Simulation tools for the LHC

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The LHC is on track!

but where are we heading...?

Are we ready?

NLO

Exp-TH communication

Very exotic models

Exotic models

Effective theories

DECAY CHAINS

MATRIX ELEMENTS

Advanced analysis techniques

Multi-jet samples

Cluster/Grid computing

Merging ME/PS

DECAY PACKAGES

Testing / robustness

User friendliness

Yes! (but still work to do)

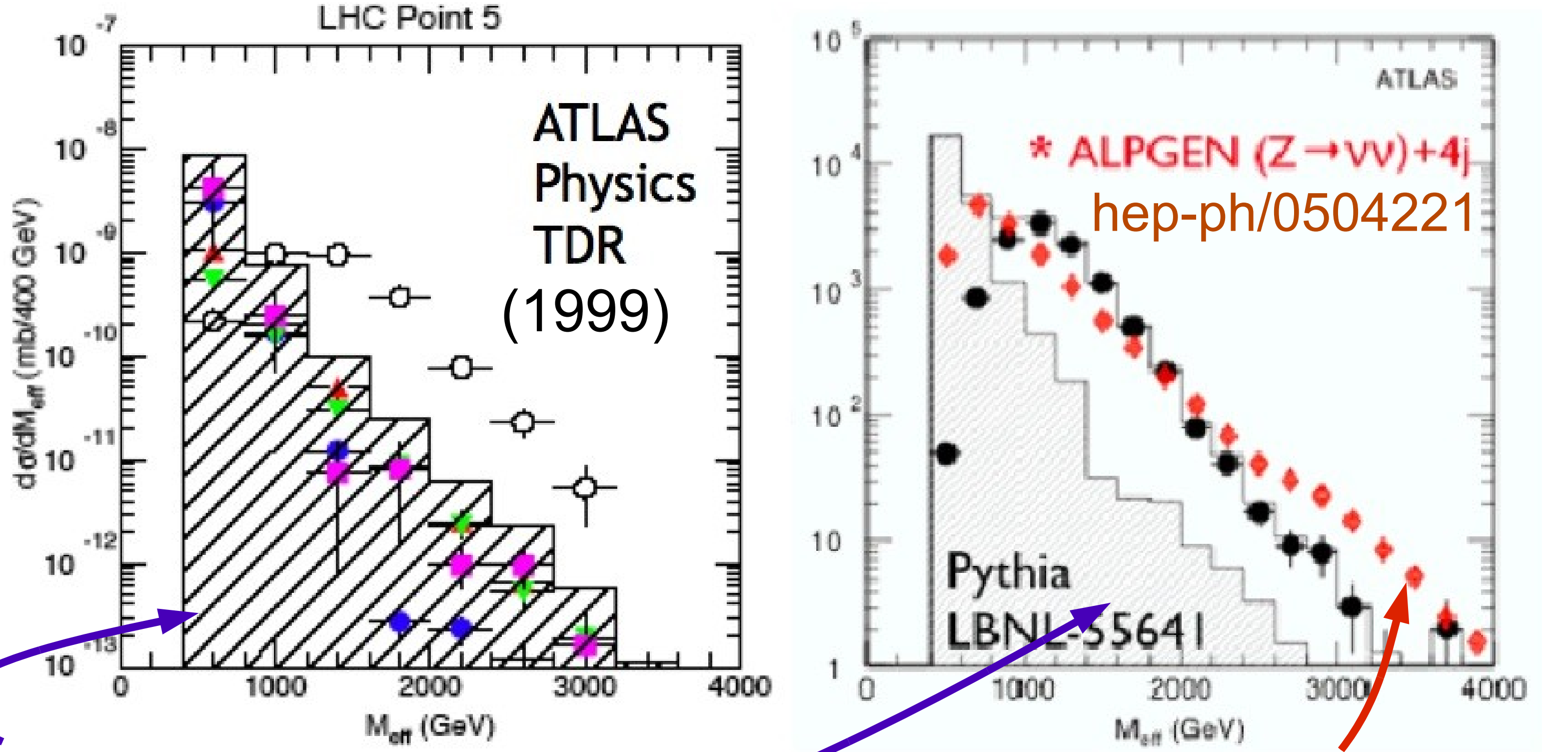
Amazing progress in simulations in recent years!

Some selected topics:

- Automatic LO matrix element + parton shower matching (SM + BSM)
- Multi-parton NLO calculations
- NLO calculations + parton showers
- Public/general fast detector simulation
- BSM: From Lagrangean to simulation
- And at the end: Model communication and model building approaches!

QCD radiation in SM backgrounds

Proper simulation of QCD radiation necessary in SM backgrounds



All SM backgrounds
(by parton shower MC)

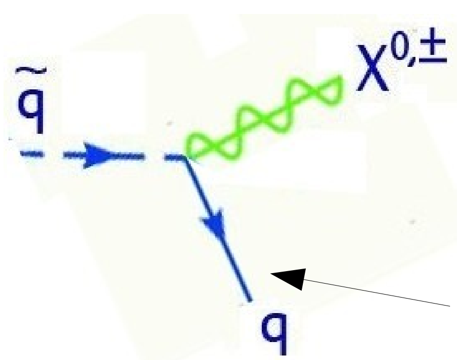
Z+4 jets background only
(by matrix element MC)

Same SUSY signal, after missing E_T- and 4 jet-cuts

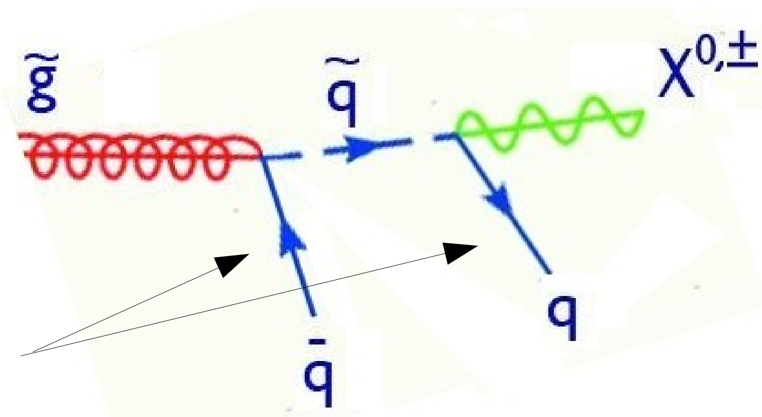
QCD radiation in BSM production

[arXiv:0810.5350]

- What about BSM production?
  - Hard jets from decays
  - Large masses → Standard simulation (parton shower) expected to be more accurate
- Example: Gluino-squark separation



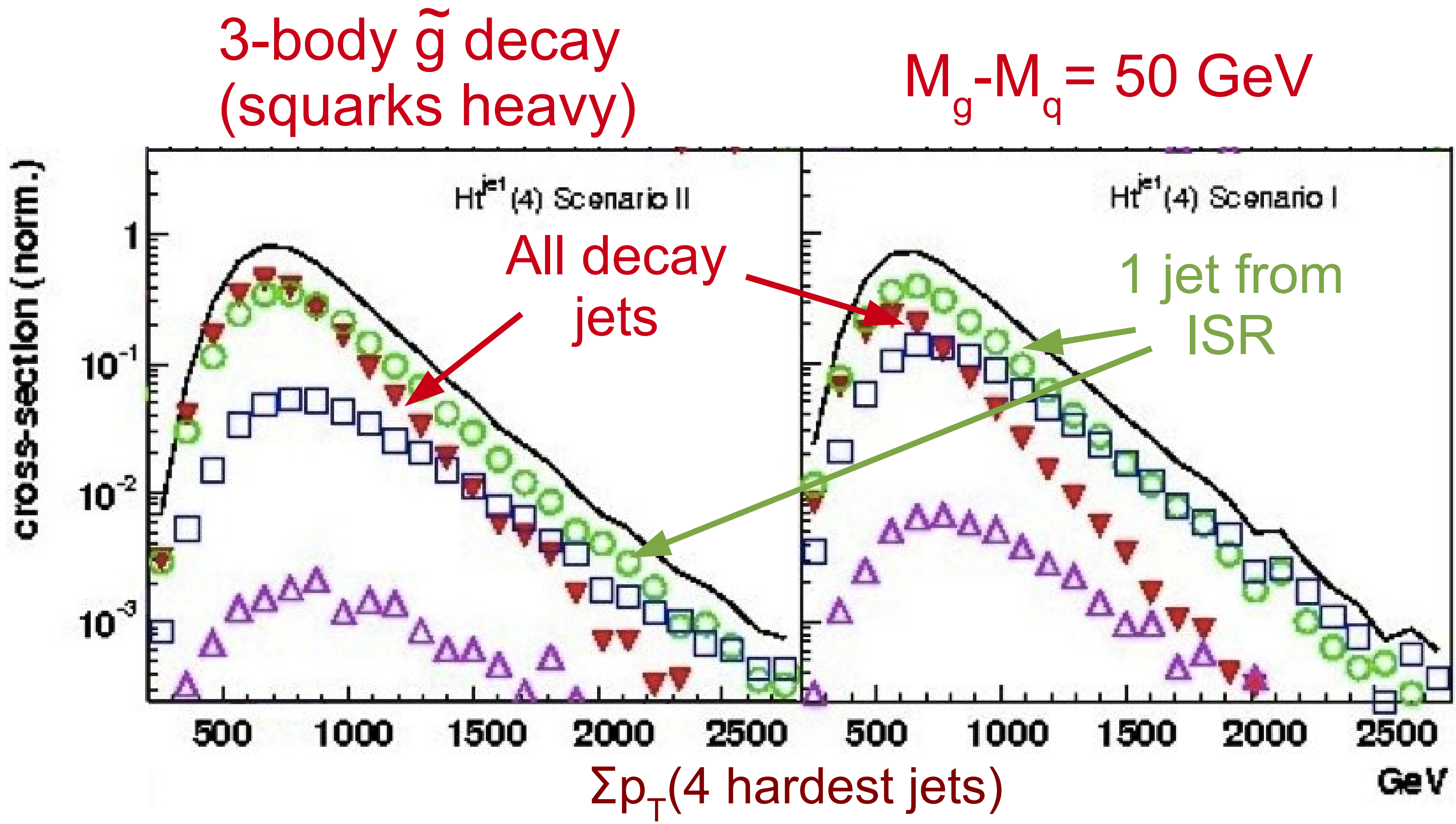
Differ by 1 jet – easy to tell the difference?



