Searches for new heavy resonances in the dilepton final state in CMS

Jan-Frederik Schulte

4th PIKIO meeting - University of Kentucky

September 16, 2017

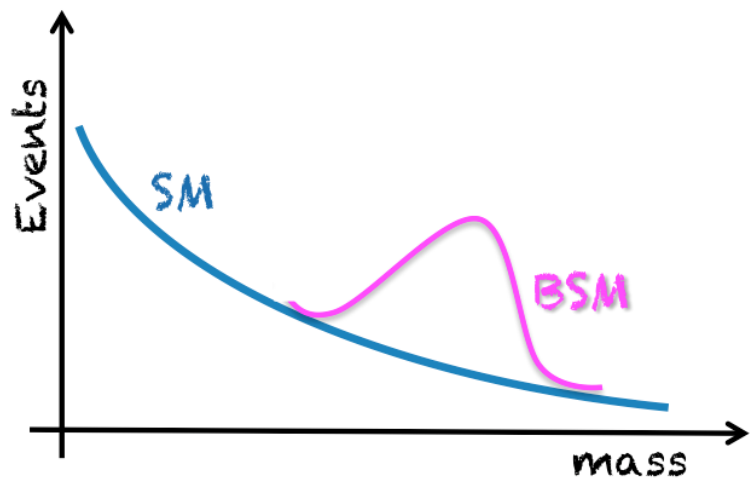
PURDUE UNIVERSITY®

Introduction

Searching for new heavy resonances at the LHC

- Search for new phenomena is key element of the physics program of the LHC
- High mass resonances would be a undeniable sign of physics beyond the Standard Model
- Dilepton mass spectrum has been fruitful place for discoveries in the past

- Searching in high mass tails $\rightarrow$ Distinct signature with low SM backgrounds
- Simple signatures allow for largely model-independent searches
- We focus on resonances decaying into *ee* or $\mu\mu$ pairs
- Great experimental mass resolution: 1.3%-2.4% (7%) for ee ($\mu\mu$) at 1 TeV



- Latest public result from ICHEP 2016 with 13 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13$ TeV

Motivation for searches in dilepton

Spin 1 resonances

- New heavy gauge bosons, cousins of the SM Z, occur in many models of new physics including new $U(1)$ groups
  - Sequential Standard Model (SSM) as a benchmark: Z' is heavier copy of Z, same couplings
  - GUT theories with $E(6)$ or $SO(10)$ groups that break down into a group structure containing $U(1)$ at lower energies
  - Left-Right symmetric models that introduce a $SU(2)_R$
  - Dark Matter models including a Spin 1 mediator particle that can be produced at the LHC

Spin 2 resonances

- In Randall-Sundrum models with additional extra dimensions, Spin 2 gravitons can be resonantly produced at the LHC

Non-resonant models

- Signature of new physics not necessary resonant. Non-resonant excess at high mass expected in models of
  - Quark substructure which manifests as a contact interaction at LHC energies
  - ADD Large extradimension models

