TeV Scale Resonances in CMS

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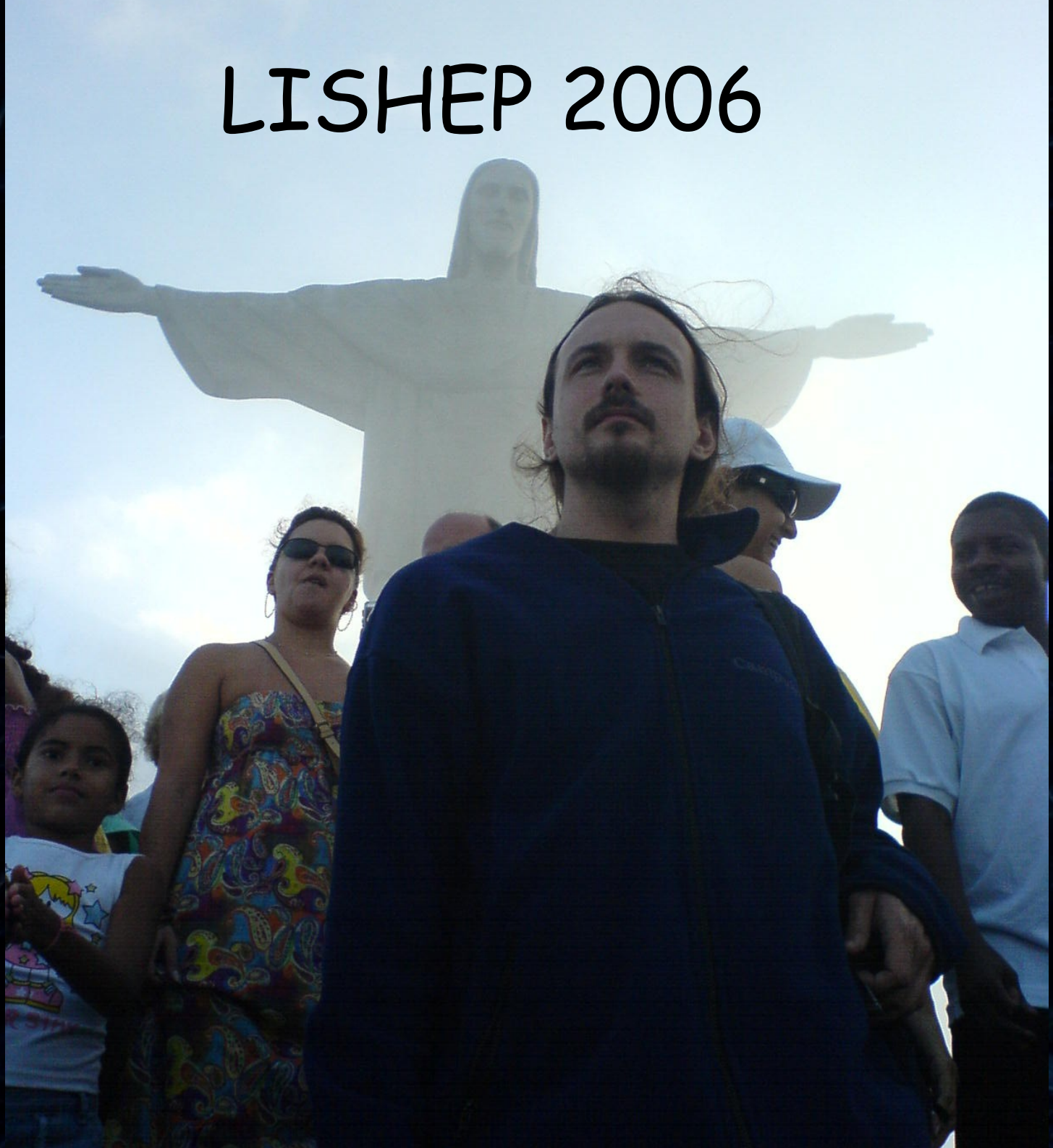
(CALTECH)
For the CMS Collaboration

LISHEP 2011
Rio de Janeiro

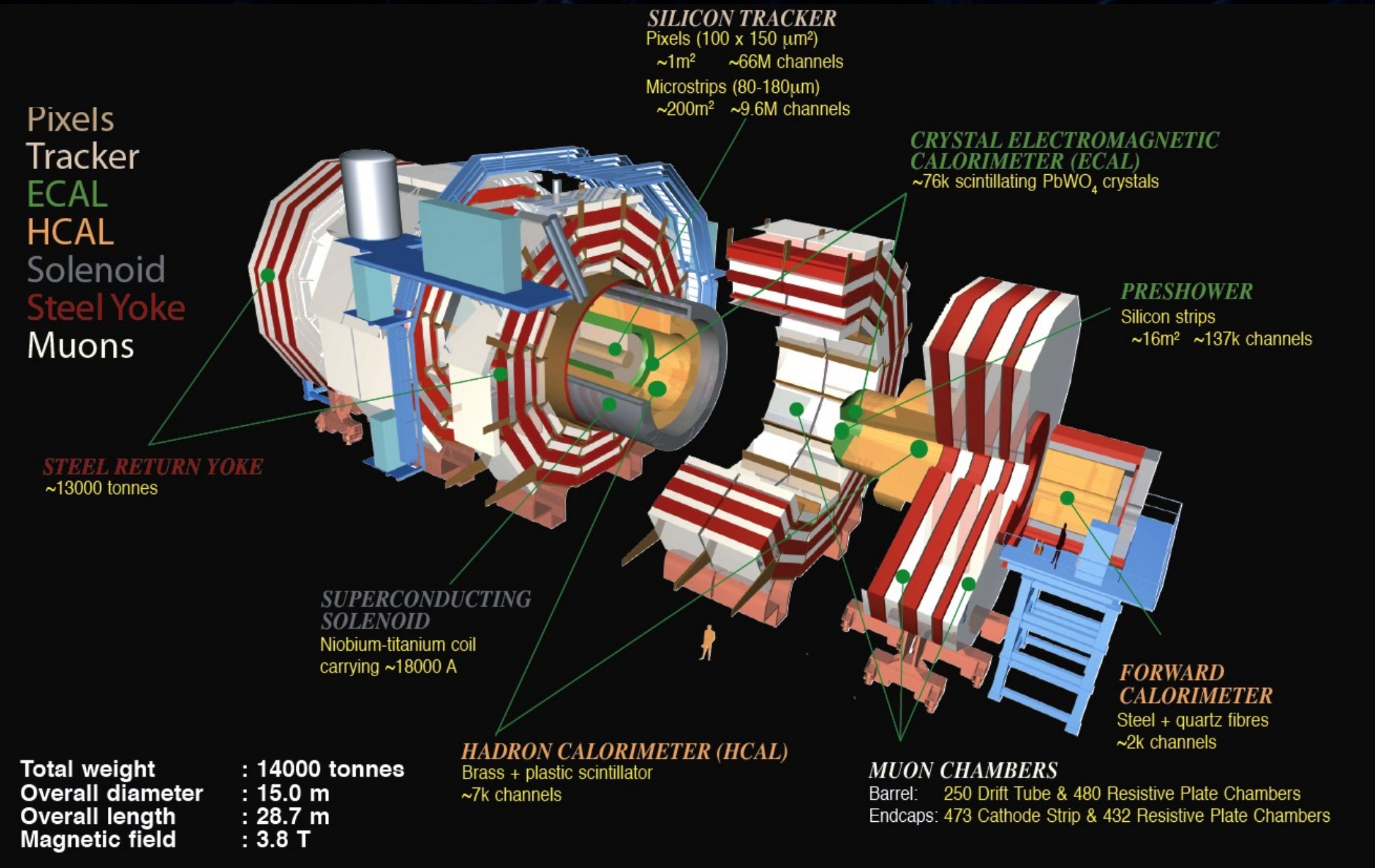
LISHEP 2006



Outline

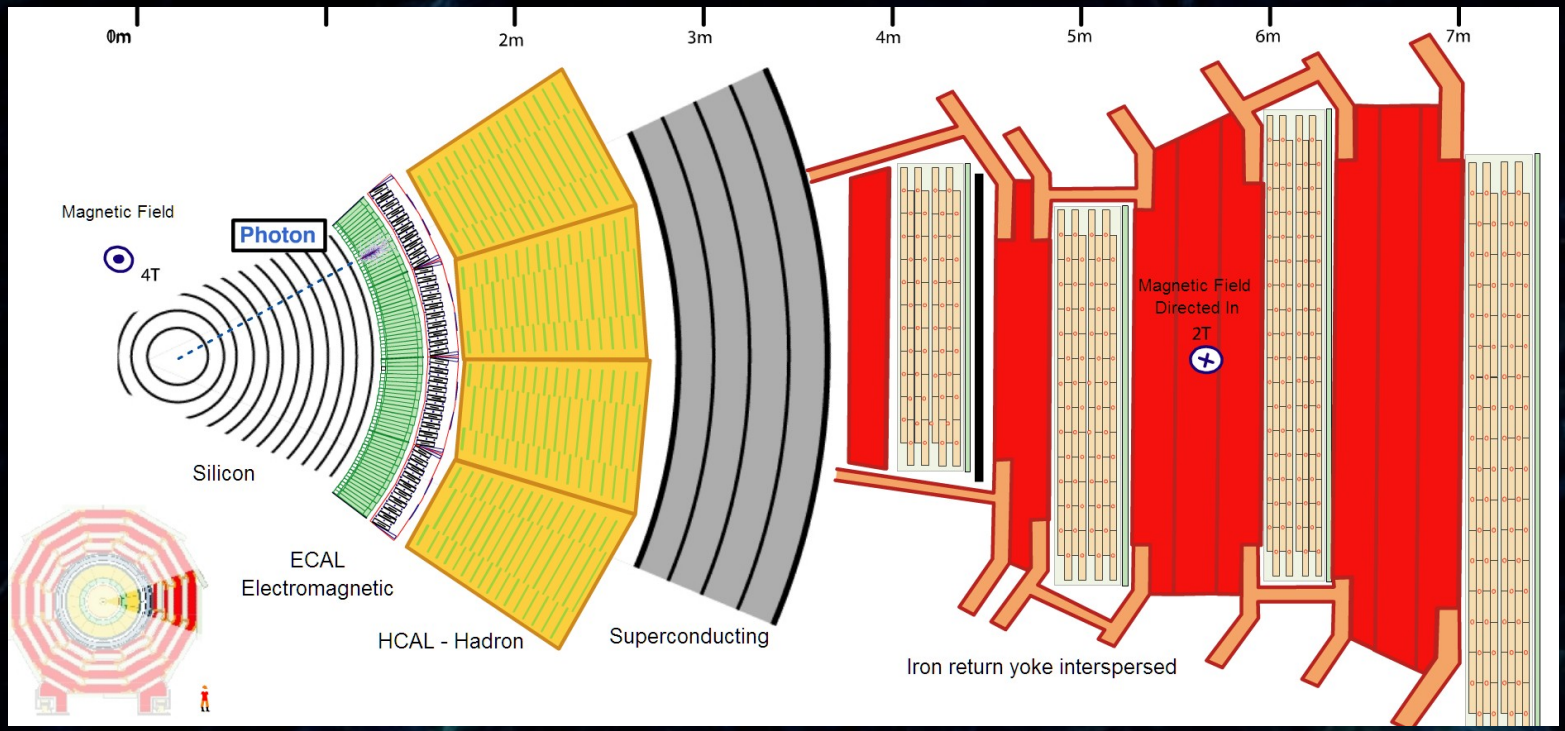
- The CMS detector
- Object reconstruction
- TeV scale resonance searches