QCD radiation in BSM production

600 GeV gluino pair production

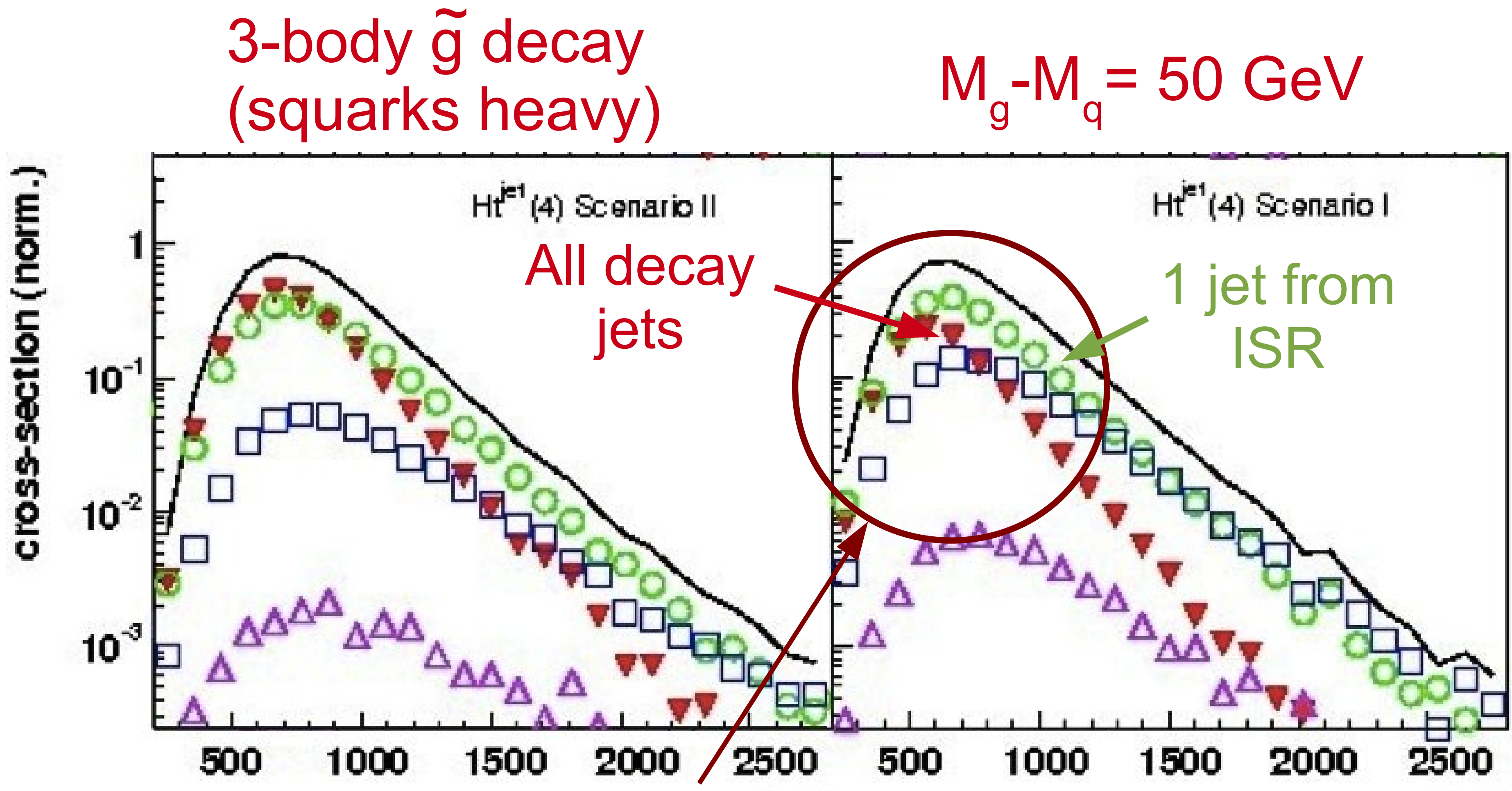
ISR = Initial state radiation



QCD radiation in BSM production

600 GeV gluino pair production

ISR = Initial state radiation



> 60% of events have ISR jet among 4 hardest jets!

QCD radiation in BSM production

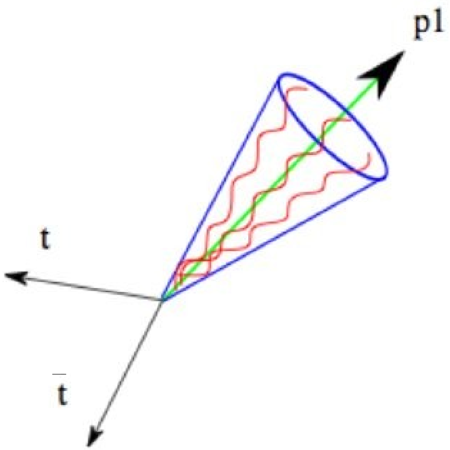
- Especially for small mass splittings – need proper QCD simulation
- Standard Pythia/Herwig doesn't do the job
- Need Matrix Element - Parton Shower matching
- MadGraph/MadEvent + Pythia can do automatic matching for SM or any BSM models!

Matching of ME and PS

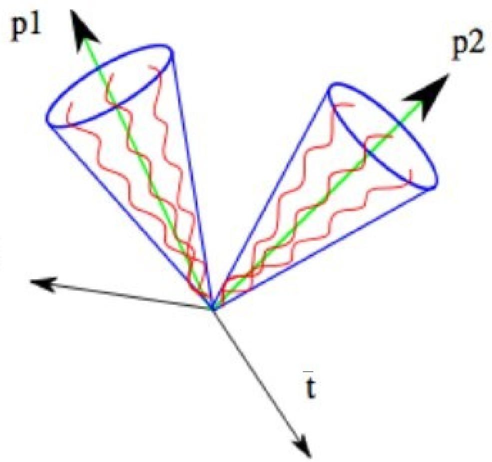
- The matrix element and parton shower formulations apply to different regions of phase space
  - Parton showers are necessary in the regions where radiation is soft or collinear
  - Matrix elements are necessary for description of high-p_T, widely separated jets
- To correctly describe full phase space, they must be combined
- Criteria:
  - No overcounting or undercounting of radiation
  - Reproduce the inclusive cross section
  - Smooth distributions in all kinematical observables

Matching of ME and PS

Double-counting between multiplicity samples



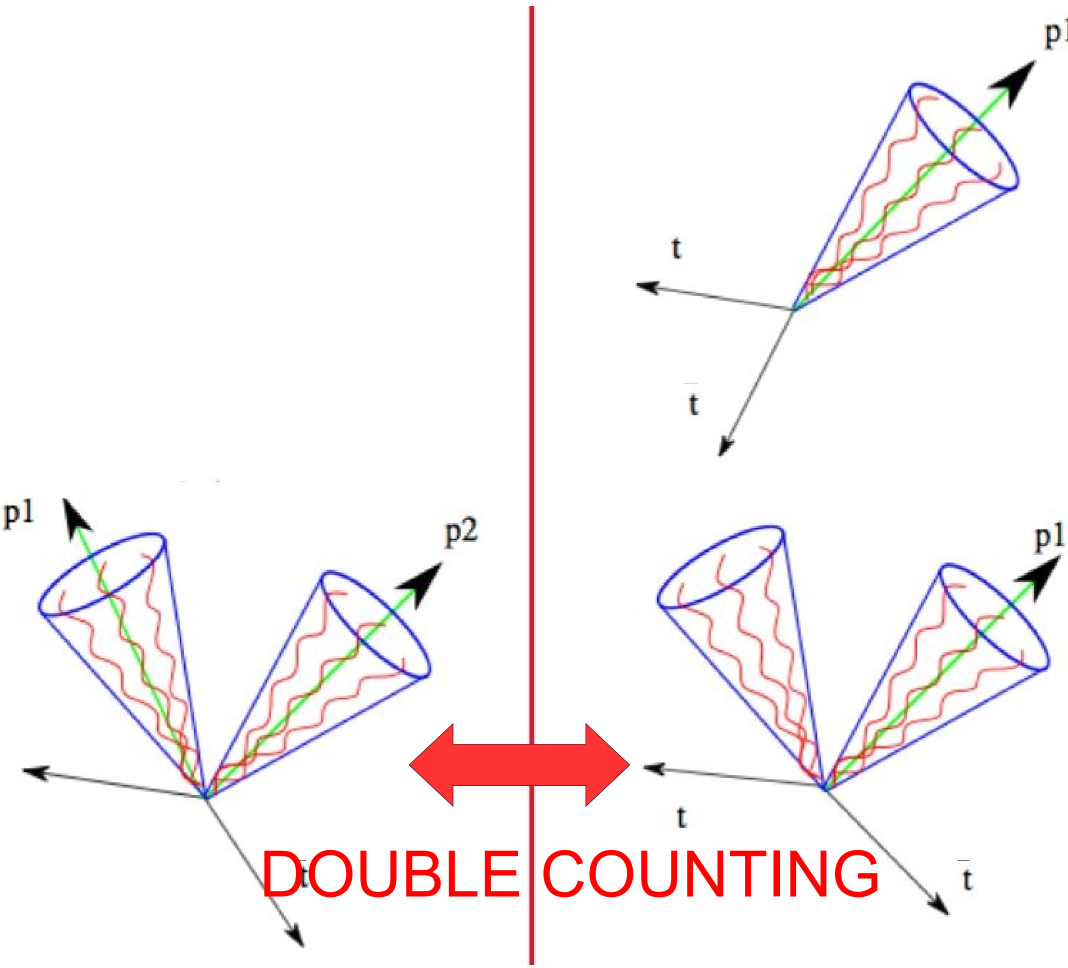
1-parton sample
(no hard PS radiation)



