Searches for BSM physics in final states with jets and leptons+jets at CMS

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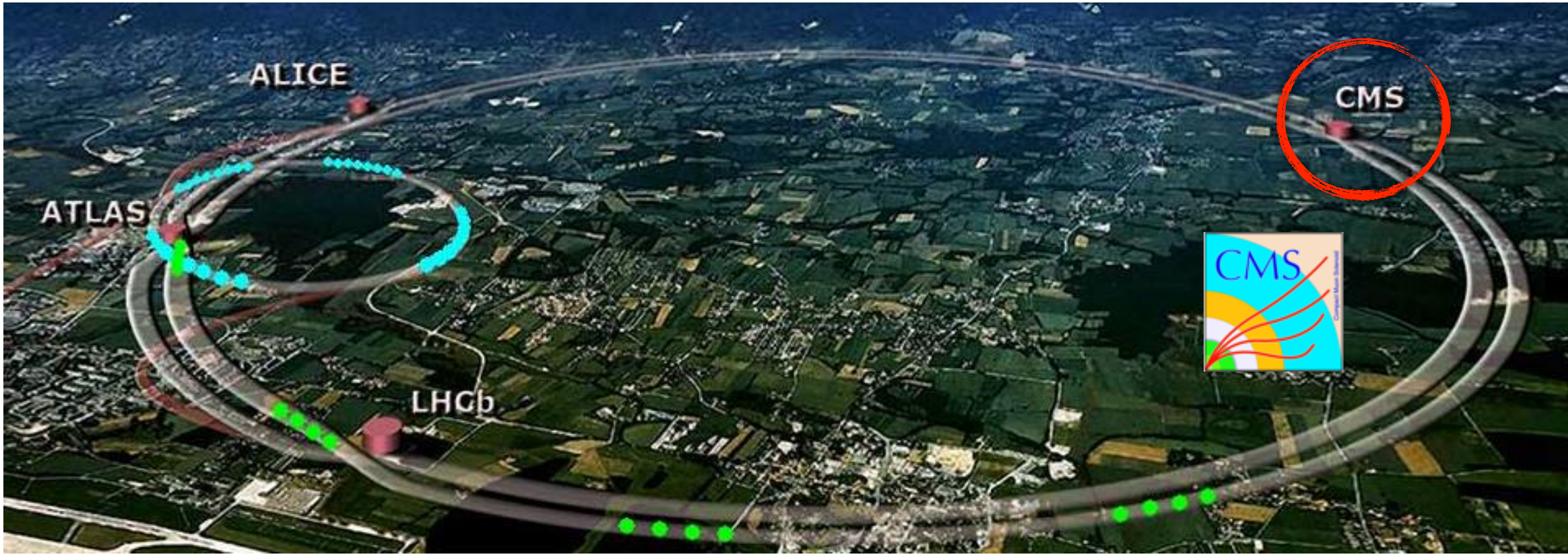
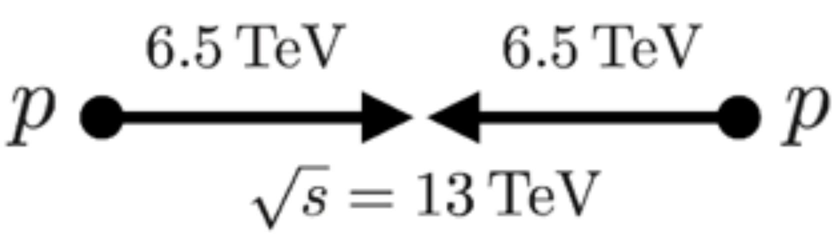
Large Hadron Collider (LHC)

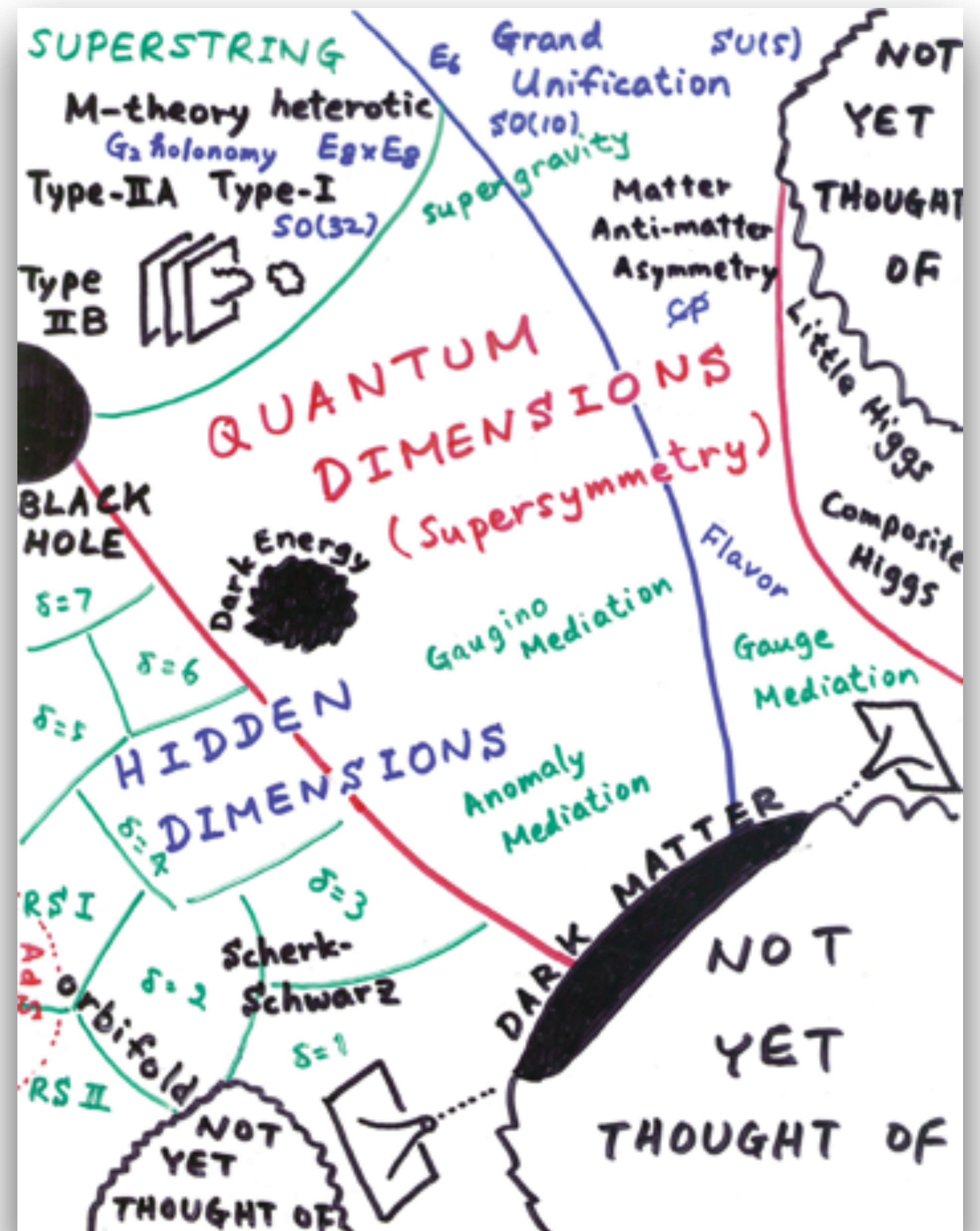




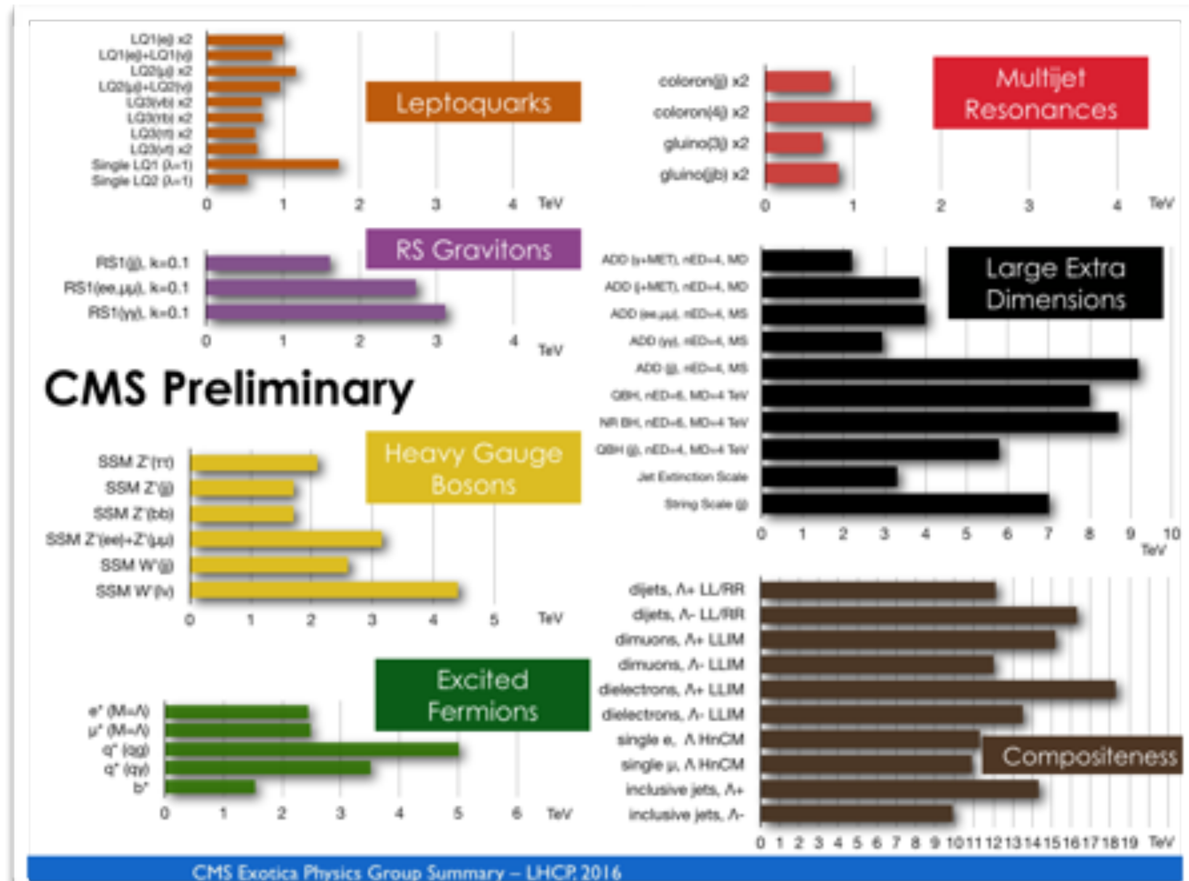
- Still many unanswered questions in Standard Model (SM)
  - what is dark matter? where is all the antimatter in the universe? why gravity is so weak? etc..
- **LHC is the ideal place to find new physics beyond SM at the TeV scale**

