TOOLS 2010 Summary Talk

Fawzi BOUDJEMA LAPTH-Annecy, France

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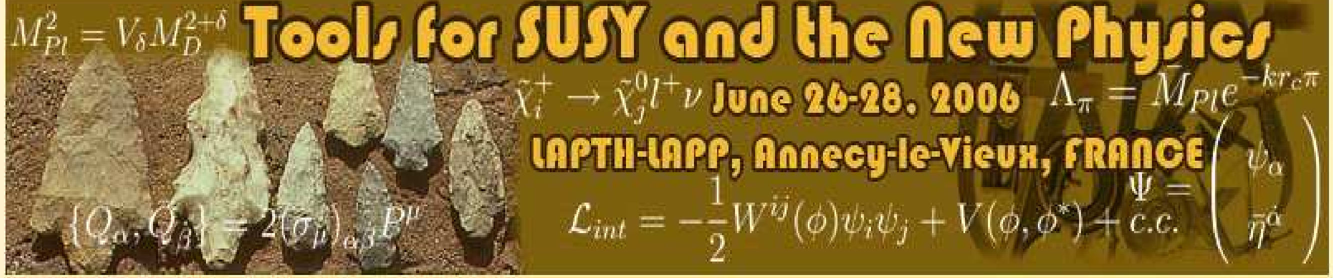
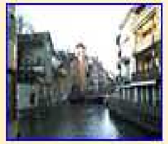


Welcome | Registration | Program | Participants | Accomodation | Committee

TOOLS 2006



Tools for Susy and the New Physics
June 26-28, 2006 LAPTH-LAPP, Annecy-le-Vieux, France

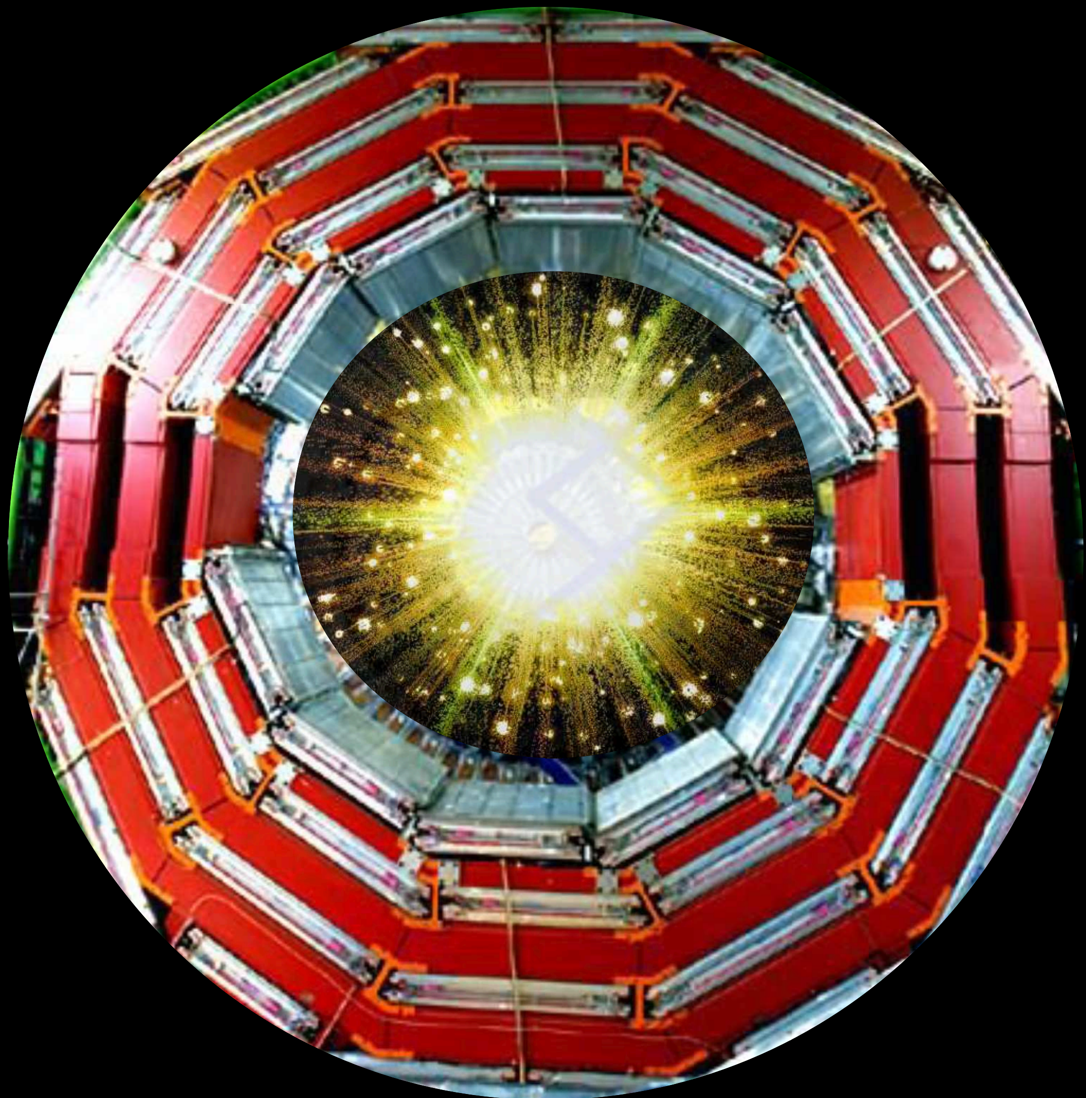
The aim of the Workshop is to review the main calculational tools, including generators and Monte-Carlos, for the beyond standard model particle searches at present and future colliders as well as in non collider physics experiments such as dark matter searches. Apart from the talks, discussion sessions are planned. In these round tables we expect to discuss how the existing programs could be improved, how to incorporate different existing constraints, how to best present future data and how modules from different codes could sewn together and interchanged.

Tools for SUSY : 1998 - 1999 - 2000

Secretariat

TOOLS 2006 (Organisation Email) : tools2006@lapp.in2p3.fr
Secretary : Turc-Poencier Dominique Tel : +33 4 50 09 16 84

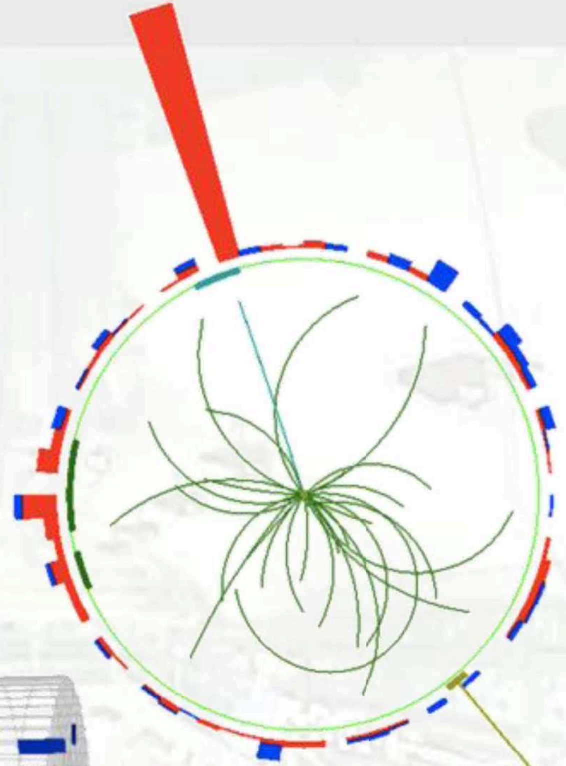
For a looooooooooong
time we had this:

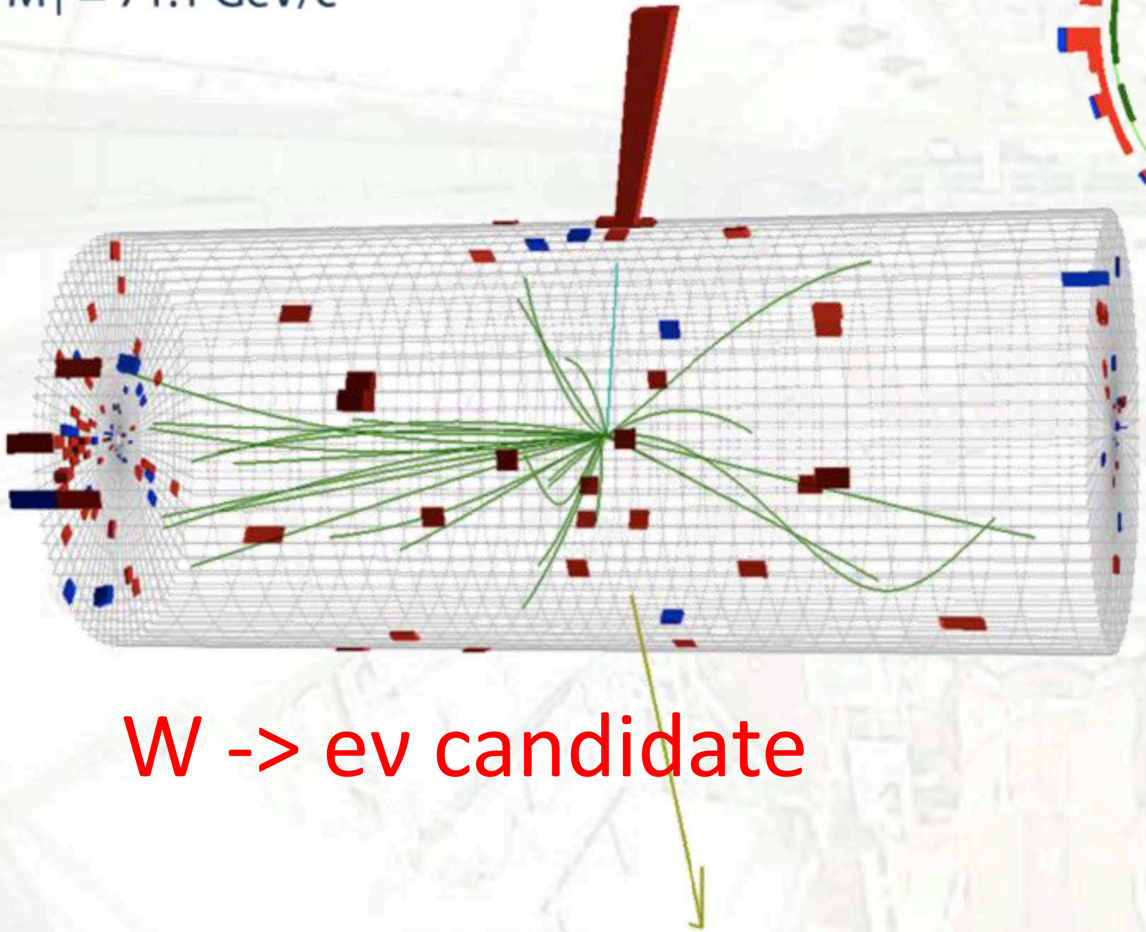


Now at last, we are blessed with this!

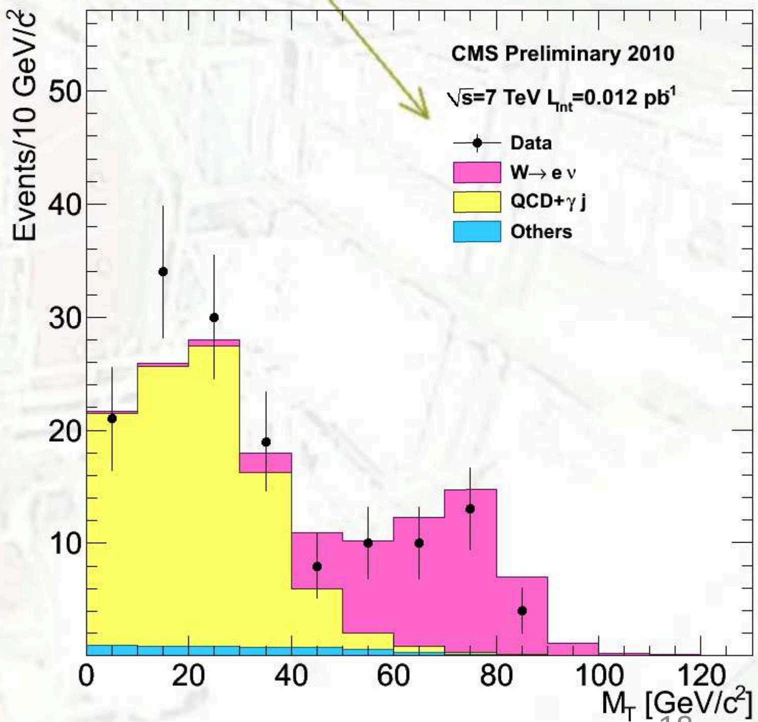
CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2





W -> eν candidate

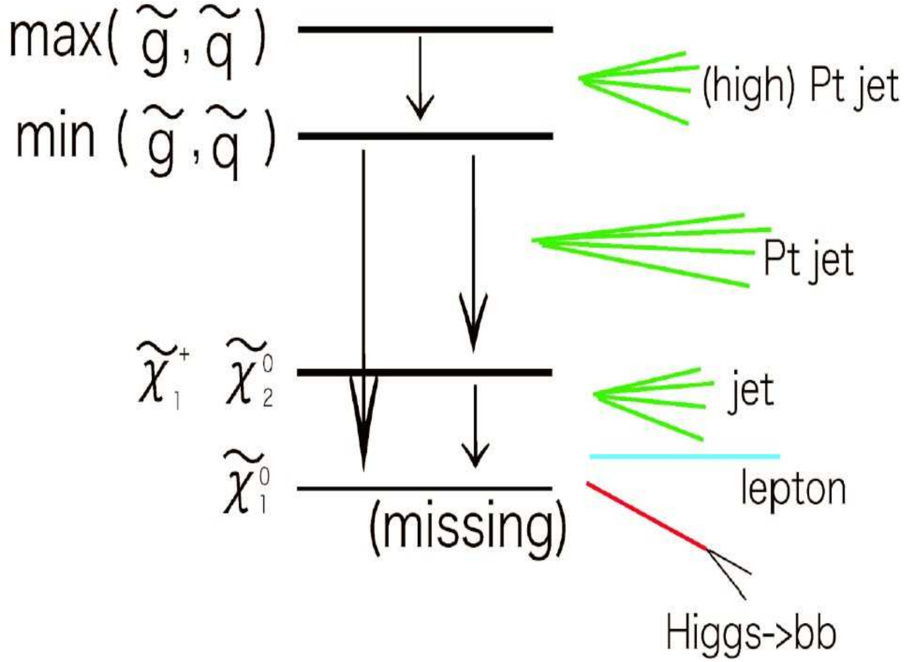


SUMMARY

- CMS successfully performing: collected ~30nb^{-1} so far.
- Various physics simulation tools have been used to explore physics opportunities with CMS for SM and diverse BSM models
- With the present minimum bias and underlying event data, tuning of MCs already started – but we need to implement more systematic approaches
- CMS has incorporated a majority of existing tools into its framework. Implementation becomes easier when the tools have uncomplicated workflows, follow standards such as LHE, SLHA, and allow easy access to input parameters.
- We also welcome a common act towards understanding MC parameters, higher-order cross sections and theoretical uncertainties.

Turn on the machine!

in 1998 we were told to expect an early SUSY discovery



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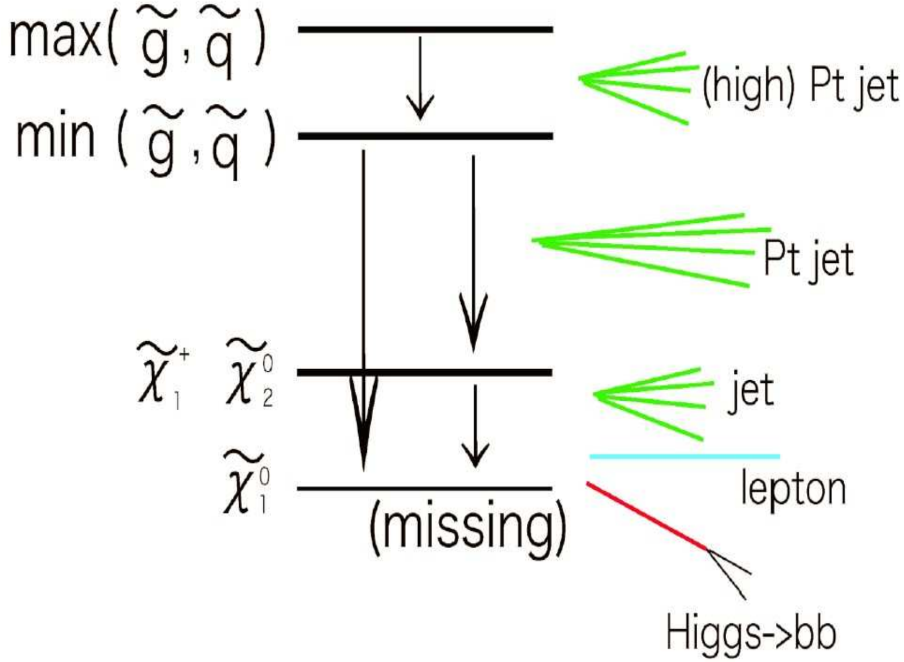
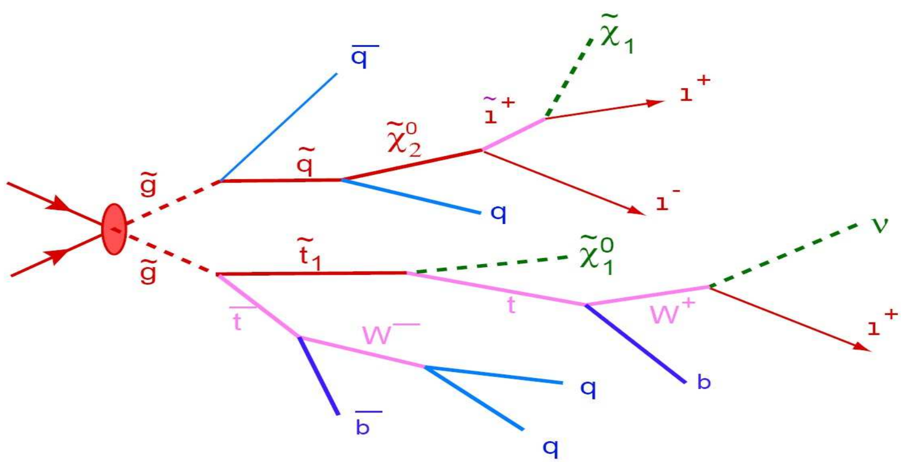
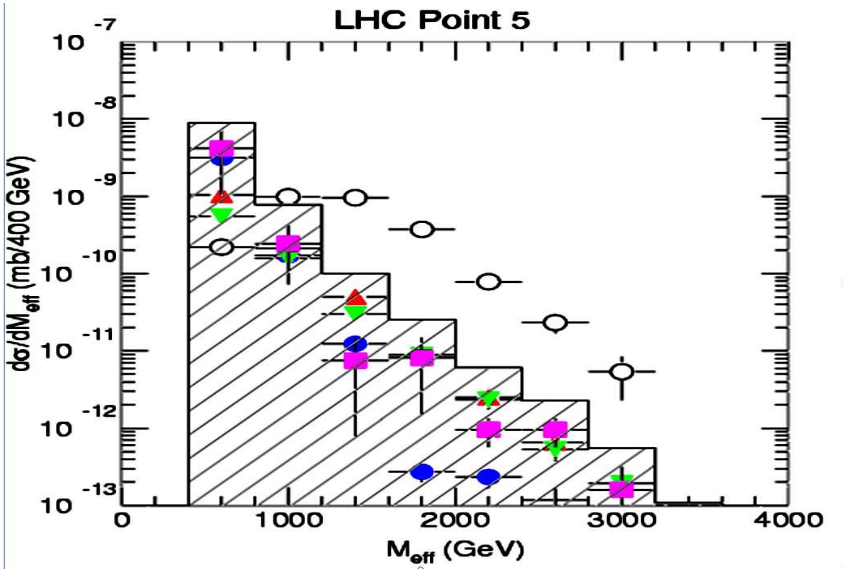


