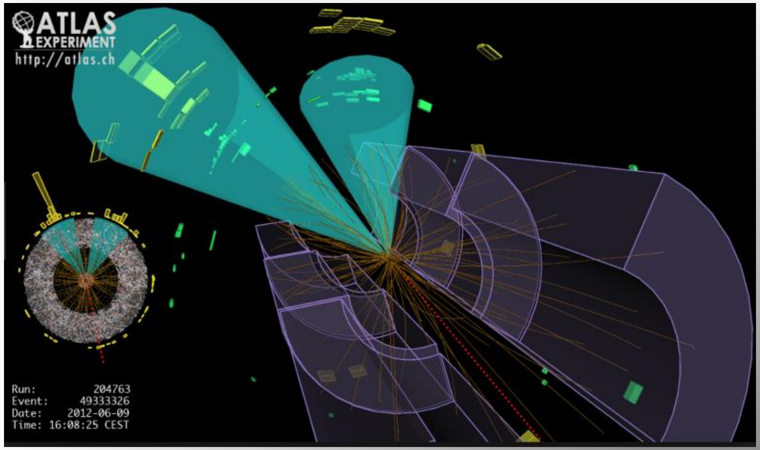
Recent Results from the LHC
Beyond the Standard Model

Albert De Roeck
CERN, Geneva, Switzerland
Antwerp University Belgium
UC-Davis California USA
NTU, Singapore

4th January 2018

Spåtind 2018 - Nordic Conference on Particle Physics



Collision at 7 TeV in ATLAS with large missing E_T

Outline

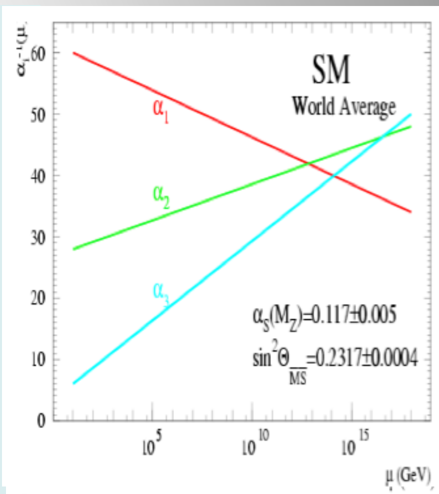
- Introduction: Searches for New Physics
- Supersymmetry Searches
- Exotica Searches
- New Experiments at the LHC?
- Summary

Physics Case for High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

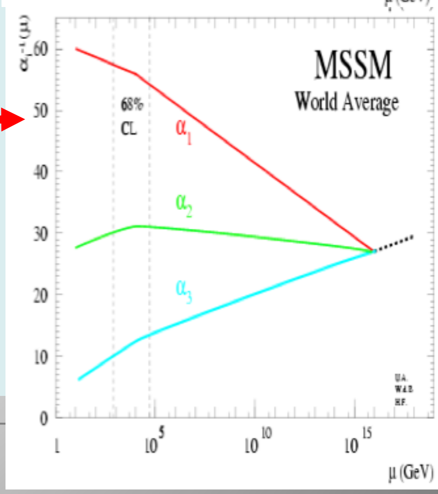
Discover physics beyond the Standard Model

Reminder: The Standard Model
- tells us how but not why
  3 flavour families? Mass spectra? Hierarchy? 19 parameters!
- needs fine tuning of parameters to level of 10^{-30} !
- has no connection with gravity
- no unification of the forces at high energy



Most popular extensions around 2000 and afterwards

- Supersymmetry
- Extra space dimensions



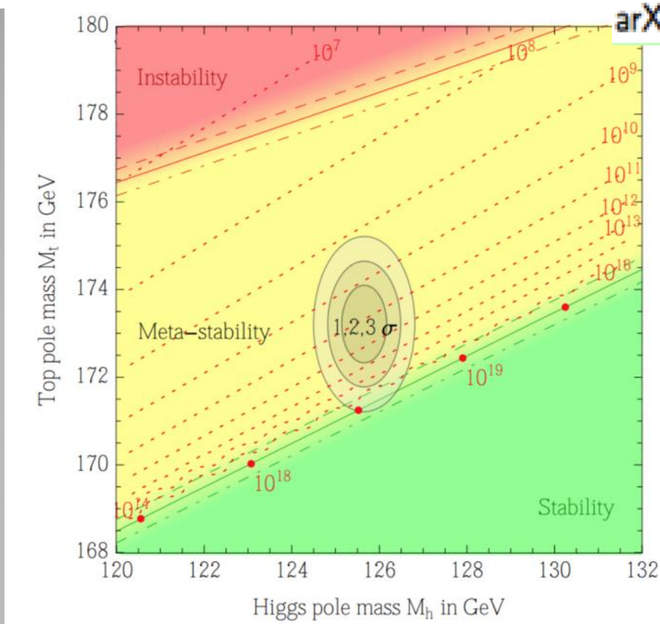
Many other ideas: More symmetry and gauge bosons, composite Higgs models, L-R symmetry, quark & lepton substructure, Little Higgs models, Technicolor, Hidden Valleys, Vector-like quarks…

Higgsless models rather disfavoured these days

Physics Beyond the Standard Model?

Important SM parameter → stability of EW vacuum

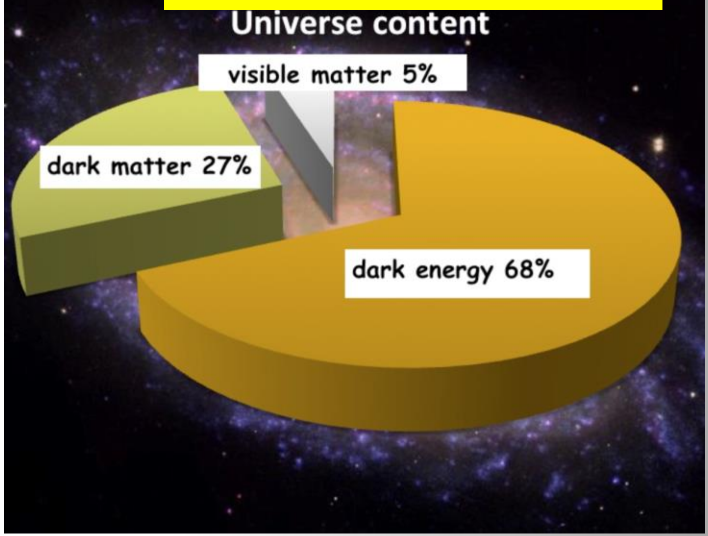
arXiv:1205.6497



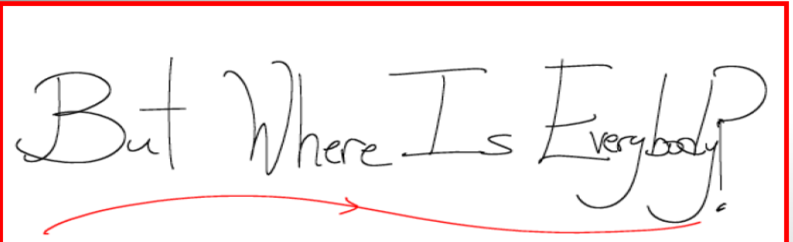
arXiv:1403.6535

A Higgs at 125 GeV
Precise measurements of the top quark and the Higgs mass

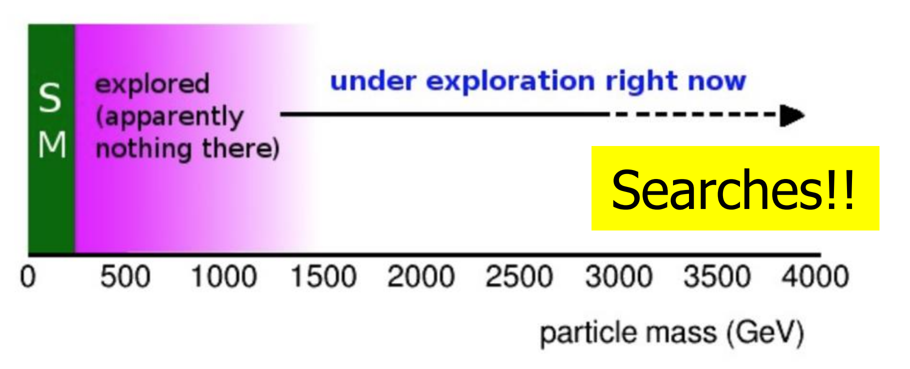
We also know that:



New Physics inevitable?
But at which scale/energy?



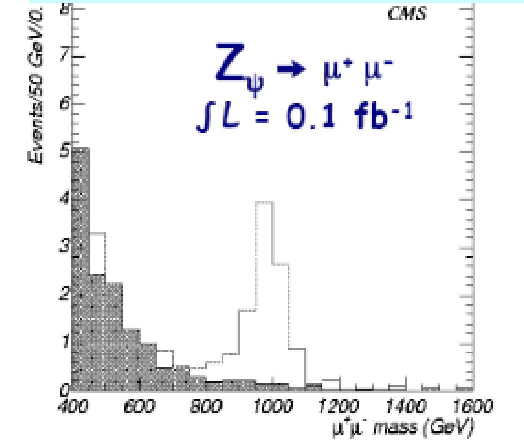
N. Arkani-Hamed



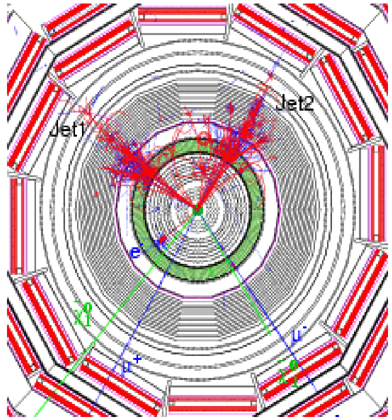
Searches!!

New Physics?

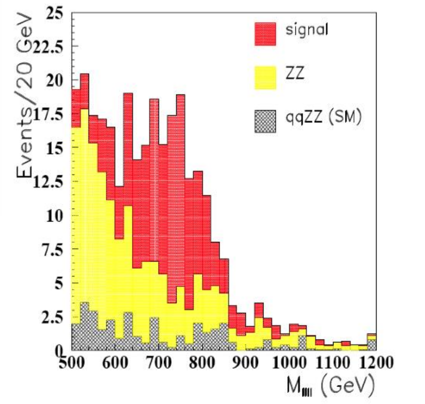
New Gauge Bosons?



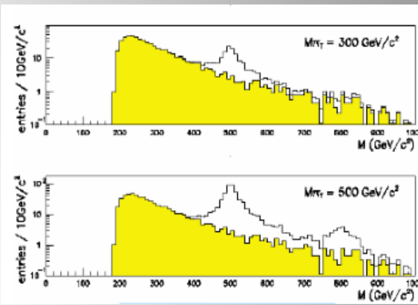
Supersymmetry



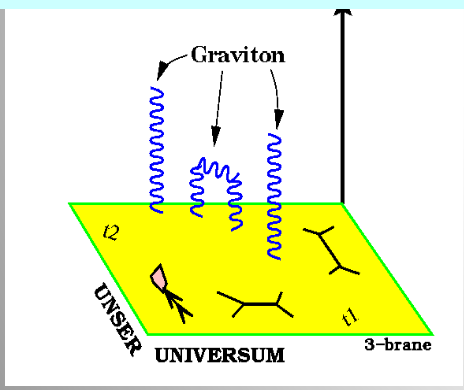
ZZ/WW resonances?



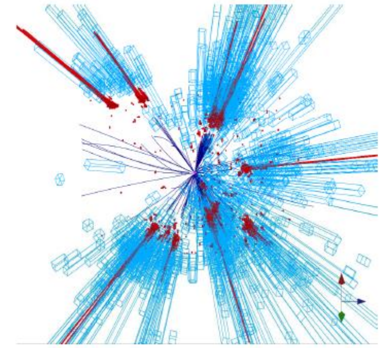
Technicolor?



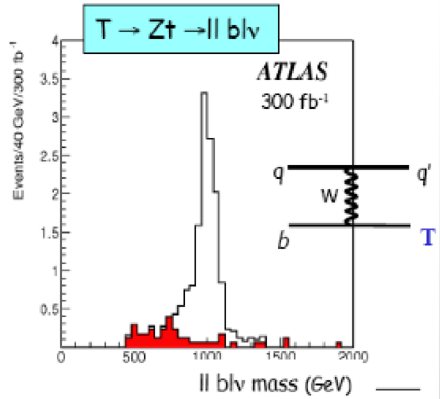
Extra Dimensions?



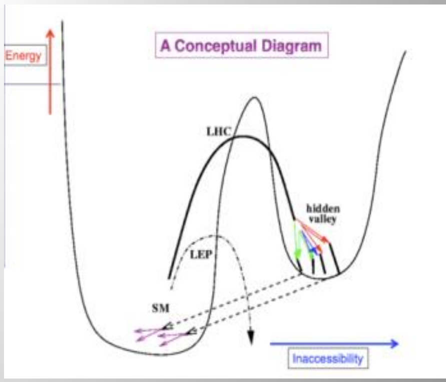
Black Holes???



Little Higgs?



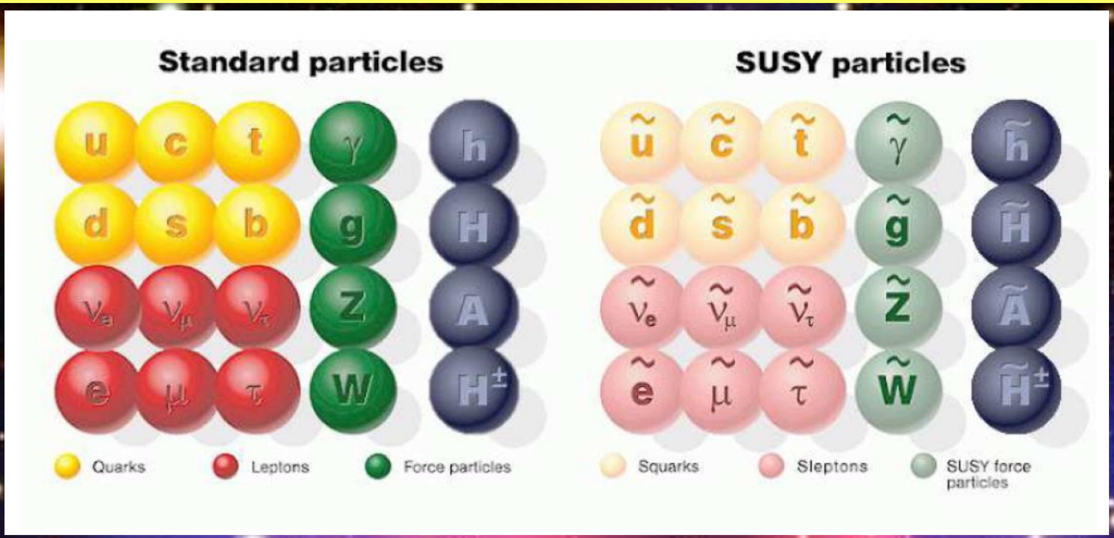
Hidden Valleys?



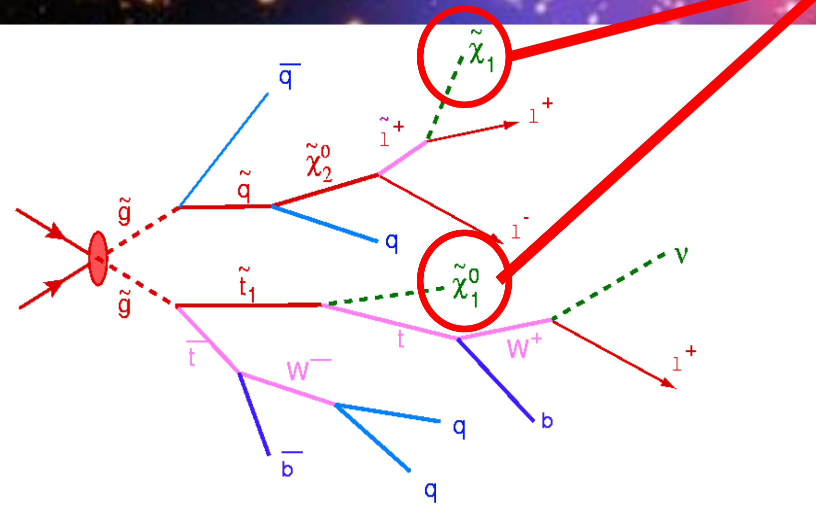
What stabelizes the Higgs Mass? Many ideas, not all popular any more

A large variety of possible signals. We have to be ready for that

Supersymmetry: a new symmetry in Nature?



Candidate particles for Dark Matter
⇒ Produce Dark Matter in the lab

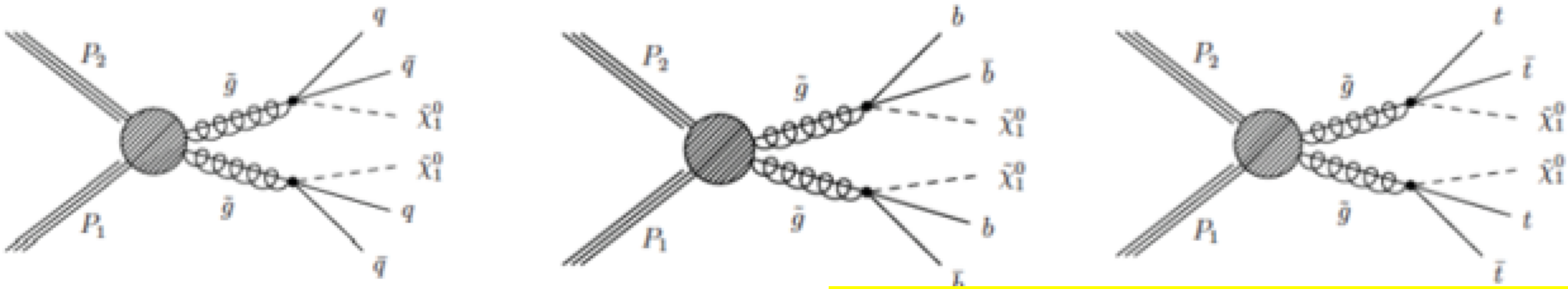


SUSY particle production at the LHC

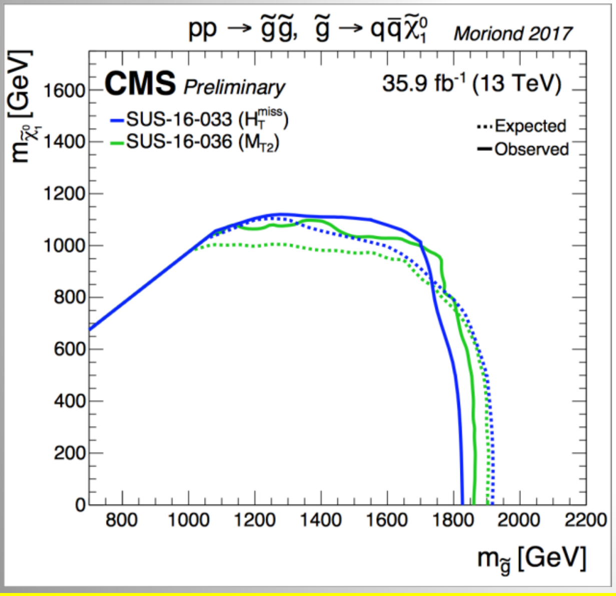
"One day all these trees will be SUSY phenomenology papers"

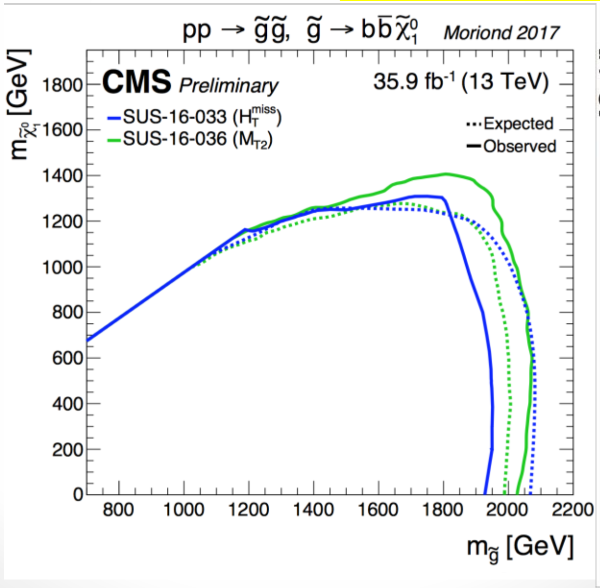
adac

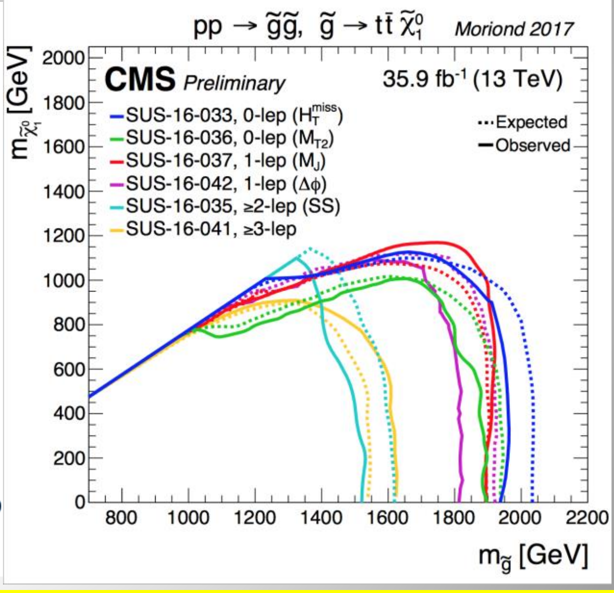
Supersymmetry: Gluinos



Interpretation in simplified models (SMS)







No significant signal to date

Within the context of the SMS:

Exclude with gluino masses ~ 2100 GeV for neutralino masses up to 800 GeV

What is really needed from SUSY?

