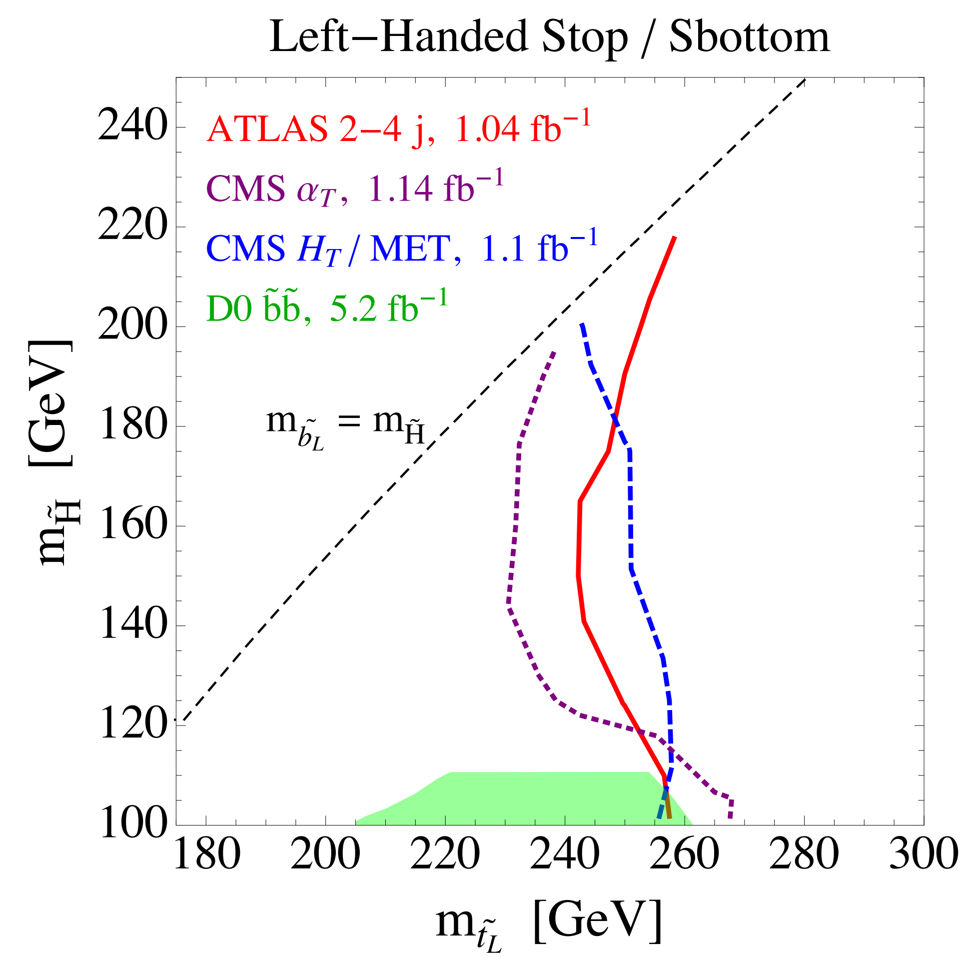
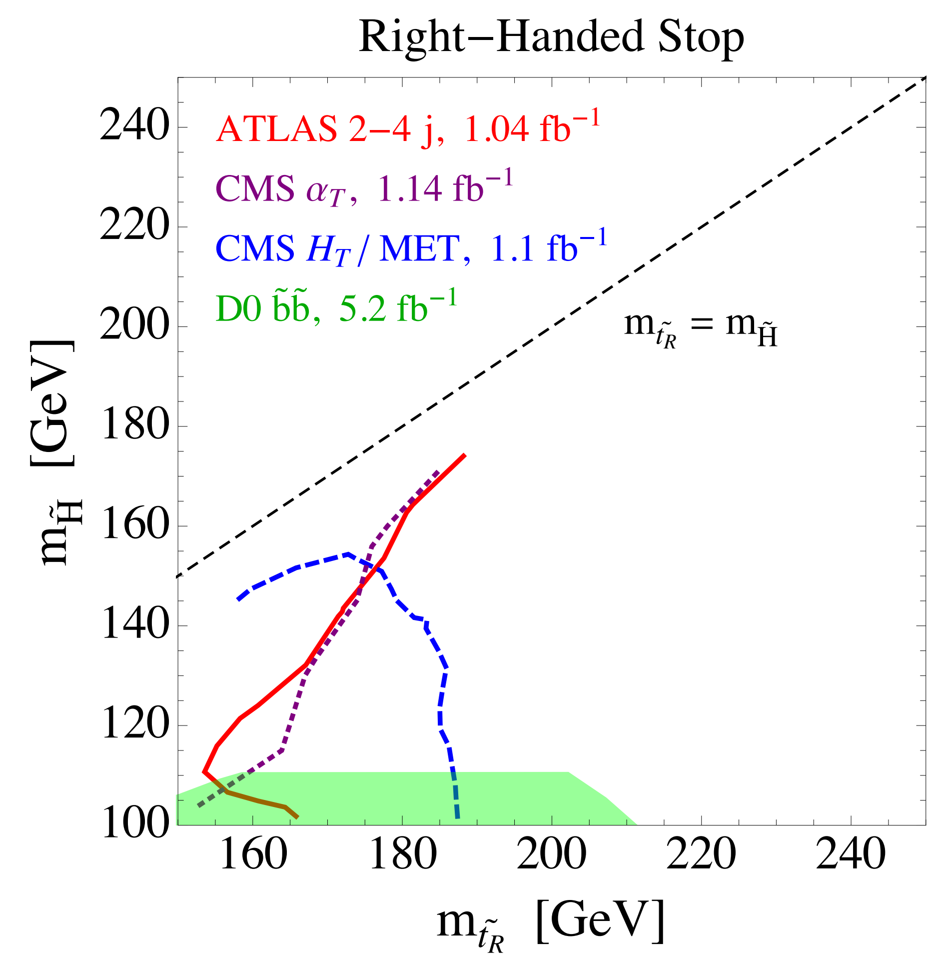
# ATOM

## Automatically testing new theories with existing results




(With collaborators Christian Bauer, Michele Papucci, Tomer Volansky, Andreas Weiler)


Christopher Vermilion

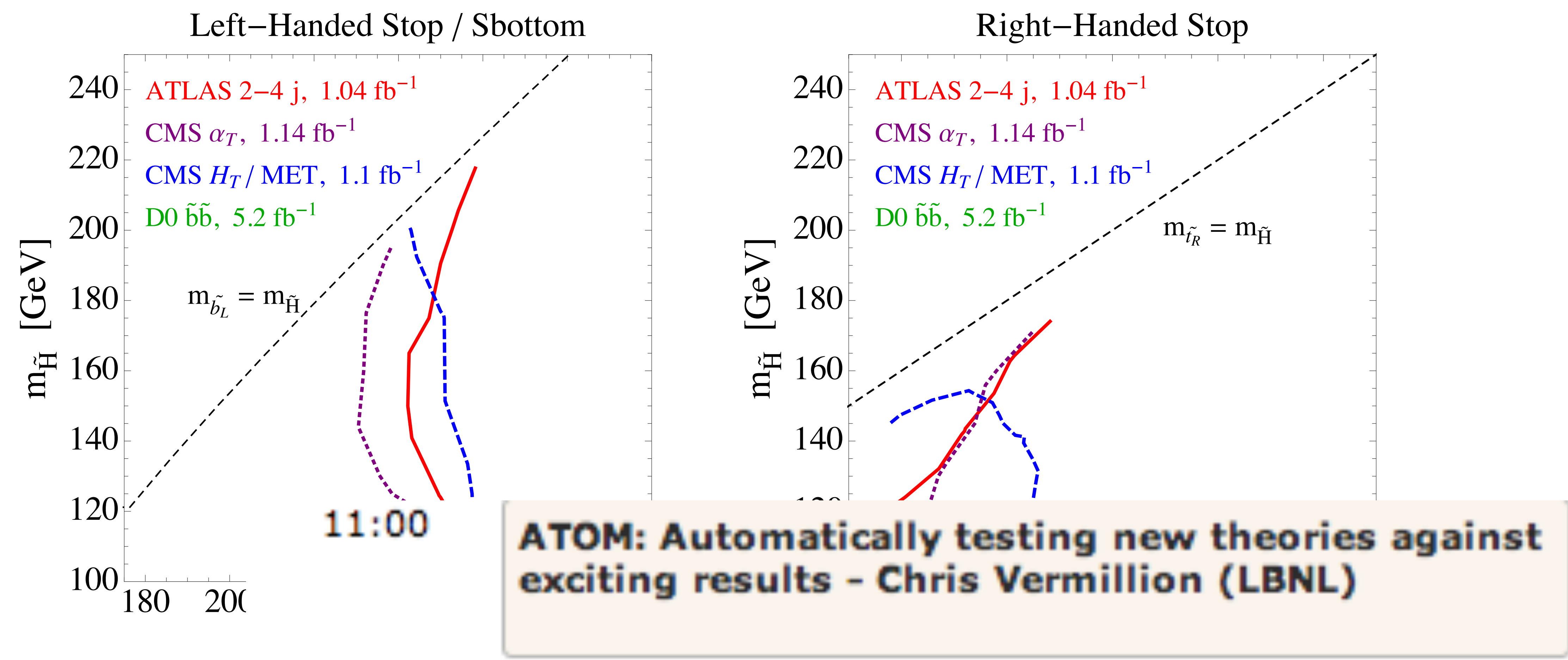

MC4BSM Workshop

Cornell University

3/24/12

# ATOM

## Automatically testing new theories with exciting results




(With collaborators Christian Bauer, Michele Papucci, Tomer Volansky, Andreas Weiler)


Christopher Vermilion


MC4BSM Workshop

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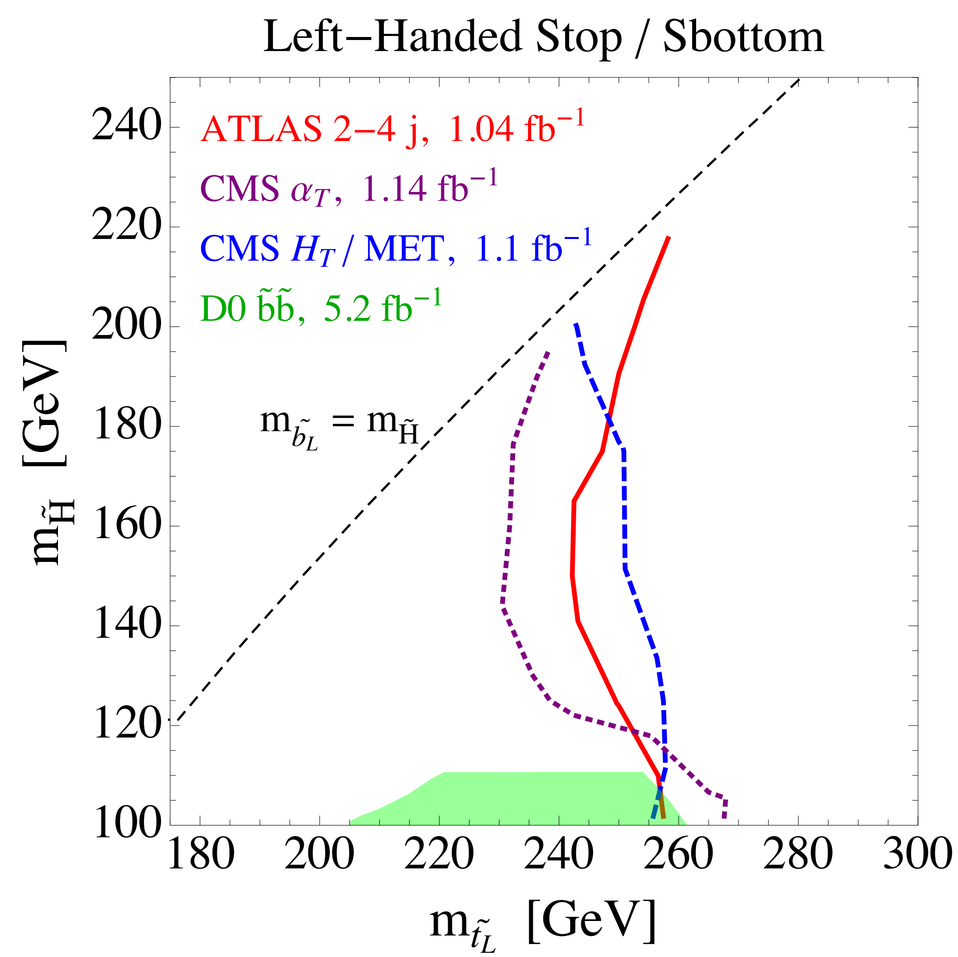
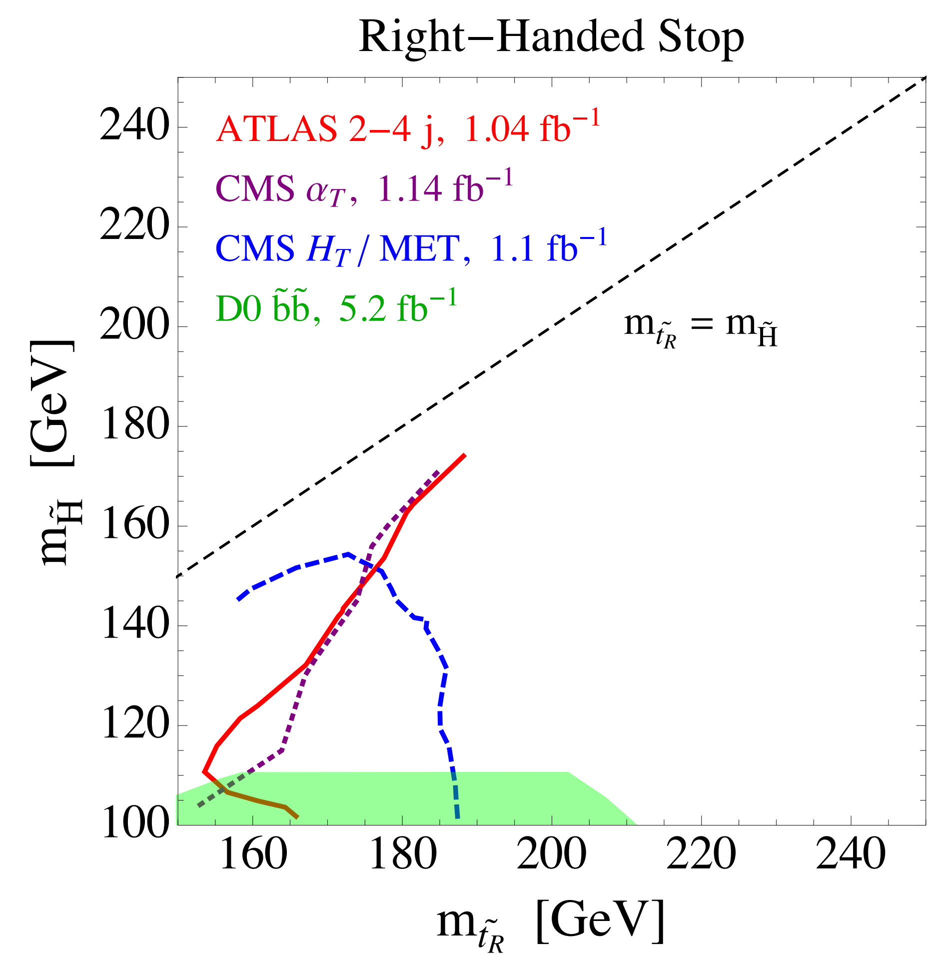
# ATOM: Automated Tester of Models

## Automatically testing new theories with exciting results

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# The problem

New Model

?