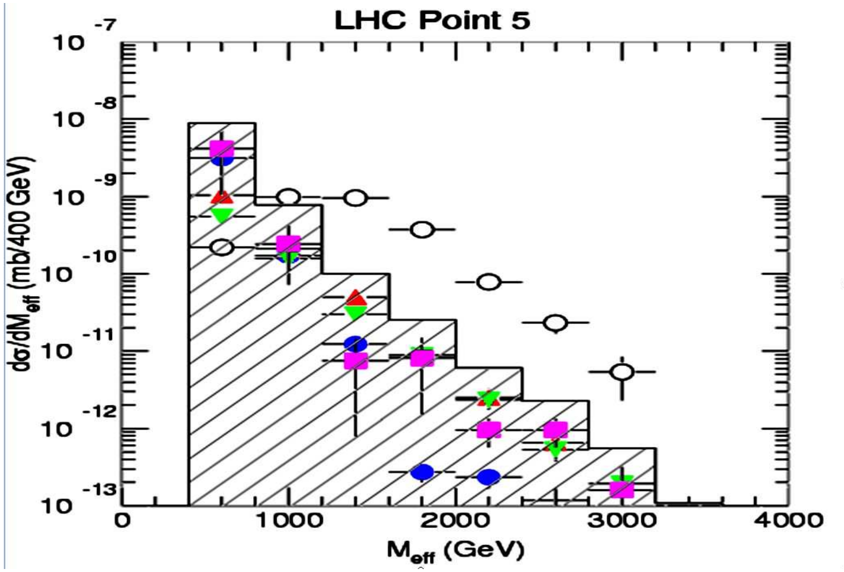


ATLAS TDR (same with CMS)



ATLAS TDR 98
(mSUGRA point, PreWMAP)

ATLAS TDR (same with CMS)



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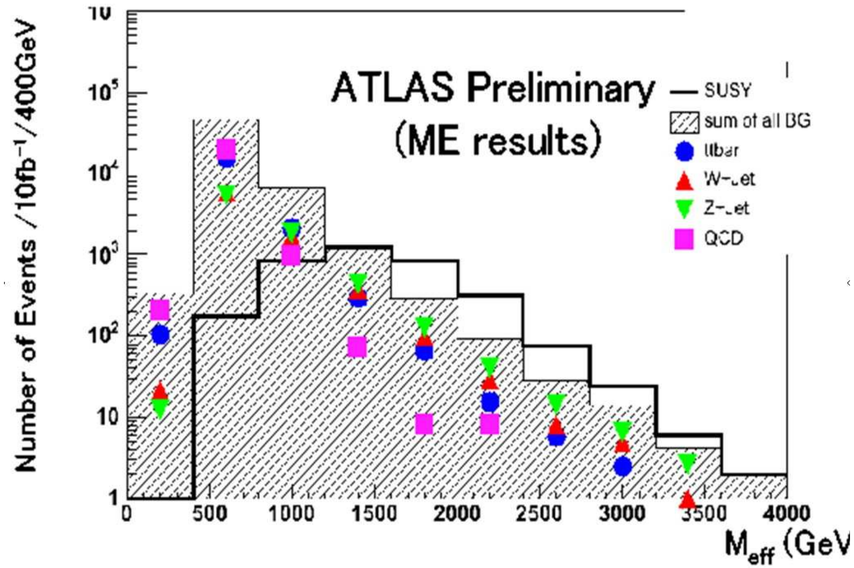

ATLAS 2006

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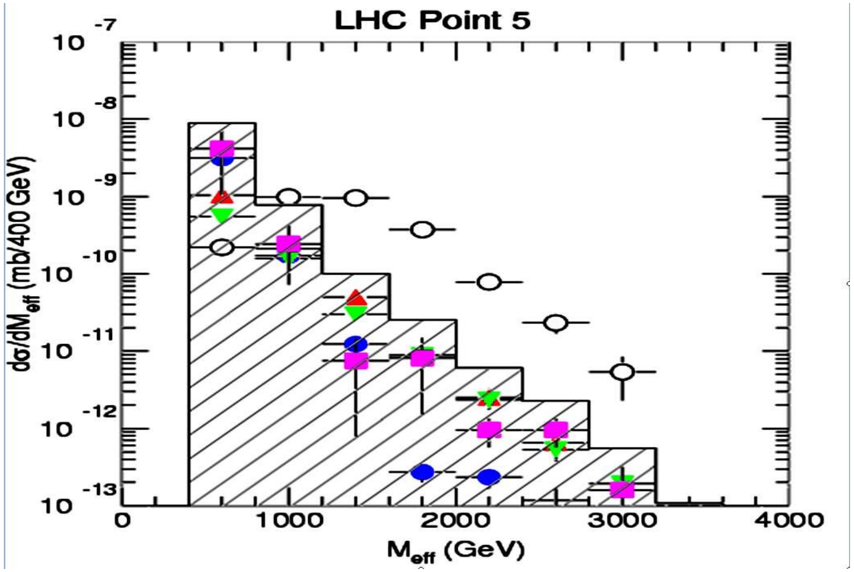

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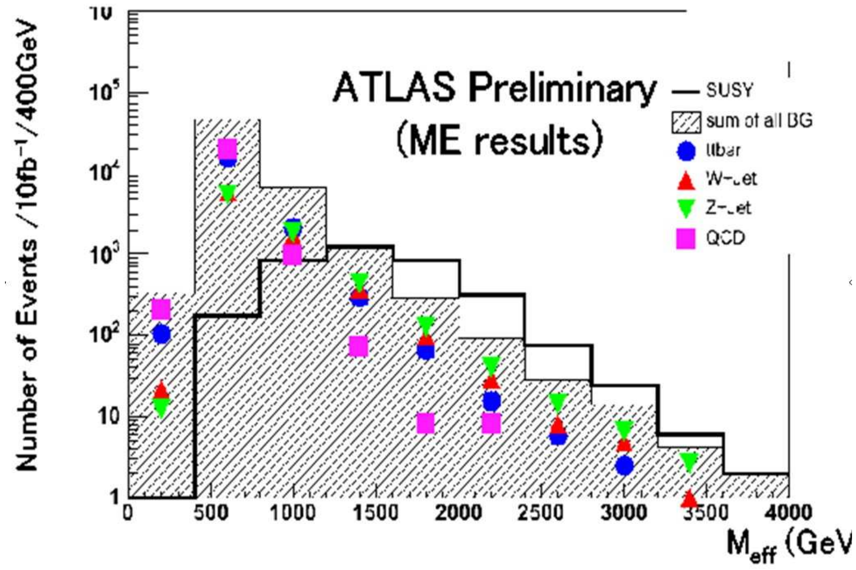
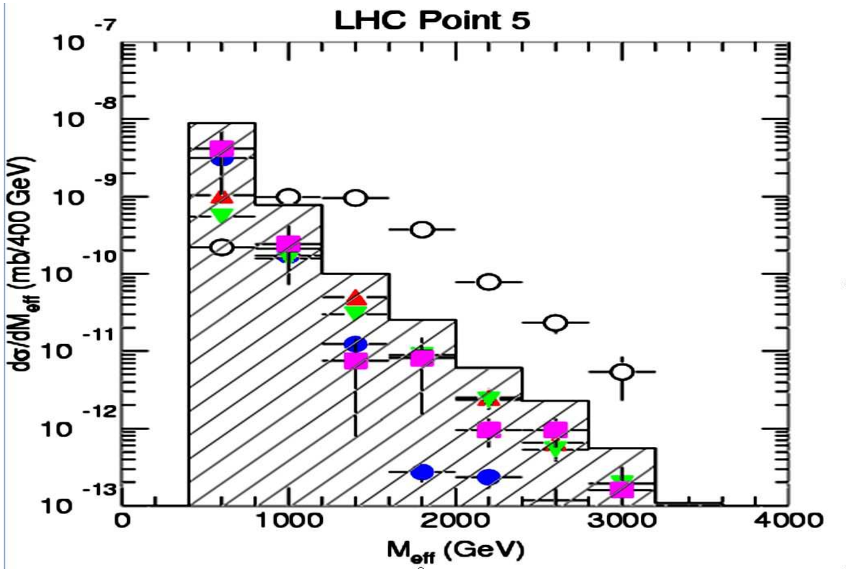


ATLAS 2006

What happened?

ATLAS TDR (same with CMS)



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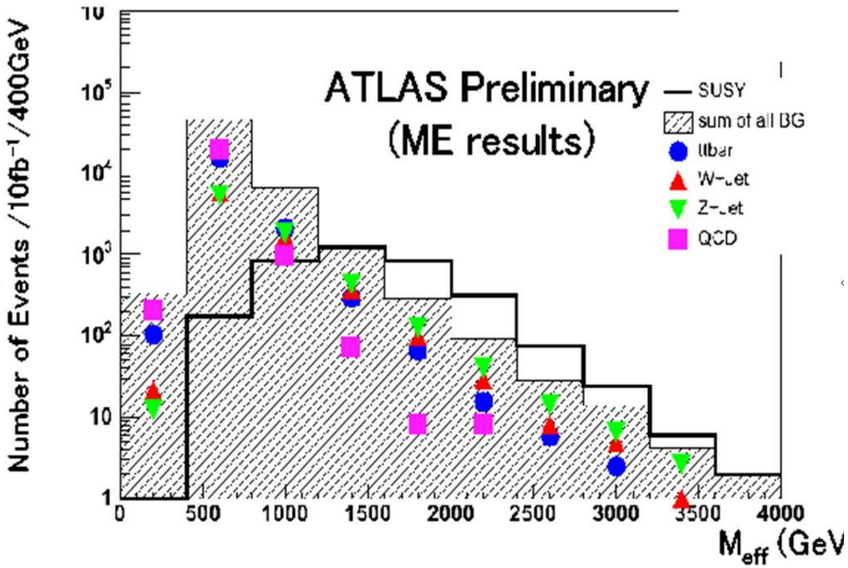
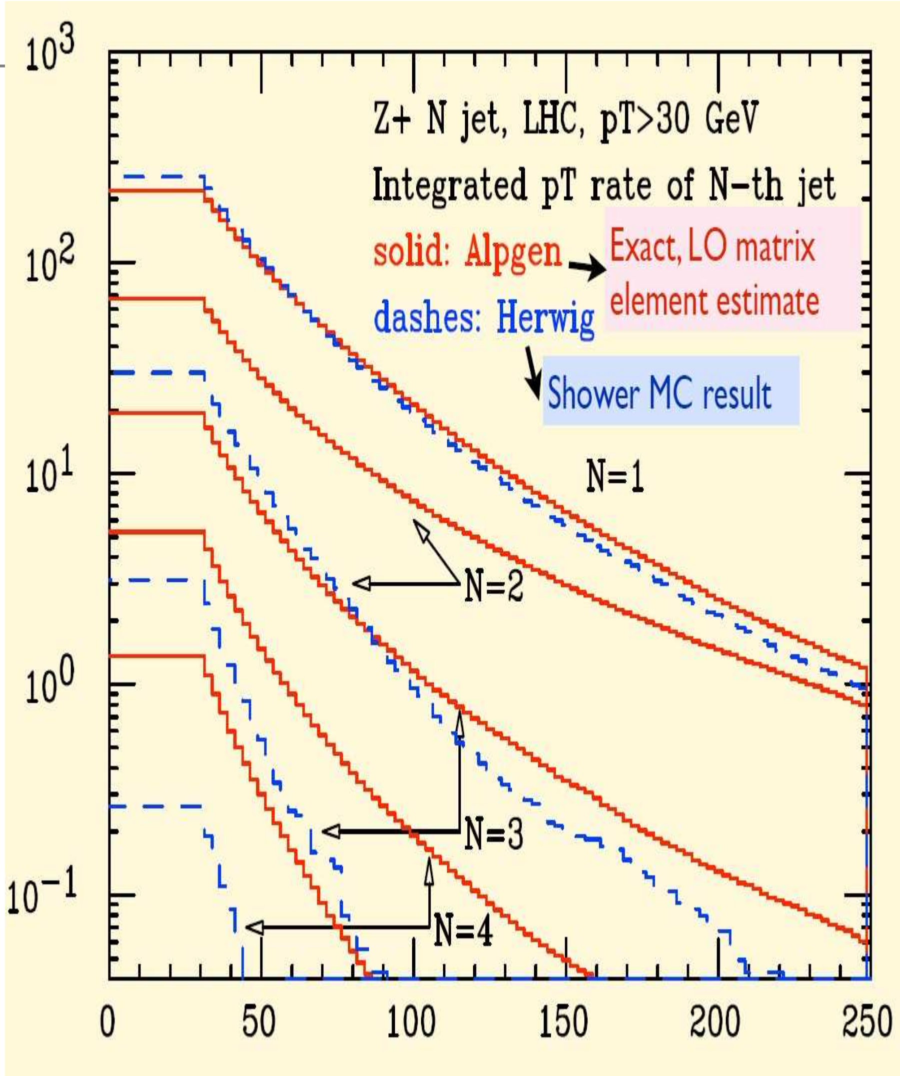


ATLAS 2006

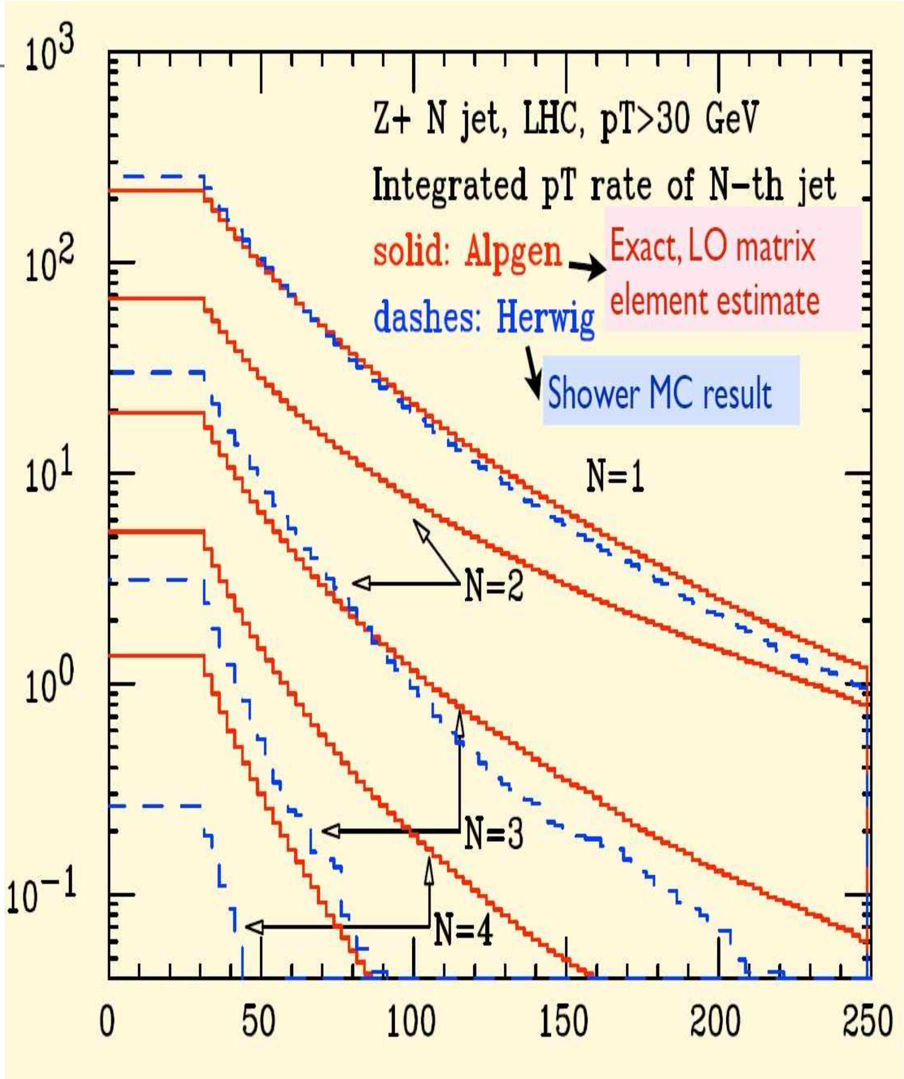
QCD and SM processes can also produce hard jets! and these were lacking in PS/MC

ME vs PS: Limitations of PS, improvement PS (See Peter R.)



- PS do not describe hard jets
- ME do but in practice can not produce as many jets as PS
- ME evaluates the complete set of all diagrams/configurations: costly
- some real progress has been made in interfacing ME with PS
- CKKW, MLM matching
- Still, all of this at leading order

ME vs PS: Limitations of PS, improvement PS (See Peter R.)



