MC Tuning from TeV to LHC based on Dijet Azimuthal Decorelations

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TeV4LHC Workshop – September 16, 2004

- Motivation / Observable
- Experimental Results
- Fixed Order pQCD Description
- MC Tuning to TeV Data
- Extrapolation to LHC Energies?

in collaboration with: A. Kupčo, M. Begel, C. Royon, M. Zieliński

Monte Carlos – what can be tuned?

event topology: fundamental signature + broad features + fine details

Monte Carlo Event Generators:

- LO Matrix Elements for fundamental process (e.g. $2 \to 2$) $\to$ normalization uncertainty!
- perturbative parton cascade models (based on soft and collinear approximations)
- phenomenological models for non-perturbative phase (hadronization, underlying event)

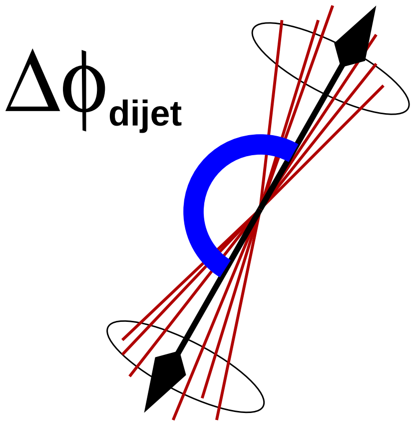
Tuning MCs?

- LO MEs are exact (use most recent α_s and MRST/CTEQ pdfs)
- everything else can be tuned!! – plenty of parameters in PYTHIA / less in HERWIG

How to tune MCs? (don't use "hard" parameters to fix "soft" physics)

- **first:** find k-factor to fix normalization problem – or use normalized differential distrib.
- **second:** use "broad" event features to tune "hard" physics $\Leftarrow$ scope of this talk
- **third:** tune soft physics to describe finer details

Dijet Azimuthal Decorrelations



Dijet Production:

azimuthal opening angle between both leading p_T jets:

- limit: exactly two jets, no further radiation $\Rightarrow$ $\Delta\phi_{\text{dijet}} = \pi$

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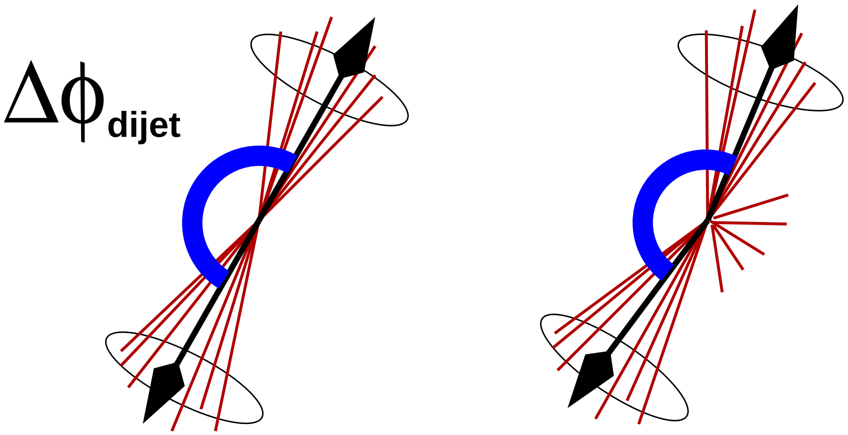

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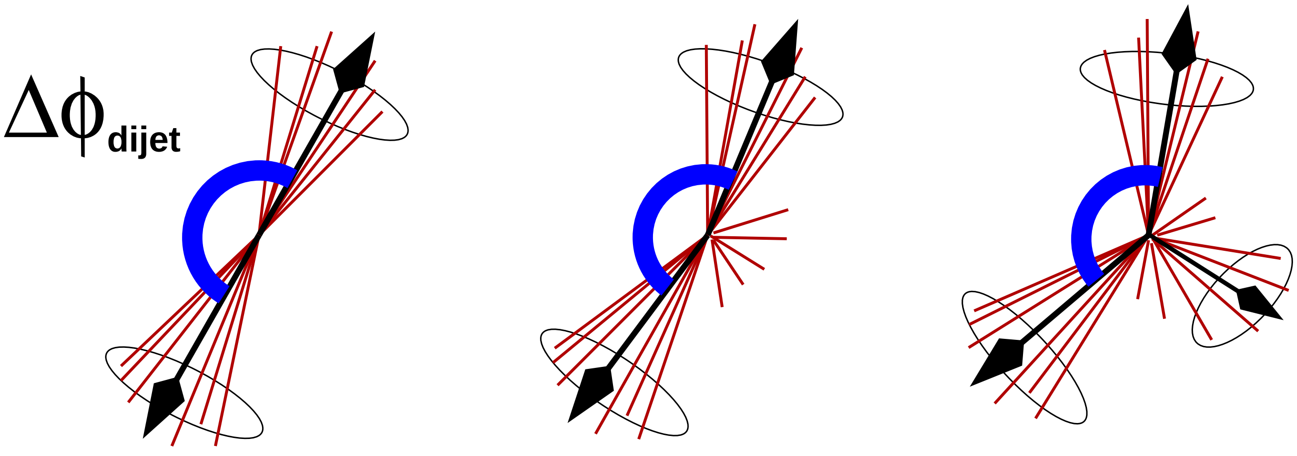

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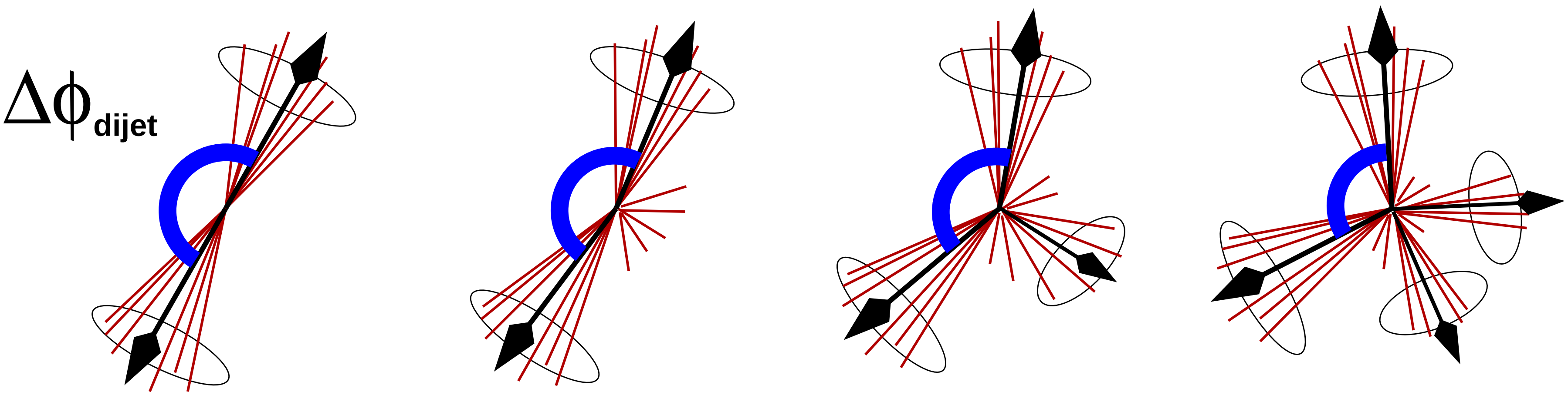