End 2011: Revision!

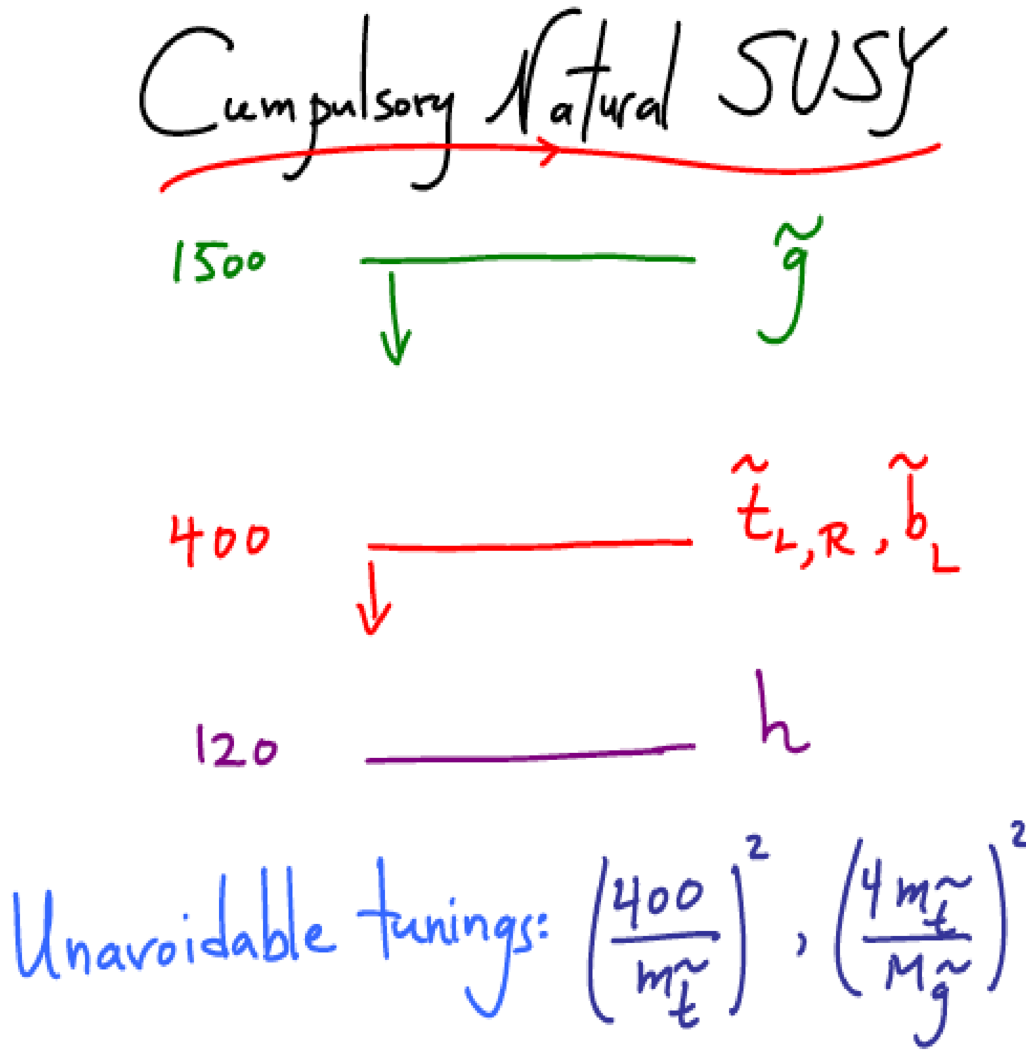
N. Arkani-Ahmed
CERN Nov 2011

and many many more ..

LHC data end 2011
Stops > 200-300 GeV
Gluino > 600-800 GeV

Moving away from constrained SUSY models to ‘natural’ models

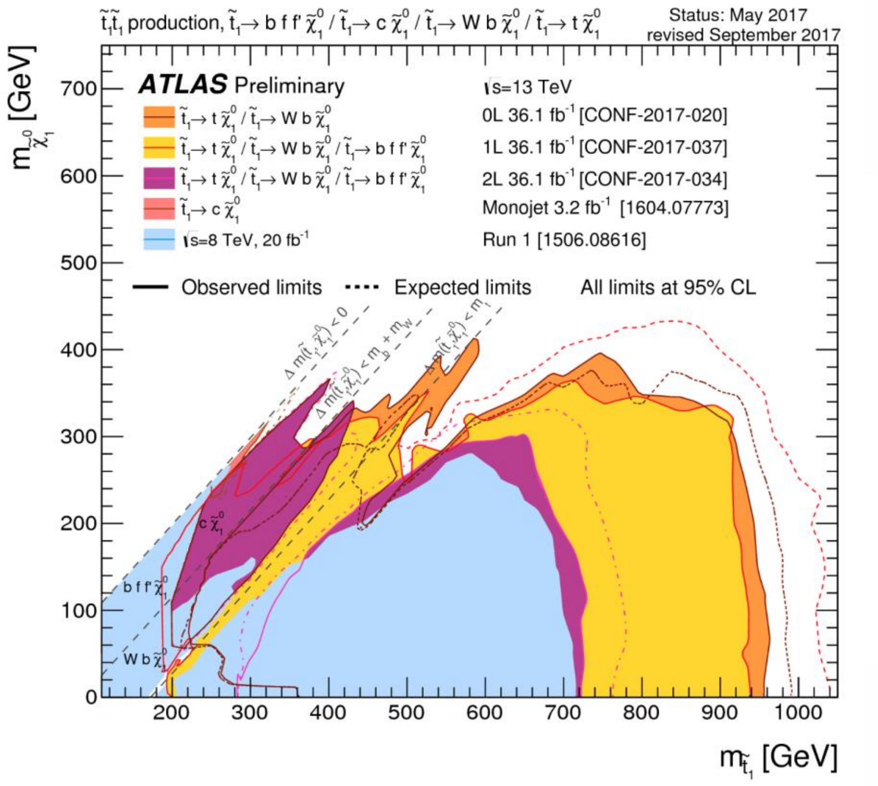
Natural SUSY survived LHC so far, but we are getting close to push it to its limits!

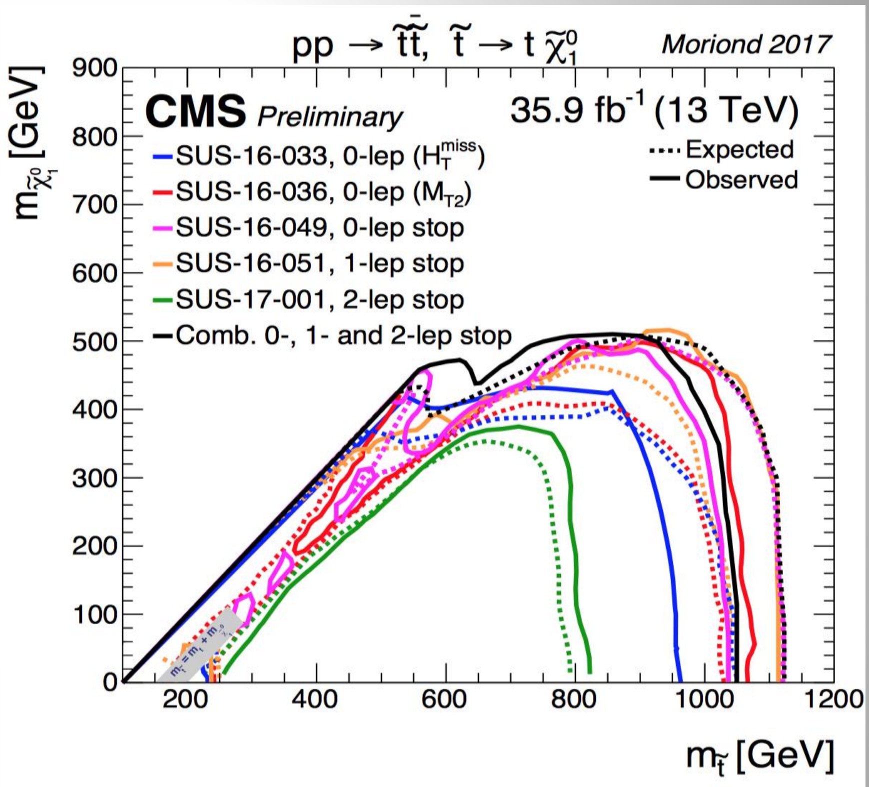


Also:Barbieri & Giudice (1988): Natural Models!

Top Squark Search Summaries

Partner of the top quark – the stop– plays prominent role in Natural Models





Within the context of the SMS:

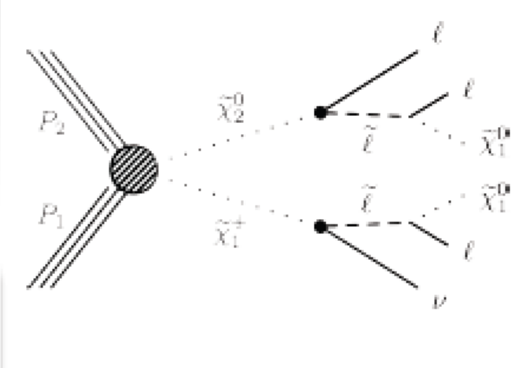
Exclude with masses up to 1000 GeV for neutralino masses up to 500 GeV

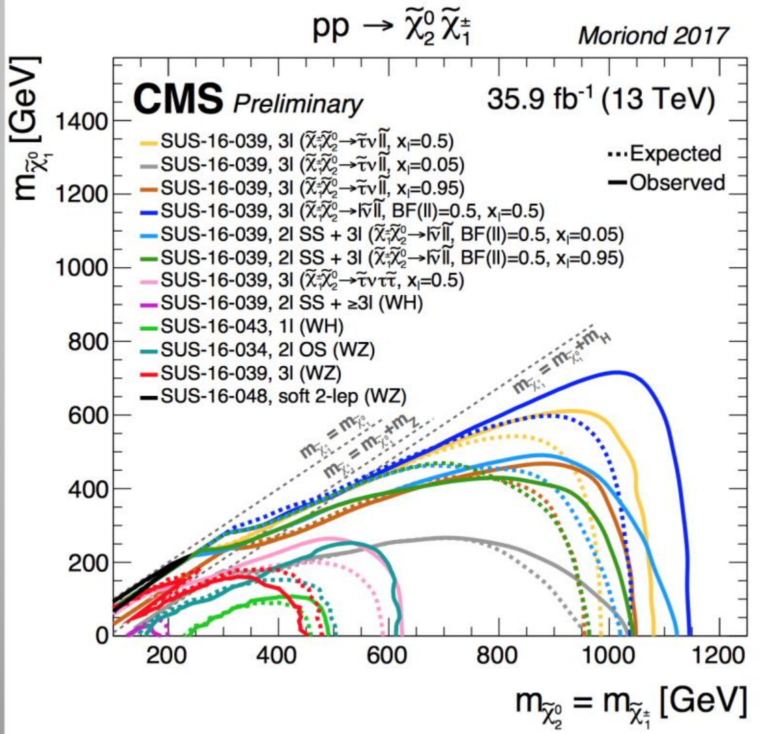
Sensitivity is ~ 200-400 GeV better than Run-1 reach & gaps being covered

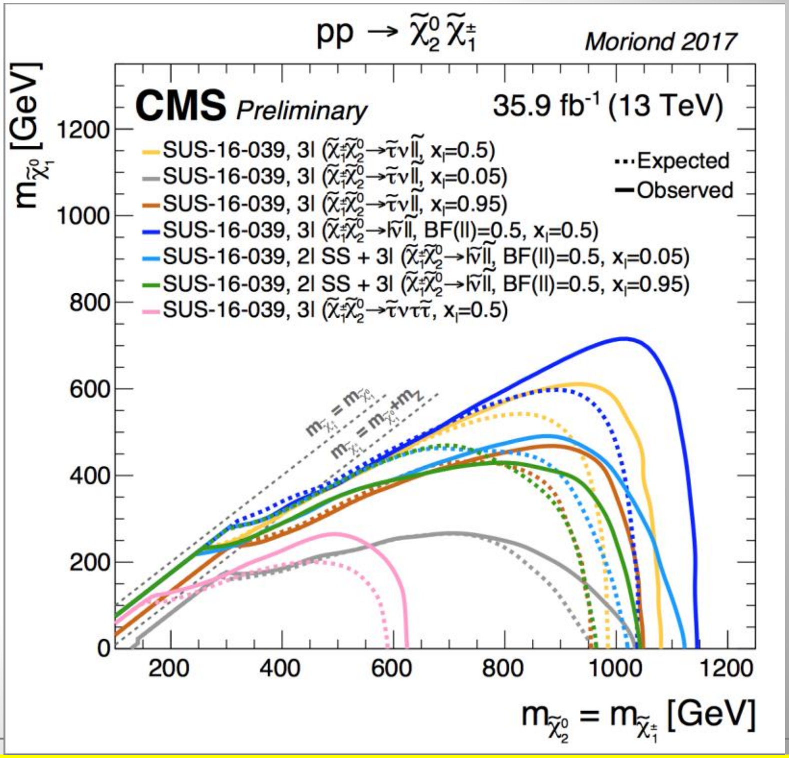
Is this getting critical for Natural Models??

Chargino and Neutralino Production

Direct production of "electroweakino pairs
- Decays via sleptons /sneutrinos
- Using benchmarks to illustrate different scenarios
- Multilepton searches (incl. taus)

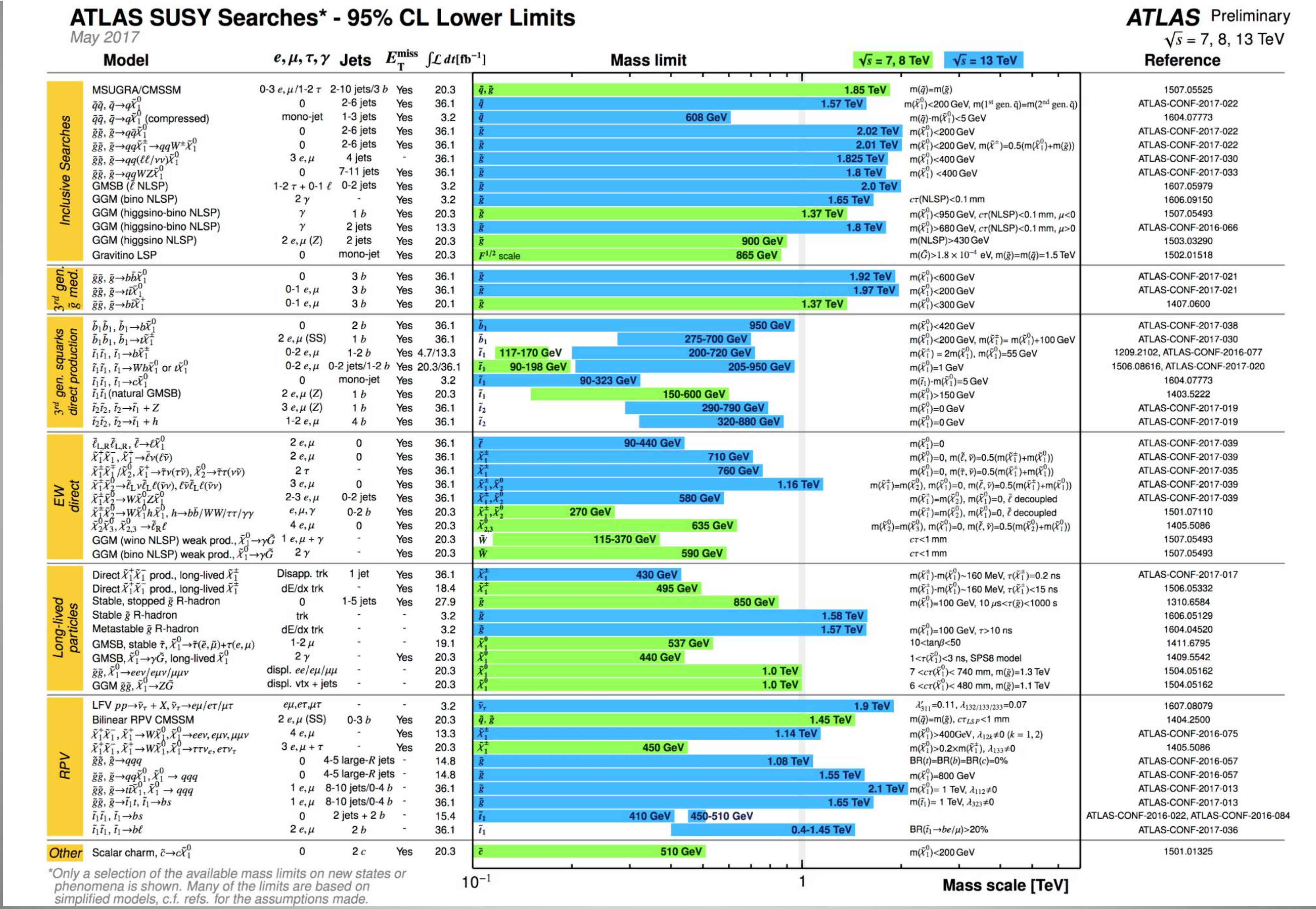






Exclude masses up to 1100 GeV for neutralino masses up to 600 GeV

The SUSY SEARCH Chart So Far…



Phenomenological MSSM analysis

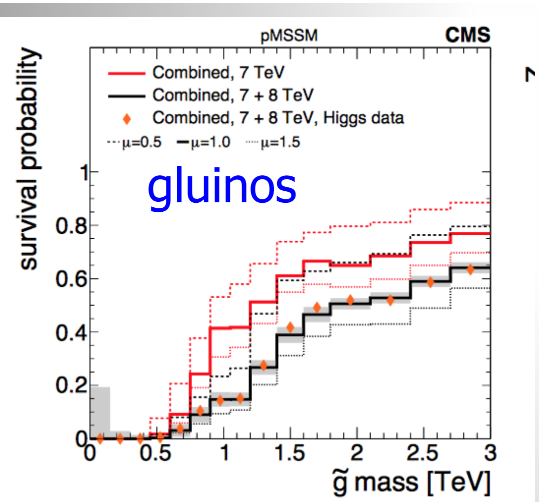
SMS don't always fully cover signatures…

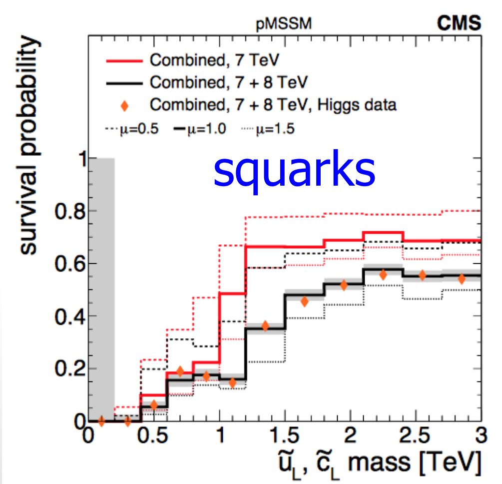
-> the 19 parameter phenomenological MSSM (pMSSM) analyses

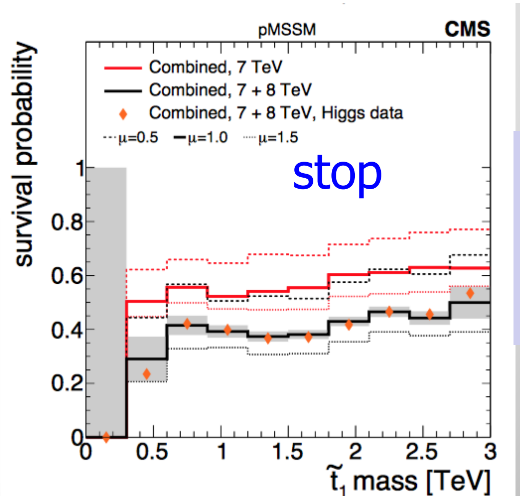
arXiv:1606.03577

- three independent gaugino mass parameters M_1, M_2, and M_3,
- the ratio of the Higgs vacuum expectation values $\tan\beta = v_2/v_1$,
- the higgsino mass parameter μ and the pseudoscalar Higgs boson mass m_A,
- 10 independent sfermion mass parameters $m_{\tilde{F}}$, where $\tilde{F} = \tilde{Q}_1, \tilde{U}_1, \tilde{D}_1, \tilde{L}_1, \tilde{E}_1, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3$ (for the 2nd generation we take $m_{\tilde{Q}_2} \equiv m_{\tilde{Q}_1}, m_{\tilde{L}_2} \equiv m_{\tilde{L}_1}, m_{\tilde{U}_2} \equiv m_{\tilde{U}_1}, m_{\tilde{D}_2} \equiv m_{\tilde{D}_1}$, and $m_{\tilde{E}_2} \equiv m_{\tilde{E}_1}$; left-handed up- and down-type squarks are by construction mass degenerate), and
- the trilinear couplings A_t, A_b and A_τ.

$$-3 \le M_1, M_2 \le 3\,\text{TeV},$$
$$0 \le M_3 \le 3\,\text{TeV},$$
$$-3 \le \mu \le 3\,\text{TeV},$$
$$0 \le m_A \le 3\,\text{TeV},$$
$$2 \le \tan\beta \le 60,$$
$$0 \le m_{\tilde{Q}_{1,2}}, m_{\tilde{U}_{1,2}}, m_{\tilde{D}_{1,2}}, m_{\tilde{L}_{1,2}}, m_{\tilde{E}_{1,2}}, m_{\tilde{Q}_3}, m_{\tilde{U}_3}, m_{\tilde{D}_3}, m_{\tilde{L}_3}, m_{\tilde{E}_3} \le 3\,\text{TeV},$$
$$-7 \le A_t, A_b, A_\tau \le 7\,\text{TeV},$$







Based on 8 TeV data limits

10^8 points sampled: Leads to softer limits on the sparticles masses

Gluinos > 500 GeV, stops > 300 GeV => there is still low mass phase space left!