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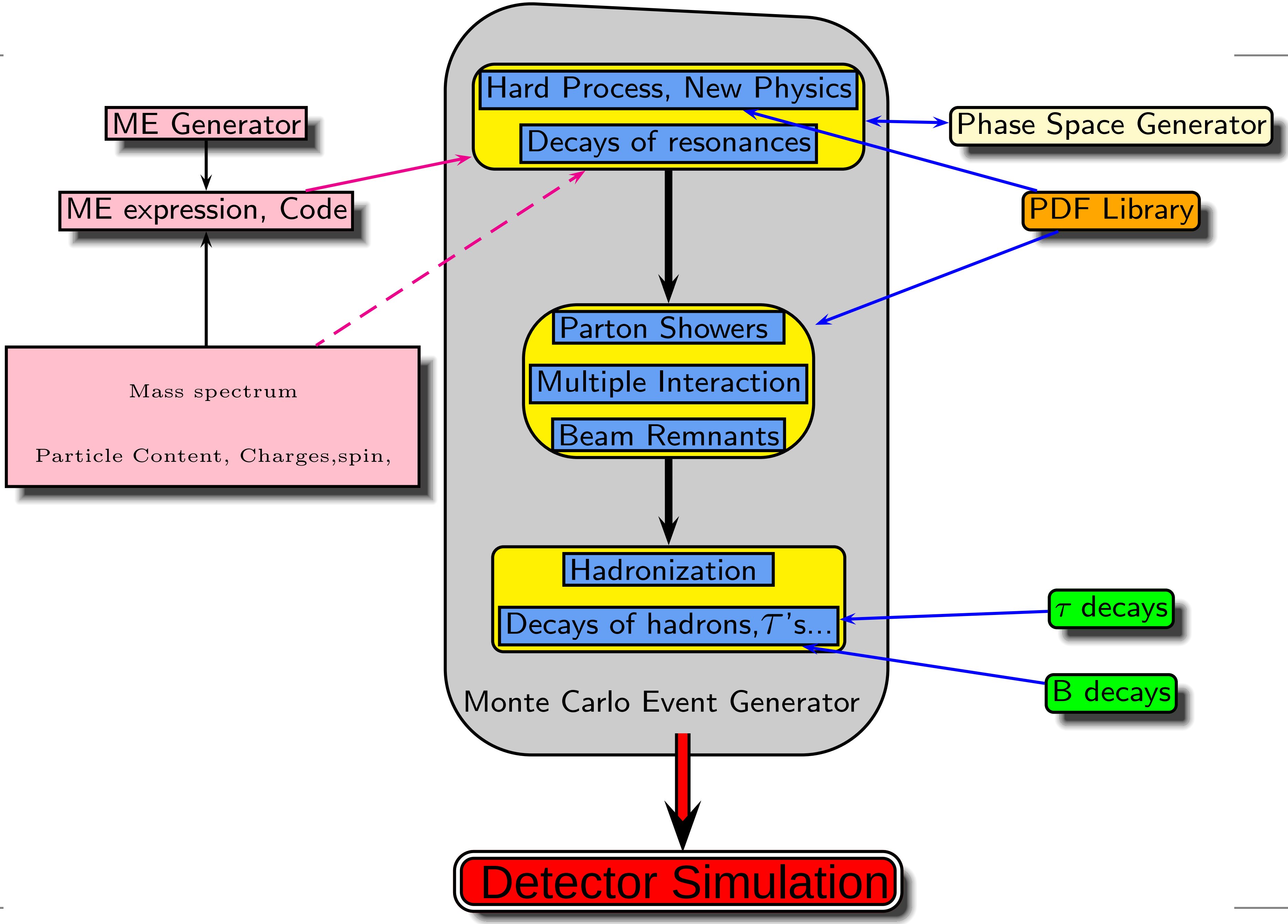
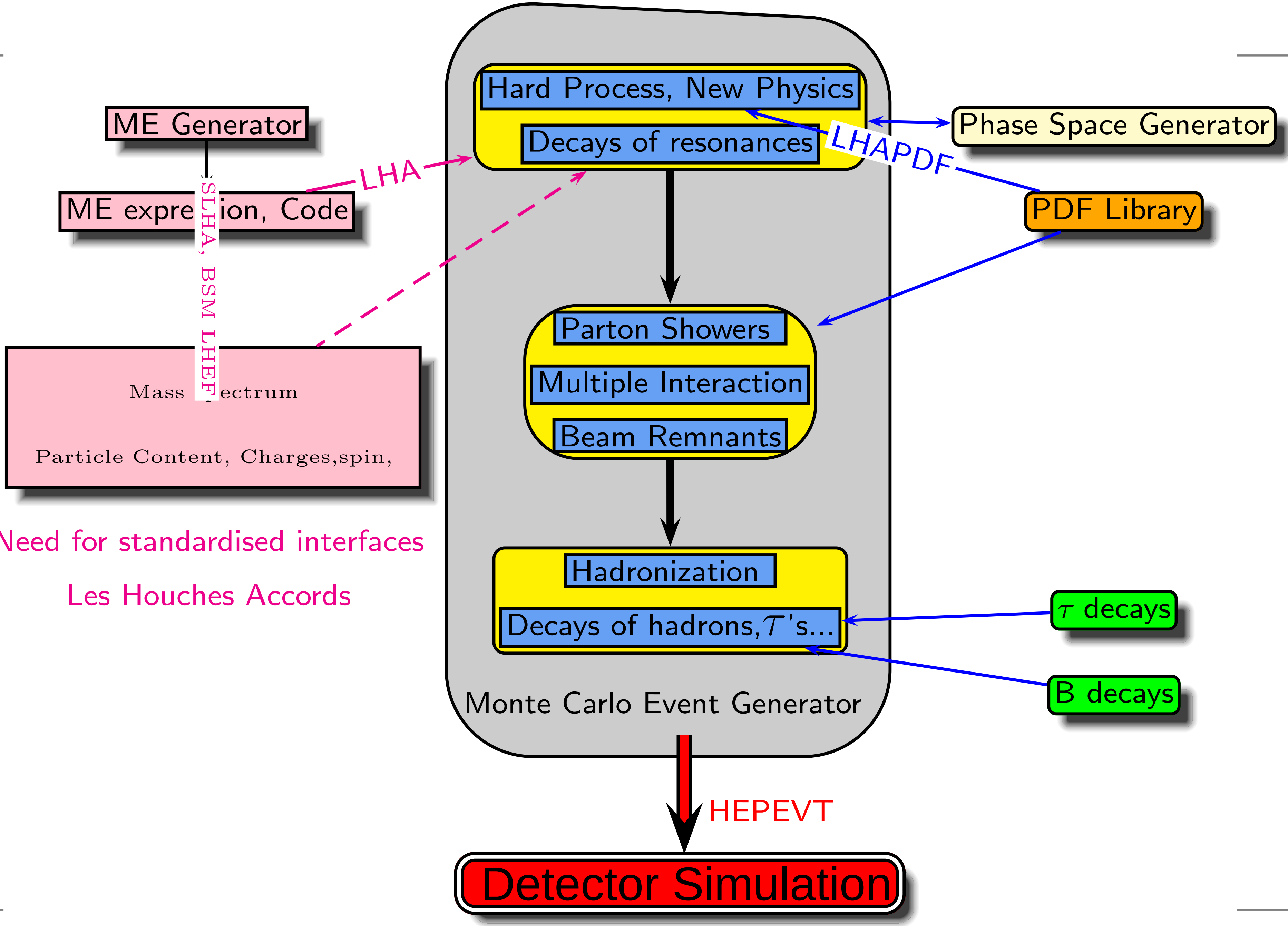
- ME evaluates the complete set of all diagrams/configurations: costly
- some real progress has been made in interfacing ME with PS
- CKKW, MLM matching
- Improvement MC/@NLO and POWHEG (higher multiplicity + NLO-Hamilton+Nason)

Putting all together

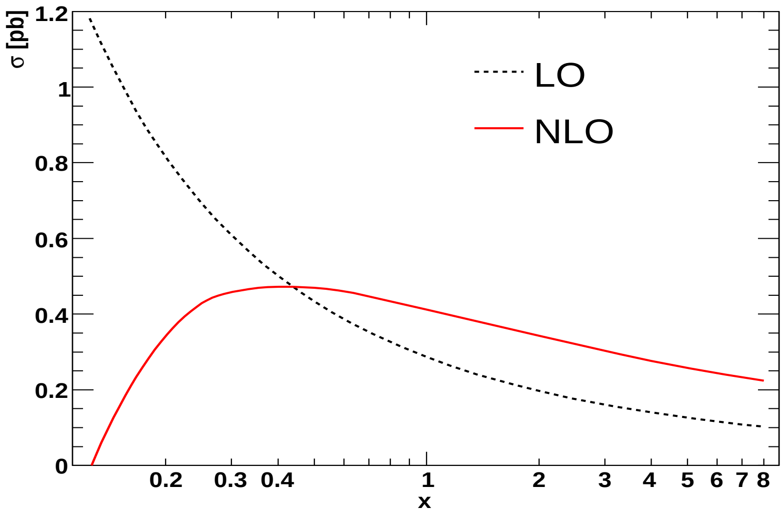


Putting all together, Les Houches Accords

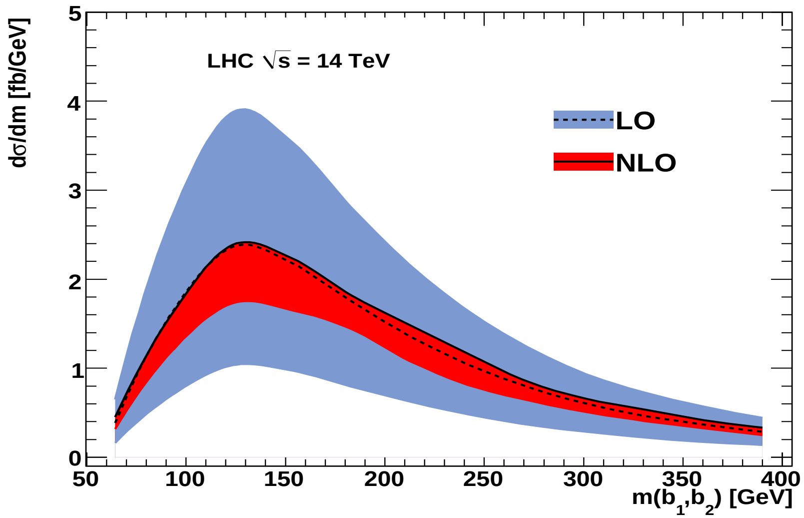


Need for standardised interfaces

Les Houches Accords



The dependence of the LO and NLO prediction of $pp(q\bar{q}) \to b\bar{b}b\bar{b} + X$ at the LHC ($\sqrt{s} = 14$ TeV) on the renormalisation scale $\mu_R = x\mu_0$ with $\mu_0 = \sqrt{\sum_j p_T^2(b_j)}$. The factorisation scale is fixed to $\mu_F = 100$ GeV.



Invariant mass (m_{bb}) distribution of the two leading b-quarks . The LO/NLO bands are obtained by varying the renormalisation scale μ_R between $\mu_0/4$ and $2\mu_0$ with $\mu_0 = \sqrt{\sum_j p_T^2(b_j)}$. The full (dashed) line shows the NLO (LO) prediction for the value $\mu_R = \mu_0/2$.

what NLO brings

- LO predictions only qualitative, due to poor convergence of perturbative expansion $\alpha_s \sim 0.1 \rightarrow$ NLO can be $\mathcal{O}(30-100)\%$
- First prediction of normalization of cross-sections is at NLO less sensitivity to unphysical input scales (renormalization,factorization)
- more physics at NLO
  - parton merging to give structure in jets
  - more species of incoming partons enter at NLO
  - initial state radiation effects
- a prerequisite for more sophisticated calculations which match NLO with parton showers

Usual procedure and normalisation with data.....

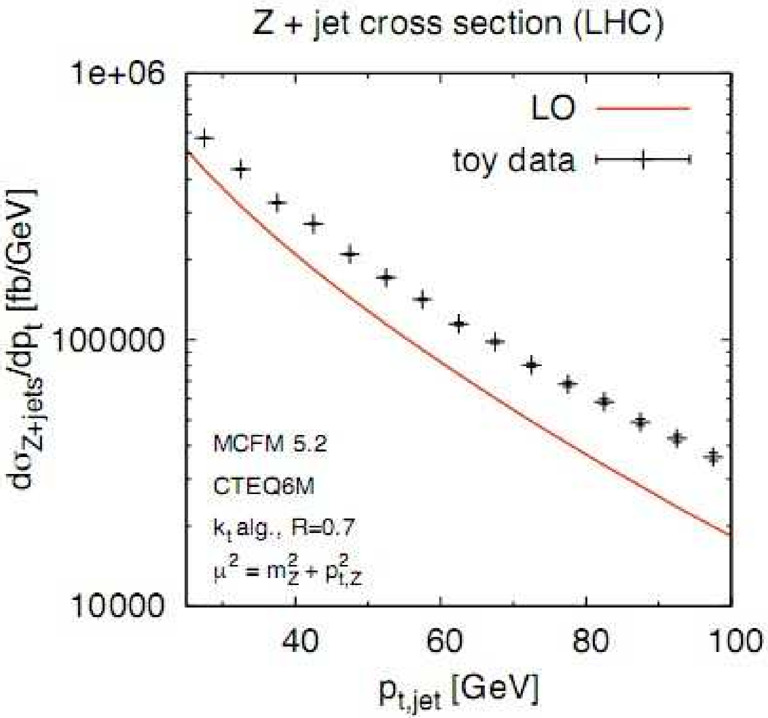
- Stage 1: get control sample in low pt region (little SUSY contamination)
- Stage 2: once LO is validated using data, trust it in signal region

Example for Salam, Zanderighi et al, high Use W+1 jet known at NLO to see how good this works

Is NLO really needed?

Stage 1:

get control sample (K-factor)



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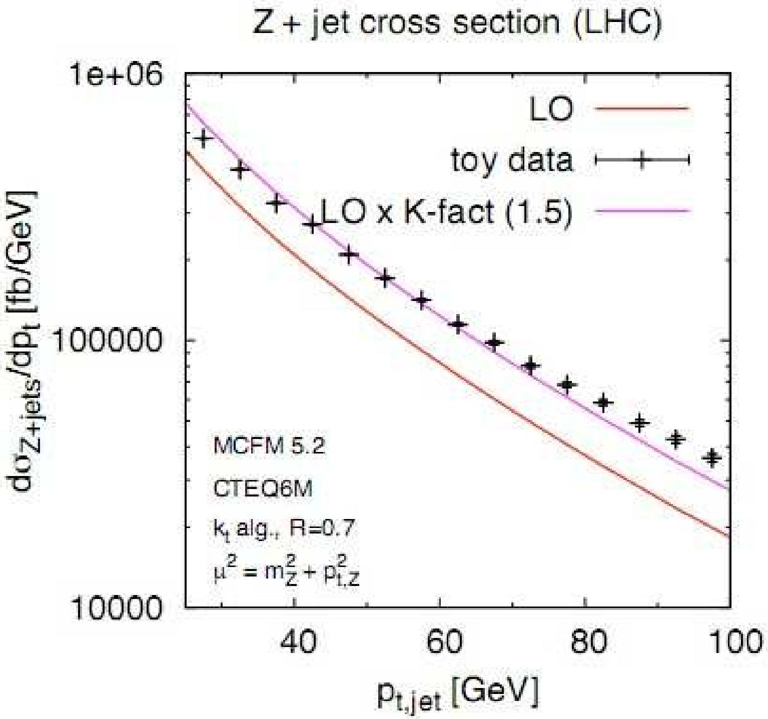

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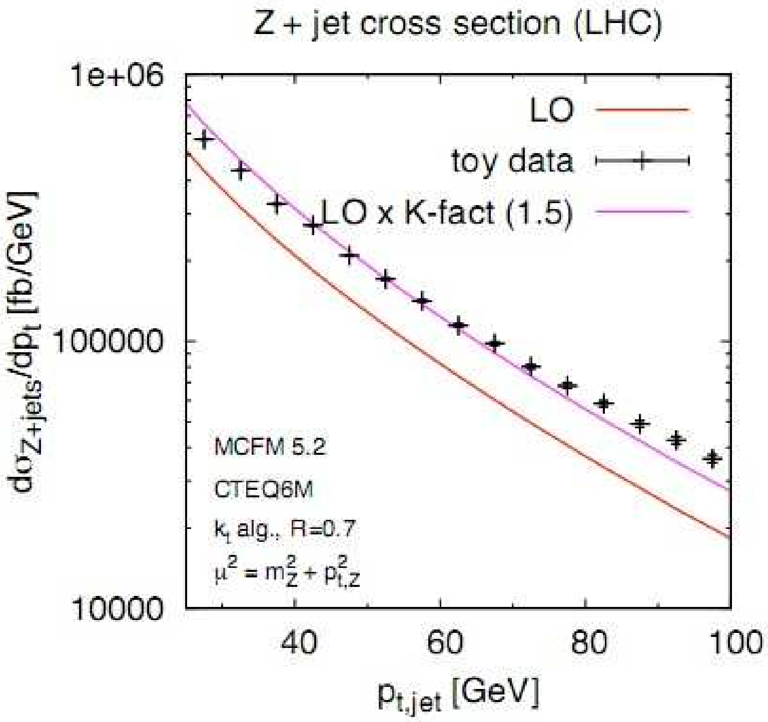
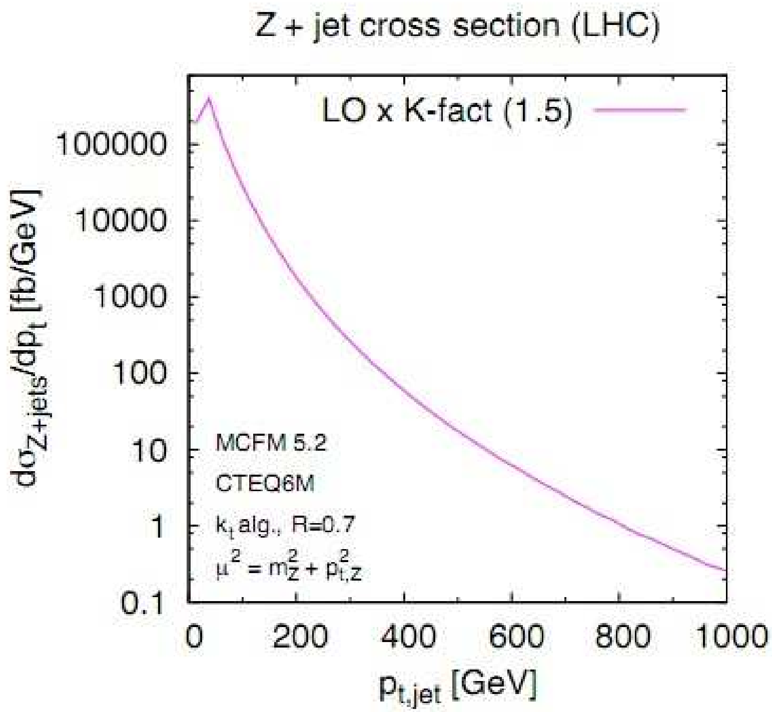


