MC tools for the VLHC

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What do we need from MC tools for the VLHC?

- At this stage, tools for the evaluation of the physics potential and for the design of appropriate detectors.
- Most deficiencies and unknowns will be sorted out with the first data, turning the MC's into discovery and analysis tools

The assessment of the readiness of MC tools for VLHC studies depends on several factors:

- Physics to be done, and detector capabilities
- Luminosity
- Energy

In this talk I will review the open issues, the ongoing progress, and the prospects for new developments of relevance for LHC and VLHC physics

3' progress report on MC's for hadron colliders

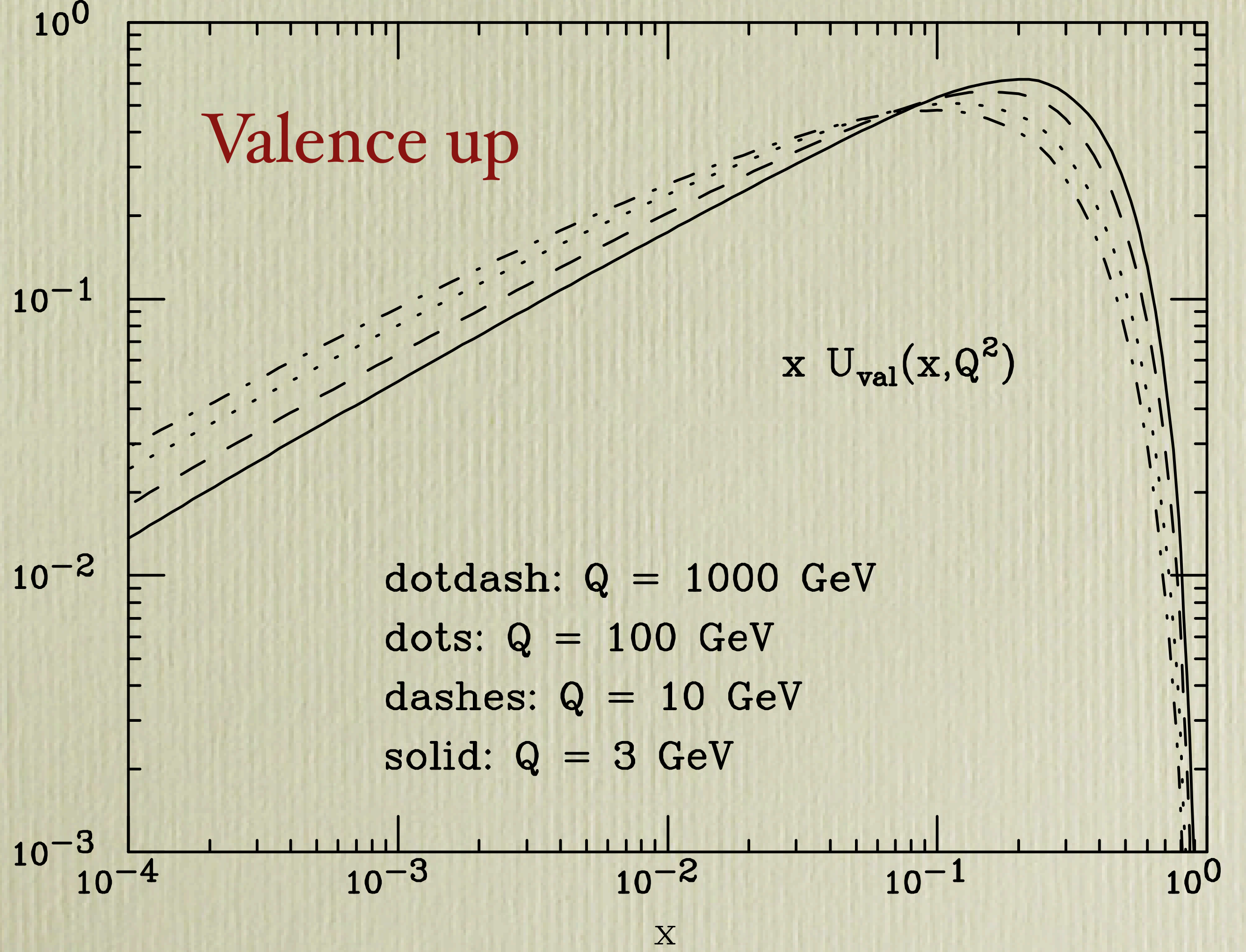
- New techniques and new codes to describe, at LO, complex multijet final states:
  - most SM processes with up to 8 final-state hard objects (partons, gauge bosons, leptons) can be calculated
  - new techniques available to consistently merge these calculations with shower MC's
- New techniques and new codes for NLO, parton-level, event generators
  - most SM processes with 2 and some with 3 final-state hard objects (3 jets, W/Z+2jets) are calculated and encoded
- New technique and new code to consistently merge NLO calculations with full shower and hadronization evolution:
  - so far available for single and double gauge boson production, and for heavy quark pairs
- C++ versions of main shower MC's being readied, improved descriptions of shower evolution, hadronization, etc etc

Very active area of research, amazing new achievements and very powerful tools being developed for Tevatron and LHC

Physics objectives and objects

- Discovery of new phenomena:
  - high-Et observables:
    - direct: production of new particles, M up to 20÷30% E_{beam}

BSM simulations



Physics objectives and objects

- Discovery of new phenomena:
  - high-Et observables:
    - direct: production of new particles, M up to 20÷30% E_{beam}
    - indirect: anomalies in expected spectra, e.g. high-Et jets
  - low-Et observables:
    - low-rate production of "light" objects (e.g. HH production)
    - rare decays (H→ , Bs→ , t→Zc, ...)
  - Notice: final states of very massive objects will still be often dominated by few-100 GeV observables:
    - massive SUSY states will cascade decay
    - W/Z/H/top are often part of the decay chains, and the reconstruction of dijet inv masses in the 100-200 GeV range will be crucial

BSM simulations

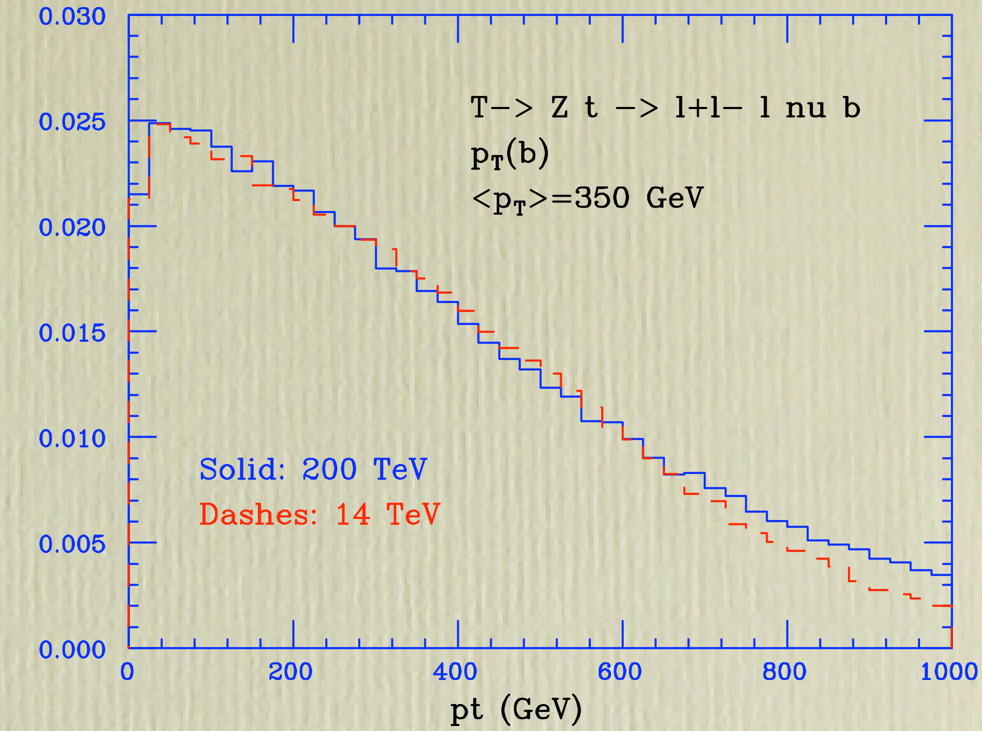
bg control, PDFs, NLO

bg control

bg control, multijet final states

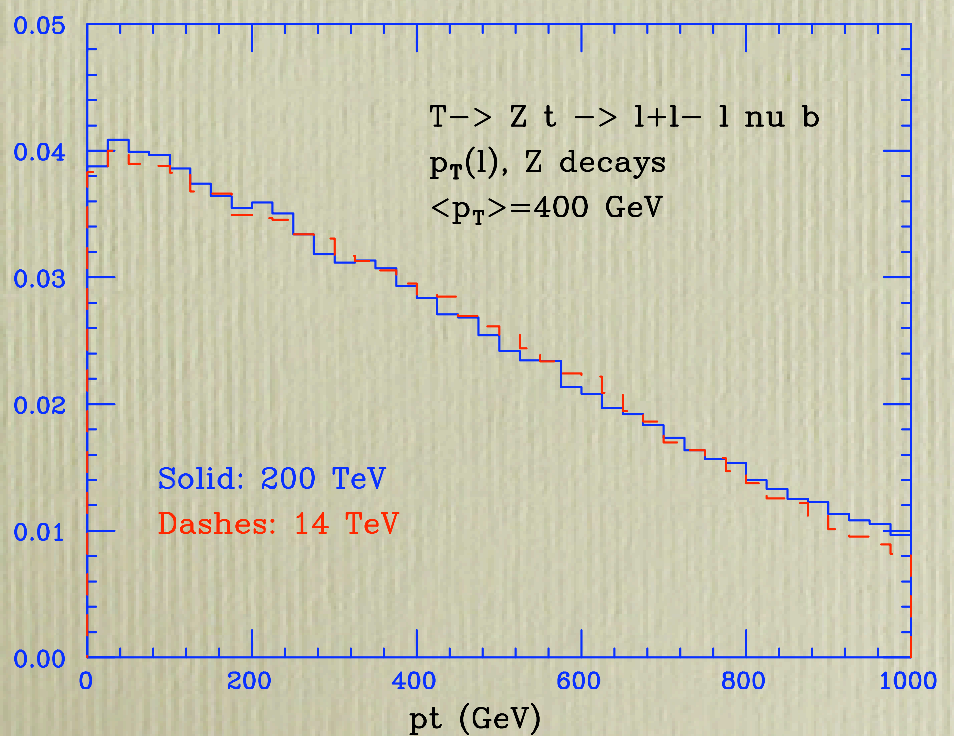
Example, T decays in little-Higgs models