The CMS detector



Photon Identification

- Photon = deposit in ECAL, no track

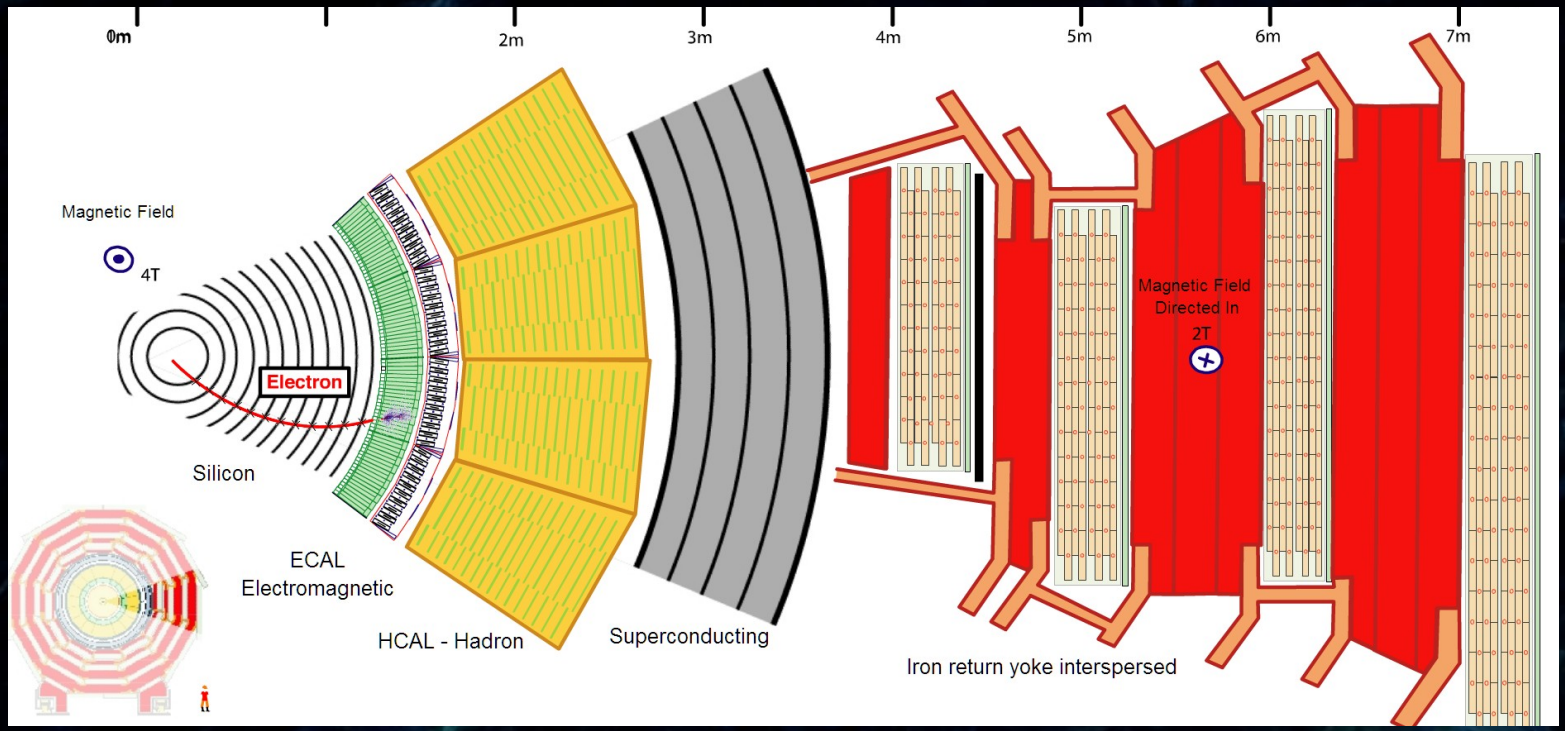


Photon Identification

- Photon = deposit in ECAL, no track
- Identification requirements:
  - Tracker Isolation $E_T < 2.0 + 0.001 * E_T^{SC}$
  - ECAL Isolation $E_T < 4.2 + 0.006 * E_T^{SC}$
  - HCAL Isolation $E_T < 2.2 + 0.025 * E_T^{SC}$
  - H/E (ratio of HCAL/ECAL energy) < 0.05
  - Shower shape selection (require small spread in eta)
  - (optional) Pixel match veto – reject events with pixel track compatible with the supercluster

Electron Identification

- Electron = deposit in ECAL + Tracker track
- Dedicated reconstruction of high energy electrons

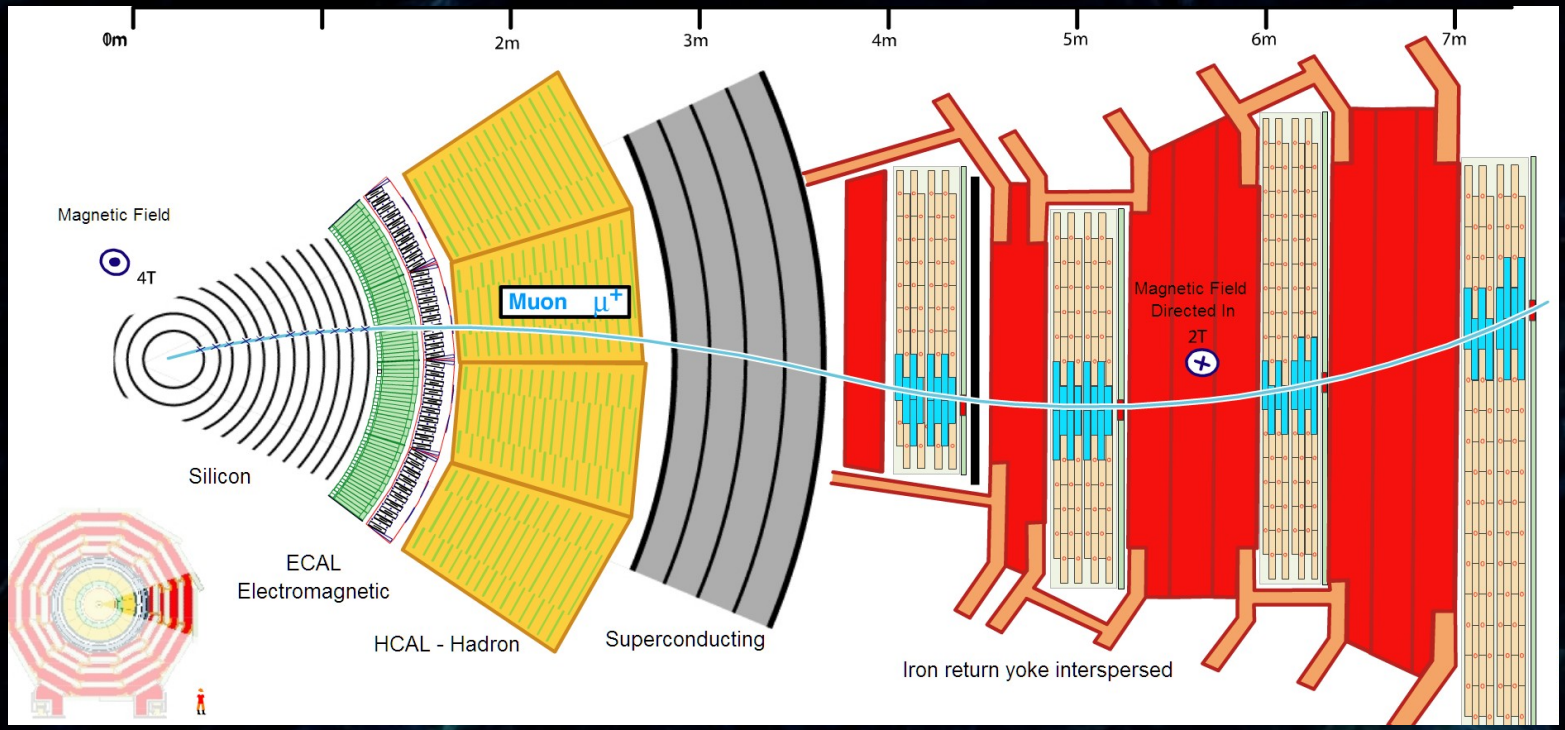


Electron Identification

- Electron = deposit in ECAL + Tracker track
- Dedicated reconstruction of high energy electrons
  - Energy measurement from ECAL supercluster energy
  - Require electron to be „ECAL driven"
  - Reject superclusters close to the gap between barrel and endcap
  - Matching between the supercluster and tracker track
  - H/E (ratio of HCAL/ECAL energy) < 0.05
  - Isolation in ECAL, HCAL and Tracker
  - Shower shape selection (require small spread in eta)

Muon Identification

- Muon = Tracker track + track in the Muon System
- High pT muon momentum measurement challenging due to very small curvature and electromagnetic showering in the iron yoke



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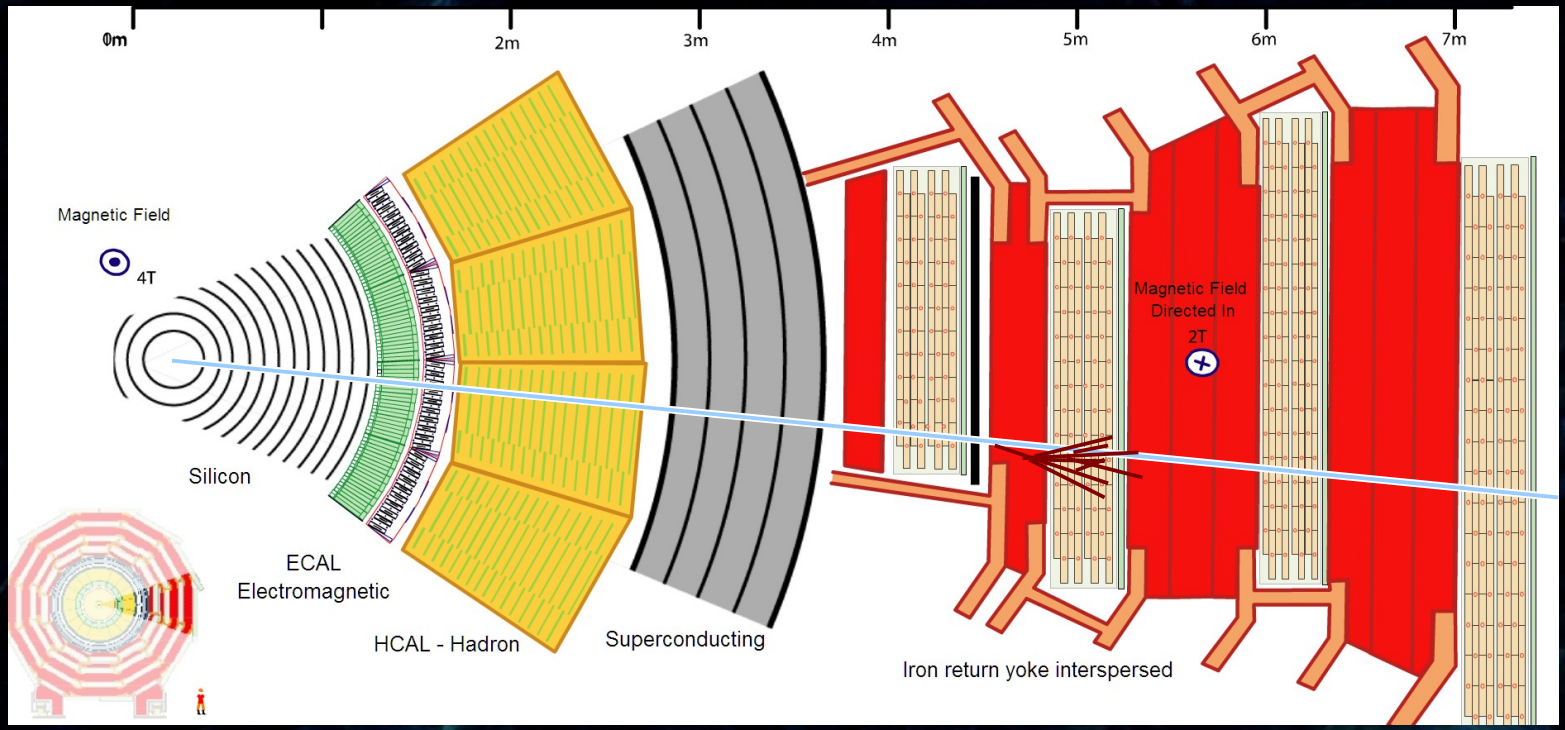
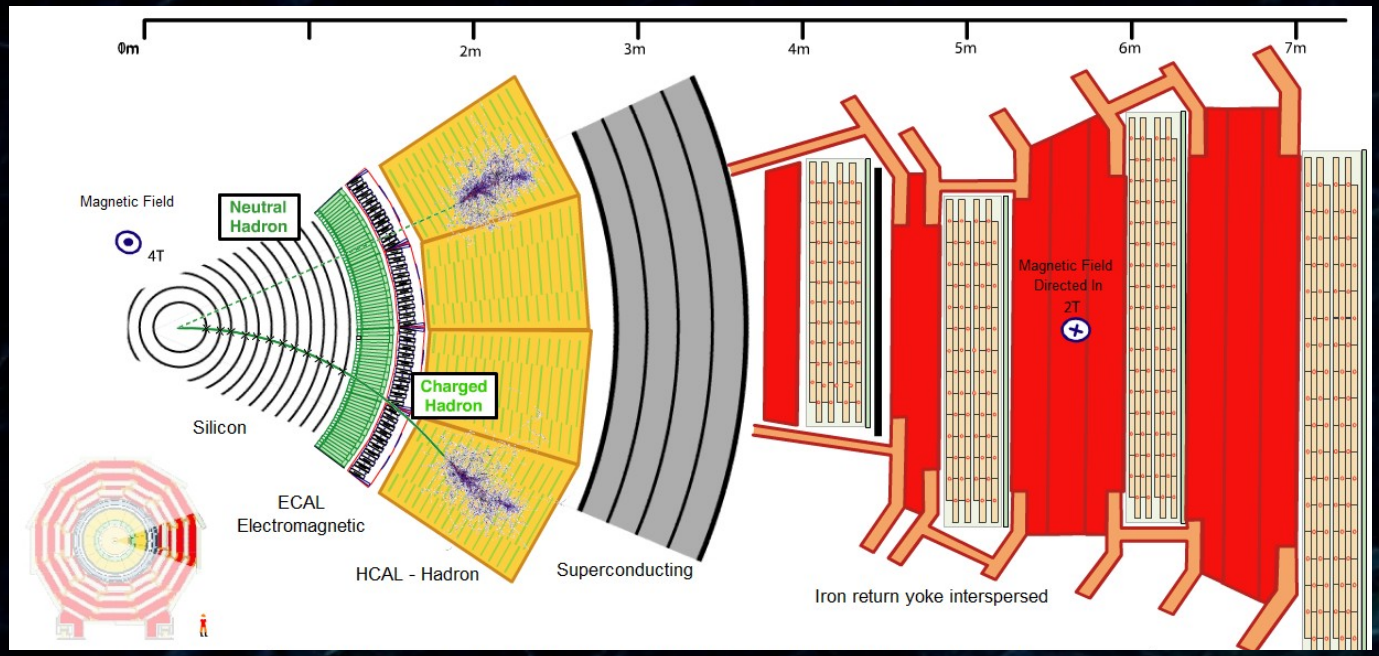


