# News from MadGraph/MadEvent

Johan Alwall, SLAC

For the MG/ME team

P. Demin, S. de Visscher, R. Frederix, M. Herquet,
F. Maltoni, T. Stelzer
+ P. Artoisenet, C. Duhr, O. Mattelaer
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LoopFest VII, Buffalo, Mar 14-16, 2008

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+ Our Golden Users

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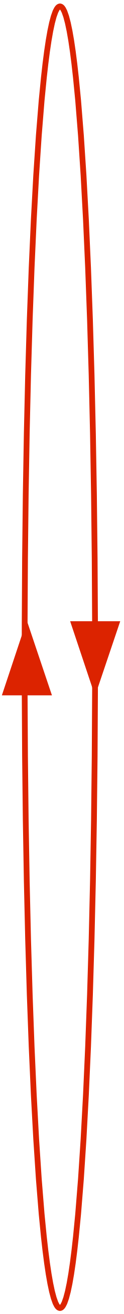
# Motivation: Minimal strategy for BSM physics



1. Find excess(es) over SM background
   *Fully exclusive description for rich and energetic SM final states (multi-jets+EW/QCD). Flexible MC to be validated and tuned. Accurate predictions (NLO, NNLO) for “standard candle” SM xsecs.*
2. Identify finite set of coarse models compatible with excess(es)
   *“Inverse problem” tools, e.g. OSETs.*
3. Look for predicted excesses in other channels
   *Simulation of any BSM signature: Fast path from model to events.*
4. Mass spectrum, quantum numbers, couplings
   *Accurate ME-based description for final state distributions keeping all relevant information (e.g. decay chains with spin)*
5. Determine underlying model
   *Accurate predictions for primary parameters (e.g. spectrum calcs)*
6. Refine
   *Off-shell effects, Matrix Element methods, Global fits (e.g. Sfitter)*

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# MadGraph/MadEvent

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

- Web generation:
  - 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 modest farms.
  - Returns cross section, parton-level events, plots.
- Advantages:
  - Reduces overhead to getting results
  - Events can easily be shared/stored
  - Quick response to user requests and to 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

# Recent and ongoing developments

- 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.]
- Automatic dipole subtraction [R. Frederix, N. Greiner]

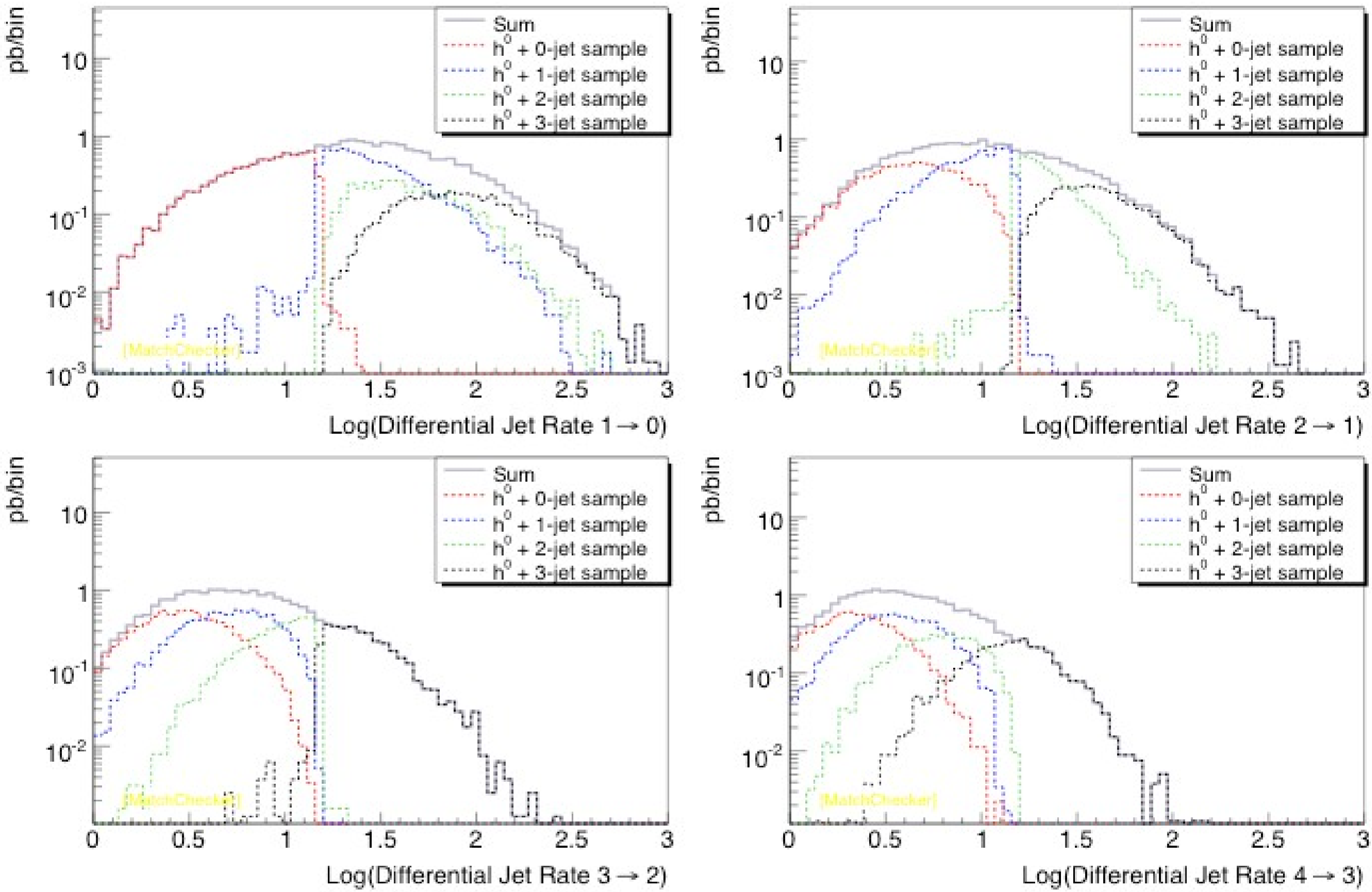
# ME+PS matching/merging

[JA; JA, F. Maltoni, S. de Visscher]

- $k_T$ 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
- Matching in BSM processes (e.g. gluino/squark)