Stage 2:
extrapolate to the signal region



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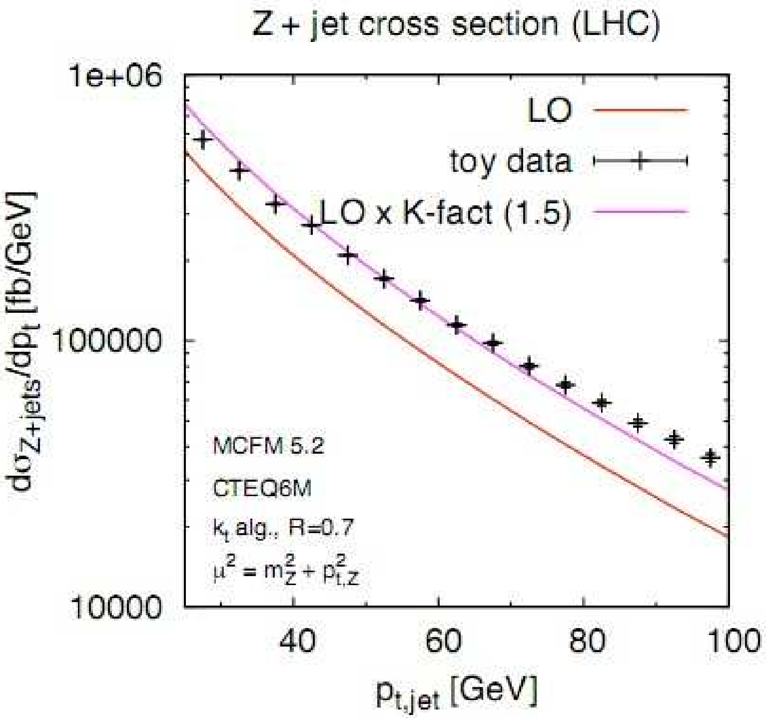

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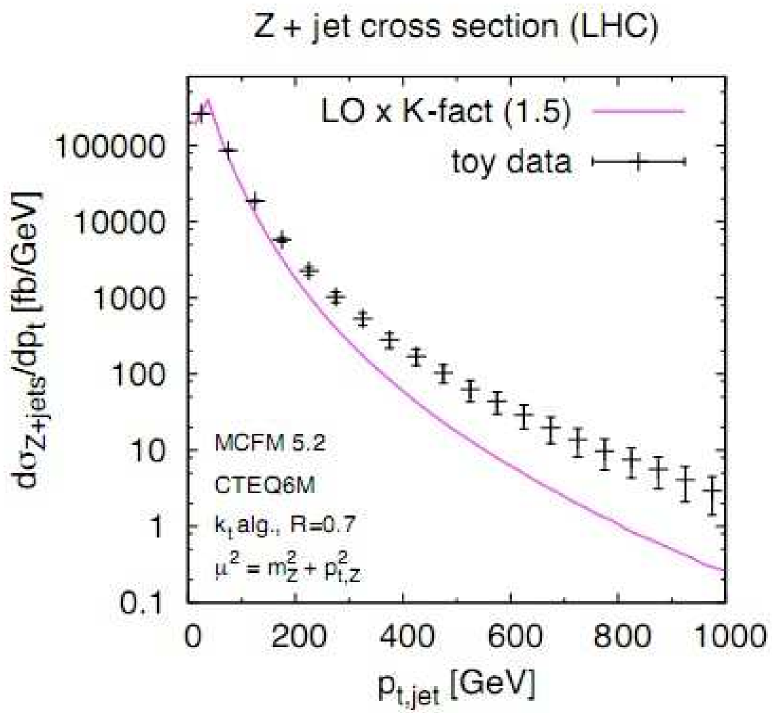

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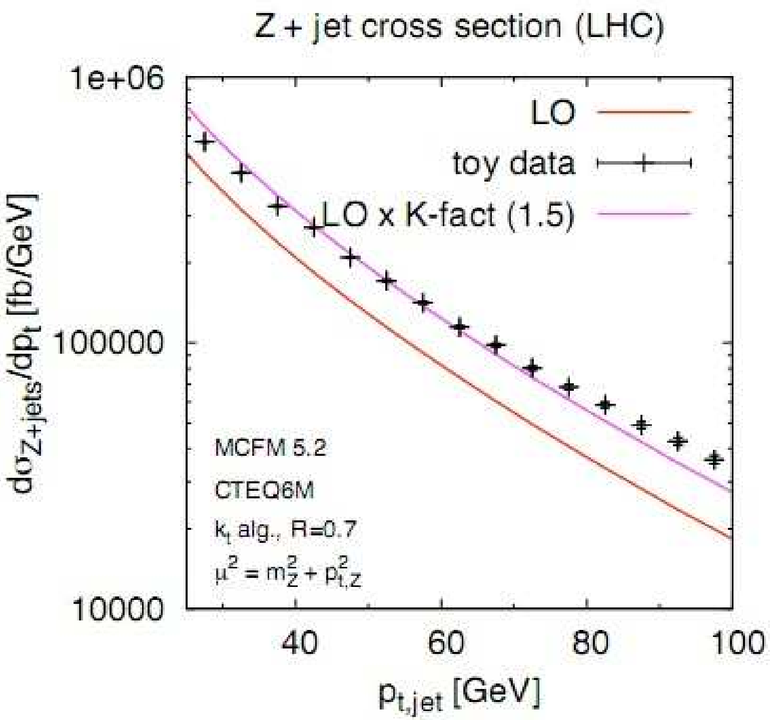

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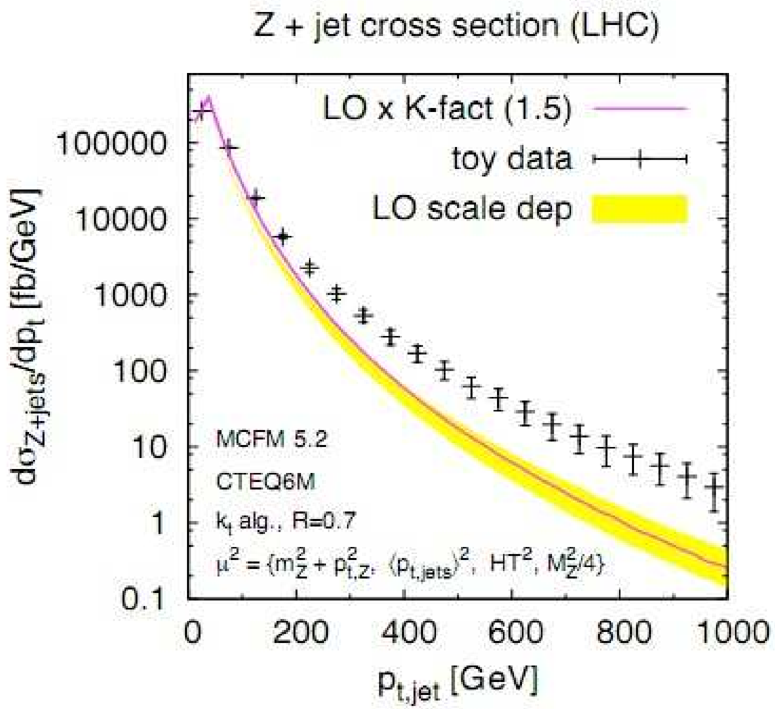

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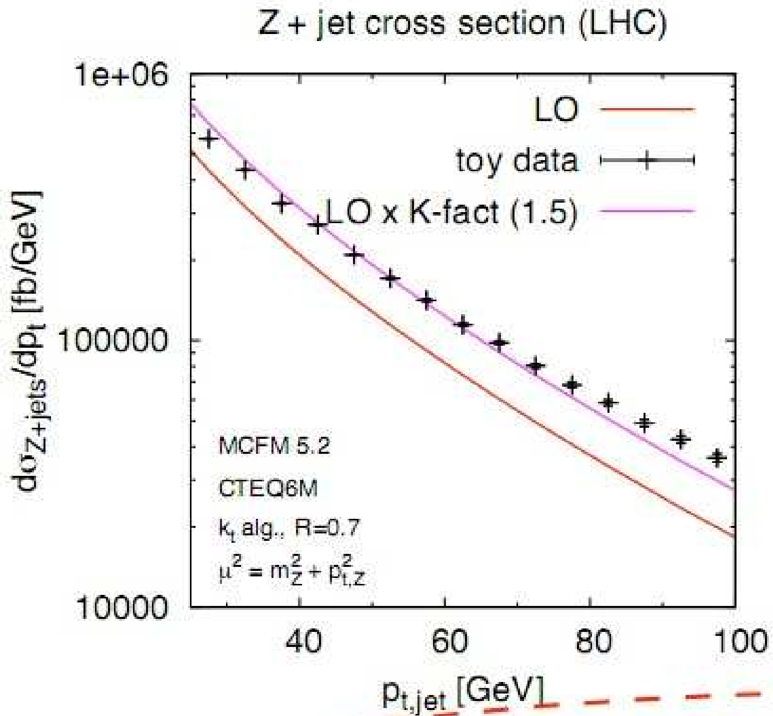
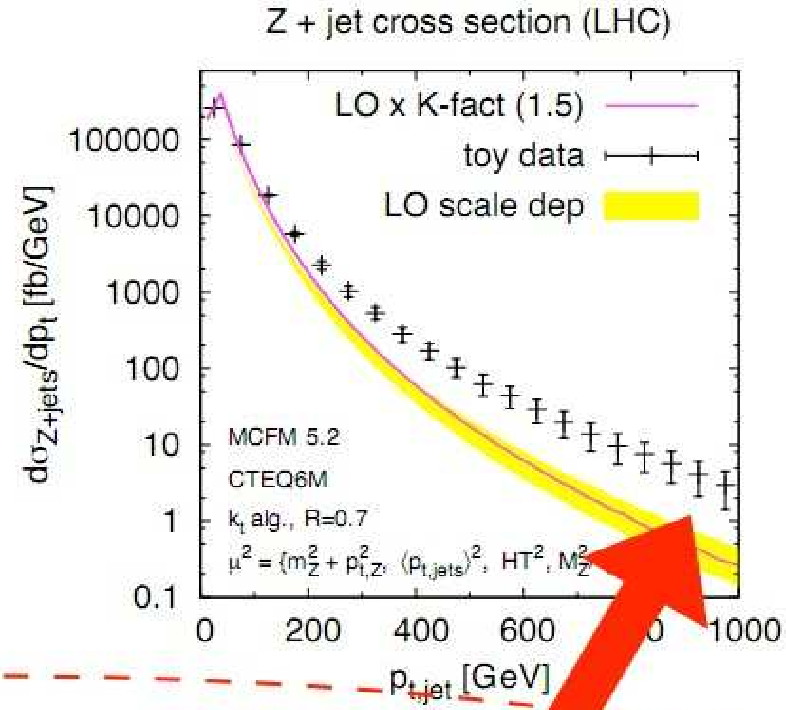
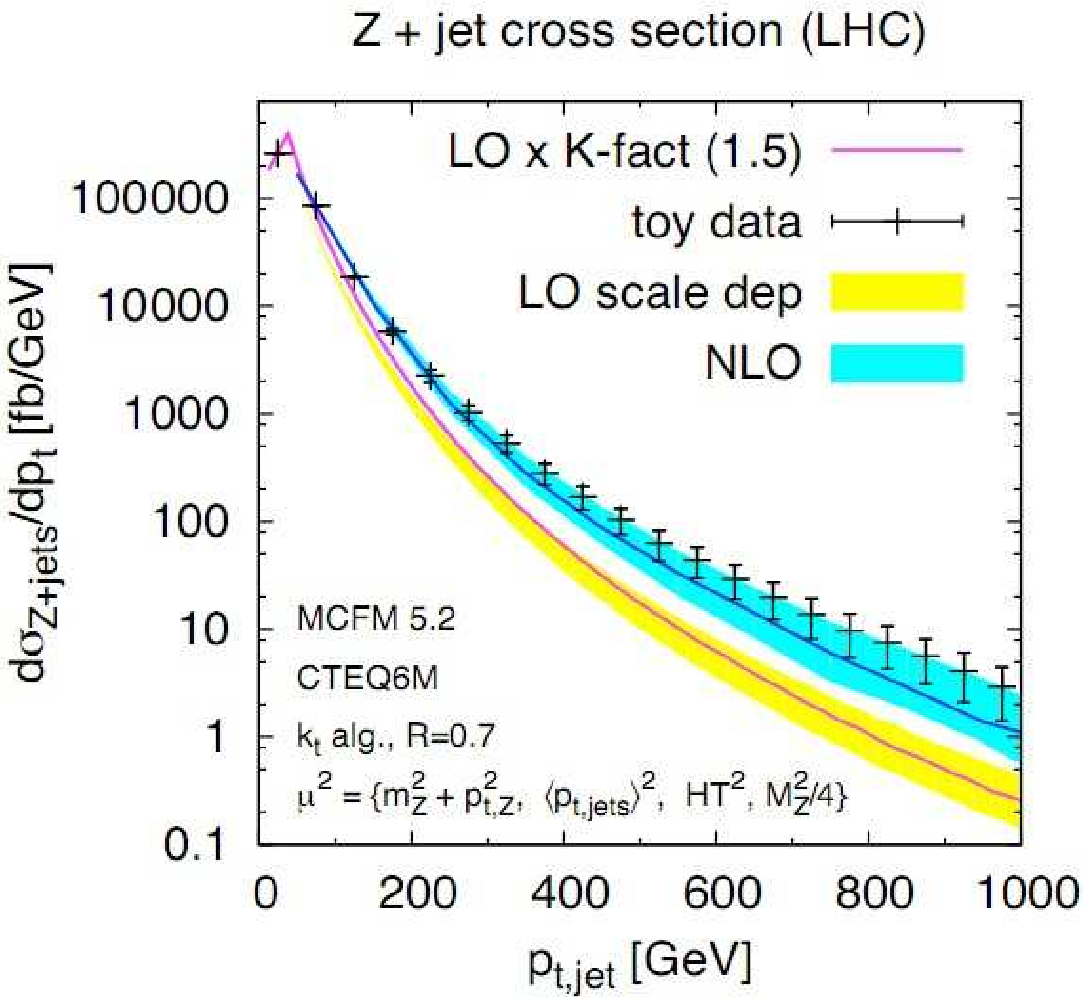


Stage 2:
extrapolate to the signal region



Factor 10 excess. 6σ deviation.
Discovery ??

No, just plain NLO QCD...



NB: source of large K-factor understood [soft Z radiated from hard jets]

See Butterworth, Davison, Salam, Rubin '08

The dreamer's wishlist for NLO processes

Single boson	Diboson	Triboson	Heavy flavor
$W + \leq 5j$	$WW + \leq 5j$	$WWW + \leq 3j$	$t\bar{t} + \leq 3j$
$W + b\bar{b} + \leq 3j$	$WW + b\bar{b} + \leq 3j$	$WWW + b\bar{b} + \leq 3j$	$t\bar{t} + \gamma + \leq 2j$
$W + c\bar{c} + \leq 3j$	$WW + c\bar{c} + \leq 3j$	$WWW + \gamma\gamma + \leq 3j$	$t\bar{t} + W + \leq 2j$
$Z + \leq 5j$	$ZZ + \leq 5j$	$Z\gamma\gamma + \leq 3j$	$t\bar{t} + Z + \leq 2j$
$Z + b\bar{b} + \leq 3j$	$ZZ + b\bar{b} + \leq 3j$	$WZZ + \leq 3j$	$t\bar{t} + H + \leq 2j$
$Z + c\bar{c} + \leq 3j$	$ZZ + c\bar{c} + \leq 3j$	$ZZZ + \leq 3j$	$t\bar{b} + \leq 2j$
$\gamma + \leq 5j$	$\gamma\gamma + \leq 5j$		$b\bar{b} + \leq 3j$
$\gamma + b\bar{b} + \leq 3j$	$\gamma\gamma + b\bar{b} + \leq 3j$		$b\bar{b}\,t\bar{t}$
$\gamma + c\bar{c} + \leq 3j$	$\gamma\gamma + c\bar{c} + \leq 3j$		
	$WZ + \leq 5j$		
	$WZ + b\bar{b} + \leq 3j$		
	$WZ + c\bar{c} + \leq 3j$		
	$W\gamma + \leq 3j$		
	$Z\gamma + \leq 3j$		

Les Houches 2009 Experimenter's Wishlist

Process ($V \in \{Z, W, \gamma\}$)	Comments
Calculations completed since Les Houches 2005	
1. $pp \to VV$jet	WWjet completed by Dittmaier/Kallweit/Uwer; Campbell/Ellis/Zanderighi. ZZjet completed by Binoth/Gleisberg/Karg/Kauer/Sanguinetti
2. $pp \to$ Higgs+2jets	NLO QCD to the gg channel completed by Campbell/Ellis/Zanderighi; NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier
3. $pp \to V\,V\,V$	ZZZ completed by Lazopoulos/Melnikov/Petriello and WWZ by Hankele/Zeppenfeld (see also Binoth/Ossola/Papadopoulos/Pittau)
4. $pp \to t\bar{t}\,b\bar{b}$	relevant for $t\bar{t}H$ computed by Bredenstein/Denner/Dittmaier/Pozzorini and Bevilacqua/Czakon/Papadopoulos/Pittau/Worek
5. $pp \to V$+3jets	calculated by the Blackhat/Sherpa and Rocket collaborations
Calculations remaining from 2005,	**completed since**
6. $pp \to t\bar{t}$+2jets	relevant for $t\bar{t}H$ computed by Bevilacqua/Czakon/Papadopoulos/Worek
7. $pp \to VV\,b\bar{b}$,	relevant for VBF $\to H \to VV$, $t\bar{t}H$
8. $pp \to VV$+2jets	relevant for VBF $\to H \to VV$ VBF contributions calculated by (Bozzi/)Jäger/Oleari/Zeppenfeld
NLO calculations added to list in 2007	
9. $pp \to b\bar{b}b\bar{b}$	$q\bar{q}$ channel calculated by Golem collaboration
NLO calculations added to list in 2009	
10. $pp \to V$+4 jets	top pair production, various new physics signatures
11. $pp \to Wb\bar{b}j$	top, new physics signatures
12. $pp \to t\bar{t}t\bar{t}$	various new physics signatures
Calculations beyond NLO added in 2007	
13. $gg \to W^*W^*$ $\mathcal{O}(\alpha^2\alpha_s^3)$	backgrounds to Higgs
14. NNLO $pp \to t\bar{t}$	normalization of a benchmark process
15. NNLO to VBF and Z/γ+jet	Higgs couplings and SM benchmark
Calculations including electroweak effects	
16.**NNLO QCD+NLO EW for W/Z**	precision calculation of a SM benchmark

Physics!!!

(Gleisberg, Hoeche, Krauss, Schoenher
Schumann, Siegert, Winter)

NLO with **BlackHat+Sherpa**

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

(S. Catani, M.H. Seymour,1997)

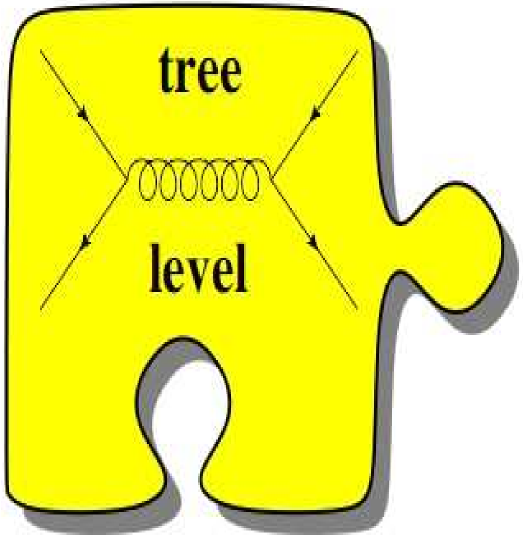
(T. Gleisberg, F. Krauss, 2007)

+

(a glance to NLO automation!)

