Commissioning of Leptons and Prospects for Searches of Leptoquarks, W' and Z' in CMS

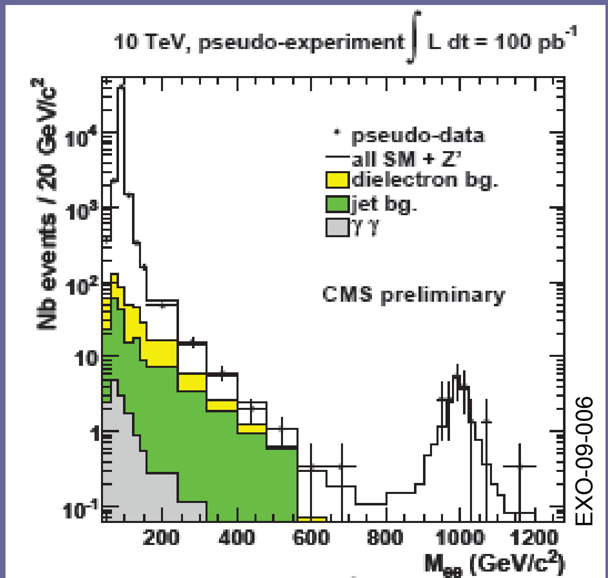
Kerstin Hoepfner
RWTH Aachen, III. Phys. Inst. A

On behalf of the CMS Collaboration

Beyond the Standard Model? → Search for W‘, Z‘ or leptoquarks

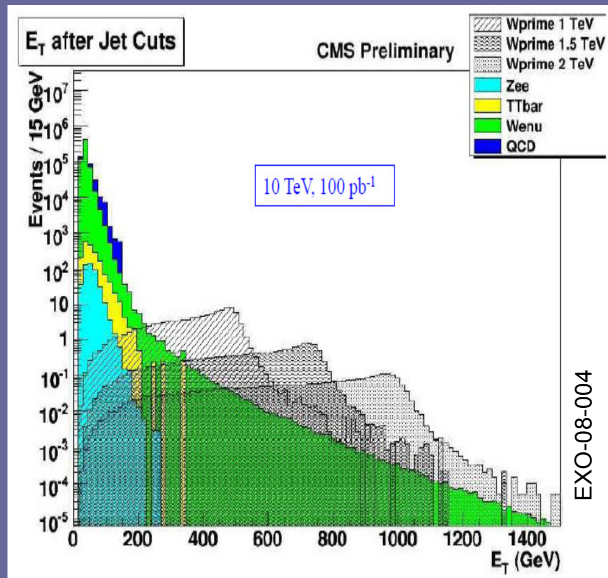
Different signals, largely based on very high p_T leptons (electrons, muons) with $p_T > 200$ GeV

Resonance Z‘ → $\ell\ell$



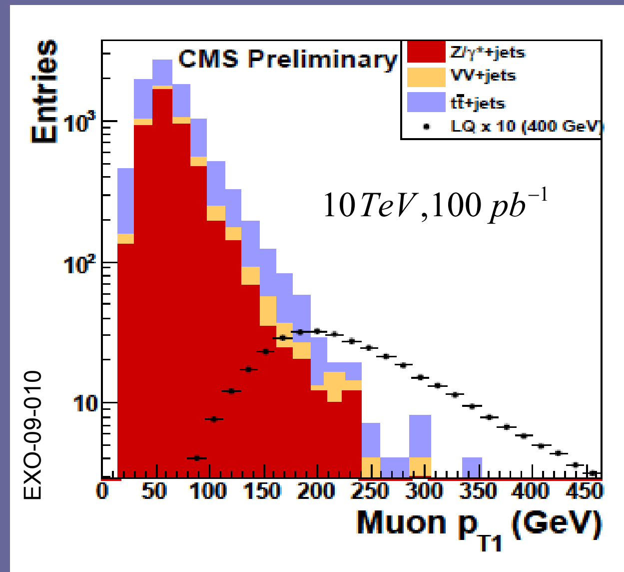
Peak in invariant mass spectrum M_{ee} or $M_{\mu\mu}$

W‘ → $\ell\nu$



Excess in electron E_T or muon p_T spectrum

Leptoquarks → $\ell\ell$ j j

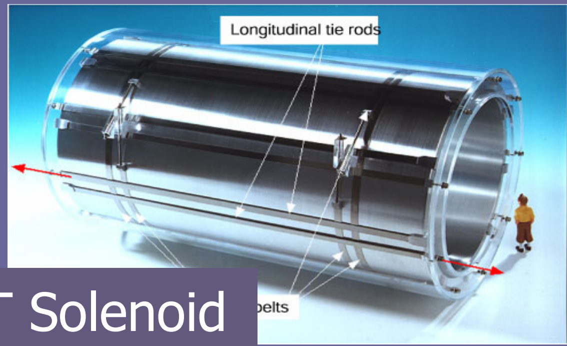


Excess in ℓq invariant mass and di-lepton or di-jet spectrum

The CMS Original Concept

Guiding channels: H → ZZ → $\ell^+ \ell^- \ell^+ \ell^-$, H → $\gamma\gamma$

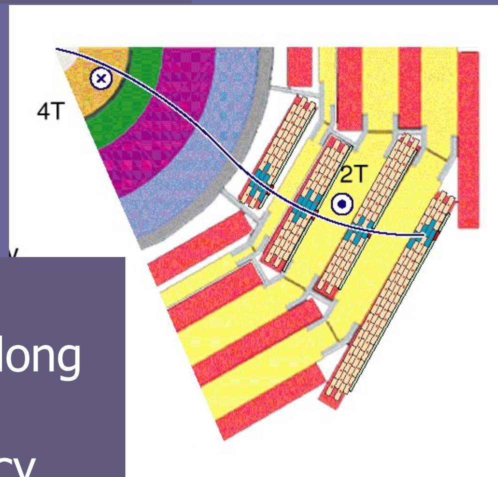
Optimized for high p_T leptons (and γ)



3.8T Solenoid

- Good momentum resolution with high B-field

$$\frac{\Delta p}{p} \sim p$$



4 muon stations along the track, redundancy

- Excellent and redundant muon identification

- Very high energy resolution for electrons and photons

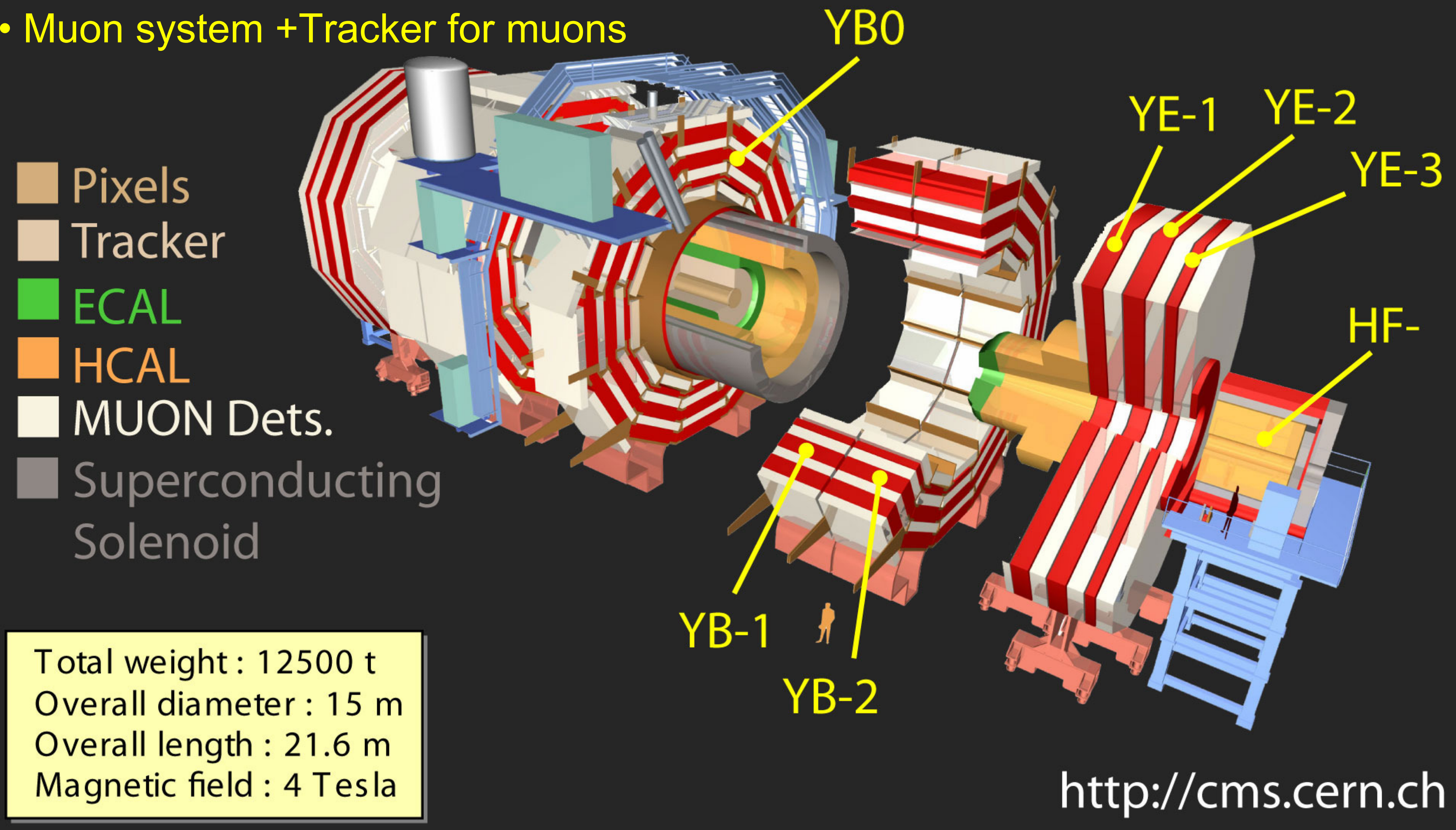
$$\frac{\Delta E}{E} \sim \frac{1}{\sqrt{E}}$$

