# Effects of Jet Matching in BSM Signals

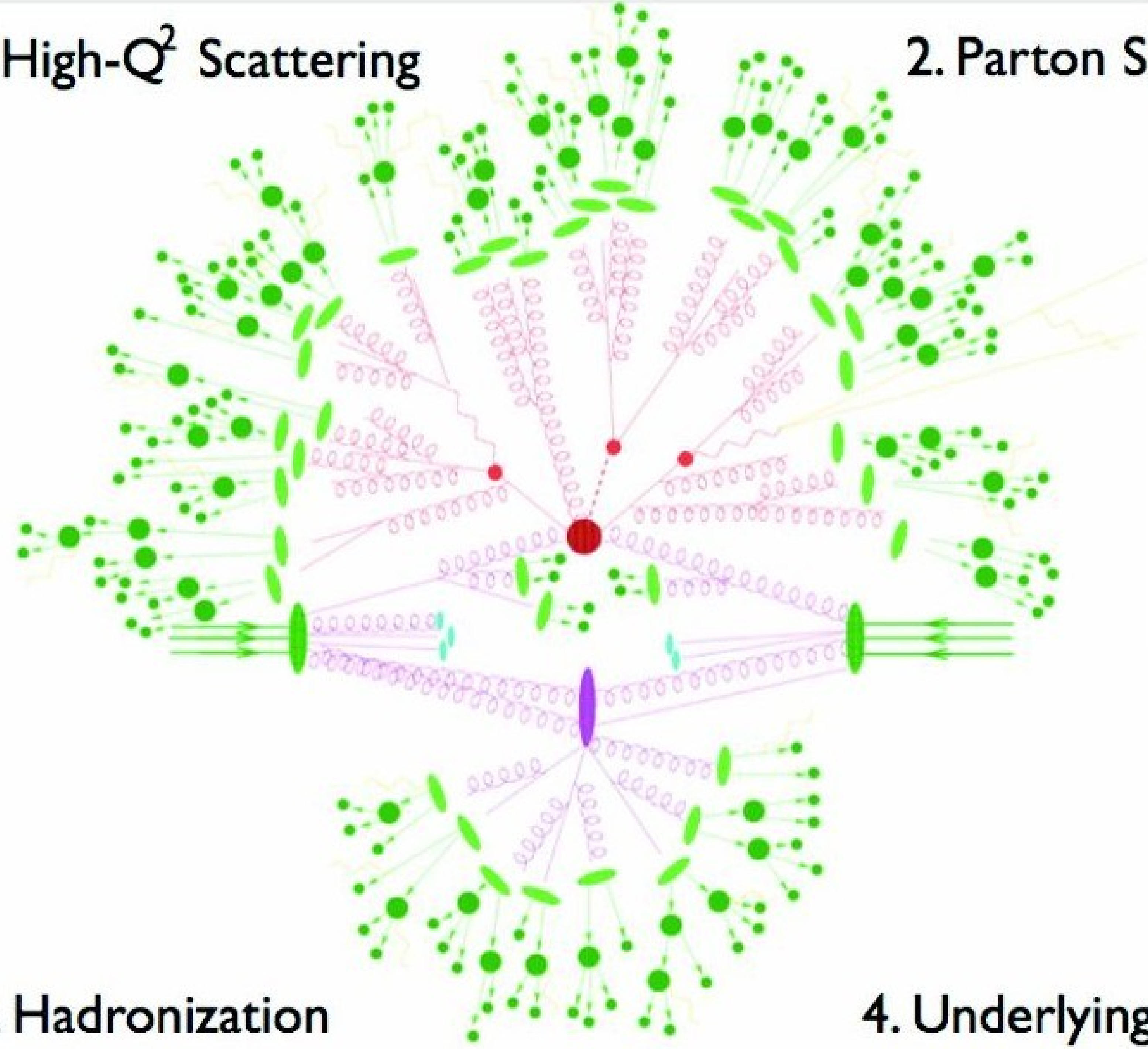
Johan Alwall, SLAC

With Simon de Visscher and Fabio Maltoni
(Université de Louvain)

arXiv:0810.xxxx (very soon!)

IPMU Seminar, Tokyo, Japan, 14 Oct 2008

# Introduction – The Big Picture



1. High-$Q^2$ Scattering

2. Parton Shower

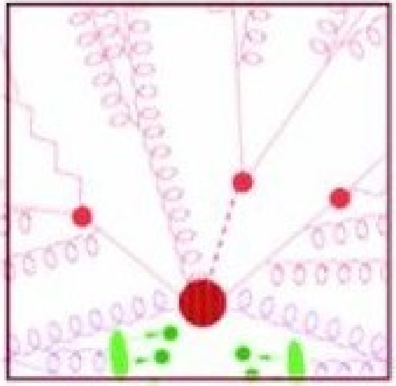
3. Hadronization

4. Underlying Event

## 1. High-$Q^2$ Scattering

2. Parton Shower

☞ where new physics lies



☞ process dependent

☞ first principles description

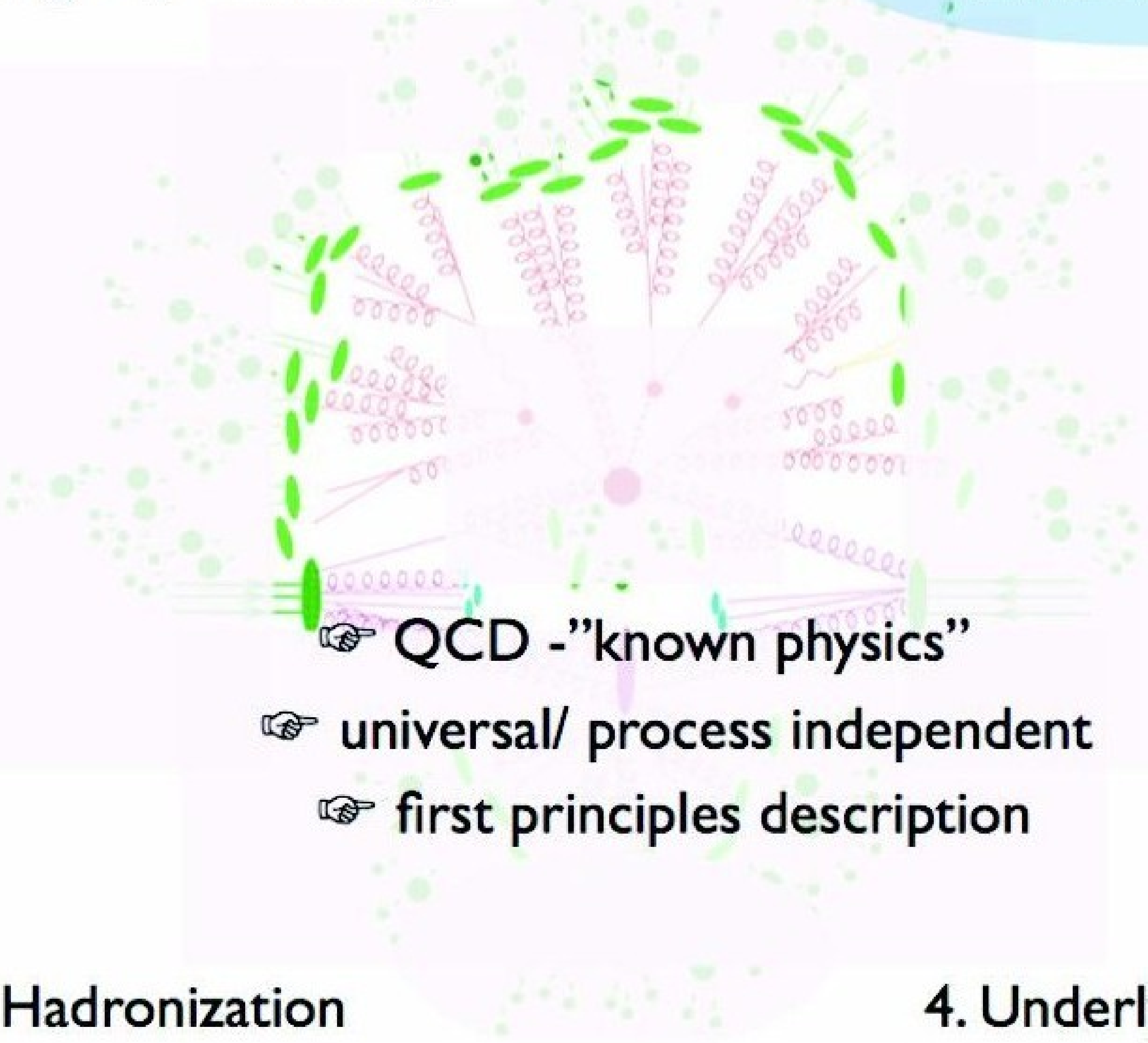
☞ it can be systematically improved

3. Hadronization

4. Underlying Event

1. High-$Q^2$ Scattering

**2. Parton Shower**



- ☞ QCD -"known physics"
- ☞ universal/ process independent
- ☞ first principles description

