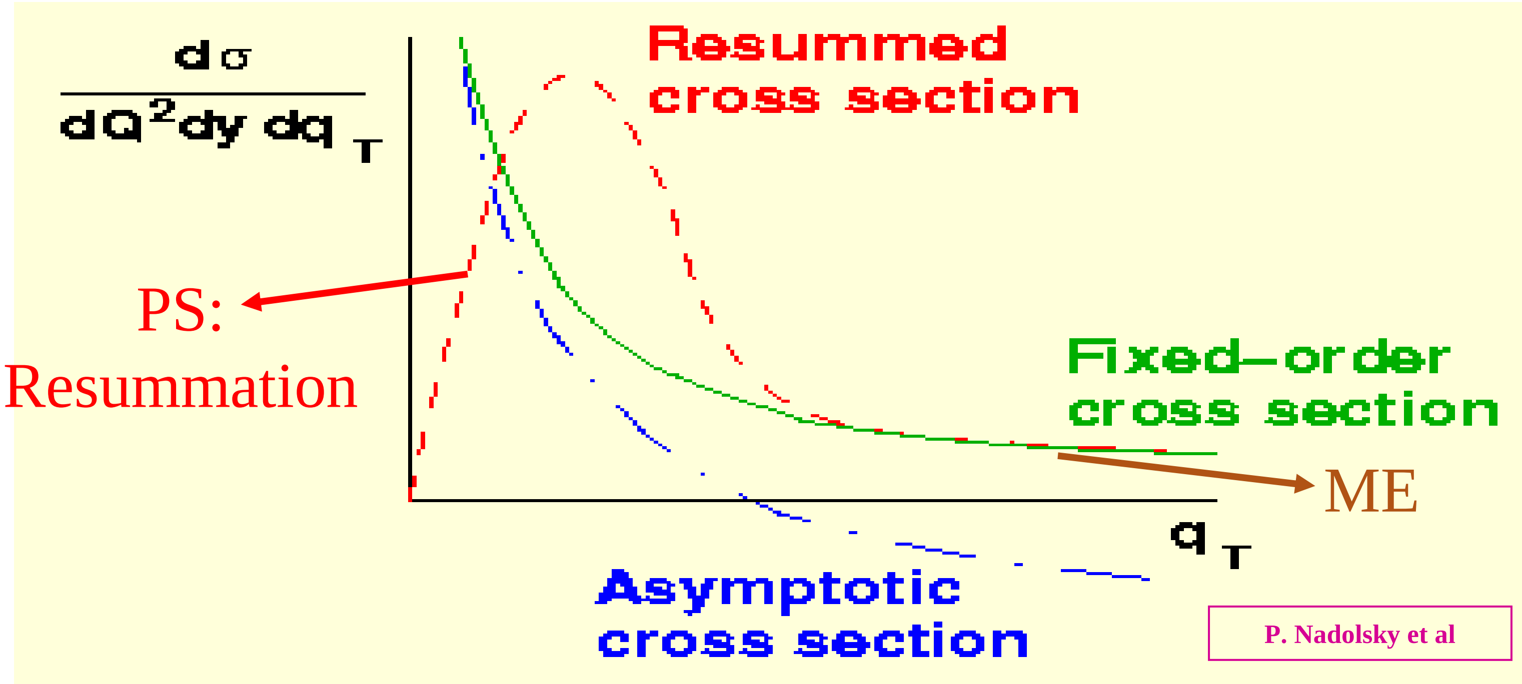
Background Studies in MC: Generators for V+jets

OUTLINE

I. Introduction
II. PS Generators
III. FOME Generators
IV. Conclusions and Prospects

I. Introduction

- **What are the important features to get a reliable description of the V+jets phenomenology at Hadron Colliders?**
  - Need to get both hard (ME pQCD) and soft physics (resummation, UE,…) right, plus correct values for flavor ratios (V+HF-jets / V+LF-jets)
  - Essentially the shapes of the distributions:
    - $p_T(V)$: bkgd kinematics, mET studies/certification, JES,…
    - N_{jets}: especially W+4jets (bkgd for t+tbar → l+jets),…



I. Introduction

- **There are 2 classes of Event Generators:**
  1. **The « Parton Shower » Generators (aka MC)**
  2. **The « Matrix Element » Generators (aka FOME)**

Basic « How To »

PS

- Start from 2→N (LO) ME, w/ N up to 2/3
- Radiate IS and FS gluons
- Start parton showers from those
  - note that each branching iteratively decreases Q(node i)< Q(hard scatter) … downto Q(node f)~Λ_{QCD}
  => it creates a natural link between the hard scatter and the hadronization scale
- Underlying event (including MPI)
- Decay of unstable particles
- …
- SHAPES: accurate at Leading Log (LL)
- RATES: purely LO normalization is retained

ME

- Start from FIXED ORDER (wrt α_S) ME for 2→N processes, w/ N up to 8 (LO) or 2/3 (NLO)
- Cut off divergent regions of the phase space
- Produce exclusive parton level final states in the rest of the phase space
- …
- SHAPES&RATES: purely the chosen fixed order (LO or NLO)

I. Introduction

- There are 2 classes of Event Generators:
  1. The « Parton Shower » (aka MC) Generators
  2. The « Matrix Element » (aka FOME) Generators

PS

Advantages:

• Generate inclusive samples (generate in one shot, directly comparable to data)

Drawbacks:

• Does not account for quantum interferences between compatible transition amplitudes

• Additional jets are mostly produced in special corners of the available phase space (due to the soft and collinear approximation)

Examples:

Pythia, Herwig, Isajet,…

Ariadne (Dipole Showers)

ME

Drawbacks:

• Have to generate exclusive samples (generate in many steps, then mix and merge the samples)

Advantages:

• Explicitely accounts for quantum interferences between compatible transition amplitudes

• Additional jets are correctly produced over the available phase space, but not in some corners (due to singularities of the ME in the soft and collinear regions)

Examples:

Alpgen, Sherpa, Comphep, Vecbos,…

mc@nlo,...

I. Introduction

- **In summary:**
  1. **The « Parton Shower » Generators: are well suited for describing jets evolution**
  2. **The « Matrix Element » Generators: are well suited for describing hard/wide angle emissions**

So in fact (as many opposed concepts) they are very complementary

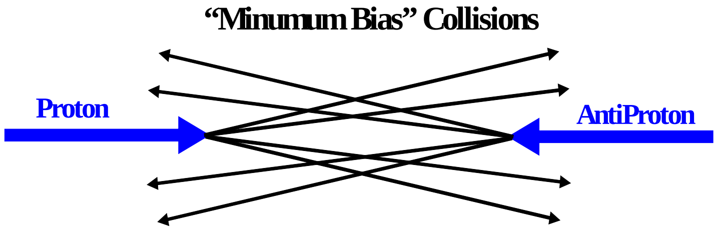
Hence the huge efforts in the past years to combine their virtues

Main problem: ME and PS populate partly overlapping regions of the phase space
=> naive combination of ME & PS leads to a double-counting issue (bias on shapes)

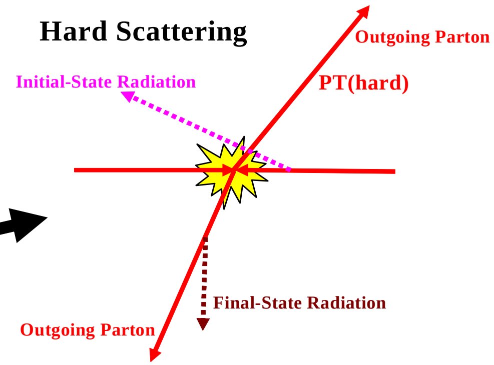
The Underlying Event

R. Field

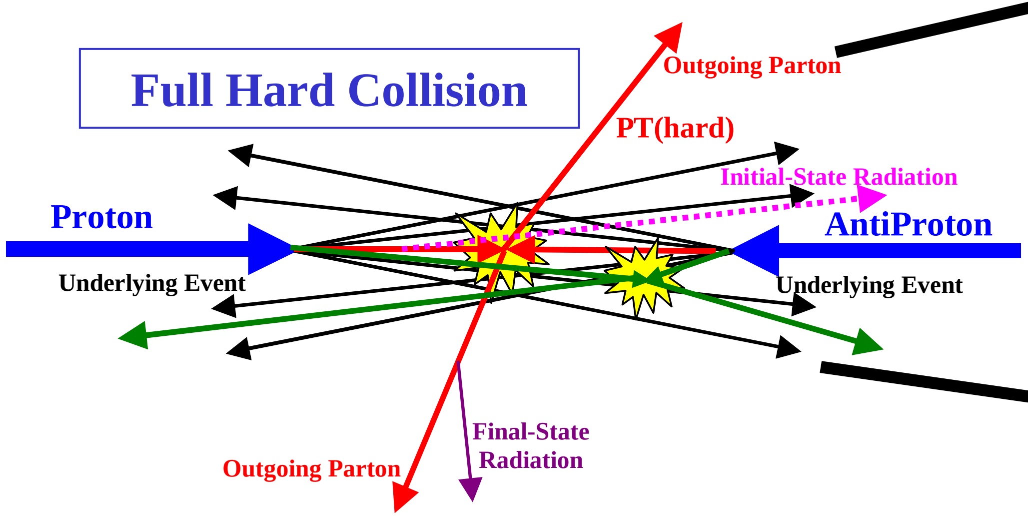
Minimum Bias Collision



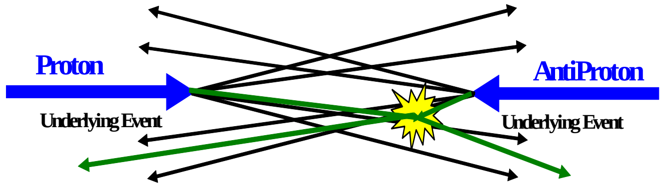
Hard Scattering



Full Hard Collision



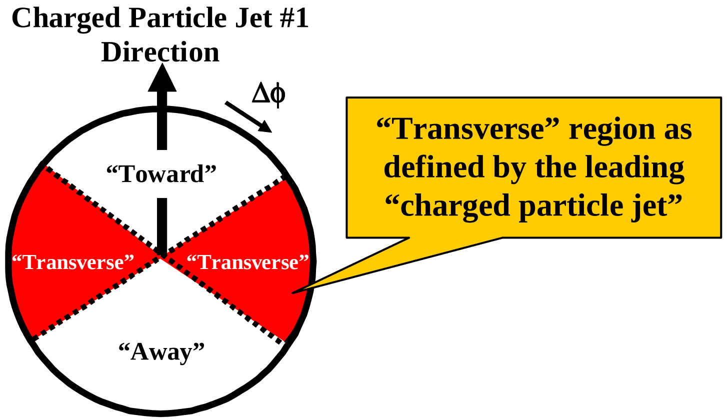
Underlying Event

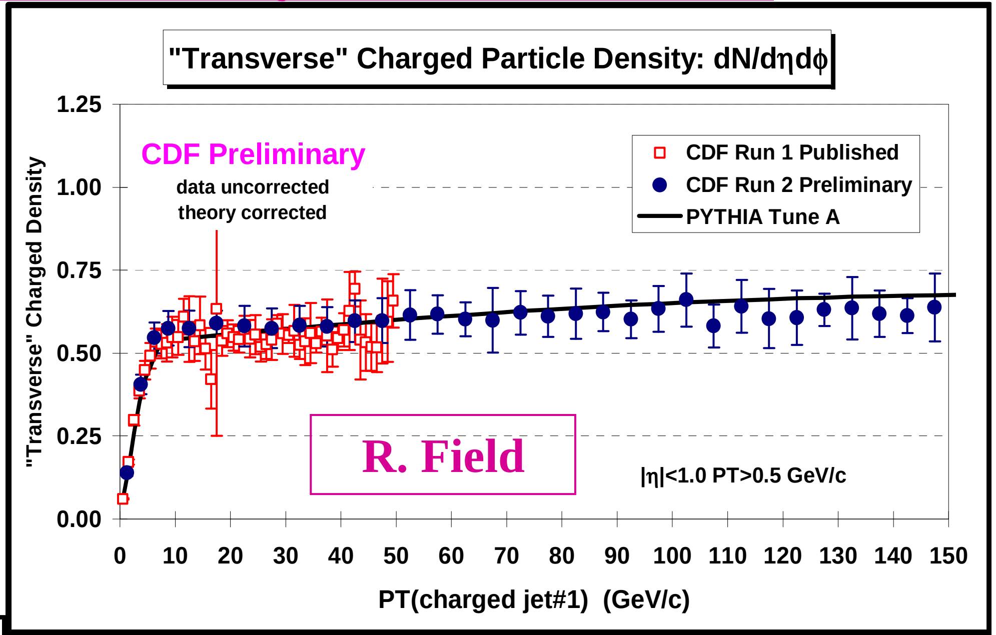


Note: MPI contributes mainly to soft physics just because it occurs at Q_{2nadry} << $Q_{hard\ scatt}$, but it's still a perturbative process

