Searches for Exotic Phenomena with the CMS Experiment

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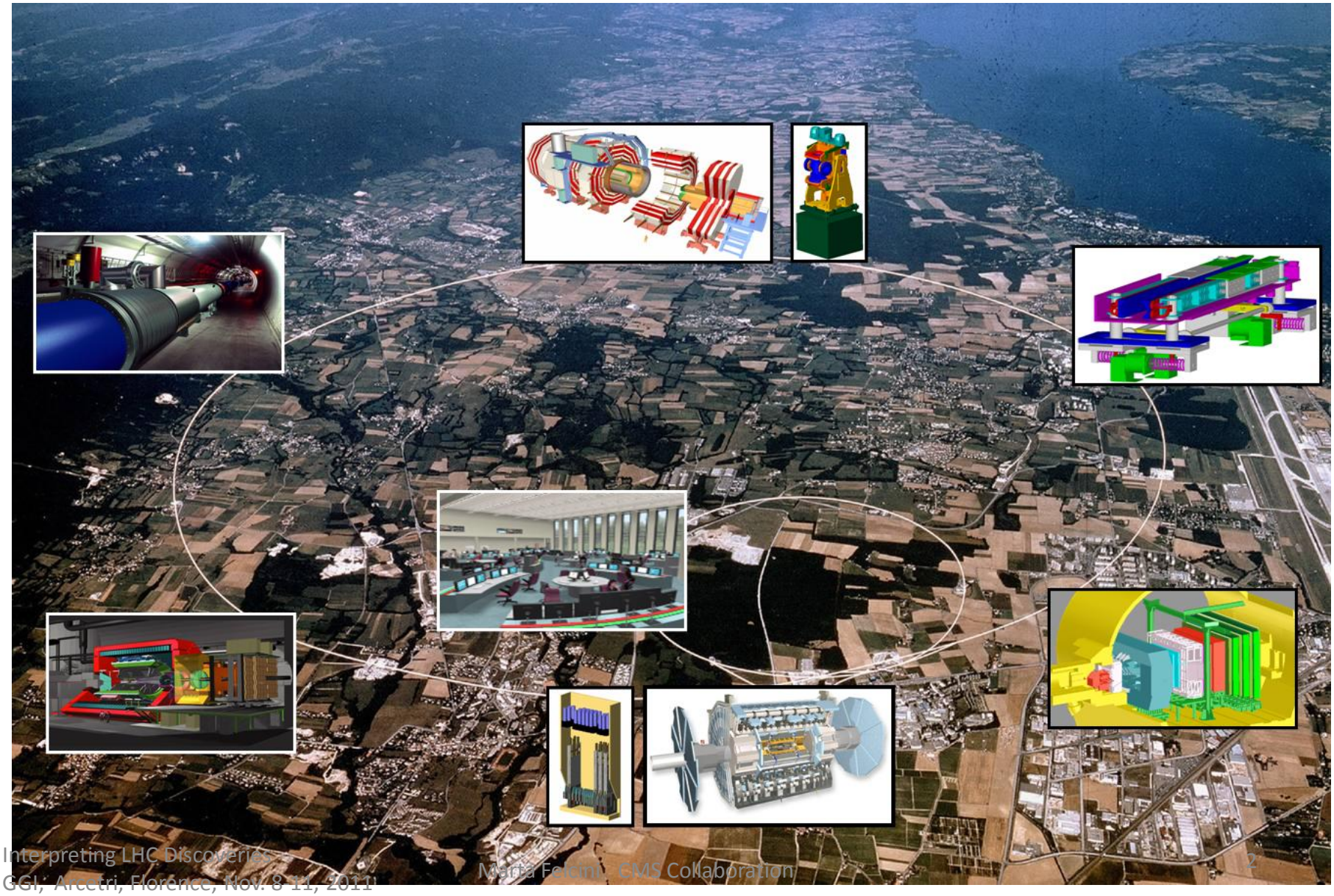
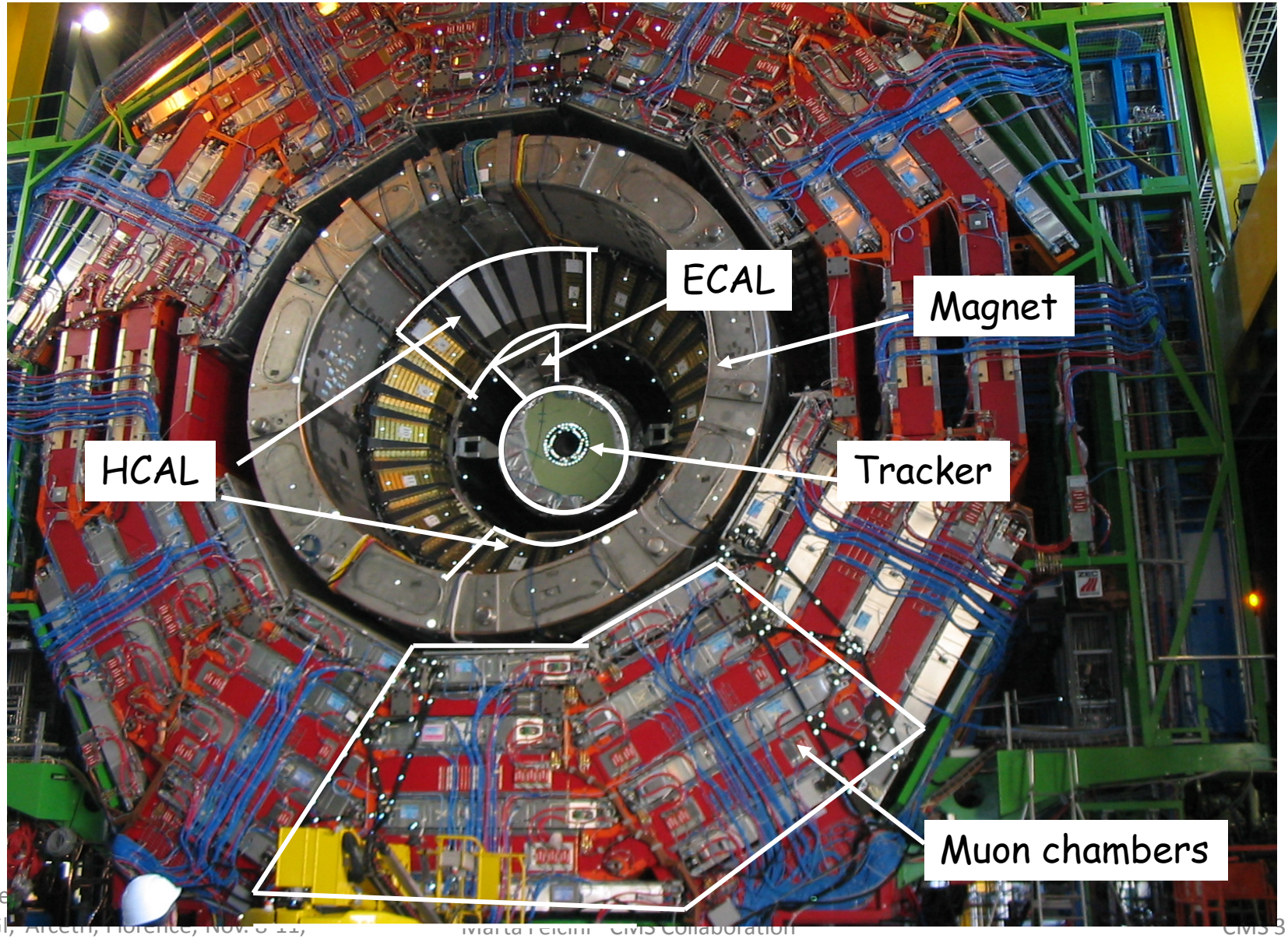
on behalf of the
CMS Collaborations

