MC(4BSM) Overview

Kentarou Mawatari
健太郎，馬渡

Laboratoire de Physique
Subatomique et de Cosmologie
Grenoble

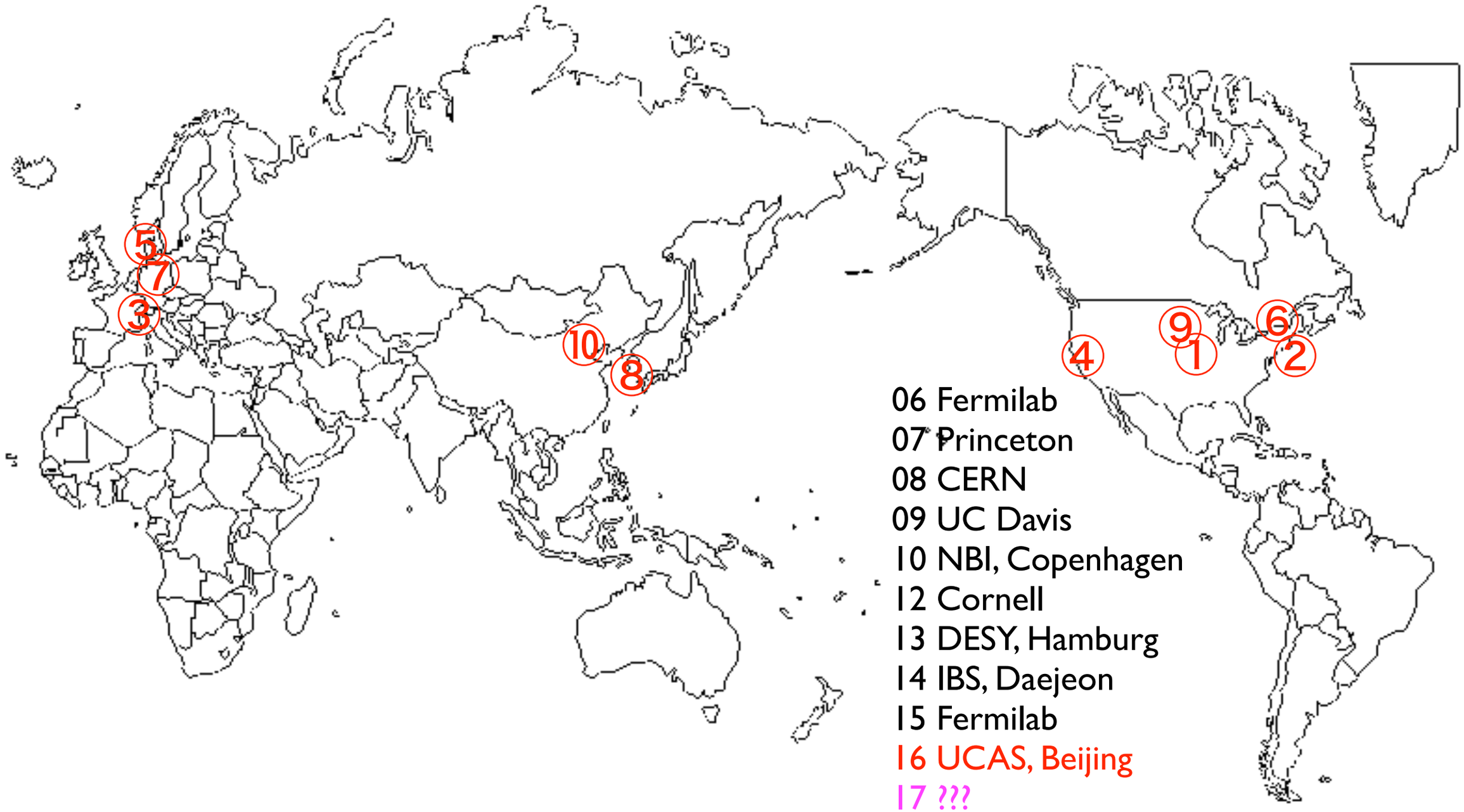
1. History of MC4BSM
2. BSM workflow at the LHC
3. Beyond LO+PS
4. Summary and outlook

disclaimer (Who am I?)

- I'm a pheno person.
- I'm a heavy user of MC tools, but not a real developer…
- I'd stayed for 5 years in Brussels and worked with 'MAD' people, so…

1. History of MC4BSM

10th anniversary of MC4BSM !



06 Fermilab
07 Princeton
08 CERN
09 UC Davis
10 NBI, Copenhagen
12 Cornell
13 DESY, Hamburg
14 IBS, Daejeon
15 Fermilab
16 UCAS, Beijing
17 ???

MC4BSM before the LHC …

1st workshop: MARCH 20-21, 2006 (FERMILAB)

This mini-workshop aims to gather together theorists and experimentalists interested in developing and using Monte Carlo tools for Beyond the Standard Model Physics in an attempt to be prepared for the analysis of data focusing on the Large Hadron Collider. Since a large number of excellent tools already exist for the study of low energy supersymmetry and the MSSM in particular, this workshop will instead focus on tools for alternative TeV-scale physics models. The main goals of the workshop are:

- To survey what is available. To provide feedback on user experiences with Monte Carlo tools for BSM.
- To identify promising models (or processes) for which the tools have not yet been constructed and start filling up these gaps.
- To propose ways to streamline the process of going from models to events, i.e. to make the process more user-friendly so that more people can get involved and perform serious collider studies outside of the MSSM.

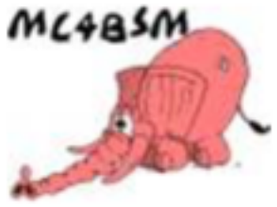
We envision a small but intensive workshop with a small number of talks and ample time for discussions between model builders, Monte Carlo experts, and experimentalists interested in exotics searches at the Tevatron and the LHC.

The first MC4BSM (2006) agenda

Monday, March 20		
8:45-9:10	*** REGISTRATION ***	
9:10-9:20	Welcome and Introduction [ppt] [pdf]	Organisers
9:20-9:50	Exhortation [ppt]	A. de Roeck
9:50-10:20	Signals for a Warped Extra Dimension	K. Agashe
10:20-10:50	Warped/Composite Phenomenology Simplified	R. Sundrum
10:50-11:00	Questions and Discussion	
11:00-11:30	*** COFFEE ***	
11:30-12:00	Little Higgs models	M. Schmaltz
12:00-12:30	Herwig & Pythia [ppt] [pdf]	P. Richardson
12:30-1:00	Questions and Discussion	
1:00-2:00	*** LUNCH ***	
2:00-2:30	Higgs, neutralinos and exotics beyond the MSSM [pdf]	P. Langacker
2:30-2:50	Non-standard Higgses in SUSY [pdf]	D.E. Kaplan
2:50-3:10	Improving Monte Carlos using SCET [ppt] [pdf]	M. Schwartz
3:10-3:30	New physics with LHCFast [pdf]	D. Walker
3:30-3:45	Questions and Discussion	
3:45-4:15	*** COFFEE ***	
4:15-4:30	Summary of survey results [pdf]	K. Matchev

Tuesday, March 21		
9:00-9:30	BSM Processes with Pandora [pdf]	M. Peskin
9:30-10:00	Bard [pdf]	S. Mrenna
10:00-10:30	Questions and Discussion	
10:30-11:00	*** COFFEE ***	
11:00-11:30	Two Brief Sketches: (1) Higgsless Models (2) Z' Preferring the 3rd Generation [pdf]	E. Simmons
11:30-12:00	Universal Extra Dimensions [pdf]	H. Cheng
12:00-12:30	CalcHEP & CompHEP	A. Pukhov
12:30-1:00	Questions and Discussion	
1:00-2:00	*** LUNCH ***	
2:00-2:20	Twin Higgs with CompHEP [pdf]	S. Su
2:20-2:40	KK vs. SUSY with Herwig [ppt]	I. Yavin
2:40-3:00	Top partners at the LHC with MadGraph [pdf]	M. Reece
3:00-3:20	Little Higgs w/ T-parity with CompHEP [pdf]	A. Belyaev
3:20-3:40	Little Higgs w/ T-parity with MadGraph [pdf]	J. Hubisz
3:40-4:00	European Connection [pdf]	M. Muhlleitner

MC4BSM in the LHC era



The 10th Monte Carlo Tools for Physics Beyond Standard Model---MC4BSM 2016 Beijing

MC4BSM is a series of workshops aiming to gather theorists and experimentalists interested in developing Monte Carlo tools to simulate collider signatures of Beyond the Standard Model Physics, and to use such tools in phenomenological studies and in searches for new physics at energy frontier colliders.

