SEARCHES FOR NEW HEAVY RESONANCES AT THE LHC

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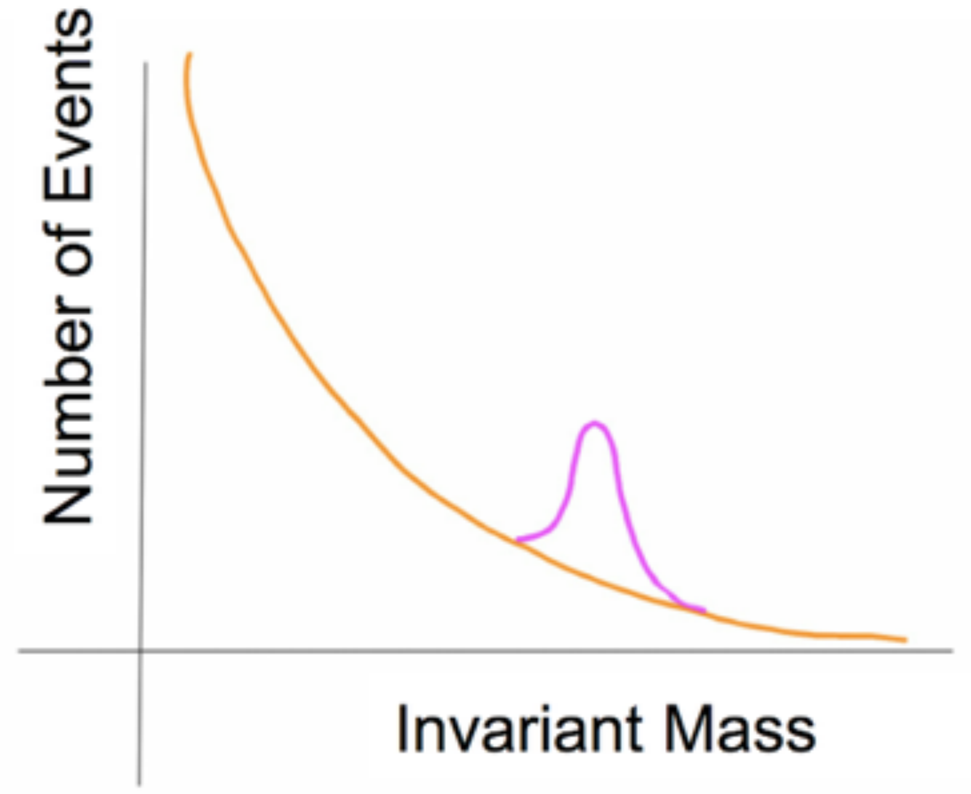
WHY HIGH MASS RESONANCES

- Resonances represent **the simplest way to discover new particles**
  - striking and incontrovertible signature
- A **statistically significant peak over a smooth background**
  - experimentally robust
  - small systematics
  - difficult for unknown backgrounds to mimic
- The **most important search when new energies** are explored
  - the goal of LHC
  - particularly relevant at start-up (Run2)



RESONANCES IN PAST DISCOVERIES

EW LETTERS 2 DECEMBER 197

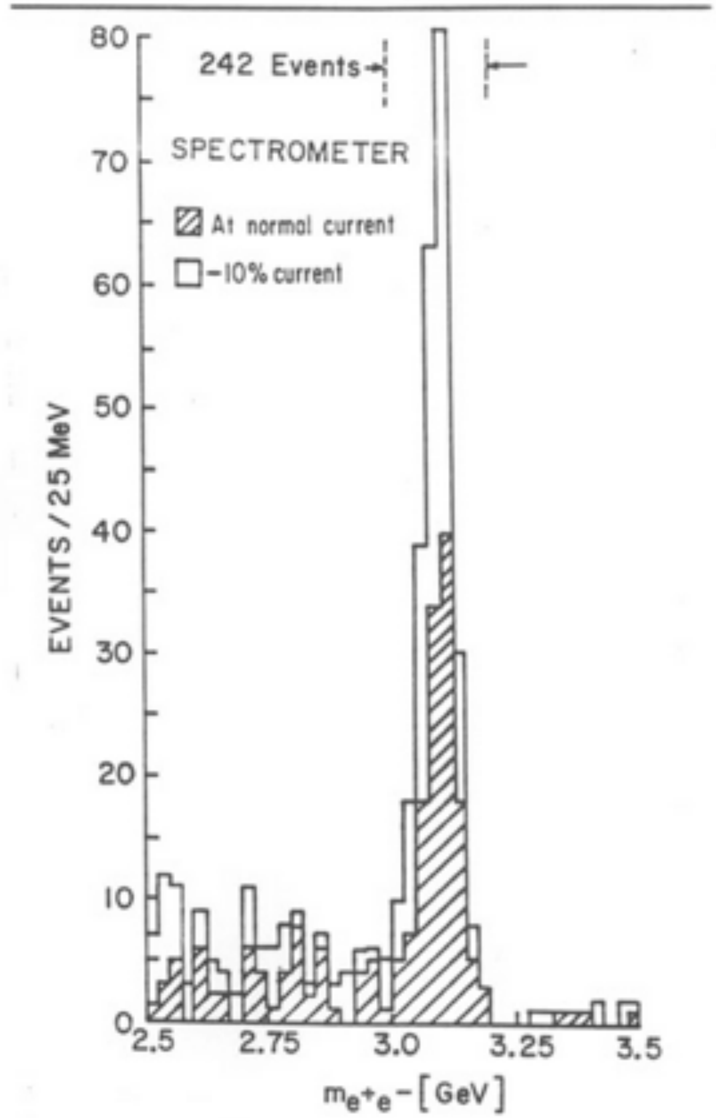
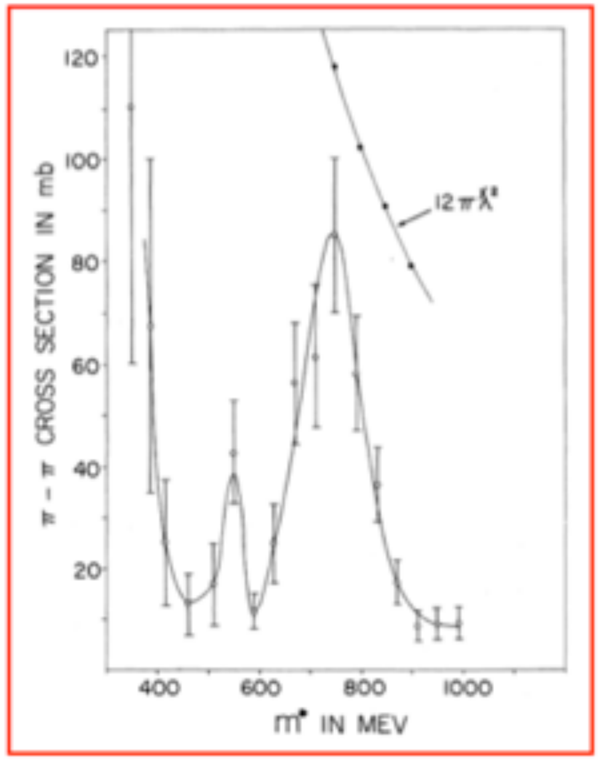


FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted wing that the peak is independent of spectrometer rents. The run at reduced current was taken two nths later than the normal run.

1961: $\rho(770) \to \pi\pi$



PhysRevLett.6.628

1961: $K^*(892) \to K\pi$

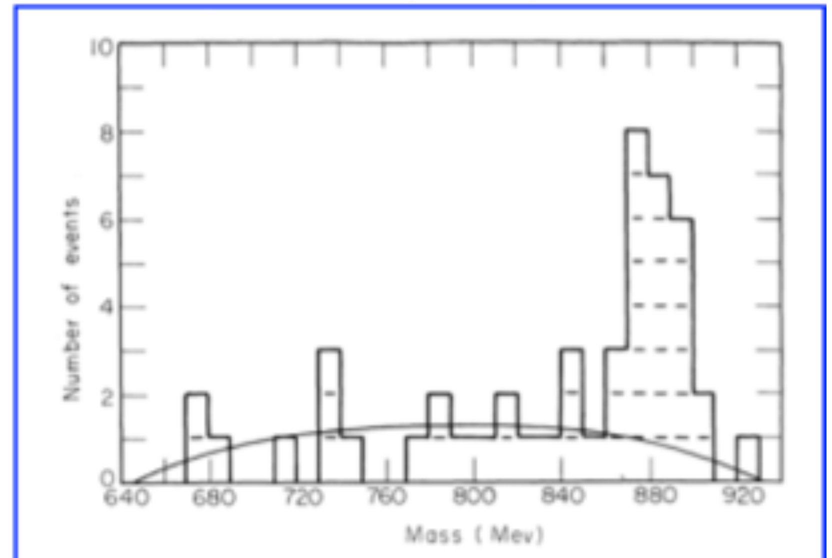
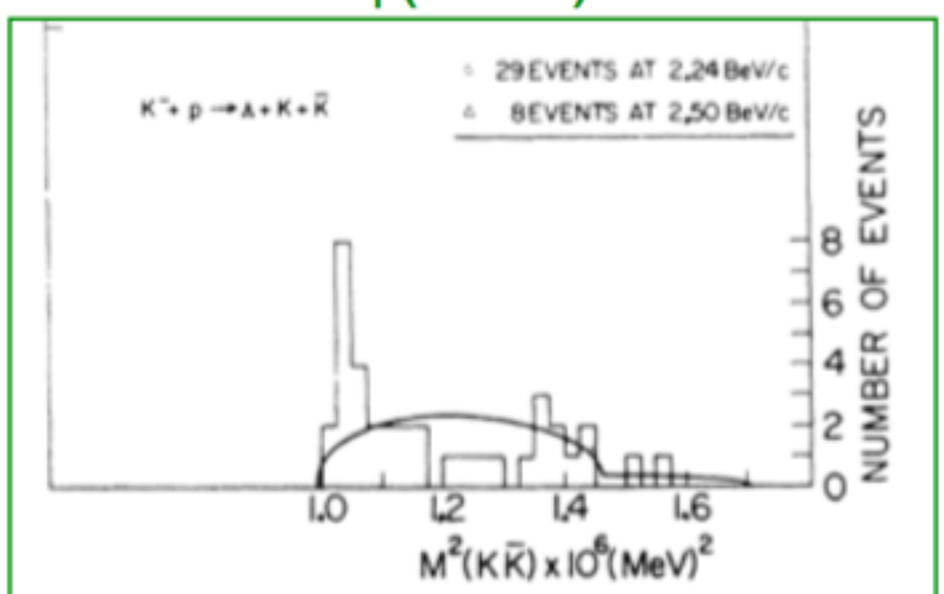


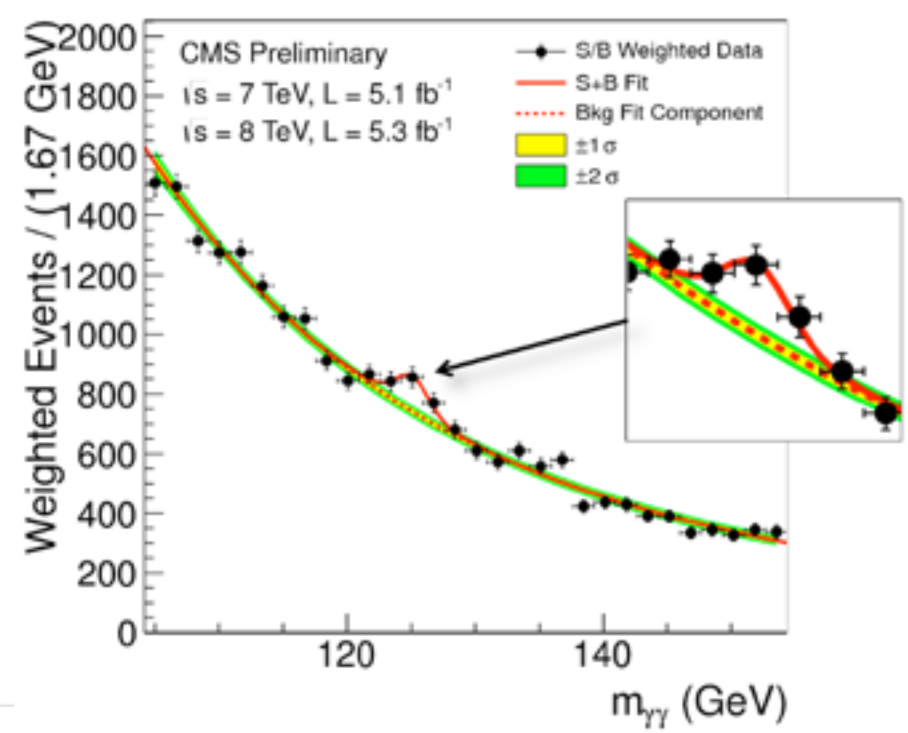
FIG. 2. Mass spectrum of the $\bar{K}^0 - \pi^-$ system. The solid line represents the phase-space curve normalized to background events.

PhysRevLett.6.300

1961: $\phi(1020) \to KK$

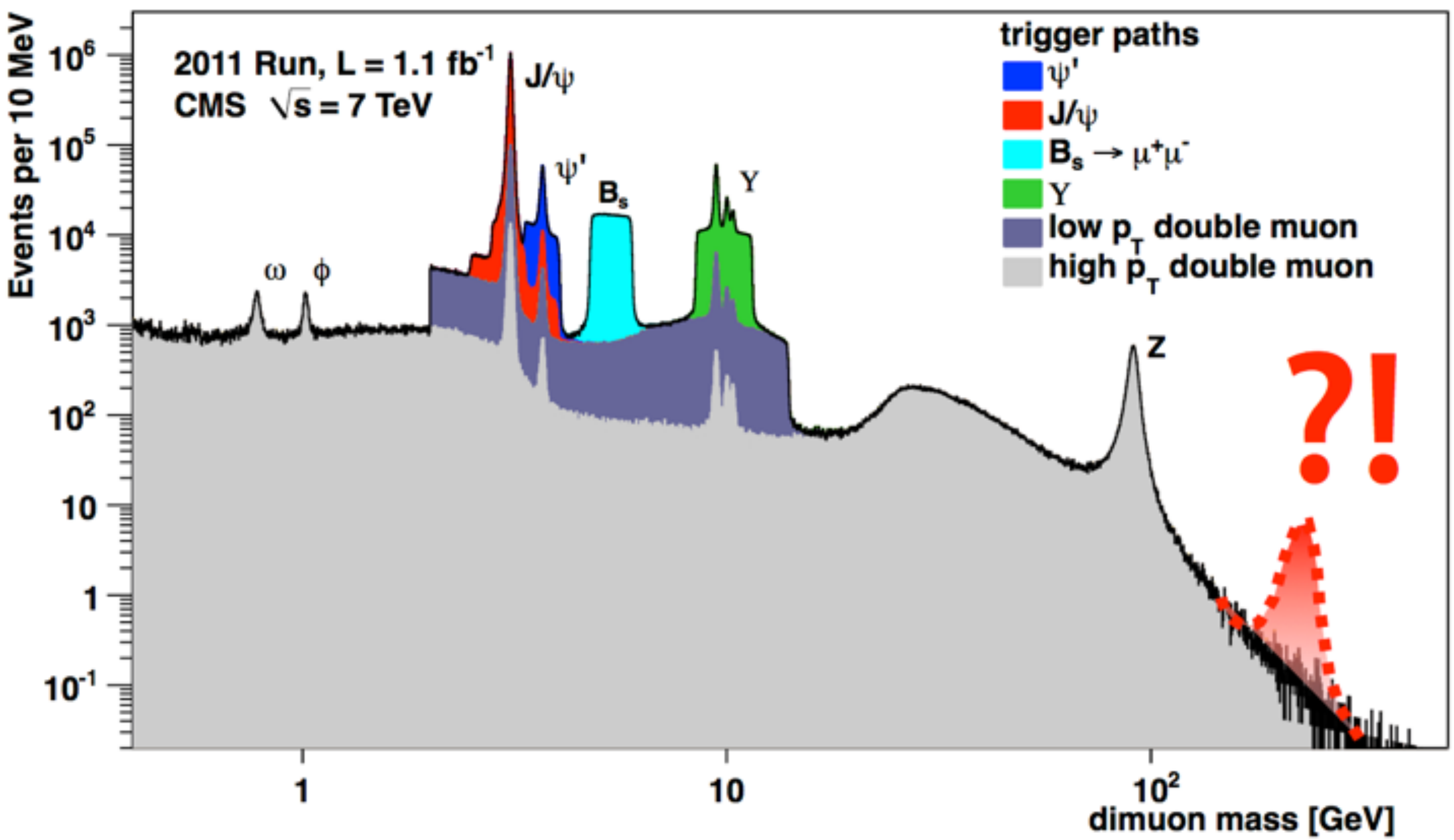


PhysRevLett.9.180



Pros in High Mass Searches

- Searches with **small systematics**
  - compared to searches based on tails (Missing ET)
- **Model-independent probe** to new physics
- Predicted in **many beyond SM scenarios**



FROM THEORY TO SIGNATURES

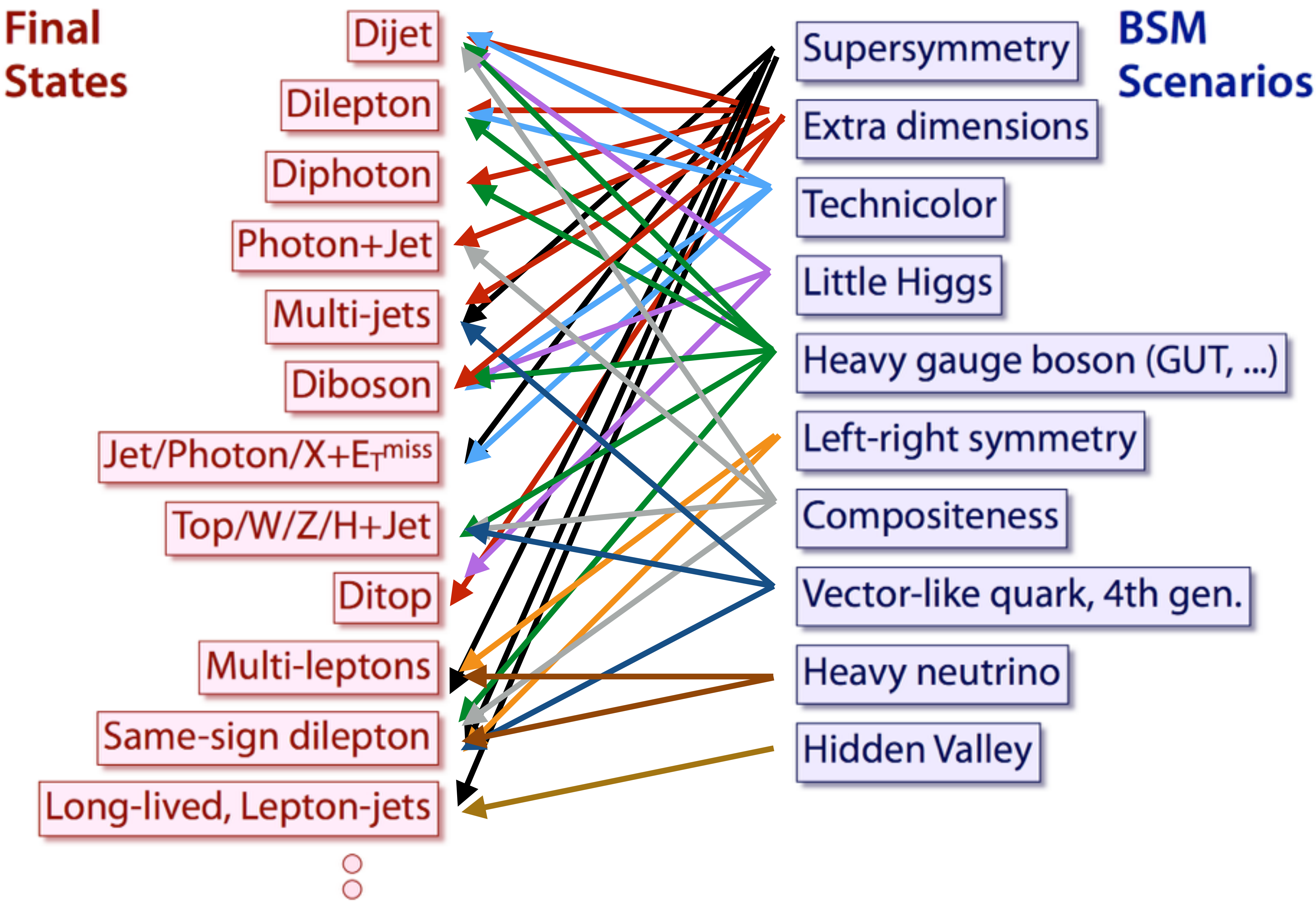
Final States

- Dijet
- Dilepton
- Diphoton
- Photon+Jet
- Multi-jets
- Diboson
- Jet/Photon/X+E_T^{miss}
- Top/W/Z/H+Jet
- Ditop
- Multi-leptons
- Same-sign dilepton
- Long-lived, Lepton-jets
- ⋮

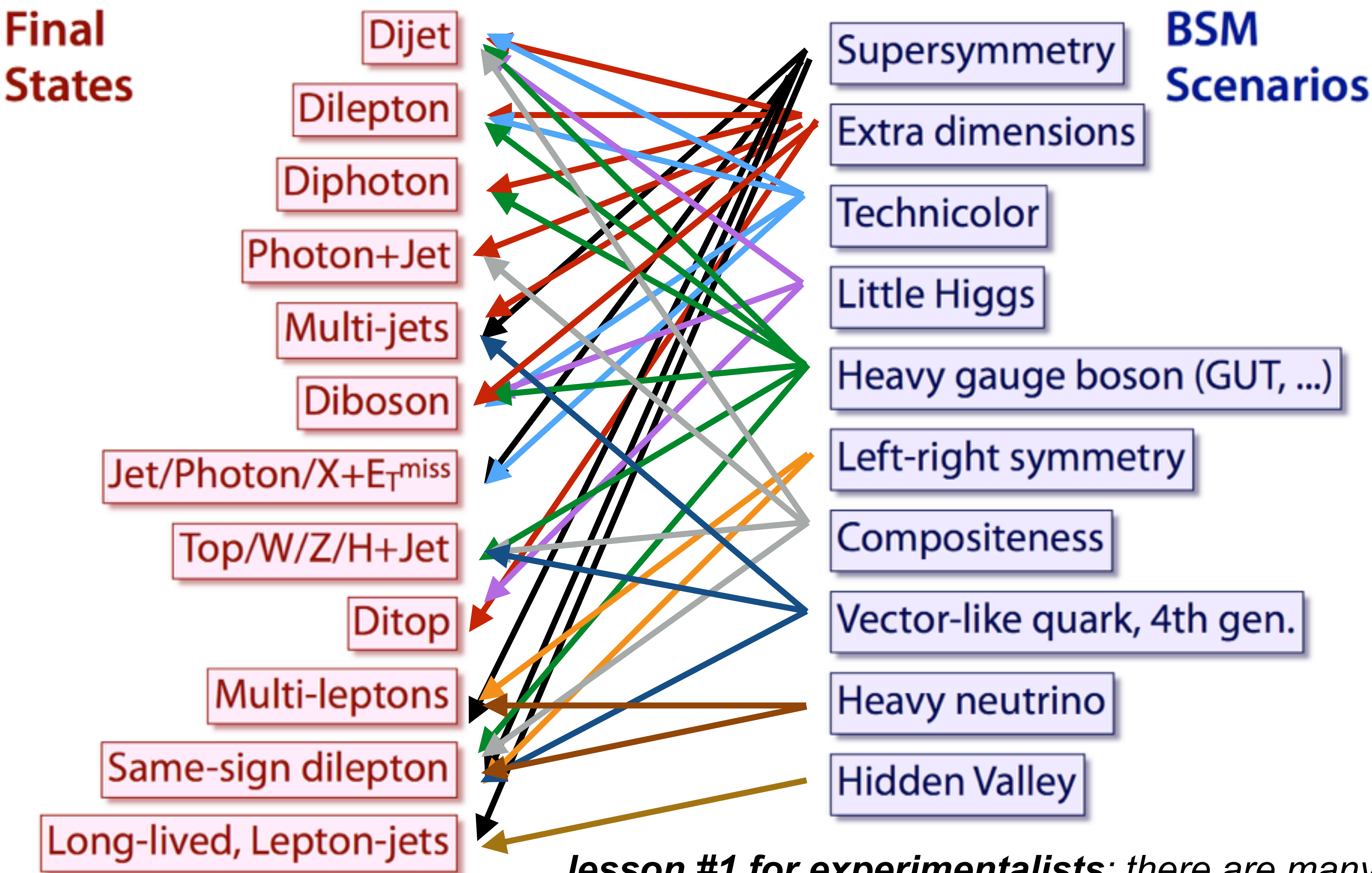
BSM Scenarios

- Supersymmetry
- Extra dimensions
- Technicolor
- Little Higgs
- Heavy gauge boson (GUT, ...)
- Left-right symmetry
- Compositeness
- Vector-like quark, 4th gen.
- Heavy neutrino
- Hidden Valley

FROM THEORY TO SIGNATURES

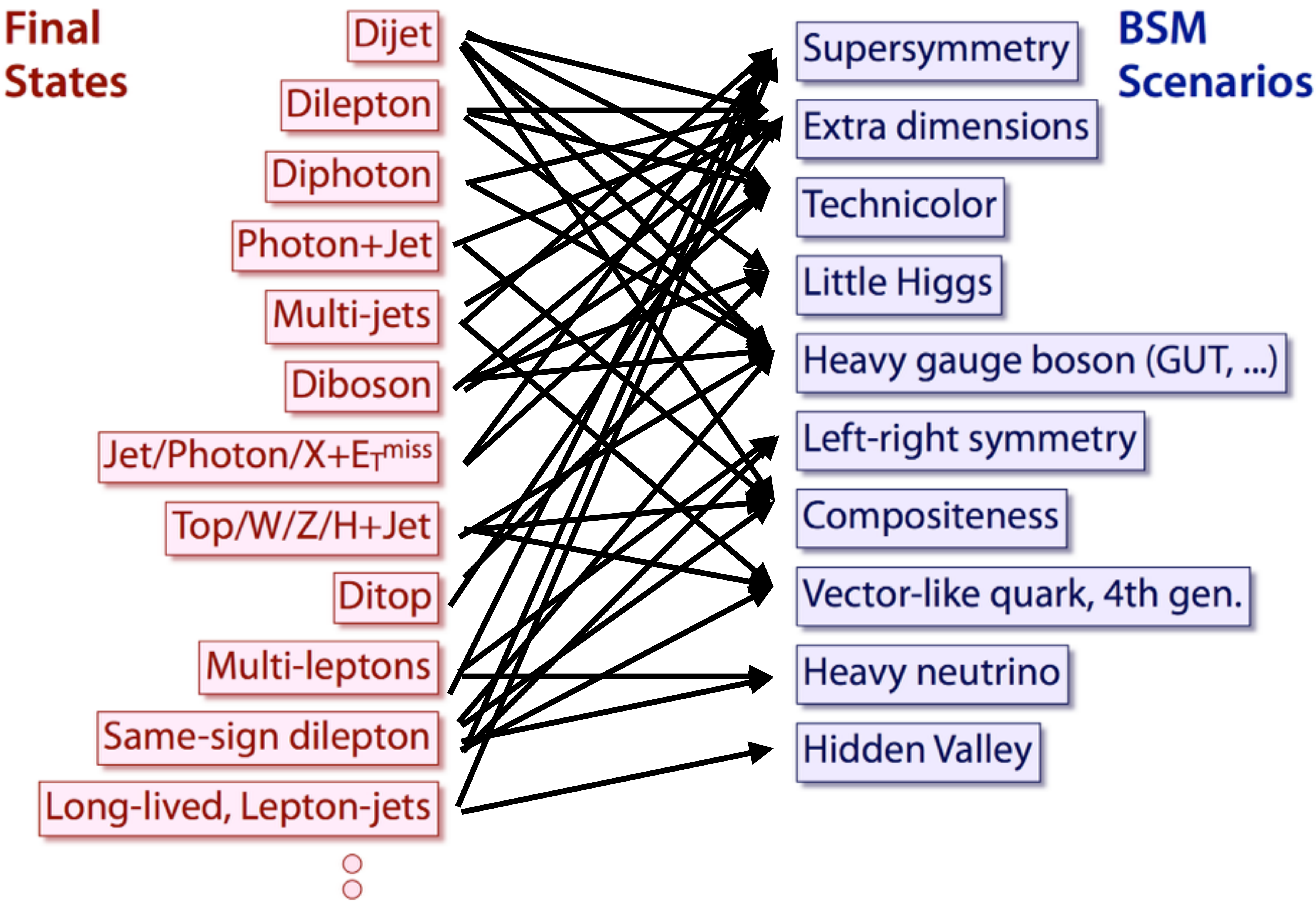


From Theory to Signatures

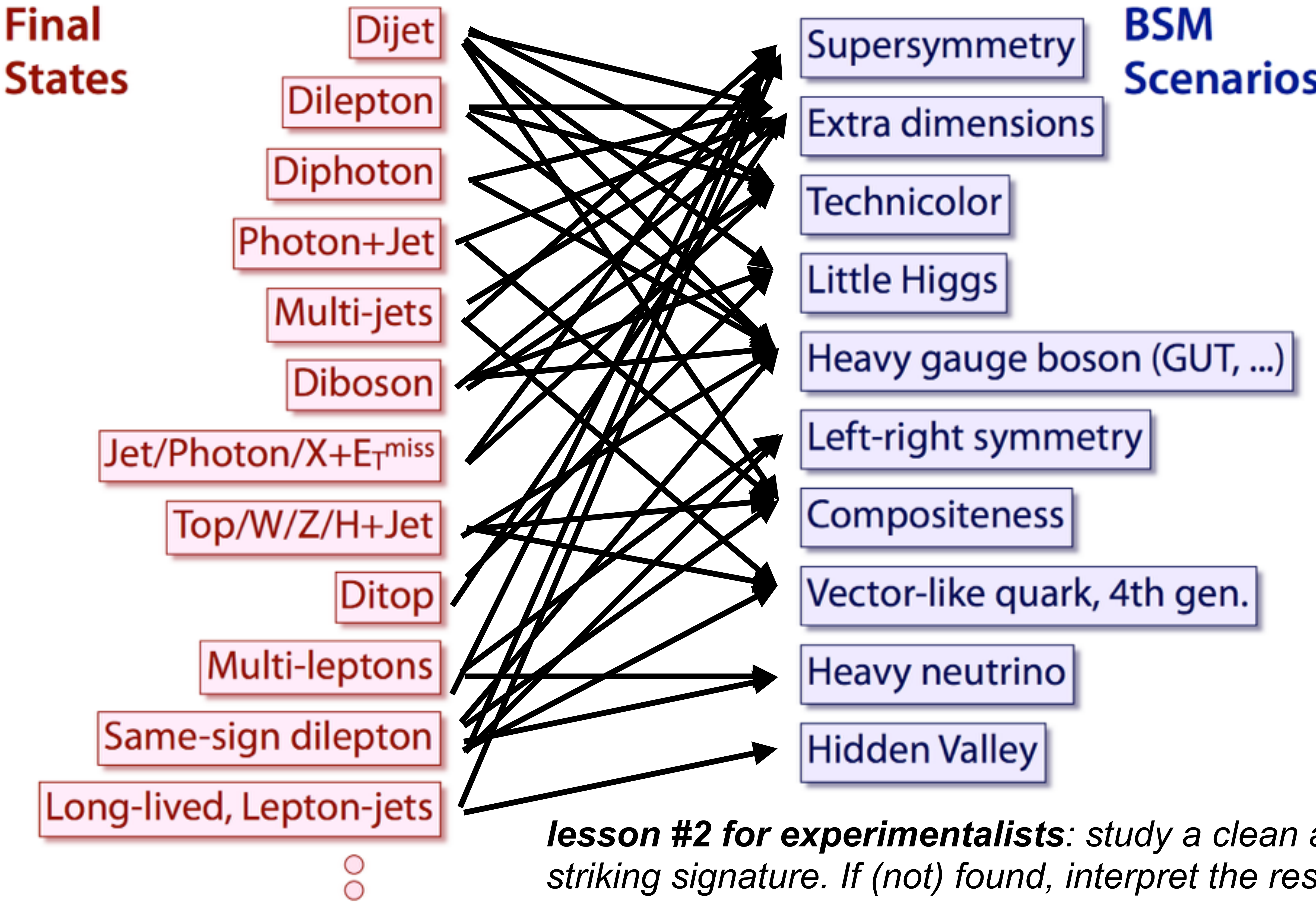


lesson #1 for experimentalists*: there are many theory models predicting whatever final state you like*

FROM SIGNATURES TO THEORY



FROM SIGNATURES TO THEORY



lesson #2 for experimentalists*: study a clean and striking signature. If (not) found, interpret the result*

FROM SIGNATURES TO THEORY

Final States

Dijet

Dilepton

Diphoton

Photon+Jet

Diboson

This Talk

Biased list!