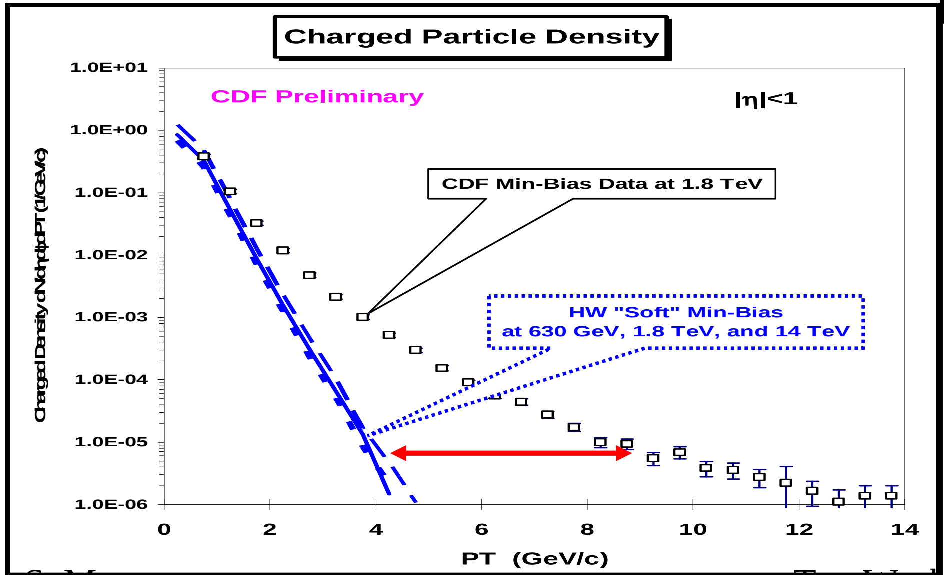
II. The PS Generators

Transverse Charged Particle Density @ CDF Run I/II





- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run I



MPI contribution to UE

II. The PS Generators

PYTHIA 6.2

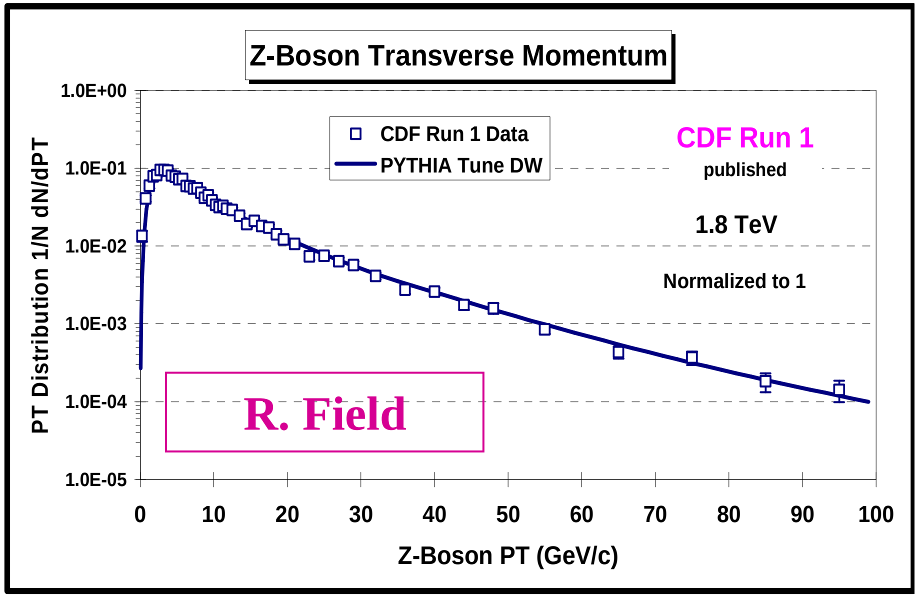
UE and $p_T(V)$ @ CDF Run I

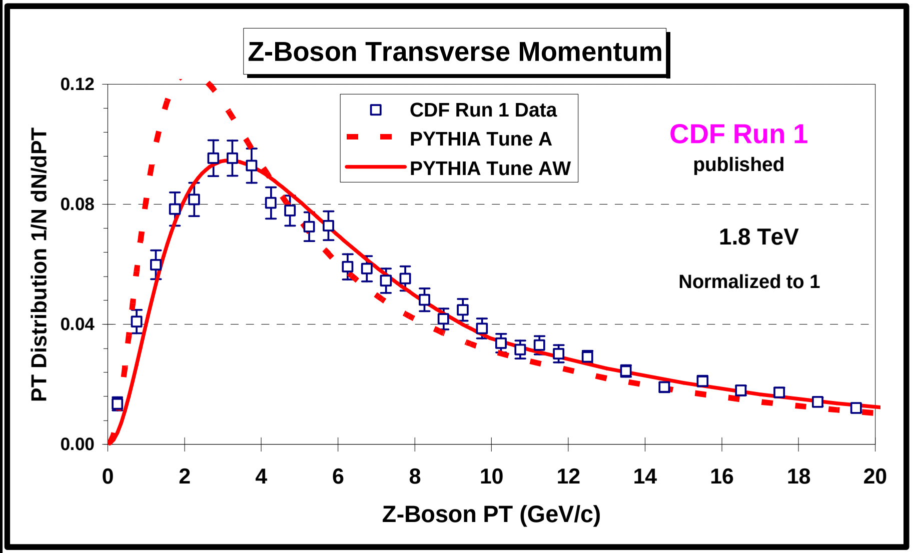
UE Params

ISR Params

Intr. k_T

Parameter	Tune A / AW	Tune DW / DWT	Tune QW
PDF	CTEQ5L	CTEQ5L	CTEQ6.1M
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 / 1.9409 GeV	1.1 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 / 1.96 TeV	1.8 TeV
PARP(90)	0.25	0.25 / 0.16	0.25
PARP(62)	1.0 / 1.25	1.25	1.25
PARP(64)	1.0 / 0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	1.0 / 2.1	2.1	2.1
PARP(93)	5.0 / 15.0	15.0	15.0





II. The PS Generators

Conclusions

• Starting from a V+0jet ME, one can reweight PS wrt to V+1jet ME_so as to describe the V+jets samples. This, w/ large intr. k_T, fits CDF & D0 Run I $p_T(V)$, ie: Pythia v6.1, Herwig v6.1. This procedure cannot be easily generalized to other processes…

• It's possible to tune the PS generators on data in order to make them reproduce:

- the UE
- the $p_T(V)$
- the dijet azimuthal decorrelation,
- the bb azimhthal decorrelation and sub-process fractions (gluon splitting, flavour excitation, flavour creation)

• These tunings require to take into account the MPI

• They improve the simulation of soft processes (min. bias) as well as the soft part of the hard scatterings

II. The FOME Generators

Alpgen & the « MLM » Matching

- Generate a parton level configuration based on LO ME, w/ N_{part} hard partons
- Apply kinematical cuts on those configs: p_{Tpart}^{min} and $\Delta R_{part\text{-}part}$
- Perform PS (no showers veto, no Sudakov form factor reweighting)
- Cluster the partons using a jet reco algo: E_{Tj}^{min}, ΔR_j
- Match parton to parton jets:
  - for each ME parton select a parton jet based on $\min(\Delta R_{part\text{-}j})$
  - if this $\min(\Delta R_{part\text{-}j}) < \Delta R_j$ the parton is matched
  - a parton jet can be matched only to a single ME parton
  - Exclusive matching:
    - Keep the event only if each parton is matched to a jet & $N_{part}=N_{jets}$
  - Inclusive matching:
    - Keep the event only if each parton is matched to a jet & $N_{part}<N_{jets}$
- ickkw option: reweight events by $\alpha_S(k_T^2)/\alpha_S(Q_{HS}^2)$ calculation at each node of the PS
- Public code available in Alpgen v2 (LHA interface to Herwig and Pythia)

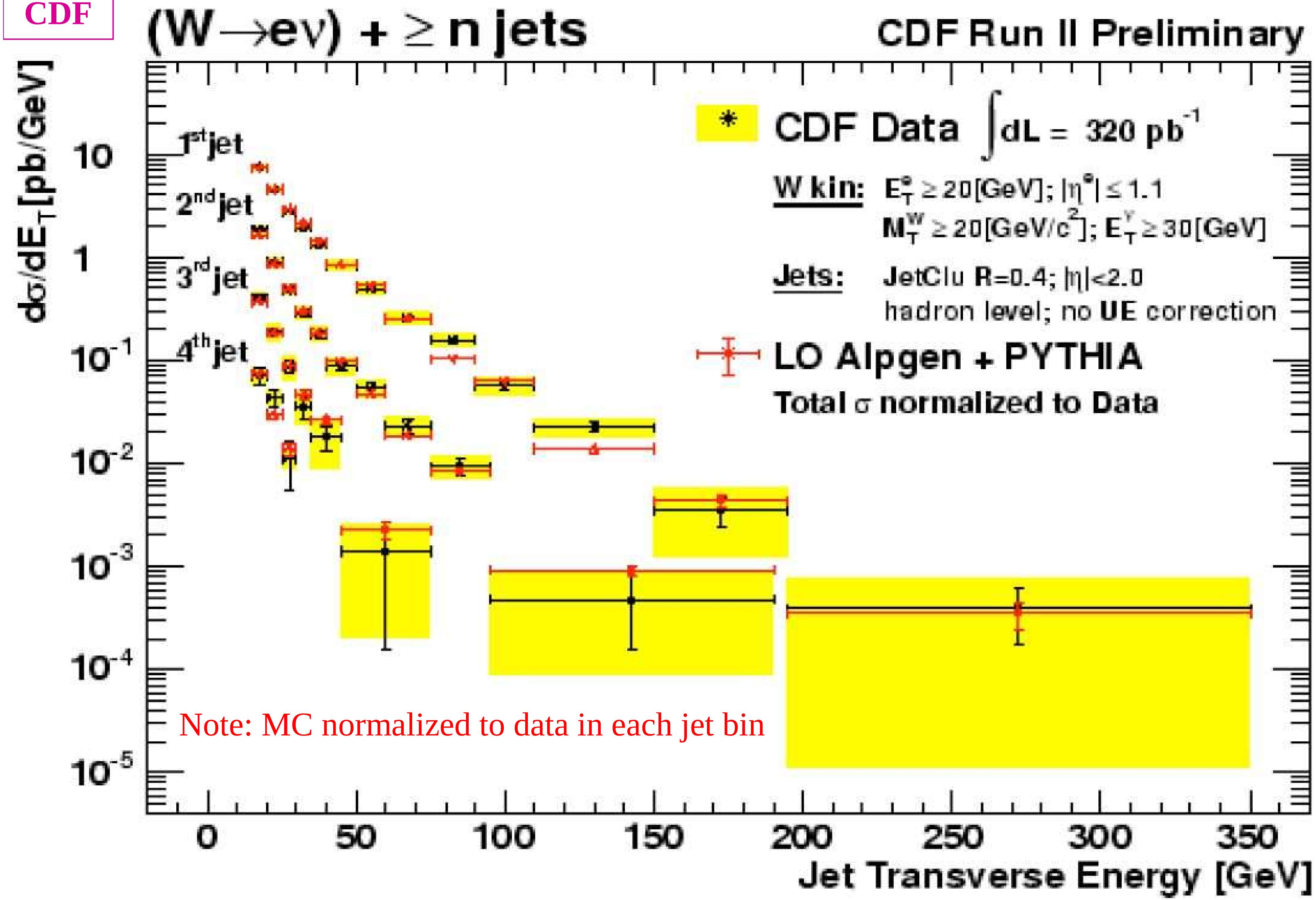
. REF:

. Alpgen Doc: M.L. Mangano, http://m.home.cern.ch/m/mlm/www/alpgen/alpdoc.pdf

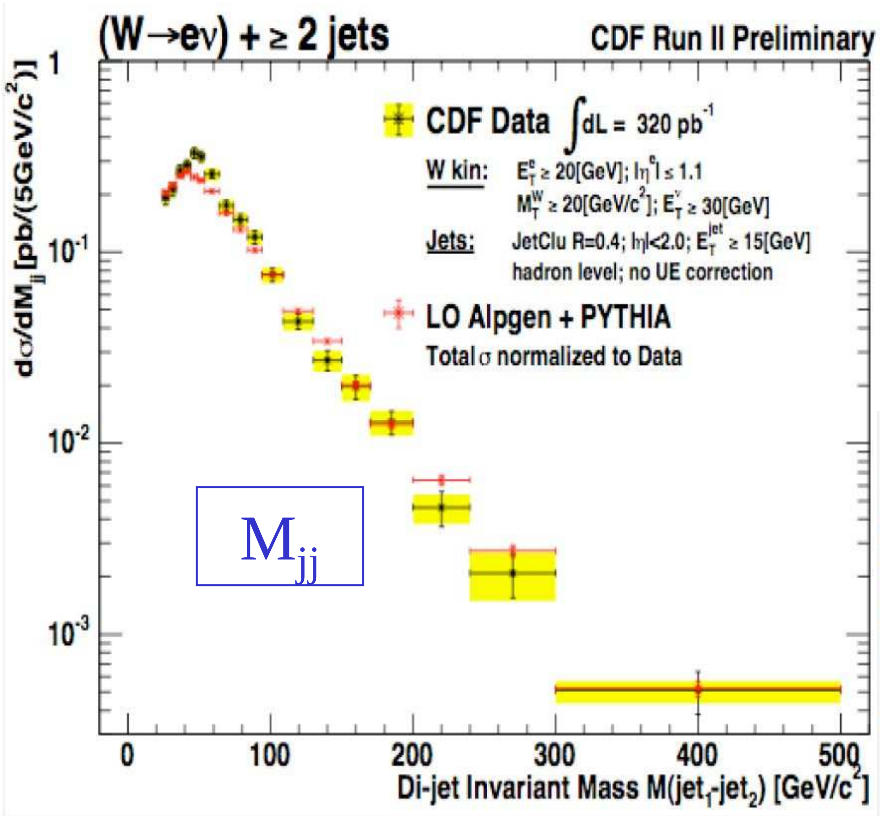
. hep-ph/0602031, "Matching Parton Showers and Matrix Elements" by S. Hoeche, F. Krauss, N. Lavesson, L. Lönnblad, M.L. Mangano, A. Schaelicke, S. Schumann

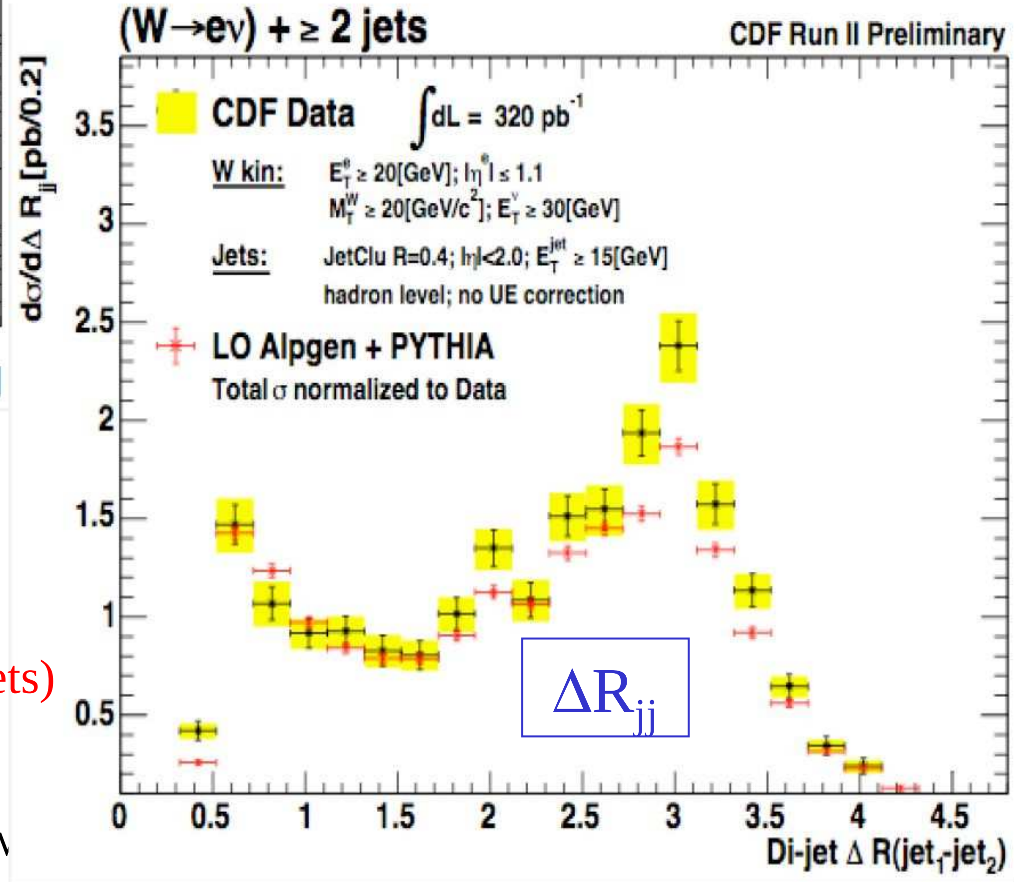
II. The FOME Generators

CDF



II. The FOME Generators





Note:
MC normalized to the measured σ_{incl}(W+2jets)

II. The FOME Generators

Sherpa & the « CKKW » Matching

F. Krauss et al.

. Applies to e^+e^- -> jets+X (slightly modified for hadron collisions)

. Try to separate the contributions of ME and PS in the phase space using a k_T cluster paramater y_{ini}

. ME and PS are matched w/:

- modified ME (Sudakov FF and $\alpha_S(k_T^2)/\alpha_S(Q^2)$ reweighting)
- modified showers (vetos to cancel y_{ini} dependance at NLL accuracy)

. Reminder k_T clustering (Durham algo):

$$y_{ij} = \frac{2 \times \min(E_i, E_j)^2 \times (1 - \cos\theta_{ij})}{Q^2} = \frac{k_T^2}{Q^2}$$

- if $y_{ij} > y_{cut}$ the objects i and j are resolved
- elseif $y_{ij} < y_{cut}$ objects i and j are clustered => $4\text{-}p_{ij} = 4\text{-}p_i + 4\text{-}p_j$

- Note: Process indepenedent procedure!!!

