Searches for exotic physics at CMS

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on behalf of the CMS Collaboration

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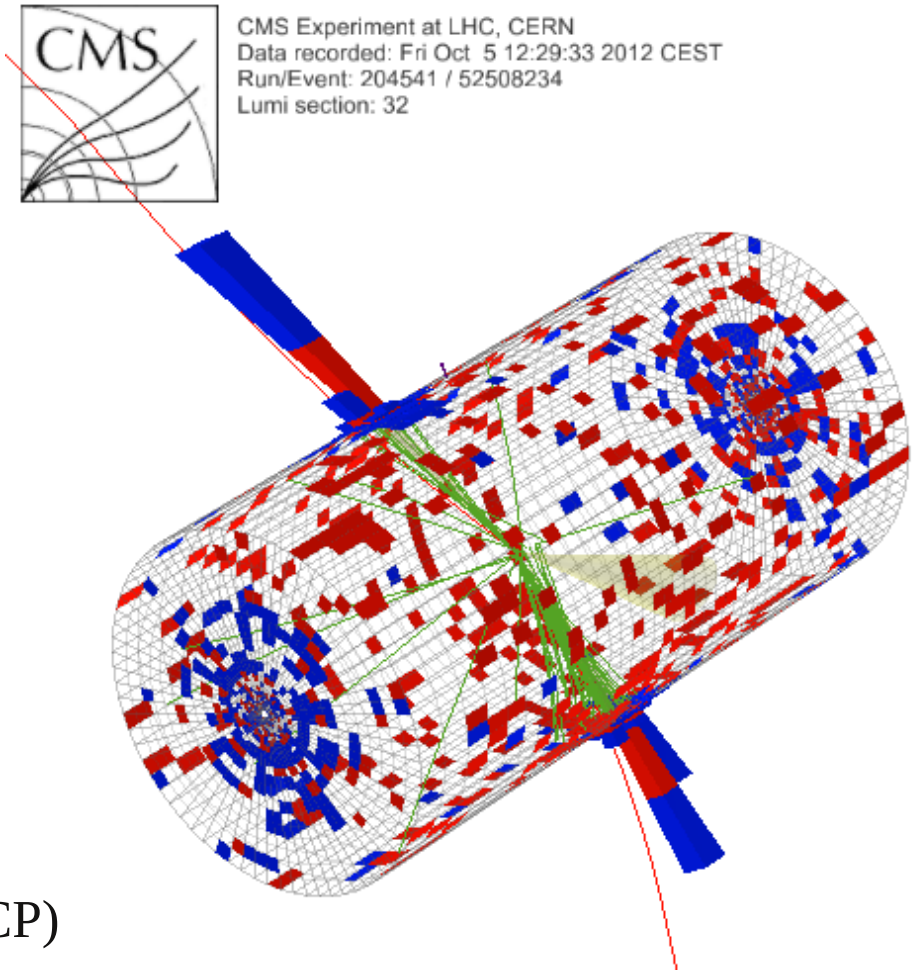
Outlook

- Introduction
- Limited time available, I will focus on few highlights
  - excellent design and detector performances, crucial for a successful search program
  - very competitive results of the searches at CMS. Unfortunately, no discoveries... yet ;-)
  - very broad spectrum of physics and signatures
- Recent results on:
  - Heavy Stable Charged Particles (HSCP)
  - Searches with jets
  - $W' \rightarrow tb$
  - W' and Z' with leptons

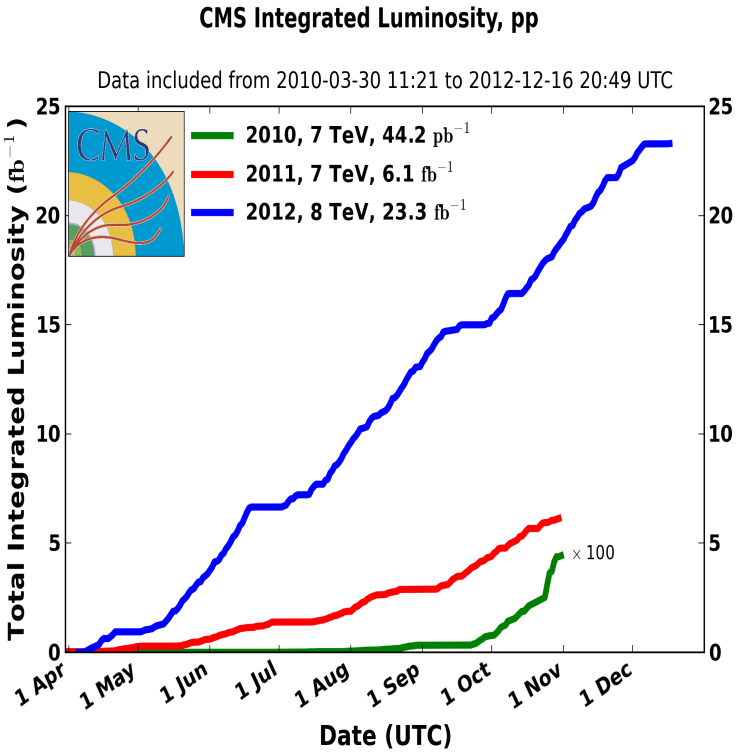


Event with highest dijet mass (M_{JJ}=5.15 TeV)

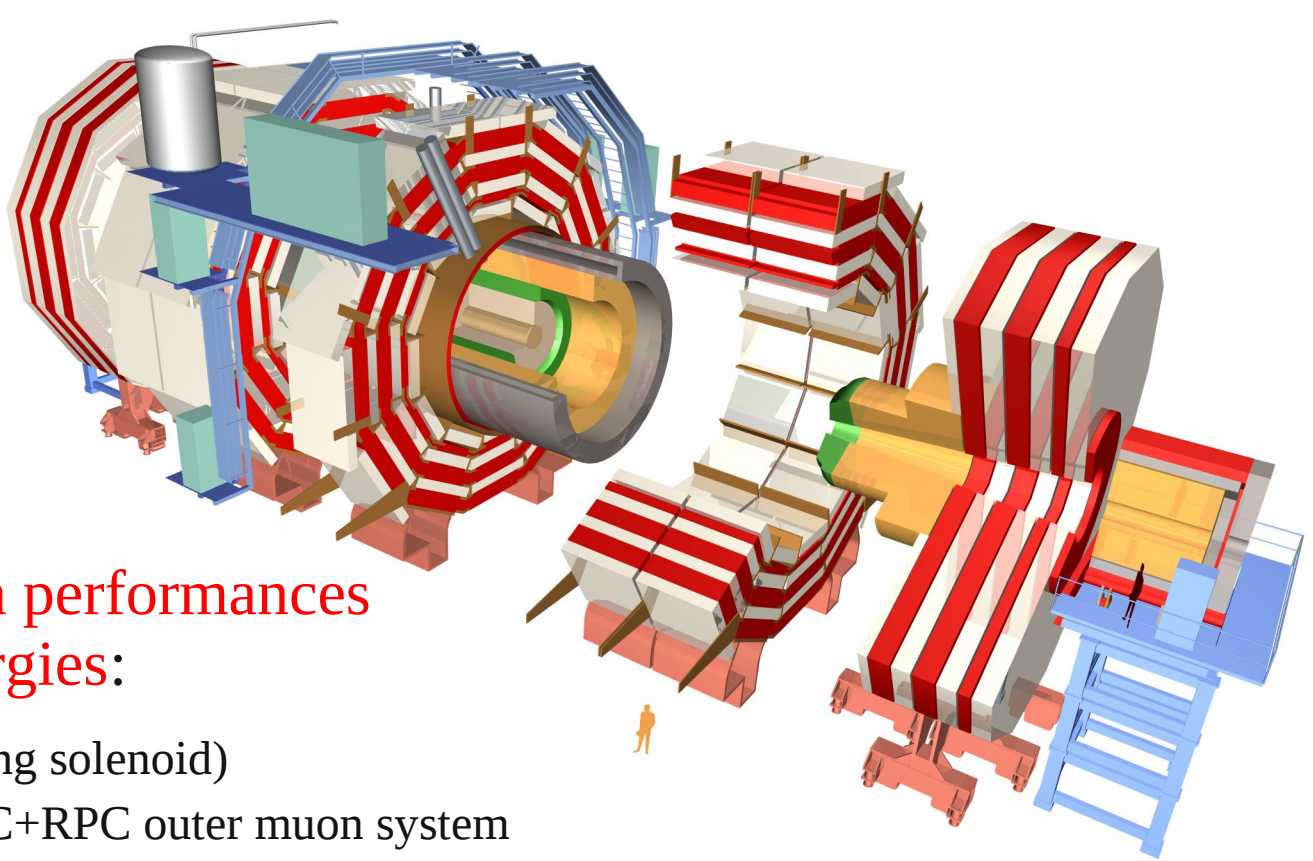
Introduction

- Higgs-boson discovered but the story cannot end here
  - still many open questions in physics: naturalness, DM, masses, matter-antimatter...
- LHC and CMS built for discovering new physics, still lots of potential
  - one can rule out some BSM models or scenarios, but the definitive proof or exclusion of a theory can come only from a positive experimental finding

