# Effects of Jet Matching in BSM Signals

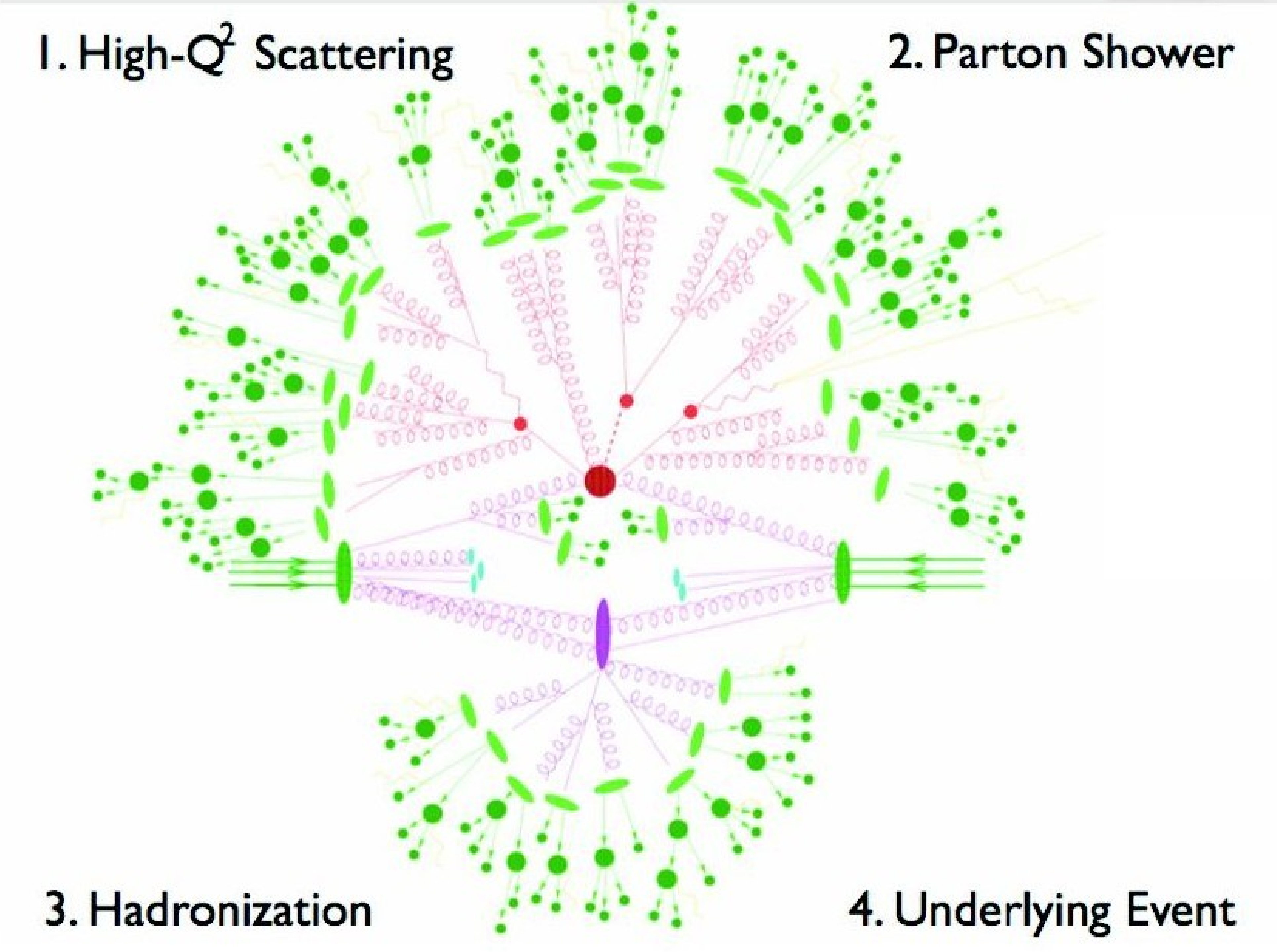
Johan Alwall, SLAC

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

arXiv:0810.xxxx (very soon!)

IPMU Seminar, Tokyo, Japan, 14 Oct 2008

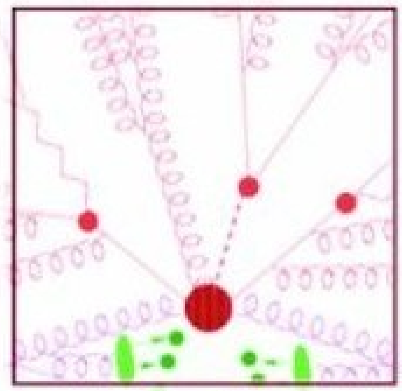
# Introduction – The Big Picture


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

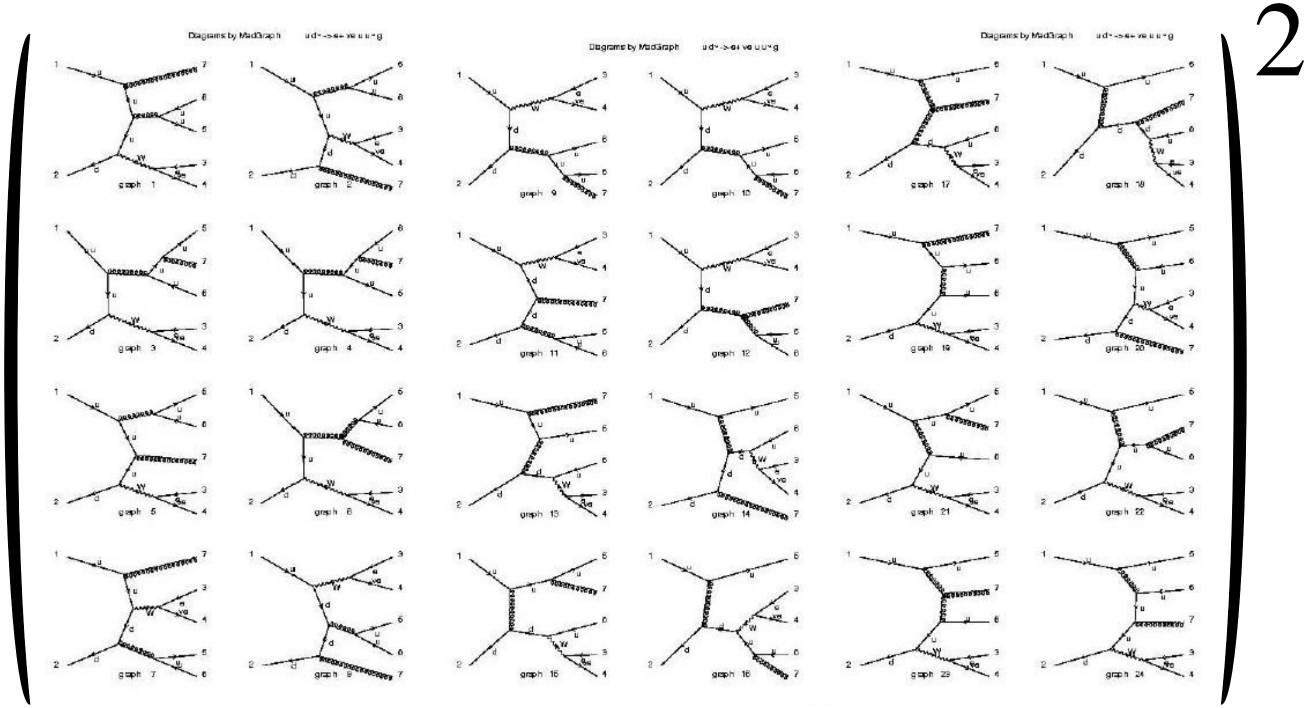
4. Underlying Event

# How to describe QCD emissions

- Matrix Element Generators

- Parton Showers

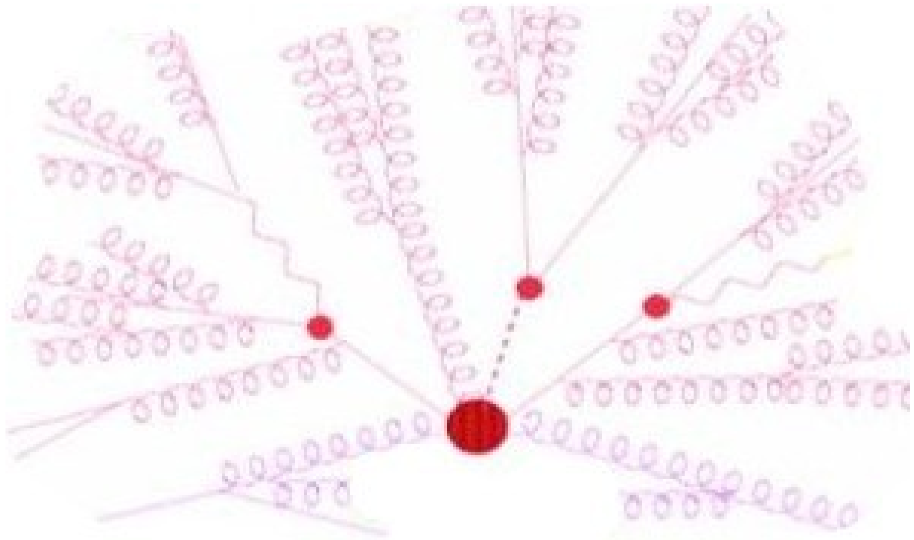
# Matrix Element Generators



Diagrams for $u\bar{d} \to e^+\nu_e u\bar{u}g$ 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 | Parton showers |
|---|---|
| 1. Fixed order calculation | 1. Resums logs to all orders |
| 2. Computationally expensive | 2. Computationally cheap |
| 3. Limited number of particles | 3. No limit on particle multiplicity |
| 4. Valid when partons are hard and well separated | 4. Valid when partons are collinear and/or soft |
| 5. Quantum interference correct | 5. Partial quantum interference through angular ordering |
| 6. Needed for multi-jet description | 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

