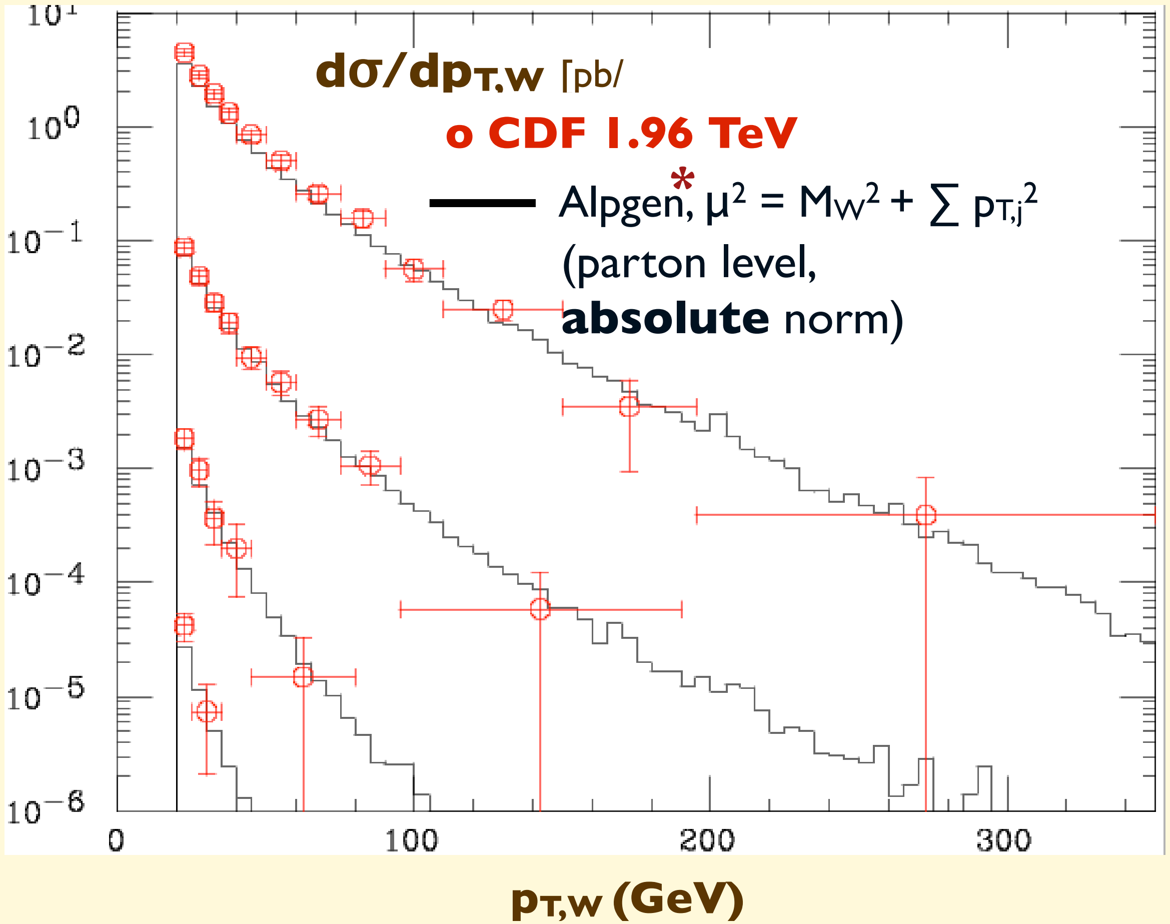
+ ST cut

+ pt_{lept}<20

 SUSY

Validation: comparison of jet Et spectra in [W→e/μ ν] +multijet events, replace e/μ with τ in MC.

Example: Tevatron data

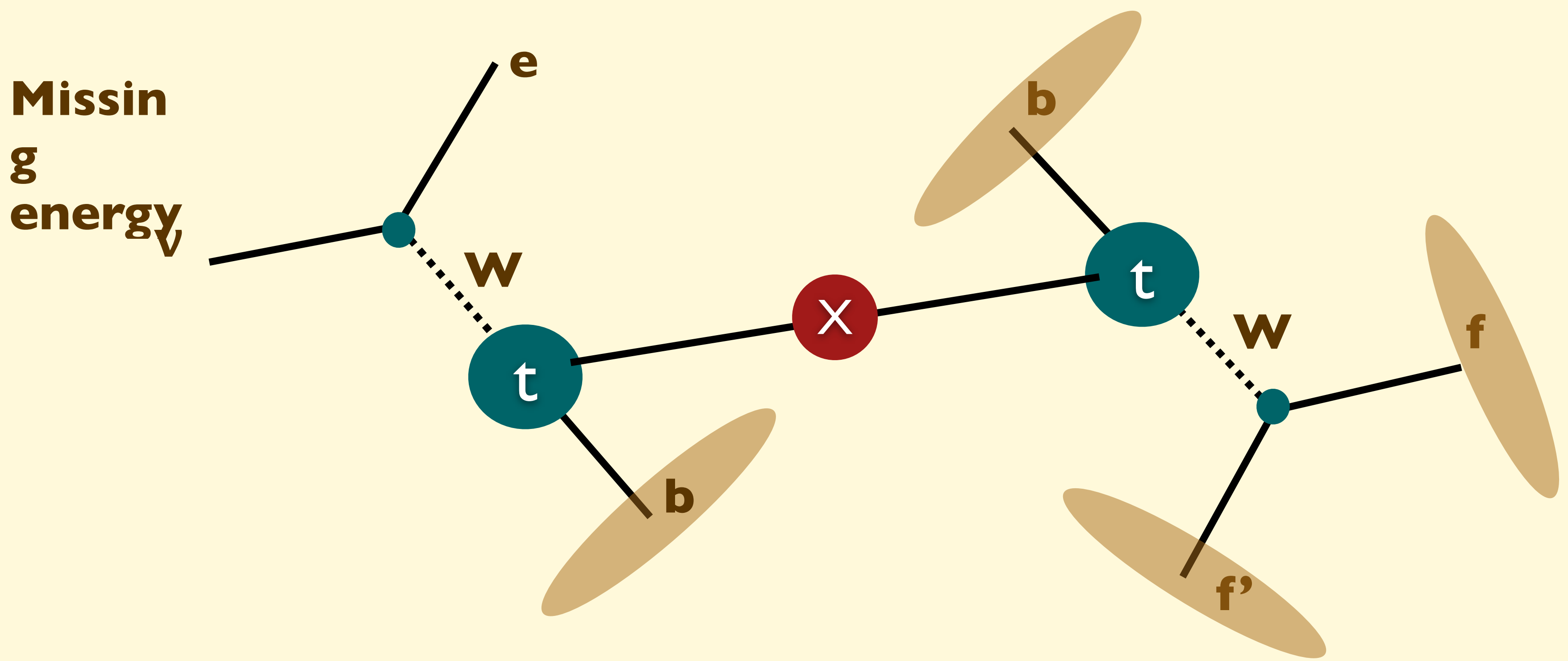


* any other PL ME generator (Vecbos, Madgraph, etc) would give the same result

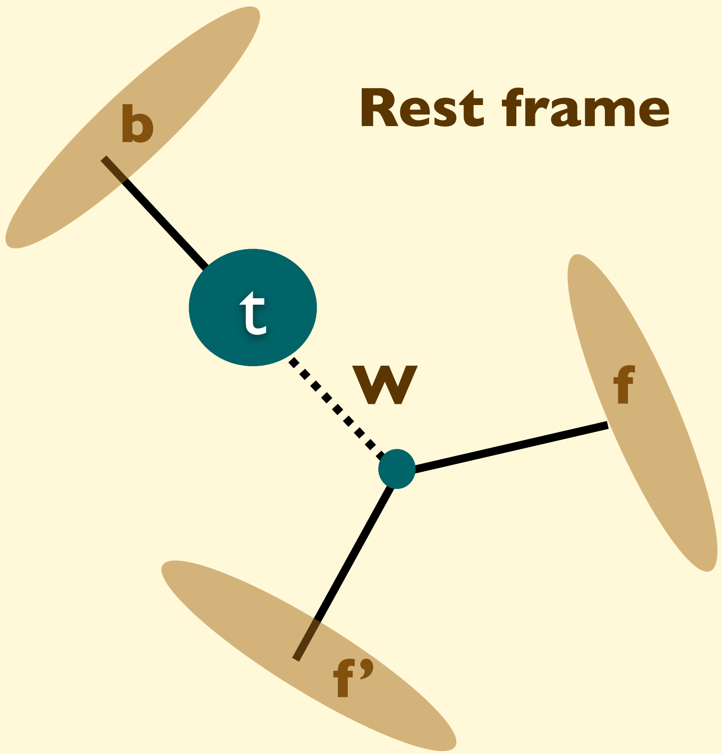
Key experimental issue:
at large jet multiplicity and MET, the non-W bg to [W→e/μ ν]+multijet is very very large*! So the control sample itself is dominated by backgrounds yet harder to estimate .....