– corresponds to signatures with largest discovery potential at the start of Run2

SEARCH STRATEGY

1. Pick your **favorite di-object** final state
   - crucial expertise in reconstruction and detector
2. Be **as model-independent as possible**
   - do not design selection based on a particular model
   - be loose in kinematics
3. **Reconstruct invariant mass**

at high energies

$$M = \sqrt{2E_1E_2(1 - cos\theta)}$$

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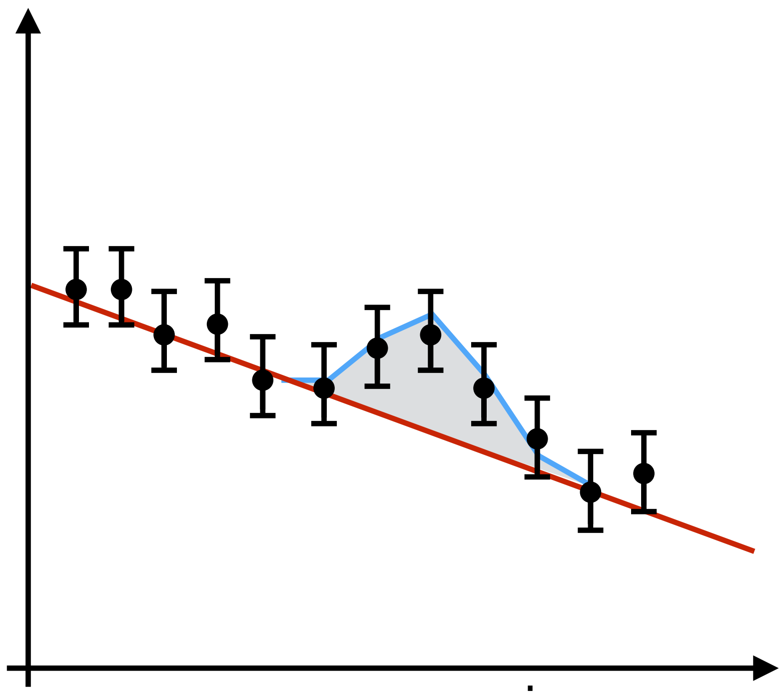
4. Simple **signal extraction**
   - cut and count techniques
   - likelihood fit based on a smooth background + gaussian-like signal



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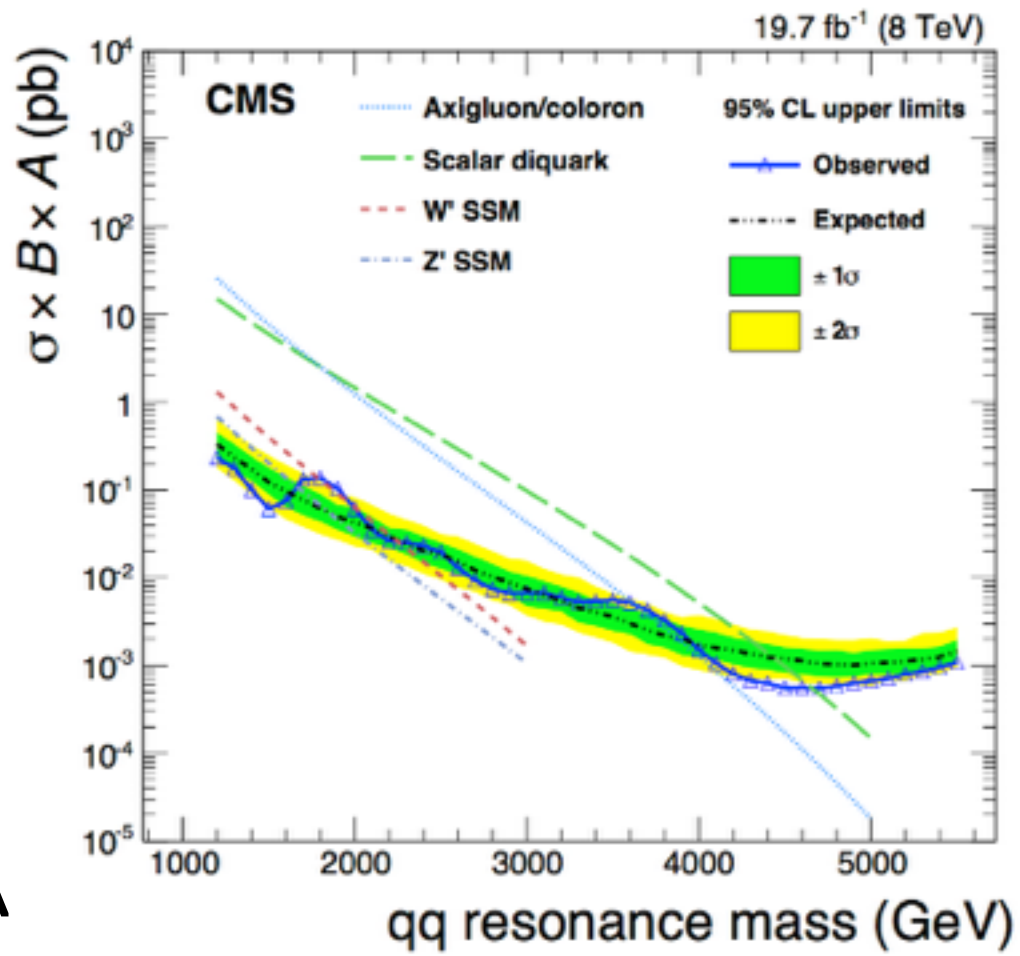
   – e.g. report excesses/limits in σ x BR x A



Search Strategy

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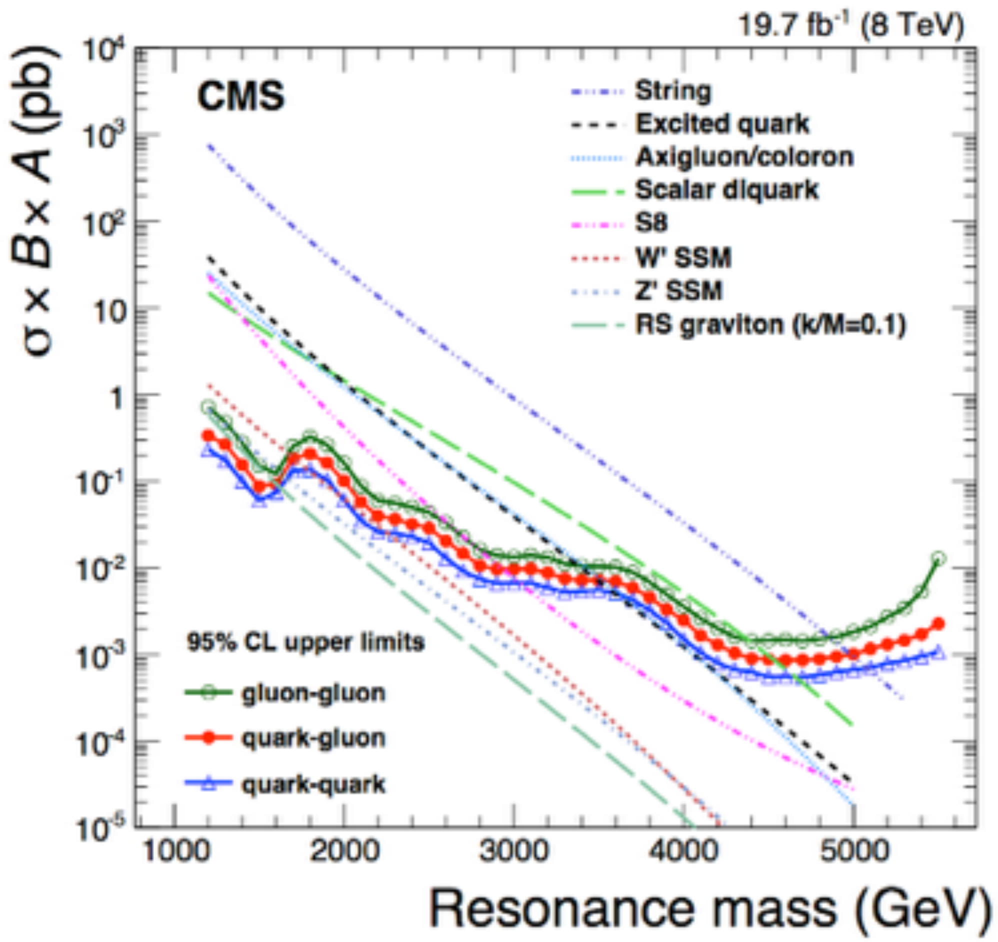
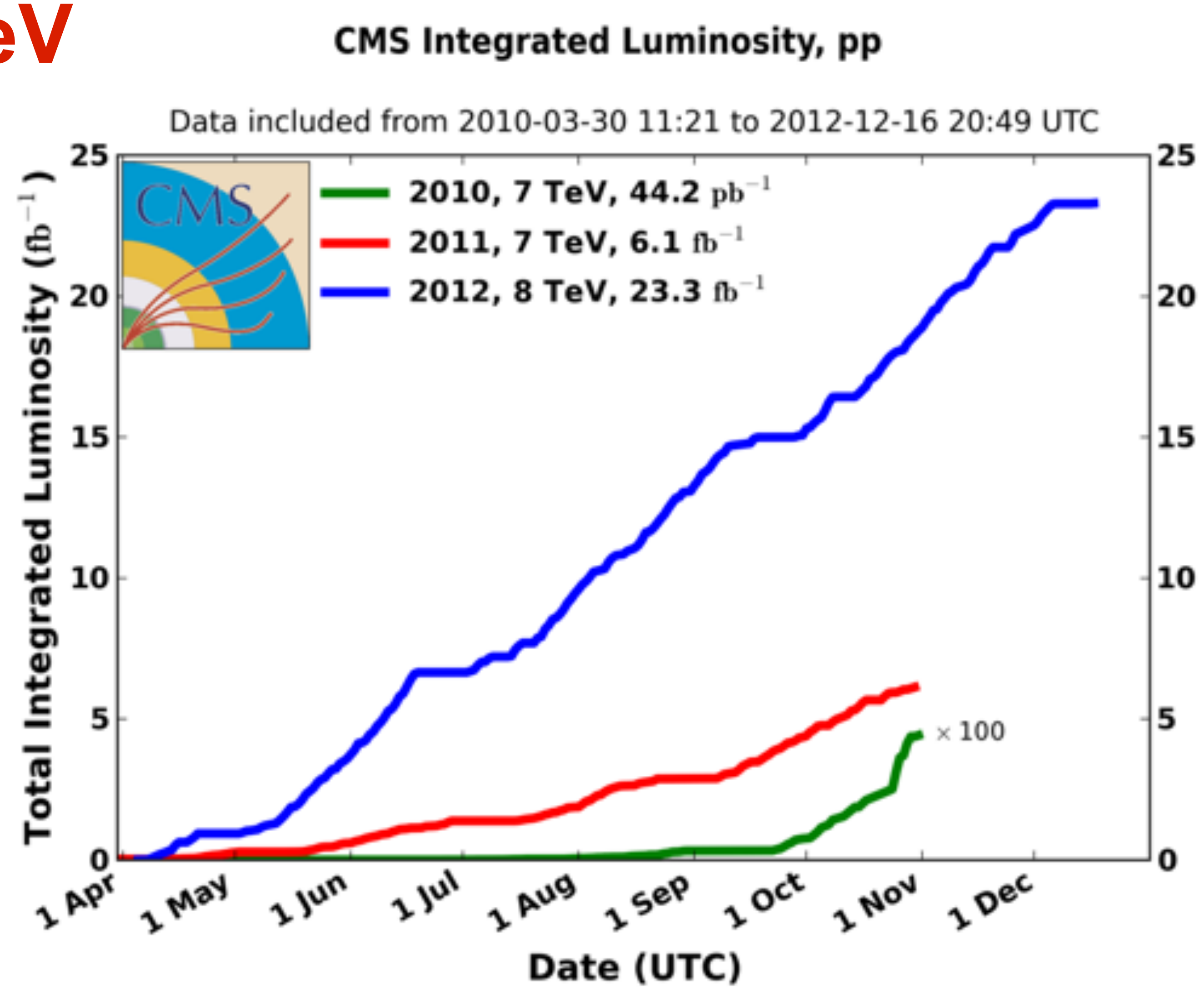


6. Put **constraints in several BSM scenarios**

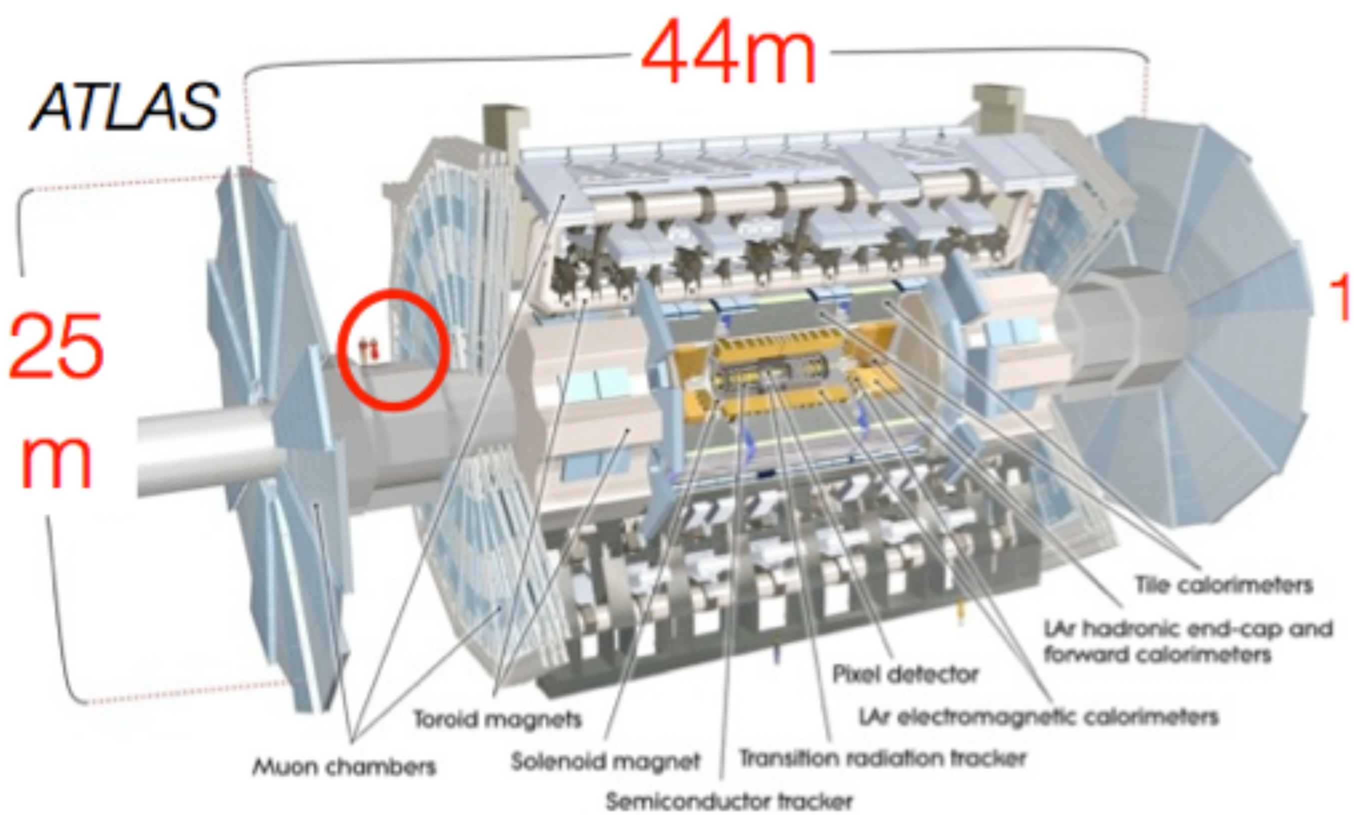
LHC

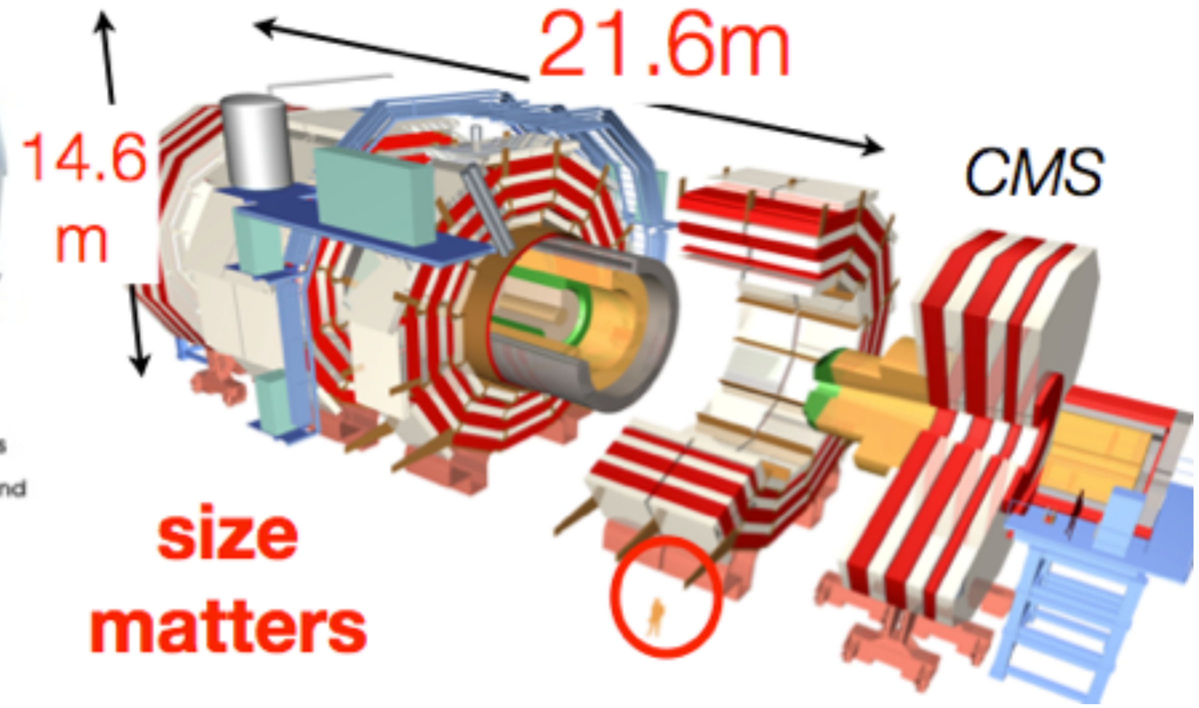
- **pp collisions at 7TeV and 8TeV**
- **great performance, beyond expectations**
  - luminosity peak ~8 10^{33} $cm^{-2}s^{-1}$
  - 300 pb^{-1}/day
  - 50 ns bunch spacing



- **~23 fb^{-1} @ 8TeV** recorded (+~6fb^{-1}@ 7TeV)
  - **results shown with ~20 fb^{-1} at 8 TeV**
- **~ <20 collisions> per crossing**

ATLAS AND CMS





	ATLAS	CMS
Magnetic Field	solenoid (2 T) + toroid (0.5÷1T)	3.8 T solenoid + return yoke
Tracker	Si pixel, strips + TRT	Si pixel, strips
EM Calorimeter	Pb + LAr	$PbWO_4$ crystals
Had Calorimeter	Fe+scint./Cu+LAr/W+Lar (≥11λ)	Brass+scintillator(≥7λ)/Fe+quartz
Muon	air-toroid muon spectrom.	iron return-yoke muon spectrom.
Trigger	L1+RoI-based HLT	L1+HLT

OBJECTS IN HIGH MASS SEARCHES

	pros	*cons*	*resolution*	*calibration*
jets	large cross sections involved	resolution not great. calibration not trivial	5-10%	gamma+jet, multijet, extrapolations
electrons	relatively clean	high pt electrons not fully contained	1-2% at high masses	Z->ee and extrapolations
muons	very clean	need precise tracker alignment	3-10% at high masses	Z->mumu and extrapolations
photons	relatively clean	no control samples for scale determination	1-2% at high masses	Z->ee and extrapolations
missing ET	tagging for W'	hard to calibrate, tails due to detector noise	-	gamma,Z + jets

OBJECTS IN HIGH MASS SEARCHES

I will concentrate on these ones

				on
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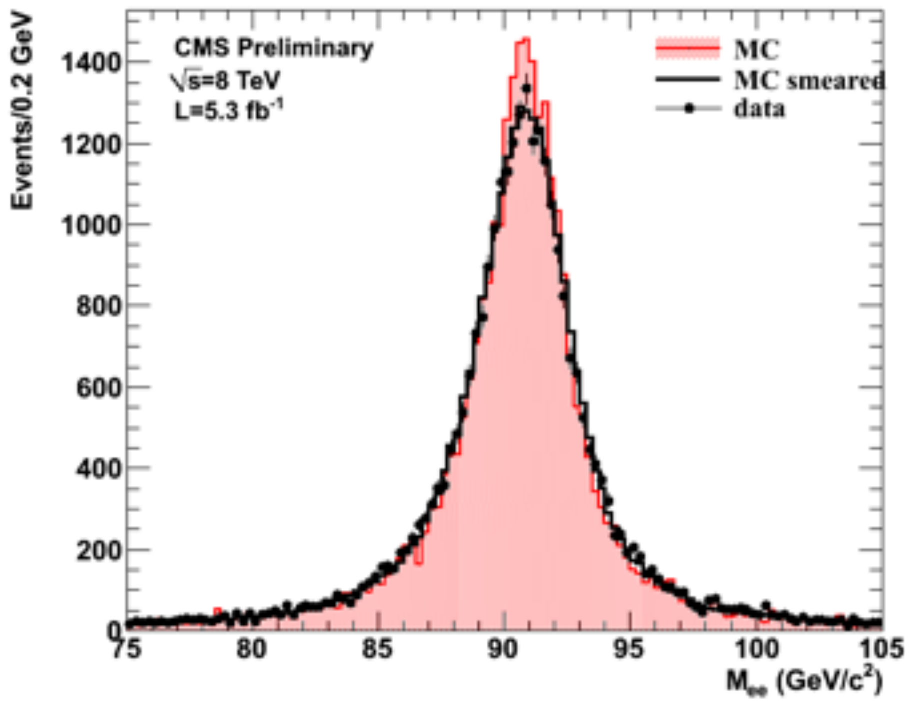
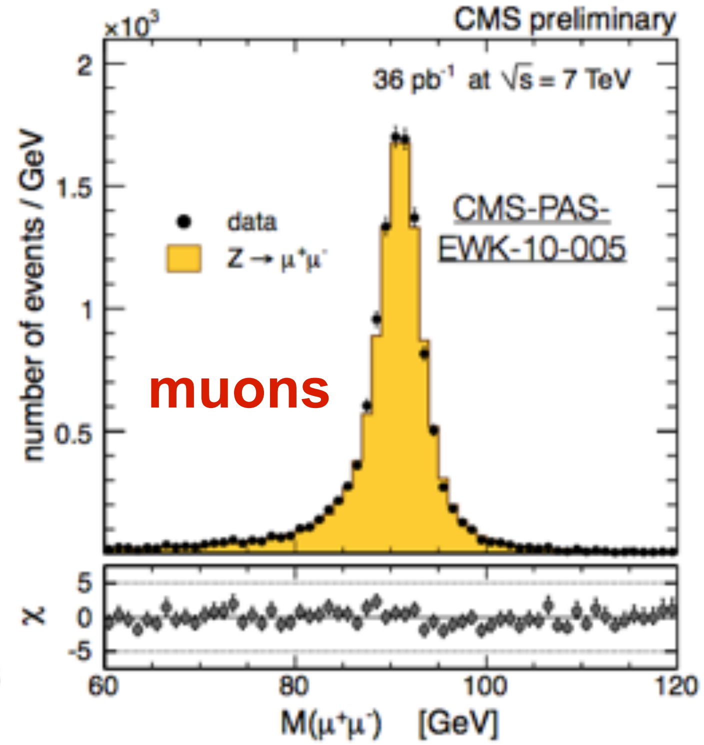
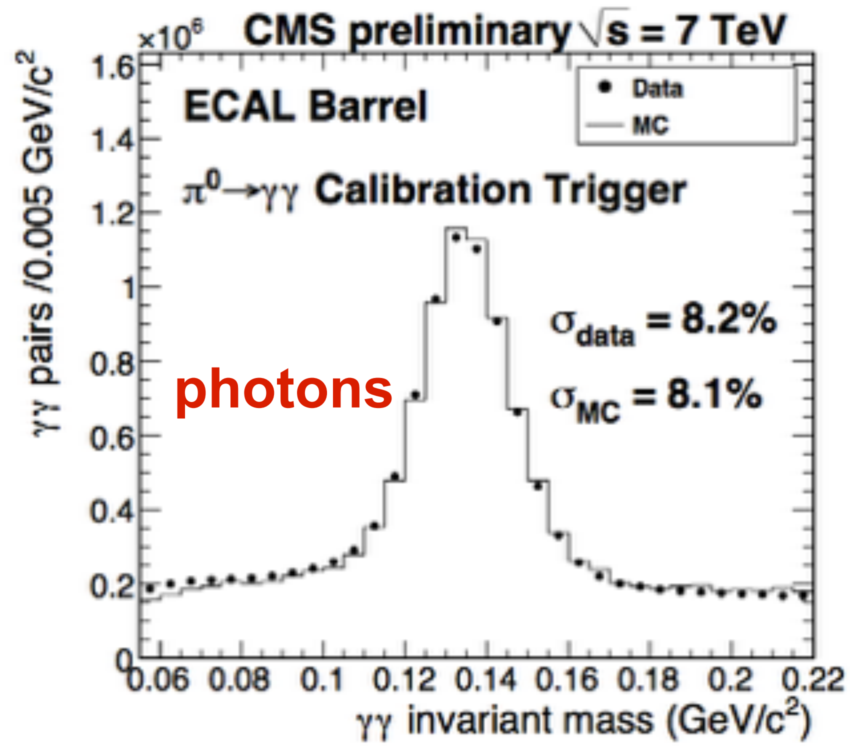
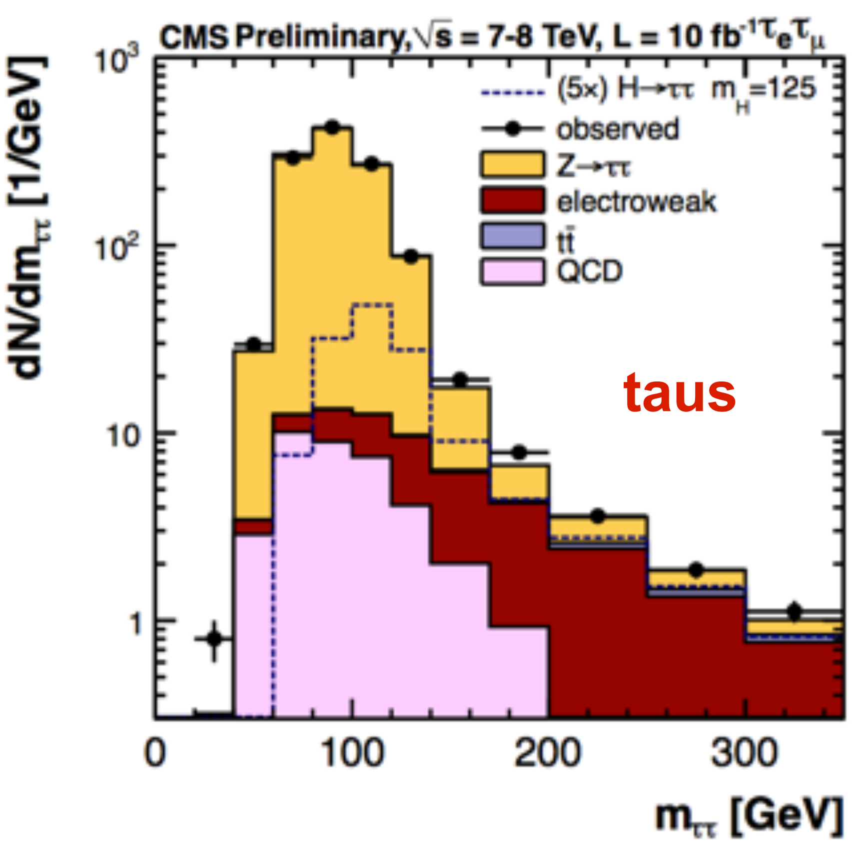
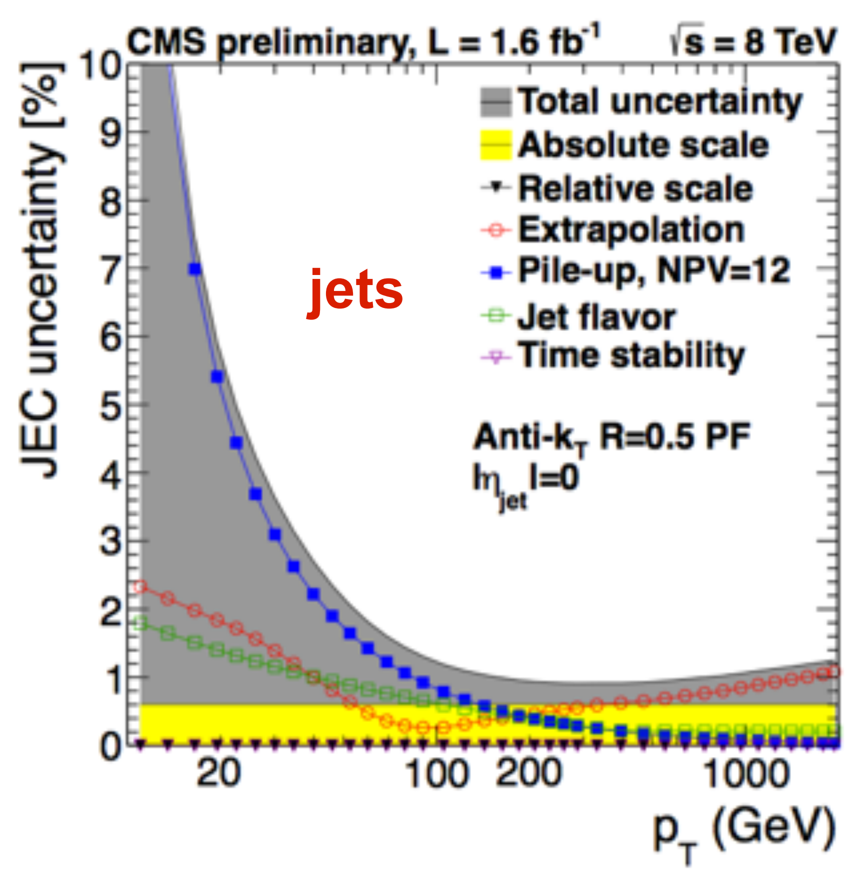
PERFORMANCE OF RECONSTRUCTION

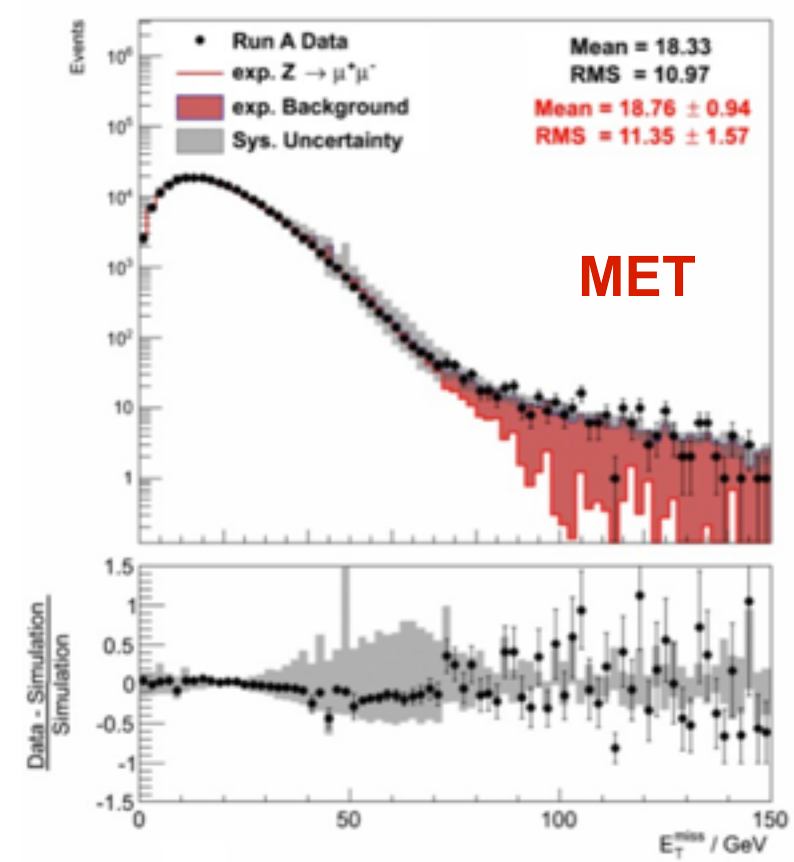












Performance of Reconstruction

electrons

scale known to 0.5%

muons

scale known to better than 1.0%

photons

scale known to better than 1.0%

taus

identified with ~70% efficiency and ~5% fake rate

(b-)jets

scale known to 1%-5% (p_T and η dep.)

