Search for New Physics with CMS

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On behalf of the CMS Collaboration

New Trends in High Energy Physics 2016

Budva, Becici, Montenegro
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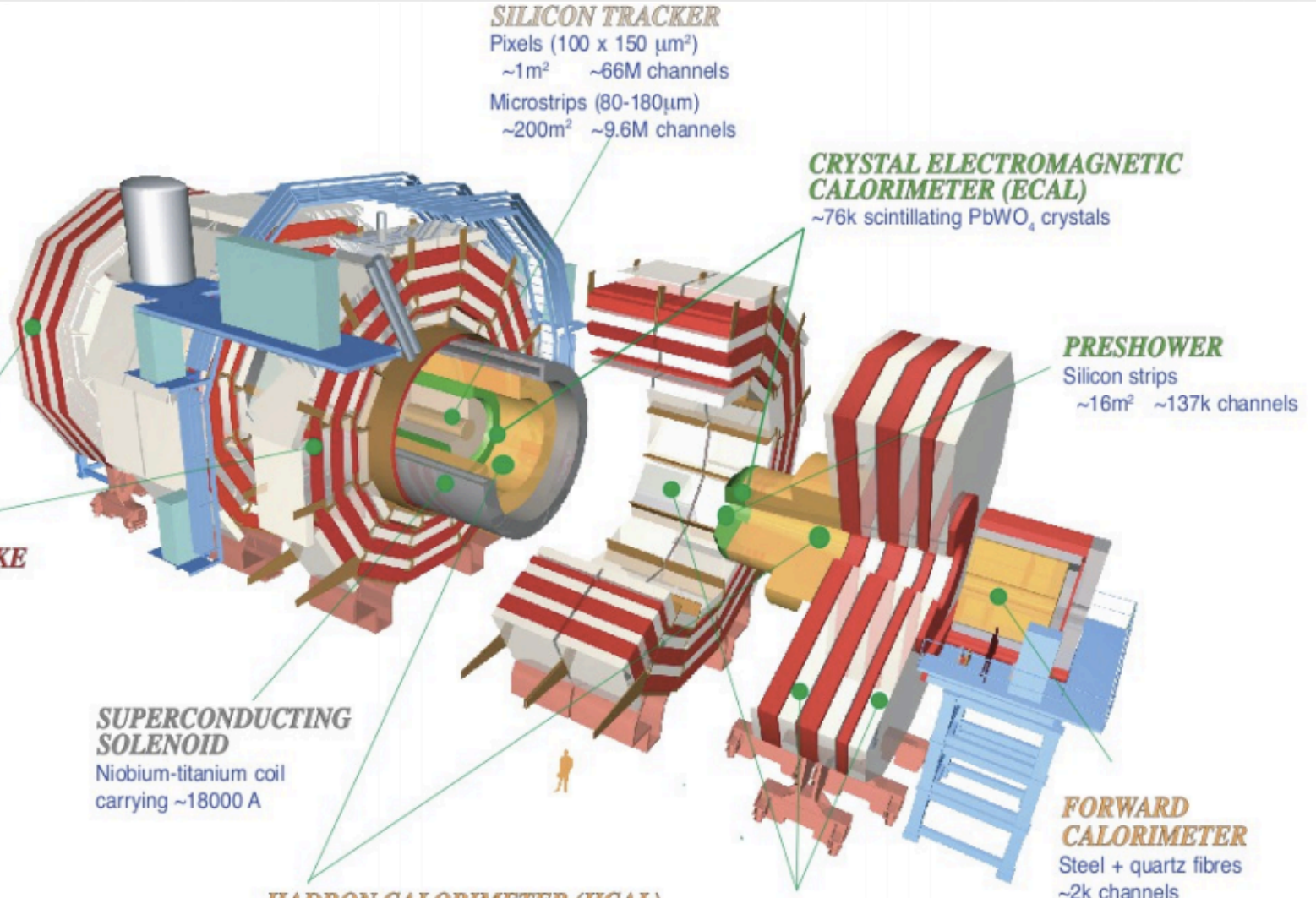
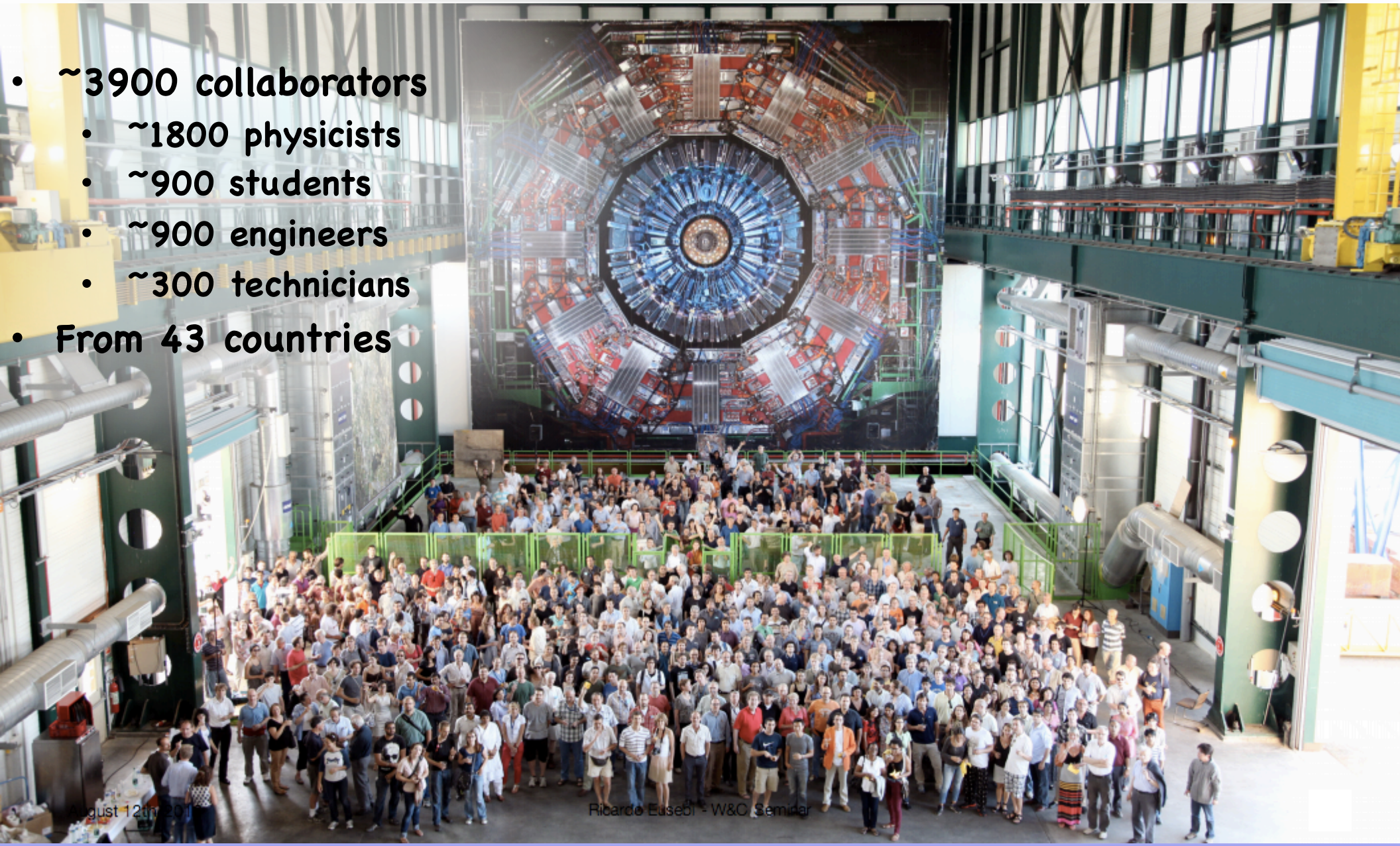
CMS Detector



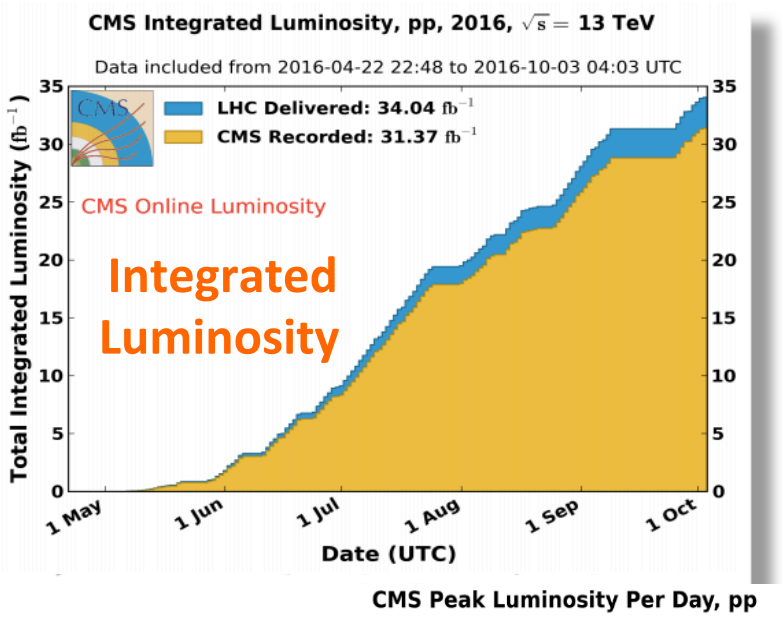
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

CMS Collaboration

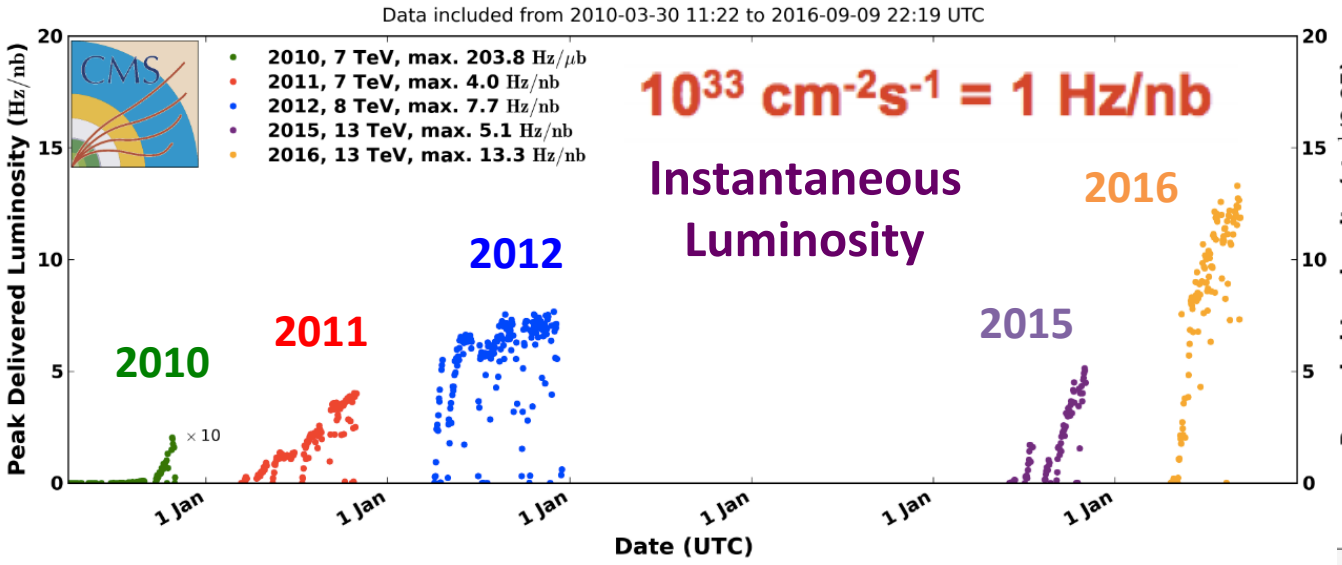
- ~3900 collaborators
  - ~1800 physicists
  - ~900 students
  - ~900 engineers
  - ~300 technicians
- From 43 countries

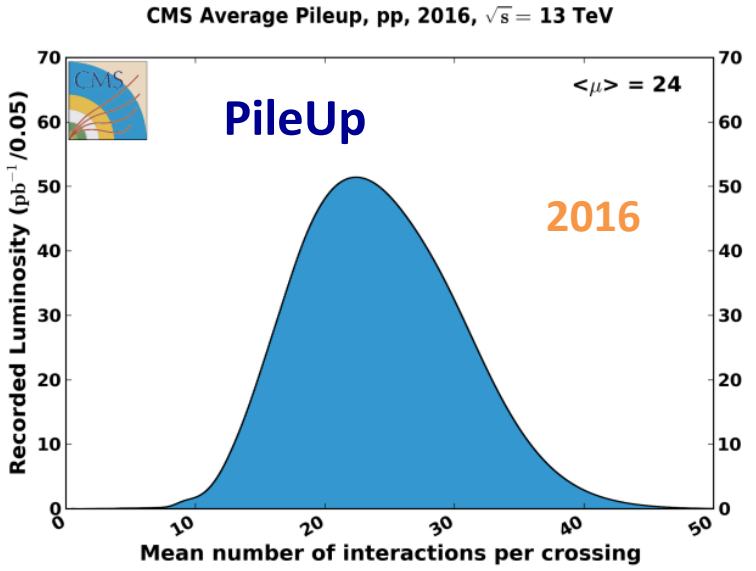


LHC Run 2 @ 13 TeV

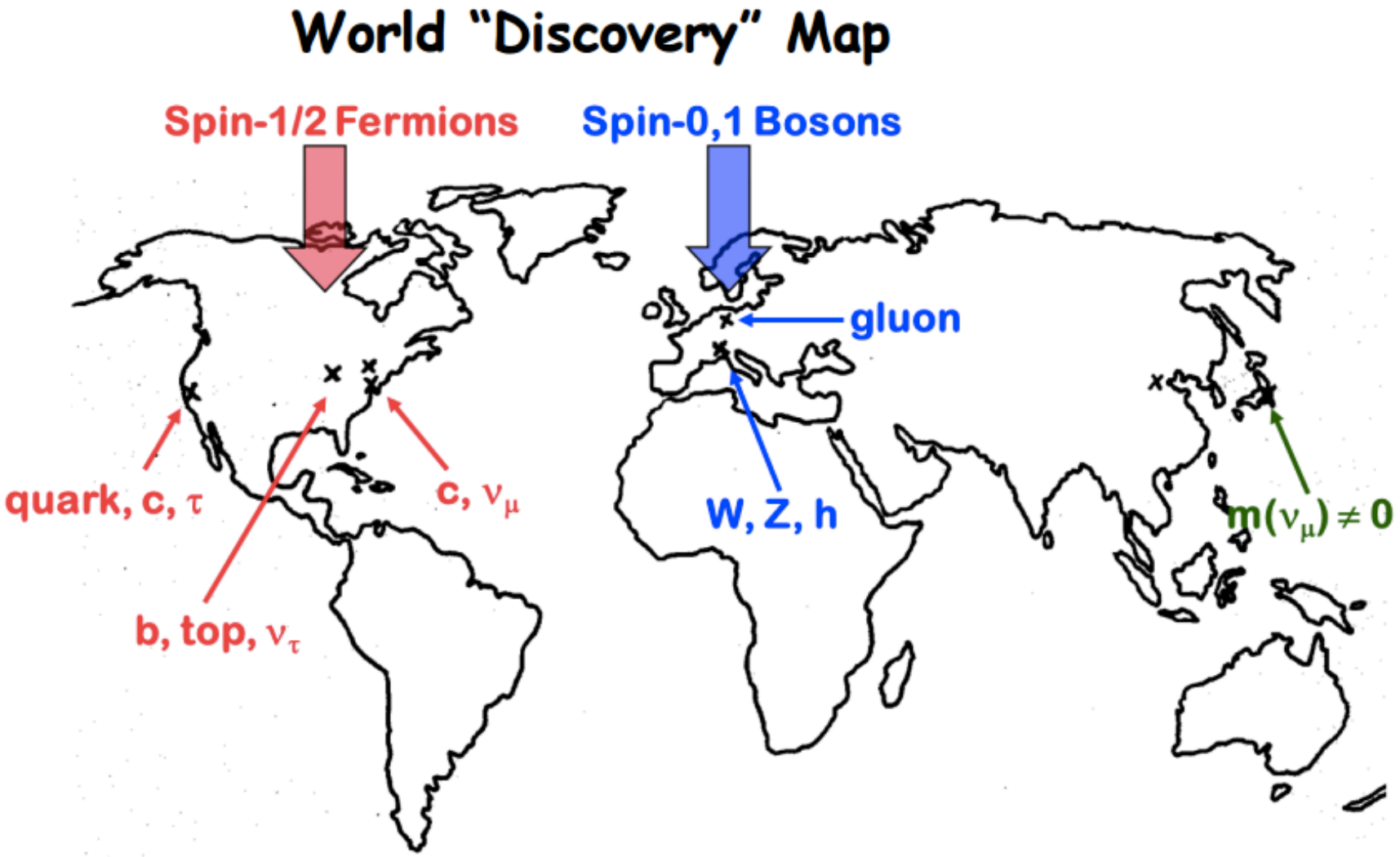


- Run 2 Dataset
  - 2015: ~3 /fb
  - 2016: ~30 /fb,
  - 13 /fb analyzed & presented at ICHEP
  - expect ~40/fb by the end of the year
- Excellent detector performance
- High data-taking efficiency
  - ~ 92% of delivered data are recorded
  - ~ 92.5% if those are certified and used for physics analyses

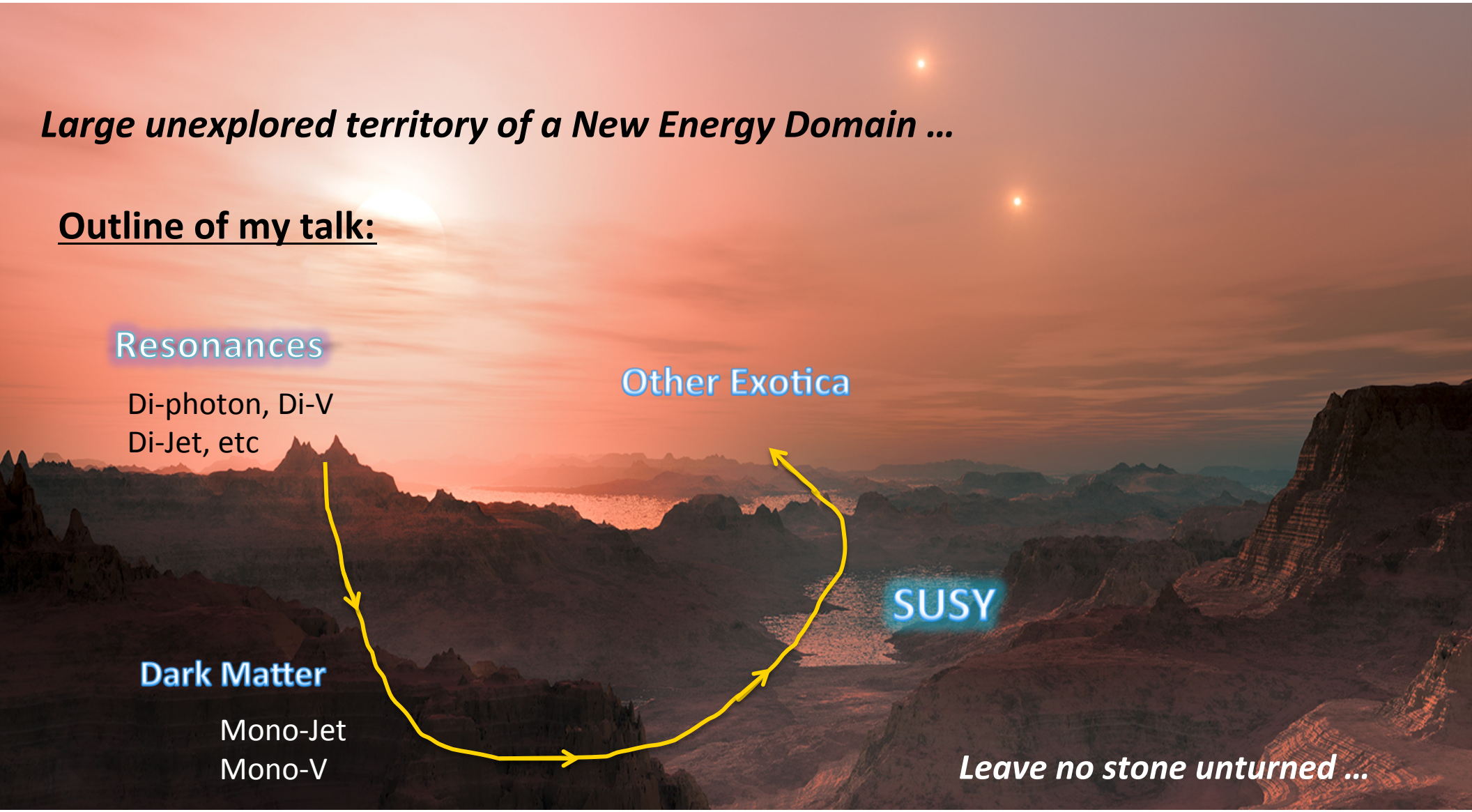




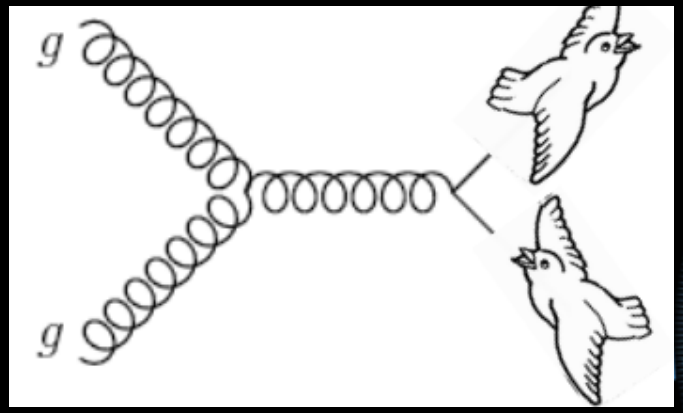
We are Up for Discoveries ..