SUSY (as seen outside HEP…)

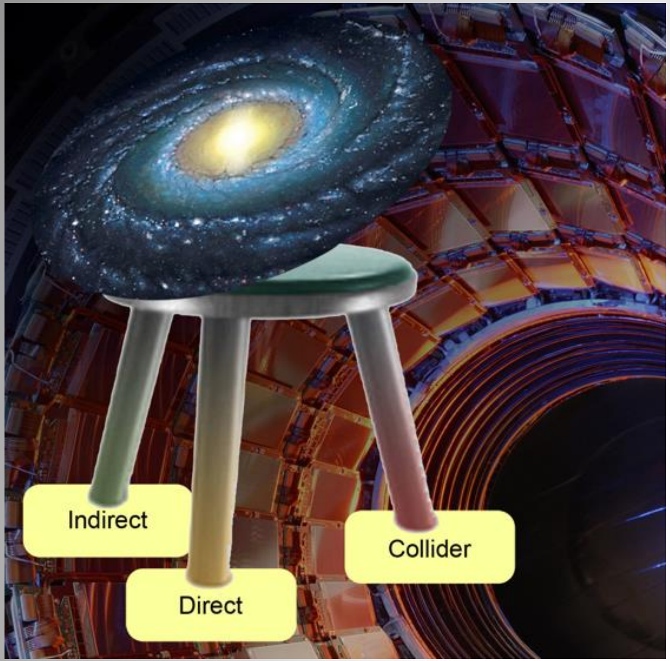
November ‘16 ago on the web page of The Economist (!?!):

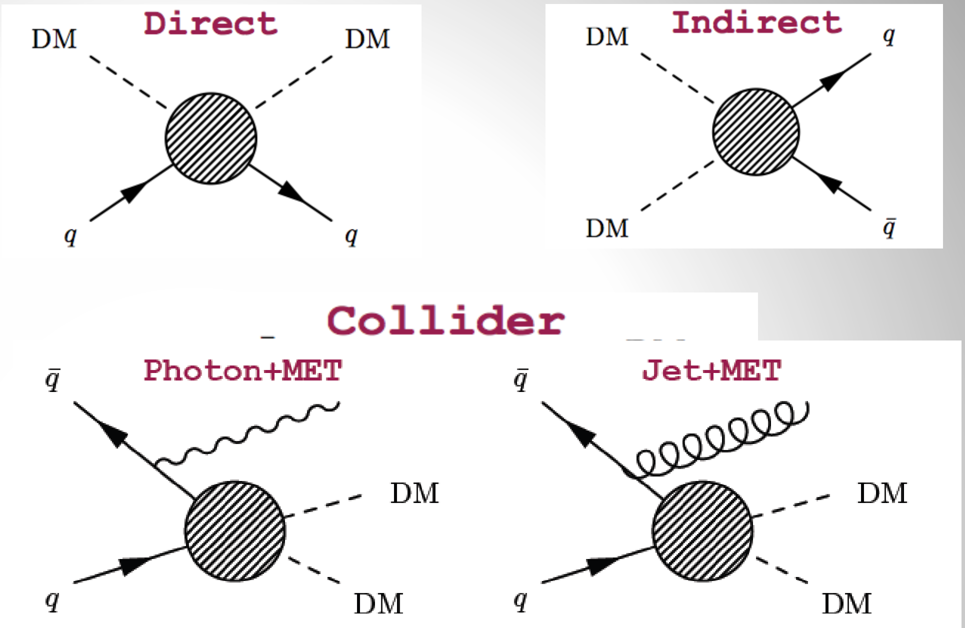
Supersymmetry is a beautiful idea. But no evidence supports it

But we are not giving up as yet!!!

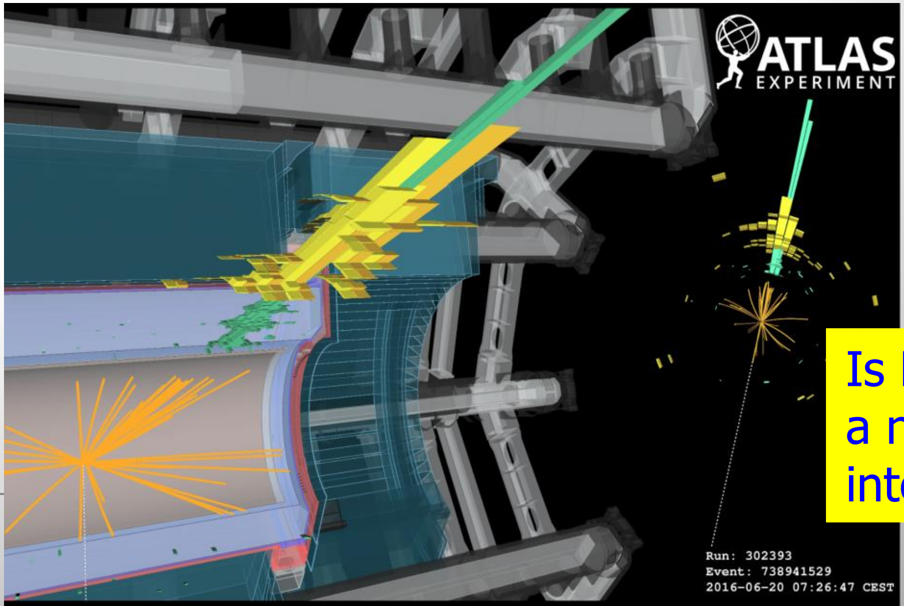
http://www.economist.com/news/science-and-technology/21709946-supersymmetry-beautiful-idea-there-still-no-evidence-support-it

Dark Matter Searches at the LHC





- Identifying Dark Matter is one of the most important questions in physics today!
- It is likely a new as yet undetected particle
- Can it be produced at the LHC?



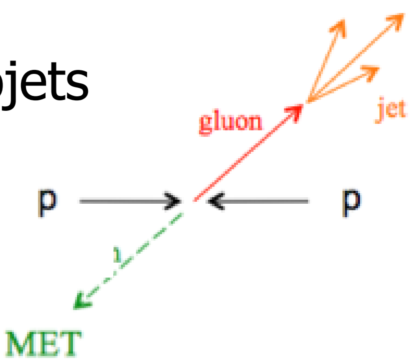
Is Dark Matter a new weakly interacting particle?

Mono-object Searches in CMS

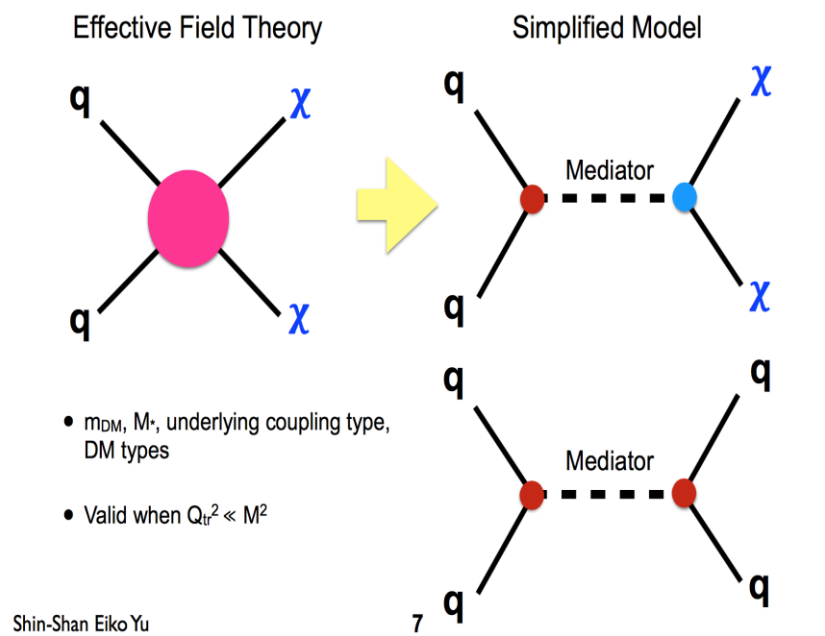
- Mono-jets: Generally the most powerful
- Mono-photons: First used for dark matter Searches
- Mono-Ws: Distinguish dark matter couplings to u- and d-type of quarks
- Mono-Zs: Clean signature
- Mono-Tops: Couplings to tops
- Mono-Higgs: Higgs-portals
- Higgs Decays?

Are Dark Matter weakly interacting massive particles (WIMPs?)

Example Monojets



Dark Matter?

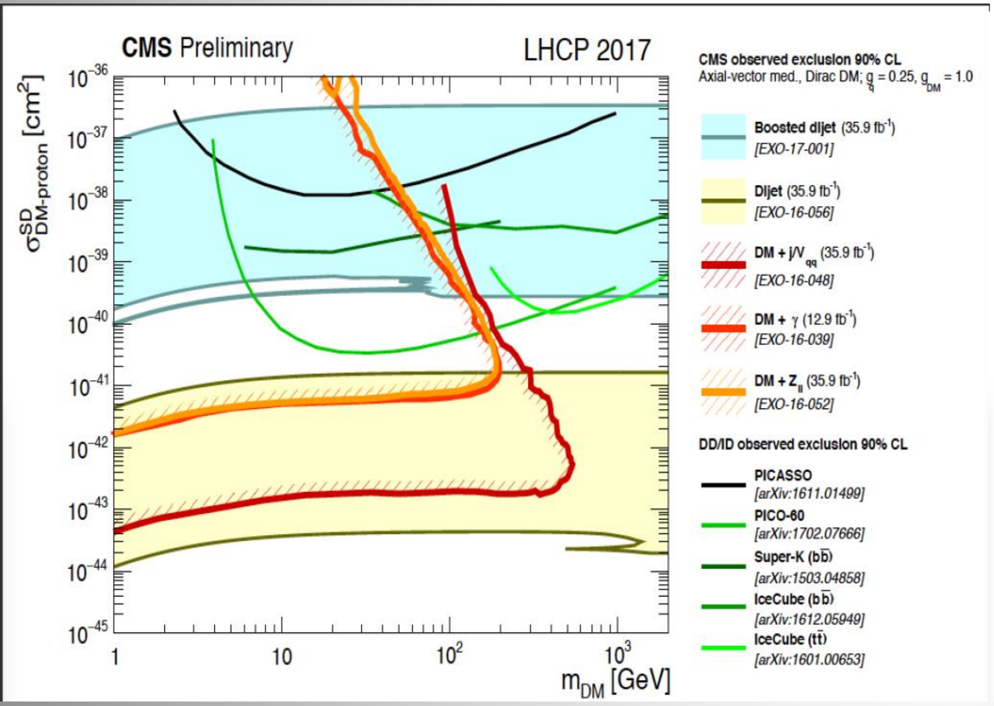


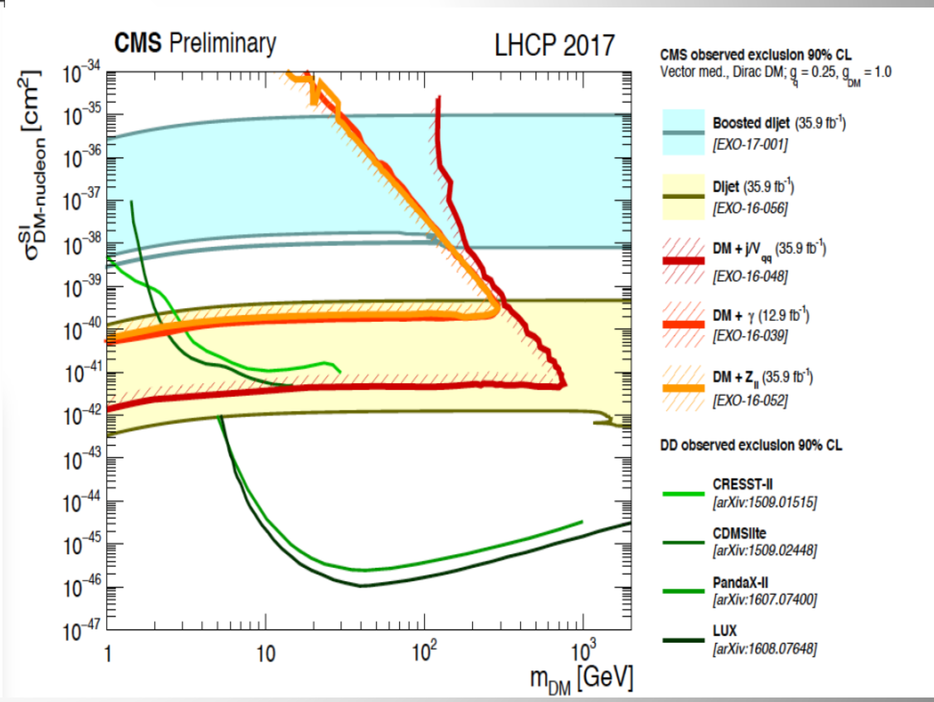
Comparison with Direct Detection

No signal seen in any of the "mono"-signals so far -> limits

Axial-vector mediator and Spin-dependent direct limits

Vector mediator and Spin-independent direct limits

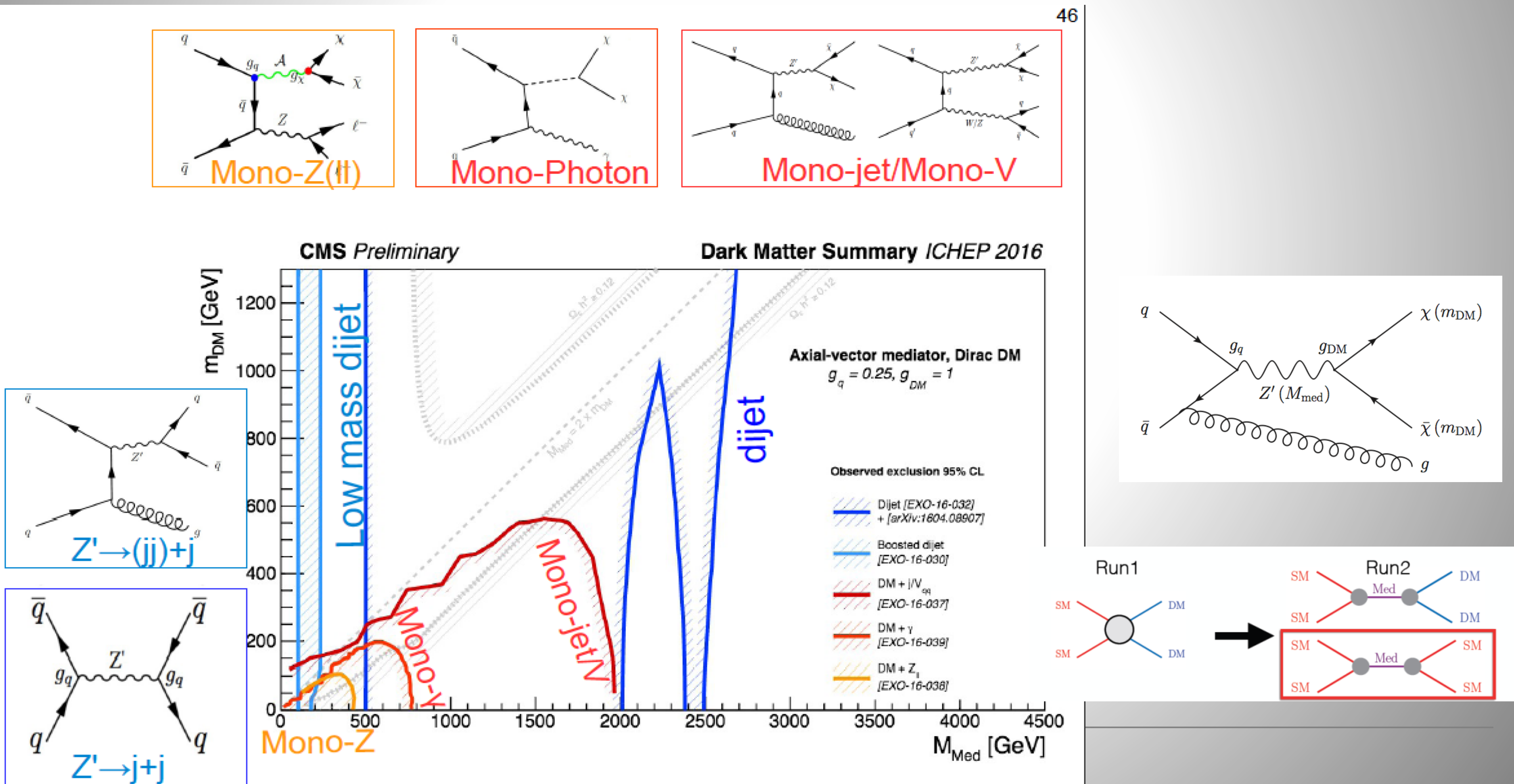




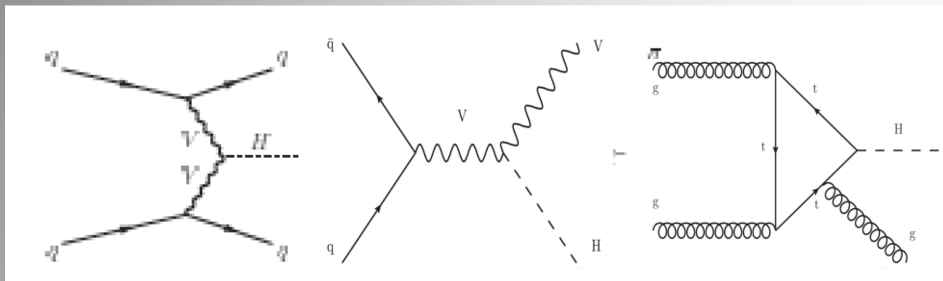
90% CL limits

Dark Matter Searches: Evolution

•New developments with Simplified Models allow for including many more search channels such as dijets, dileptons... (aka “In Search for the Mediator”)



Invisible Higgs Decay Channel

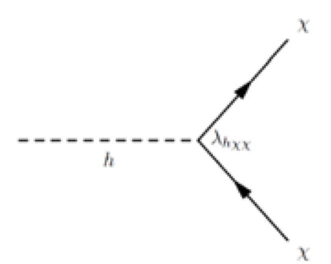


Search for invisible Higgs decays using

$Z+H \rightarrow$ 2 leptons + missing E_T

VBF $H \rightarrow$ 2 jets + missing E_T

Possible decay in Dark Matter particles (if $M<M_H/2$): Higgs Portal Models

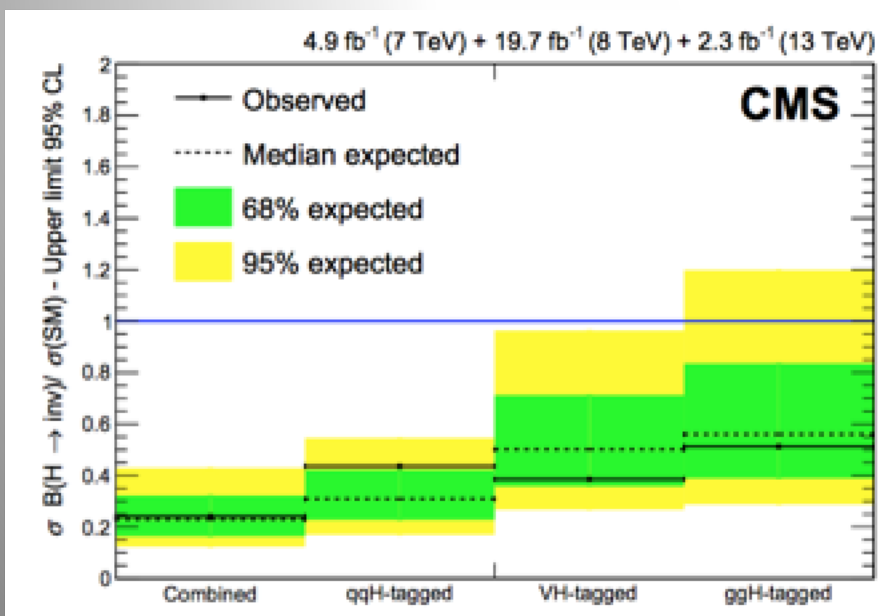


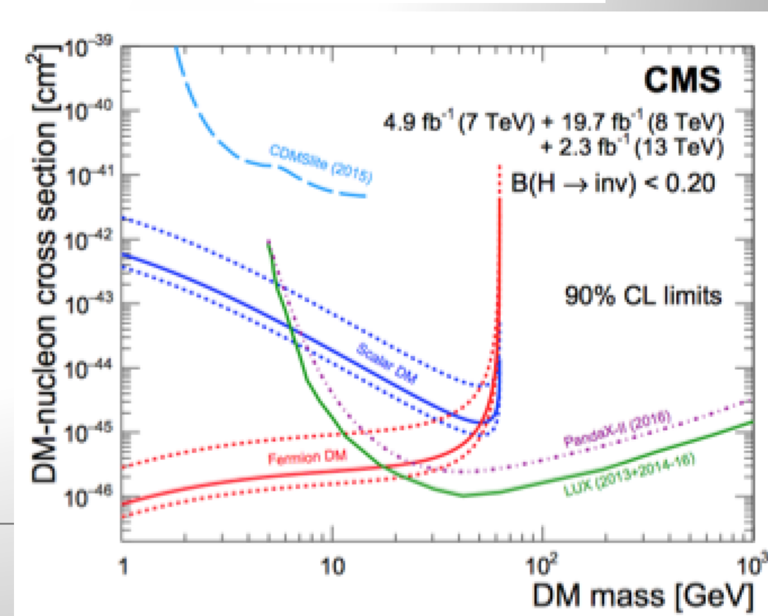
Combined result from the three channels

BR(H→invisible)<24%(23% exp) at 95% CL.