Analysis strategy

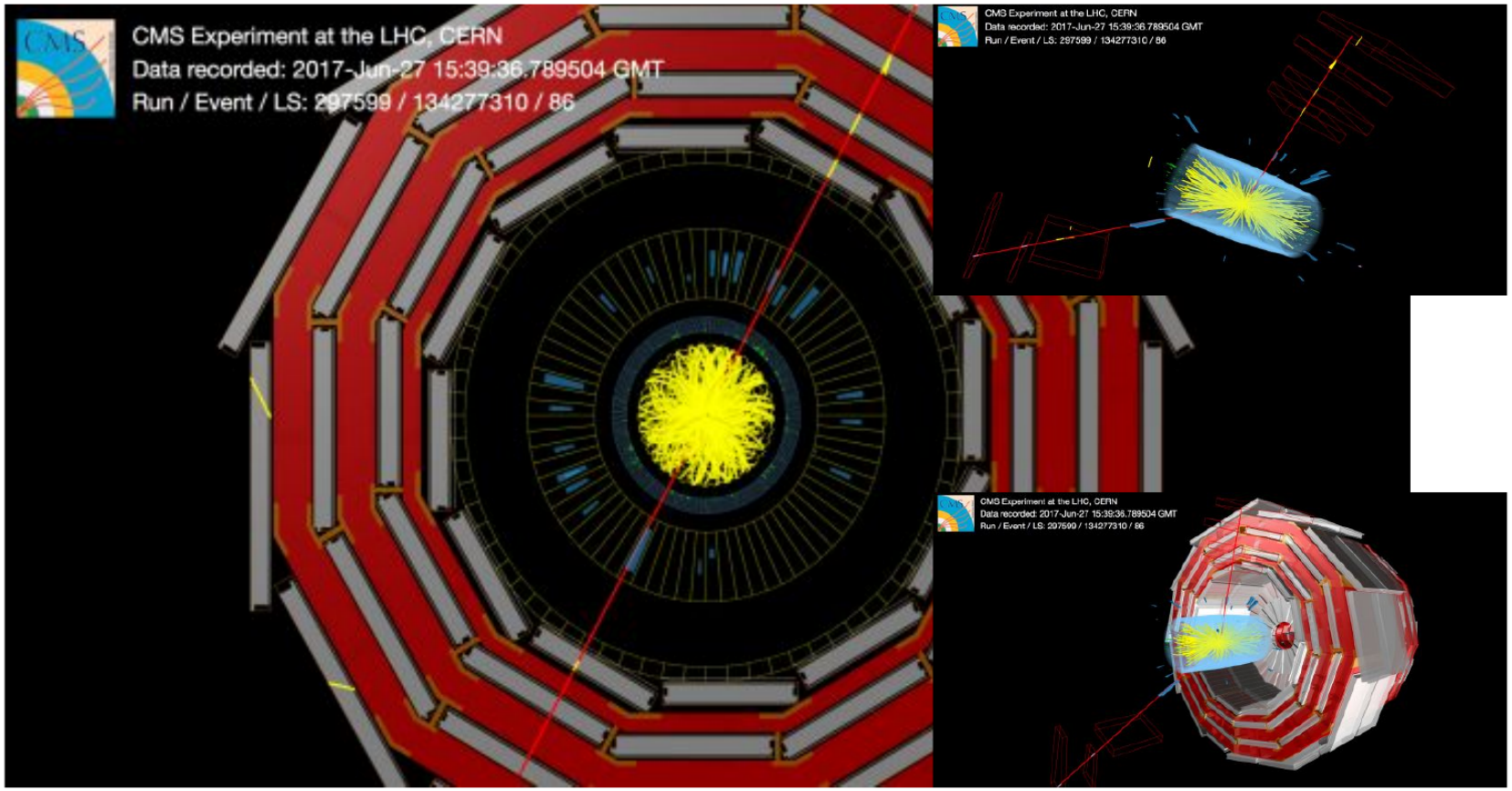
- Pretty simple analysis strategy: Select events with two high p_{T} leptons, ignore everything else
- Challenge: Lepton trigger, reconstruction, and ID at unprecedented p_{T}*s*
  - Z' group strong contributer to CMS efforts on these topic
  - Dedicated high p_{T} lepton IDs used for both electrons and muons

- Standard Model backgrounds estimated mostly from simulation
- Dominant Drell–Yan background simulated in Powheg, corrected to NNLO in QCD + NLO in EWK
- Profiting from recent theoretical developments, for example to nail down photon-induced Drell–Yan production (LUXqed PDFs)

- Sum of all backgrounds fit with empirically found function to get prediction for statistical analysis