✓ Viable

✳ Ruled Out

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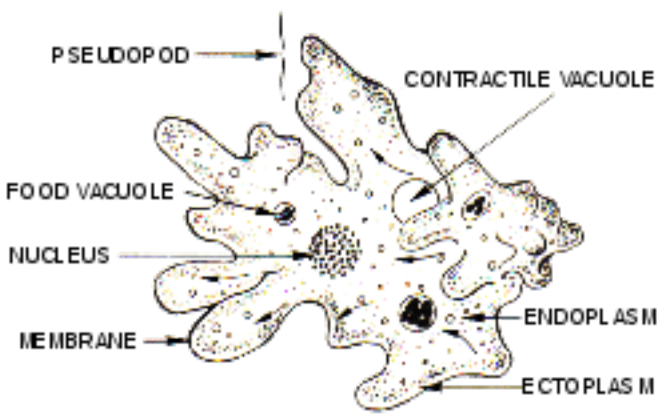
New Model

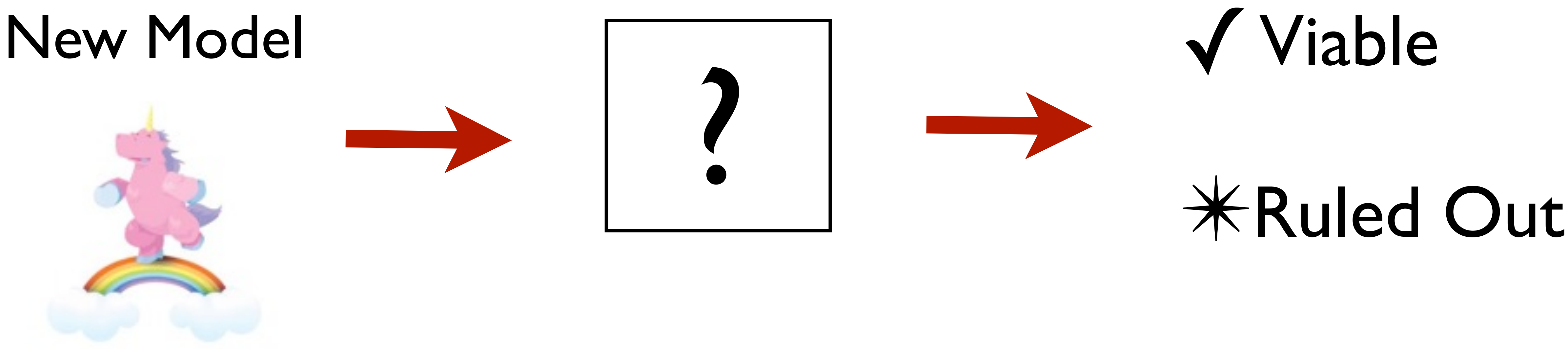



→ ? →

✓ Viable

✳ Ruled Out

# The problem



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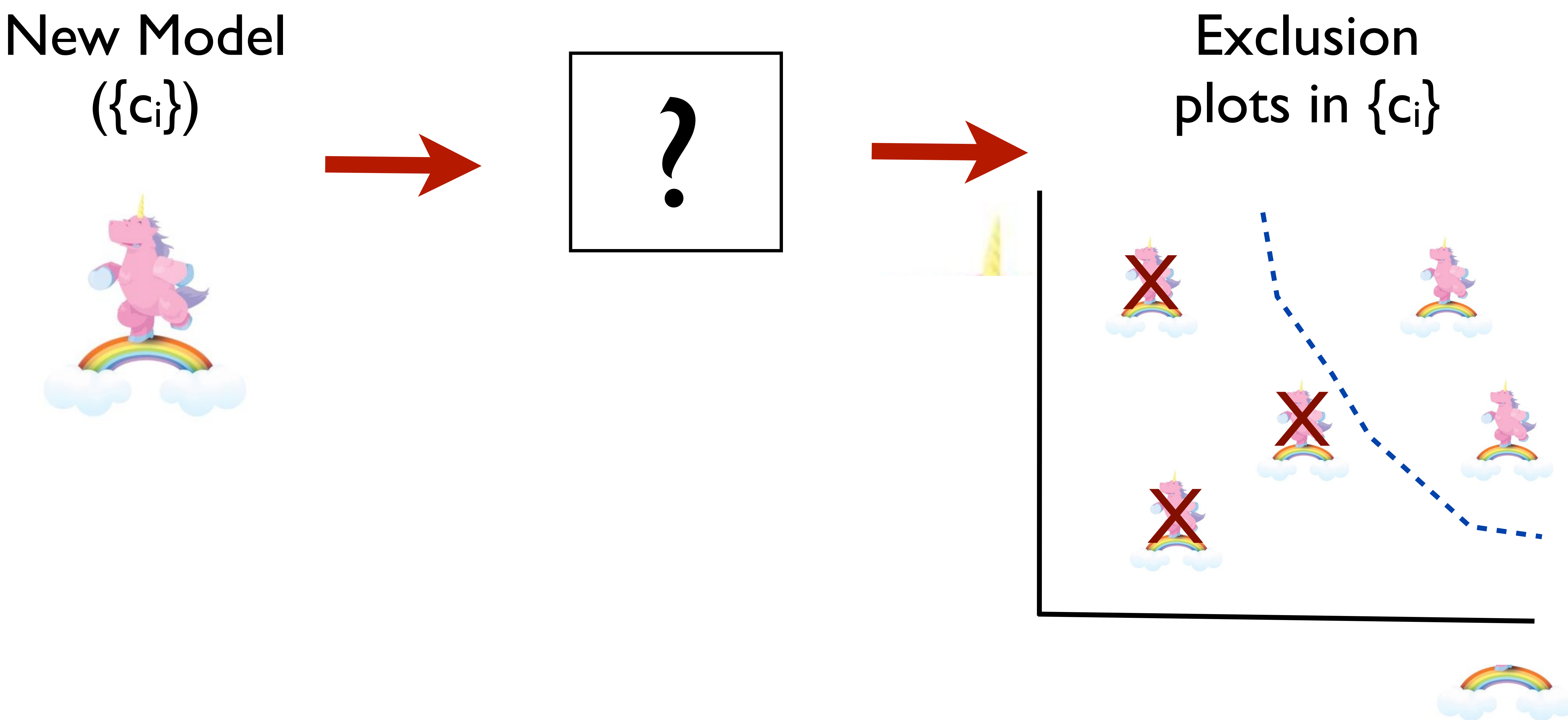
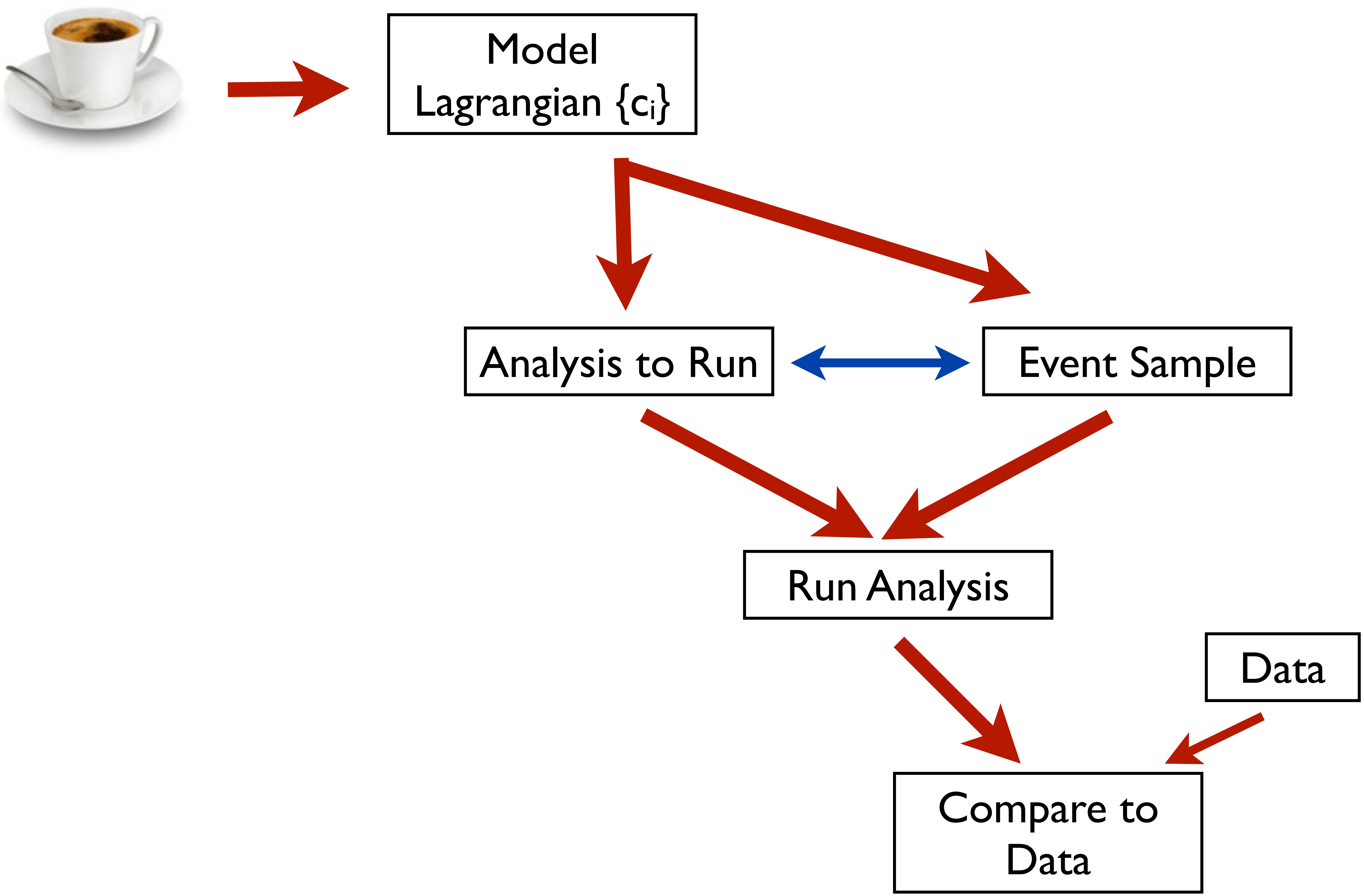
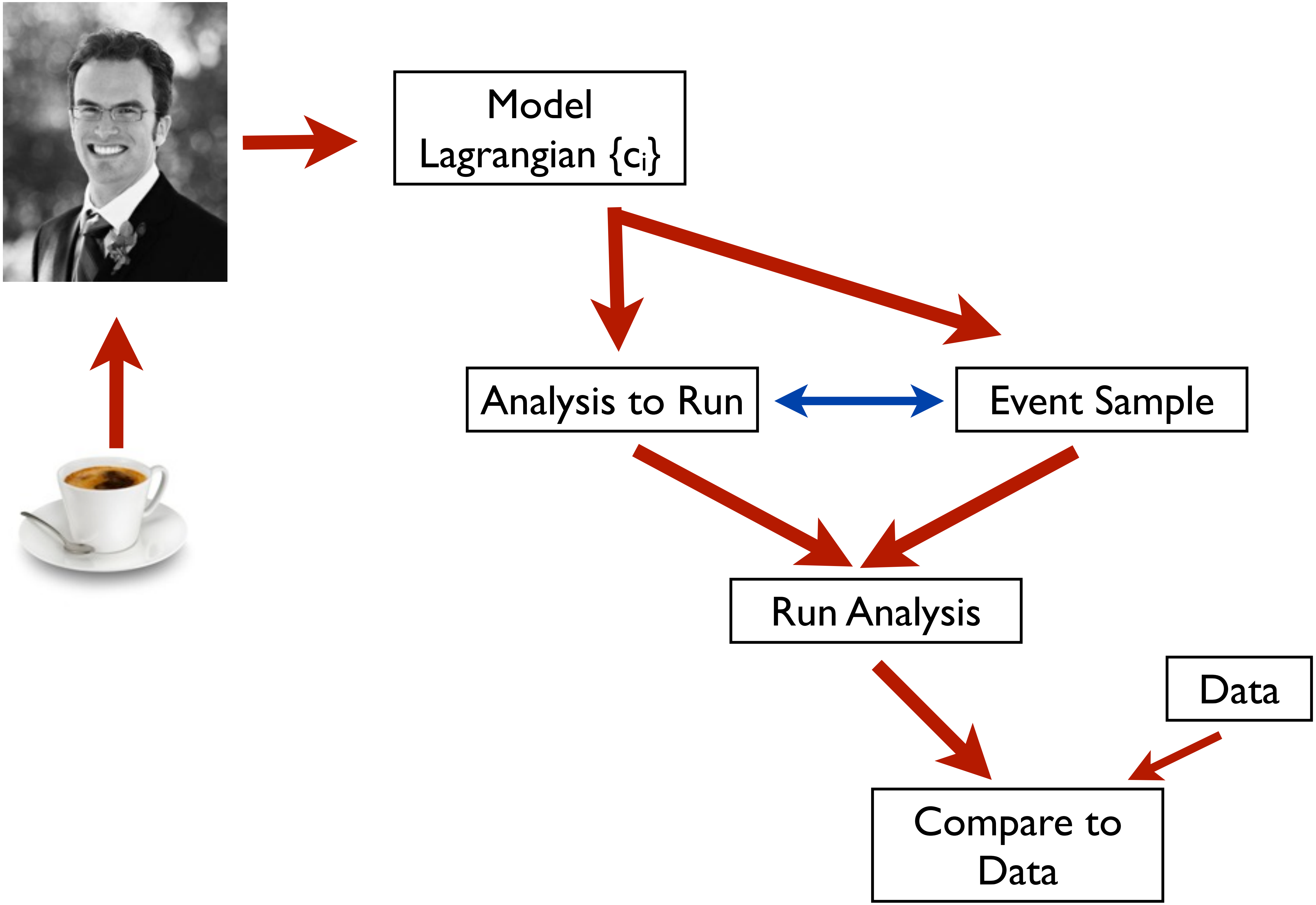



Model
Lagrangian $\{c_i\}$
Analysis to Run
Event Sample
Run Analysis
Data
Compare to
Data


Model
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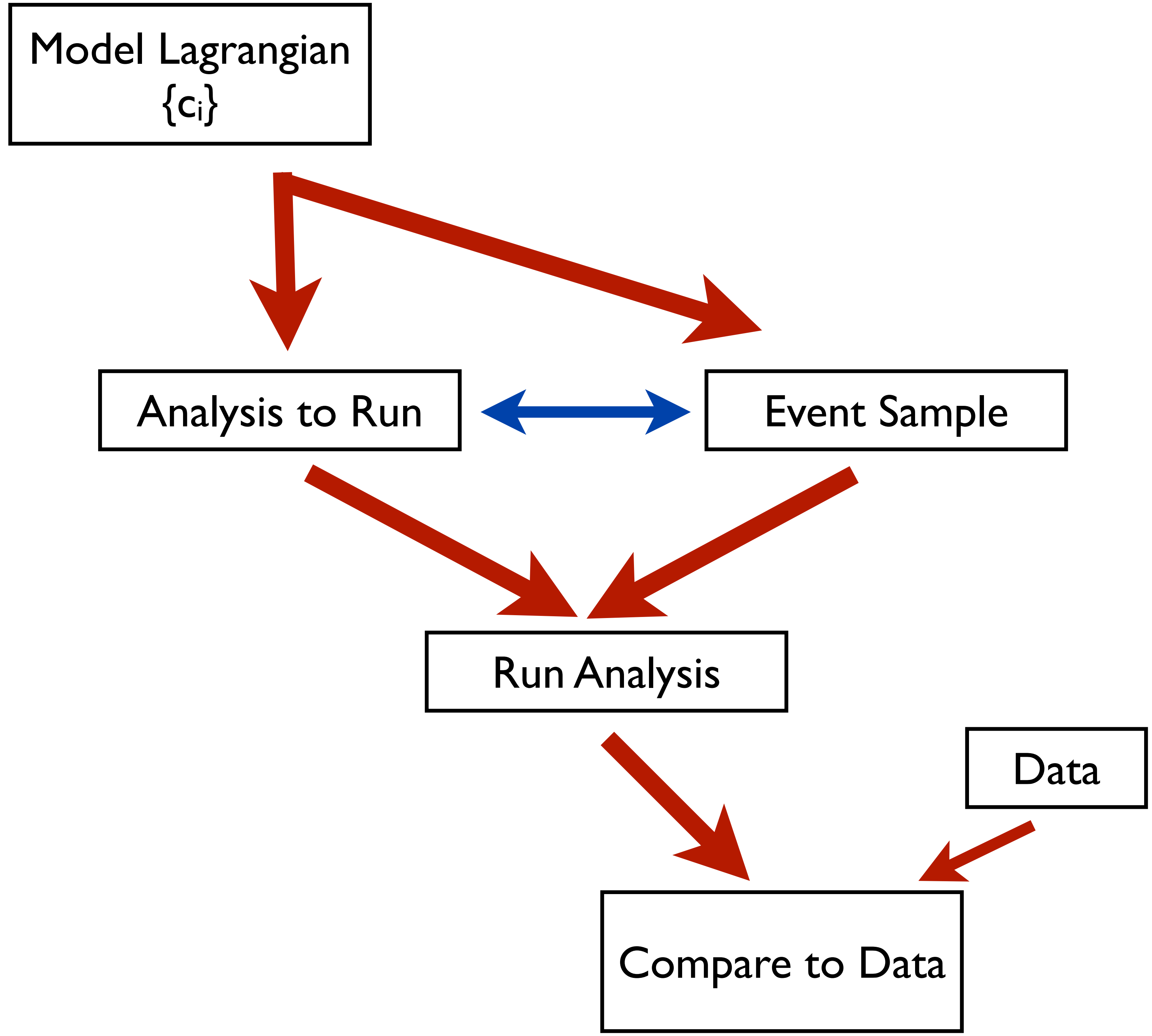
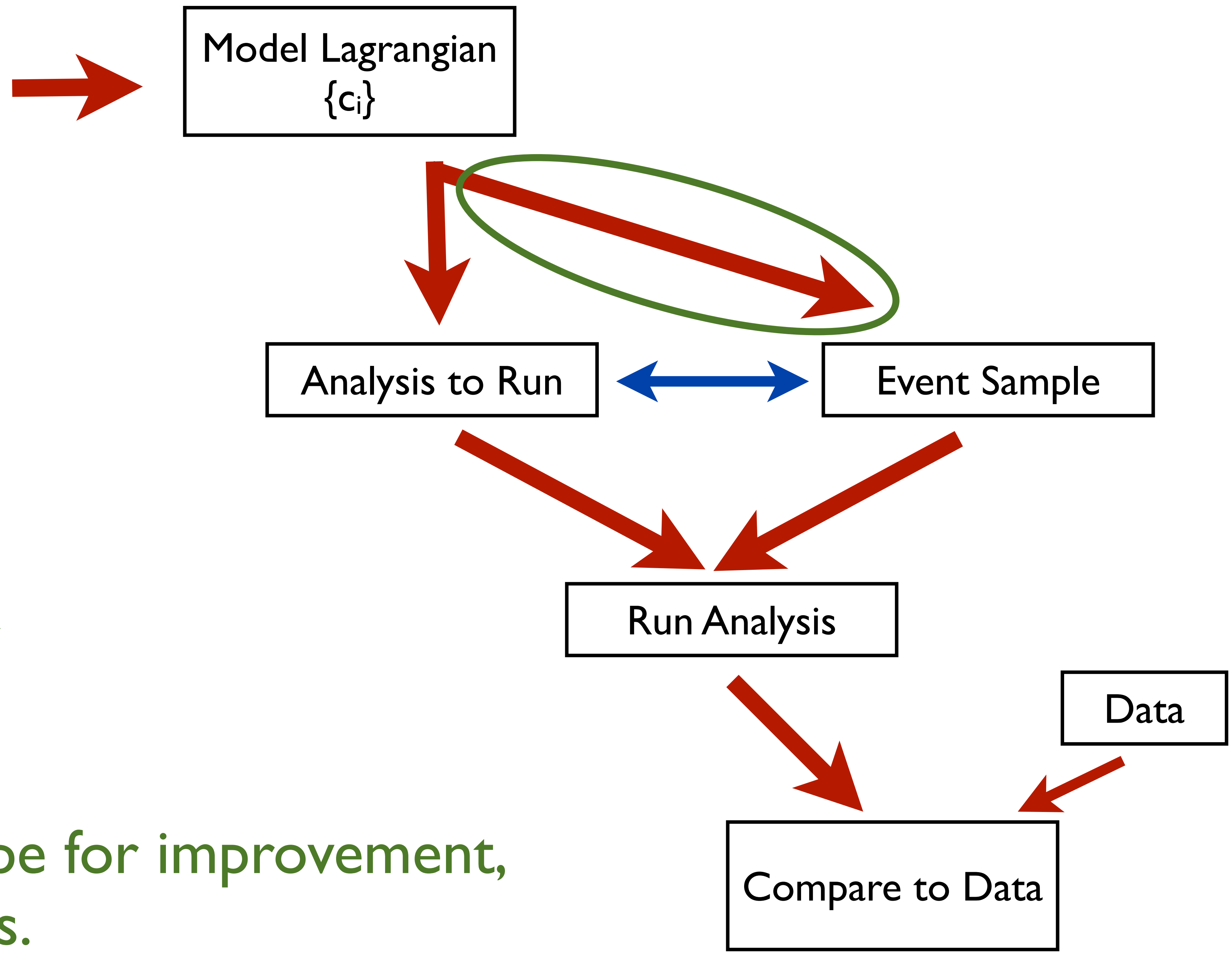