for a Higgs with a mass of 125 GeV

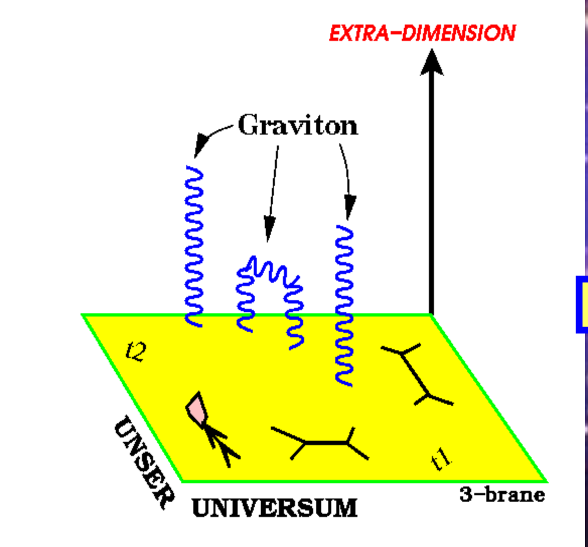
arXiv:1610.09218

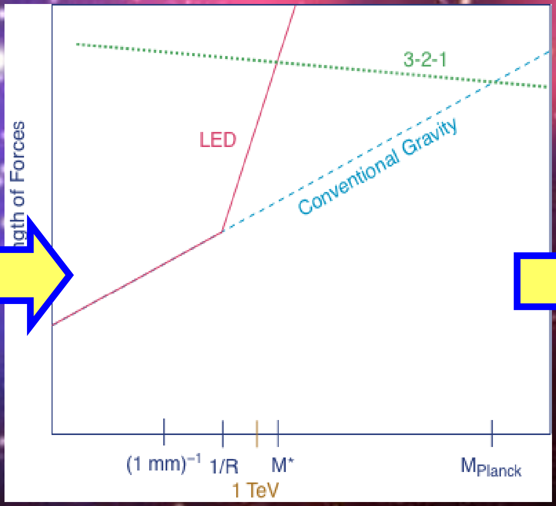




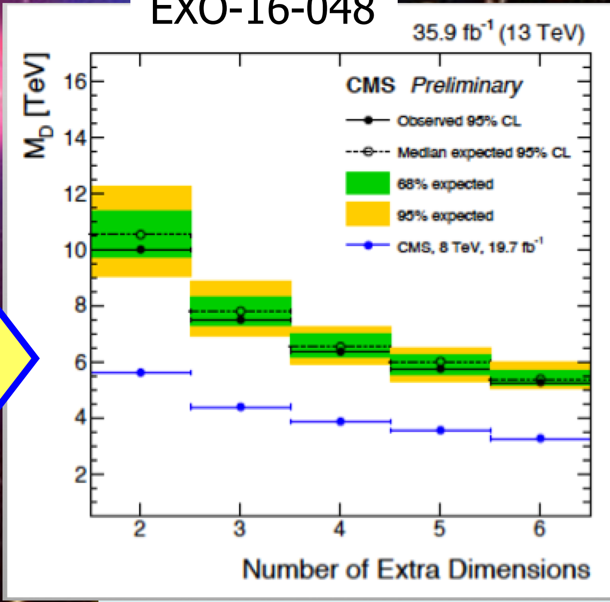
Extra Space Dimensions

Problem: $m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\text{ GeV}$ ⟷ $M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\text{ GeV}$





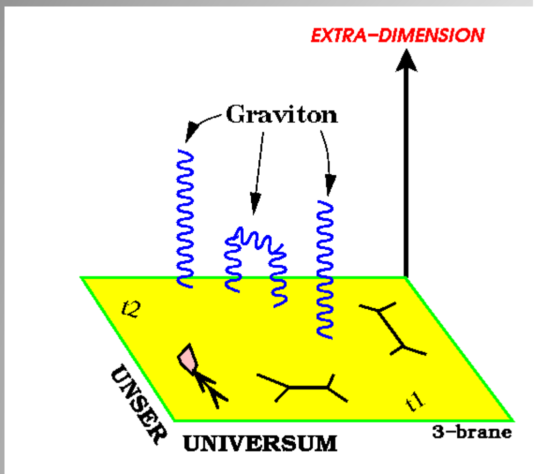
EXO-16-048



The Gravitational force can become strong!

No signal found yet
New Planck scale is larger than 6-10 TeV

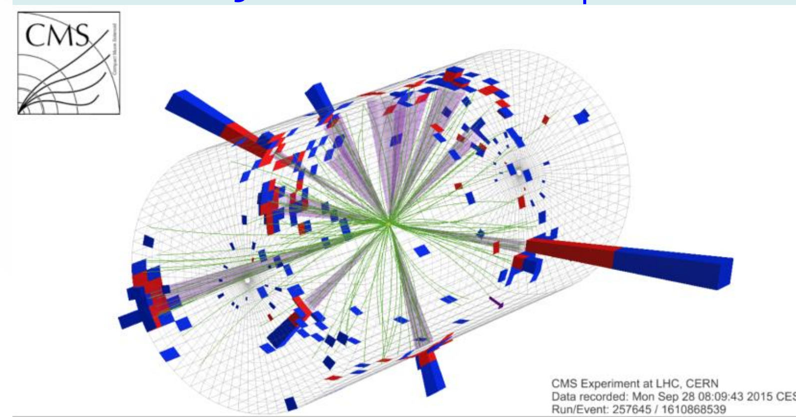
Search for Micro Black Holes



Extra Dimensions!

Planck scale
a few TeV?

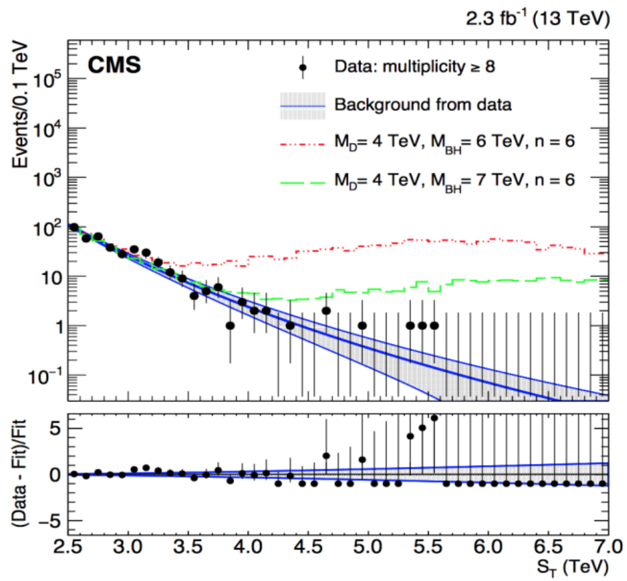
2015: 12 jet event with S_T=5.4 TeV

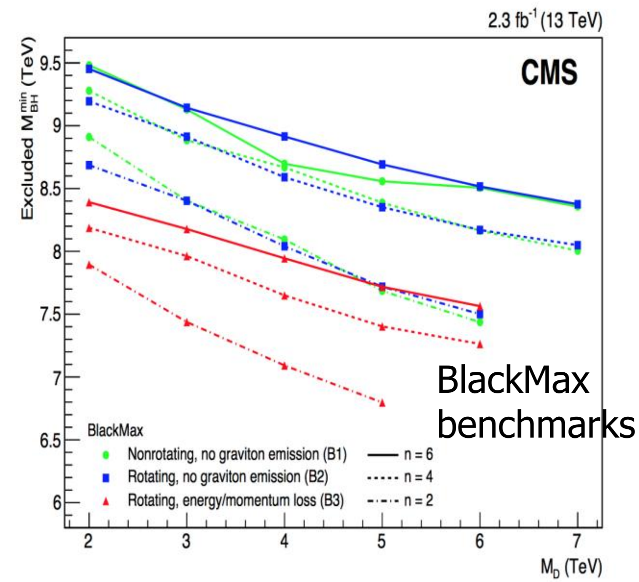


arXiv:1705.01403

Look for the decay producs
of an evaporating black hole

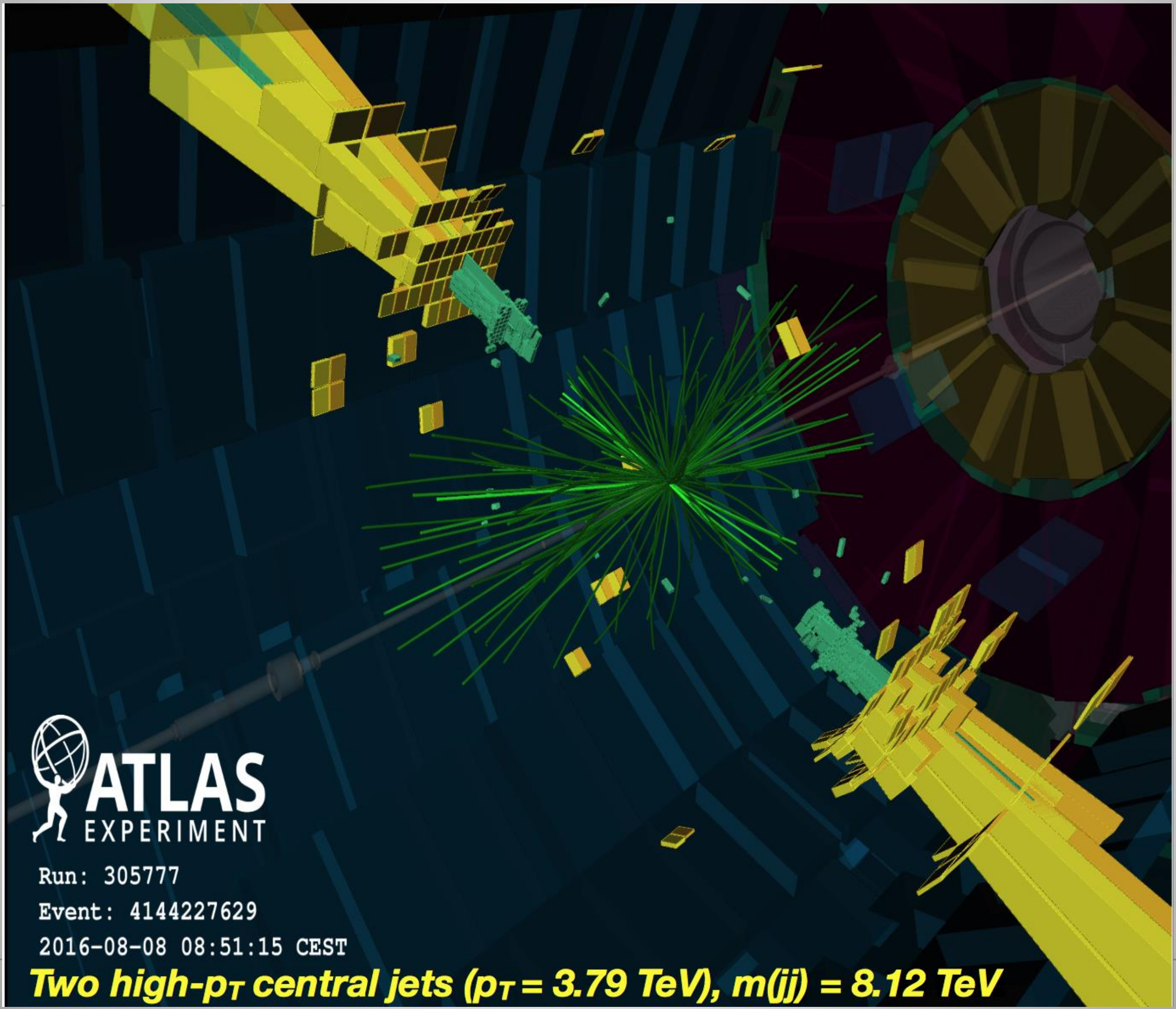
- Define S_T to be the scalar sum of all high p_T objects found in the event
- Look for deviations at high S_T





Black hole mass excluded in range below ~8-9 TeV depending on assumptions

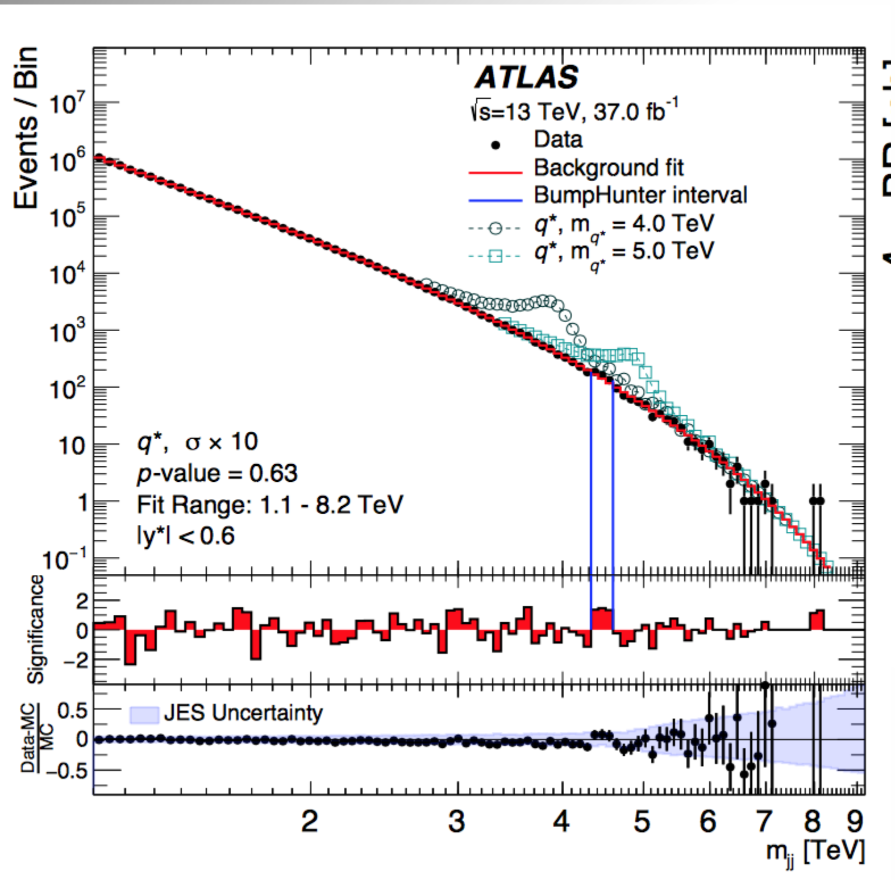
Dijet Resonance Searches @13TeV



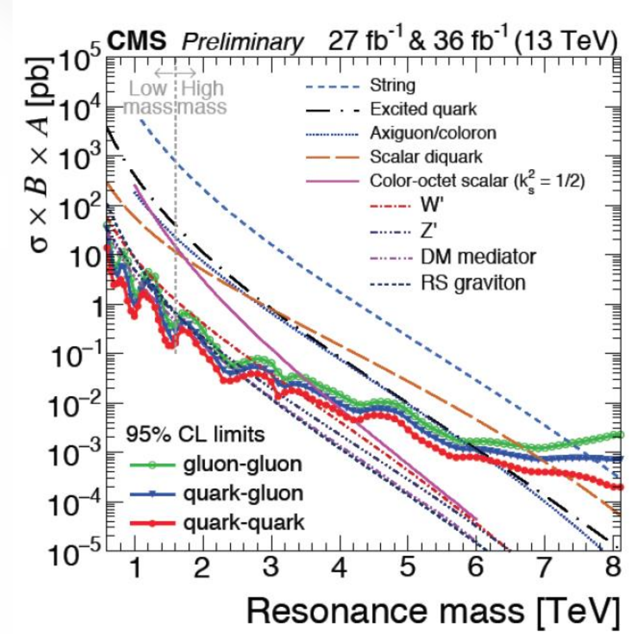
Dijet Resonance Searches @13TeV

arXiv:1703.09127

Background: QCD smooth shape fit



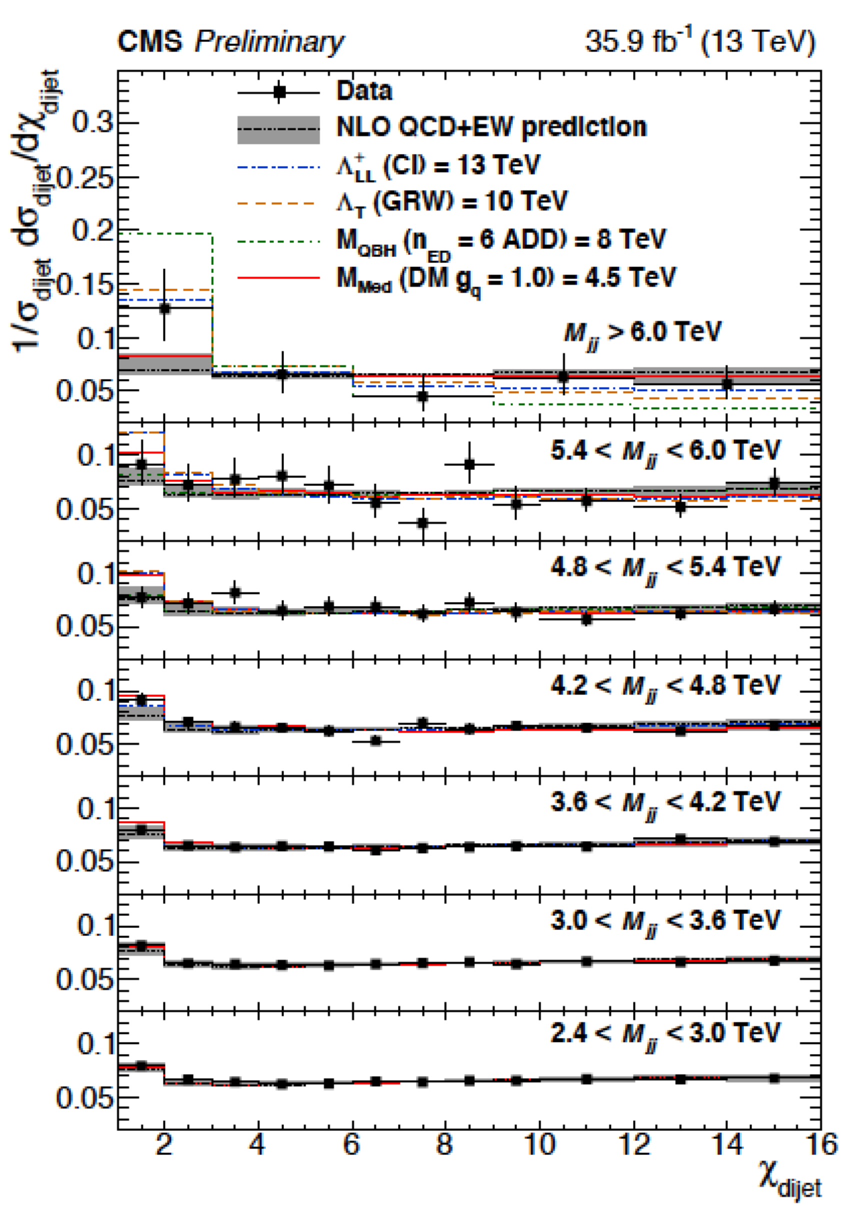
EXO-16-056



Model	Final State	Observed (expected) mass limit [TeV] 36 fb^{-1} 13 TeV	12.9 fb^{-1} 13 TeV	2.4 fb^{-1} 13 TeV	20 fb^{-1} 8 TeV
String	qg	7.7 (7.7)	7.4 (7.4)	7.0 (6.9)	5.0 (4.9)
Scalar diquark	qq	7.2 (7.4)	6.9 (6.8)	6.0 (6.1)	4.7 (4.4)
Axigluon/coloron	$q\bar{q}$	6.1 (6.0)	5.5 (5.6)	5.1 (5.1)	3.7 (3.9)
Excited quark	qg	6.0 (5.8)	5.4 (5.4)	5.0 (4.8)	3.5 (3.7)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.4 (3.6)	3.0 (3.3)	—	—
W′	$q\bar{q}$	3.3 (3.6)	2.7 (3.1)	2.6 (2.3)	2.2 (2.2)
Z′	$q\bar{q}$	2.7 (2.9)	2.1 (2.3)	—	1.7 (1.8)
RS Graviton ($k/M_{PL} = 0.1$)	$q\bar{q}$, gg	1.7 (2.1)	1.9 (1.8)	—	1.6 (1.3)
DM Mediator ($m_{DM} = 1$ GeV)	$q\bar{q}$	2.6 (2.5)	2.0 (2.0)	—	—

36 fb^{-1} limits from 13 TeV between 1.7 and 7.7 TeV, dependent on model

Dijet Angular Correlations



$$= e^{|y_1 - y_2|} \approx \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

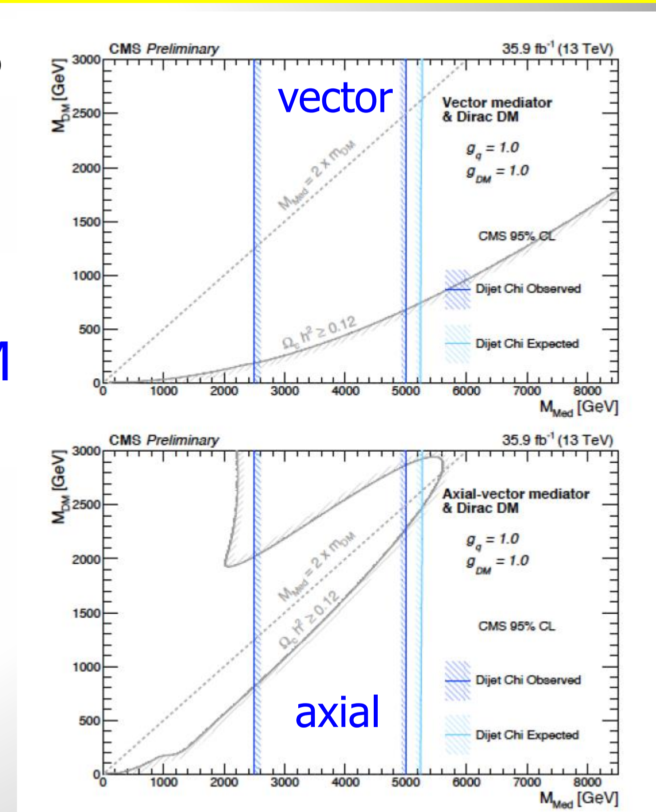
θ^*: jet angle to beam axis in dijet rest frame

Contact interactions, EDs, BHs, dark matter searches…

CIs: Exclusion up to 13 TeV (dest. int) and 17 TeV (const. int.)