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

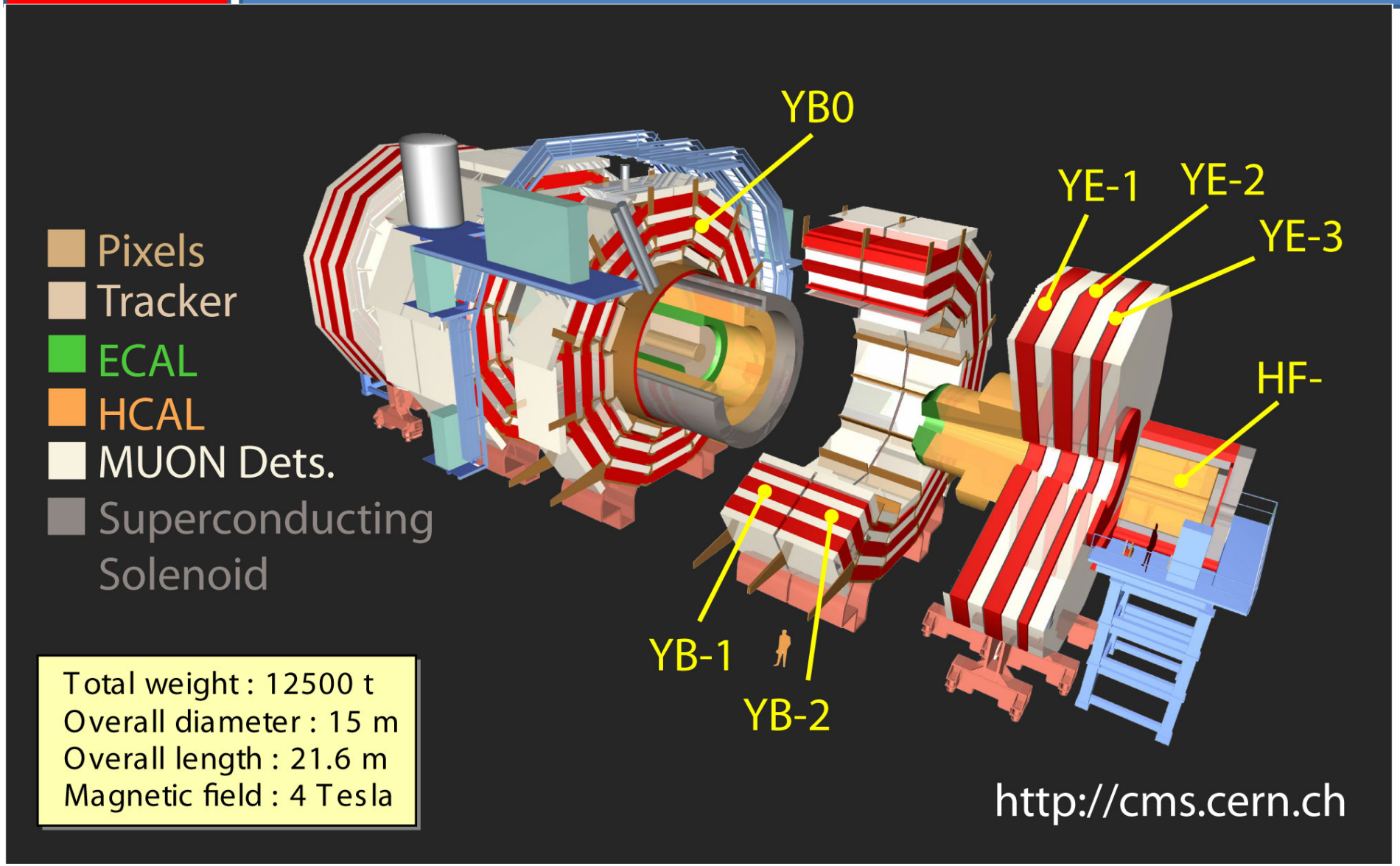
LHC Accelerator and Detectors



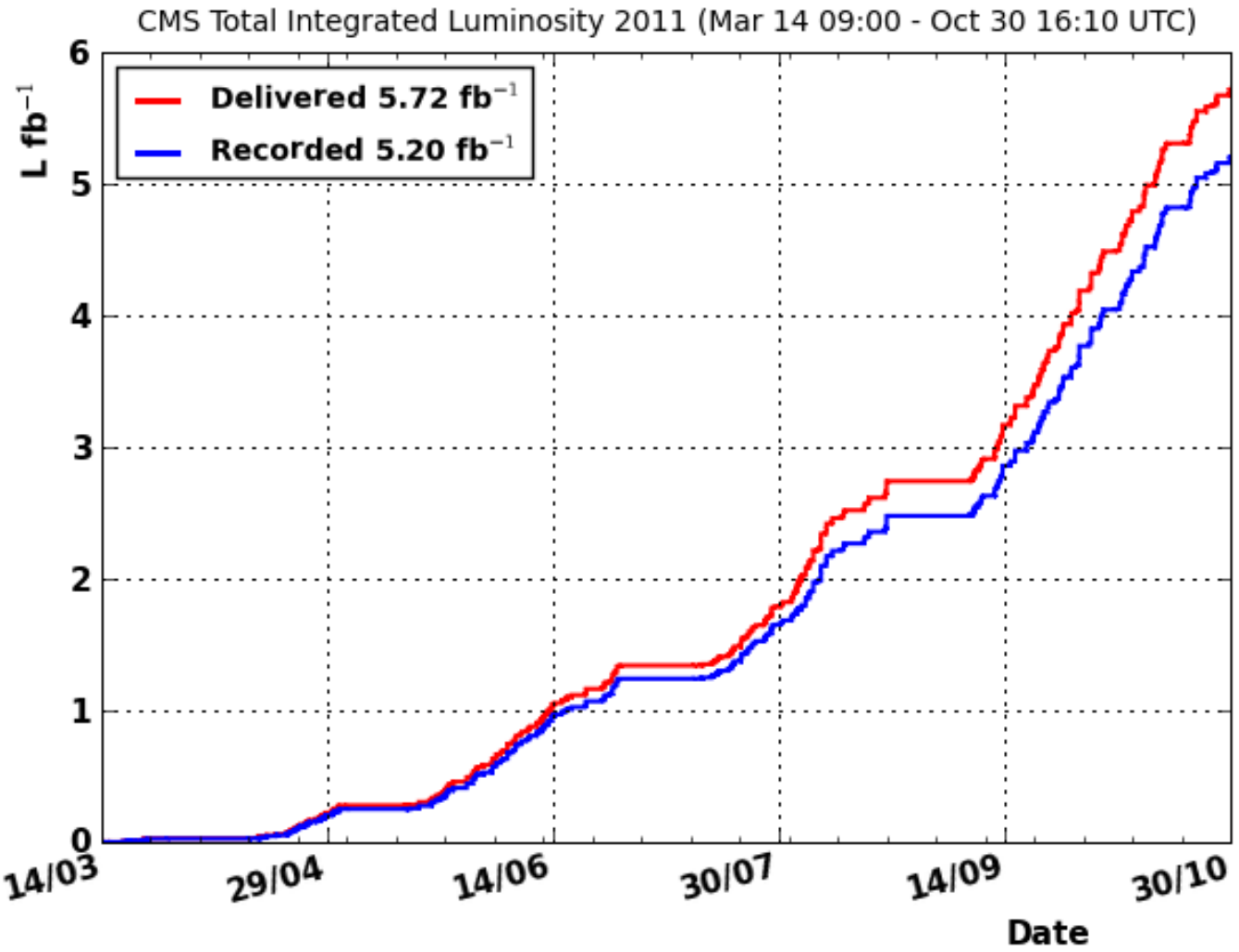
The CMS Detector



Exploded View of CMS

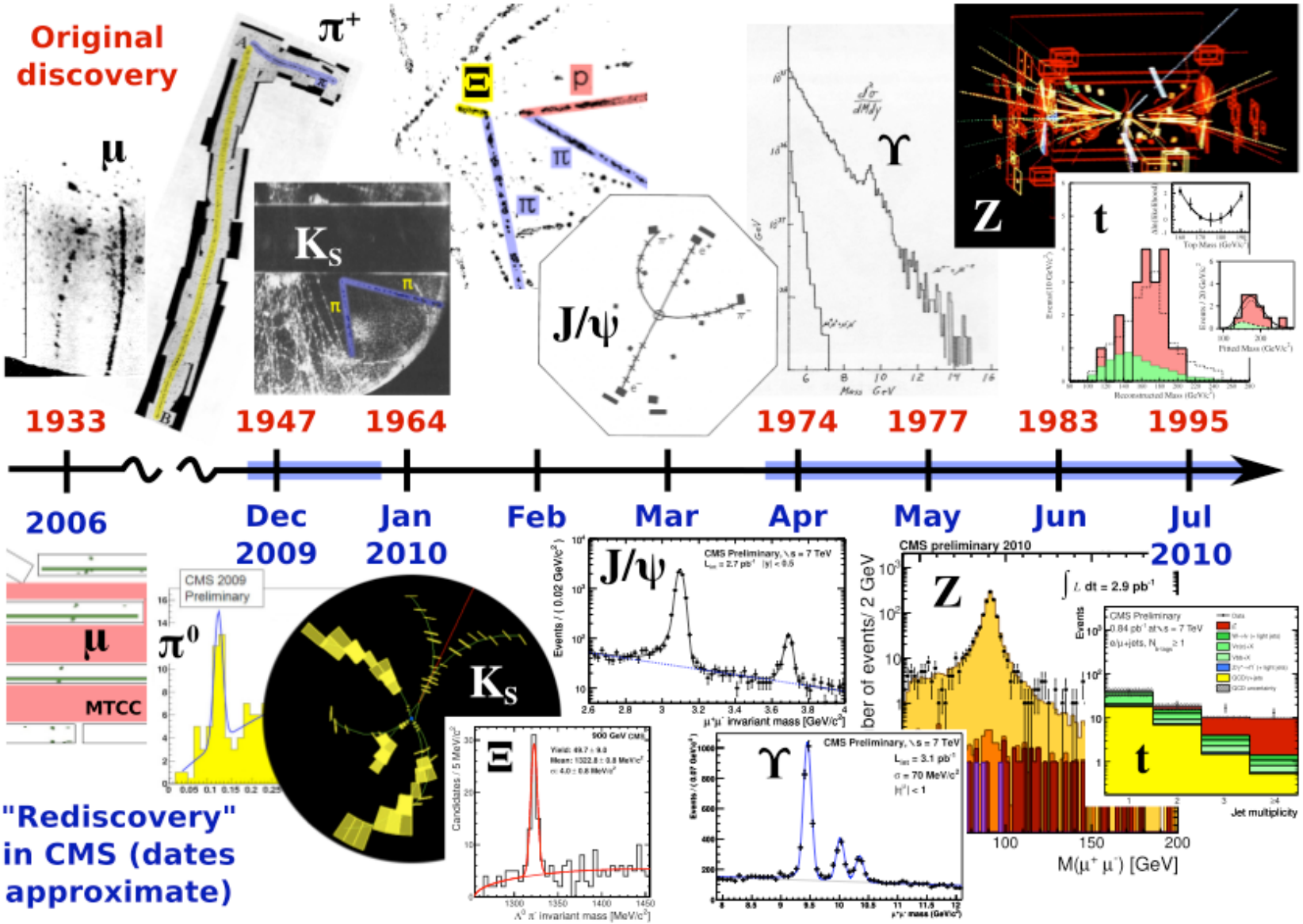


CMS Integrated Luminosity in 2011



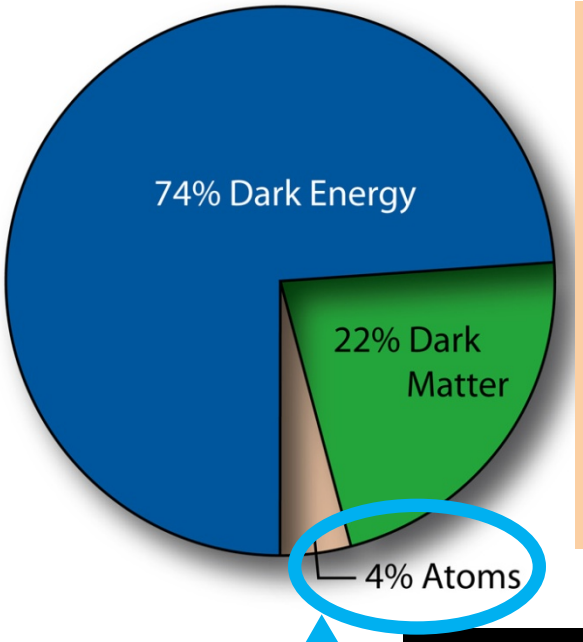
https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

Standard Model re-established at 7 TeV

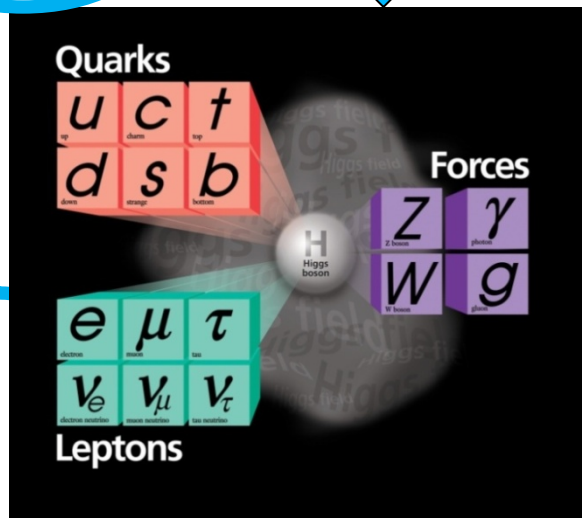


Biggest Evidence for BSM Physics

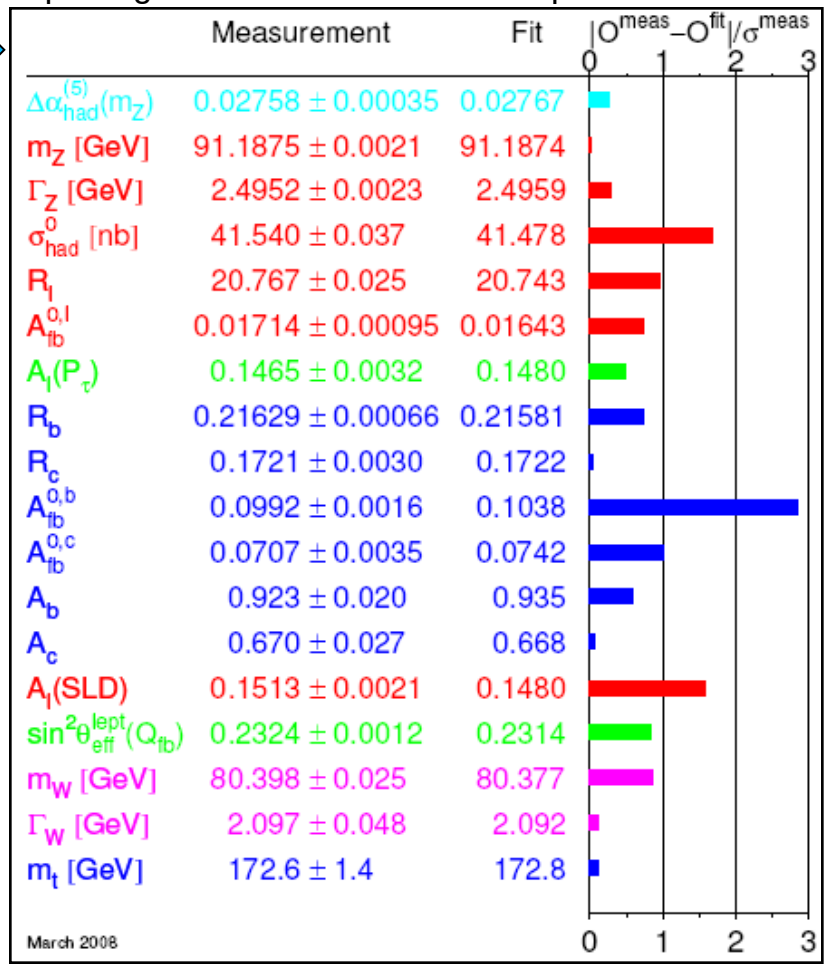
Credit: NASA / WMAP Science Team



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

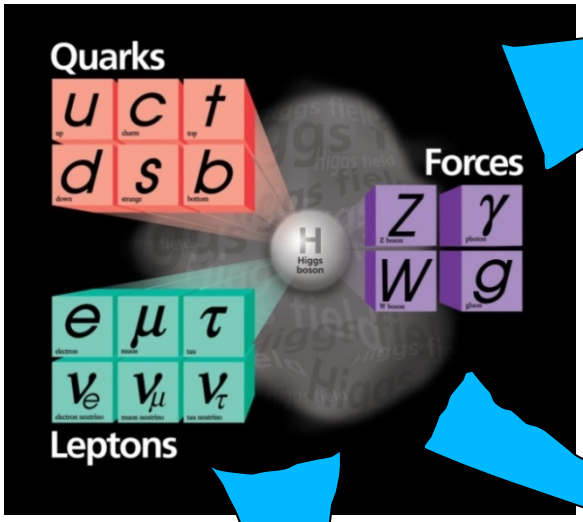


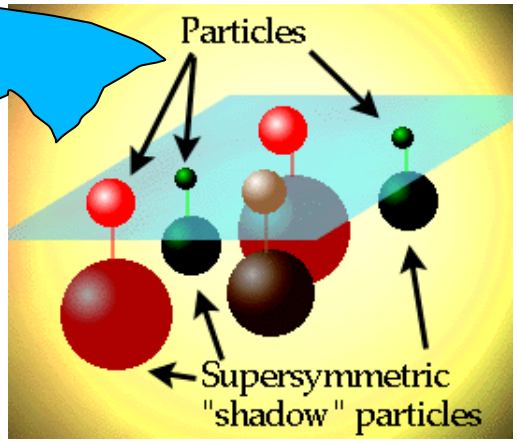
http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2011

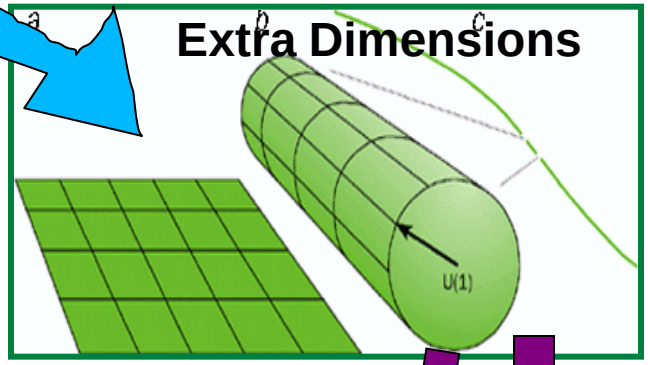


Good news!!!
Lots more to discover…

Beyond the Standard Model



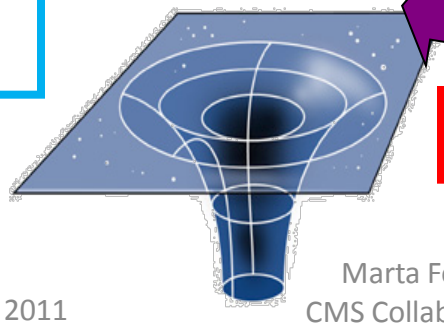




Extended Gauge Symmetries, Fourth generation, Little Higgs,...

Z',W',b',t',ν',l',...