# Example of validation: H+jets

## Higgs production from gluon fusion at LHC



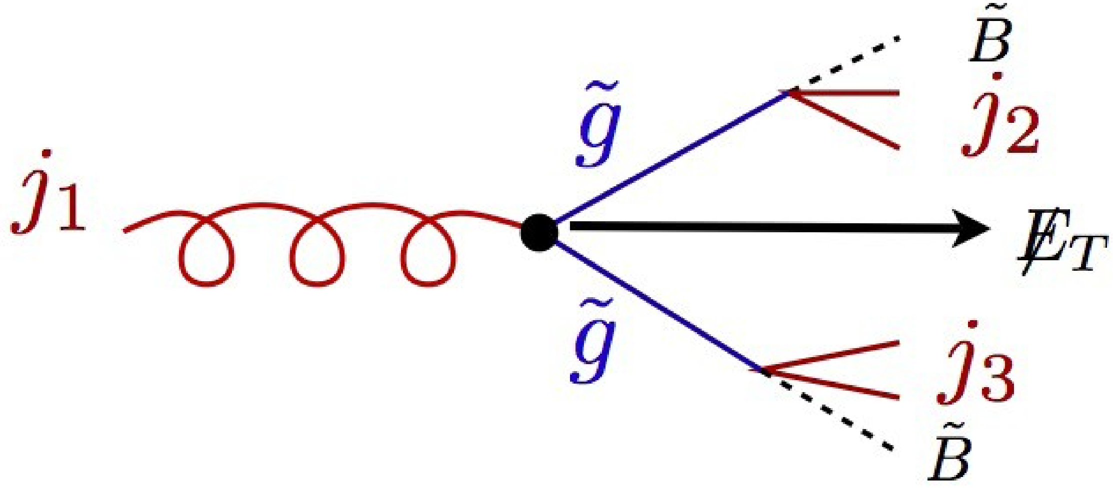

Plots by MatchChecker [de Visscher]

# Gluinos + jets

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

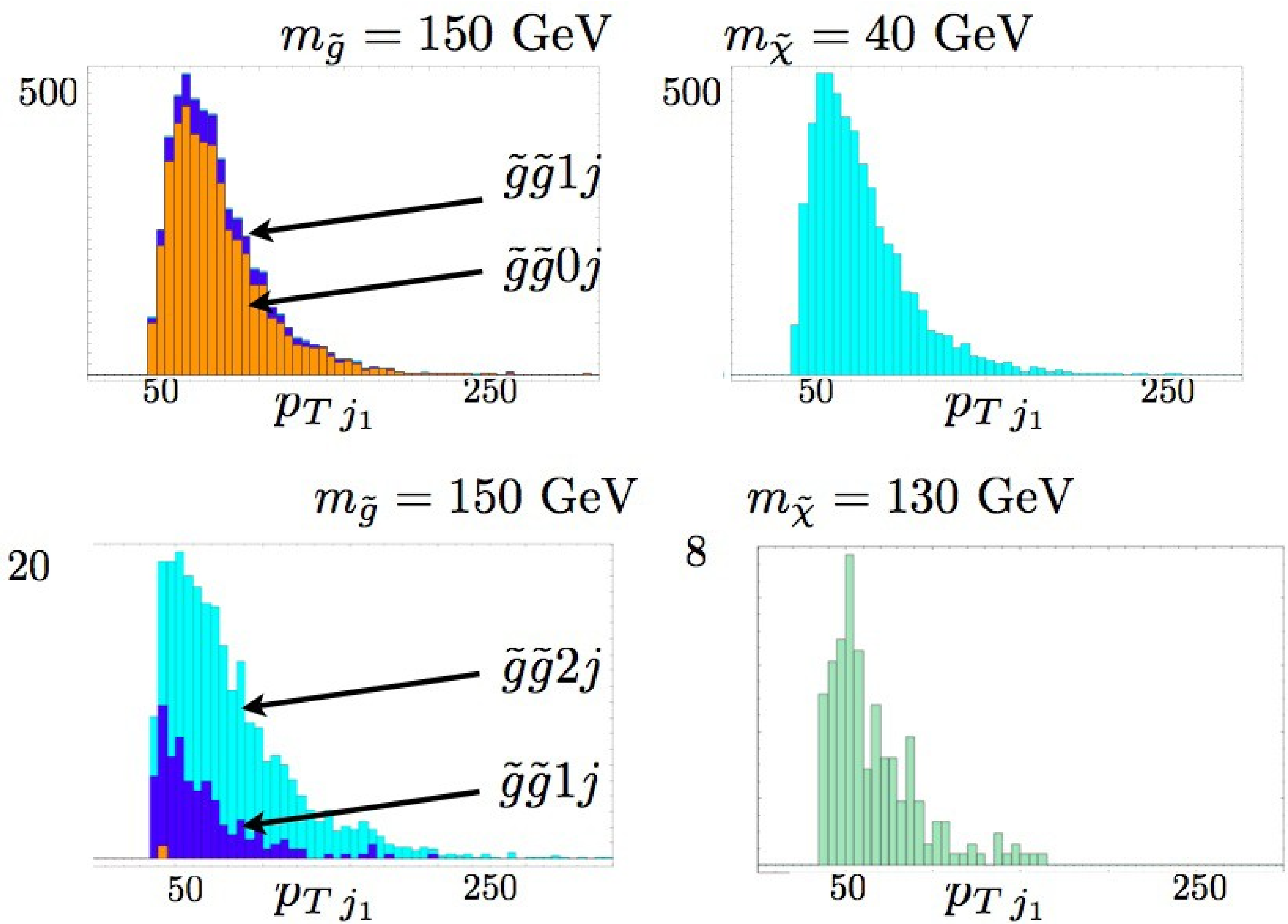
Special difficulty when decay products are soft (nearly degenerate masses):

