Looking under the Lamp Post:

Finding New Physics in SM Measurements

Next Steps in the Energy Frontier -- Hadron Colliders
Fermilab
Batavia, Illinois

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Overview

Introduction

How do you **define a SM measurement?**
How will this definition evolve @ 100 TeV?

A Working Definition:
You produce something that
(1) you know exists,
(2) directly,
and then you study it, usually
(3) in great detail

(3) follows from cross sections usually
being huge (high statistics = precision),
which is usually due to (1)

Introduction

So various SM production processes of

jets
leptons
bottoms
tops
W, Z
higgs

in various combinations will fall under the auspice of some future "SM group", including many processes which today we'd call VERY RARE.

Introduction

Compare this to "BSM searches", which usually
cut away SM-like distributions.

But this BSM search strategy relies on the assumption that
NP production processes have different kinematics than
SM, i.e.

different mass scales
(most importantly in final state).

Easy to violate this assumption.

Introduction

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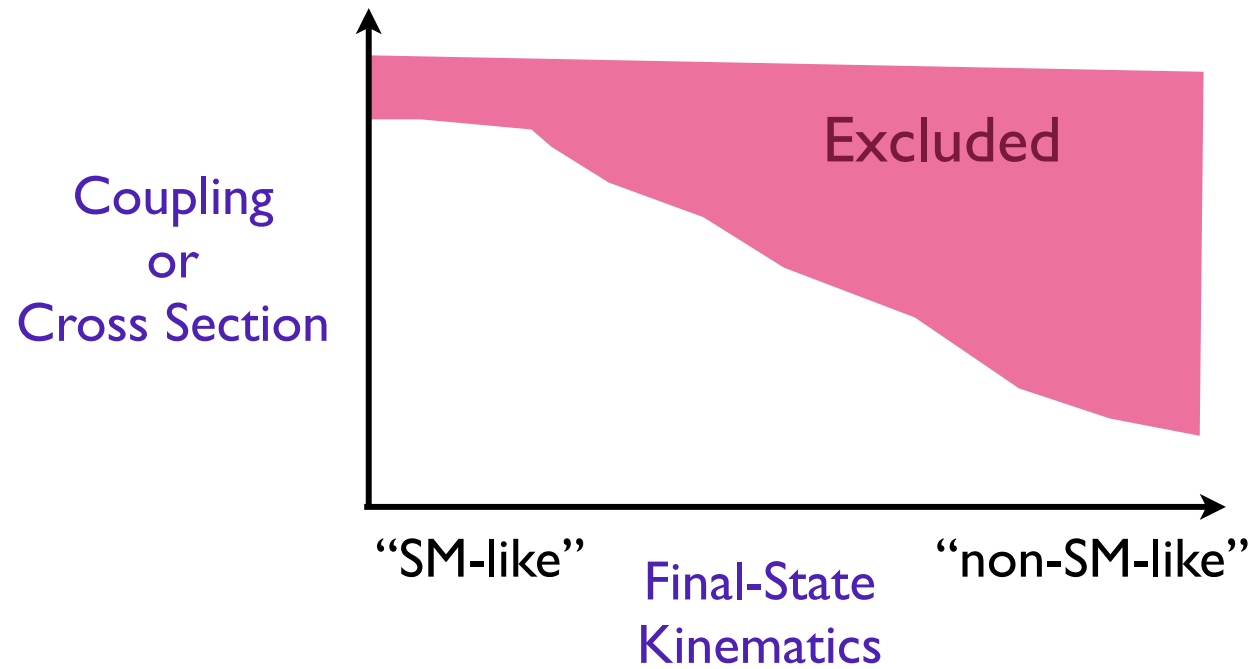cut away SM-like distributions.

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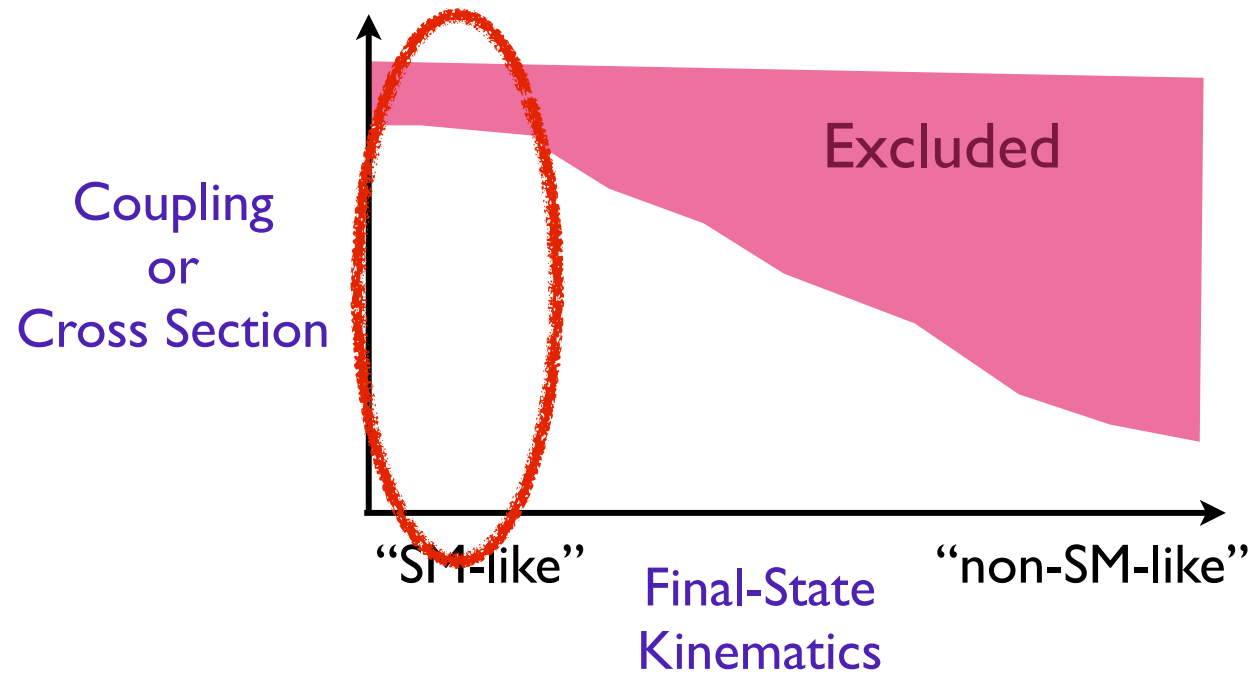(most importantly in final state).

Easy to violate this assumption.