Muon Identification

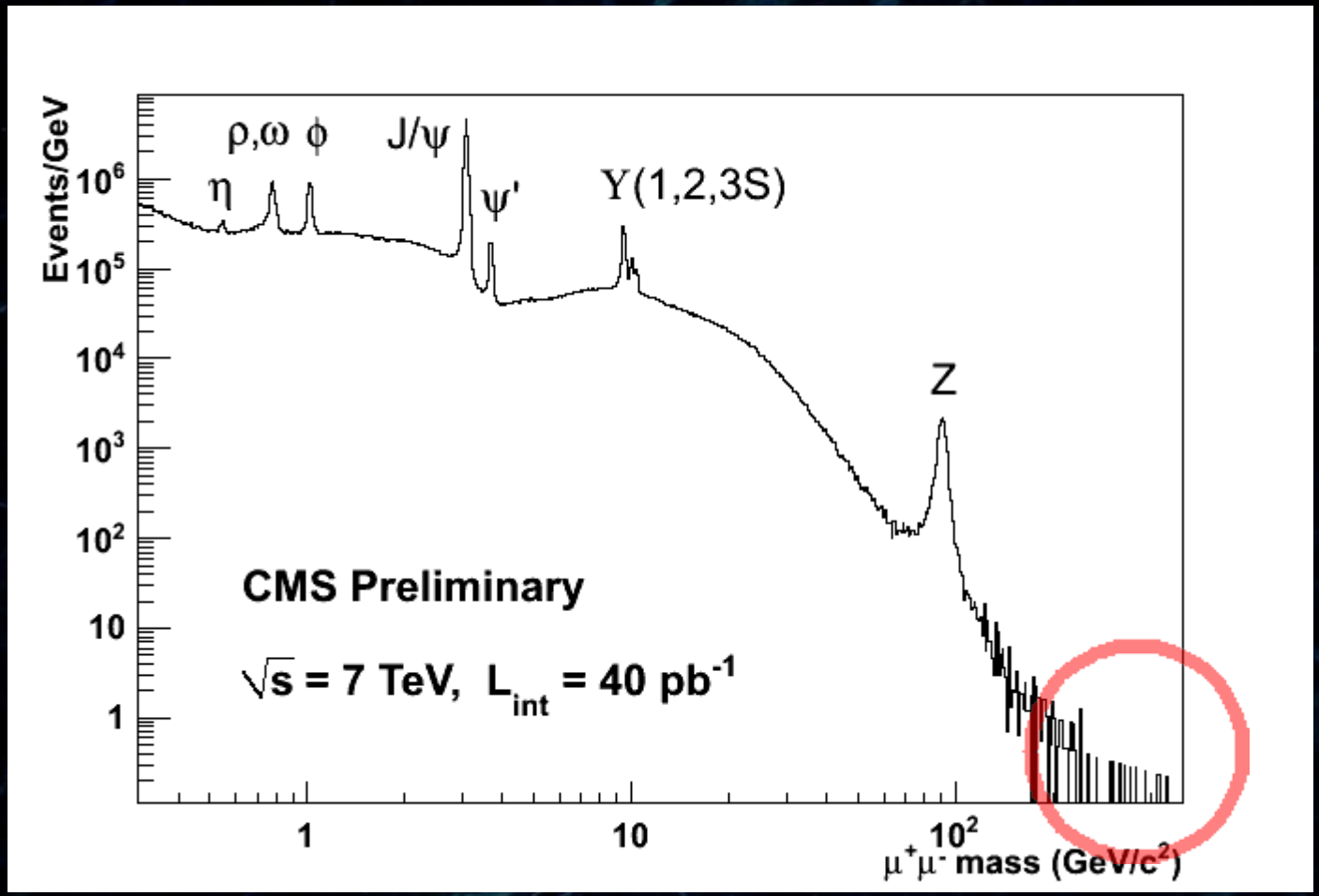
- Muon = Tracker track + track in the Muon System
- High pT muon momentum measurement challenging due to very small curvature and electromagnetic showering in the iron yoke
- Identification requirements:
  - Reconstructed by both outside in „global muon" and inside out „tracker muon" algorithm, global track χ^2/ndf < 10
  - Number of matched muon stations with track segments > 1
  - Number of tracker hits > 10, number of pixel hits > 0
  - Impact parameter with respect to primary vertex < 2mm
- Dedicated momentum reconstruction for high pT, including rejection of muon stations with showers etc.

Jet identification

- Jets identified using a particle flow algorithm
  - combining tracker and calorimeter information to reconstruct the full list of particles in the event
  - Particles are then clustered into jets
  - Anti-k_t algorithm used for clustering (0.5, 0.7 cone sizes)



The Analyses


Events/GeV
10^6
10^5
10^4
10^3
10^2
10
1
ρ,ω φ
η
J/ψ
ψ'
Υ(1,2,3S)
Z
CMS Preliminary
$\sqrt{s}$ = 7 TeV, L_{int} = 40 pb^{-1}
1
10
10^2
$\mu^+\mu^-$ mass (GeV/c^2)

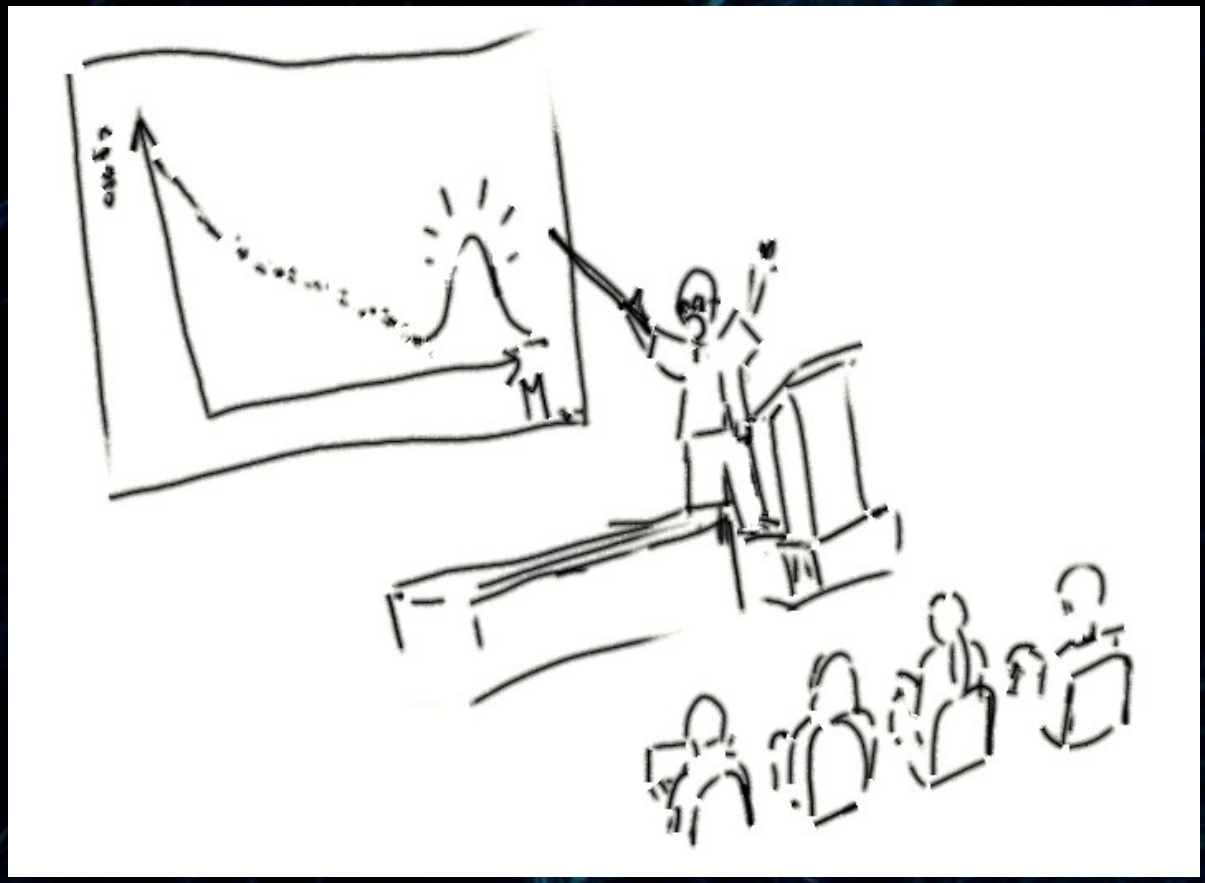
Di-lepton resonances

- Theoretical motivation:
  - A new heavy gauge boson Z' is predicted in a number of BSM theories
  - Benchmark models: Z'_{SSM}, GUT-inspired Z'_{ψ} and Randall-Sundrum gravitons
- Signal process: $qq \rightarrow Z'/G^* \rightarrow l^+l^-$; $gg \rightarrow G^* \rightarrow l^+l^-$
- Backgrounds
  - Drell-Yan di-leptons
  - Other sources of dileptons: $t\bar{t}$, tW, dibosons
  - Misidentified leptons: W+jets, QCD
  - Cosmic-ray muons

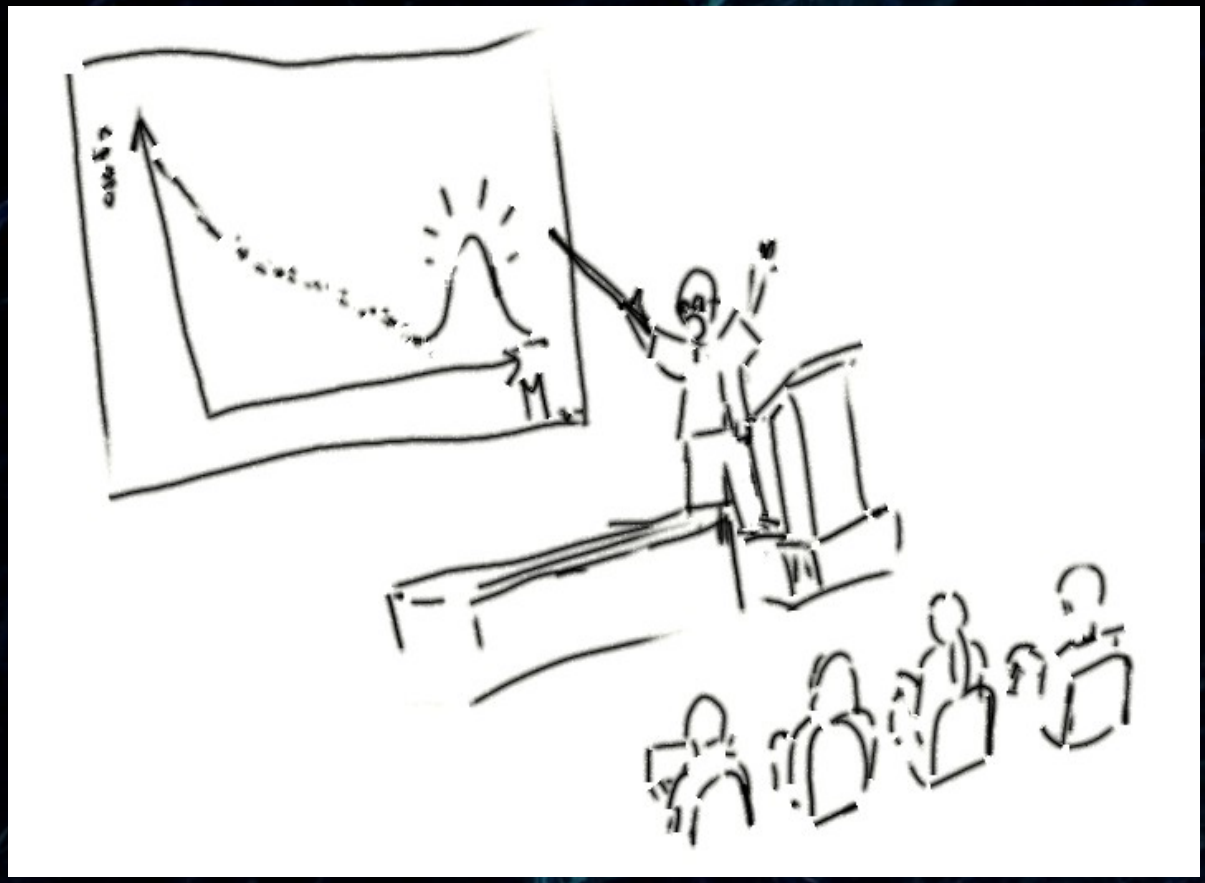
Di-lepton analysis

- Select events with a single muon (up to 15 GeV) or double ECAL cluster (up to 22 GeV) triggers
- Require two isolated reconstructed leptons (opposite charge requirement for muons)
- Cosmic-ray muons suppressed by rejecting events with back-to-back muons (require angle < π-0.02 rad)
- Analysis based on shape (unbinned maximum likelihood fits) – robust against normalization uncertainties
  - normalized to the Z^0 peak to convert the limit on number of signal events into a limit on cross-section
- Combine electron and muon likelihoods

