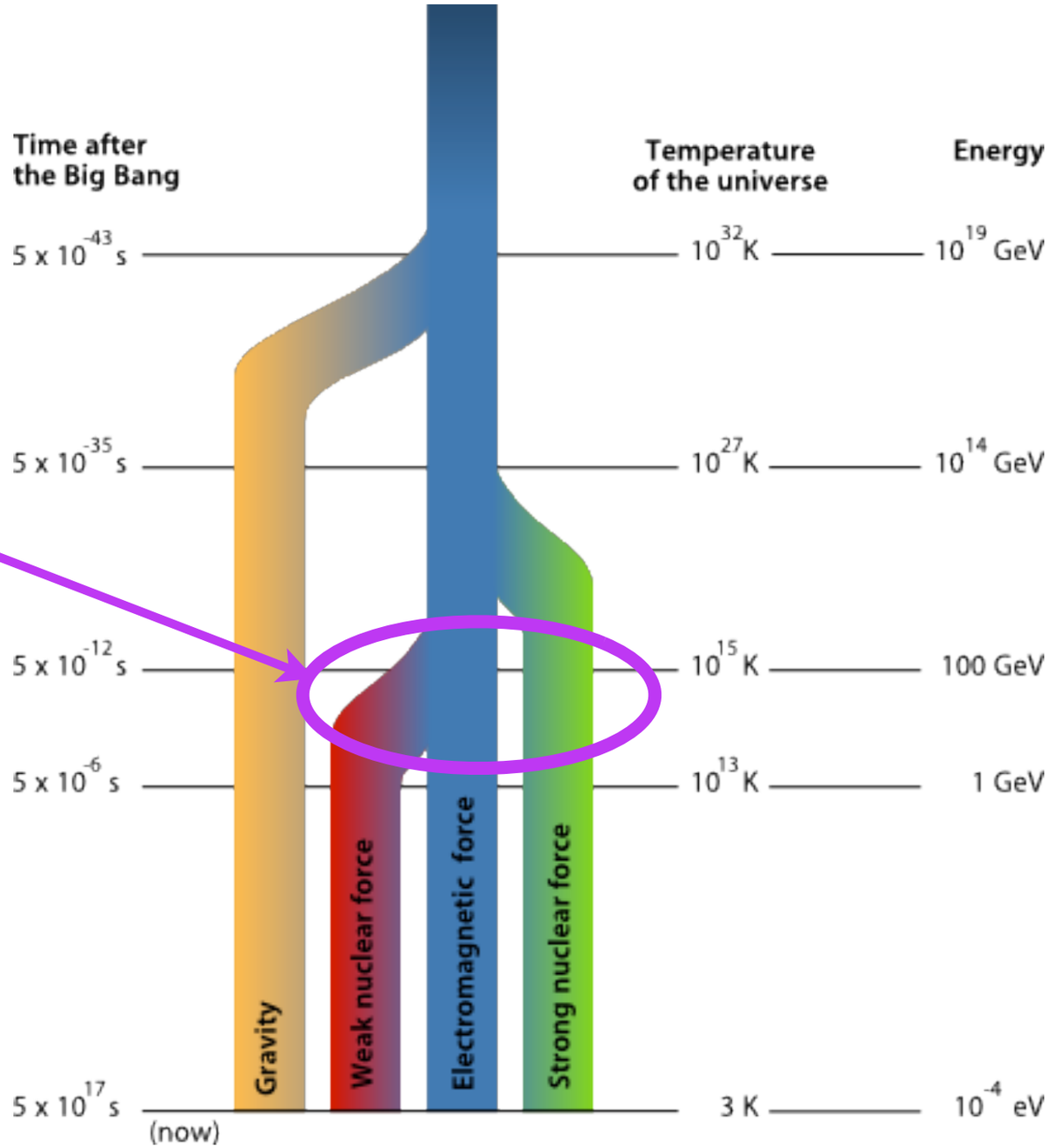
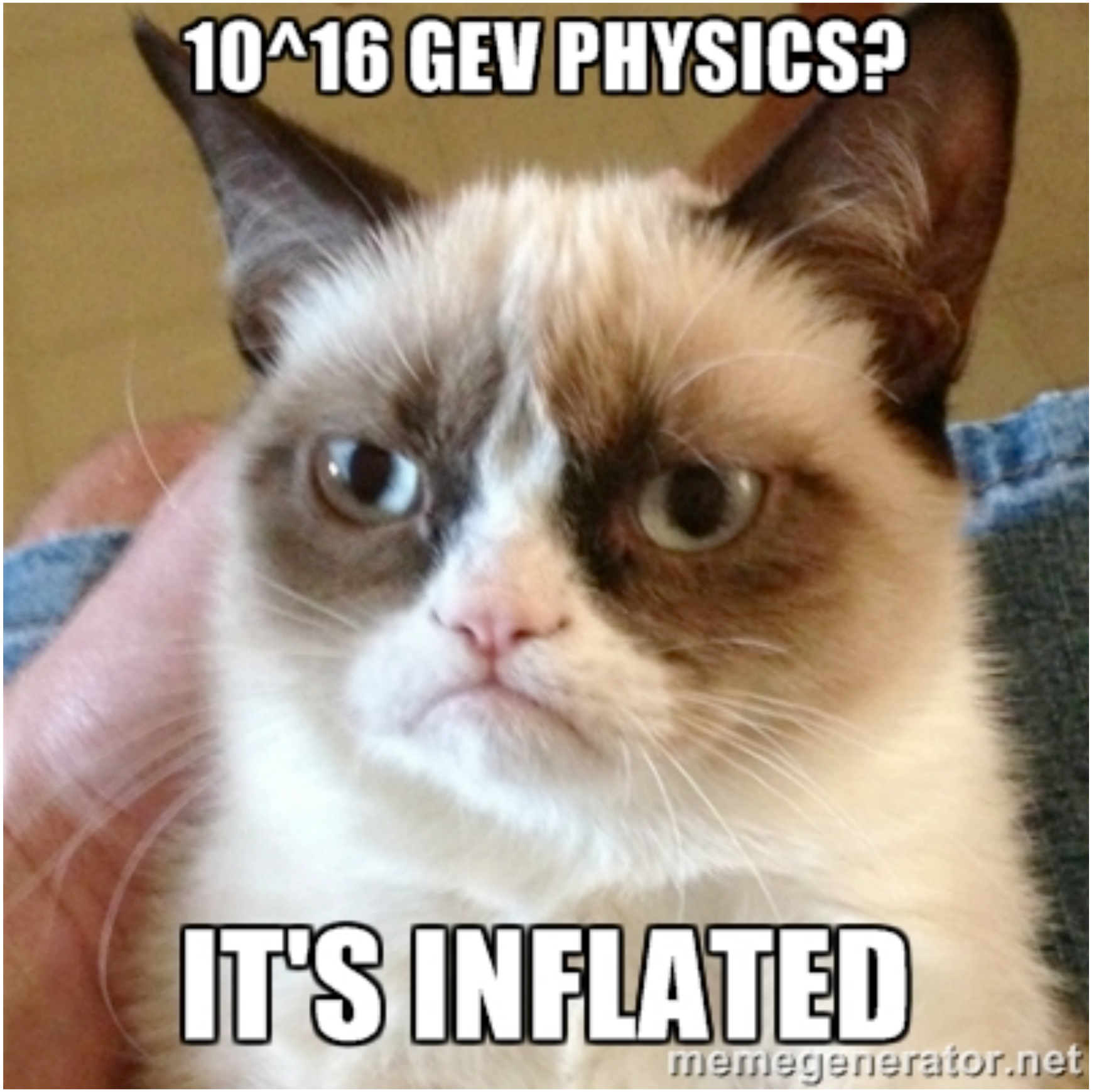
Winter 2014 Physics Results from CMS

Yuri Gershtein

LHC is exploring EWSB

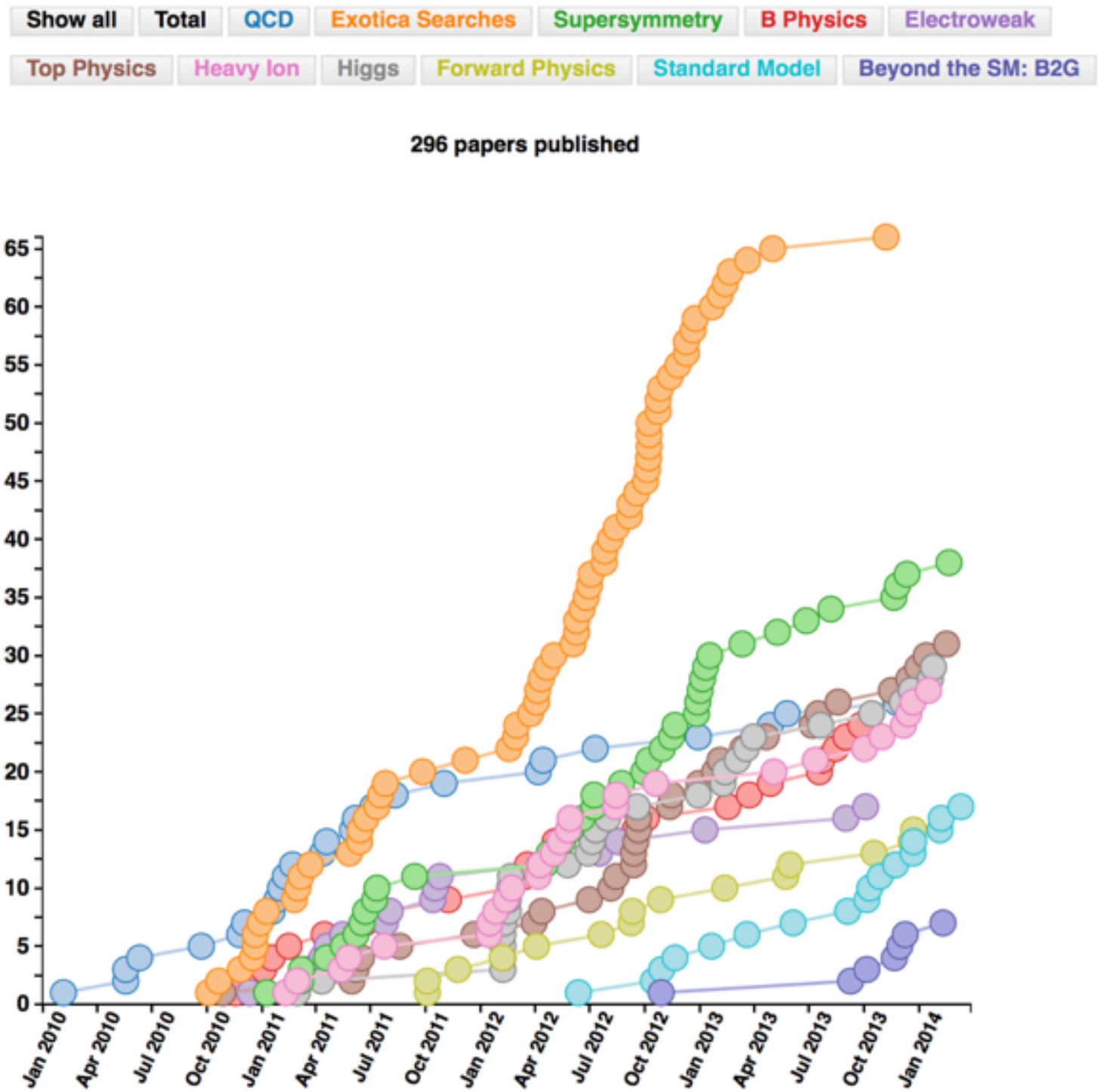
We are here




10^16 GEV PHYSICS?
IT'S INFLATED
memegenerator.net

CMS Physics Output

- recently submitted 300th physics paper
  - plus, there are preliminary results



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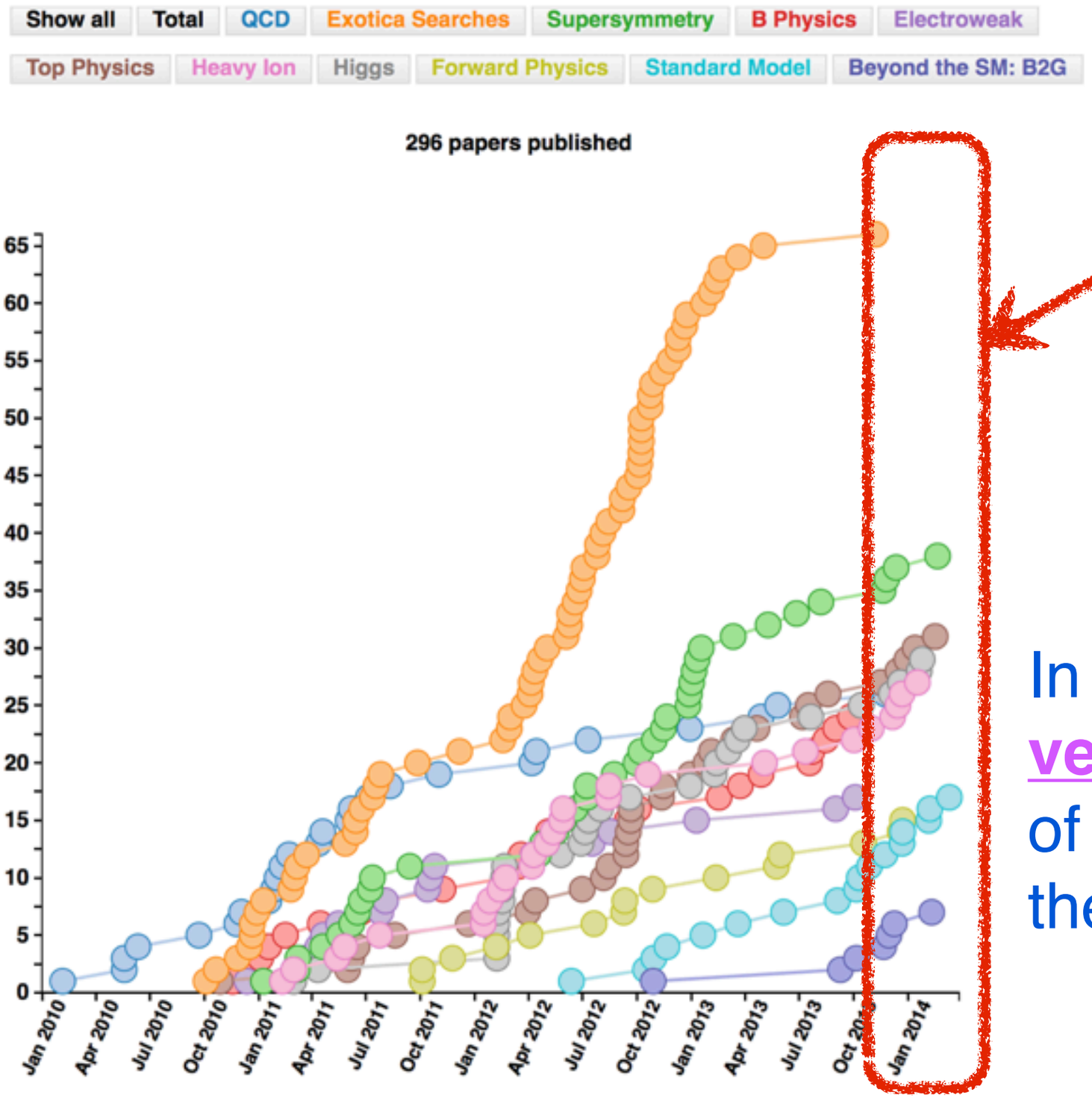


About three dozens new results for Moriond

In this talk:
very personal choice
of a couple of topics on these themes

In Torrential Detail

- for the full picture see https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

CMS Physics Results

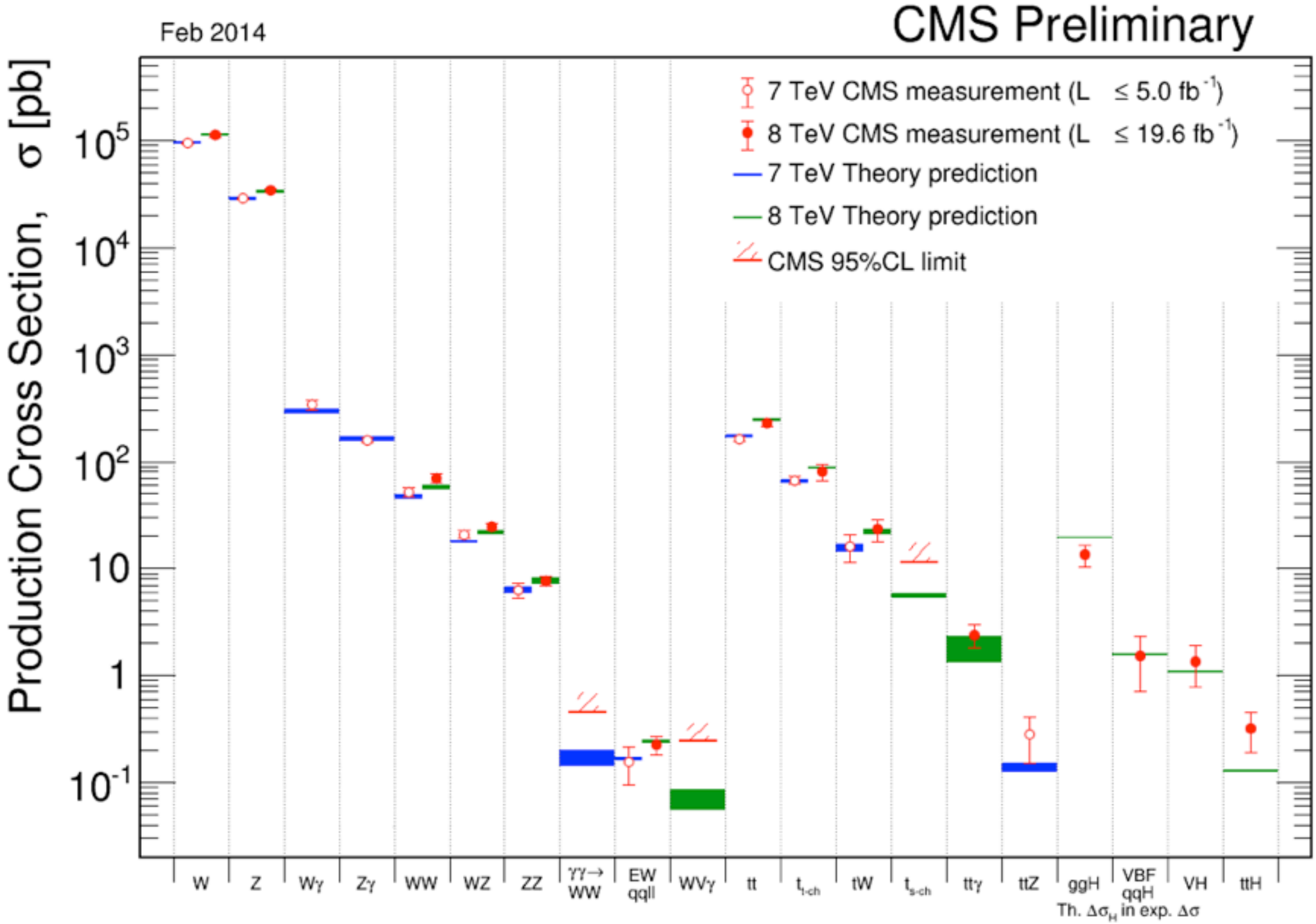
General Information

- All CMS public results can be found in CDS , and are categorized by subject (group) in this page.
- Publications and preprints on **collision data**, ordered by time, are available at this link.
- Publications on cosmic-ray data can be found here; the paper on muon charge ratio is available here .
- The complete list of publications is here.
- Preliminary results **on collision data at 0.9, 2.36, 7, and 8 TeV** are described in Physics Analysis Summaries; Monte Carlo studies can be found here.
- Public performance plots are shown in Detector Performance Summaries.
- For any questions, please contact the CMS Physics Coordinator, Luca.Malgeri@cernSPAMNOT.ch

Physics Analyses

Physics Analysis Group	Group page	Publications	Preliminary Results	Monte Carlo studies
Combined Results	Plots and results			
Forward and Small-x QCD Physics	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
B Physics and Quarkonia	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Standard Model Physics (Vector Bosons & Jets)	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Top Physics	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Higgs Physics	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Supersymmetry	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Exotica	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Beyond 2 Generations	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries
Heavy-Ion Physics	Plots and Results	Papers	Physics Analysis Summaries	Physics Analysis Summaries

SM @ CMS


CMS Preliminary
Feb 2014
Production Cross Section, σ [pb]
10^5
10^4
10^3
10^2
10
1
10^{-1}
7 TeV CMS measurement (L ≤ 5.0 fb^{-1})
8 TeV CMS measurement (L ≤ 19.6 fb^{-1})
7 TeV Theory prediction
8 TeV Theory prediction
CMS 95%CL limit
W
Z
Wγ
Zγ
WW
WZ
ZZ
γγ→ WW
EW qqll
WVγ
tt
$t_{t\text{-ch}}$
tW
$t_{s\text{-ch}}$
ttγ
ttZ
ggH
VBF qqH
VH
ttH
Th. $\Delta\sigma_H$ in exp. $\Delta\sigma$

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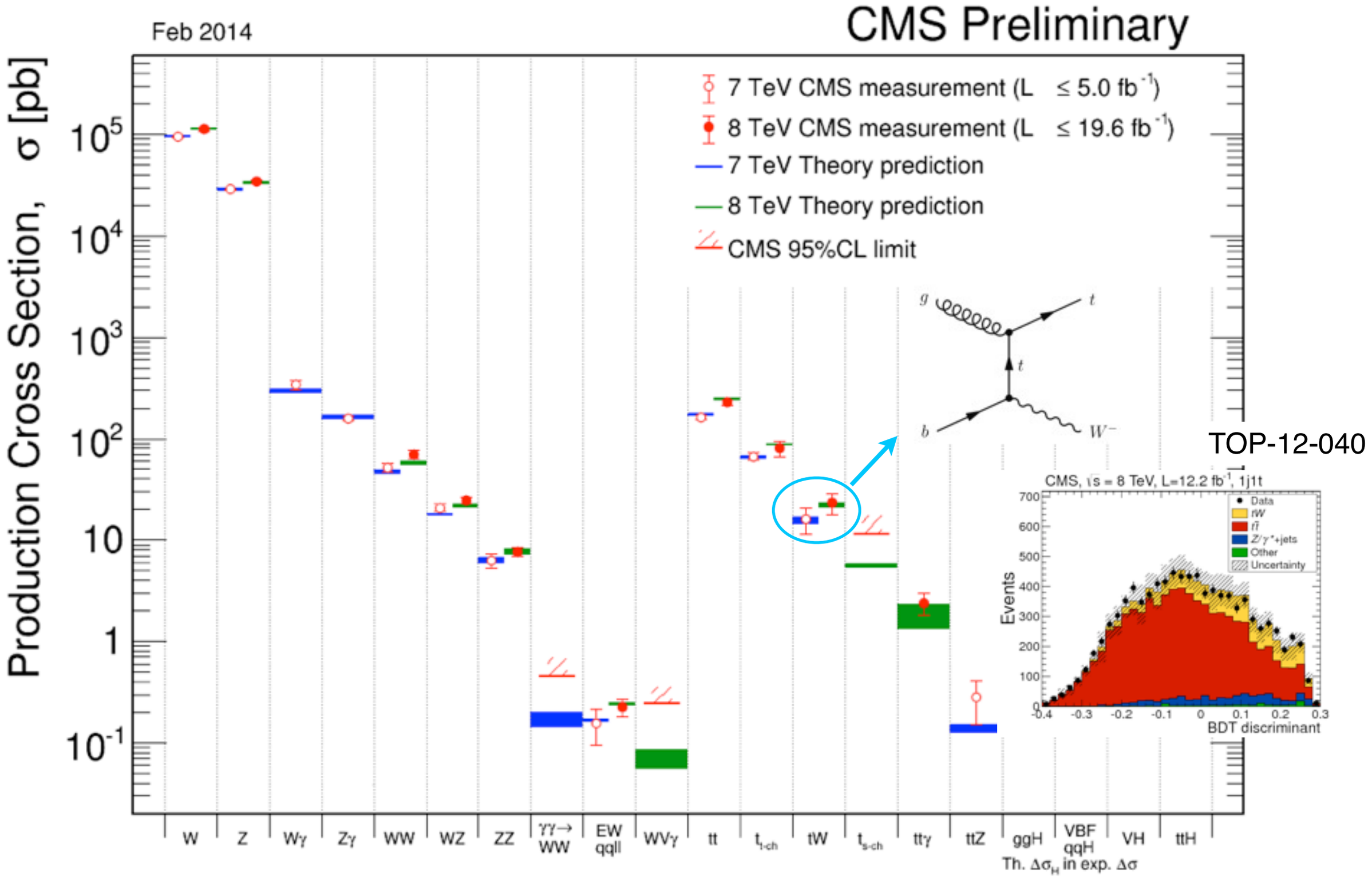
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8 TeV Theory prediction
CMS 95%CL limit
TOP-12-040
CMS, √s = 8 TeV, L=12.2 fb-1, 1j1t
Data
tW
tt̄
Z/γ*+jets
Other
Uncertainty
Events
BDT discriminant
W
Z
Wγ
Zγ
WW
WZ
ZZ
γγ→ WW
EW qqll
WVγ
tt
t-ch
tW
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ttZ
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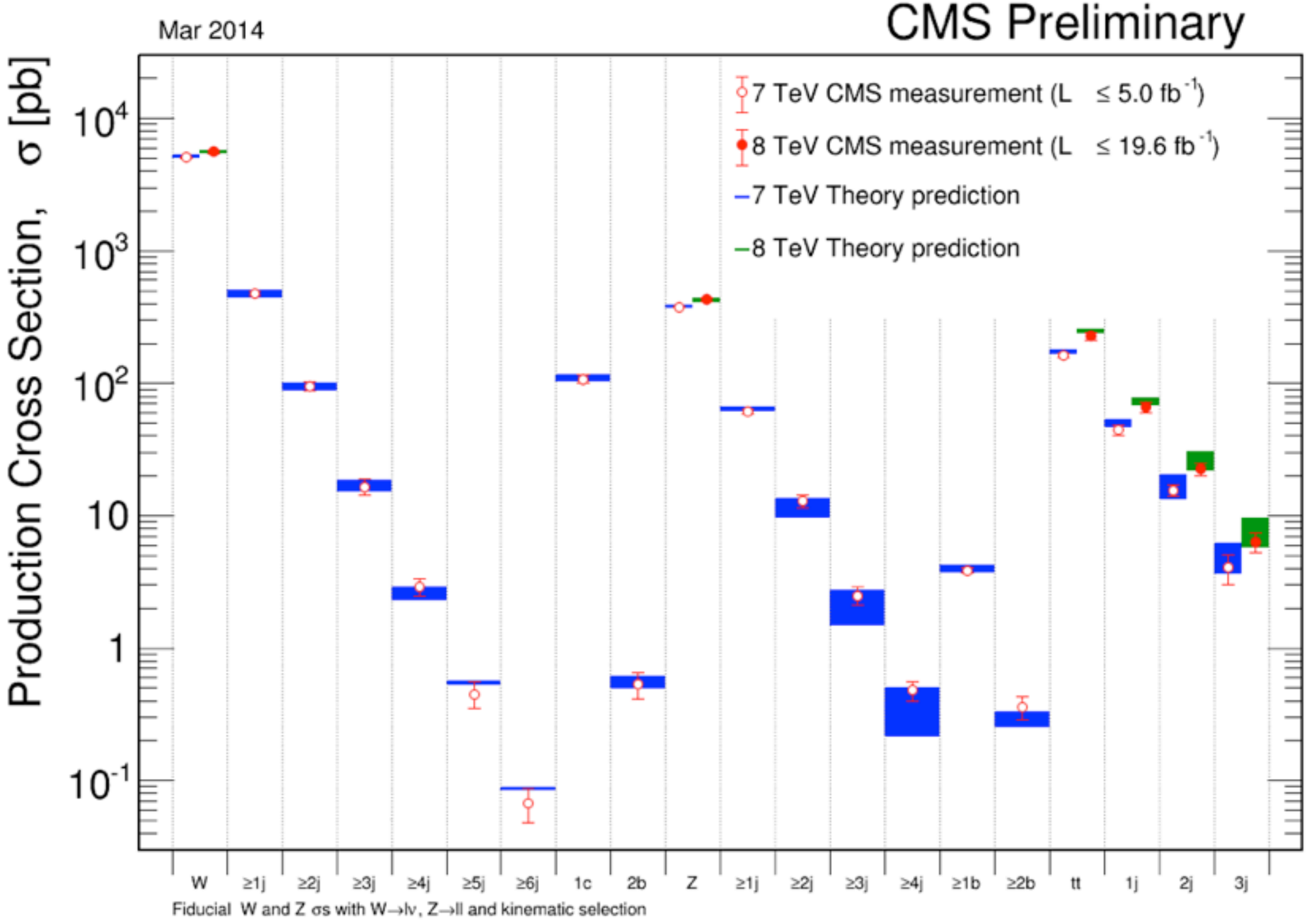
VH
ttH
Th. Δσ_H in exp. Δσ

