Status of Fast Simulations

A group of us on CMS were asked by the physics coordinator to make a case for a Fast Simulation

This is a repeat, meant to spark discussion

This is NOT a CMS talk

These are OUR thoughts and do not reflect on CMS in any way

No promises, implicit or explicit

SuperFastSim

(or SUSY FastSim)

J. Lykken, K. Matchev, S. Mrenna, M. Pierini, M. Spiropulu

October 31, 2011

Background

- Computer simulations are an integral part of what we do
  - physics simulations: provided by theorists
  - detector simulations: provided by the experiments
- The detector is an extremely complex instrument: need to balance speed versus realism
  - fullsim: realistic, but slow; internal to the collaboration
  - fastsim (CMS): faster, approximate, internal to CMS
    - can we make it even faster? can we make it public?
  - generic public toy detector simulations (PGS, Delphes, cmsjet)
- Theorists (and funding agencies?) have always appealed for
  - open access to the data
  - open access to a reliable detector simulation
- CMS week in Brussels (Sept 2011); following KM's talk, a charge from G. Rolandi:
  - to "formulate a concrete proposal"
  - the proposal was written and circulated ~2 weeks ago

1 4 5 2 3

Proposal for a CMS-specific, public, super-fast simulation tool

Outline of this talk

timeline

1. What are the issues we are trying to address?
2. What is a Super-fast Simulation?
3. How can we implement it?
4. The value to CMS as an internal tool
5. The possibility of a publicly available tool

Physics Issues

- The proposal is driven by physics considerations
  - arise in the context of new physics searches
- Very many theory models
  - lots of effort behind searches; signature-based approaches
  - low pay-off if considering only 1 or 2 theory models per analysis
- Very many parameters in each model
  - models like MSUGRA are not generic enough
- Some layer of detector simulation is needed for quantitative results
- Currently, it takes a long time to simulate a dense grid in the parameter space of a specific model with sufficient statistics.
  - simulating a coarse grid and interpolating may miss features
  - Monte Carlo statistics may be insufficient for rare signatures and problematic for limit setting

More, better, faster, cheaper?

- How can we make our new physics searches more comprehensive?
  - by analyzing more models (and more general models)
  - on better (finer) parameter scan grids
  - faster than before
  - at a lower FTE cost
- Two options: DIY or recruit someone else (e.g. theorists)
- DIY option - will necessarily involve a combination of both
  - employing "simplified models" characterization of the new physics
    - keeps only the relevant (mass) parameters
    - sufficiently general and model-independent
  - employing new, super-fast detector simulation (this proposal)
    - what if there is a discovery tomorrow?
- What is the role of the theorists?

Sociology issue

- The interactions between theorists and experimentalists benefit both sides
  - theorists write papers offering ideas and models
    - this motivates experimental searches
  - experimentalists write papers on the results from those searches
    - this stimulates new ideas and models
    - theorists collect citations
  - theorists write new papers offering new ideas and models
    - experimentalists collect citations
    - this motivates new experimental searches
  - etc.
- Theorists do a valuable service to the community by
  - creating and maintaining theory Monte Carlos
    - theory Monte Carlos are open source
    - theorists do not charge experiments a user fee

Sociology issue

- Traditionally, detector simulation is done by experimentalists
- Times are changing: theorists are now becoming more and more knowledgeable about detector simulation
  - a series of workshops and schools: “SUSY Recast”, UC Davis 2011; TASI-2011, UC Boulder; MC Tools for LHC, 2007-2012; MC4BSM workshops, 2006-2012; TOOLS workshops, 2006-2010; LHC Olympics, 2005-2007
- Expert theorists/phenomenologists could be asked to perform the model interpretation of our published results
  - they will be doing it anyway, using whatever toy detector simulation they can find: atlfast, cmsjet, PGS, Delphes
  - none of those are properly validated, not maintained by any collaboration
  - we could provide theorists with the proper CMS-specific tool
- This option saves manpower and creates goodwill

What is SuperFastSim?

- An emulation of the CMS detector which is
  - good-enough for most practical purposes
    - "good enough" = ~ reproduces Fast/FullSim for a range of signals
    - "most practical purposes" = allows
      - a theorist to check if a model is ruled out by a particular CMS analysis (SIGNAL ONLY)
      - an experimentalist to roughly cross-check another CMS/ATLAS analysis
  - simple: we are not talking about reproducing all features found in fullsim or even fastsim
    - "simple" = can be understood by a theorist or an undergraduate

What is SuperFastSim?

- An emulation of the CMS detector which is
  - fast: will allow a quick turnover time (few hours)
    - “fast” = much faster than fastsim, can be run on a laptop
    - Relevant benchmark: Pythia event generation time
    - For example, timing test for the LM1 study point
      - Delphes (out of the box): 17 events/sec
      - Fastsim: 1 event/sec

What is needed for a SuperFastSim?

- Collect all relevant experimental input
  - Turn the experimental input into functions folding the detector response for every object.
  - Example:
    - Jet reconstruction efficiency and resolutions as a function of generator level P_T and eta of the genjet
    - Many more examples in the Physics TDR
- Are they all publicly available?
  - Need for a single and reliable reference source
    - a paper, a note or a twiki
- Action item: collect and publish (on an official twiki) the most current results on resolutions and efficiencies for all relevant physics objects.
- Once those are publicly available, ANYONE can use them to build a CMS-specific tool.

How to implement a SuperFastSim

- Option I: retune a public parameterized simulation, e.g. Delphes
  - a configuration module specifies the geometry and resolutions
  - smearing of tracks and energy deposits
  - standard isolation requirements and standard jet algorithms
- Option II: look-up tables mapping
  - generator-level objects with MC truth coordinates (P_T,eta,phi)
  - reconstructed (PAT?) objects with measured (P_T,eta,phi)
- Requirements in either case:
  - good: reasonably accurate parameterization of CMS detector, validated against fullsim results for signal from various analyses
  - fast: much faster than fastsim
  - the tool outputs standard CMS objects (nothing too exotic)
  - well documented
    - what is the degree of applicability and accuracy (signals only)

What about the existing tools?