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



# Gluinos + jets (cont.)

Matched    Unmatched

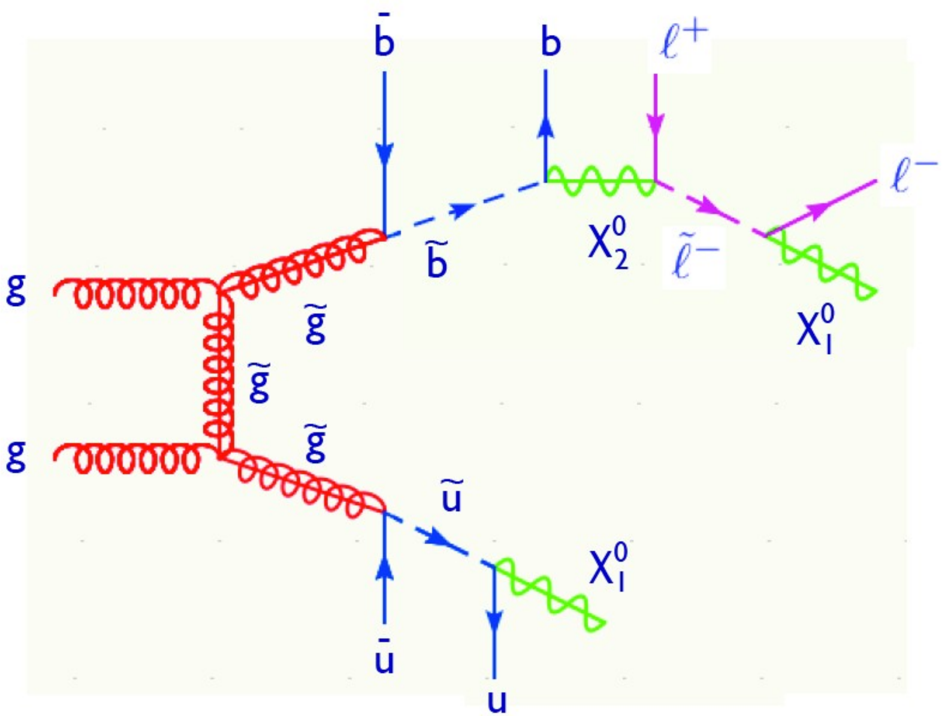



Tevatron, after 2-jet and missing $E_T$ cuts

# 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

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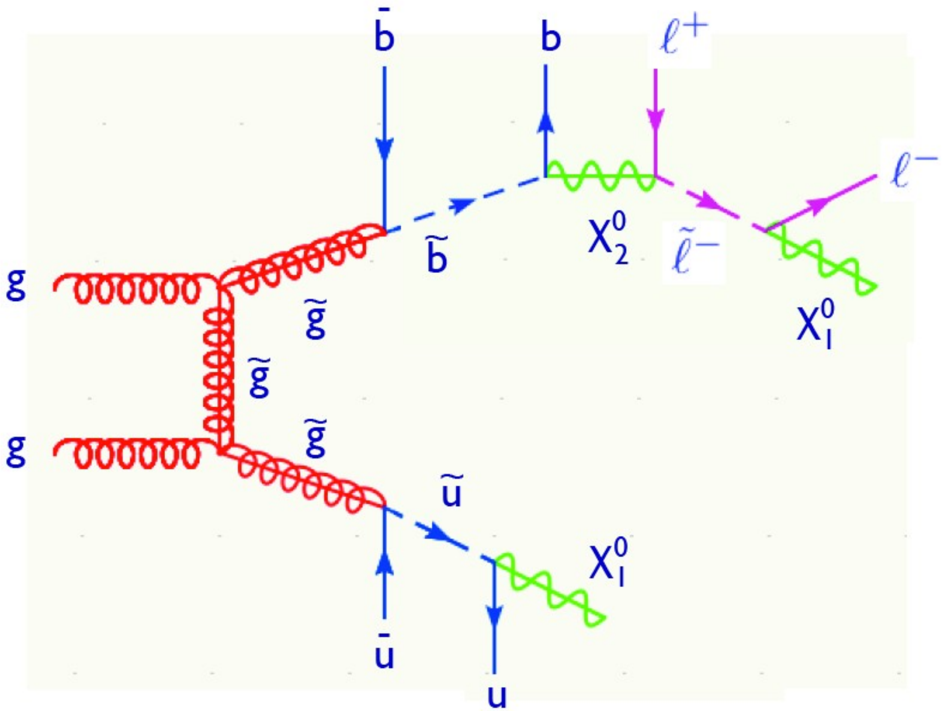


1. Full matrix element with all correlations between production and decay
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Example simplification: factorize process before scalar decay

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

Decay scalars at event level with MG or BRIDGE

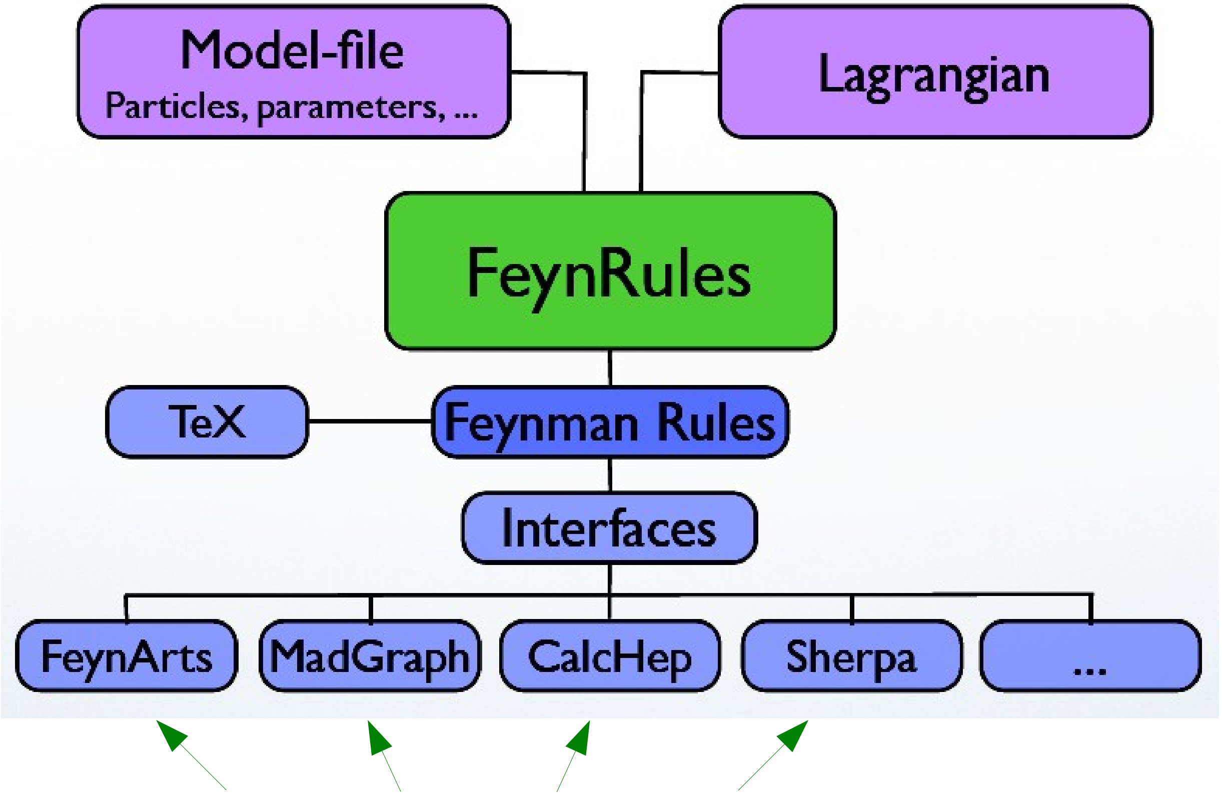
[P. Meade, M. Reece, 2007]