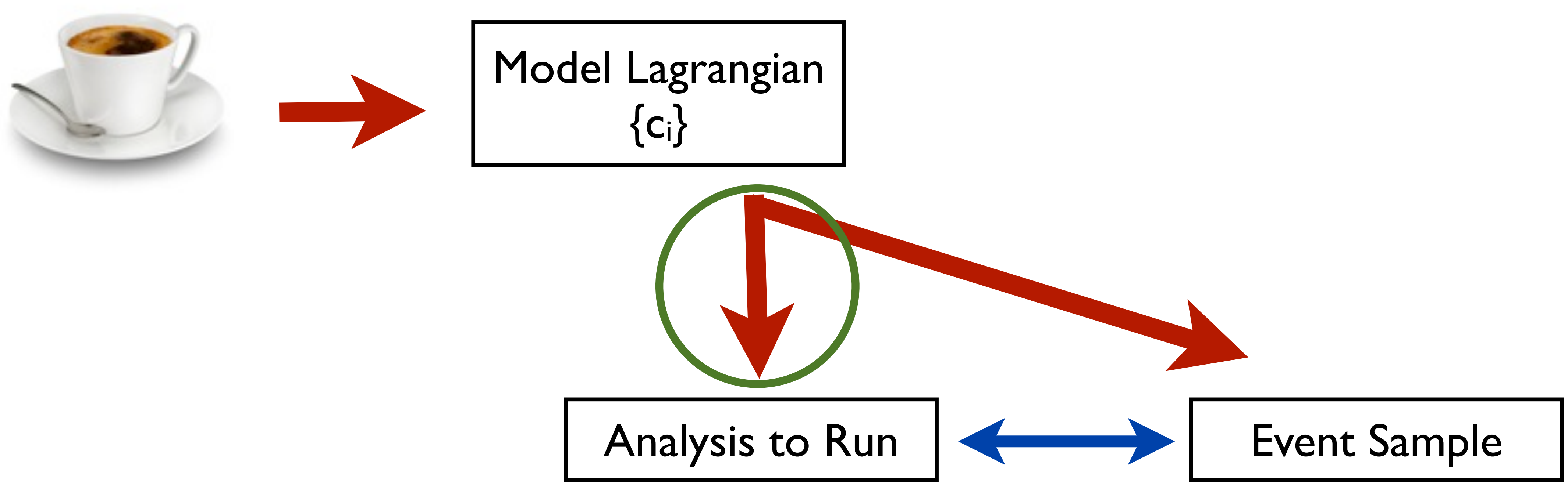

Leave this part to the model builders...

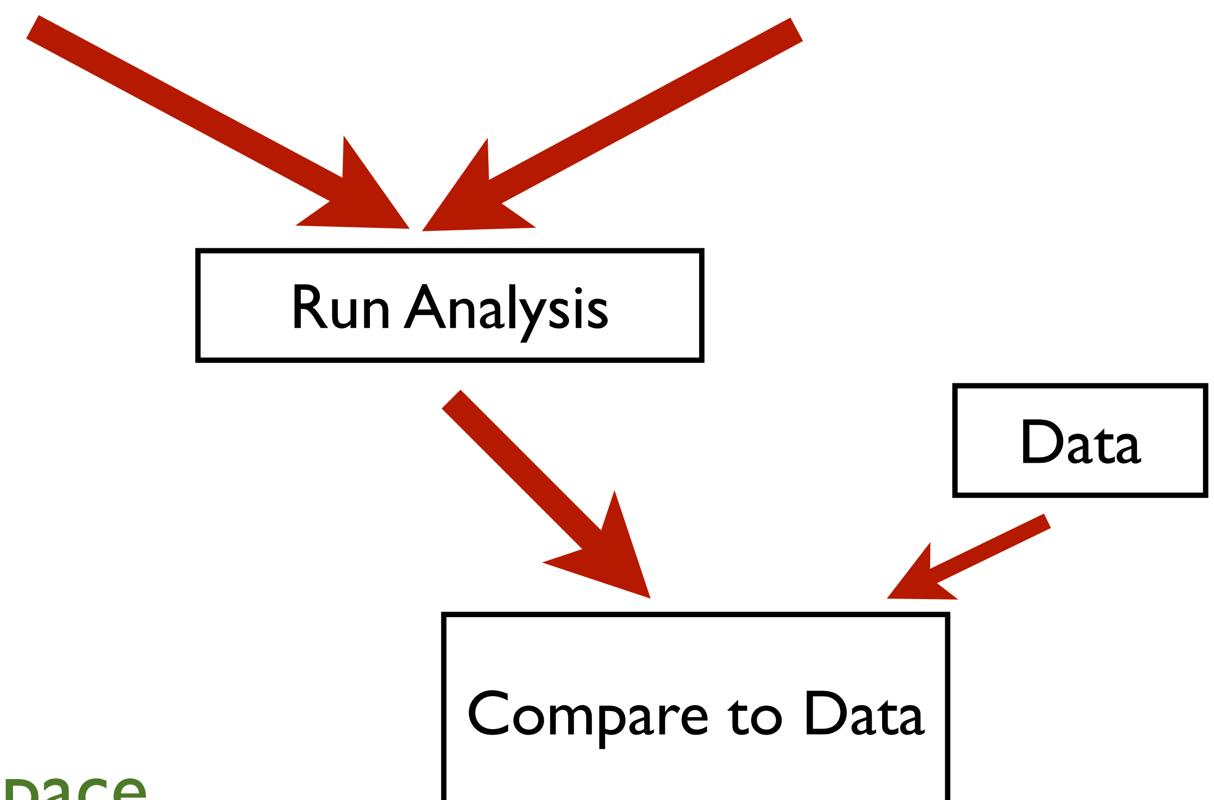



Lots of tools for this step.

Surely some scope for improvement, but not our focus.

What events to generate? More later...



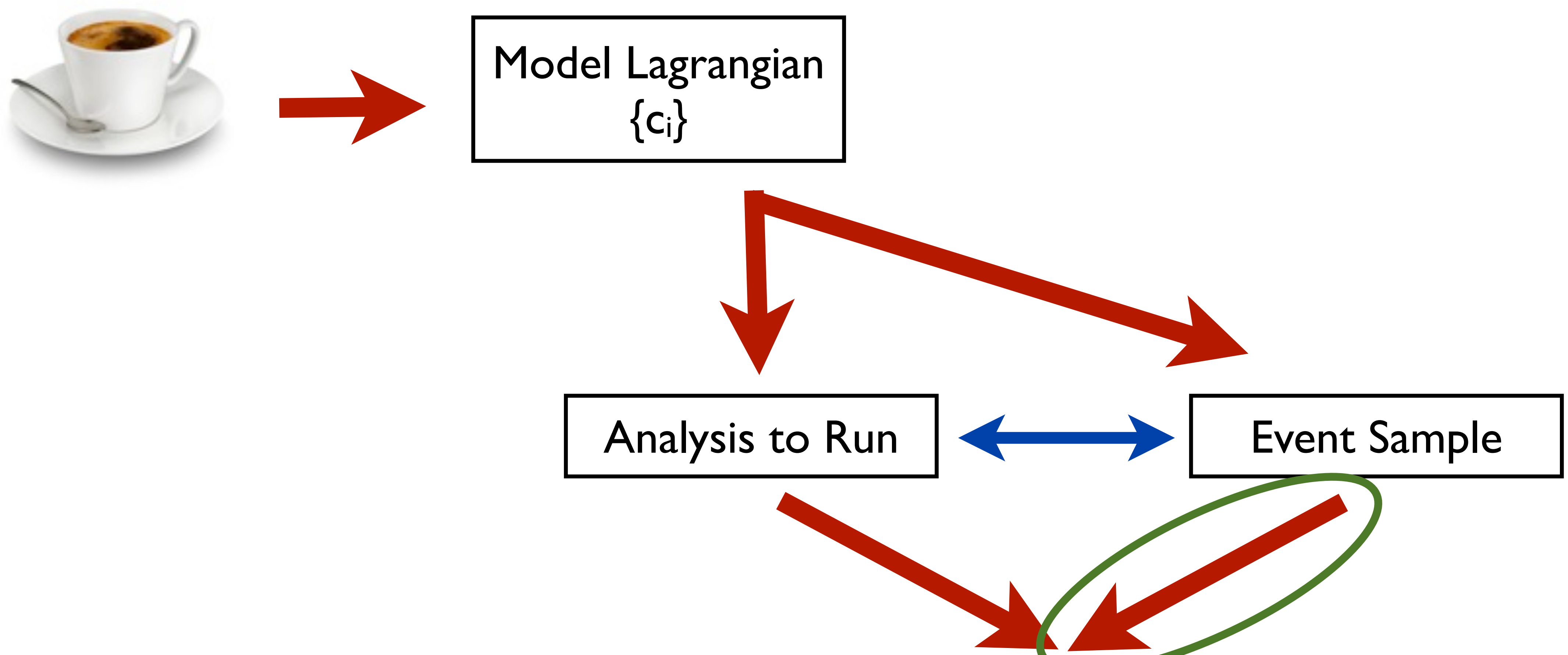



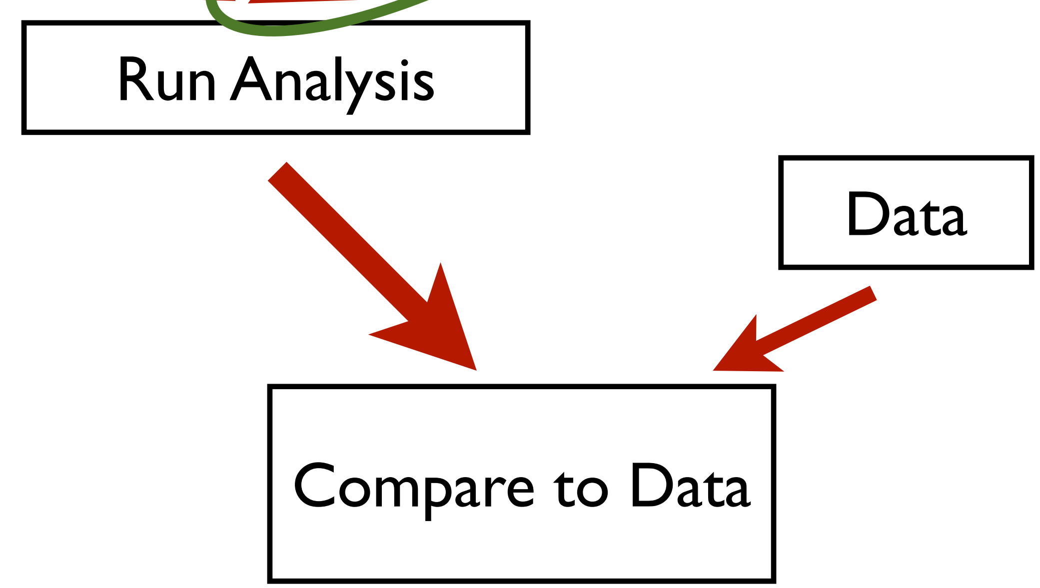

Should be straightforward for "good model builders" -- what are the interesting signatures of this model?

But...