- We don’t want to reinvent the wheel. There is experience with other existing parameterized detector simulators.
- So far, no dedicated global effort to benchmark how well they work.
- It is worth comparing PGS and/or Delphes output to CMS specific emulations.
  - There are preliminary studies, e.g. M. Pierini et al, S. Sekmen et al, K. Matchev et al, others...
- Feedback on where parameterized detector simulators don’t work is also useful to the experiment.

13

How can it be used internally to CMS?

- Does my analysis have sensitivity to model X?
- Why is the ATLAS limit worse at this (M_0,$M_{1/2}$) point?
- How much does my analysis benefit from raising the energy to 8 TeV?
- How much does my analysis benefit from changing my cuts like my competitors do?
- Quick preliminary scans to find out
  - which (simplified) models an analysis is sensitive to
  - what (range of) model parameters an analysis is sensitive to, e.g.
    - what sort of grid to use for MSUGRA scans
- Outreach activities, working with undergraduates, etc.

Long term prospects

- This is a very straightforward proposal
  - For all practical purposes it is already done in an incoherent way by various people
  - The proposal is to streamline and integrate this activity
- Good news: we are volunteering the manpower to get this going.
- If this turns out to be beneficial, manpower will not be an issue since people will want to use it.
- We welcome parties interested in contributing to the development and testing of the tool to join in.

Action items

- Collect available fast and simple parameterizations in a single twiki, implement in a standalone tool.
  - timescale: ~Thanksgiving 2011 (if we started today)
- Compare to the performance of PGS and DELPHES
  - timescale: ~Christmas 2011
- Prepare a beta version of the SuperFast tool for testing and gauging potential interest within CMS
  - timescale: ~Winter 2012 (?)
- Once a stable release is available, consider the option of making it public to the theorists
  - timescale: ~Summer 2012 (?)

BACKUPS

Frequently asked questions

- What is the single most important benefit to CMS?
  - Decrease of turnaround time for implementation of new ideas
    - feasibility studies
    - cover a lot more simplified models, even faster
- If this idea is so great then how come ATLAS has not done it already?
  - Not all great ideas come from ATLAS.
  - We cannot be sure that they are not doing it already
- How many FTEs will this idea cost in support and maintenance? Are you sure?
  - The proposal estimates an initial cost of 0.5 FTE over a few months, then a yearly maintenance cost of 0.1 FTE.
    - this is just an estimate
    - no, we are not sure

Frequently asked questions

- Doesn't the simplified model approach already solve the problem of the multitude of theory models?
  - The simplified model approach is already a huge step in the right direction
    - one SM study covers many theory models sharing the same event topology
    - still there are many more event topologies giving the same experimental signature: each topology needs to be separately studied, hence the theory space of simplified models is still large
- Why not just let theorists who want to test their models inside CMS?
  - This is not what CMS wants.
  - This is not what theorists want.
    - theorists prefer to be independent
    - theorists do not want to learn how to run fullsim: too hard and time-consuming

Frequently asked questions

- What is PGS?
  - PGS stands for Pretty Good Simulation: a toy simulation (in fortran) of a generic high-energy physics collider detector with:
    - tracking system
    - electromagnetic and hadronic calorimetry
    - muon system
  - Formerly called SHW: originally created by John Conway (UC Davis) for the SUSY-Higgs Workshop at Fermilab 1998.
  - Widely used by theorists for the LHC Olympics exercises.
  - Configurable detector parameters and resolutions
  - PGS is designed to be fast, so it is missing:
    - magnetic field
    - secondary interactions, multiple interactions, z-vertex spread
    - bremsstrahlung, photon conversion, detector material
    - decays in flight

Frequently asked questions

- What is Delphes?
  - A toy detector simulator analogous to PGS but written in C++.
- Isn't fastsim good enough? Let's make the fastsim public instead.
  - The goal is to have something much faster than fastsim.
  - Fastsim is already public*. No theorist is using it.
- Why not publish the fullsim code?
  - This is not what theorists want (or can handle).
- Different analyses are using different object definitions. Which one will be implemented in the tool?
  - Most of them. The user should be able to toggle between different object definitions depending on the particular CMS analysis being referred to.

FAQ: the public option

- If the tool is made public:
  - How will that impact the visibility of our papers? Will theorists be more likely or less likely to read our papers instead of ATLAS's?
    - Much more likely (obviously).
  - Who owns it?
    - No one. It is open source.
    - A CMS team (including but not limited to the people behind the proposal) releases periodic updates with retuned efficiencies reflecting significant changes in running conditions.
  - Won't theorists misuse it? Who is doing QM of the results produced with this tool?
    - Mistakes will be caught by responsible theory referees.
  - What if some theorist finds that the tool does not reproduce our published efficiencies?
    - The tool is tuned to the published efficiencies, therefore
      - the theorist made a mistake
      - the theorist used an obsolete version of the tool
      - the theorist used the tool in the wrong region of phase space