3. Hadronization

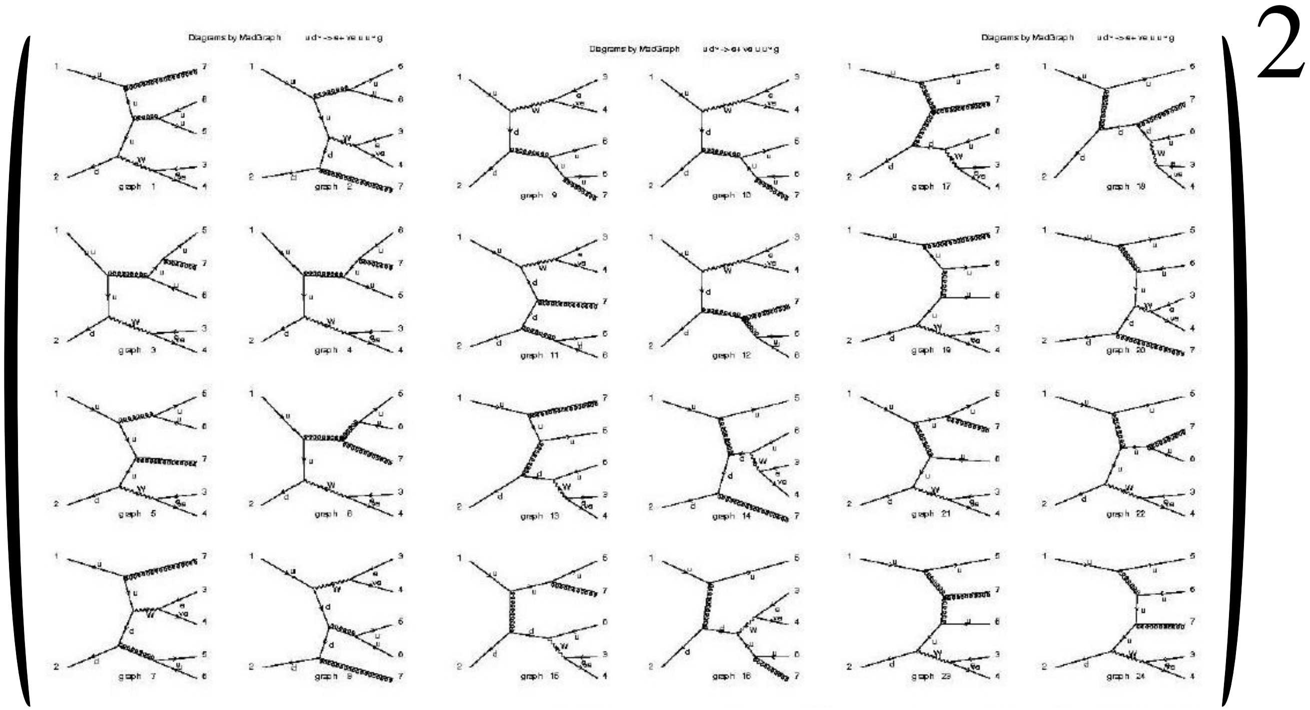
4. Underlying Event

# How to describe QCD emissions

- Matrix Element Generators

- Parton Showers

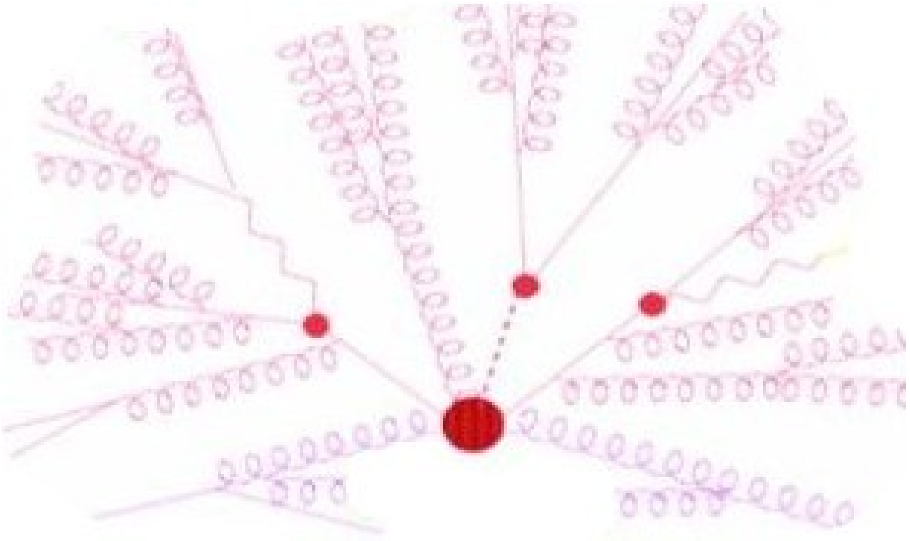
# Matrix Element Generators



Diagrams for $u\bar{d} \rightarrow e^+\nu_e u\bar{u}g$ by MadGraph

- Use full Matrix Element information
- Different methods in different generators
  - MadGraph, Grace, Sherpa: Feynman diags + Helicity ampls
  - AlpGen, Helac: Recursion relations
  - Whizard: 1POW/DAG optimization

# Parton Showers



- Based on soft-collinear approximation
- Markov process to perform subsequent QCD emissions (due to factorization)
- Strict ordering of emissions in ordering variable
  - $Q^2$ (Pythia < 6.3), $p_T$ (Pythia > 6.3, Ariadne)
  - $\theta E$ (Herwig)

# Jet matching/merging

## Matrix elements

1. Fixed order calculation
2. Computationally expensive
3. Limited number of particles
4. Valid when partons are hard and well separated
5. Quantum interference correct
6. Needed for multi-jet description

## Parton showers

1. Resums logs to all orders
2. Computationally cheap
3. No limit on particle multiplicity
4. Valid when partons are collinear and/or soft
5. Partial quantum interference through angular ordering
6. Needed for hadronization/ detector simulation

Complementary approximations

Need to combine without double counting

# Matching schemes

## The simple idea behind matching

- Use matrix element description for well separated jets, and parton showers for collinear jets
- Phase-space cutoff to separate regions

$\Longrightarrow$ No double-counting between jet multiplicities

## Difficulties

- Get smooth transition between regions
- No/small dependence from precise cutoff
- No/small dependence from largest multiplicity sample

## How to accomplish this

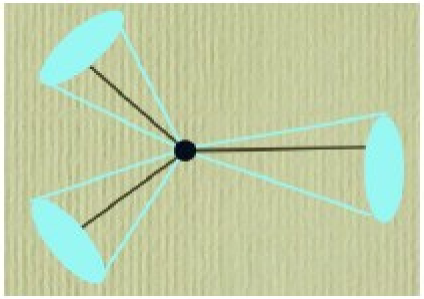
- CKKW scheme (Catani, Krauss, Kuhn, Webber)
- Lönnblad scheme
- MLM scheme

# MLM matching

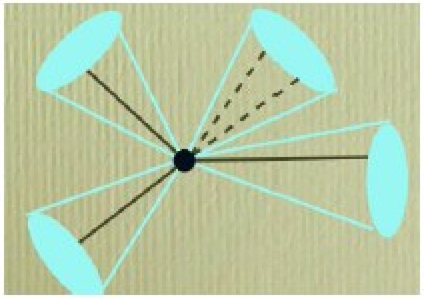
J.A. et al. [arXiv:0706.2569],
cf. M.L. Mangano [2002, Alpgen home page]

## Use shower hardness to separate ME/PS

1. Generate multiparton event with cut on jet $k_T$
2. Cluster event and use $k_T^2$ for $\alpha_s$ scale
3. Shower event (using Pythia) starting from hard scale
4. Collect showered partons in $k_T$ jets with $k_{T\text{cut}} > k_{T\text{min}}$
5. Keep event only if each jet matched to one parton
6. For highest multiplicity sample, allow extra jets softer than $k_{T\text{min}}$

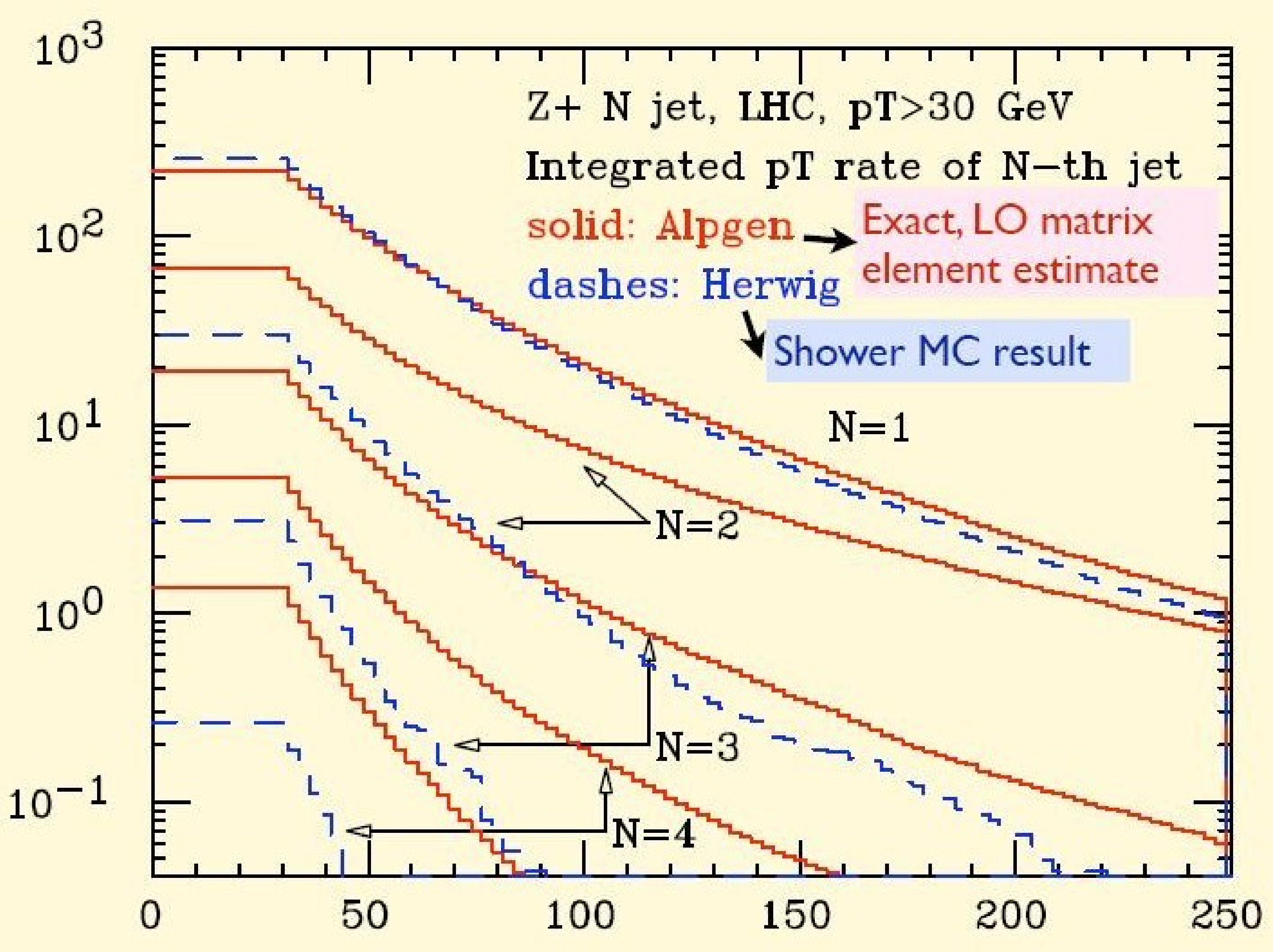


Keep



Discard unless highest multiplicity

# Impact of matching on Z+jets



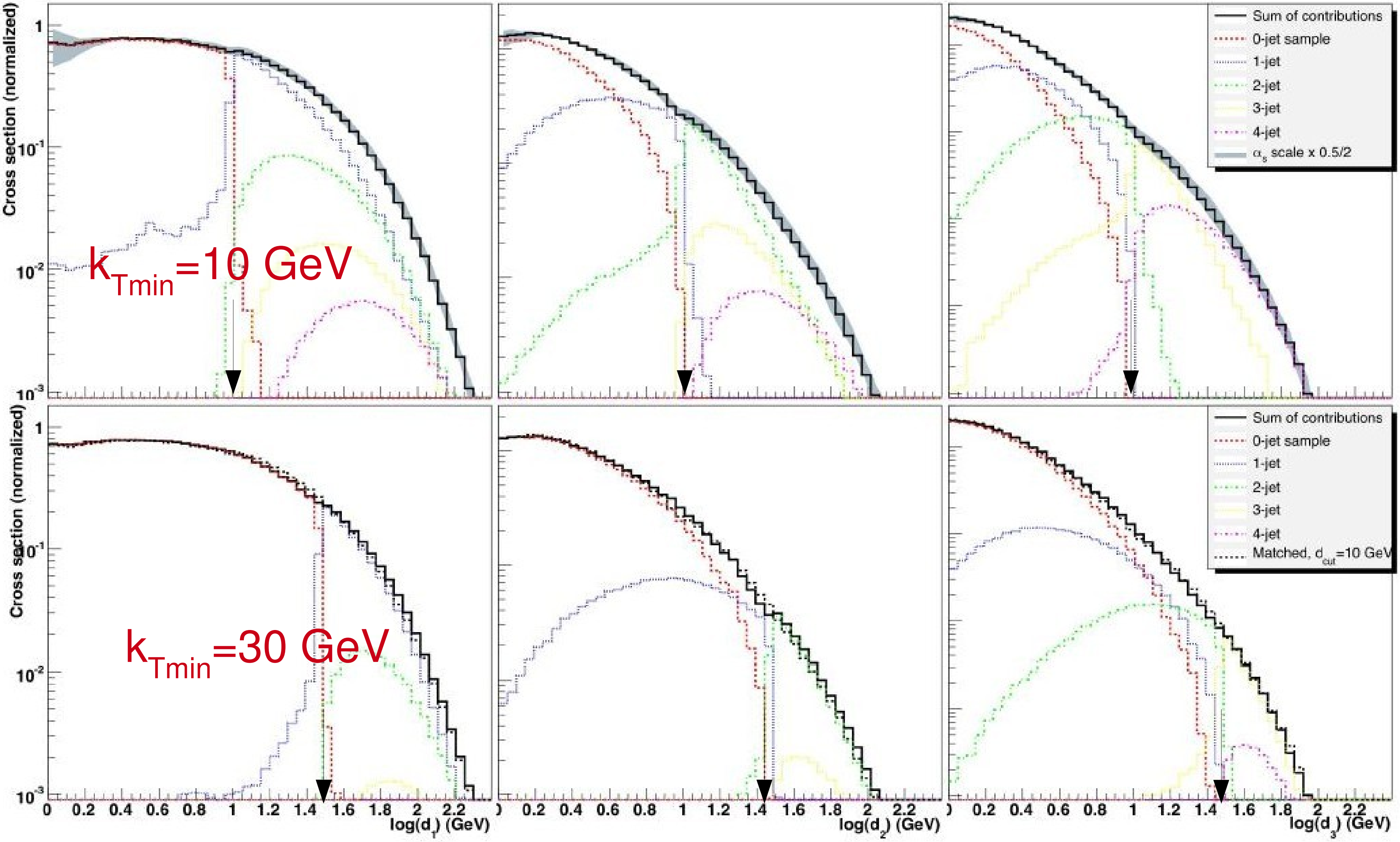
Matching vital to get multijet backgrounds right!

