



The Galileo Galilei Institute for Theoretical Physics
Arcetri, Florence

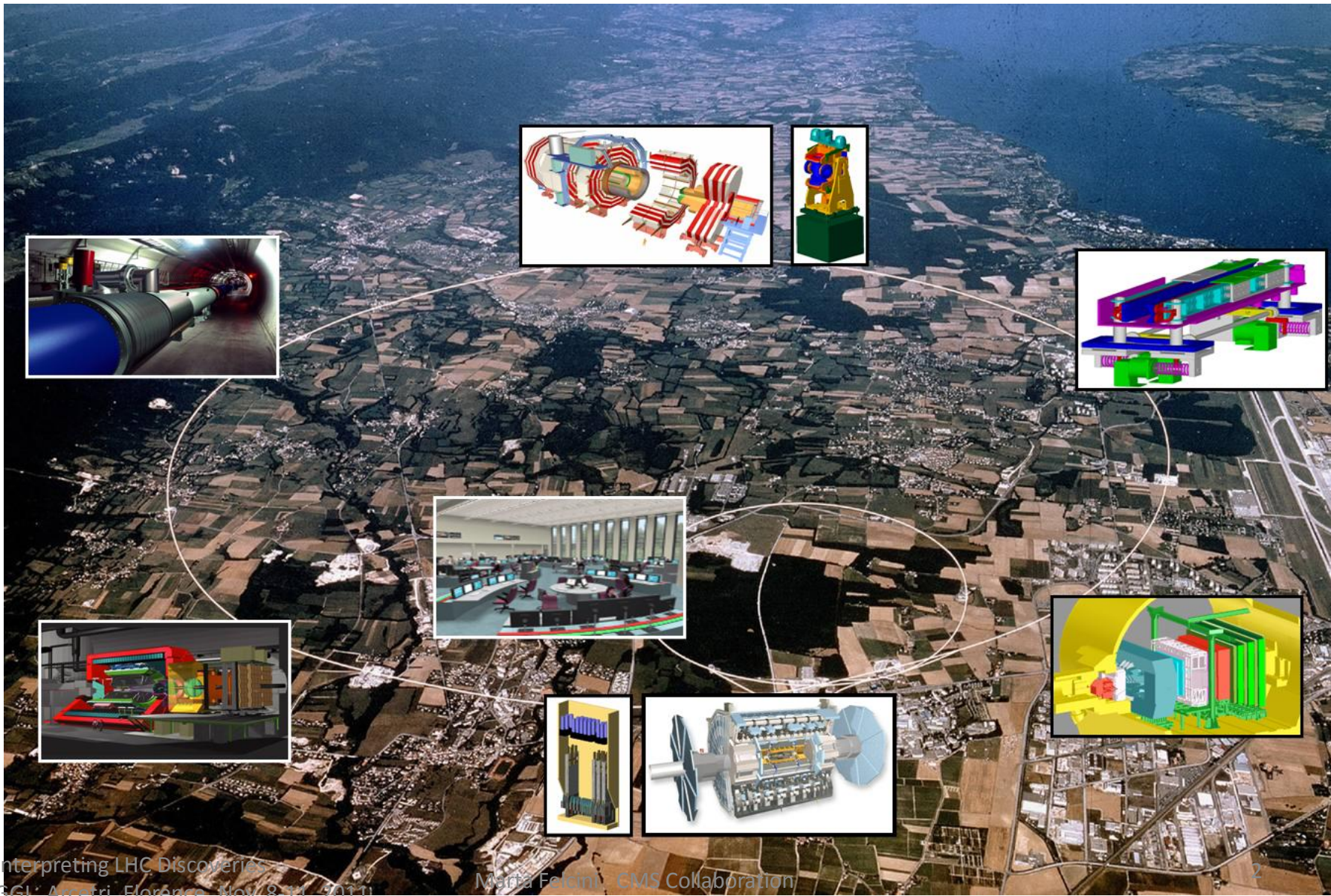


Searches for Exotic Phenomena with the CMS Experiment

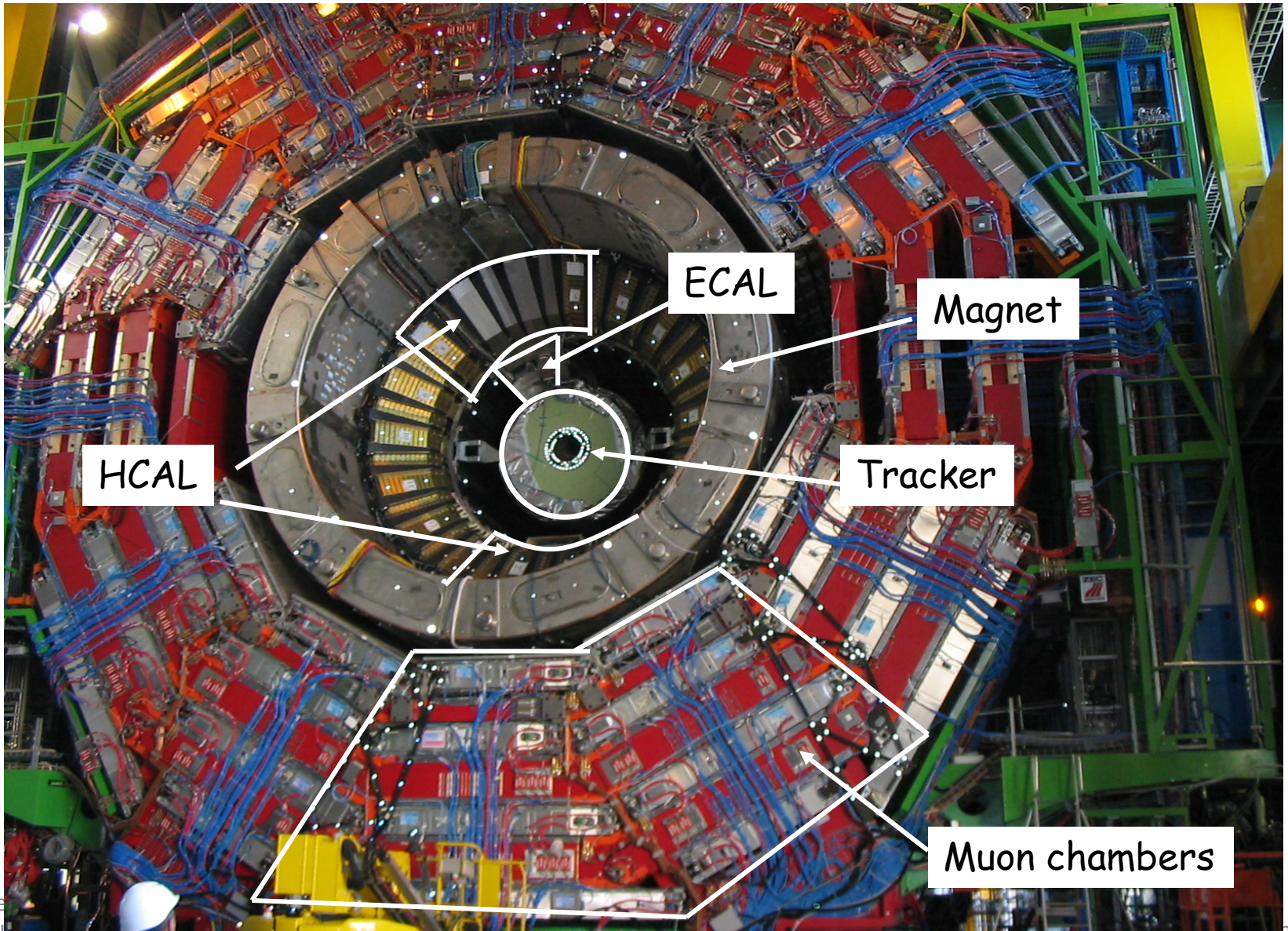
Marta Felcini
IFCA, Santander
on behalf of the
CMS Collaborations

Interpreting LHC Discoveries
Galileo Galilei Institute for Theoretical Physics
November 8-11, 2011, Arcetri, Florence, Italy