Perturbative QCD at work



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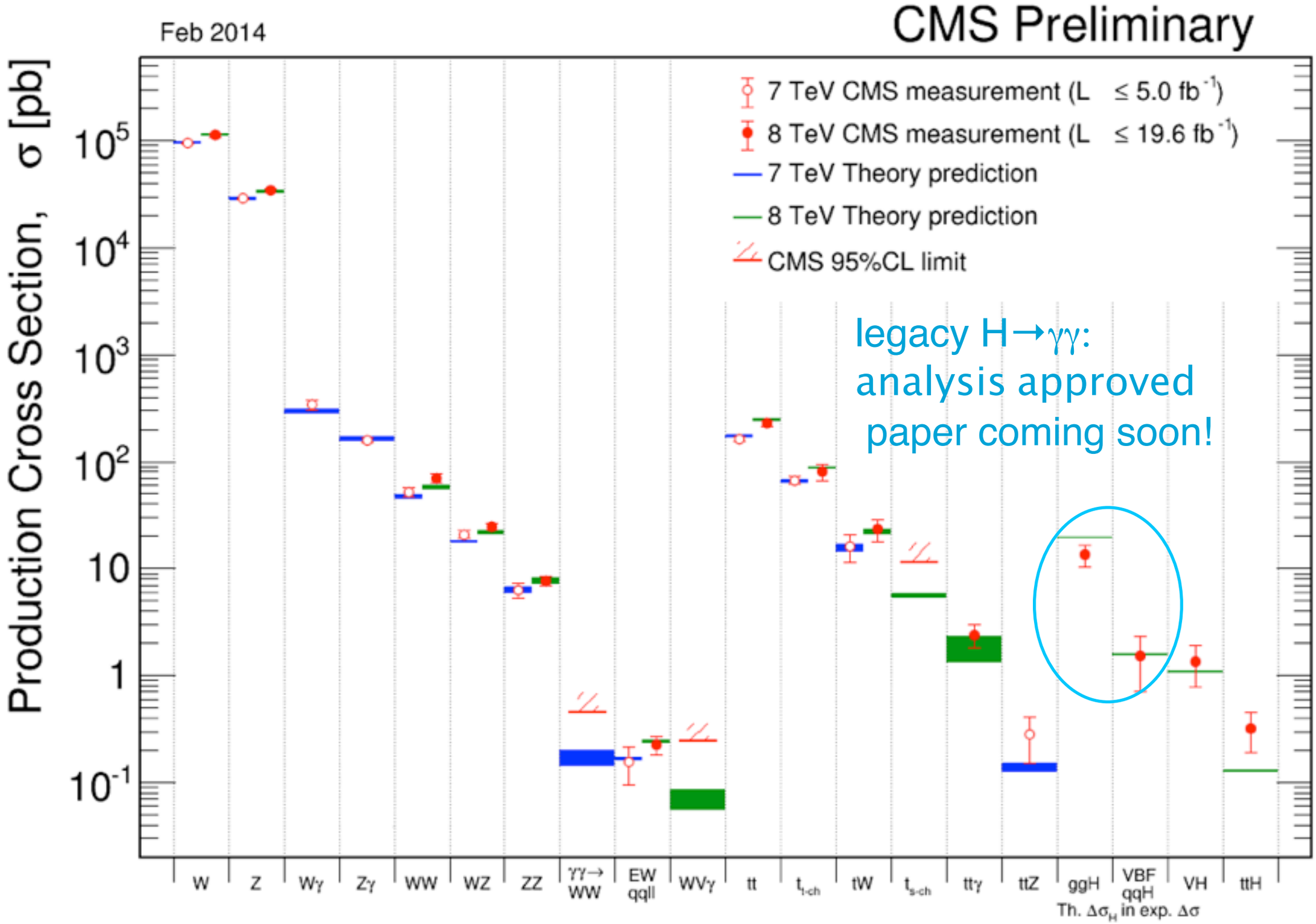
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legacy H→γγ:
analysis approved
paper coming soon!
W
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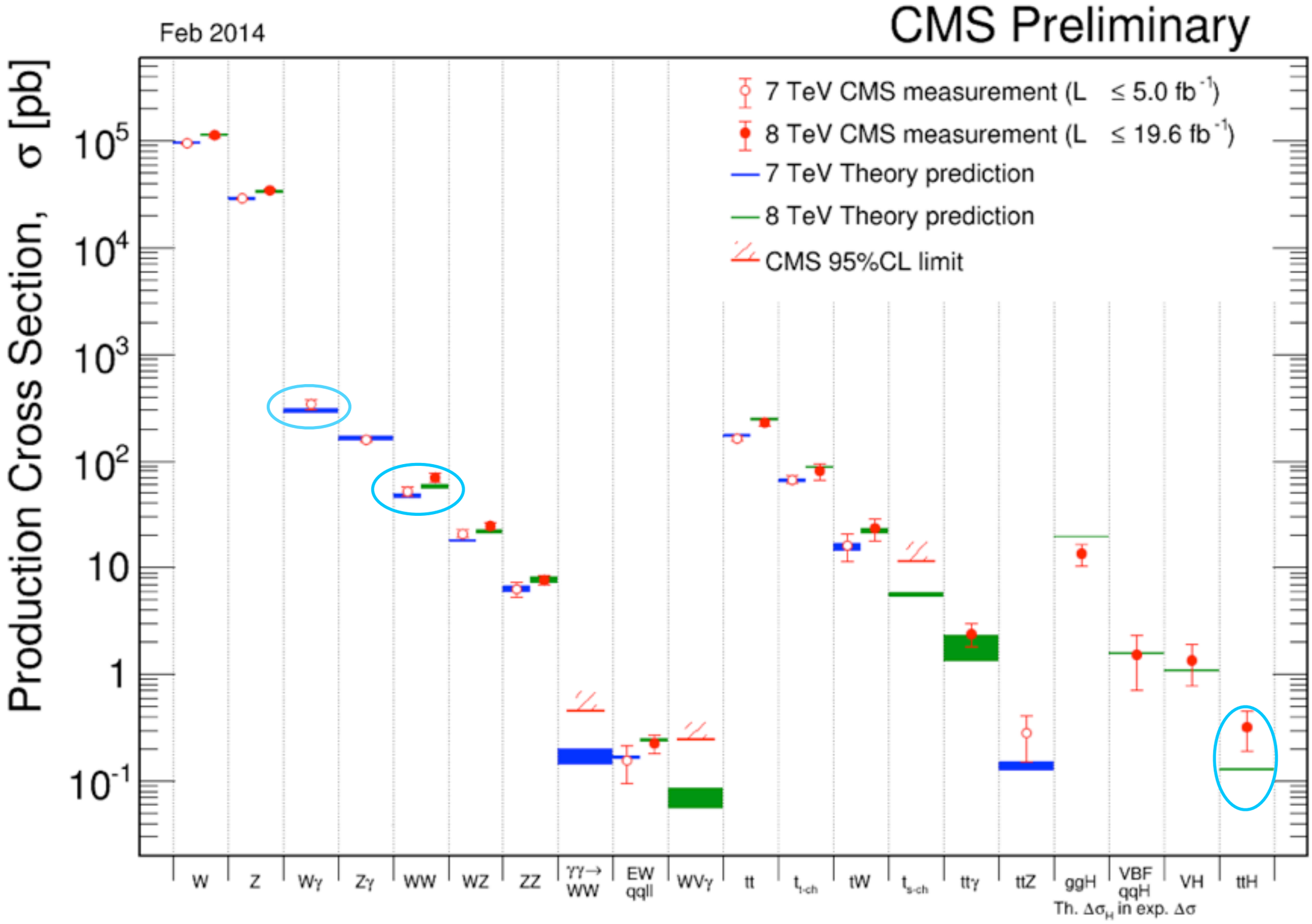
Th. Δσ_H in exp. Δσ

SM @ CMS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Th. Δσ_H in exp. Δσ

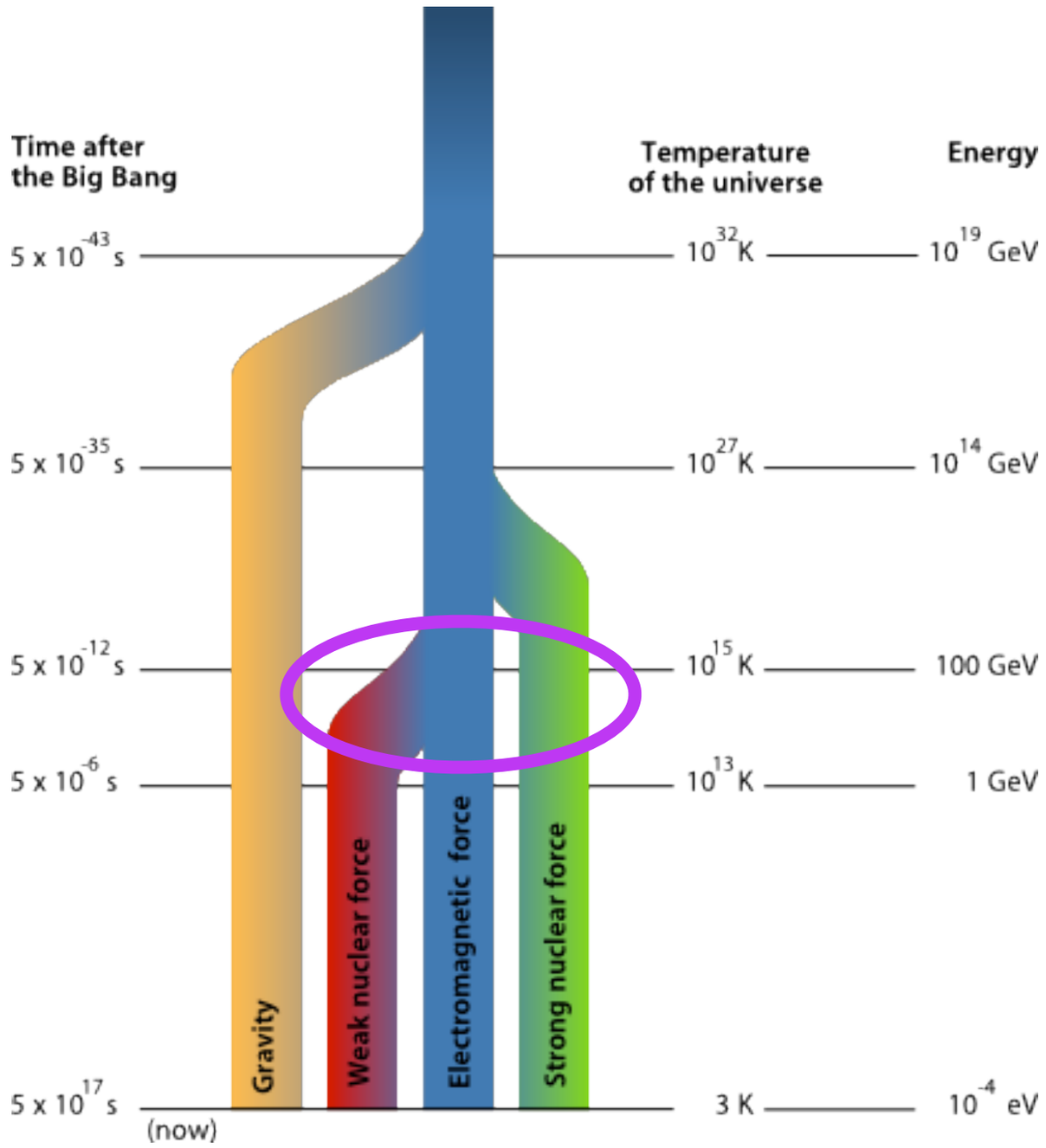
LHC is exploring EWSB

Fundamental scalar *exists!*

Are there more of them?

Every time you produce a Higgs boson you are learning a bit more about EWSB

Every time you produce W/Z at large √s you probe EWSB



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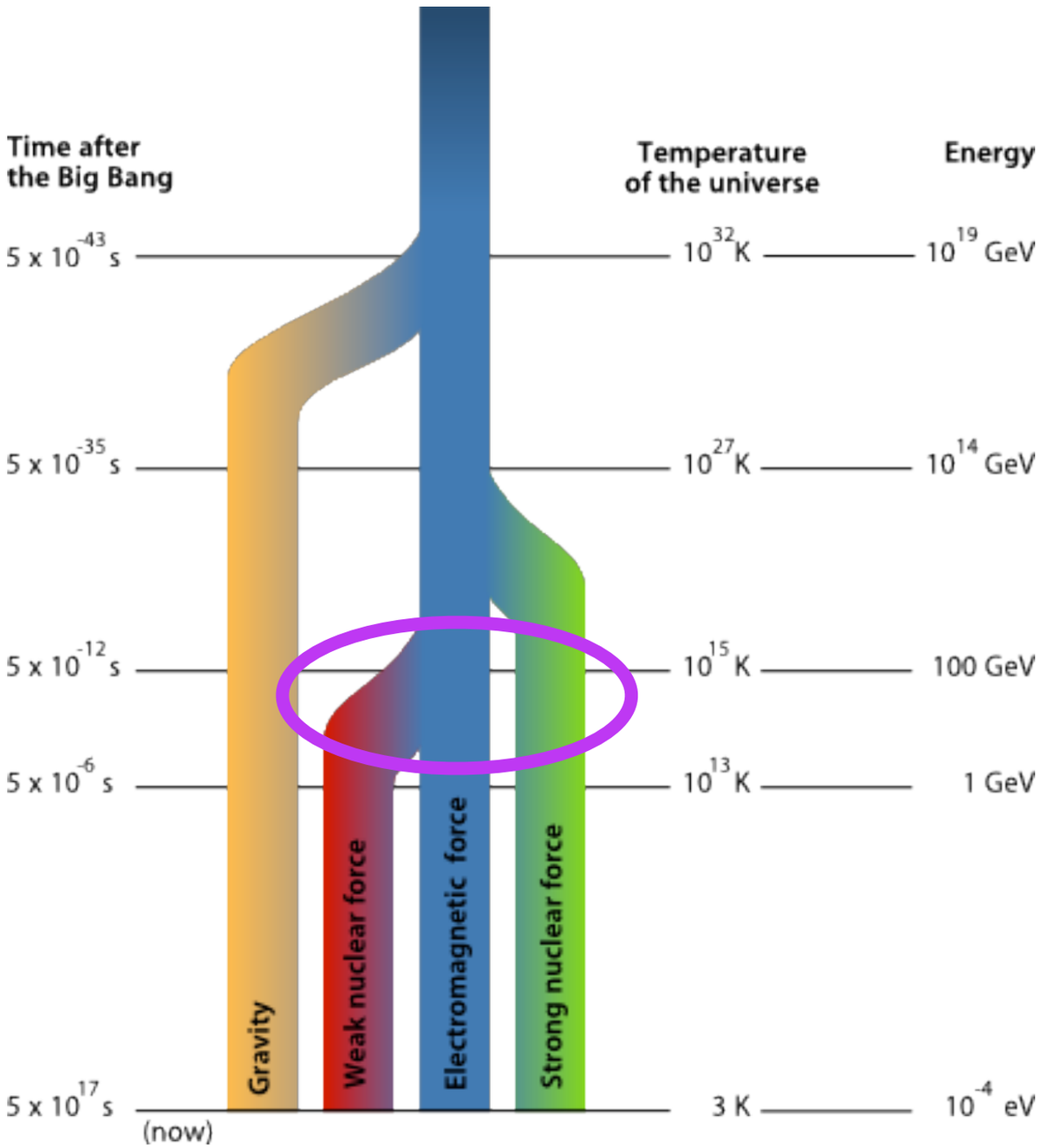
In this talk:

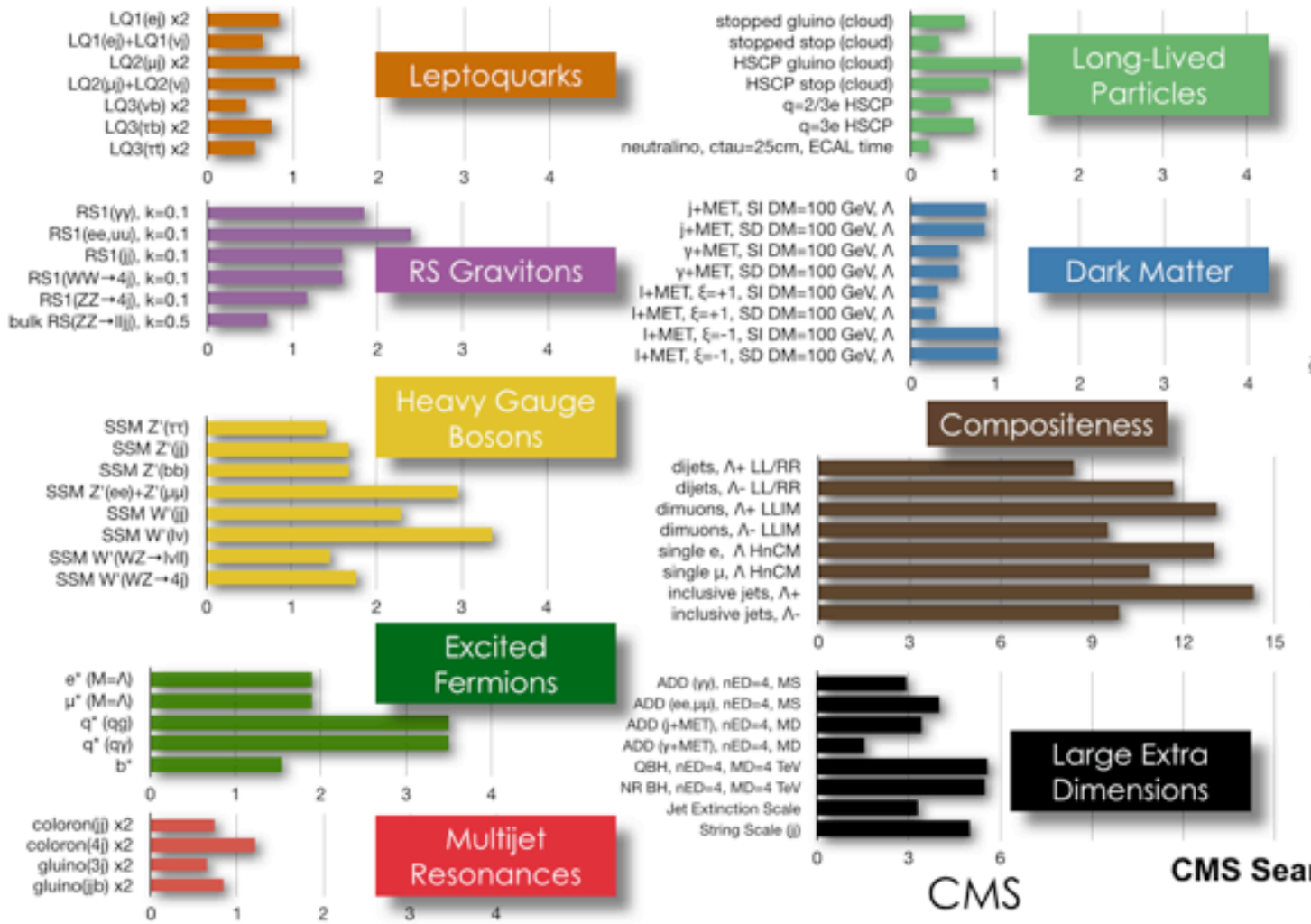
★ Long-lived particles (in Higgs decays)

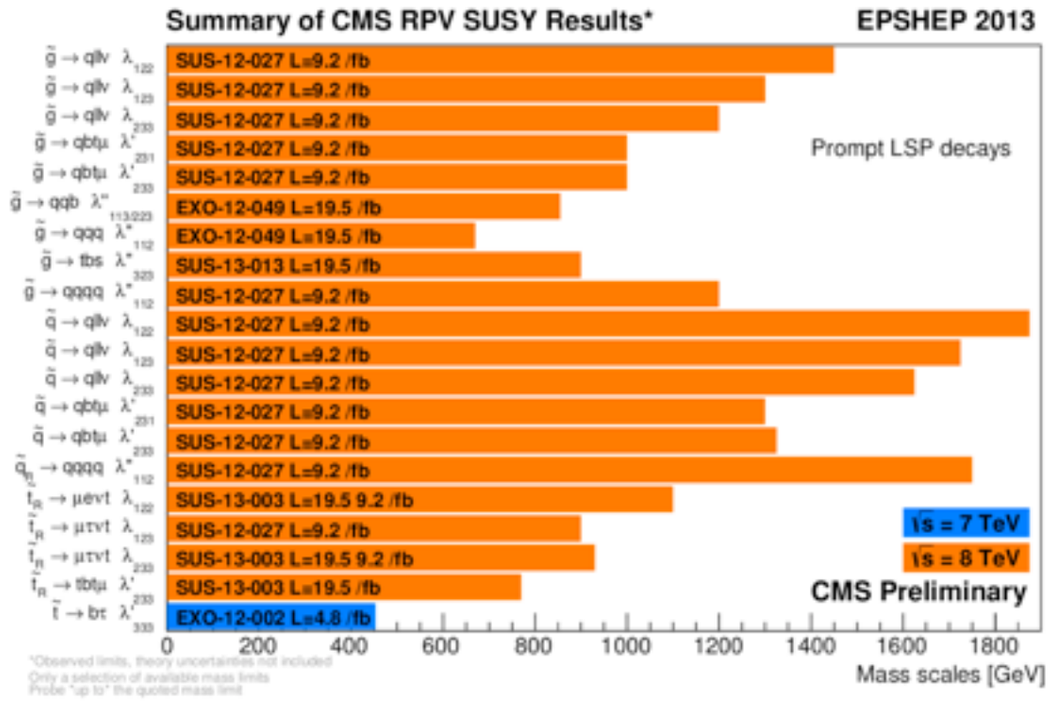
★ Higgs as a new physics tag (i.e. in SUSY searches)

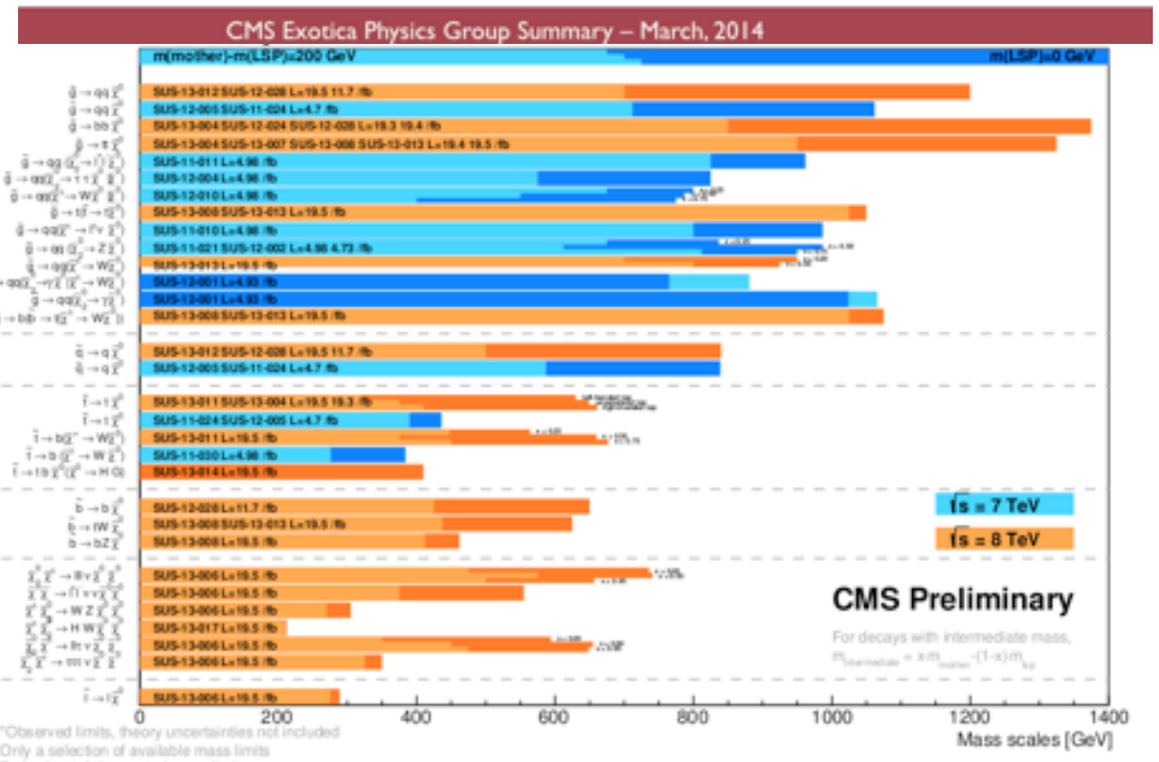
★ plus a few more

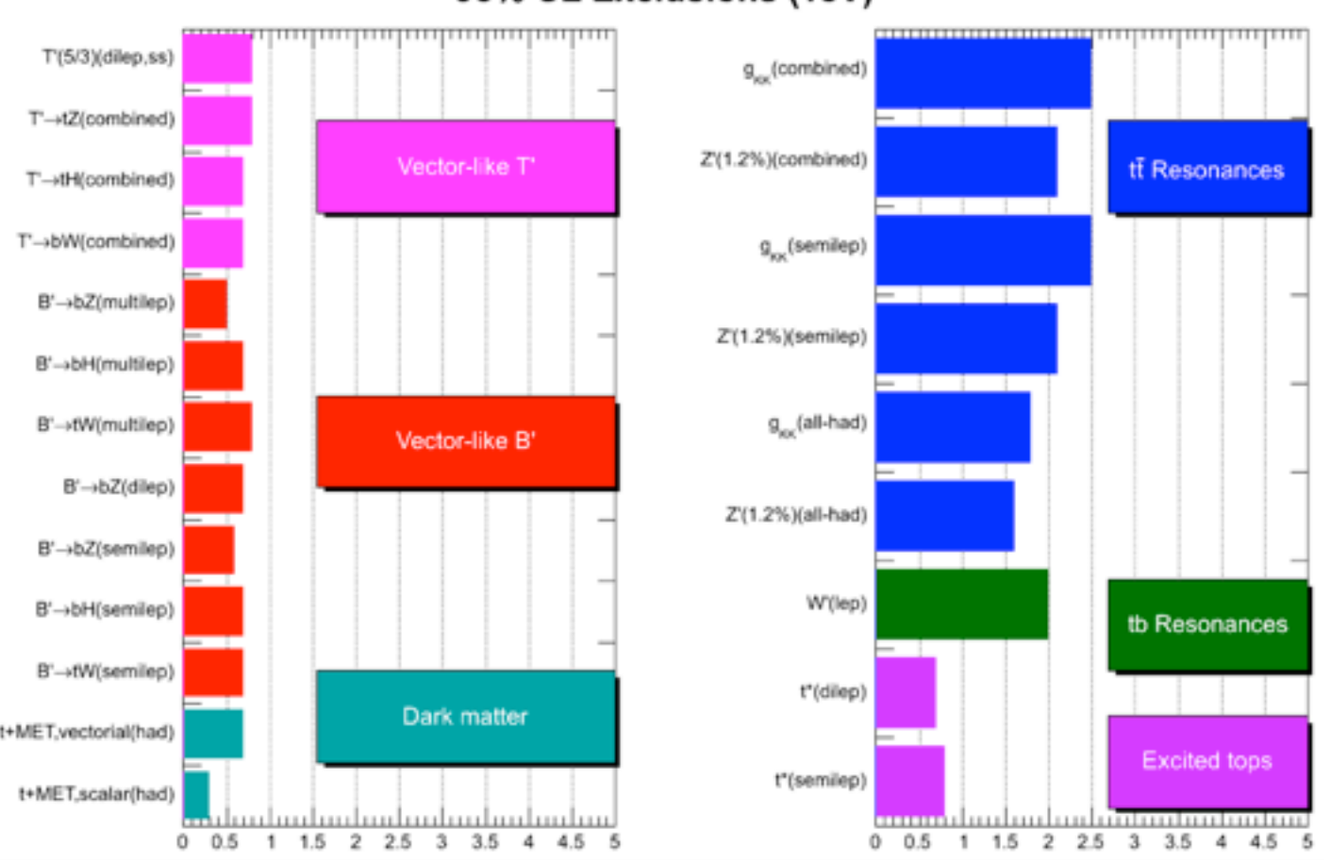


New Physics









Yuri Gershtein, FNAL

Long-lived particles

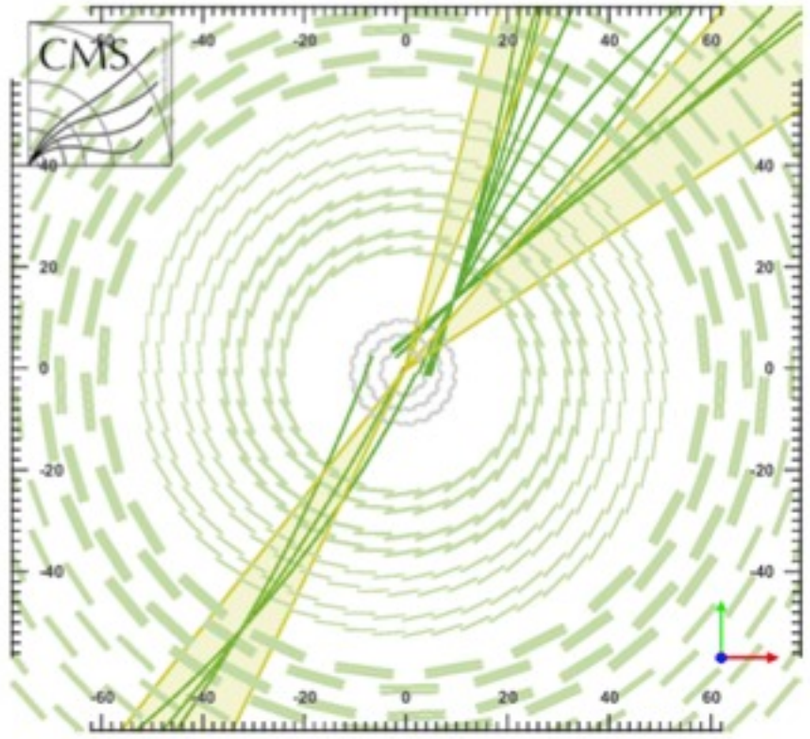
- Large number of well-motivated scenarios predict long-lived particles
  - hidden valley models
  - rare Higgs decays (the one at 125 GeV or a new one) - if there are HVs, Higgs may the particle that senses them most: $H \to XX, \quad X \to f\bar{f}$
  - RPV SUSY $\tilde{q} \to q\chi^0(\to \ell^+\ell^-\nu)$ (or H cascade)

