Some (Very) Experimental Thoughts on the LHC

Tim Nelson

SLAC ATLAS EXPERIMENT

KITP - The First Year of the LHC

“The First Year of the LHC”

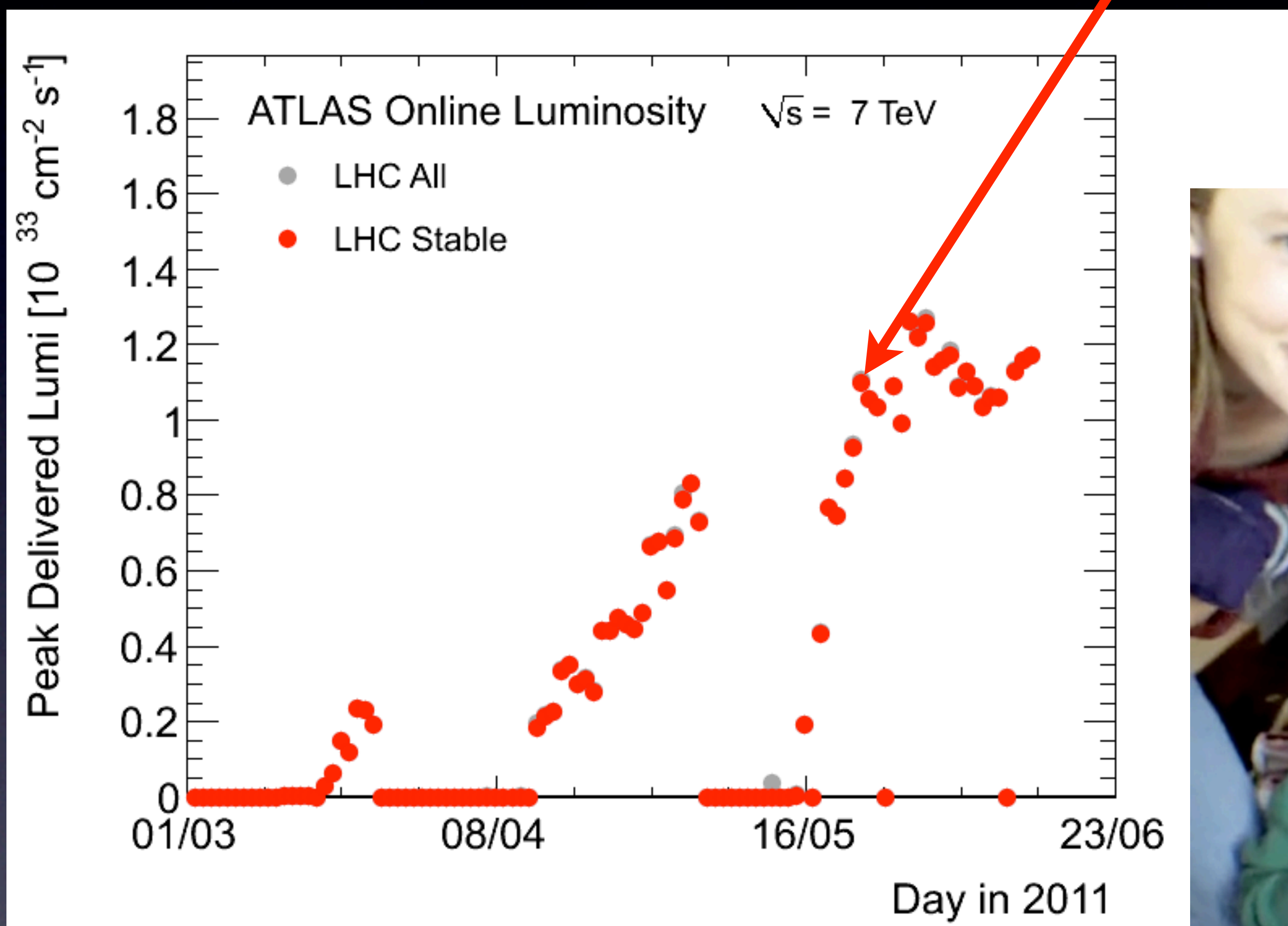
- Which “LHC”?
  - The machine
  - The experiments
  - The data and physics
- Some news and opinions on all of this. (not necessarily fair and balanced)

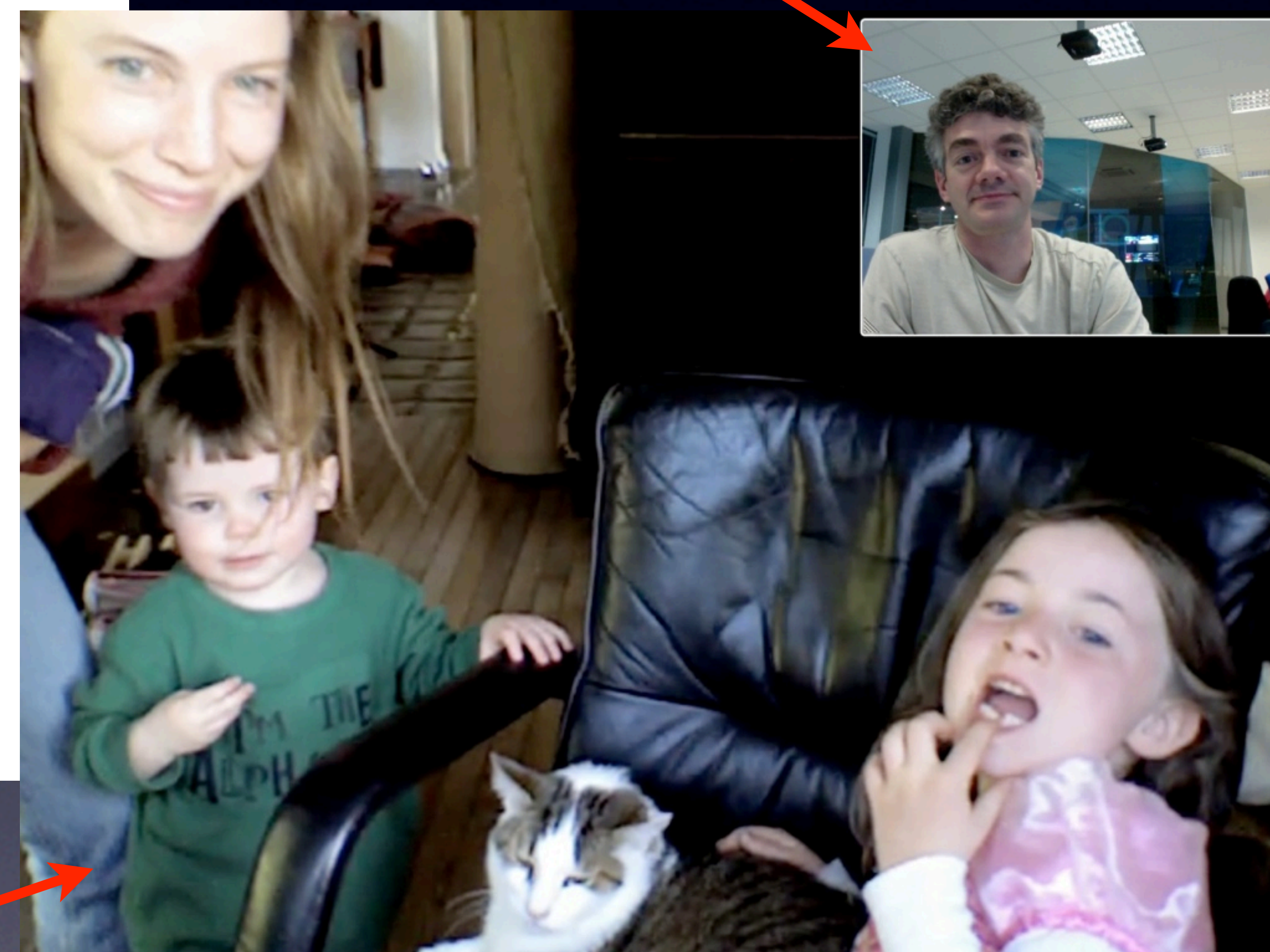
The Machine

- The *actual* first year of the LHC was pretty rough!
- Silver lining: a lot of work was done to understand the machine before trying again.
- Stray baguettes (which are everywhere in France) aside, the restart has been amazing.
- New records almost weekly.

Sunday, May 22, ~2:30 AM CET - $1.1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Already achieved goal for the *run.*