Black Holes



Graviton

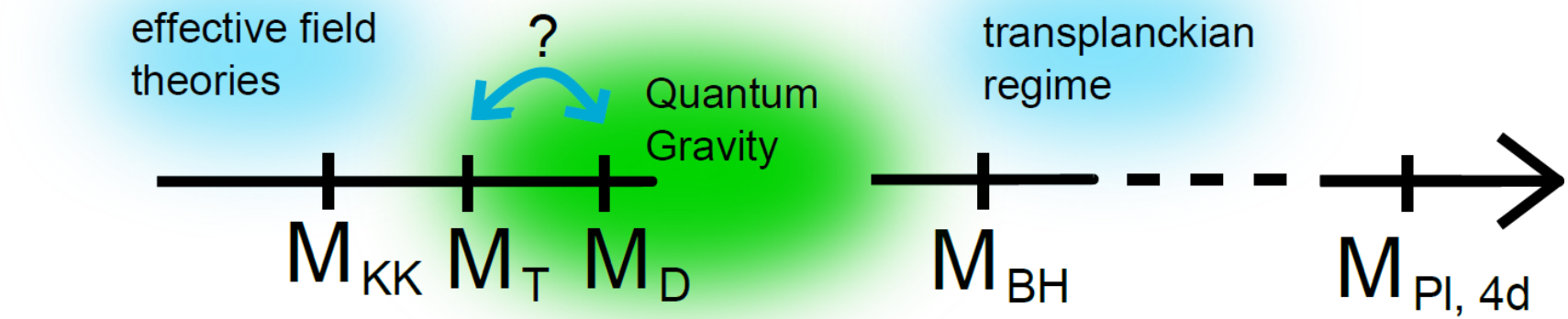
Many possible BSM directions…

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

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

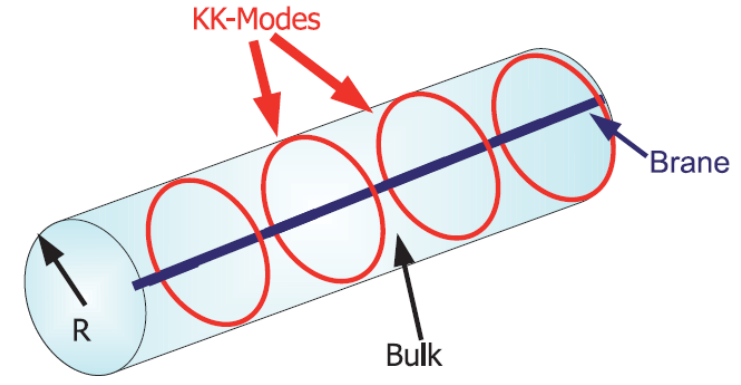
multijet based search

S. A. Schmitz, 2011

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 $[\Lambda_T]$

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

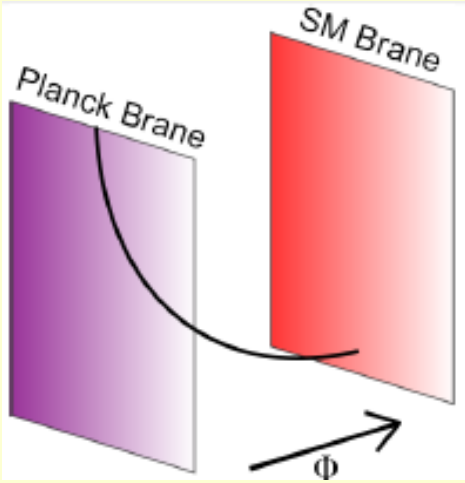
3) J. Hewett $[\eta_G]$

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



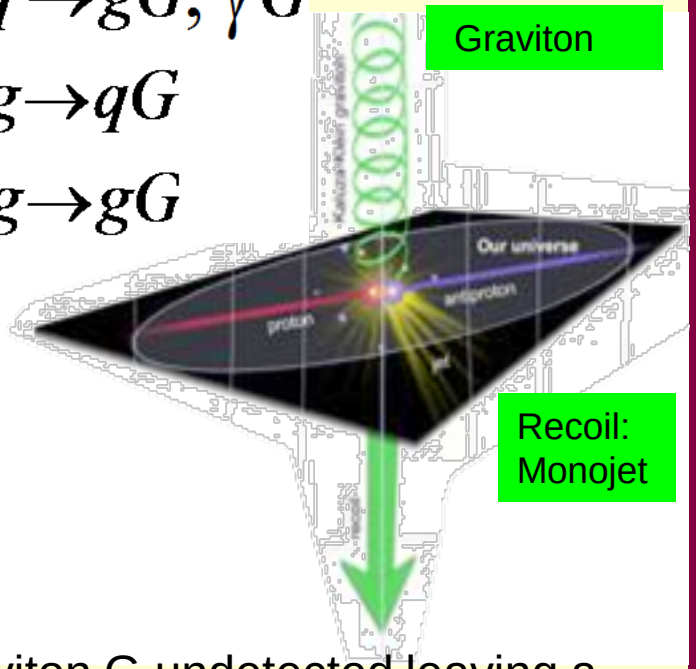
Exp.tal results interpreted in terms of

- graviton mass M_1
- coupling parameter $\tilde{k} \equiv k/\overline{M}_{Pl}$

Extra Dimensions Phenomenology

Graviton Emission

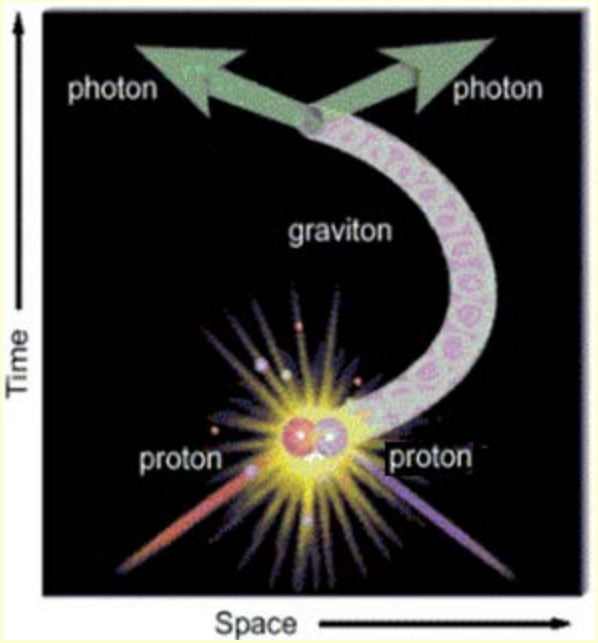
$$q\bar{q} \rightarrow gG, \gamma G$$
$$qg \rightarrow qG$$
$$gg \rightarrow gG$$



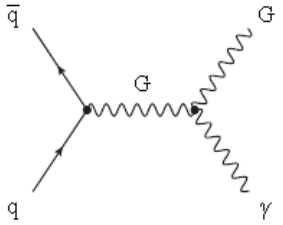
Graviton G undetected leaving a final state gluon, quark.or photon.
Signature:
single jet or photon + missing E_T.

Graviton Exchange

Single G → narrow resonance
Multi KK states→ broad enhancement
in $\gamma\gamma$, e^+e^- or $\mu^+\mu^-$ mass distributions

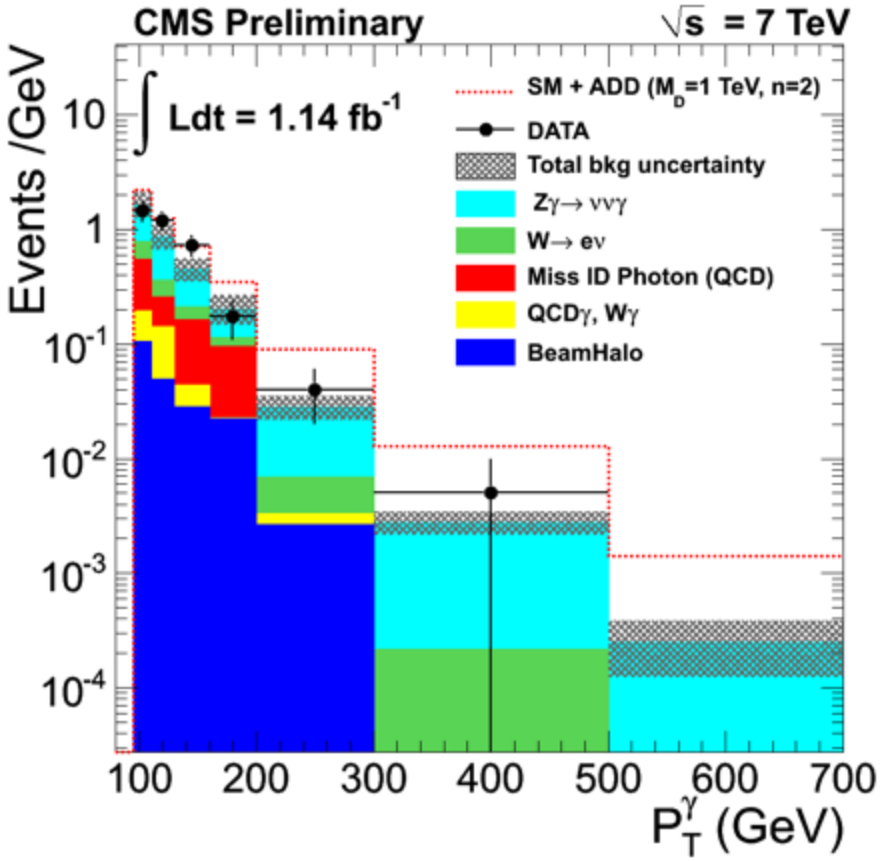


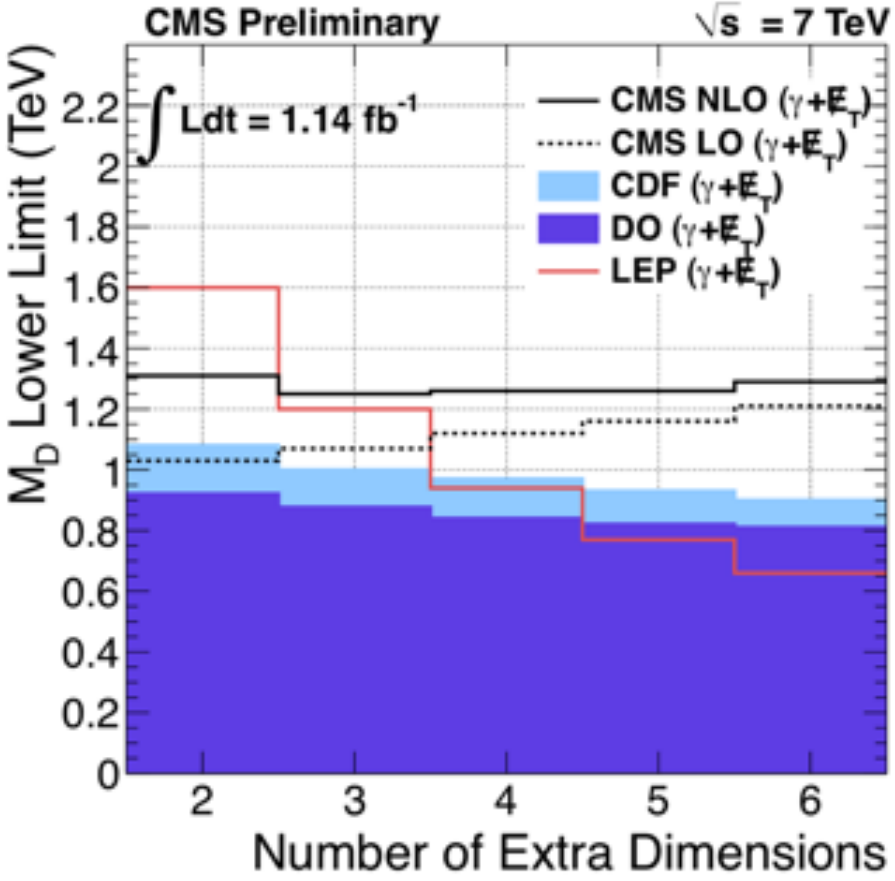
Single photon + missing E_T



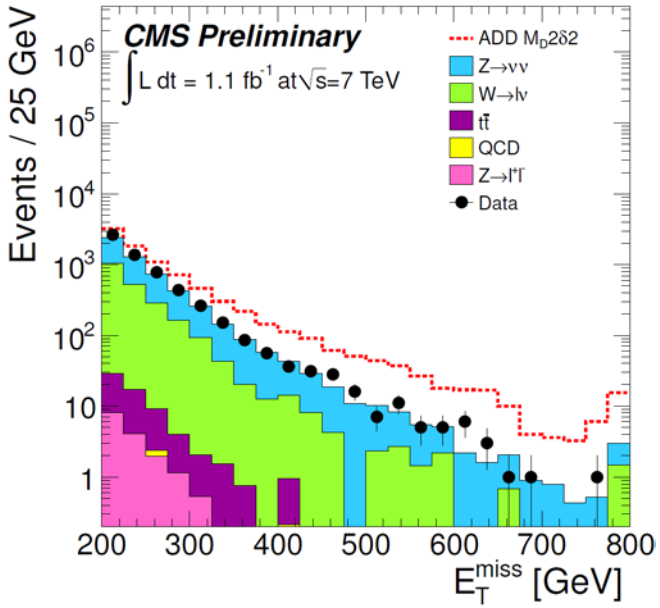
Search for an excess of events in photon high pT distribution

