



Maxime Gouzevitch



CMS New fermions and gauge interactions

(On behalf of the CMS collaboration)

- 1) Finding our way through the new physics jungle.
- 2) « EW » like models: Z' searches
- 3) « EW » like models: W' searches
- 4) « QCD » like models: Axiguons, Colorons, Cl .
- 5) 7 TeV summary and 8 TeV prospects.



Finding our way through the new physics jungle



1.1) New bosons zoology in the Standard Model pool

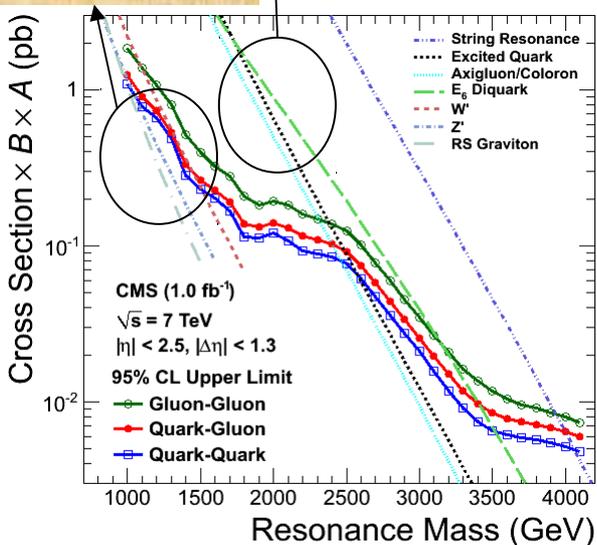
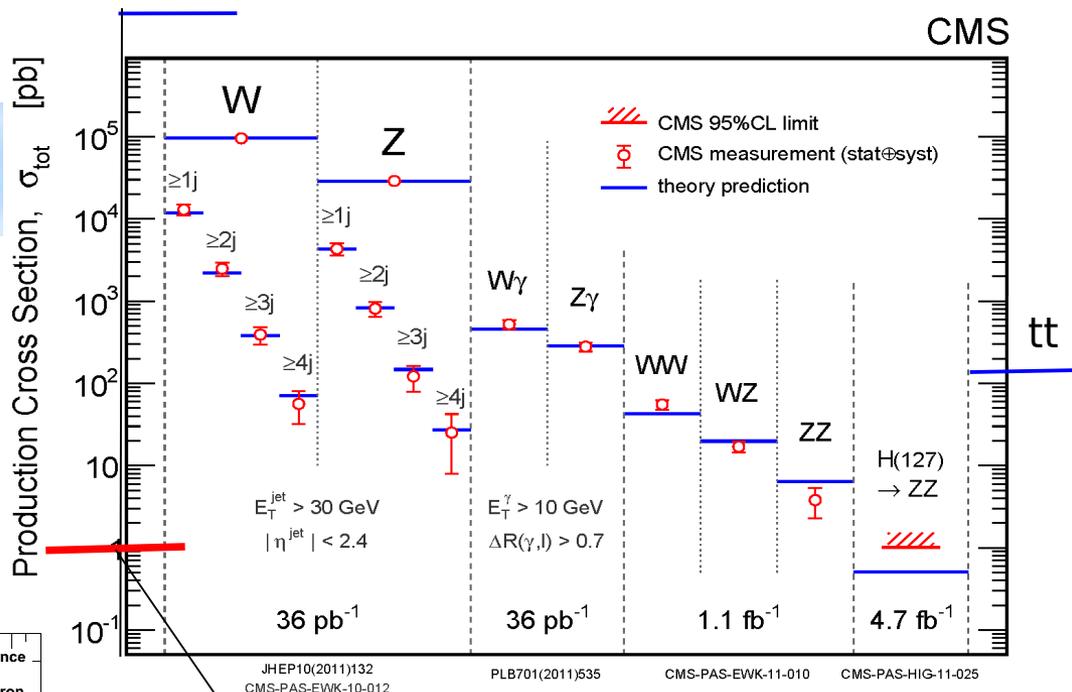
Axigluons
Colorons
Hyper- ρ

« QCD »
like models

Z', W' :
Strings, E6,
SSM, KK tow.
topcolor

« EW »
like models

$P_{T,jet} > 0.1 \text{ TeV}$



Motivation of new models :
EWSB, GUT,
left-right asymmetry of the SM,
extra-dimensions.

1.1) New bosons zoology: Disclaimer & apologizes



Are not covered in this talk due to time limitations such interesting subjects as:

- Gravity based gauge interactions.
- **Leptoquarks** (see J. Hirschauer talk tomorrow).
- **Indirect searches in loops.**

Those subjects are presented in the plenary talk Monday by C. Leonidopoulos.

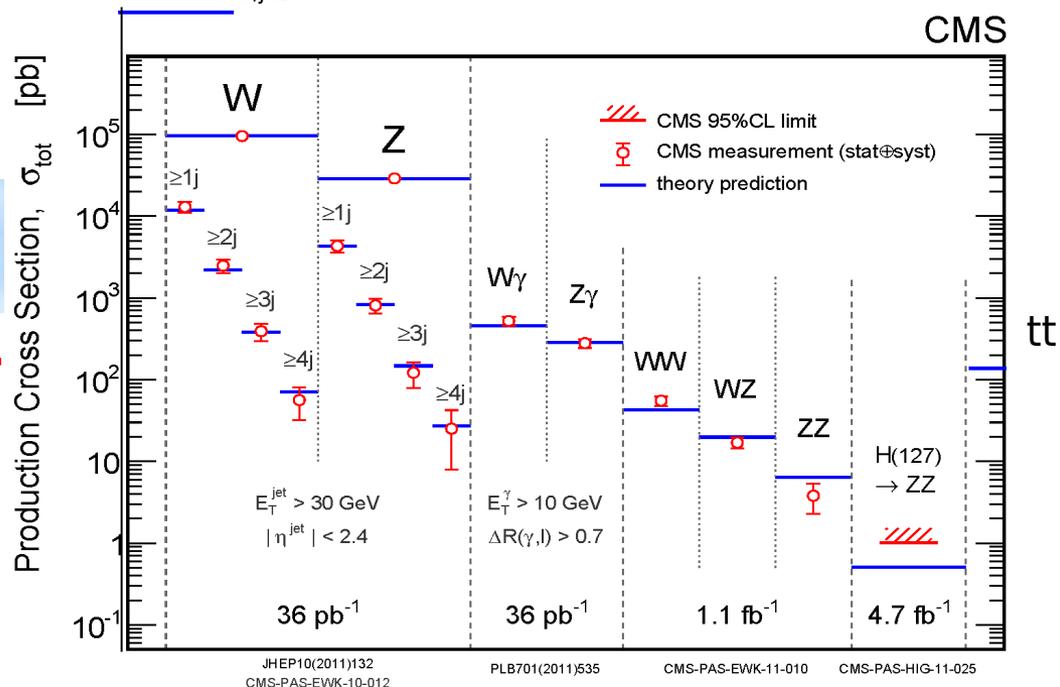
The searches for new gauge interactions have more weight in this talk than the searches for the new fermions.

1.2) Background challenge

$$P_{T,jet} > 0.1 \text{ TeV}$$

« QCD »
like models

« EW »
like models



« QCD » like models :

- couples usually to colored particles.
- EW backgrounds negligible.
- QCD irreducible background calculated @NLO or fitted from data.

« EW » like models :

- Final states usually enriched in isolated leptons: kills QCD.
- Dominated by EW backgrounds (tt, W/Z, W/Z+jets).
- EW irreducible background calculated @NLO (@NNLO) or/and fitted from data.

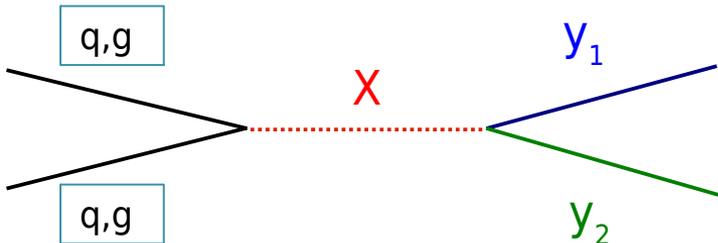
Many exceptions to the previous “rules” :

- tt → « QCD » like models
- Z' → jets

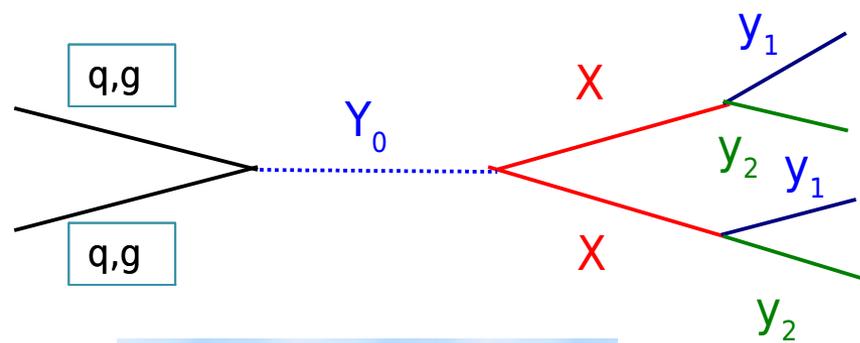
1.3) New bosons: direct searches

- We look for **heavy bosons** in the tails of SM: light bosons either already excluded either swamped in the background.
- **S-channel production**: “easy to explore” when possible.
- **Paired production**: If a conservation law (R-parity) forbids S-channel or S-channel already explored: paired production used. Less background but usually low production cross section.

S-channel production



Paired production



X : new boson
Y₀: new or SM boson
y₁, y₂ : SM particles

1.4) How things happens in reality

Our approach is
« Final state » driven

- O(100) channels.
- Reconstruct objects:
 - Leptons: e, μ , ν =MET, tau.
 - Quarks: q,g=jets, top.
 - Bosons: W, Z, γ .
- Estimate Backgrounds:
Data driven methods
- Estimate efficiencies/uncertainties
- Unfold if necessary
- Converts SM measurements into Exotic searches.

- A group combine and pilot individual channels.
- Analyses more « Model driven »

« Theories considered as strategic »
Higgs, SUSY

Benchmark models are set up.

