Fastlim

Michele Papucci, LBNL

M.P., K. Sakurai, A. Weiler, L. Zeune - 1402.0492

MC4BSM, SLAC, May 12th 2017

Fastlim (+Atom, EWKfast)

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I.-W.Kim, M.P., K. Sakurai, A. Weiler
E.Bagnaschi, M.P., K. Sakurai, A. Weiler, L. Zeune

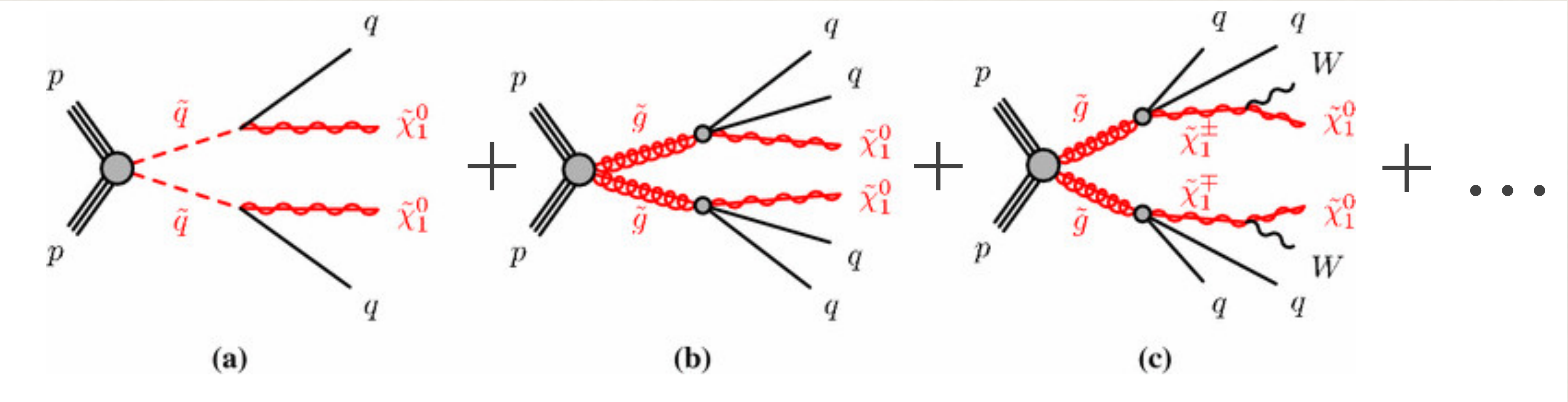
MC4BSM, SLAC, May 12th 2017

Simplified Models & Recasting

- Simplified models are a "basis" for decomposing more complex models
- Event yields of simplified topologies → limits on full models

In principle:

MSSM =



+ …

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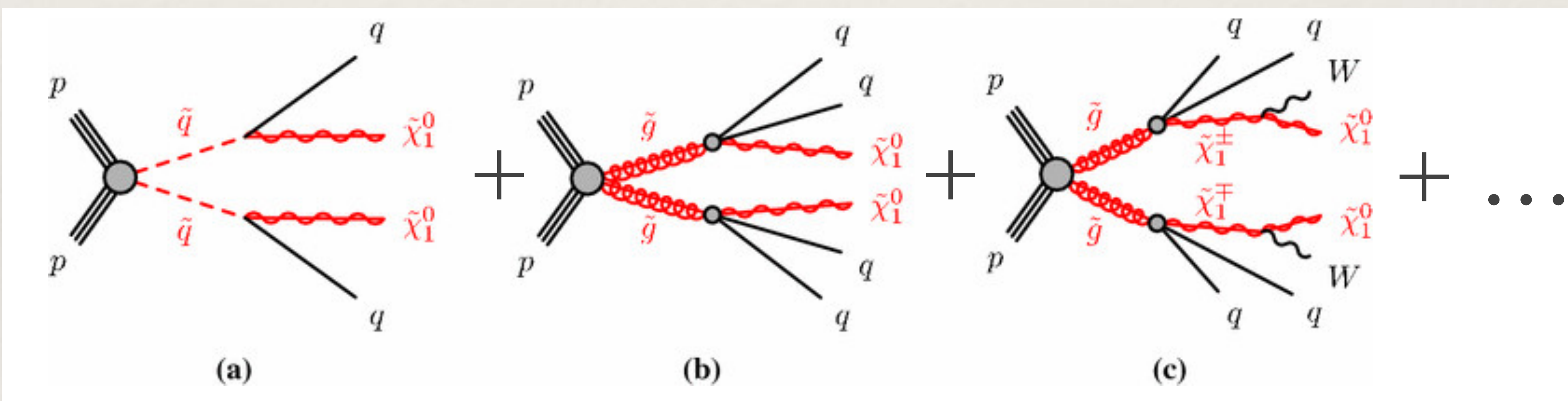


+ …

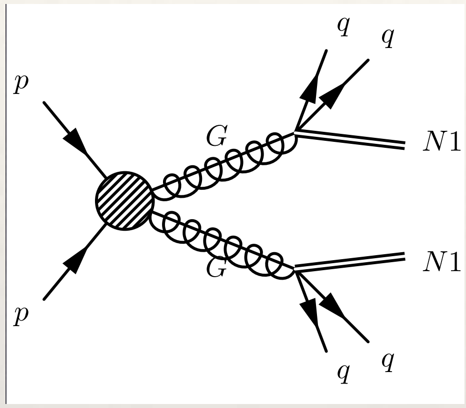
Different points in parameter space → Different weighing between simplified topologies b/c of different xsecs and BRs

Useful approach for large parameter scans!

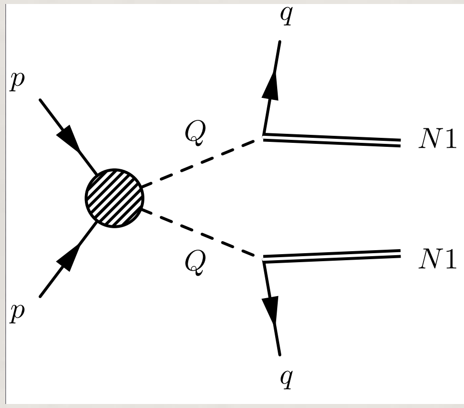
Simplified Models & Recasting

- For a given analysis (a):

$$\sigma_{\text{vis}}^{(a)} =$$



$+$



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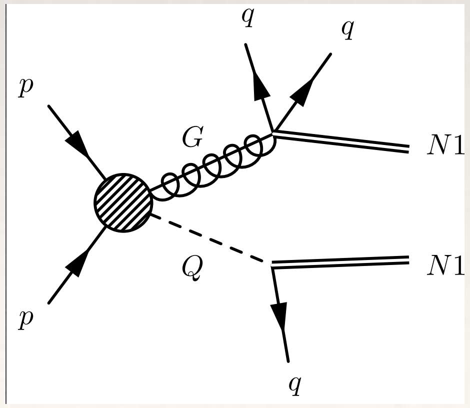

$+\ldots$

Simplified Models & Recasting

- For a given analysis (a):

$$\sigma^{(a)}_{\rm vis} = \epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}^0_1 : \tilde{g}\to qq\tilde{\chi}^0_1}(m_{\tilde{g}}, m_{\tilde{\chi}^0_1}) \quad \sigma_{\tilde{g}\tilde{g}}(m_{\tilde{g}}, m_{\tilde{q}})(BR_{\tilde{g}\to qq\tilde{\chi}^0_1})^2 \quad +$$

$$\epsilon^{(a)}_{\tilde{q}\to q\tilde{\chi}^0_1 : \tilde{q}\to q\tilde{\chi}^0_1}(m_{\tilde{q}}, m_{\tilde{\chi}^0_1}) \quad \sigma_{\tilde{q}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}})(BR_{\tilde{q}\to q\tilde{\chi}^0_1})^2 \quad +$$

$$\epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}^0_1 : \tilde{q}\to q\tilde{\chi}^0_1}(m_{\tilde{g}}, m_{\tilde{q}}, m_{\tilde{\chi}^0_1}) \ \sigma_{\tilde{g}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}}) \ 2\cdot BR_{\tilde{g}\to qq\tilde{\chi}^0_1}\cdot BR_{\tilde{q}\to q\tilde{\chi}^0_1} + \ldots$$