Highest mass dimuon event

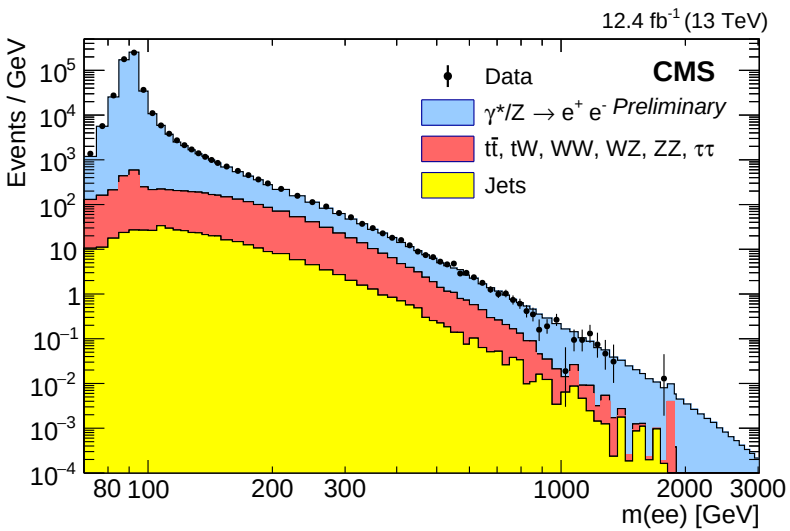
First nice events in 2017: high mass $\mu\mu$