- Impressive range of BSM searches at CMS, thanks to the versatility of the detector and the amount of nice pp collisions provided by LHC
  - SUSY: not covered in this talk
  - Beyond-Two-Generations (B2G): new physics with particles decaying in b and/or t quarks
  - Exotica: all other searches at CMS
- Updates with full luminosity (19.6 fb^{-1}) collected at $\sqrt{s}$=8 TeV



CMS



CMS is designed for high performances over a large range of energies:

- **3.8T B-field** (super-conducting solenoid)
- All-Si inner tracker; DT+CSC+RPC outer muon system
- Muon resolution <10% at p_T=1 TeV
- Well calibrated and aligned: bias on $Z \rightarrow \mu\mu$ mass <0.1%
- $PbW0_4$ crystal ECAL; $\sigma(E)/E$ const term: ~0.5% (barrel), <2% (endcaps)
- $Z \rightarrow ee$ resolution btw 1% and 4%, depending on η and ele quality
- Brass-scintillator sampling HCAL
- Flexible trigger system, output at 10^5 (300) Hz at L1 (HLT)

Heavy Stable Charged Particles

CMS-PAS-EXO-12-026

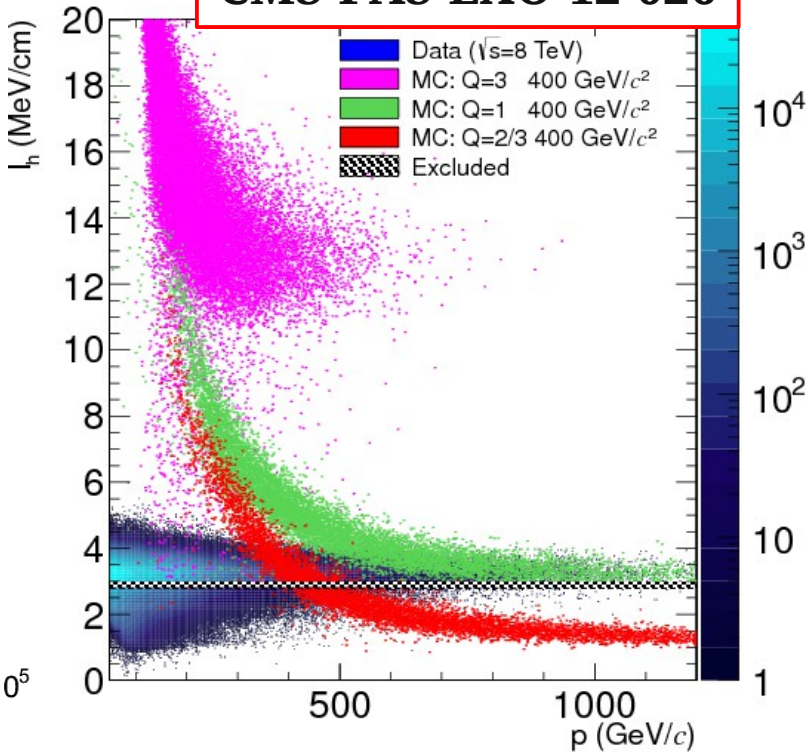
Several BSM scenarios predict heavy long-lived particles with $\beta<1$: hadron-like (split-SUSY with R-hadrons from gluinos or stops, GMSB with stau NLSP) and lepton-like (new leptons with $Q\neq\pm e$)

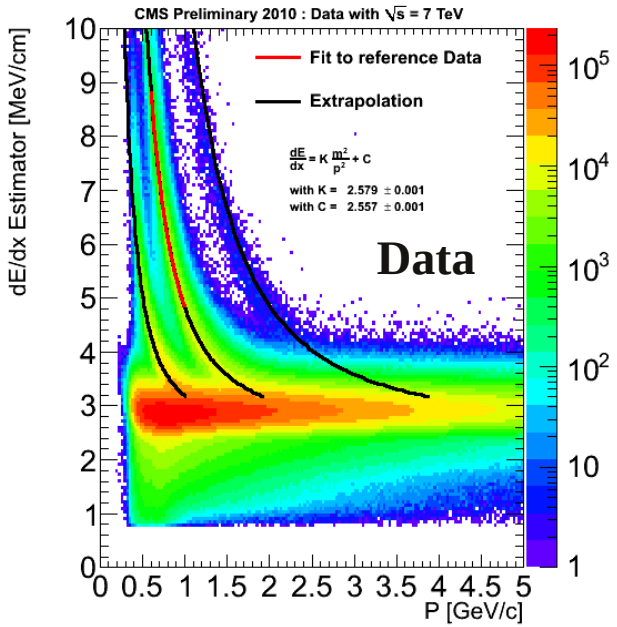
Charged particle, low $\beta \rightarrow$ large energy deposited in the tracking detector via ionization

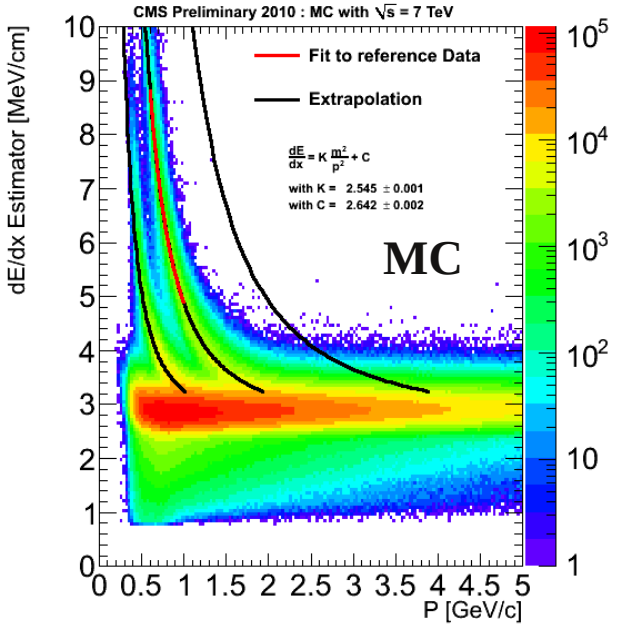
$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{1/k}$$

k = 2

c_i = charge collected at each measurement point







Analog read-out of TK is of great help in this analysis. Huge work calibrating and aligning the Si TK. Final result is a detector well under control.

