Search for new physics with high pT leptons

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on behalf of the CMS collaboration

Outline

- Introduction
- CMS in brief
  - ECAL
  - muon system
- High-p^T leptons and analysis strategy
  - reconstructions
  - selection
- Searches with high-p^T leptons in the final state
  - Z' -> ll
  - W' -> lν
  - scalar LQ pair -> lljj
- Summary

Motivations

- Many physics theories have been built to extend the SM
- These theories foresee a quantity of new particles
- Look for of new physics with high-p^T leptons in the final state

- Left-right symmetry of electroweak interactions
  - Extend the SM gauge group to include right-handed interactions
- Extra dimensions
  - Kaluza-Klein (KK) tower of heavy copies of all SM fields
- General extensions of the SM gauge group
  - e.g. Little Higgs models
- .....

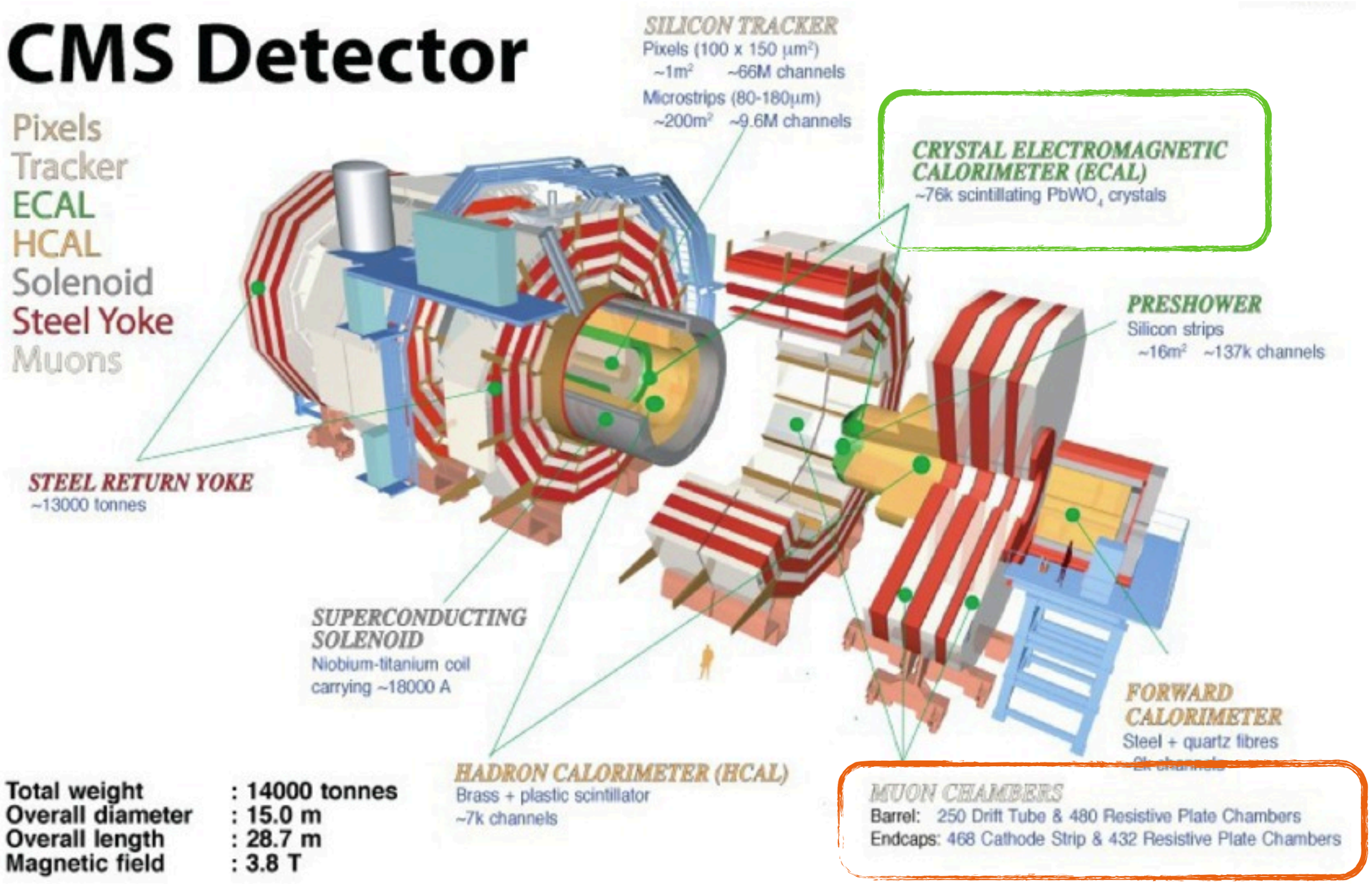
} W', Z'

- Technicolor
- GUT
- Composite models
  - Higgs not just an elementary particle
- .....

} LQ

The CMS detector

- Full 2010 dataset used in the analysis presented (~35 pb^{-1} @ 7 TeV)



High p^T leptons and strategy

- Detect high-pT leptons means to optimize reconstruction and identification in order to maximize the efficiency in the high-pT region
  - Electrons:
    - Electromagnetic clusters with consistent shower shape
    - Spatially matched to a reconstructed track in η and φ
    - Isolated in calorimeter and tracker
  - Muons:
    - Tracks in muon system matched to tracks in inner tracking system
    - Isolated in tracking system and calorimeter
    - More than 10 hits in silicon tracker
    - Transverse impact parameter < 2mm

- CaloDriven
- resol gets better with E
- jet background

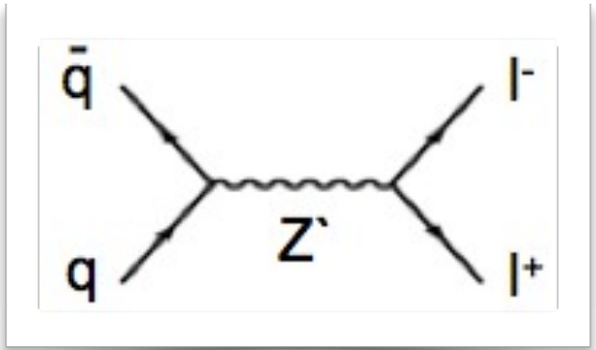
- TrackerDriven
- resol gets worse with p^T
- cosmic background (pair)

- Robust and efficient lepton trigger is needed

- General strategy:
  - excess in data in the high P_T region with respect to the SM expectations (MC)
  - if no excess is observed -> determine the exclusion limit.
- It is crucial to have a good description of the backgrounds
  - accurate shape model
  - accurate normalization

Z' -> ll

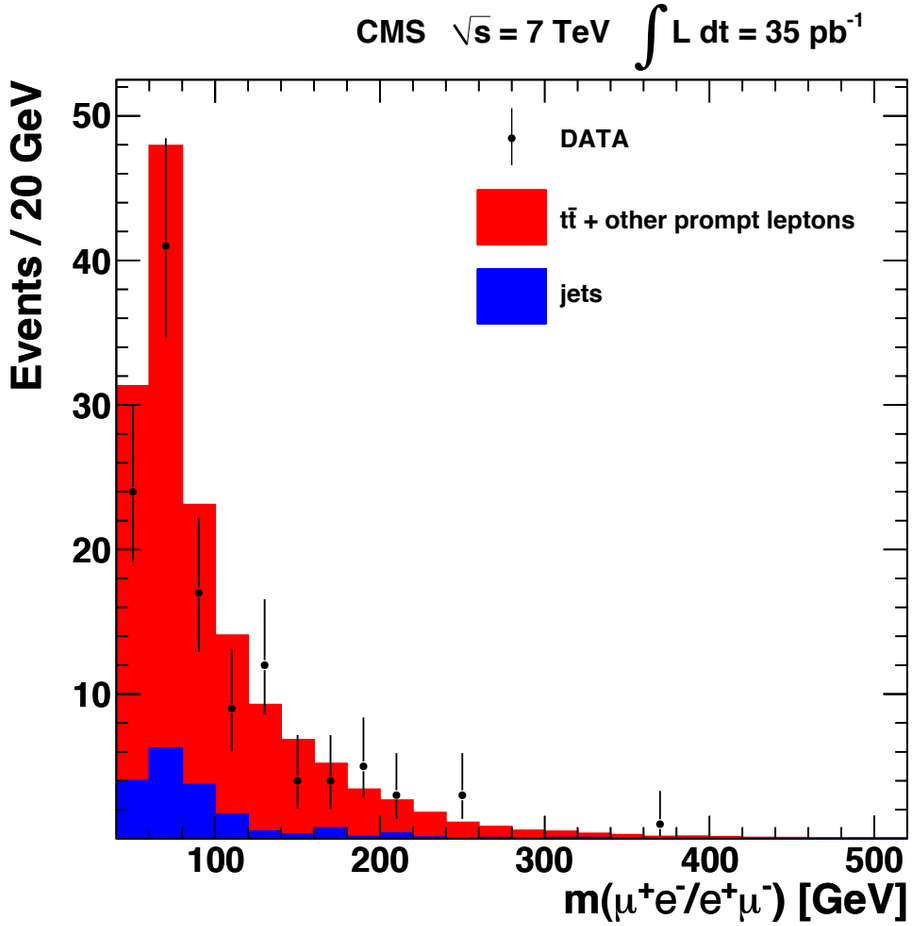
- Clean signature with 2 high-p^T leptons in the final state passing the eleId or muId
- Focus on Z' and RS Graviton models as benchmark
- Complementary searches: lepton univer., different subdet., ...



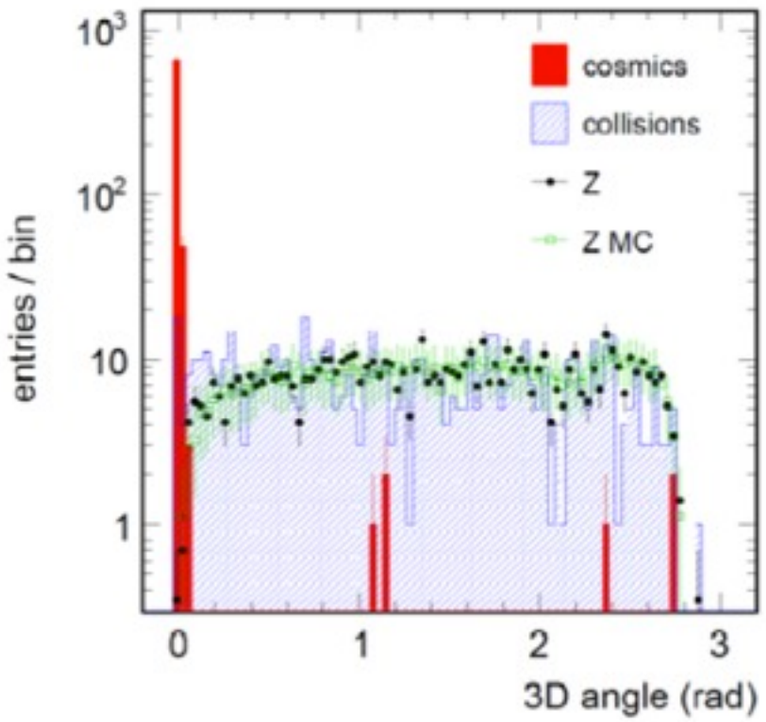
- Main backgrounds:
  - SM Drell-Yan -> irreducible
    - normalized to data
  - TTbar + TTbar-like -> two real leptons (tt,WZ,WW,tW,Z->ττ)
  - Jet Background -> jet fakes a lepton (W+jet,di-jet)
    - fake rate method
  - Cosmics muons bkg -> di-muons from cosmic-rays
    - impact parameter selection
    - 3D angle between the two muons selection

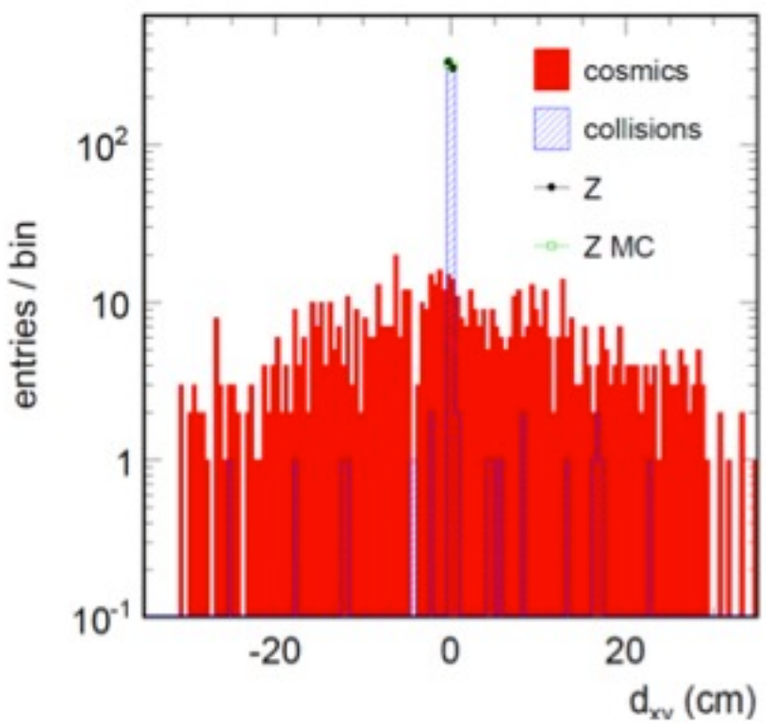
- The bkg with prompt leptons is from MC but cross checked against the e-mu spectrum