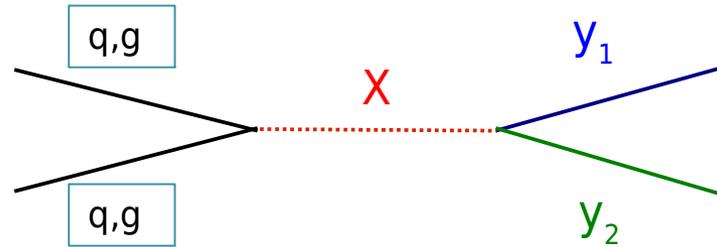
Most of analyses try to stay « model independent »

Typical benchmark models :
Resonance Mass vs Width

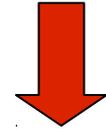
« Other Theories zoology »



1.4) Global approach: example of S-channel



$X \rightarrow y_1 y_2$
channel
 $M(X), M_T(X)$



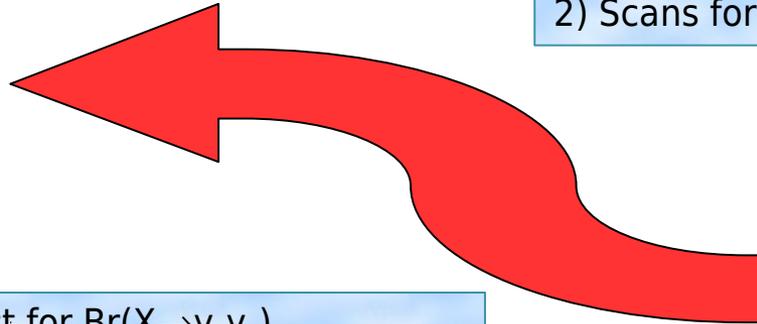
Need a width hypothesis

- 1) "Narrow width hypothesis":
Width < Reso.
- 2) Scans for different width hypotheses.



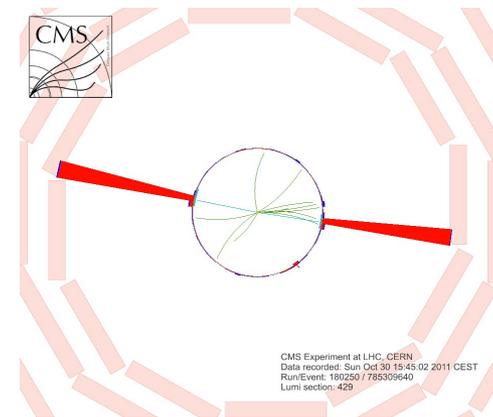
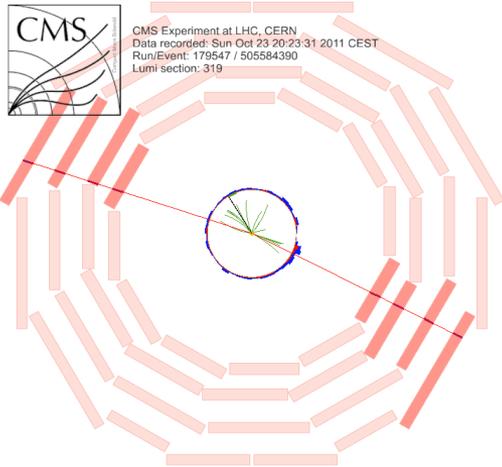
Set « model independent » limits

Set model production limits

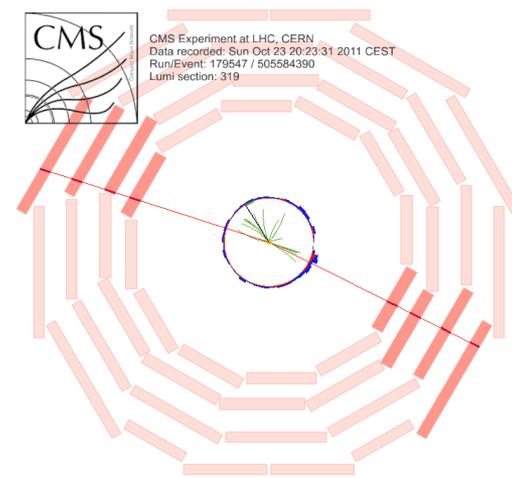
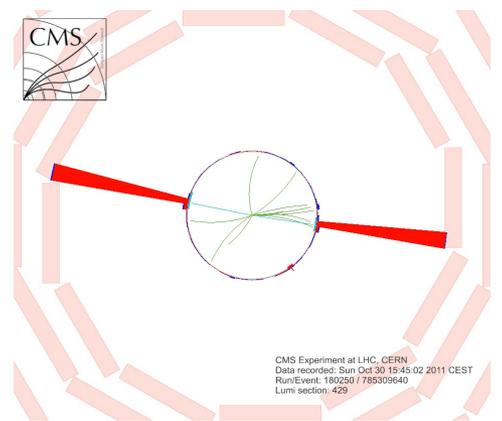


Correct for $Br(X \rightarrow y_1 y_2)$

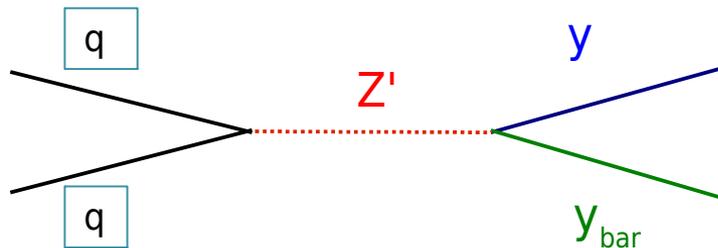
- 1) Br fixed by the Gauge group and coupling: axiguons.
- 2) Br a free parameter W', Z'
 - One can mimic the standard model.
 - Take indirect constraint from loops.



Z' searches



2.1) Search for EW like models: Z'



* For a detailed presentation of tt searches see A. Hinzmann talk tomorrow.

Channel	Analysis	Lumi
Leptons : $ee, \mu\mu$	EXO-11-019 : Dilepton bump search	4.7 fb ⁻¹
Leptons : $\tau\tau$		
Quarks : qq - jet-jet	EXO-11-015 : Dijet bump search 10.1016/j.PhysLetB.2011.09.015	1.0 fb ⁻¹
Quarks : bb - jet-jet		
Quarks : tt	EXO-11-006* : Full hadronic	4.6 fb ⁻¹
	PAS TOP-11-009* : Semi leptonic	4.9 fb ⁻¹
	PAS EXO-11-055* : Semi leptonic μ	1.1 fb ⁻¹
	PAS EXO-11-092* : Semi leptonic e	4.7 fb ⁻¹
Bosons : ZZ, WW		

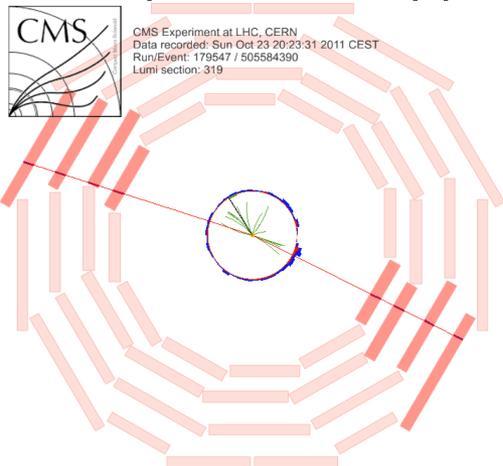
2.1) Search for EW like models: Z'

- 7 TeV program: CMS tend the full coverage of Z' searches in all final states.
 - explore all channels = reduce model dependence.
 - = reduce experimental uncertainties dependence.
- there are always models tailored to a given channel:
fermiophobic Z' , Z' as tt resonant states...

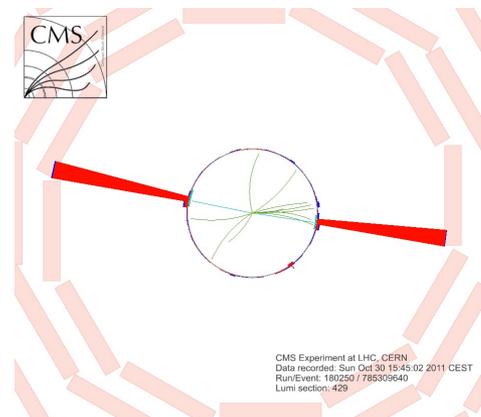
Channel	Analysis	Lumi
Leptons : $ee, \mu\mu$	EXO-11-019 : Dilepton bump search	4.7 fb ⁻¹
Leptons : $\tau\tau$		
Quarks : qq - jet-jet	EXO-11-015 : Dijet bump search <small>10.1016/j.PhysLetB.2011.09.015</small>	1.0 fb ⁻¹
Quarks : bb - jet-jet		
Quarks : tt	EXO-11-006* : Full hadronic	4.6 fb ⁻¹
	PAS TOP-11-009* : Semi leptonic	4.9 fb ⁻¹
	PAS EXO-11-055* : Semi leptonic μ	1.1 fb ⁻¹
	PAS EXO-11-092* : Semi leptonic e	4.7 fb ⁻¹
Bosons : ZZ, WW		

2.2) Search for EW like models: $Z' \rightarrow ee, \mu\mu$

We request two opposite charge same flavor isolated leptons.

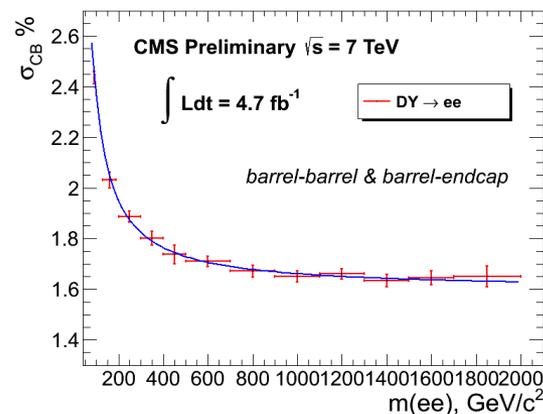


- Reconstructed with tracker+Muon chambers
- Resolution worsen with P track since lower curvature.