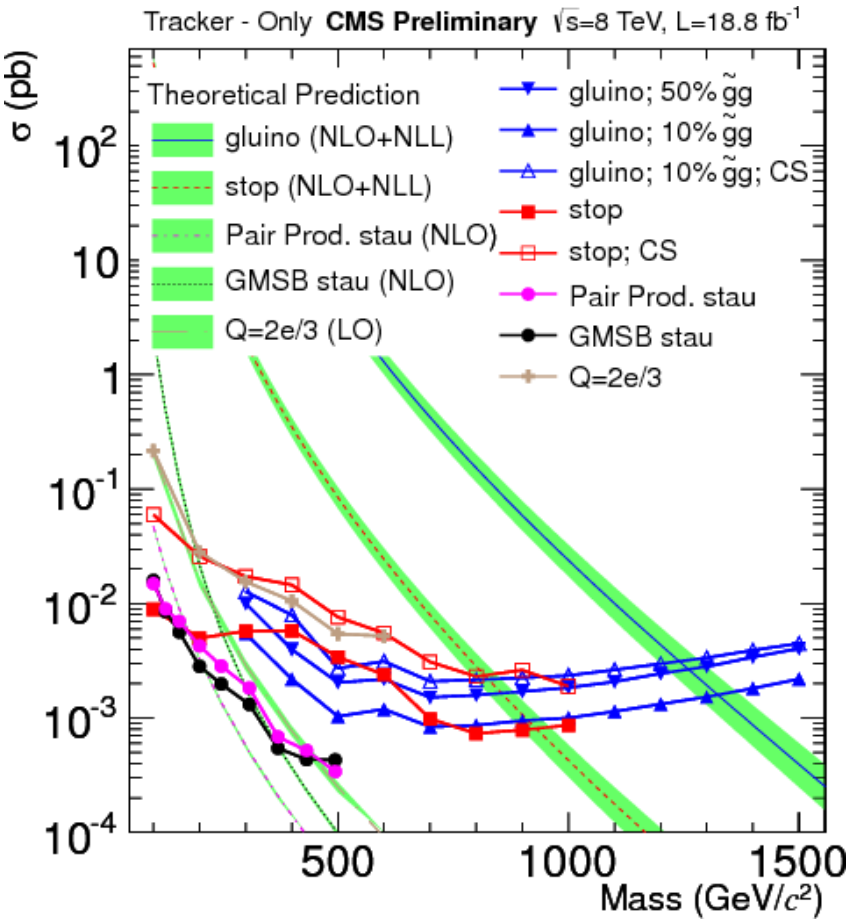
dE/dX very well reproduced by simulation

CMS-PAS-EXO-12-026

Several topologies studied: track measured
in SiTK, Muon system or both (account for possible charge flipping)

ToF measurement
in the Muon system

$$\beta^{-1} = 1 + \frac{c\delta_t}{L} \longrightarrow$$ ~7% resolution



Event selection:

- special ID for taking into account $Q \neq \pm e$
- well iso track, p_T >45 GeV (>80 GeV for muon-only)
- I_h > 3.0 MeV/cm
- if track in muon system: $\beta^{-1}>1$, $\sigma(\beta)<0.07$

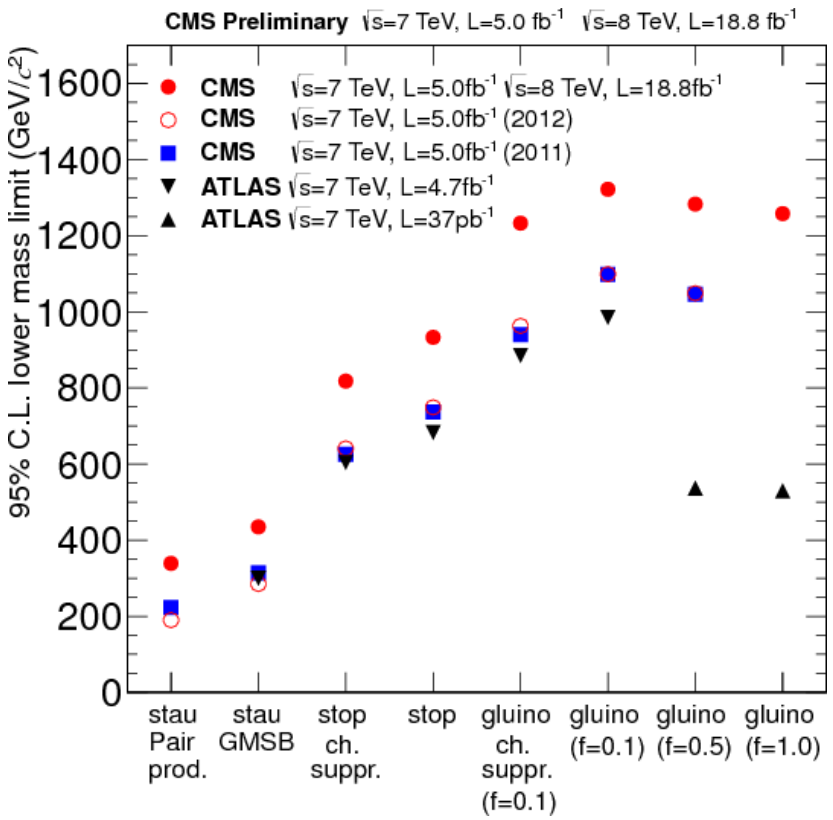
Reconstruct mass of HSCP candidate via:

$$I_h = K\frac{m^2}{p^2} + C$$

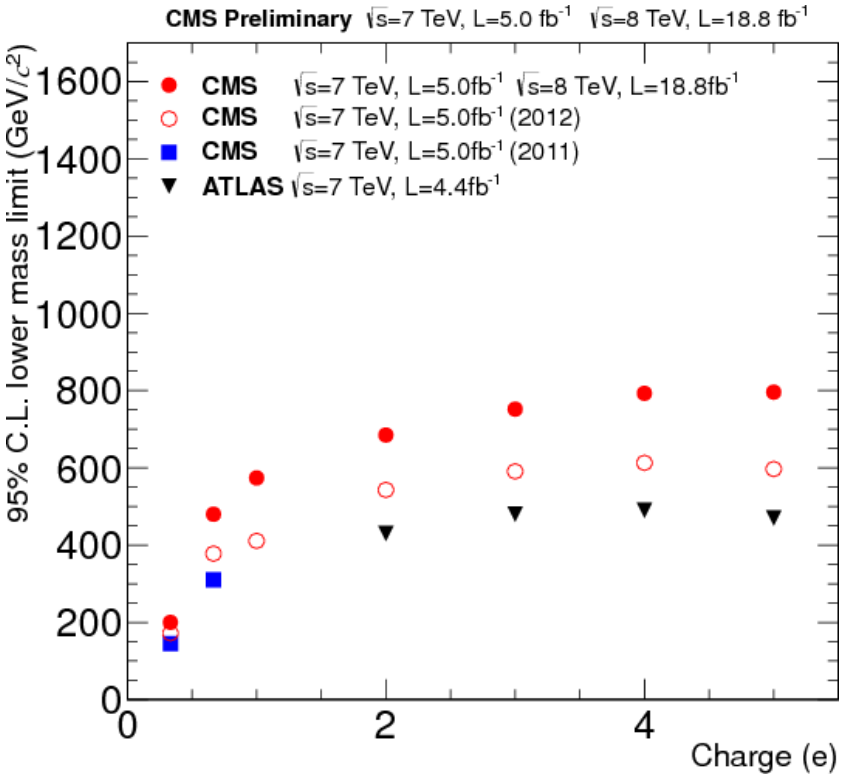
(K and C: constants
in Bethe-Bloch formula,
determined from sample of
low momentum protons)