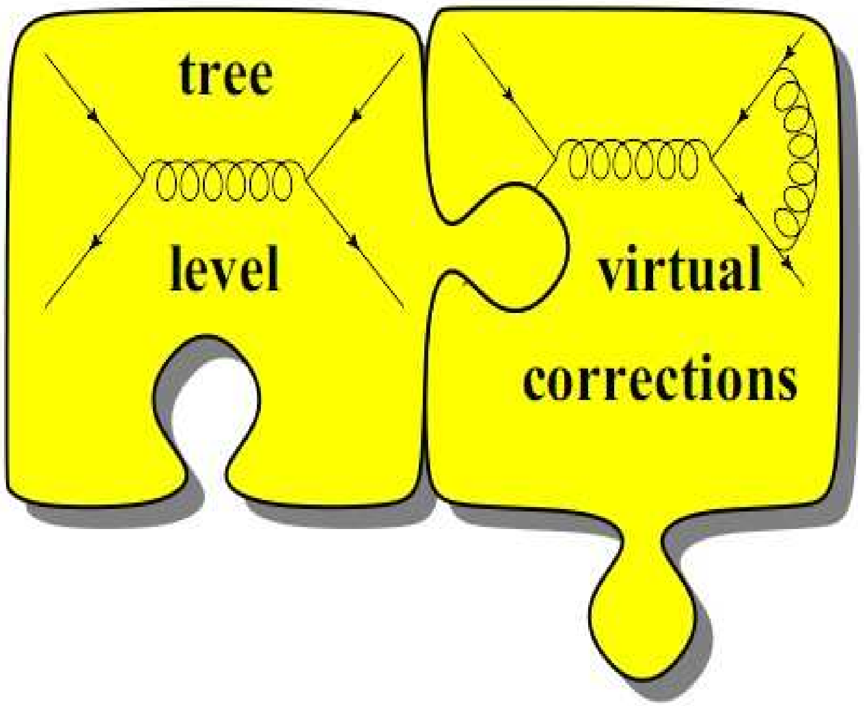
High level of automatisation, public

- ALPGEN (Mangano et al.)
- CalcHEP (Pukhov,Belyaev,Christensen)
- CompHEP (Boos et al.)
- Grace (Yuasa et al.)
- HELAS/PHEGAS (Papadopoulos et al.)
- MADGRAPH/MADEVENT (Maltoni,Stelzer)
- O'Mega/WHIZARD (Kilian,Moretti,Ohl,Reuter)
- SHERPA/Amegic (Krauss,Kuhn)

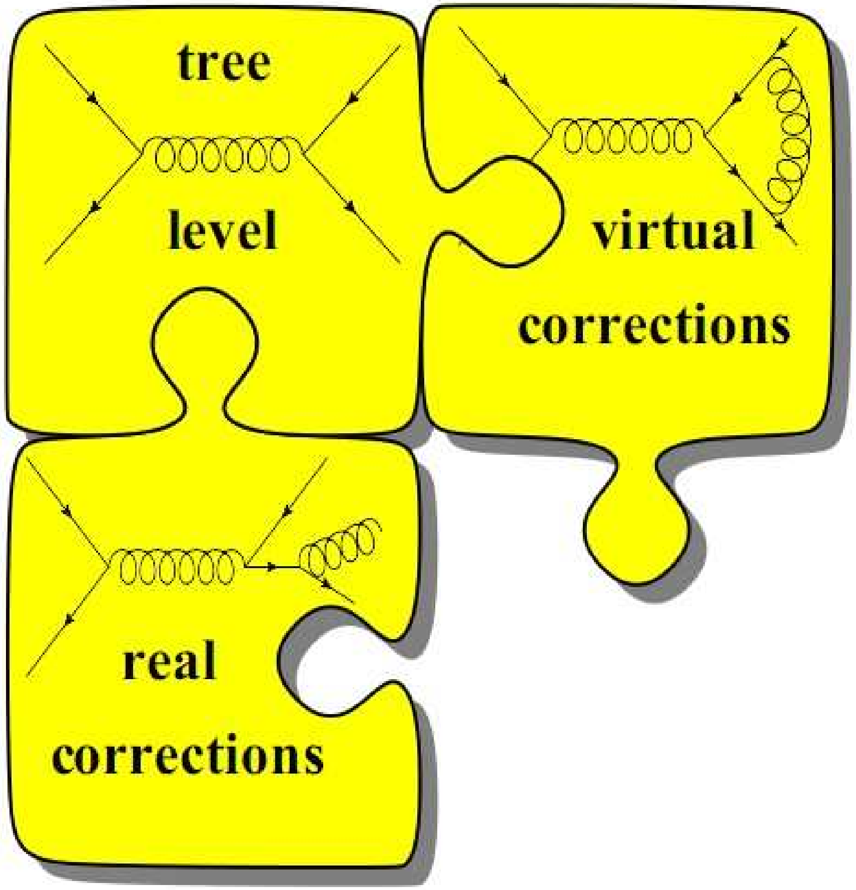


virtual Corrections:

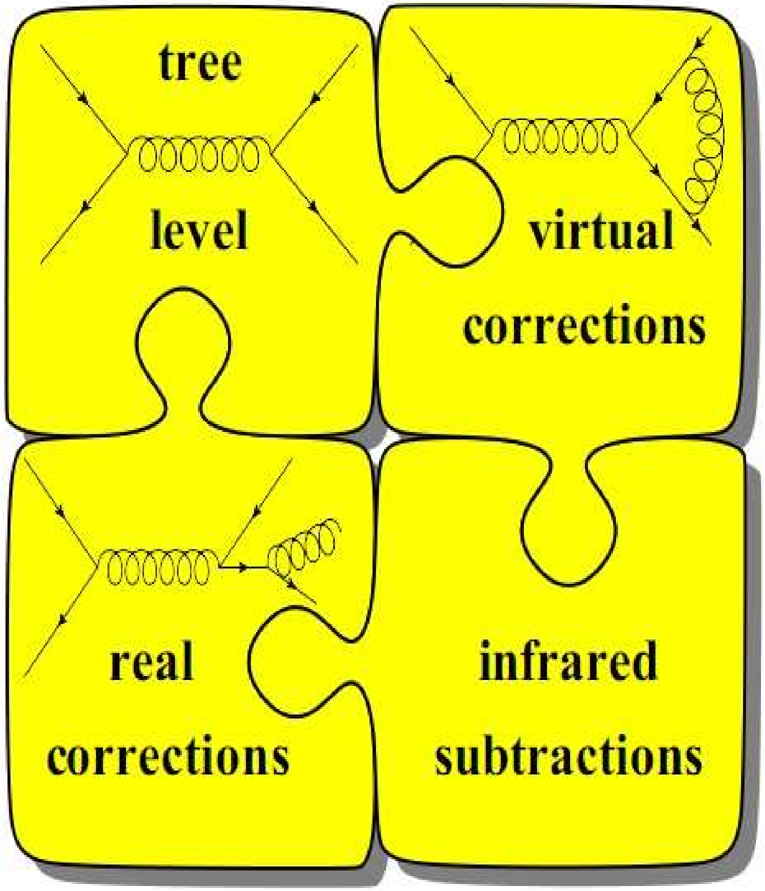
- Feynmanians
  - FeynArts/FormCalc (Hahn,Perez-Victoria,v.Oldenborgh
  - Grace-loop (Shimzu et al.
  - Golem (Binoth et al,)
  - SloopS (Boudjema et al.)
  - Many Process Specific few)
- Unitaritarians/cuts (at amplitude leve so)
  - HELAC-1LOOP+CutTools (v.Hameren,Ossola,Papadopoulos
  - BlackHat (Berger et al.)
  - Rocket (Ellis, Melnikov, Zanderighi)
  - Generalized Color-Dres Unitarity (Giele,Kunszt,Winter



Radiation, in principle same as tree-level



- Catani-Seymour dipoles
  - `AutoDipole` (Hasegawa, Moch, Uwer)
  - `HELAC-DPOLE` (Czakon, Papadopoulos, Worek)
  - `MadDipole` (Frederix, Gehrmann, Greiner)
  - `Sherpa` (Gleisberg, Krauss)
  - `TevJet` (Seymour, Tevlin)
- `MadFKS` (Frederix, Frixione, Maltoni, Stelzer)




2 Higgs phenomenology
3. New NLO calculations/ wishlist
4. NLO techniques Standardization/automation
5. NLO + parton shower
09.06.2009

Warning ! Used by Thomas often at LH09

" ....NLO tools are not DAUs..." (Stefan Dittmaier)

DAU= dummst anzumehmender user = most imaginable ignorant user

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DAU= dummst anzumehmender user = most imaginable ignorant user

A Dahu, quoi..! as I told him for a multi-leg alpine (?) animal...

FeynArts and FormCalc

Thomas Hahn

Max-Planck-Institut für Physik
München

Automated Diagram Evaluation

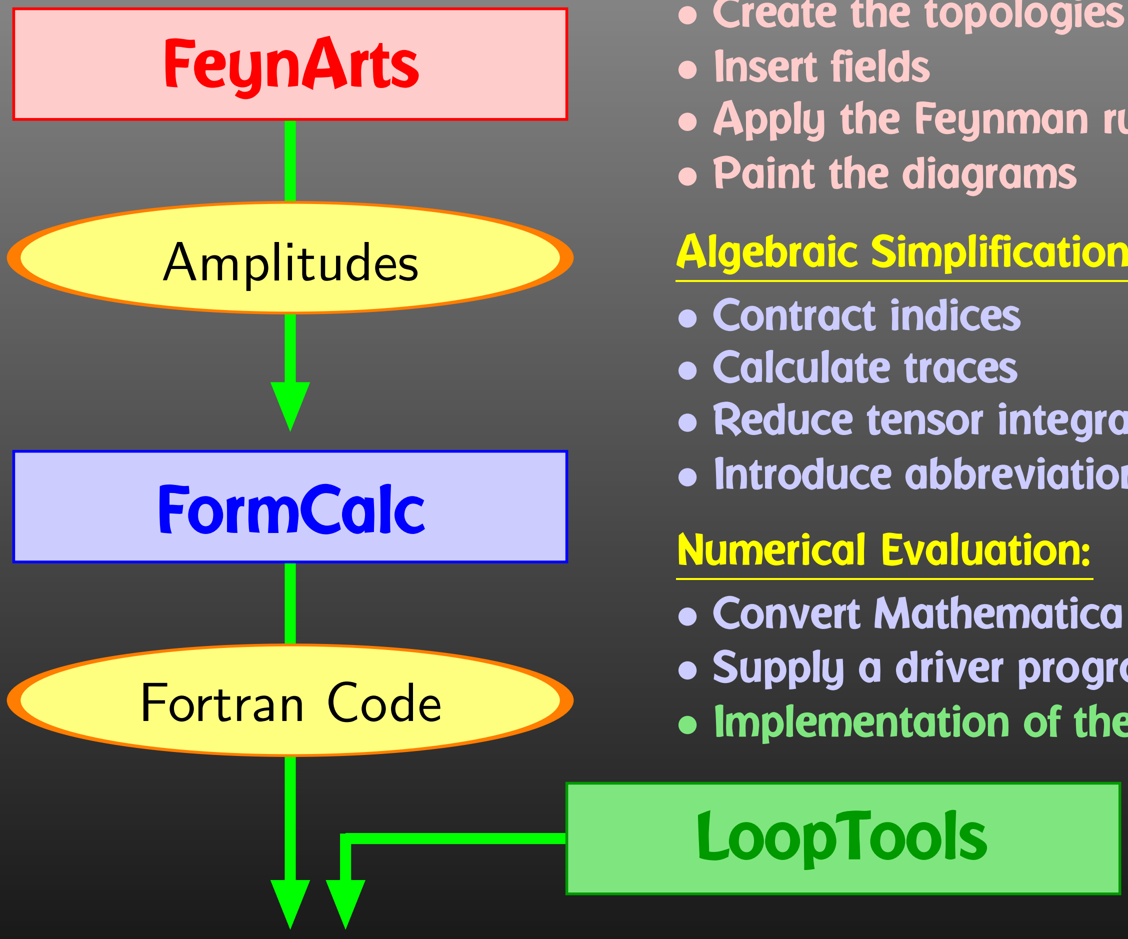


Diagram Generation:

- Create the topologies
- Insert fields
- Apply the Feynman rules
- Paint the diagrams

Algebraic Simplification:

- Contract indices
- Calculate traces
- Reduce tensor integrals
- Introduce abbreviations

Numerical Evaluation:

- Convert Mathematica output to Fortran code
- Supply a driver program
- Implementation of the integrals

Symbolic manipulation (Computer Algebra) for the structural and algebraic operations.

Compiled high-level language (Fortran) for the numerical evaluation.

$|\mathcal{M}|^2 \longrightarrow$ **Cross-sections, Decay rates, . . .**

Algebraic Simplification

The amplitudes output by FeynArts so far are in **no good shape for direct numerical evaluation.** Some objects must/should be handled symbolically, e.g. tensorial objects, Dirac traces, dimension (D vs. 4).

- contract indices as far as possible,
- evaluate fermion traces,
- perform the tensor reduction,
- add local terms arising from D·(divergent integral),
- simplify open fermion chains,
- simplify and compute the square of SU(N) structures,
- "compactify" the results as much as possible.

Sigma Chains

Define Sigma matrices and 2-dim. Spinors as

$$\sigma_\mu = (\mathbb{1}, -\vec\sigma)\,, \qquad \langle u|_{4\mathrm{d}} \equiv \big(\langle u_+|_{2\mathrm{d}}\,, \langle u_-|_{2\mathrm{d}}\big)\,,$$

$$\overline\sigma_\mu = (\mathbb{1}, +\vec\sigma)\,, \qquad |v\rangle_{4\mathrm{d}} \equiv \begin{pmatrix} |v_-\rangle_{2\mathrm{d}} \\ |v_+\rangle_{2\mathrm{d}} \end{pmatrix}.$$

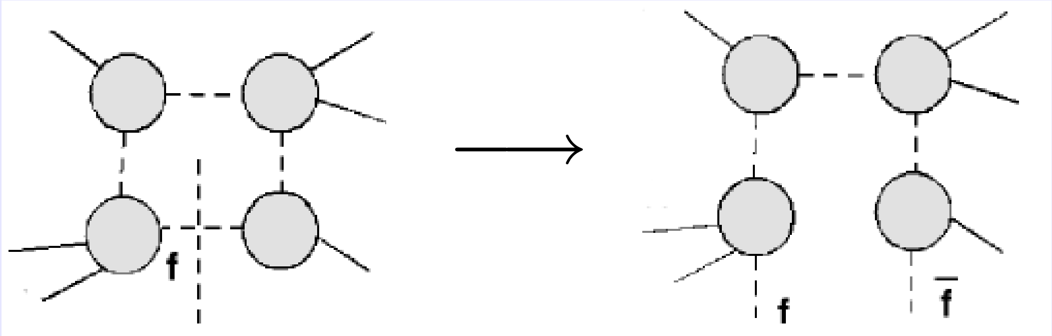
Using the chiral representation it is easy to show that every chiral 4-dim. Dirac chain can be converted to a *single* 2-dim. sigma chain:

$$\langle u|\,\omega_-\gamma_\mu\gamma_\nu\cdots|v\rangle = \langle u_-|\,\overline\sigma_\mu\sigma_\nu\cdots|v_\pm\rangle\,,$$

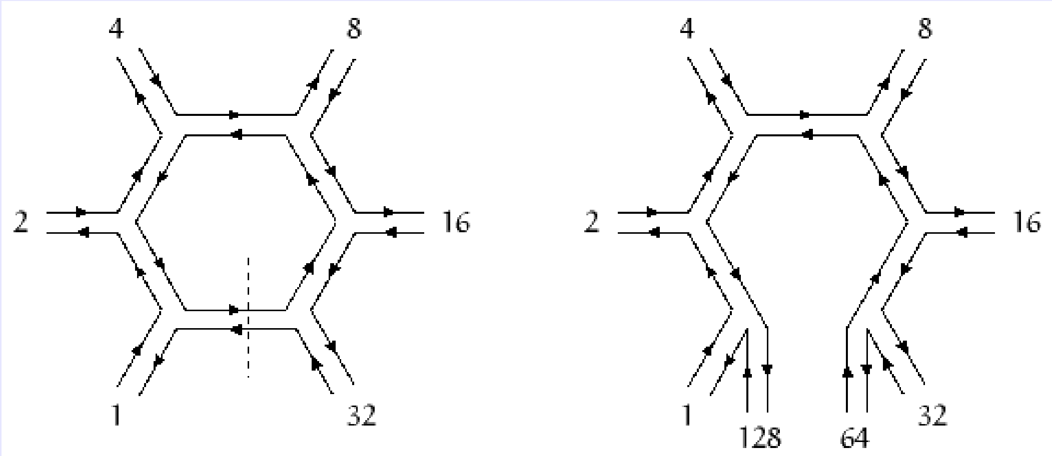
$$\langle u|\,\omega_+\gamma_\mu\gamma_\nu\cdots|v\rangle = \langle u_+|\,\sigma_\mu\overline\sigma_\nu\cdots|v_\mp\rangle\,.$$

Recursion Relations at 1-loop (cutting)

- OPP + hard-cut allow to use *the same tree-level Recursion Relations* for $m+2$ tree-like structures



- The color can be treated *as at the tree level*



On-shell Methods for ttbar + jets with Polarization

Andrew Larkoski
SLAC, Stanford University
with M. Peskin, to appear

TOOLS 2010, June 29, 2010

```
ERROR: undefinedresource
OFFENDING COMMAND: findresource

STACK:

/0
/CSA
/0
/CSA
-mark-
```

- Most of what was discussed was based on Feynman graphs
- Many new techniques have appeared, in fact intense activity
- SYM/Wilson Loops, integrability,

Yuri Dokhsitzer: "virtual SUSY is helping QCD *(twistor techniques!)*, QCD will pay back discovering *"real"* SUSY