LHC Accelerator and Detectors



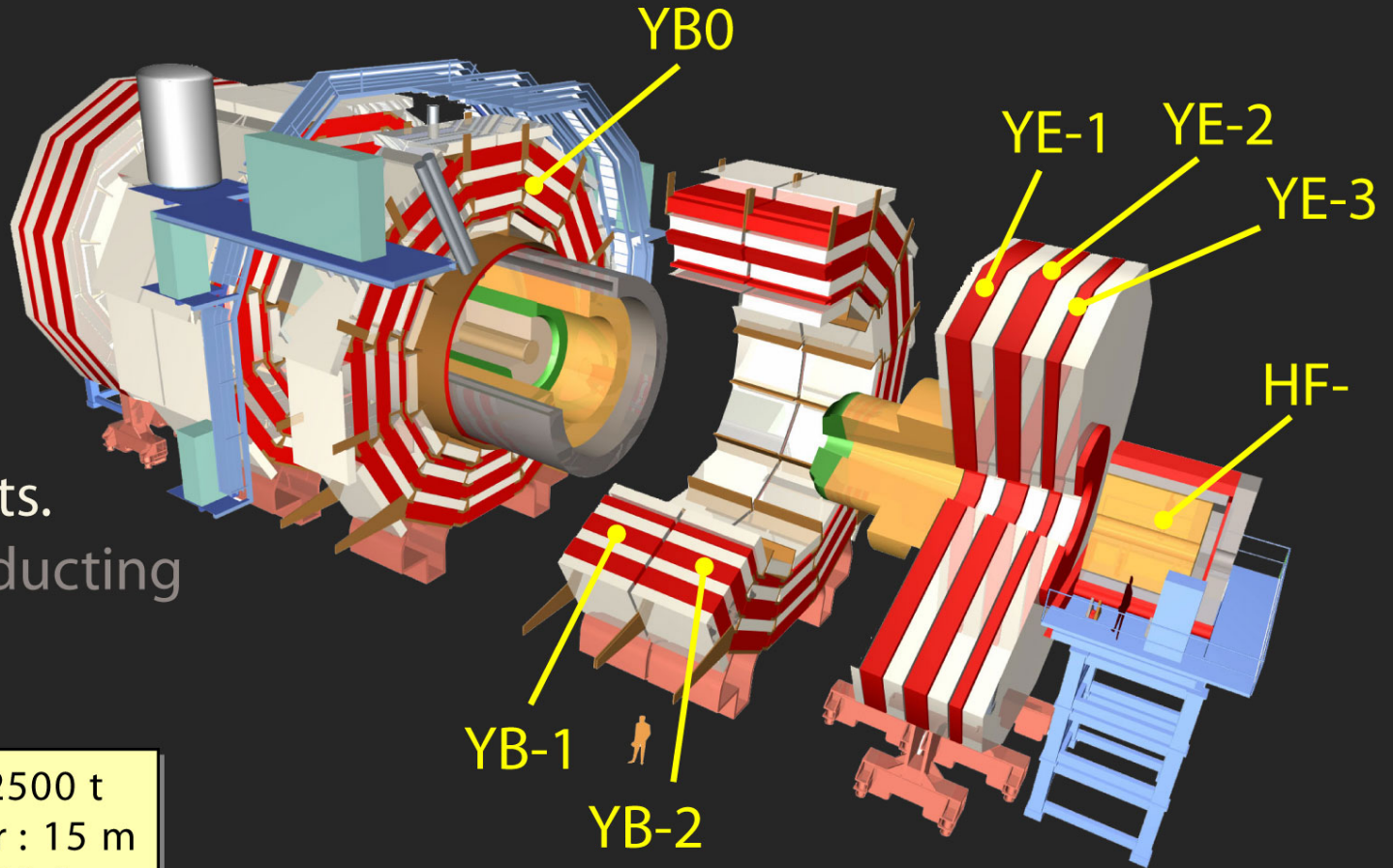
The CMS Detector





Exploded View of CMS

- Pixels
- Tracker
- ECAL
- HCAL
- MUON Dets.
- Superconducting Solenoid

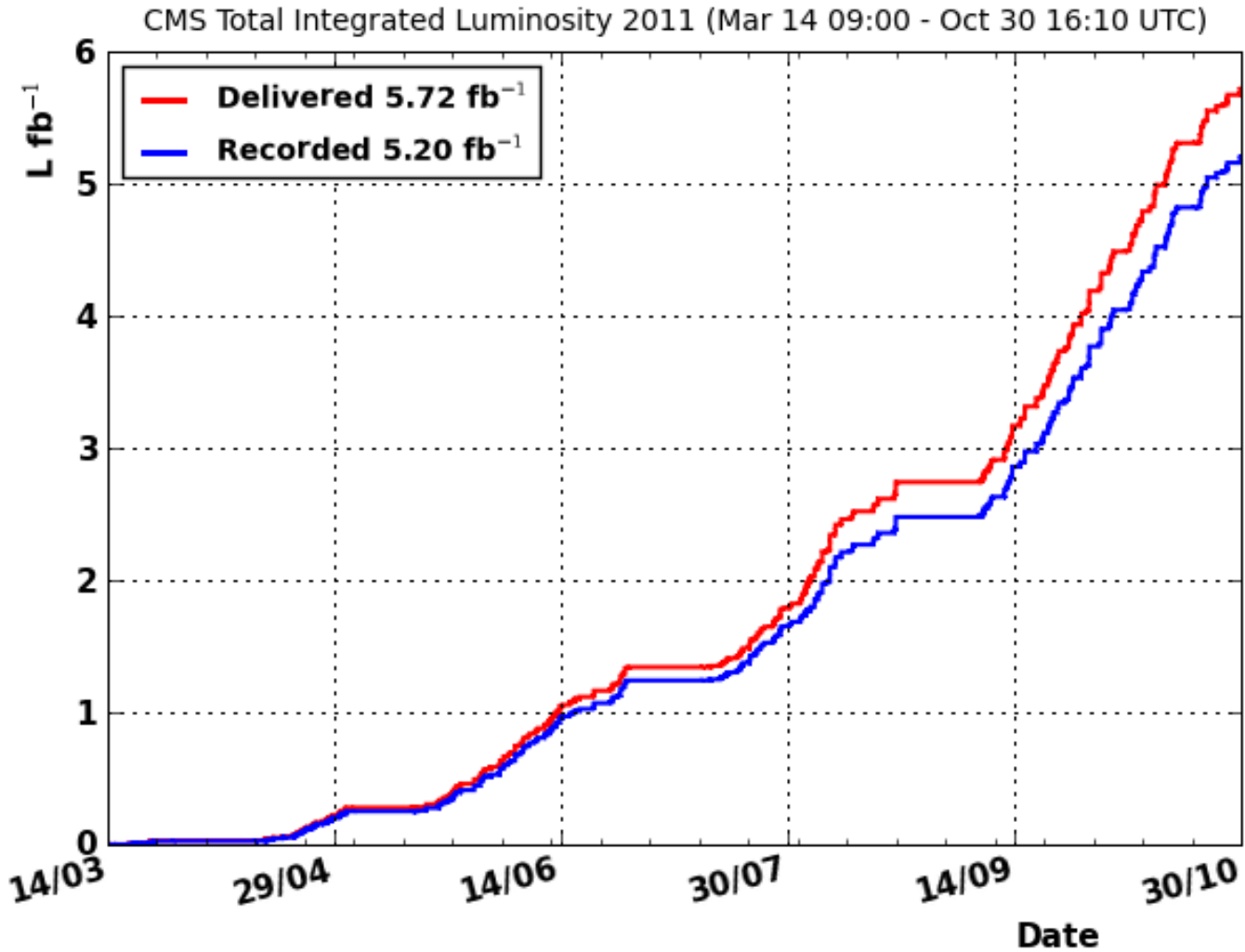


Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

<http://cms.cern.ch>

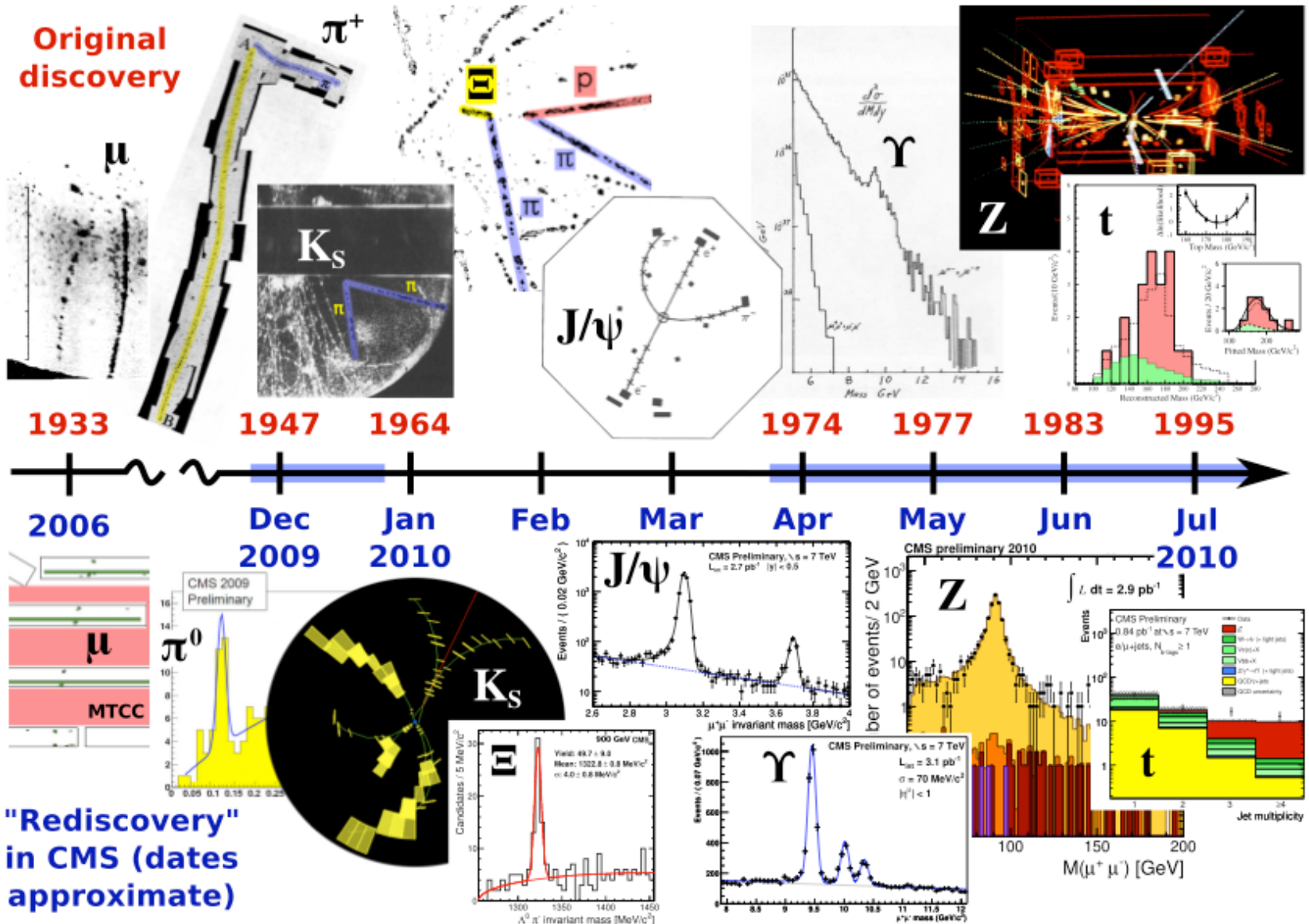


CMS Integrated Luminosity in 2011



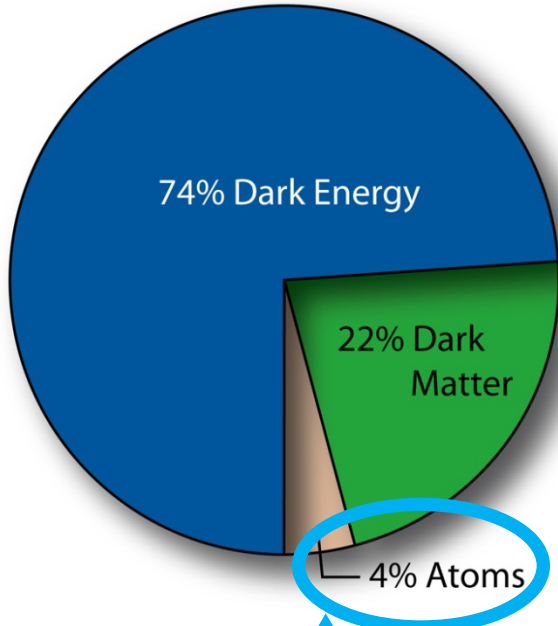
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults>

Standard Model re-established at 7 TeV

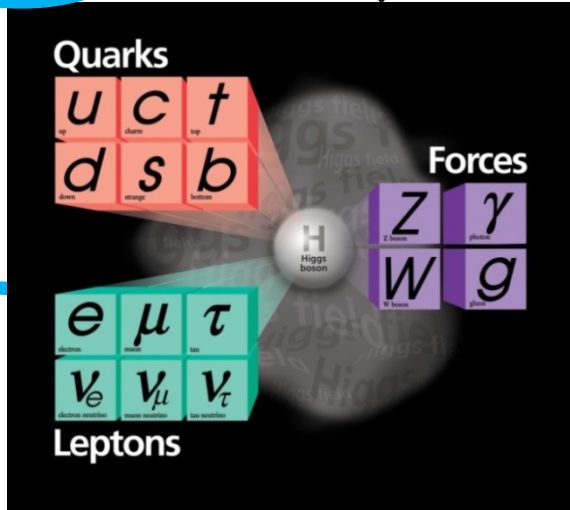


Biggest Evidence for BSM Physics

Credit: NASA / WMAP Science Team



Standard Model of Particle Physics very successful ... in explaining what makes 4% of the Universe



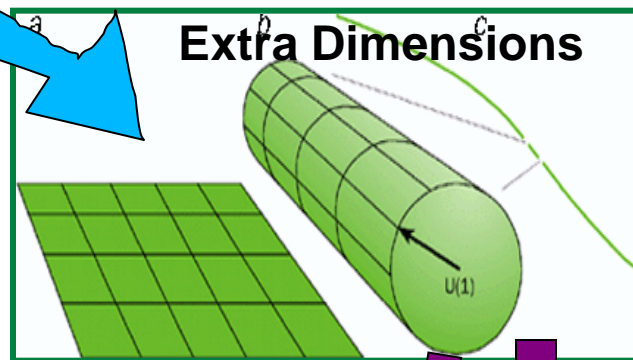
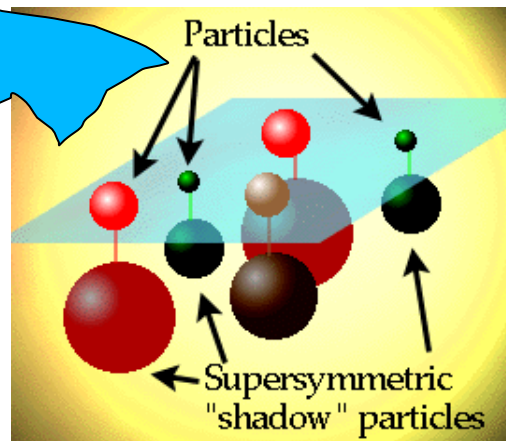
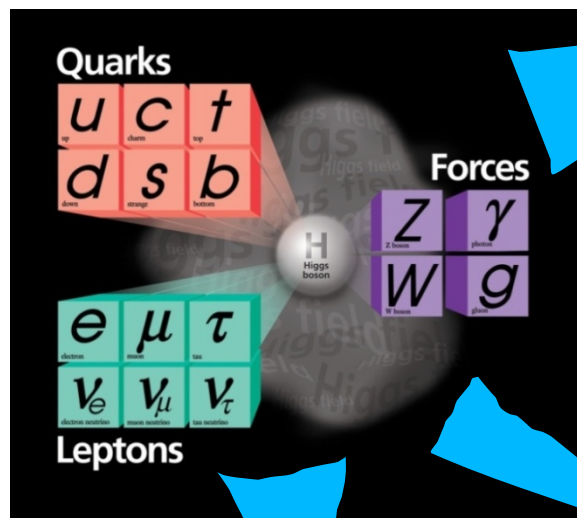
<http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2011>

	Measurement	Fit	$\frac{ O^{\text{meas}} - O^{\text{fit}} }{\sigma^{\text{meas}}}$
$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767	0.1
m_Z [GeV]	91.1875 ± 0.0021	91.1874	0.05
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	0.3
σ_{had}^0 [nb]	41.540 ± 0.037	41.478	1.6
R_l	20.767 ± 0.025	20.743	0.9
$A_{\text{fb}}^{0,l}$	0.01714 ± 0.00095	0.01643	0.8
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480	0.4
R_b	0.21629 ± 0.00066	0.21581	0.7
R_c	0.1721 ± 0.0030	0.1722	0.02
$A_{\text{fb}}^{0,b}$	0.0992 ± 0.0016	0.1038	2.8
$A_{\text{fb}}^{0,c}$	0.0707 ± 0.0035	0.0742	1.2
A_b	0.923 ± 0.020	0.935	0.6
A_c	0.670 ± 0.027	0.668	0.05
$A_l(\text{SLD})$	0.1513 ± 0.0021	0.1480	1.5
$\sin^2\theta_{\text{eff}}^{\text{lept}}(Q_{\text{fb}})$	0.2324 ± 0.0012	0.2314	0.8
m_W [GeV]	80.398 ± 0.025	80.377	0.8
Γ_W [GeV]	2.097 ± 0.048	2.092	0.1
m_t [GeV]	172.6 ± 1.4	172.8	0.1

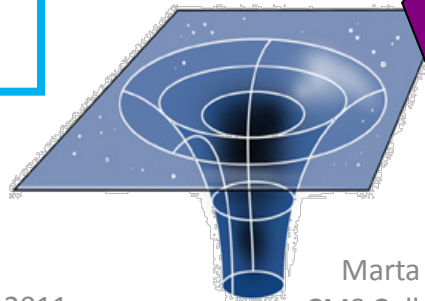
March 2008

**Good news!!!
Lots more to discover...**

Beyond the Standard Model



Black Holes



Graviton

Many possible BSM directions...

Need navigation aid
=> specific BSM models: important as a reference (benchmarks)

to set-up the experimental search strategies
=> particularly trigger (on-line) selections
"an event not passing the trigger is lost forever"

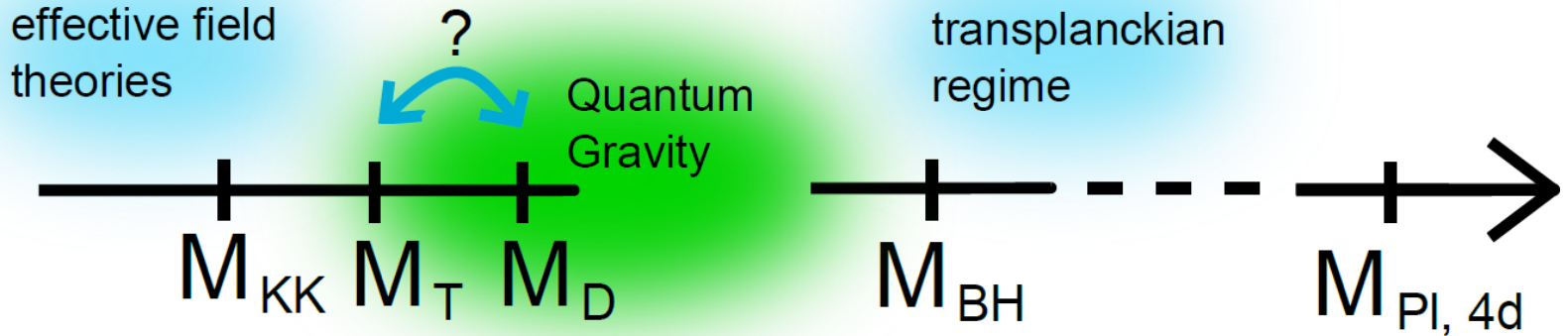
... but always with an open mind for surprises

Extended Gauge Symmetries,
Fourth generation,
Little Higgs,...