2-parton sample
(no hard PS radiation)

Matching of ME and PS

Double-counting between multiplicity samples



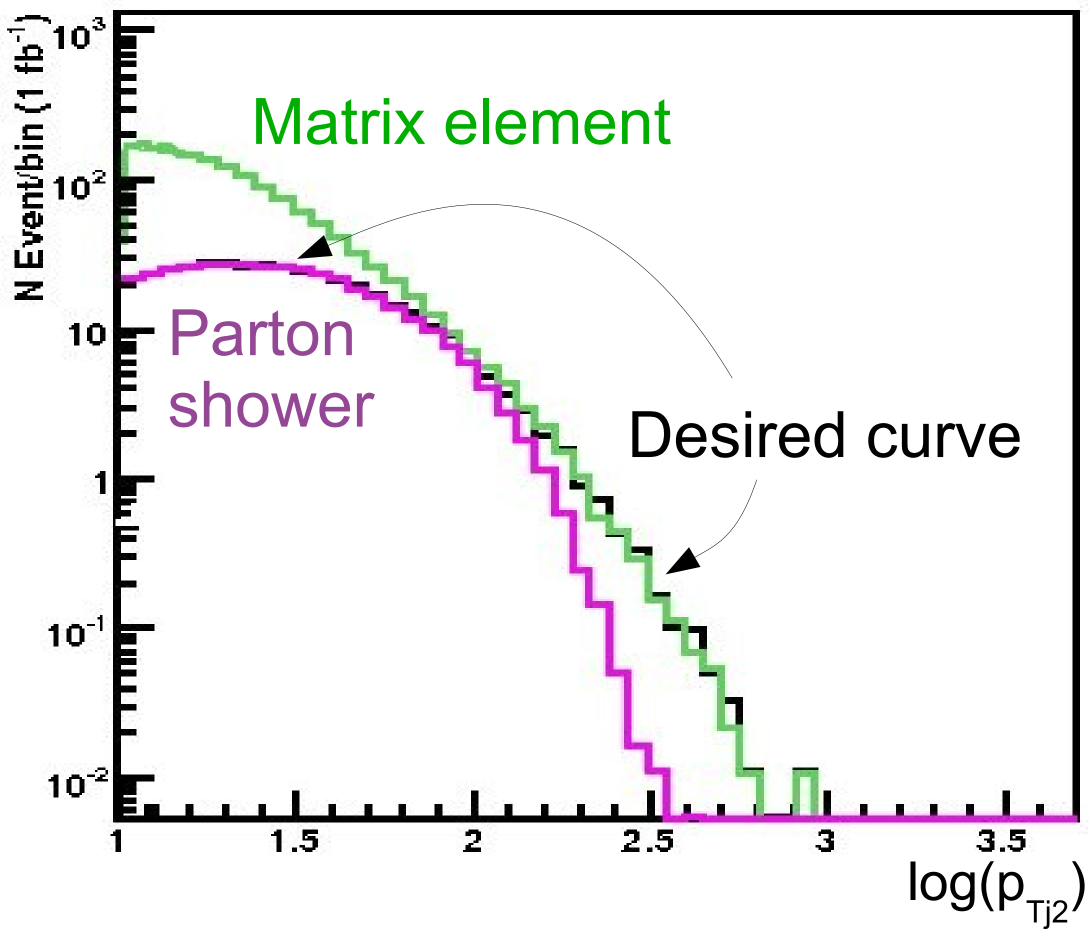
1-parton sample
(no hard PS radiation)

2-parton sample
(no hard PS radiation)

1-parton sample
+ hard PS radiation

Matching of ME and PS

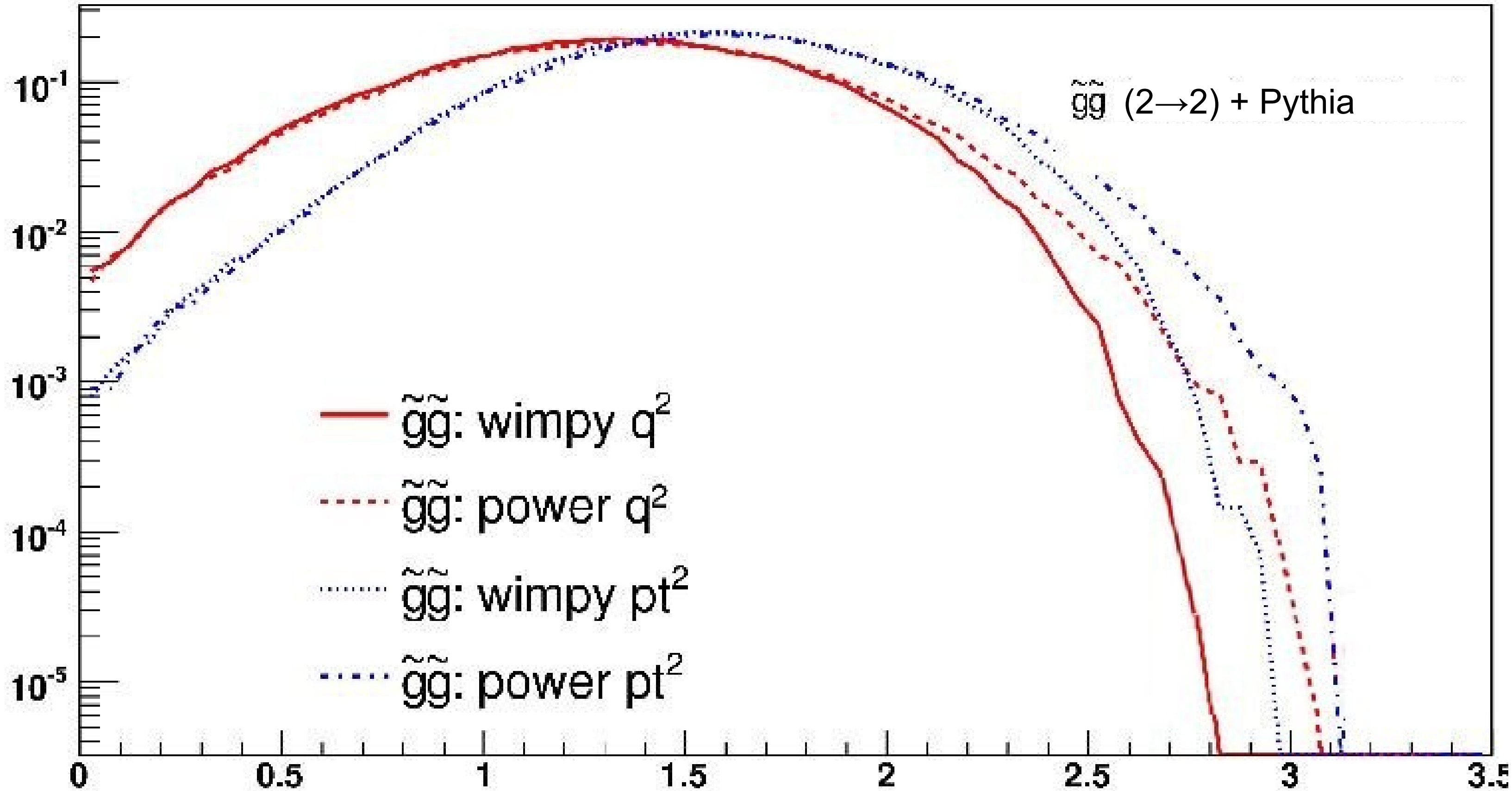
Reglarization of matrix element divergence