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

# FeynRules

[C. Duhr + MC collaborators]

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




Interfaces available

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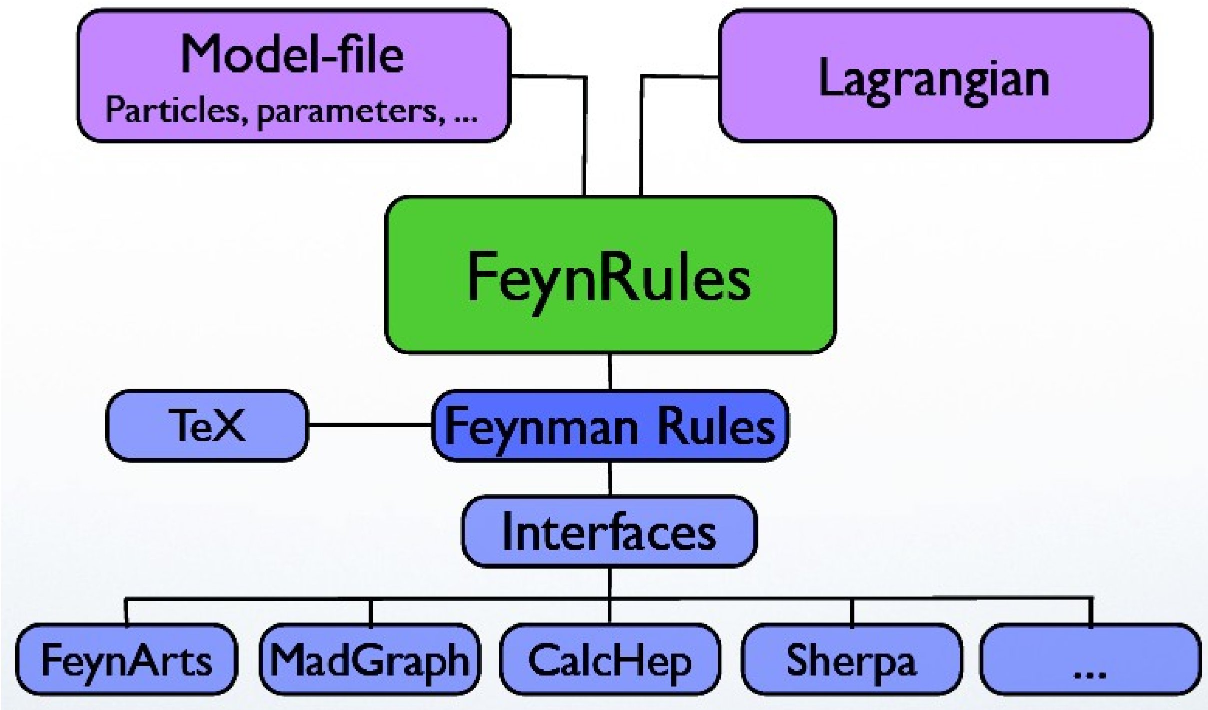


$$\begin{aligned}\kappa^{-1}\mathcal{L}_{\mathrm{F}}^{\vec{n}}(\kappa) &= \frac{1}{2}\Big[(\tilde{h}^{\vec{n}}\eta^{\mu\nu} - \tilde{h}^{\mu\nu,\vec{n}})\overline{\psi}i\gamma_\mu D_\nu\psi \\ &\quad - m_\psi\tilde{h}^{\vec{n}}\overline{\psi}\psi + \frac{1}{2}\overline{\psi}i\gamma^\mu(\partial_\mu\tilde{h}^{\vec{n}}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

...

Interfaces available

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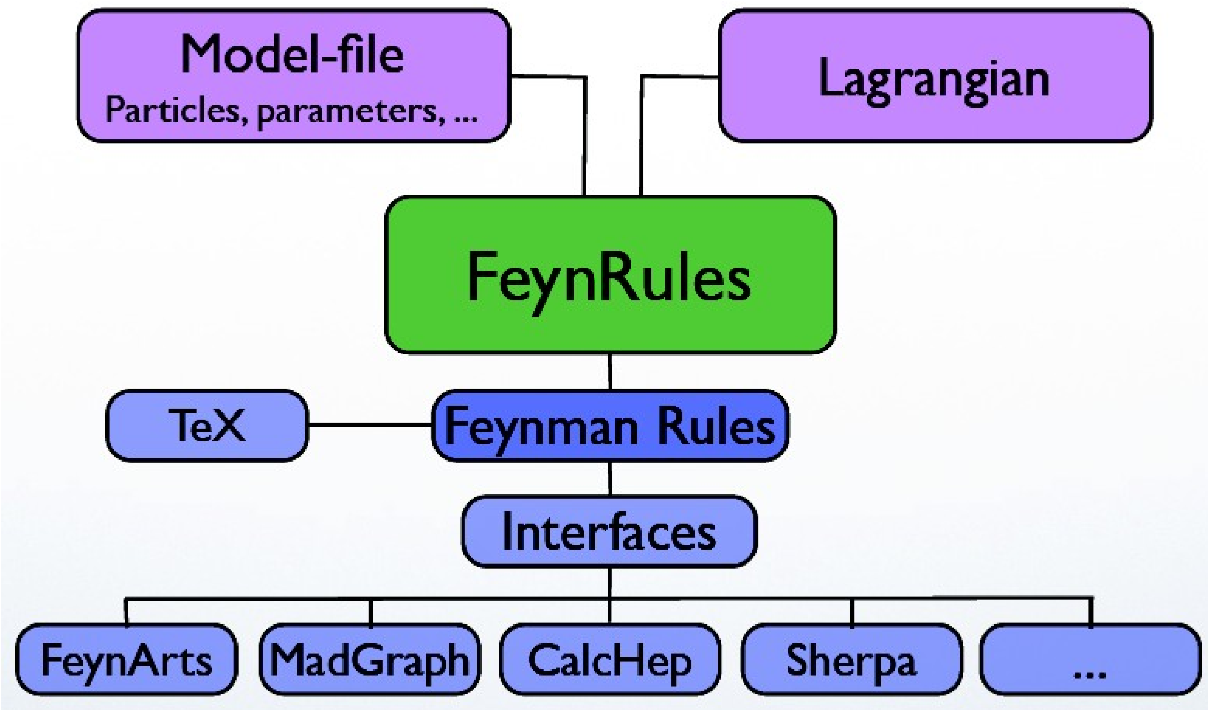