# Matching in MG/ME+Pythia

[MG/ME = MadGraph/MadEvent, an automatized Matrix Element generator and event generator, see arXiv:0706.2334]

- $k_T$ and cone jet MLM schemes
- New “shower $k_T$” scheme
- Both $Q^2$ and $p_T$-ordered Pythia showers
- Extensively validated in V+jets [arXiv:0706.2569], VV+jets, t pair+jets, H+jets and inclusive jets
- Only generator that allows matching in BSM processes (e.g. gluino/squark production)

# Smoothness of matching



$k_{Tmin}$=10 GeV

$k_{Tmin}$=30 GeV

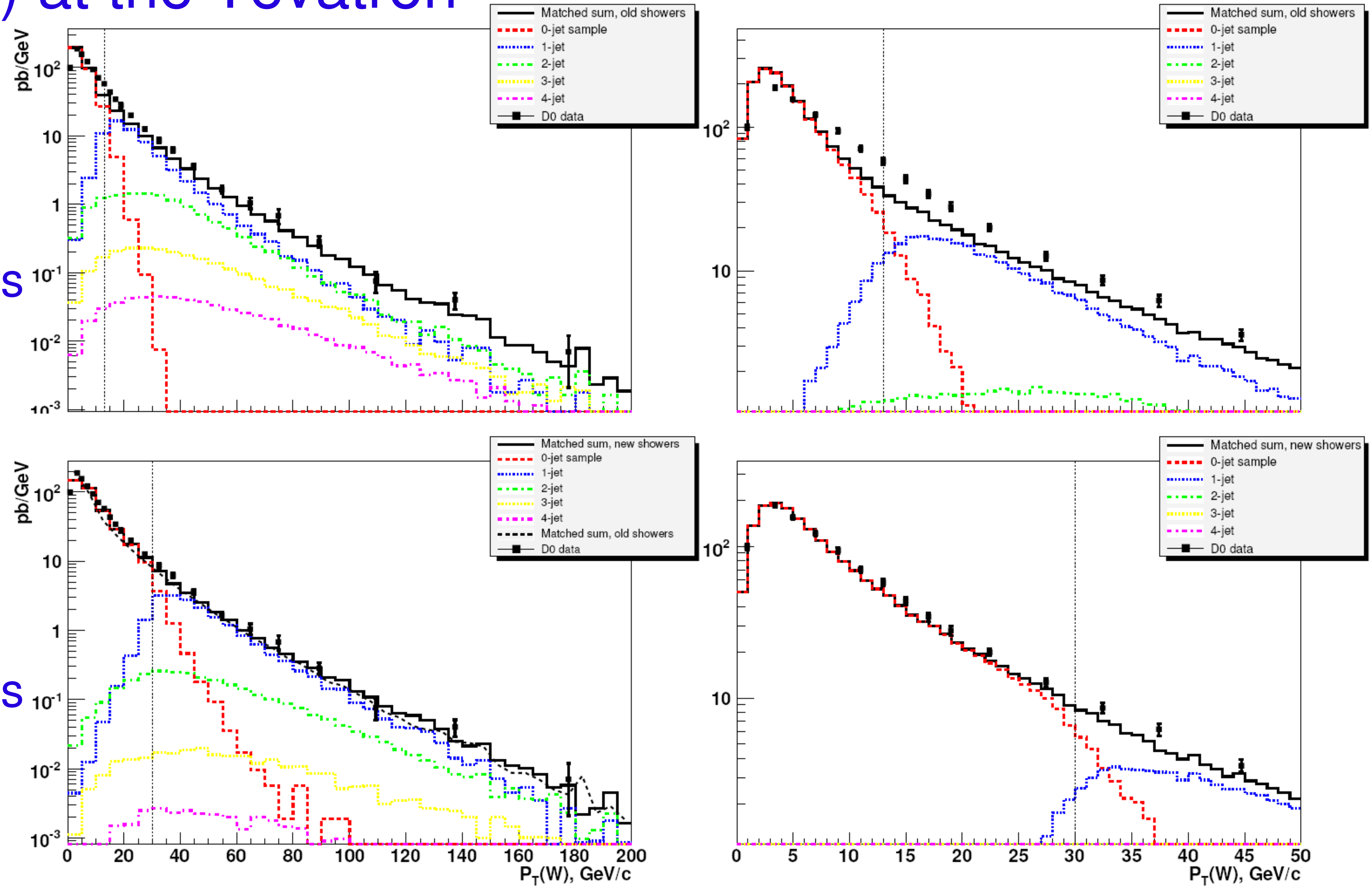
Diff. jet rates by MadEvent+Pythia in W+jets prod. at the Tevatron

# Comparison with Tevatron Data

## $p_T(W)$ at the Tevatron

“Old” Pythia showers

“New” Pythia showers



Tail given by ME, head by pure showers

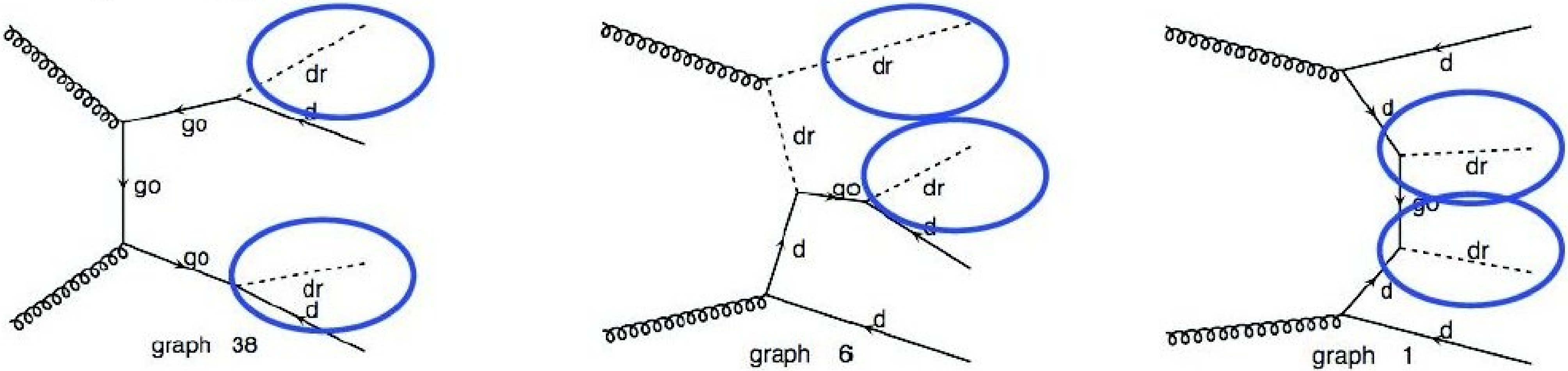
# Matching in gluino/squark production

- We know that matching is vital for jet production in SM backgrounds
- But is it relevant for heavy QCD particle production?
  - Very hard jets from decays
  - Parton showers more accurate for larger masses
- Turns out there are many cases where matching has a large impact!
- Most important at hadron colliders: ISR matching

# Double counting

- Special difficulty in SUSY matching – double counting between squark and gluino production

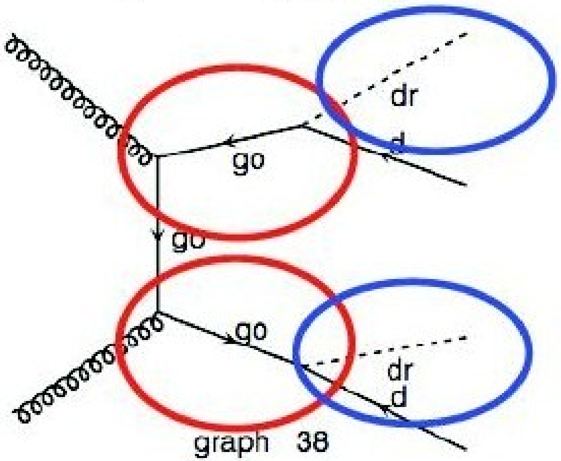
Example: $\tilde{q}\tilde{q}jj$



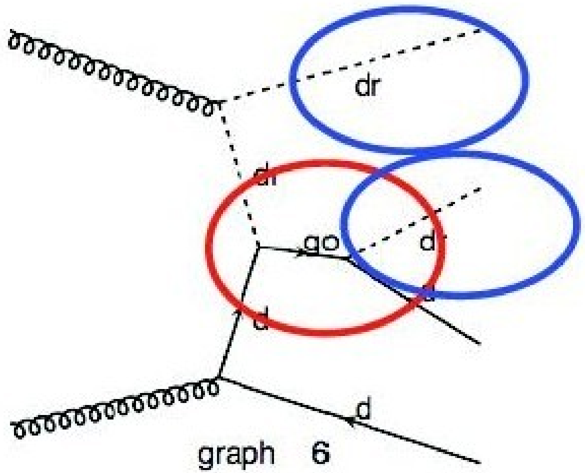
# Double counting

- Special difficulty in SUSY matching – double counting between squark and gluino production