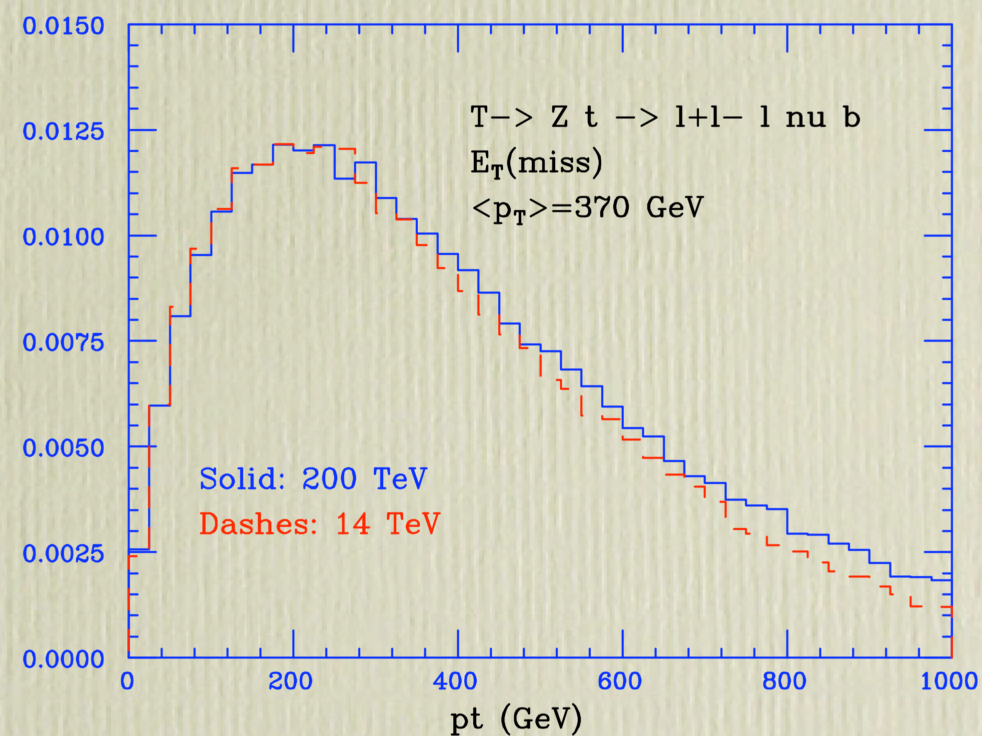
See e.g. Perelstein, Peskin, Pierce, hep-ph/0310039



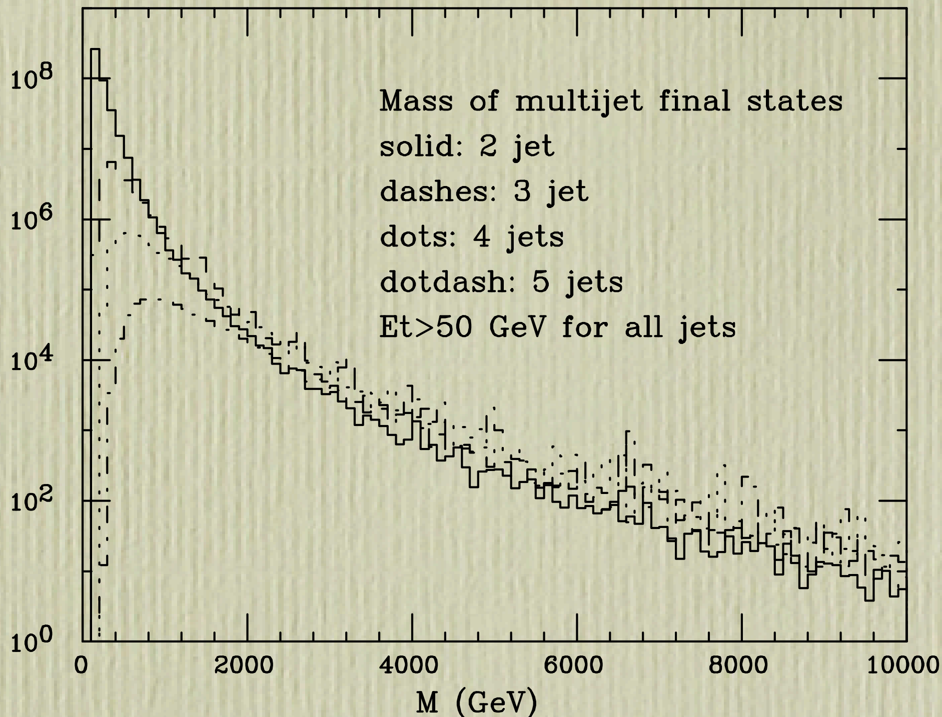
T→Zt, assuming m_T=2 TeV:

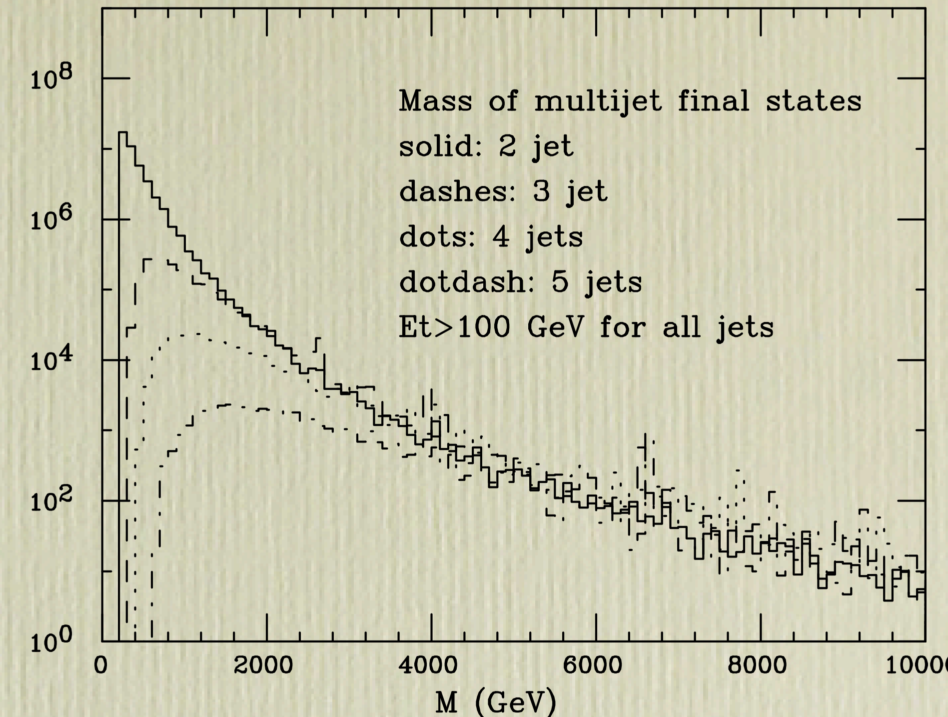
the spectrum of decay products is independent of √S, but the difference in structure of the UE at the two energies can have a big impact (e.g. on the missEt significance)

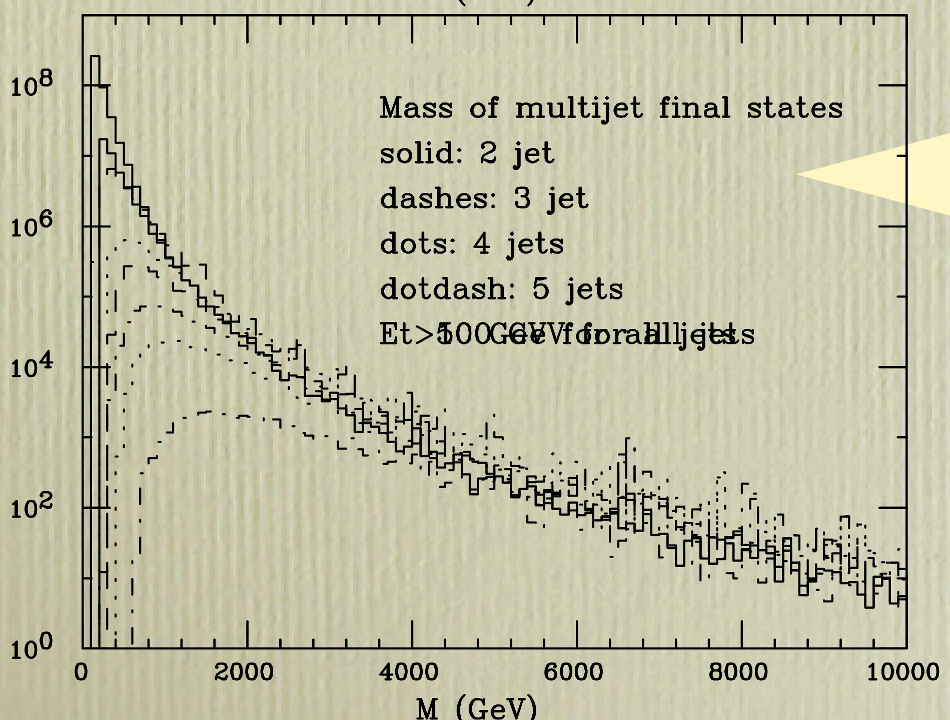




Multijet QCD backgrounds at high mass







Two plots overlayed

High-mass final states are dominated by multijet configurations: need for reliable multijet MC's

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- Precision measurements:
  - SM parameters
  - BSM parameters (masses, couplings)

BSM simulations

bg control, PDFs, NLO

bg control

bg control, multijet final states

bg control, NLO, NNLO

On the role of NLO, NNLO, ...