Fully active ECAL made of crystals

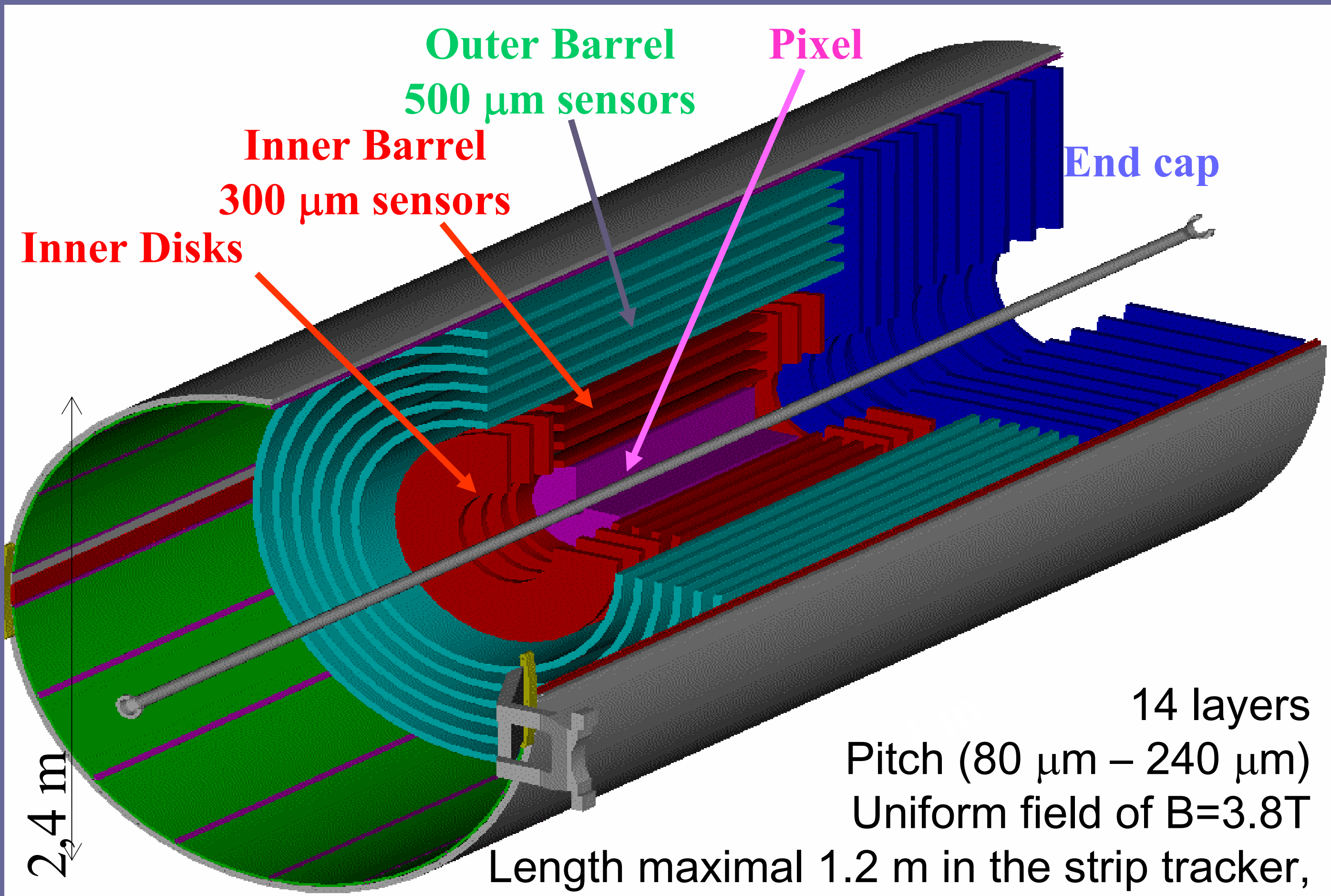
The CMS Detector

For signals in this talk:

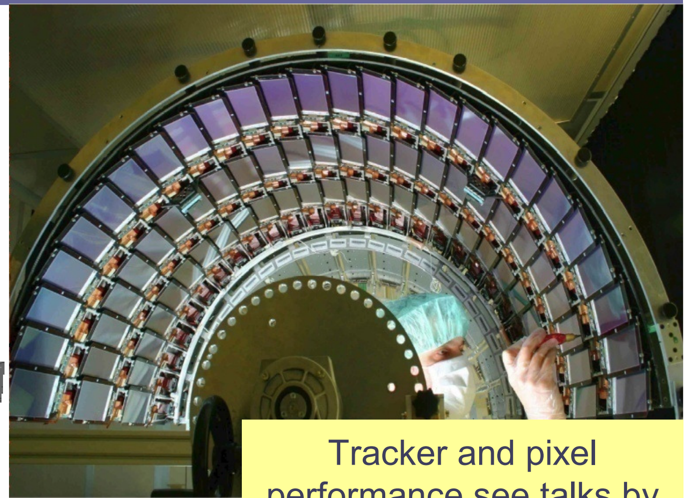
- ECAL + Tracker for electrons
- Muon system +Tracker for muons



CMS Full Silicon Tracker



14 layers
Pitch (80 μm – 240 μm)
Uniform field of B=3.8T
Length maximal 1.2 m in the strip tracker, seeded by the pixel



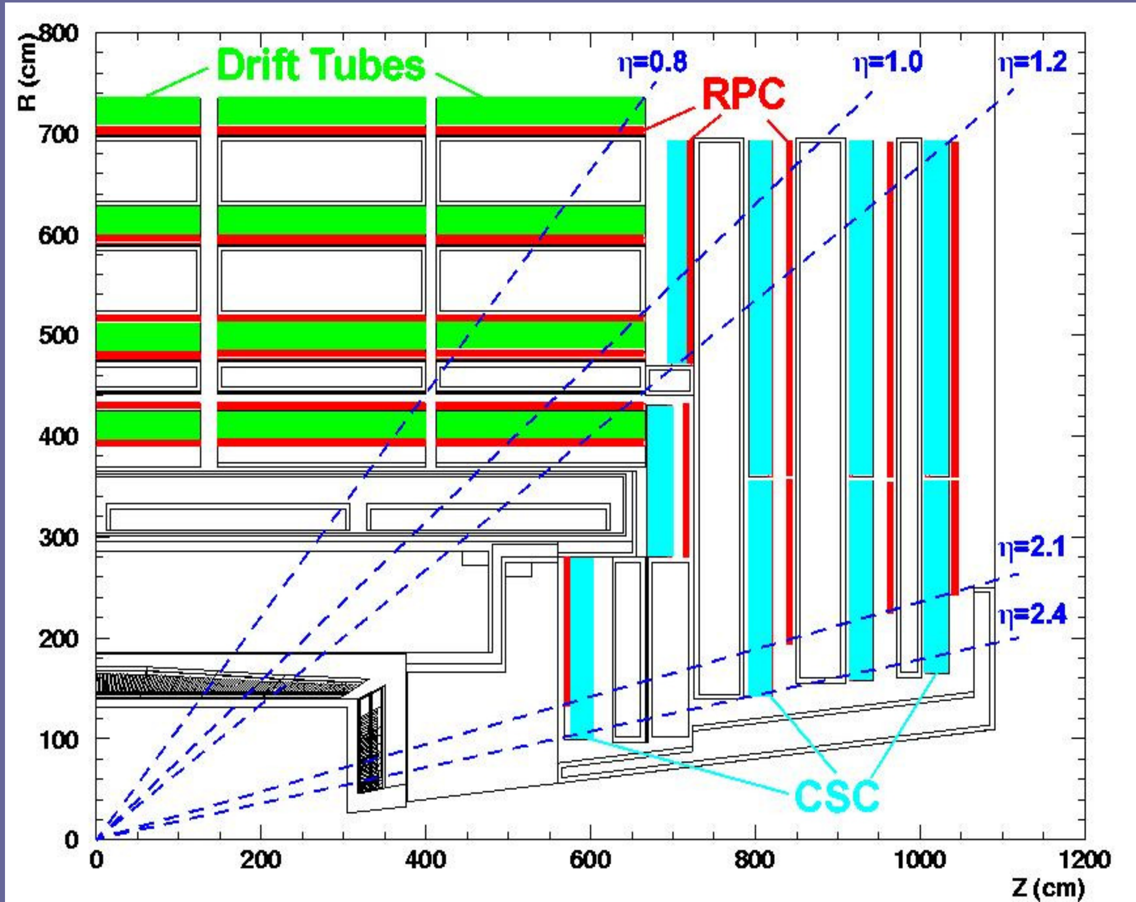
Tracker and pixel performance see talks by L.DEMARIA, V.RADICCI

Goal: Reconstruction of

- isolated tracks with $\varepsilon > 0.95$
- high p_T tracks within jets with $\varepsilon > 0.9$

Requires $$\frac{\Delta p}{p} \approx \left(\frac{pitch}{100\,\mu m}\right)\left(\frac{3.8T}{B}\right)^2\left(\frac{1.2\,m}{L}\right)\left(\frac{p}{TeV}\right)$$
$$\approx 1.2\%@100GeV$$

CMS Muon System



Muon Barrel 0 < |η| < 1.2

- 5 barrel wheels, iron return yoke for the solenoid magnet
- Almost no B-field at chamber positions
- 250 Drift Tube (DT) Chambers
- 480 Resistive Plate Chambers (RPC)