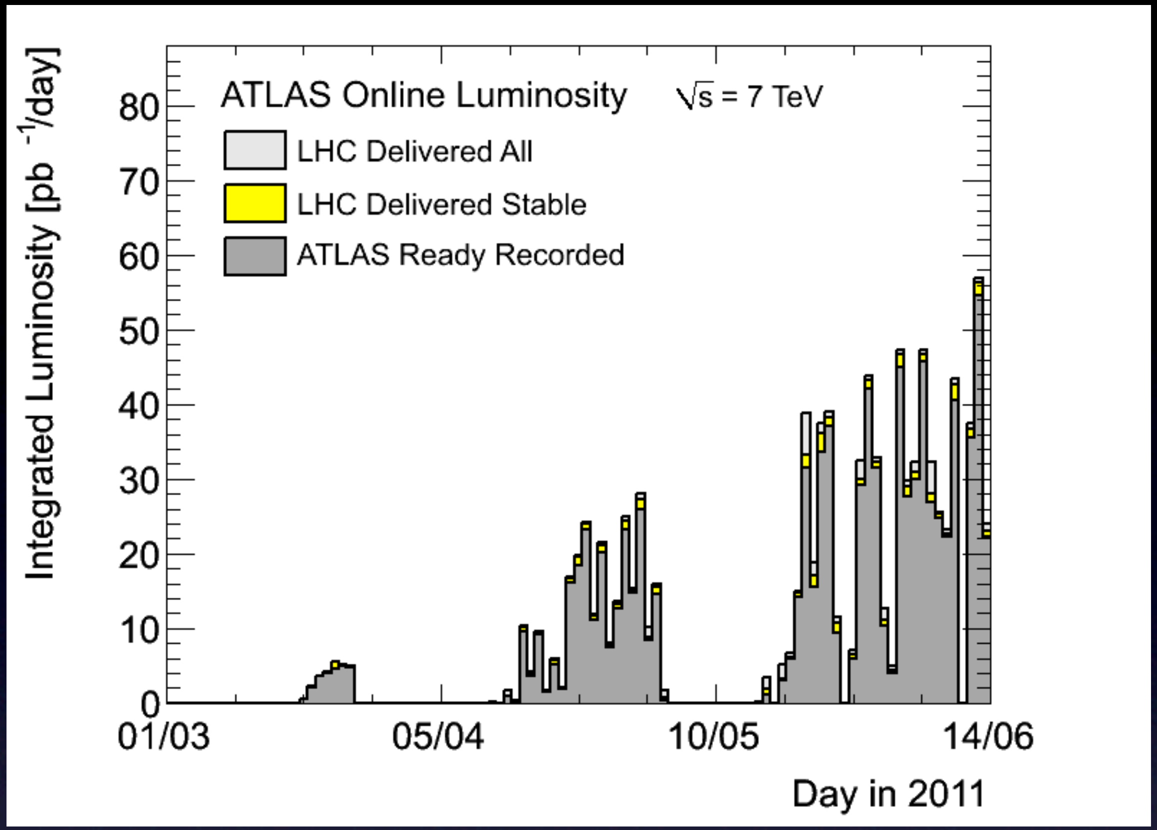


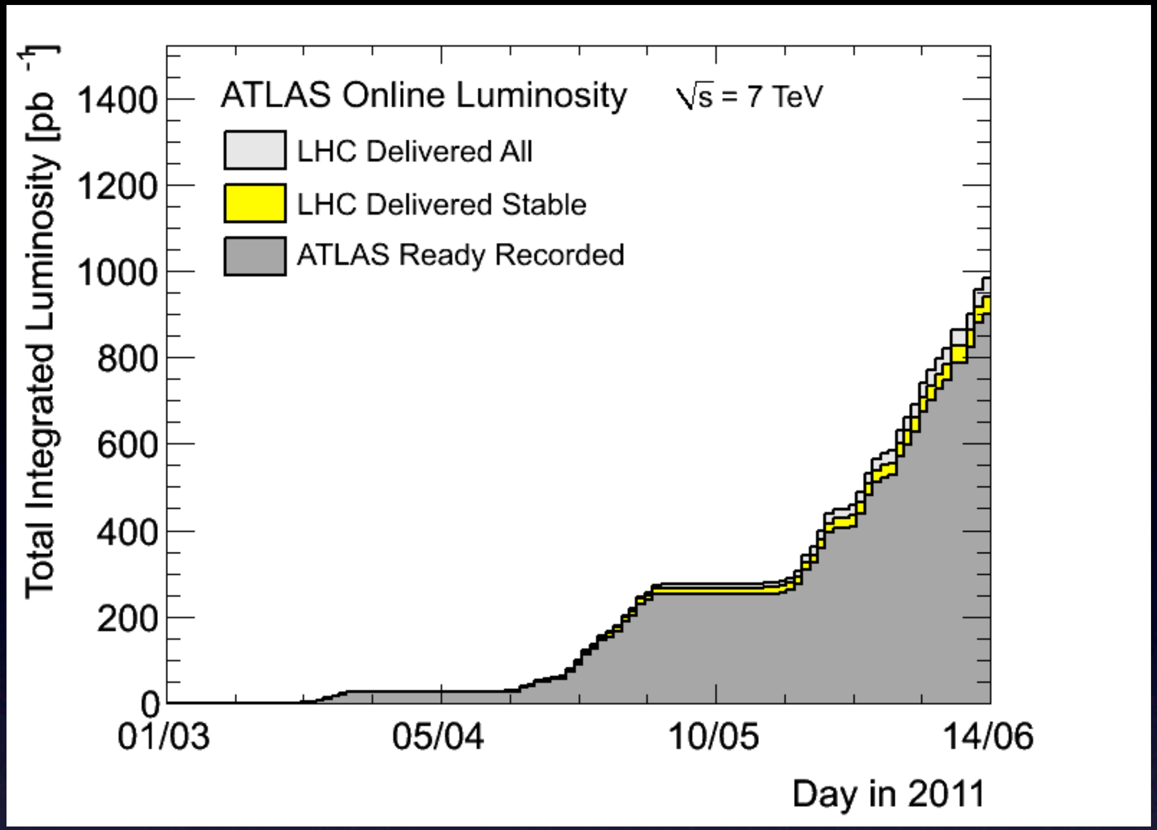


Saturday May 21, ~5:30 PM PDT

LHC Plans

- Currently working to establish reliable and consistent running in the vicinity of $1 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Recent scares in machine operation: possible that future gains will be approached more cautiously.
- Once 1 fb^{-1} is surpassed, I expect to see a push to $\sim 1.6 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, still with 50 ns bunch spacing.
- Talk of $5 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 50 ns bunch spacing this year: this means ~20 pileup events per collision!
- 25 ns bunch spacing coming soon?





- Simply achieving smooth running at *current* luminosities results in 3-4 fb^{-1} in October.
- If there are further improvements, we could have significantly more than 5 fb^{-1}.

Questions

- Will we stay at 7 TeV? Data from tests on splices may create confidence in an energy increase.
- When is enough, enough? Once we have 10 fb^{-1}, do we need more data before an energy upgrade if nothing has been found yet? Not clear that energy upgrade can be accelerated.
- Even if not ready for energy upgrade, smooth running increases effort available to invest in future gains.

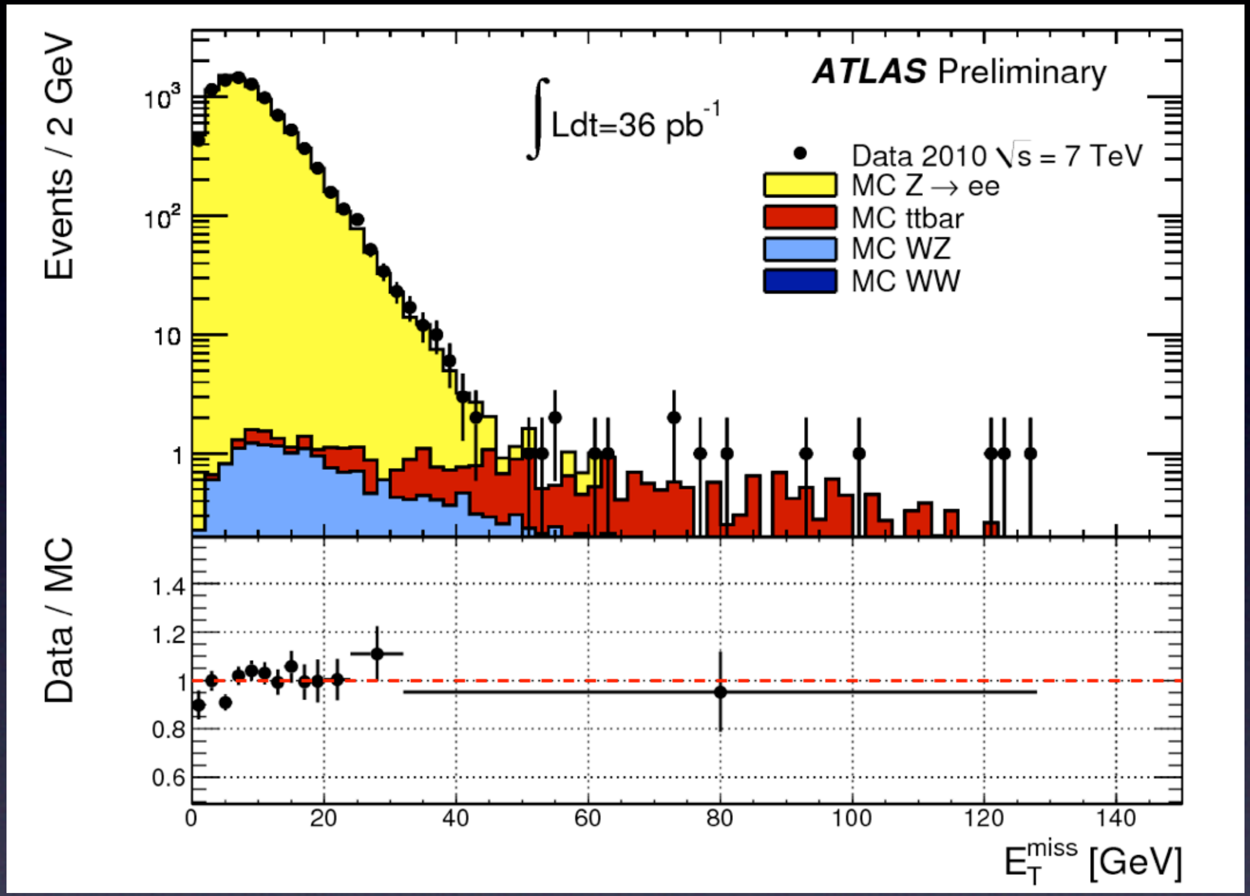
The Experiments*

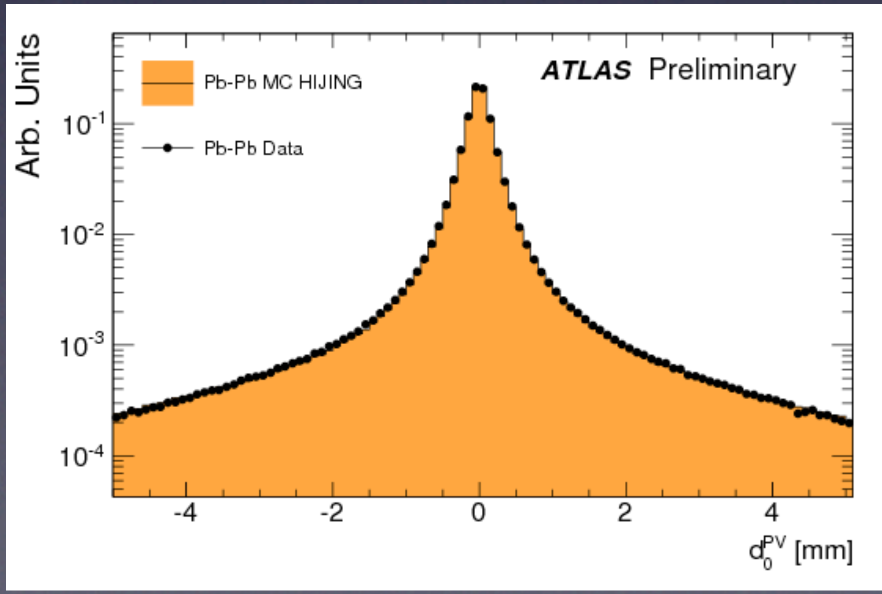
- Delays due to LHC accident were enormously beneficial to the detectors also
- Commissioning has gone extraordinarily well
- Our detectors are better understood now than other detectors I have worked with after several years of running.

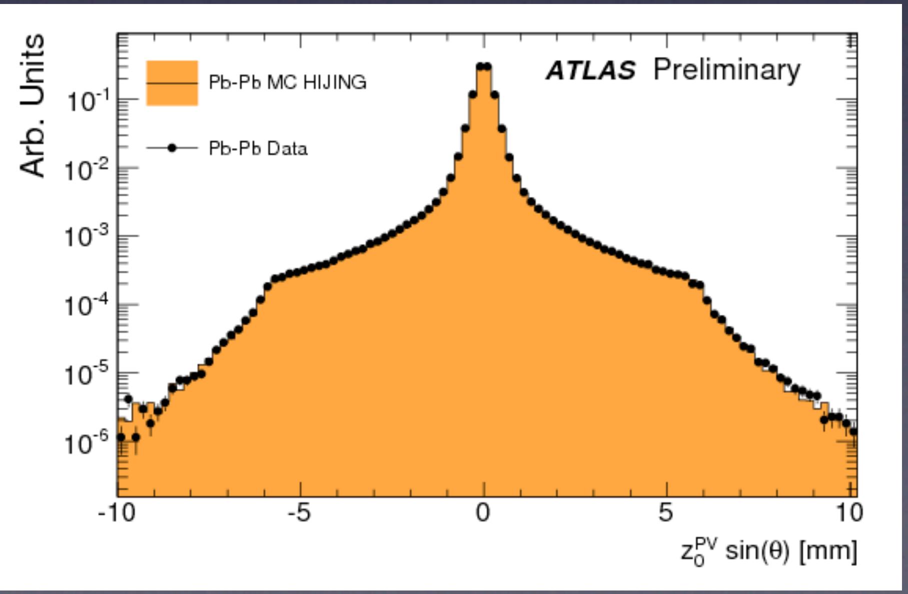
*I know much more about the situation on ATLAS than CMS

Detector Performance

3000 physicists in need of service work results in exquisitely calibrated detectors







Detector Problems

- A number of ATLAS subsystems battling ongoing problems: some are easier to live with than others.
- Some are becoming more severe with increasing luminosity; it's not clear if there is a show stopper at 5×10^{33} $cm^{-2}s^{-1}$ and 50ns spacing, but there could be.
- I know CMS has had some annoyances too, but do not know the status there well enough to comment.