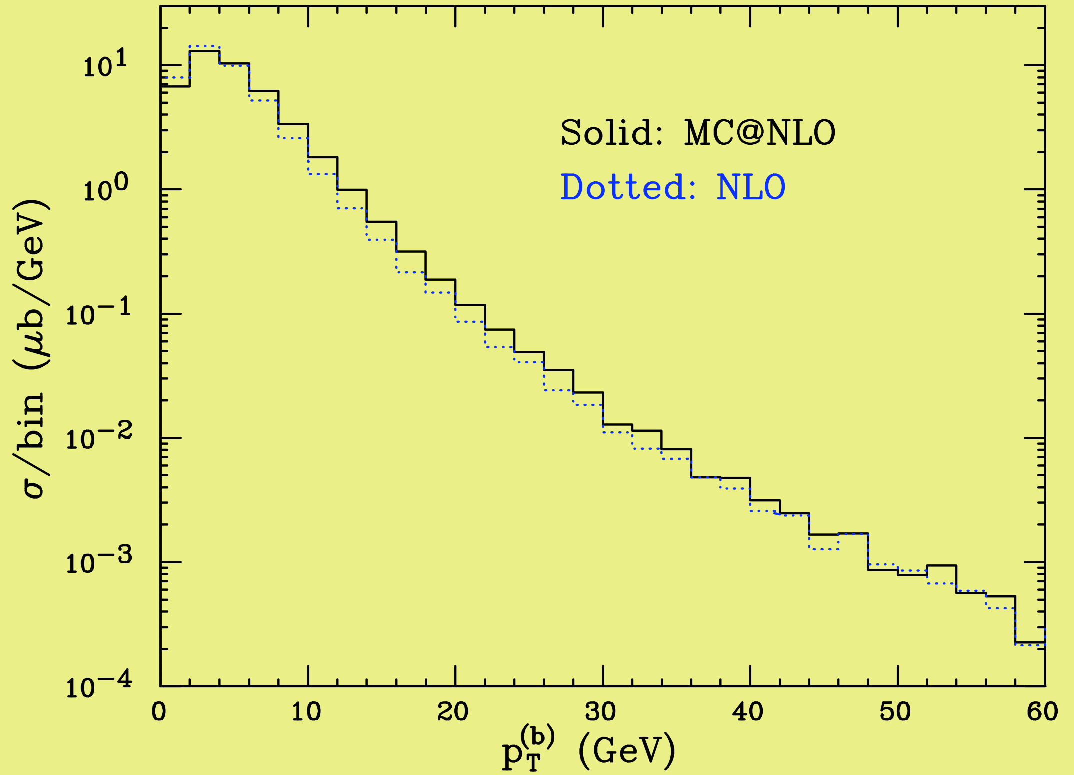
- (N)NLO calculations are essential to extract reliable estimates of the total production rates
- It is highly non-trivial, however, to establish an accurate connection between what is calculated and what is observed.
- QCD physics at LEP taught us that the concept of IR and collinear safety, while essential to justify the use of fixed-order perturbative calculations, does not guarantee the accuracy of such calculations.
- The impact of power corrections, as well as of the resummation of large logs, is crucial for a faithful description of the data. This is true even at high-Q

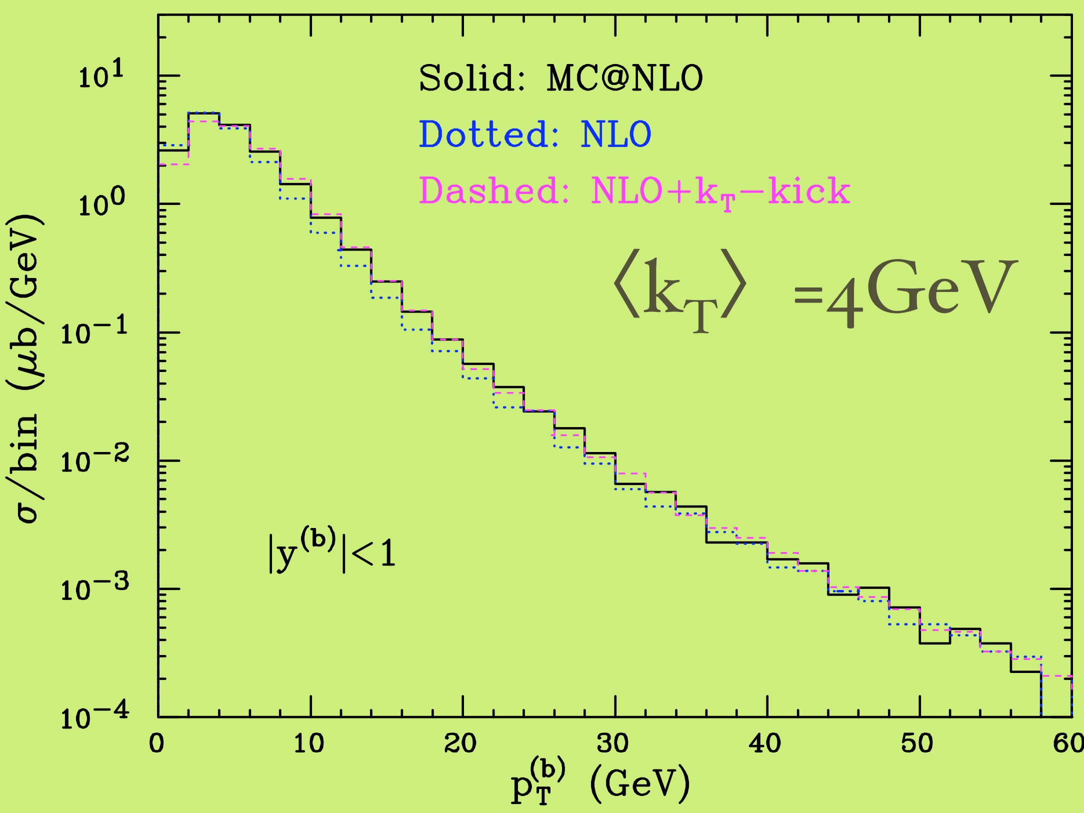
NLO vs shower: b production as a test case

Frixione, Nason, Webber, hep-ph/0305252: merging of the NLO calculation with the Herwig parton shower

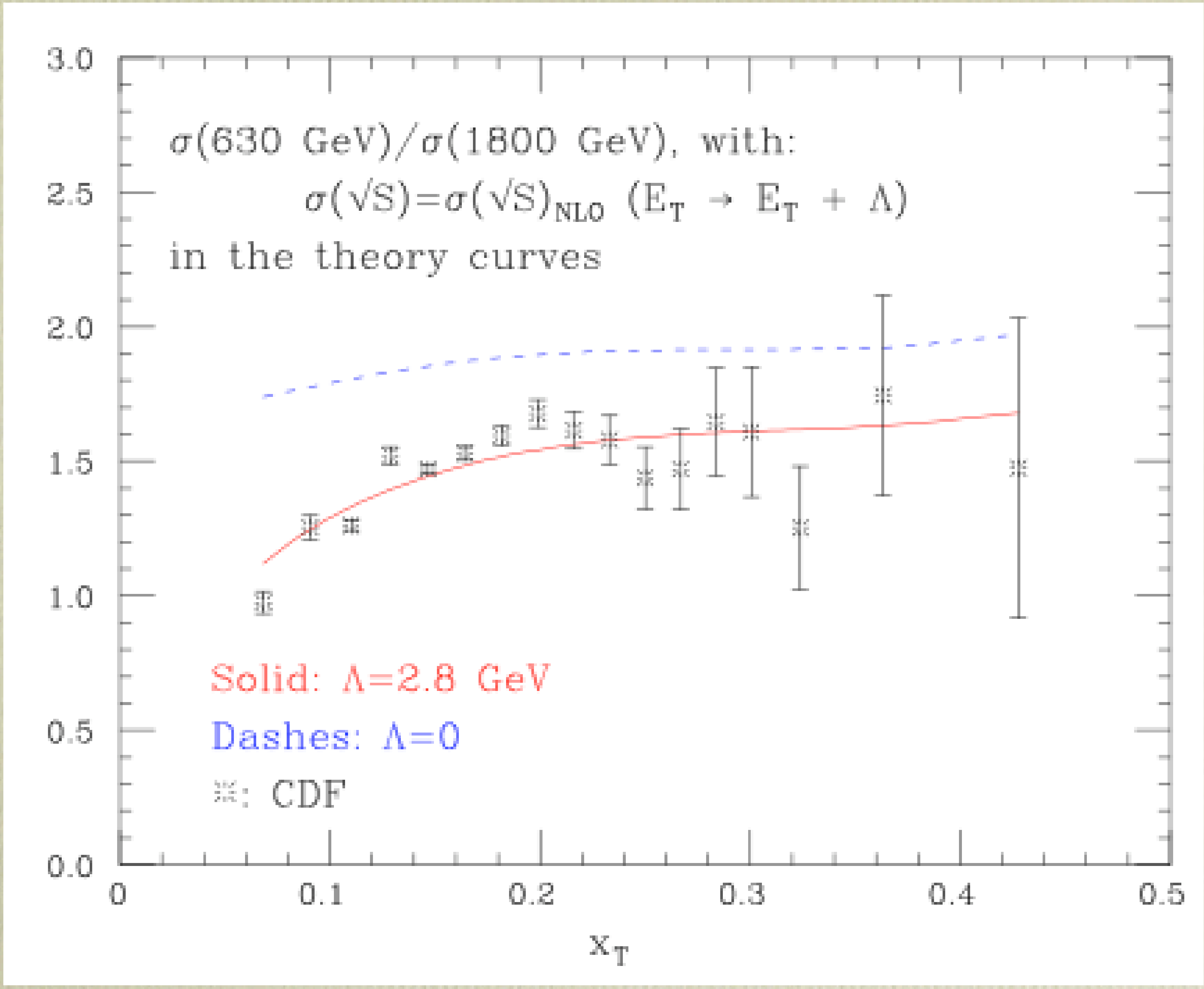
Shower corrections are large, and strongly modify the shape of the spectrum, even at large pt, far away from the natural Sudakov region