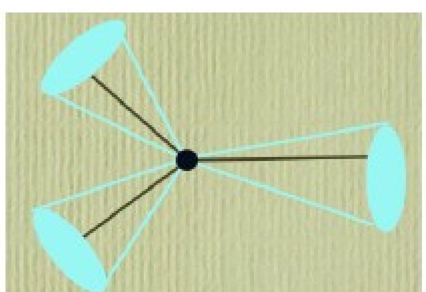
- CKKW scheme (Catani, Krauss, Kuhn, Webber)
- Lönnblad scheme
- MLM scheme

# MLM matching

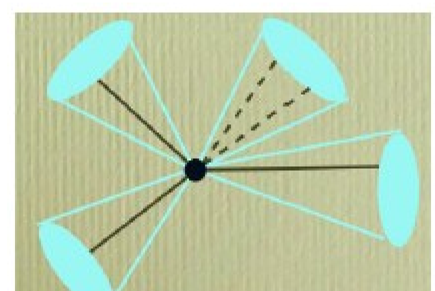
J.A. et al. [arXiv:0706.2569],
cf. M.L. Mangano [2002, Alpgen home page]

**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 $k_{T\text{min}}$

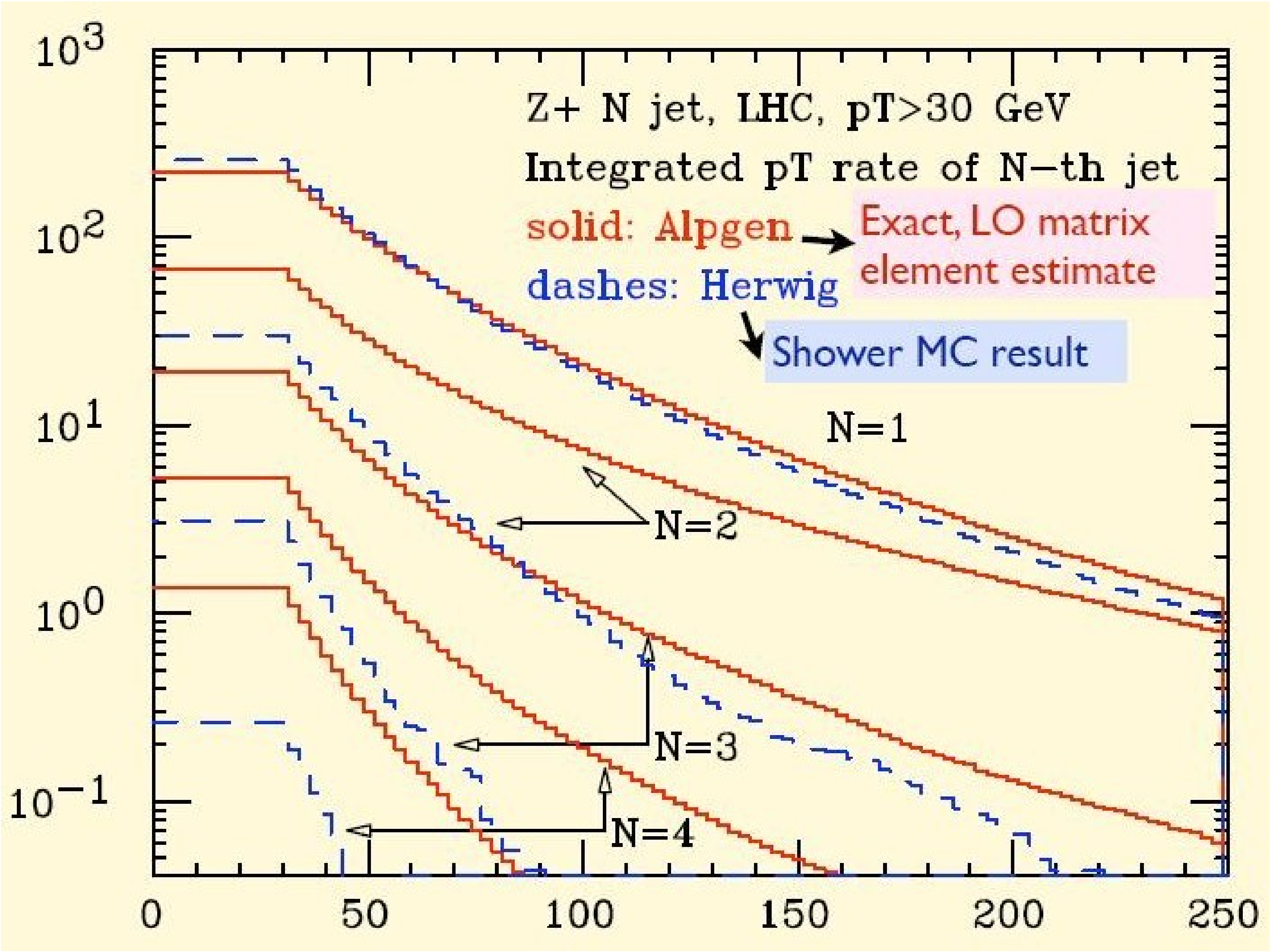


Keep



Discard unless highest multiplicity

# Impact of matching on Z+jets



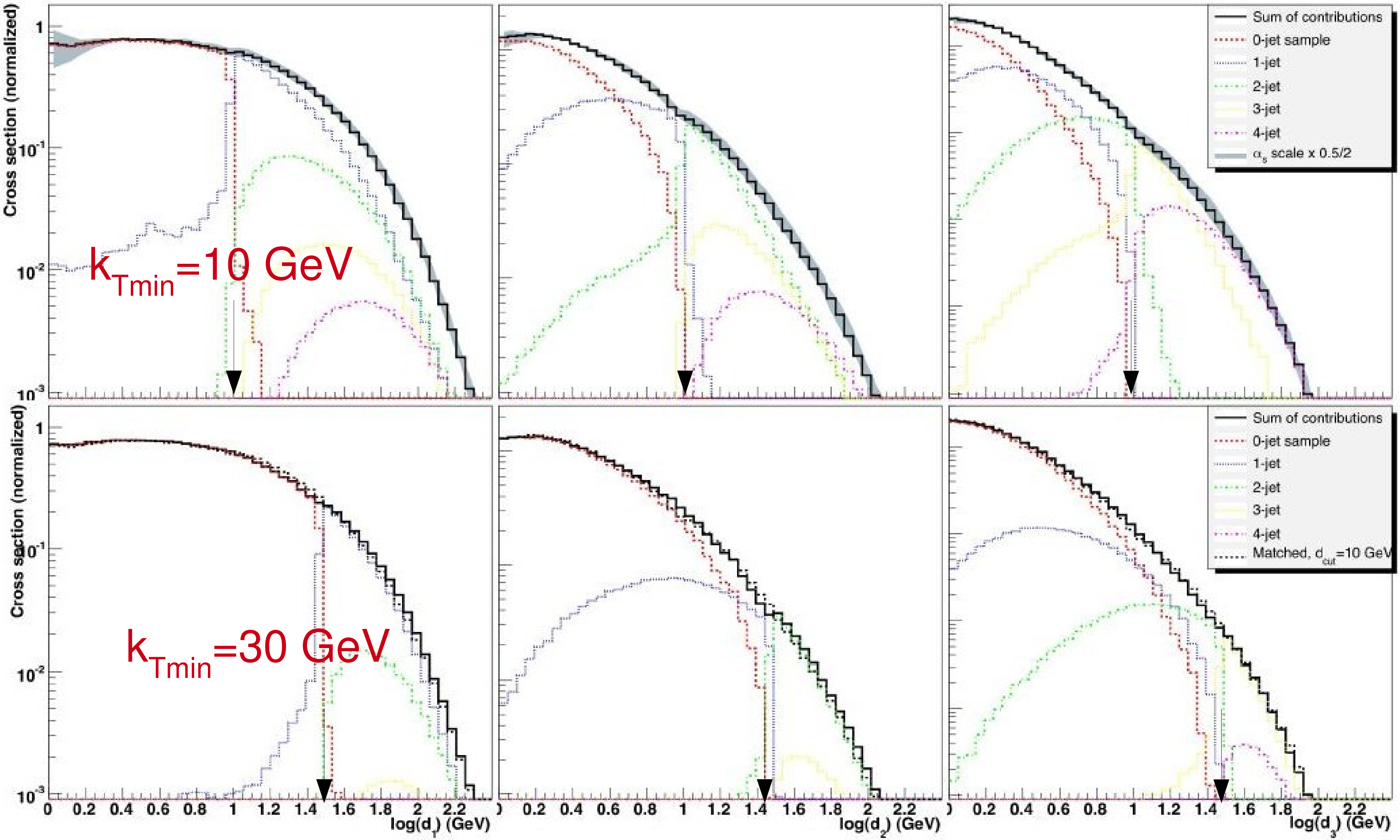

Matching vital to get multijet backgrounds right!