$Z', W', b', t', \nu', l', \dots$



Search for Extra Dimensions



RS model with AdS_5 geometry


ADD model with toroidal extra dimensions

black holes with semi classical arguments

single graviton KK mode to: dielectron, dimuon diphoton

graviton production: monojet, monophoton
graviton exchange: diphoton, dimuon

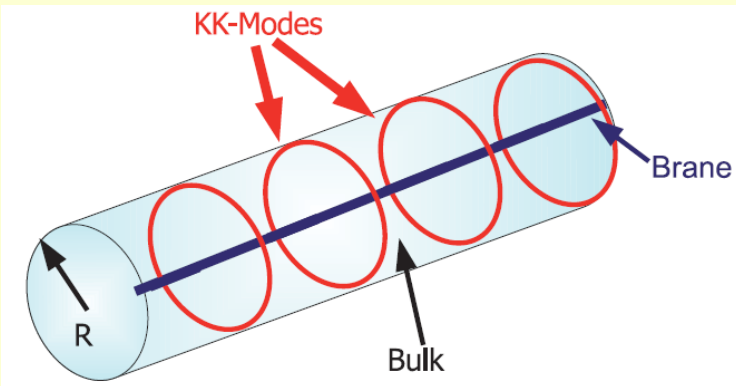
multijet based search



Extra Dimensions Models for Interpretation

Large Extra Dimensions - ADD Models

- Standard Model confined to a brane
- Gravitons propagate in the bulk
- Broad signal from many KK states



Exp.tal results interpreted in terms of

- effect. Planck scale: $M_D \sim (M_{Pl}^2 R^{-n})^{1/(n+2)}$
- other parameters:

1) GRW: G. F. Giudice, R. Rattazzi,
J. D. Wells [Λ_T]

2) HLZ: T. Han, J. D. Lykken, R. Zhang
[M_s, n]

3) J. Hewett [η_G]

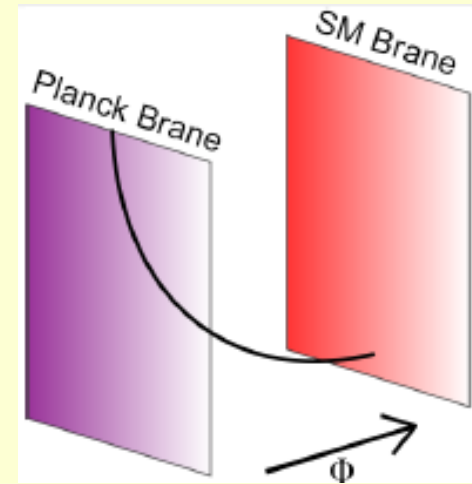
Interpreting LHC Discoveries

Warped Extra Dimensions - RS Models

- Warped metrics

$$ds^2 = e^{-2kr_c\phi} \eta_{\mu\nu} dx^\mu dx^\nu + r_c^2 d\phi^2$$

- resonant signal from single KK state



Exp.tal results interpreted in terms of

- graviton mass M_1
- coupling parameter $\tilde{k} \equiv k/M_{Pl}$

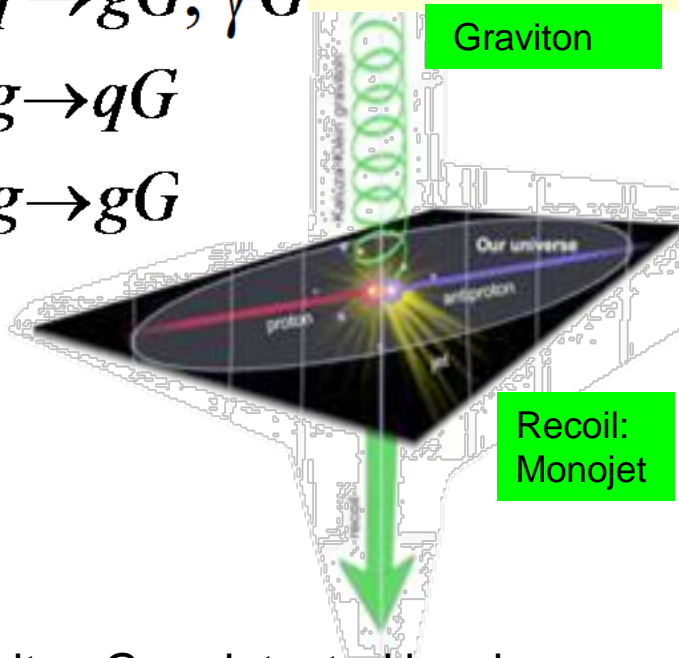
Extra Dimensions Phenomenology

Graviton Emission

$$q\bar{q} \rightarrow gG, \gamma G$$

$$qg \rightarrow qG$$

$$gg \rightarrow gG$$



Graviton

Recoil:
Monojet

Graviton G undetected leaving a final state gluon, quark or photon.

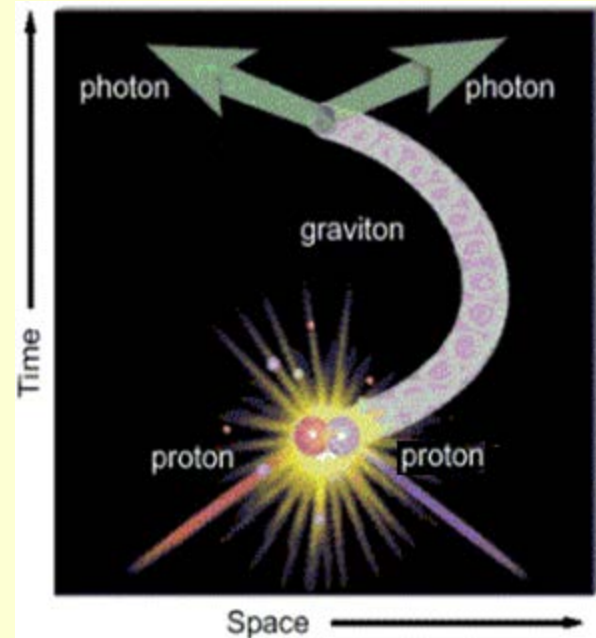
Signature:

single jet or photon + missing E_T .

Graviton Exchange

Single G \rightarrow narrow resonance

Multi KK states \rightarrow broad enhancement
in $\gamma\gamma$, e^+e^- or $\mu^+\mu^-$ mass distributions

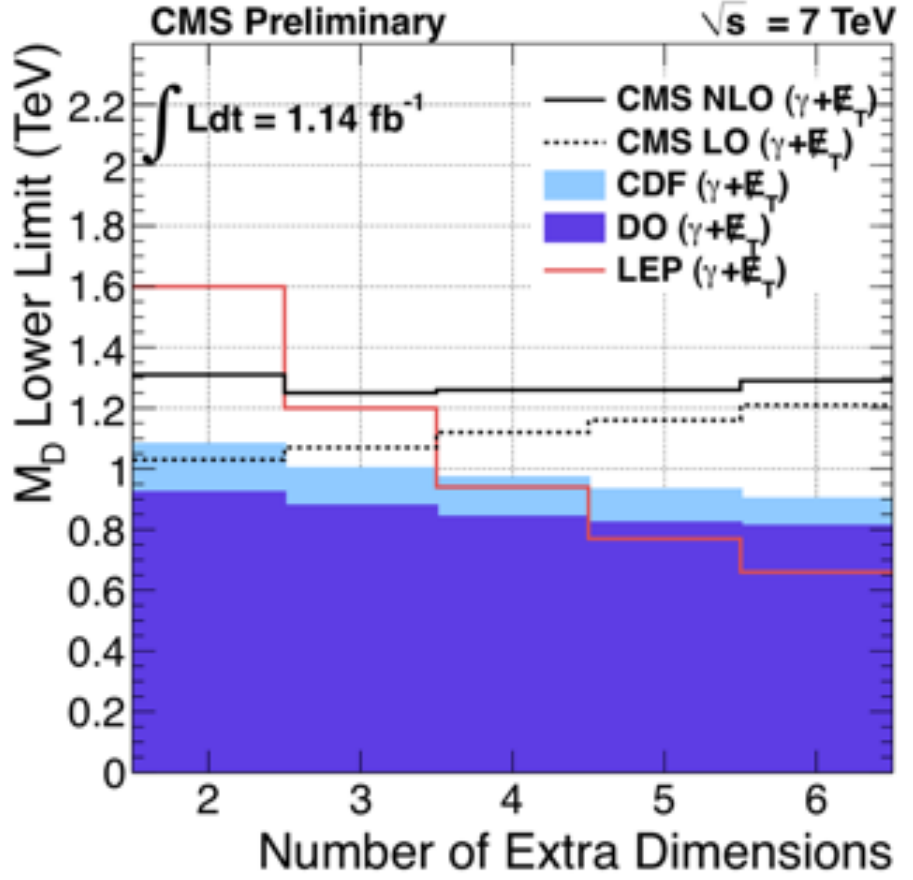
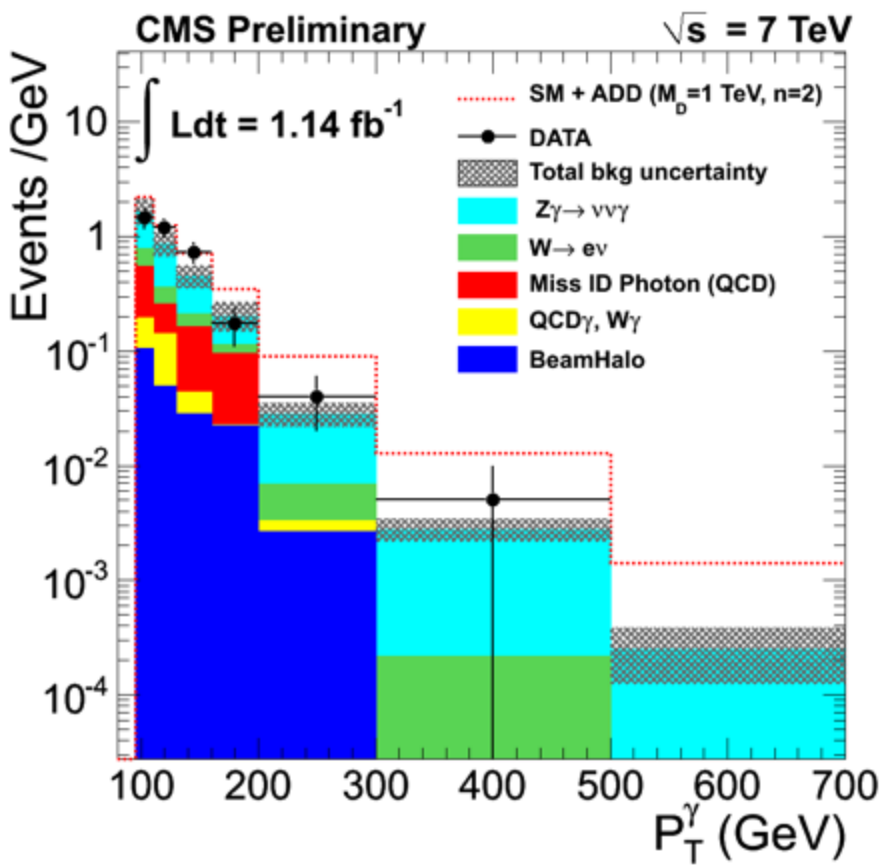
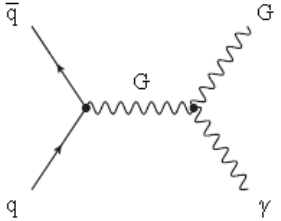




Single photon + missing E_T

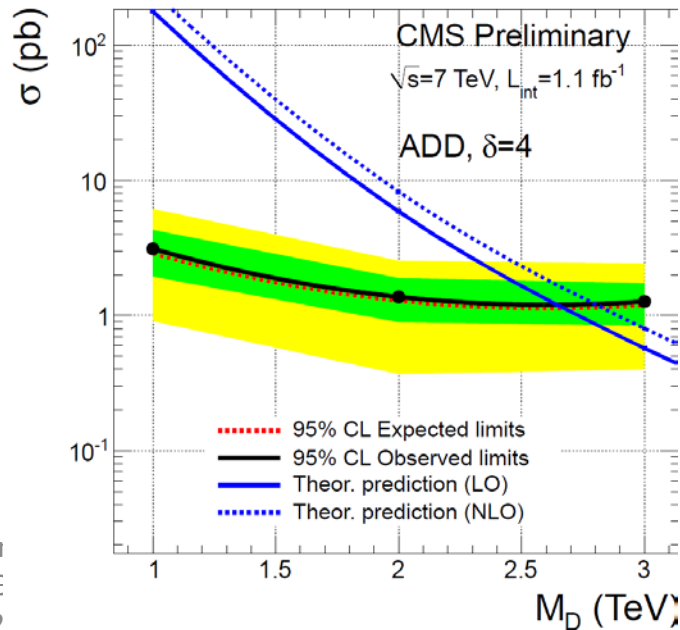
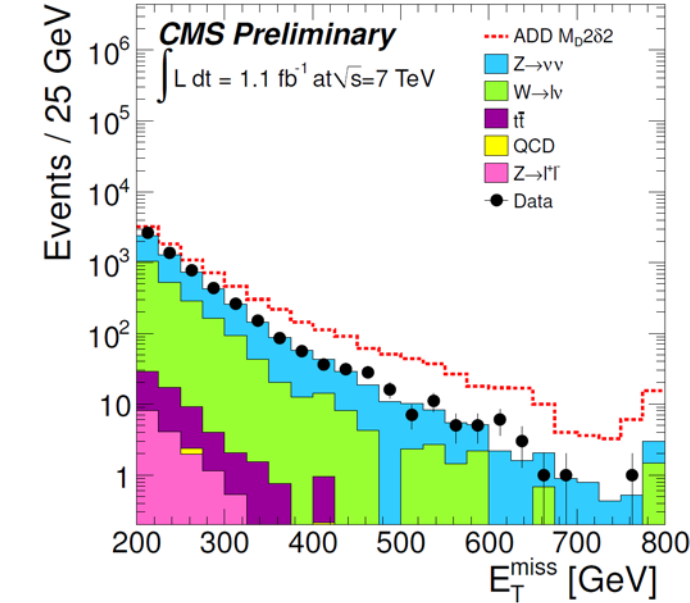
Search for an excess of events in photon high p_T distribution