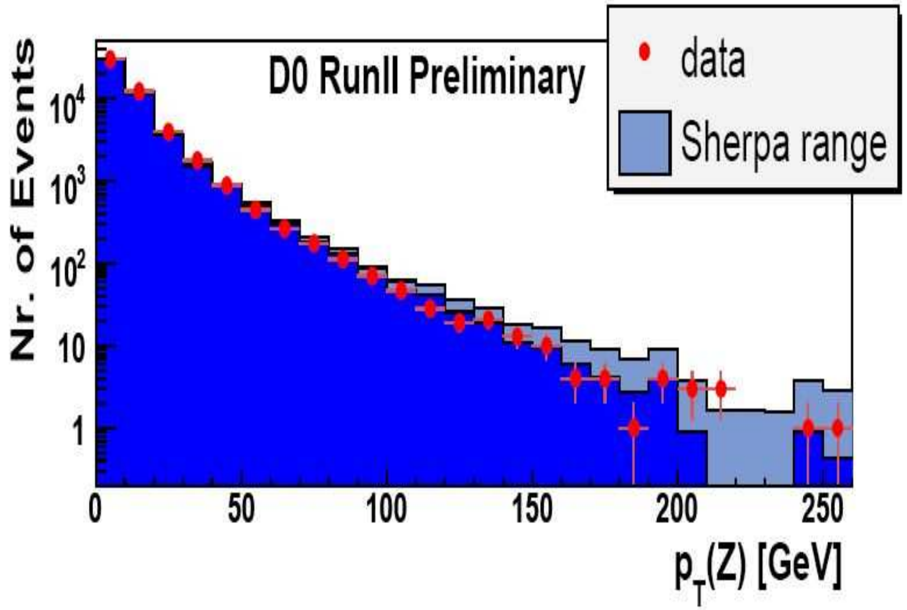
. REF:

S. Catani, F. Krauss, B. Webber, R. Kuhn, JHEP11 (2001) 063
"QDC Matrix elements + parton showers"

$$\int \mathcal{L}dt = 950\ pb^{-1}$$

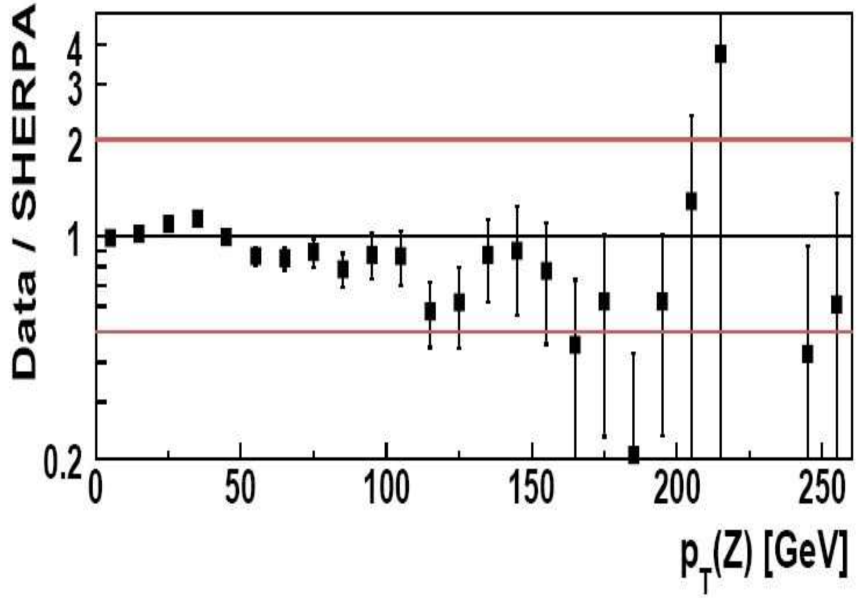
Sherpa v1.0.6

- PDF: CTEQ6LL
- ME: γ^*/Z+0/1/2/3jets
- kT cut: $(20\ \text{GeV})^2/(1960\ \text{GeV})^2$
- MI: ZB data superimposed to HS
- MC normalized to data



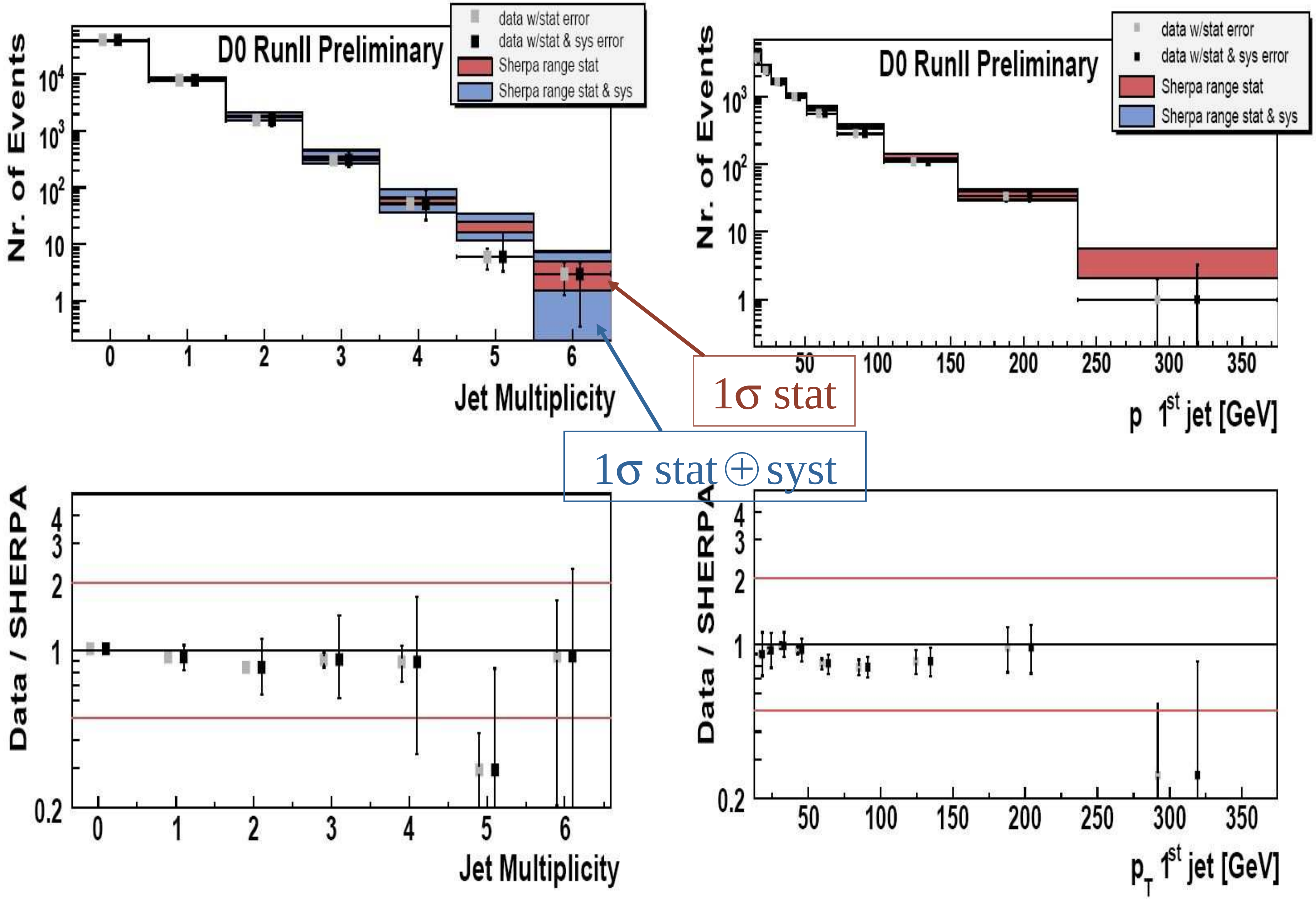
Event Selection:

- EM ID:
  - $e^{+/-}$ L(shower shapes, track match, E/p, EMF, track DCA, isolation)
  - 2 isolated $e^{+/-}$, p_T>25 GeV, $|\eta|$<1.1 & 2.5
  - 70 < M_{ee} < 100 GeV

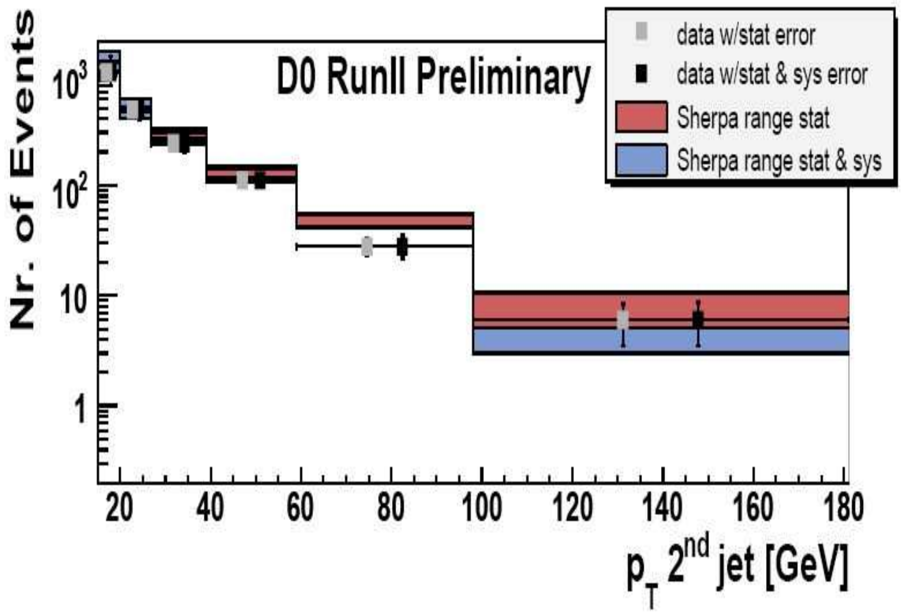


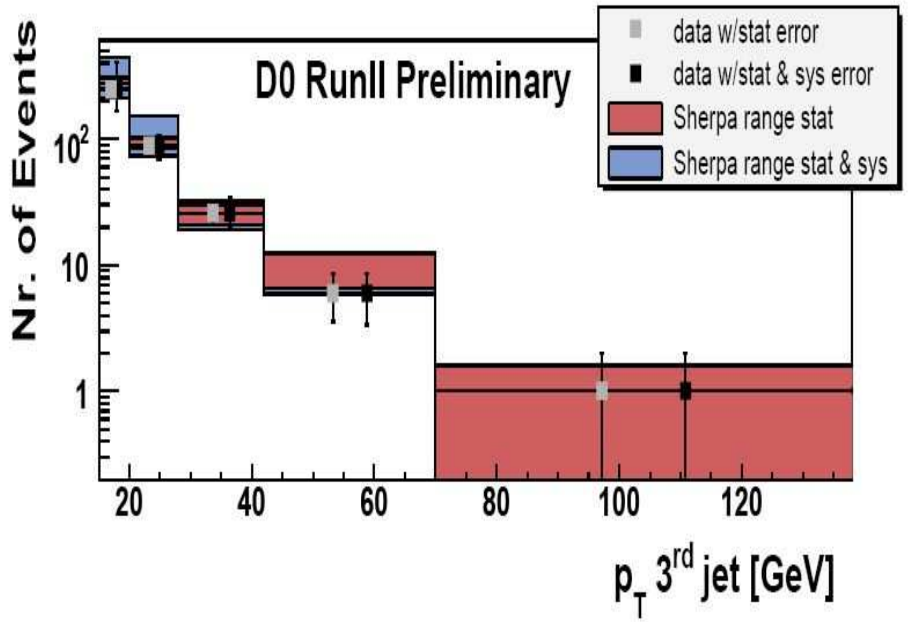
Event Selection Cont'd:

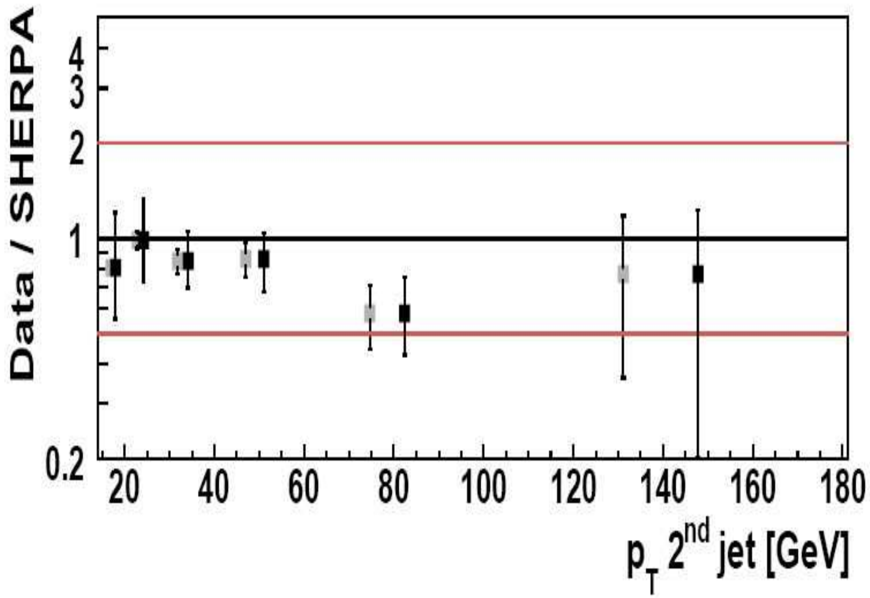
- Jet ID:
  - Reco: ΔR=0.5
  - trigger confirmed
  - p_T>15 GeV, $|\eta|$<2.5
  - $\Delta R(e,j)$>0.5