2nd QCD radiation jet in top pair production at the LHC

Shower parameter dependence

QCD radiation for different Pythia shower params

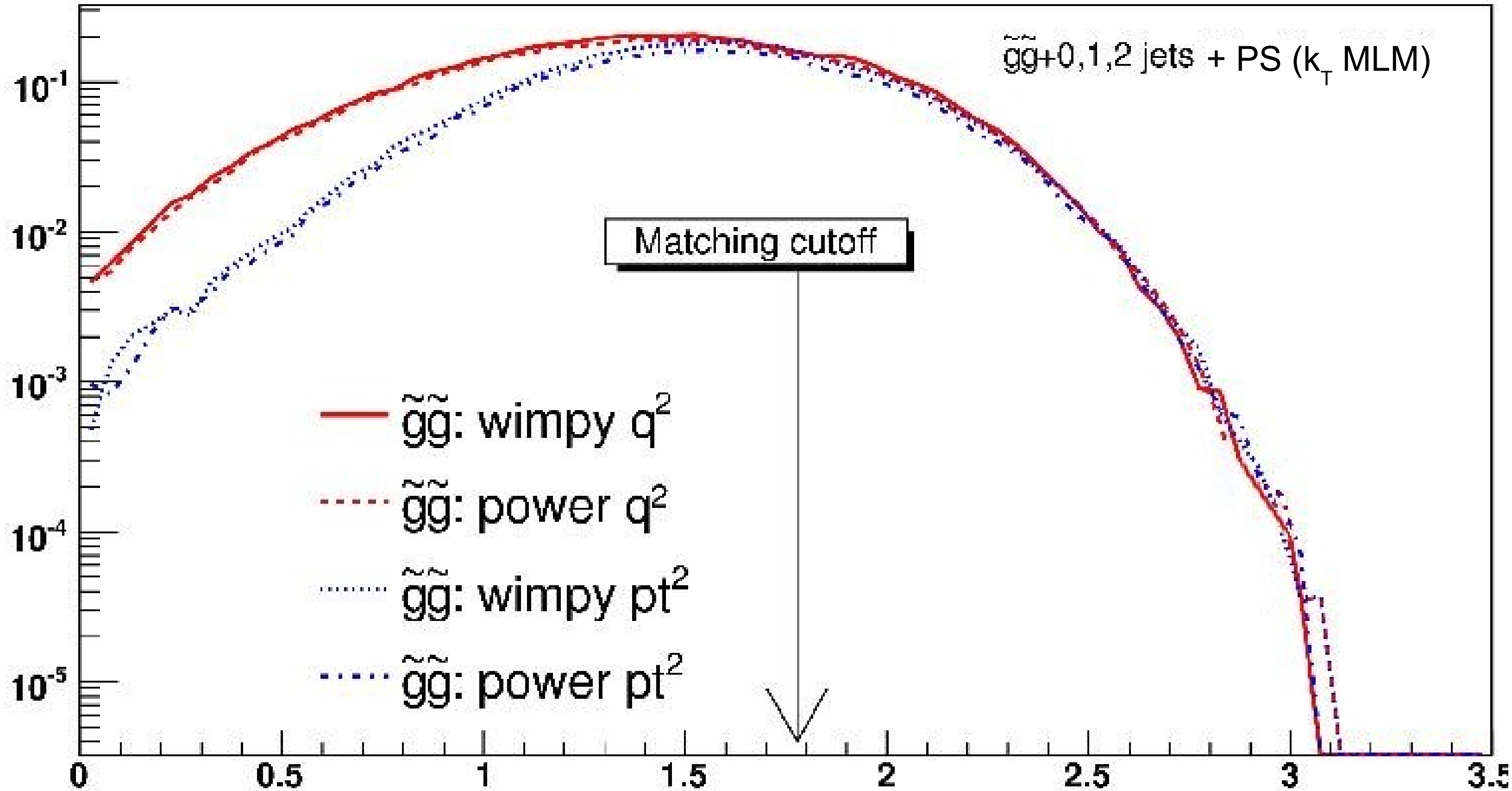


log(p_T for 2[nd] radiated jets) (GeV)

600 GeV gluino pair production at the LHC

Shower parameter dependence

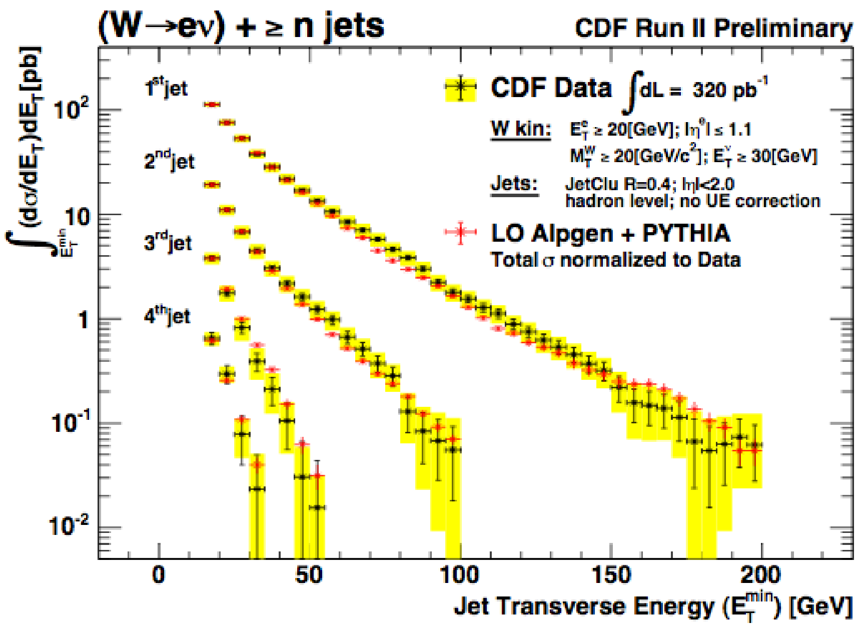
QCD radiation after matching with MG/ME

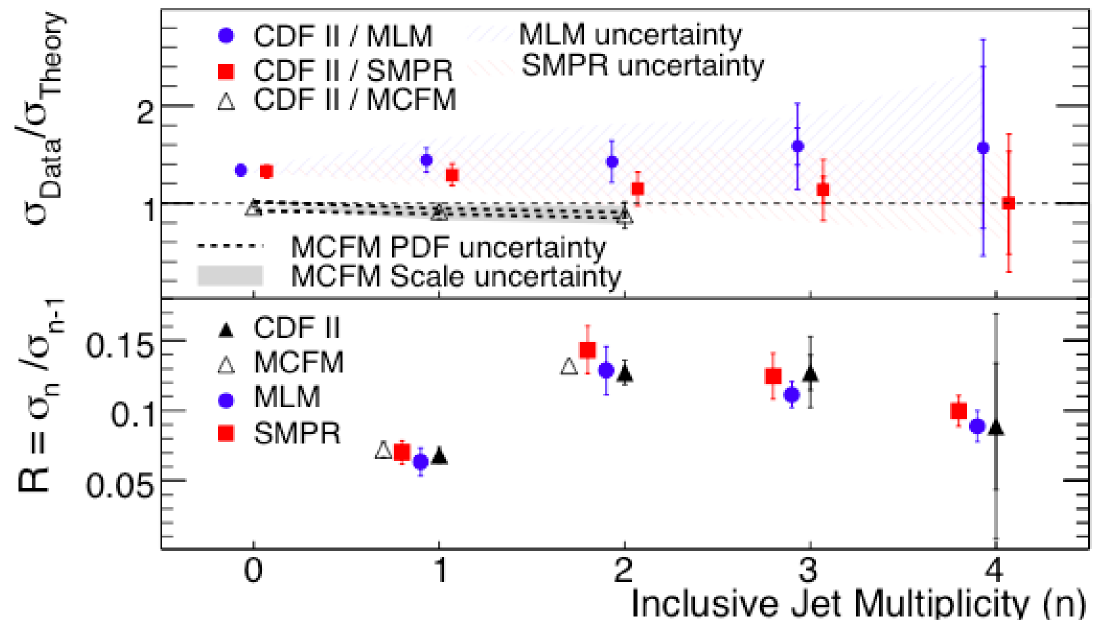


log(p_T for 2nd radiated jets) (GeV)

600 GeV gluino pair production at the LHC

Matching at the Tevatron

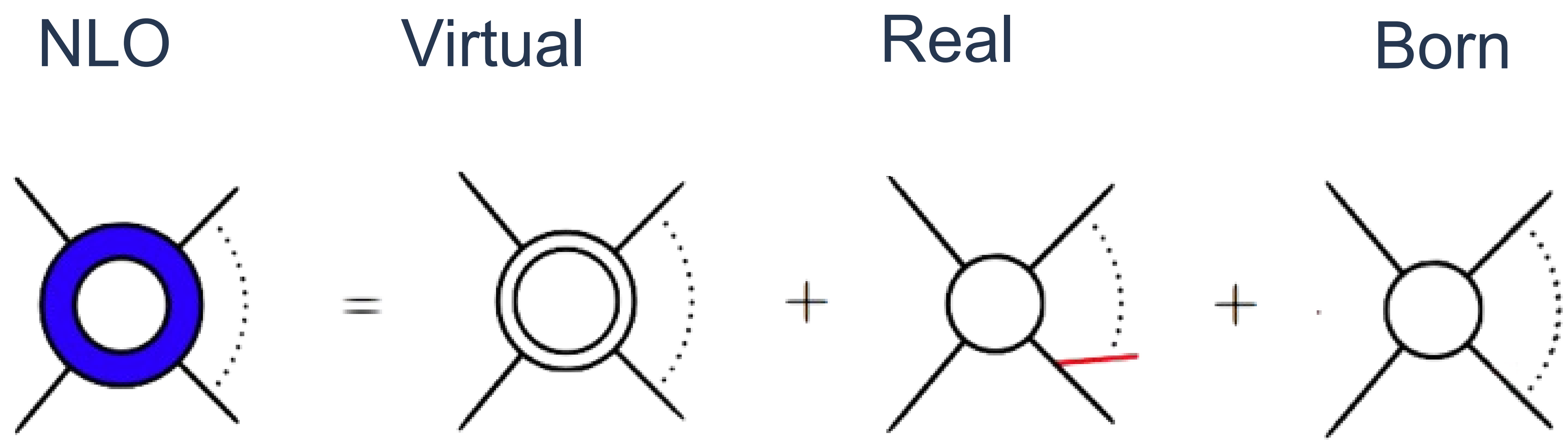




- Very good agreement in shapes (left) and in relative normalization (right).
- Different matching schemes in excellent agreement

