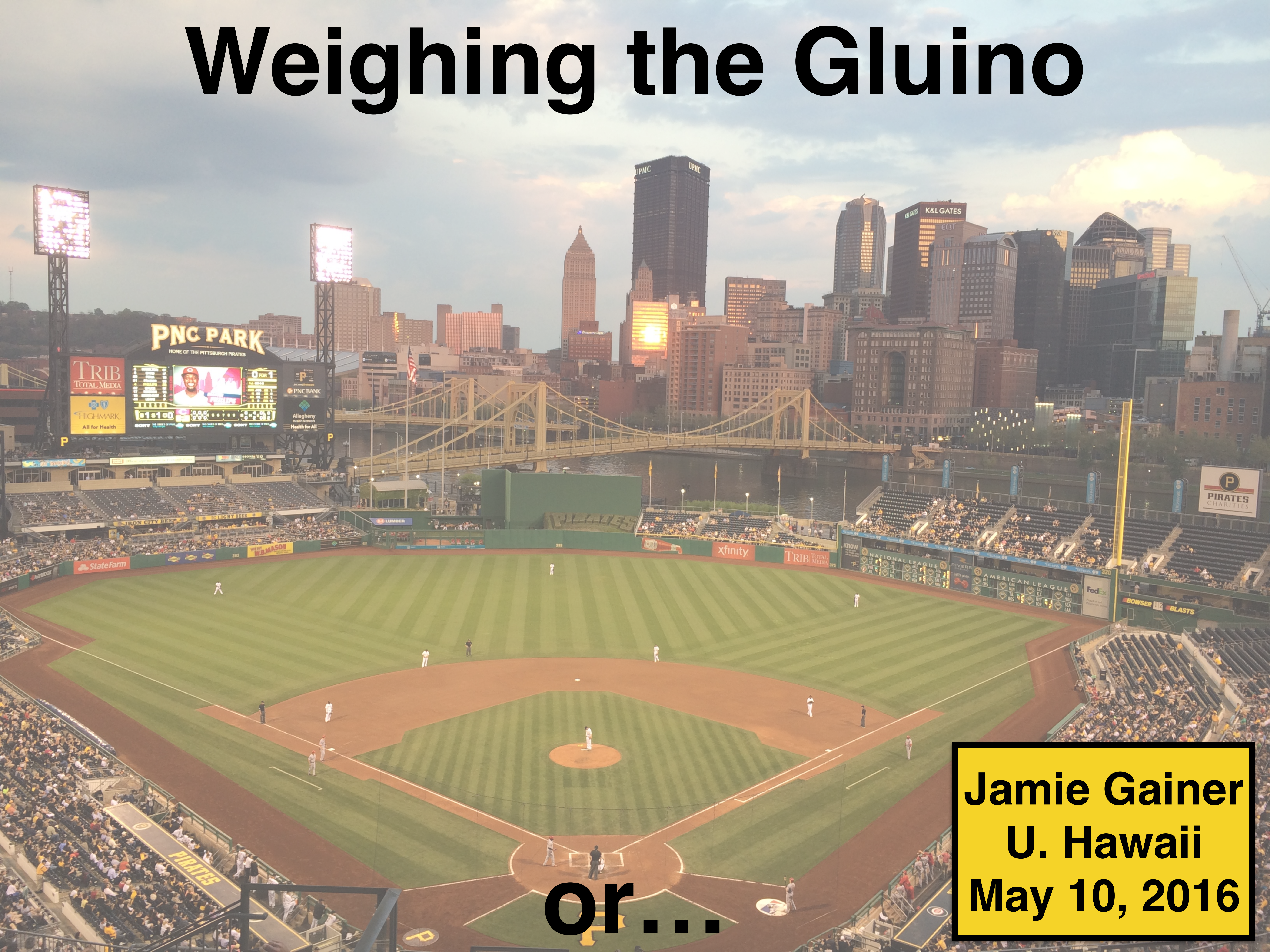
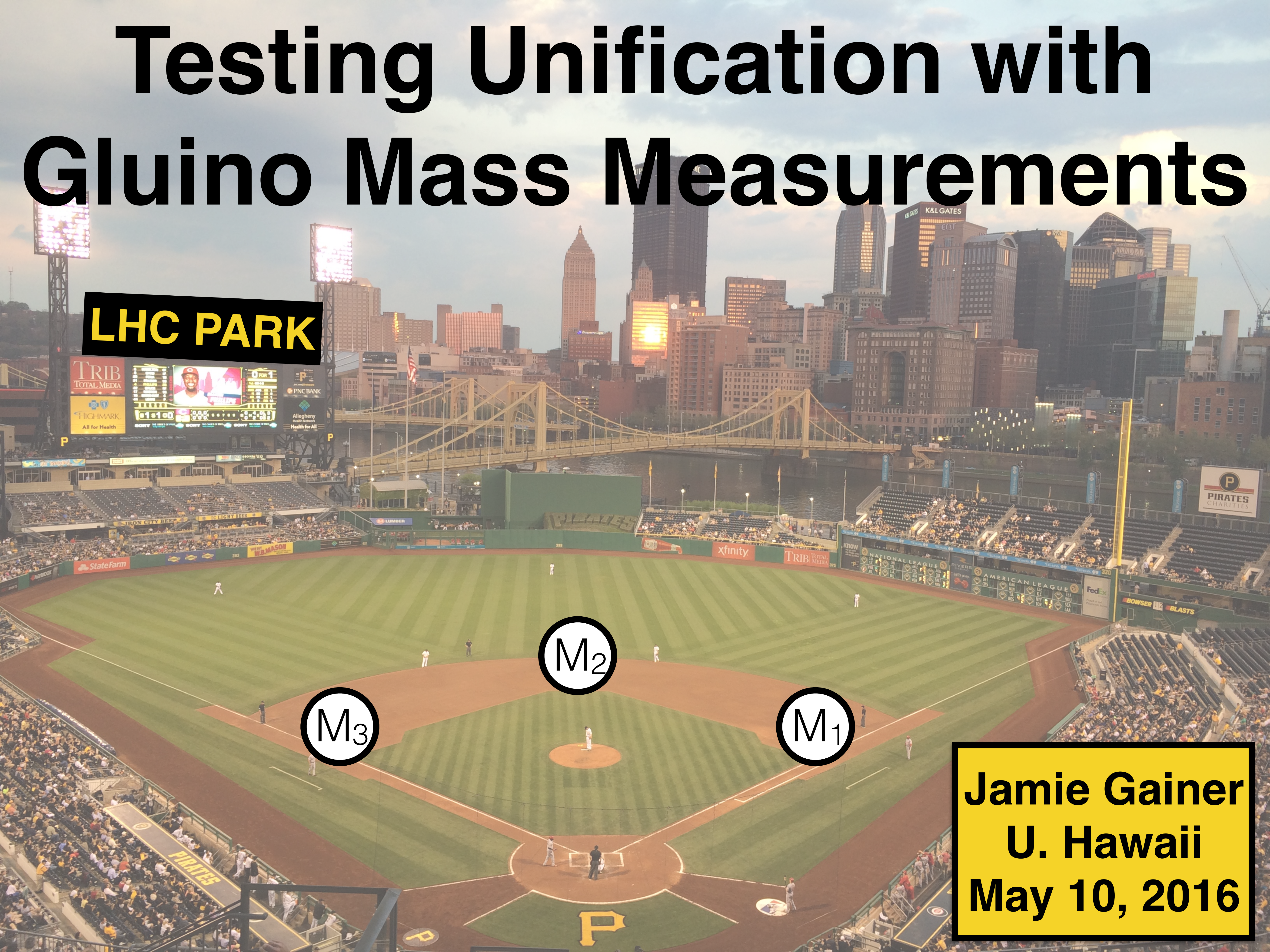
Weighing the Gluino