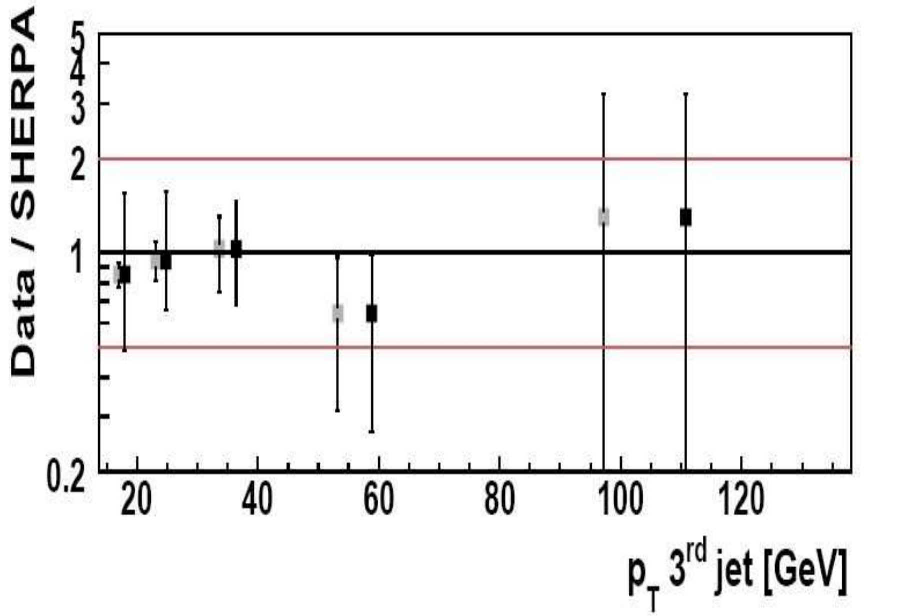


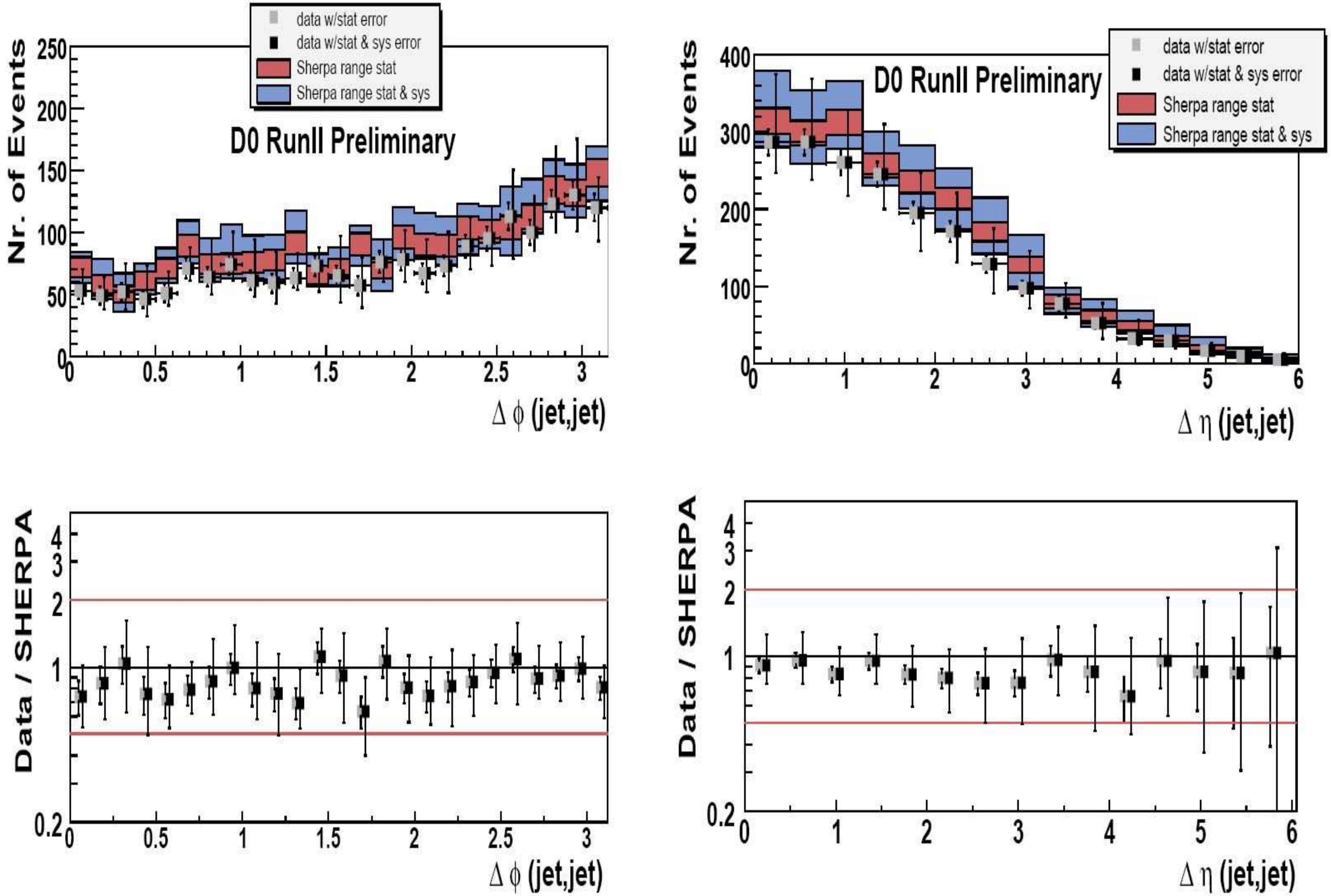
D0 RunII Preliminary
data w/stat error
data w/stat & sys error
Sherpa range stat
Sherpa range stat & sys
Nr. of Events
Jet Multiplicity
p 1st jet [GeV]
1σ stat
1σ stat ⊕ syst
Data / SHERPA
Jet Multiplicity
p_T 1st jet [GeV]


D0 RunII Preliminary
data w/stat error
data w/stat & sys error
Sherpa range stat
Sherpa range stat & sys
Nr. of Events
p_T 2nd jet [GeV]


D0 RunII Preliminary
data w/stat error
data w/stat & sys error
Sherpa range stat
Sherpa range stat & sys
Nr. of Events
p_T 3rd jet [GeV]


Data / SHERPA
p_T 2nd jet [GeV]


Data / SHERPA
p_T 3rd jet [GeV]

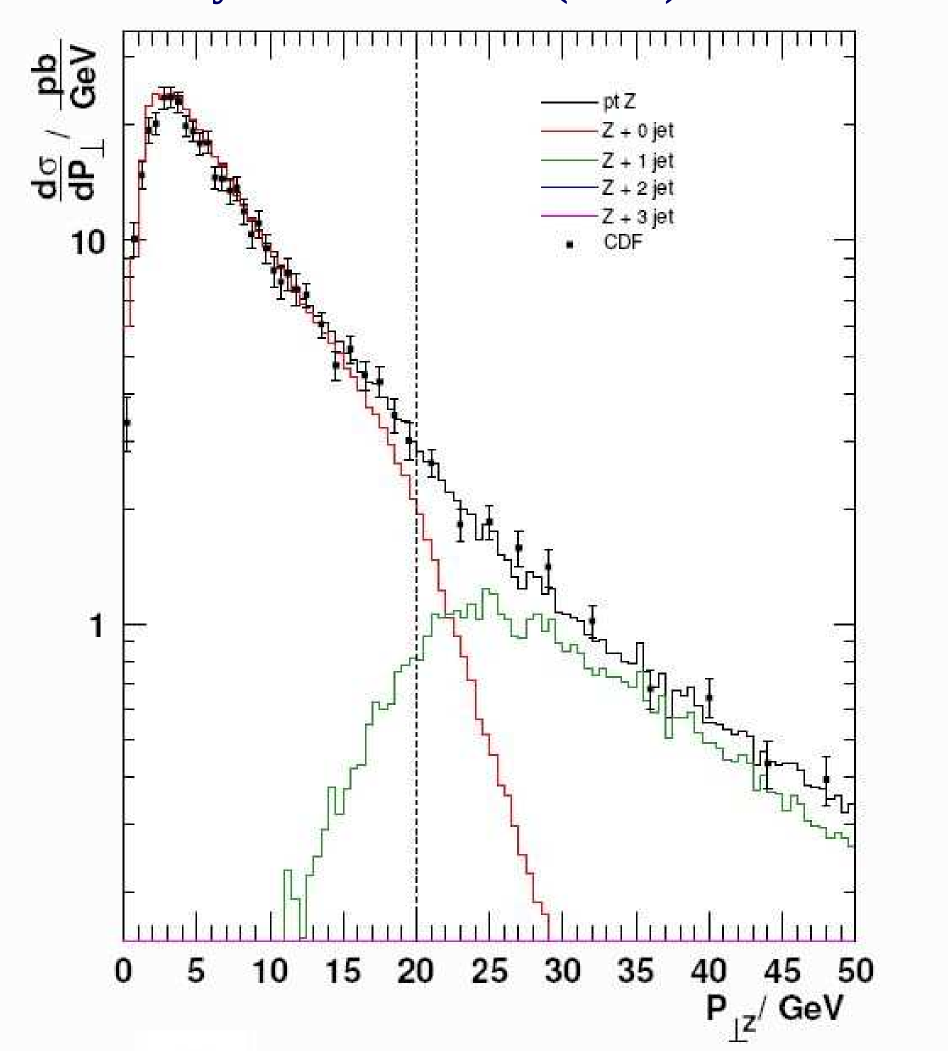

data w/stat error
data w/stat & sys error
Sherpa range stat
Sherpa range stat & sys
D0 RunII Preliminary
Nr. of Events
Δ φ (jet,jet)
Δ η (jet,jet)
Data / SHERPA