- Maybe not obvious over all of param. space
- Even "good theorists" might miss things!
  - On top of signature, ideal to have encyclopedic knowledge of past analyses
- ... weed out "bad model builders" more easily

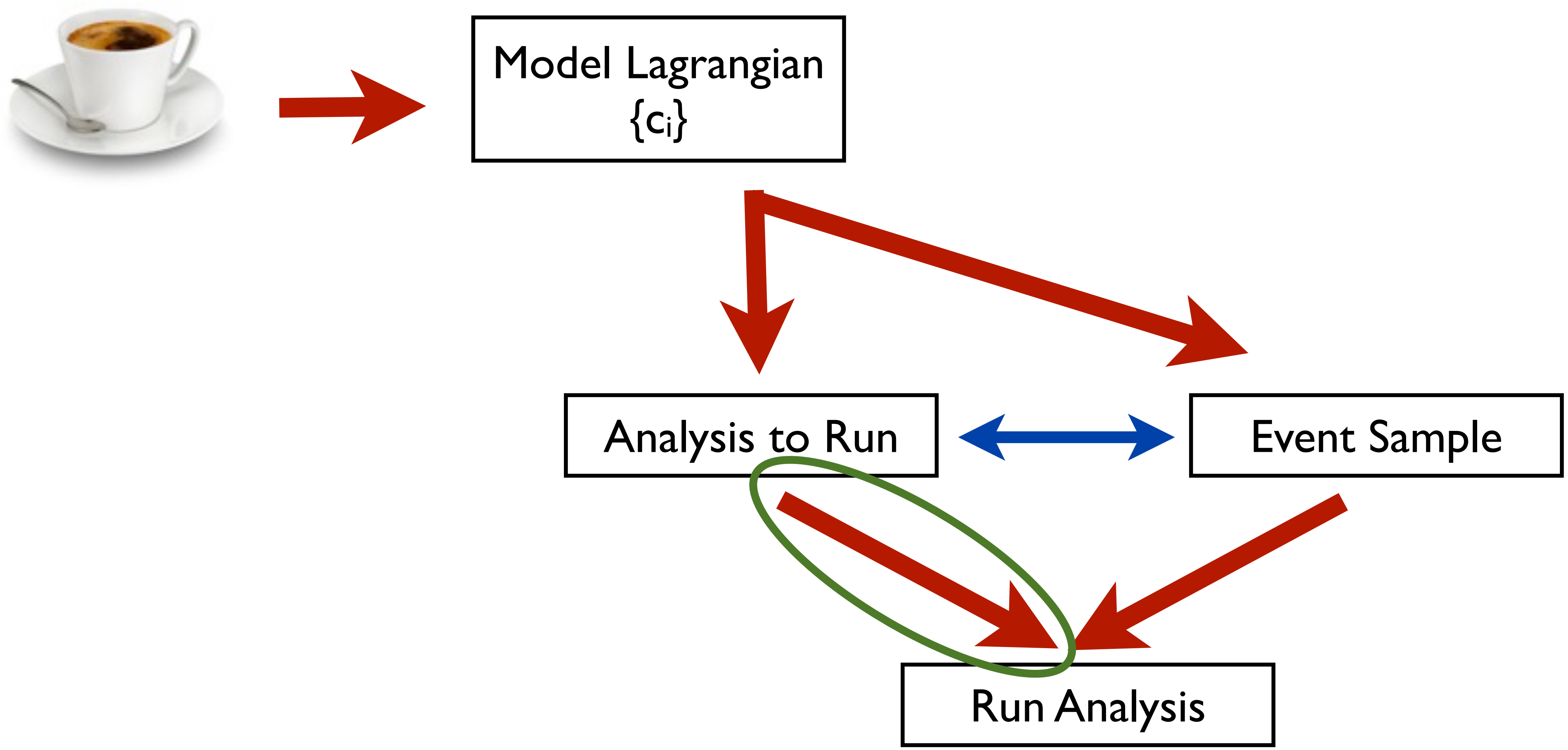
(Professor vs. Rick Field)

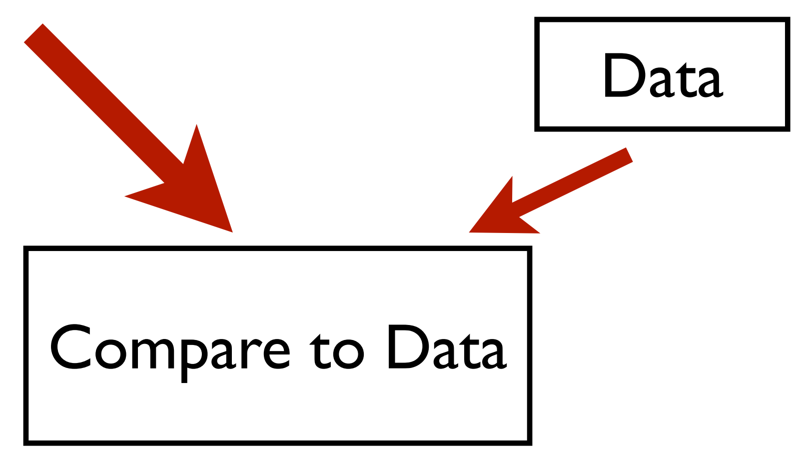



Haven't addressed yet *what kind of events.*

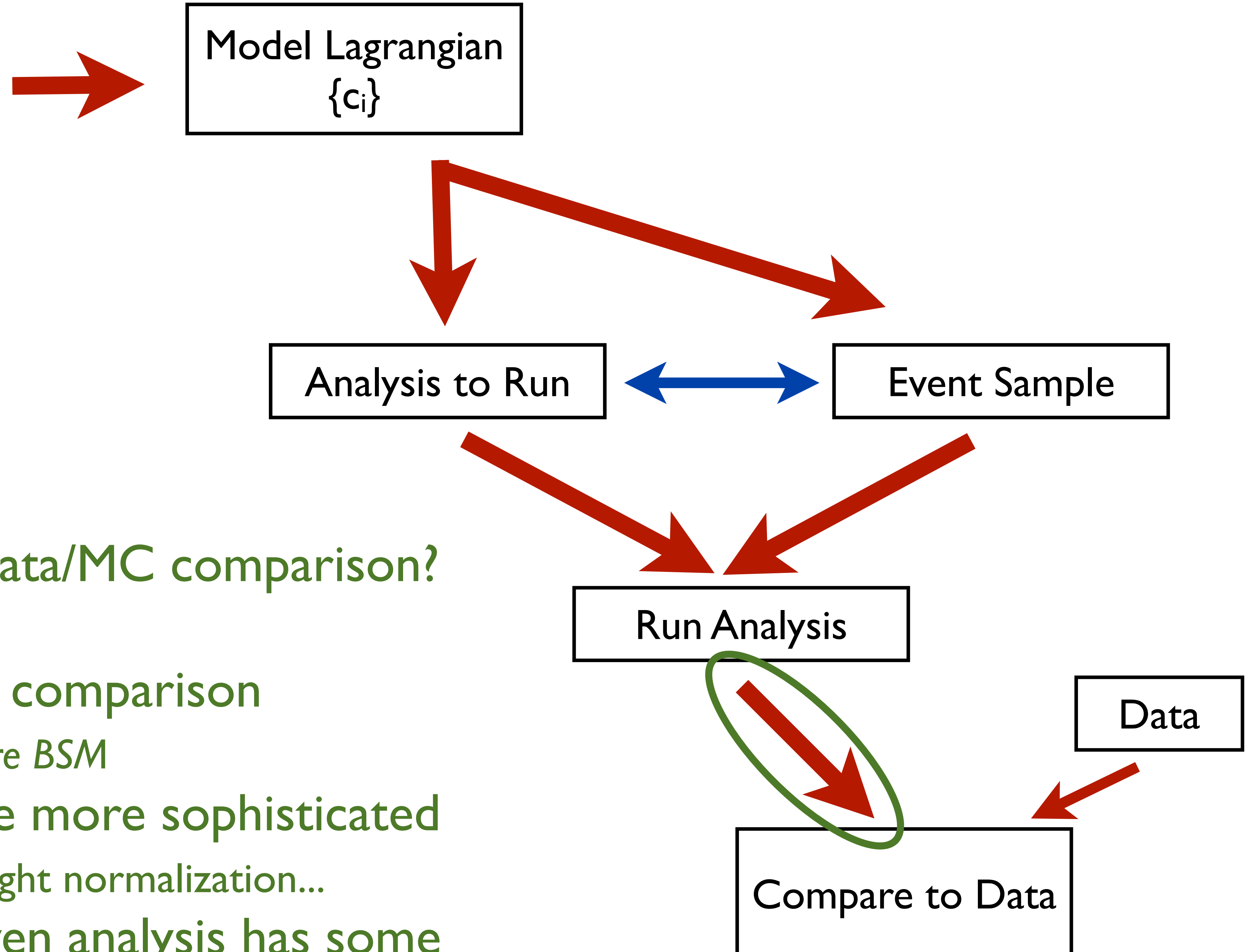
- Full detector (experimentalists' code)
  - compare to raw data
- Semi-realistic detector (PGS)
  - compare to raw data and hope you're close?
- Particle-level
  - compare to unfolded data OR parameterize efficiencies



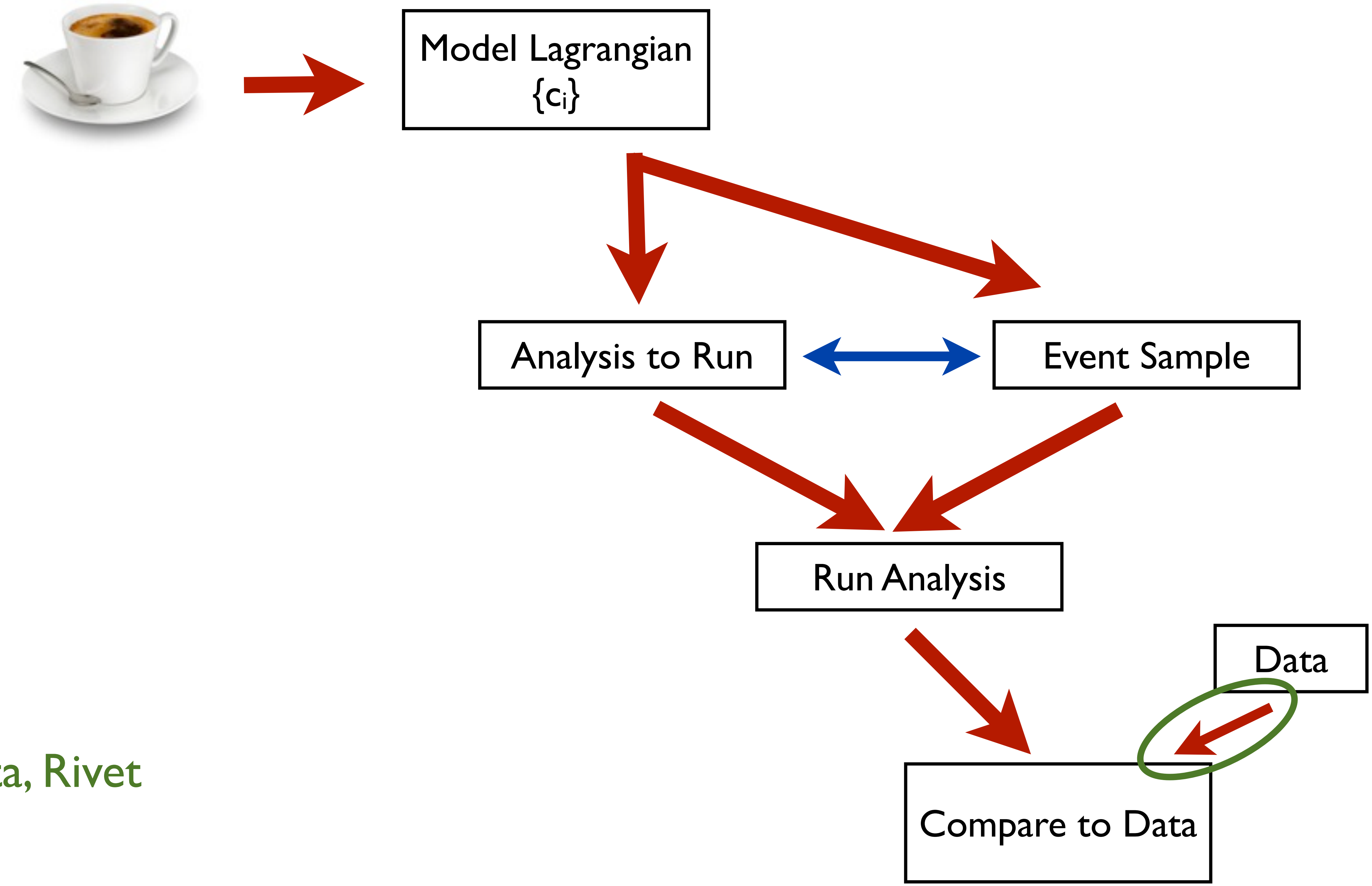

How is analysis implemented?

- Hand-code from paper
- Use experimentalists' implementation
- **Standardize: Rivet**




What is the right data/MC comparison?

- Simple, crude: $\chi^2$ comparison
  - Works if MC is *pure BSM*
- Can steadily make more sophisticated
  - shapes, etc. need right normalization...
- In general, any given analysis has some accompanying statistical analysis
  - **RooStats provides a framework here...**




Hepdata, Rivet

# The ATOM Model

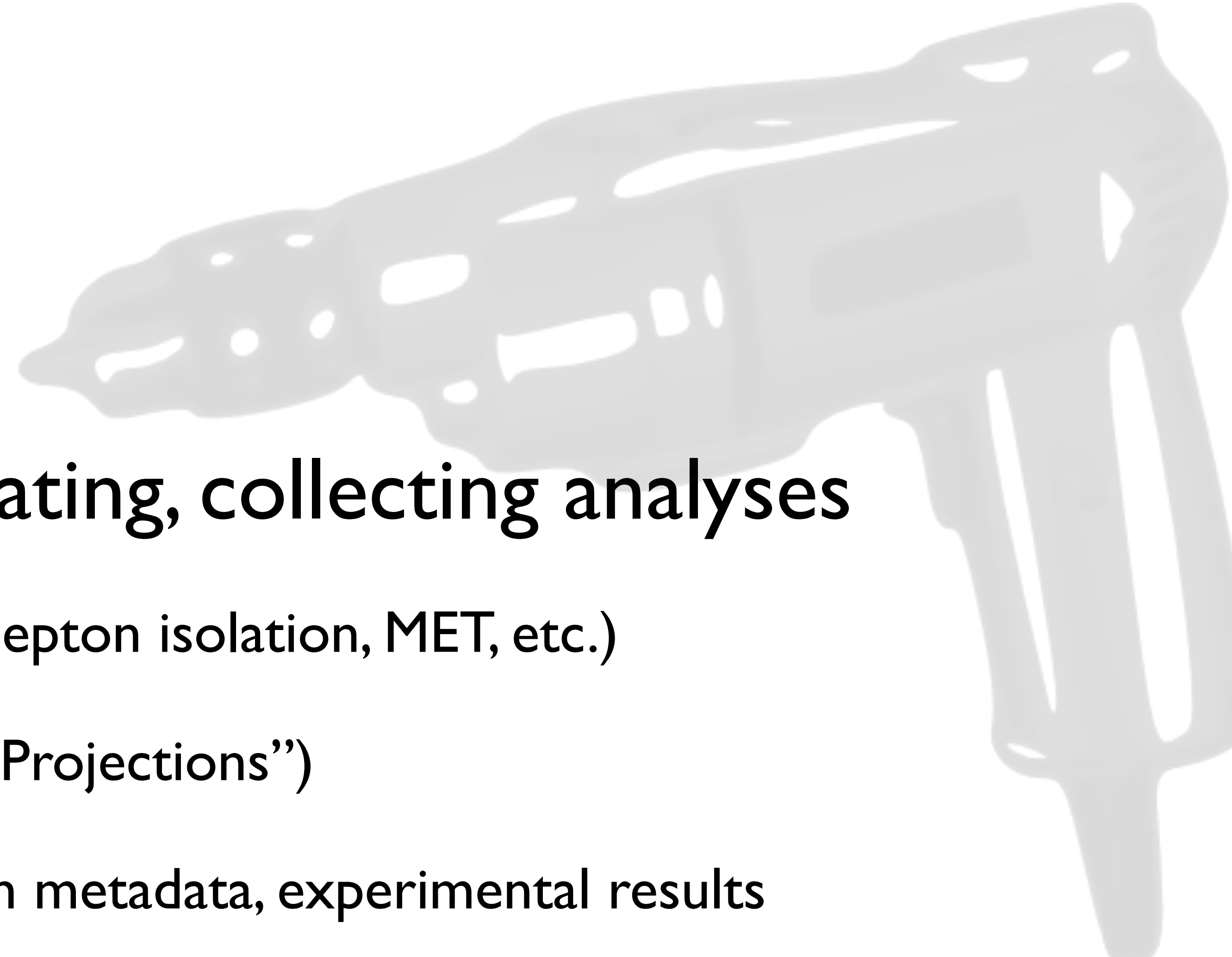
Basic idea: use existing (and growing Rivet library) to automatically run all available analyses.

Throw everything at the wall, see what sticks.

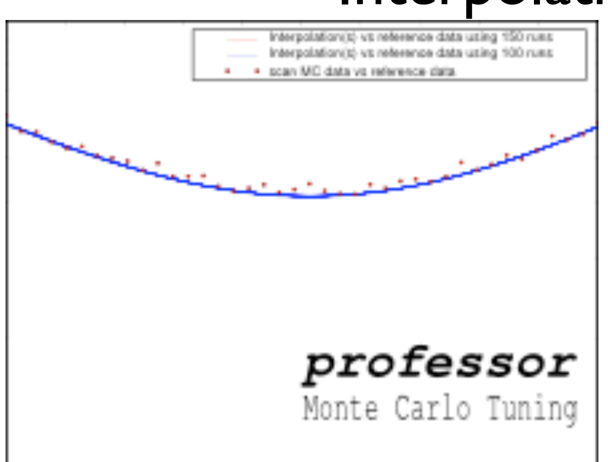
Other than publishing data and writing or validating Rivet analysis, no experimentalist input.

**Goal is not to be 100% correct, but to start with a black-box, automated approach, and see how well you can do.**

# Rivet/Professor



- Rivet:  Framework for creating, collecting analyses
    - Common set of tools (FastJet jets, lepton isolation, MET, etc.)
    - Efficiently re-uses measurements ("Projections")
    - Simple way to store an analysis with metadata, experimental results
    - **Designed to run at particle level:  comparison needs unfolding!**
- Professor:  Framework for MC tuning, using Rivet
    - "Interpolating functions" describe MC observables as f(tune)




Built for MC tuning.  Do we get analysis reuse for free?