Since 2006, nine workshops have been held in this series, hosted in USA, Switzerland, Denmark, Germany, and Korea. The focus of MC4BSM-2016 in Beijing will include: **1) to report new features and new developments** of general-purpose MC tools, such as CalcHEP, CompHEP, FDC, Herwig, Madgraph, Pythia, Sherpa, Whizard, and others; **2) to discuss the experimental needs** from the LHC, from dark matter experiments, and from physics studies of future colliders, including the ILC, the circular Higgs factories (CEPC/FCC-ee), Z-factories, and a 100 TeV proton collider (SPPC/FCC-hh); **3) to offer tutorials** to senior PhD students, postdocs, and young faculty interested in using MC tools in their research.

The 10th MC4BSM (2016) Agenda

	July20(Wed)	July 21 (Th)	July22(Fri)	July 23(Sat.)	July24(Sun)
06:30-08:00	Breakfast				
08:20-08:30	Opening	-		-	-
08:30-09:00	**ATLAS: Status Report**	**Overview of NLO and beyond**		**BSM Overview**	**CEPC : Status Report**
09:00-09:30	**CMS: Status Report**	**ILC physics**			**CEPC Detector**
09:30-10:00	**MCOverview**	**FDC/Quarkonium**		**Higgs Overview**	**FCC-hh/SppC physicsstudies**
10:00-10:30		**Grace**		**BSM 1**	**PDF @LHC and FCC**
10:30-10:50	Coffee break			Coffee Break	
10:50-11:20	**Herwig**	**Madgraph**		**BSM 2**	**Boosted Objects(SM)**
11:20-11:50	**Pythia**	**Whizard**		**BSM 3**	**Boosted Objects(BSM)**
11:50-12:20	**Sherpa**	**CompHEP**	Excursion (Mutianyu Great Wall)	**Checkmate**	**MadAnalys**
12:20-14:00	Lunch Break			Lunch Break	
14:00-14:30	**Matching& Merging**	**CalcHeP**		**FastLim**	**Delphes**
14:30-15:00		**Gosam**		**Darkmatter**	**MT2**
15:00-15:30	**GAMBIT**	**Wzd@NLO**		**FeynRules for BSM**	Tutorial(4)
15:30-16:00	Coffee Break			Coffee Break	
16:00-16:30	Tutorial(1)	**Fastjet**		Tutorial(3)	Tutorial(4)
16:30-18:00		Tutorial(2)			
18:00-18:30					**Summary**

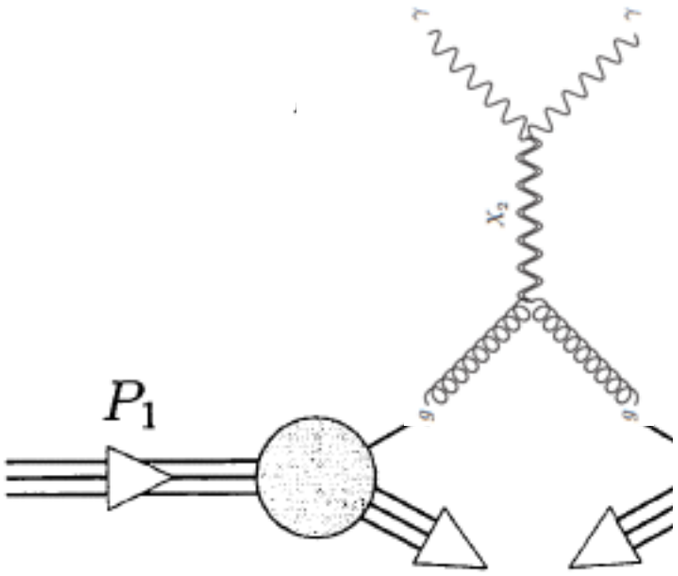
- 4 days (8:30 - 18:30)
- more than 100 participants
- LHC results
- beyond LHC
- beyond LO
- tutorials
- 17 tools + more

MC4BSM survey

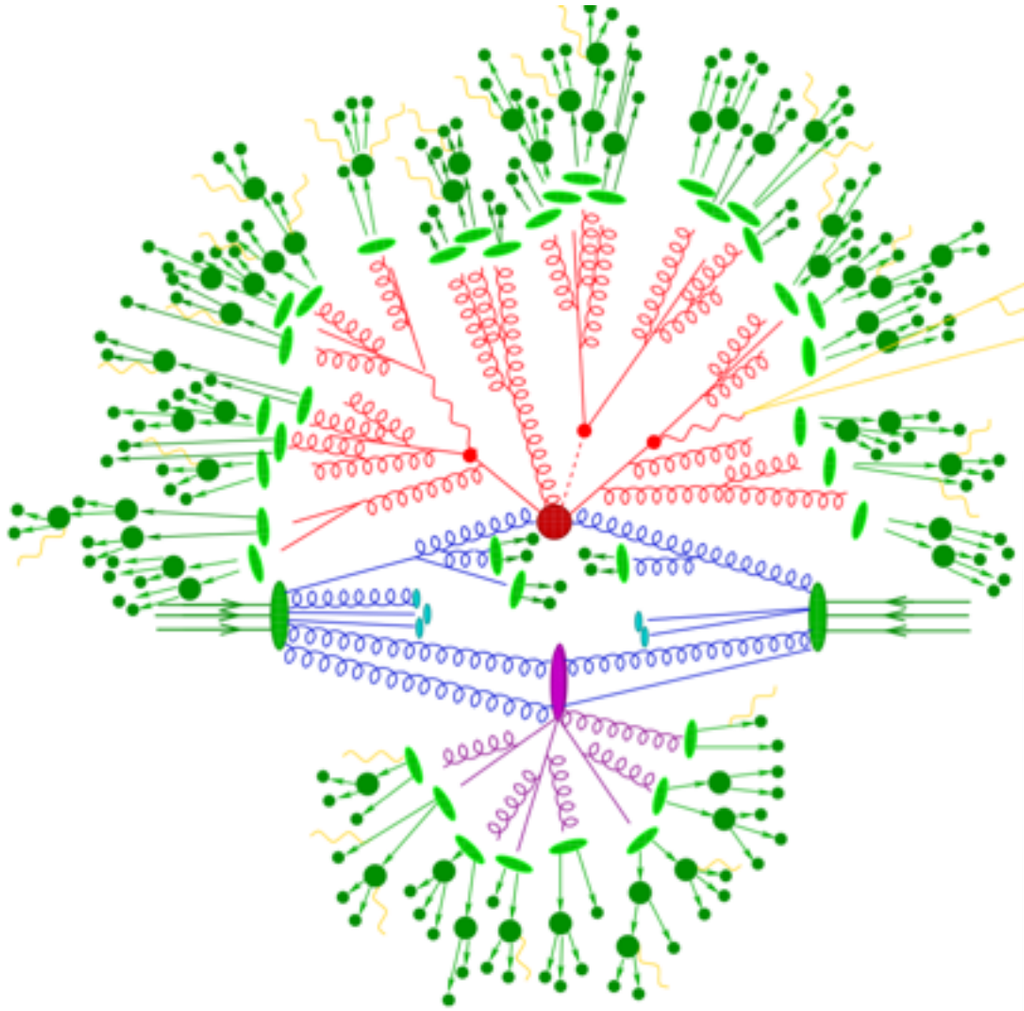
1. Who are theorists/experimentalists ?
2. Who are young? Who are PhD students ?
3. How many tools among 17 have you ever heard ?
4. How many tools among 17 have you ever used ?