* Mostly b/c SL decays, together with mismeasurement of jet ET, but also t-tbar

Top final states



Top final states

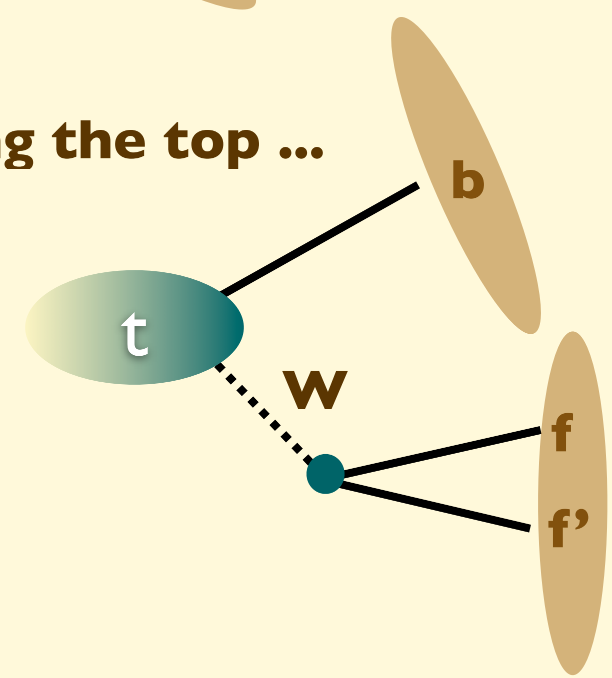


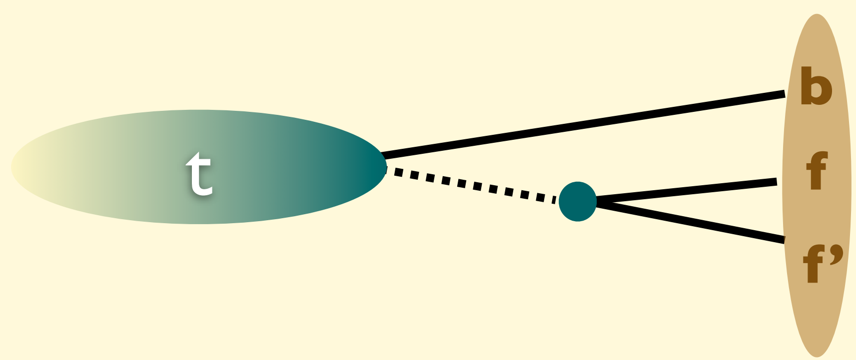
Rest frame

$$p_b = \frac{m_{top}^2 - m_W^2}{2\, m_{top}}$$

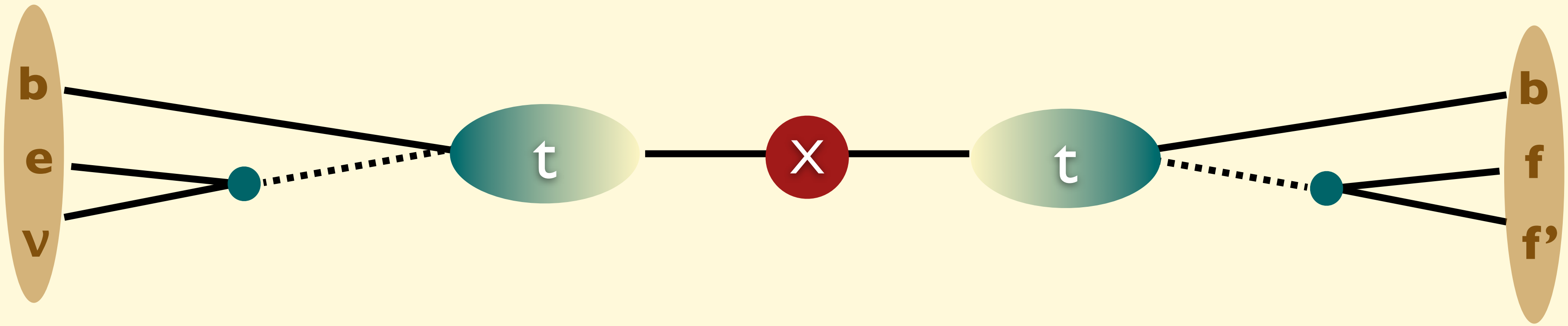
$$p_f^{max} = \frac{m_W}{2}\,\frac{m_{top}^2 + m_W^2}{2\, m_{top}\, m_W}$$

Boosting the top ...



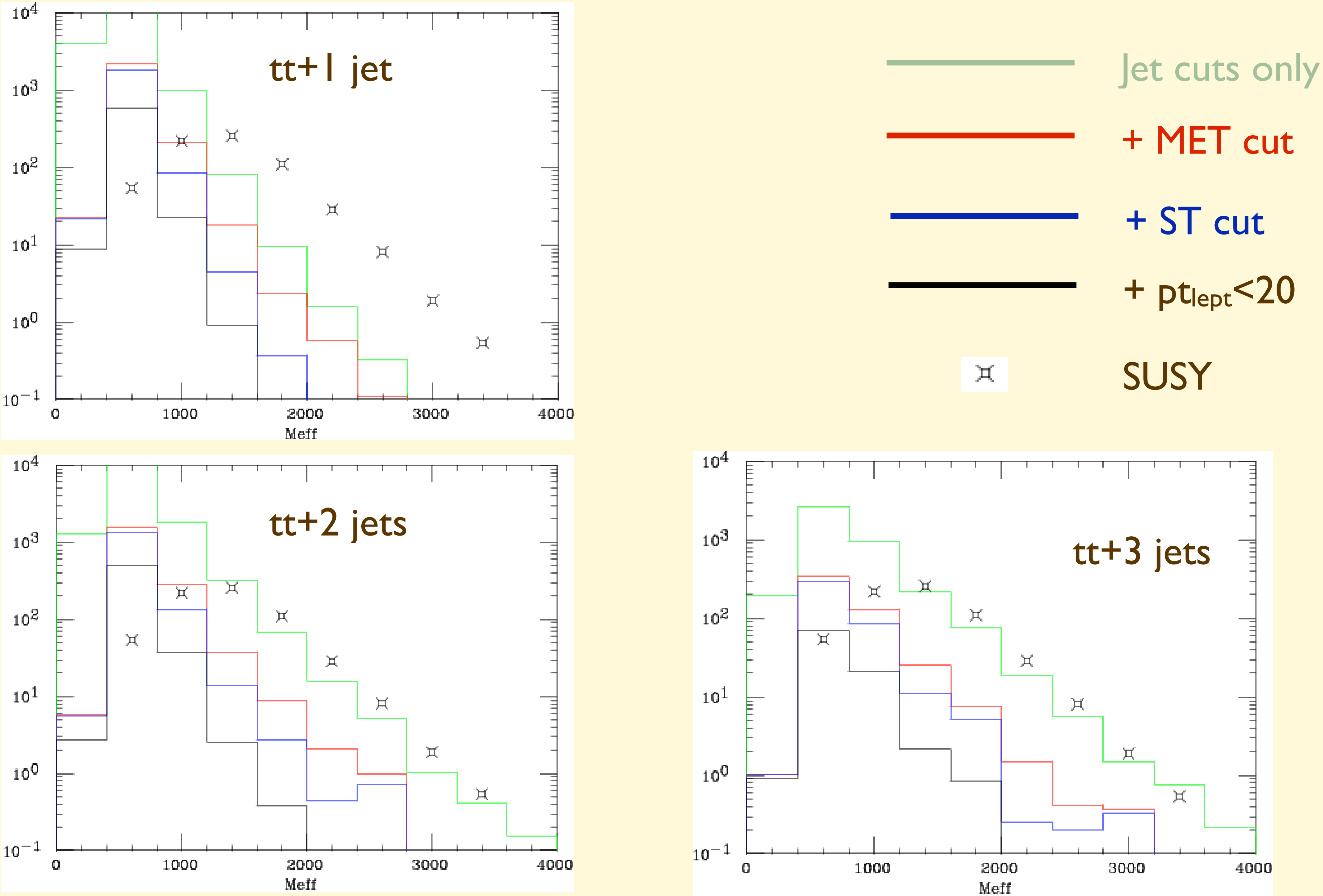


Top final states



Large Meff leads to highly collimated final states

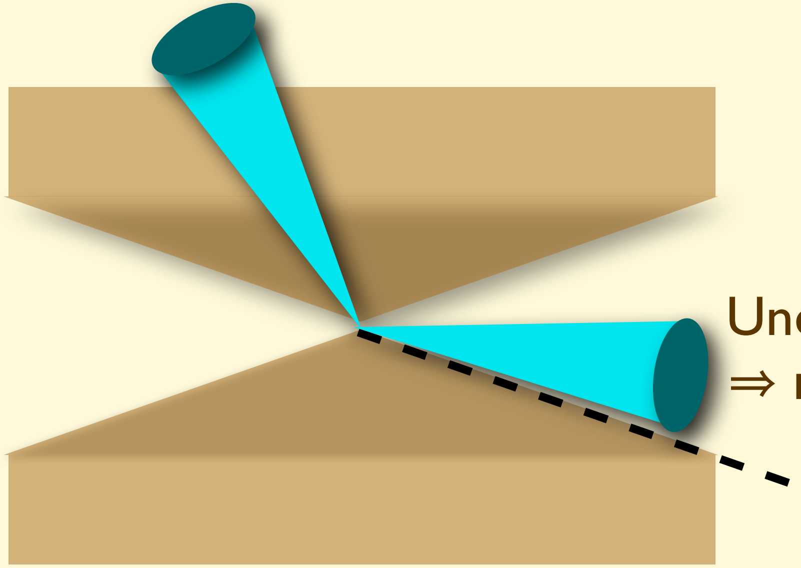
Sphericity and multi-jet cuts very effective against the leading-order t-tbar contribution!



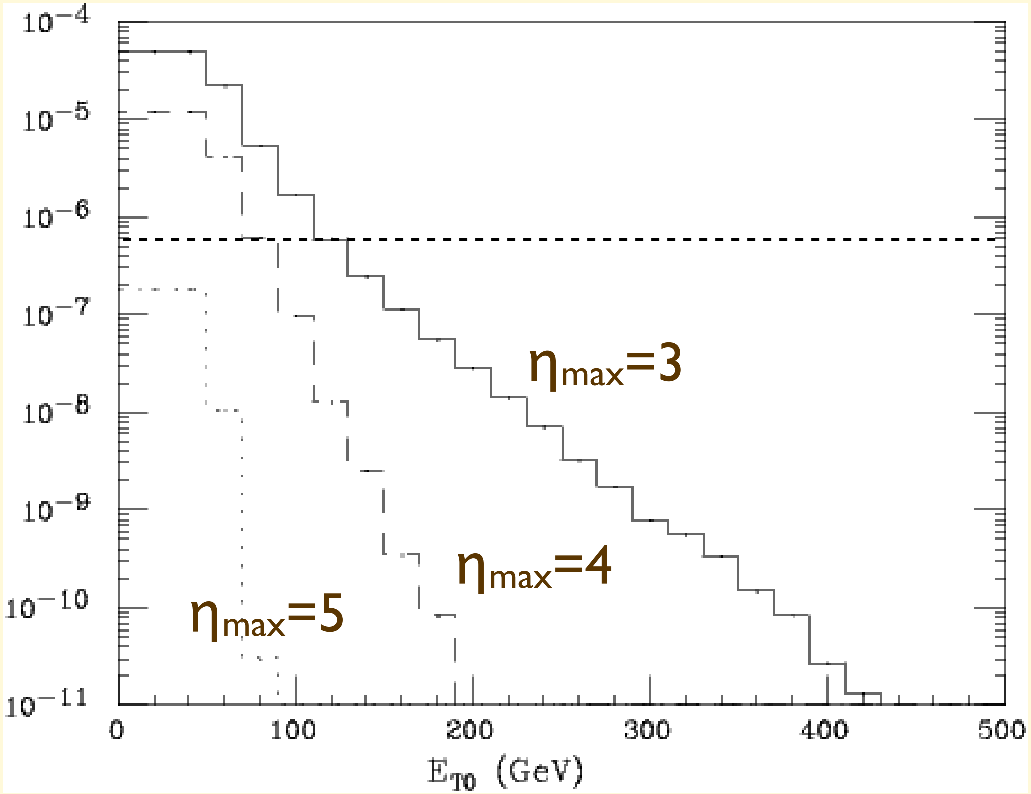
High jet multiplicities dominate the rate!!

Requires accurate treatment of tt+multijet final states: how do we validate the MC description?

