(Highlights from) New Physics searches at CMS

Maurizio Pierini

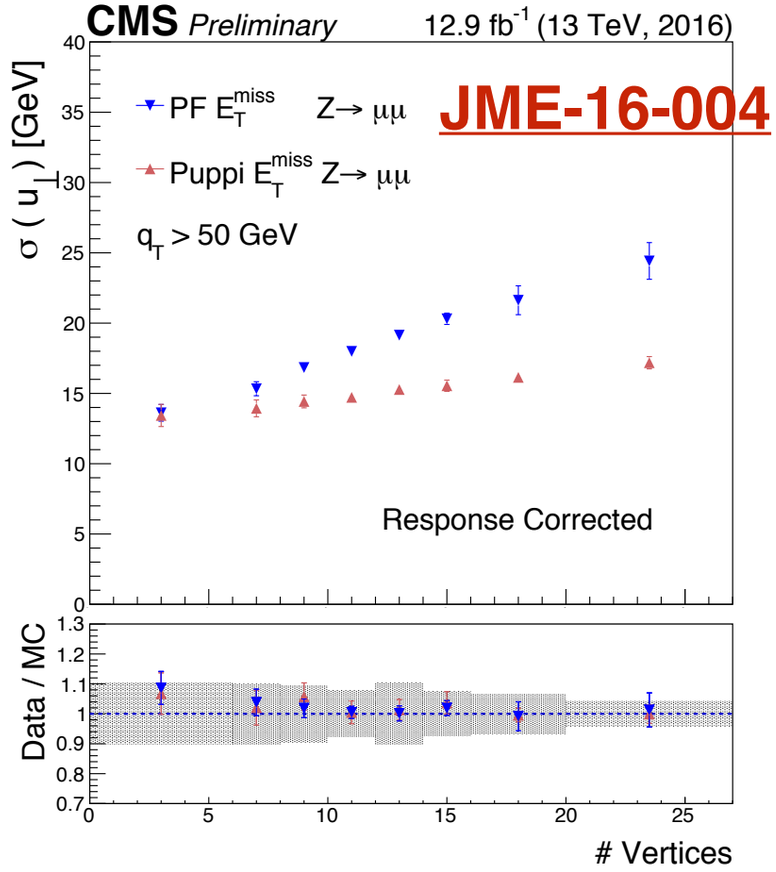
Disclaimer

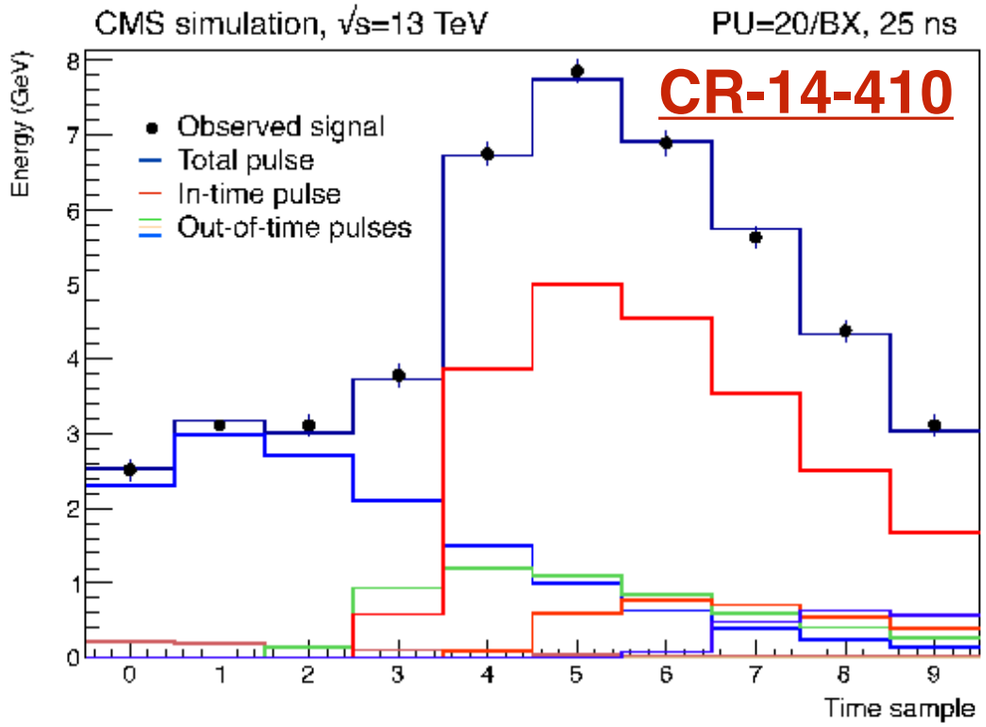
- Cannot fit all CMS searches in 30 min
- So, I picked some of the results to pass some message
- The bottom line is the same:
  - we are not done yet !!!
  - with new ideas, we are going beyond our limits
  - we are searching in all possible directions. Hopefully we are not combing the desert!

The Run I legacy…

LHC Run II challenges

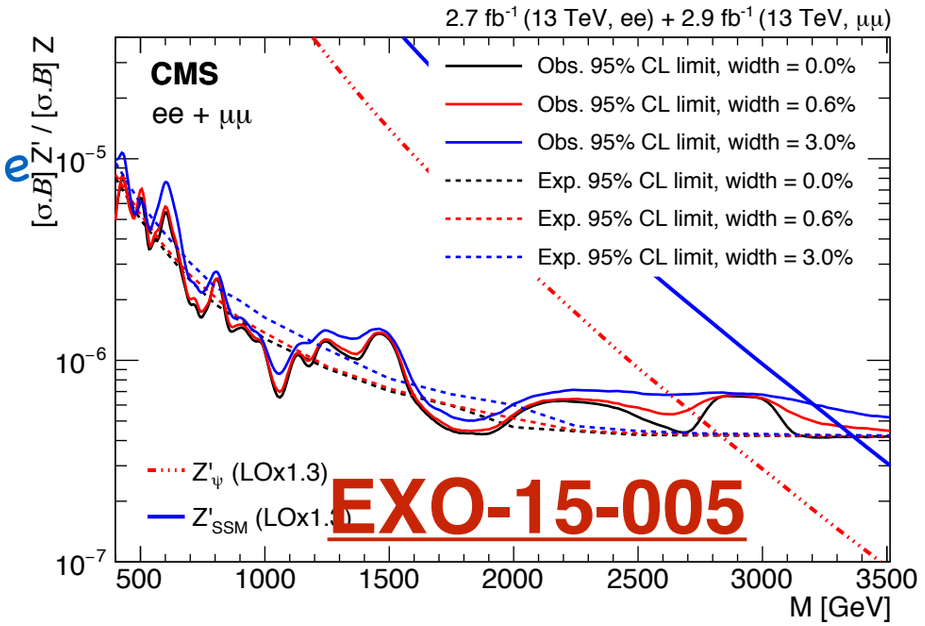
- Data in Run II are more complex
  - High luminosity was reached increasing pileup
    - data quality deteriorates with number of vertices
      - progresses made on cleanup techniques, e.g. PUPPI
    - keeping trigger manageable becomes complicated
      - increase thresholds -> reduce sensitivity
- 25 ns bunch spacing -> pileup from previous and following bunch crossing
  - use signal timing to clean-up event
  - careful with implications for NP signals



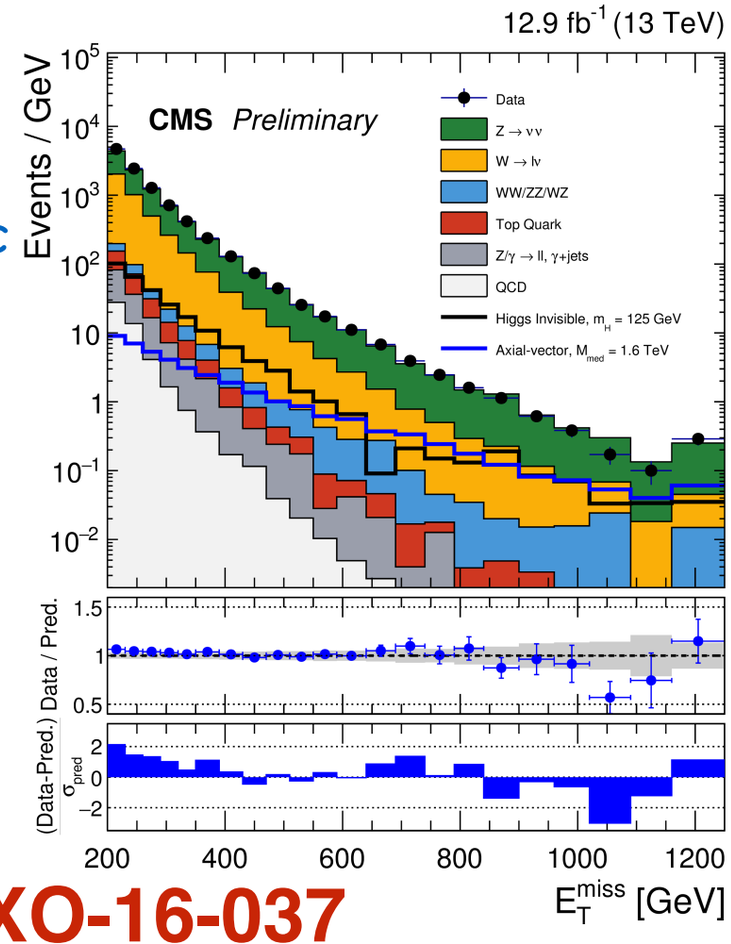


Overview of the search program

- **Narrow resonances**
  - Signal comes with a clear signature. First hints might not be clear (see diphoton) but eventually more data would tell us
  - When jets are involved, complications emerge
    - trigger becomes an issue for not-so-heavy resonances
    - Large backgrounds (here substructure helps)



- **Everything else**
  - other searches are typically conducted on tails (of kinematic quantities, object multiplicities, detector signal like dE/dx)
  - thanks to small background, can probe small signals ($\sigma <$ fb^{-1})
  - (so far) strategy effective thanks to LHC energy increase
  - we might have to focus more on the bulk (and change strategy). See DM/SUSY searches for a successful example

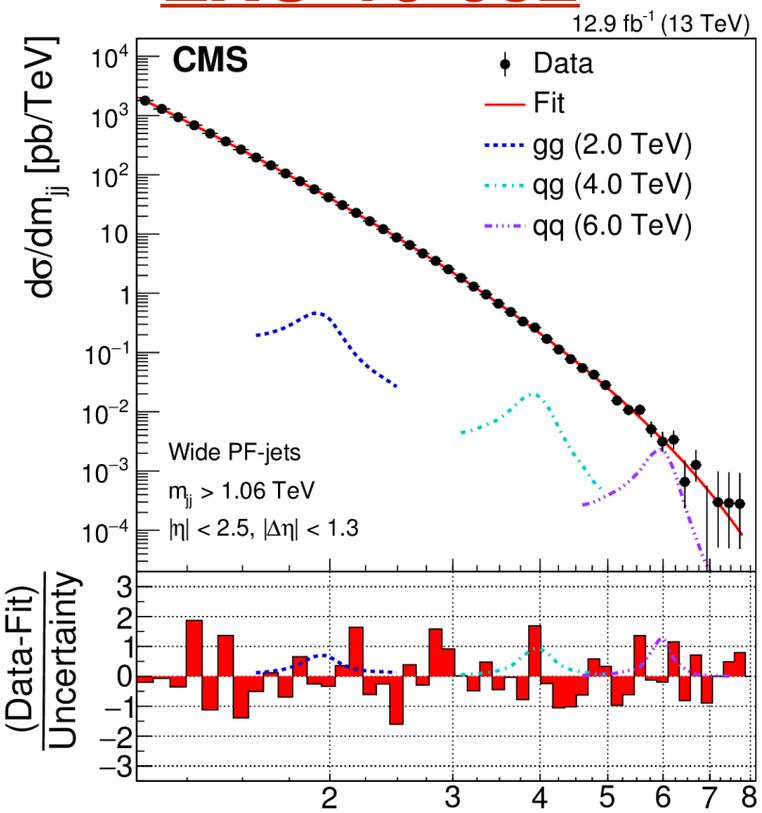


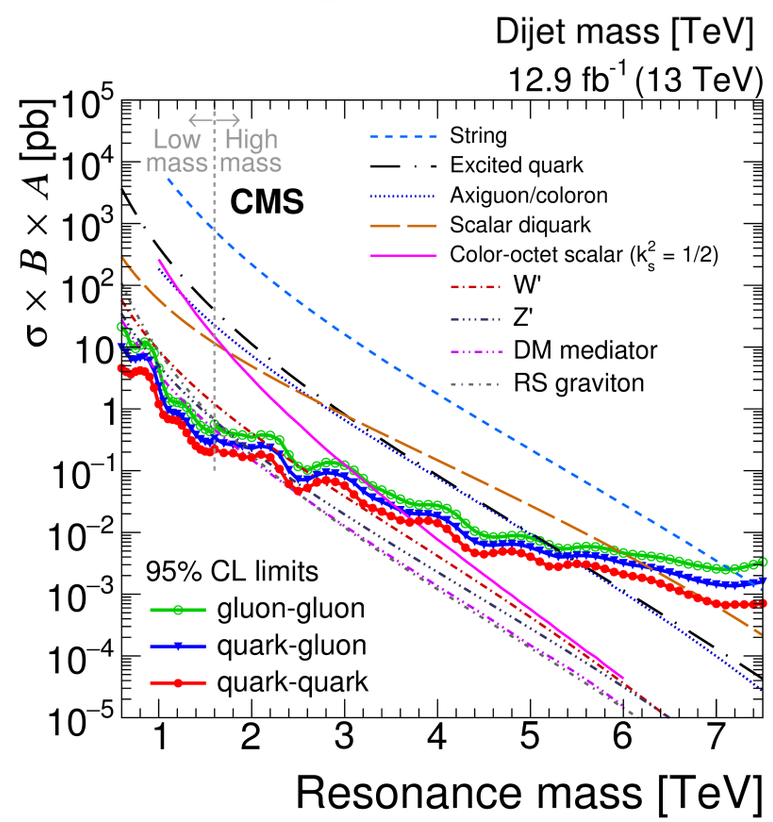
New Resonances

General Strategy

- For a given final state, select objects (e, μ, jet, τ, γ, ...) according to standard recipes
- Form invariant-mass of the object
- Measure the background from a control sample or fitting the distribution with ansatz functions
- **MODEL "INDEPENDENT":** For a given mass assumption (*), a limit on the xsec is derived
- **MODEL "DEPENDENT":** xsec limit is turned into a mass limit once a specific model is assumed

EXO-16-032

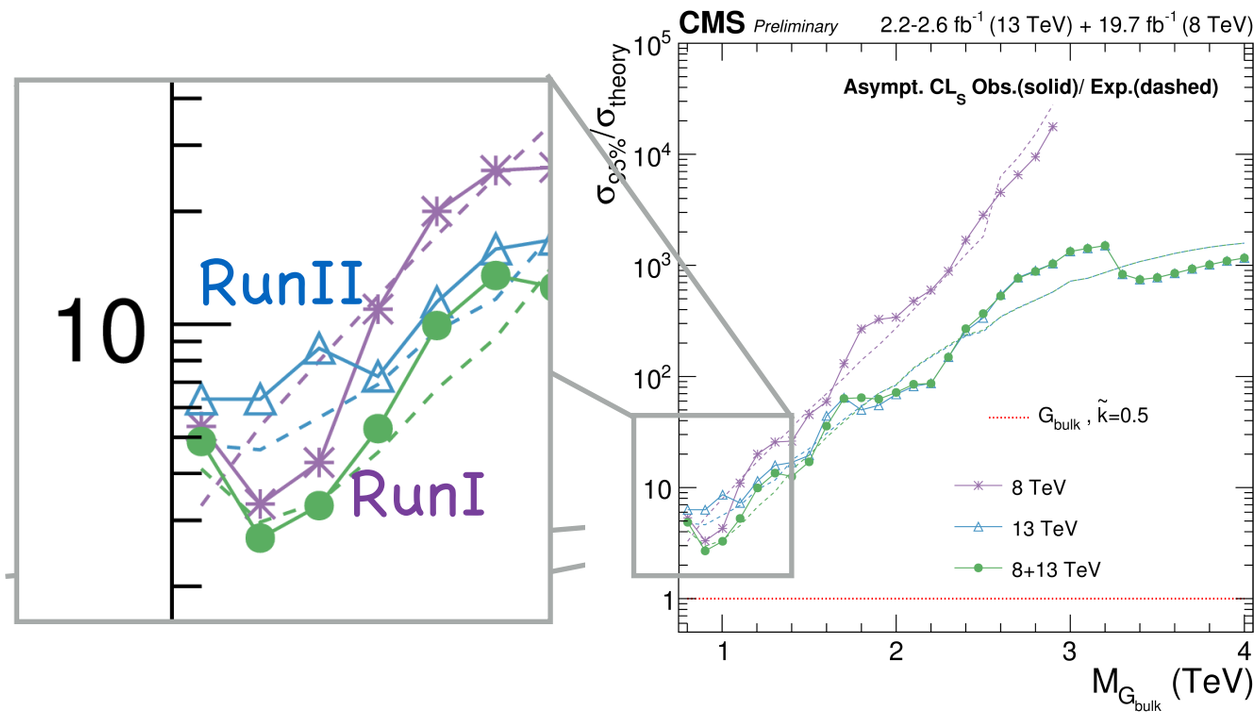


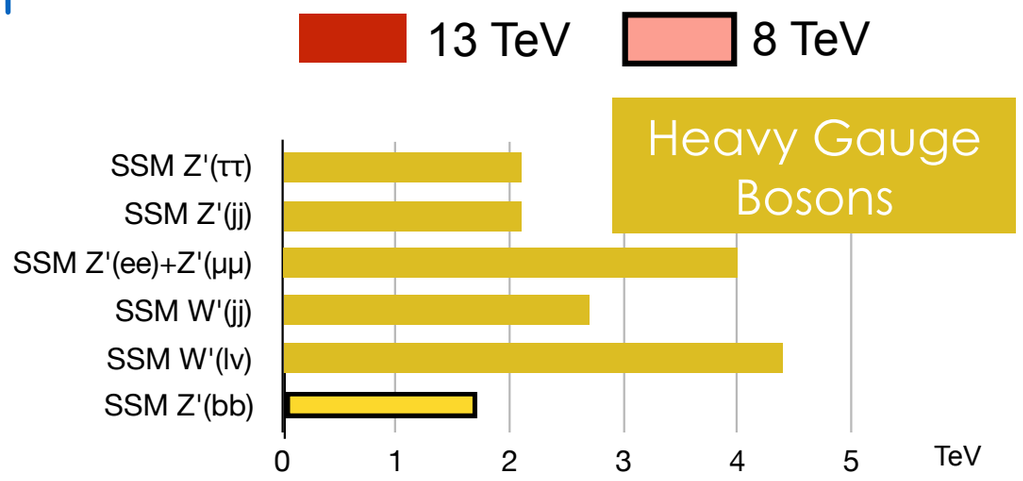


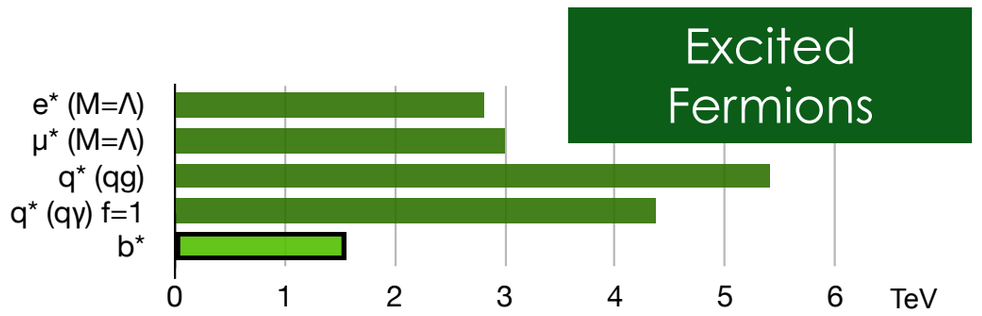
(*) since the signal shape depends on the mass, this is not as "model-independent" as it might sound

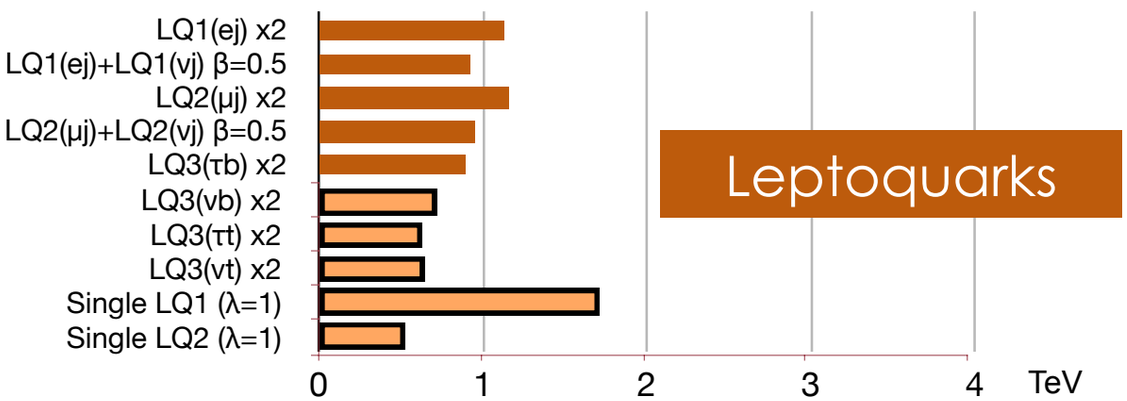
Resonance limits

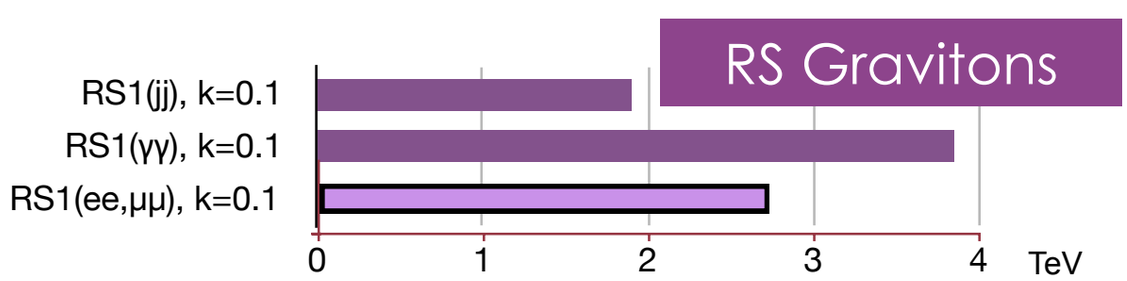
- Ongoing campaign to update all Run I results with Run II data
- Thanks to the higher energy, mass limits from Run II early superseded Run I results
- Energy gain depends on resonance mass
  - Only with 2016 data, Run II results improves Run I across the full mass range
- A complete picture will emerge by the Summer, wh 2016 data will be fully analyzed





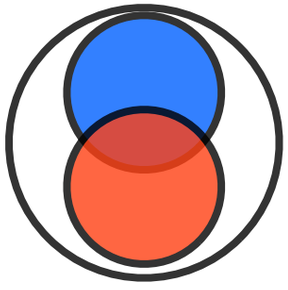






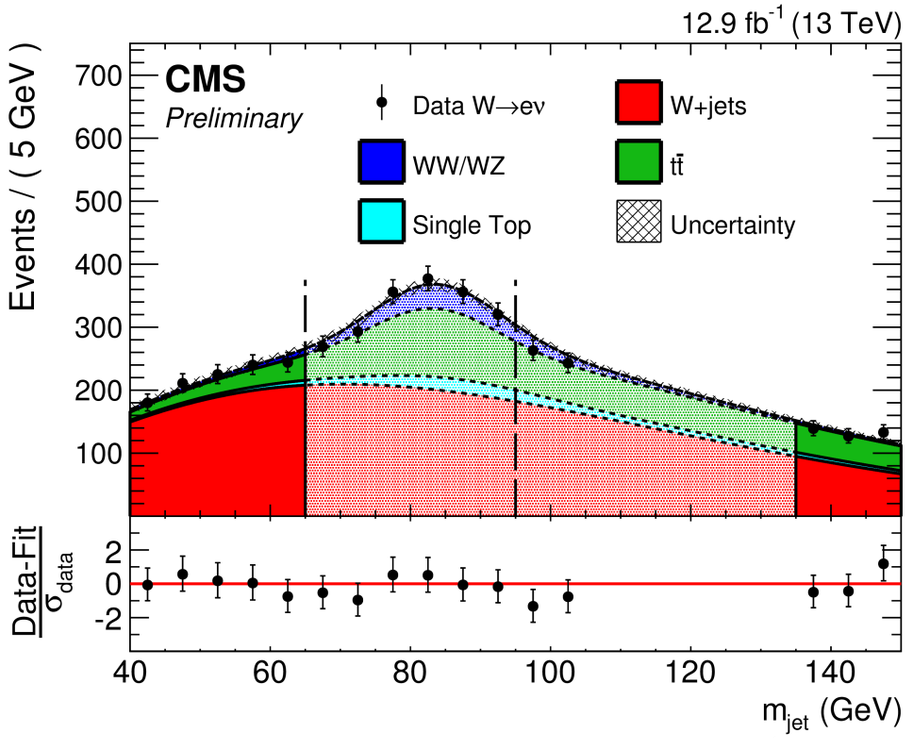
Boosted jets

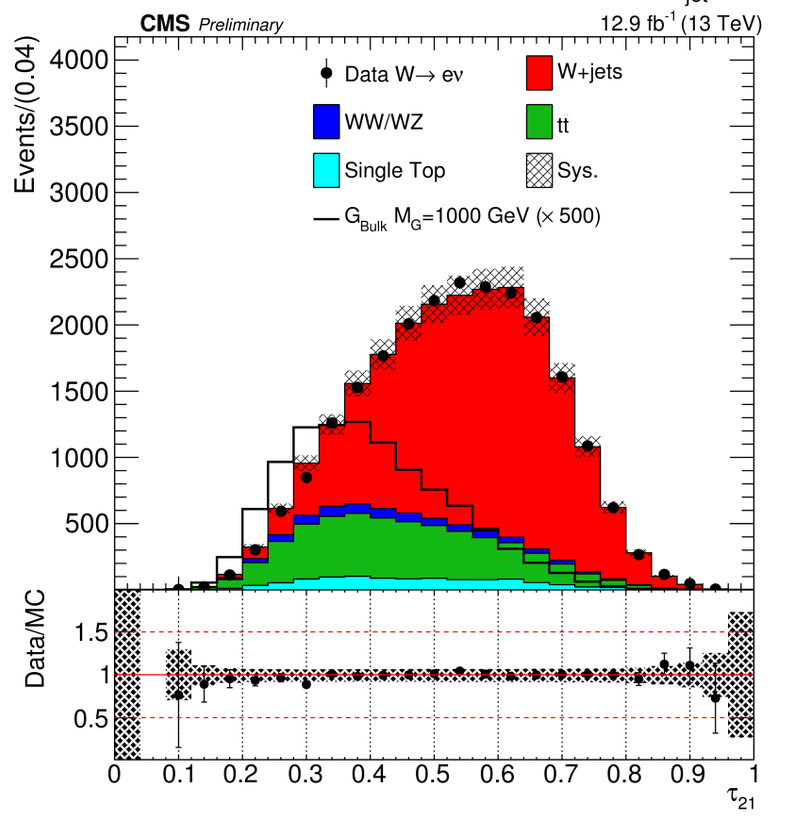
- Boosted-jet tagging was a major advance of Run I search program
  - Allowed to probe high-pT top/W/Z/H events with good efficiency (~50%) will reducing QCD bkg by a factor ~10
- Strategy customised on specific cases
  - 2-subjet: Boosted V→qq
  - 3-subjet: Boosted t→W(qq)q
  - 2-subjet + b-tagging: H→bb