Detector Future

- Some near-term upgrades are the works, but most are very minor.
- Exception: a new inner pixel layer for ATLAS (IBL), is essential if success with the machine continues.
- The LHC accident resulted in a major divestment from upgrade funding in the US and elsewhere.
- The high-luminosity detector upgrades are at risk of being caught flat-footed if LHC success continues.

Baguette et Buerre Physics

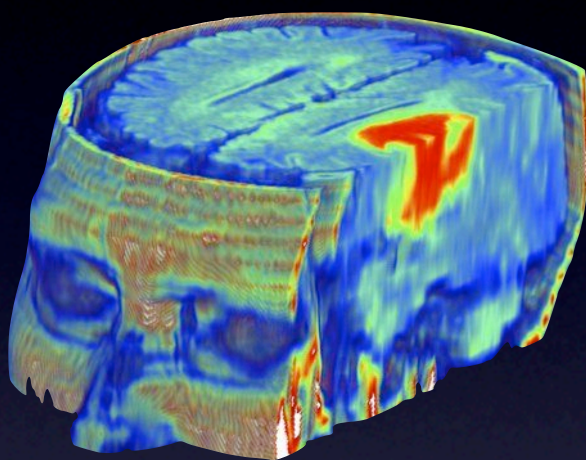
Higgs + SUSY + Z' + ℓ^* + q^* + leptoquarks + ... =

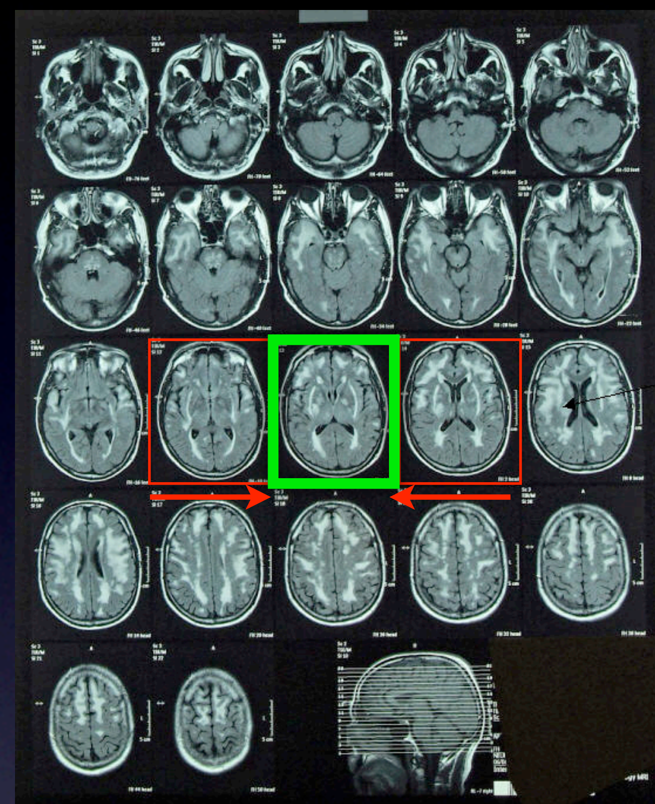
$$a \cdot \text{leptons} + b \cdot \text{photons} + c \cdot \text{jets} + d \cdot \text{btags} + \text{MET}$$

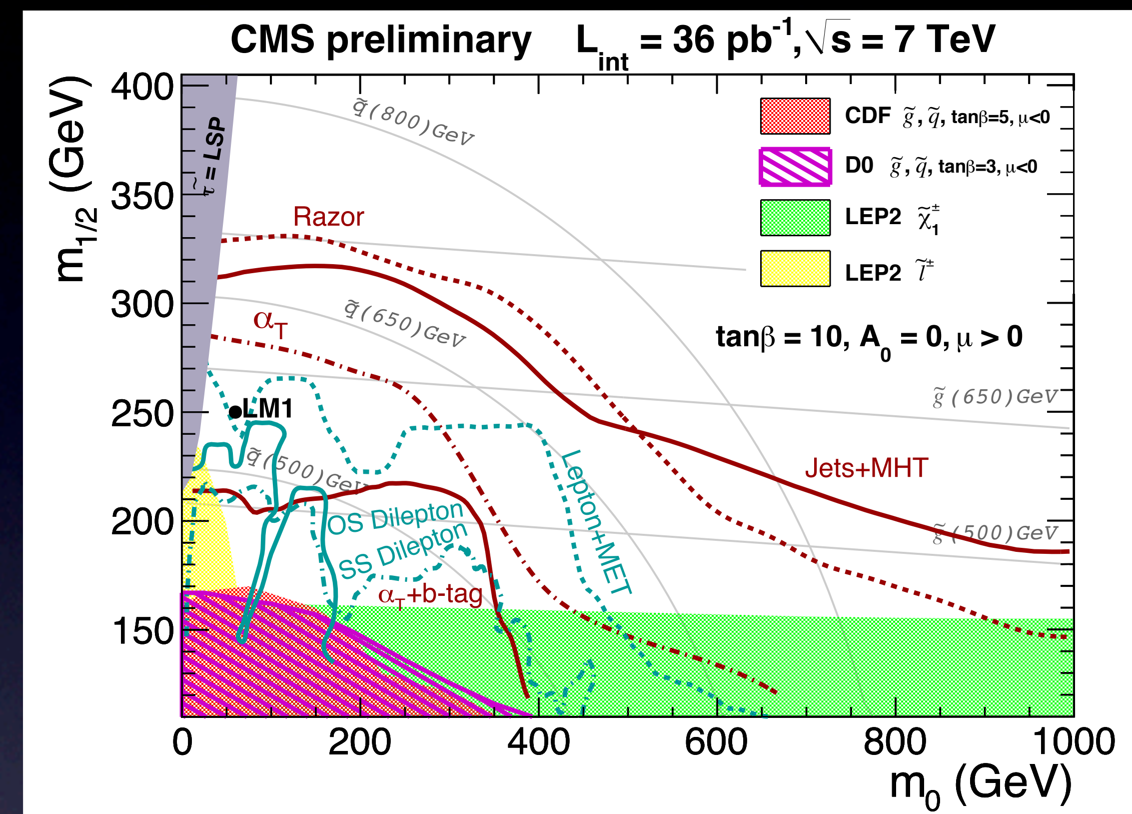
- If we trusted SM MC, could do a single multidimensional comparison between the data and MC to look for new physics*
- We don't, and the necessity for data driven background models is what forces us to slice cross-sections through the signature space.

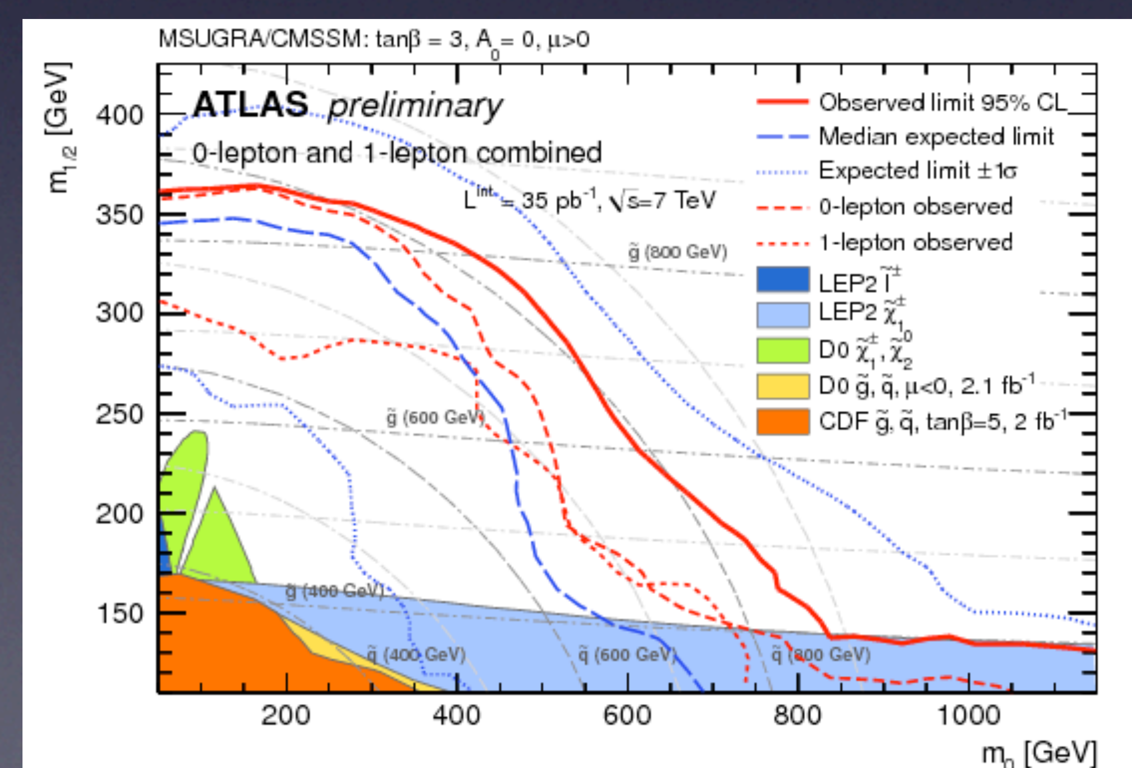
*has been tried before: leads to few answers, many questions.

Slicing and Dicing New Physics









We rely upon you to tell us which are the interesting slices!

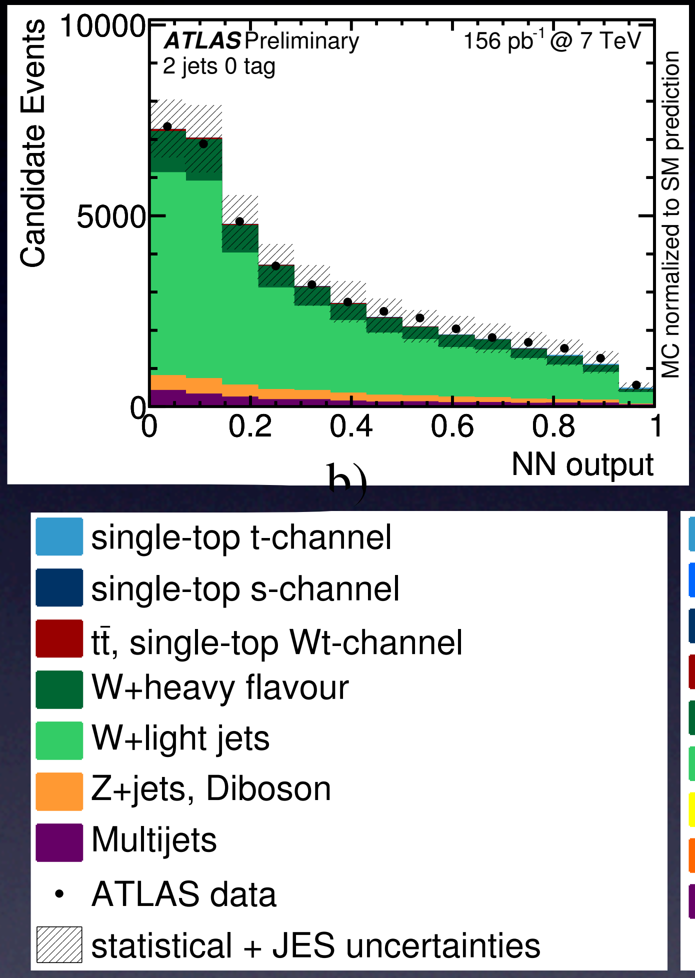
Where are We Now?