ME-PS matching by now mature and well-tested

NLO Calculations

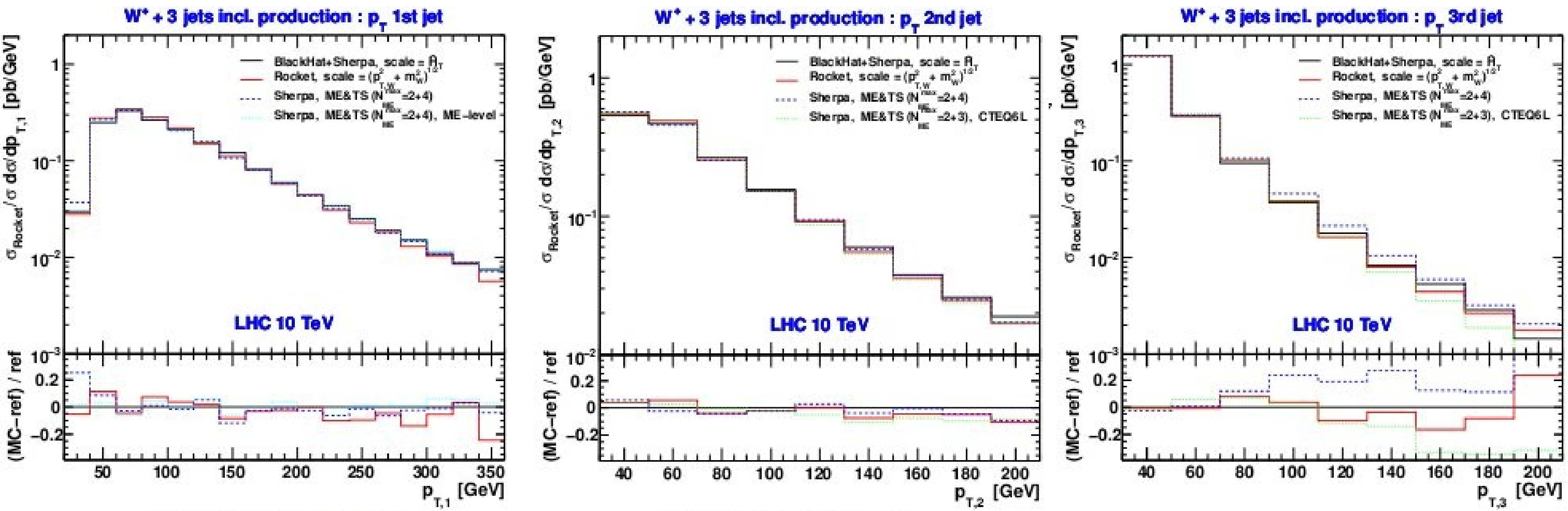


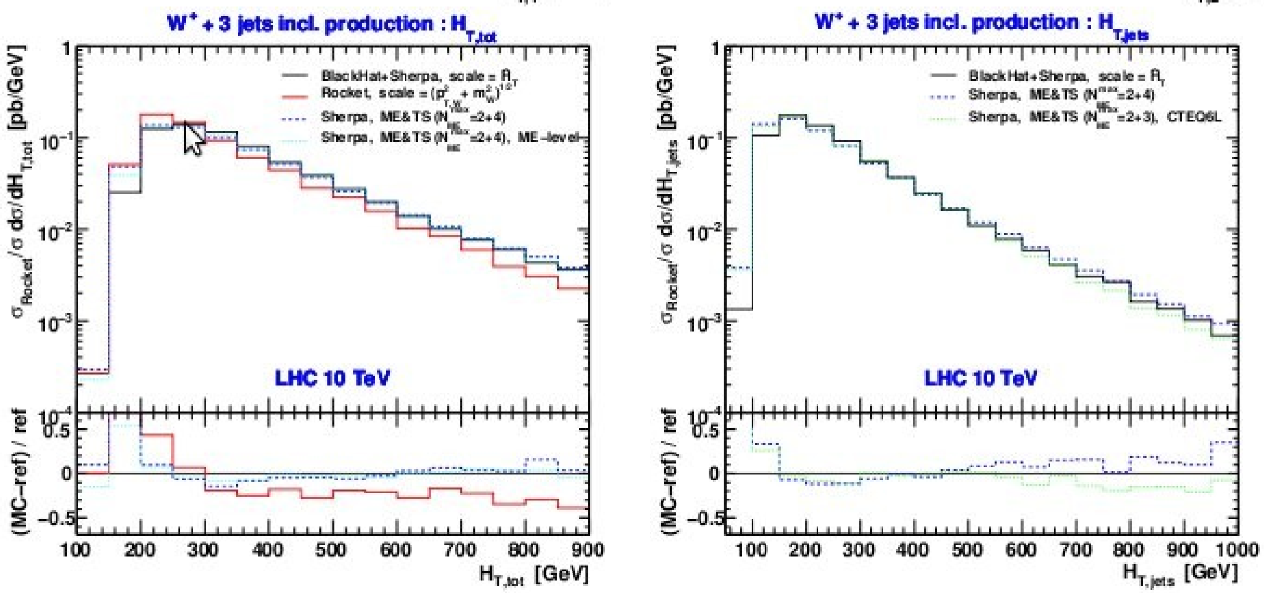
$$\sigma^{\mathrm{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

Multi-parton loop calculations

- Automatized loop calculations:
  - BlackHat: p p → W + 4 j [arXiv:1009.2338]
  - GOLEM: $q\,\bar{q}$ → 4 b [1001.4905], ZZ + 1j [0911.3181]
  - NLO MadGraph (using CutTools/OPP approach [arXiv:0711.3596])
- By-hand multi-parton loop calculations:
  - ROCKET: p p → W + 3 j [arXiv:0901.4101]
- Comparison (BlackHat + Rocket + Sherpa CKKW)
  - 1003.1241 (sec. 12) shows excellent agreement

NLO + CKKW comparison





W+3jets, 10 TeV LHC
All curves normalized to ROCKET cross section, BlackHat used as reference.

[1003.1241]

Automatic real corrections

- Catani-Seymore dipole subtraction
  - Sherpa [arXiv:0709.2881]
  - MadDipole [arXiv:0808.2128, 1004.2905]
- FKS (Frixione, Kunszt, Signer) subtraction
  - MadFKS [arXiv:0908.4272]
  - Used for MC@NLO
- Work for both SM and BSM

NLO + parton showers

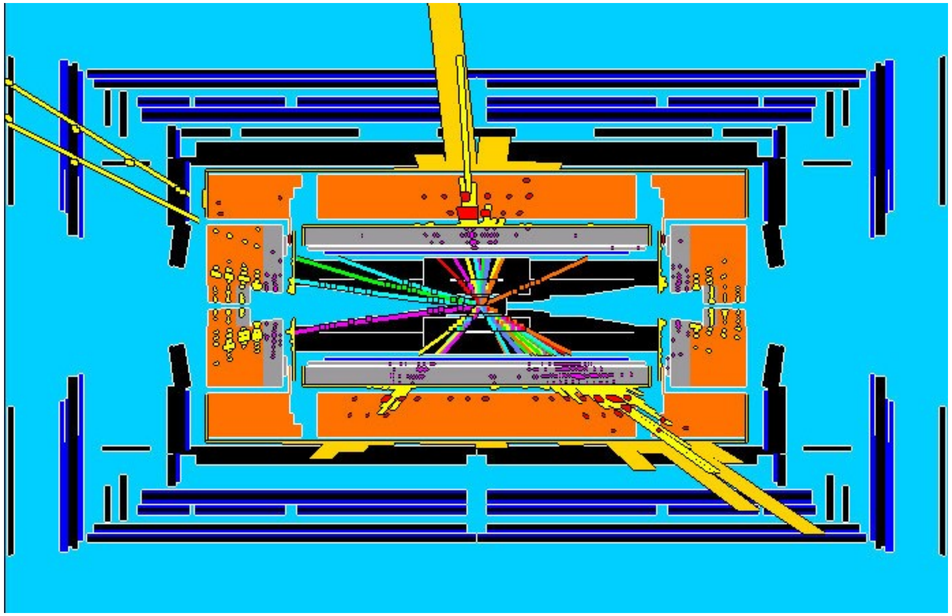
Two approaches:

- MC@NLO: Counterterms for parton shower
  - Implemented processes: Higgs boson, single vector boson, vector boson pair, heavy quark pair, single top, Drell-Yan, Higgs+W/Z (with Herwig 6.5)
  - Now also with Pythia (arXiv:1002.4293)
  - Automatization under way! (Frederix, Frixione)
- POWHEG: Parton shower independent, all-posive weights
  - POWHEG BOX, allows easy implementation of new processes (arXiv:1001.2747, 1002.2581)