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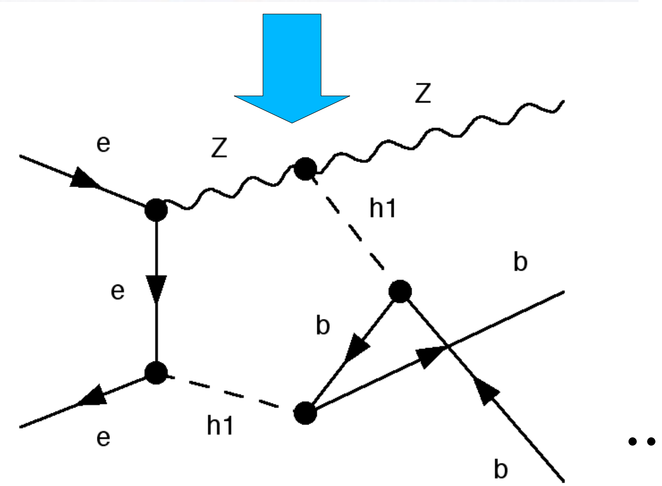


Interfaces available

# 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

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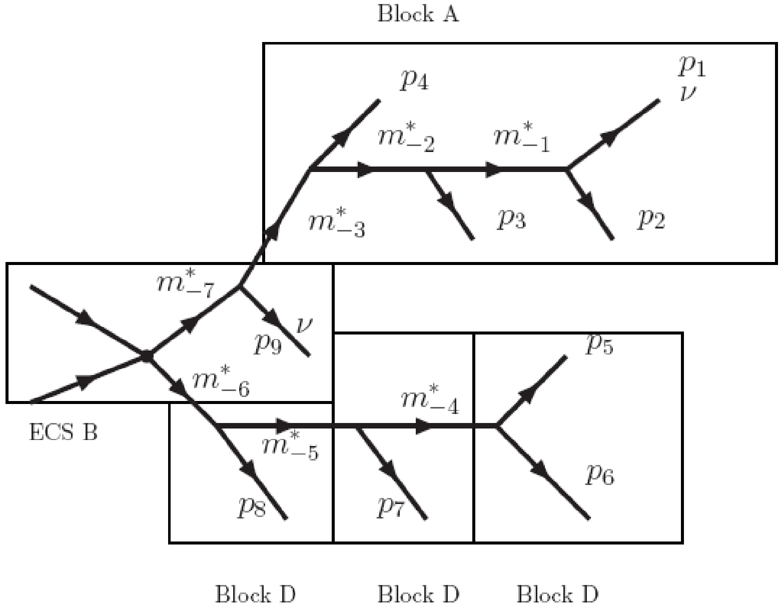


Phase space integration using automatic change to variables aligned with peaks

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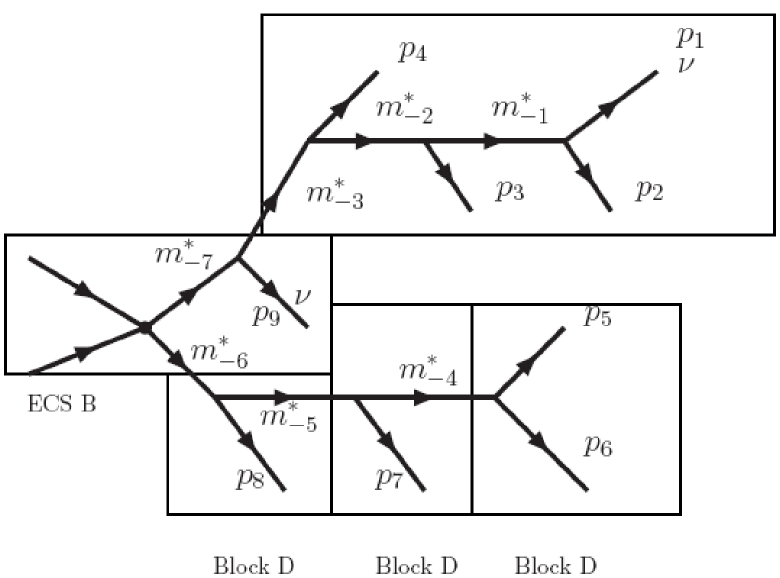
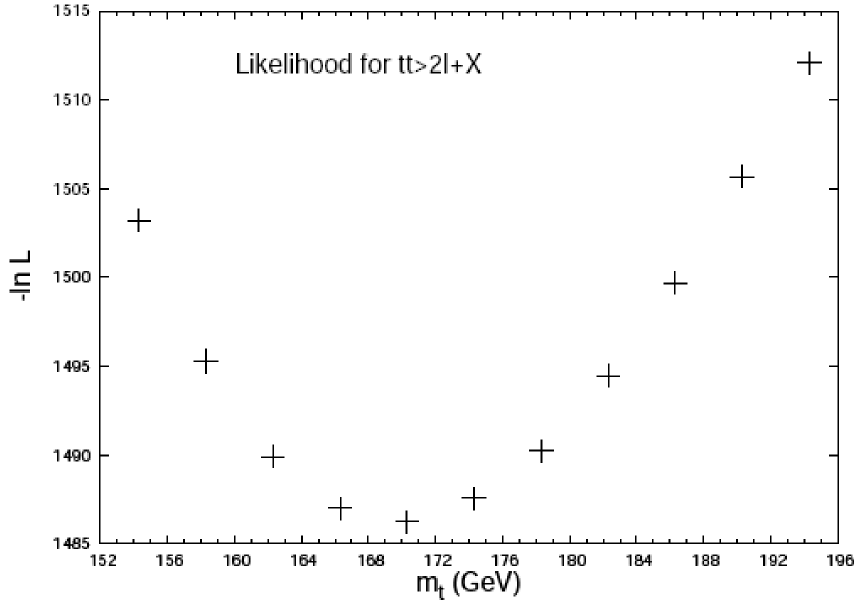