The impact of higher-order logarithmic corrections, as described by a shower MC, is often more important than that of NLO corrections. The knowledge of exact NLO corrections is useless unless these are complemented by a complete description of the initial- and final-state evolution





Example: impact of power corrections in jet production at the Tevatron



Example: accuracy in the extraction of the W cross-section

- NNLO total X-sections known, residual theory uncertainty ~few%.
- MC necessary to evaluate acceptance, and therefore total σ, to be compared with inclusive calculation.
- Effects other than NNLO seem to be have an effect on acceptance more important than the NLO-NNLO difference.

□(W)	MRST 2000	MRST 2001
NLO		
Fnal	2.39	2.41
LHC	20.5	20.6
NNLO		
Fnal	2.51	2.50
LHC	19.9	20.0

Acceptance for lepton with p_T>20 GeV and $|\eta|$<2.5, using different parameters or approximations

LO	LO, Γ_W=0	LO, no spin corr's	LO, PDF= CTEQ6.19	W+jet, Et>5GeV	Herwig LO	MC@NLO
0.4890(2)	0.4971(2)	0.5259(2)	0.5245(2)	0.5324(2)	0.5063	0.5575

On the role of NLO, NNLO, ...

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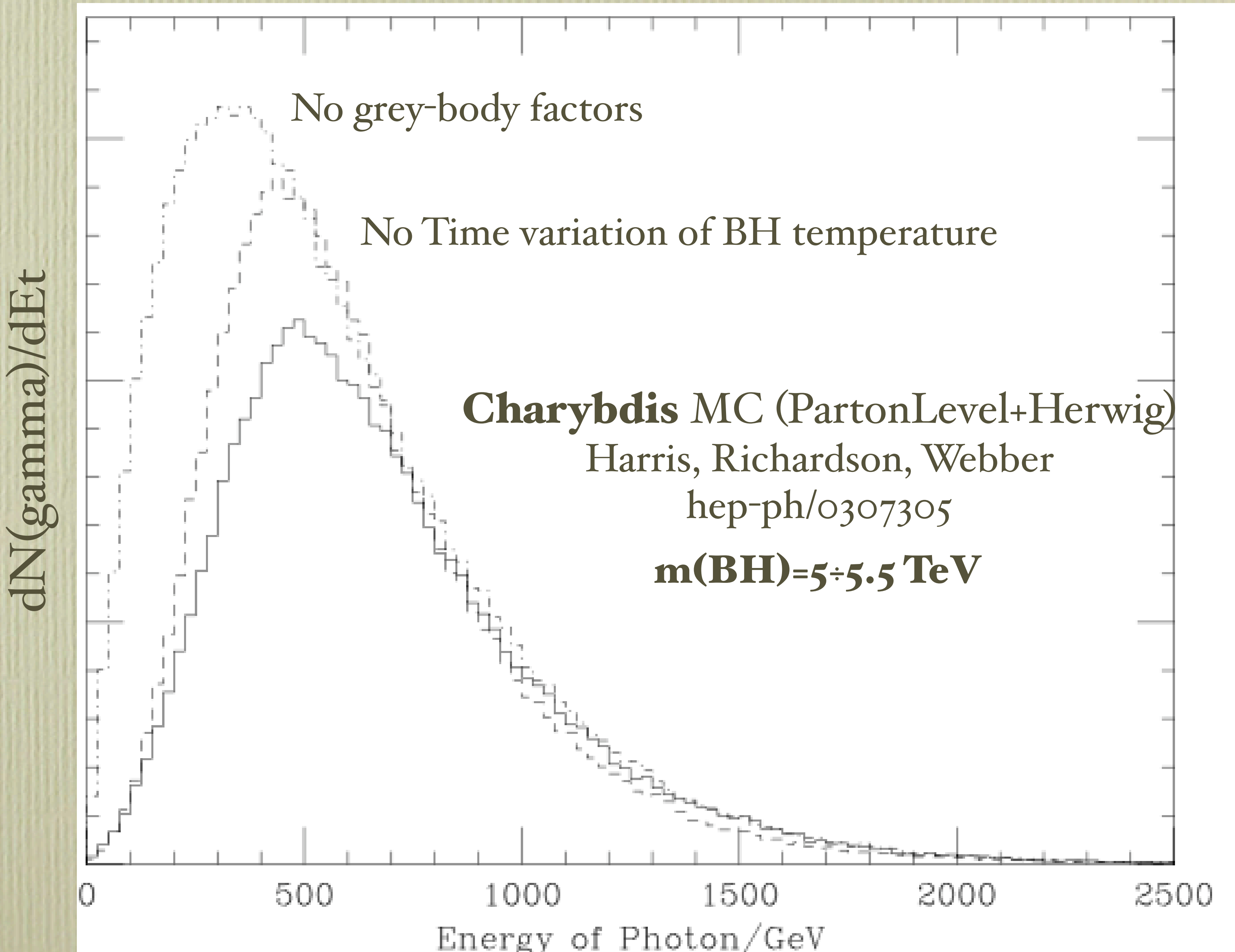
- QCD physics at LEP taught us that the concept of IR and collinear safety, while essential to justify the use of fixed-order perturbative calculations, does not guarantee the accuracy of such calculations.
- The impact of power corrections, as well as of the resummation of large logs, is crucial for a faithful description of the data. This is true even at high-Q
- **A balance between perturbative accuracy and realism in the description of the physical observables (e.g. in the description of the structure of an experimental jet) is mandatory**

NLO results are available today for most processes of interest. The technique by Frixione and Webber allows their consistent merging with shower MC's. Extension to NNLO is far from being even just theoretically formulated, let alone numerically implemented.

MC’s for new physics

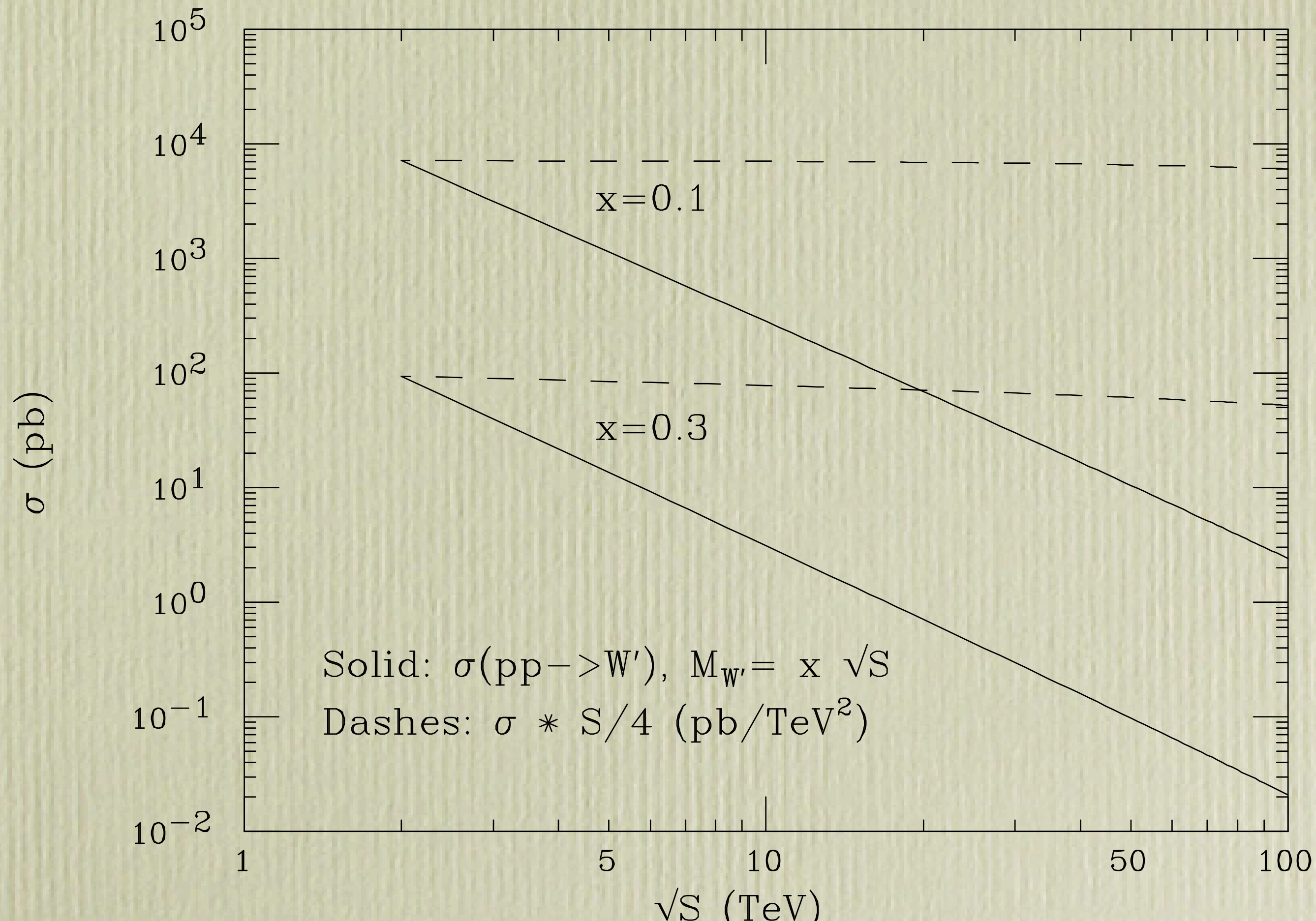
- Development of tools for signals is typically less difficult than for backgrounds. New processes are usually implemented in the MC’s shortly after their invention ...
- Universal convention established (”LesHouches Accord”) to format the output of BSM matrix element calculations in a way compatible with merging with full parton shower generators: final states suitable for detector simulation
- Examples:
    - W’, Z’ etc commonly available
    - SUSY spectra, production and decays in the main MC’s. This includes beyond MSSM cases, such as RPV
    - includes shower evolution off non-standard colour flows (e.g. RPV squark→qq)
    - BH production and decays recently encoded, including grey-body factors, time-dependence effects in the evaporation