How useful is this SM-measurement vs BSM-search separation?
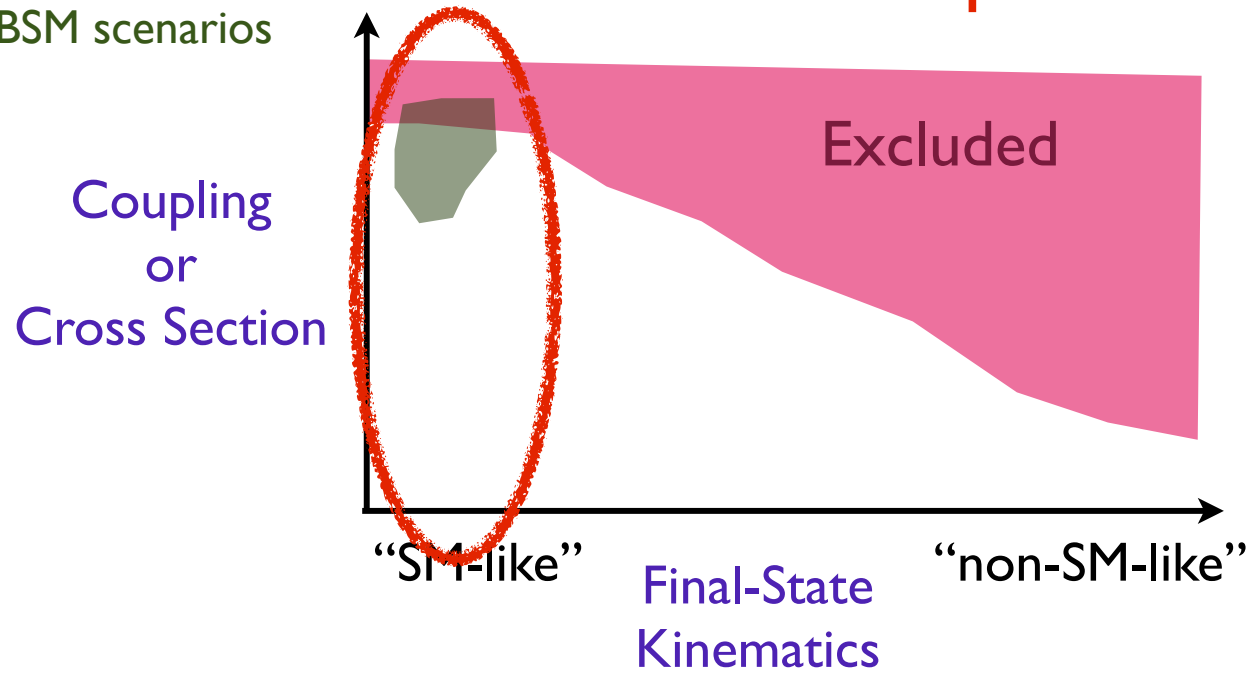
Overview

Coupling
or
Cross Section

Excluded

"SM-like"   Final-State   "non-SM-like"
                 Kinematics

Overview

Coupling
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"SM-like"

Final-State
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"non-SM-like"

Overview

Current SM measurements already help exclude some motivated BSM scenarios

Will discuss some recent examples

Coupling or Cross Section

Excluded
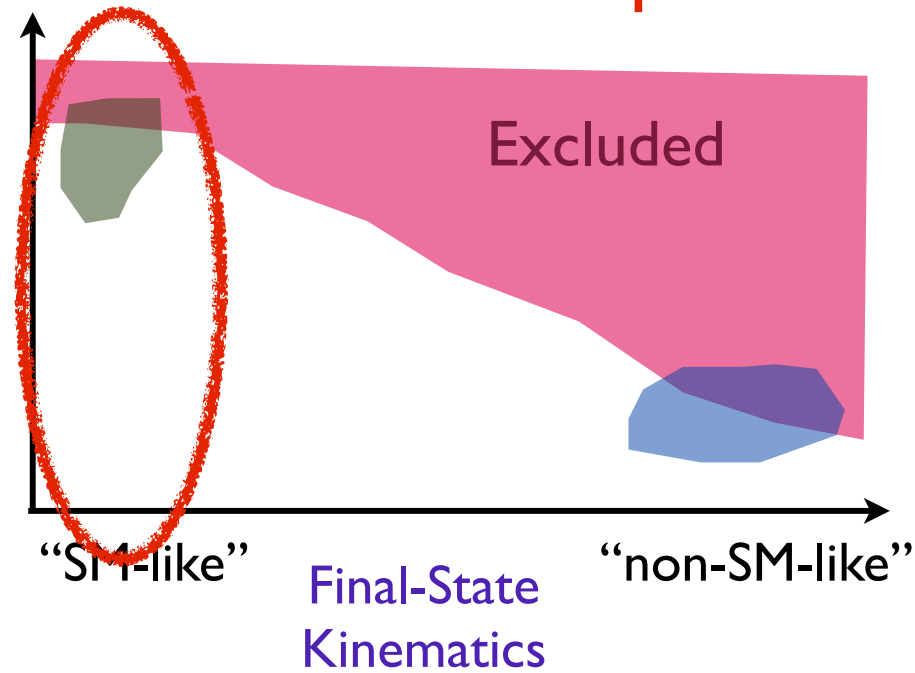
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"non-SM-like"

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Excluded

Inclusive nature of SM measurements makes them useful tools to look for subtle or entirely **unexpected** BSM signals

"SM-like"

"non-SM-like"