FAQ: the internal option

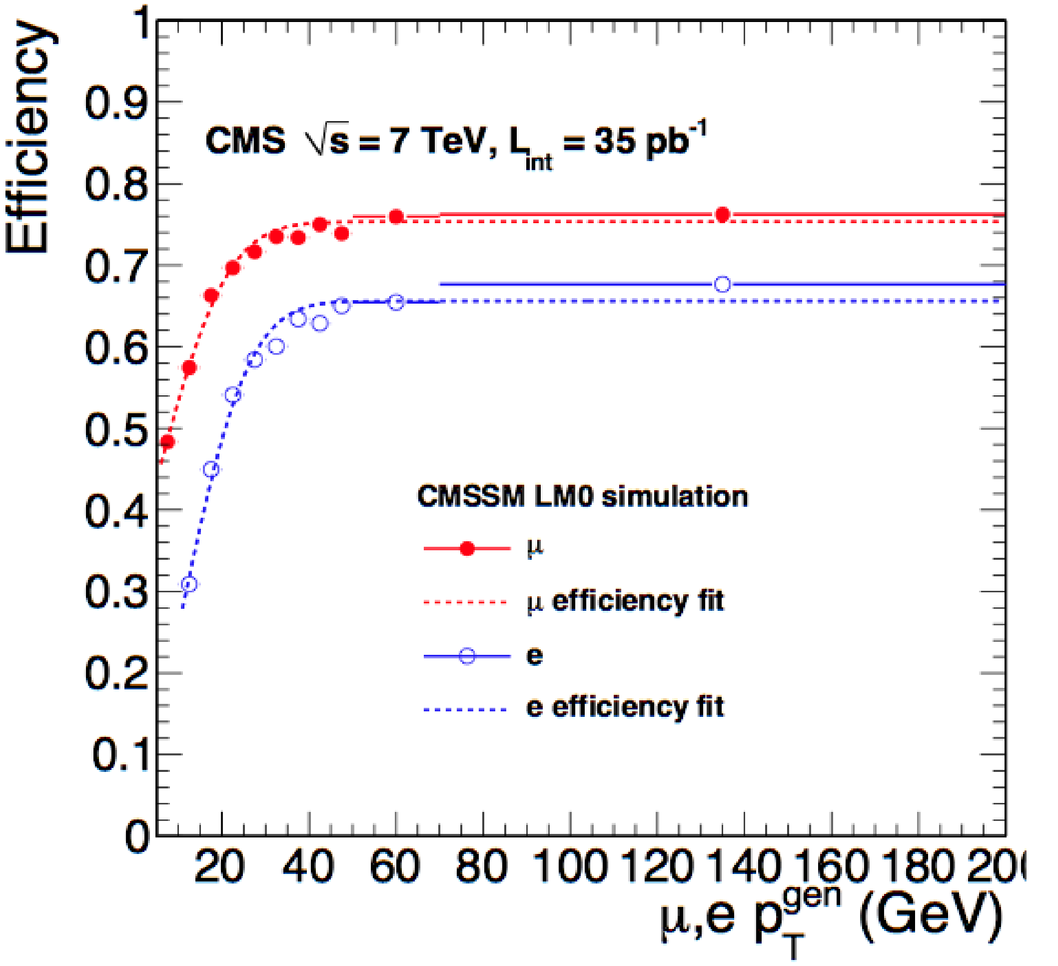
- If the tool is kept internal:
  - How will that impact the visibility of our papers? Will theorists be more likely or less likely to read our papers instead of those by ATLAS?
    - More likely - our papers will have a lot more theory models interpreted. A theorist would be able to find something close to his/her favorite model.
  - Won’t experimentalists misuse it? Who is doing QM of the results produced with this tool?
    - Mistakes will be caught by responsible referees.

MORE BACKUPS

Third method: emulation+theorists

- The experiments provide fits to the average reconstruction efficiencies
  - e, mu and tau
  - now also for H_T and MET
- The curves are derived for a given benchmark point (LM0 or LM6)
- Correction for busy events
  - more likely to fail isolation