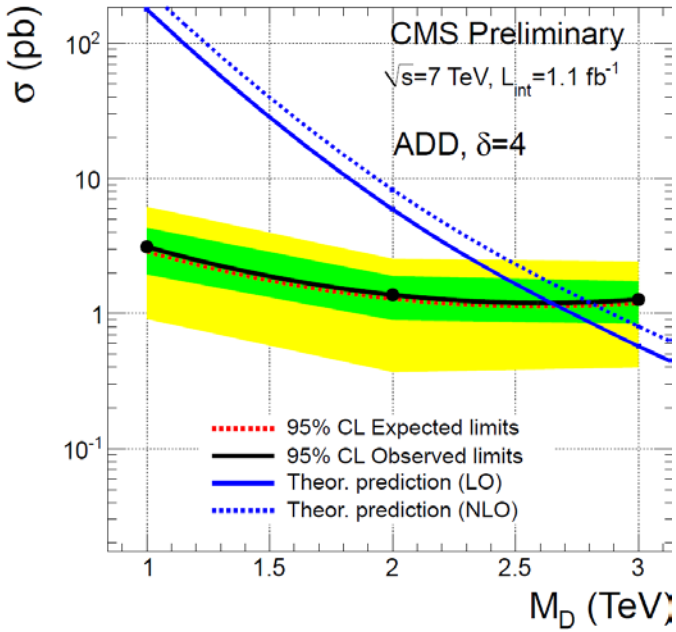
CMS PAS EXO-11-058



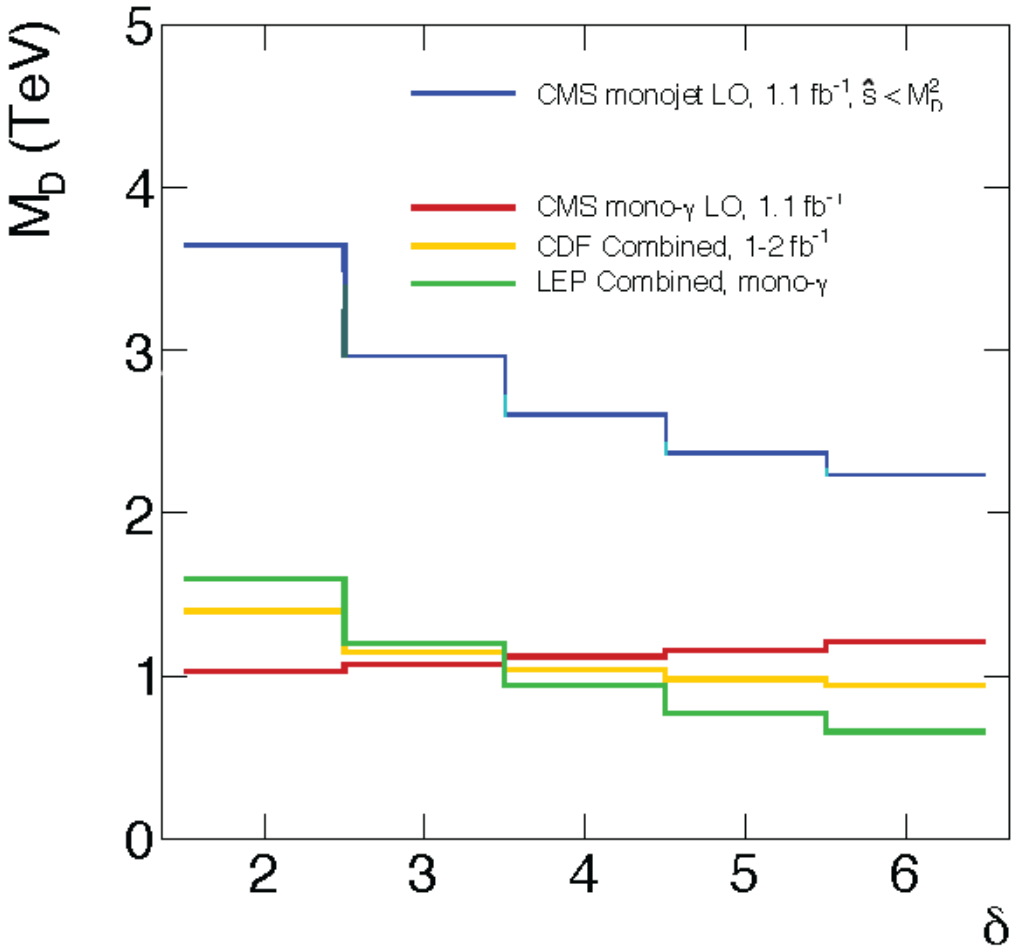


Single jet + missing E_T

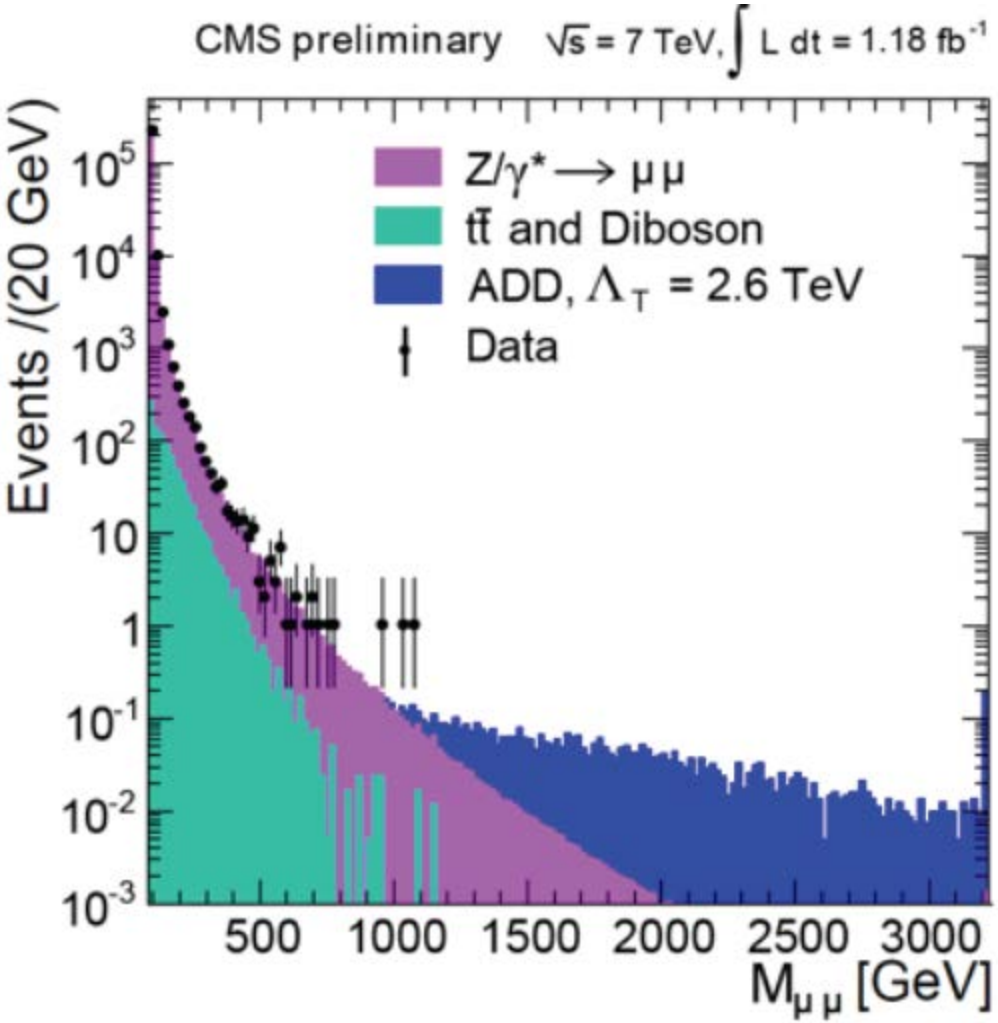




CMS PAS EXO-11-059



Non-resonant μμ and γγ



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

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

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

Lower limit on M_S (TeV)

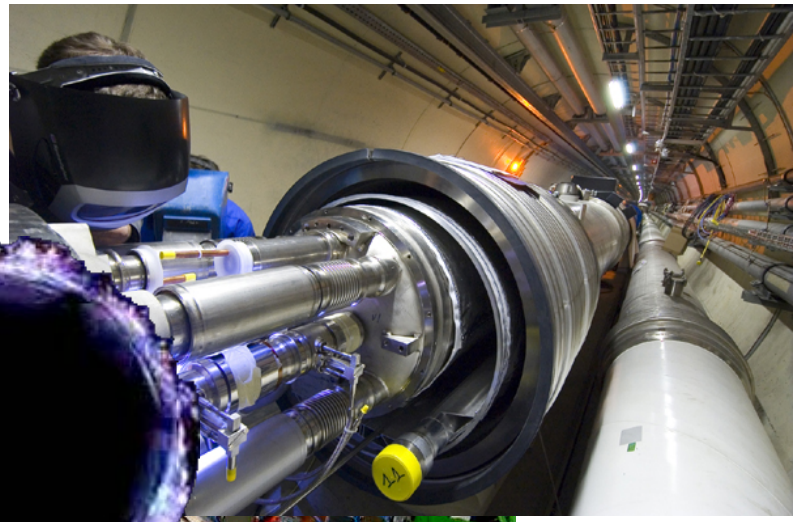
	n = 2	n = 3	n = 4	n = 5	n = 6	n = 7
μμ	2.6	3.1	2.6	2.3	2.1	2.0
γγ	3.2	3.4	2.8	2.6	2.4	2.2

μμ **CMS PAS EXO-11-039**

γγ **CMS PAS EXO-11-038**

Black Holes

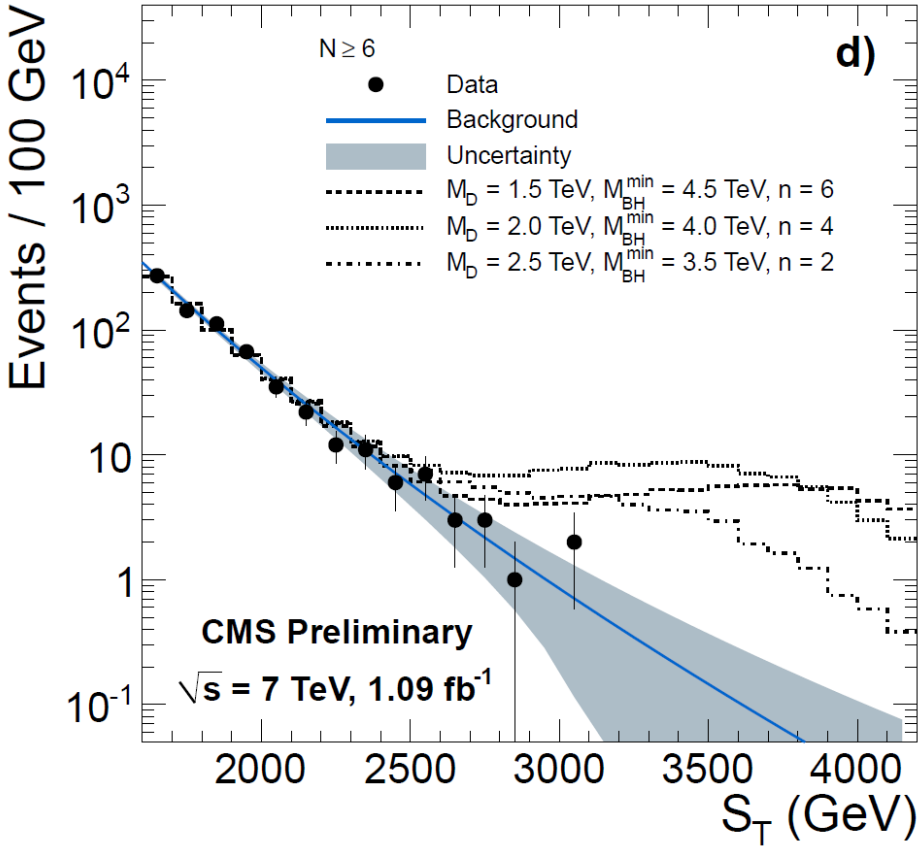
- **Reduced Planck mass scale due to large EDs → increased Schwarzschild radius → immediate decay due to Hawking radiation**
- **Large cross-sections O(100 pb)**
- **Signature: events with high particle multiplicities and high transversal momentum**

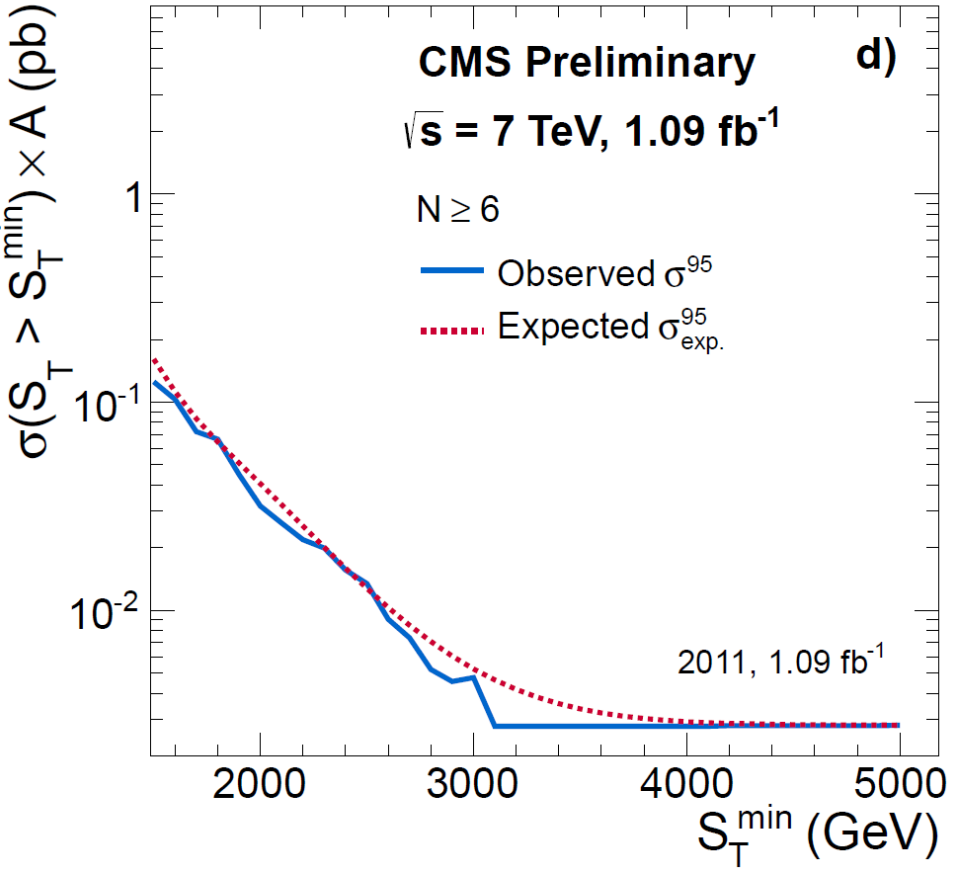


Stephen Hawking visiting CMS

Black Holes Searches

CMS: PAS EXO-11-071



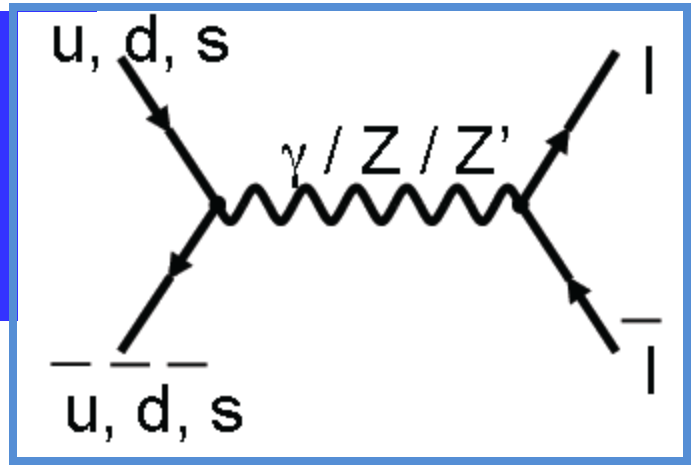


Upper Limits (evt count) as a function of
S_T = sum of transverse momenta
N = reconstructed object multiplicity

