New Physics with $1\,\mathrm{fb}^{-1}$ in ATLAS

Frank E. Paige, Brookhaven National Laboratory

LHC will begin operation with $L \sim 10^{29}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Initial design is $L \sim 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, but exact schedule is unclear.

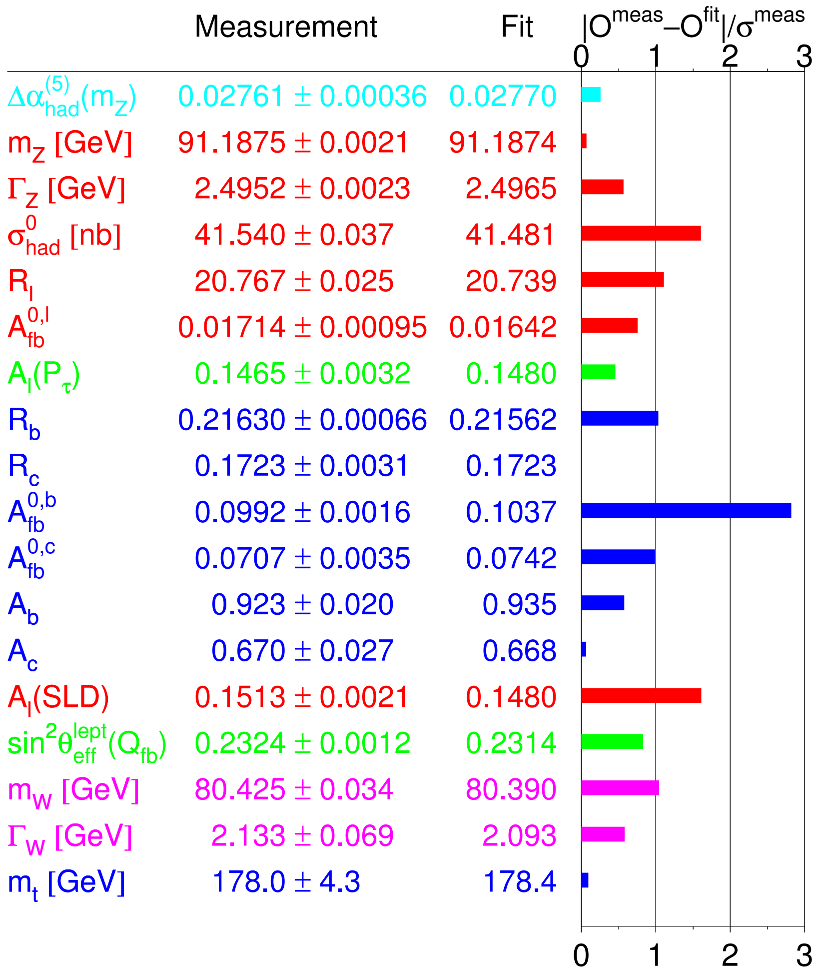
Plausible luminosity for initial physics is $1\,\mathrm{fb}^{-1}$. Now being studied in "Computing System Commissioning" (CSC) work by ATLAS — slowly.

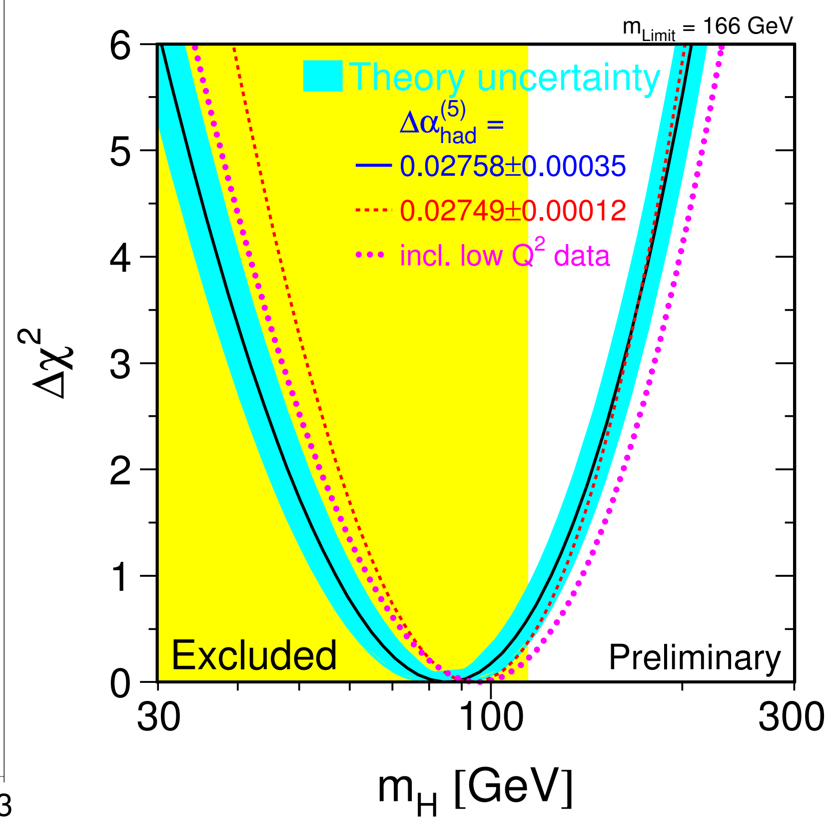
Craig Buttar discussed Standard Model (SM) physics. Will concentrate on new physics searches:

- Higgs — probably not with $1\,\mathrm{fb}^{-1}$
- SUSY — very possible with $1\,\mathrm{fb}^{-1}$
- Exotics — everything else

Higgs

Precision data consistent with Standard Model and light Higgs:

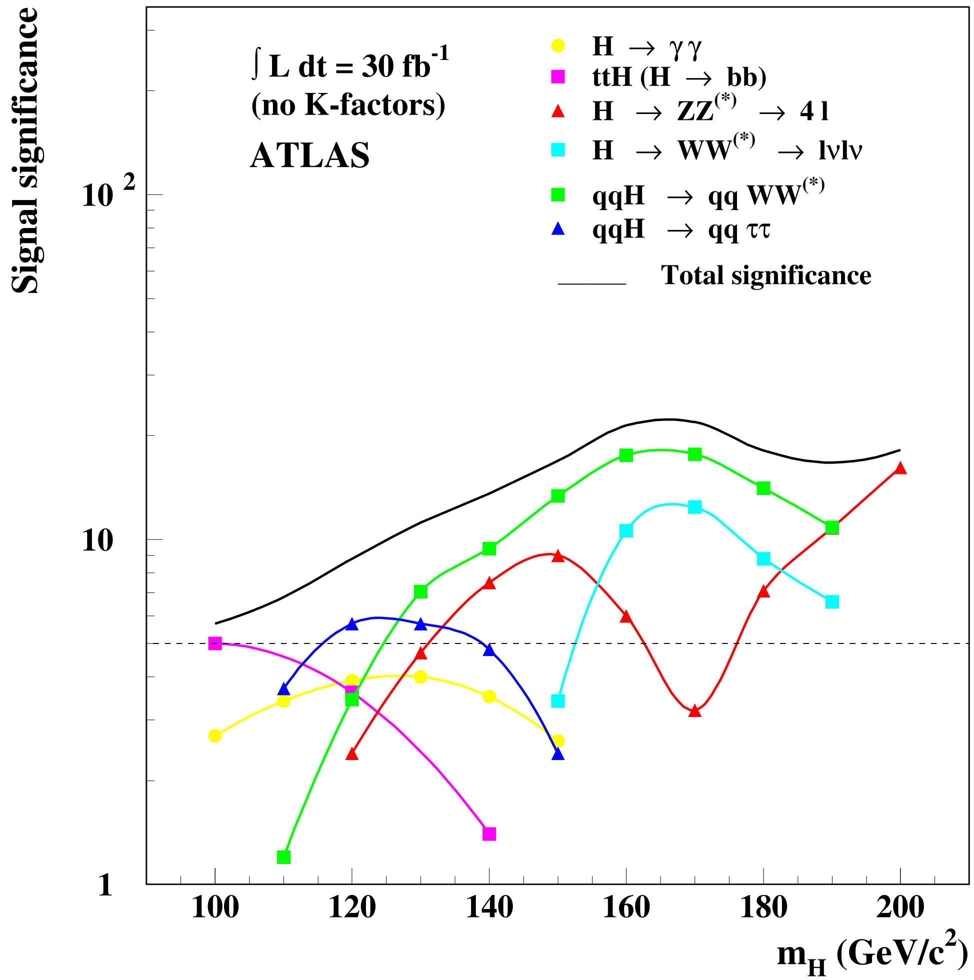




Old ATLAS plot: discovery in whole mass range possible with 30 fb^{-1}.

But discovery looks unlilely for any mass with 1 fb^{-1}.

Vector boson fusion channels ($qqH \to qqWW^*$ and $qqH \to qq\tau\tau$) need good understanding of detector. Reduces chance of discovery with early data.



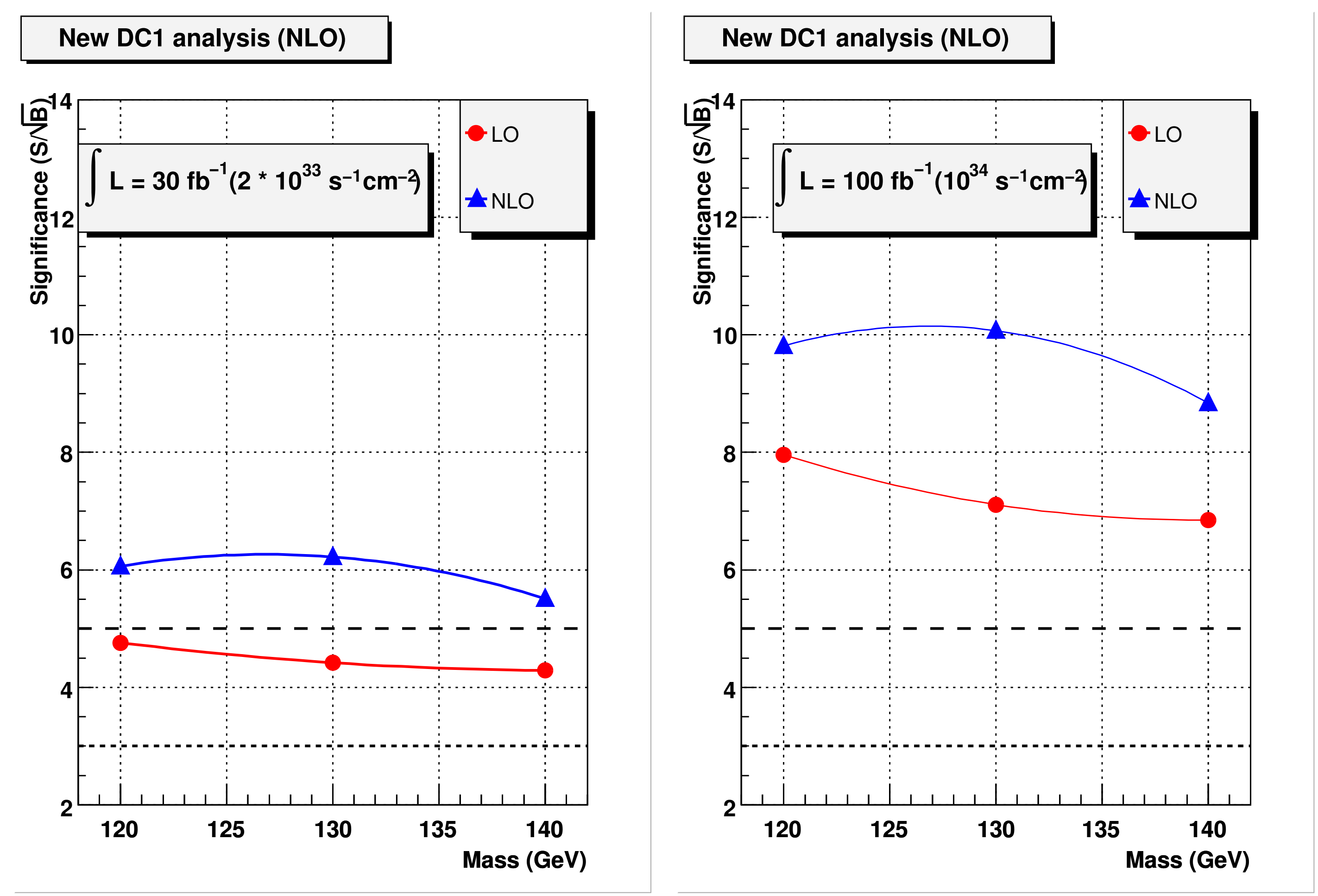
New work has improved situation, even though detector simulation is more realistic. Discovery unlikely with 1 fb^{-1}, but "evidence" possible.