Final-State Kinematics

Overview

Current SM measurements already help exclude some motivated BSM scenarios

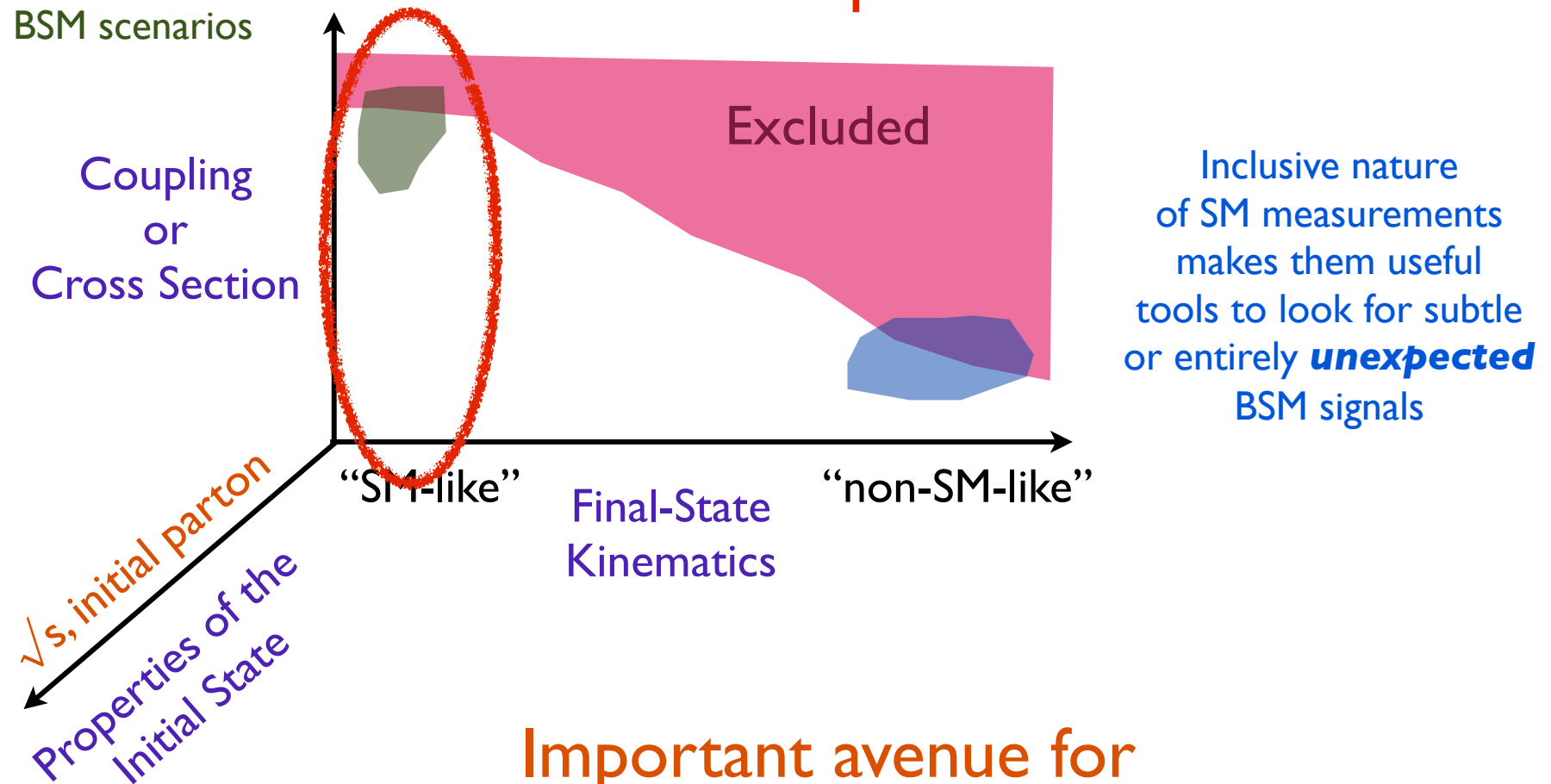Will discuss some recent examples

Coupling or Cross Section

Excluded

Inclusive nature of SM measurements makes them useful tools to look for subtle or entirely *unexpected* BSM signals

$\sqrt{s}$, initial parton

Properties of the Initial State

"SM-like"

Final-State Kinematics

"non-SM-like"

Important avenue for future measurements

Mangano, Rojo 1206.3557

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Recent Examples
of
Looking Under the Lamp Post

Dibosons

BSM in Dibosons

- It has long been appreciated that *e.g.* SUSY could show up in WW/ZZ cross section measurements (or H → VV*) via *e.g.* sleptons or leptonically decaying EWinos.
  Basically anything decaying to 4l or 2l + a bit of MET

  Lisanti, Weiner 1112.4834
  Feigl, Rzehak, Zeppenfeld 1205.3468
  DC, Jaiswal, Meade 1206.6888
  Rolbiecki, Sakurai 1303.5696
  DC, Jaiswal, Meade, Tien 1304.7011
  DC, Meade, Tien 1406.0848
  Kim, Rolbiecki, Sakurai, Tattersall 1406.0858

- Important aside: the artificial separation of SM-measurements vs BSM-search & inherent assumptions could lead to us doing NEITHER correctly. e.g. BSM contamination of H → WW* control region, which could lead to incorrect higgs signal strength measurements.
  Data-driven methods must be applied with great care!

WW Cross Section

- Especially interesting right now: all leptonic σ_{WW} measurements at 7 & 8 TeV are ~15-20% high, > 3 sigma combined significance

- ATLAS + CMS 7 TeV & CMS 8 TeV 3.5 fb^{-1} analyses were tantalizing but had some MC issues.

- 20% Excess has been confirmed by recent, improved ATLAS 8 TeV 20 fb^{-1} analysis, which observed σ_{WW} = 71.4 ± 9 pb vs expected 58.7 ± 3 pb (2.2 sigma excess by itself) and raises overall discrepancy (naive combination) to almost 4 sigma.

WW Cross Section

- Most credible SM explanation is unaccounted-for resummation effects on the jet pT distribution of inclusive WW production, which affects the exclusive zero-jet WW cross section prediction.

  Two calculations recently attempted to address this **jet veto uncertainty**. There is some disagreement between the results -- **watch this space!**
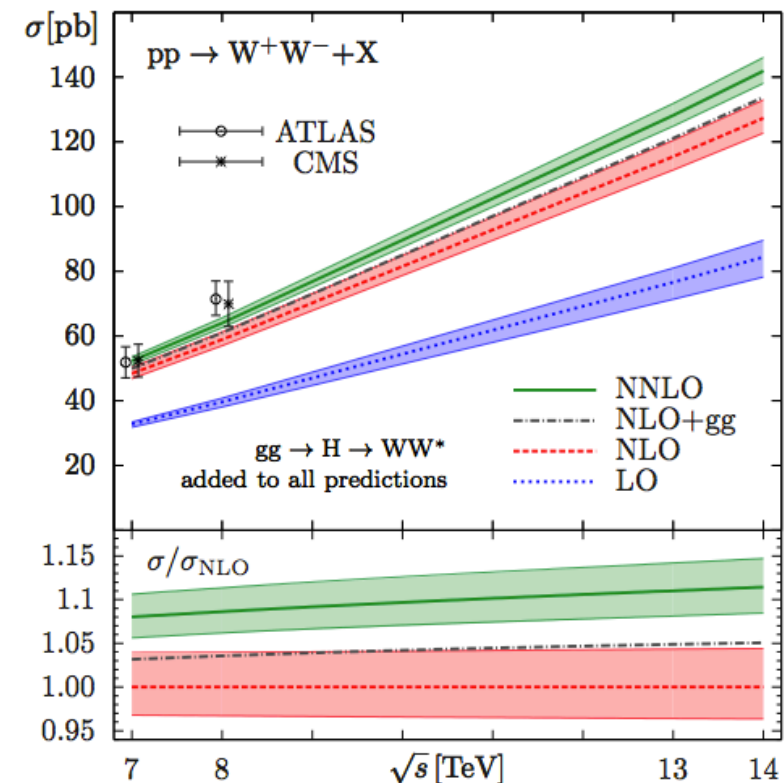
  Meade, Ramani, Zeng 1407.4481
  Jaiswal, Okui 1407.4537

- There was also a very recent update on NNLO calculation of σ_WW.
  8 TeV: NNLO/NLO ~ 1.09,
  so ATLAS excess goes from
  2.2 to 1.4 sigma

  Gehrmann, Grazzini, Kallweit, Maierhofer, von Manteuffel, Pazzorini, Rathlev, Tancredi 1408.5243

- Need confirmation, differential analysis.