CMS PAS EXO-11-058

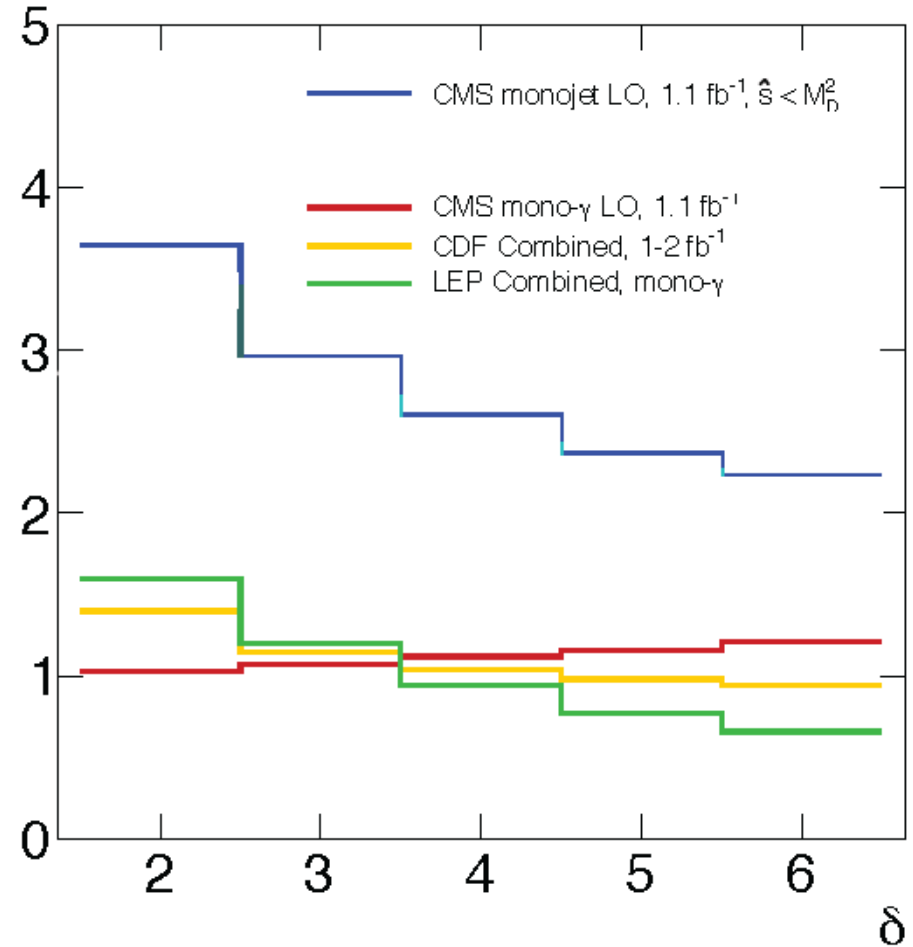


Single jet + missing E_T

CMS PAS EXO-11-059



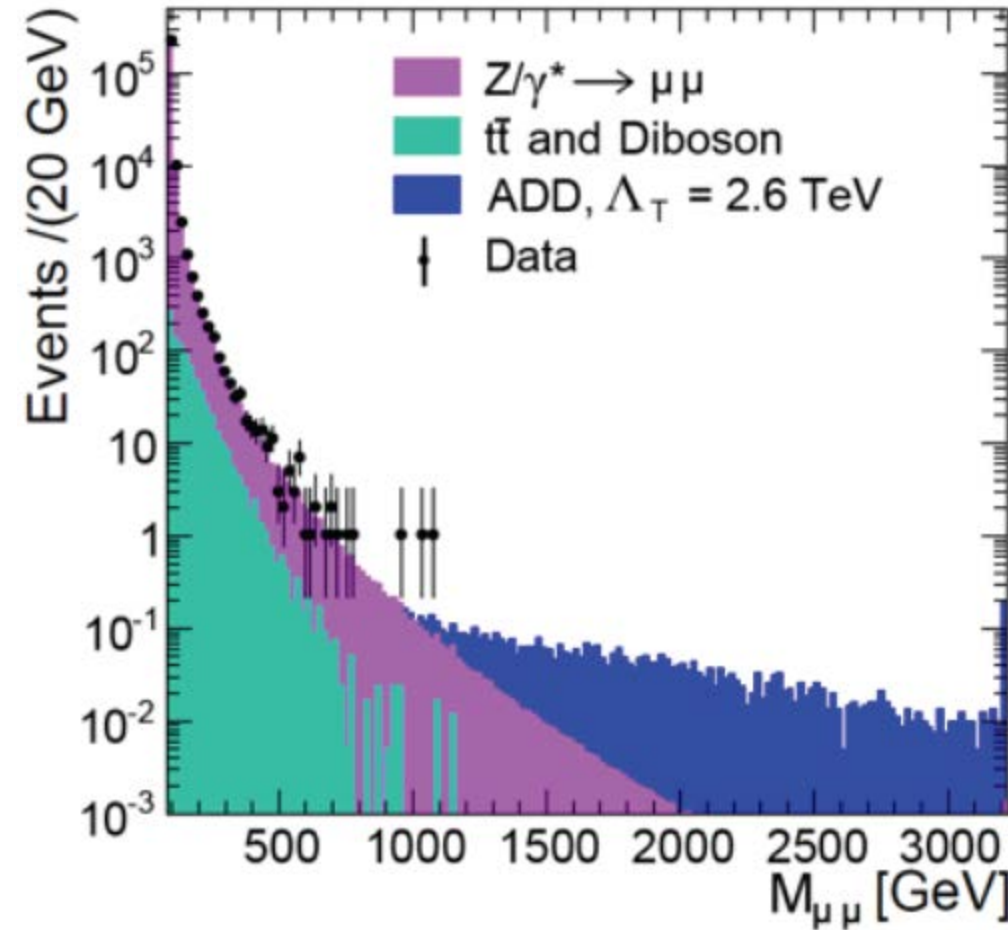
M_D (TeV)





Non-resonant $\mu\mu$ and $\gamma\gamma$

CMS preliminary $\sqrt{s} = 7 \text{ TeV}, \int L dt = 1.18 \text{ fb}^{-1}$



$$\sigma_{\text{ADD}} = \sigma_{\text{SM}} + A\eta_G \sigma_{\text{int}} + B\eta_G^2 \sigma_{\text{ED}}$$

$$\eta_G = \mathcal{F} / M_S^4$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{s}\right) & \text{if } n_{\text{ED}} = 2 \\ \frac{2}{(n_{\text{ED}} - 2)} & \text{if } n_{\text{ED}} > 2 \end{cases}$$

Lower limit on M_S (TeV)

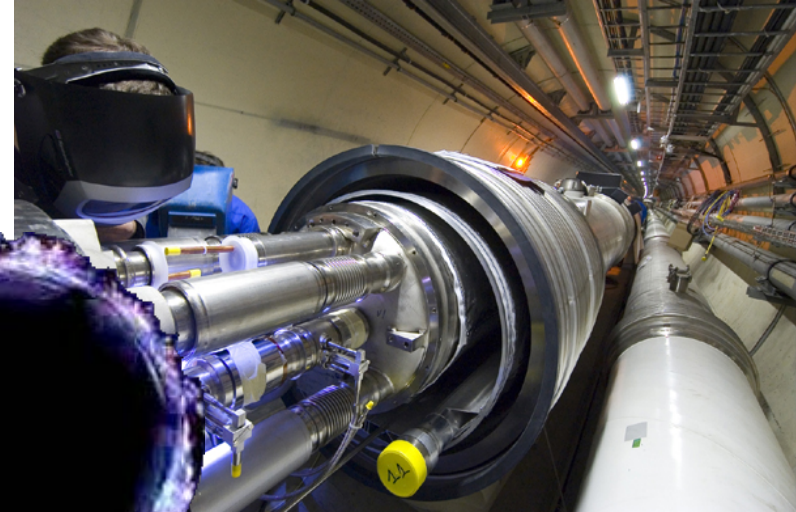
	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
$\mu\mu$	2.6	3.1	2.6	2.3	2.1	2.0
$\gamma\gamma$	3.2	3.4	2.8	2.6	2.4	2.2

$\mu\mu$ CMS PAS EXO-11-039

$\gamma\gamma$ CMS PAS EXO-11-038

Black Holes

- Reduced Planck mass scale due to large EDs → increased Schwarzschild radius → immediate decay due to Hawking radiation
- **Large cross-sections $O(100 \text{ pb})$**
- **Signature: events with high particle multiplicities and high transversal momentum**

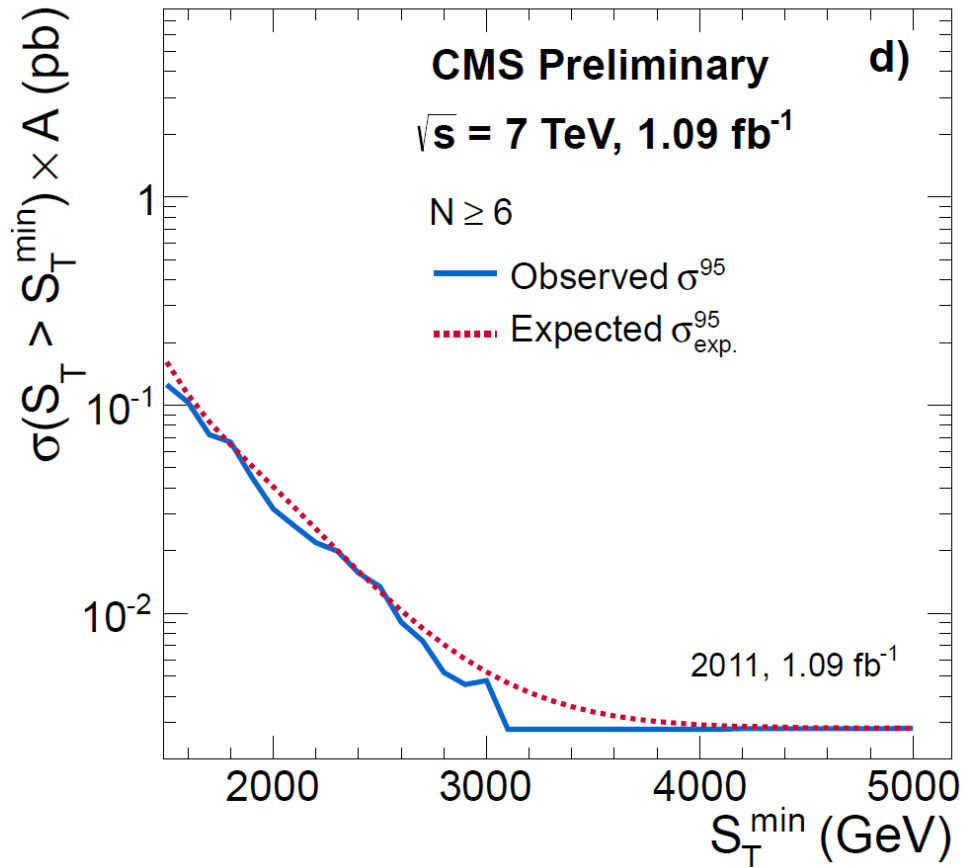
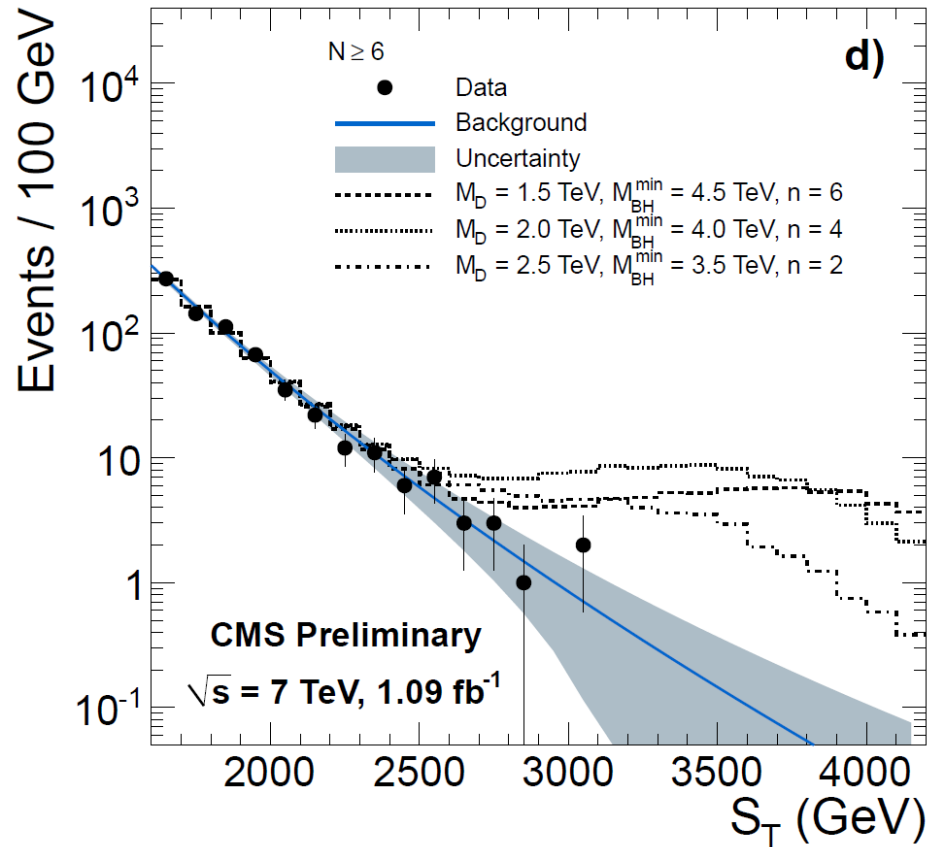


**Stephen Hawking
visiting CMS**



Black Holes Searches

CMS: PAS EXO-11-071

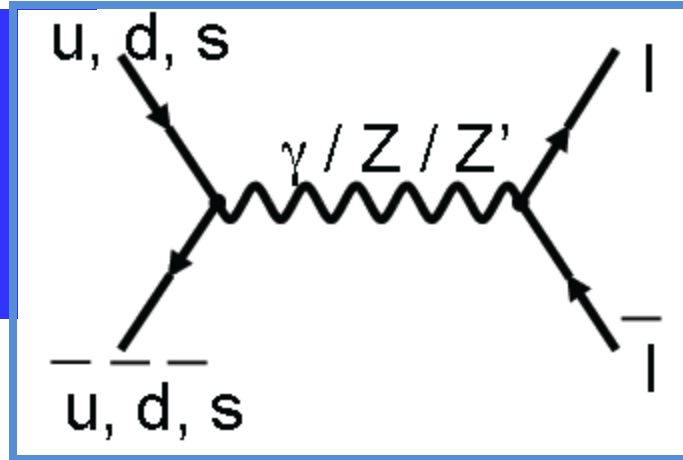


Upper Limits (evt count) as a function of
 S_T = sum of transverse momenta
 N = reconstructed object multiplicity

Search for Heavy Resonances

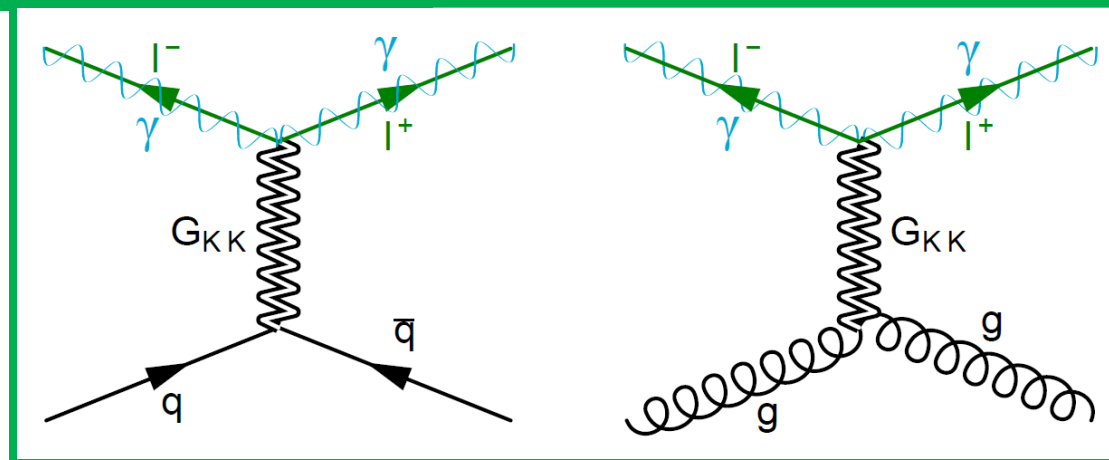
Extended Gauge Symmetries:

- Z_{SSM} in Sequential Standard Model
- Z' from E6 and SO(10) GUT
- Narrow heavy particles from Technicolor
- ...