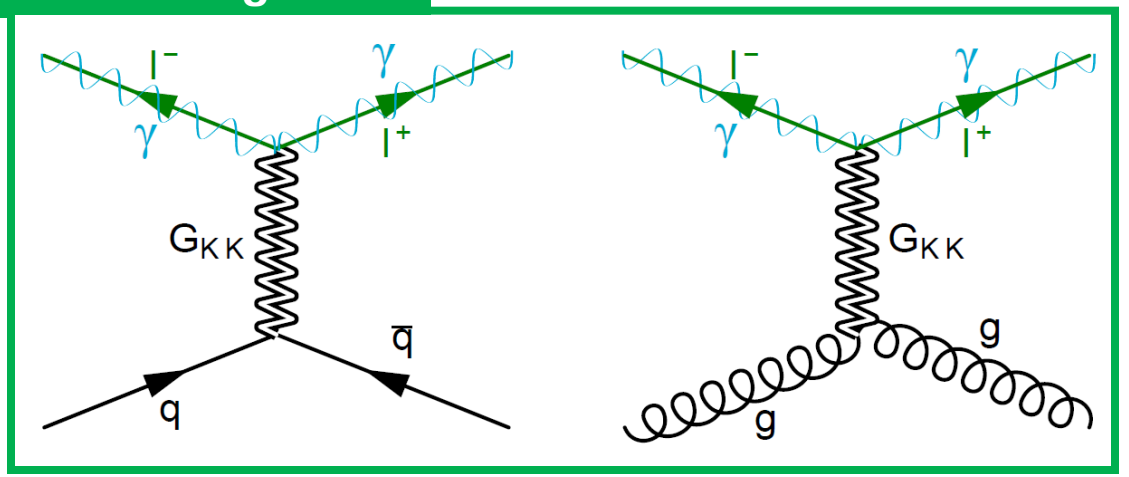
Search for Heavy Resonances

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

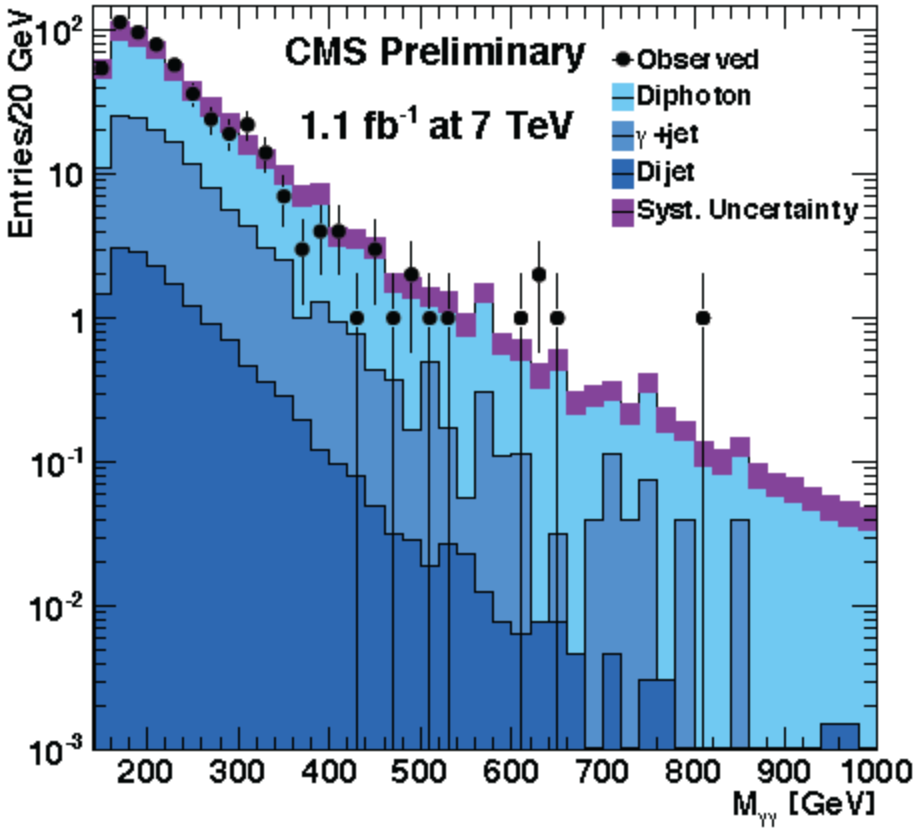
…



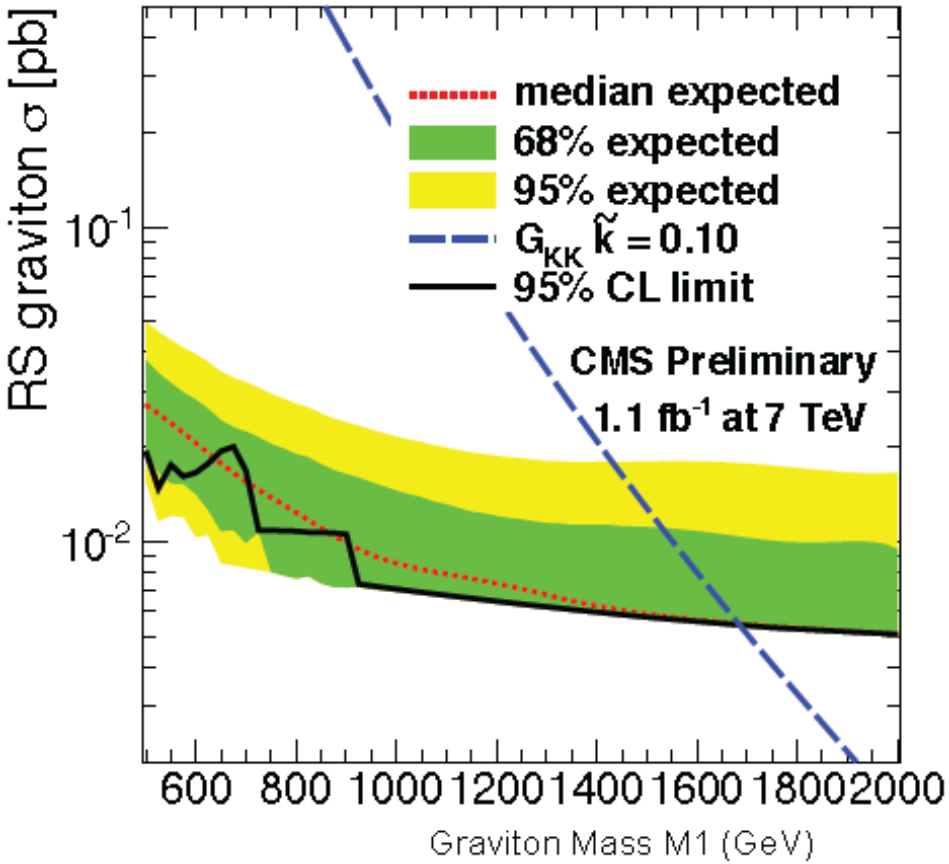
Extra Dimensions Models
- RS Kaluza Klein Graviton Exchange



Diphoton Resonances

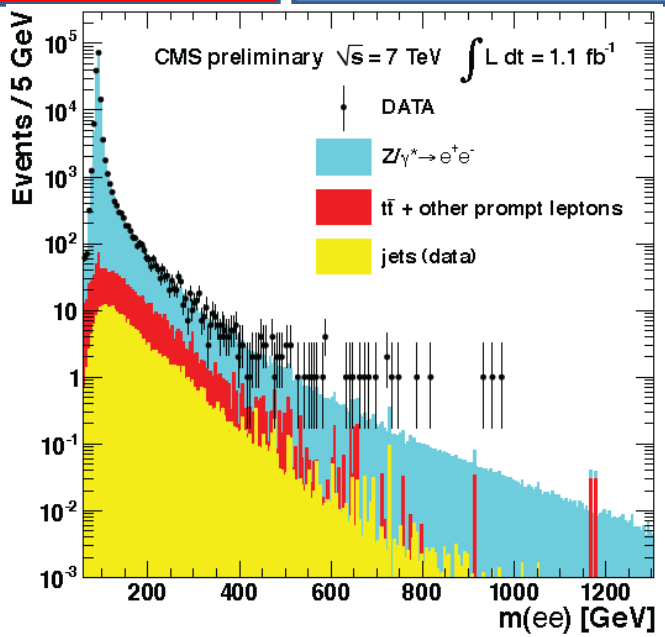


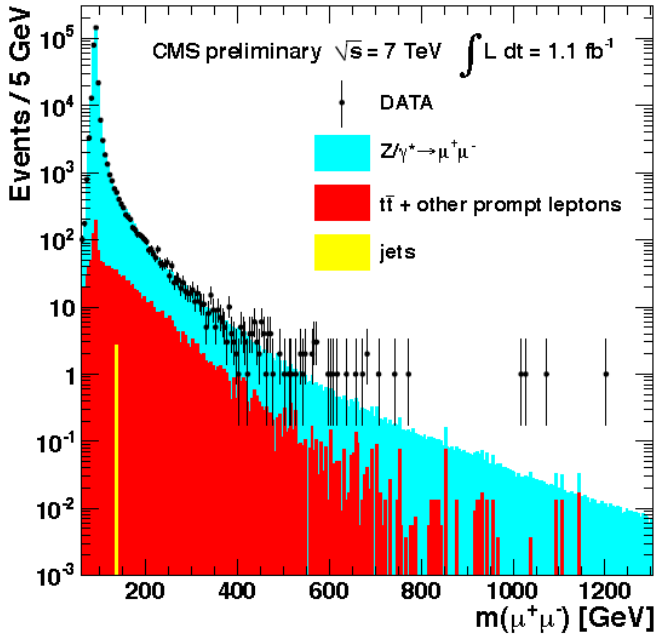
CMS: PAS EXO-11-038



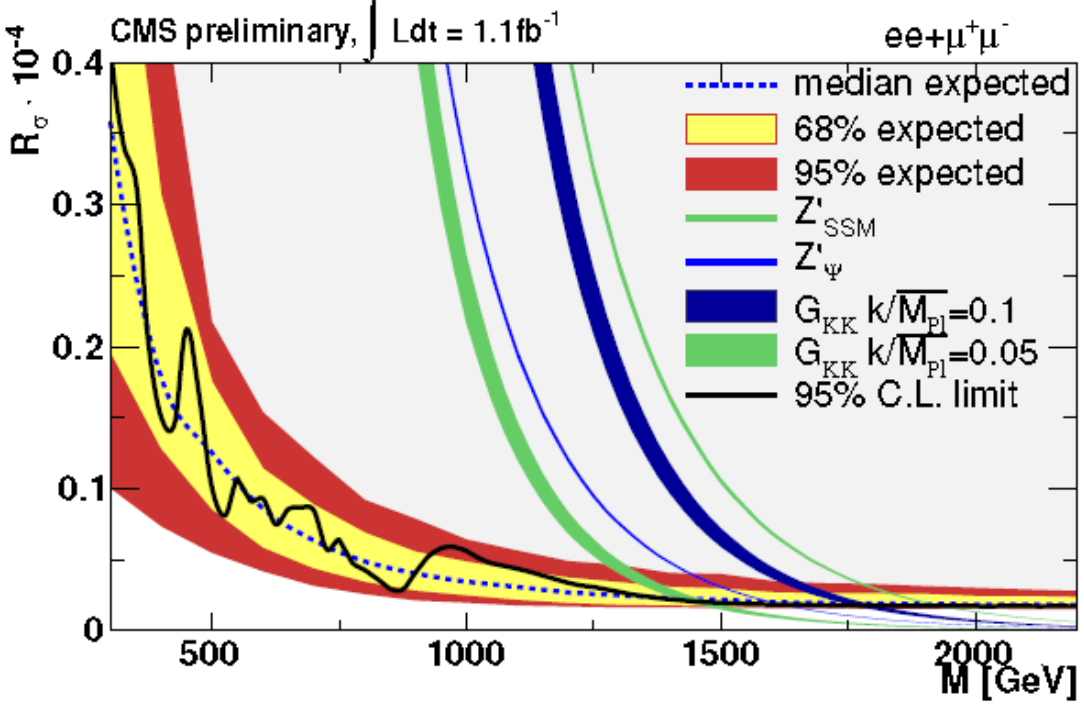
RS KK Graviton k/M_{Pl}	Mass Limit (TeV)
0.05	1.36
0.10	1.68

Dilepton Resonances





CMS: PAS EXO-11-019

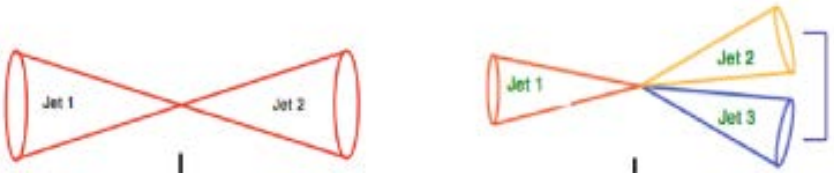


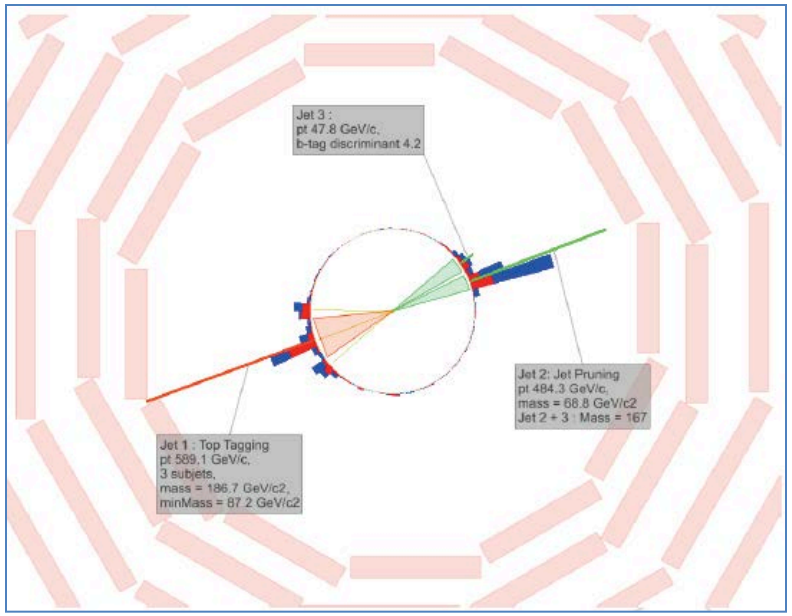
Signal	Mass Limit (TeV)
RS KK Gravitons, k/M_{Pl} = 0.05-0.1	1.45 - 1.78
Sequential Standard Model Z'_{SSM}	1.94
Super-String inspired models, Z'_ψ	1.62

Top Pair Resonances

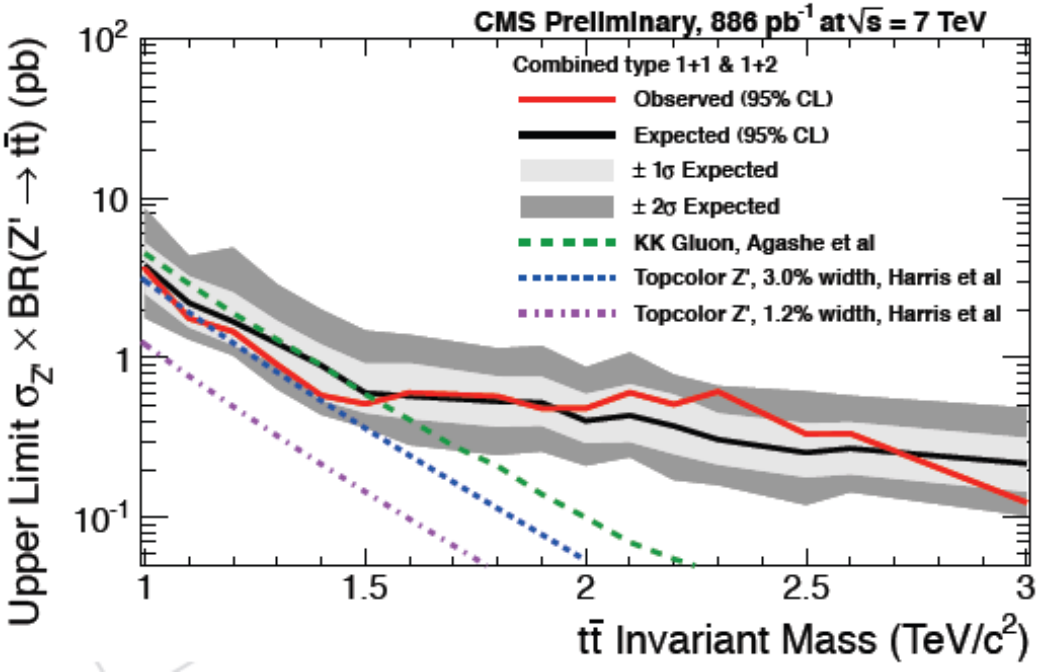
Search in the all hadronic decay channel for top pair
Tops are boosted for high mass particle, jets merge
Use fat jet algorithms and apply jet pruning to find sub-jets