Great Idea: A New Physics Model

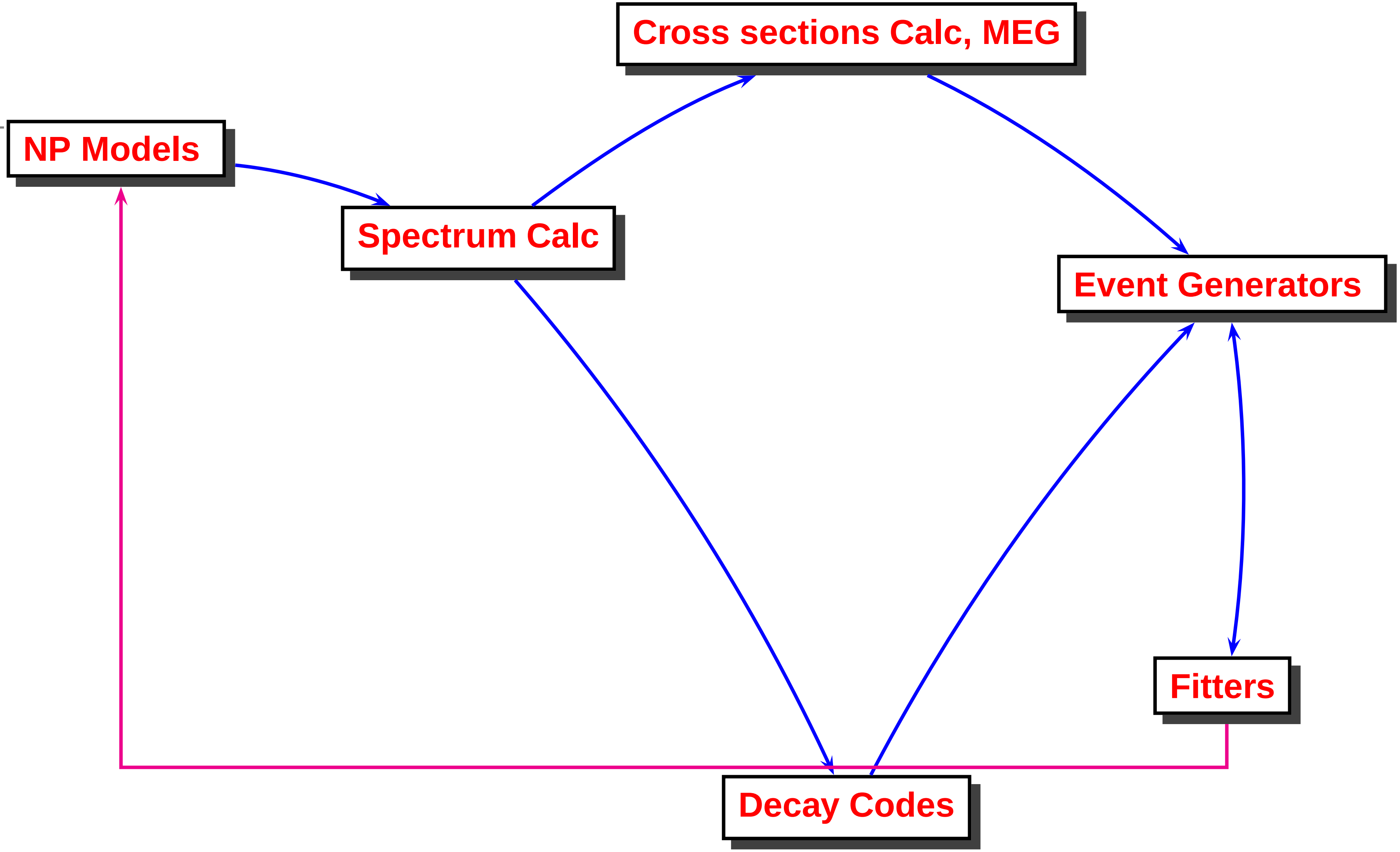
FINAL AIM

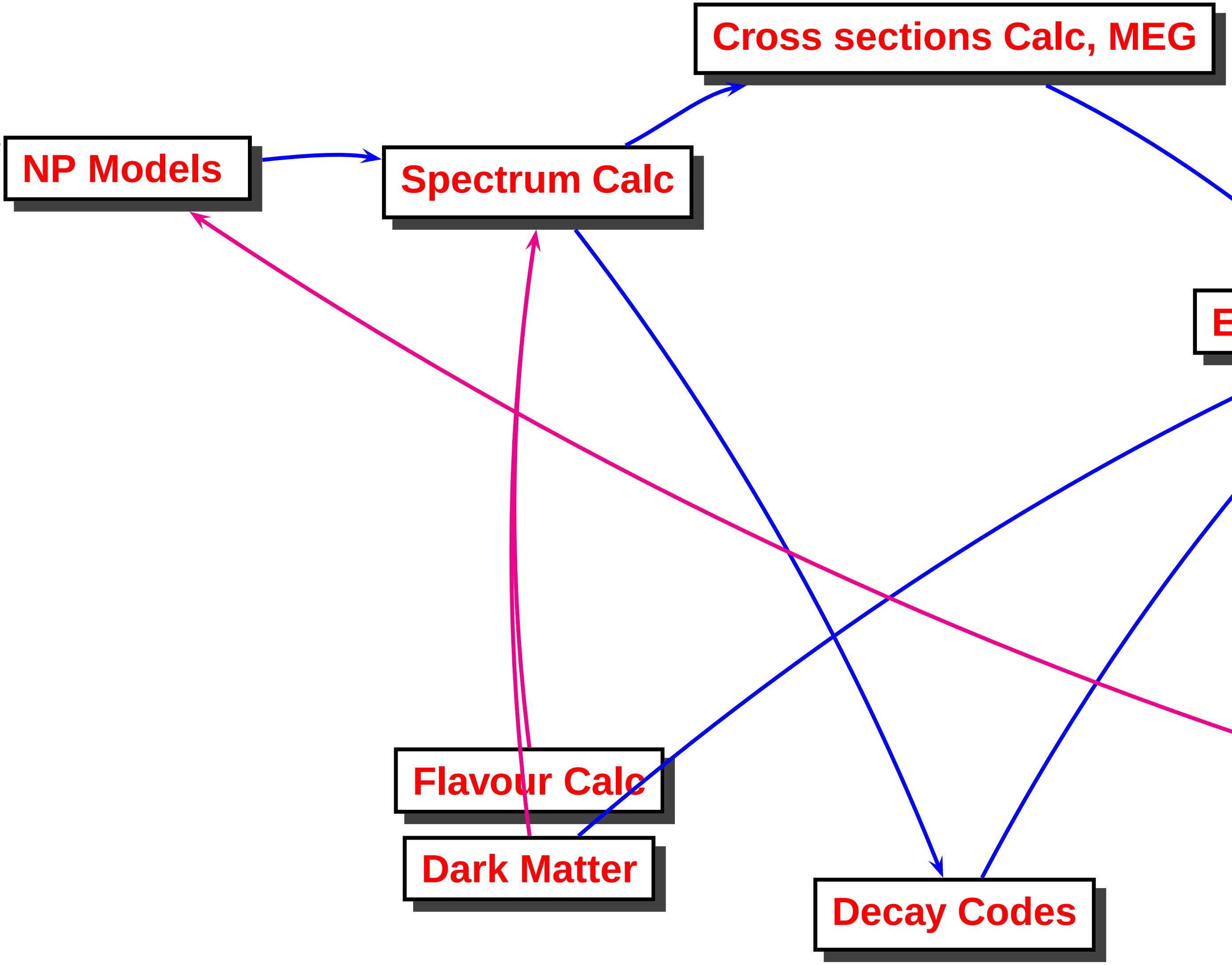
Nobel Prize if LHC validates!

NP Models

FINAL AIM

Event Generators


Cross sections Calc, MEG
NP Models
Spectrum Calc
Event Generators
Fitters
Decay Codes


Cross sections Calc, MEG
NP Models
Spectrum Calc
Event Generators
Flavour Calc
Fitters
Dark Matter
Decay Codes

Cross sections Calc, MEG

NP Models

Spectrum Calc

- SUSY
  - MSSM
  - mSUGRA
  - GMSB, AMSB
  - NMSSM
  - RPV, CPV,...

Event Generators

- TeXColour
- Extra-dim
- Little Higgs
- $f^\star, V'$
- Black Holes (!)

Flavour Calc

Dark Matter

Decay Codes

Fitters

Cross sections Calc, MEG

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Spectrum Calc

- FeynHiggs
- NMHDECAY$\star$
- RGE Codes
  - Isasusy
  - SoftSusy
  - Spheno
  - Suspect

Event Generators

Flavour Calc

Dark Matter

Fitters

Decay Codes

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Event Generators

Flavour Calc

- $(g-2)_\mu$
- $b \to s\gamma$
- $B_s \to \mu^+\mu^-$
- Asym, $\Delta M, \cdots$

Fitters

Decay Codes

Dark Matter

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Flavour Calc

Dedicated Codes

- SusyBSG
- SuperIso

Dark Matter

Cross sections Calc, MEG

- Tree-level,any
  - CalcHEP, CompHEP
  - GRACE, FORMCalc
  - Madgraph
  - SHERPA/Amegic++
  - Whizard/O'Mega
- 1-loop dedicated
  - AF's SLEPTONS
  - Prospino, hprod
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Event Generators

Fitters

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Event Generators

Fitters

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- BRIDGE
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Dark Matter

- SIsoRelic
- micrOMEGAs
  SloopS⋆
- DARKSUSY
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Black Holes

CatFish, Charybdis,

TrueNoir

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$\mathcal{L}$

Feynman rules

(Eff. Pot.)

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manual

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LanHEP/FeynRules

Feynman rules

(Eff. Pot.)

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automated

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(Eff. Pot.)

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Cross talks

SLHA,BSM-LHEF

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FeynRules

Claude Duhr
in collaboration with N. D. Christensen and B. Fuks

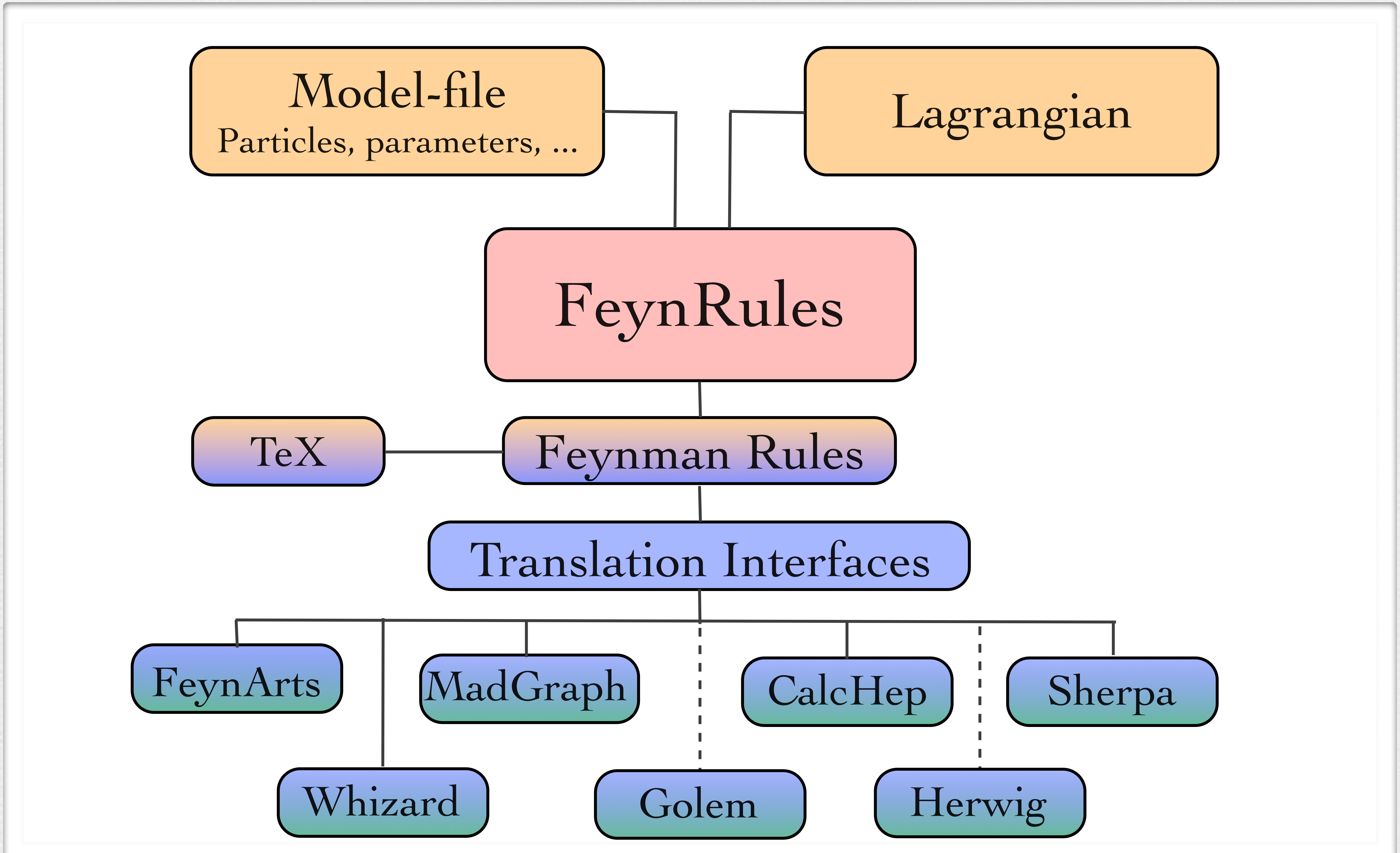
+ P. de Aquino, C. Degrande, D. Grellscheid, W. Link, F. Maltoni,
+ O. Mattelaer, T. Reiter, C. Speckner, S. Schumann, M. Wiebusch

Tools 2010
Winchester, June 30th 2010

Outline

- What is FeynRules..?
- New developments:
  - ➡ New interfaces (FeynArts, Whizard, UFO)
  - ➡ Support for Weyl fermions and superfields
  - ➡ Diagonalization of mass matrices
- Live demonstration

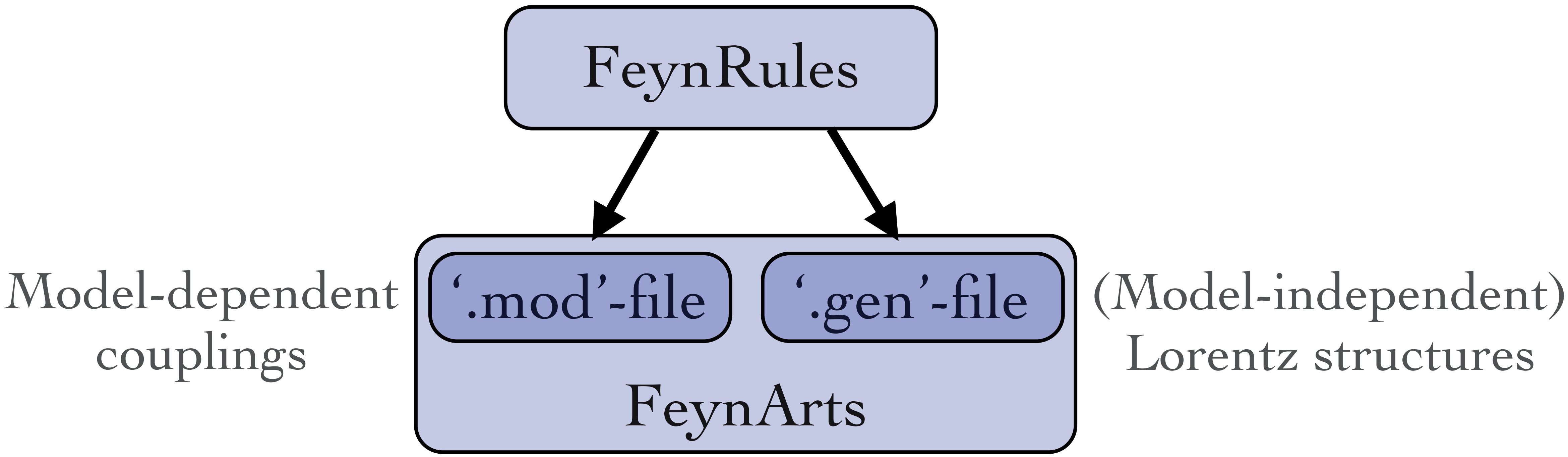
FeynRules



Model-file
Particles, parameters, ...
Lagrangian
FeynRules
TeX
Feynman Rules
Translation Interfaces
FeynArts
MadGraph
CalcHep
Sherpa
Whizard
Golem
Herwig

FeynArts interface (C. Degrande, CD)

- A new interface to FeynArts is being developped that allows to implement arbitrary Lorentz structures.



- This development goes along with a new version of FormCalc able to deal with multi-fermion interactions.

The UFO

(P. de Aquino, CD, D. Grellscheid, W. Link, O. Mattelaer, T. Reiter)

UFO = Universal FeynRules Output

- Idea: Create Python modules that can be linked to other codes and contain all the information on a given model.
- The UFO is a self-contained Python code, and not tied to a specific matrix element generator.
- Golem, MadGraph 5 and Herwig++ will use the UFO.
- The development of the UFO goes hand in hand with the development of ALOHA (Automatic Language-independent Output of Helicity Amplitudes), a code that allows to create HELAS routines from the UFO.

Motivation

- LanHEP was developed since 1994 as a part of CompHEP project to help to create new physical models starting from the Lagrangian, the first goal was MSSM.
- A physical model in CompHEP is defined by the tables of parameters, particles and interaction vertices with implicit Lorentz structure.
- Flexible model format allows to introduce into CompHEP new gauge theories as well as various anomalous terms.
- This job is rather straightforward and can be done manually, it requires careful calculations and in the modern theories with many particles and vertices can lead to errors and misprints.
- Automatic tool is required.

- The LanHEP program is written on C programming language, external mathematical software is NOT required.
- LanHEP read input file which describes the physical model by the set of statements. Large projects can be split to several files.
- Conditional processing of the model file allows the user to use the same input file(s) for several species of the physical model. This feature allows, for example, to chose gauge fixing and MSSM extensions by setting some switches instead of creating several slightly different input files.
- Command-line tool: no graphical interface means easy compilation on any platform where 32-bit C compiler exists.

LanHEP features

- 2-component fermion notation makes possible the introduction of supersymmetric Lagrangian in a more natural way, closer to the form used in most textbooks on the supersymmetry.
- Superpotential can be used for supersymmetric theories; this option allows to introduce easily various extensions of MSSM (R-parity violation, NMSSM, etc). Yukawa and F^*F terms are now automatically derived by the program.
- Extra dimensions: automatic generation of interaction of KK modes and 5th components of vectors.
- Generating Hermitian conjugate terms allow to simplify model description.
- Constructing the ghost Lagrangian from BRST transformation.
- Conterterms can be generated if the necassy shifts for parameters and fields are prescribed.