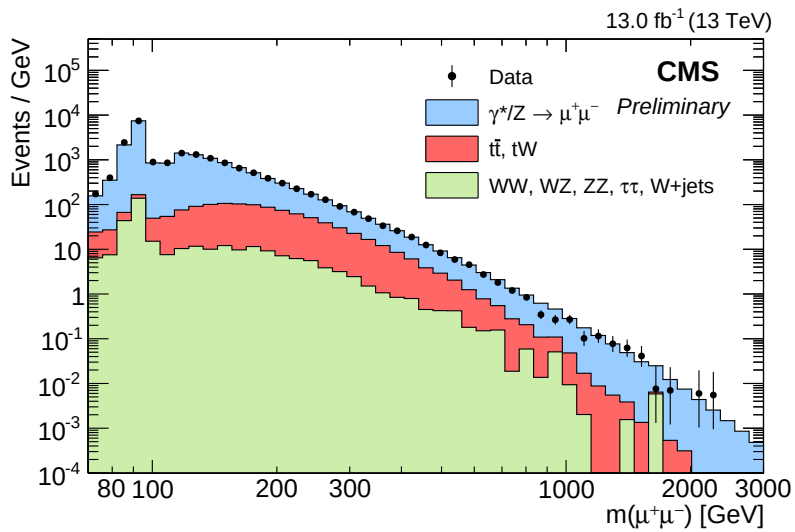


Highest dimuon mass candidate in CMS data: 2.4 TeV

Latest public results

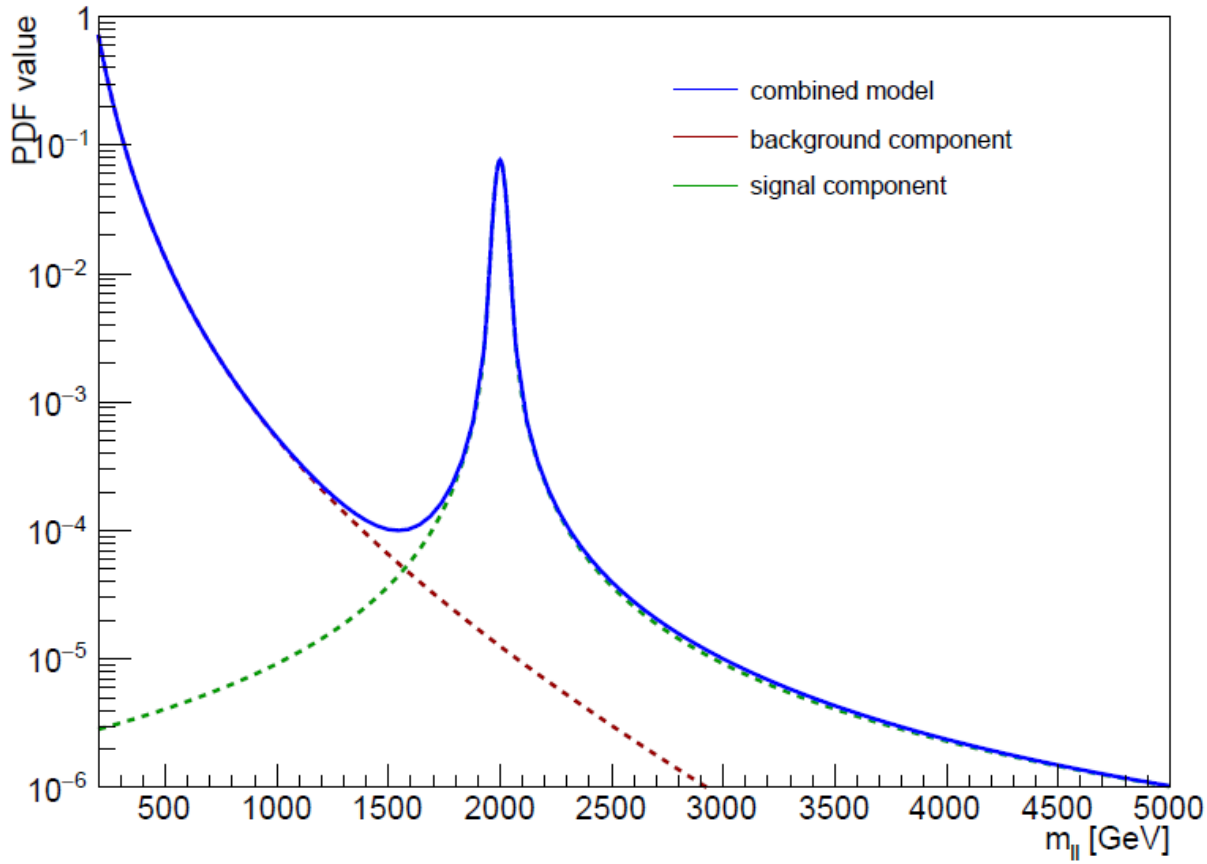
- Latest public results from ICHEP 2106
- Very good agreement between data and background simulation in both channels
- No sign for the existence of new physics