Forward Muon 0.9 < |η| < 2.4

- Arranged in 2 x 3 disks
- 4 muon stations in 2/3 rings
- Inhomogenous field with B<1.2 T
- 250 Cathode Strip Chambers (CSC)
- 483 Resistive Plate Chambers (RPC)

Muon performance see talk by Luca SCODELLARO

Momentum resolution up to ~100 GeV limited by multiple scattering in the iron, $\Delta p/p \sim 10\%$@100 GeV

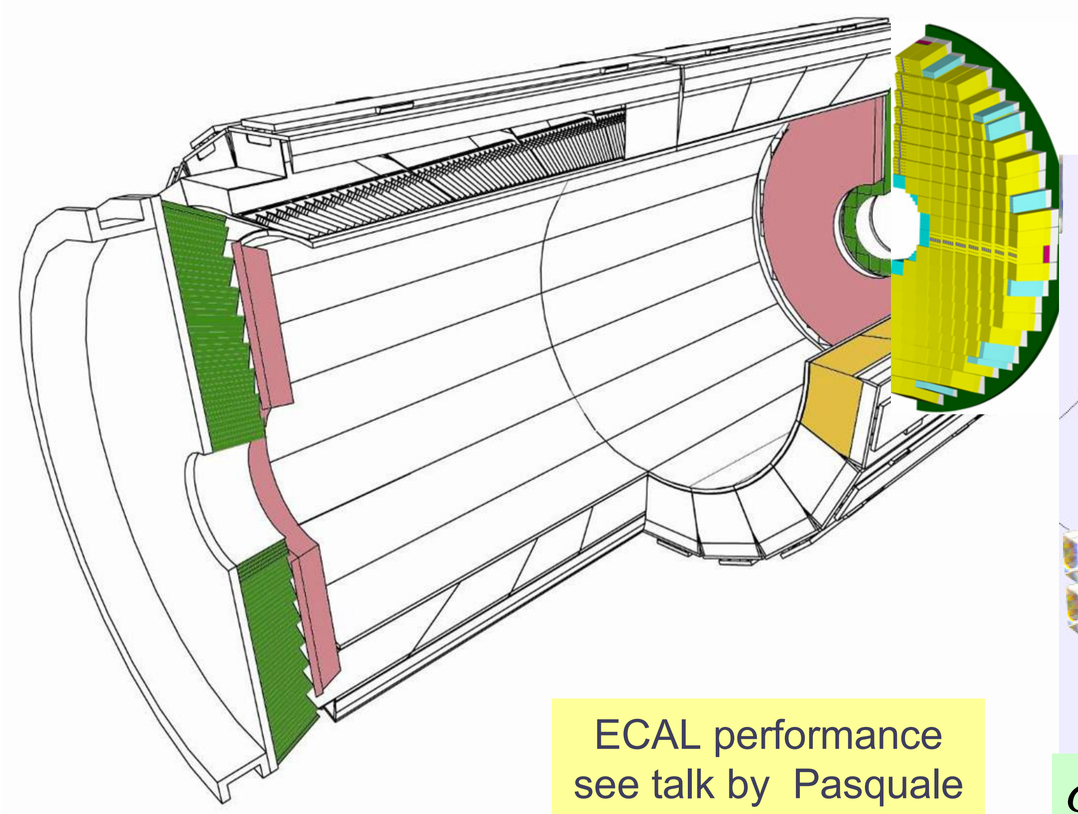
Combination with high resolution silicon tracker → few %

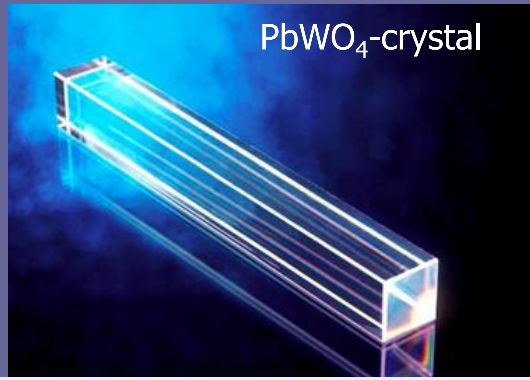
For $p_\mu \sim O(\mathrm{TeV})$, muon system resolution is dominating → $\Delta p/p \sim 10\%$

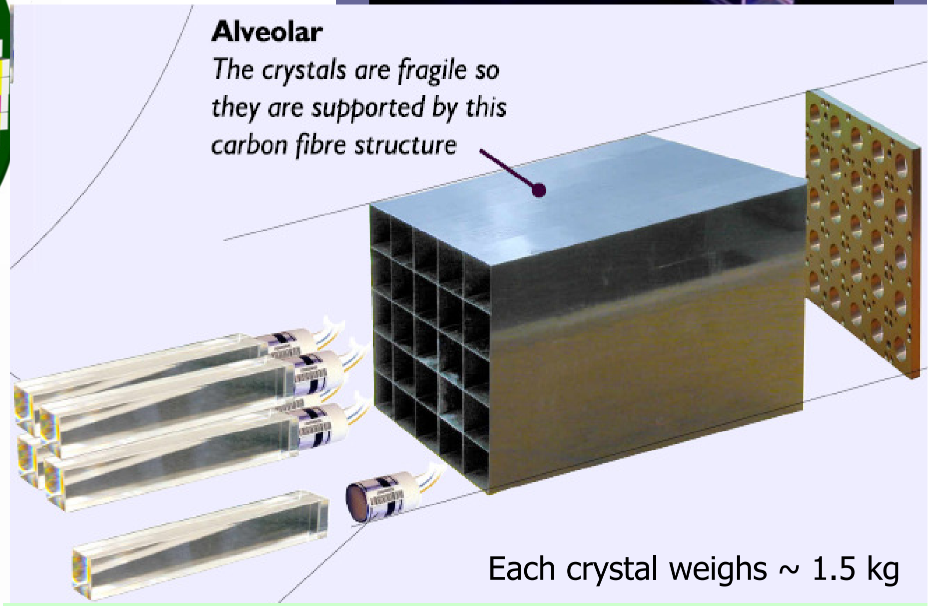
CMS Electromagnetic Calorimeter

Fully active ECAL, made of $PbWO_4$ crystals (CMS development)

Arranged in 36 barrel supermodules (61200 crystals, 67.4t) and 4 end-cap D's (14648 crystals, 22.9t)







ECAL performance see talk by Pasquale MUSELLA

$$\frac{\sigma_E}{E} \cong \frac{0.01}{\sqrt{E[GeV]}} \oplus 0.005 \oplus \frac{0.2}{E[GeV]}$$

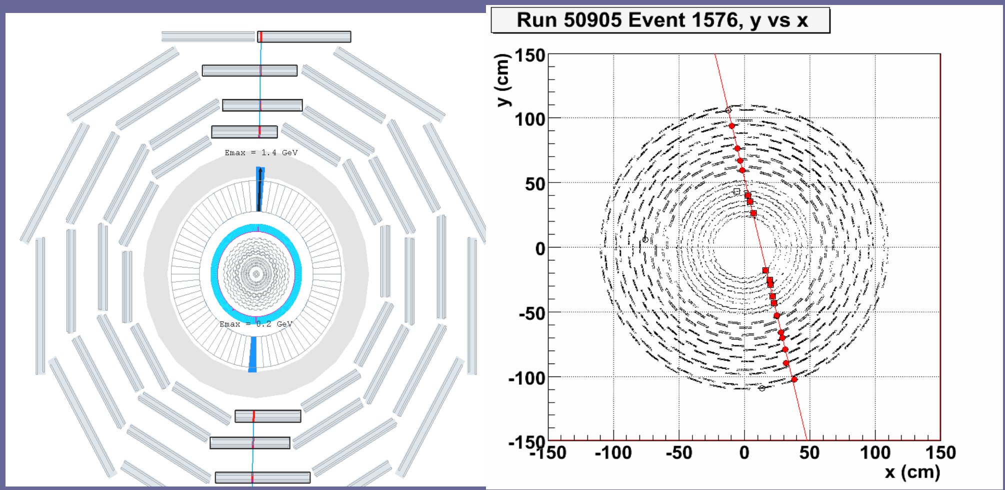
Operating at B=3.8T

Temperature stabilized to mK for light output

Laser system for calibration (crystals darken from radiation)

Commissioning with Cosmic Muons and Beam Splash Events

Vertical Cosmic Muons (CRAFT)

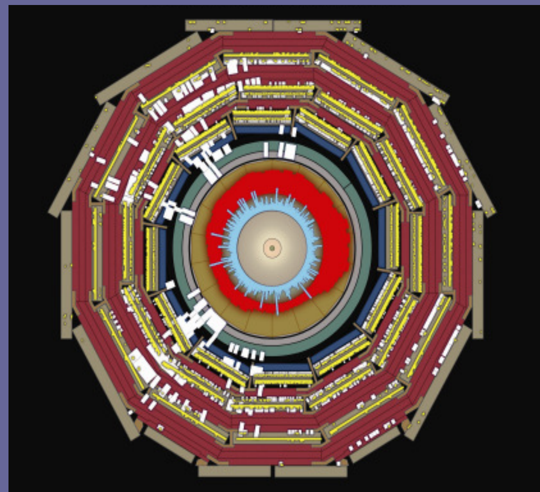


In total ~350 million triggers

Used for studies of

- Reconstruction (tracker, muon, global)
- Trigger performance and efficiency
- Alignment of tracker and muon system and global alignment