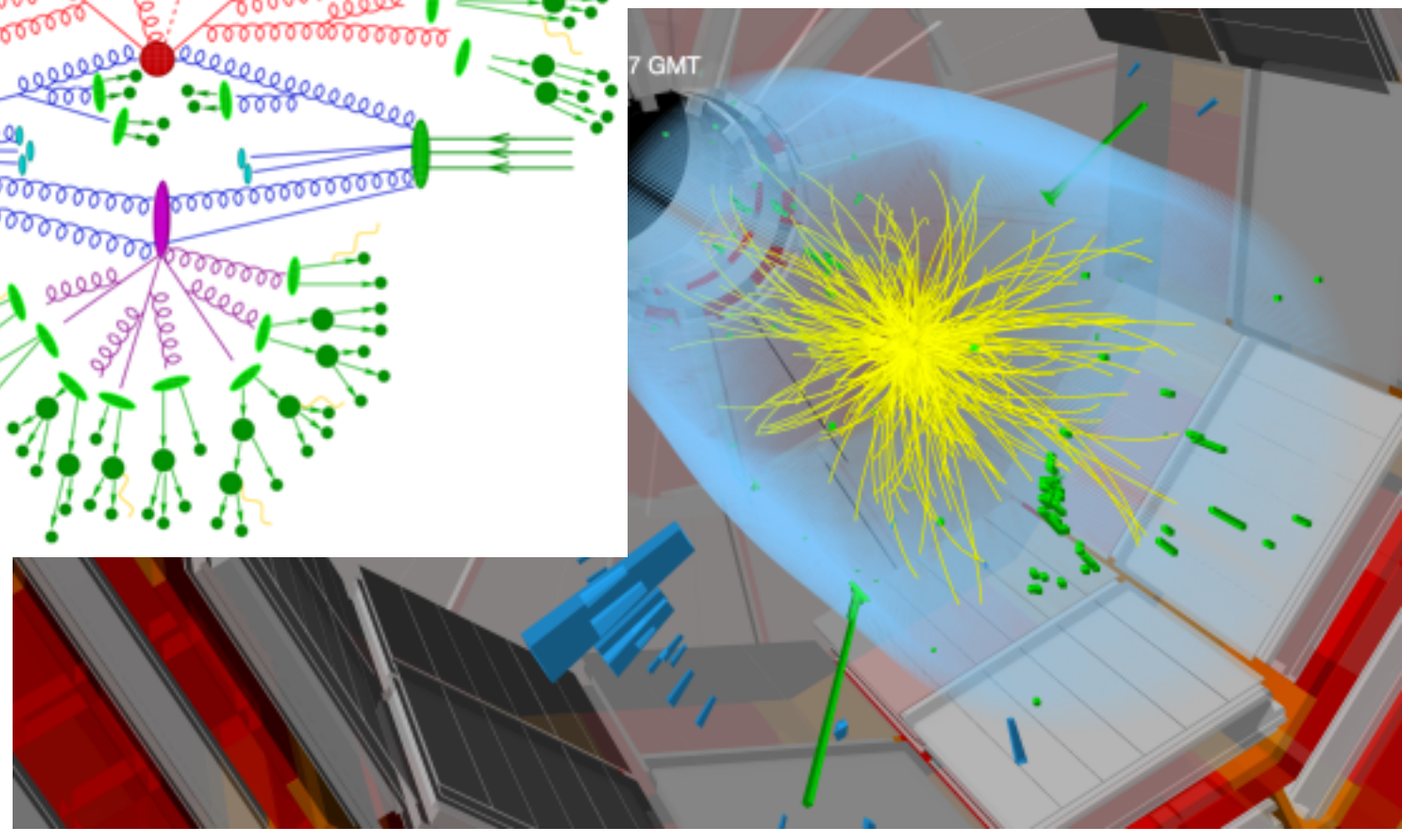
Herwig, Pythia, Sherpa, GAMBIT, Grace, FDC,
MadGraph, Whizard, CompHEP, CalcHEP, Gosam, Fastjet,
Checkmate, FastLim, FeynRules, MadAnalysis, Delphes

Why do we need MC event generators ?

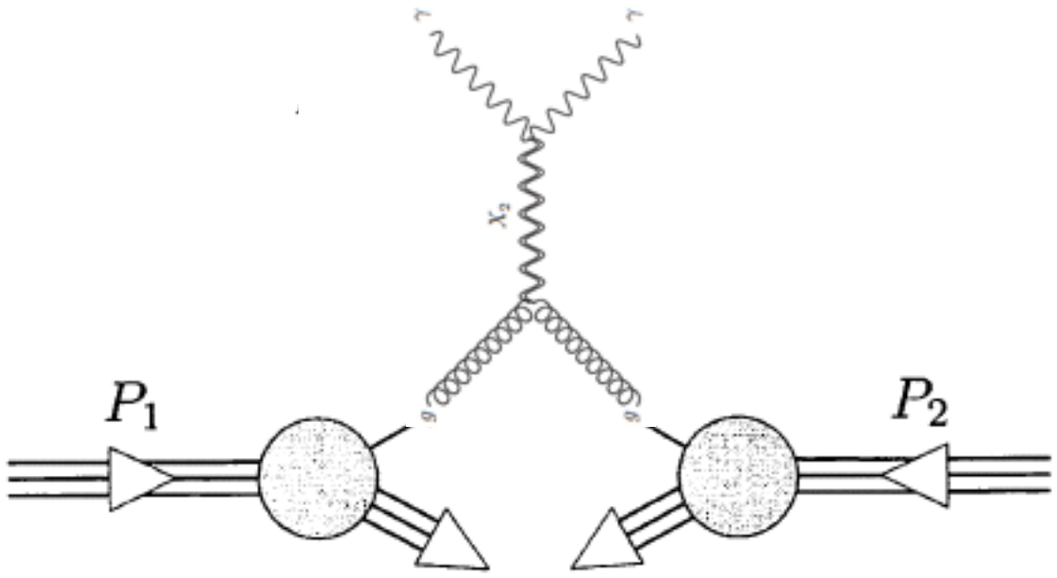


→ need to produce fully exclusive events to be compared with data.

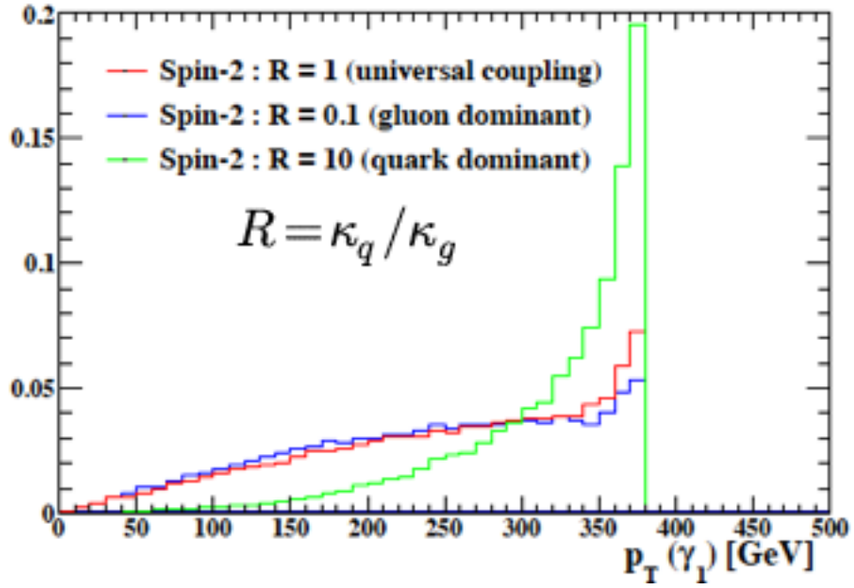




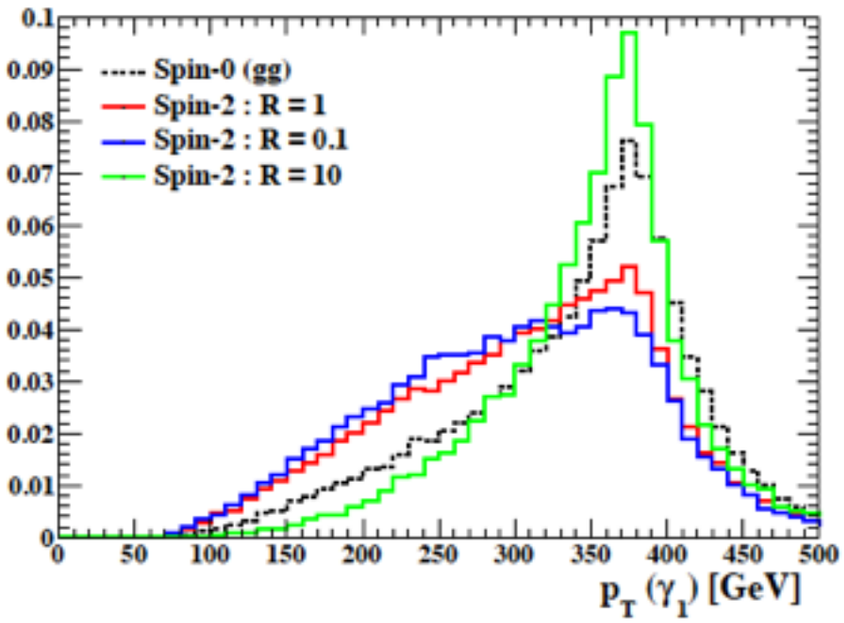
Why do we need MC event generators ?