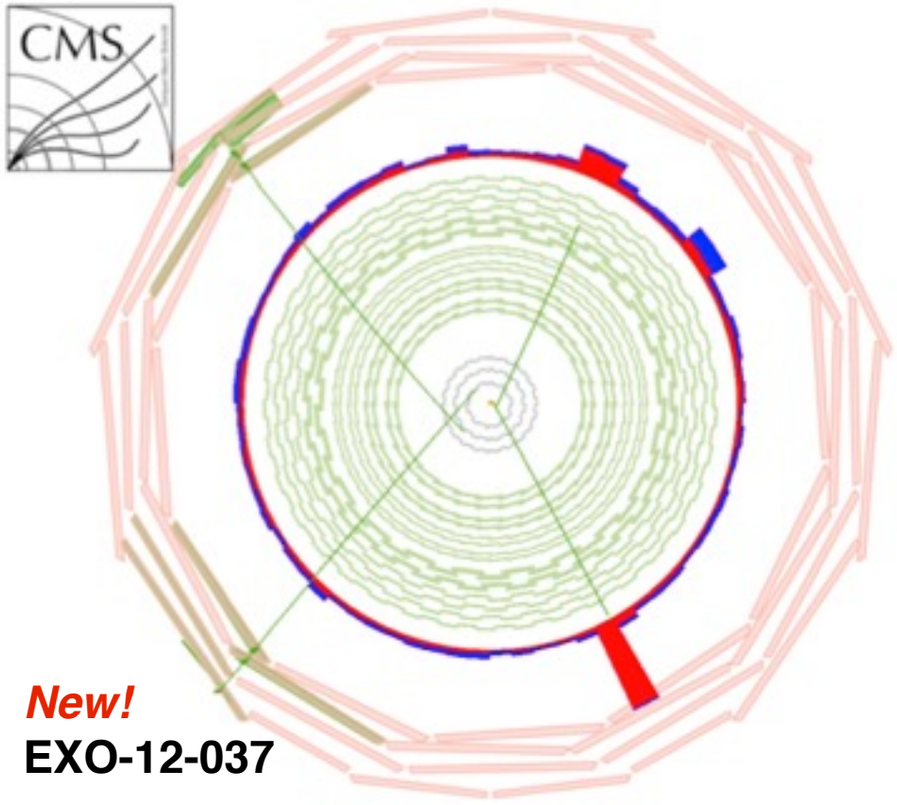
generic search, benchmark points

M_{H^0} (GeV/c^2)	M_X (GeV/c^2)	$c\tau$ (cm)
1000	350	(3.5, 35.0, 350.0)
1000	150	(1.0, 10.0, 100.0)
1000	50	(0.4, 4.0, 40.0)
1000	20	(0.15, 1.5, 15.0)
400	150	(4.0, 40.0, 400.0)
400	50	(0.8, 8.0, 80.0)
400	20	(0.4, 4.0, 40.0)
200	50	(2.0, 20.0, 200.0)
200	20	(0.7, 7.0, 70.0)
125	50	(5.0, 50.0, 500.0)
125	20	(1.3, 13.0, 130.0)

$M_{\tilde{q}}$ (GeV/c^2)	$M_{\tilde{\chi}_1^0}$ (GeV/c^2)	$c\tau$ (cm)
1500	494	16.0
1000	148	6.0
350	148	17.3
120	48	16.5

EXO-12-038



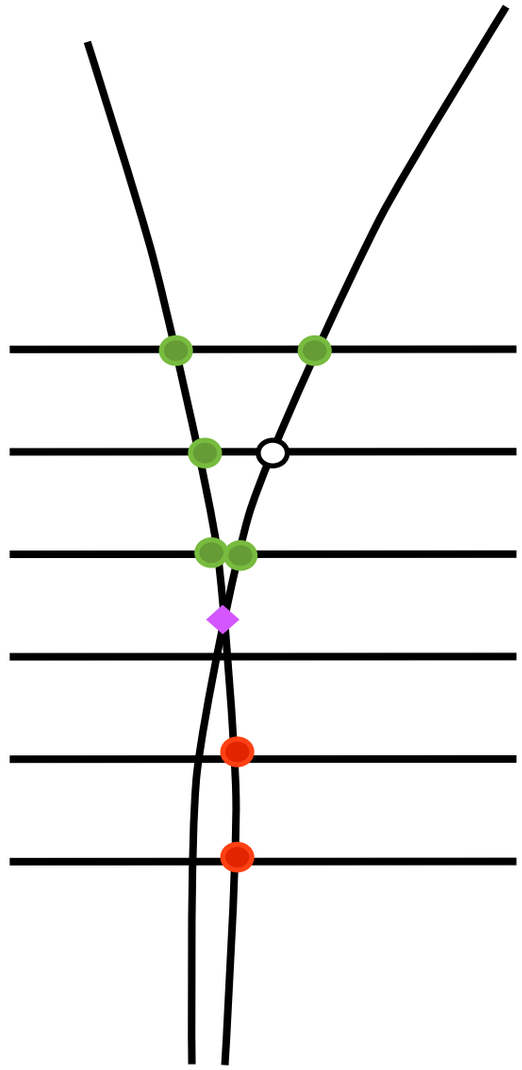


New!

EXO-12-037

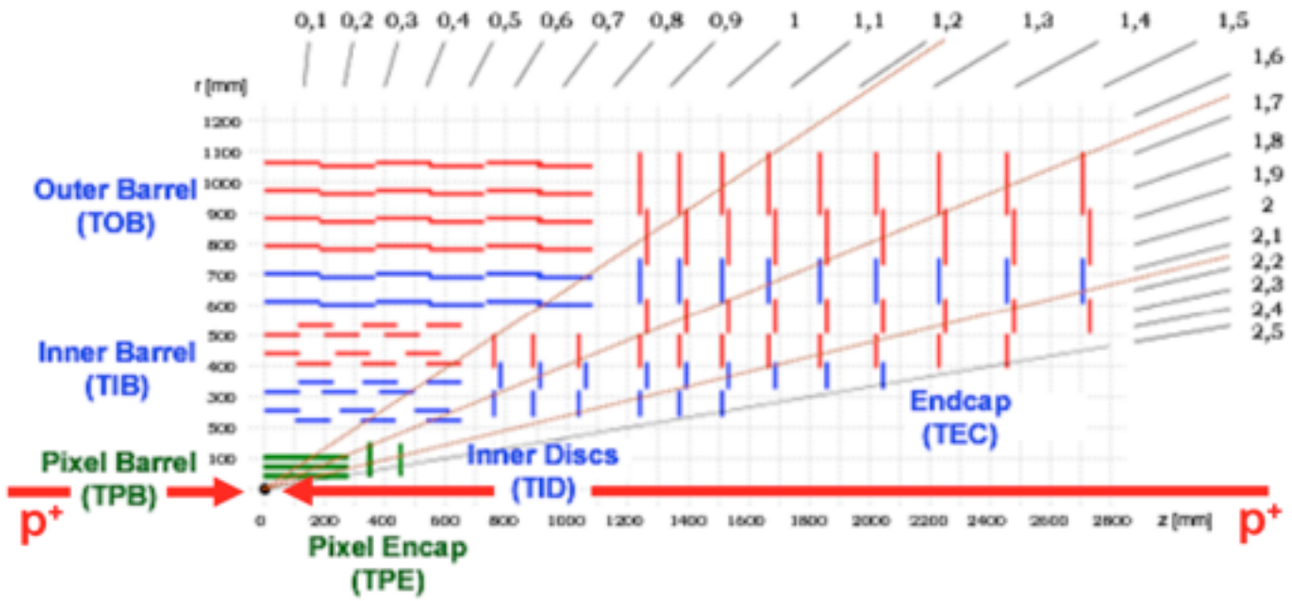
Strategy

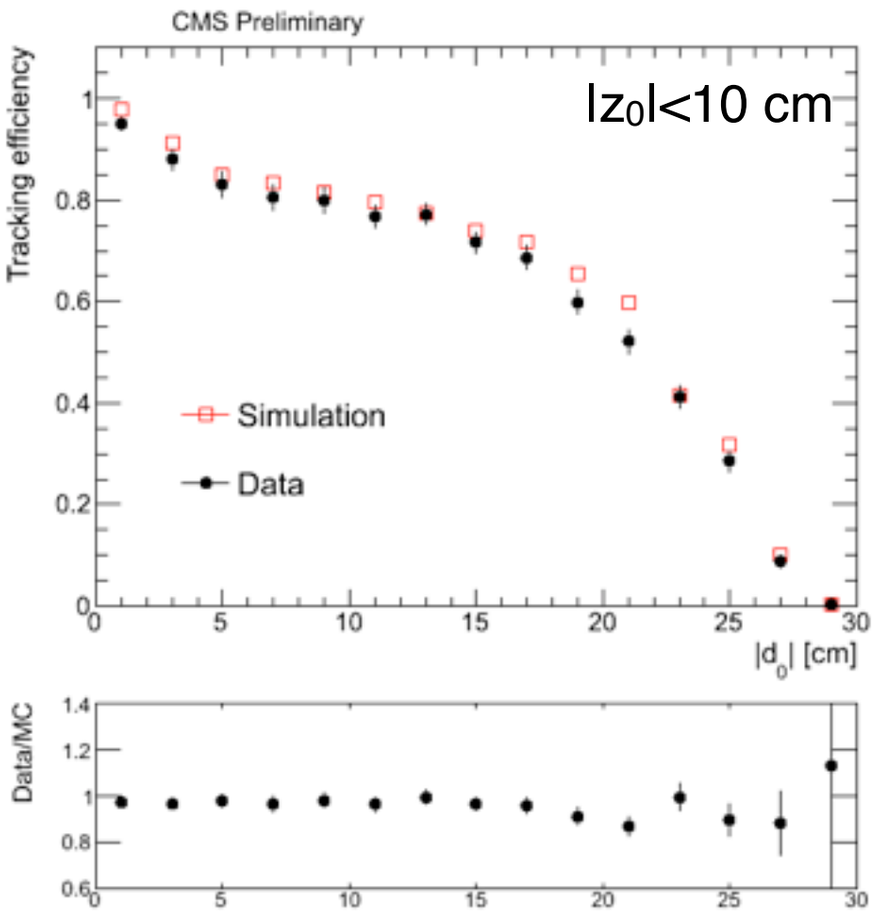
- Di-electron decay: trigger on di-photons
  - offline match tracks to photons
- Di-muon decay: trigger on pairs of not-back-to-back muons, as reconstructed in the muon system (no track requirement)
  - offline match tracks to those muons
- require them to fit into a good vertex and be isolated
- refit PV excluding the two candidate tracks
- require each candidate track to have high significance impact parameter
- impose extra track quality cuts
  - no hits where hits should be
  - hits where hits should not be (before the vertex)

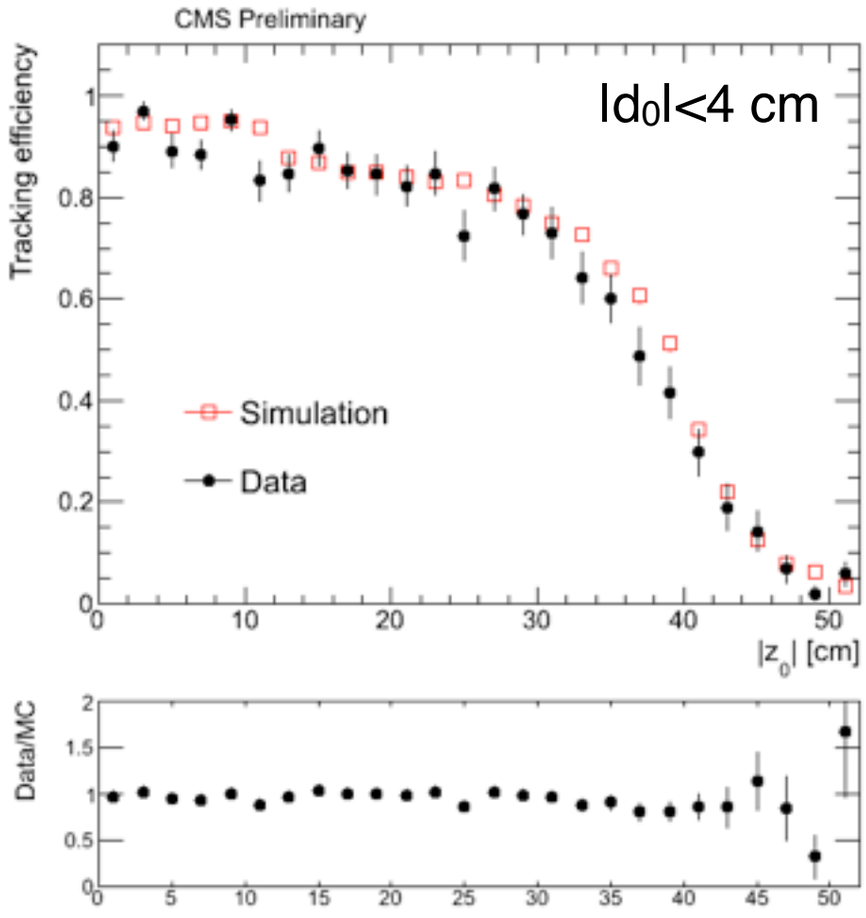


Reconstruction of high IP tracks

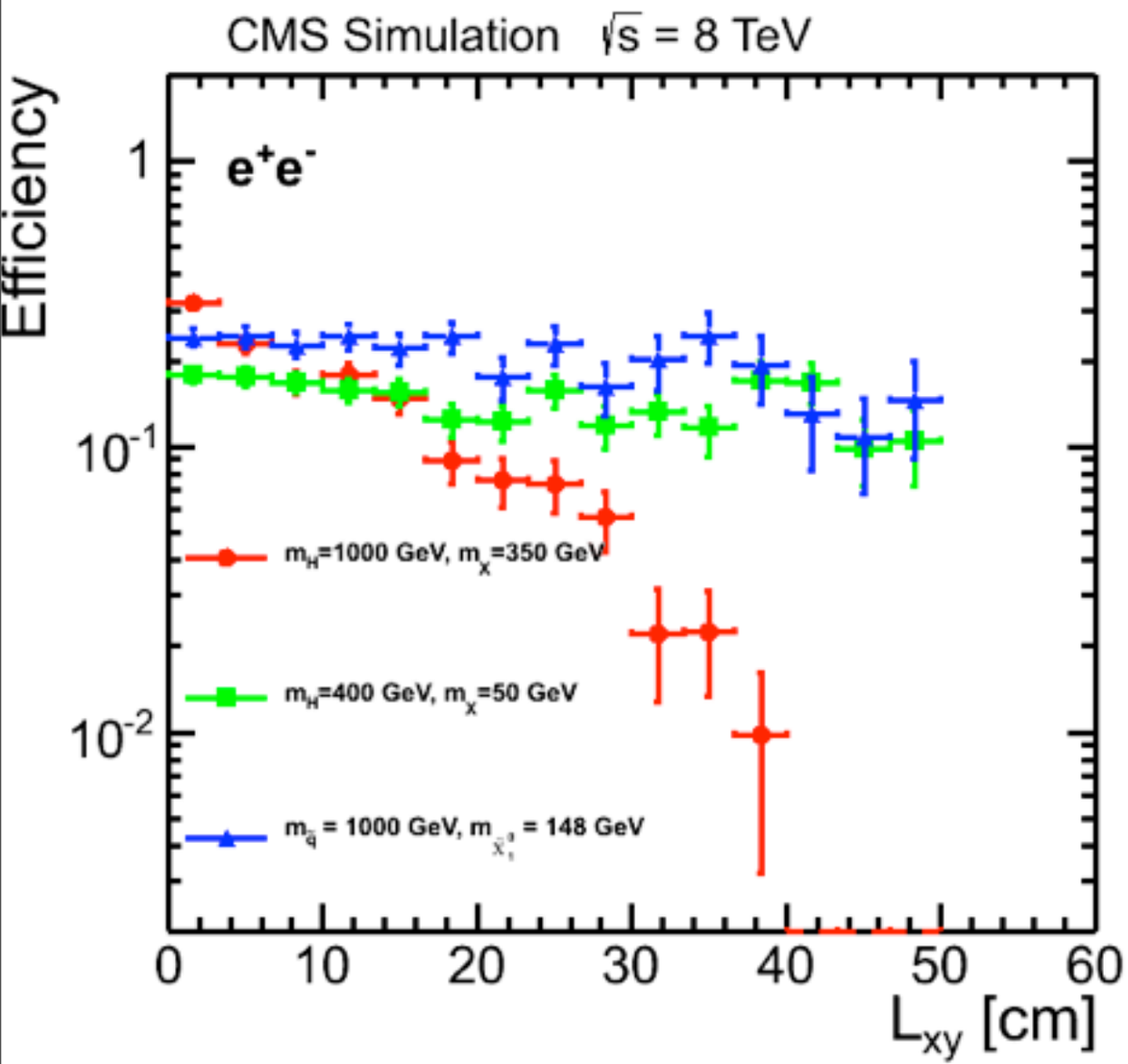
- Many tracking iterations
  - used hits are removed so successive iterations run on smaller hit collection
- Some ~fundamental constraints
  - track should have at least two 2D measurements
- Check track reconstruction with data
  - cosmics, imbedding, K^0_S

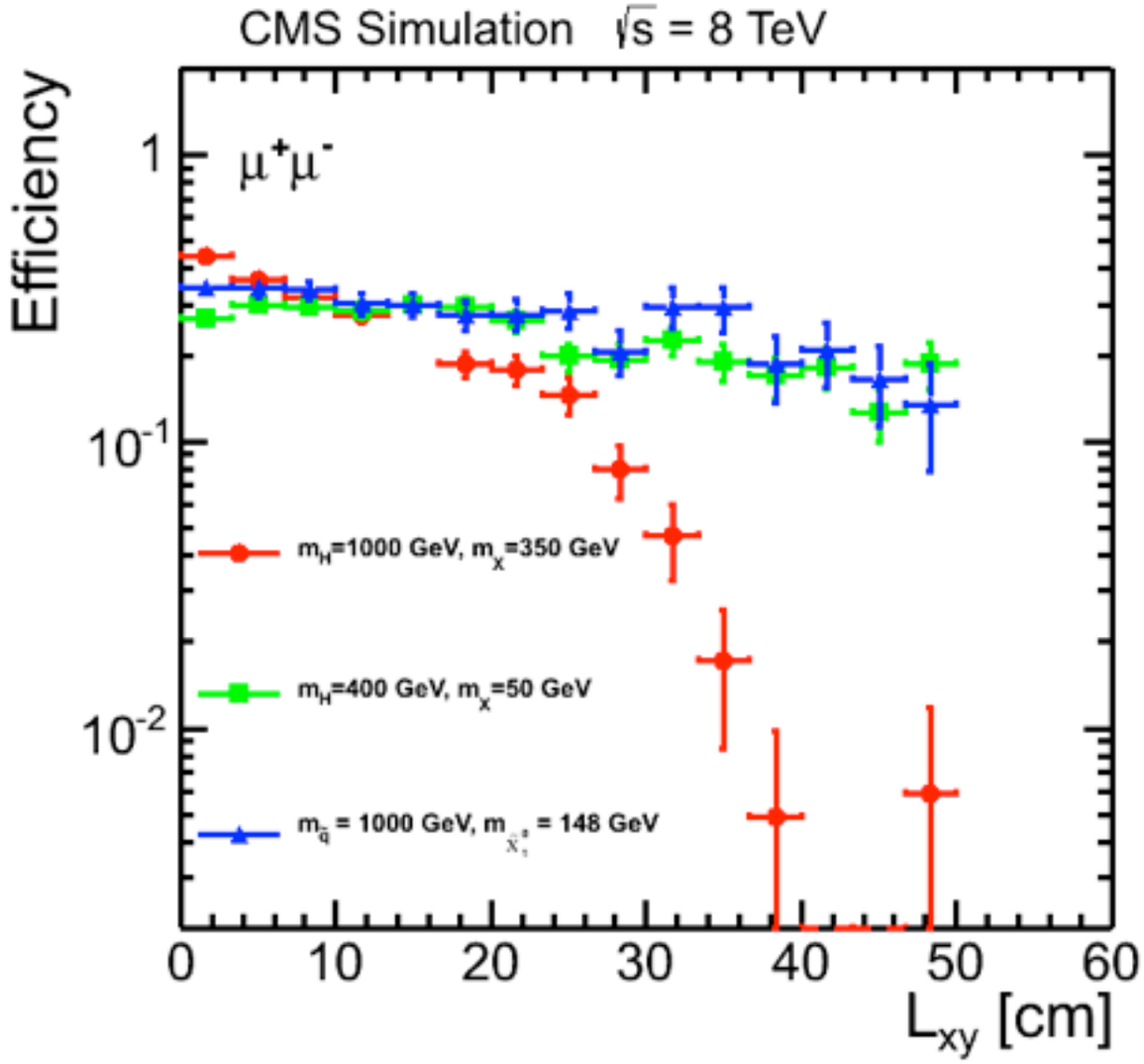






Signal Efficiency

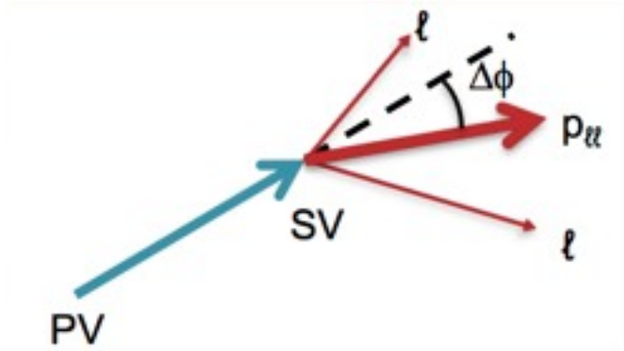


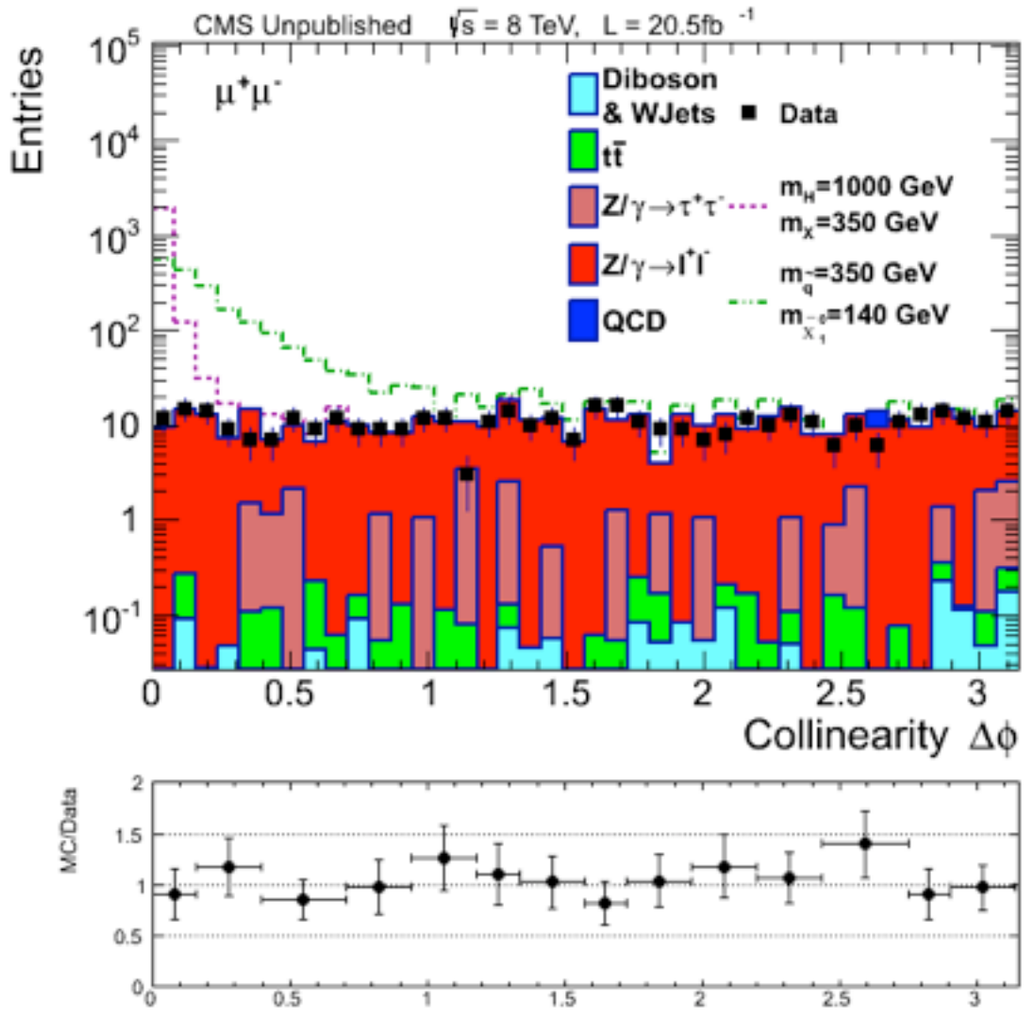


- efficiency is zero for L_{xy} > 50 cm
- inefficiency at high IP shows up for some of the models

Control regions

- Signal vertices should point along momentum, background is uniform





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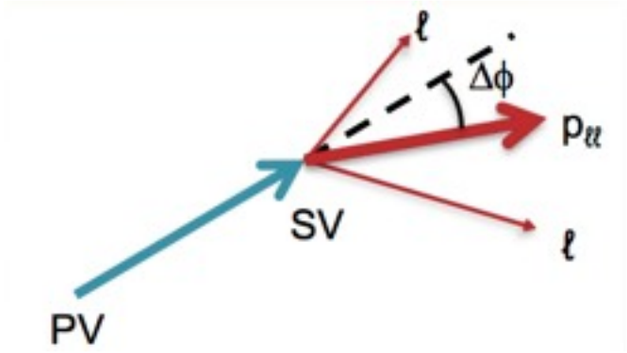