- Complete MSSM in unitary and t'Hooft-Feynman gauges with the Higgs sector by linking with the FeynHiggs, effective potential is used to take into account radiative corrections to Higgs masses and interaction; mSUGRA and GMSB by means of SLHA interface
- MSSM extensions include:
  - MSSM with R-parity violation
  - Model with gravitino and sgoldstinos
  - NMSSM (an extension of the MSSM by a gauge singlet N with hypercharge 0)
  - MSSM with CP violation
- Complete Leptoquark model which includes Yukawa couplings for all types of LQ, gauge couplings and anomalous gauge couplings for vector LQ
- Complete two-Higgs-doublet model with conserved or broken CP invariance
- Anomalous quartic vector bosons self-couplings

Summary

- Effective and well-tried tool for creation of new physical model for CompHEP
  - Lagrangian can be written in form close to textbooks, in terms of initial fields before symmetry breaking
  - SUSY-friendly: 2-component fermions and superpotential notation
  - New feature: KK modes in models with extra dimensions
  - Checking the correctness of the model, simplifying the expressions for vertices
- Extentions of CompHEP tables format
- LaTeX output
- FeynArts output
- Counterterms generation for 1-loop computation
- The program is available at

  `http://theory.sinp.msu.ru/~semenov/lanhep.html`

Better

Check List

Leading order matrix element generation	No limitations except time W+5 jets/$t\bar{t}$+4 jets realistic
BSM, any renormalizable model	Yes
Decay Chains	No limitations, fast
Color structures	No limitations
Extended color structures (6, 27, ε^{ijk})	Available (not yet tested)
Effective theories (>4-particle vx)	Yes, no limitations
Recursion relations for multijets	To be implemented
NLO real corrections	To be implemented
NLO loop calculations	To be implemented
Output in any language/format	No limitations, Fortran (MG/ME 4) available

BSM: UFO AND ALOHA

- New FeynRules output including color and lorentz structures.
  [Duhr et al]

UFO = Universal FeynRules Output

- Automatic Helas Amplitude Generation for any new model (including effective theory)
  [P. de Aquino, W. Link, OM]

ALOHA = Automatic Language-independent Output of Helicity Amplitudes

CalcHEP

Neil D. Christensen
University of Wisconsin - Madison

The past: WHIZARD 1.x (current: 1.95)

- Matrix elements: O'Mega, (Madgraph, CompHEP)
- Phase space parametrization automatically tailored to matrix element
- Beam modelling:
  - ILC: polarization, ISR, beamstrahlung via CIRCE / CIRCE2
  - LHC / Tevatron: parton distributions via PDFlib / LHApdf
- Fragmentation and hadronization: PYTHIA
- Event generation:
  - Event output in standard formats (e.g. LHA, StdHEP),
  - Integrated analysis facilities; histogram output as postscript / pdf
- Many BSM models: MSSM, NMSSM, Little Higgs, UED, Z', ...
- Technicalities:
  - FORTRAN 95 for phase space / infrastructure / physics
  - Makefiles and PERL for steering and code generation
  - Custom input files for process definition (compile time), simulation setup, cut and analysis definitions (runtime)

The future — WHIZARD 2.1 / 3.0

In preparation for version 2.1:

- Parton shower matching (D. Wiesler)
- Intrinsic parton shower implementation (S. Schmidt)
- Intrinsic module for multiple interactions (H.-W. Boschmann)
- Interface to NLO amplitudes (BLHA) and automatic dipole substraction (J. Reuter, S. Schmidt, C.S.)
- Generalized lorentz structures (T. Ohl)
- Parallelization (W. Kilian)

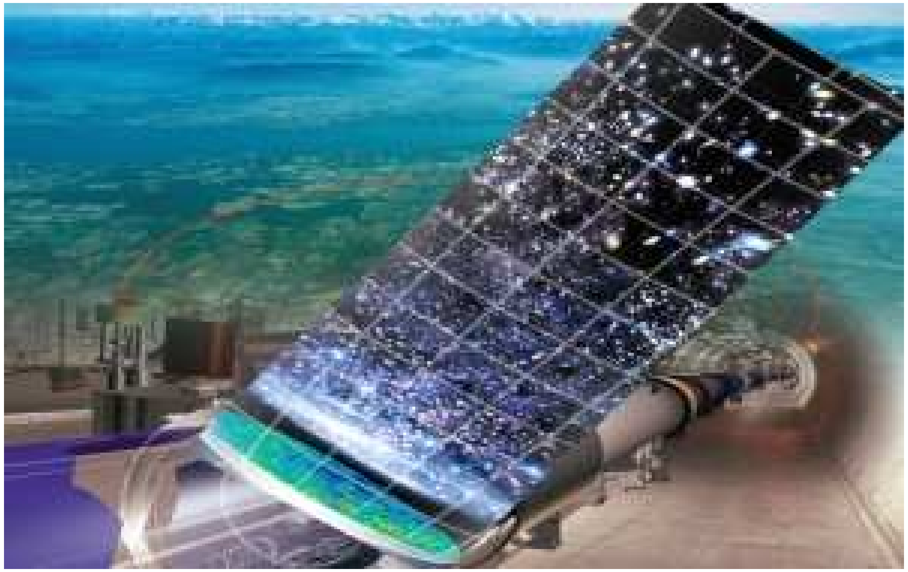
Plans for 3.0:

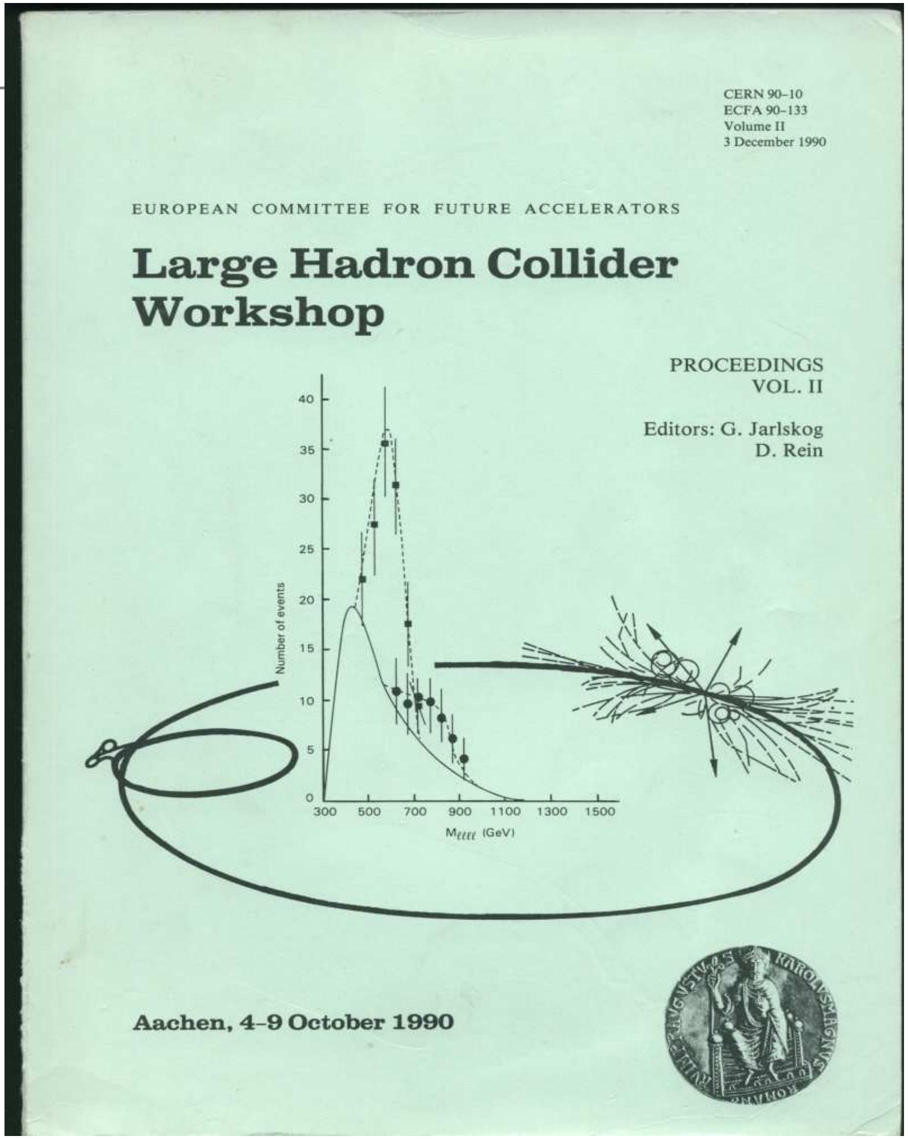
- GPU massive parallel computing
- τ decay module / interface
- Dark matter relic computation (“dark WHIZARD”)

LanHEP as prototype for automatic Feynman rules generation

- LanHEP Developed since 1994 as a part of CompHEP to help from the Lagrangian the complete set of Feynman rules, the first goal was MSSM.
- can now output to FeynArts/FeynCalc
- extremely powerful, extended to one-loop
- free software (no need for external tools,...Mathematica)
- recently (2008) FeynRules is on the market, more limited though for the moment but much more attractive: can output to many formats and MEG
- urge LANHEP to do the same
- learn form each other but avoid the mono-culture

LHC Dark Matter Connection





no mention of a connection, despite a SUSY WG

There is a mention of LSP to be stable/neutral because of cosmo reason, but no attempt at identifying it or weighing the universe at the LHC

LHC: Symmetry breaking and Higgs

New Paradigm, Dark Matter is New Physics. Dark Matter is being looked for everywhere

New Paradigm, Particle Physics to match the precision of recent cosmological measurements

Need powerful, modular and versatile tools

Tools for DM/ Collider Physics/ Flavour for a general NP

Models of New Physics: Symmetry breaking and DM

- The SM Higgs naturalness problem has been behind the construction of many models of New Physics: at LHC not enough to see the Higgs need to address electroweak symmetry breaking
- DM is New Physics, most probable that the New Physics of EWSB provides DM candidate, especially that
- All models of NP can be made to have quite easily and naturally a conserved quantum number, Z_2 parity such that all the NP particles have $Z_2 = -1$ (odd) and the SM part. have $Z2$ even (Z_3 can work also)
- Then the lightest New Physics particle is stable. If it is electrically neutral then can be a candidate for DM
- This conserved quantum number is not imposed just to have a DM candidate it has been imposed for the model to survive

Symmetry breaking and DM

- Survival

  evade proton decay

  indirect precision measurements (LEP legacy)

- Examples:

  R-parity and LSP in SUSY (majorana fermion)

  KK parity and the and LKP in UED (gauge boson)

  T-parity in Little Higgs with the LTP (gauge boson)

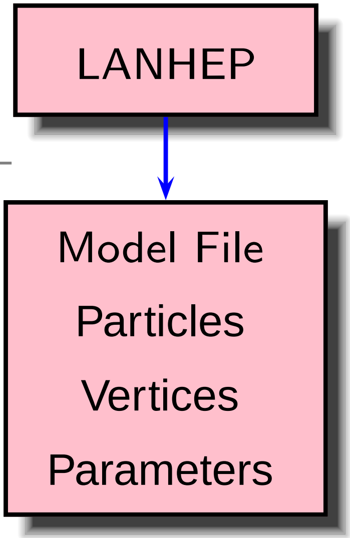
  LZP (warped GUTs) (actually it's a Z_3 here) (Dirac fermion)

  even modern technicolour has a DM candidate

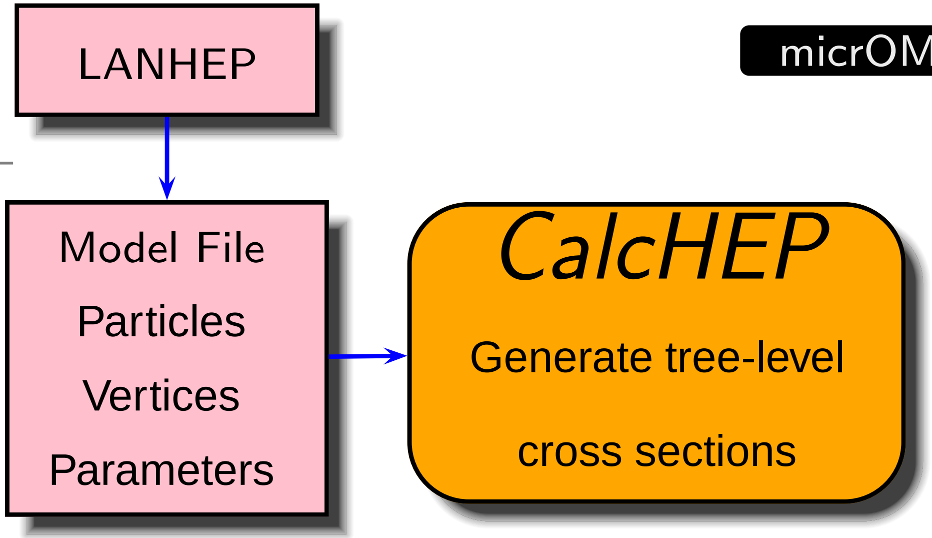
LANHEP

micrOMEGAs

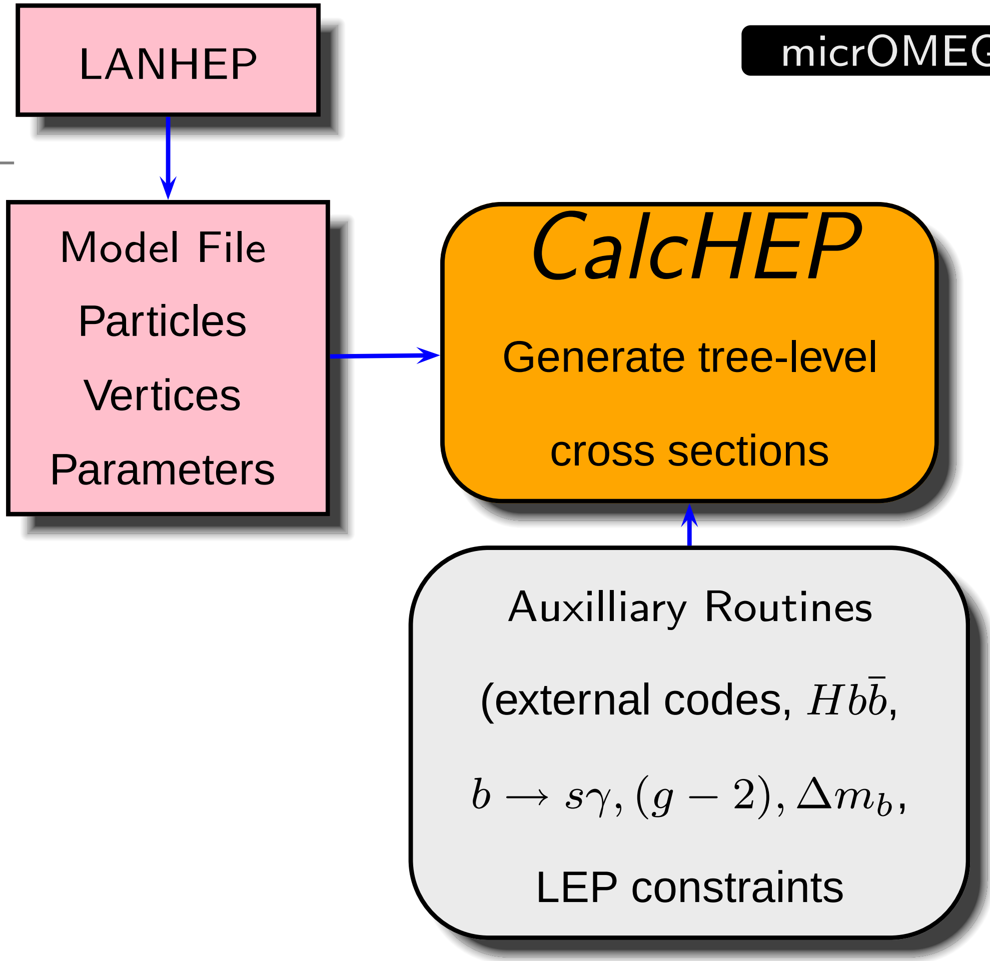
micrOMEGAs



micrOMEGAs


LANHEP
Model File
Particles
Vertices
Parameters
CalcHEP
Generate tree-level
cross sections