Biggest change is from including NLO corrections for both $H \to \gamma\gamma$ signal and SM $\gamma\gamma$ backgrounds. Improves not just rate but S/B: $K = 1.8$ for signal, smaller for backgrounds.

Also analysis improvements:

- Better γ identification using θ strips in calorimeter and tracker isolation.
- Better γ identification using tracker isolation.
- Improved γ energy calibration (out-of-cone corrections, modulations from accordion geometry).
- Better vertex algorithms and hence z-resolution.
- Better background subtraction using sidebands.

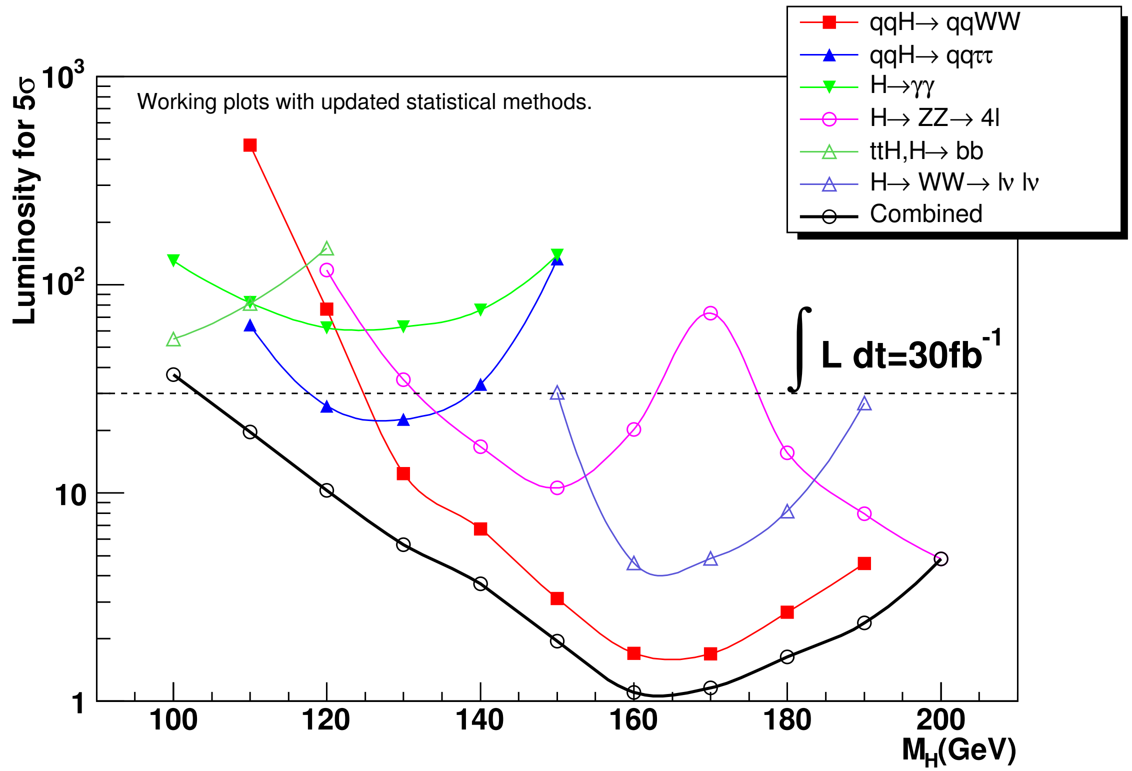
Net result is large improvement in $H \to \gamma\gamma$ significance [Carminati]:



Still no discovery with $1\,\mathrm{fb}^{-1}$, but required luminosity reduced.

ATLAS

Can combine various measurements. Warning: some channels ($H \to \gamma\gamma$, $H \to 4\ell$) are simple, while others ($qqH \to qq\tau\tau$) are sensitive to detector performance. Ignoring this [Cranmer, et al.]:



Do not expect discovery with $1\,\mathrm{fb}^{-1}$ even with optimistic performance. But 95% exclusion of some masses should be possible.

Two best measurements of $\sin^2\theta_w$, A_{LR} from SLC and A^b_{FB} from LEP, are inconsistent by $\sim 3\sigma$ [Marciano]:

$$\begin{aligned} \sin^2\theta_W &= 0.2307(3) \qquad A_{LR} \\ \sin^2\theta_W &= 0.2320(3) \qquad A^b_{FB} \end{aligned}$$

A_{LR} alone is consistent with (light) supersymmetry, but alone A^b_{FB} is consistent with heavy Higgs and large S, T.

No good reason to select data in this way, but does suggest we should not be too confident heavy Higgs is excluded.

Search for Higgs with $M > 200\,\mathrm{GeV}$ is not irrelevant.

SUSY

SUSY is well motivated extension of Standard Model. SUSY with R parity and masses $\lesssim 1\,\text{TeV}$ provides

- Unification of couplings
- Stabilization of Higgs mass
- Good candidate $\tilde{\chi}_1^0$ for cold dark matter

Typical SUSY cross section is 1–10 pb $\Rightarrow$ early discovery possible.

SUSY production at LHC typically dominated by $\tilde{g}$ and $\tilde{q}$. Produce cascade decays to invisible $\tilde{\chi}_1^0$, giving multiple jets, $\not\!\!E_T$, and perhaps one or more $e/\mu/\tau$.

Need to understand both jets and $\not\!\!E_T$.

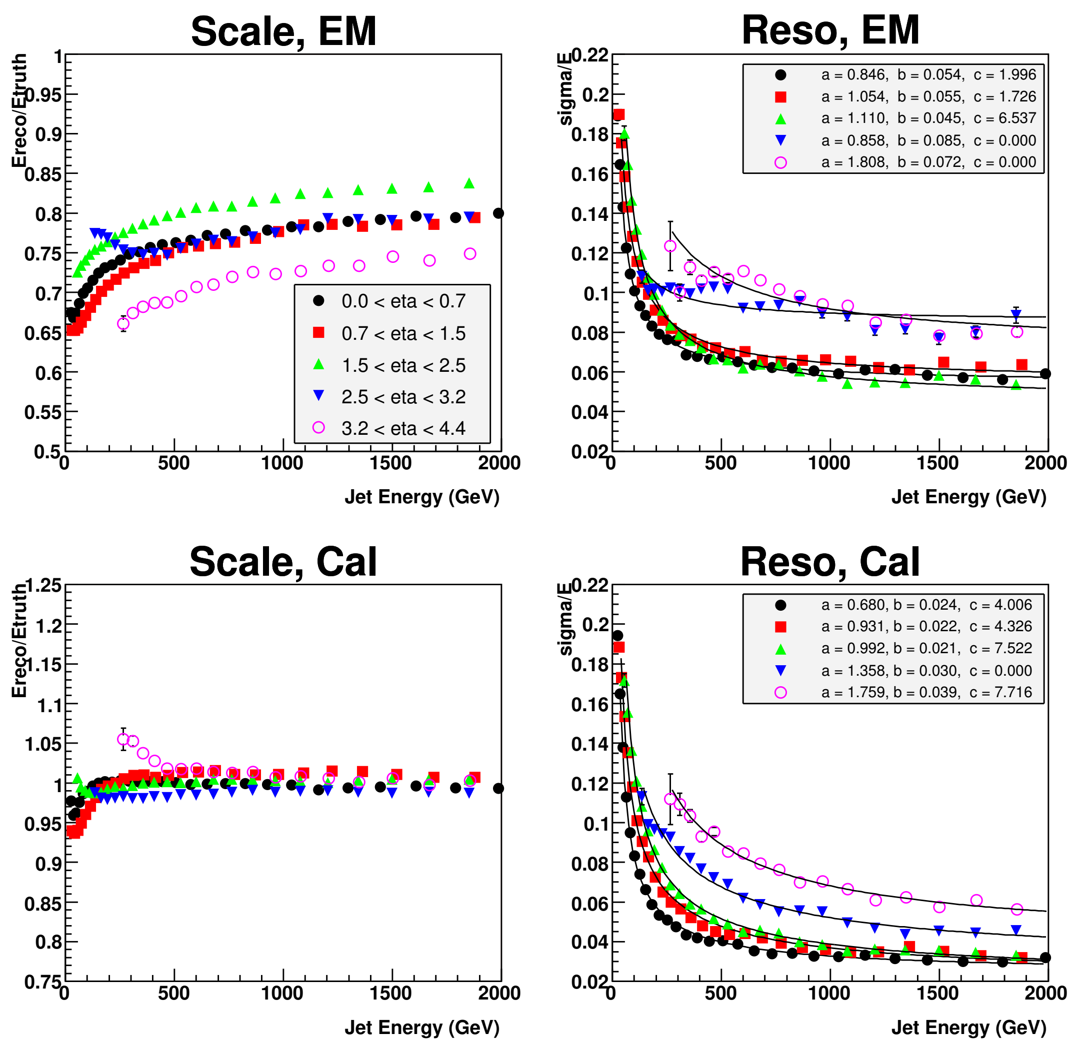
Jet Calibration: ATLAS calorimeter optimized for EM response, so hadronic energy scale is wrong. Jets are EM/hadronic mixture. Apply weighting using fact that EM showers are smaller.

Several approaches:

Sampling weights based on depth.

“H1” weights based on E/V for cells (shown).

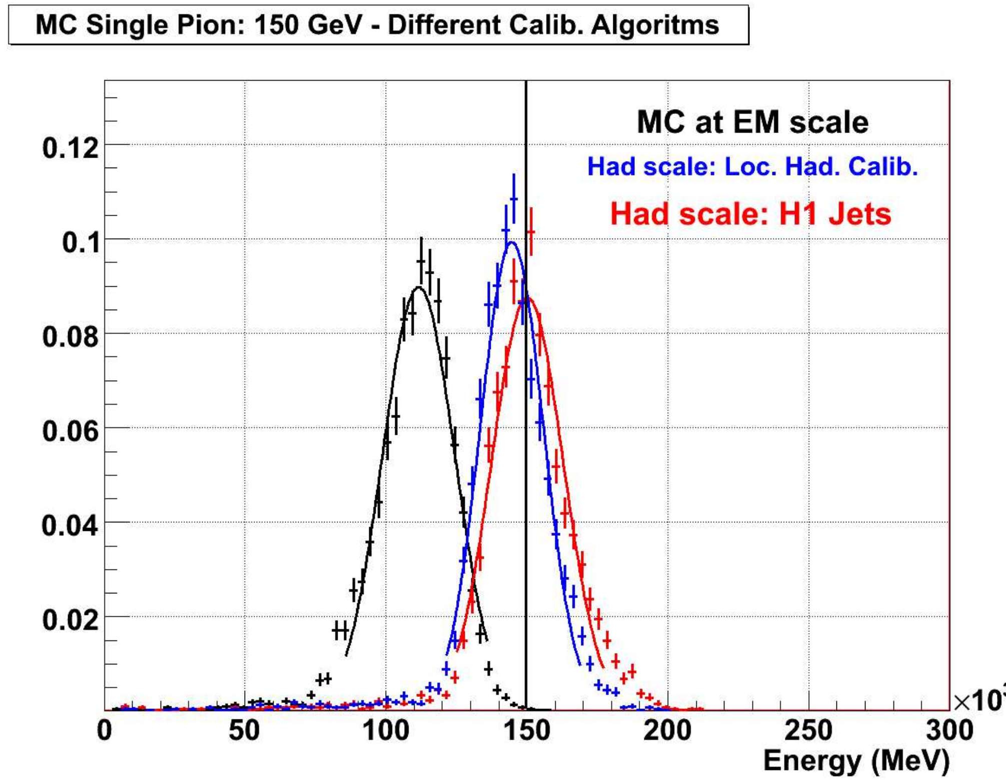
Local calibration weights based on classification of clusters.