Instrumental sources of missET, example: incomplete calorimeter η coverage



σ(jet-jet with MET> E_{To}) / σ(pp→X)

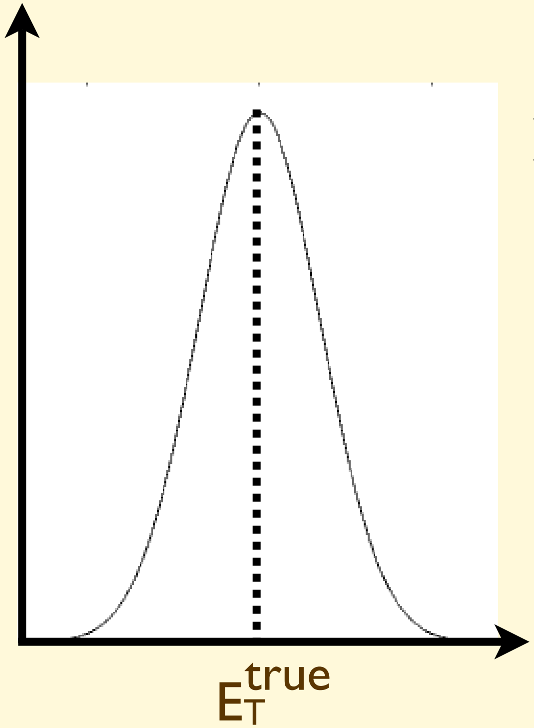


cfr:
$\sigma(W \to l\nu)/\sigma(pp \to X) \approx 6 \times 10^{-7}$

NB:
At $L=10^{34}$ cm^{-2} s^{-1},
⟨N(pp collisions)⟩ ≈ 20

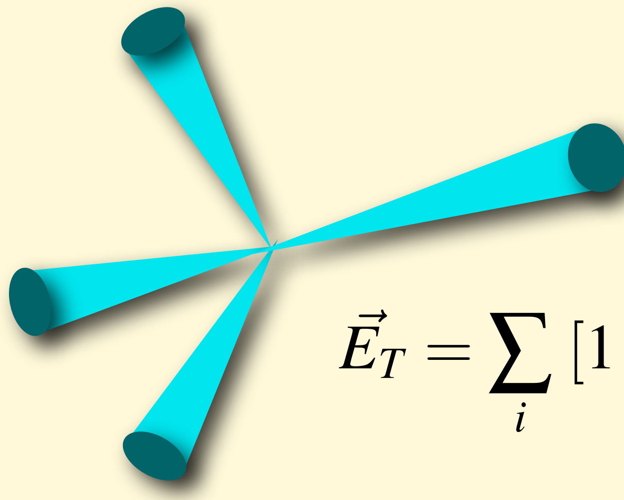
⇒ **probability 20x larger**

Instrumental sources of missET, example: jet energy resolution



$$\mathrm{Prob}[p_T] \propto \exp - \frac{(p_T - p_T^{\mathrm{true}})^2}{\sigma^2}$$

$$\sigma = C\sqrt{E_T^{\mathrm{true}}/\mathrm{GeV}}, \quad C = O(1)$$

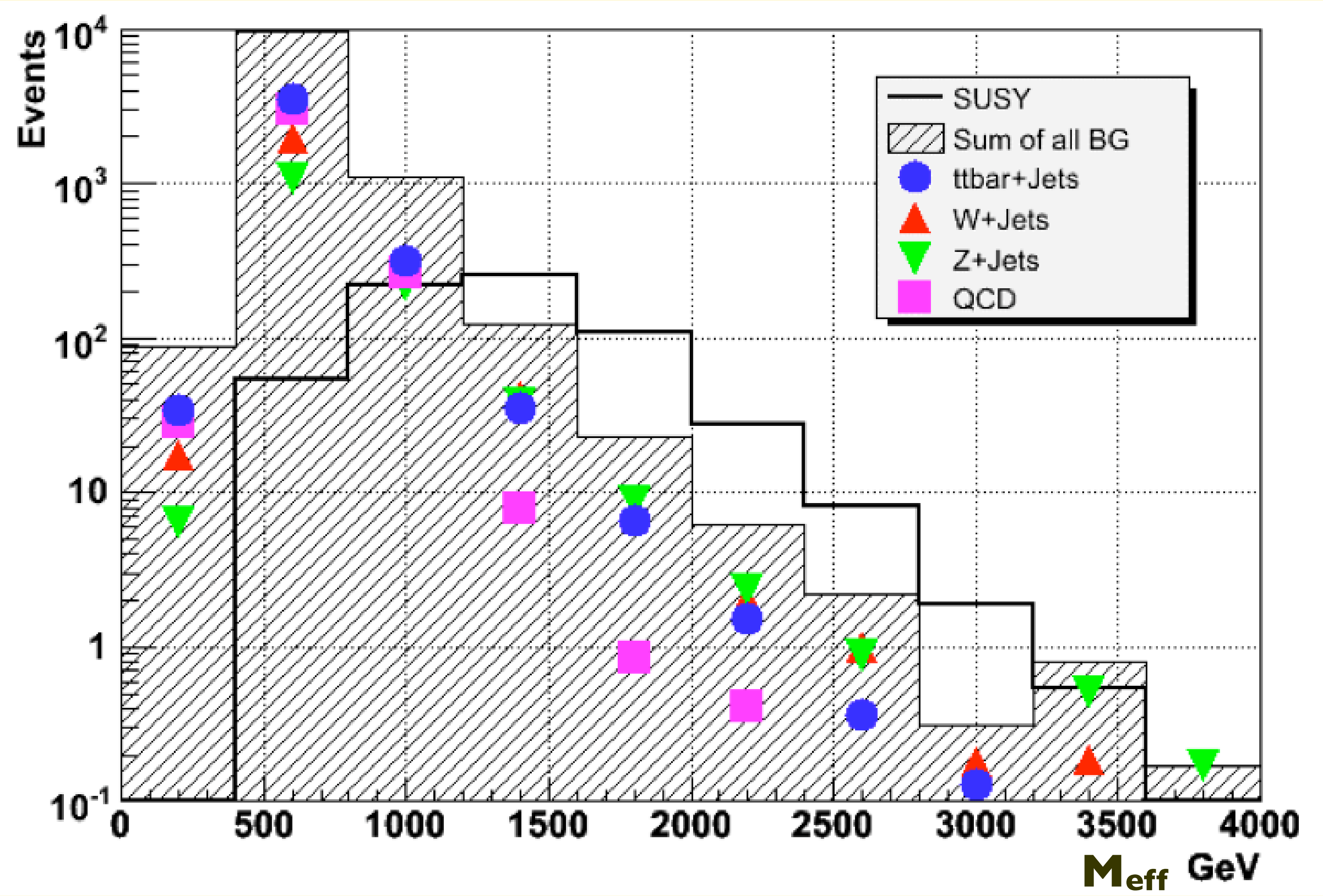


$$\vec{E}_T = \sum_i \left[1 + \delta_i\right] \vec{p}_{T,i}^{\,\mathrm{true}} = \sum_i \delta_i \, \vec{p}_{T,i}^{\,\mathrm{true}}$$

$$\langle |\vec{E}_T|^2 \rangle = \sum_{i,j} \langle \delta_i \delta_j \rangle \vec{p}_{T,i} \cdot \vec{p}_{T,j} \qquad \langle \delta_i \delta_j \rangle = \frac{C^2}{p_{T,i}} \delta_{ij}$$

$$\langle \mathrm{MET} \rangle = C \sqrt{\sum_i p_{T,i}}$$

Overall result, after the complete detector simulation, etc....



Tools: examples for Z/W/γ+jets

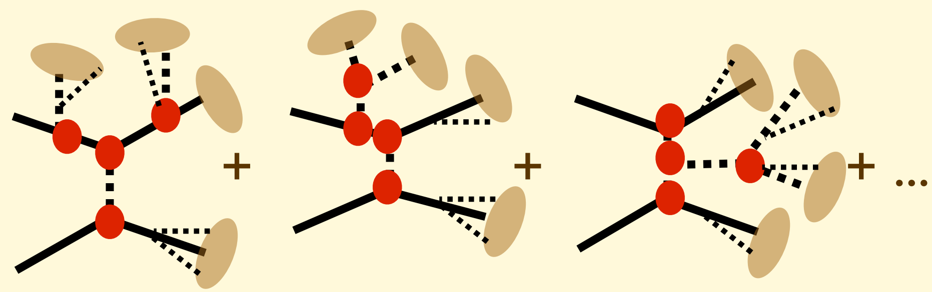
- Parton-level LO matrix element generators (e.g. Vecbos)
- LO ME + shower MCs, with **merging of different jet multiplicities** (up to 4–6 jets, depending on code)**:**
  - ALPGEN (MLM merging scheme)
  - ARIADNE (Lonnblad merging)
  - HELAC, MadEvent (MLM merging)
  - SHERPA (CKKW merging)
- NLO PL matrix element generators:
  - DYRAD (up to 1 jet @ NLO)
  - MCFM (up to 2 jets @NLO)
- MC@NLO (inclusive W @NLO)
- Resummed inclusive W pt spectra (RESBOS)

Accuracy of multijet merging/matching schemes:

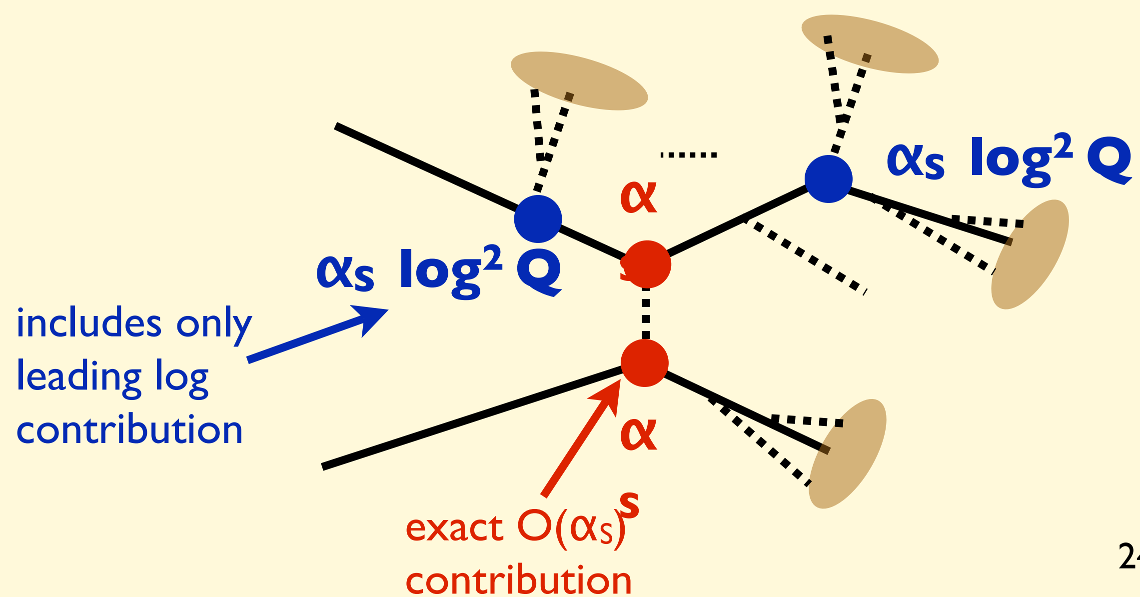
$\alpha_s^N \sum_{n=0,\dots,\infty} \alpha_s^n \log^{2n} Q$ accuracy for observables whose Leading Order contribution is of $O(\alpha_s^N)$

Examples:

- W pt: N=1
- m[jj] in W+jets: N=2
- pT [t tbar]: N=3
- ET [4th jet in 4-jet events]: N=4