CDF & D0 Run I

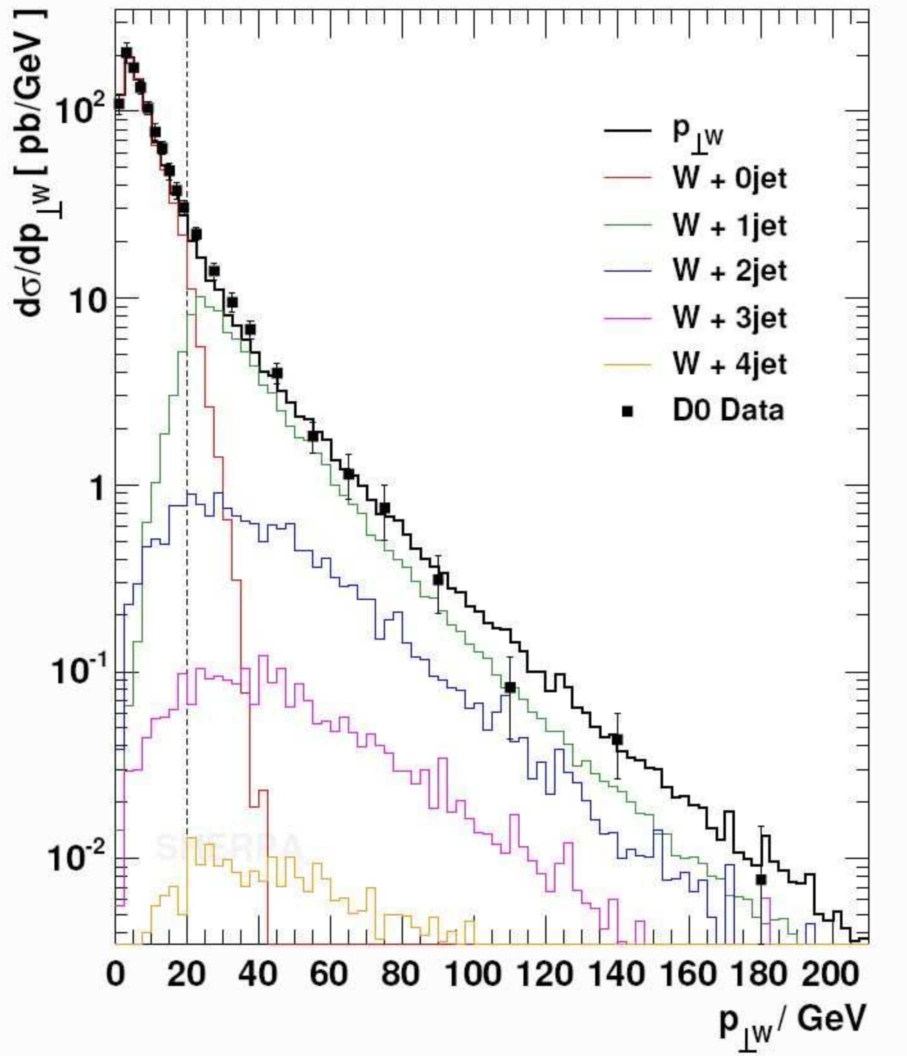
S. Höche

Sherpa x K-factor

Ref: Phys. Rev. Lett. 84 (2000) 845-850



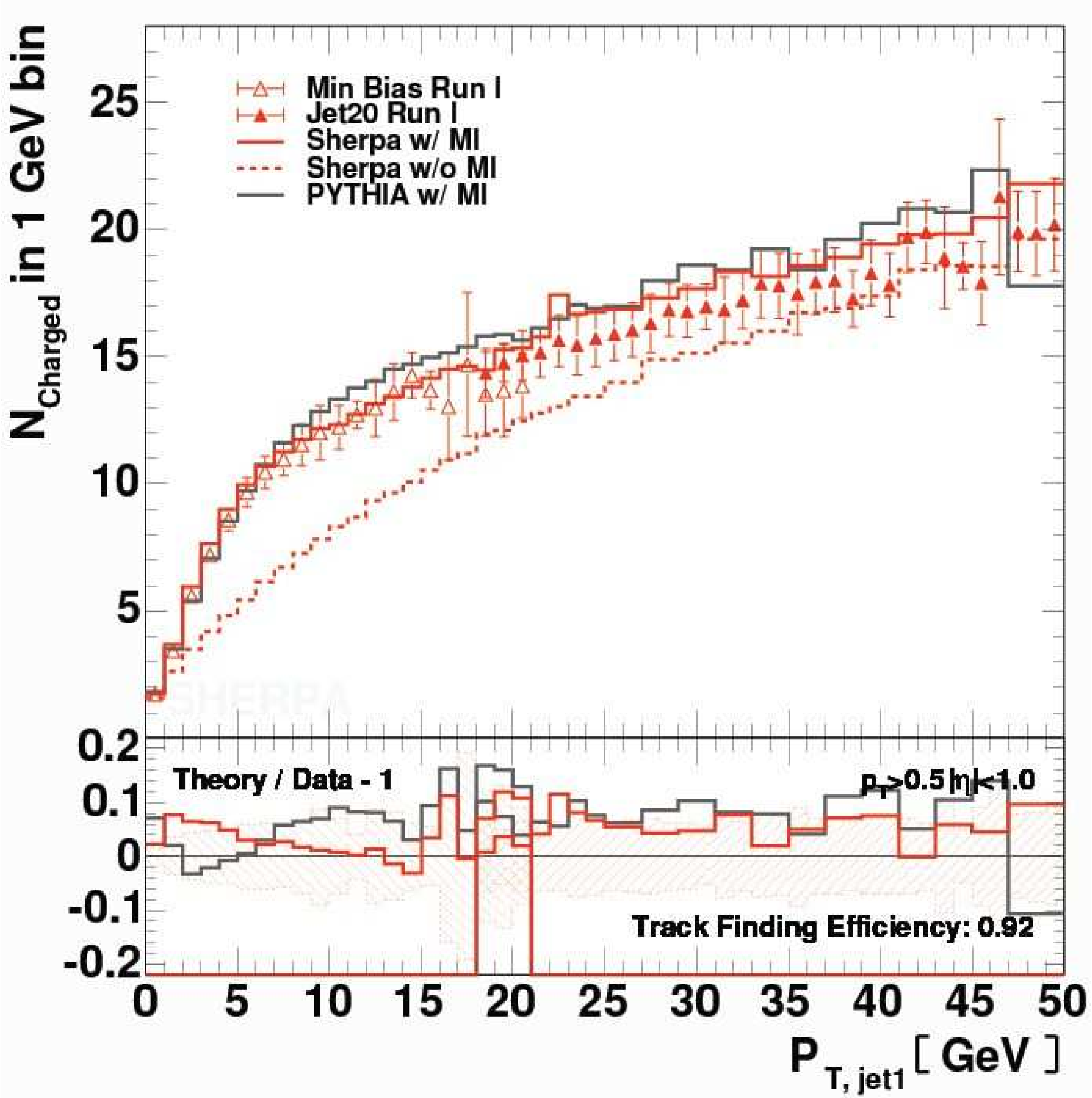
Ref: Phys. Lett. B513 (2001) 292-300



CDF Run I

S. Höche

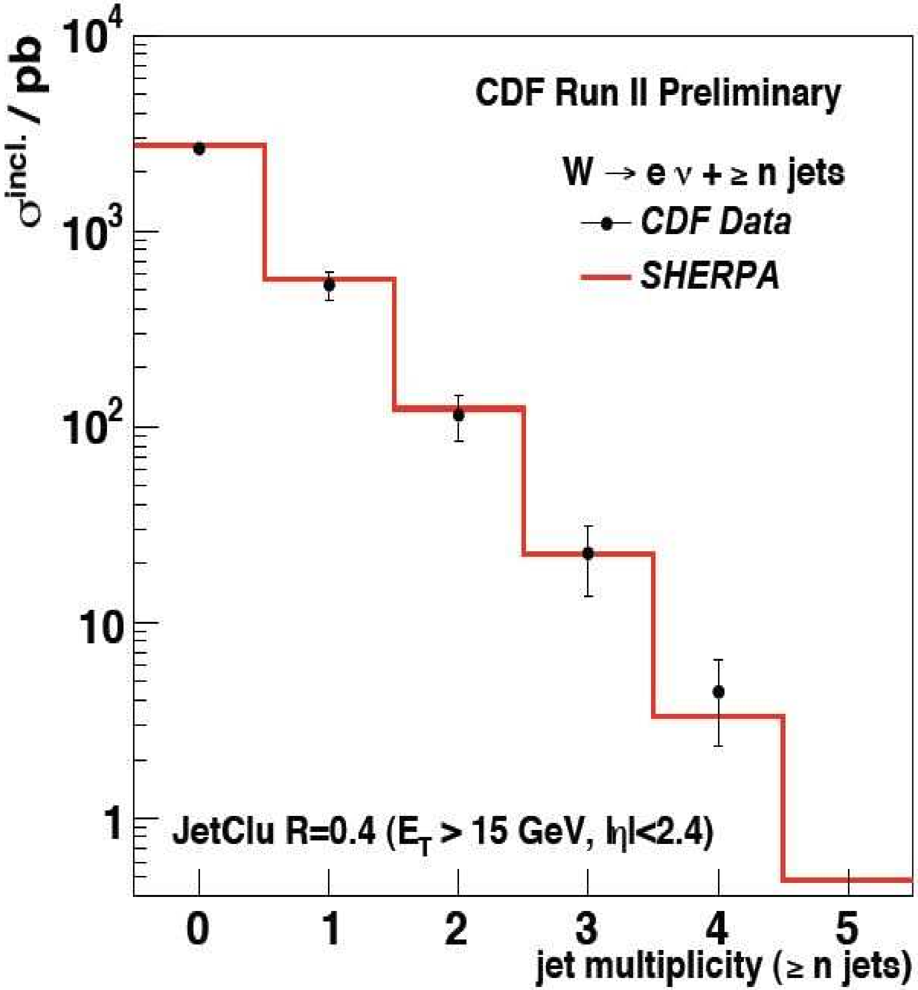
Sherpa Tuned UE

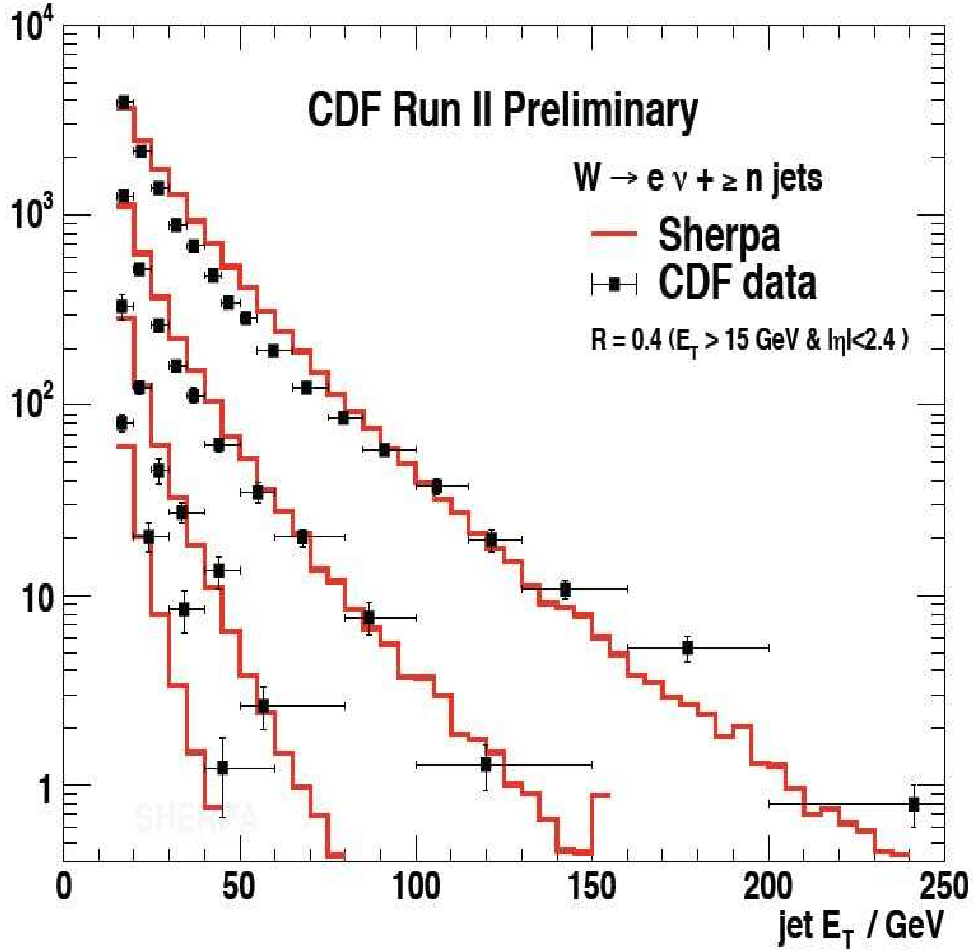


CDF Run II

S. Höche

Sherpa x K-factor





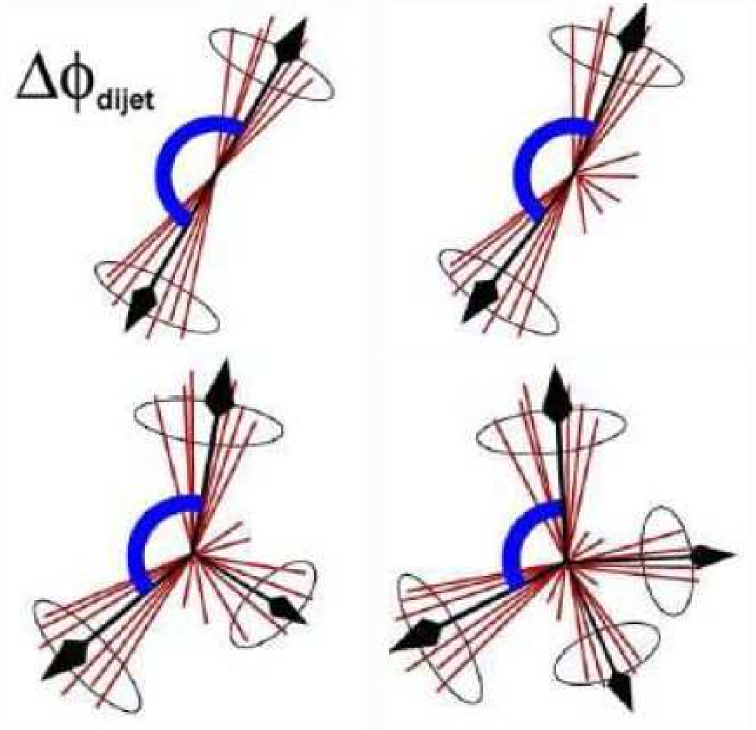
D0 Run II

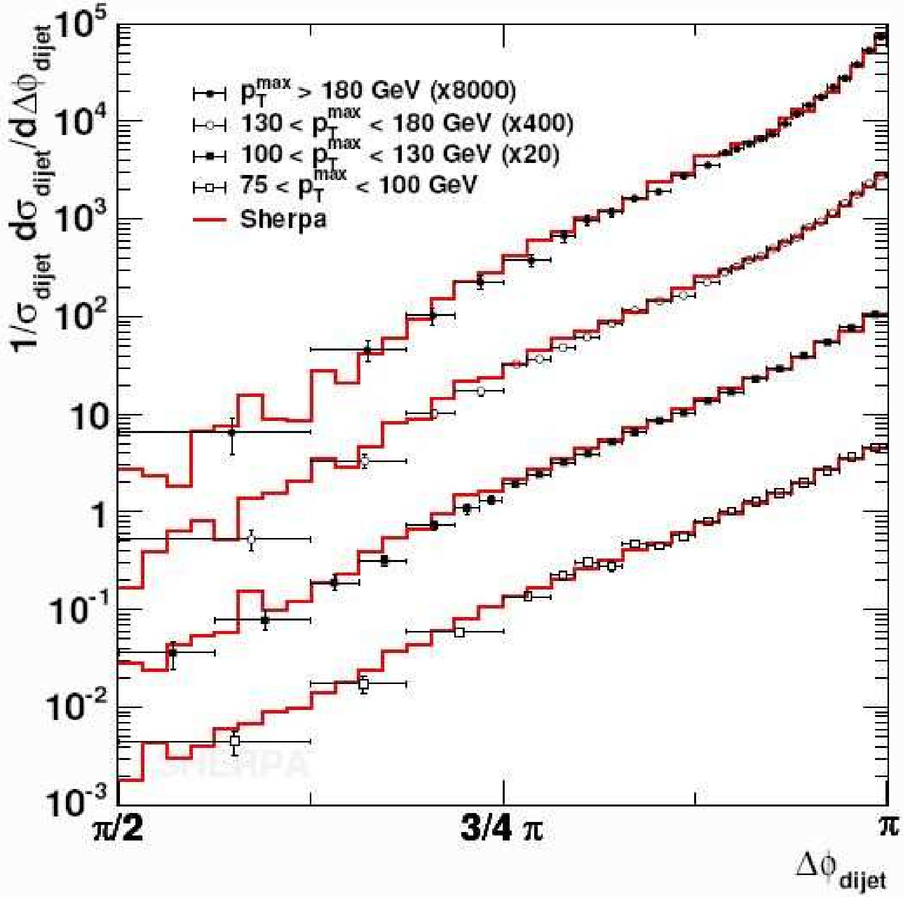
S. Höche

- Central dijet events incl. Sample:
  - $\Delta R=0.7$
  - $p_T(j2)>40$ GeV
  - $|y_{jets}|<0.5$

$$\int \mathcal{L}dt = 150\ pb^{-1}$$

Ref: Phys. Rev. Lett. 94 (2005) 221801





II. The FOME Generators

Pythia's Variant of the « CKKW » Matching

- **Start w/ parton level configuration based on LO ME**
- **Feed Pythia w/ this using the full flavor and color flow**
- **Perform a k_T clustering to determine "nodal values"**
- **Events are reweighted by $\alpha_S(k_T)/\alpha_S(M_Z)$ factor for each cluster**

  $e^+e^- \to \gamma^*/Z \to 2p$: 0 α_S reweighting,

  3p: 1 α_S reweighting,…

  np: (n-2) α_S reweighting
- **The clustering yields a parton shower (PS) history where each line is weighted by a Sudakov form factor**
- **Primary partons are showered in Pythia from Q_{max}@ nodal value down to $Q=\Lambda_{QCD}$**
- **In the PS each emission w/ $k_T > k_T min$ is vetoed!!!**
- **To account for unknown higher order contributions (mainly leading logs), the events w/ largest nber of partons is not vetoed**

. REF: S. Mrenna and P. Richardson, JHEP05 (2004) 040
"Matching matrix elements and parton showers with HERWIG and PYTHIA"

II. The FOME Generators

Madgraph+Pythia

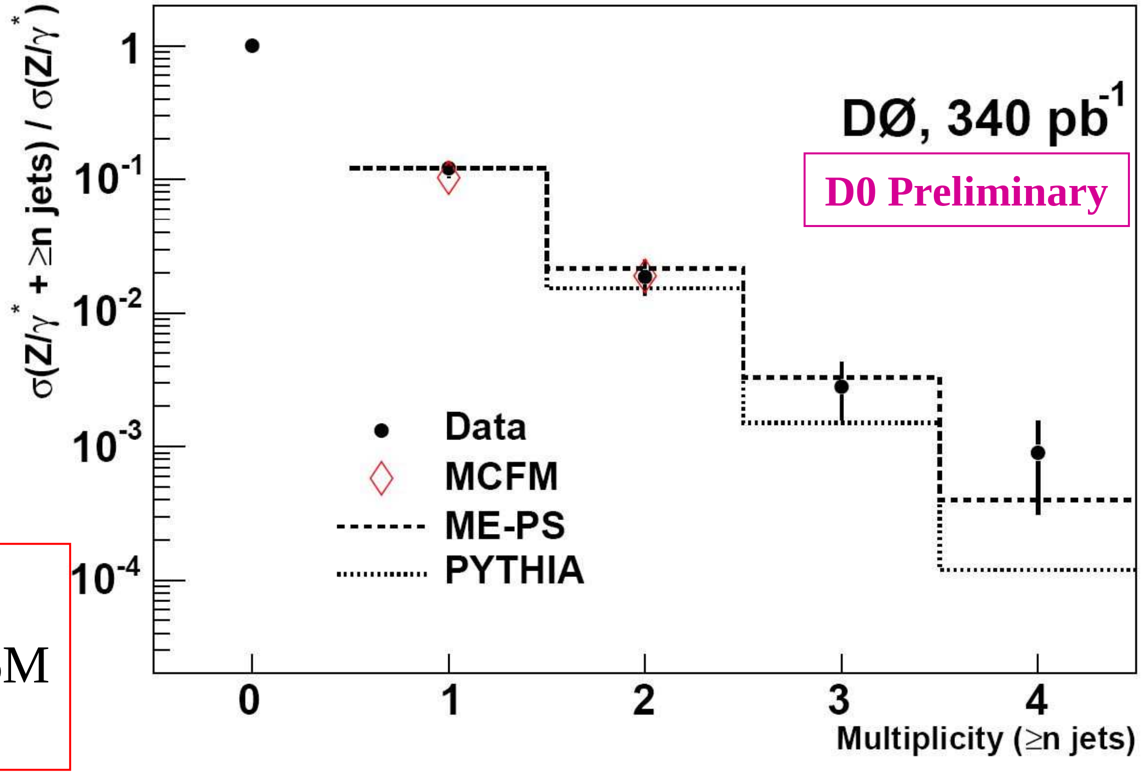
• Patriot samples provided by S. Mrenna for CDF and D0 Run II

$$\gamma^* / Z(+jets) \rightarrow e^{\pm}e^{\mp}$$

Madgraph+Pythia:
• ME: Magraph v2
• PS: Pythia v6.2
• ME-PS Matching:
modified CKKW (not public)
• PDF: CTEQ6LL
• $Q_F=M_Z$, $Q_R=p_T(jet)$ or $k_T(jet)$