ATLAS

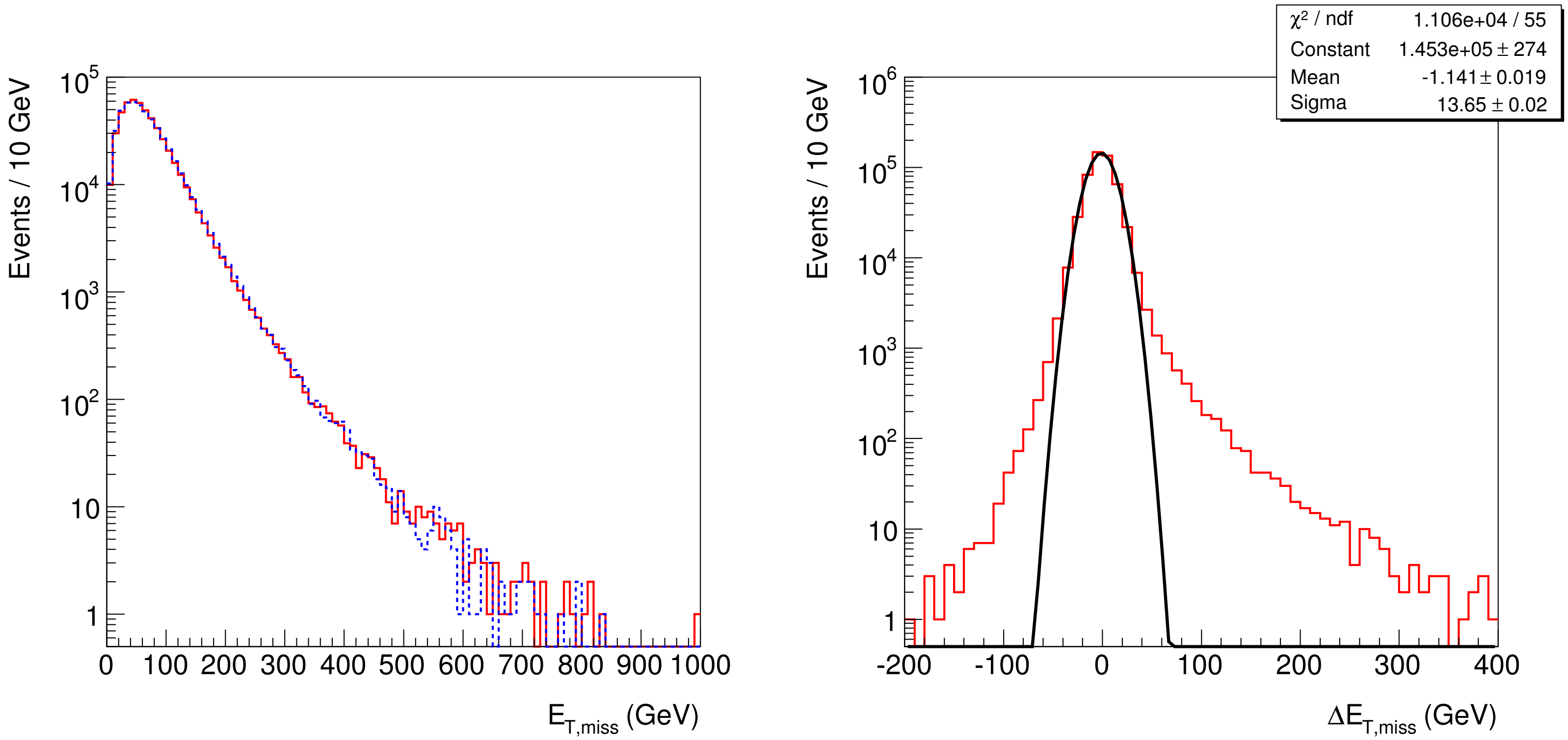
Existing weights tuned to match reconstructed and truth jets. Combine many effects.

Work pretty well for single pions in test beam.



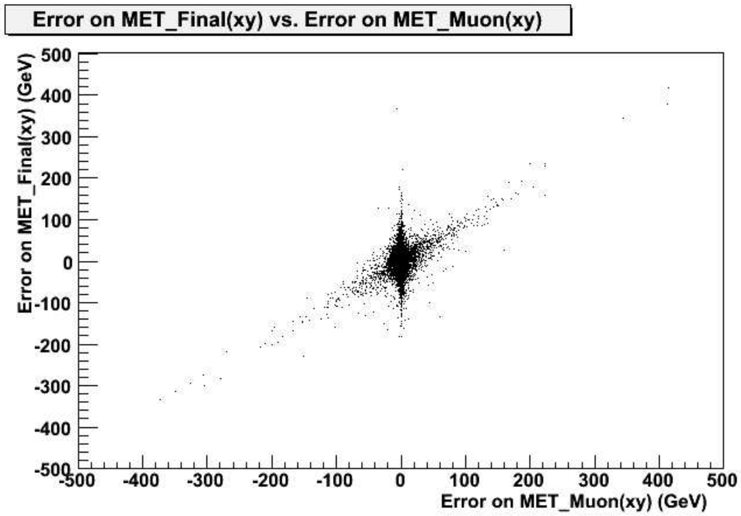
Existing jet calibrations not adequate for precision measurements. But given $\sigma \sim p_T^{-4}$, jet scale uncertainty probably less important than higher order QCD corrections.

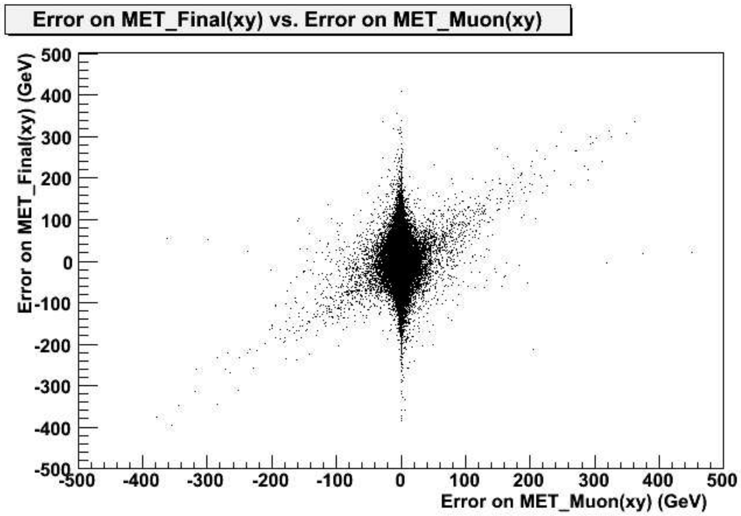
$\not\!\!E_T$ Resolution and Tails: QCD multijet cross section much larger than SUSY $\Rightarrow$ $\not\!\!E_T$ is essential. Resolution is not Gaussian; simulated SUSY sample shows good average agreement but large tails:



$\not\!\!E_T$ from beam-gas, cosmics, hardware problems,… are not included. Work has started on "event cleaning."

Fake $\not\!\!E_T$ arises from mismeasured jets and fake/missing muons. Scatter plots for SUSY point (left) and jets with $560 < p_T < 1120\,\mathrm{GeV}$ (right):





(Muon) track finding is biased towards high p_T. Can generate fakes with many missing hits or from punch-through showers. Usually poor match to inner detector.

Should be able to reduce muon contribution further.

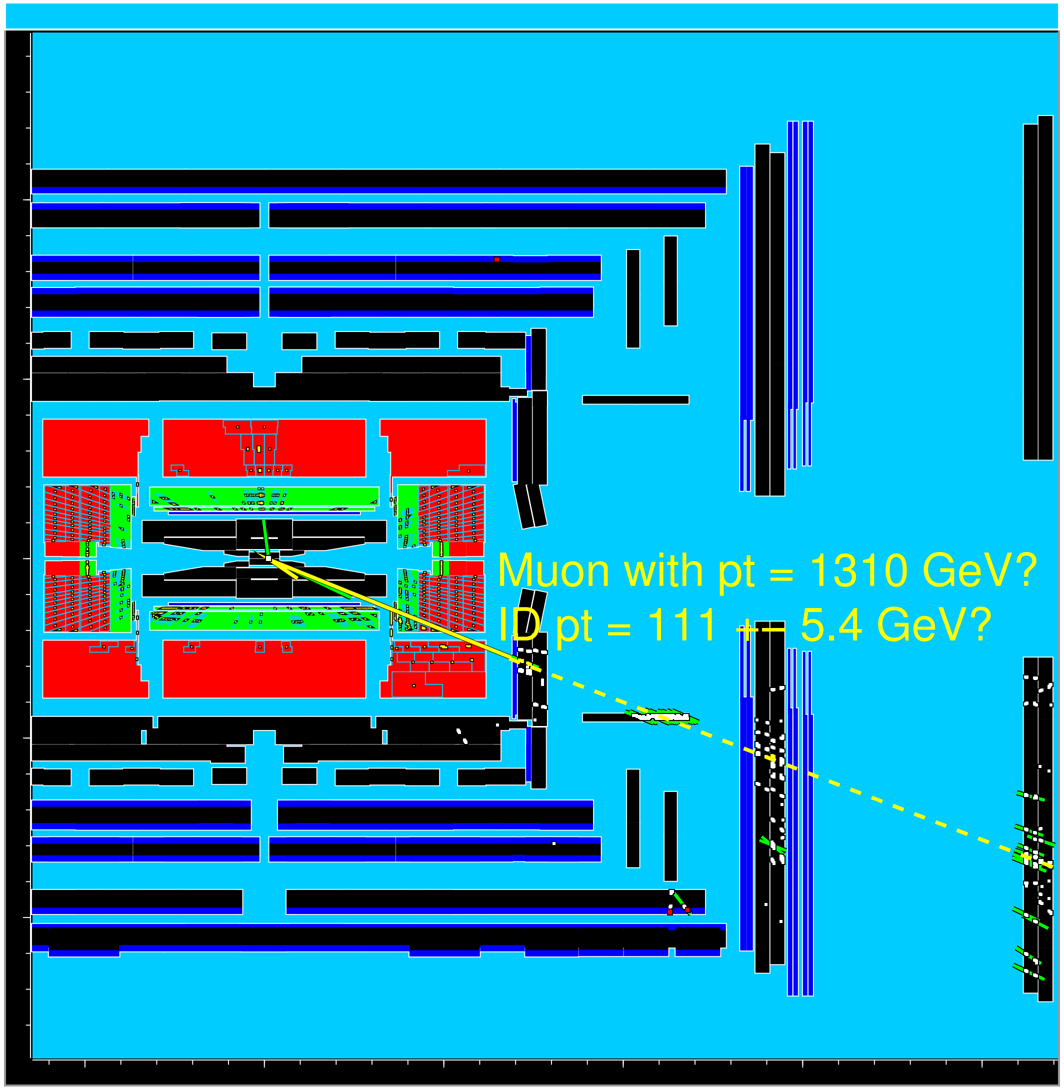
ATLAS

Bad event from summer 2006 reconstruction:

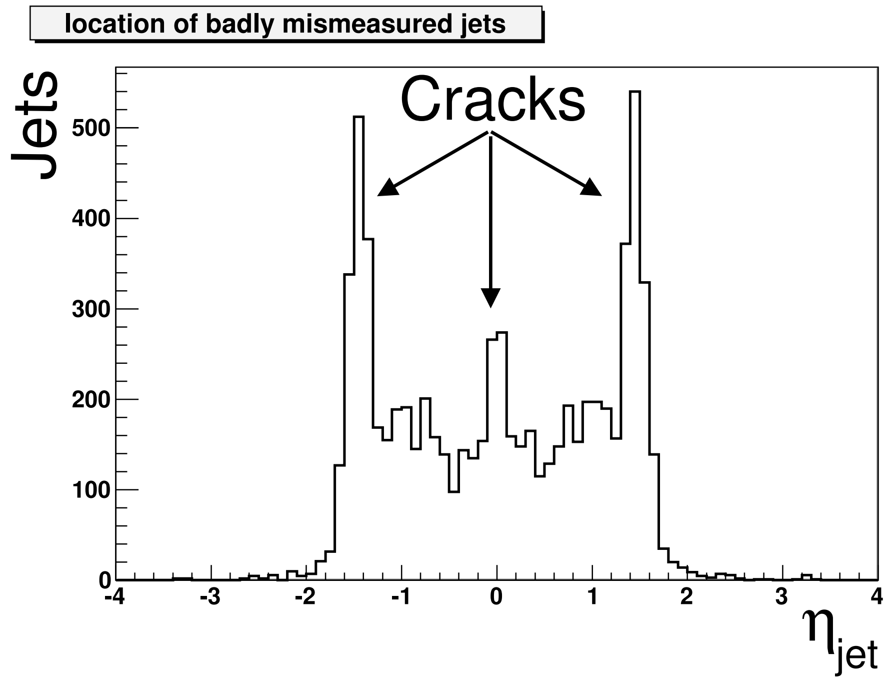
Jet in crack ⇒ many hits in muon chambers.

$\not{E}_T = 1266\,\mathrm{GeV}$, "muon" with $p_T = 1310\,\mathrm{GeV}$ matched to ID track with $p_T = 111\,\mathrm{GeV}$.

Rejection of such events has improved; expect more improvement.

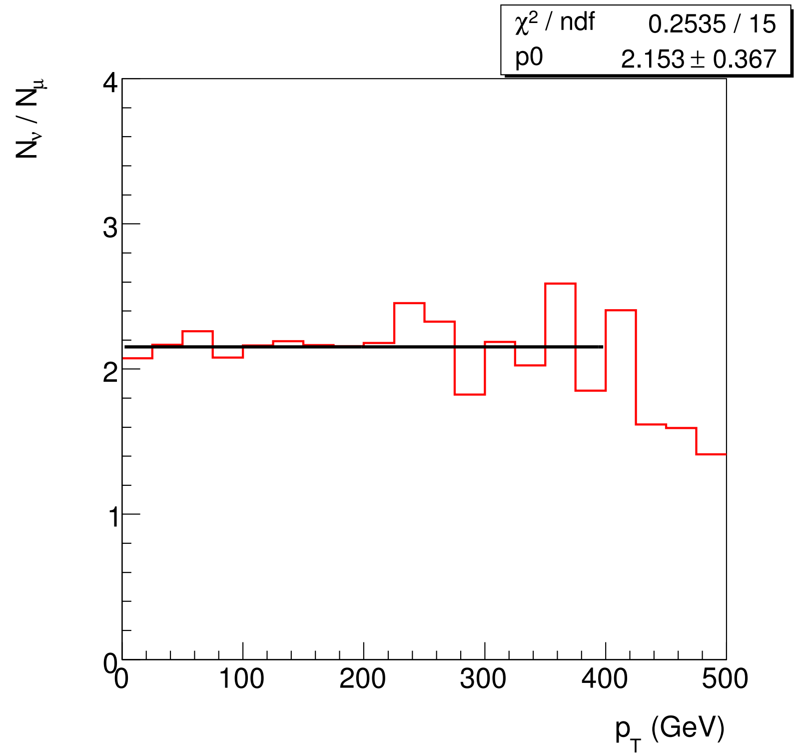


For remaining events worst measured jet is often (not always) in crack regions — $\eta = 1.5$ corresponds to barrel-endcap transition:



Should be possible to reduce $\not\!\!E_T$ tail from mismeasured jets by vetoing jets in $\eta = 1.5$ cracks. But significant contribution will remain.

QCD jets also have real $\not{E}_T$ from c and b quark decays. Can measure using non-isolated muons and/or b vertex tagging. Result for true non-isolated ν/μ ratio from QCD jets:



Caveats: Must treat τ's separately. Must determine μ efficiency in jets (and p_T dependence of b-tagging efficiency). Needs work.

Inclusive SUSY Searches

Many analyses based on mSUGRA with parameters m_0, $m_{1/2}$, A_0, $\tan\beta$, $\mathrm{sgn}\,\mu$ (roughly) consistent with Higgs and CDM constraints:

mSUGRA parameters for full simulation (masses in GeV):

SU1: 70, 350, 0, 10, +

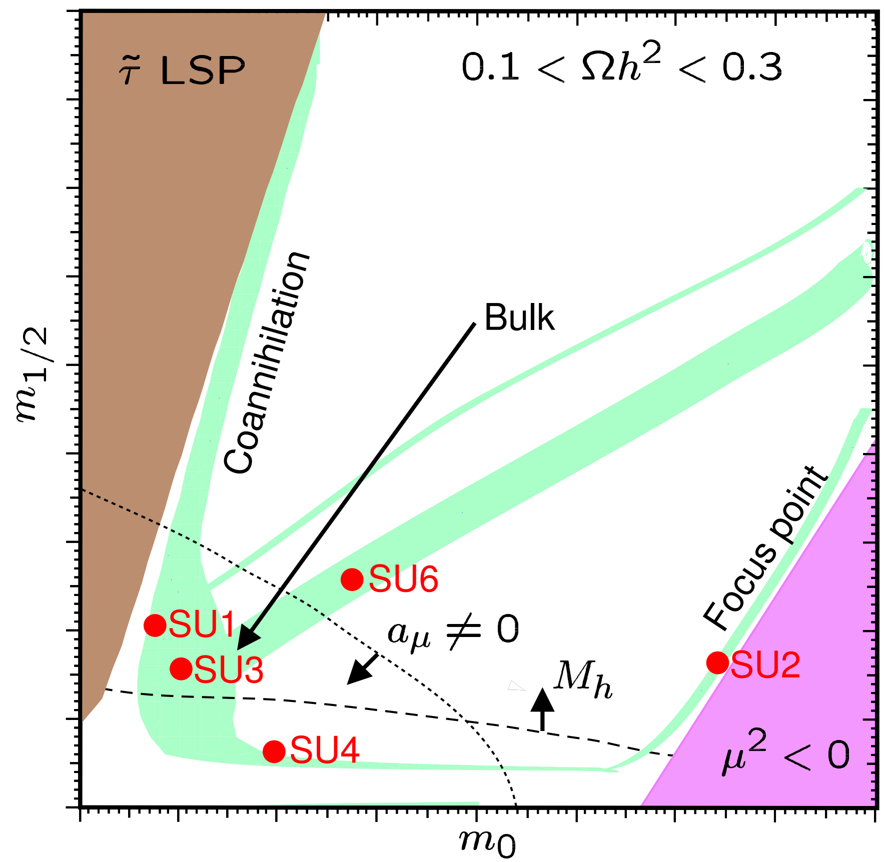
SU2: 3550, 300, 0, 10, +

SU3: 100, 300, -300, 6, +

SU4: 200, 160, -400, 10, +

SU6: 320, 375, 0, 50, +

Spectrum and decays from Isajet, generation with Herwig.



Warning: CDM constraints in mSUGRA arise from large $\mu \Rightarrow$ bino LSP and inefficient annihilation. Several issues:

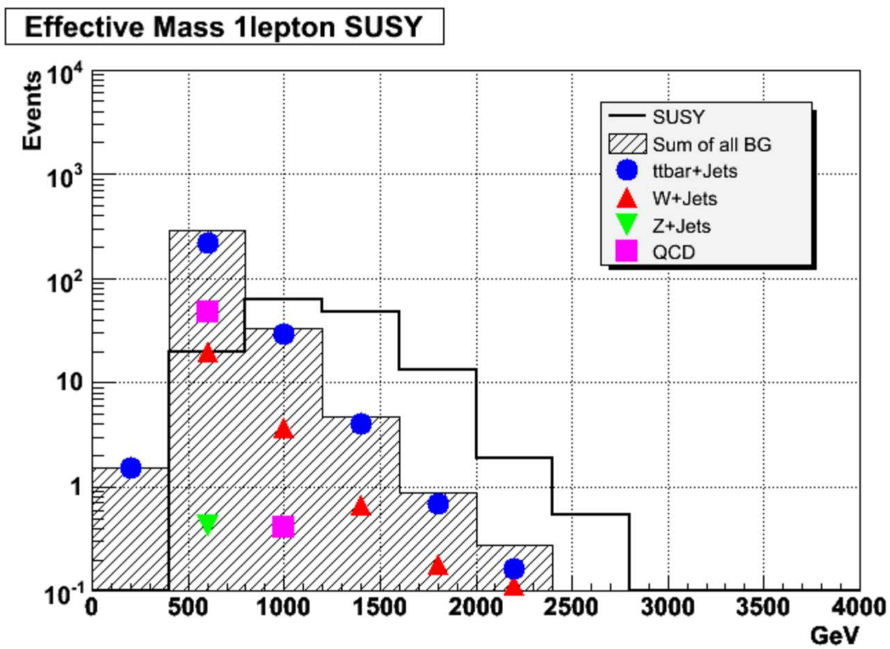
- μ is SUSY conserving, c.f. N^kMSSM.
- Scalar unification hard to achieve in models.
- Higgs in different GUT representation than squarks/sleptons.

Treating μ as arbitrary $\Rightarrow$ much larger range of m_0, $m_{1/2}$ allowed by CDM. May need to adjust M_A as well to satisfy $b \to s\gamma$ constraint.