WW Cross Section

- Most credible SM exp~~lanation~~ ... ~~tion~~
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  which affects the excl~~usive...~~ ~~diction.~~

  Two calculations recently a~~...~~ ng 1407.4481
  veto uncertainty. There~~...~~ ui 1407.4537
  between the results -- **wat~~ch...~~**

> Experimental Analyses actually use NLO+gg, so the NNLO calculation may only account for ~5% of 20% excess? Unclear.... (??)
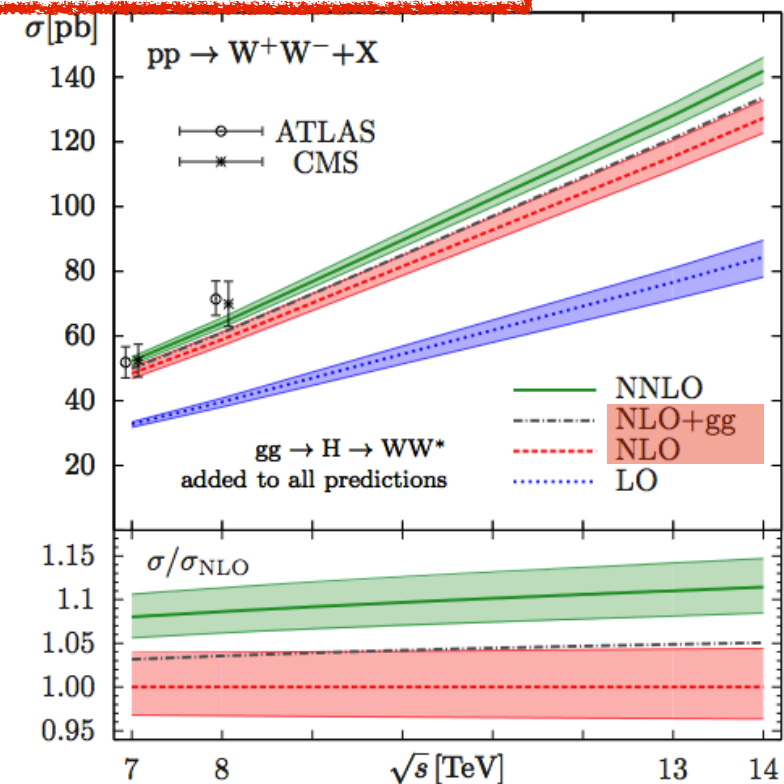
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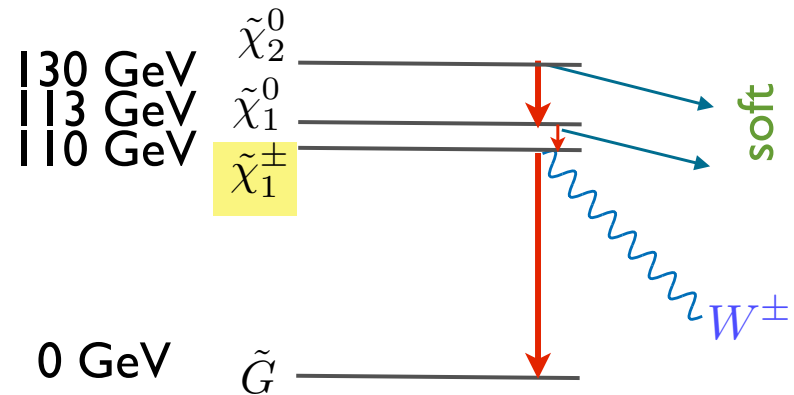 Gehrmann, Grazzini, Kallweit, Maierhofer, von Manteuffel, Pazzorini, Rathlev, Tancredi 1408.5243

- Need confirmation, differential analysis.

Figure: $pp \to W^+W^- + X$; σ [pb] vs $\sqrt{s}$ [TeV]. ATLAS, CMS data points. NNLO, NLO+gg, NLO, LO predictions; $gg \to H \to WW^*$ added to all predictions. Lower panel σ/σ_{NLO}.

WW Cross Section

There are very plausible BSM explanations for the excess!