- Procedure tested on boosted-top control samples with real data

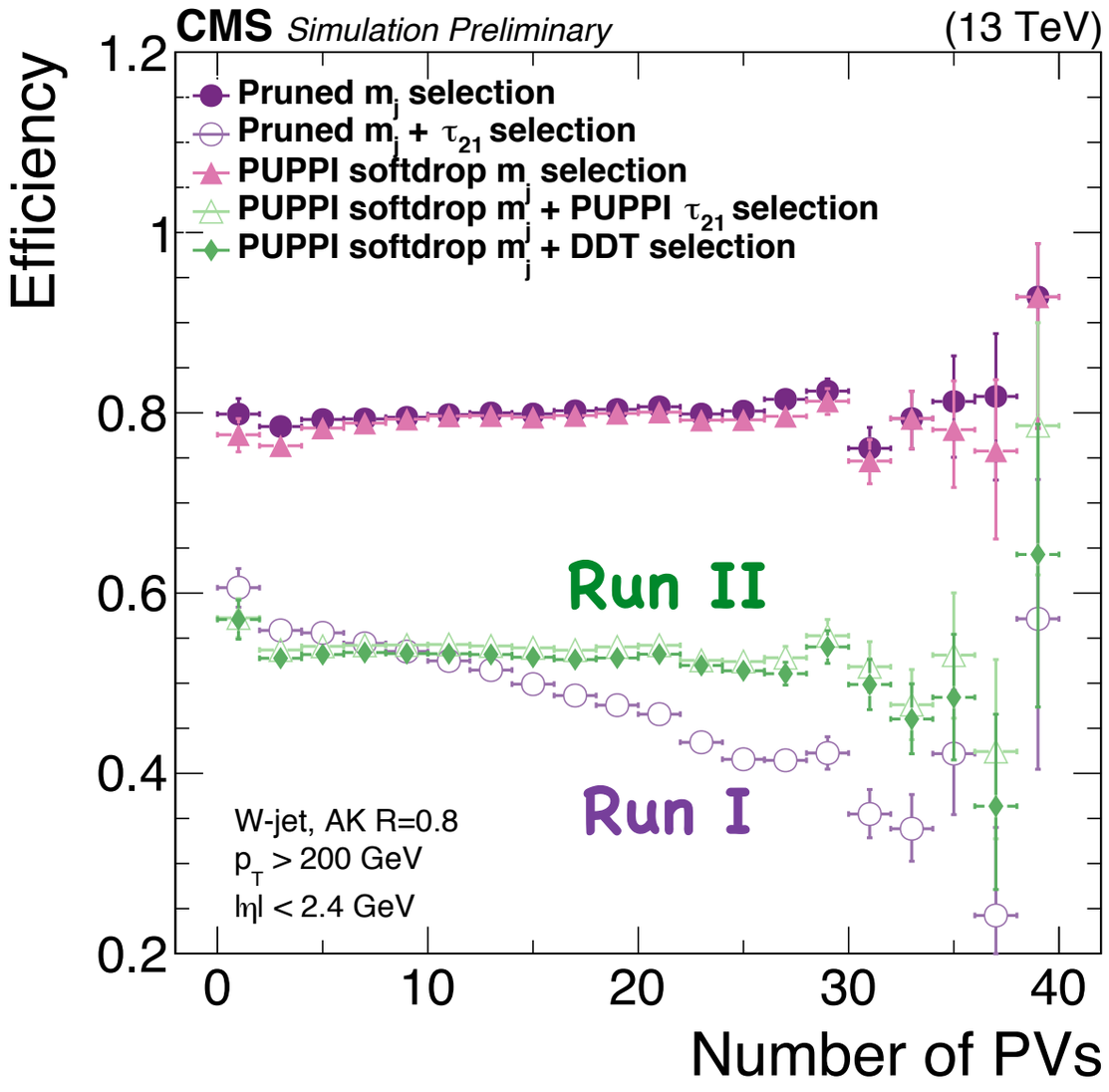
B2G-16-020

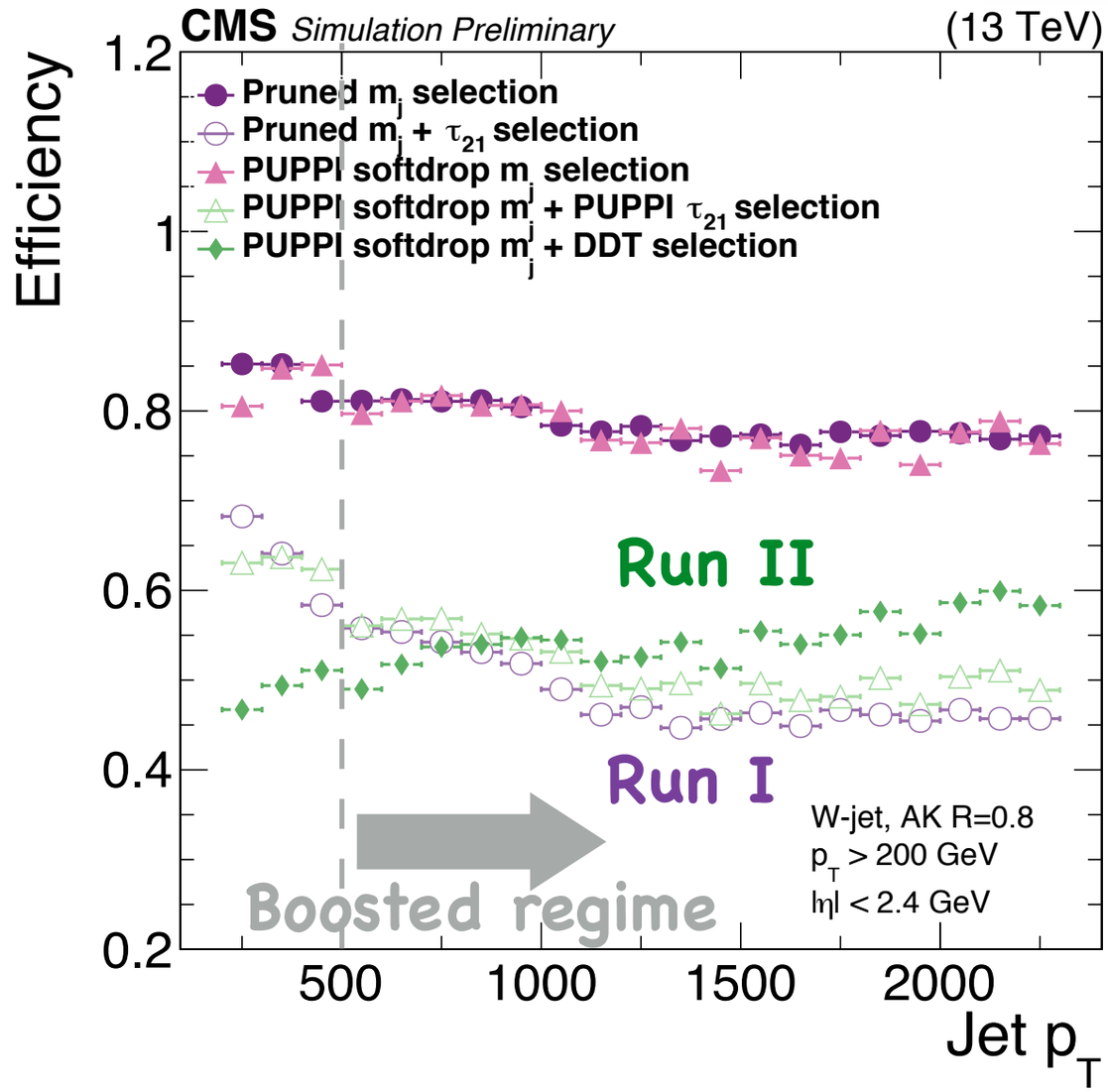




Boosted jets in Run II

- The larger PU contamination introduced dependencies of the Run I tagging strategy
- Taggers re-defined exploiting new PU removal (PUPPI) at best (e.g., moved to softdrop)



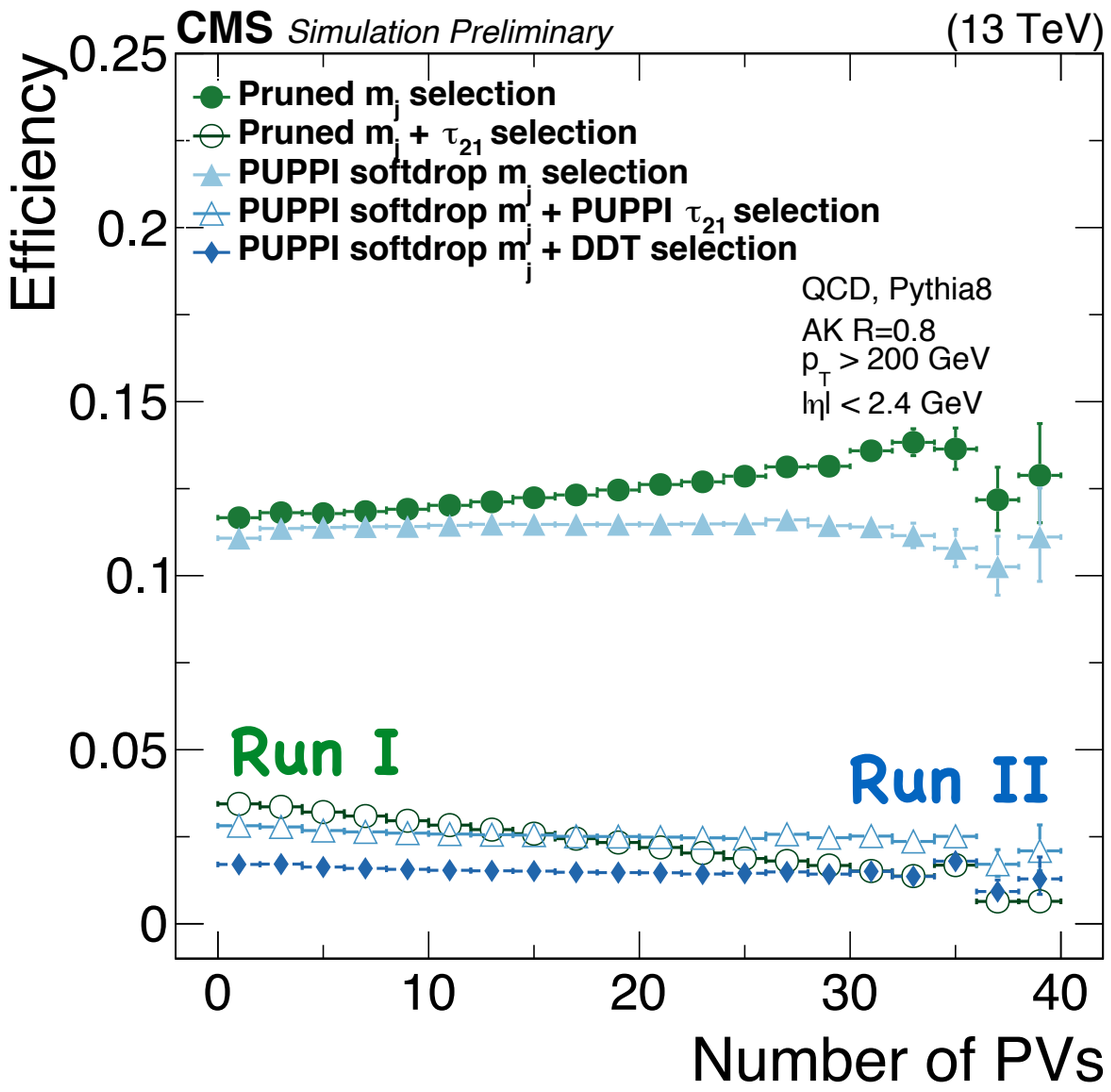


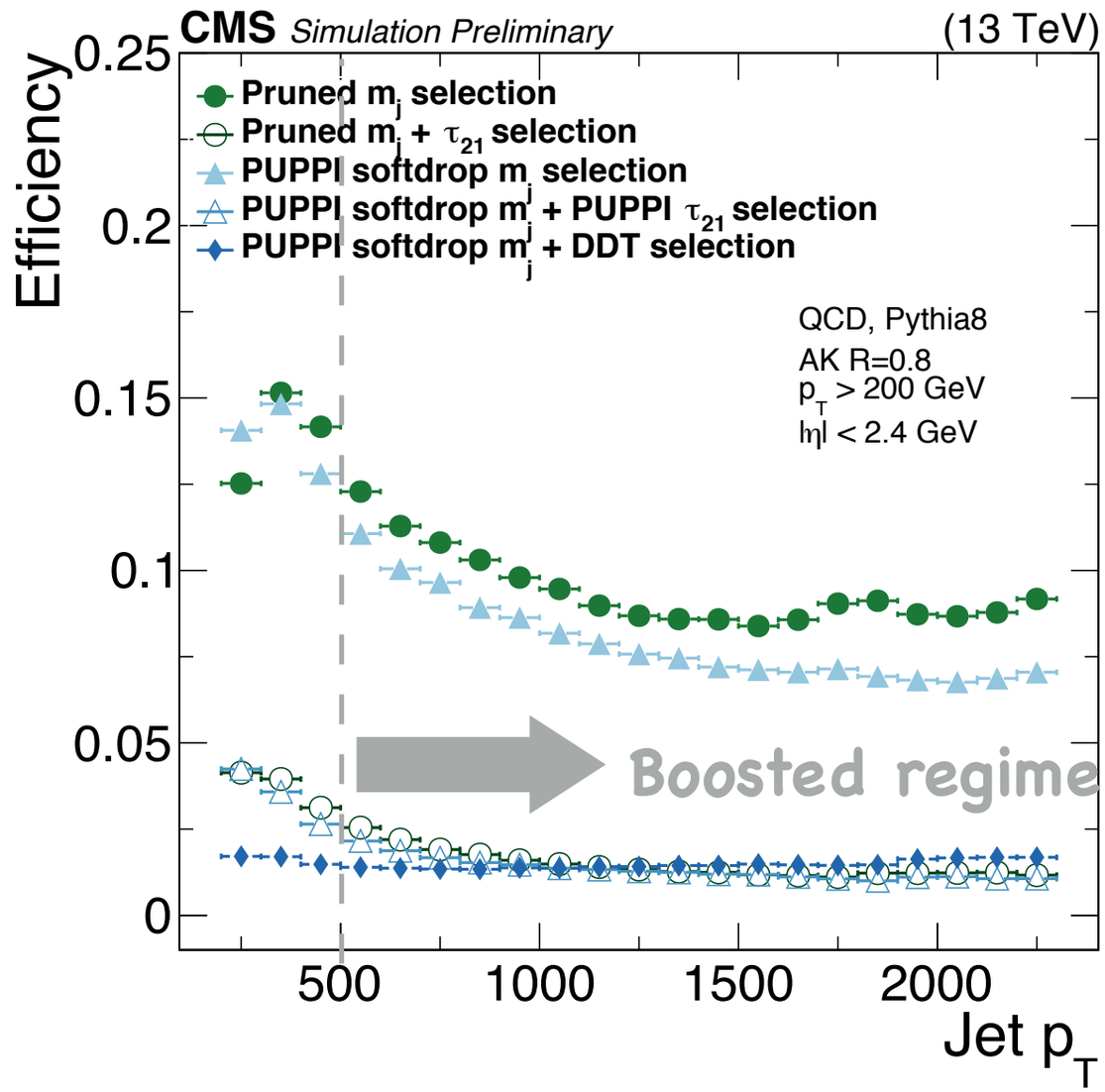
- Example: V tagging efficiency

DP-16-039

Boosted jets in Run II

- The larger PU contamination introduced dependencies of the Run I tagging strategy
- Taggers re-defined exploiting new PU removal (PUPPI) at best (e.g., moved to softdrop)





- Example: mistag rate of QCD jets as V-tagged jets

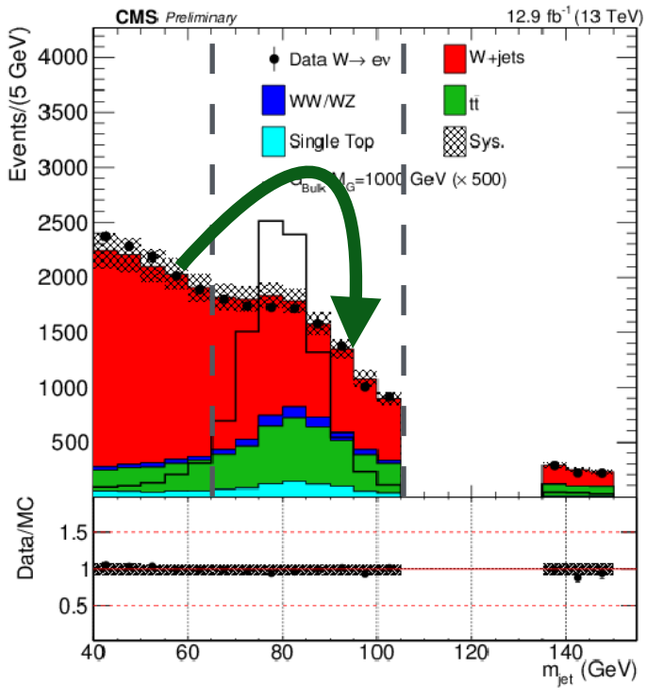
DP-16-039

Search Strategies

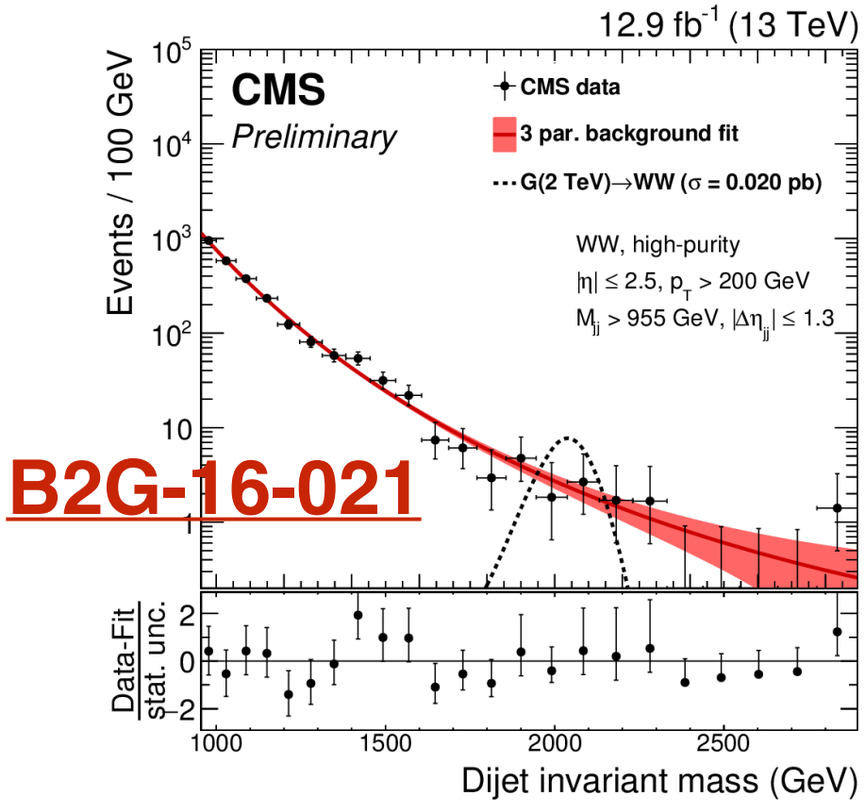
- Background fitted with ansatz function (as for dijet)

- Use MC-assisted data-driven technique: rescale bin-by-bin the mj sideband by MC ratio

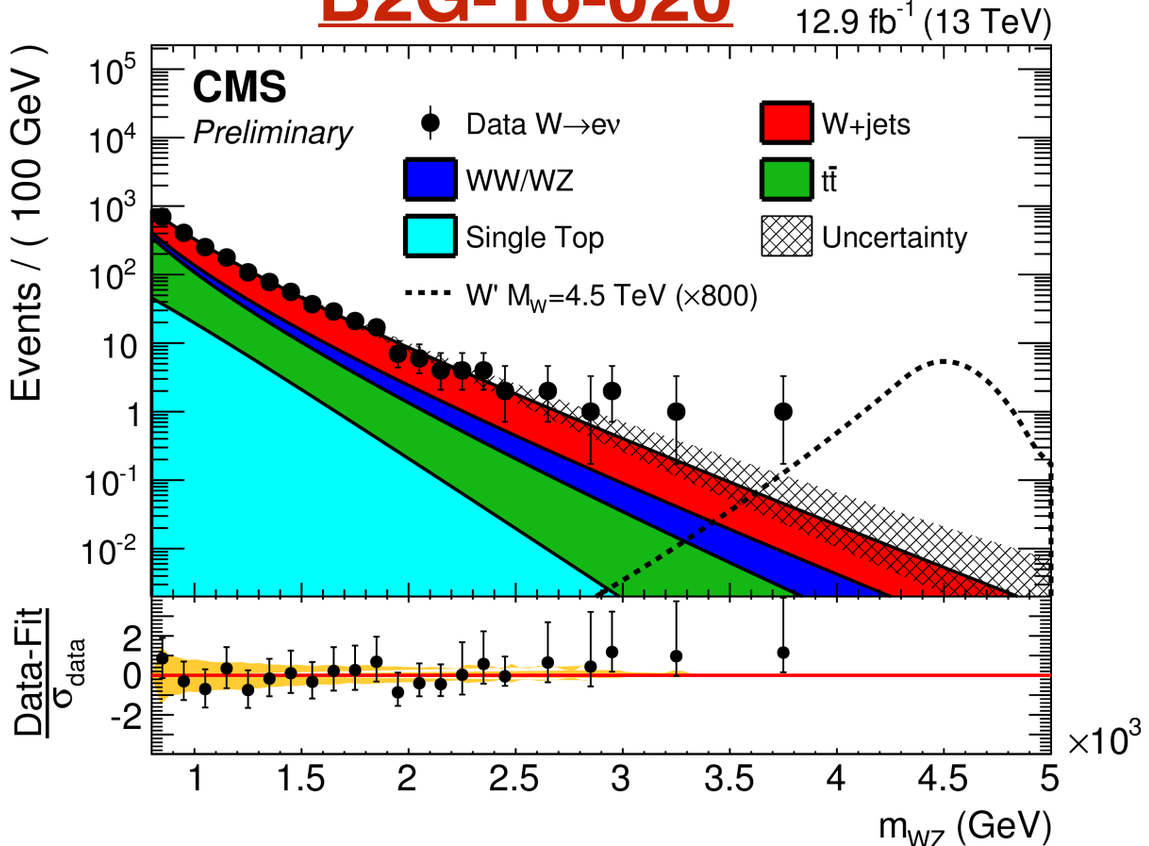
- When possible, both methods applied and compared (for cross validation)