MET

Nice agreement with simulation
Deep understanding of impact of PU

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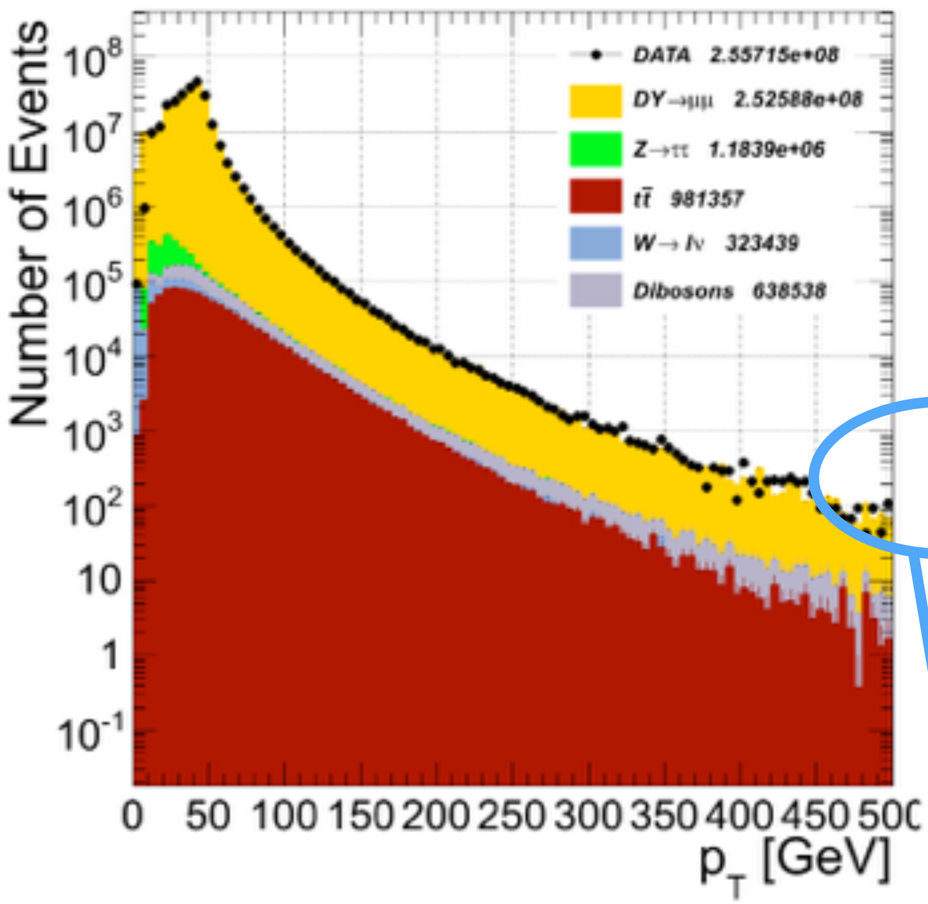
MET

Nice agreement with simulation
Deep understanding of impact of PU

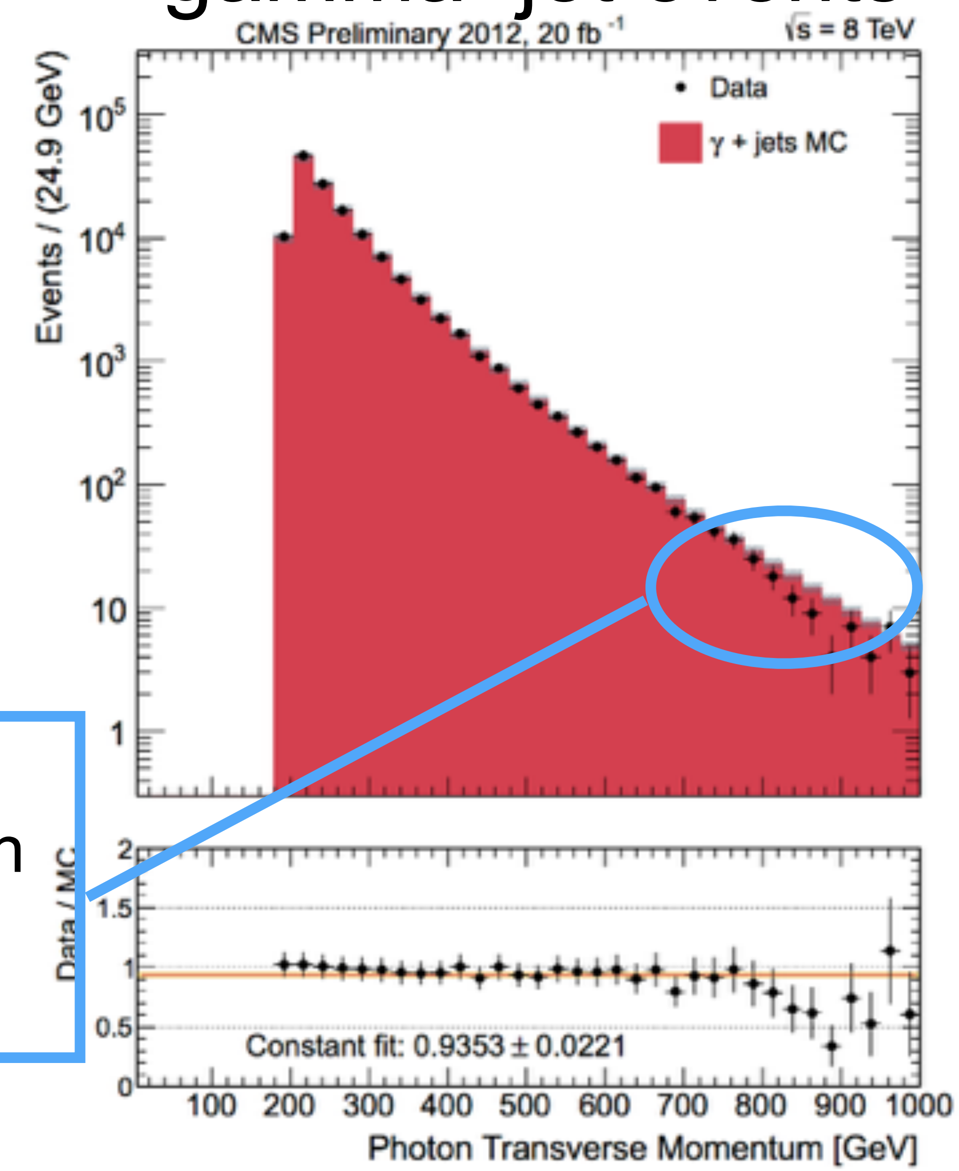
But this is for particles from SM processes!
Heavy resonances produce **very energetic objects!**

HIGH MASS: A LIFE W/OUT CONTROL SAMPLES

Z->mumu events



gamma+jet events

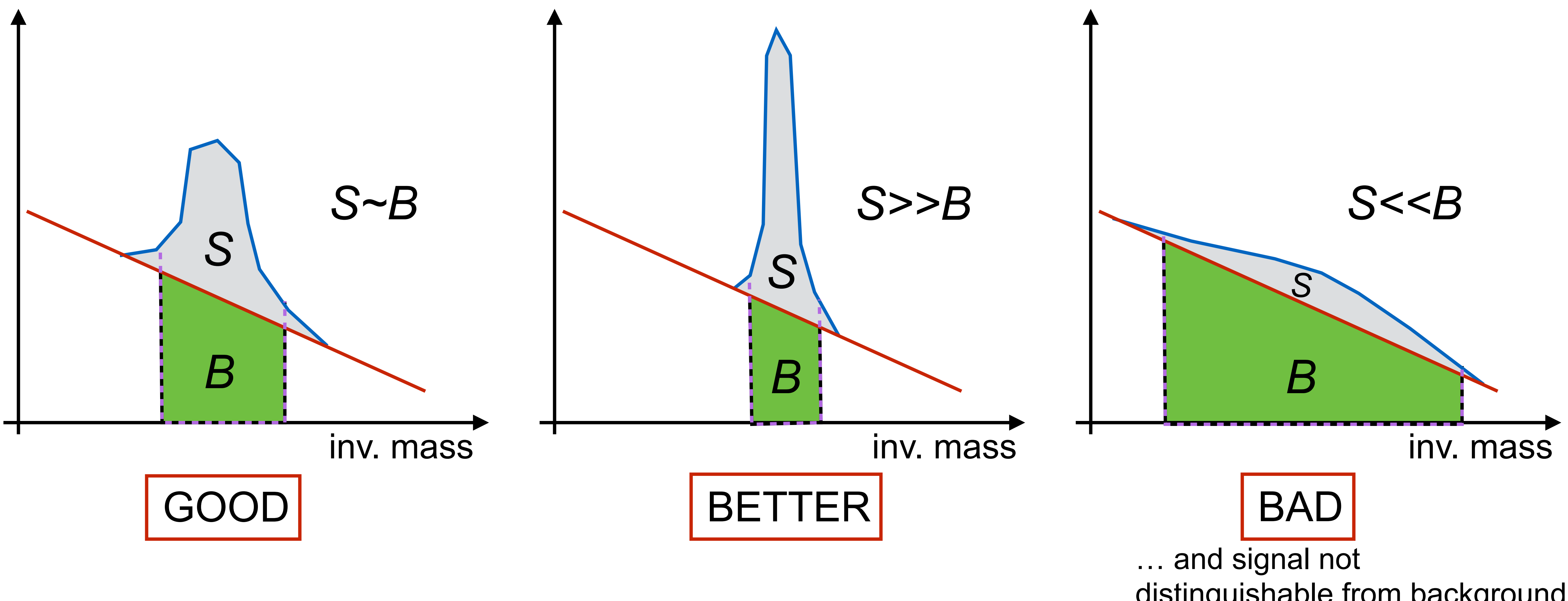


not enough events to calibrate in region where signal is expected!

- Need to be sure that:
  - **efficiency of energetic objects is not zero**
  - **resolution under control**
- In extreme cases **resonance can be hidden!**

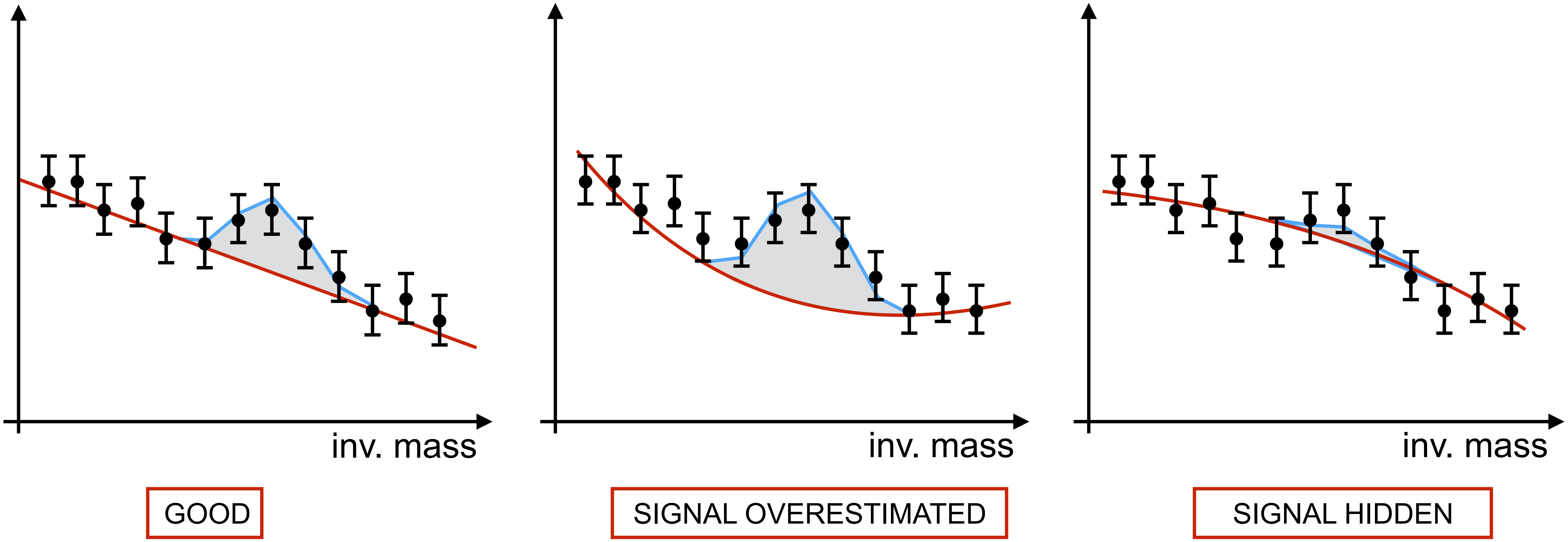
EXPERIMENTAL ISSUES: RESOLUTION

- **Mass resolution crucial in resonance searches**
  1. statistical power inversely proportional to the mass resolution
  2. resonance hidden by bad understanding of resolution
- Need ad-hoc studies and calibration strategies at such large momenta



EXPERIMENTAL ISSUES: BACKGROUND

- **Accurate background estimate to not bias** signal extraction
  - signal can be overestimate (or even fake excess)
  - signal can be missed
- **Two techniques**
  - background shape from MC and normalize in control region (usually low mass) + theory/experimental systematics
  - parameterize background shape and fit parameters directly on data



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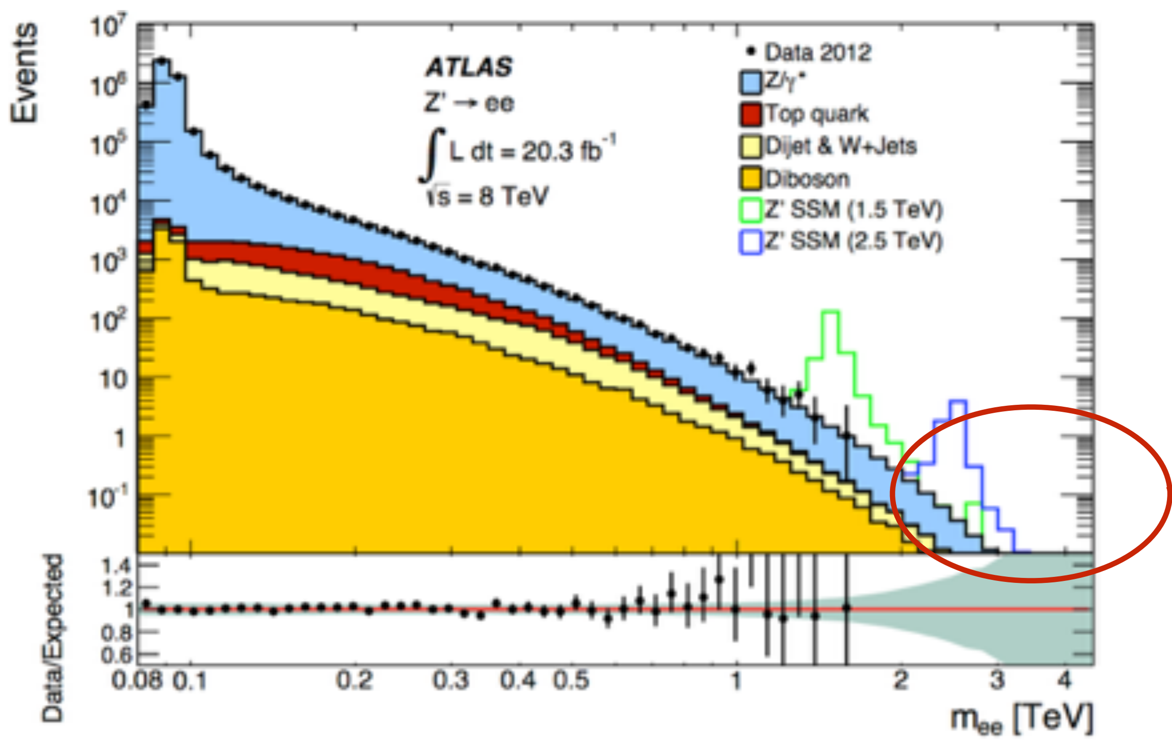
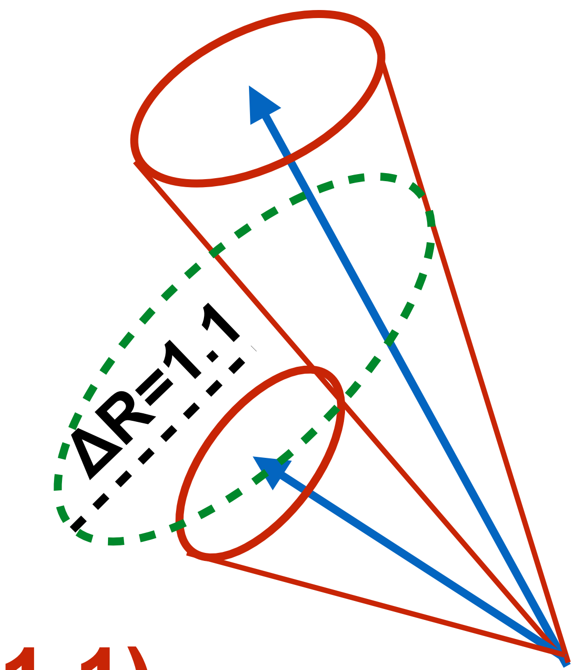


At very high masses no events to tune background. Extrapolation needed

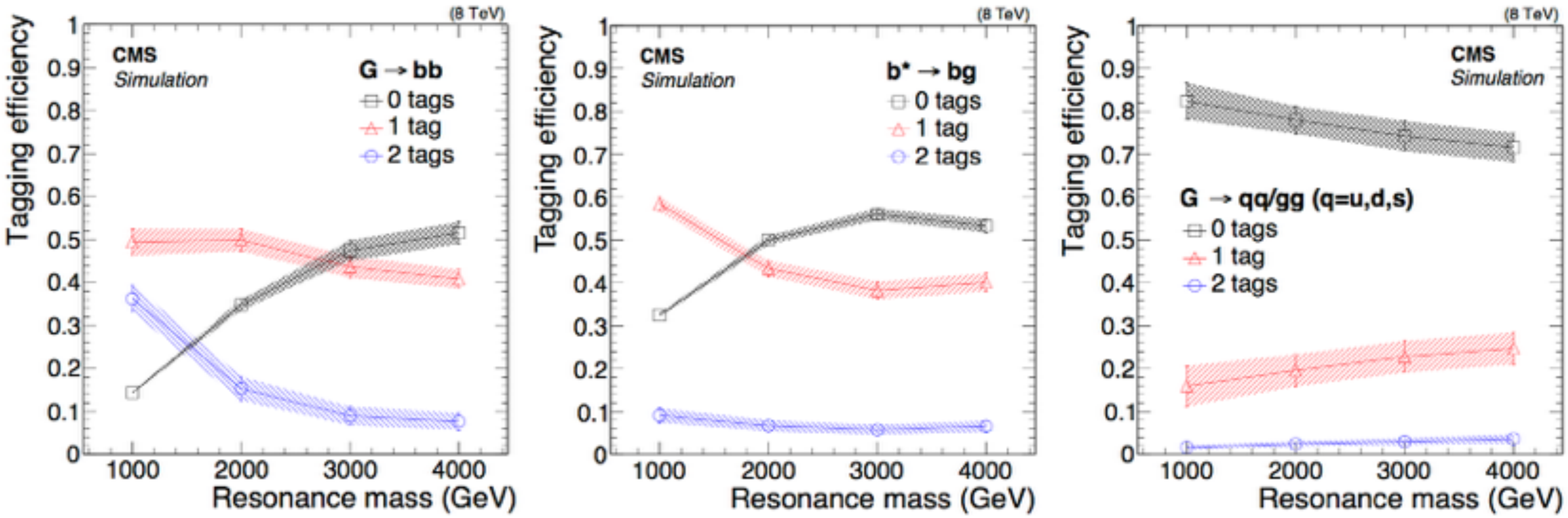
DIJET: INTRODUCTION

- **Straightforward search, two high pT jet**
- **Different search strategies:**
  - narrow resonances
  - resonances in b jets
  - wide resonances
- **Gluon radiation recovered in wide jets (ΔR=1.1)**
- **Several interpretations. Among them:**
  - excited quarks (q_*) including excited b quarks (b_*)
  - the color-octet scalar (S8) resonances
  - new gauge bosons (W′ and Z′) with SM-like couplings (SSM);
  - Randall–Sundrum (RS) gravitons (G)
  - QBHs



DIJET: SELECTION (CMS)

- **Trigger** requirements:
  - **L1**: HT > 150GeV,
  - **HLT:** HT>650GeV or m_{jj}>750GeV with |Deta|<1.5
- **Kinematics**: pT(jet) > 30GeV, |eta| < 2.5, m_{jj} > 890GeV
- **btagging**: combined secondary vertex (CSV)
  - to increase sensitivity in resonances decaying in bjets (Z', RS graviton, b*)

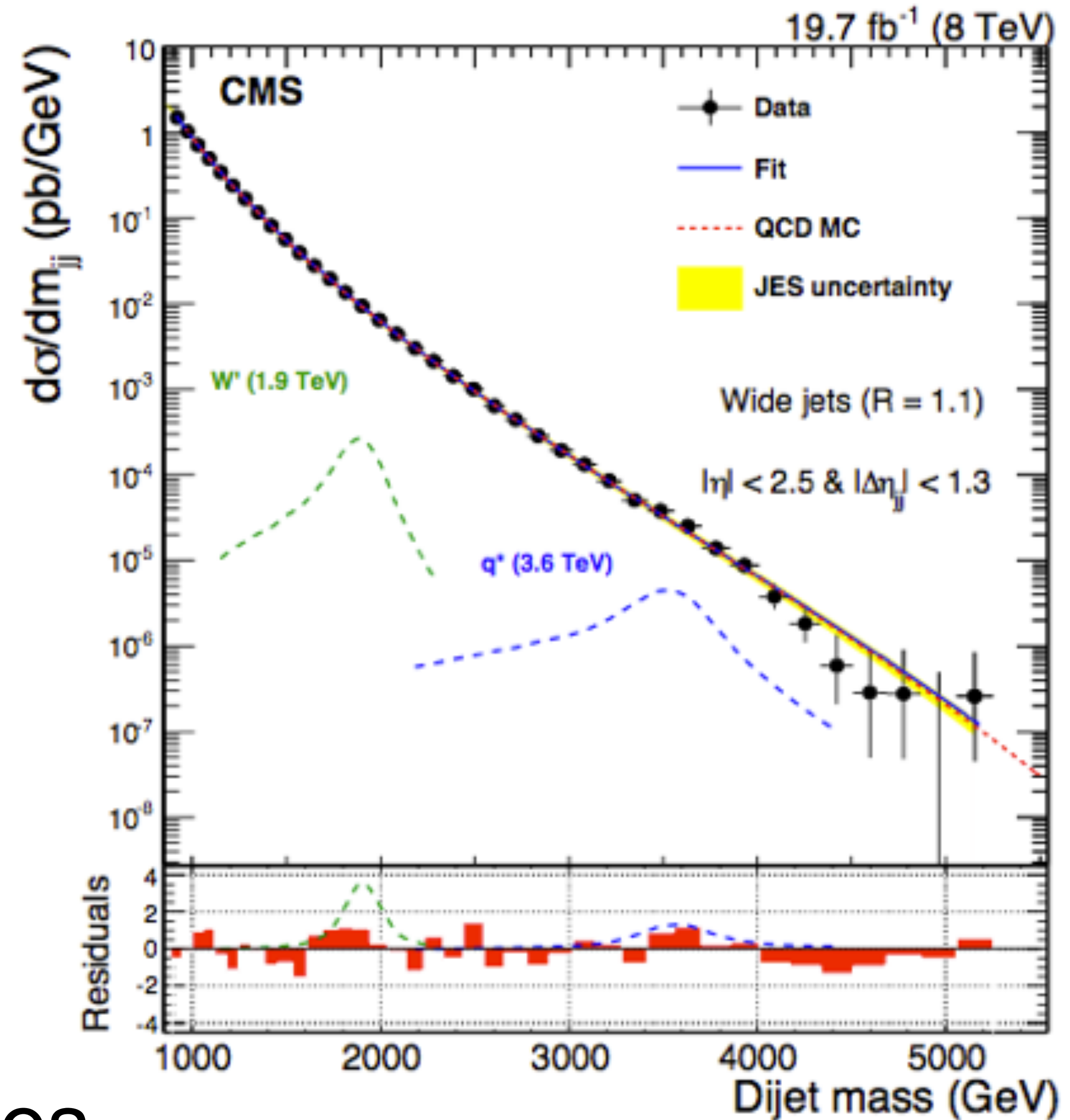


DIJET: SPECTRUM AND MODELING (CMS)

- **Background fitted** with

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}} \qquad x = m_{jj}/\sqrt{s}$$

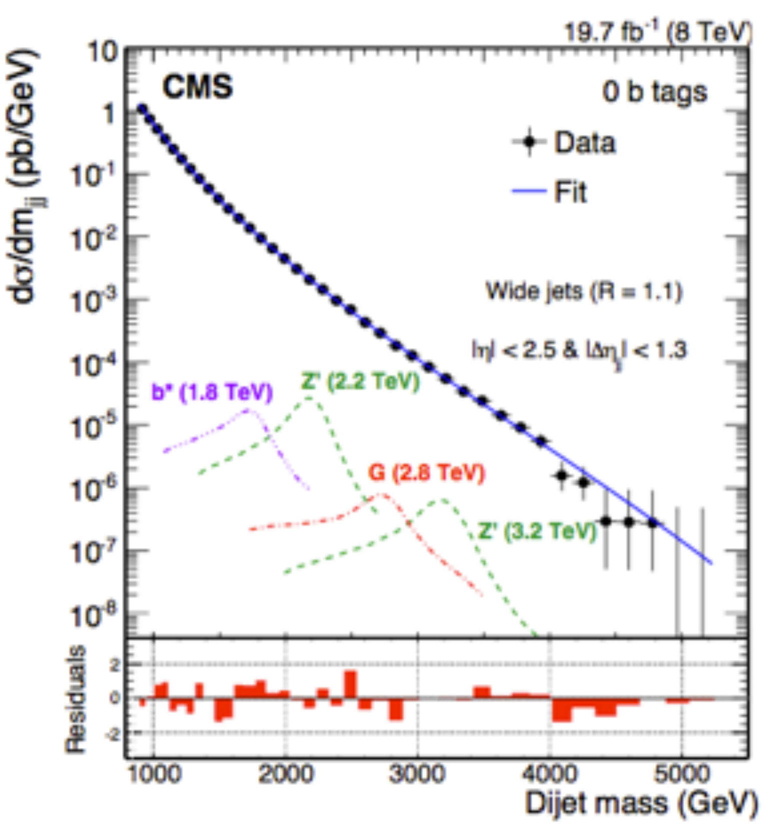
- **Signal shape** for:
  - RS gravitons (gg and qq)
  - excited quarks for (gq)
  - for b* enriched b categories used
- **Wide resonances** RS gravitons
  - k/MPl parameter varied, up to 30%
- **QBH modeled** with different masses
  - shapes independent on MD and n
- **Signal extracted** using a binned likelihood approach