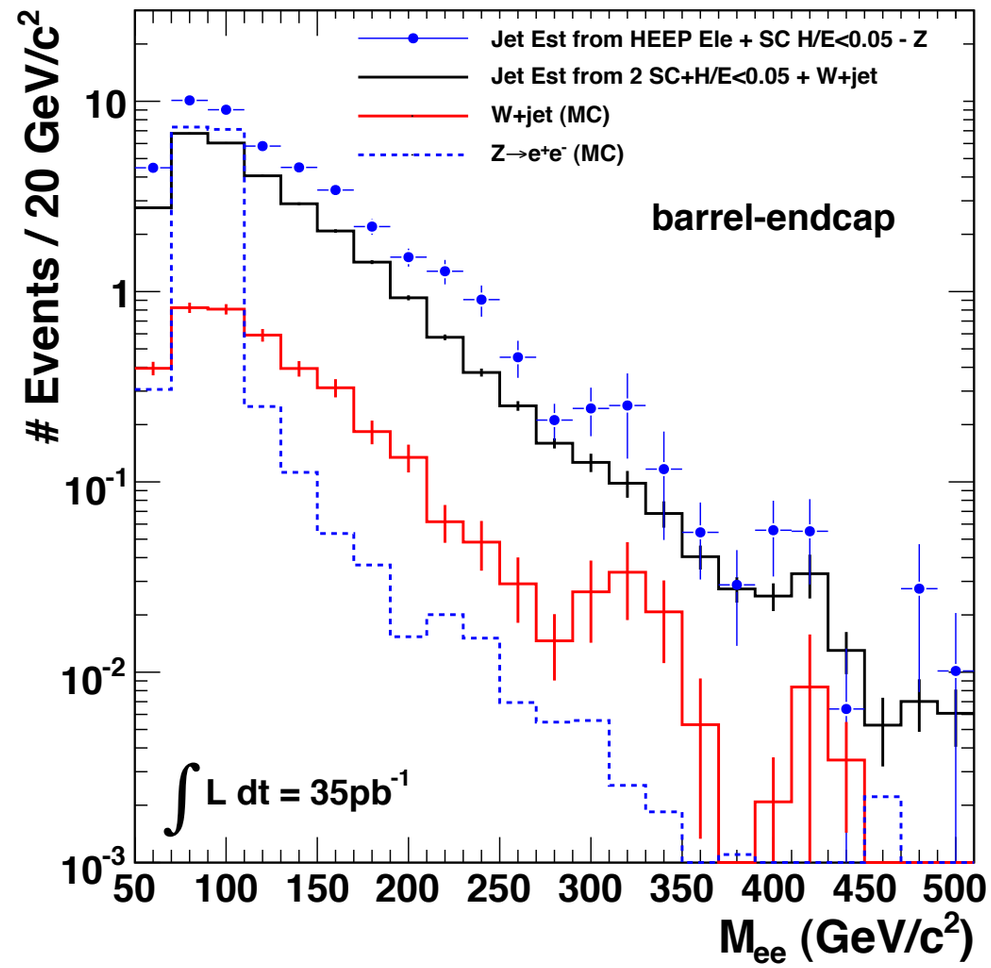
	M>60 GeV/c²	M>120 GeV/c²	M>200 GeV/c²
data	95 ± 10 (stat)	33 ± 6 (stat)	6 ± 2 (stat)
MC	80.4 ± 2.4 (sys)	27.1 ± 0.8 (sys)	7.0 ± 0.2 (sys)



Cosmics and jets background

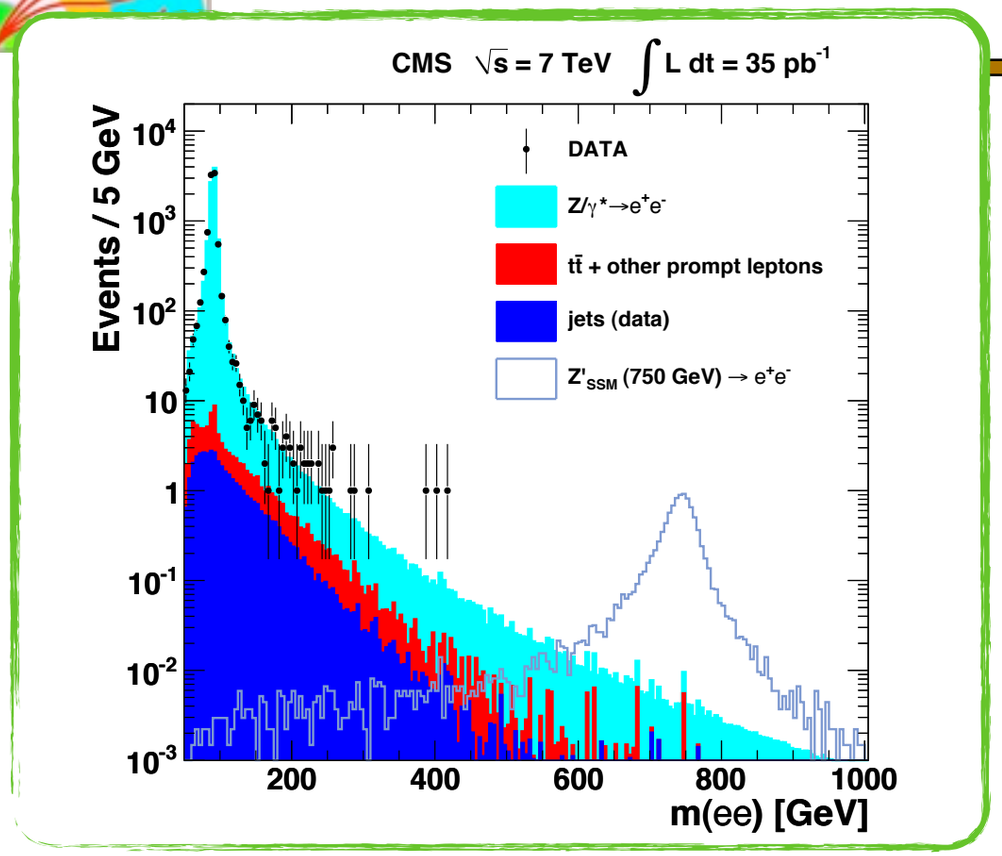






- Measure probability (or fakerate) for a jet which is reconstructed as a SC with H/E <0.05 to pass eleId selection
- Apply it to 2 SC or 1 SC + 1 HEEP events
- Take difference between two estimates as fake rate systematic

Final selection and results

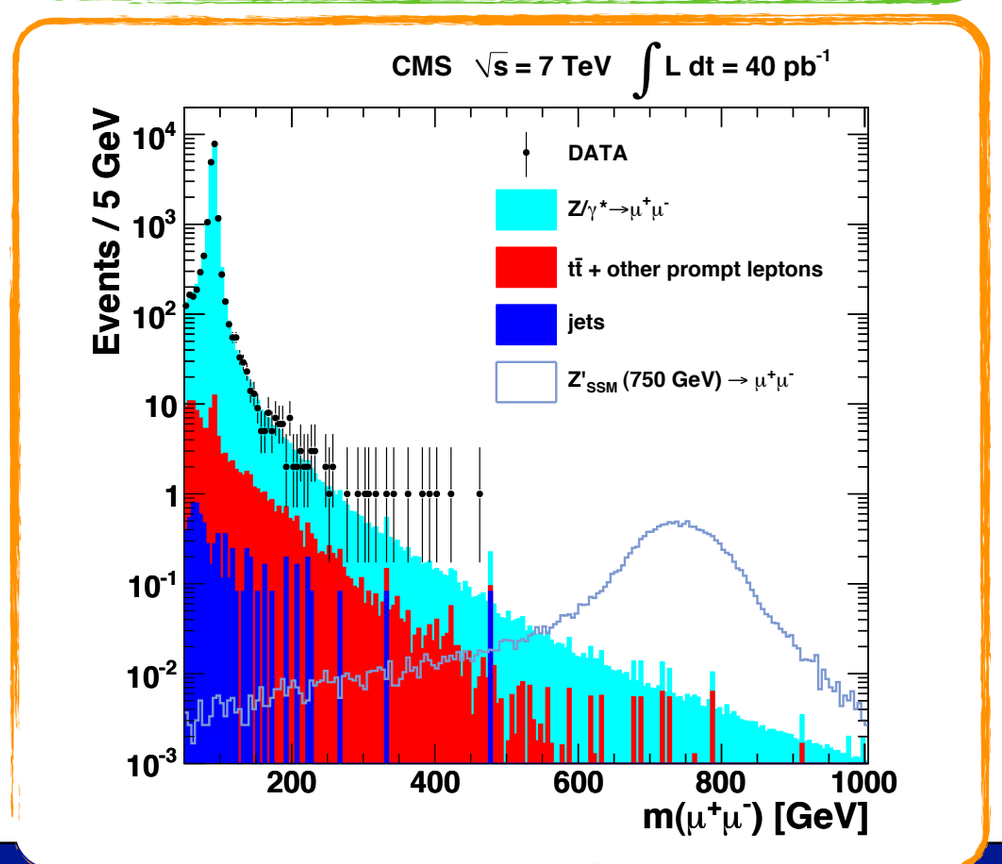


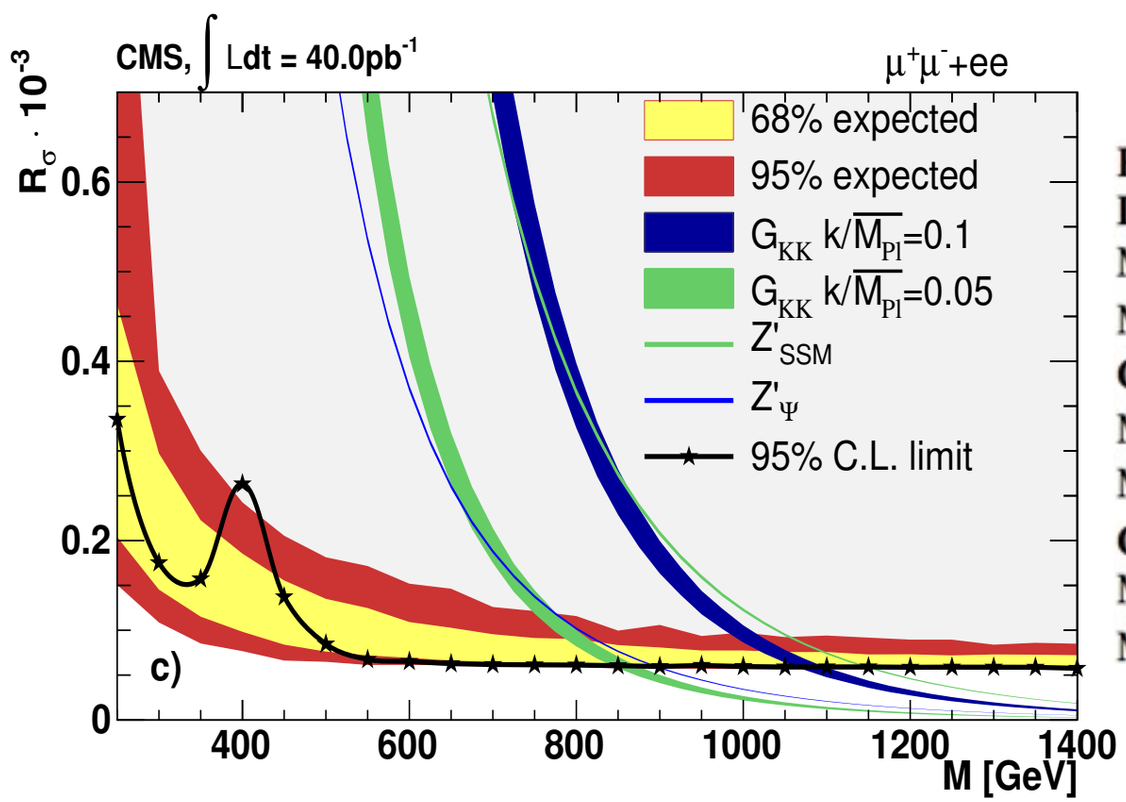
- By focusing on the ratio, the uncertainty on the integrated lumi is eliminated

$$\frac{\sigma \times BR(Z')}{\sigma \times BR(Z^0)} = \frac{N(Z')}{N(Z^0)} \times \frac{A(Z^0)}{A(Z')} \times \frac{\epsilon(Z^0)}{\epsilon(Z')}$$

Channel	μμ	ee	combined
Z_{SSM}	1027 GeV	958 GeV	1140 GeV
Z_ψ	792 GeV	731 GeV	887 GeV
G_{kk}, k/M_{Pl} = 0.05	778 GeV	729 GeV	855 GeV
G_{kk}, k/M_{Pl} = 0.10	987 GeV	931 GeV	1079 GeV

Exclusion @ 95% C.L.