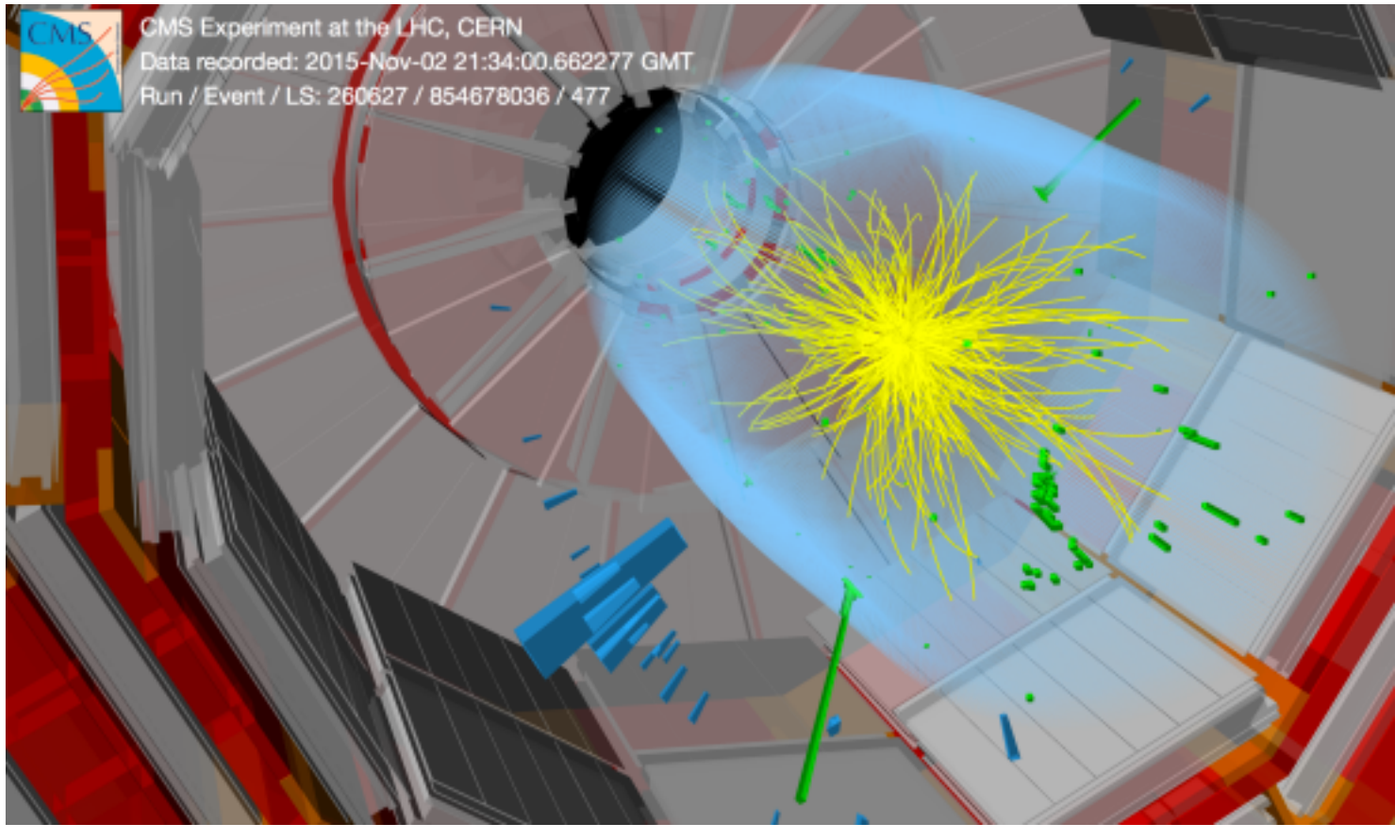


Martini, KM, Sengupta [PRD, 1601.05729]

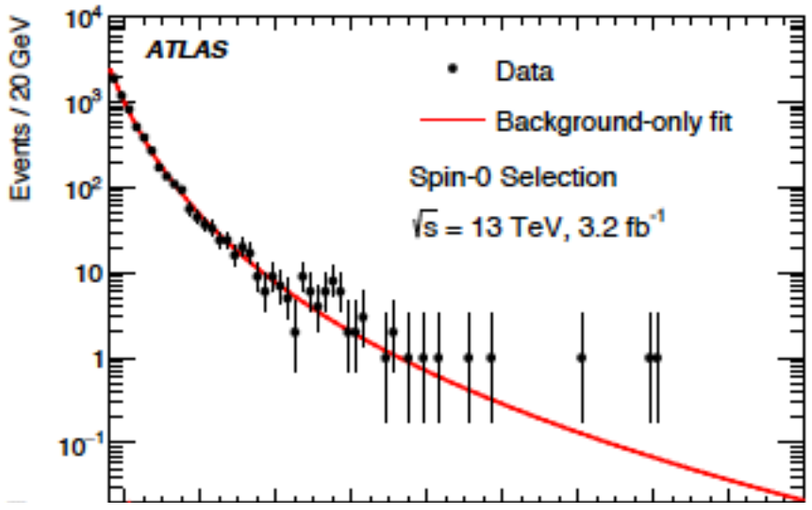


[Bernon, Goudelis, Kraml, KM, Sengupta, JHEP 1603.03421]





Do we need MC for the γγ resonance search ?



ATLAS [1606.03833]

7.2 Functional-form approach

A family of functions, adapted from those used by searches for new physics signatures in dijet final states [48], is chosen to describe the shape of the invariant mass distribution:

$$f_{(k)}(x; b, \{a_k\}) = N(1 - x^{1/3})^b x^{\sum_{j=0}^{k} a_j (\log x)^j}, \quad (3)$$

where $x = m_{\gamma\gamma}/\sqrt{s}$, b and a_k are free parameters, and N is a normalization factor. The number of free parameters describing the normalized mass distribution is thus $k + 2$.

To validate the choice of this functional form and to derive the corresponding uncertainties, the method detailed in Ref. [49] is used to check that the functional form is flexible enough to accommodate different physics-motivated underlying distributions. A large sample of diphoton pseudo-data is produced using the DIPHOX NLO computation, where the photon four-vectors are smeared with the detector resolution, and also with SHERPA generated samples which are then passed through the full detector simulation and the

Do we need MC for the γγ resonance search ?

ATLAS Higgs diphoton [1408.7084]

Process	Generator	Showering	PDF set	Order of calculation
ggF	POWHEG-BOX	PYTHIA8	CT10	NNLO(QCD)+NLO(EW)
VBF	POWHEG-BOX	PYTHIA8	CT10	NLO(QCD+EW)+app.NNLO(QCD)
WH	PYTHIA8	PYTHIA8	CTEQ6L1	NNLO(QCD)+NLO(EW)
ZH	PYTHIA8	PYTHIA8	CTEQ6L1	NNLO(QCD)+NLO(EW)
$t\bar{t}H$	POWHEL	PYTHIA8	CT10	NLO(QCD)
$tHbj$	MADGRAPH	PYTHIA8	CT10	NLO(QCD)
tHW	MADGRAPH5_AMC@NLO	HERWIG++	CT10	NLO(QCD)
bbH	-	-	-	5FS(NNLO)+4FS(NLO)
$\gamma\gamma$	SHERPA	SHERPA	CT10	
γ–jet	SHERPA	SHERPA	CT10	
jet–jet	PYTHIA8	PYTHIA8	CTEQ6L1	

None of searches can be done without MC.

2. BSM workflow at the LHC

MC generators 10 years ago…

Durham University

HERWIG and PYTHIA

Peter Richardson

IPPP, Durham University

MC generators 10 years ago…

Built In Models

	HERWIG	PYTHIA
SUSY	✓	✓
SUSY+RPV	✓	✓
RS Gravitons	✓	✓
Z'/W'	✗	✓
Technicolor	✗	✓
Left-Right Models	✗	✓
Compositeness	✗	✓
Excited fermions	✗	✓
Leptoquarks	✗	✓
Fourth generation	✗	✓

MC4BSM 20th March 7

MC generators 10 years ago…

Conclusions

- The existing HERWIG and PYTHIA programs will remain the workhorses of event simulation in the near future.
- Unlikely to be any new models implemented in them directly.
- New processes should use the Les Houches.
- The simulation in the new C++ generators will be different and hopefully allow more models to be studied.

BSM workflow: about 10 years ago…

- take a BSM model (symmetry, particle contents,…), i.e. Lagrangian
  - derive the Feynman rules
    - draw Feynman diagrams for our interesting 2→2 processes
    - compute the amplitude (squared)
      - implement it into a generator manually
        - generate events
          - parton-shower/hadronisation

        Herwig, Pythia
        - detector simulation
          - analysis

BSM workflow: now

at NLO

- take a BSM model (symmetry, particle contents,…), i.e. Lagrangian
  - derive the Feynman rules

model files →

DM physics tool

DM annihilation
DM-N cross section

- draw Feynman diagrams for our interesting any processes
- compute the amplitude (squared) — Matrix-element generator
  - ~~implement it into a generator manually~~
  - generate events