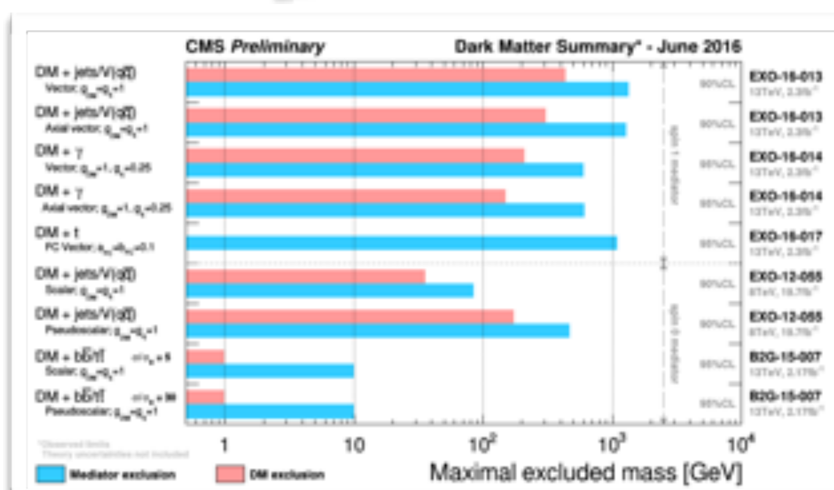
Physics beyond SM

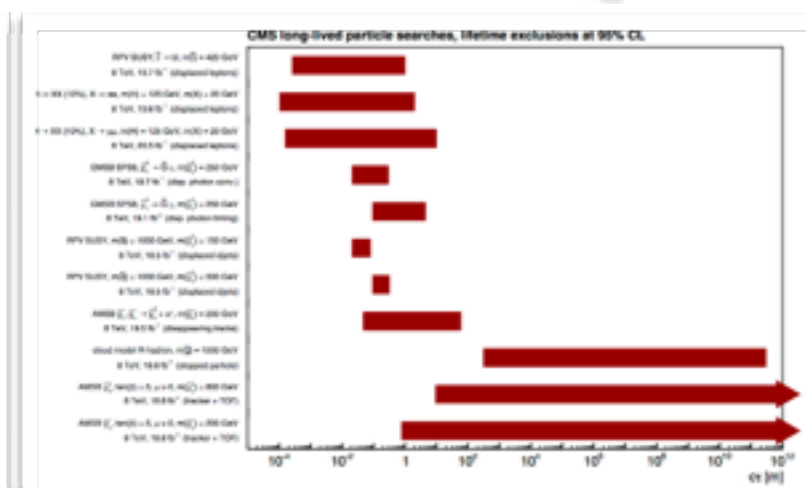
Many theory predictions



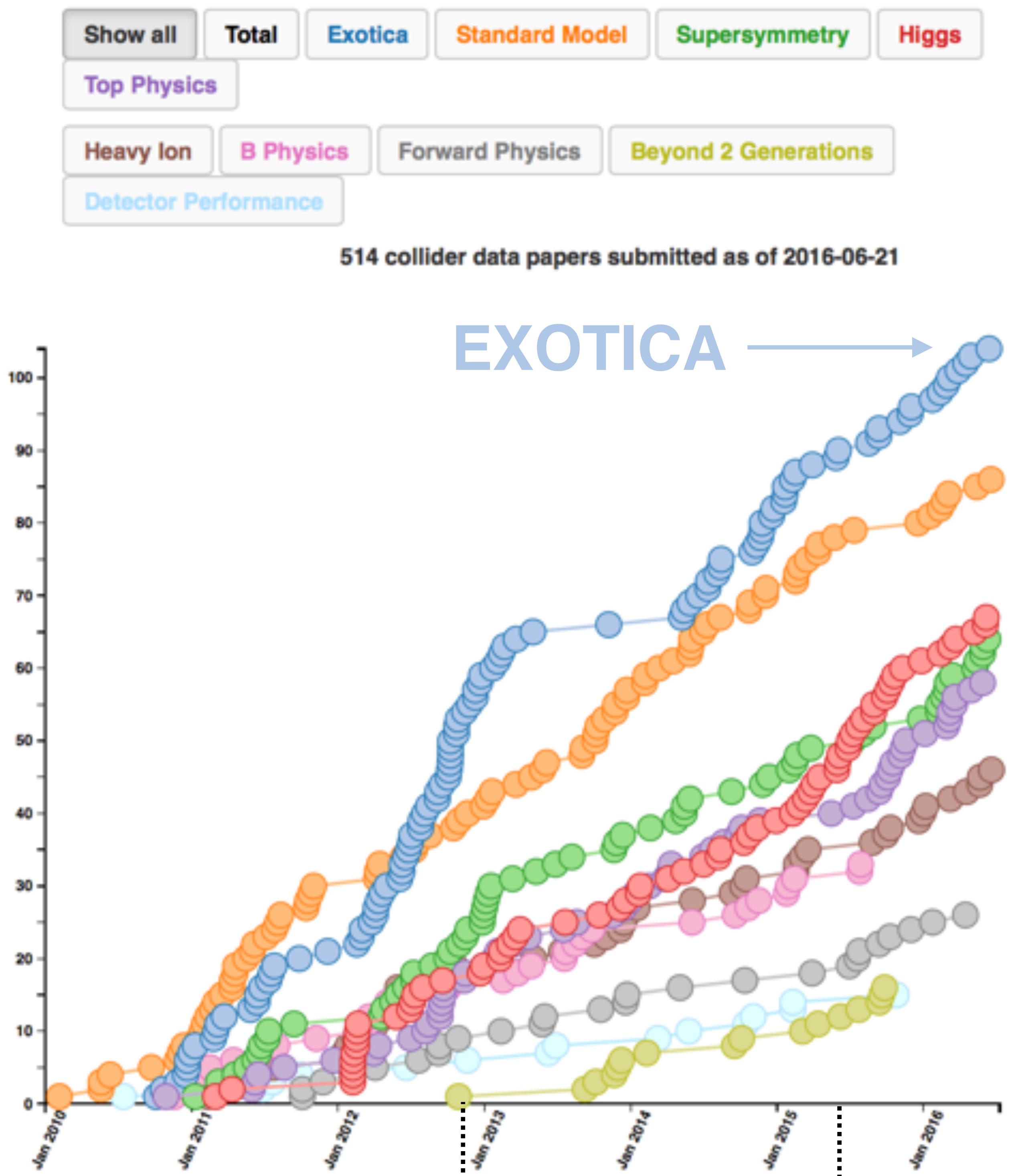
Many searches in CMS







CMS publications

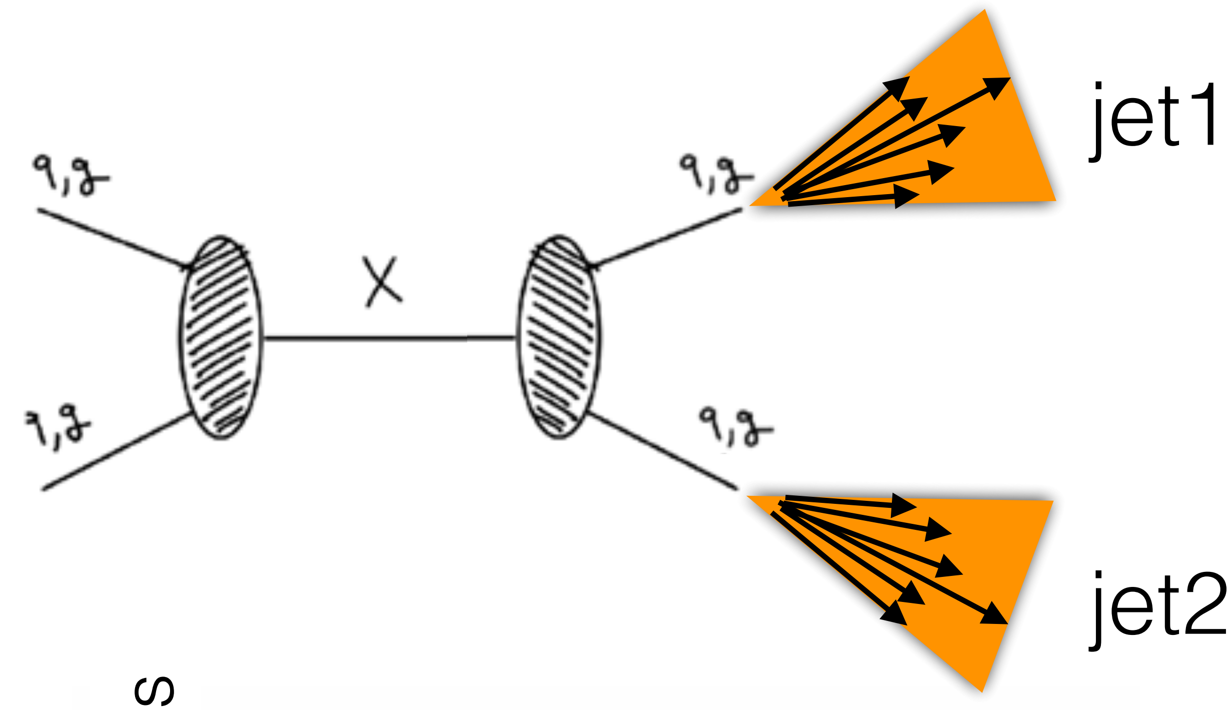


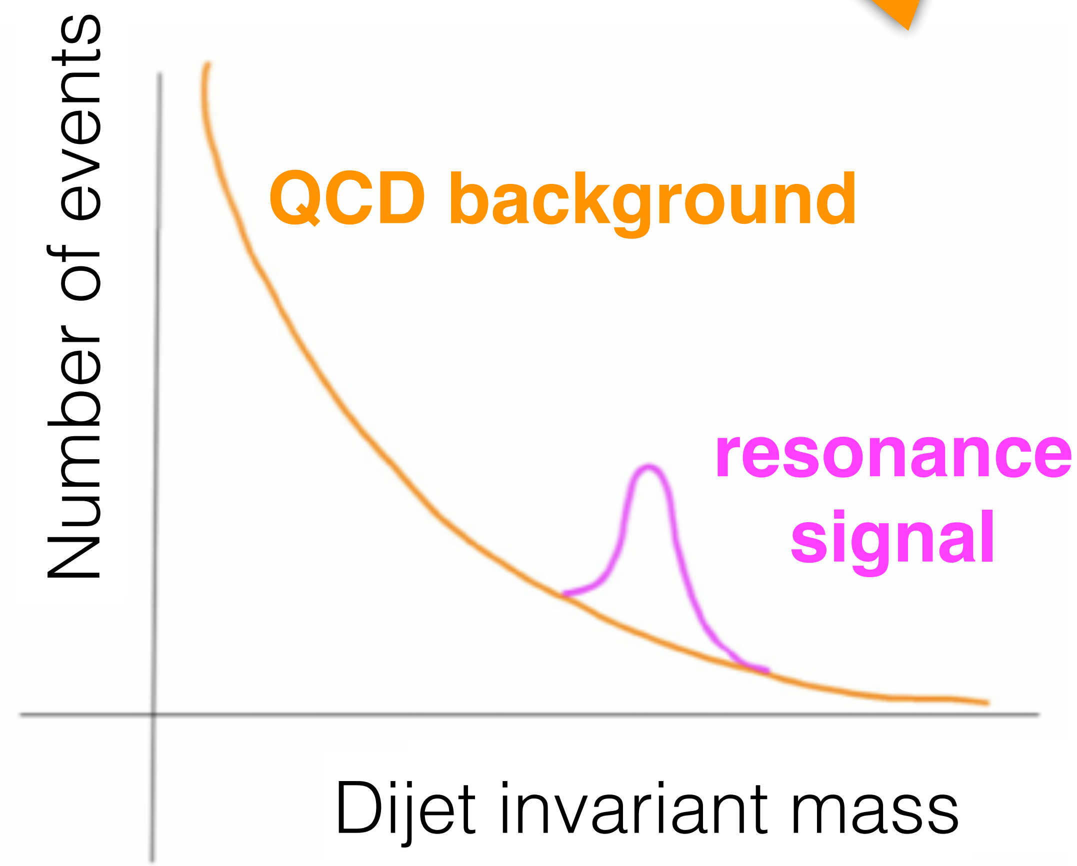
Run1: 7 & 8 TeV | Technical stop | Run2: 13 TeV

- Searches for new physics produce the largest number of publications in CMS
  - ~100 from Exotica
  - ~65 from Supersymmetry
  - ~15 from B2G
- In this talk, focus on some Exotica signatures of **new physics in jets and leptons +jets final state**
  - selection of few recent results

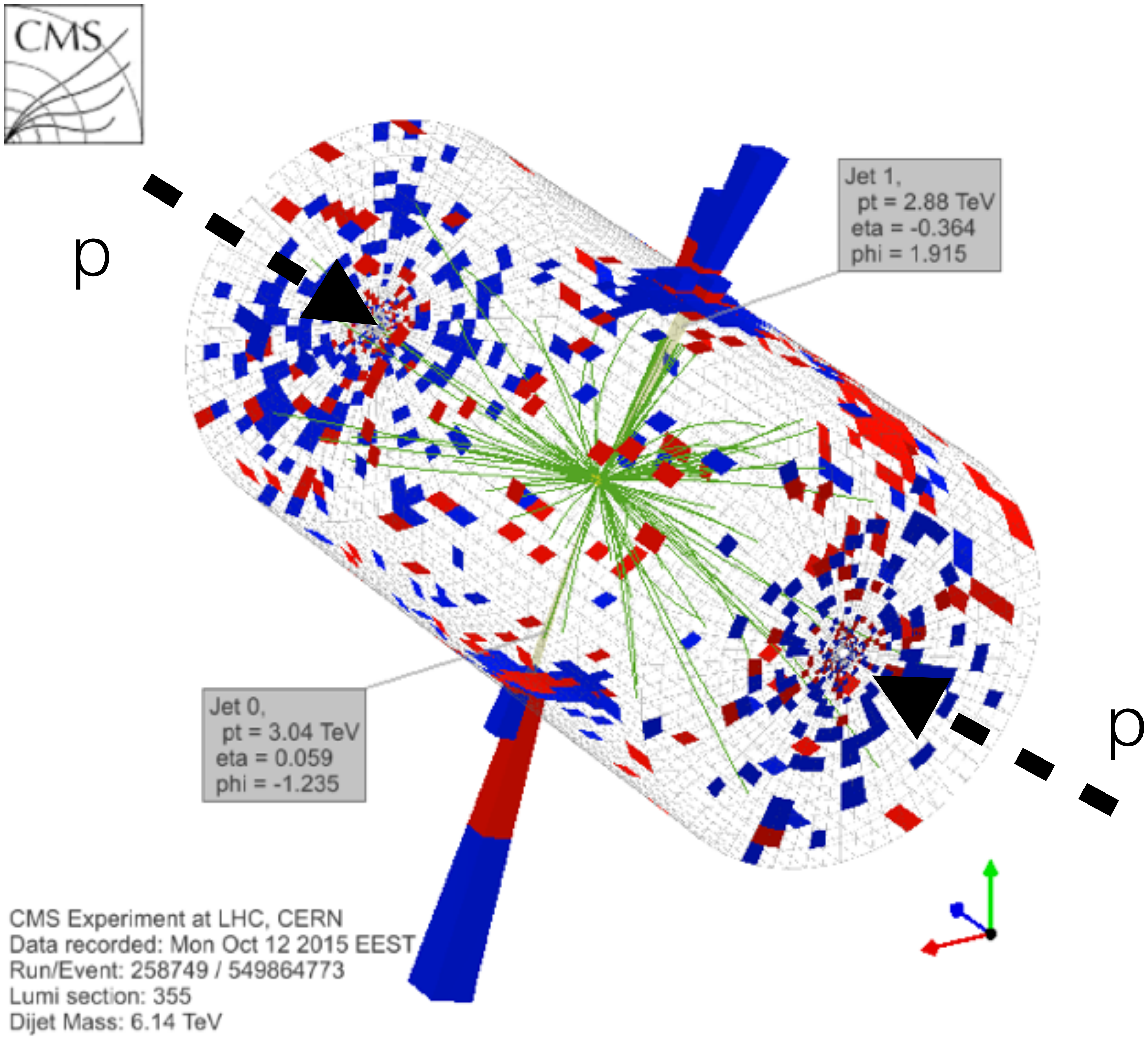
Dijet resonances

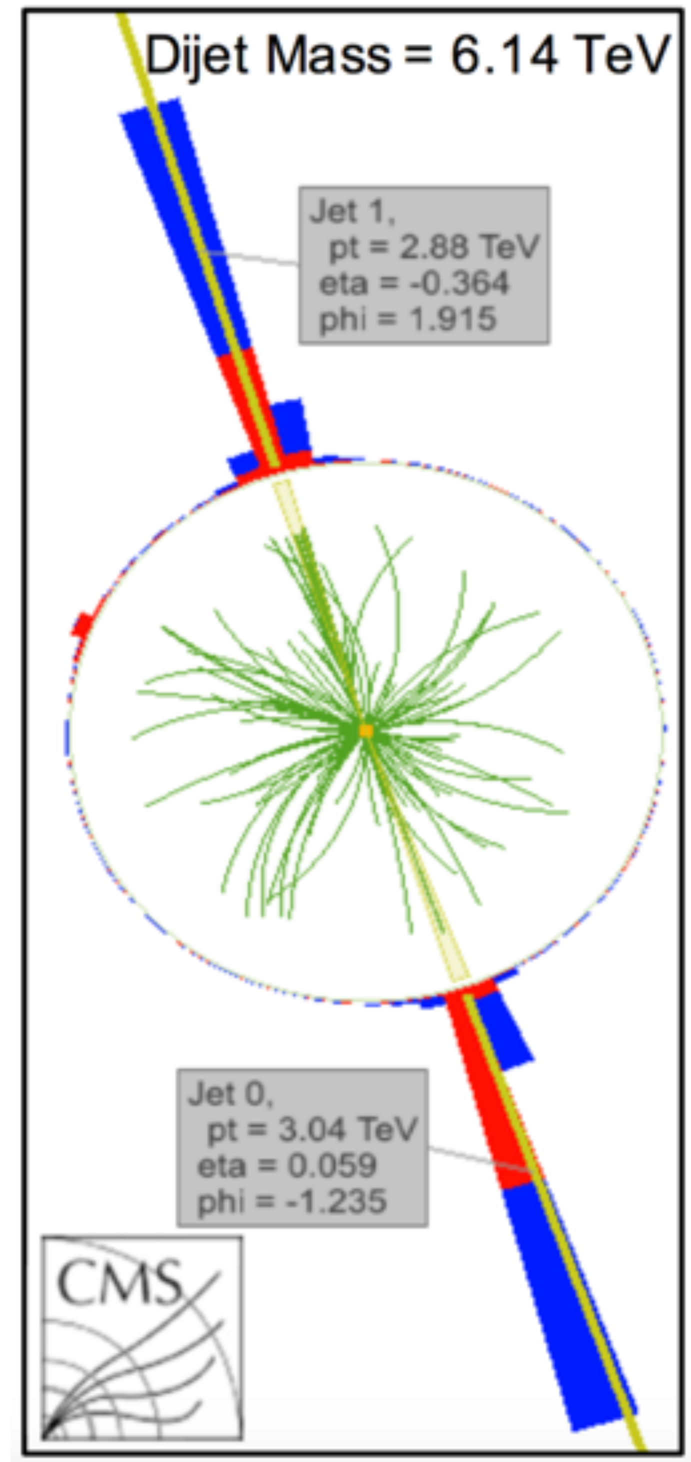
- Nearly any new resonance that might be seen at LHC should couple to quarks/gluons
  - **dijet final state**
- Search strategy
  - look of narrow bump in dijet invariant mass spectrum
- <u>High-mass</u> search using standard data stream (mass > 1 TeV)
- <u>Low-mass</u> search using special data stream (mass < 1 TeV)