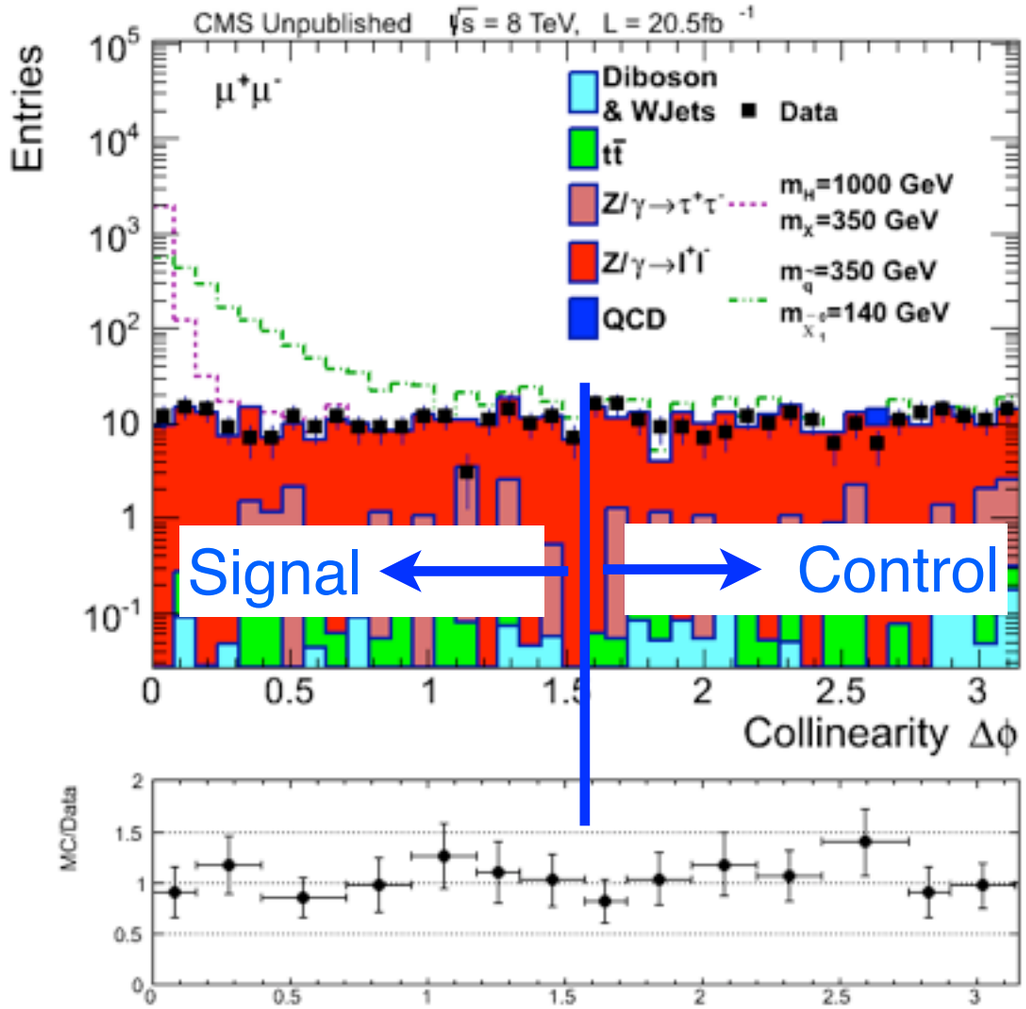

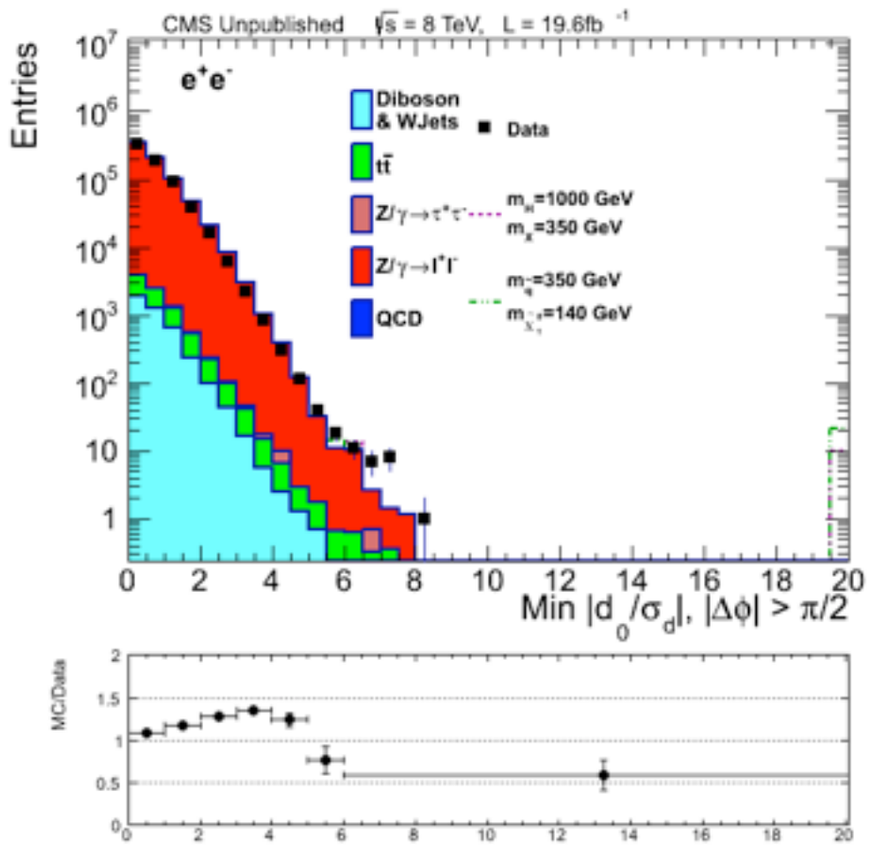

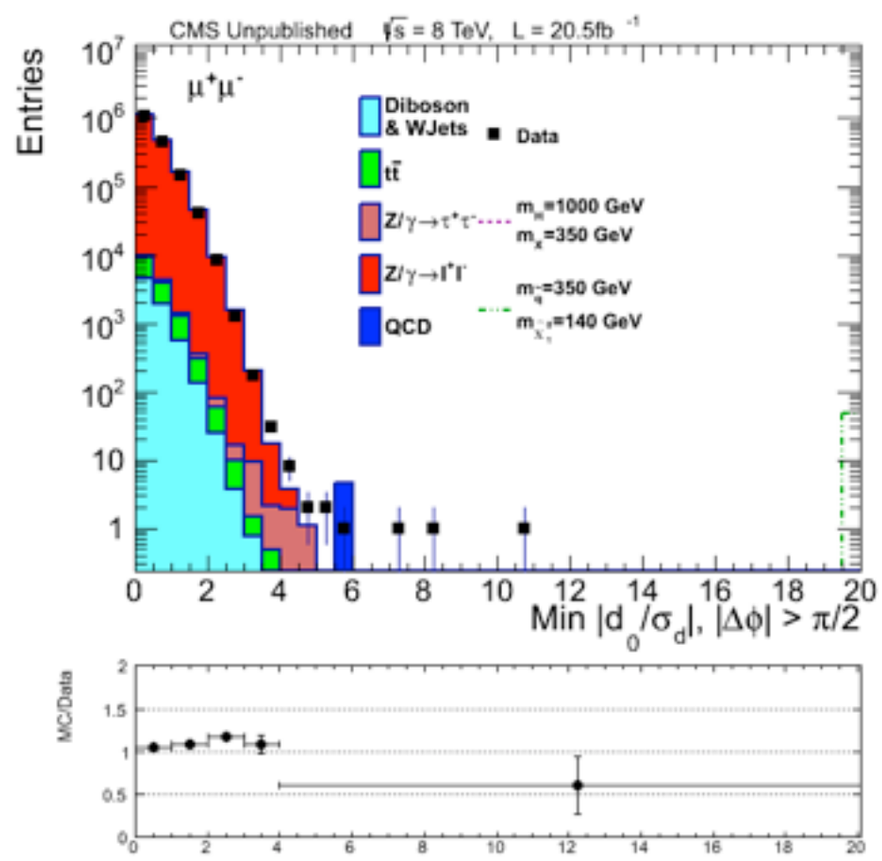

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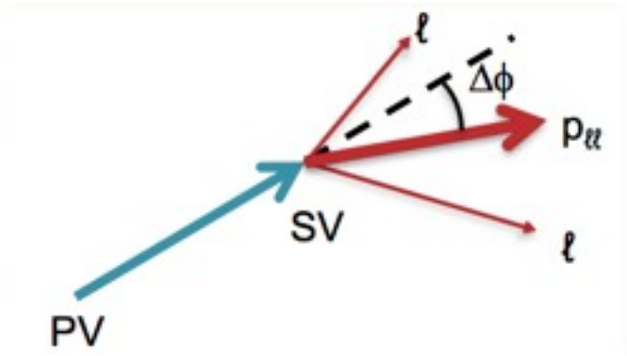
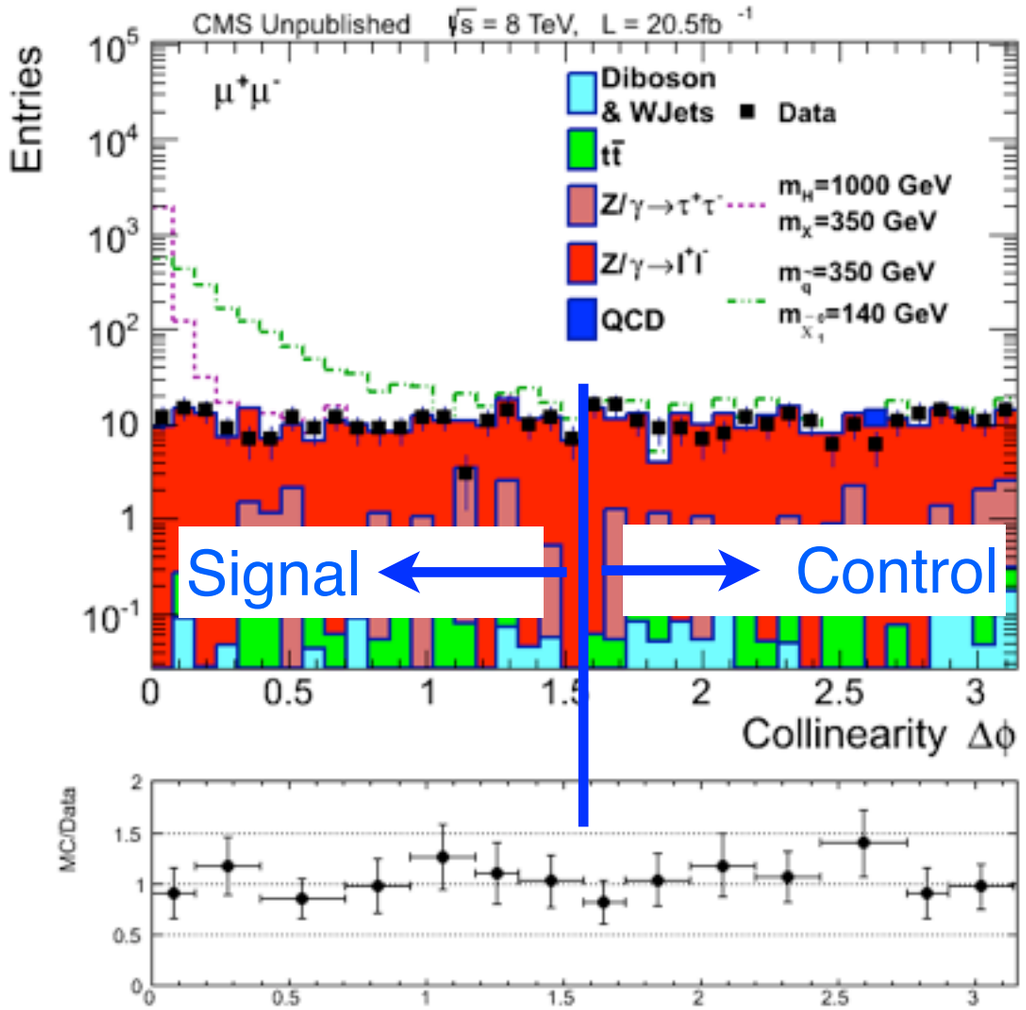
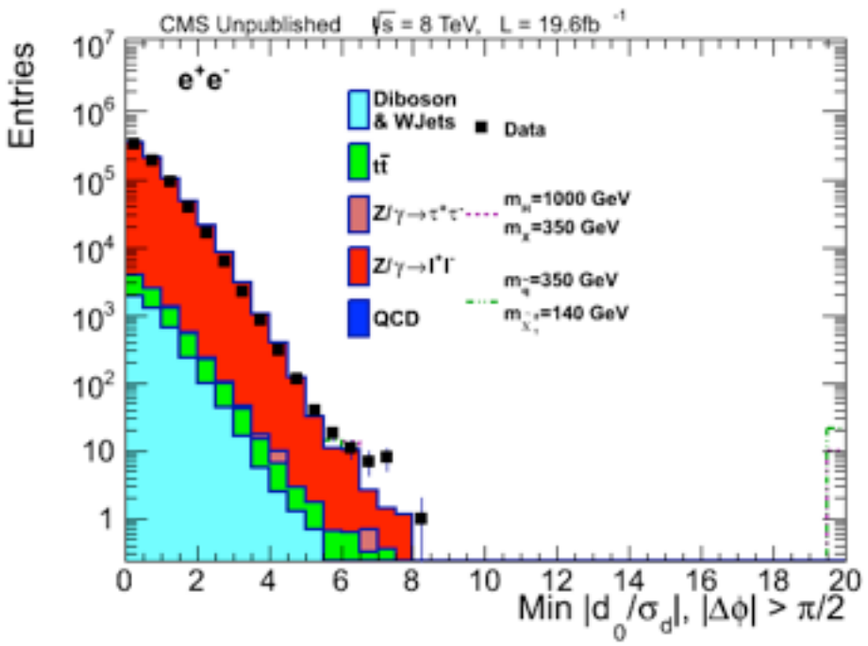
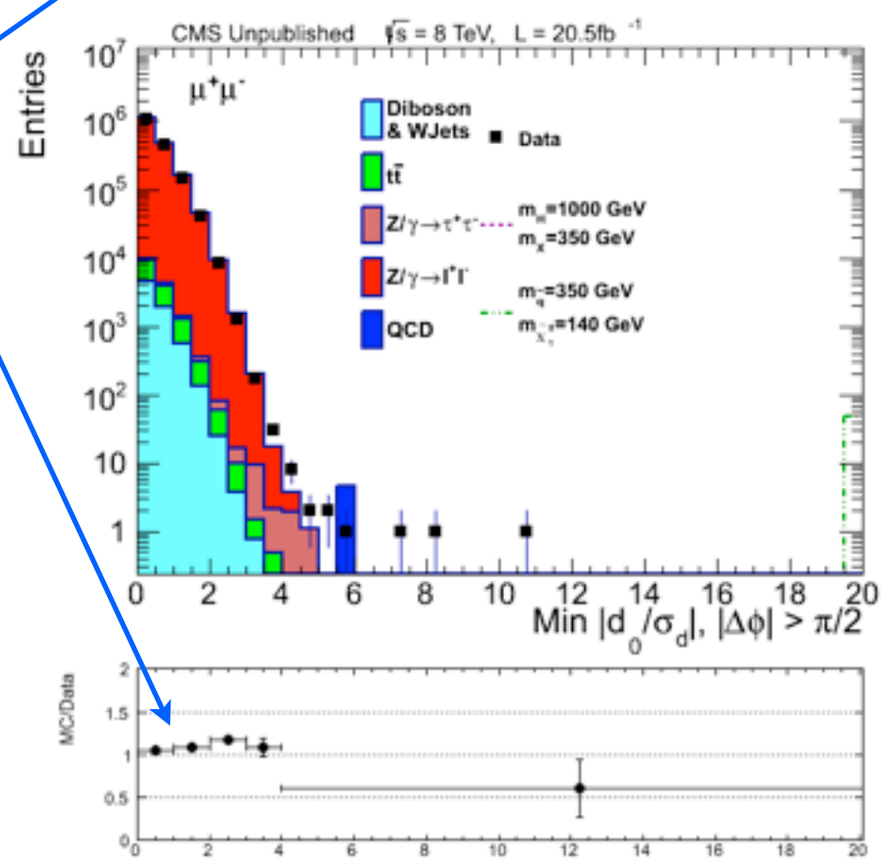




An ~OK data-MC agreement

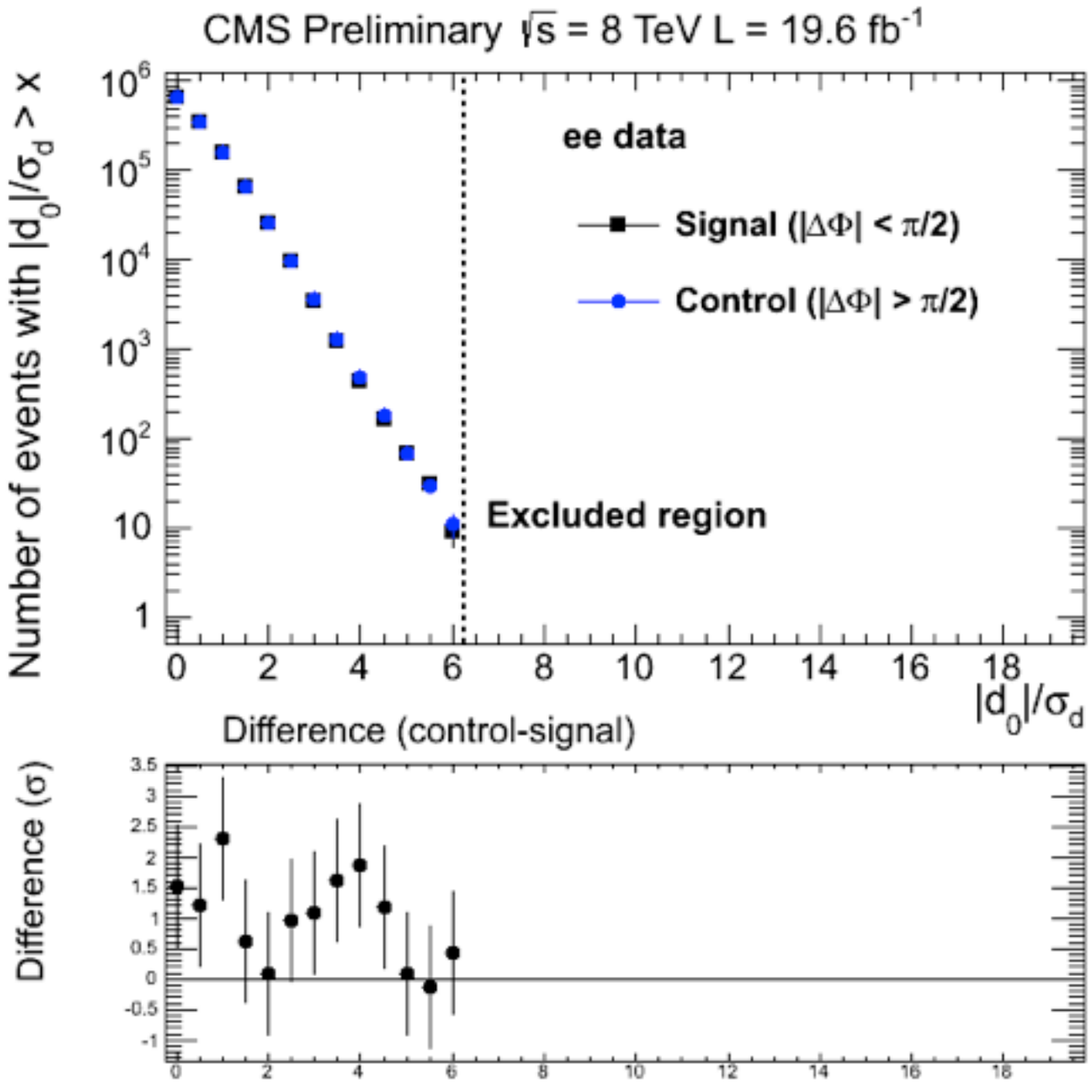
But still get backgrounds from control region

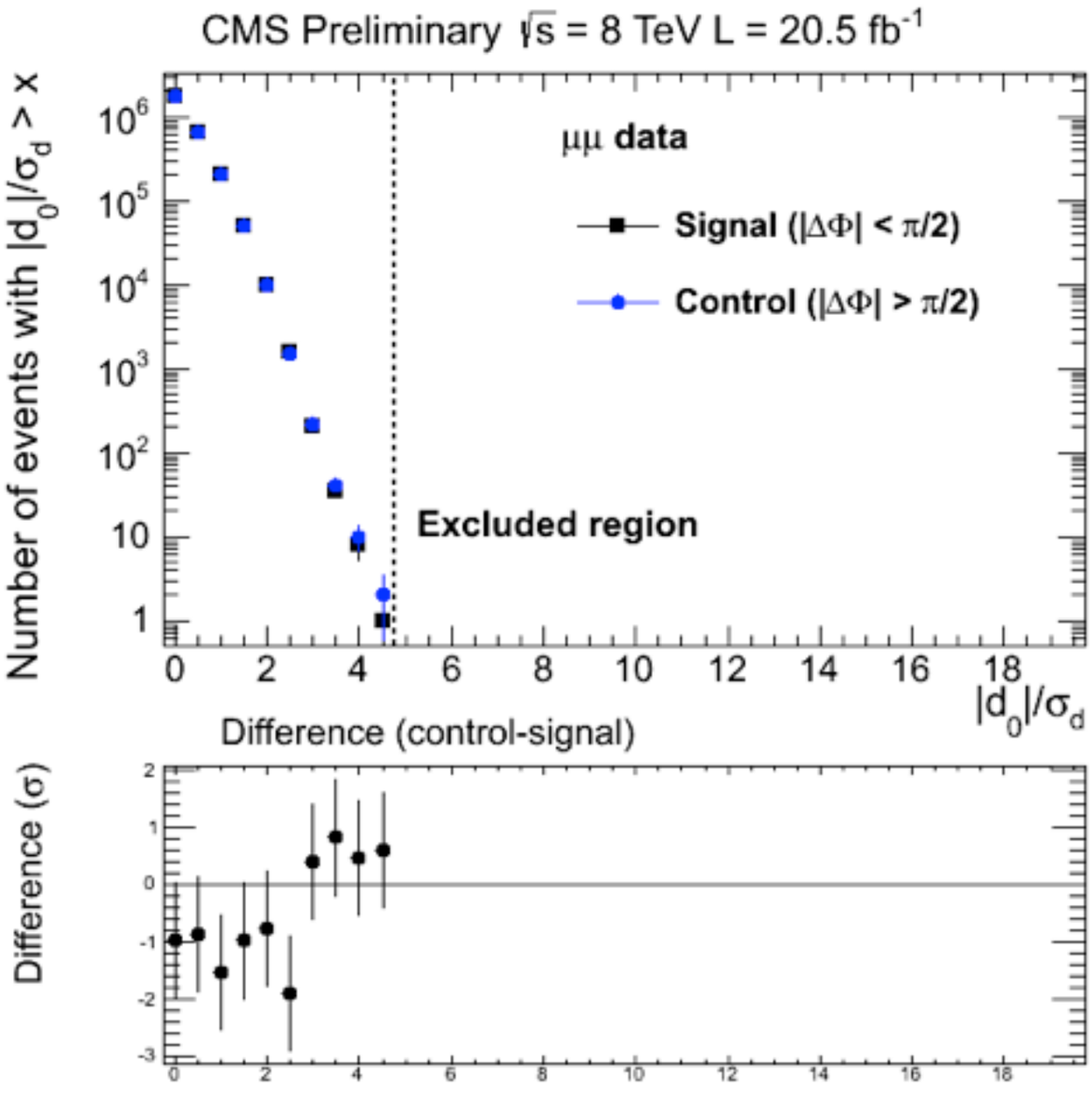




Test of Background Modeling

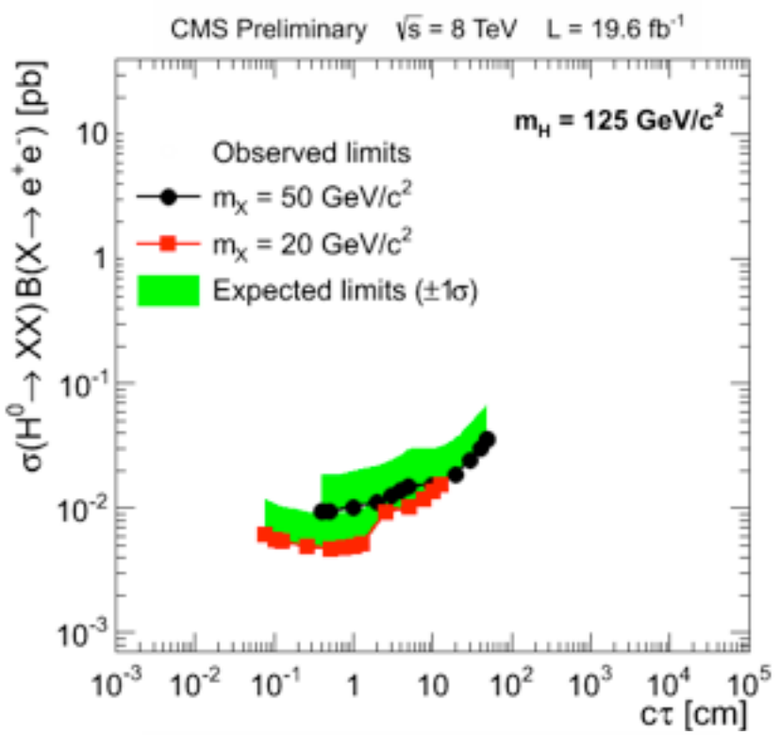
- Compare small IP significance distributions
  - high sensitivity to the tracker alignment: see effects that are washed out for long tracks originating at the vertex
- After the additional alignment corrections see very good closure

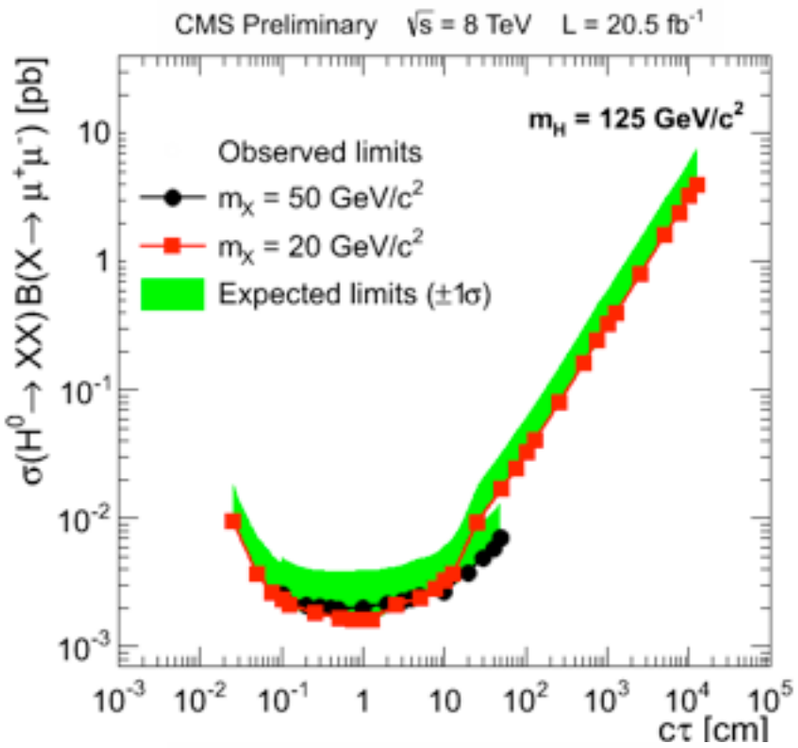


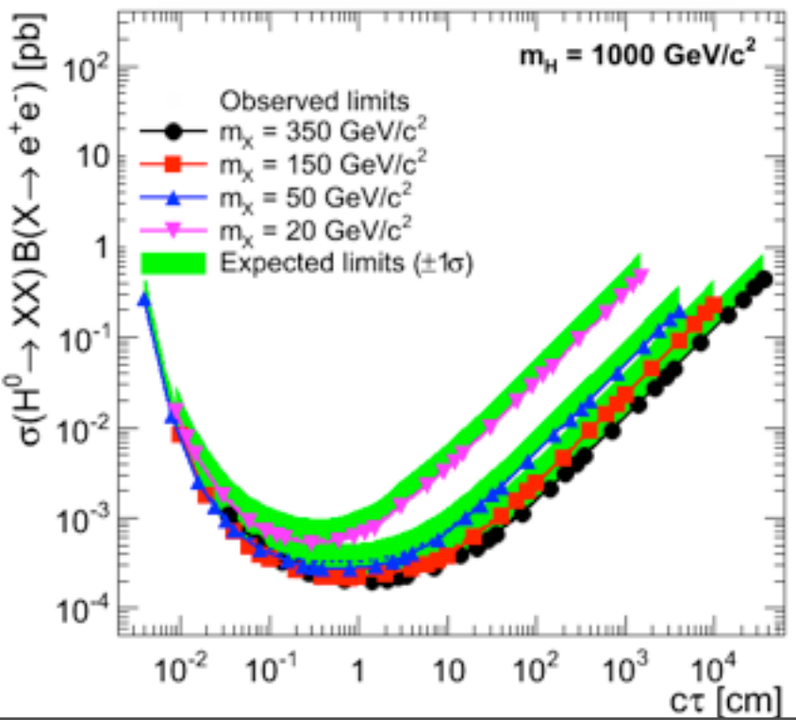


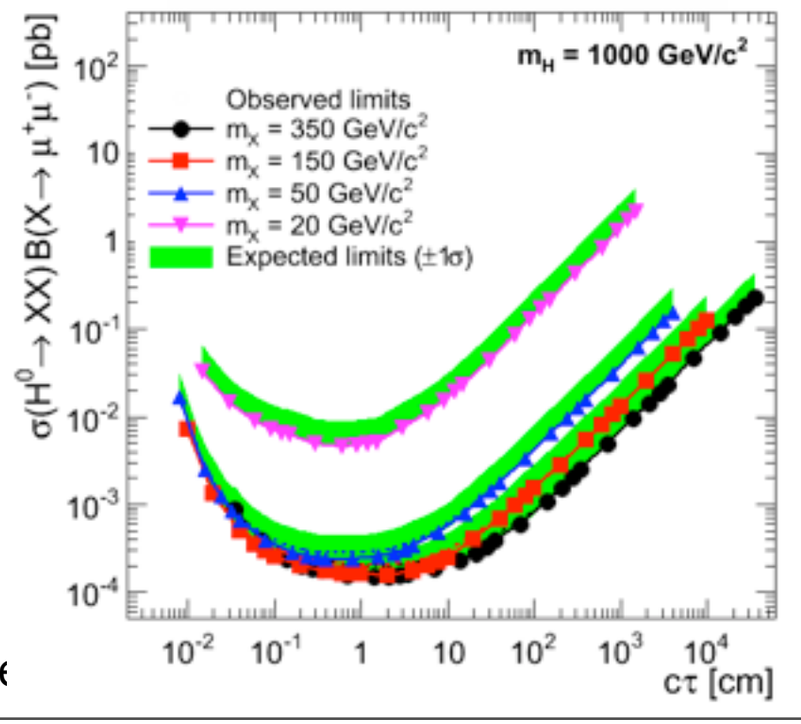
Results

- for the signal region (IP significance > 12σ) observe no events in either signal (|ΔΦ|<π/2) or control (|ΔΦ|>π/2) samples