Horizontal Beam Splash Events

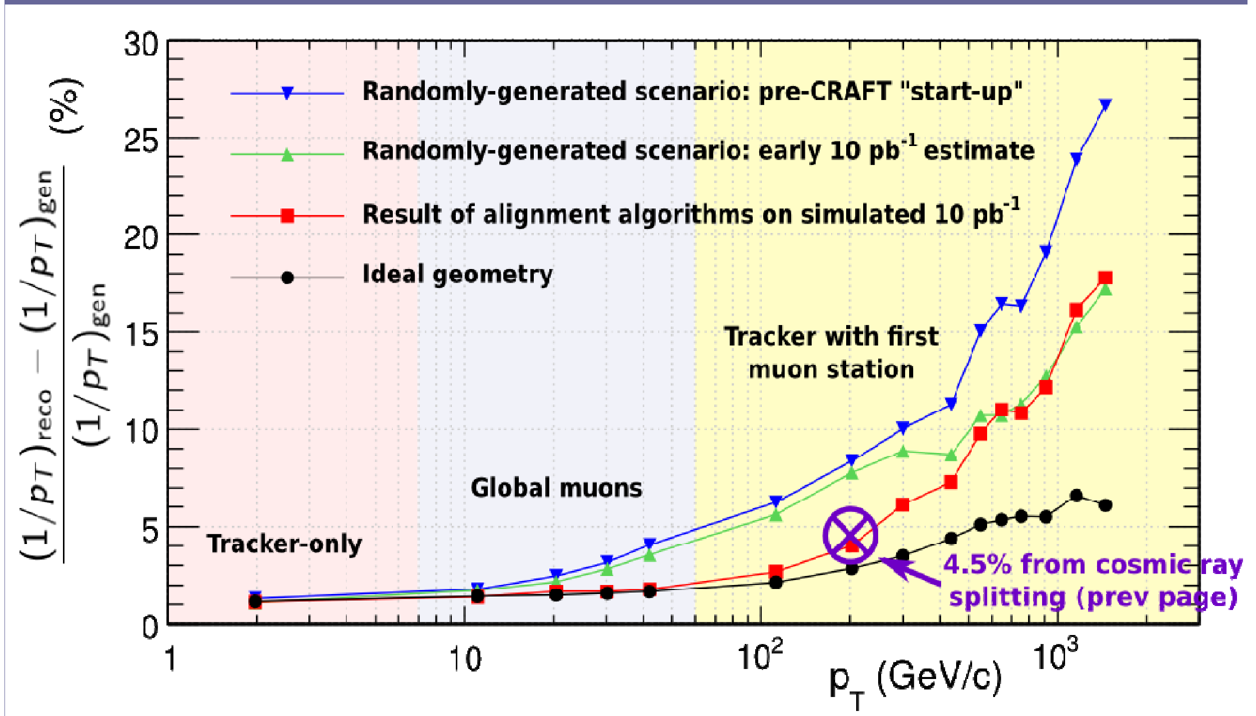


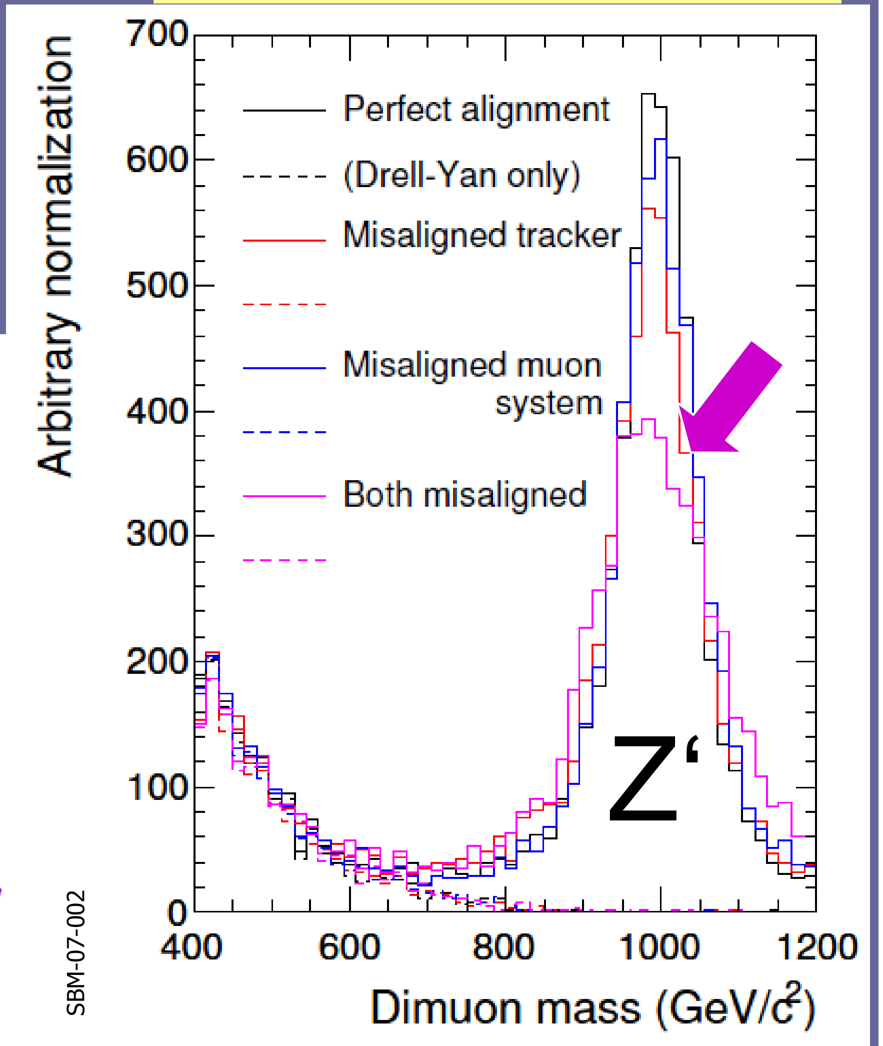
- For alignment of muon endcaps with respect to each other (cannot be done with cosmics since rate of horizontal cosmics is too low)
- Large energy deposition in calorimeters useful to study performance (although very limited statistics)

Impact of Alignment

- Big progress in alignment with tracks using cosmic ray tracks
- Complementary to hardware (laser) align.
- Improves the CMS start-up conditions. Now (after cosmics analysis) better than earlier estimates for 10 TeV MC samples

Z' → μμ sensitive to tracker – muon alignment



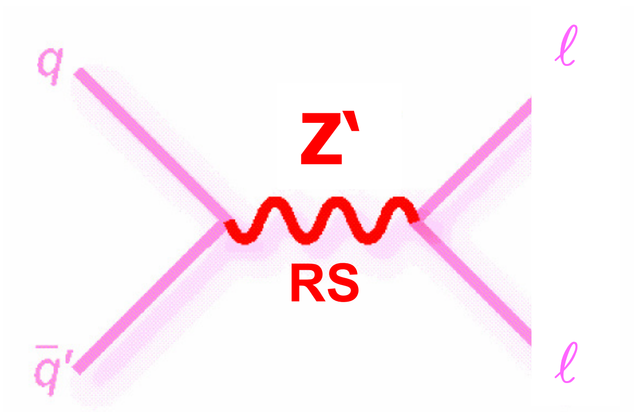


Heavy Vector Bosons

- Some theories predict heavy siblings of SM Z and W → Z' and W'
- For experimental search, assume similar decays as for Standard Model (plus decay into top quarks)

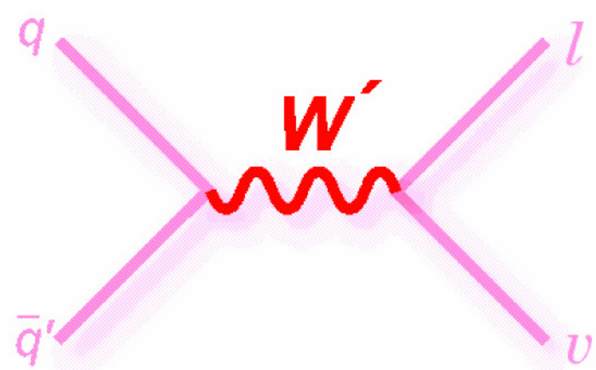
  Signatures: Z' → $\ell\,\ell$, Z' → qq and W' → q ν, W' → $\ell\,\nu$

Z'/RS → $\mu\mu$, ee



Exp. Z' limit = 700-100 GeV depending on model (FNAL), 900 GeV for RS gravitons

W' → e ν, μ ν

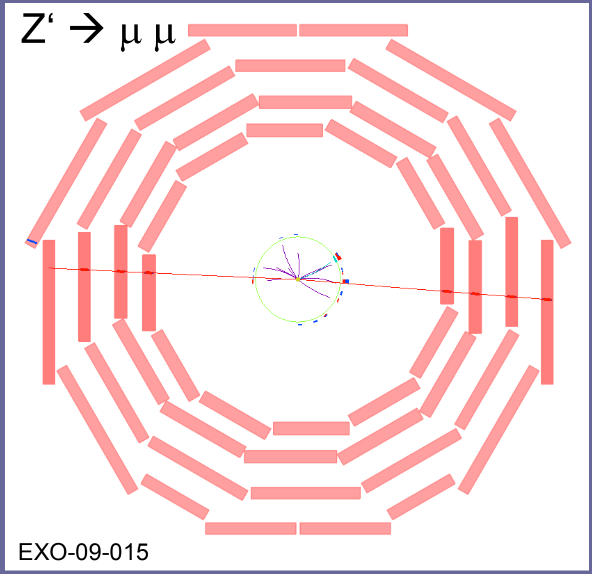


Experimental limit = 1 TeV (FNAL, W'→e ν)

- Results are sensitive to alignment (especially muon channel)

Can be found/excluded already with ~100 pb^{-1} luminosity at LHC c.o.m=7 TeV. Key searches for new physics with early data.