One-lepton mode: Require multiple jets, large $\not{E}_T$, and one e or μ [Kente Oe]. Then plot

$$M_{\text{eff}} = \not{E}_T + \sum_j p_{T,j} + \sum_\ell p_{T,\ell}$$

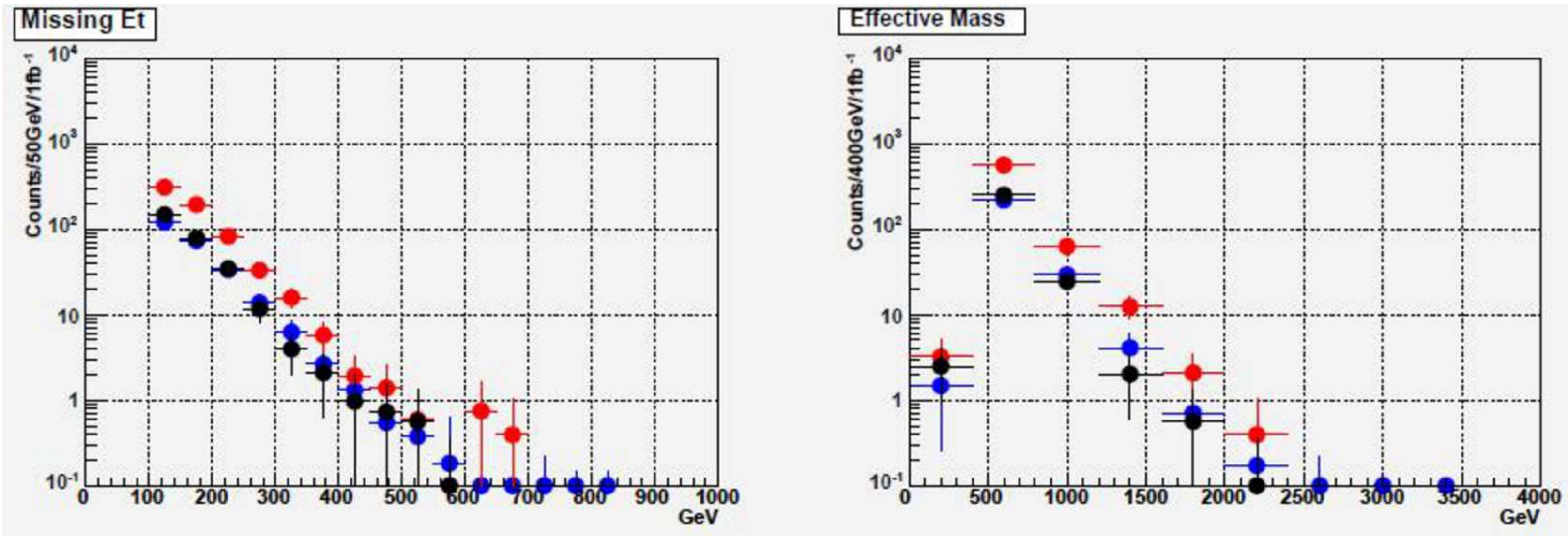
Typical result (mSUGRA, $m_0 = m_{1/2} = 400\,\text{GeV}$):



Dominant backgrounds are $W+$jets and $t\bar{t}+$jets. Calculated here using ALPGEN (LO matrix elements).

ATLAS

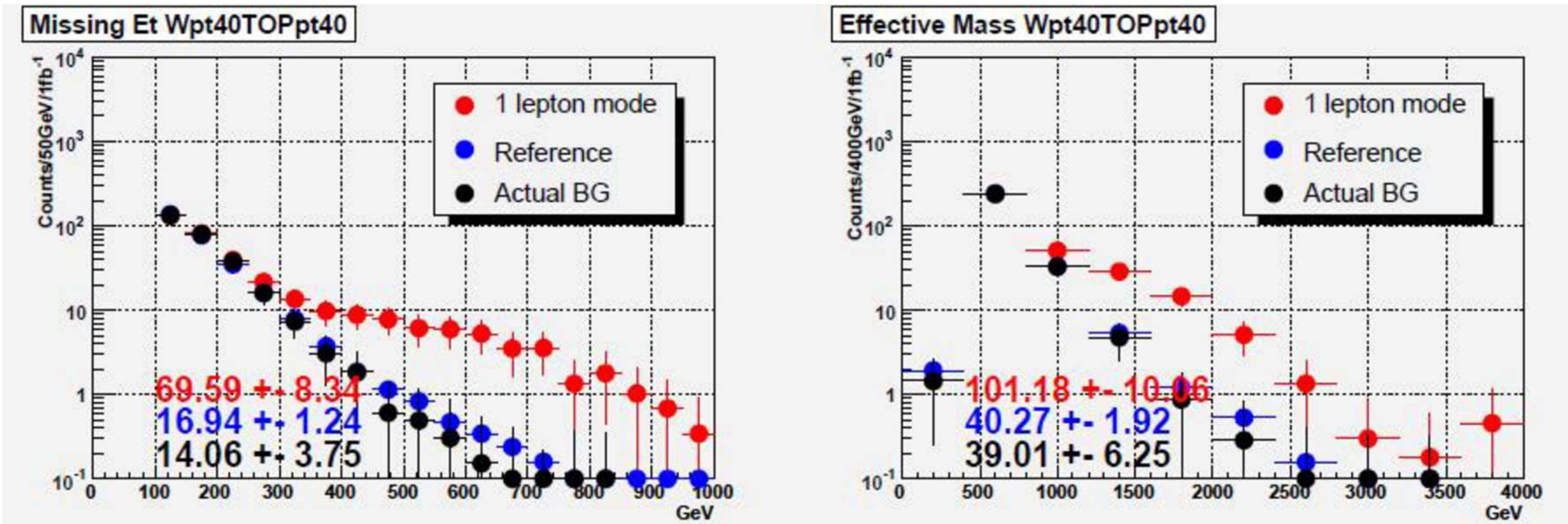
Reasonable agreement using ALPGEN with $p_T > 15\,\mathrm{GeV}$ (red), ALPGEN with $p_T > 40\,\mathrm{GeV}$ (blue), and MC@NLO (black) for $\not\!\!E_T$ (left) and M_{eff} (right):



Waiting for NNLO corrections to $W + 4\,\mathrm{jets}$....

Meanwhile, must measure Standard Model signals in presence of SUSY background [sic].

Transverse mass M_T is weakly correlated with other variables. But flat distribution for SUSY, while $M_T < M_W$ for $t\bar{t}$ + jets and W + jets. Use $M_T < M_W$ to normalize background:



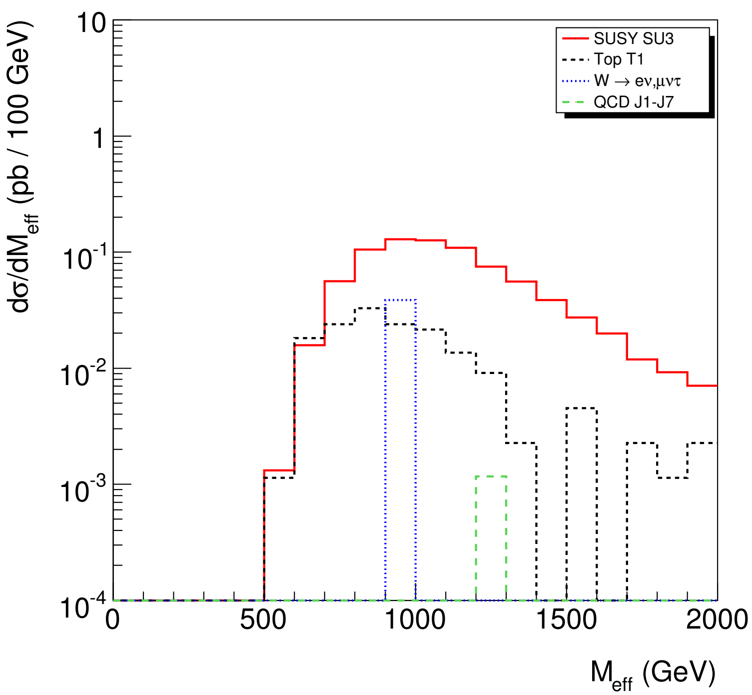
It works! Can use data to determine background and search for excess.

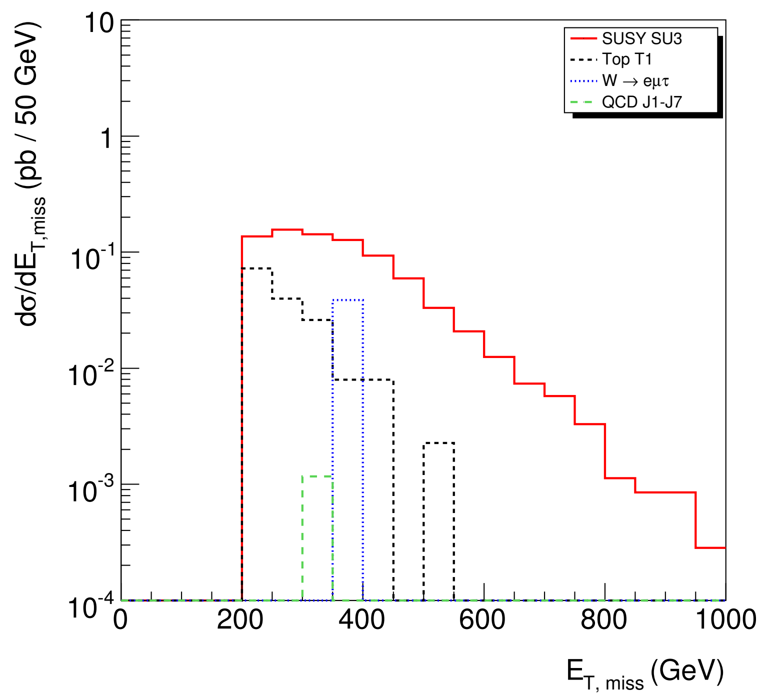
(But please keep working on those NNNLO corrections. . . .)

ATLAS

One-τ Mode: Even in mSUGRA τ decays are different from e, μ decays. Often dominant, especially for $\tan\beta \gg 1$.

Hadronic τ'ss ⇒ narrow, low-multiplicity jets. Much more background than for e, μ, but reconstructed τ makes QCD background negligible. Result for SU3 [FEP]:

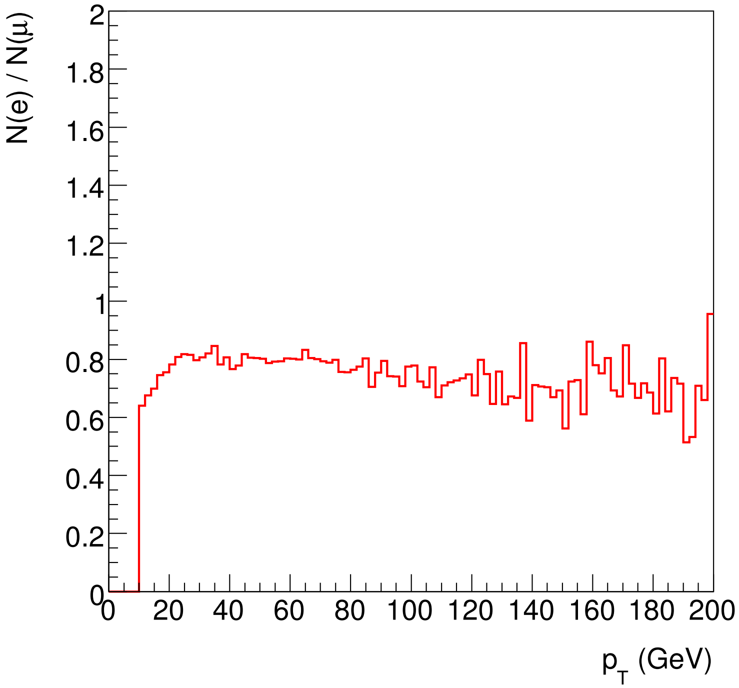


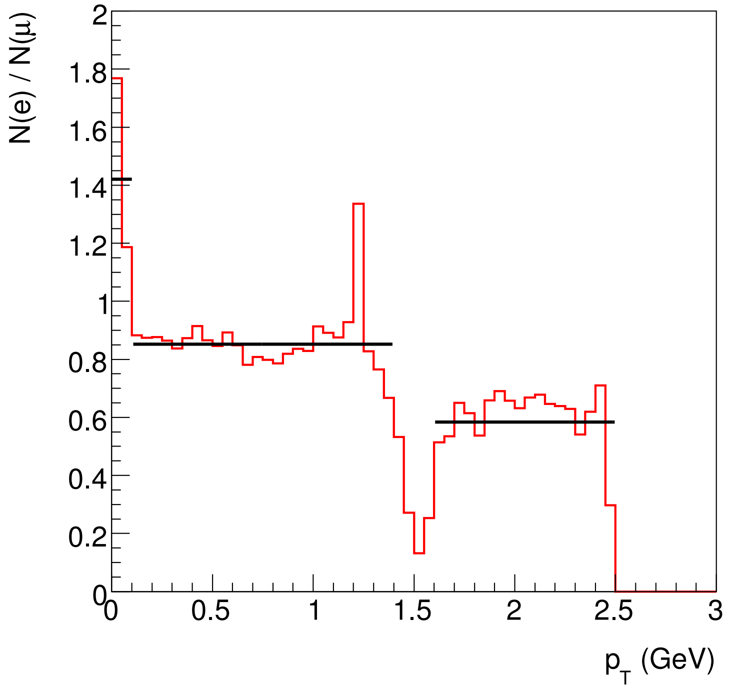


Searches using hadronic τ's need more study.