B2G-16-021

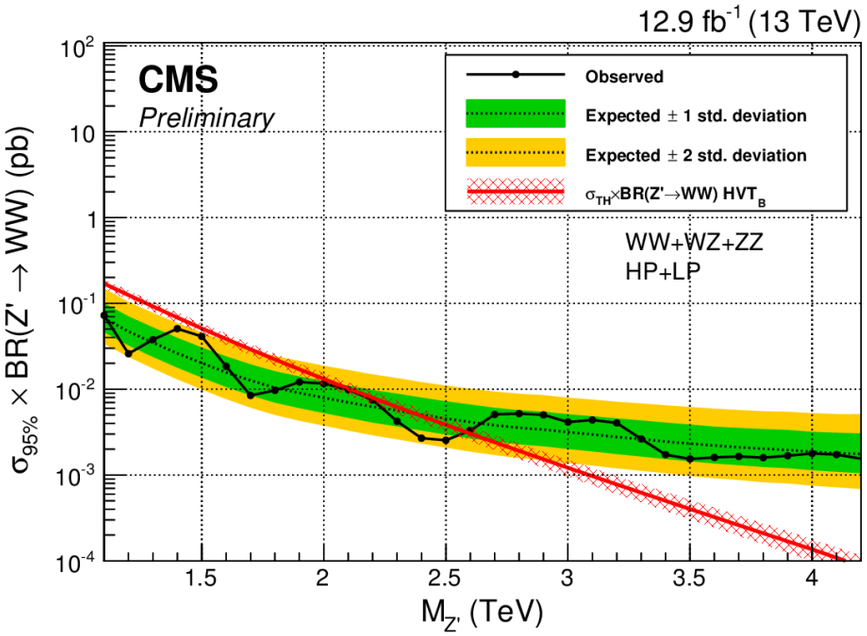


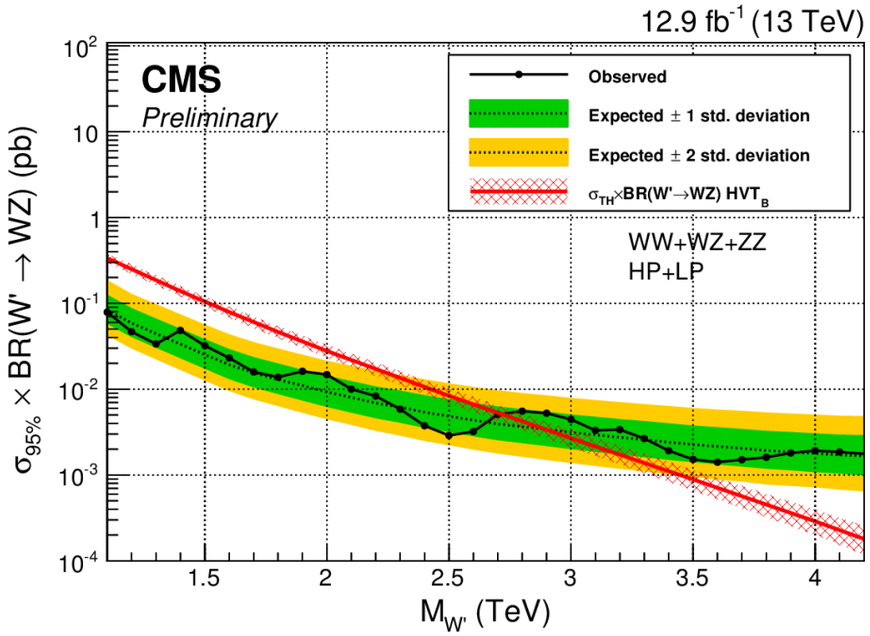
B2G-16-020

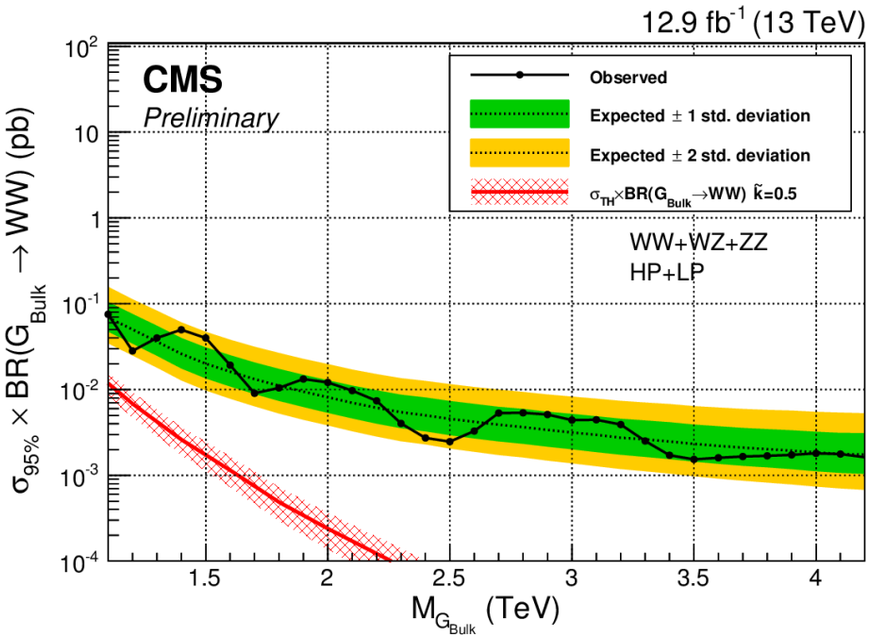


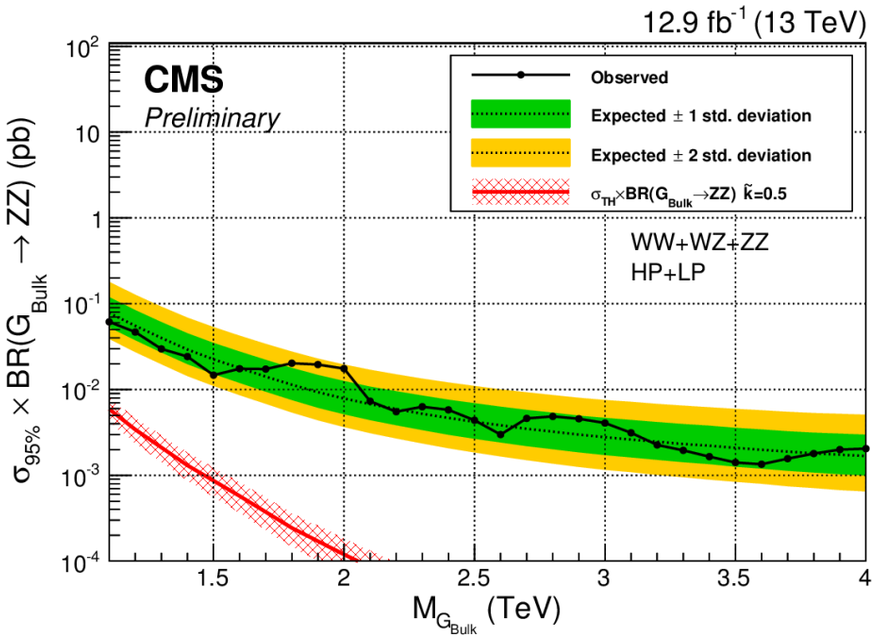
No signal seen yet

EXAMPLE: limits on HVT from fully-hadronic ZZ/ZW/WW search



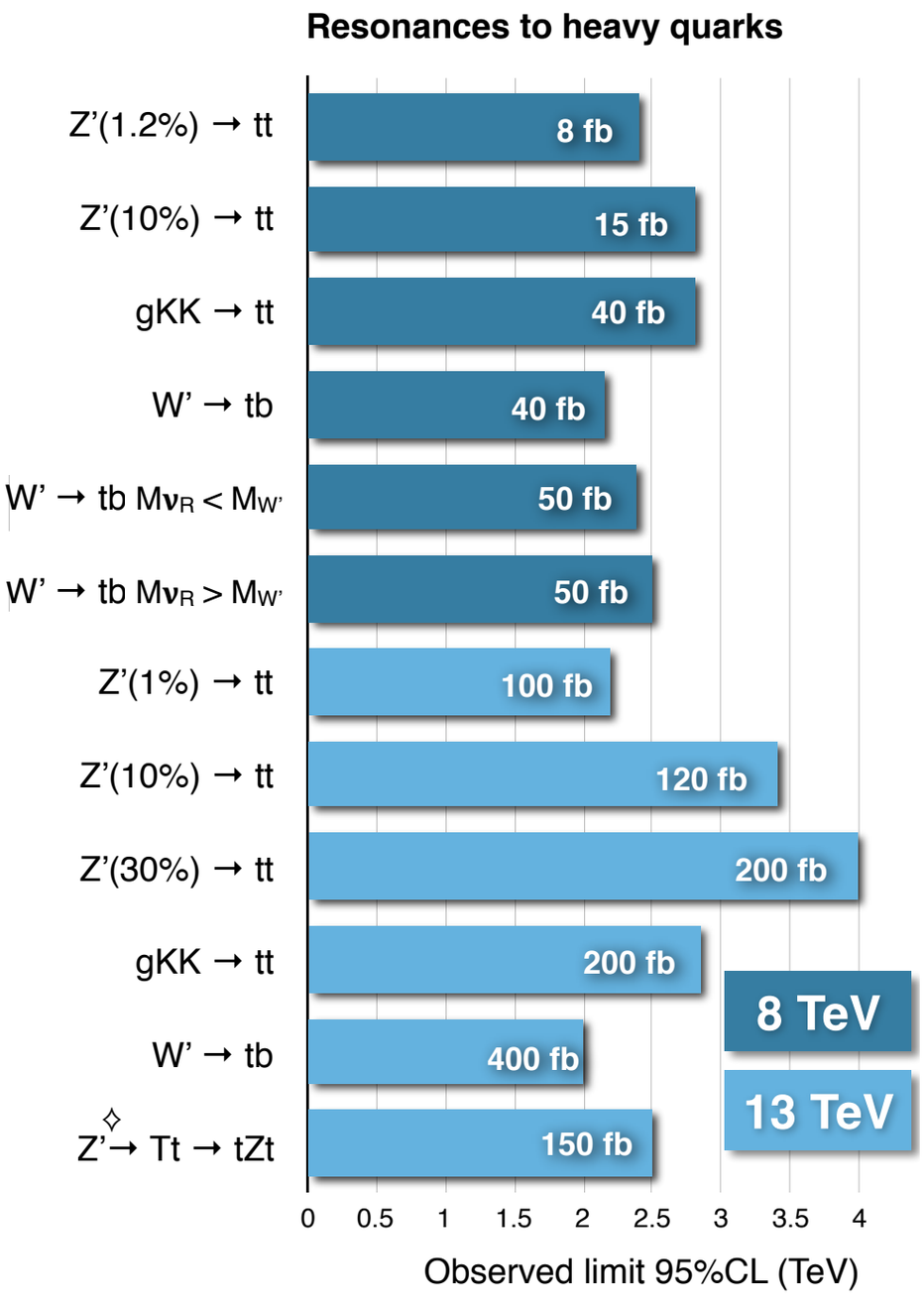


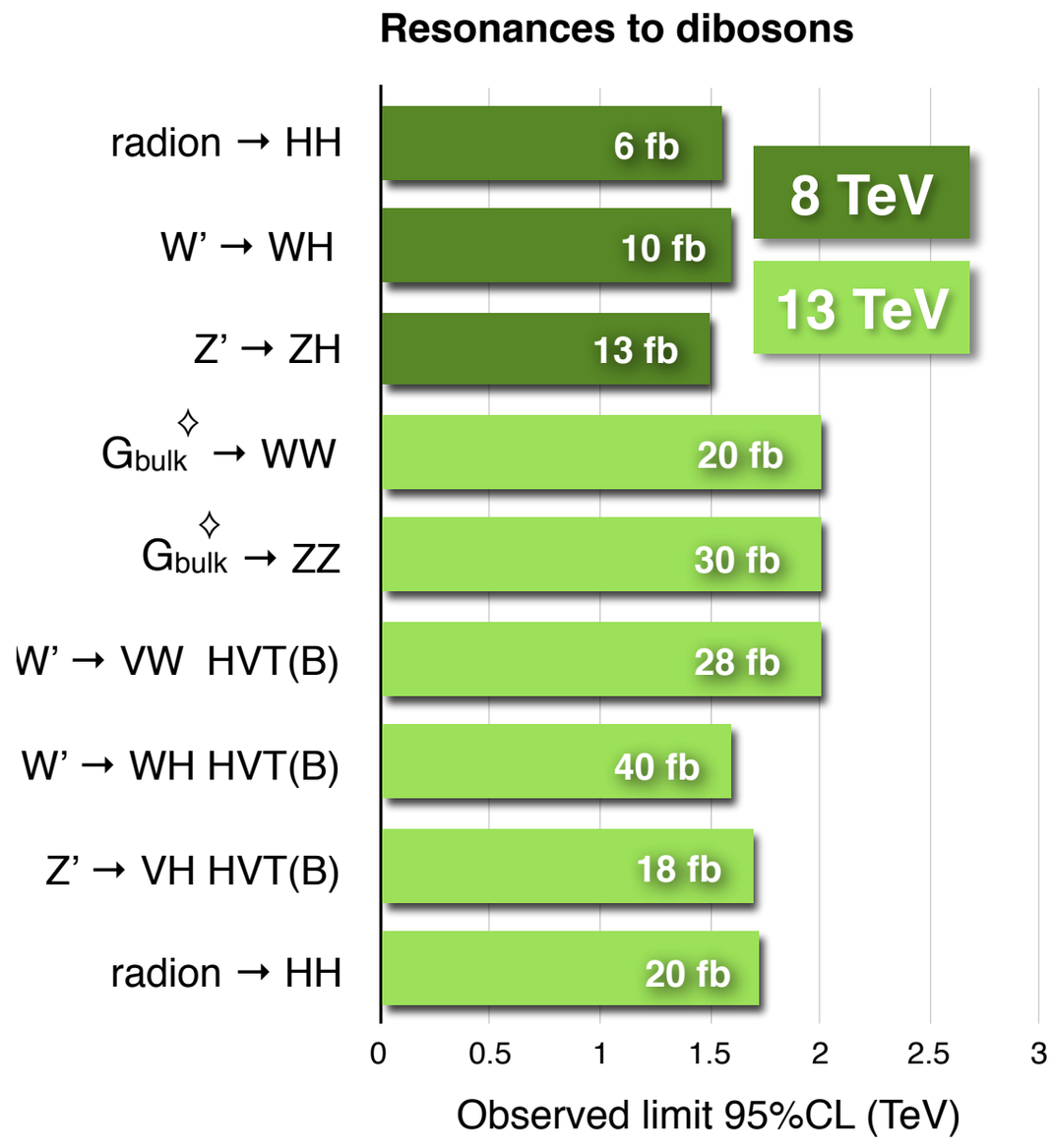




B2G-16-021

Mass limits reached 1 TeV overall



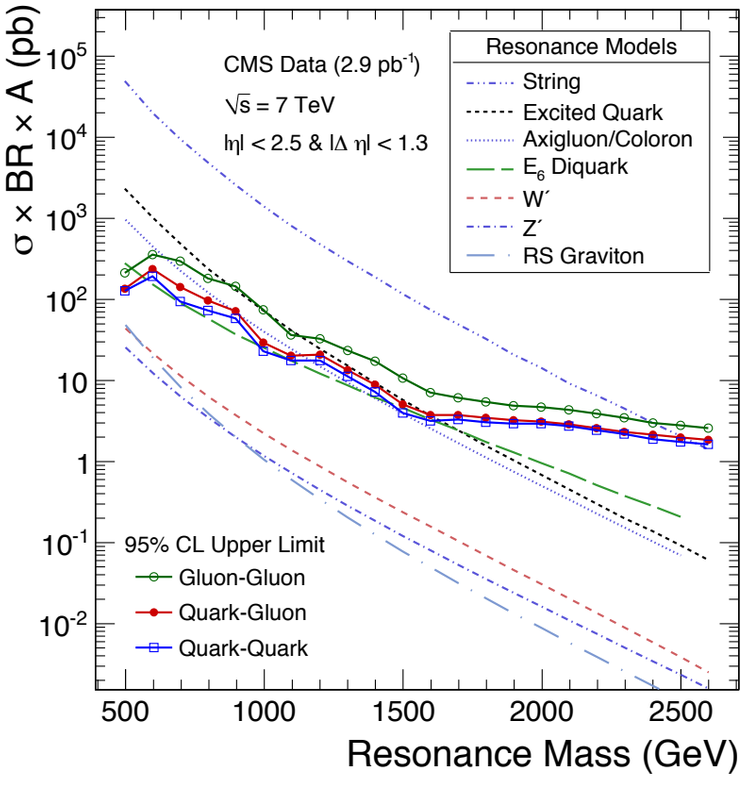


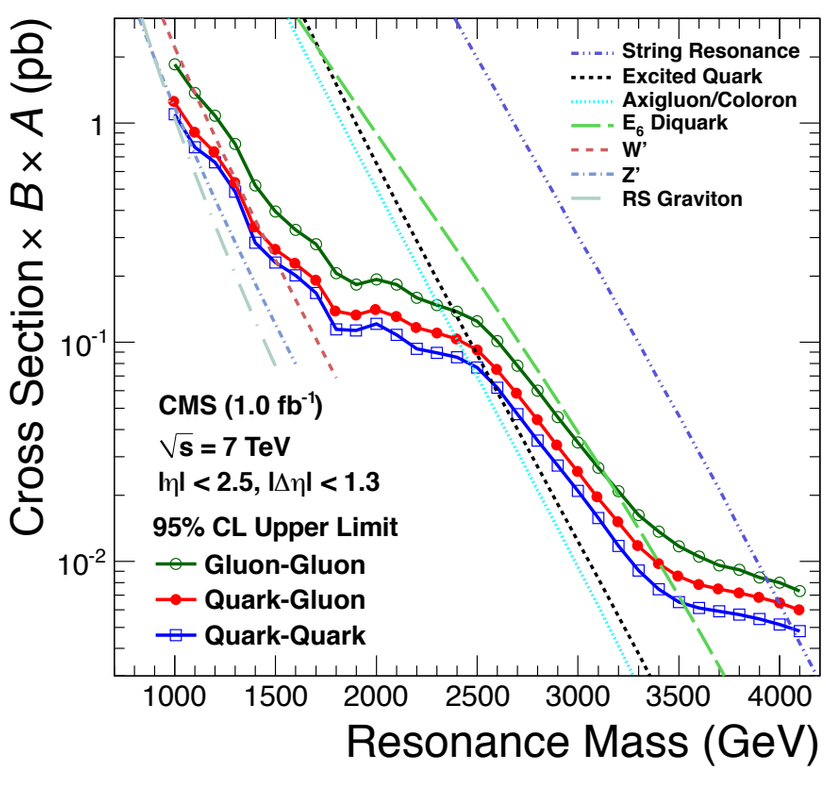
The low-mass challenge

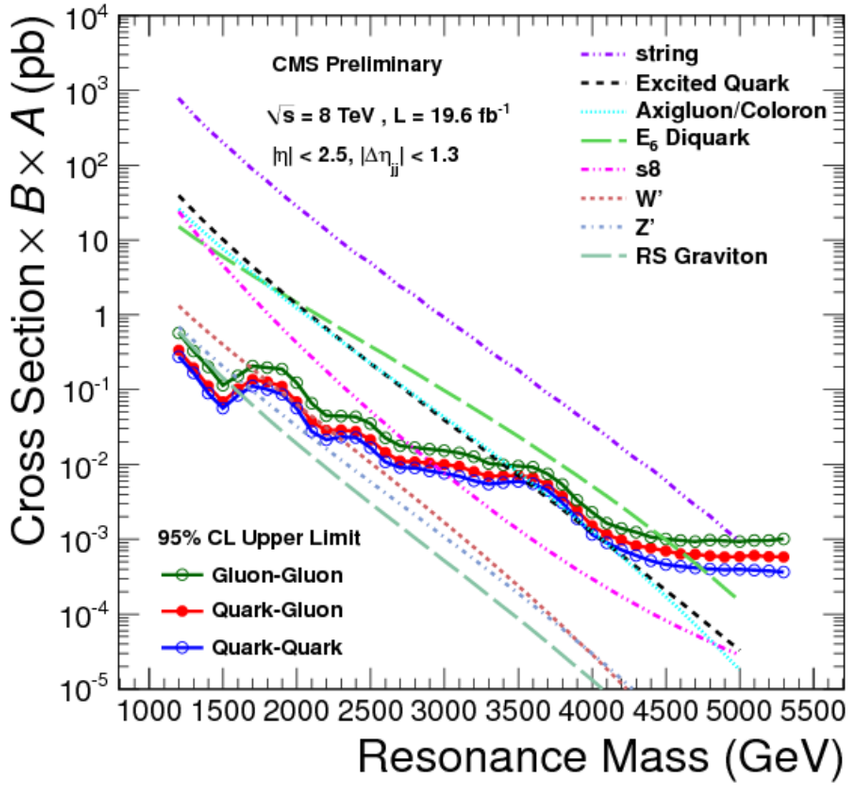
Blind spots

- With increasing luminosity, we are forced to apply tighter trigger requirements
- Sooner or later, trigger-thresholds increase becomes a problem (at least for fully-hadronic channels)
- Example: Dijet resonance search in Run I

$3\,pb^{-1}$ 7TeV	$1\,fb^{-1}$ 7TeV	$20\,fb^{-1}$ 8TeV

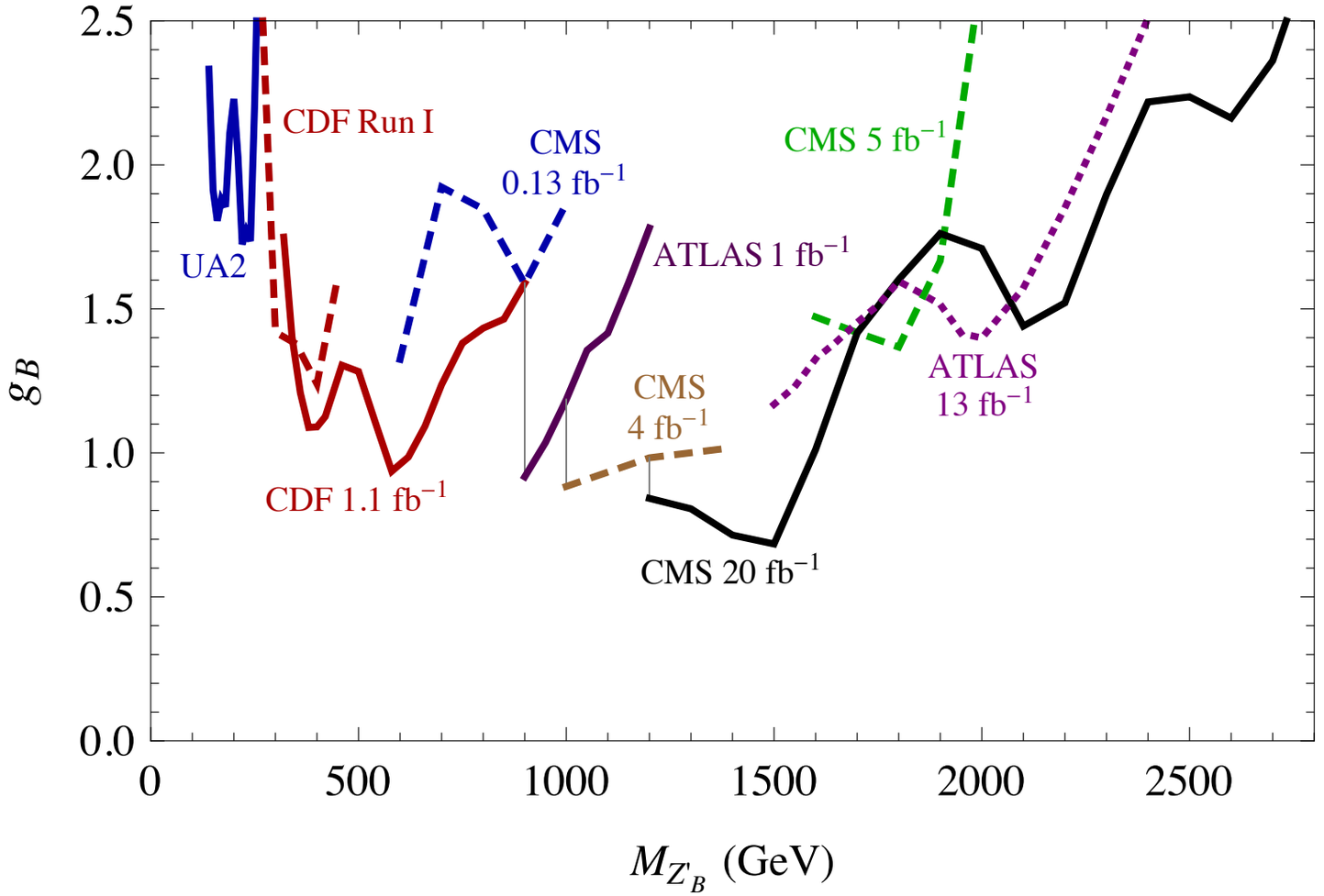




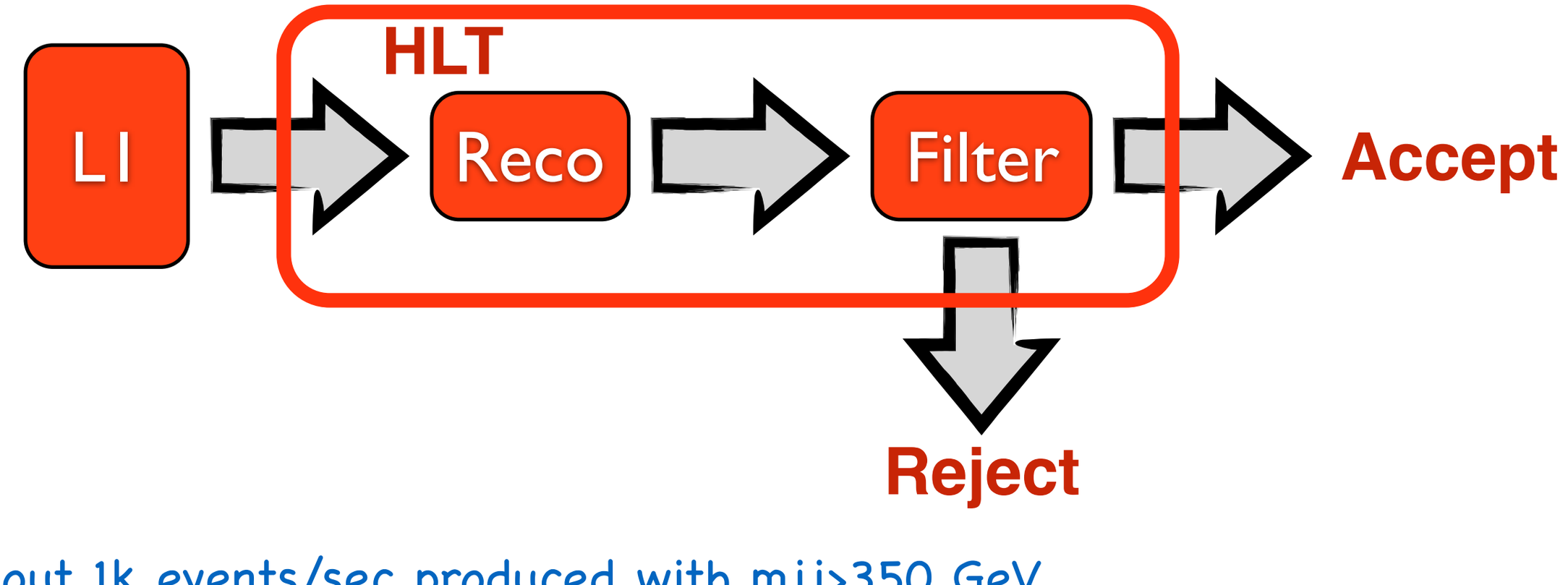


Blind spots

- With increasing luminosity, we are forced to apply tighter trigger requirements
- Sooner or later, trigger-thresholds increase becomes a problem (at least for fully-hadronic channels)
- Example: Dijet resonance search in Run I