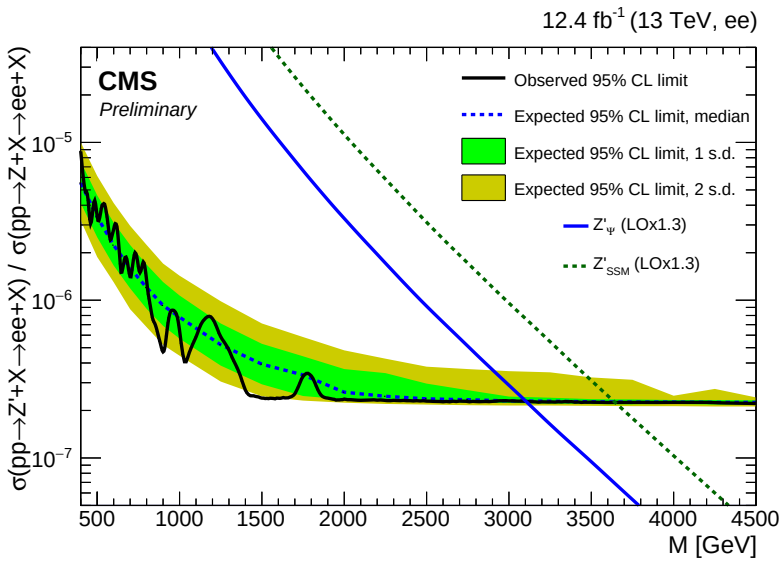
Statistical analysis

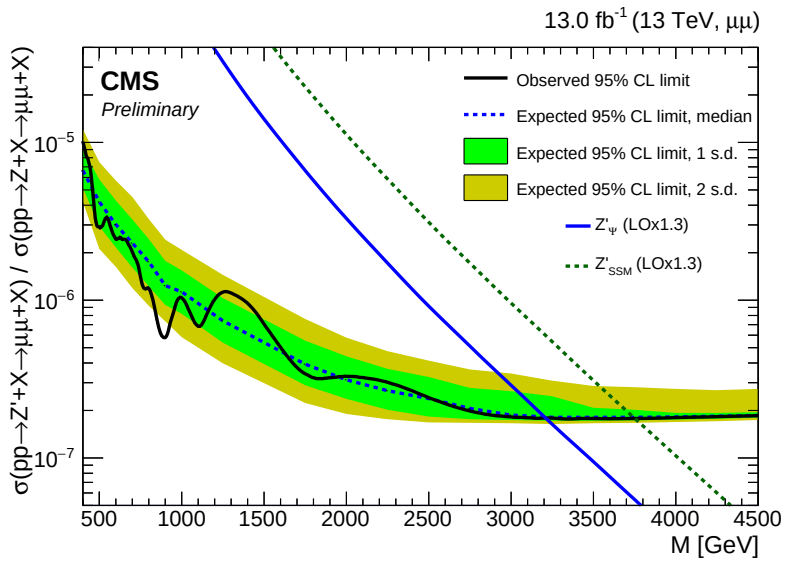
- For statistical interpretation we perform an unbinned maximum likelihood fit to the mass distribution
- Signal modelled as Breit-Wigner $\otimes$ Gaussian assuming narrow width (0.6%)
- Systematic uncertainties modelled with log-normal distribution
- Bayesian limits calculated using a Markov-Chain MC



Statistical analysis

- For statistical interpretation we perform an unbinned maximum likelihood fit to the mass distribution
- Signal modelled as Breit-Wigner $\otimes$ Gaussian assuming narrow width (0.6%)
- Systematic uncertainties modelled with log-normal distribution
- Bayesian limits calculated using a Markov-Chain MC