Simplified Models & Recasting

- For a given analysis (a):

$$\sigma_{\text{vis}}^{(a)} = \epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}_1^0:\tilde{g}\to qq\tilde{\chi}_1^0}(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) \quad \sigma_{\tilde{g}\tilde{g}}(m_{\tilde{g}}, m_{\tilde{q}})(BR_{\tilde{g}\to qq\tilde{\chi}_1^0})^2 \quad +$$

$$\epsilon^{(a)}_{\tilde{q}\to q\tilde{\chi}_1^0:\tilde{q}\to q\tilde{\chi}_1^0}(m_{\tilde{q}}, m_{\tilde{\chi}_1^0}) \quad \sigma_{\tilde{q}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}})(BR_{\tilde{q}\to q\tilde{\chi}_1^0})^2 \quad +$$

$$\epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}_1^0:\tilde{q}\to q\tilde{\chi}_1^0}(m_{\tilde{g}}, m_{\tilde{q}}, m_{\tilde{\chi}_1^0}) \; \sigma_{\tilde{g}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}}) \; 2 \cdot BR_{\tilde{g}\to qq\tilde{\chi}_1^0} \cdot BR_{\tilde{q}\to q\tilde{\chi}_1^0} + \ldots$$

Depends on analysis - need MC simulation - VERY SLOW

Simplified Models & Recasting

- For a given analysis (a):

$$
\begin{aligned}
\sigma_{\text{vis}}^{(a)} = \; & \epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}^0_1:\tilde{g}\to qq\tilde{\chi}^0_1}(m_{\tilde{g}}, m_{\tilde{\chi}^0_1}) \; \sigma_{\tilde{g}\tilde{g}}(m_{\tilde{g}}, m_{\tilde{q}}) (BR_{\tilde{g}\to qq\tilde{\chi}^0_1})^2 \; + \\
& \epsilon^{(a)}_{\tilde{q}\to q\tilde{\chi}^0_1:\tilde{q}\to q\tilde{\chi}^0_1}(m_{\tilde{q}}, m_{\tilde{\chi}^0_1}) \; \sigma_{\tilde{q}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}}) (BR_{\tilde{q}\to q\tilde{\chi}^0_1})^2 \; + \\
& \epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}^0_1:\tilde{q}\to q\tilde{\chi}^0_1}(m_{\tilde{g}}, m_{\tilde{q}}, m_{\tilde{\chi}^0_1}) \; \sigma_{\tilde{g}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}}) \; 2 \cdot BR_{\tilde{g}\to qq\tilde{\chi}^0_1} \cdot BR_{\tilde{q}\to q\tilde{\chi}^0_1} + \ldots
\end{aligned}
$$

Depends on analysis - need MC simulation - VERY SLOW

Indep. of analysis

Simplified Models & Recasting

- For a given analysis (a):

$$\sigma^{(a)}_{\mathrm{vis}} = \epsilon^{(a)}_{\tilde{g}\to qq\tilde{\chi}^0_1 : \tilde{g}\to qq\tilde{\chi}^0_1}(m_{\tilde{g}}, m_{\tilde{\chi}^0_1}) \; \sigma_{\tilde{g}\tilde{g}}(m_{\tilde{g}}, m_{\tilde{q}}) (BR_{\tilde{g}\to qq\tilde{\chi}^0_1})^2 +$$

$$\epsilon^{(a)}_{\tilde{q}\to q\tilde{\chi}^0_1 : \tilde{q}\to q\tilde{\chi}^0_1}(m_{\tilde{q}}, m_{\tilde{\chi}^0_1}) \; \sigma_{\tilde{q}\tilde{q}}(m_{\tilde{g}}, m_{\tilde{q}}) (BR_{\tilde{q}\to q\tilde{\chi}^0_1})^2 +$$

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Depends on analysis - need MC simulation - VERY SLOW

Indep. of analysis

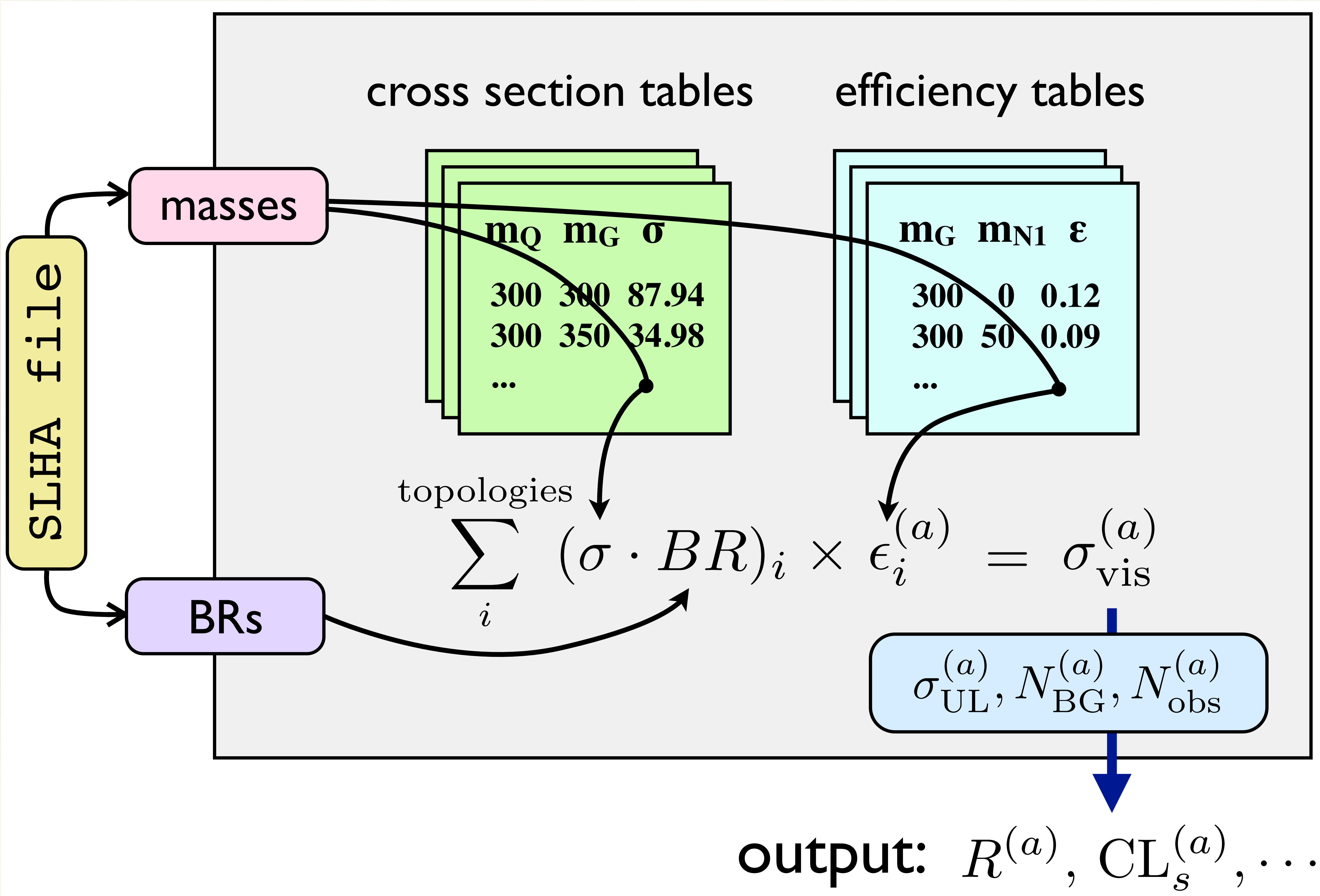
Indep. of analysis - analytical - VERY FAST

Recasting with SMS - Recipe

- Tabulate efficiencies for simplified topologies once and for all for each experimental analysis
- Tabulate cross sections once and for all for each production channel
- Parameter scan:
  - for each point in parameter space compute only spectrum and branching ratios / mixing matrices (SLHA File) (e.g. with SUSYHit, SoftSUSY, SDECAY, Spheno, …)
  - combine SLHA info with pre-tabulated info and get limit on the fly

Fastlim

https://fastlim.web.cern.ch



Pros & Cons

$$N_{\mathrm{SUSY}}^{(a)} = \sum_{i}^{\mathrm{all\ \ topologies}} \epsilon_i^{(a)} \cdot \sigma_i \cdot \mathcal{L}_{\mathrm{int}}$$

