New physics simulations
From Lagrangians to events… and back

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27 February – 4 March 2023

Outline

MC simulations & new physics

Towards the characterisation of new physics

- About the nature of an observation
  - ➙ Fitting and (re)interpreting deviations
  - ➙ Prospective collider studies of varied signals

- Final words on the nature of any potential BSM
  - ➙ Accurate measurements
  - ➙ Precise predictions mandatory

Goal of all lectures at this school

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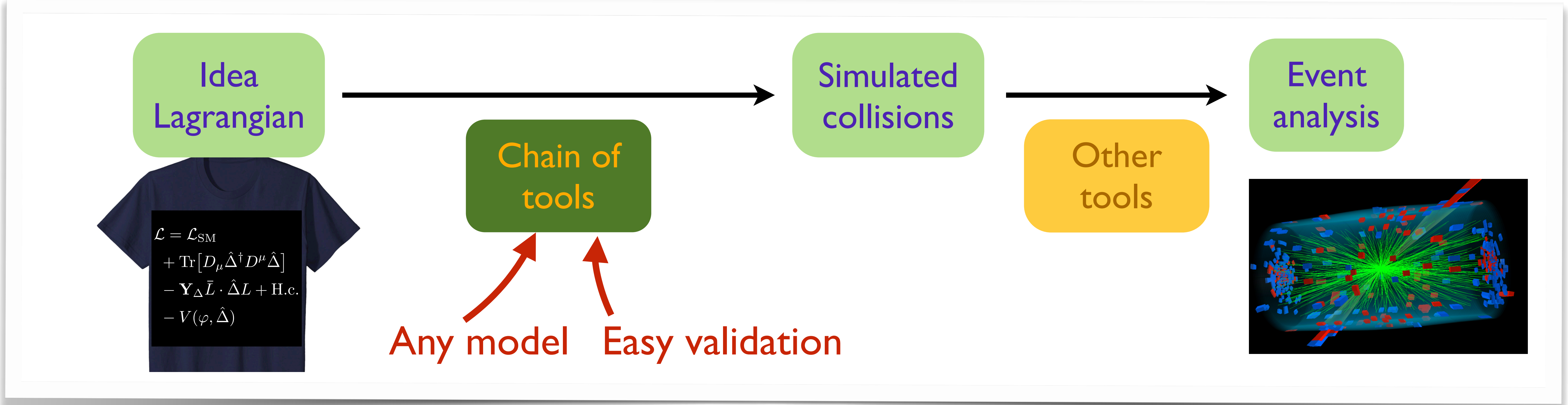
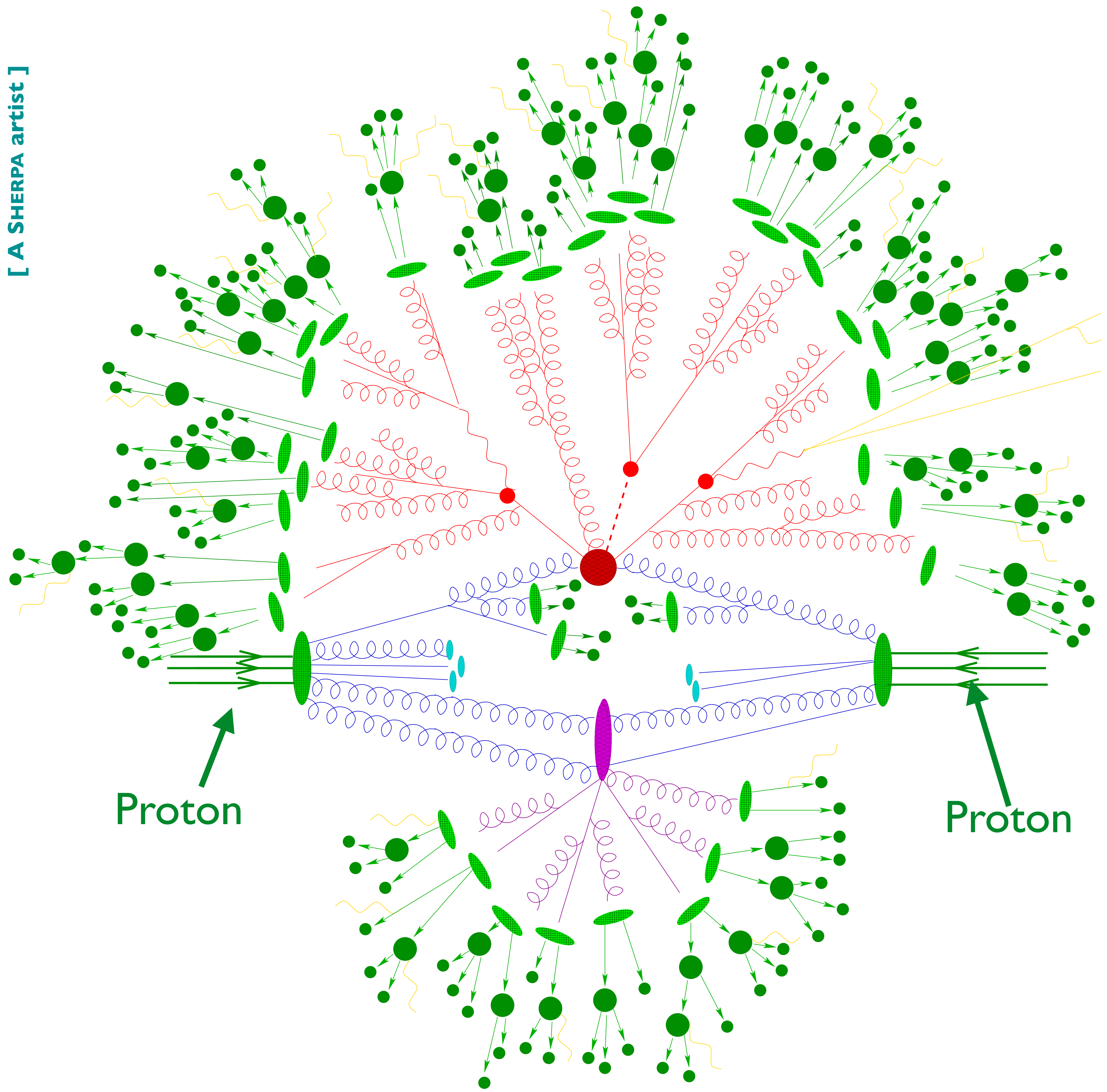
New physics simulations standard today

- 20 − 25 years of developments ➙ LO simulations ≡ bread and butter
- Simulations at NLO (QCD) easily achieved



Deciphering a proton collision



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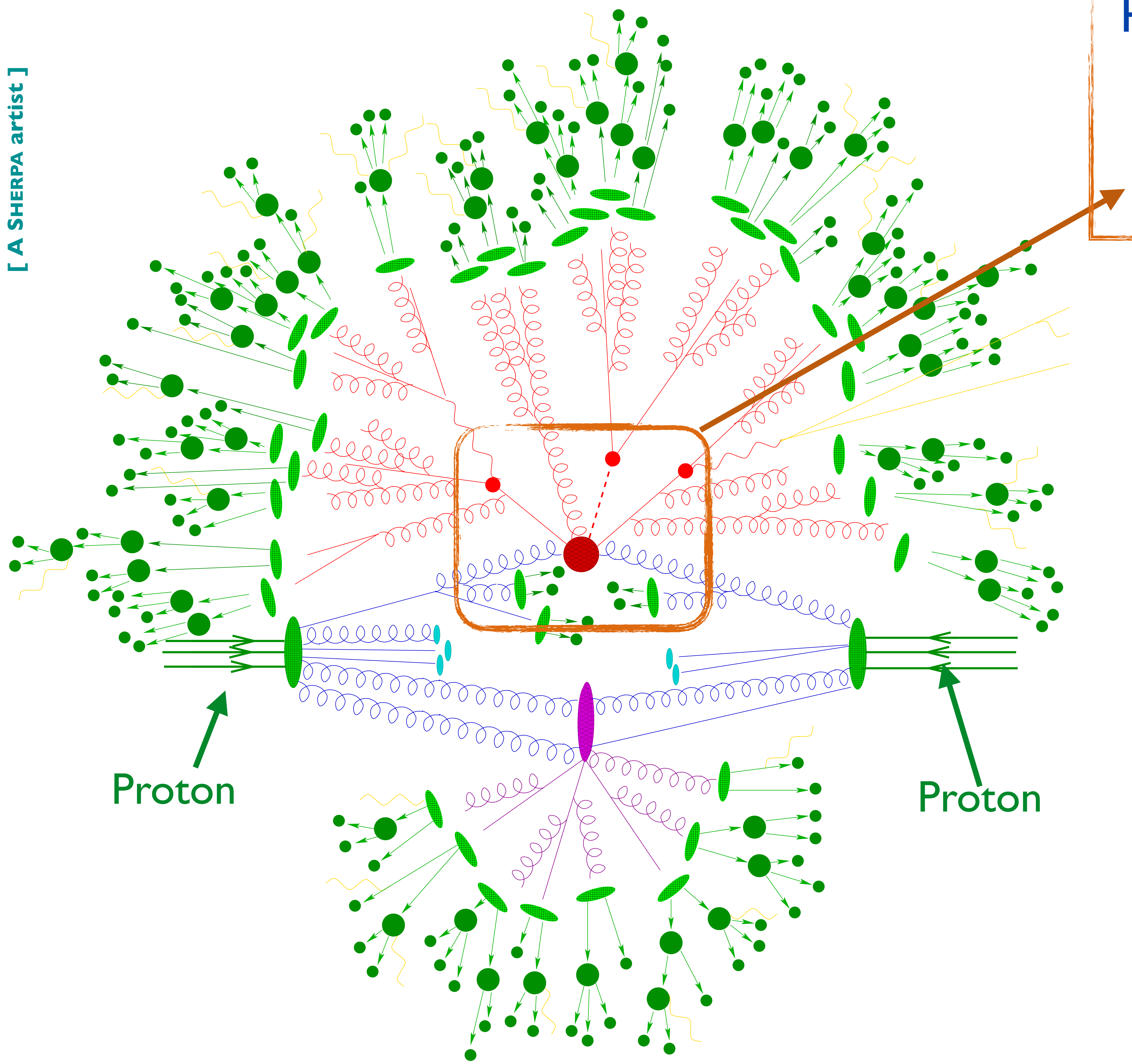

Hard process

- Depends on the model (SM/BSM)
- Perturbative QCD
- Core #1 of this talk

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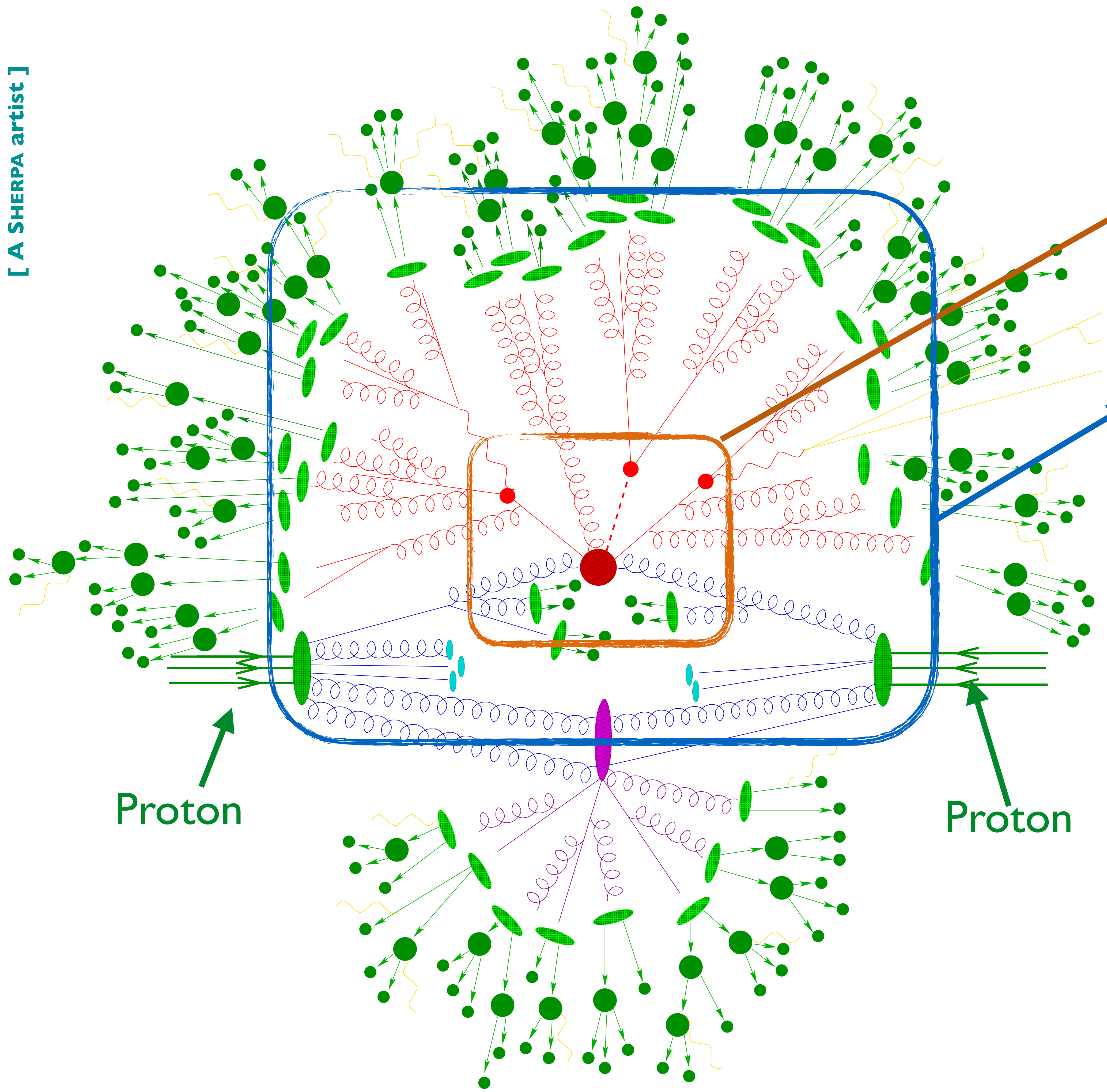

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Parton showering
- Universal (QCD)

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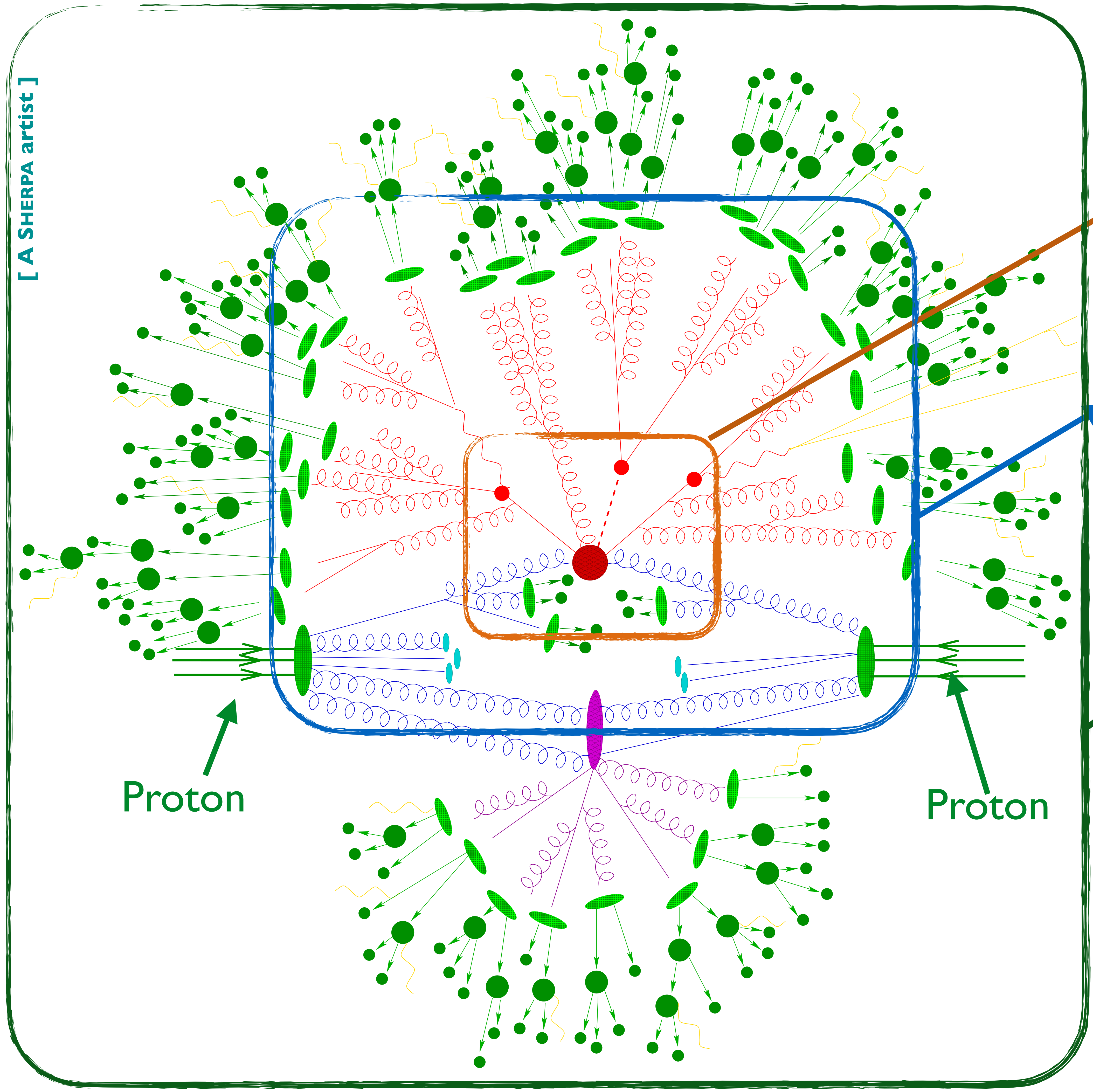

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Hadronisation
- Model-based, universal

Underlying event
- Model-based, non-universal

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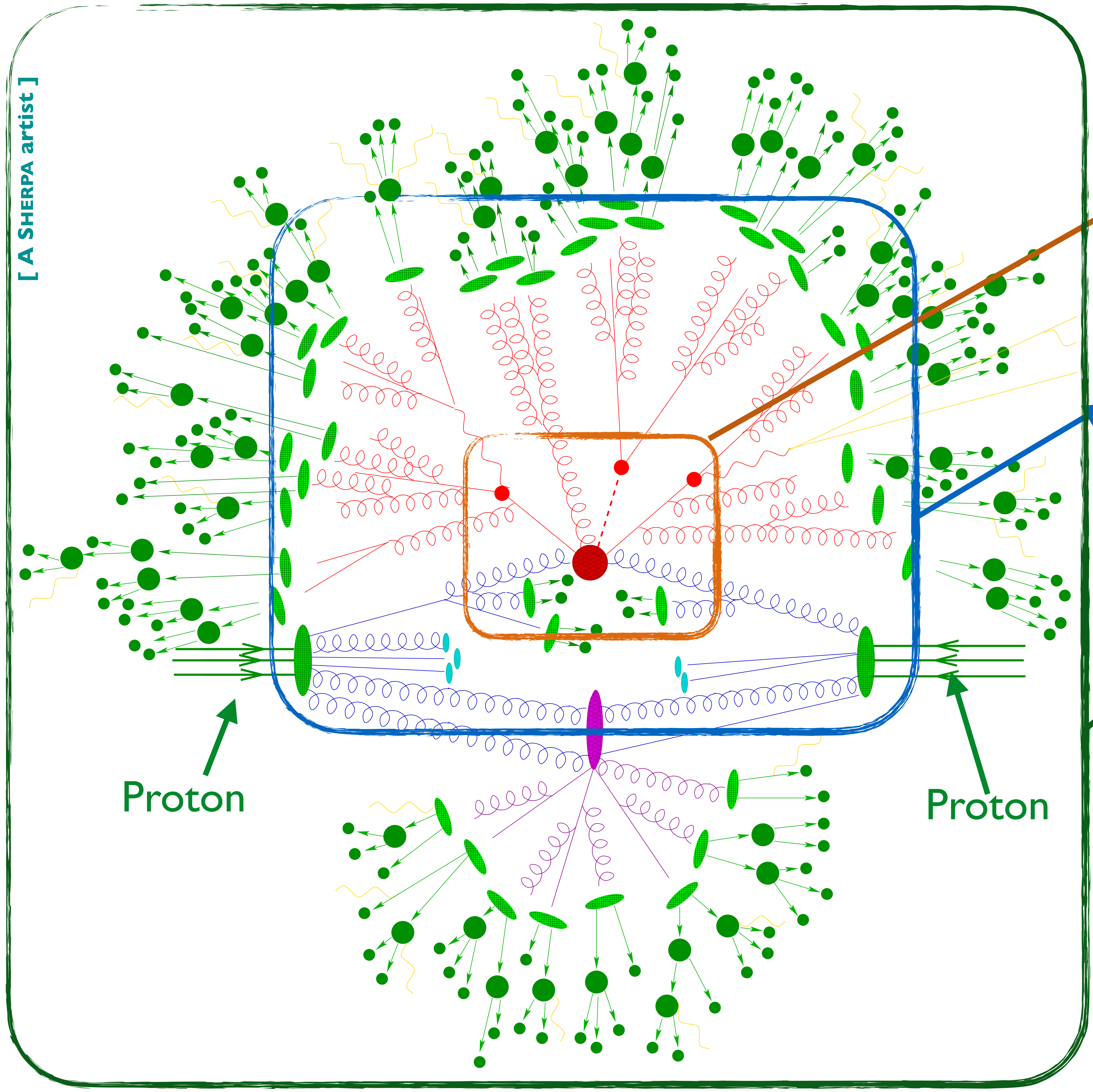

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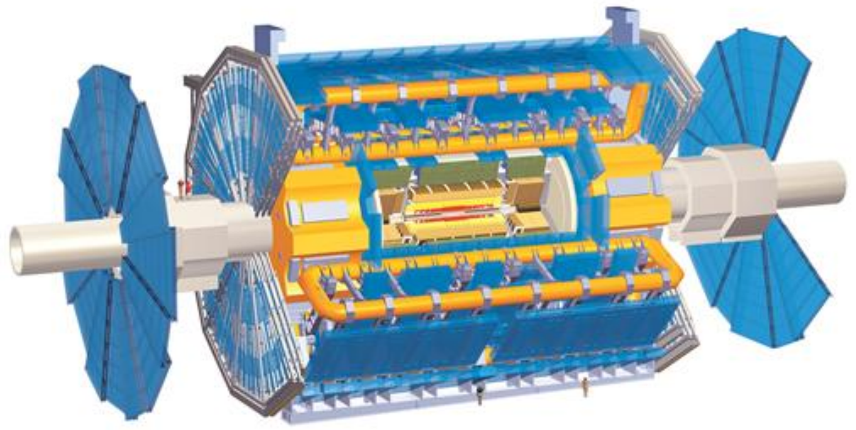
Detector simulation