EXO-16-046

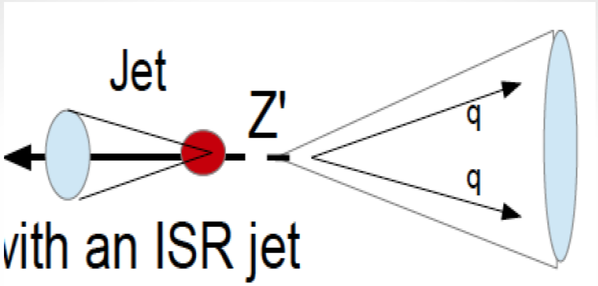
Exclusion in the DM plane



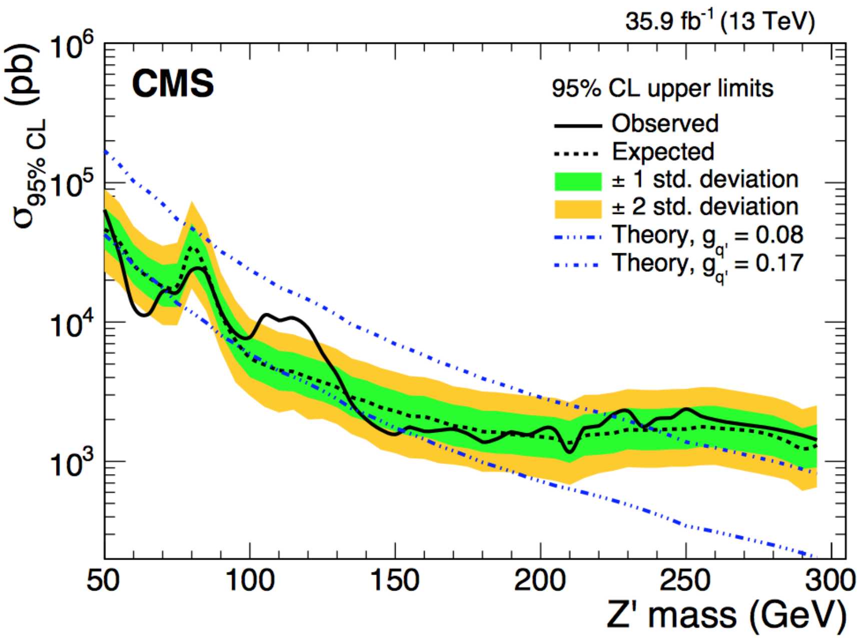
Search for Light Vector Resonances

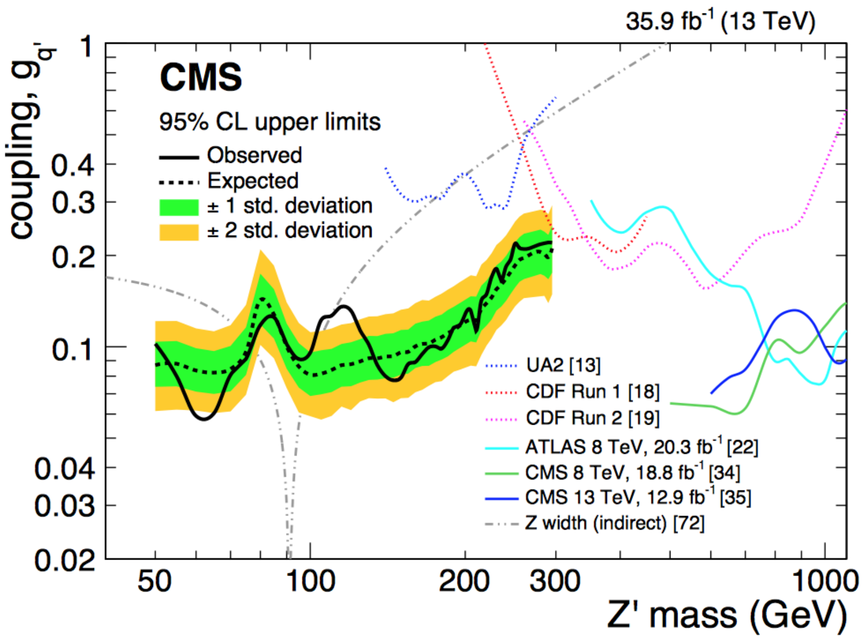
arXiv:1710.00159

Bump hunting in dijets produced with an ISR jet or high p_T jet to give the trigger



- AK8 jet: p_T>500 GeV
- Jet substructure





Sensitivity 'beats' the old UA2 result, going now well below 140 GeV

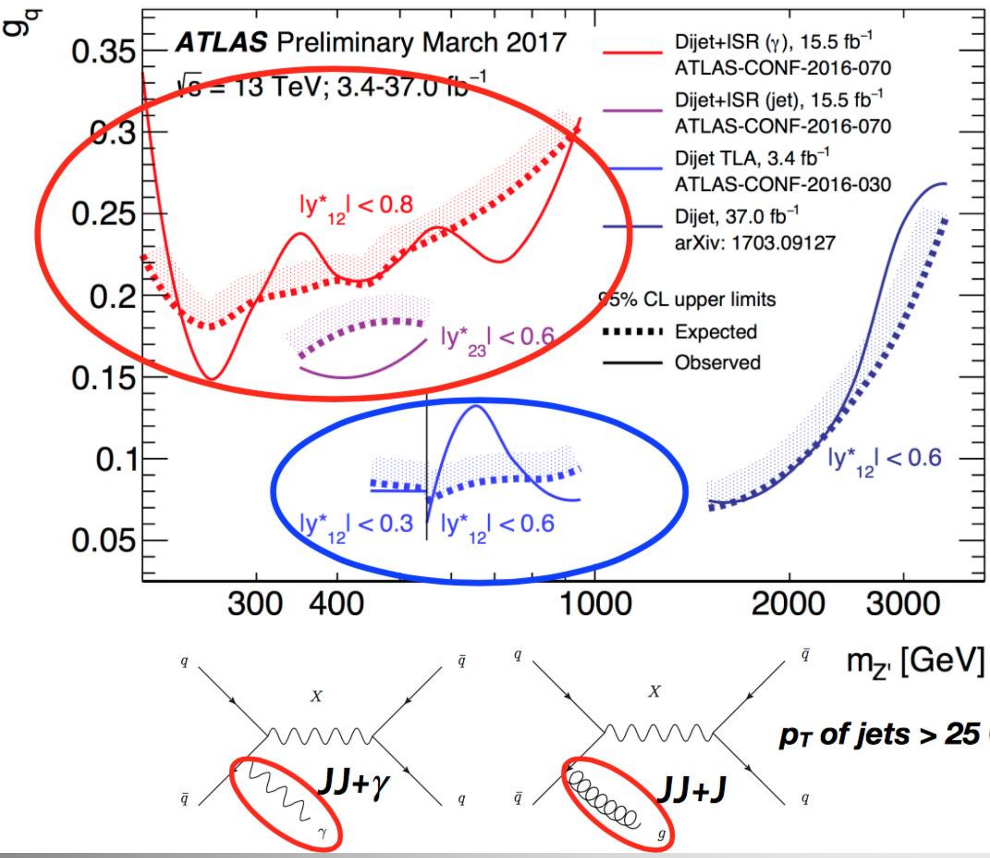
Mild excess around 115 GeV observed: 2.9σ (2.2σ) local (global) significance

Analysis at the Trigger Level

Decide at the trigger level that the event is of interest, and read out only part of the event data of interest -> reduce event size -> allow higher rate

Trigger level analysis

ATLAS-CONF-2016-030
ATLAS-CONF-2016-070



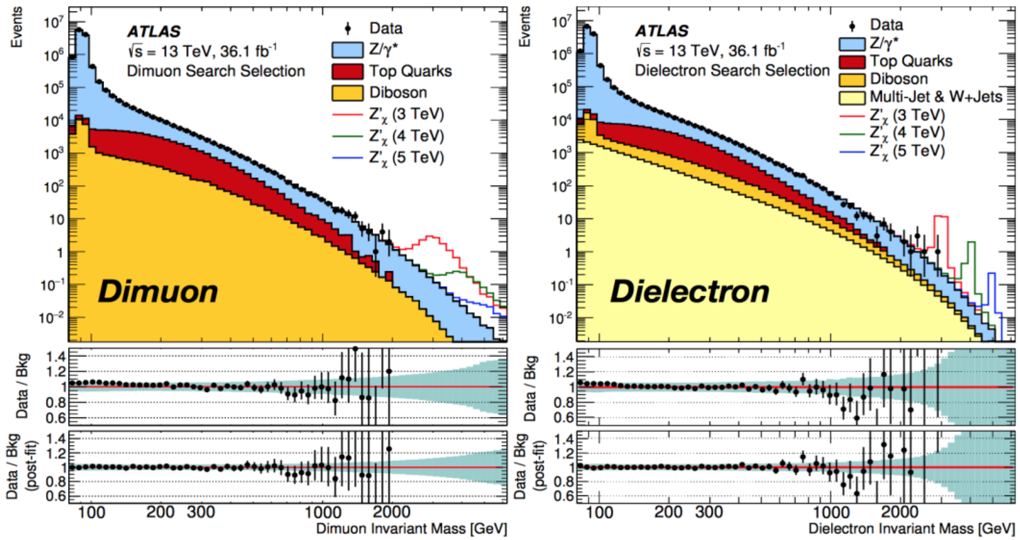
p_T of jets > 25 GeV

- In order to expand dijet analysis at low m_{JJ} region
  - ***✗ fully lower the jet thresholds at the trigger level, but will exponential increase bandwidth***
  - ***✓stores partial event informations (5% of full event size)***
    - dedicated jet calibration for trigger level jets
  - ***✓ Trigger selection ISR objects to reach low m_{JJ} region***
    - ***JJ+γ: single-photon trigger (E_T>140Gev)***
    - ***JJ+J: single-jet trigger (p_T>380 GeV)***

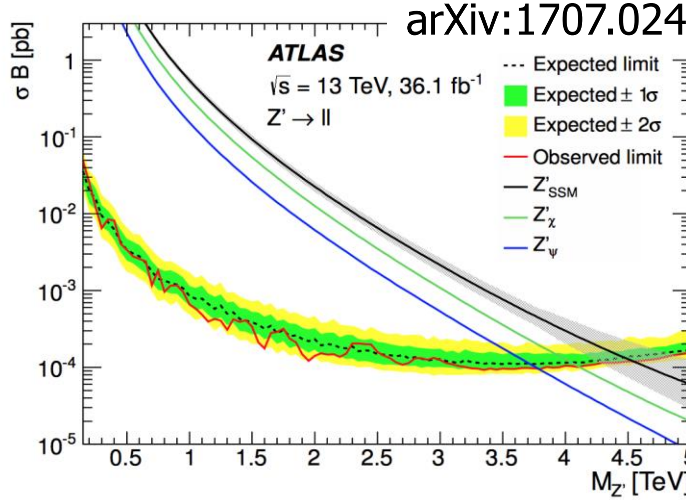
A lot of opportunities for new ideas at the LHC experiments

Dilepton Searches

Search for dilepton resonances (Z'…) or lepton+MET (W'…) searches

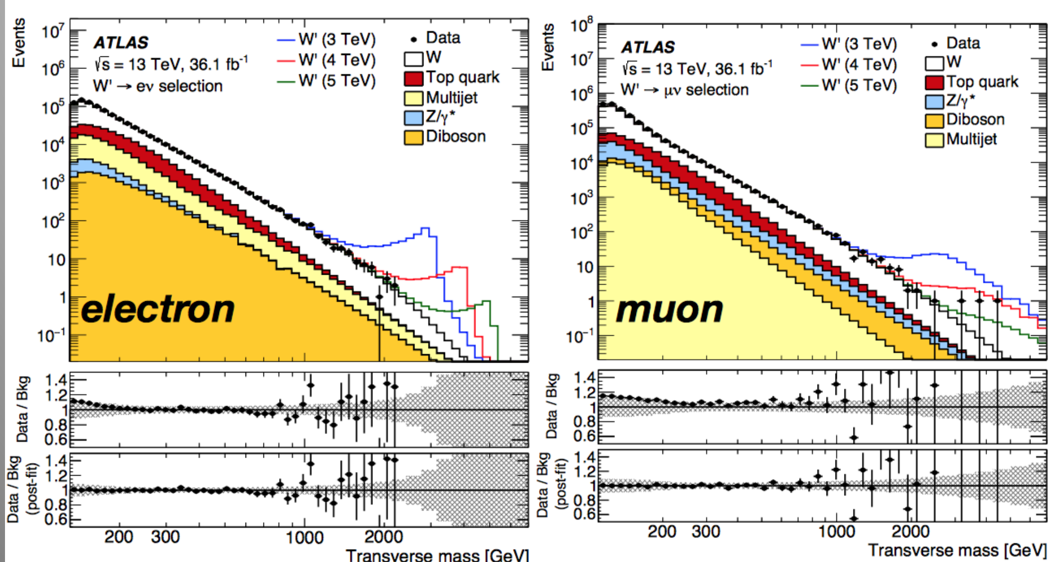


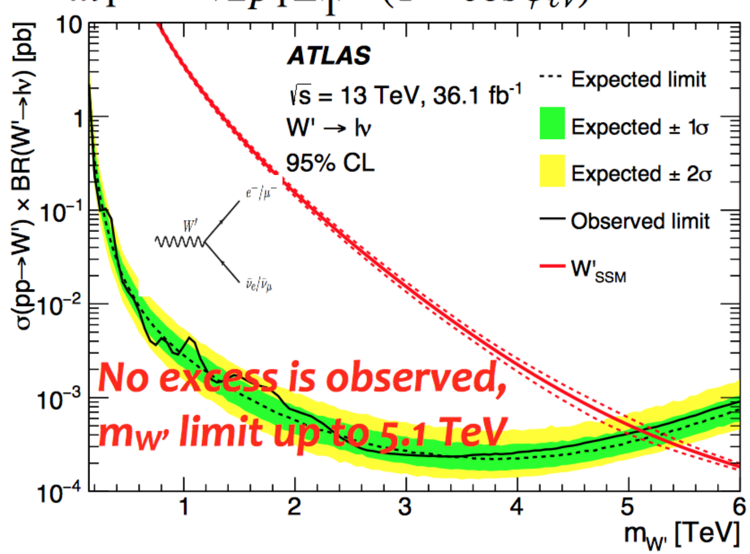
arXiv:1707.02424



arXiv:1706.04786

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\phi_{\ell\nu})}$$



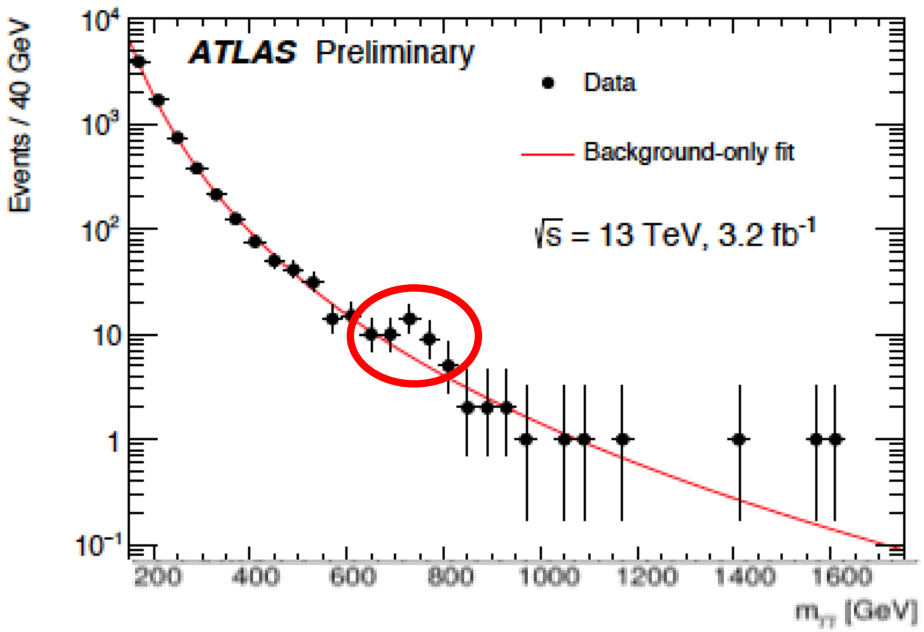


A New Particle at 750 GeV: X → γγ ?

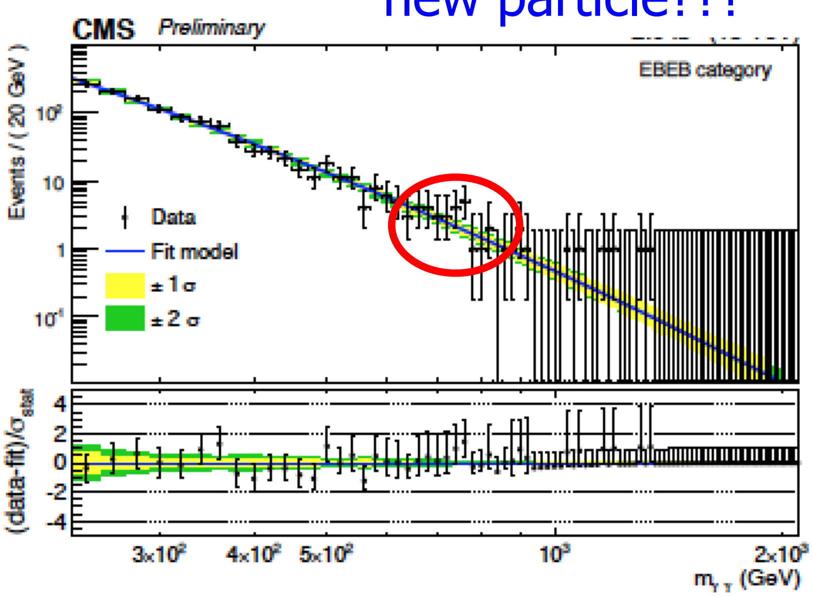
Excitement in December 2015

->Some excitement on an mild observed excess in both experiments for a diphoton mass of around 750 GeV

ATLAS-CONF-2015-081



CMS EXO-15-004



A totally unexpected new particle???

Statistical fluctuation? A new resonance? ???

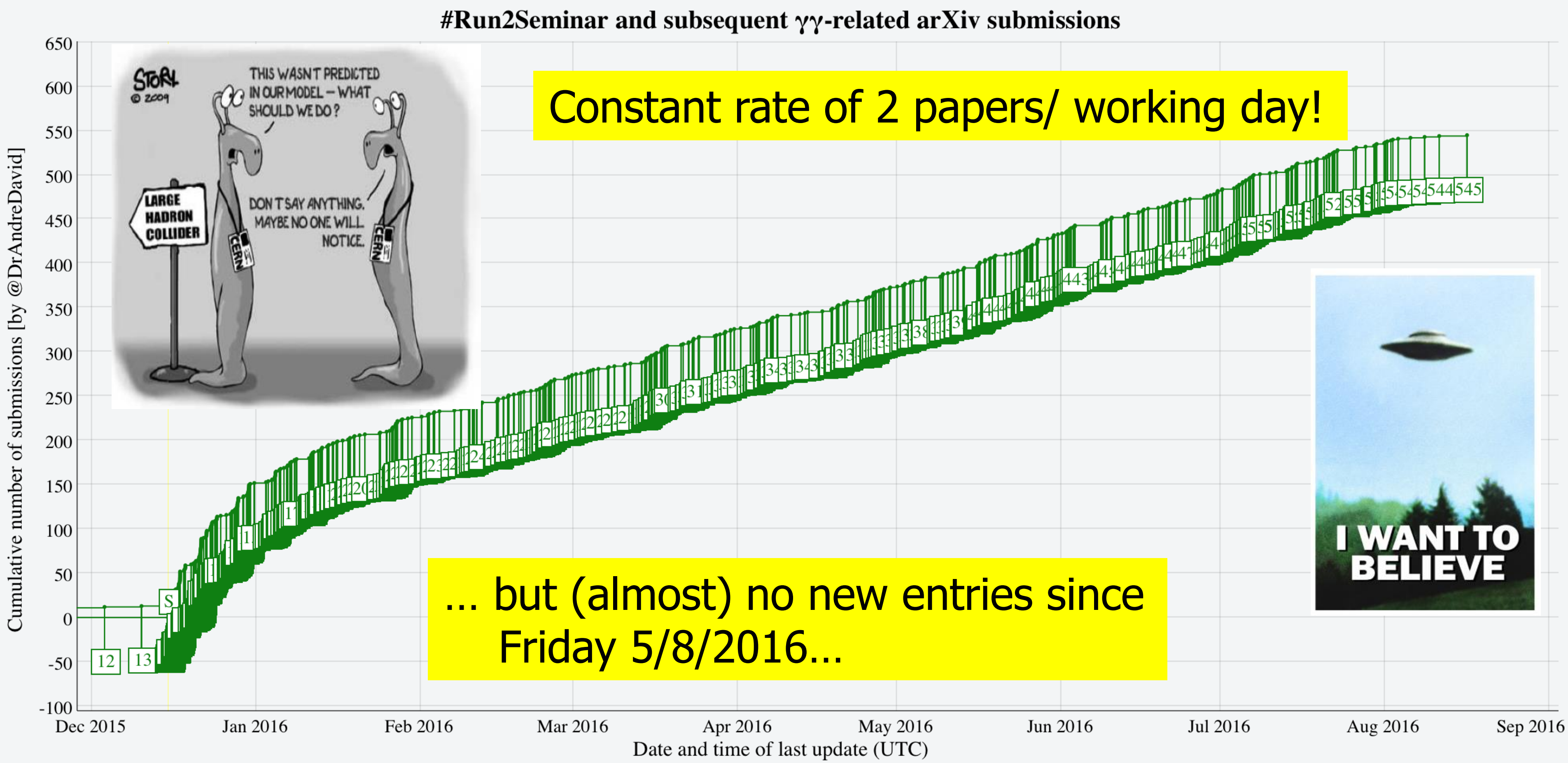
Moriond: CMS: 3.4 σ ! ATLAS up to 3.9 σ !! (local significances)

Reaction of the Theory Community

Andre David: http://jsfiddle.net/adavid/bk2tmc2m/show/

27/8/2016

About 540 “interpretation” papers being submitted



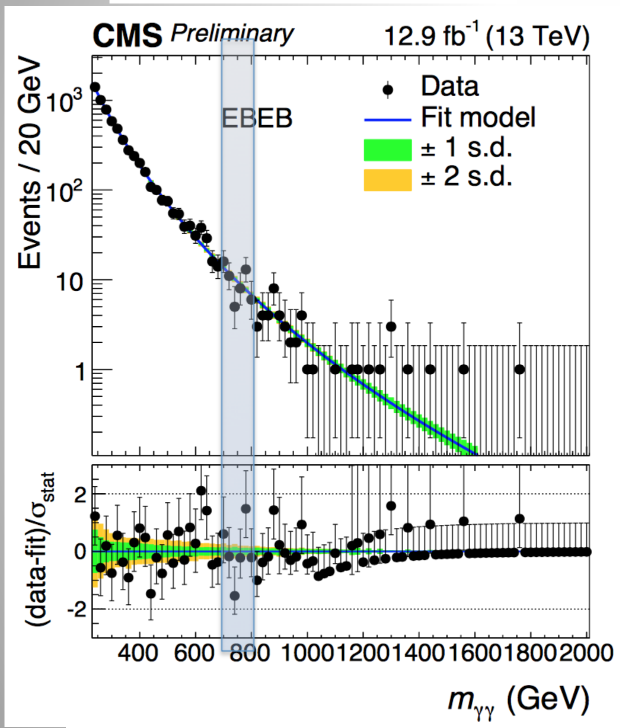
Constant rate of 2 papers/ working day!