Highest dijet mass event (~6 TeV)

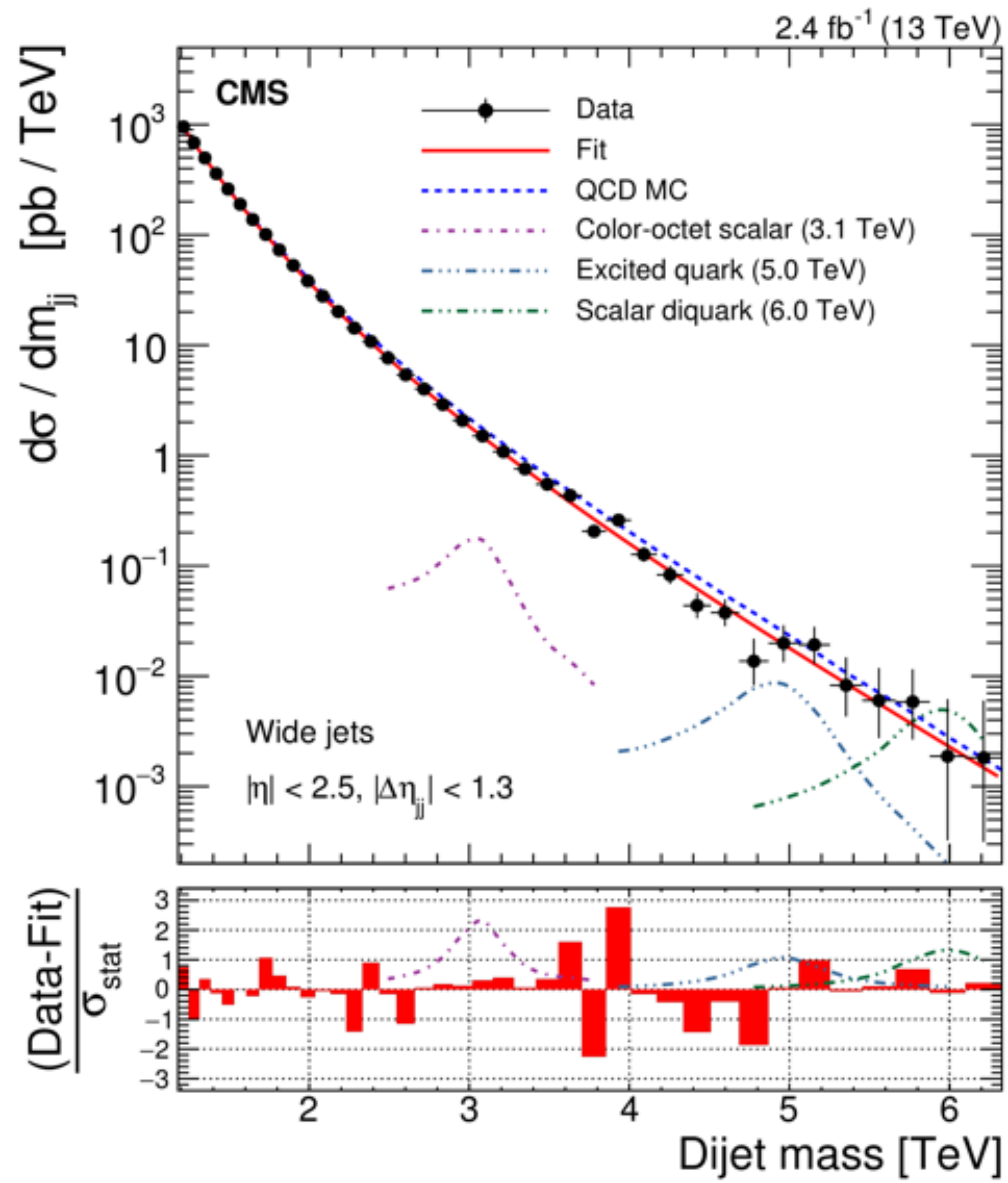




High-mass dijet search

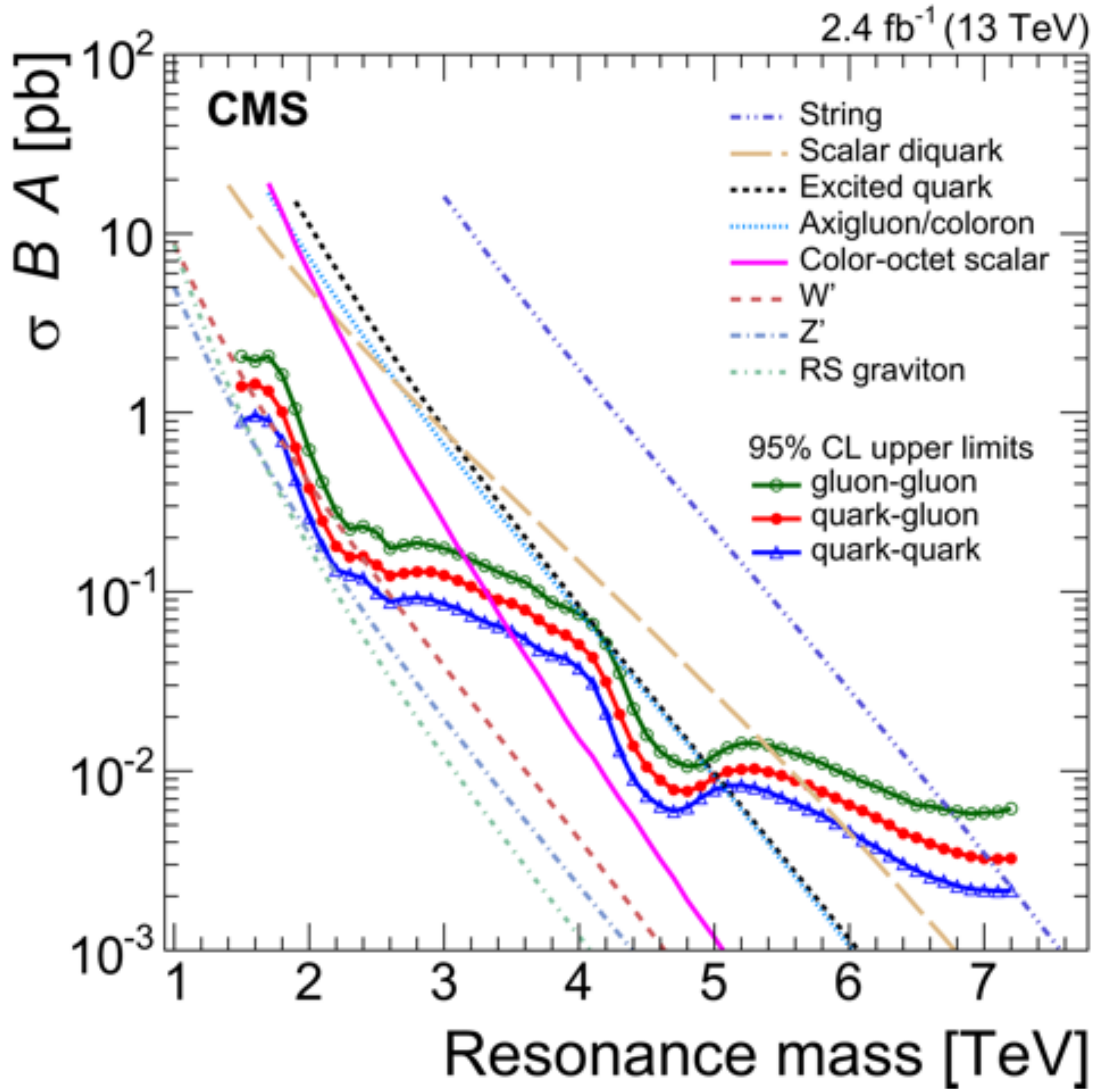
- Trigger selection
  - $H_T = \sum_{jets} p_T^i > 800\text{GeV}$
- Wide jets (R=1.1) used to recover final state radiation
  - improve energy scale and resolution
- Fit data with smoothly falling background function
  - same parameterization successfully used in previous searches

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0 (1-x)^{P_1}}{x^{P_2 + P_3 \ln(x)}} \qquad x = \frac{m_{jj}}{13000}$$

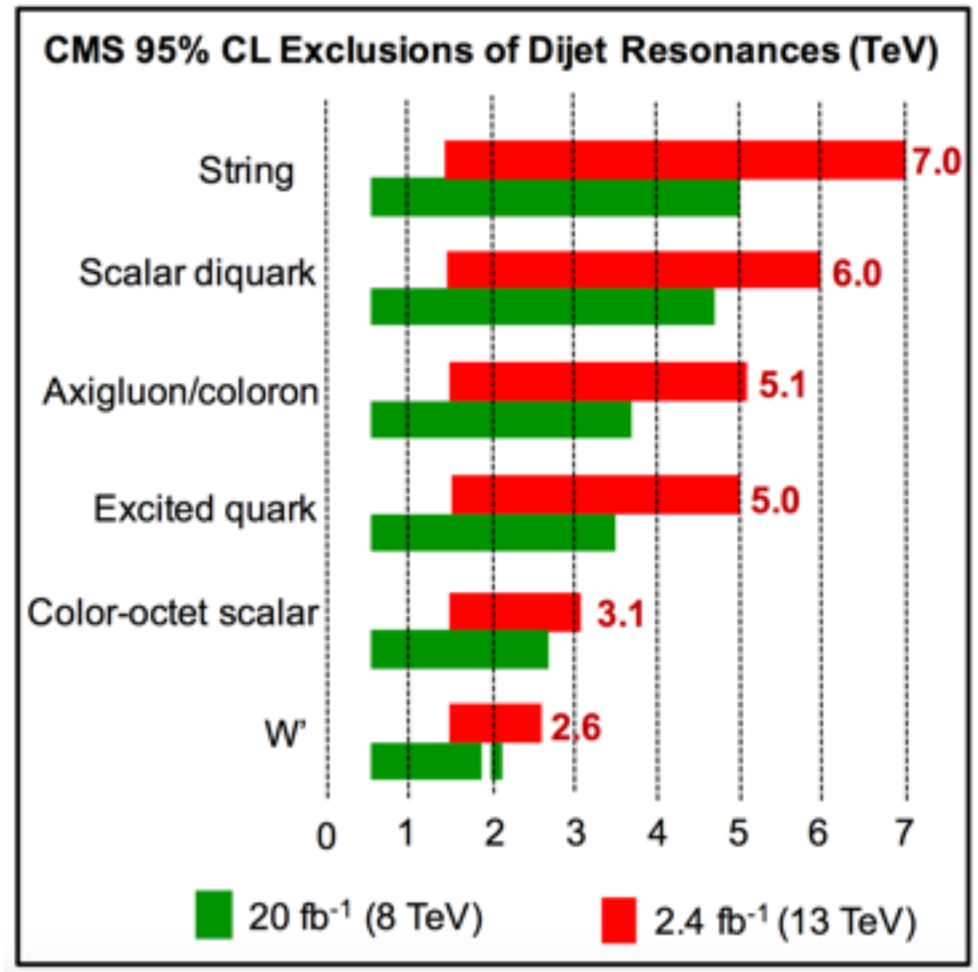


- **No new resonance observed**, set limits

High-mass limits at 13 TeV



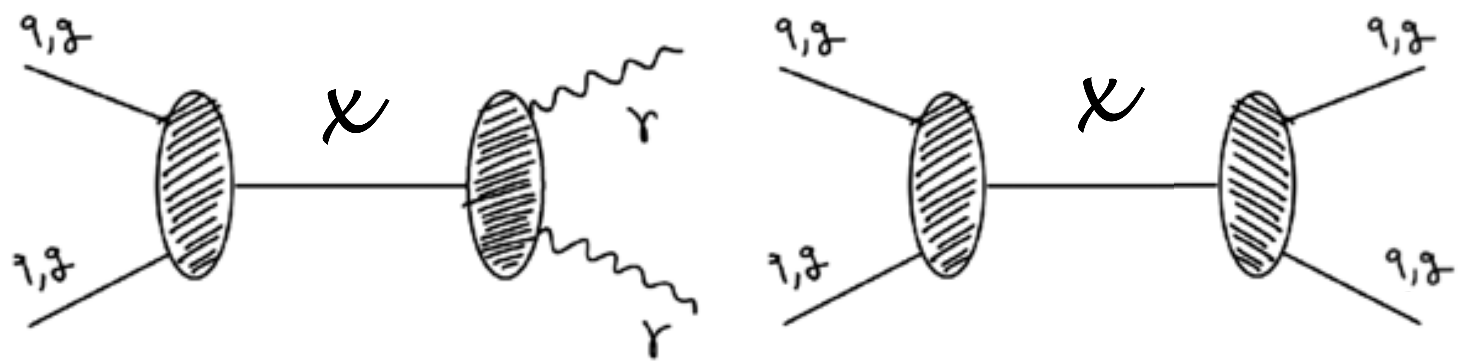
Phys. Rev. Lett. 116 (2016) 071801 [1]



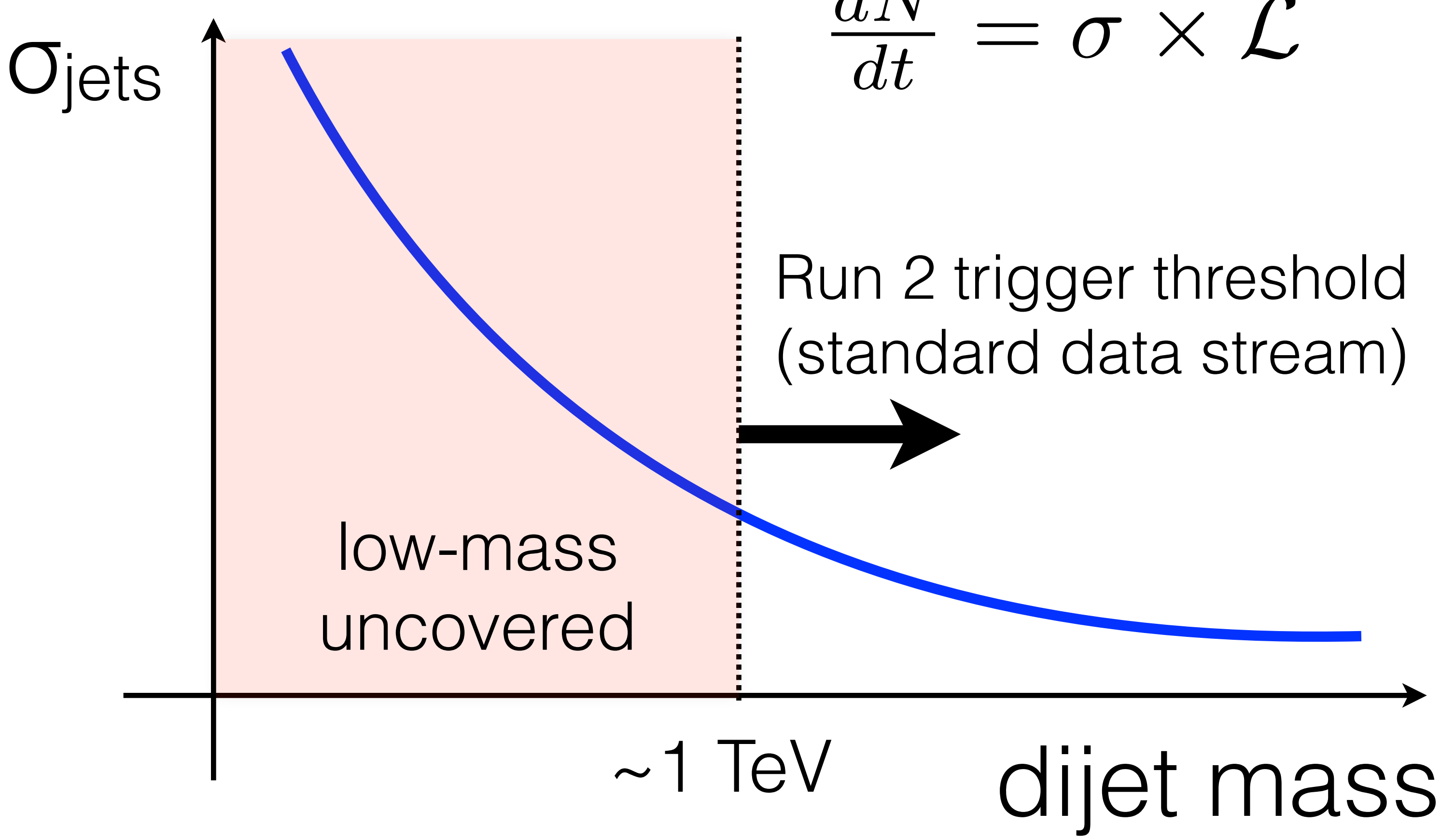
- Different final states considered: **qq**, **qg**, **gg** resonances
- **More sensitive than Run1** for resonance masses >2 TeV