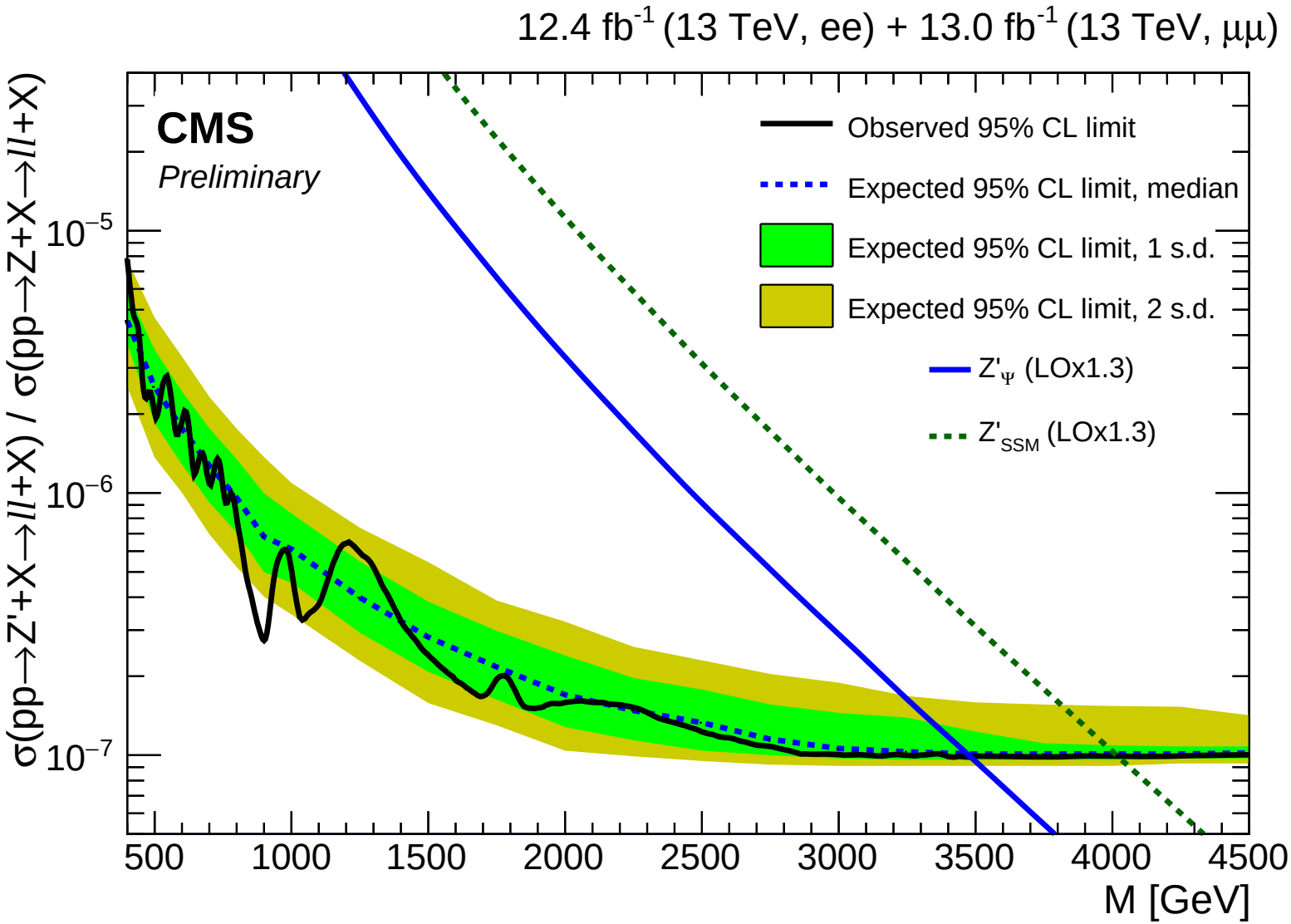




- Interpreted in SSM Z' and $E(6)$ GUT inspired Z'_ψ

Combined limits

- Channels combined for more stringent limits
- Lower limit of 4 TeV for SSM Z' and 3.5 TeV for Z'_ψ