Extra Dimensions Models

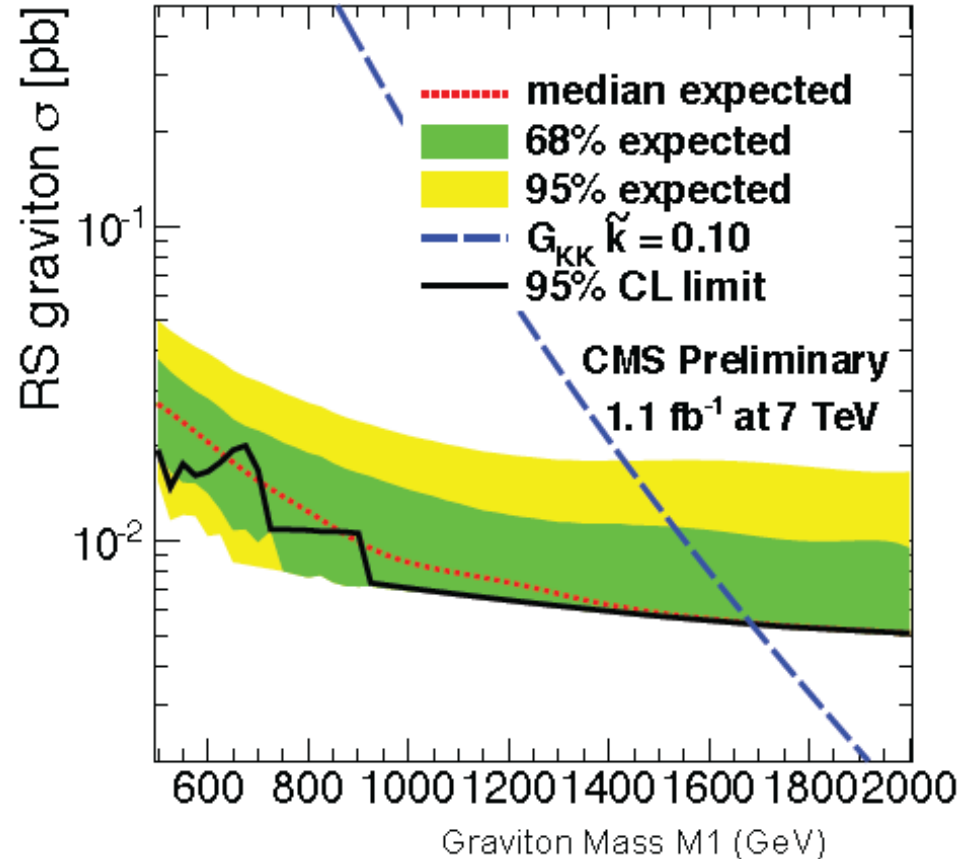
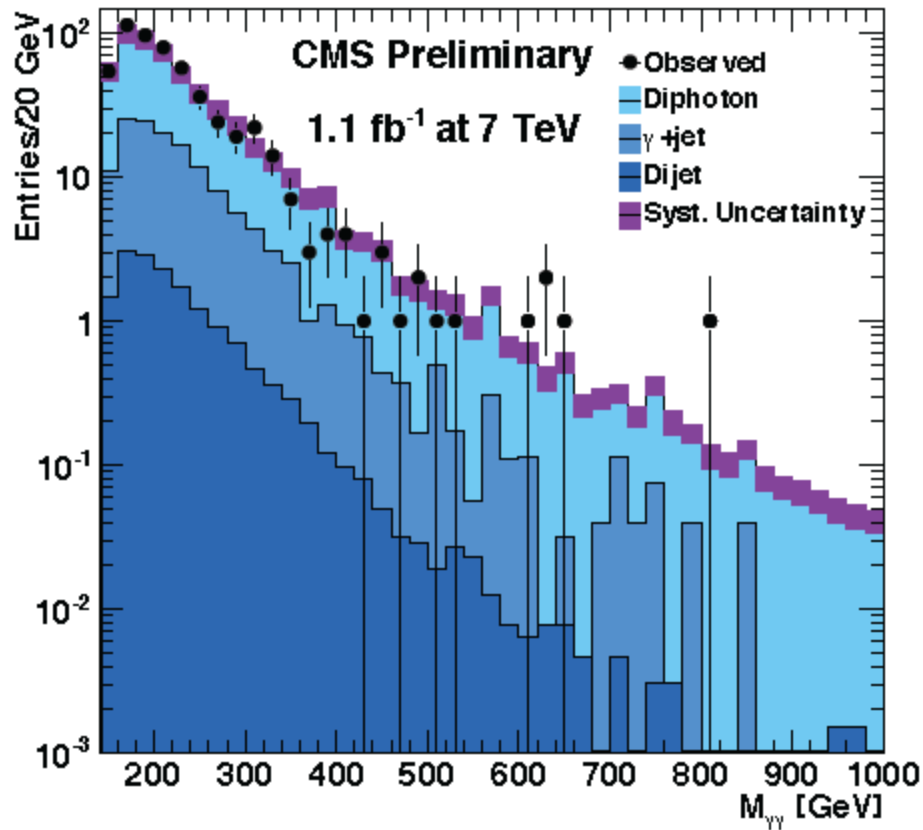
- RS Kaluza Klein Graviton Exchange





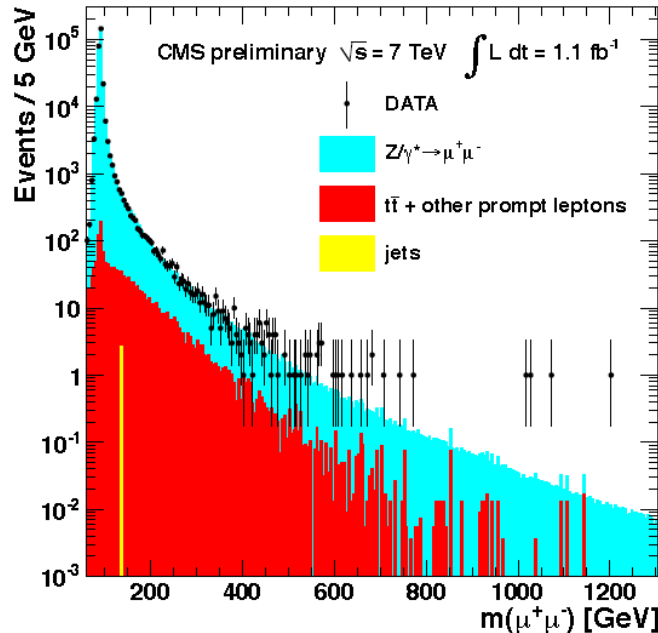
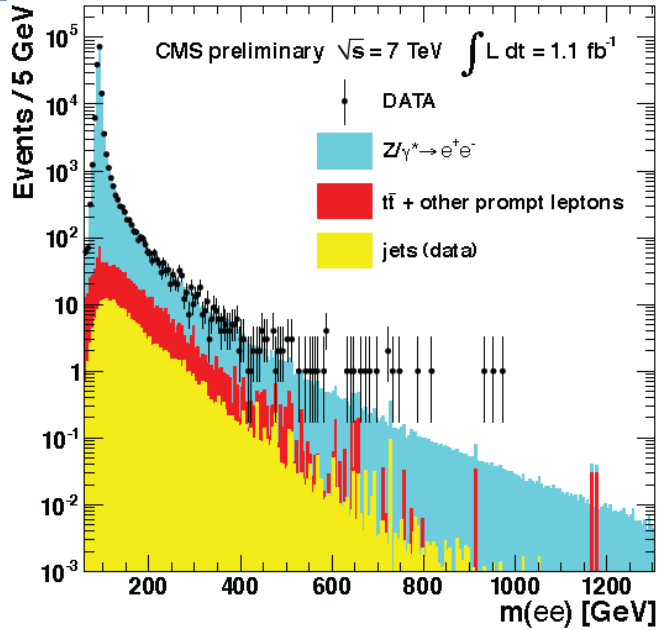
Diphoton Resonances

CMS: PAS EXO-11-038

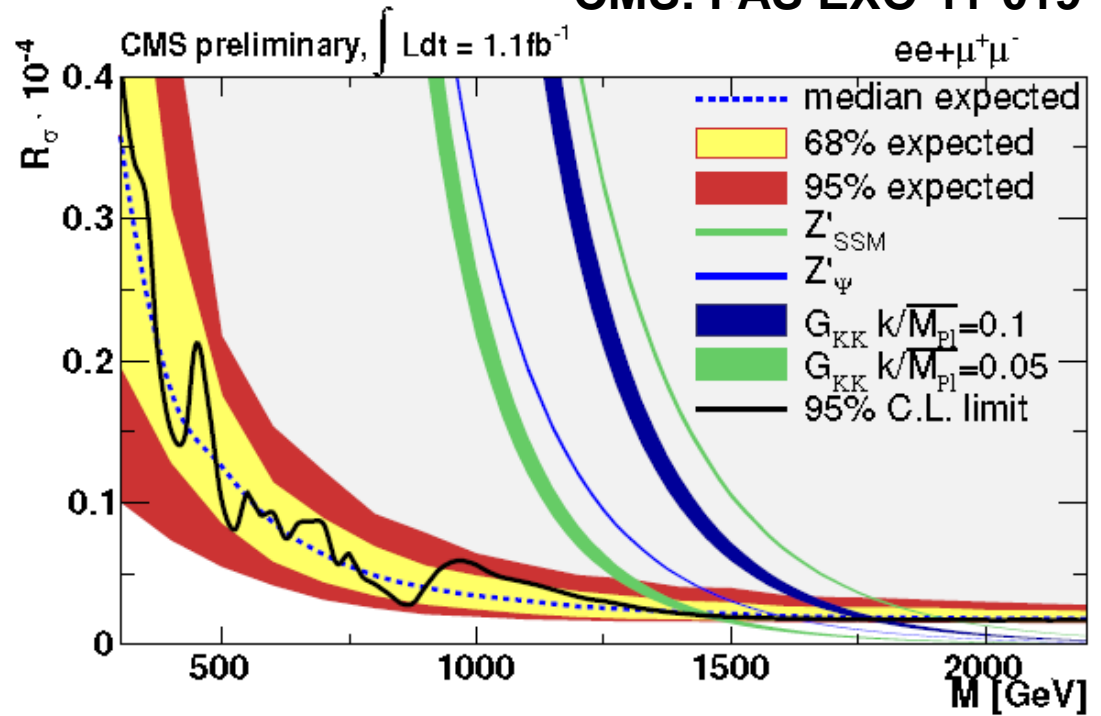


RS KK Graviton k/M_{Pl}	Mass Limit (TeV)
0.05	1.36
0.10	1.68

Dilepton Resonances



CMS: PAS EXO-11-019

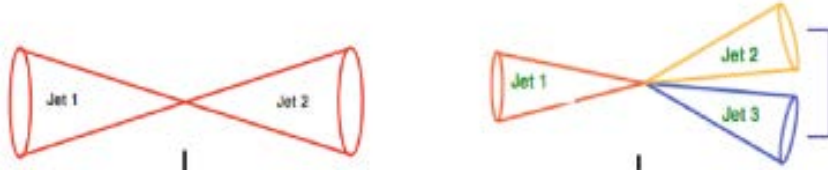


Signal	Mass Limit (TeV)
RS KK Gravitons, $k/M_{\text{pl}} = 0.05-0.1$	1.45 - 1.78
Sequential Standard Model Z'_{SSM}	1.94
Super-String inspired models, Z'_{ψ}	1.62