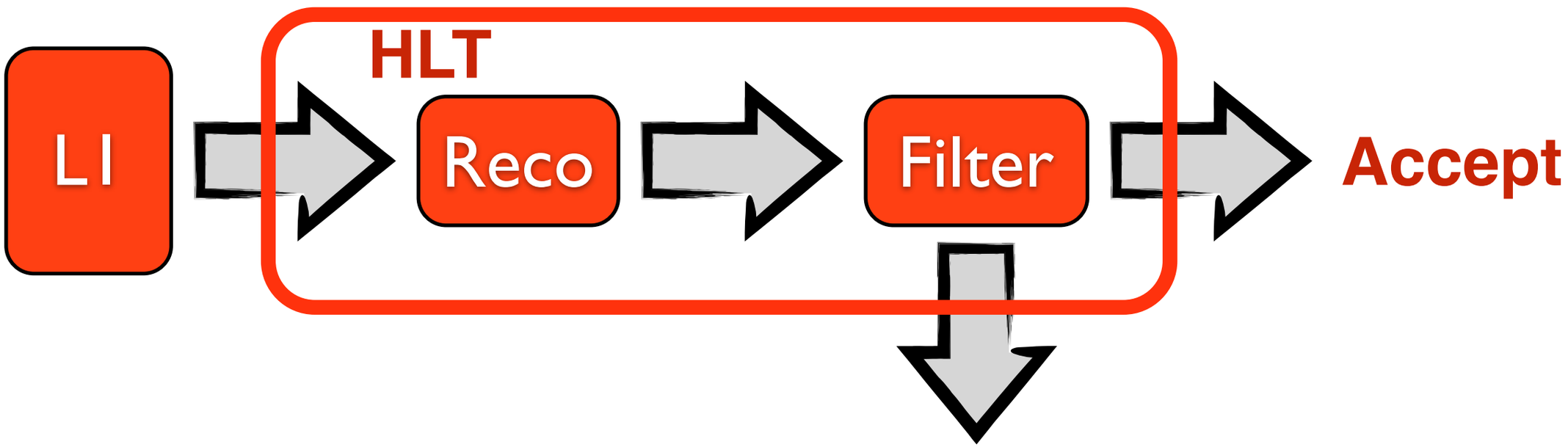


Limited Bandwidth



- About 1k events/sec produced with mjj>350 GeV
- The full CMS program runs with a bandwidth budget of 1kHz
- About 40 Hz dedicated to this analysis. We cannot keep everything
- The moment we drop the event, we know a lot about it (e.g., jet momenta) with a coarser precision than offline (faster reconstruction →less precise reconstruction)

Data Scouting

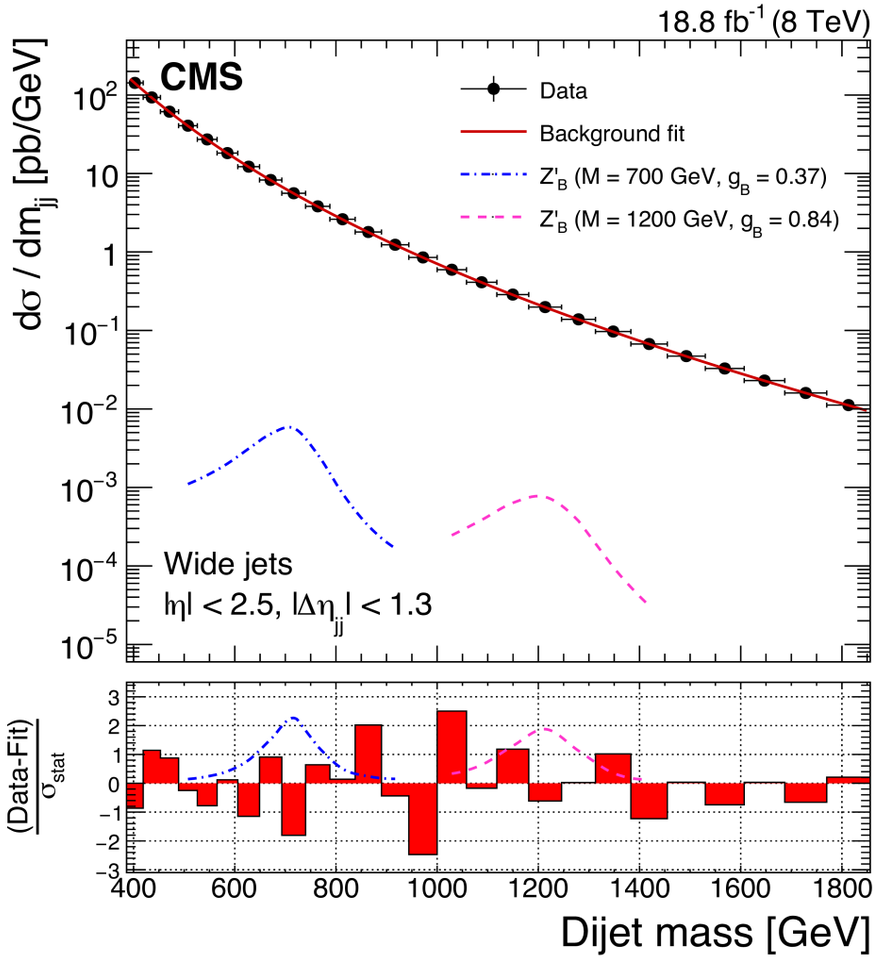


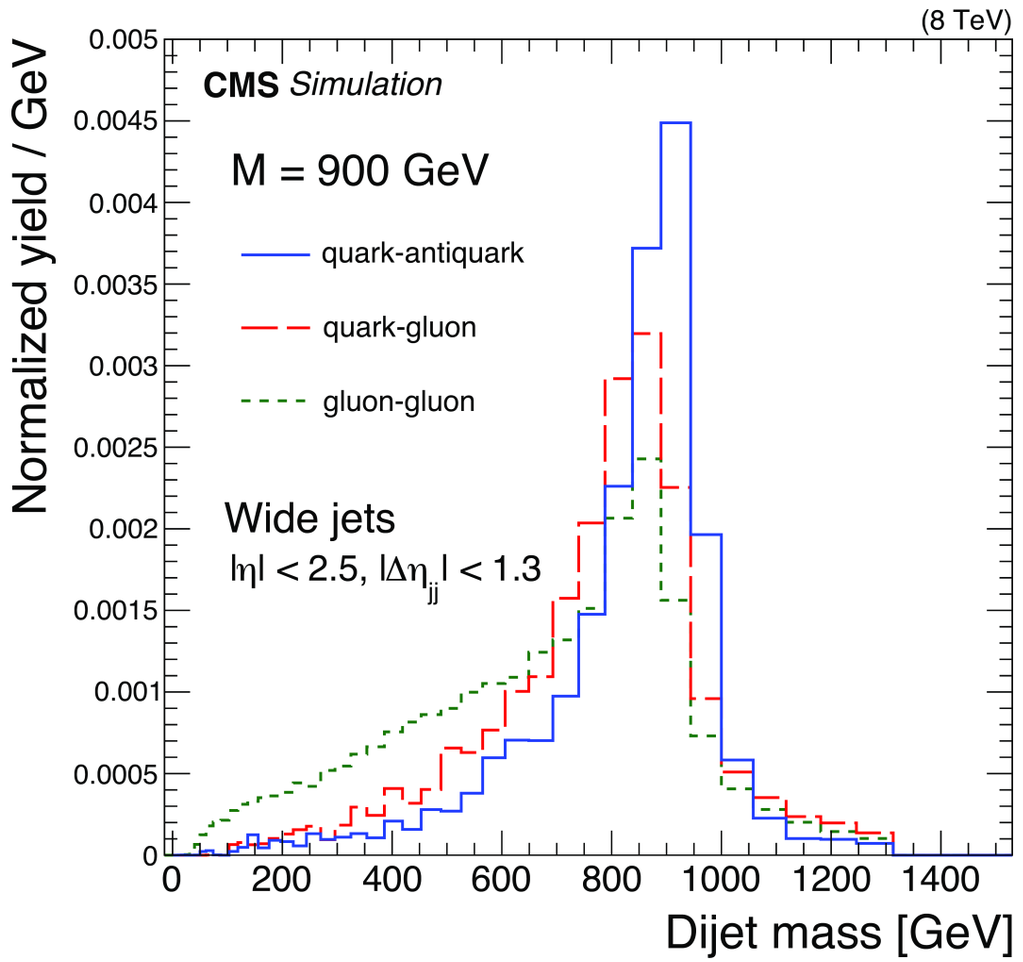
scouting: save 4momenta of jets@HLT

- Instead of dropping events, save limited information (jet 4-mom)
- ~5 kB/evt rather than ~500 kB/evt
- @ 1 kHz, take same disk/evt than ordinary 10 Hz
- PRO: can go beyond the trigger/processing limitations
- CON: limited info in case debug is needed (e.g., no event display)

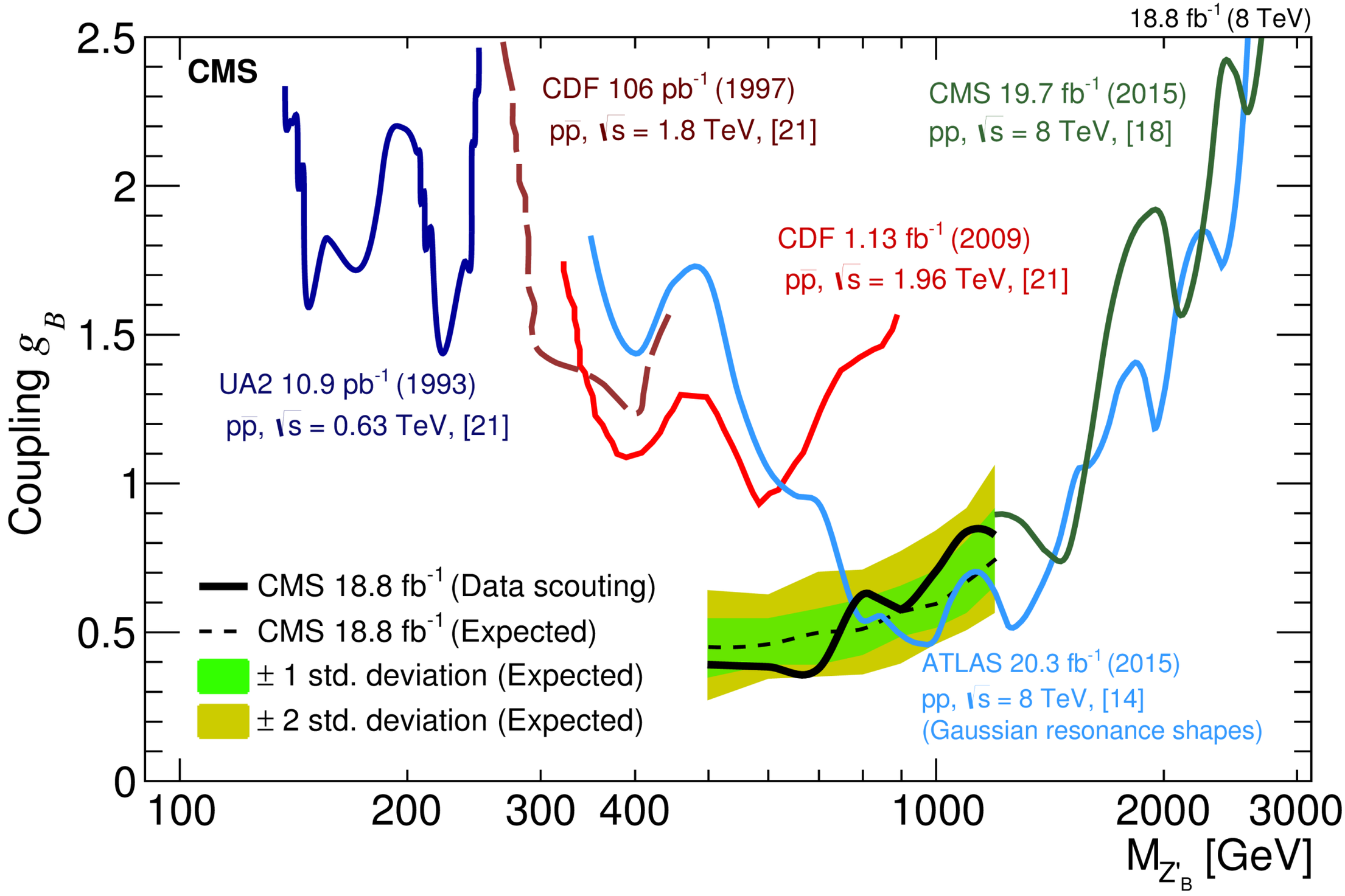
Dijet search with scouting data

- Build the dijet invariant mass from online-reconstructed jets
  - correct for jet energy as measured offline + online/offline correction (turned out to be negligible)
  - Signal shape very close to offline
- Run the same analysis as the "classic" dijet (fit, exclusion, mass limits)



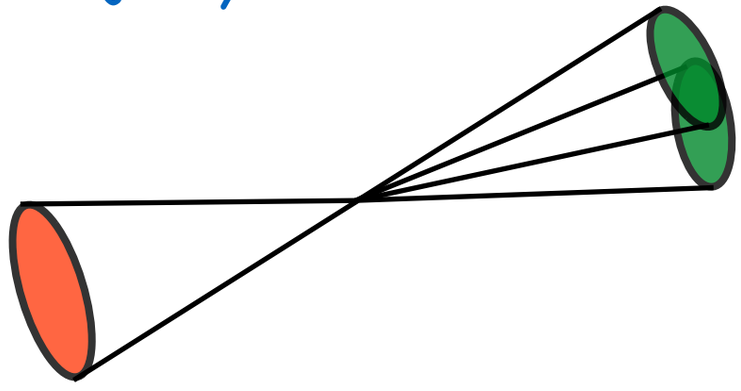


Dijet search with scouting data

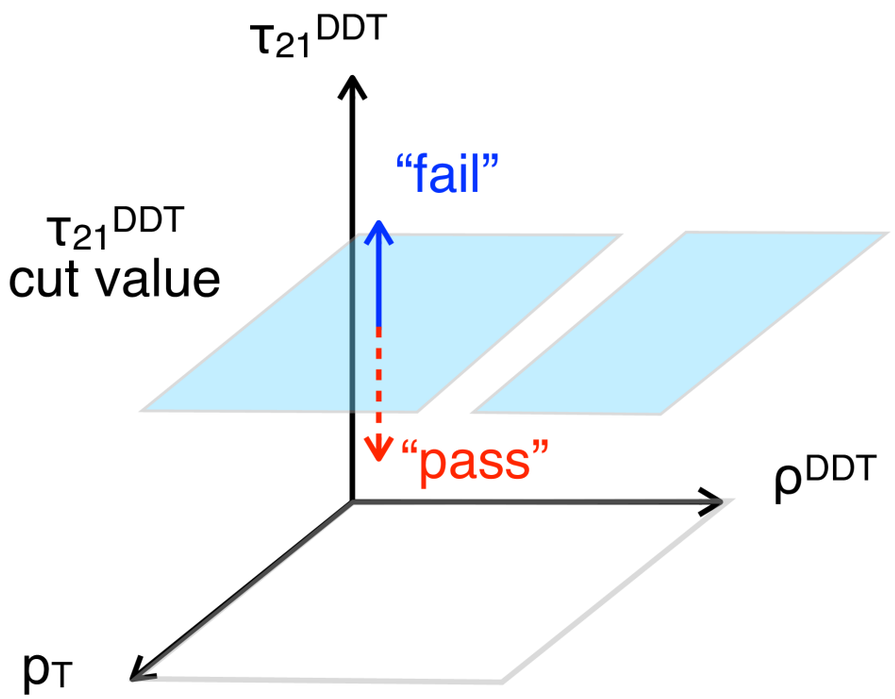


The other way: ISR tag

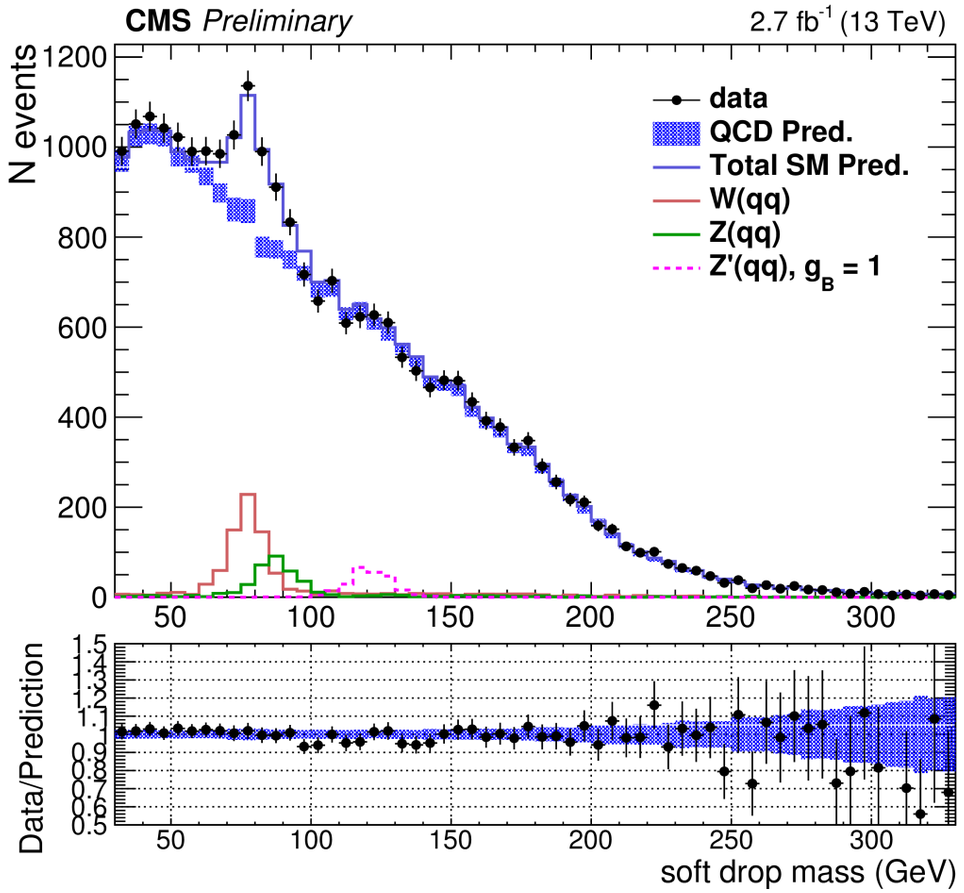
- For every pp-> X you cannot trigger on, there is a pp-> X+jet you could look for
  - For high-enough jet pT events become accessible
  - This has a cost in data size (effective prescale)
  - Topology change (the **X system** is boosted, recoiling against the **ISR jet**)



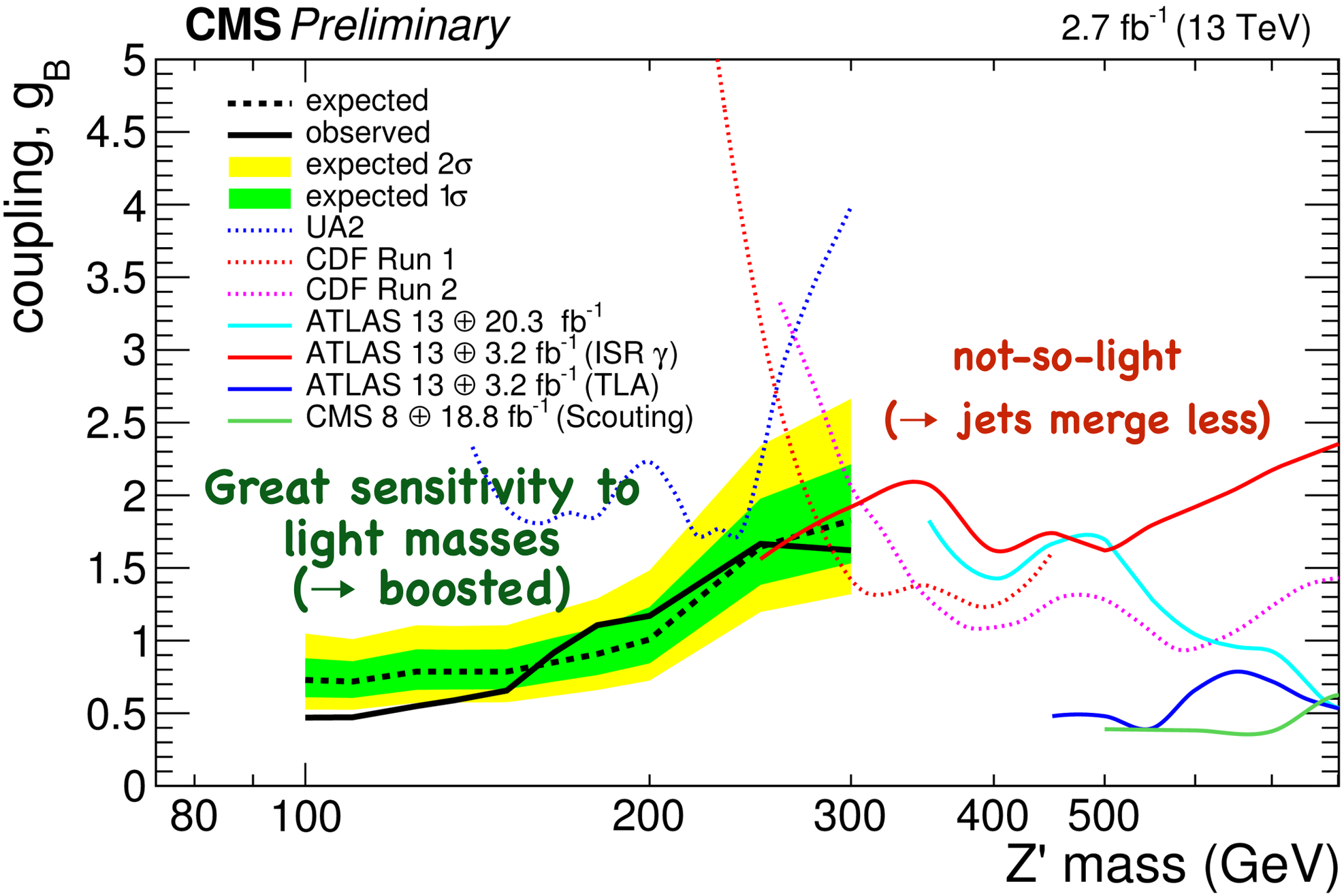
- Example: CMS ISR dijet search -> search for massive single jet in dijet events



EXO-16-030



The other way: ISR tag

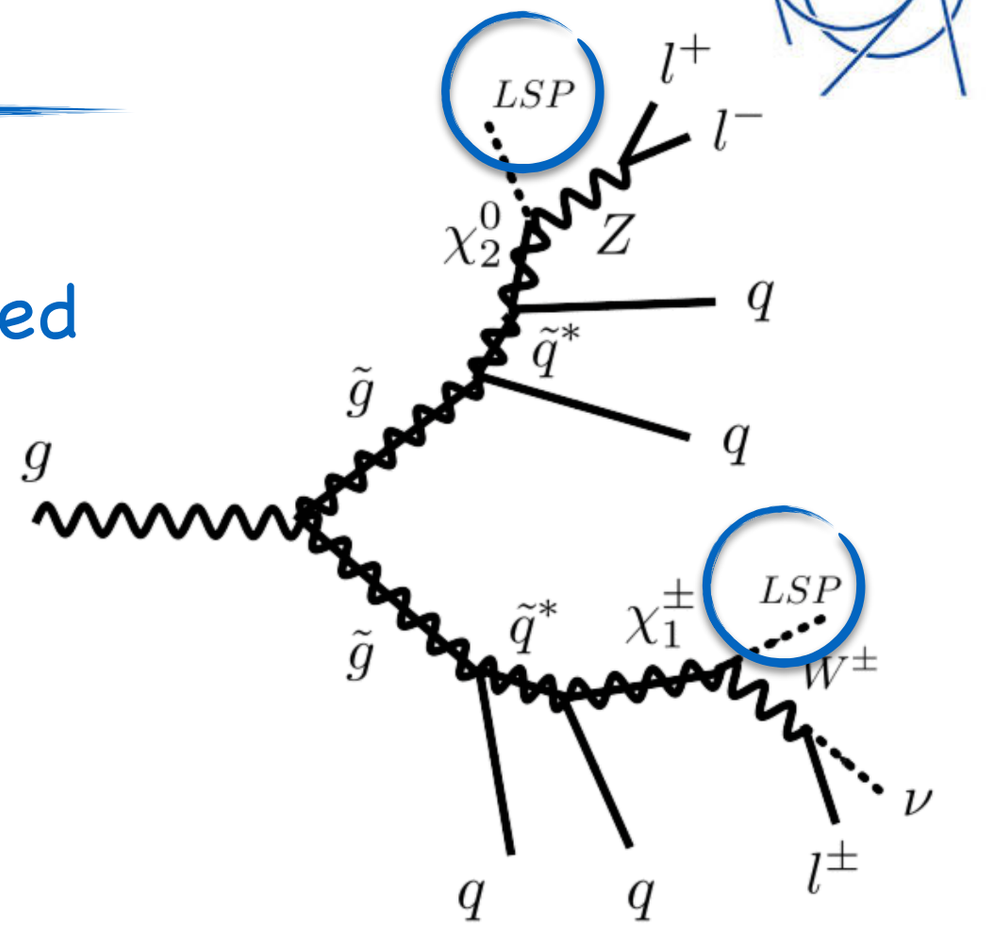


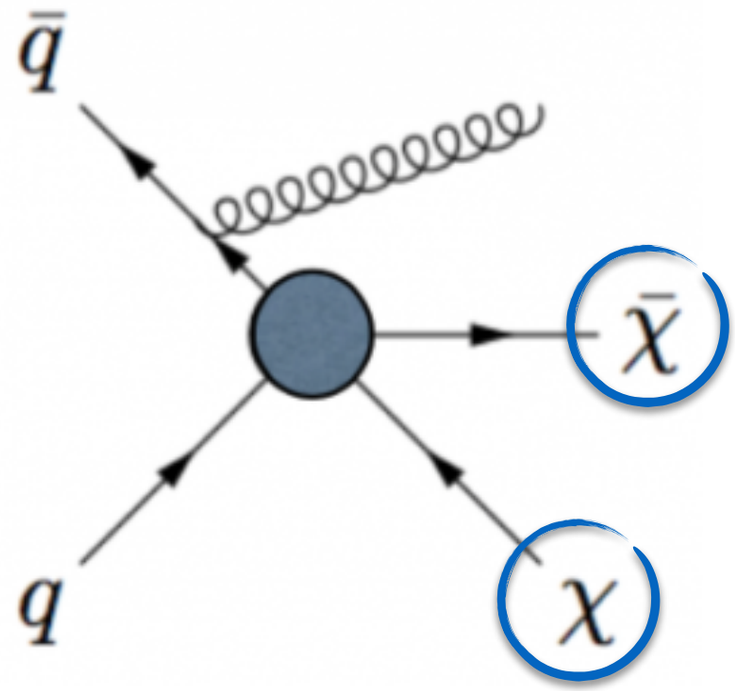
EXO-16-030

Search for invisible particles

General strategy

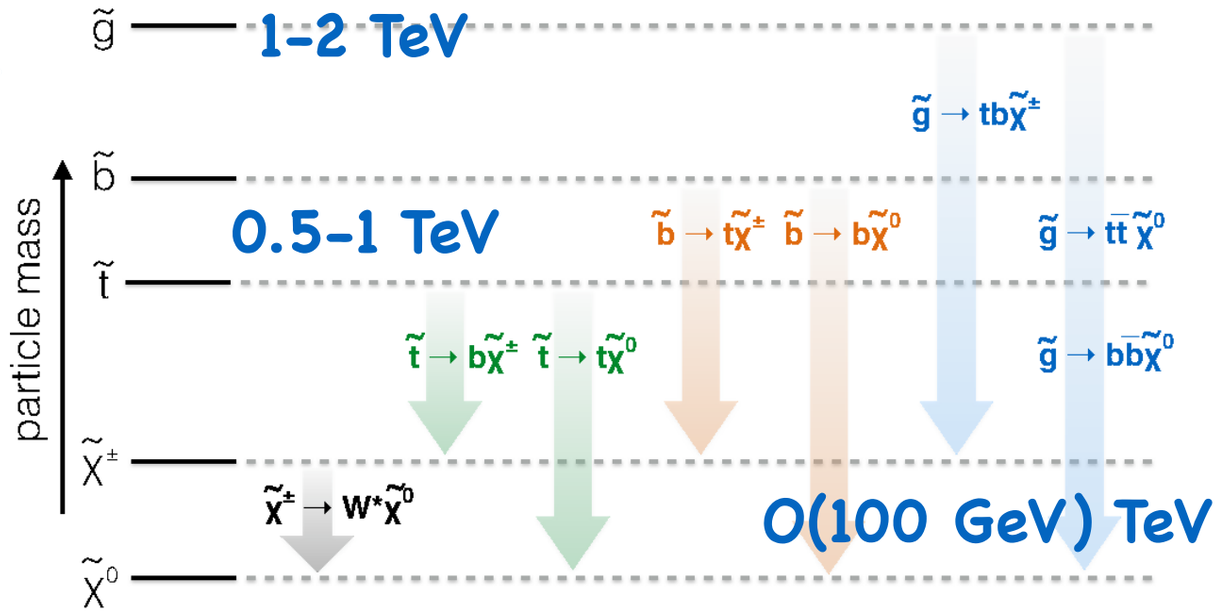
- Invisible massive particles could be produced @LHC, resulting into unbalanced events
  - Theory proxy: Dark Matter as a fundamental particle
- Two strategies in place:
  - DM pair-production from **cascade decays** of heavier partners (aka SUSY)
  - DM pair-production, through some (on-shell) **mediator** (Z, H, new scalar, new vector, ...) + radiation of something