Low-mass dijet search

- **Important to cover the full mass range in BSM searches**
- Hot topic
  - diphoton excess at 750 GeV [2]
  - decays to jets are expected
- Experimental difficulties
  - large dijet cross section at hadron colliders at low-mass
  - limited resources to process and store data
  - trigger thresholds raise with increasing inst. luminosity($\mathcal{L}$)



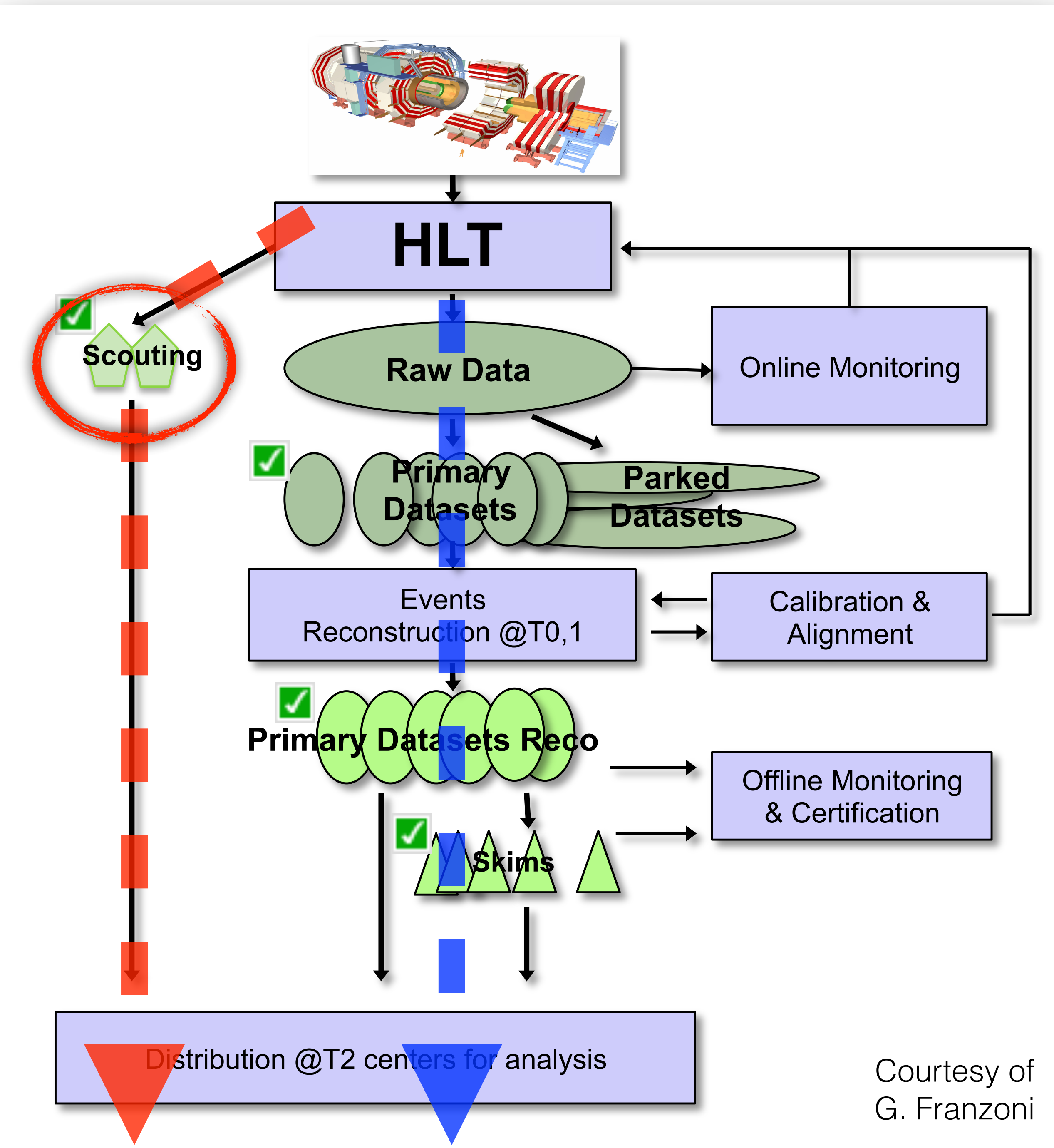
$$\frac{dN}{dt} = \sigma \times \mathcal{L}$$



"Data scouting" in CMS

First introduced by CMS in 2011 [3,4]

Physics Goal: recover sensitivity to new physics in phase space not accessible via the **standard trigger selection**



Courtesy of G. Franzoni

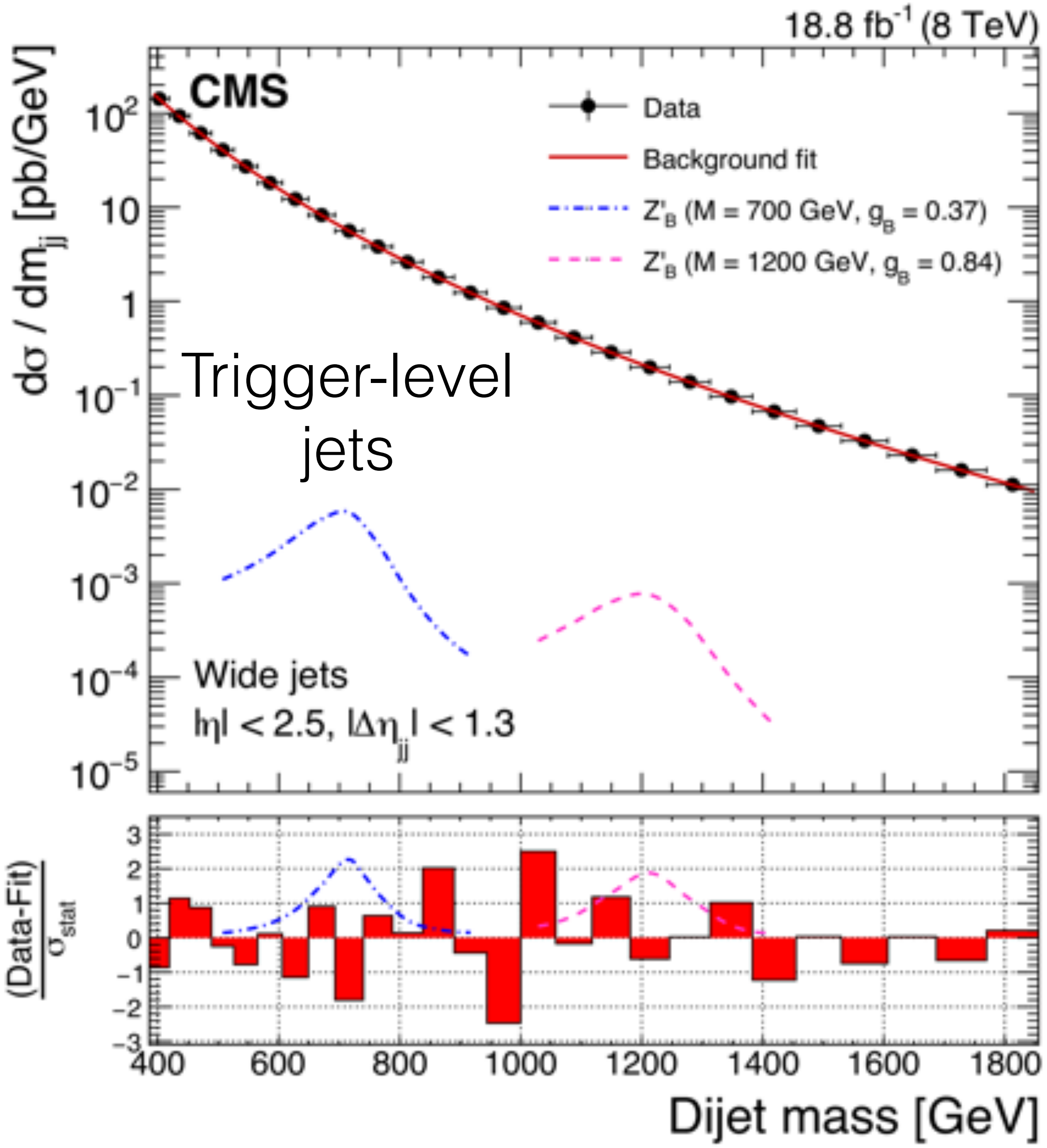
	Main data stream	Data scouting
Trigger selection	All CMS triggers ex. for dijet $H_T > 800\mathrm{GeV}$	Low-pT jet triggers $H_T > 250\mathrm{GeV}$
Event rate	~1 KHz	~4 KHz
Event content	FULL (RAW data + offline reconstruction)	REDUCED (store calo jets reconstructed at trigger level)
Bandwidth	~1 GB/s	~0.01 GB/s

1 calo scouting event $\sim$ 3KB $\sim \frac{1}{10}$

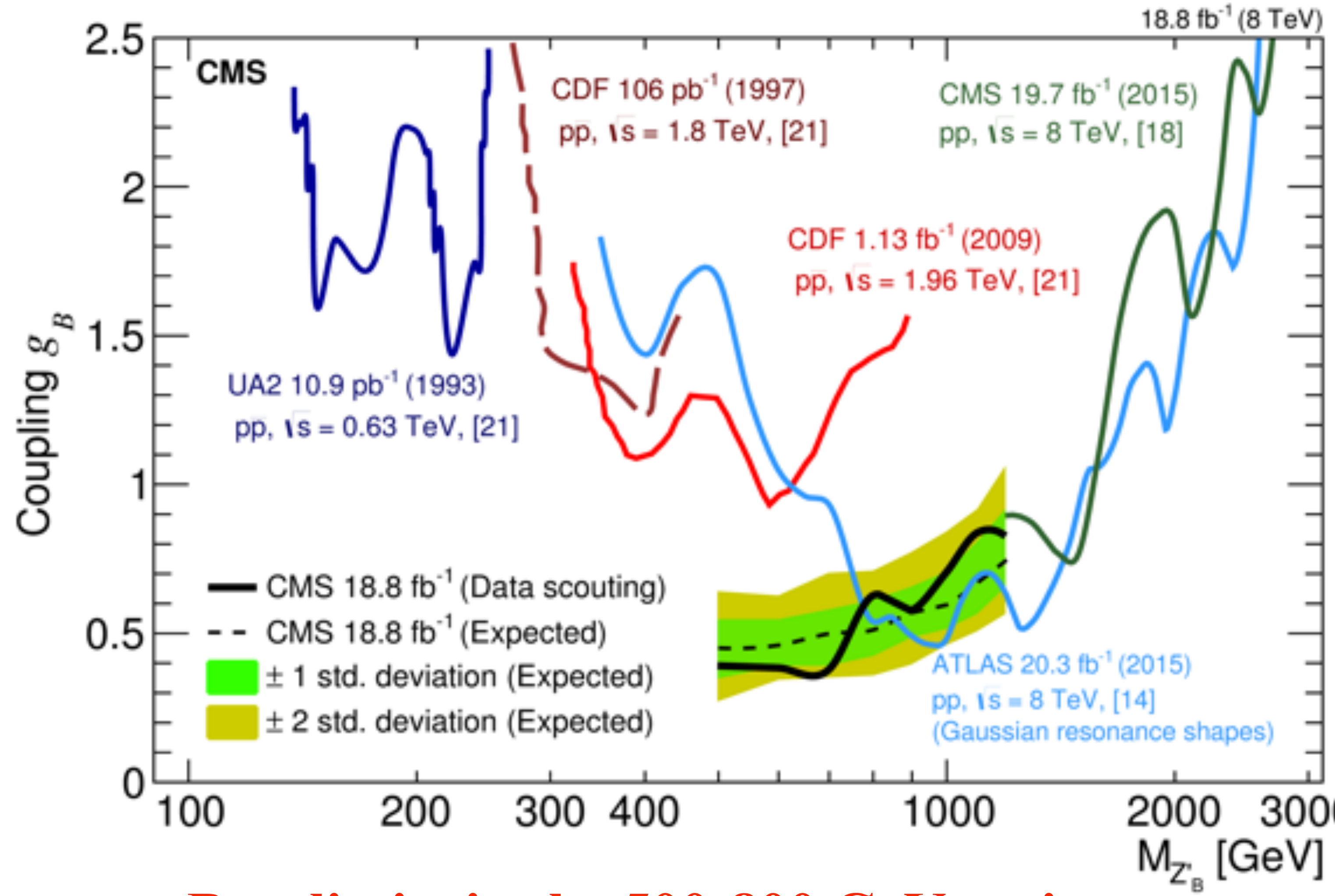
cmslogo.gif

Low-mass limits at 8 TeV

https://arxiv.org/abs/1604.08907, Accepted by PRL [5]