Dileptons: To avoid FCNC, $\tilde{\chi}_2^0 \tilde{\ell}^{\pm} \ell^{\mp} \to \tilde{\chi}_1^0 \ell^+ \ell^-$ should give only $e^+ e^-$ and $\mu^+ \mu^-$, while most backgrounds also give $e^{\pm} \mu^{\mp}$.

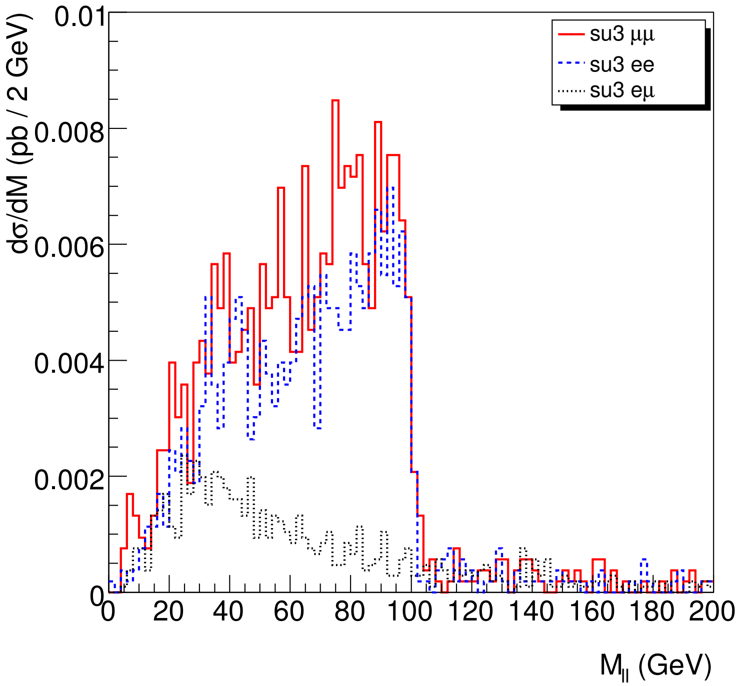
Relative reconstructed rates for top sample:

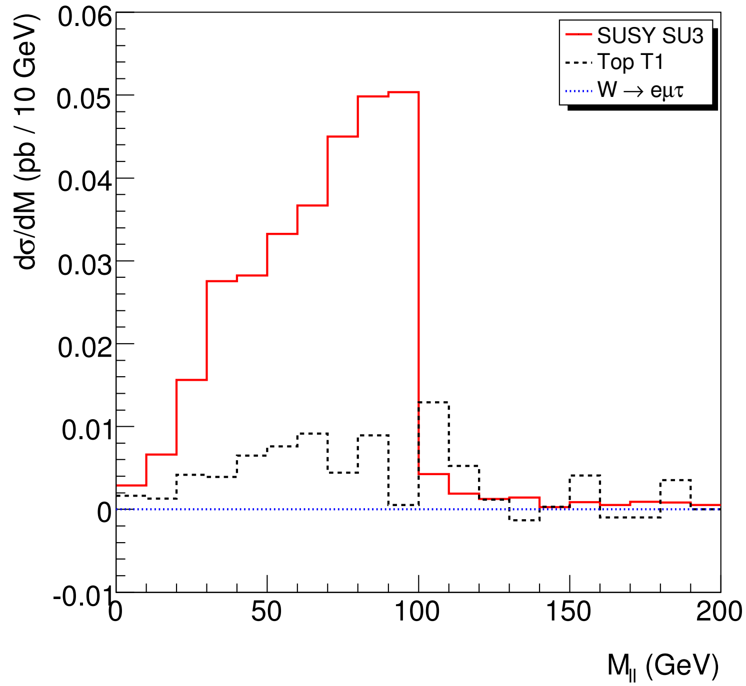




Poor e acceptance at low p_T is reconstruction artifact, but η dependence reflects real detector effects.

Plot dilepton distributions for SU3 and dominant top background correcting just for η dependence in a few bins [FEP]:



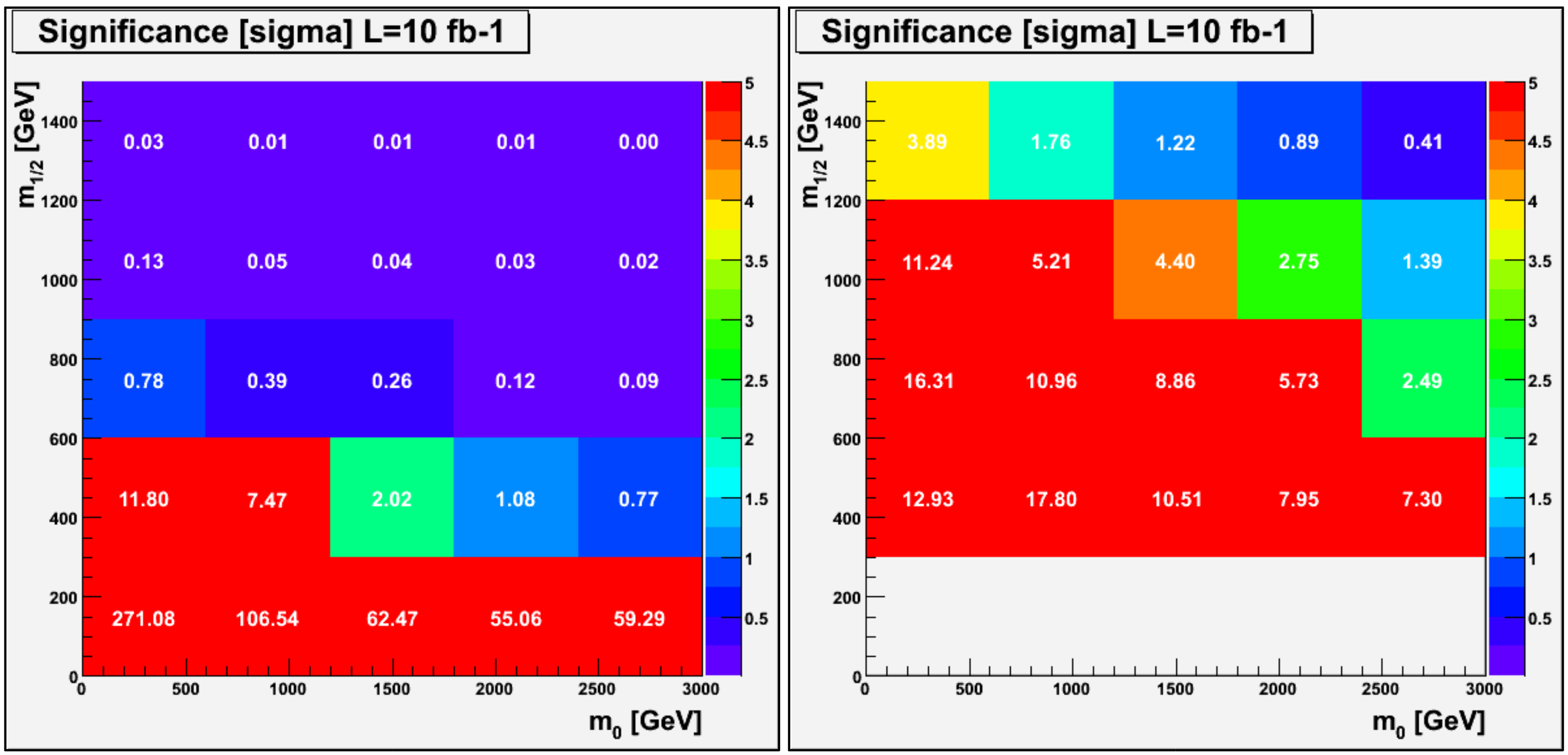


Can observe dilepton endpoint from $\tilde{\chi}_2^0$ decay. But mean top background is clearly nonzero. Need to improve efficiency correction.

ATLAS

TVMA Analysis: TVMA optimizes cuts for muti-variable analysis. CERN group [Eifert et al.] has used it to improve cut-based analysis. Variables are $\not\!\!E_T$, M_T, $\sum_j p_{T,j} + \sum_\ell p_{T,\ell}$, N_j, and reconstructed M_t.

Best performance is for analysis optimized at each point. But just two analyses are almost as good. Result for $10\,\mathrm{fb}^{-1}$:



ATLAS

Questionable whether we can utilize optimized analysis with initial data, but we can learn lessons from it.

If SUSY exists at 1 TeV mass scale, could discover it with first $1\,\mathrm{fb}^{-1}$.

Search relies heavily on $\not\!\!E_T \Leftrightarrow$ needs entire calorimeter to be working and reasonably calibrated.

Quasi-Stable SUSY Charged Particles

Some SUSY models predict quasi-stable charged particles:

- GMSB with long-lived NLSP $\tilde{\ell}$ at bottom of decay chain.
- Split SUSY with super-heavy scalars: $\tilde{g}$ forms long-lived charged or neutral R hadrons.

Any heavy particle loses $\sim 3\,\text{GeV}/\beta^2$ from dE/dx and $\lesssim 1\,\text{GeV}$ per interaction. Looks like muon with $p_T \sim m \geq 100\,\text{GeV}$ but $\beta < 1$.

ATLAS muon system gives $\sim 1\,\text{ns}$ time resolution over $\sim 10\,\text{m}$.

Detailed GEANT models for R hadrons available [Kraan; Mackeprang, Rizzi]. Can have charge exchange — c.f. low energy hadronic interactions.

Must modify muon reconstruction for $\beta < 1$. Not (yet) done for new software.

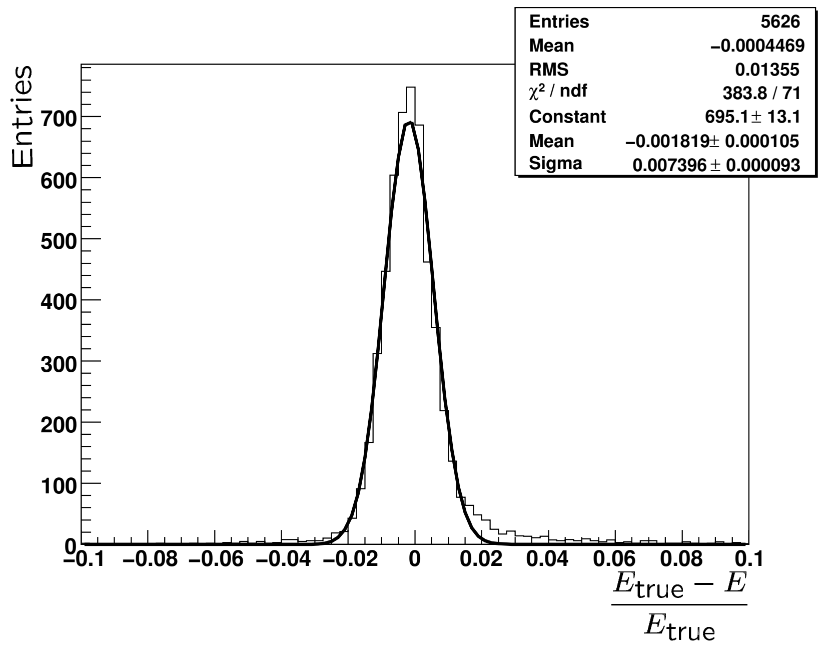
Exotics

Anything new except Higgs and SUSY. Many models, but only a few basic signatures. A few examples. . . .