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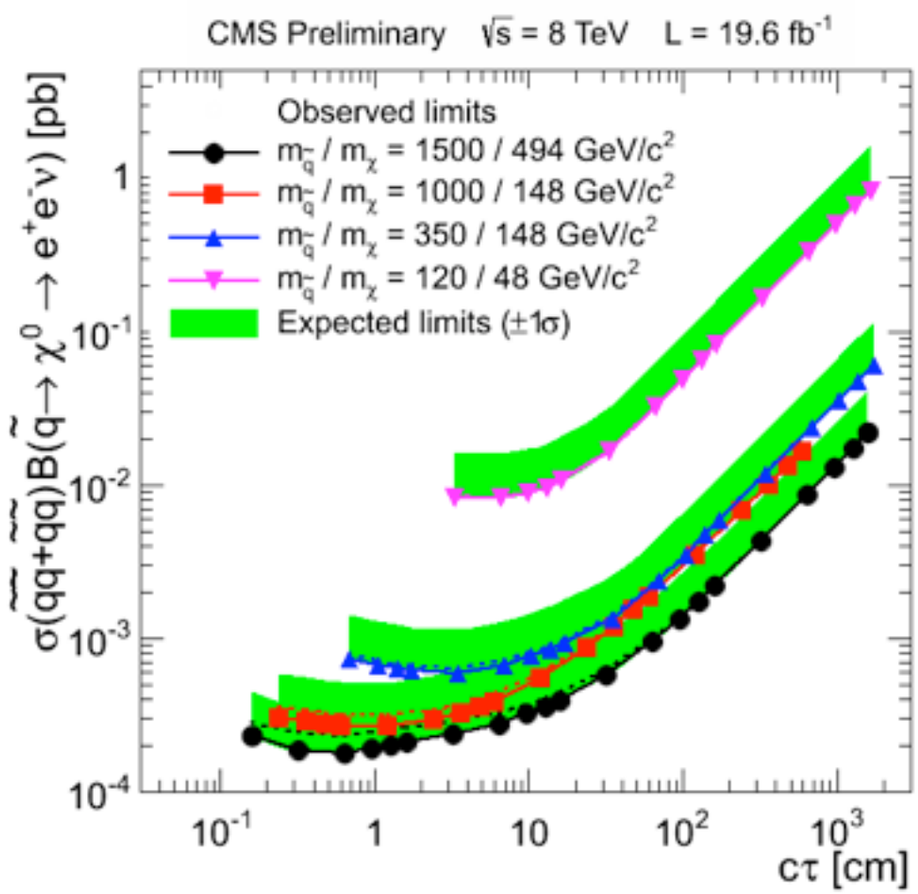
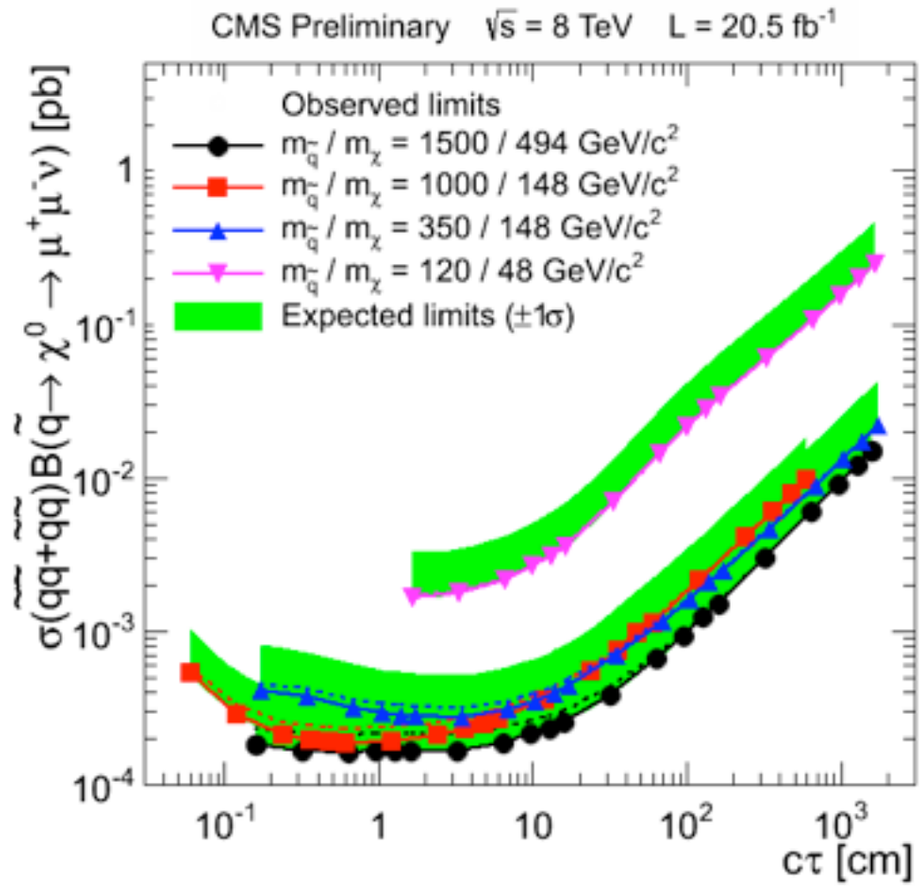
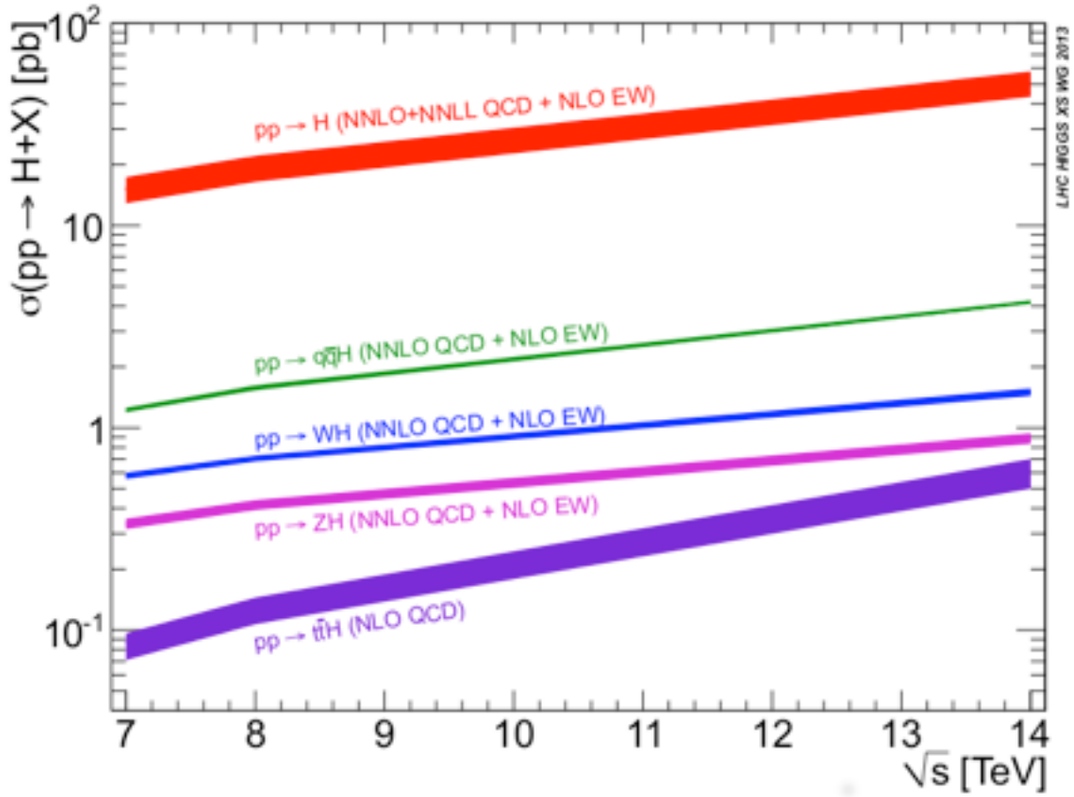




Higgs as New Physics Tag

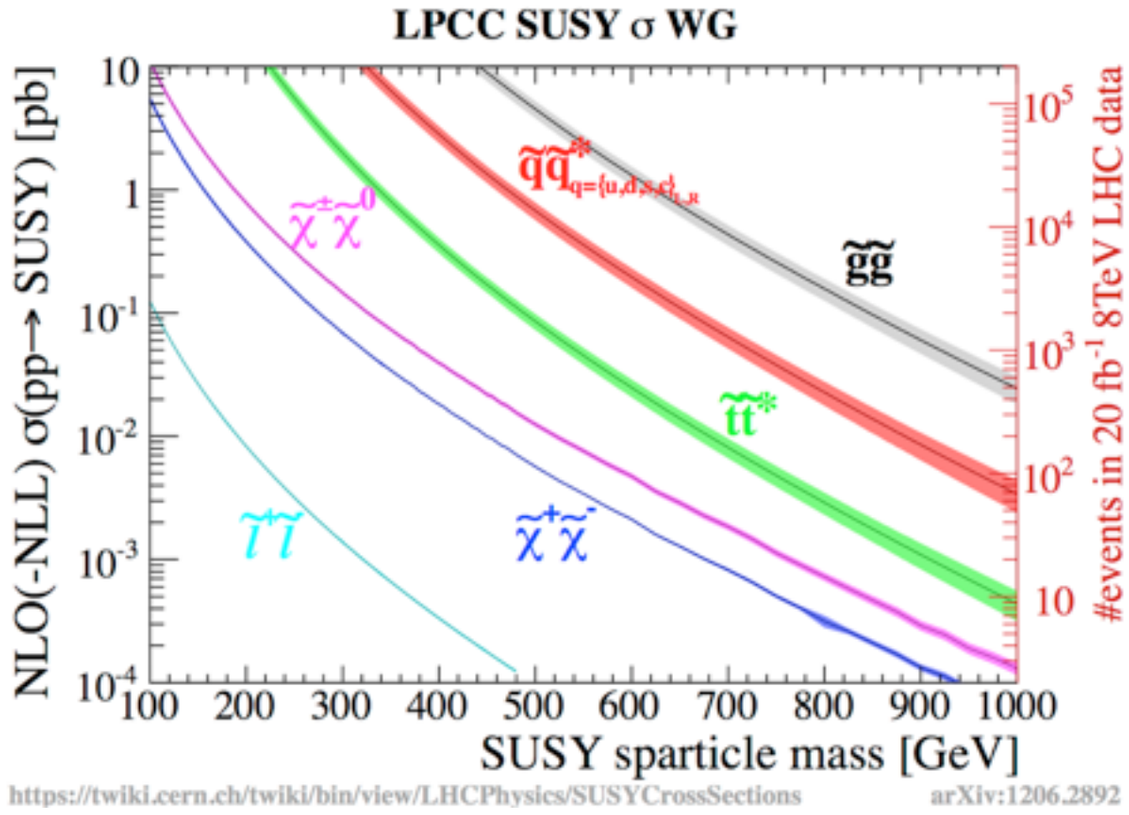
- New physics (SUSY?) cascades may produce higgses as copiously as W's and Z's - but the SM Higgs cross section is tiny compared to W/Z
  - single W: 10^5 pb
    - W+lots of jets (aka top): 10^3 pb
  - single h: 20 (50) pb
    - h + lots of jets (tth): 0.1 (0.6) pb
  - ***requiring higgs production is a New Physics booster***
  - even paying $2 \cdot 10^{-3}$ penalty for $\gamma\gamma$ branching one gets ~reasonable number of events
    - $5/\text{fb} \cdot 0.5\text{pb} \cdot 2 \cdot 2 \cdot 10^{-3} =$ 10 events



- Impact way beyond just SUSY - every time you produce a Higgs you explore EWSB: SUSY here is just a great way to "generate signatures" with Higgs + stuff.

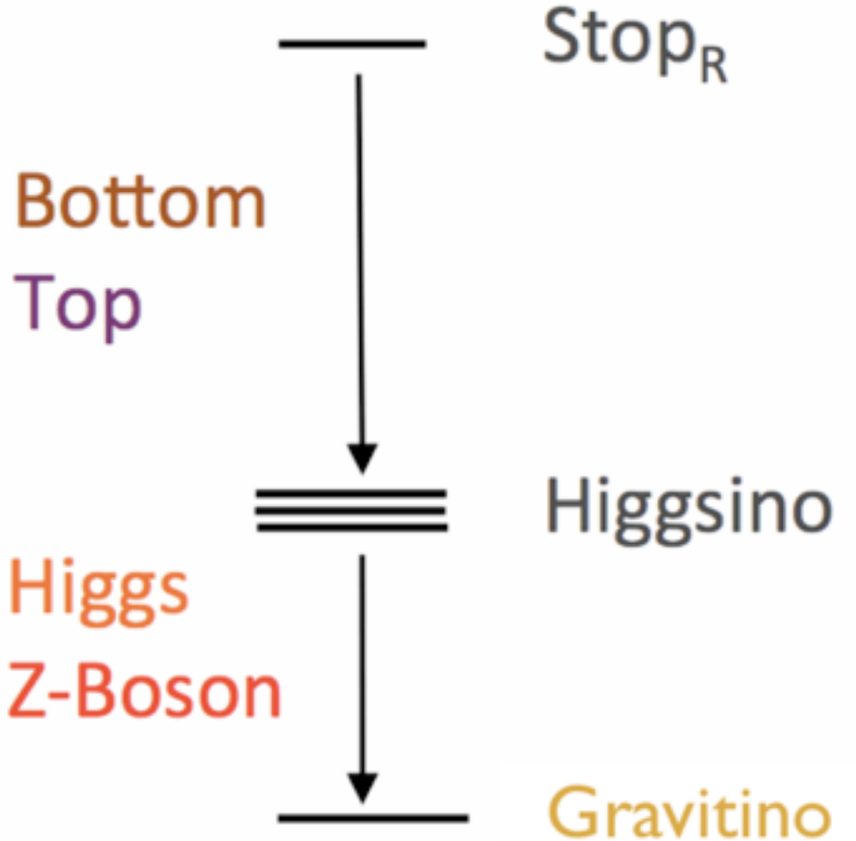
Higgs as New Physics Tag

- New physics (SUSY?) cascades may produce higgses as copiously as W's and Z's - but the SM Higgs cross section is tiny compared to W/Z
  - single W: 10^5 pb
    - W+lots of jets (aka top): 10^3 pb
  - single h: 20 (50) pb
    - h + lots of jets (tth): 0.1 (0.6) pb
  - ***requiring higgs production is a New Physics booster***
  - even paying $2 \cdot 10^{-3}$ penalty for $\gamma\gamma$ branching one gets ~reasonable number of events
    - $5/\text{fb} \cdot 0.5\text{pb} \cdot 2 \cdot 2 \cdot 10^{-3} =$ 10 events

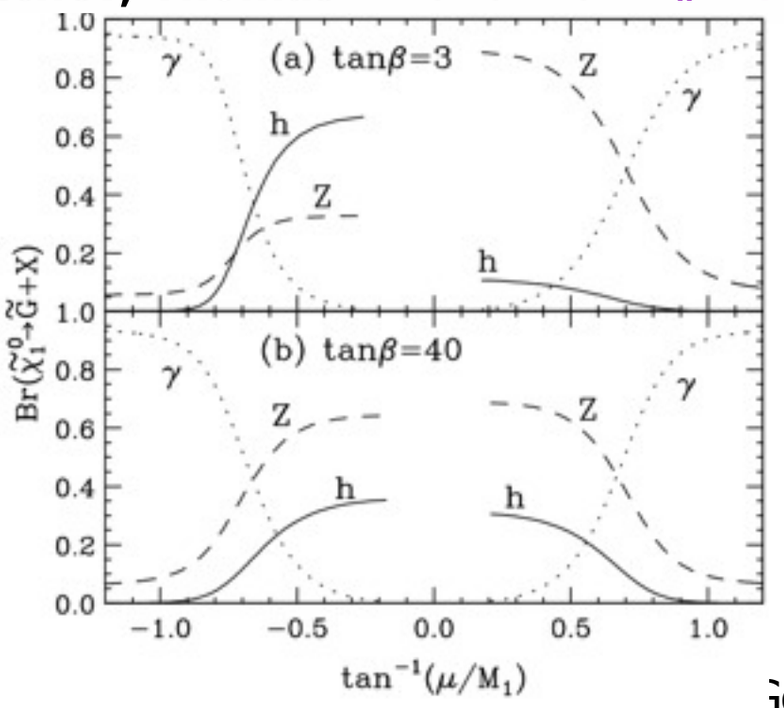


- Impact way beyond just SUSY - every time you produce a Higgs you explore EWSB: SUSY here is just a great way to "generate signatures" with Higgs + stuff.

"Natural"-ish SUSY



Matchev, Thomas PRD62:077702 **M_h=105 GeV**

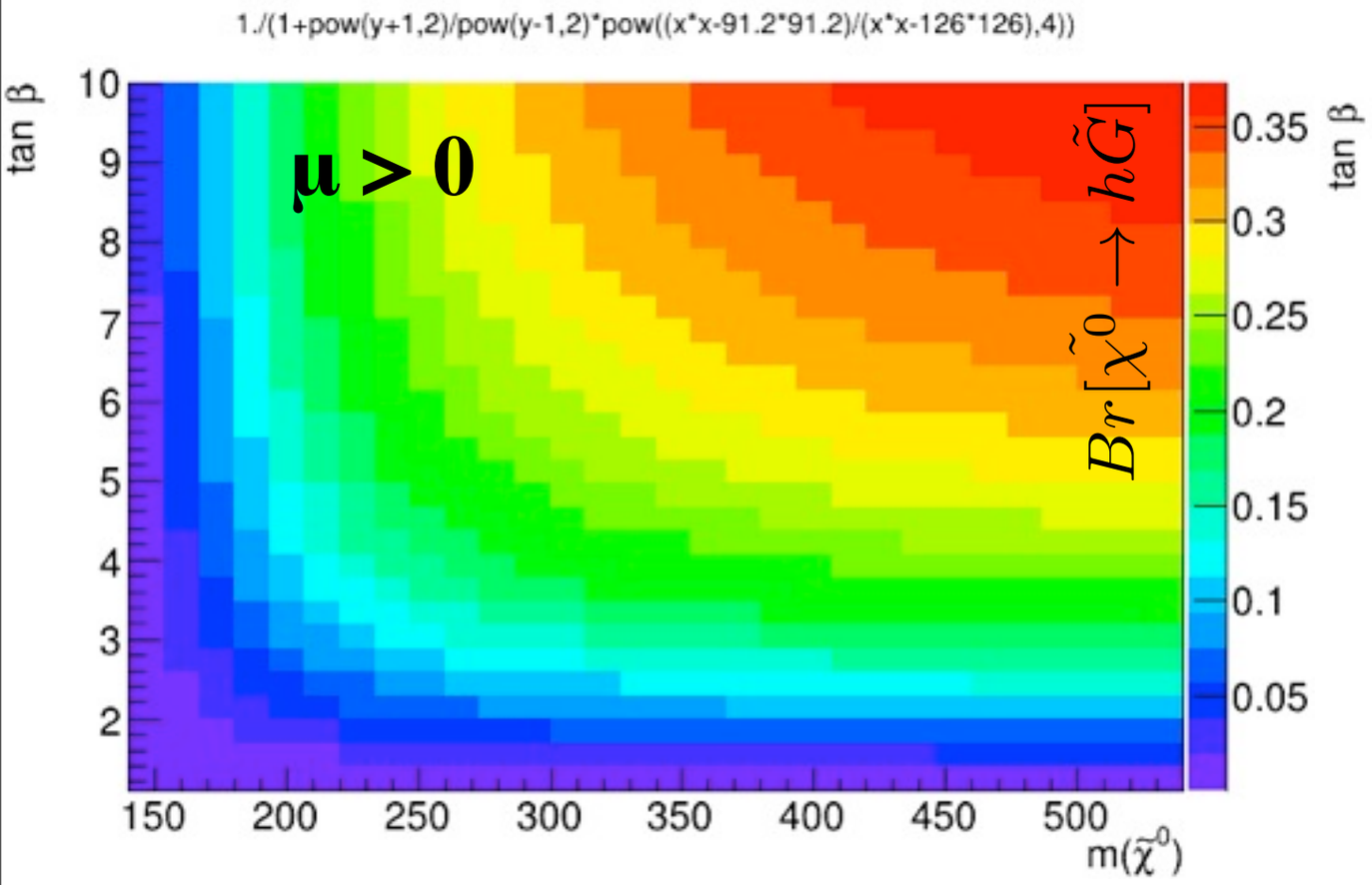


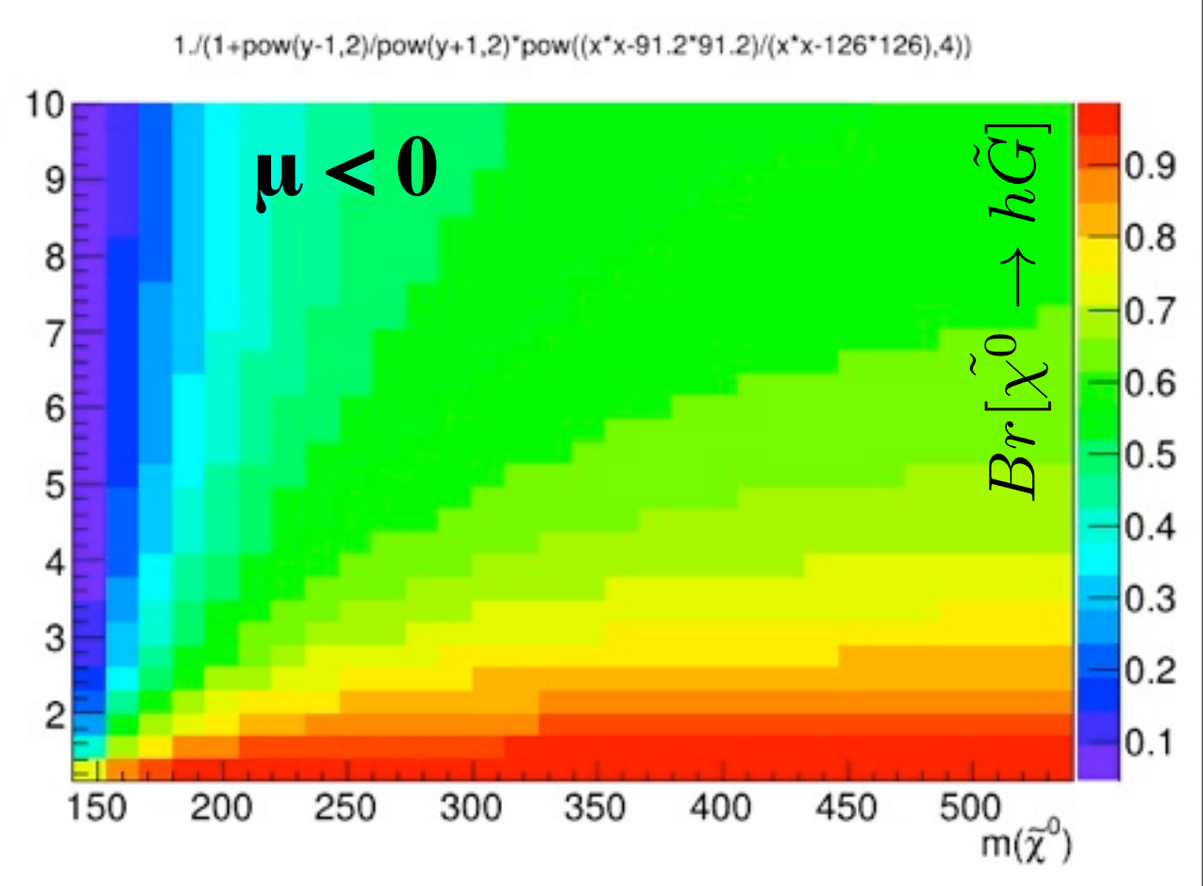
- can be quite stealthy
- if $M_{\tilde{t}_R} - M_{\tilde{\chi}^0}$ is below top mass the decay is mostly to chargino and b
- chargino decays into soft pion(s) and lightest neutralino
  - b-jets may be soft, especially for smaller mass splittings
- In GM, lightest higgsino decays
  - not very often to photons
  - Z's and higgses - more higgses at low tan β

$Br[\tilde{\chi}^0 \to h\tilde{G}]$ and $Br[\tilde{\chi}^0 \to Z\tilde{G}]$

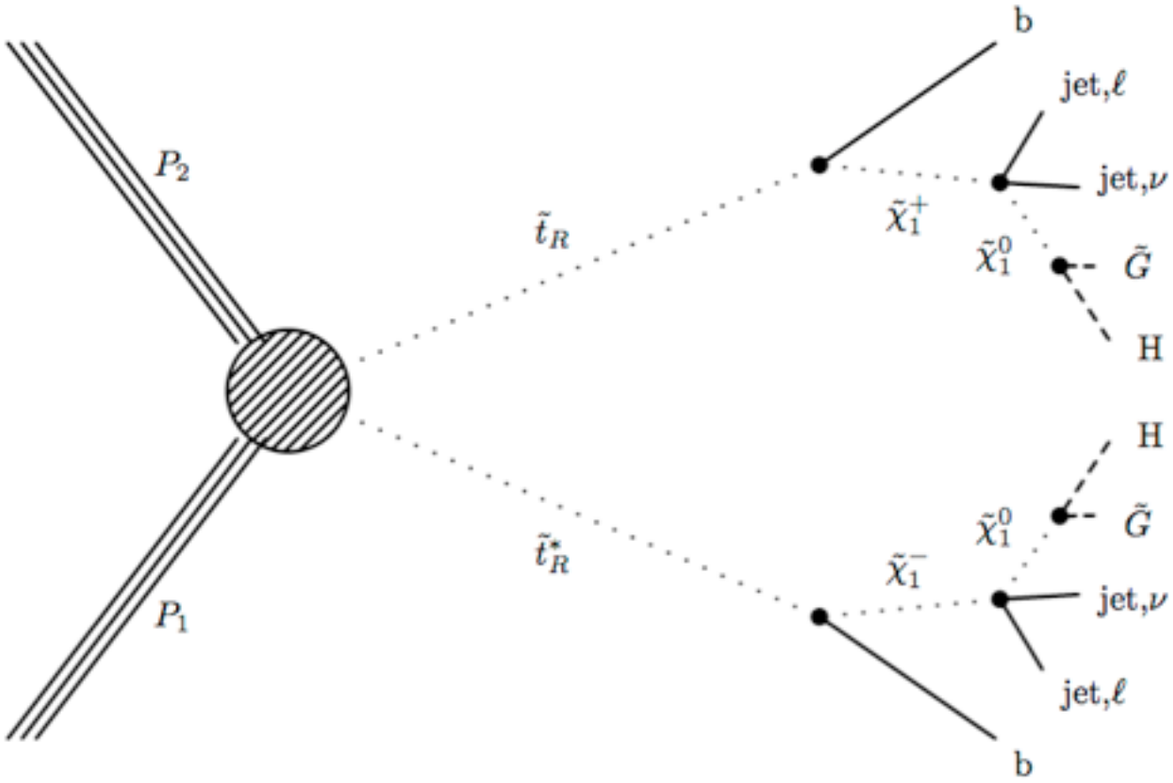
- using formulae from Meade, Reece & Shih arXiv:0911.4130 [hep-ph]
  - assume large M_1 and M_2, $m_h \ll m_H, m_A$

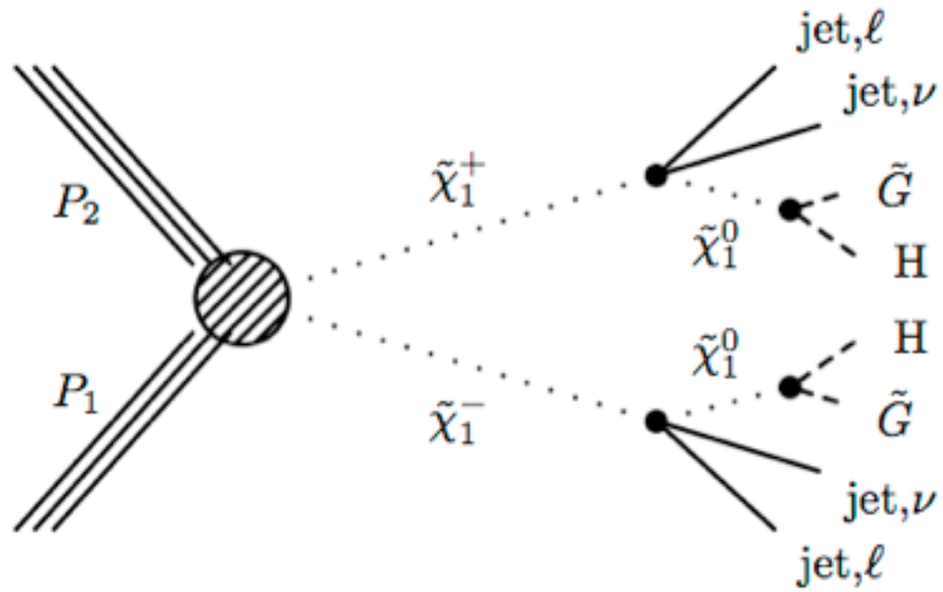
$$\Gamma(\tilde{\chi}_1^0 \to \tilde{G} + Z) = \frac{1}{4}(s_\beta + \eta c_\beta)^2 \left(1 - \frac{m_Z^2}{m_{\tilde{\chi}_1^0}^2}\right)^4 \mathcal{A} \qquad \Gamma(\tilde{\chi}_1^0 \to \tilde{G} + h) = \frac{1}{4}(s_\beta - \eta c_\beta)^2 \left(1 - \frac{m_h^2}{m_{\tilde{\chi}_1^0}^2}\right)^4 \mathcal{A}$$