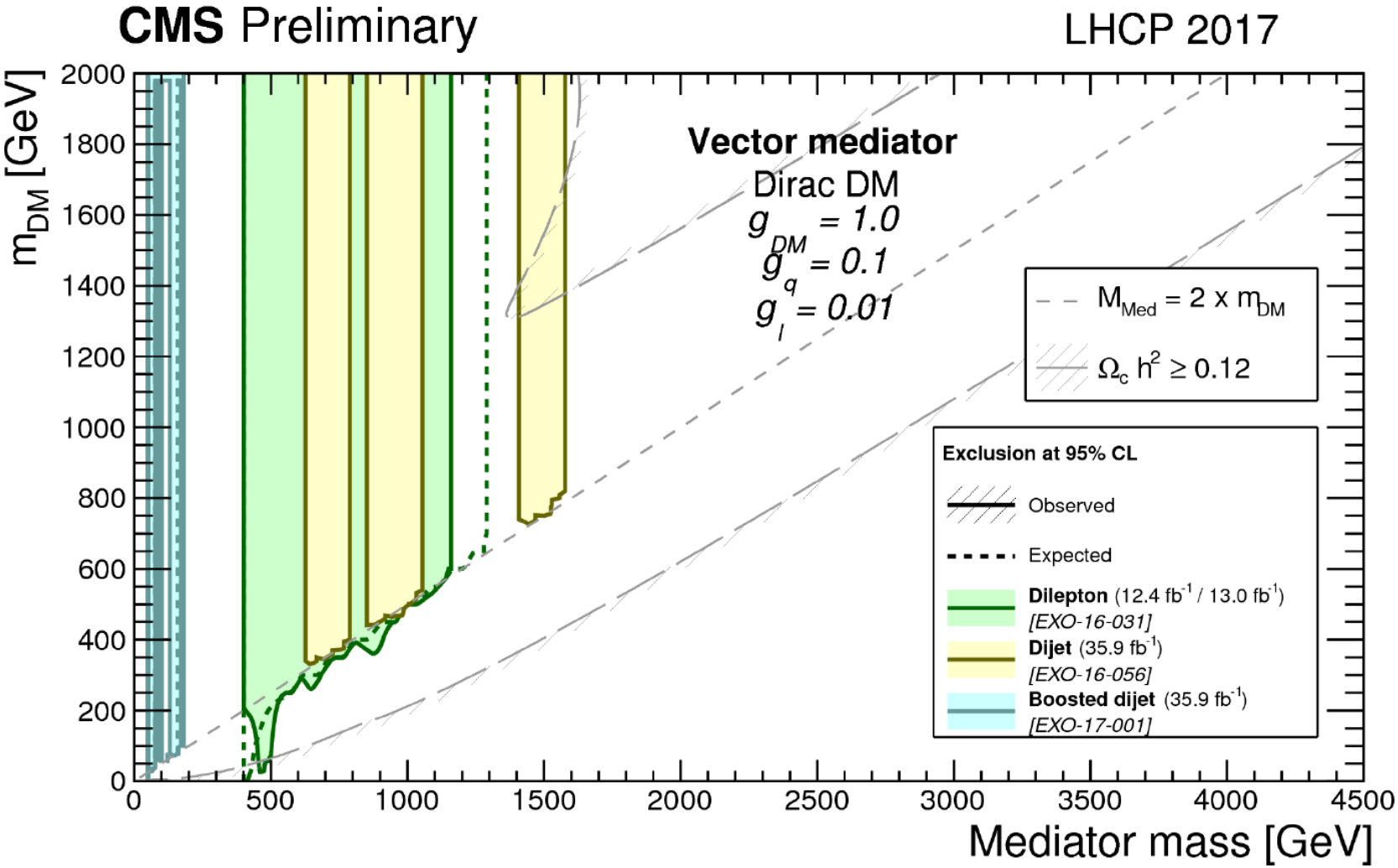
Dark Matter reinterpretation

- Dark Matter interpretation of LHC analyses have gained popularity later
- A variety of possible final states are considered
- Interpretation is done in Simplified Models which assume the existence of a mediator particle which is produced in the proton-proton collisions and can decay into the DM particle
- But we have actually higher sensitivity to these mediators looking for their decay back into SM particles
- Dilepton channel is latest addition to this search strategy

- LHC Dark Matter working group formulated two benchmark points
  - Vector mediator with couplings to DM, quarks, leptons of $g_{\mathrm{DM}} = 1.0$, $g_q = 0.1$ and $g_\ell = 0.01$
  - Axial-Vector mediator with $g_{\mathrm{DM}} = 1.0$, $g_q = 0.1$ and $g_\ell = 0.1$