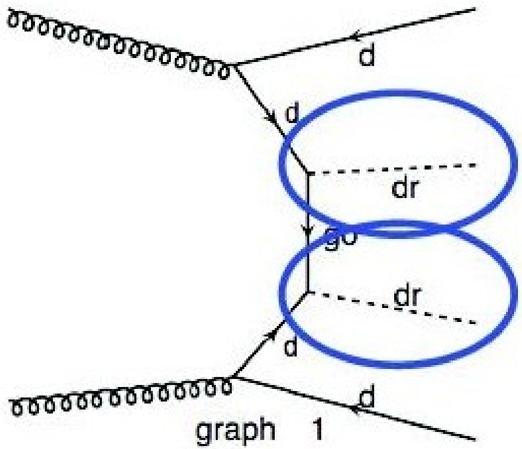
**Example:** $\tilde{q}\tilde{q}jj$



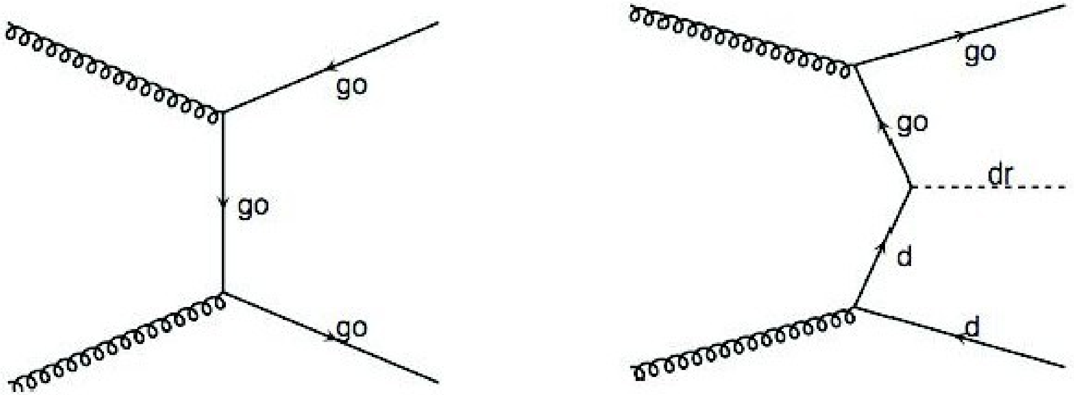
graph 38



graph 6



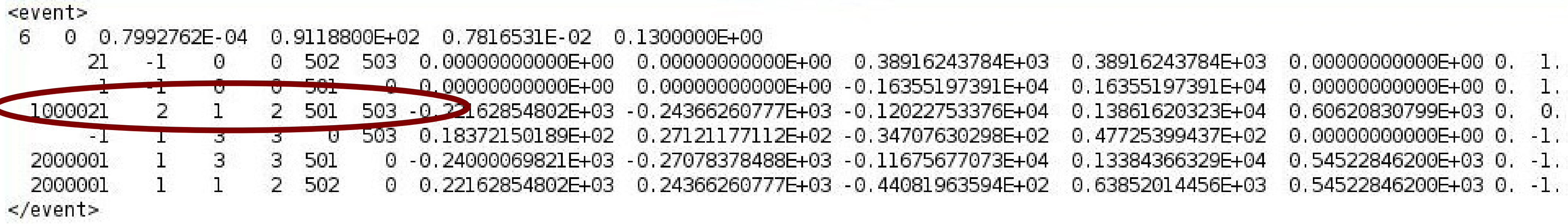
graph 1



Double counted with on-shell gluino prod with $\tilde{g} \to \tilde{d}_R+q$

# Double counting

- Solved by keeping track of on-shell resonances in the production event files



```
<event>
 6   0  0.7992762E-04  0.9118800E+02  0.7816531E-02  0.1300000E+00
       21   -1    0    0  502  503  0.00000000000E+00  0.00000000000E+00  0.38916243784E+03  0.38916243784E+03  0.00000000000E+00 0.  1.
       -1   -1    0    0  501    0  0.00000000000E+00  0.00000000000E+00 -0.16355197391E+04  0.16355197391E+04  0.00000000000E+00 0.  1.
  1000021    2    1    2  501  503 -0.22162854802E+03 -0.24366260777E+03 -0.12022753376E+04  0.13861620323E+04  0.60620830799E+03 0.  0.
       -1    1    3    3    0  503  0.18372150189E+02  0.27121177112E+02 -0.34707630298E+02  0.47725399437E+02  0.00000000000E+00 0. -1.
  2000001    1    3    3  501    0 -0.24000069821E+03 -0.27078378488E+03 -0.11675677073E+04  0.13384366329E+04  0.54522846200E+03 0. -1.
  2000001    1    1    2  502    0  0.22162854802E+03  0.24366260777E+03 -0.44081963594E+02  0.63852014456E+03  0.54522846200E+03 0. -1.
</event>
```

  - Allows to remove double-counted events after production

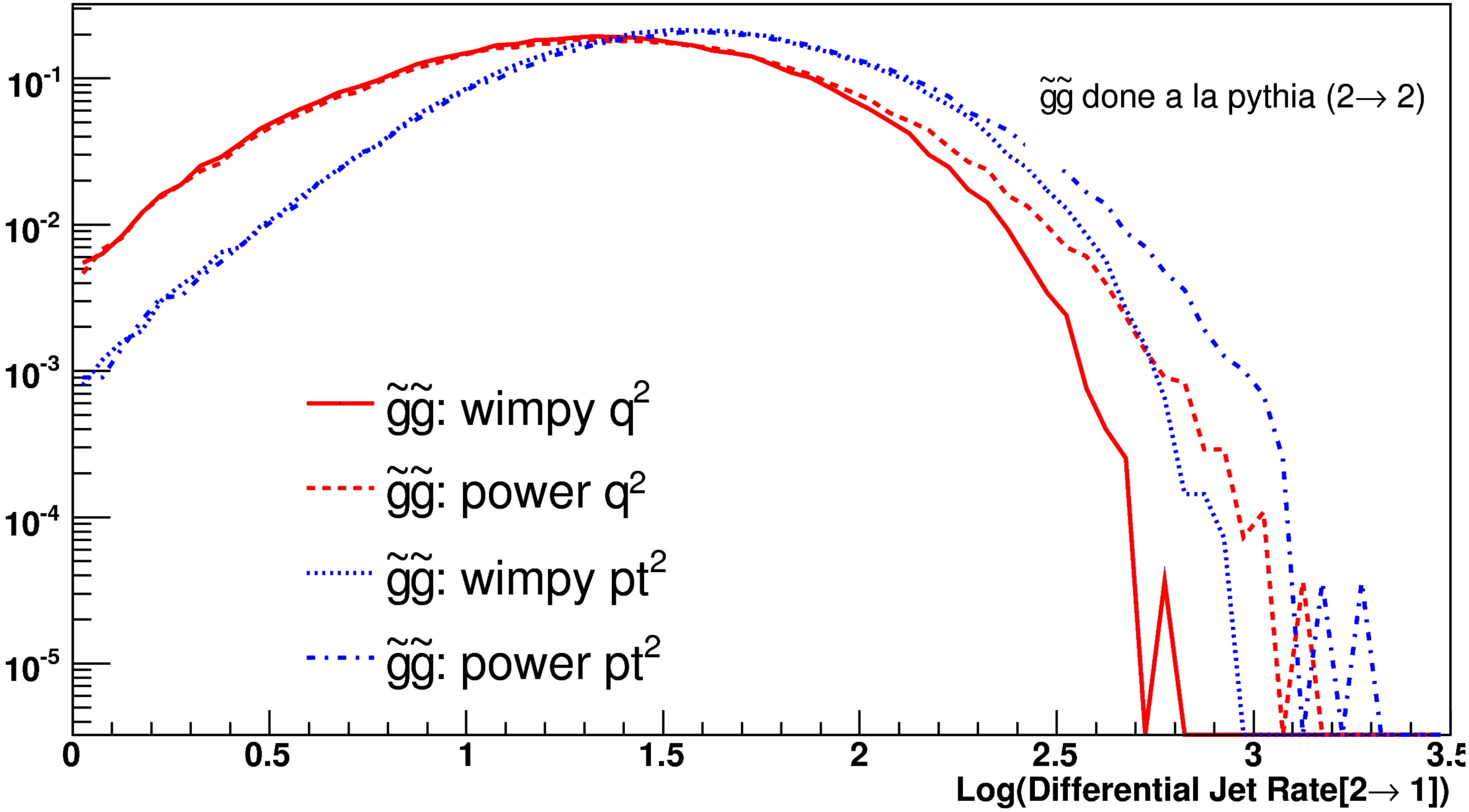
- Double-check – perform generation without resonant diagrams (gauge-inv. only in NWA!)
  - Excellent agreement

# Shower parameter dependence

- Shower “tweakable”
  - Strength for fitting data (after-the-fact)
  - Weakness for predictivity
- Most important parameters used here:
  - Type of shower ($Q^2$ or $p_T$-ordered)
  - Shower starting scale
    - Factorization scale - “wimpy”
    - Total energy of collider - “power”
- Matching quite insensitive to shower parameters

# Shower parameter dependence

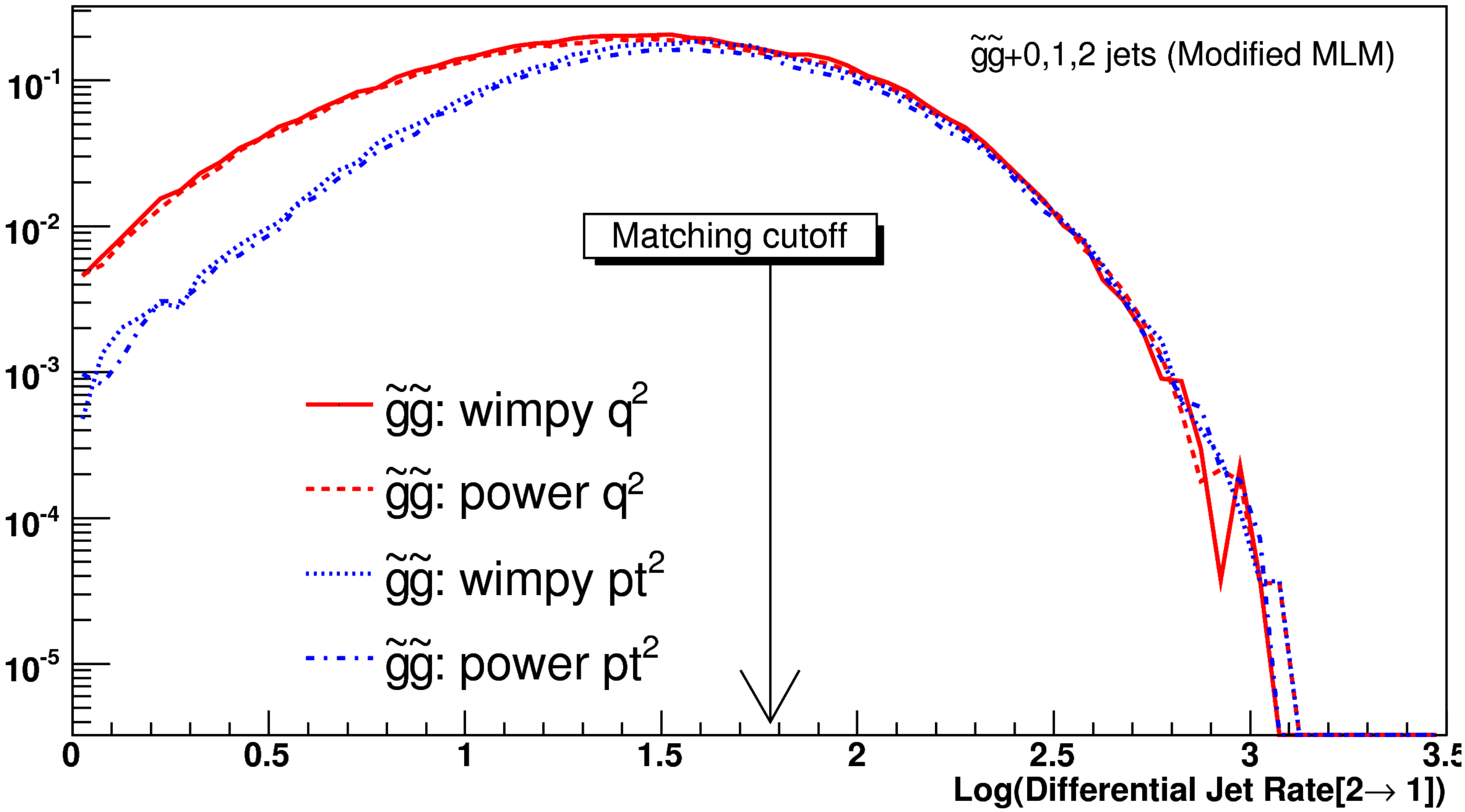
## ISR jets for different Pythia shower params