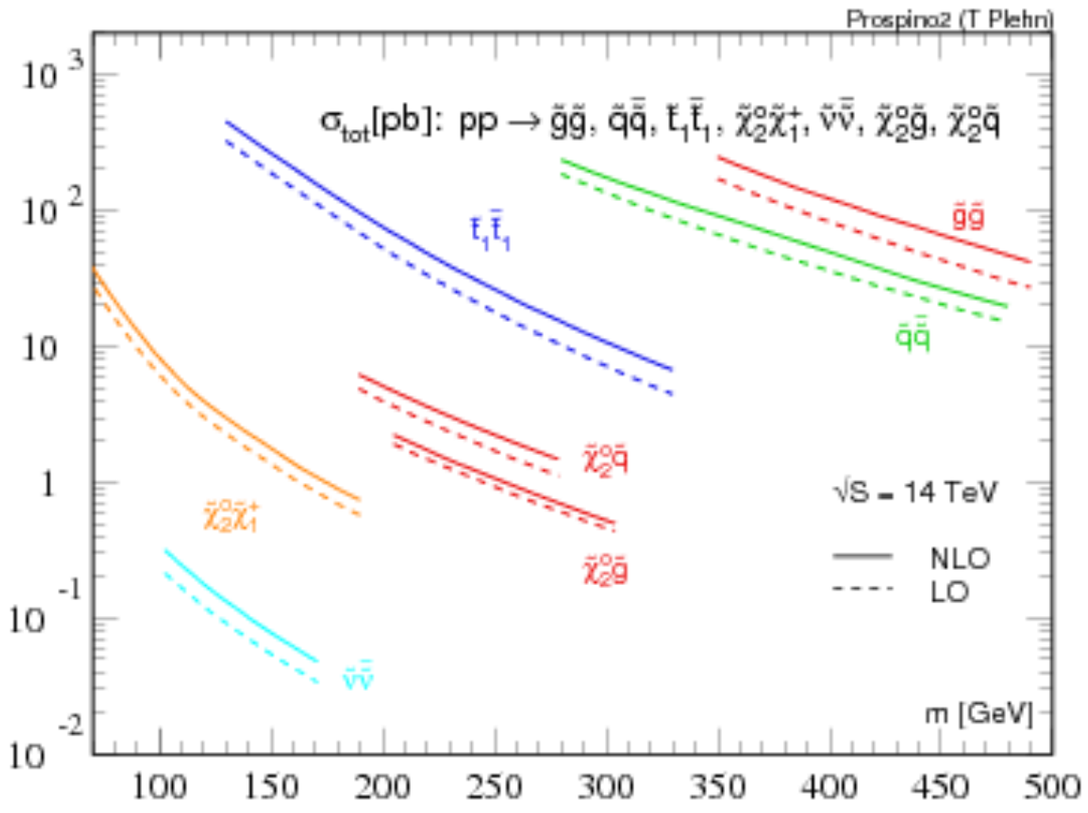




The Natural SUSY paradigm

- Run I searches left us with a "minimal natural SUSY spectrum
- Three classes of analyses
  - gluino production: large xsec for multi-body final states with b-jets
  - squark production: moderate xsec for tt/tb/bb+MET
  - ewkinos: small xsec for diboson+MET
- Mixed processes not explicitely explored (just a matter of interpretation, to a large extent)

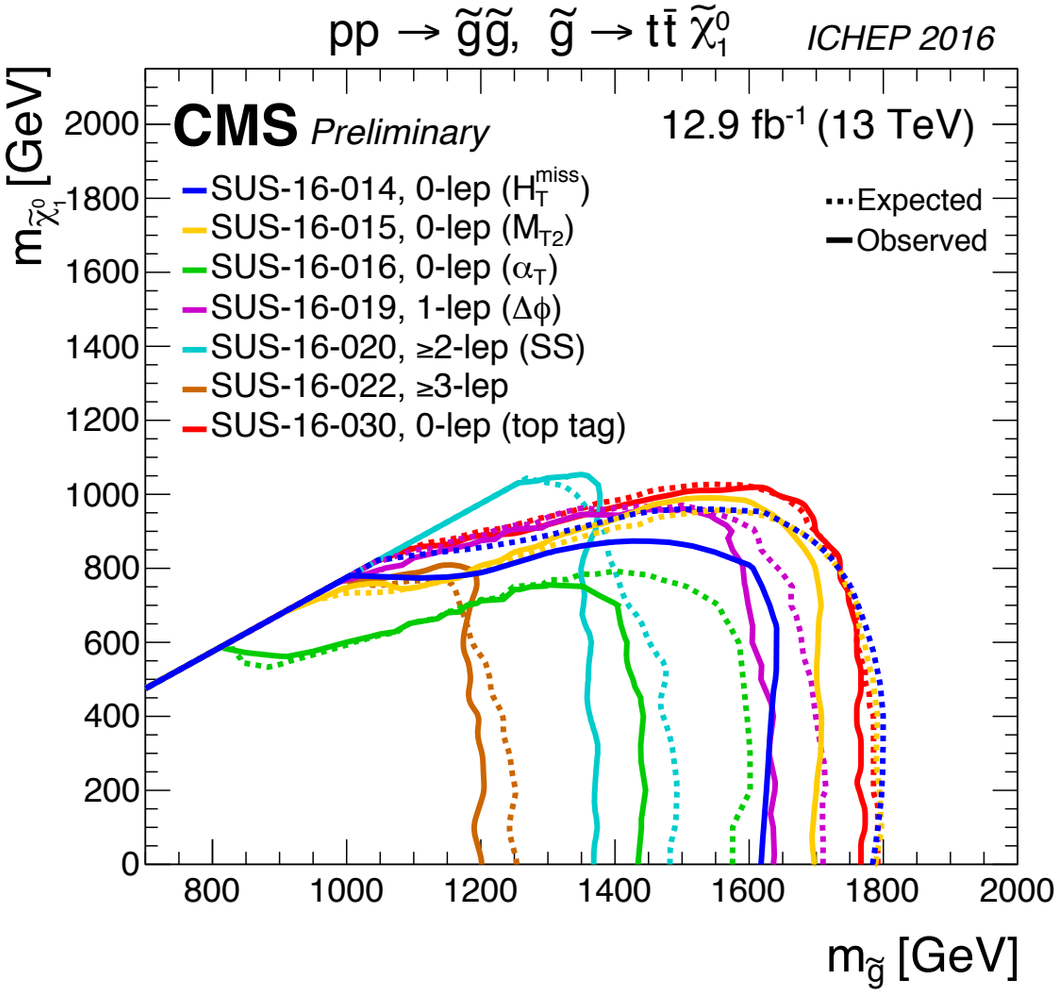


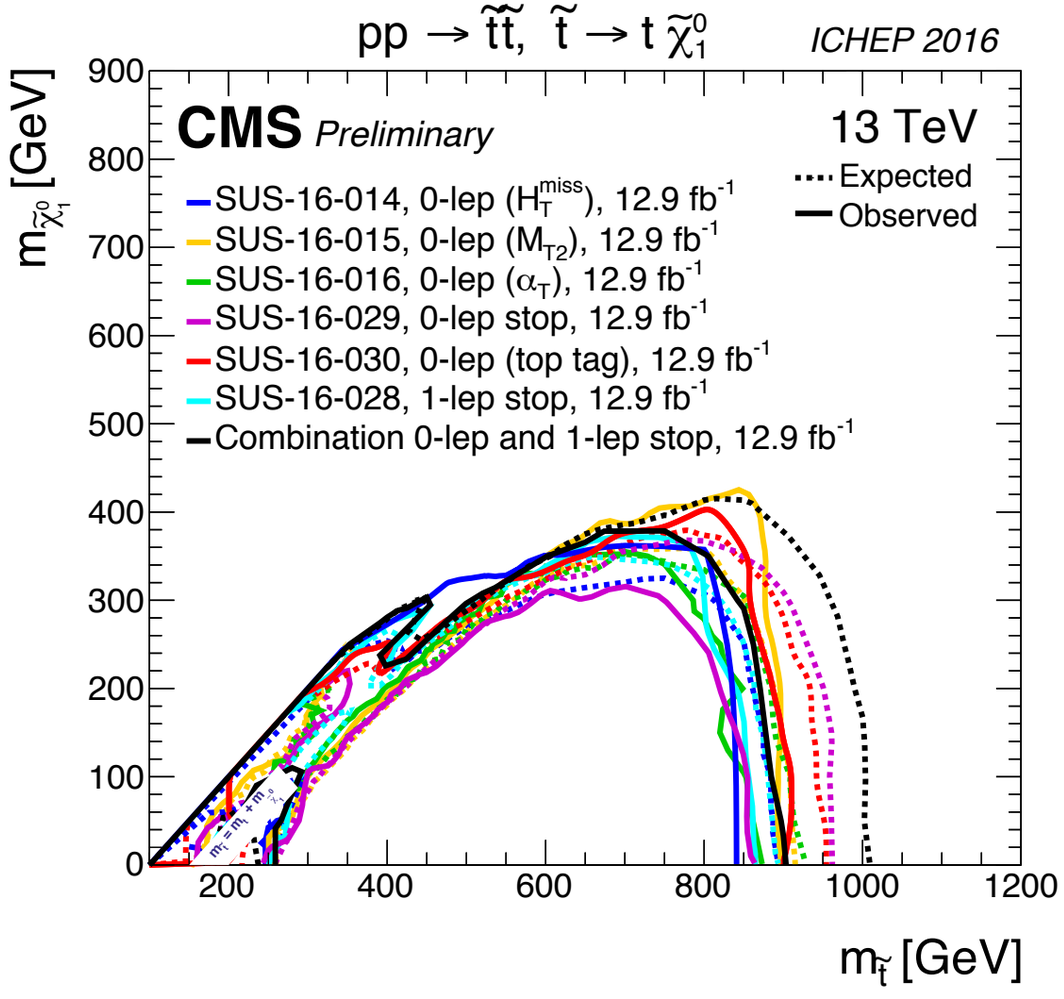


Natural SUSY vs. data

- Many techniques developed, using different kinematic variables and MC-assisted data driven techniques (based on W+jet, tt, g+jet etc control samples) [No time to go through all them]

- Clear picture emerges: Natural SUSY spectrum largely probed. Still room for SUSY to hide ("stealthy" valleys, compressed spectra), as long as the gluino is not accessible

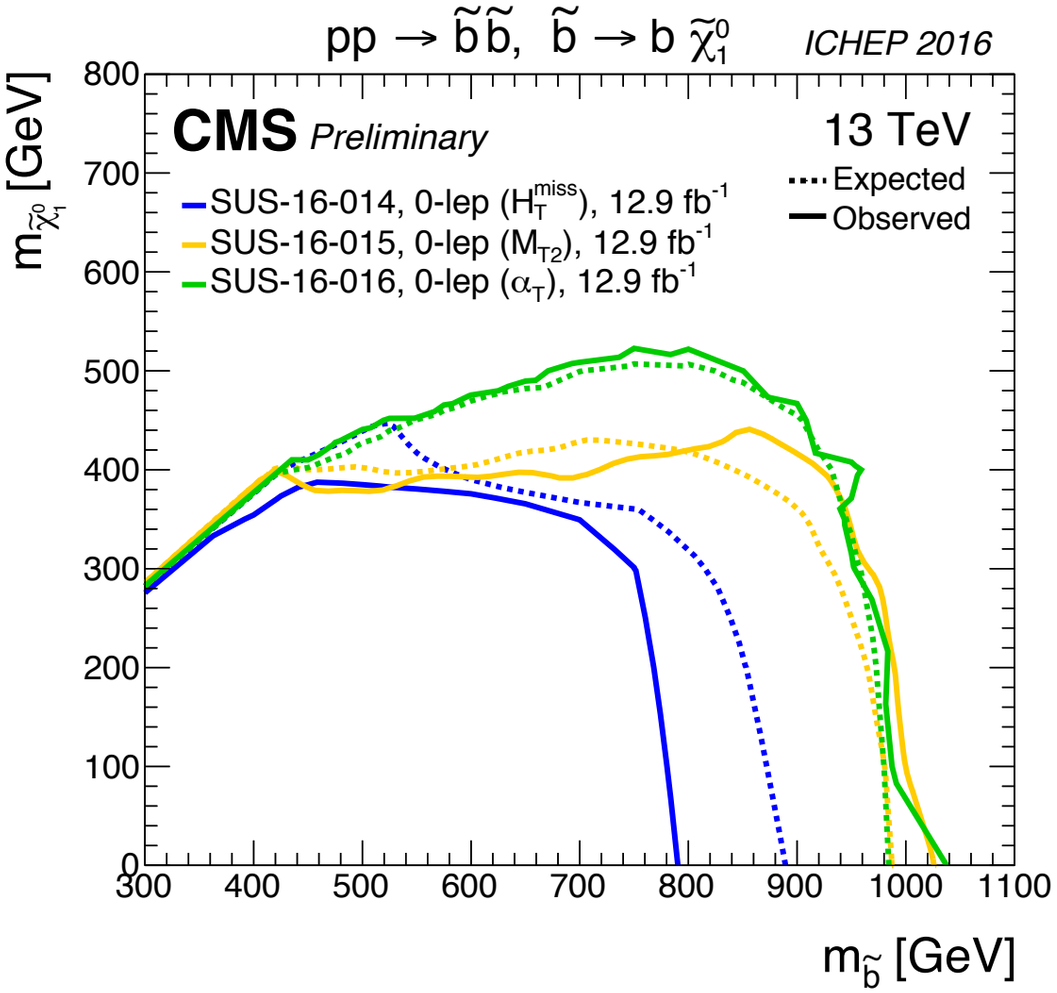


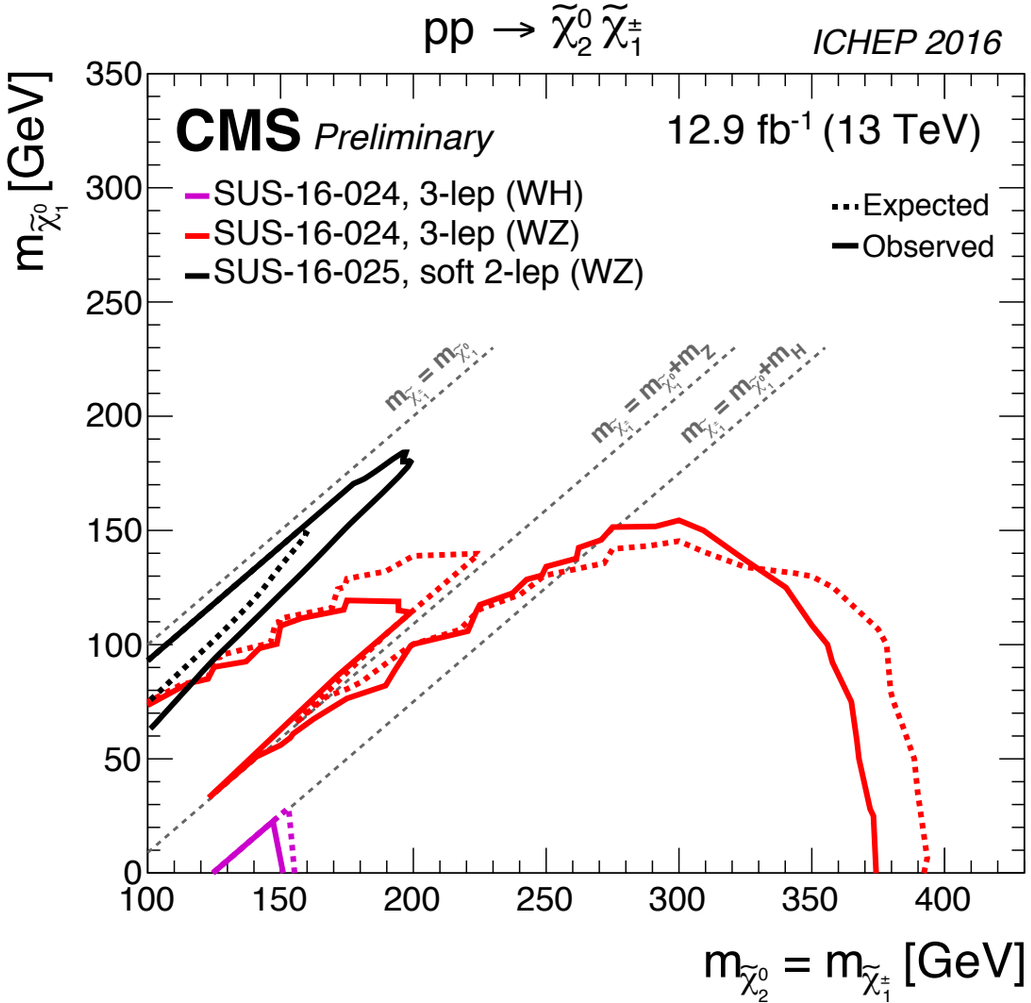


Natural SUSY vs. data

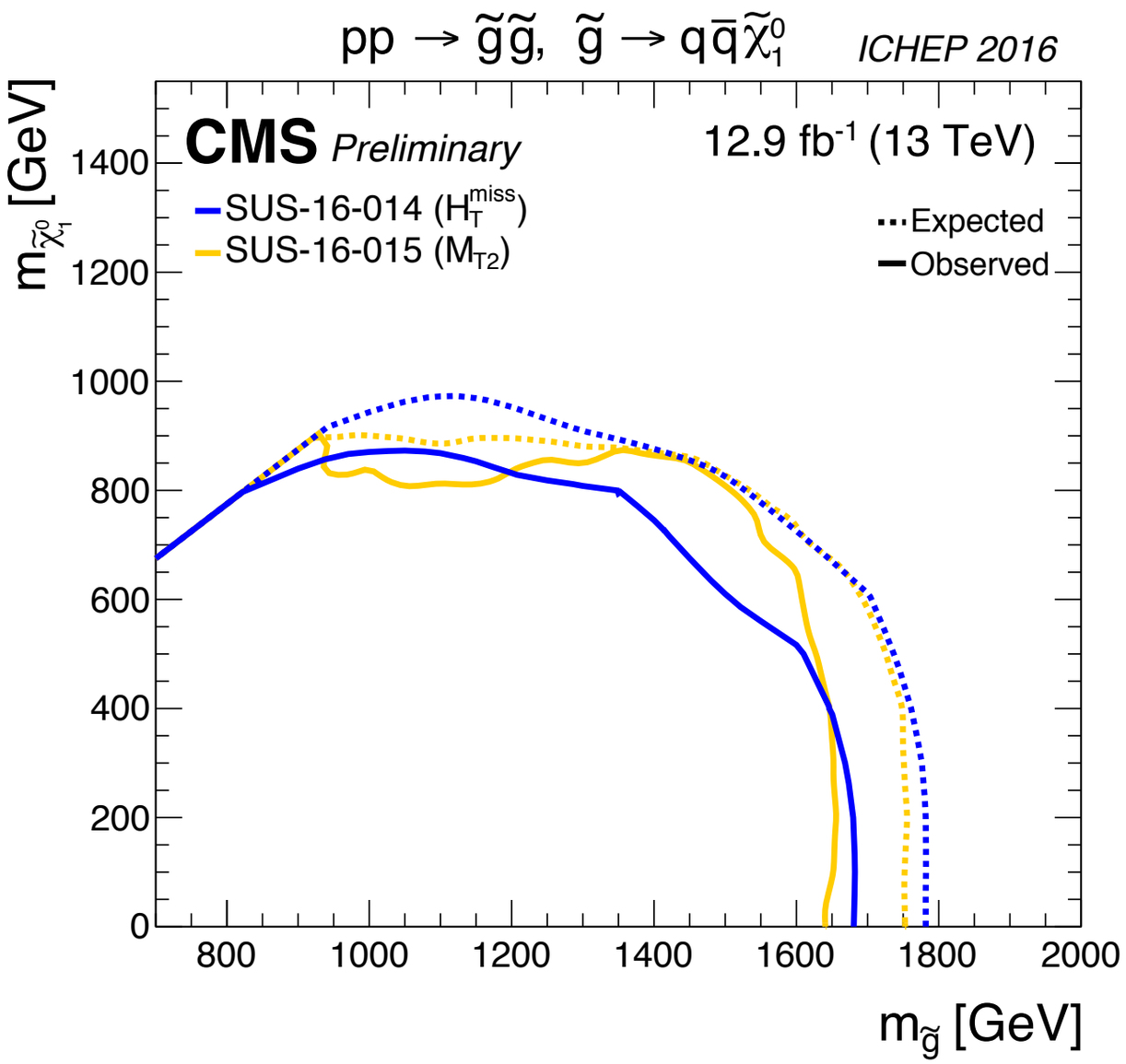
- Many techniques developed, using different kinematic variables and MC-assisted data driven techniques (based on W+jet, tt, g+jet etc control samples) [No time to go through all them]

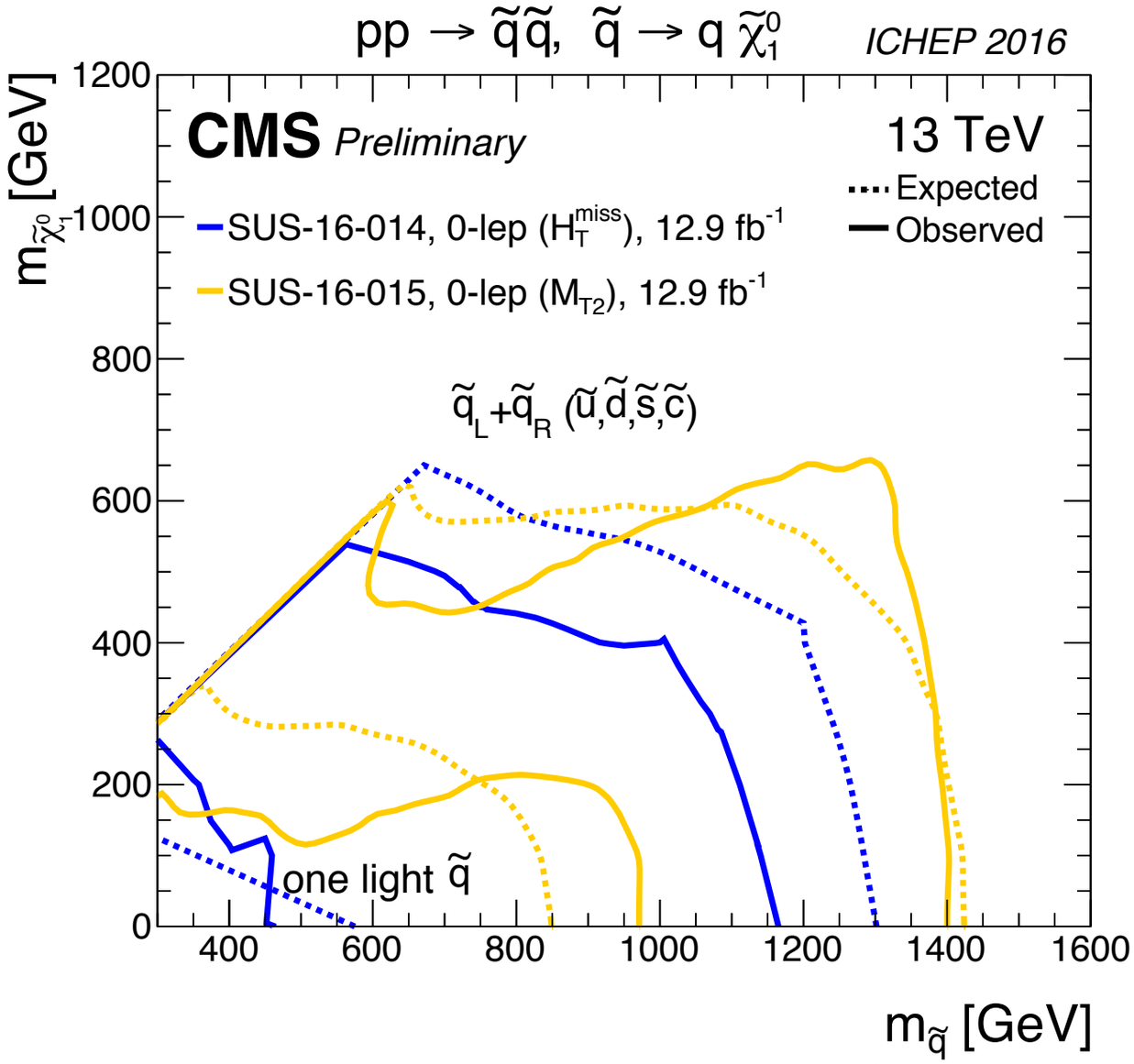
- Clear picture emerges: Natural SUSY spectrum largely probed. Still room for SUSY to hide ("stealthy" valleys, compressed spectra), as long as the gluino is not accessible