Published CDF/D0 limits

D0, ee,γγ 5.4 fb⁻¹:

$M(Z'_{SSM}) > 1023$ GeV

$M(G_{KK}, k/M=0.1) > 1050$ GeV

CDF, μμ, 2.3 fb⁻¹:

$M(Z'_{SSM}) > 1030$ GeV

$M(G_{KK}, k/M=0.1) > 921$ GeV

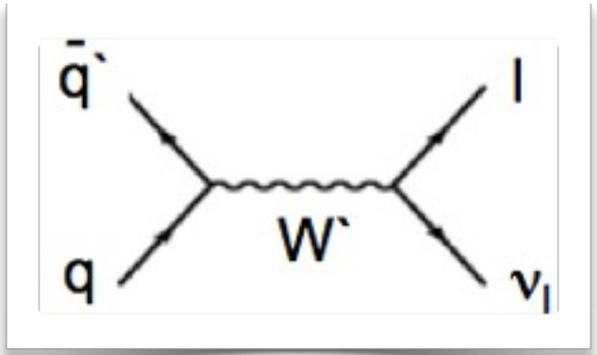
CDF, ee , 2.5 fb⁻¹:

$M(Z'_{SSM}) > 963$ GeV

$M(G_{KK}, k/M=0.1) > 848$ GeV

W' -> lν

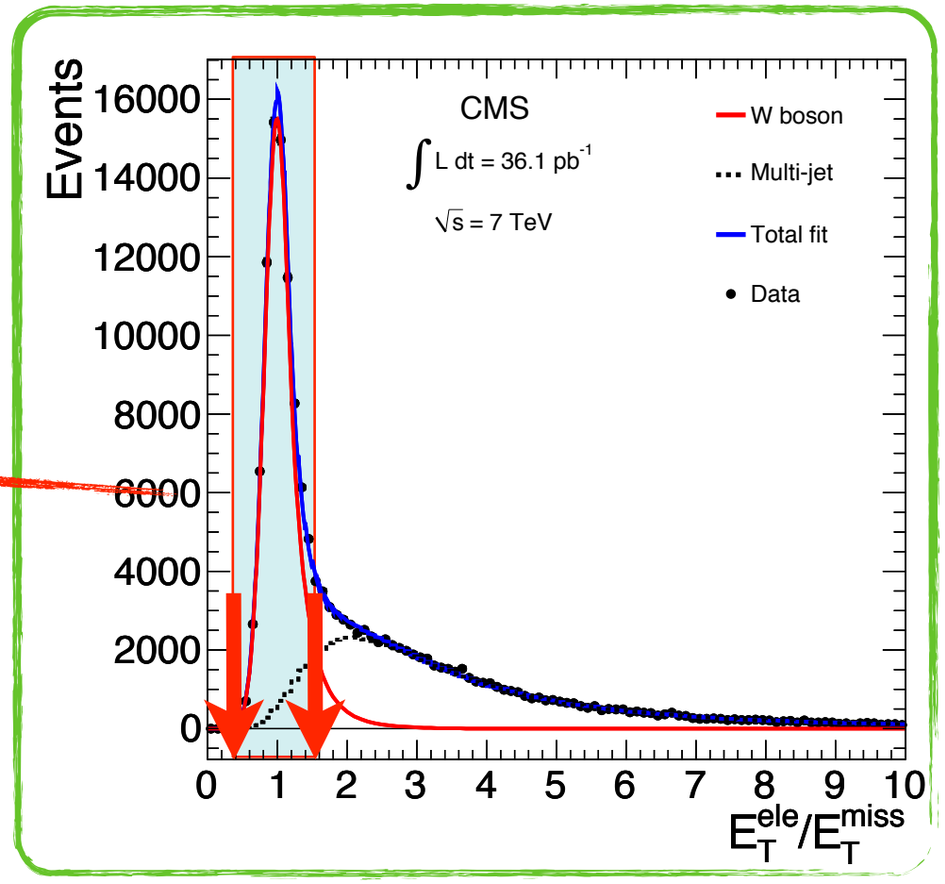
- Altarelli reference model tested (carbon copy of SM W boson)
- Signature: single and isolated high-pT lepton + large MET



- Kinematic selections:
  - Δφ (lepton, MET) > 2.5
  - 0.4 < lepton ET / MET < 1.5

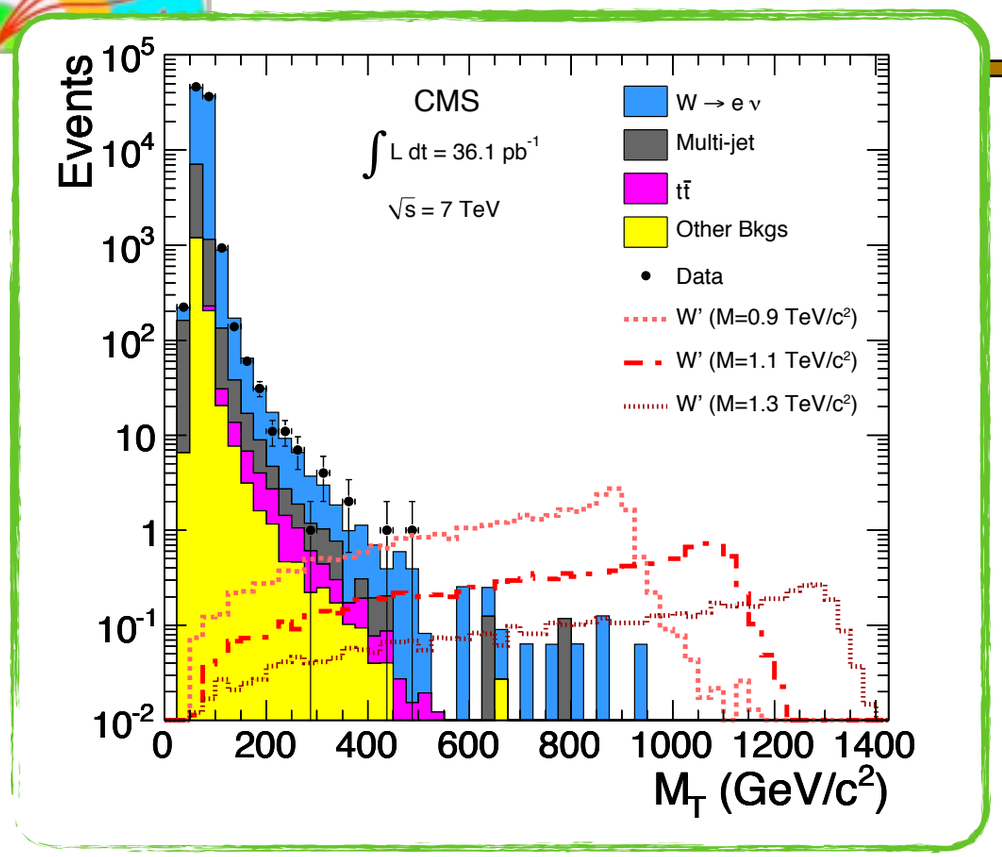
  } lepton and MET balance: both module and direction

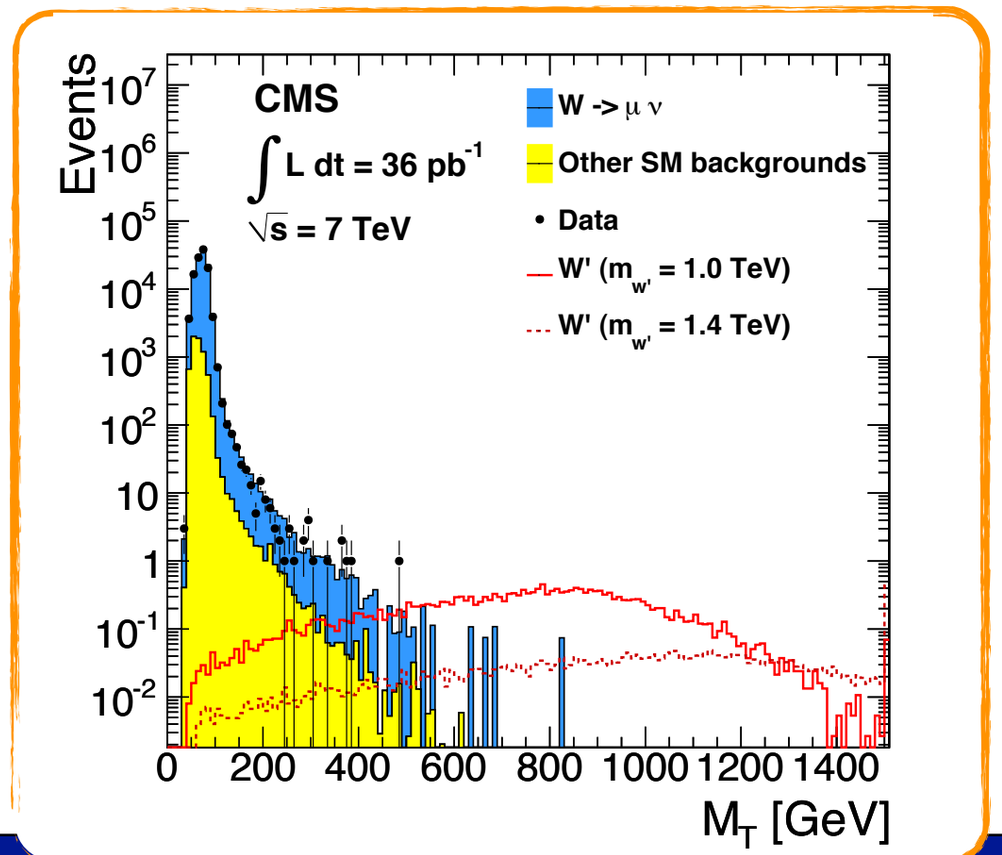
- Main background: irreducible Standard Model W -> lν
- Bkg estimate in the high-pT region: two different approaches for electron and muon channels
  - Invert the isolation requirement and use the shape of M^T from non-isolated electrons
  - Fit data E^T/MET distribution with QCD template (from non-iso) + W template (from MC), leaving the two normalizations as free parameters.
  - M^T spectra are normalized to the template area in the region 0.4 < Et/MET < 1.5



  - Sideband fit in a region where signal ~1%
    - Breit-Wigner fit in the range: 180 GeV < M^T < 350 GeV
  - Extrapolation in the high-p^T region
  - Cross check with MC