**Direct Production
of EWinos in GMSB**

130 GeV $\tilde{\chi}_2^0$

113 GeV $\tilde{\chi}_1^0$

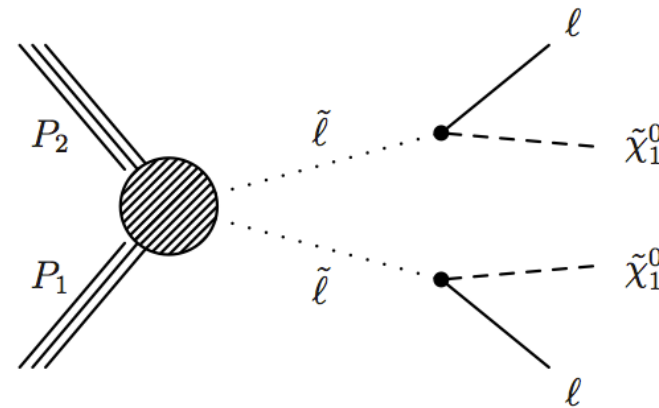110 GeV $\tilde{\chi}_1^\pm$

soft

$W^\pm$

0 GeV $\tilde{G}$

DC, Jaiswal, Meade   1206.6888

Sleptons

Can also give thermal Bino
and explain (g-2)$_\mu$
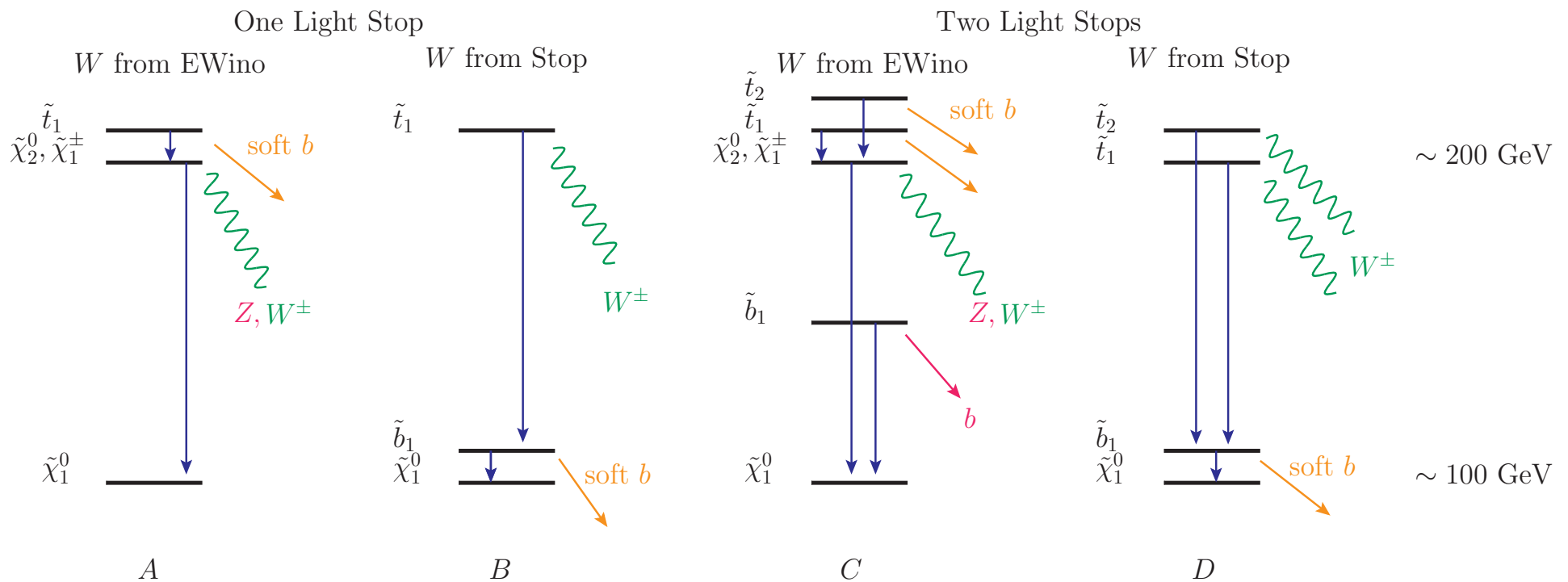
Somewhat disfavored by
recent ATLAS8 analysis.

P_2 $\tilde{\ell}$ ℓ $\tilde{\chi}_1^0$

P_1 $\tilde{\ell}$ $\tilde{\chi}_1^0$ ℓ

DC, Jaiswal, Meade, Tien 1304.7011

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WW Cross Section

There are very plausible BSM explanations for the excess!

Natural Stops!

One Light Stop

Two Light Stops

W from EWino | W from Stop | W from EWino | W from Stop

$\tilde{t}_1$
$\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$
soft b
$Z, W^\pm$
$\tilde{\chi}_1^0$

$\tilde{t}_1$
$W^\pm$
$\tilde{b}_1$
$\tilde{\chi}_1^0$
soft b

$\tilde{t}_2$
$\tilde{t}_1$
$\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$
soft b
$Z, W^\pm$
$\tilde{b}_1$
b
$\tilde{\chi}_1^0$

$\tilde{t}_2$
$\tilde{t}_1$
$W^\pm$
$\tilde{b}_1$
$\tilde{\chi}_1^0$
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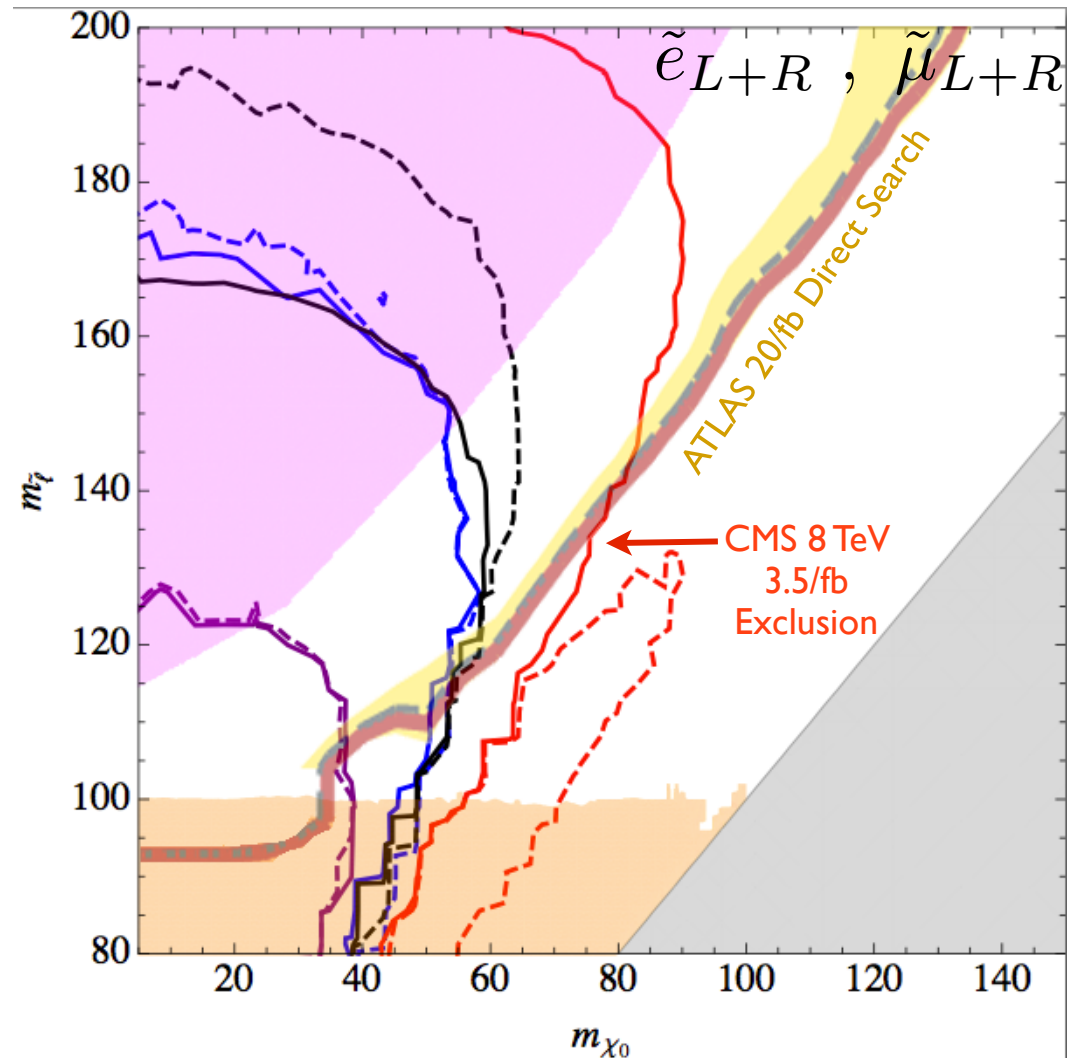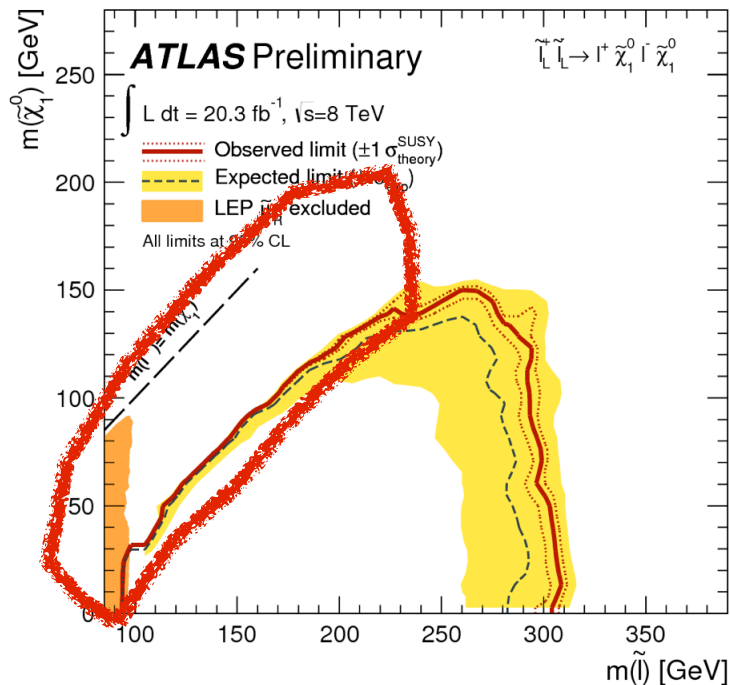~ 200 GeV