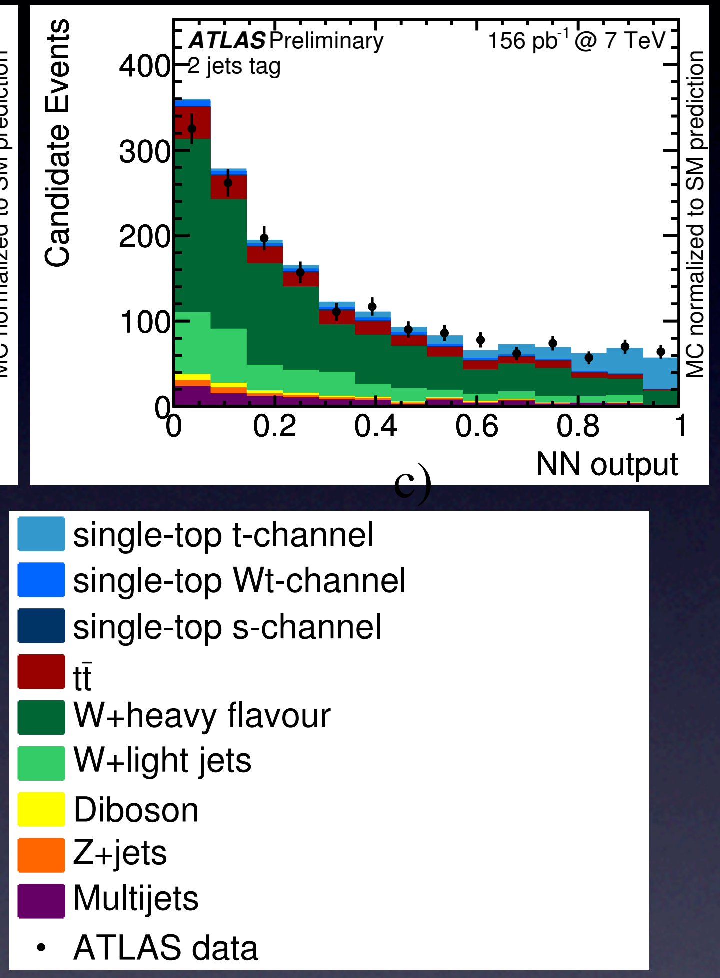
- the SM is still there
  - beginning to see some nice precision tests

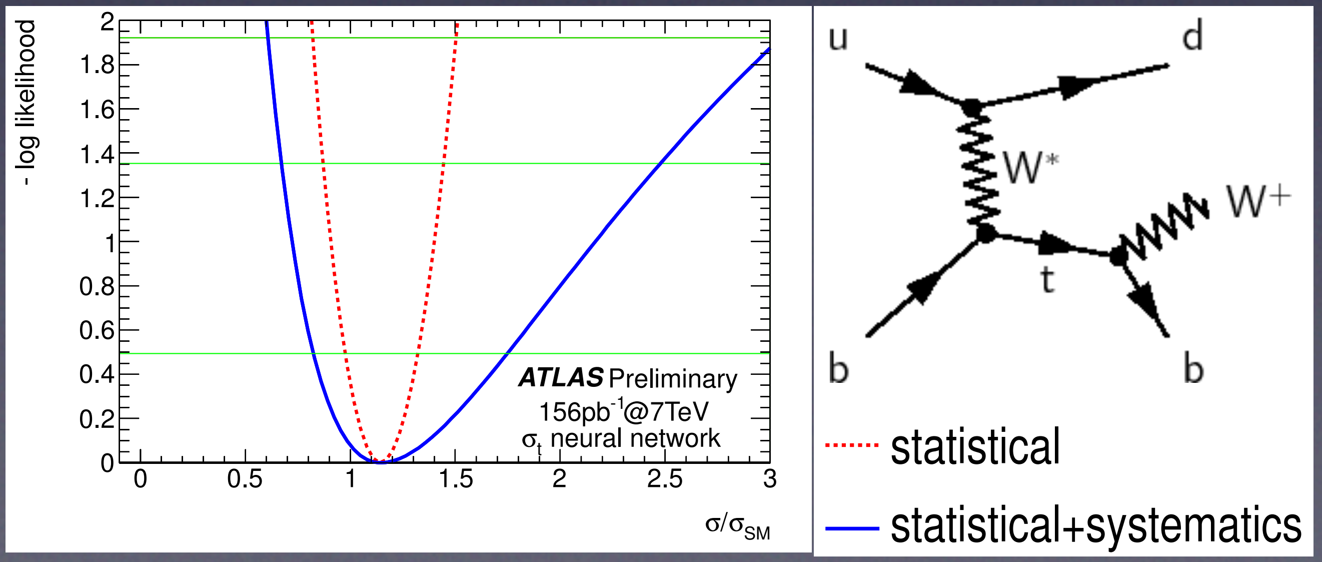
new: 156 pb^{-1}

t-channel
single top
at ATLAS

ATLAS-CONF-2011-088







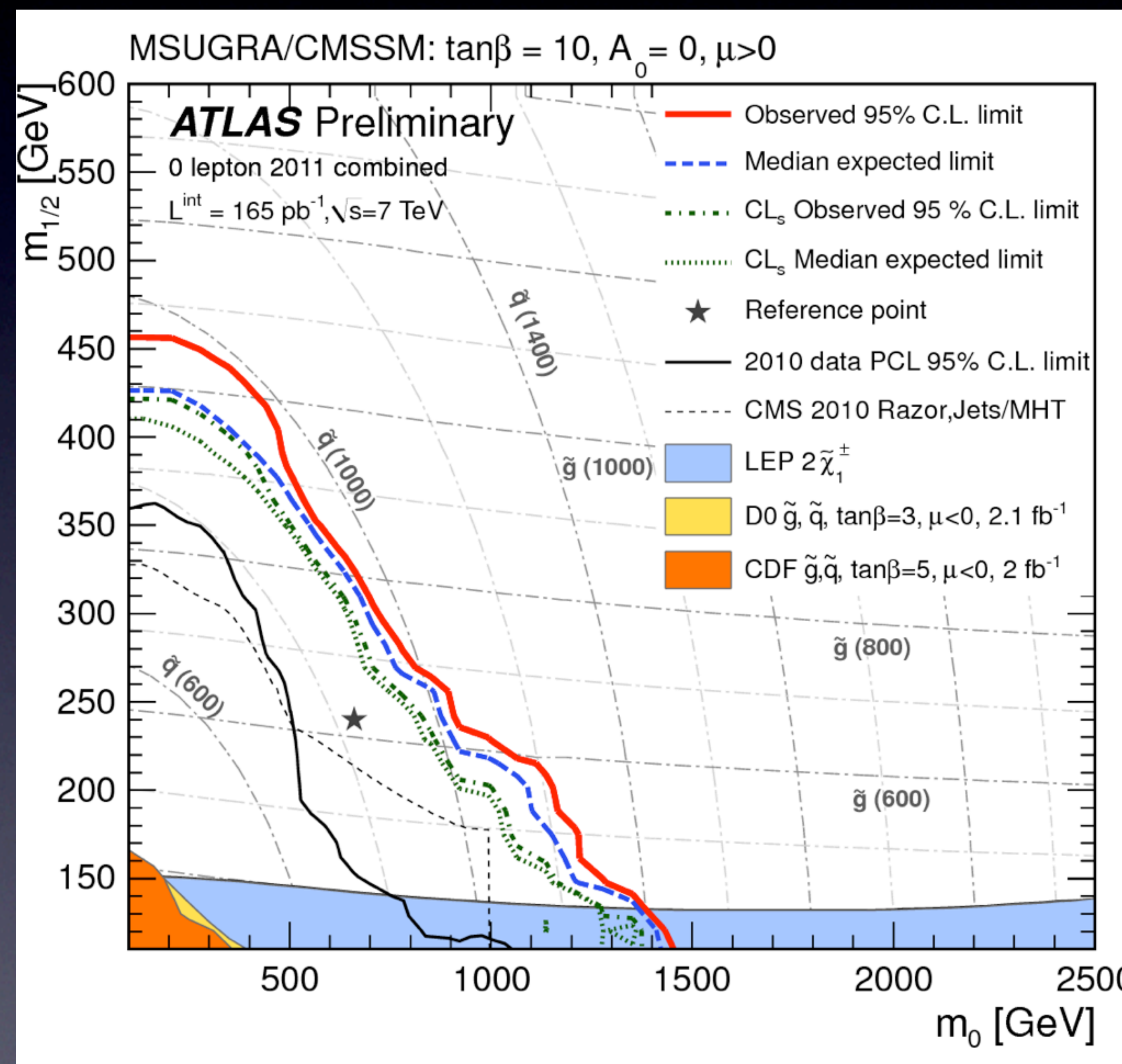
Where are We Now?

- SUSY not found yet
  - sensitivity to mass scale is approaching 1TeV

new: 165 pb^{-1}

SUSY 0-lepton results from ATLAS

ATLAS-CONF-2011-086



Where are We Now?

- no Higgs
  - but things begin to get interesting with ~20×data!