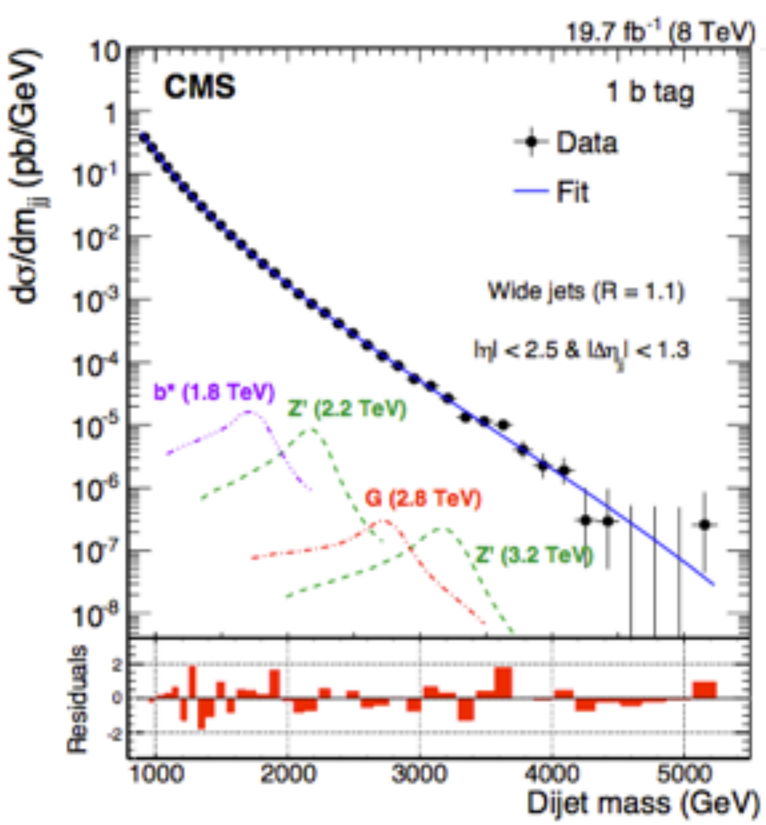
DIJET: B-TAGGING CATEGORIES

- no excess

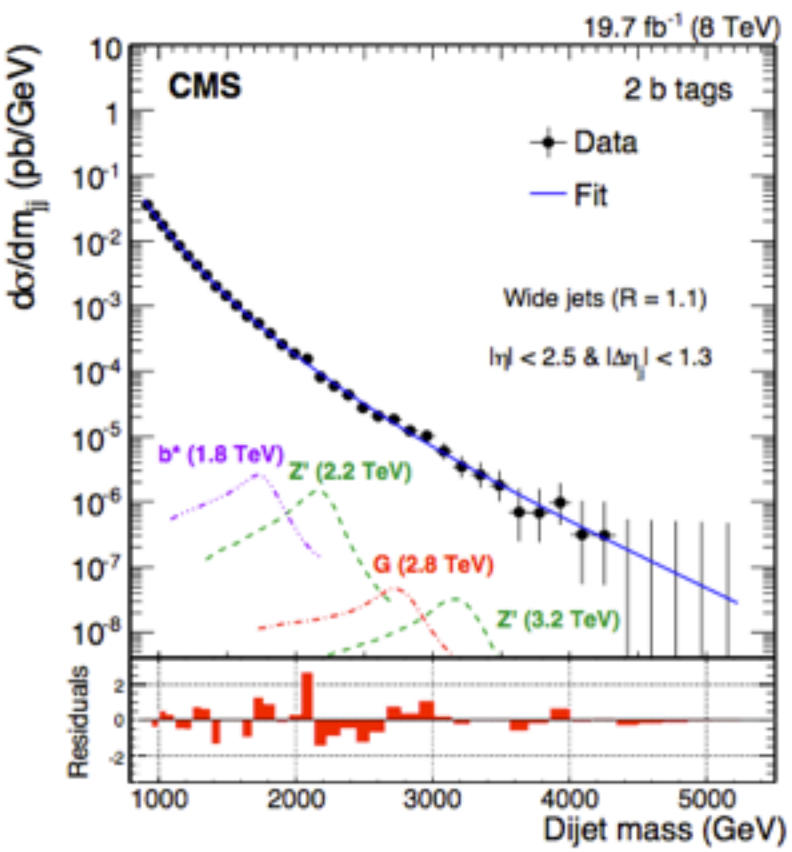
0 btag



1 btag

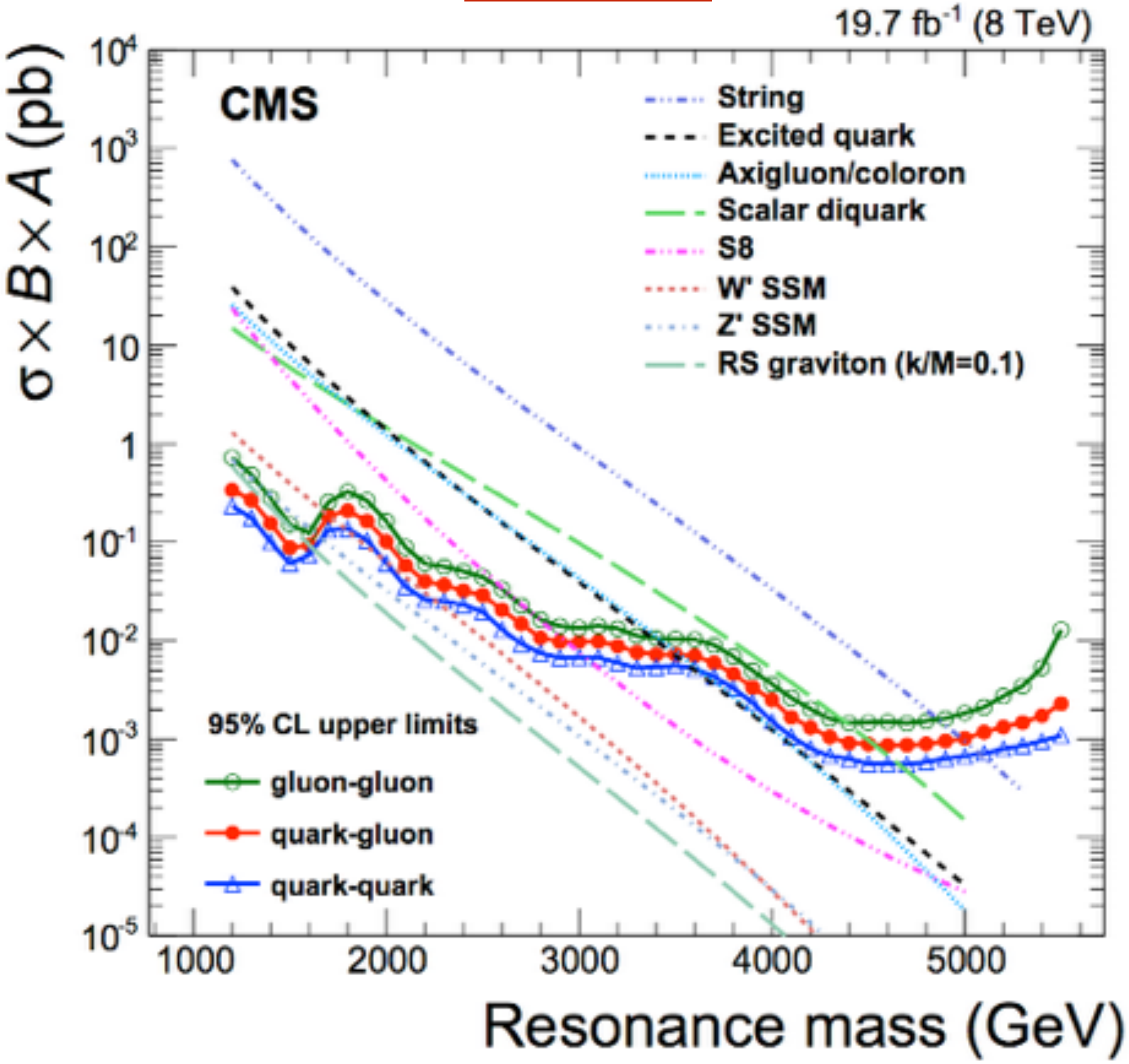


2 btags

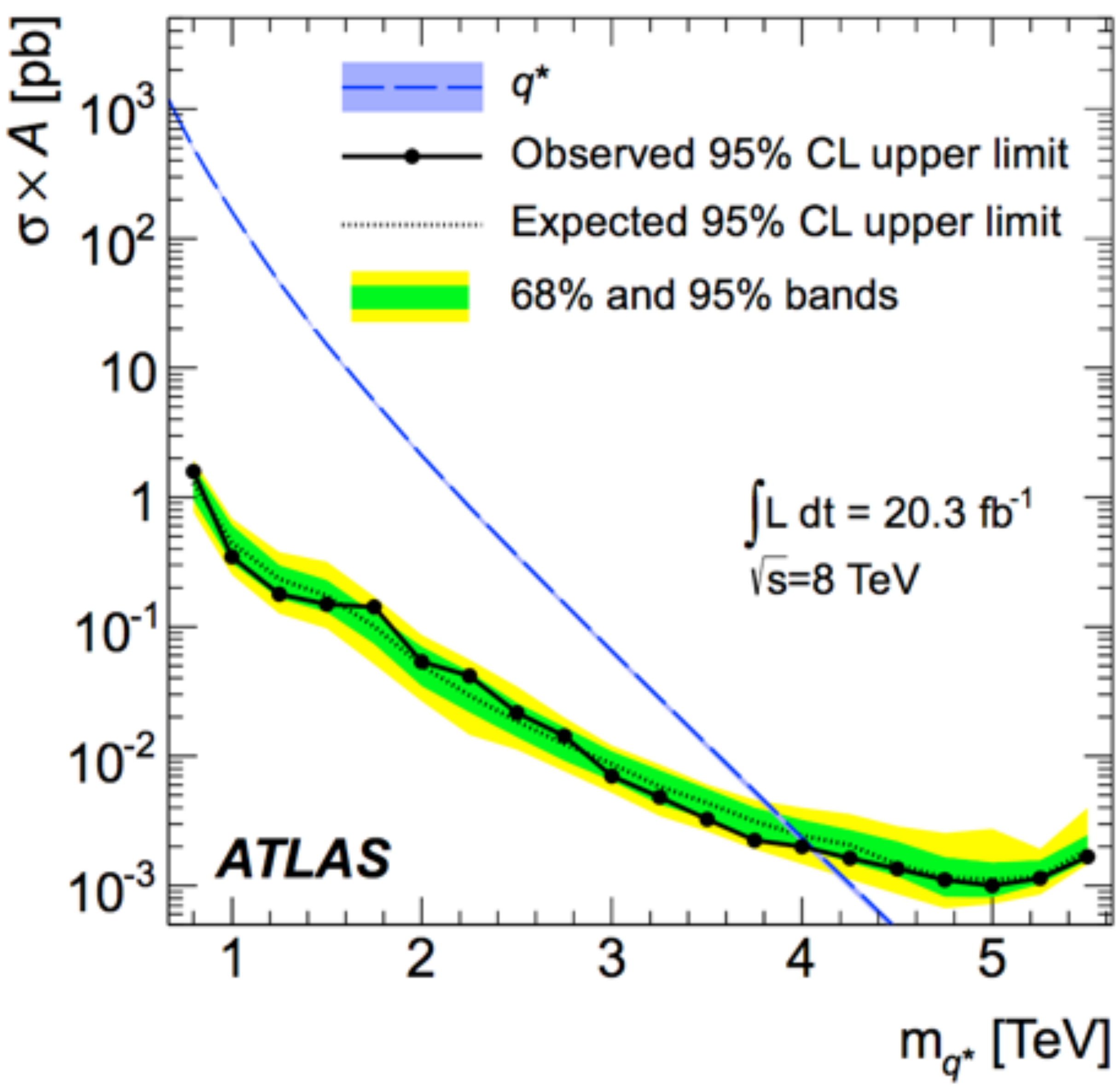


DIJET: LIMITS (I)

CMS



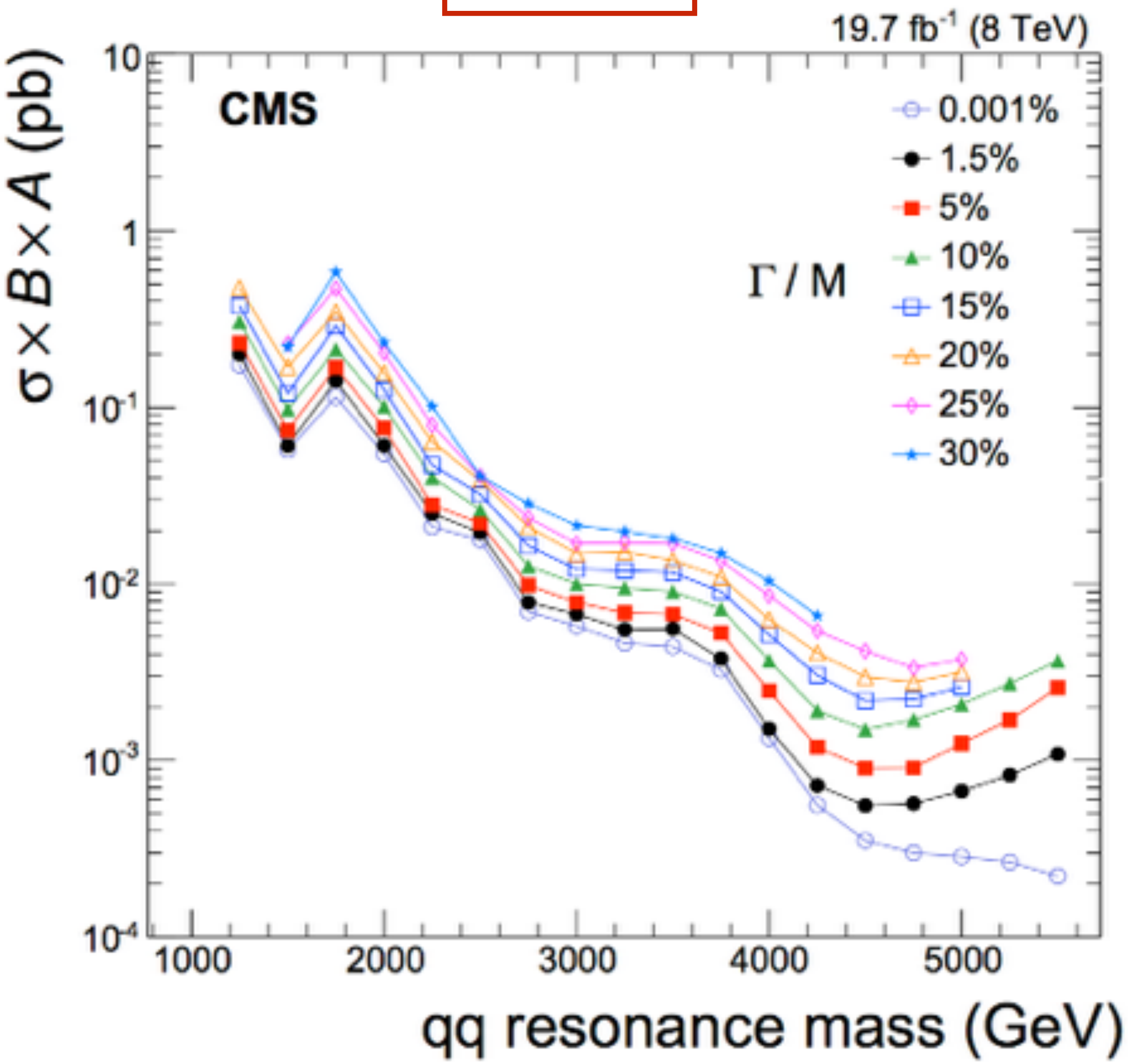
ATLAS



DIJET: LIMITS (II)

- **Limits for wide resonances**
- Similar results for ATLAS and CMS

CMS



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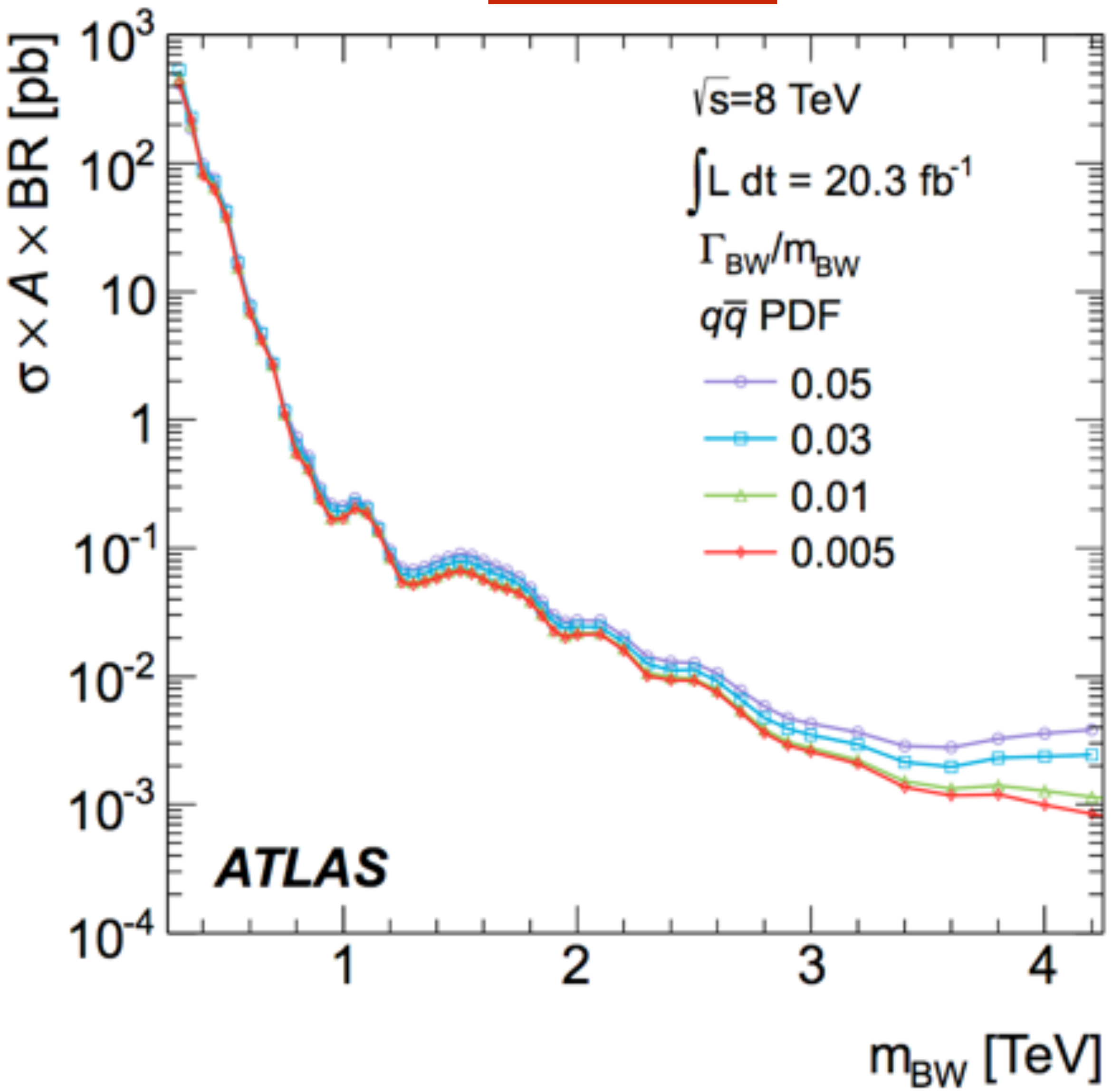


DIJET: INTERPRETATION

CMS

Model	Final state	Observed mass exclusion (TeV)	Expected mass exclusion (TeV)
Inclusive search			
String resonance (S)	qg	[1.2,5.0]	[1.2,4.9]
Excited quark (q^*)	qg	[1.2,3.5]	[1.2,3.7]
E_6 diquark (D)	qq	[1.2,4.7]	[1.2,4.4]
W' boson (W')	$q\bar{q}$	[1.2,1.9] + [2.0,2.2]	[1.2,2.2]
Z' boson (Z')	$q\bar{q}$	[1.2,1.7]	[1.2,1.8]
RS graviton (G), $k/\overline{M}_{\mathrm{Pl}} = 0.1$	$q\bar{q} + gg$	[1.2,1.6]	[1.2,1.3]
b-enriched search			
Excited b quark (b^*)	bg	[1.2,1.6]	
Wide resonance search			
Axigluon (A)/coloron (C)	$q\bar{q}$	[1.3,3.6]	
Color-octet scalar (S8)	gg	[1.3,2.5]	

ATLAS

Model and Final State	95% CL Limits [TeV] Expected	Observed
$q^* \to qg$	3.99	4.09
$s8 \to gg$	2.83	2.72
$W' \to q\bar{q}'$	2.51	2.45
Leptophobic $W^* \to q\bar{q}'$	1.93	1.75
Leptophilic $W^* \to q\bar{q}'$	1.67	1.66
QBH black holes (q and g decays only)	5.82	5.82
BLACKMAX black holes (all decays)	5.75	5.75

DILEPTON: INTRO

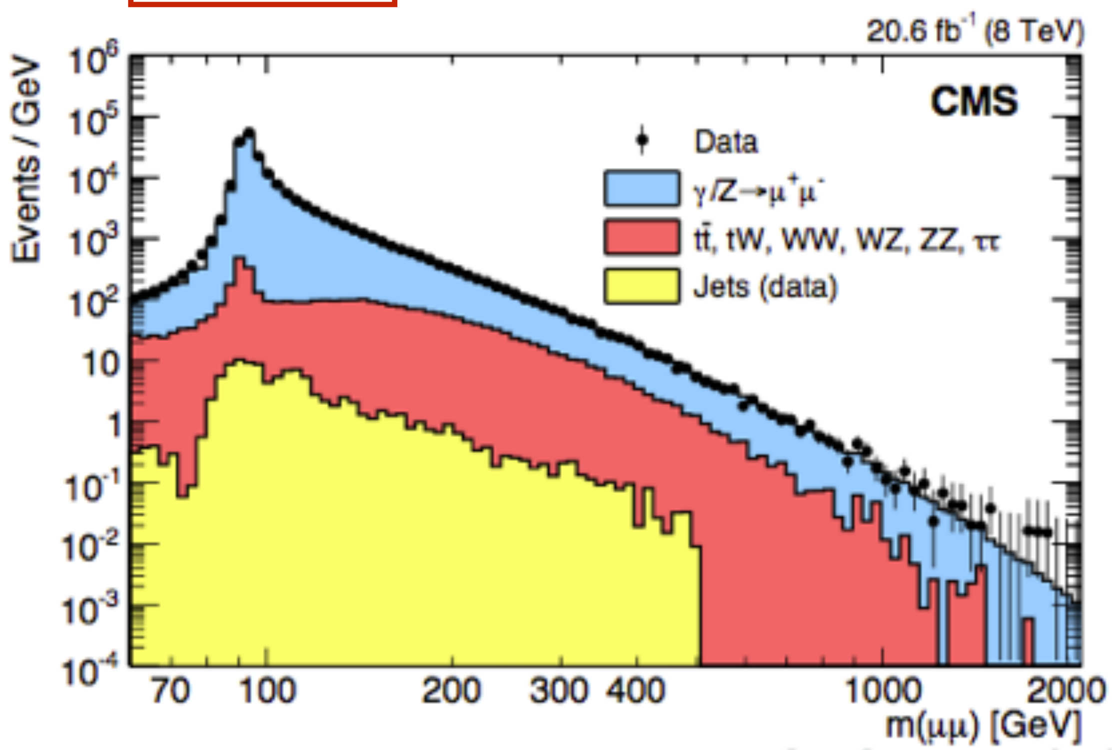
- **Both di-electron and di-muon channels**
  - loose selection search for a narrow resonance
  - main background Drell-Yan events
  - virtually background free above 1.5 TeV
- **Kinematic selection:**
  - trigger: single and double lepton triggers
  - offline: pt(leptons)>25-40 GeV + isolation
  - A x efficiency not very different between spin 1 and 2 resonances
- **Efficiency**: Z-based tag and probe for linearity check
- **Interpretations for resonance:**
  - Z'_{SSM}, Z'_{ψ}
  - Kaluza-Klein graviton (G_{kk})

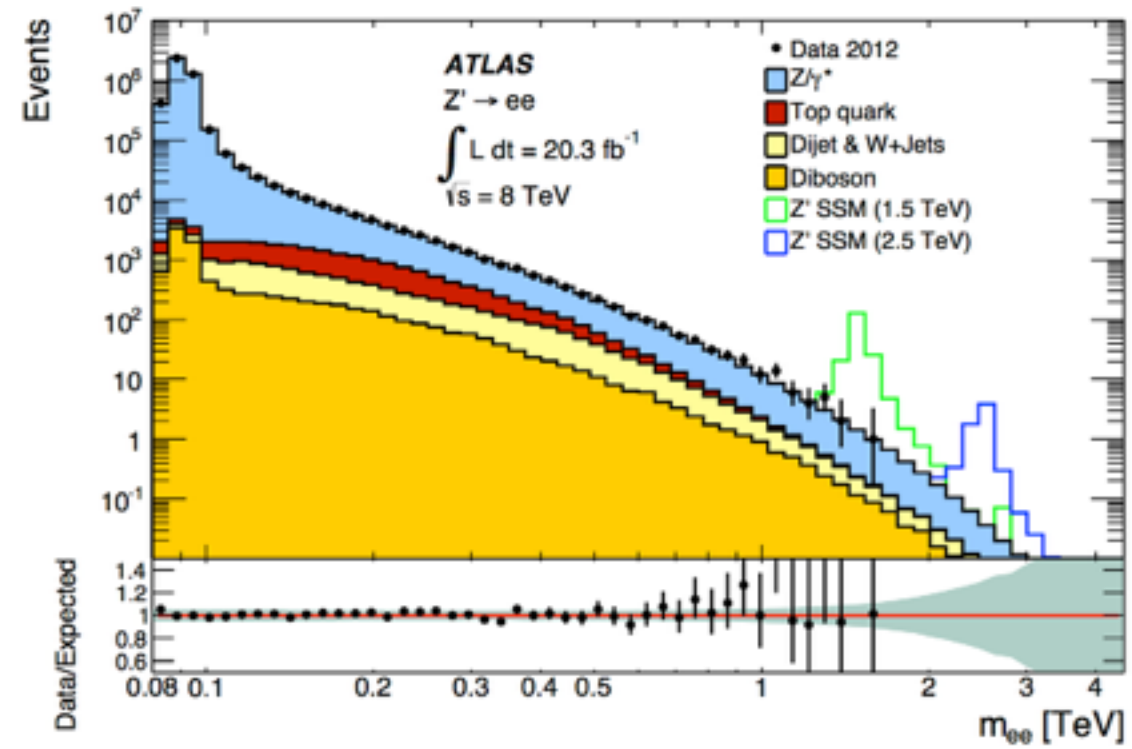
DILEPTON: SPECTRUM

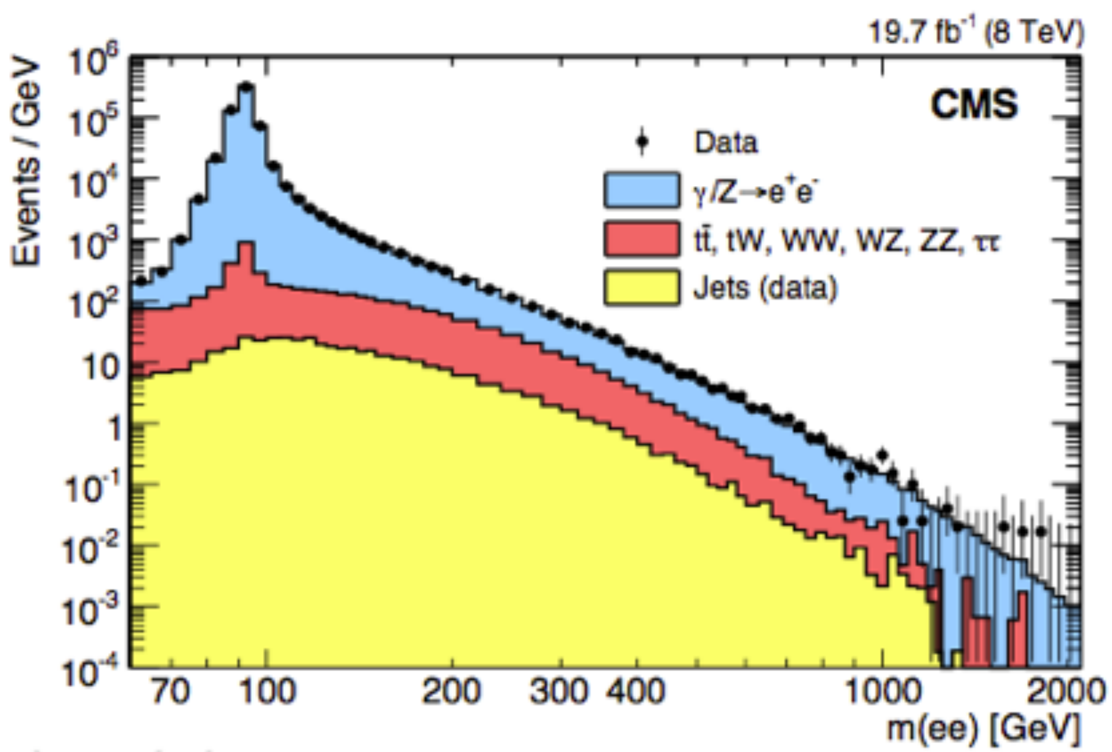
no evident excess

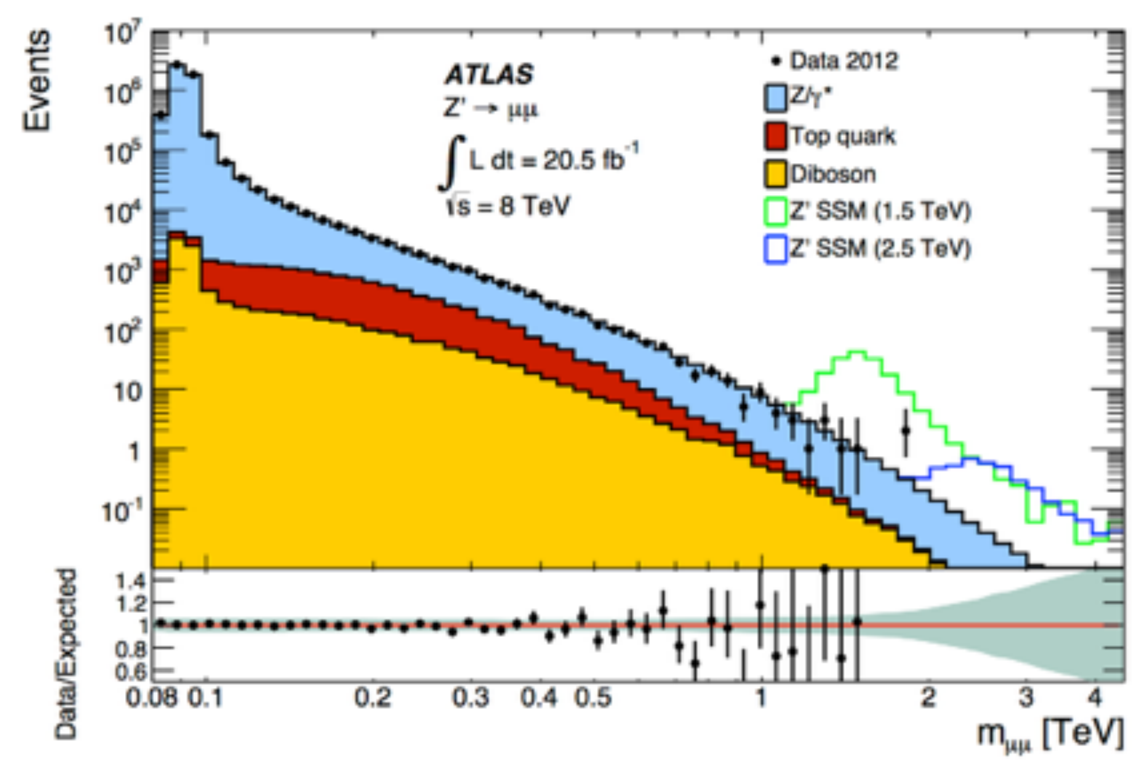
CMS

ATLAS









DILEPTON: LIMIT EXTRACTION

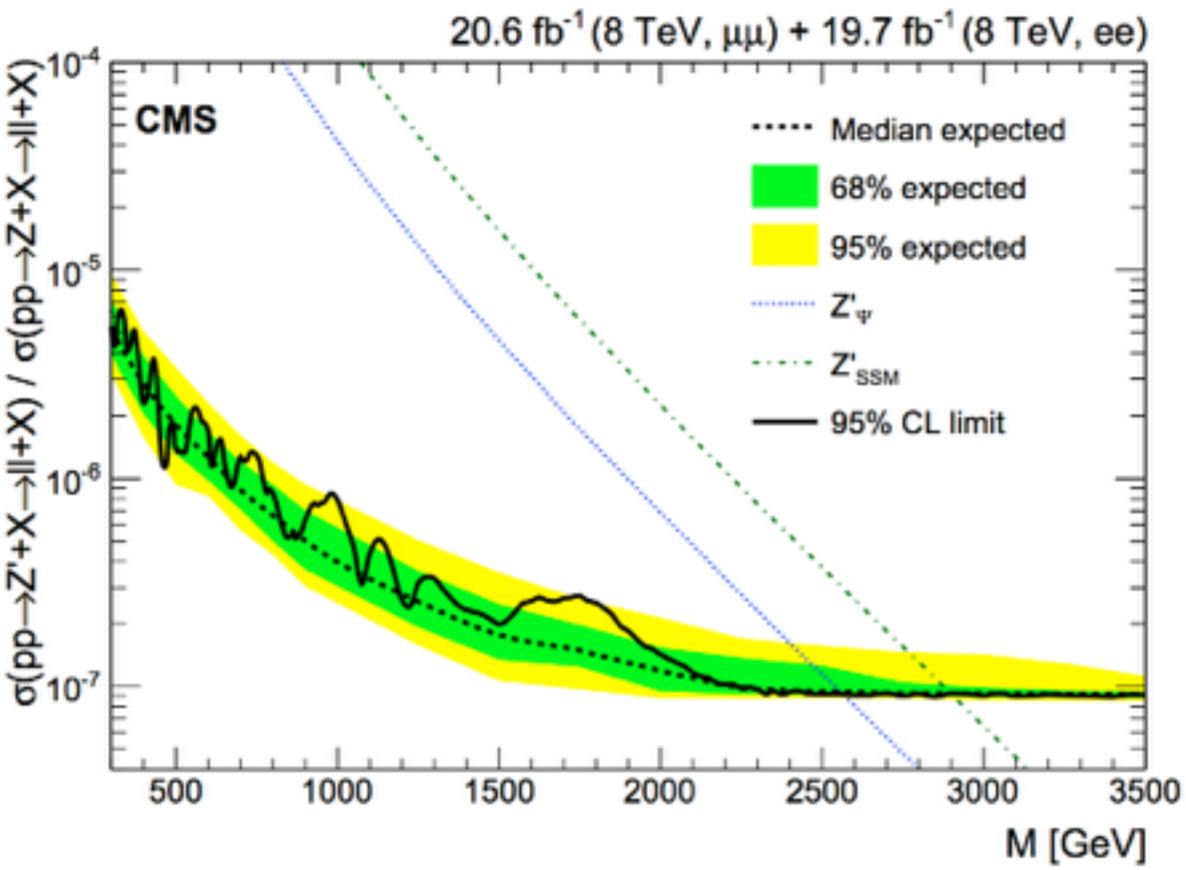
- **CMS**: to reduce systematics due to efficiency, extracted via :