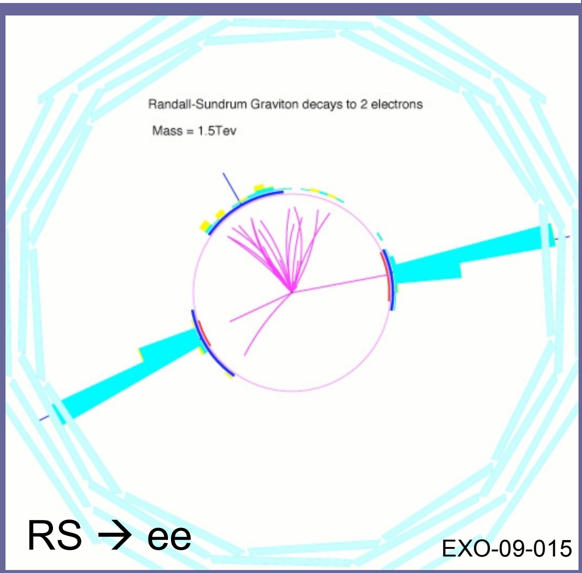
Z‘ → $\ell^+\ell^-$ with ℓ = e, μ



Search for new, narrow resonances in di-lepton spectrum with $M_{\ell\ell}$ > 800 GeV/c^2

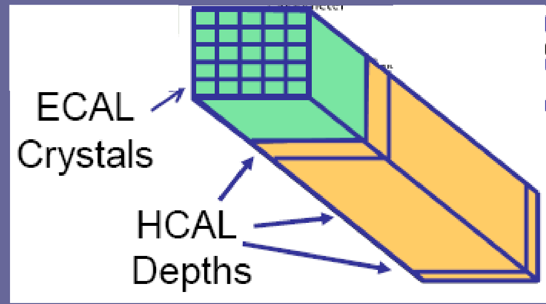
Full DY spectrum, Z-peak region provides large statistics of $\ell^+\ell^-$ pairs → extrapolate to higher p_T

Develop strategies for high energy electron (isolation, selections cuts) and muon (reconstructors) pairs.
These lepton selections are also used for W‘ and leptoquark searches

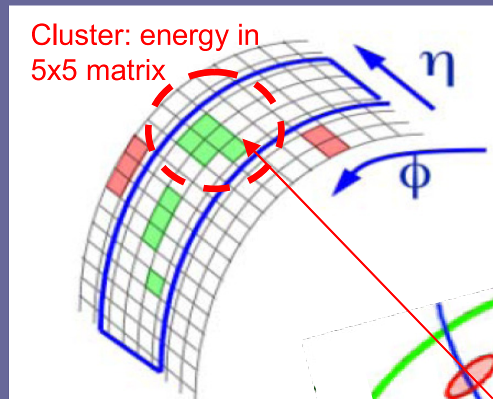


How to Select High p_T Electrons

1. Standard electron ID: single electron trigger.
   Form clusters of EM energy → combine with pixel hits → search for tracker hits (min 5 hits/track)

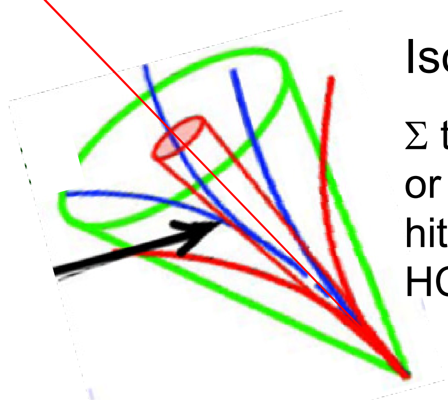


2. E_T > 25 (50) GeV, $|\eta|$ < 2.5



3. Matching in η, ϕ with a tracker track

4. Deposits most of its energy in ECAL, very little in HCAL



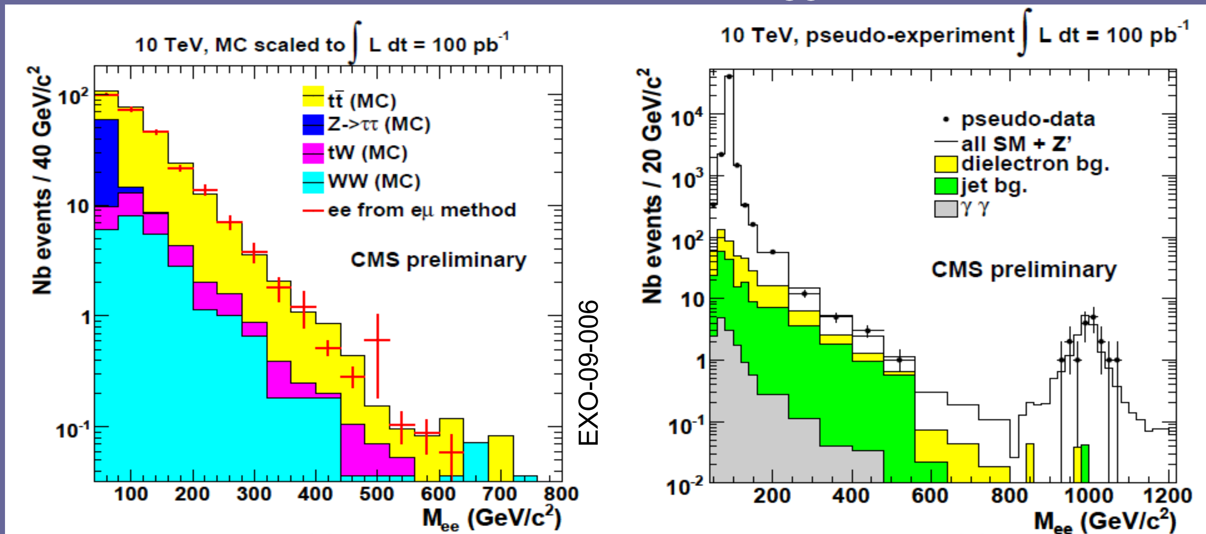
5. Shower shape (e^- shower more narrow than jets)

6. Calorimeter isolation (within a cone of ΔR<0.3) to reject jets

7. Tracker isolation

Z‘ → e^+e^- : Efficiencies & Background

- Study di-electron mass spectrum from Z-peak to high masses
- Almost no SM background for M_{ee}> 600 GeV



With E_T>50 GeV, 100 pb^{-1}

Both e pass high p_T selection

501 (pseudo) data

54.1+4.3(stat)+8.5(sys) background events

- Di-electron background from eμ-method
- Jet background with fake rate method 4.5 events with est. 50% sys. error
- Electron efficiency from data with „tag and probe“ 93.9% (Barrel), 94.3% (EC)

  Eff. scale factor for high mass evolution ±0.1/0.2(stat) ±1.7/3.8%(sys) Barrel/EC
- Check linearity of ECAL calibration (Testbeams ~300 GeV)
  - Method: compare hottest crystal in 5x5 matrix to surrounding 24 crystals
  - Achieved resolution with assumed 100 pb^{-1} (4-9)% in EC, (13-16)% in Barrel

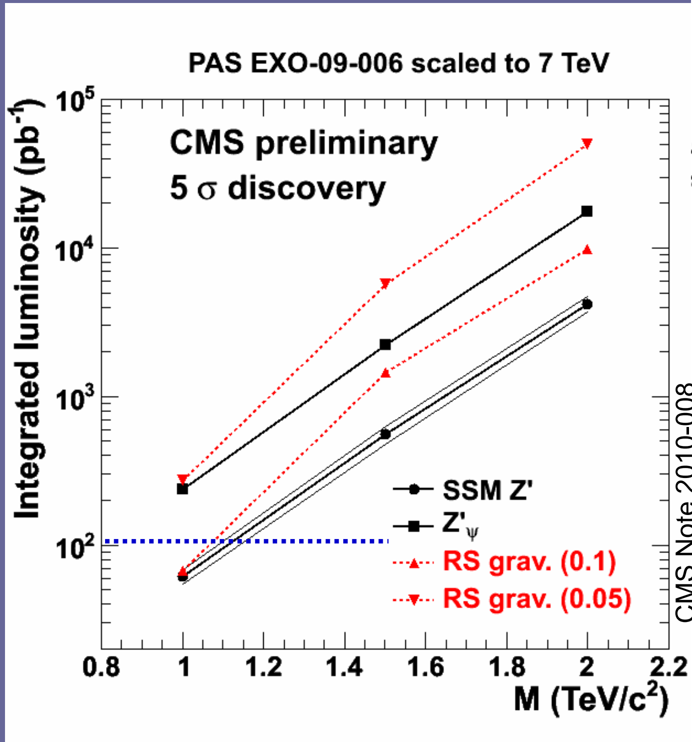
Sensitivity for Z‘ → $e^+ e^-$

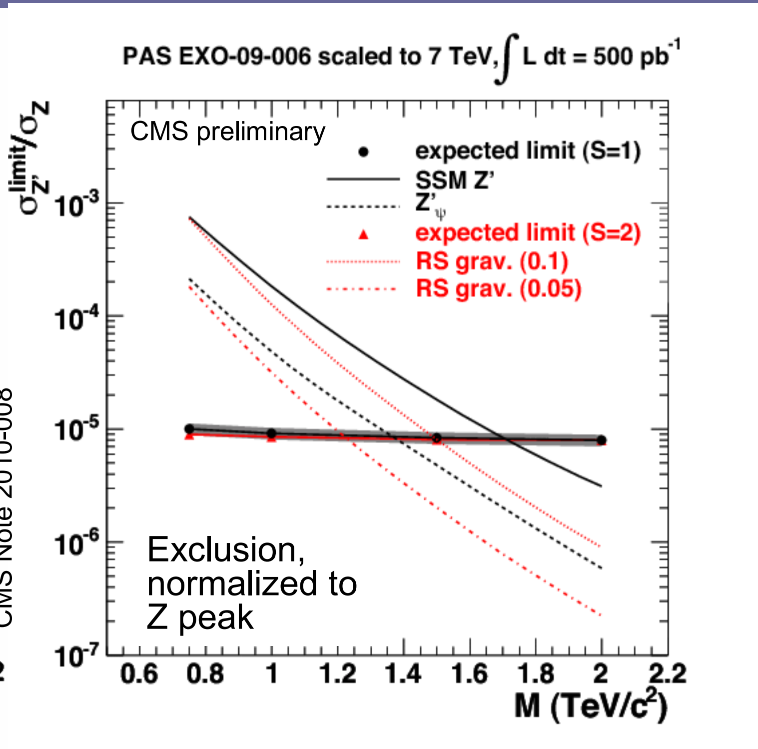
Reach scaled from c.o.m.= 10 TeV to 7 TeV for different SSM Z‘ masses

Integrated luminosity for 5σ discovery and exclusion, in a given model and fixed resonance mass

Starts to become interes-ting with 100 pb^{-1} of 7 TeV data.