# 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



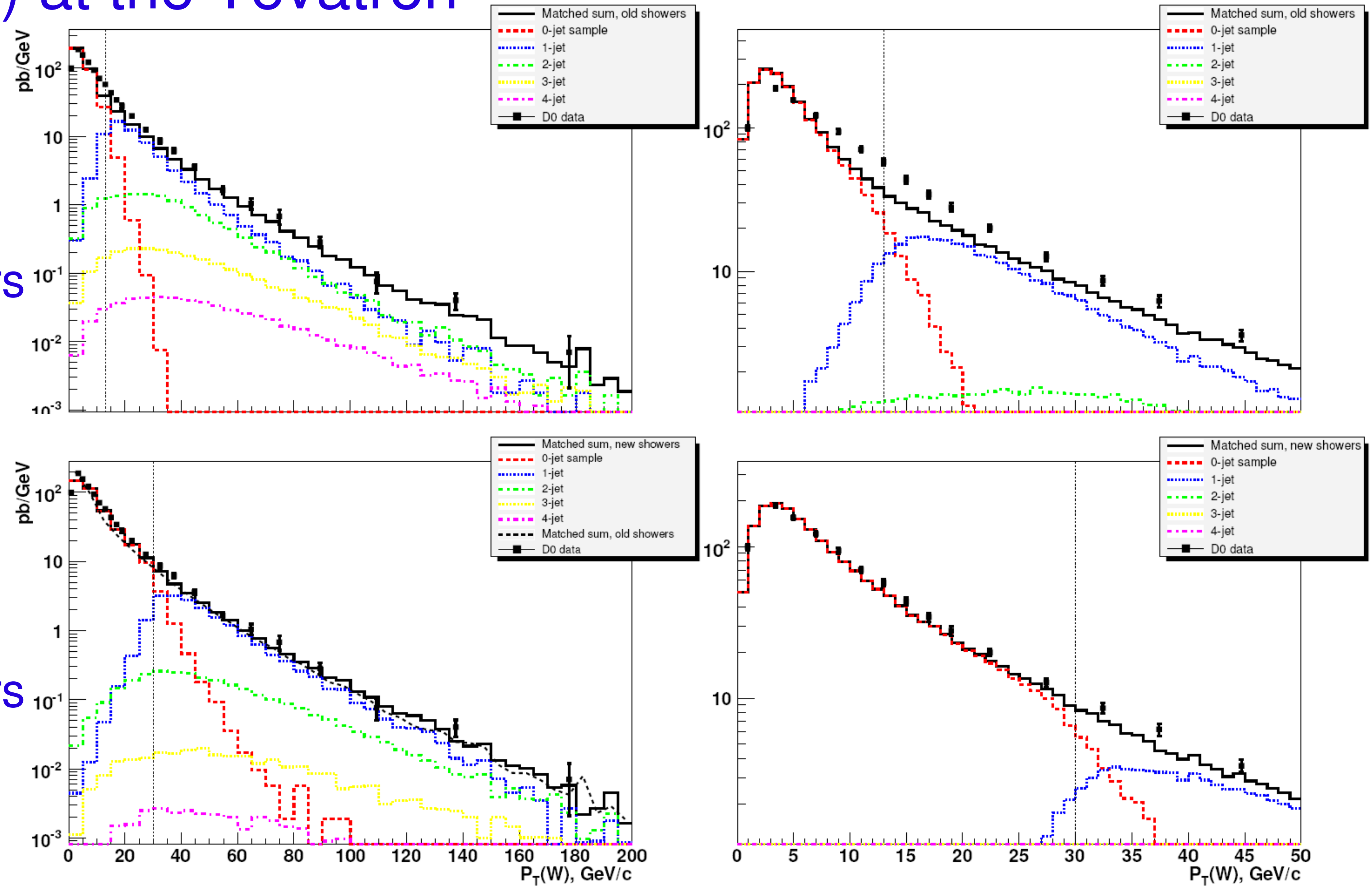

Diff. jet rates by MadEvent+Pythia in W+jets prod. at the Tevatron

# Comparison with Tevatron Data

## $p_T(W)$ at the Tevatron

“Old” Pythia showers

“New” Pythia showers




Tail given by ME, head by pure showers

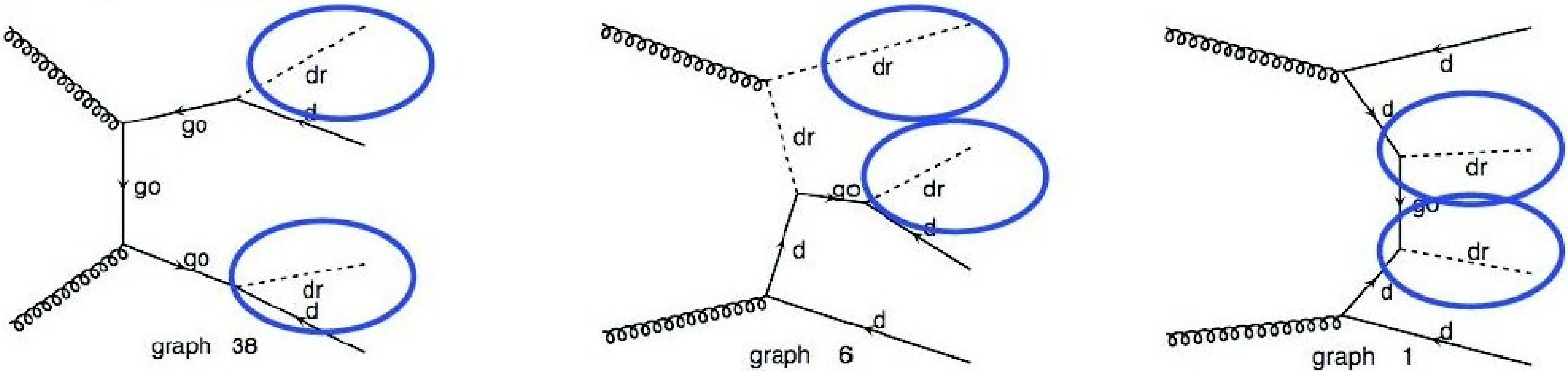
# Matching in gluino/squark production

- 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

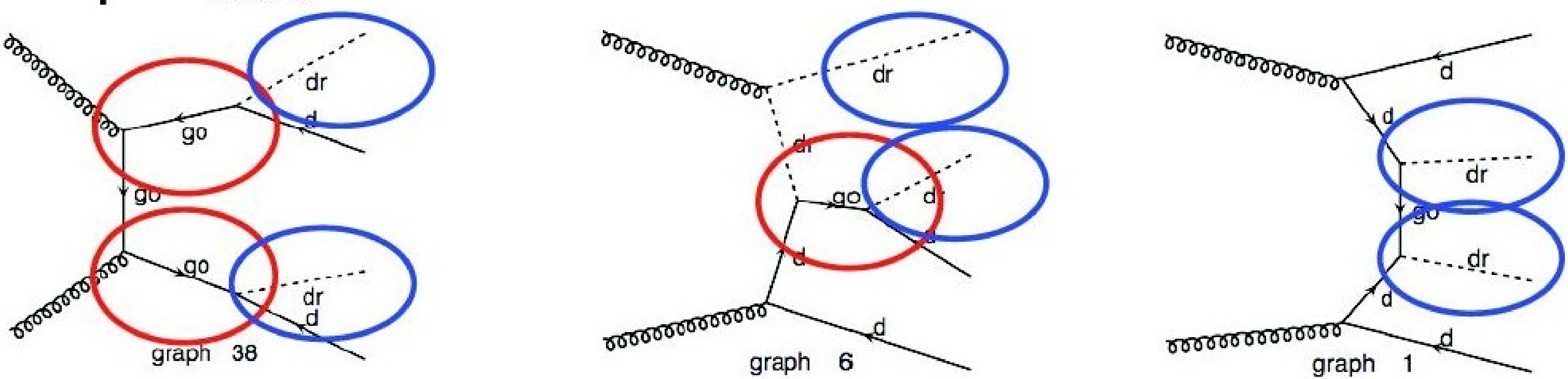
Example: $\tilde{q}\tilde{q}jj$

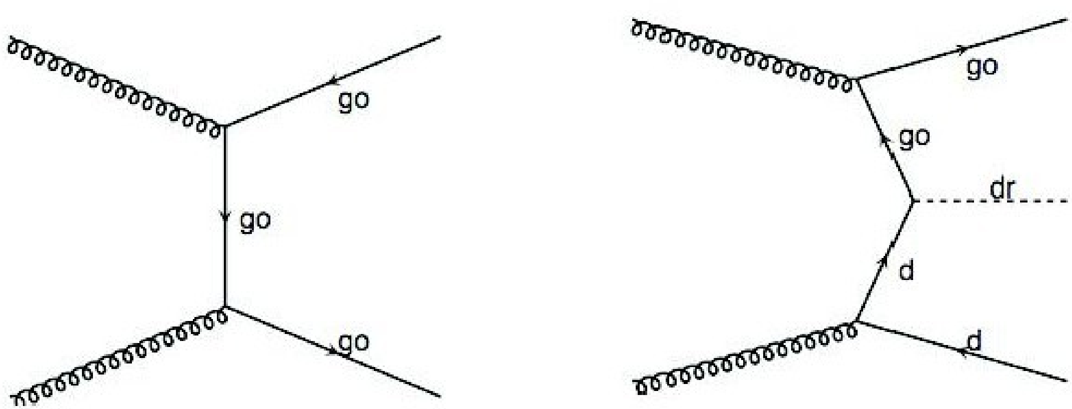


# Double counting

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

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




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