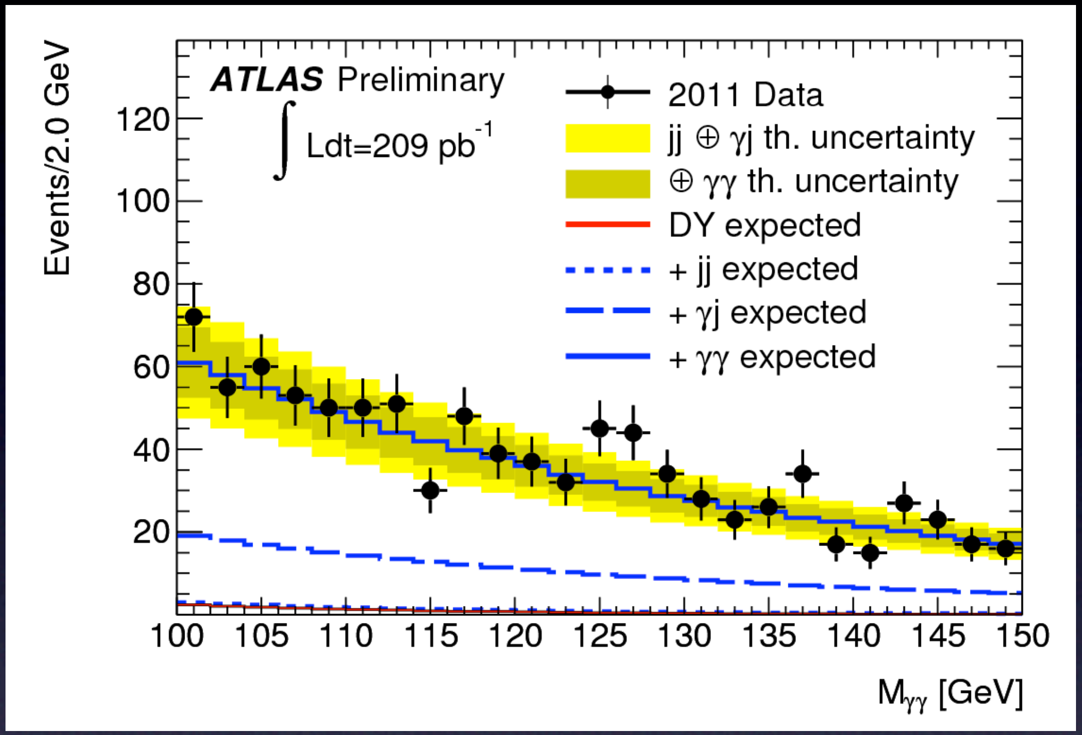
new: 209 pb^{-1}

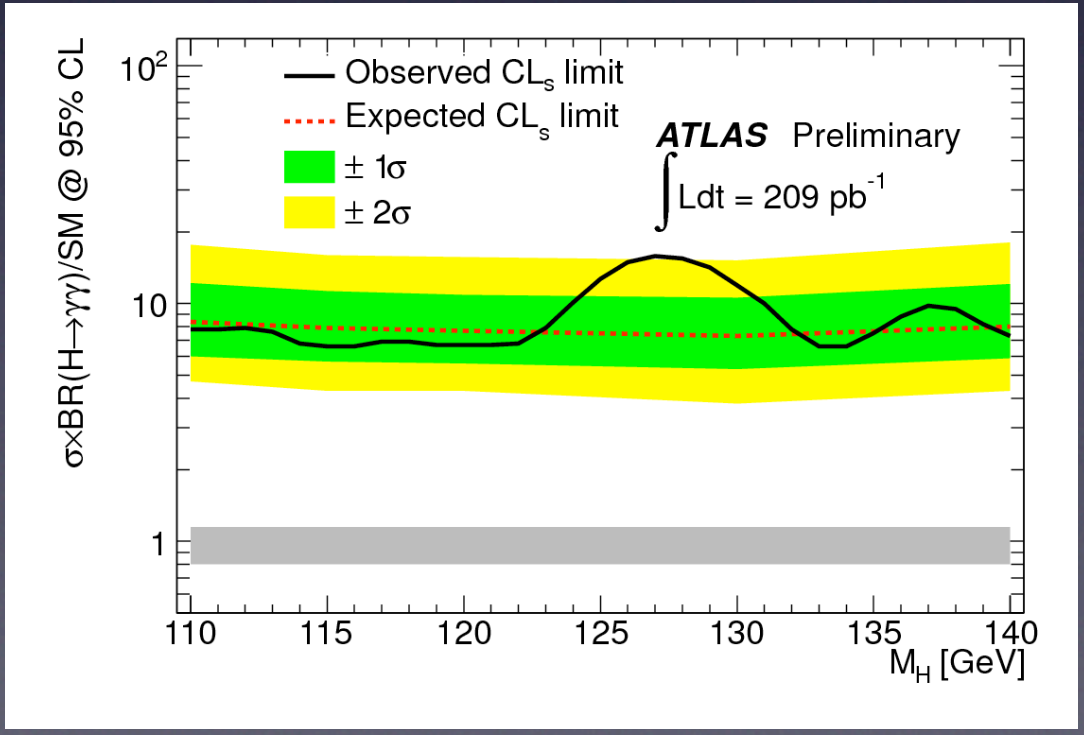
$H \to \gamma\gamma$

results from

ATLAS

ATLAS-CONF-2011-085





Where are We Now?

- no Z′, W′, gravitons technicolor, etc...
  - probing mass scales above 1TeV

new from ATLAS

Z′ w/ 167 pb^{-1}

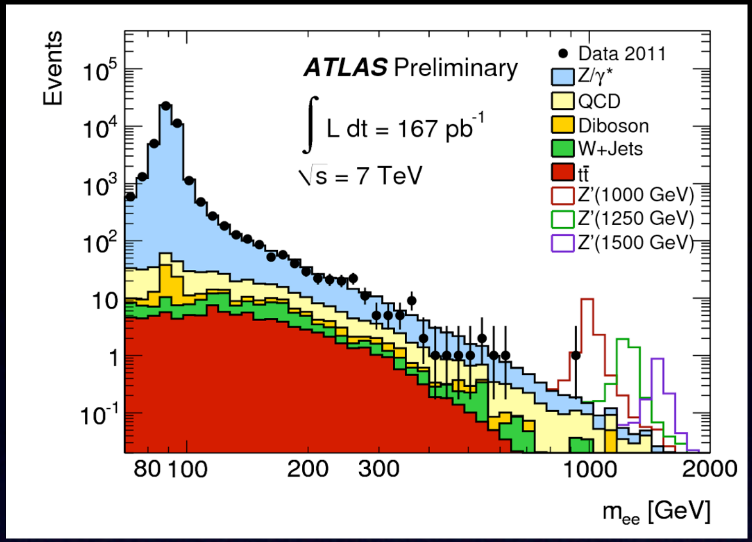
ATLAS-CONF-2011-083

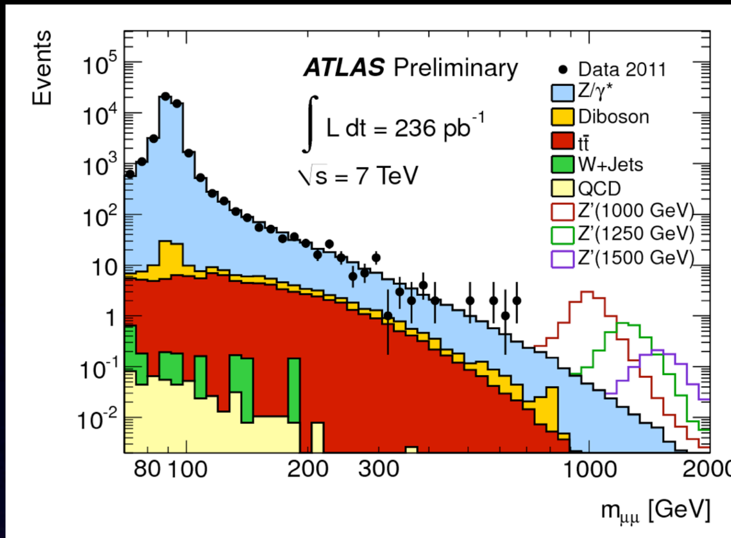
W′ w/ 205 pb^{-1}

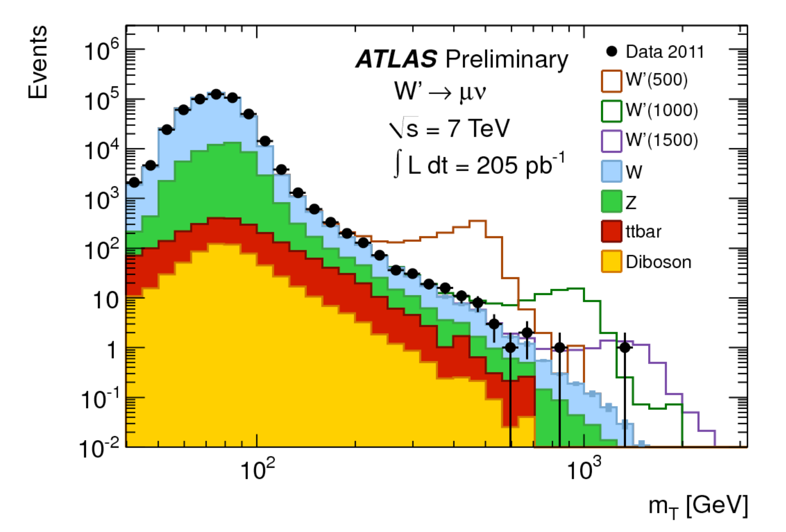
ATLAS-CONF-2011-082

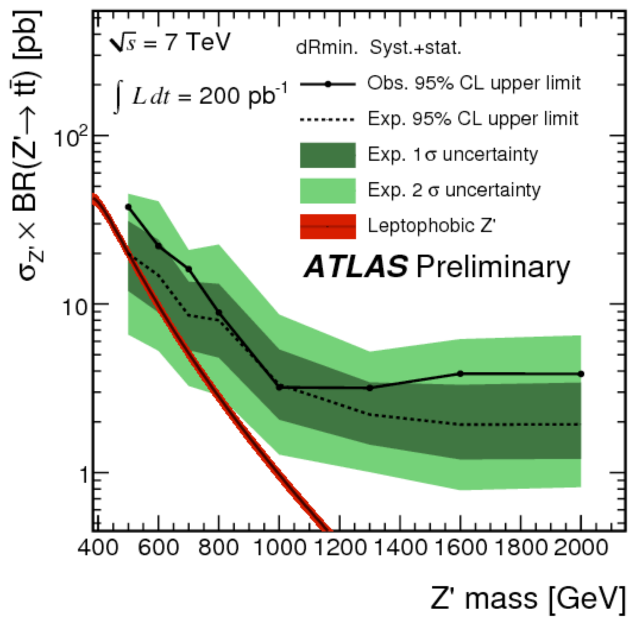
$t\bar{t}$ resonance w/ 200 pb^{-1}

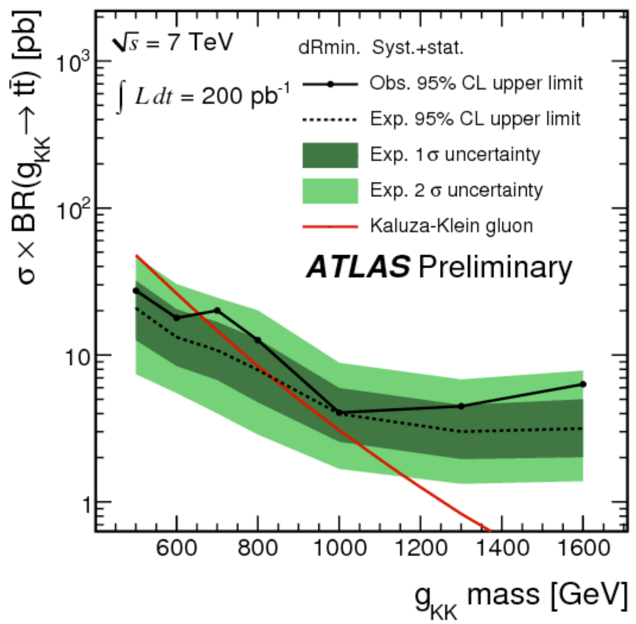
ATLAS-CONF-2011-087











Where are We Going?

- An army of analyzers will slice the bread-and-butter search space along every conceivable axis.
- There are some very skilled people among them that should be able to ensure the quality of these results.
- *Pay careful attention to how backgrounds are modeled when judging the quality of a result!*
- By the end of the year, we should have some truly impressive sensitivity to SUSY, Z', etc, and hopefully we will find something remarkable!!

What Keeps Me Up at Night

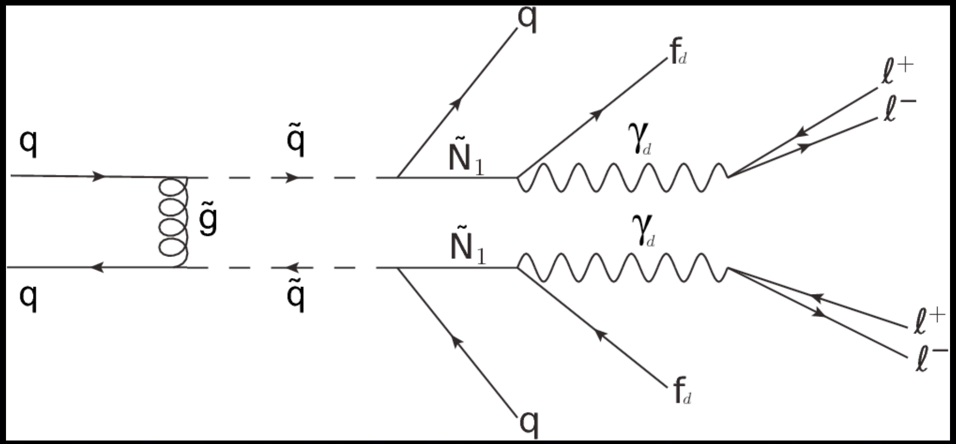
- What if we don't find anything? Data doubling won't come so quickly in the future.
- If that happens, is there really nothing there, or are we just not looking closely enough?
- In our hubris, have we designed detectors that are only good at seeing what we expect to find? What if new physics is, well... spicier?

