MadGraph/MadEvent
– News and developments –

Johan Alwall, SLAC

With the MG/ME team

P. Demin, S. de Visscher, R. Frederix, M. Herquet,
F. Maltoni, T. Stelzer
+ P. Artoisenet, C. Duhr, O. Mattelaer
+ S. Mrenna, T. Plehn, D. L. Rainwater

SMU, Dallas, 22 Jan 2009

Outline

- Introduction to MadGraph/MadEvent 4
- Demonstration of MG/ME on the Web
- Recent developments of MG/ME
- Matrix element / Parton shower jet matching
- Decay chains
- Other recent developments
- Conclusions

MadGraph/MadEvent

[Long, Stelzer, 1994; Maltoni, Stelzer, 2003]

- Matrix element event generation for any process:
  - User requests a process (ex. pp>tt~jjj) and the corresponding code is generated on the fly.
  - User inputs model/collider-parameters/cuts, and code runs in parallel on our farms or locally.
  - Returns cross section, parton-level events, plots.
- Advantages:
  - Reduces overhead to getting results
  - Events can easily be shared/stored
  - Allows user to focus on physics & new ideas!
- Limitations:
  - Optimization on single procs limited by generality
  - Tree-level amplitudes based on Feynman diagrams

MadGraph/MadEvent 4

[JA et al., arXiv:0706.2334]

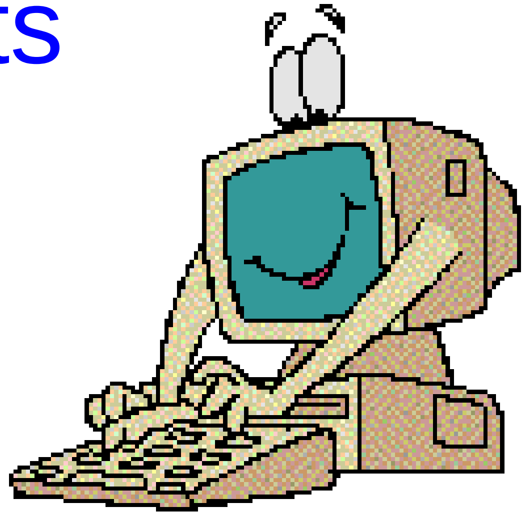
- Complete web simulation: MadEvent → Pythia → PGS
- Personal web databases
- Multiple processes in single code & generation
- Standalone MadGraph version for theorists
- New complete models: SM, HEFT, MSSM, 2HDM
- USRMOD: Easy New Model implementation
- Les Houches Accord (LHEF) for parton-level event files
- "SUSY Les Houches Accord" for model parameters
- Merging/matching w/ Pythia parton showers
- Analysis platforms: ExRootAnalysis and MadAnalysis

How do I use MG/ME 4?

1. Open your browser
2. Go to one of our sites
3. Create a process
4. Generate events

Sounds easy? It is!

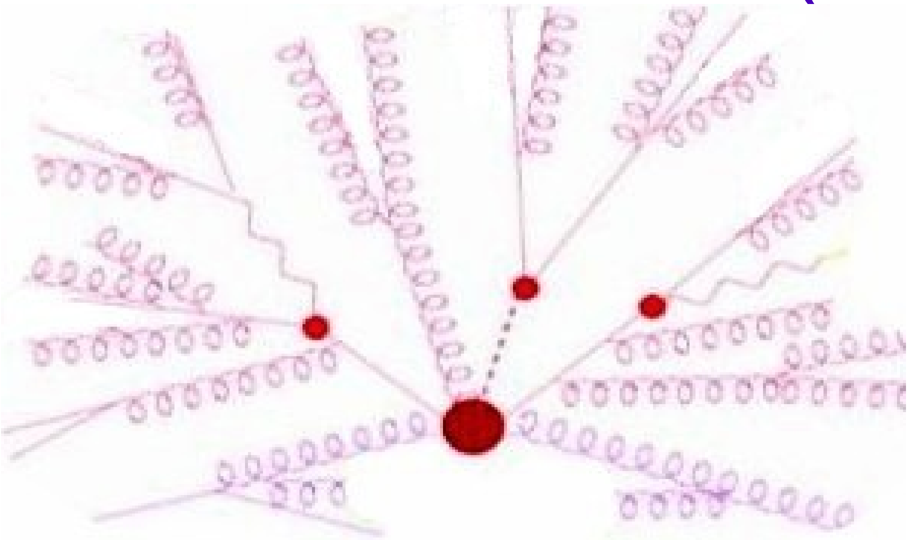
Let me show you!



Recent and ongoing developments

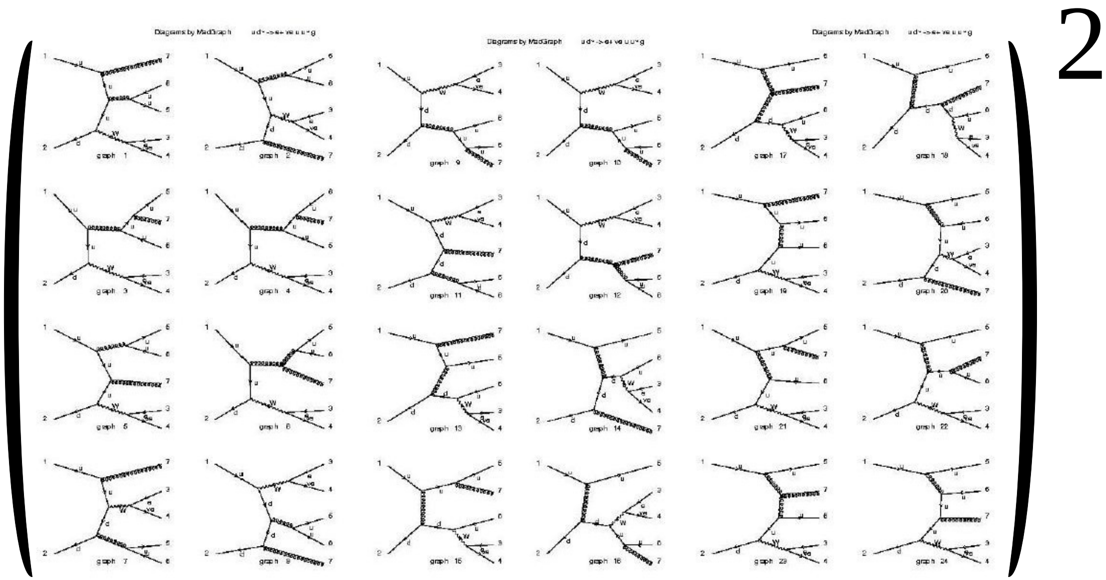
- Matching for SM&BSM processes [JA] ✓
- Staged web simulation :
  LHEF → Pythia → PGS [JA et al.] ✓
- Decay chain specifications [JA, T. Stelzer] ✓
- Decay width calculation A>BC... [JA] ✓
- Grid Version [Mad Team] ✓
- LHC event repository [Mad Team]
- FeynRules [C. Duhr et al.] ✓
- MadWeight [P. Artoisenet et al.] ✓
- MadOnia [P. Artoisenet et al.] ✓
- Automatic dipole subtraction [R. Frederix, N. Greiner] ✓

Parton Showers (PS)



- Based on soft-collinear approximation
- Step-by-step subsequent QCD emissions
  - Fast, computationally cheap
  - No limit on particle multiplicity
- Necessary for interfacing to hadronization
- Formally correct only close to collinear region