- 🙂 Missing topologies → lower yields → exclusions always conservative
- 🙂 Fast: <1sec per point
- ☹️ Only efficiencies for 1-,2-step (and some of the 3-step) topologies can be practically tabulated (2D, 3D grids) → no long decay chains
- 😐 Easy to estimate coverage: $\sum_{i}^{\mathrm{topologies}} \sigma_i \Big/ \sigma_{\mathrm{SUSY}}$
- ☹️ Approximations: NWA, no chirality / spin correlations (→ O(20%) uncert')

Fastlim

https://fastlim.web.cern.ch

```
$ ./fastlim.py slha_files/testspectrum.slha
```

```
----------    Cross Section    ----------
Ecm          Total    Implemented   Coverage
8TeV    750.049fb      559.215fb      74.56%

---------------------------------------------------------------------------------------------
           Analysis   E/TeV   L*fb     Signal Region:  Nev/N_UL      CLs
---------------------------------------------------------------------------------------------
ATLAS_CONF_2013_047       8    20.3          A Loose:     1.0771    0.0498   <== Exclude
ATLAS_CONF_2013_047       8    20.3         A Medium:     0.4211        --
ATLAS_CONF_2013_047       8    20.3         B Medium:     1.2380        --   <== Exclude
ATLAS_CONF_2013_047       8    20.3          B Tight:     0.0639        --
ATLAS_CONF_2013_047       8    20.3         C Medium:     4.4634        --   <== Exclude
ATLAS_CONF_2013_047       8    20.3          C Tight:     1.1229        --   <== Exclude
...
```

Result summary

Fastlim

https://fastlim.web.cern.ch

```
$ ./fastlim.py slha_files/testspectrum.slha
```

```
##################################################
    Branching Ratio x Cross Section @ 8 TeV
##################################################
--------------------------------------------------
Production:    Xsec/fb       Rate
     Total:    750.049    100.00%
     T1_T1:     91.441     12.19%
     B1_B1:    119.231     15.89%
       G_G:    481.097     64.14%
     T2_T2:     58.281      7.77%
--------------------------------------------------
Output processes upto 0.5%
         Process:   Br*Xsec/fb     Rate     Accum
 GbB1tN1_GbB1tN1:    238.16703   31.75%    31.75%   <== Implemented
 GbB1tN1_GtT1tN1:    177.01613   23.60%    55.35%
     B1tN1_B1tN1:    111.58518   14.88%    70.23%   <== Implemented
     T1tN1_T1tN1:     84.06936   11.21%    81.44%   <== Implemented
...
```

Coverage information

Fastlim

https://fastlim.web.cern.ch

```
$ ./fastlim.py slha_files/testspectrum.slha
```

Analysis details

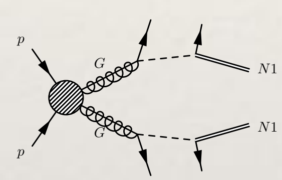
```
###########################################################
                 Analyses Details
###########################################################
-----------------------------------------------------------
[ATLAS_CONF_2013_047]
0 leptons + 2-6 jets + Etmiss [squarks & gluinos] at 8TeV with $20.3fb^{-1}$
http://cds.cern.ch/record/1547563
Ecm/TeV = 8
lumi*fb = 20.3
   #----  E Medium  ----#
   Nobs:              41
   Nbg:               30.0(8.0)
   Nvis_UL[observed]: 28.6
           Process       Nev     R[obs]
             Total  189.7060     6.6277 <== Exclude
   GbB1tN1_GbB1tN1  146.4262     5.1157
   GtT1tN1_GtT1tN1   14.5884     0.5097
   GbB1bN1_GbB1tN1    9.9914     0.3491
       T1tN1_T1tN1    6.3902     0.2233
       B1tN1_B1tN1    6.2758     0.2193
       T2bN1_T2tN1    1.9137     0.0669
...
```

Fastlim 1.0 (2014)

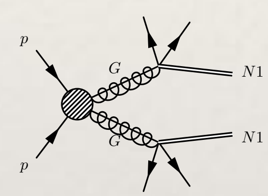
- Cross sections for colored sparticles @ 7 and 8 TeV

Fastlim 1.0 (2014)

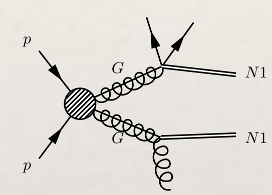
- Cross sections for colored sparticles @ 7 and 8 TeV
- Topologies involving 3rd generation:



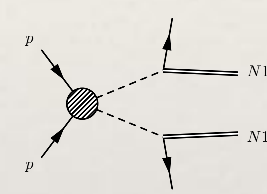
GbB1bN1_GbB1bN1
GbB1bN1_GbB1tN1
GbB1tN1_GbB1tN1
GtT1bN1_GtT1bN1
GtT1bN1_GtT1tN1
GtT1tN1_GtT1tN1
(GbB2bN1_GbB2bN1)
(GbB2bN1_GbB2tN1)
(GbB2tN1_GbB2tN1)
(GtT2bN1_GtT2bN1)
(GtT2bN1_GtT2tN1)
(GtT2tN1_GtT2tN1)
[GbB1bN1_GbB2bN1]
[GbB1bN1_GbB2tN1]
[GbB1tN1_GbB2bN1]
[GbB1tN1_GbB2tN1]
[GtT1bN1_GtT2bN1]
[GtT1bN1_GtT2tN1]
[GtT1tN1_GtT2bN1]
[GtT1tN1_GtT2tN1]



GbbN1_GbbN1
GbbN1_GbtN1
GbbN1_GttN1
GbbN1_GqqN1
GbtN1_GbtN1
GbtN1_GttN1
GbtN1_GqqN1
GttN1_GttN1
GttN1_GqqN1
GqqN1_GqqN1



GbbN1_GgN1
GbtN1_GgN1
GgN1_GgN1
GgN1_GttN1
GgN1_GqqN1



T1bN1_T1bN1
T1bN1_T1tN1
T1tN1_T1tN1
(B1bN1_B1bN1)
(B1bN1_B1tN1)
(B1tN1_B1tN1)
(B2bN1_B2bN1)
(B2bN1_B2tN1)
(B2tN1_B2tN1)
(T2bN1_T2bN1)
(T2bN1_T2tN1)
(T2tN1_T2tN1)

Fastlim 1.0 (2014)

- Cross sections for colored sparticles @ 7 and 8 TeV
- Topologies involving 3rd generation:
- 10 ATLAS 8TeV analyses

Name	Short description	$E_{\rm CM}$	$\mathcal{L}_{\rm int}$	# SRs
ATLAS_CONF_2013_024	0 lepton + (2 b-)jets + MET [Heavy stop]	8	20.5	3
ATLAS_CONF_2013_035	3 leptons + MET [EW production]	8	20.7	6
ATLAS_CONF_2013_037	1 lepton + 4(1 b-)jets + MET [Medium/heavy stop]	8	20.7	5
ATLAS_CONF_2013_047	0 leptons + 2-6 jets + MET [squarks & gluinos]	8	20.3	10
ATLAS_CONF_2013_048	2 leptons (+ jets) + MET [Medium stop]	8	20.3	4
ATLAS_CONF_2013_049	2 leptons + MET [EW production]	8	20.3	9
ATLAS_CONF_2013_053	0 leptons + 2 b-jets + MET [Sbottom/stop]	8	20.1	6
ATLAS_CONF_2013_054	0 leptons + $\geq$ 7-10 jets + MET [squarks & gluinos]	8	20.3	19
ATLAS_CONF_2013_061	0-1 leptons + $\geq$ 3 b-jets + MET [3rd gen. squarks]	8	20.1	9
ATLAS_CONF_2013_062	1-2 leptons + 3-6 jets + MET [squarks & gluinos]	8	20.3	13
ATLAS_CONF_2013_093	1 lepton + bb(H) + Etmiss [EW production]	8	20.3	2