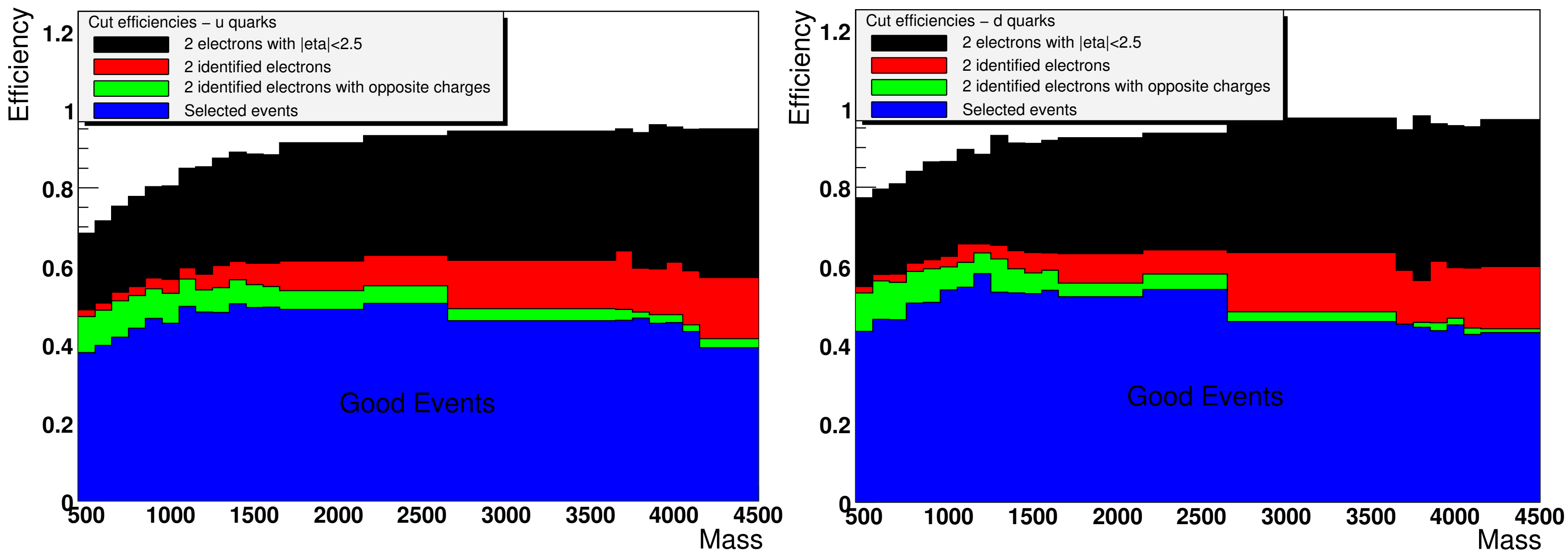
Recent $Z' \to e^+e^-$ analysis [Ledroit, Morel, Trocme] using CDDT [hep-ph/0408098] parameterization of plausible models.

Standard e reconstruction not really optimized for high p_T but seems OK. Resolution for 1.5 TeV is $< 1\%$.

Reconstruction efficiency seems reasonable.



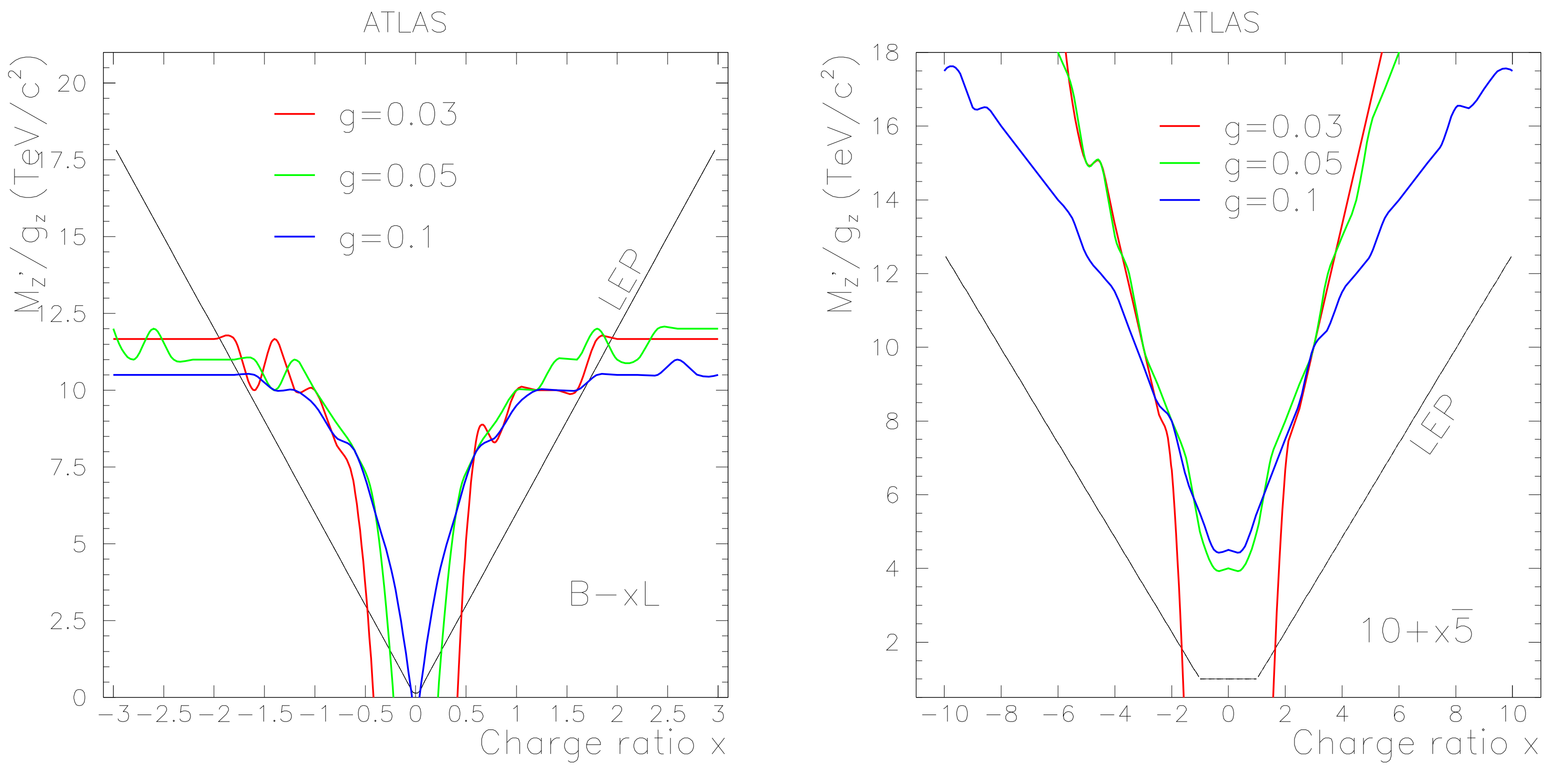
Since symmetrized decay is $1+\cos^2\theta^*$, have universal efficiencies for dominant $u\bar{u}$ (left) and $d\bar{d}$ (right) processes:



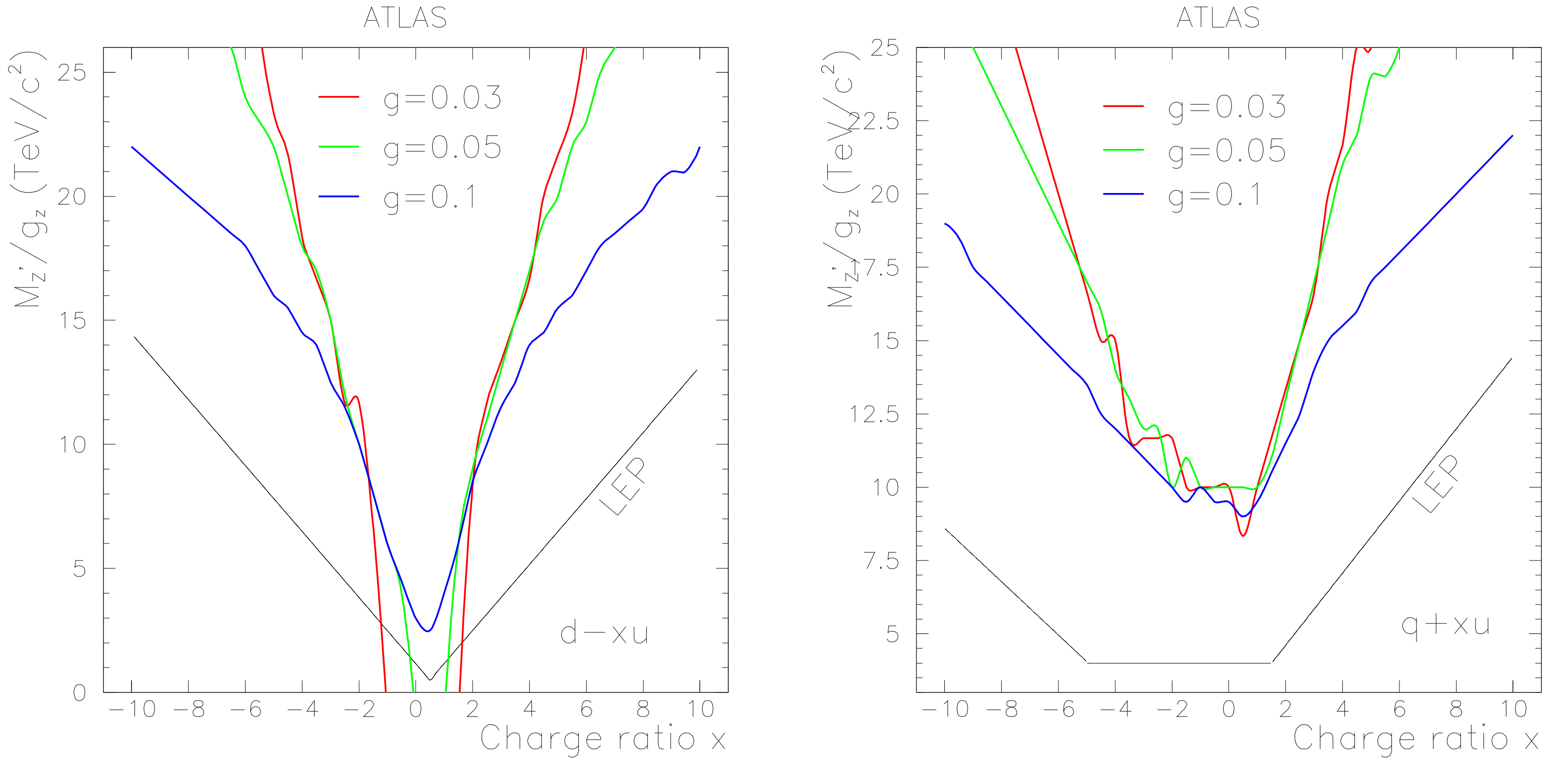
Rather similar; use $u\bar{u}$ to be conservative.

Following plots show reach for $400\,\mathrm{pb}^{-1}$ for four CDDT classes. Reach is somewhat better than for LEP or Tevatron; will improve with more luminosity.