Example: Black Hole production and decay at LHC



Luminosity vs Energy: an example, W' production

$$\sigma = \frac{A}{M^2}\int_{\tau=M^2/S}^{1} \frac{dx}{x} f_1(x,M^2)\, f_2(\tau/x,M^2) = \begin{cases} \log(S) & \text{for } M = \text{constant} \\ 1/S & \text{for } M^2/S = \text{constant} \end{cases}$$



The high-mass frontier requires L∝S even in hadronic collisions

High energy: small x issues

Why an issue? Emphasis towards high-Q phenomena!

- It's a high-luminosity problem: what is the structure of the 100's or 1000's of simultaneous events and how does it affect the final states?
  - $\sigma(E_{T,jet}>10$ GeV, $\sqrt{S}=200$ TeV$)=170$mb $\equiv$ σ_{tot}
  - Each event will have at least a couple of 10 GeV jets. Large average jet multiplicity in the range 20-50 GeV, affecting reconstruciton of multi-jet decays, affecting isolation and definition of prompt leptons: will it be possible to identify W's?
  - Rate and spectrum of forward jets (affecting missEt)
  - Average particle multiplicity and spectrum (affecting occupancy in the trackers)
- With the exception of non-cascade decays of super-massive objects (e.g. Z'→ , Z'→jet jet, etc), the presence of this "white noise" has potentially dramatic effects on the ability to do physics.
- **Issue: How reliably can we predict these low-x phenomena?**

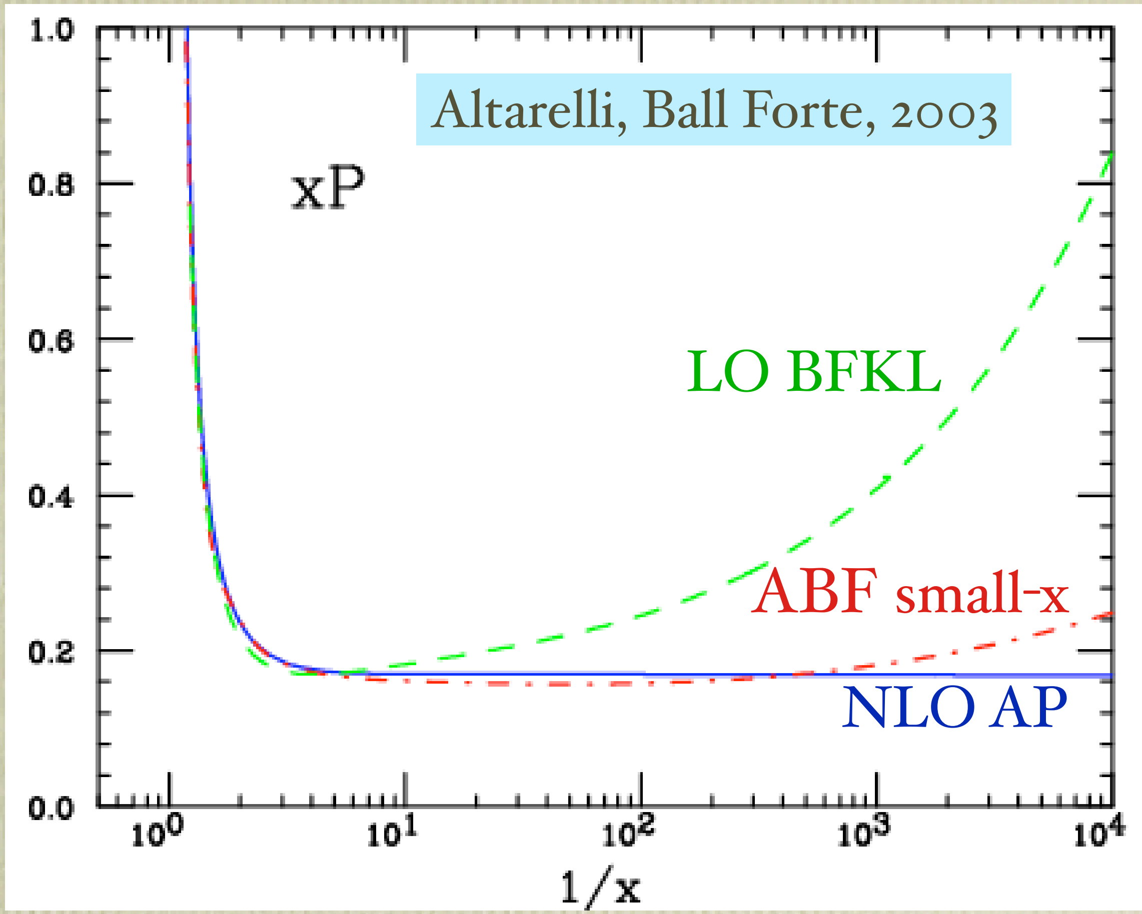
What do we know about low-x in hadronic collisions?

- Common lore, based on LO BFKL analysis, that large logarithmic terms ($\alpha_s \log(1/x)$) lead to strong corrections to predictions based on fixed-order PT and AP PDF evolution. This would invalidate standard MC approaches
- No evidence of a small-x logs at HERA, cross-sections behave as predicted by NLO AP evolution

Progress in the understanding of small-x effects in SF's

Altarelli, Ball, Forte, hep-ph/0306156
Ciafaloni, Colferai, Salam, Stasto, hep-ph/0307188

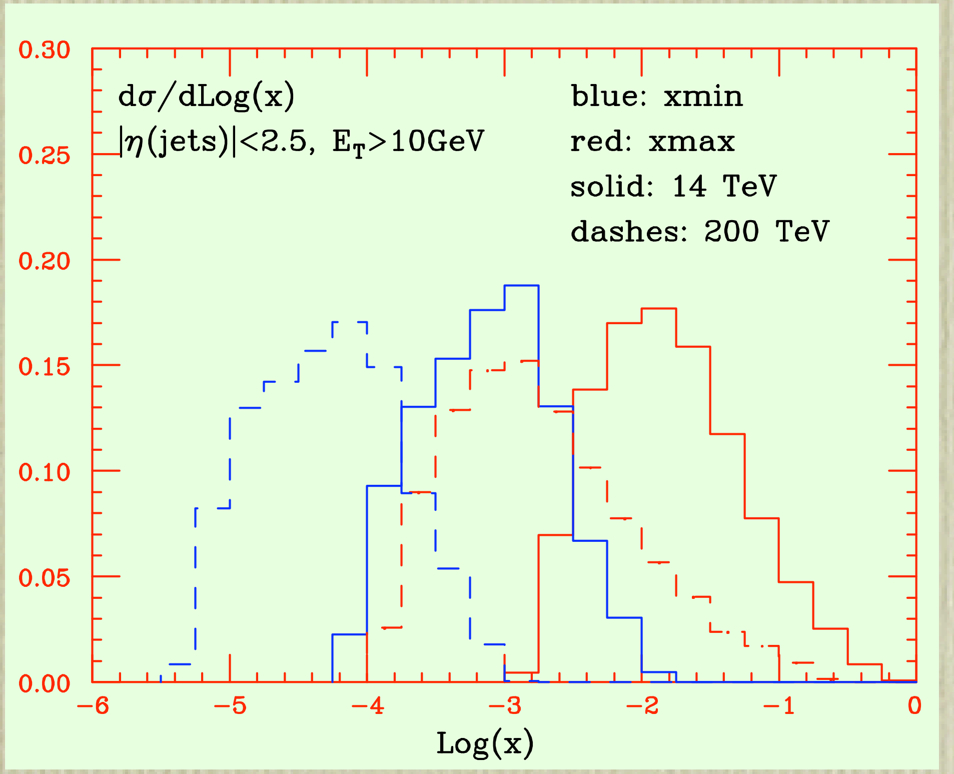
Improved treatment of resummation of $\alpha_s \log(1/x)$ terms smooths out the highly singular behaviour of the BFKL splitting kernels, and leads to agreement with standard NLO AP evolution down to the $x=10^{-4}$ region, consistently with the analyses of the HERA data.