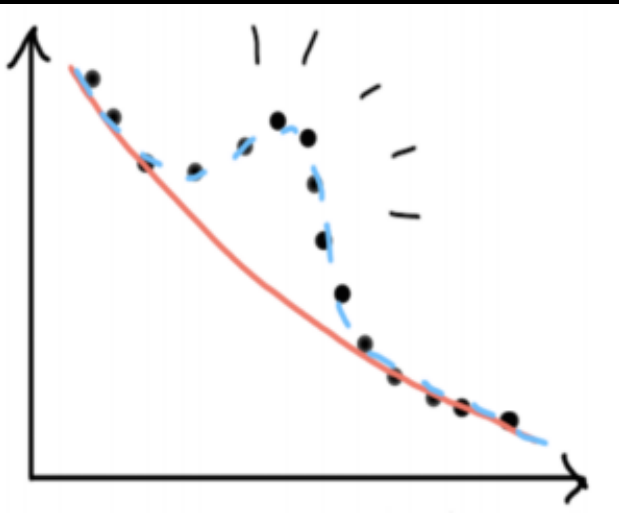


New Physics Searches Landscape



Resonances

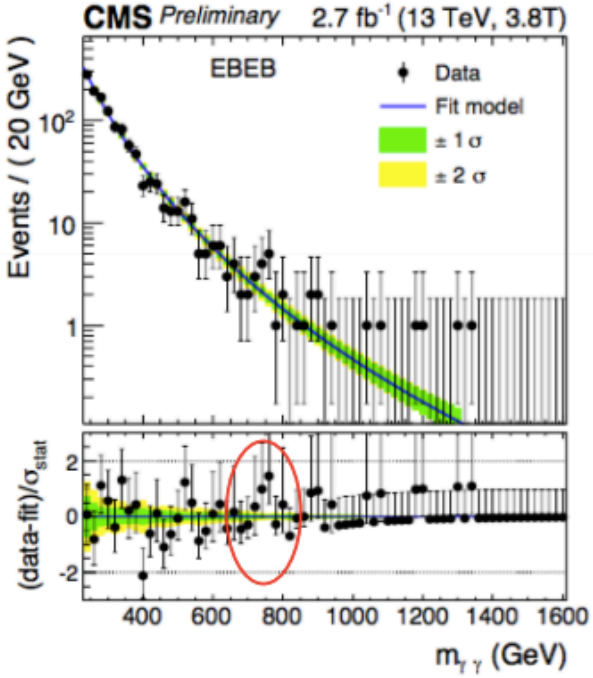




Search for Di-Photon Resonance

2015 Data

Phys. Rev. Lett. 117

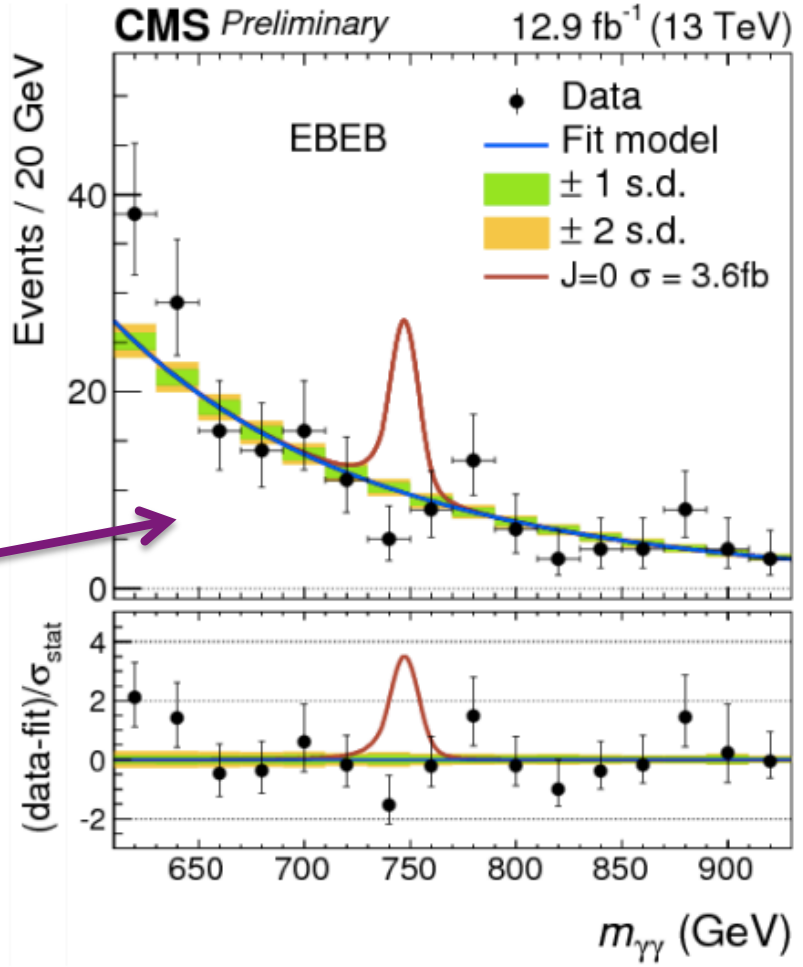


2016 Data

Background fit with

$$g(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\log(m_{\gamma\gamma})}$$

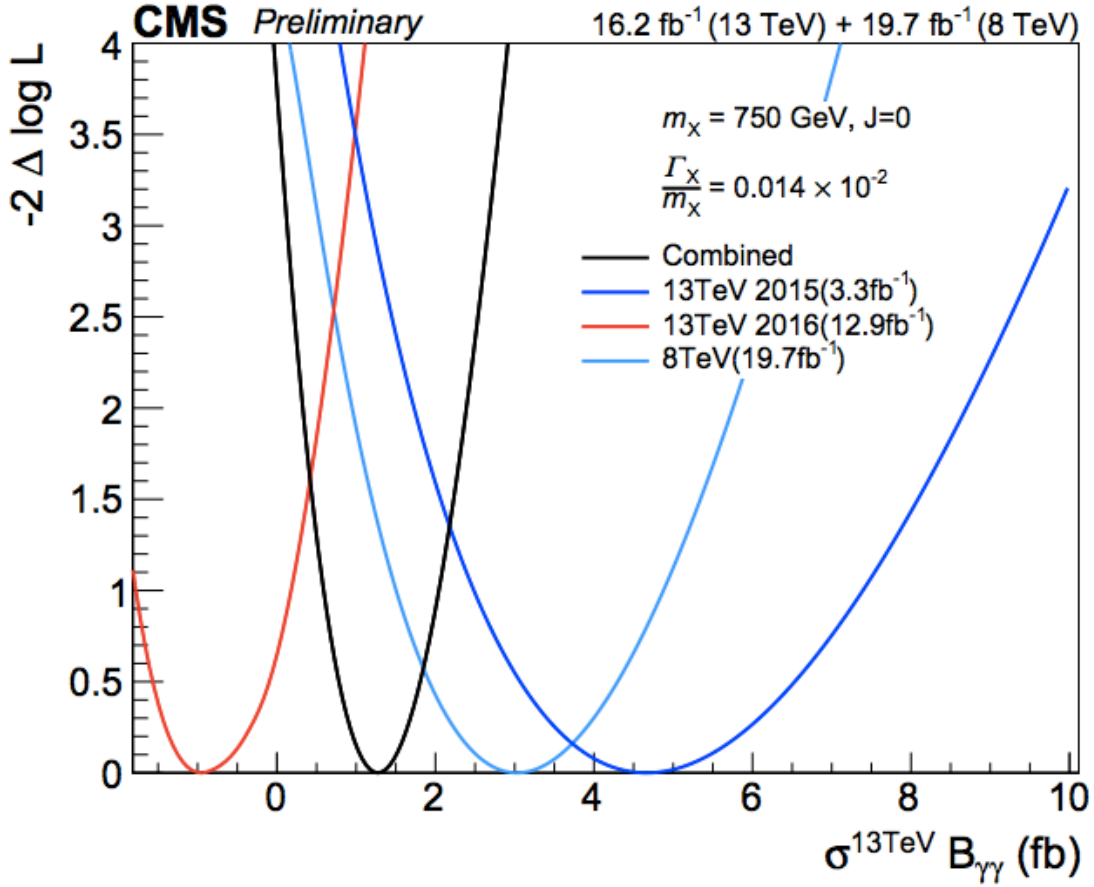
What we would have seen

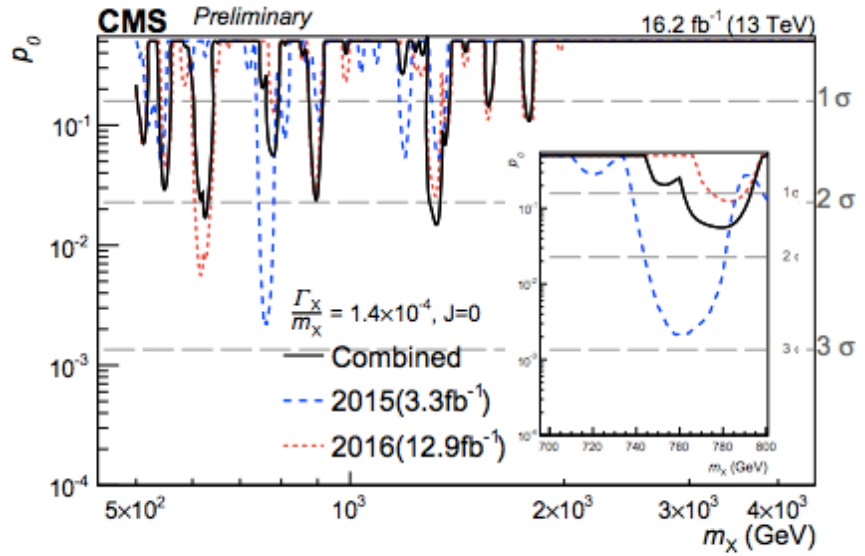


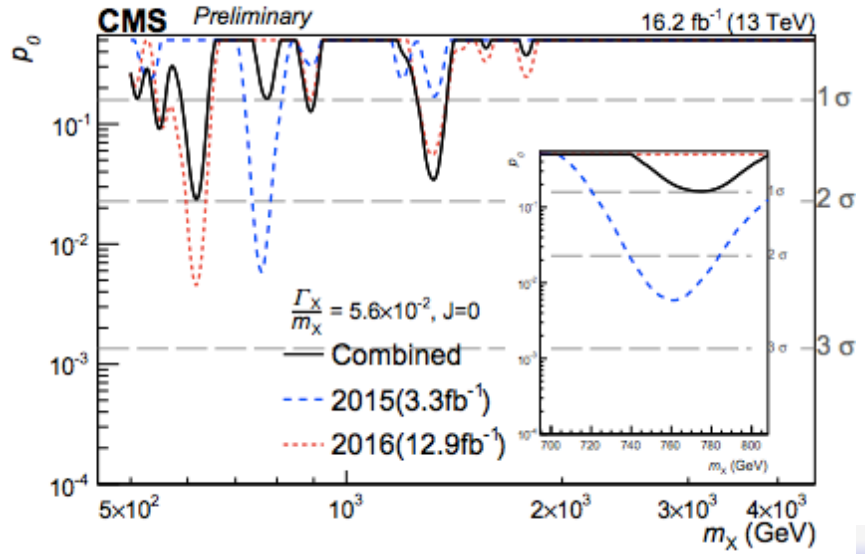
Most Significant Excess	2015	2015+8 TeV
Mass (GeV)	760	750
Local Significance	2.9σ	3.4σ
Global Significance	$< 1\sigma$	1.6σ

Compatibility with Previous Results

- No evidence for a di-photon resonance with larger 2016 dataset !



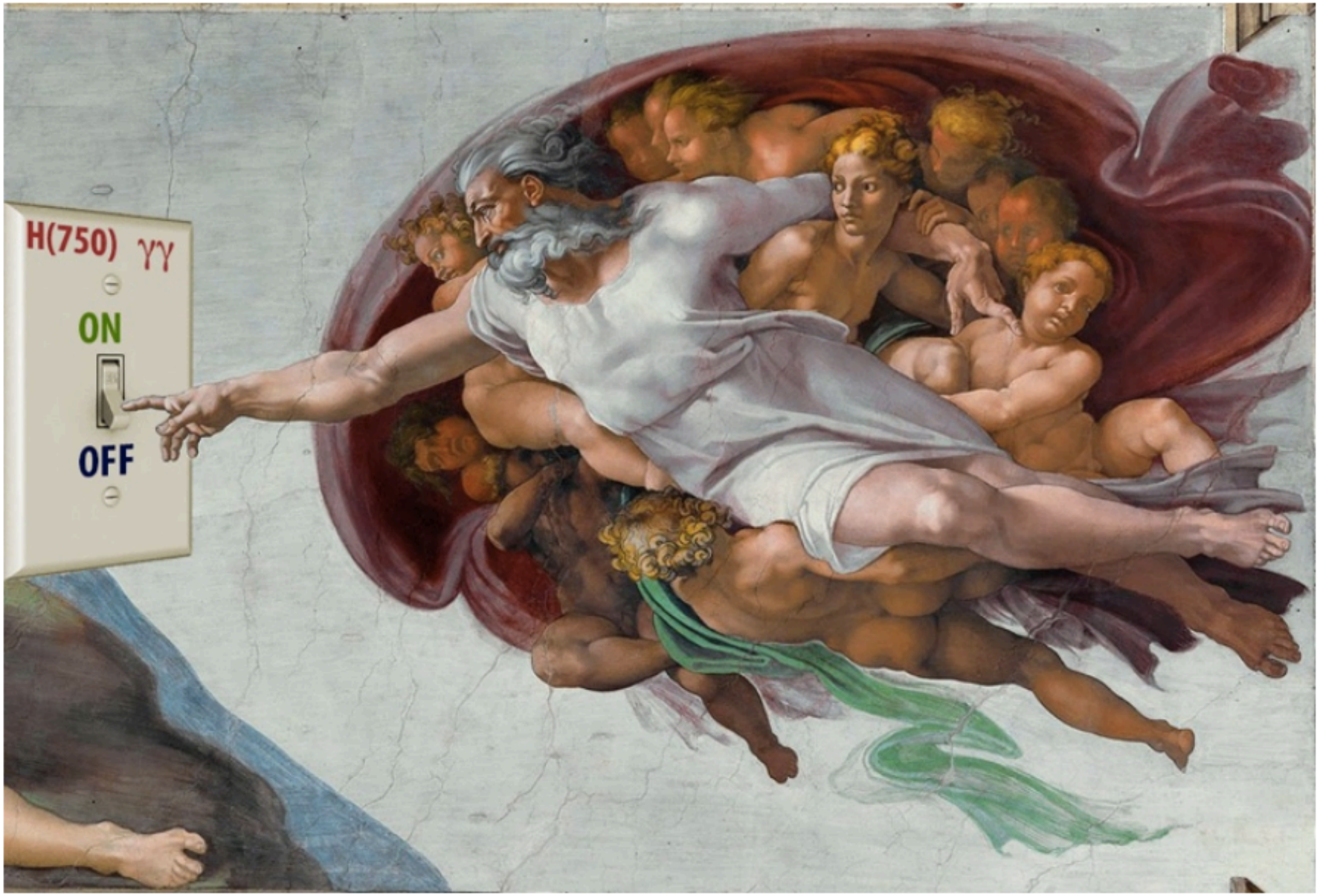




2.9 σ => 0.8 σ significance with 2016 data

CMS-PAS-EXO-16-027

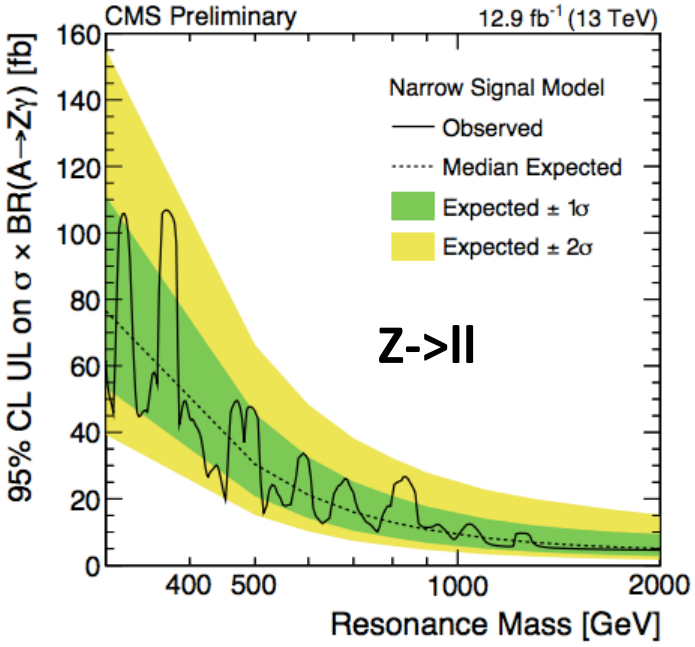
Di-Photon Resonance is Gone …

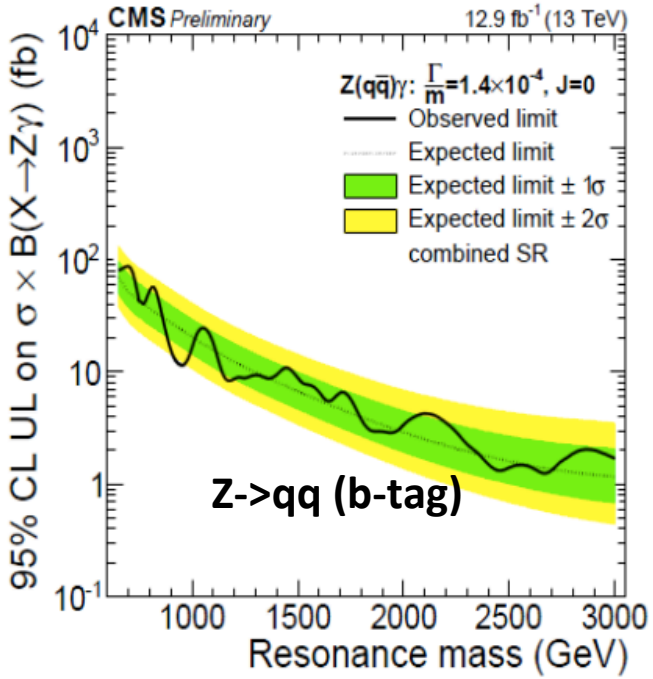


Search for Zγ Resonance

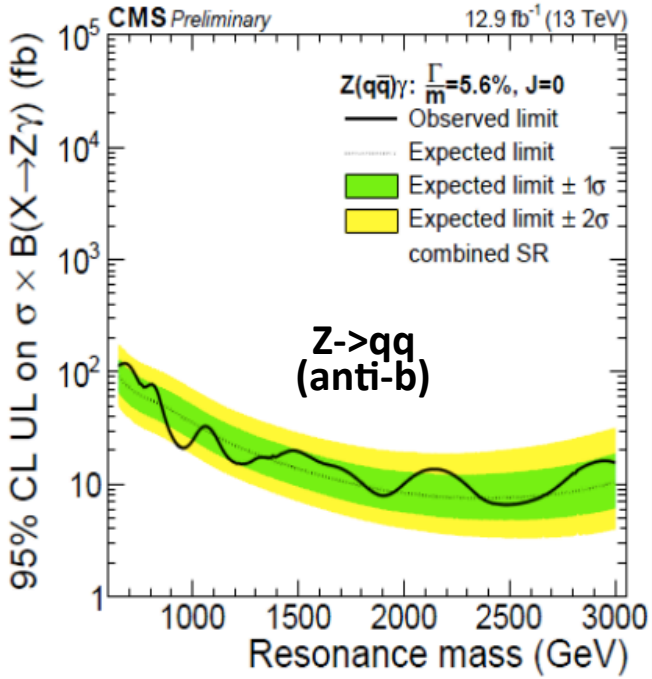
- Complementary to a possible γγ resonance
- Leptonic search Z(ll)γ at low masses
- Boosted hadronic search Z(qq) γ at using b-tag info and jet substructire at high masses

CMS-PAS-EXO-16-034



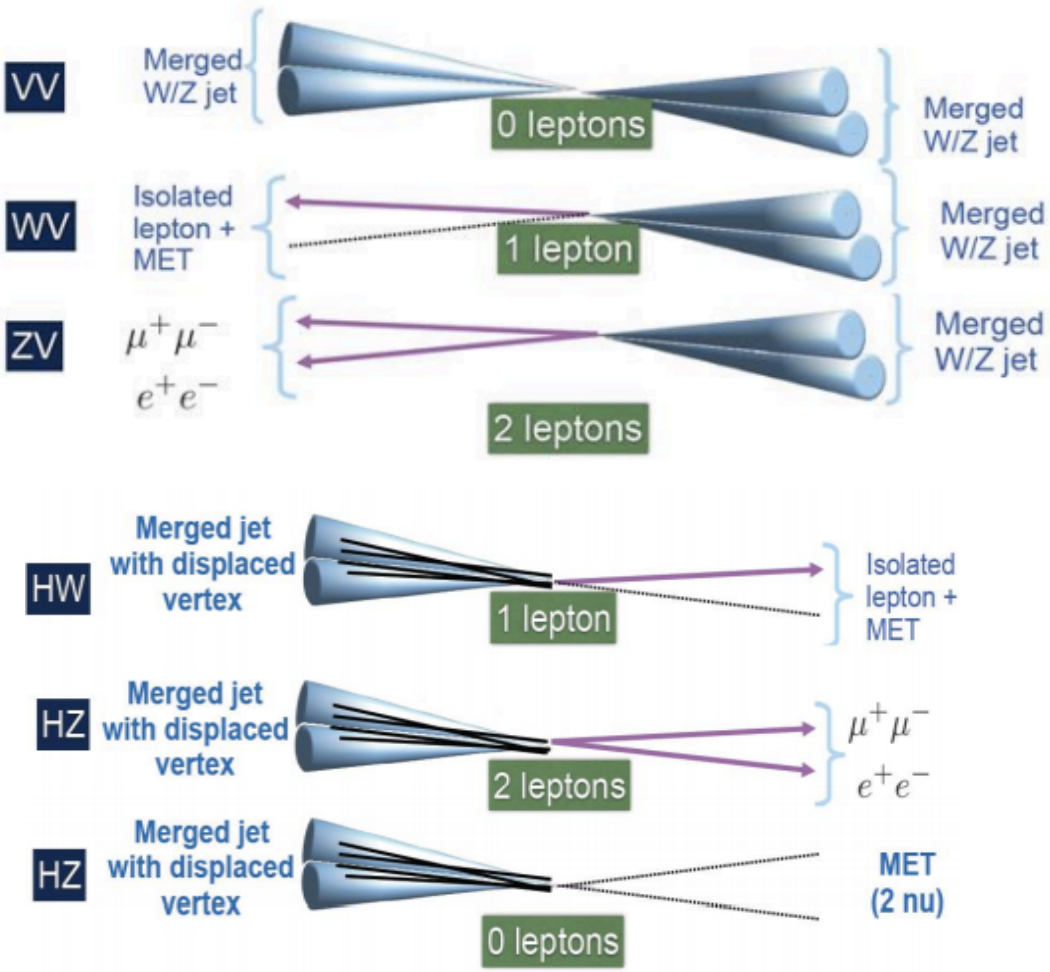


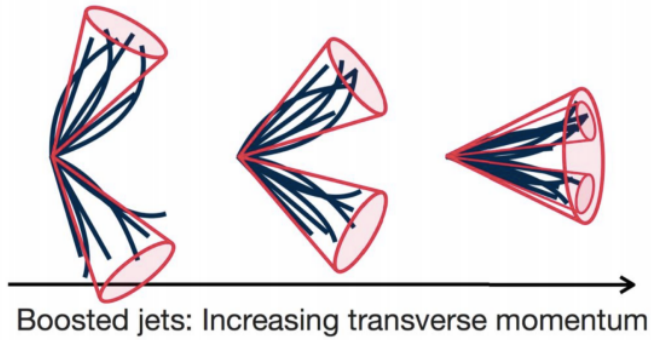
CMS-PAS-EXO-16-035

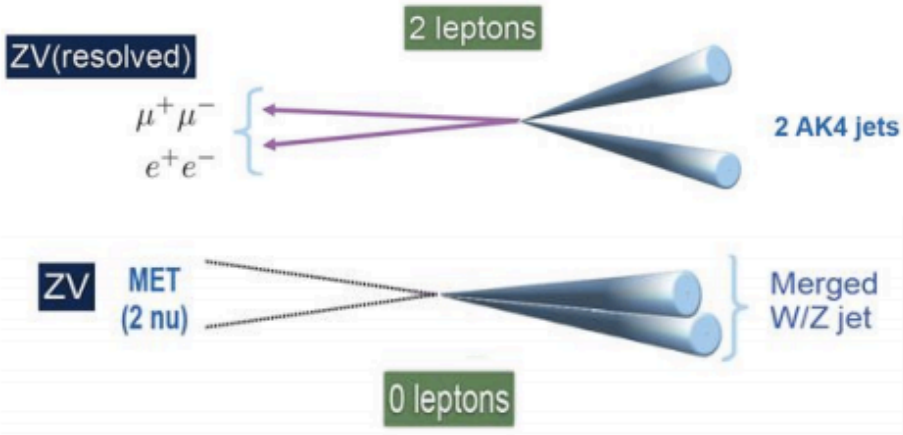


Di-Boson Resonances

- Tag boosted W, Z and H-bosons using jet substructure algorithms

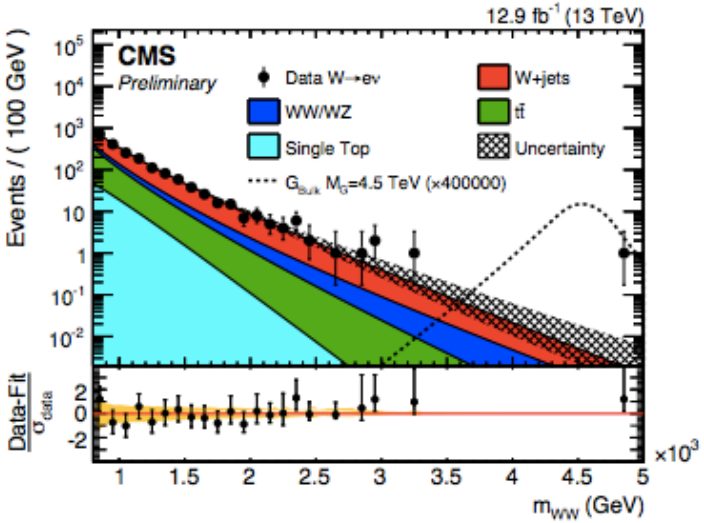


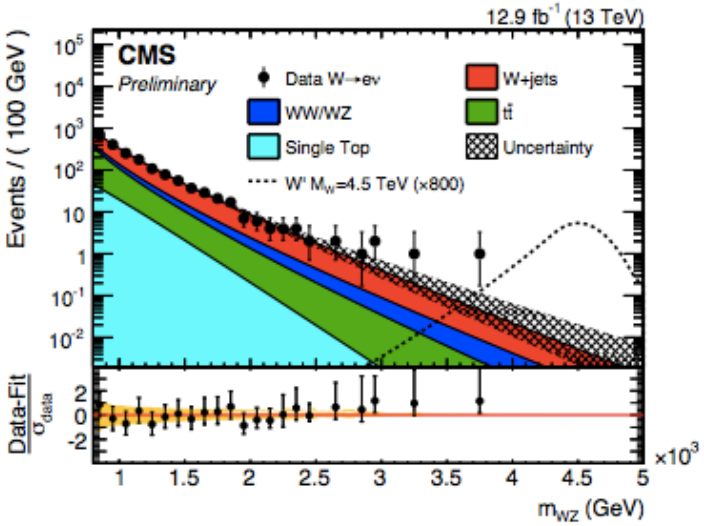




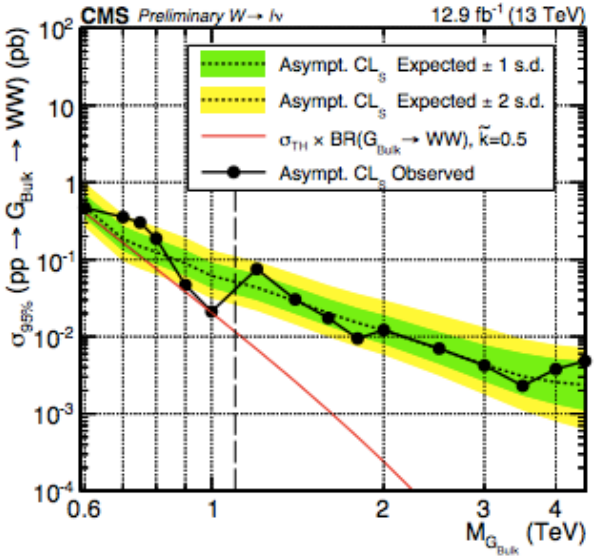
Resonant W(lν)V(qq)