CMS PAS-EXO-11-006



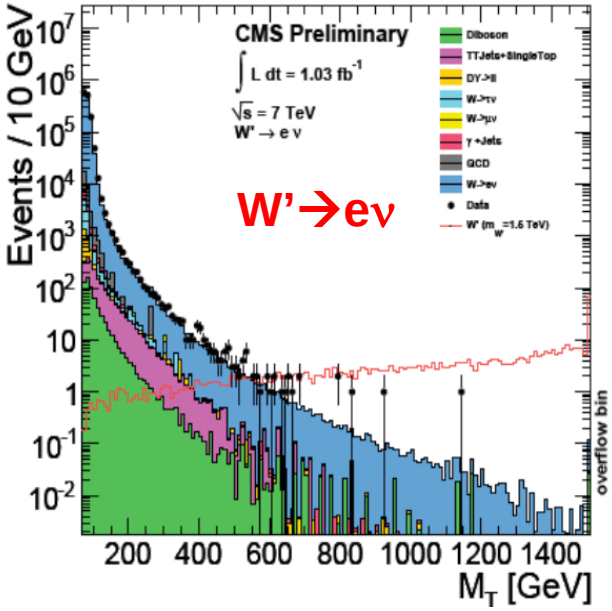


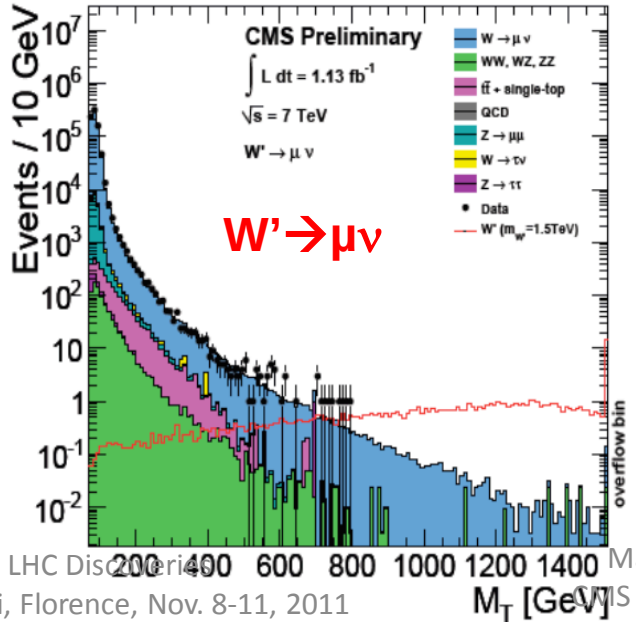
Exclude KK-Gluons 1<M<1.5 TeV



Heavy W-like Vector Bosons

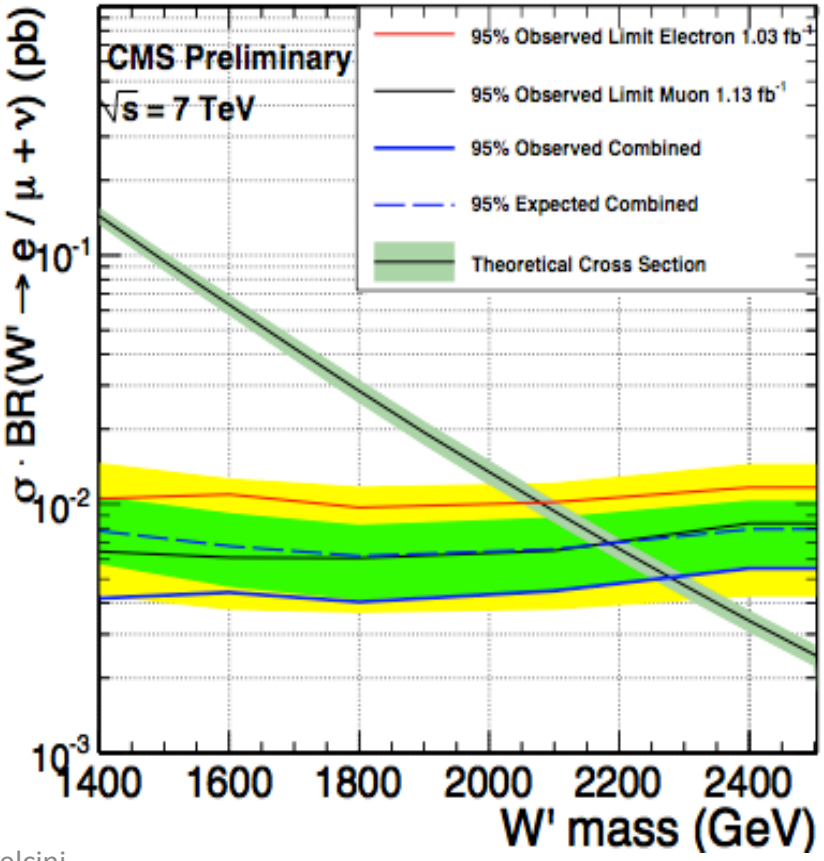
Look for Jacobian peak in transverse mass



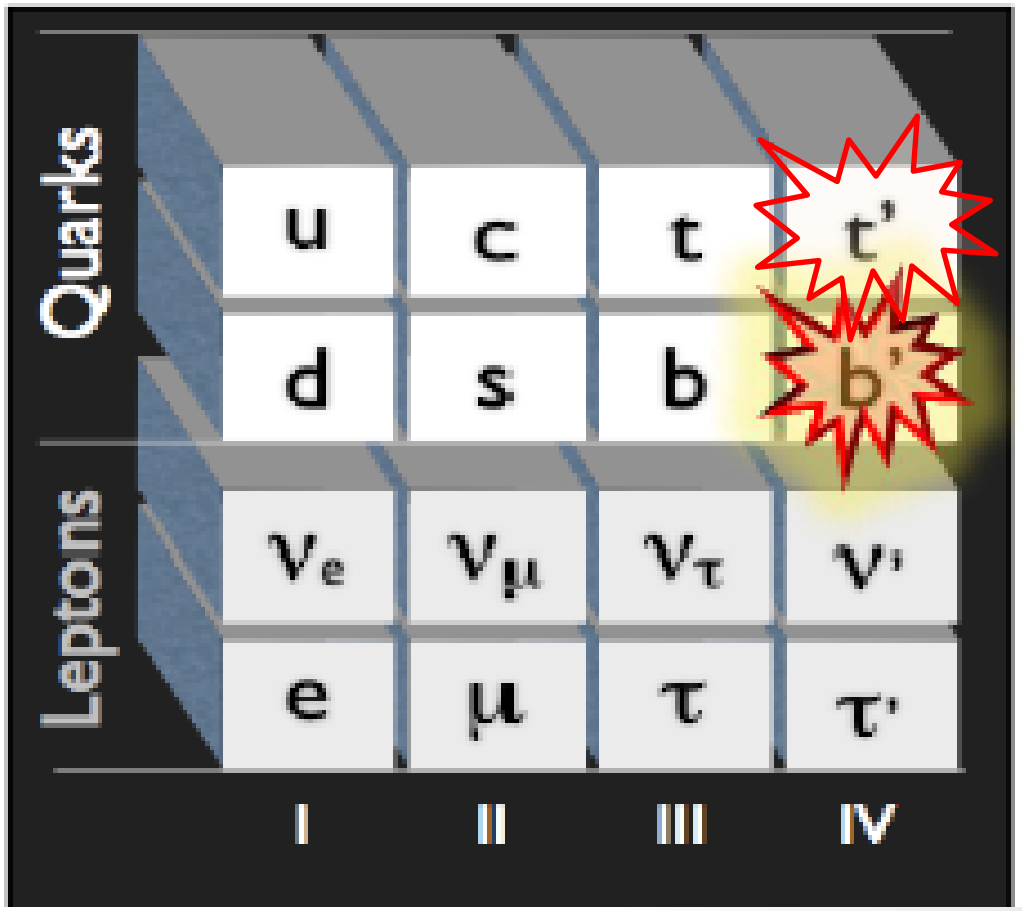


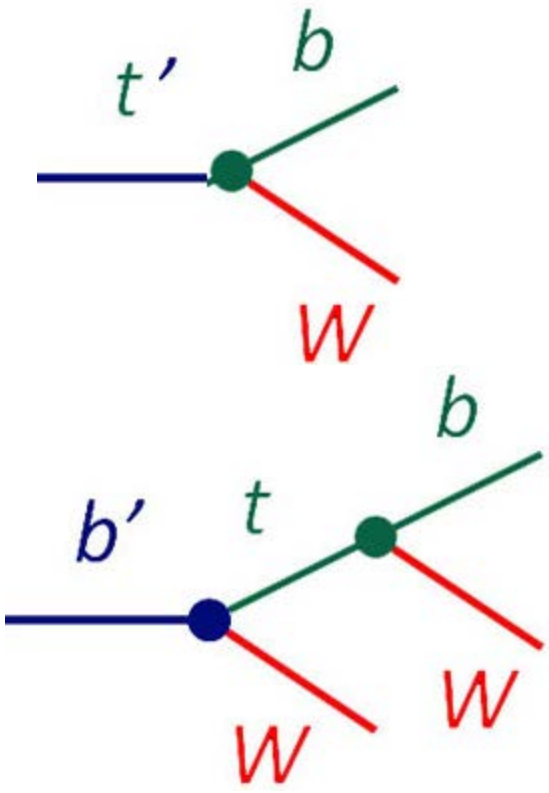
CMS: PAS EXO-11-024

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



Fourth Generation Search



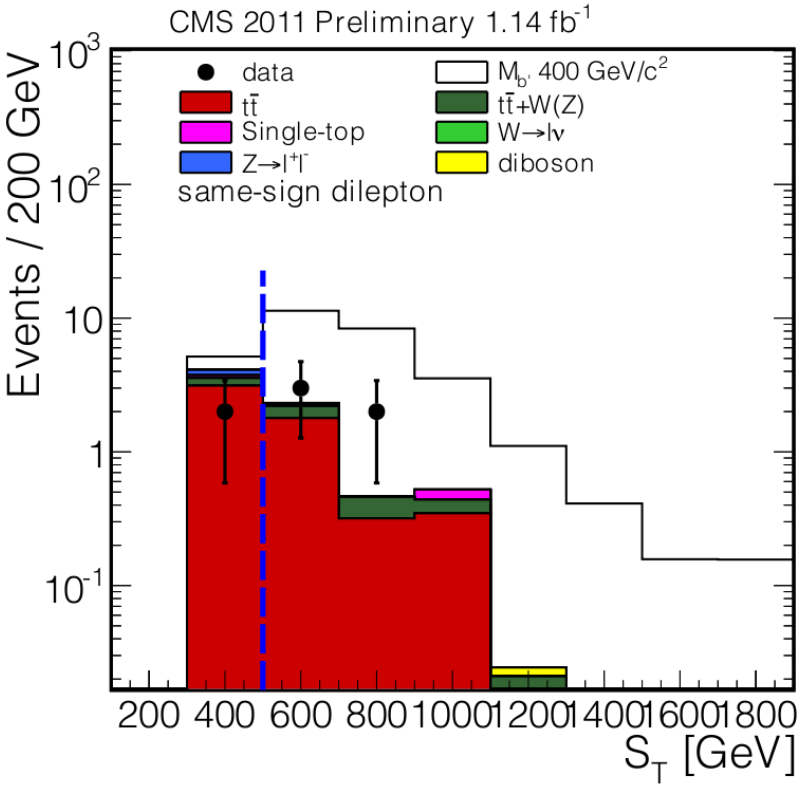


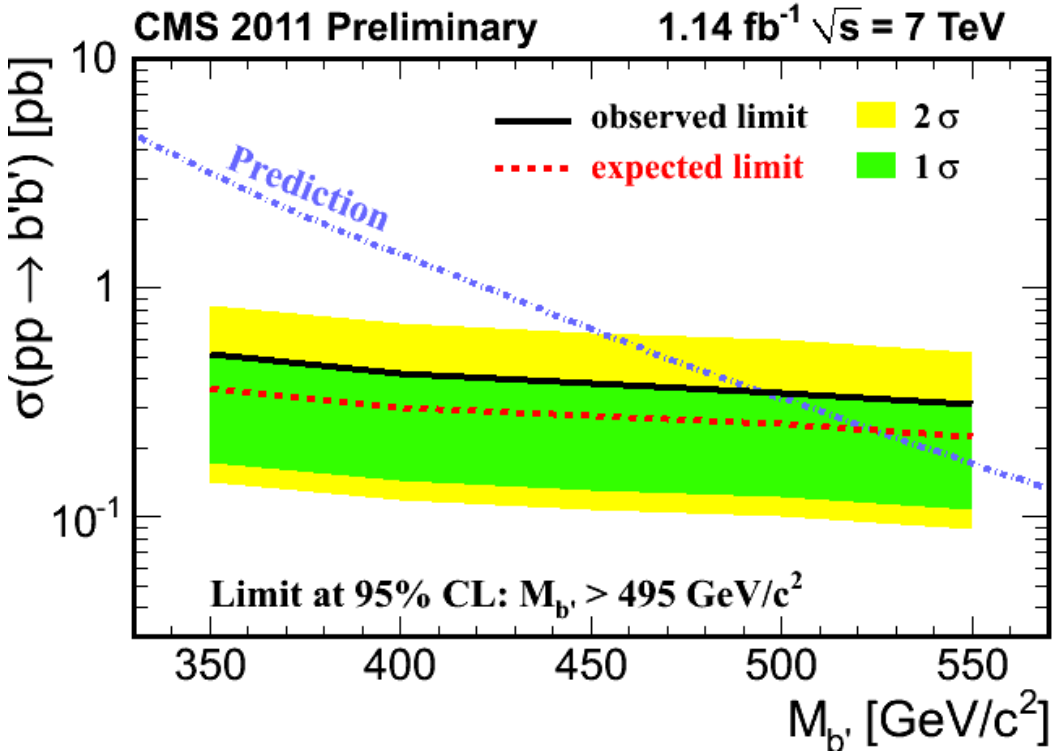
Heavy Bottom-like Quark b'→ t + W

- b'b' pair production
- BR(b'→tW) = 100%
- Decay : b'b'→tWtW→**bbW+W-W+W-**
- **Same sign dileptons or trileptons**

CMS PAS EXO-11-036

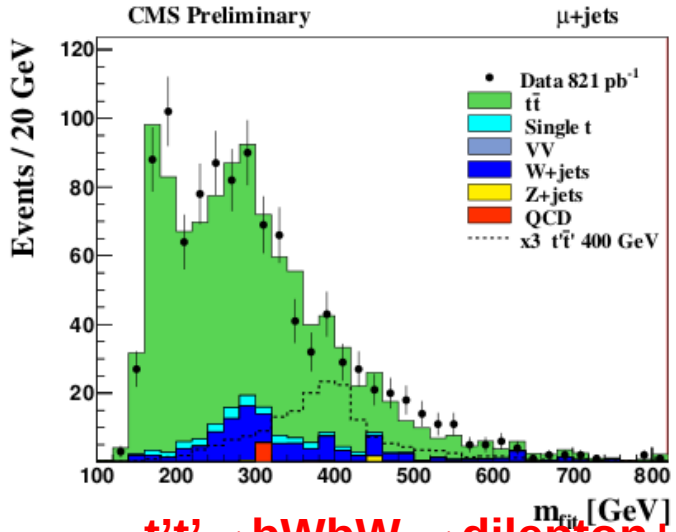
Cross-section upper limit translating into **b' mass lower limit $M_{b'}$>495 GeV for BR(b'→ tW)=100%**