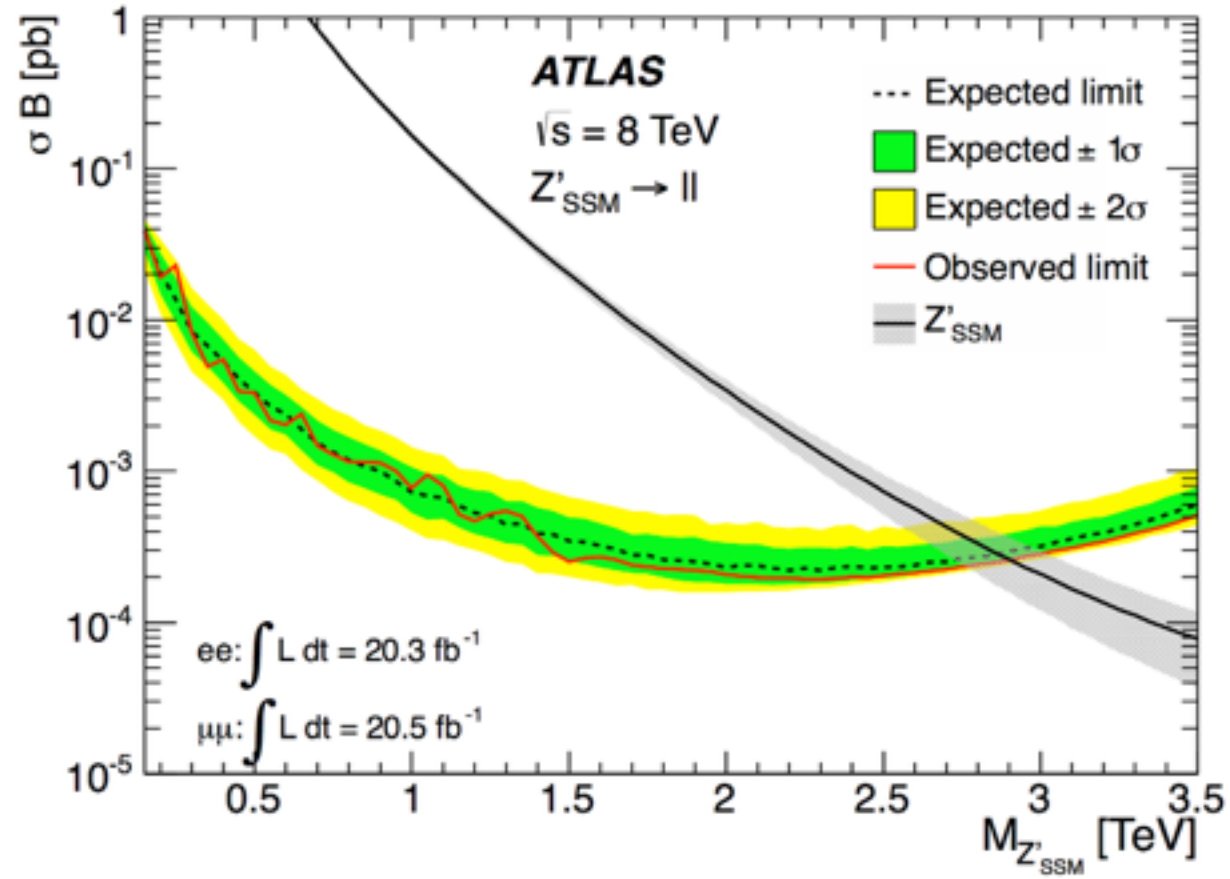
$$R_\sigma = \frac{\sigma(\mathrm{pp} \to \mathrm{Z}' + X \to \ell\ell + X)}{\sigma(\mathrm{pp} \to \mathrm{Z} + X \to \ell\ell + X)}$$

  - Z' events counted in mass ± 5%, Z in mass ± 30GeV
  - mass window form Z' to reduce interference and PDF effects
- **ATLAS**: MC shapes with a likelihood fit assuming no interference
- **DY background from MC** (shape is parametrized for CMS)
- **Fake leptons** from data-driven approaches
- **Systematics** (similar between experiments):
  - efficiency (PDF-detector) 3-6% in acceptance
  - alignment in muons 5%(resonant) up to 41% for non-resonant
  - PDF in background 5-10% dependent on mass

DILEPTON: INTERPRETATION

- **Very similar limits set by the two experiments**
- **Z’ excluded below 2.5 - 3 TeV**





Z'_{SSM}	m < 2.90 TeV
Z_ψ	m < 2.57 TeV
G_{KK}	m < 2.73, 2.35, and 1.27 TeV

for couplings of 0.10, 0.05, and 0.01

Z'_{SSM}	m < 2.90 TeV
Z_ψ	m < 2.51 TeV
G_{KK}	m < 2.68, 2.28, and 1.25 TeV

for couplings of 0.10, 0.05, and 0.01

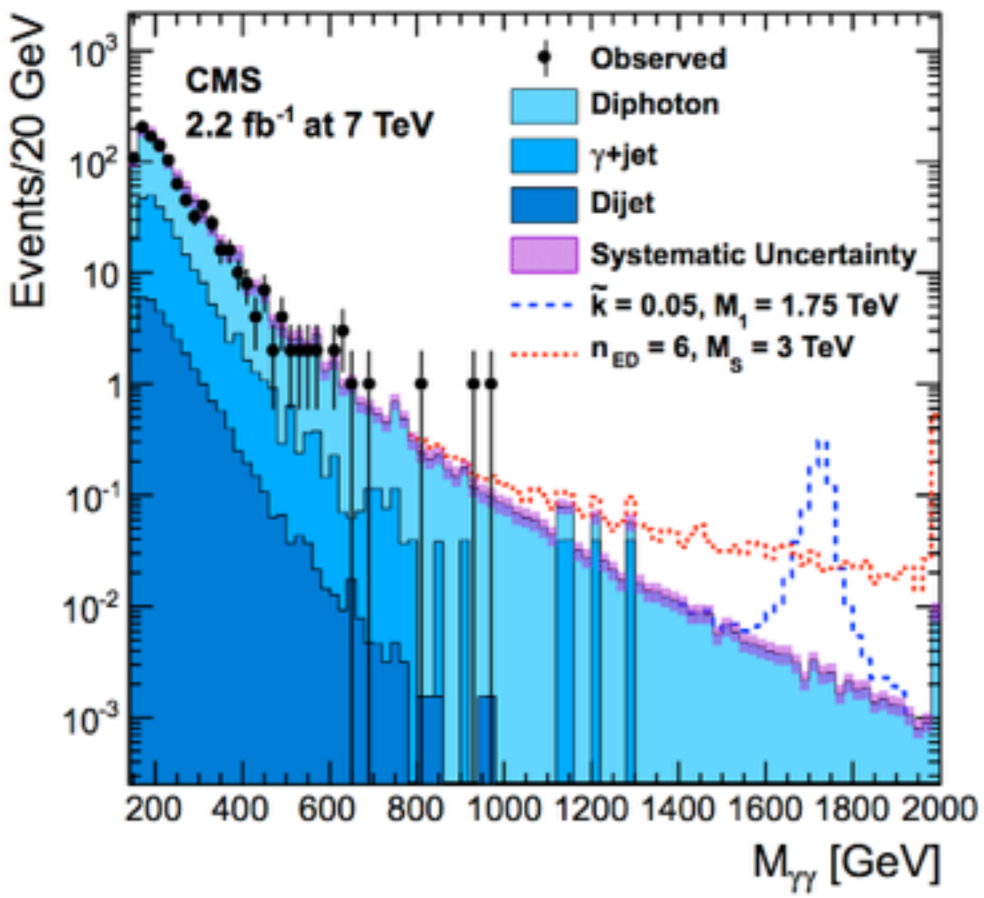
DIPHOTON: INTRO

- Approach **very similar to the dielectron analysis**
- **Diphoton triggers**, pT > 20 GeV
- Selection based on simple kinematics and isolation criteria
- **Main background**: SM diphoton production
  - shape taken from MC
  - normalization from low mass region
- **Fake photon contribution from control samples**
  - less than 10% of total background

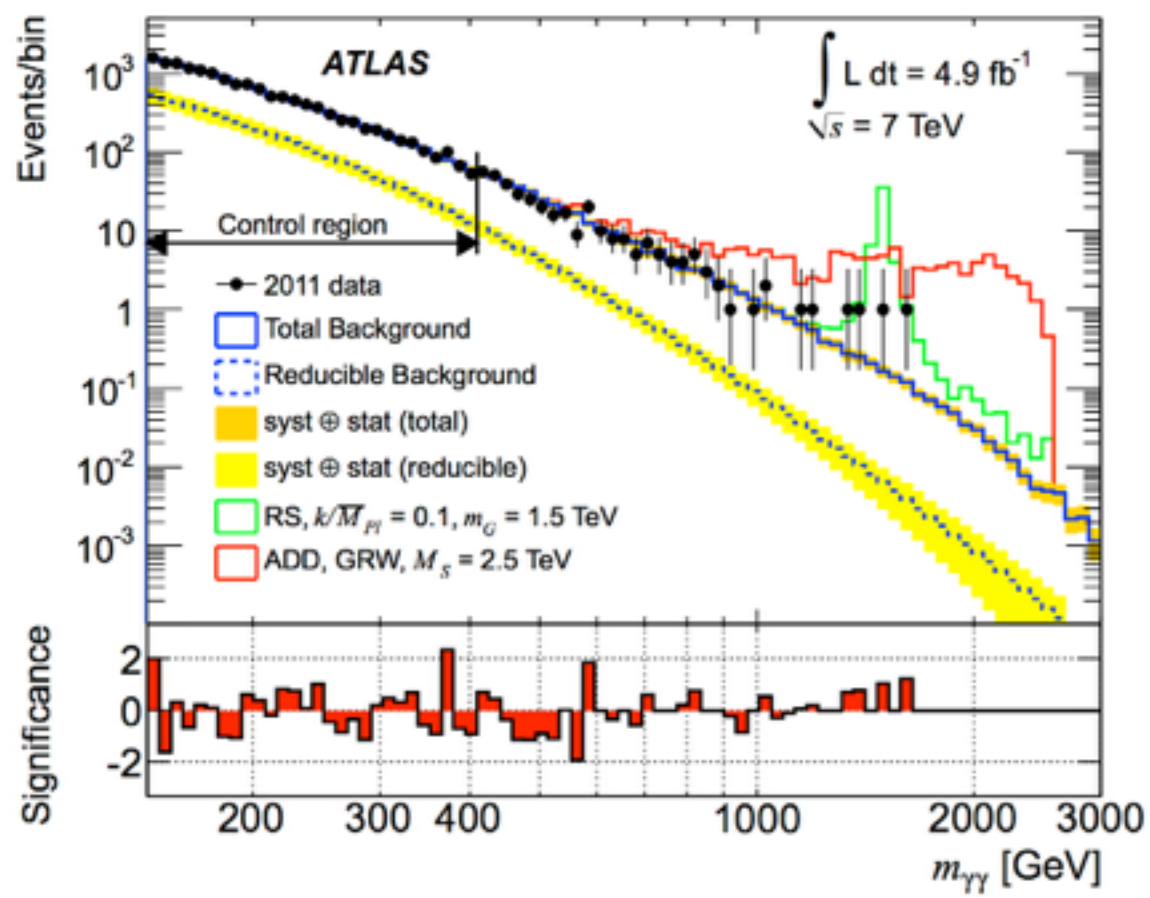
DIPHOTON: SELECTION AND SPECTRA

- Results only **with partial statistics (2 - 5 fb^{-1})**
  - maybe update soon with full statistics
- **No excess**
- Limits on RS Graviton set in the range ~1 – 2 TeV depending on k/M_{Pl}

CMS

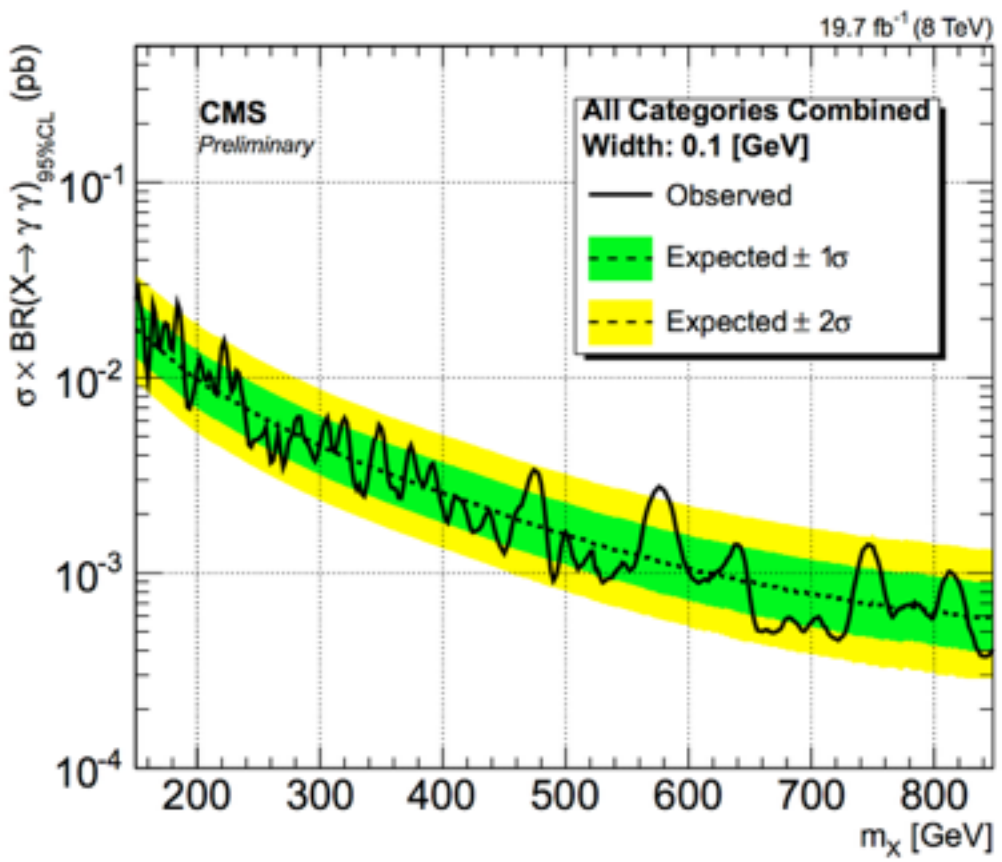


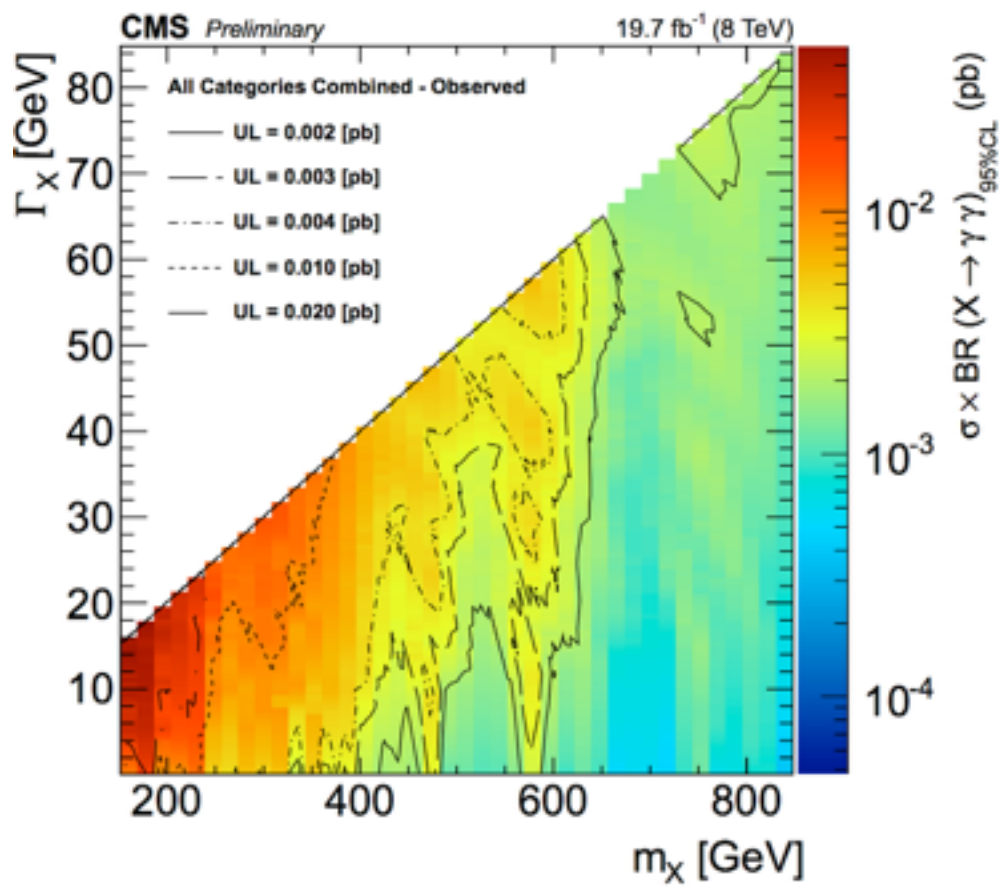
ATLAS



DIPHOTON: INTERMEDIATE MASSES

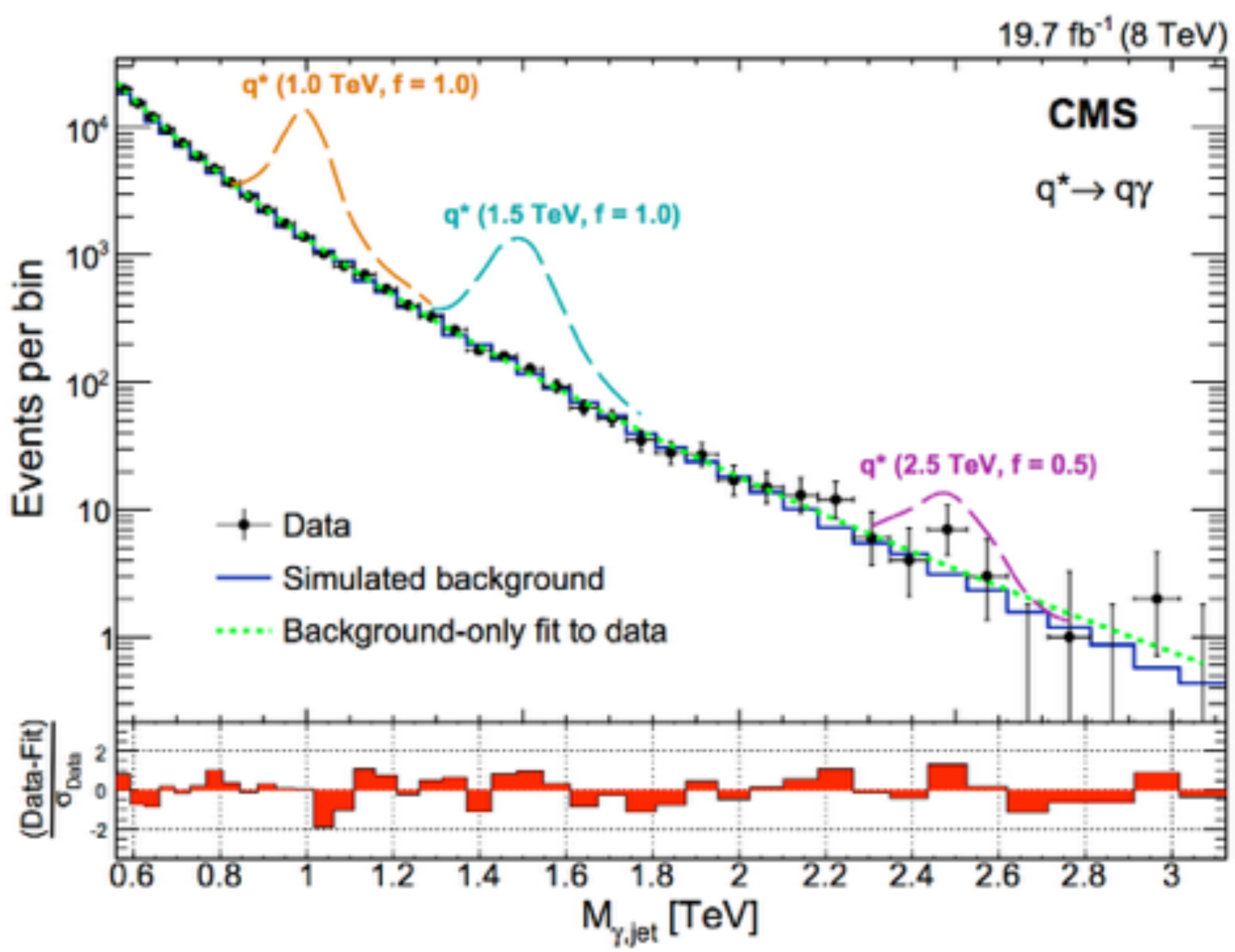
- New interest in **scrutinize the intermediate mass range** (<1TeV), done in both experiments
  - in principle RS gravitons already excluded in such region
- Simple **by-product of Higgs to diphoton** analysis, extending search to larger masses and **studying different widths**
- Mass limits for a possible Higgs-like scalar

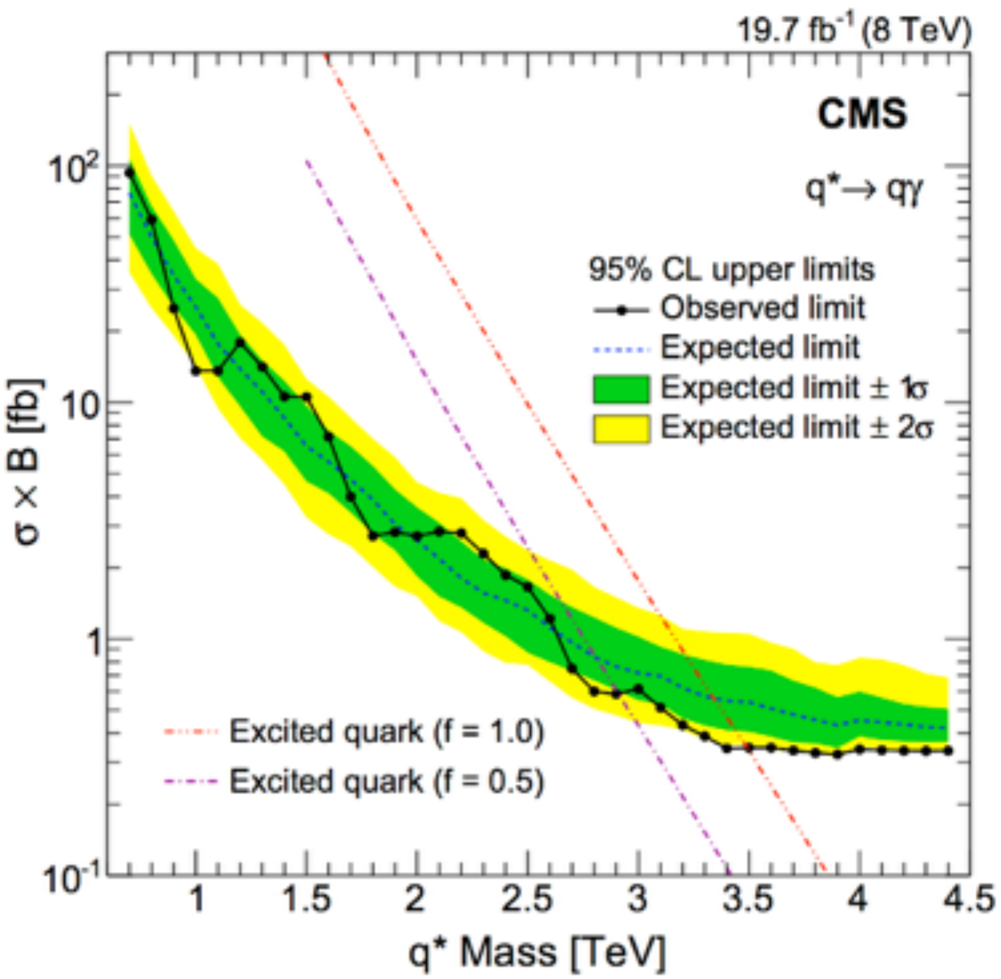




PHOTON+JET

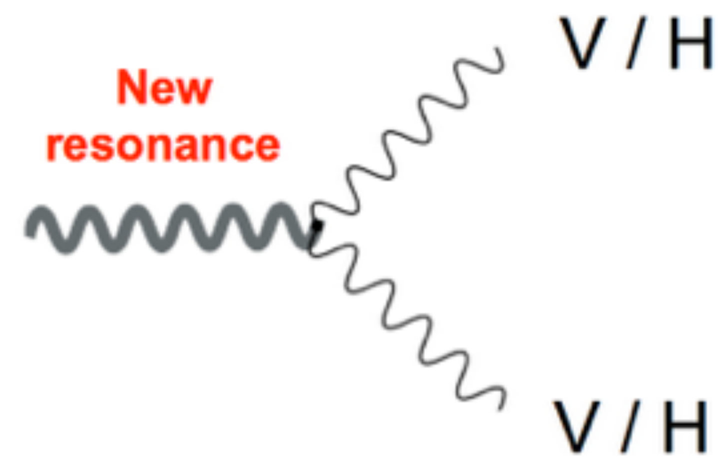
- **≥1 photon + ≥1 jet** (p_T >170 GeV)
- Further **requirements on topology**
  - $\Delta R(\gamma, \text{jet}) > 0.5$
  - $\Delta\eta(\gamma, \text{jet}) < 2.0$, $\Delta\varphi(\gamma, \text{jet}) > 1.5$
- Interpreted in **excited quarks scenario**





DIBOSON: INTRO

- Searching from **new resonances** decaying in **two massive bosons**
- **Analysis strategy** determined by
  - boson decay modes
  - mass of the resonance and boost
- **Clean experimental signature**
- In case of discovery, possible to measure properties from **angular distributions** of the decay products
- Several **different combinations** studied
- **Only few examples given** in the talk

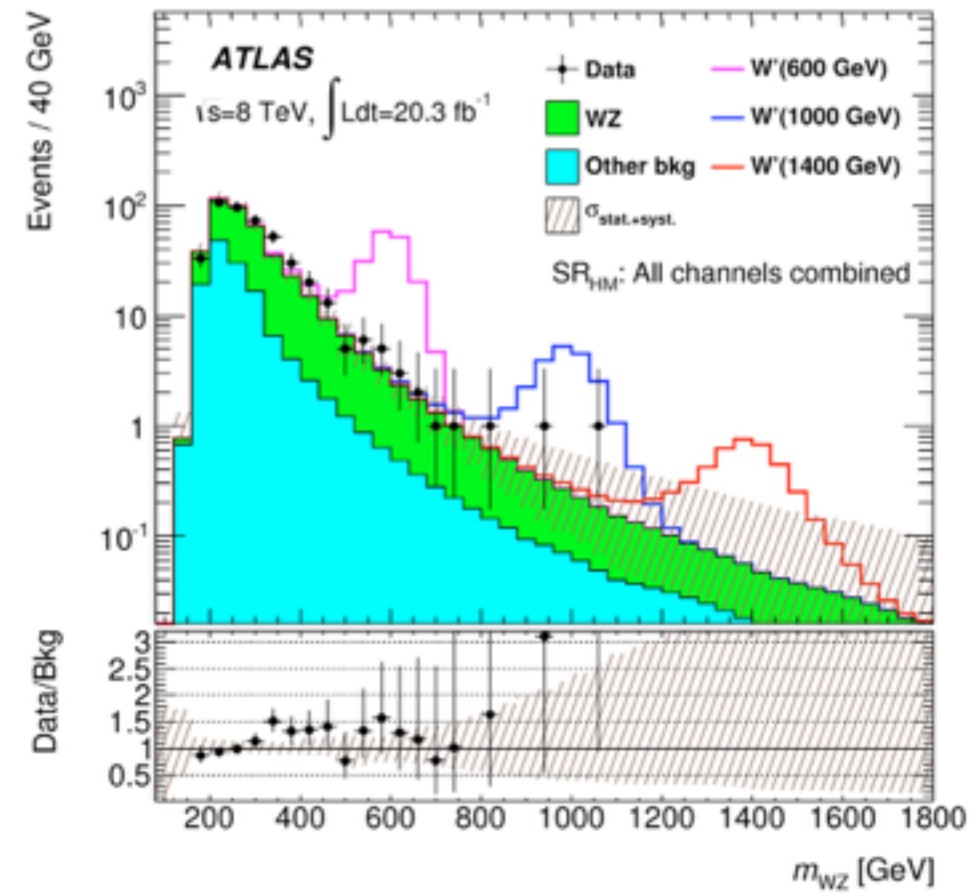


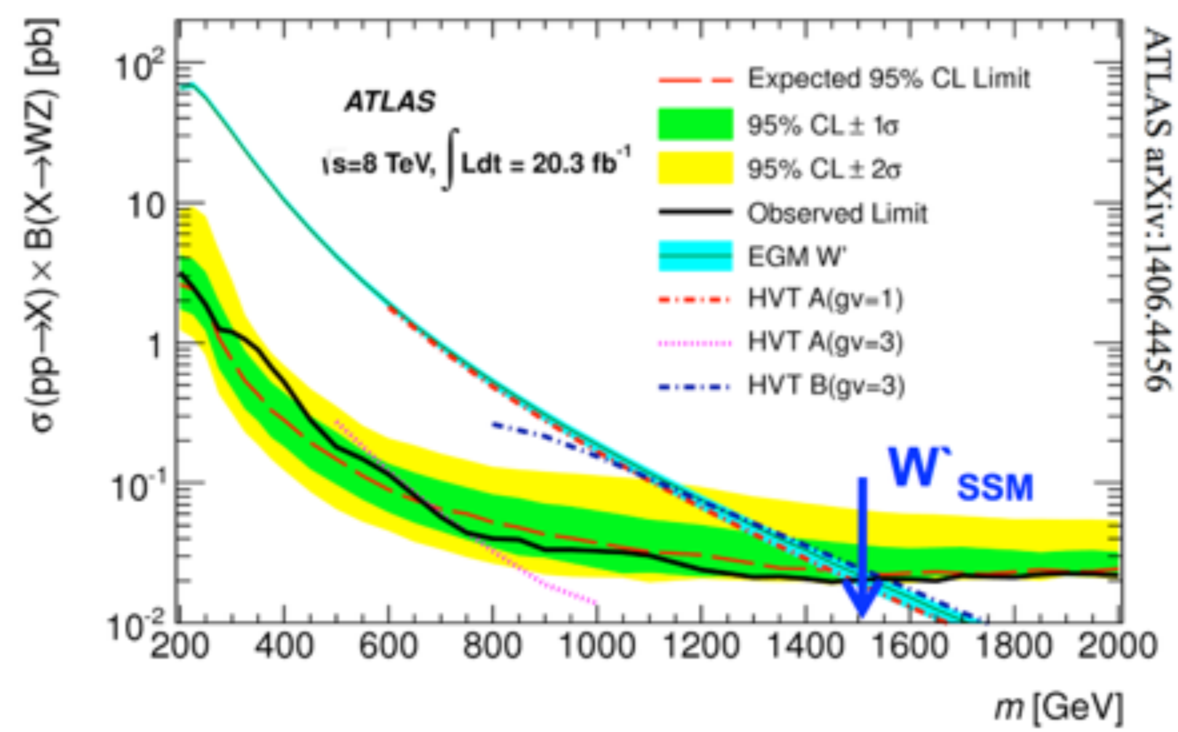
W **Z** **H**

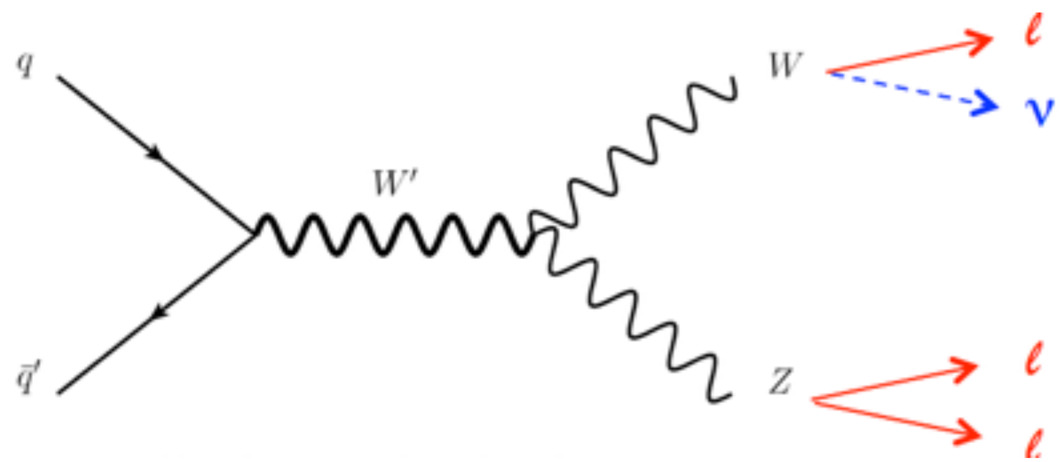
$M_W \sim 80.3$ GeV	$M_Z \sim 91.2$ GeV	$M_H \sim 125$ GeV
$W \to qq$ ~ 67%	$Z \to qq$ ~ 70%	$H \to bb$ ~ 57%
$W \to \ell\nu$ ~ 33%	$Z \to \nu\nu$ ~ 20%	$H \to WW$ ~ 21% $H \to ZZ$ ~ 2.5%
	$Z \to \ell\ell$ ~ 10%	$H \to \tau\tau$ ~ 6%
		$H \to \gamma\gamma$ ~ 0.2%