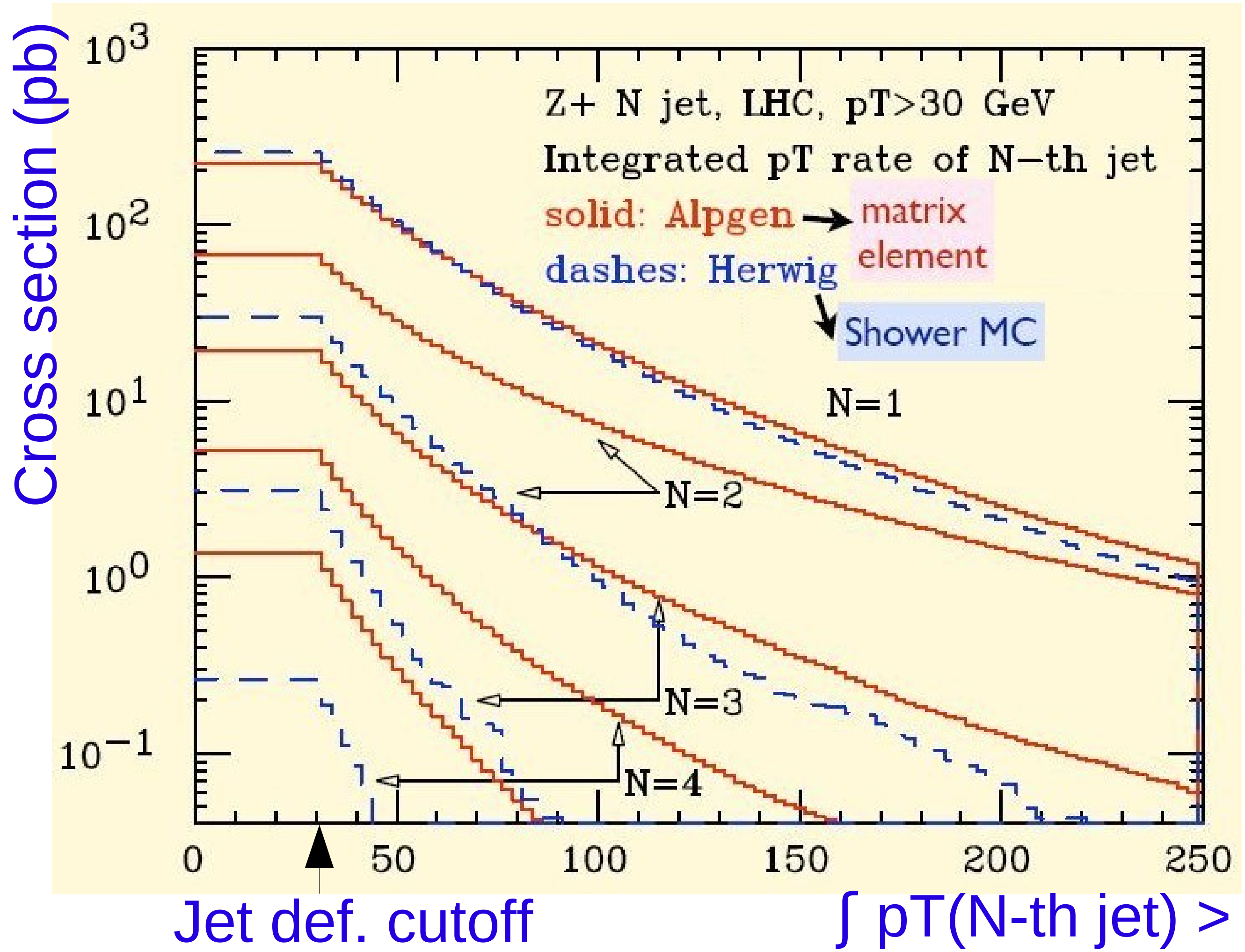
Matrix Elements (ME)



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

- Correct description away from the collinear region
  - – diverges in the collinear region
- Includes interference and finite terms
- Necessary for calculation of high-energy jets
- Fixed particle multiplicity
- Slow, computationally heavy

Importance of Matrix Elements



Parton showers get multiple hard jet production from QCD radiation wrong by orders of magnitude

Matching ME and PS

Difficulties combining the two descriptions:

- Same phase space configuration can be described by both n+1-parton ME event and n-parton event + PS
  $\rightarrow$ Double counting
- Transition between ME and PS should be smooth
- Cross section should not be affected
- Minimize dependence on highest ME multiplicity

Solutions:

- Catani, Krauss, Kuhn, Webber [2001]
- Lönnblad [2001]
- M.L. Mangano [2002, 2006]

Matching ME and PS

Common approach for all matching schemes:

- Separate “hard jet” and “soft/collinear jet” regions using phase-space cutoff
- Allow ME jets to populate only “hard” region and PS emissions only “soft” region
- Modify ME description to mimick the parton shower near the cutoff
  - Reweighting of α_s in each emission vertex
  - “Sudakov reweighting” to account for no PS emissions in hard region and ensure stable cross section

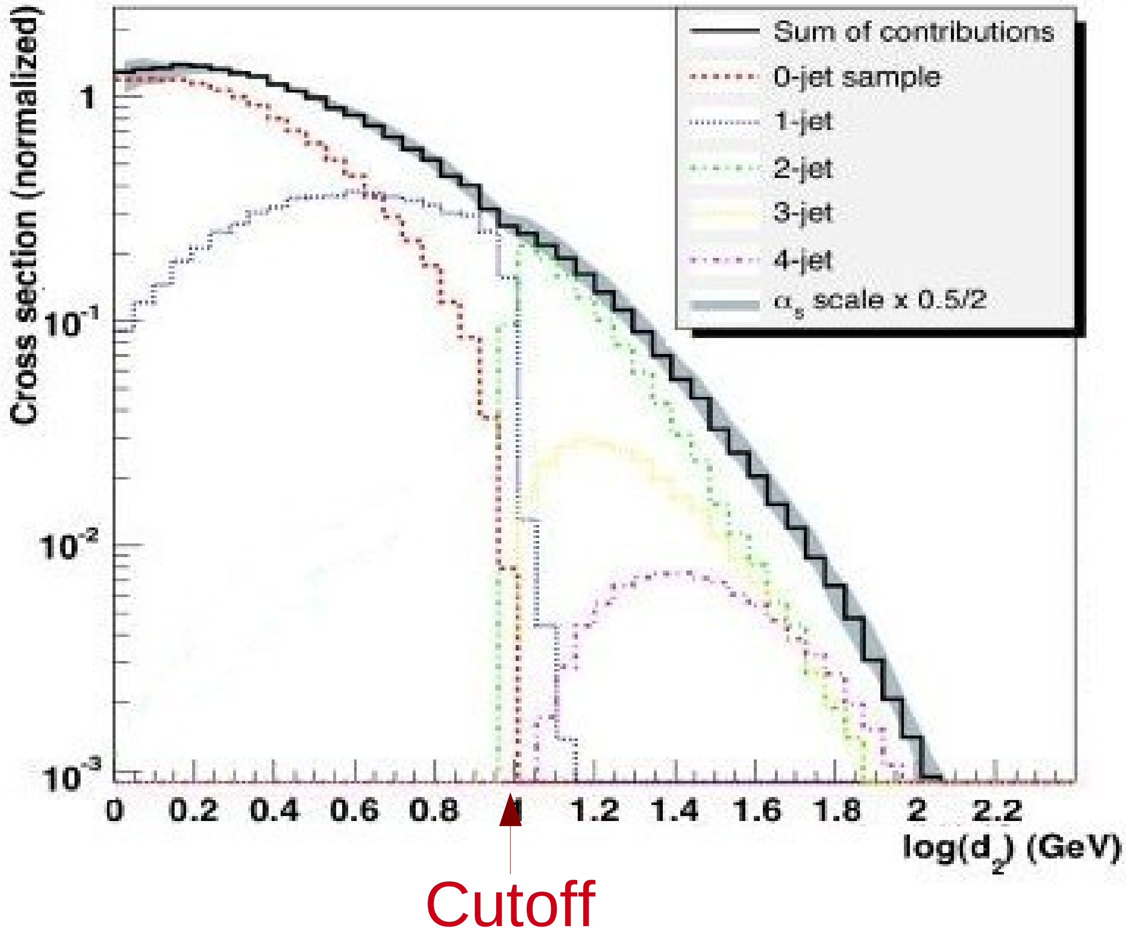
Done differently in different schemes

MadGraph/MadEvent+Pythia

- Matching schemes implemented: k_T and cone jet MLM schemes, new "shower k_T" scheme
- Both Q^2- and p_T-ordered Pythia parton showers
- Extensively validated, W+jets compared with other generators [arXiv:0706.2569]
- Allows matching in most SM and BSM processes (including gluino/squark production)