- Model background shape by a parameterized function

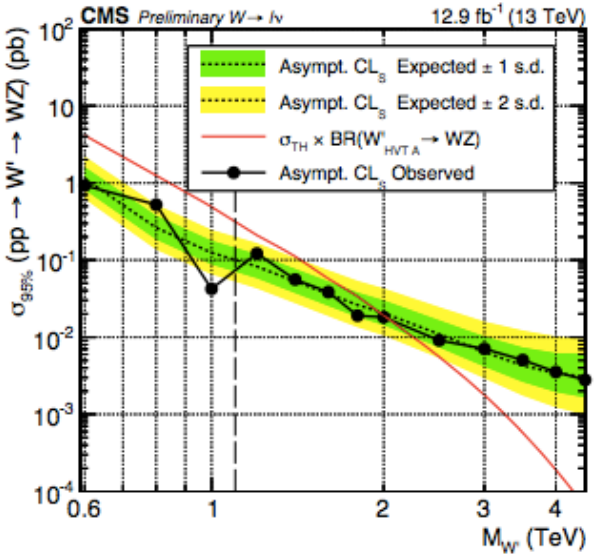




spin 2 hypothesis

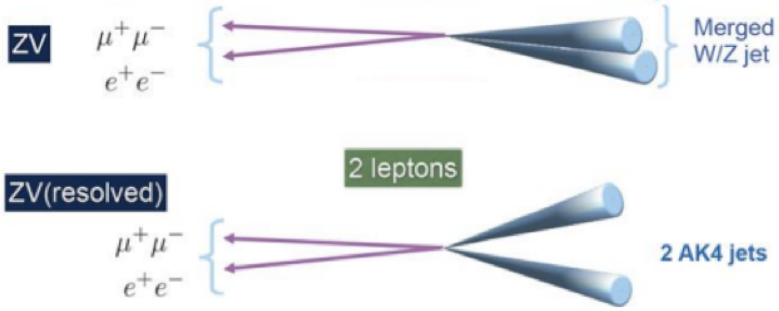


spin 1 hypothesis

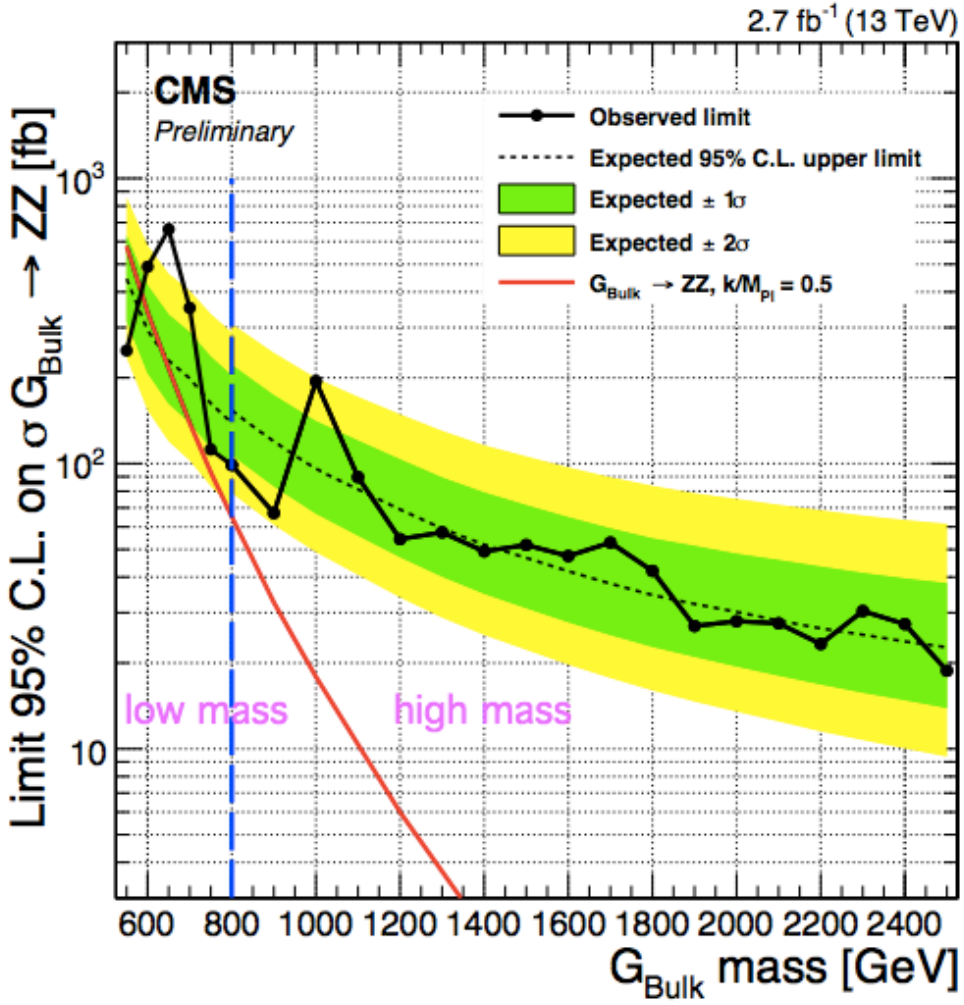


CMS-PAS-B2G-16-020

Resonant Z(ll)V(qq)



- Resolved hadronic V analysis at low mass
- Merged jet at high masses



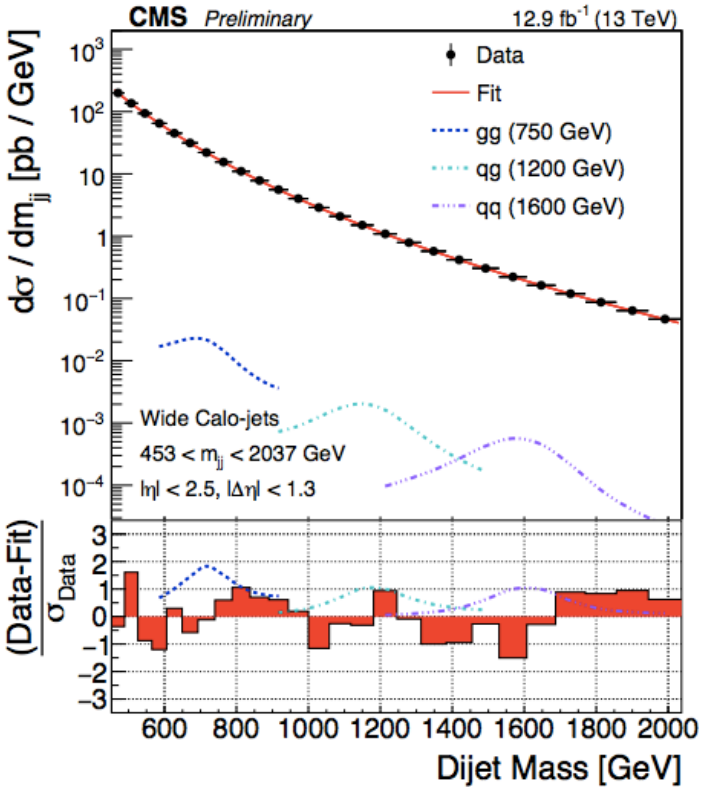
CMS-PAS-B2G-16-010

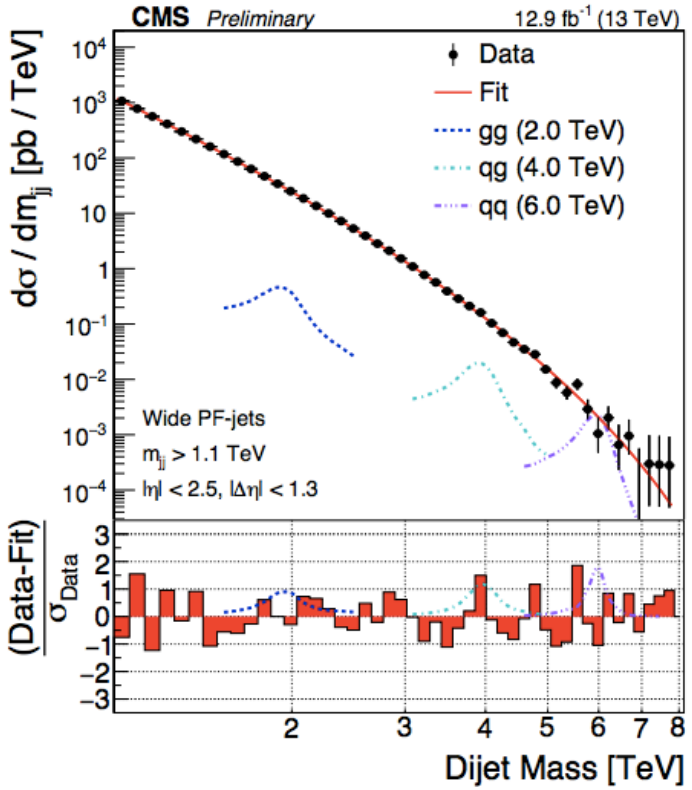
Search for Di-Jet Resonances

CMS-PAS-EXO-16-032

- Any resonance coupling to quarks/ gluons.
- Strong production -> high rate, high mass reach
- Dedicated low-mass and high-mass searches
- Data scouting at low-masses: low trigger threshold by storing reduced info

Fit to line-shapes of detector resolution gaussians convoluted with theoretical BW shapes





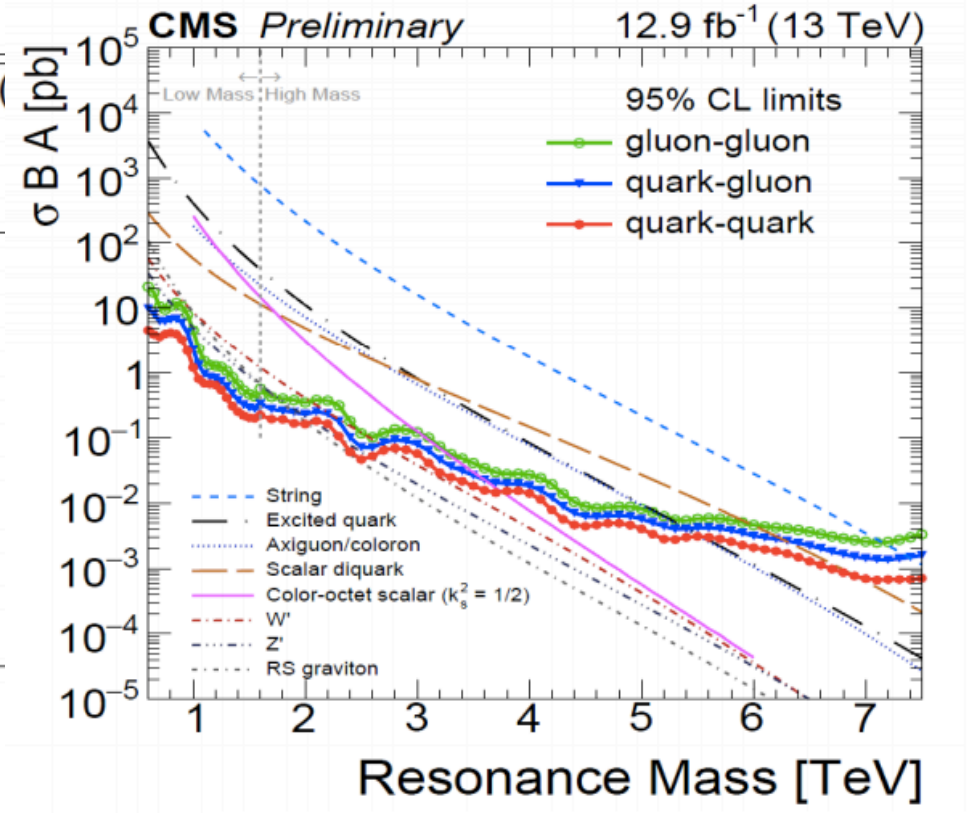
Di-Jet Interpretations

- Predicted by BSM models: axigluons, colorons, W′/Z′ bosons, color octet scalars, string resonances, RS, etc.

CMS-PAS-EXO-16-032

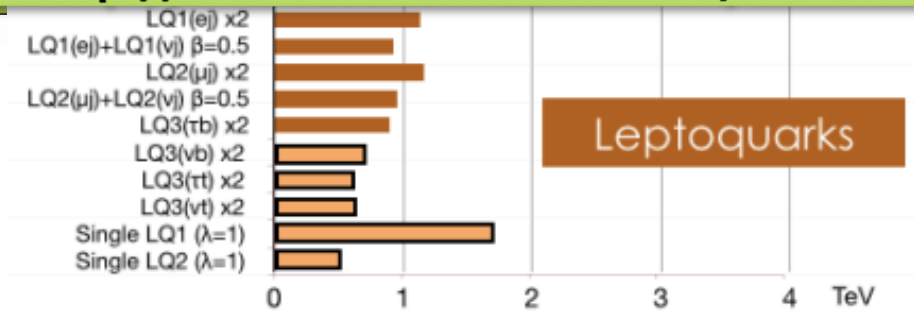
Model	Final State	Observed ($12.9\ \text{fb}^{-1}$ 13 TeV
String	qg	7.4 (7.4)
Scalar diquark	qq	6.9 (6.8)
Axigluon/coloron	$q\bar{q}$	5.5 (5.6)
Excited quark	qg	5.4 (5.4)
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.0 (3.3)
W′	$q\bar{q}$	2.7 (3.1)
Z′	$q\bar{q}$	2.1 (2.3)
RS Graviton	$q\bar{q}$, gg	1.9 (1.8)

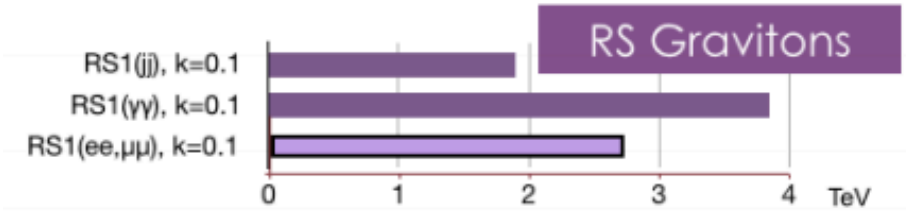
Up to 7.4 TeV



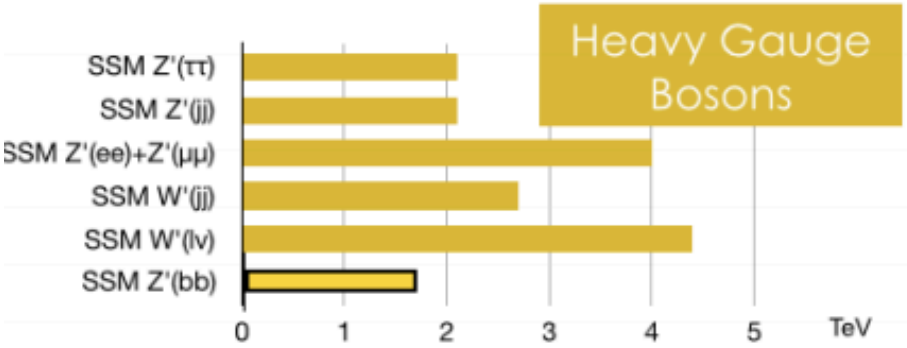
Exotica Summary I

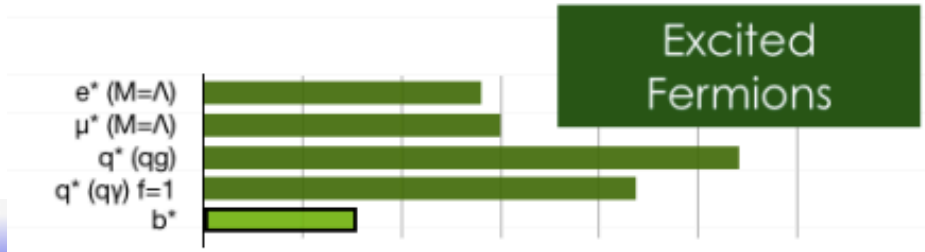
http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

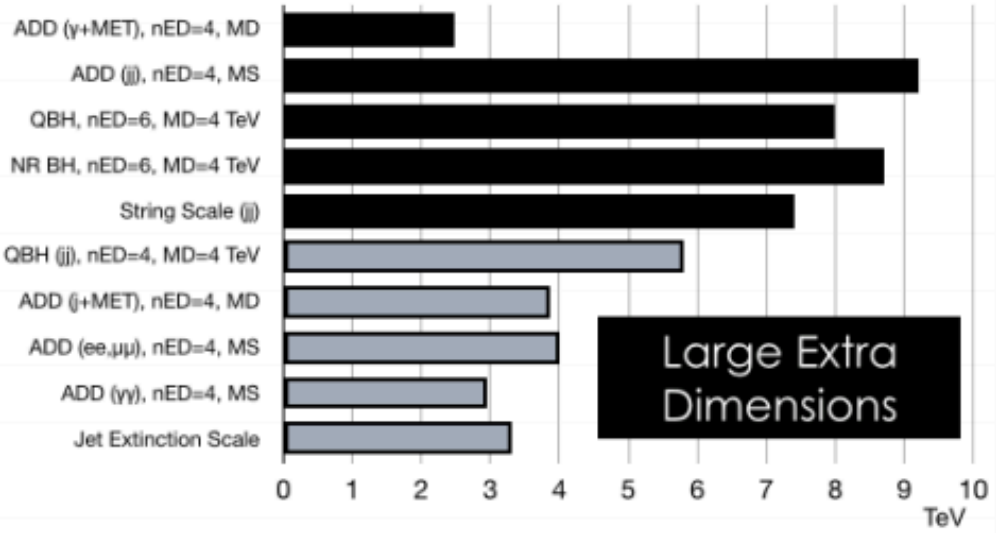


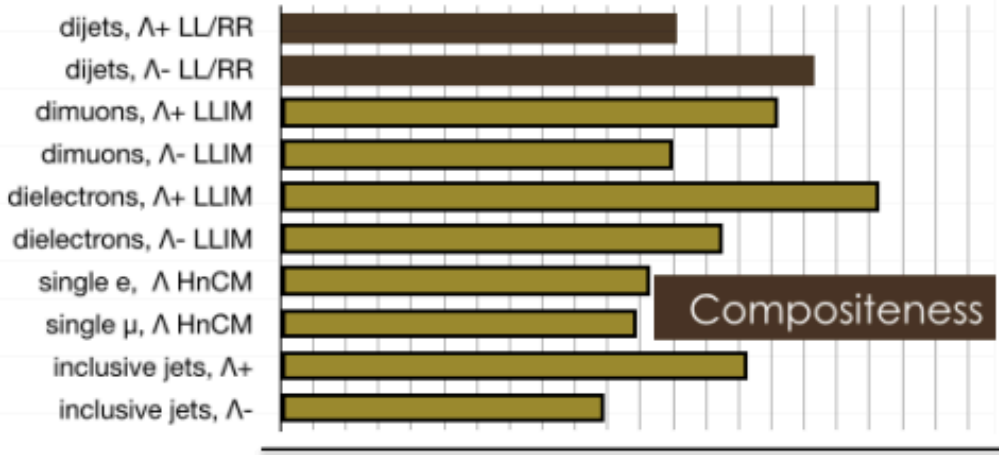


CMS Preliminary









Exotica Summary II

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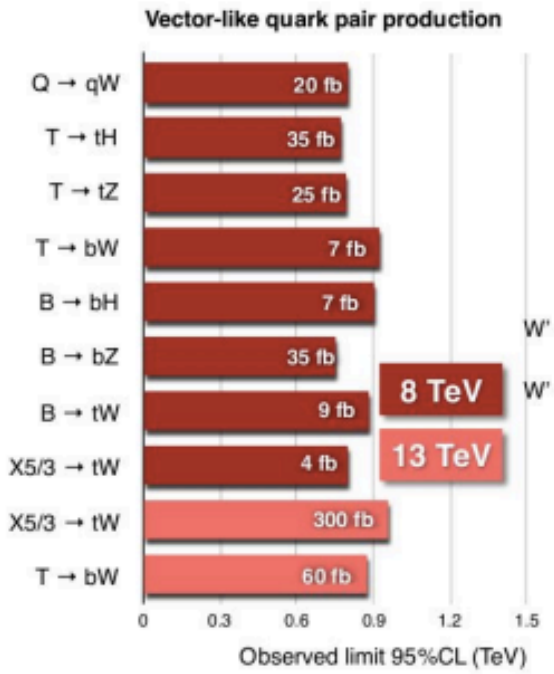
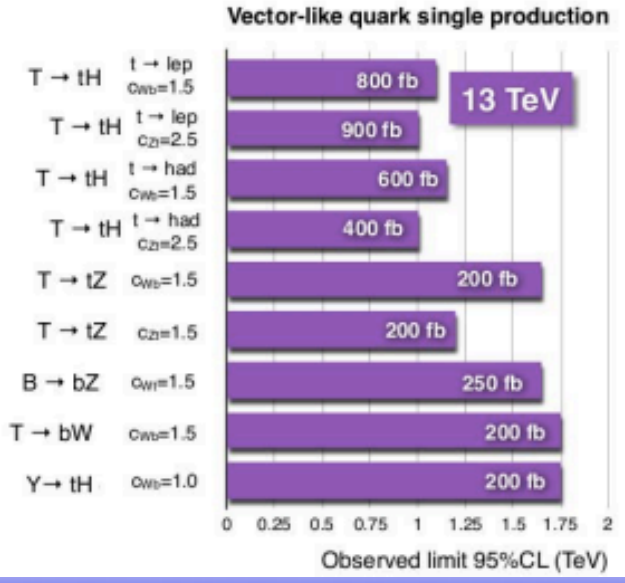
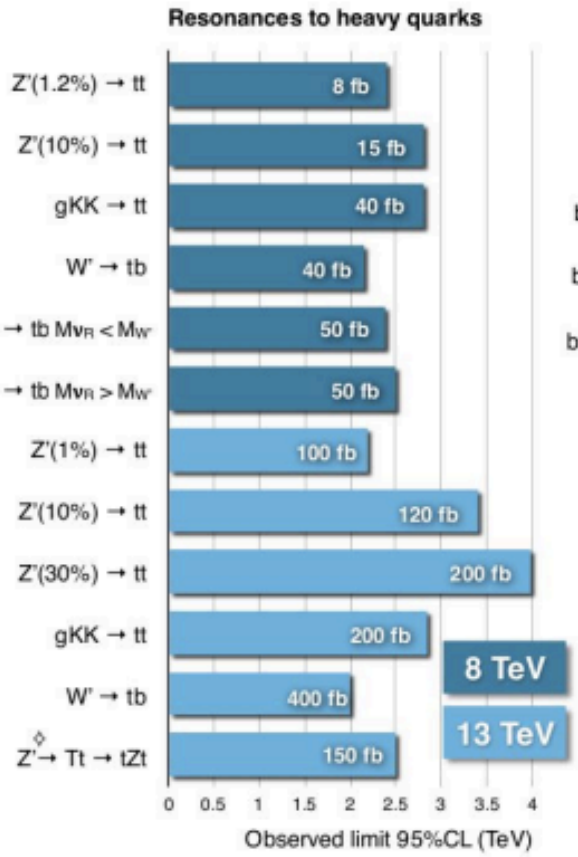
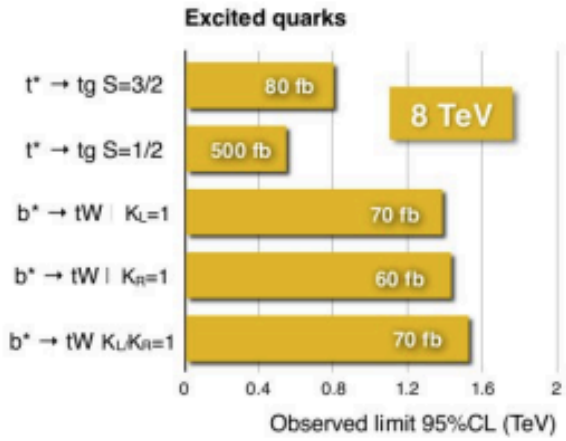
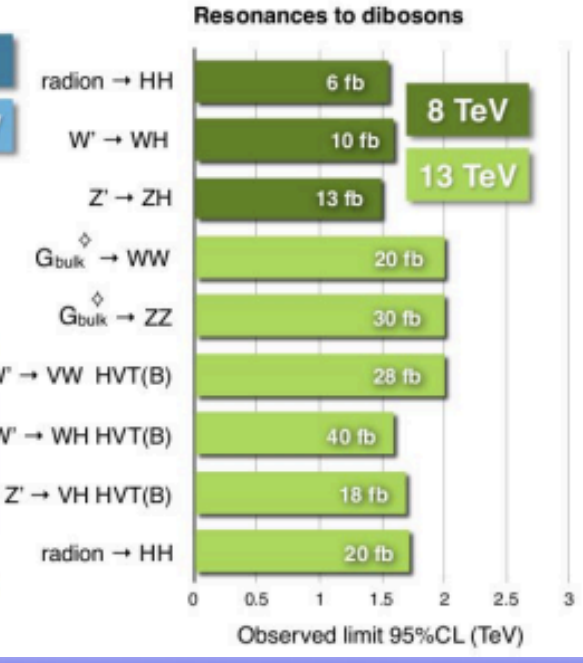