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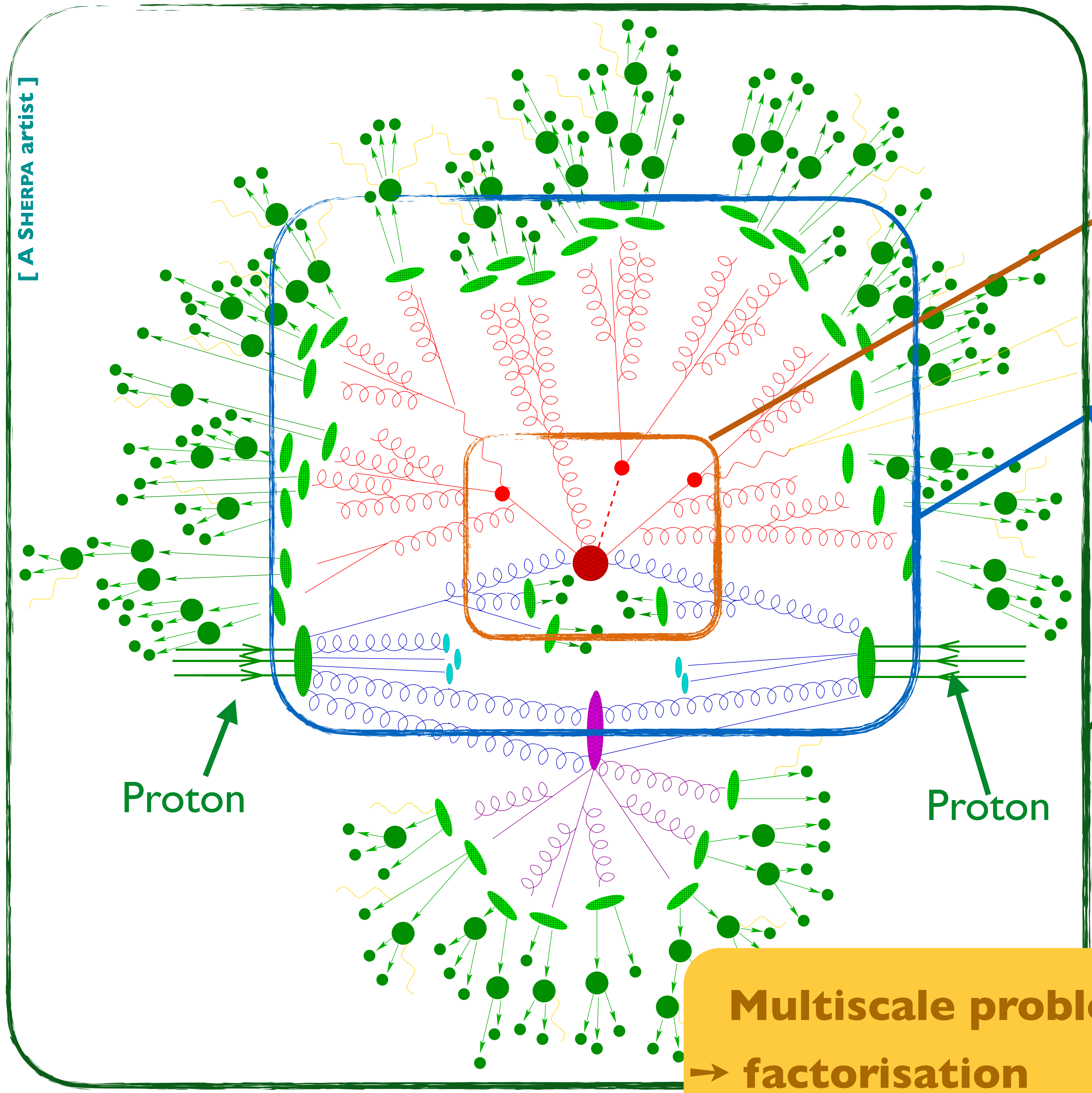

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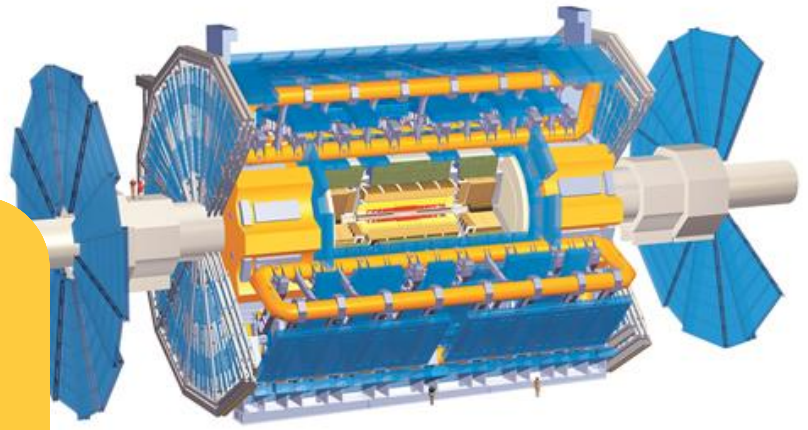

Multiscale problem
→ **factorisation**
→ **one tool / step**

SM and BSM simulations: the status

SM simulations under good control

- Relevant LHC processes: known with a very good precision
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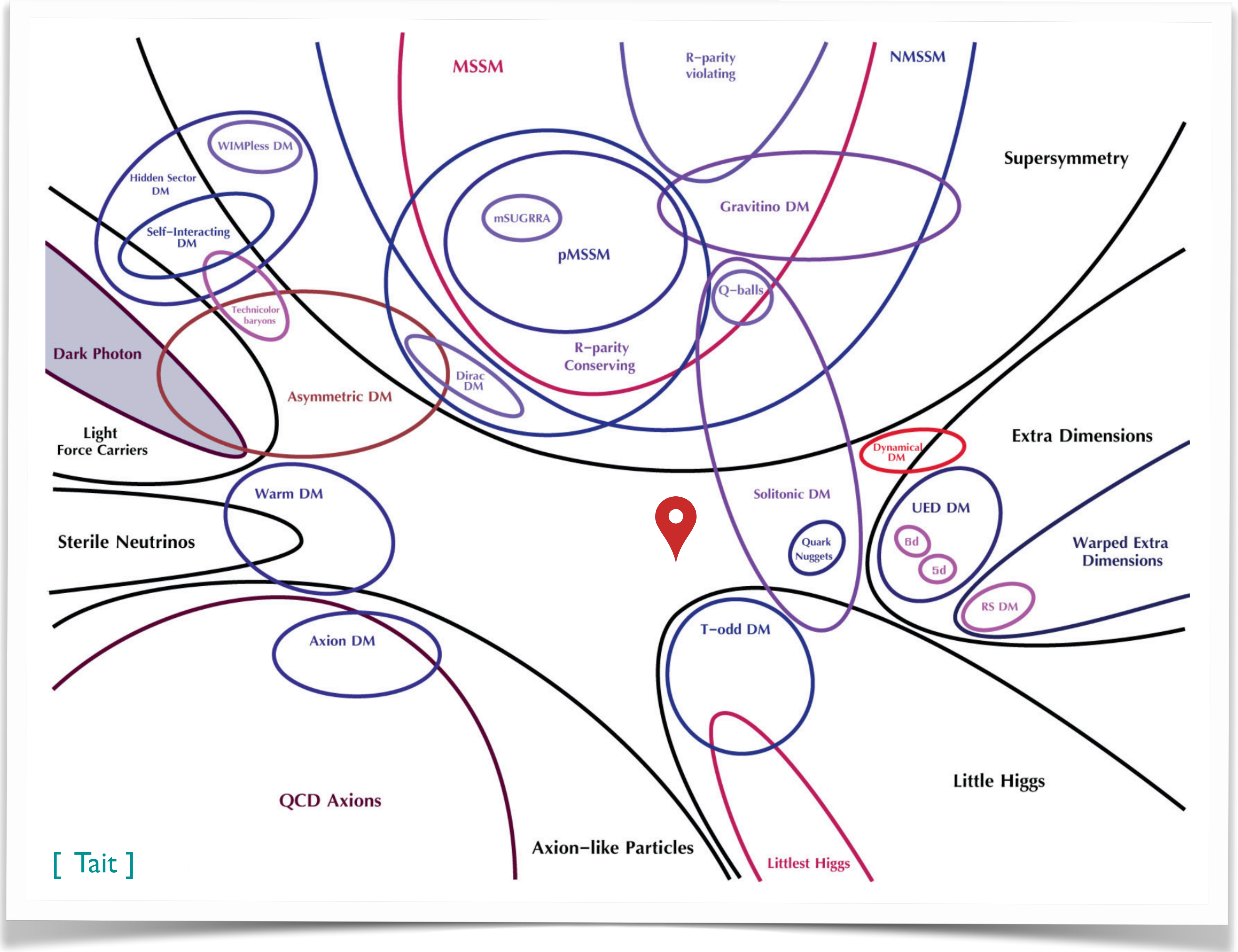
Different challenges for new physics

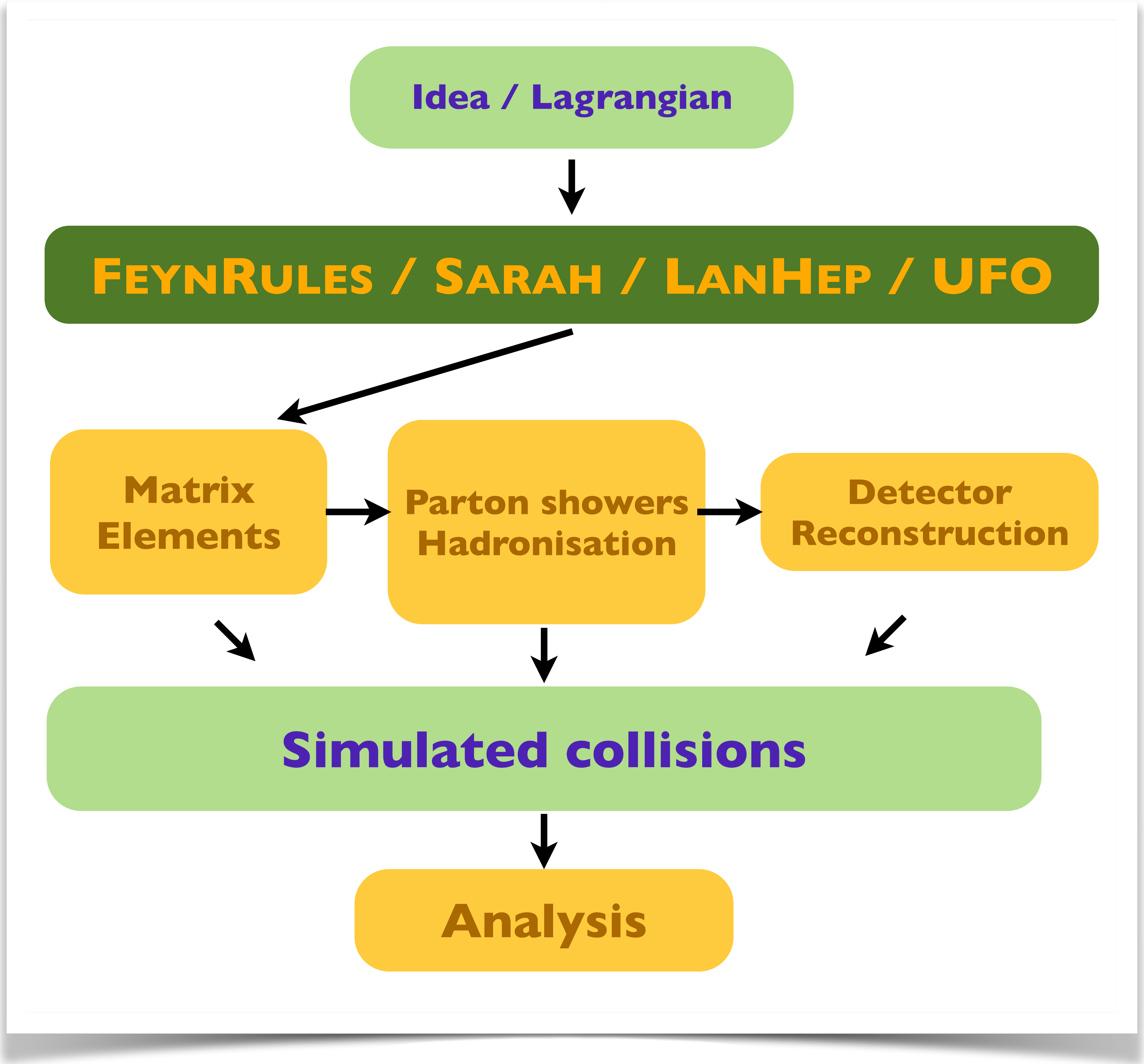
- No sign of new physics
- SM-like measurements
  ➙ no leading candidate theory
- Plethora of models to consider
  ➙ many implementations in tools

Despite of this, new physics is standard today



Connecting ideas to simulations…

[Christensen, de Aquino, Degrande, Duhr, BF, Herquet, Maltoni & Schumann (EPJC`11)]



- Model building
- Hard scattering
  - ⋆ Feynman diagram and amplitude generation
  - ⋆ Monte Carlo integration
  - ⋆ Event generation
- QCD environment
  - ⋆ Parton showering
  - ⋆ Hadronisation
  - ⋆ Underlying event
- Detector simulation
  - ⋆ Simulation of the detector response
  - ⋆ Object reconstruction
- Event analysis
  - ⋆ Signal/background analysis
  - ⋆ LHC recasting

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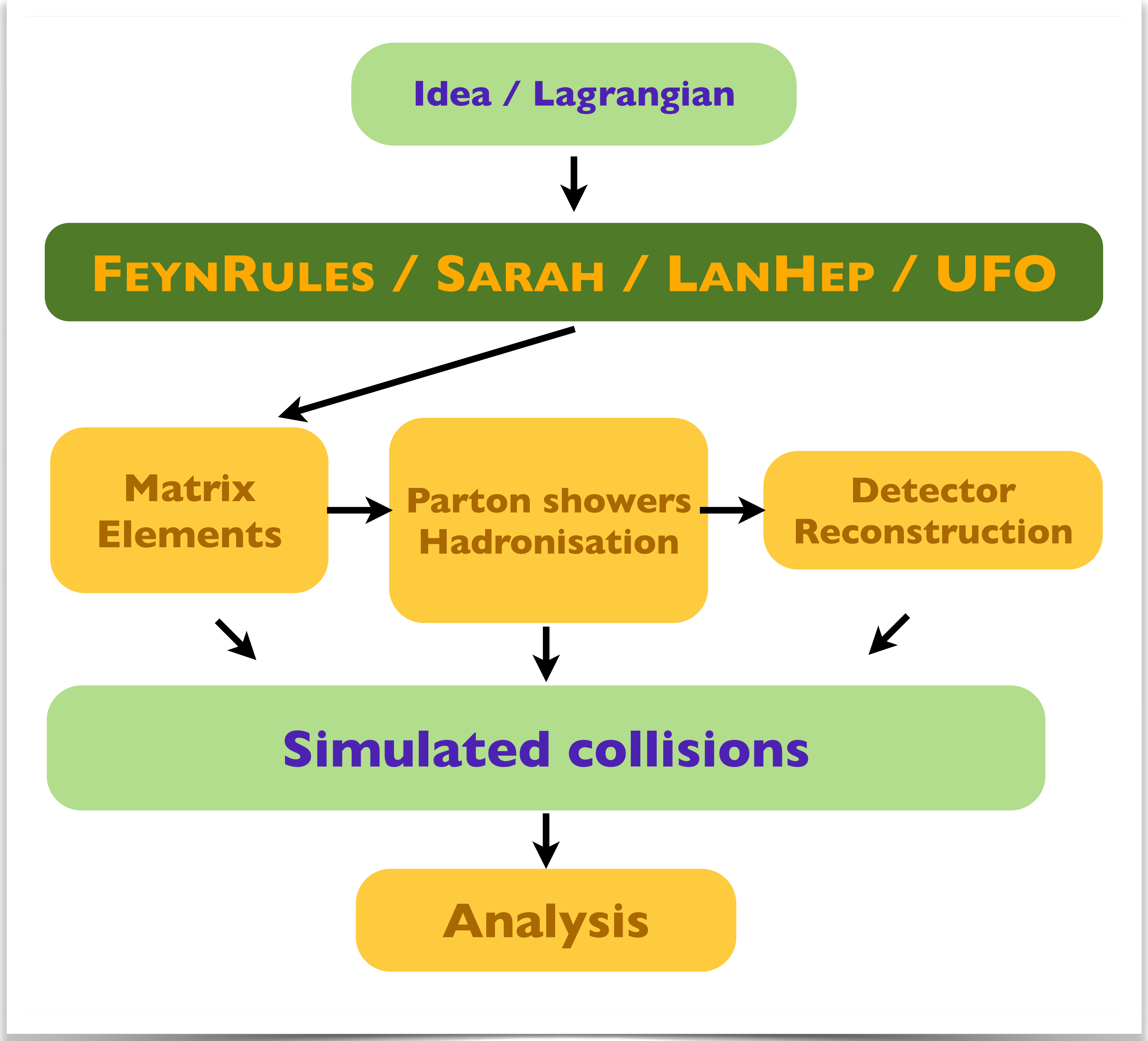

- Model building → FEYNRULES, LANHEP, SARAH UFO
- Hard scattering
  - ⋆ Feynman diagram and amplitude generation
  - ⋆ Monte Carlo integration
  - ⋆ Event generation

  → CALCHEP, HERWIG++, MG5_AMC, SHERPA, WHIZARD, …
- QCD environment
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  → HERWIG, PYTHIA, SHERPA
- Detector simulation
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  → DELPHES RIVET / MADANALYSIS 5 – SFS
- Event analysis
  - ⋆ Signal/background analysis
  - ⋆ LHC recasting

  → RIVET / MADANALYSIS 5

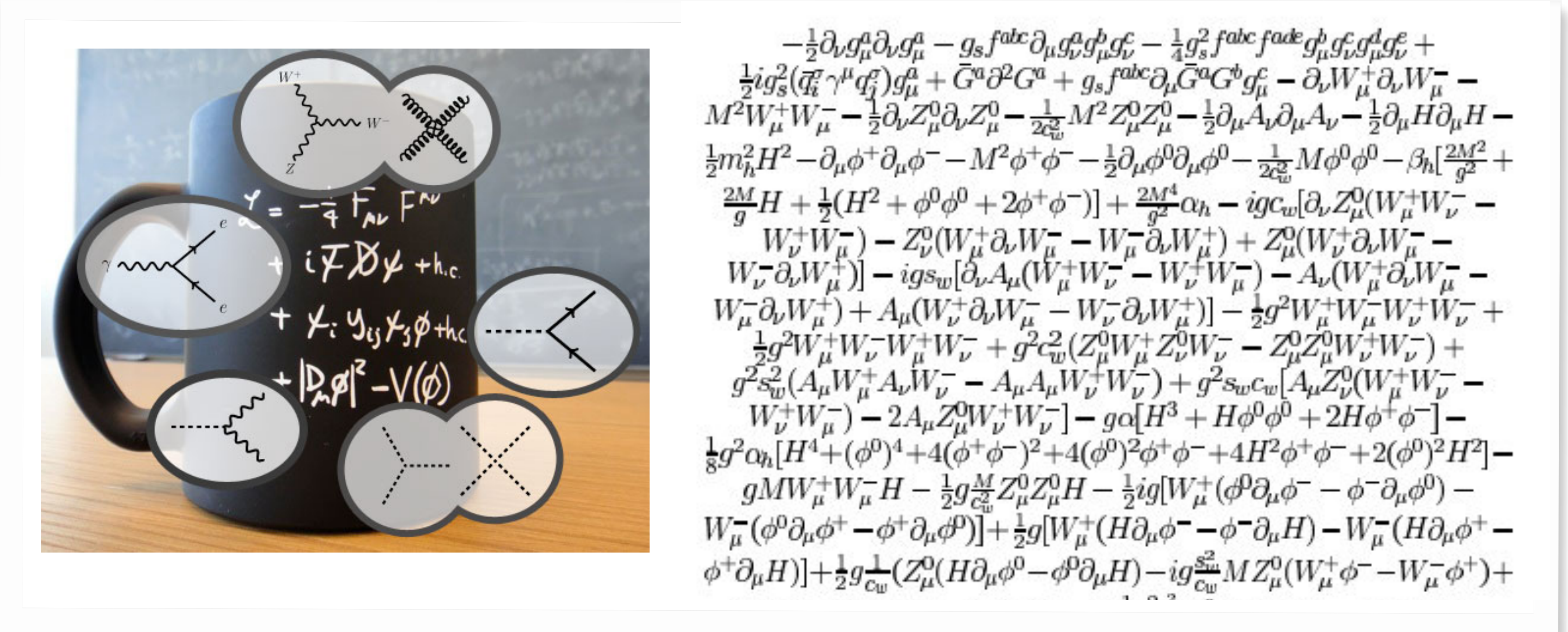
Outline

1. A comprehensive approach for Monte Carlo simulations
2. **Implementing models into Monte Carlo event generators**
3. From events to Lagrangian: reinterpretation of the results of the LHC
4. Summary

The role of the Lagrangian

Implementation of a new physics model in an MC programme

- Definition: particles, parameters and vertices (≡ Lagrangian)
  ➞ translated in some programming language
- Tedious, time-consuming, error prone
- Beware of restrictions/conventions



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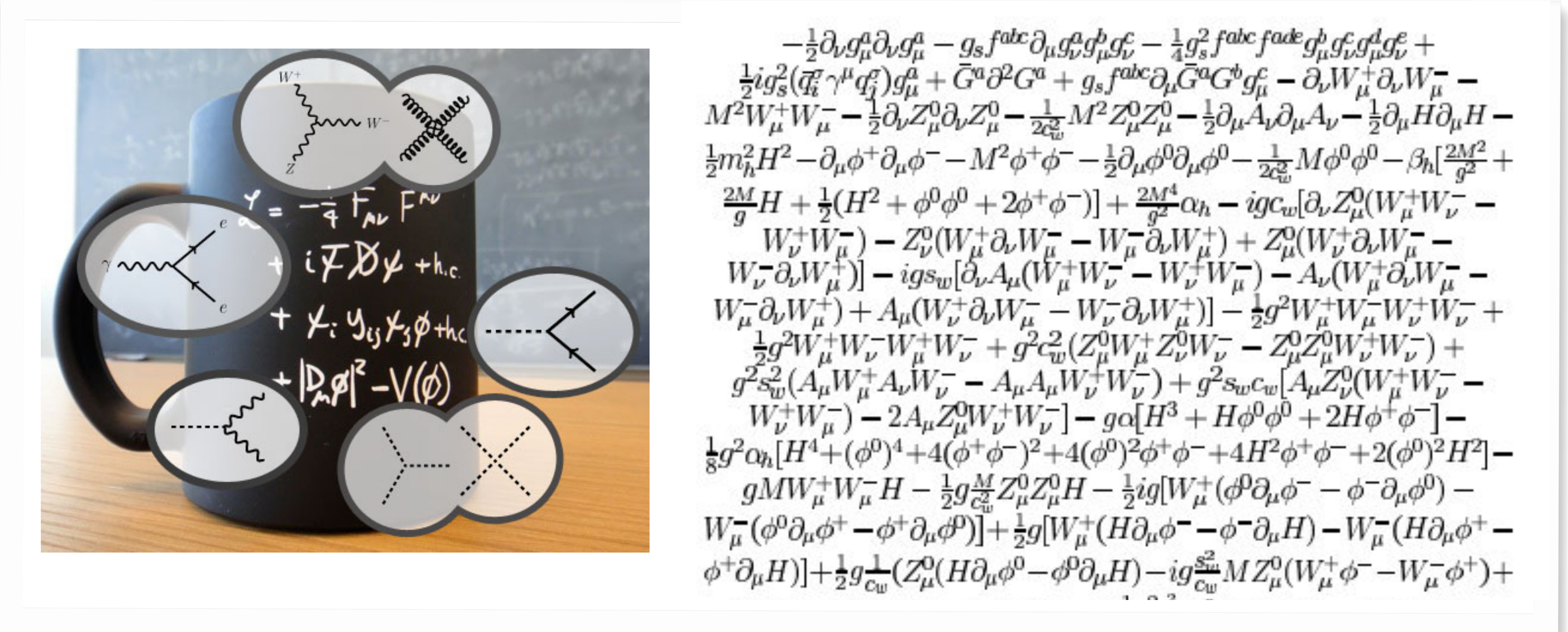