Lumi of 500…1000 pb^{-1} expected after 2010/11 data taking at 7 TeV





Systematic uncertainties included:

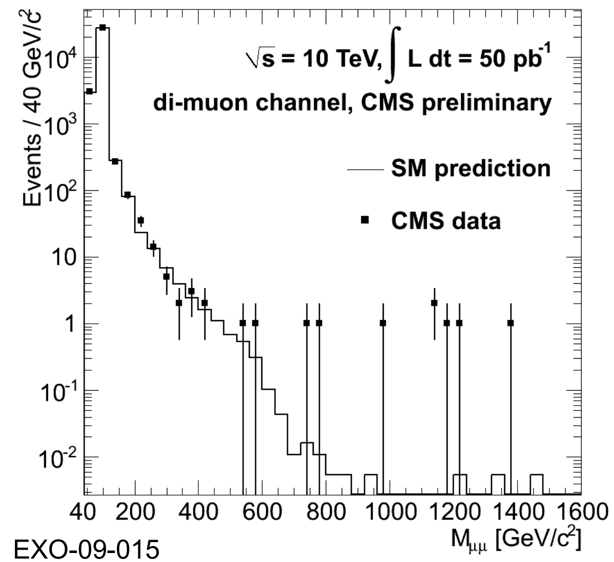
- 4% uncertainty on selection efficiency in resonance mass region (T&P)
- Impact on invar. mass when extrapolating DY background to resonance region: approximated by changing DY by 50%
- Additional global uncertainty of 10% incl. K-factor and PDF, affecting both signal and background

Z' → $\mu^+ \mu^-$

- Study di-muon mass spectrum from Z-peak to high masses
- High mass region almost free of SM events but mis-reconstruction can yield additional background → alignment needs to be understood

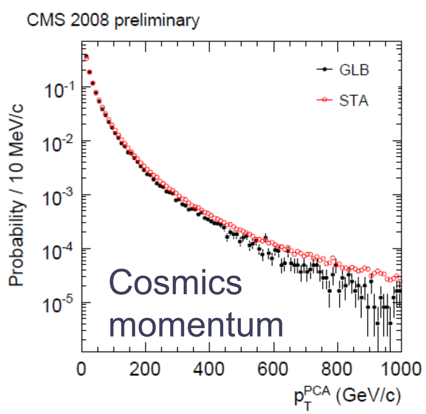
- Overall muon efficiency (from MC tag-and-probe) at the Z-peak = (97.6±0.6)%
  Simulation shows no dependence on p_T within 1%
- Require opposite charges
  charge mis-assignment measured with cosmics to be <0.5%@500 GeV and <1.5%@1TeV

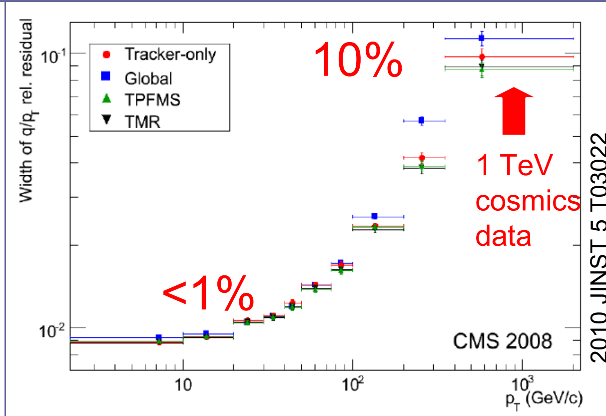
Di-muon mass spectrum for 50 pb^{-1} at 7 TeV in case of evidence for a Z' with m =1.24 TeV



EXO-09-015

Performance results from cosmics data





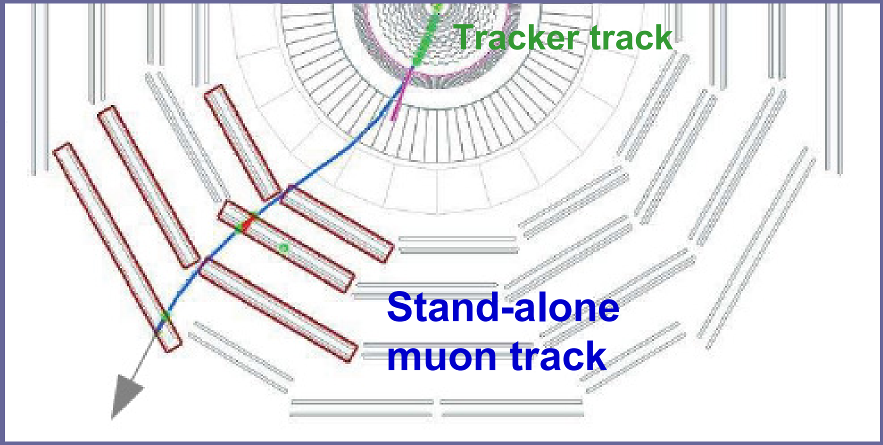
Muon momentum resolution up to O(TeV)

Developed method to combine electron and muon channel based on likelihoods

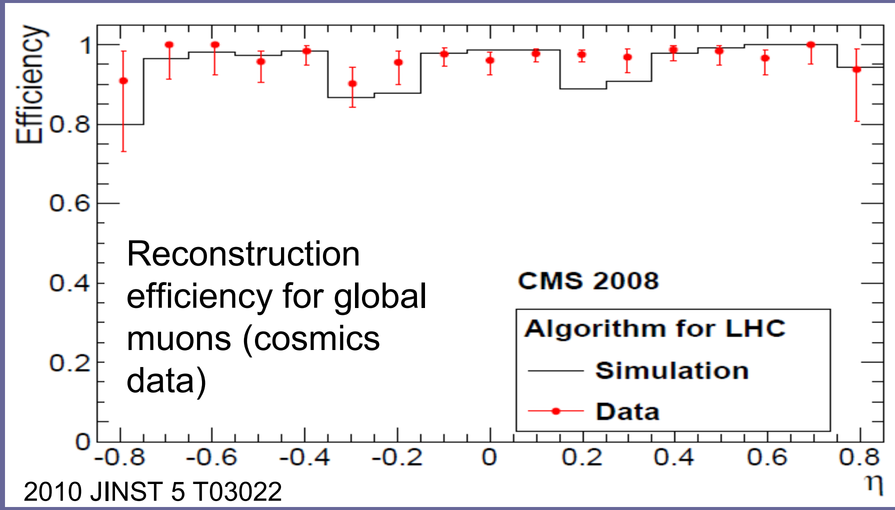
How to Select High p_T Muons

1. Single muon trigger p_T>9 GeV
   15 GeV for higher peak luminosity
2. Calorimetric energy ~ MIP. $|\eta| < 2.1$
3. Highly redundant muon system. Recon-struction of „stand-alone" tracks, matching and global fit with tracker hits
   (different reconstruction algorithms, dedicated ones for TeV muons to treat showering)
4. Tracker quality cuts
   tracker >10 hits, χ^2 / N_{dof} <10,
   p_T(tracker) > 60 GeV
5. Isolated track to suppress non-promt muons: Σp_T < 10 GeV in a ΔR < 0.3 cone around muon

Suppress contamination of cosmics with timing, impact parameter, acollinearity



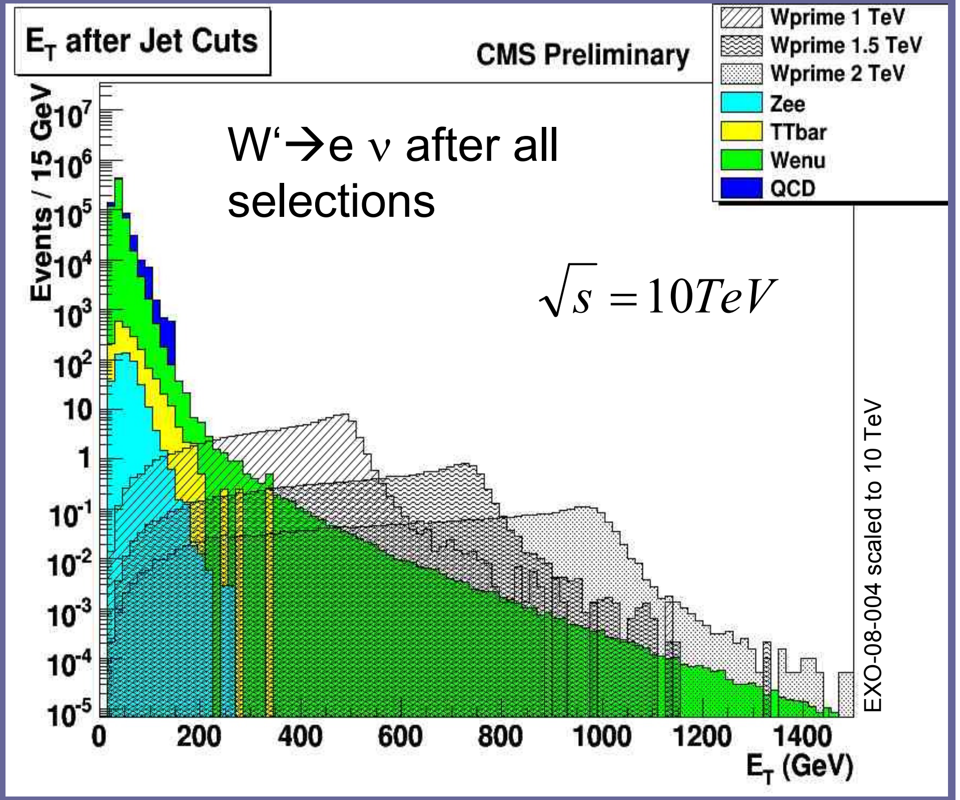
Many reconstruction studies done with 350 mill. cosmic triggers and pp-like reco