Spicy Physics

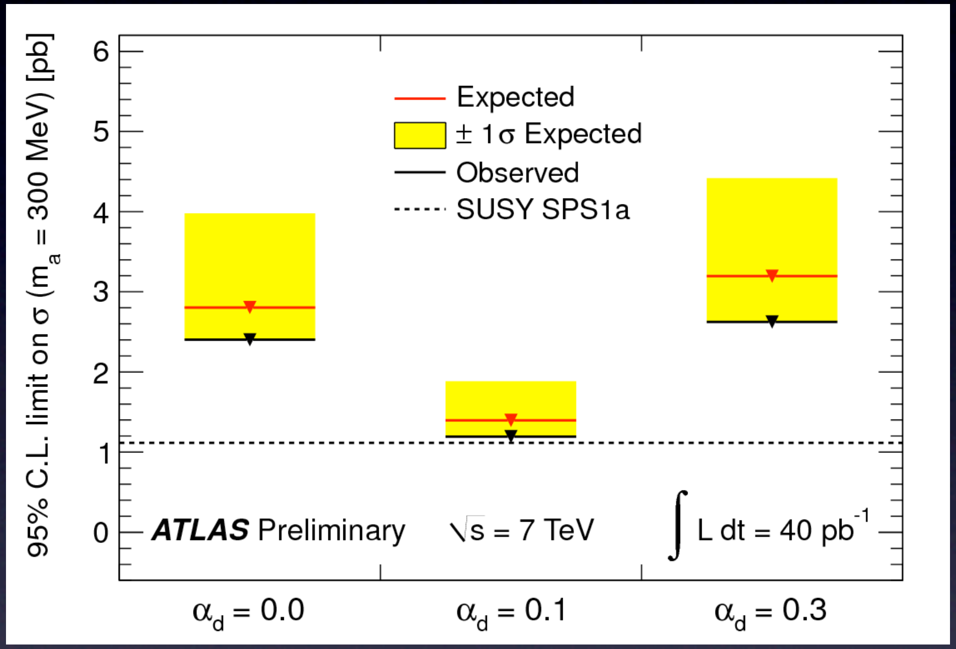
- hidden valleys - displaced jets
- dark photons - lepton jets
- black holes - unusual event p_T
- Stable Massive Particles - bizarre tracks, cal clusters
  - R-hadrons
  - quirks
  - monopoles / dyons
  - ???

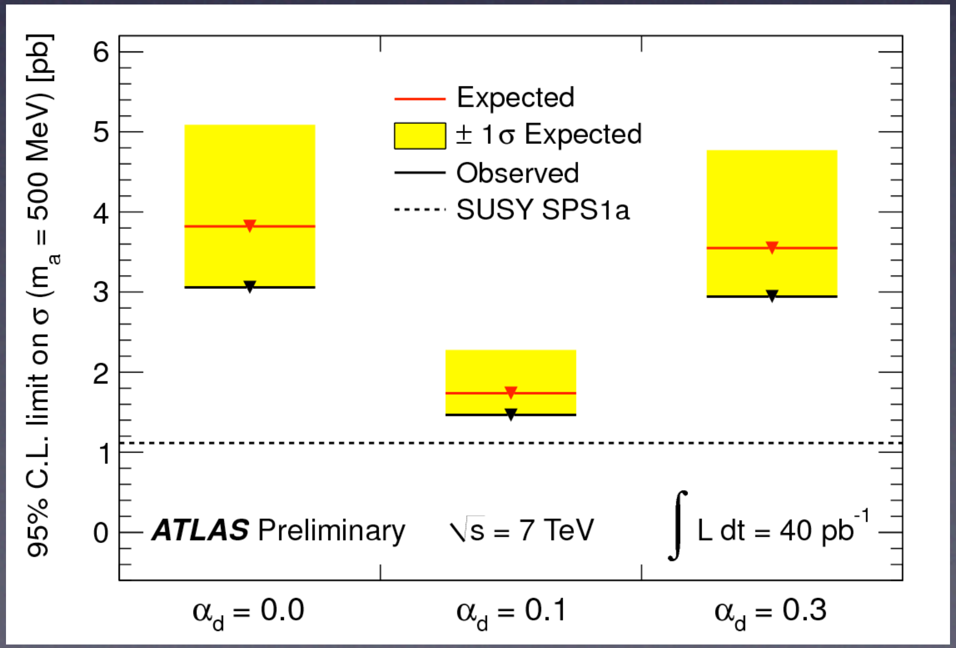
These things require a different level of creativity.

Lepton Jets



- Search for jets of leptons from dark photons produced in SUSY cascades
- First search at ATLAS, in muon mode just completed.



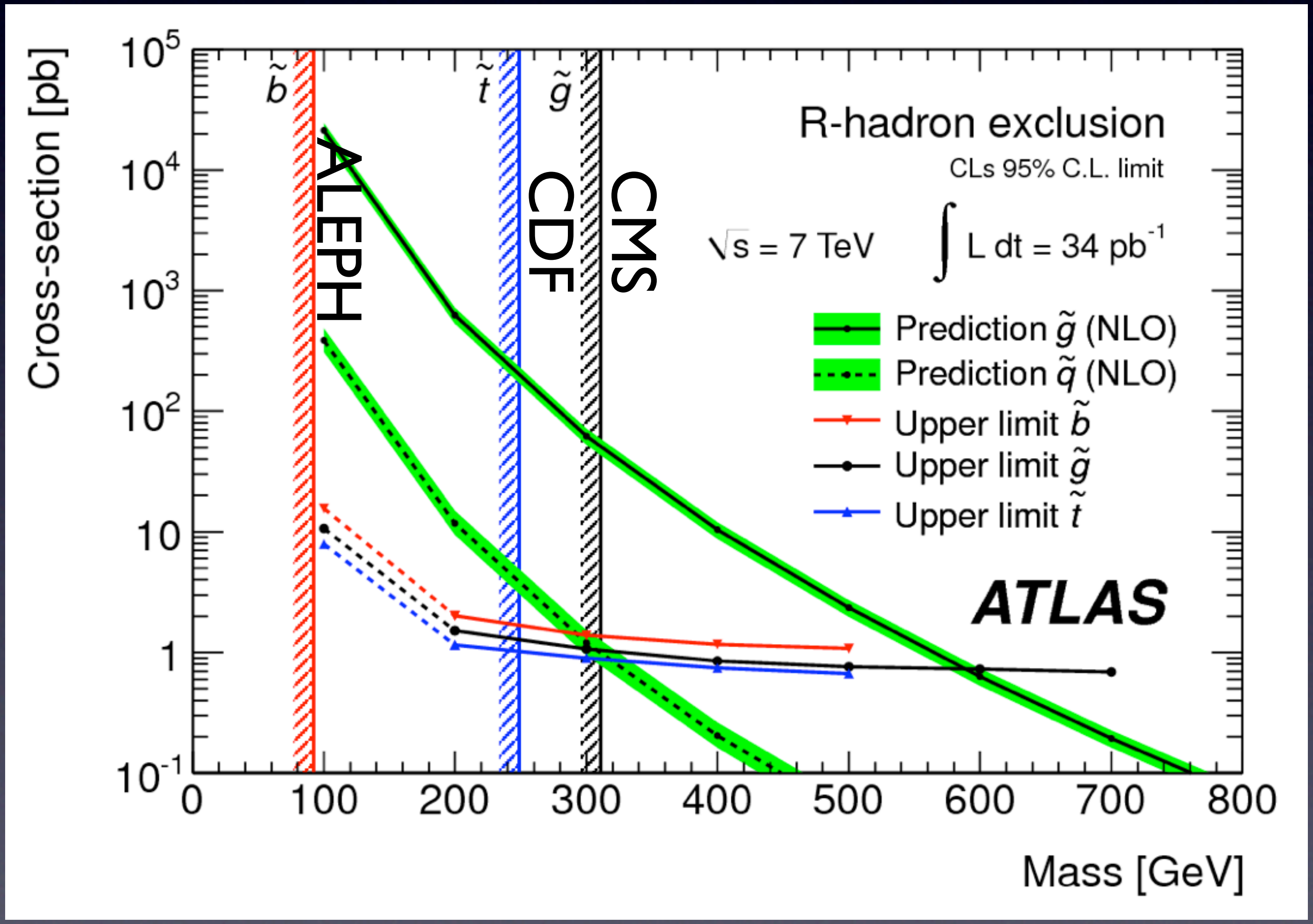


ATLAS-CONF-2011-076

Emanuel Strauss - SLAC

R-Hadrons

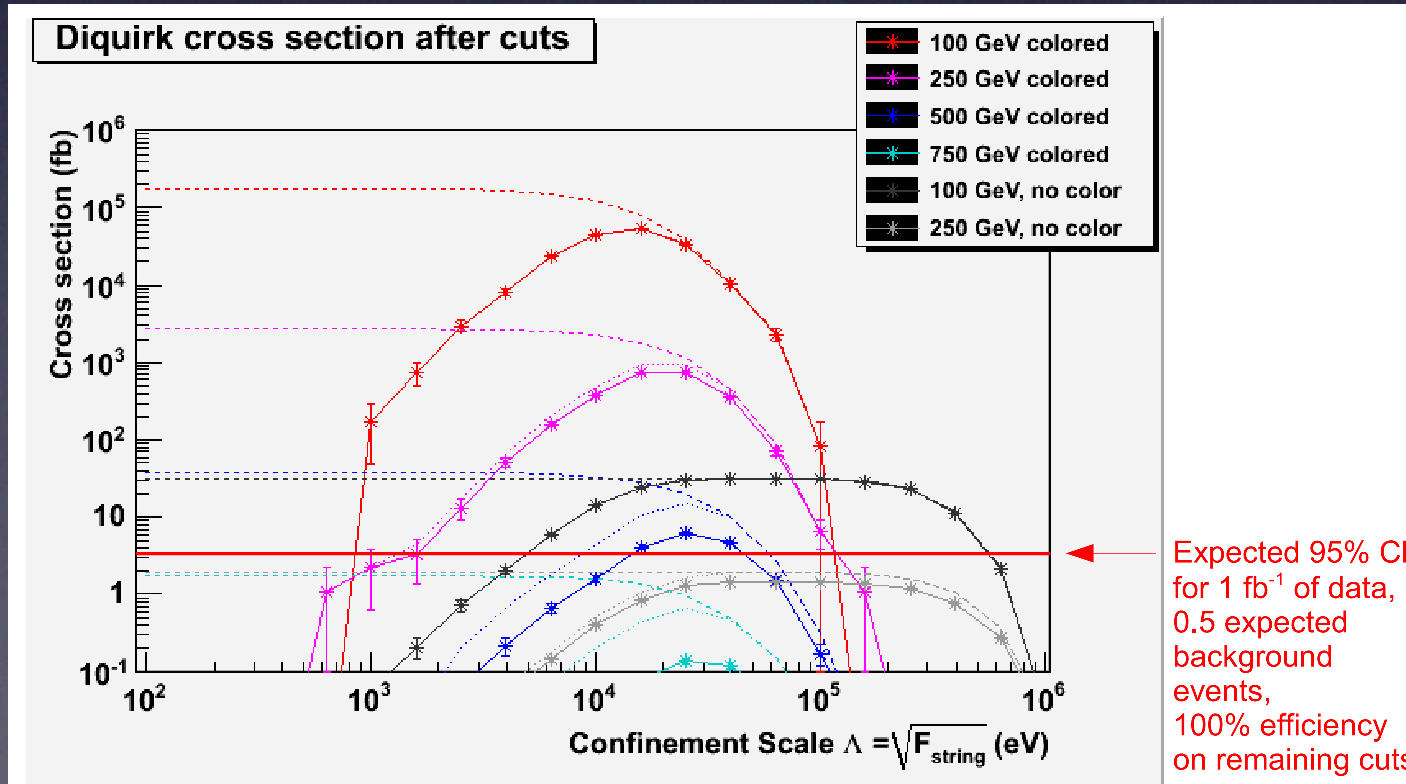
- SMP search using track dE/dx + HCal TOF *ArXiV:1103.1984*
- SLAC working on a complementary, stopped gluino search (Cogan, Haas, Jackson) requires empty buckets in LHC bunch structure



Quirks

- Additional SU(N) with $\Lambda_{conf} << M_Q$ leads to macroscopic bound states.
- Quirks connected by “infracolor” strings
- Working with Markus Luty and Jared Evans to refine search strategy.
- Stanford student, Jim Black, has developed a fully relativistic simulation of quirk motions.