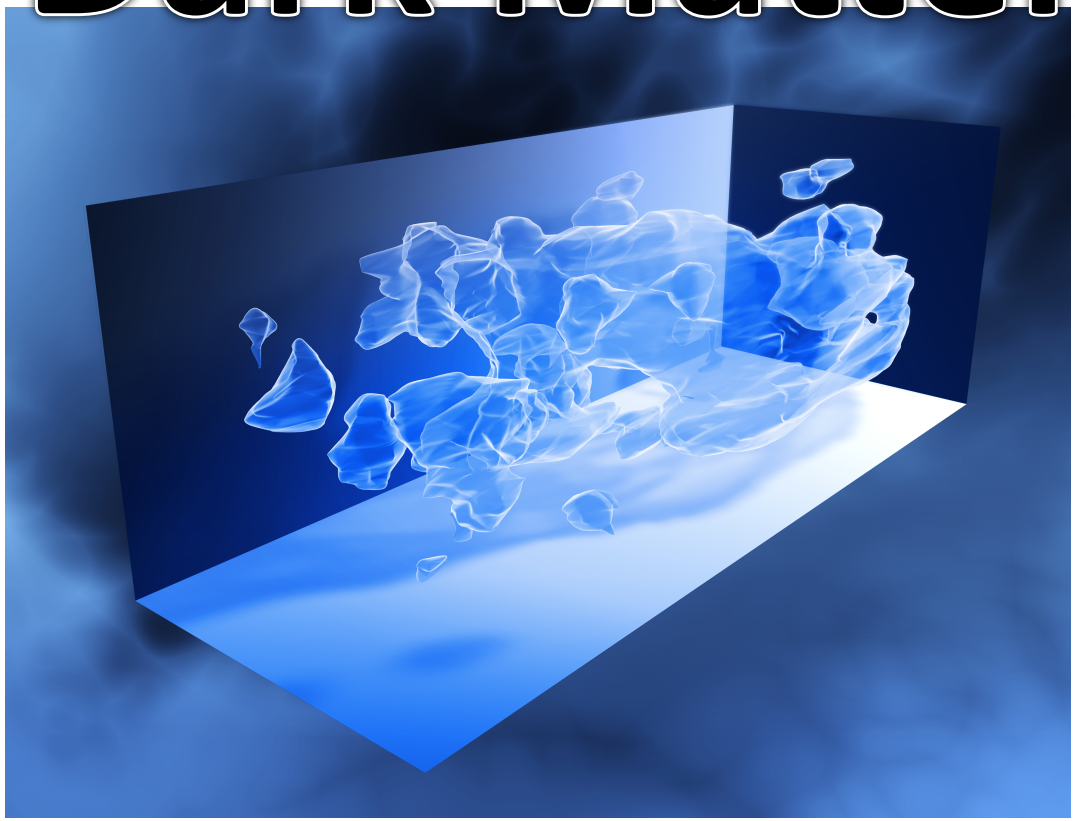


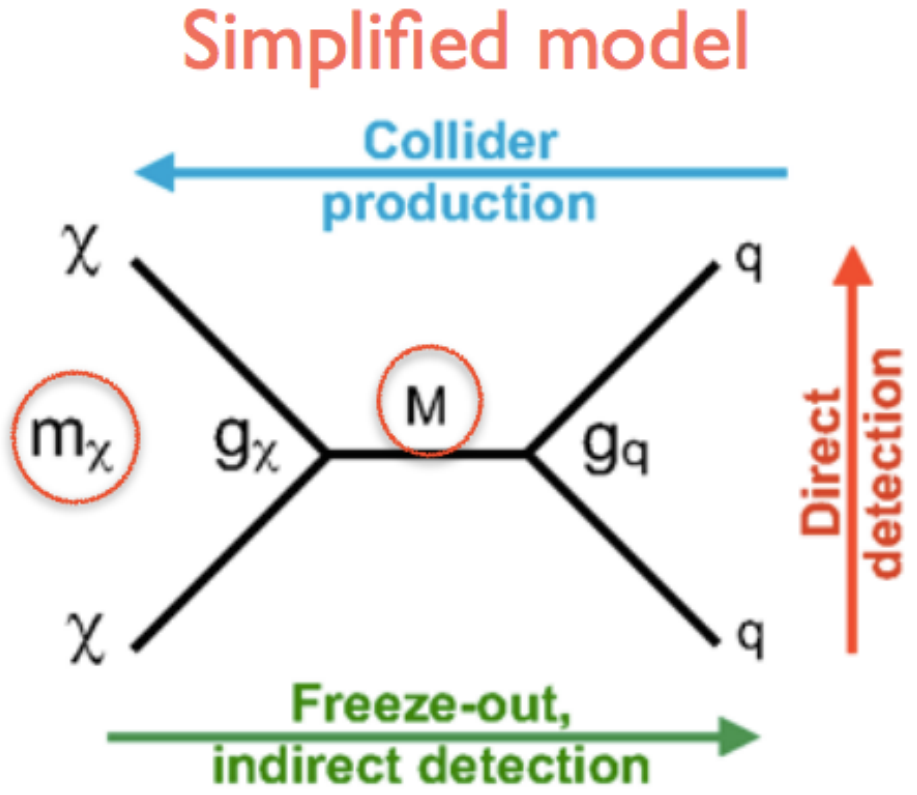




B2G
new physics searches with heavy SM particles

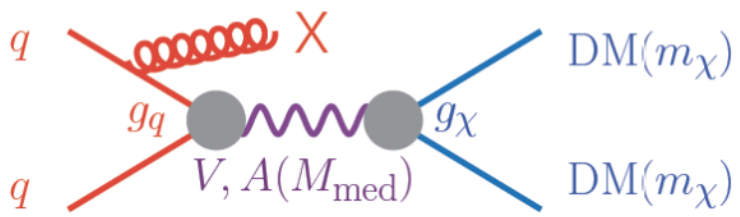
Dark Matter



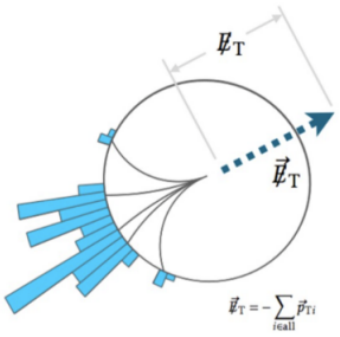


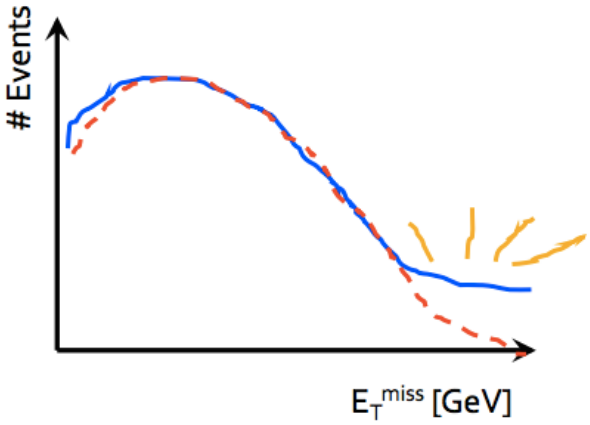
- Interpretation within Simplified models
- Four parameters: DM mass, Mediator mass, SM and DM couplings
- Couplings chose to keep the mediator width/mass below ~10%

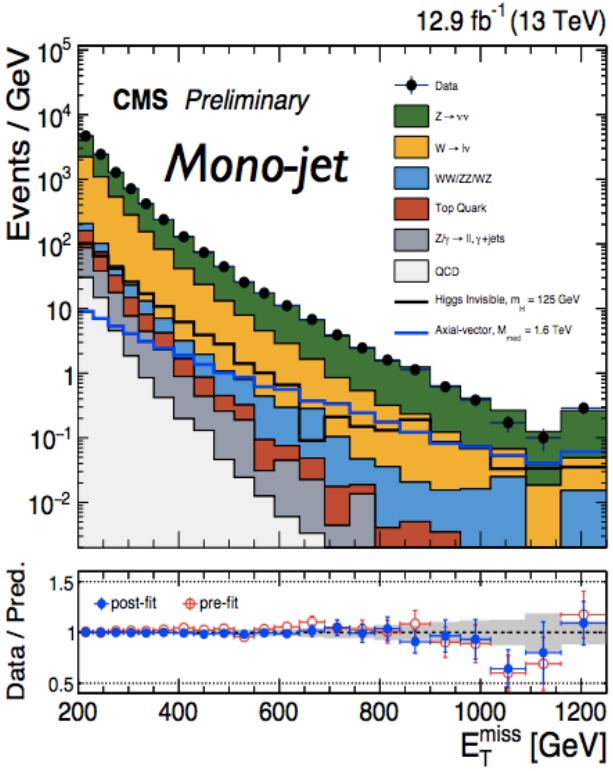
Mono-X Searches

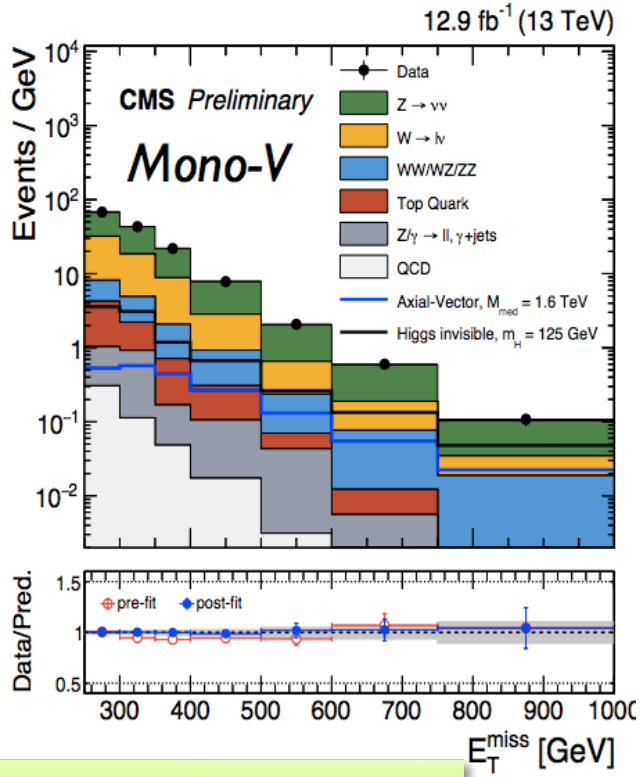


- Trigger on Initial State Radiation
- Search for mono-object recoiling against MET
- Main backgrounds: Z(νν)+jets, W(lν)+jets (lost lepton)
- Background estimation using control regions: ll+jets, γ+jets, l+jets





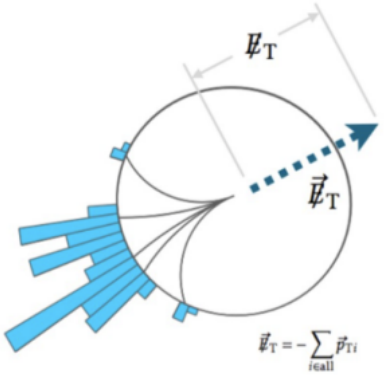




CMS-PAS-EXO-16-037

Mono-X Searches

- Search for mono-object recoiling against MET



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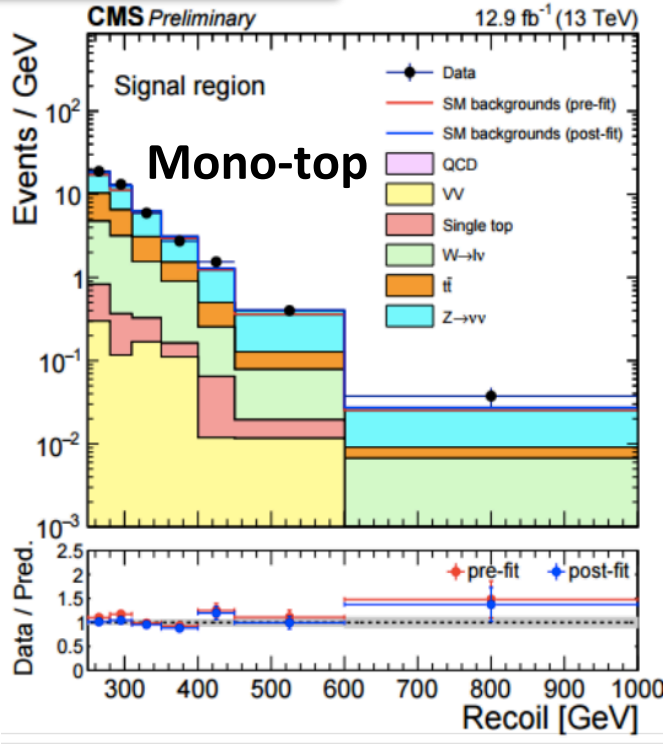
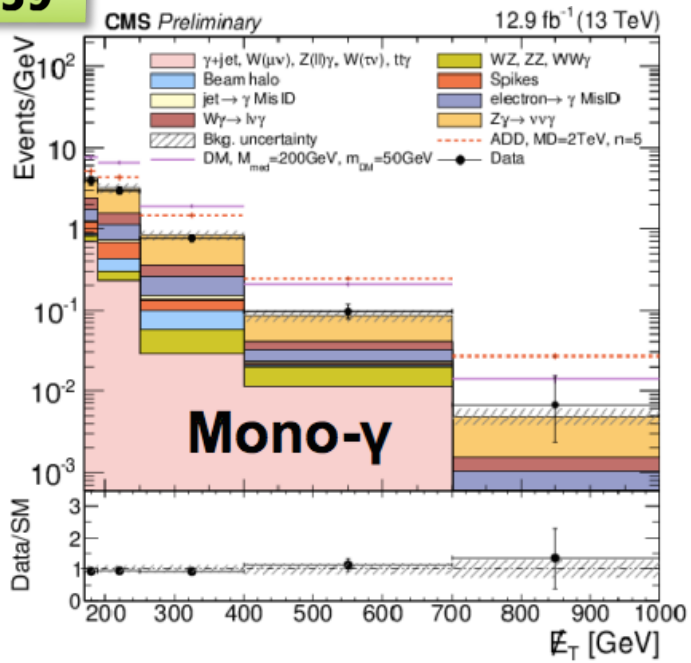
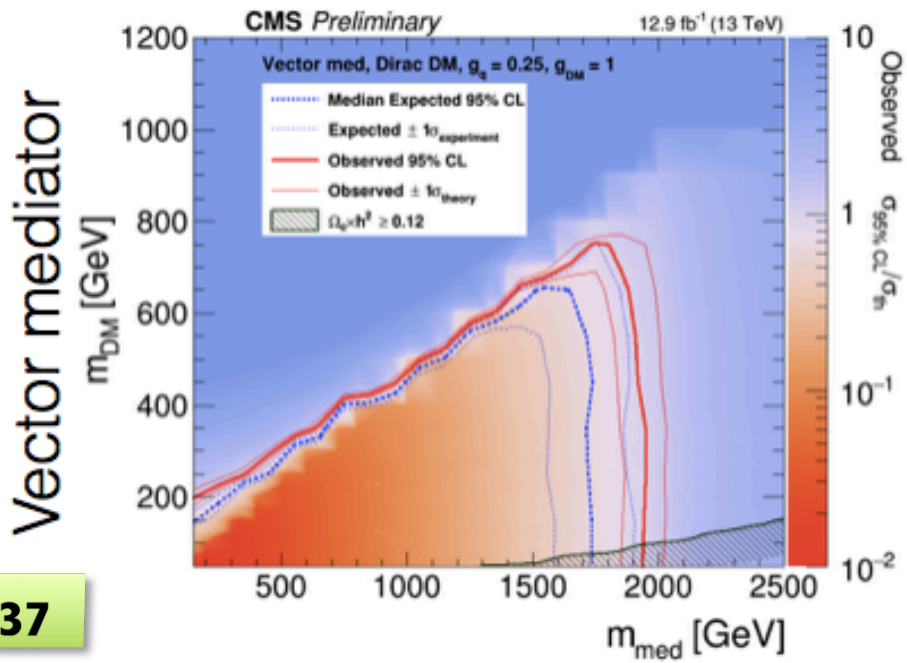