… but (almost) no new entries since Friday 5/8/2016…

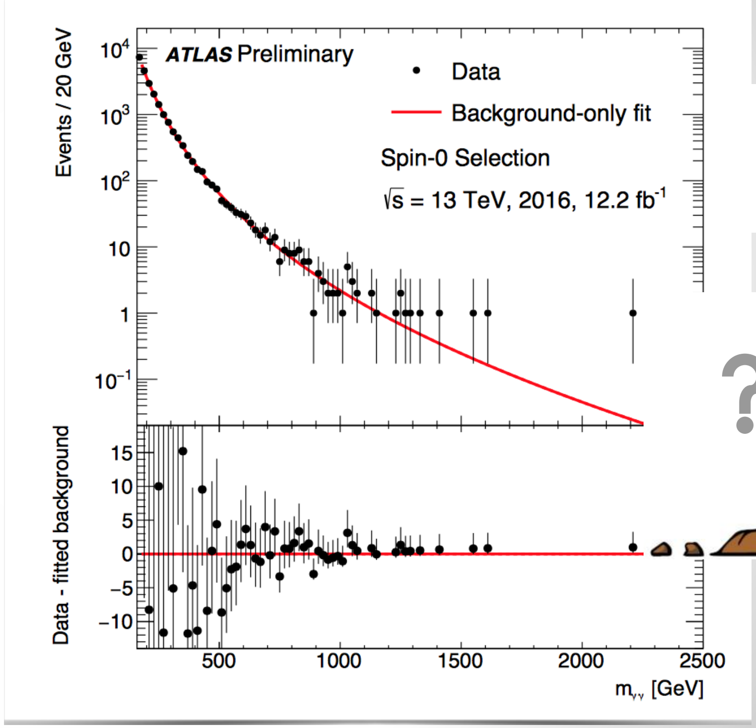
A new Particle at 750 GeV: X → γγ ?

August 2016: Opening of the 2016 data box (4 x 2015 data!!)

CMS-EXO-16-027



ATLAS-CONF-2016-059



Spin-0 analysis

The excess is NOT seen in the new data from 2016!

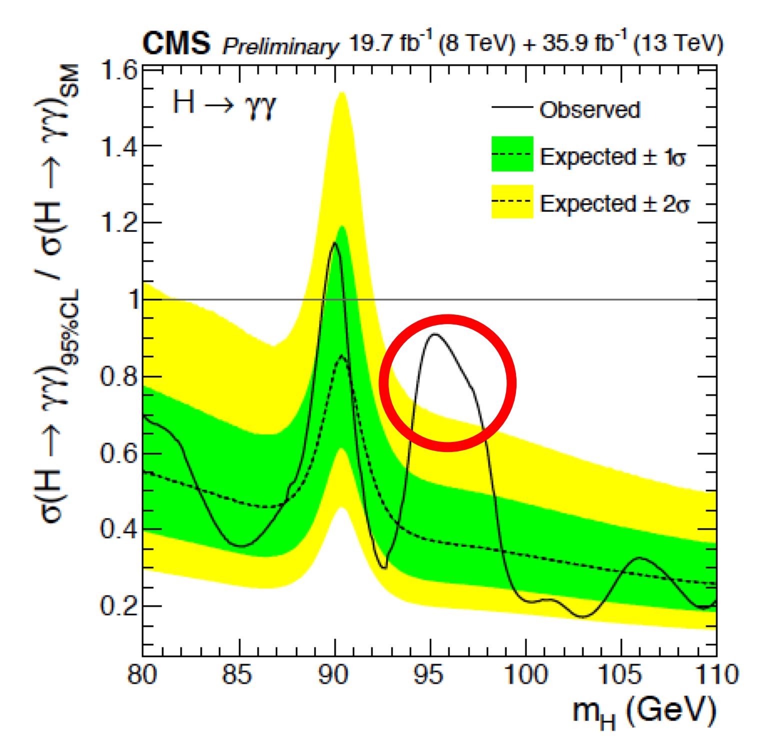
So, not for this time, but a sign of new physics can be found any time now
We need only one significant deviation of the Standard Model to show the way!

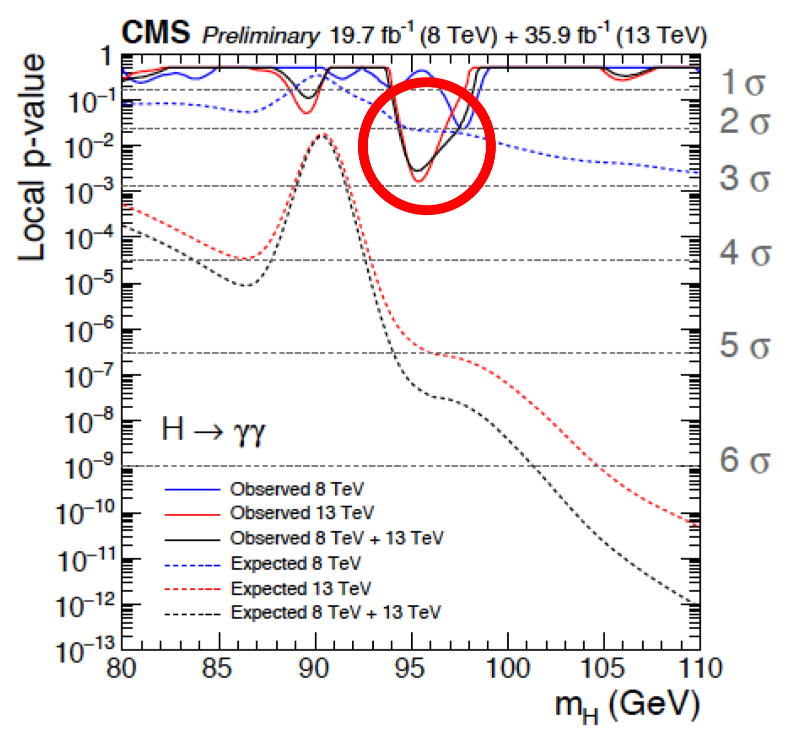
Is 96 GeV the New 750 GeV (?)

A new result released this August 2017: A search for X->γγ at low mass

An excess is observed in the 8 TeV data (2σ at 97.6 GeV) and 13 TeV (2.9σ at 95.3 GeV) -> Combined gives a 2.8σ excess at 95.3 GeV

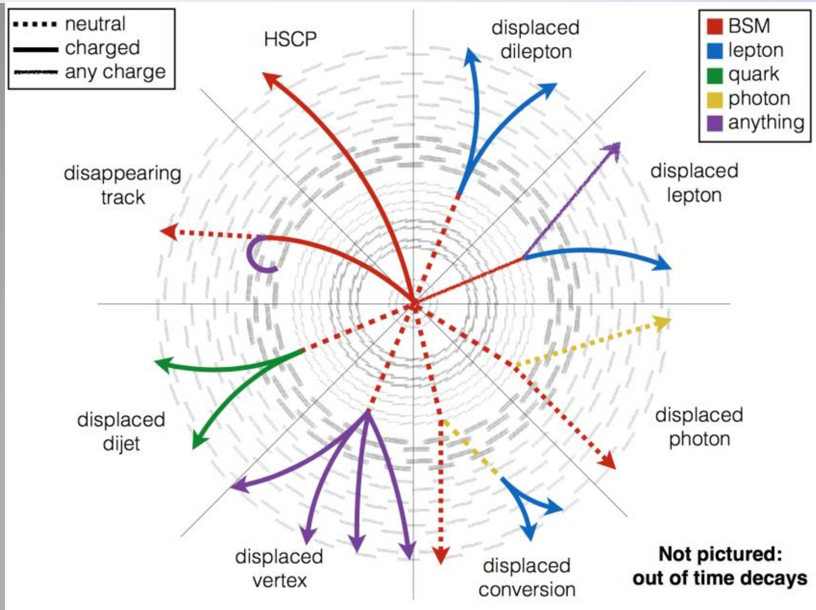
CMS-HIG-17-013





So far seen only in CMS. Waiting for the ATLAS data to be released… ☺ !!

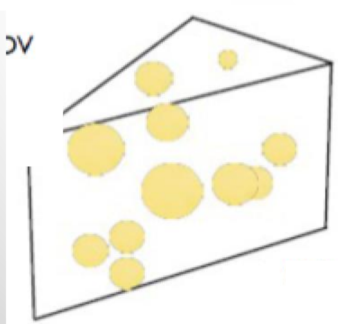
Searches for Long Lived Particles

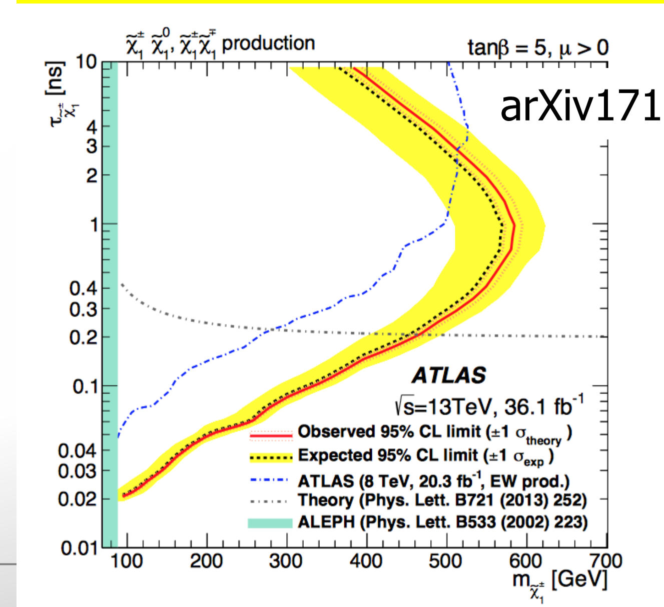


Increasing interest and effort:
Look for unusual signals in the detector from long-lived particles

- Example stopped tracks -> Search for charginos, almost degenerate with neutralinos (eg AMSB models)

Present coverage?



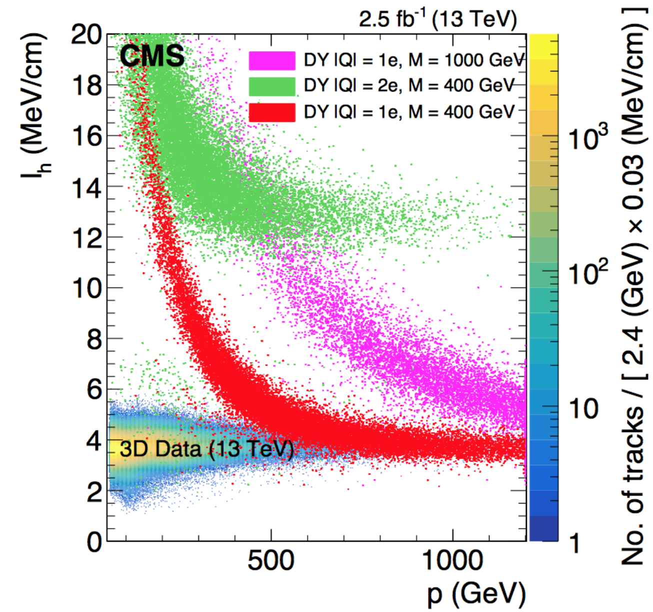


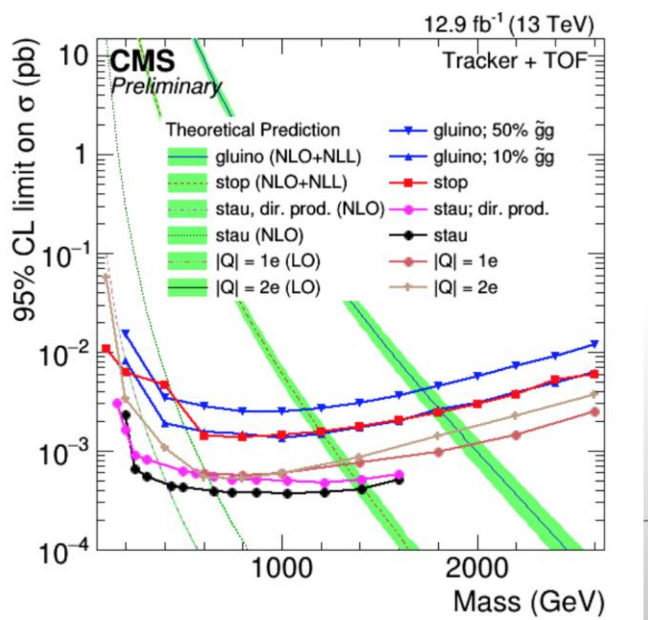
arXiv1712.02118

LHC-wide organized study ->
https://indico.cern.ch/e/LHC_LLP_October_2017

A White Paper in preparation!

Heavy Stable Ionizing Particles





Detection techniques used for (multiple/fractional) heavy stable charge particles

- Abnormal energy loss (de/dx)
- Slower than speed of light (lowβ) via time of flight measurements with the muon system

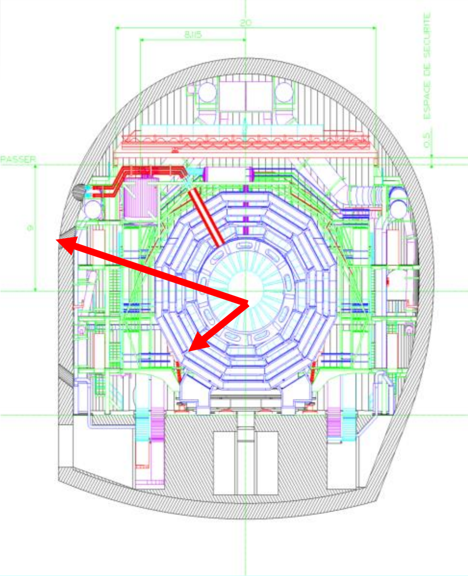
Time of flight $$\frac{1}{\beta} = 1 + \frac{c\delta_t}{L}$$ EXO-16-036

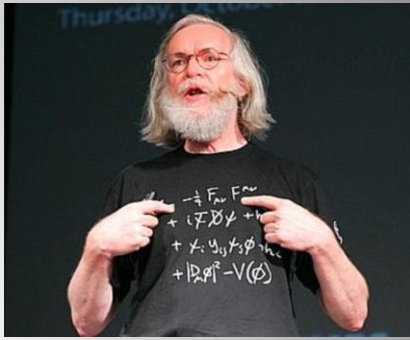
Model	Analysis	Mass Limits
Gluino $f = 0.1$	tracker-only tracker+TOF	$M > 1850(1850)$ GeV $M > 1810(1810)$ GeV
Gluino $f = 0.1$ CS	tracker-only	$M > 1840(1840)$ GeV
Gluino $f = 0.5$	tracker-only tracker+TOF	$M > 1760(1760)$ GeV $M > 1720(1720)$ GeV
Gluino $f = 0.5$ CS	tracker-only	$M > 1800(1800)$ GeV
Stop	tracker-only tracker+TOF	$M > 1250(1250)$ GeV $M > 1200(1200)$ GeV
Stop CS	tracker-only	$M > 1220(1220)$ GeV
GMSB Stau	tracker-only tracker+TOF	$M > 660(660)$ GeV $M > 660(660)$ GeV
Pair Prod. Stau	tracker-only tracker+TOF	$M > 170(170)$ GeV $M > 360(360)$ GeV
DY $Q = 1e$	tracker-only tracker+TOF	$M > 720(720)$ GeV $M > 730(730)$ GeV
DY $Q = 2e$	tracker-only tracker+TOF	$M > 670(750)$ GeV $M > 890(890)$ GeV

Searches for Exotic Long Lived Particles

E.g. Split Supersymmetry

- The only light particles are the Higgs and the gauginos
  - Gluino can live long: sec, min, years!
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles
- Hidden valley models: Plethora of possibilities for long lived neutrals
- Many more models: Neutral Naturalness, GMSB, AMSB, Dark showers





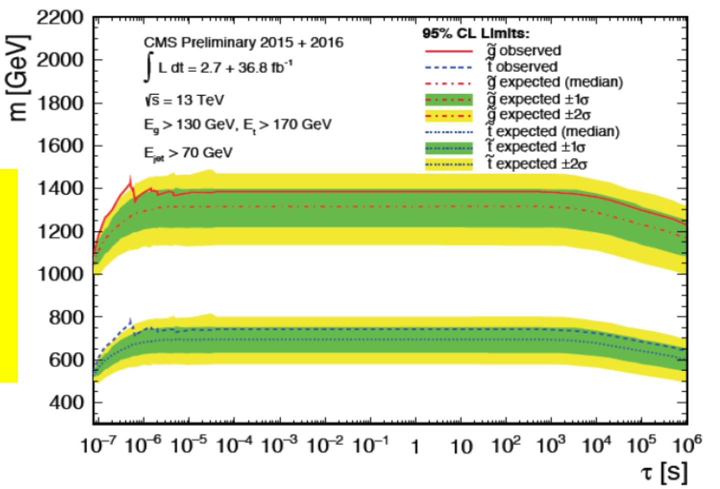
EG:ADR, J. Ellis et al. hep-ph/0508198

Sparticles stopped in the detector, walls of the cavern, or dense ‘stopper’ detector. They decay after hours---months…

⇒Challenges to the experiments!

Analysis searching for “decays” in calorimeter

Limits on M_{stop} ~744 GeV and M_{gluino} ~1385 GeV 95% CL for lifetimes from 10 μsec to 1000s



EXO-16-004

LHC White Paper in Preparation

Web page: https://indico.cern.ch/event/649760

Searches for long-lived particles at the LHC: Second workshop of the LHC LLP Community

17 Oct 2017, 16:00 → 20 Oct 2017, 18:00 Europe/Zurich

Giambiagi Lecture Hall (ICTP, Trieste, Italy)

Albert De Roeck (CERN), Bobby Samir Acharya (Abdus Salam Int. Cent. Theor. Phys. (IT)), Brian Shuve (SLAC National Accelerator Laboratory), James Beacham (Ohio State University (US)), Xabier Cid Vidal (Universidade de Santiago de Compostela)

White paper — chapter statuses and roundtable
[draft here (18 Oct)]

- Simplifed models — First draft done!
- Experimental coverage — First draft essentially done!
- Triggers, upgrades, HL- / HE-LHC opportunities
  — First draft in progress
  —> discussion today [live doc!]
- Re-interpretations / recommendations
  — First draft imminent!
- Backgrounds — First draft imminent!
- Dark showers
  — First draft (summarizing status and advertising for the future) imminent!

White Paper being finalized

Input from ATLAS, CMS, LHCb, proposed specialized experiments and theory

Complete by early 2018

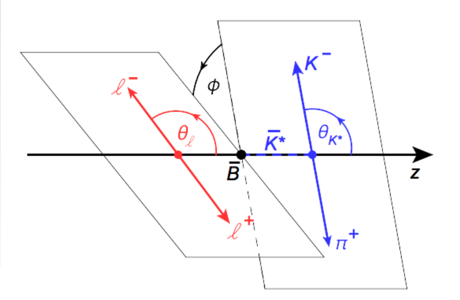
Also meetings with LHC DM group planned

New Physics in Rare Decays?