# Current Rivet analyses

- ALEPH_1991_S2435284
- ALEPH_1996_S3196992
- ALEPH_1996_S3486095
- ALEPH_2004_S5765862
- ALICE_2010_S8624100
- ALICE_2010_S8625980
- ALICE_2010_S8706239
- ATLAS_2010_CONF_2010_031
- ATLAS_2010_CONF_2010_049
- ATLAS_2010_CONF_2010_081
- ATLAS_2010_CONF_2010_083
- ATLAS_2010_S8591806
- ATLAS_2010_S8817804
- BELLE_2006_S6265367
- CDF_1988_S1865951
- CDF_1990_S2089246
- CDF_1991_S2313472
- CDF_1993_S2742446
- CDF_1994_S2952106
- CDF_1996_S3108457
- CDF_1996_S3349578
- CDF_1996_S3418421
- CDF_1997_S3541940
- CDF_1998_S3618439
- CDF_2000_S4155203
- CDF_2000_S4266730
- CDF_2001_S4517016
- CDF_2001_S4563131
- CDF_2001_S4751469
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- CDF_2004_S5839831
- CDF_2005_S6080774
- CDF_2005_S6217184
- CDF_2006_S6450792
- CDF_2006_S6653332
- CDF_2007_S7057202
- CDF_2008_LEADINGJETS
- CDF_2008_NOTE_9351
- CDF_2008_S7540469
- CDF_2008_S7541902
- CDF_2008_S7782535
- CDF_2008_S7828950
- CDF_2008_S8093652
- CDF_2008_S8095620
- CDF_2009_NOTE_9936
- CDF_2009_S8233977
- CDF_2009_S8383952
- CDF_2009_S8436959
- D0_1996_S3214044
- D0_1996_S3324664
- D0_1998_S3711838
- D0_2000_S4480767
- D0_2001_S4674421
- D0_2004_S5992206
- D0_2006_S6438750
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- D0_2008_S7719523
- D0_2008_S7837160
- D0_2008_S7863608
- D0_2009_S8202443
- D0_2009_S8320160
- D0_2009_S8349509
- D0_2010_S8566488
- D0_2010_S8570965
- D0_2010_S8671338
- DELPHI_1995_S3137023
- DELPHI_1996_S3430090
- DELPHI_2002_069_CONF_603
- DELPHI_2003_WUD_03_11
- E735_1998_S3905616
- EXAMPLE
- H1_1994_S2919893
- H1_1995_S3167097
- H1_2000_S4129130
- JADE_OPAL_2000_S4300807
- LHCB_2010_S8758301
- MC_DIJET
- MC_DIPHOTON
- MC_GENERIC
- MC_HJETS
- MC_JETS
- MC_LEADINGJETS
- MC_PHOTONJETS
- MC_PHOTONJETUE
- MC_SUSY
- MC_TTBAR
- MC_WJETS
- MC_WWJETS
- MC_ZJETS
- MC_ZZJETS
- OPAL_1993_S2692198
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... and growing!

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- H1_1995_S3167097
- H1_2000_S4129130
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- LHCB_2010_S8758301
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... and growing!

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- ALICE_2010_S8625980
- ALICE_2010_S8706239
- ALICE_2011_S8909580
- ALICE_2011_S8945144
- ATLAS_2010_CONF_2010_049
- ATLAS_2010_S8591806
- ATLAS_2010_S8817804
- ATLAS_2010_S8894728
- ATLAS_2010_S8914702
- ATLAS_2010_S8918562
- ATLAS_2010_S8919674
- ATLAS_2011_CONF_2011_090
- ATLAS_2011_CONF_2011_098
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- ATLAS_2011_I925932
- ATLAS_2011_I926145
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- ATLAS_2011_S9002537
- ATLAS_2011_S9019561
- ATLAS_2011_S9041966
- ATLAS_2011_S9108483
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- ATLAS_2011_S9128077
- ATLAS_2011_S9131140
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- ATLAS_2011_S9225137
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- D0_2010_S8566488
- D0_2010_S8570965
- D0_2010_S8671338
- D0_2010_S8821313
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- DELPHI_1996_S3430090
- DELPHI_2002_069_CONF_6[illegible]
- DELPHI_2003_WUD_03_11
- E735_1998_S3905616
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- H1_1994_S2919893
- H1_1995_S3167097
- H1_2000_S4129130
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- JADE_OPAL_2000_S4300807
- LHCB_2010_S8758301
- LHCB_2011_I917009
- LHCB_2011_I919315
- MC_DIJET
- MC_DIPHOTON
- MC_GENERIC
- MC_HJETS
- MC_IDENTIFIED
- MC_JETS
- MC_LEADJETUE
- MC_PDFS
- MC_PHOTONJETS
- MC_PHOTONJETUE
- MC_SUSY
- MC_TTBAR
- MC_VH2BB
- MC_WJETS
- MC_WPOL
- MC_WWJETS
- MC_XS
- MC_ZJETS
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- OPAL_1998_S3780481
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- STAR_2008_S7869363
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# Current Rivet analyses (4/2011)

## 6 ATLAS, 0 CMS

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- ALEPH_1996_S3196992
- ALEPH_1996_S3486095
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- CDF_1994_S2952106
- CDF_1996_S3108457
- CDF_1996_S3349578
- CDF_1996_S3418421
- CDF_1997_S3541940
- CDF_1998_S3618439
- CDF_2000_S4155203
- CDF_2000_S4266730
- CDF_2001_S4517016
- CDF_2001_S4563131
- CDF_2001_S4751469
- CDF_2002_S4796047
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- CDF_2005_S6080774
- CDF_2005_S6217184
- CDF_2006_S6450792
- CDF_2006_S6653332
- CDF_2007_S7057202
- CDF_2008_LEADINGJETS
- CDF_2008_NOTE_9351
- CDF_2008_S7540469
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- CDF_2008_S7782535
- CDF_2008_S7828950
- CDF_2008_S8093652
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- CDF_2009_NOTE_9936
- CDF_2009_S8233977
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- CDF_2009_S8436959
- D0_1996_S3214044
- D0_1996_S3324664
- D0_1998_S3711838
- D0_2000_S4480767
- D0_2001_S4674421
- D0_2004_S5992206
- D0_2006_S6438750
- D0_2007_S7075677
- D0_2008_S6879055
- D0_2008_S7554427
- D0_2008_S7662670
- D0_2008_S7719523
- D0_2008_S7837160
- D0_2008_S7863608
- D0_2009_S8202443
- D0_2009_S8320160
- D0_2009_S8349509
- D0_2010_S8566488
- D0_2010_S8570965
- D0_2010_S8671338
- DELPHI_1995_S3137023
- DELPHI_1996_S3430090
- DELPHI_2002_069_CONF_603
- DELPHI_2003_WUD_03_11
- E735_1998_S3905616
- EXAMPLE
- H1_1994_S2919893
- H1_1995_S3167097
- H1_2000_S4129130
- JADE_OPAL_2000_S4300807
- LHCB_2010_S8758301
- MC_DIJET
- MC_DIPHOTON
- MC_GENERIC
- MC_HJETS
- MC_JETS
- MC_LEADINGJETS
- MC_PHOTONJETS
- MC_PHOTONJETUE
- MC_SUSY
- MC_TTBAR
- MC_WJETS
- MC_WWJETS
- MC_ZJETS
- MC_ZZJETS
- OPAL_1993_S2692198
- OPAL_1998_S3780481
- OPAL_2001_S4553896
- OPAL_2004_S6132243
- PDG_HADRON_MULTIPLICITIES
- PDG_HADRON_MULTIPLICITIES_RATIOS
- SFM_1984_S1178091
- STAR_2006_S6500200
- STAR_2006_S6860818
- STAR_2006_S6870392
- STAR_2008_S7869363
- STAR_2008_S7993412
- STAR_2009_UE_HELEN
- UA1_1990_S2044935
- UA5_1982_S875503
- UA5_1986_S1583476
- UA5_1987_S1640666
- UA5_1988_S1867512
- UA5_1989_S1926373
- ZEUS_2001_S4815815

... and growing!

# Current Rivet analyses (3/2012)

29 ATLAS, 14 CMS

- ALEPH_1991_S2435284
- ALEPH_1996_S3196992
- ALEPH_1996_S3486095
- ALEPH_1999_S4193598
- ALEPH_2004_S5765862
- ALICE_2010_S8624100
- ALICE_2010_S8625980
- ALICE_2010_S8706239
- ALICE_2011_S8909580
- ALICE_2011_S8945144
- ATLAS_2010_CONF_2010_049
- ATLAS_2010_S8591806
- ATLAS_2010_S8817804
- ATLAS_2010_S8894728
- ATLAS_2010_S8914702
- ATLAS_2010_S8918562
- ATLAS_2010_S8919674
- ATLAS_2011_CONF_2011_090
- ATLAS_2011_CONF_2011_098
- ATLAS_2011_I919017
- ATLAS_2011_I925932
- ATLAS_2011_I926145
- ATLAS_2011_I944826
- ATLAS_2011_S8924791
- ATLAS_2011_S8971293
- ATLAS_2011_S8983313
- ATLAS_2011_S8994773
- ATLAS_2011_S9002537
- ATLAS_2011_S9019561
- ATLAS_2011_S9041966
- ATLAS_2011_S9108483
- ATLAS_2011_S9120807
- ATLAS_2011_S9126244
- ATLAS_2011_S9128077
- ATLAS_2011_S9131140
- ATLAS_2011_S9212183
- ATLAS_2011_S9225137
- ATLAS_2012_I1083318
- ATLAS_2012_I1084540
- BELLE_2006_S6265367

- CDF_1988_S1865951
- CDF_1990_S2089246
- CDF_1993_S2742446
- CDF_1994_S2952106
- CDF_1996_S3108457
- CDF_1996_S3349578
- CDF_1996_S3418421
- CDF_1997_S3541940
- CDF_1998_S3618439
- CDF_2000_S4155203
- CDF_2000_S4266730
- CDF_2001_S4517016
- CDF_2001_S4563131
- CDF_2001_S4751469
- CDF_2002_S4796047
- CDF_2004_S5839831
- CDF_2005_S6080774
- CDF_2005_S6217184
- CDF_2006_S6450792
- CDF_2006_S6653332
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- CDF_2008_S7540469
- CDF_2008_S7541902
- CDF_2008_S7782535
- CDF_2008_S7828950
- CDF_2008_S8093652
- CDF_2008_S8095620
- CDF_2009_NOTE_9936
- CDF_2009_S8233977
- CDF_2009_S8383952
- CDF_2009_S8436959
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- CDF_2010_S8591881_QCD
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- CMS_2010_S8656010
- CMS_2011_S8884919
- CMS_2011_S8941262
- CMS_2011_S8950903
- CMS_2011_S8957746
- CMS_2011_S8968497
- CMS_2011_S8973270
- CMS_2011_S8978280
- CMS_2011_S9086218
- CMS_2011_S9088458
- CMS_2011_S9120041
- CMS_2011_S9215166
- CMS_QCD_10_024

- D0_1996_S3214044
- D0_1996_S3324664
- D0_2000_S4480767
- D0_2001_S4674421
- D0_2004_S5992206
- D0_2006_S6438750
- D0_2007_S7075677
- D0_2008_S6879055
- D0_2008_S7554427
- D0_2008_S7662670
- D0_2008_S7719523
- D0_2008_S7837160
- D0_2008_S7863608
- D0_2009_S8202443
- D0_2009_S8320160
- D0_2009_S8349509
- D0_2010_S8566488
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- DELPHI_1996_S3430090
- DELPHI_2002_069_CONF_6(
- DELPHI_2003_WUD_03_11
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- EXAMPLE
- H1_1994_S2919893
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- JADE_1998_S3612880
- JADE_OPAL_2000_S4300807
- LHCB_2010_S8758301
- LHCB_2011_I917009
- LHCB_2011_I919315
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- MC_DIPHOTON
- MC_GENERIC
- MC_HJETS
- MC_IDENTIFIED
- MC_JETS
- MC_LEADJETUE
- MC_PDFS
- MC_PHOTONJETS
- MC_PHOTONJETUE
- MC_SUSY
- MC_TTBAR
- MC_VH2BB
- MC_WJETS
- MC_WPOL
- MC_WWJETS
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- STAR_2009_UE_HELEN
- TASSO_1990_S2148048
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- UA5_1982_S875503
- UA5_1986_S1583476
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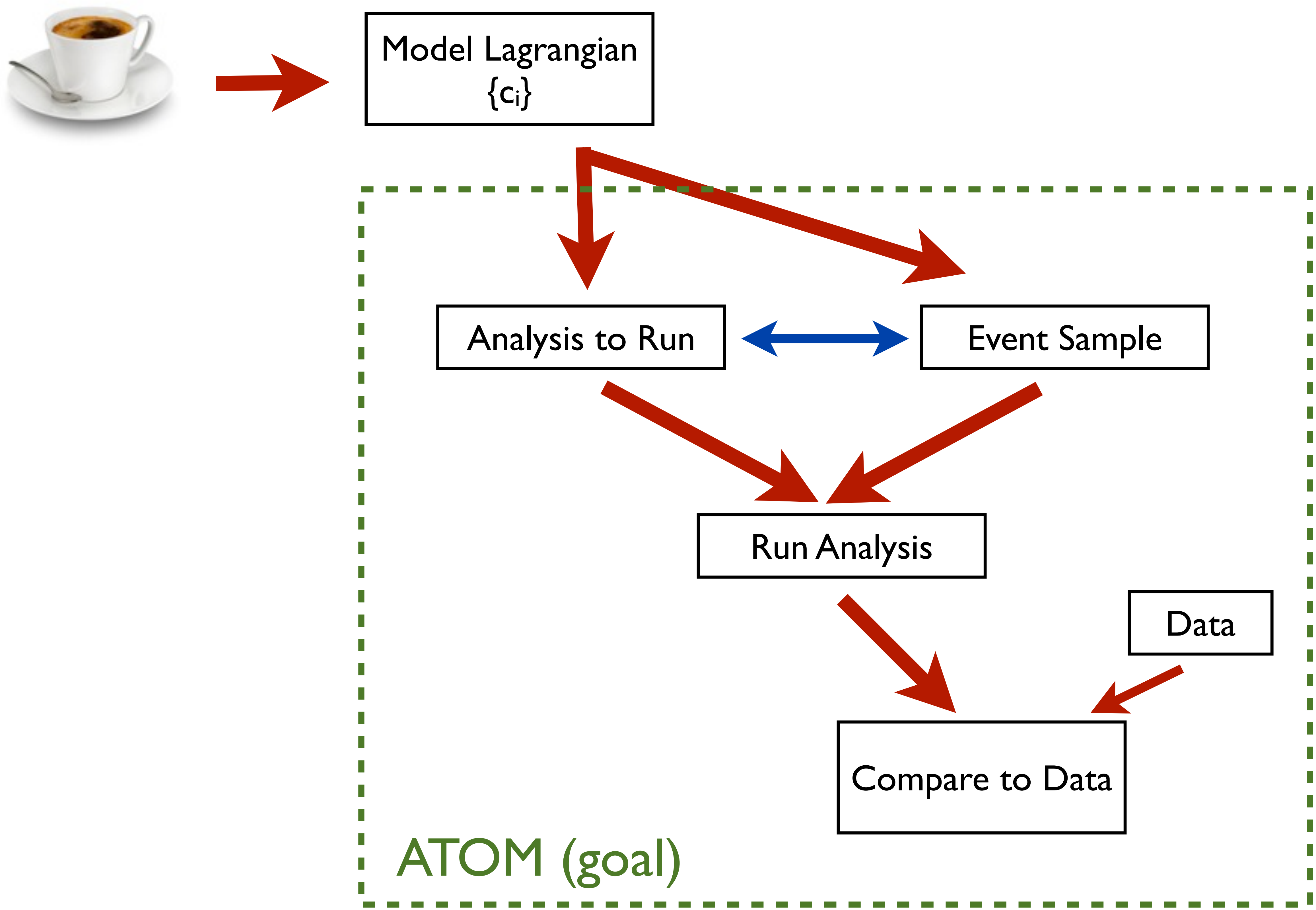
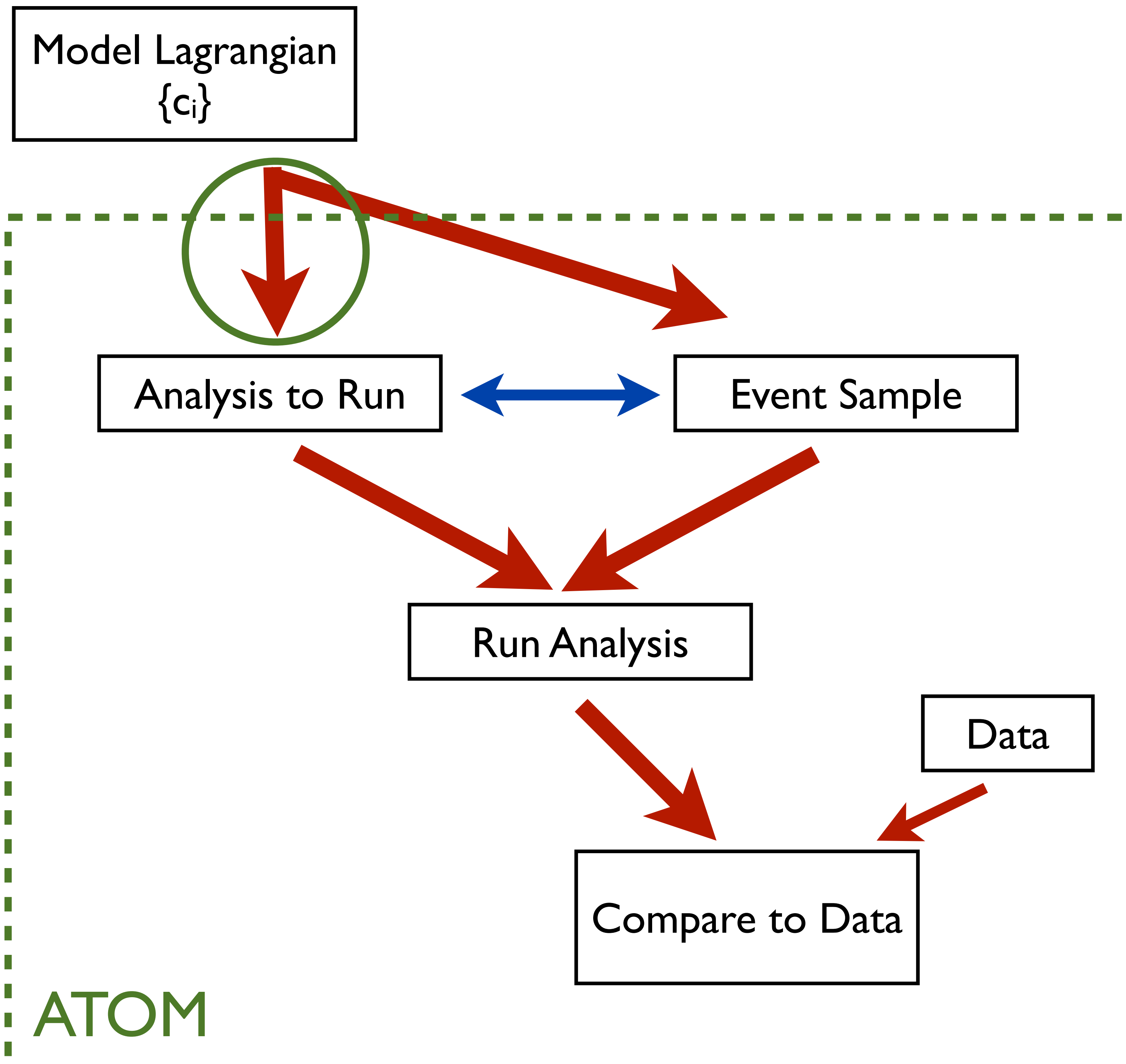
- UA5_1989_S1926373
- ZEUS_2001_S4815815