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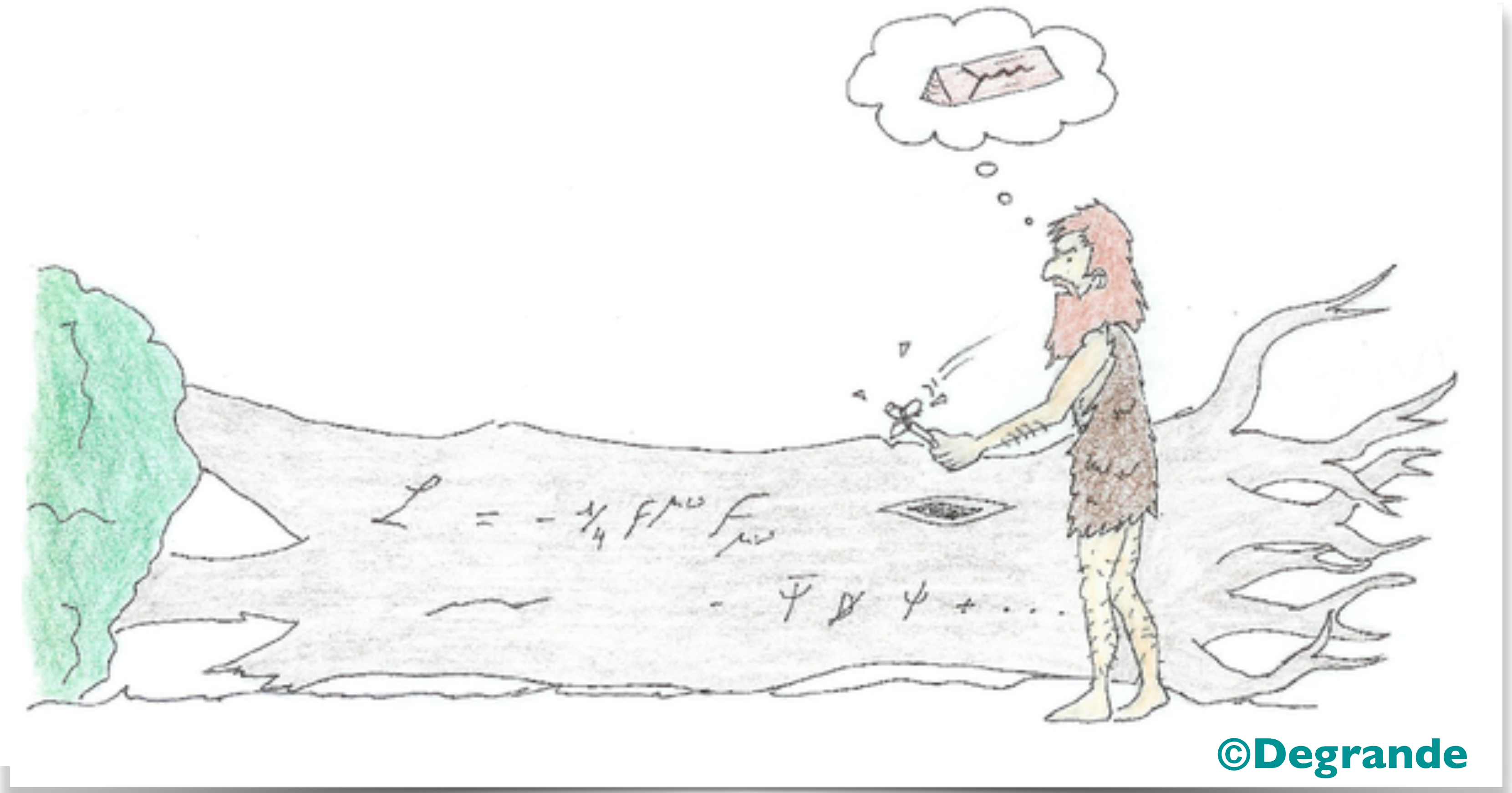
★ Highly redundant (each tool, each model)

★ No-brainer tasks (from Feynman rules to codes)



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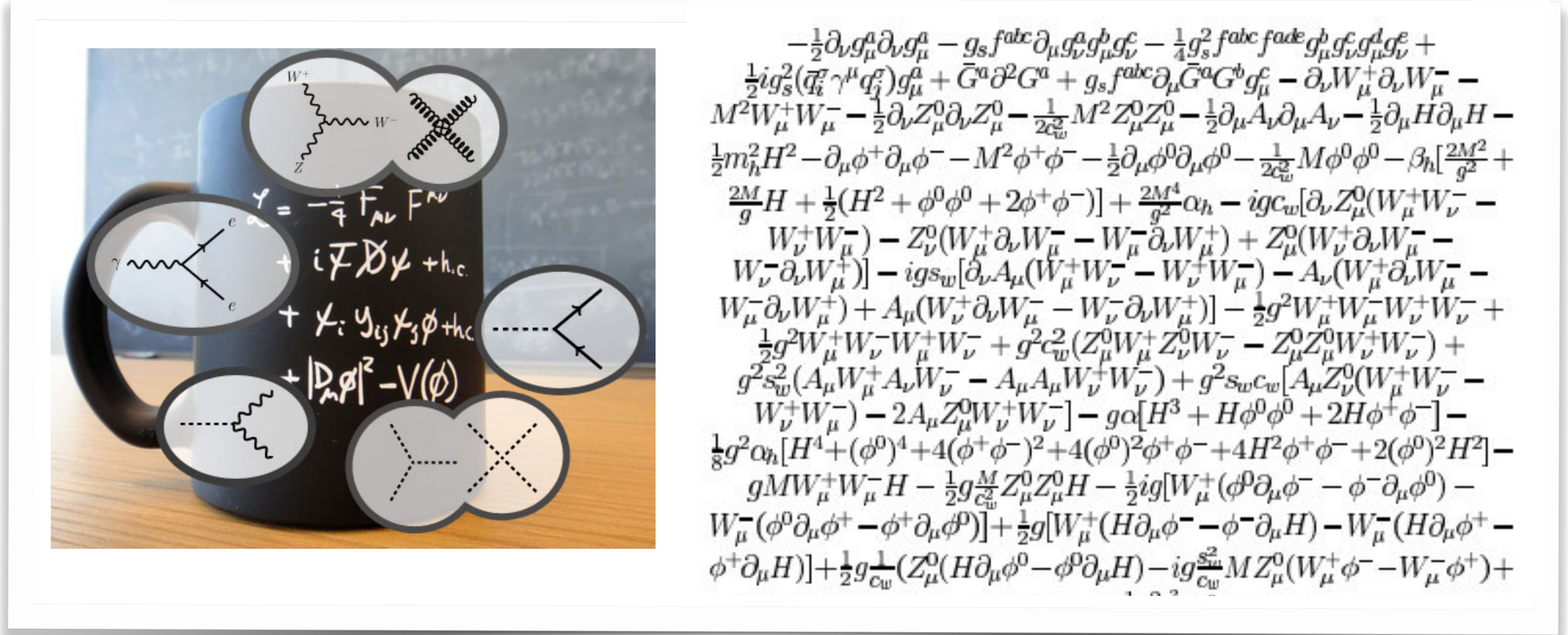

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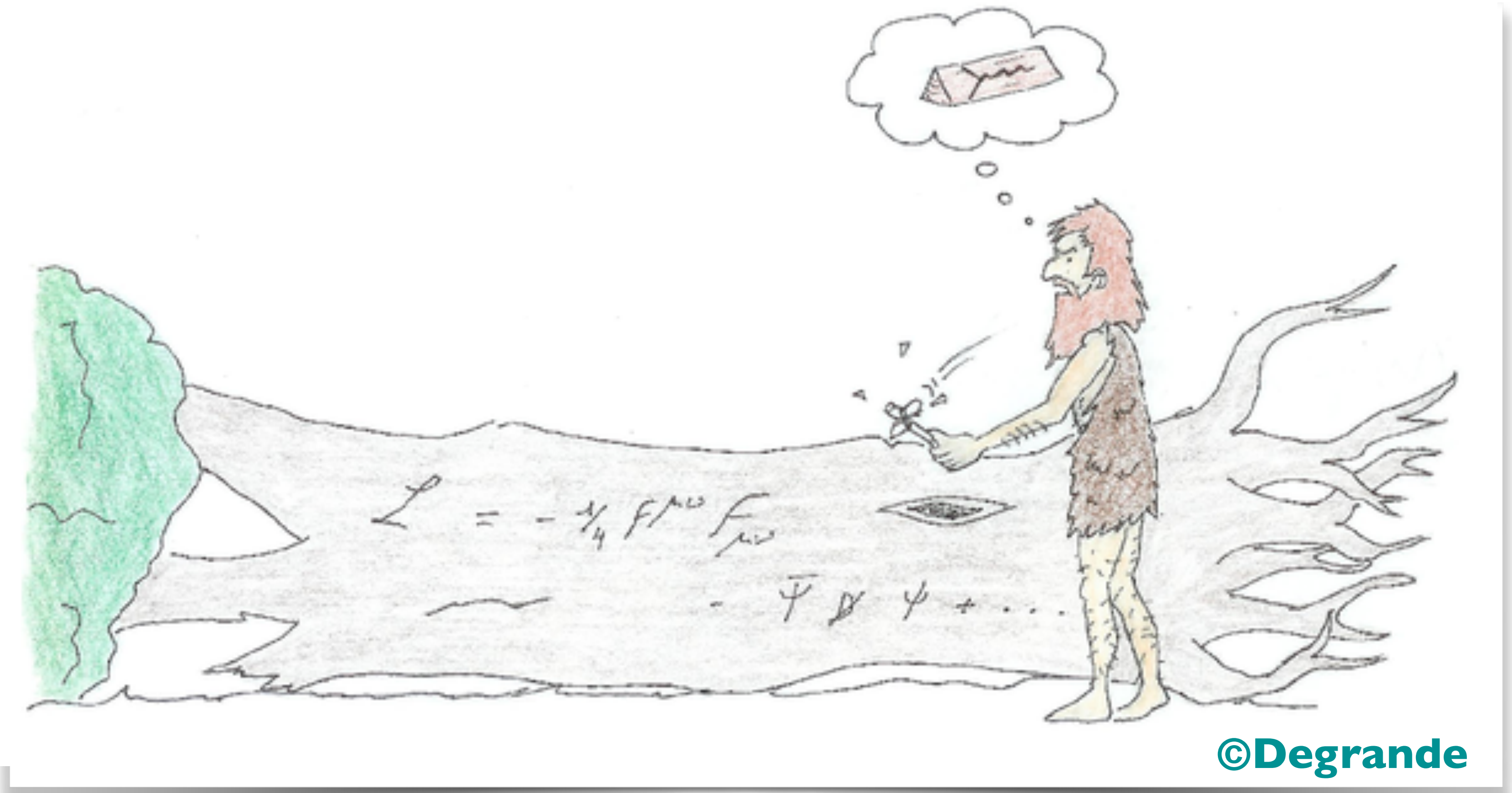
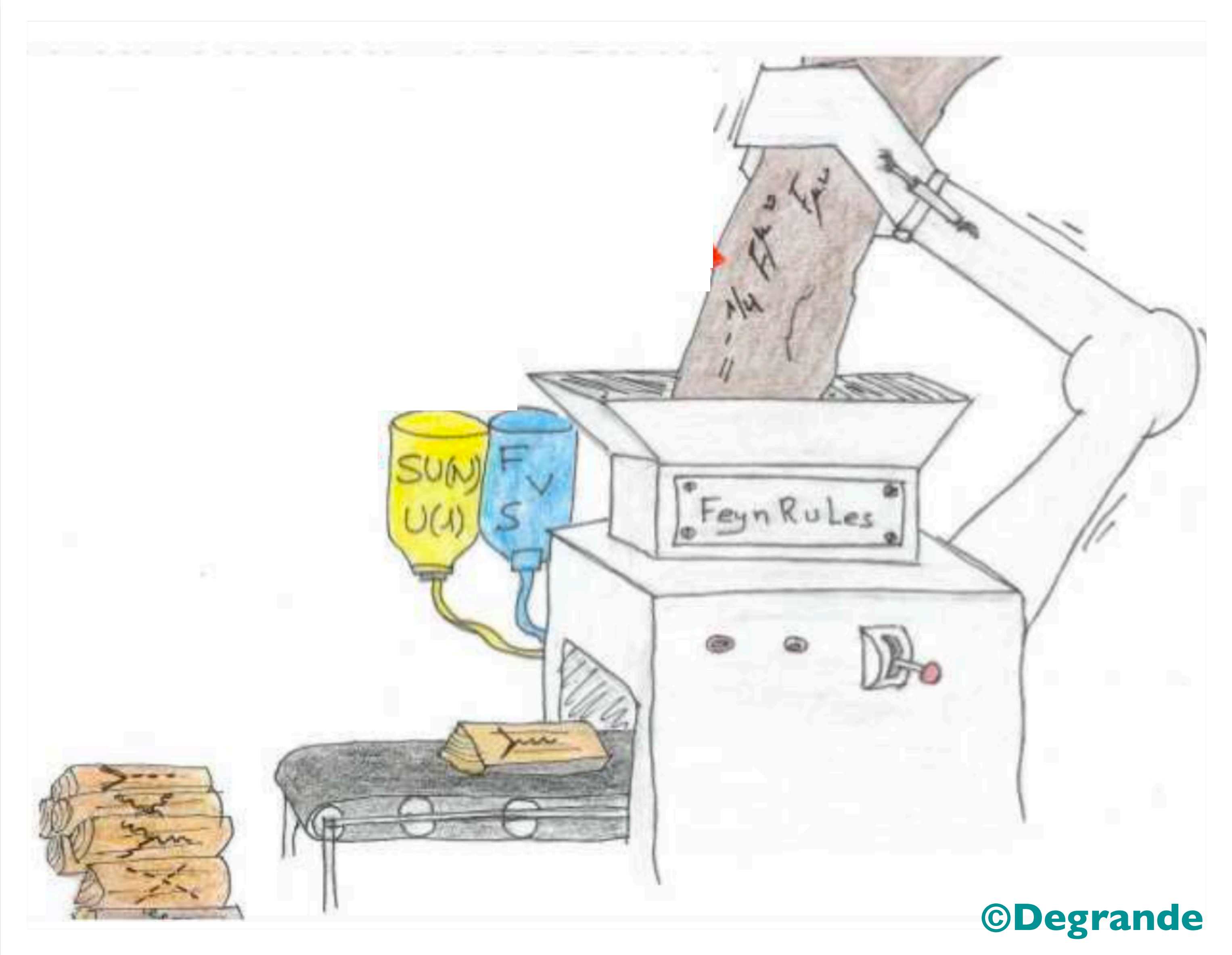


Systematisation
Automation



Programmes connecting Lagrangians and HEP software

The FEYNRULES platform (since 2009)

- Working environment: MATHEMATICA
  - ⋆ Flexibility, symbolic manipulations, easy implementation of new methods, *etc*.
  - ⋆ Many plugins (superspace, spectrum, decays, NLO, *etc*.)
- Interfaces to many MC tools
  - ⋆ Dedicated interfaces (CALCHEP, FEYNARTS)
  - ⋆ Generic interface: UFOs (MG5_AMC, HERWIG, SHERPA, WHIZARD, …)
- Very few limitations on models
  - ⋆ Higher-dimensional operators supported
  - ⋆ Spins (up to 2); colour structures (1, 3, 6, 8)

[Christensen & Duhr (CPC '09)]
[Alloul, Christensen, Degrande, Duhr & BF (CPC'14)]

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LanHEP (since 1997)

- Working environment: C
- Initially restricted to CalcHEP/CompHEP
- Later interfaced to FeynArts/UFOs

[Semenov (CPC'98); Semenov (CPC'16)]

The SARAH package (since 2010)

- Working environment: Mathematica
- Spectrum generator, indirect constraints
- Interfaced to many tools (CalcHEP, FeynArts, UFO, Whizard)

[Staub (CPC'10); Staub (CPC'14)]

Interfacing Lagrangians and MC tools

How to link a Lagrangian to a given MC tool?

- Model Feynman rules (vertices, particle content, *etc.*)
- Removal of vertices not compliant with the tool
  ➙ Colour structures
  ➙ Lorentz structures
- Translation to a specific format and programming language

➙ not efficient
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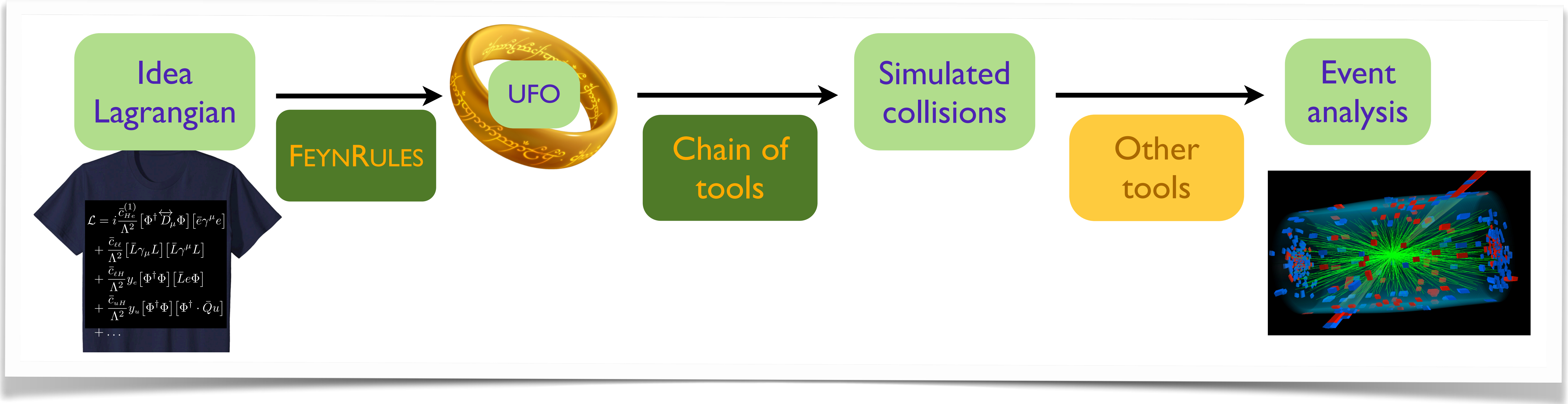
The UFO: one format to rule them all



The Universal FEYNRULES Output

The UFO in a nutshell

[Degrande, Duhr, BF, Grellscheid, Mattelaer, Reiter (CPC '12)]
[Degrande, Duhr, BF, Hirschi, Mattelaer, Pagani, Shao *et al.* (*in prep.*)]

©Degrande

- UFO ≡ Universal FEYNRULES output ➞ Universal Feynman Output
  - ⋆ Universal as not tied to any specific programme
- Set of PYTHON files to be linked to any code
- A PYTHON model with full information
  - ⋆ Generic colour and Lorentz structures
  - ⋆ Up to software to enforce restrictions on acceptable colour/Lorentz structures
- Allows for next-to-leading order calculations

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Initially designed as the MG5aMC model format, UFOs now standard

FeynRules | Sarah | LanHEP

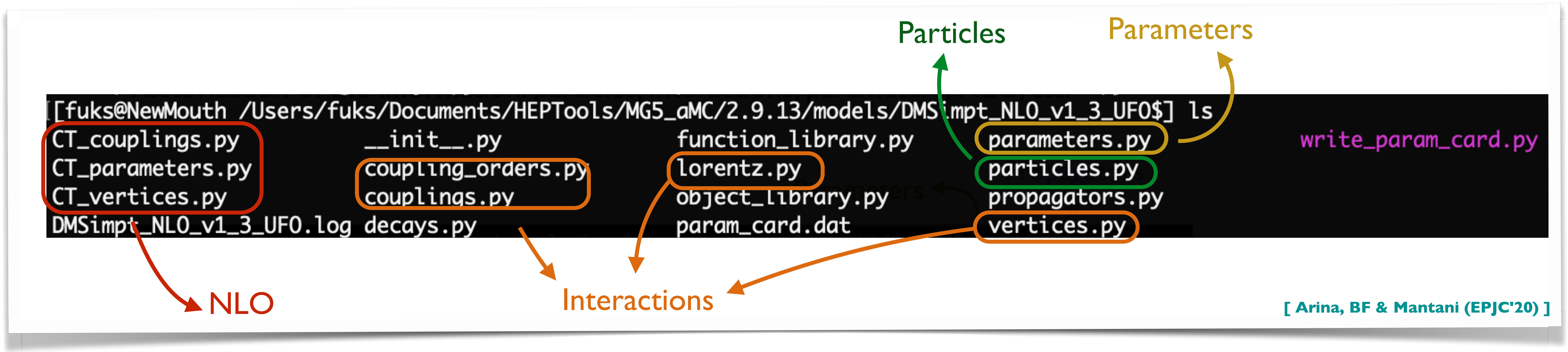
Aloha | Contur | GoSam | Herwig ++ | MadDM

MadGraph5_aMC@NLO | MadAnalysis 5 | Sherpa | Whizard

The UFO in practice

The UFO ≡ set of PYTHON files

- Factorisation of the information in mandatory and optional files
  - → particles
  - → parameters
  - → interactions
  - → extra stuff (NLO, decays, propagators, functions, *etc.*)
- Economical implementation of vertices and structures through recycling across the model



[Arina, BF & Mantani (EPJC'20)]

The UFO: particles & parameters

Particles ≡ instances of the particle class

- Attributes: spin, colour representation, mass, width, *etc.*
- Antiparticles automatically derived

```
go = Particle(pdg_code = 1000021,
              name = 'go',
              antiname = 'go',
              spin = 2,
              color = 8,
              mass = Param.Mgo,
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Parameters ≡ instances of the parameter class

- External parameters: Les Houches-like structure
- PYTHON-compliant formula for the internal parameters

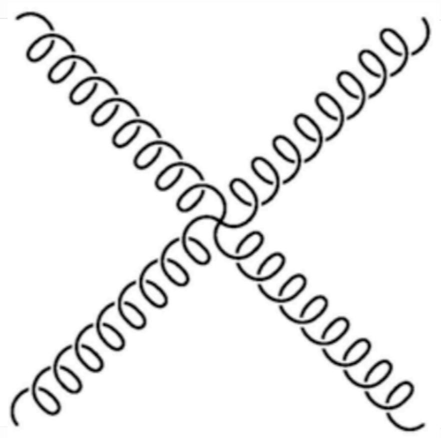
```
aS = Parameter(name = 'aS',
               nature = 'external',
               type = 'real',
               value = 0.1184,
               texname = '\\alpha _s',
               lhablock = 'SMINPUTS',
               lhacode = [ 3 ])