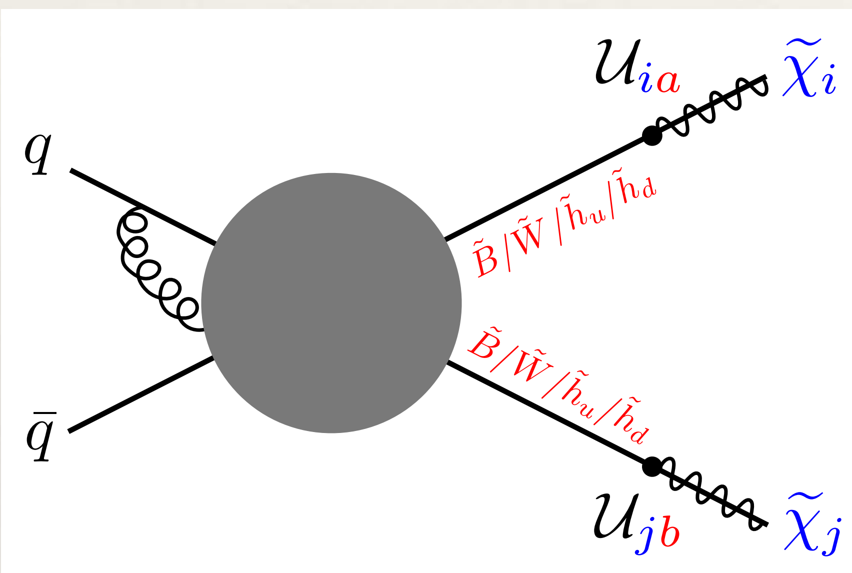
Fastlim 2.0 (2017)

- Colored sparticles & Electroweakino cross sections for LHC Run I and II → EWKfast
- Efficiency grids publicly provided by the experiments
- New efficiency grids / new analyses → Atom

Electroweakino cross sections

w/ E.Bagnaschi, K.Sakurai, A.Weiler, L.Zeune

- Fast EW Triplet+Doublet+Singlet(s) (N)MSSM cross sections:



$$\sigma(pp \to \widetilde{\chi}_i \widetilde{\chi}_j) = \sum_{I=\{a,b,c,d\}} \bar{\mathcal{T}}_I^{ij} \bar{\mathcal{F}}_I(m_{\widetilde{\chi}_i}, m_{\widetilde{\chi}_j}, \mathbf{m}_{\widetilde{q}}),$$

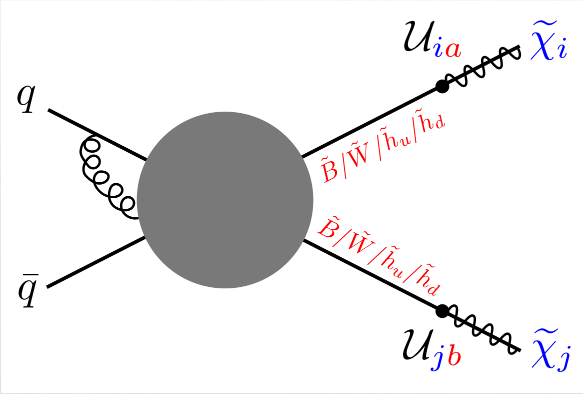
$$\bar{\mathcal{T}}_I^{ij} = \mathcal{U}_{ia}\mathcal{U}_{jb}\mathcal{U}_{ic}^{*}\mathcal{U}_{jd}^{*}$$

- Use gauge eigenstates!
- Kinematics+PDF is encoded in the F_I functions. Coefficients are just fixed functions of the mixing matrices (contained in the SLHA file)
- Various relations can be used to reduce number of F_I functions

Electroweakino cross sections

w/ E.Bagnaschi, K.Sakurai, A.Weiler, L.Zeune

- In the limit of decoupled gluinos:
    - neutralino pair prod': 5 functions
    - chargino pair prod': 6 functions for i=j, reduces to 3 functions for i≠j
    - chargino neutralino prod': 6 functions
    - Total: 4 2D (ewk masses m_i m_j) + 13 3D grids (ewk masses m_i m_j + squark mass(es))
- Pre-tabulate using available tools (Prospino, Resummino, …)
- Very fast cross section computation: O(1sec) → easy to scan over full SUSY EW parameter space



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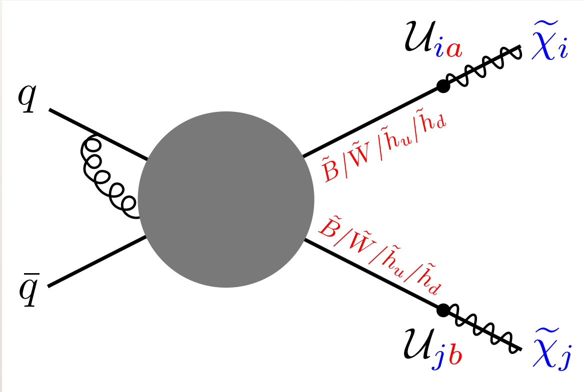

Stand-alone package for cross-section calculation:

EWKfast

Atom 1.0 (2017)

w/ I.-W.Kim, K.Sakurai, A.Weiler

2010→2012 earlier collab. w/ C.Bauer, C.Vermillion, T.Volansky, D.Neuenfeld

- Reinterpretation of LHC results based on MC Event files as input
- Alternative to Rivet, Checkmate, MadAnalysis, etc. — why need another tool? Each tool has a different focus…
- Theorist-level recasting is intrinsically an (uncontrolled) extrapolation:

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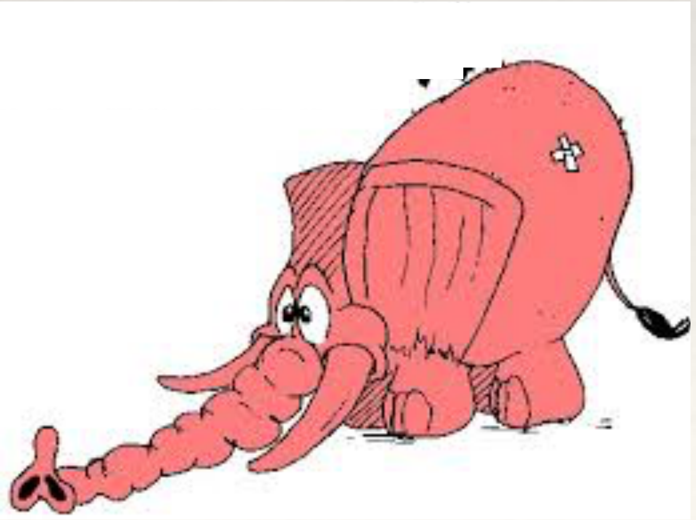


Recasting experimental analyses 101

Take search X setting limits for model A

↓

Write code to mock up search X
(not enough info → introduce approximations)

↓

Generate events for model A, use them with mocked-up analysis, compare results with published experimental results

Validation (most time consuming part)

Use mocked-up analysis with model B

Extrapolation!!

↓

Extract approximate limits of search X for model B

Atom 1.0 (2017)

w/ I.-W.Kim, K.Sakurai, A.Weiler

earlier collab. w/ C.Bauer, C.Vermillion, T.Volansky, D.Neuenfeld

- Reinterpretation of LHC results based on MC Event files as input
- Alternative to Rivet, Checkmate, MadAnalysis, etc. — why need another tool?
- This type of recasting is intrinsically an (uncontrolled) extrapolation:
  - modeling of detector/analysis procedure based on partial (folded) information on a given signal model to be used on different models
  - Assessing/estimating reliability of extrapolation is as important as the result itself
  - Moving forward in LHC program → more exotics signals investigated and potential problems will only get worse

Atom 1.0 (2017)