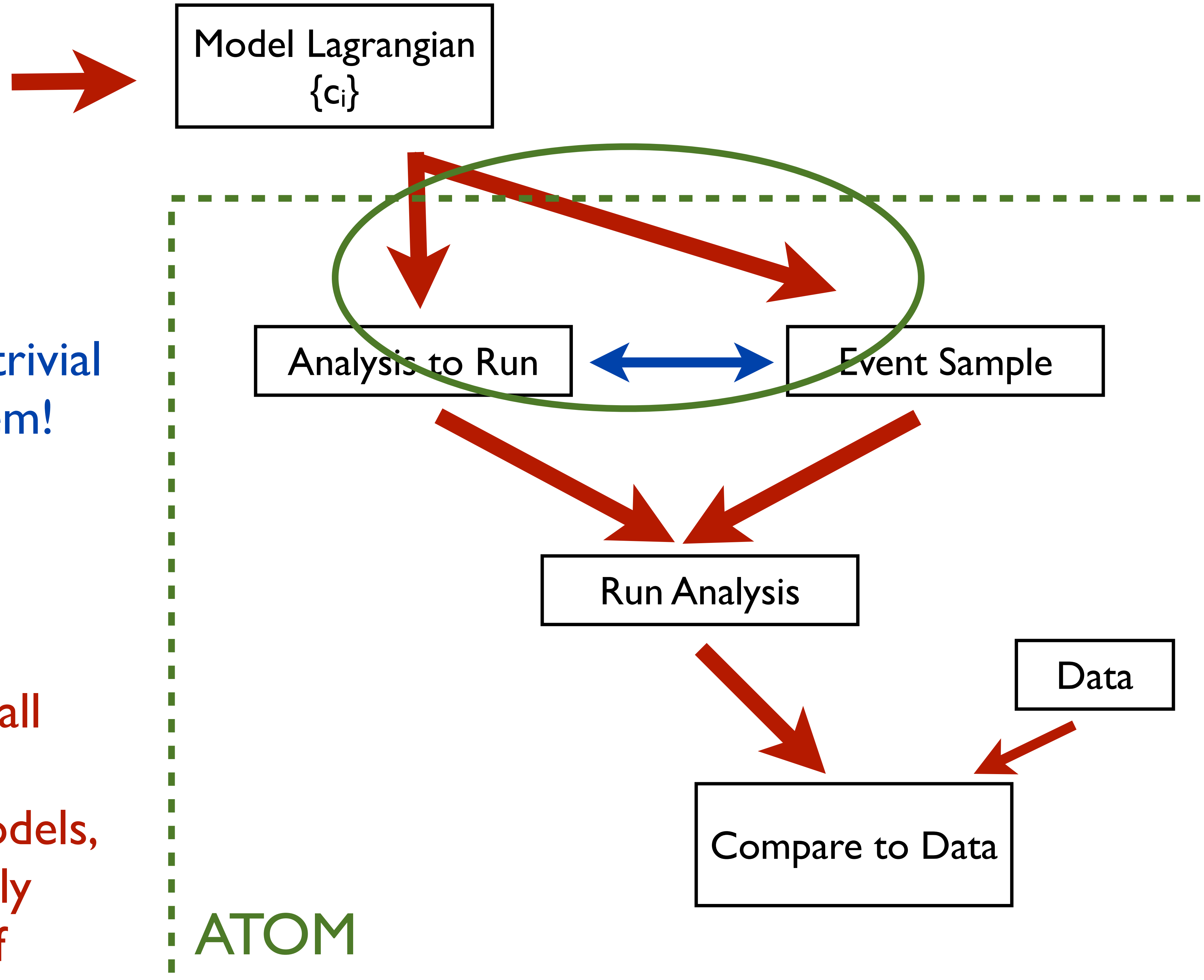


Model Lagrangian
{ci}
Analysis to Run
Event Sample
Run Analysis
Data
Compare to Data
ATOM (goal)




Analysis selection trivial -- just try all of them!

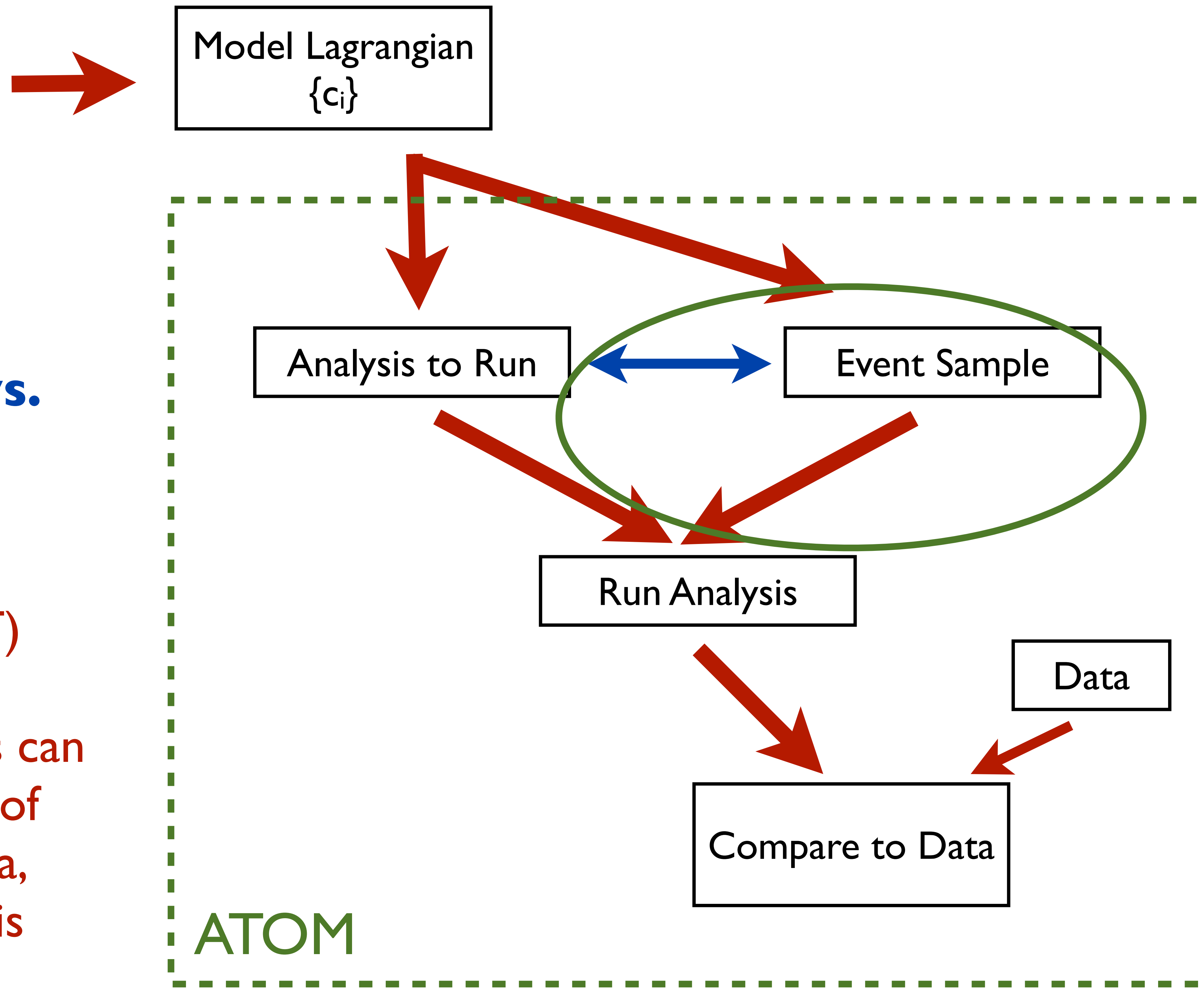
Rivet makes this *feasible* and *efficient*.




Analysis selection trivial -- just try all of them!

But...

- Same events for all analyses?
- OK for many models, but not all -- apply looser version of analysis at ME level? *




## Particle-level vs. detector-level

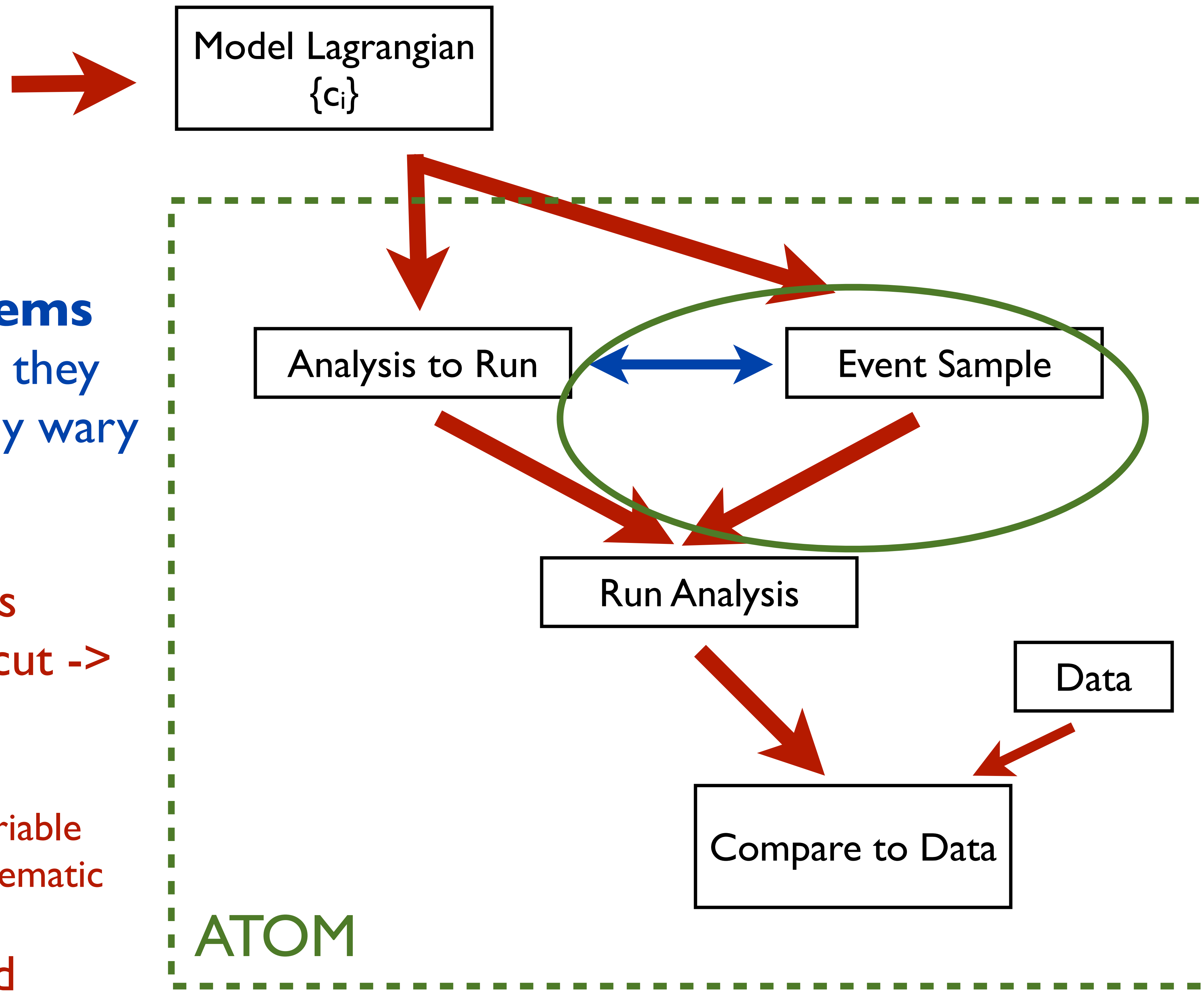
- Detector-level "ideal" (RECAST)
- ATOM: if analysis can be cast in terms of particle-level data, then maybe this is good enough

ATOM advantage: no detector sim is easier, doesn't require experimentalist intervention

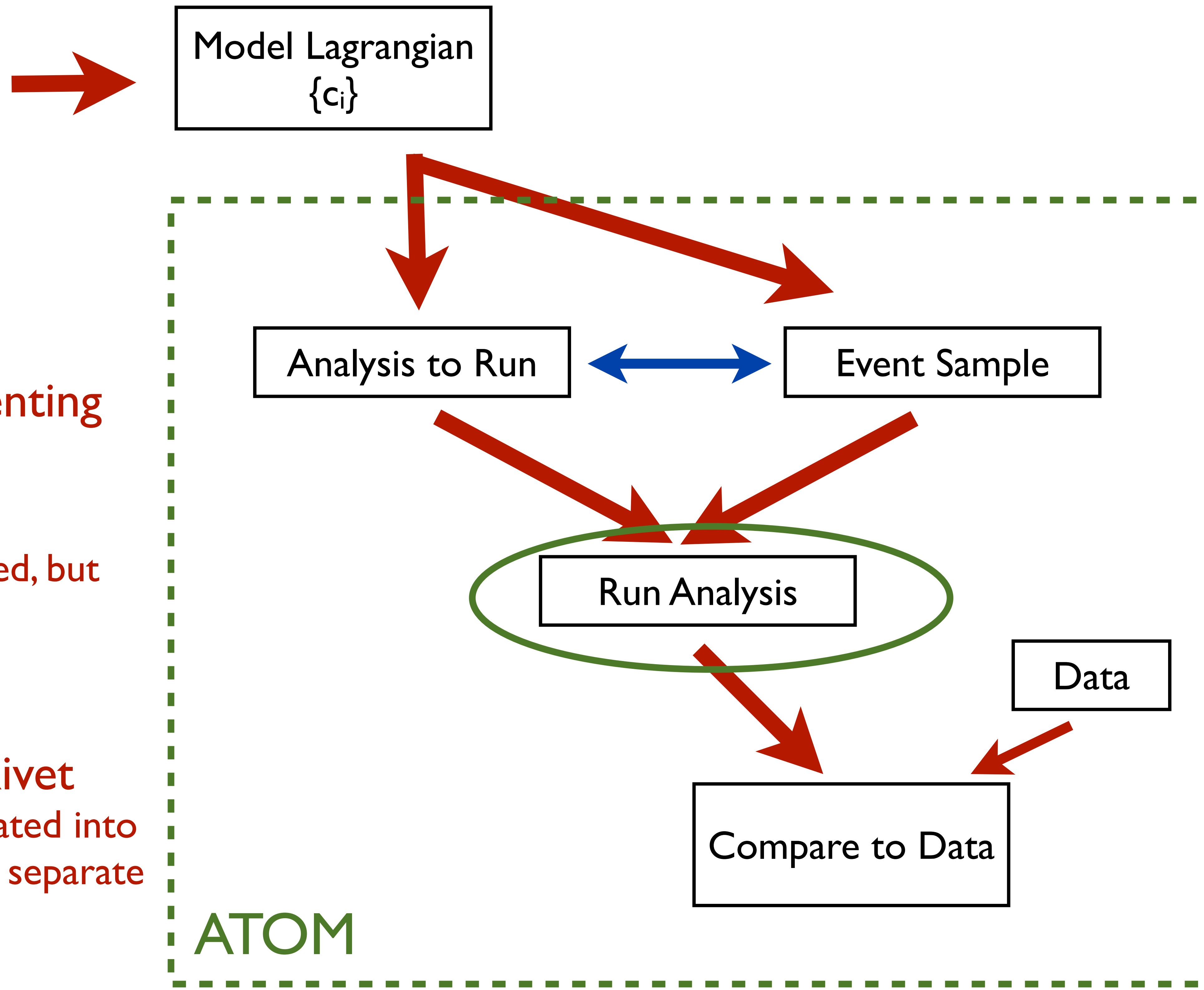
**“Flags”: try to anticipate problems**

Alert the user when they should be particularly wary of the results!