G = Parameter(name = 'G',
              nature = 'internal',
              type = 'real',
              value = '2*cmath.sqrt(aS)*cmath.sqrt(cmath.pi)',
              texname = 'G')
```

The UFO: strategy for interactions

Decomposition in a spin x colour basis (coupling strengths ≡ coordinates)

- Example: the quartic gluon vertex



$$
\begin{aligned}
& i g_s^2 \, f^{a_1 a_2 b} f^{b a_3 a_4} \left(\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4}\right) \\
& \quad + i g_s^2 \, f^{a_1 a_3 b} f^{b a_2 a_4} \left(\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4}\right) \\
& \quad + i g_s^2 \, f^{a_1 a_4 b} f^{b a_2 a_3} \left(\eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4}\right)
\end{aligned}
$$

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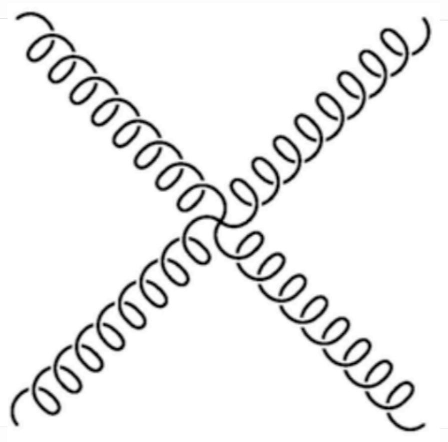
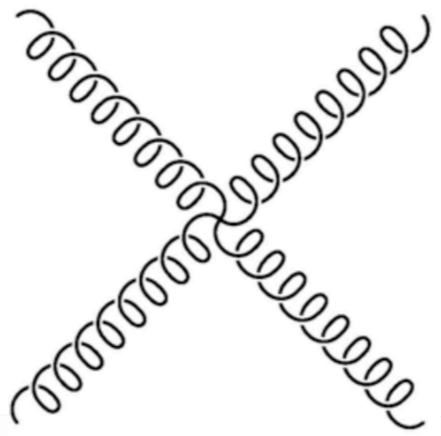


$$ig_s^2\, f^{a_1a_2b} f^{ba_3a_4}\,(\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4}) + ig_s^2\, f^{a_1a_3b} f^{ba_2a_4}\,(\eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4}) + ig_s^2\, f^{a_1a_4b} f^{ba_2a_3}\,(\eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4})$$

- UFO version



$$\left(f^{a_1a_2b} f^{ba_3a_4},\ f^{a_1a_3b} f^{ba_2a_4},\ f^{a_1a_4b} f^{ba_2a_3}\right) \times \begin{pmatrix} ig_s^2 & 0 & 0 \\ 0 & ig_s^2 & 0 \\ 0 & 0 & ig_s^2 \end{pmatrix} \begin{pmatrix} \eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} \\ \eta^{\mu_1\mu_4}\eta^{\mu_2\mu_3} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4} \\ \eta^{\mu_1\mu_3}\eta^{\mu_2\mu_4} - \eta^{\mu_1\mu_2}\eta^{\mu_3\mu_4} \end{pmatrix}$$

- ⋆ 3 elements for the colour basis
- ⋆ 3 elements for the spin (Lorentz structure) basis
- ⋆ 9 coordinates (6 are zero, only 1 encoded)

Information split across several files