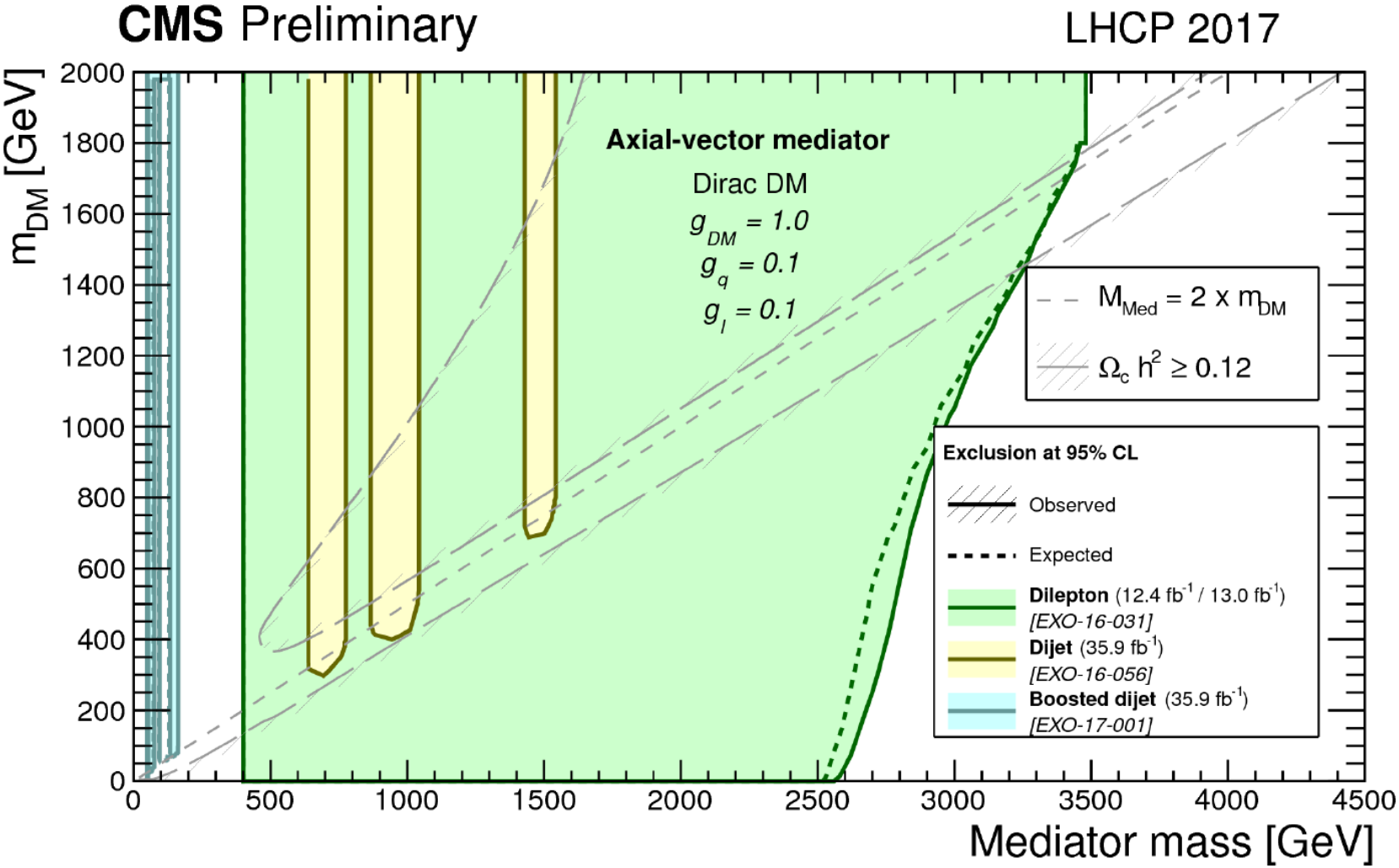
- Analysis reinterpreted taking into account varying decay width over the M_{DM}-M_{Med} mass plane

Vector Model



- Relatively small mass limits because of the small lepton couplings in this model
- Limit on mediator mass up to 1.2 TeV depending on DM mass

Axial-Vector Model



- Much stronger limit because of higher lepton coupling of the mediator
- Excludes mediator masses below 2.5-3.4 TeV, depending on DM mass
- Vastly improves limits set by dijet analyses

Summary & Outlook

- Search for new physics in the dilepton invariant mass spectrum offers excellent discovery potential
- Current CMS results have sensitivity to new particles with masses up to 4 TeV, depending on the model
- Dark Matter reinterpretation as recently been added, making this search even more interesting

- New result with the full 2016 dataset is almost ready for publication, expected very soon
- Will increase sensitivity by a couple of 100 GeV
- Significant expansion of the interpretation in preparation
  - Go beyond narrow width
  - Add interpretation in RS gravitons, more Z' models
  - Consider non-resonant signature in Contact Interaction and ADD extra dimensions