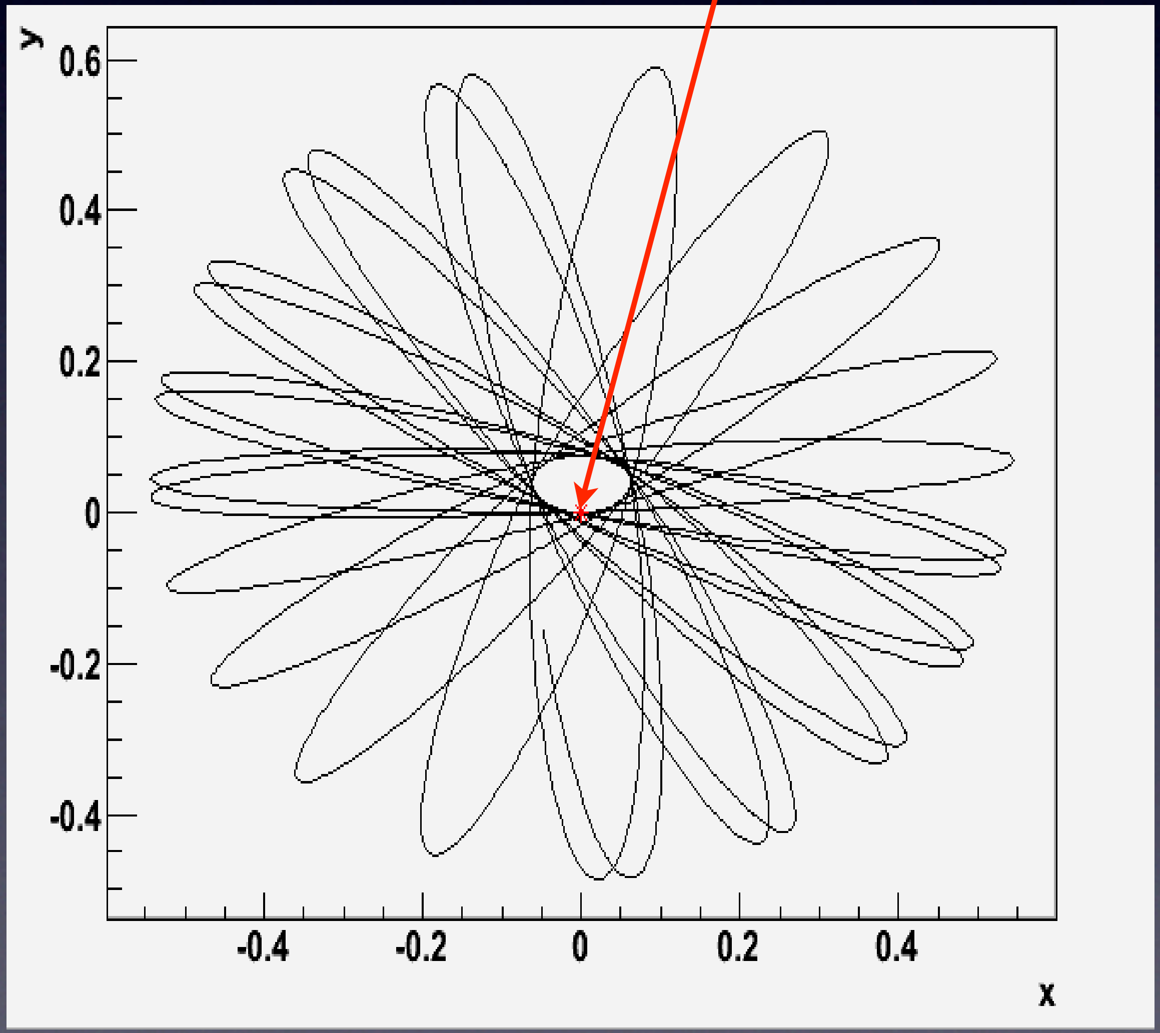
	Cross section (fb), p_T > 40 GeV	Cross section (fb), ME_T > 100 GeV, $\|\eta\|$ < 2.0
100 GeV colored	$8.44 * 10^5$	$1.8 * 10^5$
250 GeV colored	$1.10 * 10^4$	$2.7 * 10^3$
500 GeV colored	155	38
750 GeV colored	7.4	1.7
1000 GeV colored	0.52	0.12
100 GeV uncolored	187	32
250 GeV uncolored	9.6	1.9



Quirks

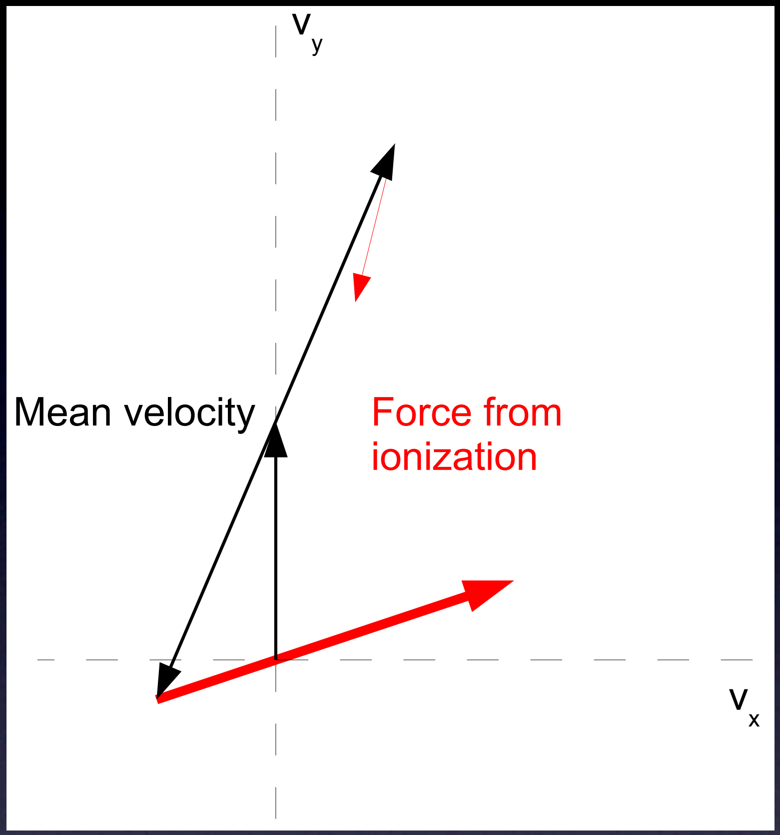
- Lesson 1: Magnetic fields do not randomize quirk motions preventing re-annihilation.
- Lesson 2: Considering motion in 3d provides an important correction to re-annihilation probabilites