Leptophobic Z'->qq model $\frac{g_B}{6} Z'_{B\mu}\bar{q}\gamma^{\mu}q$

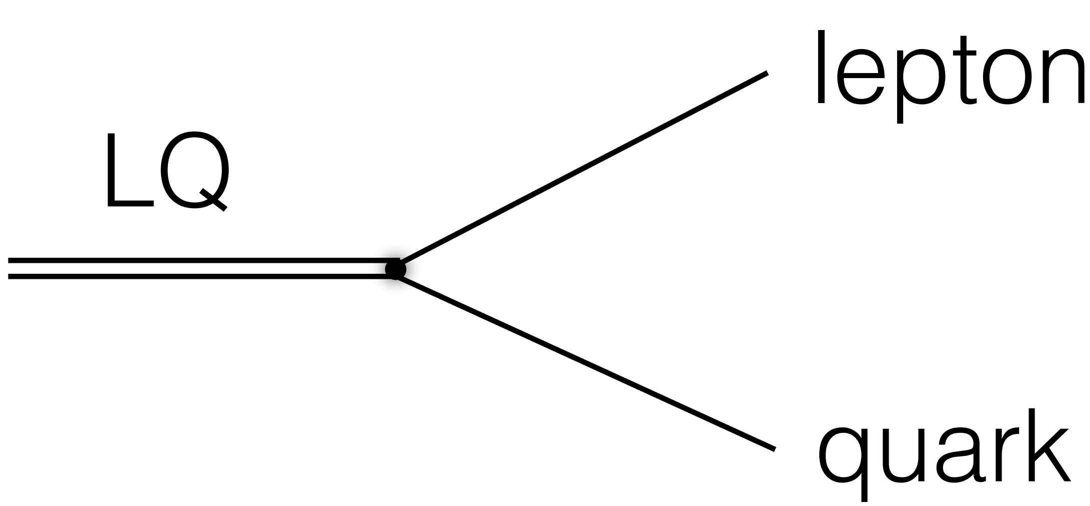


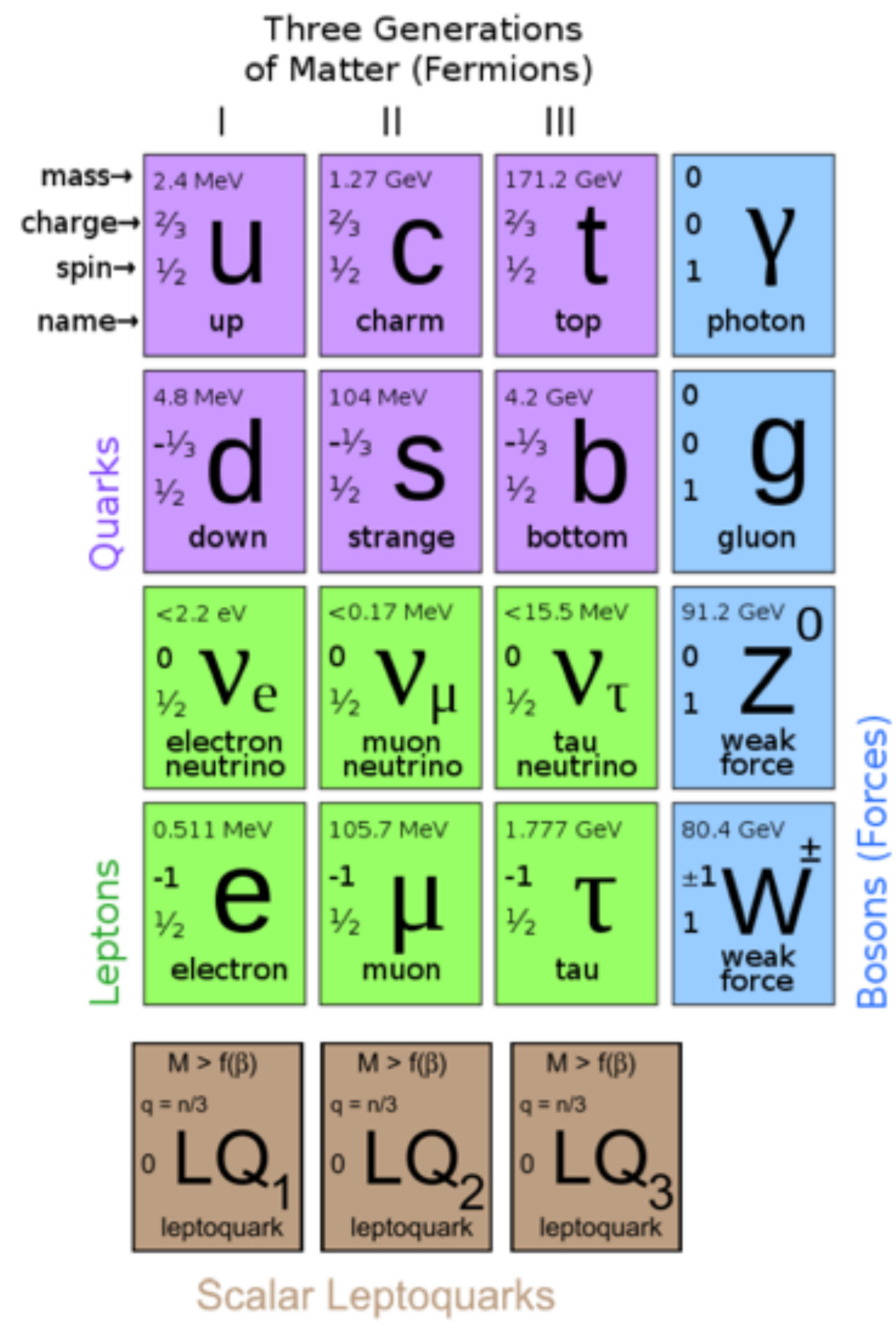
- No excess at 750 GeV

- **Best limits in the 500-800 GeV region**
- Recently ATLAS released similar analysis with 13 TeV data (called "TLA", trigger level analysis) [6]
  - similar sensitivity of CMS 8 TeV, no excess

Leptoquarks (LQ)

- Predicted by many BSM theories: grand unified theories, composite models, technicolor, superstring-inspired, SUSY RPV, and others
- Possible **explanation for observed quark-lepton symmetry of SM**
- Spin 0 or 1, coloured, fractional electric charge, carry both baryon and lepton number
  - proton is stable → baryon and lepton number conserved separately
  - FCNC suppressed in SM → only coupling within each generation

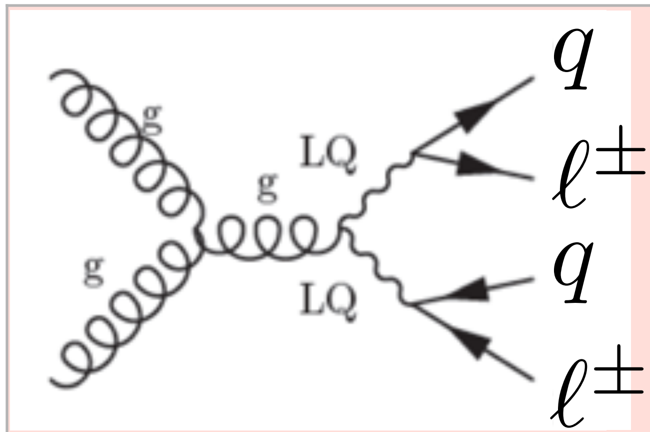
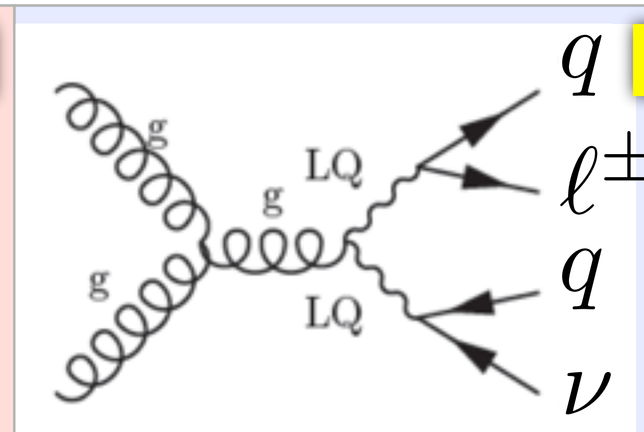
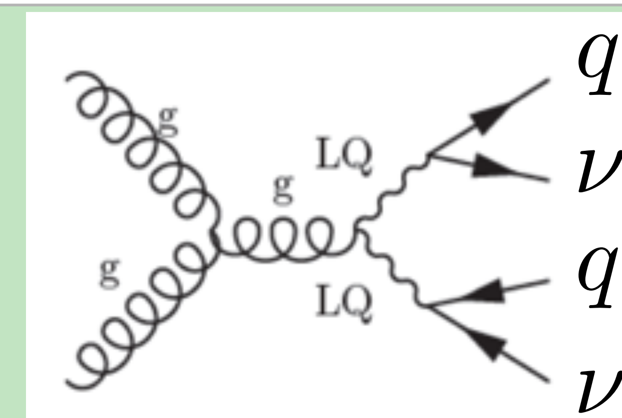




LQ model and signatures

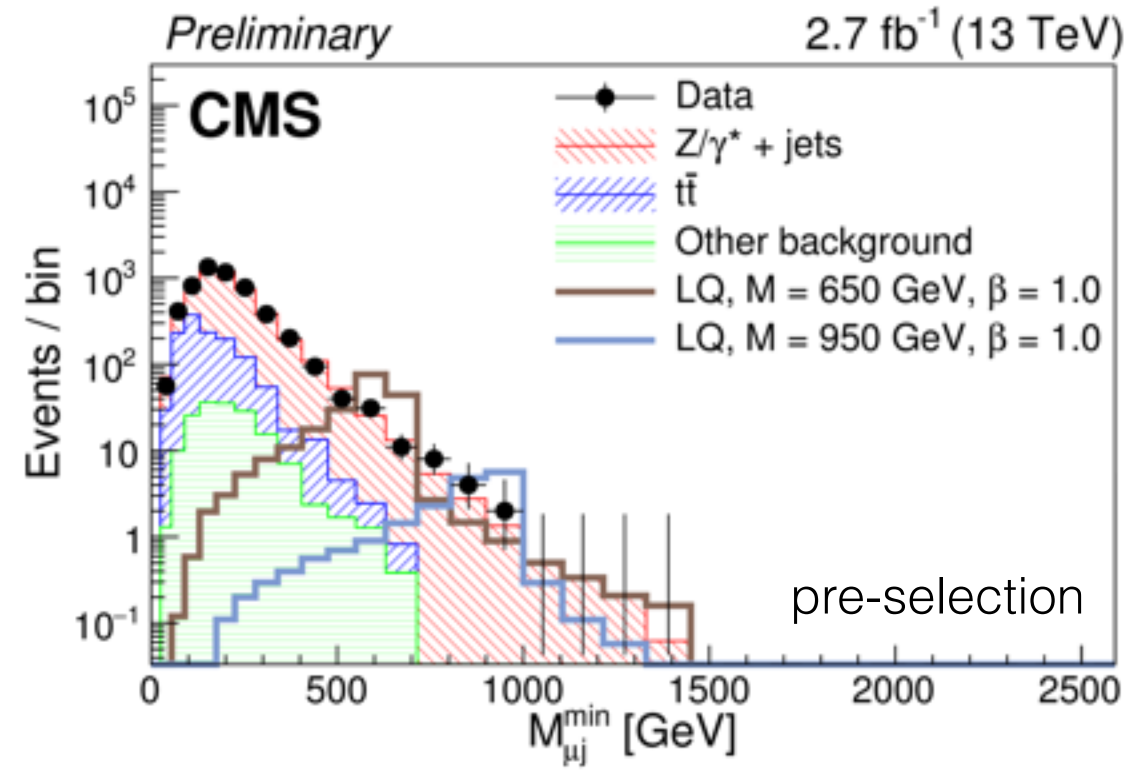
- Pair-production cross section known at NLO
  - independent of unknown l-q-LQ coupling
- Several different final states
  - rich physics program in CMS
  - **interesting signatures also beyond leptoquark models**

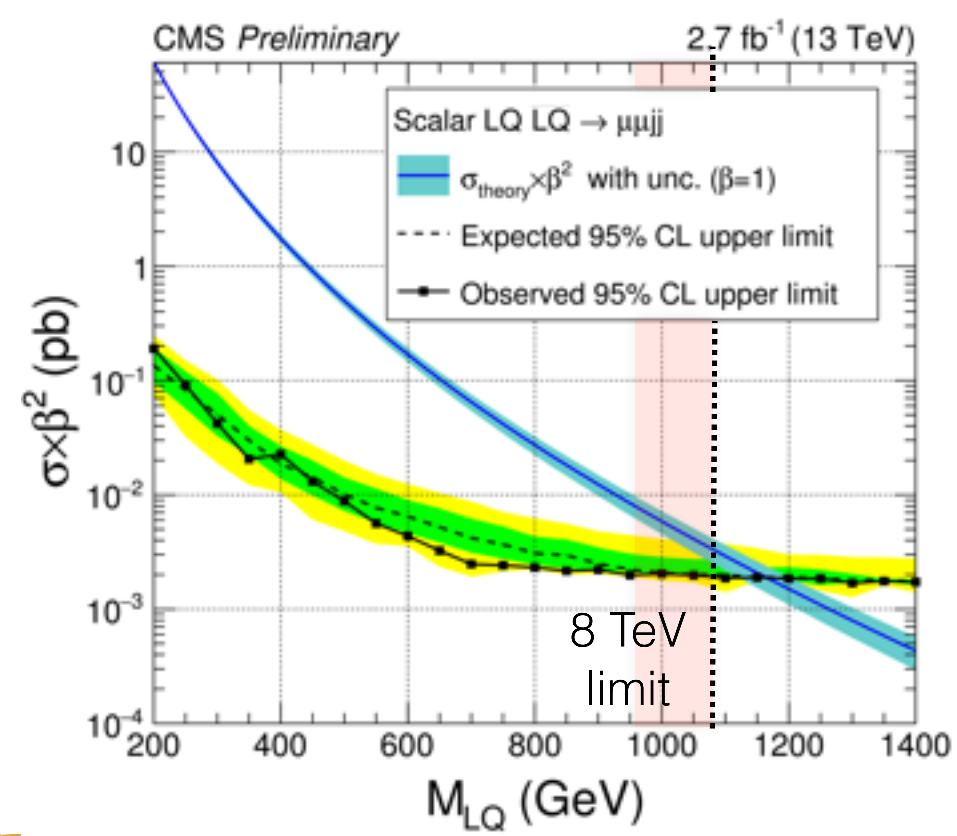
Model parameters	
M_{LQ}	LQ mass
β	$BR(LQ \to \ell^{\pm} q)$
λ	$\ell - q - LQ$ coupling

β^2	$2\beta(1-\beta)$	$(1-\beta)^2$
		
2 leptons + 2 jets	**1 lepton + 2 jets + MET**	**2 jets + MET**
EXO-16-007: μμjj (13TeV) **EXO-16-016:** ττ+jj (13TeV) **EXO-12-041**: eejj, μμjj (8TeV) **EXO-14-008**: ττ+tt (8TeV) **EXO-12-032**: ττ+bb (8TeV) **EXO-12-043**: singleLQ eej, μμj (8TeV)	**EXO-12-041**: evjj, μvjj (8 TeV) *Final state covered also by CMS SUSY searches*	**EXO-11-030**: vvbb (7 TeV) *Final state covered also by CMS SUSY searches*

LQ2 - μμqq

- 2 muons + 2 jets [7]
- Selection optimized for each LQ mass hypothesis
  - $M_{\mu\mu}$: dimuon invariant mass
  - S_T : $p_T(\mu_1) + p_T(\mu_2) + p_T(jet_1) + p_T(jet_2)$
  - $\mathbf{M^{min}_{\mu j}}$: smaller of two LQ masses which minimizes LQ-LQ mass difference
- Counting experiment
  - **no excess in data**
- Exclude scalar LQ2 with mass < 1150 GeV and β=1
  - exceeding 8 TeV limits