# 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>
```

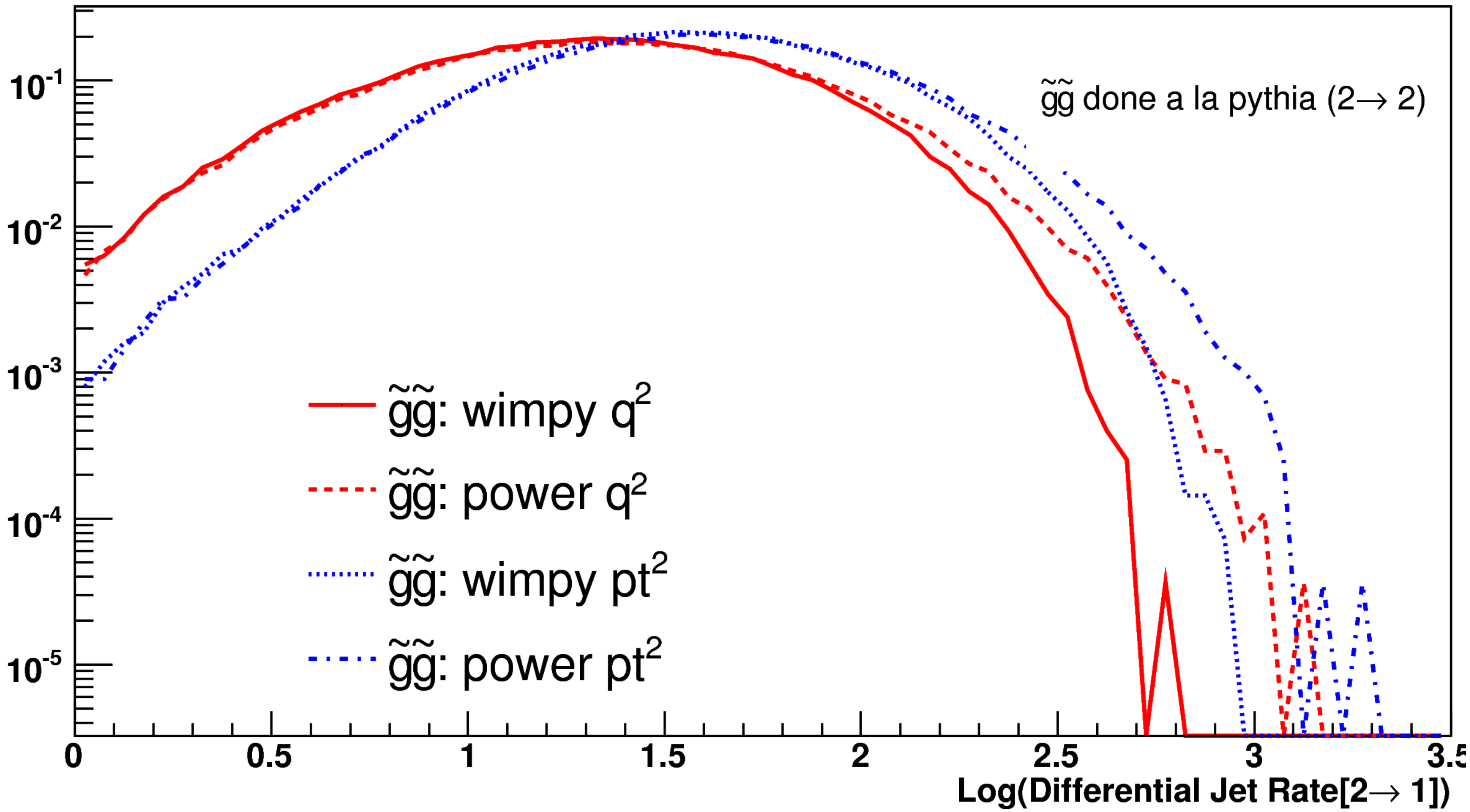
  - Allows to remove double-counted events after production
- Double-check – perform generation without resonant diagrams (gauge-inv. only in NWA!)
  - Excellent agreement

# 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

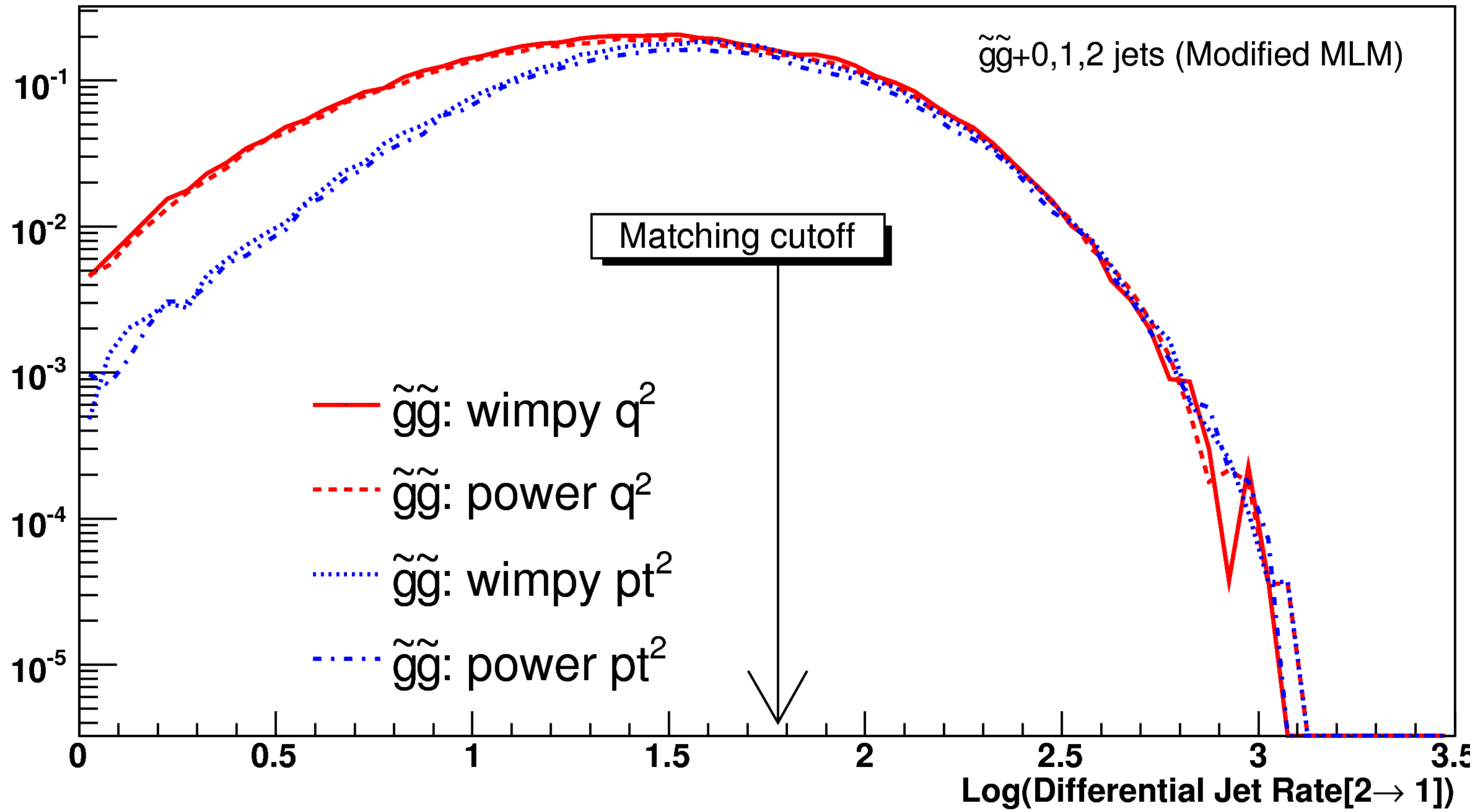
## ISR jets for different Pythia shower params




## 600 GeV gluino pair production at the LHC

# Shower parameter dependence

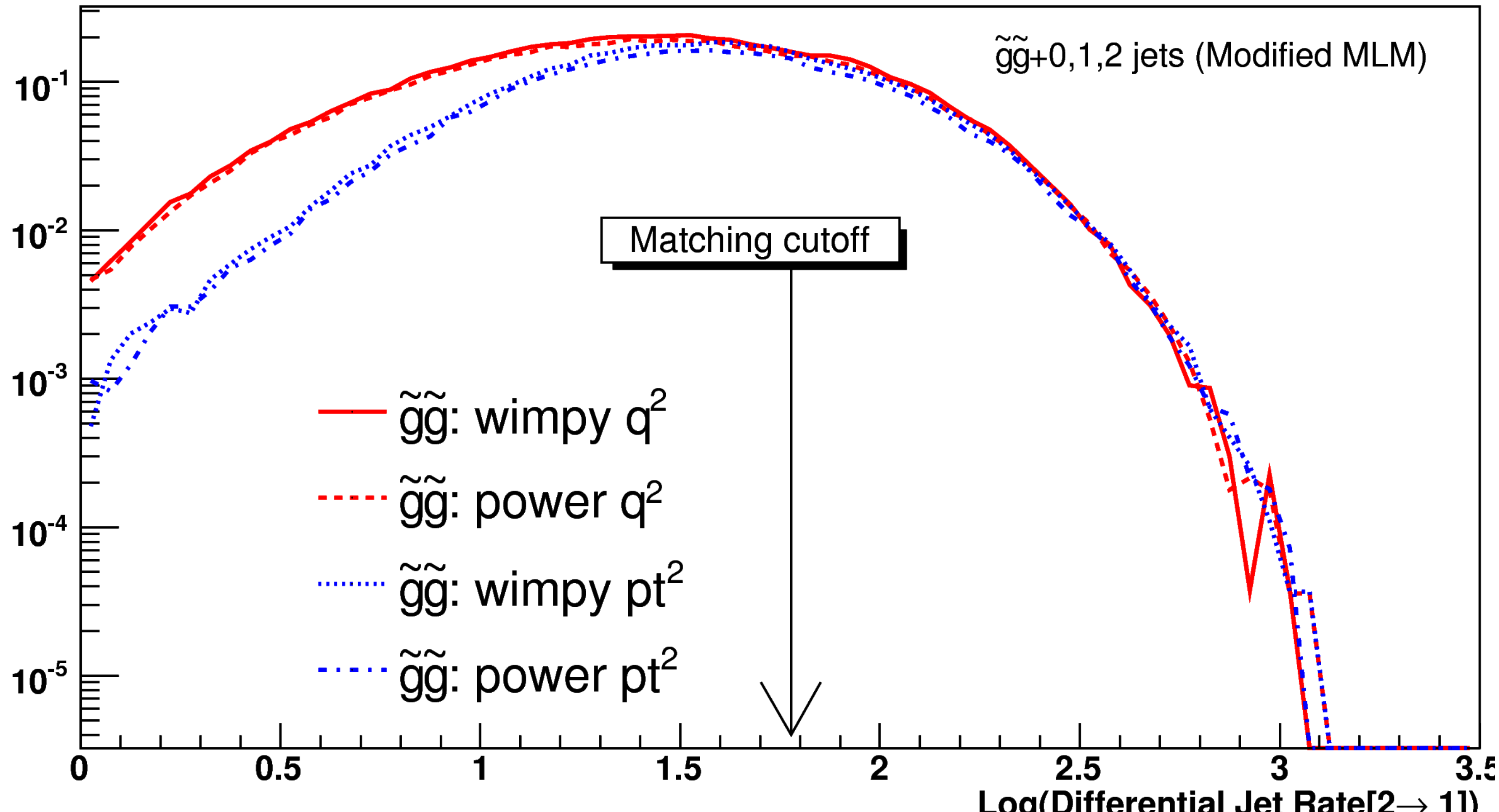
## ISR jets after matching with MG/ME




600 GeV gluino pair production at the LHC

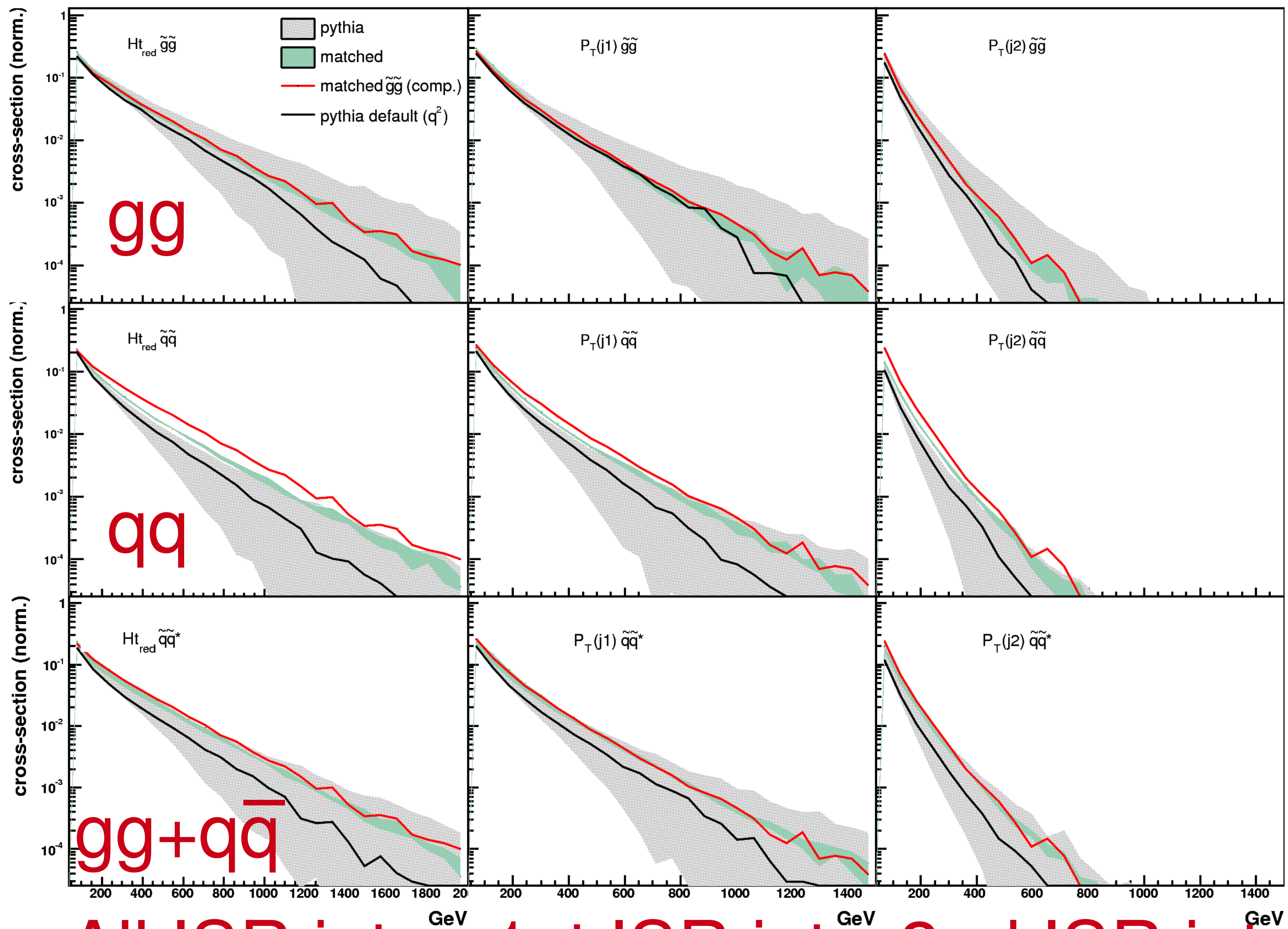
# Shower parameter dependence

ISR jets after matching with MG/ME




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