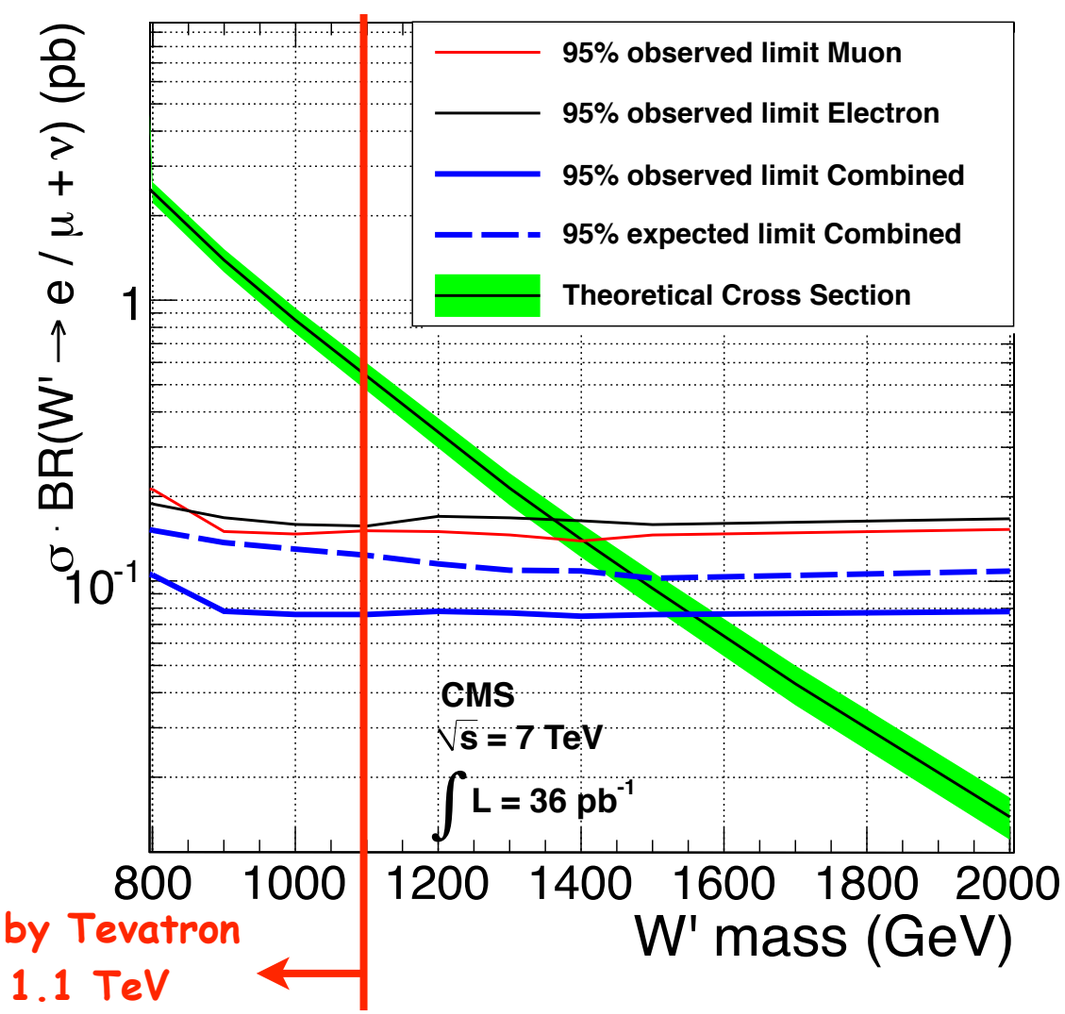
Final selection and results





- Good agreement between data and SM prediction
- Exclusion limit up to M(W') = 1.58 TeV @ 95% C.L.
- Cut and count method: sliding search window to optimize the limit

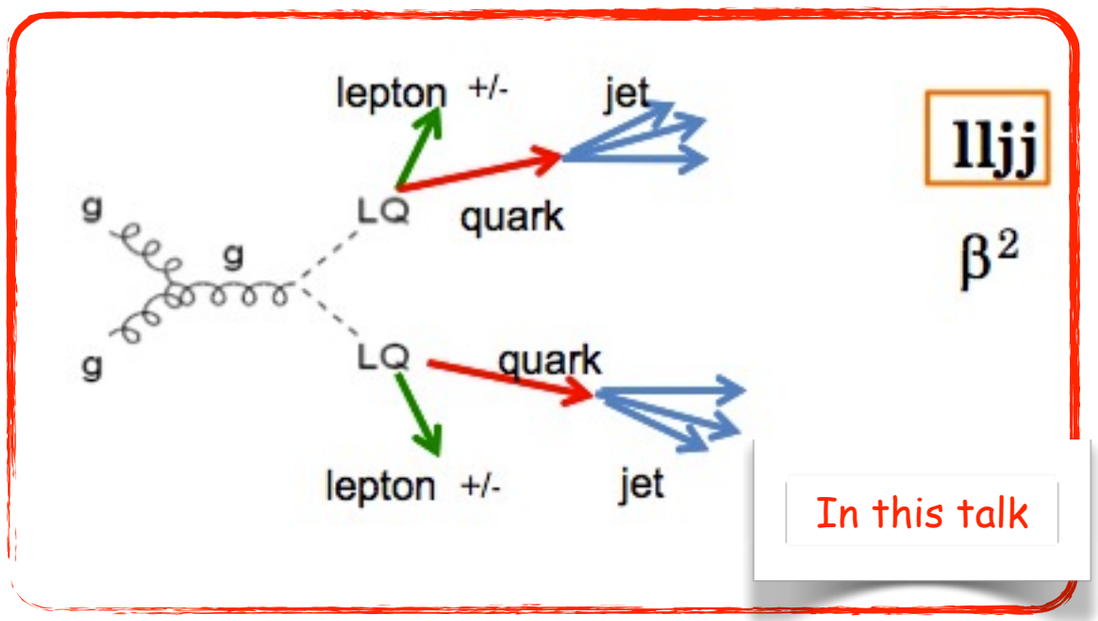
$$M_T = \sqrt{2 \cdot E_T^{ele} \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{eE_T^{miss}})}$$



Excluded by Tevatron below 1.1 TeV

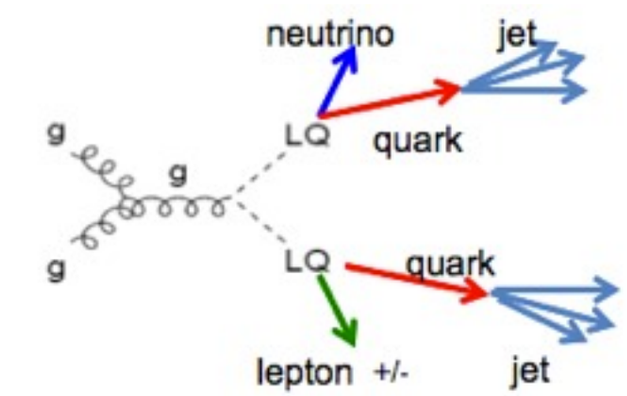
Scalar LQ pair -> lljj

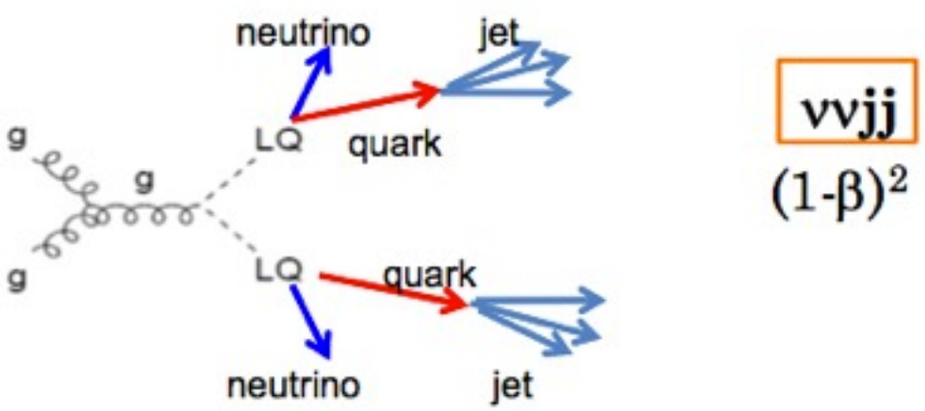
- Three LQ generations and three signatures
- Characterized by two free parameters
  - M_{LQ} = LQ mass
  - λ = LQ - l - q coupling < λ_{EM} ~ 0.3
- Mainly produced via gloun-gluon fusion
  - λ independent



- Event selection:
  - at least: 2 isolated high-pT leptons, 2 high-pT jets
  - a lower cut on M_{ll} to remove Z+jets bkg
  - $S^T = p^T(l_1) + p^T(l_2) + p^T(j_1) + p^T(j_2) > f(M_{LQ})$

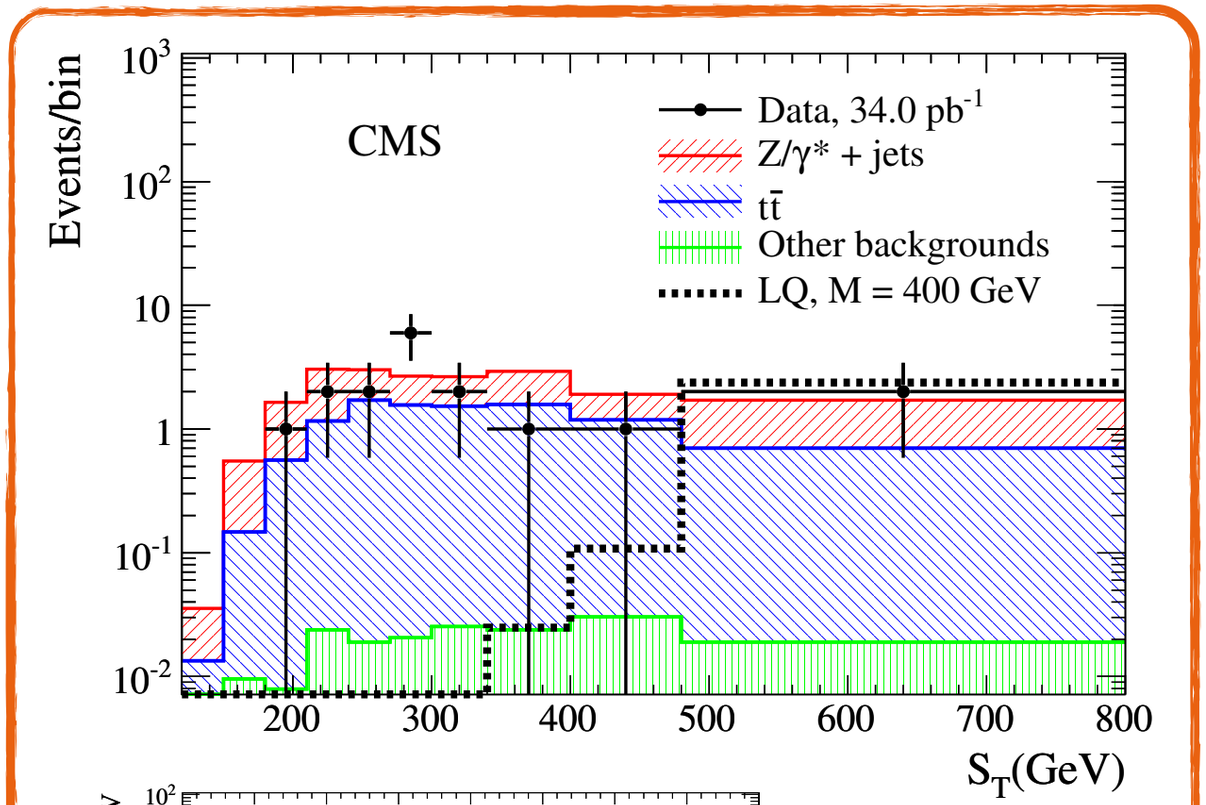
- Background estimate (in common for e and mu):
  - Z+jets and TTbar are the dominant backgrounds
    - Shape from MC
    - normalization from DATA
  - The small QCD background is determined from data
    - fake rate method