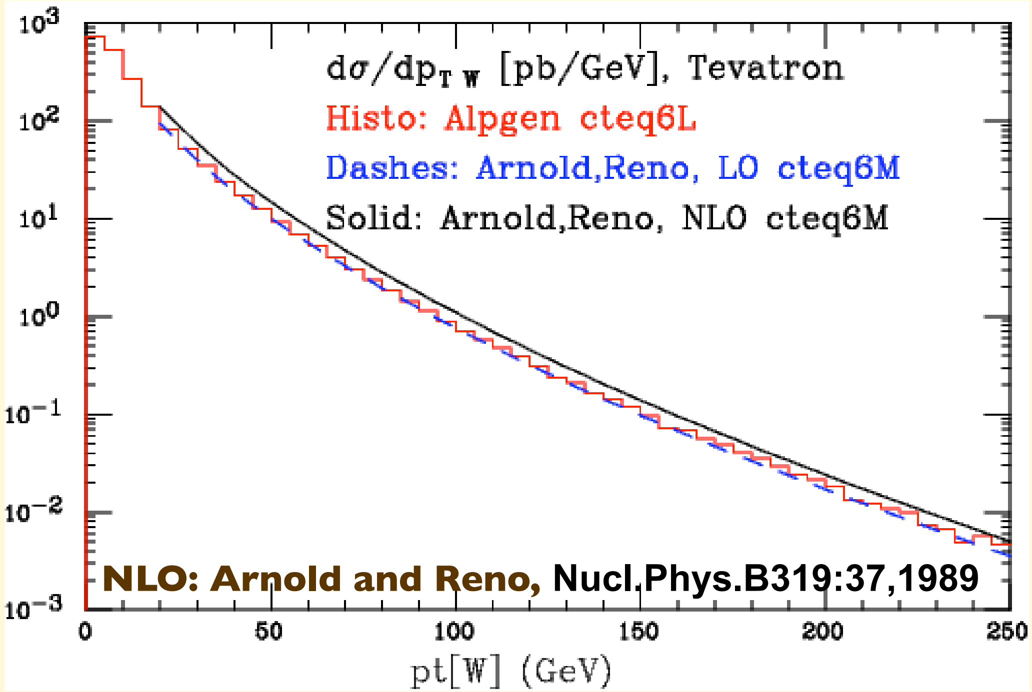


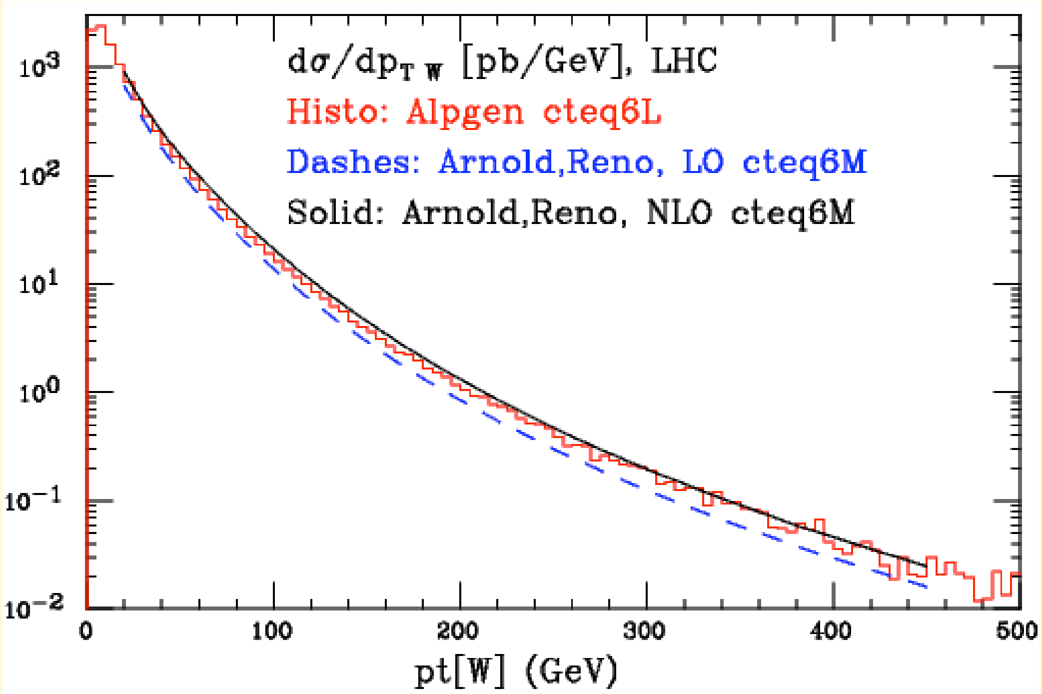
Cfr $\alpha_s^2 \sum_{n=N-2,\dots,\infty} \alpha_s^n \log^{2n} Q$ accuracy for standard shower MC



Validation against NLO and Tevatron data

Inclusive W pt spectrum: LO with (MLM) matching vs NLO

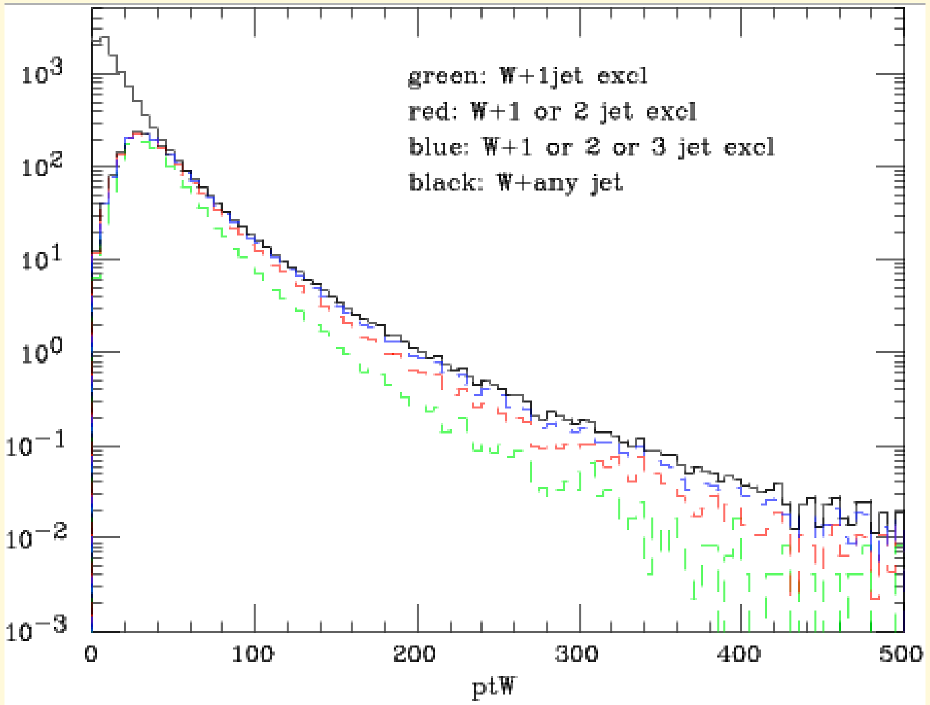




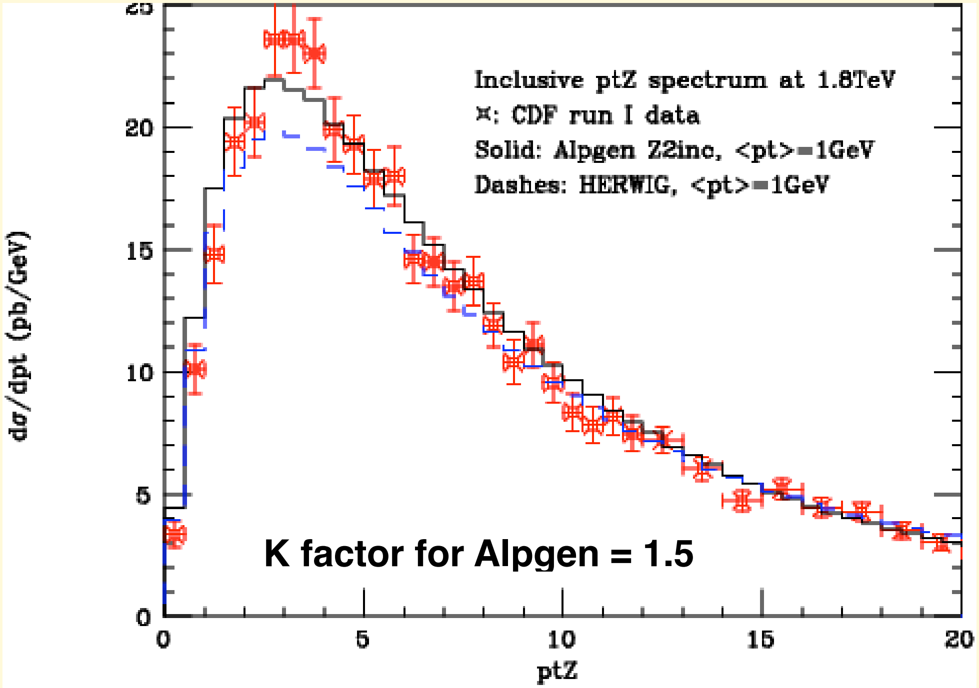
ME+shower with merging of multiparton MEs :

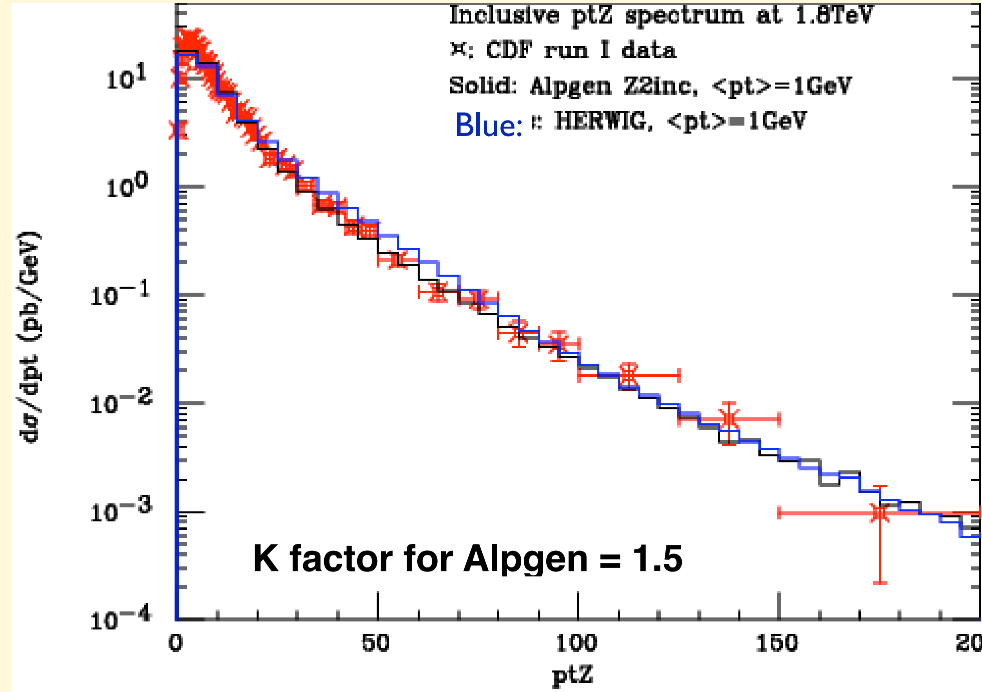
- The inclusive rate can be represented by the sum of multijet final state contributions: at high pt multijet final states dominate over the W + 1 jet rate!