Z'->dileptons results

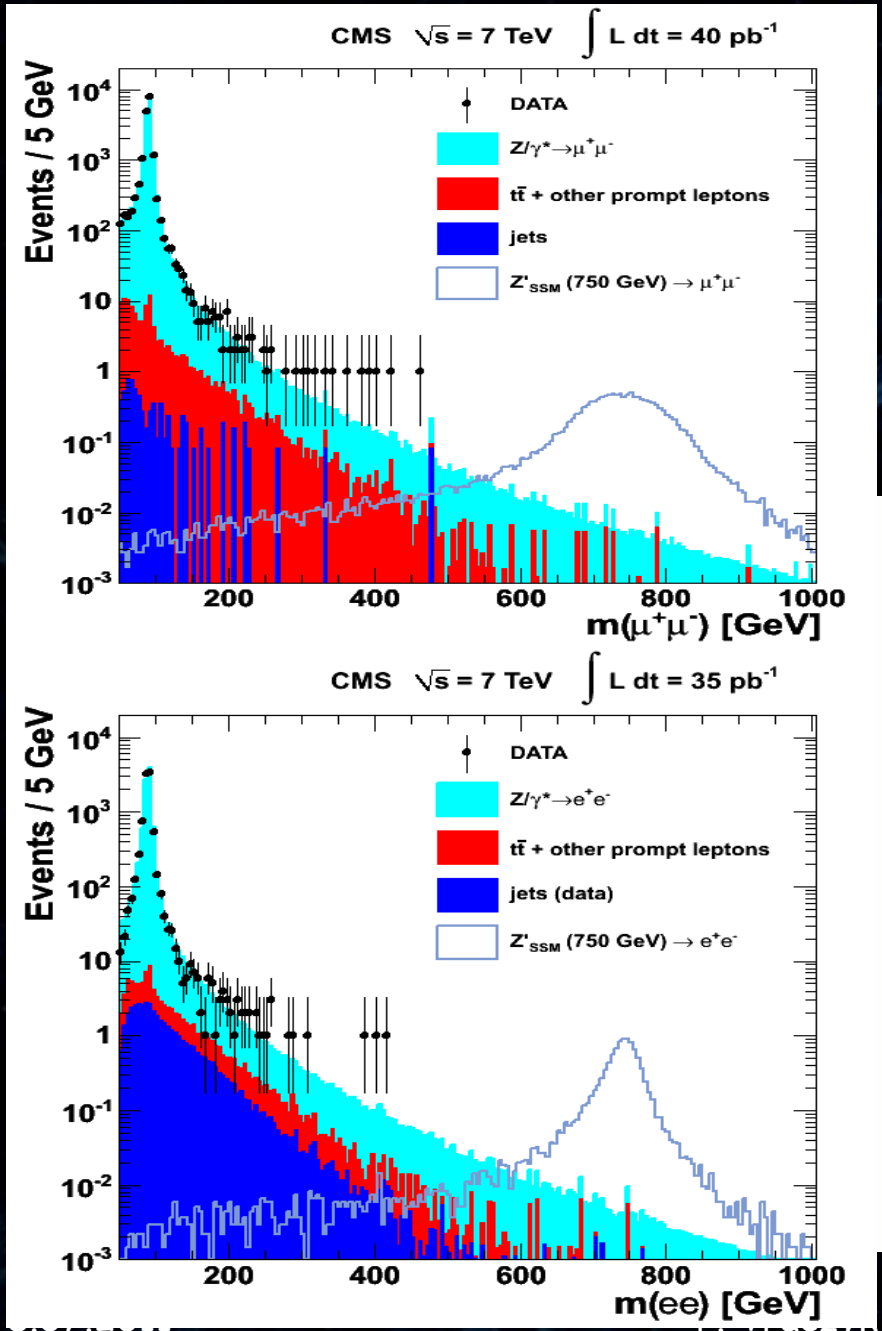


Z'->dileptons results



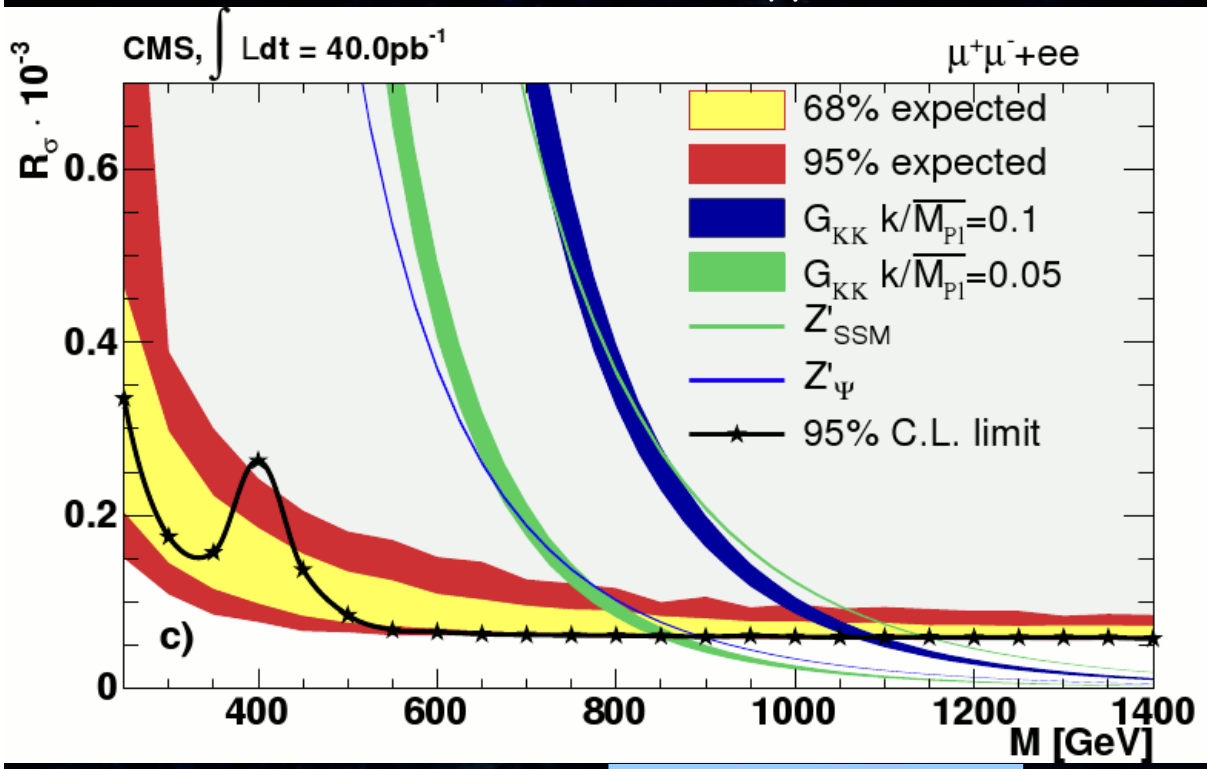
...not yet.

Z'->dileptons results



Exclude at 95% C.L.

Z'_{SSM} below 1140 GeV, Z_Ψ below 887 GeV, RS G^* below 855 (1079) GeV for k/M_{Pl}=0.05 (0.1)



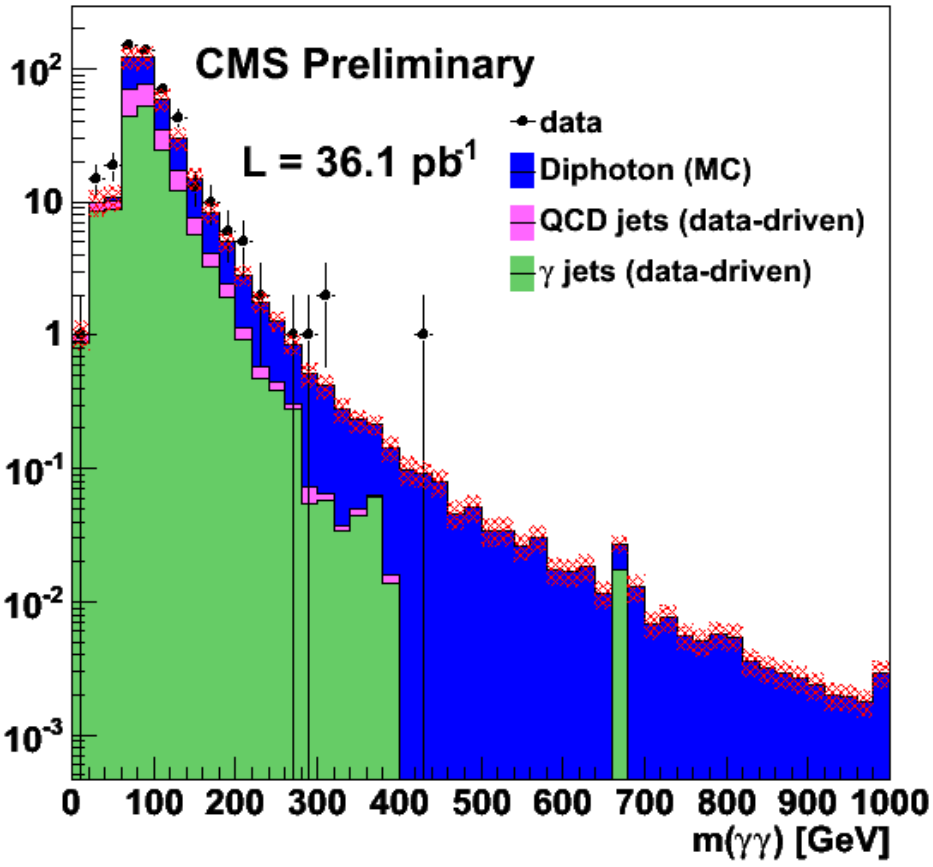
1103.0981 (hep-ex)

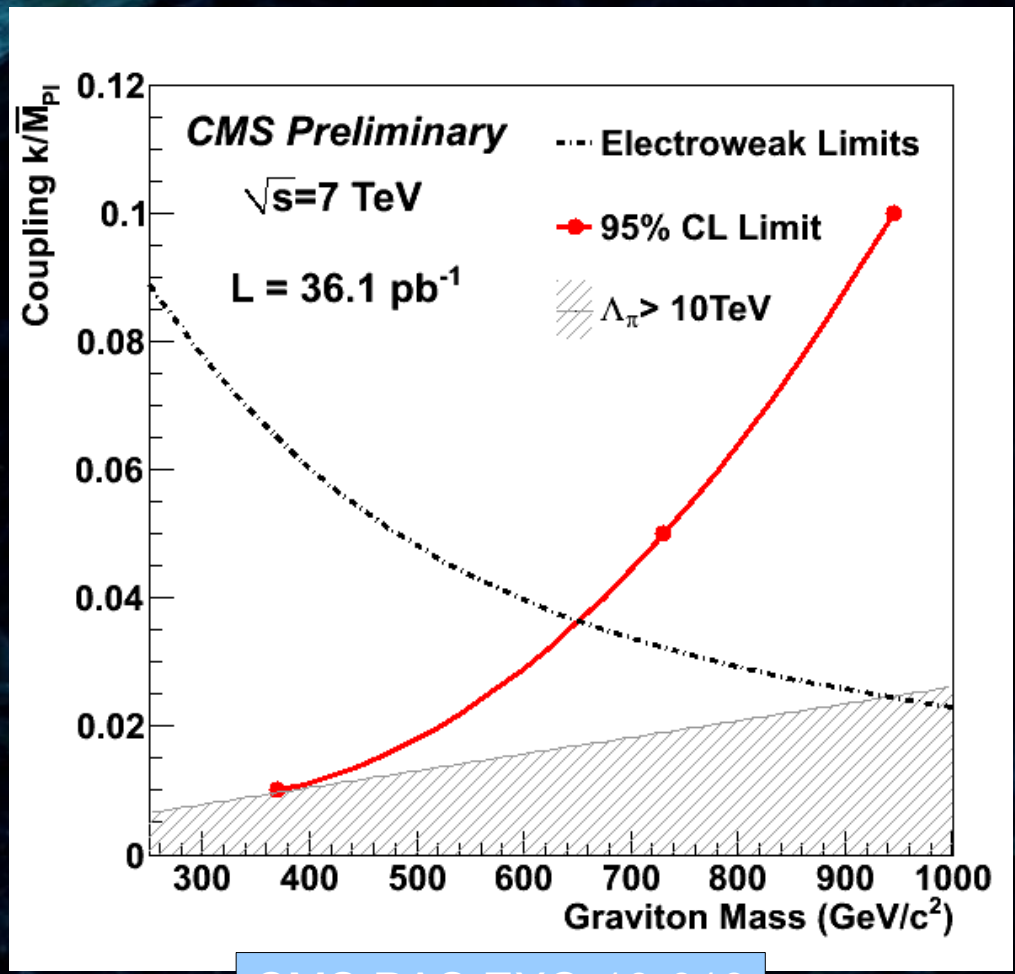
Di-photon resonances

- Theoretical motivation:
  - Unlike the Z', the RS graviton decays to photon pairs (BR 2x larger than the di-muon or di-electron decay)
- Signal process: $qq/gg \rightarrow G^* \rightarrow \gamma\gamma$
- Backgrounds:
  - SM prompt $\gamma\gamma$ production from quark annihilation ("Born") and gluon fusion ("Box") process
  - Events with misidentified photons: γ+jets, dijets, $Z \rightarrow ee$ - rates estimated from data
- Analysis: use double photon trigger (up to 17/22 GeV), select events with 2 photons in the ECAL barrel; count events above a mass cutoff