Phase space integration using automatic change to variables aligned with peaks




Find likelihood for model parameters (here top mass)

# Automatic dipole subtraction

[R. Frederix, N. Greiner]

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

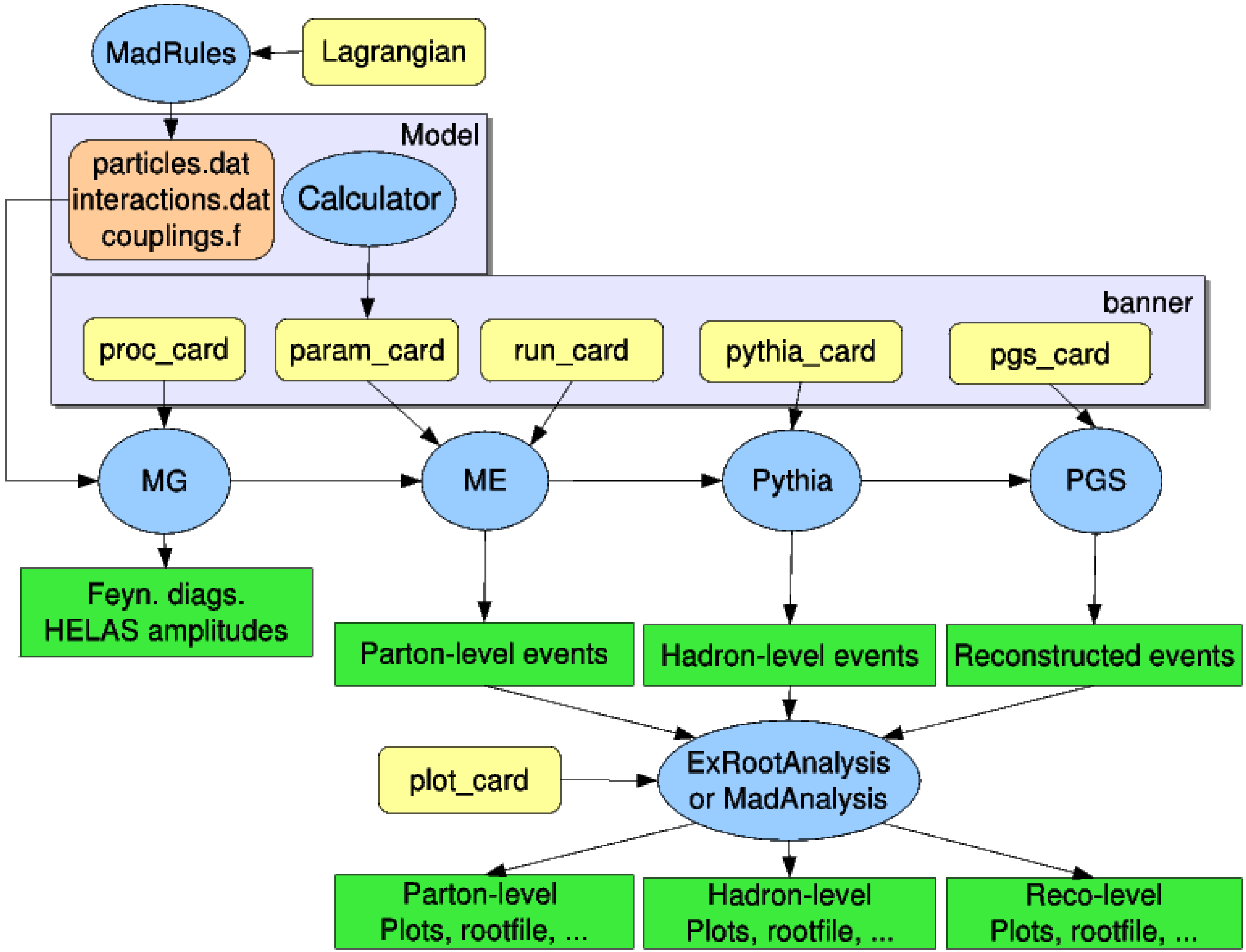
- Goal: Automatic divergence subtraction for reals of any NLO calculation
  - Catani-Seymour subraction scheme
  - Both for SM and BSM
  - Compatible also with MG standalone
- Alpha version (FS dipoles) working
  - IS-FS and IS-IS dipoles in bugfix mode

# Conclusions

- LHC poses new challenges to the MC community
- Continuous developments and ongoing projects
- MadGraph/MadEvent approach:
  - Building a community
    - Web based : public clusters with personal DB's, Twiki, 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 (staged) simulation chain via web + Grid version
    - SM and BSM : signal and backgrounds (including multi-jet samples with ME/PS merging)
    - TH and EXP tools : StandAlone, ExRootAnalysis, MatchChecker, MadWeight,...