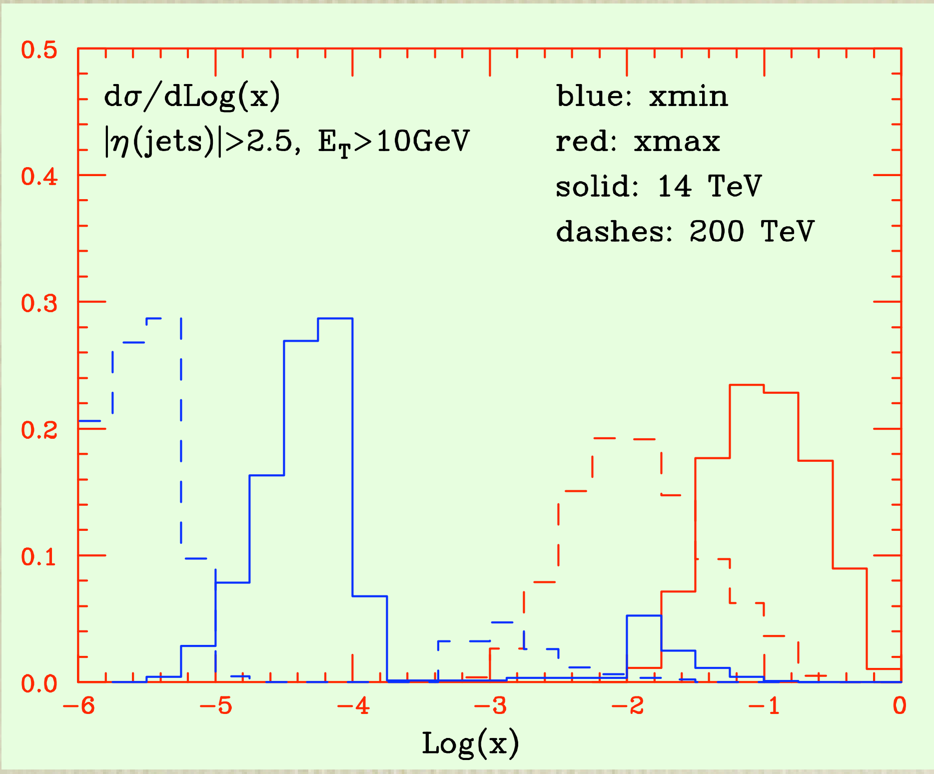


The question remains open as to whether the structure of the final state predicted by the AP evolution is correct (multiplicities, spectra, etc).

TOOLS AND VALIDATION ON DATA NEEDED

x spectra in low-Et dijet events

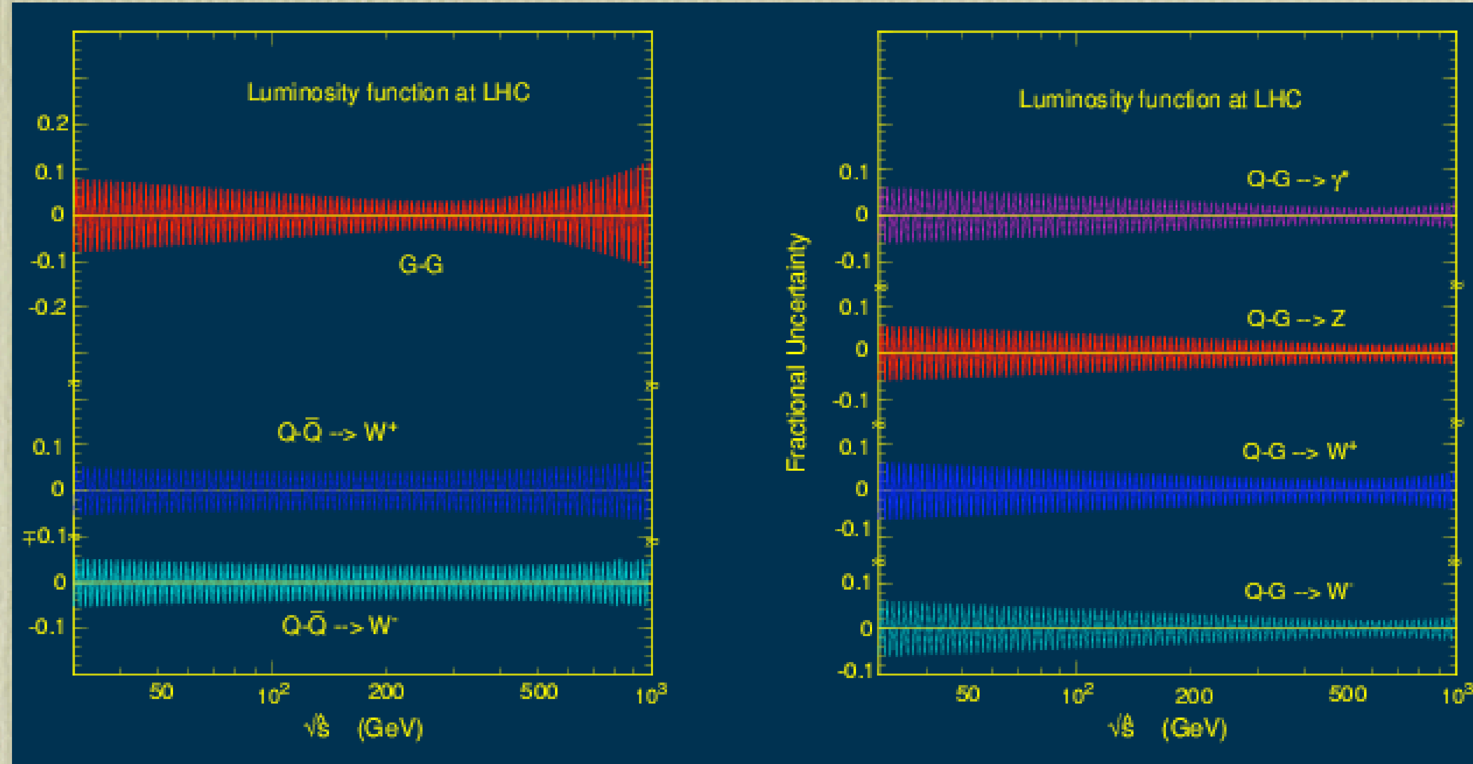


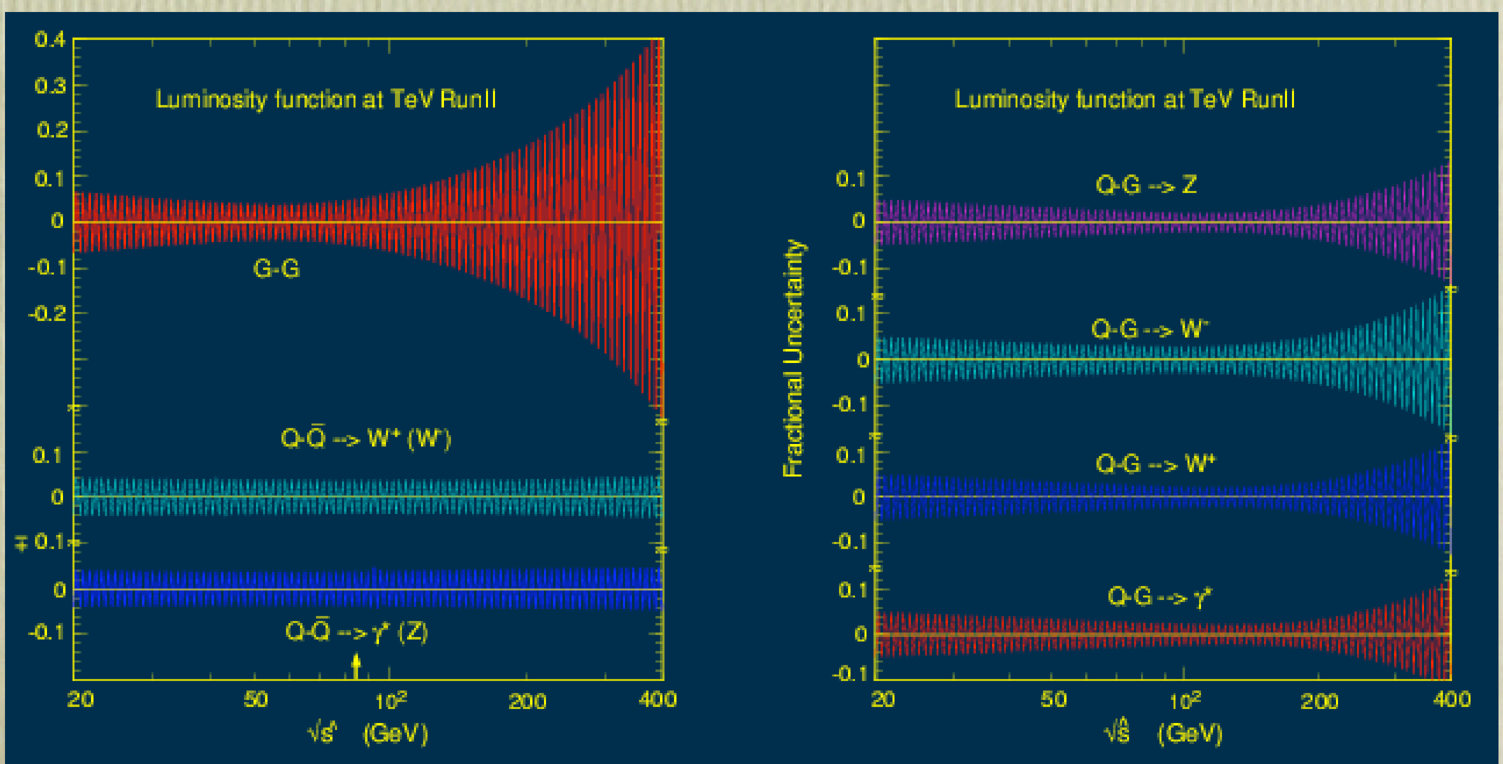


The range of x probed at the VLHC for central production of 10 GeV jets (the bulk of the total cross-section) can be explored at the LHC with forward production

PDF uncertainties

CTEQ6M analysis of systematic uncertainties on the partonic luminosity, as a function of partonic CM energy





Accurate predictions for the LHC will require:

+ NNLO evolution kernels
+ NNLO coeff functions
+ more data at low/high x and larger Q: use LHC?