CMS PAS SUS-10-004

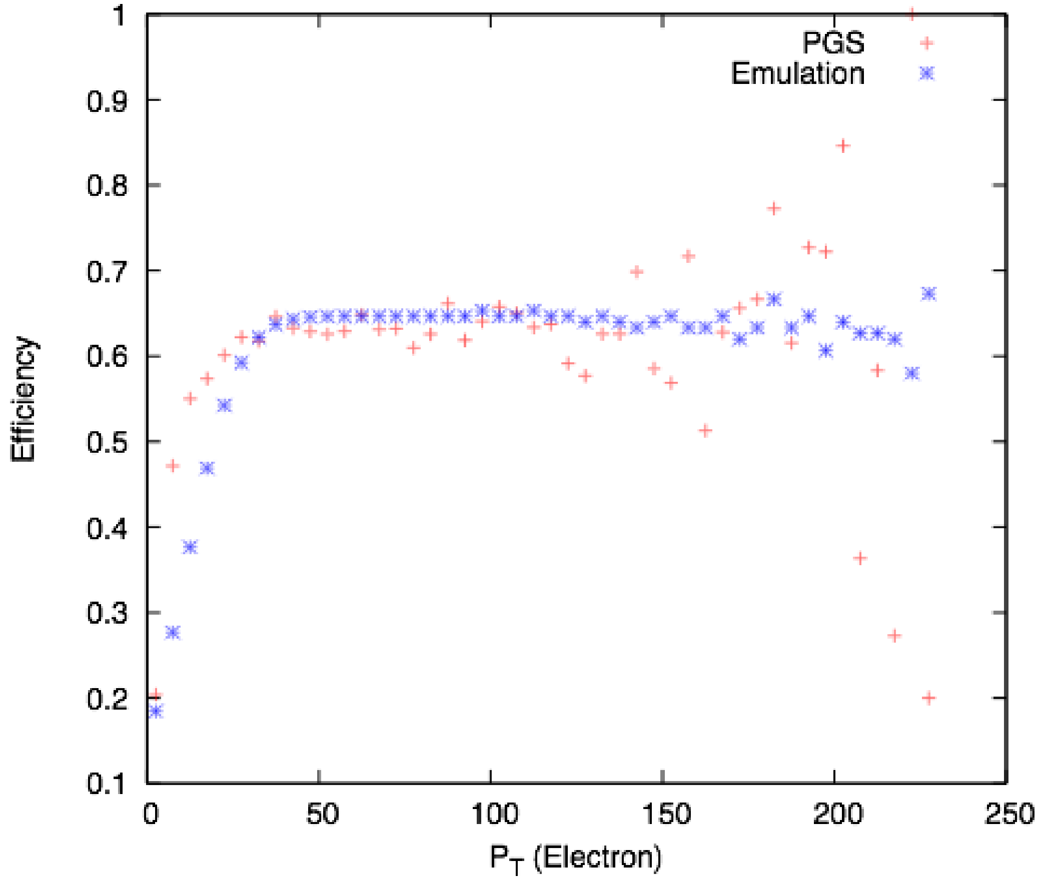


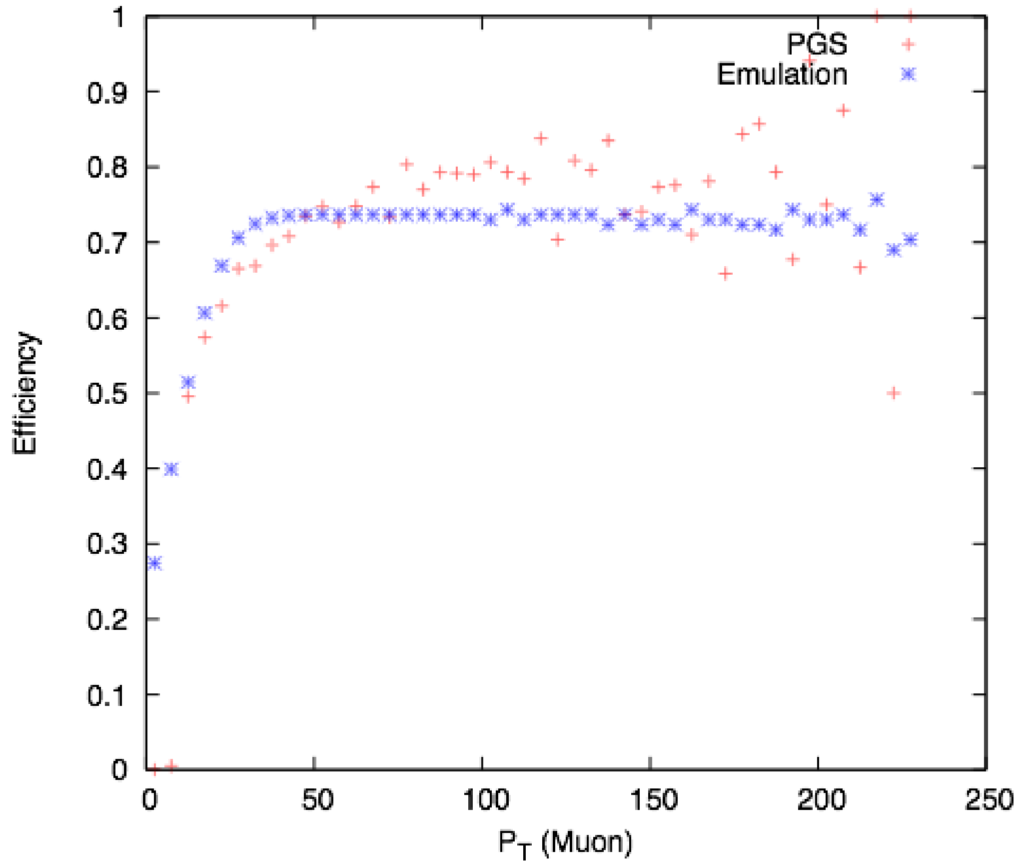
$$\epsilon(p_T, N_{trk}) = p_1 + p_2\left(erf\left(\frac{p_T - p_T^{thr}}{p_3}\right) - 1\right) - 0.1\,\frac{N_{trk} - 25}{10}$$

How “good” is PGS?

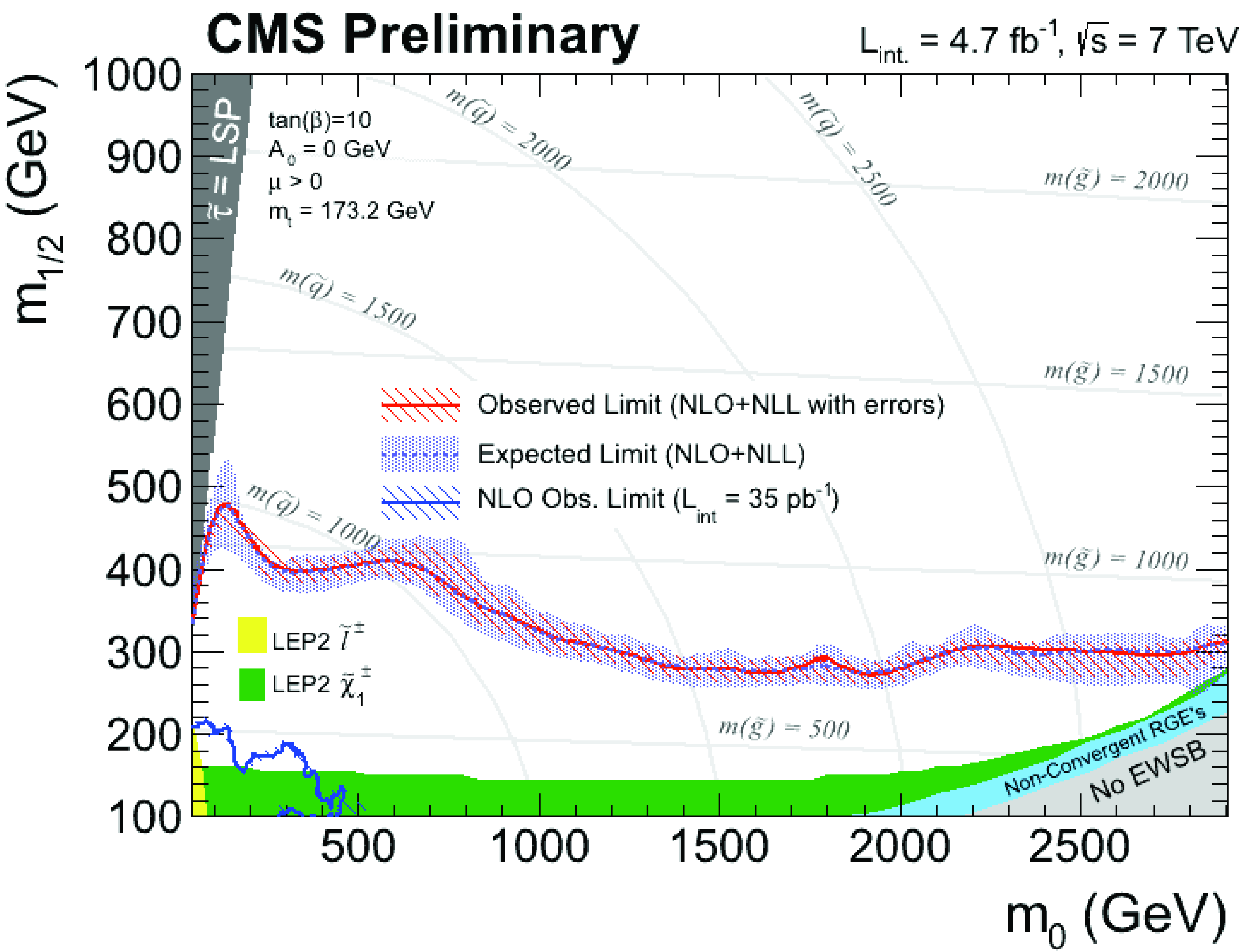
- Comparison of PGS output to CMS emulation
  - lepton efficiencies at LM0 study point