# 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

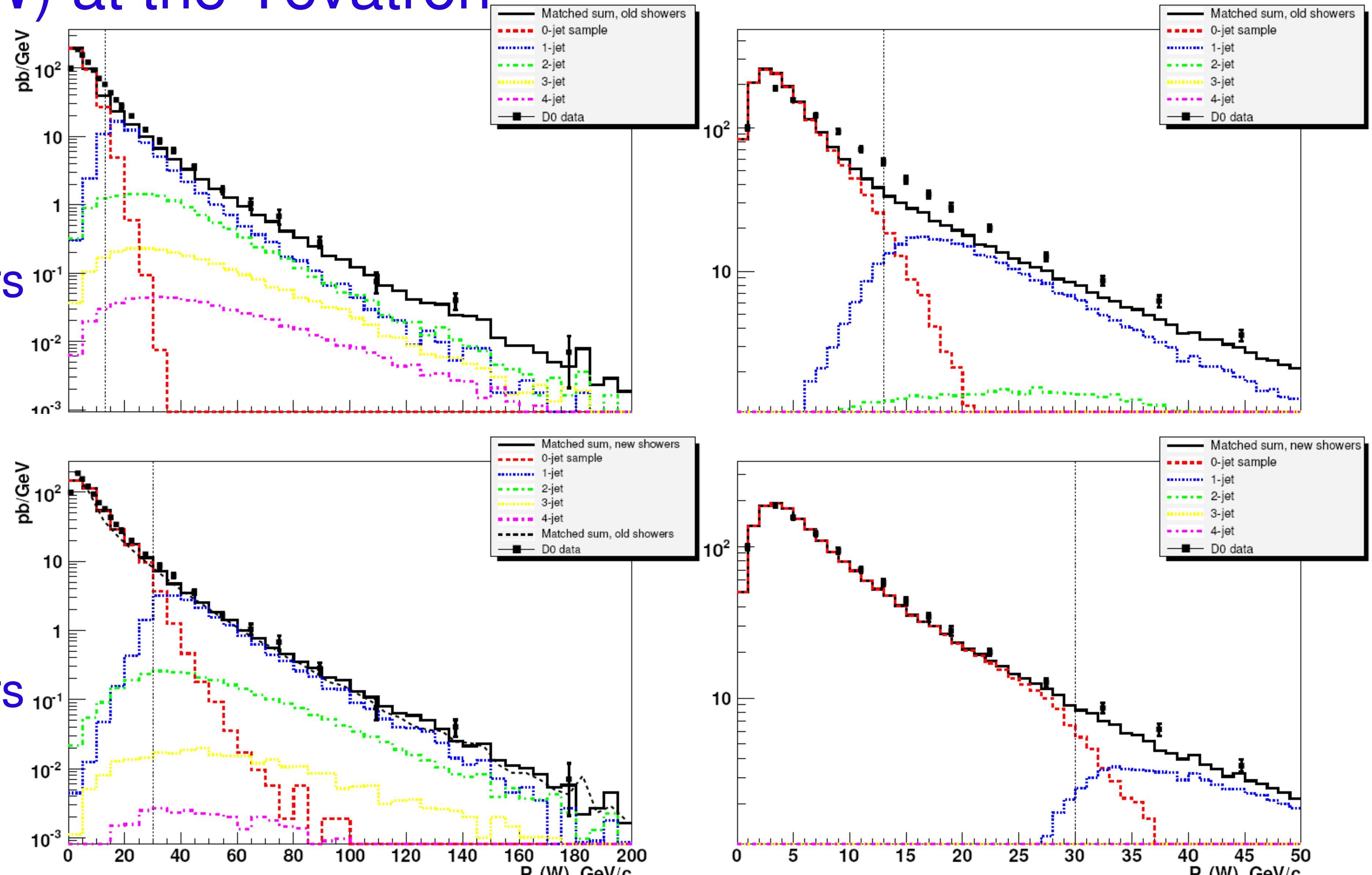
- Keep/reject event based on $k_T$ of hardest shower emission (as reported by Pythia)
- Highest multiplicity treatment as in CKKW, use min dparton as cutoff
- No jet clustering
- No need of "fiducial region", can use $k_T^{match} = d_{cut}^{ME}$
- Need similar kT definitions in ME and PS (only "new",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

# Difference between Pythia showers

## $p_T(W)$ at the Tevatron

"Old" Pythia showers

"New" Pythia showers

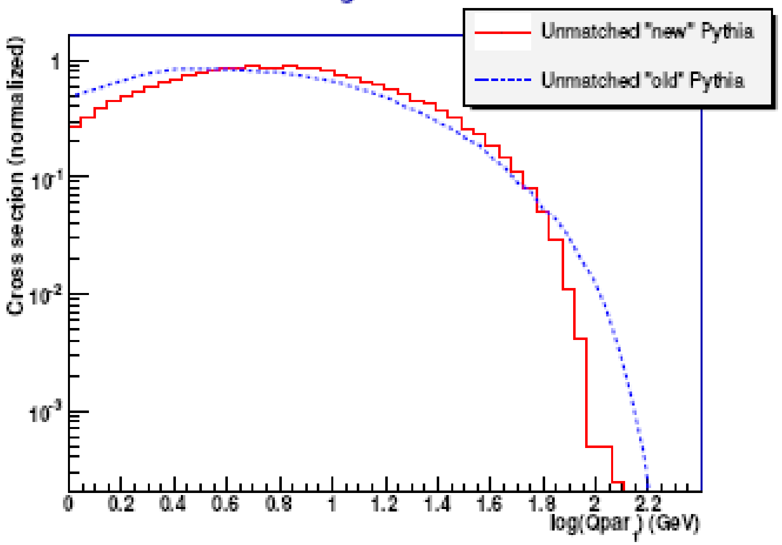



Tail well described by both (given by ME) but head quite different

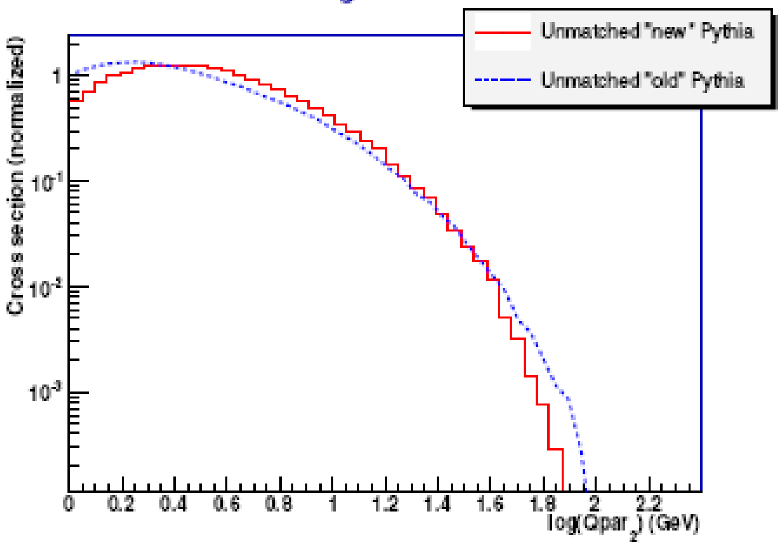
# Comparisons between old and new Pythia showers