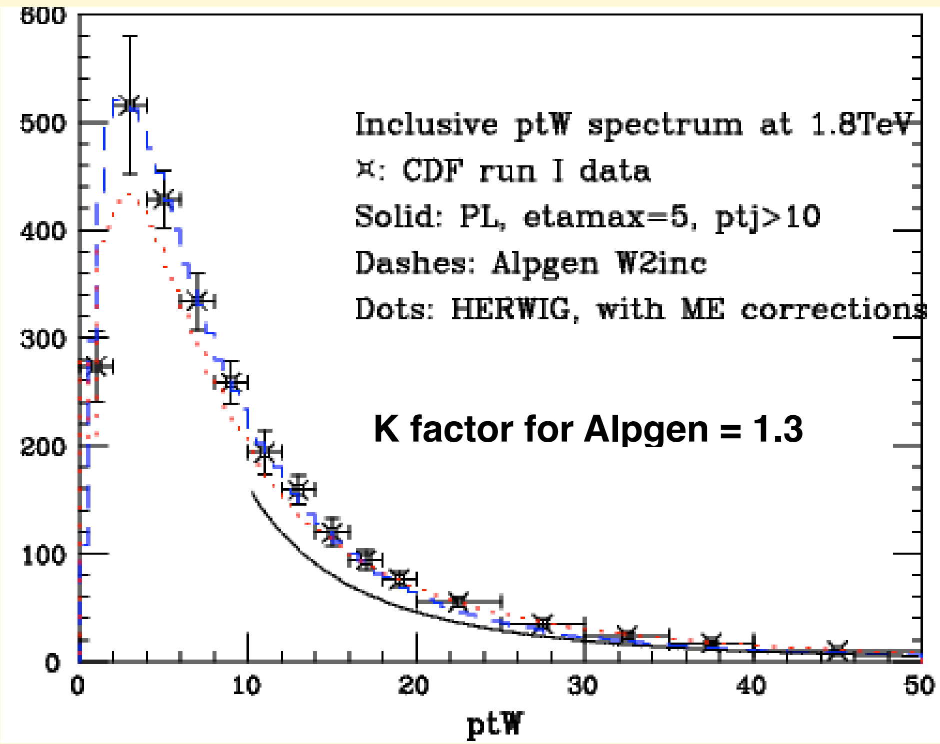
- The matching algorithm carefully combines the independent multijet final states into a fully inclusive sample

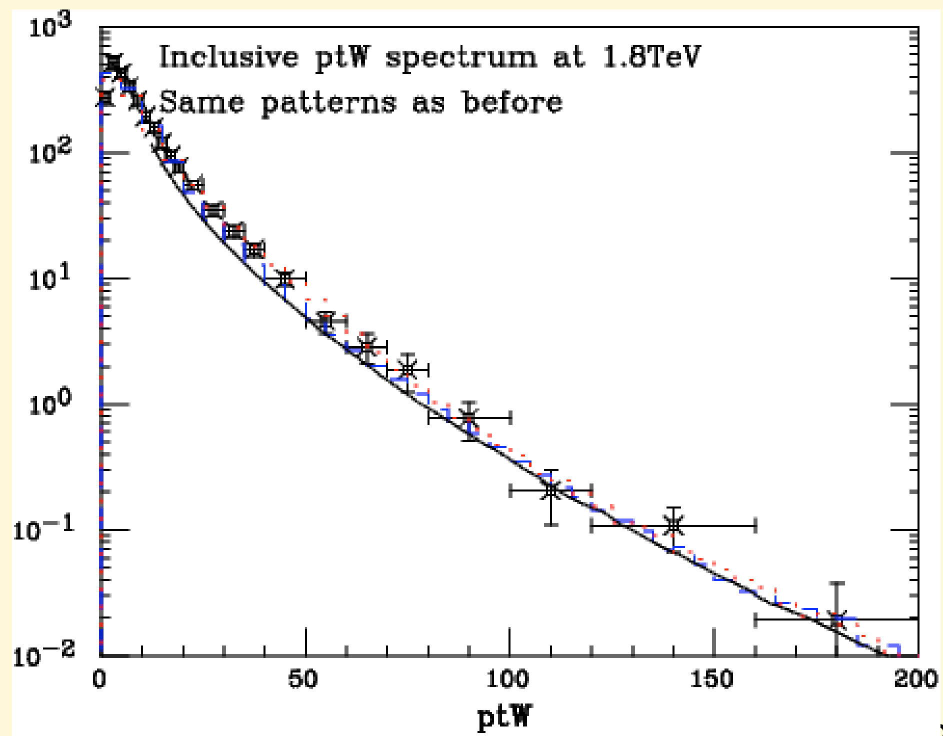


Comparisons with data: Inclusive Z/W pt spectrum at 1.8 TeV (CDF data)



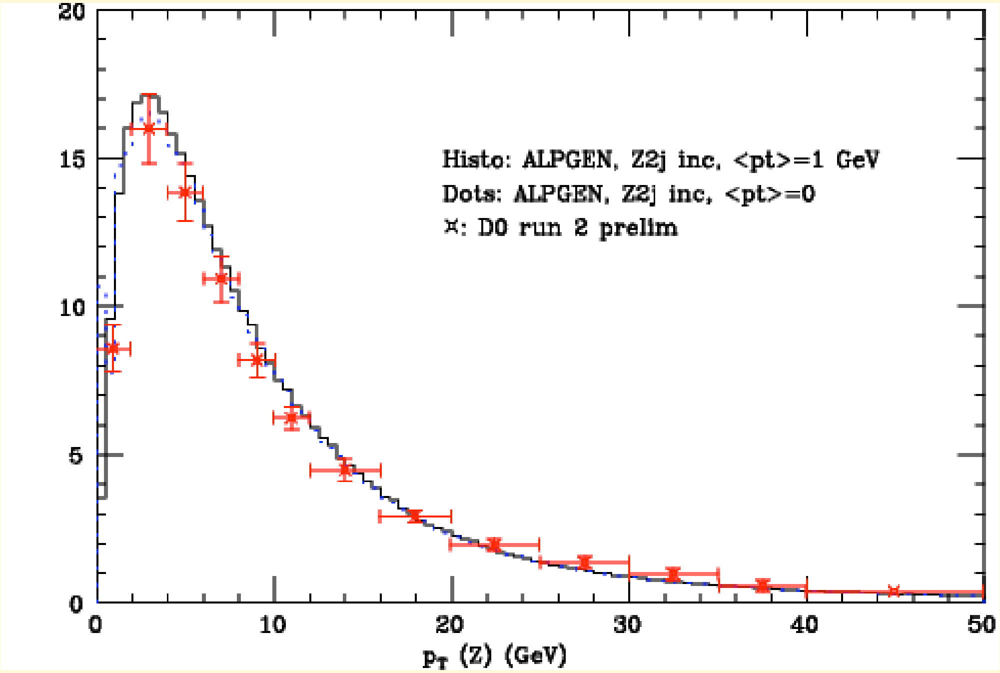


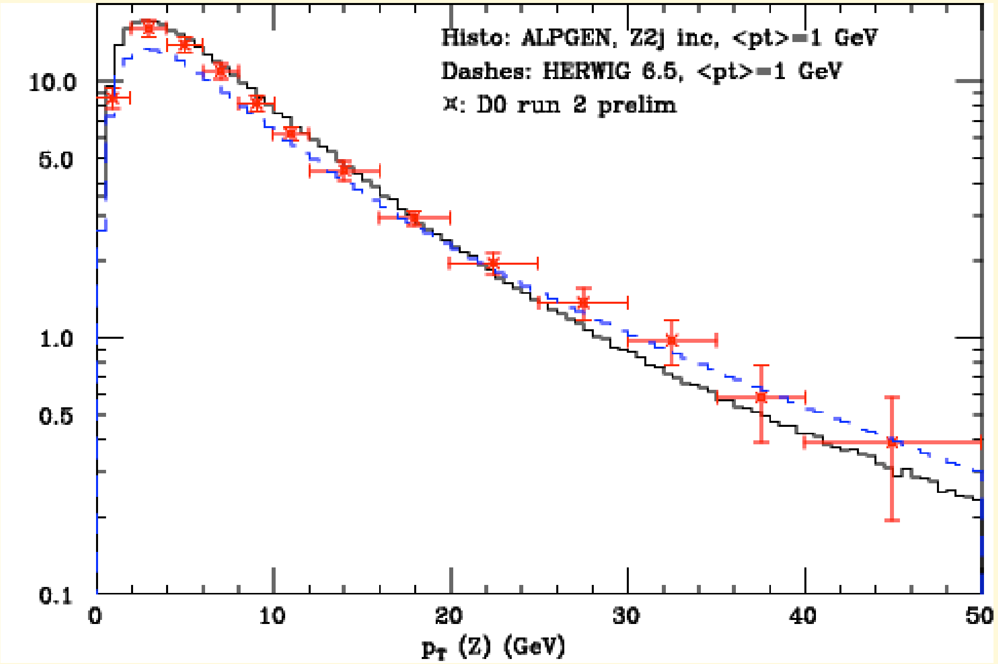


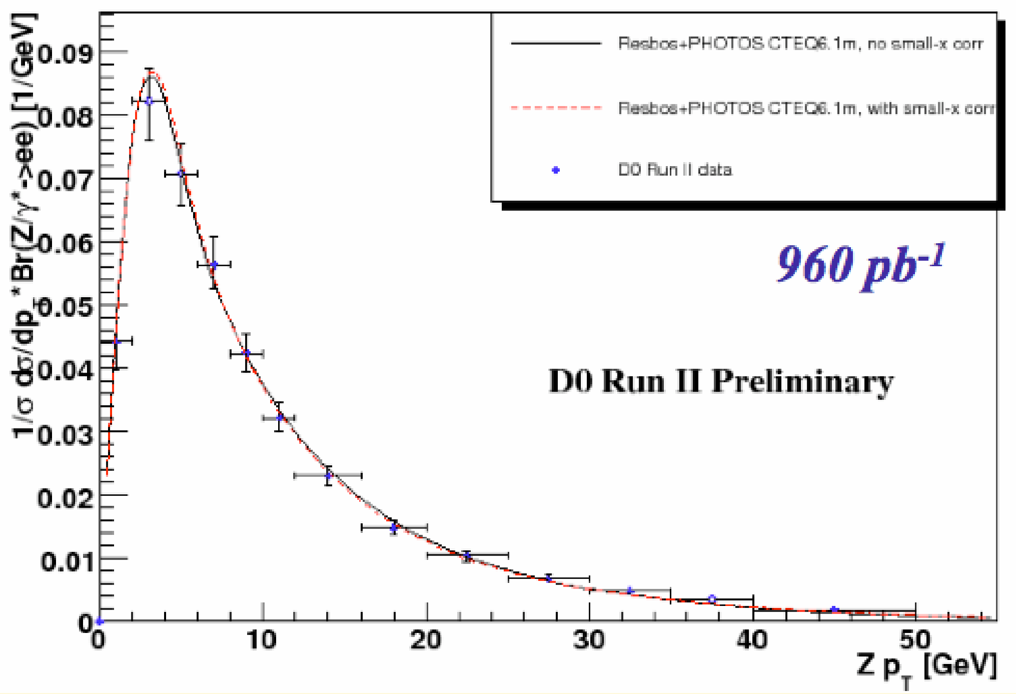


Comparisons with D0 data: Inclusive Z pt spectrum at 1.96 TeV

(D0 data: http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/EW/E18/E18.pdf)