or…

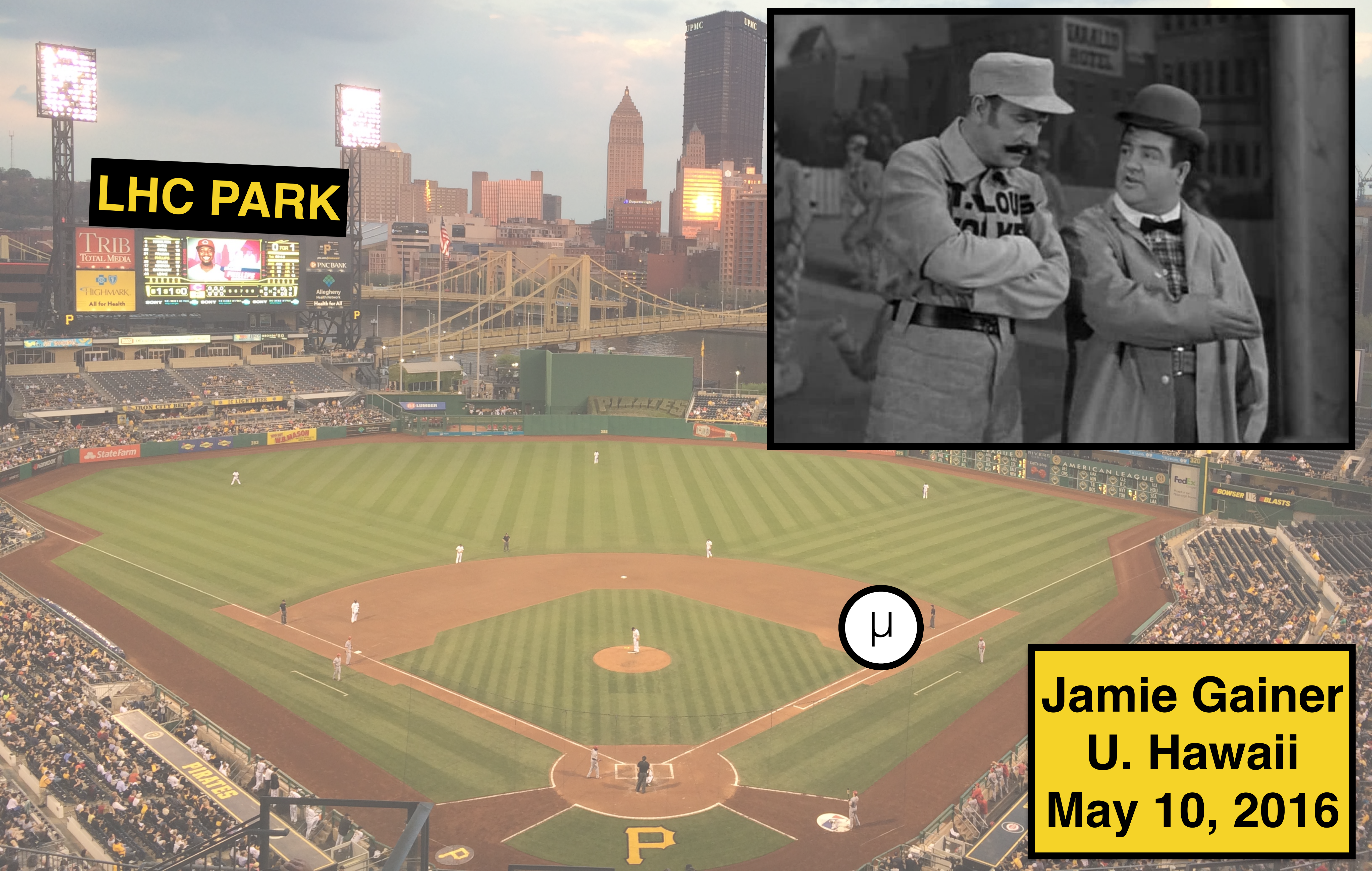
Jamie Gainer
U. Hawaii
May 10, 2016

Testing Unification with Gluino Mass Measurements



Jamie Gainer
U. Hawaii
May 10, 2016

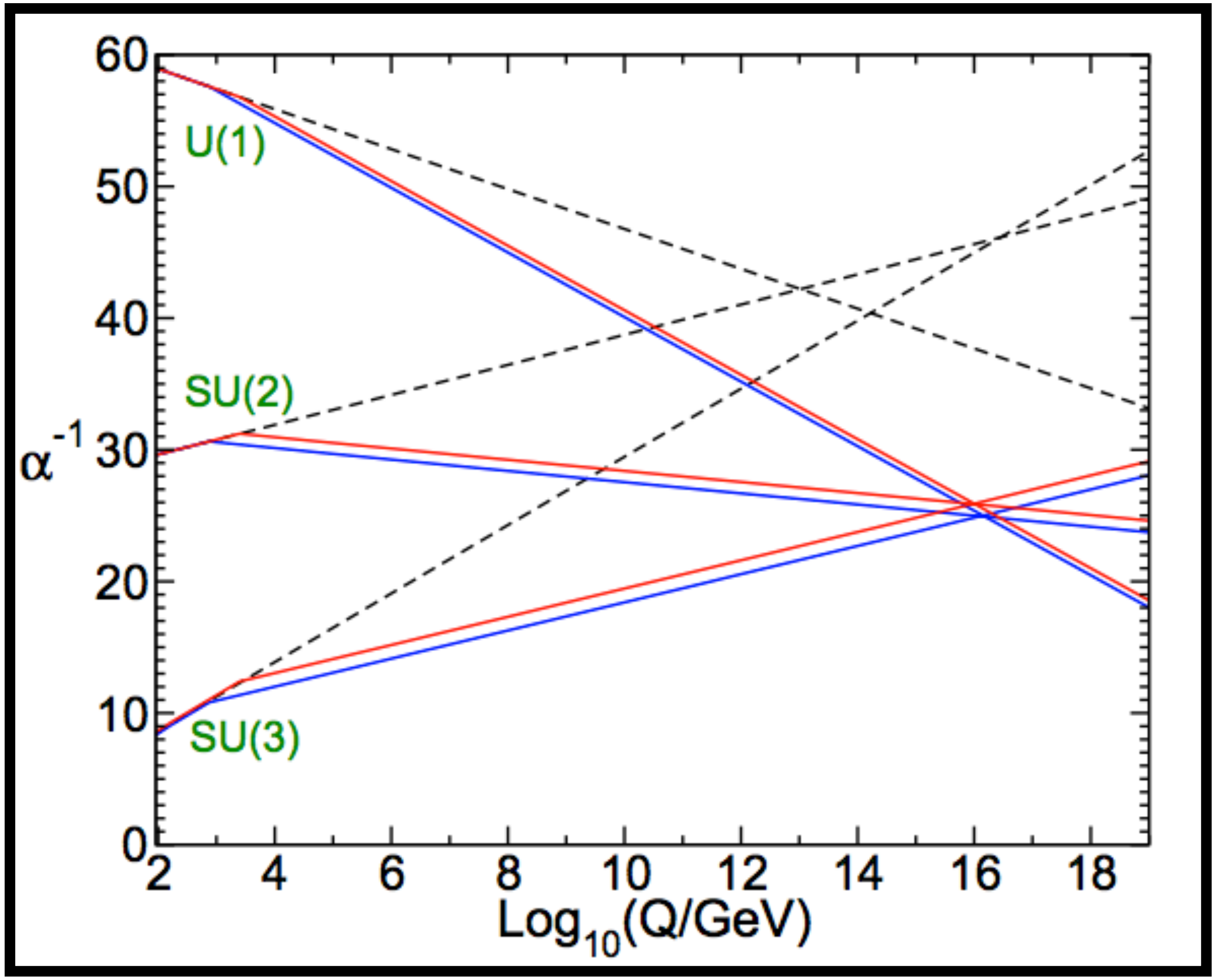
Mu’s on First?