600 GeV gluino pair production at the LHC

# Shower parameter dependence

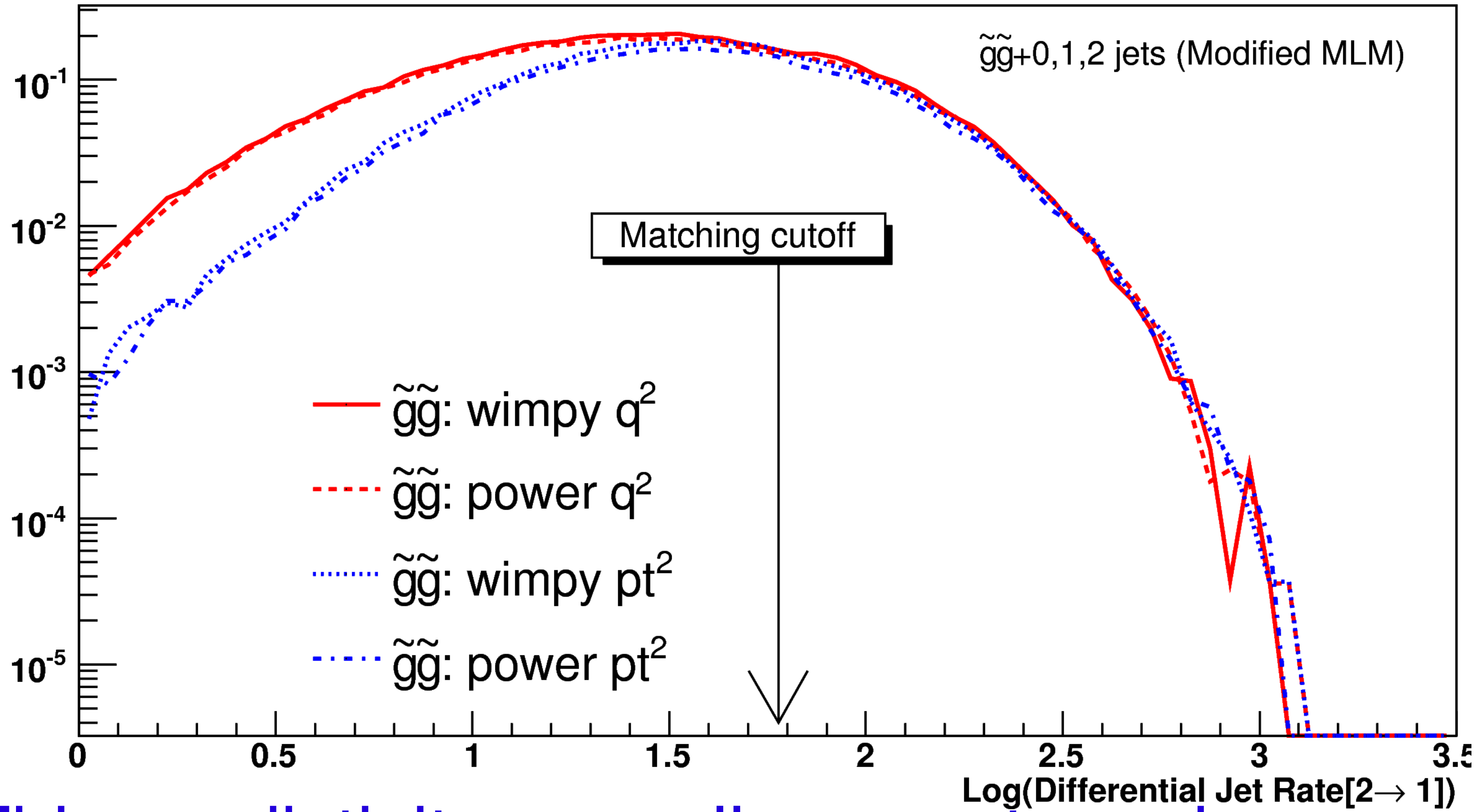
## ISR jets after matching with MG/ME



600 GeV gluino pair production at the LHC

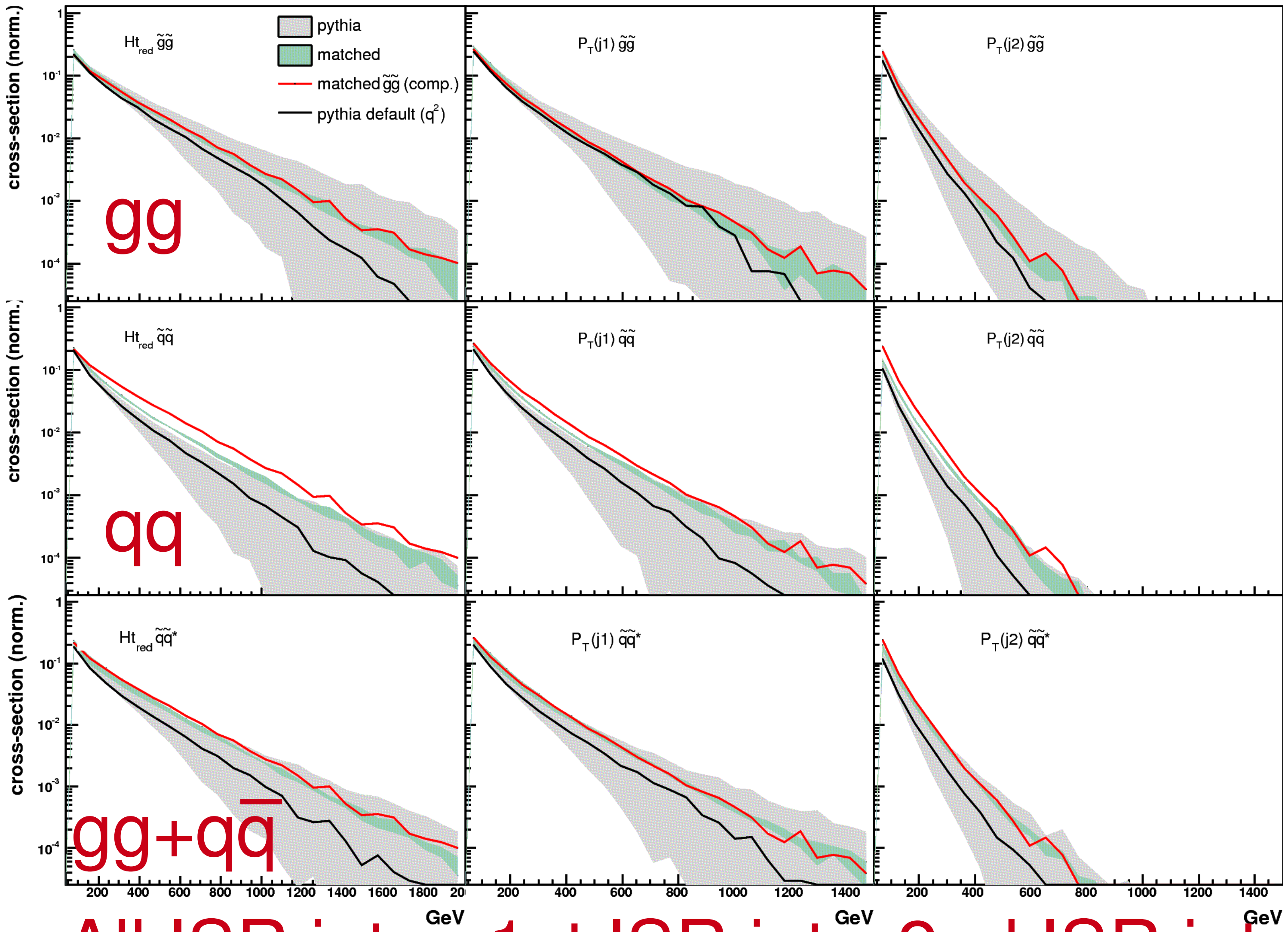
# Shower parameter dependence

## ISR jets after matching with MG/ME



This predictivity now allows us to make proper investigations of dependence on different factors

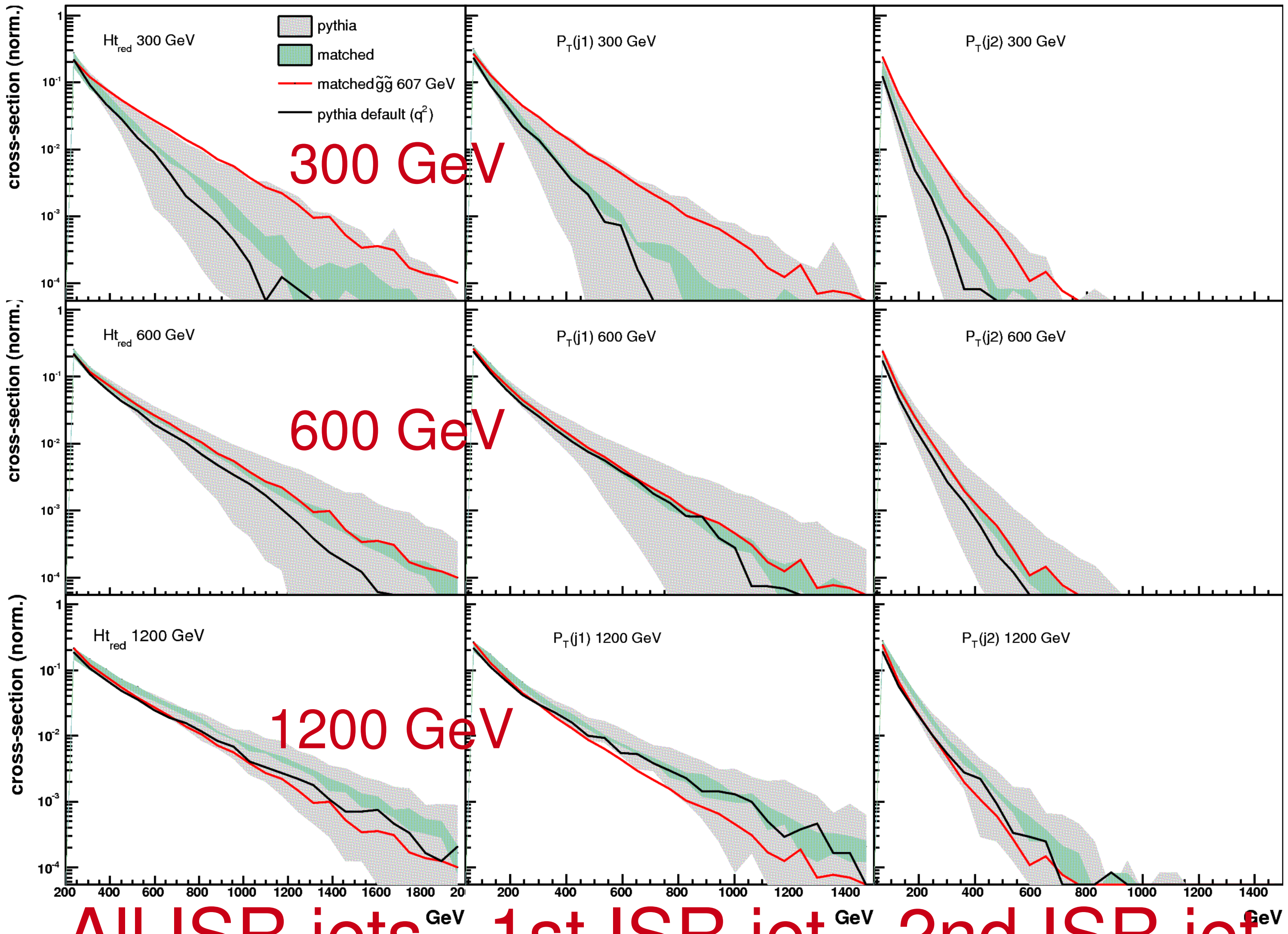
# Dependence on the initial state: gg, qq, q$\bar{q}$



All ISR jets 1st ISR jet 2nd ISR jet

No single shower tune for all initial states!

# Dependence on the produced particle mass



300 GeV

600 GeV

1200 GeV

All ISR jets 1st ISR jet 2nd ISR jet

## Can ISR help determine overall mass scale?

# Impact of matching with decay

Matching obviously important for radiated jets, but what about including decay jets from the squarks/gluinos?

Still important in many scenarios!