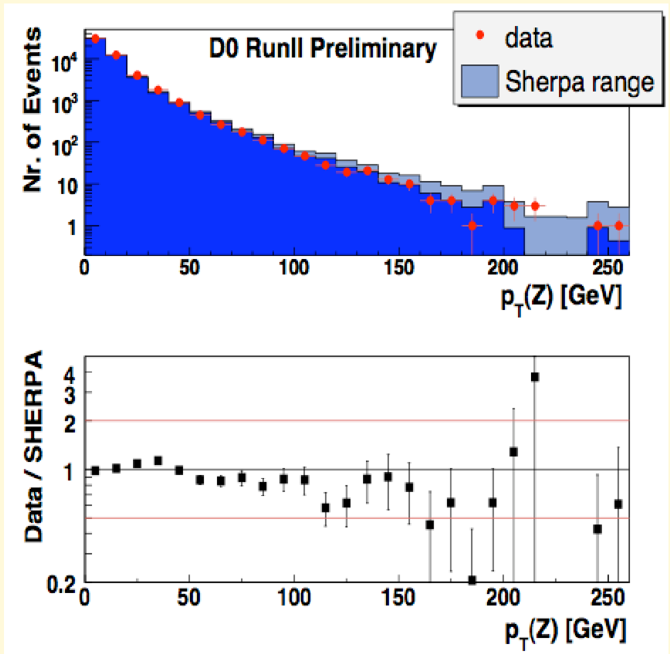


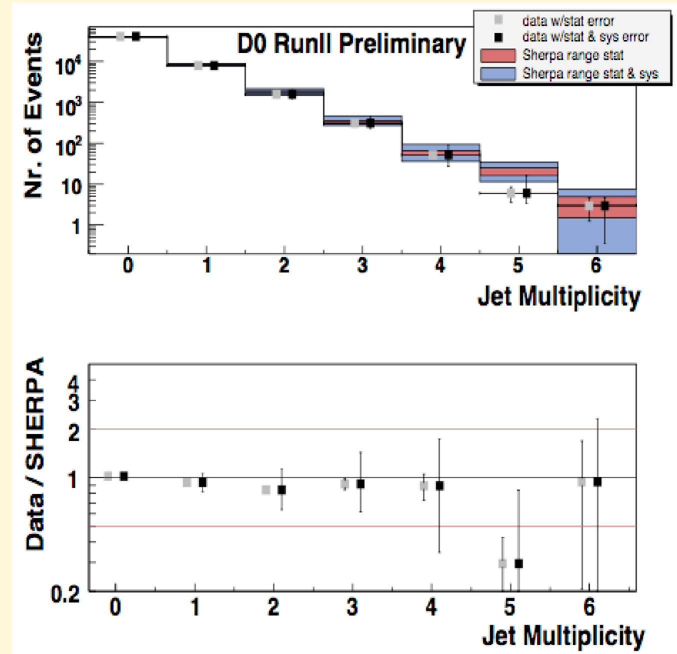




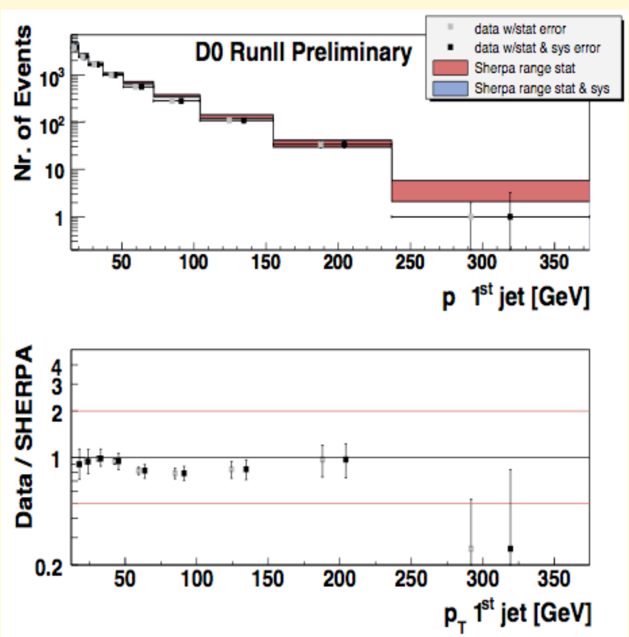
Comparisons with D0 data: Sherpa, Z + jets at 1.96 TeV

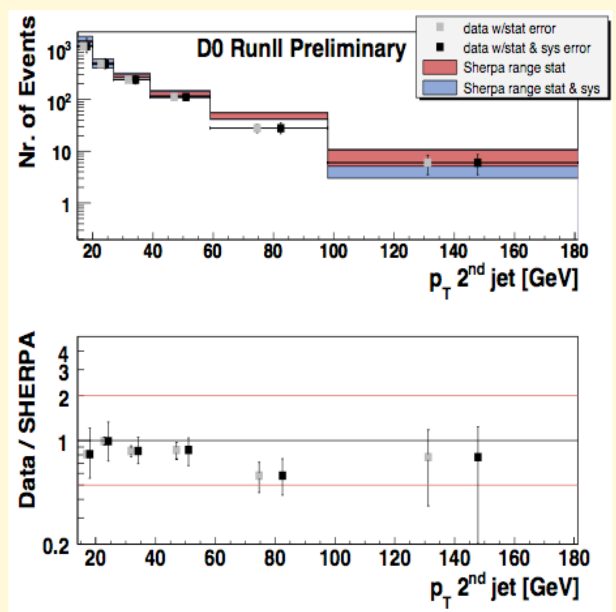
(Analysis: http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H15/H15.pdf)