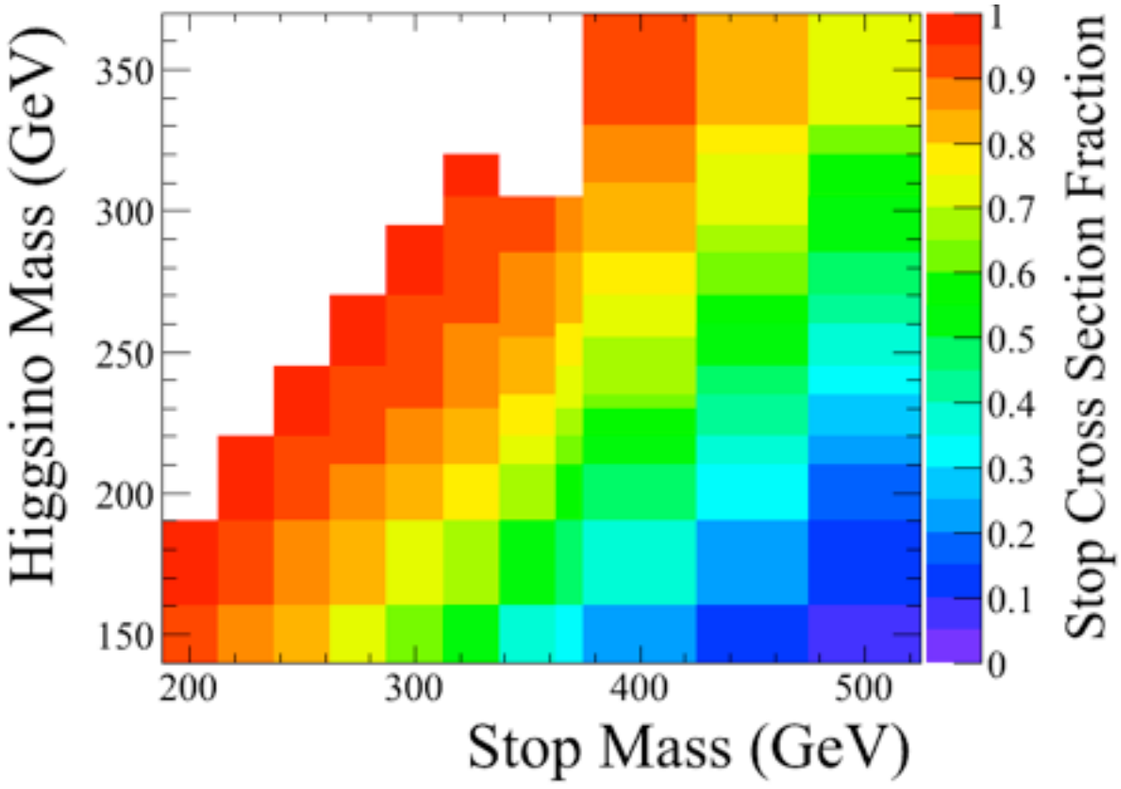


"Minimal" model



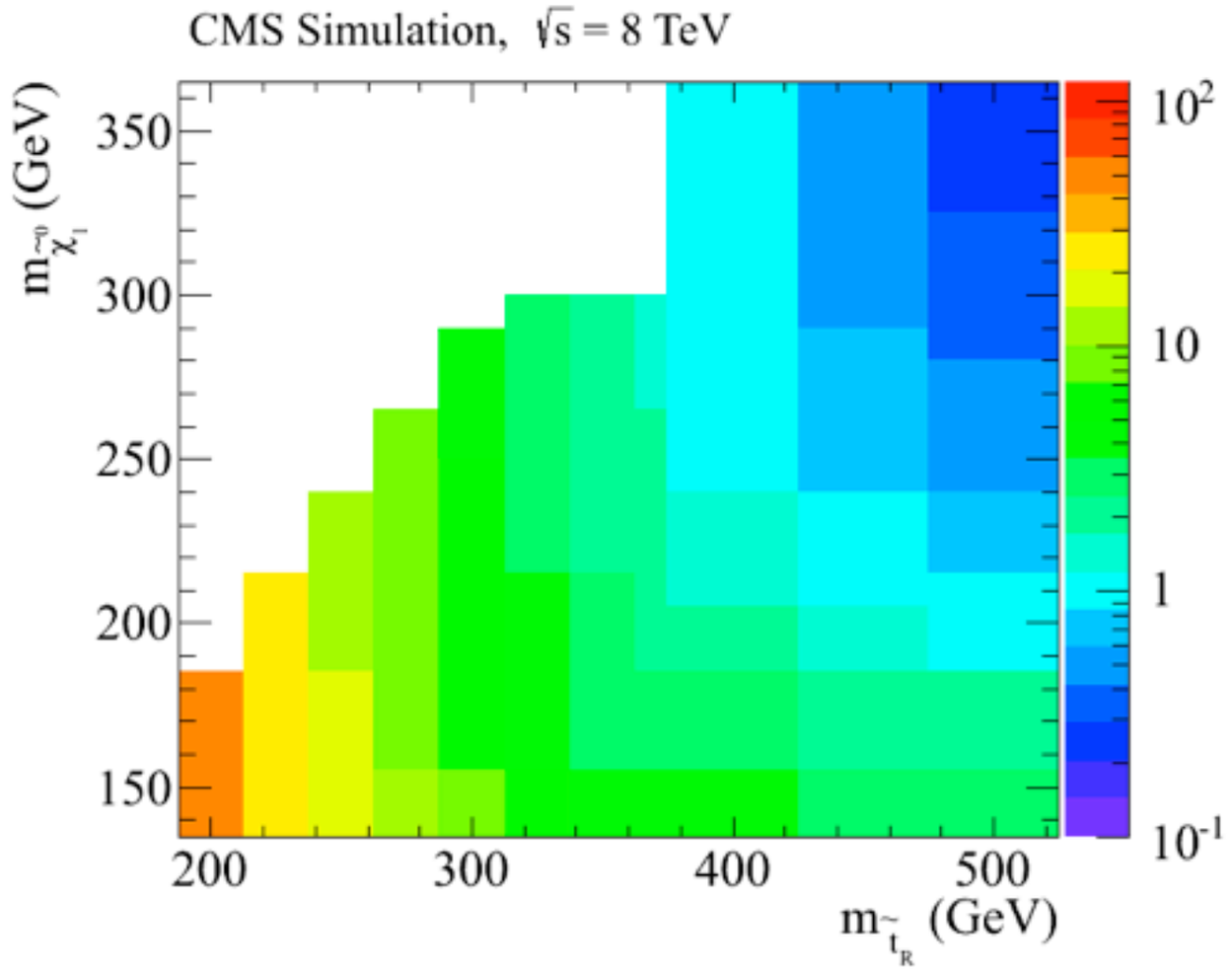


- Consider both strong and direct EWK production
- Two higgses per event, plus *b*-jets from stop: **γγ**bb final state
- For cases when $\tilde{\chi}^0 \to Z\tilde{G}$ is large, need to combine with multi-leptons (coming soon)



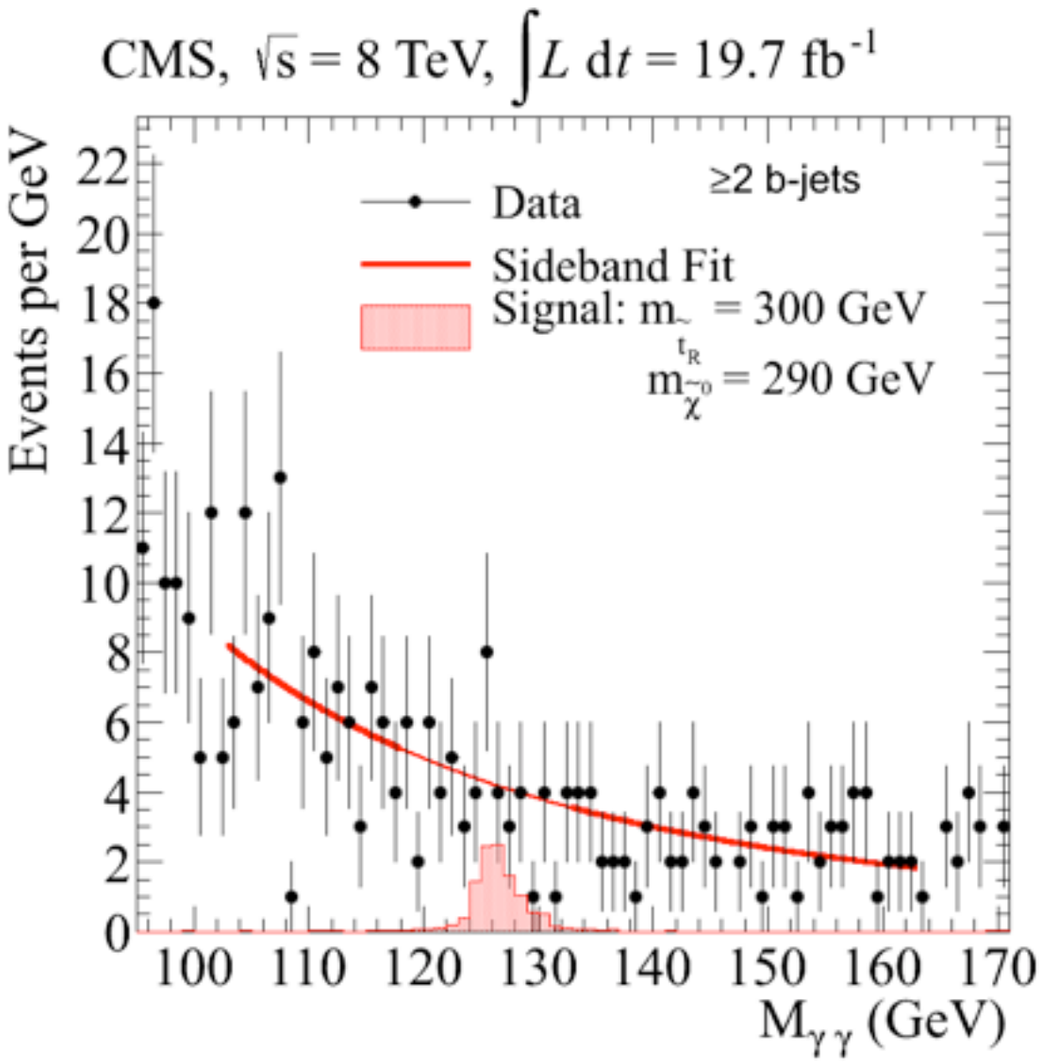
Why use $\gamma\gamma$ channel for searches

- Start with $2 \cdot 10^{-3}$ suppression
- But
  - looking for relatively quiet events without large MET or very energetic jets - huge QCD and EWK backgrounds otherwise
  - still, a few pb σ·Br
  - narrow peak gives a very reliable way to estimate the backgrounds
  - SM Higgs background is negligible



Event Selection

- ≥2 isolated photons, E_T>40, 25 GeV, |η|<1.44 (barrel)
- ≥2 b-jets (CSV-medium + CSV-loose)
- Higgs mass window: 120 < $m_{\gamma\gamma}$ < 131 GeV



- Fit excluding 118-133 GeV window
  - negligible dependence on fit function, use power law
- 46 events, 46.5±3.8 expected
- Looking in mass window looses us a bit of sensitivity, but allows us to easily scan a variety of kinematic distributions in the events
- determine background from sidebands
  - average lower and upper, add half of the difference as extra error

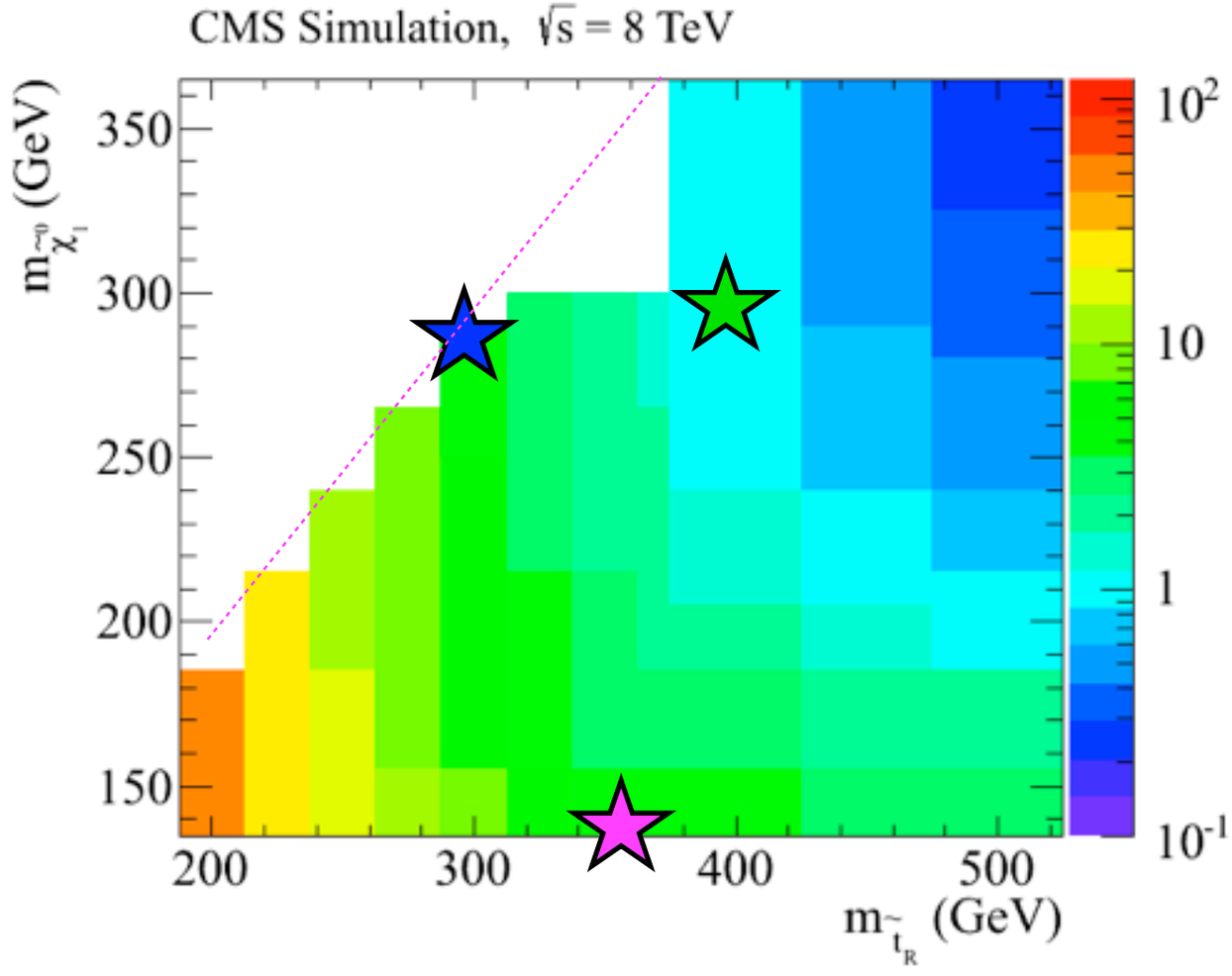
Event Kinematics

- kinematics is different from point to point
  - number of taggable b-jets
  - fraction of events where the two b-jets from higgs

★ χ^0 ~ at rest, moderate $p_T(h)$, MET

★ smaller $p_T(h)$, MET + extra b's

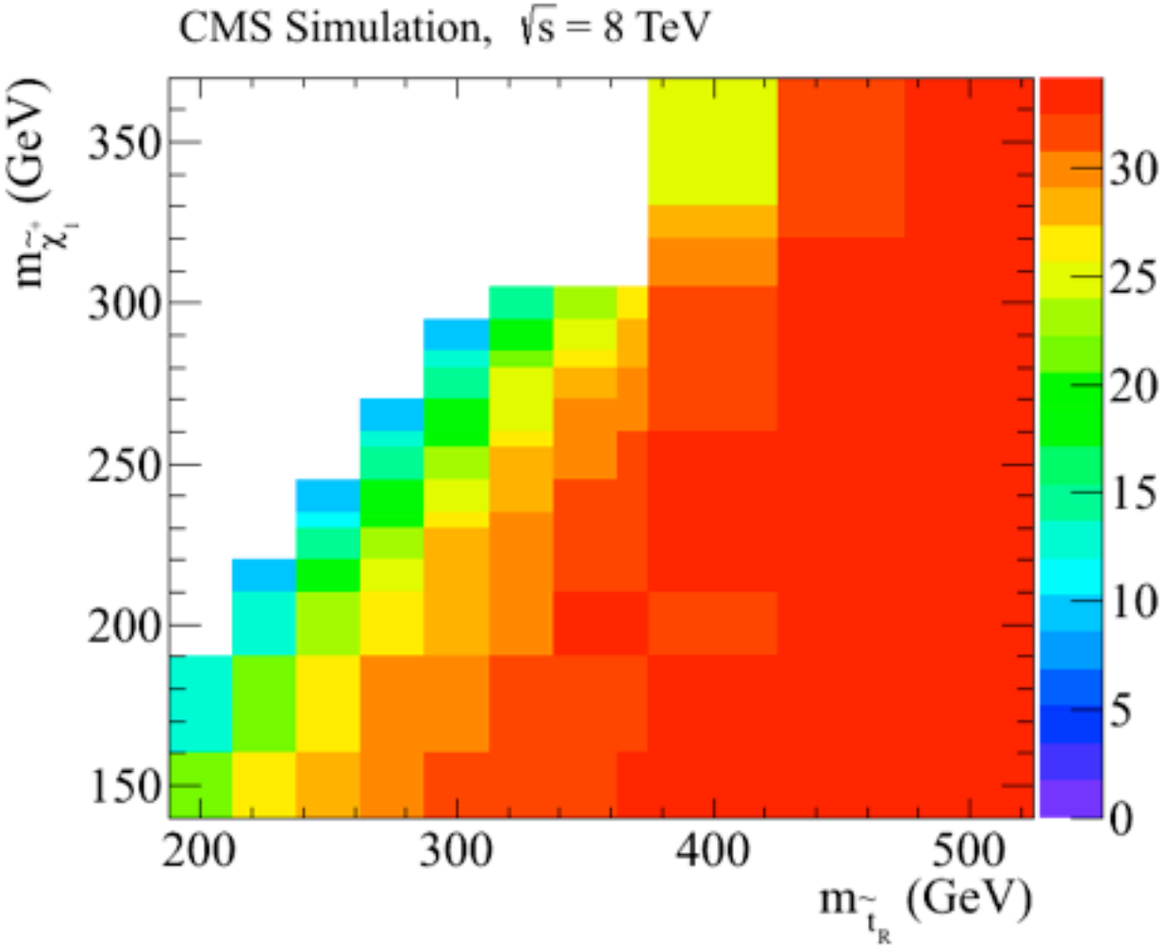
★ χ^0 ~ at rest, small $p_T(h)$, MET



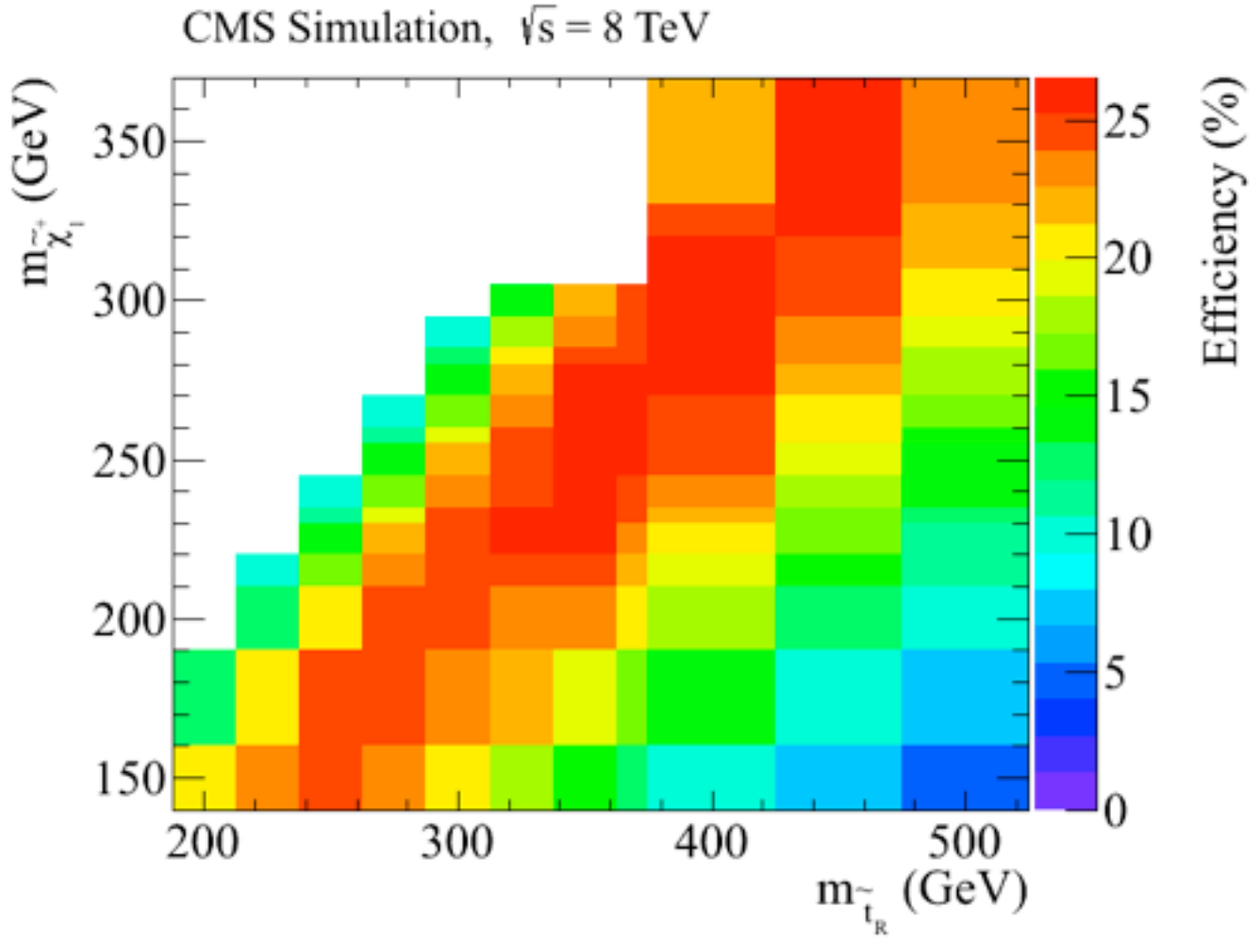
Signal Efficiency

- efficiency on the diagonal does not vanish
- efficiency to EWK production is much smaller then to strong production

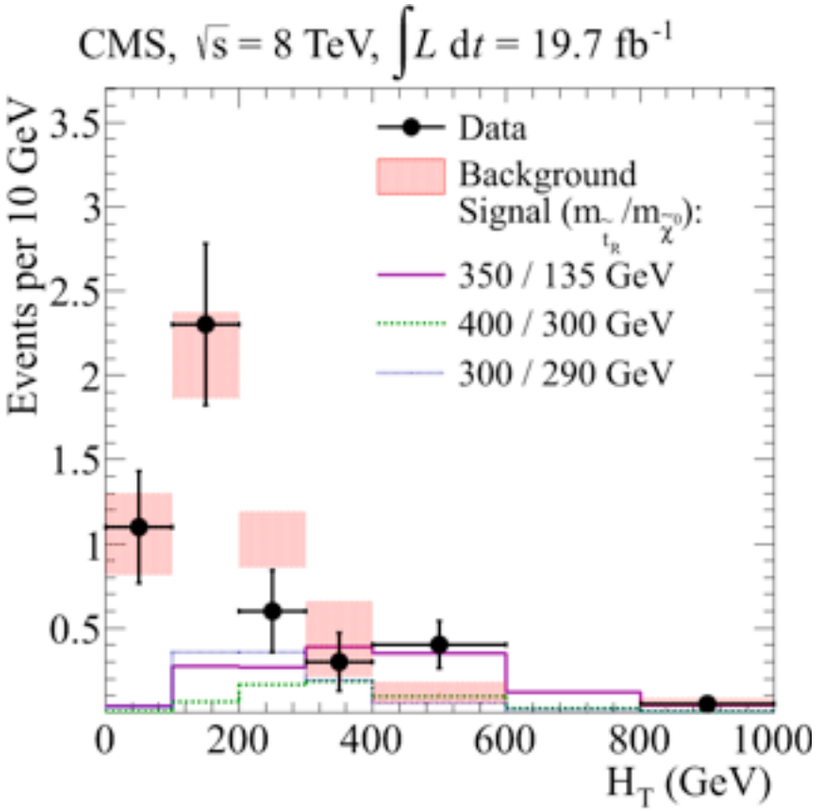
stop only

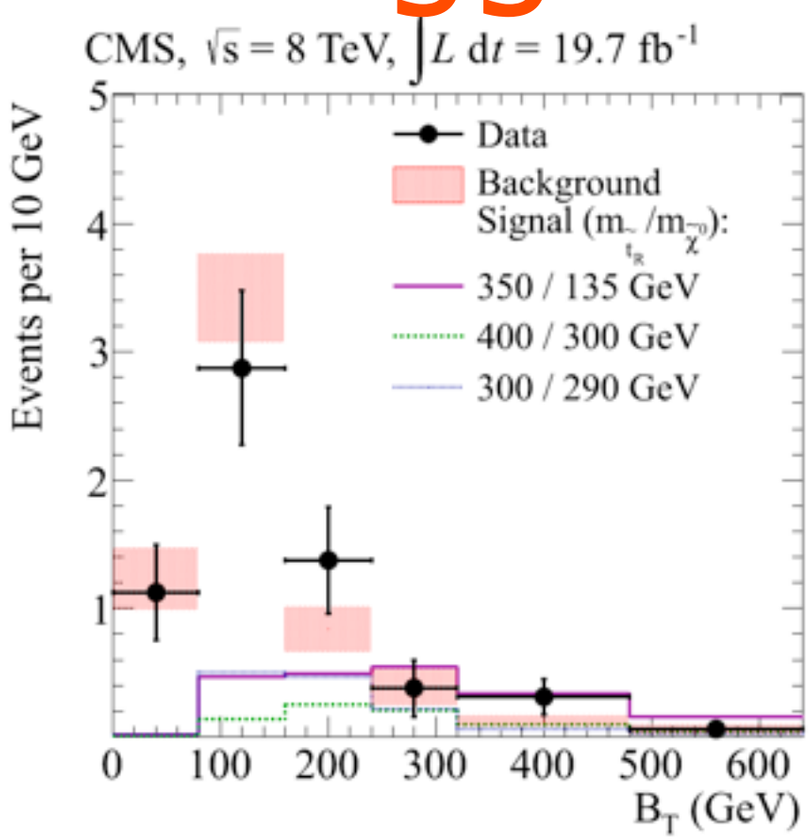


stop+EWK

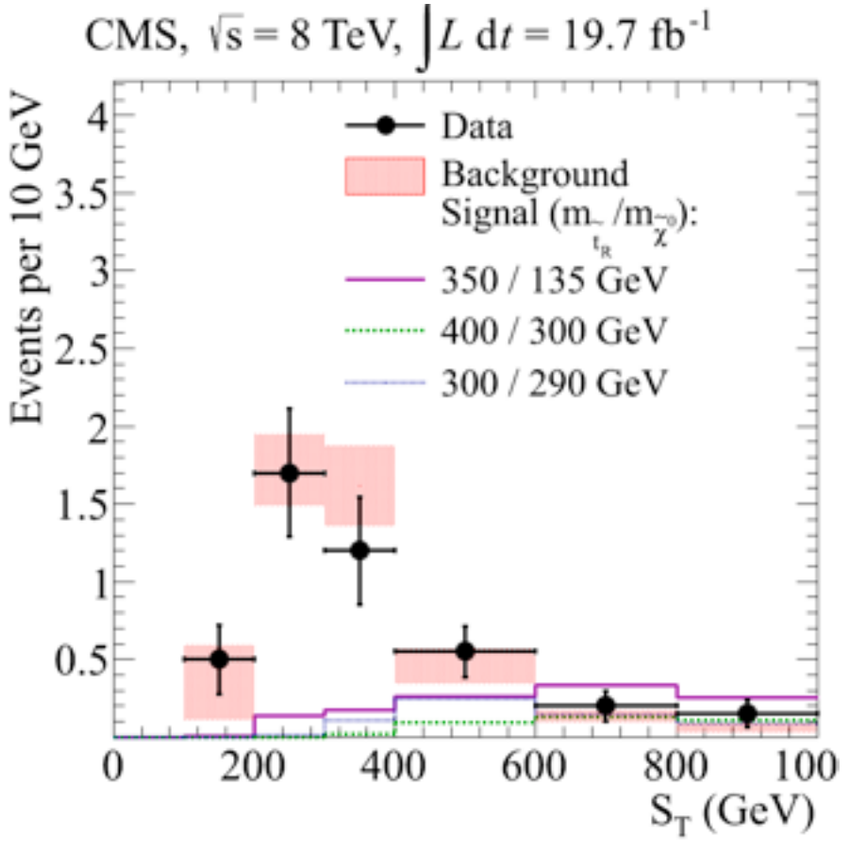


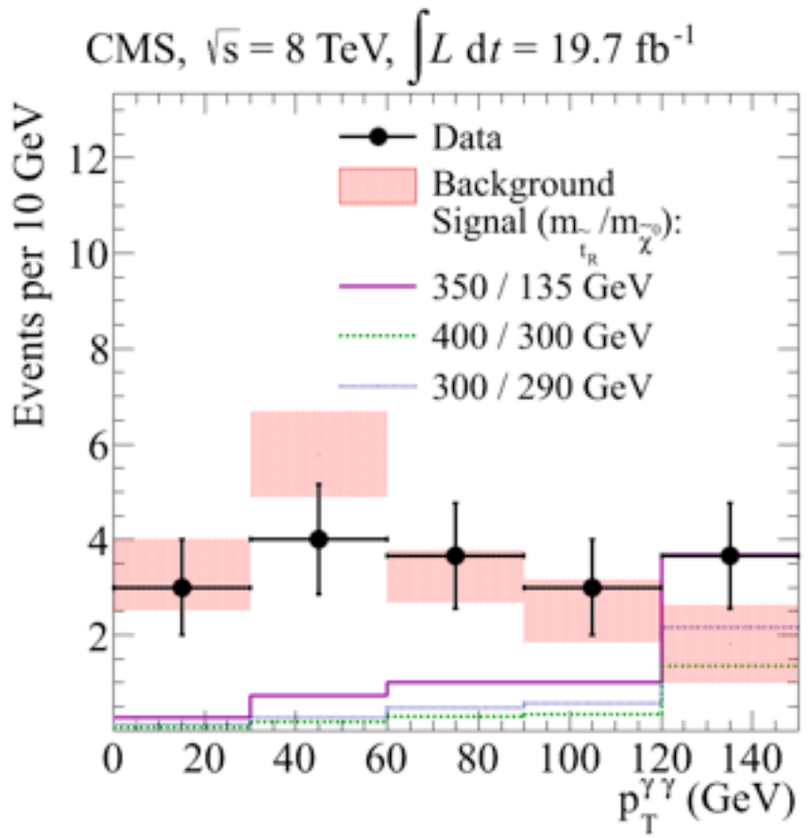
Events with higgs tag + 2 b's

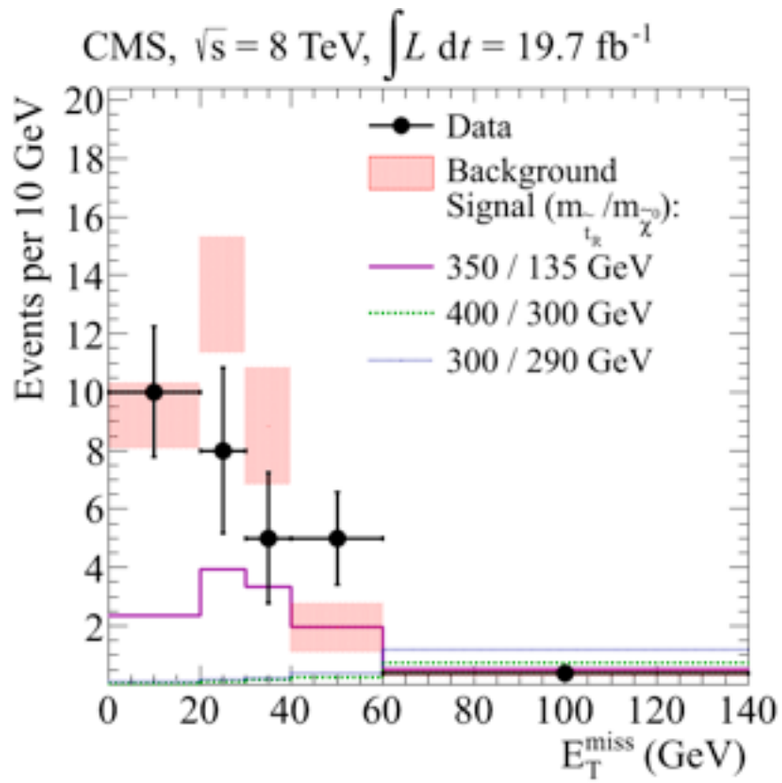




- Points - evts with higgs tag
- Rectangles - sidebands
- Lines - stop MC
- Simple and robust BG prediction allows for quick exploration