DIBOSON: LEPTONIC CHANNELS

- **Fully leptonic final state**
- **Small background from MC**
  - non resonant WZ
- Low BR but **very clean**
- **Analysis Strategy**
  - search for bump in M_{WZ} spectrum
  - neutrino p_z from W mass constraint
  - acceptable resolution
    - (~10% at 1 TeV)

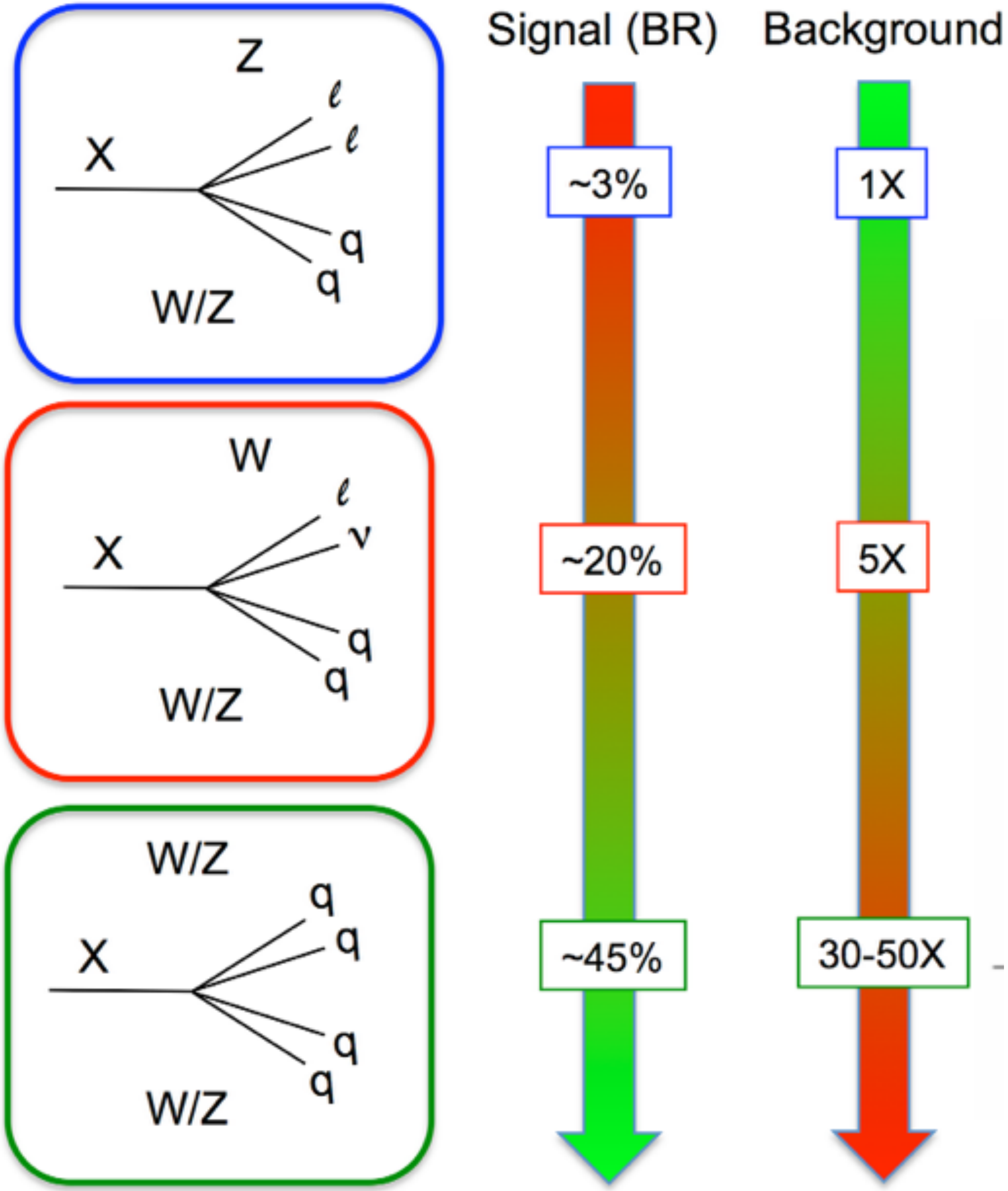






DIBOSON: HADRONIC CHANNELS

- **Pro and cons** of different decay modes
  - **leptons**: cleaner but less frequent
  - **jets**: large BRs but dirty

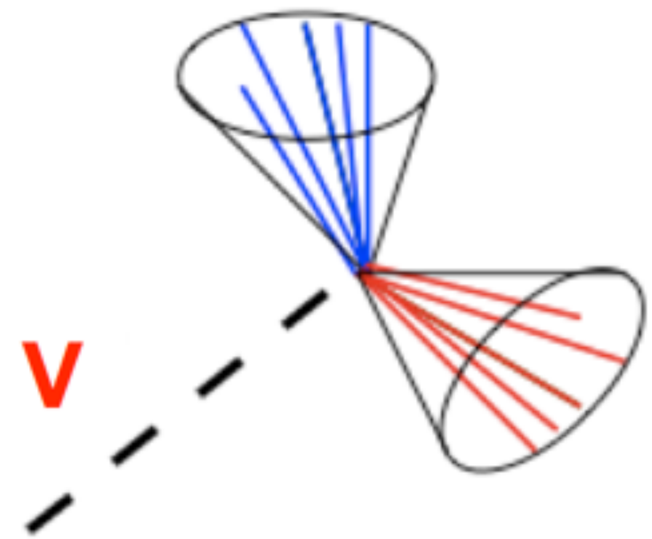


DIBOSON: BOOSTED HADRONIC V DECAYS

- Opening angle between jets

$$\Delta R_{qq}^{\min} \approx \Delta\theta_{qq}^{\min} \approx 2\frac{M_V}{p_{T,V}}$$

- **Low p_T**: separated



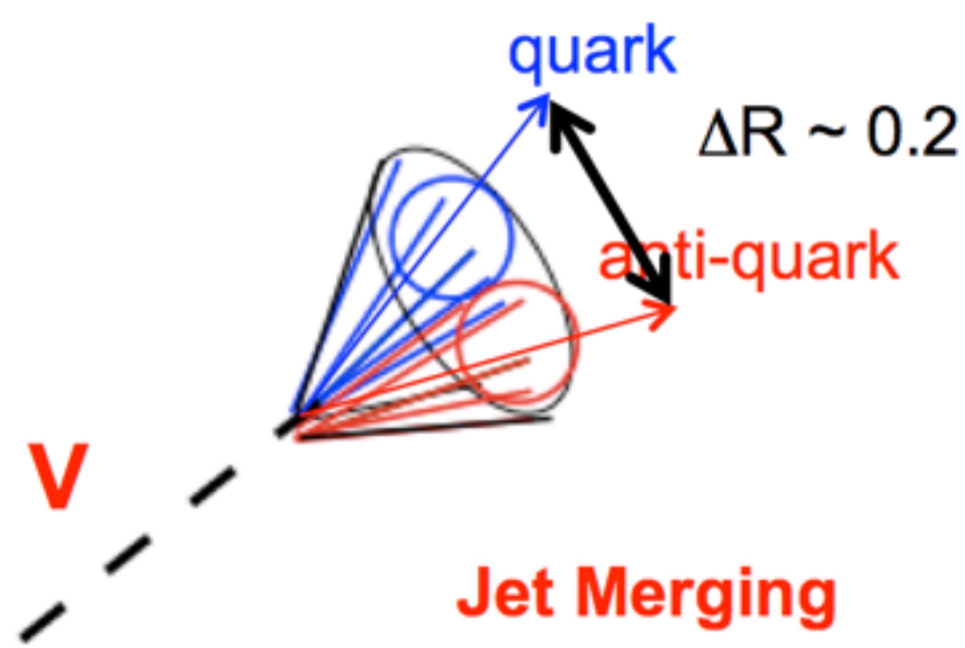
- **High p_T**: merging

  Example

  M_{reso} = 2 TeV

  $p_T(V)$ ~ 1 TeV ➡ $\Delta R_{qq}^{\min} \approx 0.2$

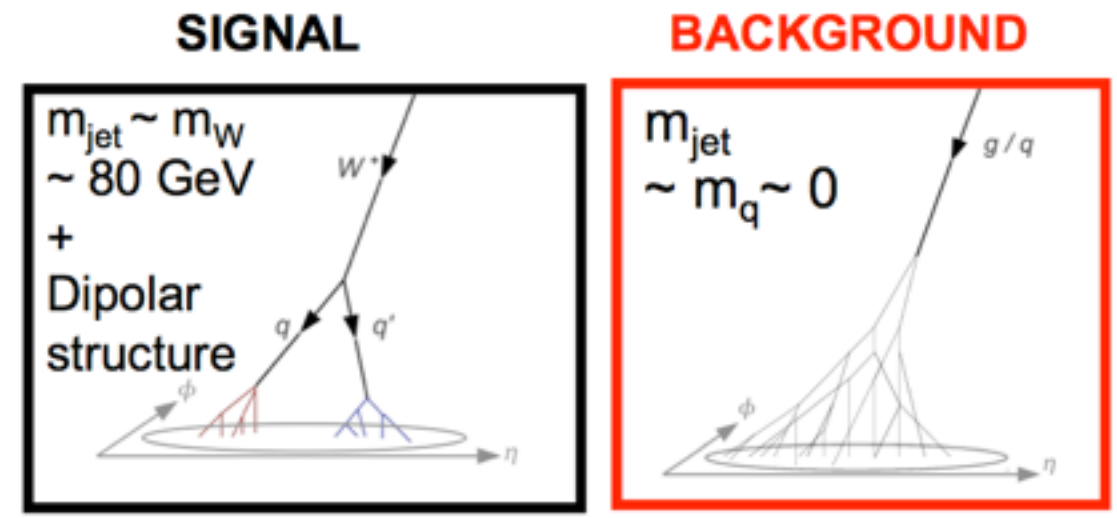
  M_V ~ 100 GeV



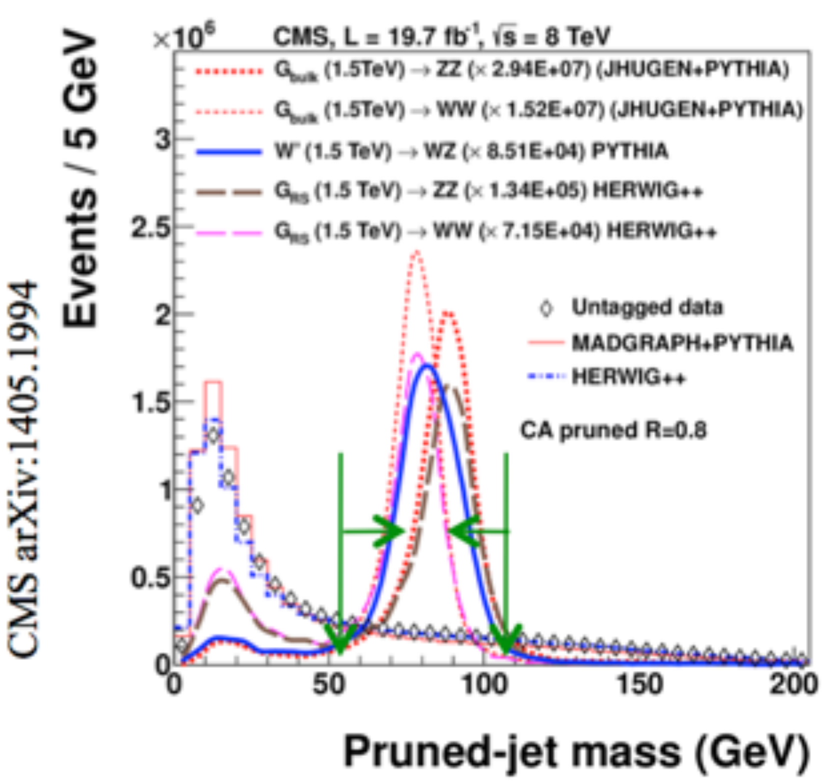
How to Tag Boosted V Decays

Several algorithms:

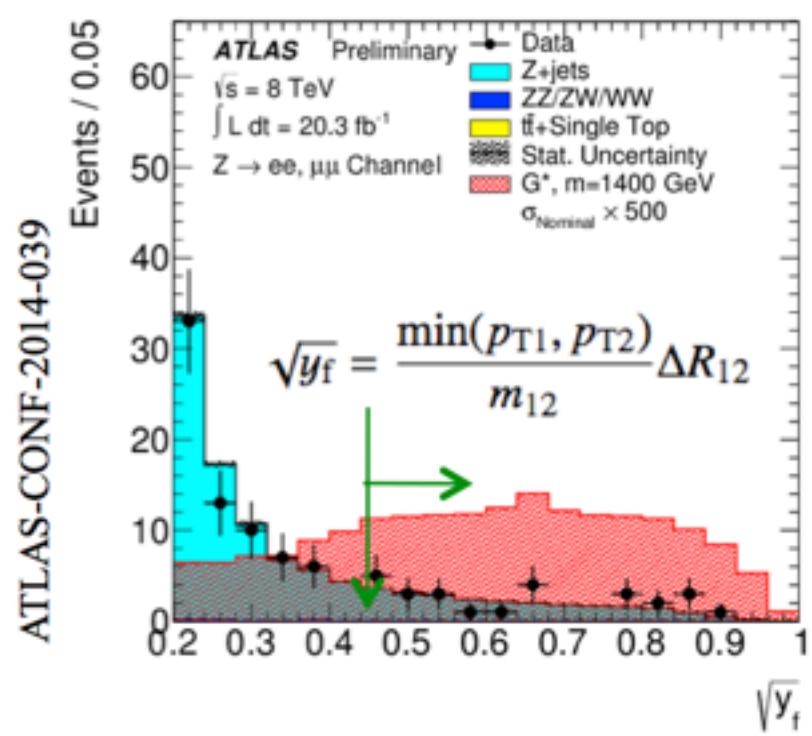
- **Jet trimming, pruning, filtering, …**
  - Remove soft component of jet, reducing effects of pileup and UE
- **Substructure variables**
  - Built from subjets after jet declustering



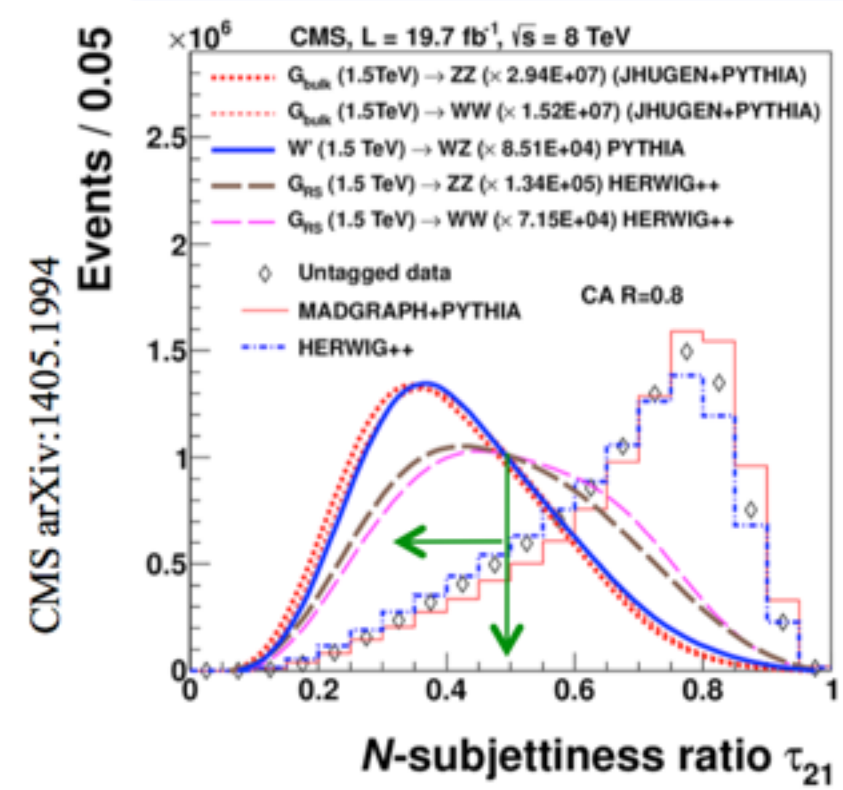
Jet mass



Momentum Balance

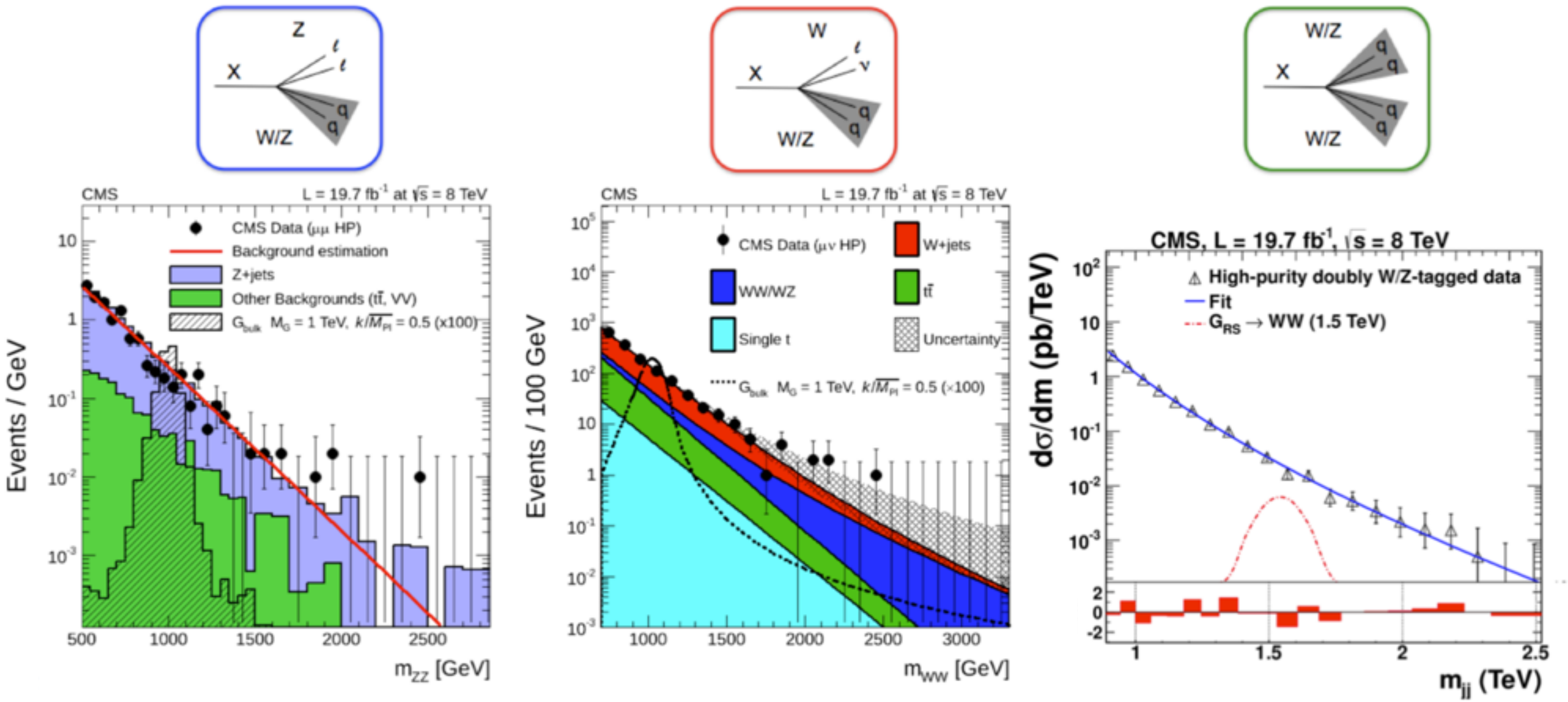


N-subjettiness τ_N (topological compatibility with N subjets)

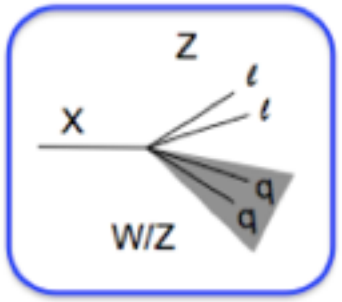


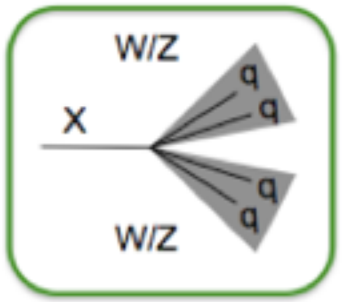
DIBOSON: SPECTRUM AND FIT

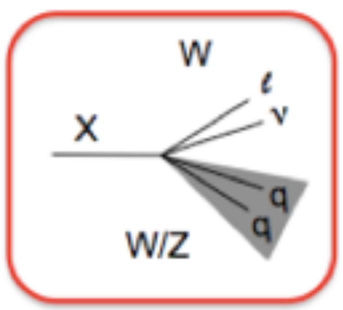
- **Background** from 1) jet mass sideband in data 2) fit to data with smoothly falling function (a-la dijet analysis)
- **m_{VV} resolution ~3-6%**

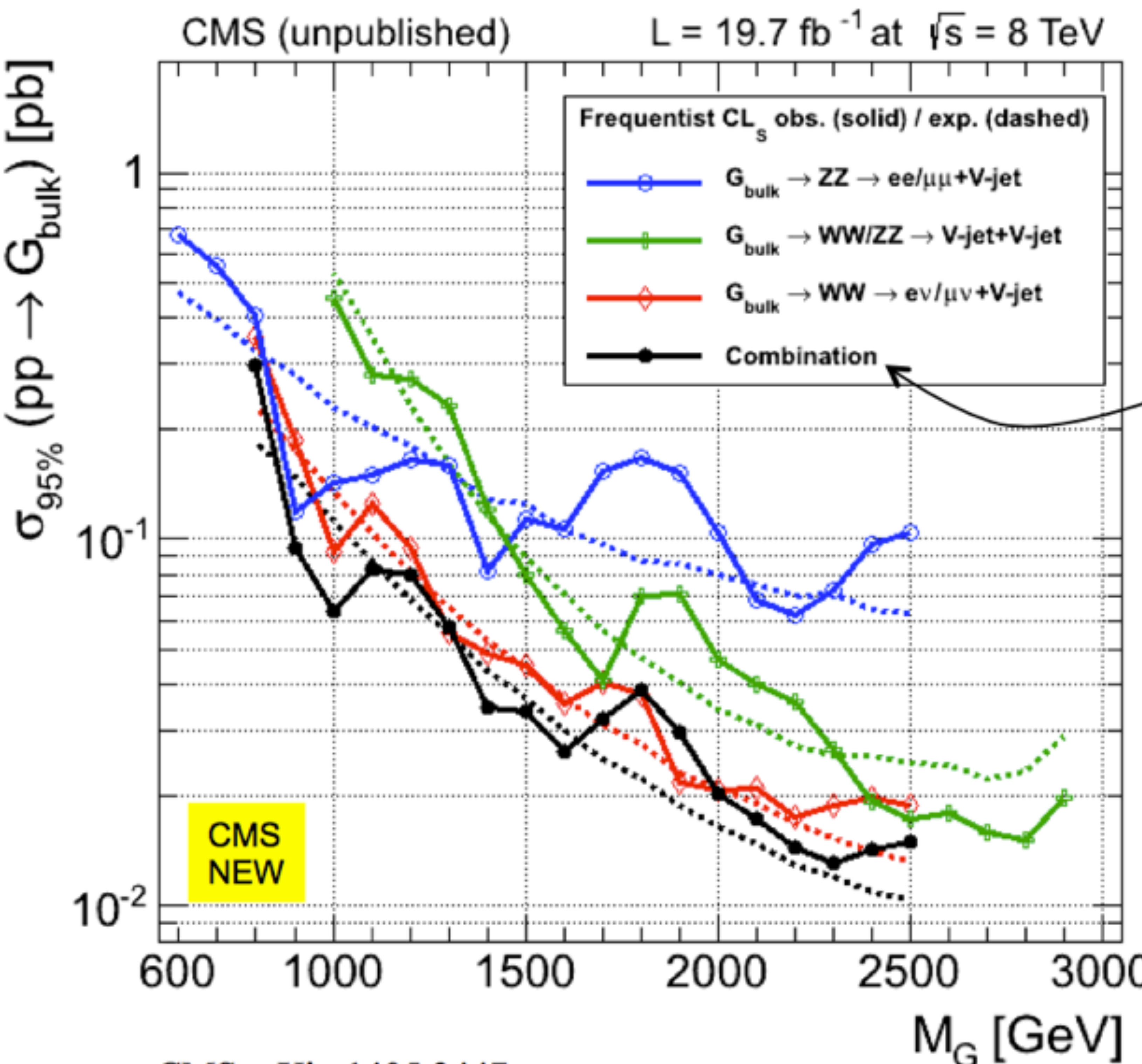


DIBOSON: INTERPRETATION









CMS arXiv:1405.3447

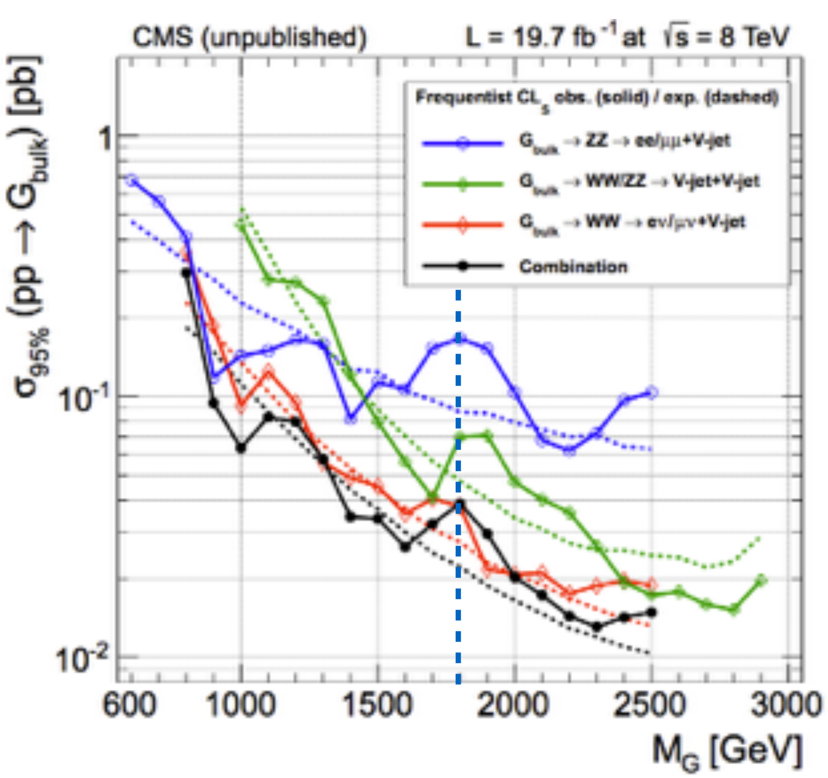
Bulk graviton (arXiv:hep-ph/0701186)

Combination assuming **BRs and efficiencies of narrow bulk graviton** model

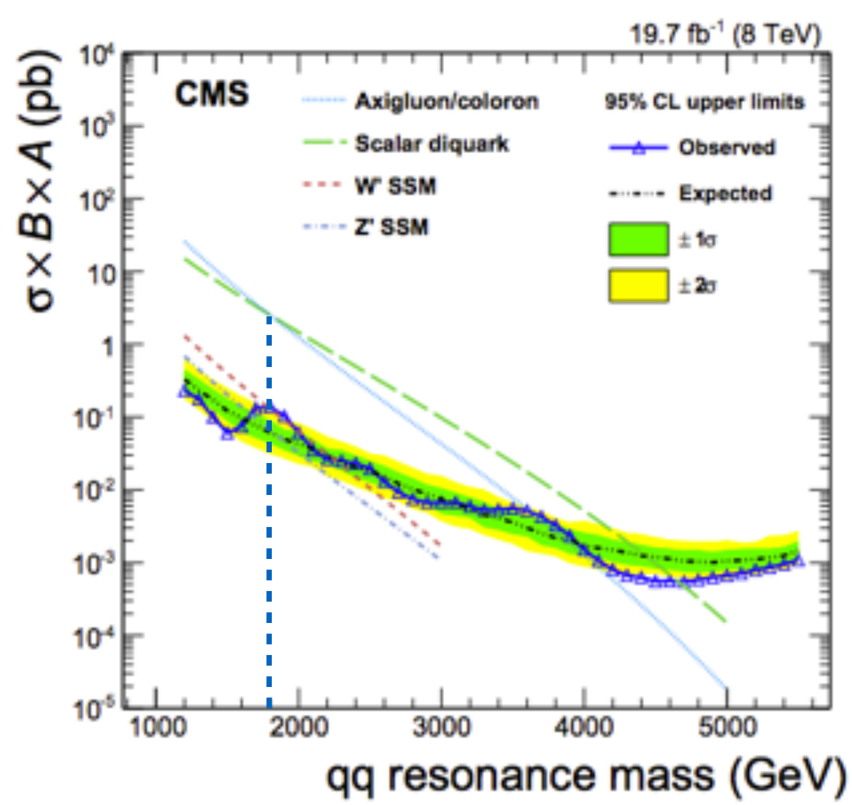
Largest excess at M~1.8 TeV (<1.5σ)

IN SUMMARY: DID WE SEE ANYTHING?