```
[fuks@NewMouth /Users/fuks/Documents/HEPTools/MG5_aMC/2.9.13/models/DMSimpt_NLO_v1_3_UFO$] ls
CT_couplings.py         __init__.py           function_library.py    parameters.py        write_param_card.py
CT_parameters.py        coupling_orders.py    lorentz.py             particles.py
CT_vertices.py          couplings.py          object_library.py      propagators.py
DMSimpt_NLO_v1_3_UFO.log decays.py            param_card.dat         vertices.py
```

NLO predictions in a nutshell

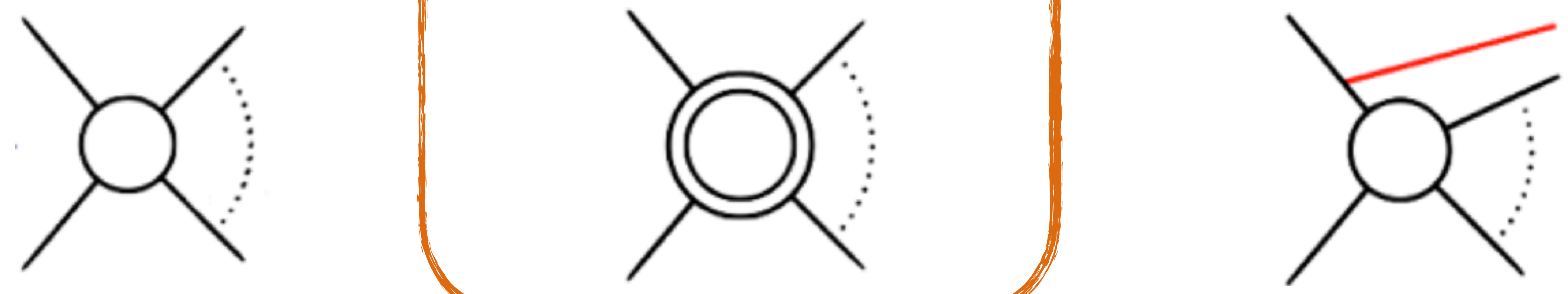
- Three ingredients: the Born, virtual loop and real emission contributions

$$\sigma_{NLO} = \int \mathrm{d}^4\Phi_n \mathcal{B} + \int \mathrm{d}^4\Phi_n \int_{\text{loop}} \mathrm{d}^d\ell \ \mathcal{V} + \int \mathrm{d}^4\Phi_{n+1} \ \mathcal{R}$$

Born

Virtuals: one extra power of α_s and divergent

Reals: one extra power of α_s and divergent



UFOs @ NLO: generalities

NLO predictions in a nutshell

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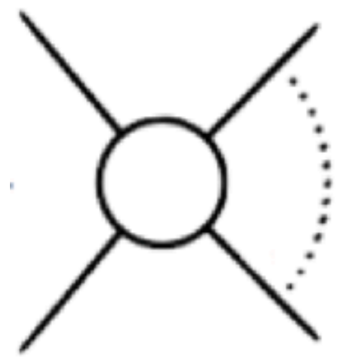
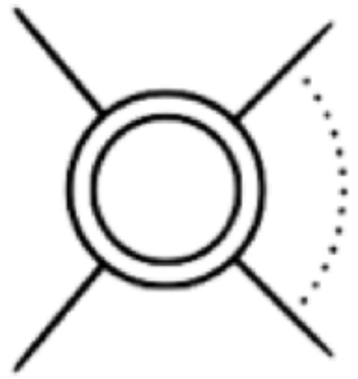
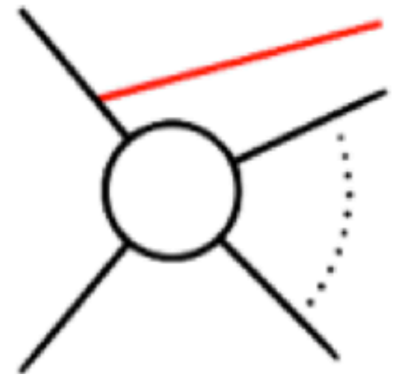
Born



Virtuals: one extra power of α_s and divergent



Reals: one extra power of α_s and divergent



Goal: automated predictions, for any process in any model

- Dimensional regularisation
  ➝ Calculations in $d = 4 - 2\varepsilon$ dimensions
  ➝ Divergences explicit ($1/\varepsilon^2$, $1/\varepsilon$) after reduction of tensor integral reduction
- Numerical methods in 4 dimensions ➝ R_1 and R_2 terms
- Renormalisation ➝ counterterms

Extra information needed

UFO@NLO

[Ossola, Papadopoulos, Pittau (NPB'07)]
[Ossola, Papadopoulos, Pittau (JHEP'08)]

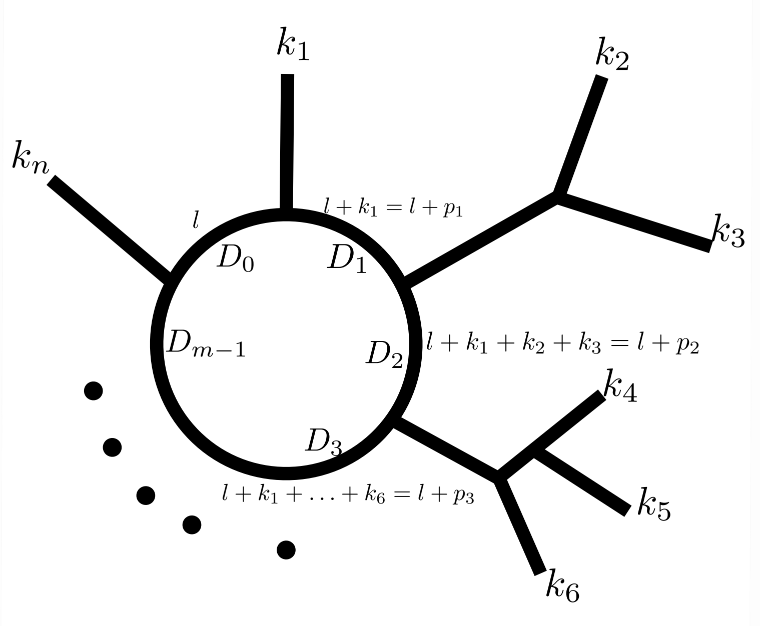
UFOs @ NLO in practice

The reduction must be performed in a *d*-dimensional space

$$\int \mathrm{d}^d\ell \frac{N(\ell,\tilde{\ell})}{\bar{D}_0\bar{D}_1\cdots\bar{D}_{m-1}}$$

with $\bar{\ell} = \ell + \tilde{\ell}$

D-dim 4-dim (-2ε)-dim



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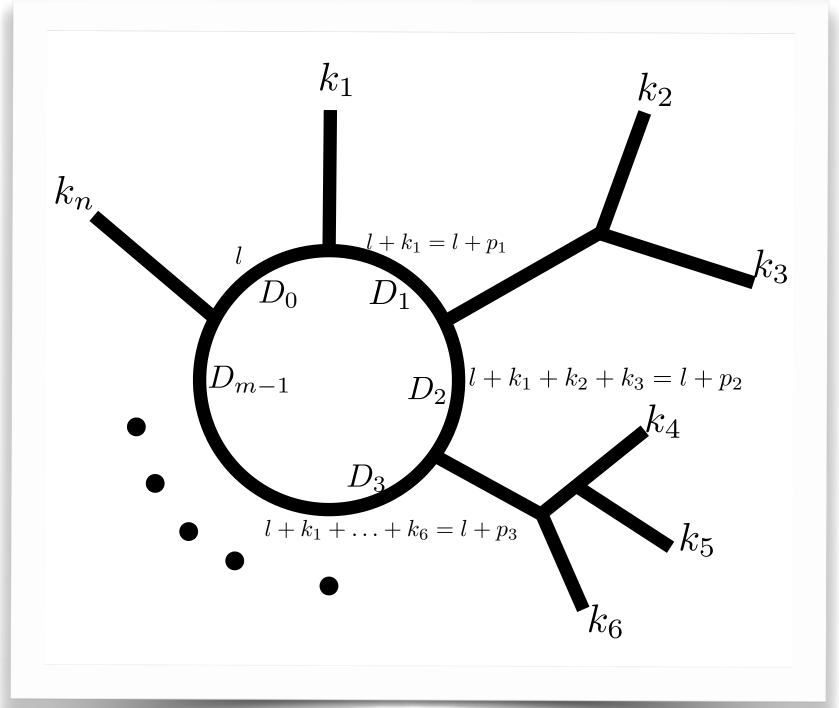
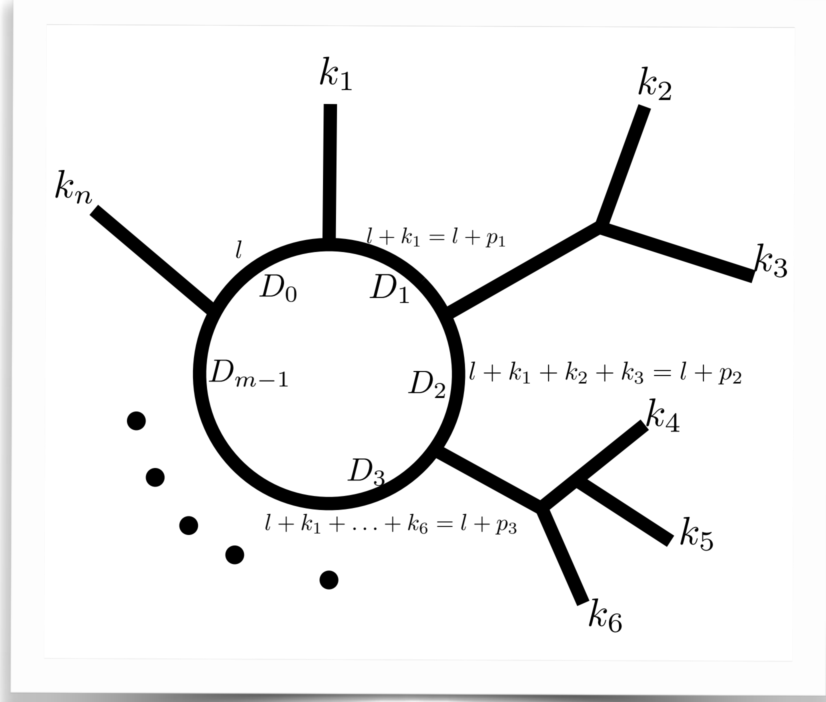


R_I terms from denominators

- *d*D *vs.* 4D internal propagators ($\bar{D}_i \to D_i$)
- Computed on the fly (a few non-zero extra integrals)

UFOs @ NLO in practice



The reduction must be performed in a *d*-dimensional space

$$\int \mathrm{d}^d\ell \frac{N(\ell,\tilde{\ell})}{\bar{D}_0\bar{D}_1\cdots\bar{D}_{m-1}} \quad \text{with } \bar{\ell} = \ell + \tilde{\ell}$$

D-dim 4-dim (-2ε)-dim

R_1 terms from denominators

- *d*D *vs.* 4D internal propagators ($\bar{D}_i \to D_i$)
- Computed on the fly (a few non-zero extra integrals)

R_2 terms from numerators

- Process-dependent contributions proportional to $\tilde{\ell}^2$
- Renormalisable theory
  - ➛ Extra diagrams with special Feynman rules (*R_2 Feynman rules*)
  - ➛ Connected to the UV structure of the integrals (like counterterms)
- Derivation of these extra Feynman rules
  - ➛ Finite number of R_2's from the bare Lagrangian
  - ➛ Calculated together with UV counterterms
  - ➛ The NLOCT package [Degrande (CPC'15)]

UFO @ NLO

NLO simulations with FEYNRULES & MG5_AMC

[Christensen, de Aquino, Degrande, Duhr, BF, Herquet, Maltoni & Schumann (EPJC`11)]

Idea / Lagrangian

↓

FEYNRULES / UFO

↓

Matrix Elements

↓

Collider observables

↓

Phenomenology

Model building: from Lagrangian to tools

- FEYNRULES ➞ UFO (@NLO)
- PYTHON representation of the theory
- Automation of one-loop calculations

[Alloul, Christensen, Degrande, Duhr & BF (CPC'14)]
[Degrande, Duhr, BF, Mattelaer & Reither (CPC'12)]
[Degrande (CPC'15)]

Hard-scattering process with MG5_aMC

- Feynman diagrams, matrix elements
- Perturbative series (LO/NLO)