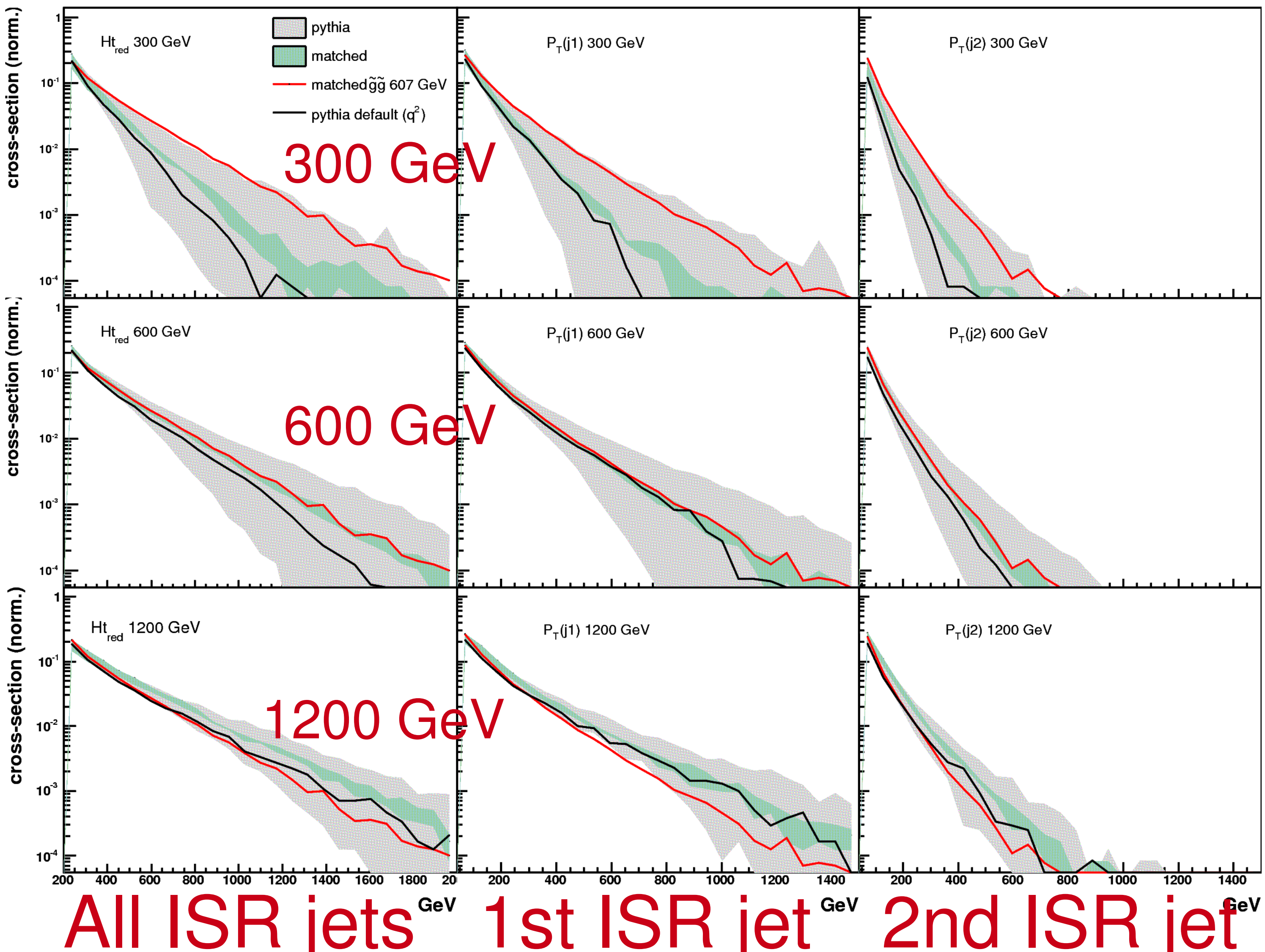
# Dependence on the initial state: gg, qq, q$\bar{q}$




All ISR jets 1st ISR jet 2nd ISR jet

No single shower tune for all initial states!

# Dependence on the produced particle mass




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!

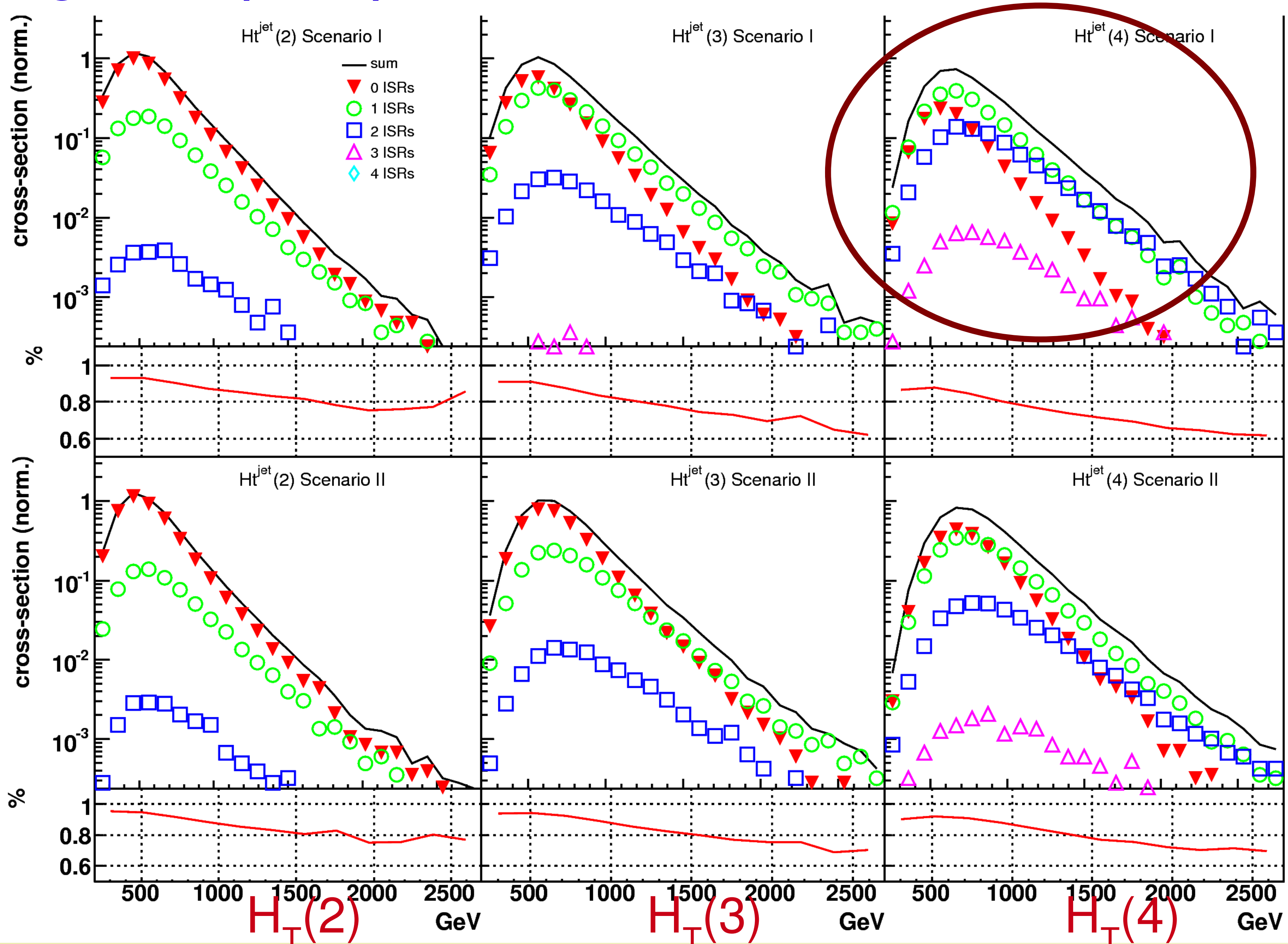
Example: Small mass splitting between gluino and squark – gives gluino decay with 2 hard + 2 soft jets

# Impact of matching with decay

## 600 GeV gluino pair production

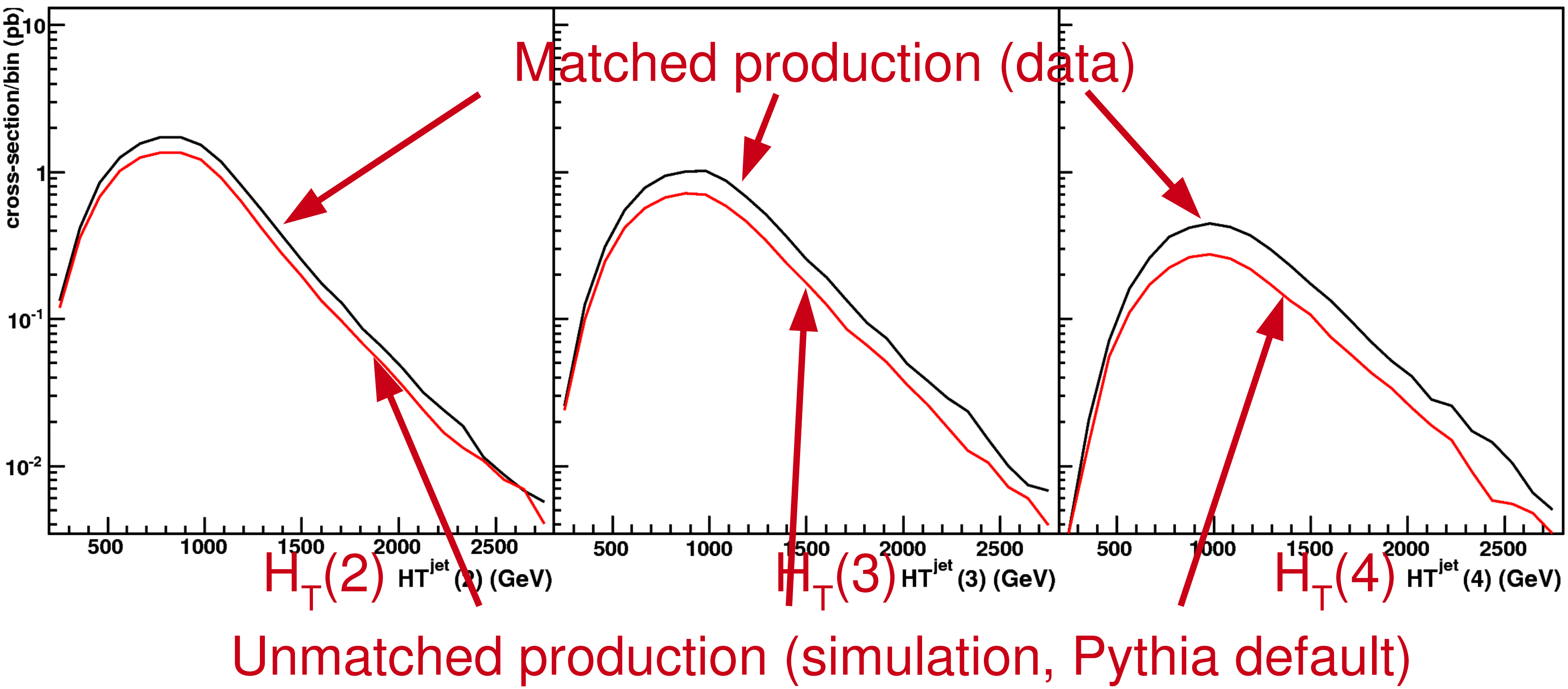
$M_{g}-M_{q}=$ 50 GeV

squarks heavy – 3-body ~g decay



# Risk for misinterpretation

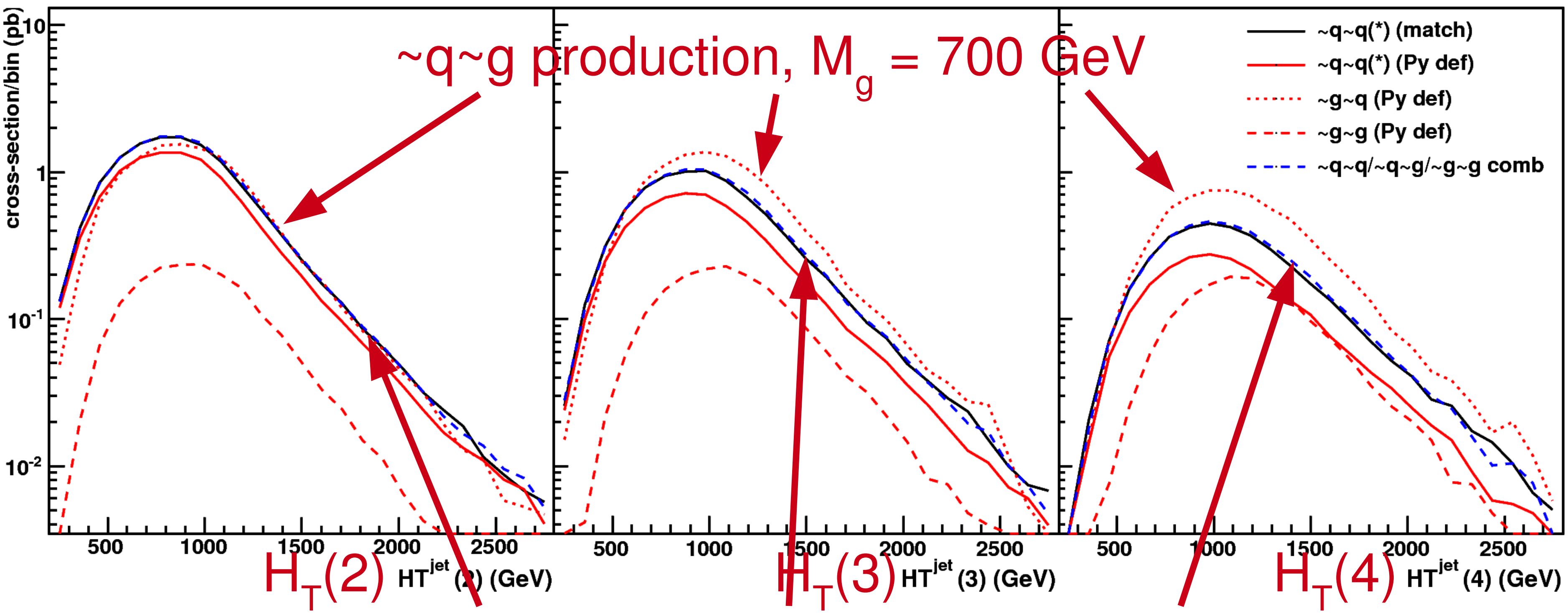