- Sensitivity to cuts (10% shift in m_cut -> 50% shift in acceptance, e.g.)
  - especially if cut variable has significant systematic uncertainty
- Particularly weird signatures (very large number of jets, isolated leptons, etc.)




Lots of scope for smart flagging, but there is tension between sophistication and generality...




- RECAST: implementing analyses up to experimentalists
  - could be standardized, but not necessary
- ATOM: code is standardized via Rivet
  - “flags” either integrated into analysis or added as separate analysis

Downside: limited to what is implemented in Rivet (but this is growing)

ATOM is one of several reasons to push for Rivet to be comprehensive!

# Outstanding problems

- Can we automate generating the right event sample for a given analysis?
- Can many/most/all analyses really be implemented in Rivet, acting on *particle-level* data?
- How sophisticated/useful can flags be? Can this compensate for not using detector sim., or is that hopeless?
  - To what extent does flagging require re-writing analyses?
- To what extent will collaborations support Rivet analyses and/or RECAST approach?
  - Is some sort of hybrid the right way?
- How to implement statistical comparisons? Can this be standardized?

# Les Houches recommendations

## Searches for New Physics: Les Houches Recommendations for the Presentation of LHC Results

*Coordinators: S. Kraml[1], S. Sekmen[2,3];*
*B.C. Allanach[4], P. Bechtle[5], G. Belanger[6], K. Benslama[7], C. Balazs[8], A. Belyaev[9,10], M. Dolan[11], B. Fuks[12], M. Campanelli[13], K. Cranmer[14], J. Ellis[3,15], M. Felcini[16], D. Guadagnoli[17], J.F. Gunion[18], S. Heinemeyer[16], M. Kadastik[19], M. Krämer[20], J. Lykken[21] F. Mahmoudi[3,22], M. Mangano[3], S.P. Martin[23,24,25], H. Prosper[2], T. Rizzo[26], T. Robens[27], M. Tytgat[28], A. Weiler[5]*
*underlined: editors*

**Abstract**
We present a draft set of recommendations for the presentation of LHC results on searches for new physics, which are aimed at providing a more efficient flow of scientific information between the experimental collaborations and the rest of the high energy physics community, and facilitating the interpretation of the results in a wide class of models. Implementing these recommendations would aid the full exploitation of the physics potential of the LHC.

https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=173341

1. (a) Provide a clear, explicit description of the analysis in publications. In particular, the most crucial information such as basic object definitions and event selection should be clearly displayed in the publications, preferably in tabular form, and kinematic variables utilised should be unambiguously defined. Further information necessary to reproduce the analysis should be provided on a suitable common platform.

   (b) Provide a common analysis database where all the experimental results are stored together with all necessary information about the analyses, including well-encapsulated functions, such as multivariate analysis (MVA) functions if they are needed.

2. (a) Provide histograms or functional forms of efficiency maps wherever possible in the auxiliary information, along with precise definitions of the efficiencies, and preferably provide them in standard electronic forms that can easily be interfaced with simulation or analysis software.

   (b) Provide and maintain a public simulator developed by the collaboration, or provide official support of an existing one. The public simulator would provide the mapping from the pre-detector data to the post-reconstruction data.

3. (a) Provide all crucial numbers regarding the results of the analysis, preferably in tabulated form in the publication itself. Further relevant information, like fit functions or distributions, should be provided as auxiliary material.

# Some results (slides from Andreas Weiler)

arXiv:1110.6926

DESY 11-193
CERN-PH-TH/265

## Natural SUSY Endures

Michele Papucci,[1,2] Joshua T. Ruderman,[1,2] and Andreas Weiler[3,4]

[1] *Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720*

[2] *Department of Physics, University of California, Berkeley, CA 94720*

[3] *DESY, Notkestrasse 85, D-22607 Hamburg, Germany*

[4] *CERN TH-PH Division, Meyrin, Switzerland*

### Abstract

The first 1 $\text{fb}^{-1}$ of LHC searches have set impressive limits on new colored particles decaying to missing energy. We address the implication of these searches for naturalness in supersymmetry (SUSY). General bottom-up considerations of natural electroweak symmetry breaking show that higgsinos, stops, and the gluino should not be too far above the weak scale. The rest of the spectrum,

# Large signature space

arXiv:1110.6926

| | ATLAS | | | CMS | | |
|---|---|---|---|---|---|---|
| | channel | $\mathcal{L}$ [fb$^{-1}$] | ref. | channel | $\mathcal{L}$ [fb$^{-1}$] | ref. |
| jets + $\not\!\!E_T$ | 2-4 jets | 1.04 | [1] | $\alpha_T$ | 1.14 | [11] |
| | 6-8 jets | 1.34 | [2] | $H_T$, $\not\!\!H_T$ | 1.1 | [12] |
| $b$-jets (+ l's + $\not\!\!E_T$) | $1b, 2b$ | 0.83 | [3] | $m_{T2}$ $(+b)$ | 1.1 | [13] |
| | $b + 1l$ | 1.03 | [4] | $1b, 2b$ | 1.1 | [14] |
| | | | | $b'b' \to b + l^\pm l^\pm, 3l$ | 1.14 | [15] |
| | | | | $t't' \to 2b + l^+l^-$ | 1.14 | [16] |
| multilepton (+ $\not\!\!E_T$) | $1l$ | 1.04 | [5] | $1l$ | 1.1 | [17] |
| | $\mu^\pm\mu^\pm$ | 1.6 | [6] | SS dilepton | 0.98 | [18] |
| | $t\bar{t} \to 2l$ | 1.04 | [7] | OS dilepton | 0.98 | [19] |
| | $t\bar{t} \to 1l$ | 1.04 | [8] | $Z \to l^+l^-$ | 0.98 | [20] |
| | $4l$ | 1.02 | [9] | $3l, 4l + \not\!\!E_T$ | 2.1 | [21] |
| | $2l$ | 1.04 | [10] | $3l, 4l$ | 2.1 | [22] |

non susy analyses

# Large signature space

arXiv:1110.6926

| | ATLAS | | | CMS | | |
|---|---|---|---|---|---|---|
| | channel | $\mathcal{L}$ [fb$^{-1}$] | ref. | channel | $\mathcal{L}$ [fb$^{-1}$] | ref. |
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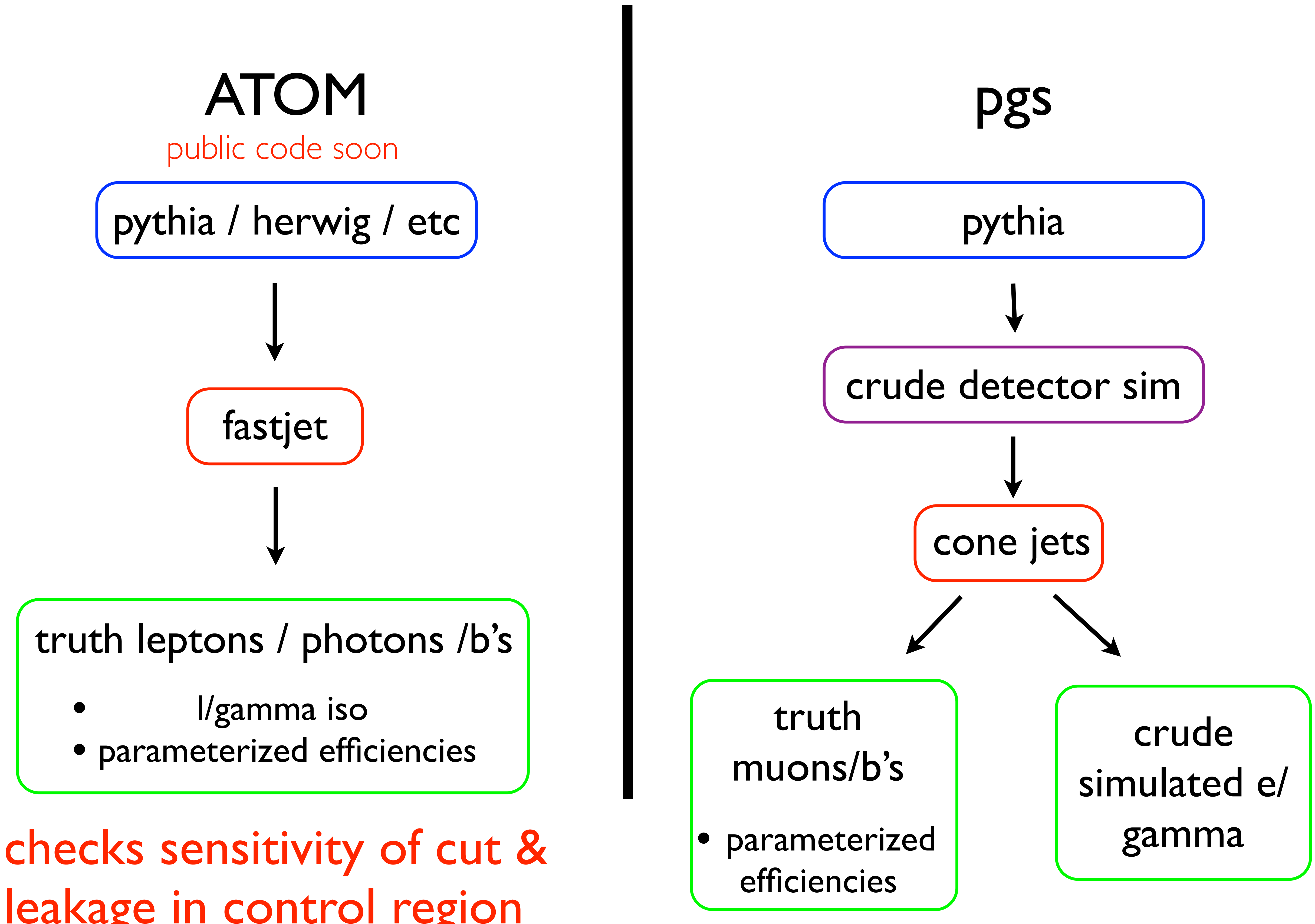
| | ~~$2l$~~ | 1.04 | [10] | ~~$3l, 4l$~~ | 2.1 | [22] |

non susy analyses

too recent

# our pipelines

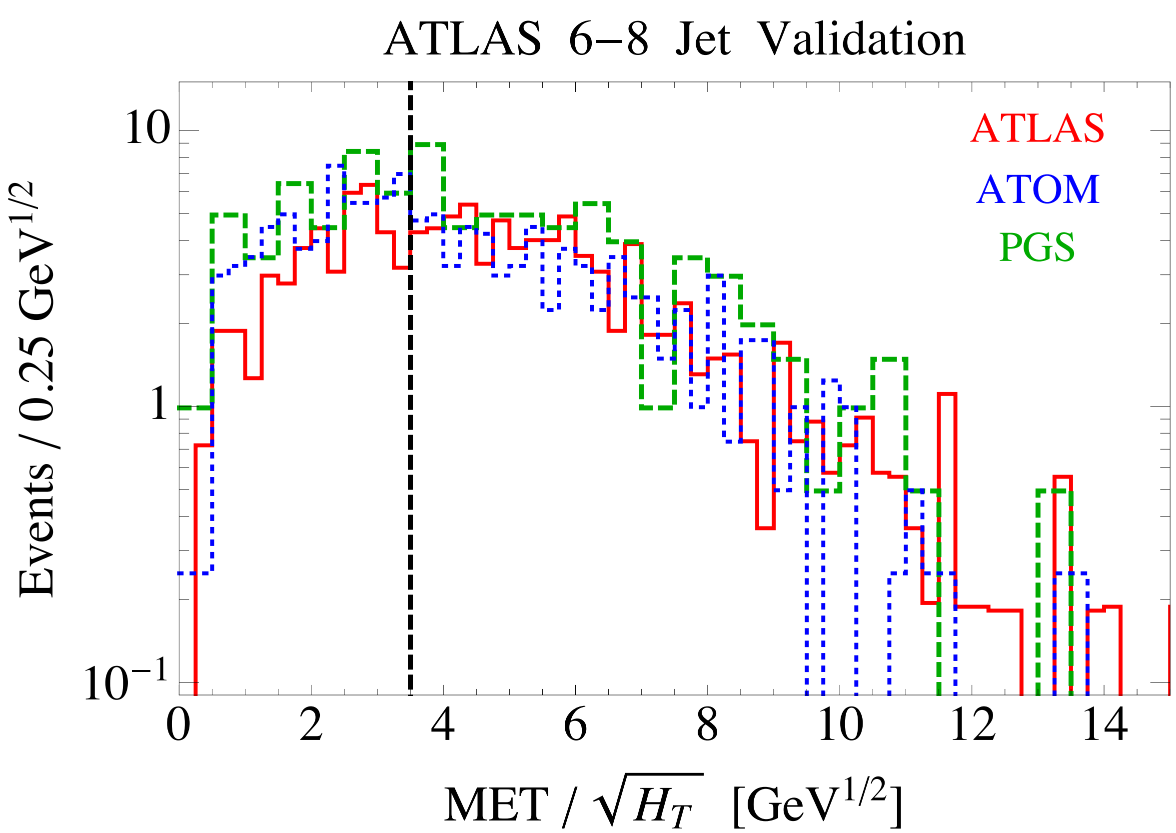


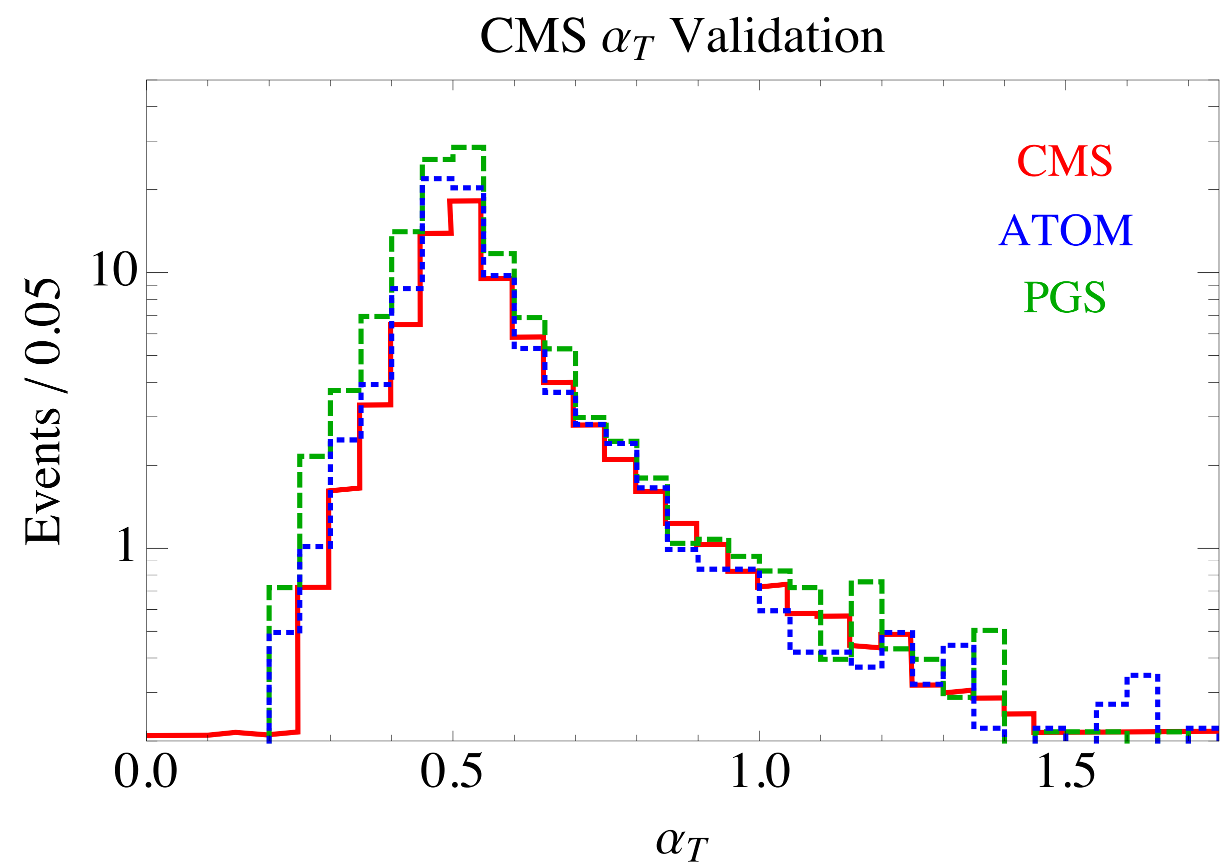
# Calibration

"theorist limits"