CMS-PAS-EXO-12-059

Results with full 7+8 TeV datasets improve noticeably previous exclusion limits



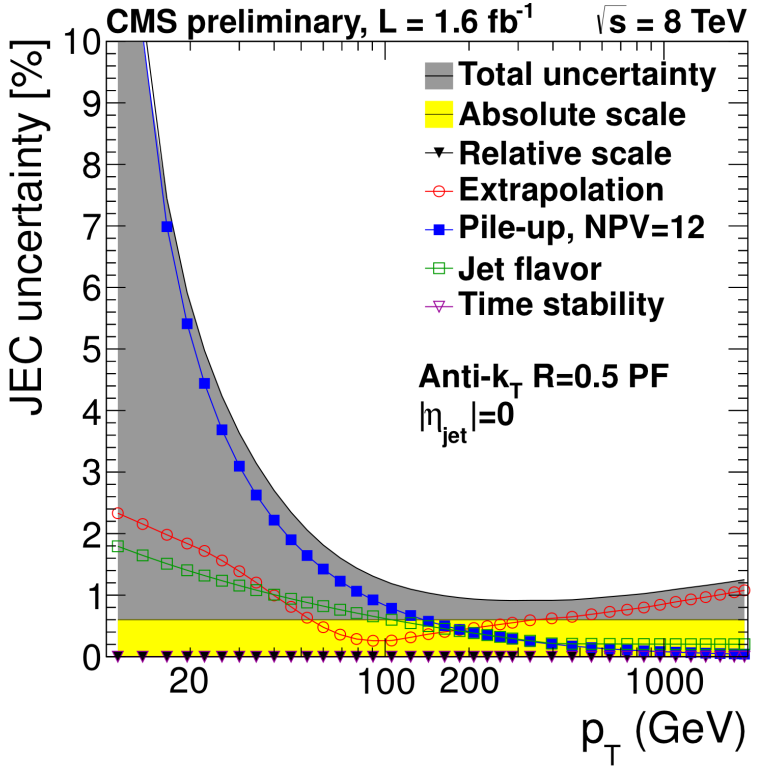
Hadron-like HSCP, staus

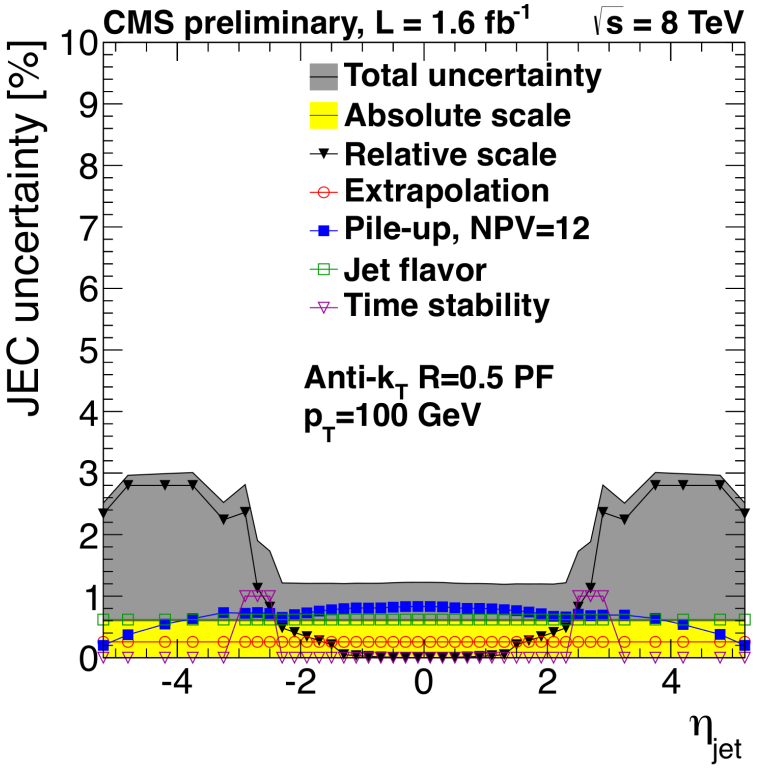


Lepton-like HSCP

Jets at CMS

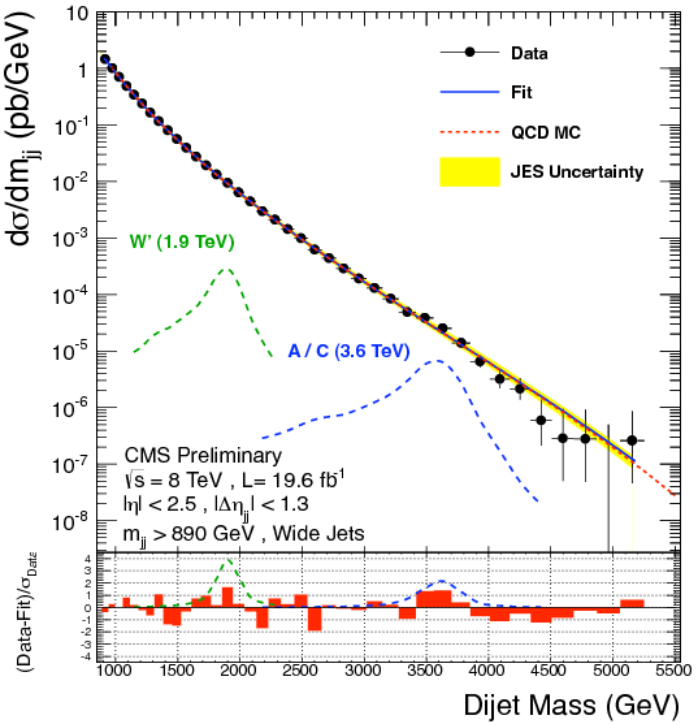
- Plenty of BSM models with high-p_T jets in final state. Lot of focus on this type of searches
- Need extremely well calibrated calorimeters and jets
- Particle-Flow algorithm merges information from tracks and calo, boost of performances.
- Pile-up energy subtraction techniques
- Final result: **calibration at percent level** for jets with p_T>100 GeV and central rapidities
- Missing transverse energy (MET) performances strictly related to jets, profits from these calibs.





Dijets

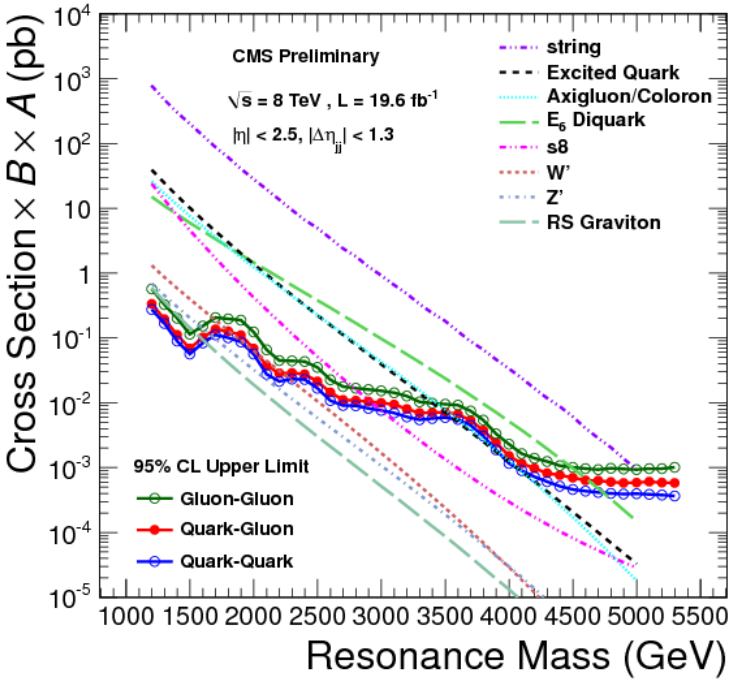
CMS-PAS-EXO-12-059



Bump search in invariant mass spectrum of dijet system:

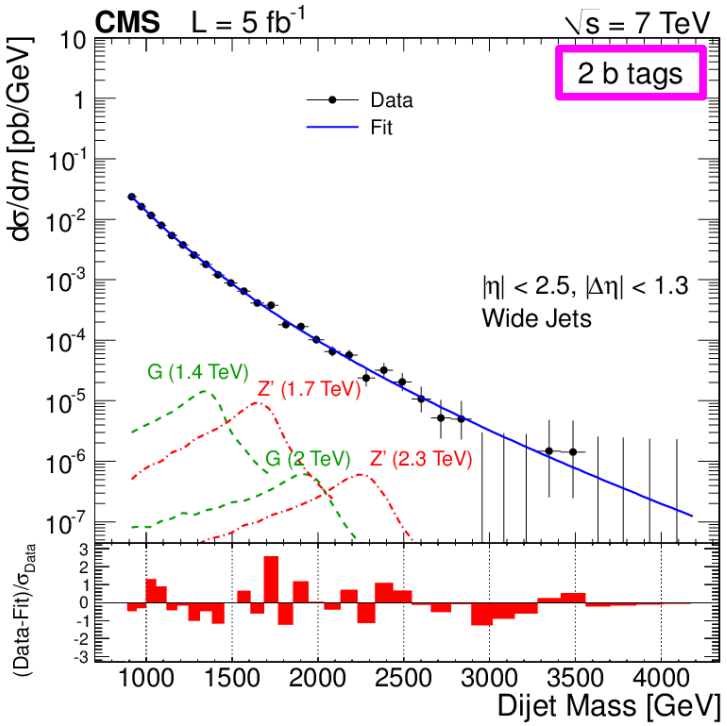
- Trigger on H_T (scalar sum E_T) > 650 GeV, M_{JJ}>750 GeV
- AK5 jets, loose jetID, $|\eta|<2.4$, M_{JJ}> 890 GeV
- QCD FSR recover in an enlarged cone (1.1) around AK5
- Fit M_{JJ} spectrum with S+B hypothesis
- Different signal mass resolutions depending on parton type in final state (g radiates more than q)
- Limits set on a plethora of models, pushing them at higher and higher scales.