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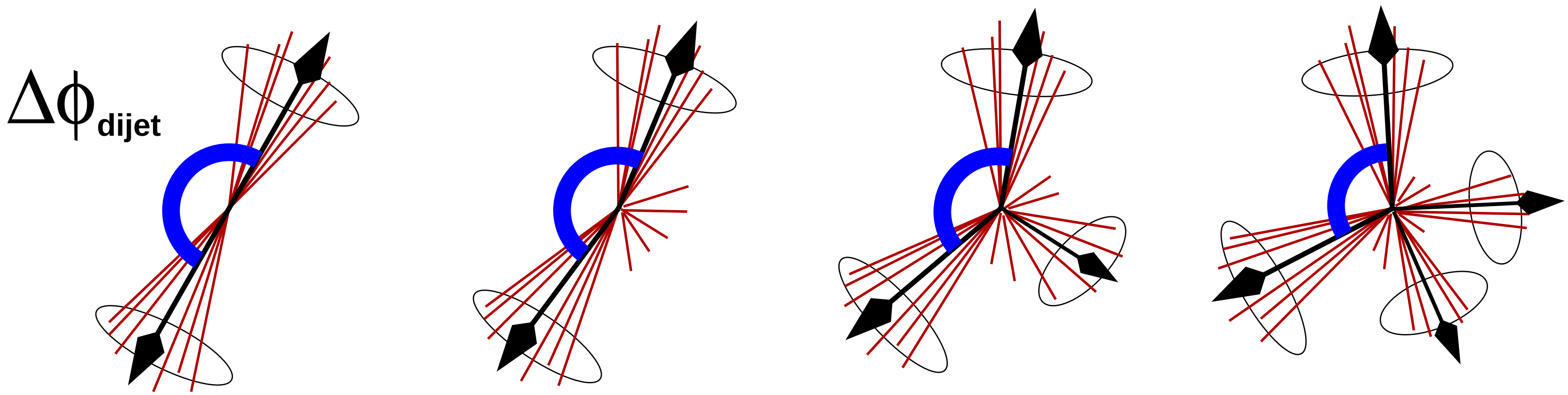

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$\Rightarrow$ $\Delta\phi_{\text{dijet}}$ distribution is sensitive to higher order pQCD effects without requiring the reconstruction of additional jets (Yes: this is an experimental advantage!!)

$\Rightarrow$ $\Delta\phi_{\text{dijet}}$: examine transition between soft and hard physics, based on single observable

Defining the Observable

- define the jets using iterative, seed-based midpoint cone algorithm
  with $R_{\text{cone}} = 0.7$ in rapidity and azimuthal angle
  (the “Run II cone algorithm” $\Leftarrow$ Run II Workshop)

- Define the observable to be the normalized differential $\Delta\phi_{\text{dijet}}$ distribution:

$$\frac{1}{\sigma_{\text{dijet}}} \cdot \frac{d\sigma_{\text{dijet}}}{d\Delta\phi_{\text{dijet}}}$$

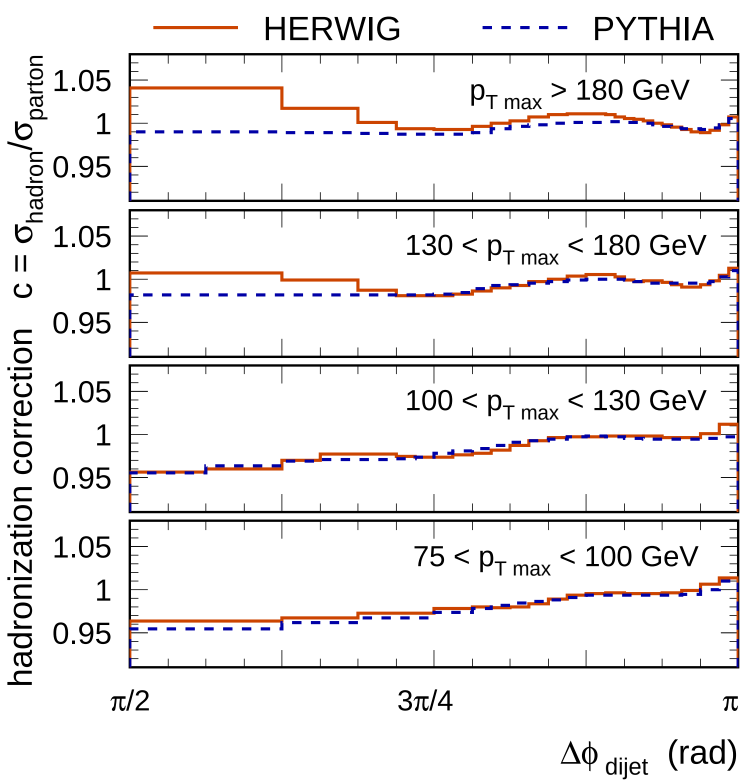
- measure the observable as a function of a hard scale:
  $\Rightarrow$ in four different regions of the leading jet p_T – starting at $p_T^{\text{max}} > 75$ GeV
  requiring the second leading p_T jet to have $p_T > 40$ GeV

- require that both leading p_T jets have central rapidity $|y_{\text{jet}}| < 0.5$