micrOMEGAs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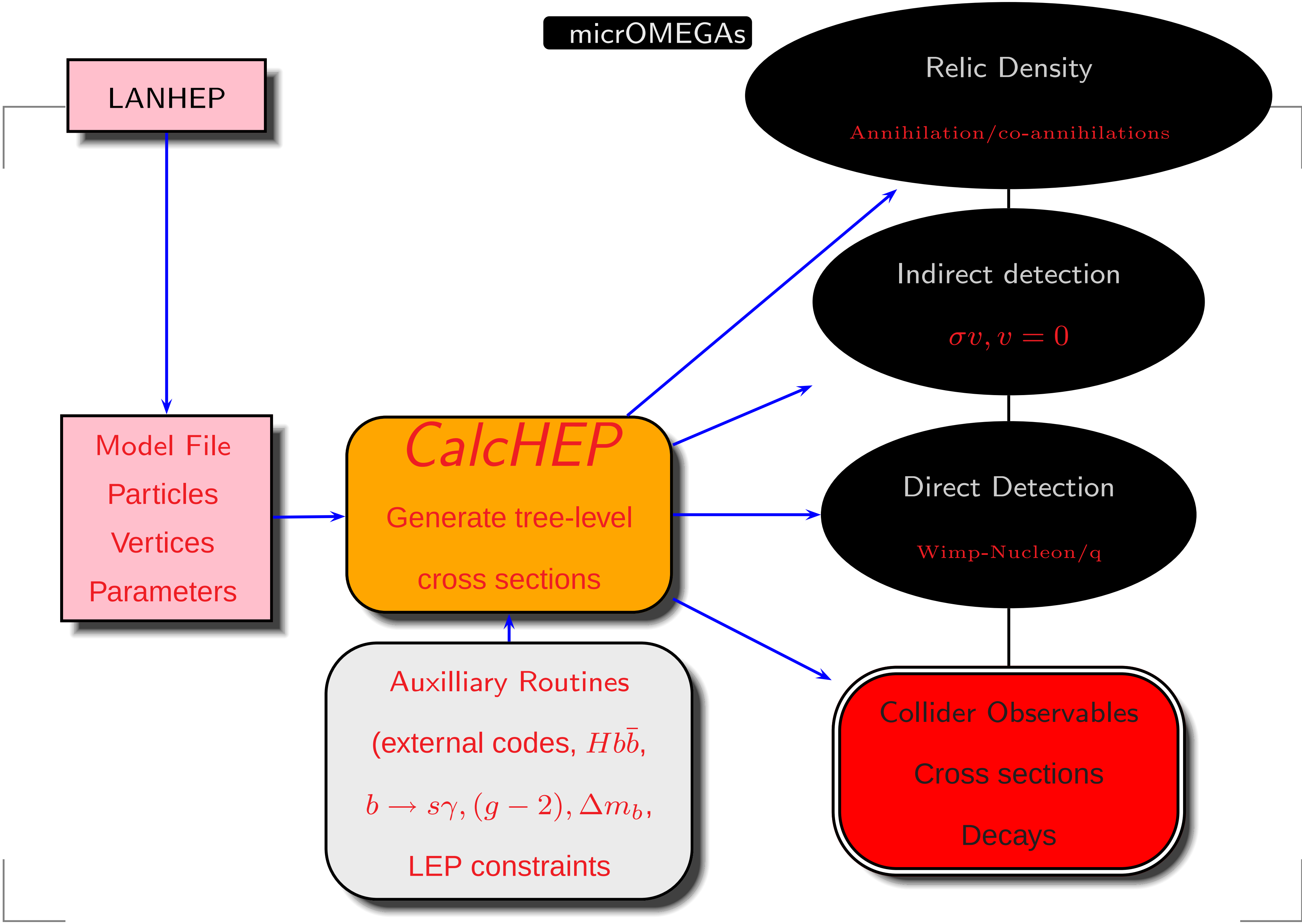
Auxilliary Routines
(external codes, $Hb\bar{b}$,
$b \to s\gamma, (g-2), \Delta m_b$,
LEP constraints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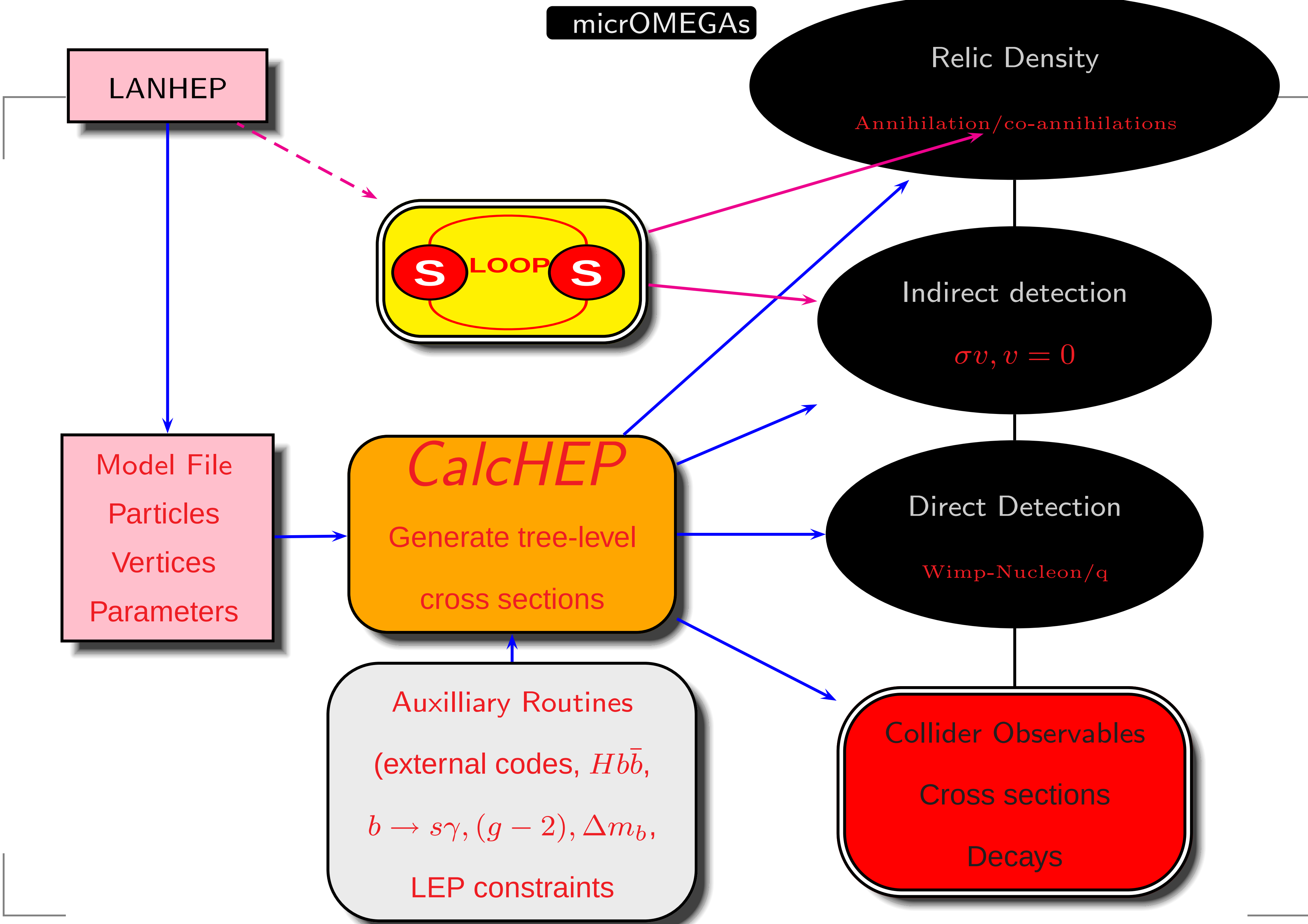
(external codes, $Hb\bar{b}$,
$b \to s\gamma, (g-2), \Delta m_b$,
LEP constraints
Relic Density
Annihilation/co-annihilations
Indirect detection
$\sigma v, v = 0$
Direct Detection
Wimp-Nucleon/q
Collider Observables
Cross sections
Decays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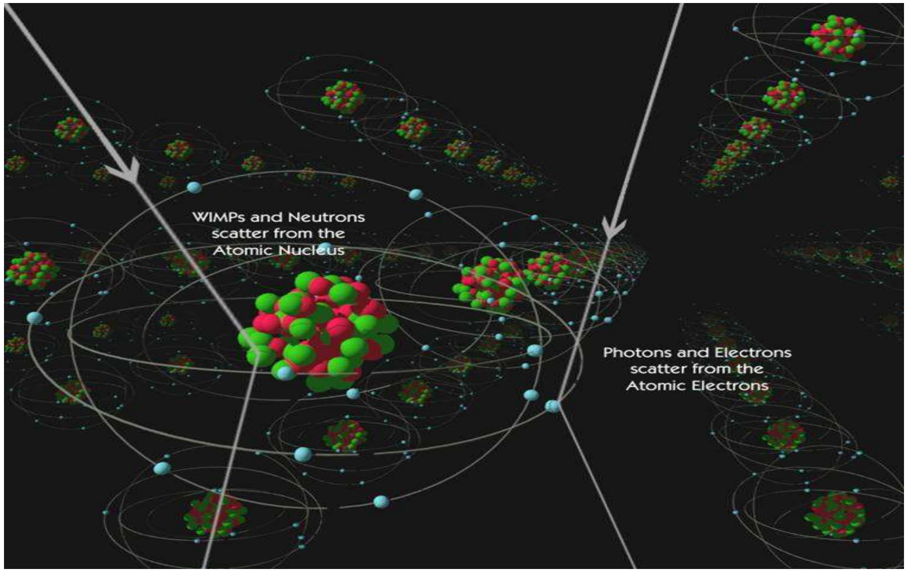
Direct detection

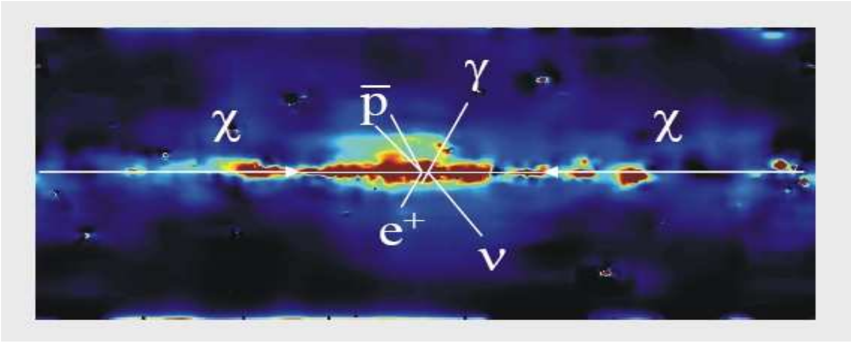


$\chi\mathcal{N} \to \chi\mathcal{N}$ **to** $\chi N \to \chi N\ (N = n, p)$

to $\chi q \to \chi q$

ingredients/Modules: dark matter density and modulation, velocity distribution quark content in nucleon, Nuclear form factors,.....

Indirect Detection

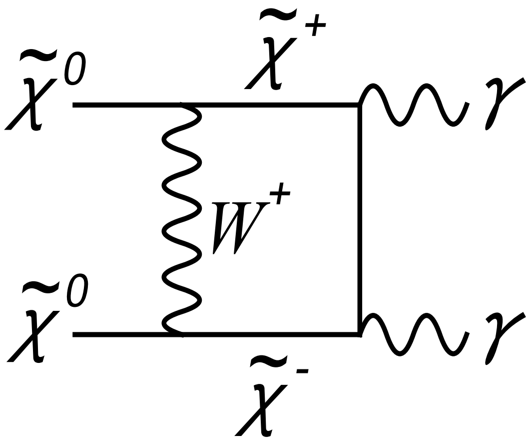


Annihilation into photons

$$\frac{d\Phi_\gamma}{d\Omega dE_\gamma} = \sum_i \underbrace{\frac{dN^i_\gamma}{dE_\gamma}\sigma_i v \frac{1}{4\pi m^2_\chi}}_{\text{Particle physics}} \underbrace{\int (\rho + \delta\rho)^2 dl}_{\text{Astro}}$$

$\gamma' s$: Point to the source, independent of propagation model(s)

- continuum spectrum from $\tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow f\bar{f}, \ldots,$ hadronisation/fragmentation ($\rightarrow \pi^0 \rightarrow \gamma$) done through isajet/herwig
- Loop induced mono energetic photons, $\gamma\gamma$, $Z\gamma$ final states

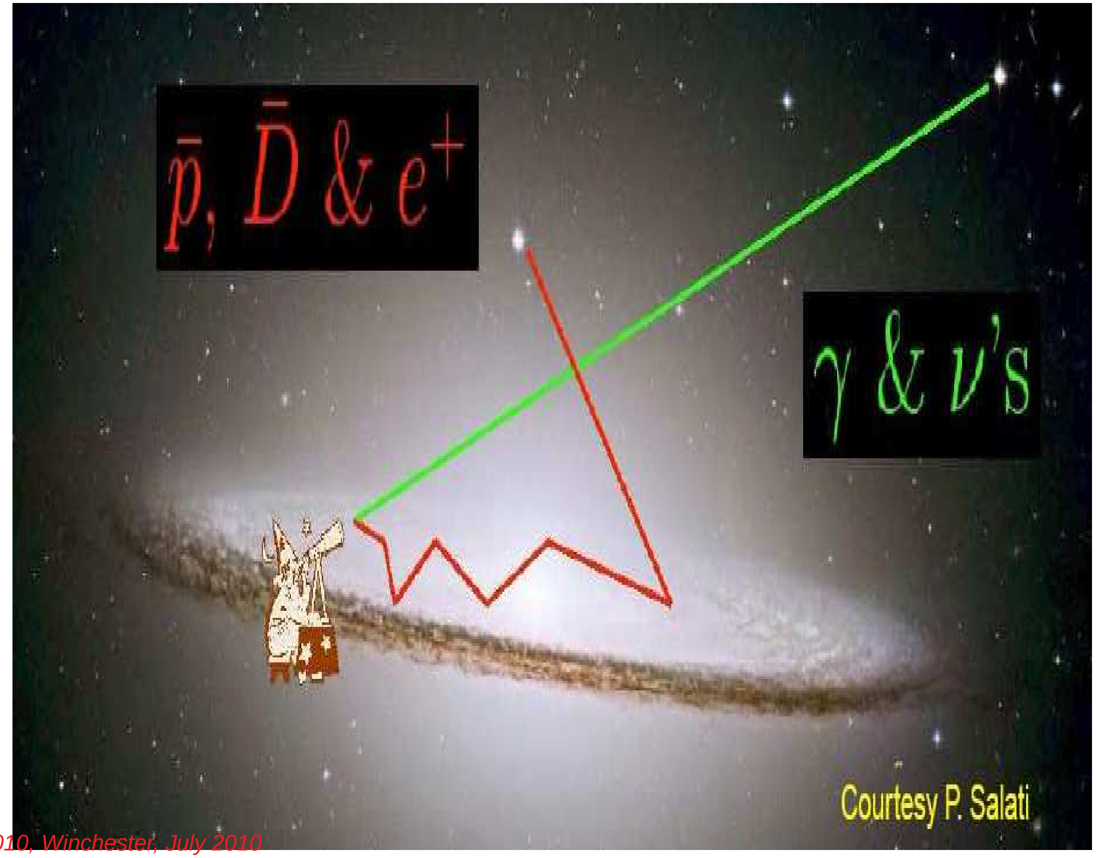


ACT: HESS, Magic, VERITAS, Cangoroo, ...

Space-based: AMS, Fermi-LAT, Egret,...

Annihilation into $e^+, \bar{p}, \bar{D}$

$$\frac{d\Phi_{\bar{f}}}{d\Omega dE_{\bar{f}}} = \sum_i \underbrace{\frac{dN^i_{\bar{f}}}{dE_{\bar{f}}} \sigma_i v \frac{1}{4\pi m_\chi^2}}_{\text{Particle physics}} \underbrace{\int (\rho + \delta\rho)^2 P_{prop}}_{\text{Astro}}$$



ACT: HESS, Magic, VERITAS, Cangoroo, ...

Space-based: AMS, GLAST, Egret,...

Annihilation into $e^+, \bar{p}, \bar{D}$

$$\frac{d\Phi_{\bar{f}}}{d\Omega dE_{\bar{f}}} = \sum_i \underbrace{\frac{dN^i_{\bar{f}}}{dE_{\bar{f}}}\sigma_i v \frac{1}{4\pi m_\chi^2}}_{\text{Particle physics}} \underbrace{\int (\rho + \delta\rho)^2 P_{prop}}_{\text{Astro}}$$

ACT: HESS, Magic, VERITAS, Cangoroo, ...

Space-based: AMS, GLAST, Egret,...

charged particles: Model of propagation and background

- Halo Profile modeling, clumps, cusps,..boost factors,...

Present measurement at 2σ $\boxed{0.0975 < \omega = \Omega_{\rm DM} h^2 < 0.1223}$ **(6%)**

future (SNAP+Planck) $\rightarrow < 1\%$

Need more Precise Predictions

γ ray-line is a one-loop calc.

SLOOPS

N. Baro, FB, G. Chalons, S. Hao, A. Semenov, (D. Temes)

- Need for an automatic tool for susy calculations
- handles large numbers of diagrams both for tree-level
- and loop level
- able to compute loop diagrams at $v = 0$: dark matter, LSP, move at galactic velocities, $v = 10^{-3}$
- ability to check results: UV and IR finiteness but also gauge parameter independence for example
- ability to include different models easily and switch between different renormalisation schemes
- Used for SM one-loop multi-leg: new powerful loop libraries (with Ninh Le Duc, Sun Hao)

Progress/Conclusions

- A lot of progress and a lot of tools
- more and more on modularity and exchange of modules
- much easier now to contribute a new model
- Flexibility is the key

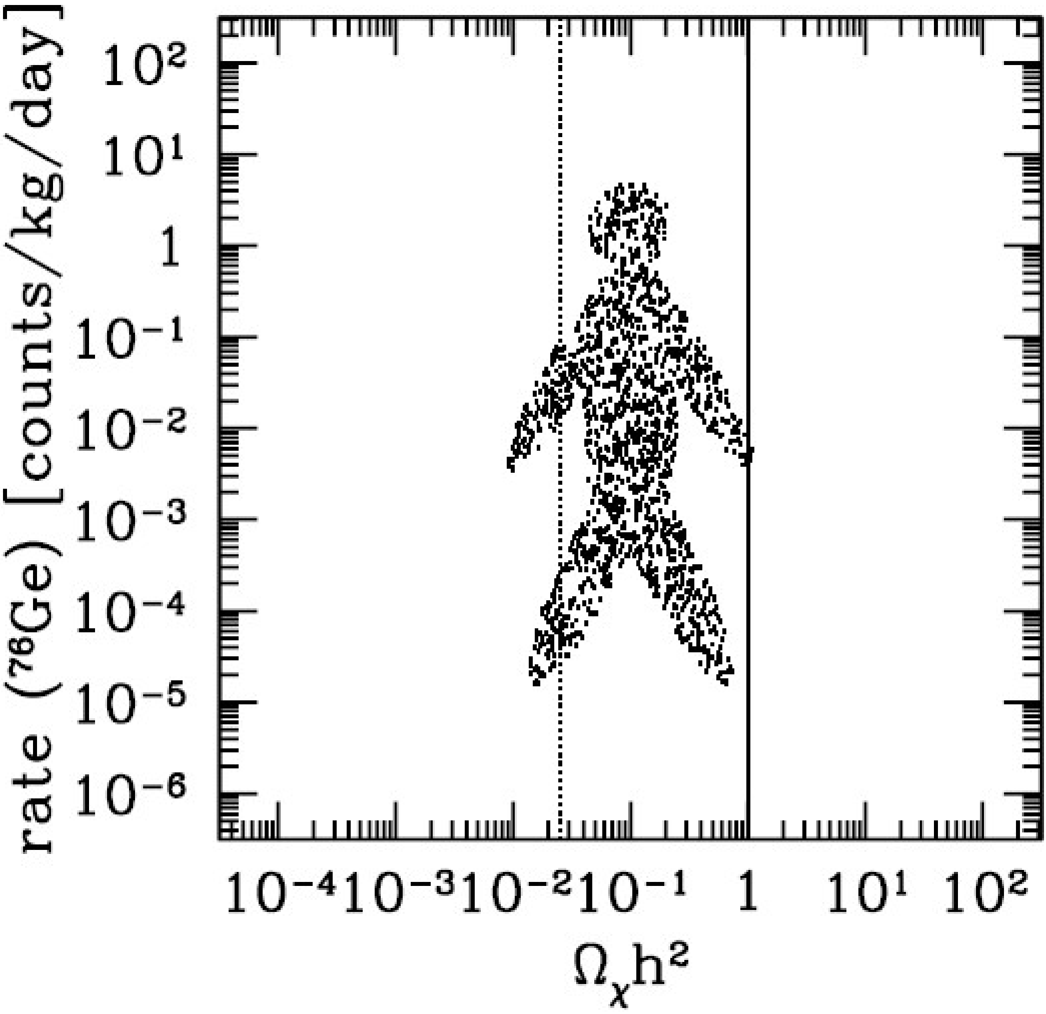
  [-] Need to be ready to implement a model quickly

  [-] Check output with different ME Calc./MC/MG
- This is now possible, while earlier even parameters of simple models hard wired, model implementation needed experts
- Now many tools automatize the different steps and as long as

  [-] particles has spin ≤ 2

  [-] Standard couplings through known Lorentz structures, this preclude higher order operators but things will change soon here (ALOHA)

  [-] decay chain does not end up in higher order or unusual colour representation (hadronisation issue)



rate (^{76}Ge) [counts/kg/day]
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10^1
10^2
$\Omega_\chi h^2$