Selection optimized using Monte-Carlo and IDEAL detector geometry

W'→ $\ell + \nu$ (ℓ =e, μ)

- Rather background free for p_T>200 GeV if leptons are well reconstructed
- Electron channel: dedicated selections of isolated high p_T electrons (see Z') provides good S/B ratio
- Muon channel: similar kinematic selections as for electrons BUT muon mis-reconstruction creates additional background
- Main background: SM W-boson
  - Boosted W → rejected by the jet veto
  - Off-shell W → irreducible
  - W with mis-reconstructed leptons (mainly muon channel)



Needs:

- Good electron ID and E_T
- Muon ID and correct p_T
- Reasonable jet energy scale for jet veto
- MET if strategy with MET

W' Analysis Strategy

- Uses similar selection criteria for high p_T leptons as Z' search. Not a clean peak, needs also reliable E_T^{miss}
- Potentially larger impact of alignment since no invariant mass but just excess in high p_T lepton spectrum

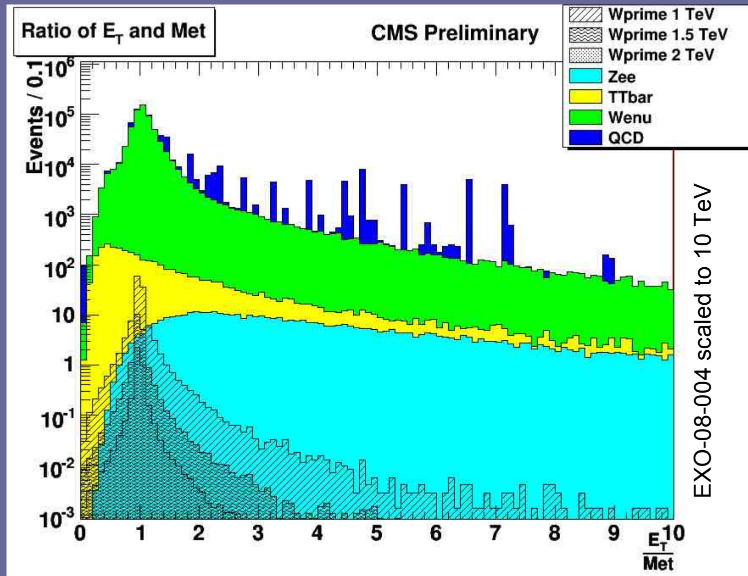
Event numbers for backgrounds and signal W'→ℓν, 100 pb^{-1}, IDEAL cond.

10 TeV | 7 TeV

Sample	x-section (pb)	p_T > 100 GeV/c 100 pb^{-1}	p_T>200 GeV
W	1.17E4	1356	7.3
QCD	5.2E10	35	1.6
Z/Drell-Yan	1.42E3	218	0.3
t-tbar	450	522	1.6
W' (1.0 TeV)	1.5	104	43
W' (1.5 TeV)	0.24	17	5.4
W' (2.0 TeV)	5.4E-2	4	0.7

Possible strategies (tested with MC)

1. Without E_T^{miss}, veto jets with p_T>100 GeV opposite to the lepton
2. With E_T^{miss} and kinematic selections on ratio E_T / E_T^{miss} and angle (E_T, MET)
3. MHT < 200 GeV instead of E_T^{miss}



⇨ E_T^{miss} performance in data is good. Probably can work with strategy 2

Sensitivity W'→e ν

Our sensitivity studies uses CLs method

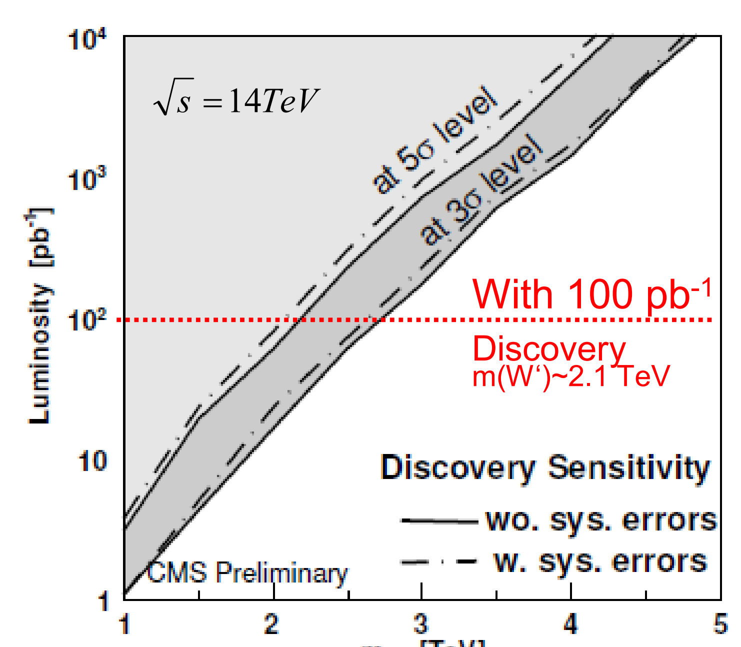
- Discovery 1-CL_b < 5 (3) σ
- Exclusion CL_s < 2 σ

Systematic uncertainties included in W'→e ν
Tested some worst case scenarios. No parameter prevents discovery or improved exclusion limit

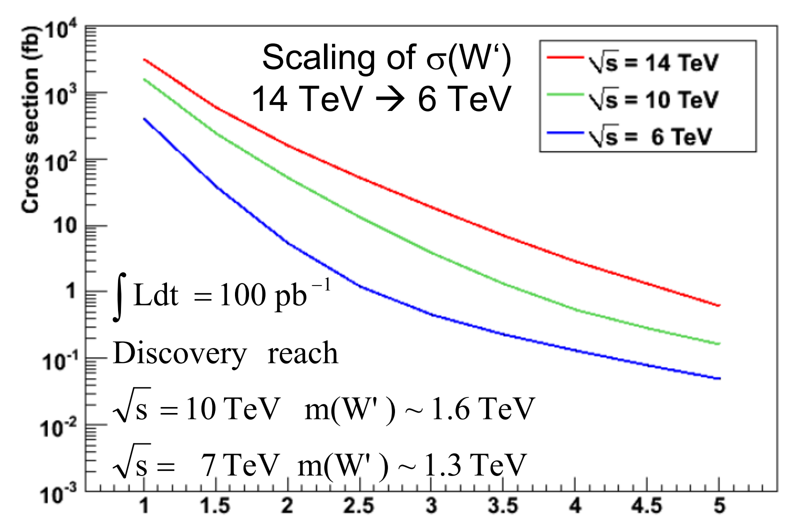
Uncertainty	Expected	Worst case tested in MC
ECAL calibration	1.5% Barrel, 4% EC	--
Jet energy scale	7%	30%
Cross section	10%	20%, QCD 50%
Lumi	10%	30%

Extended reach when combining electron and muon channel.

Needed luminosity for discovery of W'→eν using strategy 2 (with missing E_T and kinematic selections)



EXO-08-004

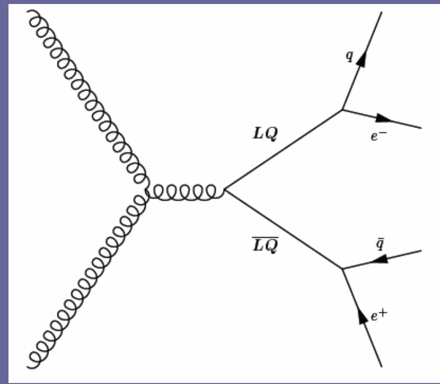


AN 2009-008

Leptoquarks → leptons + jets

- Particles that carry both **color** and **lepton flavour,** allow transitions $\ell \leftrightarrow q$
- LQ produced in pairs
- 1. generation: electrons + jets, e ν + jets