Results of matching

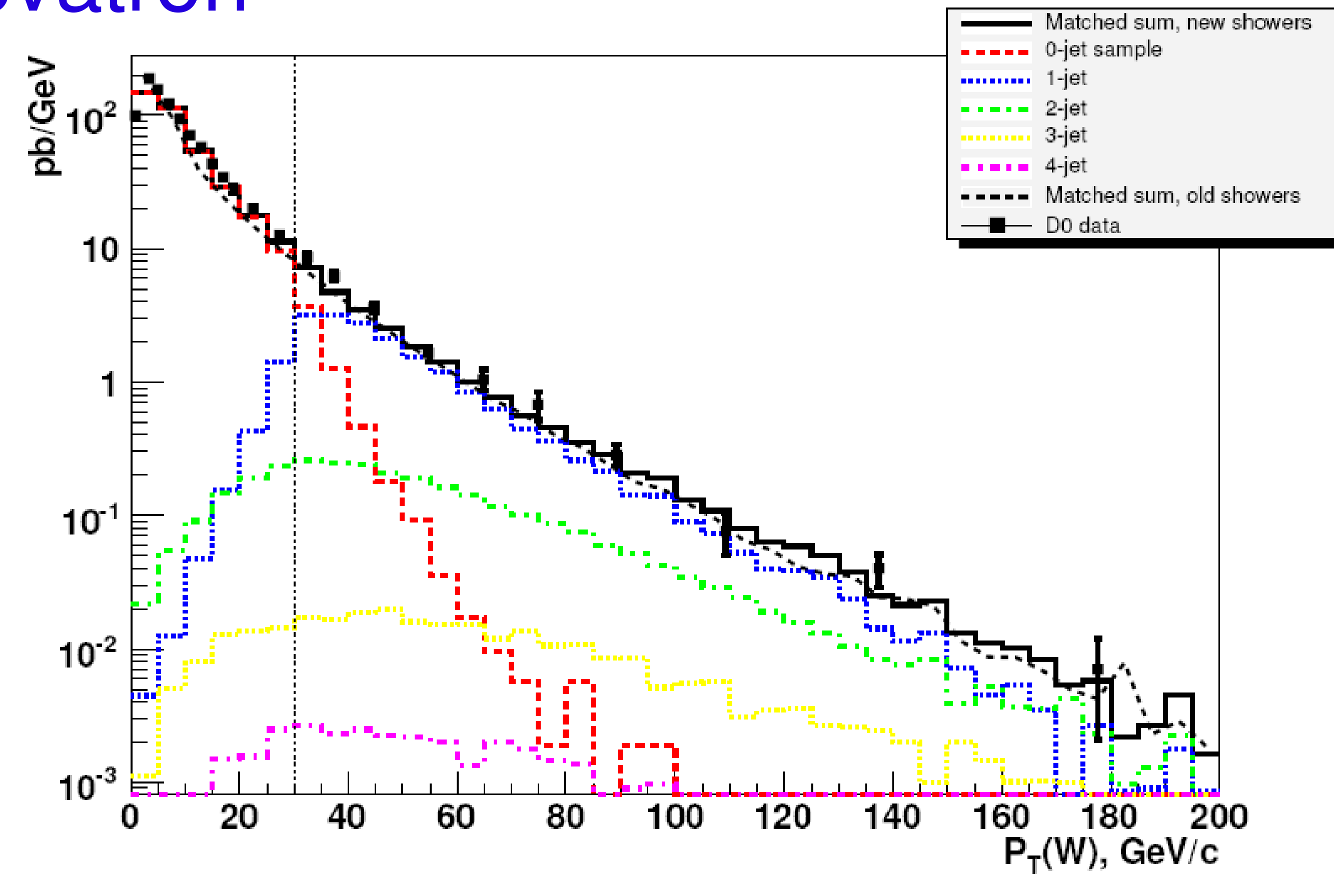
Jet resolution scale for 1 → 2 jets ~ $p_T(2^{nd}$ jet)



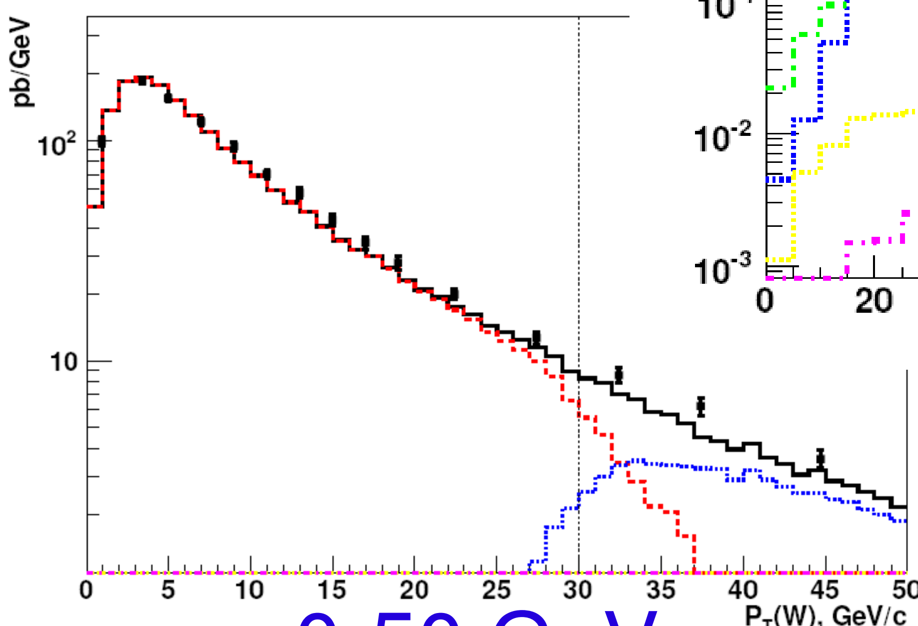
W+jets production at the Tevatron
MadEvent+Pythia k_T jet MLM scheme