And not just natural SUSY

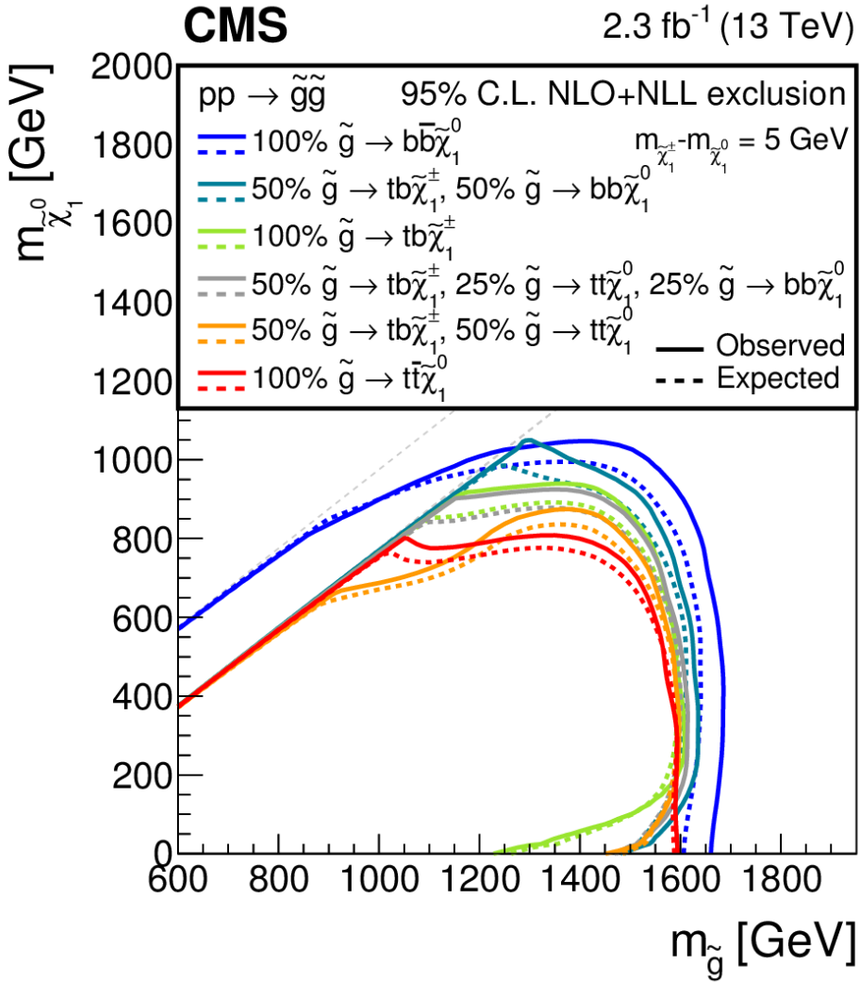


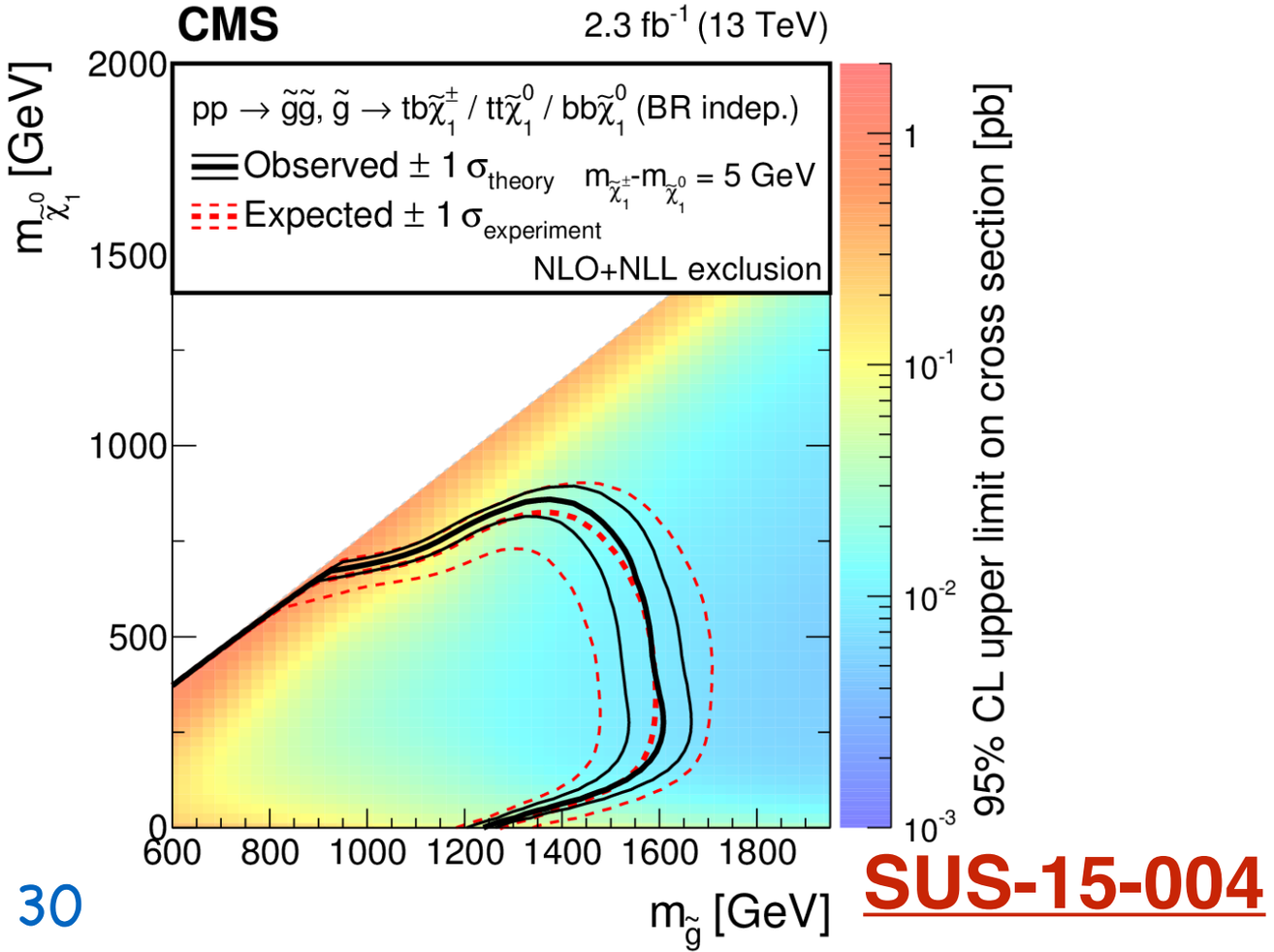


- Same techniques applied to events with 0 b-tagged jets
  - Comparable limits for gluinos.
  - Weaker bounds for 1-flavor squarks (more bkg from V+jets

An important remark

- In general, keep in mind that these results are based on simplified models
  - Assumed **Xsec under decoupling limit** for the rest of the spectrum
  - Assumed **100% BRs** for decay chains (not consistent with real Natural SUSY scenario)
- While the single result depends on this assumption, the overall picture from all final states is quite stable. Example: BR-independent results with razor 0lep+1lep "boxes"

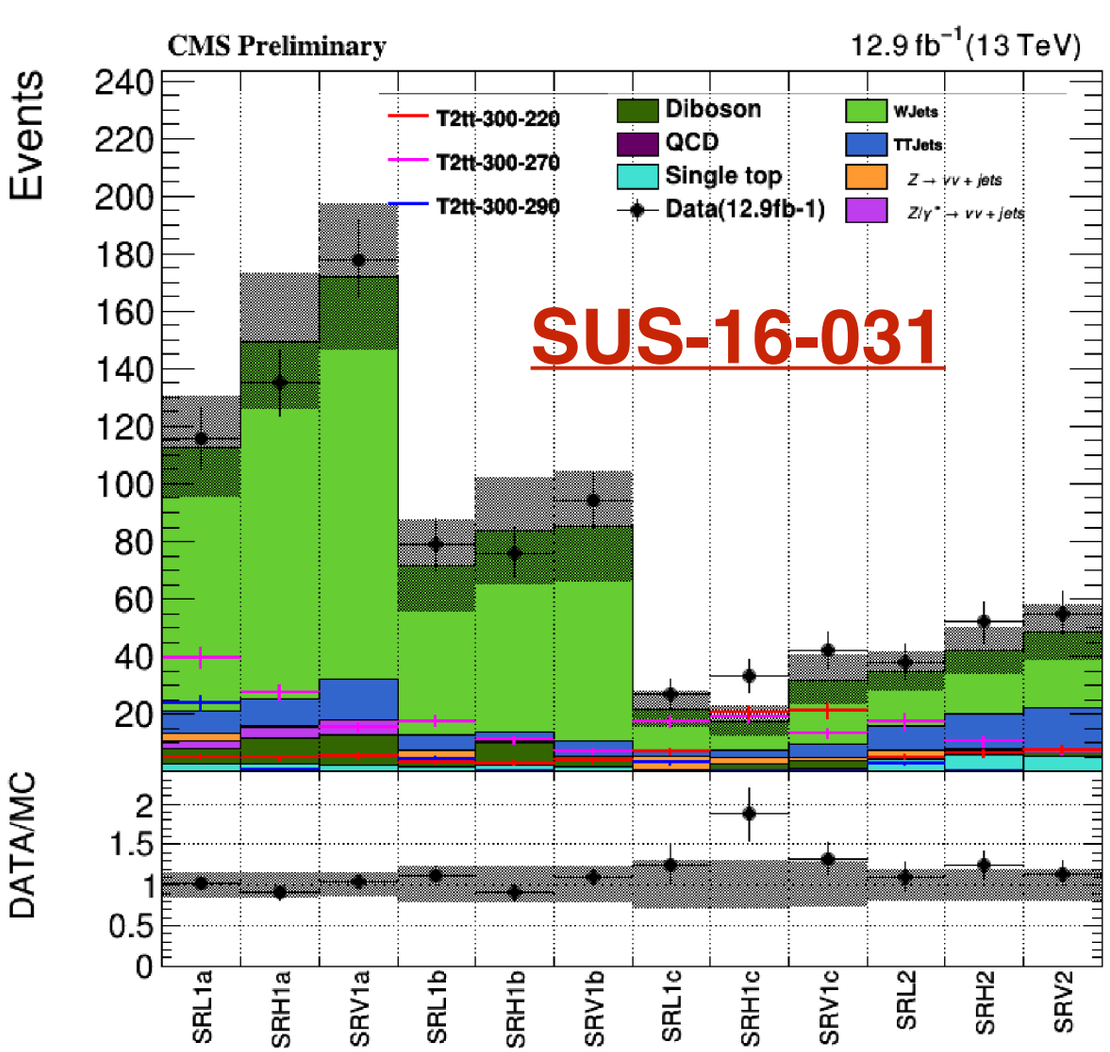


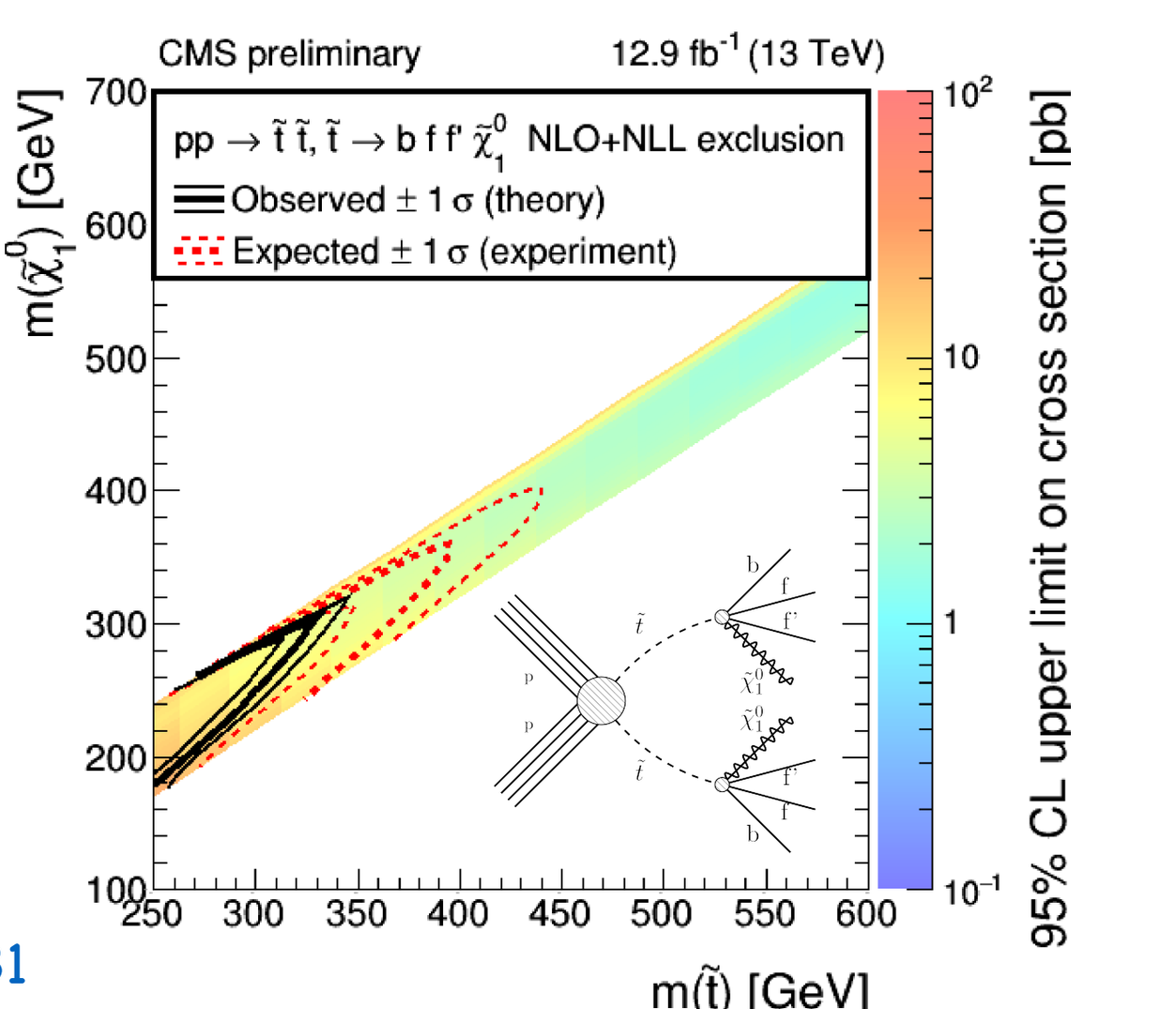


SUS-15-004

Searching in the corners

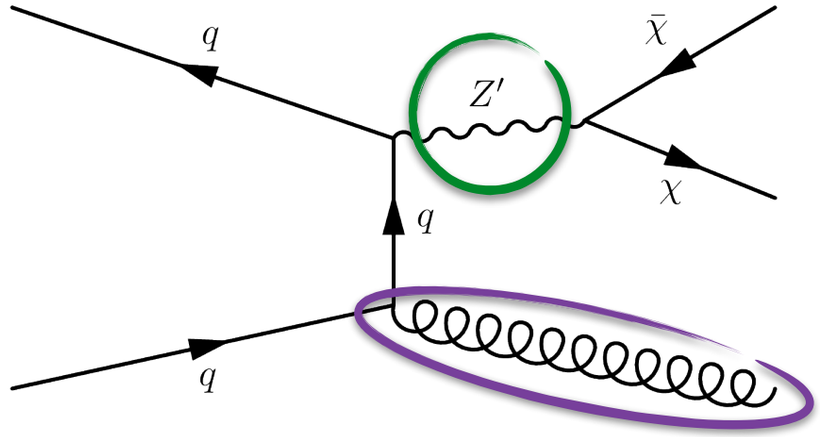
- A light stop not excluded by "traditional" searches if close in mass to LSP
- Dedicated search decided, looking for soft leptons recoiling vs. high-pT jet
- Different signs regions, for different mass-split values
- Control regions (and MC ratios) used to constraint SM background

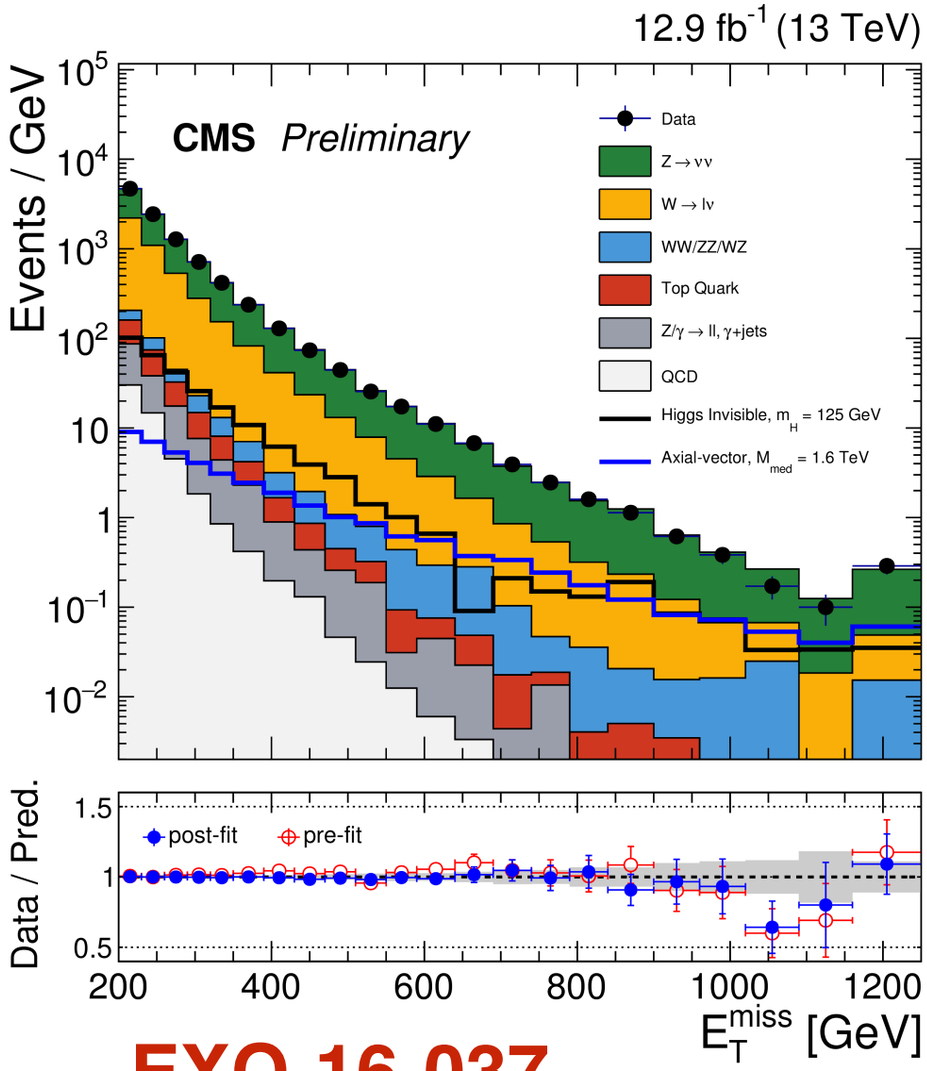




Mono-X searches for DM

- DM production detectable if recoiling **against something**
  - A jet or a boosted particle decaying to jets (Z/W/H) [monojet]
  - One or two heavy-flavor quarks [mono-b/ mono-t]
  - One photon [mono-photon] or heavy boson [mono-Z, mono-W, ...]
- In addition, one could directly probe the **mediator** (e.g., with dijet resonance searches)
- SM provides control samples to constraint main backgrounds (e.g., Z(νν)+jet from γ+jet and Z(ll)+jet)

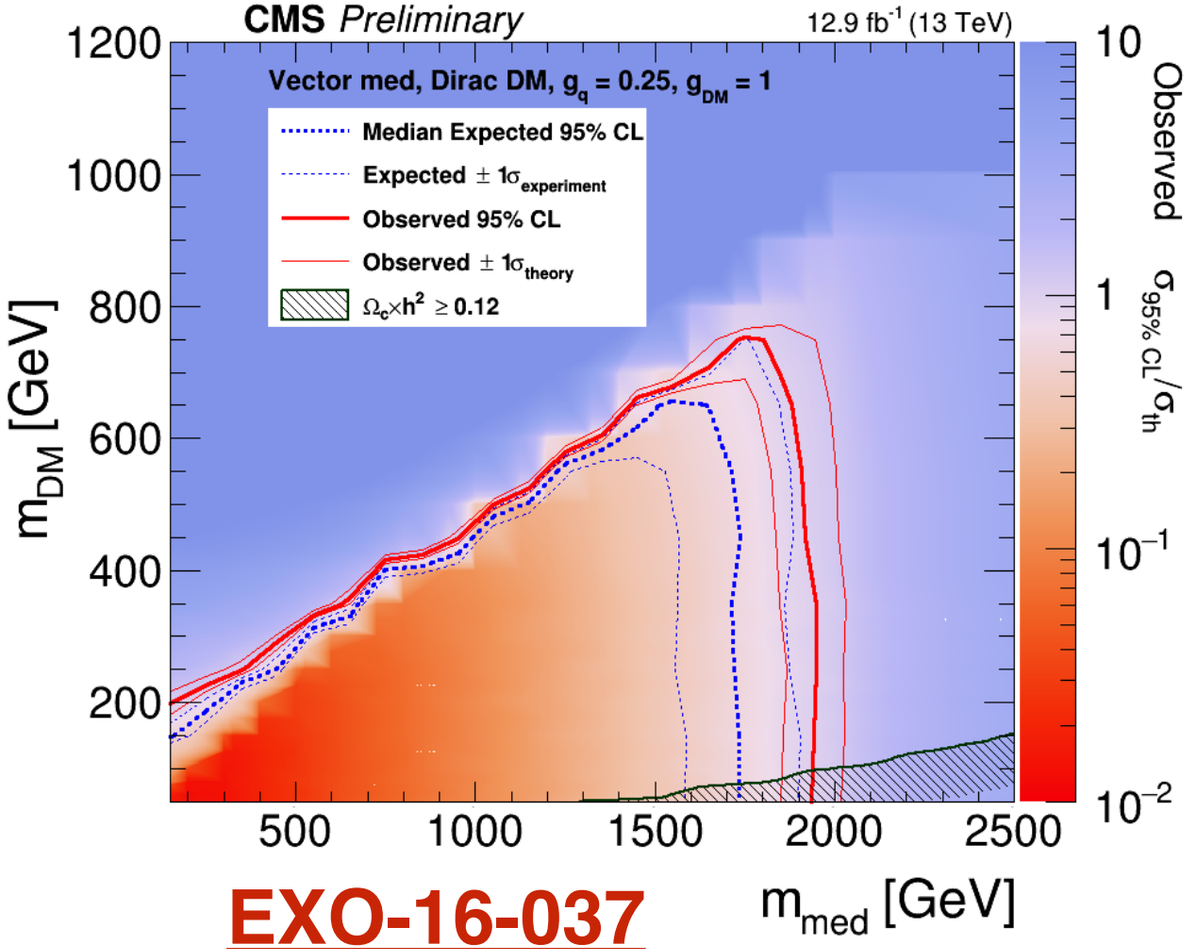




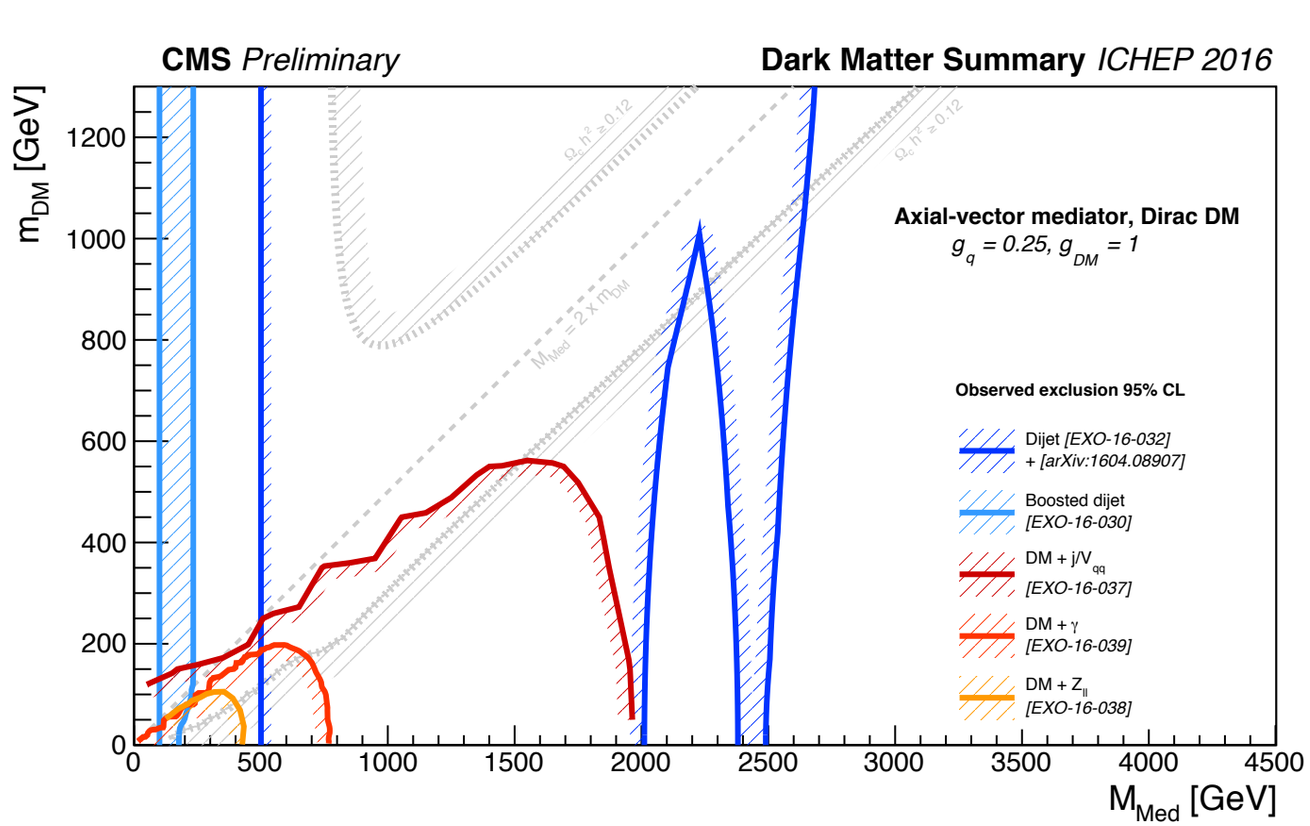
EXO-16-037

Results and interpretation

- Limits put on production cross section for different mediator hypotheses
  - scalar/axial/vector/…, narrow or wide, etc
- Limits translated to the coupling vs mass plane, where different analyses put different bounds
- Bounds derived for scattering cross section (to compare to direct detection)