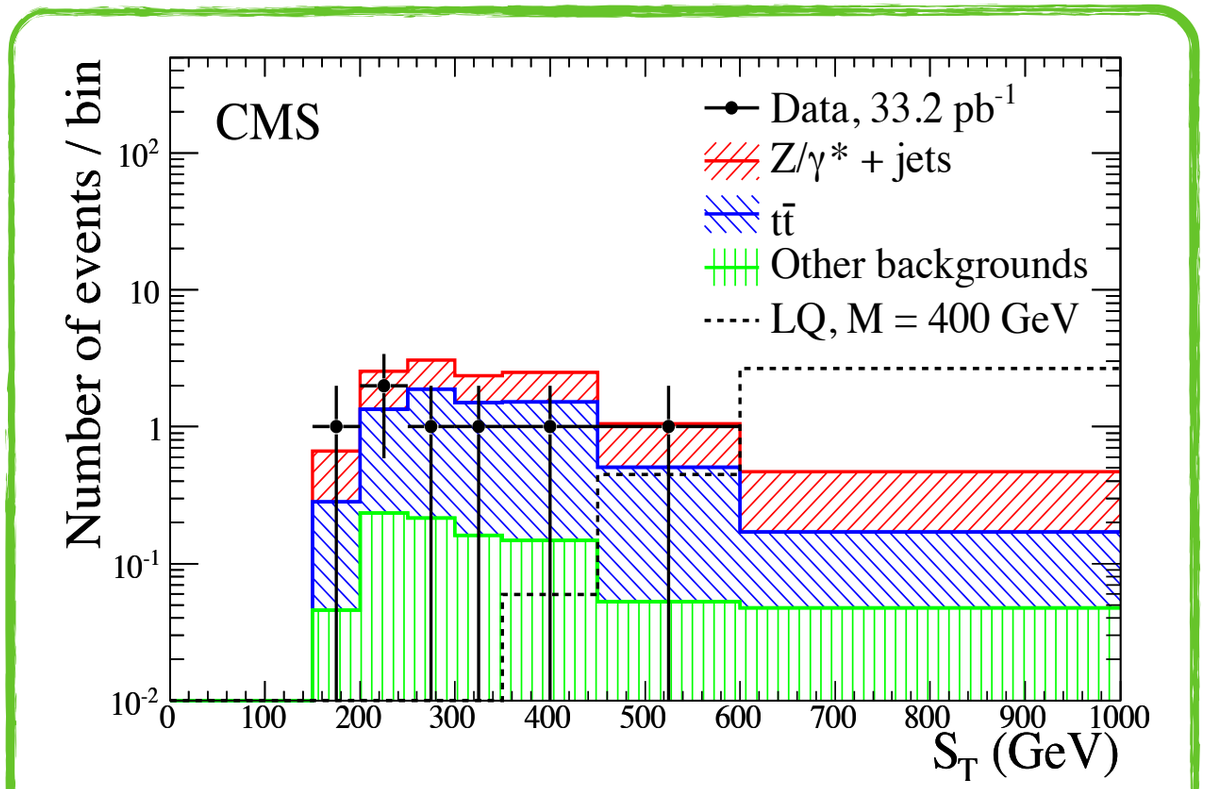


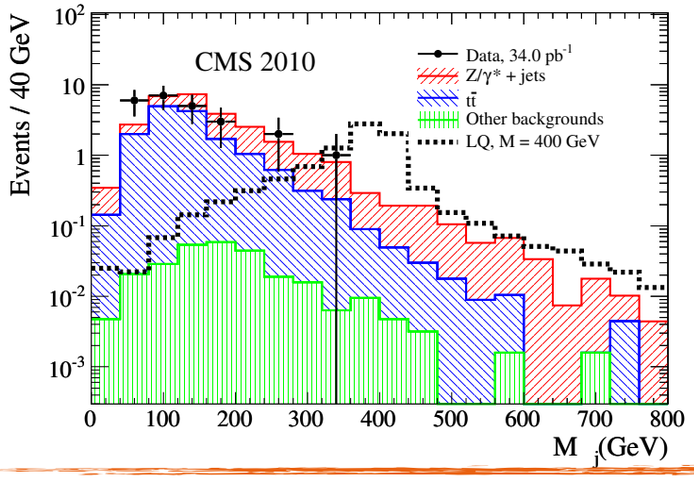


Final selection

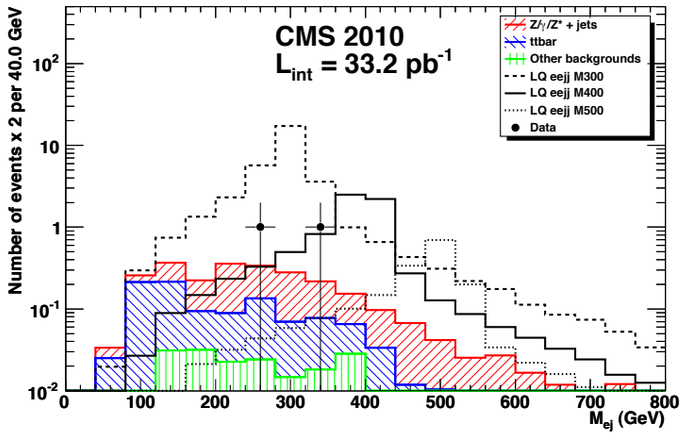
- M_{ll} and S^T are the two most powerful variables in discriminating signal and bkg
- M_{ll} and S^T have been optimized using a Bayesian approach to minimize upper limit in a 35 pb^{-1} scenario
  - $M_{ee} > 125$ GeV ; $M_{\mu\mu} > 115$ GeV ; $S^T > f(M_{LQ})$





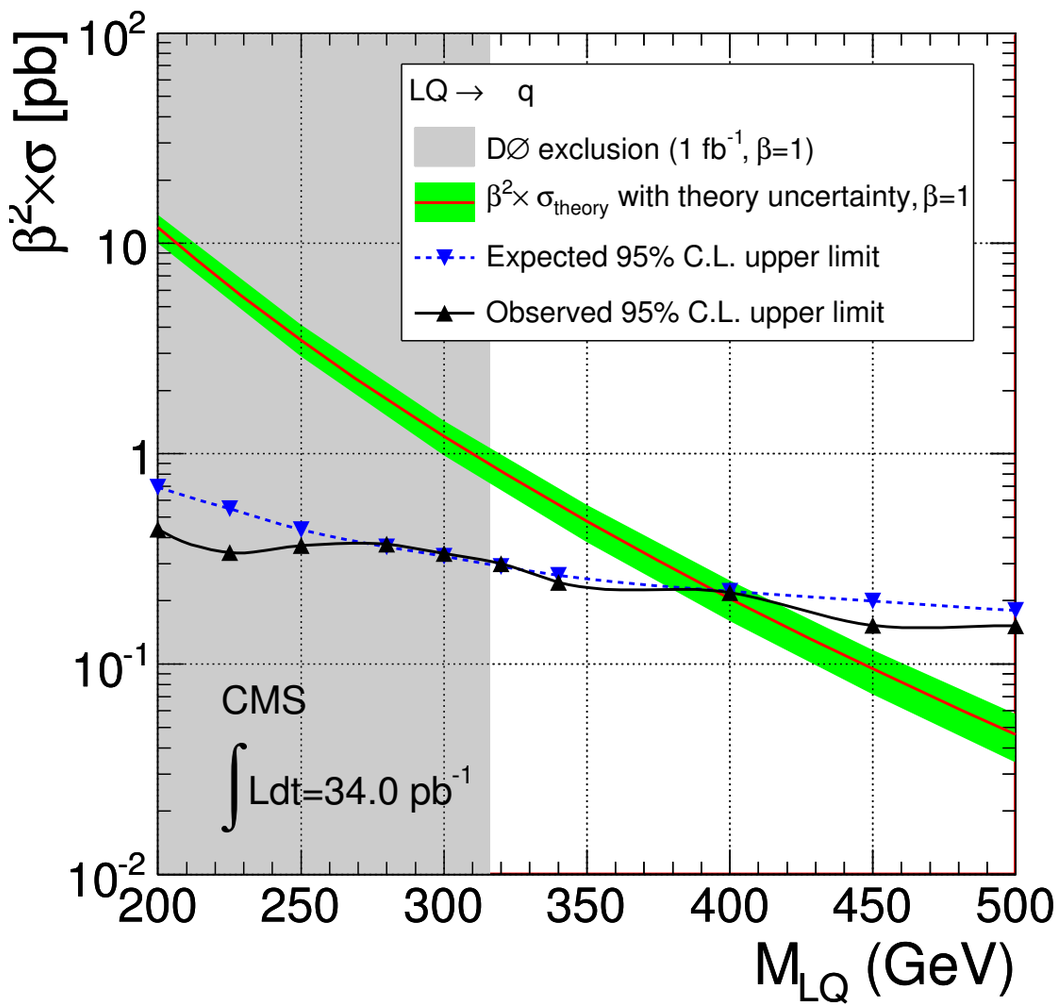


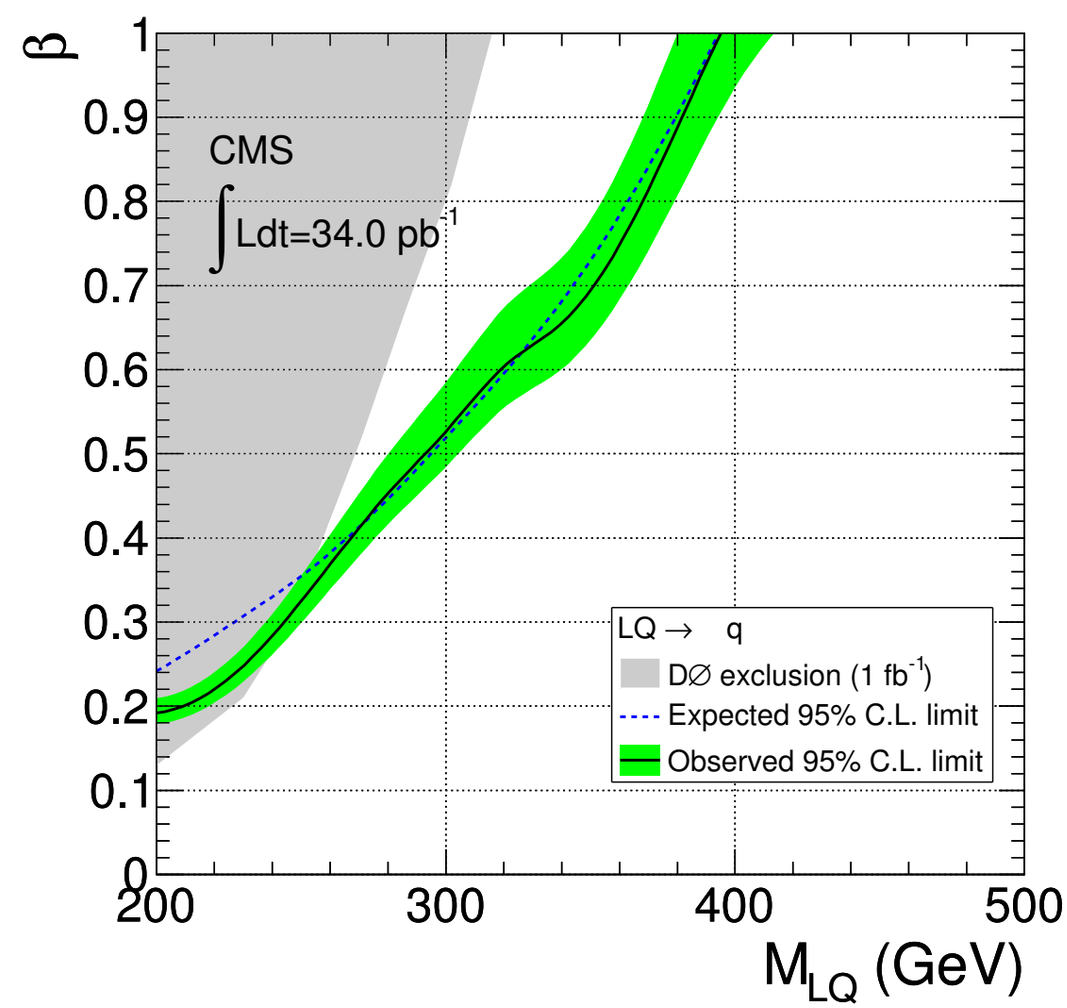
M_{lj} is affected by combinatorics



Limits on σ_{prod}(LQ pair) and M_{LQ}

- The data are consistent with SM background expectation
  - Upper limits on the LQ cross section are set using a Bayesian approach
- The existence of first and second generation LQs with mass below 384 and 394 GeV, respectively, are excluded for β=1





Summary

- Good understanding of the detector and backgrounds in a variety of channels
  - data-driven background estimation in most cases
- Searches for new physics phenomena with high-p^T leptons in the final state have been performed
- No excess found in DATA
- New exclusion limits for Z', W' and LQ pair

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

BACKUP

muon and electron ID

- Muon identification and quality cuts:

- Tracker & global muon
- ≥ 11 silicon tracker hits
- ≥ 1 pixel hit
- χ^2 / Ndof < 10
- Transverse impact parameter d0 < 0.02 cm (order of magnitude tighter than VBTF recommondation)
- At least 2 matched muon segments

HEEP Selection cuts v3.0

Official HEEP Selection v3.0 (Current Version)		
Variable	Barrel	Endcap
E_T	> 25 GeV	> 25 GeV
$\lvert\eta_{sc}\rvert$	< 1.442	$1.560 < \lvert\eta_{sc}\rvert < 2.5$
isEcalDriven	=1	=1
$\lvert\Delta\eta_{in}\rvert$	< 0.005	< 0.007
$\lvert\Delta\varphi_{in}\rvert$	< 0.09	< 0.09
H/E	<0.05	<0.05
$\sigma_{i\eta i\eta}$	n/a	<0.03
E^{2x5}/E^{5x5}	>0.94 OR $E^{1x5}/E^{5x5} > 0.83$	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et	<2.5 for Et<50 else <2.5+0.03*(Et-50)
Had Depth 2 Isolation	n/a	<0.5
Track Isol: Trk Pt	<7.5	<15