LHE file → parton-shower/hadronisation — Shower MC

HEP file → detector simulation

LHCO file → analysis

LHE (Les Houches Events) file

e.g. p p > $X_2(750)$ + j

```
<event>
 4   1  0.6550800E-01  0.7503518E+03  0.7818608E-02  0.9634799E-01
       21   -1    0    0  503  501  0.00000000000E+00  0.00000000000E+00  0.43371314688E+03  0.43371314688E+03  0.00000000000E+00 0.  1.
       21   -1    0    0  501  502  0.00000000000E+00  0.00000000000E+00 -0.46216691603E+03  0.46216691603E+03  0.00000000000E+00 0. -1.
  5000002    1    1    2    0    0 -0.21657595712E+02  0.76645677682E+01  0.10748726997E+03  0.75801141829E+03  0.75000000000E+03 0.  2.
       21    1    1    2  503  502  0.21657595712E+02 -0.76645677682E+01 -0.13594103912E+03  0.13786864462E+03  0.00000000000E+00 0. -1.
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</mgrwt>
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```

MC4BSM2016 tools

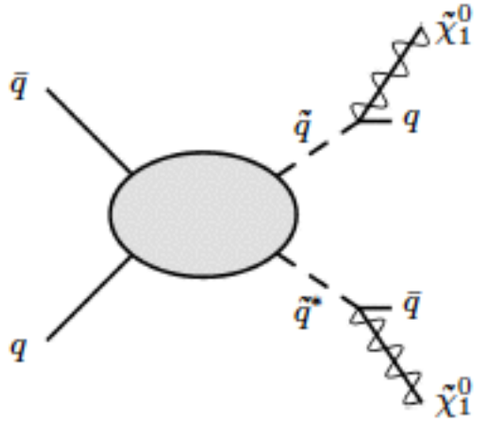
- take a BSM model (symmetry, particle contents,…), i.e. Lagrangian
  - derive the Feynman rules — FeynRules
    - draw Feynman diagrams for our interesting any processes
      - compute the amplitude (squared) — Grace, MadGraph, Whizard, CompHEP, CalcHEP, FDC, Gosam
        - generate events
          - parton-shower/hadronisation — Herwig, Pythia, Sherpa
            - detector simulation — Fastjet, Delphes
              - analysis — GAMBIT, Checkmate, FastLim, MadAnalysis

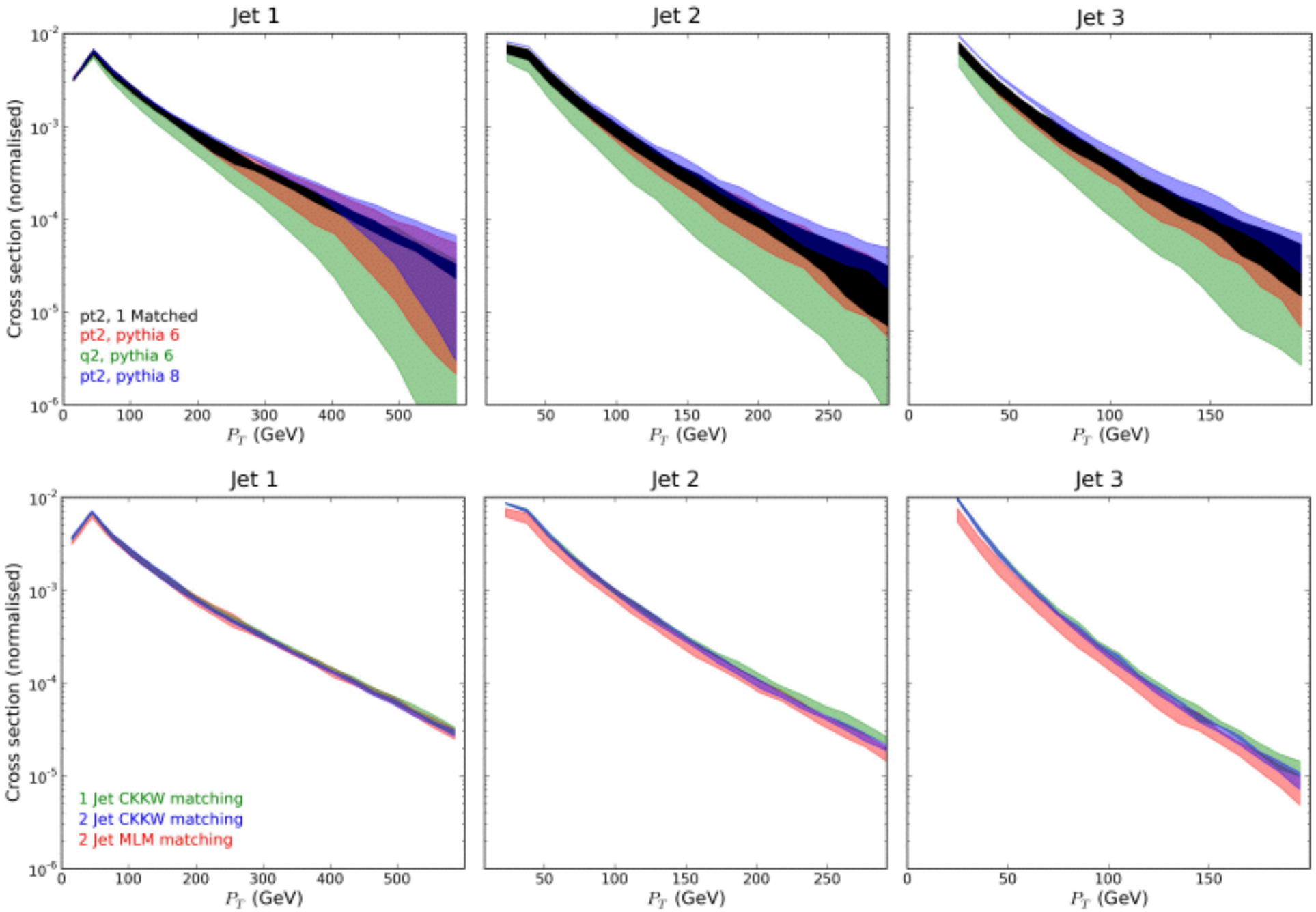
micrOMEGAs
MadDM

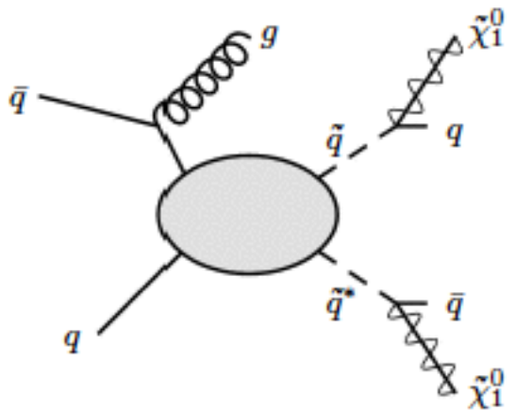
3. Beyond LO+PS

PS alone vs. ME+PS merging

Dreiner, Kraemer, Tattarsall [1211.4981]

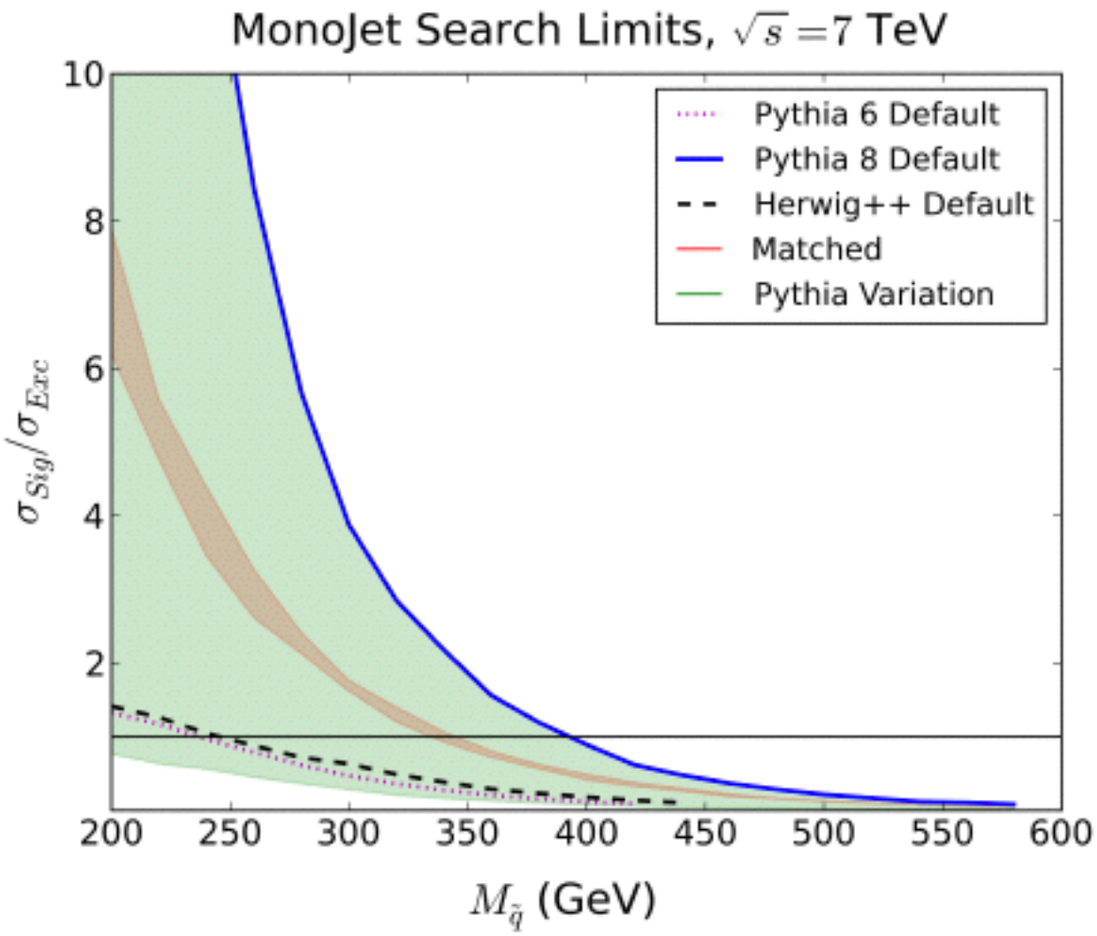






PS alone vs. ME+PS merging

Dreiner, Kraemer, Tattarsall [1211.4981]



- Improving QCD predictions and reducing MC uncertainties.