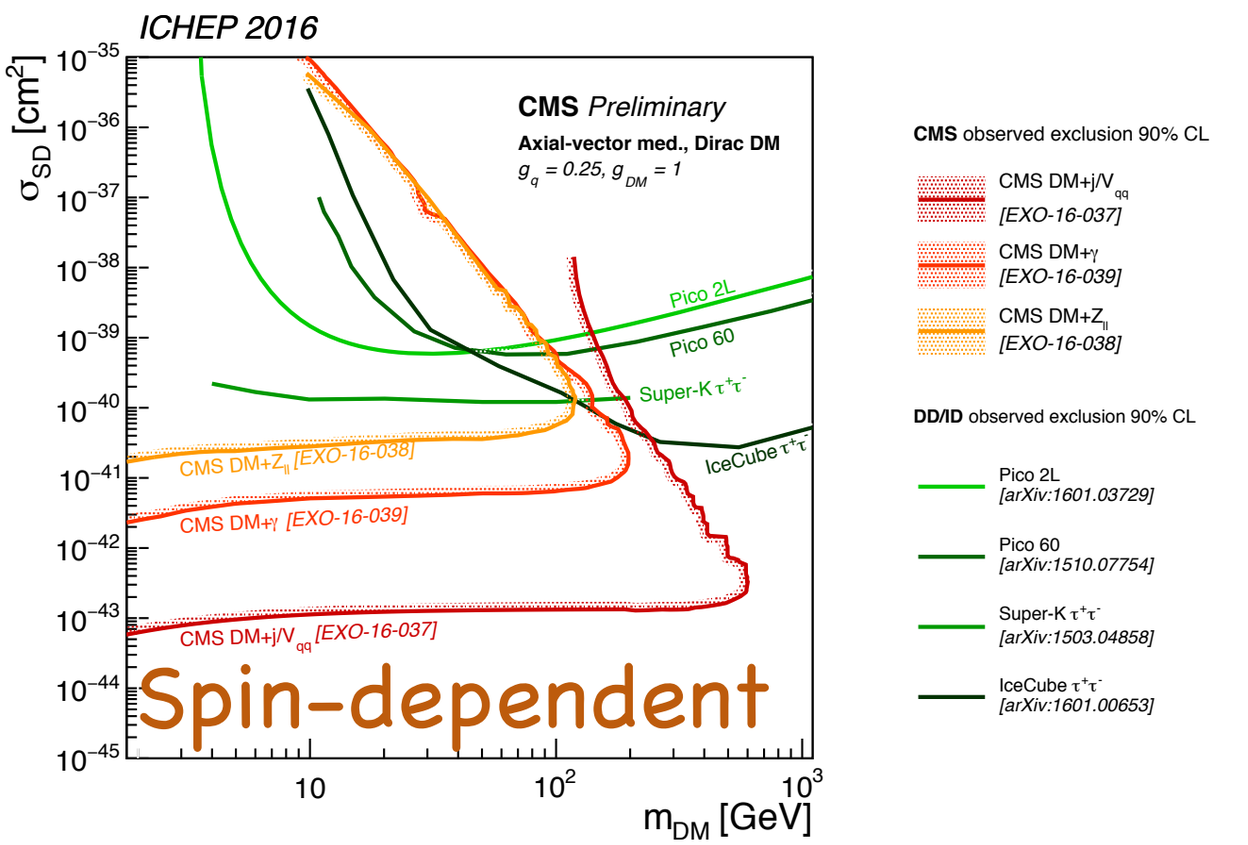
EXO-16-037

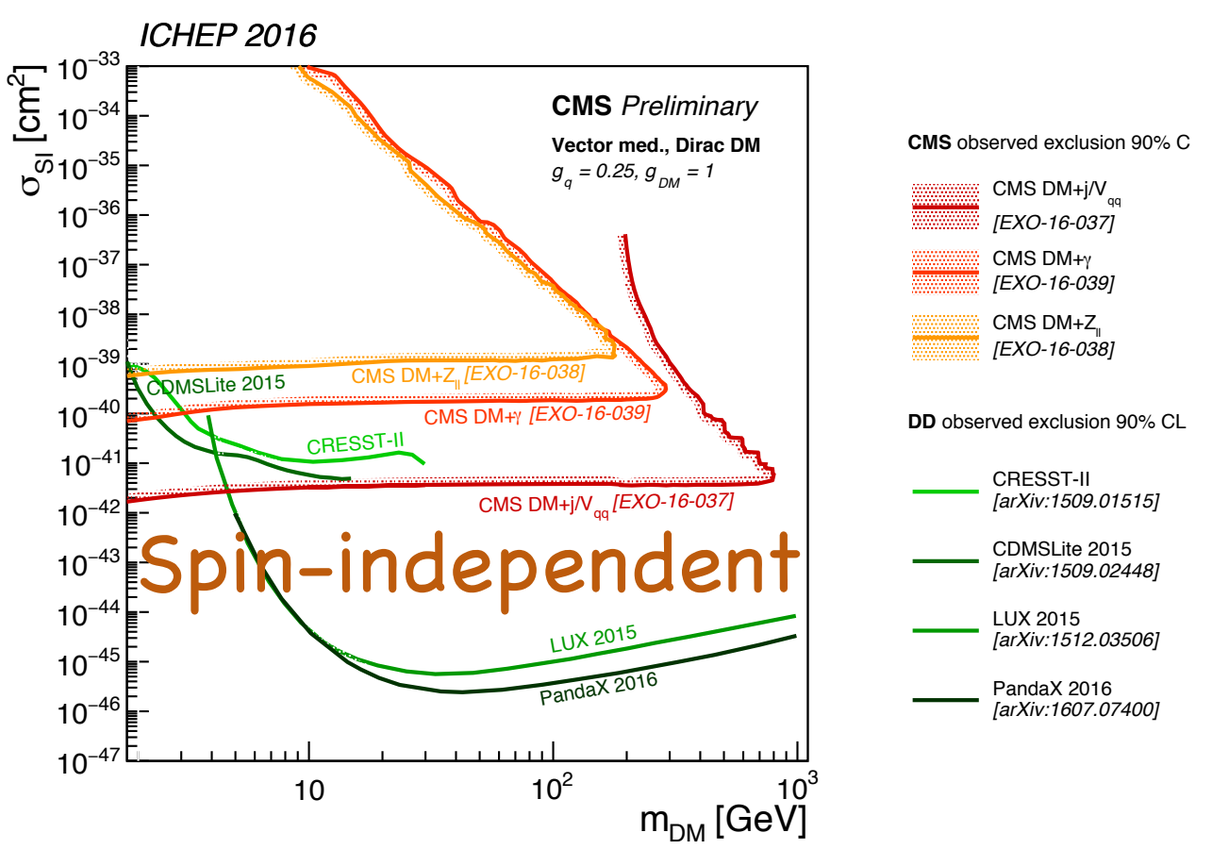


DP-16-057

Results and interpretation

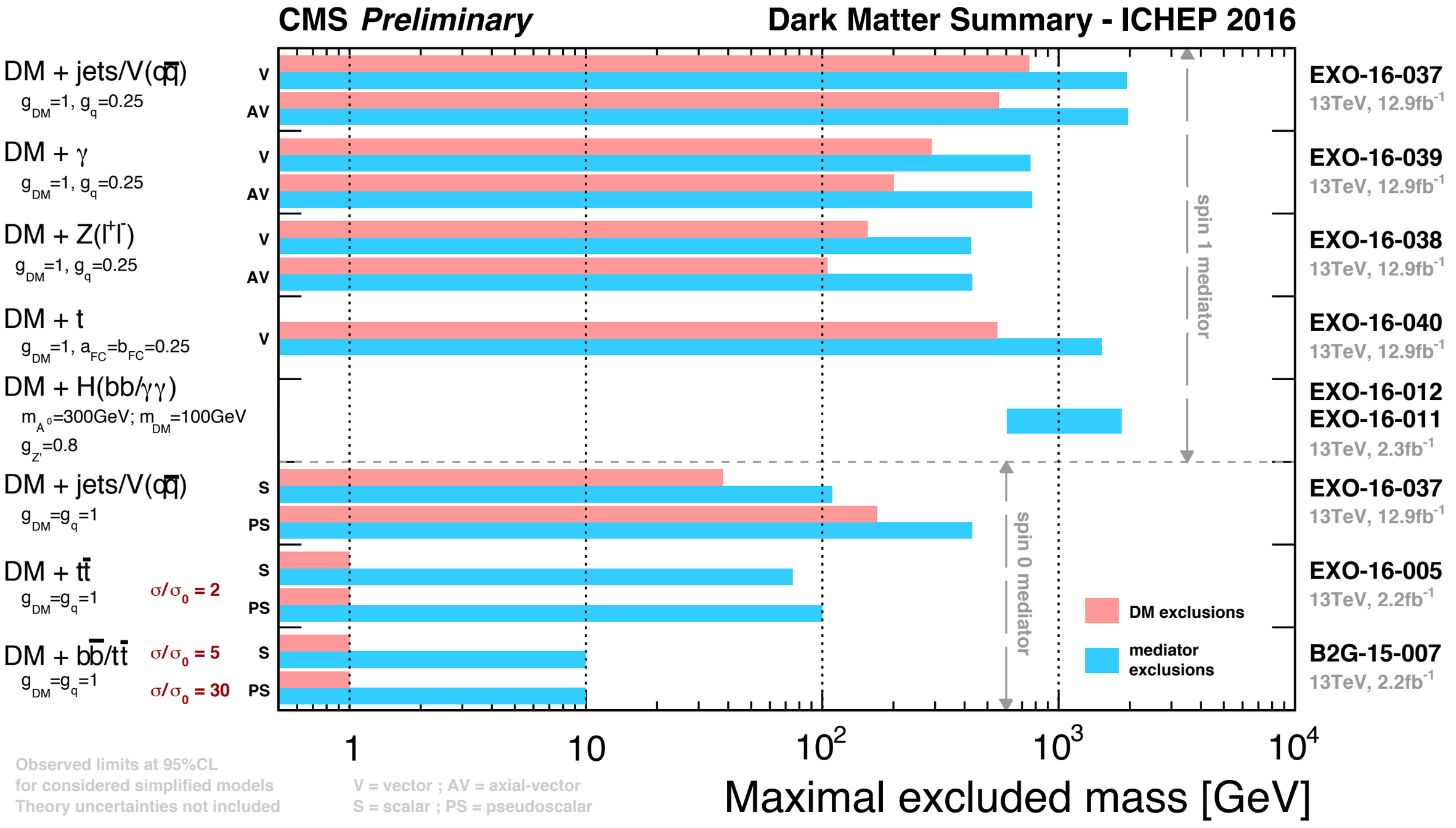
- Limits put on production cross section for different mediator hypotheses
  - scalar/axial/vector/…, narrow or wide, etc
- Limits translated to the coupling vs mass plane, where different analyses put different bounds
- Bounds derived for scattering cross section (to compare to direct detection)





DP-16-057

DM/mediator exclusion

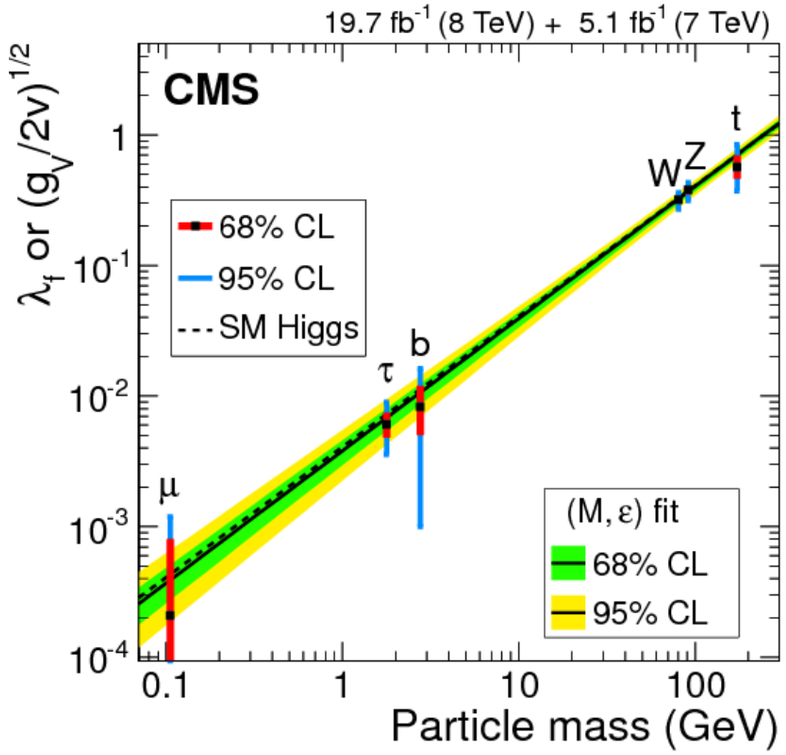


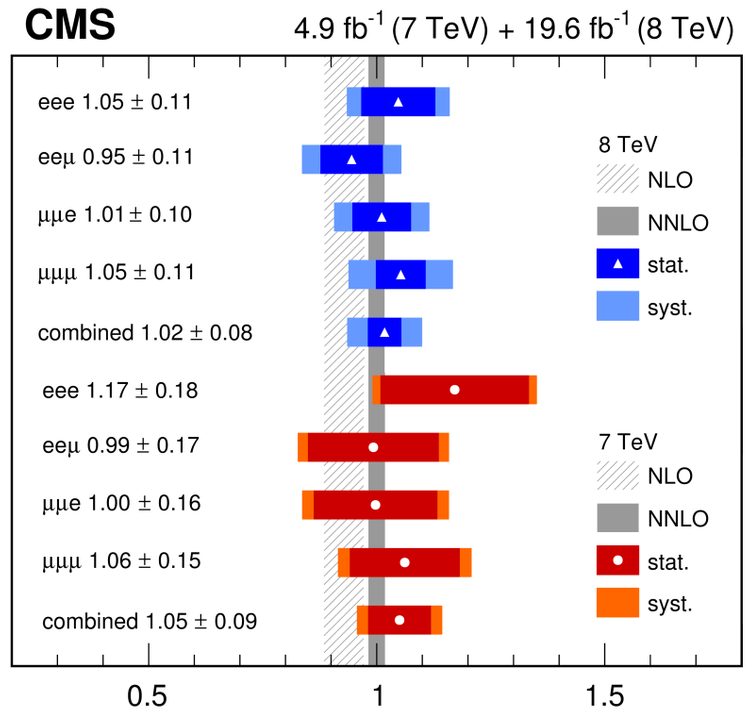
Much more than this…

- Cannot cover the full search program
  - top partners
  - Right-handed neutrinos
  - …
- Check our web pages for recent **preliminary** and **published** results
- Stay tuned for updates @ Winter and Summer conferences

The indirect probe

- LHC can also probe new physics indirectly
  - Higgs couplings / anomalous TGCs / flavor
  - (Re)measuring the SM in these new conditions is as effective as searching for new particles directly
- Outnumbered on this front → progresses are slower, surprises could be behind the corner
- In perspective (300 fb^{-1}) this might become the most effective front for new physics searches





SMP-14-014

Outlook

- With the data collected so far, we capitalise largely on the Run I -> Run II energy increase
  - Still need to analyse the full dataset in all aspects
  - Complete delivery expected by Summer 2017
- If no evidence for new physics emerges, the rule of the game will change
  - Will have to look for deviations in the bulk of kinematic distributions -> understand SM backgrounds and trust more predictions
  - Will have to look into tough corners (compressed spectra, exotic signatures, etc)
- The low-ending fruit season might be over soon. It is time to climb the tree

Backup

LHC Run I legacy

- Extensive analysis of 7TeV and 8TeV data didn't show hints of new physics

- Searched in many directions, but mainly focused on low-hanging fruits

  - mainly **narrow** resonances (with some attempt to look for wide ones)

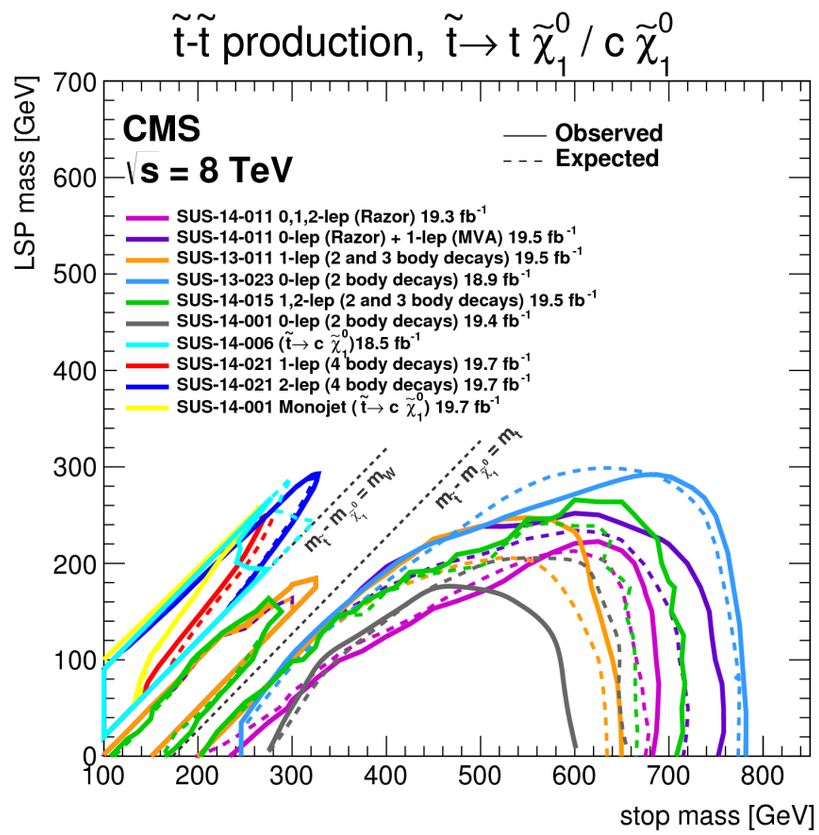
  - mainly on the **tails** of kinematic distributions (e.g., TeV SUSY)

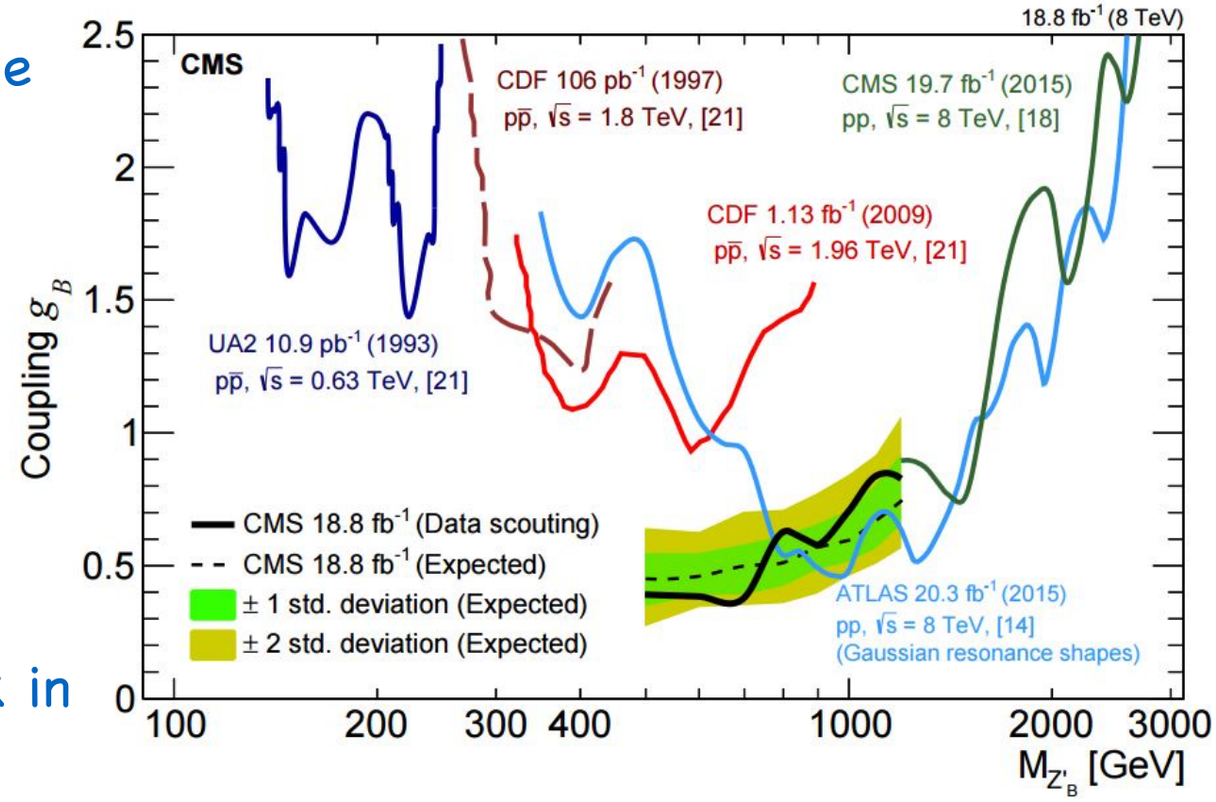
  - Look for **extreme** exotic signatures (e.g., large displacement of high-pT jets)

- Choices driven by boundary conditions

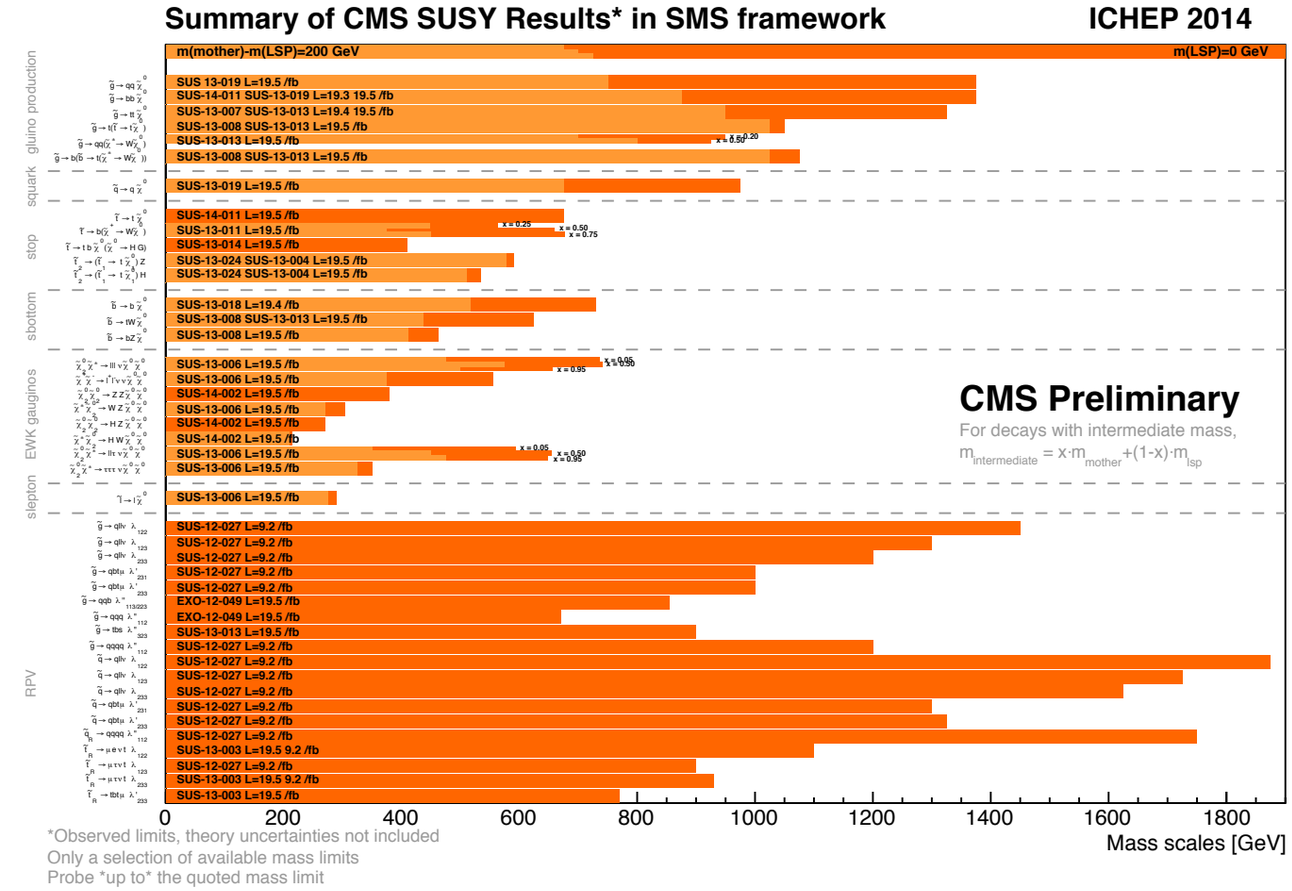
  - Limitations at trigger (but work done to overcome this)