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    - the total b cross-section (central region) is OK!

b production at Run II

Major new developments:

- CDF's ability to reach pt(b)=0
- Better knowledge of fragmentation functions from LEP/SLD Cacciari, Greco, Nason

Results (b):

CDF:

$\sigma(b, |y|<1) = 29.4 \pm 0.6 \; ^{+6.2}_{-5.4}$

NLO QCD:

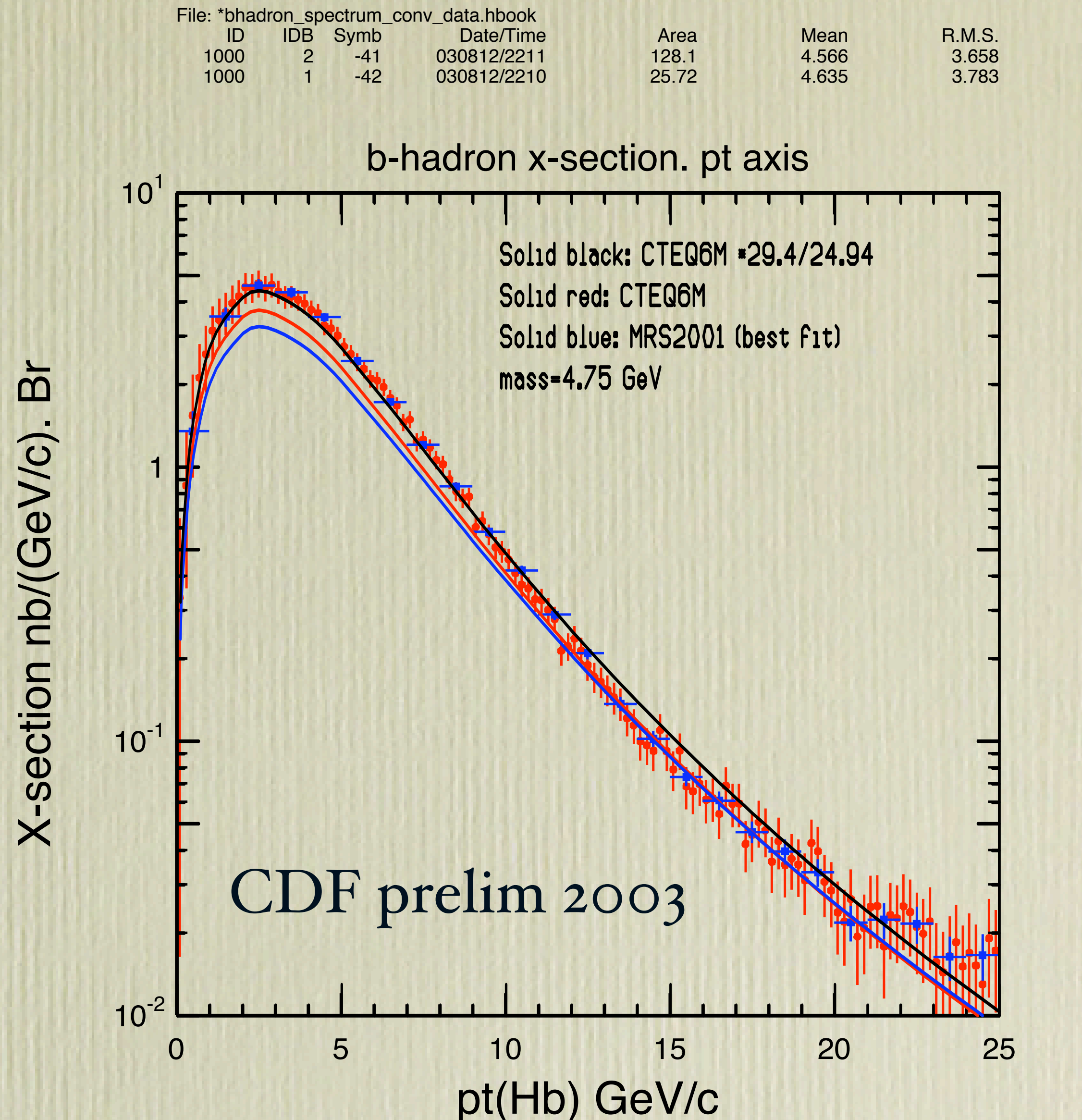
$\sigma(b, m_b=4.75, |y|<1) = 23.7 \; ^{+5.6}_{-3.5}$