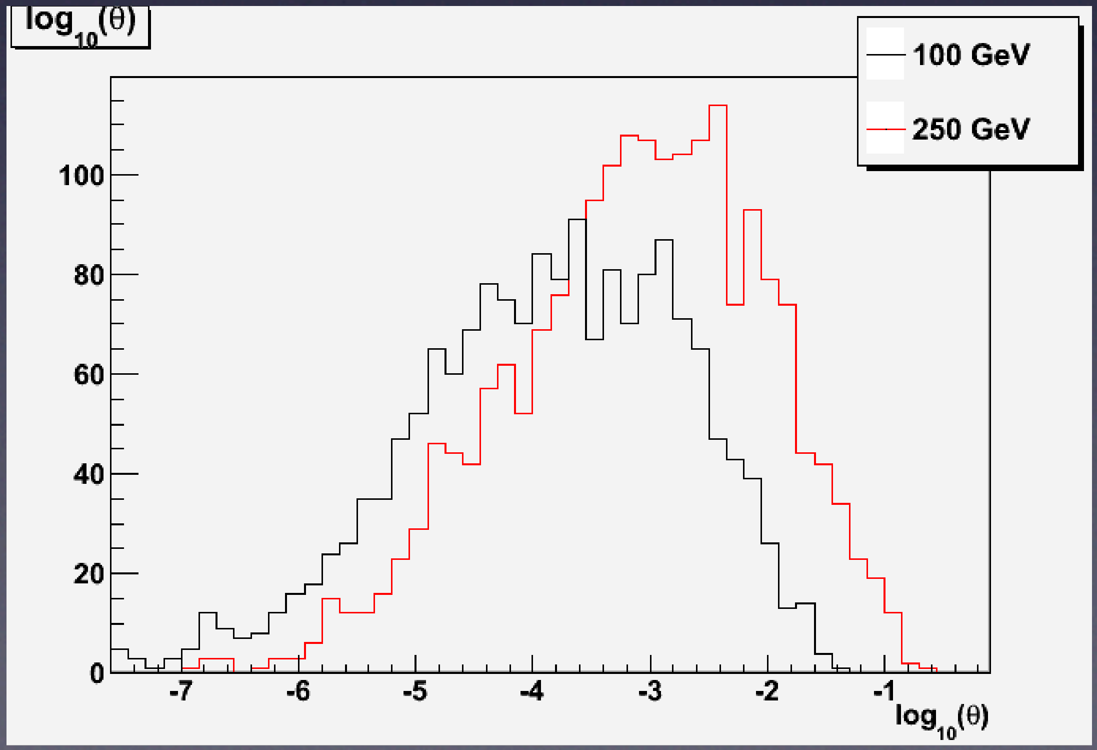
CM of quirk pair



Quirks

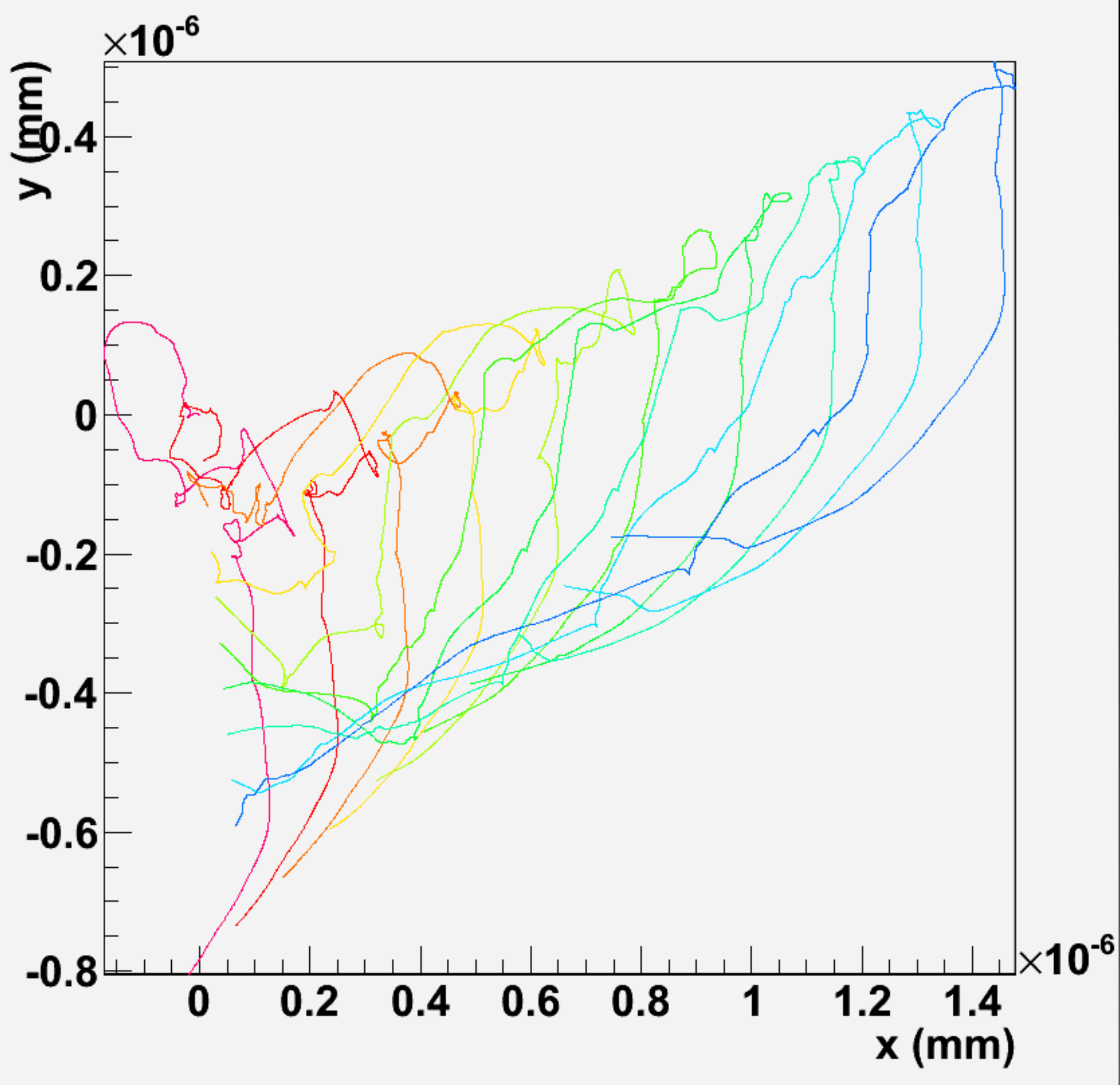
- Lesson 3: averaged over an oscillation, there can be a transverse force on the quirk pair with consequences for tracking efficiency.





Quirks

- Lesson 4? Can infracolor strings form loops and cross themselves when quirks pass nearby?
- We need to capture as much of this in a Geant 4 simulation as possible

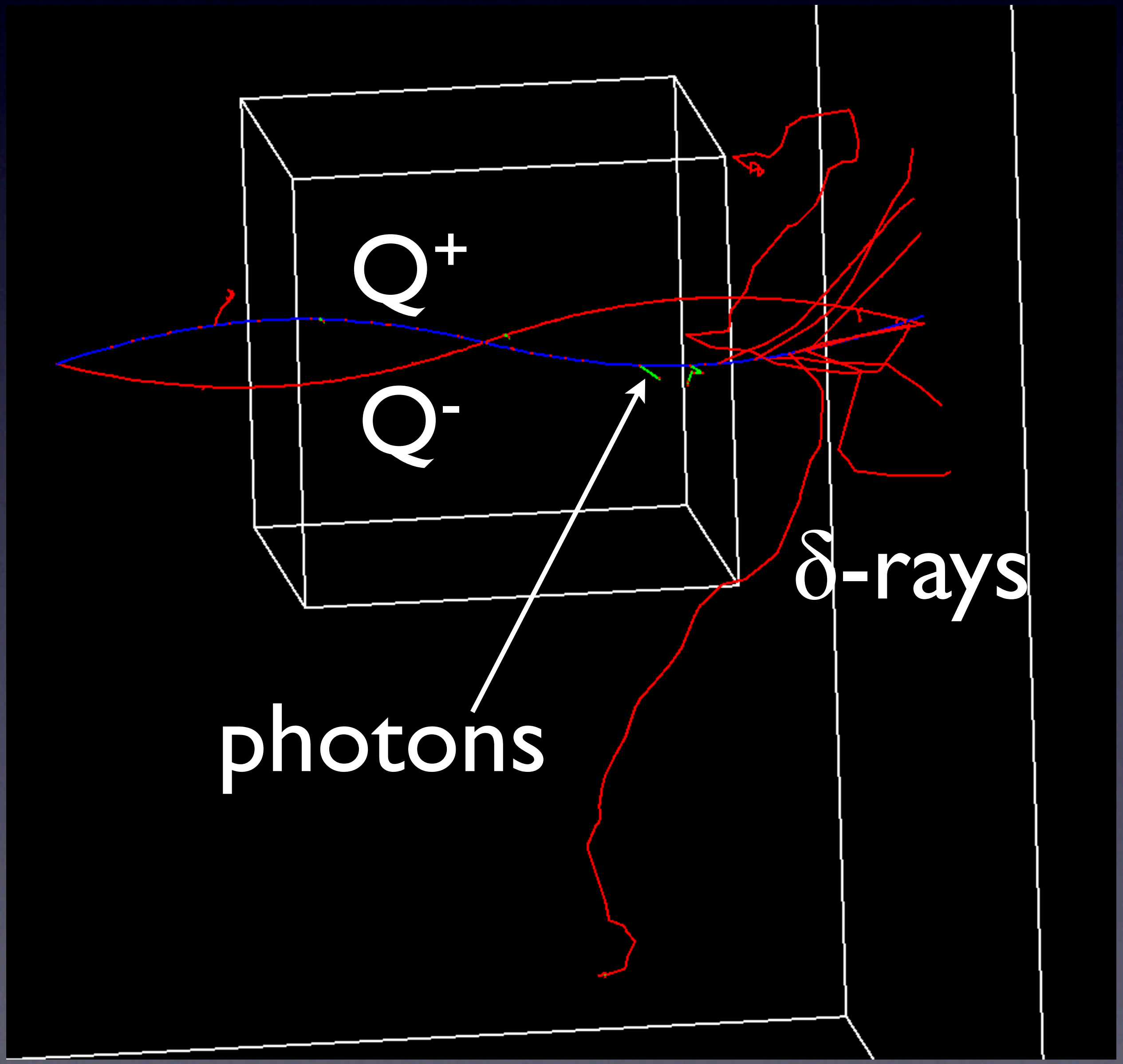


Infracolor string (1000 TeV/m) after 6cm Pb

Quirks

- Not trivial: must change the way particles are propagated through the detector
- An initial version is complete. Markus and Jared finishing the physics description now.
- We hope to have a result for mesoscopic quirks by the end of the year.

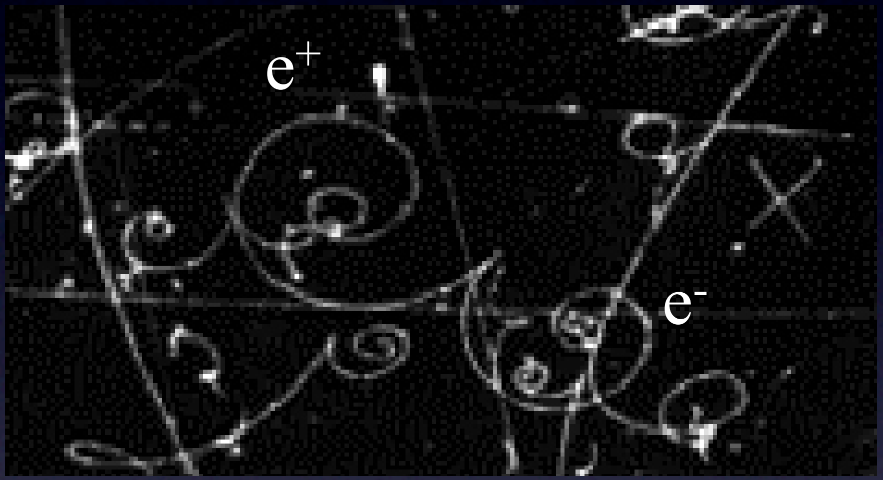
Single quirk oscillation in Al



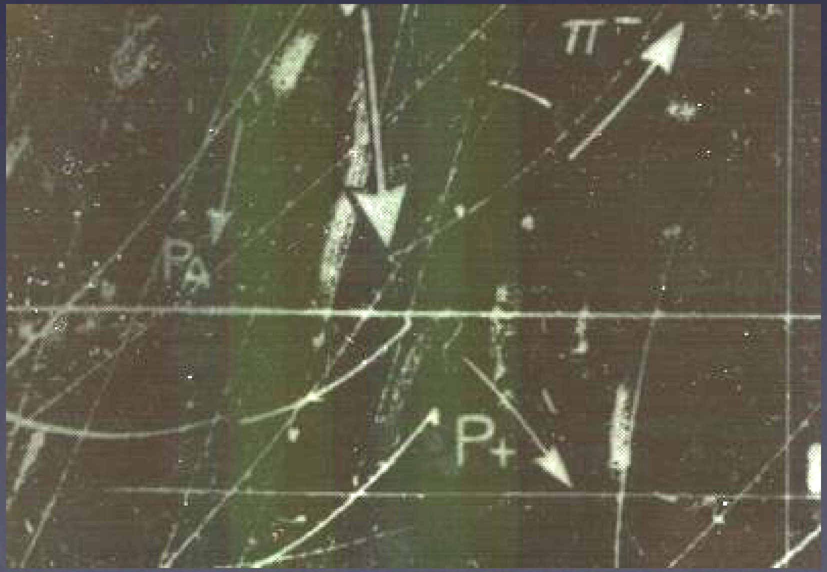
Thinking more Generally

- As a "tracking person" I have a fundamental belief in the power of these tools.
- What kinds of tracks would represent remarkable discoveries simply on their own?

Anti-matter (1932)



Strangeness (1947)



NOTs
(new odd tracks)

investigating:

- missing hits/stubs
- kinks
- low dE/dx

Katie Malone - Stanford

Exotics

Unusual Energy Deposition, Timing, and Tracks

Rouven Essig, Patrick Meade, Jing Shao, Tomer Volansky, and Itay Yavin

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Signature Keywords: Exotics, CHAMPS, kinks, weird tracks, intermittent tracks, reduced hits, new stable particles, fractional charge

Model Keywords: Supersymmetry (GMSB), Quirks

Disclaimer

This note is still very preliminary. Please use with caution. For more details, MC implementations or updates, please contact one of the authors.

Signatures	Simplified Model	Theories
dE/dx + timing (slow)	$m_X \gtrsim 100\,\mathrm{GeV}$, $c\tau_X \to \infty$	Quirks, long-lived sparticles ($\tilde{l}$, $\tilde{t}_1$ ...)
dE/dx + timing (fast)	$m_X \gg m_Y \gtrsim 100\,\mathrm{GeV}$, $c\tau_X \to 0$, $c\tau_Y \to \infty$	same as above
kink	$q_X = q_Y \neq 0$, $q_Z = 0$, $c\tau_X \lesssim \mathcal{O}(1)m$	degenerate chargino/LSP
reduced hits	$1/6 \lesssim q_X < 1$, $c\tau_X \gtrsim \mathcal{O}(1)m$	fracitonally charged particles
Intermittent tracks	$m_X \gtrsim 100\,\mathrm{GeV}$, X color charged	long-lived gluino/squark

Barriers

For many of these analyses,

- the Monte Carlo isn't there
- there aren't any efficient triggers
- required data not in standard datasets
- high-luminosity setup eliminates data streams

We need your help defining and motivating the interesting searches to solve these problems.

Waiting for Godot

- When new physics arrives, will we recognize it?
- What follies shall we occupy ourselves with while we wait?

Ambulance Chasing?

If we do our job correctly, you shouldn't be wondering if we got it right when we report something!

Summary

- The LHC and it's detectors are performing fantastically overall.
- Significant results are beginning to appear: This is a great Summer for this Workshop!
- It won't be long before much of the bread-and-butter signature space has been examined.
- Figuring out how to gain, and maintain, sensitivity to more bizarre signatures is an important next step.