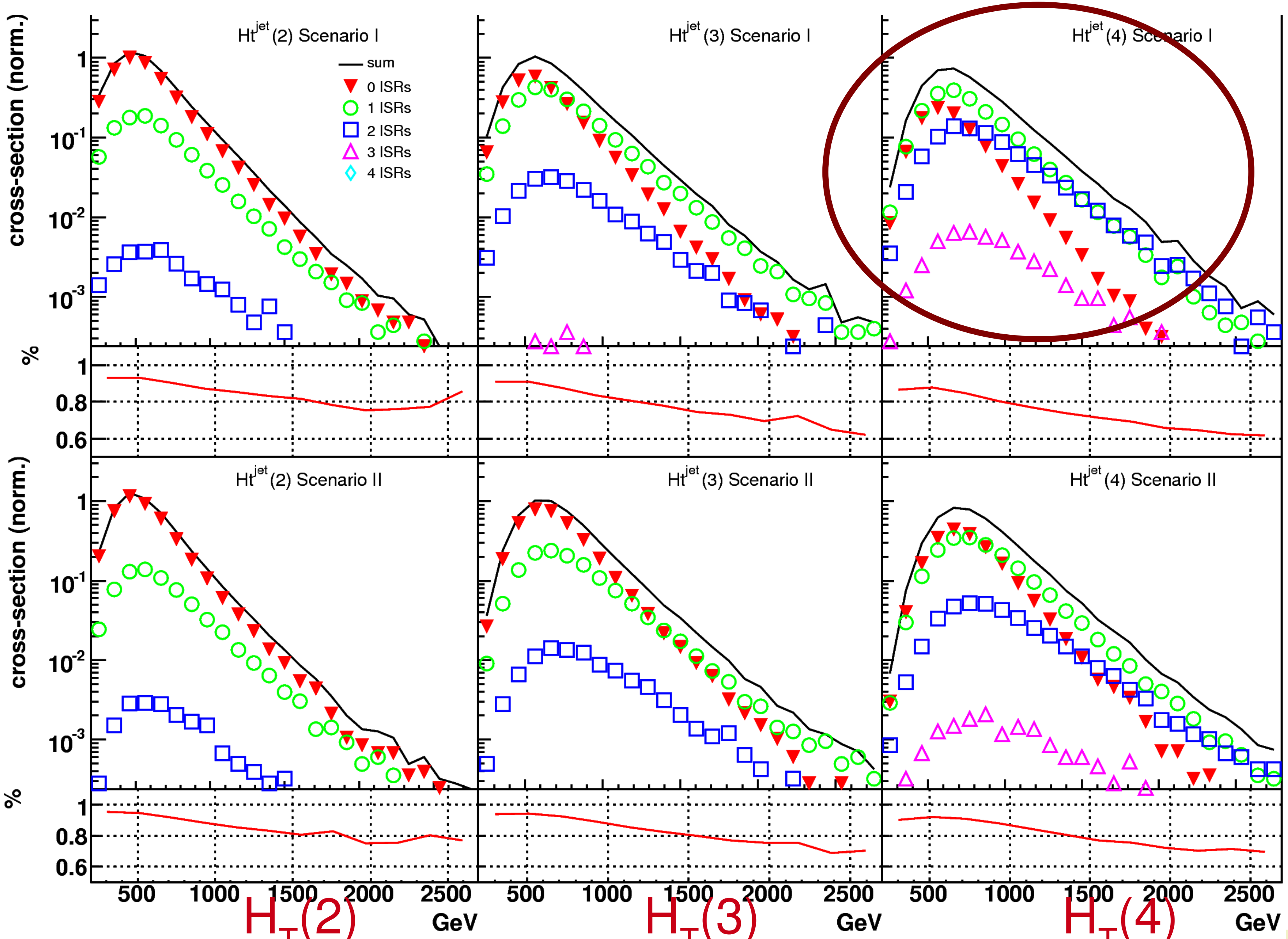
Example: Small mass splitting between gluino and squark – gives gluino decay with 2 hard + 2 soft jets

# Impact of matching with decay

## 600 GeV gluino pair production

$M_g$-$M_q$=
50 GeV

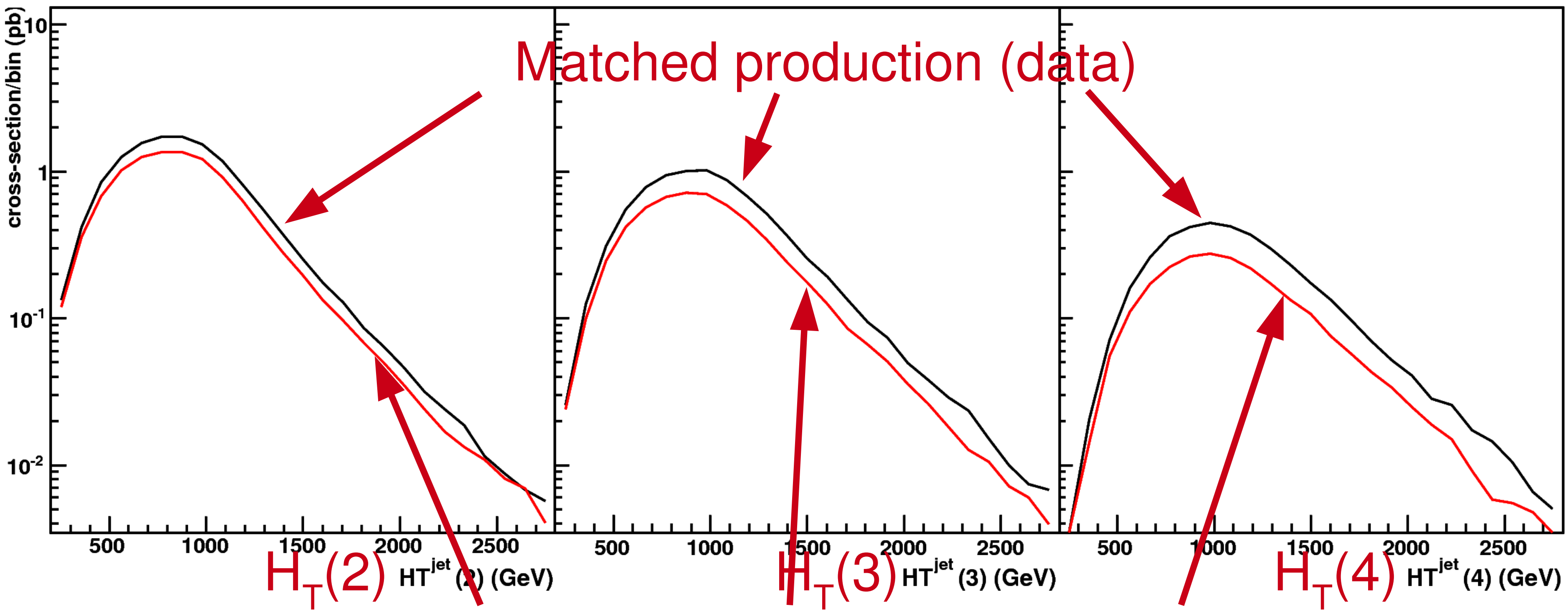
squarks
heavy –
3-body
~g decay



$H_T(2)$ $H_T(3)$ $H_T(4)$

# Risk for misinterpretation

## Scenario: sqsq production only (gluinos heavy)



Matched production (data)

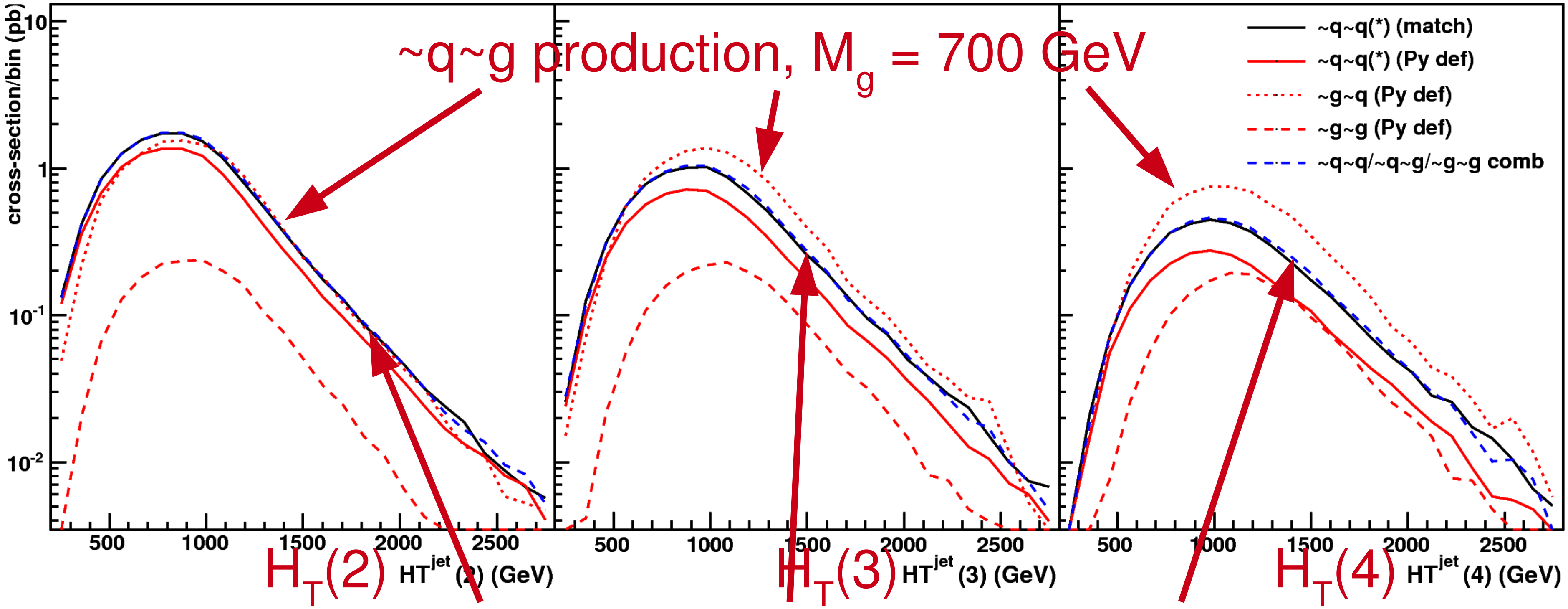
$H_T(2)$ $H_T(3)$ $H_T(4)$

Unmatched production (simulation, Pythia default)

Looks like we're missing gluino component!