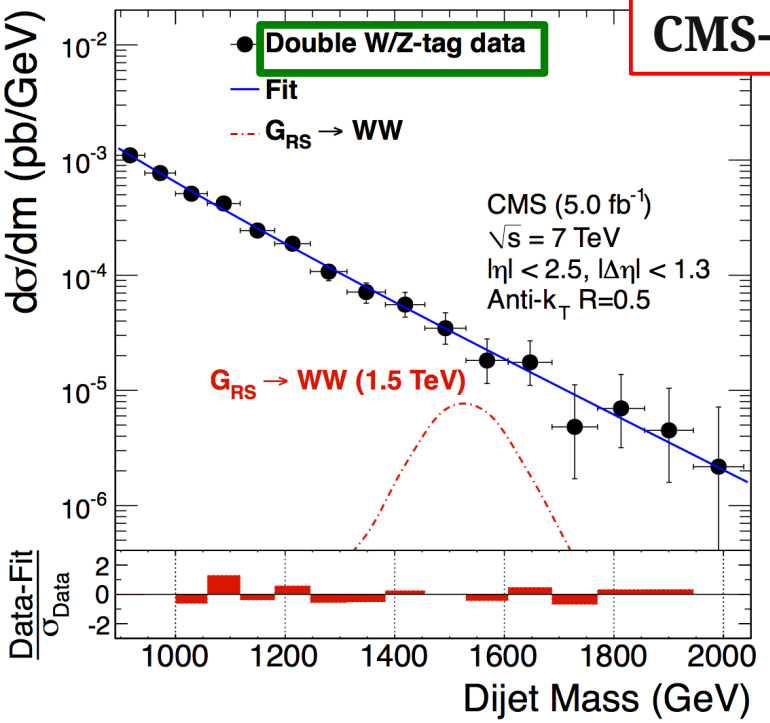
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]

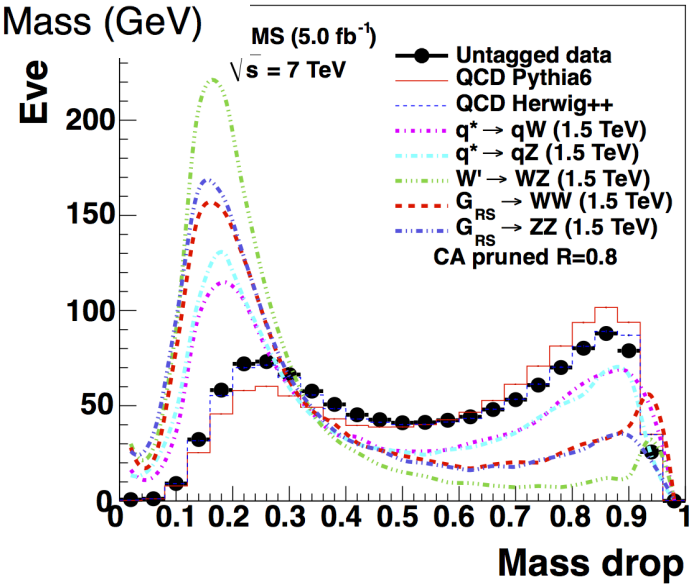


More and more jets

CMS-PAS-EXO-11-094
CMS-PAS-EXO-11-095







Can add more info for improving sensitivity:

- b-tag
- jet substructure for jets from V (V=W, Z)

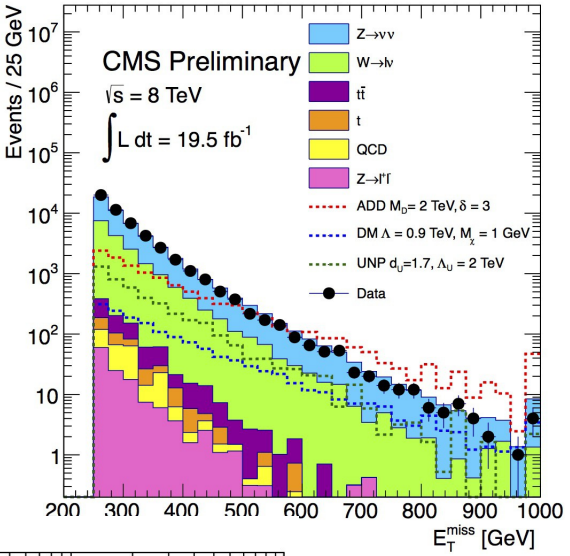
Study energy flow inside jet for identifying substructure compatible with $V \rightarrow qq$.

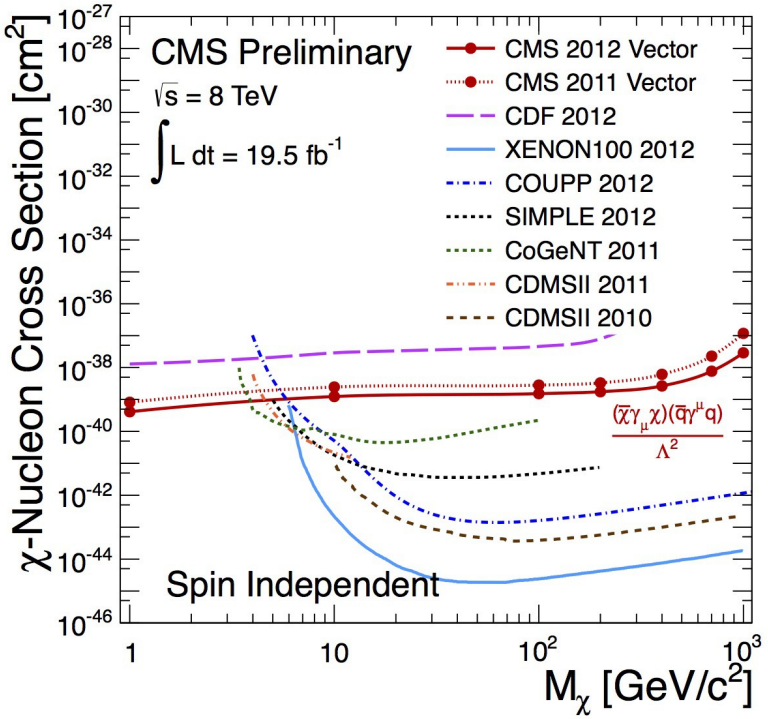
Public results still with 7 TeV data,
expect more and more like this in the future !

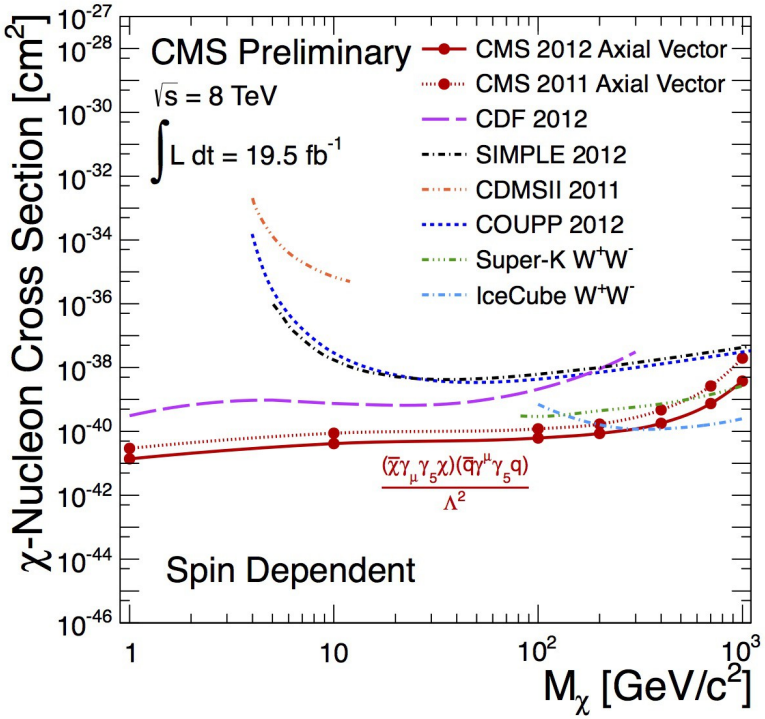
Monojet

CMS-PAS-EXO-12-048

- High-p_T jet + MET, count events with MET above threshold
- Data-driven V+jets estimation from control regions
- No excess, limits set on ADD large ED and DM production
- DM interpretation exploits effective lagrangian formalism. Can be compared to direct DM searches under specific assumptions on the lagrangian.