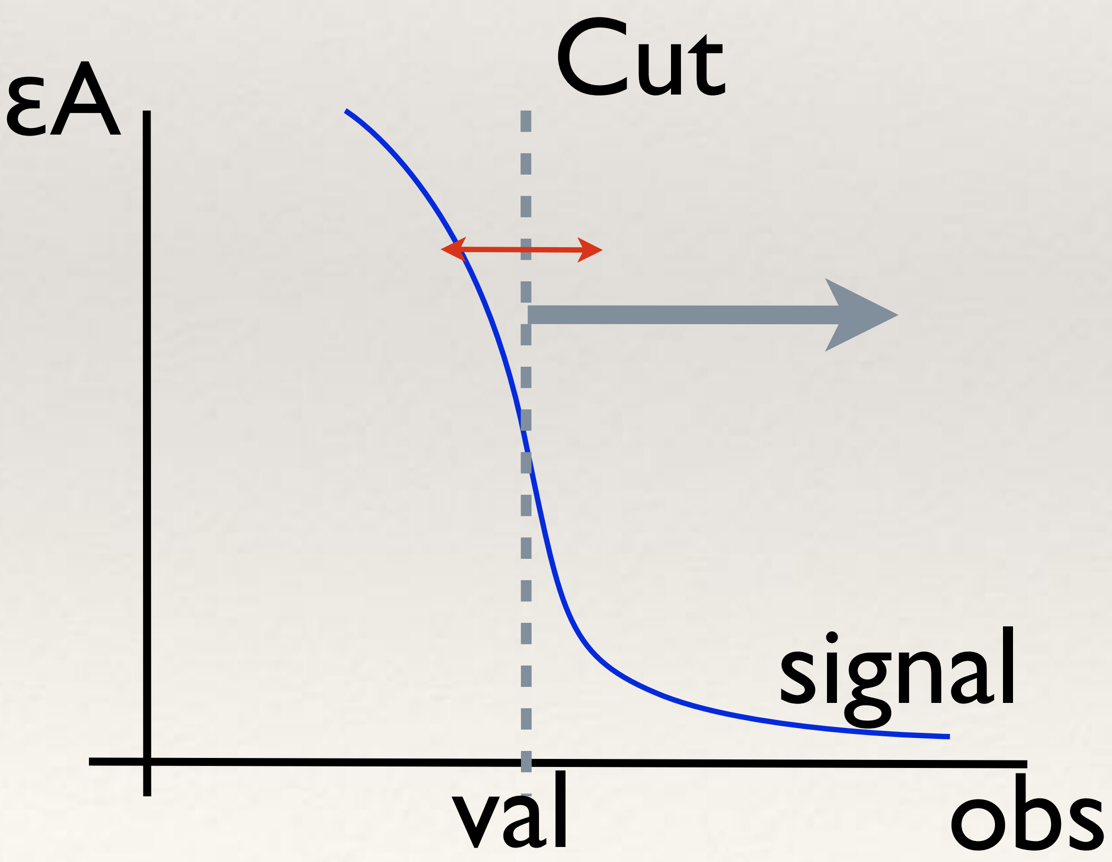
w/ I.-W.Kim, K.Sakurai, A.Weiler

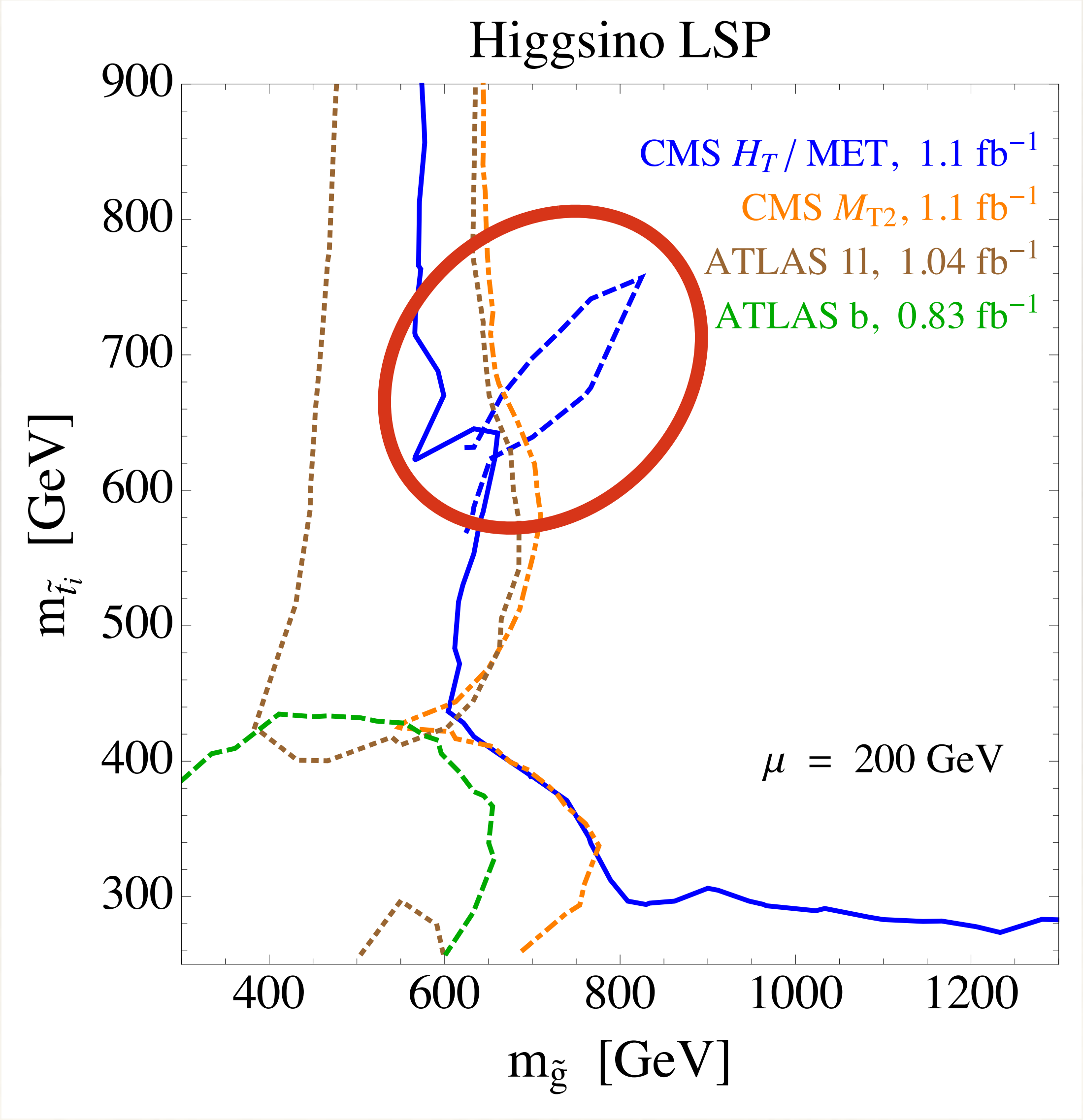
earlier collab. w/ C.Bauer, C.Vermillion, T.Volansky, D.Neuenfeld

- Goal of Atom:
  - provide reinterpretation results AND enough additional information to help user decide whether they can be trusted
- Multi-pronged approach:
  - Full support for multiple event weights to assess theoretical uncertainties
  - Simple (and efficient) way to run simultaneously different versions of an analysis differing by description of detector effects (no recompilation, aggressive caching for speed)
  - Expandable (plug-in) system of warnings for detecting common situations invalidating the results
    - strong cut sensitivity
    - leakage of signal in control regions
    - …

Warnings

- Sensitivity to cuts: $\partial \log \epsilon / \partial \log \mathrm{obs}|_{\mathrm{obs=val}}$ for all cuts automatically
  - if large means approximate detector description may have large impact!





from 1110.6926

"Atom" (Automatic Tester Of Models) In A Nutshell

LHE
StdHEP
HepMC
Weights (LHEv3)
KFactors (0,1,2D grids)
Atom (previous run info)

Events

"Atom" (Automatic Tester Of Models) In A Nutshell

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HepMC
Weights (LHEv3)
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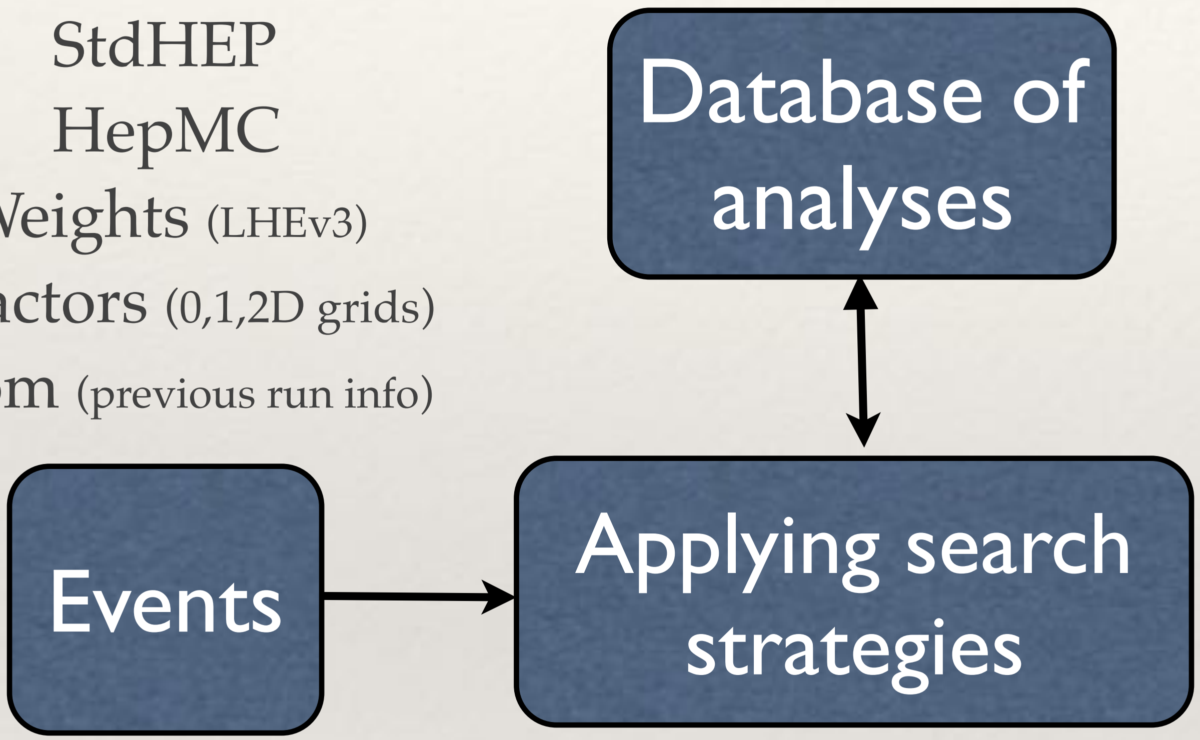
Atom (previous run info)