~ 100 GeV

A B C D

WW Cross Section

- Even if BSM explanations don't pan out, we should be using the WW cross section measurement to **set new exclusions on these BSM scenarios!**

DC, Jaiswal, Meade, Tien 1304.7011

Fill gaps in BSM searches

Top Pair Production

Stops hiding on top of tops

- Well known blind spot when looking for SUSY stops: what if stop mass = top mass, and stop decays look like top decays?

- Stop cross section is much smaller than top cross section (0.15 x), difficult to detect the excess.

- Experimental uncertainty of top cross section measurement is ~ 5% (systematics dominated)

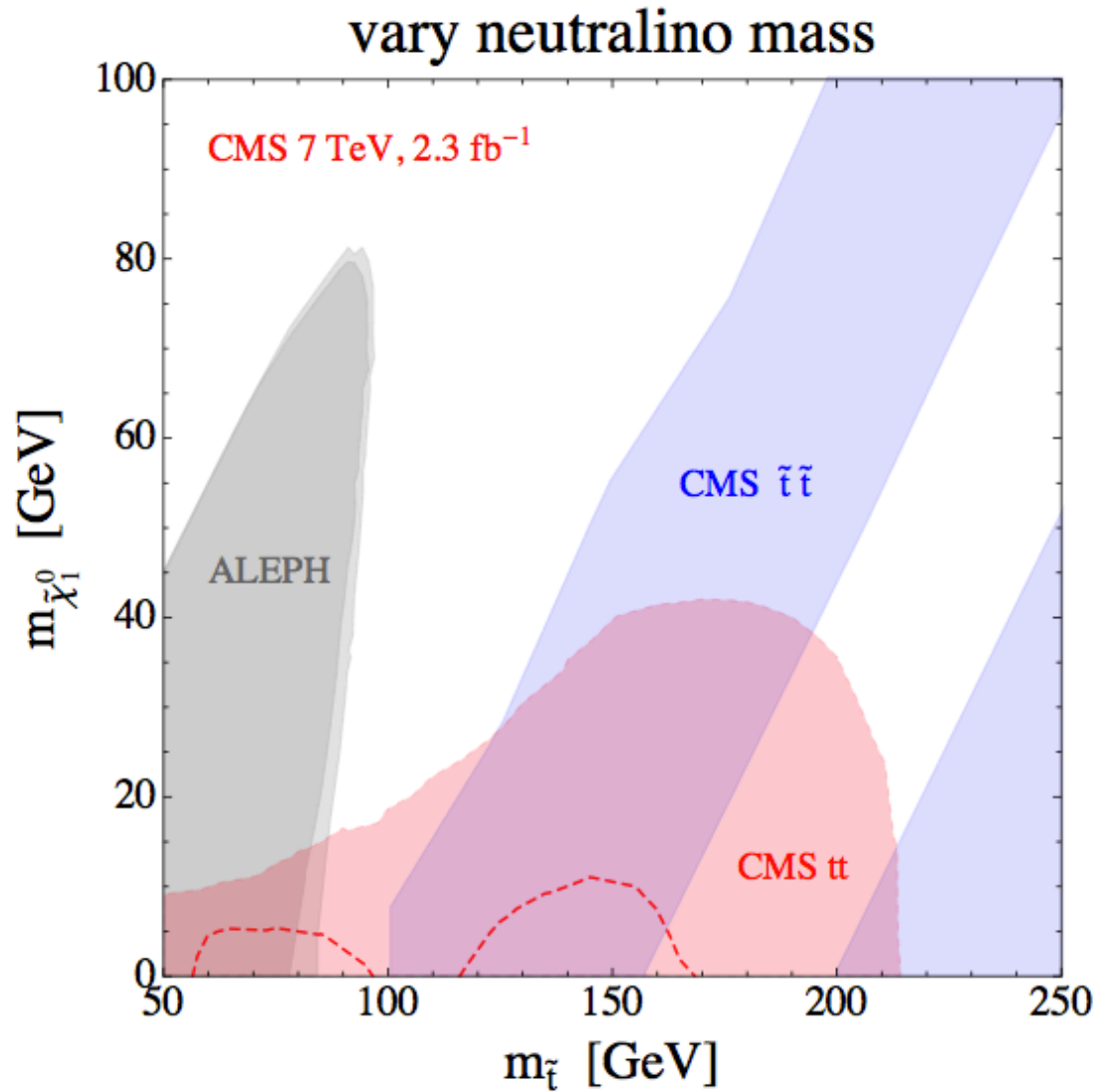- Recent progress in NNLO+NNLL calculations reduced theoretical uncertainties to be ~ exp uncertainties:

$$\sigma_{t\bar{t}}^{LHC7} = 172^{+4.4}_{-5.8}(\text{scale})^{+4.7}_{-4.8}(\text{pdf})\,\text{pb for } m_t = 173.3\,\text{GeV}$$

Czakon, Fiedler, Mitov, 1303.6254
Czakon, Mitov 1112.5675

- It is now feasible to use top cross section measurement to start excluding stealth stop models! Czakon, Mitov, Papucci, Rudermann, Weiler 1407.1043