Matrix elements vs. Parton showers

ME

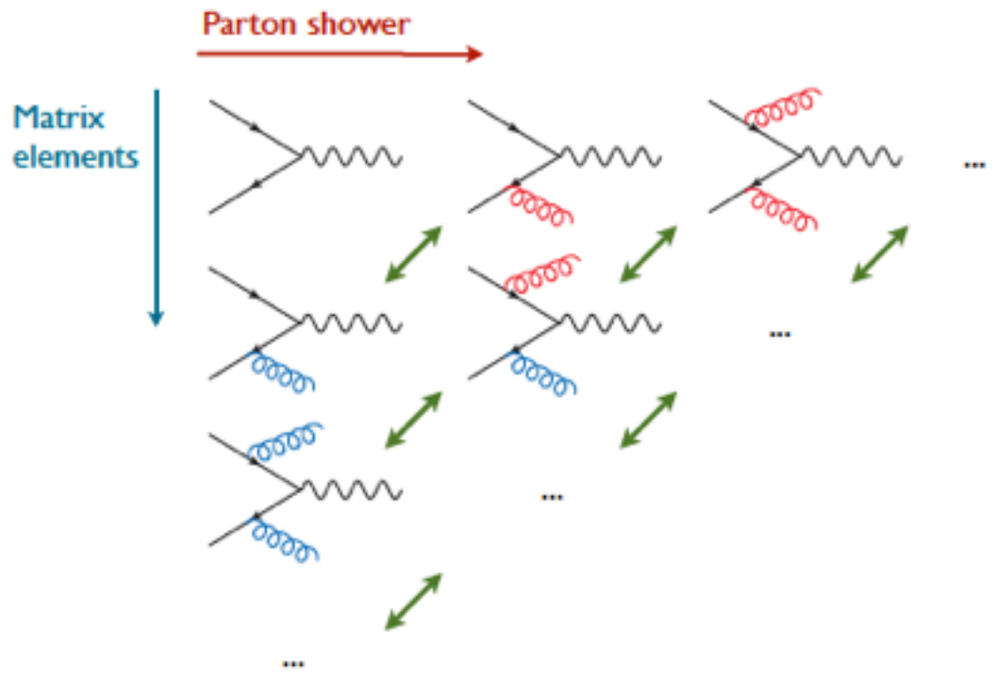
- Fixed order calculation
- computationally expensive (limited number of particles)
- Valid when partons are hard and well separated

PS

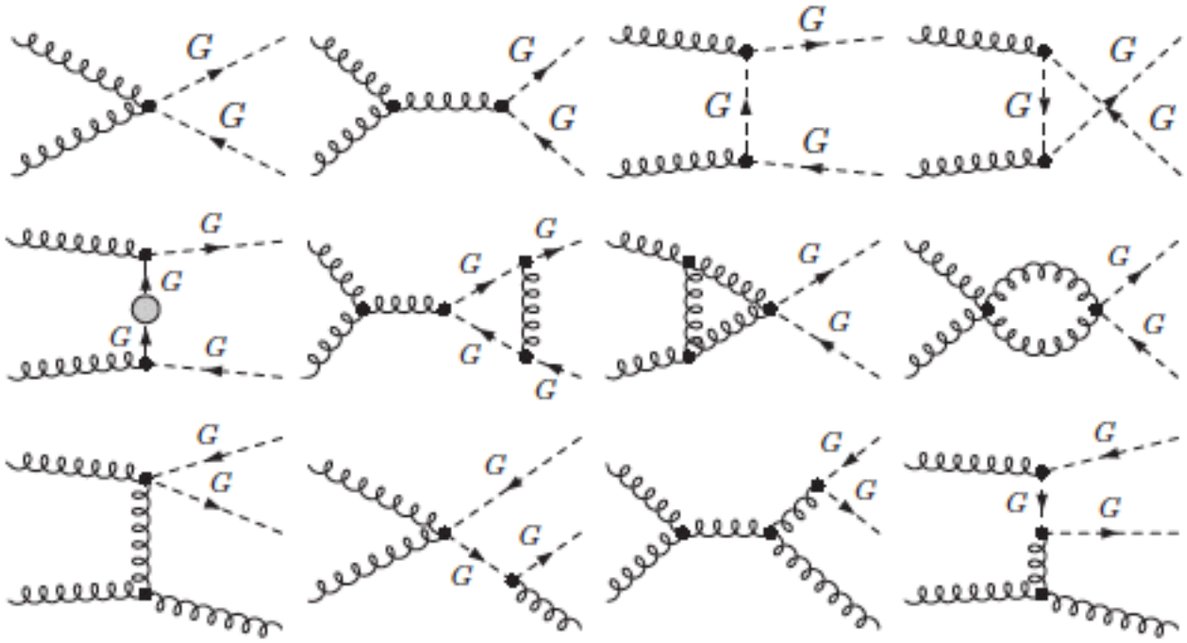
- Resums logs to all orders
- computationally cheap (No limit on particle multiplicity)
- Valid when partons are collinear and/or soft

Let's merge them!

But without double counting



NLO+PS



Born

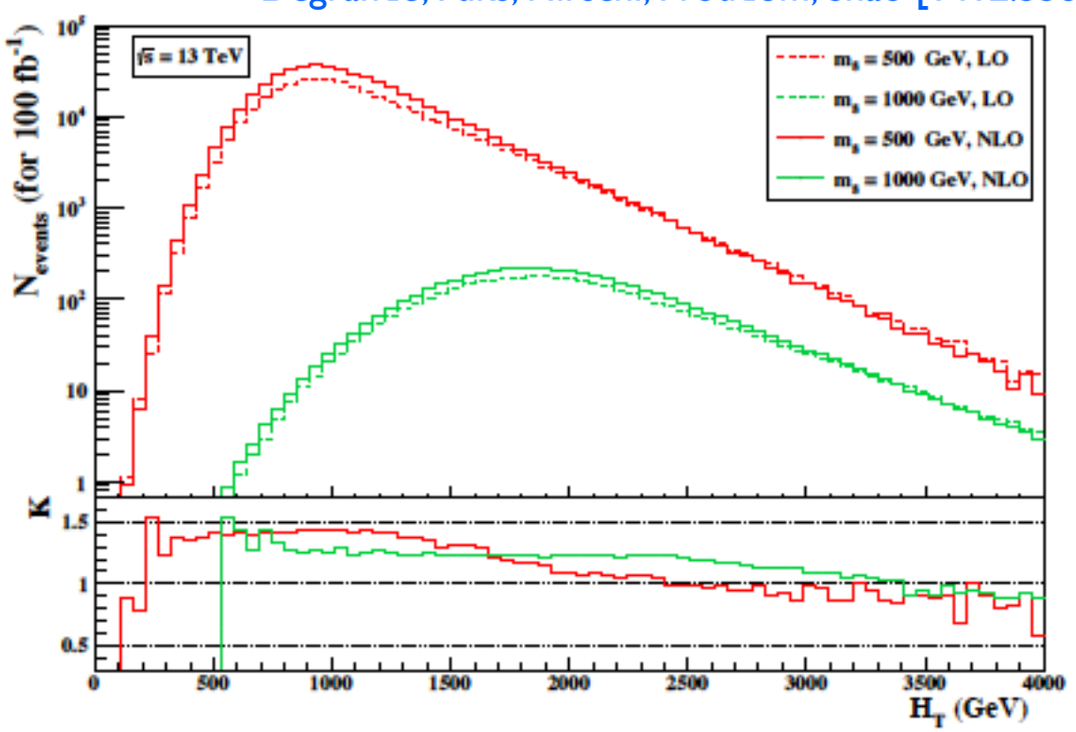
virtual

real

NLO ME + PS
without double counting

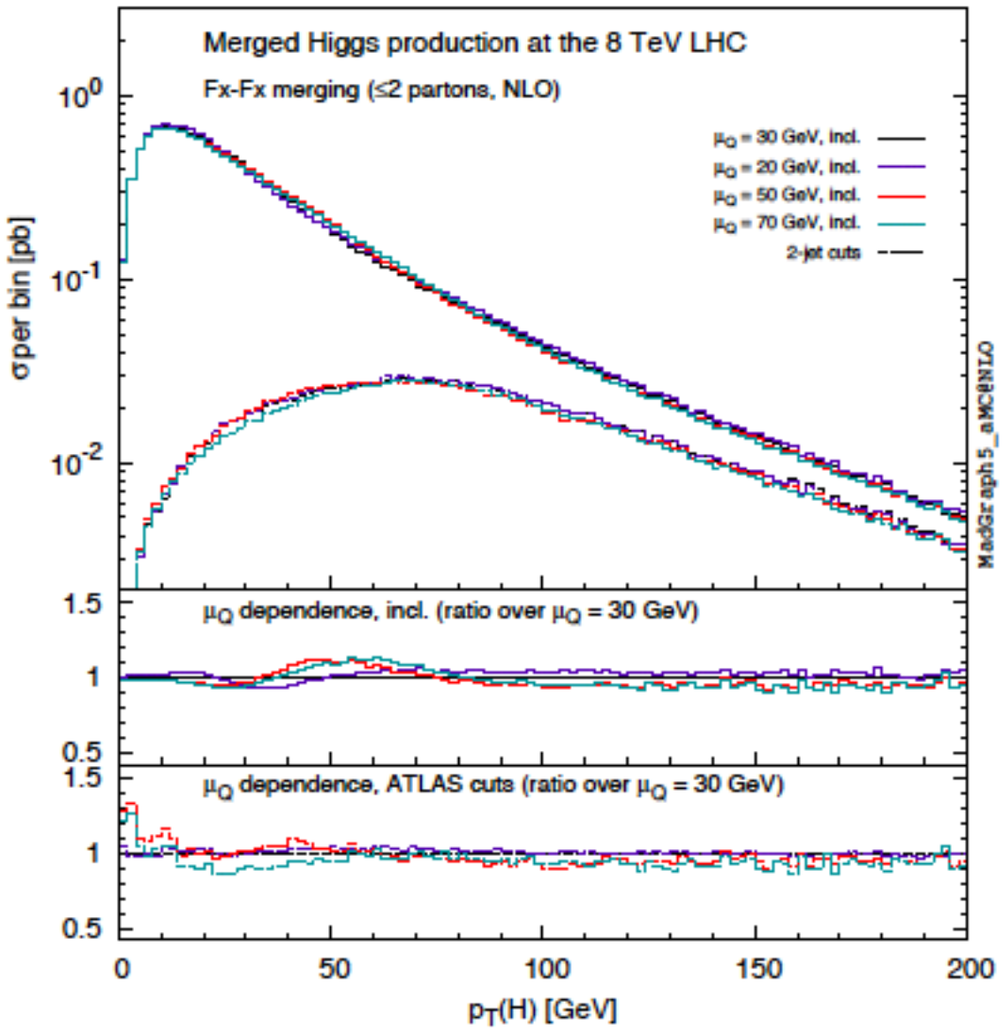
m_8 [GeV]	8 TeV $\sigma^{\rm LO}$ [pb]	8 TeV $\sigma^{\rm NLO}$ [pb]
100	$3854^{+34.4\%}_{-24.1\%}$	$5573^{+14.9\%\,+1.6\%}_{-13.6\%\,-1.6\%}$
250	$38.89^{+41.3\%}_{-27.7\%}$	$54.32^{+14.5\%\,+3.9\%}_{-14.6\%\,-3.9\%}$
500	$0.5878^{+47.6\%}_{-30.0\%}$	$0.7431^{+15.8\%\,+7.6\%}_{-16.2\%\,-7.6\%}$