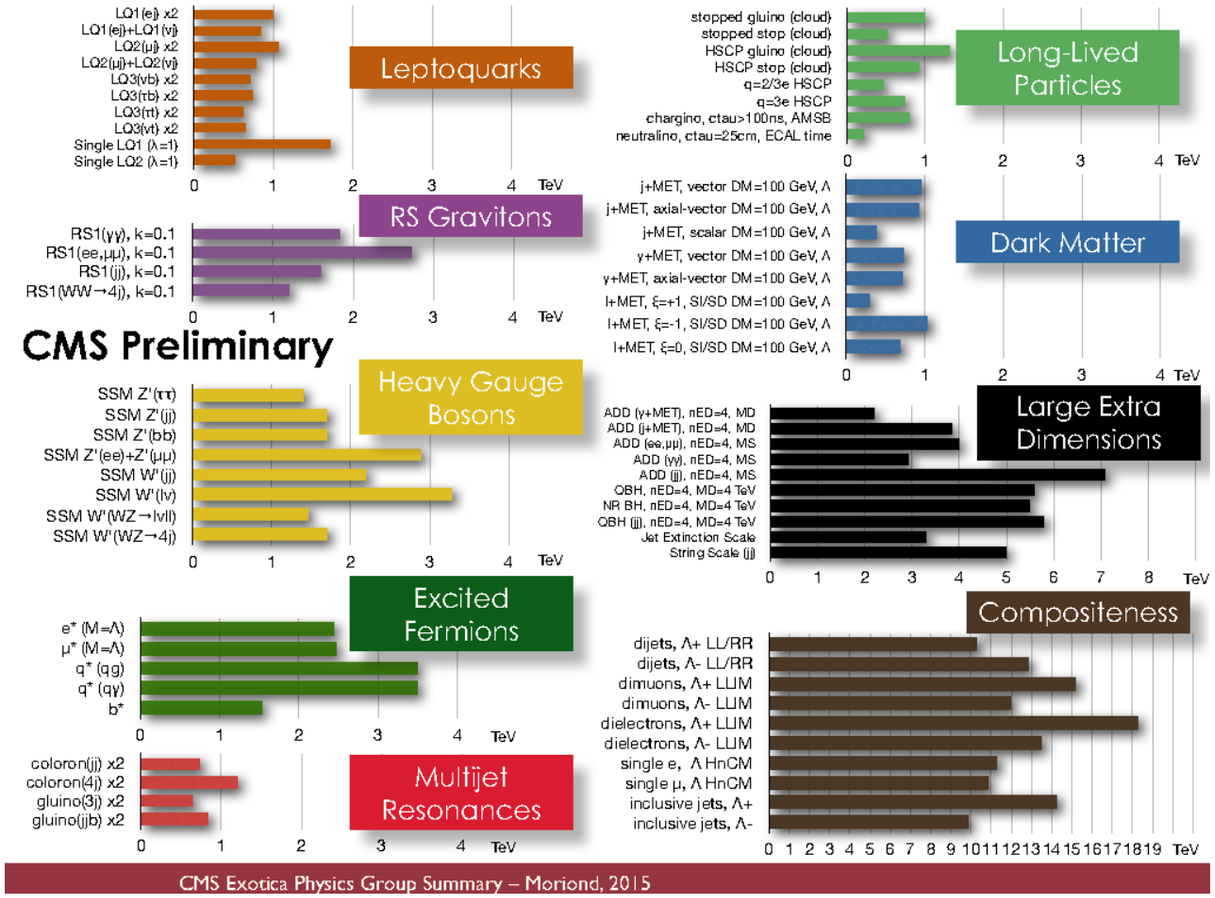
  - Data-driven background estimates (but work done to "test" pQCD predictions will pay back in the future)



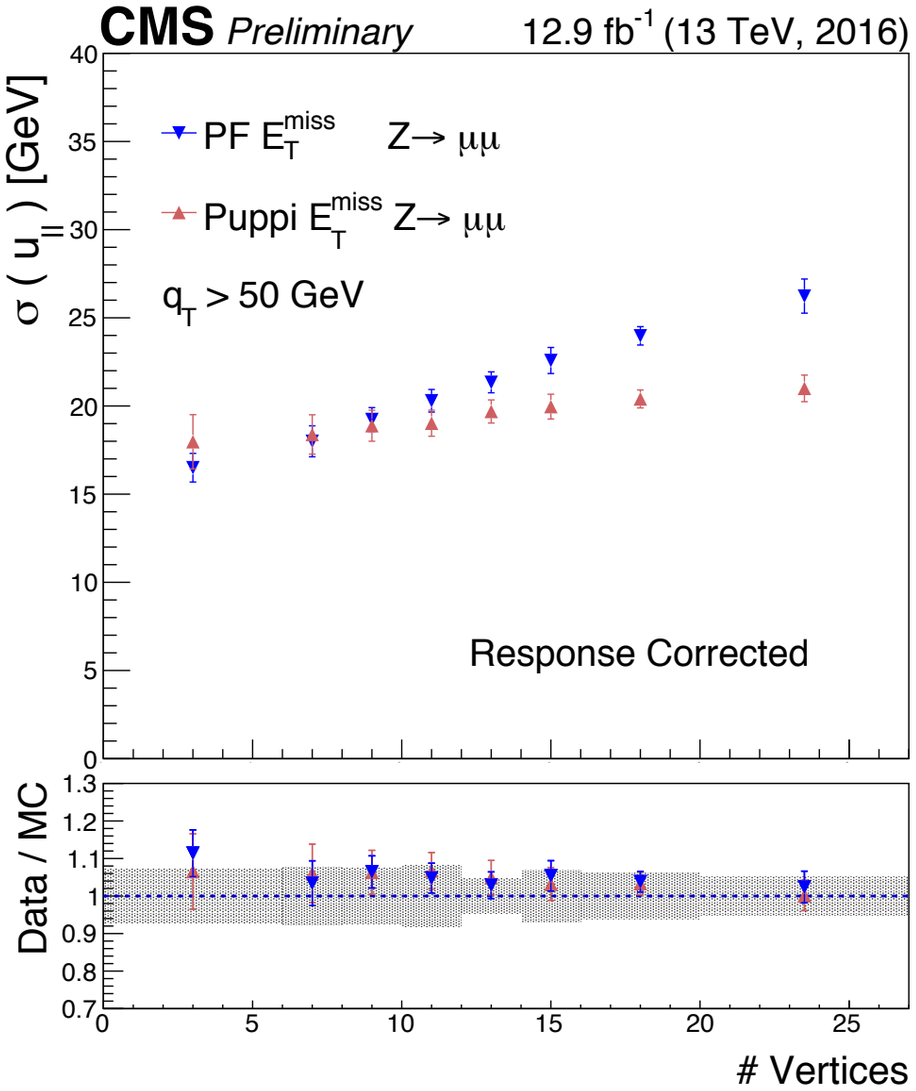


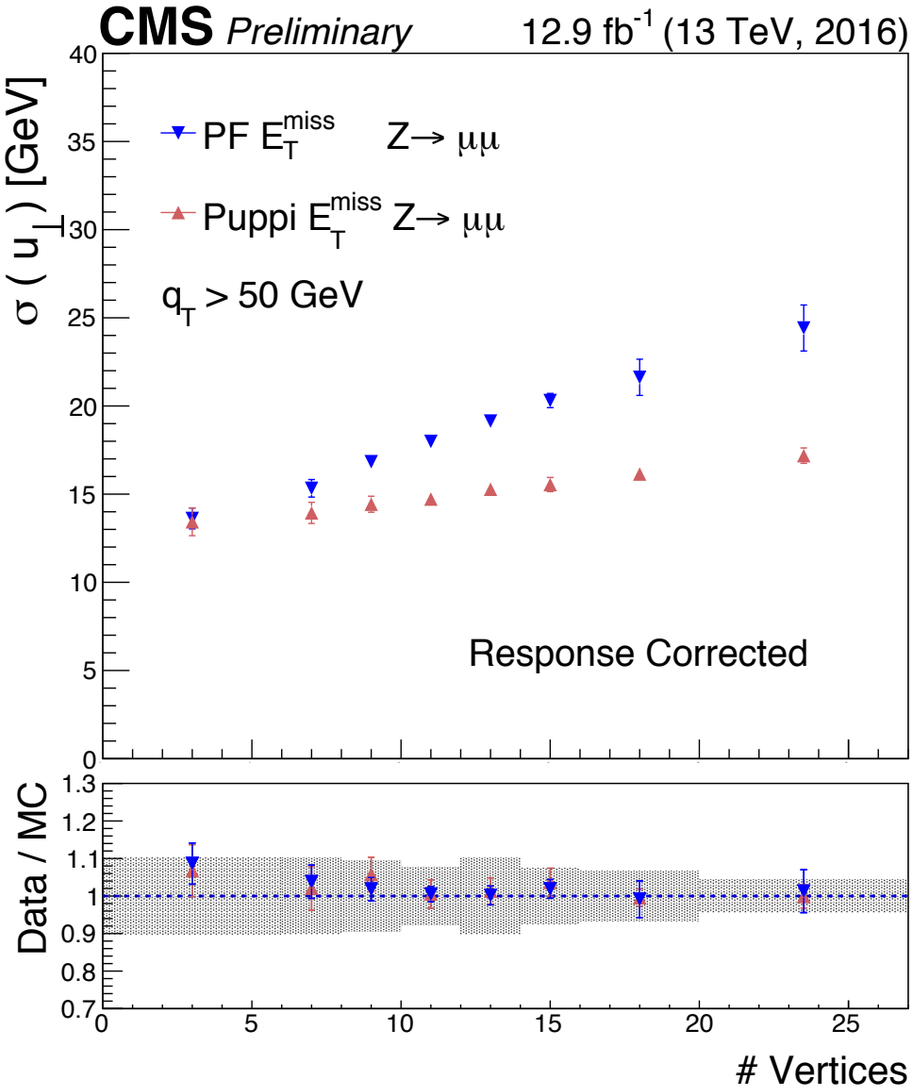
LHC Run I legacy

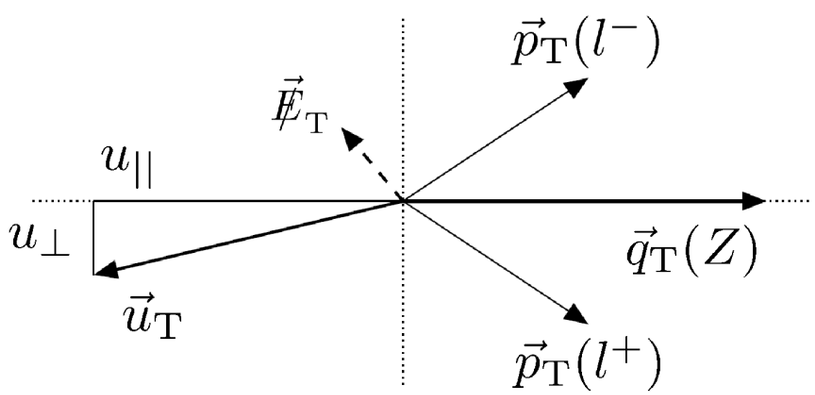




PUPPI MET

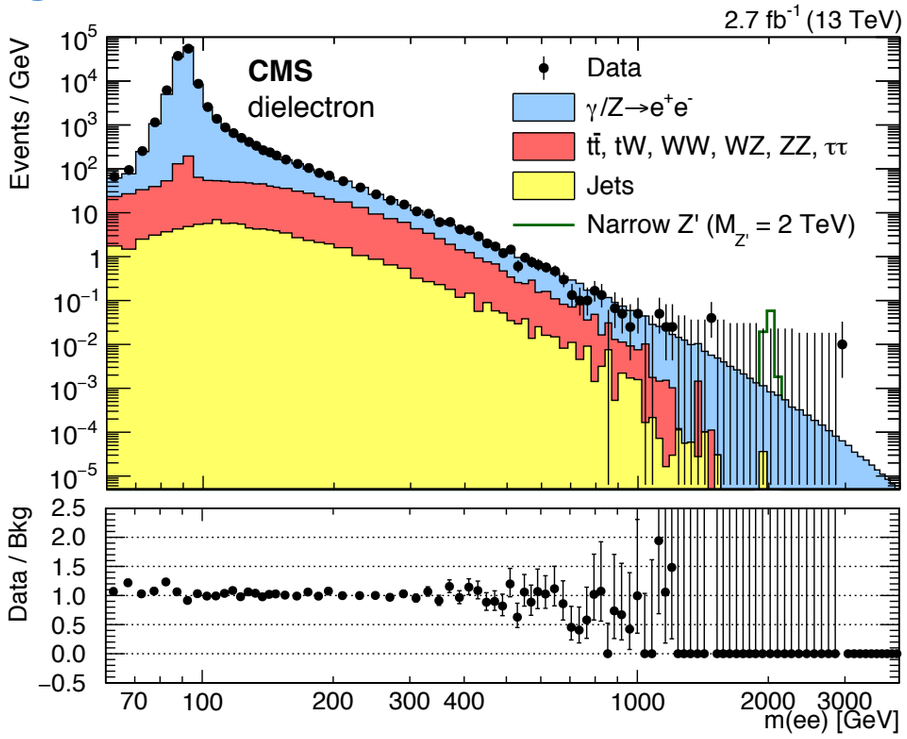

CMS Preliminary
12.9 fb-1 (13 TeV, 2016)
PF E_T^miss Z→ μμ
Puppi E_T^miss Z→ μμ
q_T > 50 GeV
Response Corrected
σ (u_∥) [GeV]
Data / MC
Vertices

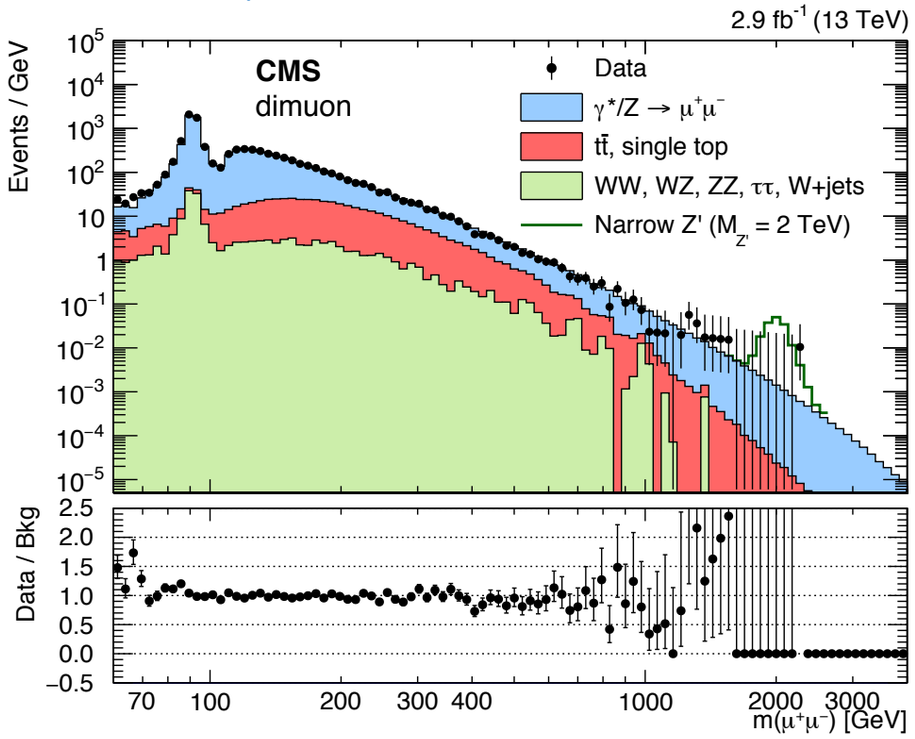

CMS Preliminary
12.9 fb-1 (13 TeV, 2016)
PF E_T^miss Z→ μμ
Puppi E_T^miss Z→ μμ
q_T > 50 GeV
Response Corrected
σ (u_⊥) [GeV]
Data / MC
Vertices

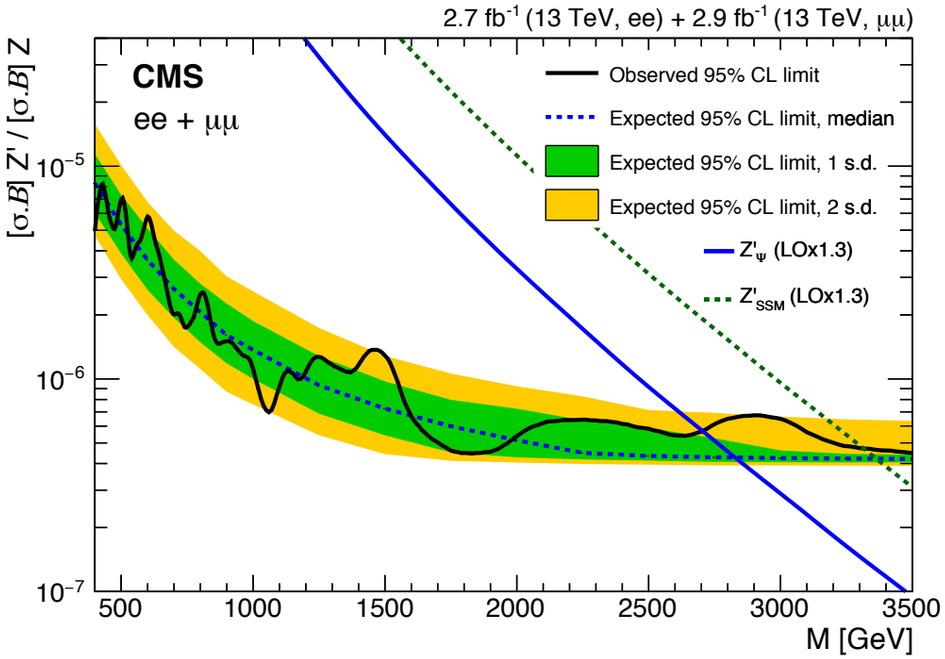

$\vec{p}_{\mathrm{T}}(l^-)$
$\vec{\not{E}}_{\mathrm{T}}$
$u_{||}$
$u_{\perp}$
$\vec{q}_{\mathrm{T}}(Z)$
$\vec{u}_{\mathrm{T}}$
$\vec{p}_{\mathrm{T}}(l^+)$

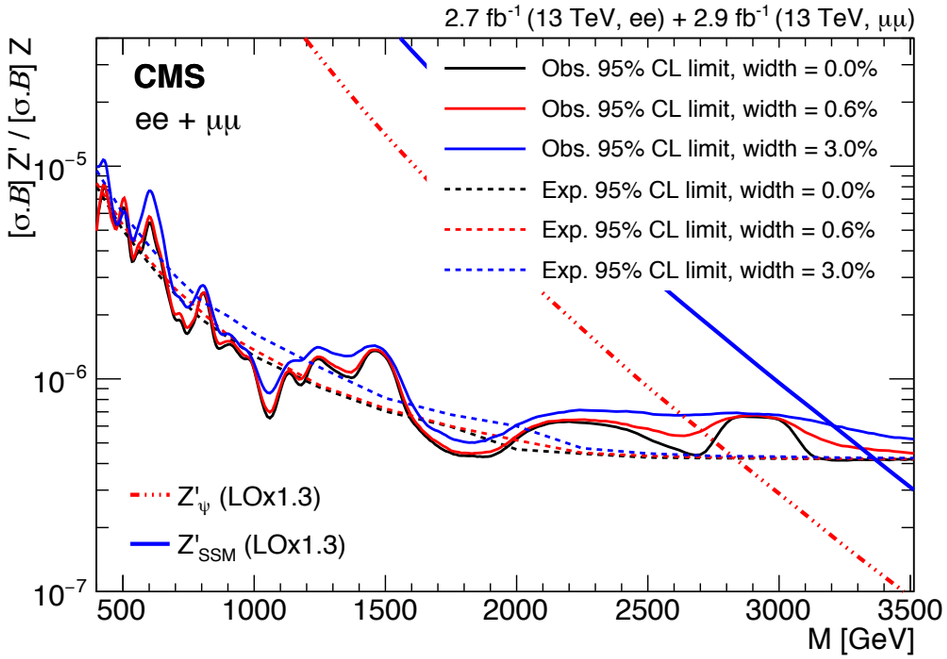
DiLepton search

Bkg from NLO MC (x NNLO multiplicative xsections)



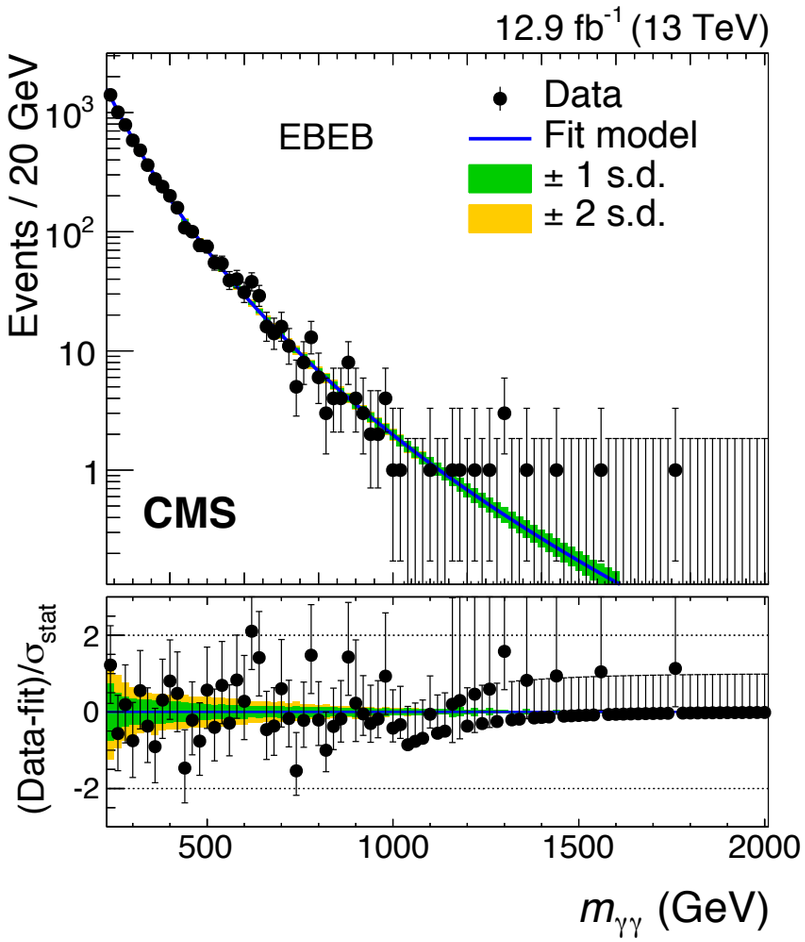


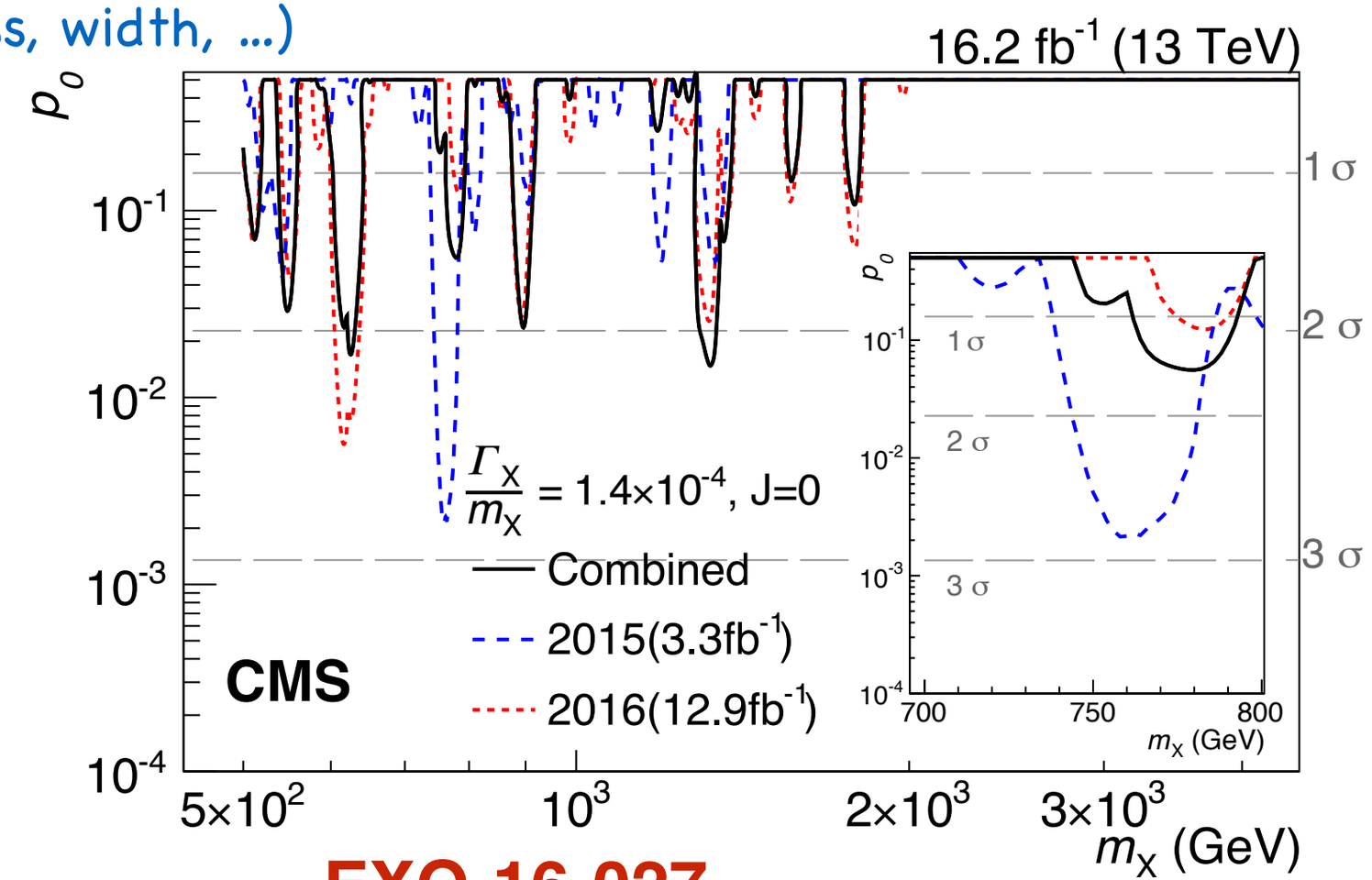




Digamma search

- I don't have to tell you why this became a priority at some point...
- Analysis straight-fwd
  - Photons selected with usual ID (isolation & energy cluster shape), different for barrel and endcap
  - Fit the $m_{\gamma\gamma}$ distribution to an ansatz function (for bkg) + signal peak (assuming different signal hypotheses, mass, width, ...)





EXO-16-027