Differential jet rates in $W$ production at the Tevatron

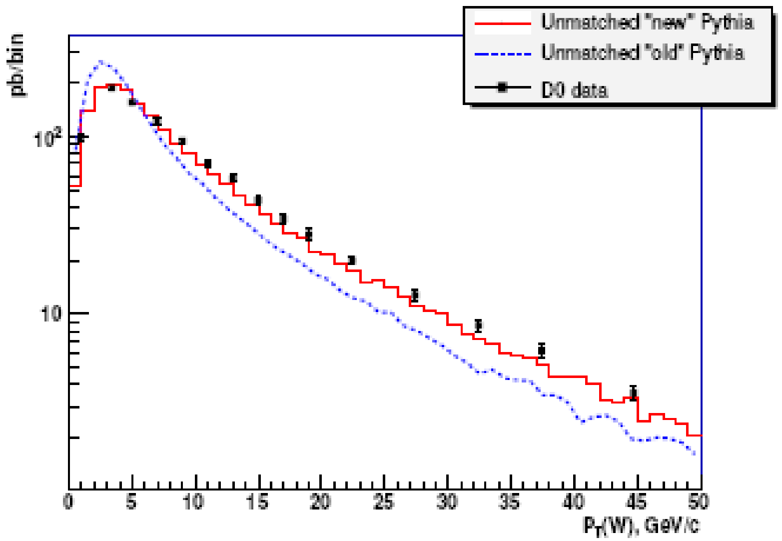
$0 \longrightarrow 1$ jet rate

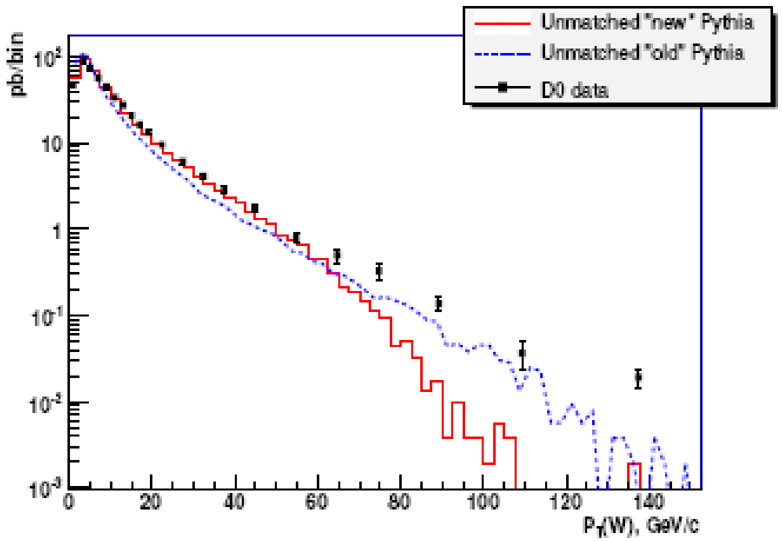



$1 \longrightarrow 2$ jet rate




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



# Model building with FeynRules

- Step 1: Add all the parameters of the new sector to the model file:

```
f1 == {Value -> 600,
       InteractionOrder -> {QED, -1}},

l1 == {Value -> 0.25,
        InteractionOrder -> {QED, 2}},

ca == {Value -> 0.896242},
```

ca: Cosine of the mixing angle

$$L = -\frac{1}{2}(D_\mu \Phi)^\dagger (D_\mu \Phi) - \frac{\lambda_0}{8}(\Phi^\dagger \Phi - f_0^2)^2 - \frac{1}{2}(\partial_\mu H)^2 - \frac{\lambda_1}{8}(2 f_1 H - \Phi^\dagger \Phi)^2$$

Slides from C. Duhr, MC4BSM 2008

# Model building with FeynRules

- **Step II:** Add all the particles of the new sector to the model file:

Mass eigenstate

```
S[1] == {
  ClassName -> h1,
  SelfConjugate -> True,
  Mass -> {Mh1, 78.5}},
```

```
S[2] == {
  ClassName -> H,
  SelfConjugate -> True,
  Unphysical -> True,
  Definitions -> {H -> sa h1 +ca h2}}
```

Mixing

$$L = -\frac{1}{2}(D_\mu\Phi)^\dagger(D_\mu\Phi)$$
$$-\frac{\lambda_0}{8}(\Phi^\dagger\Phi - f_0^2)^2$$
$$-\frac{1}{2}(\partial_\mu H)^2$$
$$-\frac{\lambda_1}{8}(2f_1 H - \Phi^\dagger\Phi)^2$$

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# Model building with FeynRules

- Step III: The lagrangian describing the new sector (Unitary gauge)

```
Φ = {0, h + f0}

LHill = -1 / 2 del[H, mu] ^2 -
  l1 / 8 (2 f1 H - HC[Φ].Φ) ^2
```

$$-\frac{1}{2}\,\partial_{\mathrm{mu}}(H)^2 - \frac{1}{8}\,\mathrm{l1}\left(2\,\mathrm{f1}\,H - \Phi^{\dagger}.\Phi\right)^2$$

$$L = -\frac{1}{2}(D_\mu\Phi)^\dagger(D_\mu\Phi)$$

$$-\frac{\lambda_0}{8}(\Phi^\dagger\Phi - f_0^2)^2$$

$$-\frac{1}{2}(\partial_\mu H)^2$$

$$-\frac{\lambda_1}{8}(2f_1 H - \Phi^\dagger\Phi)^2$$

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# Phenomenology with FeynRules

- The results obtained by FeynRules can be easily exported to FeynArts:

```
WriteFeynArtsOutput["HillModel.mod",{LSM + LHill}, FlavorExpand → SU2W]
```

− − − FeynRules interface to FeynArts − − −

C. Duhr, 2007

- This produces a FeynArts model-file which can be read by FeynArts.

```
topo = CreateTopologies[1, 2 → 3,
   ExcludeTopologies → Internal];
Amp = InsertFields[topo,
        {F[2, {1}], -F[2, {1}]} → {V[2], F[4, {3}], -F[4, {3}]},
        Model → HillModel];
```

- The results obtained by FeynRules can be easily exported toMC generators:

```
WriteMGOutput[LSM + LHill]
```

− − − FeynRules interface to MadGraph − − −

C. Duhr, M. Herquet

- Etc.

Slides from C. Duhr, MC4BSM 2008