RS $G^* \rightarrow \gamma\gamma$ results

- RS gravitons excluded below 931 (729) GeV for k/M_{Pl}=0.1 (0.05)

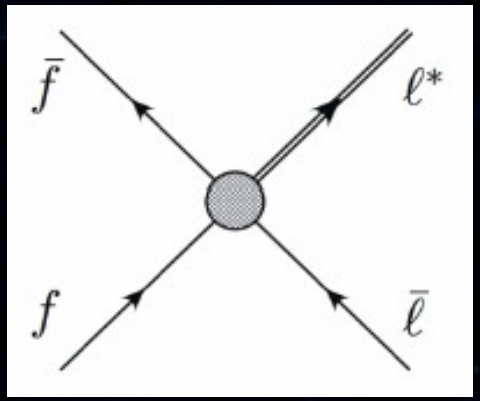




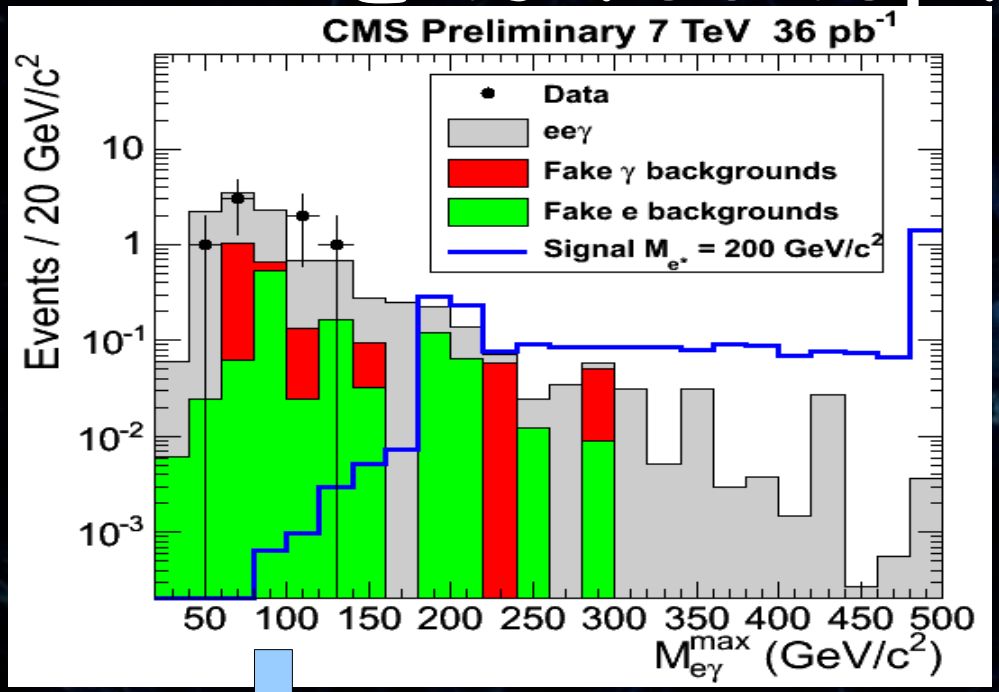
CMS PAS EXO-10-019

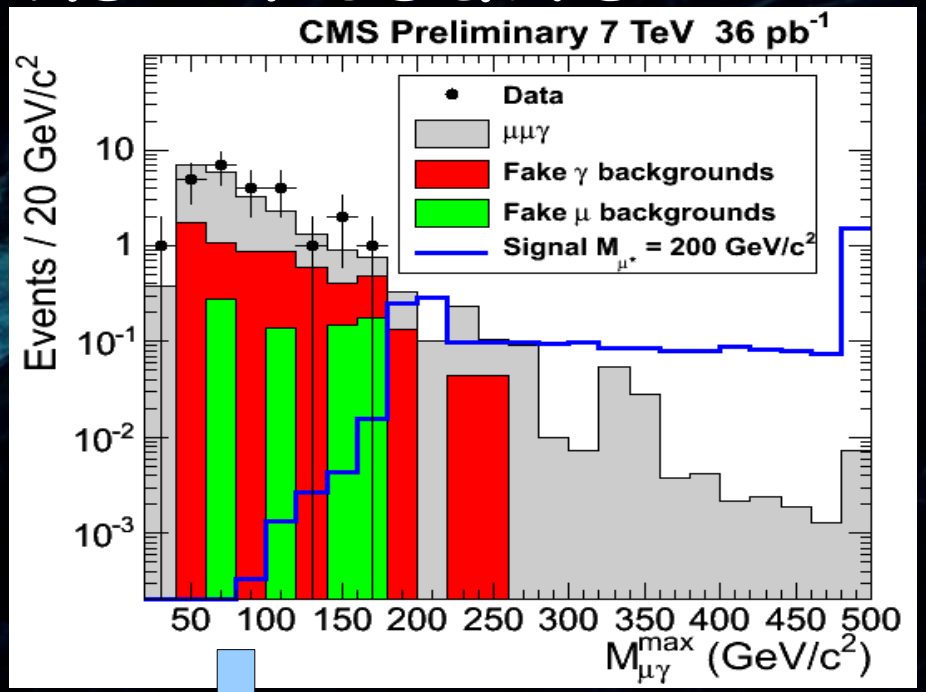
Lepton-photon resonances

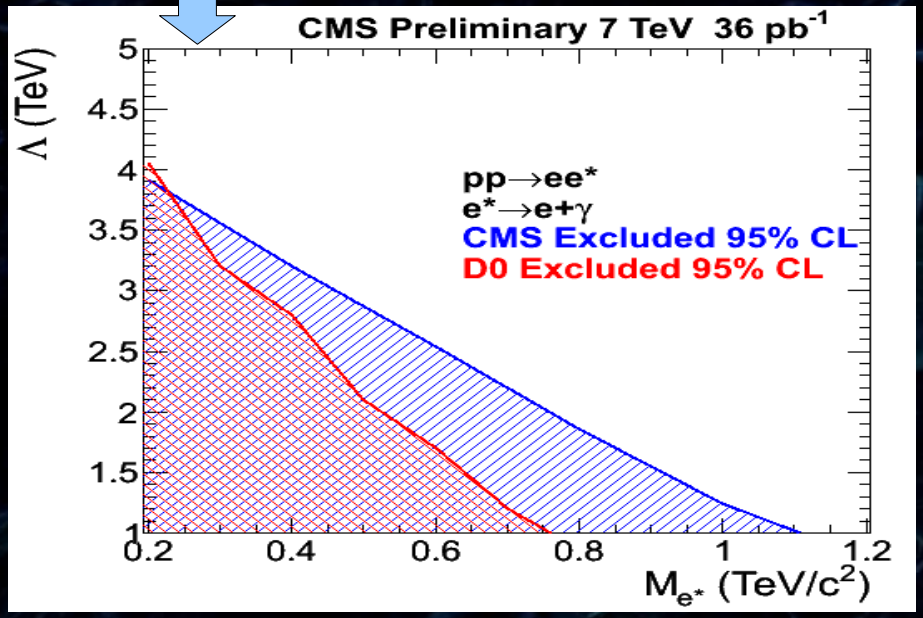
- Theoretical motivation:
  - Explaining the Standard Model lepton mass hierarchy through lepton sub-structure
- Signal process: $qq \rightarrow ll^* \rightarrow ll\gamma$
  - Two theory parameters: contact interaction scale Λ and excited lepton mass M*
- Backgrounds
  - Real $ll\gamma$ events: mainly $Z\gamma$, also dibosons, $t\bar{t}$, $\gamma\gamma$
  - Events with jets misidentified as leptons and photons: mainly Z+jets and $W\gamma$+jets – estimated from data
- Analysis: count events with an isolated photon and 2 isolated leptons above a $ll\gamma$ mass cutoff

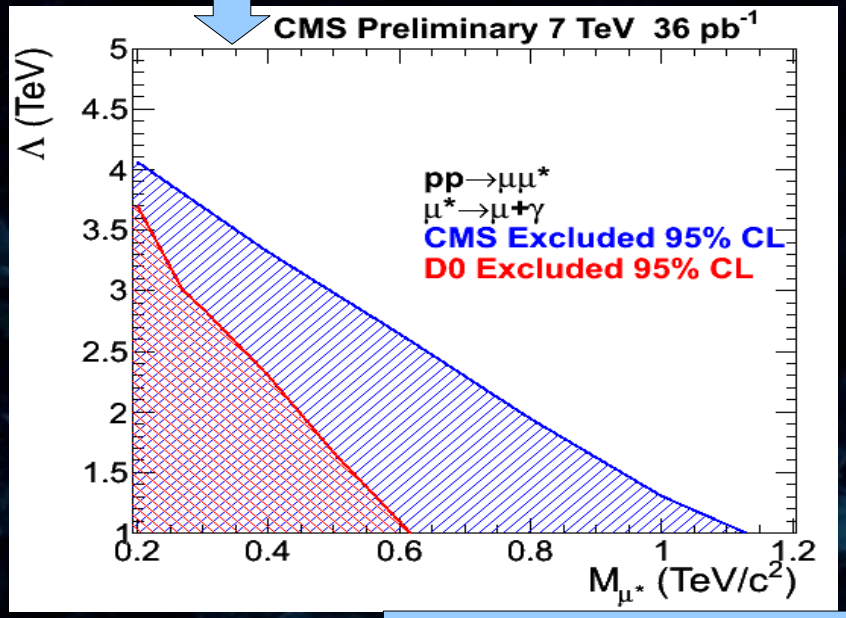


Excited leptons - results









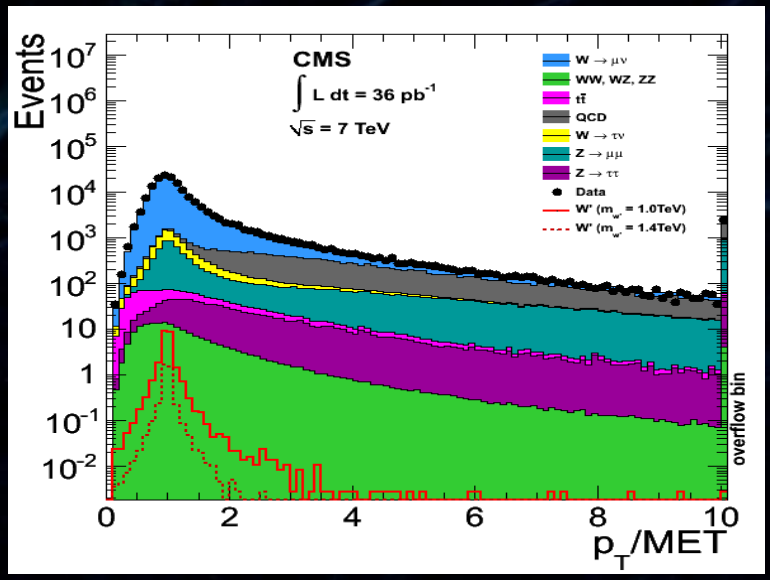
Lepton-neutrino resonances

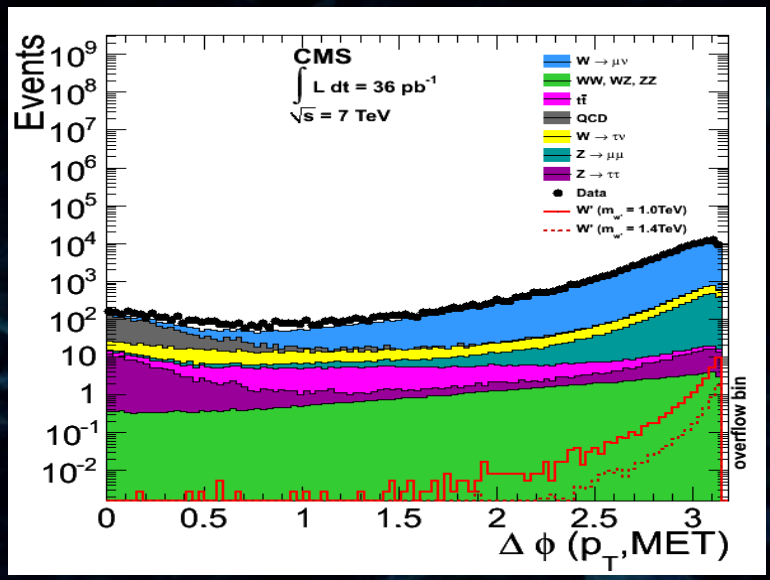
- Theoretical motivation:
  - New charged gauge bosons W' appearing in many SM extensions: LR-symmetric models, Little Higgs models, extra dimensions etc.
- Signal process $q\bar{q}' \rightarrow W' \rightarrow l\nu$
- Backgrounds
  - SM W production, $t\bar{t}$, dibosons, Drell-Yan
  - Misidentified leptons in QCD events (mainly electrons)
  - Cosmic-ray muons