Jamie Gainer
U. Hawaii
May 10, 2016

Unification in SUSY

- One of the strongest arguments for the MSSM has been gauge coupling unification



- Couplings unify at $\sim 10^{16}$ GeV in MSSM
- Couplings do not seem to unify in the Standard Model

S. Martin, "A Supersymmetry Primer"
SUSY masses varied between 750 GeV and 2 TeV

N.B.: All equations in this talk are stolen from this reference

Unification in SUSY

$$\beta_{M_a} \equiv \frac{d}{dt} M_a = \frac{1}{8\pi^2} b_a g_a^2 M_a \qquad \beta_{g_a} \equiv \frac{d}{dt} g_a = \frac{1}{16\pi^2} b_a g_a^3$$

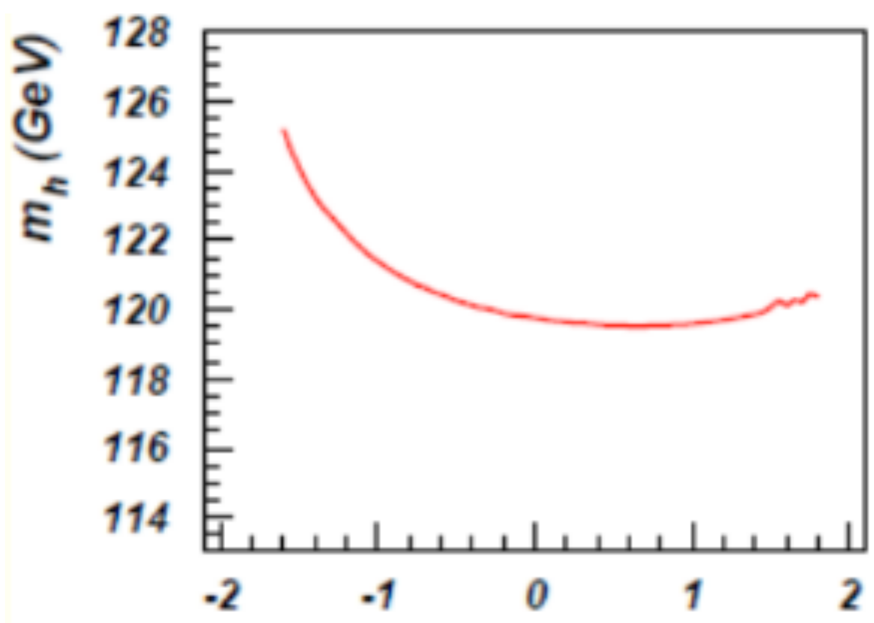
- Using advanced mathematics (the quotient rule) we find that at 1-loop, M/g^2 is RGE-invariant

- In SUGRA models, gaugino mass unification at high scales leads to a specific prediction for the ratio gaugino masses that could be measured by an experiment, ~1:2:6

- Testing this assumption will give us insight into physics at very high energy scales

Radiative Natural SUSY

- As Xerxes Tata discussed yesterday (in SUSY I) "Radiatively Natural SUSY" (Baer, Barger, Huang, Mickelson, Mustafayev, Sreethawong, and Tata (2013)) is a compelling framework



- Large negative A_0 suppresses stop contributions to Higgs mass
- Higgsinos are light, often the LSP. The second neutralino and lightest chargino are have similar masses to the LSP

- So we'll be considering the scenario where stops are necessarily too light, the LSP is Higgsino-like and fairly light, and the gluino will be heavier.

M_1 and M_2

- Testing gaugino mass unification requires measuring M_1, M_2, and M_3

- Even if we cannot measure the Wino or Bino mass directly we can infer masses from mass splittings

$$m_{\tilde{C}_2} = |\mu| + \frac{I m_W^2(\mu + M_2 \sin 2\beta)}{\mu^2 - M_2^2} + \ldots$$

$$m_{\tilde{N}_3}, m_{\tilde{N}_4} = |\mu| + \frac{m_Z^2 (I - \sin 2\beta)(\mu + M_1 c_W^2 + M_2 s_W^2)}{2(\mu + M_1)(\mu + M_2)} + \ldots,$$