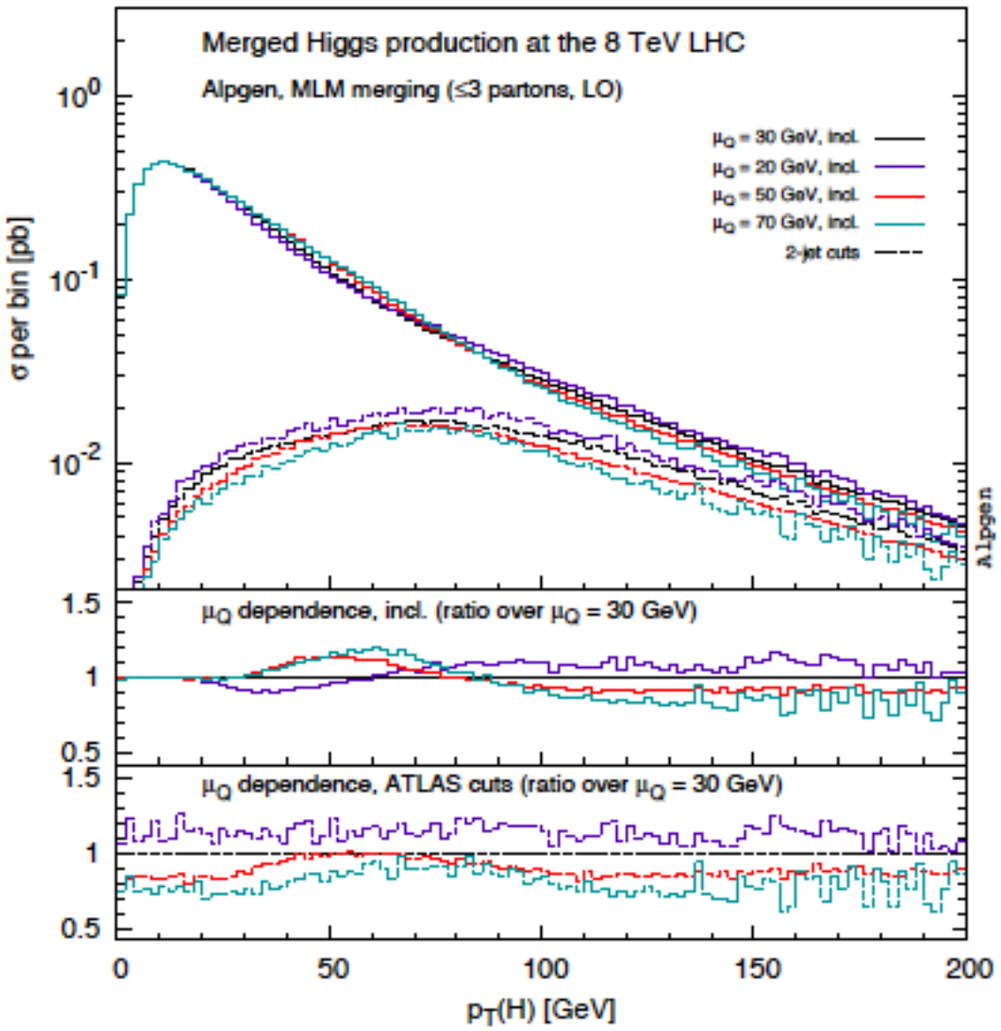
Degrande, Fuks, Hirschi, Proudom, Shao [1412.5589]



ME+PS merging @NLO

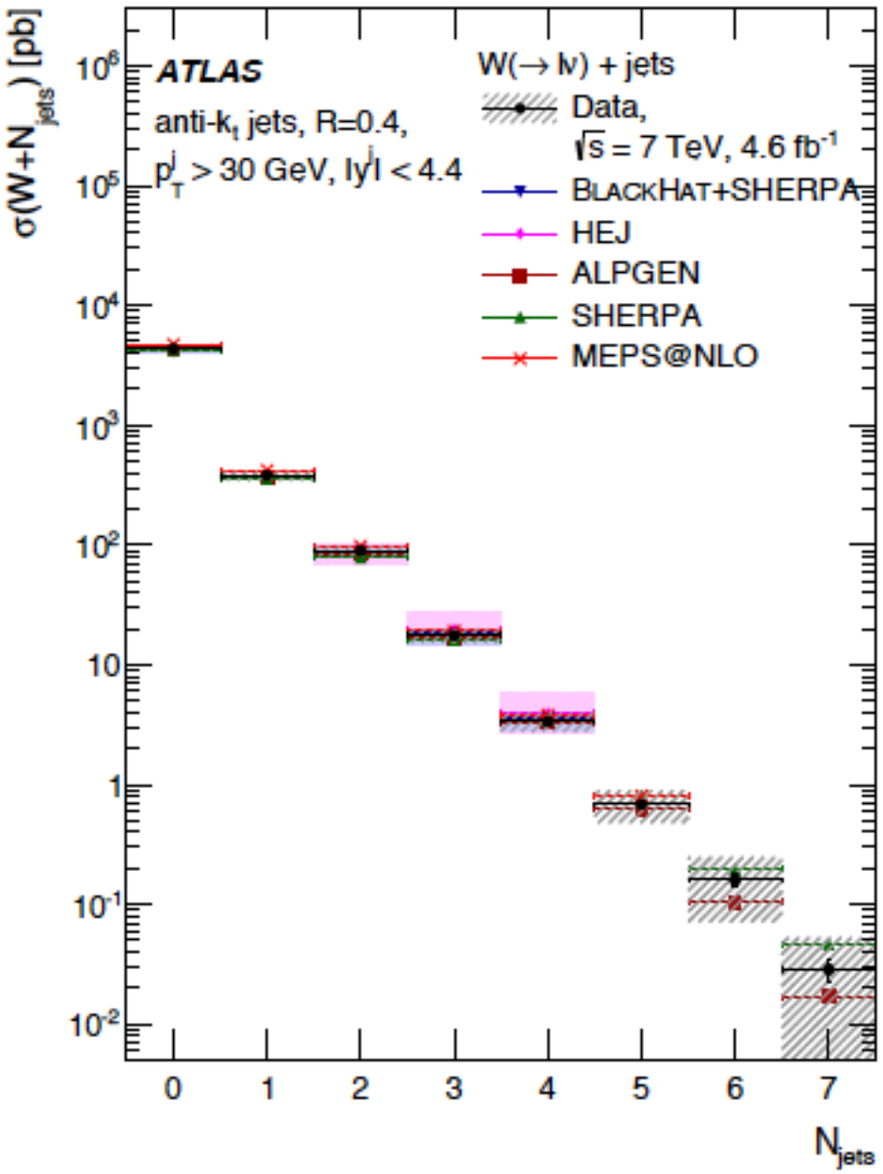
MadGraph5_aMC@NLO [1405.0301]

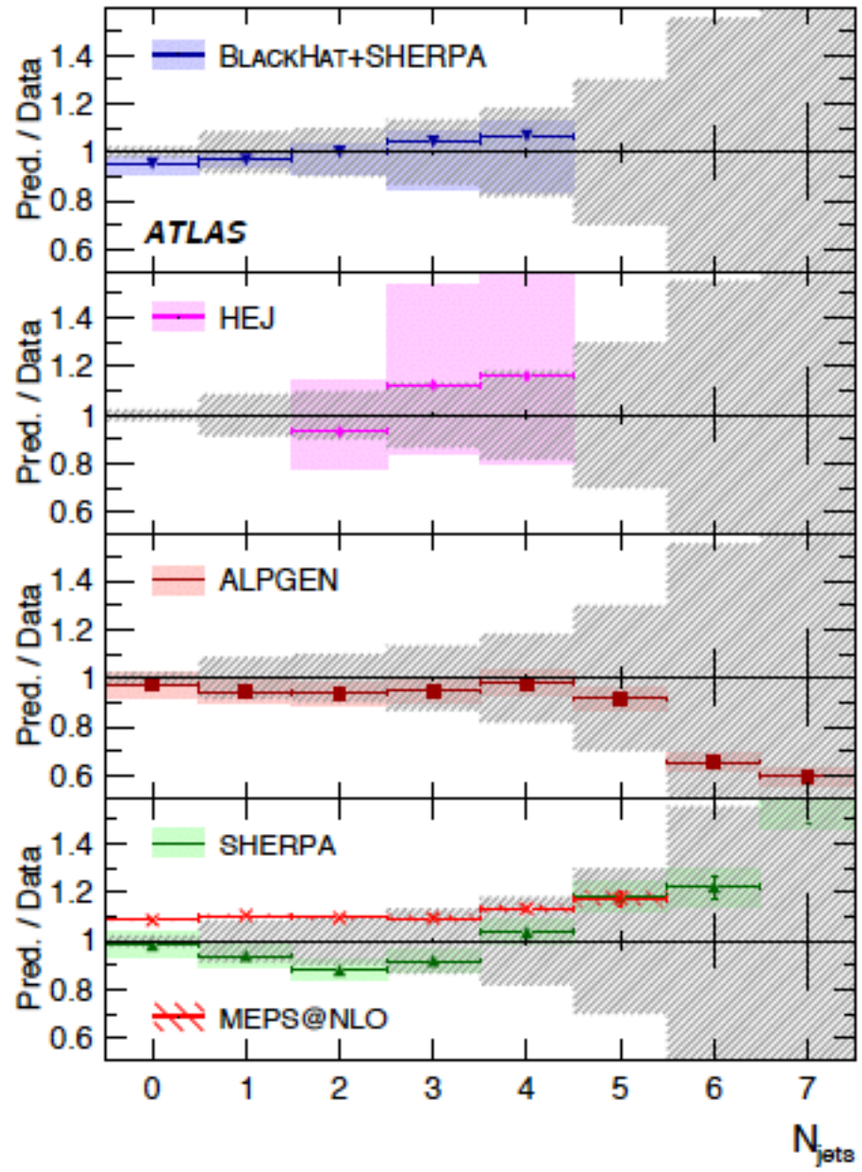




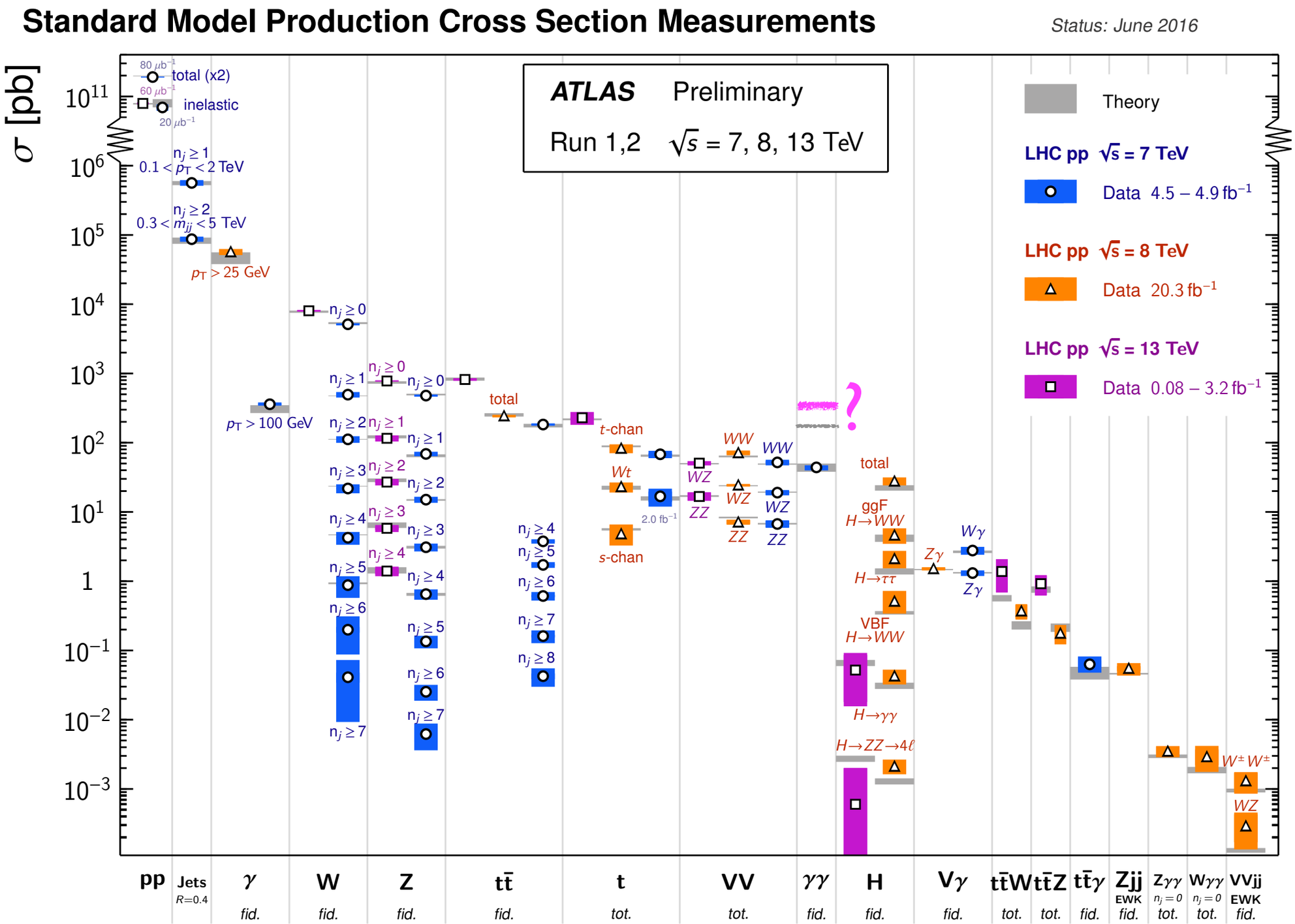
ME+PS merging @NLO

ATLAS [1409.8639]





Amazing… precision SM backgrounds



4. Summary and outlook

Summary and outlook

- Congratulation on the 10th anniversary of MC4BSM!
  — Impressive progresses during the last 10 years.
  - We can simulate any processes in any BSM models at the tree level by ME+PS merging.
  - NLO+PS matching/merging MC tools provide more reliable predictions, and are becoming the new standard.
  - Fully automatic NLO-QCD computations for SM processes as well as for several BSM processes, e.g. simplified SUSY and DM models, are already publicly available.
- What is the next? What should we do toward MC4BSM2026?