Comparison with Tevatron Data

$p_T(W^{+/-})$ at the Tevatron



0-200 GeV



0-50 GeV

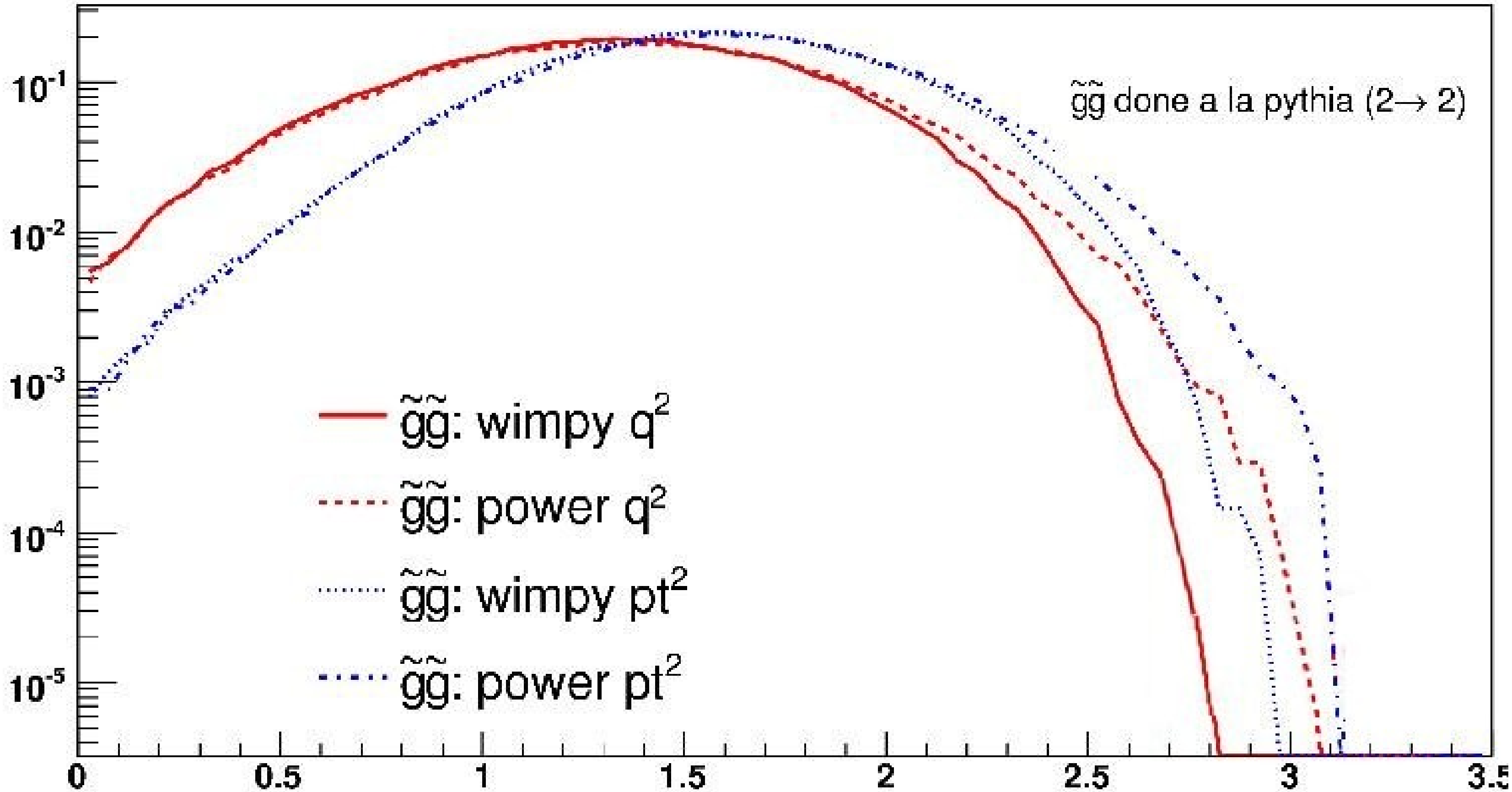
Matching in New Physics production

JA, de Visscher, Maltoni [arXiv:0810.5350]

- We know that matching of ME+PS is vital for jet production in SM backgrounds
- But is it relevant for heavy BSM particle production?
  - Very hard jets from decays
  - Parton showers expected to be more accurate for larger masses
  - Using gluino and squark production as example
- Turns out there are many cases where matching is necessary for precise description!

Shower parameter dependence

QCD radiation for different Pythia shower params

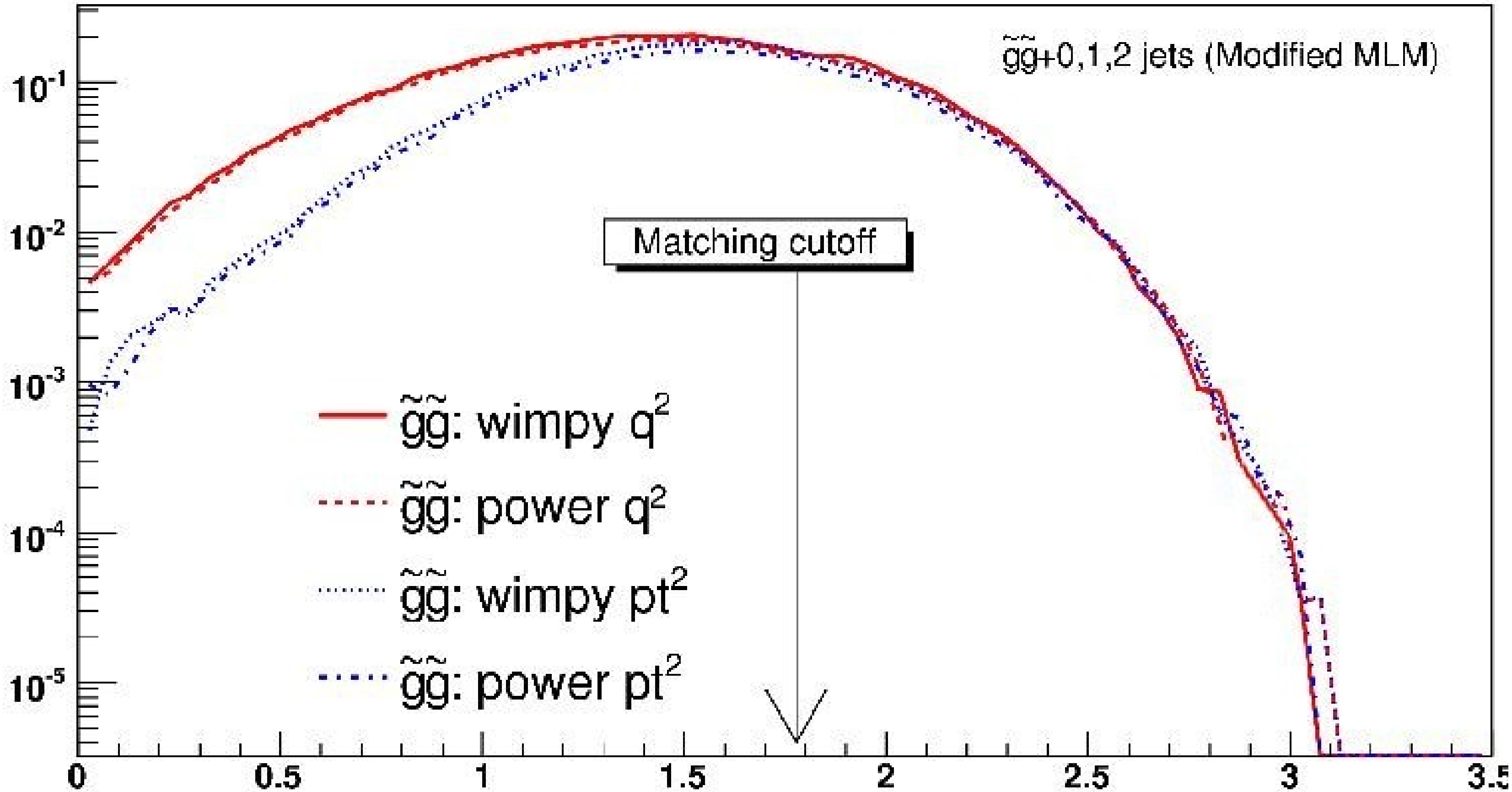


log(Jet resolution scale for 1 → 2 jets) (GeV)

600 GeV gluino pair production at the LHC

Shower parameter dependence

QCD radiation after matching with MG/ME



log(Jet resolution scale for 1 → 2 jets) (GeV)