Pythia:
• PDF: CTEQ5L
• $Q_F=Q_R=M_Z$

MCFM:
• PDF: CTEQ6M
• $Q_F=Q_R=M_Z$

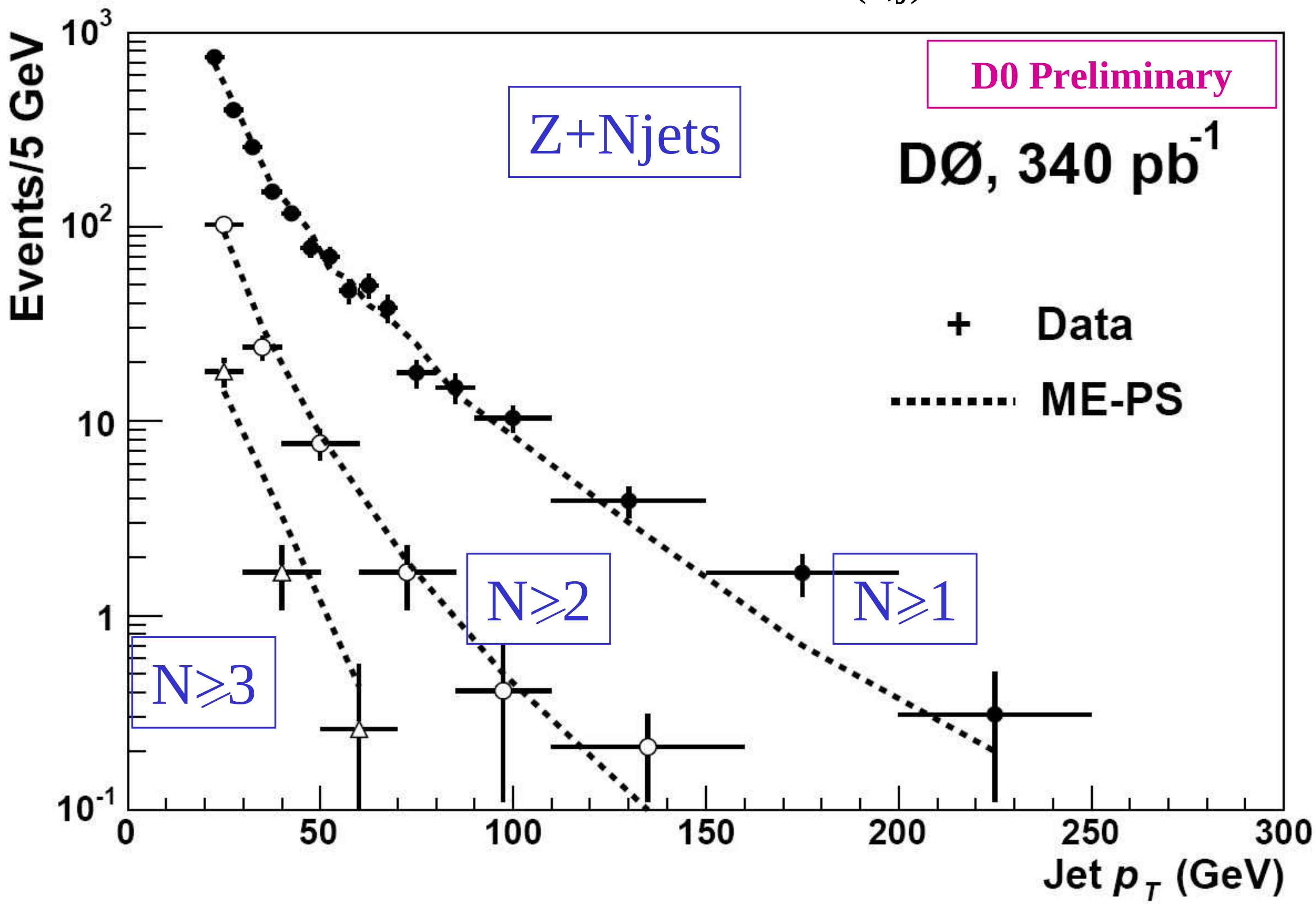


Event Selection:

- EM ID:
  - 2 isolated e, pT>25 GeV, |η|<1.1
  - at least 1 track match, E/p
  - shower shapes

Event Selection Cont'd:

- Jet ID:
  - Reco: ΔR=0.5
  - trigger confirmed
  - pT>20 GeV, |η|<2.5
  - ΔR(e,j)>0.4



II. The FOME Generators

MC@NLO

S. Frixione, P. Nason, B. Webber

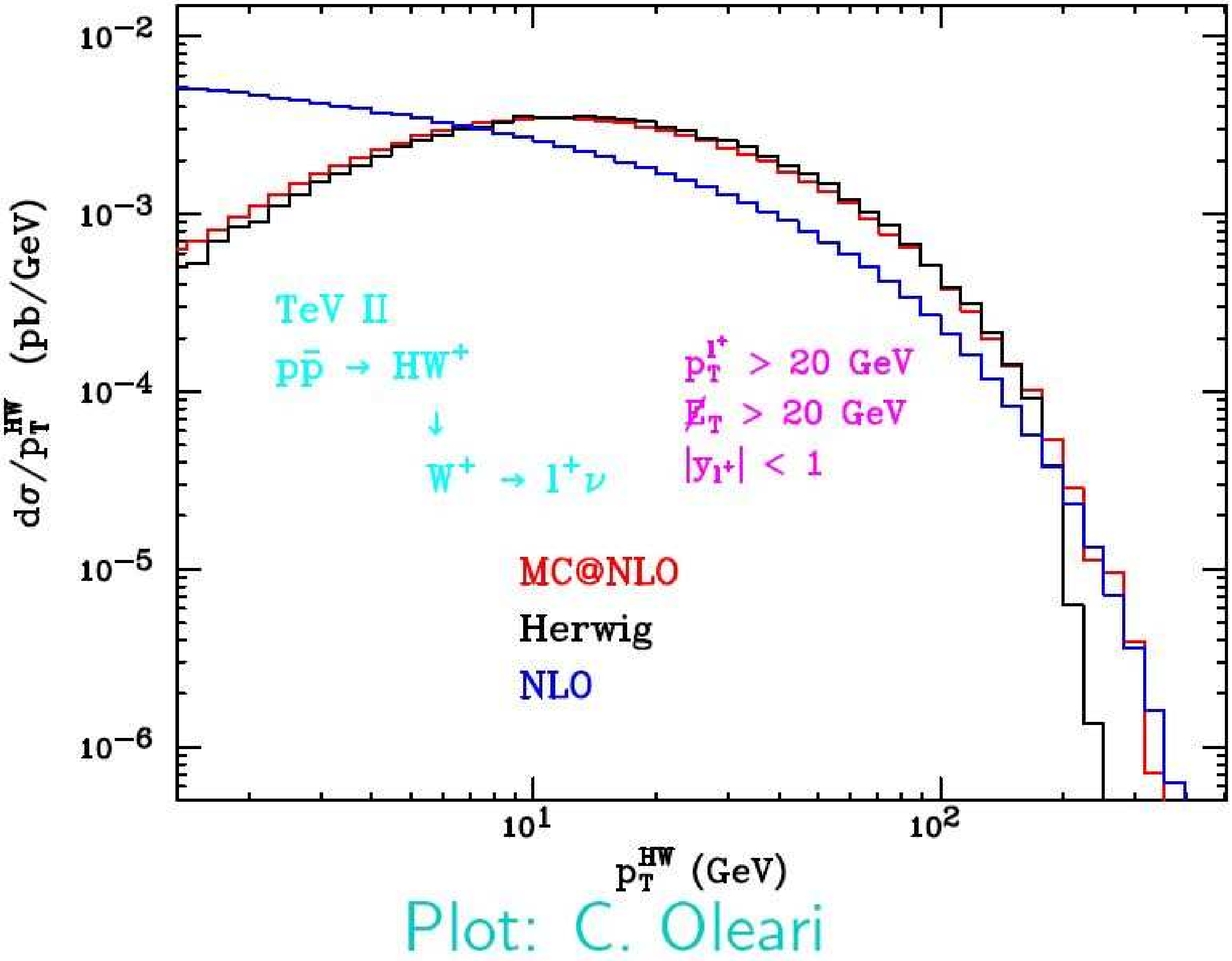
- Main Features:
  - Shapes: NLO up to 1st emission, PS for the rest
  - Rates: NLO normalization

- Method:
  - NLO modified terms for real IR divergences
  - uses 1st order PS expressions
  - process dependent!!!
  - complicated machinery that works only w/ Herwig PS

  => more modular approach ongoing w/ Herwig++

II. The FOME Generators

MC@NLO



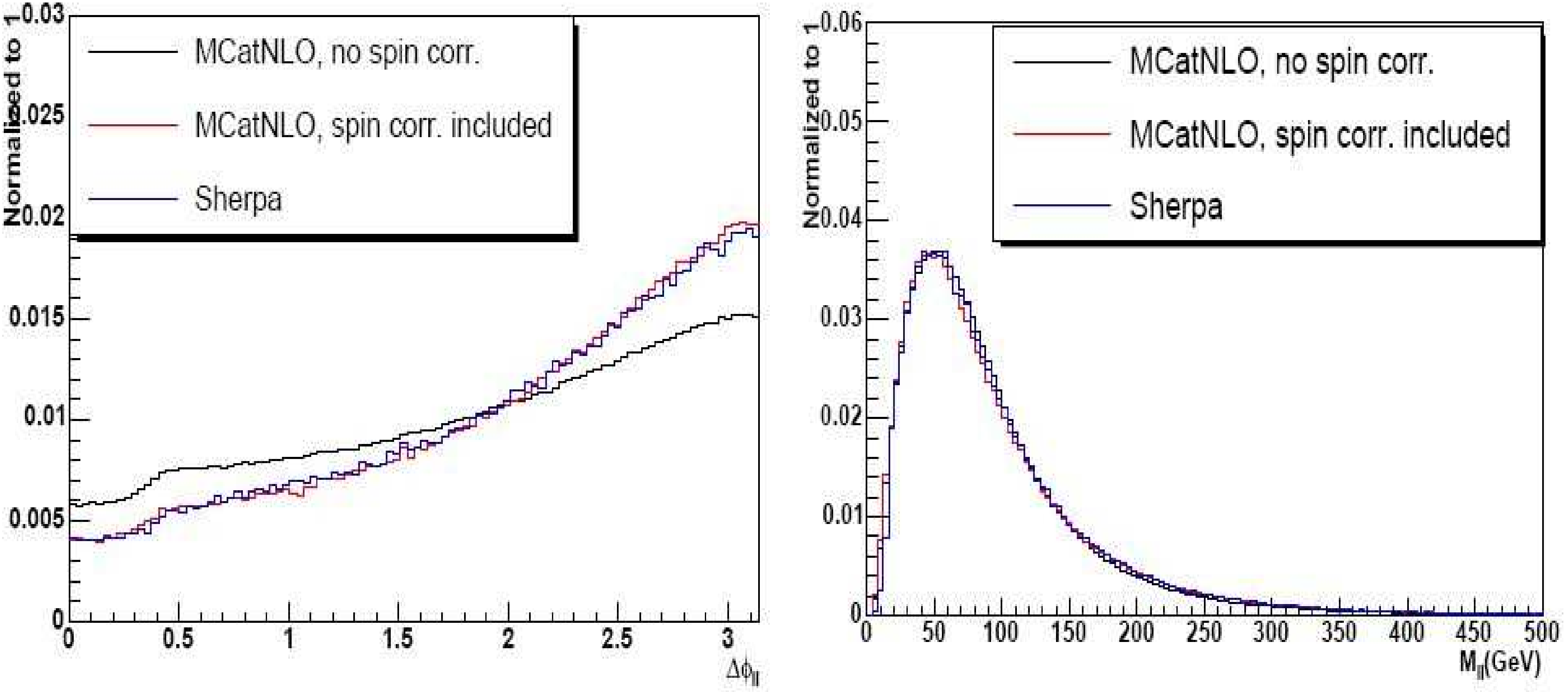
S. Frixione

II. The FOME Generators

MC@NLO Spin Correlations

S. Frixione

$W^+W^- \rightarrow 2l + mET$

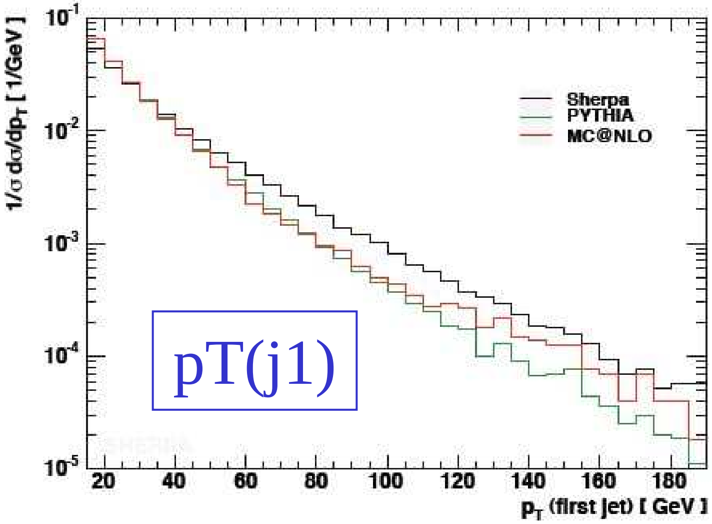


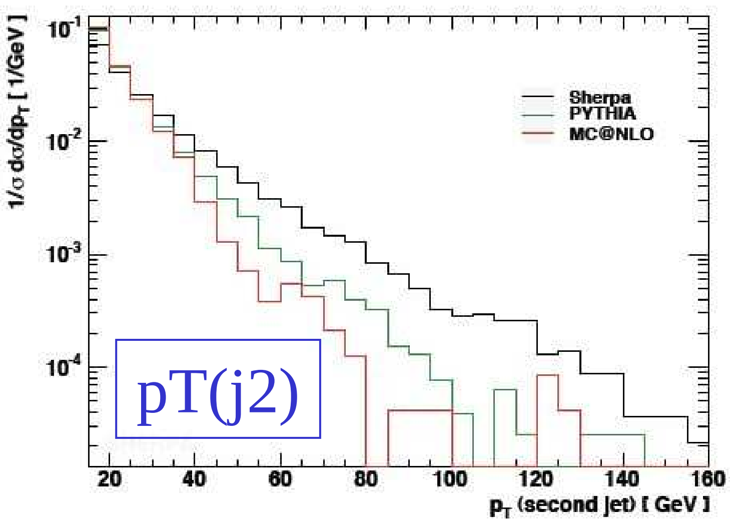
Plots: B. Quayle (preliminary)