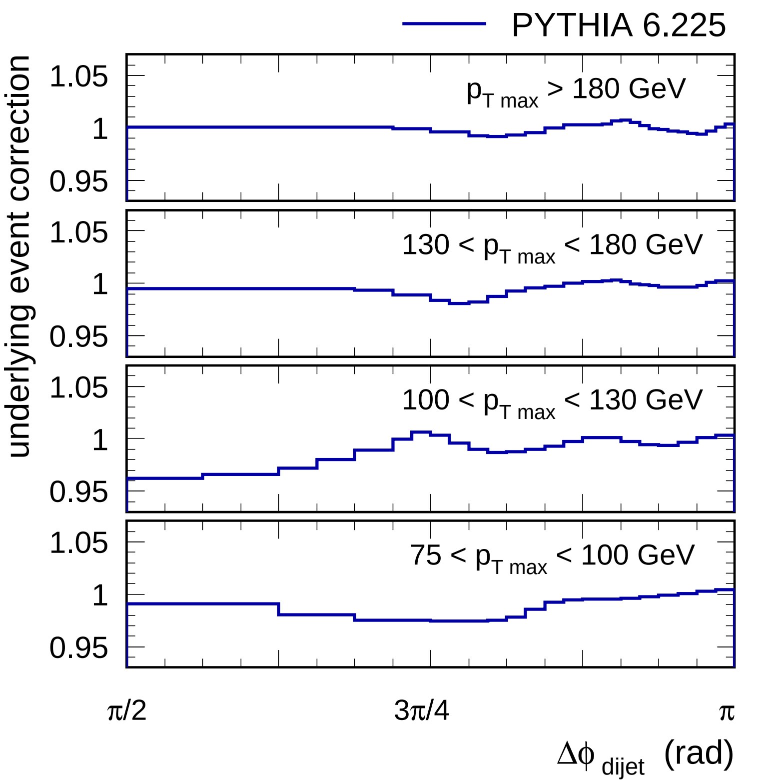
the $\Delta\phi_{\text{dijet}}$ distribution is a three-jet observable! the ratio is $\propto \alpha_s^3/\alpha_s^2$
recently available: NLO pQCD predictions for 3-jet observables: pQCD at $\mathcal{O}(\alpha_s^4)$
(NLOJET++, Z. Nagy)

Non-Perturbative Effects

Hadronization Corrections: $\frac{\text{Obs.}_{\text{hadron}}}{\text{Obs.}_{\text{parton}}}$

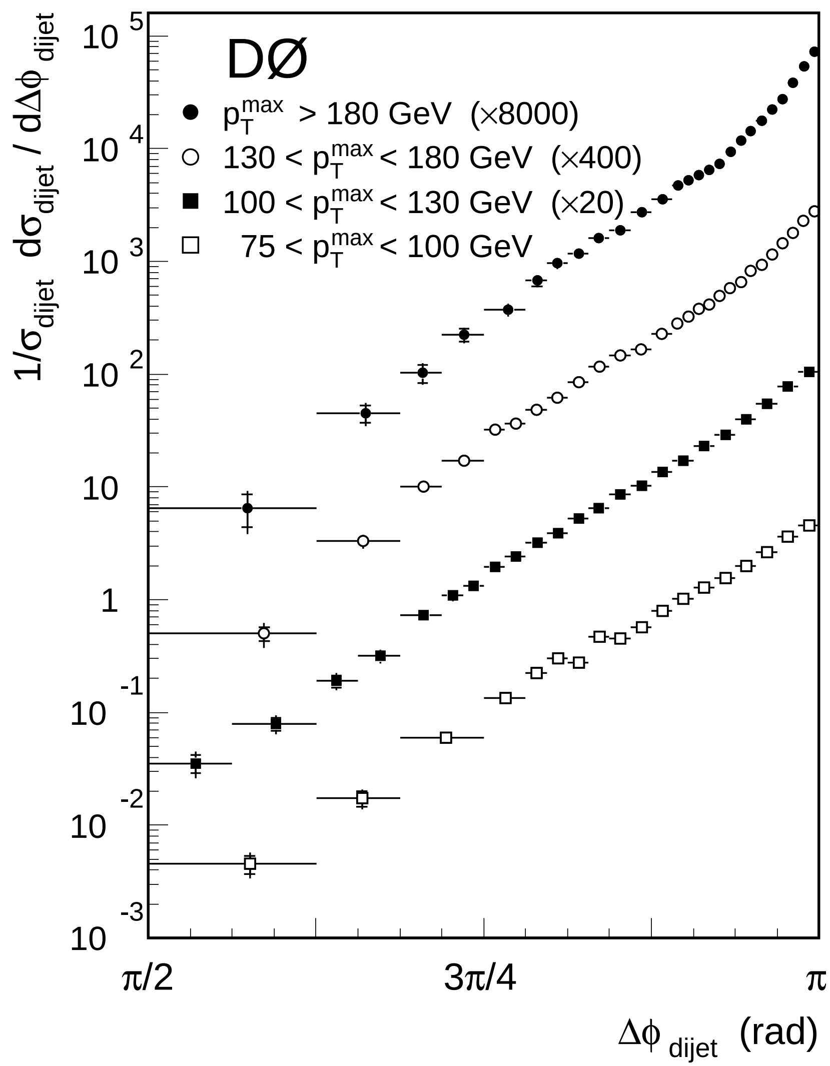


Underlying Event: $\frac{\text{Obs.}_{\text{with UEVT}}}{\text{Obs.}_{\text{w/o UEVT}}}$



Non-perturbative effects are below 5% $\Longrightarrow$ only sensitive to perturbative effects

Experimental Results



First Tevatron Run II QCD Jet Publication
hep-ex/0409040 submitted to PRL today!

- data in four p_T^{max} regions:

⇒ more strongly peaked at high p_T^{max}

⇒ decreasing by more than 4 orders of magnitude from $\Delta\phi_{\text{dijet}} = \pi$ to $\pi/2$

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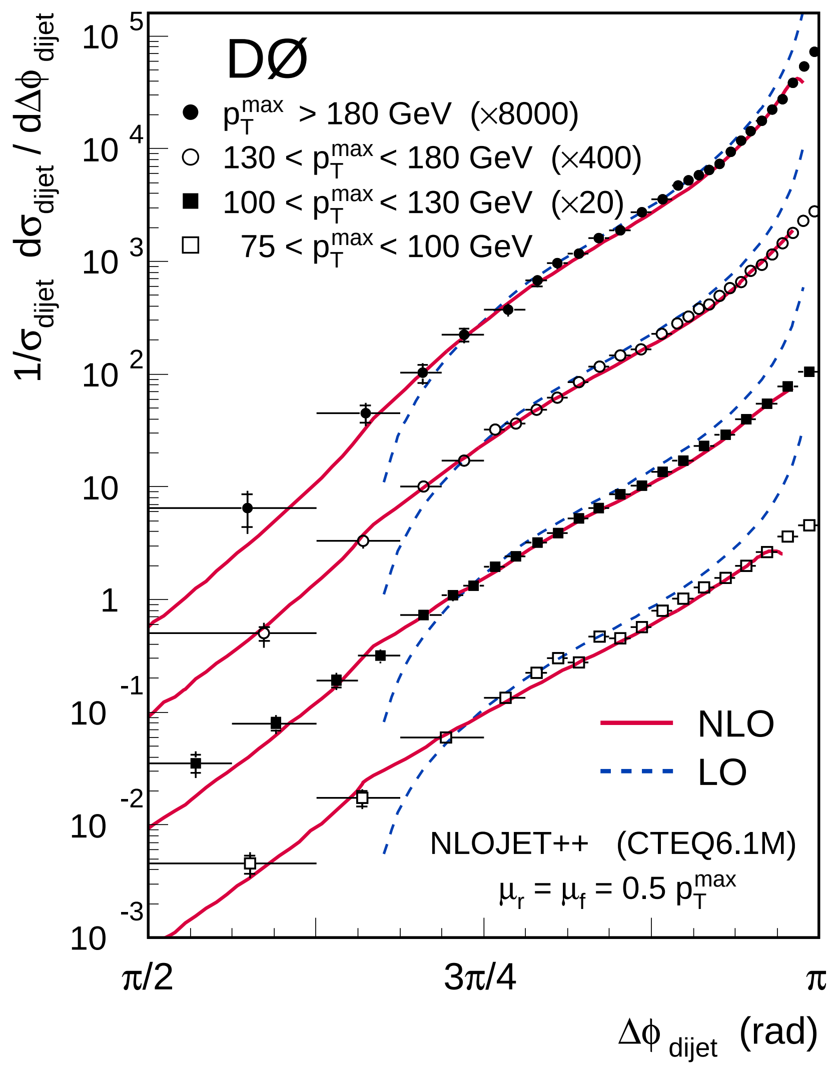