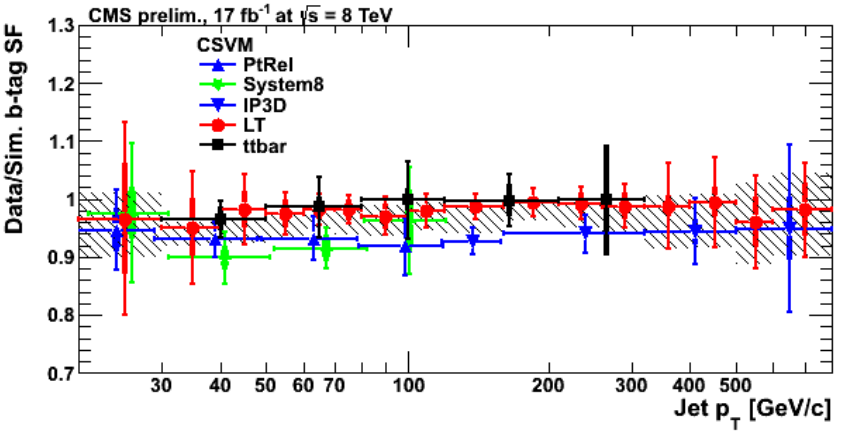




W' → tb

CMS-PAS-B2G-12-010

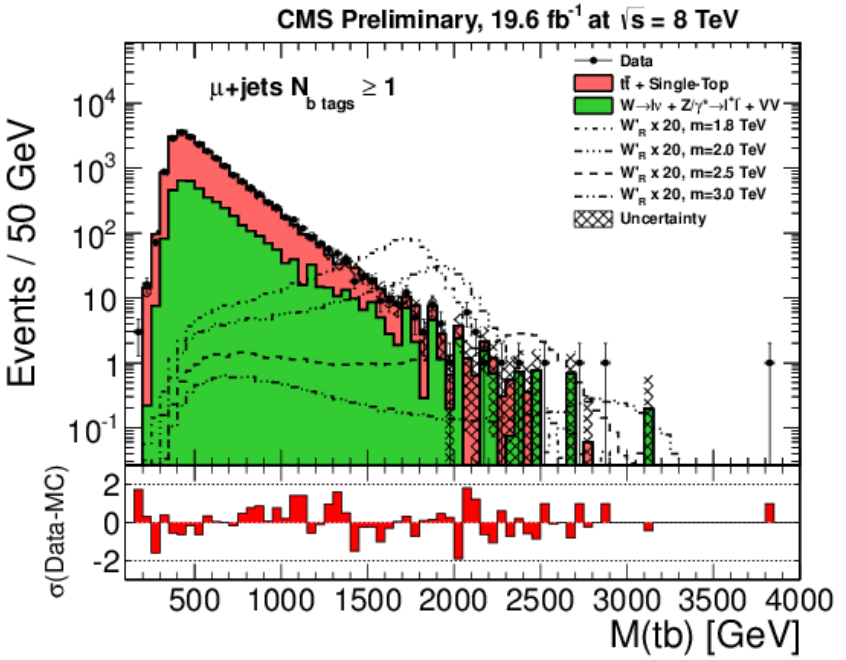
b-tagging at high energies is crucial for many analyses. Several ways implemented to measure data-to-MC scale factors from control regions. Combination gives b-tagging systematics under control also at high p_T .



W' → tb exploits well b-tag capabilities of CMS

Analysis strategy:

- W' → tb → bbW → bb$\ell\nu$
- Exactly one e or μ with $p_T > 50$ GeV
- Leading jet $p_T > 120$ GeV, second jet $p_T > 40$ GeV
- At least one of the jets has to be b-tagged.
- b-tag sidebands to control shapes of $t\bar{t}$ and W+jets
- ν kinematics by constraining $\ell\nu$ to W mass
- top kinematics from combination that gives mass closest to nominal top mass



→ **Full reconstruction of decay kinematics**
(not possible with W' → $\ell\nu$)

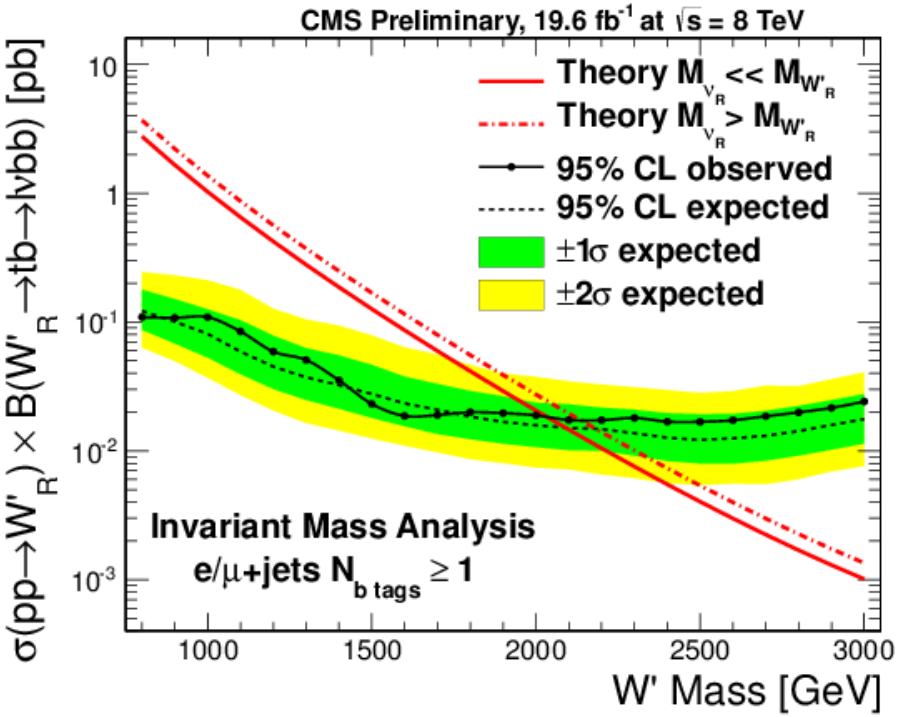
W' → tb

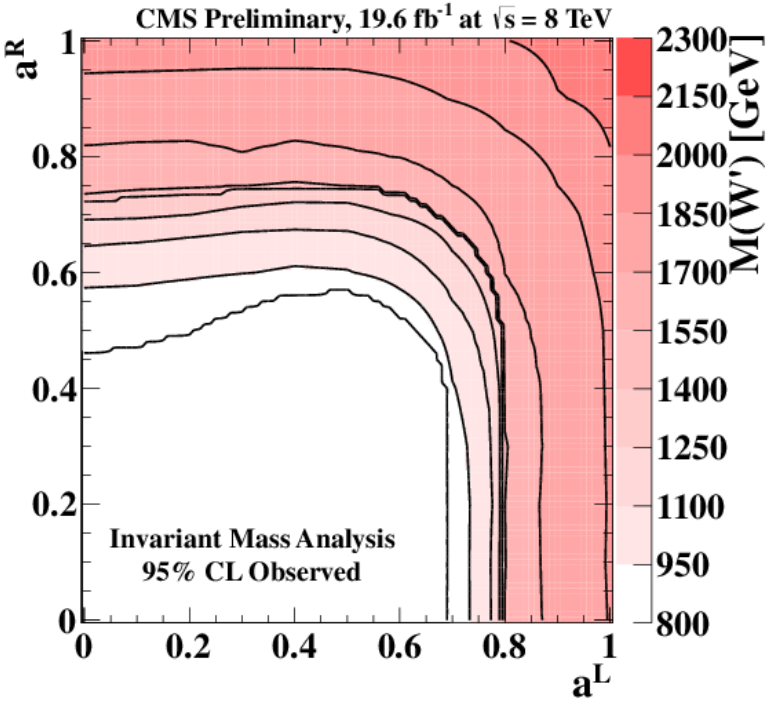
CMS-PAS-B2G-12-010

Extensions of SM predict additional gauge bosons: SSM, UED, little Higgs...
Alternatively, write most generic effective Lagrangian of the interaction btw W' and f:

$$\mathcal{L} = \frac{V_{f_i f_j}}{2\sqrt{2}} g_w \bar{f}_i \gamma_\mu \left(a^R_{f_i f_j} (1+\gamma^5) + a^L_{f_i f_j} (1-\gamma^5) \right) W'^\mu f_j + \text{H.c.}$$

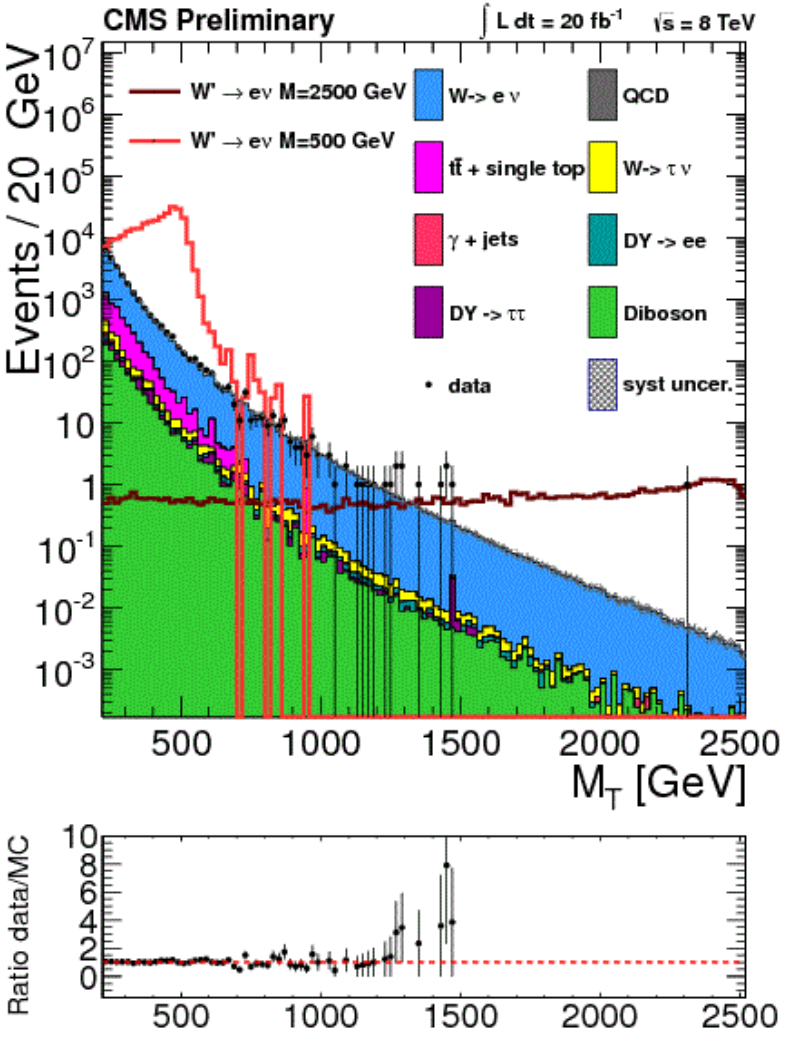
Can set limits on a pure right-handed W' (a^R=1, a^L=0) or in the (a^R,a^L) plane





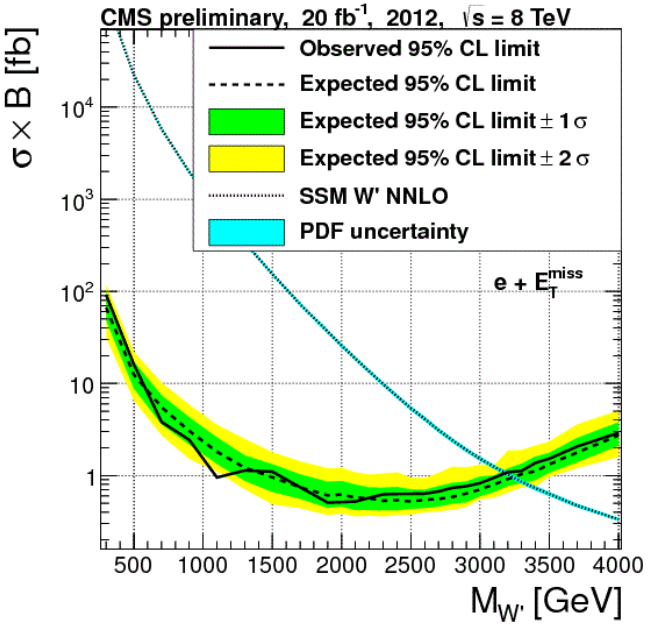
$W' \to \ell\nu$

CMS-PAS-EXO-12-060



- High-p_T μ (e) with p_T>45 GeV (100 GeV), passing ID tuned for high-momentum objects. Veto on 2nd lepton.
- $0.4 < p_T / \text{MET} < 1.5$; $\Delta\phi_{\ell\nu} < 0.8\,\pi$
- Look for excess in tail of M_T (peak for SSM W', smooth deviation for CI)

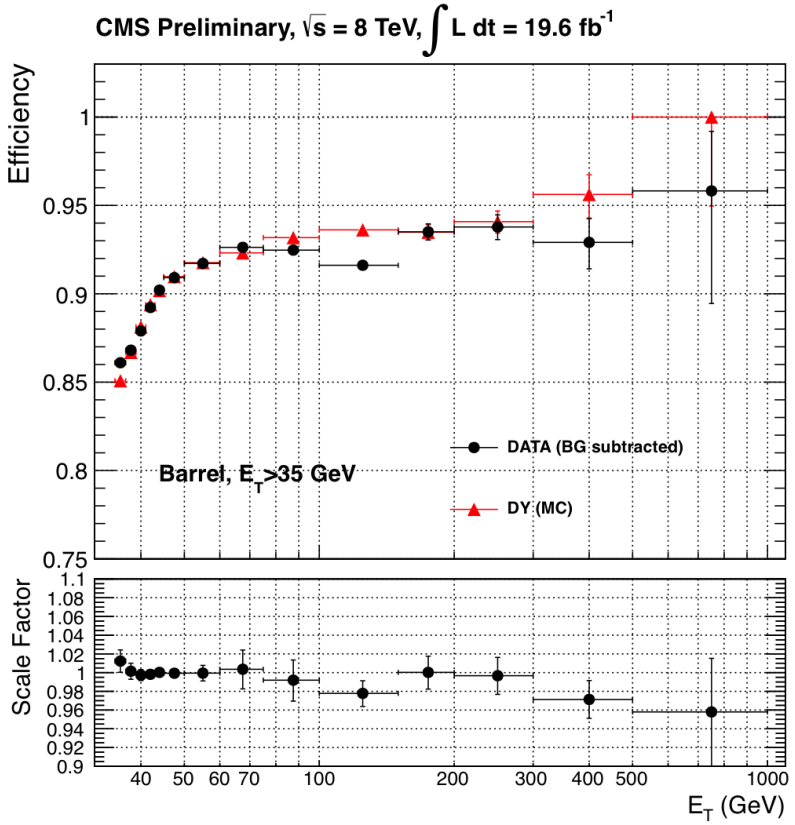
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos\Delta\phi_{\ell,\nu})}$$