II. The FOME Generators

MC@NLO

S. Höche



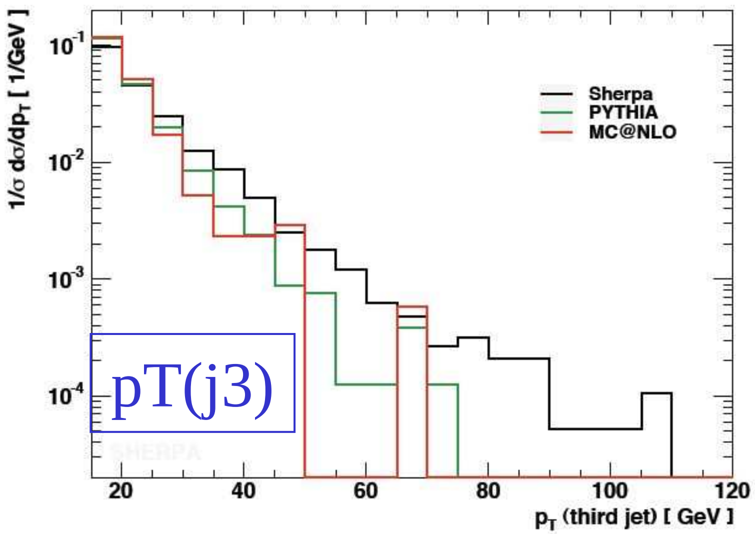


W(+jets)→eν @TEVATRON

Sherpa

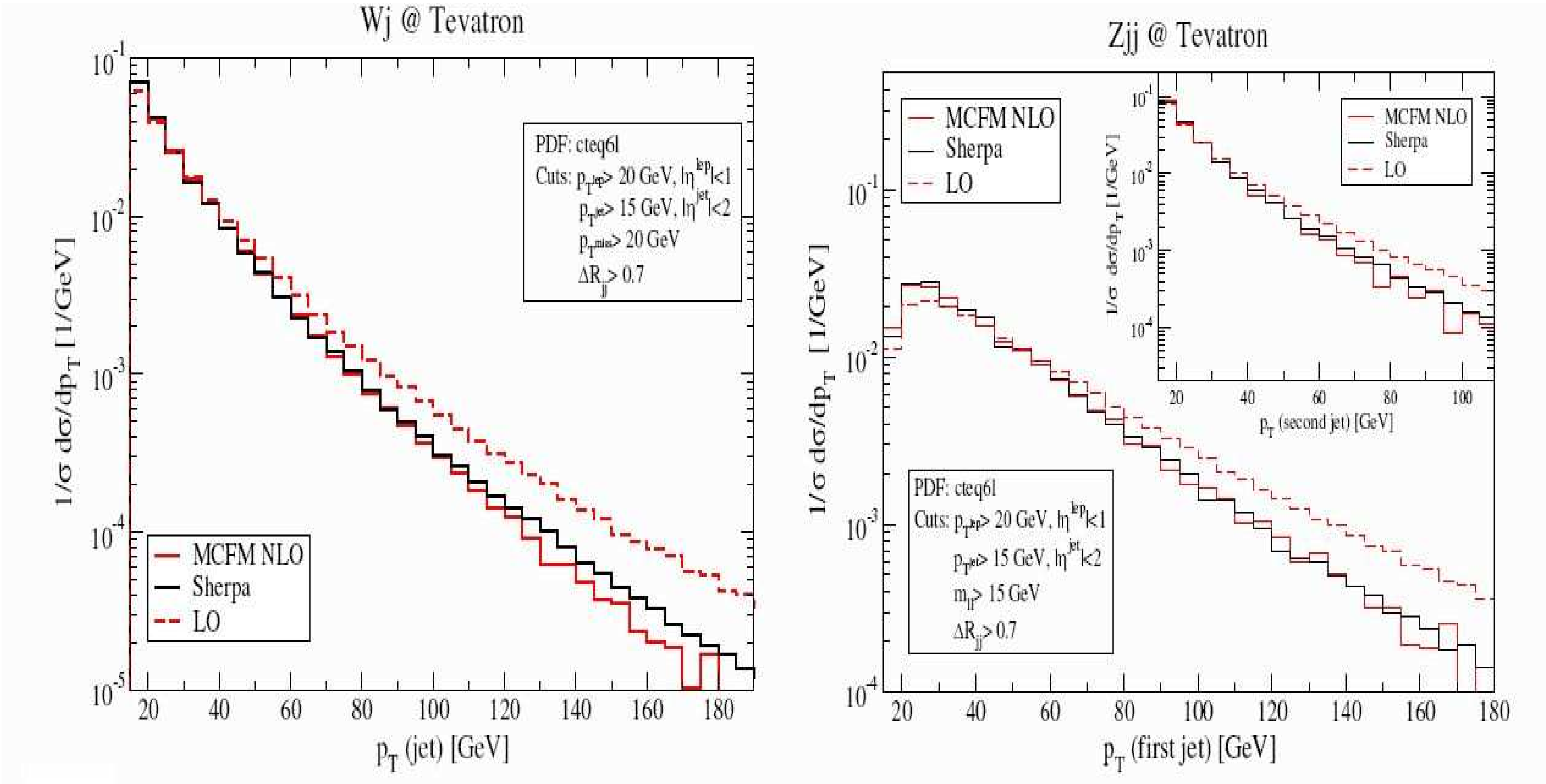
Pythia

MC@NLO



II. The FOME Generators

MCFM vs Sherpa



II. The FOME Generators

MCFM

- It's not an Event Generator: it's a FOME (N)LO cross sections calculator
- A large variety of SM processes are available at LO and NLO
- Differential σ are also available (check possible shape differences between LO and NLO distributions, ie single top)

- Open issue that I recently encountered:
  - At D0 starting from the Alpgen v1 era we set a method (Method 1) to normalize Alpgen V+jets samples
  - Method 1: use MCFM to derive a K-factor per jet bin i
    - K-factor(bin i)=σ_{incl}^{NLO}(V+i jets) / σ^{LO}(V+i jets)
  - Double counting Issue w/ Method 1:
    - The LO ME for V+(i+1) jets is doubly counted wrt to the real NLO ME for V+i jets!!!

II. The FOME Generators

MCFM

• Numerical check:

Moriond 06	D0 Prel.	CDF Prel.
$\sigma(\gamma^*/Z \rightarrow ee)$ pb	264.9+/-20.2	255.8+/-16.8
L_{int} pb^{-1}	177	72

$$3.37\%(5166_{excl} + 2172_{excl} + 867_{incl}) = 276.2\ pb$$ Method 1

$$3.37\%(7245_{incl} + 2785_{incl} + 867_{incl}) = 366.8\ pb$$ Method 2

• Method 2: derive a global K-factor for the merged V+jets inclusive sample

$$\text{K-factor} = \frac{[\sigma_{excl}(V+0j) + \sigma_{excl}(V+1j) + \sigma_{incl}(V+2j)]\_NLO}{[\sigma(V+0j) + \sigma(V+1j) + \sigma(V+2j)]\_LO}$$

At least method yields an NLO σ which compatible w/ measured σ

V. Conclusions and Prospects

- **This talk is a quick overview of the « frenetic » activities occuring in close concertations (thanks to many useful workshops) between phenomenologists and experimentalists (especially from TEVATRON collaborations)**

- **Single top and top pair productions both lead to multijet (+leptons) topologies**

=> **mc@nlo is not best suited for describing the V+jets bkgd for these studies, but it's still interesting to check some rates and shapes against other NLO tools**

⇒ **my favourite tools are Alpgen and especially Sherpa, which seems very complete and efficient at describing both hard and soft aspects of the V+jets processes**

V. Conclusions and Prospects

- **K-factor are large and should be included in all LHC simulationsfor both signals and backgrounds. MCFM is the main tool for this… but one needs to apply a proper prescription to normalize merged V+jets samples**

- **LO ME and PS are now married and has enabled sensible progress in accurate description of V+jets. Ideas and work is ongoing towards extending this at NLO (might not cover most of the sub-processes by the start-up of LHC)**

- **Even when doing high p_T physics, do not neglect UE, it's effect growth w/ CoM energy. As it affects both tracker and calorimeter occupancy, look out at isolation and biases on top mass!!!**
  But the extrapolation to LHC is very inacurrate, so new tuning on LHC data will be necessary.

BACK-UP

Some Definitions

- **MI: multiple pp or ppbar collisions in a given bunch crossing**
- **MPI: multiple parton interactions in a given pp or ppbar collision**
- **Minimum Bias:**
  - **it's a trigger condition (not a physics process per say)**
  - **low pT QCD, (SD single arm), DD are the contributing sub-processes**
  - **Note: UE in most hard collisions also fire this trigger term**
- **UE: interactions of spectator partons, including possible MPI**
- **Pile-Up: signals overlapping in time in a sub-detetctor (personal definition)**
- **PS: parton shower**
- **FOME: Fixed Order Matrix Elements**

II. The PS Generators

1. Final State Showers (forward evolution)

- Sudakov Form Factor:

$$\Delta_{a \to bc}(t_0, t) = \exp\left(-\int_{t_0}^{t} \frac{dt'}{t'} \int dz \frac{\alpha_S(k_T^2)}{2\pi} P_{a \to bc}(z) \right)$$

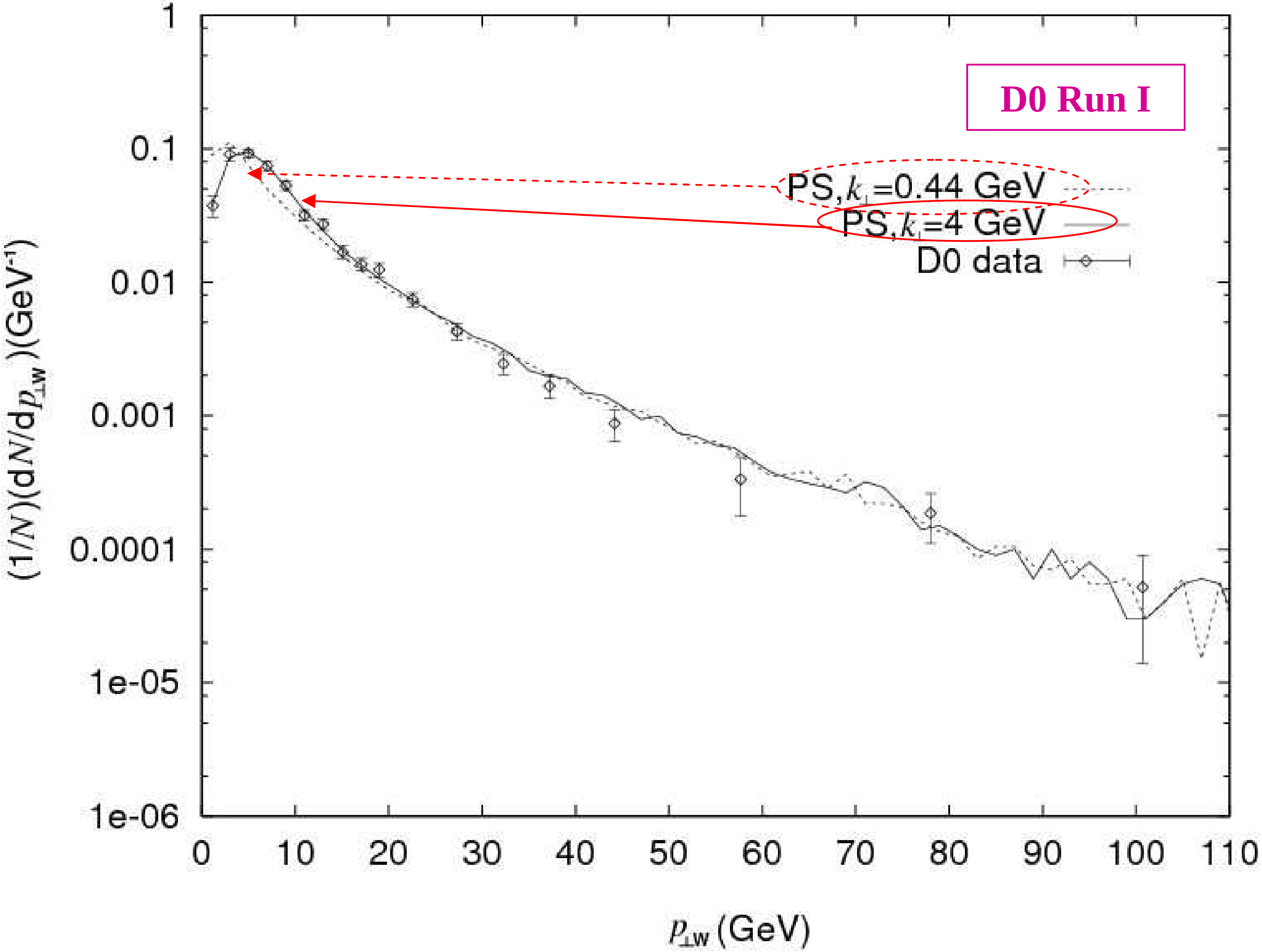
- Interpretation: 1-$\mathcal{P}$(for a to split into b+c between t_0 and t)

2. Initial State Showers (backward evolution)

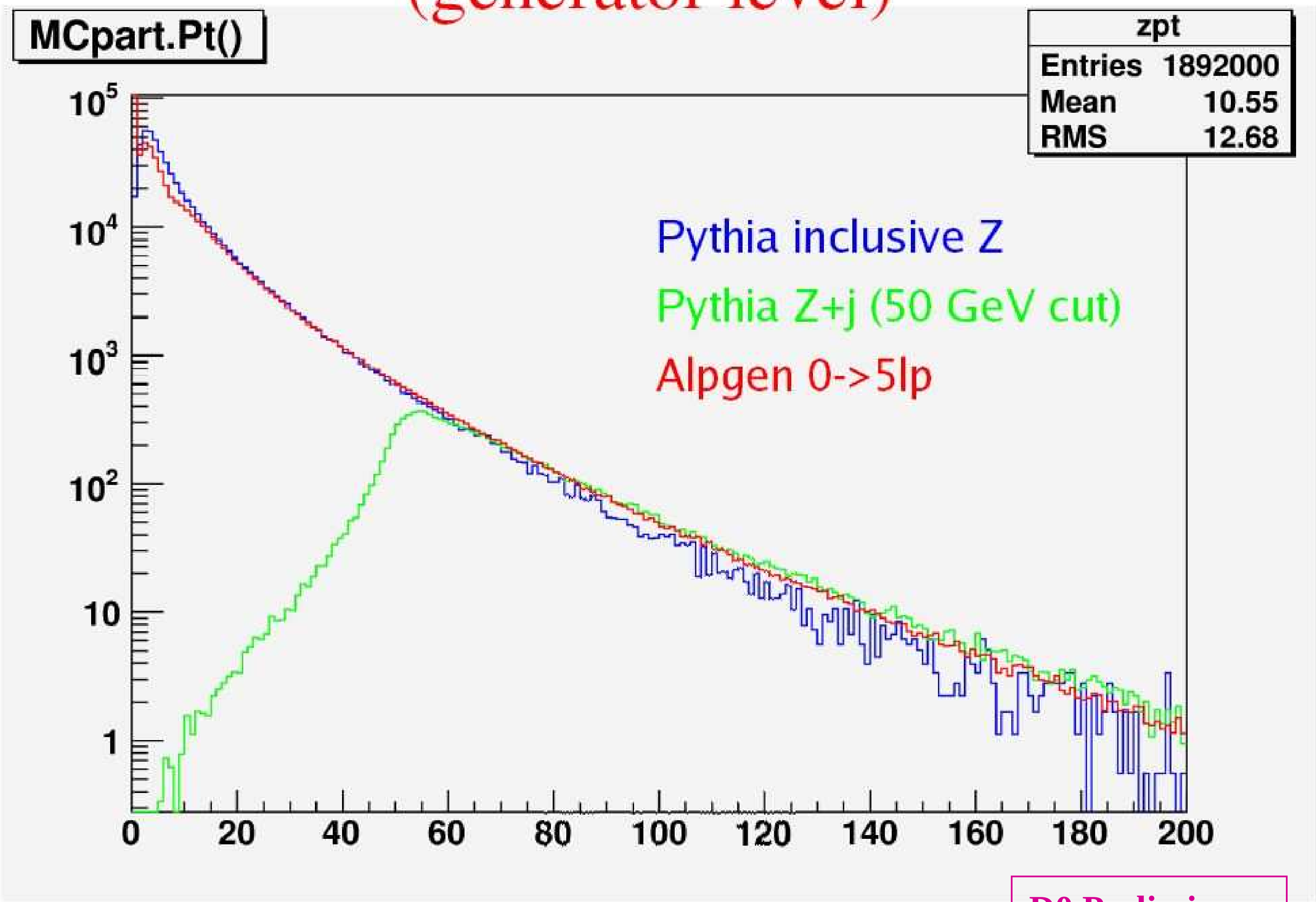
- In principle equivalent to FS showers
  - but both end fixed => quite different in practice
- DGLAP Equations:
  - Start at HS Q^2
  - Evolve backwards
  - Weight w/ PDFs at each x and t

Reweighting PS for X+0jet wrt to X+1jet ME (X: colour singlet)
Note: only the first emission is corrected

T. Sjöstrand, G. Miu (99)



(generator level)



D0 Preliminary
L. Duflot

New Approaches – Why Bother?