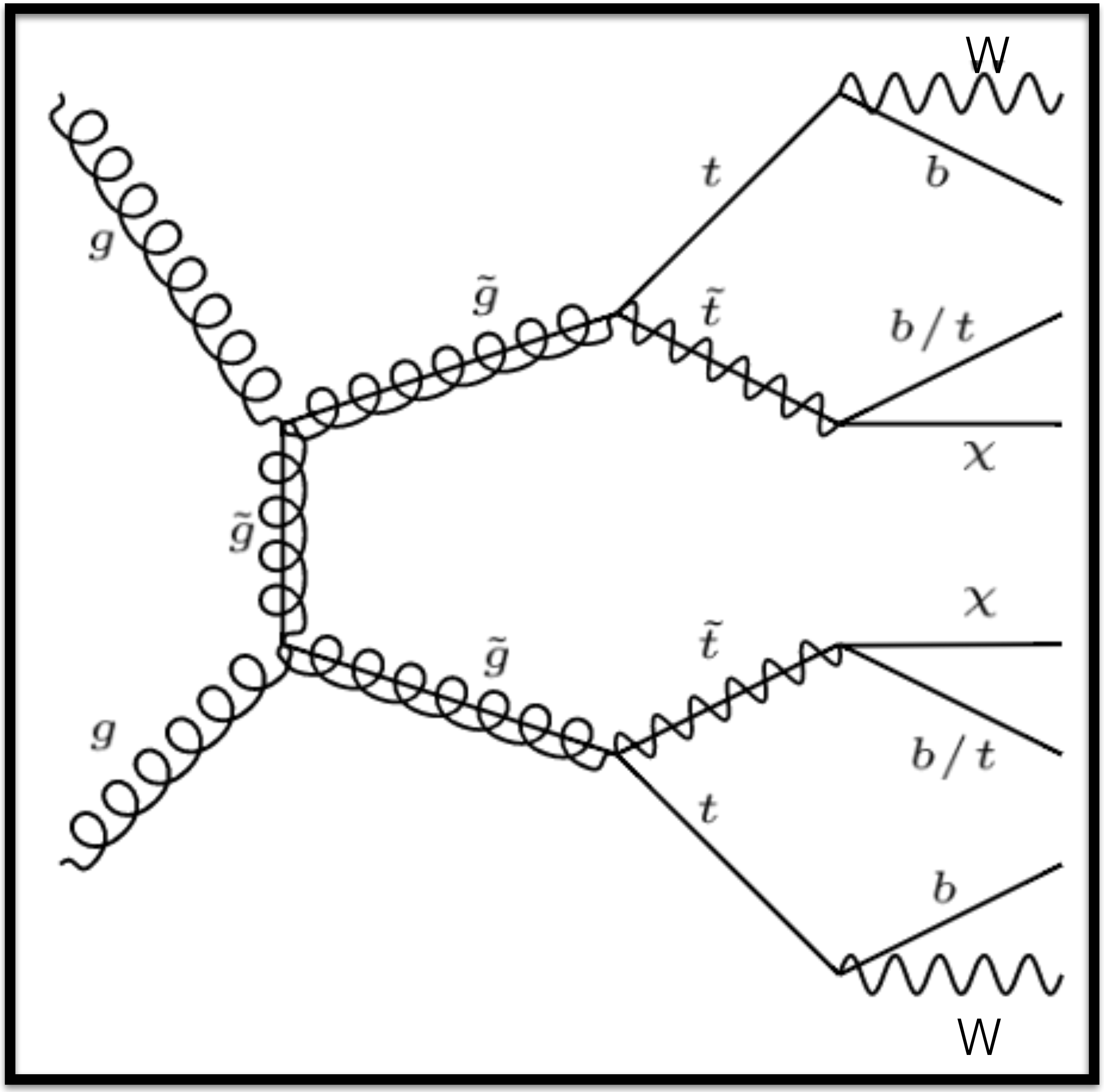
$$|\mu| + \frac{m_Z^2 (I + \sin 2\beta)(\mu - M_1 c_W^2 - M_2 s_W^2)}{2(\mu - M_1)(\mu - M_2)} + \ldots$$

perfect for a linear collider!
see e.g. Choi, Kalinowski, Moortgat-Pick, and Zerwas (2002), studies for various linear colliders.
For a discussion in the context of RNS, see Baer, Barger, Huang, Mickelson, Padeffke-Kirkland, and Tata (2015)

- I'm going to spend the rest of the talk on measuring M_3, i.e., gluino mass measurement

What google thinks you mean by “M_1” and “M_2”

Our Topology



- Diagram representing a large number of closely related channels
- All events have 4 b's, generally significant missing energy
- If you'd prefer, you can think of the goal as being to measure gluino masses with this topology for a particular range of sparticle masses and ignore the RNS motivation

Also $q\bar{q}$ production…

Gluino Mass Measurements