LQs event yeld

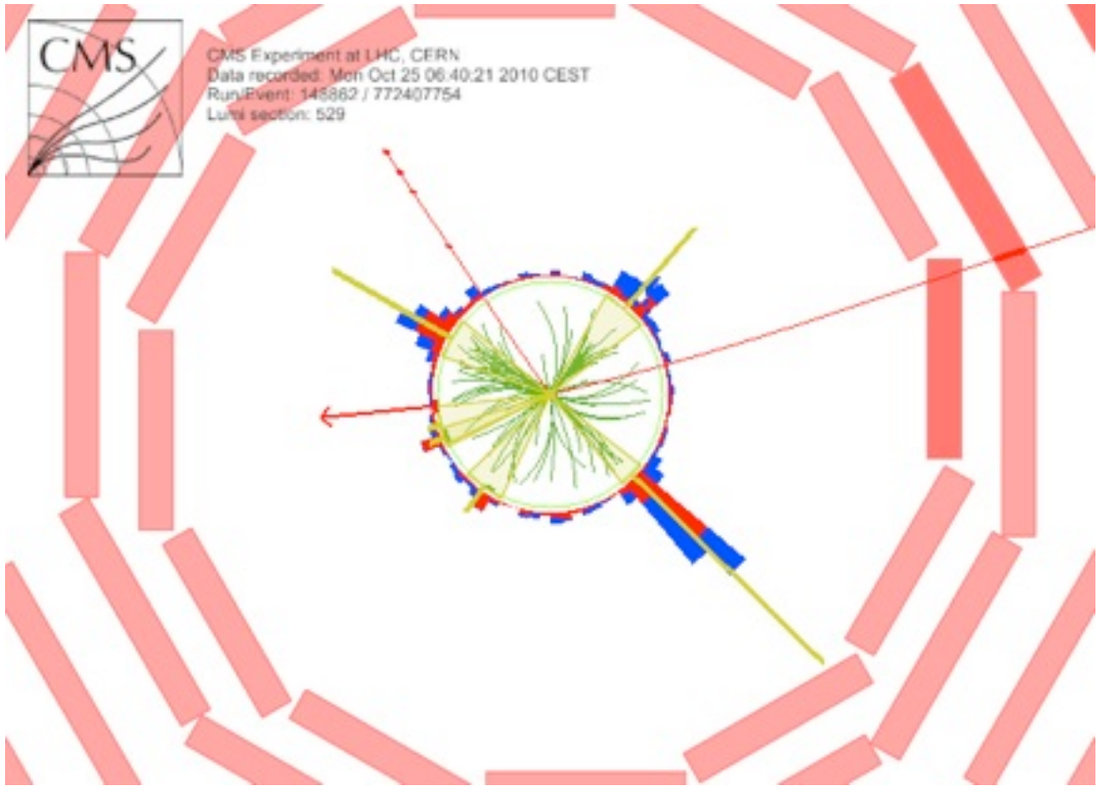
2 electrons P_T>30 GeV, |η|<2.5; 2 jets P_T>30 GeV, |η|<3; ΔR(e,j)>0.7; M_{ee}> 125 GeV; S_T>f(M_{LQ})

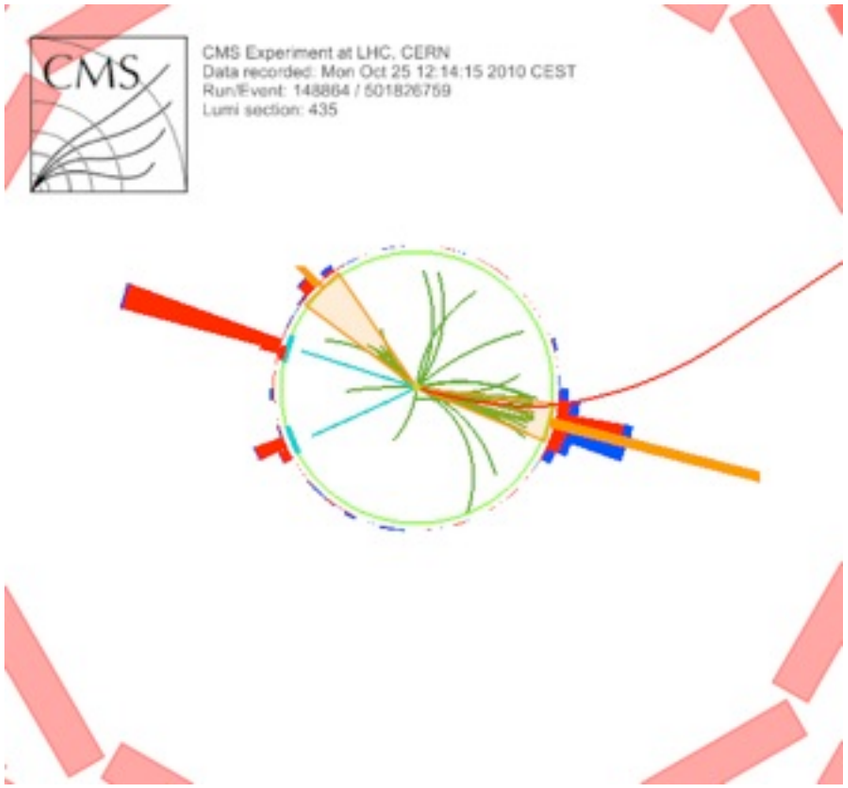
M_{LQ} (S_T Request) [GeV]	MC Signal Samples Selected Events	Acceptance ×Efficiency	Monte Carlo Background Samples Selected Events in $t\bar{t}$ + jets	Z/γ + jets	Others	All	Events in Data
250 (S_T >400)	43.8±0.2	0.380±0.002	1.1 ±0.06	1.3 ±0.1	0.14±0.02	2.5 ±0.1	1
300 (S_T >470)	17.3±0.1	0.430±0.002	0.44±0.04	0.75±0.07	0.10±0.02	1.3 ±0.1	1
340 (S_T >510)	8.88±0.04	0.469±0.002	0.27±0.03	0.56±0.06	0.08±0.02	0.91±0.08	1
400 (S_T >560)	3.55±0.02	0.522±0.002	0.17±0.02	0.41±0.05	0.06±0.02	0.63±0.06	1
450 (S_T >620)	1.70±0.01	0.539±0.002	0.10±0.02	0.28±0.05	0.02±0.01	0.41±0.06	0

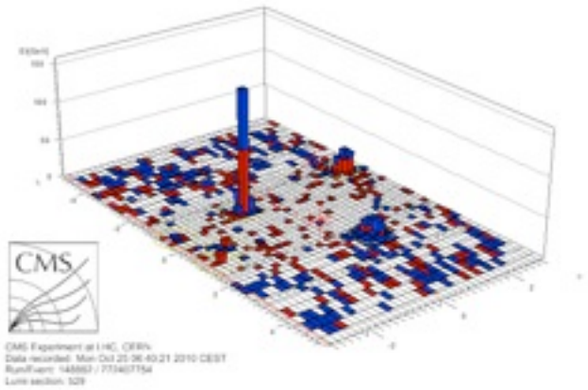
2 muons P_T>30 GeV, |η|<2.4(2.1); ΔR(μ, μ)>0.3; 2 jets P_T>30 GeV, |η|<3; $M_{\mu\mu}$>115 GeV; S_T>f(M_{LQ}) GeV

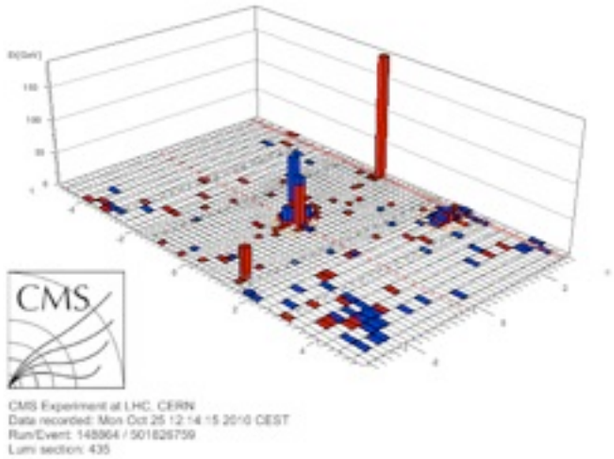
M_{LQ}	S_T	Z/γ^*+jets	$t\bar{t}$	Other Bkg	All Bkg	Data	S	ϵ_S
250	400	1.92 ± 0.03	1.60 ± 0.08	0.05 ± 0.01	3.57 ± 0.09	3	51.5 ± 5.2	0.437 ± 0.003
300	449	1.53 ± 0.03	0.98 ± 0.06	0.04 ± 0.01	2.54 ± 0.07	3	21.3 ± 2.1	0.518 ± 0.004
340	530	0.79 ± 0.01	0.34 ± 0.04	0.01 ± 0.00	1.14 ± 0.04	1	9.8 ± 1.0	0.508 ± 0.003
400	560	0.67 ± 0.01	0.27 ± 0.03	0.01 ± 0.00	0.94 ± 0.03	1	4.0 ± 0.4	0.578 ± 0.004
450	620	0.49 ± 0.01	0.16 ± 0.02	0.01 ± 0.00	0.66 ± 0.03	0	1.9 ± 0.2	0.600 ± 0.004