Stops hiding on top of tops

vary neutralino mass

CMS 7 TeV, 2.3 fb^{-1}

CMS $\tilde{t}\tilde{t}$

ALEPH

CMS tt

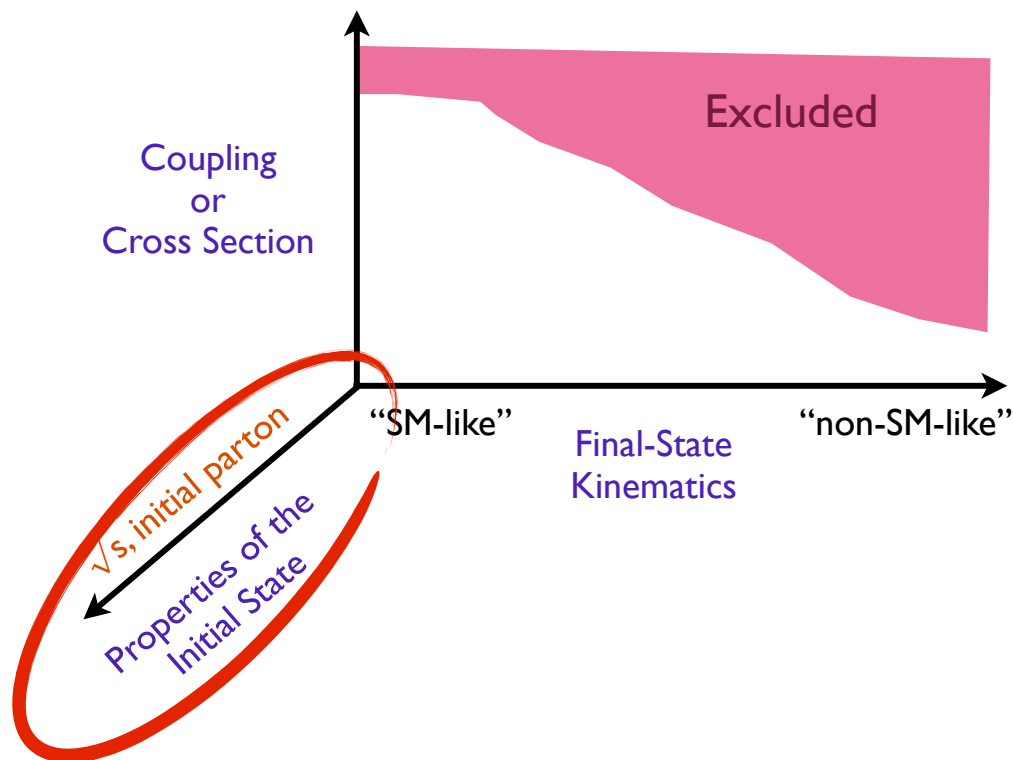$m_{\tilde{\chi}_1^0}$ [GeV]

$m_{\tilde{t}}$ [GeV]

Czakon, Mitov, Papucci, Rudermann, Weiler 1407.1043

These two examples looked at *absolute* SM vs BSM differential cross section predictions at (essentially) a single center-of-mass energy.

Hopefully, these particular BSM possibilities will be discovered or ruled out by the time we build a 100 TeV collider, but the general issue will remain.

It's possible to improve on this approach by exploiting data from collisions at different energies.

Exploiting Initial State Dependence

8 TeV

14 TeV

100 TeV

Coupling
or
Cross Section

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"SM-like"   "non-SM-like"

Final-State
Kinematics

√s, initial parton

Properties of the
Initial State

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Precision could mean everything

- Previous examples already demonstrated: finding BSM in SM measurements requires very precise theory predictions and small systematic errors in the measurement.

  Finding ways to reduce large theory uncertainties (PDF, scale) and experimental systematics (luminosity, ??) is crucial!

- It is very well-known that **ratios of observables** can be used to reduce many correlated uncertainties.
  $\Rightarrow$ e.g. an official experimental measurement of $\sigma(WW)/\sigma(ZZ)$ could be very interesting...

Hadronic collision data at
$$\sqrt{s} = 8 , \quad 14 , \quad ??? , \quad 100 \ \text{TeV}$$
suggests new approach to both of these issues

Mangano, Rojo
1206.3557

Exploiting √s-dependence

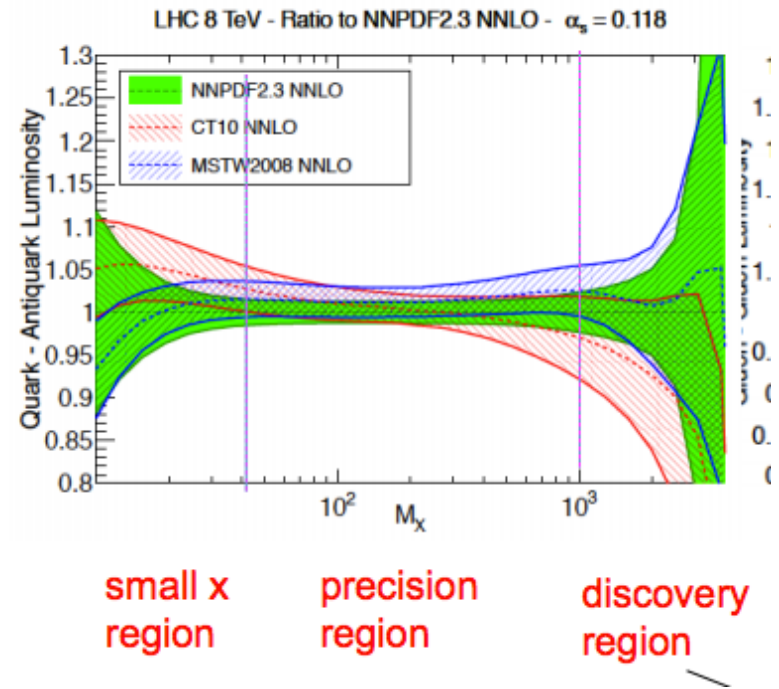Focus on two highlights from Mangano, Rojo 1206.3557