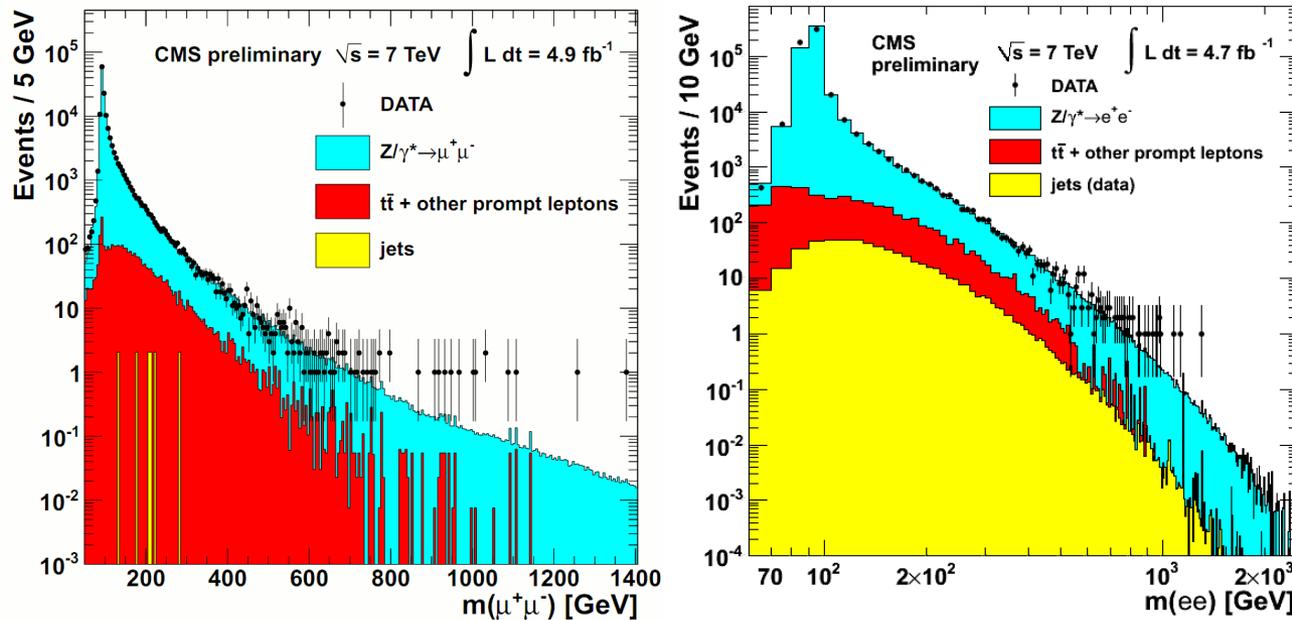


- Reconstructed with ECAL matched to a track:
- $E_T > 35(40)$ GeV in barrel (endcap).
- Resolution improves with E.

$M_{\mu\mu}$ (TeV)	$\Delta m_{\mu\mu}/M_{\mu\mu}$ (%)
1	6
2	12



2.3) Search for EW like models: $Z' \rightarrow ee, \mu\mu$

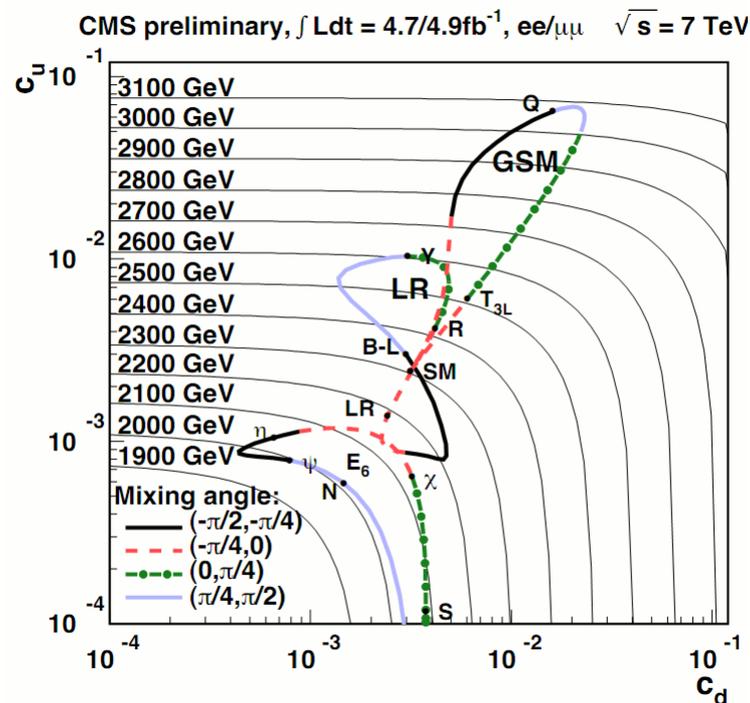
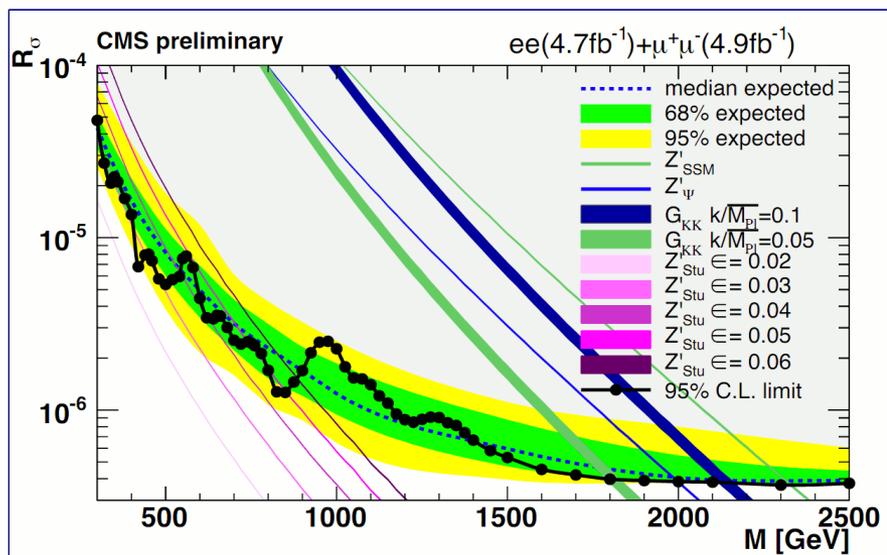


$$R_\sigma = \frac{\sigma(pp \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(pp \rightarrow Z + X \rightarrow \ell\ell + X)}$$

- Irreducible background: POWHEG + normalization to data. Proton PDF uncertainties included.
- Cosmic muons: removed by vertex/timing matching cuts.
- Leptons from QCD: removed by isolation criteria.
- Fake electrons: γ / jets faking electrons – transverse shower shapes and tracks matching.

2.5) Search for EW like models: $Z' \rightarrow ee, \mu\mu$

- Background shape taken from simulation: $m^{-k}e^{-am}$.
- Signal shape: BW convoluted with a Gaussian.
- Systematic uncertainties: 5-10% coming from difference in efficiencies between Z' and Z .
- No excess found. Limits set with Bayesian approach.



model	exclude mass (GeV/c^2)
SSM Z'	2120
Z'_{Ψ}	1805

- Generic limits: coupling (width) vs mass.

2.7) Search for EW like models: Z'

$M(ee), M(\mu\mu)$ EXO-11-019

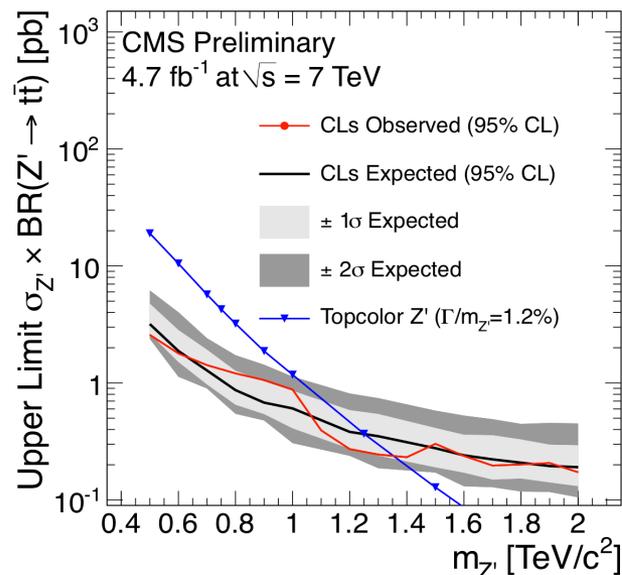
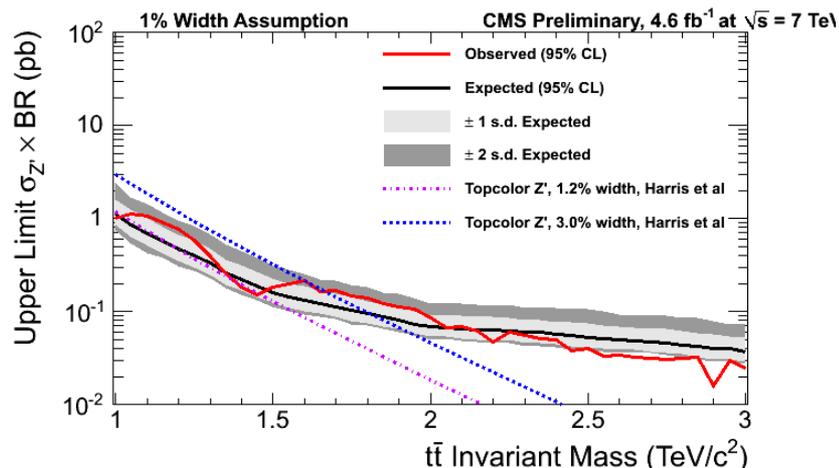
$M(jj)$ EXO-11-015

$M(tt)$ semi-leptonic - boosted
 μ +jets EXO-11-055
 e +jets EXO-11-092

model	exclude mass (GeV/c^2)
SSM Z'	2120
$Z'\psi$	1805

Just start to be sensitive at 1 fb⁻¹.

Start to be sensitive to topcolor Z' .