- Automation from the UFO information

[Alwall et al. (JHEP'14)]
[Frederix, Frixione, Hirschi, Pagani, Shao & Zaro (JHEP`18)]
[Frixione, BF, Hirschi, Mawatari, Shao, Sunder & Zaro (JHEP`19)]

Collider phenomenology

- Matching with parton showers
- Hadronisation models
- Detector simulation

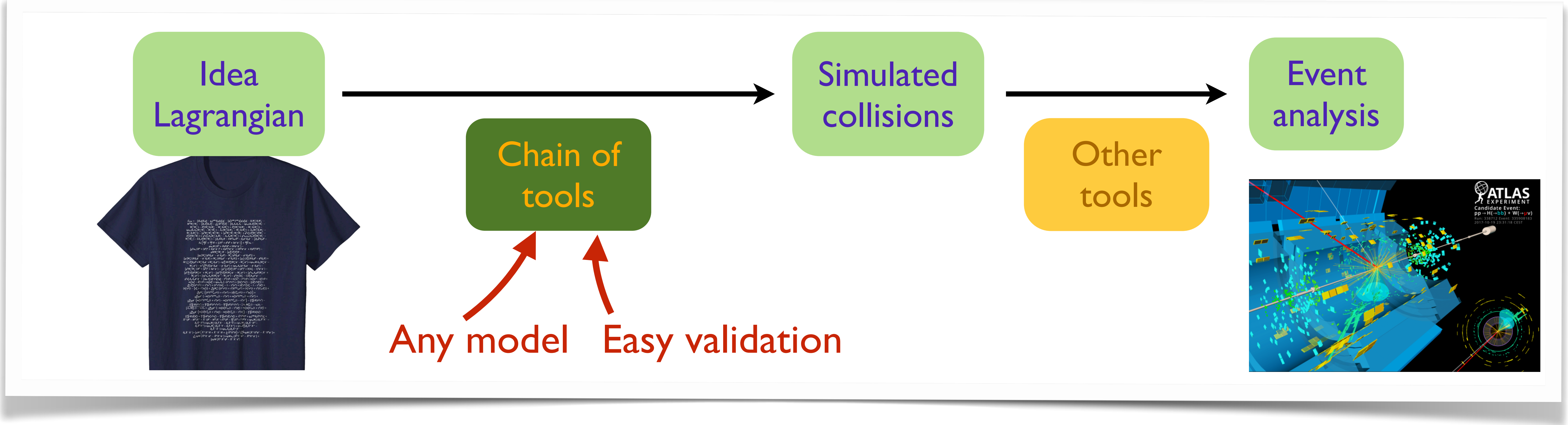
See all other lectures

Outline

From Lagrangians to events

New physics simulations standard today

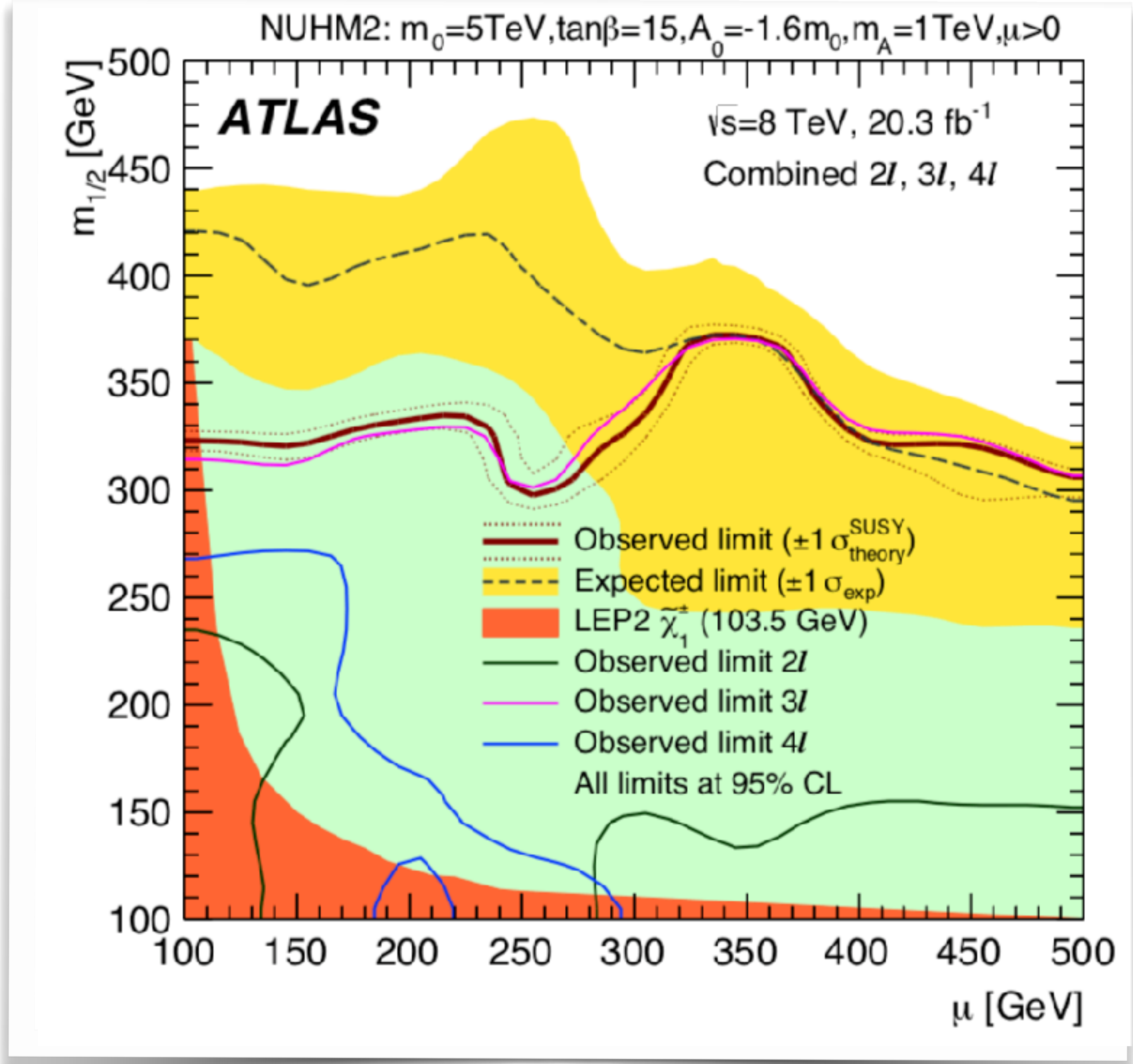
- 20 − 25 years of developments
- Simulations at LO/NLO easily achieved

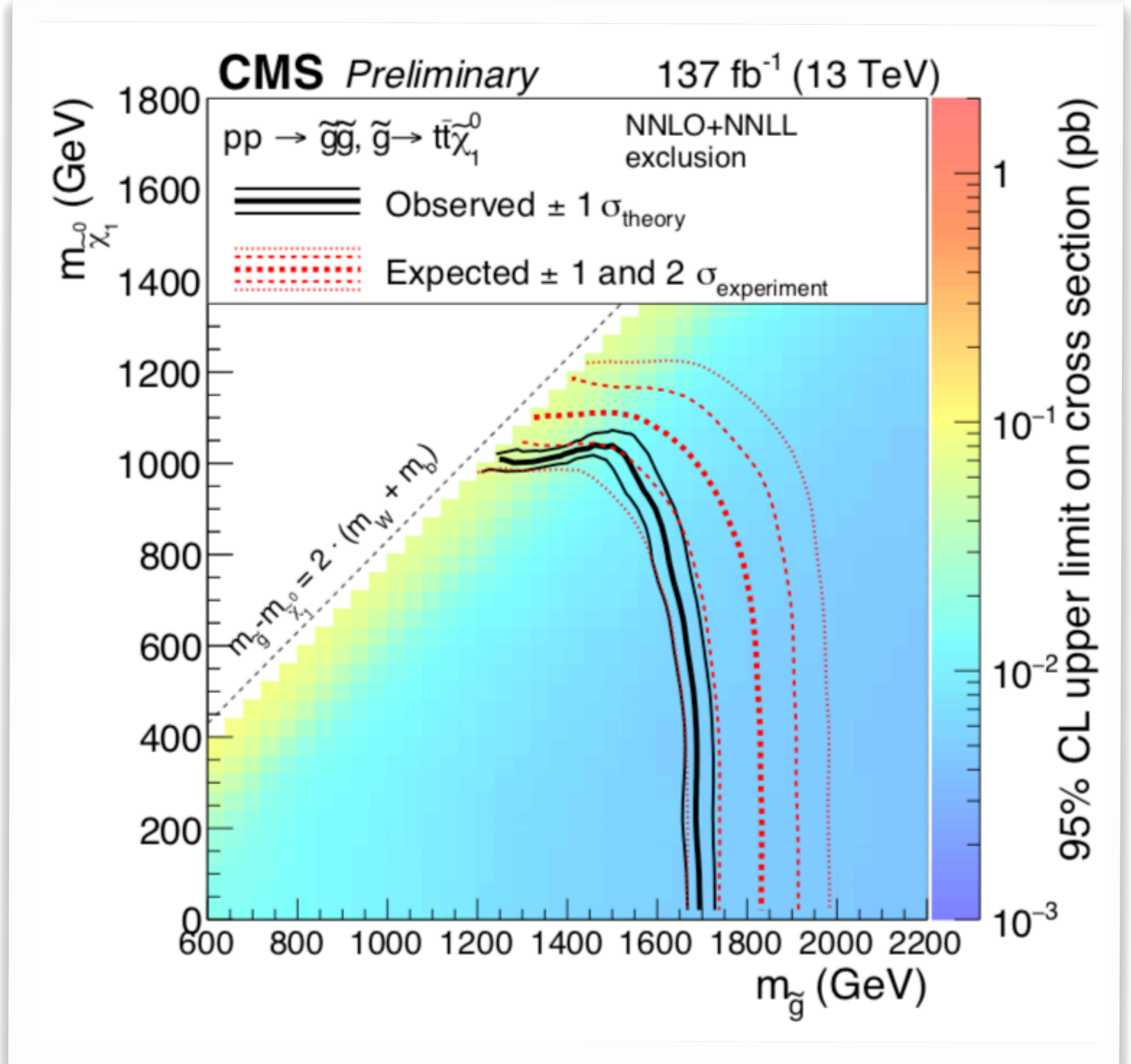


Let’s reverse the chain…

LHC ≡ discovery machine

- Many ATLAS and CMS searches for new physics
- Interpretation within popular frameworks and simplified models





New physics results at the LHC

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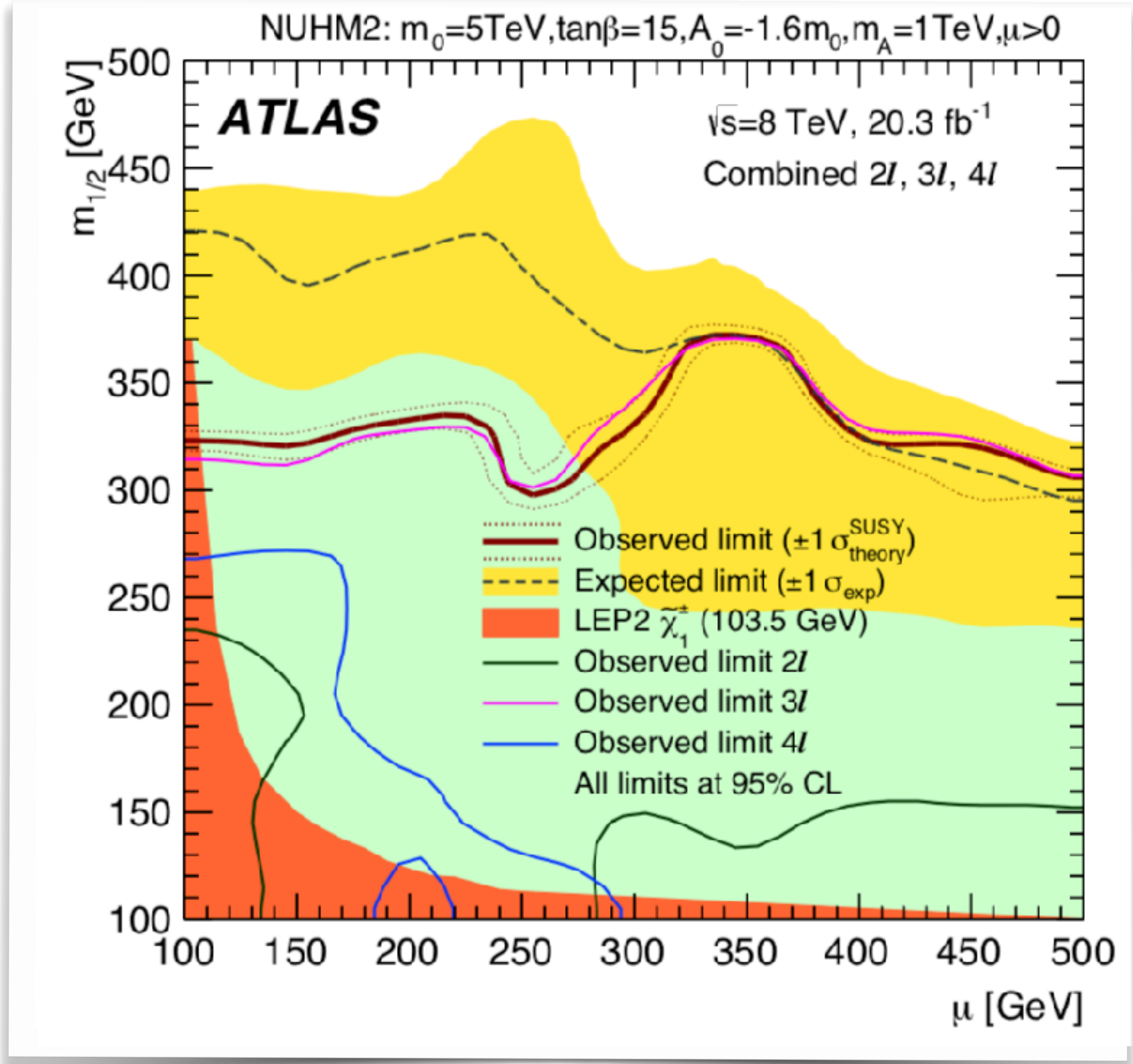
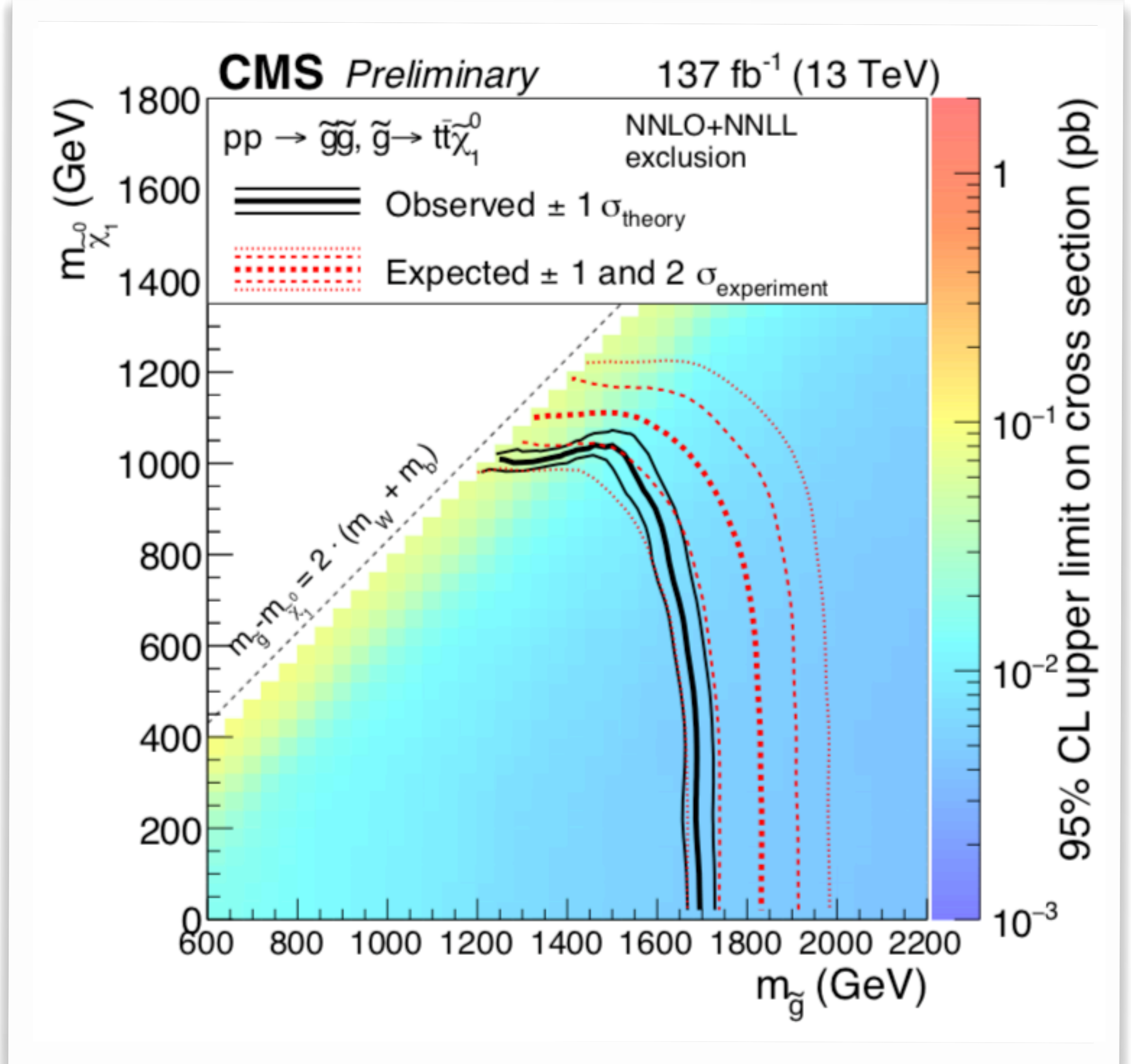




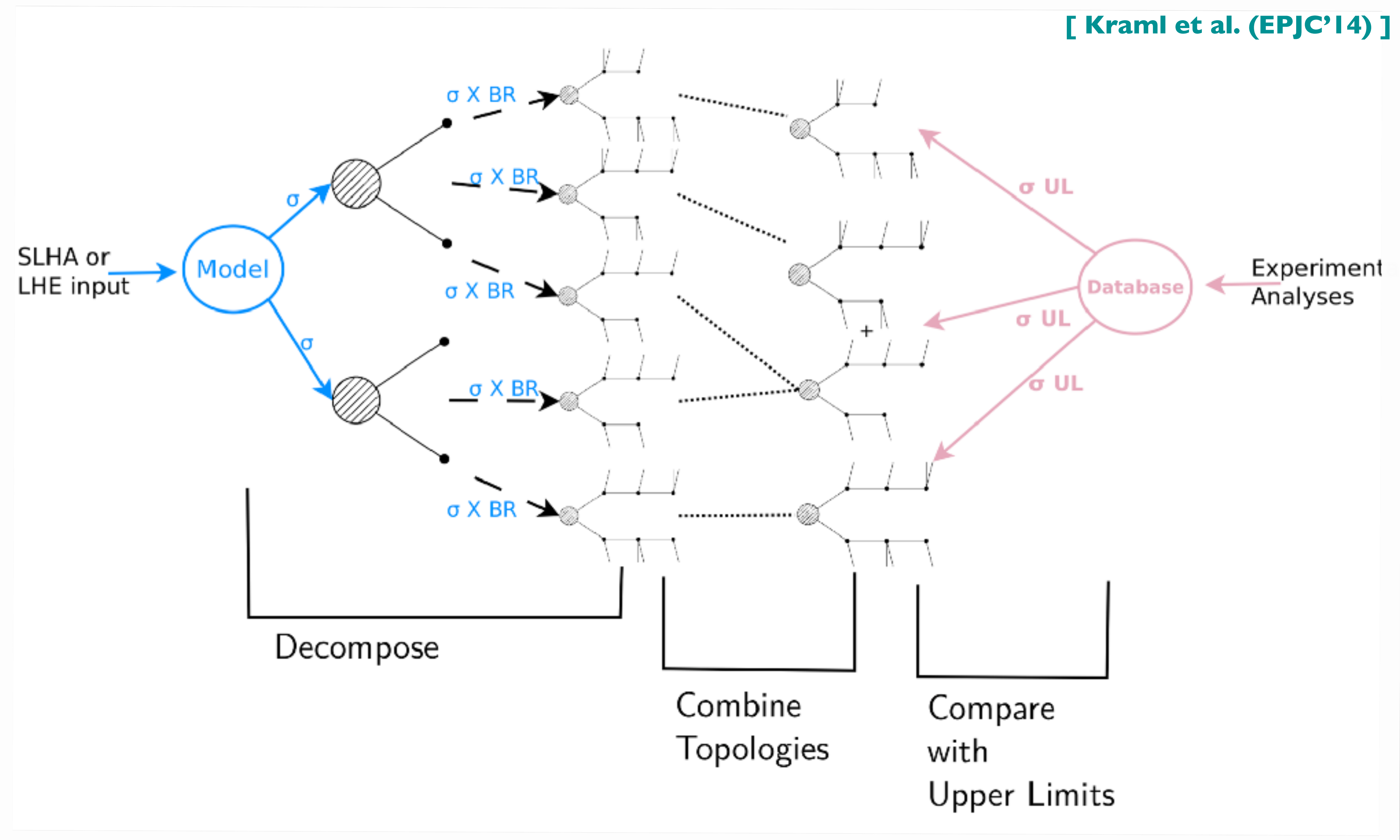
Need for reinterpretations in all kinds of models

Simplified Model Spectra (SMS)

The SMS-based reinterpretation framework

- Decomposition of all signatures of a theory into SMS signatures
- Fiducial cross sections on the basis of public efficiency maps
- Comparisons to published upper bounds

Main features



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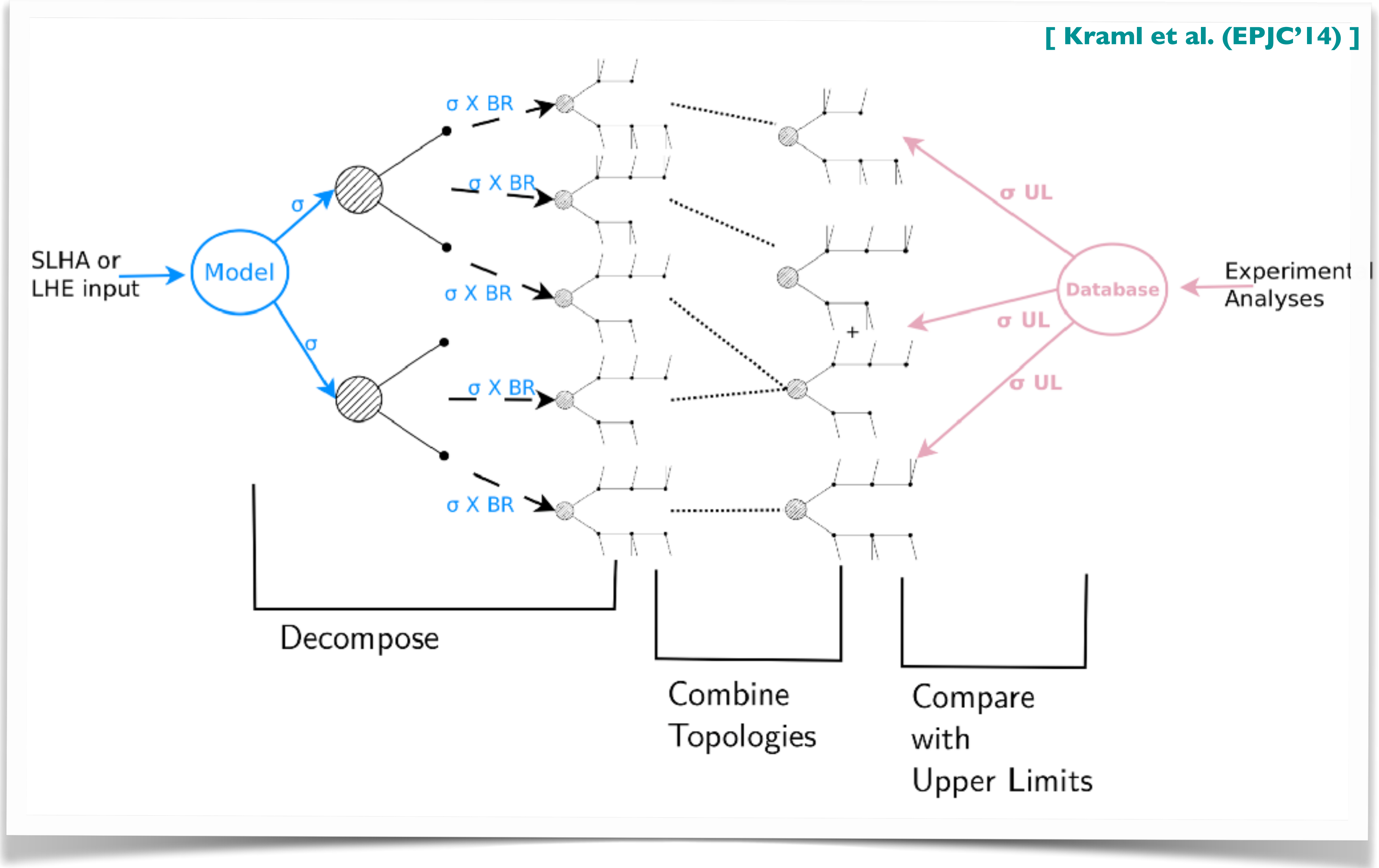

- Rather fast
- Often conservative
  - ⋆ Different kinematics
  - ⋆ Asymmetric decays

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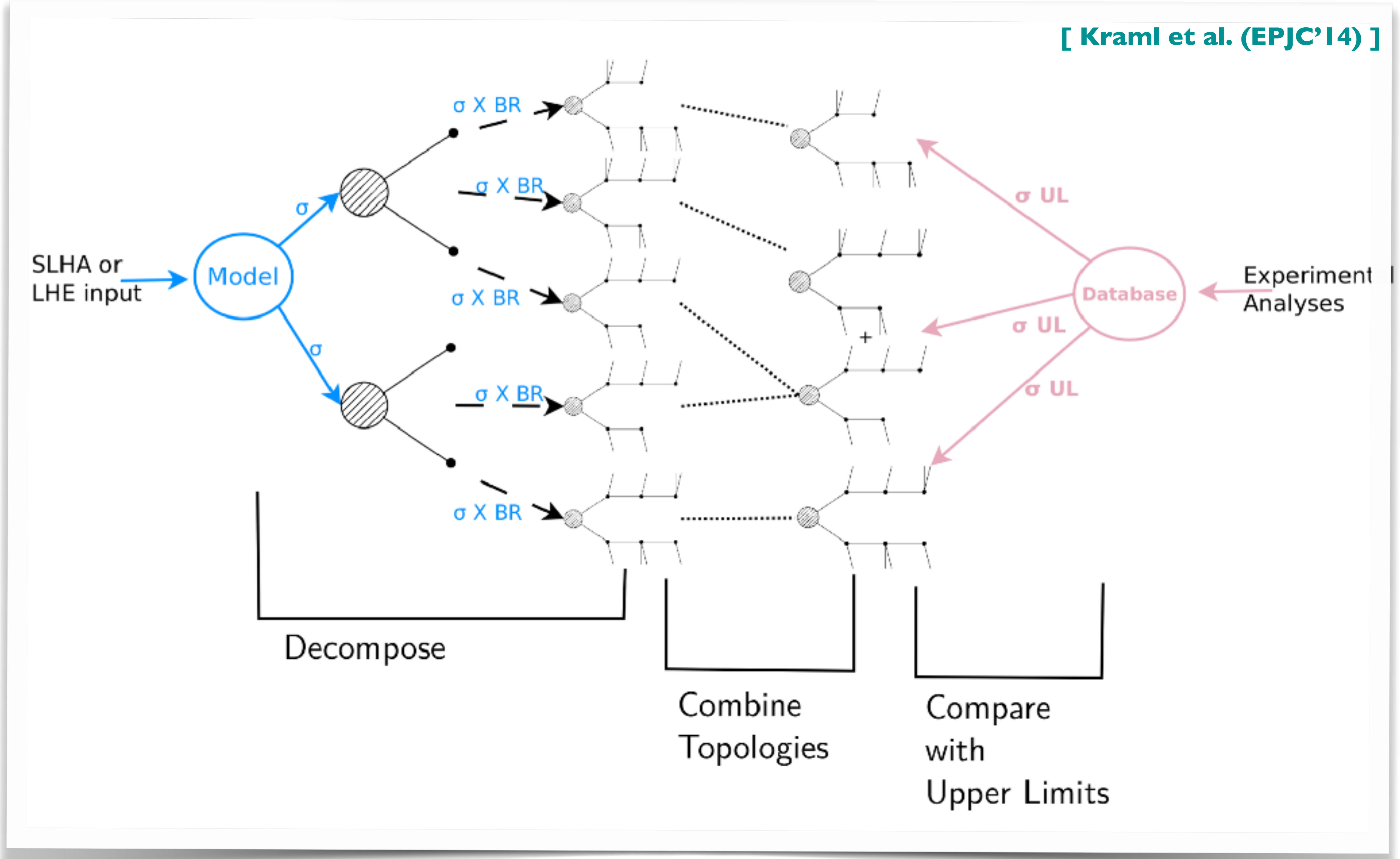
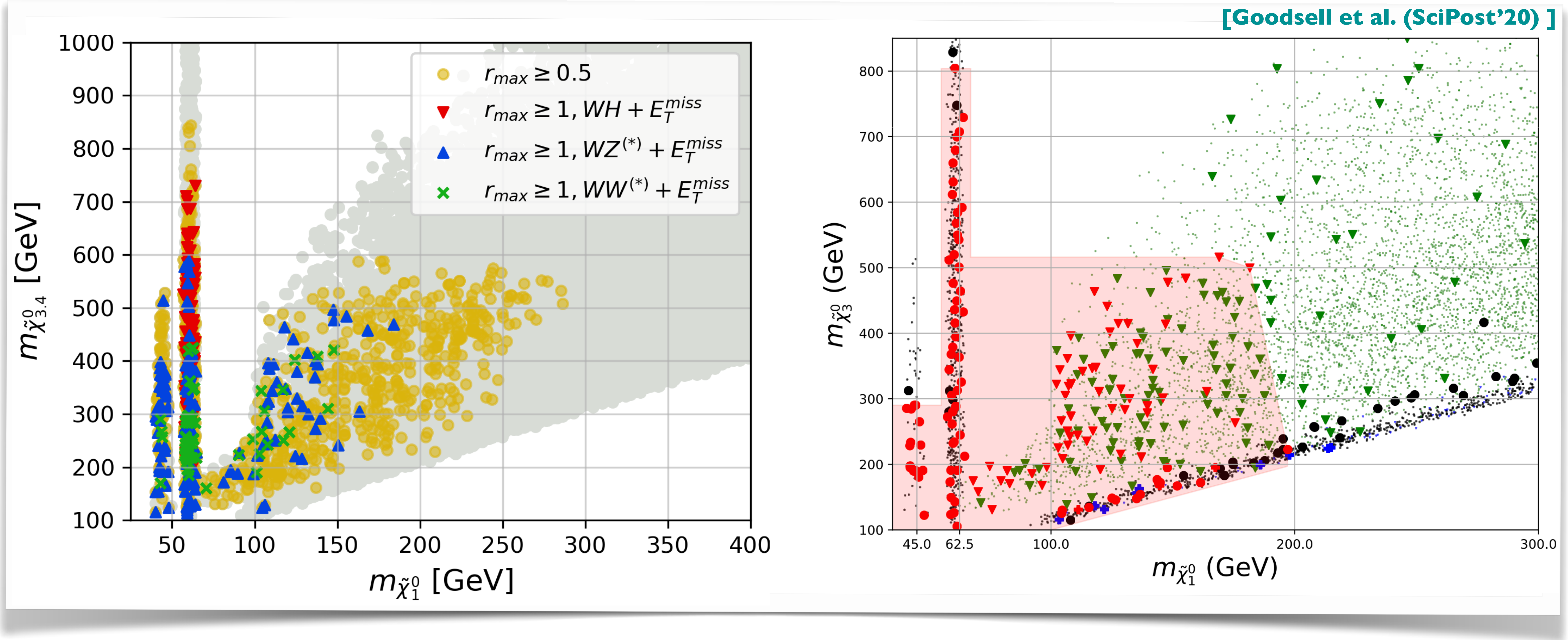


- Rather fast
- Often conservative
  - ⋆ Different kinematics
  - ⋆ Asymmetric decays
- A generic program: SmodelS
  - ⋆ $O(100)$ available analyses
  - ⋆ Prompt and LLP decays
  - ⋆ Available from GITHUB [Kraml et al. (EPJC'14)] [Kraml et al. (LHEP'20)]
- Dark photons: DARKCAST
  - ⋆ Available from GITLAB [Ilten et al. (JHEP'18)]

SMS reinterpretation tools - examples



DGMSSM at the LHC

- Exploring SUSY with Dirac gauginos
- Models not considered by ATLAS/CMS
- Left: points excluded by SMODELS (with $r \geq 1$)
- Right: comparison with full recasts (from MADANALYSIS 5)
  - ➙ SMS approach fair enough
  - ➙ Far from full recasts
- SMS approach *much* faster

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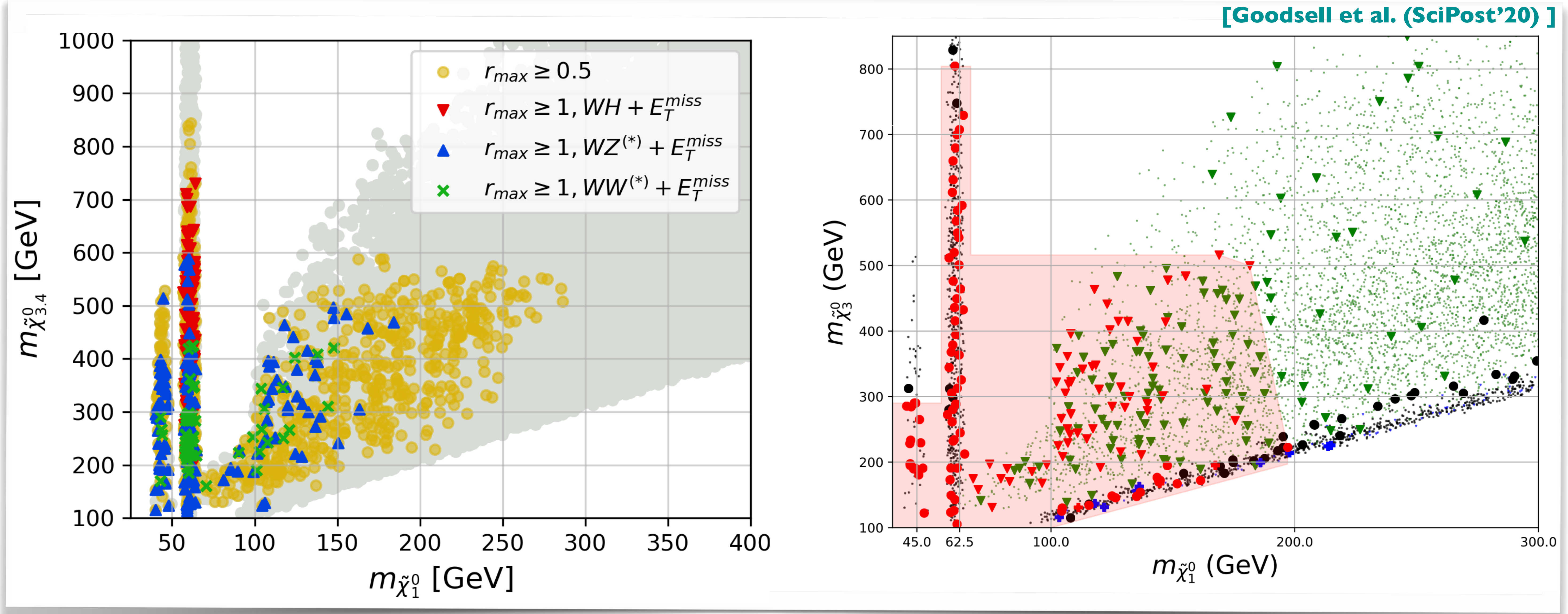

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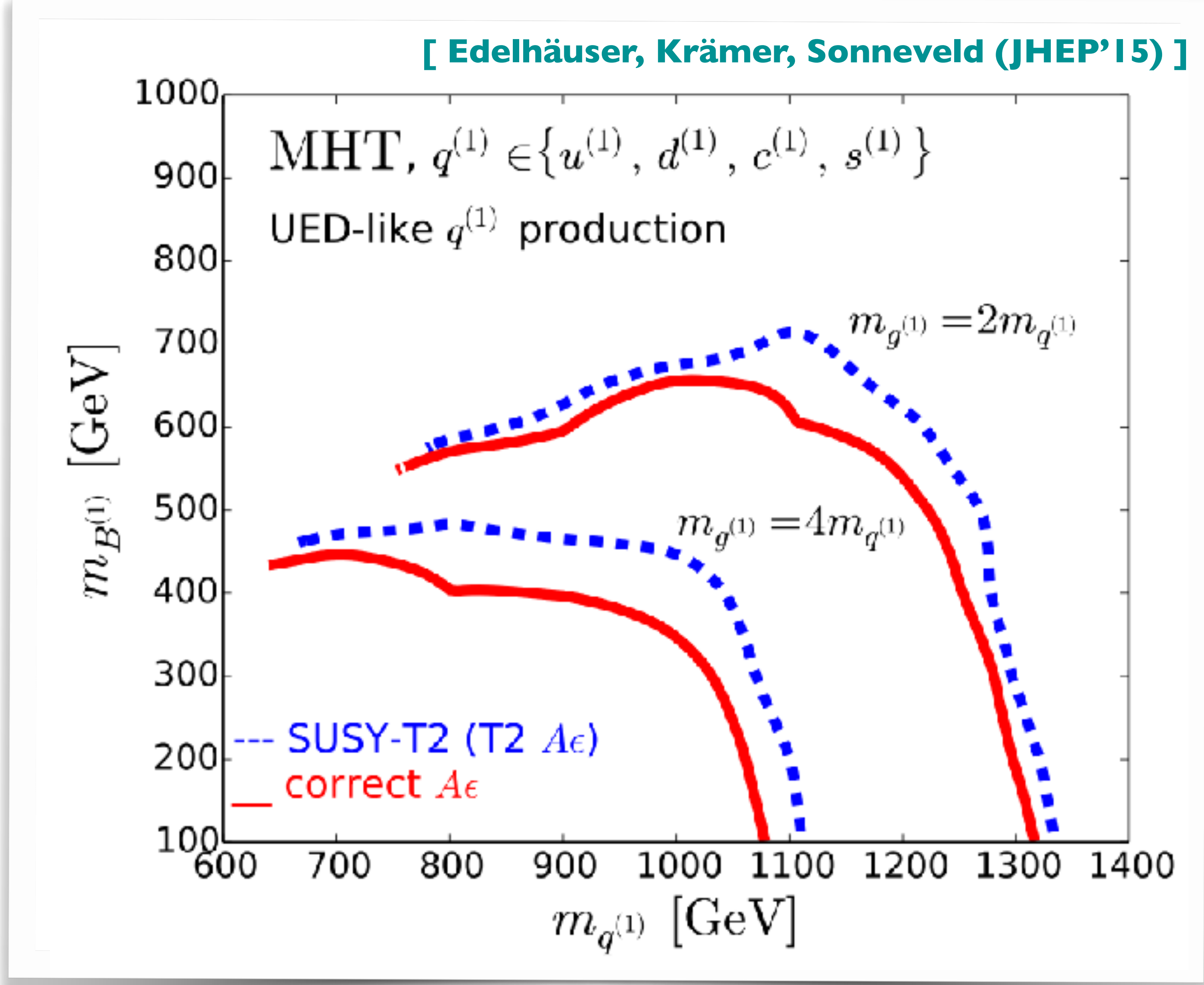


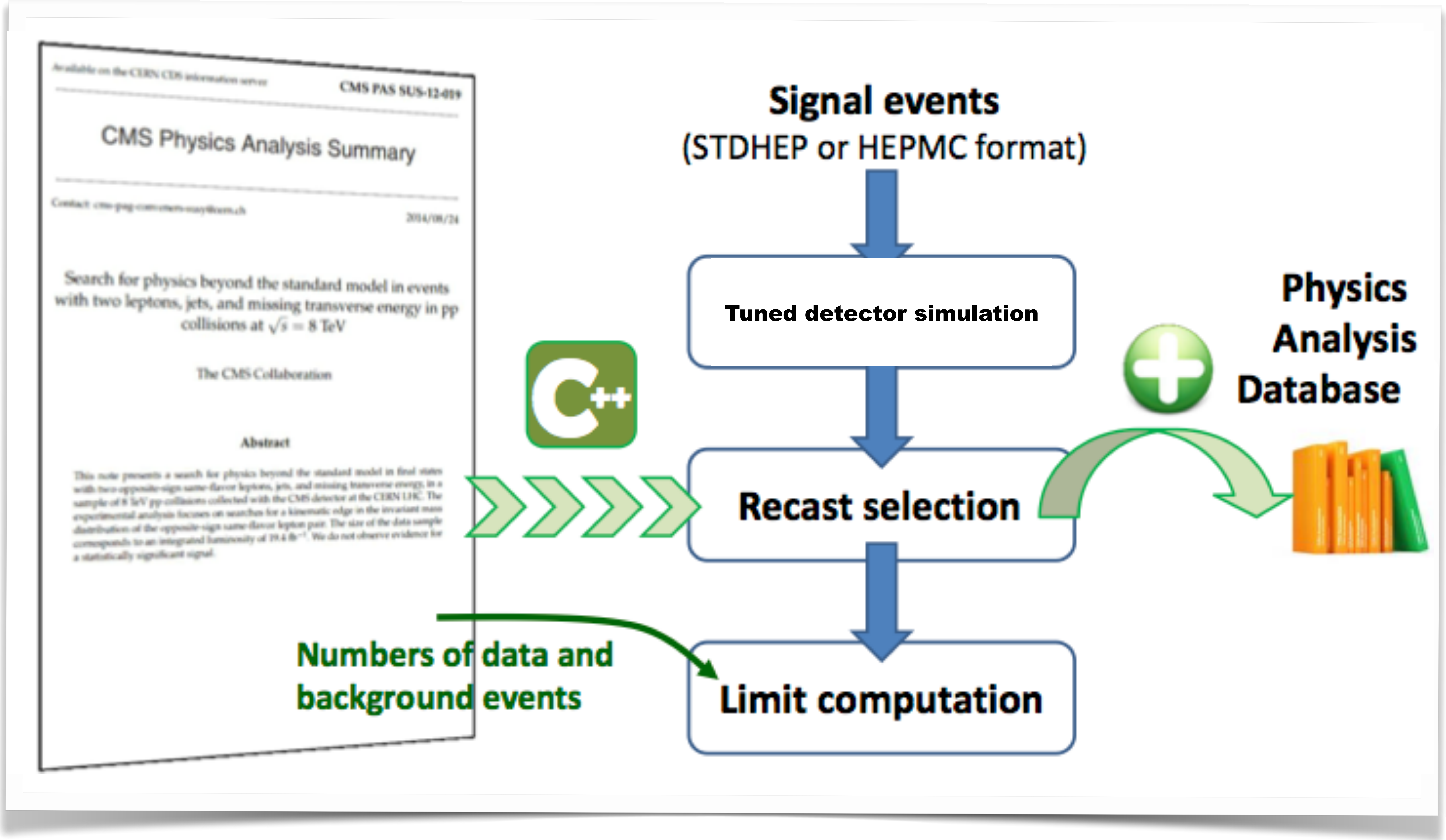
SUSY *vs* extra dimensions

- Using SUSY searches to constrain KK excitations
  - ➙ Blue: SMS approach
  - ➙ Red: full recast
- Efficiencies depend on particle spins
  - ➙ SMS approach often fair enough
  - ➙ SMS approach often too aggressive

Beyond the SMS approach

SMS often not sufficient to study all interesting new physics realisations

- More accurate detector simulations
  → mimicking ATLAS / CMS
- New frameworks for LHC re-interpretations
  → Easy (re-)implementations of searches
  → Test of signals fully automated



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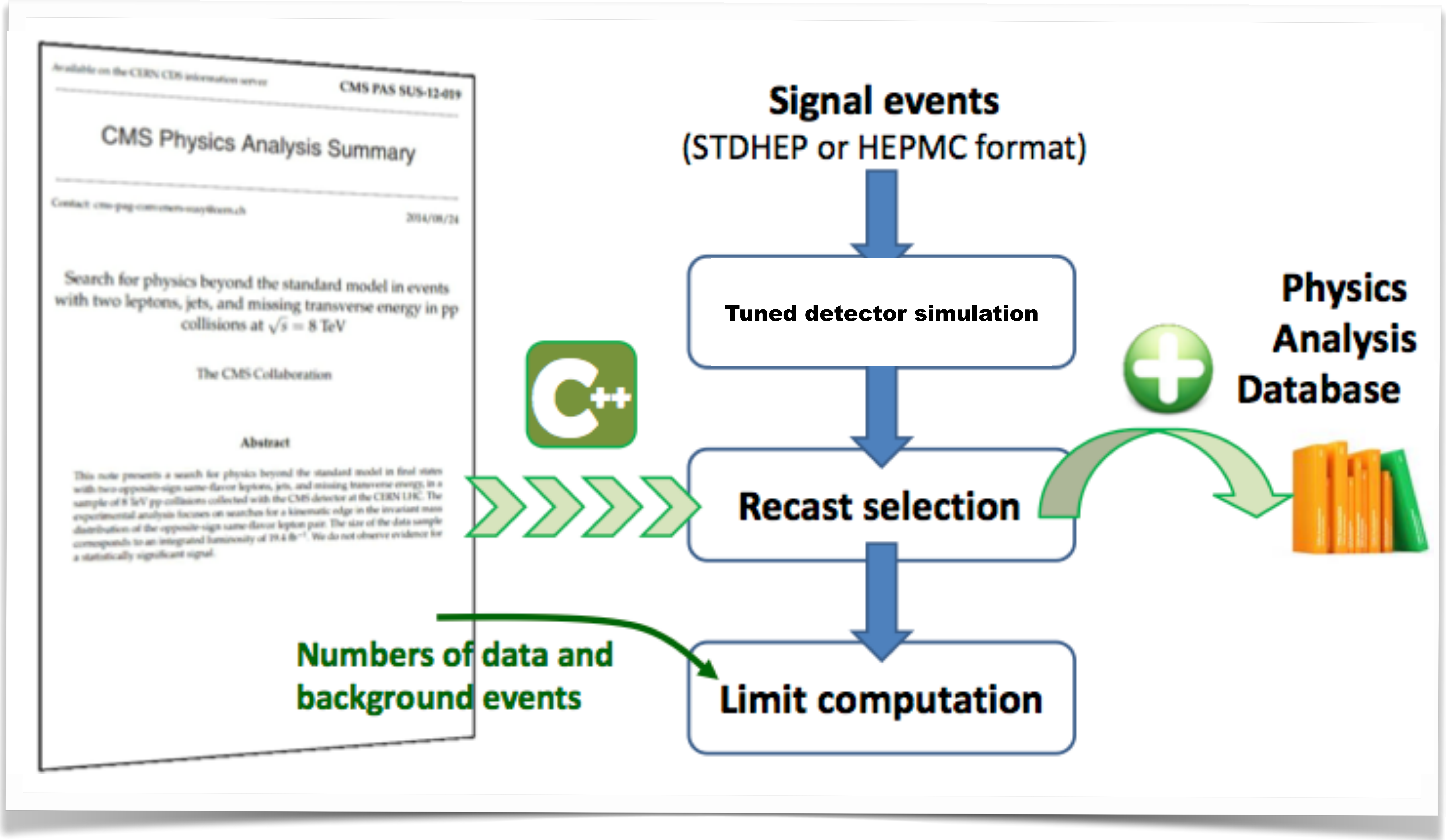


The detector is the key

- Close to a real detector (slower)
  ➝ from particles to tracks/hits
  ➝ resolutions, efficiencies, *etc.*
  ➝ *à la Delphes 3* [de Favereau et al. (JHEP`14)]
- Based on transfer functions (faster)
  ➝ From MC particles
  ➝ Resolutions, efficiencies, …
  ➝ *à la* RIVET, MADANALYSIS 5 − SFS
  [Araz, BF & Polykratis (EPJC`21)]
  [Bierlich et al. (SciPost`20)]
- Unfolding
  ➝ No need for a detector

Examples from public programmes

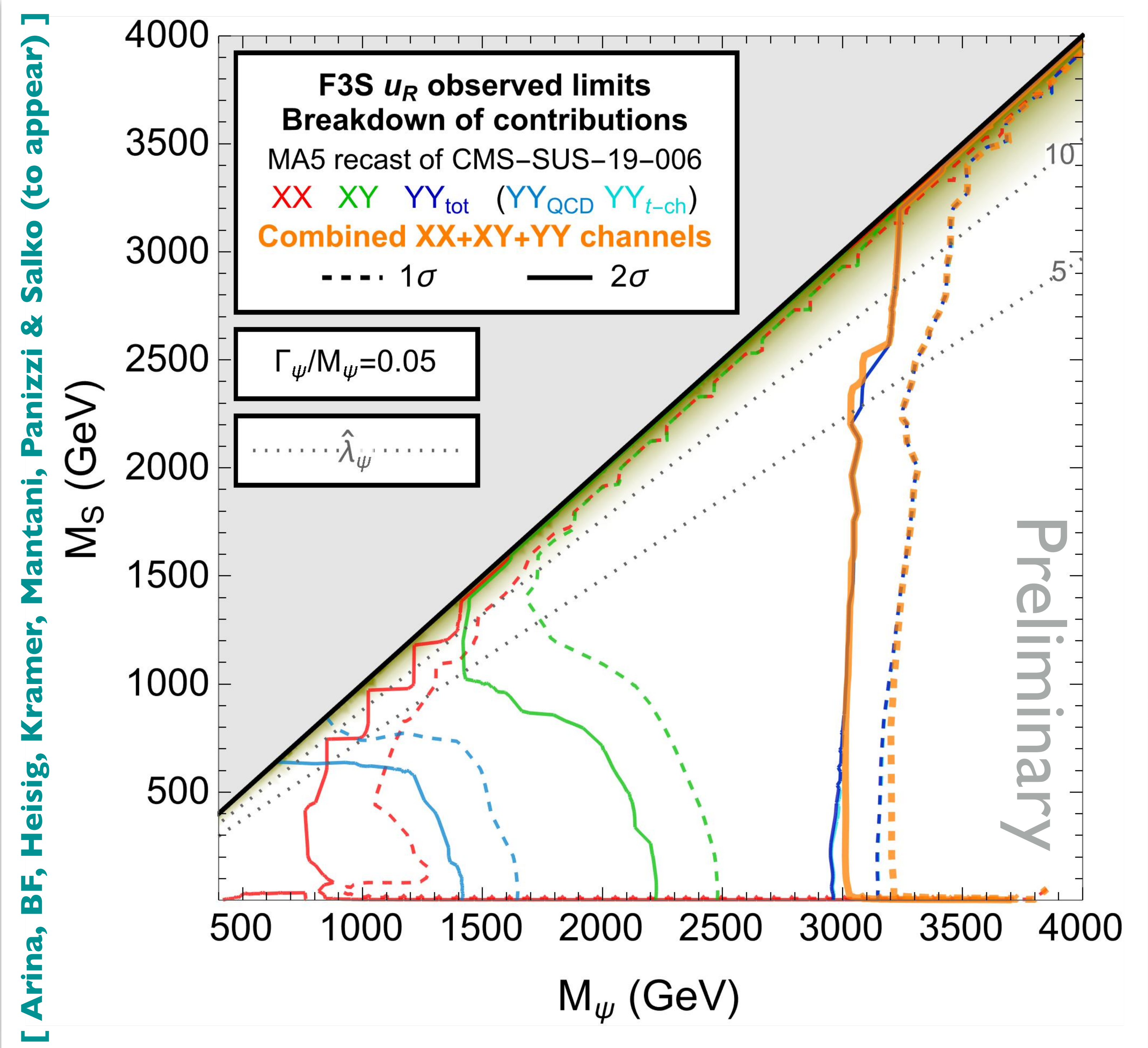
Detector based on (customised) DELPHES 3