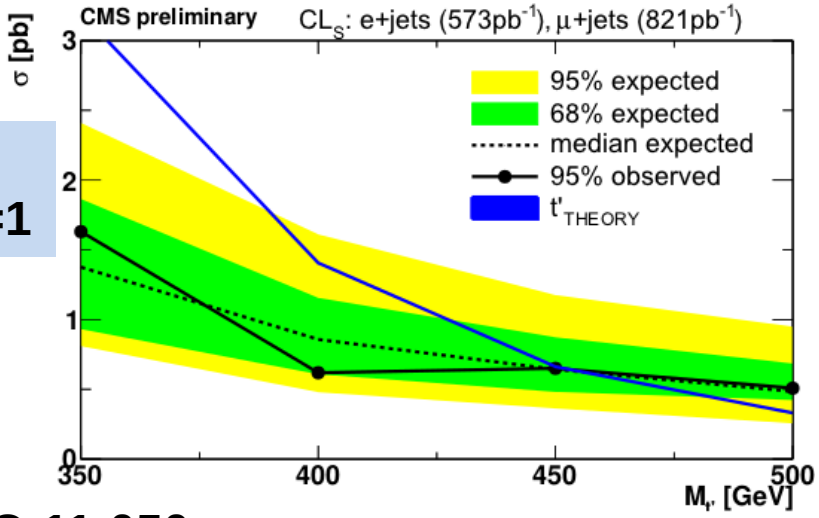


Heavy Top-Like Quark t'→b+W

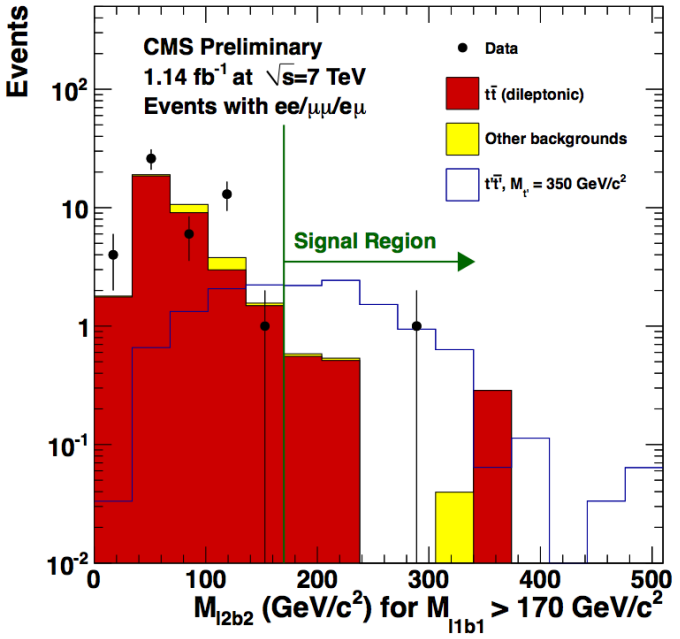
t't'→bWbW→lepton+jets CMS PAS EXO-11-051



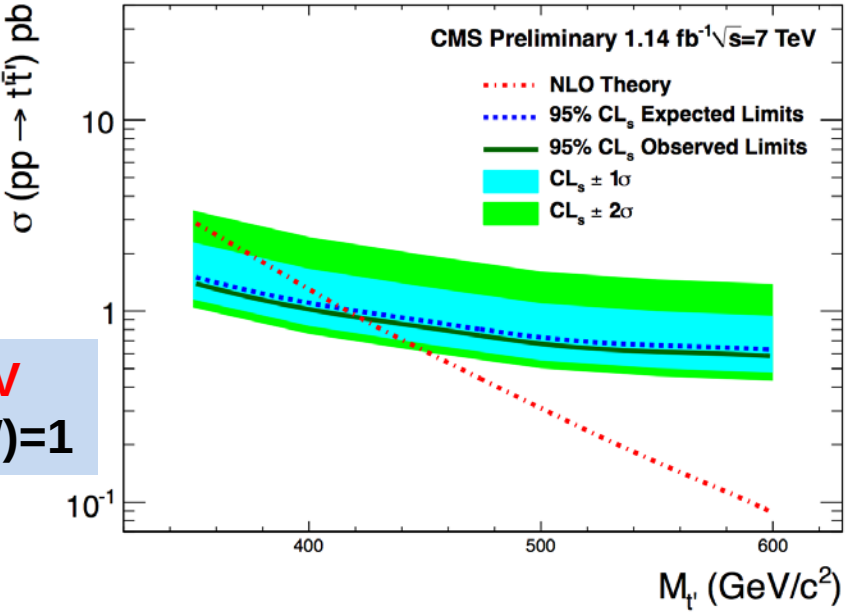
m(t') > 450 GeV
for BR(t'→ bW)=1



t't'→bWbW →dilepton+jets CMS PAS EXO-11-050



m(t') > 422 GeV
for BR(t'→ bW)=1



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

Search for multiple b and W FS

➔t'b→bWb

➔b't→tWbW→bWWbW

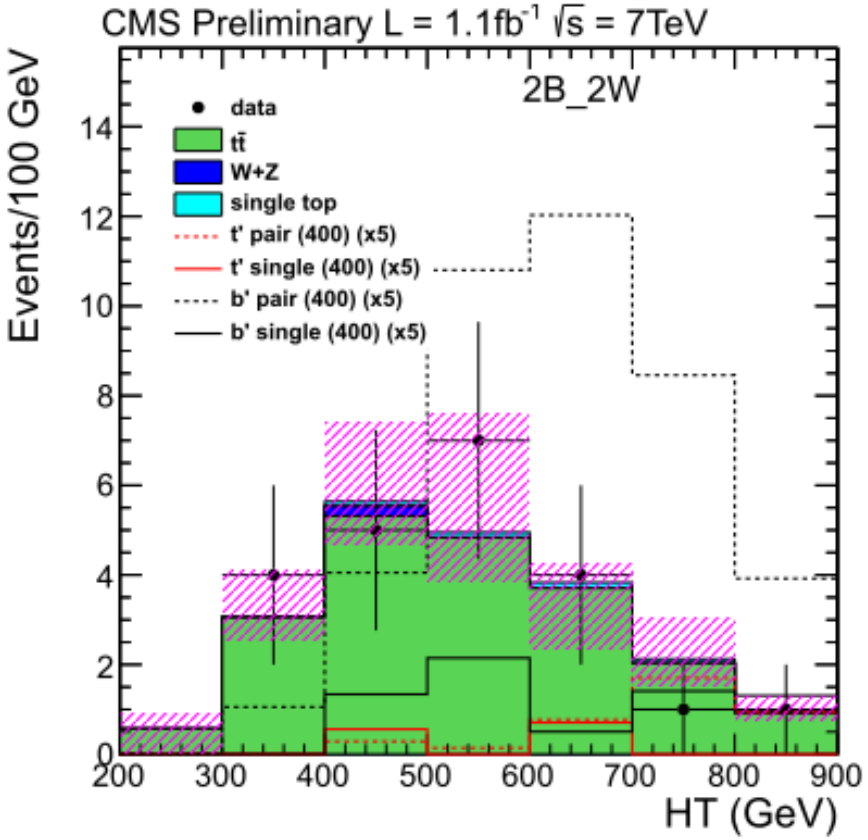
➔t't'→bWbW

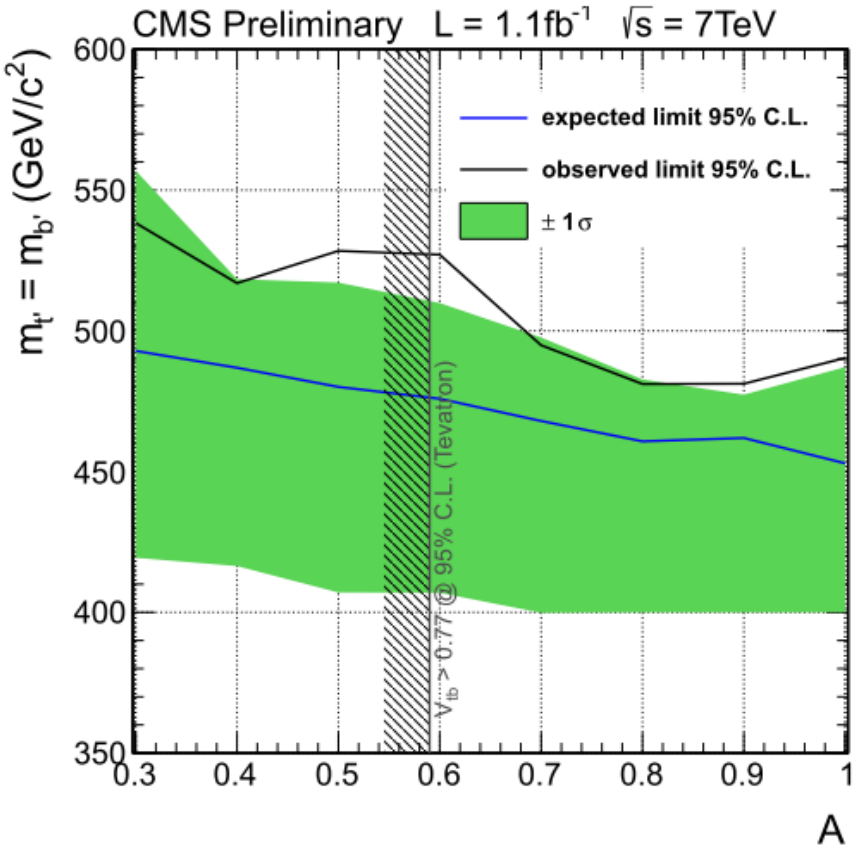
➔b'b'→tWtW→bWWbWW

CMS PAS EXO-11-054

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

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



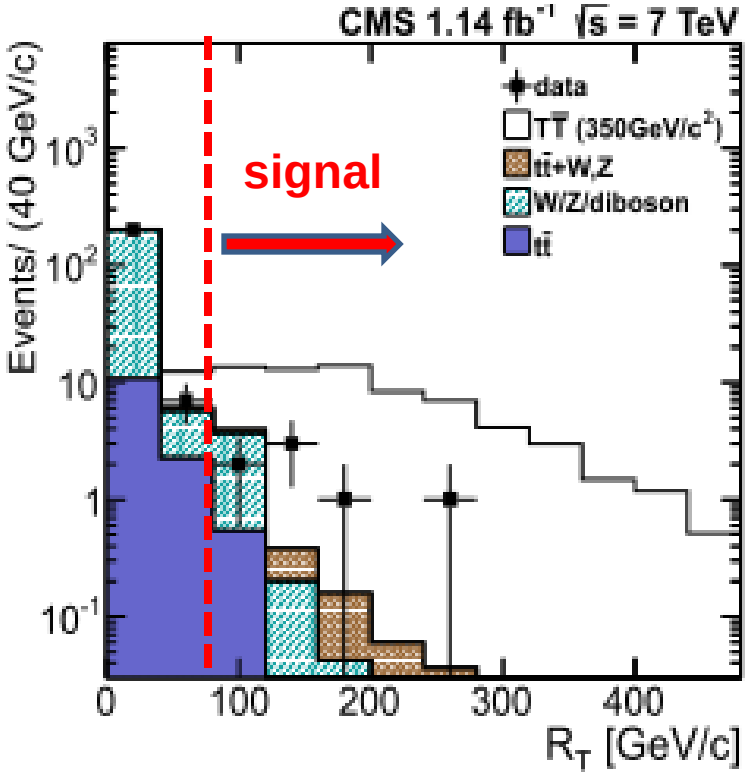


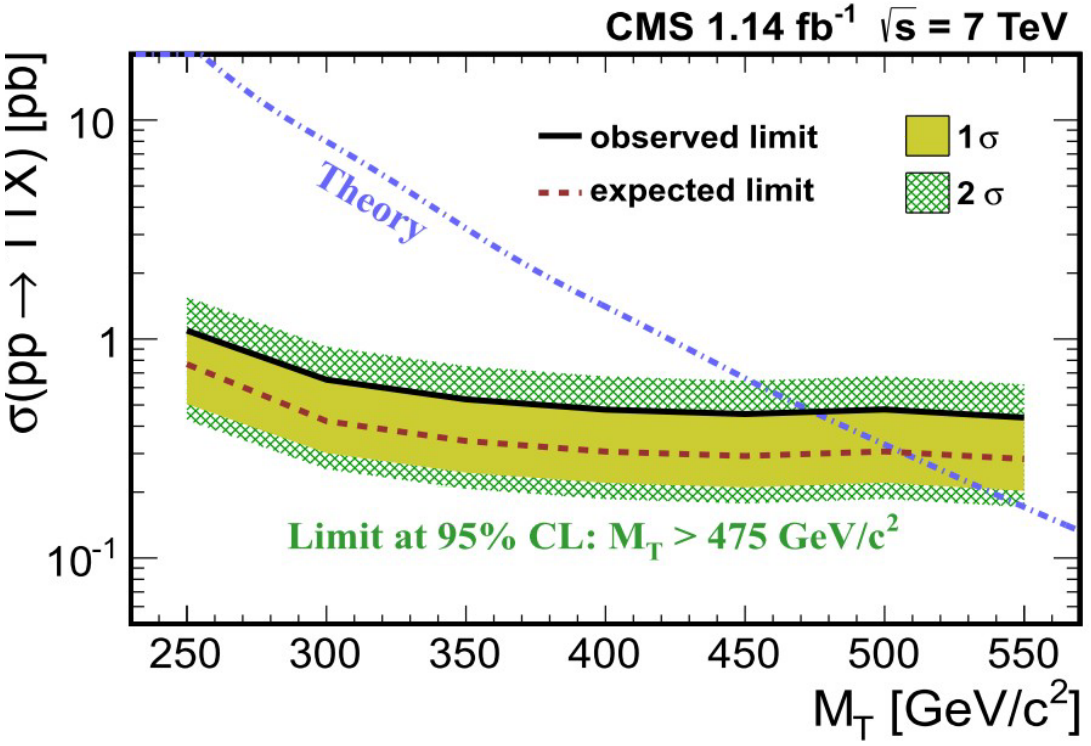
Vector-like Heavy Top T→ tZ

- **Vector-like charge 2/3 heavy top (T)**
- **FCNC tZ decay**
- Decay Chain: TT→**tZtZ→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→ tZ)=100%