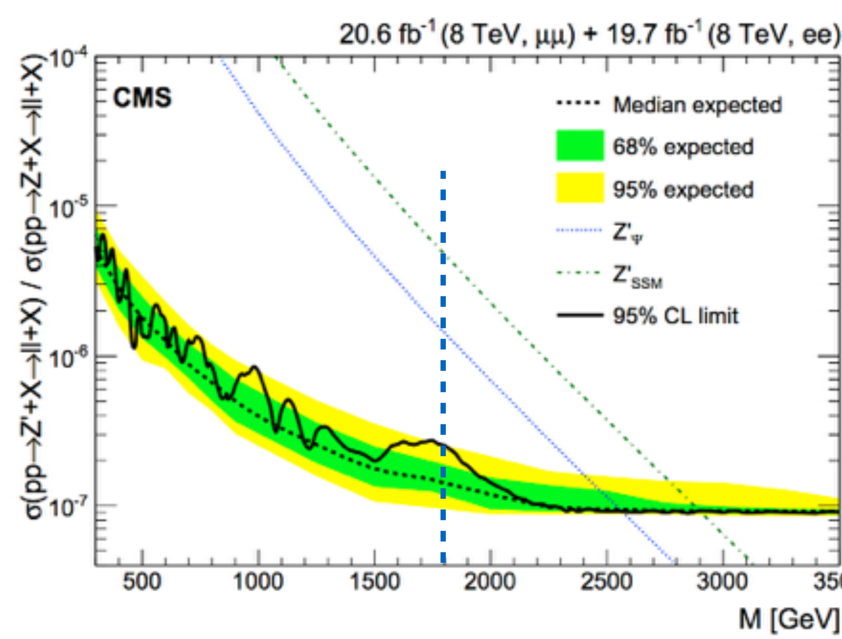
- **The answer is NO**
- But **excesses** (not very significant) here and there **deserving another look** with more data
- **Example**: some activity at 1.8 TeV seen by CMS
  - different excesses seen in other analyses not covered in this talk



~1.5 σ (local)



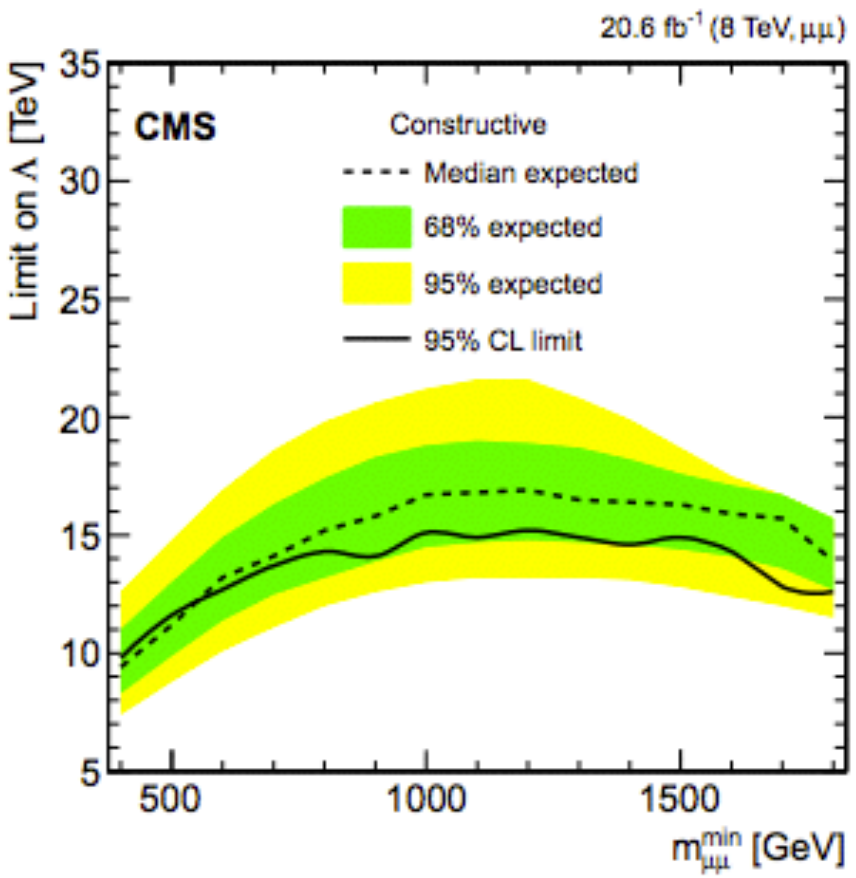
~2 σ (local)

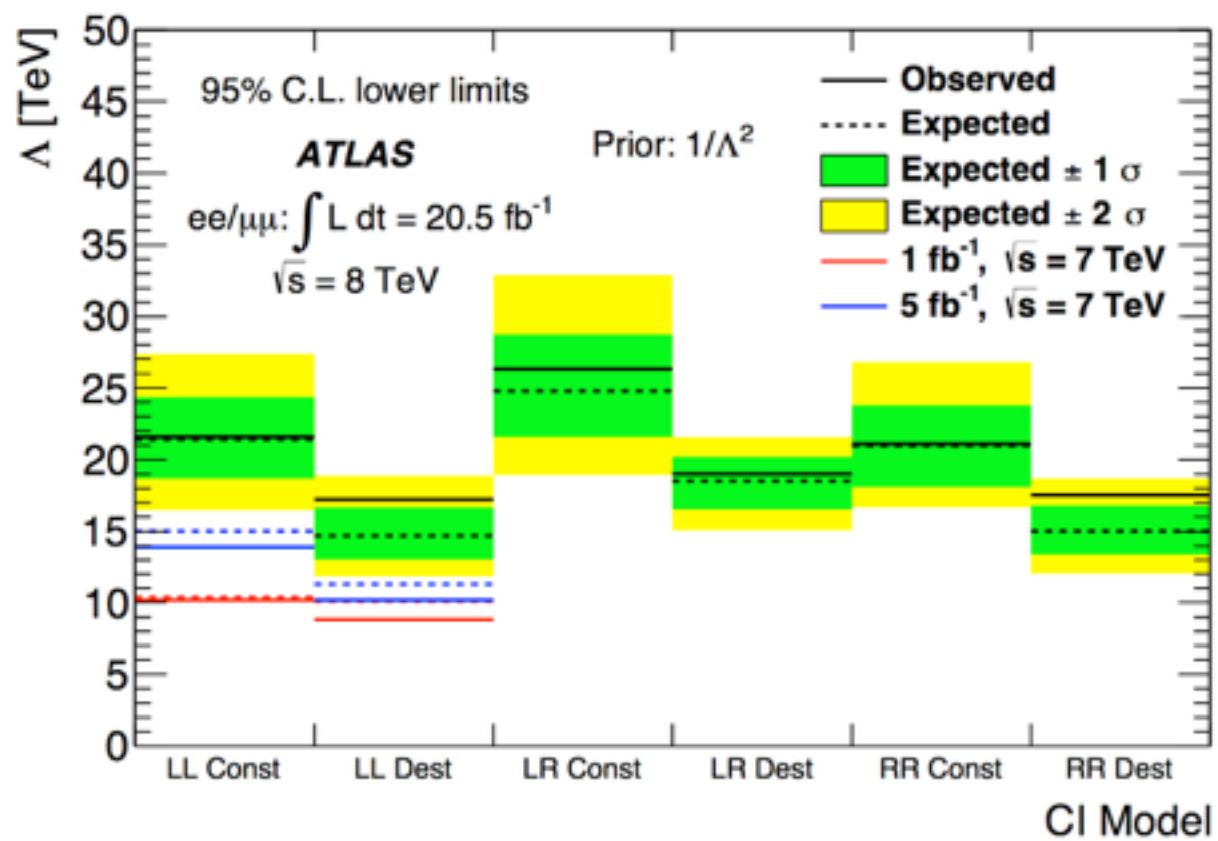


~2 σ (local)

NON-RESONANT SEARCHES

- Not discussed in this talk but almost **every bump hunting converted in the search for broad excess**
  - interpreted in several scenarios, Contact Interactions, ADD, etc…
  - **more difficult than resonance search** (just cut-and-count and conservative systematics)
  - **no excess**





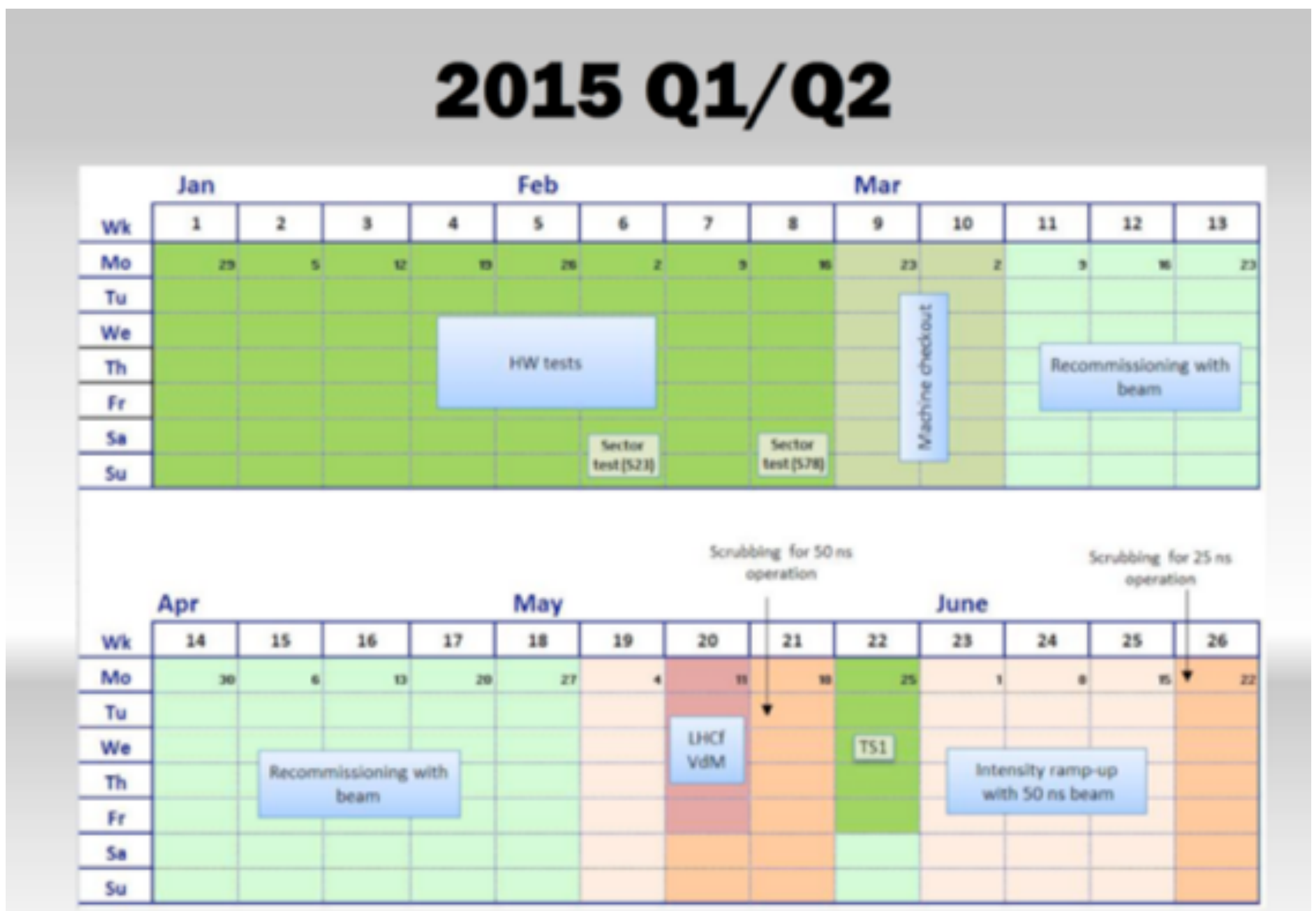
EXPAND THE SEARCHES

EXPAND THE SEARCHES

INCREASE CENTER OF MASS ENERGY

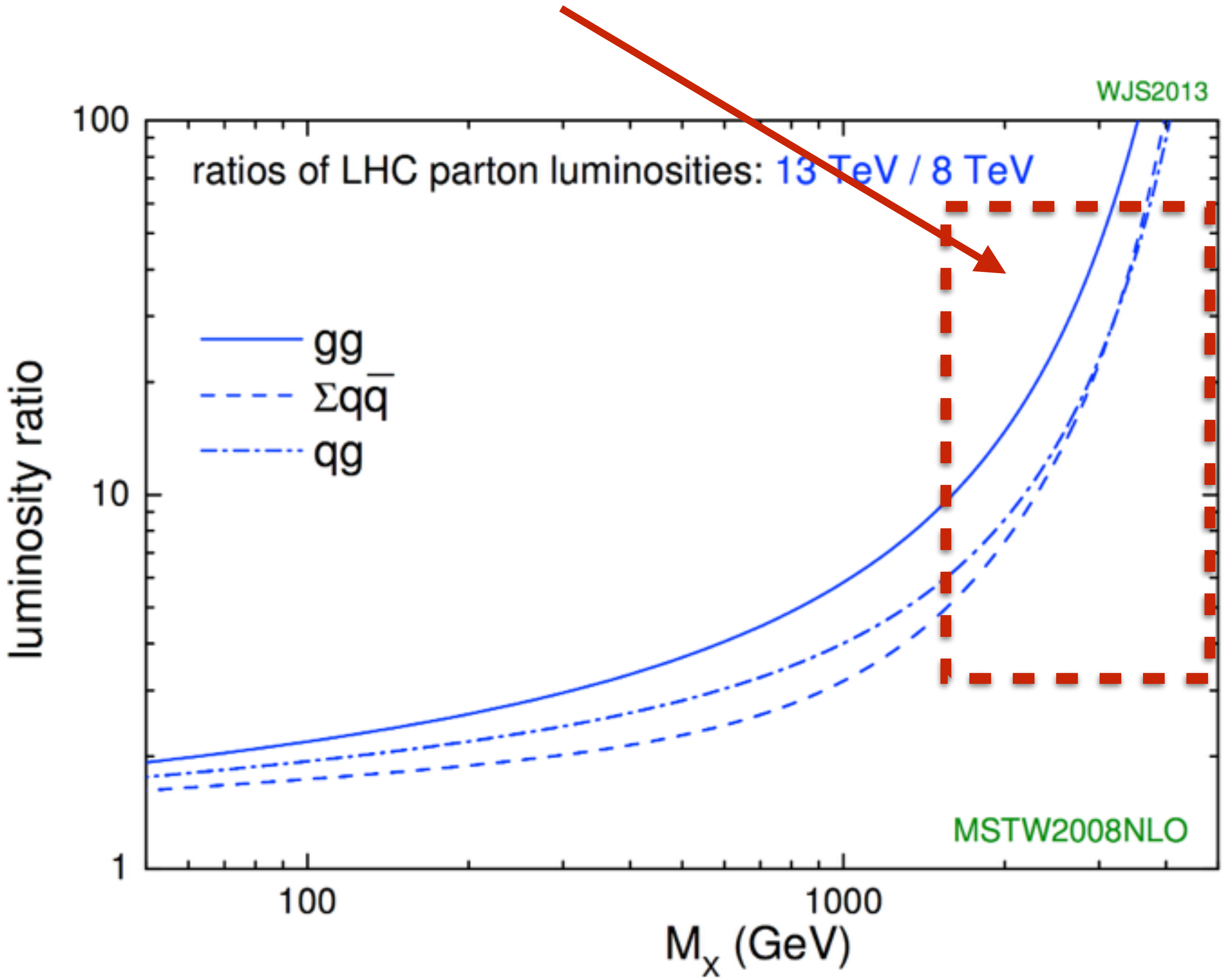
LHC PLANS

- **First collisions**: **middle of May** (no scrubbing)
- **Collisions for Physics**: **June/July**
- **~1 fb^{-1}** with **50ns** bunch spacing (first three weeks)
- **~10 fb^{-1}** with **25ns** bunch spacing (by the end of the year)



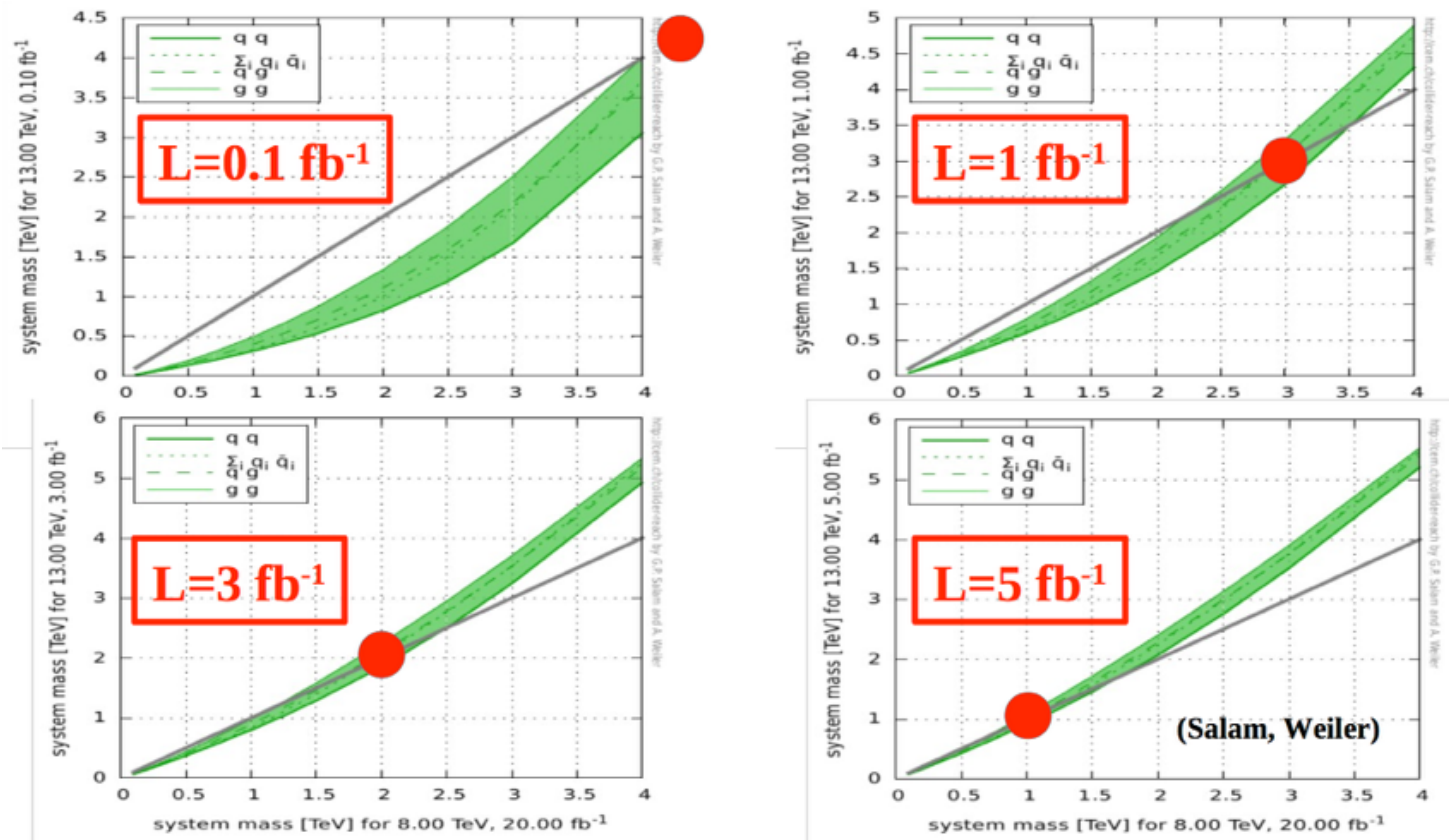
Parton Luminosity Ratio

- For high mass searches **parton luminosity counts**!
  - **Huge ratio in the interesting (not yet excluded) region**



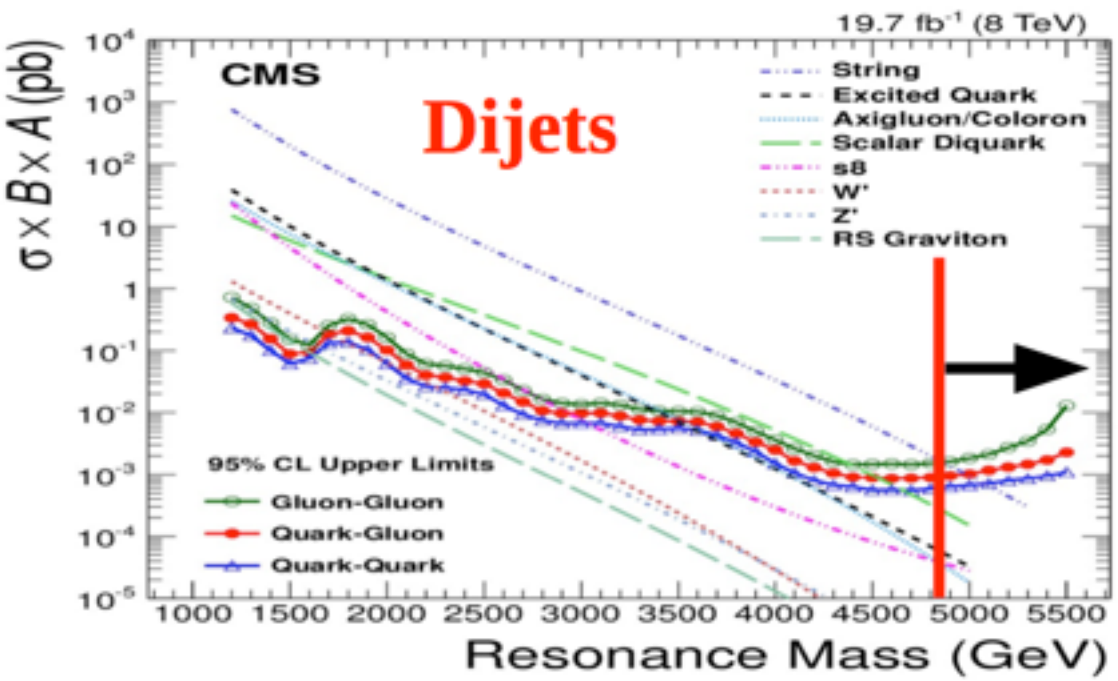
PHYSICS POTENTIAL VS LUMINOSITY

- Sensitive to **masses above 3 TeV with just 1 fb^{-1}**
- We can redo **all past searches with 5 fb^{-1}** (i.e. results for Moriond 2016)

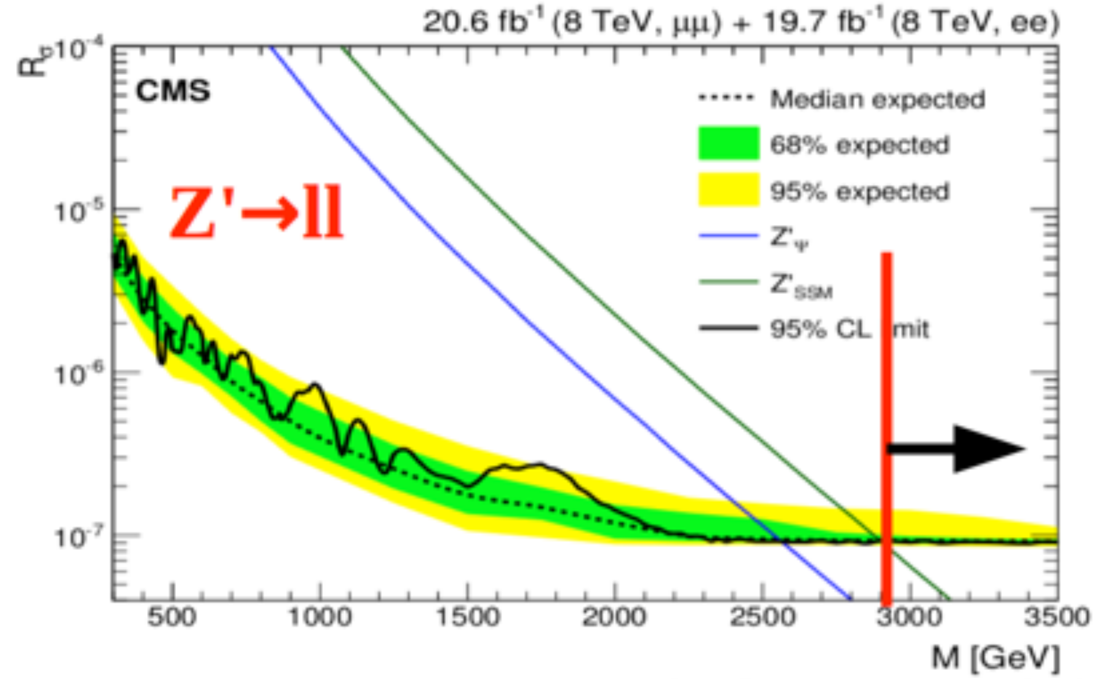


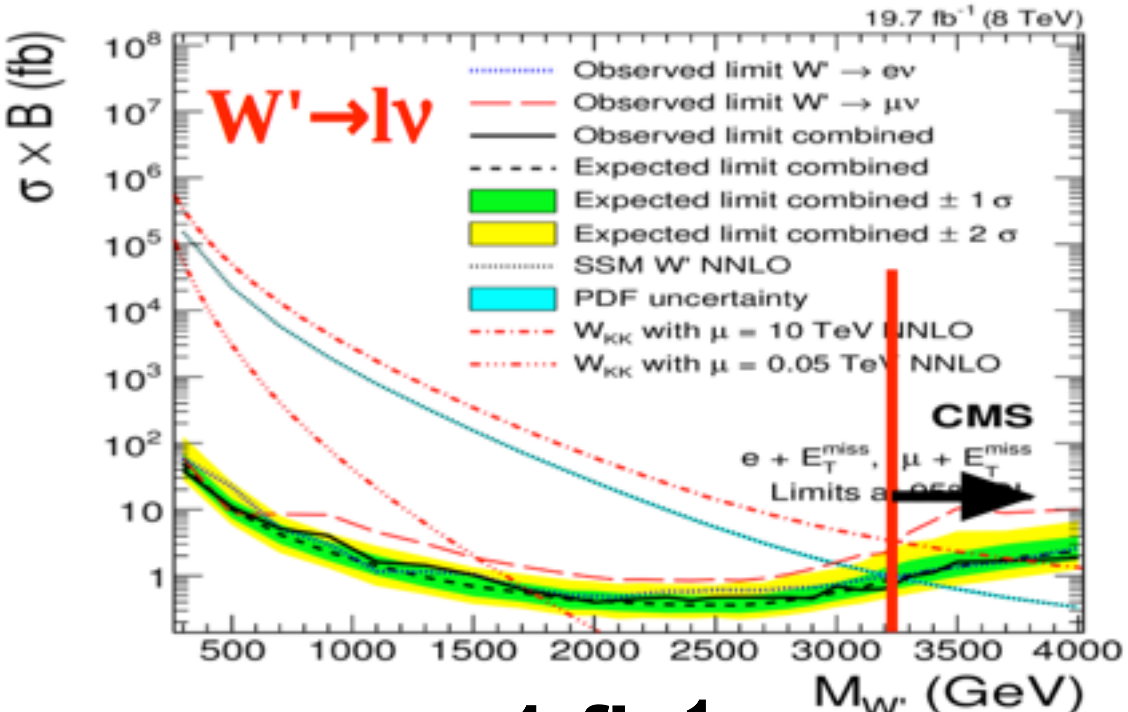
How Much Luminosity?

100 pb^{-1}

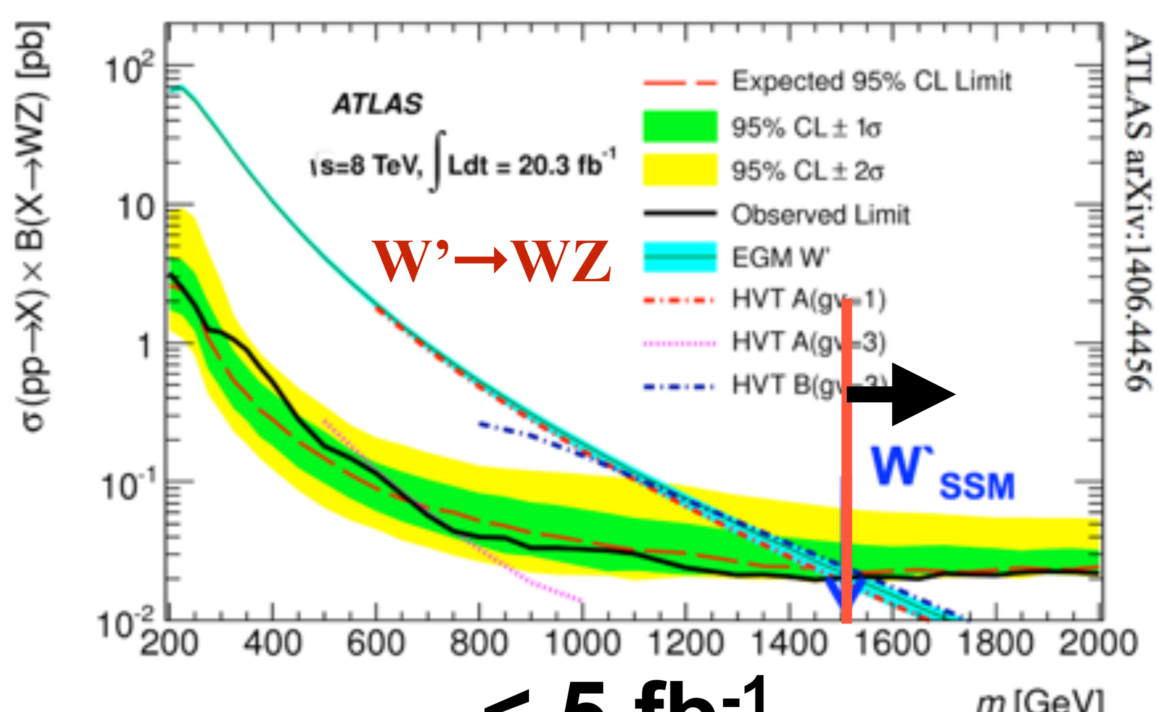


1 fb^{-1}





1 fb^{-1}



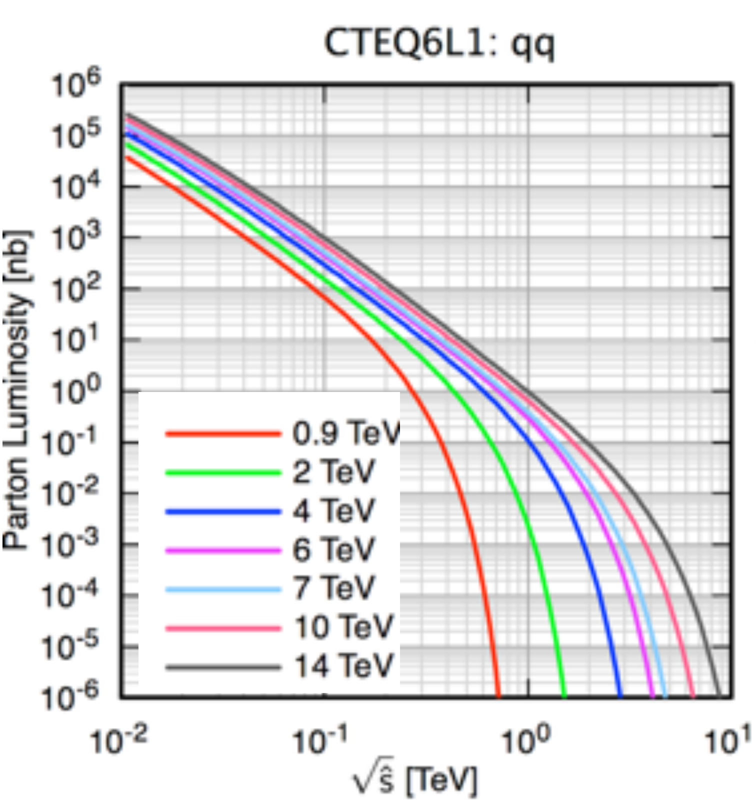
< 5 fb^{-1}

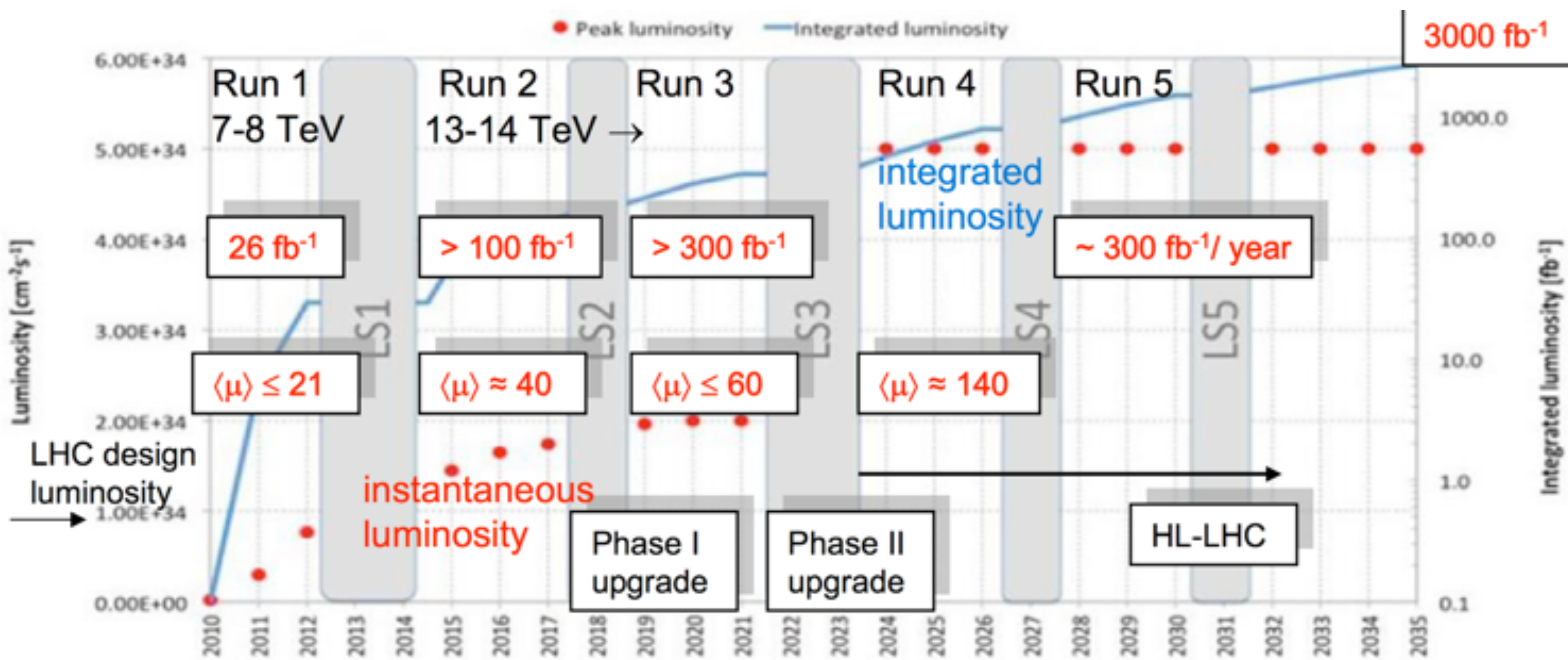
What to Expect in '15-'16: Summary

- **After 1 fb^{-1} at 50 ns** bunch spacing (three weeks after startup)
  - first dijet results
  - all bump huntings look for "unexpected signals"
- **After 3 fb^{-1} at 25 ns** bunch spacing (September 2015?)
  - almost all high mass resonance searches start to be sensitive and can produce a public result
  - check 8 TeV excesses
  - look for more "unexpected signals"
- **After 10 fb^{-1}**, i.e. end of the year but presented in Moriond 2015
  - in principle all analyses can be repeated
- **End of 2015**: almost all high mass searches public
- **End of 2016 (>30 fb^{-1})**: full CMS physics program
  - with several additions and new ideas