$W' \rightarrow l\nu$ analysis

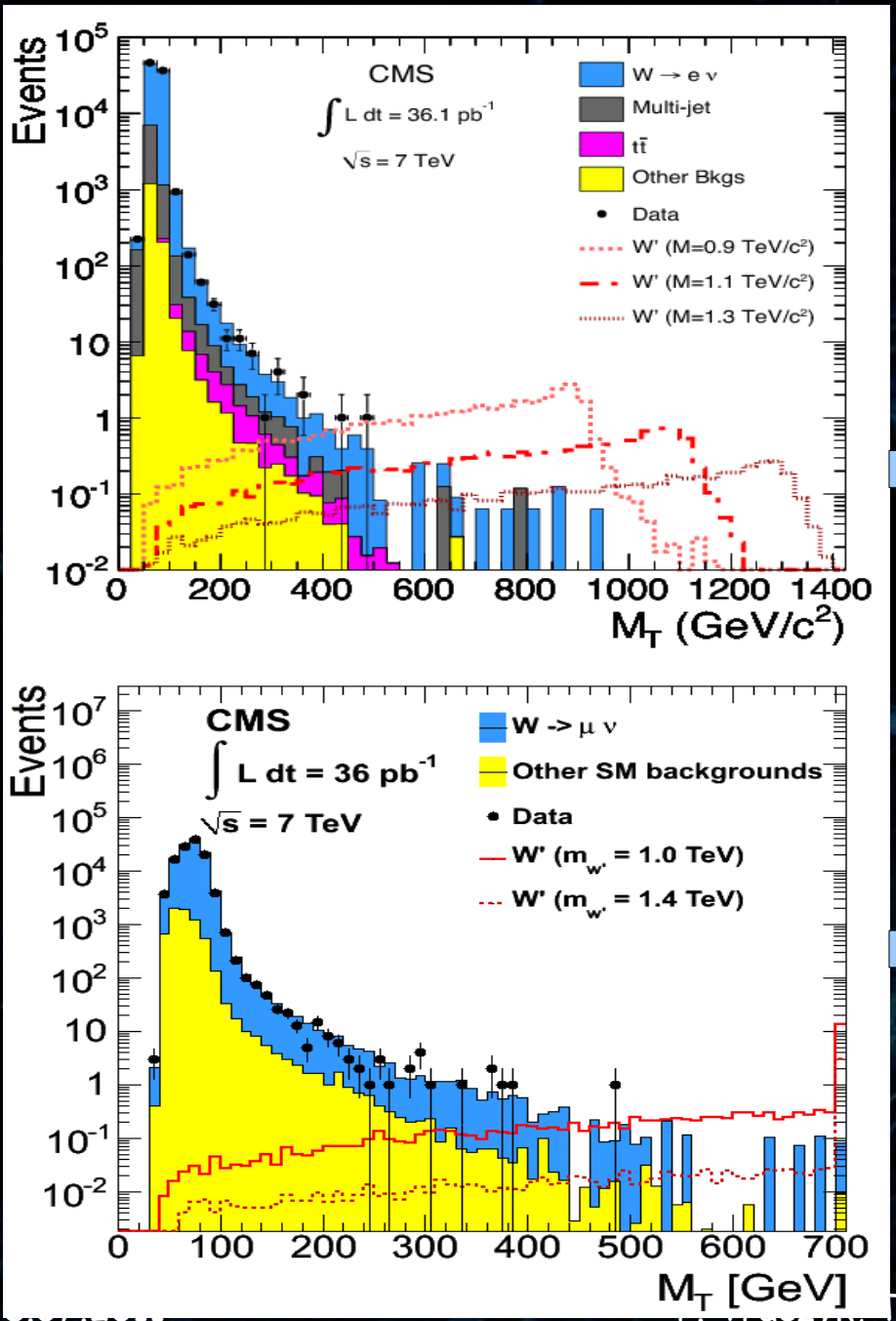
- Events selected with single electron/muon triggers
- Offline select events with a single isolated lepton
- Kinematic cuts: require lepton p_T to satisfy $0.4 < p_T/E^T_{miss} < 1.5$ and $\Delta\phi > 2.5$
- Additional cut on muon impact parameter d_{xy}<0.02 cm to remove cosmic-ray background
- Count events above an M_T cutoff

$$M_T = \sqrt{2(p_T^l \cdot c)E_T^{miss}(1 - \cos\Delta\phi_{l,\nu})}$$

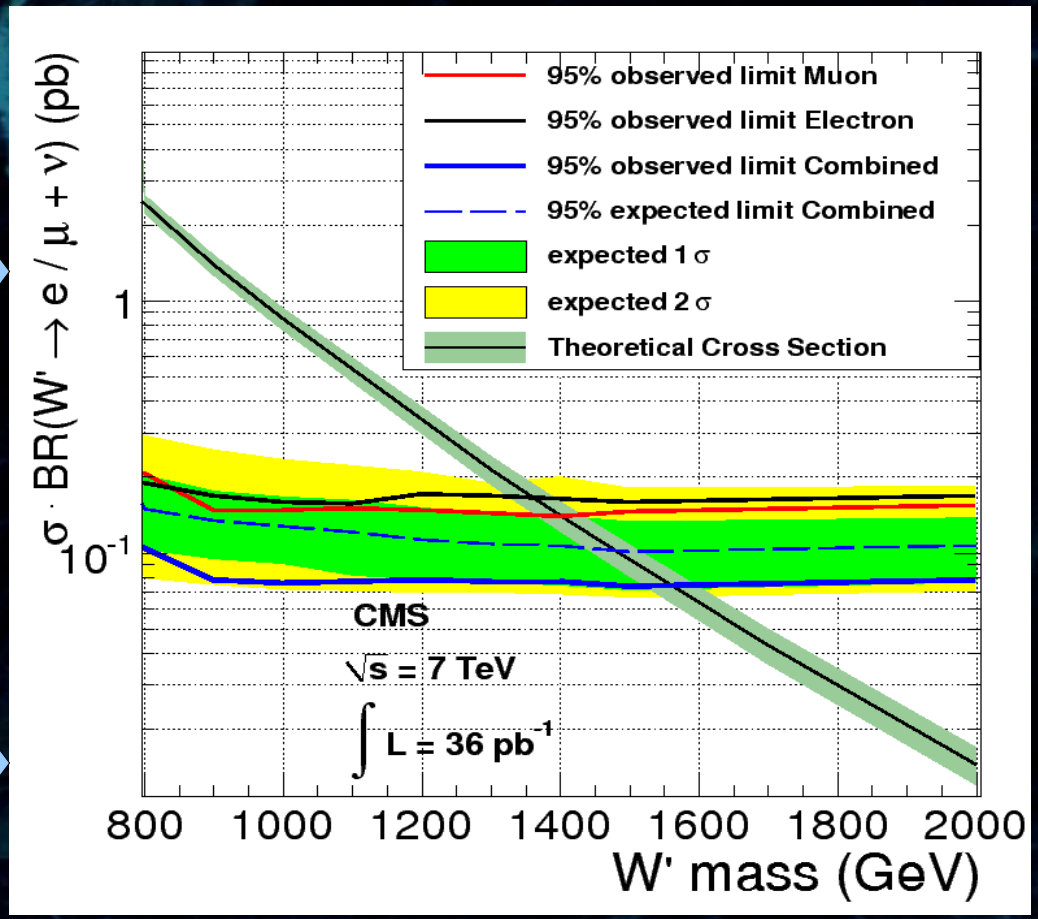




W′→lν results



10.1016/j.PhysLetB.2011.02.048
1103.0030 (hep-ex)



Combined 95% C.L. limit on W′ with SM-like couplings: 1.58 TeV

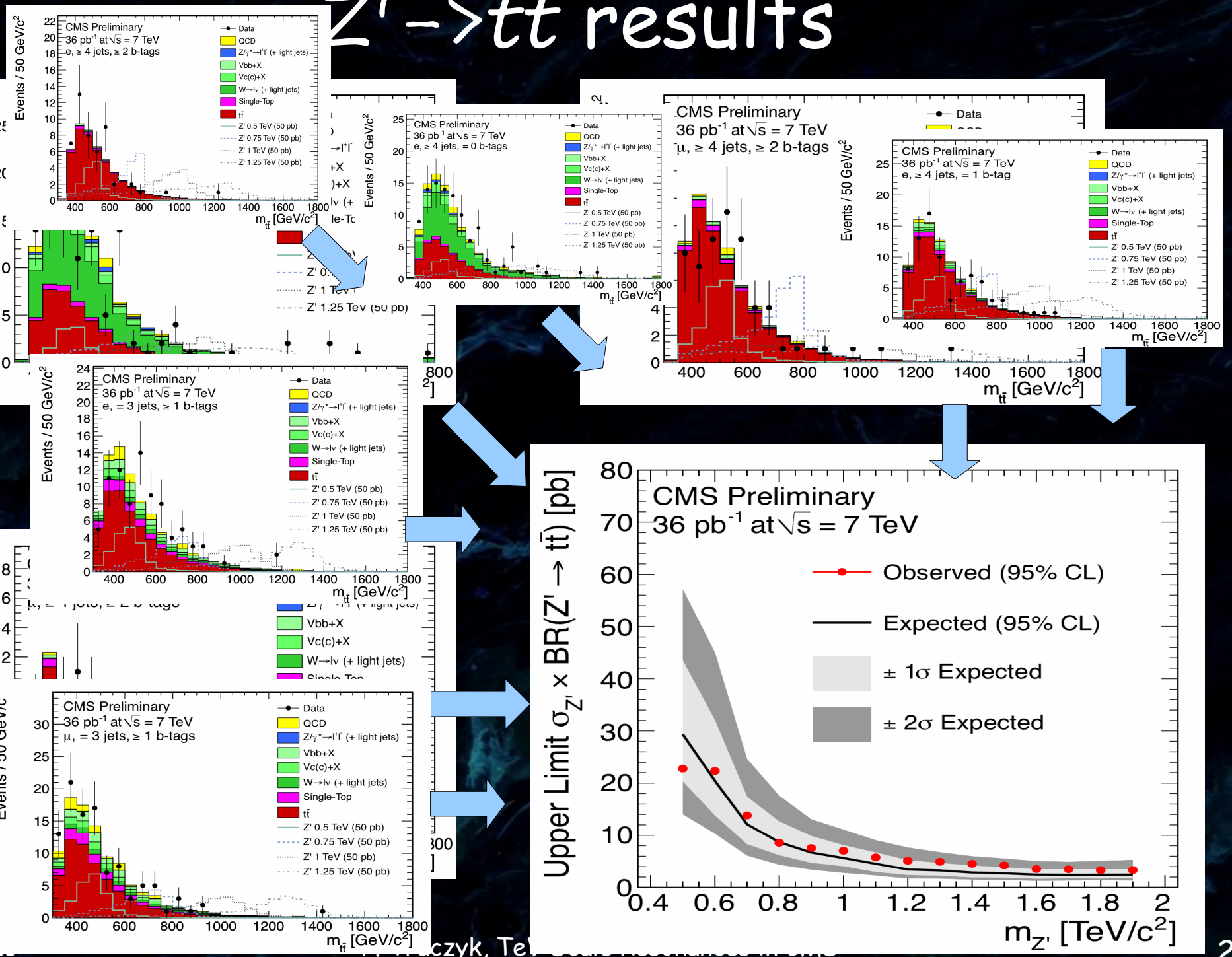
$t\bar{t}$ resonances

- Theoretical motivation:
  - New bosons with enhanced coupling to top quarks appear in many SM extensions (dynamical symmetry breaking, little higgs, extra dimensions etc)
- Signal process $qq \rightarrow Z' \rightarrow t\bar{t} \rightarrow WbWb \rightarrow l\nu+3j$
- Backgrounds
  - SM $t\bar{t}$ production, single top production
  - $W/Z/\gamma$ + jets (suppressed by requiring 3+ jets)
  - QCD multijet production (suppressed by lepton isolation requirement)

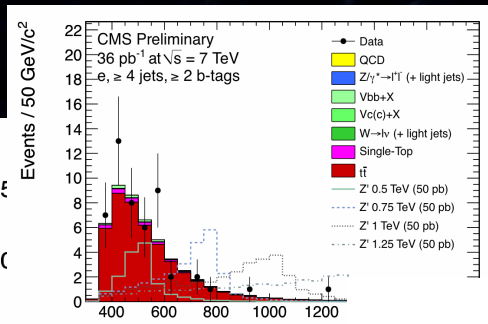
$t\bar{t}$ final state reconstruction

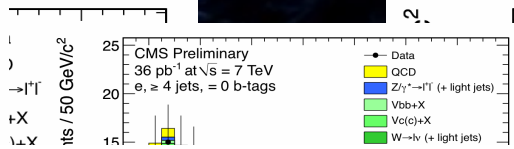
- Select events using a single electron/muon trigger
- Require exactly one isolated lepton and 3+ jets
- Analysis in 4x2 event categories:
  - Electron / muon
  - 3 jets (1 *b*-tag) / 4+ jets (no *b*-tag) /
    4+ jets (1 *b*-tag) / 4+ jets (2 *b*-tags)
- Jet *b*-tagging with secondary vertex reconstruction
  - tuned to give 2% mistag rate on 100 GeV light flavor jets and 60% efficiency for *b*-jets in $t\bar{t}$ decays in the barrel region
- Simultaneous unbinned maximum likelihood shape fits in all 8 categories to extract limits