"Atom" (Automatic Tester Of Models) In A Nutshell

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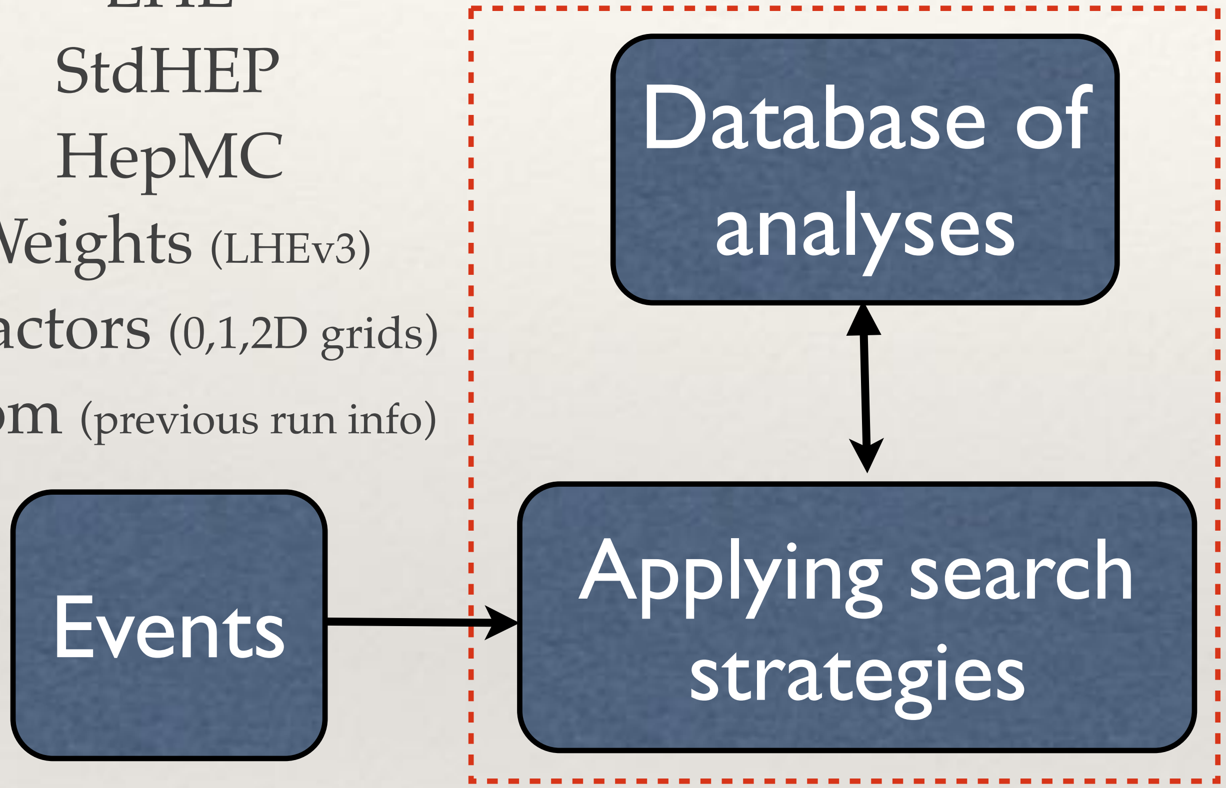
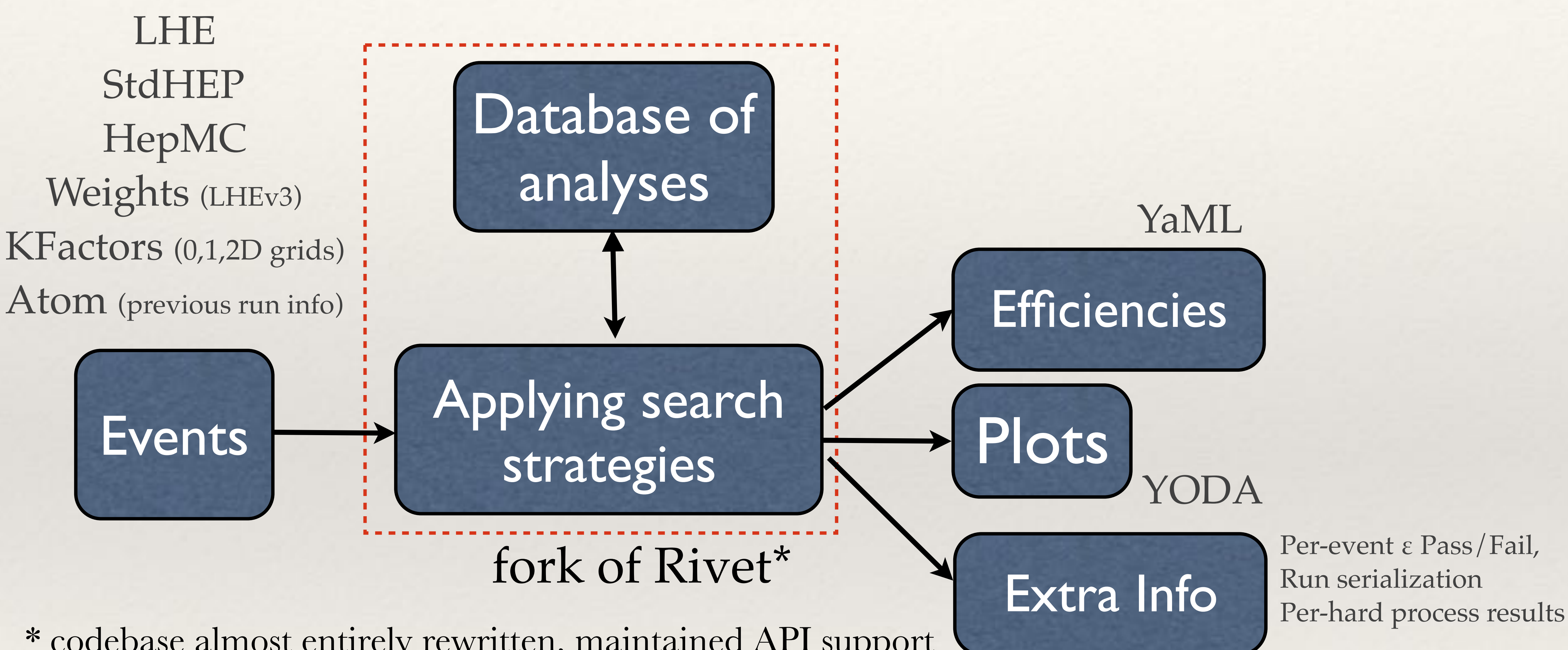


fork of Rivet*

* codebase almost entirely rewritten, maintained API support for analyses → can run Rivet analyses

“Atom” (Automatic Tester Of Models) In A Nutshell



* codebase almost entirely rewritten, maintained API support for analyses → can run Rivet analyses