- Obviously this isn't the first time someone has talked about measuring the gluino mass

- In the interest of minimizing (maximizing?) non-citational irritation, I will just show results from one paper— (Gjelsten, Miller, Osland; 2005)— which measured gluino mass at SPS1a

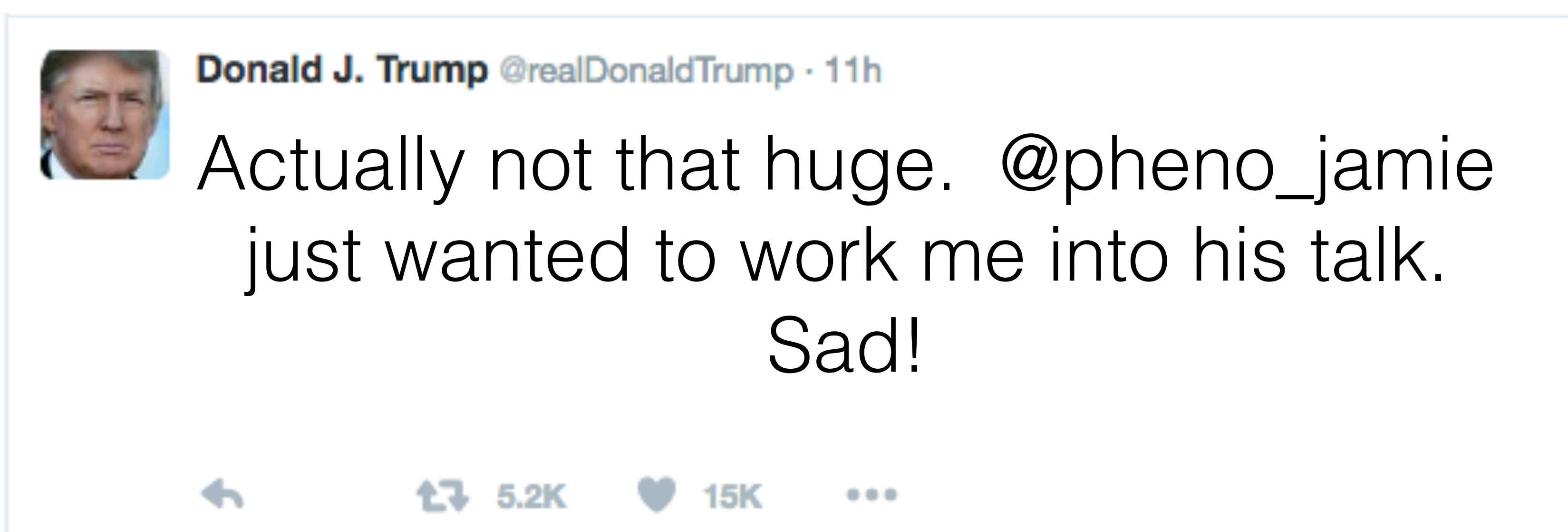
	Nom	Mean	RMS
$m_{\tilde{\chi}_1^0}$	96.1	96.3	3.7
$m_{\tilde{l}_R}$	143.0	143.2	3.7
$m_{\tilde{\chi}_2^0}$	176.8	177.0	3.6
$m_{\tilde{q}_L}$	537.2	537.5	6.0
$m_{\tilde{b}_1}$	491.9	492.2	12.5
$m_{\tilde{g}}$	595.2	595.5	7.2
$m_{\tilde{l}_R} - m_{\tilde{\chi}_1^0}$	46.92	46.93	0.28
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	80.77	80.77	0.18
$m_{\tilde{q}_L} - m_{\tilde{\chi}_1^0}$	441.2	441.2	3.1
$m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0}$	395.9	396.0	11.2
$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$	499.1	499.2	5.6
$m_{\tilde{g}} - m_{\tilde{b}_1}$	103.3	103.3	9.1