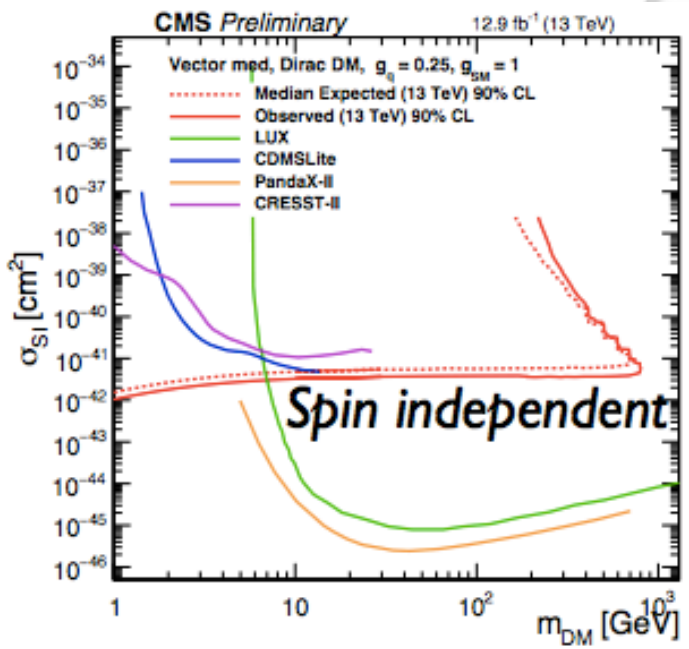
CMS-PAS-EXO-16-039

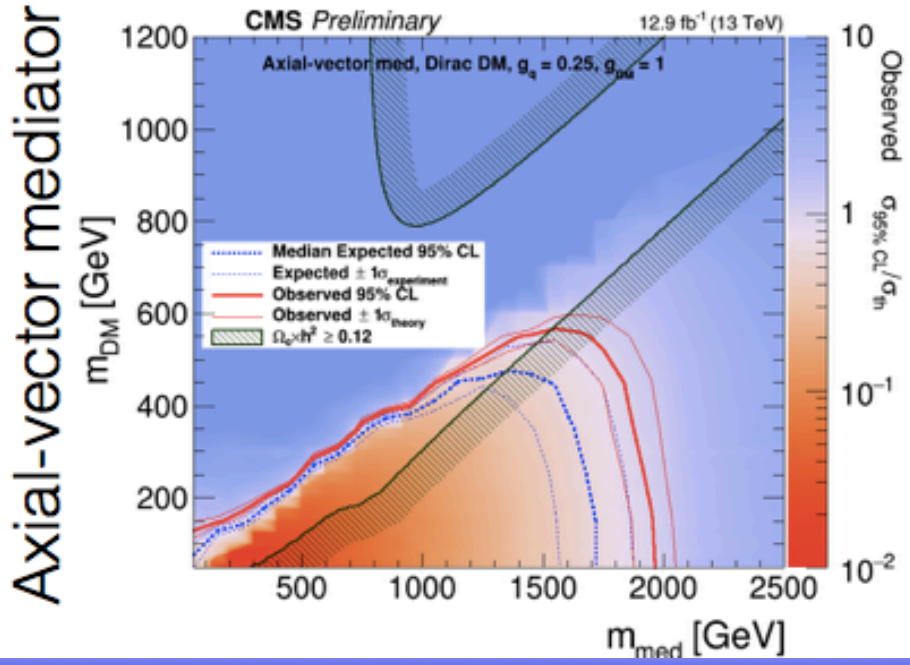


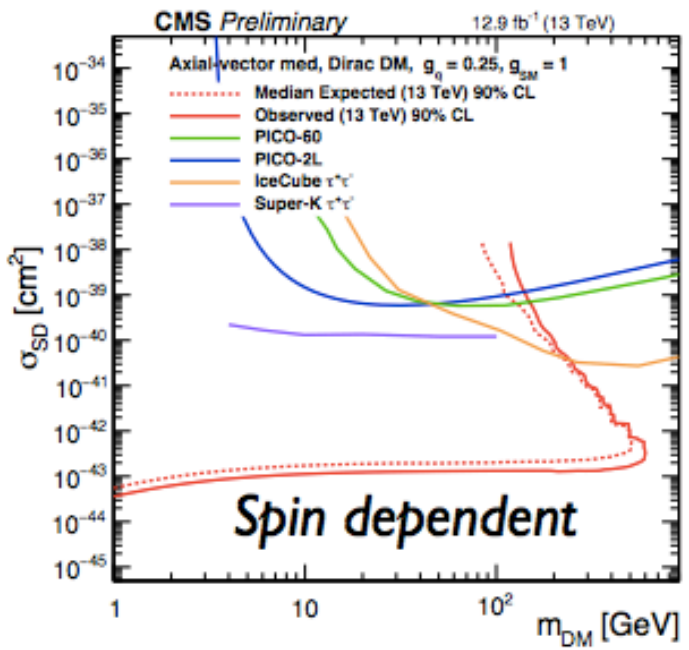
Mono-X Interpretations

CMS-PAS-EXO-16-037

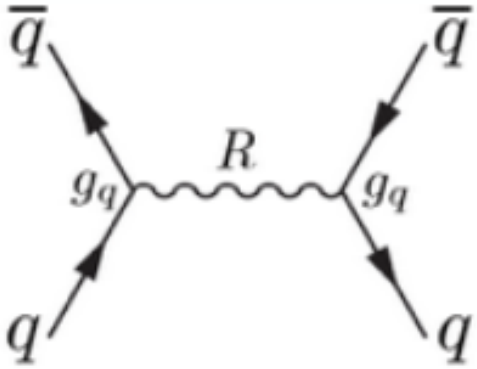






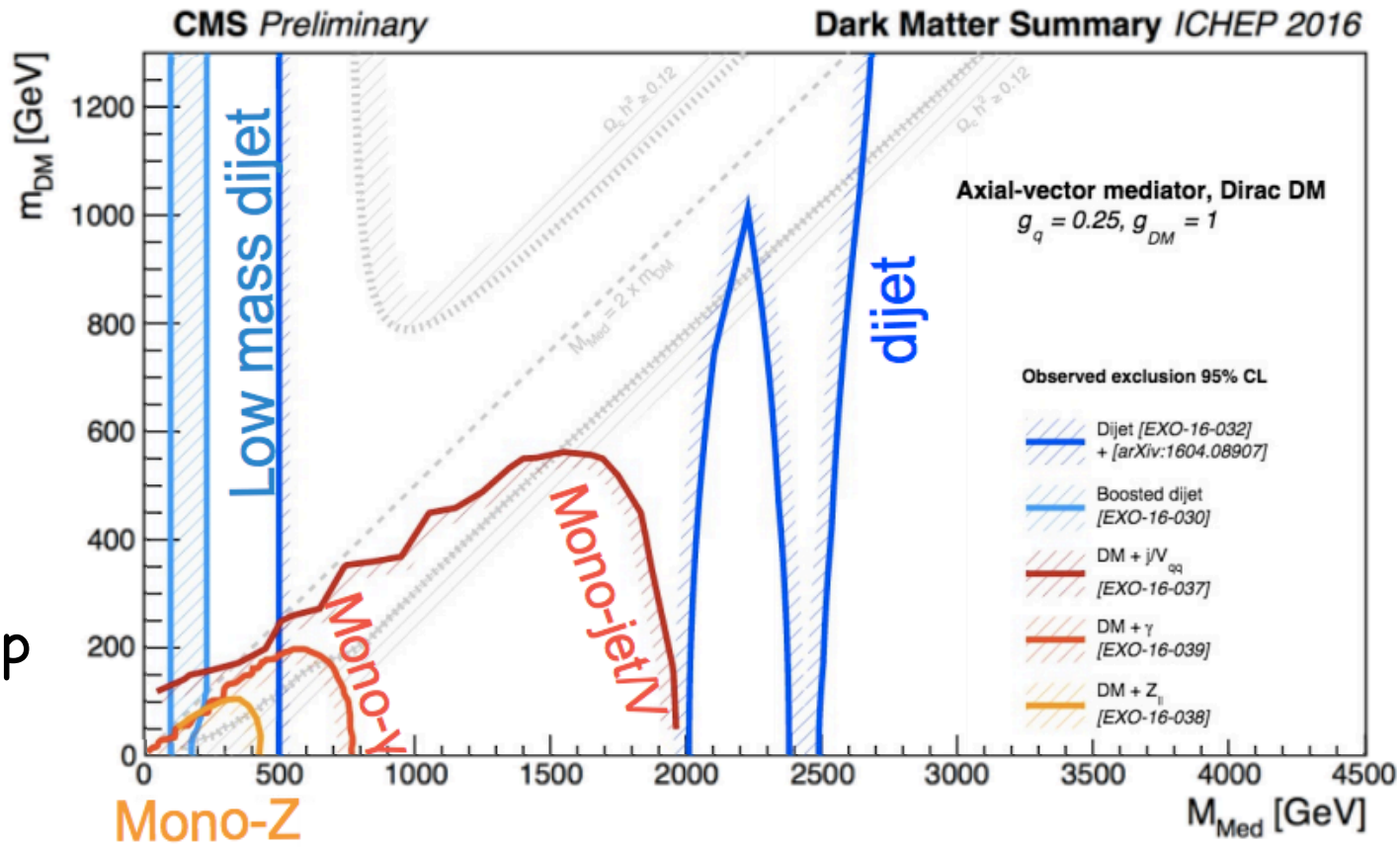


Searching for Mediator

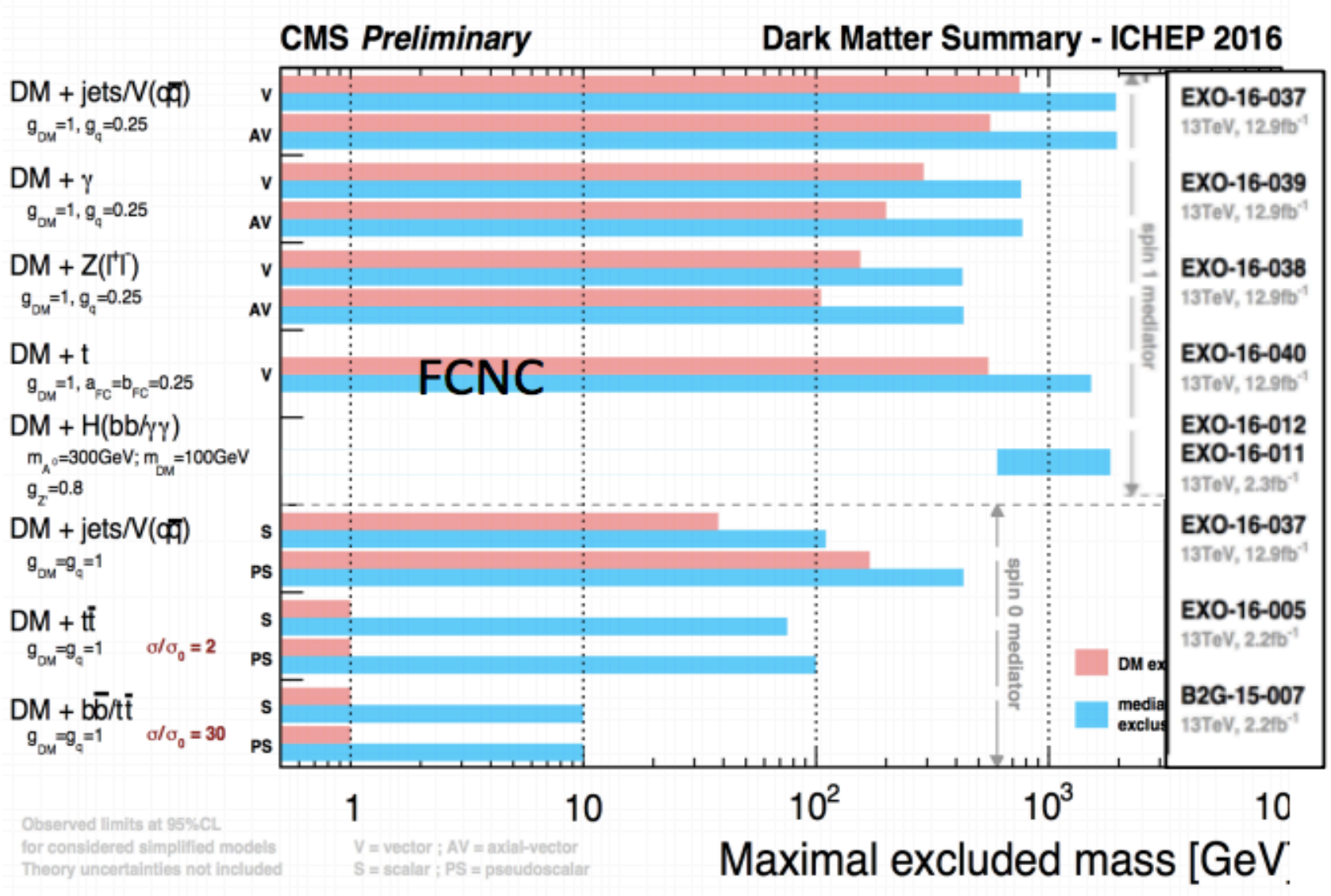


- Recycle di-jet searches

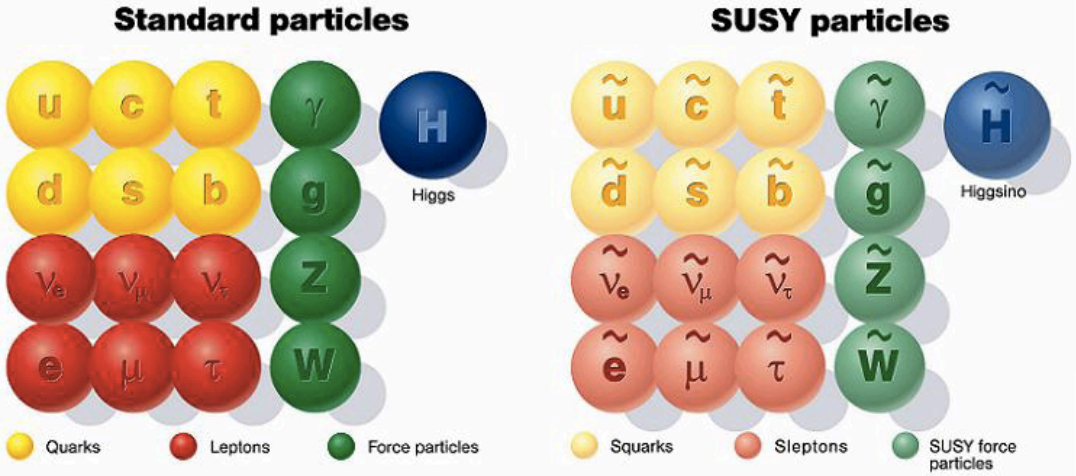
- DM exclusions up to ~550 GeV
- Vector mediator up to ~2000 GeV



Dark Matter Summary



SUSY



- SUSY is around the corner
- Which one?

SUSY Signatures

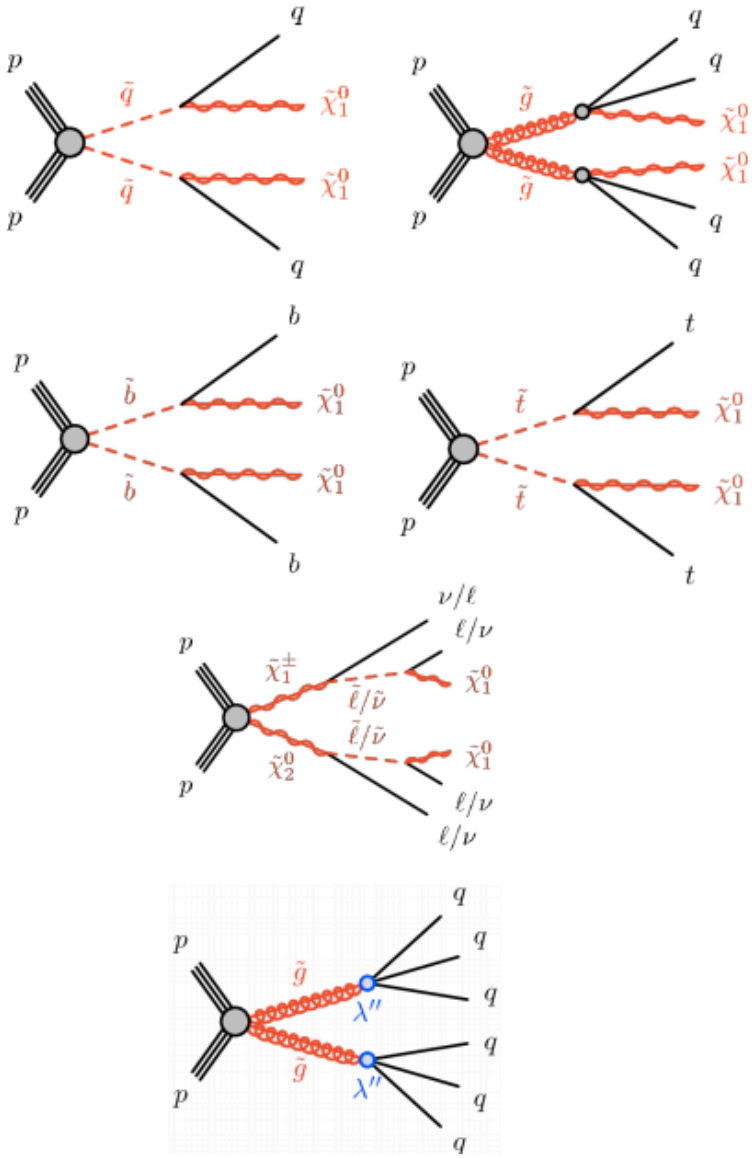
- Simplified model interpretations (BR=1, 2D-parameter scan)

- Squark and gluino production
  - Strong production
  - High cross section
  - Jets and missing E_T

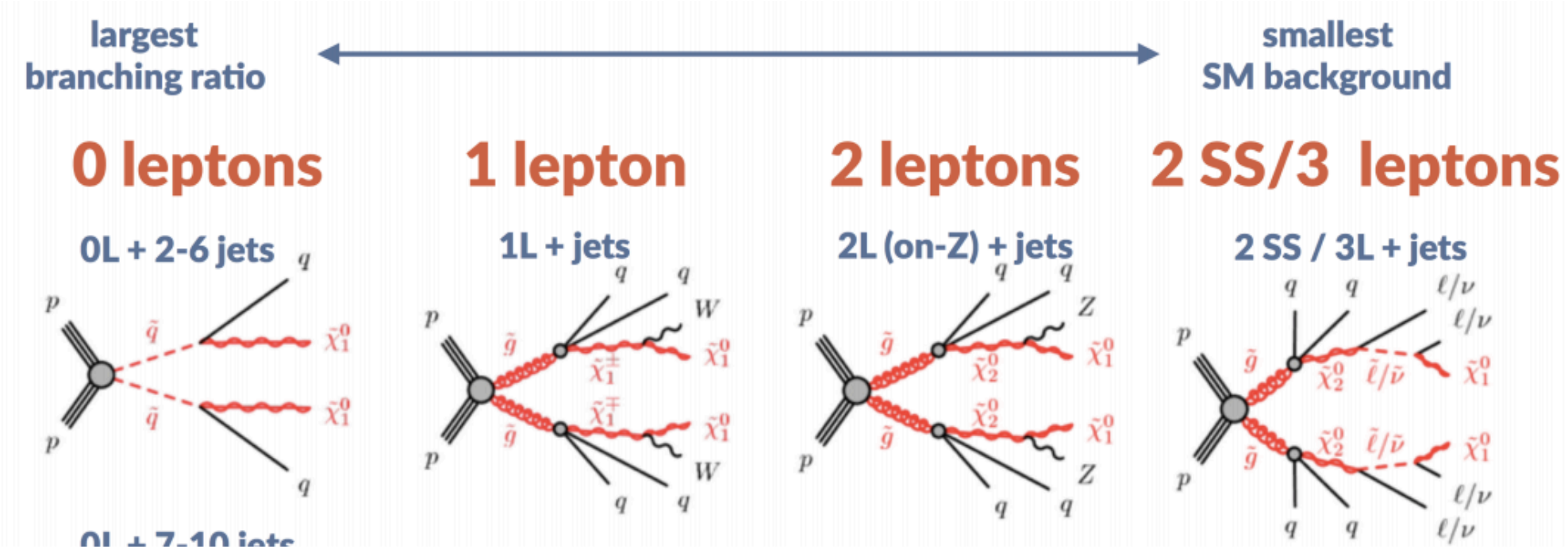
- 3rd generation squarks
  - Lower cross section
  - B-tagging

- Electroweak production
  - Low cross section, mass scale
  - Multi-lepton with missing E_T

- R-parity violating scenarios
  - No missing E_T, jets (and leptons)
  - High jet multiplicity, resonances

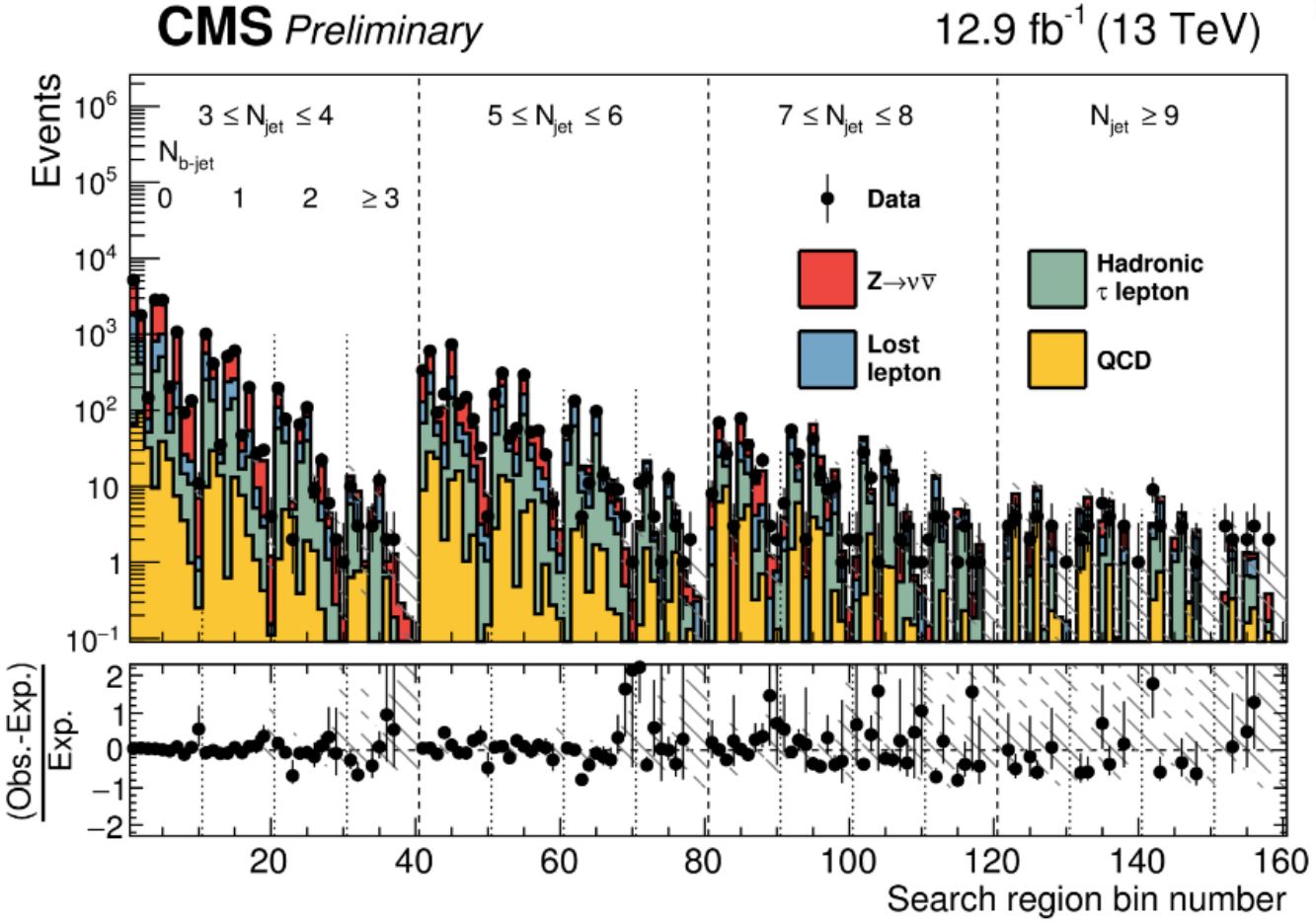


SUSY Signatures

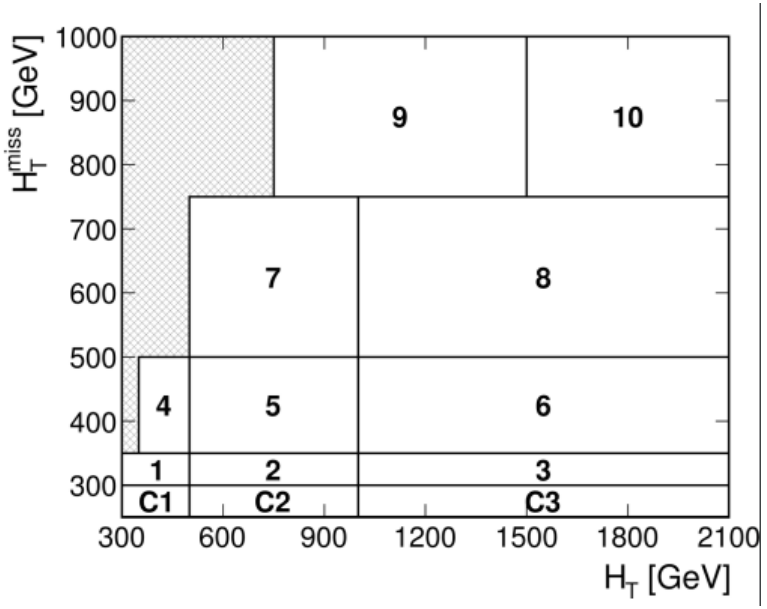


- Various signal regions to cover large range of models

Search for SUSY in Jets+MET



CMS-PAS-SUS-16-014



- Each region is further sub-divided based on # of jets, of b-jets

- Backgrounds are grouped by features : Z->νν, lost lepton, hadronic tau-lepton, QCD