$=m_T/2$

$=m_T$

$=2m_T$

$\sigma(b, m_b=4.5, |y|<1) = 28.2 \; ^{+6.3}_{-4.3}$



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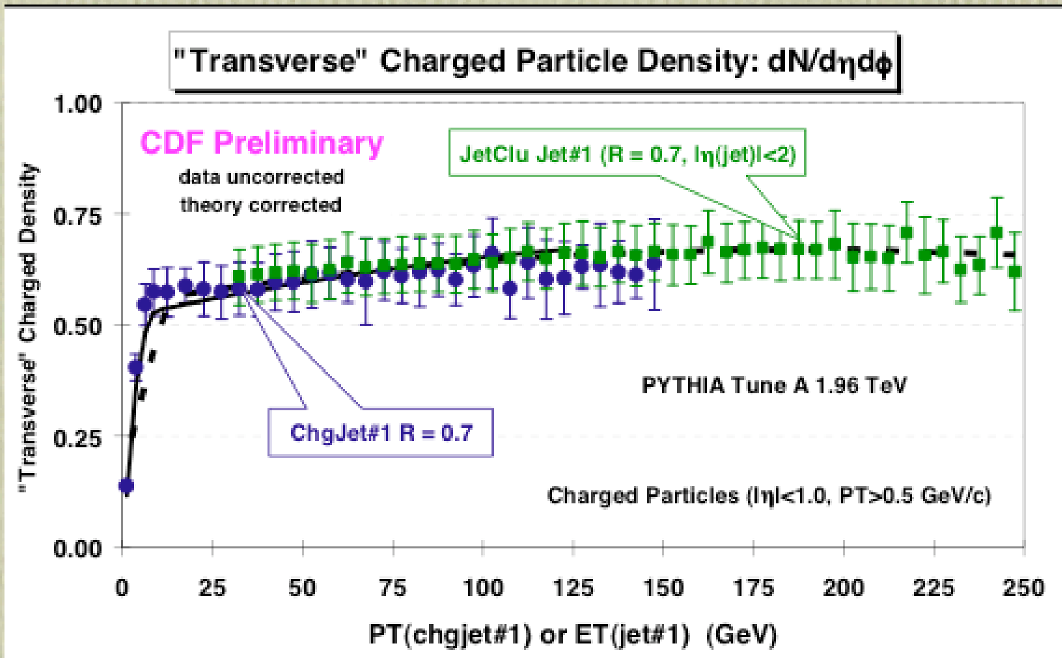
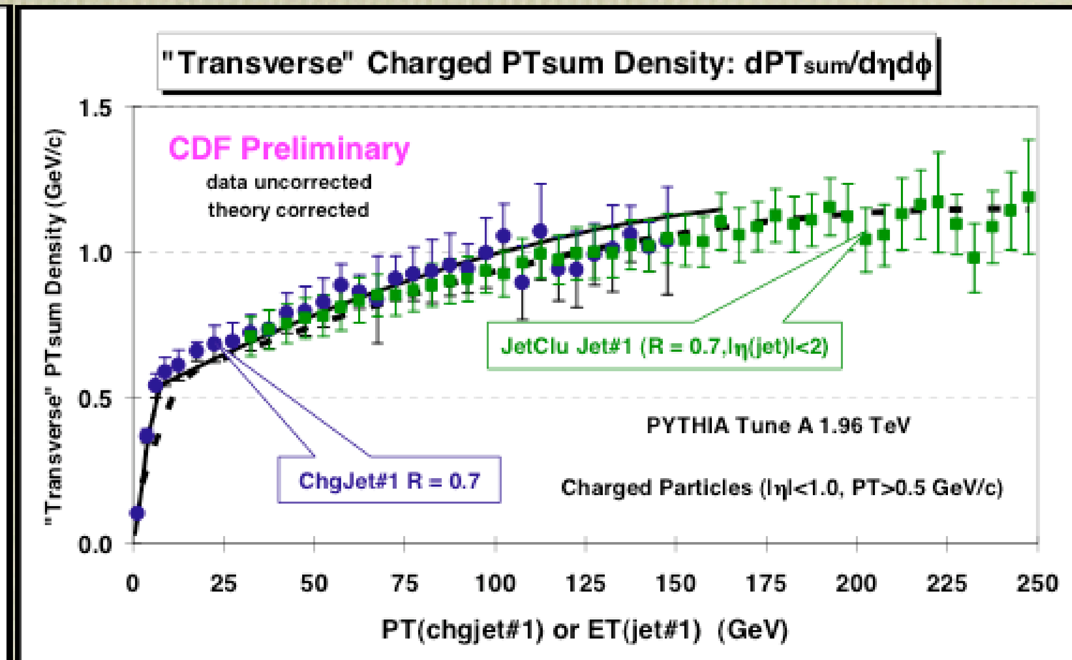
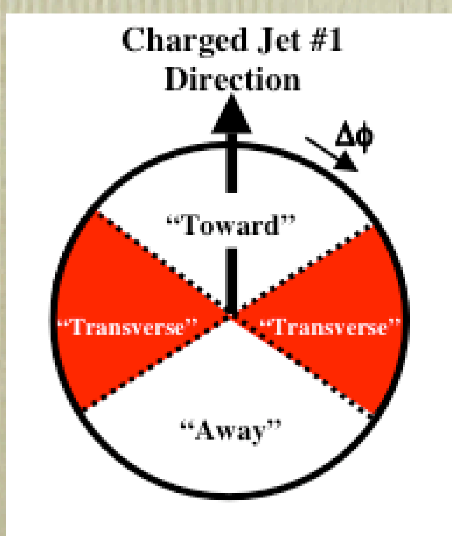
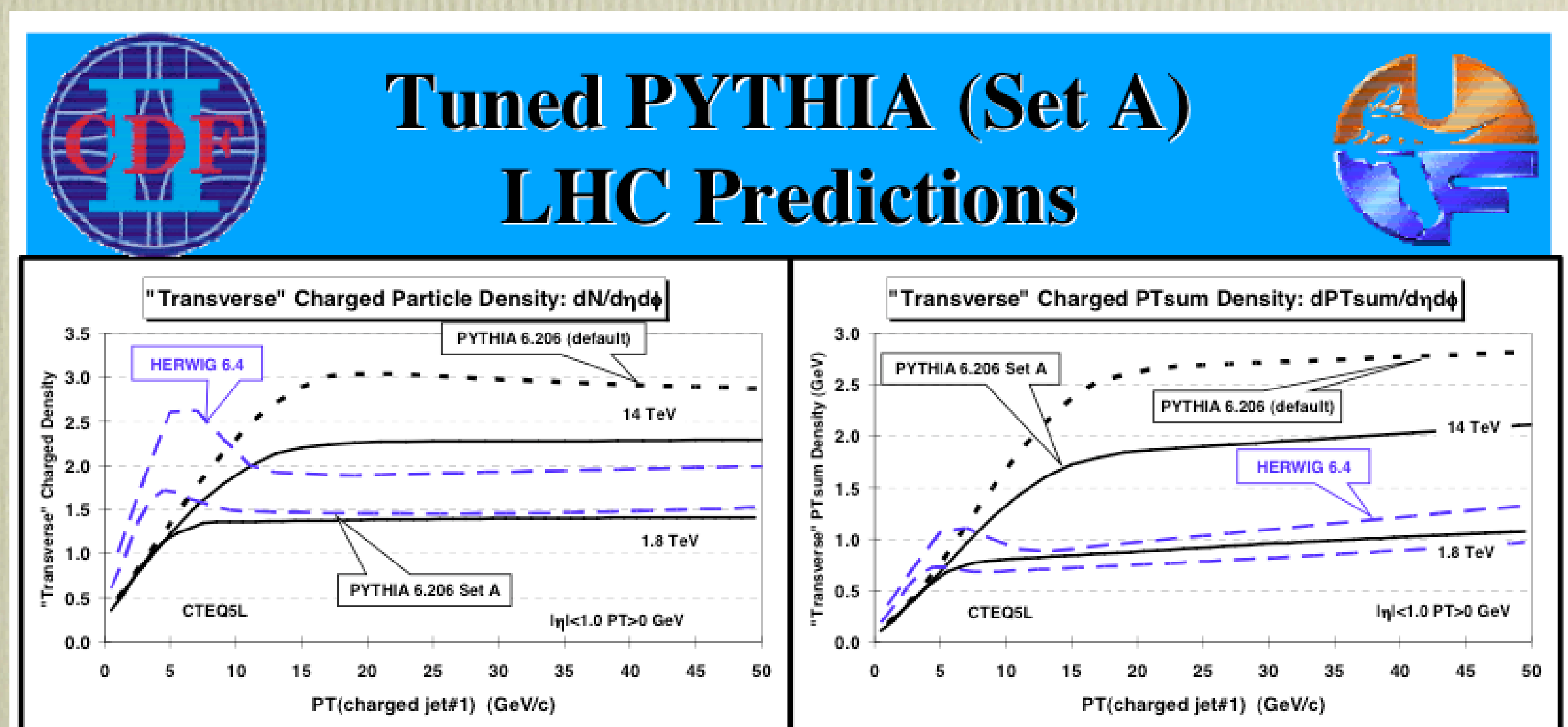
  - structure of UE event in low-Et jet production OK (with proper modeling of UE, via multiparton scattering)

MC UE tuning with CDF data (R.Field, CDF)

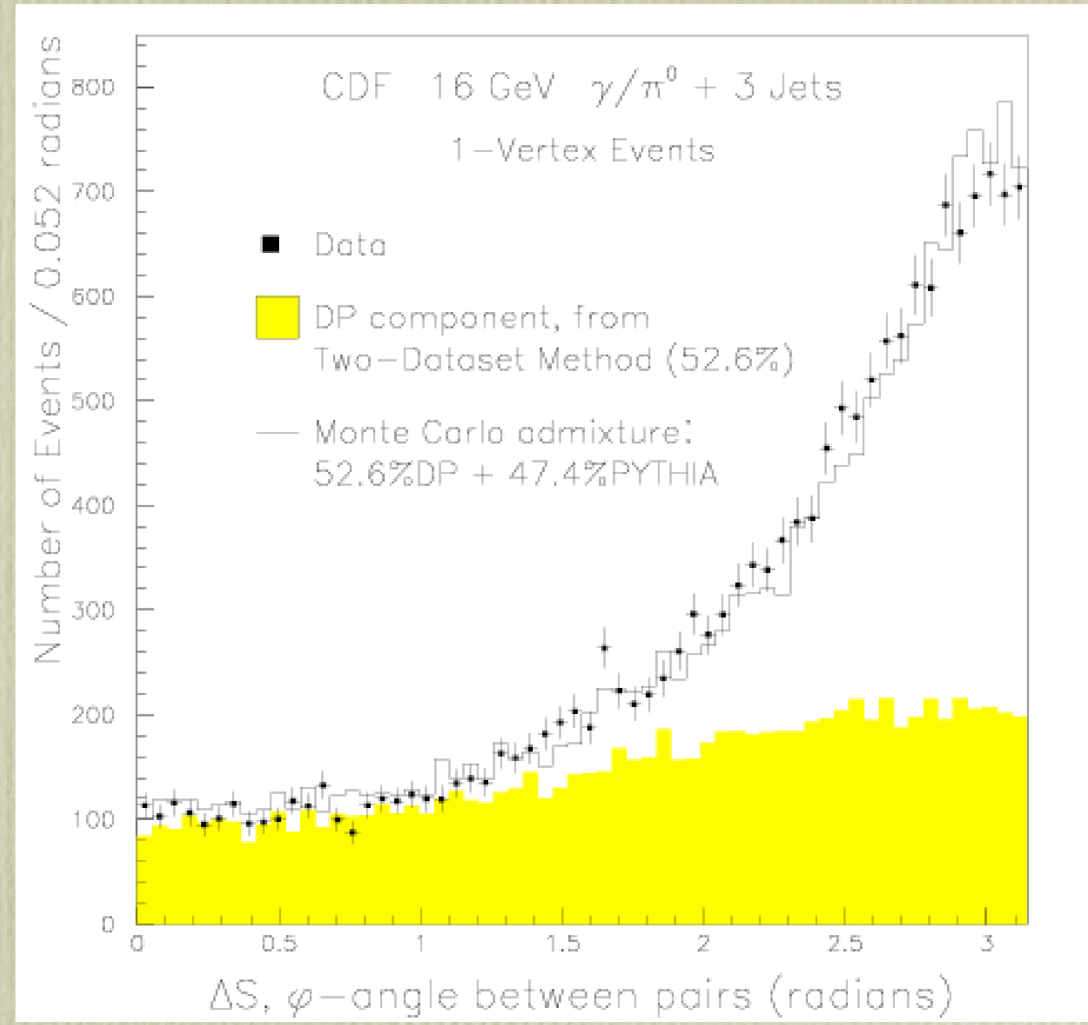








Direct evidence for multiparton collisions



Since $\sigma_{tot}=\sigma_{jet}(Et>10GeV)$, each individual collision t the VLHC will lead to multiple hard scatterings, even at low luminosity

Need concrete models to describe correlations in multiparton density distributions

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Conclusion: LHC will be crucial to give us information on low-x phenomena usable in the context of VLHC physics modeling

Conclusions

- MC development is in good health, lots of recent progress, several young and active new players
- Not enough known about the physics and detectors of a VLHC to give a clear ranking of priorities and difficulties
- Critical evaluation of what are the areas in major need of development, to ensure uniform distribution of systematic uncertainties across the different sources
- On the short term, validation against data from the Tevatron should be given high priority in the analysis plans:
  - structure of UE
  - multiparton correlations
  - description of jet structures, radiation patterns in multijet final states
- Develop analysis strategies to extract the information not available from lower energy (e.g. PDFs in new domains of (x,Q))
- At the LHC, devote enough run time at low luminosity ($10^{31\div32}$) to
  - test the quality of extrapolation from 2TeV
  - determine the missing information