Gluino mass to 1% with 300 fb^{-1}

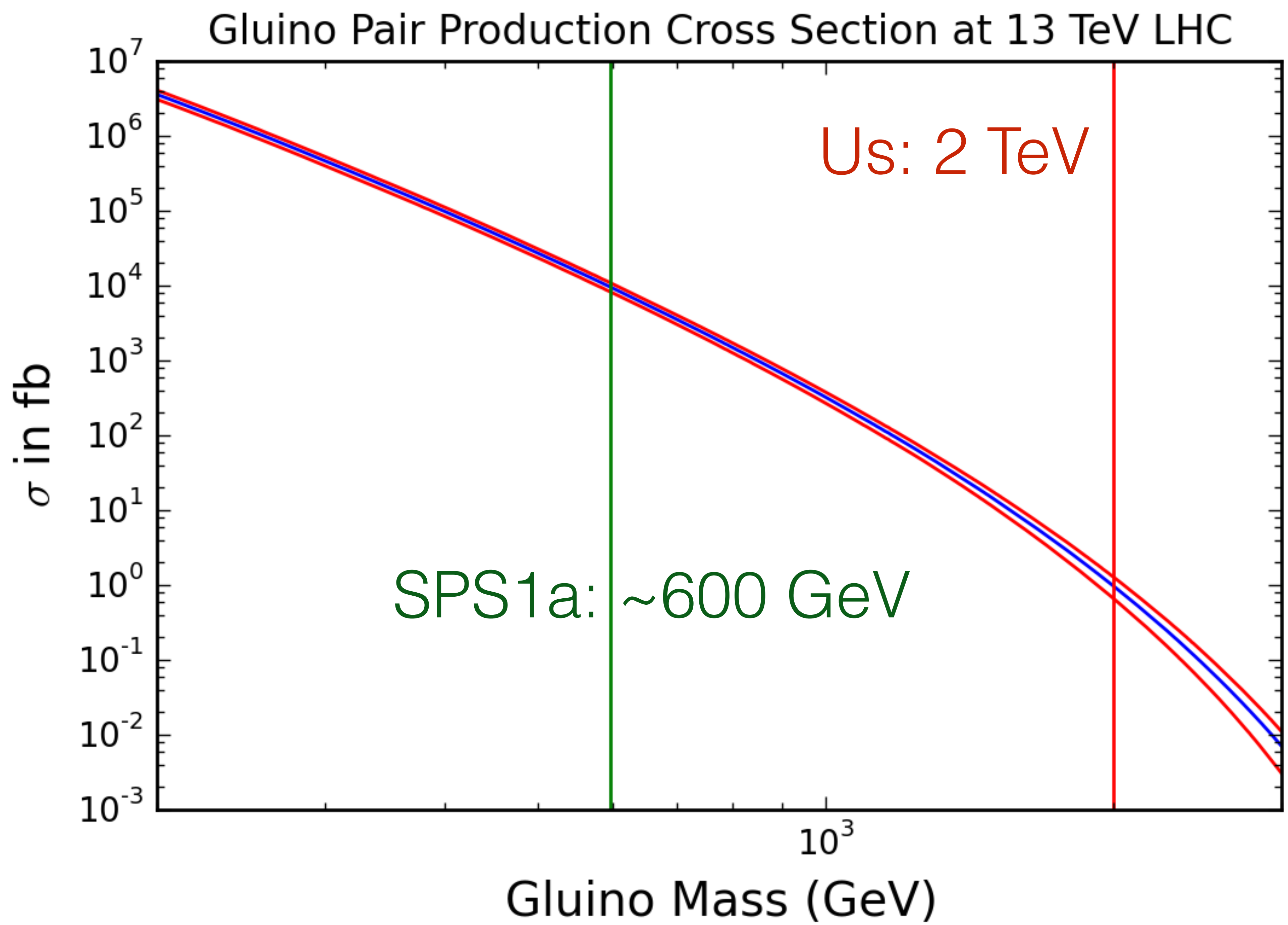
Problem solved?