600 GeV gluino pair production at the LHC

Example: Non-standard gluinos

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

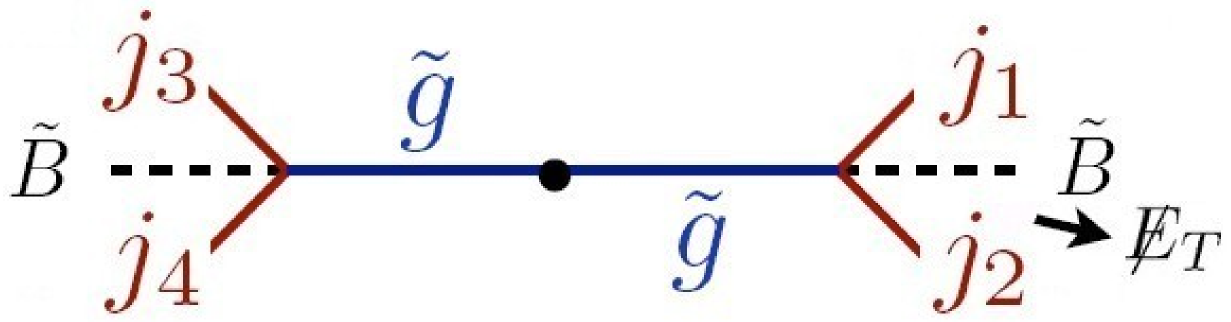
Non-unified/non-standard SUSY scenarios, and other models, can have $m_{\tilde{g}}:m_{\tilde{B}}$ ratio free

- A priori unclear where Tevatron is sensitive
- Need combination of $\not{E}_T$+1-jet, 2-jet, 3-jet and multijet searches to cover whole $\tilde{g}$-$\tilde{B}$ mass plane

Example: Non-standard gluinos

Special difficulty when decay products nearly mass-degenerate with produced particle:

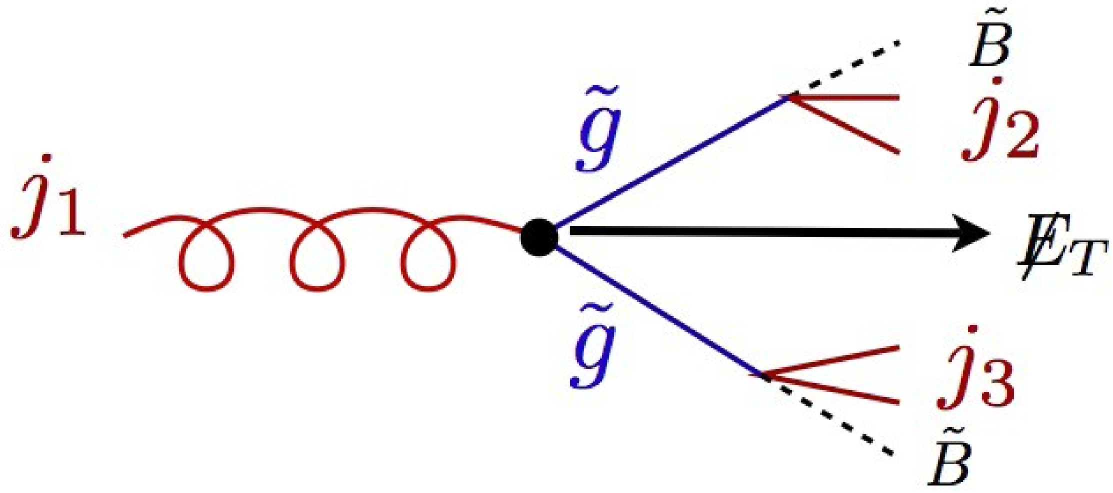
- No (small) missing transverse energy in decay



Example: Non-standard gluinos

Special difficulty when decay products nearly mass-degenerate with produced particle:

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



Example: Non-standard gluinos

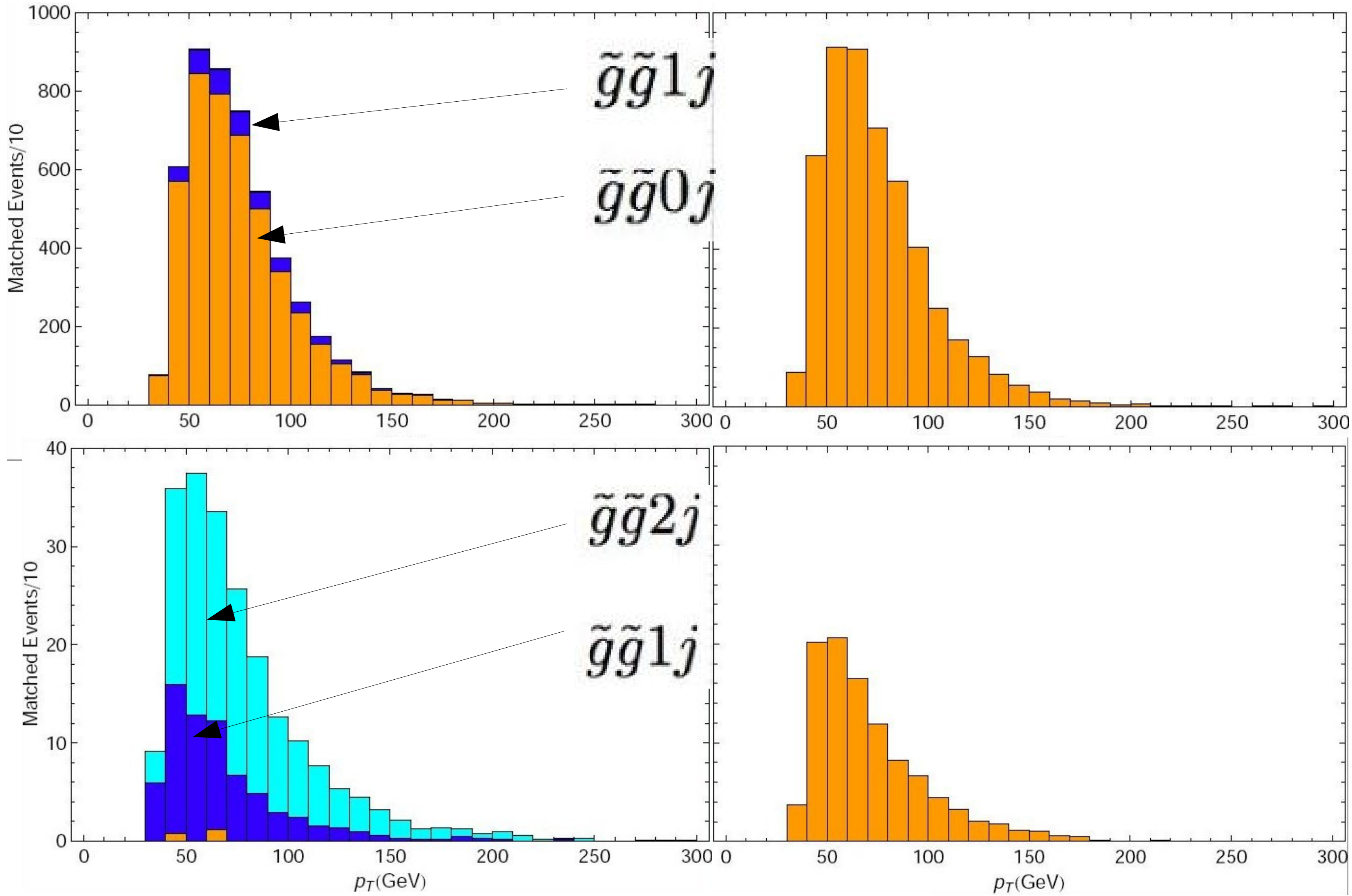
Matched Unmatched

$M_{\tilde{g}}$=150 GeV

M_B=40 GeV

$M_{\tilde{g}}$=150 GeV

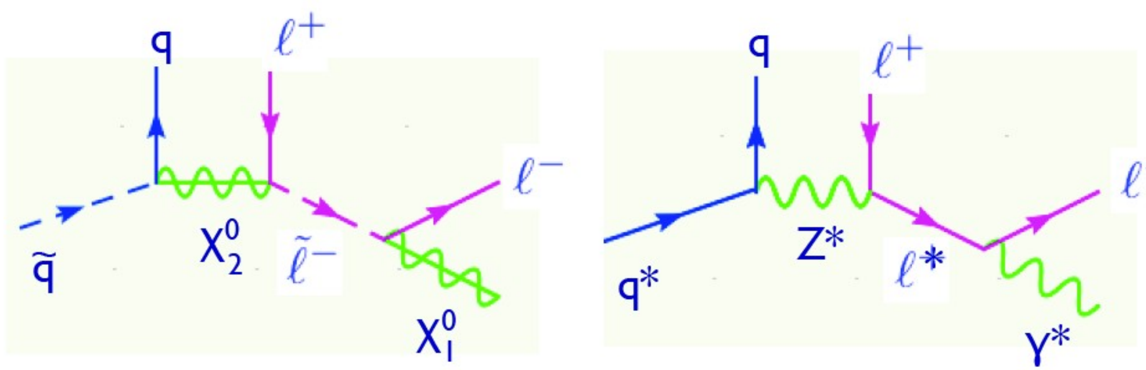
M_B=130 GeV

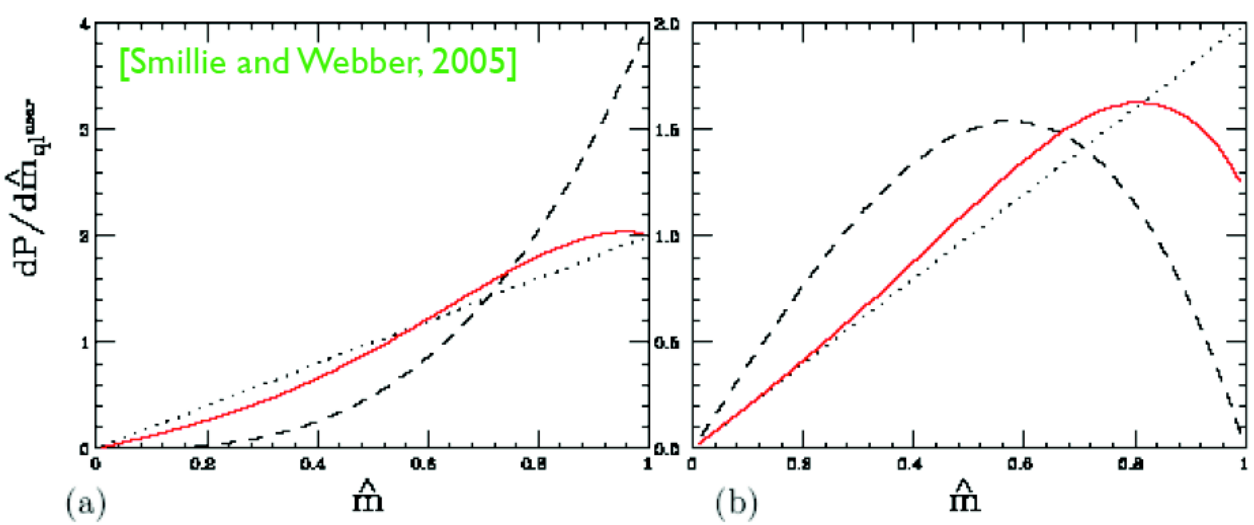


Tevatron, after 2-jet and missing E_T cuts

SUSY vs. UED – spin effects

Long decay chains give information on intermediate particle masses and spins through edge and endpoint positions and shapes





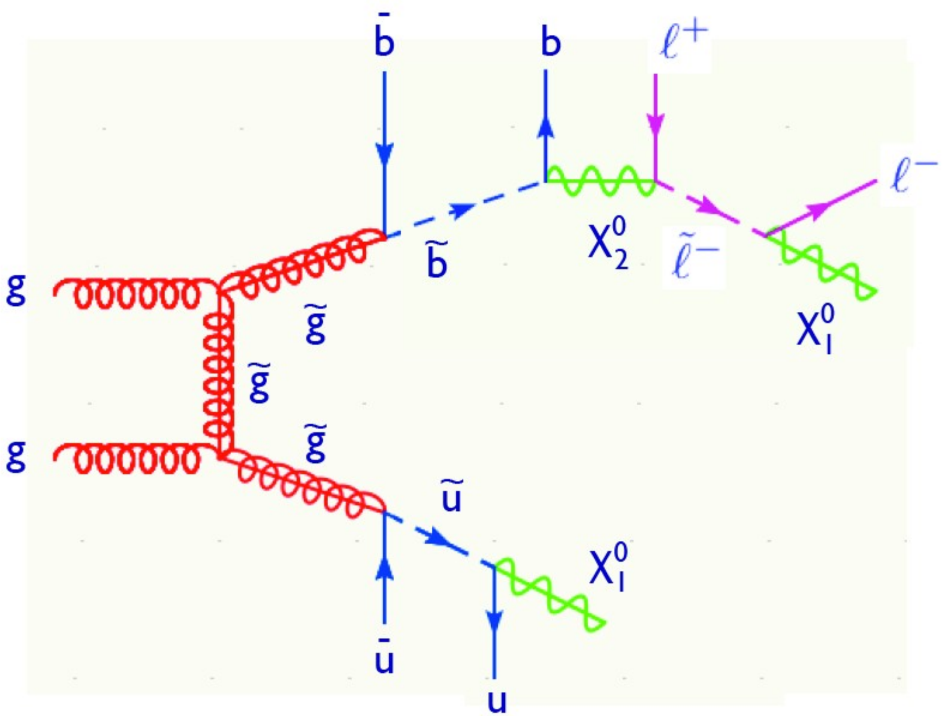
Beware of common simplifications:

1. Production and decay factorized
2. Spin ignored
3. Chains only through $1 \to 2$ decays.
4. Narrow width approximation employed.
5. Non-resonant diagrams ignored.

Decay chains

[JA, T. Stelzer]

```
gg>(go>u~(ul>u n1))(go>b~(b1>(b(n2>mu+(mul->mu- n1)))))
```

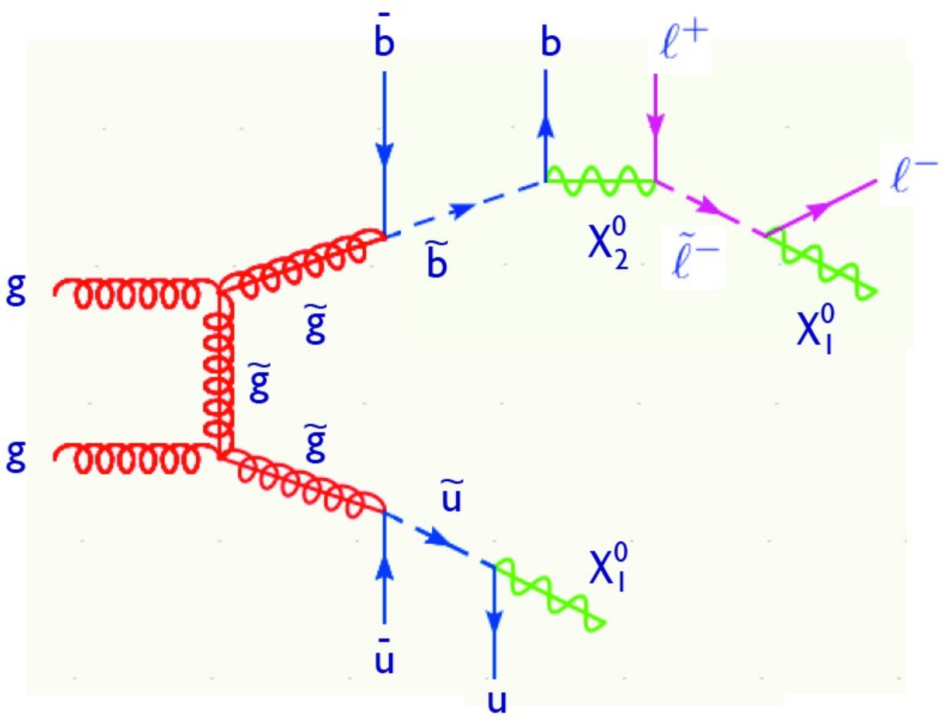


1. Full matrix element with all correlations between production and decay
2. 1 $\rightarrow$ N decays possible
3. BW for all resonances
4. Non-resonant contributions can be included only where relevant