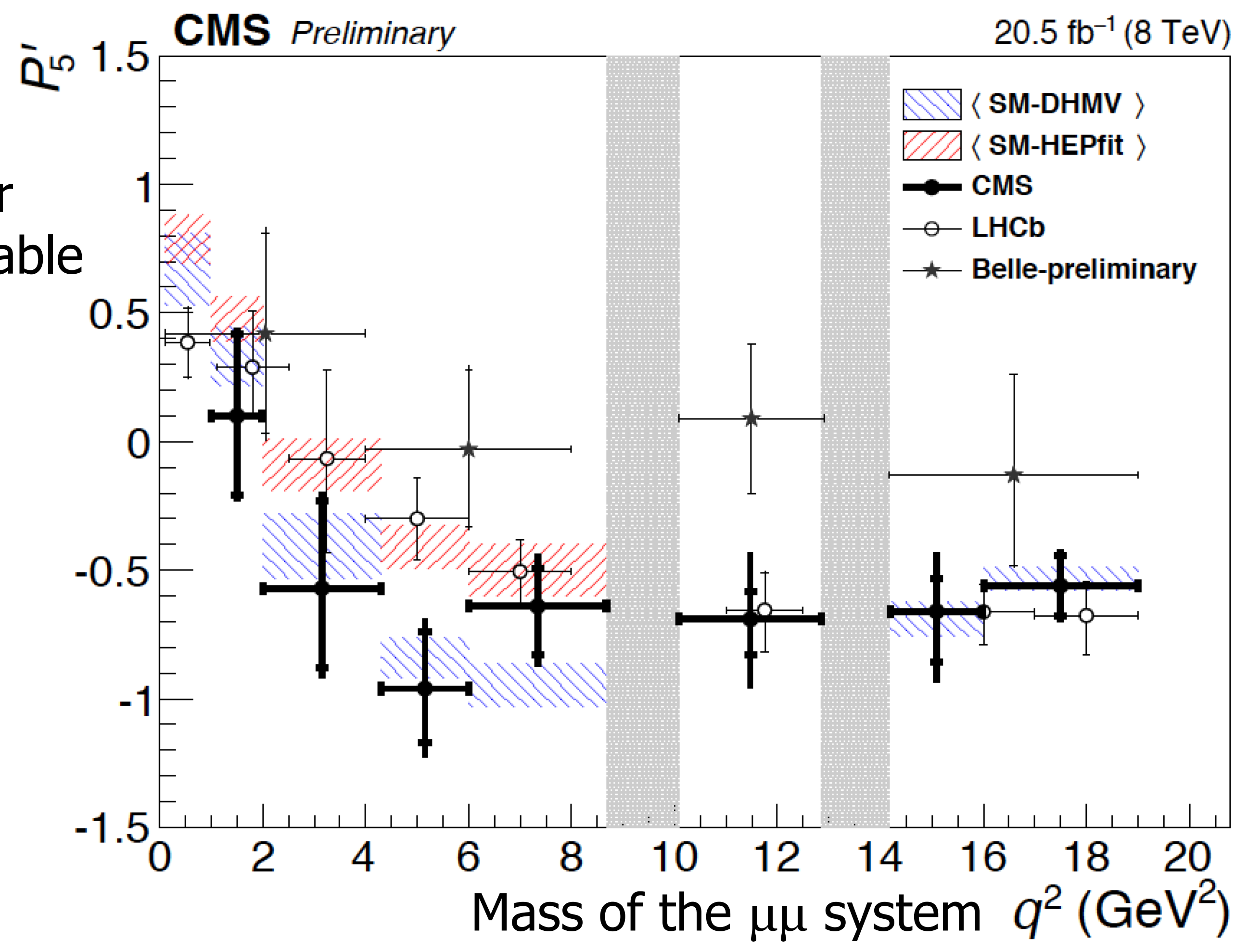
Analysis of the B0→K*μ+μ- decay (LHCb)

LHCB: arXiv:1512.04442

CMS: BPH-15-008



Angular observable



No obvious problem with the 'Standard Model' but jury still out

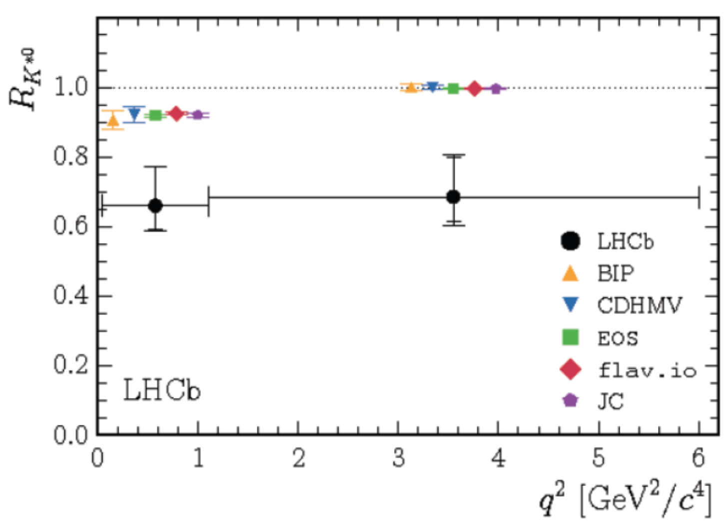
LHCb: Test of Lepton Universality

A puzzling results from the LHCb experiment…

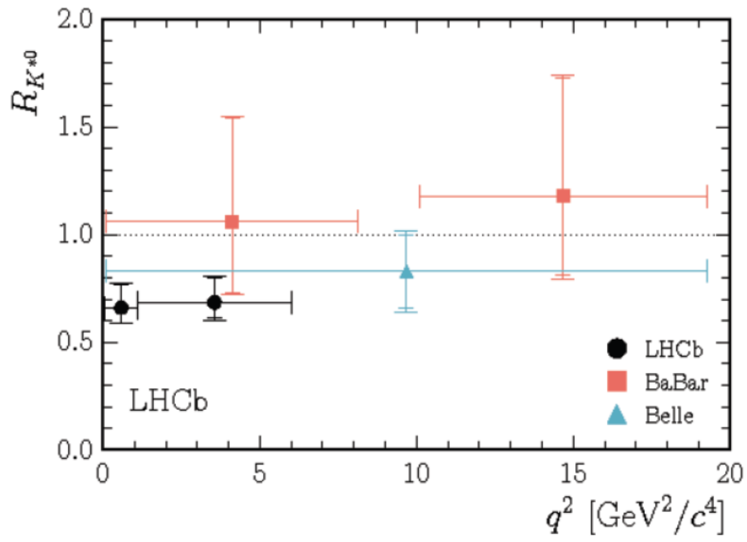
Comparing the rates of $B \to H\mu^+\mu^-$ and $B \to He^+e^-$ $H = K, K^*, \phi, \ldots$

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$

Comparison with SM predictions



Comparison with BaBar & Belle



$$R_{K^*} = \begin{cases} 0.66^{+0.11}_{-0.07}\,(\text{stat}) \pm 0.03\,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1\,\text{GeV}^2 \\ 0.69^{+0.11}_{-0.07}\,(\text{stat}) \pm 0.05\,(\text{syst}) & \text{for } 1.1 < q^2 < 6.0\,\text{GeV}^2 \end{cases}$$

2.1 - 2.3 σ

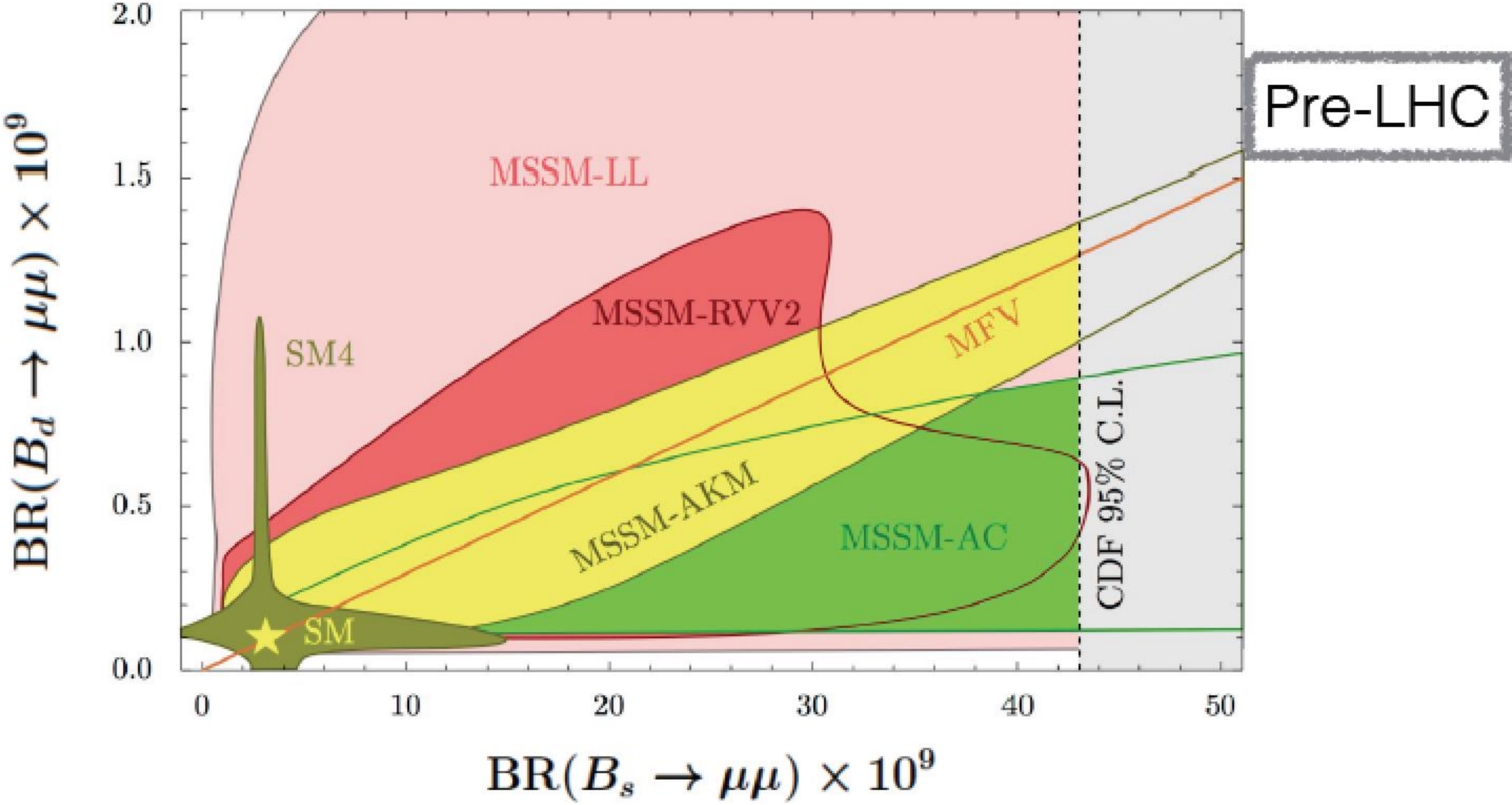
2.4 - 2.5 σ

?

Measurement of B_s-> μμ

- Sizeable effects expected in many MSSM models

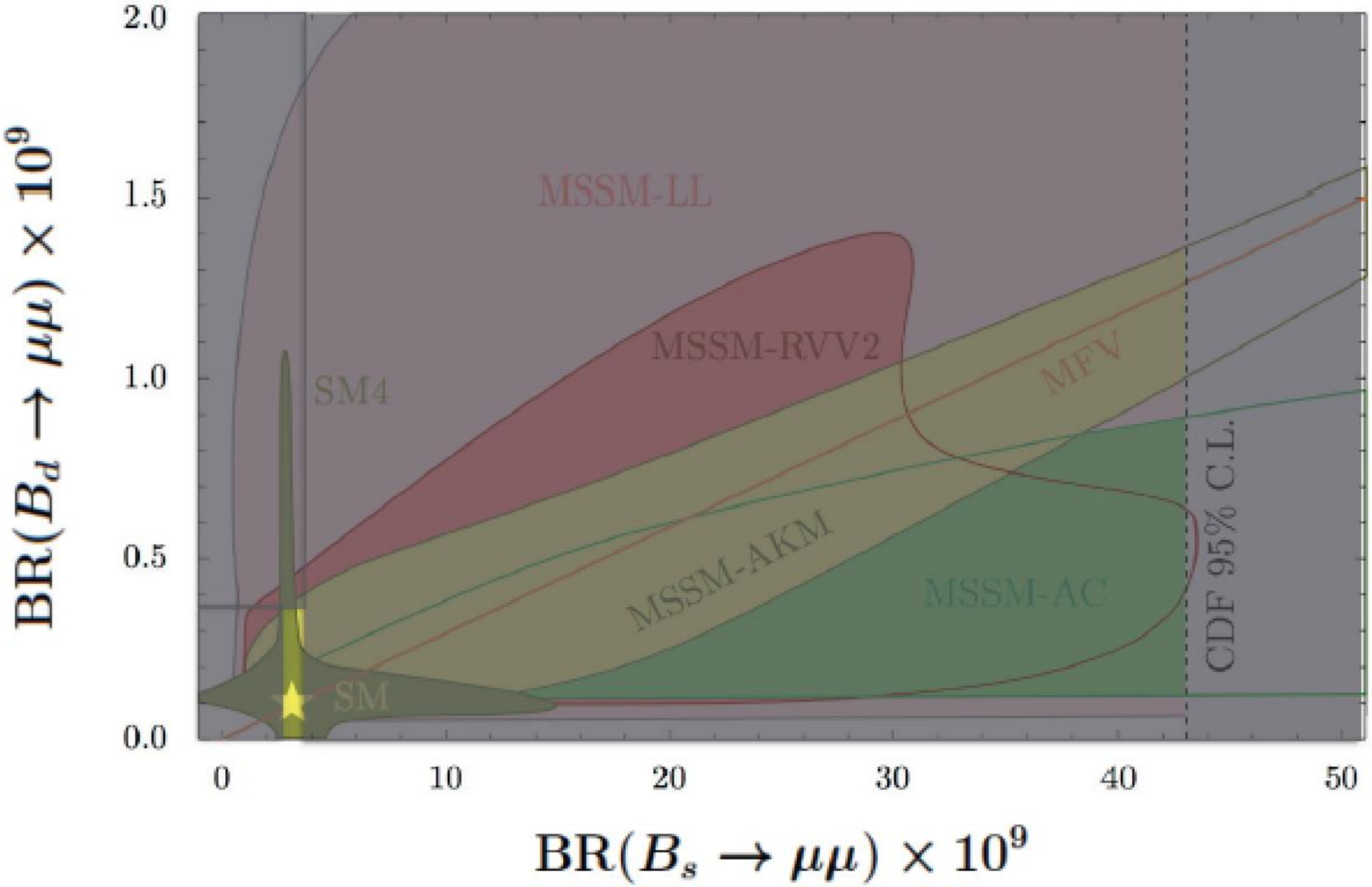
Straub, arXiv:1107.0266



Measurement of B_s-> μμ

- Sizeable effects expected in many MSSM models

Straub, arXiv:1107.0266



Now

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\quad \sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^-		1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.1 TeV η_{LL}^-		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

$\sqrt{s} = 8$ TeV $\quad \sqrt{s} = 13$ TeV

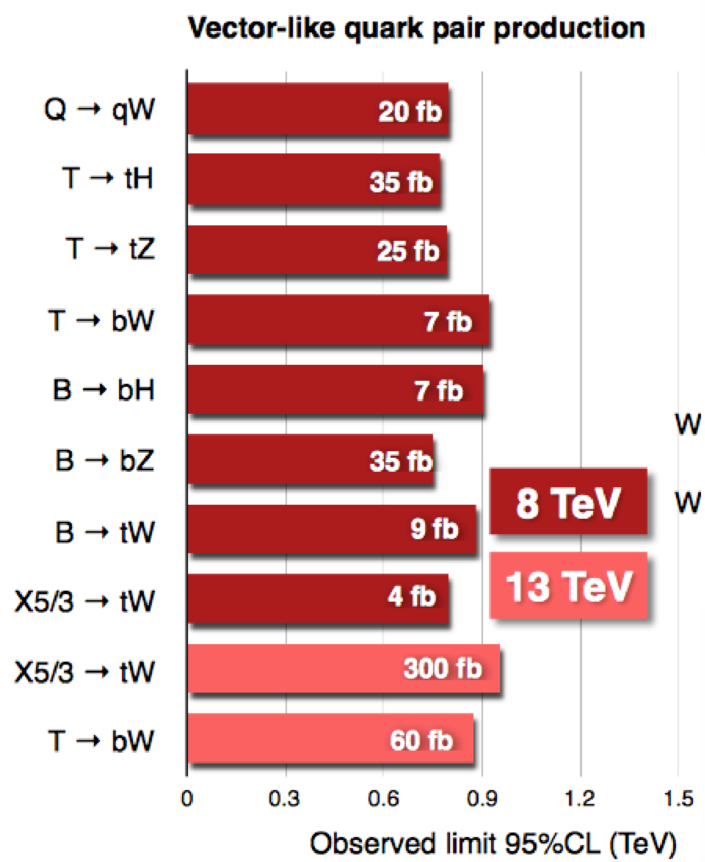
10^{-1} $\quad$ 1 $\quad$ 10 $\quad$ **Mass scale [TeV]**

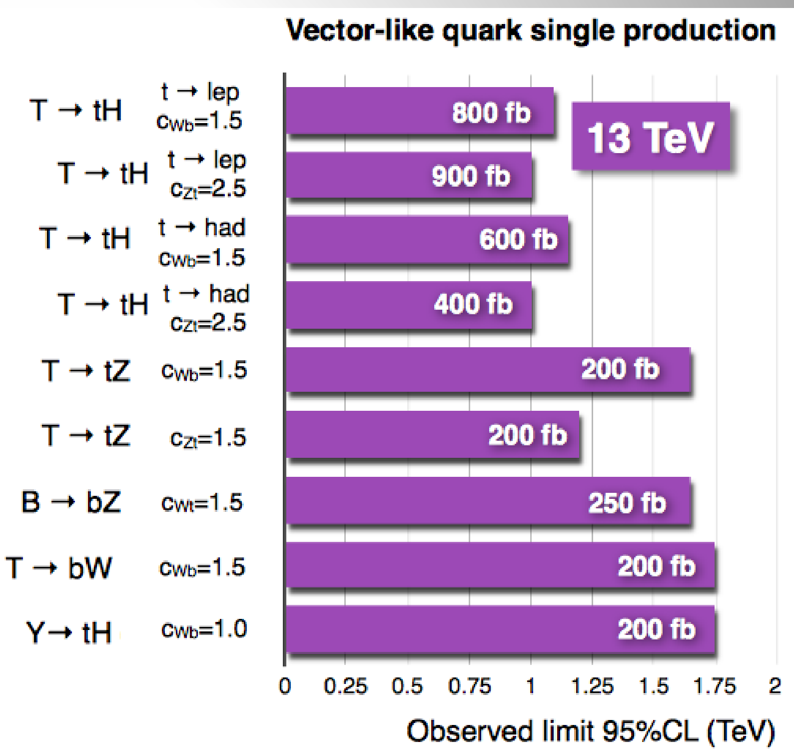
*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Vector-like Quark Production Overview

- color-triplet spin-1/2 fermions; L & R components transform the same way under weak isospin





Exclusions up to masses of 800-950 GeV and up to 1.75 TeV for singly produced VLQs (model dep.)

Composite Higgs & Little Higgs Models, Extra Dimentsions…

Are we leaving no stone unturned?

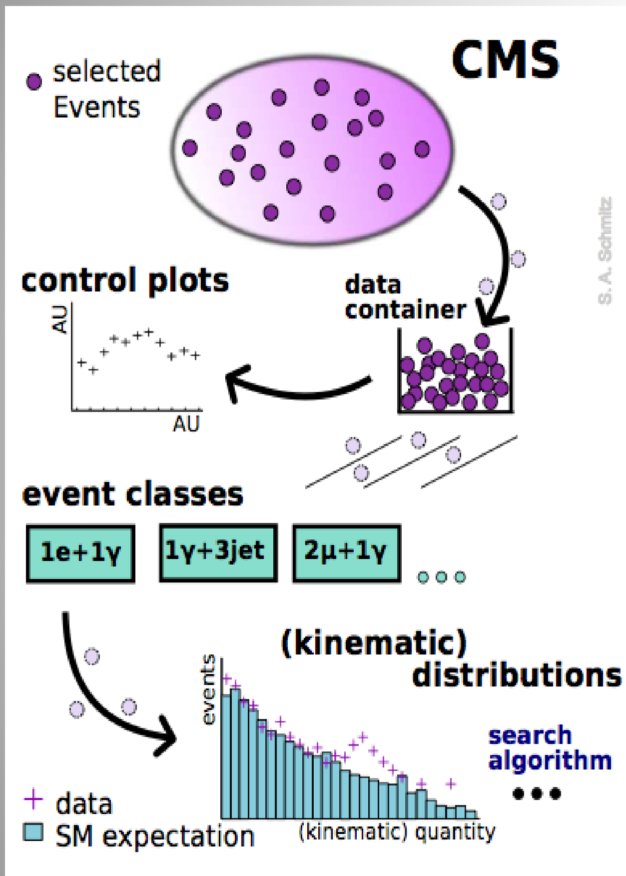
- The LHC BSM searches are indispensable and should be continued in the new energy regime and with increasing statistics.
- But if we still do not see a deviation with more than a ~2 sigma by 2022, the High Luminosity -LHC will become likely mostly a precision physics machine.
- Are we looking at the right place? Time for more effort in thinking of complementary searches?

Are we looking at the right place?

Leave no stone unturned!!

A General Search View!