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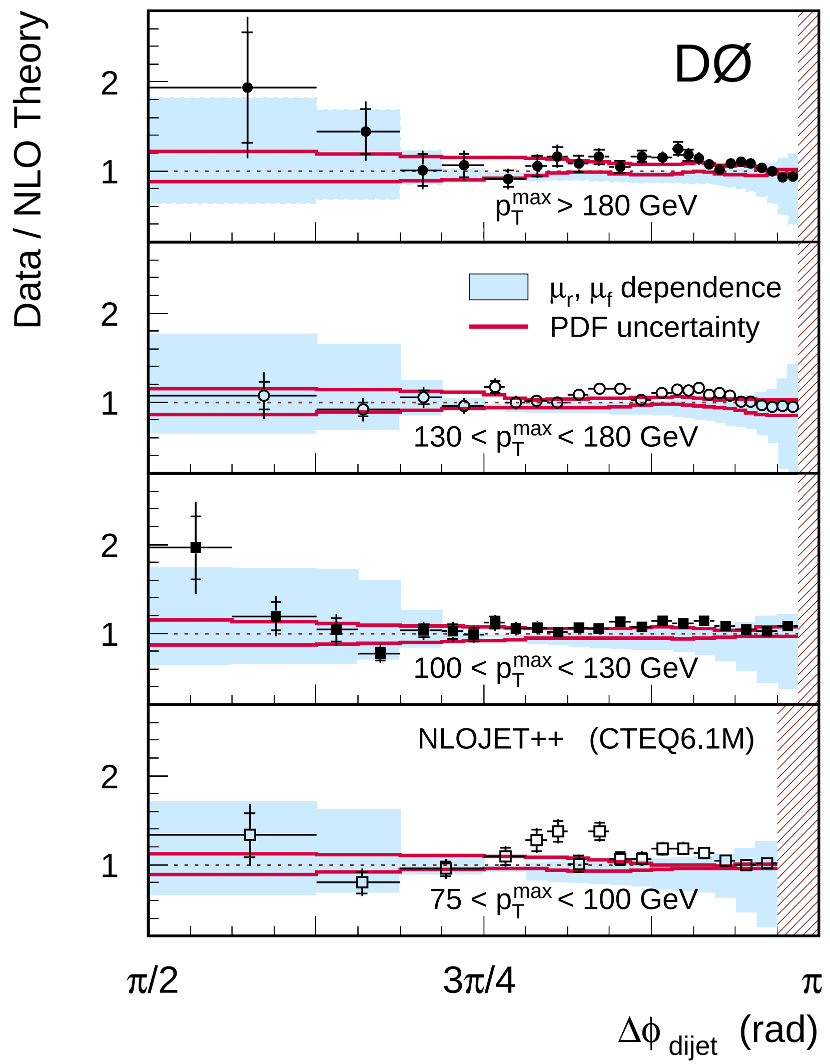
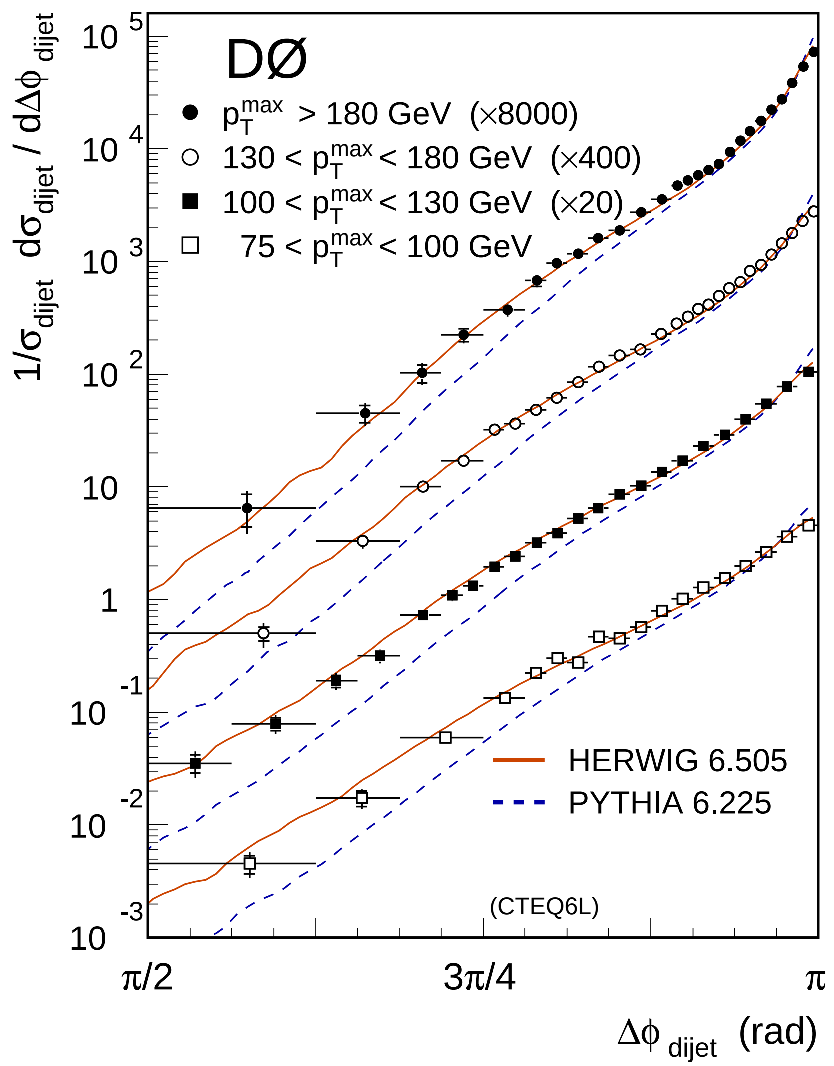
  - ⇒ more strongly peaked at high p_T^{max}
  - ⇒ decreasing by more than 4 orders of magnitude from $\Delta\phi_{\text{dijet}} = \pi$ to $\pi/2$
- LO pQCD prediction is poor
  - ⇒ reasonable only in limited $\Delta\phi_{\text{dijet}}$ range
  - ⇒ $\Delta\phi_{\text{dijet}} < 2\pi/3$ no phase space
  - ⇒ $\Delta\phi_{\text{dijet}} \rightarrow \pi$ divergence
- NLO pQCD prediction is very good
  - ⇒ (see ratios for details)