Decay chains

[JA, T. Stelzer]

```
gg>(go>u~(ul>u n1))(go>b~(b1>(b(n2>mu+(mul->mu- n1)))))
```



1. Full matrix element with all correlations between production and decay
2. 1 → N decays possible
3. BW for all resonances
4. Non-resonant contributions can be included only where relevant

Example safe simplification: factorize process at scalar decay

```
gg>(go>u~ ul)(go>b~ b1)
```

Decay scalars at event level with MG or BRIDGE

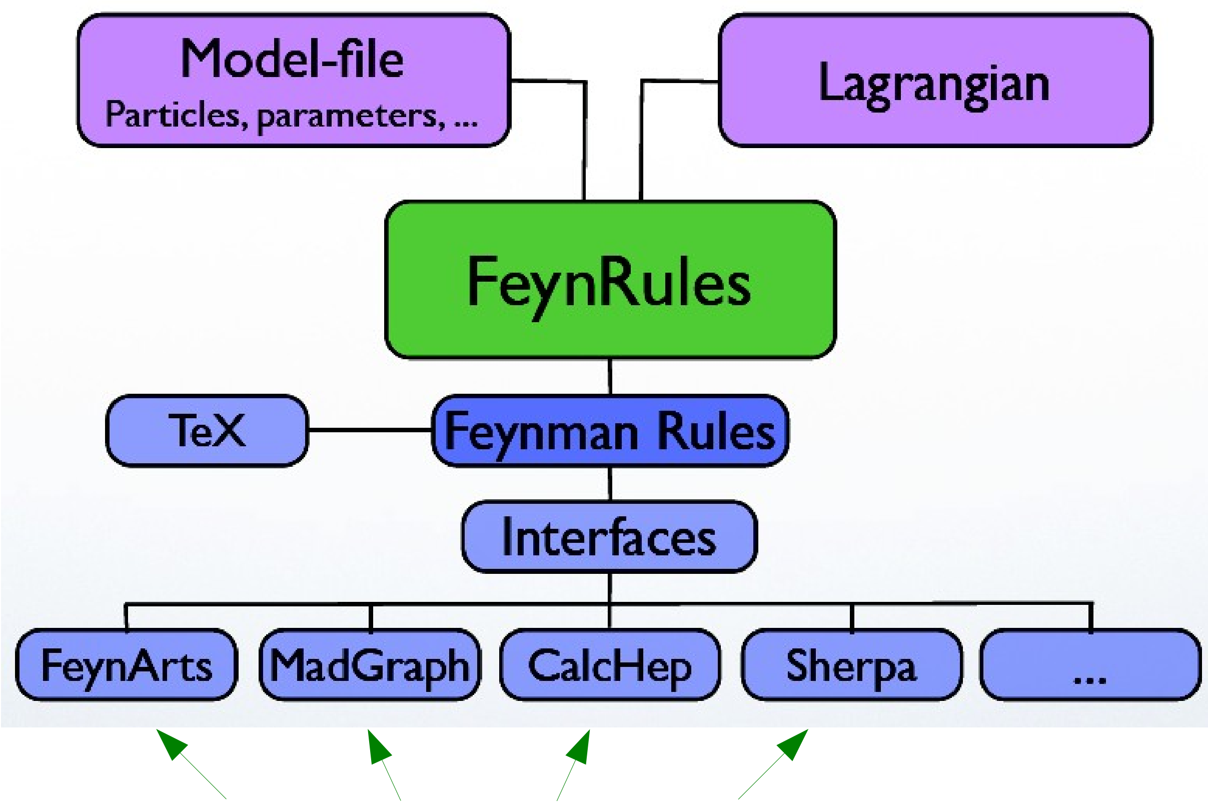
[P. Meade, M. Reece, 2007]

```
ul > u n1
b1 > b(n2>mu+(mul->mu- n1))
```

FeynRules

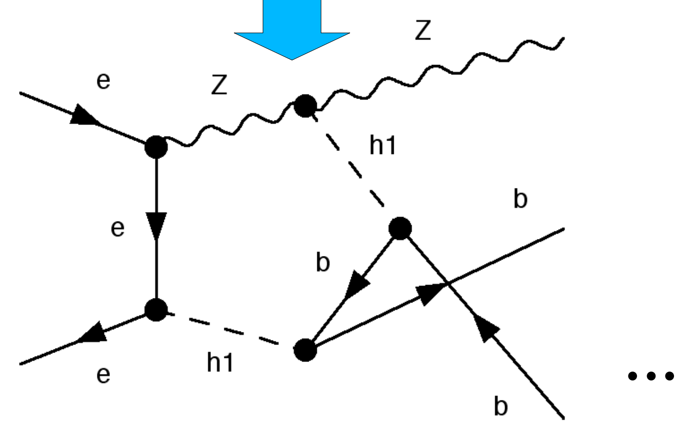
[C. Duhr + MC collaborators, arXiv:0806.4194]

New tool (Mathematica package) to extract Feynman rules and couplings from Lagrangian + Generation of MC files



Interfaces available

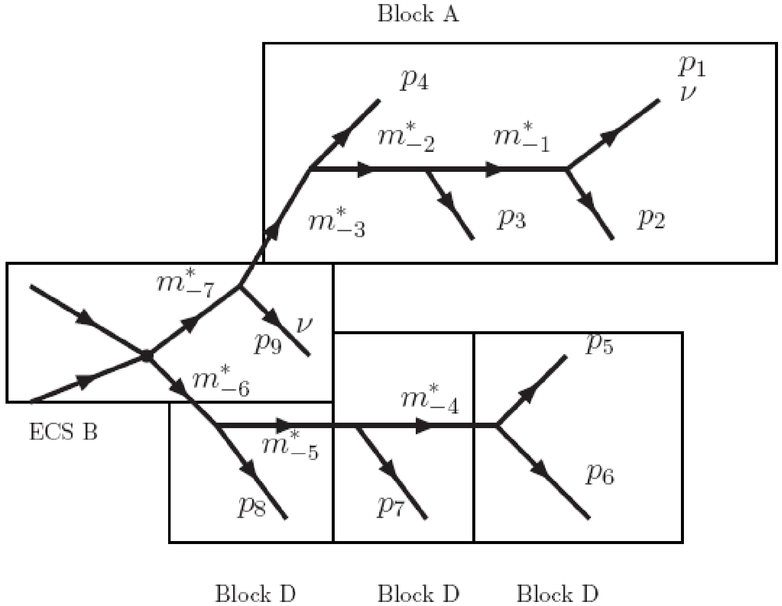
$$\kappa^{-1}\mathcal{L}_{\mathrm{F}}^{\vec n}(\kappa) = \frac{1}{2}\Big[(\tilde h^{\vec n}\eta^{\mu\nu} - \tilde h^{\mu\nu,\vec n})\overline{\psi} i\gamma_\mu D_\nu\psi - m_\psi \tilde h^{\vec n}\overline{\psi}\psi + \frac{1}{2}\overline{\psi} i\gamma^\mu(\partial_\mu \tilde h^{\vec n} - \partial^\nu \tilde h^{\vec n}_{\mu\nu})\psi\Big] + \frac{3\omega}{2}\tilde\phi^{\vec n}\overline{\psi} i\gamma^\mu D_\mu\psi - 2\omega m_\psi \tilde\phi^{\vec n}\overline{\psi}\psi + \frac{3\omega}{4}\partial_\mu\tilde\phi^{\vec n}\overline{\psi} i\gamma^\mu\psi$$