## Scenario: sqsq production only (gluinos heavy)




## Looks like we're missing gluino component!

# Risk for misinterpretation

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




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]

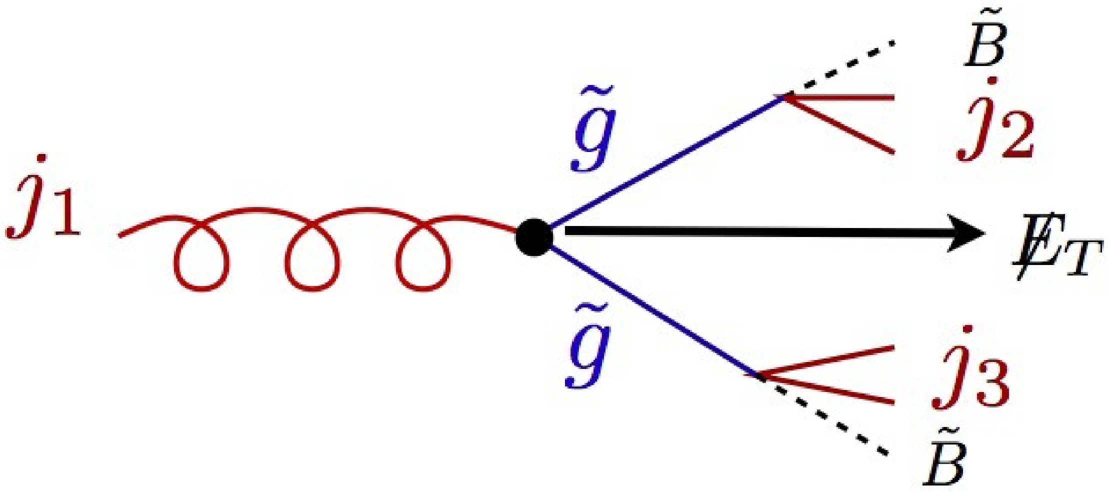
- Searches at the Tevatron have always been done in the mSUGRA framework
- mSUGRA (and mGMSB) "special" scenarios: fixed mass ratio $m_g:m_W:m_B \sim 6:2:1$
- Not representative for general MSSM (or other BSM models!)
- Study of projected exclusion region at Tevatron with free ratio $m_g:m_B$ (arXiv:0803.0019)

# Light gluinos at the Tevatron

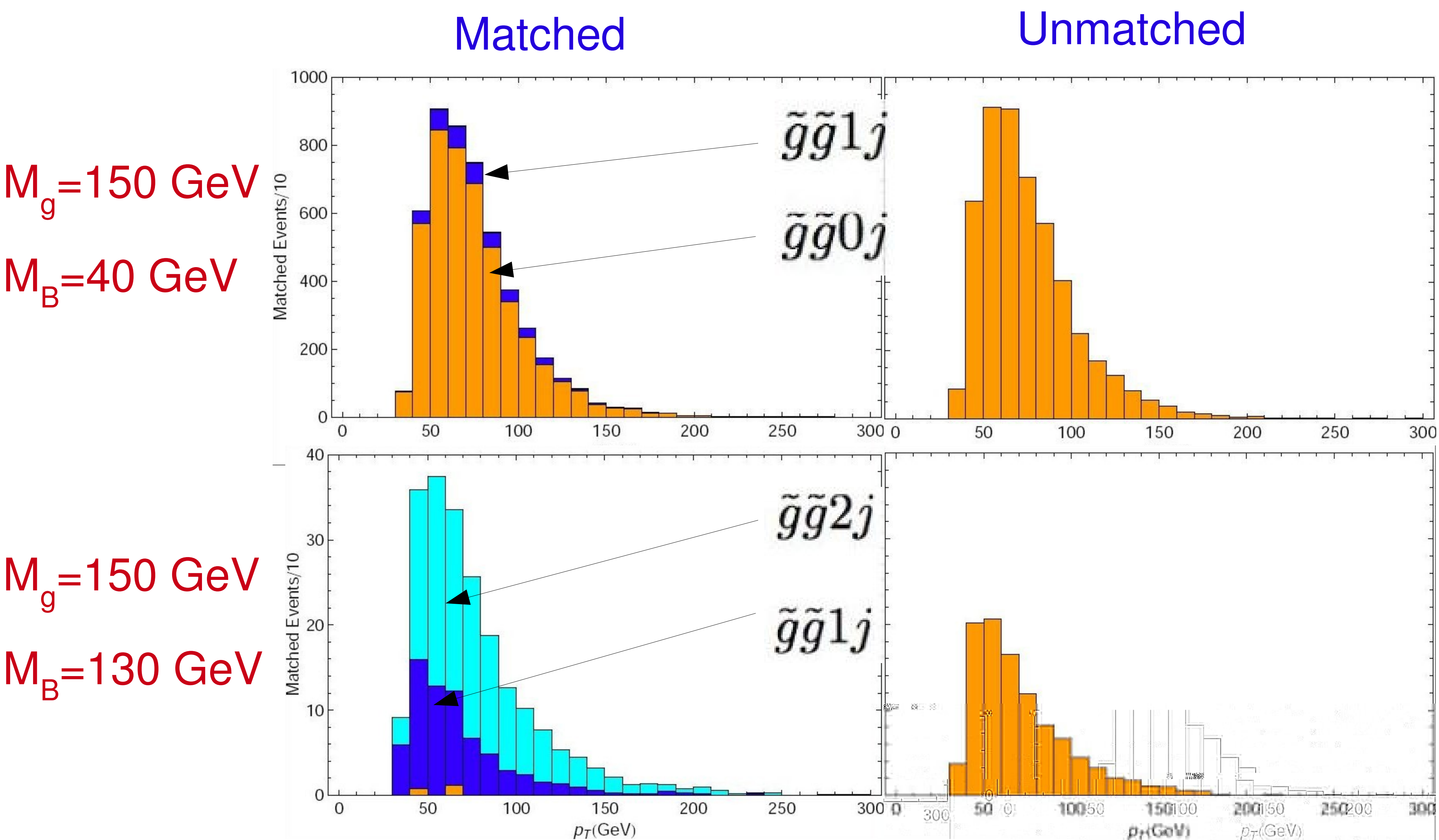
JA, Le, Lisanti, Wacker [arXiv:0803.0019, arXiv:0809.3264]

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



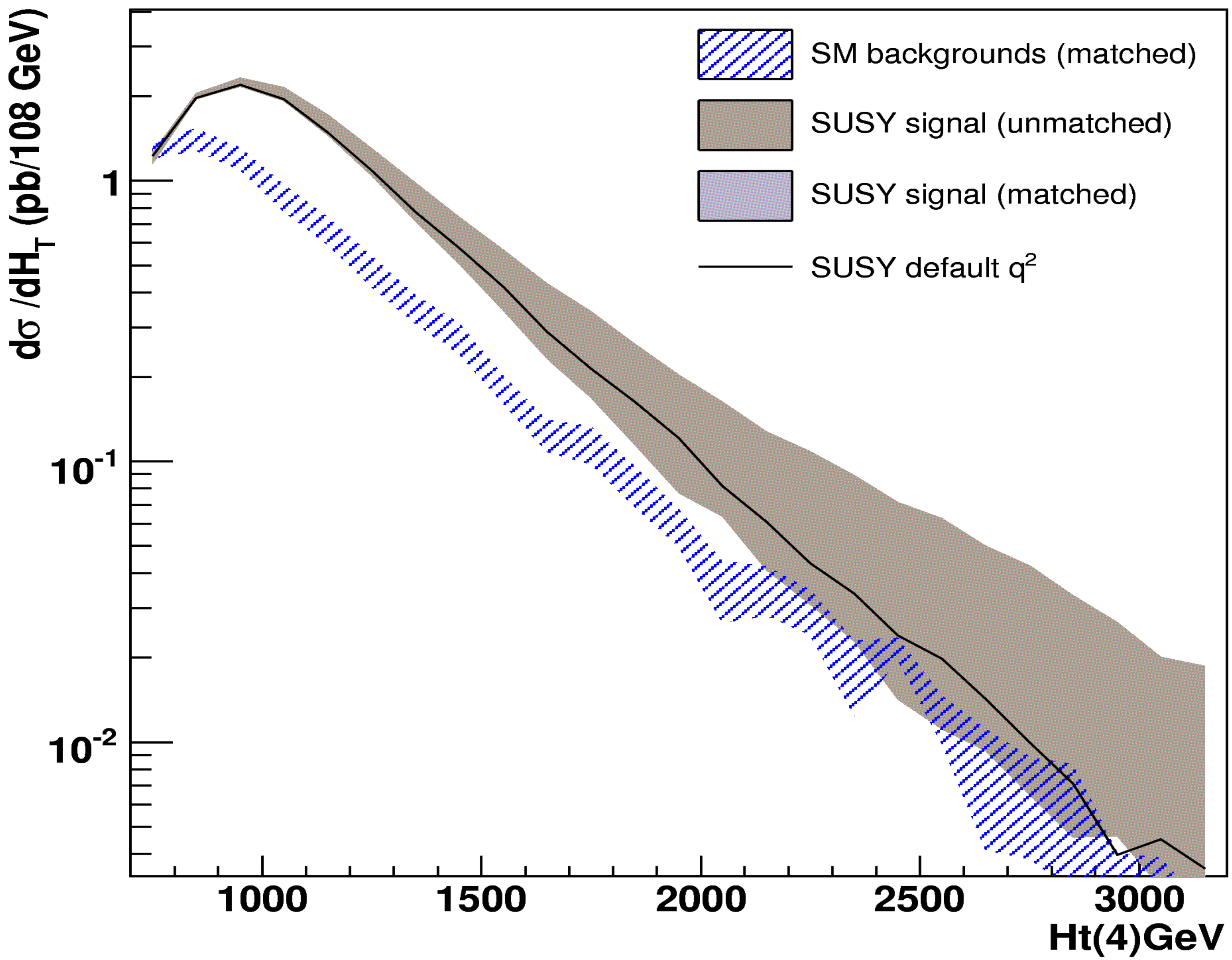