Quantitative Comparison: Data and NLO



- NLO pQCD:
  - ⇒ good description of the data on average 5–10% below data
  - ⇒ except at $\Delta\phi$ dijet close to π (soft processes – needs resummation)
- renormalization and factorization scale dependence: $0.25 p_T^{max} < \mu_{r,f} < p_T^{max}$
  - ⇒ small at intermediate $\Delta\phi$ dijet
  - ⇒ large at $\Delta\phi$ dijet $\rightarrow \pi$ (soft region)
  - ⇒ large at $\Delta\phi$ dijet $< 2\pi/3$ (only tree-level four parton final states)
- PDF uncertainty using CTEQ6.1M pdfs
  - ⇒ dominant at intermediate $\Delta\phi$ dijet larger in high p_T^{max} region

Comparison: Data and MCs



- HERWIG v6.505 (default)
  - ⇒ good description of the data over whole $\Delta\phi_{dijet}$ range
- PYTHIA v6.225 (default)
  - ⇒ significantly too low at small $\Delta\phi_{dijet}$
  - ⇒ too narrowly peaked at π

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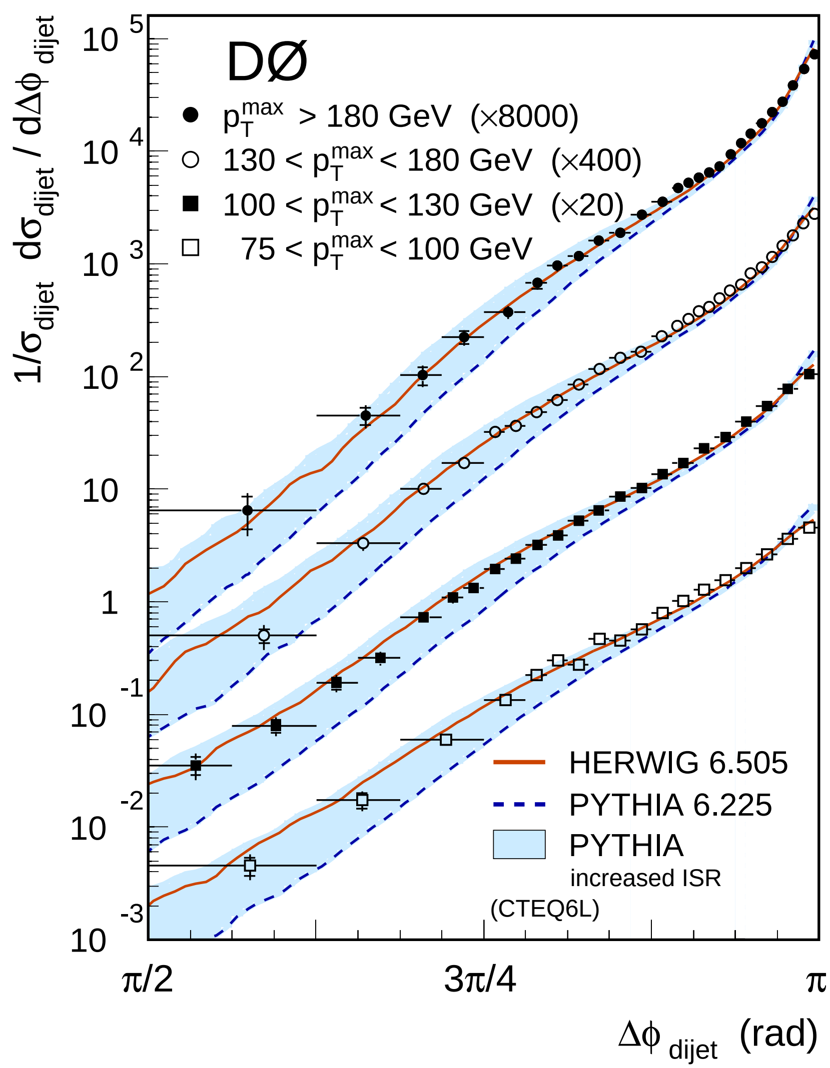

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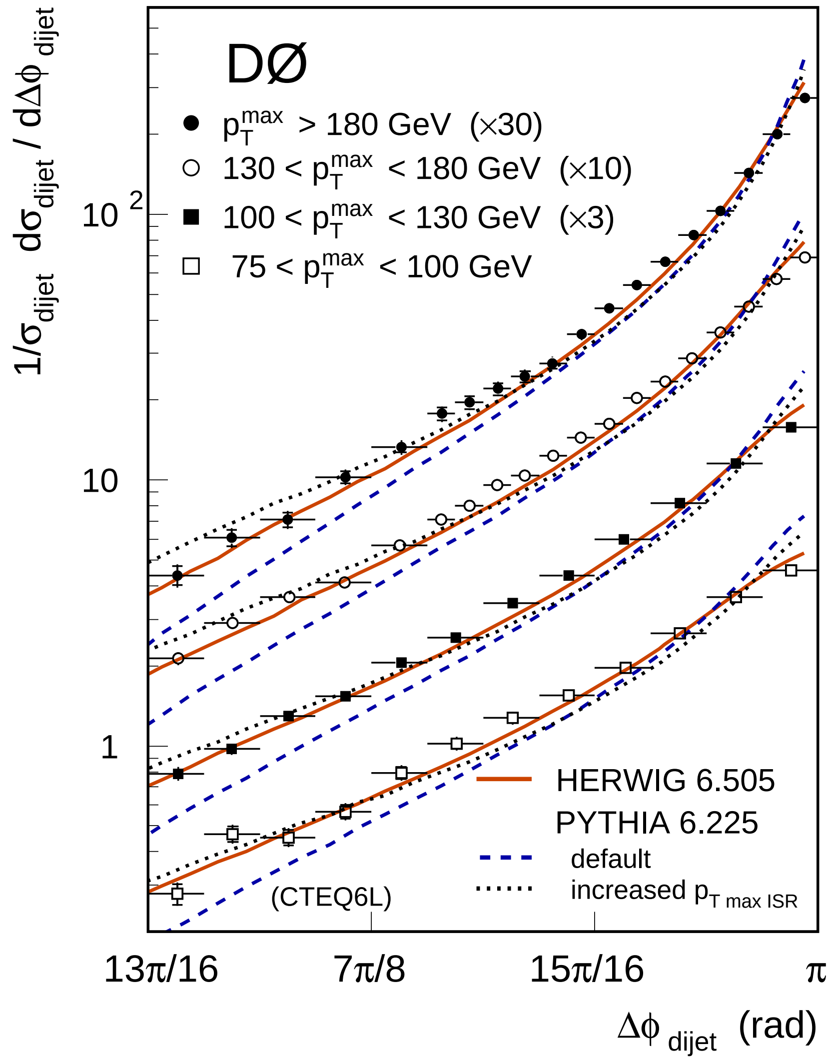
- changing maximum p_T in ISR shower (remember: Rick Field's PYTHIA "tune A")
  - ⇒ change: `PARP(67)=1.0` $\rightarrow$ `4.0`
    `PARP(67)` $\times$ hard scale ($\simeq p_T$) defines the maximum virtuality in ISR shower
  - ⇒ directly related to max. p_T in ISR shower
  - ⇒ huge effect for $\Delta\phi_{\text{dijet}}$ distribution
  - ⇒ best value somewhere between `PARP(67)=1.0` and `=4.0`
    $\Rightarrow$ **hard processes can be adjusted!**