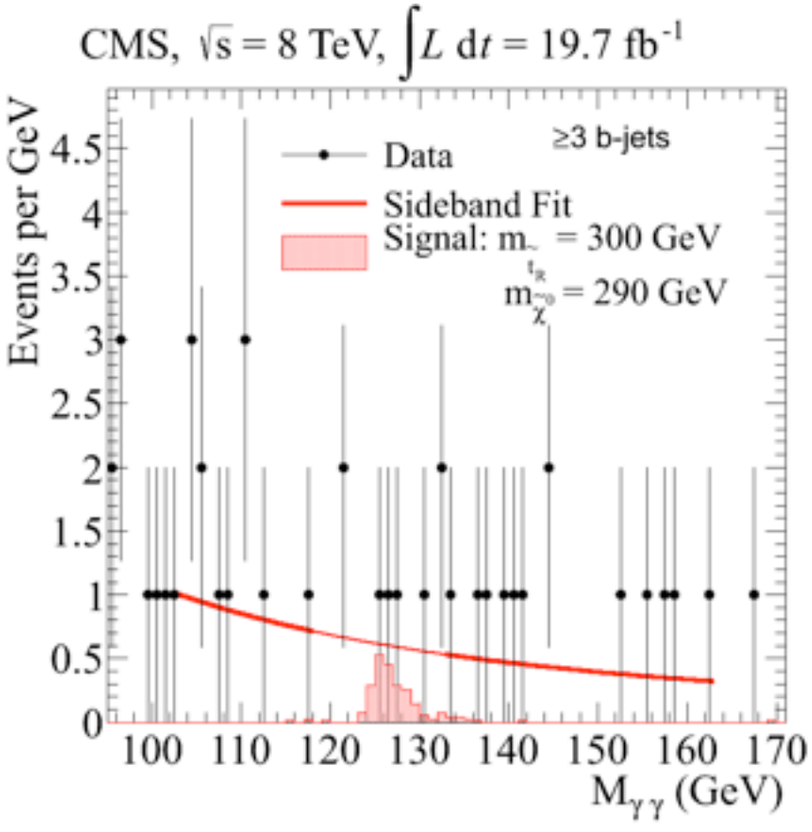


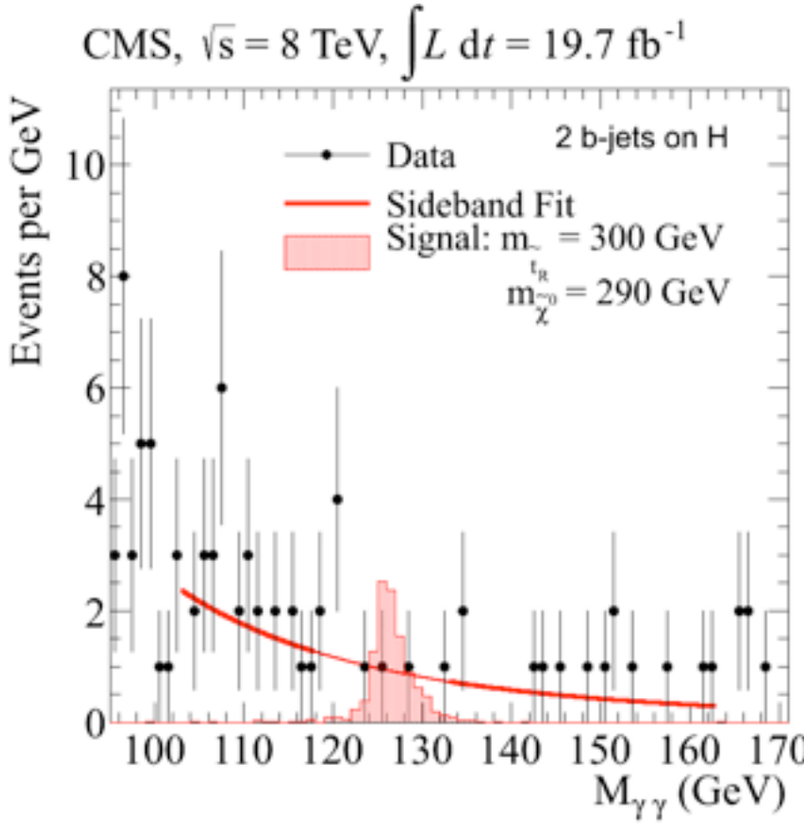
Further Event Categorization

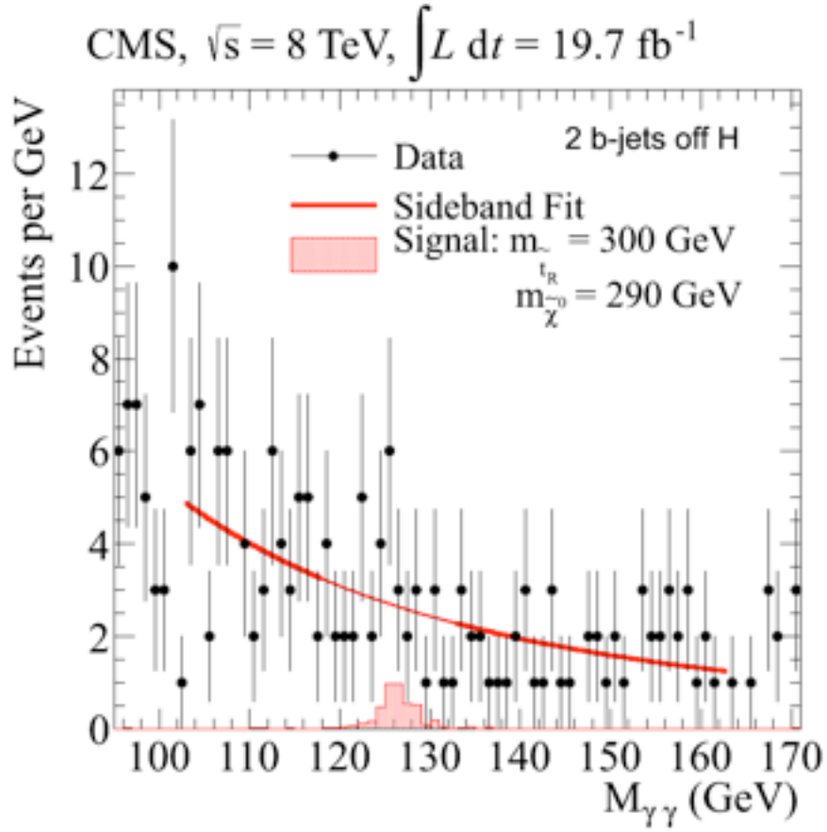
Divide events into three categories

- events with ≥3 b's
- =2 b's and 95 < m_{bb} <155 GeV
- all other events with =2 b's

Category	(i)	(ii)	(iii)
signal 350 / 135	10.7	2.0	6.8
signal 300 / 290	2.1	10.1	3.9
signal 400 / 300	4.0	1.4	2.8
expected background	6.7 ± 1.4	10.5 ± 1.8	29.7 ± 2.8
observed	6	7	33

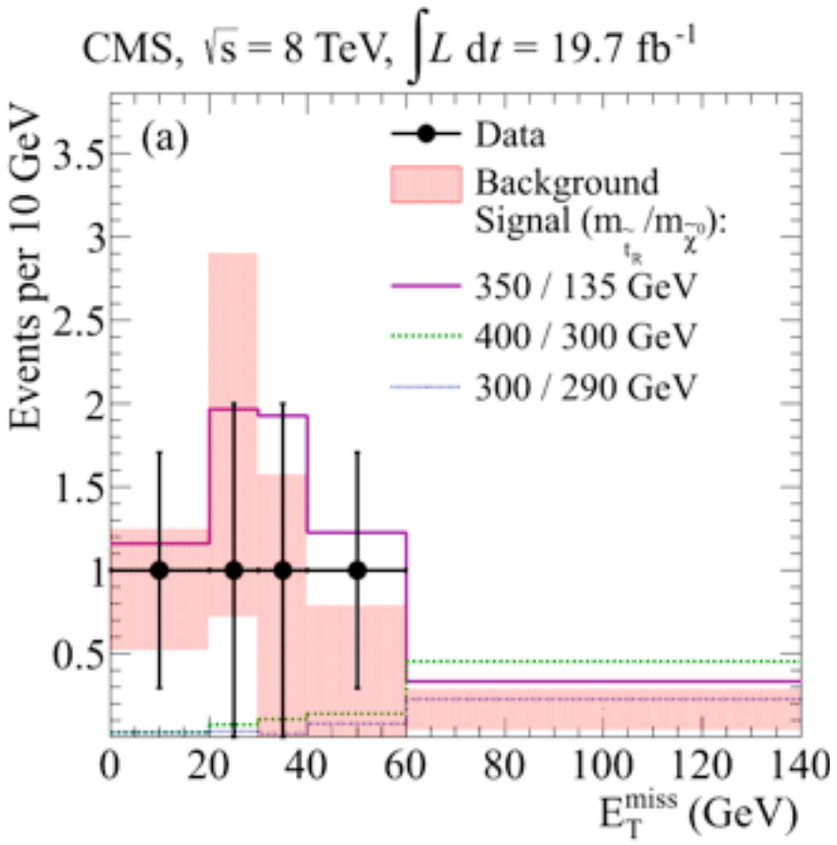


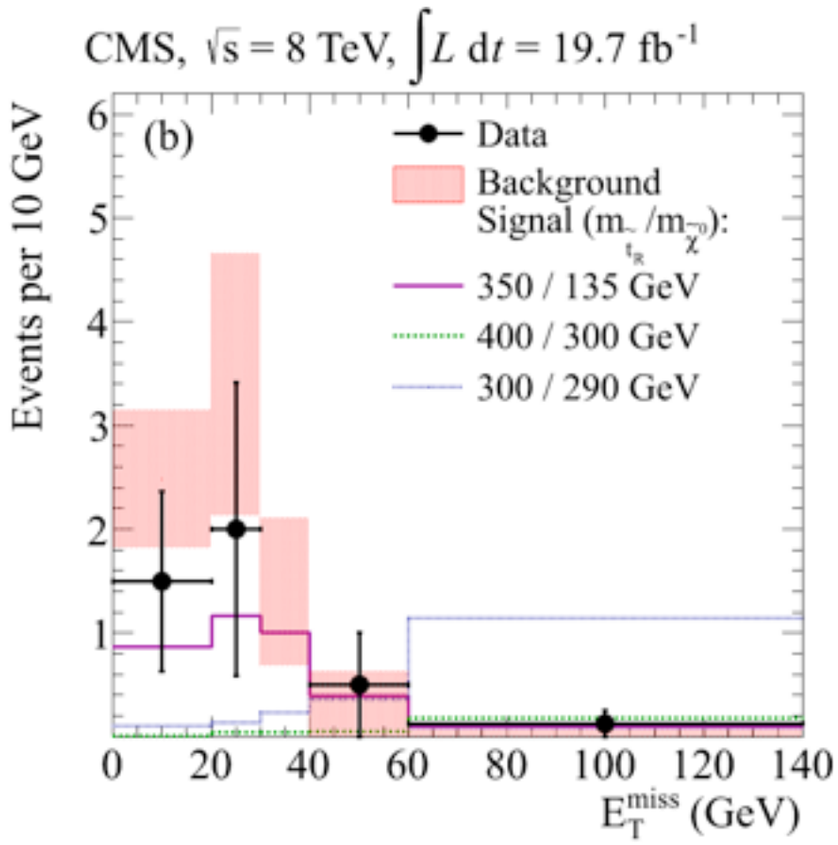


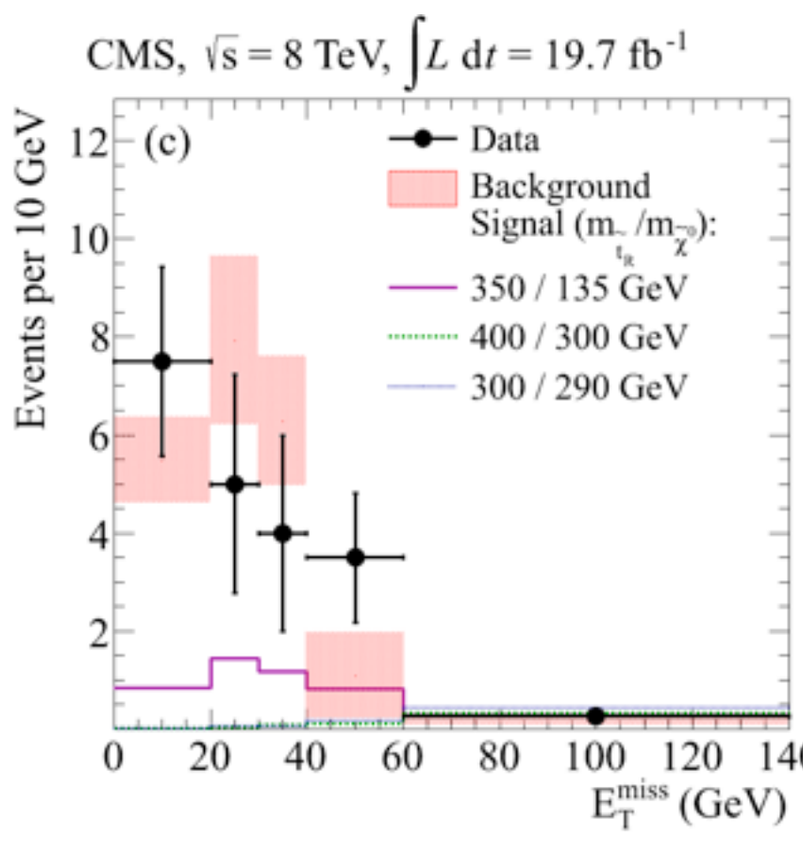


MET in categories

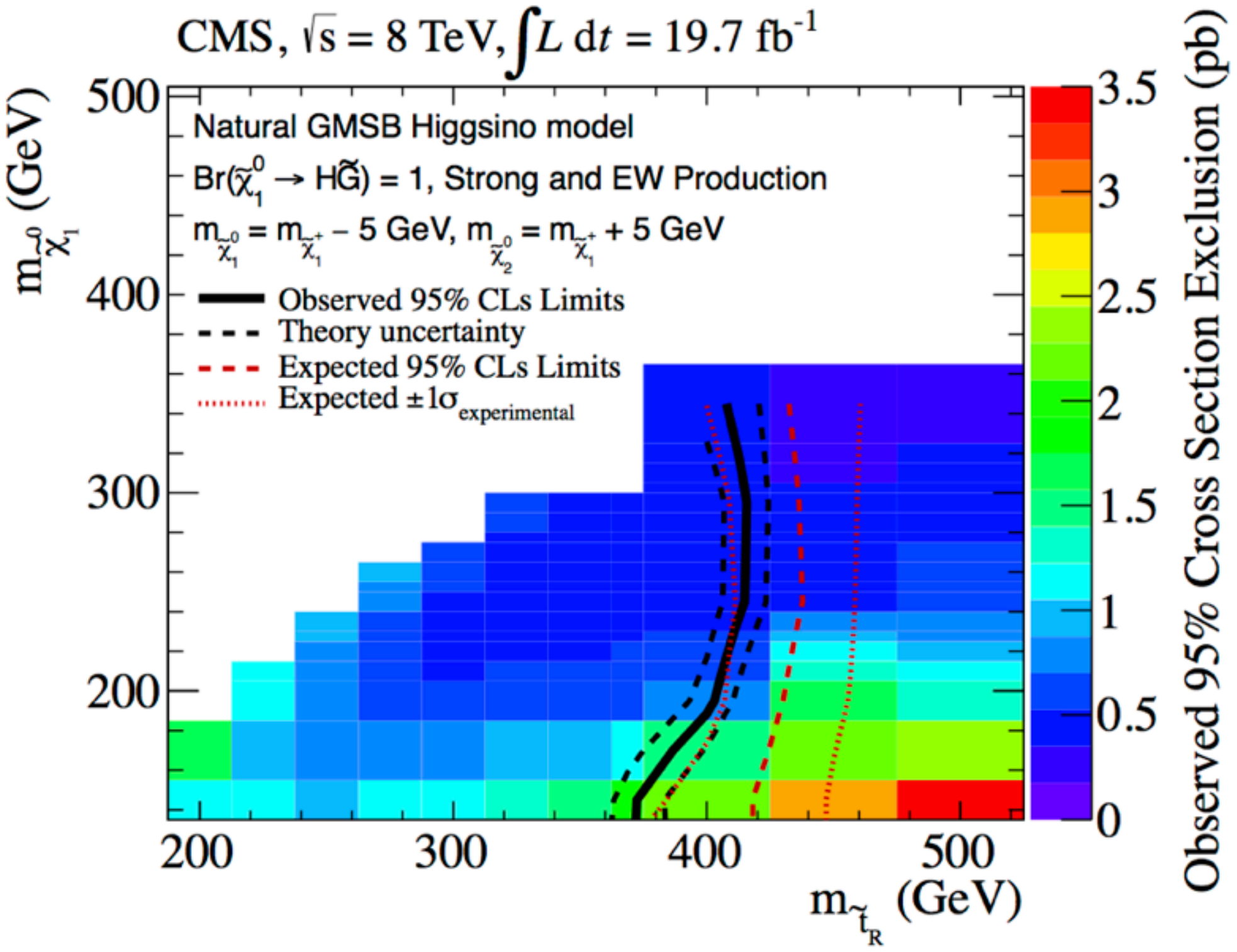
- Use binned MET distributions in the three categories for the statistical analysis of the data





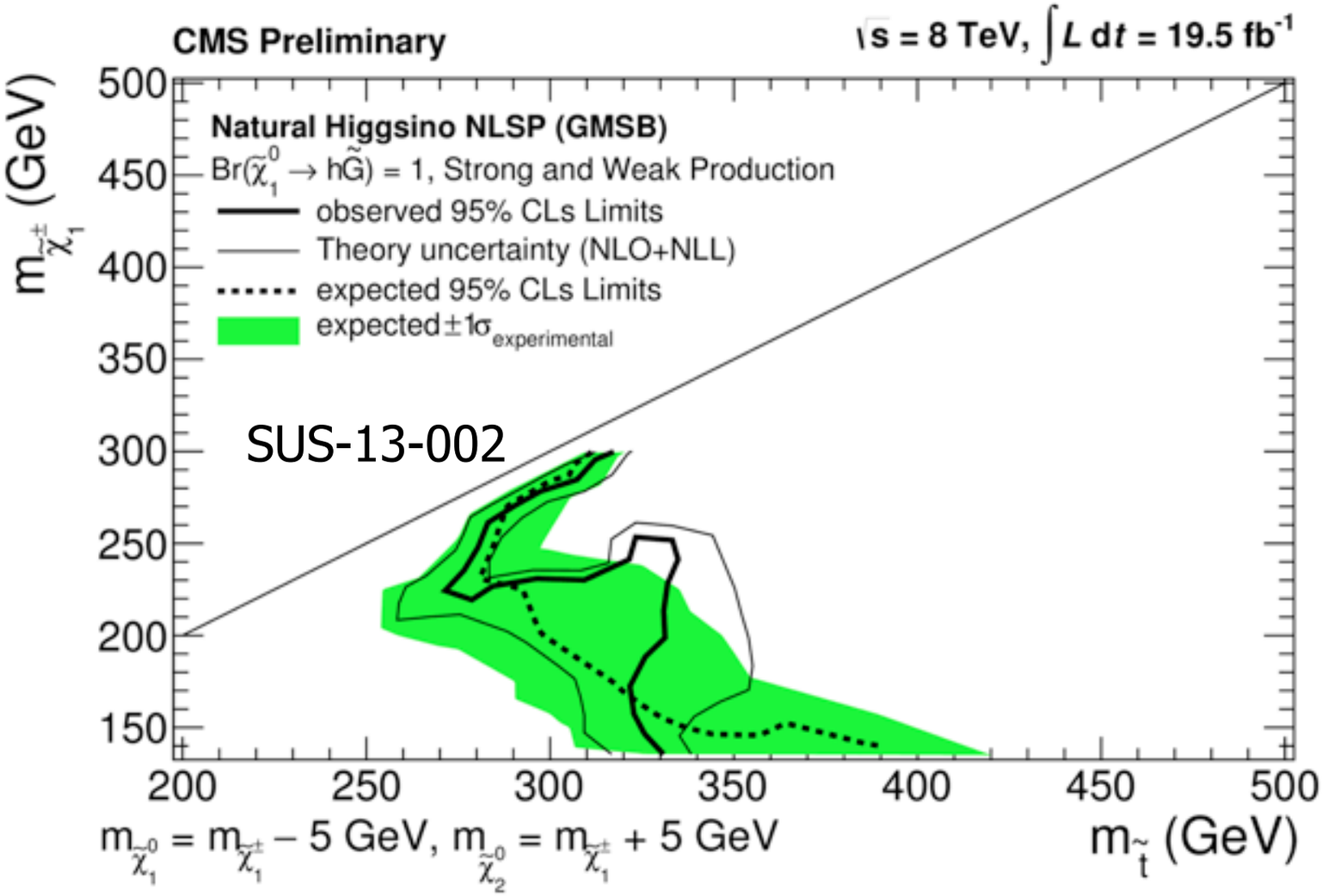


The limit


CMS, $\sqrt{s}$ = 8 TeV, $\int L\,dt$ = 19.7 fb^{-1}
Natural GMSB Higgsino model
Br($\tilde{\chi}_1^0 \to H\tilde{G}$) = 1, Strong and EW Production
$m_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_1^+} - 5$ GeV, $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^+} + 5$ GeV
Observed 95% CLs Limits
Theory uncertainty
Expected 95% CLs Limits
Expected ±1σ experimental
$m_{\tilde{\chi}_1^0}$ (GeV)
$m_{\tilde{t}_R}$ (GeV)
Observed 95% Cross Section Exclusion (pb)
500
400
300
200
200
300
400
500
3.5
3
2.5
2
1.5
1
0.5
0

Comparison with multileptons

- Higgs decays into leptons
  - mostly though WW and $\tau\tau$
  - Br[h→1 e/μ]≈11%, Br[h→2 e/μ]≈1.8%
  - Br[hh→3 e/μ]≈0.4% - comparable to $\gamma\gamma$
    - in reality, a little less sensitive - soft leptons from τ, W* and larger background (no mass peak!)