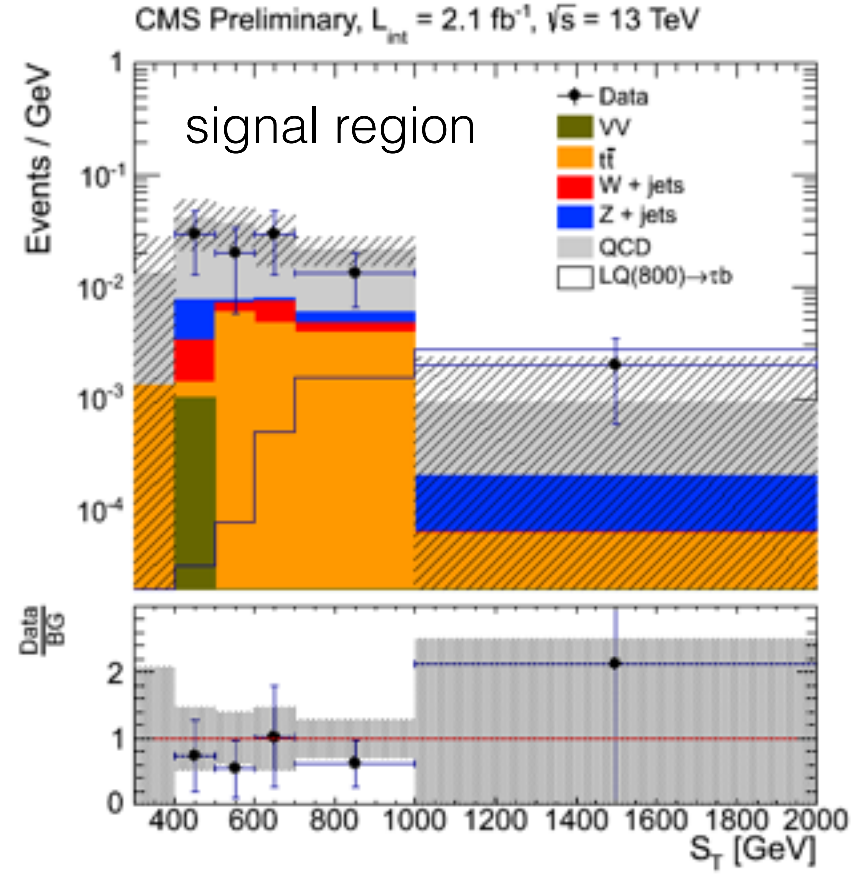


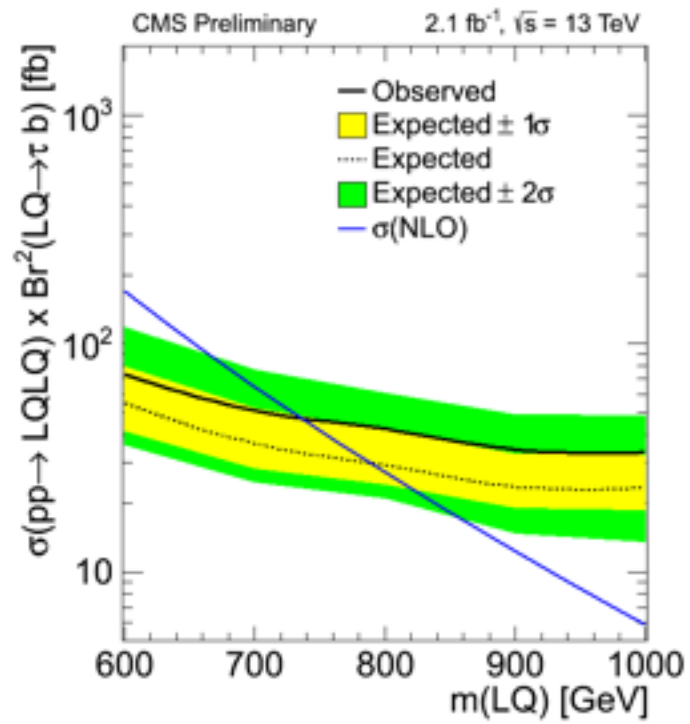


NEW

LQ3 - ττbb

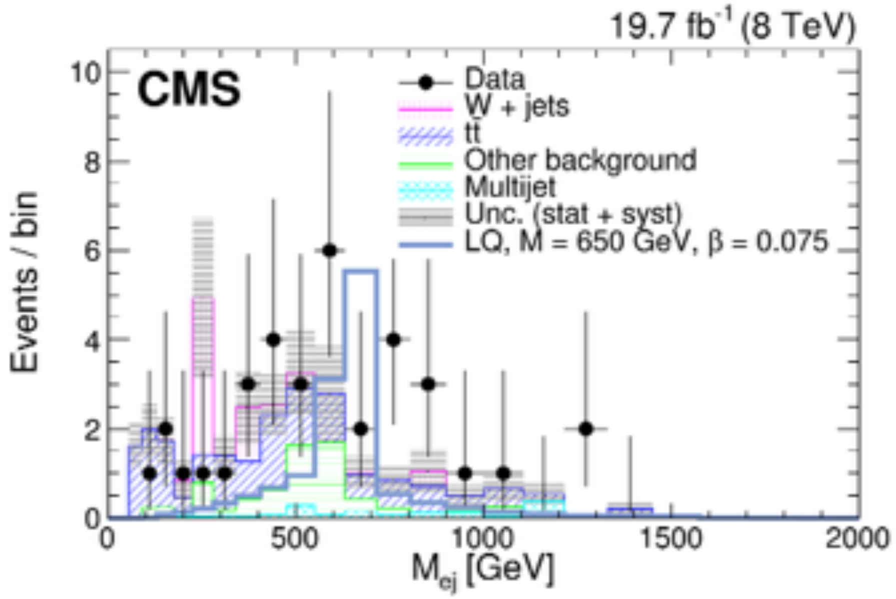
- **First search for LQ3 at 13 TeV LHC**
- 2 taus + 2 jets [8]
  - hadronic tau decays (BR = 42%)
  - no explicit jet b-tagging (model independent)
- Main physics observable
  - **S$_T$** : $p_T(\tau_1) + p_T(\tau_2) + p_T(jet_1) + p_T(jet_2)$
- Shape analysis
  - data in agreement with predictions
- Exclude scalar LQ3 with mass < 740 GeV and β=1

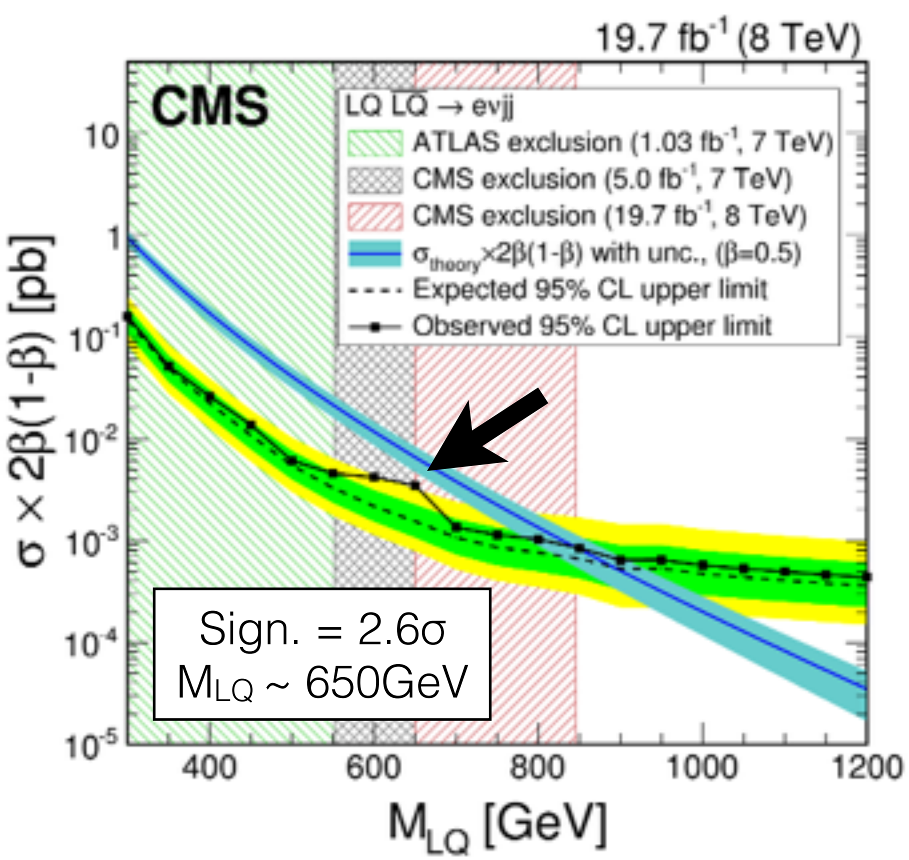




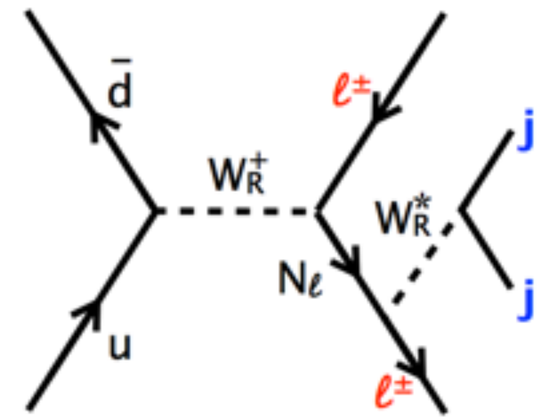
Run 1 fluctuations

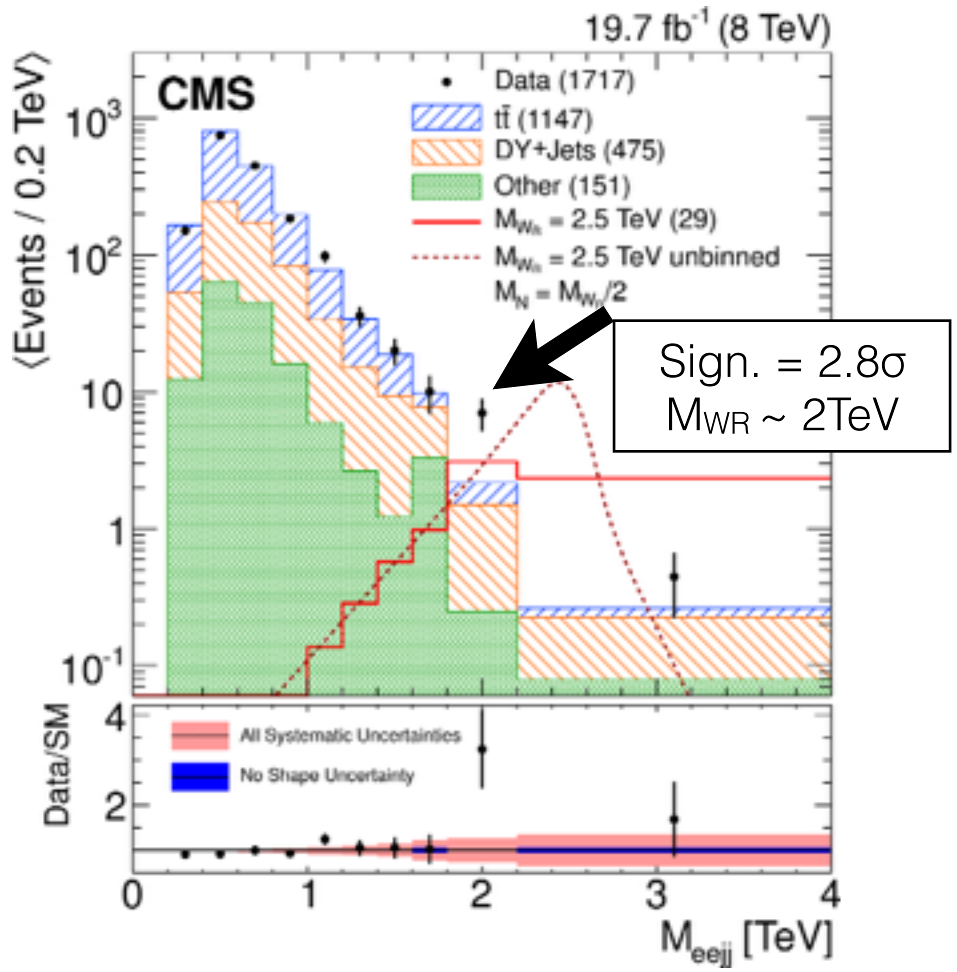
LQ1 - evjj [9]





W_R & Heavy Neutrino - eejj [10]



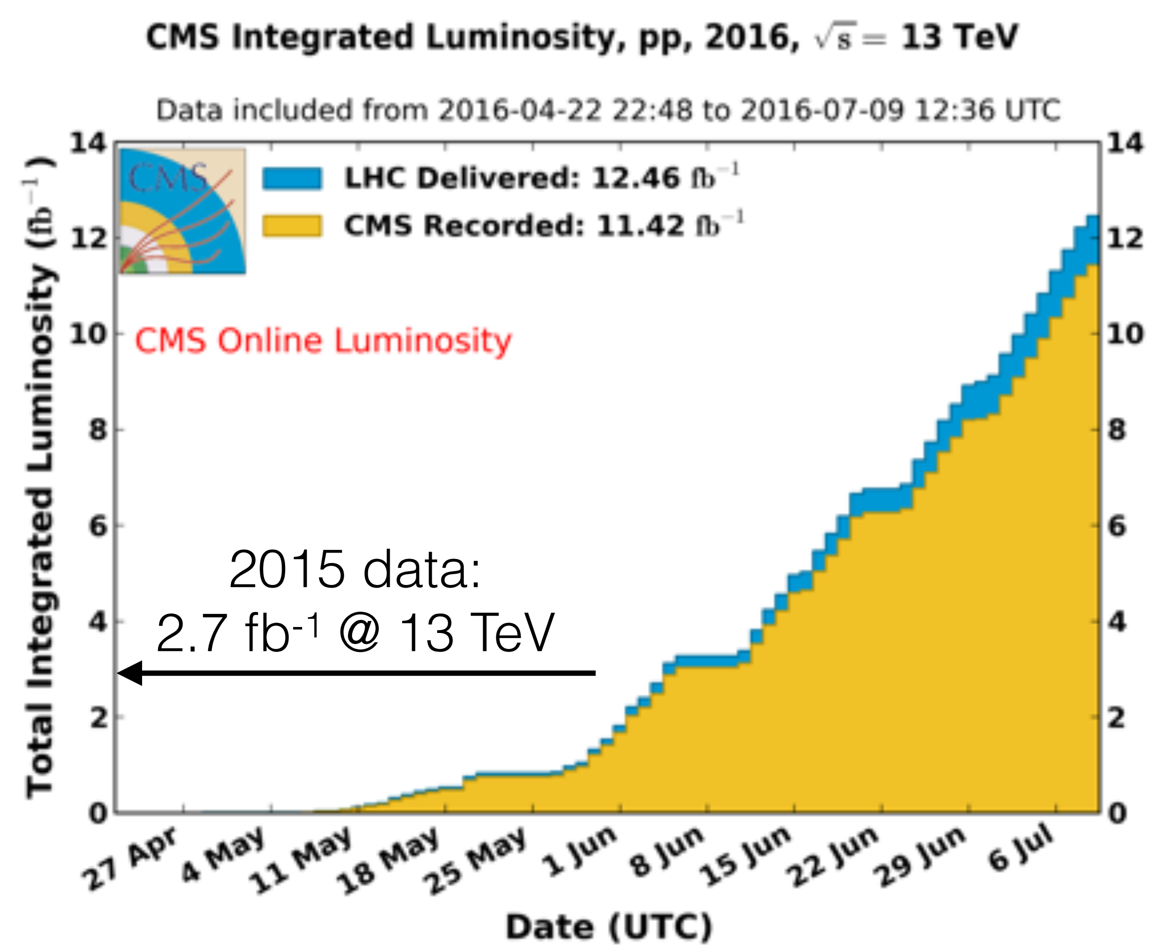


- **2-3σ excess in electron+jets final states**
- No excess in muon channels
- Looking for analysis with 13 TeV data