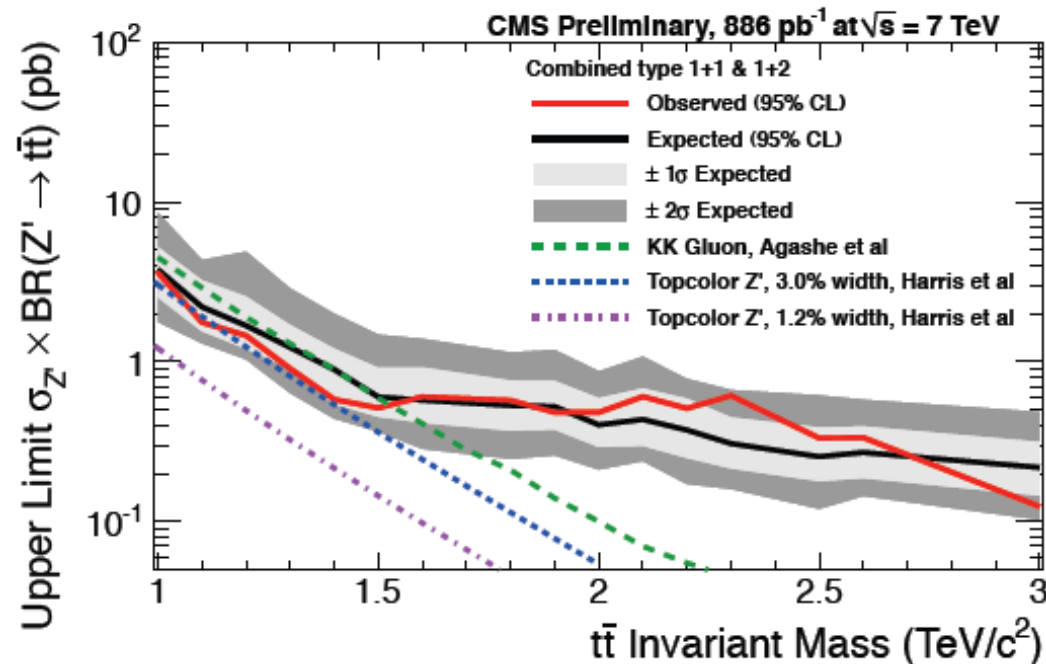
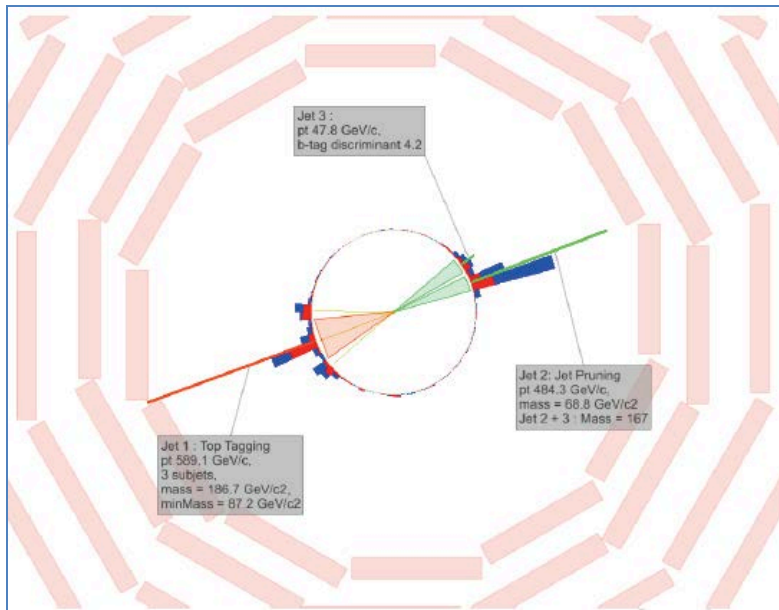
Top Pair Resonances

Search in the all hadronic decay channel for top pair
 Tops are boosted for high mass particle, jets merge
 Use fat jet algorithms and apply jet pruning to find sub-jets

CMS PAS-EXO-11-006



Exclude KK-Gluons $1 < M < 1.5 \text{ TeV}$

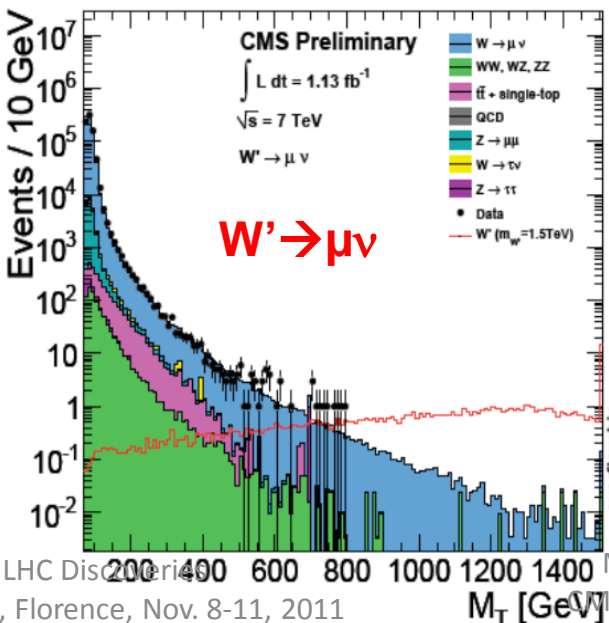
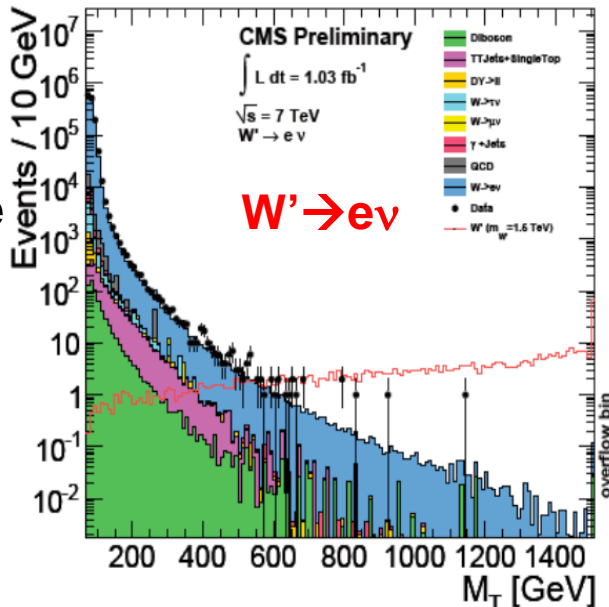




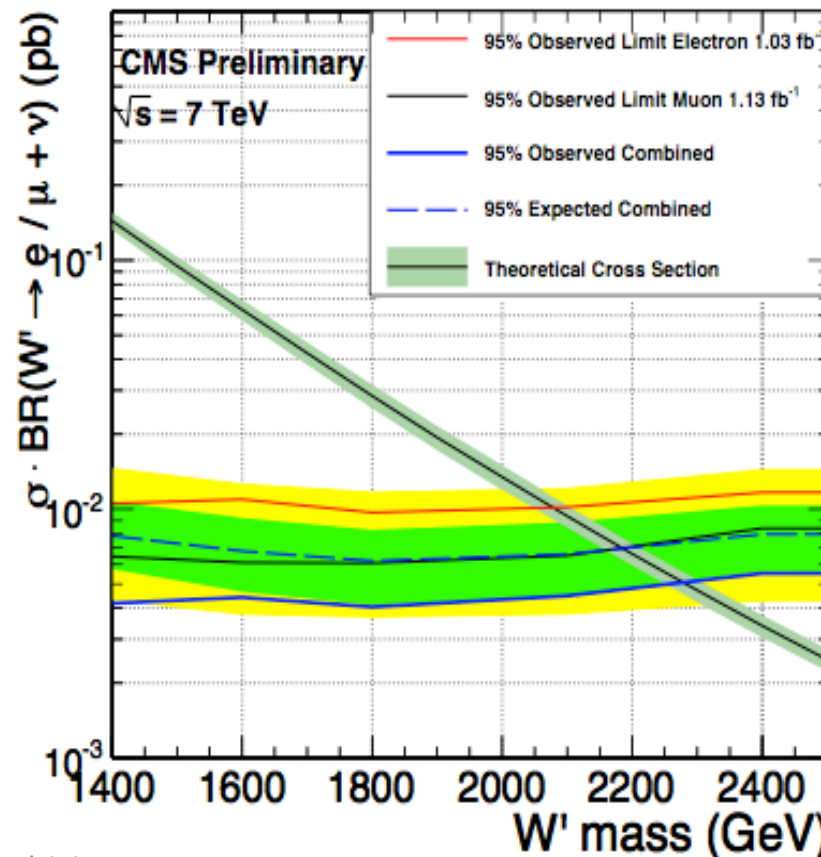
Heavy W-like Vector Bosons

Look for Jacobian peak in transverse mass

CMS: PAS EXO-11-024

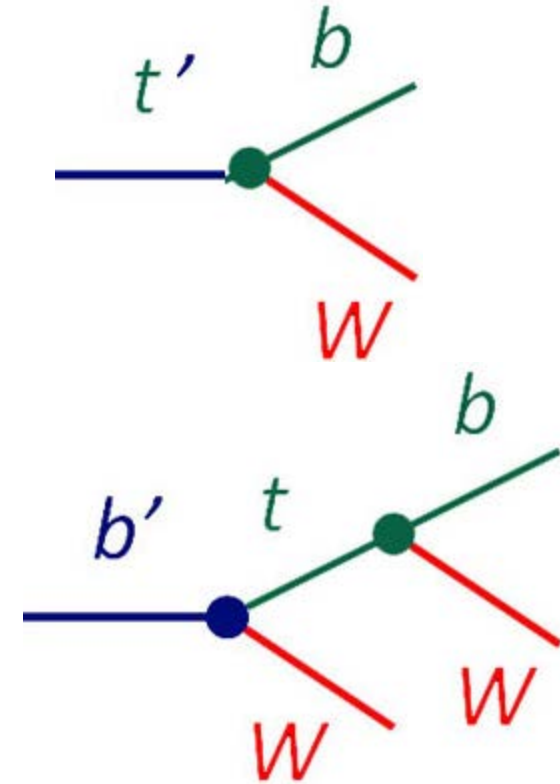


Assuming standard-model-like couplings and decay branching fractions exclude a **SSM W' with mass $< 2.27 \text{ TeV}$ (95%CL)**



Fourth Generation Search

Quarks	u	c	t	t'
	d	s	b	b'
Leptons	ν_e	ν_μ	ν_τ	ν'
	e	μ	τ	τ'
	I	II	III	IV



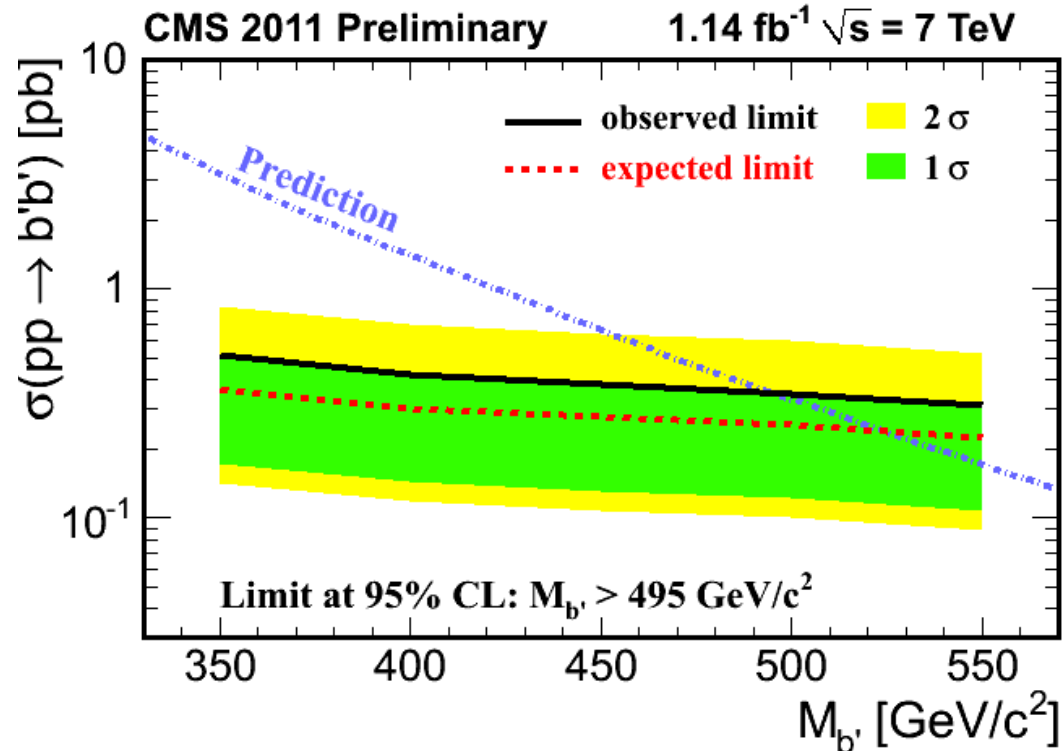
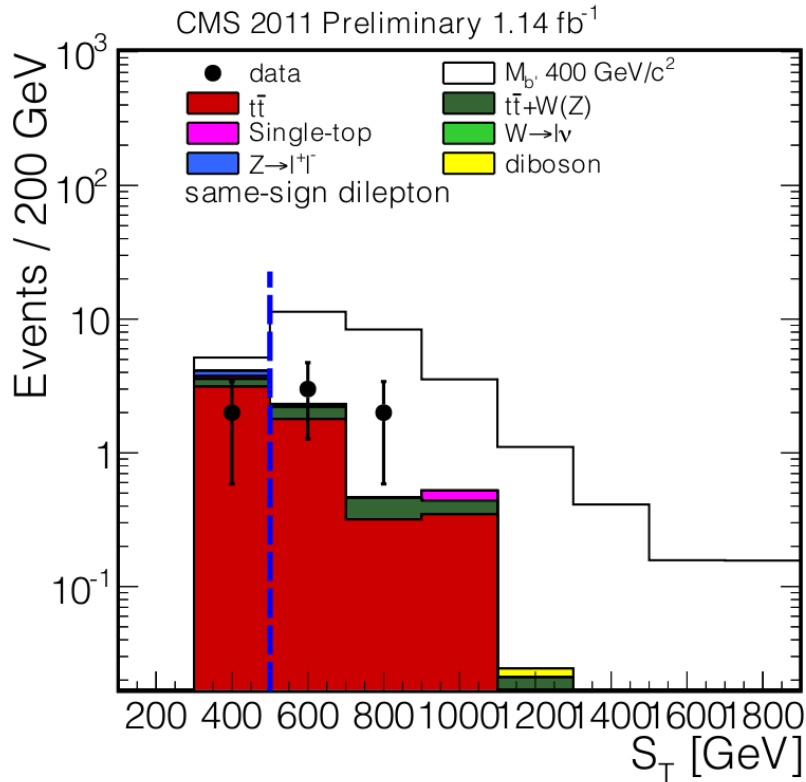


Heavy Bottom-like Quark $b' \rightarrow t + W$

CMS PAS EXO-11-036

Cross-section upper limit translating into **b' mass lower limit $M_{b'} > 495 \text{ GeV}$** for $\text{BR}(b' \rightarrow tW) = 100\%$