# Light gluinos at the Tevatron




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

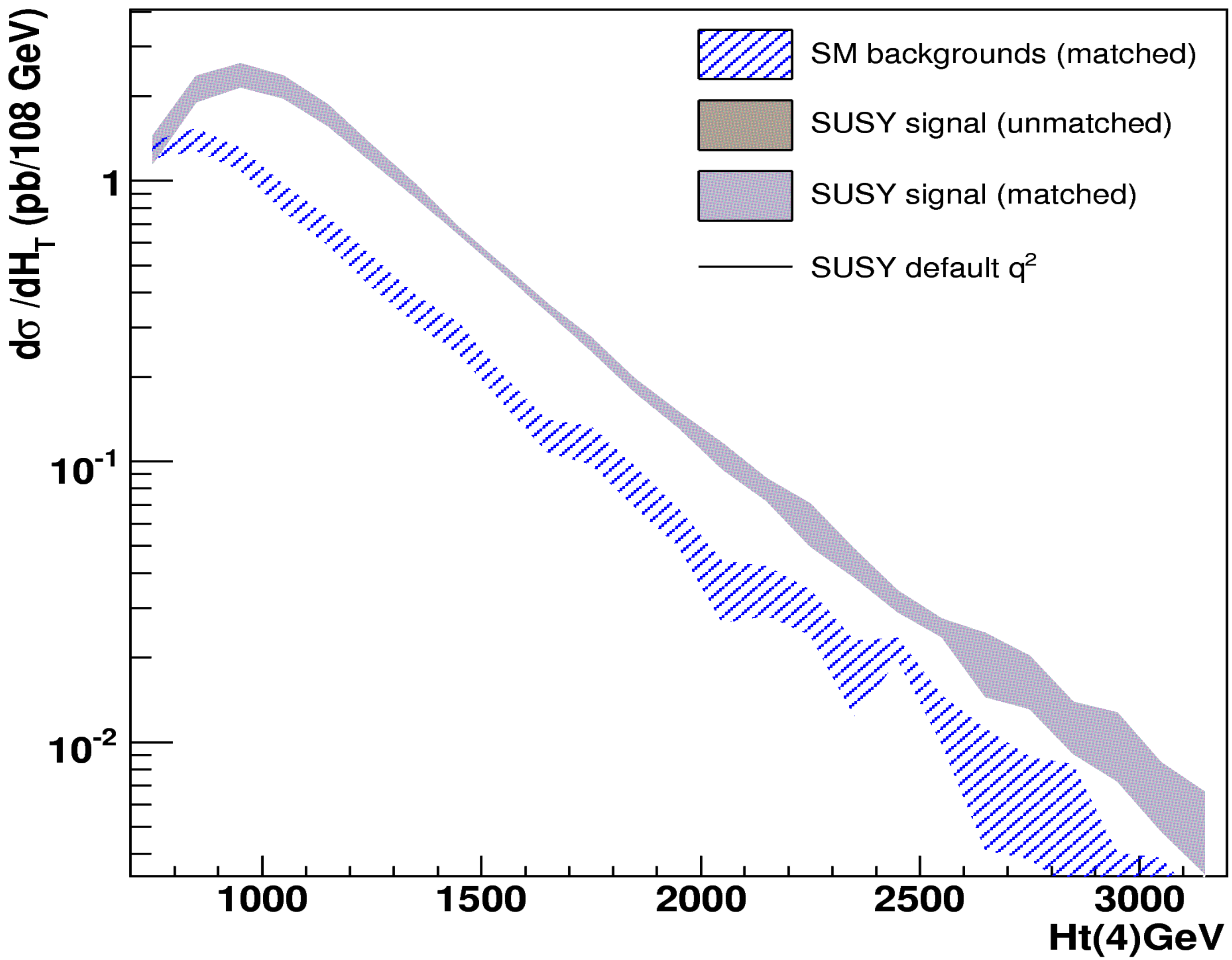
# Impact on collective exp. searches

## "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

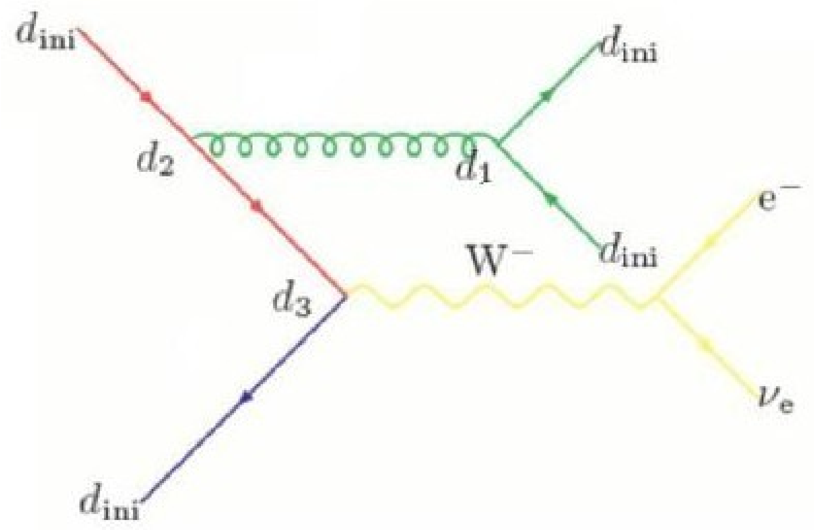
# CKKW matching

**Imitate parton shower procedure for matrix elements**

1. Choose a cutoff (jet resolution) scale $d_{\text{ini}}$
2. Generate multiparton event with $d_{\text{min}} = d_{\text{ini}}$ and factorization scale $d_{\text{ini}}$
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 $\Delta(d_j, d_{\text{ini}})/\Delta(d_i, d_{\text{ini}})$ for each parton line between vertices $i$ and $j$ ($d_j$ can be $d_{\text{ini}}$)
6. Shower event, allowing only emissions with $k_T < d_{\text{ini}}$ ("vetoed showers")