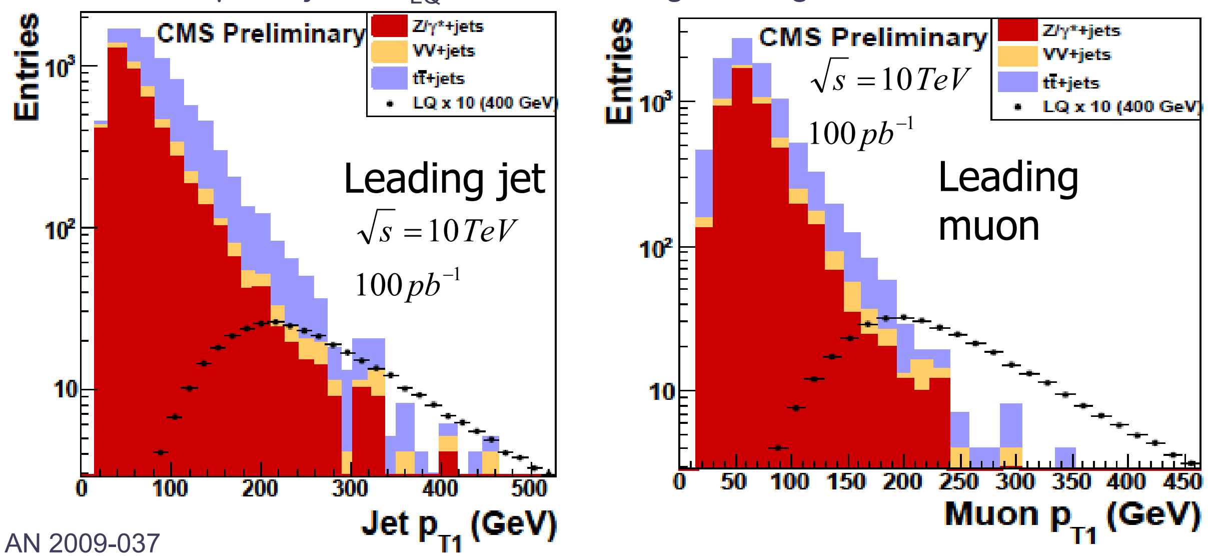
  2. generation: muons + jets, μ ν + jets
- **Striking signature** with
  - 2 high p_T leptons and
  - 2 high p_T jets



Leptons are isolated and of high p_T
Selection steps for high p_T leptons like for Z‘ and W‘

To clean jets from electrons, use (loose) high p_T electron selections

LQ →2μ + 2 jets, m_{LQ} = 400 GeV, signal magnified x10



AN 2009-037

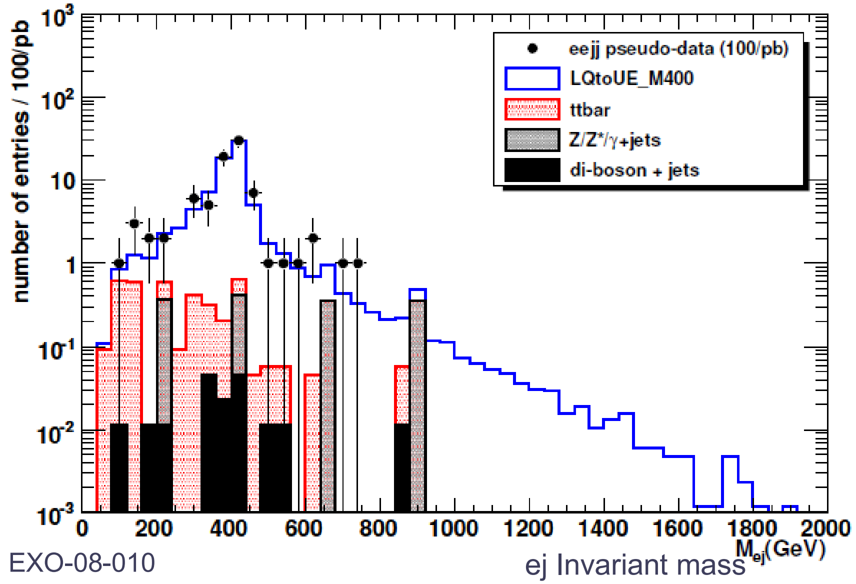
Analysis Strategy

Example: first generation LQ

1. Trigger and high p_T lepton selections similar to vector boson analyses
2. At least 2 jets, with p_T>50 GeV, $|\eta|<3$
3. $M_{\ell\ell}$ > 100 GeV (to remove Z/γ+jets)
4. Scalar sum S_T of the p_T of the 2 leading leptons and 2 leading jets (developed by D0), $S_T > f(M_{LQ})$
5. Two ej-pairs combined such that ΔM_{ej} is minimal

Invariant mass M_{lq} for 10 TeV, 100 pb-1

Clear signal after all selections



$$for\ 100\,pb^{-1}, 10TeV$$

$$N_{evt}^{signal} = 39 \pm 0.15 \qquad \varepsilon_{abs} = 0.520 \pm 0.002$$

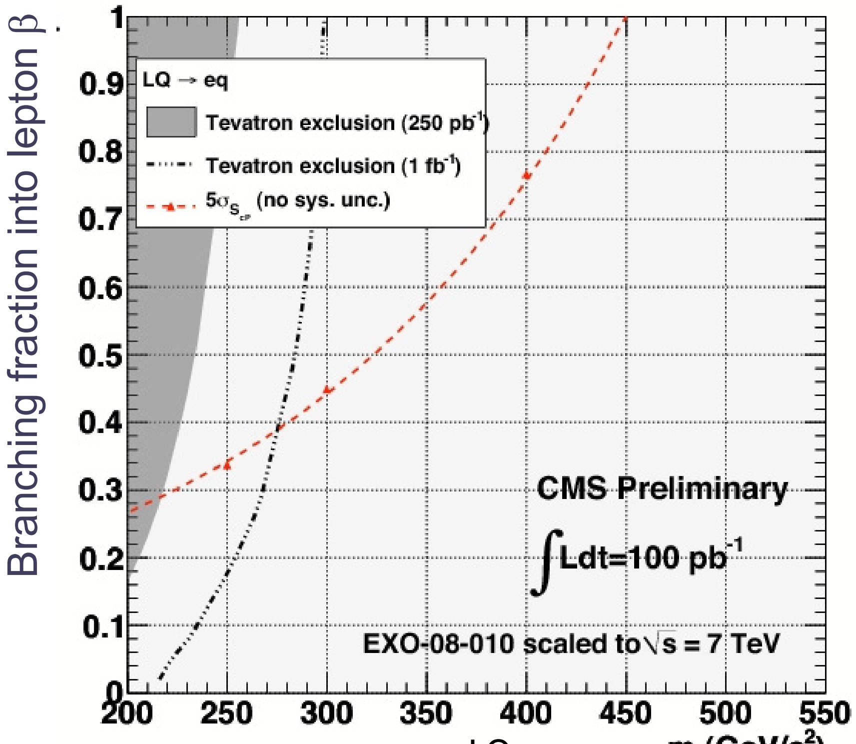
$$N_{evt}^{bkgr} = 1.5 \pm 0.3 \qquad \varepsilon_{abs} = (3.5 \pm 0.5)10^{-5}$$

Main backgrounds:

- QCD and W+jets removed by selection
- ttbar+jets, data driven method
- Z/γ+jets, get control sample by applying selection but reverse $M_{\ell\ell}$ step. Compare to Monte-Carlo

Sensitivity for Leptoquarks

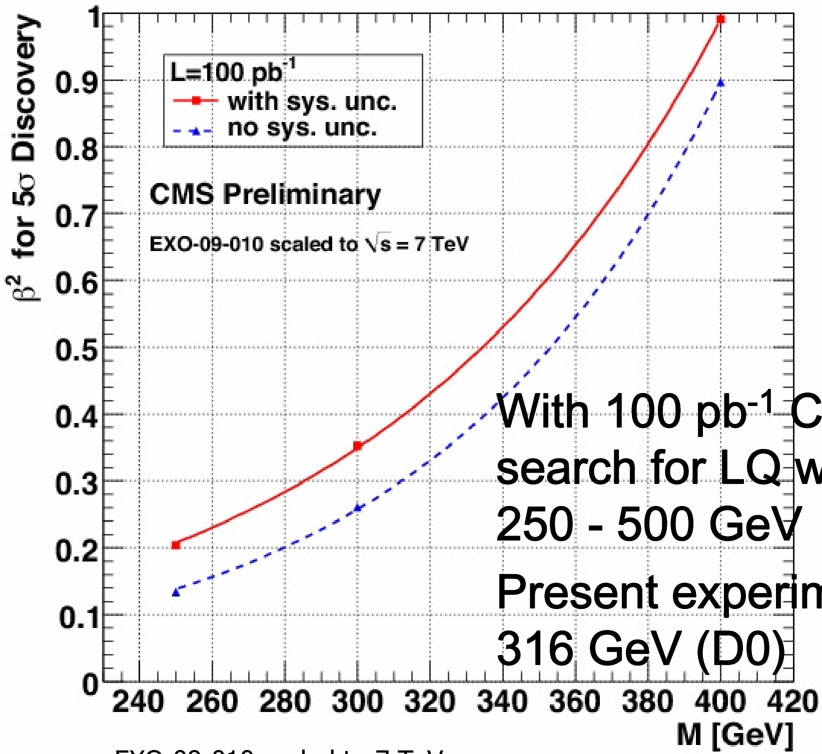
95% C.L. discovery limit: 1.generation



CMS-Note 2010-008

LQ mass

2. generation



EXO-09-010 scaled to 7 TeV

With 100 pb^{-1} CMS can search for LQ with masses 250 - 500 GeV

Present experimental limit 316 GeV (D0)

Systematic uncertainties:

- Luminosity 10%
- Signal efficiency 15%, dominated by jet energy scale
- Number of background events 30%, dominated by jet energy scale

Summary

- After 20 years of construction, CMS has began taking collision data
- For new physics, such as Z‘, W‘ and LQ, at least 100 pb^{-1} @7 TeV are needed. Signals largely based on high p_T leptons

- First phase: commissioning with cosmics and beam splash events. Helped understanding alignment and study detector performance
- Second phase, ongoing
  - Study Standard Model, background to our searches
  - Commissioning of high p_T leptons

- CMS new physics reach with 100 pb^{-1} will be competitive to existing FNAL results
  - Sensitive to W‘ of >1 TeV mass
  - Start to look for Z‘ and RS
  - LQ with masses 250-500 GeV

Is there anything beyond the Standard Model?