The Gluino Mass: Yuge?

The Gluino Mass: Yuge?



The Gluino Mass: Yuge?



- Gluino does not need to be huge: we'll consider ~2 TeV
- Gluino cross section falls quickly with gluino mass
- Calculation from LHC SUSY XSEC Working Group: Squarks Decoupled

Can we measure gluino mass with many fewer events?

- Clearly lower cross sections matter— not just quantitatively
- Total LHC production* (3 ab^{-1}) of gluinos is 3000 events
- This is this is 300 pb^{-1} for SPS1a gluino
- 1% measurement from slide 9 involved 1000 x more gluino decays than the LHC will ever have
- Optimistic projections were optimistic
- Need to do a lot more work to extract masses with smaller event samples

Do we need a miracle?

Do we need a miracle?

- I have to note that this is still work in progress—
  I can't give you a final answer

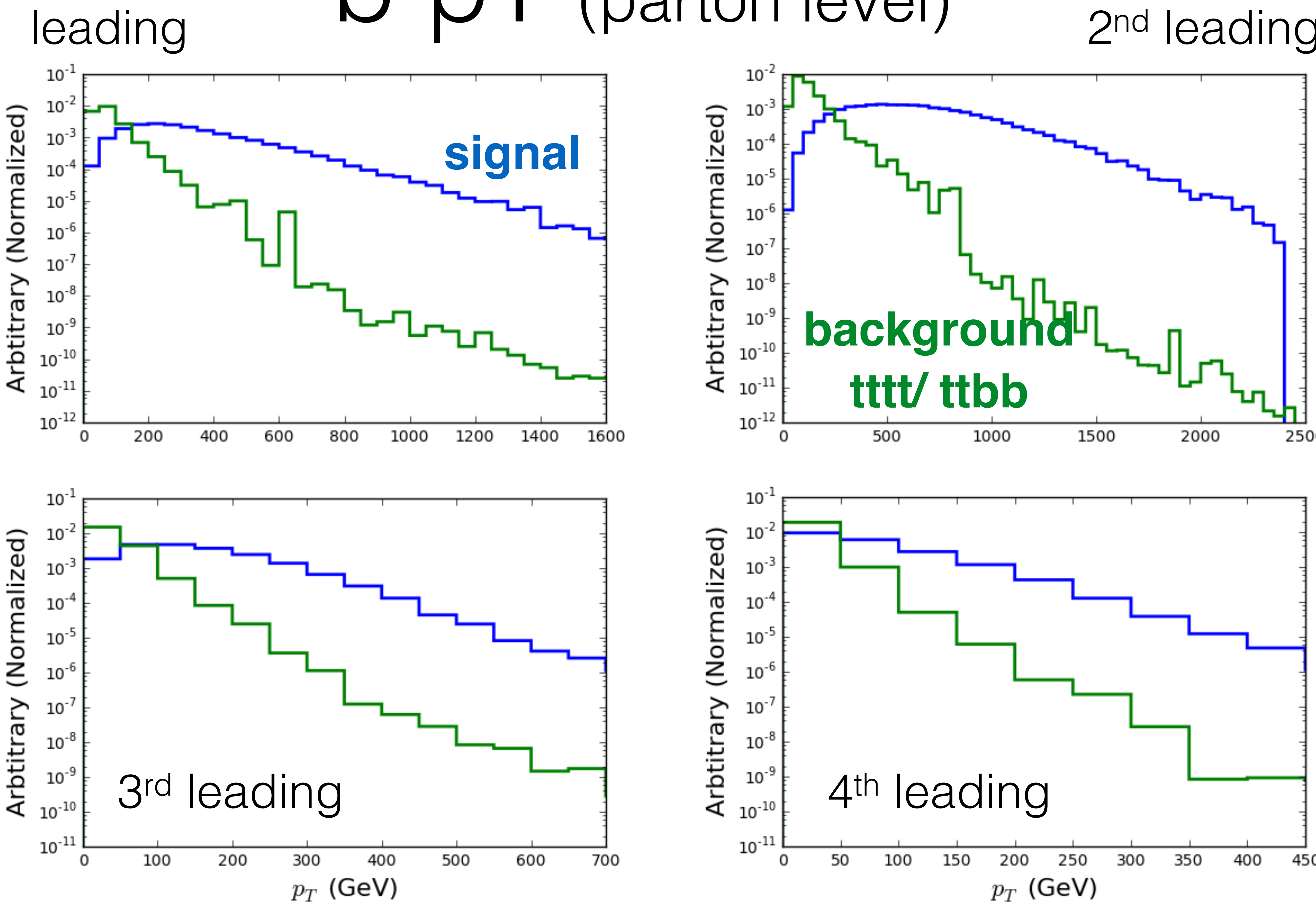
- I'll argue on the next slides that we should be able to control irreducible backgrounds.
  We can make a measurement, though the error will probably be more than 1%