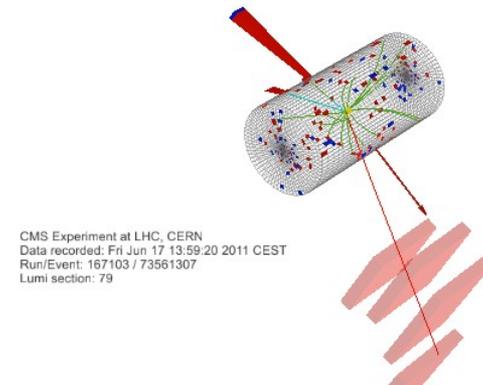
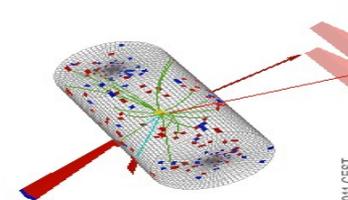
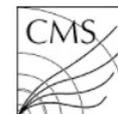
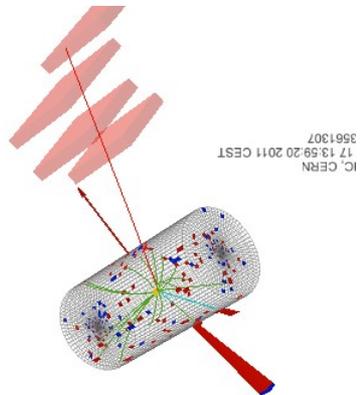
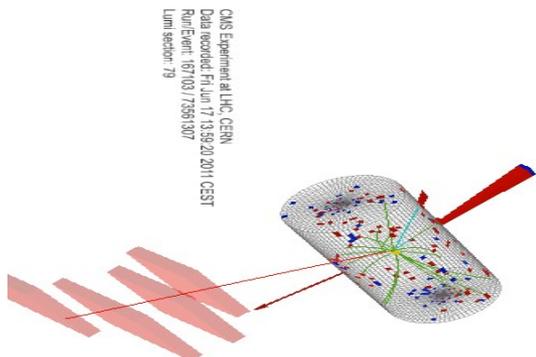
$M(tt)$ full hadronic EXO-11-006

$M(tt)$ semi-leptonic TOP-11-009

Lowest exclusions : Z' topcolor 95% up to 1.5 TeV. Largest : 2.1 TeV SSM.
 « Generic » M-W limits produced by most of the analyses.

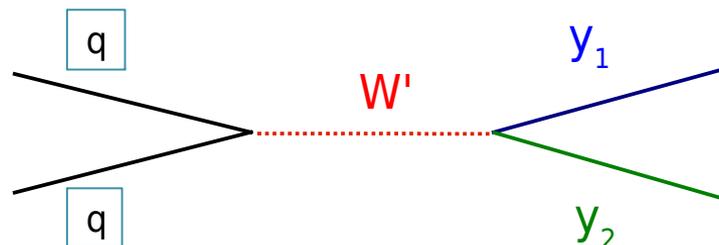


W' searches



CMS Experiment at LHC, CERN
Data recorded: Fri Jun 17 13:59:20 2011 CEST

3.1) Search for EW like models: W'



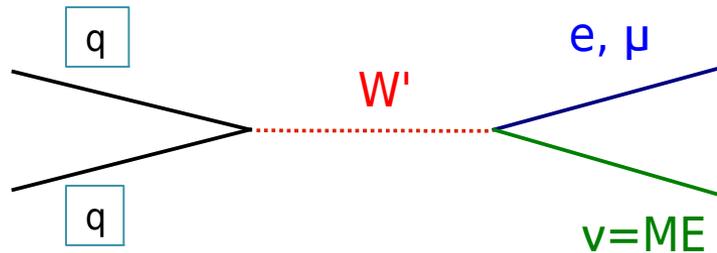
- 7 TeV program: explore all channels.
- Additional problematic: L-R symmetry of extended models.

Channel	Analysis	Lumi
Leptons : $e\nu, \mu\nu$ - MET+e, μ	EXO-11-024	4.7 fb ⁻¹
Leptons : $eN_R, \mu N_R$	PAS EXO-11-002	0.2 fb ⁻¹
Quarks : $q_u q_d$ - jet-jet	EXO-11-015 : Dijet bump search 10.1016/j.PhysLetB.2011.09.015	1.0 fb ⁻¹
Quarks : tb		
Bosons : ZW	EXO-11-041 : ZW event counting	4.7 fb ⁻¹

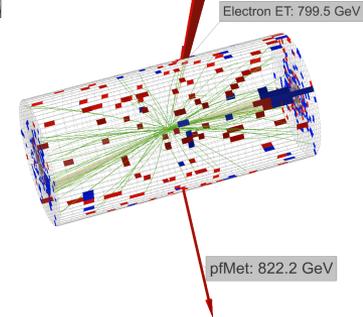
3.2) Search for EW like models: $W' \rightarrow e\nu, \mu\nu, WZ$

- $W' \rightarrow e\nu, \mu\nu$: 1 l + ME_T M_T used since ME_Z not known

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

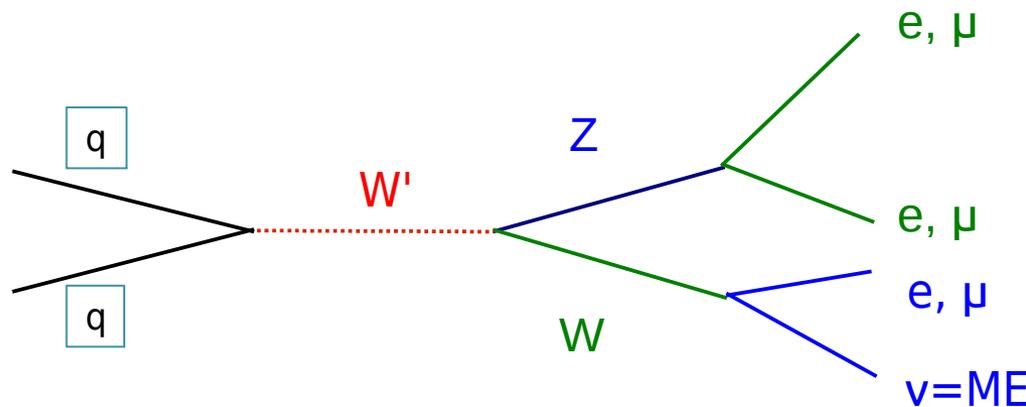


CMS Experiment at LHC, CERN
Data recorded: Wed Sep 21 11:35:51 2011 CEST
Run/Event: 176841 / 213192769
Lumi section: 189
Orbit/Crossing: 49420229 / 1640

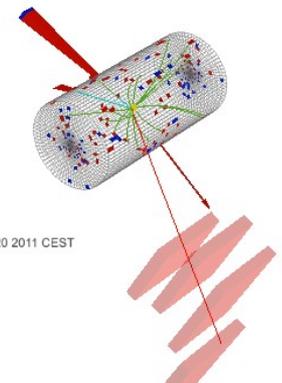


- $W' \rightarrow WZ$: 3 l + ME_T $M_{(WZ)}$ used since ME_Z constrained by

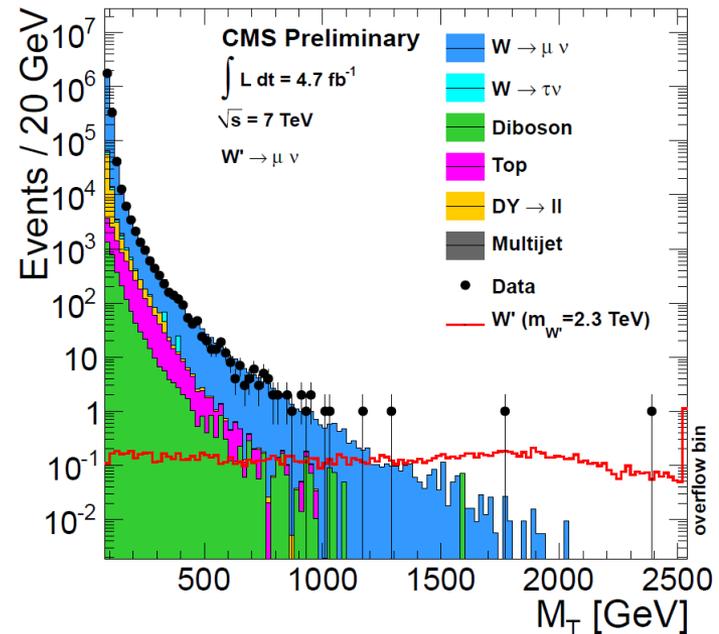
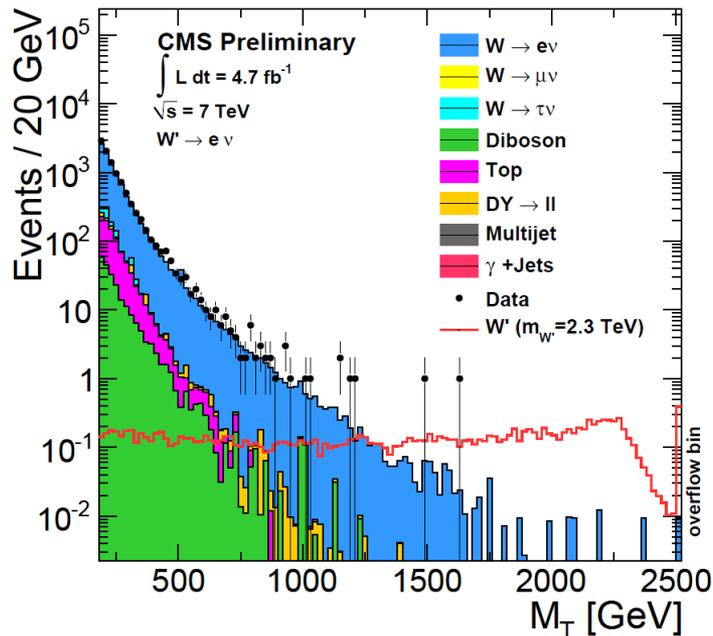
W mass



CMS Experiment at LHC, CERN
Data recorded: Fri Jun 17 13:59:20 2011 CEST
Run/Event: 167103 / 73561307
Lumi section: 79