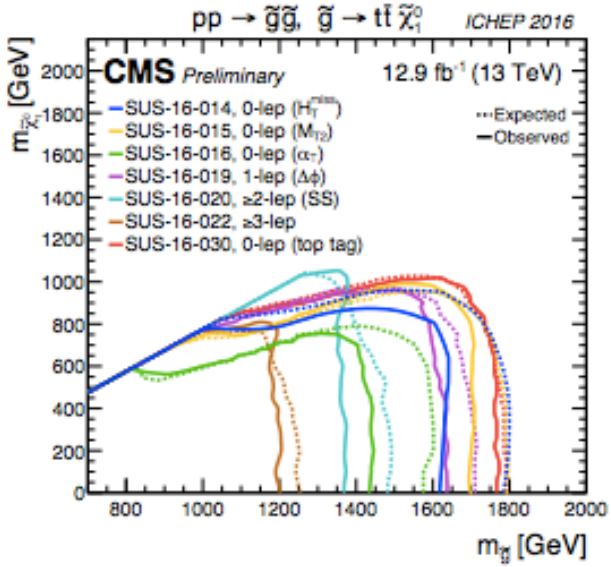
Strong Production Summary

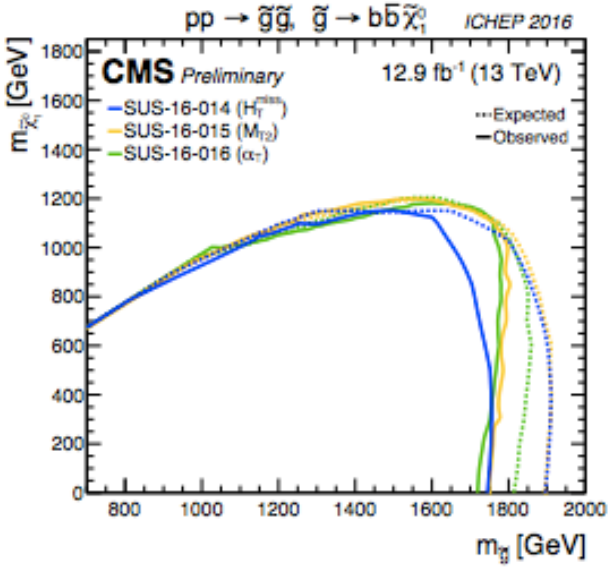
top

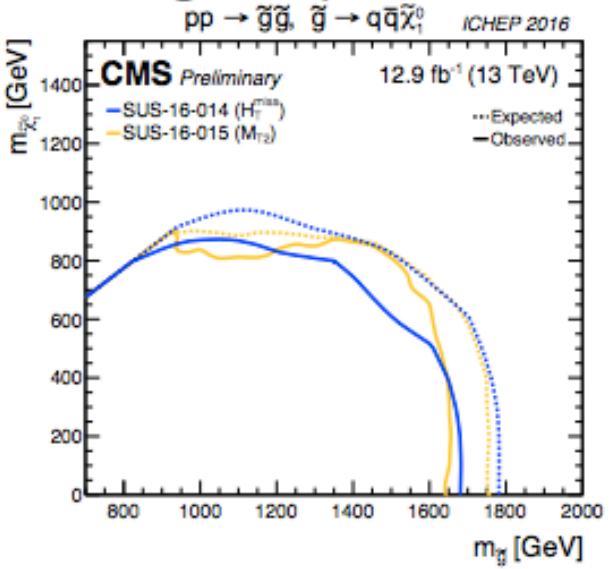
bottom

light quarks

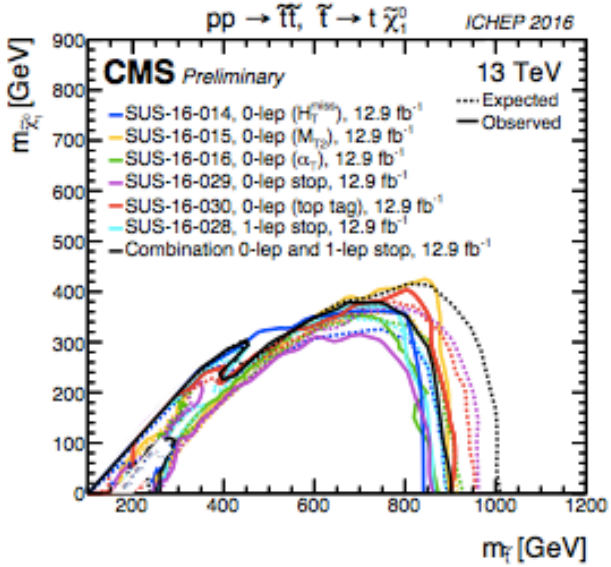
gluino production

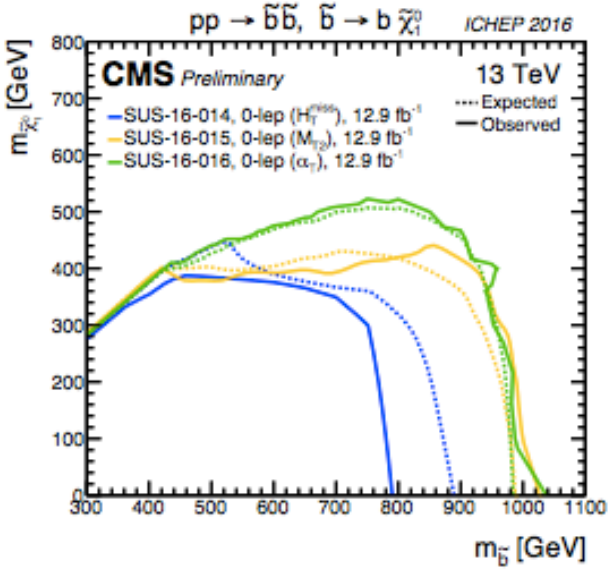


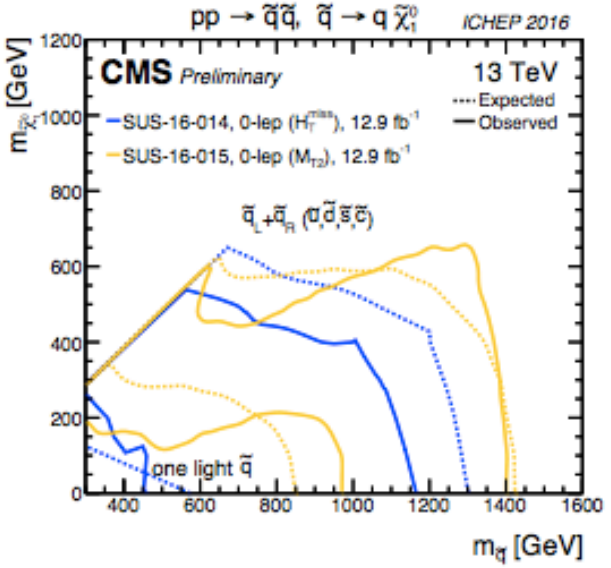




squark production



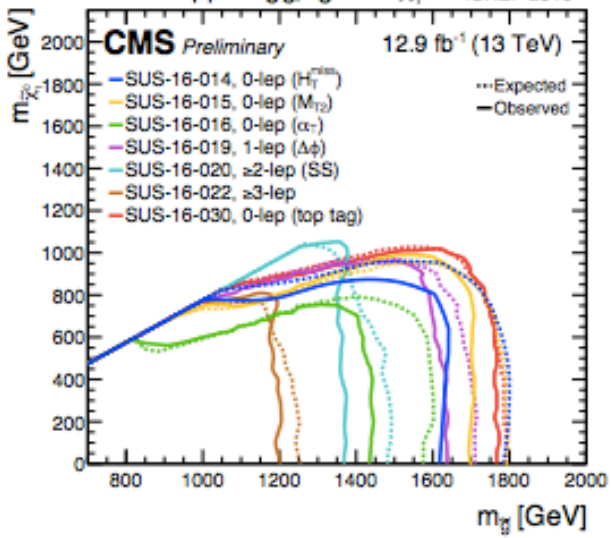




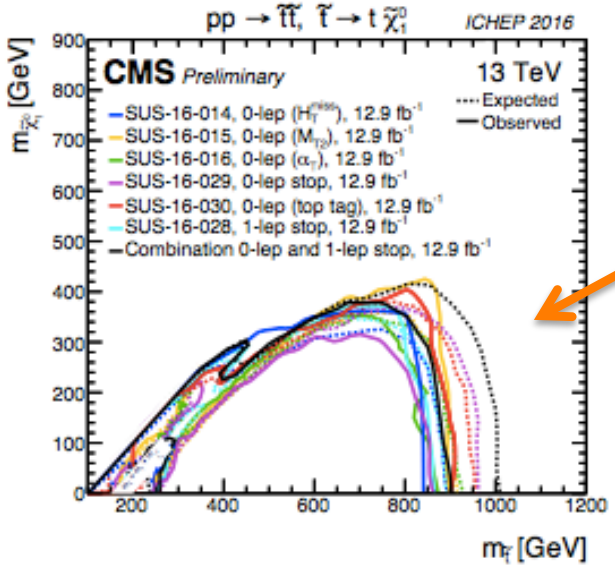
Strong Production Summary

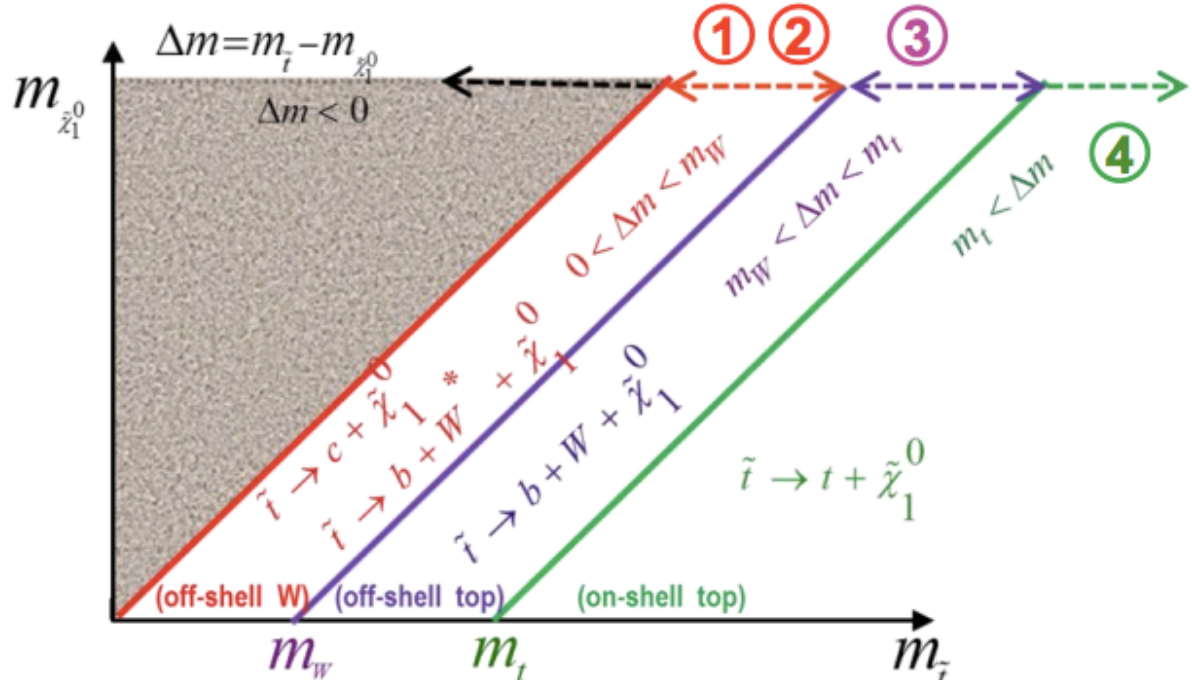
top

gluino production



squark production





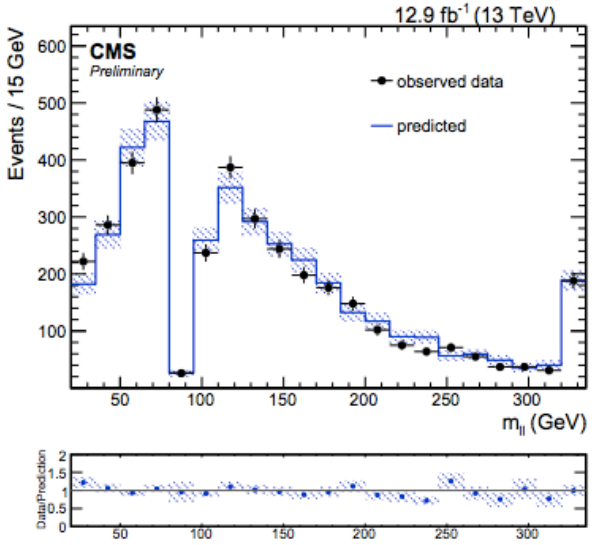
- Complex phase space structure

Di-lepton Edge Search

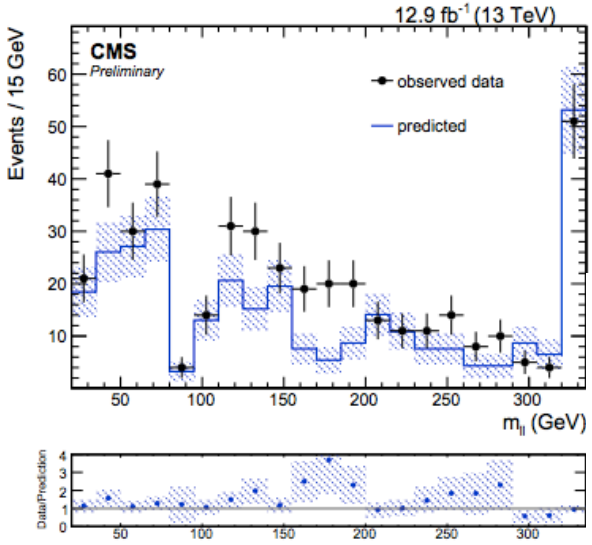
CMS-PAS-SUS-16-021

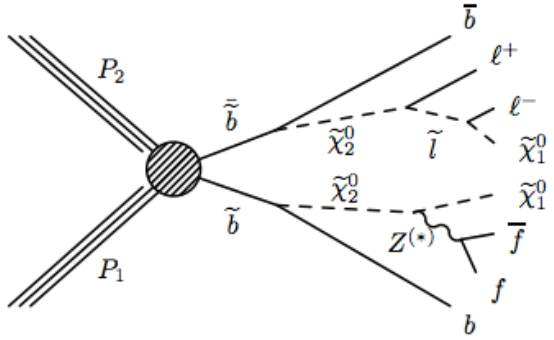
Regions based on Likelihood Discriminant

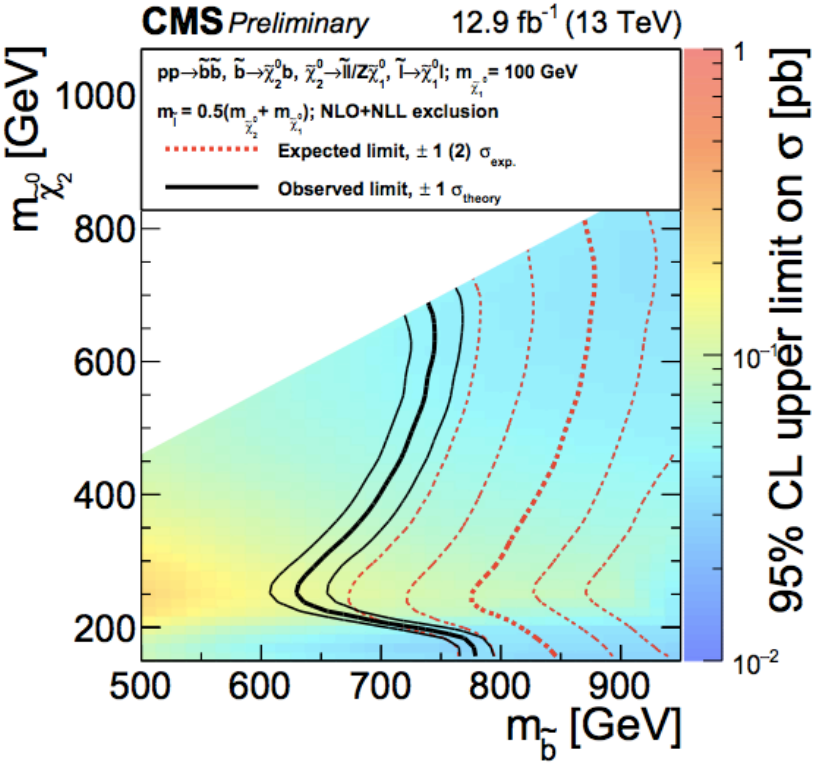
ttbar-enriched region



ttbar-depleted region



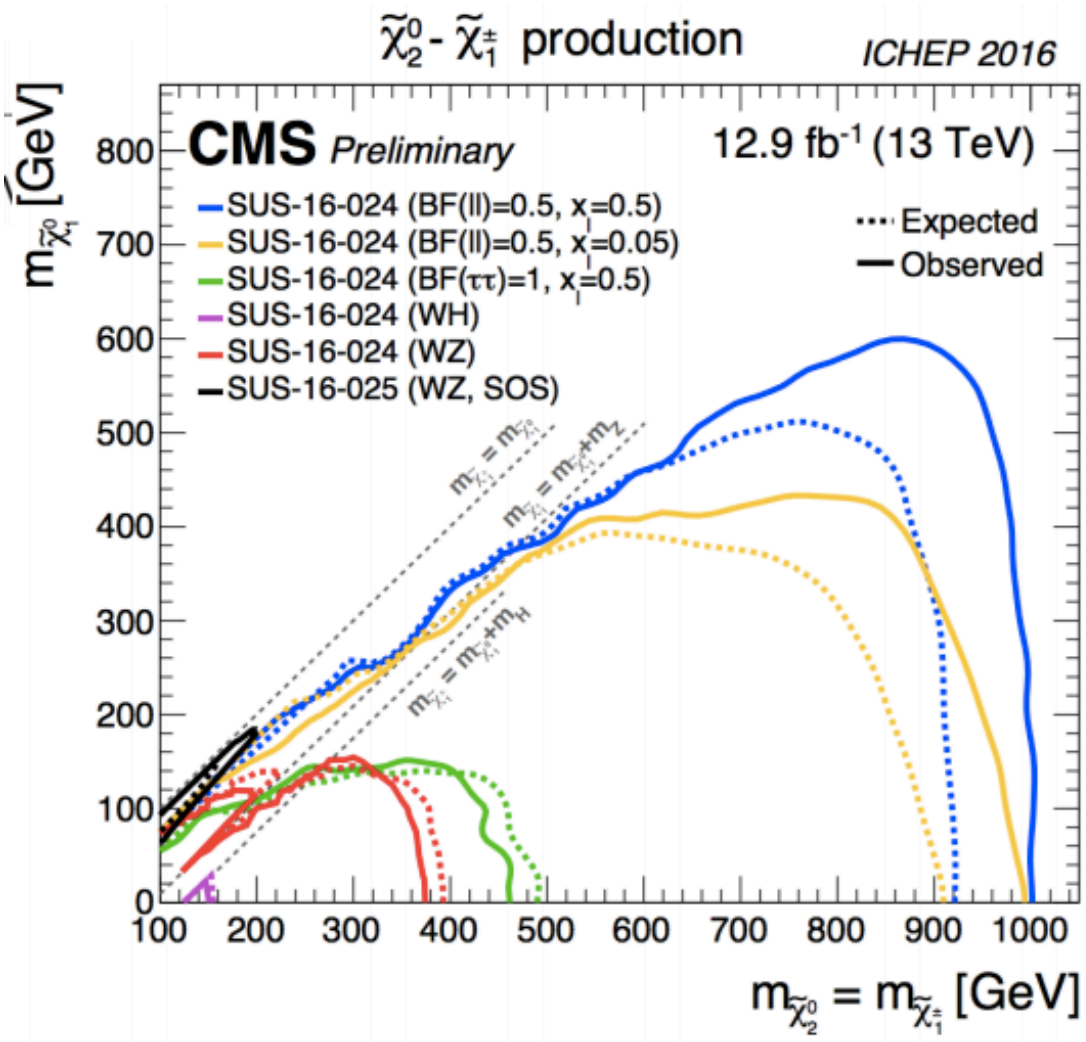




- Largest deviation 3.1σ for same-flavor dilepton events,
- $N_{jet} > 1$, $M_T < 100$ GeV, $E_T^{miss} > 150$ GeV and $p_T(ll) > 150$ GeV

Electroweak Production

Electroweak production



- 118 different search regions dependent on # jets, b-tags, leptons, flavour, charge

3l, *decay through sleptons (flavour democratic)* $m_{slep}=0.5*(m_{X1\pm}-m_{X01})$

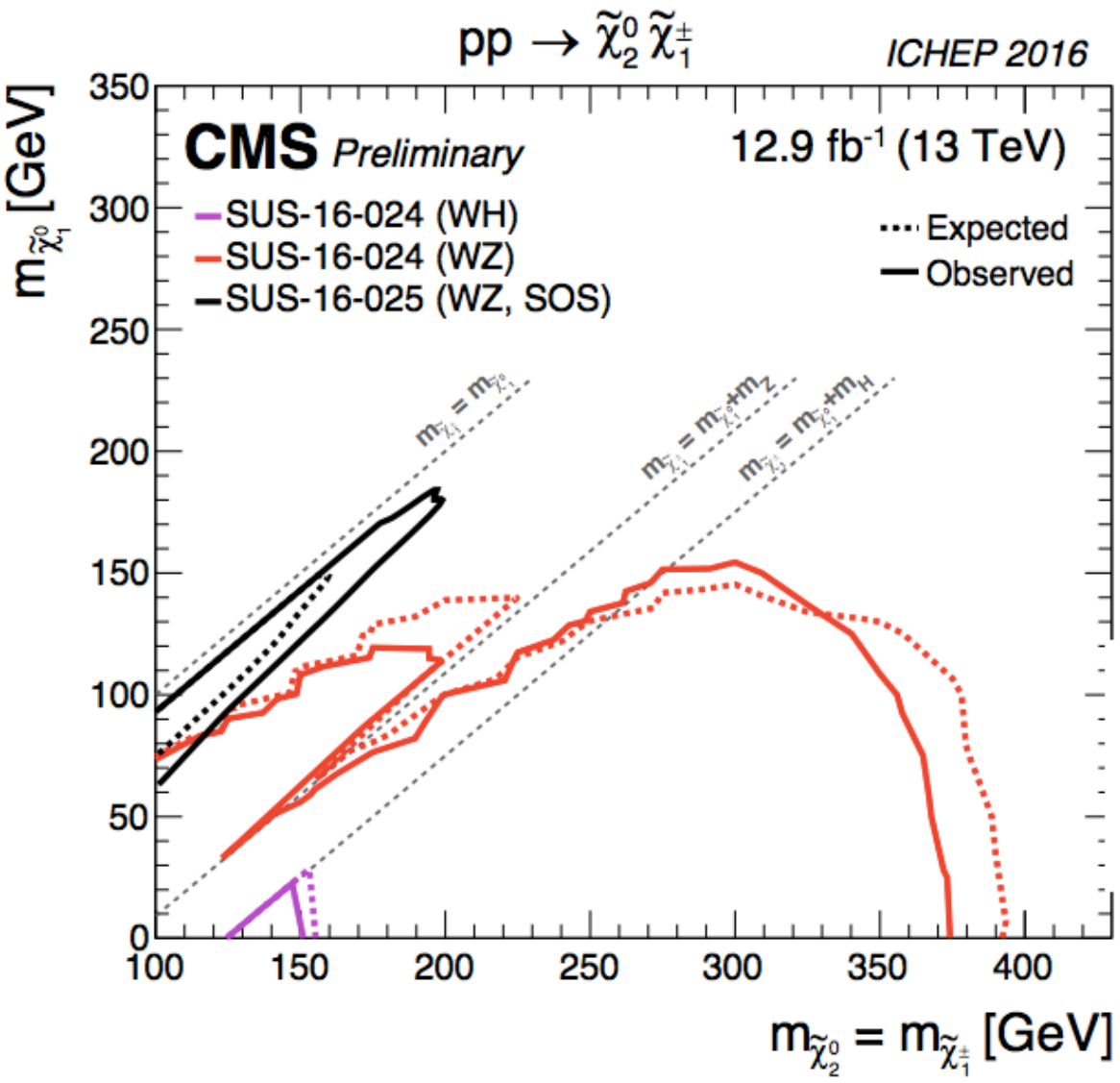
3l, *heavy sleptons, decay through WZ*

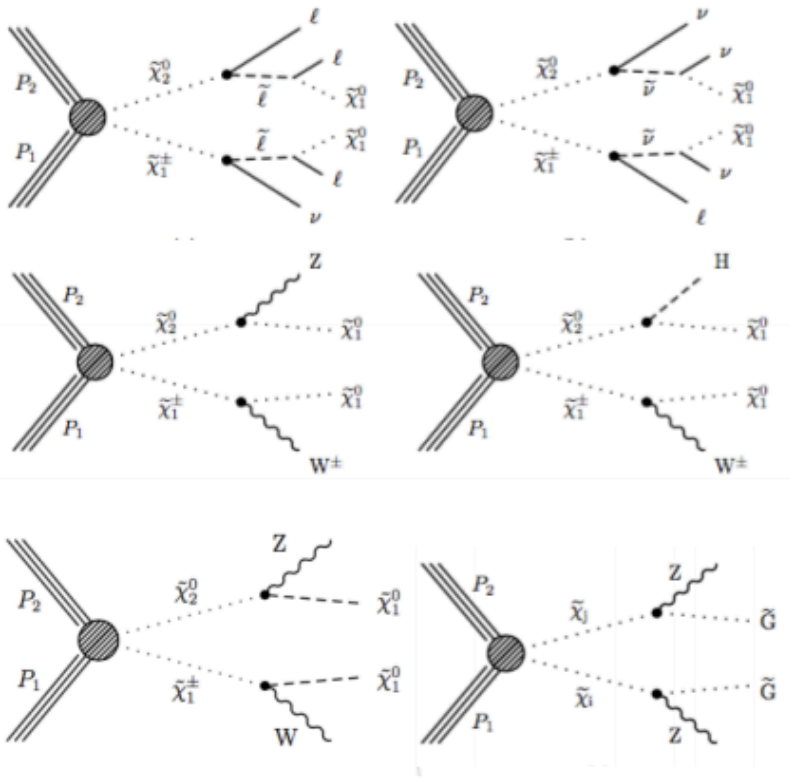
3l, *decay through staus (tau dominated)* $m_{stau}=0.5*(m_{X1\pm}-m_{X01})$