7. For highest multiplicity sample, use $\min(d_i)$ of event as $d_{\text{ini}}$

Boost-invariant $k_T$ measure:

$$\begin{cases} d_{iB} = p_{T,i}^2 \\ d_{ij} = \min(p_{T,i}^2, p_{T,j}^2) F_{ij} \end{cases}$$
$$F_{ij} = 2\left\{\cosh(\eta_i - \eta_j) - \cos(\phi_i - \phi_j)\right\}$$




- For final-state showers: Combination of NLL Sudakov factors and vetoed NLL showers guarantees independenc of $d_{ini}$ 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

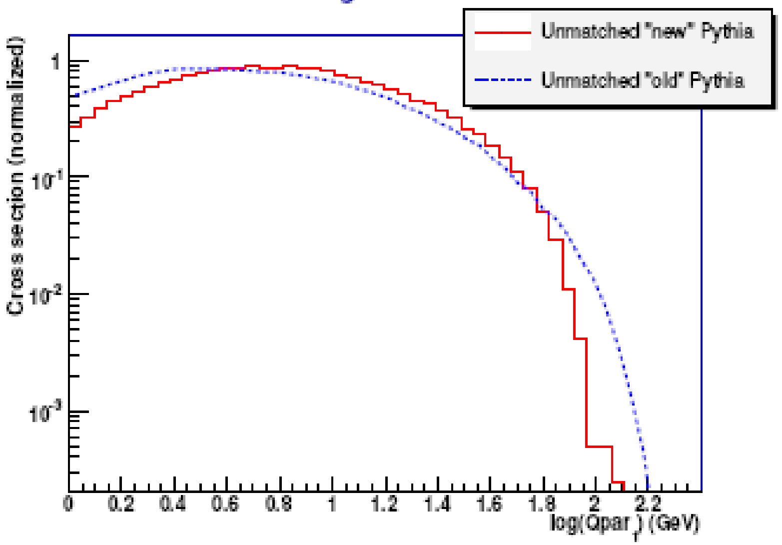
## Shower kT scheme

- 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)

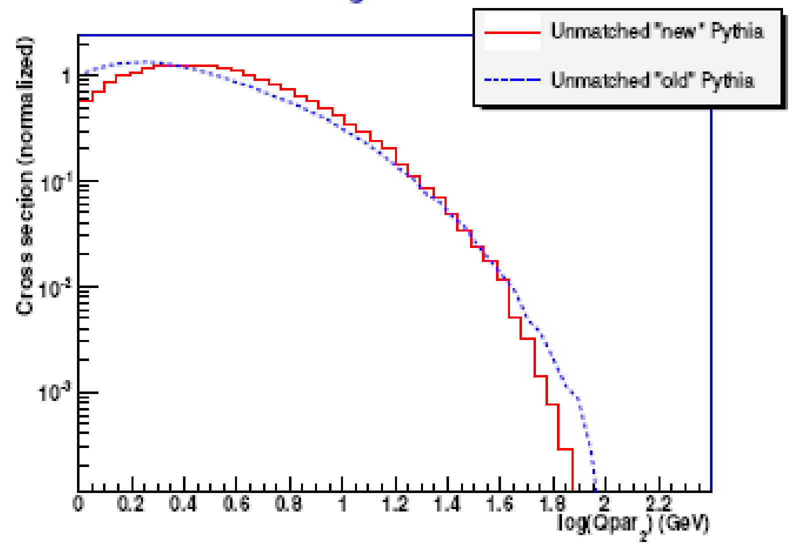
# Comparisons between old and new Pythia showers

## 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