# Risk for misinterpretation

## Scenario: ~q~q production only (gluinos heavy)



~q~g production, $M_g$ = 700 GeV

$H_T(2)$ $H_T(3)$ $H_T(4)$

Unmatched ~q~q + 25%~q~g (fits “data”)

## Easy misinterpretation: ~q~g component!

# Light gluinos at the Tevatron

JA, Le, Lisanti, Wacker [arXiv:0803.0019,
arXiv:0809.3264]

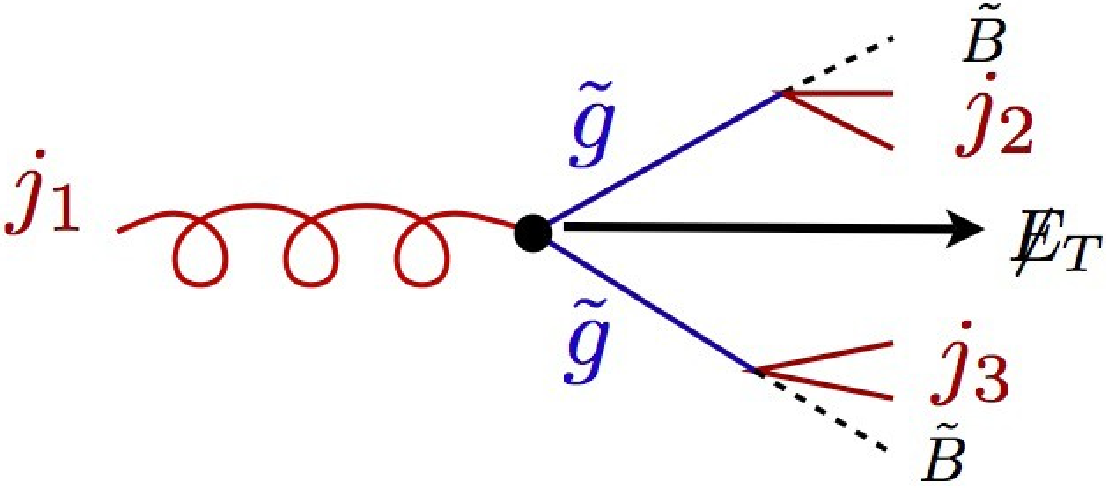
- Searches at the Tevatron have always been done in the mSUGRA framework
- mSUGRA (and mGMSB) “special” scenarios: fixed mass ratio $m_g$:$m_W$:$m_B$ ~ 6:2:1
- Not representative for general MSSM (or other BSM models!)
- Study of projected exclusion region at Tevatron with free ratio $m_g$:$m_B$ (arXiv:0803.0019)

# Light gluinos at the Tevatron

JA, Le, Lisanti, Wacker [arXiv:0803.0019, arXiv:0809.3264]

Special difficulty when decay products are soft (nearly degenerate masses):

- No (small) missing transverse energy in decay
- Need recoil agains jets to get $\not{E}_T$ signature