Reducing PDF uncertainty

Detecting BSM in SM cross section measurements

Exploiting √s-dependence

Reducing PDF uncertainty

- Already, our PDF fits are 'stretched thin' in some LHC analyses, providing a dominant source of error, especially at large x/Mx for BSM analyses.
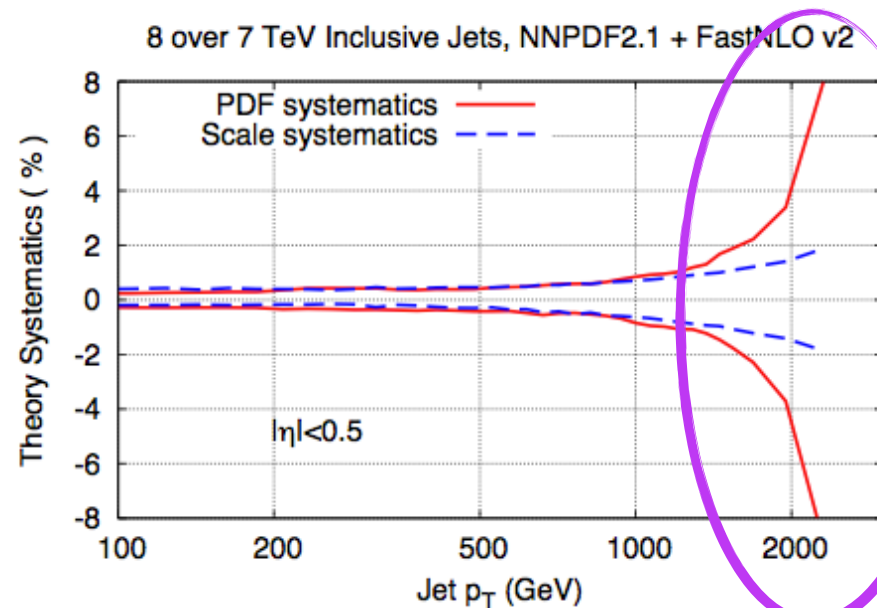

From Joey Huston's Talk this morning

- This will be an even bigger issue at a 100 TeV collider (especially anticipating theoretical progress over the next 20 years, which will likely reduce other theory uncertainties)

Exploiting √s-dependence

Reducing PDF uncertainty

- Top pair production is mostly gluon-initiated. At high tt masses, the $\sigma(tt, 8\,\text{TeV})/\sigma(tt, 7\,\text{TeV})$ or 8/14 ratio is highly sensitive to gluon PDF at high x.

- Similarly high pT jet production probes high x quark PDF

8 over 7 TeV Inclusive Jets, NNPDF2.1 + FastNLO v2

PDF systematics
Scale systematics

$|\eta|<0.5$

Theory Systematics (%)

Jet p_T (GeV)

This is a good thing!

Exploiting $\sqrt{s}$-dependence

Detecting BSM in SM cross section measurements

- Very simple idea.

  1. Different parton luminosities grow at different rates with energy

  2. SM and BSM processes with difficult-to-distinguish final states can be dominantly produced by different parton collisions.

roughly speaking, how many gluons vs quarks vs ... smash together for a 'parton-blind' process

This actually captures much of the energy-dependence of BSM searches, see **Collider Reach** Tool (Gavin Salam, Andi Weiler)

- This can serve to amplify the difference in energy-dependence of the parton-level SM vs BSM processes *themselves*.

Exploiting √s-dependence

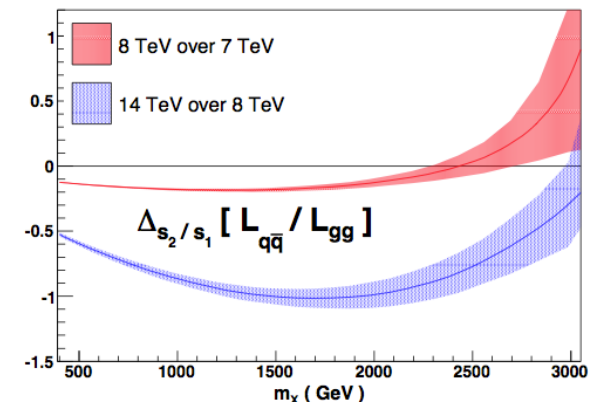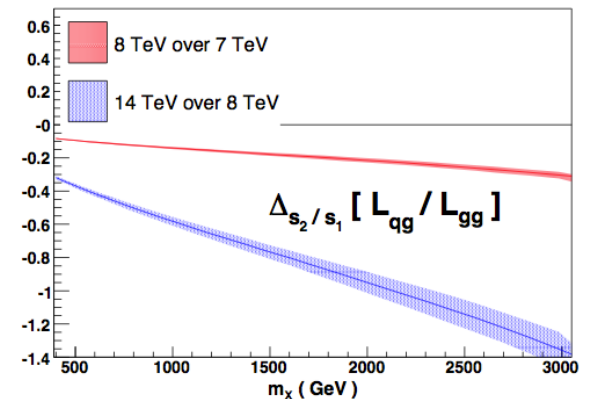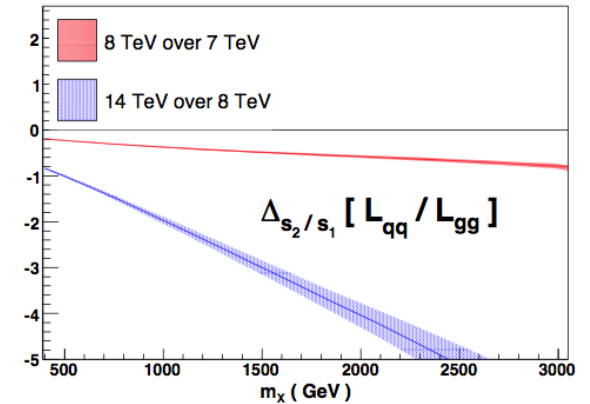## Detecting BSM in SM cross section measurements

- Simple example: high mass tt production

  SM contribution: tt (gluon-gluon dominated)

  possible BSM contribution: Z' (qq dominated), but could look for other things (that are not gg dominated)

- Differences in parton luminosity energy scaling act as a 'sensitivity multiplier'

$$\frac{\sigma_X^{\text{BSM}}(E_1)}{\sigma_X^{\text{SM}}(E_1)} \times \Delta_{E_1/E_2}\left[\frac{\sigma_X^{\text{BSM}}}{\sigma_X^{\text{SM}}}\right] > \delta_{TH} \equiv \frac{\delta R_{E_1/E_2}^{\text{SM}}}{R_{E_1/E_2}^{\text{SM}}}$$

Exploiting √s-dependence

Both of these approaches will be very powerful when spanning collision energies from 8 to 100 TeV.

Might even motivated staggered data-taking, e.g.
30, 70, 100 TeV
to improve PDFs and achieve high BSM sensitivity?

Almost Lunch Time!

Final Thoughts

- Does a SM vs BSM separation in our experimental approach even make sense? Does it cause us to miss well-motivated BSM models that are 'next door' in parameter space?

- If we find nothing at the LHC, precision measurements will be an important *raison d'être* for future colliders (think EWPT @ LEP!). Refining those approaches will be crucial for finding or excluding BSM.

- It is *very easy* to plausibly hide BSM in SM!

- There are many unexploited approaches for constraining BSM in SM, and theoretical predictions will only become more precise.

- Release measurements of ratios! Even if theoretical uncertainties are still big, experimental uncertainties will be smaller, and theoretical uncertainties will shrink eventually...