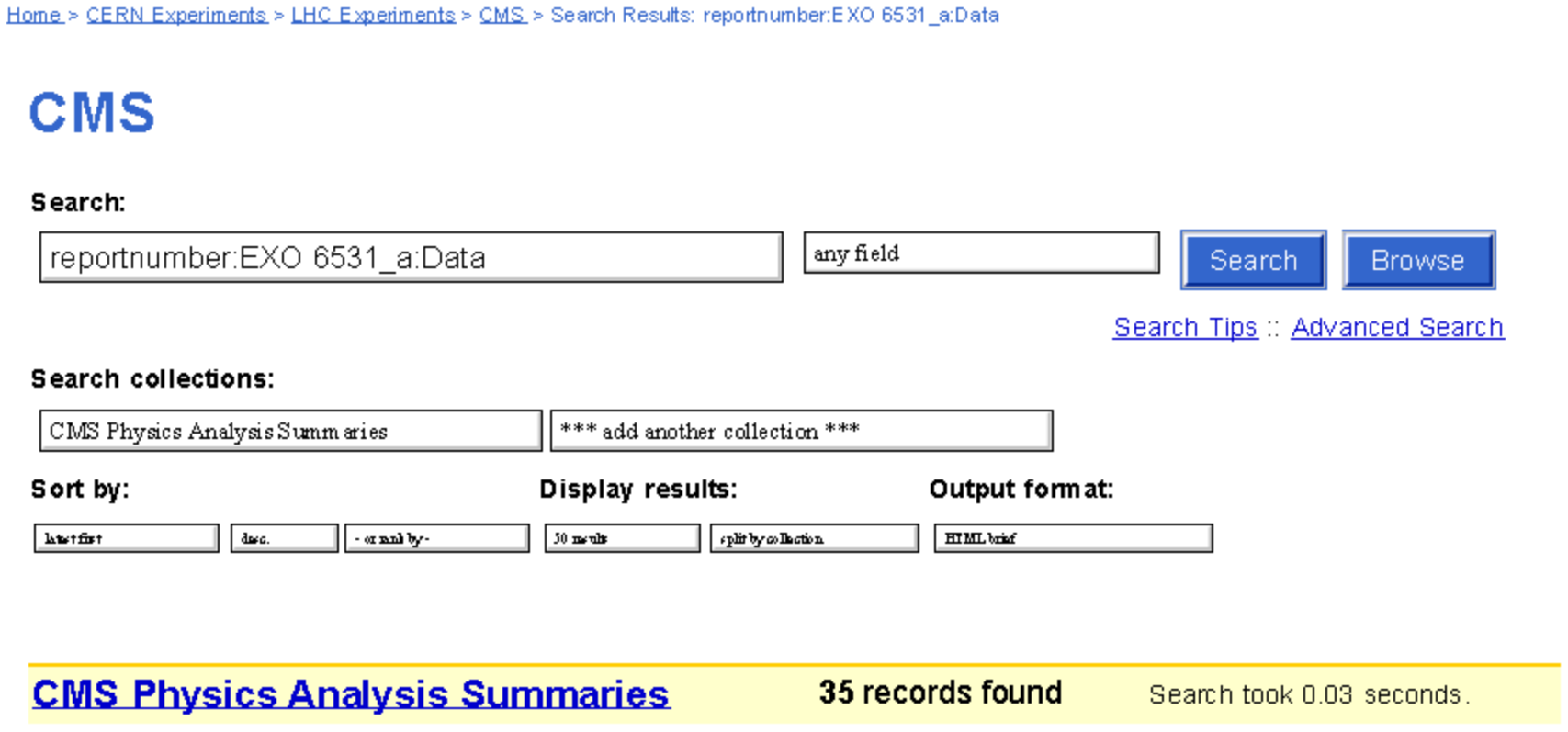




More CMS Exotic Searches Results…

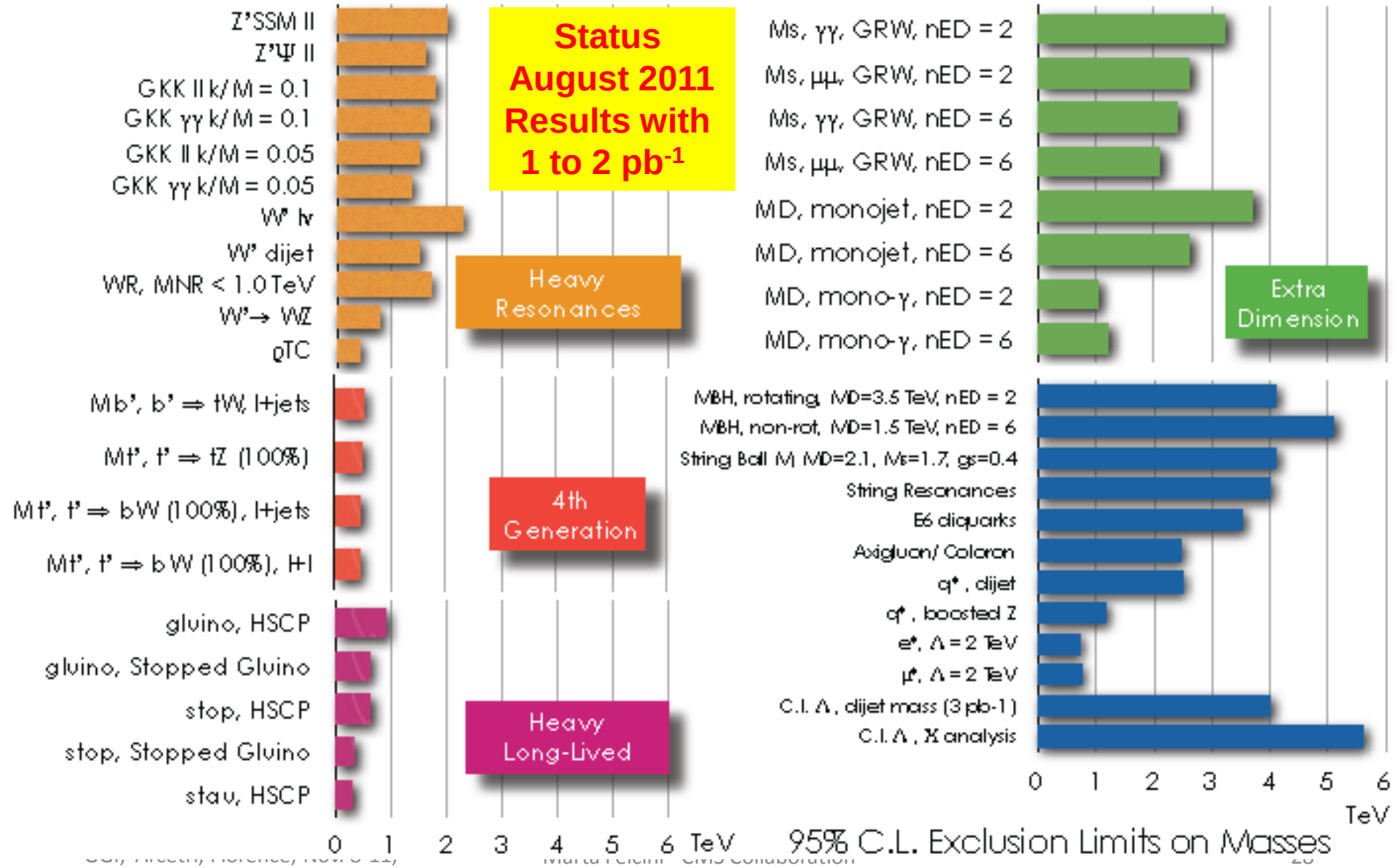
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

And in CDS: **http://cdsweb.cern.ch**



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

Overview of CMS Exotic Searches Results

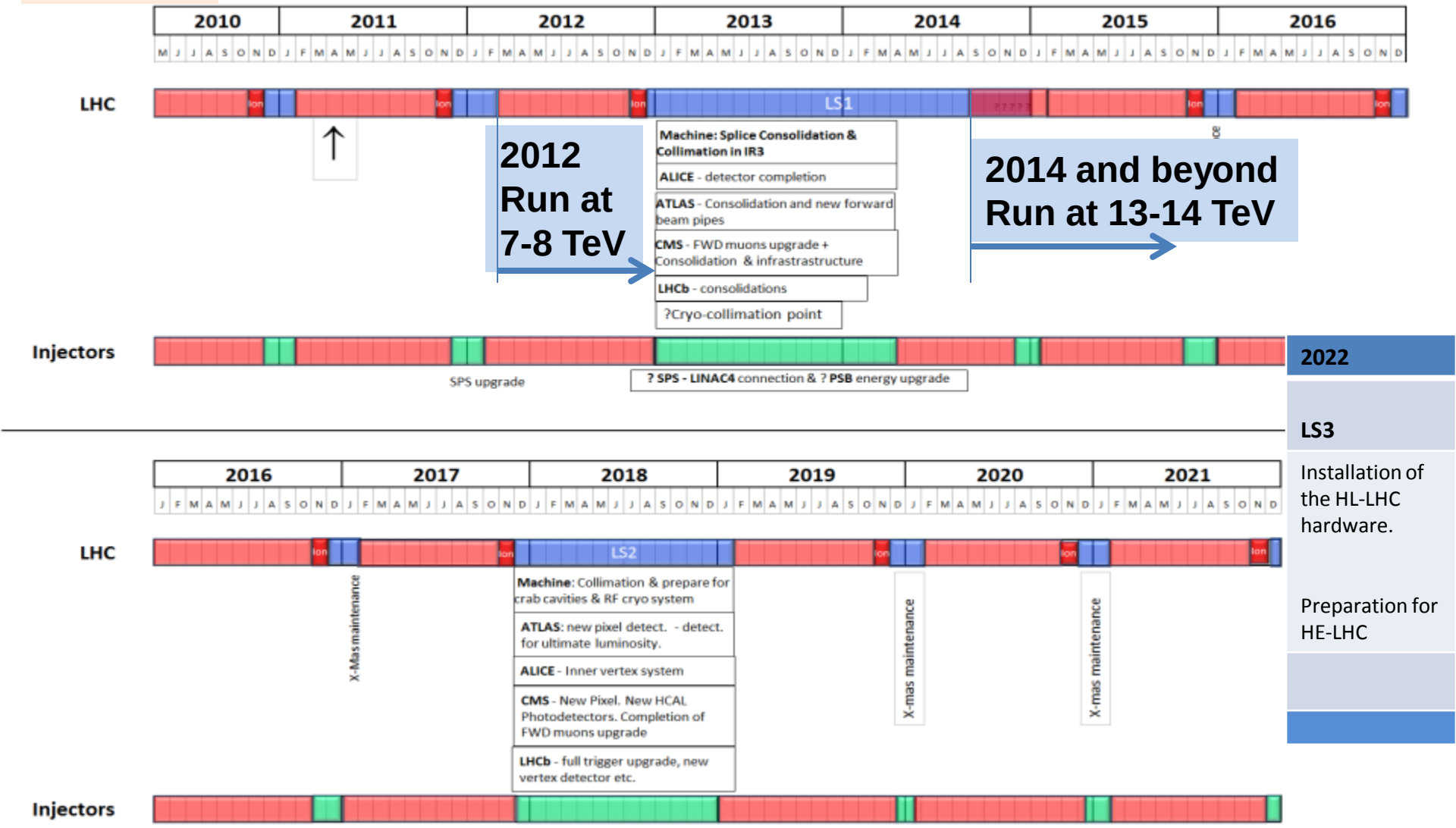


What next? LHC Plan for the next 10 years

F. Bordry
LP 2011

New rough draft 10 year plan

Not yet approved!



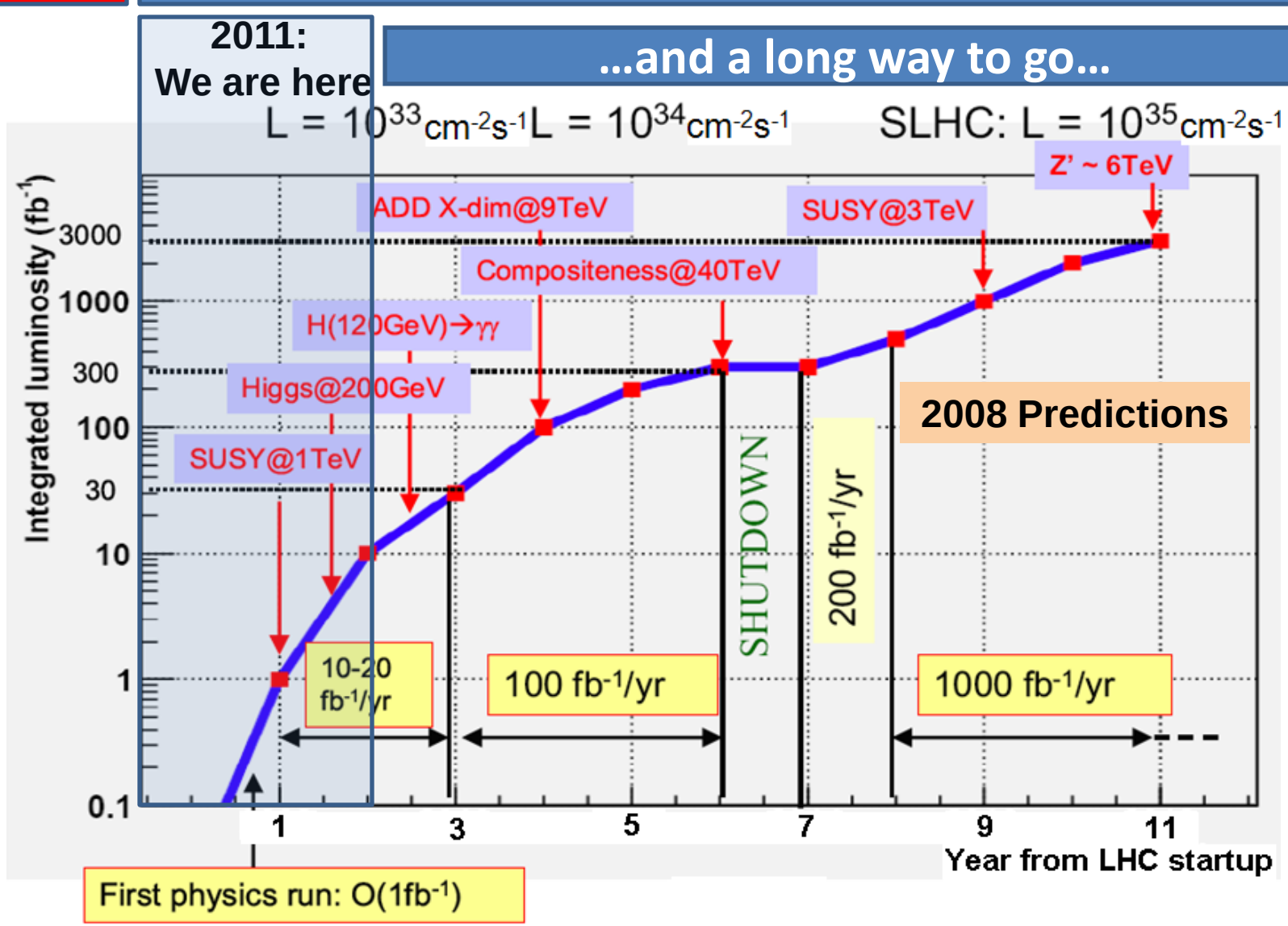
2022

LS3

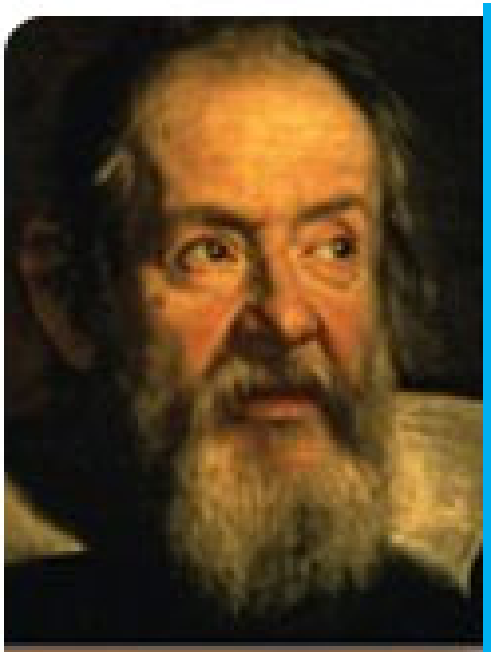
Installation of the HL-LHC hardware.

Preparation for HE-LHC

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

To the Organizers for their kind invitation.

To the colleagues in the CMS Collaborations, for all the brilliant results I have been presenting on their behalf.

And special thanks to the colleagues from whom I borrowed ideas and material for this talk:
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