ATLAS



(Couplings for each model depend on one parameter *x*.)



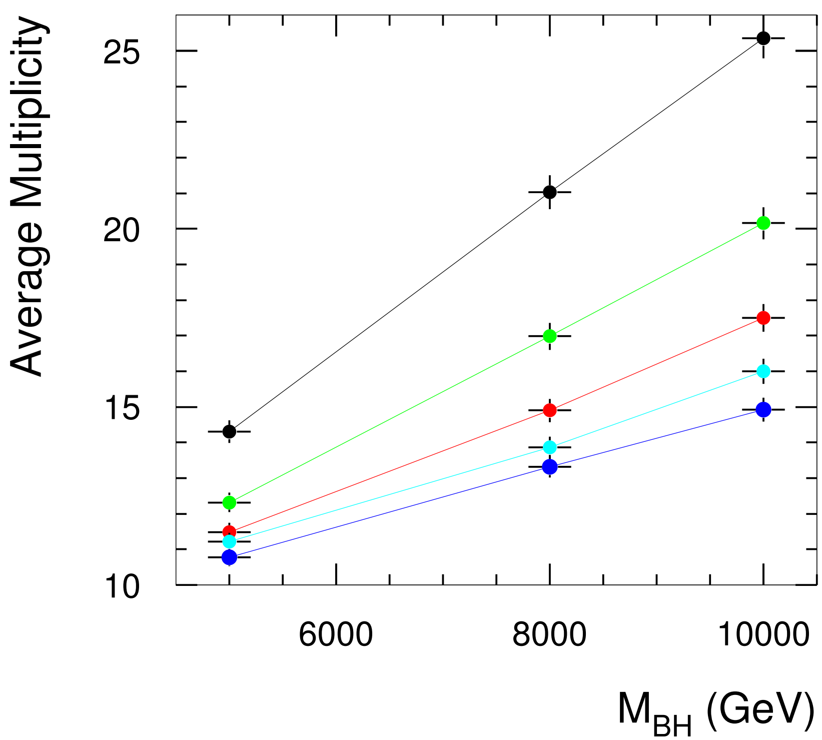
Many other analyses . . . I found this a particularly thoughtful one.

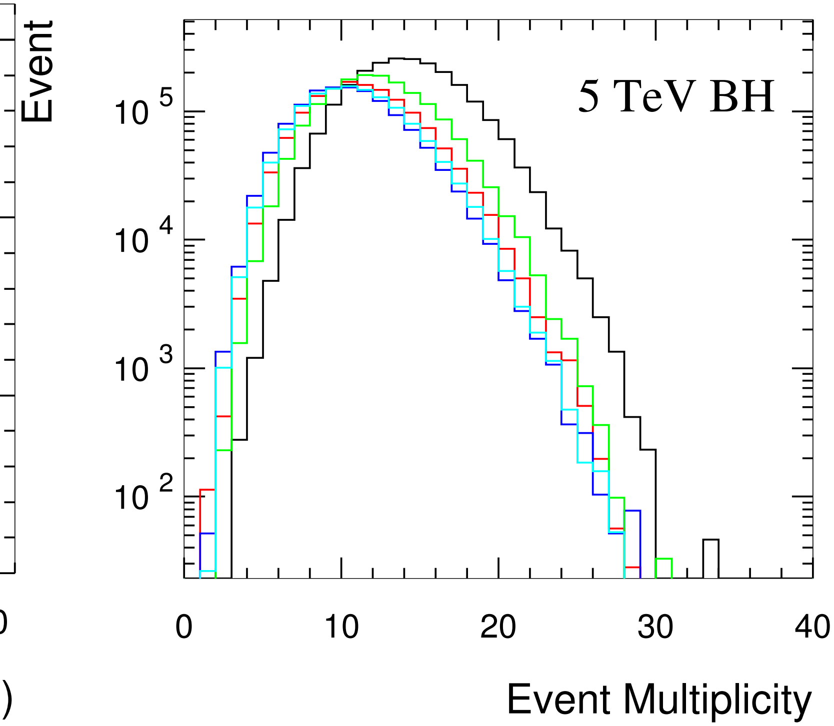
ADD Black Holes

Could have fundamental Planck scale $M_{\mathrm{Pl}} = 1\,\mathrm{TeV}$ [hep-ph/9807344] . Then black-hole production for parton collisions with $Q \gg M_{\mathrm{Pl}}$:

$$\sigma(M_{\mathrm{BH}} > 5\,\mathrm{TeV}) = 62\text{–}34\,\mathrm{pb}$$

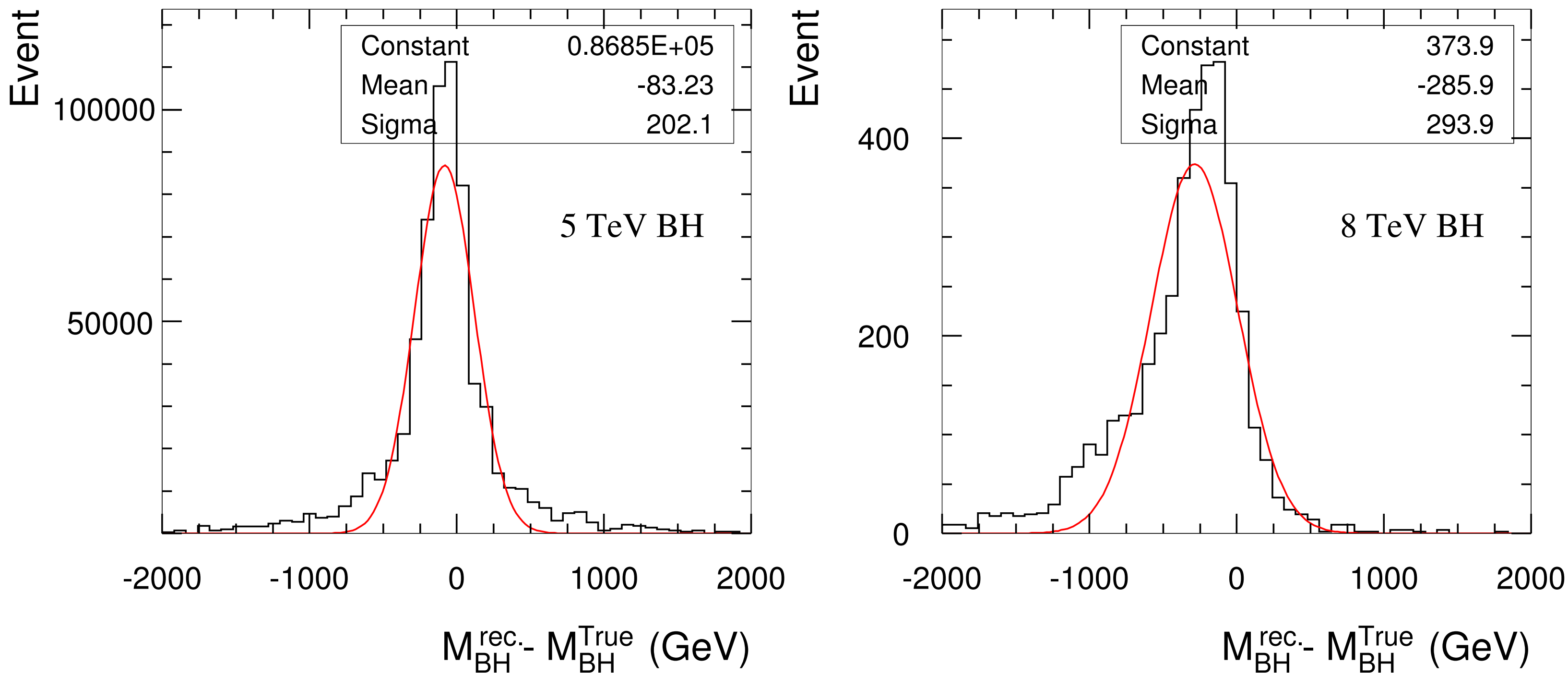
Black holes evaporate into all SM particles [hep-ph/0411022]:





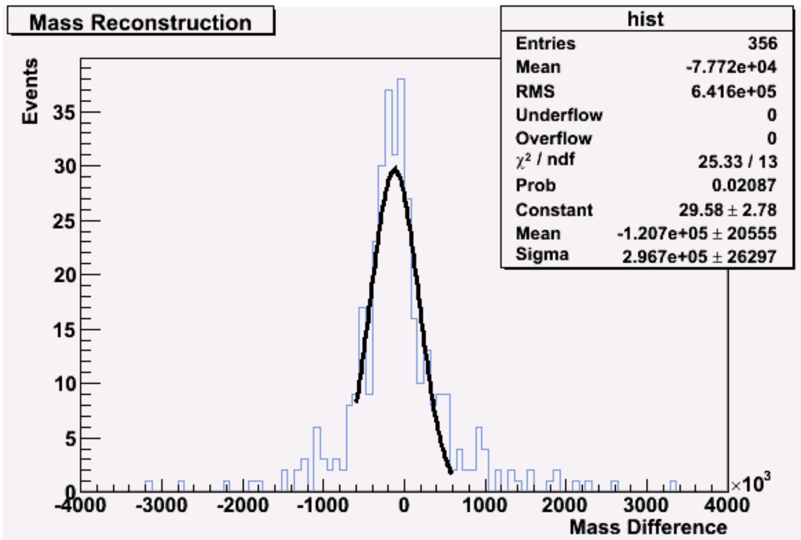
Require $\sum p_{T,J} > 2.5\,\%eV$ and ≥ 1 e, μ, or γ with $p_T > 1\,\mathrm{TeV}$. Gives 5200 BH events ($n = 6$) for $1\,\mathrm{fb}^{-1}$ with small background [Frost].

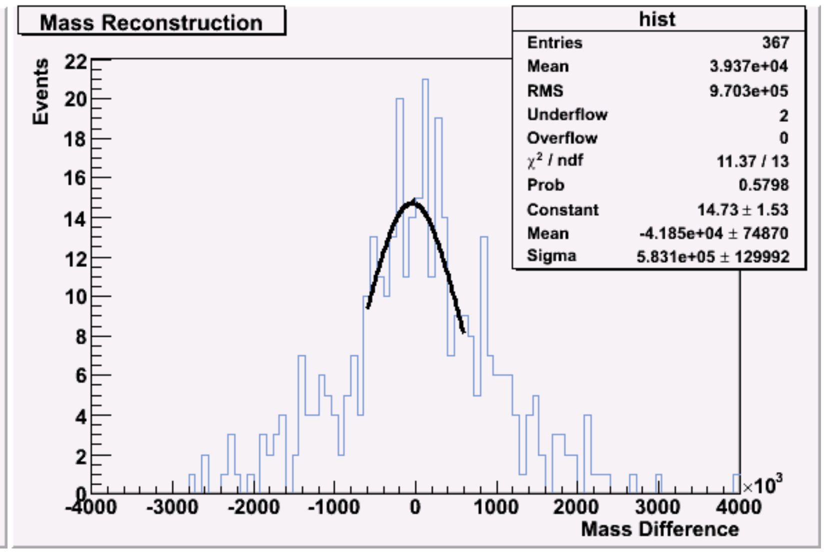
Reasonable mass resolution from reconstructing everything visible:



ATLAS

Now using full simulation to study signal and backgrounds and to optimize analysis. One example: $R = 0.4$ cone (left) works much better than $R = 0.7$:





Obviously speculative, but. . . .

Summary

We have speculated about TeV scale physics for at least 25 years. The LHC is about to provide answers.

Might well find something new with early data. SUSY? Black holes?

Really expect to find Higgs — but probably not with $1\,\mathrm{fb}^{-1}$.

Other scenarios (e.g., Little Higgs signatures) may take a long time.