- Pros and cons of existing showers, e.g.:
  - In PYTHIA, ME merging is easy, and emissions are ordered in some measure of (Lorentz invariant) hardness, but angular ordering has to be imposed by hand, and kinematics are somewhat messy. Matching not straightforward.
  - HERWIG has inherent angular ordering, but also has the 'dead zone' problem, is not Lorentz invariant and has somewhat messy kinematics. Matching not straightforward.
  - ARIADNE has inherent angular ordering, simple kinematics, and is ordered in a (Lorentz Invariant) measure of hardness, matching is straightfroward, but is primarily a tool for e^+e^-, and g→qq is 'artificial' in dipole formalism.
- These all describe LEP data well, but none are perfect (ARIADNE probably slightly the better)

•Not easy to control theoretical uncertainty on exponentiated part ☹

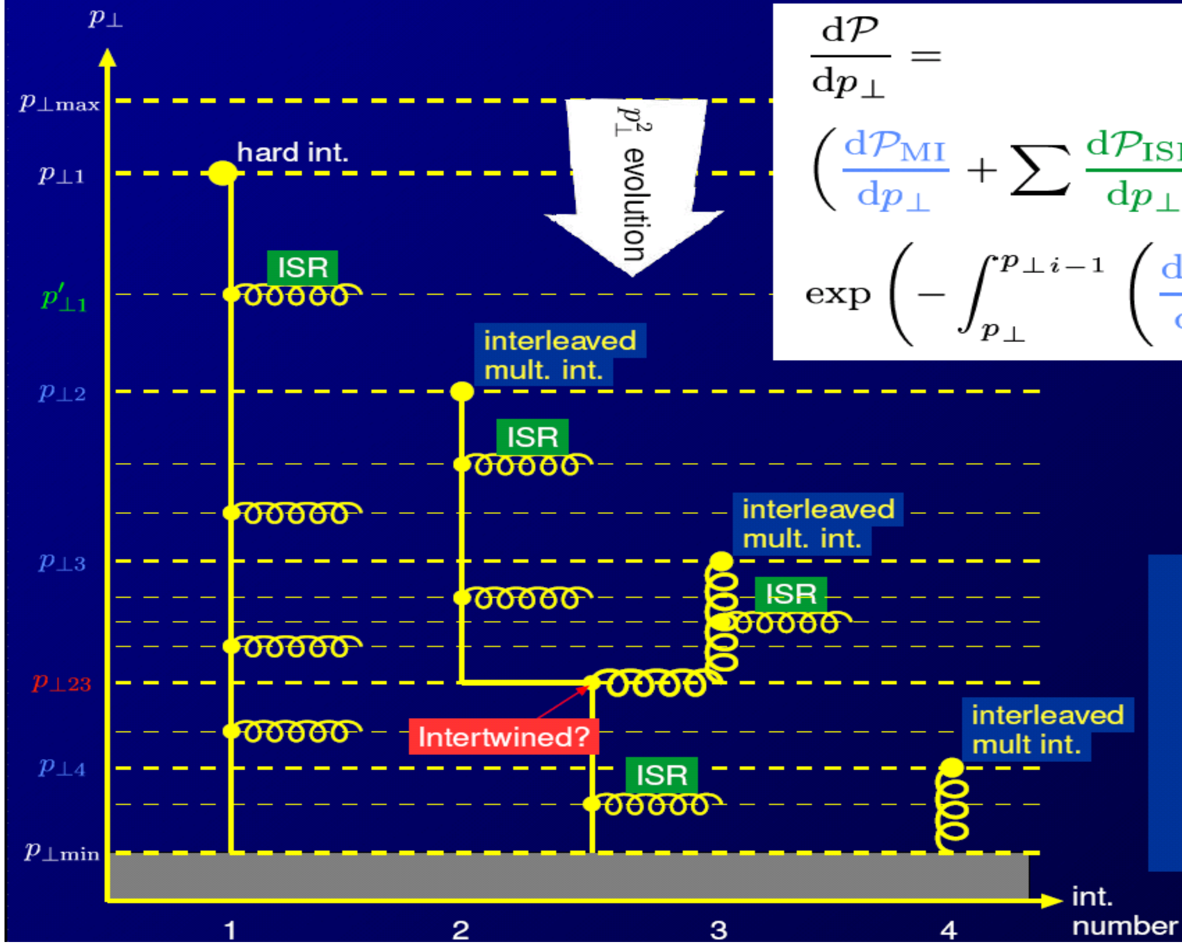
PYTHIA: PS & MPI
'Interleaved evolution'

Sjöstrand & PS : Eur.Phys.J.C39(2005)129 + JHEP03(2004)053

T. Sjöstrand, P. Skands

The new picture: start at the most inclusive level, $2 \to 2$.

Add exclusivity progressively by evolving *everything* downwards.



Pythia 6.3

$$\frac{d\mathcal{P}}{dp_\perp} = \left(\frac{d\mathcal{P}_{\rm MI}}{dp_\perp} + \sum \frac{d\mathcal{P}_{\rm ISR}}{dp_\perp} + \sum \frac{d\mathcal{P}_{\rm JI}}{dp_\perp}\right) \times \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{d\mathcal{P}_{\rm MI}}{dp'_\perp} + \sum \frac{d\mathcal{P}_{\rm ISR}}{dp'_\perp} + \sum \frac{d\mathcal{P}_{\rm JI}}{dp'_\perp}\right) dp'_\perp\right)$$

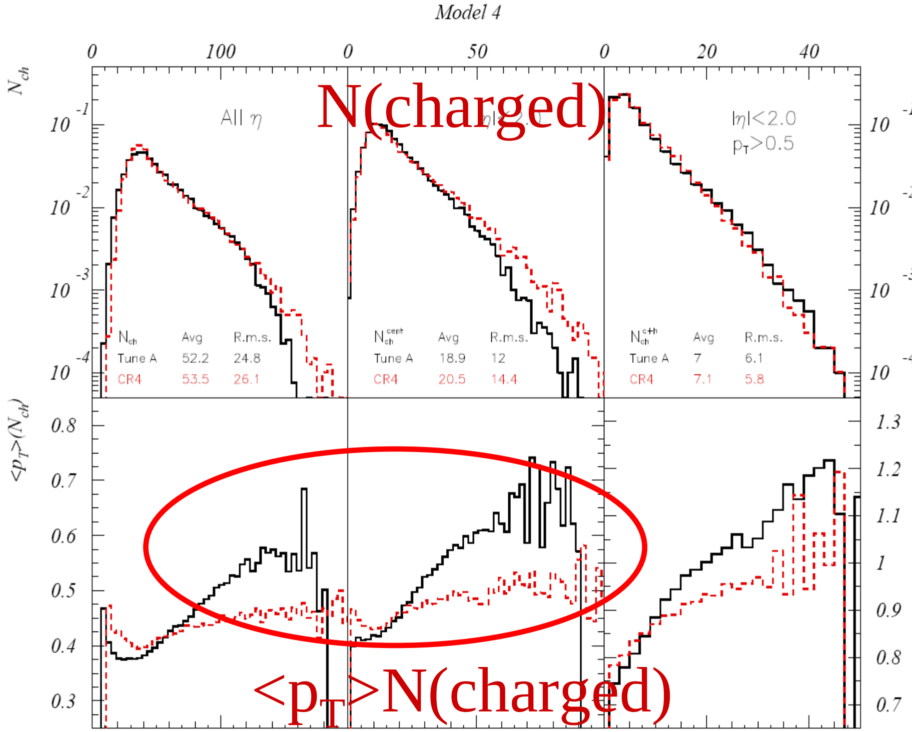
→ Underlying Event
(note: interactions correllated in colour:
hadronization not independent)

~ "Finegraining"

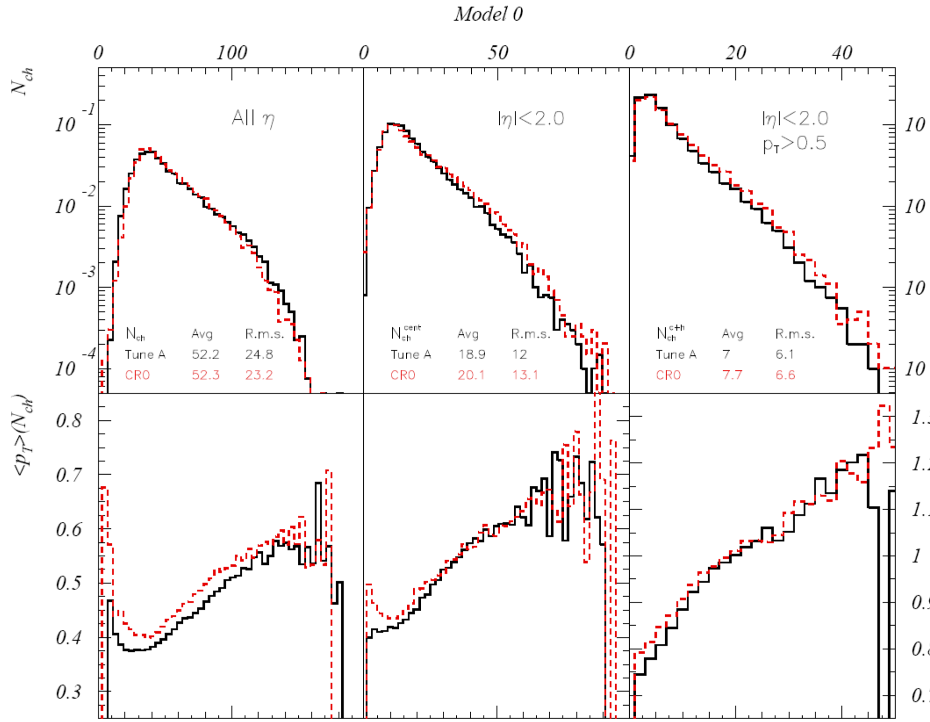
→ correlations between all perturbative activity at successively smaller scales

PYTHIA: PS & MPI
'Interleaved evolution'

Old: Tune A



New



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Pythia 6.3 : p_T-ordered showers

Note: optional. Old ones still kept as default

- Completely rewritten parton showers (both ISR and FSR)

•Hybrid parton/dipole description

–Evolution in terms of partons …

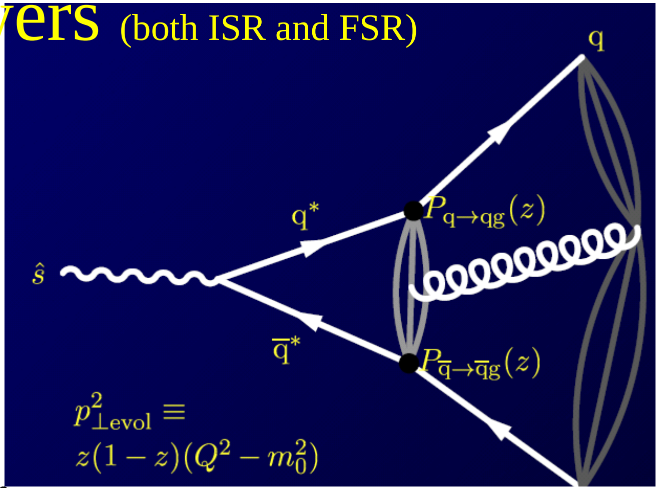
–Kinematics constructed inside dipoles assuming yet unbranched partons on shell

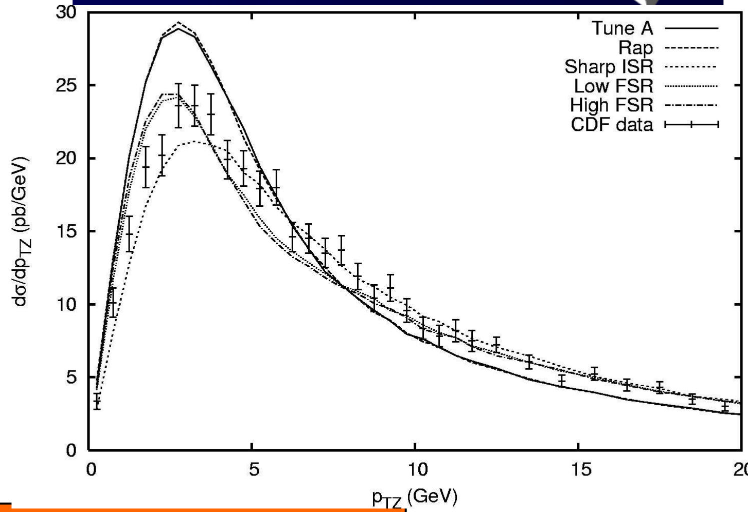
–Massive splitting functions for c, b, t, sparticles, …

–Merged with 1st order matrix elements for h/γ/Z/W production, and most EW, top, and MSSM decays

•LEP → improvement ("correct" to 1%)

•Tevatron → improvement (e.g.: DY→





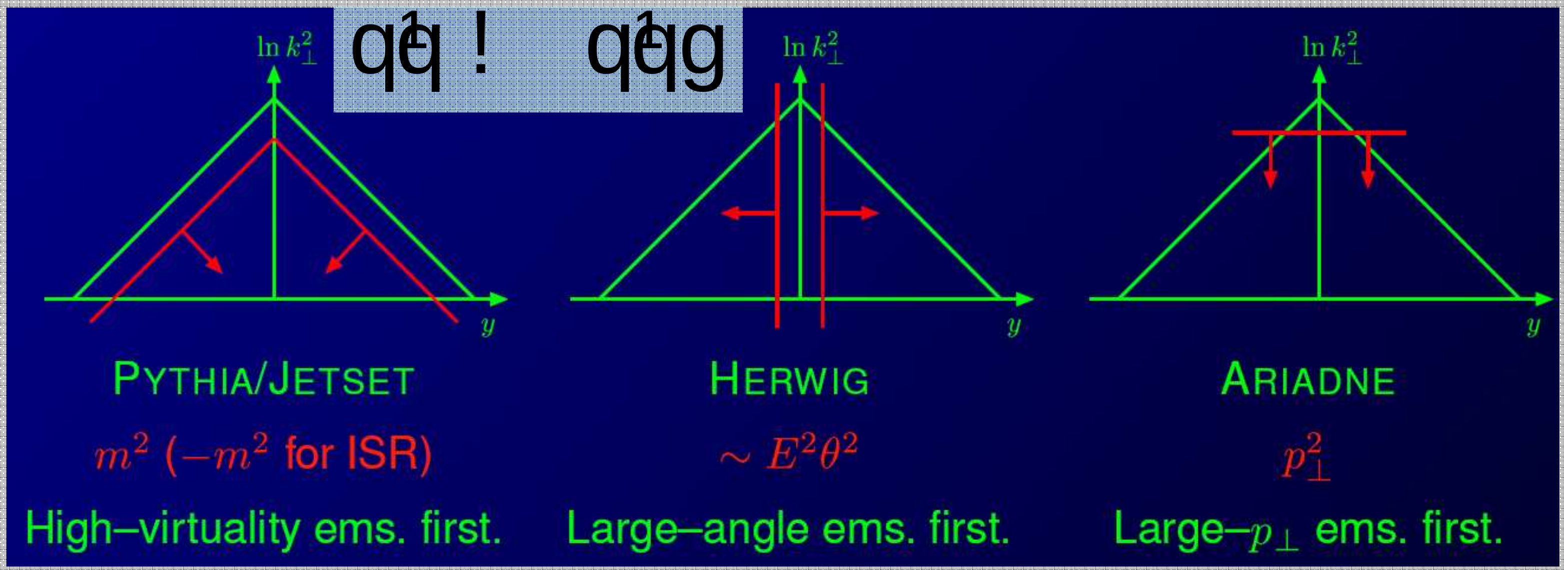
Sjöstrand & PS : Eur.Phys.J.C39(2005)129

Parton Showers: the basics

P. Skands

- Today, basically 2 approaches to showers:
  - Parton Showers (e.g. HERWIG, PYTHIA)
  - and Dipole Showers (e.g. ARIADNE).

- Essential Difference: Ordering Variable



Parton Showers: the basics

P. Skands

- Today, basically 2 approaches to showers:
  - Parton Showers (e.g. HERWIG, PYTHIA)
  - and Dipole Showers (e.g. ARIADNE).

- Another essential difference: kinematics construction, i.e. how e.g. 2→2 kinematics are 'mapped' to 2→3.