Data and MCs — looking at $\Delta\phi_{\text{dijet}} \approx \pi$



– zoom into the peak
– this is where NLO fails (soft processes!)
– where parton shower should work

use same MCs as before:

- HERWIG (default)

$\Rightarrow$ slightly to narrow — but reasonable

- PYTHIA (default)

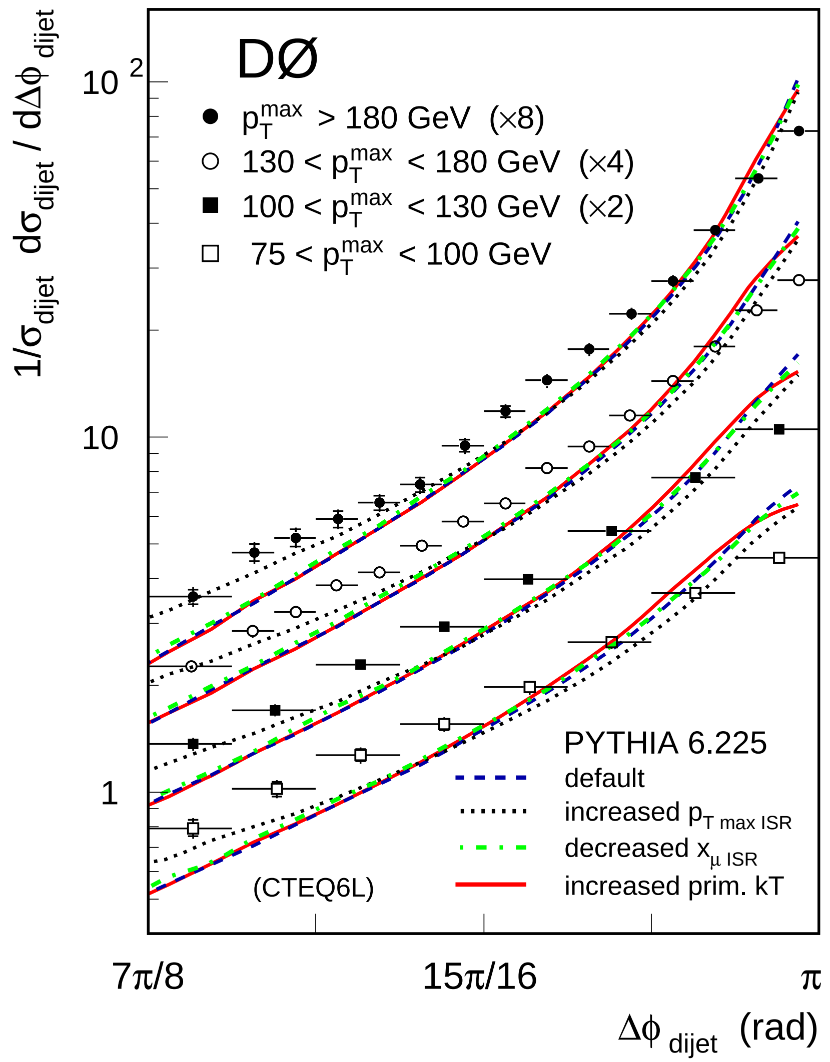
$\Rightarrow$ much too narrowly peaked at π
too low everywhere else

- PYTHIA with `PARP(67)=4.0`

$\Rightarrow$ too narrow in peak
$\Rightarrow$ too low at $\Delta\phi_{\text{dijet}} \approx 15\pi/16$
(low $\Delta\phi_{\text{dijet}}$ tail slightly high)

$\Rightarrow$ more tuning needed for PYTHIA to describe peak region (soft processes)

Tuning PYTHIA – soft processes



vary PYTHIA parameters related to ISR

- $p_{T\,\text{max ISR}}$ PARP(67)=4.0 (D=1.0)

⇒ small effect at high $\Delta\phi_{\text{dijet}}$ for low p_T^{max}

- $x_{\mu\,\text{ISR}}$ PARP(64)=0.5 (D=1.0)