LQs event display

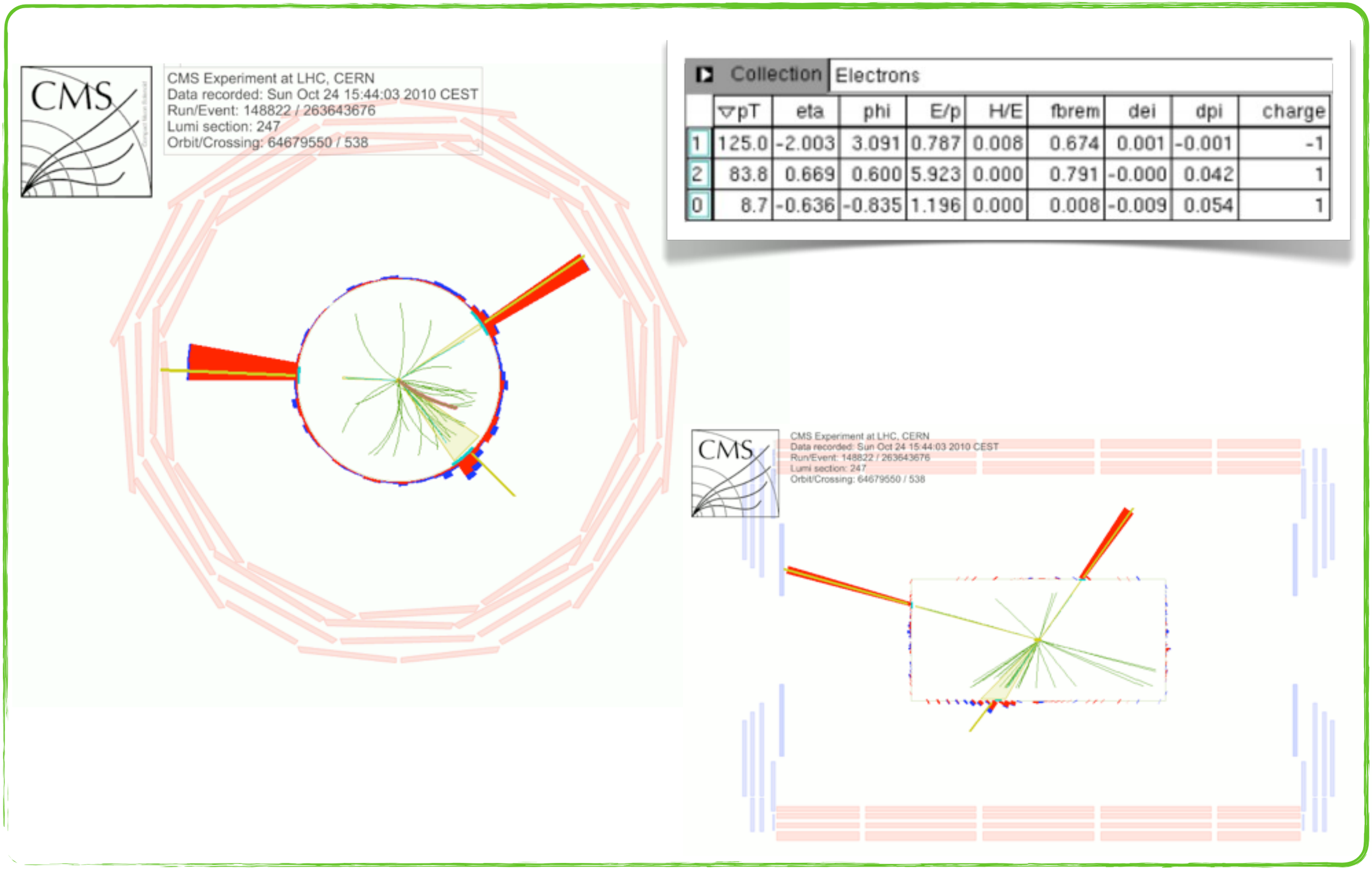








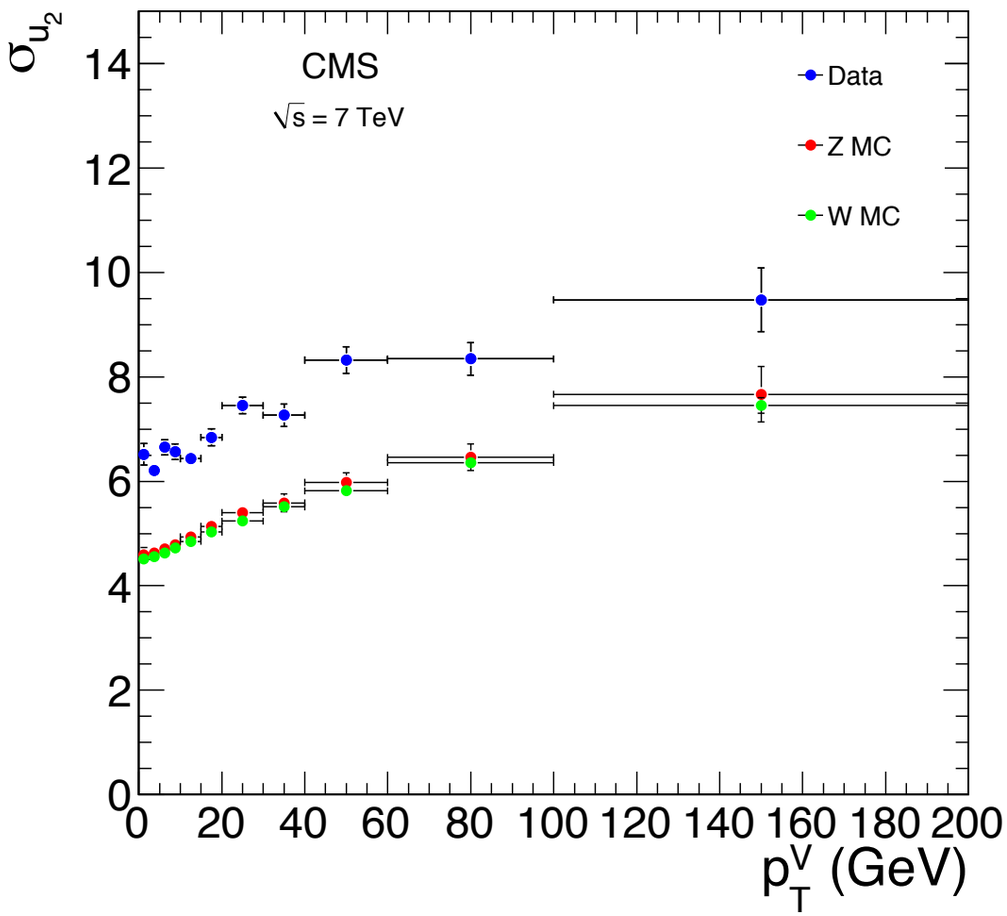
Z' high mass event display



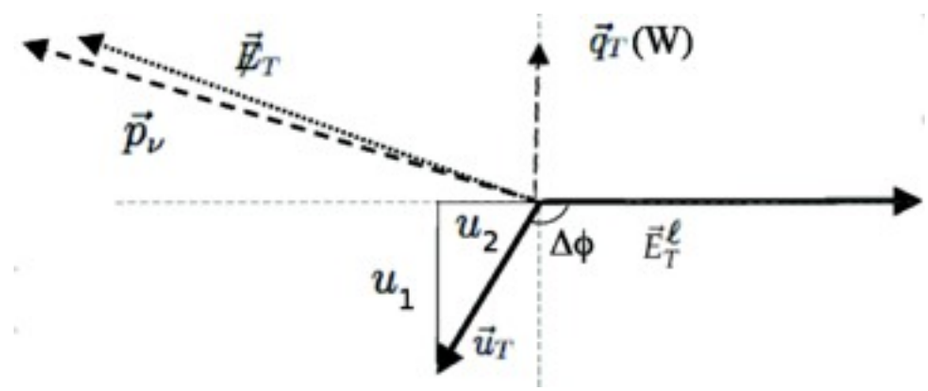
	pT	eta	phi	E/p	H/E	fbrem	dei	dpi	charge
1	125.0	-2.003	3.091	0.787	0.008	0.674	0.001	-0.001	-1
2	83.8	0.669	0.600	5.923	0.000	0.791	-0.000	0.042	1
0	8.7	-0.636	-0.835	1.196	0.000	0.008	-0.009	0.054	1

Hadron recoil

- The Wenu shape is from MC, but corrected to take into account differences between DATA and MC
- Estimate the parallel (u_1) and transverse (u_2) component of the hadron recoil in MC and DATA using Z -> ee events.



$$\vec{u_T} = -\vec{\not{E}}_{\mathrm{T}} - \sum_l \vec{E}_T^l$$



- The same procedure is used in the W cross section measurement

Wenu recoil correction

- For both u1 and u2 we are correcting for the differences between data and MC on an event by event basis

$$\sigma_{ui}(p_T^W) = \frac{\sigma_{ui}^{Zdata}(p_T^W)}{\sigma_{ui}^{Zmc}(p_T^W)} \cdot \sigma_{ui}^{Wmc}(p_T^W)$$

$$u_i = Gauss(f_{ui}(p_T^W), \sigma_{ui}(p_T^W))$$

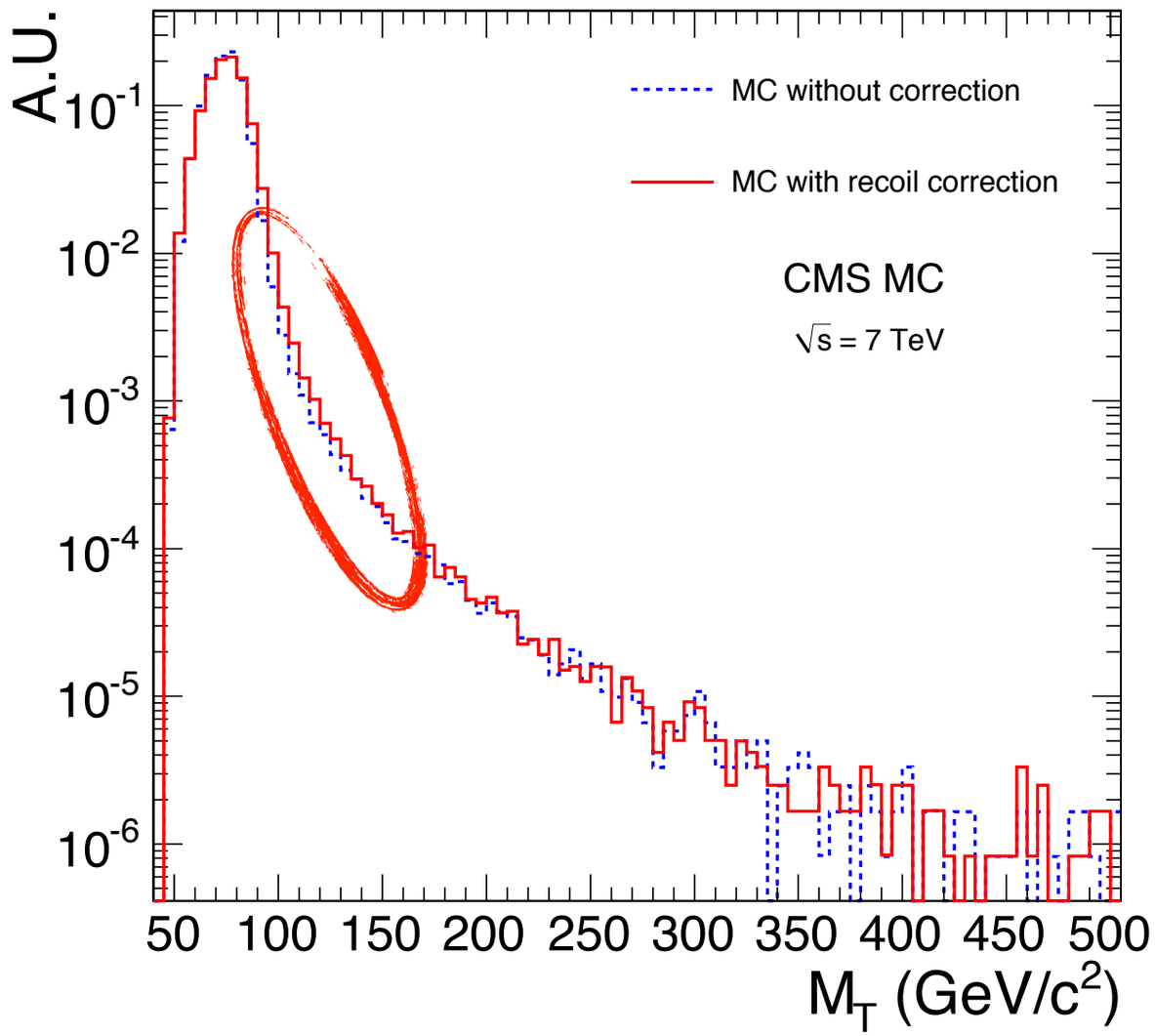
$$\vec{u_T} = \vec{u_1} + \vec{u_2}$$

$$\vec{\not{E}}_{\mathrm{T}}^{corr} = -\vec{u_T} - \vec{E}_T^{ele}$$

- Gen level MC used to extract the W P_T.

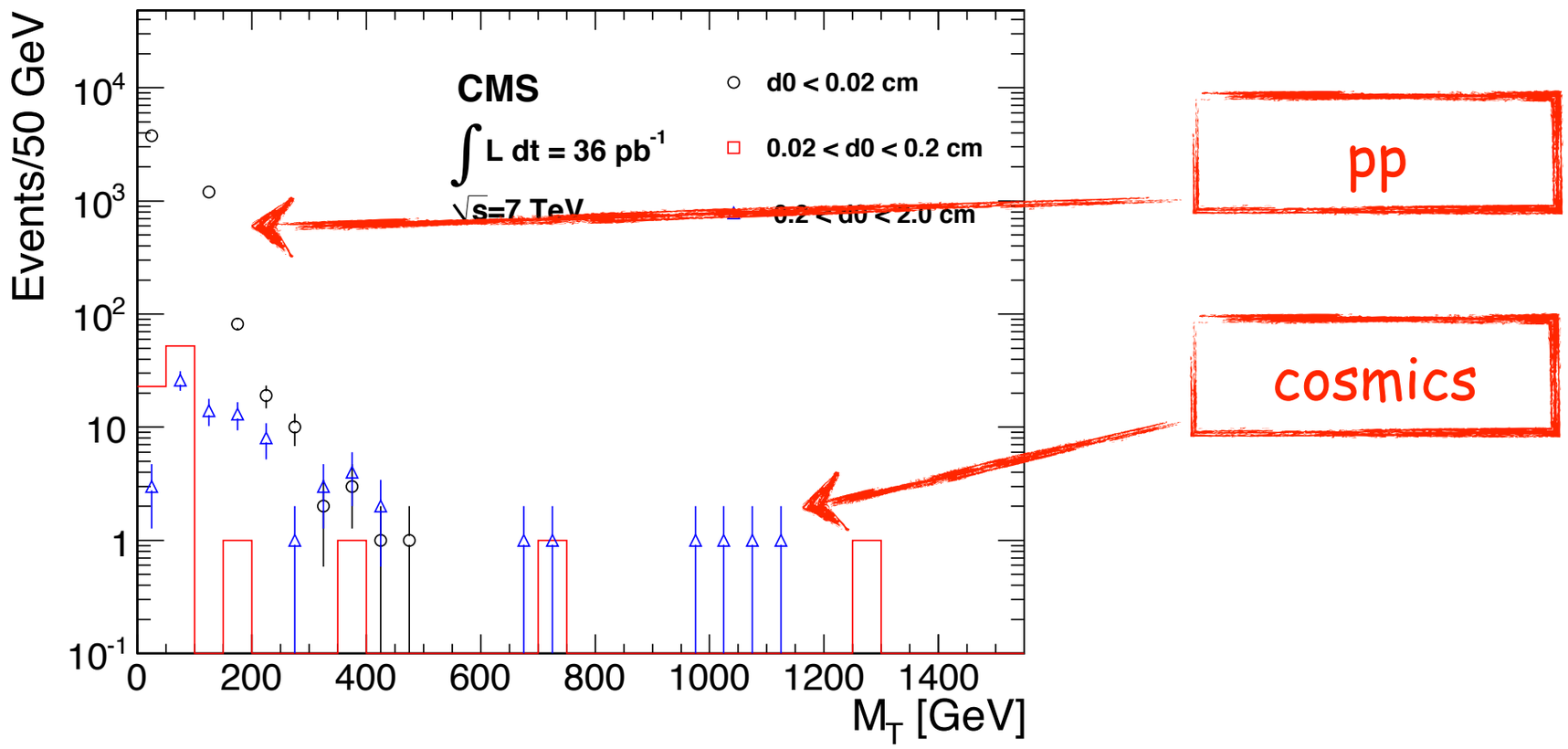
Wenu recoil correction

- After the correction, the shapes differ mainly in the region of transverse mass between 80 and 120 GeV