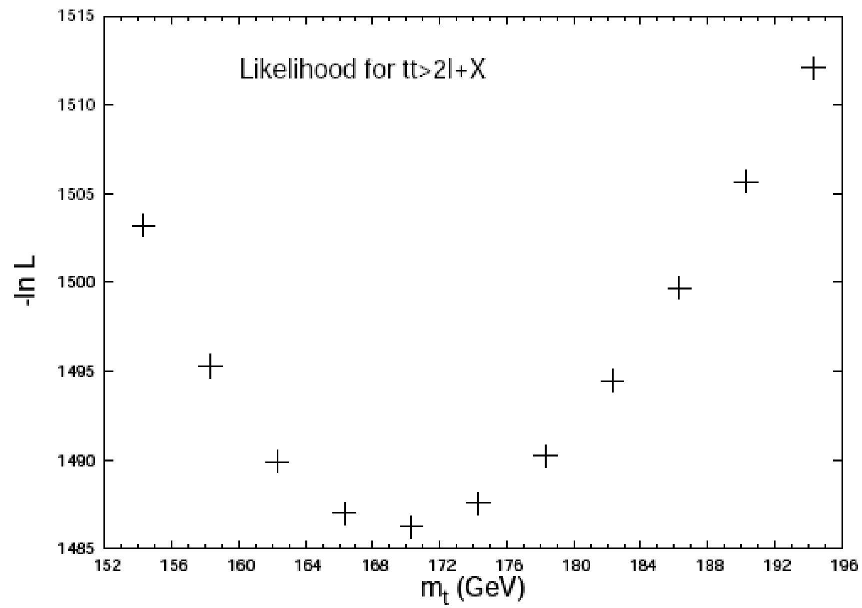


MadWeight

[P. Artoisenet, V. Lemaitre, F. Maltoni, O. Mattelaer]

Tool to find matrix element weight of exp. events for (almost) any process in any model





Phase space integration using automatic change of variables aligned with peaks

Find likelihood for model parameters (here top mass)

Automatic dipole subtraction

[R. Frederix et al, arXiv:0808.2128]

$$\sigma^{\rm NLO} = \int_{m+1} \left[d^{(4)}\sigma^R - d^{(4)}\sigma^A \right] + \int_m \left[\int_{\rm loop} d^{(d)}\sigma^V + \int_1 d^{(d)}\sigma^A \right]_{\epsilon=0}$$

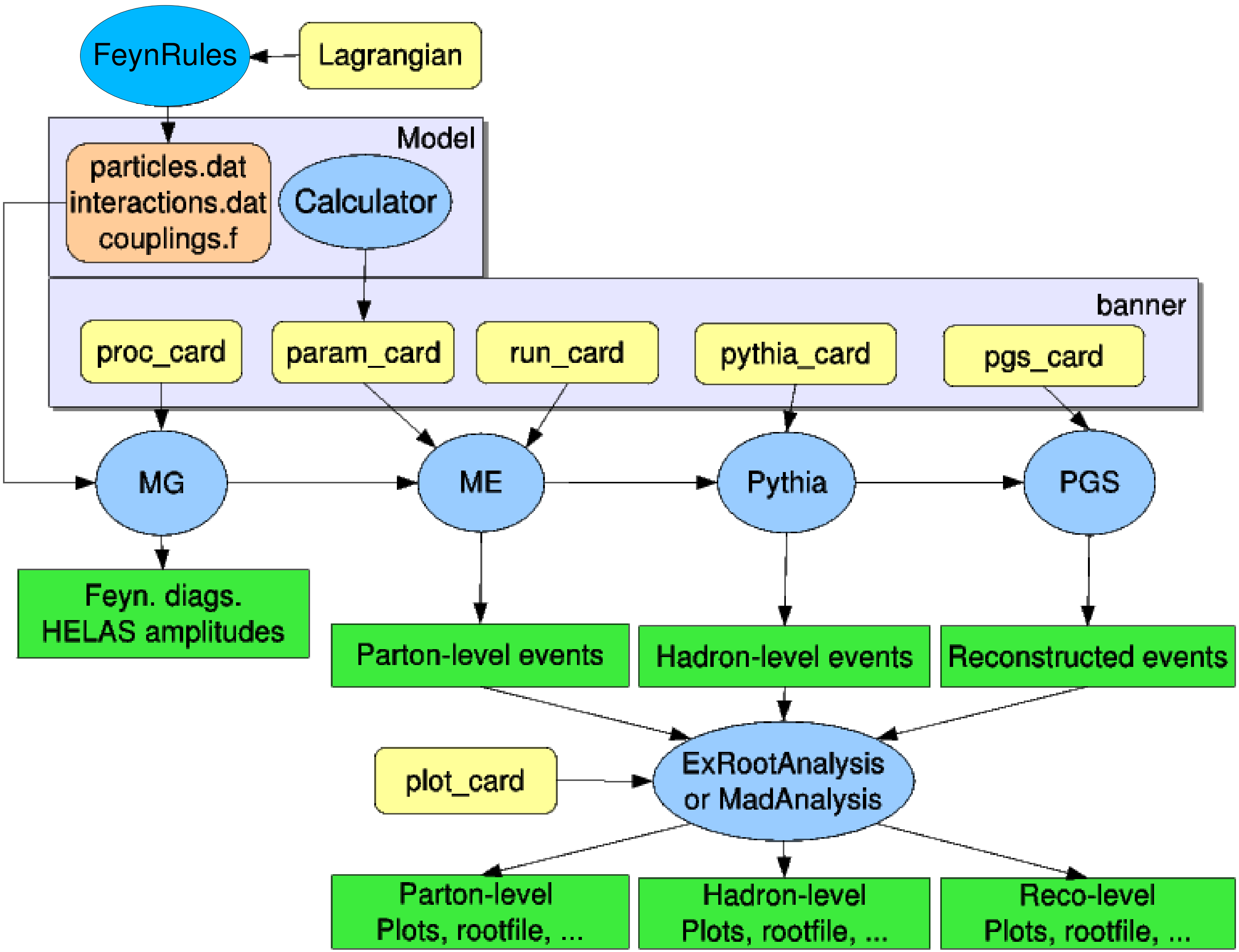
- Automatic divergence subtraction for the real contributions of any QCD NLO calculation
  - Catani-Seymour subraction scheme
  - Standalone implementation
  - Both for SM and BSM
  - Massless and massive external particles

Conclusions

- LHC poses new challenges to the MC community
- MadGraph/MadEvent approach:
  - Building a community
    - Web based : public clusters with personal DB's, Wiki, open CVS repository
    - Support to spin-offs, independent projects, and custom MC needs (Ex: BRIDGE, FeynRules, NLO, BSM implementations, ...)
  - Providing a fully-fledged platform for physics studies at colliders
    - Complete simulation chain via web + Grid version
    - SM and BSM : signal and backgrounds (including multi-jet samples with ME/PS merging)
    - TH and EXP tools : MadWeight, MadDipole, Analysis tools, ...

Backup slides

MG/ME workflow



MG/ME on the Grid

[Mad team]

- Optimized/specialized code for given process
- MG code creation as usual
- Selection of parameters (cards) as usual
- Train grids + get relative subprocess cross sections once and for all in a “gridpack”
- Quick and efficient generation of few events on single machine – only run relevant channels
- Only input: random seed, number of events

LHC event samples

[Mad team, see MadGraph Wiki]

- Provide set of samples for key SM and BSM processes at LHC including Pythia+PGS simulations
- Started generation of matched LHC backgrounds
  - W/Z/a + jets; top pairs + jets; QCD, b pairs + jets; Higgs + jets; VVV, single top, VBF, ...
- Small-size (1M) event sample + Grid code
- Samples validated by MC authors
  - Used by experiments as reference
  - Used by theorists for semi-realistic proto-analyses

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)