3l, 2lss *decay through sleptons (flavour democratic)* $m_{slep}=0.05*(m_{X1\pm}-m_{X01})$

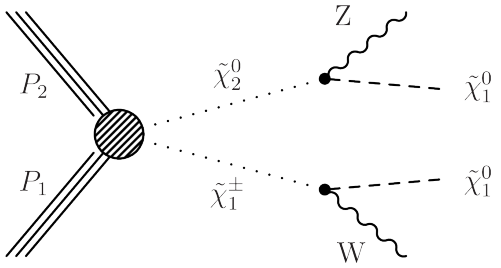
2los soft, *heavy sleptons, decay through WZ (first coverage of dM 7.5-30 GeV, limit at 175 GeV for dM=7.5)*
Milestone for Higgsino searches at LHC

Compressed Spectra

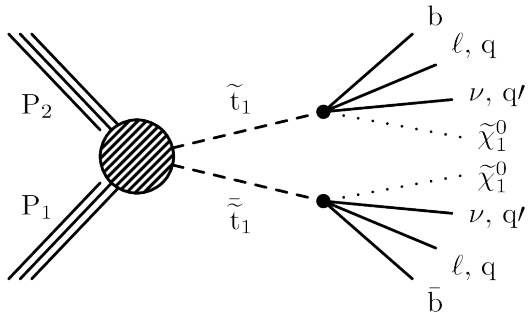


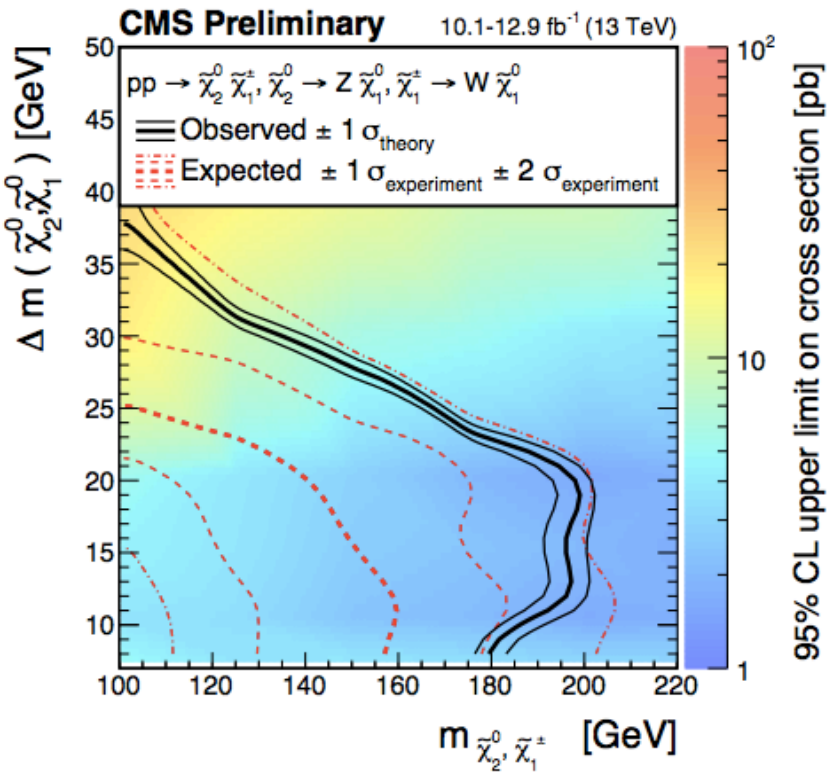


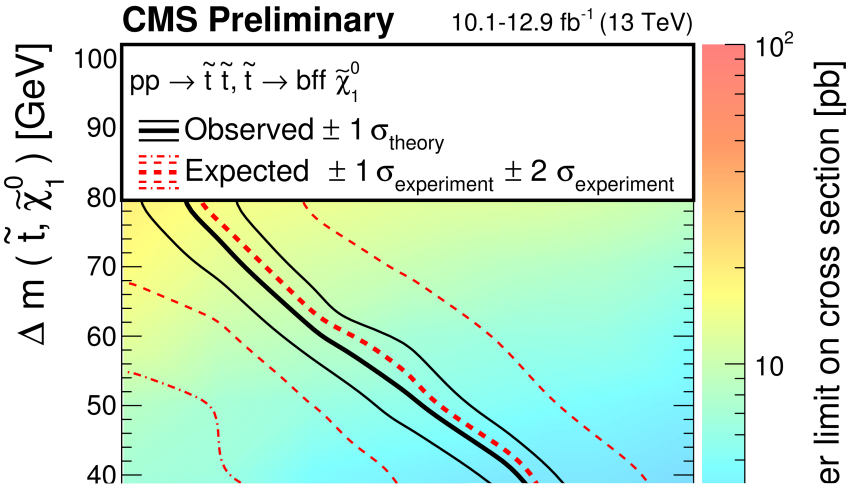
Compressed Spectra



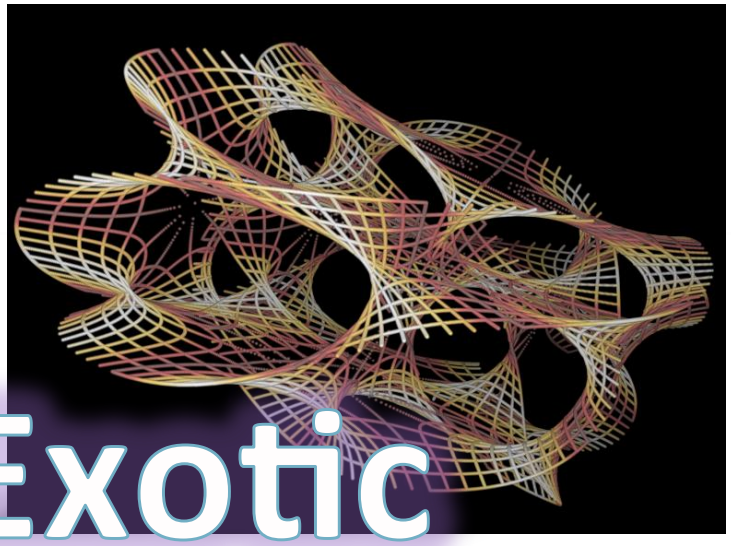
- Soft leptons from small mass splitting
- Trigger on met and/or soft muon pair



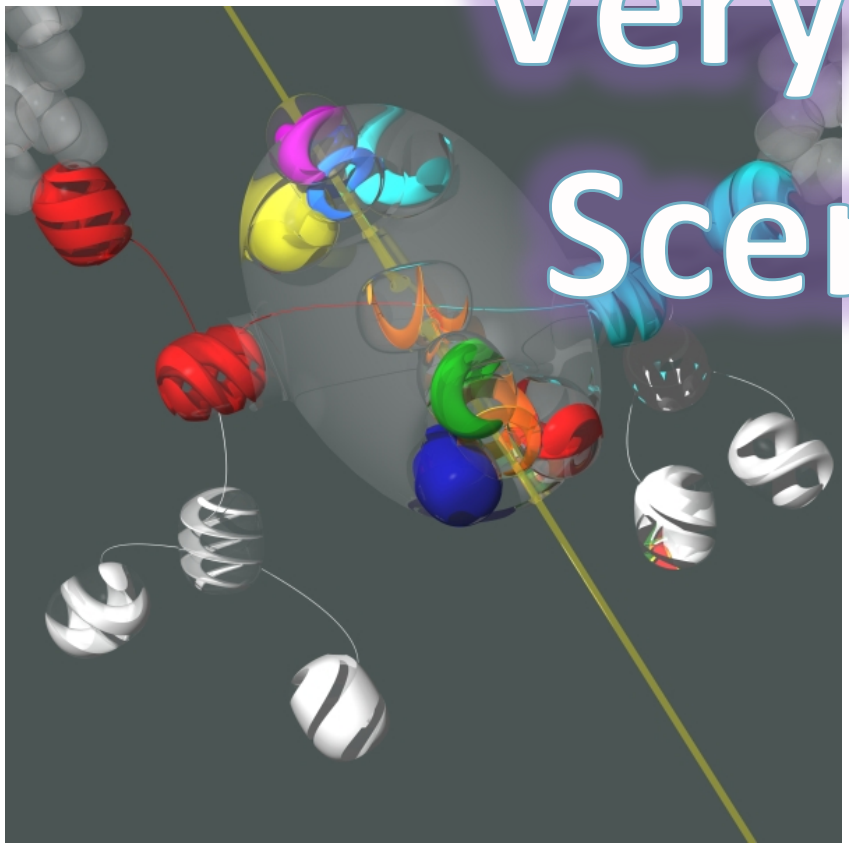




CMS-PAS-SUS-16-025



Very Exotic Scenarios



Searches for Long-Lived Particles

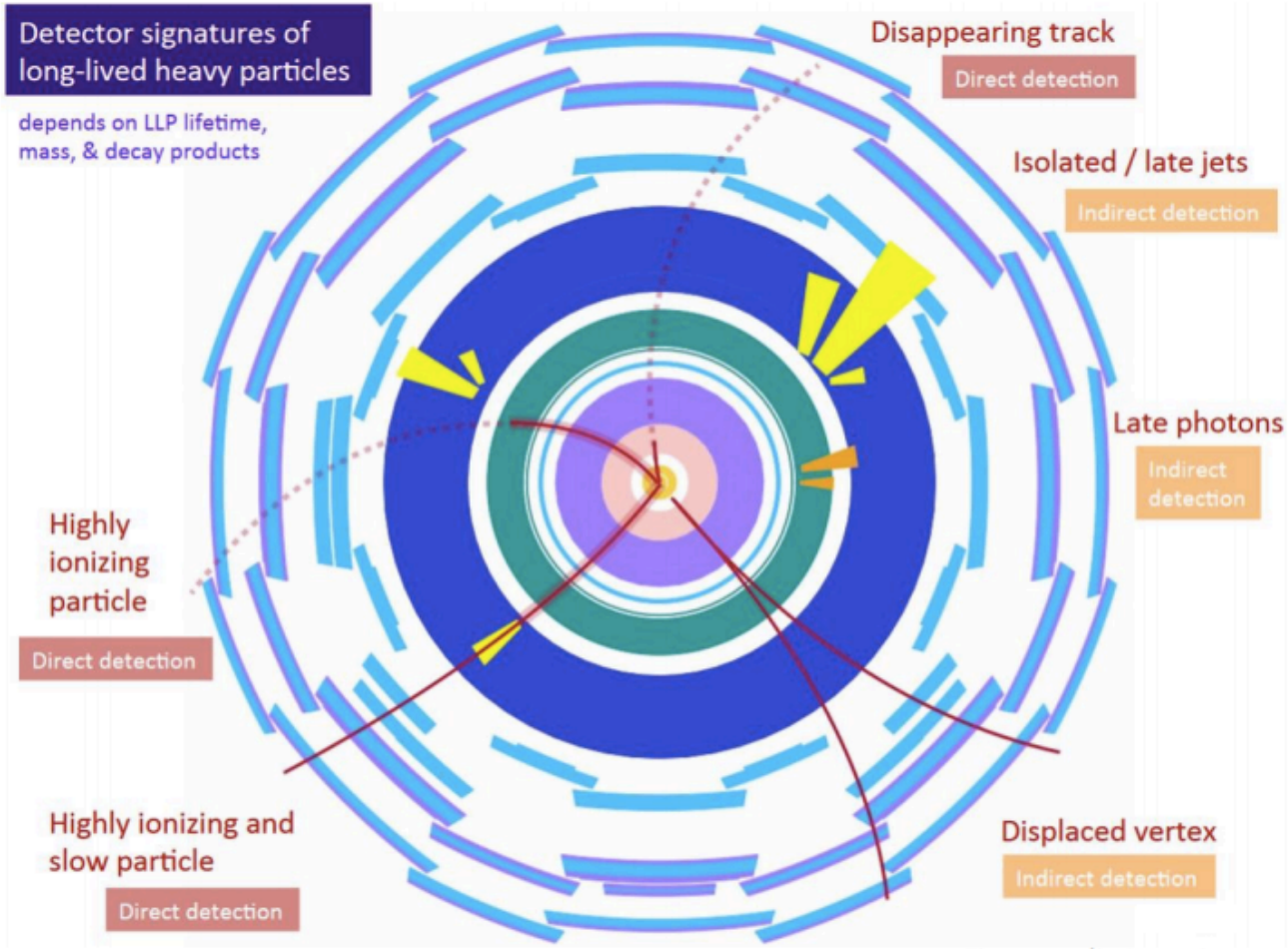


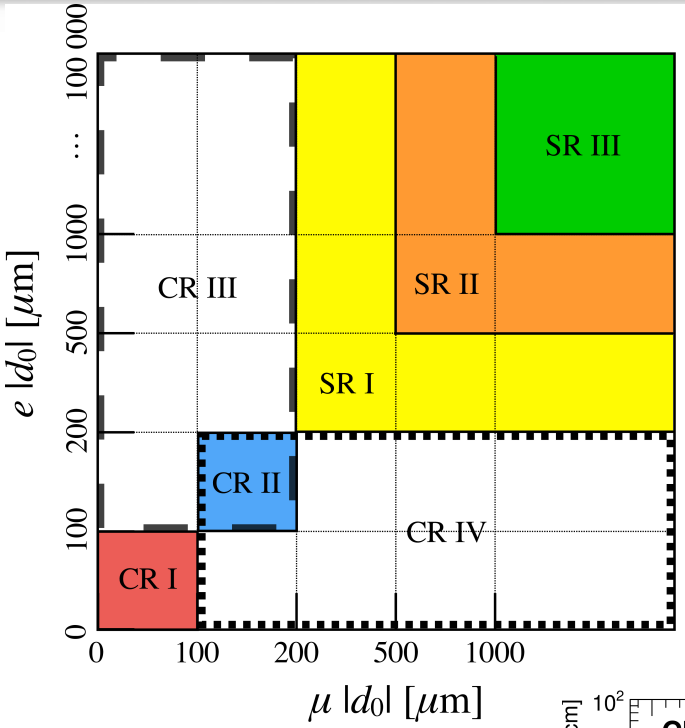
Figure credit: Laura Jeanty

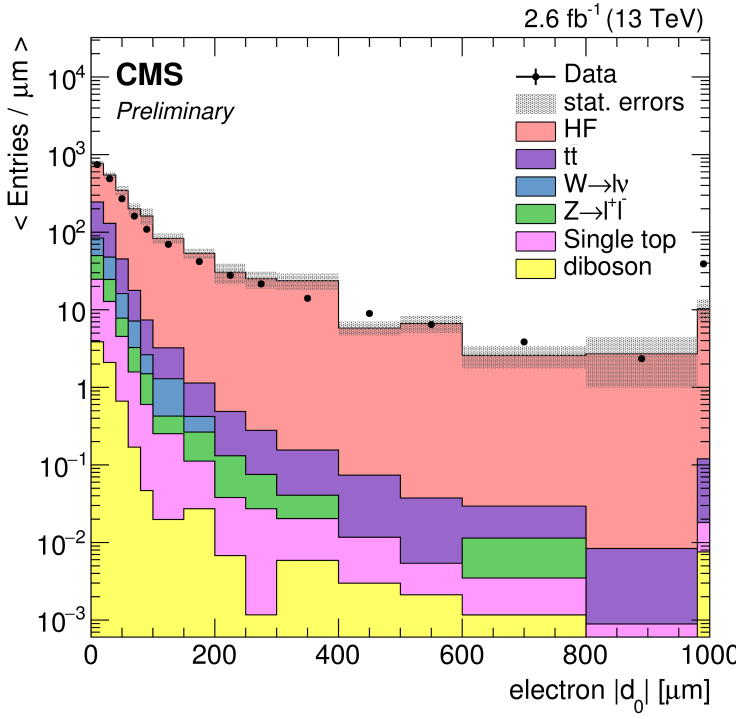
- "Long-lived" = decays within or outside of the detector volume
- LLPs appear in a variety of models
  - Split/RPV/Stealth SUSY
  - Exotic Higgs
  - Hidden Valley, etc.
- and can gain their long lifetimes via small couplings, phase space suppressions, etc.
- LLP signatures tend to be unusual and require dedicated searches & reconstruction algorithms

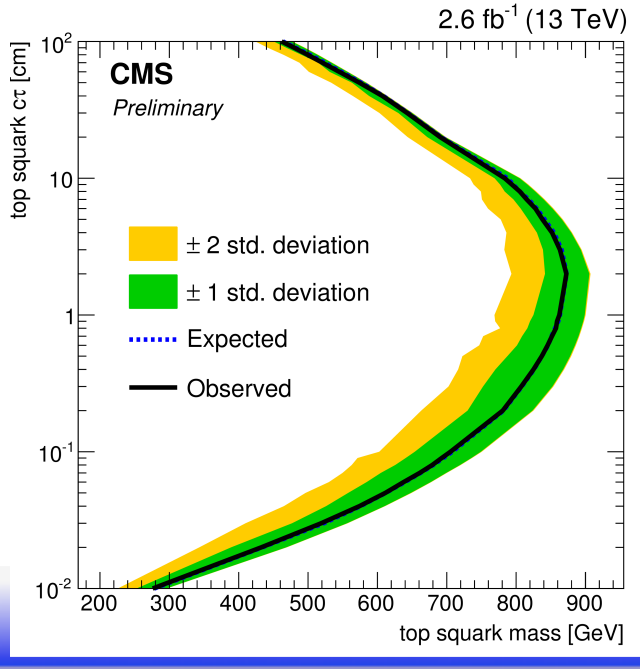
Search for Displaced Leptons

CMS-PAS-EXO-16-022

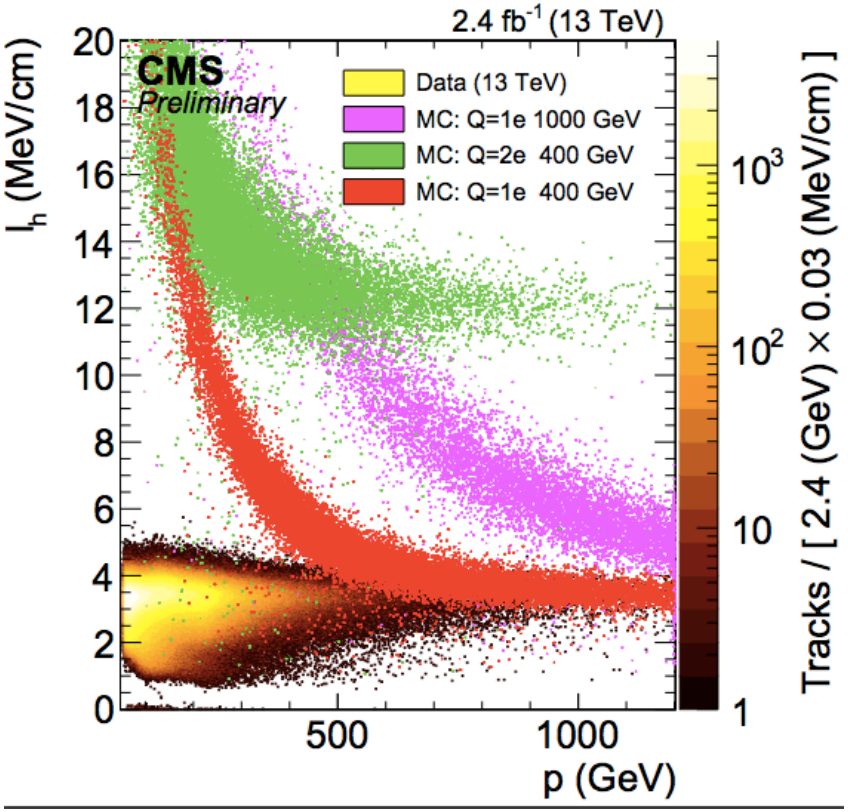
- Search for e-μ events originating from a displaced track vertex
- Background modeling is validated in control regions with small d_0







Heavy Stable Charged Particles



CMS-PAS-EXO-15-010
CMS-PAS-EXO-16-036

- HSCPs are low β particles, which might have not +/-1e charge, e.g. non-WIMP DM, e.g. gravitinos
- Low β -> long time-of flight to outer systems
- Highly ionizing -> large dE/dx = I_h
- Searches often focus on R-hadrons (hadronized gluinos or squarks), which might change sign or become neutral as they propagate

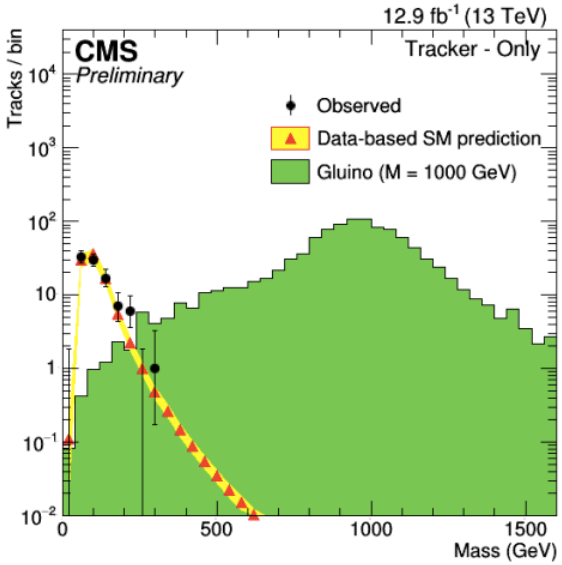
$$I_h = K\frac{m^2}{p^2} + C$$

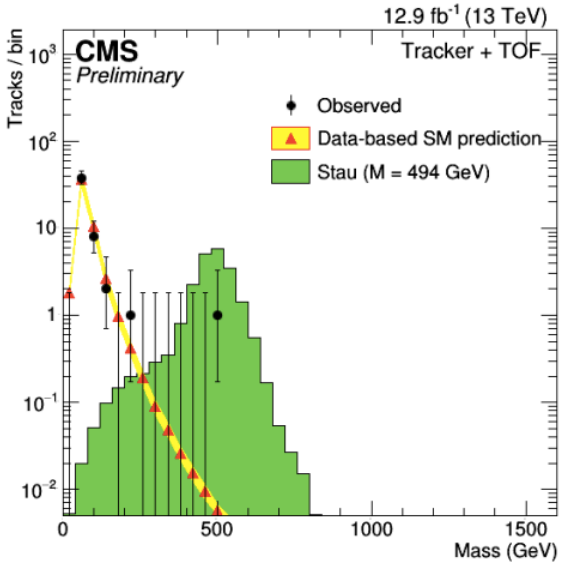
K and C are calibrated using low-energy protons