Even Longer Timescales: Run3, Run4

- **After end of Run2 statistics won't help much** in extending physics potential
  - fast **drop of parton luminosities** kills the high mass searches
- Maybe with **14 TeV energy another small addition** in reach
- **HL-LHC not very interesting for high mass searches**
- Maybe invest more on **intermediate mass region** (<1-2 TeV)



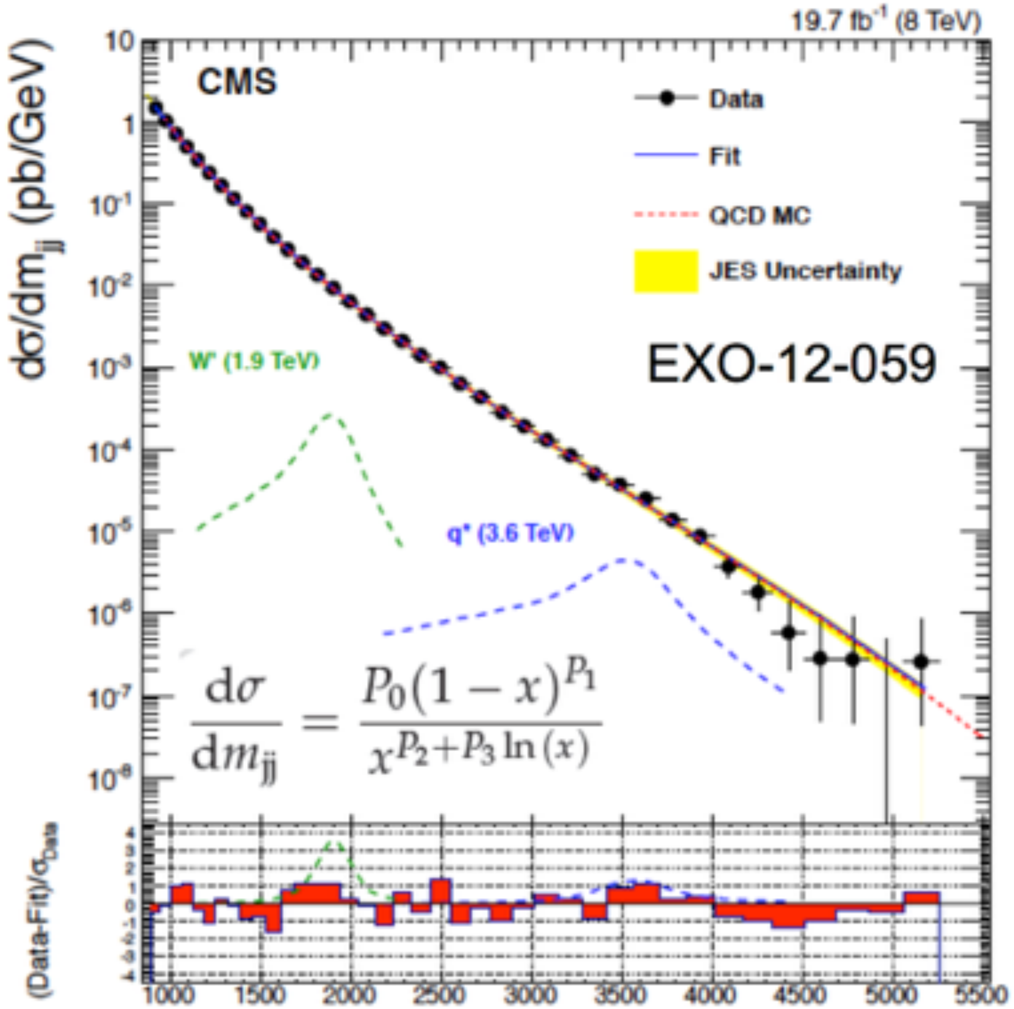


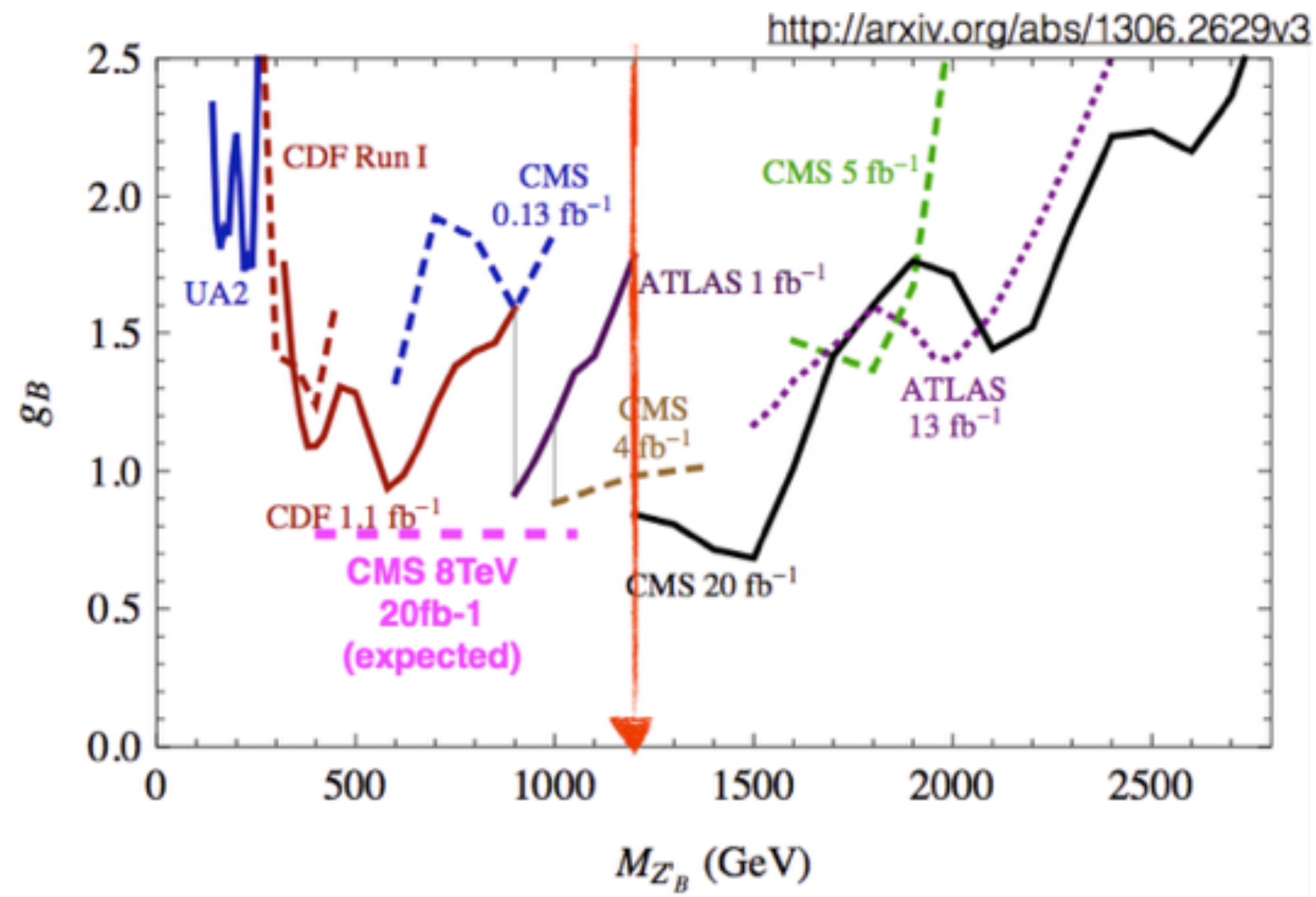
Expand the Searches

Some New Ideas

Expand the Searches: Lower Masses?

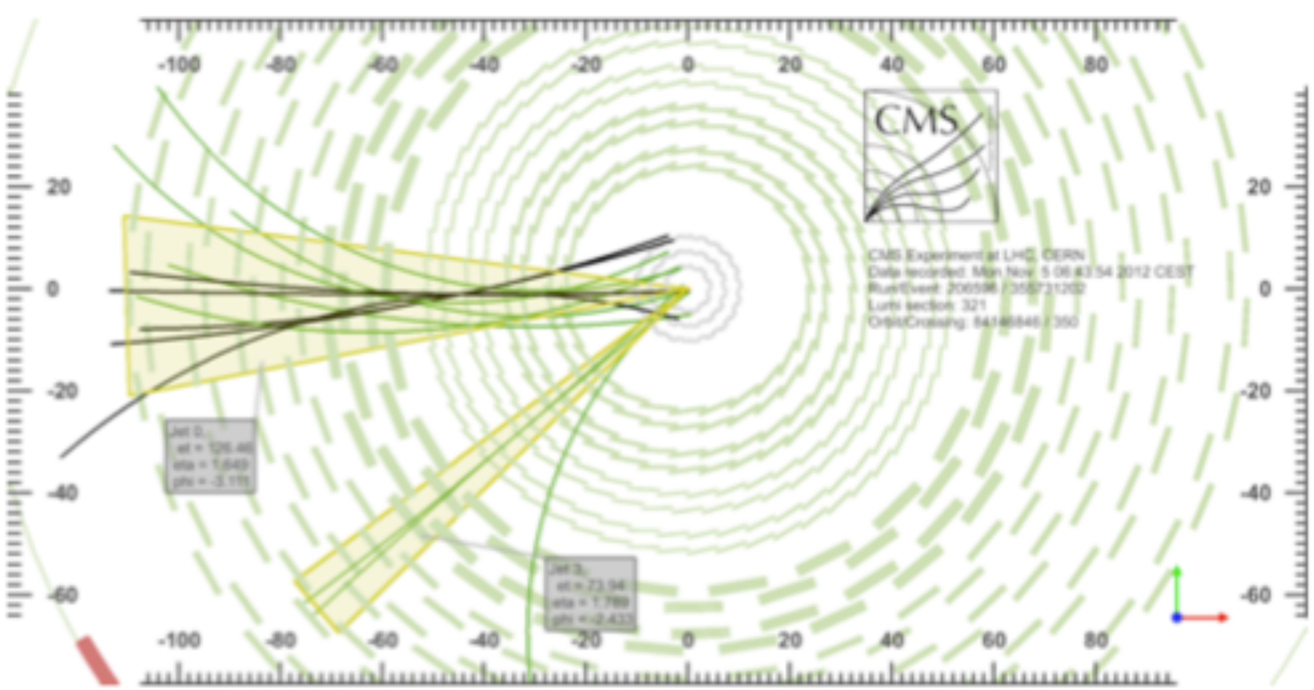
- **Resonance searches** often **done at large masses**
  - example: dijet (1 TeV)
- **Region below** still **interesting**
- In case limit due to trigger, need to implement alternative ways of storing data

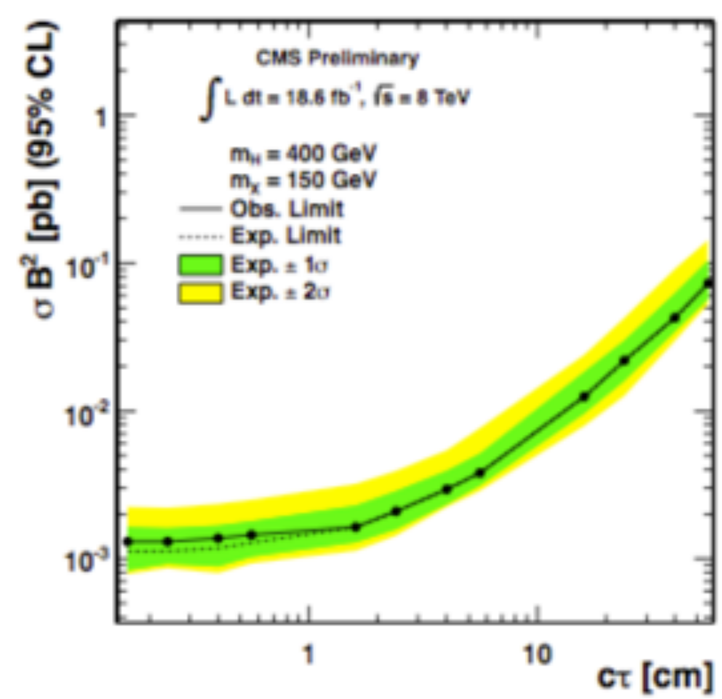




Expand the Searches: Long-Lived

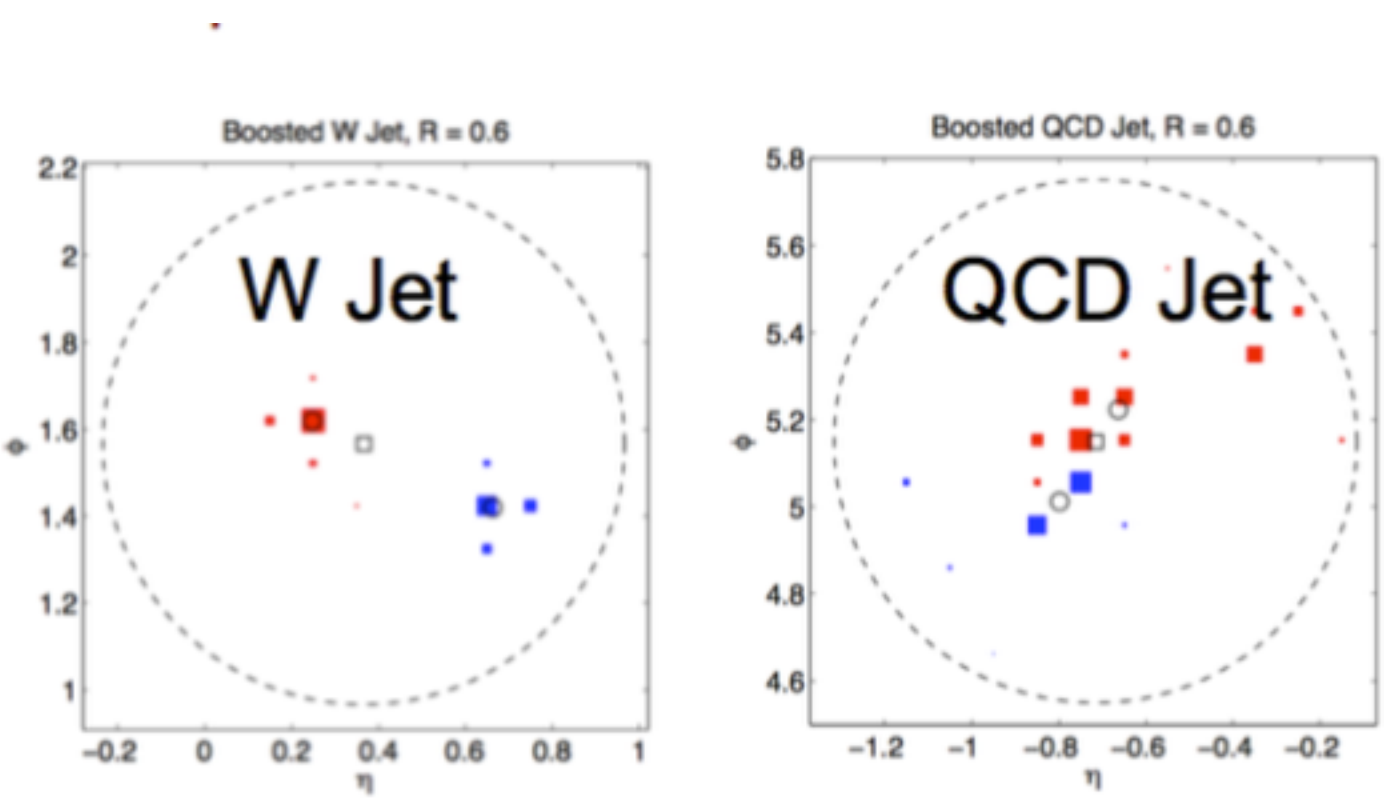
- Many LHC searches for **exotics signature search for long-lived displaced searches**
  - below case for displaced dijet analysis
- Maybe possible to **expand the resonance search by including displacement** tagging
  - feasible only at lower mass regime



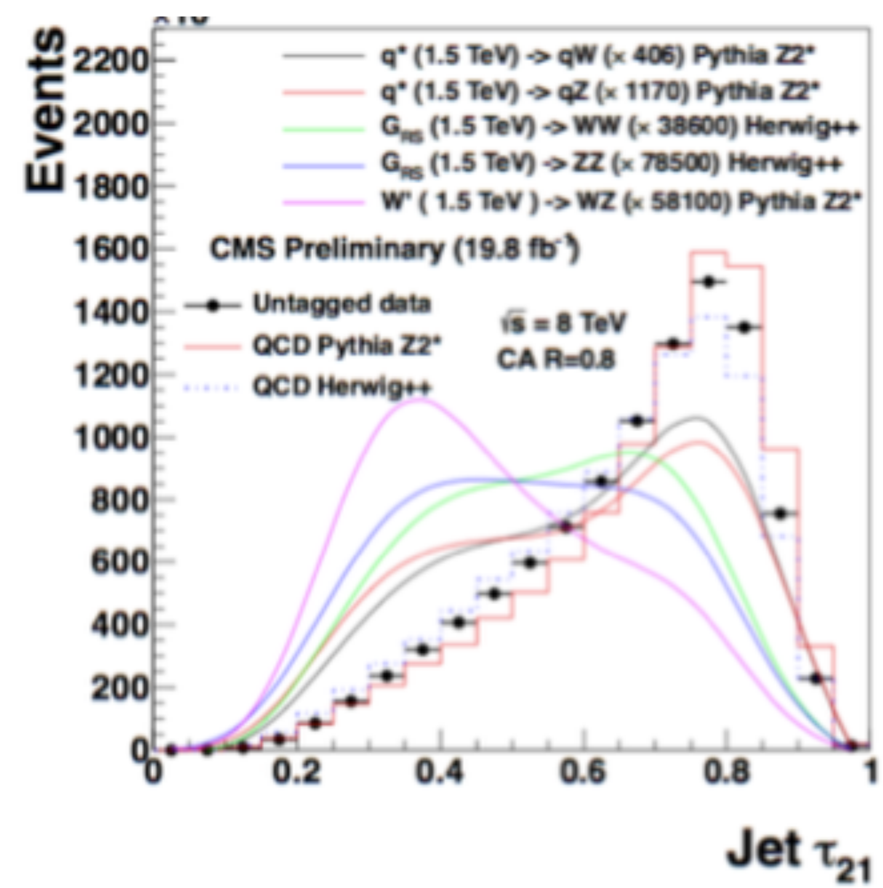


More Sub-structures

- **Substructures** now successfully used to **identify W, Z, top, and Higgs**
- Could be good to **explore use of substructures when the particle is not SM**
  - handle to **reduce backgrounds** and increase physics potential, mainly at lower masses



[Thaler, Tilburg, arXiv:1011.2268]

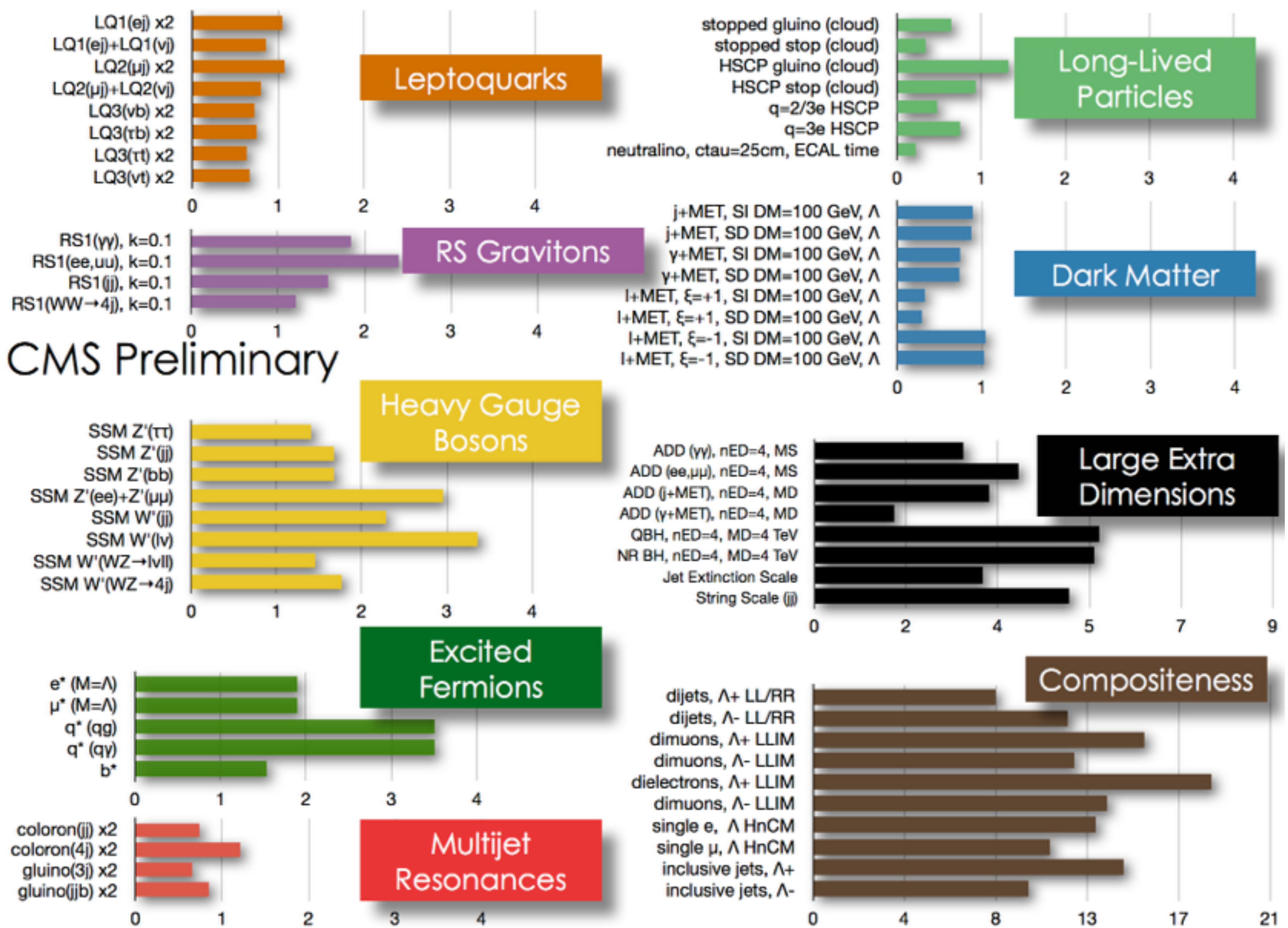


CONCLUSIONS

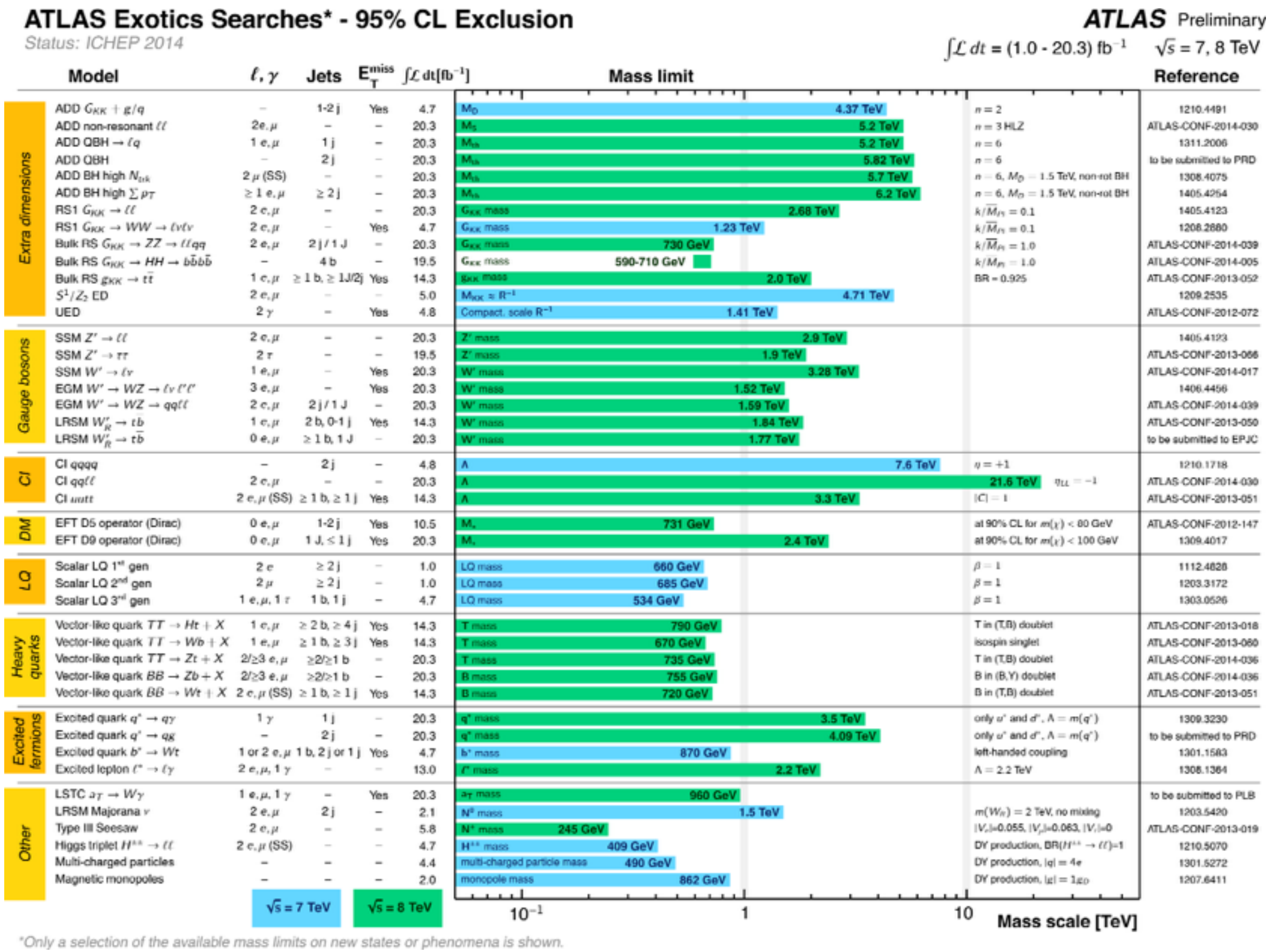
- Find **high mass resonances is the best/easiest way to discover new physics**
- **Comprehensive program for high mass resonance** searches at LHC
- Unfortunately **no sign of new physics yet**

- **Run2 @ 13TeV** (~10fb^{-1} by end of the year)
  - increase in energy **dramatically expand reach in mass**
  - **2015 is the year** of the high mass resonance searches!
- **Expect big news at Moriond 2016**
  - hopefully good news. Maybe even earlier

BACKUP



CMS Preliminary
Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(νj)
LQ2(μj) x2
LQ2(μj)+LQ2(νj)
LQ3(νb) x2
LQ3(τb) x2
LQ3(τt) x2
LQ3(νt) x2
RS Gravitons
RS1(γγ), k=0.1
RS1(ee,μμ), k=0.1
RS1(jj), k=0.1
RS1(WW→4j), k=0.1
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(bb)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lν)
SSM W'(WZ→lνll)
SSM W'(WZ→4j)
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ)
b*
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
Long-Lived Particles
stopped gluino (cloud)
stopped stop (cloud)
HSCP gluino (cloud)
HSCP stop (cloud)
q=2/3e HSCP
q=3e HSCP
neutralino, ctau=25cm, ECAL time
Dark Matter
j+MET, SI DM=100 GeV, Λ
j+MET, SD DM=100 GeV, Λ
γ+MET, SI DM=100 GeV, Λ
γ+MET, SD DM=100 GeV, Λ
l+MET, ξ=+1, SI DM=100 GeV, Λ
l+MET, ξ=+1, SD DM=100 GeV, Λ
l+MET, ξ=-1, SI DM=100 GeV, Λ
l+MET, ξ=-1, SD DM=100 GeV, Λ
Large Extra Dimensions
ADD (γγ), nED=4, MS
ADD (ee,μμ), nED=4, MS
ADD (j+MET), nED=4, MD
ADD (γ+MET), nED=4, MD
QBH, nED=4, MD=4 TeV
NR BH, nED=4, MD=4 TeV
Jet Extinction Scale
String Scale (jj)
Compositeness
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dimuons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-



Search for High Mass Resonances at the LHC

DILEPTON: SELECTION (CMS)

- **Trigger:**
  - muons: single pT > 40GeV, eta<2.1
  - electrons: dilepton pT>33GeV with some loose iso criteria (HCAL)
  - efficiency between 97 and 100%
- **Electrons**:
  - clusters are matched with pixels and then tracking is performed
  - tracking and calo isolation (DR<0.3) and cluster shape
- **Muons**:
  - pt>45GeV and deltapt/pt<0.3, eta<2.1, transverse impact parameter<0.2cm
- **Efficiency**: Z-based tag and probe for linearity check
- Acceptance * Eff not very different between spin 1 and 2 (tab)