Cosmics contamination

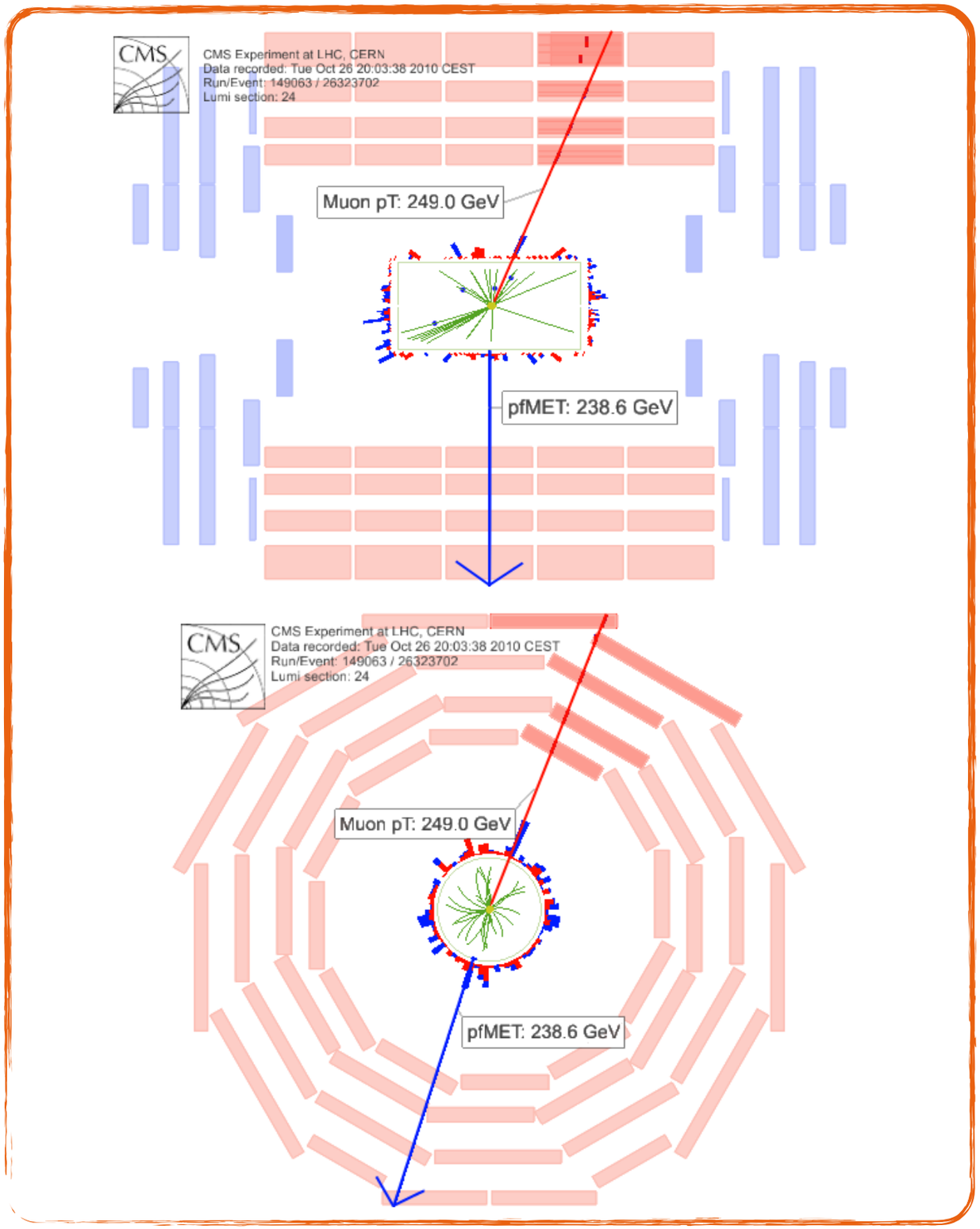
- Not taken into account in the sideband fit
- Cosmics contamination more relevant for tail of M^T distribution

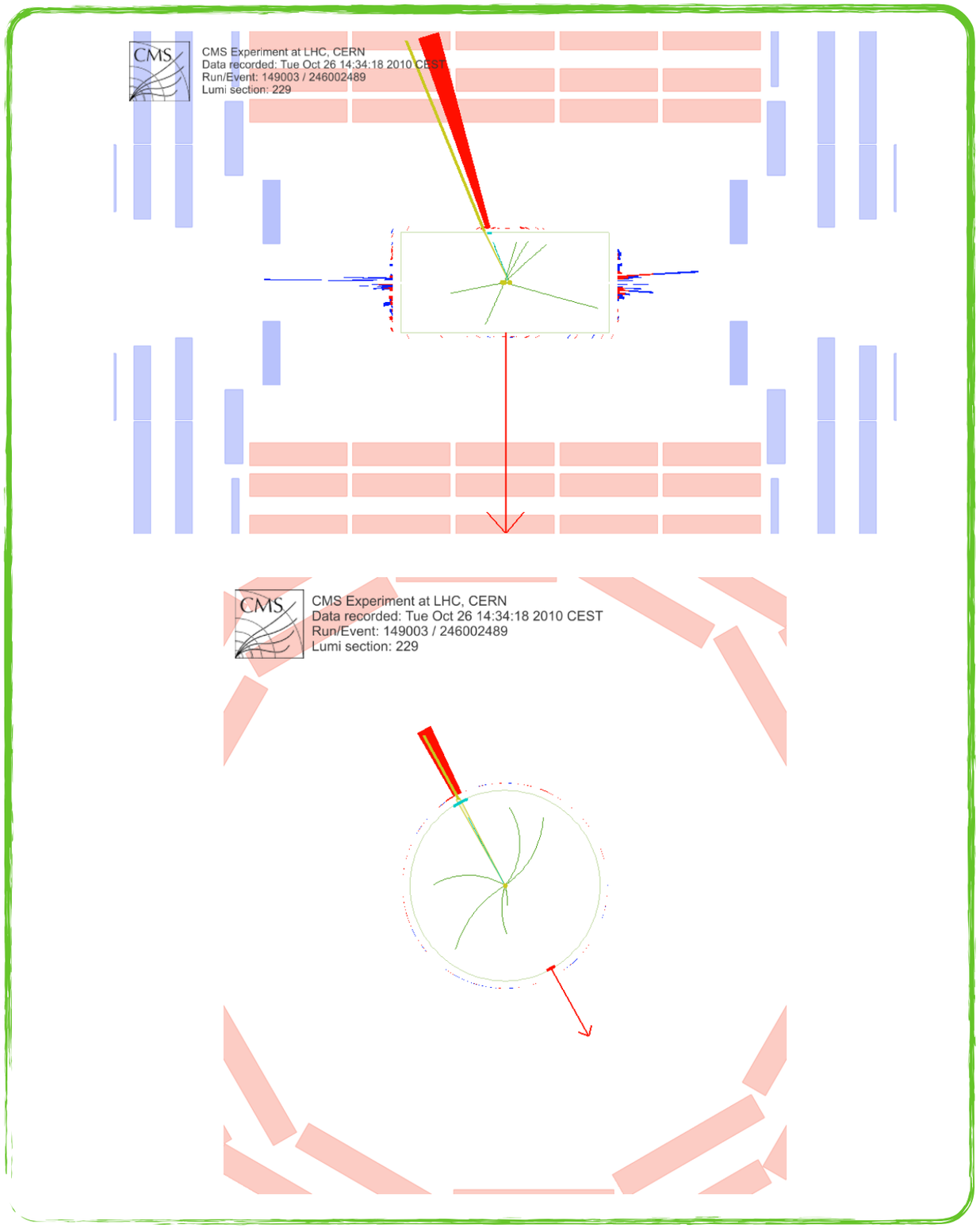


- Contamination for d0 < 0.02 cm

M_T [GeV/c^2] range	Collision background	Cosmic background	Total background
$180 < M_T < 350$	54.7 ± 7.3	0.19 ± 0.04	54.9 ± 7.3
$M_T > 350$	3.6 ± 1.0	0.15 ± 0.04	3.8 ± 1.0
$M_T > 400$	2.2 ± 0.6	0.10 ± 0.03	2.3 ± 0.6
$M_T > 500$	1.0 ± 0.3	0.08 ± 0.03	1.1 ± 0.3
$M_T > 600$	0.54 ± 0.15	0.08 ± 0.03	0.62 ± 0.15

W' event display





Bayesian upper limit

- A Bayesian tool to calculate the expected and observed 95% C.L. upper limits is used

$$\int_{-\infty}^{\sigma_{\rm up}(n)} p(\sigma|n,A,\mathcal{L},b)\mathrm{d}\sigma = \frac{\int_{-\infty}^{\sigma_{\rm up}(n)} L'(n|\sigma,A,\mathcal{L},b)\pi(\sigma)\mathrm{d}\sigma}{\int_{-\infty}^{+\infty} L'(n|\sigma,A,\mathcal{L},b)\pi(\sigma)\mathrm{d}\sigma} = 0.95$$

Flat prior

$$\pi(\sigma) = \begin{cases} 0 & \sigma < 0 \\ 1 & \sigma \geq 0 \end{cases}$$

$$L'(n|\sigma,A,\mathcal{L},b) = \int_0^{+\infty}\int_0^{+\infty}\int_0^{+\infty} L(n|\sigma,A',\mathcal{L}',b')\,\underbrace{g(A')h(\mathcal{L}')f(b')}\,\mathrm{d}A'\mathrm{d}\mathcal{L}'\mathrm{d}b'$$

$g(A'),\ h(\mathcal{L}'),\ f(b')$ **Log-normal distributions describing** uncertainties in A', $\mathcal{L}'$, b'

Poisson distribution

$$L(n|\sigma,A',\mathcal{L}',b') = \frac{(\sigma A'\mathcal{L}' + b')^n}{n!} e^{-(\sigma A'\mathcal{L}'+b')}$$

Expected upper limit

$$<\sigma_{\rm up}> = \sum_{n=0}^{+\infty} \sigma_{\rm up}(n) L(n|\sigma=0,A,\mathcal{L},b)$$

n = number of observed events
A = acceptance×efficiency
$\mathcal{L}$ = integrated luminosity
b = expected number of background events

Channel combination

- **Extension to two channels**, currently straightforward extension of the implemented Bayesian upper limit for a counting exp.

$$\Pi_{\mathbf{post}}\left(\sigma|N_{\mathbf{obs,1}},\, N_{\mathbf{obs,2}}\right) = \int dL\, d\epsilon_1\, db_1\, d\epsilon_2\, db_2 \frac{\left(\sigma\cdot L\cdot\epsilon_1+b_1\right)^{N_{\mathbf{obs,1}}}}{N_{\mathbf{obs,1}}!}\cdot e^{-(\sigma\cdot L\cdot\epsilon_1+b_1)}\cdot\frac{\left(\sigma\cdot L\cdot\epsilon_2+b_2\right)^{N_{\mathbf{obs,2}}}}{N_{\mathbf{obs,2}}!}\cdot e^{-(\sigma\cdot L\cdot\epsilon_2+b_2)} \cdot\pi\left(b_1\right)\cdot\pi\left(\epsilon_1\right)\cdot\pi\left(b_2\right)\cdot\pi\left(\epsilon_2\right)\cdot\pi\left(L\right)\cdot\pi_{poi}\left(\sigma\right)$$

- **Underlying Assumptions**:
  - Identical branching ratio for electron and muon channel
  - Uncertainty on luminosity fully correlated
  - Uncertainties on signal efficiency and background currently fully uncorrelated (also tested fully correlated → same limit)