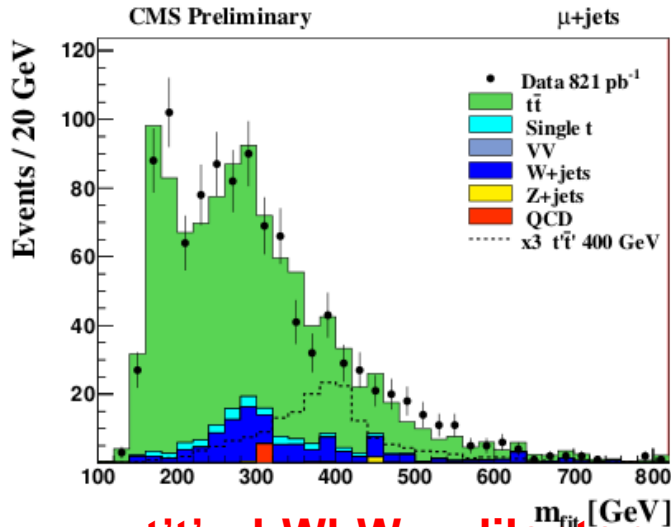
- $b'b'$ pair production
- $\text{BR}(b' \rightarrow tW) = 100\%$
- Decay : $b'b' \rightarrow tWtW \rightarrow \mathbf{bbW+W-W+W-}$
- **Same sign dileptons or trileptons**



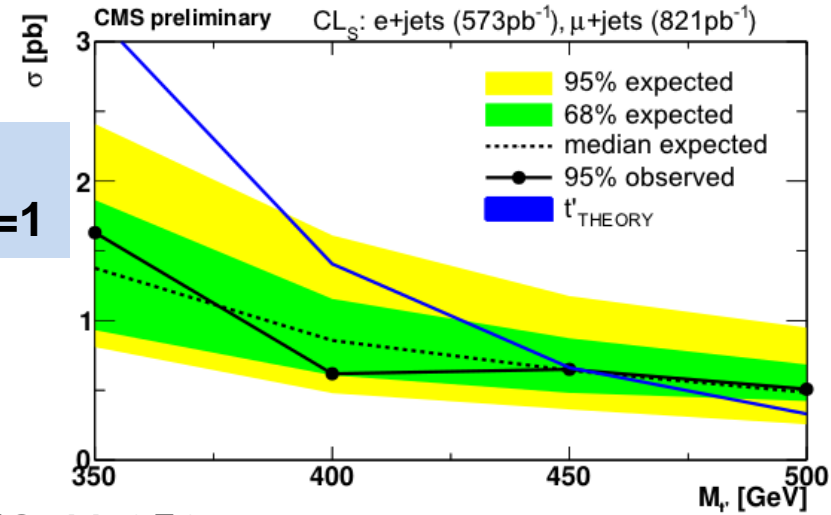


Heavy Top-Like Quark $t' \rightarrow b+W$

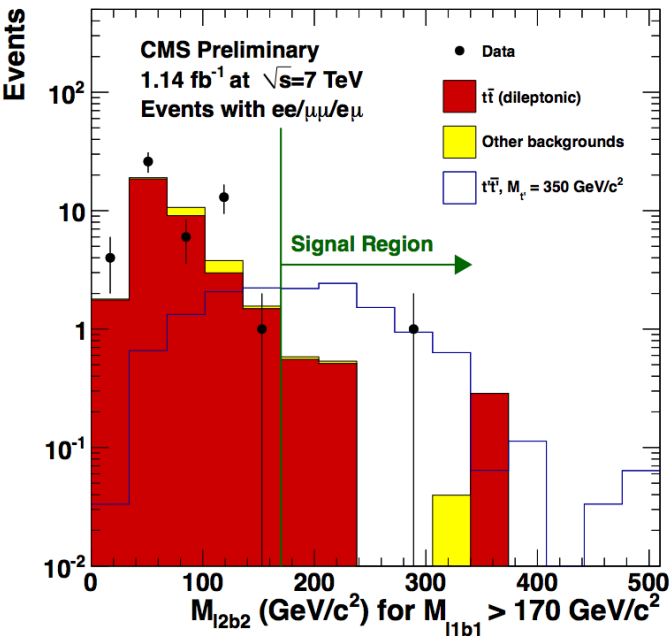
$t't' \rightarrow bWbW \rightarrow \text{lepton+jets}$ CMS PAS EXO-11-051



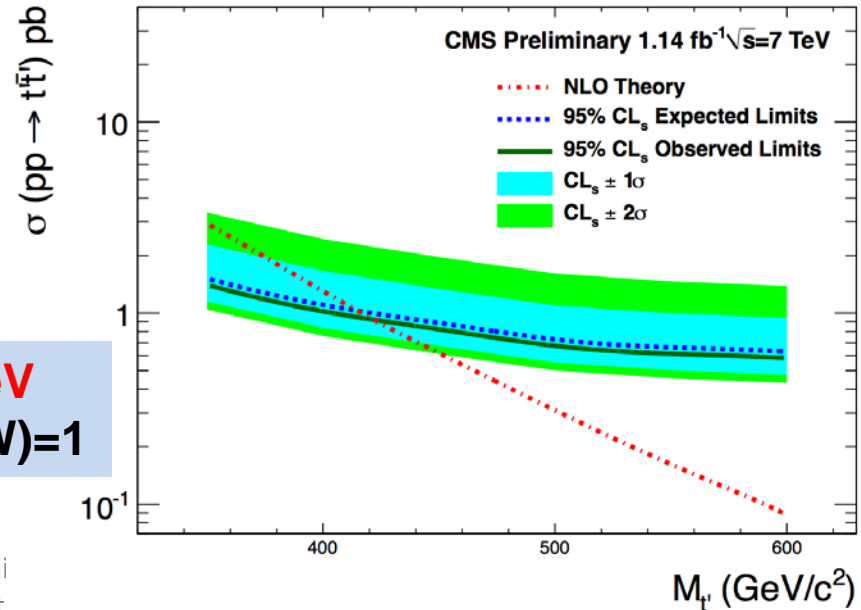
$m(t') > 450$ GeV
for BR($t' \rightarrow bW$)=1



$t't' \rightarrow bWbW \rightarrow \text{dilepton+jets}$ CMS PAS EXO-11-050



$m(t') > 422$ GeV
for BR($t' \rightarrow bW$)=1





Simultaneous t', b' search for $m_{t'} = m_{b'}$

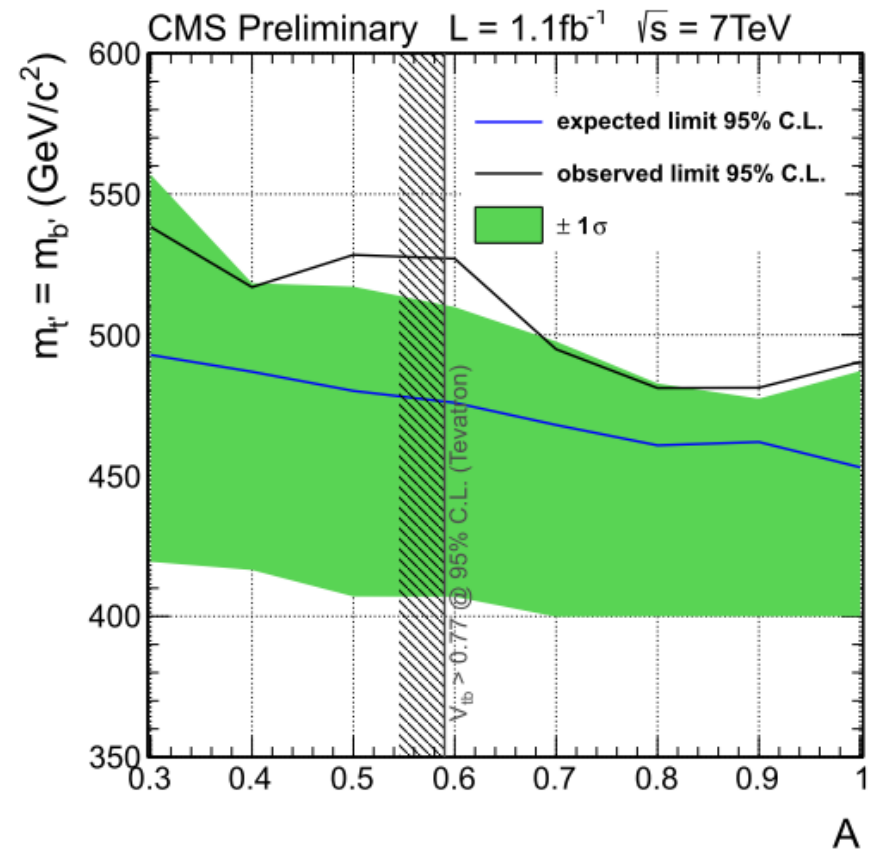
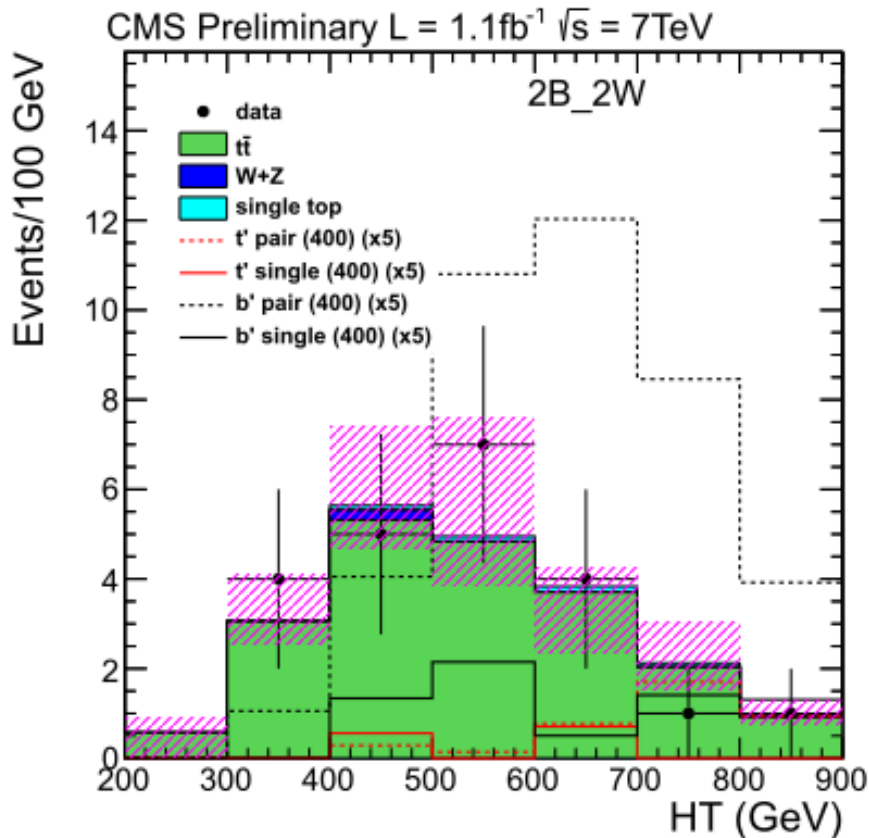
Search for multiple b and W FS

- $t'b \rightarrow bWb$
- $b't \rightarrow tWbW \rightarrow bWWbW$
- $t't' \rightarrow bWbW$
- $b'b' \rightarrow tWtW \rightarrow bWWbWW$

CMS PAS EXO-11-054

Interpretation in terms of $m_{t'} = m_{b'}$ and $A = |V_{tb}|^2 = |V_{t'b'}|^2$

$m(t') = m(b') > 490$ GeV for $A=1$

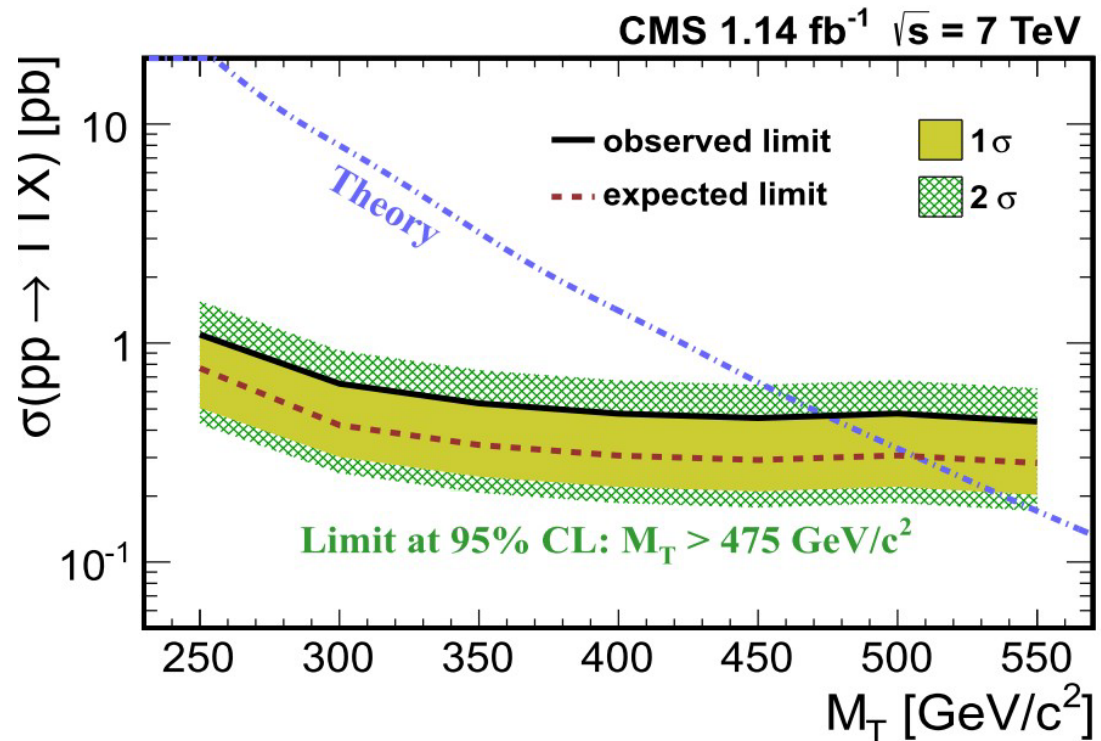
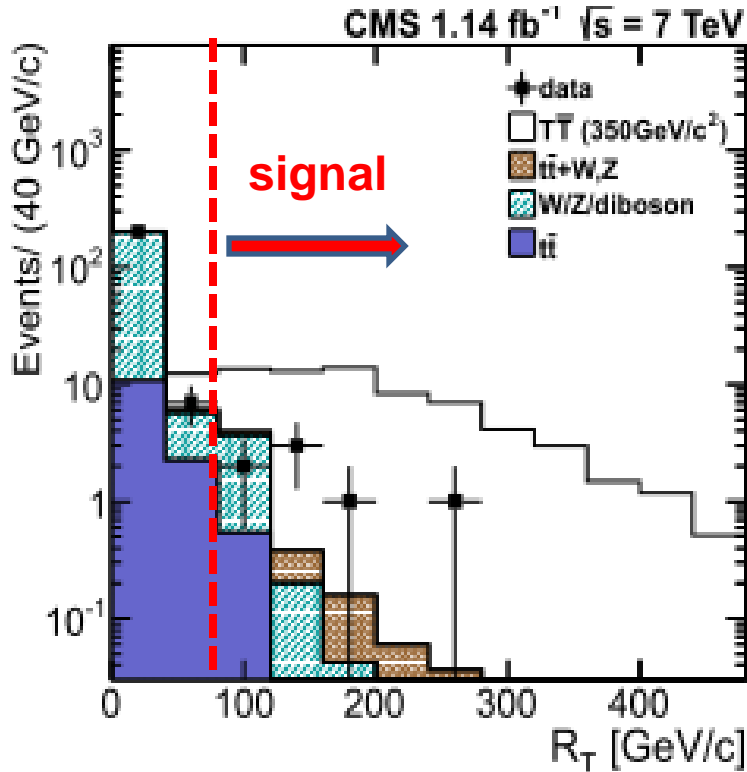


Vector-like Heavy Top $T \rightarrow tZ$

- **Vector-like charge 2/3 heavy top (T)**
- **FCNC tZ decay**
- Decay Chain: $TT \rightarrow tZtZ \rightarrow bbW+W-ZZ$
- **Signature : 3 leptons+jets**

arXiv:1109.4985v1

Cross-section upper limit translating into **T mass lower limit $M_T > 475$ GeV** for $BR(T \rightarrow tZ)=100\%$





More CMS Exotic Searches Results...