To calibrate compare:

1) key kinematical distributions
2) limits




Check:

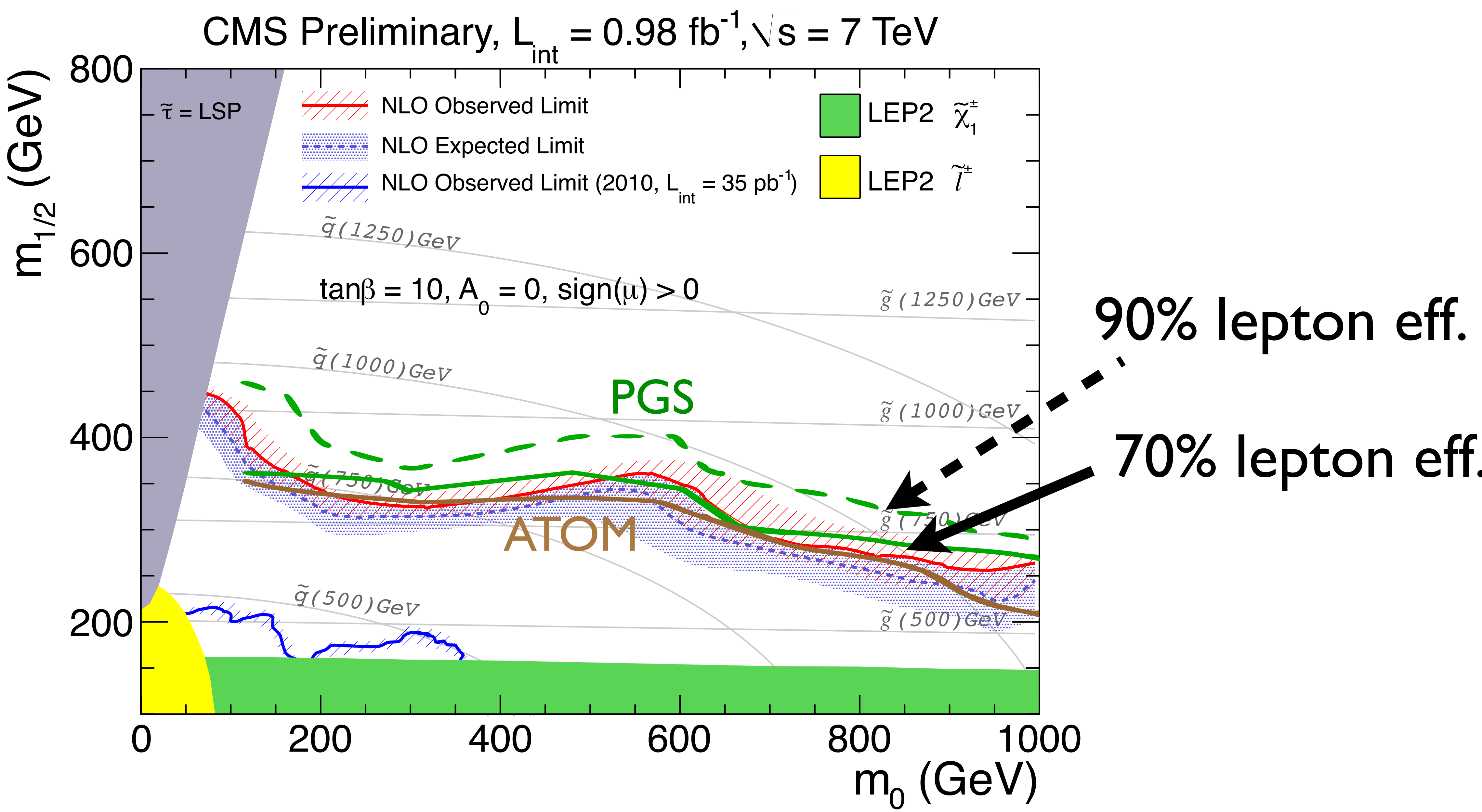
- kinematic distortions (shape)
- signal $\epsilon \times \mathcal{A}$ (normalization)

+ compare to all available limit plots…

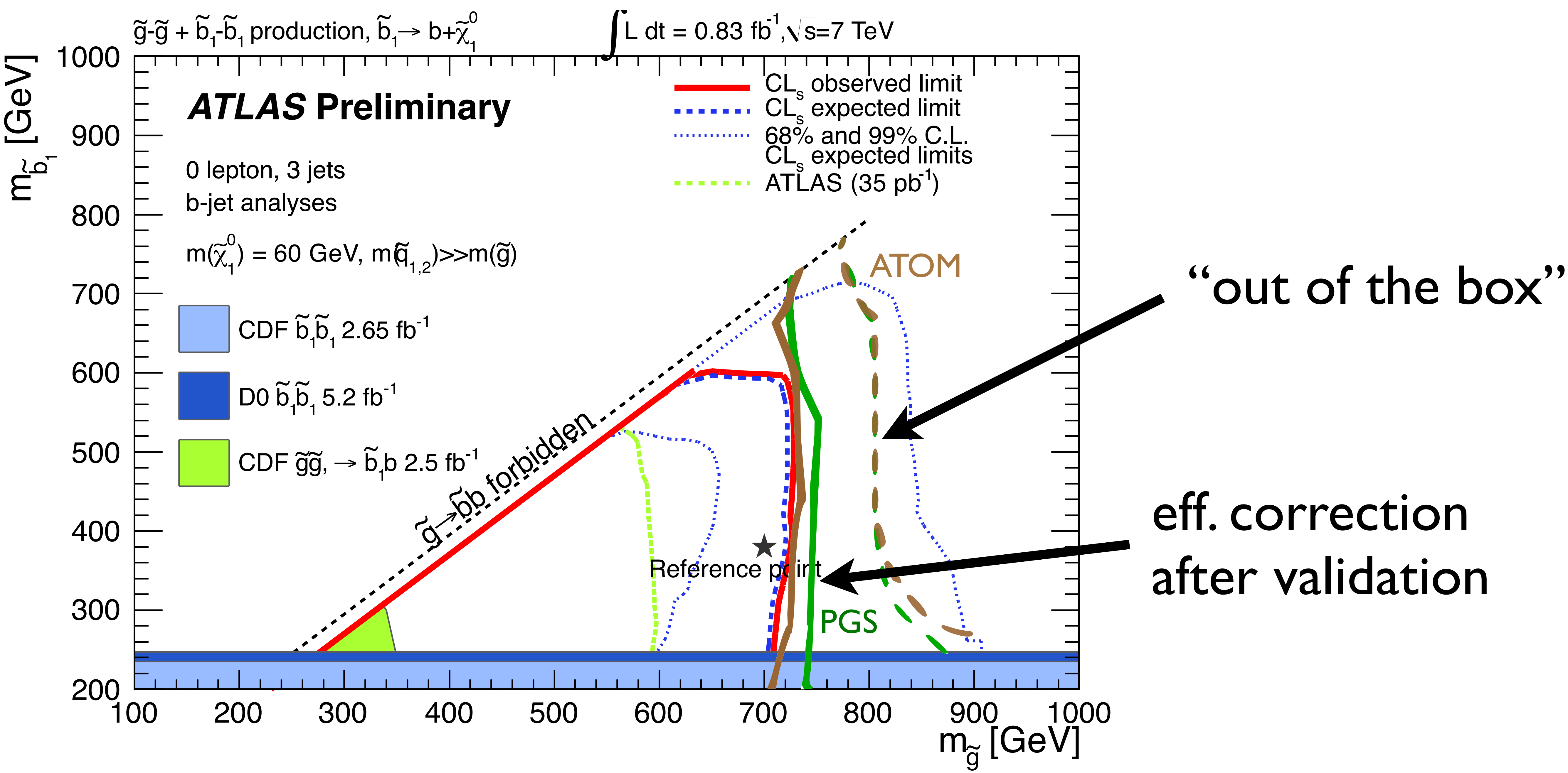
~ 50 GeV accuracy (usually better)

# Compare limits

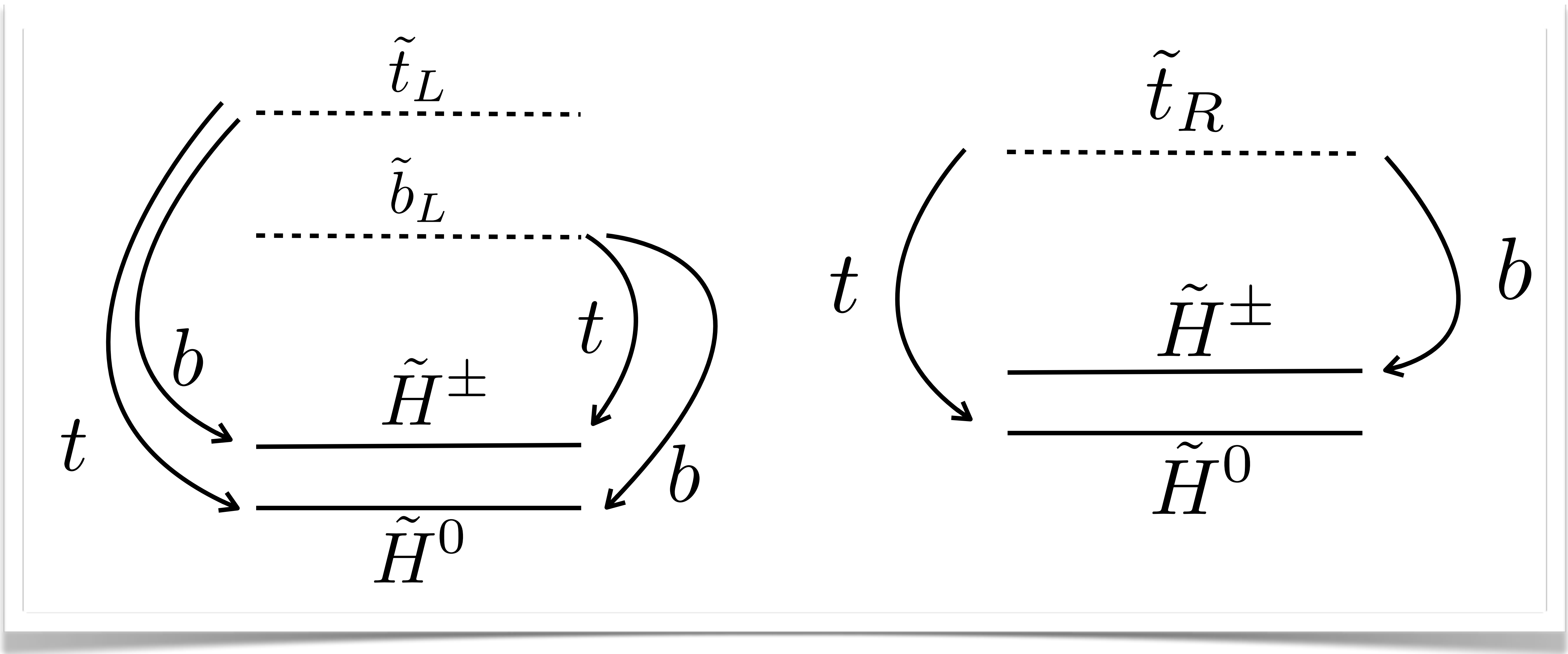
## Example: Same-Sign dilepton by CMS



# Validation using Limits



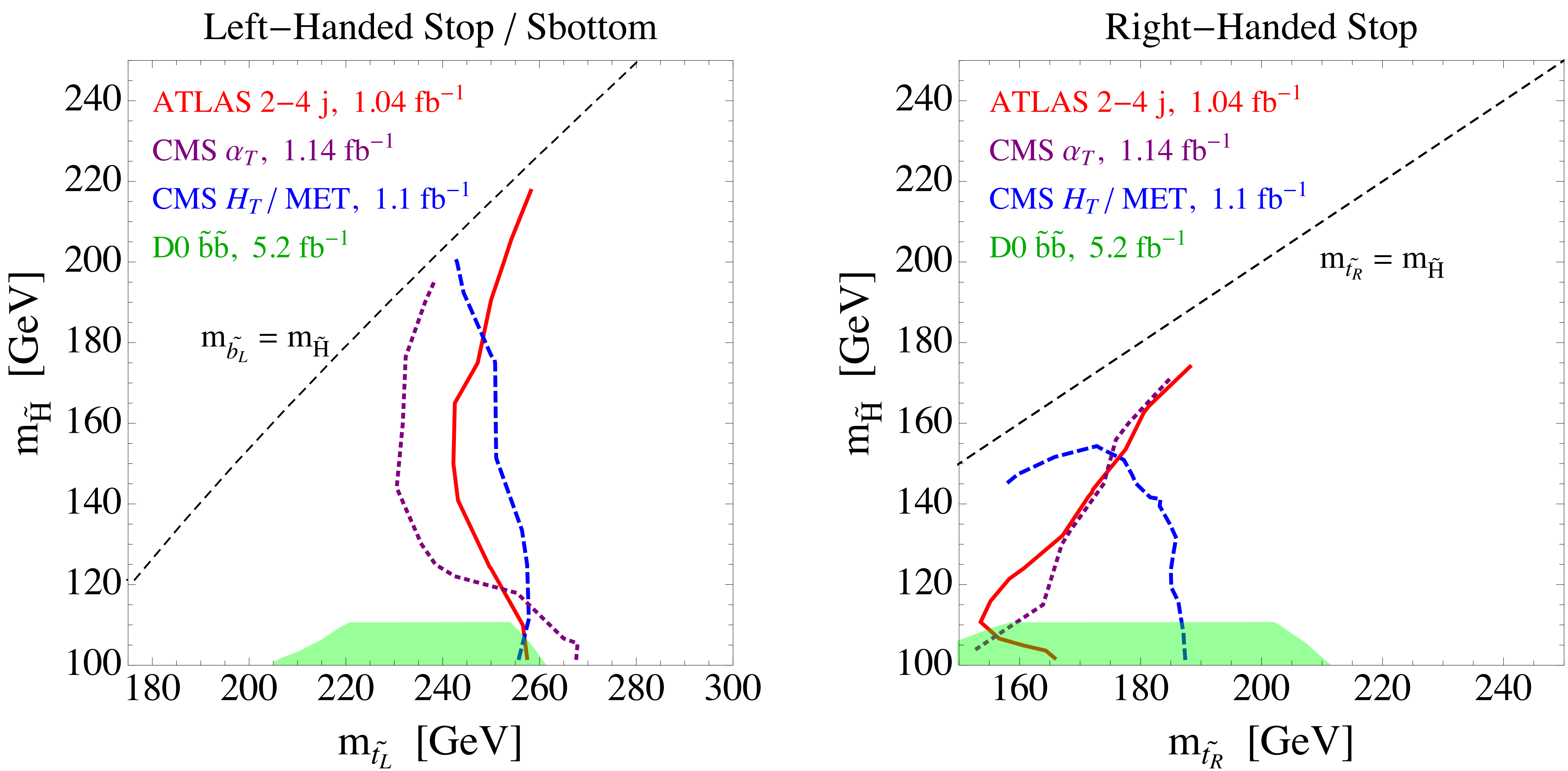
# Stops (sbottom) + Higgsinos




Stops can act as "sbottom" (bjet+χ) !

Chargino-neutralino splitting irrelevant for present searches

# Stops (sbottom) + Higgsinos




LHC surpasses Tevatron:

Strongest bounds from jets + MET

# Big picture

- ATOM's goal is to give the most reliable test of BSM versus existing data *while remaining self-contained and automatic*.
- This makes ATOM inherently less powerful and precise than, eg, the RECAST approach. But there is a big payoff in ease of use and applicability.
  - ATOM and RECAST are complementary strategies!
- Flags attempt to signal when ATOM results are likely unreliable. (It is not clear how powerful these will be!)
- Rivet is the simplest way I see to make analyses re-usable.

Goal: functional (but limited-scope) beta version to release ~~in the next month or two!~~ **soon!**

Thank you!