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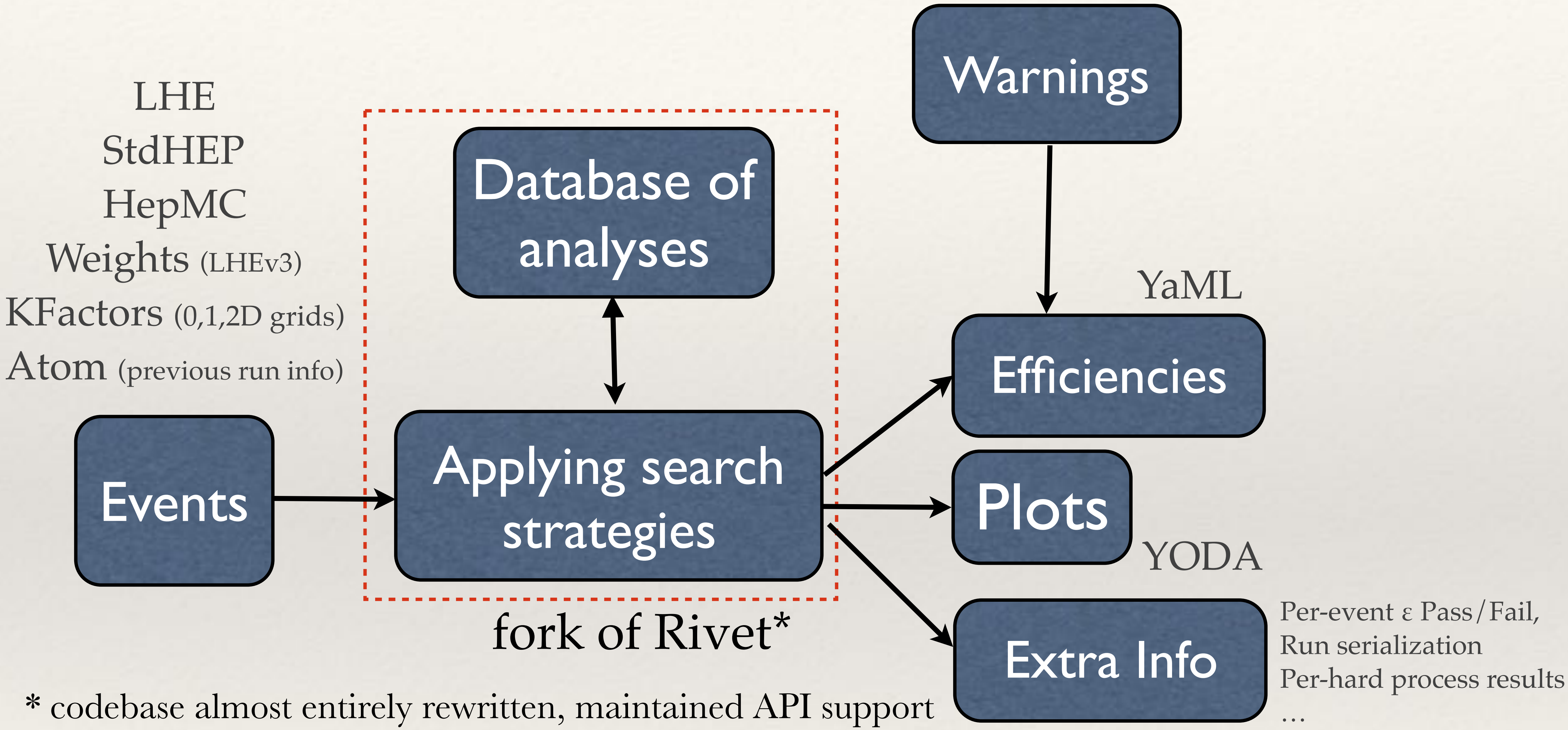

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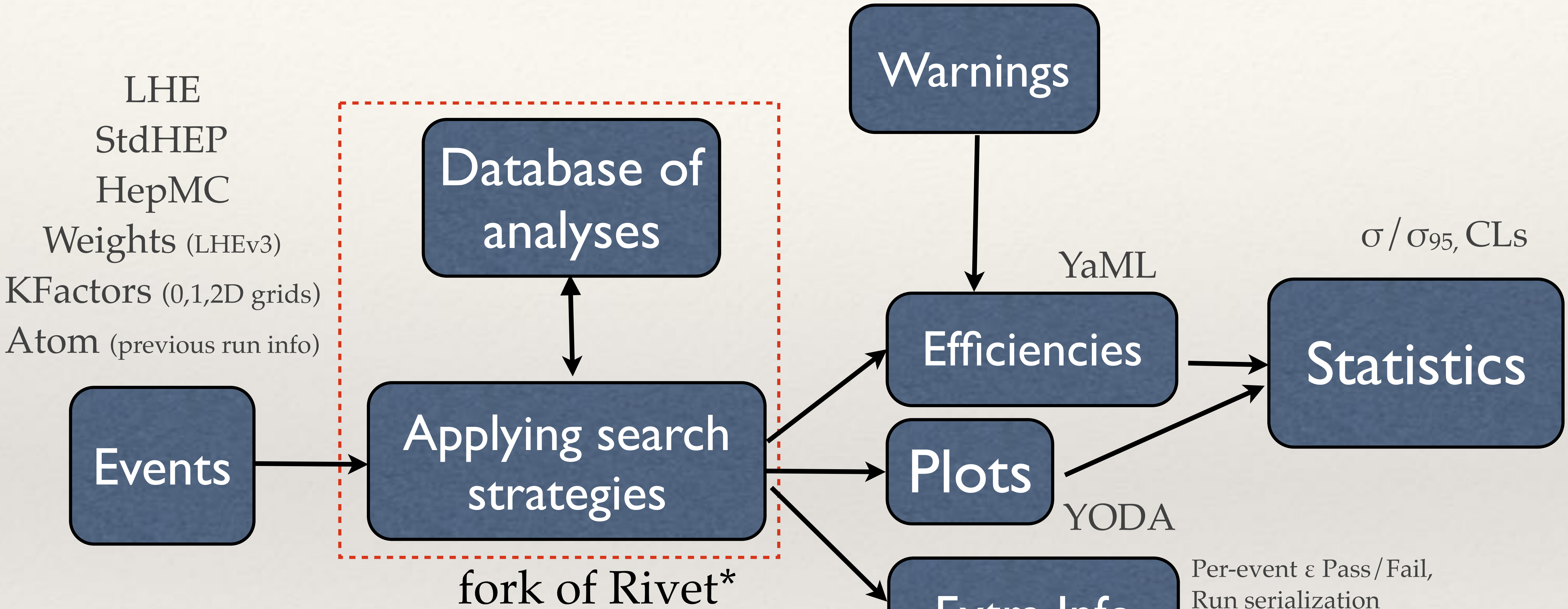

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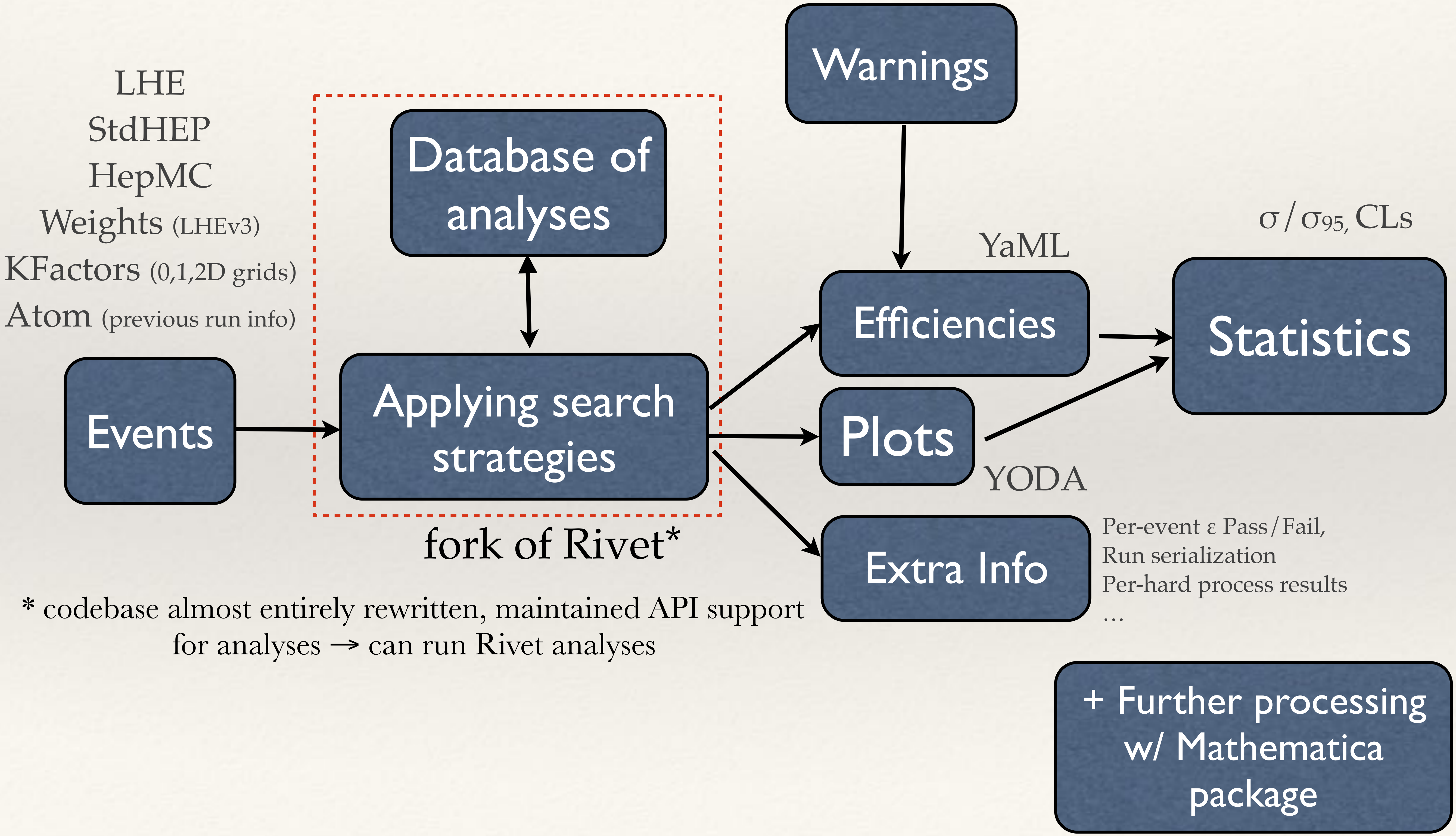