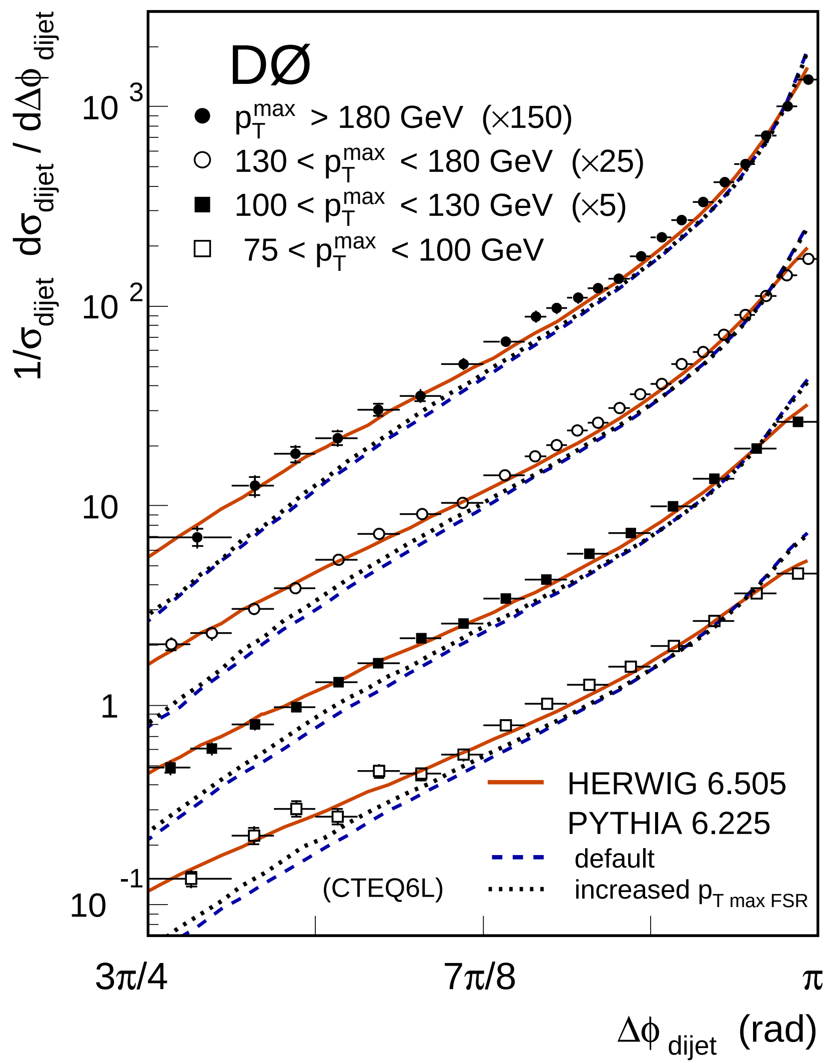
⇒ effect is negligible

- primordial k_T PARP(91)=4.0 (D=1.0)
  upper cut-off PARP(93)=8.0 (D=5.0)

⇒ very small effect at high $\Delta\phi_{\text{dijet}}$ for low p_T^{max}

⇒ **nothing helps!**

Tuning PYTHIA – soft processes



vary PYTHIA parameters related to FSR:

- $p_{T\,\text{max ISR}} \leftrightarrow$ `PARP(67)` was so successful

⇒ try the same thing for FSR

- $p_{T\,\text{max FSR}} \leftrightarrow$ `PARP(71)`

⇒ increase: `PARP(71)=8.0 (D=4.0)`

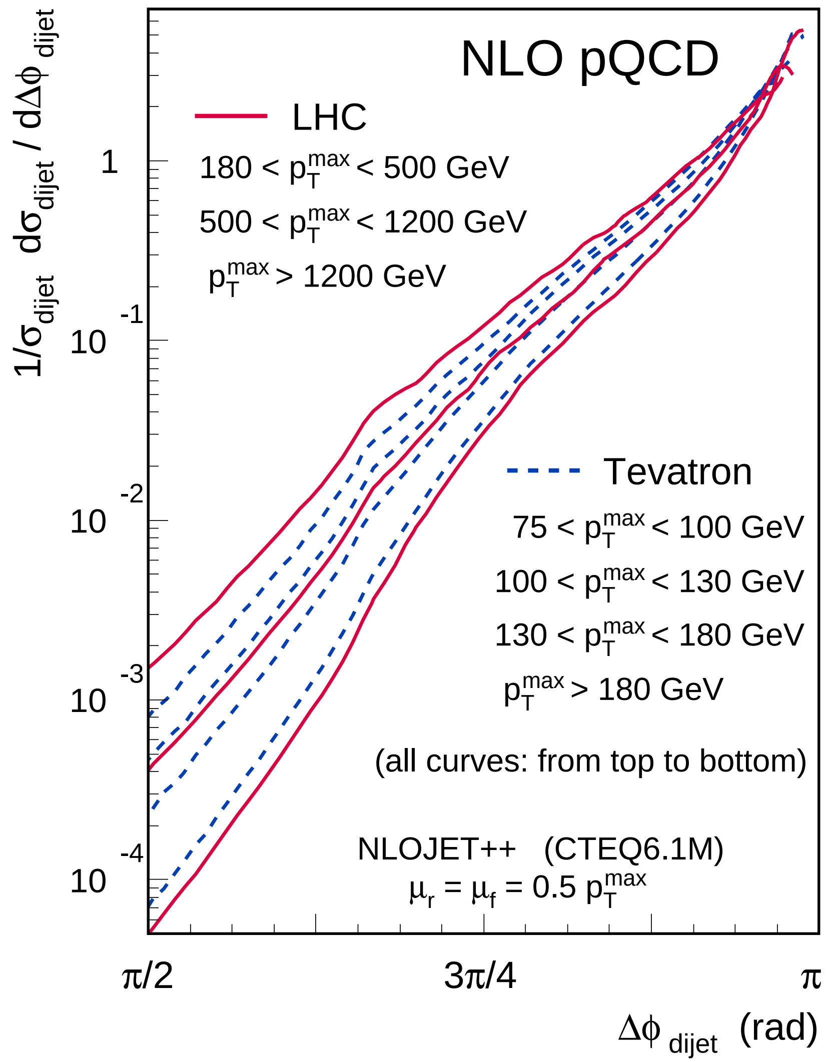
⇒ **zero effect!**

⇒ Here we ran out of ideas...

More suggestions for PYTHIA parameters variations are welcome!!

HERWIG: we tried `PTRMS=1.5 GeV (D=0)`
⇒ no effect

From Tevatron to the LHC



NLO gives a very good description
⇒ use NLO as a reference

compare NLO predictions for $\Delta\phi_{\text{dijet}}$
at Tevatron and LHC

for both: Run II cone algorithm, $|y_{\text{jet}}| < 0.5$

- Tevatron Run II (as: hep-ex/0409040)