- CHECKMATE [$O(50)$ analyses, from GITHUB]
- MADANALYSIS 5 [$O(50)$ analyses, from GITHUB and the MA5 DATAVERSE]

[Derks et al. (CPC`17) ] [ Dumont, BF, Kraml et al. (EPJC`15); Conte & BF (IJMPA`19)]

Constraining *t*-channel dark matter with jets + MET (in MADANALYSIS 5)

- SM ⊕ coloured fermion (ψ) ⊕ scalar DM (S) ⊕ coupling to u_R
- Signal modelling crucial: XX, YY and XY production @ NLO



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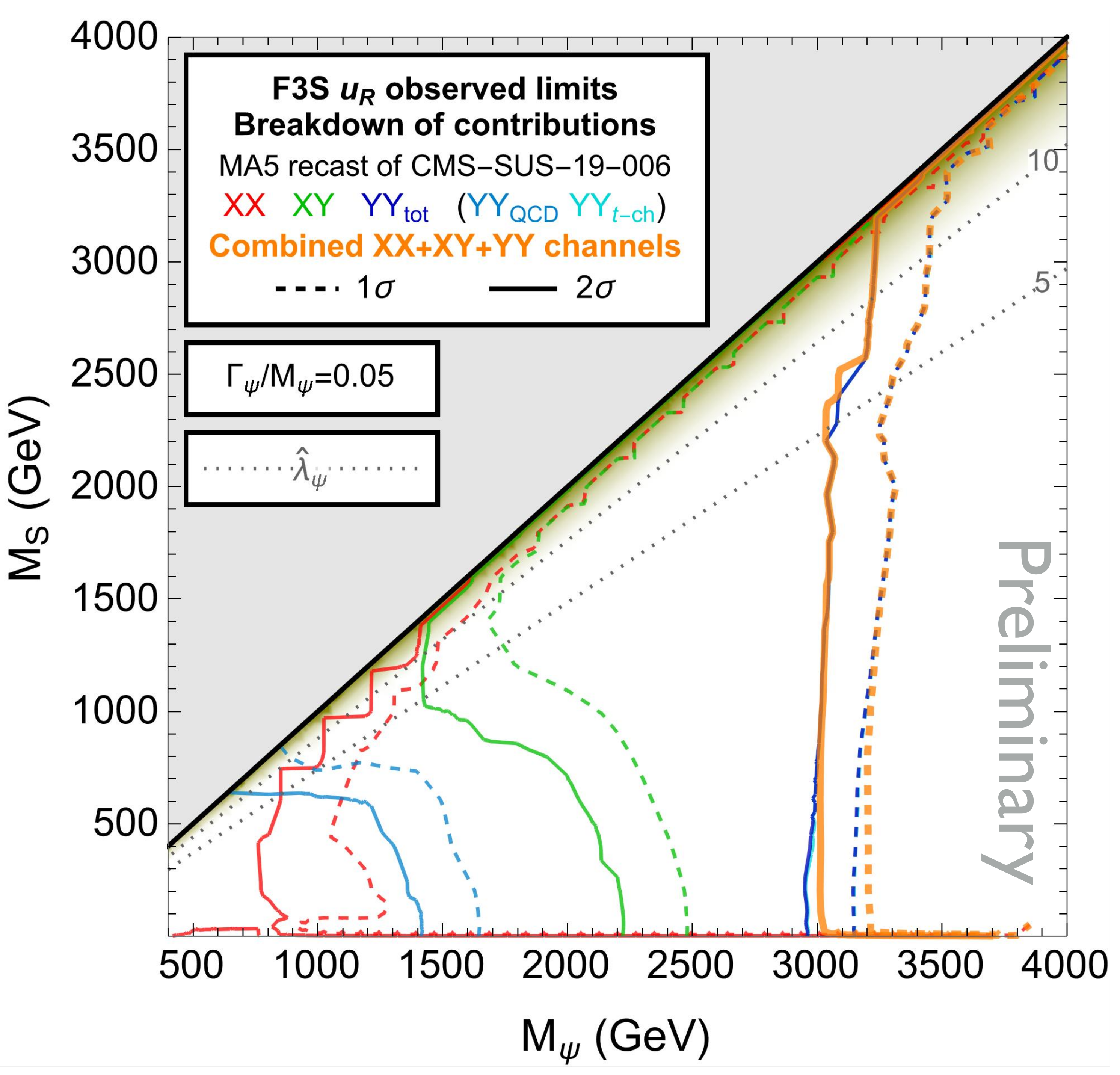
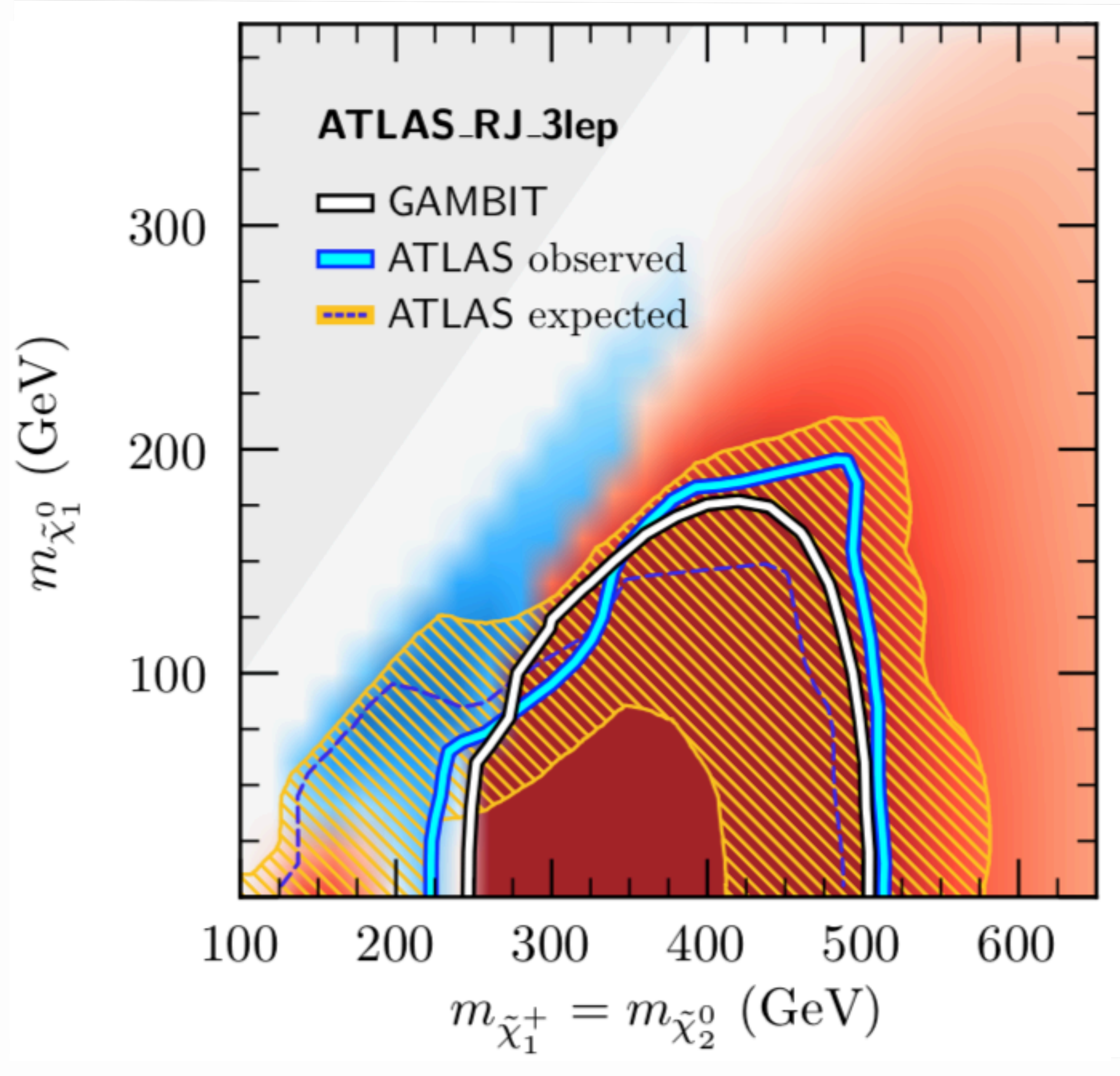


[Arina, BF, Heisig, Kramer, Mantani, Panizzi & Salko (to appear)]



[Athron et al. (EPJC`19)]

Based on transfer functions

- COLLIDERBIT [$O(40)$ analyses, from HEPFORGE]
- MADANALYSIS 5 - SFS [$O(10)$ analyses, from GITHUB and the MA5-DATAVERSE]
- RIVET [$O(30)$ analyses, from HEPFORGE]

[Balász et al. (EPJC`17) ] [Araz, BF & Polykratis (EPJC`21); Araz, BF, Goodsell & Utsch (EPJC`22)]
[Buckley et al. (2010); Bierlich et al. (SciPost`20)]

Constraining ewkinos with recursive Jigsaw (in COLLIDERBIT)

- Validation ≡ closure test

Implementing a new recast

Picking up an experimental publication

- Reading
- Understanding

✅ Relatively easy

Writing the analysis code in the tool internal language

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A 2012 TH-wishlist for high-quality recasts (1/2)
- Clear description of cuts and their sequence
- Efficiencies ($e^\pm$, $\mu^\pm$, jets, τ_h, *b*-tagging, *etc.*)
  - ➞ Including p_T/η dependence
- Efficiencies for triggers, event cleaning, *etc.*
  - ➞ Effects not manageable in fast simulations
- Special variable definitions (razor, aM_{T2}, *etc.*)
  - ➞ Snippets of code

[Les Houches Recommendations (EPJC'12)]

Implementing a new recast

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✅ Relatively easy

Accurate information for proper validation
- Efficiencies (trigger, $e^\pm$, $\mu^\pm$, *b*-tagging, JES, *etc.*)
  → including p_T/η dependence
- Detailed cutflows for well-defined benchmarks
  → Region per region information
  → Exact definition of benchmarks (spectra)
  → Event generation information (cards, tunes)
- Digitised histograms (e.g. on HEPDATA)

⚠️ Essential
❌ Often difficult!

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- Special variable definitions (razor, aM_{T2}, *etc.*)
  ➙ Snippets of code

A 2012 TH-wishlist for high-quality recasts (2/2)

- Benchmark scenarios
  ➙ Spectra / decay tables (SLHA-form)
  ➙ Several scenarios
- Monte Carlo configuration
  ➙ Cards, tunes, matching information, *etc.*
- Detailed cutflows (with correct cut ordering)
  ➙ Including (pre)selection steps (more is better)
- Kinematical distributions at different cuts
  ➙ Extra cross-checks

[Les Houches Recommendations (EPJC'12)]

10 years later…

Much better material

- Publications much clearer
- HEPDATA widely used
- Improved communication between the EXP/TH communities
- Sometimes works amazingly well: e.g. ATLAS *multijet+MET*
- Still improvable: e.g. ATLAS *dE/dx* [HSCP with large ionisation]

	ATLAS			MadAnalysis 5-SFS				
	Events	ε [%]	ε_{cut} [%]	Events	ε [%]	δ [%]	ε_{cut} [%]	R_{gap} [%]
Initial (truth $E_T^{miss} > 150$ GeV)	39598	-	100	89529	-	0.17	100	-
Lepton veto	37547	94.82	94.82	85417	95.41	0.17	95.41	0.62
$N_{jets} \leq 4$	35412	89.43	94.31	76195	85.11	0.18	89.20	4.38
$\min[\Delta\phi(jets, E_T^{miss})]$ cut	33319	84.14	94.10	69253	77.35	0.18	91.00	8.07
Leading jet > 150 GeV and $\lvert\eta\rvert < 2.4$	23134	58.42	69.43	47157	52.67	0.20	68.10	9.84
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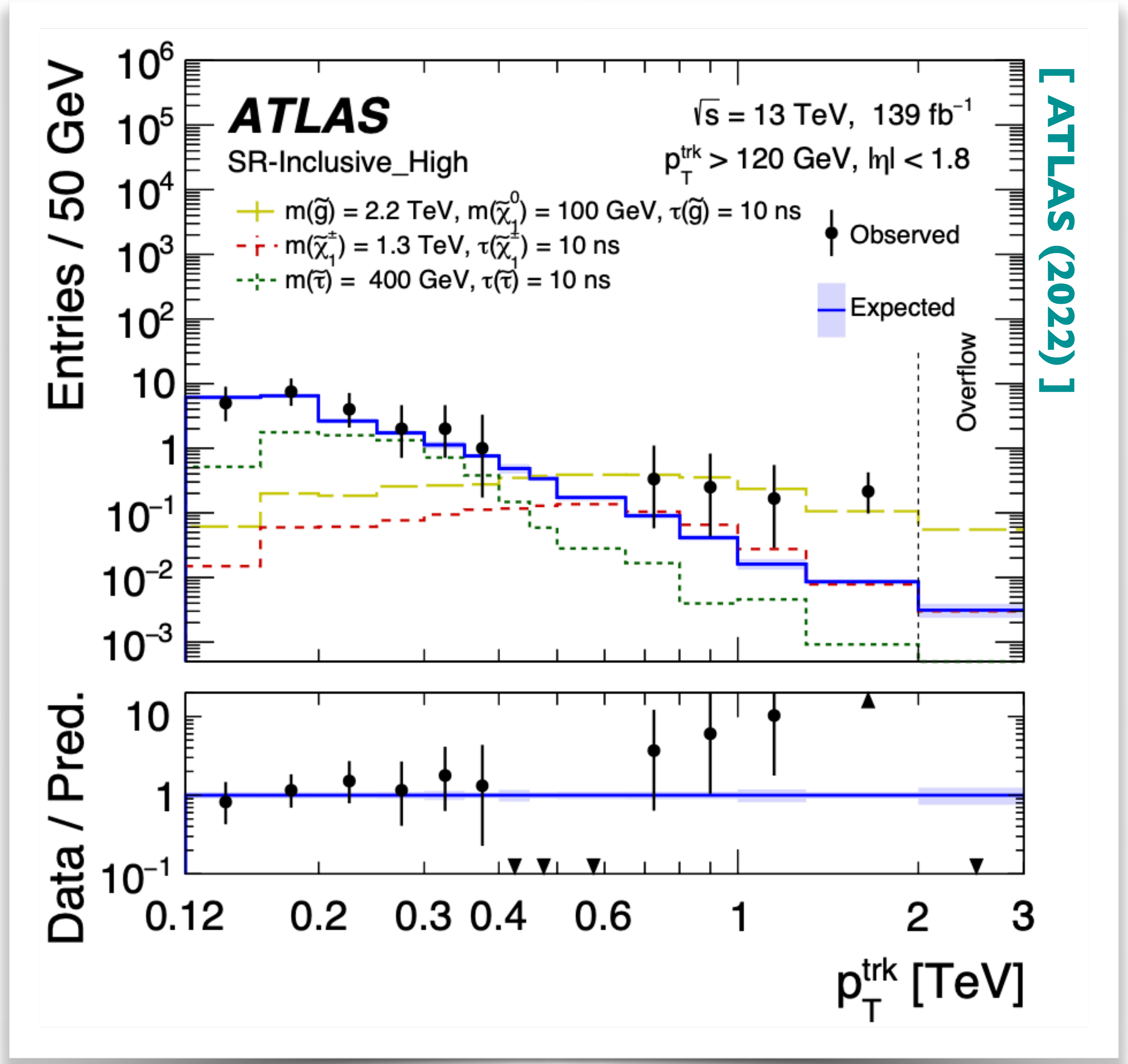
EM0	4488	11.34	-	8509	9.50	0.22	-	16.23
EM1	3789	9.57	-	7946	8.88	-	-	7.21
EM2	2857	7.21	-	6226	6.95	-	-	3.61