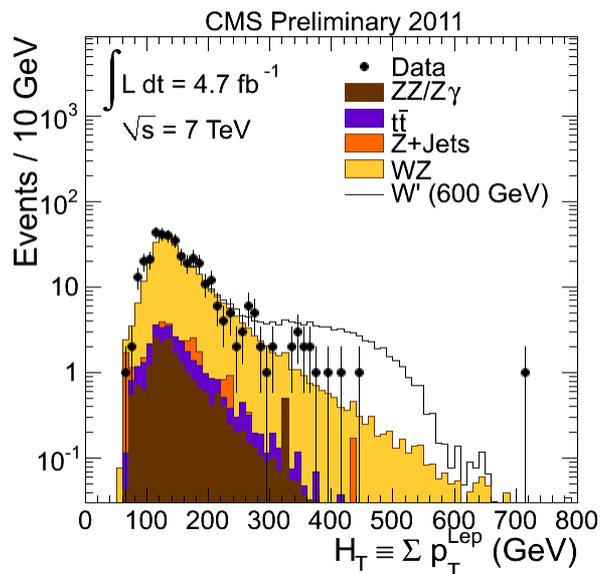
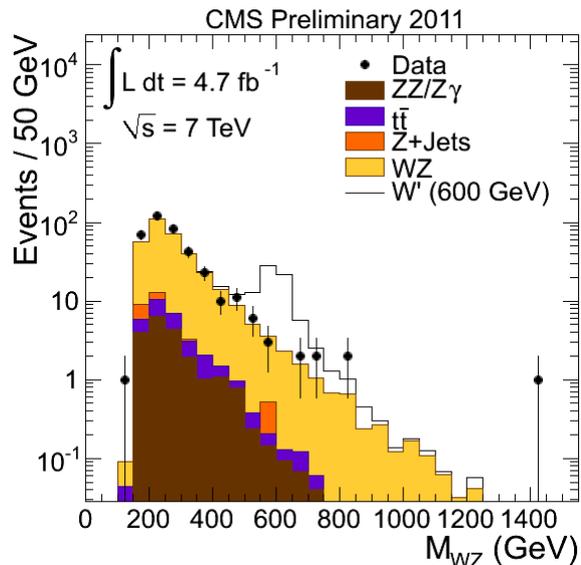


3.3) Search for EW like models: $W' \rightarrow e\nu, \mu\nu$

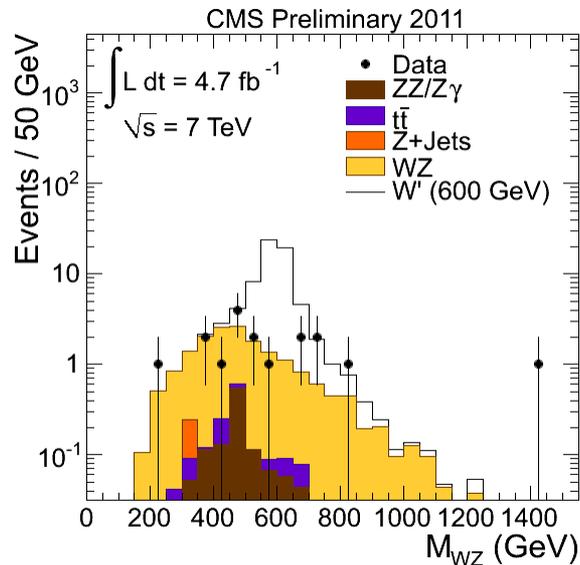


- Irreducible background: $W \rightarrow l\nu$ – generated with PYTHIA + NNLO k-factors.
- QCD: suppressed by lepton isolation + MET requirement. MET in those analyses large wrt to the pile-up effects.
- Prompt lepton + MET: tt , DY (1 lepton lost)...
- Simulated background fitted by a function: $a/(M_T + b)^c$ and normalized to data in the background region : $200 \text{ GeV} < M_T < 500 \text{ GeV}$.

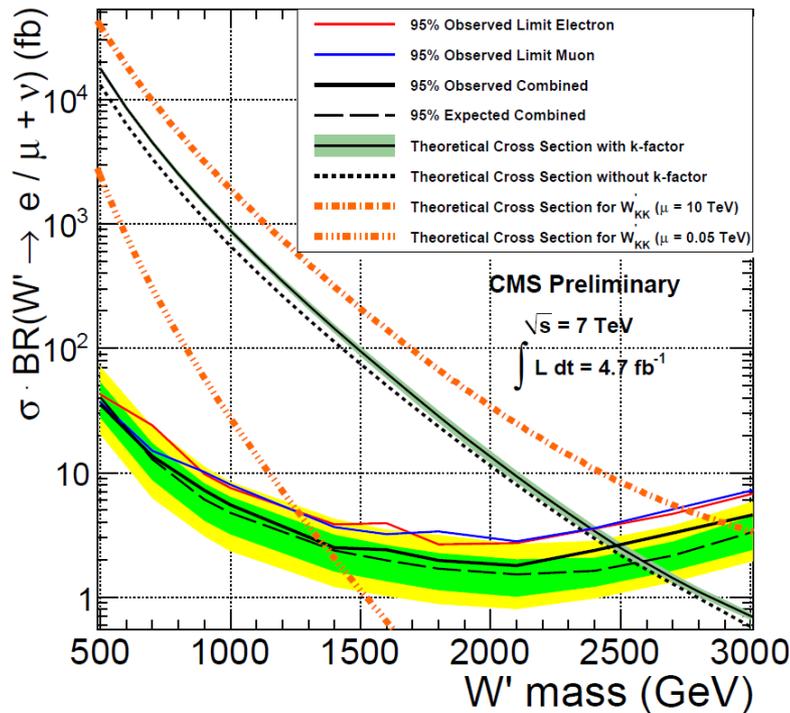
3.4) Search for EW like models: $W' \rightarrow e\nu, \mu\nu, WZ$



- Main background: WZ.
- Signal central $M_T \sim H_T$.
- SM WZ: $H_T \ll M_T$.
- Counting experiment.

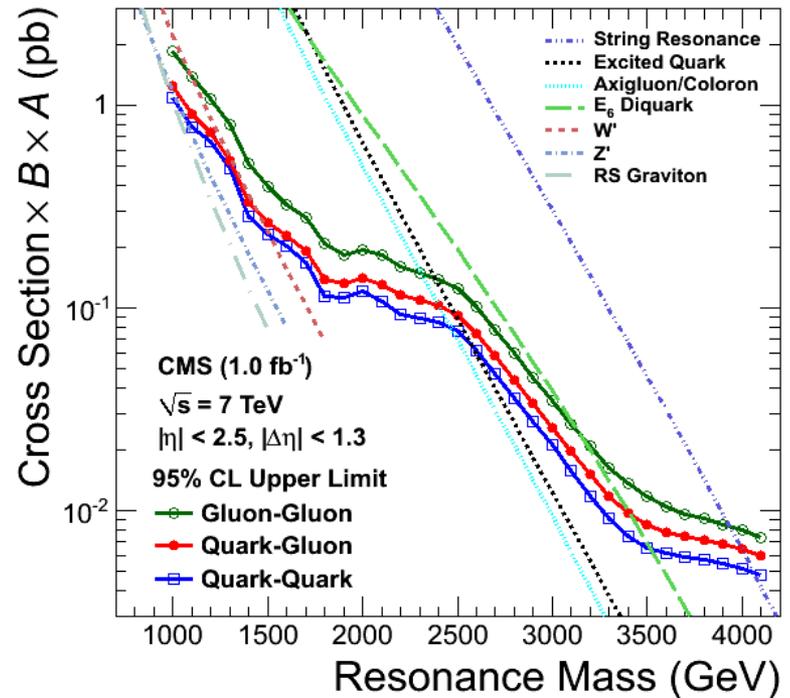


3.5) Search for EW like models: $W' \rightarrow e\nu, \mu\nu, WZ$



$M_T(e, \mu\nu)$

EXO-11-024

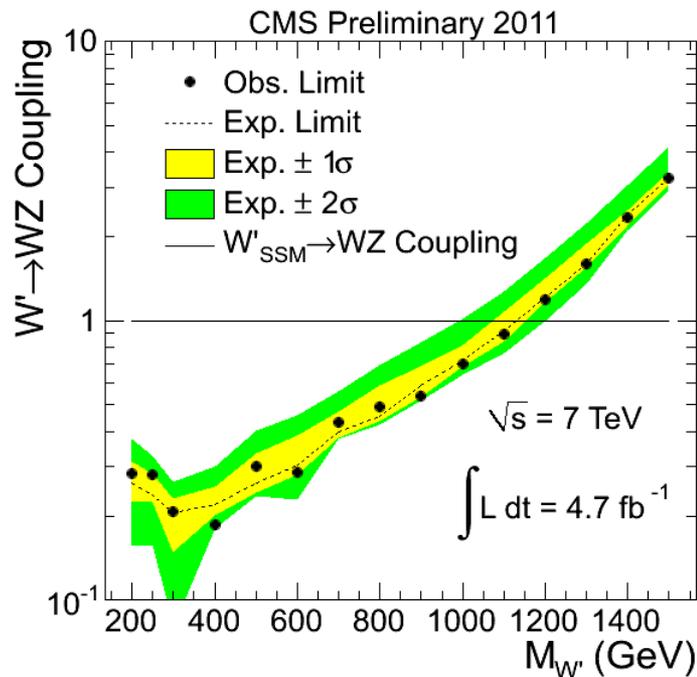


$M(\text{jet}, \text{jet})$

EXO-11-015

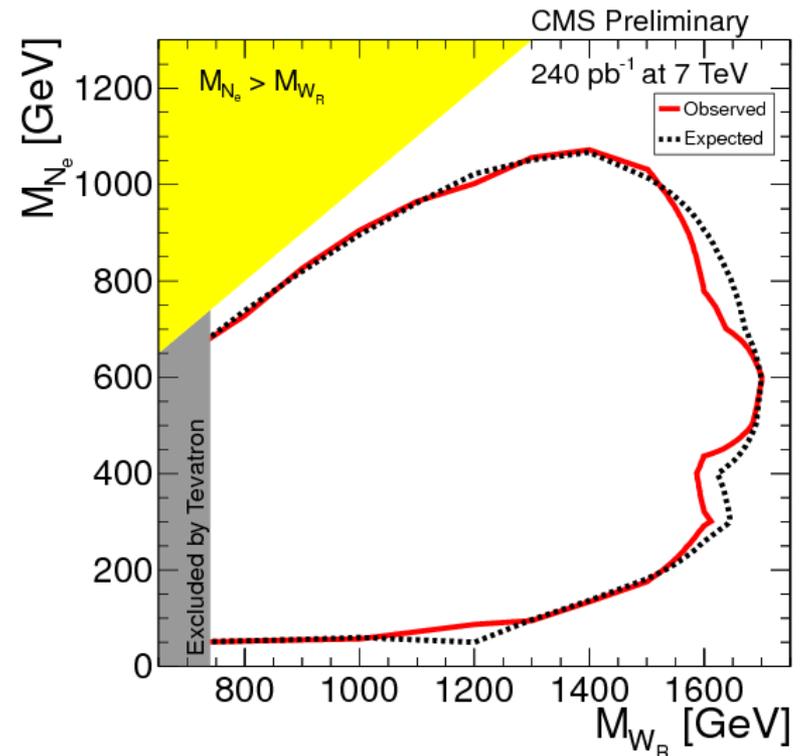
- Leptonic channel (BF = 16%) less background than hadronic (BF ~ 75%).
- W' SSM excluded below 2.5 TeV.
- Slightly Changes with W, W' interference hypotheses.