CMS-EXO-14-016



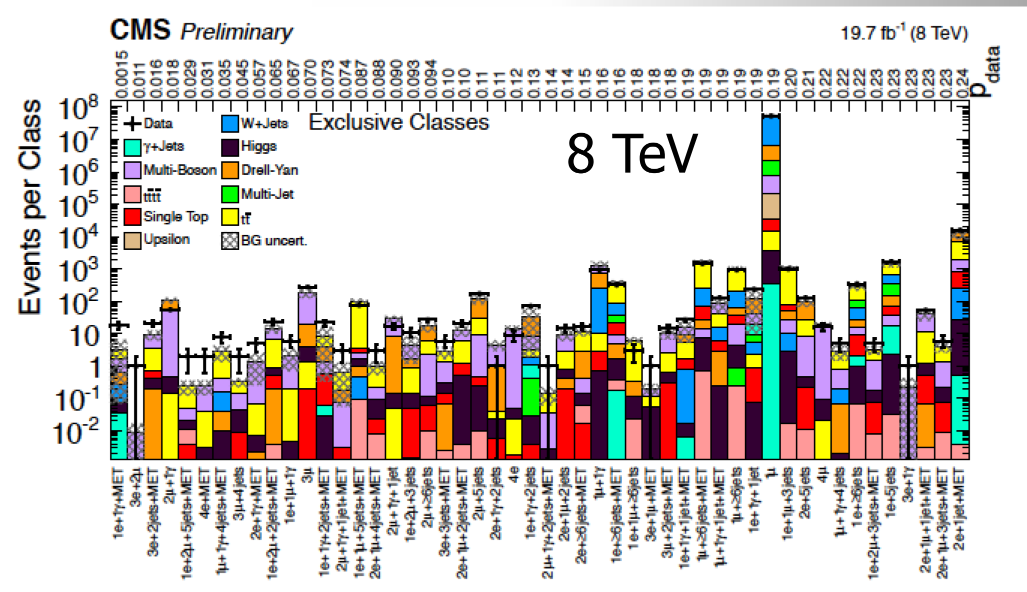
Model independent search

- Divide events into exclusive classes
- Study deviations from SM predictions in a statistical way

Distributions in each class

- $\sum p_T$ - Most general
- $M_{inv}^{(T)}$ - Good for resonances
- MET - Escaping particles

No outlying deviation found



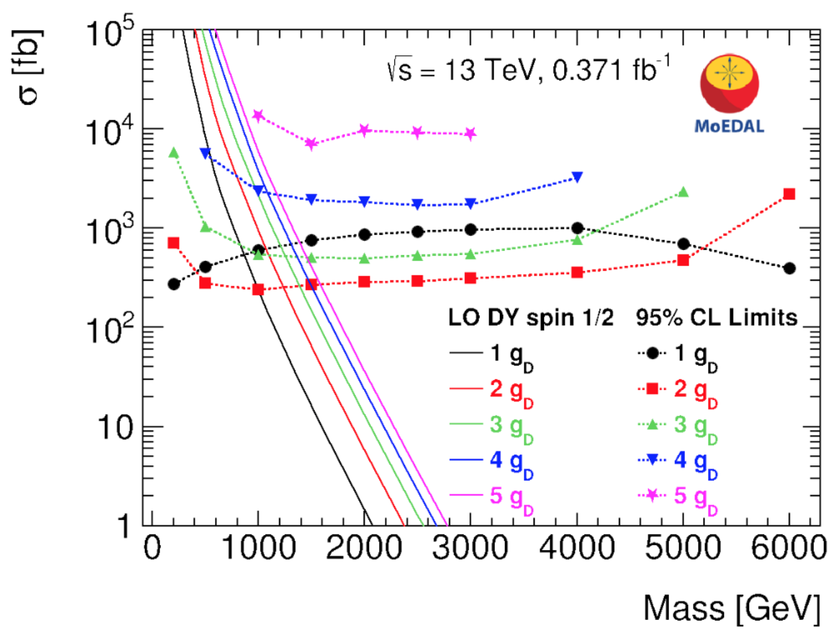
Rates (exclusive classes) as expected for 19.7 fb^{-1} for CMS

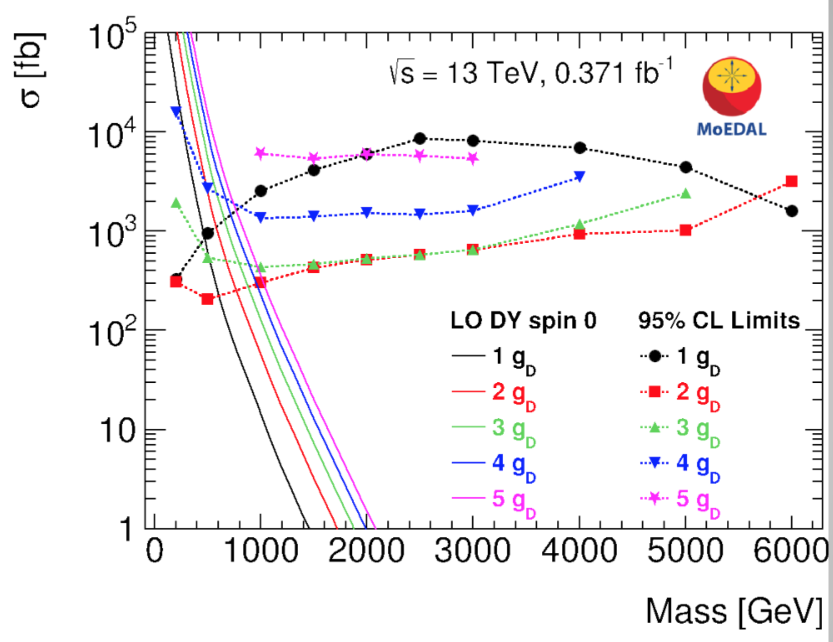
→muons, electrons, photons, MET

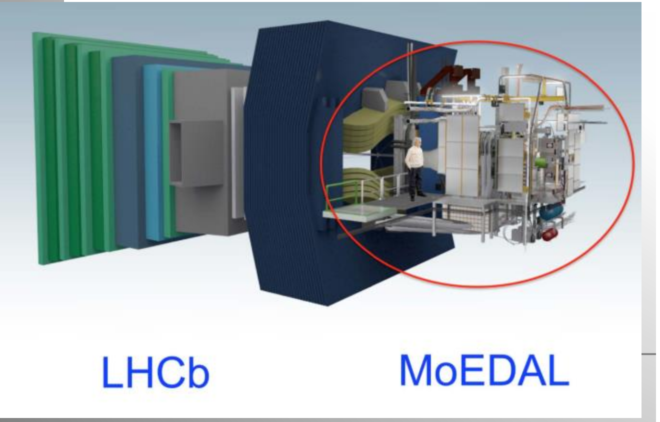
Analysis ongoing for 13 TeV

Monopole Searches: MoEDAL @ 13TeV

2015 data analysis base on 222 kg Aluminium to "stop" the monopoles and search for them with a SQUID precision magnet ($0.35\ fb^{-1}$) arXiv:1611.06817





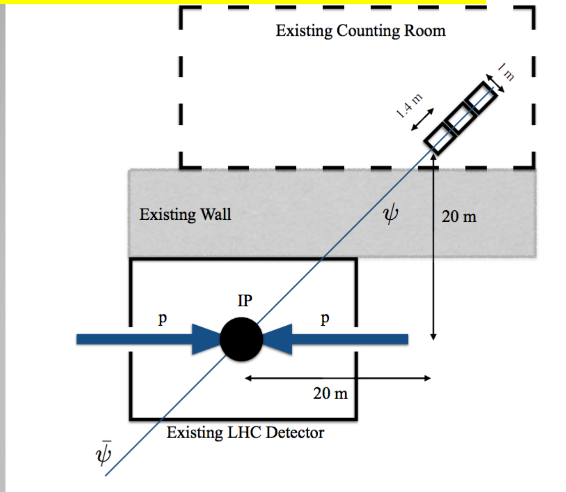


mass limits [GeV]	$1g_D$	$2g_D$	$3g_D$	$4g_D$
MoEDAL 13 TeV (this result)				
DY spin-1/2	890	1250	1260	1100
DY spin-0	460	760	800	650
MoEDAL 8 TeV				
DY spin-1/2	700	920	840	–
DY spin-0	420	600	560	–
ATLAS 8 TeV				
DY spin-1/2	1340	–	–	–
DY spin-0	1050	–	–	–

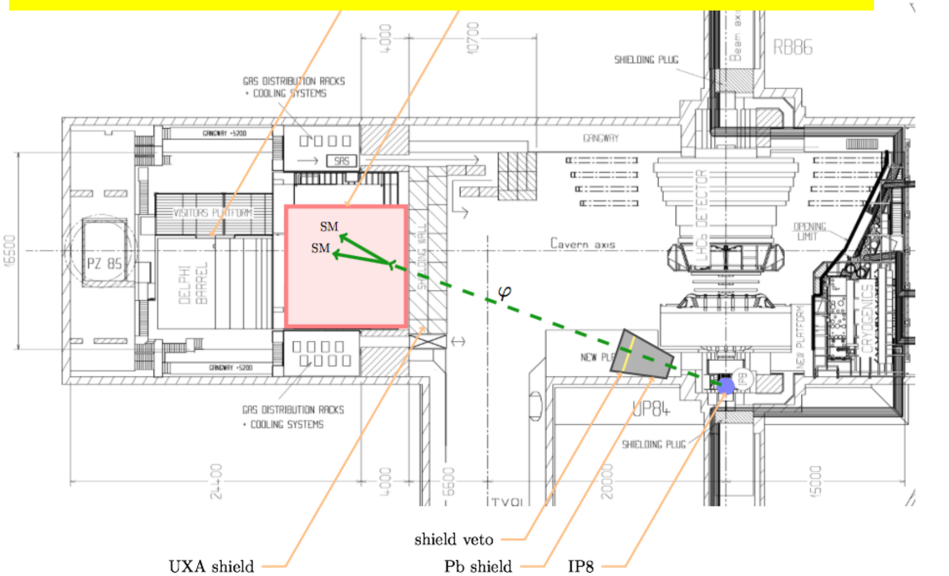
- Limits for different monopole charges
- First monopole search result @LHC at 13 TeV No signal yet..

Possible New Experiments @LHC

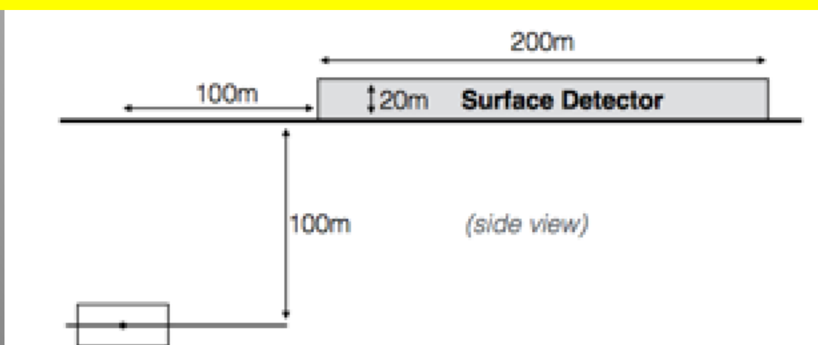
MilliQan: searches for millicharged particles



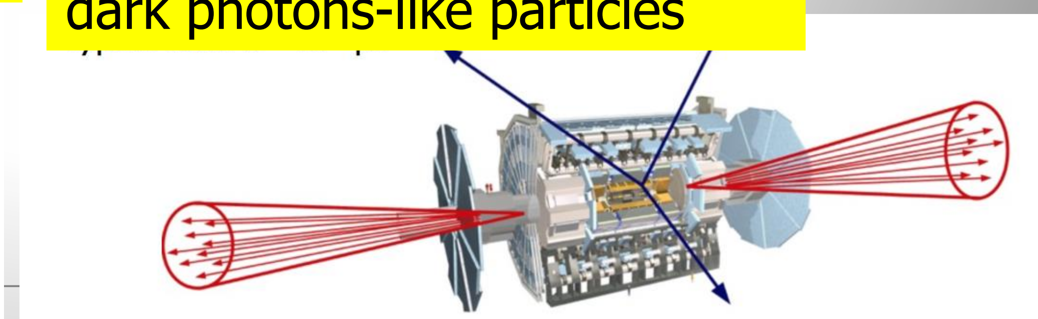
CODEX-b: searches for long lived weakly interacting neutral particles



MATHUSLA: searches for long lived weakly interacting neutral particles

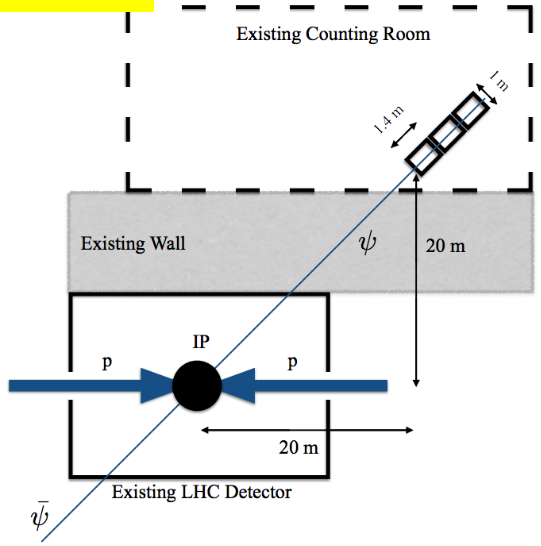


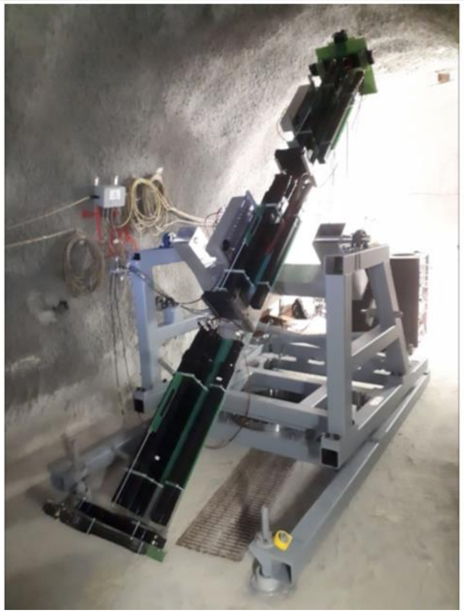
FASER: searches for long lived dark photons-like particles



Possible New Experiments @LHC

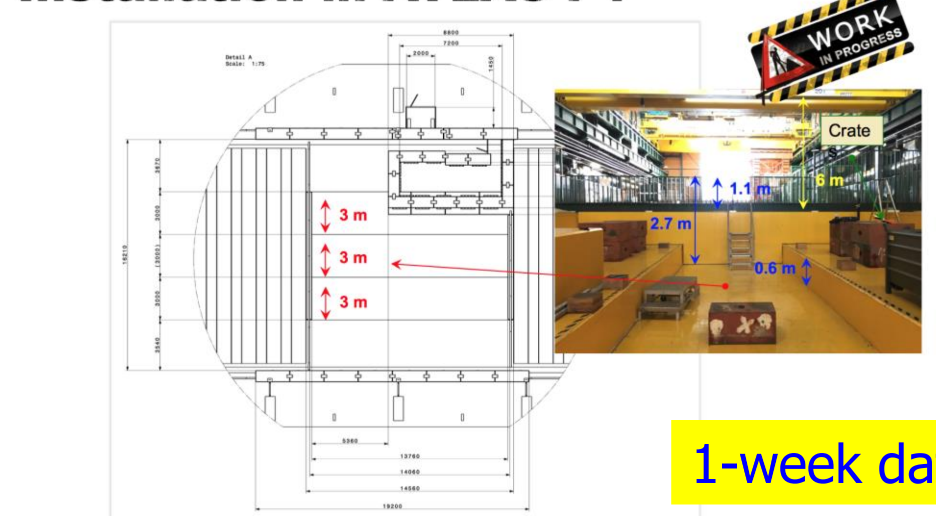
MilliQan





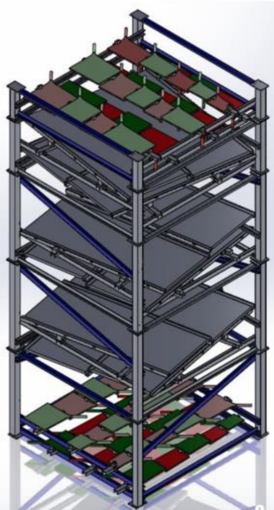
- September 2017: Installation of a 1% demonstrator.
- Collected ~ 27 fb^{-1} mostly for technical tests

Installation in ATLAS P1



MATHUSLA Test Stand

- Two scintillator layers
- Three layers of 4 RPCs each, two in x-coordinate and two in y-coordinate
- 5 m tall, 2.5 m by 2.8 m surface area
- ~1.5 ns resolution for scintillators, ~1 ns resolution for RPCs
- TDC and ADC information for each scintillator
- RPCs have readout system from ARGO which includes TDC information



1-week data taken in November

Summary

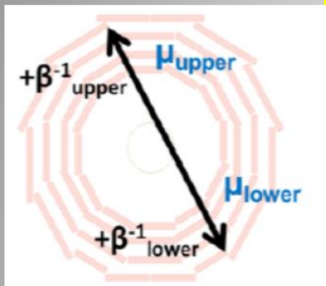
- Standard Model measurements @ 13 TeV show no surprise. E.g. W/Z and top cross sections according to expectations
- New Higgs measurements at 13 TeV. So far the Higgs is very consistent with Standard Model expectations.
- No sign of new physics in the first 13 TeV data… This starts to cut into the ‘preferred regions’ for a large number of models, like SUSY.
- Dark Matter and Long Lived Particle searches are being explored in a more systematic way
- New thinking/paradigms in Theory? Can we test it at the LHC?
- The LHC is continuing to explore the Terascale. much data to look forward to: it takes on signific to show the way!! Collected >80 fb^{-1}@ 13 TeV s

And hopefully one day soon:

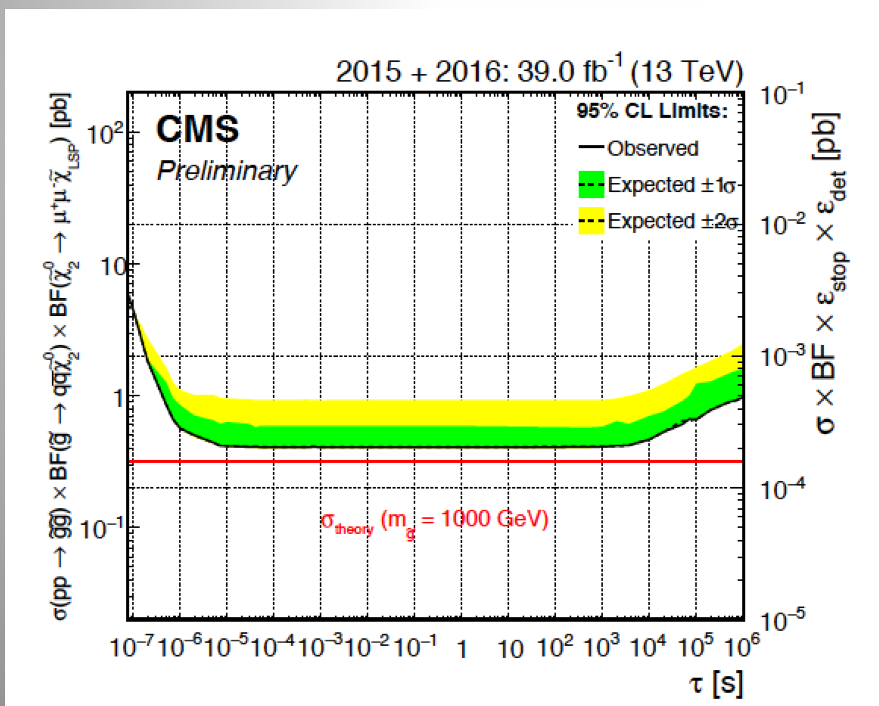
Backup

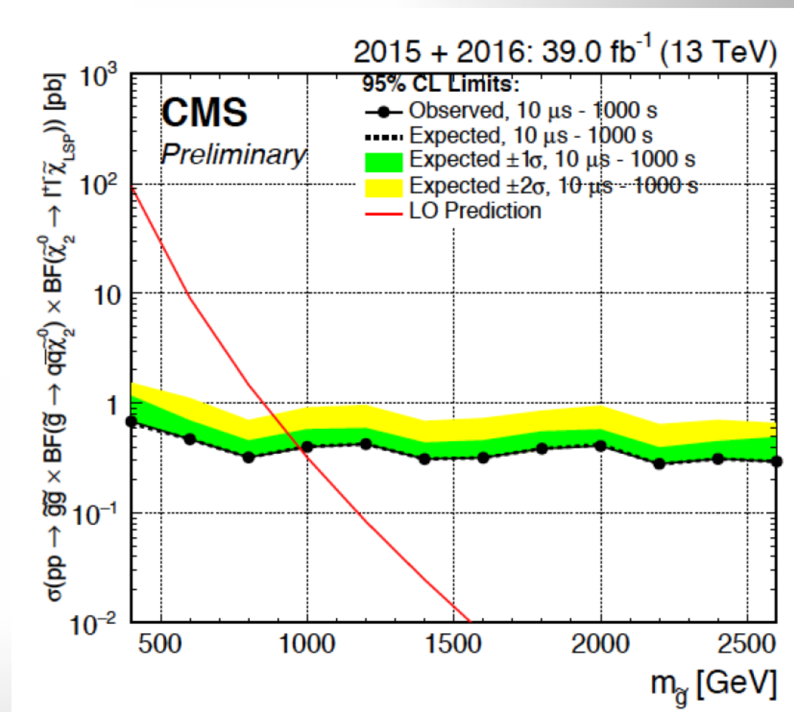
Search for Stopped Long Lived Particles

EXO-17-004



- Search for long lived particles that stop in the detector and decay into jets after some time, non-coincident with pp collisions
- 744 hours trigger lifetime in 2015/16 included in this search.
- Searches for long lived gluinos with delayed muons
- No events observed in 2015/16.





Limits on $400 < M_{gluino} < 970$ GeV 95%CL for lifetimes from 10 μsec to 1000s