Conclusions

- **Search for BSM physics continues at CMS**
  - rich physics program in final states with jets and leptons+jets (covered small part in this talk)
- **Dijet resonances**
  - new energy territory for masses > 2 TeV
  - novel *data scouting* technique extend search in sub-TeV mass region; can confirm 750 GeV diphoton excess
- **Leptons+jets searches**
  - many different final states covered in CMS
  - 2-3σ excess in eνjj and eejj Run 1 searches
- **Excellent LHC performance in 2016**
  - expect ~10 fb^{-1} for ICHEP2016 in August
  - maybe 40 fb^{-1} by the end of the year
- **Keep eyes open for LHC results !!!**

CMS Exotica Public Results
http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html



References

CMS Exotica Public Results
http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

- [1] **Dijet resonances 13 TeV**: CMS collaboration, Phys. Rev. Lett. 116 (2016) 071801, http://arxiv.org/abs/1512.01224,
- [2] **Diphoton excess 13 TeV**: CMS collaboration, http://arxiv.org/abs/1606.04093, submitted to PRL; ATLAS collaboration, http://arxiv.org/abs/1606.03833, submitted to JHEP
- [3] **Data Scouting and Data Parking:** CMS collaboration, CMS-DP-2012-022
- [4] **First dijet search with scouting at CMS**: CMS collaboration, CMS-PAS-EXO-11-094, http://cds.cern.ch/record/1461223
- [5] **Dijet search with scouting at 8 TeV**: CMS collaboration, https://arxiv.org/abs/1604.08907, Accepted for publication by PRL
- [6] **Dijet search with TLA at 13 TeV**: ATLAS collaboration, http://cds.cern.ch/record/2161135, ATLAS-CONF-2016-030
- [7] **Second generation leptoquarks at 13 TeV**: CMS collaboration, https://cds.cern.ch/record/2139349, CMS-PAS-EXO-16-007
- [8] **Third generation leptoquarks at 13 TeV**: CMS collaboration, https://cds.cern.ch/record/2159374, CMS-PAS-EXO-16-016
- [9] **First generation leptoquarks at 8 TeV**: CMS collaboration, Phys. Rev. D93 (2016) 032004, http://arxiv.org/abs/1509.03744
- [10] **W_R and Heavy neutrino at 8 TeV**: CMS collaboration, Eur. Phys. J. C 74 (2014) 3149, http://arxiv.org/abs/1407.3683

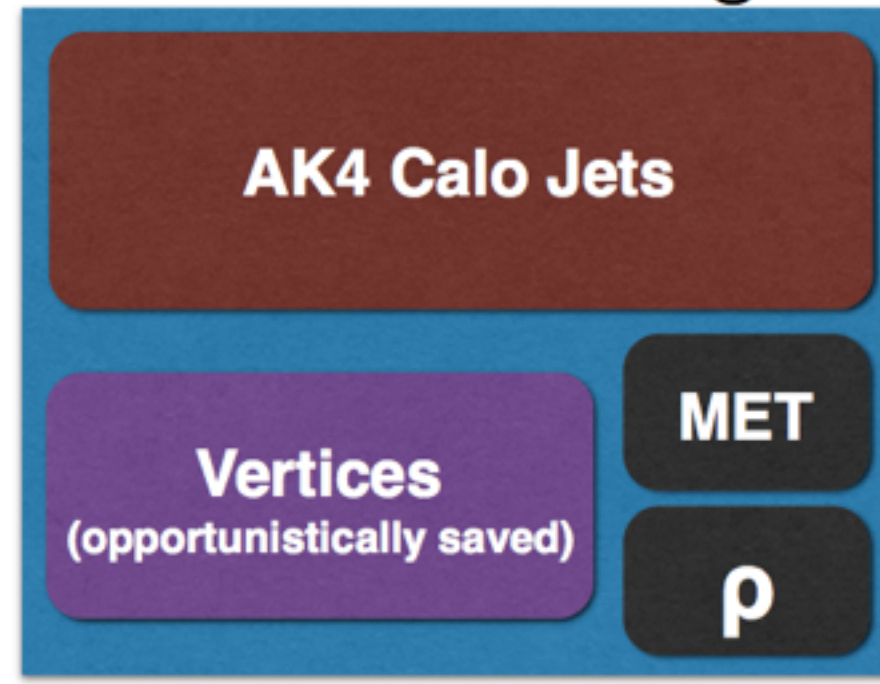
Backup slides

Data Scouting in 2015
(next 3 slides)

Event Content

- **Calo Scouting**
  - Four-momenta of Calojets with pT>20 GeV
  - Vertices (when available), “opportunistically” from other paths in the trigger table
  - Event information
    - energy density ρ (for pile-up subtraction)
    - Missing transverse energy
- **PF Scouting**
  - Four-momenta of relevant physics objects
    - e, μ, γ, PFJets, PF candidates, vertices
  - Event information (as for Calo Scouting, but with tracking)

Calo Scouting



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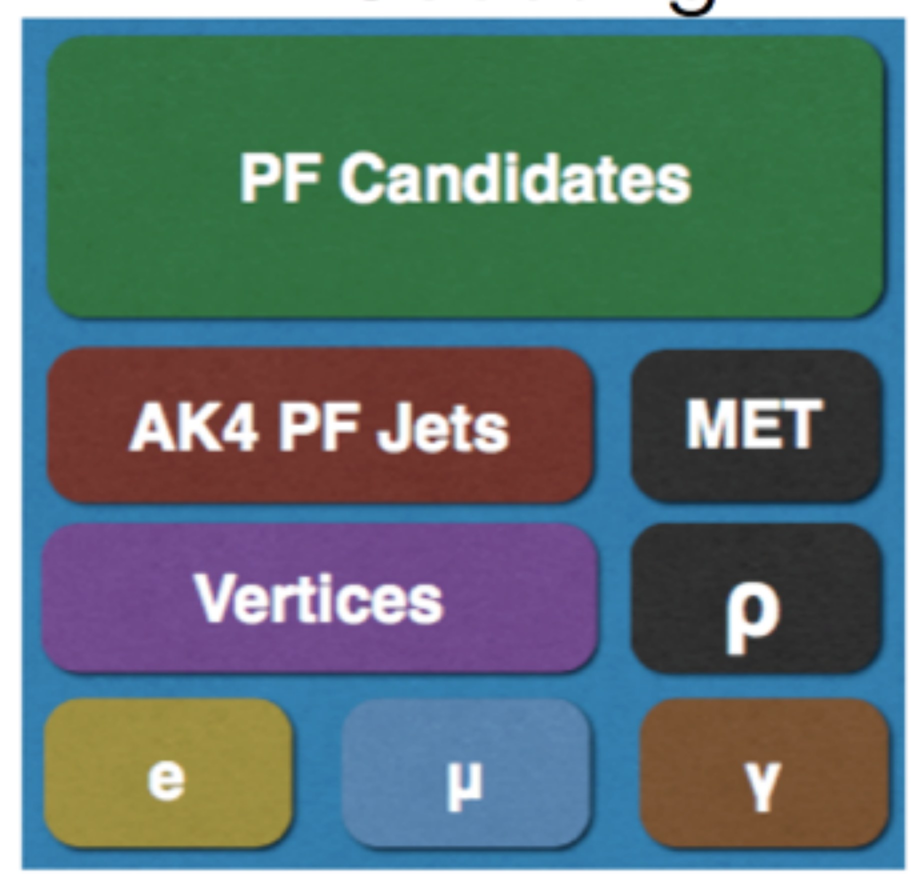
PF Scouting



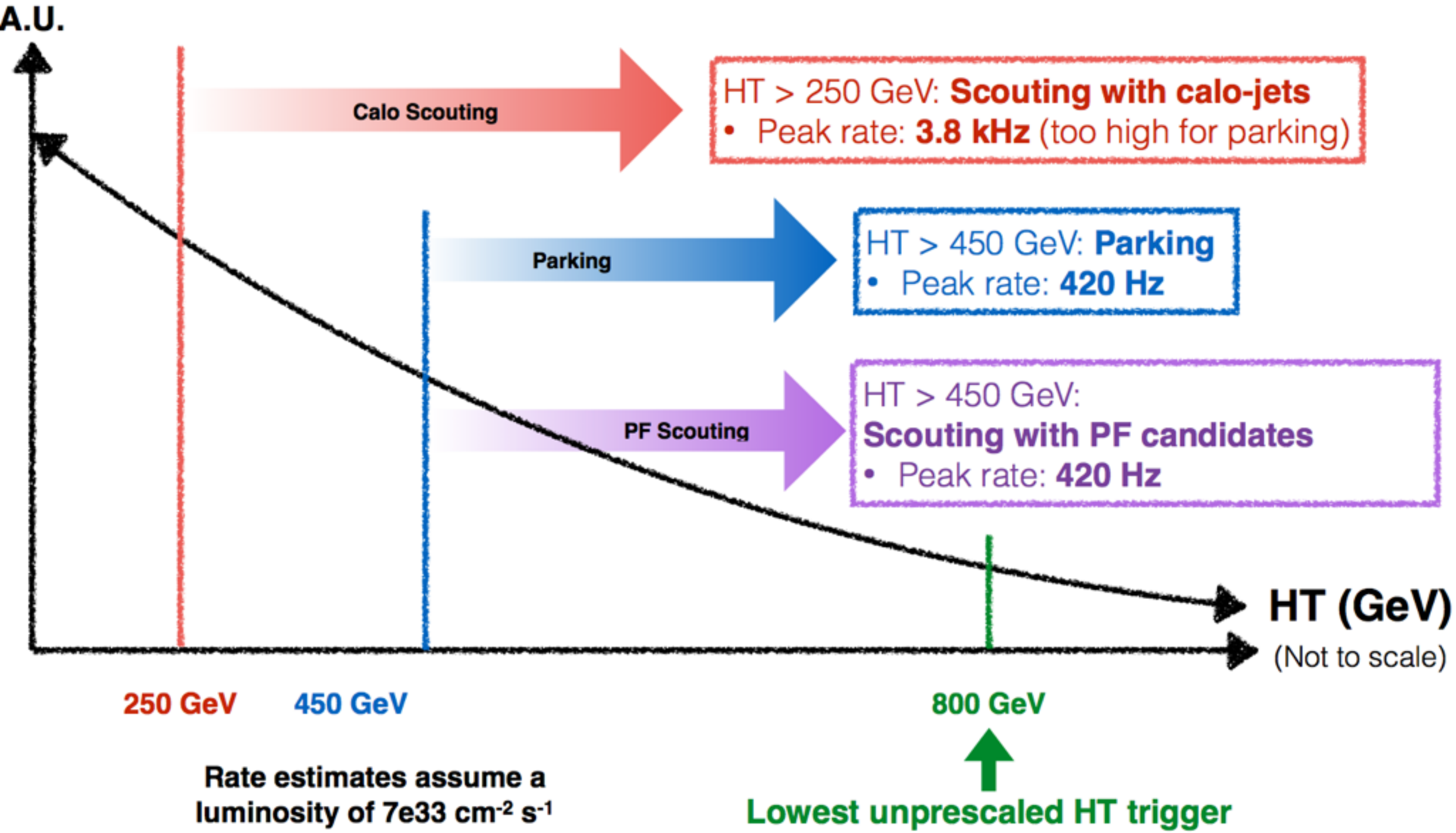
Typical size: 10 kb

Trigger Algorithms

- **Hadronic triggers**
  - collect events with HT above some threshold (PF/Calo scouting)
  - collect events in bins of HT (parking)
- **Muon Trigger**
  - collect events with muon pair having mass > 10 GeV
- **Auxiliary triggers**
  - measure L1-seed turn-on curve
  - measure efficiency of HLT selection

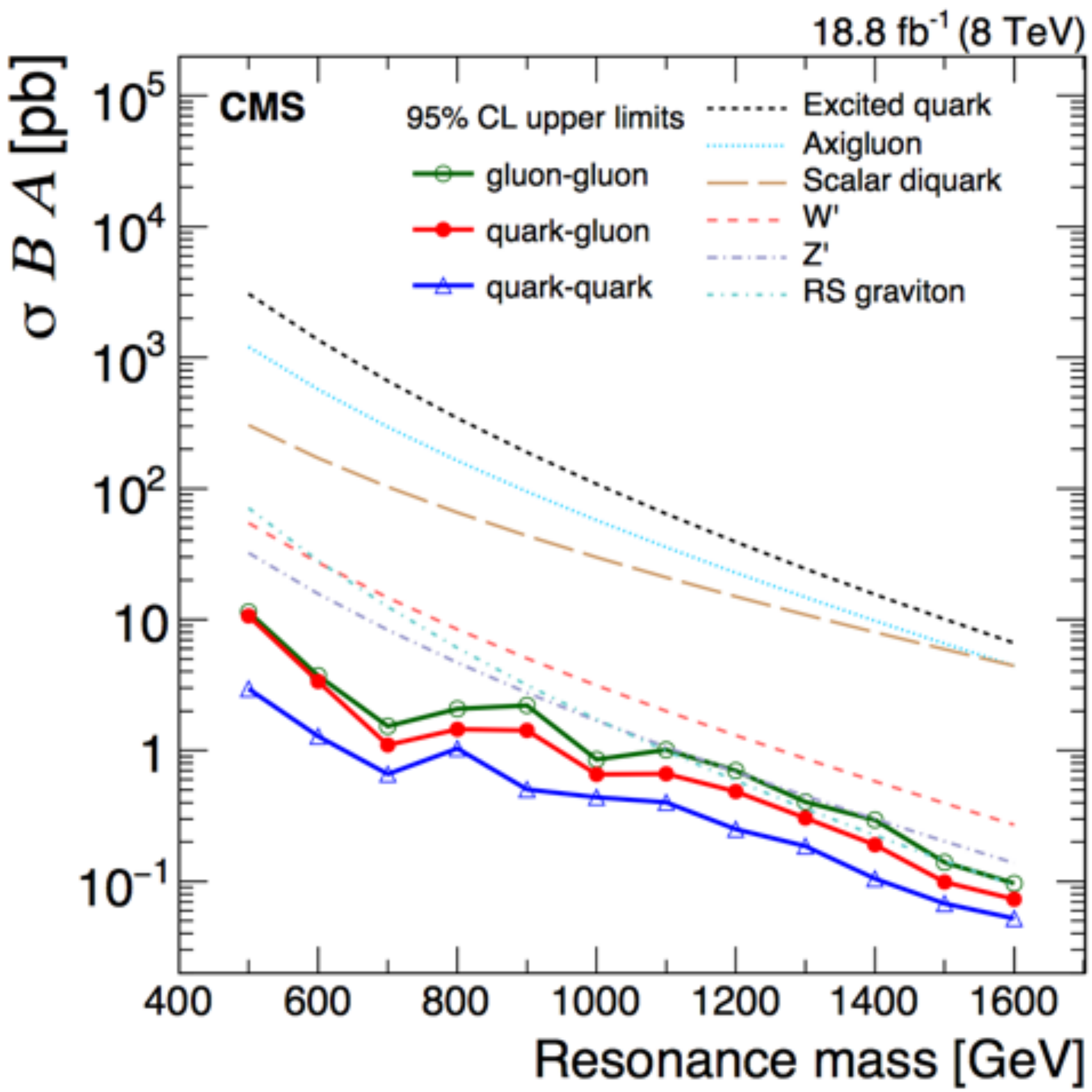
Scouting Trigger Paths	Rate [Hz] @3.2e33 $cm^{-2}s^{-1}$
DST_HT450_PFScouting	100
DST_HT250_CaloScouting	1000
DST_DoubleMu6_Mass10	140
Parking Trigger	**Rate [Hz] @3.2e33 $cm^{-2}s^{-1}$**
HLT_HT450to470	17
HLT_HT470to500	20
HLT_HT500to550	22
HLT_HT550to650	23
HLT_HT650	21
Prescaled Paths (10 Hz each)	**Purpose**
DST_L1HT_PFScouting	Measure HLT turn-ons
DST_L1HT_CaloScouting	Measure HLT turn-ons
DST_CaloJet40_PFScouting	Measure L1 turn-ons
DST_CaloJet40_CaloScouting	Measure L1 turn-ons