3.6) Search for EW like models: 2-d plots



M(ZW)

EXO-11-041



EXO-11-002

- WZ channel sensitive to fermiophobic models. Fully hadronic channel under work. Also constraint technicolor EWSB models.
- A common search for right handed neutrino + W' is performed (very low background search: 2 same sign leptons).

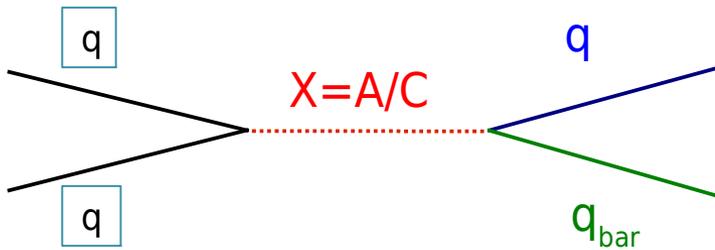


Searches for strongly coupling models



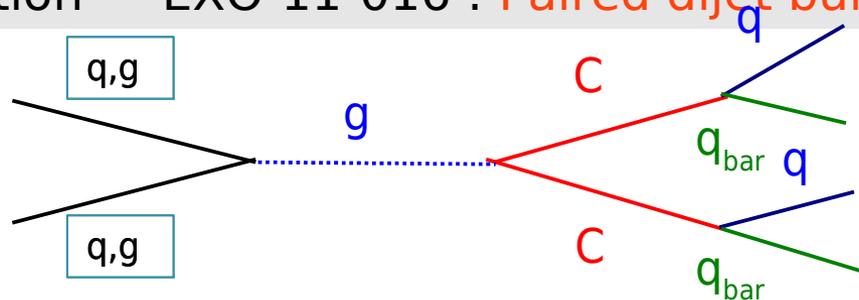
4.1) Search for strongly coupling bosons

S-channel production

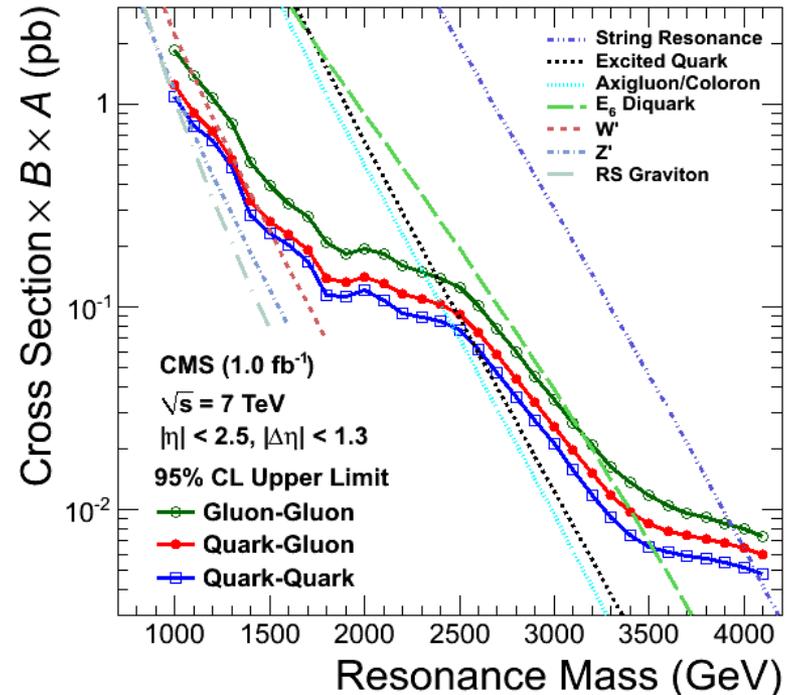
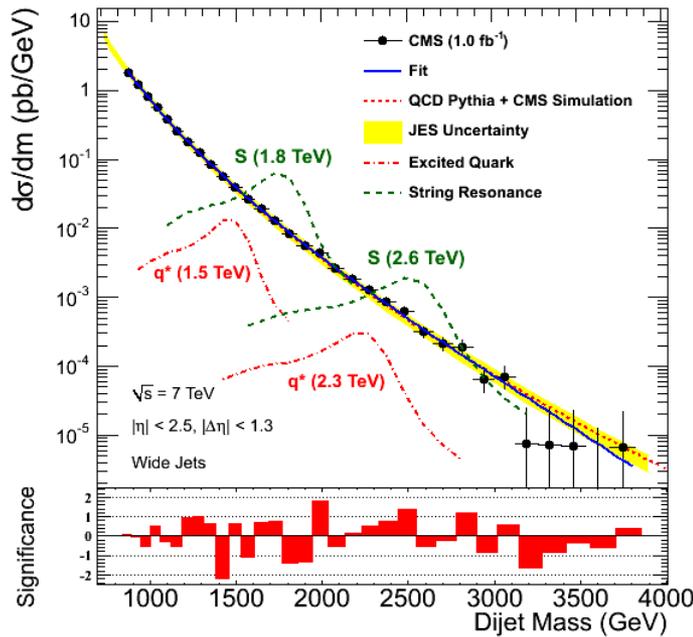


Channel	Analysis	Lumi
Quarks : qq - jet-jet	EXO-11-015 : Dijet bump search <small>10.1016/j.PhysLetB.2011.09.015</small>	1.0 fb ⁻¹
	EXO-11-017 : Dijet angular corr. <small>arXiv:1202.5535</small>	2.2 fb ⁻¹
Quarks : tt	EXO-11-006 : Full hadronic	4.6 fb ⁻¹
	PAS TOP-11-009 : Semi leptonic	4.9 fb ⁻¹
	PAS EXO-11-055 : Semi leptonic μ	1.1 fb ⁻¹
	PAS EXO-11-092 : Semi leptonic e	4.7 fb ⁻¹
Paired production	EXO-11-016 : Paired dijet bump	2.2fb ⁻¹

Paired production

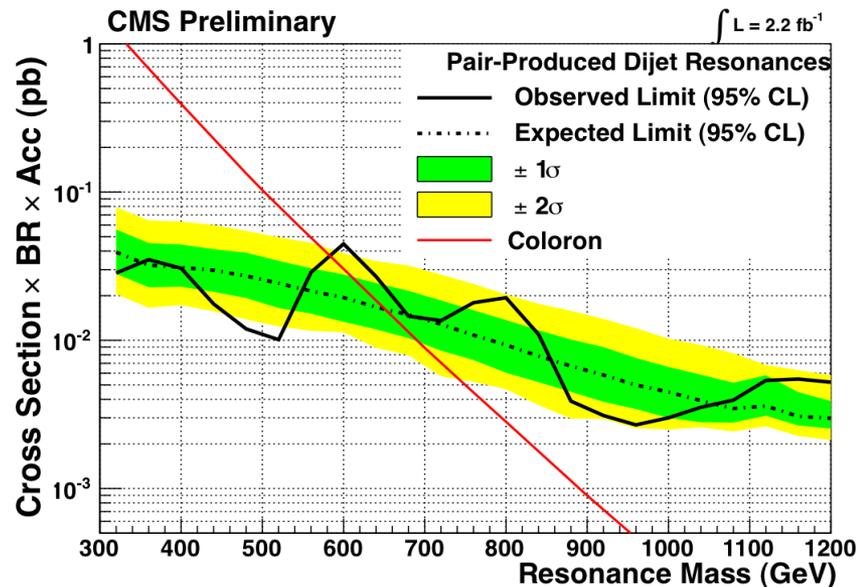
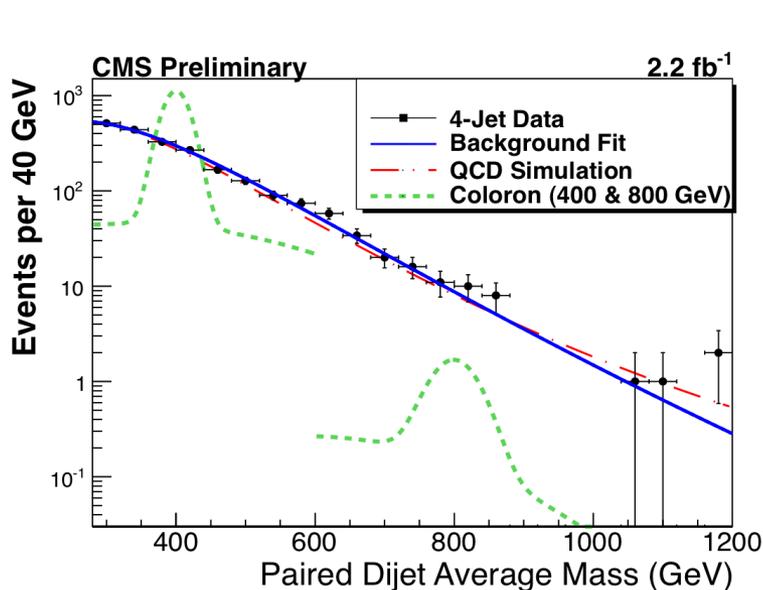