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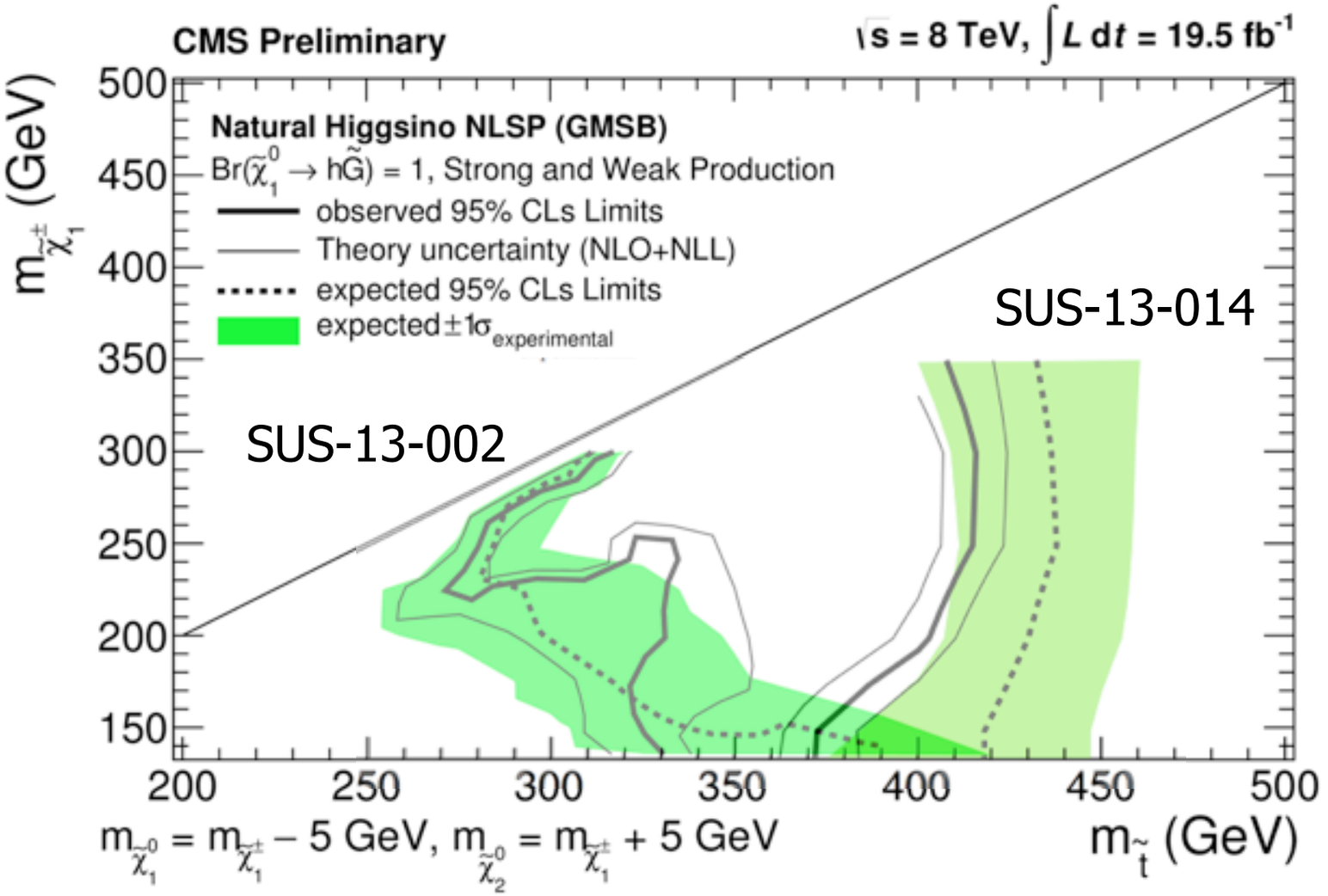
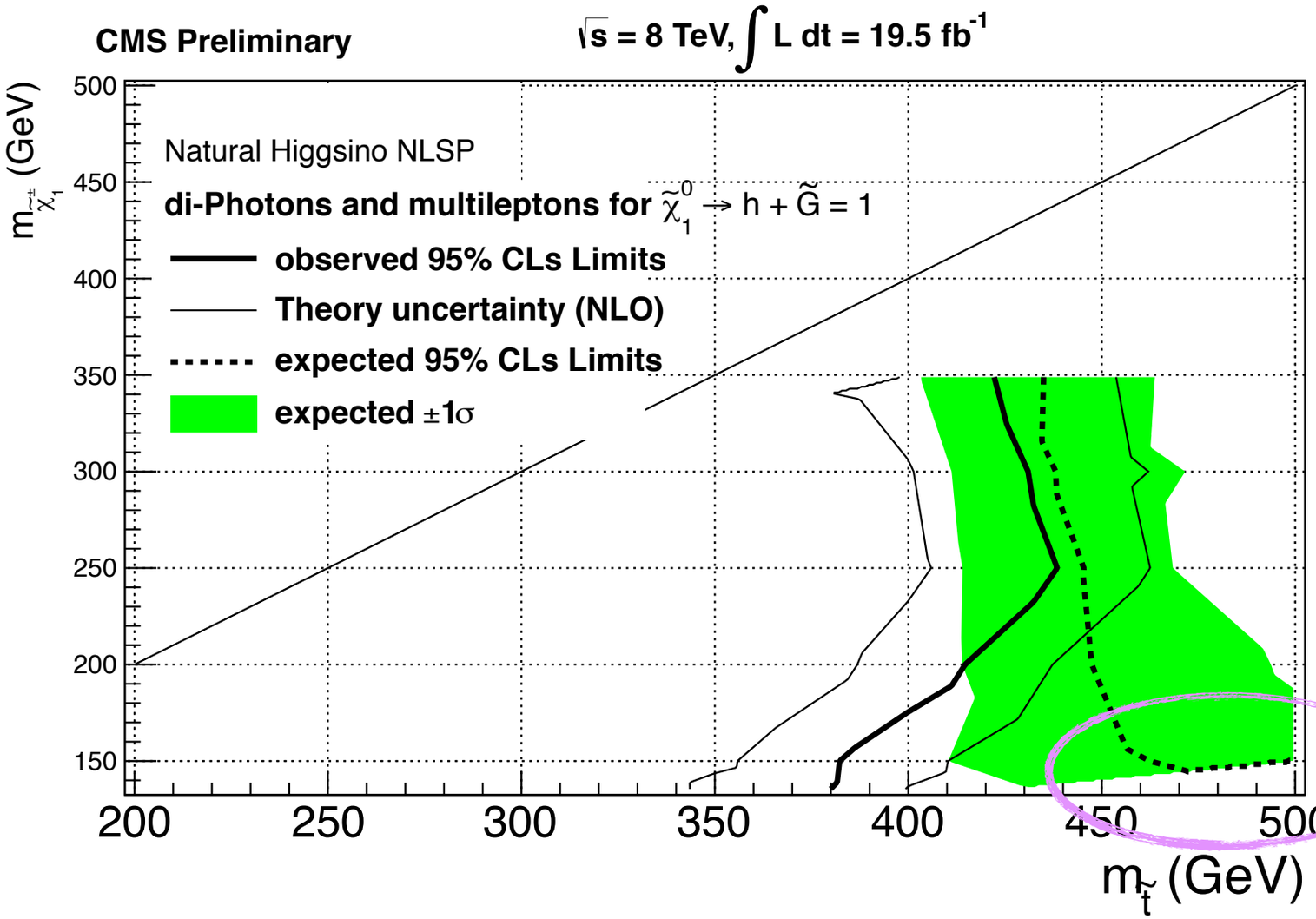


combination of 3l and $\gamma\gamma$bb

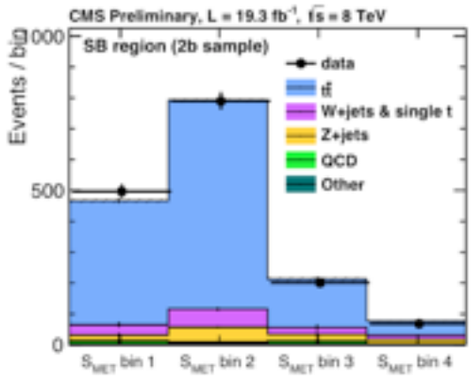


Getting sensitive to electroweak production

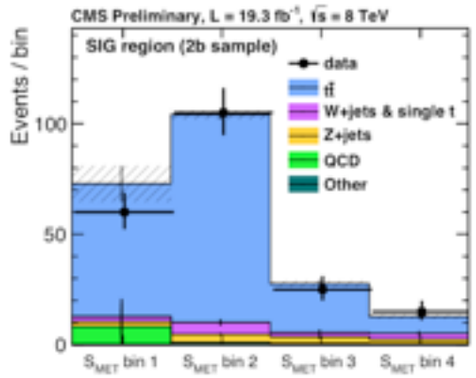
towards a grand higgsino combination

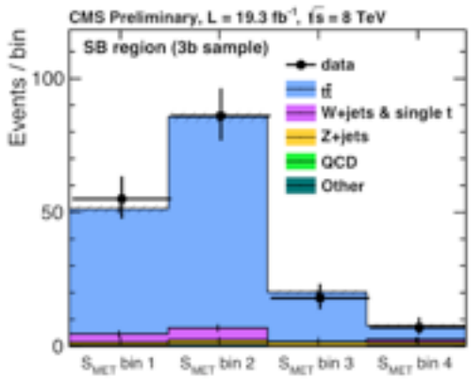
- multi-leptons (ZH, some HH) SUS-13-002
- 4b (HH) SUS-13-022

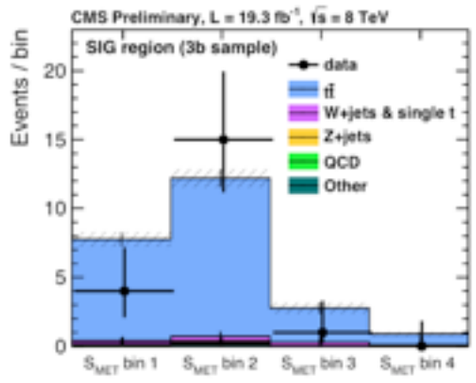
control region

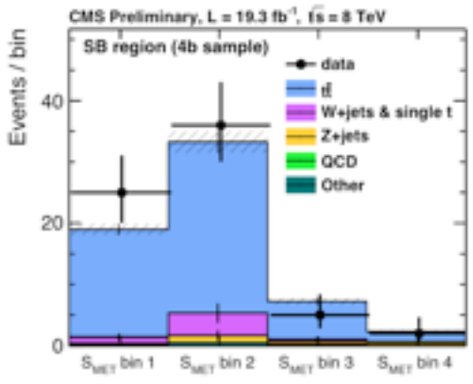


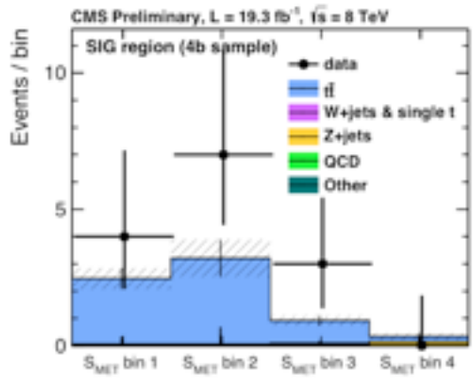
signal region



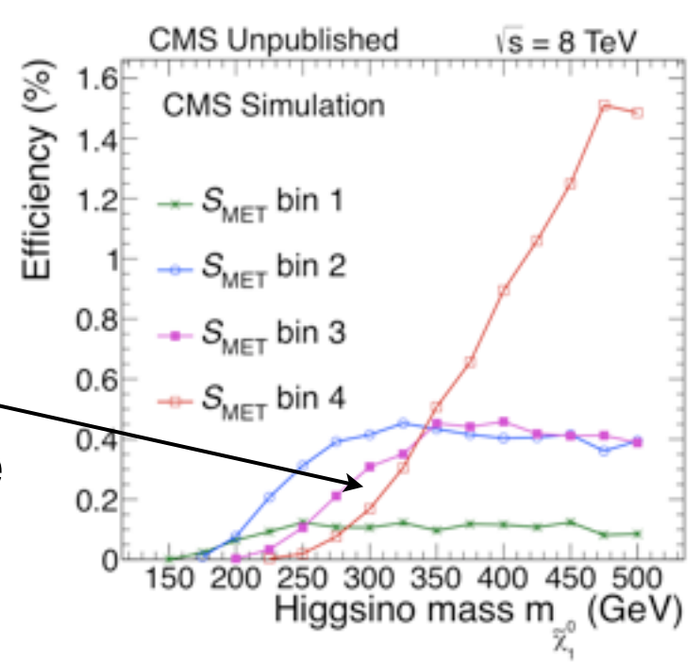


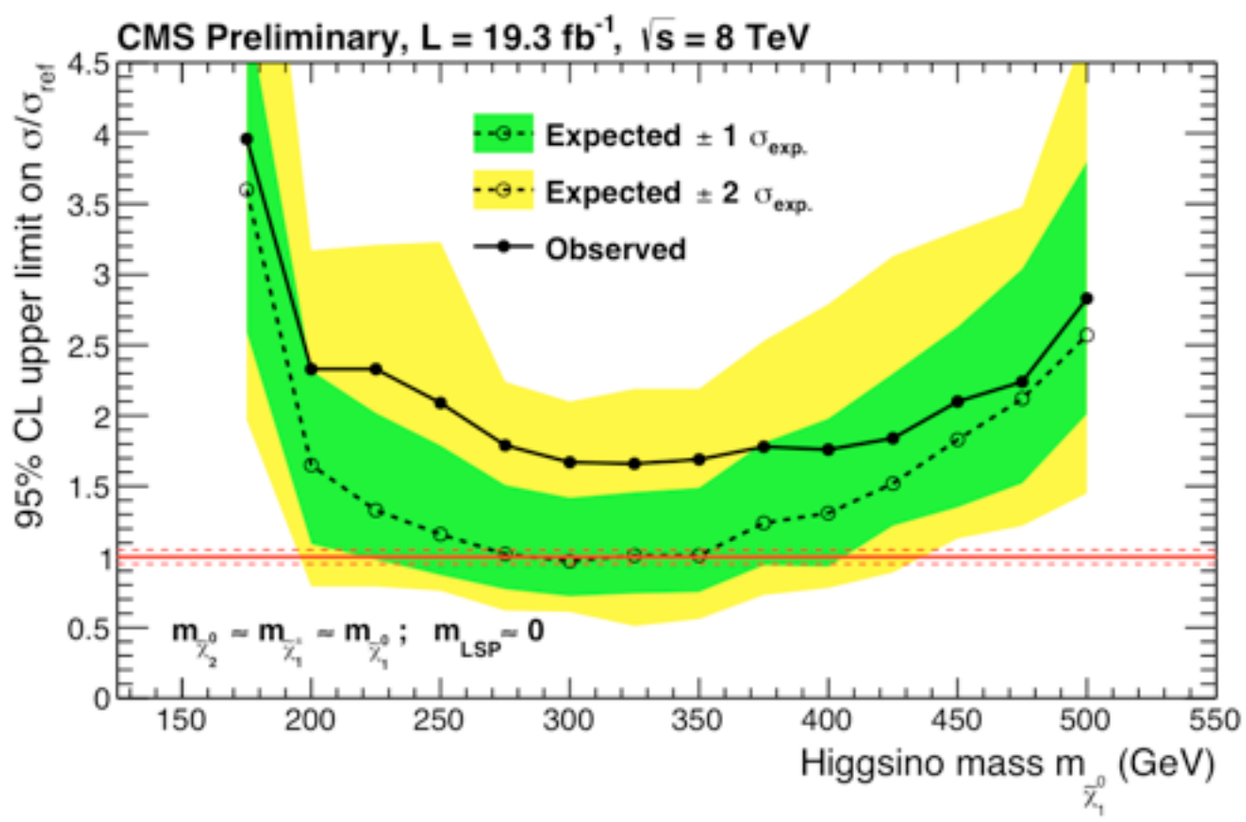






Complementary to diphotons and multileptons: sensitive to higher masses





- Plus new γγ, ZH (llbb), etc... Stay tuned!

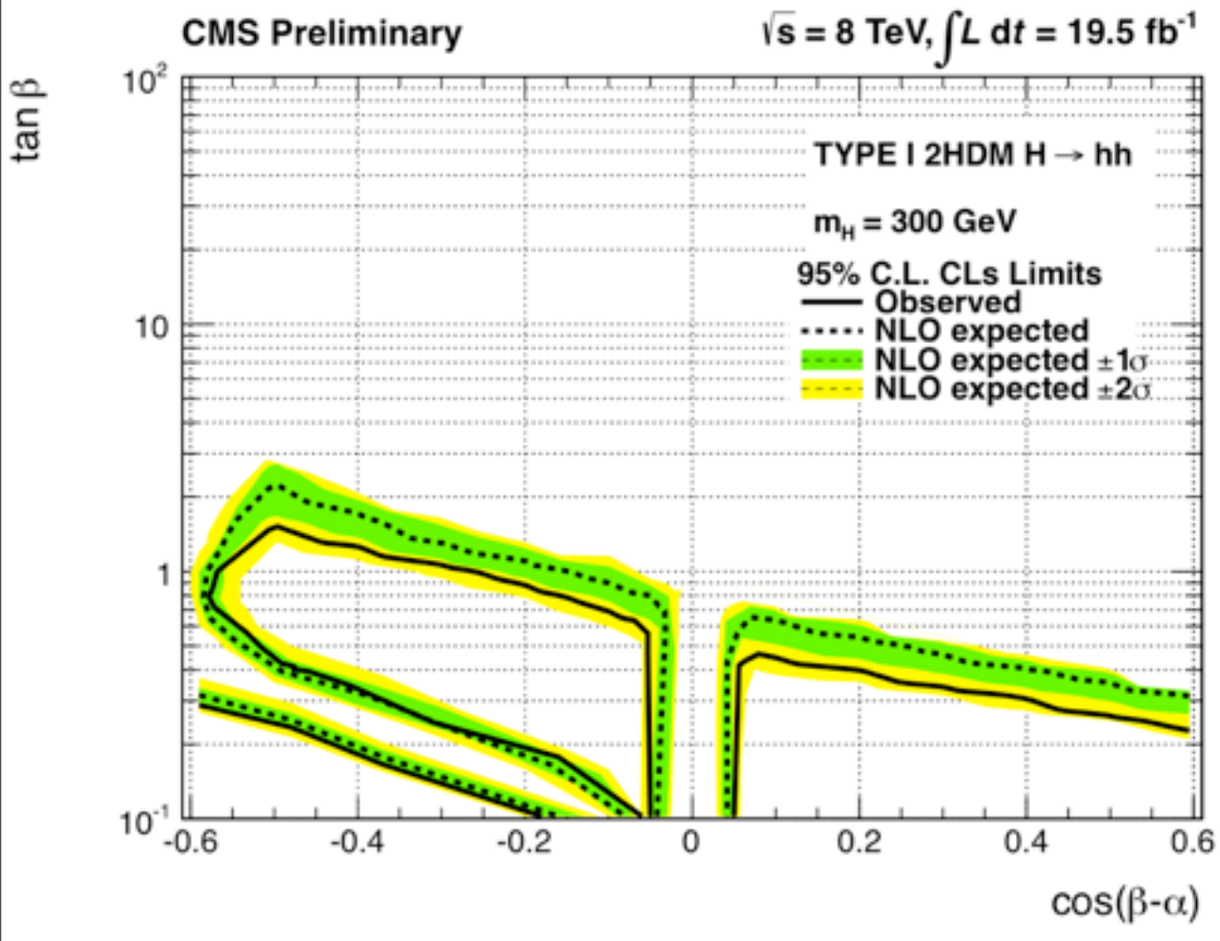
Another angle on HH/HZ final states

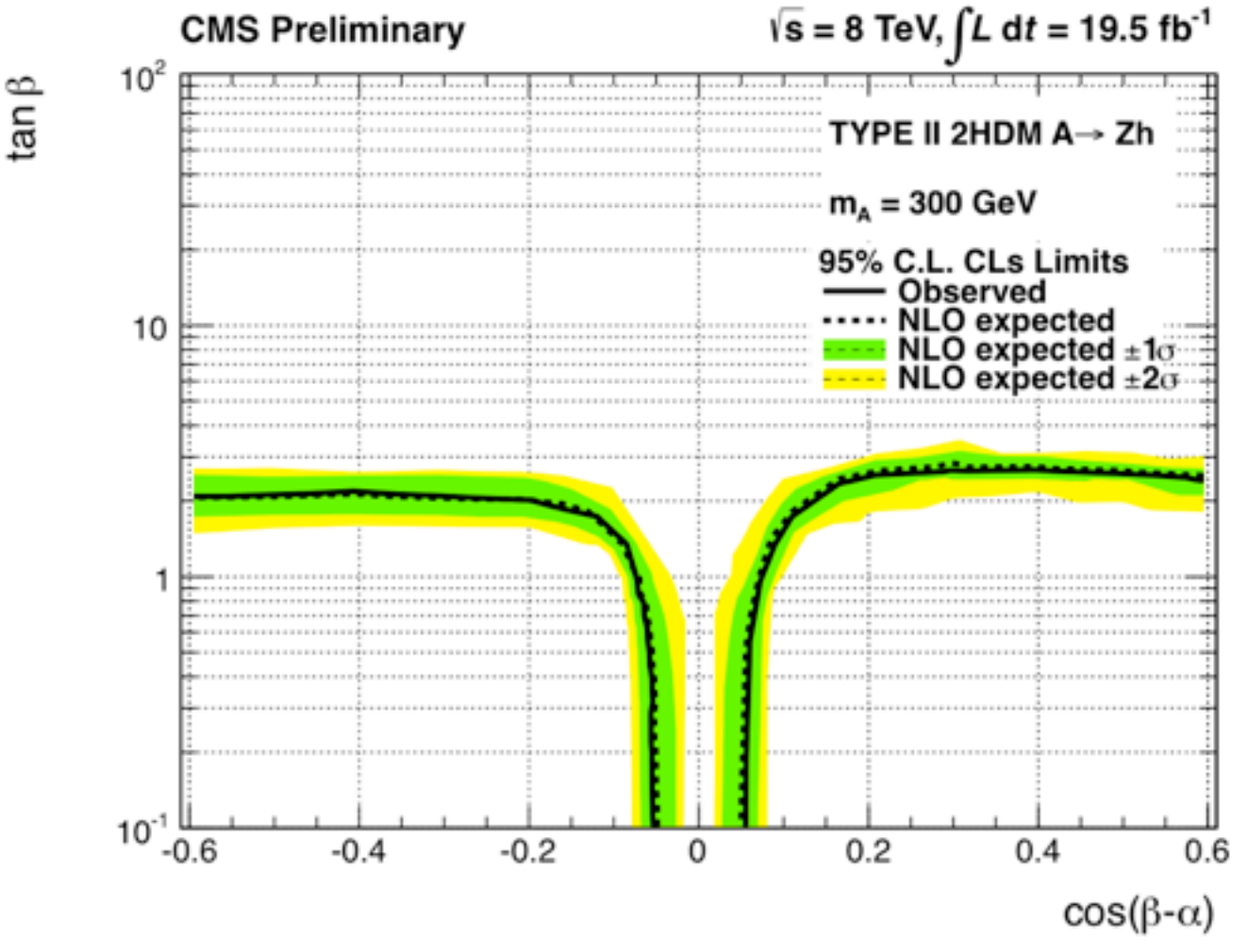
- even harder: no MET
- multileptons and diphoton+tau / e / μ

N. Craig et al arXiv:1201.0559

y_{2HDM}/y_{SM}	2HDM I	2HDM II
hVV	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
hQu	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
hQd	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
hLe	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$
HVV	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)$
HQu	$\sin\alpha/\sin\beta$	$\sin\alpha/\sin\beta$
HQd	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
HLe	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$
AVV	0	0
AQu	$\cot\beta$	$\cot\beta$
AQd	$-\cot\beta$	$\tan\beta$
ALe	$-\cot\beta$	$\tan\beta$

HIG-13-025





Higgs in Top

N. Craig *et al* PRD 86 075002 (2012)

- A complementary way to probe tiny BSM Higgs couplings: use huge top production cross section
  - i.e. FCNC t→Hc
  - diphotons have the best sensitivity
  - limit FV couplings

$$\sqrt{|\lambda^{H}_{tc}|^2 + |\lambda^{H}_{ct}|^2} < 0.14.$$

most sensitive channels with H→ γγ + e/μ

E_T^{miss} [GeV]	$N_{b\text{-jets}}$	data	background	signal	efficiency [10^{-5}]
50–100	≥ 1	1	2.3 ± 1.2	2.88 ± 0.39	3.1 ± 0.4
30–50	≥ 1	2	1.1 ± 0.6	2.16 ± 0.30	2.4 ± 0.3
0–30	≥ 1	2	2.1 ± 1.1	1.76 ± 0.24	1.9 ± 0.3
50–100	0	7	9.5 ± 4.4	2.22 ± 0.31	2.4 ± 0.3
> 100	≥ 1	0	0.5 ± 0.4	0.92 ± 0.14	1.0 ± 0.2
> 100	0	1	2.2 ± 1.0	0.94 ± 0.17	1.0 ± 0.2

HIG-13-034

Higgs Decay Mode	observed	expected	1σ range
$H \to WW^*$ ($\mathcal{B} = 23.1\,\%$)	1.58 %	1.57 %	(1.02–2.22) %
$H \to \tau\tau$ ($\mathcal{B} = 6.15\,\%$)	7.01 %	4.99 %	(3.53–7.74) %
$H \to ZZ^*$ ($\mathcal{B} = 2.89\,\%$)	5.31 %	4.11 %	(2.85–6.45) %
combined multileptons (WW^*, $\tau\tau$, ZZ^*)	1.28 %	1.17 %	(0.85–1.73) %
$H \to \gamma\gamma$ ($\mathcal{B} = 0.23\,\%$)	0.69 %	0.81 %	(0.60–1.17) %
combined multileptons + diphotons	0.56 %	0.65 %	(0.46–0.94) %

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  - precision measurements
    - 7 & 8 TeV
      - M_t = 172.22 ± 0.73 GeV (TOP-14-001)
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    - displaced objects
    - low-MET / low HT SUSY searches

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    - 7 & 8 TeV
      - M_t = 172.22 ± 0.73 GeV (TOP-14-001)
  - beginning to see results of "hard" searches
    - displaced objects
    - low-MET / low HT SUSY searches
- Higgs tagging is becoming a powerful tool for EWSB exploration
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    - 7 & 8 TeV
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  - new, tough challenges - **but...**

Never Underestimate Ingenuity of Physicists with Lots of Data!

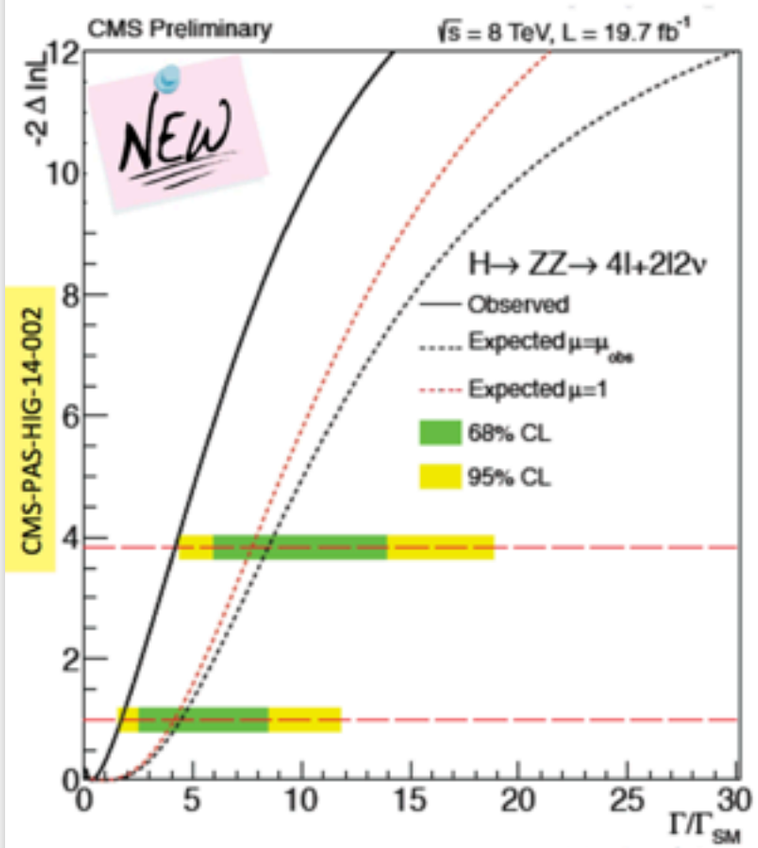
New Ideas

Constraint on the Γ_H from $H^*(126) \rightarrow ZZ$

4l analysis: 2D likelihood in m_{4l} and D_{gg}

2l2ν analysis: 1D likelihood with m_T or E_t^{miss}

Combined fit using the measured yield at the peak in H->ZZ->4l as constraint



	4ℓ	2ℓ2ν	Combined
Expected 95% CL limit, r	11.5	10.7	8.5
Observed 95% CL limit, r	6.6	6.4	4.2
Observed 95% CL limit, Γ_H(MeV)	27.4	26.6	17.4
Observed best fit, r	$0.5^{+2.3}_{-0.5}$	$0.2^{+2.2}_{-0.2}$	$0.3^{+1.5}_{-0.3}$
Observed best fit, Γ_H(MeV)	$2.0^{+9.6}_{-2.0}$	$0.8^{+9.1}_{-0.8}$	$1.4^{+6.1}_{-1.4}$

Obs.(exp.) @95% C.L:

$\Gamma_H < 4.2(8.5)\ \Gamma_H^{SM}$

$\Gamma_H < 17.4\ (35.3)$ MeV

Considerable improvement w.r.t. previous CMS direct contraint on Γ_H

N. De Filippis — Moriond QCD, La Thuile, Italy, March 22-29, 2014 — 21

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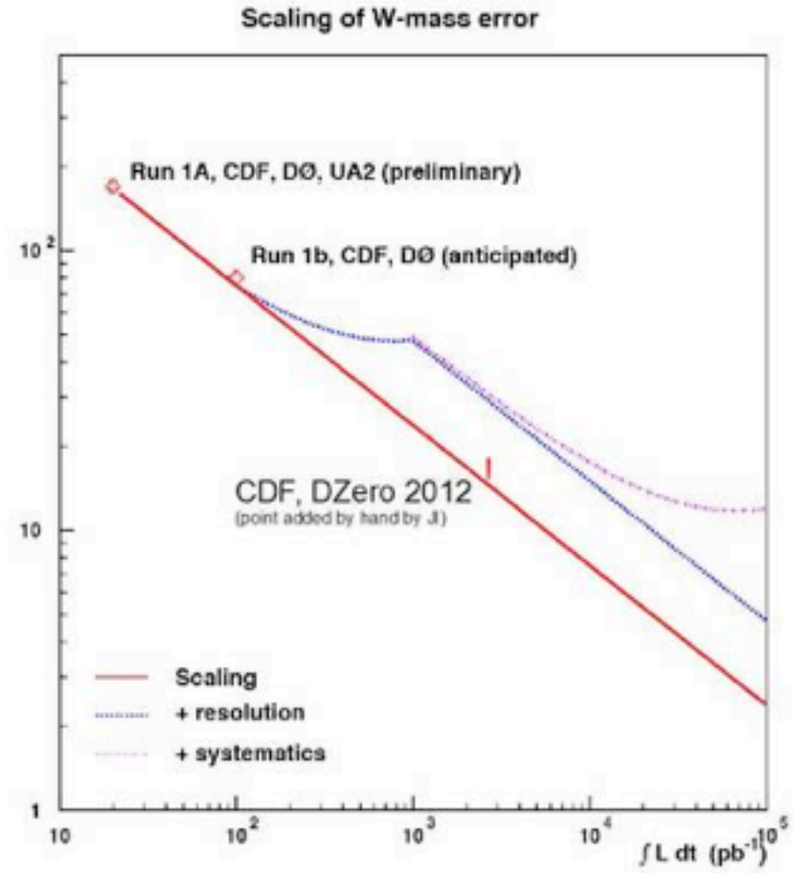
Control of systematic errors

- A plot from 1996 report from TeV-2000
- Extrapolations without exact knowledge of upgraded detector performance, how to deal with pile-up, how will the theory errors evolve, etc…



Report of the TeV-2000 Study Group: SLAC-REPRINT-1996-085, FERMILAB-PUB-96-082

Tevatron EWWG: arXiv:1204.0042 [hep-ex]

LHC exploration only just begun!

An amazingly interesting place to be