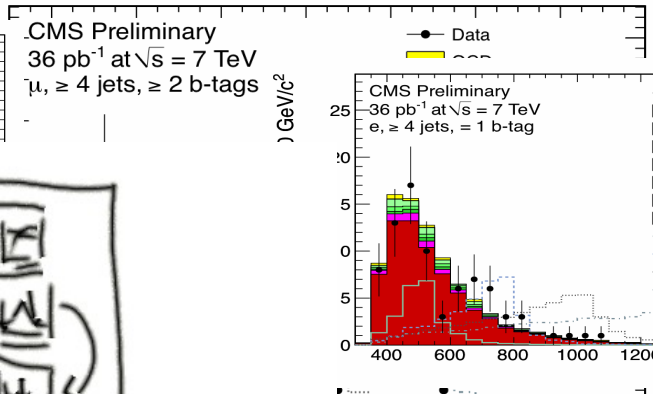
$Z' \to t\bar{t}$ results

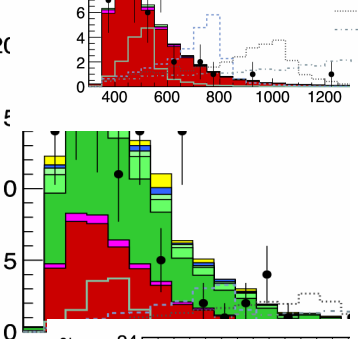


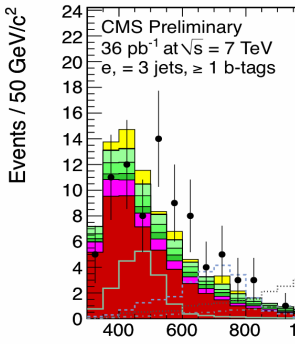
$Z' \to t\bar{t}$ results

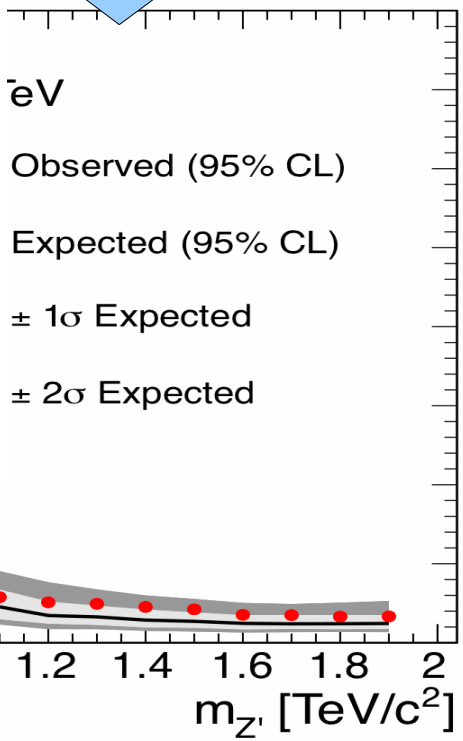


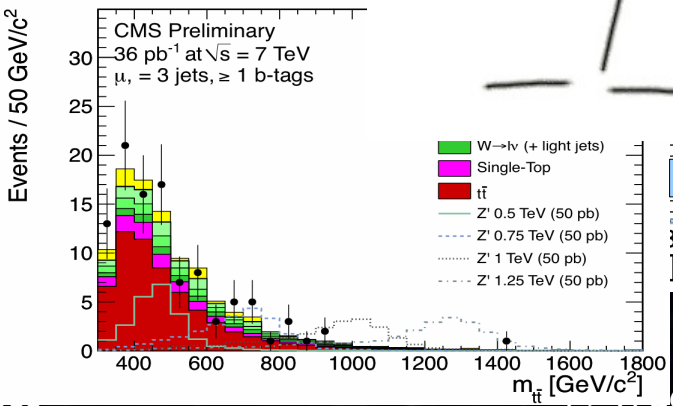


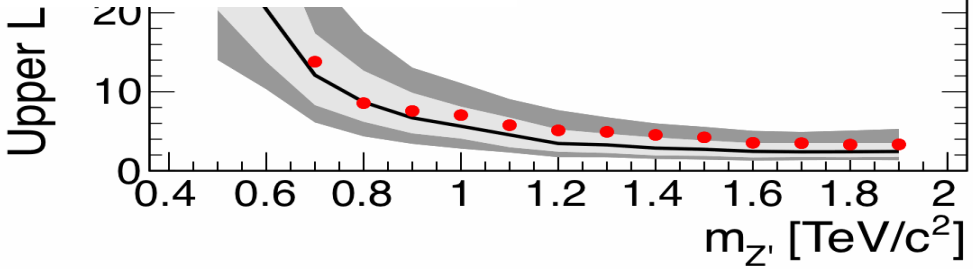




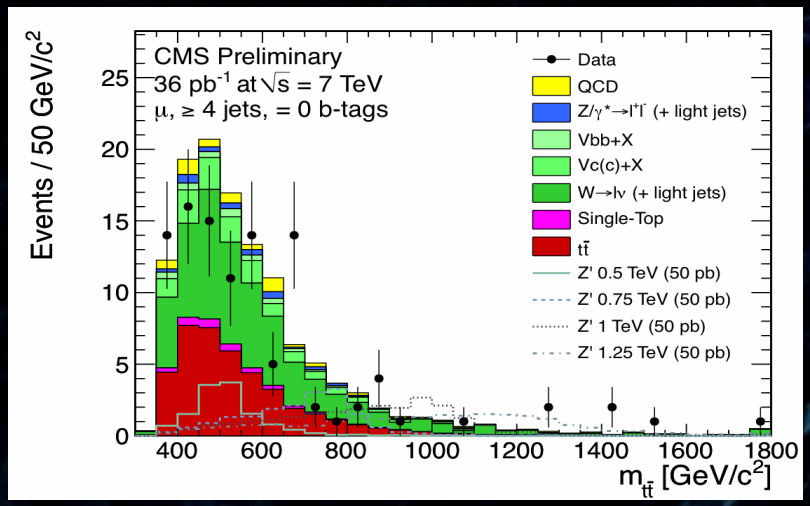


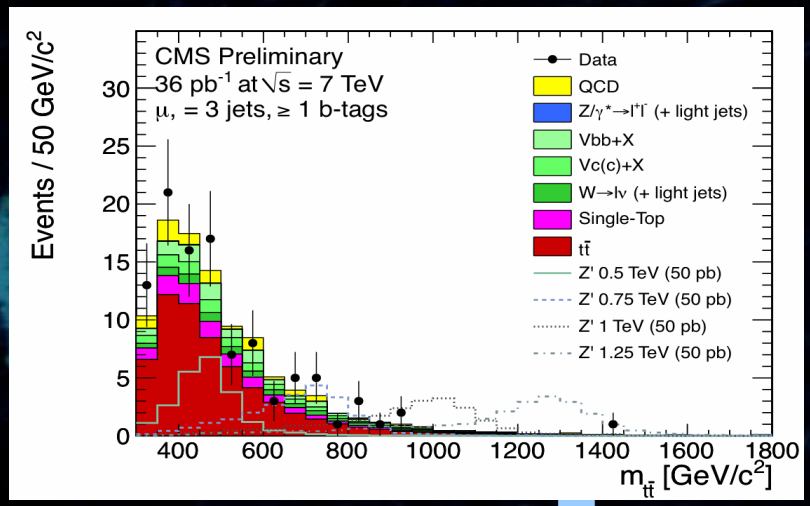


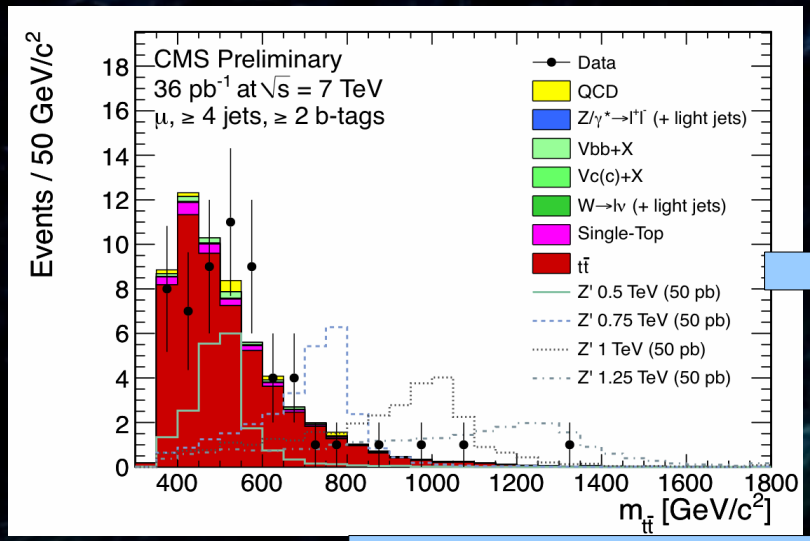


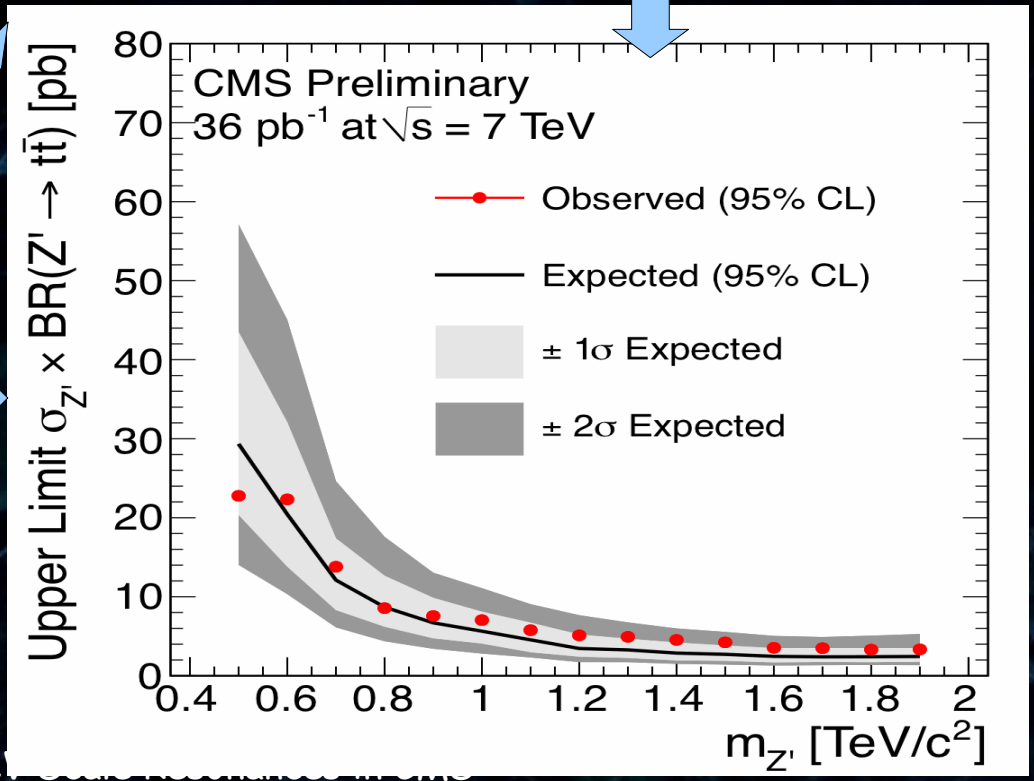


$Z' \to t\bar{t}$ results







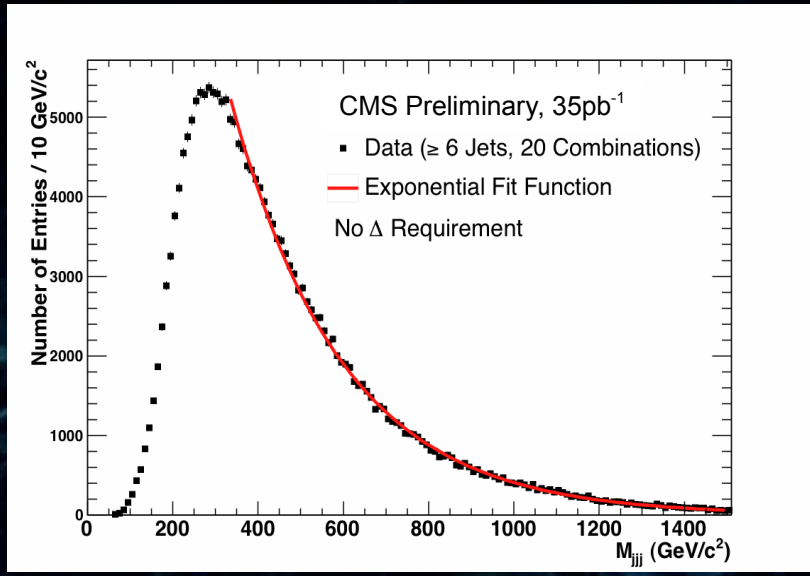


CMS PAS TOP-10-007

Multijet resonances

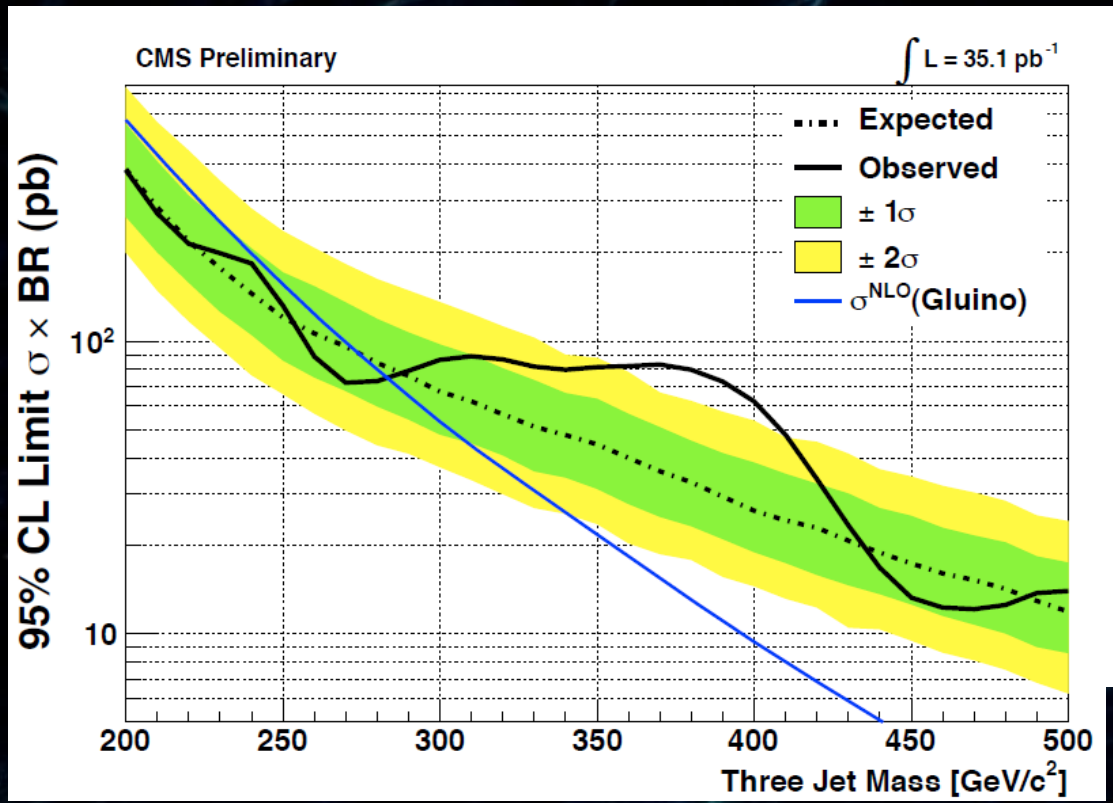
- Theoretical motivation:
  - RPV SUSY gluino decaying into qqq final states, variations of technicolor models
- Signal process: $pp \rightarrow QQ \rightarrow qqqqqq = 3j + 3j$
- Backgrounds:
  - QCD multijets + combinatorics
  - Each 6 jet final state = 20 jet triplets
  - Reduce combinatorial background by requiring

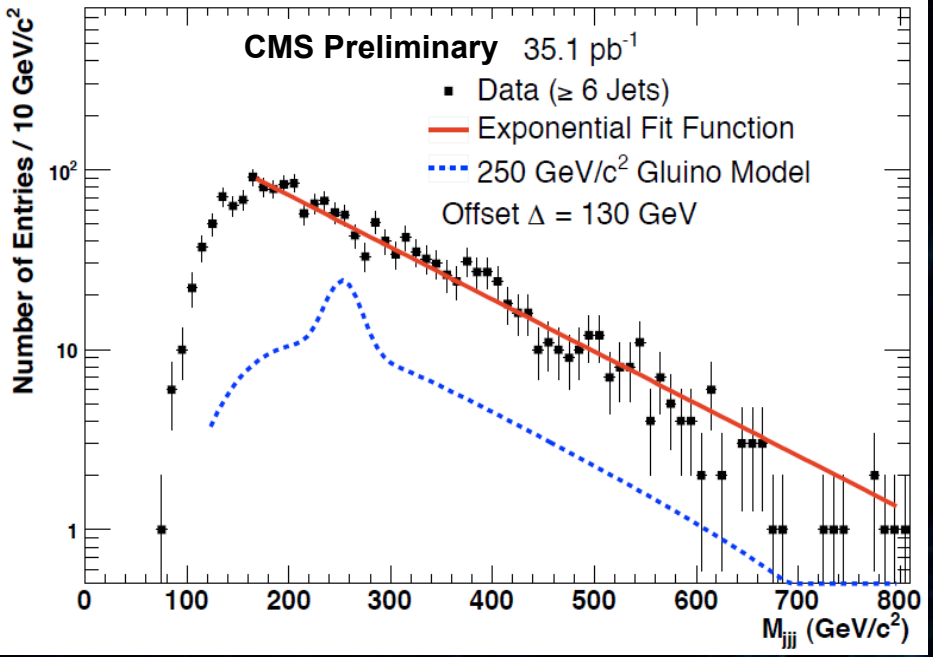