- dE/dx can be inverted to make a mass measurement

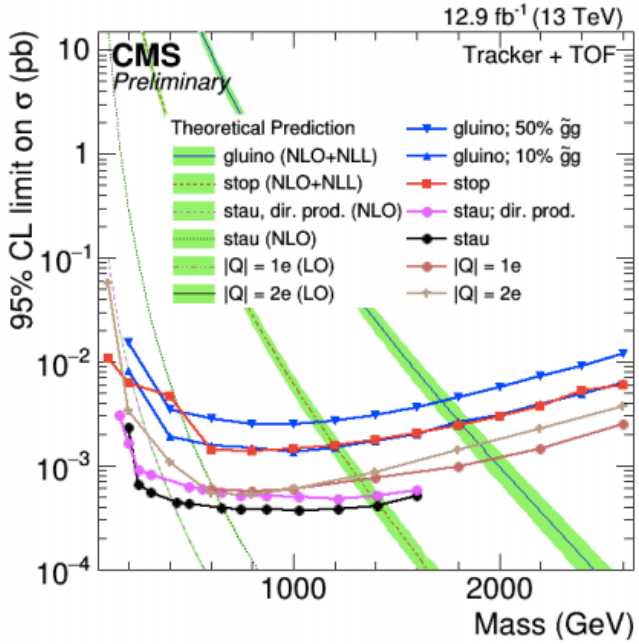
HSCPs Interpretations

CMS-PAS-EXO-16-036



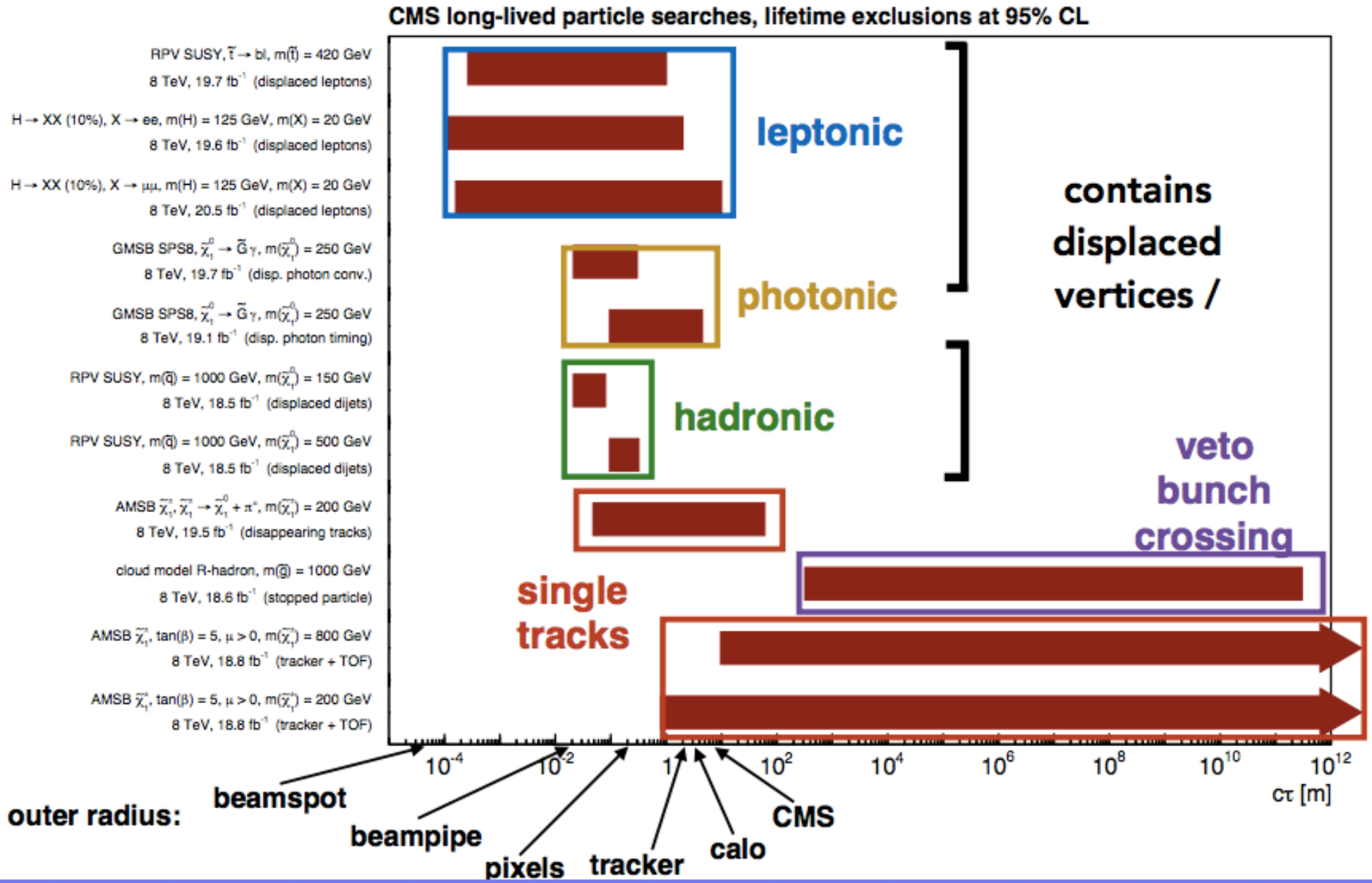


	Selection cuts				Numbers of events 2016	
	p_T (GeV)	I_{as}	$1/\beta$	Mass (GeV)	Pred.	Obs.
Trk-only	> 65	> 0.3	-	> 0	92.4 ± 18.9	94
				> 100	43.2 ± 8.9	46
				> 200	4.3 ± 0.9	7
				> 300	0.86 ± 0.18	0
				> 400	0.25 ± 0.05	0
Trk+TOF	> 65	> 0.175	> 1.250	> 0	53.1 ± 10.6	50
				> 100	7.7 ± 1.5	8
				> 200	0.82 ± 0.17	2
				> 300	0.15 ± 0.03	1
				> 400	0.04 ± 0.01	1



- Separate Tracker-only and Tracker+TOF searches are performed
- Background estimation is validated using control regions with relaxed dE/dx and $1/\beta$ criteria

Long-Lived Particles Summary



Public CMS Results

http://cms-results.web.cern.ch/cms-results/public-results/publications/

Exotica | Standard Model | Supersymmetry | Higgs | Top Physics

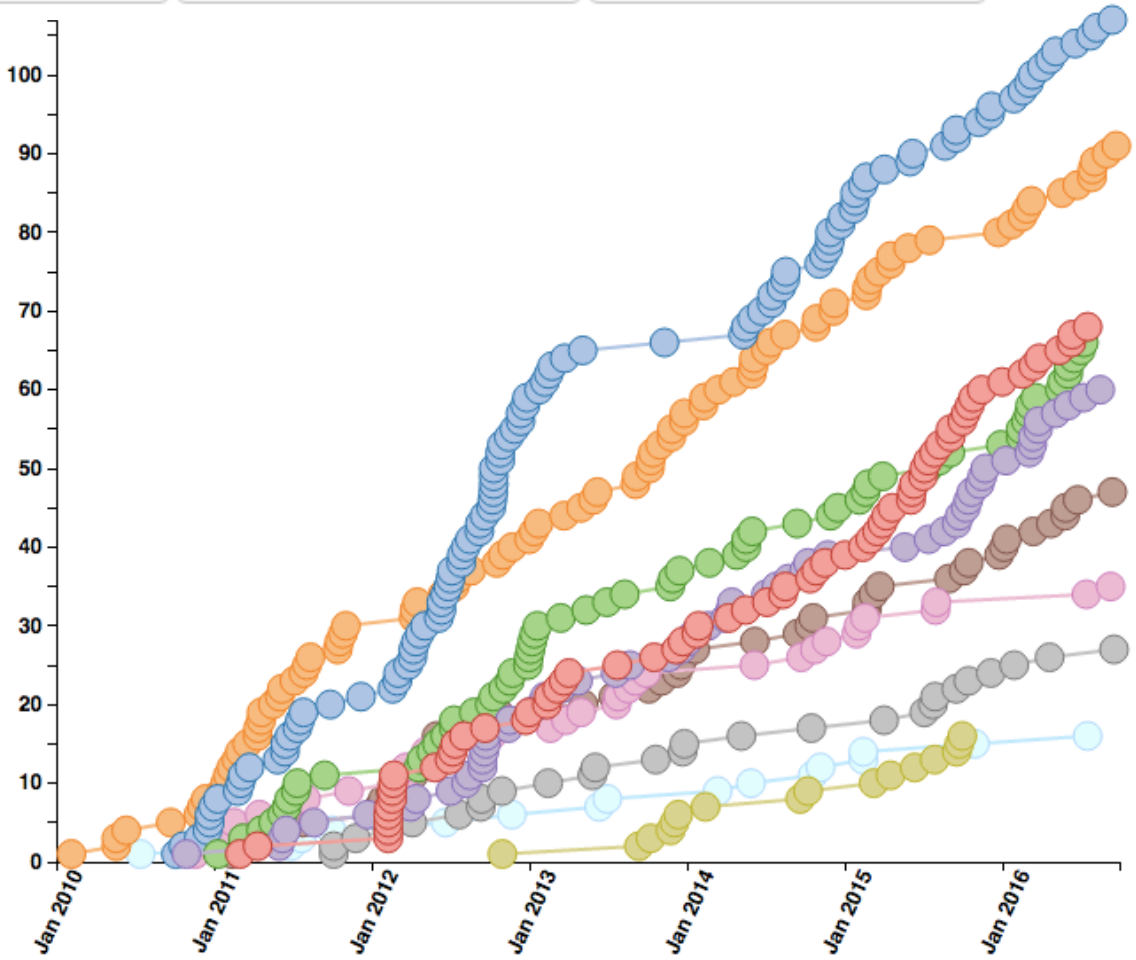
Heavy Ion | B Physics | Forward Physics | Beyond 2 Generations | Detector Performance

532 collider papers submitted and counting

~180 Run 2 public results

No significant deviations with respect to the SM to-date !

Expect lots of new results with full 2016 dataset at Winter 2017 conferences

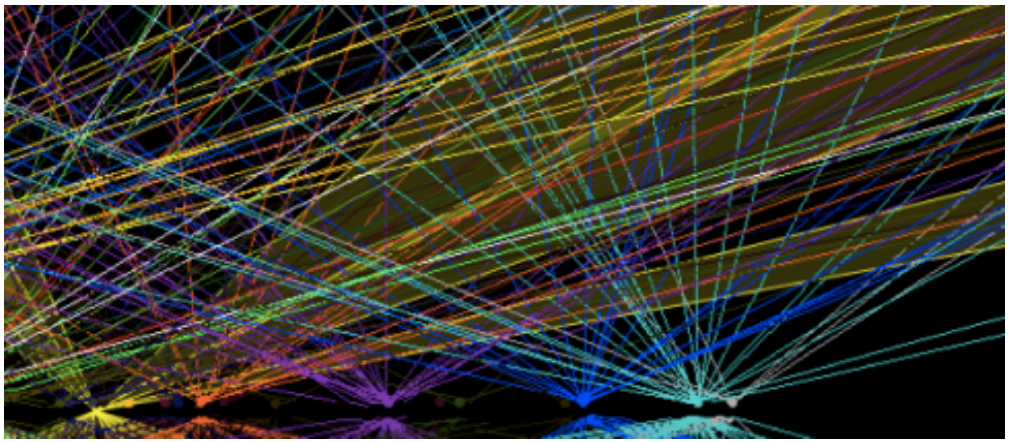


Conclusions

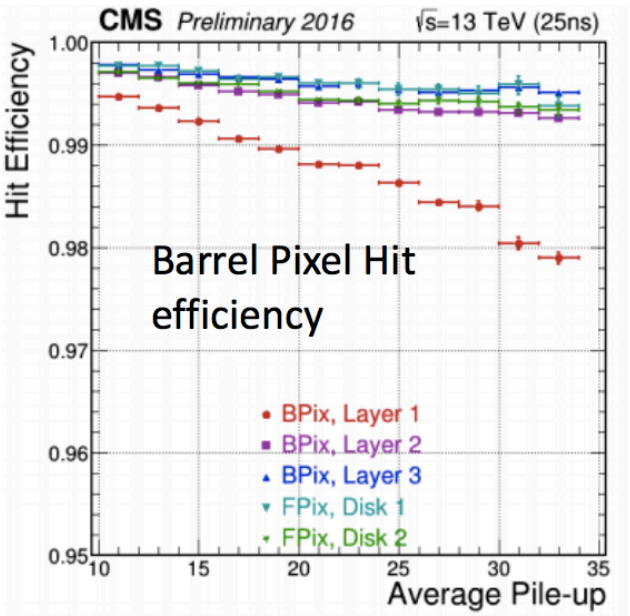
- Exploration of the new energy regime of 13 TeV has started
- Good reasons to believe that there exists the physics beyond the SM
- The LHC machine is performing spectacularly well
- CMS has a vivid program on searches for new physics
- Wide range of new physics channels being probed
- No evidence of New Physics so far
- We are still at the beginning of the long journey

High Luminosity -> High Pileup

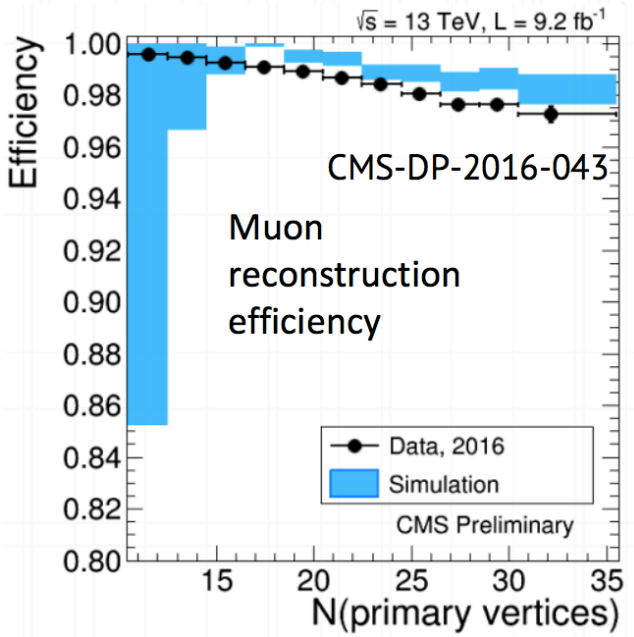
- Dealing with high pileup is a challenge

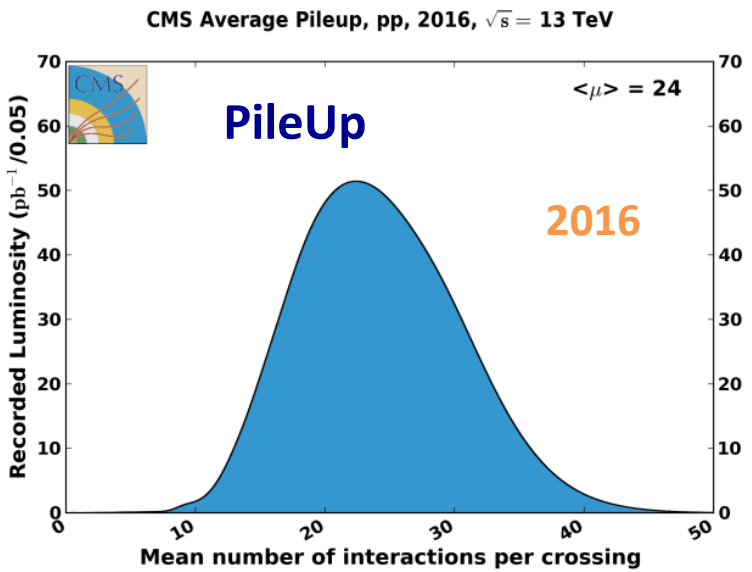


Pixel Hit Efficiency



Muon Efficiency

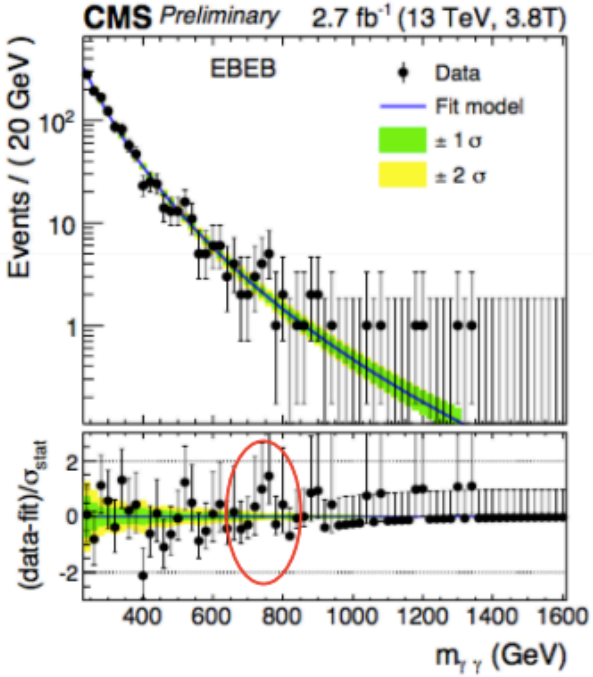




Search for Di-Photon Resonance

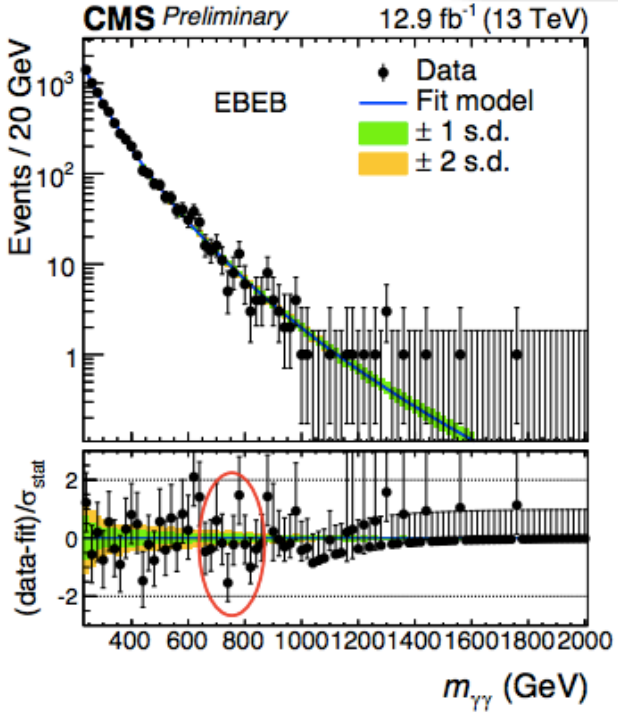
2015 Data

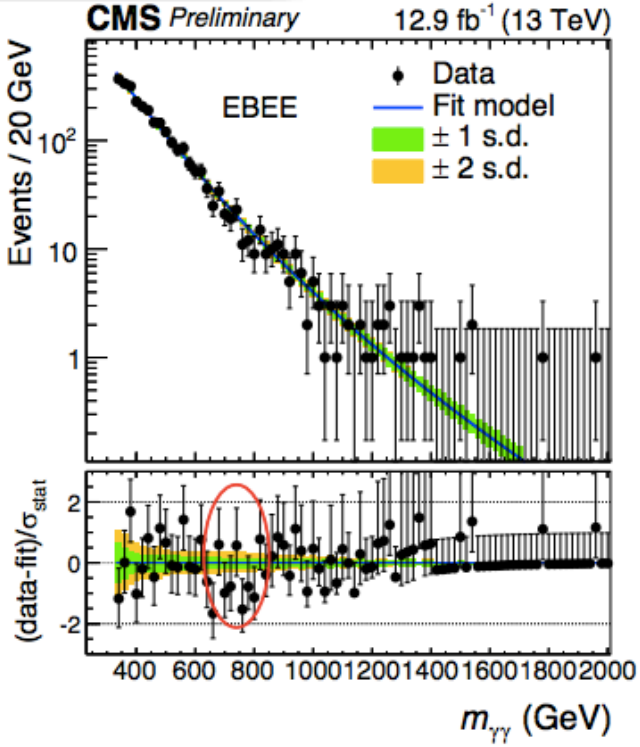
Phys. Rev. Lett. 117



2016 Data

CMS-PAS-EXO-16-027

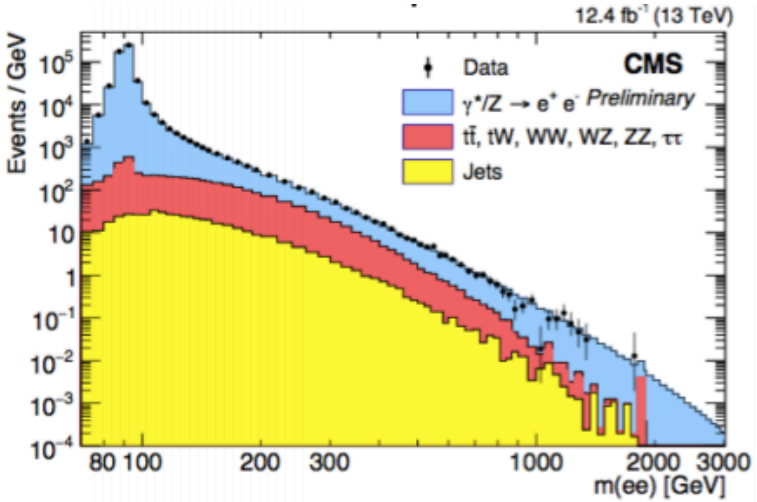


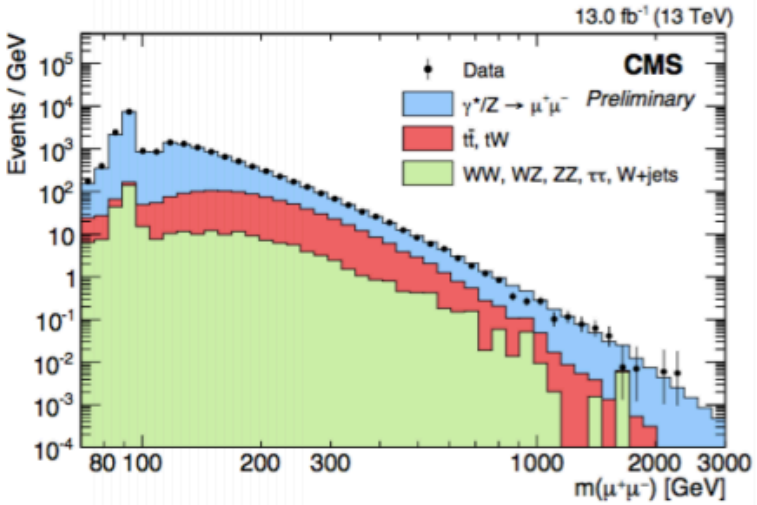


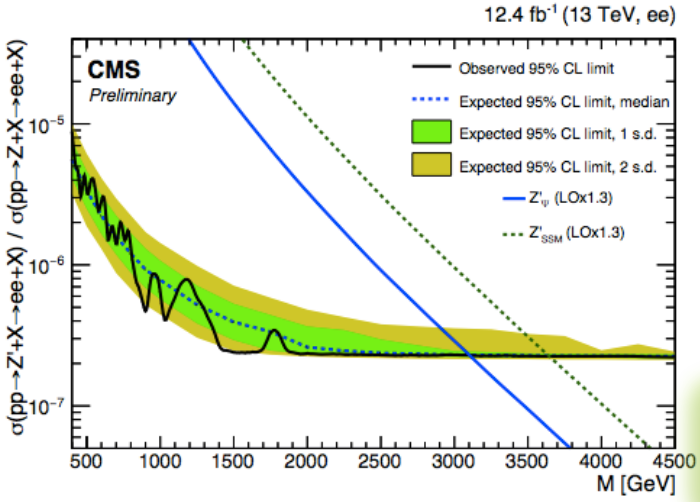
- No evidence for a di-photon resonance with larger 2016 dataset !

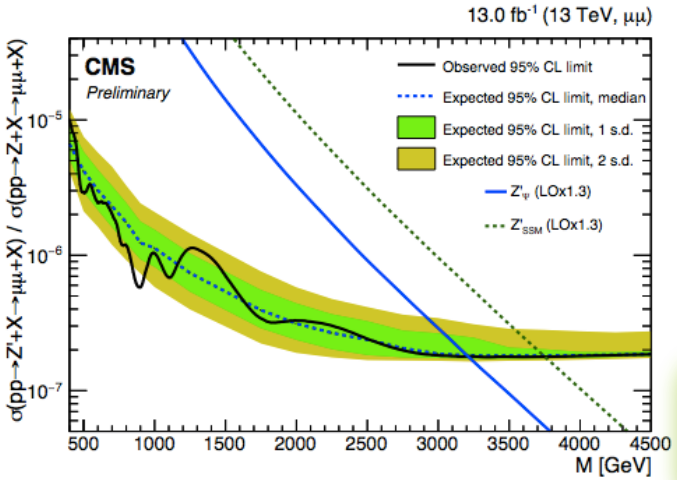
Search for Di-Lepton Resonances

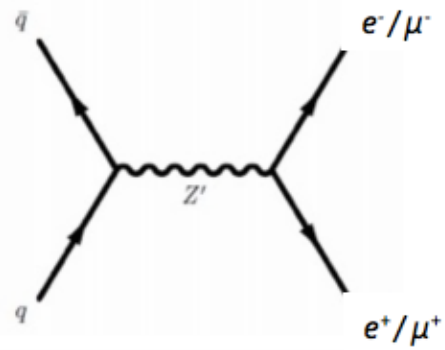
- Additional gauge boson from breaking higher-energy symmetry groups
- Very clean signature











$M_{Z'(SSM(}$ > 3.65 TeV

CMS-PAS-EXO-16-031

$M_{Z'(SSM)}$ > 3.75 TeV

The LHC Timeline

LHC / HL-LHC Plan