4.2) Search for strongly coupling bosons: Dijets



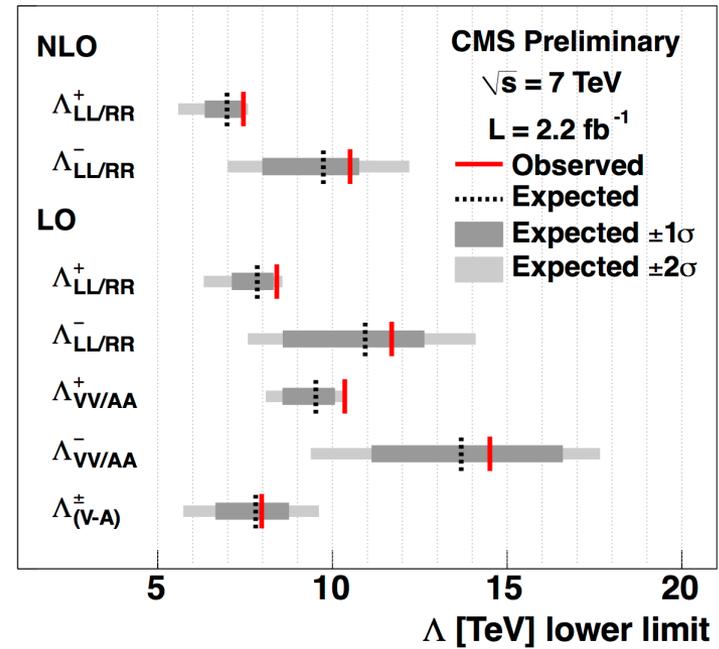
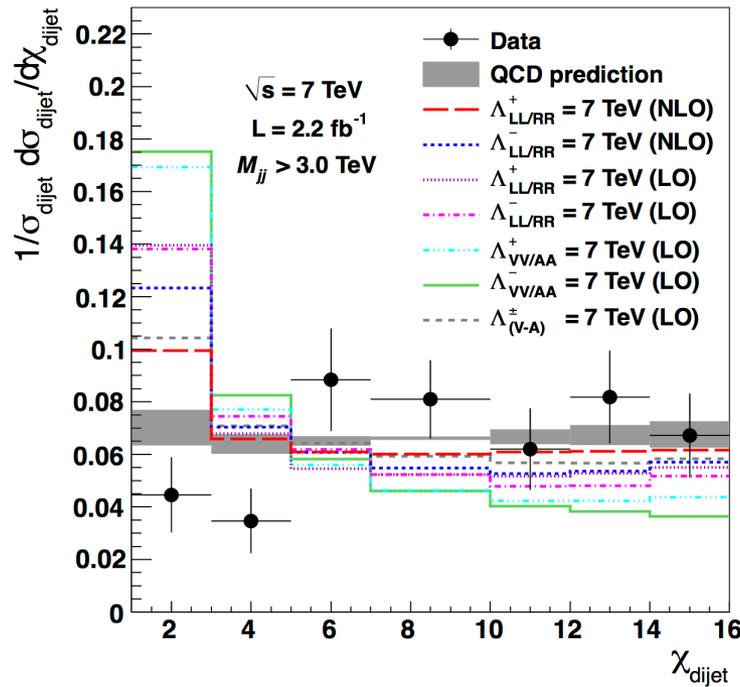
- Two jets with $|\Delta\eta| < 1.3$.
- The only background which matters is QCD: use empiric function.
- Mass spectrum more complicated than Z', W': BW deformed by QCD radiation. Wide jets: collect FSR radiation around leading jets.
- Axigluons excluded up to 3.2 TeV.

4.3) Search for strongly coupling bosons: paired Dijets



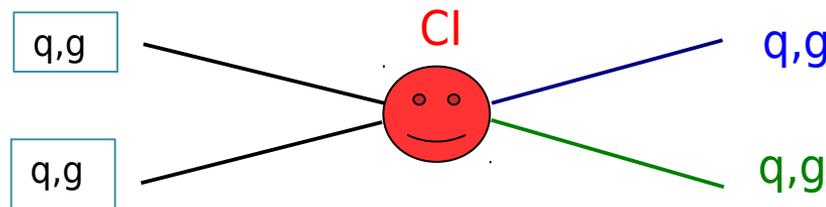
- 4 jets events (dijet pairs) : both pairs shall have a similar invariant mass.
- Only important background: QCD. Well described in shape by PYTHIA and fitted with same background function than dijets.
- Coloron model coupling to gluons excluded up to 560 GeV in the paired production.

4.5) Search for new gauge interactions: CI



- Two jets: measure $\exp(|\Delta\eta|)$ in regions of $M(\text{jet-jet})$.
- QCD: $M(\text{jet-jet}) < 1 \text{ TeV}$; CI: $x = \exp(|\Delta\eta|) \sim 1$, $M(\text{jet-jet}) > 3 \text{ TeV}$.
- NLO calculations normalized to data in the QCD region.
- Different CI models excluded above 7 TeV.

S-channel production

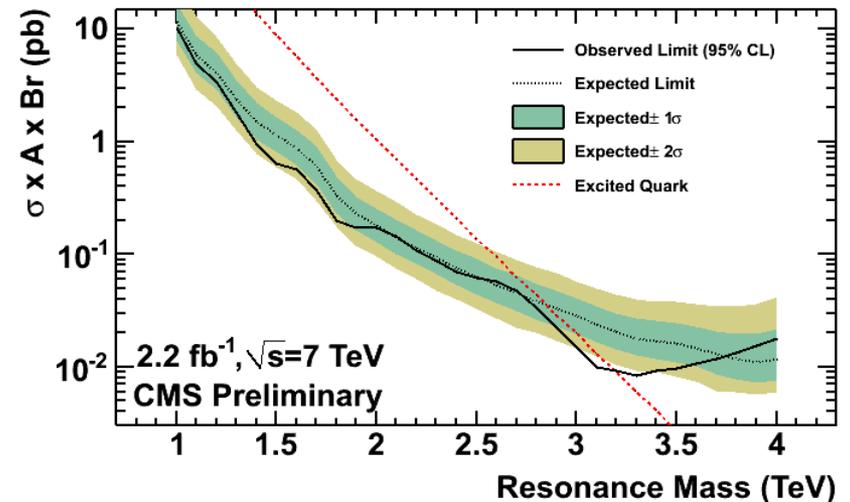
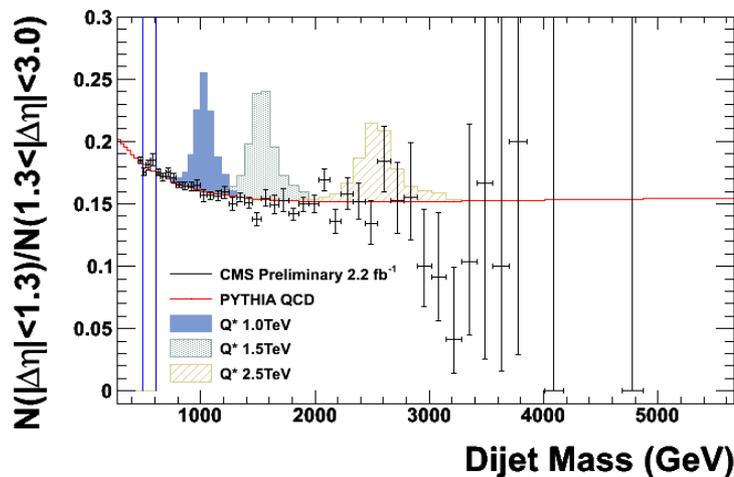




7 TeV status and 8 TeV prospects

Status of the search for new fermions

- 1) 4th generation searches: b' , t' . Not presented here since mainly related to the top final state.
- 2) Heavy right helicity neutrino partner: N_R . Search within the SSM L-R model ([EXO-11-002](#)). Exclusion in 0.5-1 TeV region for W' with masses below 1.6 TeV.
- 3) Quarks substructure:
 - CI ([EXO-11-017](#)) excluded above 7 TeV for most of the models. CI in inclusive jets are under study.
 - Q^* excluded for masses below 3.2 TeV from Dijet Angular Ratio ([EXO-11-026](#)).



1) The search for new gauge interactions beside SUSY is very active:

- « QCD models » usually exclude below 3 TeV
- « EW models » usually excluded below 1-2 TeV

2) The search specificities:

- The searches are mainly channel driven:
12 analyses cited here.
- The heritage of 7 TeV would a complete spectrum over all possible S-channels and few paired production searches.
- Many analyses looks for narrow width approx.

3) Two general tendencies we shall encourage:

- 2-d search: Resonance mass vs Width.
- Establish common generic models like in SUSY.
- Coordinate different channels.