$$M_{jjj} < \sum_{i=1}^{3} |p_T^{\text{jet}}|_i - \Delta$$



Multijet resonance results

- No significant deviation from expectations observed
- Limits on σxBR set using binned likelihood shape fits. RPV gluino mass excluded up to 270 GeV at 95% C.L.





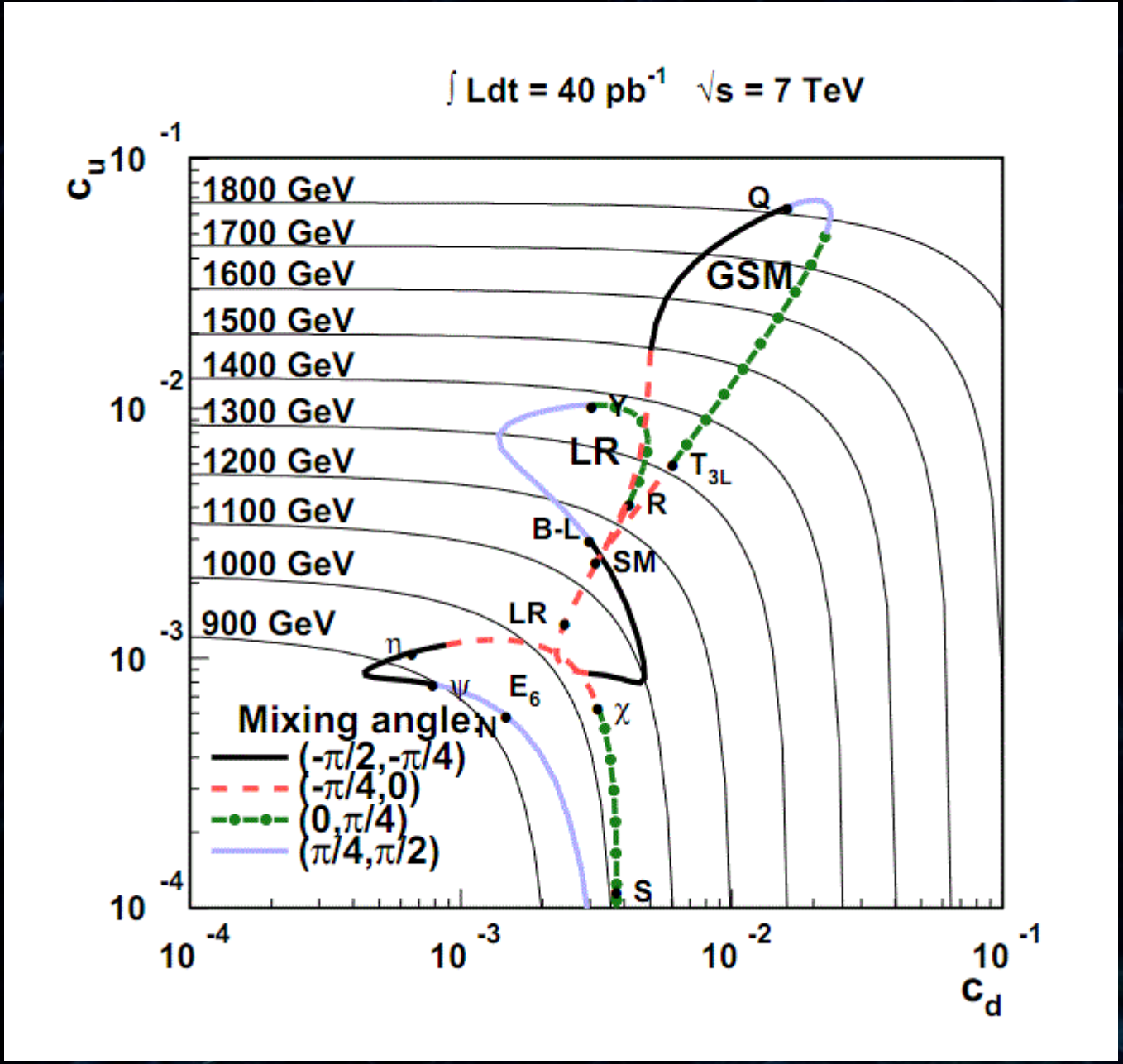
CMS PAS EXO-11-001

Summary

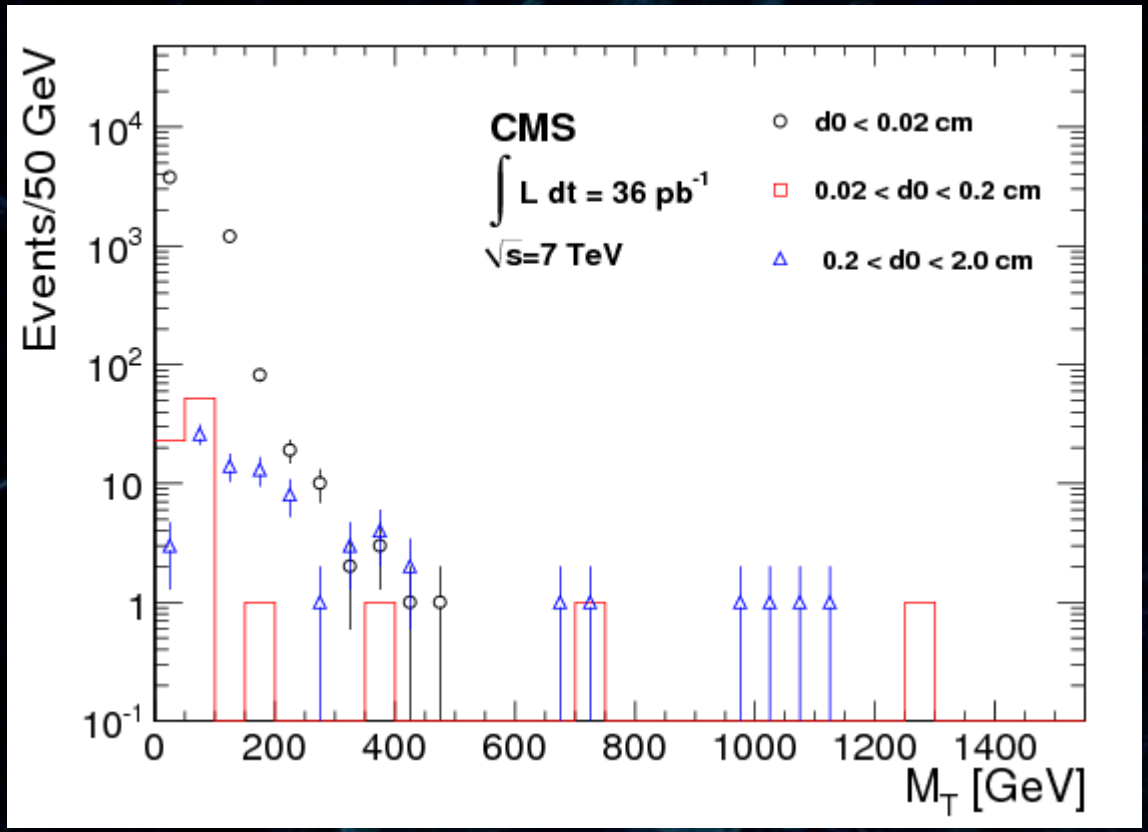
- Searches for new resonances in 2010 LHC data give limits reaching into new territory
- 95% C.L. Exclusions for:
  - RPV gluino mass up to 270 GeV
  - W' with SM-like couplings mass up to 1.58 TeV
  - μ^* (e^*) with mass up to M=745 (720) GeV for Λ=2 TeV
  - RS $G^* \rightarrow \gamma\gamma$ below 931 (729) GeV for k/M_{Pl}=0.1 (0.05)
  - In dilepton channel: Z'_{SSM} below 1140 GeV, Z_Ψ below 887 GeV, RS G^* below 1079 (855) GeV for k/MPl=0.1 (0.05)
- Currently analyzing ~20x more data in search for discoveries, stay tuned:
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Backup

Z' limits in the c_u/c_d plane



Cosmic muons in W' search



Muon resolution from cosmics