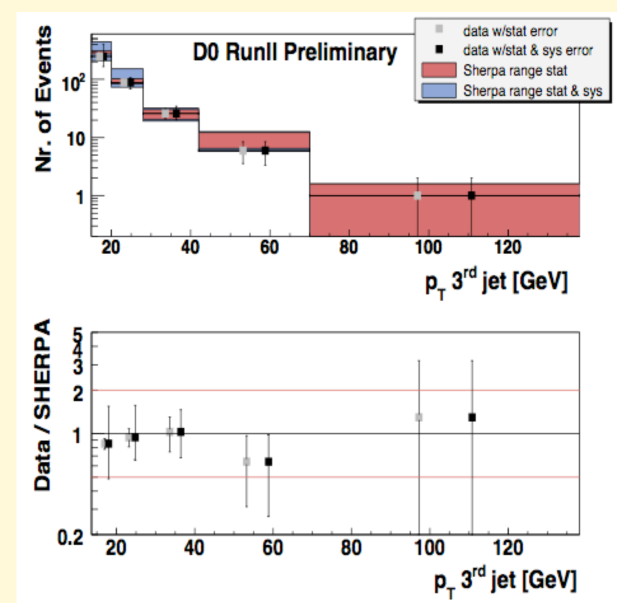




Data and MC normalized to the total number of events

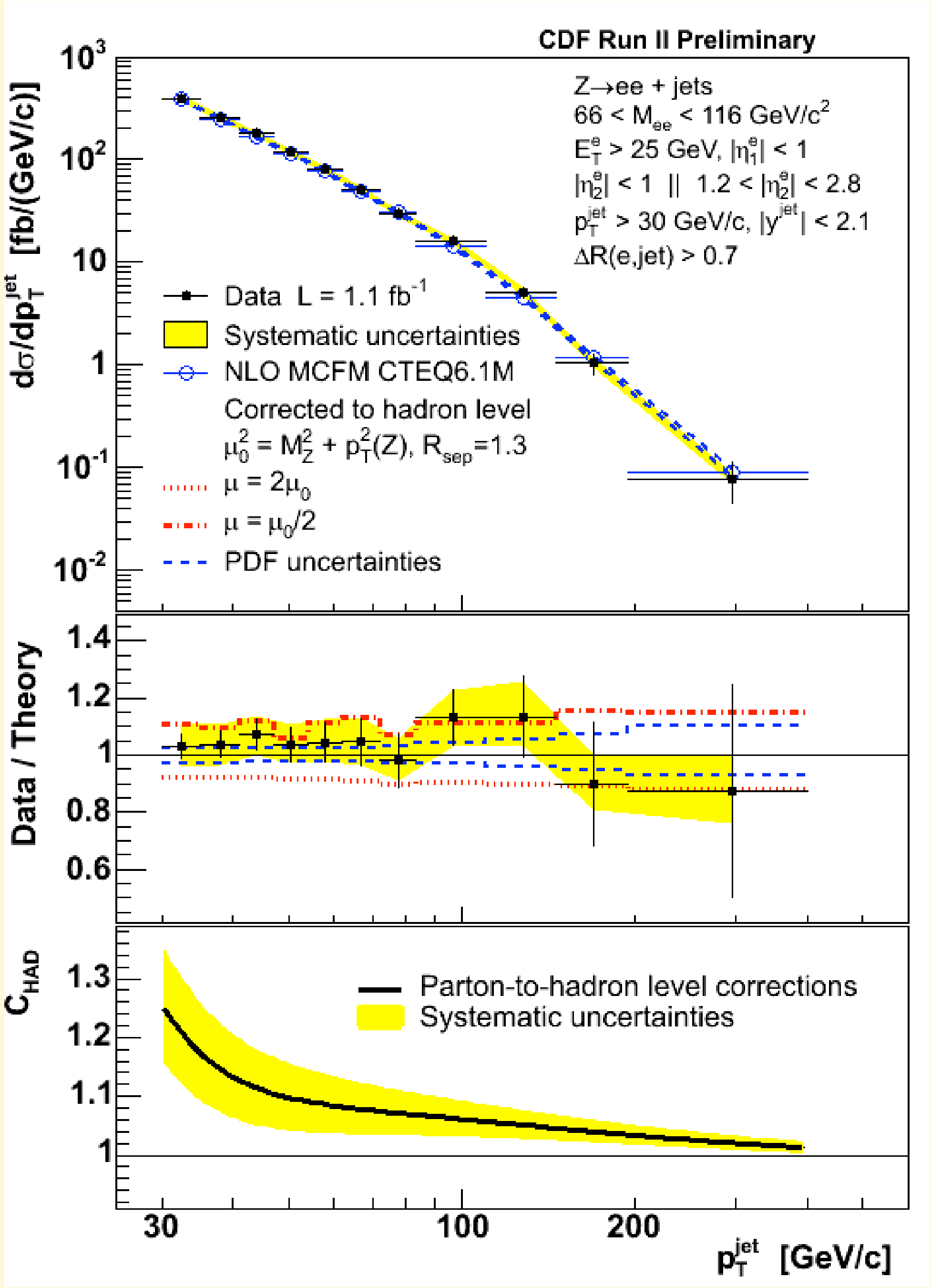




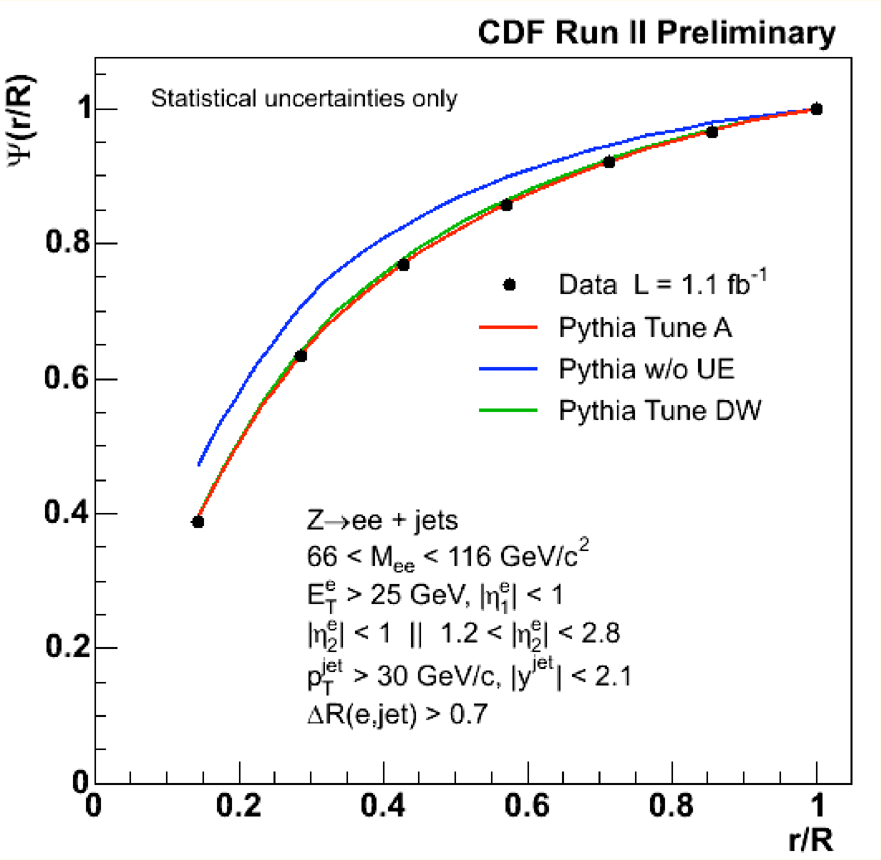


Leading jet in Z+jets: NLO vs CDF data

(Analysis web page: http://www-cdf.fnal.gov/physics/new/qcd/zjets_07/public.html)



Integrated jet shape



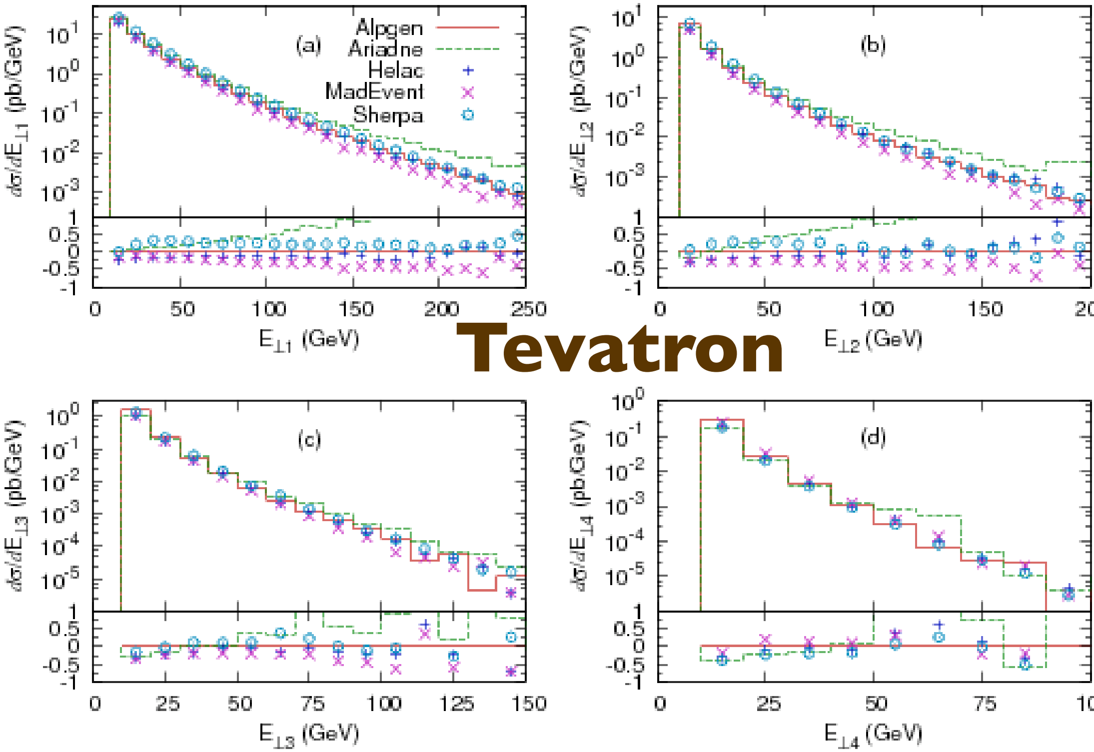
Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions *

Alpgen, Ariadne, Helac, MadEvent, Sherpa

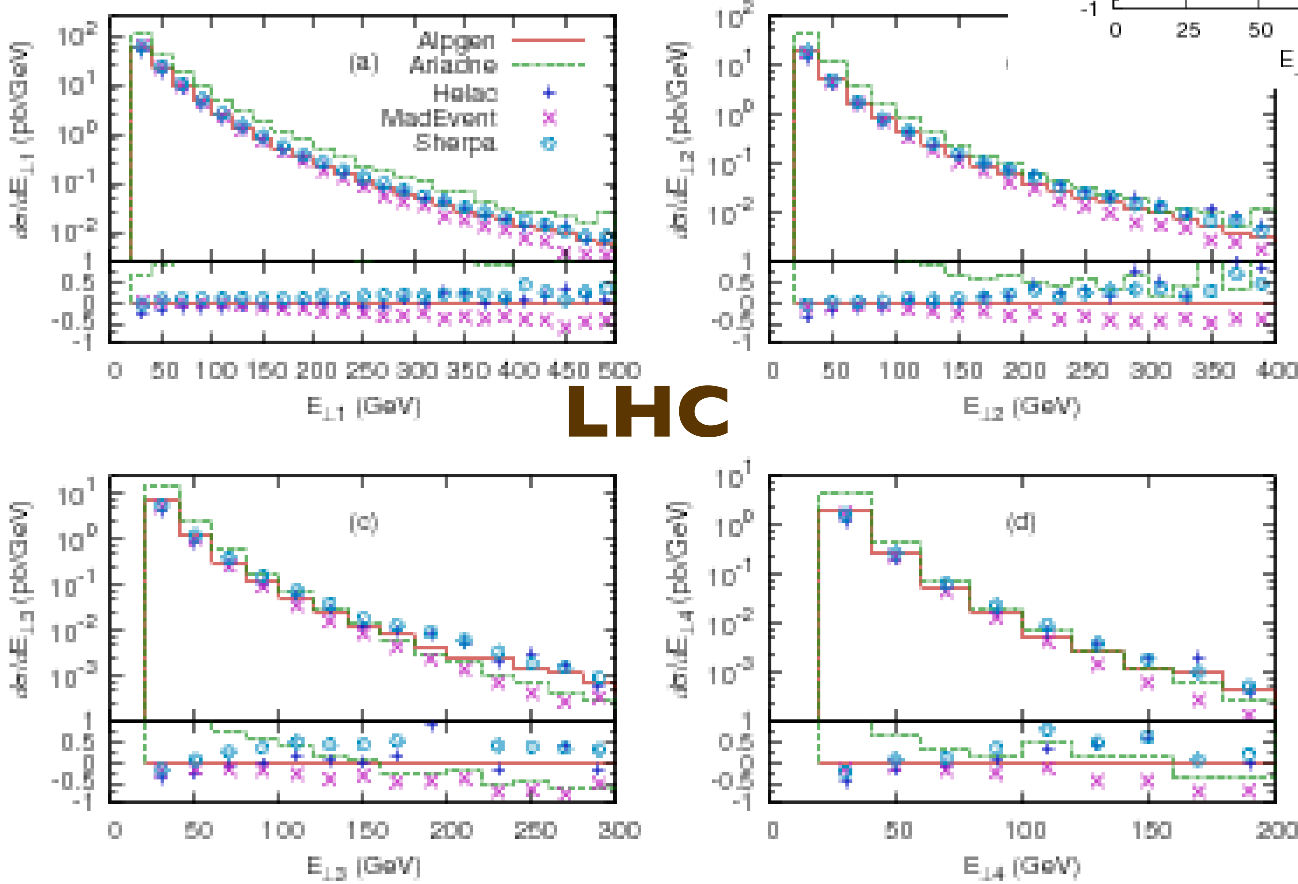
J. Alwall[1], S. Höche[2], F. Krauss[2], N. Lavesson[3], L. Lönnblad[3], F. Maltoni[4], M.L. Mangano[5], M. Moretti[6], C.G. Papadopoulos[7], F. Piccinini[8], S. Schumann[9], M. Treccani[6], J. Winter[9], M. Worek[10,11]