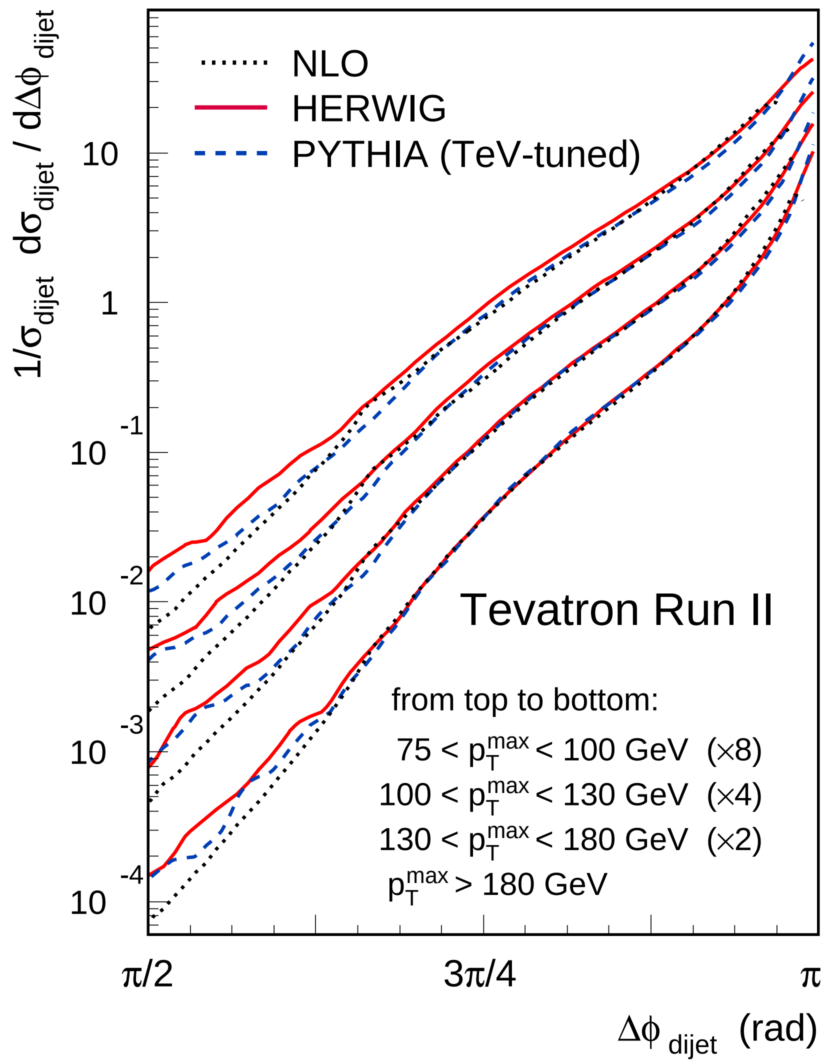
⇒ $p_{T\,2} > 40$ GeV
⇒ four p_T^{max} regions

- LHC

⇒ $p_{T\,2} > 80$ GeV
⇒ three p_T^{max} regions

⇒ The chosen p_T^{max} ranges for the LHC results cover the spread of the Tevatron results

A last look at the Tevatron ...



best description by PYTHIA
for `PARP(67)` between `D=1.0` and `4.0`

- tune `PARP(67)` to NLO

⇒ result: `PARP(67)=2.5 (D=1.0)`

⇒ this setting is now referred to as "TeV-tuned"

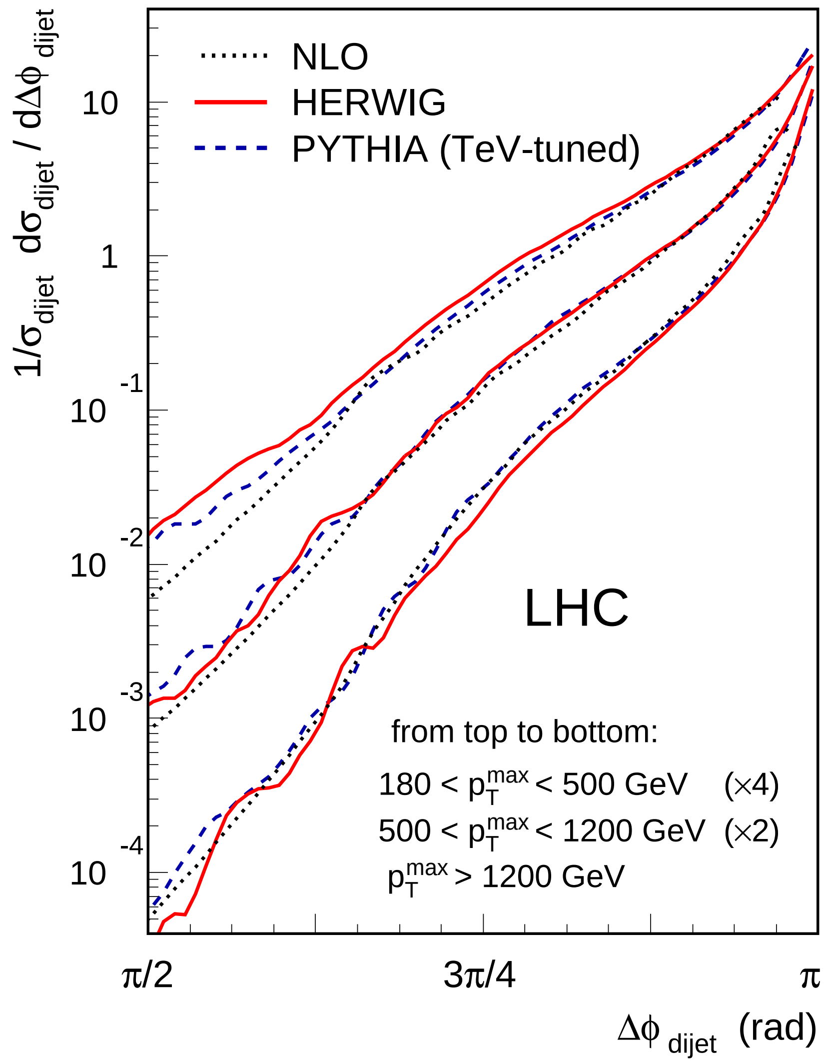
- (ignore the peak region...)

⇒ good agreement:
HERWIG ≈ PYTHIA ≈ NLO

Question:

Can this good agreement (and the tune) be transferred to the LHC?

... and a first look at the LHC



... a huge success!!! – ... expected??

- PYTHIA (TeV-tuned)

⇒ the good agreement with NLO at Tevatron Run II energies is reproduced at LHC energies!!

- HERWIG (default)

⇒ small differences:
broader at low p_T^{max}
narrower at large p_T^{max}

⇒ Both Monte Carlos are in good agreement with NLO predictions

Summary and Conclusions

using Dijet Azimuthal Decorrelations to test & tune Monte Carlo event generators:

- normalized distribution

$\Rightarrow$ not affected by poor absolute normalization of LO Matrix Elements

- not sensitive to non-perturbative effects (hadronization, underlying event)

$\Rightarrow$ allows to tune perturbative parameters in MCs w/o interference of “soft parameters”

- strategy must be:

$\Rightarrow$ tune “hard parameters” first — then the “soft parameters”

$\Rightarrow$ e.g. order: Dijet Azimuthal Decorrelations $\rightarrow$ Jet Shapes $\rightarrow$ Underlying Event

- HERWIG: not much to tune (no parameters / but also: not necessary)
- PYTHIA: only sensitivity: $p_{T\,\mathrm{max\,ISR}}$ – result: `PARP(67)=2.5 (D=1.0)`

$\Rightarrow$ this should be the basis for a new Tevatron tune (“tune A-prime”?)

surprise: PYTHIA tuning can be transferred to LHC energies
$\Longrightarrow$ very promising for tuning MCs for LHC!