- Practically a big part of the answer will involve

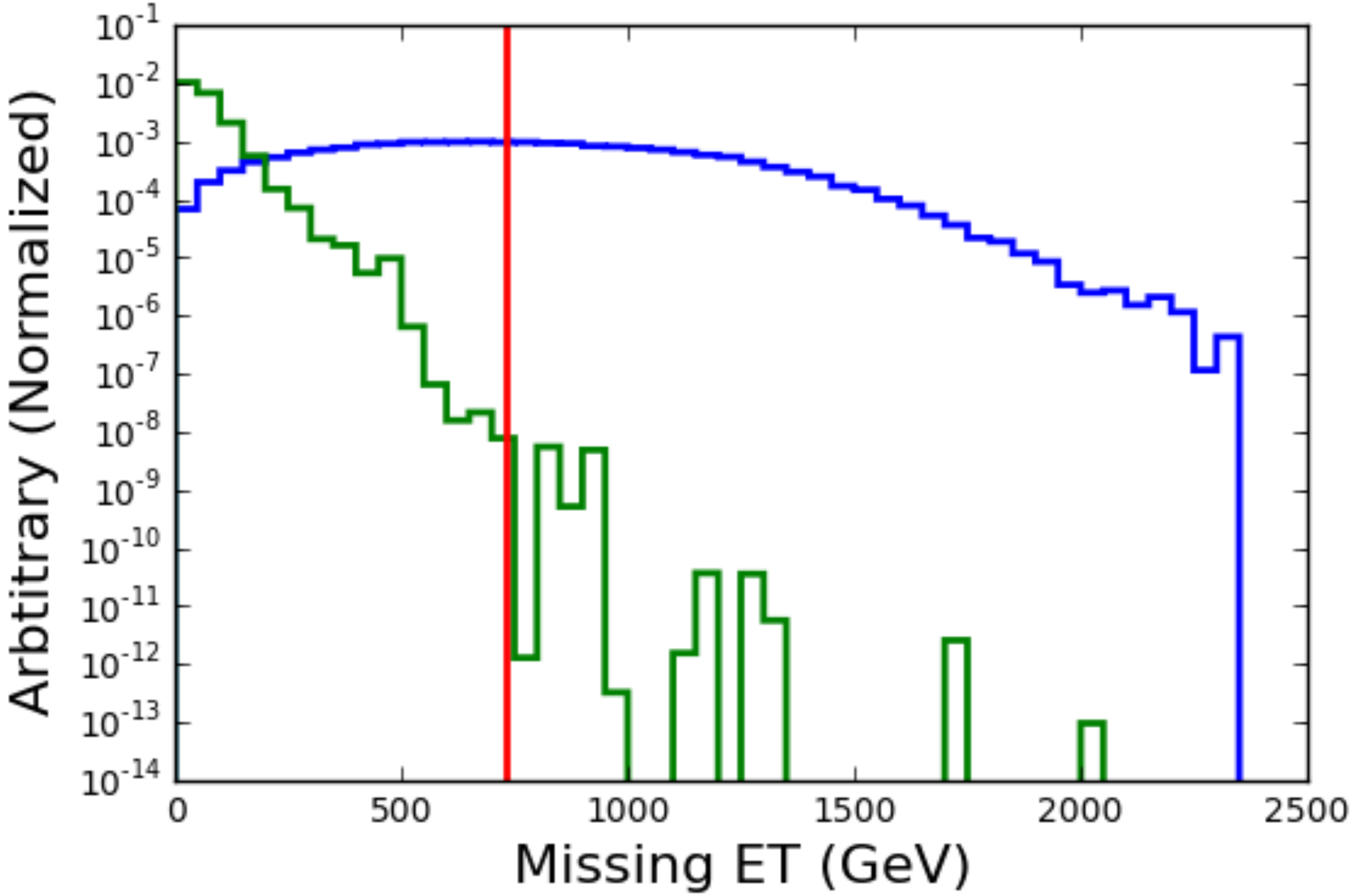
  - Use of good variables (M_{T2} and its descendants)

  - Use of multiple variables (MVAs: neural nets, boosted decision trees, likelihood methods/ Matrix Element Method, etc.)

b pT (parton level)



Missing Energy (PYTHIA Level)



Kinematic Variables

- Kinematic variables like M_{T2} are an important part of SUSY mass measurements.
  For reviews c.f. e.g. (Barr and Lester 2010) and
  (Barr, Khoo, Konar, Kong, Lester, Matchev, Park; 2011)

- Optimization of M_{T2}-like variables includes

  1. Subsystems

  2. Constraints (in optimization)

- **OPTIMASS**:
  (Cho, Gainer, Kim, Lim, Matchev, Moortgat, Pape, Park; 2016)
  Interface with MINUIT2 (as implemented in ROOT) to calculate constrained subsystem M2-variables

Multivariate Analyses

- Need to maximize sensitivity by using many variables
- **Boosted decision trees**, **neural nets** most common approaches
- **Matrix Element Method**: analytical calculation of likelihoods. Nice for theorists, c.f. e.g. (Gainer, Lykken, Matchev, Mrenna, Park; 2013)
- **Numerical likelihood/ template** methods: derive likelihood numerically from Monte Carlo

Can combine with “kinematic variable” approach. E.g. the M_2 variable from the proceeding slide could be one of the variables wrt which we consider the likeliho or we could feed it to a neural net.

B-Tagging Simulation

- If I had time I'd talk about b-tagging for this analysis
- Critical— but challenging at high pT
- Approach: demand 2 b-tags, but treat all hard jets as b's
- Fun with Delphes…

Conclusions

- Interesting to see how well the gluino mass can be measured
- Focusing on a motivated SUSY framework, but lessons learned should be more general
- Kinematic Variables and/or Multivariate Analyses are important (and probably necessary) tools
- Stay tuned!