arXiv:0706.2569

W+multijet, jet E_T spectra

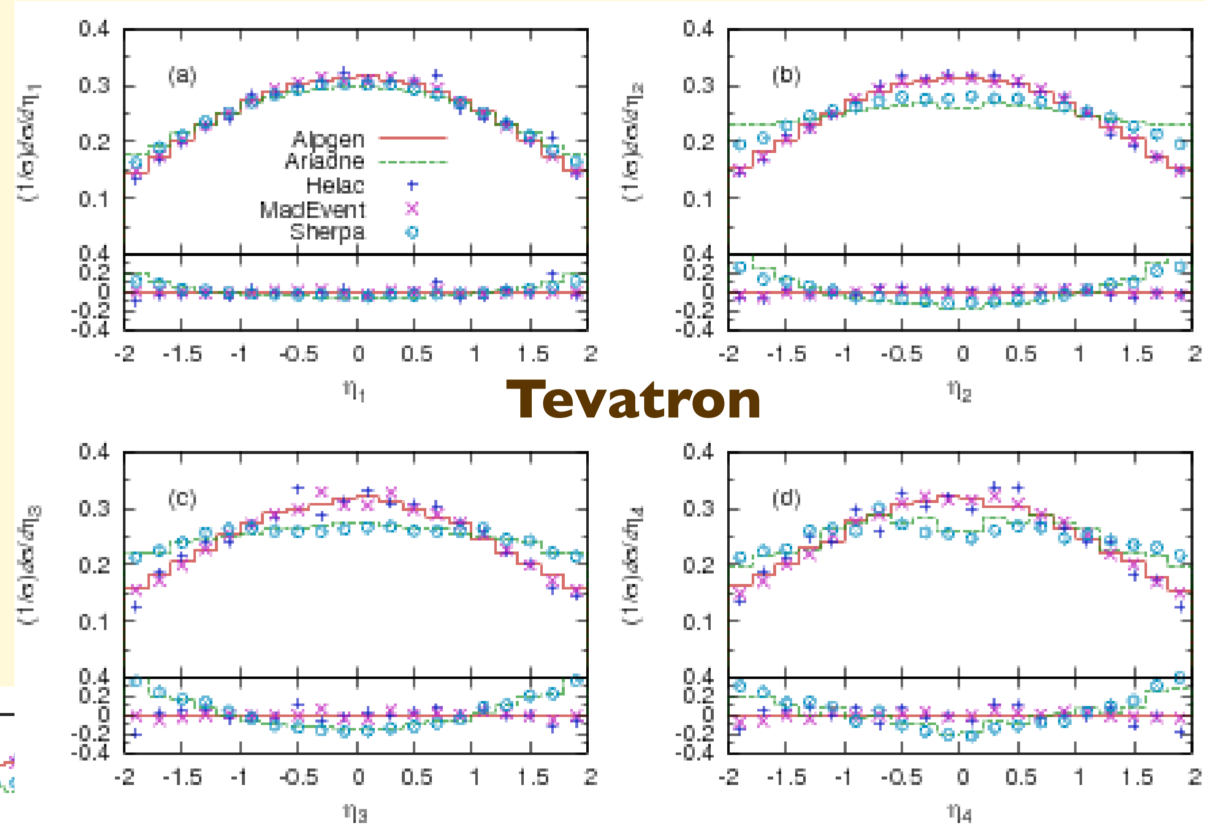


Tevatron

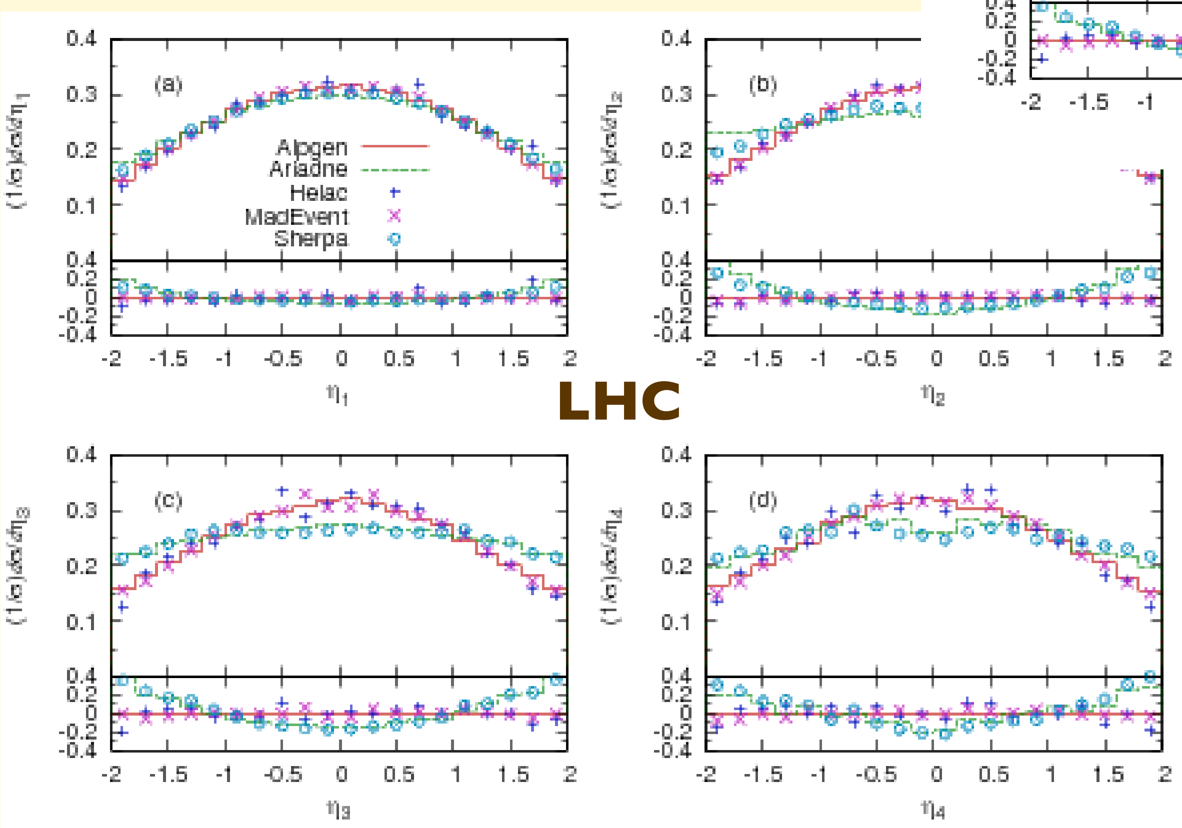


LHC

Jet rapidity distributions



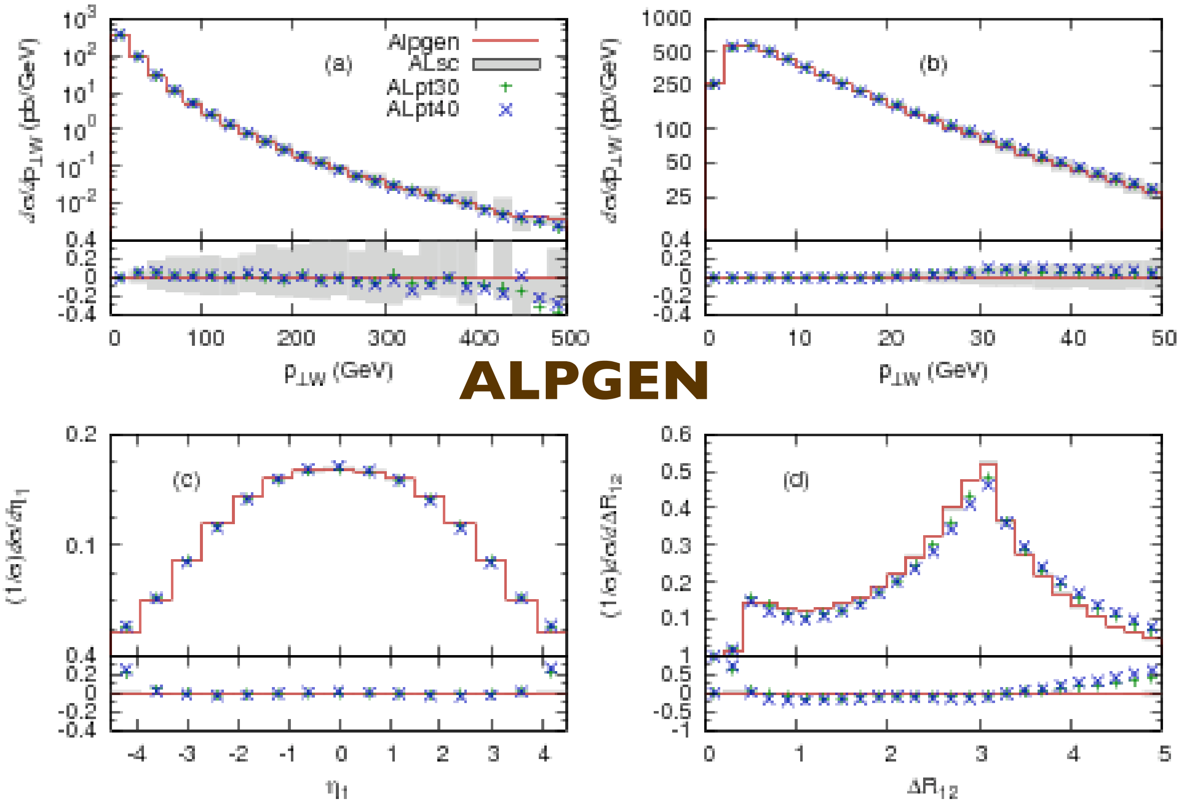
Tevatron



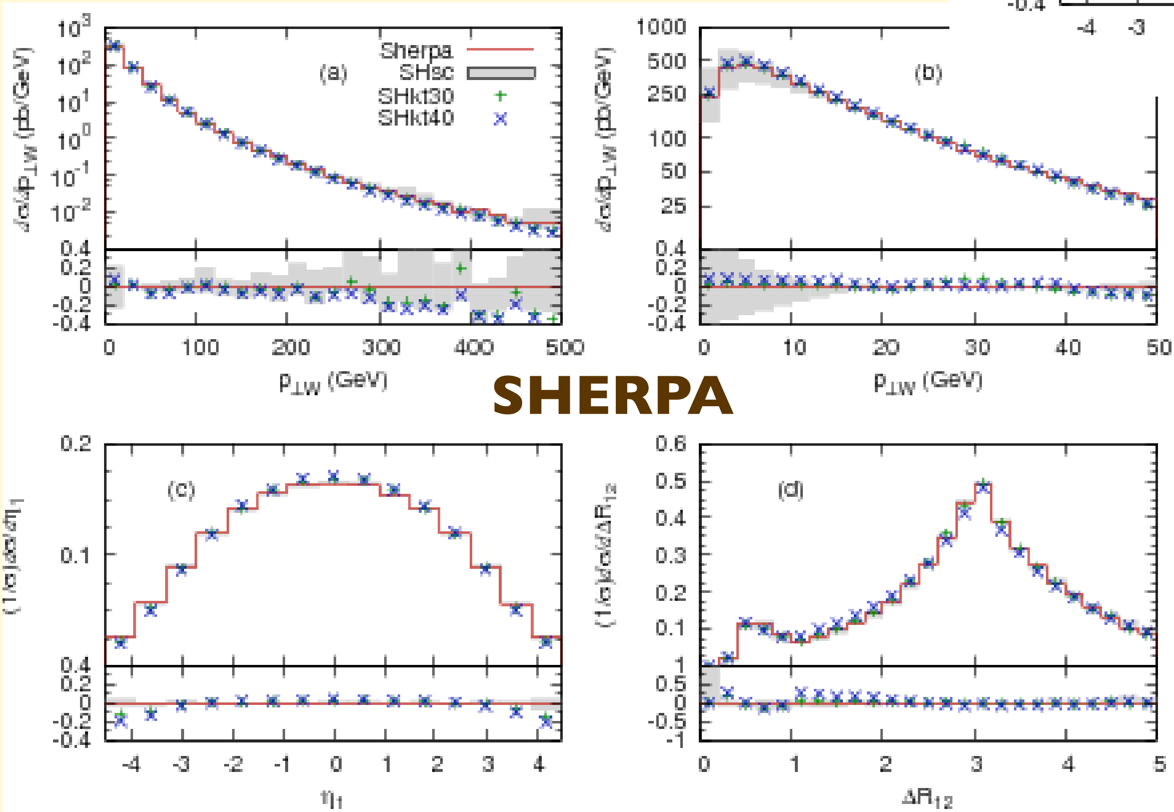
LHC

Examples of systematic uncertainty studies

LHC energy



ALPGEN



SHERPA

Conclusions

- Basic MC tools for backgrounds to SUSY at the LHC are becoming mature
- Validation efforts of MC tools for SM physics are underway at the Tevatron

On the other hand ...

- More work required to reach a firm control of all needed bg channels to the most general SUSY signal at LHC (e.g. jets+MET in association with multiple leptons, heavy quarks, photons, etc)

... we have the tools, but how do we prove them right ?

- The definition of an overall and coherent campaign of MC testing, validation and tuning at the LHC will probably happen only once the data are available, and the first comparisons will give us an idea of how far off we are.