KM,Park,Sarangi 2011





SS dileptons: interpretation in cMSSM



- Extend to about 1 TeV in gluino/squark masses

Efficiency Model

- **Problem:** how to apply these results to an arbitrary model?
- **Goal**: allow others to determine if arbitrary model X is excluded by comparing expected yield to signal yield upper limit

$$N(\text{model X}) = \mathcal{L} \times \sigma \times A \times \varepsilon$$

$\mathcal{L}$ (luminosity) → provided by experimentalists
σ (cross section) and A (acceptance) → calculated by theorists for model X
ε (efficiency) → depends on detector AND model X kinematics

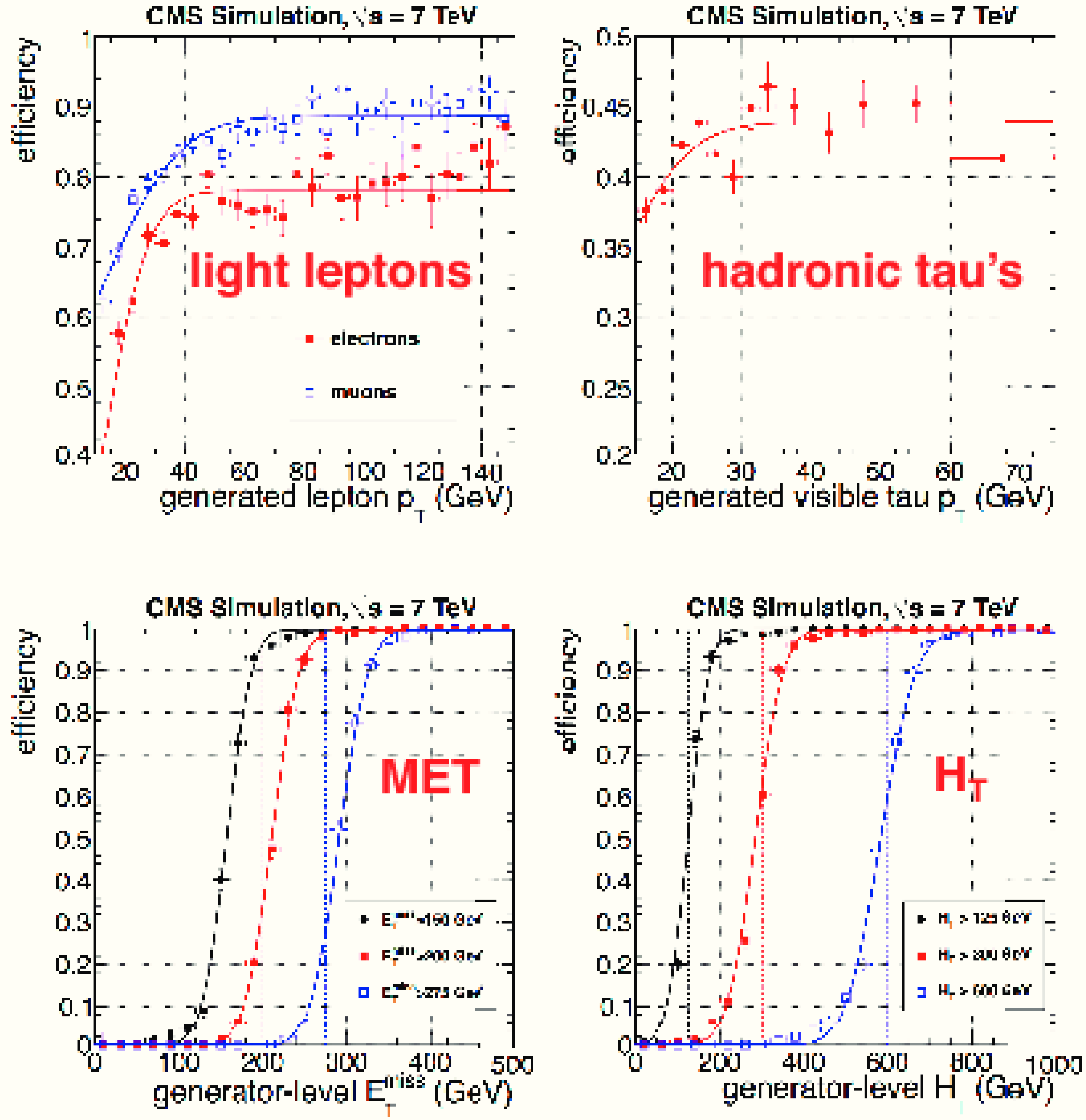
- Recipe: provide selection efficiencies for **basic physics objects** (leptons, H_T, MET) → allow estimation of model X efficiency using simple generator-level studies

Efficiency Model

- **Efficiency model:**
  - Shown: OS analysis, provided for other analyses as well
  - Efficiencies of physics objects vs. gen-level quantities

- **Procedure:**
  - Implement model X in MC
  - Apply analysis selections to gen-level quantities
  - Use efficiency model to scale gen-level yields to "reco-level"

- **This is an approximation**
  - Tested *with several CMSSM points*, agreement within ~15%



Look Up Table

Reco Object → Particle-level Object (best match)

Pairs of Reco Objects → Single or Pairs of Particle-level Objects

Particle-level Object(s) → Reco Object(s)

Proof-of-Principle:

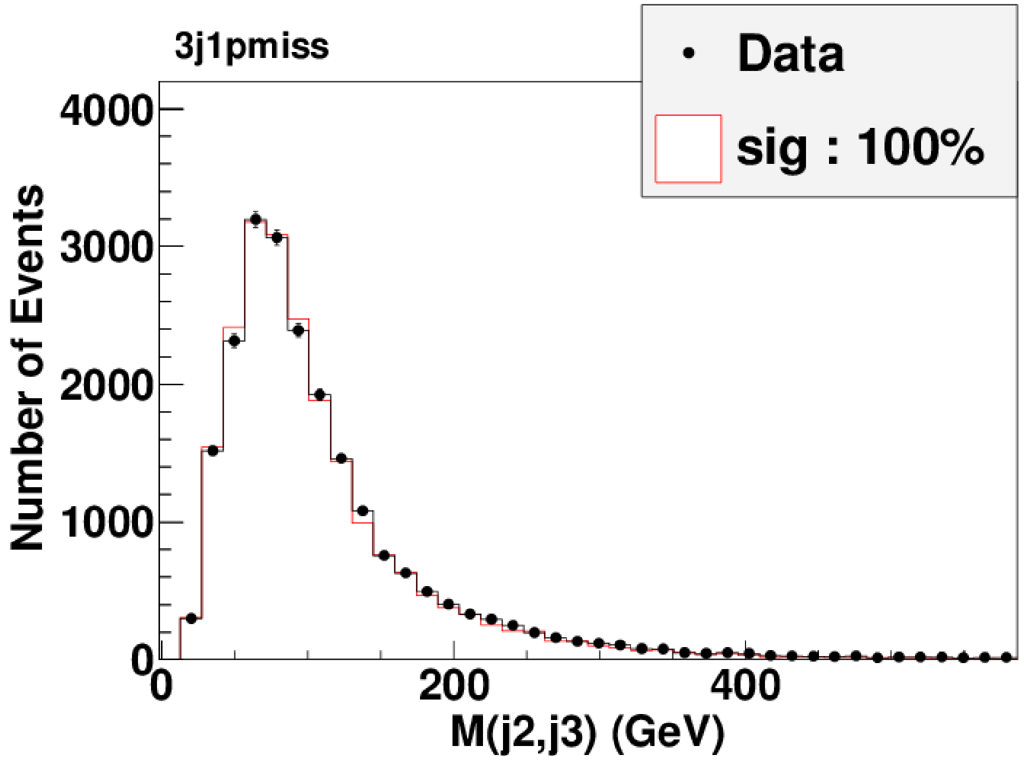
200K T2 (squark-antisquark SMS) FastSim events to create TurboSim morphisms file

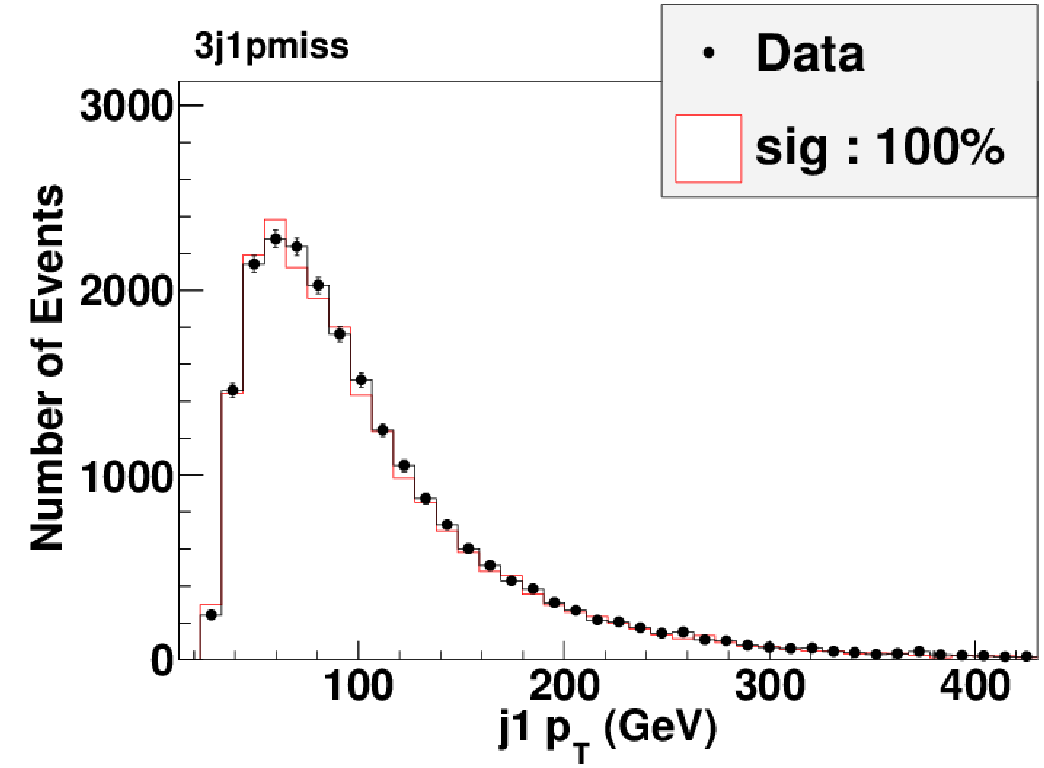
100K T1 (gluino-gluino SMS) particle level events are morphed