Challenges @8 TeV

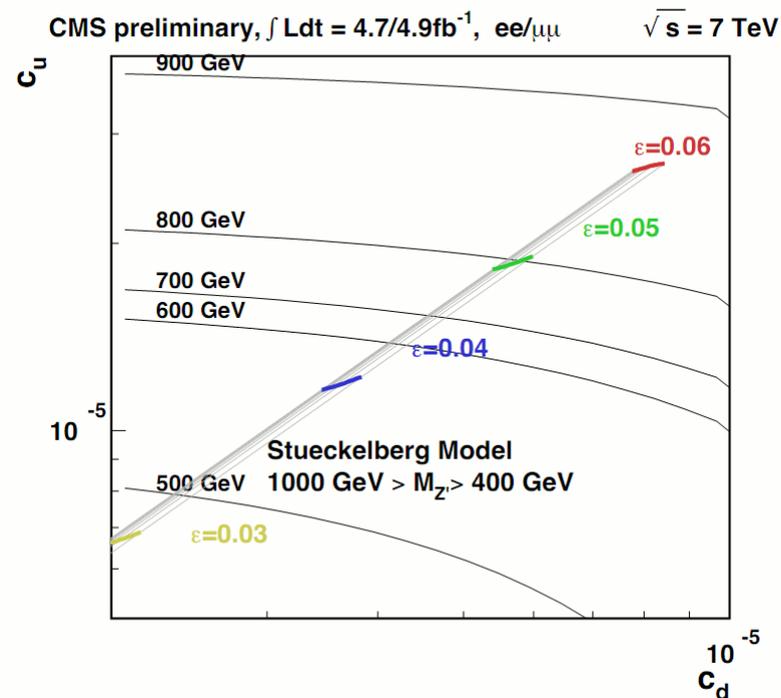
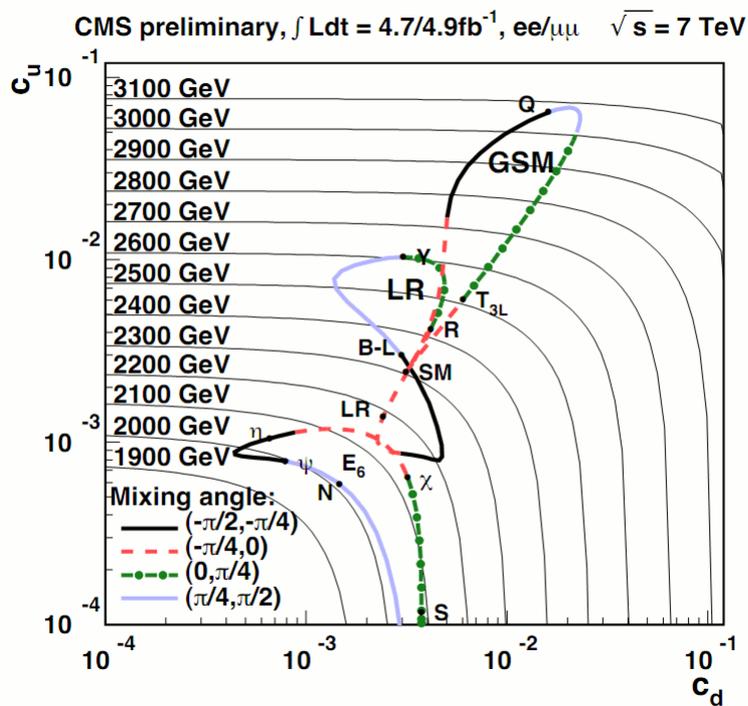
- 1) Basic S-channel searches are well established and would be probably repeated at 8 TeV:
 - Main challenge: keep trigger rate under control with larger lumi/pile-up
- 2) At $\sqrt{s} = 7$ TeV for $M(\text{Res}) > 4$ TeV the shape is deformed by proton PDF (not enough high x partons).
At $\sqrt{s} = 8$ TeV problem moves to $M(\text{Res}) > 5$ TeV.
- 3) Need to search in new directions: paired production, non-resonant productions, large width resonances, decay chains.
- 4) Still room free for the fermiophobic models.
- 5) Did we missed something below the TeV?
- 6) New ideas?





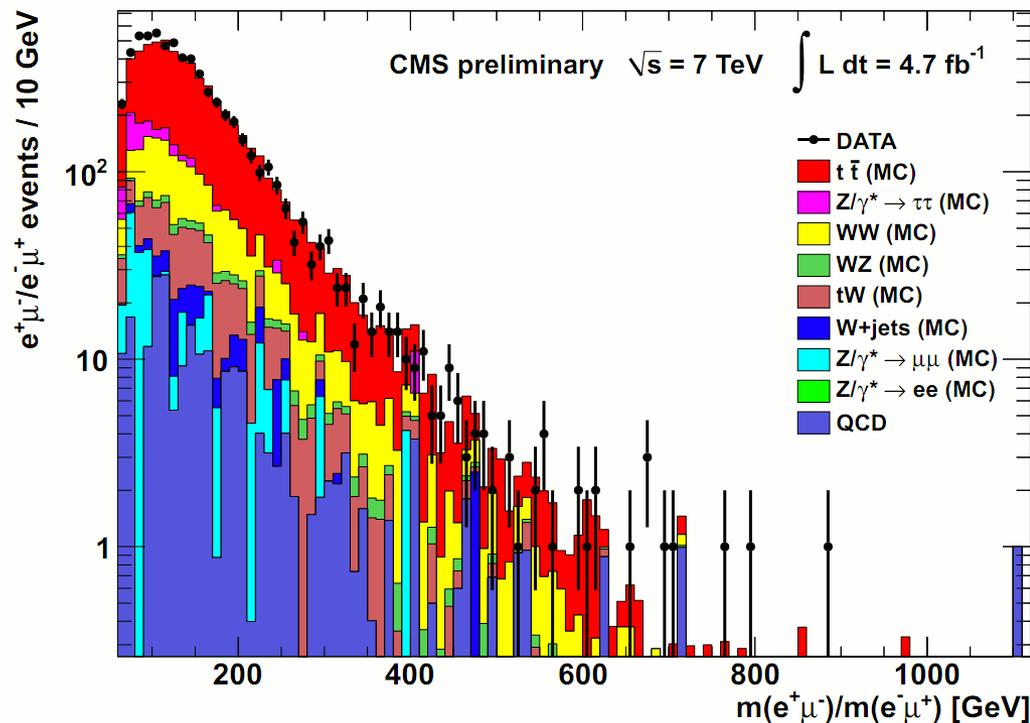
Backup

2.6) Search for EW like models: $Z' \rightarrow ee, \mu\mu$



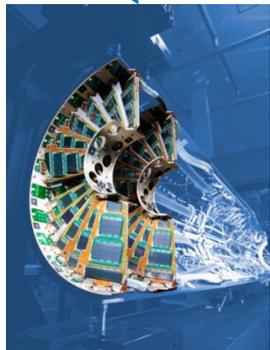
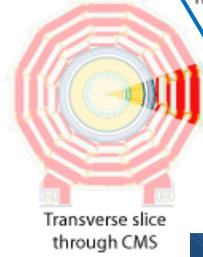
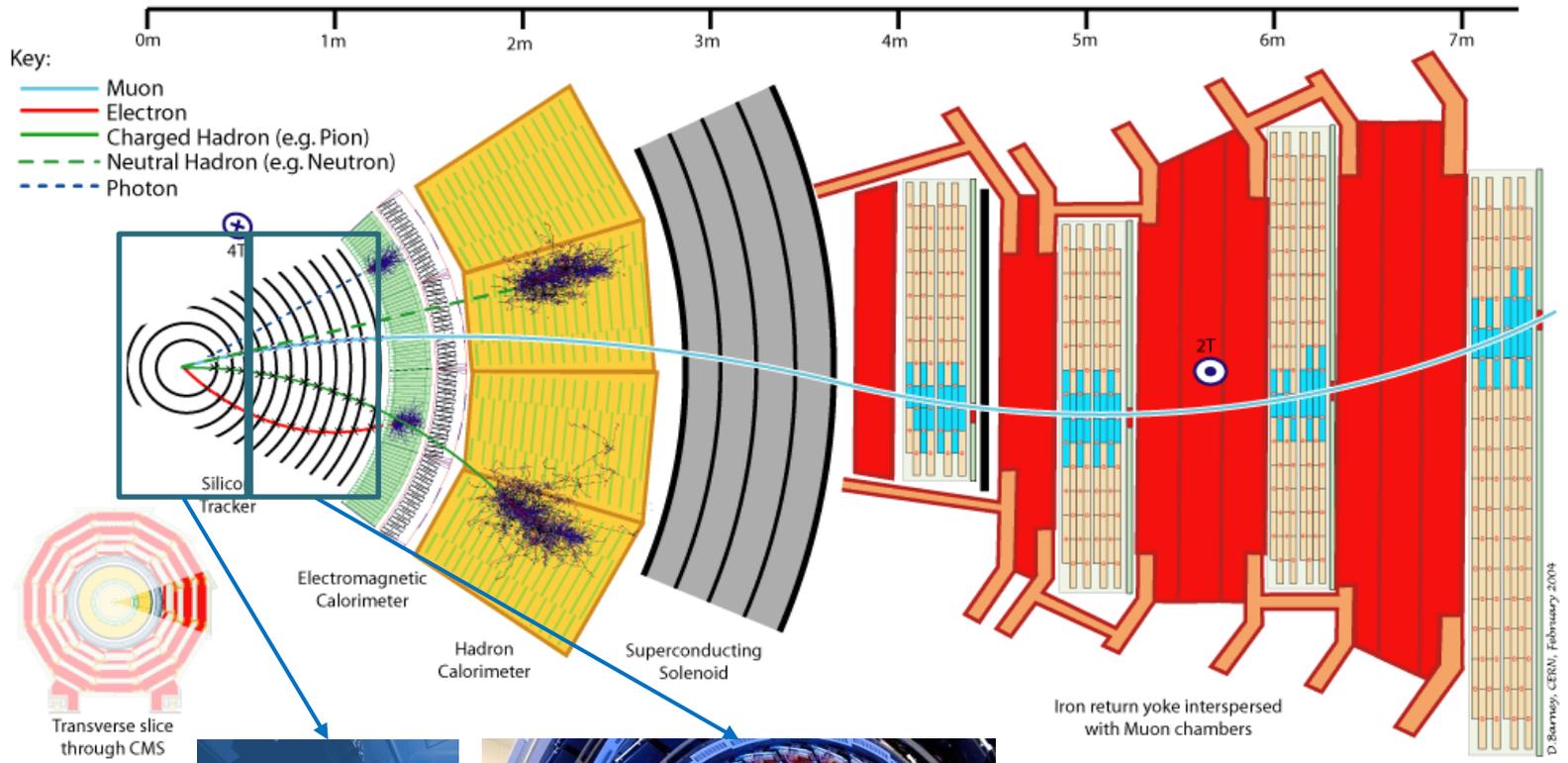
- Generic limits: coupling (width) vs mass.
- Ultimately this shall be done by most of the searches.

2.4) Search for EW like models: $Z' \rightarrow ee, \mu\mu$



- Prompt leptons backgrounds: W+jets, tt, $Z \rightarrow \tau\tau$ are flavor symmetric. Estimated out of $e\mu$ sample.

2) Tracker performance



Pixel



Strips

- Full silicium technology.
 - ~75.000.000 channels.
 Performance in collisions
 arXiv:1007.1988

CMS Experiment at the LHC, CERN