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

And in CDS: <http://cdsweb.cern.ch>

[Home](#) > [CERN Experiments](#) > [LHC Experiments](#) > [CMS](#) > Search Results: reportnumber:EXO 6531_a:Data

CMS

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Output format:

[CMS Physics Analysis Summaries](#)

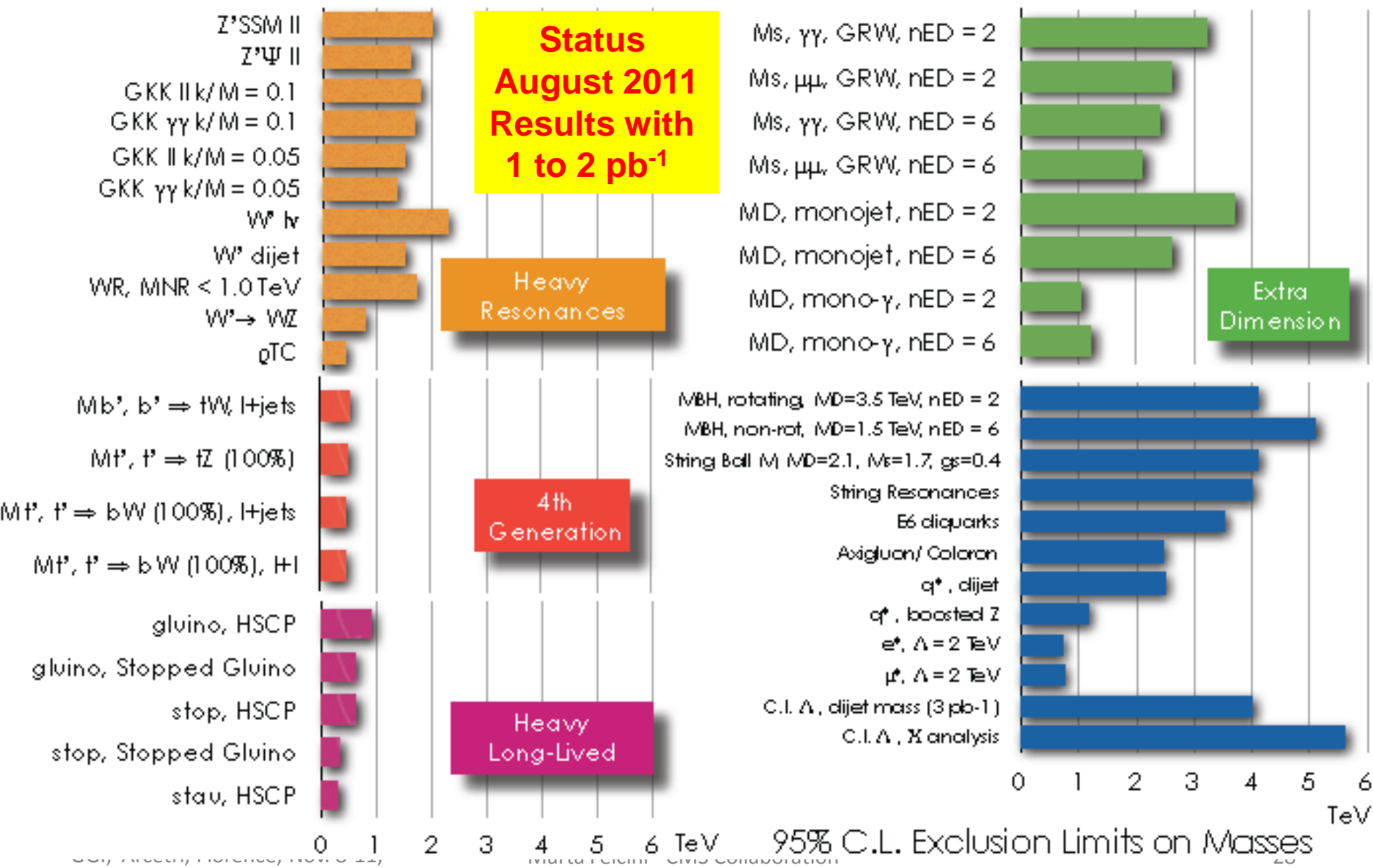
35 records found

Search took 0.03 seconds.

At present 35 Physics Analysis Summaries and much more to come with full 2011 luminosity (5/pb)



Overview of CMS Exotic Searches Results

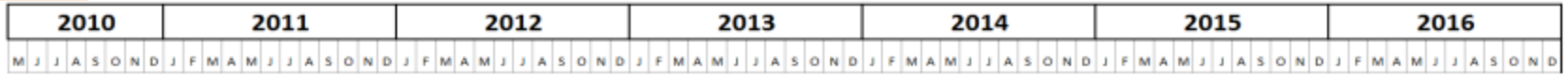


What next? LHC Plan for the next 10 years

F. Bordry
LP 2011

New rough draft 10 year plan

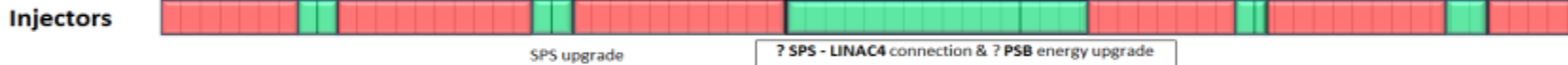
Not yet approved!



**2012
Run at
7-8 TeV**

- Machine: Splice Consolidation & Collimation in IR3
- ALICE - detector completion
- ATLAS - Consolidation and new forward beam pipes
- CMS - FWD muons upgrade + Consolidation & infrastructure
- LHCb - consolidations
- ?Cryo-collimation point

**2014 and beyond
Run at 13-14 TeV**

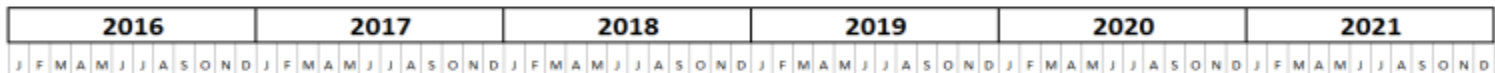


2022

LS3

Installation of the HL-LHC hardware.

Preparation for HE-LHC



X-Mas maintenance

- Machine: Collimation & prepare for crab cavities & RF cryo system
- ATLAS: new pixel detect. - detect. for ultimate luminosity.
- ALICE - Inner vertex system
- CMS - New Pixel. New HCAL Photodetectors. Completion of FWD muons upgrade
- LHCb - full trigger upgrade, new vertex detector etc.

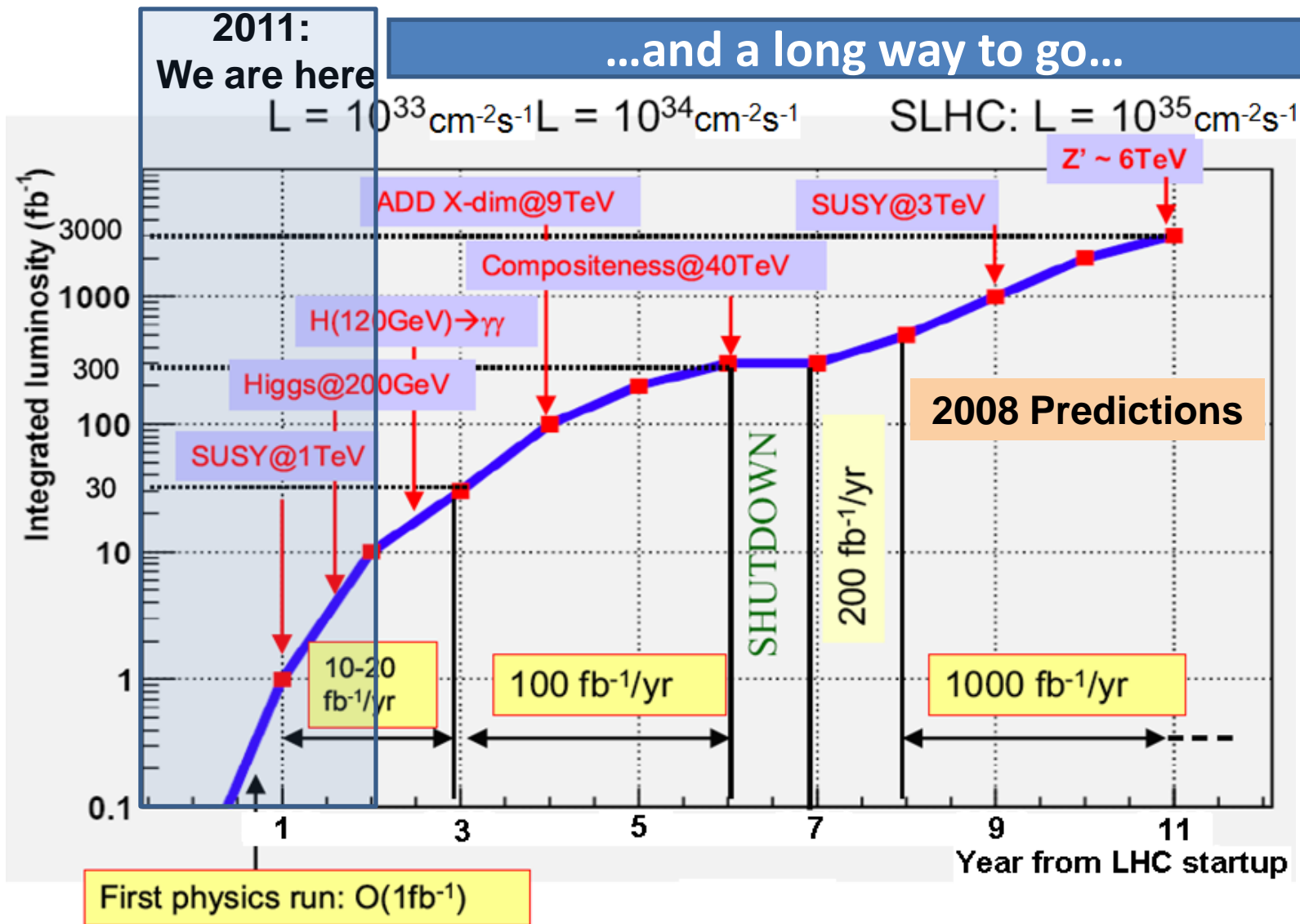
X-mas maintenance

X-mas maintenance

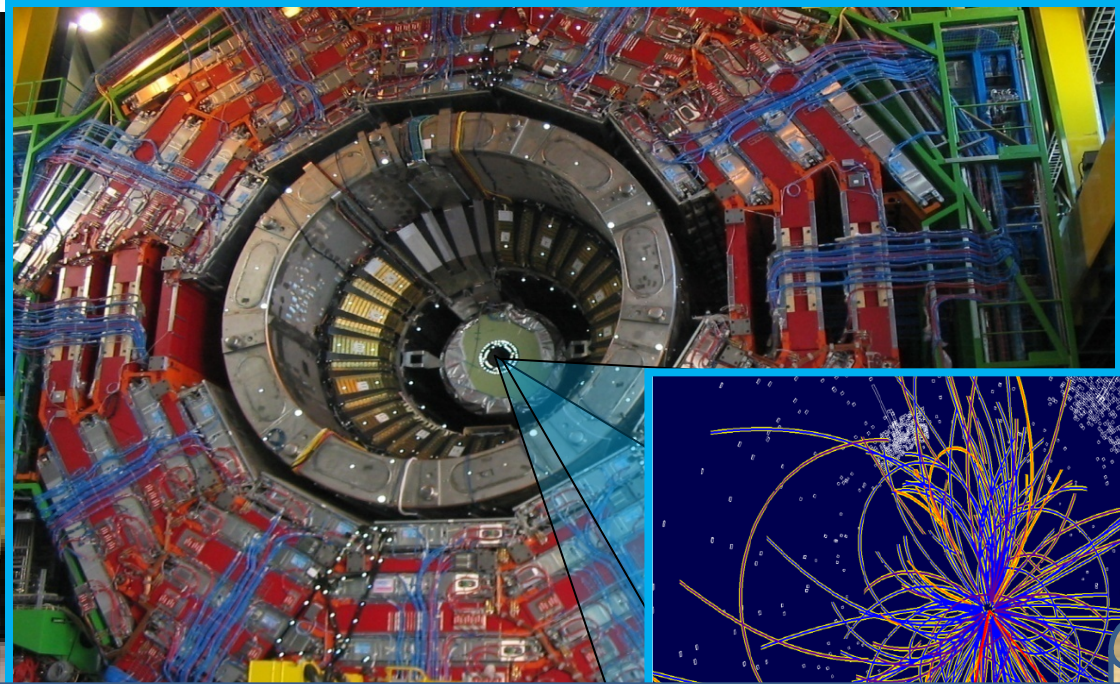




No Discovery Yet? No reason to panic...



Epilogue



*Misura ciò che è misurabile, e
rendi misurabile ciò che non lo è.*

**Measure what is measurable, and
make measurable what is not so.**

Galileo Galilei



Thank You

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