Detector simulation

Two main candidates for fast public semi-realistic detector simulation:

- PGS (by now all theorists' favorite)
- Delphes (new and hot)



Detector simulation

Two main candidates for fast public semi-realistic detector simulation:

- PGS (by now all theorists' favorite)
  - Works fine for most signal efficiencies (~20% or so)
  - Not as good for fakes (in particular tau), so background simulations not as great
  - Pretty slow (slow jet algoritm)

Detector simulation

Two main candidates for fast public semi-realistic detector simulation:

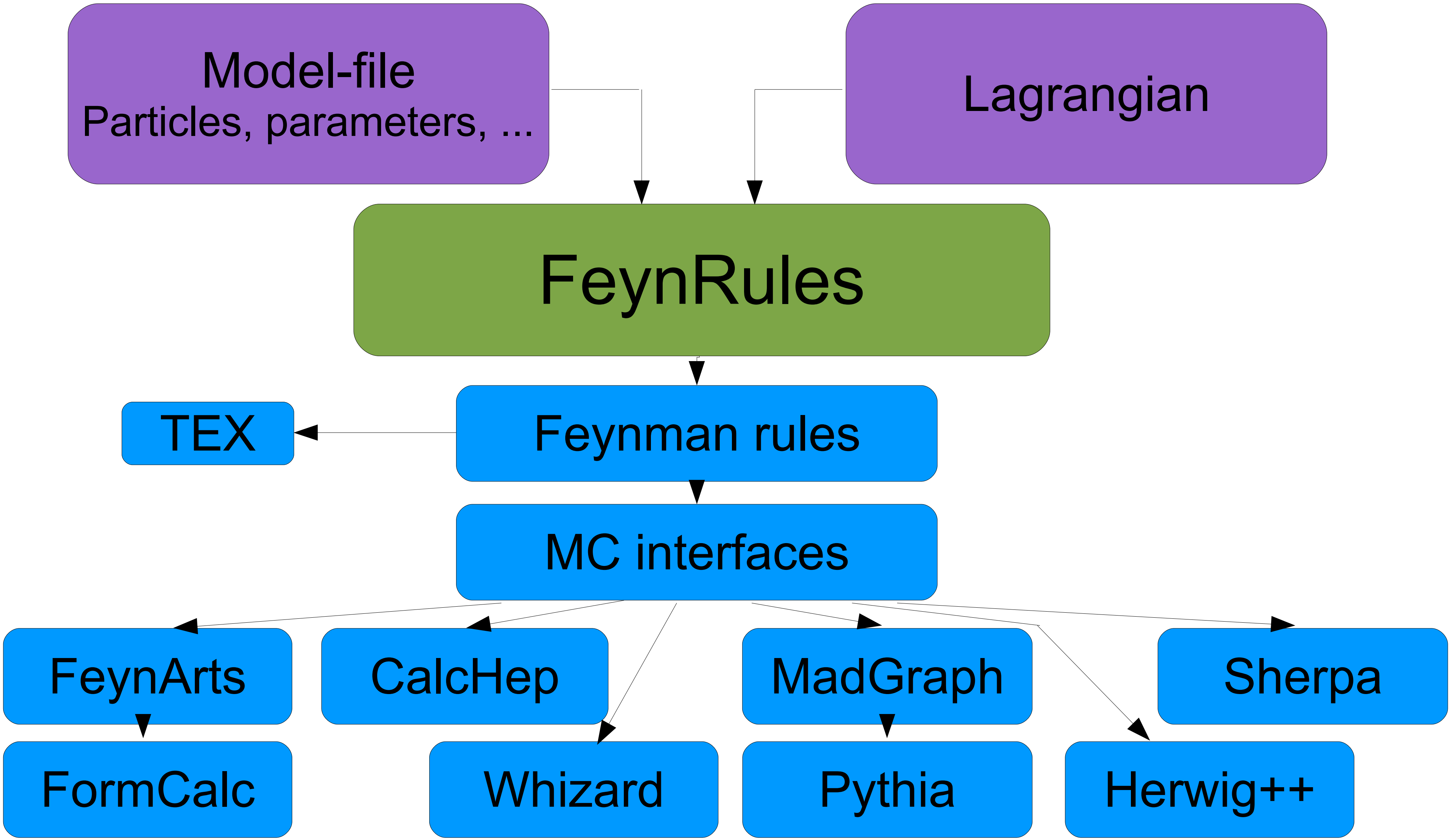
- Delphes (new and hot)
  - Written by CMS experimentalists, validated to CMS
  - Considerably more realistic than PGS (e.g. includes magnetic field)
  - Considerably faster than PGS (uses FastJet for jet reconstruction)
  - Detector and trigger settings in separate input cards
  - See arXiv:0903.2225, Delphes homepage

BSM: From Lagrangian to simulation

Two programs to calculate Feynman rules and generate generator-specific model files from Lagrangians:

- LanHep
  - Only for CalcHep/CompHep
- FeynRules [arXiv:0806.4194]
  - Interfaces for FeynArts/FormCalc, CalcHep, MadGraph/MadEvent, Sherpa, Whizard, Herwig++, ...

FeynRules



Model-file
Particles, parameters, ...
Lagrangian
FeynRules
TEX
Feynman rules
MC interfaces
FeynArts
CalcHep
MadGraph
Sherpa
FormCalc
Whizard
Pythia
Herwig++

Available models in ME generators

Built-in models:

	CalcHep	Herwig	MadGraph	Sherpa	Whizard
SM	✓	✓	✓	✓	✓
cMSSM	✓	✓	✓	✓	✓
MSSM	✓			✓	✓
NMSSM					✓
2HDM			✓		
UED	✓				✓

Available models in ME generators

Models from FeynRules:

	CalcHep	Herwig	MadGraph	Sherpa	Whizard
SM	✓	✓	✓	✓	✓
cMSSM	✓	✓	✓	✓	✓
MSSM	✓	✓ (red)	✓ (red)	✓	✓
NMSSM	✓ (red)	✓ (red)	✓ (red)	✓ (red)	✓
2HDM	✓ (red)	✓ (red)	✓	✓ (red)	✓ (red)
UED	✓	✓ (red)	✓ (red)	✓ (red)	✓

See http://feynrules.phys.ucl.ac.be/ for latest model directory

Model-building approaches

Three general approaches for model-building at the LHC:

1. Bottom-up:
   - Simple extensions to the Standard Model, perhaps inspired by subsets of larger models
   - Easy either directly in ME generator or using FeynRules (modify SM Lagrangean)
   - In MadGraph/MadEvent: USRMOD, USRMOD2
   - See e.g. arXiv:0810.3921

Model-building approaches

Three general approaches for model-building at the LHC:

2. Top-down:
   - Implement complete Lagrangean, look for large range of signatures (including SMPD, cosmology...)
   - Best done using FeynRules (and after publication, submit model to model directory)
   - In MadGraph/MadEvent 4 + most other generators: Allow simulation of renormalizable theories

Model-building approaches

Three general approaches for model-building at the LHC:

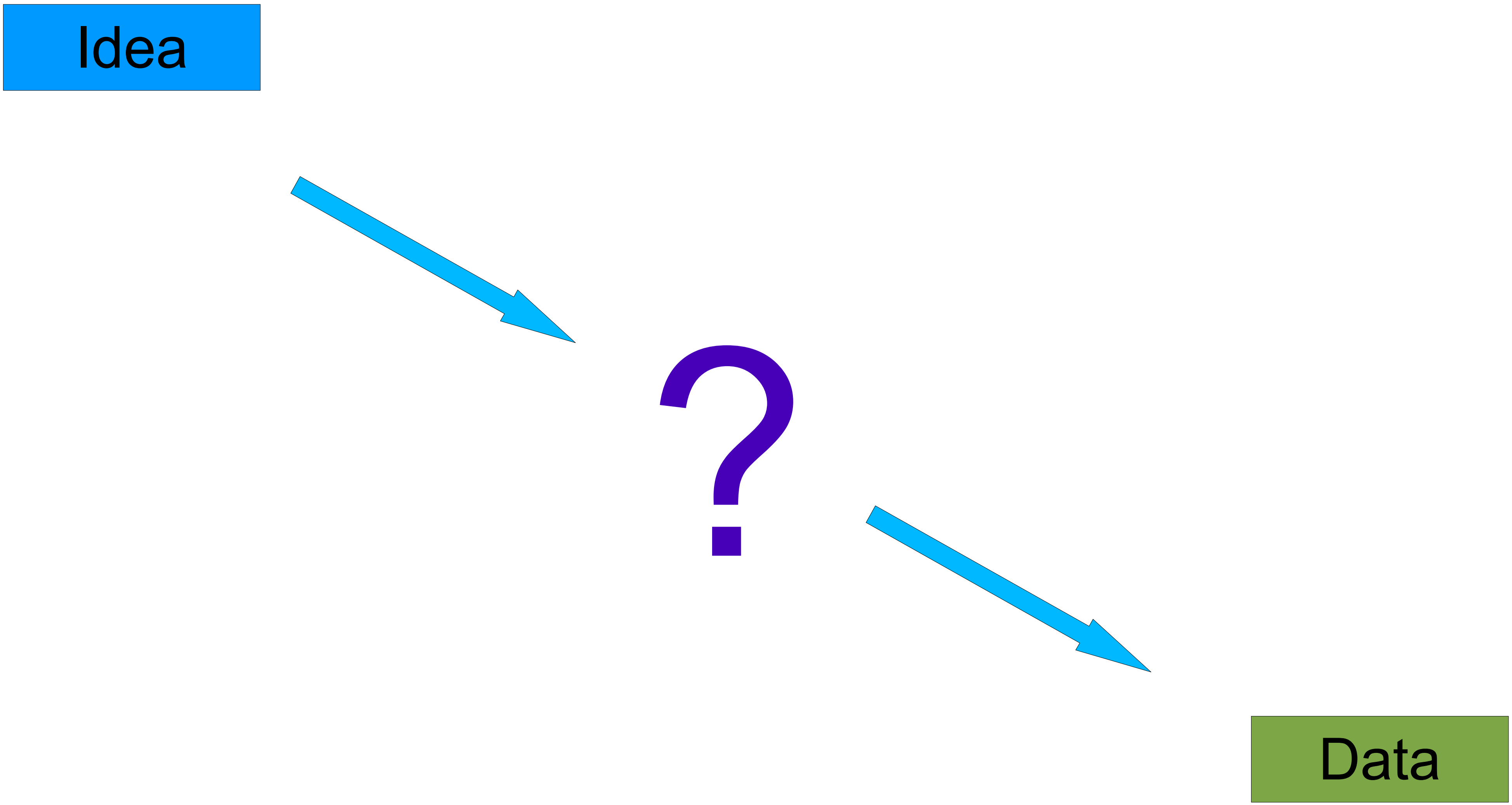
3. Effective theories:

- High-scale new physics can show up as multi-particle (contact) interactions
- With FeynRules + MadGraph 5, direct implementation/simulation of effective vertices!
  No limitation on allowed Lorentz structures/particle multiplicity – see `http://launchpad.net/madgraph5`

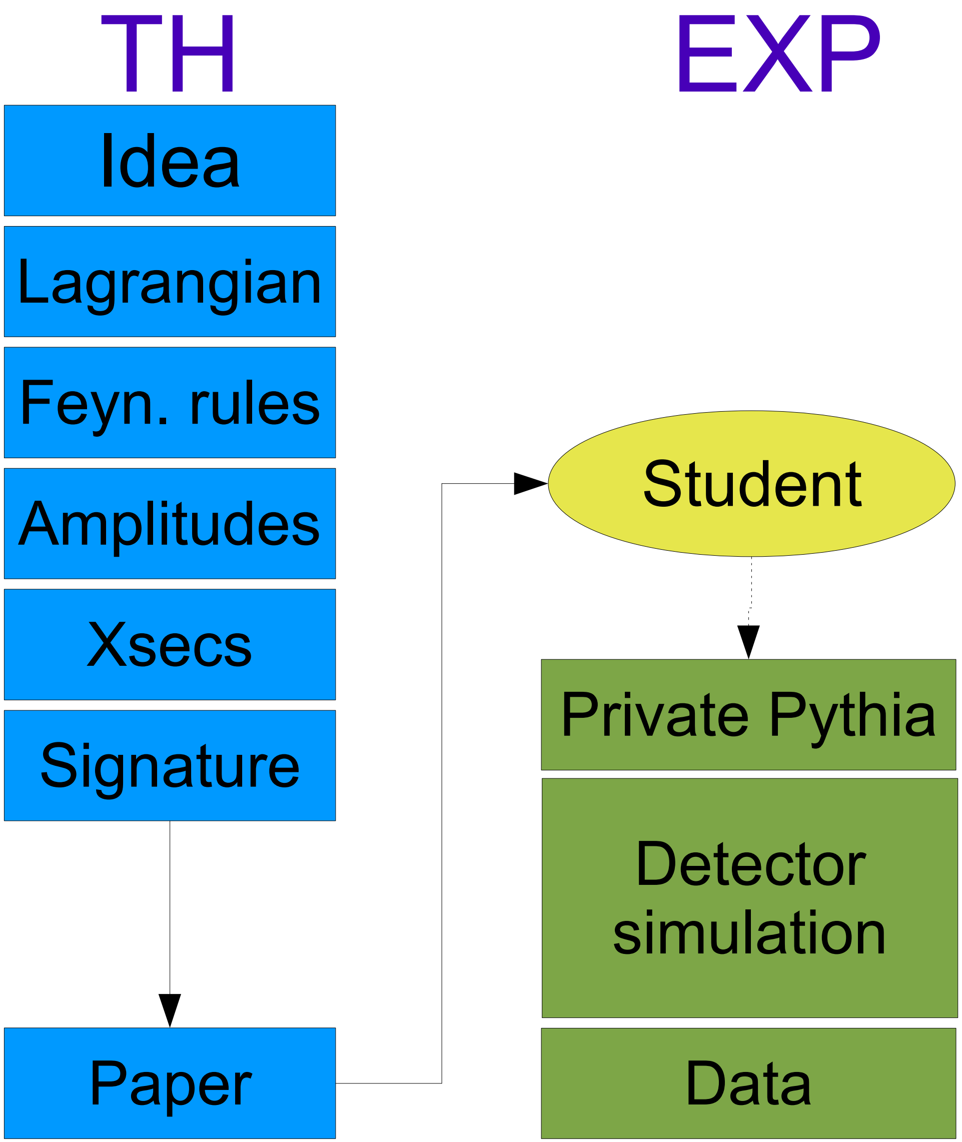
Communicating models Th-Exp

TH

EXP

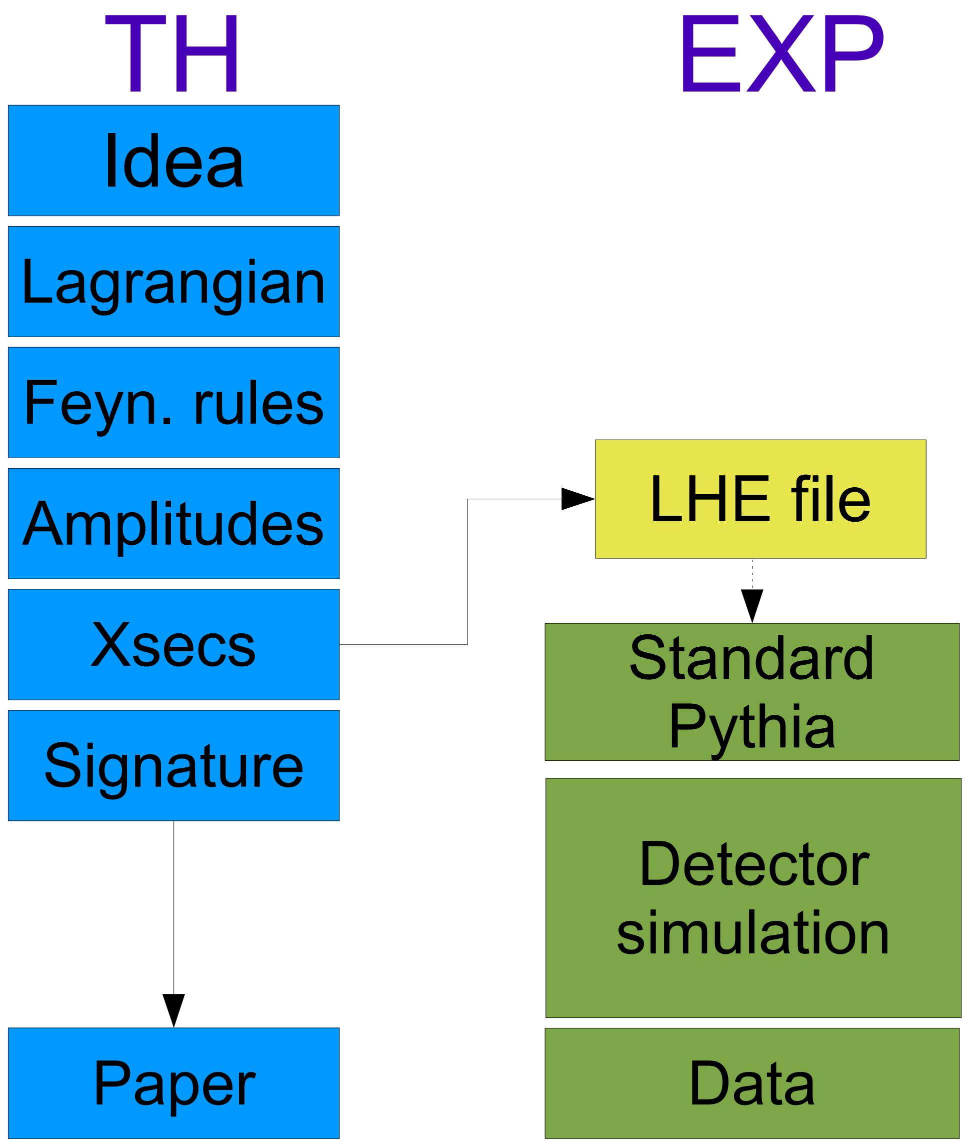


Worst solution



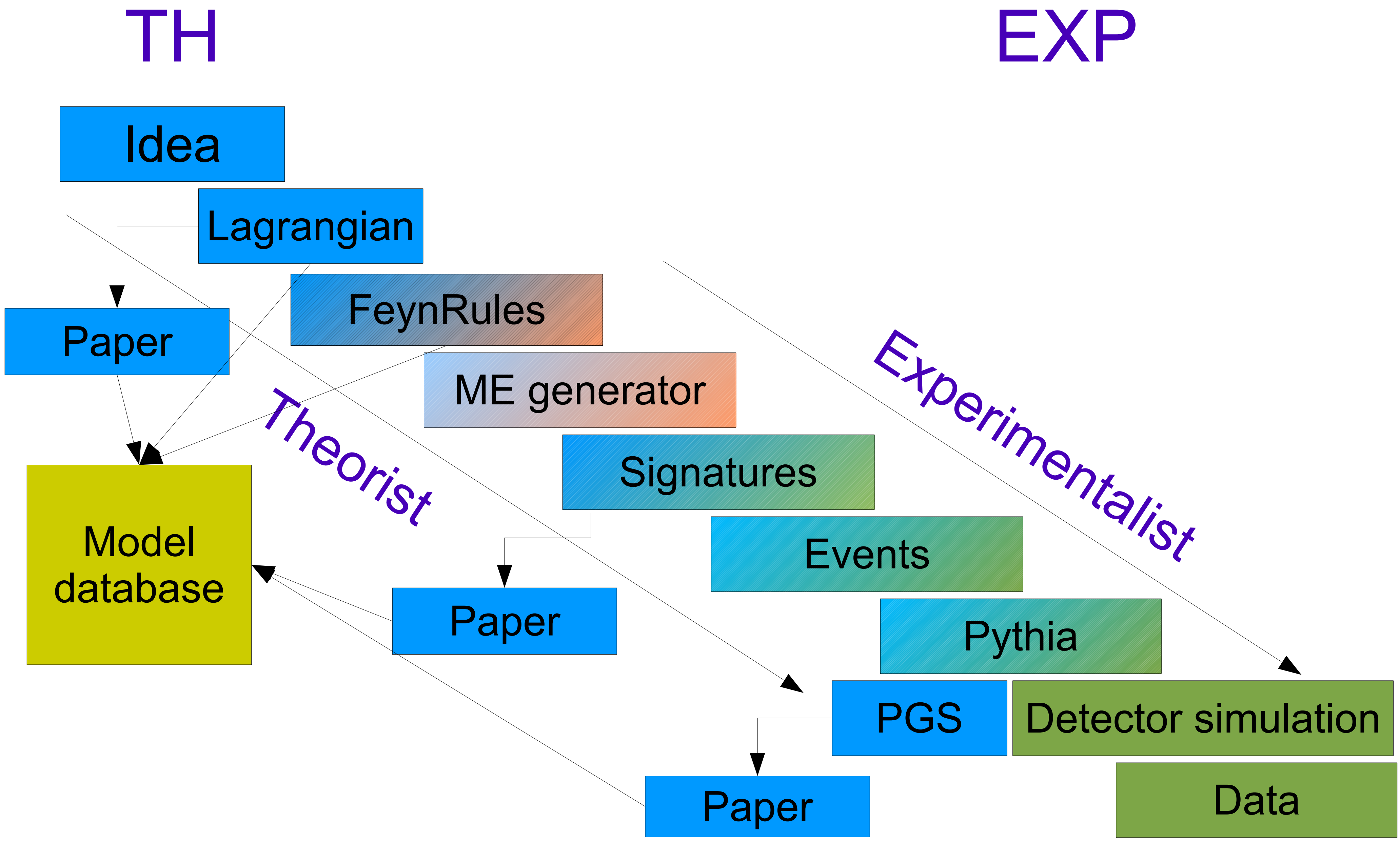
- Error prone
- Impossible to control for theorist
- Proliferation of private codes
- Non-repeatable

Slightly better solution

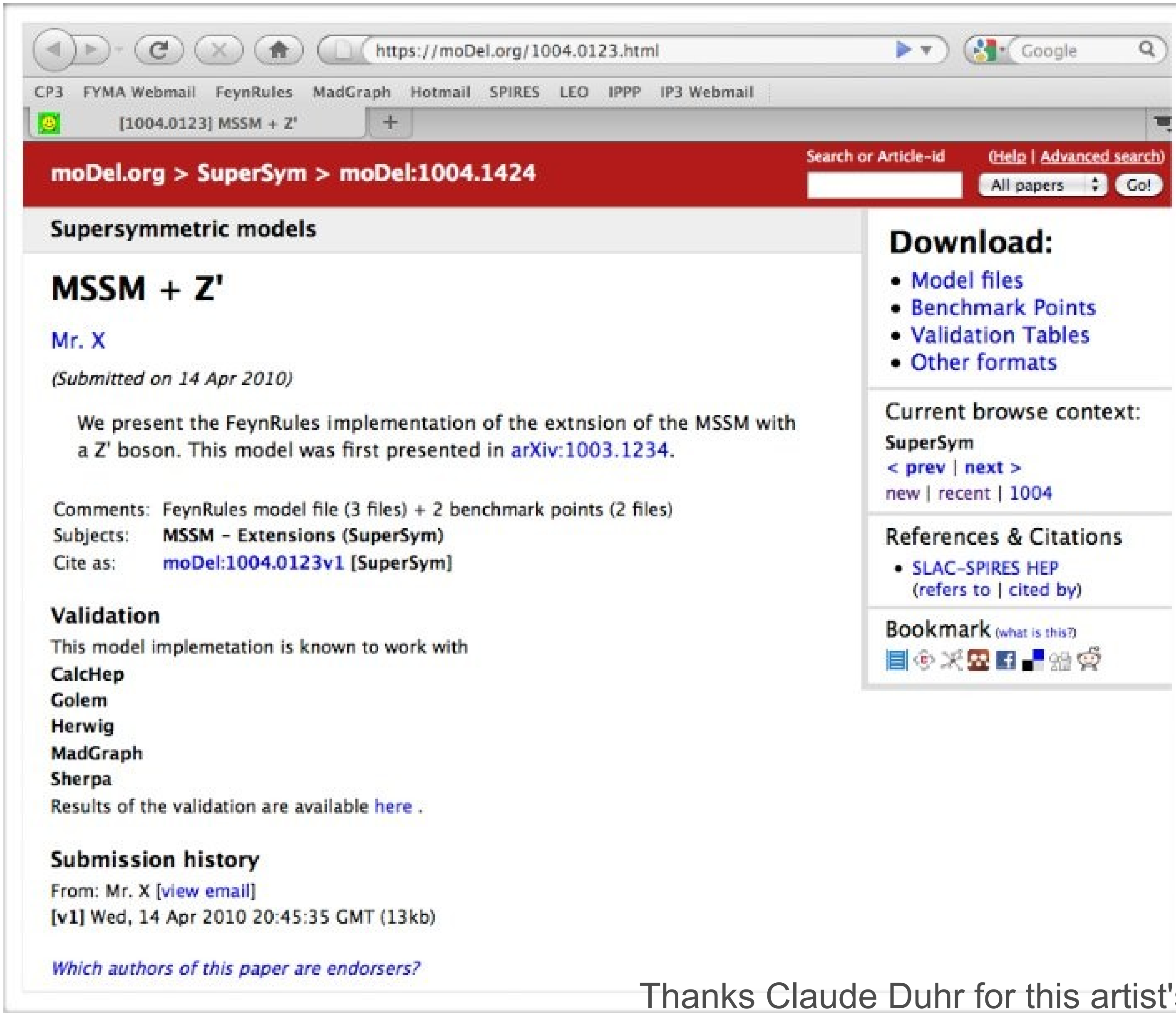


+ Well-controled by theorist
- Difficult to control for experimentalist
- Proliferation of files
- Possibly non-repeatable
- Difficult to vary parameter selection

Optimum solution



Towards an archive of models?



https://moDel.org/1004.0123.html

CP3 FYMA Webmail FeynRules MadGraph Hotmail SPIRES LEO IPPP IP3 Webmail

[1004.0123] MSSM + Z'

moDel.org > SuperSym > moDel:1004.1424

Search or Article-id (Help | Advanced search)

All papers Go!

Supersymmetric models

MSSM + Z'

Mr. X

(Submitted on 14 Apr 2010)

We present the FeynRules implementation of the extnsion of the MSSM with a Z' boson. This model was first presented in arXiv:1003.1234.

Comments: FeynRules model file (3 files) + 2 benchmark points (2 files)
Subjects: **MSSM - Extensions (SuperSym)**
Cite as: moDel:1004.0123v1 **[SuperSym]**

Validation

This model implemetation is known to work with
CalcHep
Golem
Herwig
MadGraph
Sherpa
Results of the validation are available here .

Submission history

From: Mr. X [view email]
[v1] Wed, 14 Apr 2010 20:45:35 GMT (13kb)

Which authors of this paper are endorsers?

Download:

- Model files
- Benchmark Points
- Validation Tables
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Current browse context:
SuperSym
< prev | next >
new | recent | 1004

References & Citations
- SLAC-SPIRES HEP
(refers to | cited by)

Bookmark (what is this?)

Thanks Claude Duhr for this artist's rendition!

Conclusions

Considerable progress in simulation tools in recent years, not least in:

- Simulation of multi-jets in SM and BSM
- NLO automatization (now up to W+4 jets!)
- Fast detector simulation
- Tools for automatized new physics simulation
  - Directly from Lagrangian to simulation
  - Effective vertices/contact interactions