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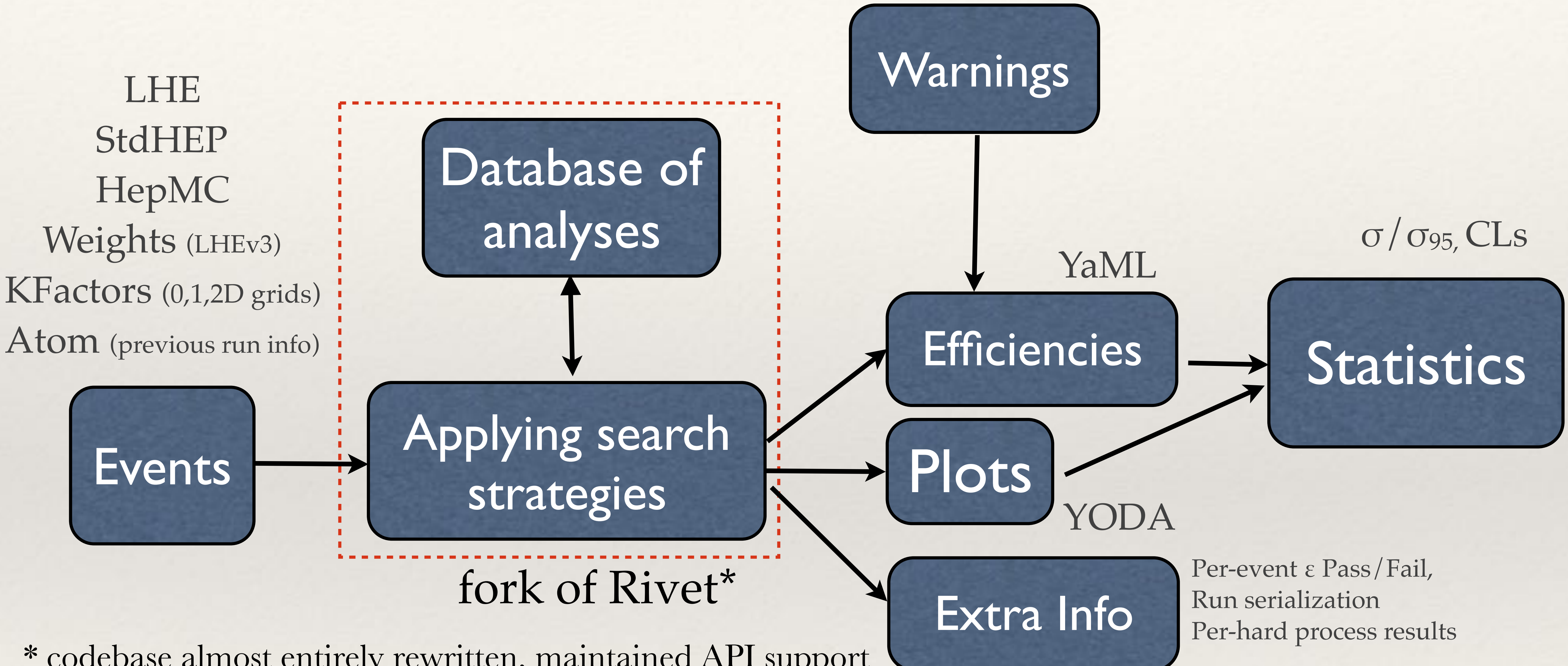

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~140 Atom analyses implemented between ATLAS/CMS, SUSY+Exotics, Run I+II

+ Further processing w/ Mathematica package

Atom for the user

Typical workflow:

- User provides a file with fully showered and hadronized signal events of the model under study (any format LHE, StdHep, HepMC,… + external weights OK)
- launch “atom” to set the various options, select the analyses & process the events. 3 modes:
  - batch (best for running on a cluster)
  - command-line
  - interactive (à la MadGraph5)
- Atom runs
- Output: files (text, pdf, …) containing plots, cut efficiencies, efficiencies of signal (and control) regions, cross sections, …
- Process the output with the provided tool to produce limits (for cut&count analyses), efficiency tables and plots, or
- Read the output files in Mathematica with the provided package for further processing

Atom for implementing new analyses

- User runs "atom-mkanalysis", which collects all the available information online and creates the analysis files (HepData + CDS + Inspire + ATLAS,CMS public pages)
- User codes the behavior of the analysis (i.e. event selections, cuts, efficiency and histogram filling) in C++. High level building blocks ("Projections") available for all the relevant objects and kinematic variables. If you know how to code a Rivet analysis you know how to code an Atom analysis. "atom-checksyntax" helps detecting common coding issues.
- User runs "atom-mkvalidation", to set up a series of runs for validating the coded analysis against the experimental information publicly available (plots, cutflow tables, etc.). (Each analysis has a validation card encoding multiple validation runs)
- User generates the event files necessary for the validation runs
- User runs "atom-validate". The validation runs are performed according to the validation cards and the comparisons summarized in a (LaTeX) pdf file.

Atom Detector parameterizations

- Smearing + Efficiency functions applied directly to truth-level objects
  - Functions specified in YaML data cards
  - Support both grids and functional forms
  - High granularity of detector description (per experiment per data taking period but can specified per-analysis)
- Our card implementation strategy: try to use "as is" efficiency/smearing curves presented by experiments in object commissioning/performance papers whenever available (easier for ATLAS)
- Atom supports:
  - Momentum smearing + identification efficiency for electron, muons, photons (both converted and unconverted), tracks, jets
  - Jet tagging/rejection ROC curve for c-,b-,light jet separately,
  - JES smearing, PU subtraction for jets
  - Tau tagging/rejection (1- and 3- prong can be separated)
  - MET smearing: correlated smearing with other objects + soft term
  - Trigger turn-on curves

Atom features grab-bag

- Projection caching: not just "equal" projections but "less/more", "truth/simulated" conditions used in caching + caching across different runs via serialization
- Split-merge of runs
- BSM reweighing
- Multi-threading*
- Preliminary support of long lived particles*
- On-the fly decay of particles based on contents of other input event files, PDG code substitutions, …
- All output information can be separated per hard process type (based on hard process ID)
- collection of bibliography associated to run (BibTeX)
- library-mode for linking against external programs (API different from Rivet)

* under testing, not in v.1.0

Conclusions

- Fastlim: recasting via simplified models → fast and suitable for large parameter scans (mostly SUSY)
- EWKfast: fast evaluation of chargino/neutralino production cross sections (with uncert’) via interpolation grids
- Atom: recasting (and new analyses development) based on MC event files.