EXAMPLE: The HT events



Rate estimates assume a luminosity of 7e33 cm^{-2} s^{-1}

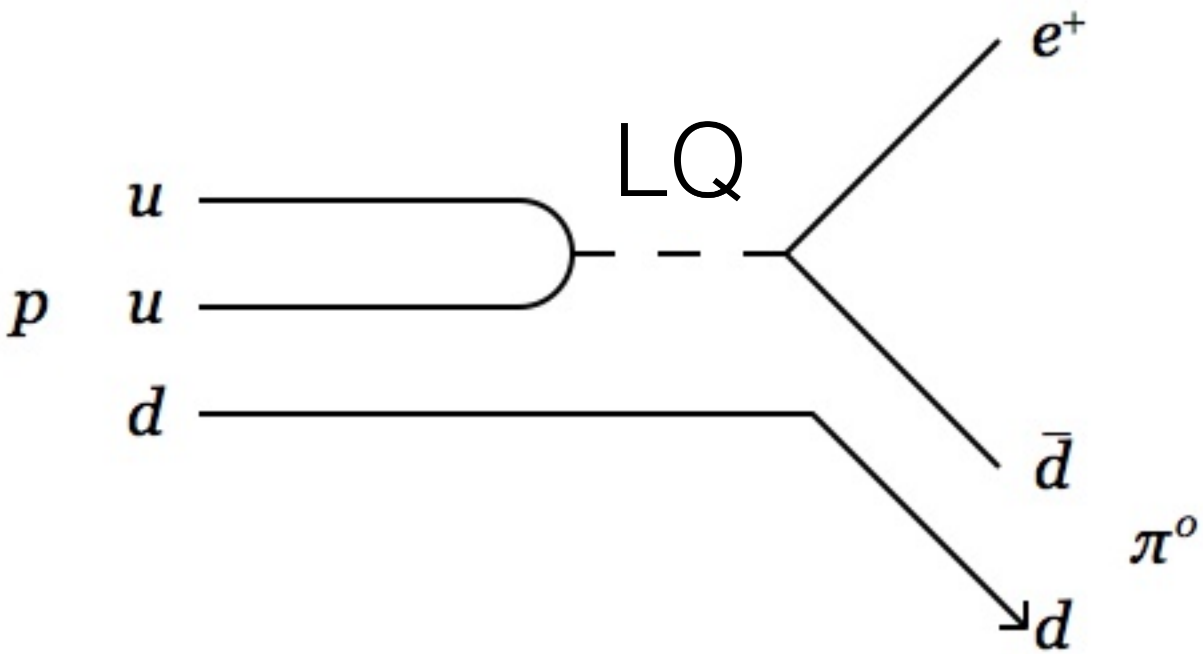
Dijet scouting limits



- Exclude "cross section X branching ratio X acceptance" of about 2 pb at 750 GeV for gg resonances
  - acceptance ~ 60% for scalar resonances

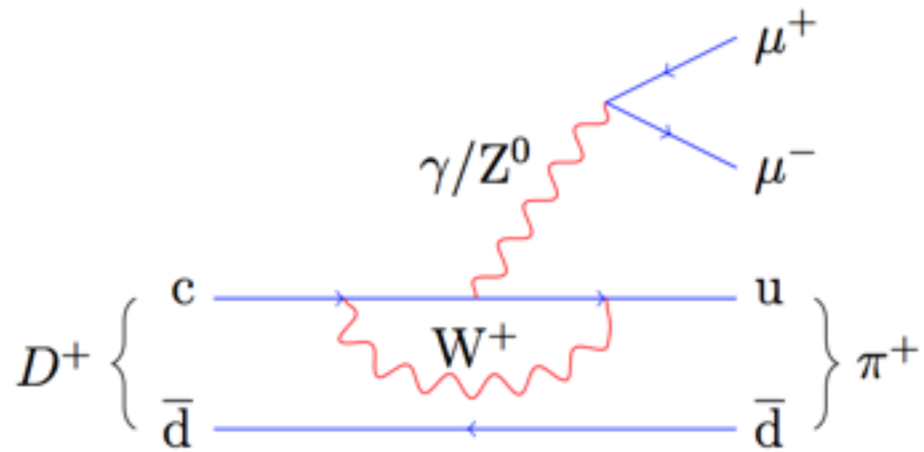
Leptoquark constraints

Proton is stable

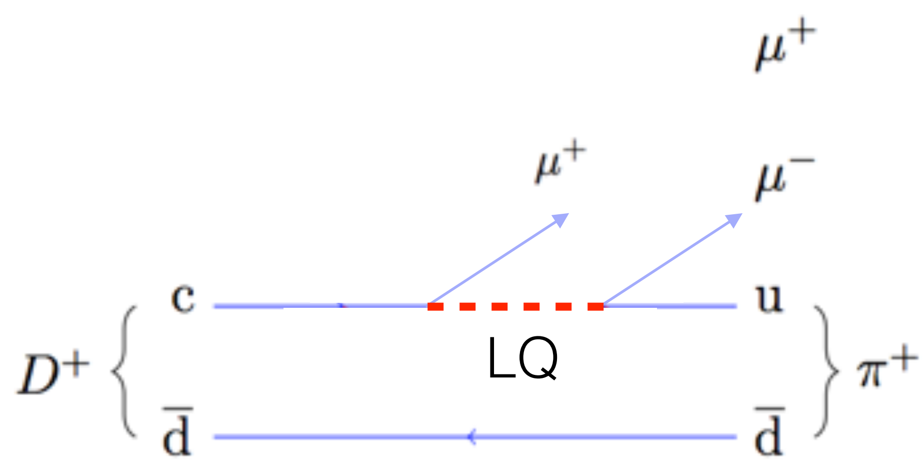


- ⇒LQ must vertices must conserve separately baryon and lepton number

FCNC suppressed in SM



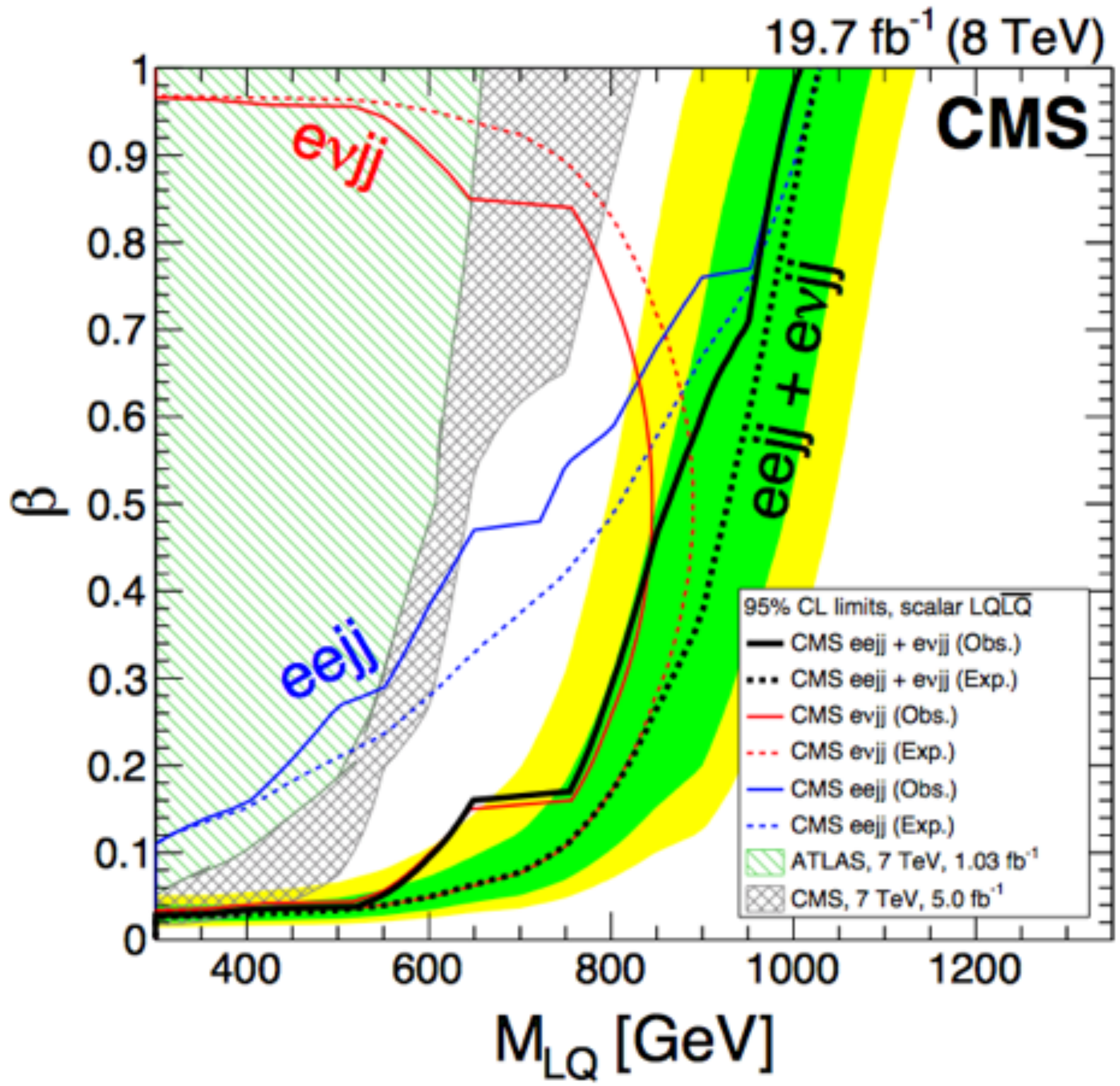
(SM)

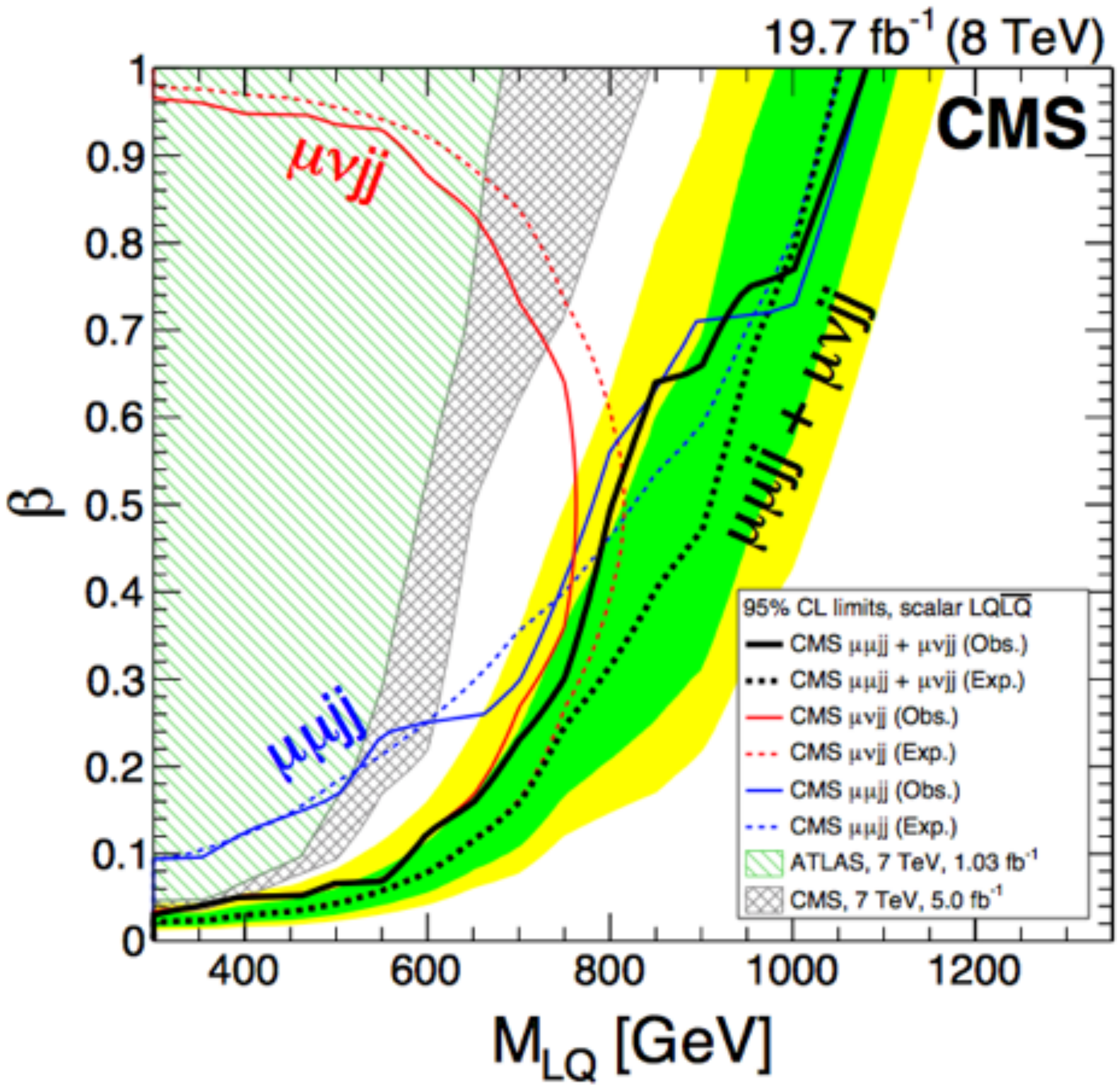


(BSM)

- ⇒LQ only couple within a single generation

LQ1 and LQ2 limits





M(lljj) spectra