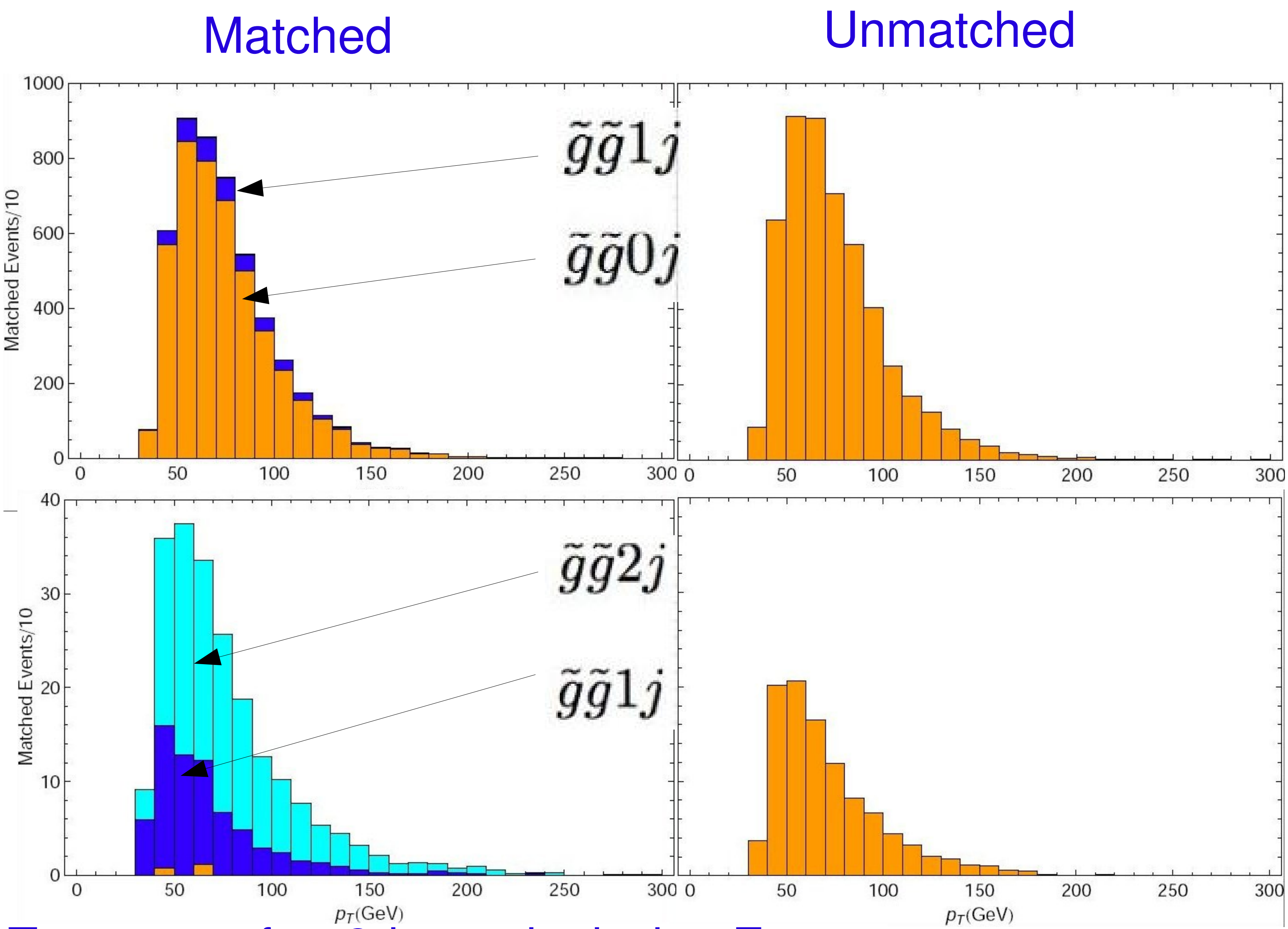
# Light gluinos at the Tevatron

$M_g$=150 GeV

$M_B$=40 GeV

$M_g$=150 GeV

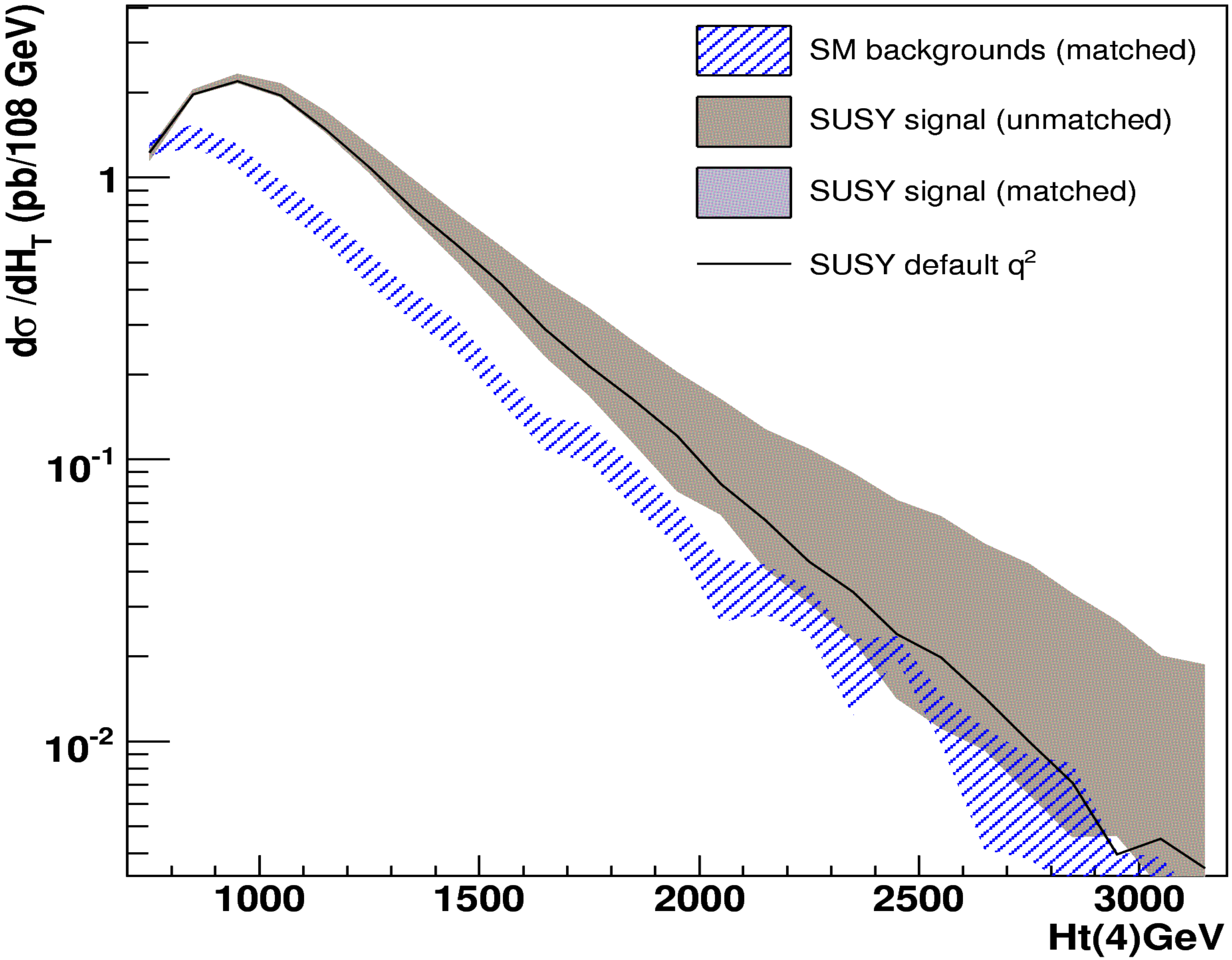
$M_B$=130 GeV



Tevatron, after 2-jet and missing $E_T$ cuts

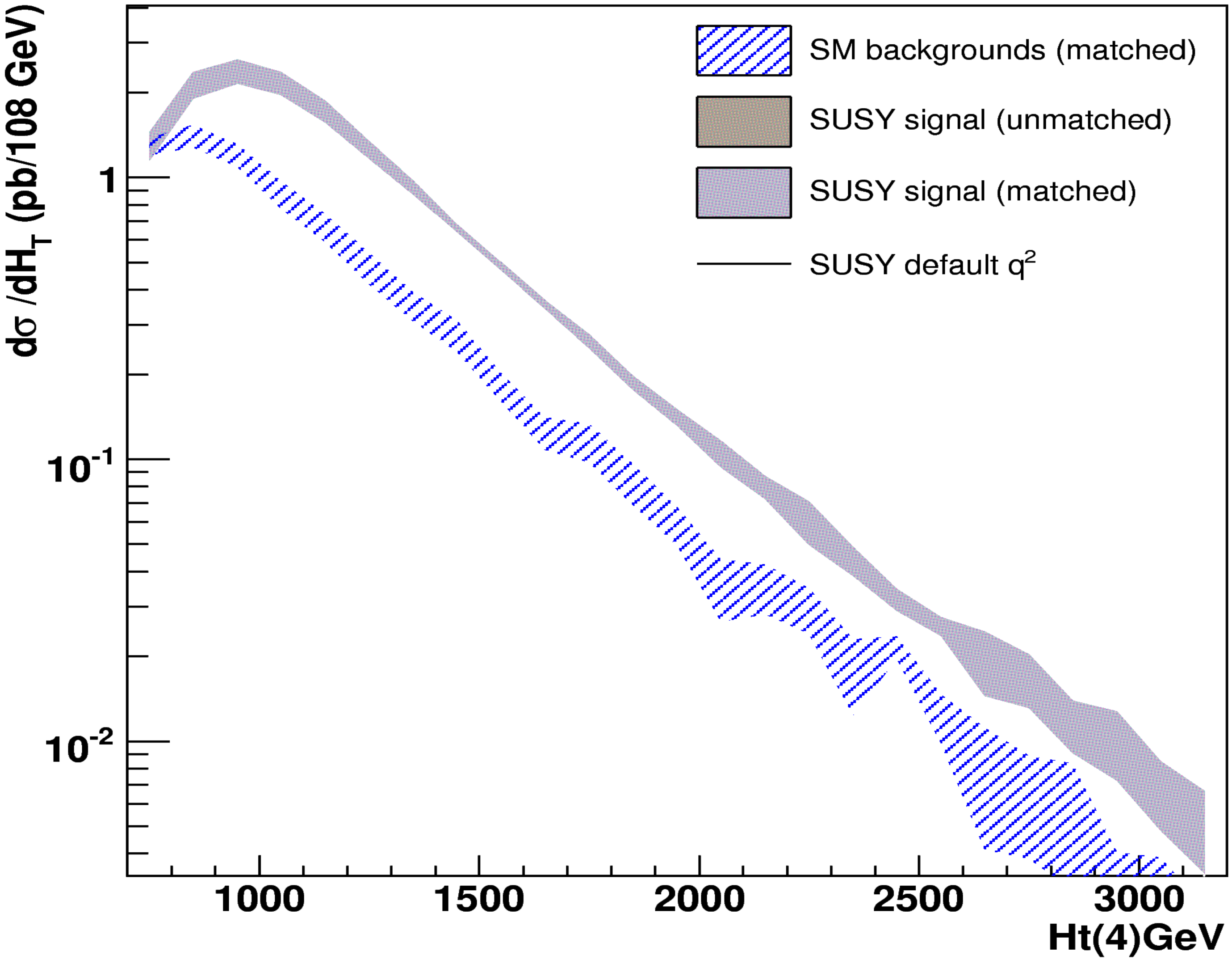
# Impact on collective exp. searches

## “SPS1a” SUSY production at the LHC - unmatched



# Impact on collective exp. searches

## “SPS1a” SUSY production at the LHC - matched

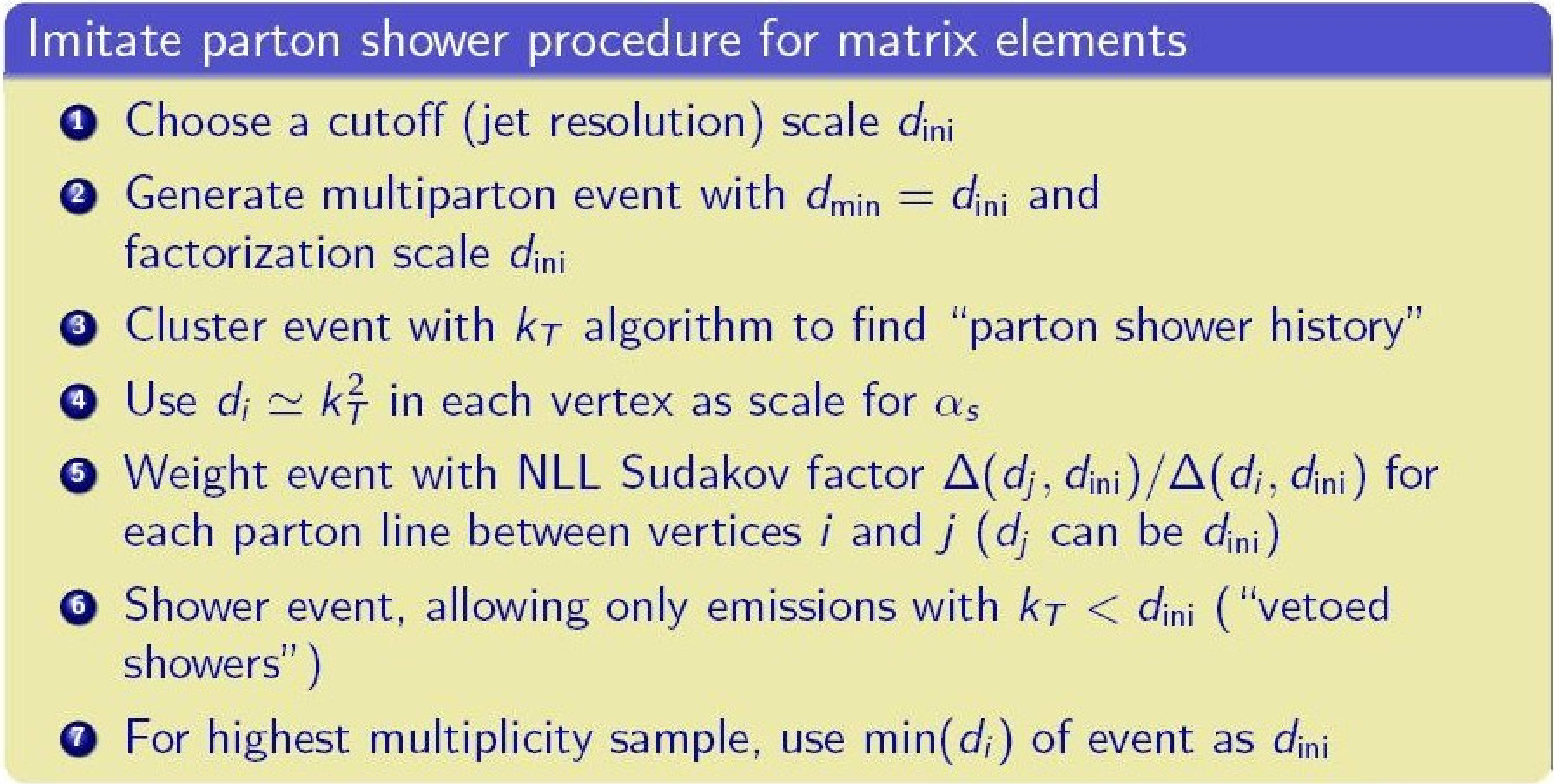


# Conclusions

- The LHC is a hadronic collider – busy and complicated QCD environment
- Any search for new physics must take QCD radiation effects into account
  - Extra jet production from ISR QCD emissions
  - Boost of the central production system
- Many scenarios where jet matching between matrix elements and parton showers is crucial to get a good description of the signal as well as SM backgrounds

# Backup slides

# CKKW matching



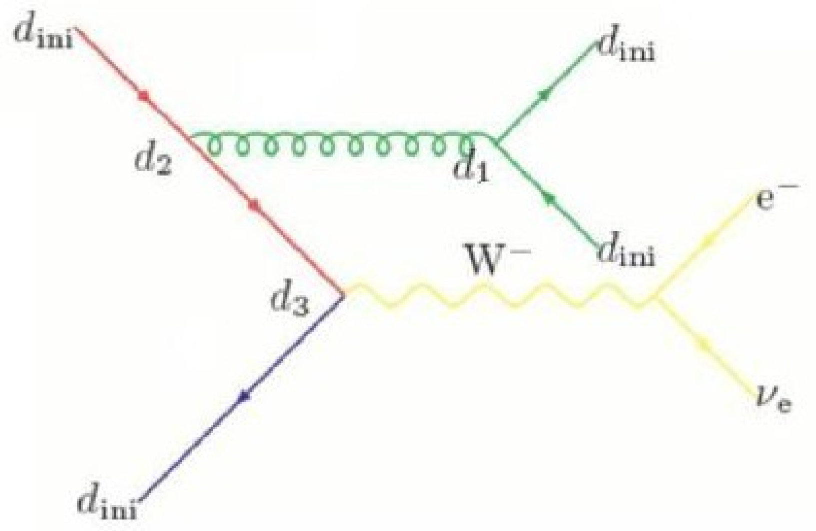
**Imitate parton shower procedure for matrix elements**

1. Choose a cutoff (jet resolution) scale $d_{\mathrm{ini}}$
2. Generate multiparton event with $d_{\mathrm{min}} = d_{\mathrm{ini}}$ and factorization scale $d_{\mathrm{ini}}$
3. Cluster event with $k_T$ algorithm to find "parton shower history"
4. Use $d_i \simeq k_T^2$ in each vertex as scale for $\alpha_s$
5. Weight event with NLL Sudakov factor $\Delta(d_j, d_{\mathrm{ini}})/\Delta(d_i, d_{\mathrm{ini}})$ for each parton line between vertices $i$ and $j$ ($d_j$ can be $d_{\mathrm{ini}}$)
6. Shower event, allowing only emissions with $k_T < d_{\mathrm{ini}}$ ("vetoed showers")
7. For highest multiplicity sample, use $\min(d_i)$ of event as $d_{\mathrm{ini}}$

Boost-invariant $k_T$ measure:

$$\begin{cases} d_{iB} = p_{T,i}^2 \\ d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) F_{ij} \end{cases}$$

$$F_{ij} = 2\{\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j)\}$$



- For final-state showers: Combination of NLL Sudakov factors and vetoed NLL showers guarantees independenc of $d_{\rm ini}$ to NLL order
- For initial-state showers: No proof but works ok
- Problem in practice: No NLL shower implementation! (Sherpa uses Pythia-like showers)

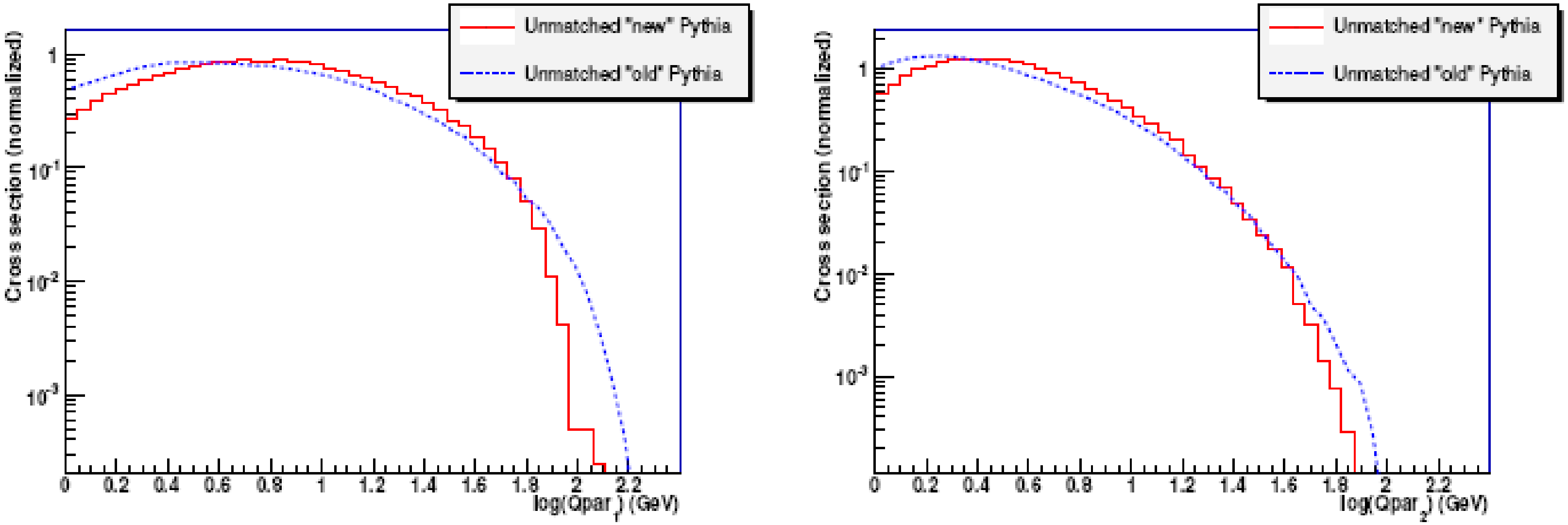
# More about matching in MG

## Shower kT scheme

- Keep/reject event based on $k_T$ of hardest shower emission (as reported by Pythia)
- Highest multiplicity treatment as in CKKW, use min dparton as cutoff
- No jet clustering
- No need of “fiducial region”, can use $k_T^{match} = d_{cut}^{ME}$
- Need similar kT definitions in ME and PS (only “new”, $p_T$-ordered showers at present)

# Comparisons between old and new Pythia showers

## Differential jet rates in $W$ production at the Tevatron


$0 \longrightarrow 1$ jet rate

$1 \longrightarrow 2$ jet rate

## $p_T(W)$ in $W$ production at the Tevatron