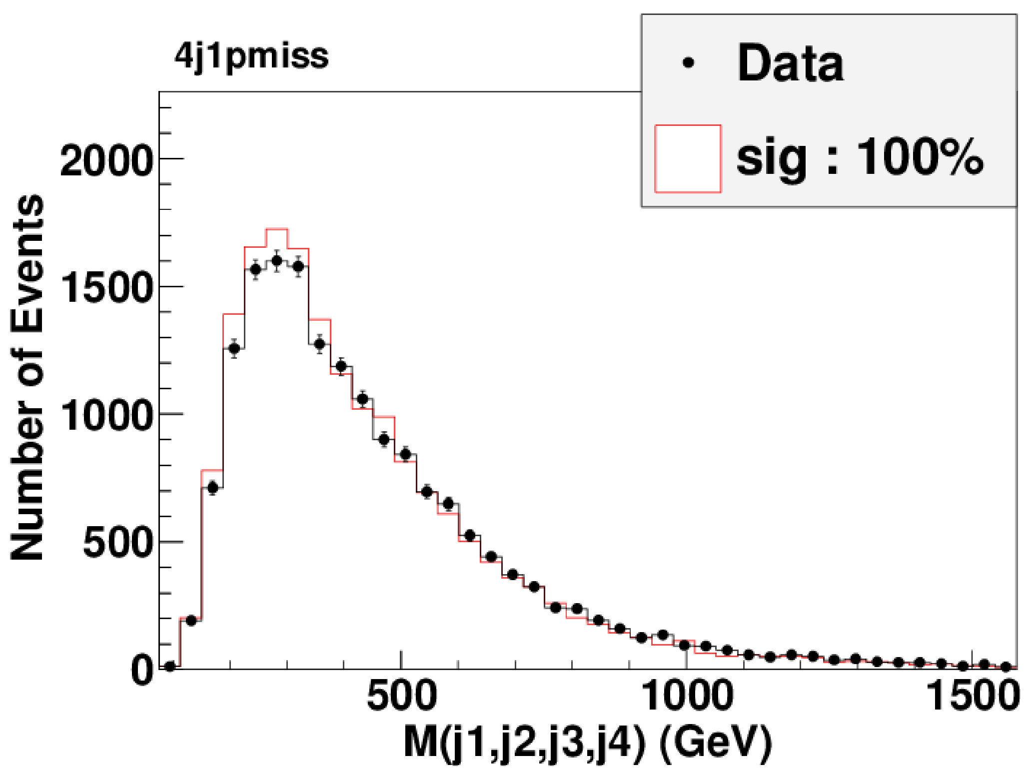
Compare to T1 with FastSim

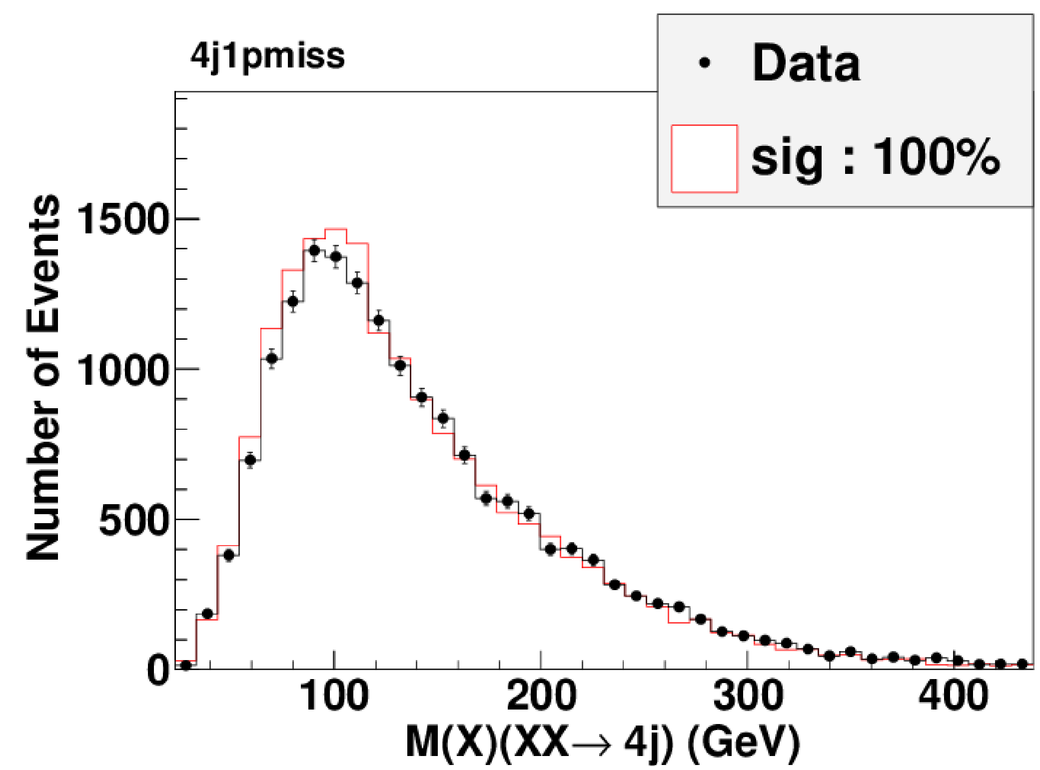
To Show: only most discrepant results

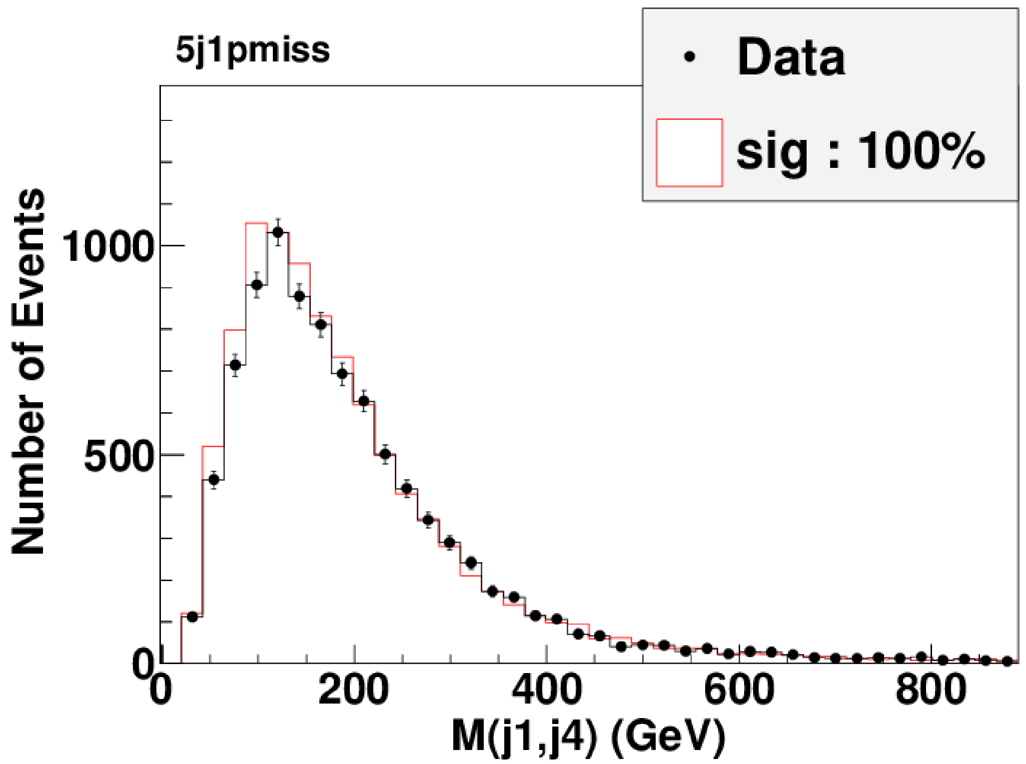
Note: only jets here

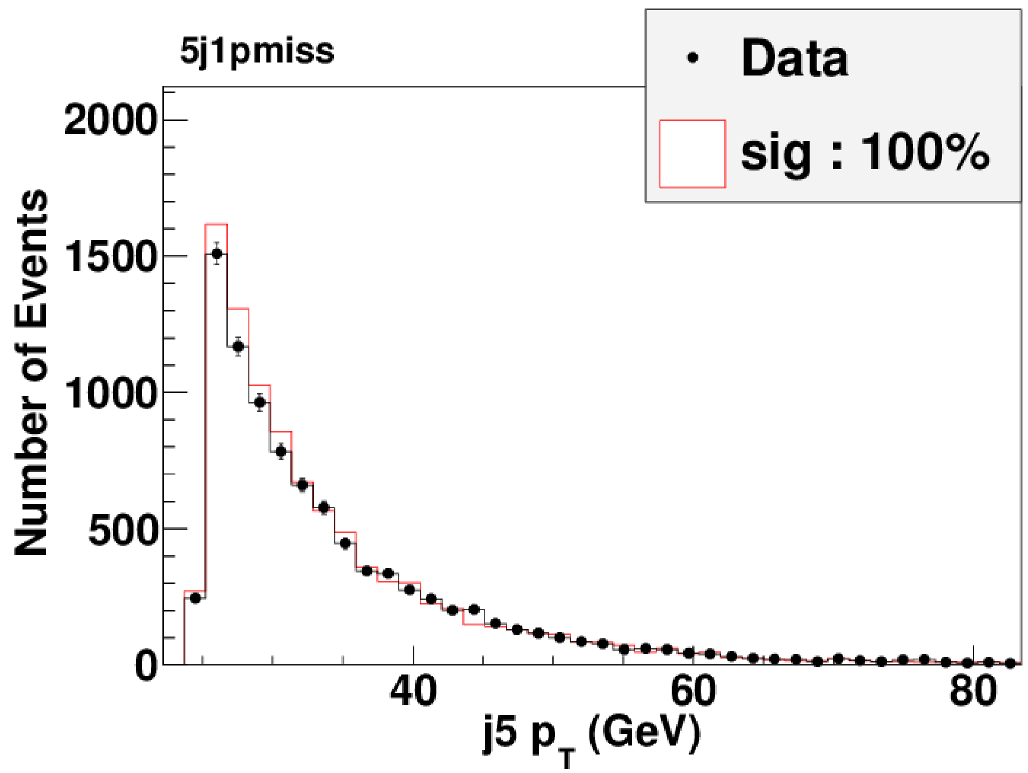

3j1pmiss
Data
sig : 100%
Number of Events
0
1000
2000
3000
4000
0
200
400
M(j2,j3) (GeV)

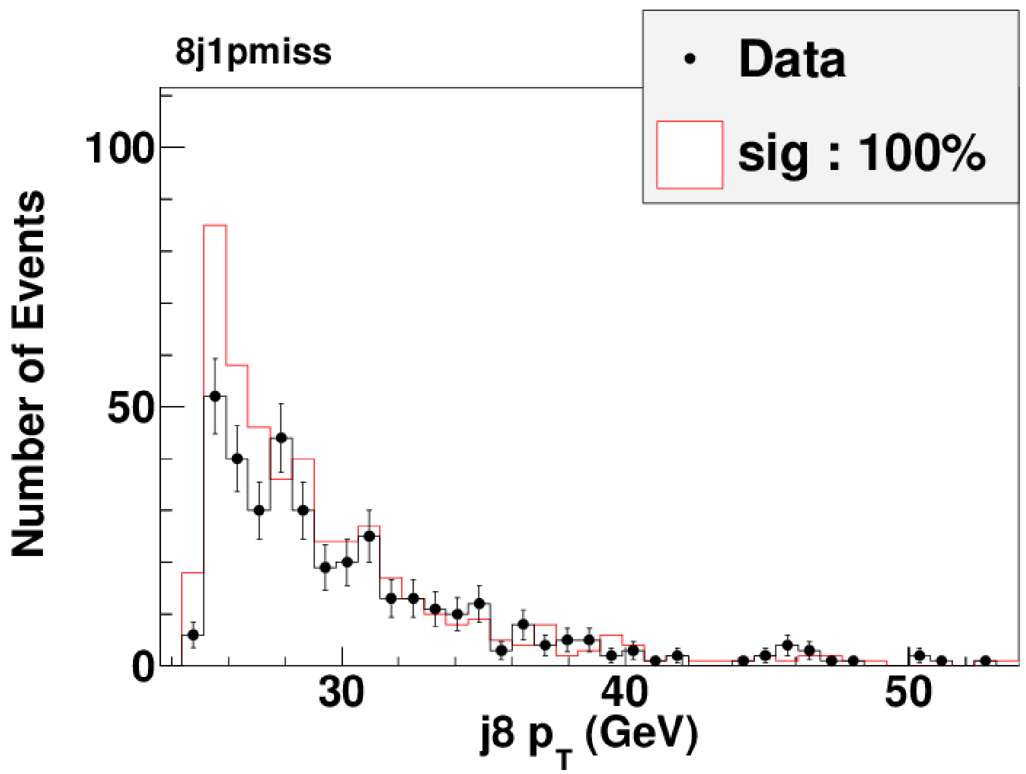

3j1pmiss
Data
sig : 100%
Number of Events
0
1000
2000
3000
100
200
300
400
j1 p_T (GeV)


4j1pmiss
Data
sig : 100%
Number of Events
0
500
1000
1500
2000
500
1000
1500
M(j1,j2,j3,j4) (GeV)


4j1pmiss
Data
sig : 100%
Number of Events
0
500
1000
1500
100
200
300
400
M(X)(XX→ 4j) (GeV)


5j1pmiss
Data
sig : 100%
Number of Events
0
500
1000
0
200
400
600
800
M(j1,j4) (GeV)


5j1pmiss
Data
sig : 100%
Number of Events
0
500
1000
1500
2000
40
60
80
j5 p_T (GeV)


8j1pmiss
Data
sig : 100%
Number of Events
0
50
100
30
40
50
j8 p_T (GeV)

Items (Questions) for Discussion

Is there a problem to be solved?

Will the theory community come to a concensus on what they need?

Can they make a cogent argument?

What will they bring to the effort?