EM3	2111	5.33	-	4621	5.16	-	-	3.19

[Agin with MADANALYSIS 5]



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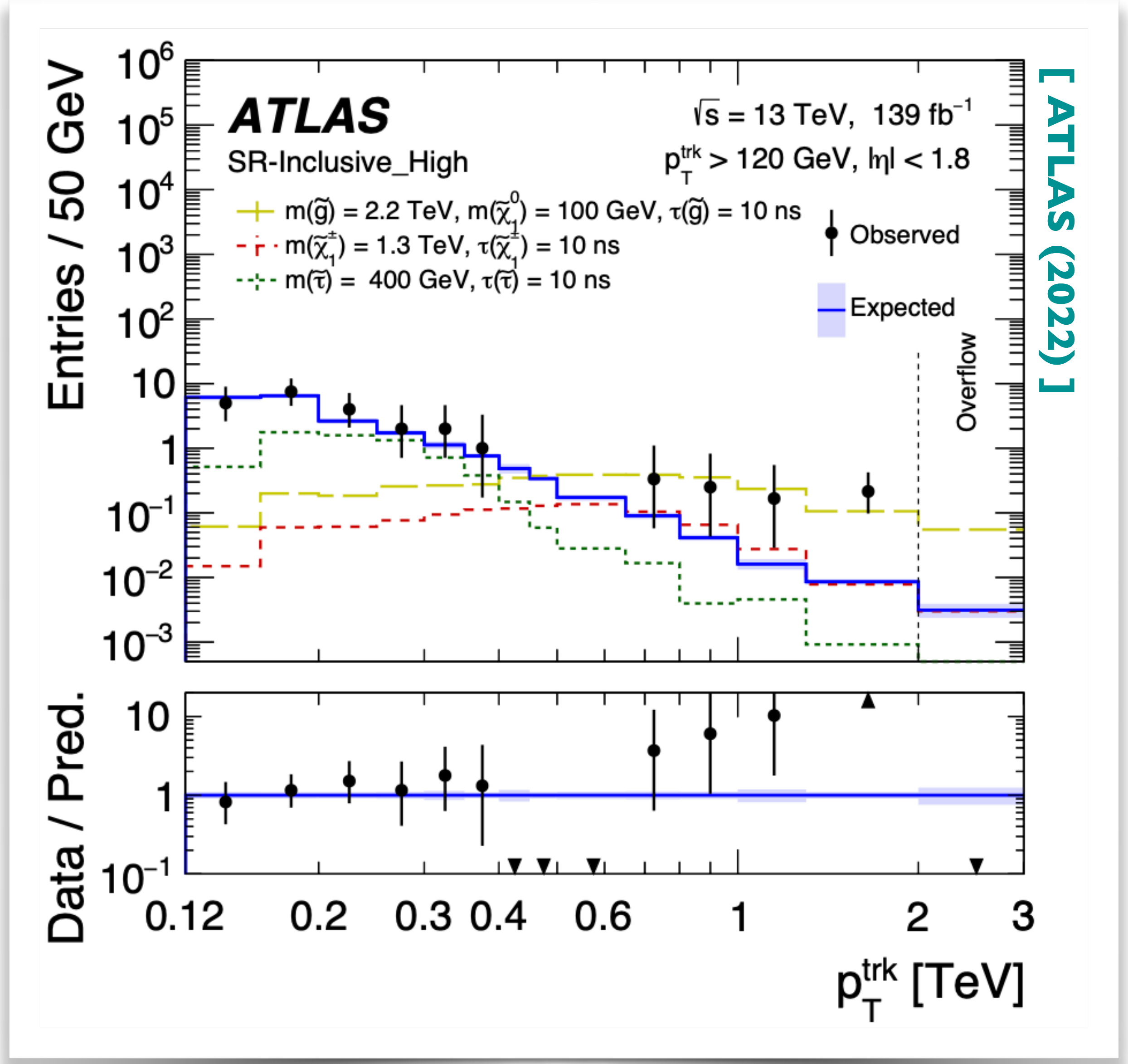
[Agin with MADANALYSIS 5]

A 2020 TH-wishlist for high-quality recasts

- Background estimates: usually provided (not systematic)
- Efficiencies
  - → Should be provided as tables / functional forms
  - → Should be broken down in sub-efficiencies (trigger, *etc.*)
- Efficiency maps: necessary for SMS-based recasting
- Monte Carlo: still very minimal
  - → SLHA files, MG5_aMC cards, PYTHIA cards, *etc.*
  - → Crucial for the validation (*cf.* MC bias)
- Cut-flows for given benchmarks
  - → not systematic (sequence, details, all SRs)



[ATLAS (2022)]

[The Reinterpretation Forum (SciPost`20)]

Strength in numbers: combination of searches

"Best signal region"

- Recast exclusions from the best region of an analysis
- Often off relative to CMS/ATLAS ➙ correlations rarely negligible

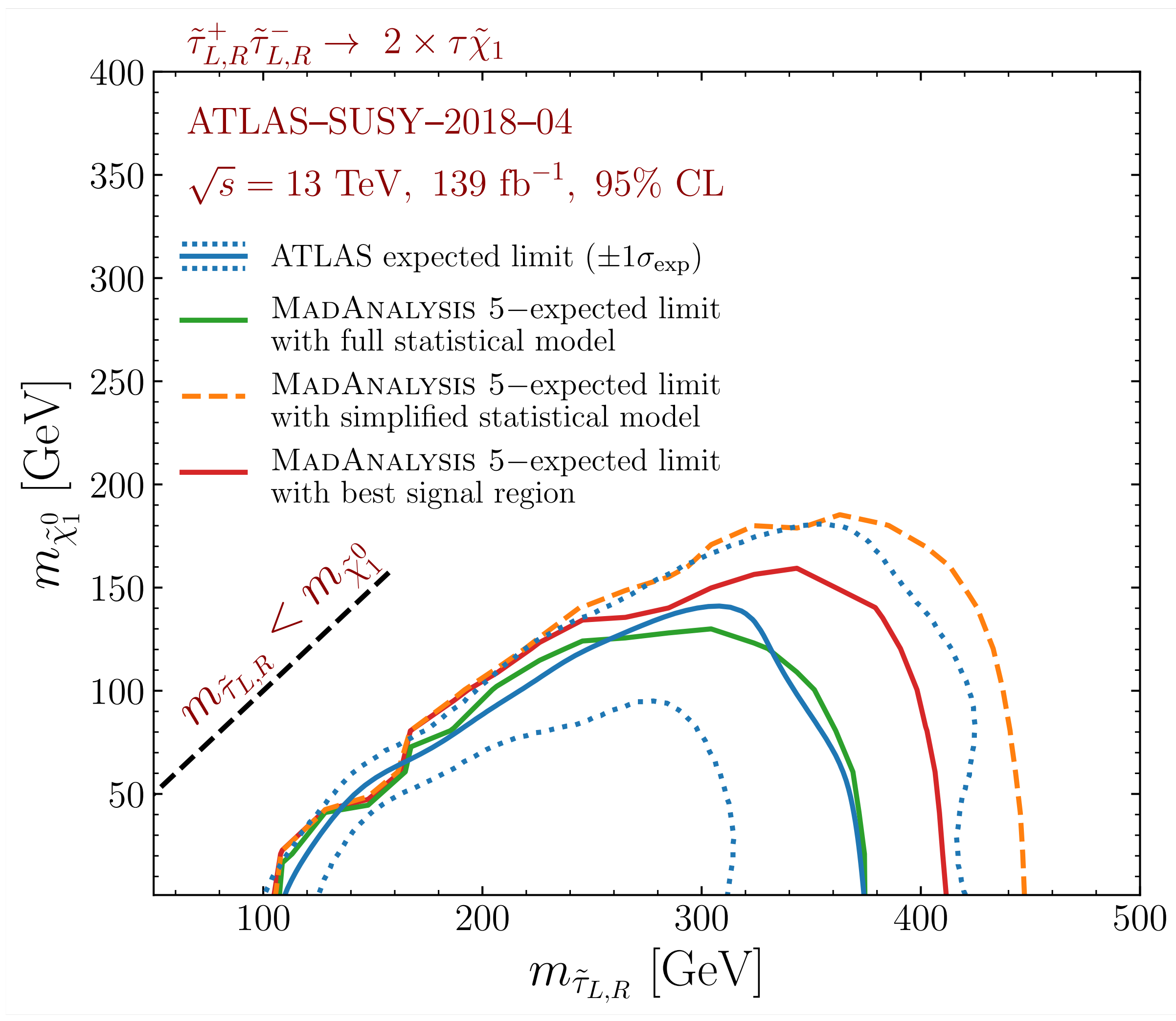
Public likelihoods

- Statistical model of an analysis ≡ complete description of the analysis
  ➙ Improving over the '*best signal region*' approach
  ➙ More realistic reinterpretations
- Simplified likelihoods by CMS / full likelihoods by ATLAS (PYHF)

$$\mathcal{L}_{\rm SR} = \prod_i e^{-(S_i+B_i+\theta_i)} \frac{(S_i+B_i+\theta_i)_i^n}{n_i!} e^{-\frac{1}{2}\theta^t V^{-1}\theta}$$

Non-Gaussian tails ignored

- CMS simplified likelihoods in SMODELS, MADANALYSIS 5 & COLLIDERBIT
- ATLAS full likelihoods in SMODELS & MADANALYSIS 5



[Alguero, Araz, BF & Kraml (SciPost'22)]

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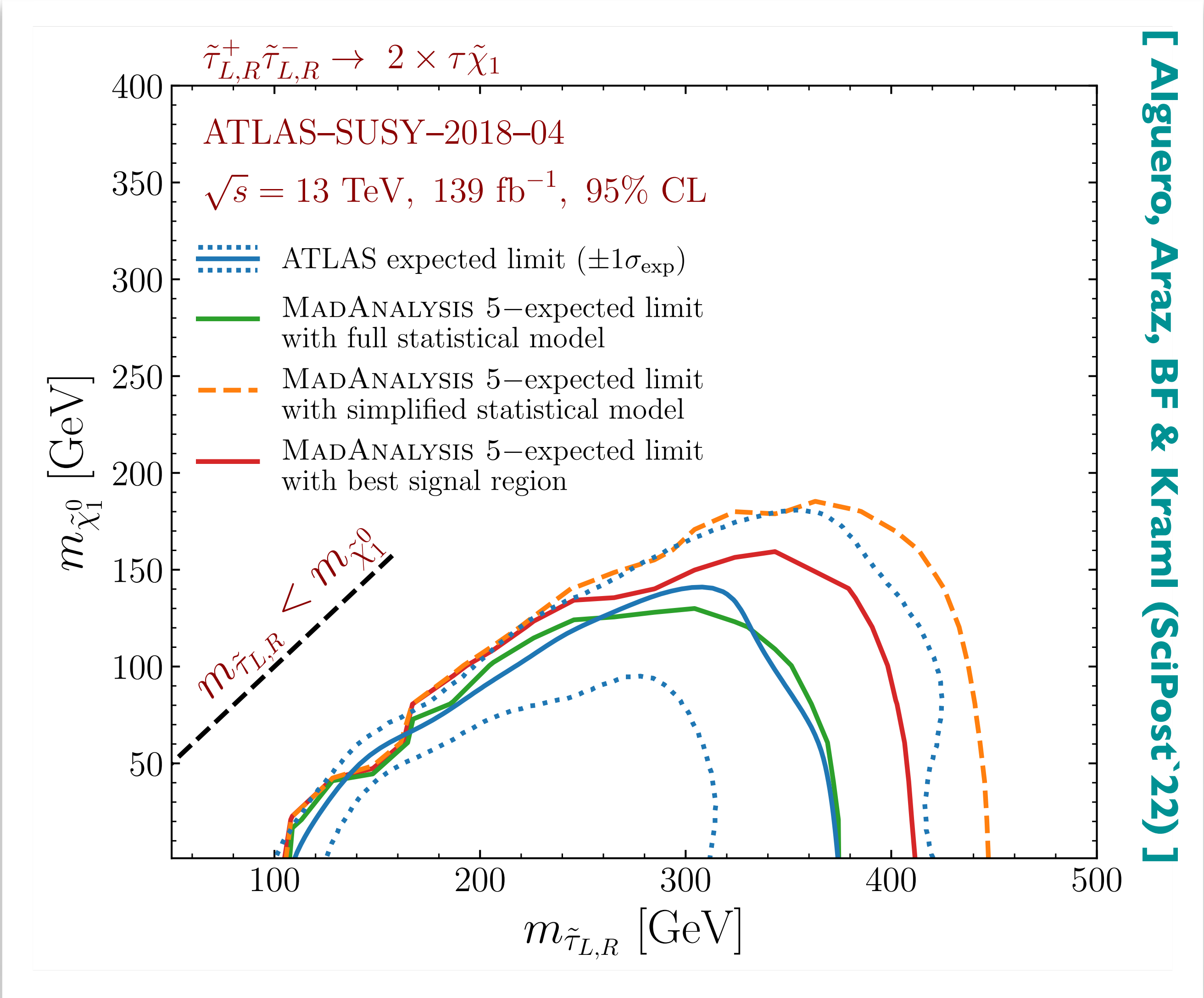
- ATLAS full likelihoods in SMODELS & MADANALYSIS 5

Development of the TACO methods to combine uncorrelated analyses

- Identification of uncorrelated SRs in different analyses
  ➙ Derivation of an approximate correlation matrix
- Optimal combinations among them (tests over 100s of regions)
  ➙ Better reinterpretation power



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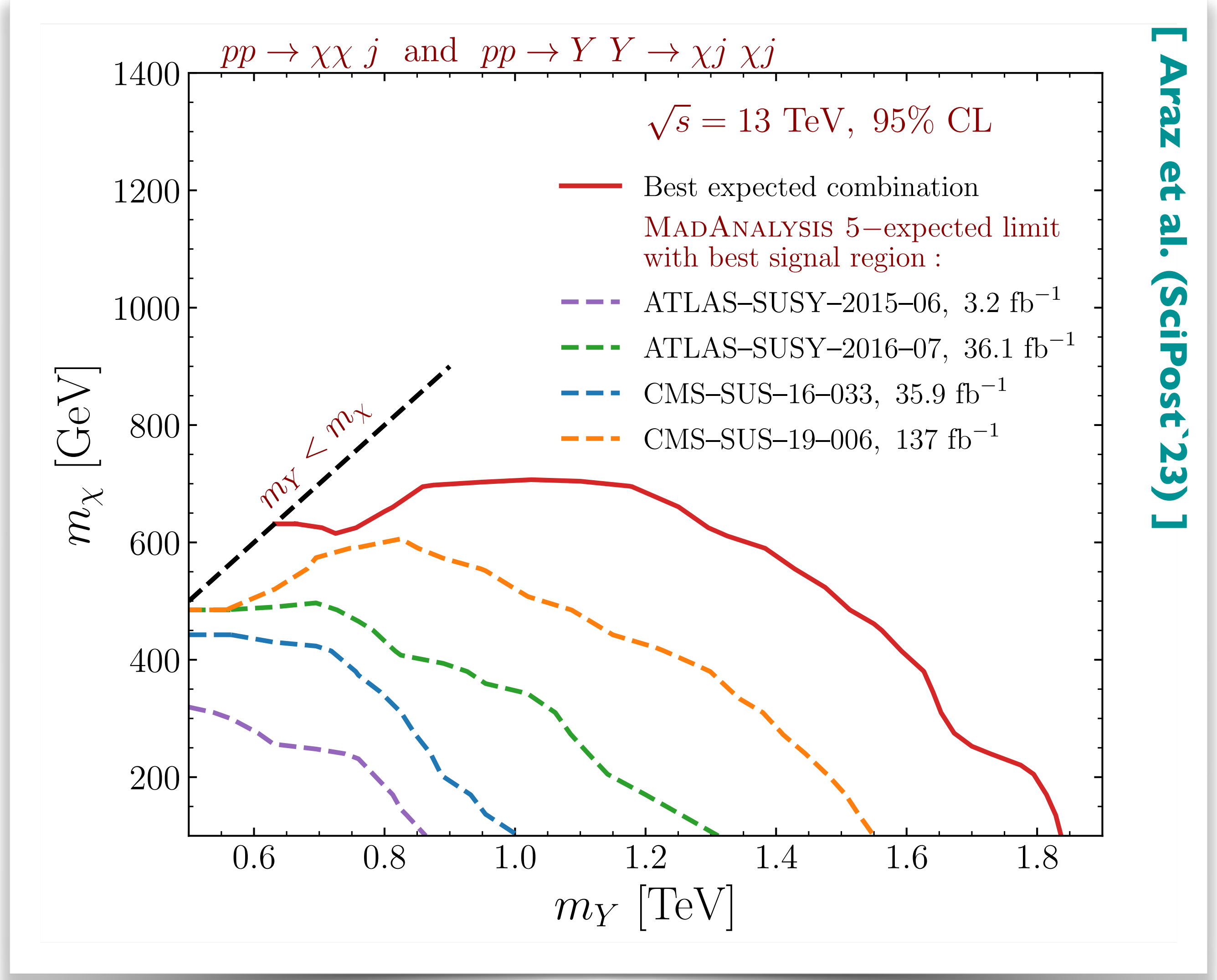


[Araz et al. (SciPost'23)]

Outline

1. A comprehensive approach for Monte Carlo simulations

2. Implementing models into Monte Carlo event generators

3. From events to Lagrangian: reinterpretation of the results of the LHC

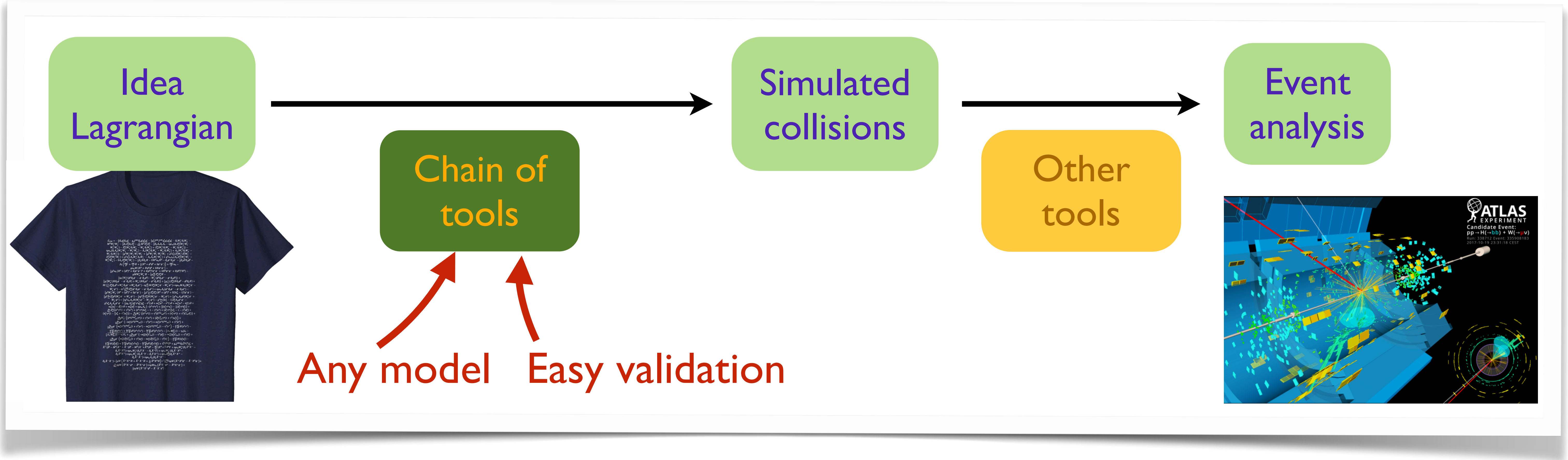
4. **Summary**

Summary

The quest for new physics is on-going

- MC tools for background/signal modelling
- Automated methods for model implementation
  ➞ Facilitates new physics simulations at (N)LO

Tutorial: Give FeynRules a try!



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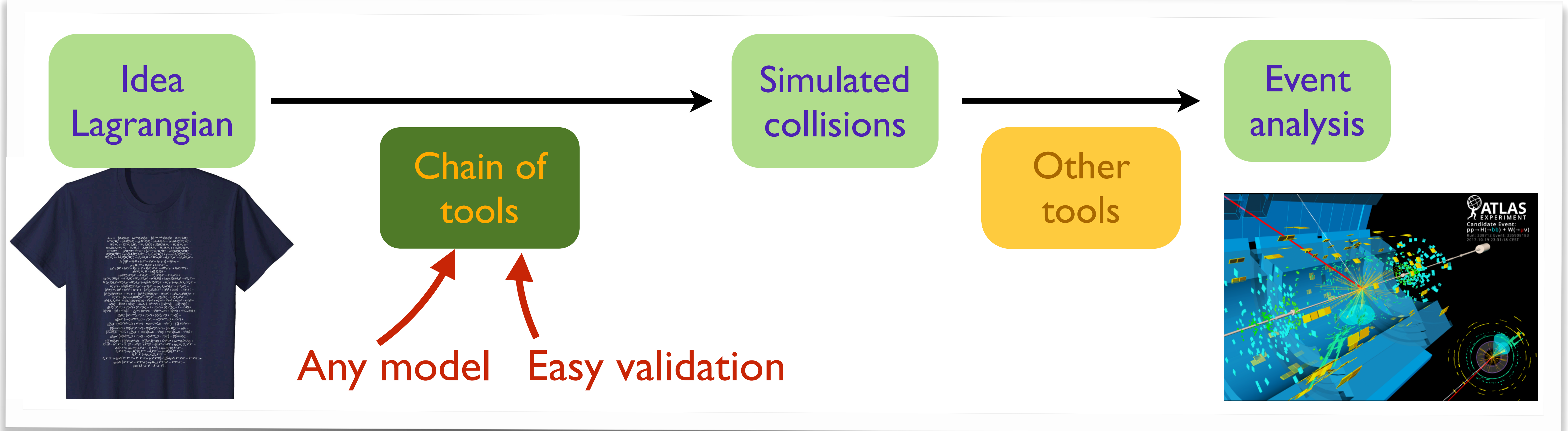

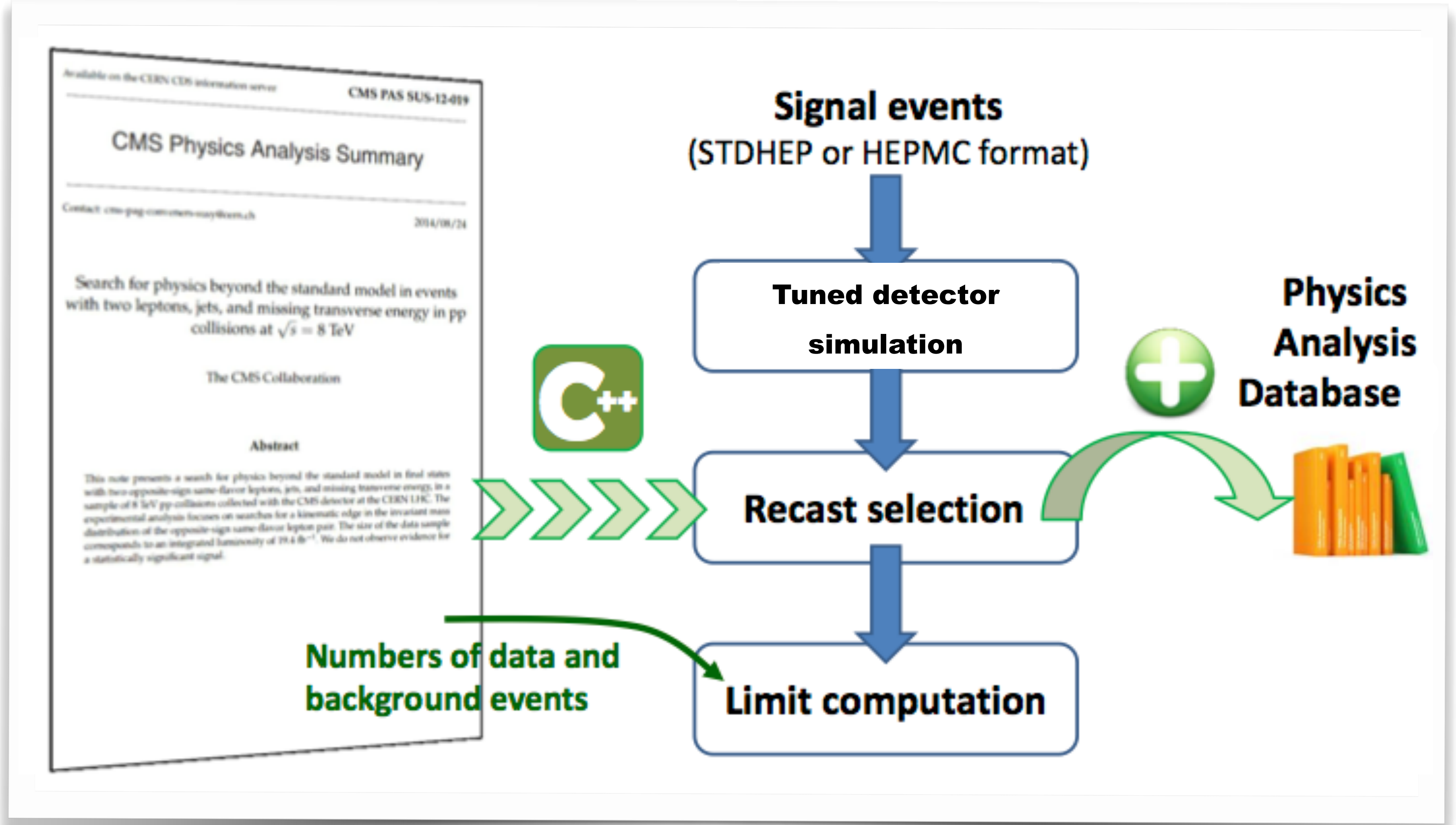

The LHC legacy

- Reinterpretation of the LHC results in any theoretical context crucial
  ➙ Two complementary approaches: simplified models and detector simulation
- Exciting on-going developments: combining & correlating

Tutorial: Give MADANALYSIS 5 a try!

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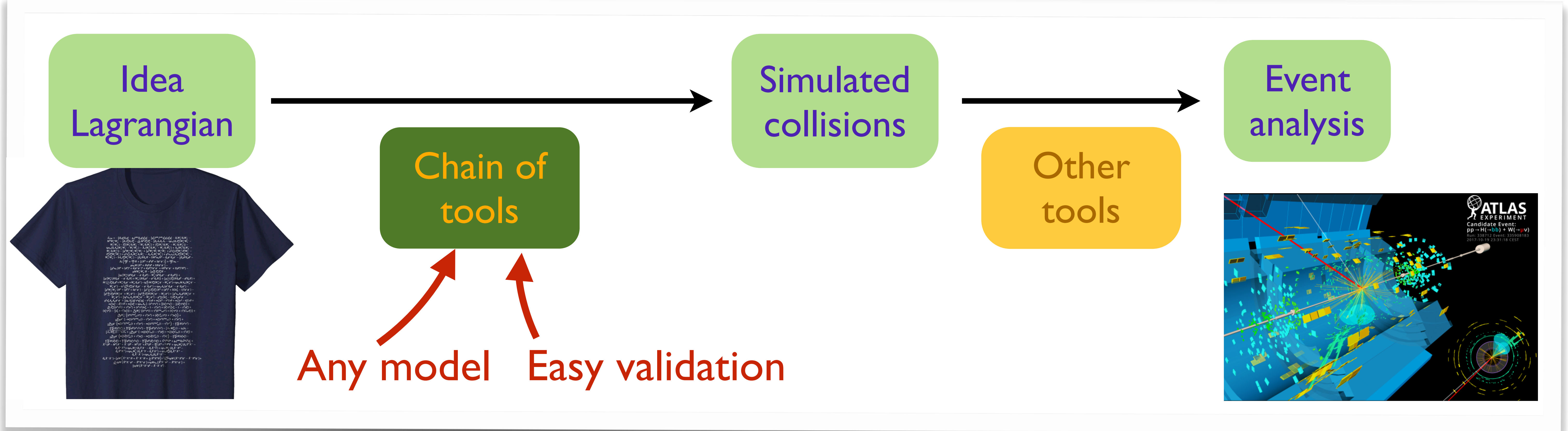
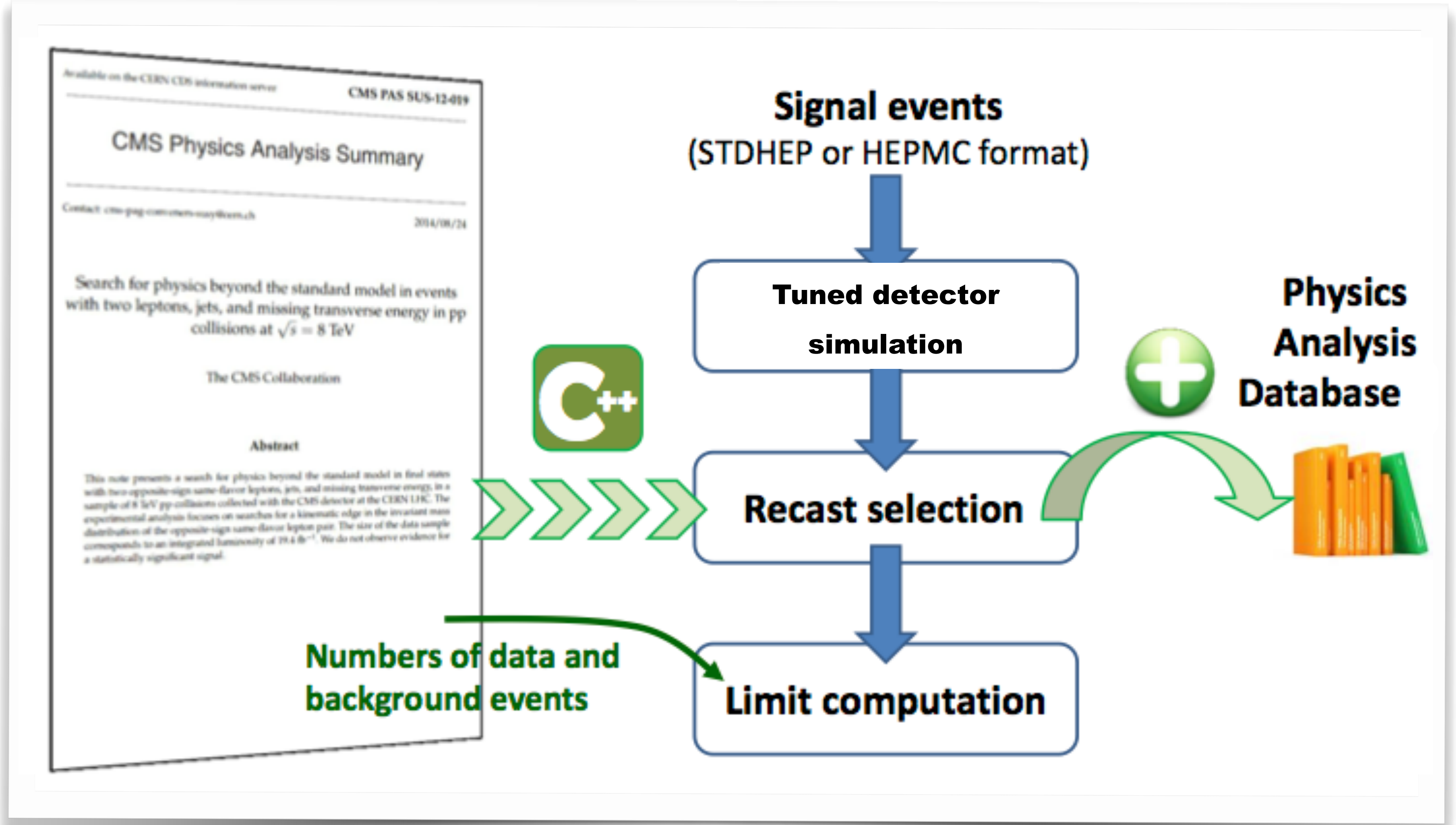
  ➙ Facilitates new physics simulations at (N)LO

Tutorial: Give FEYNRULES a try!





The LHC legacy

- Reinterpretation of the LHC results in any theoretical context crucial
  ➙ Two complementary approaches: simplified models and detector simulation
- Exciting on-going developments: combining & correlating

Tutorial: Give MADANALYSIS 5 a try!

Final last words

- **Reproducibility** ≡ ability of an entire experiment to be reproduced (possibly by an independent theoretical study)
- Need for both the TH and EXP communities to move together!