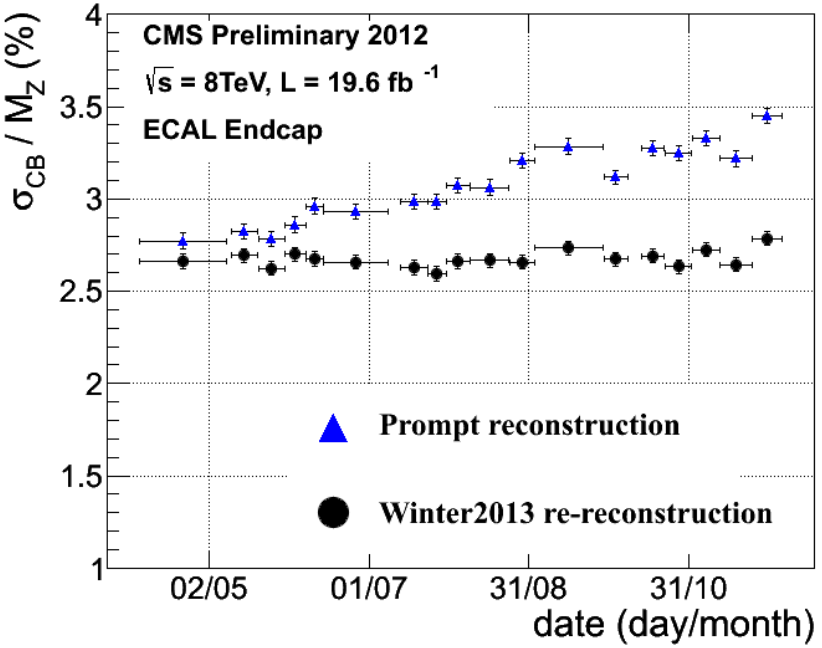


Electron reconstruction at high energies

It is mandatory to control well ID and resolution of very energetic electrons.

ECAL calibration performed with laser beams and physics candles. Validated in different ways, $Z \rightarrow ee$ is one of the main ones. Very good resolution, stable over time.





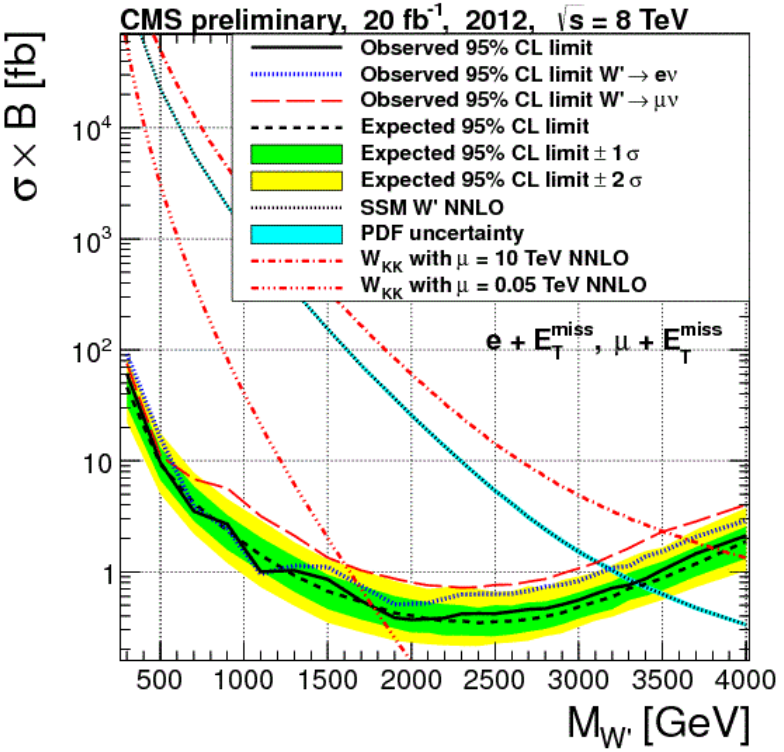
Special ID devised for high-p_T ele in order to retain high efficiency and low fake rate. Excellent level of description by the simulation.

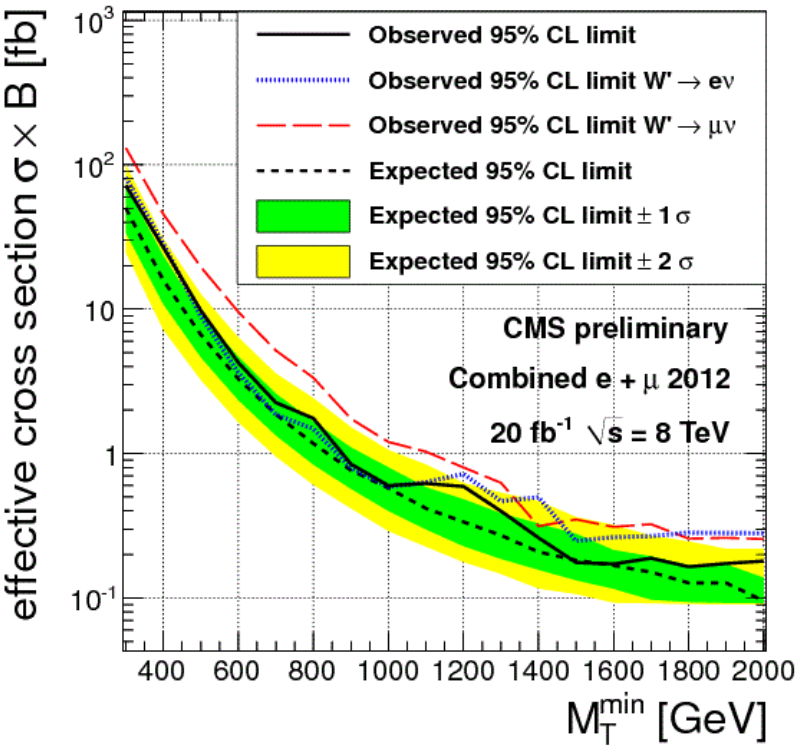
CMS-PAS-EXO-12-060

Addition of muon channel improves moderately sensitivity
(muon resolution decreases with higher p_T → smaller track sagitta).

No significant excess observed. Combined e+μ exclusion limit on SSM W': $M_{W'} < 3.3$ TeV.

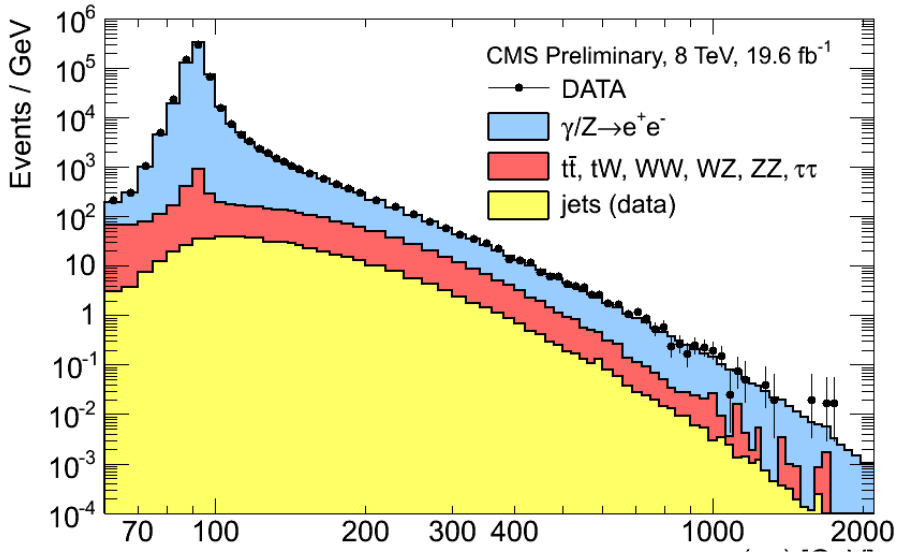
Limit on binding energy of CI (HNC model): $\Lambda < 13.0$ (10.9) TeV for e (μ).
Model-independent limit on CI set integrating M_T spectrum in the range $[M_T^{min}, \infty]$





Z' → $\ell\ell$ (ℓ=e,μ)

CMS-PAS-EXO-12-061

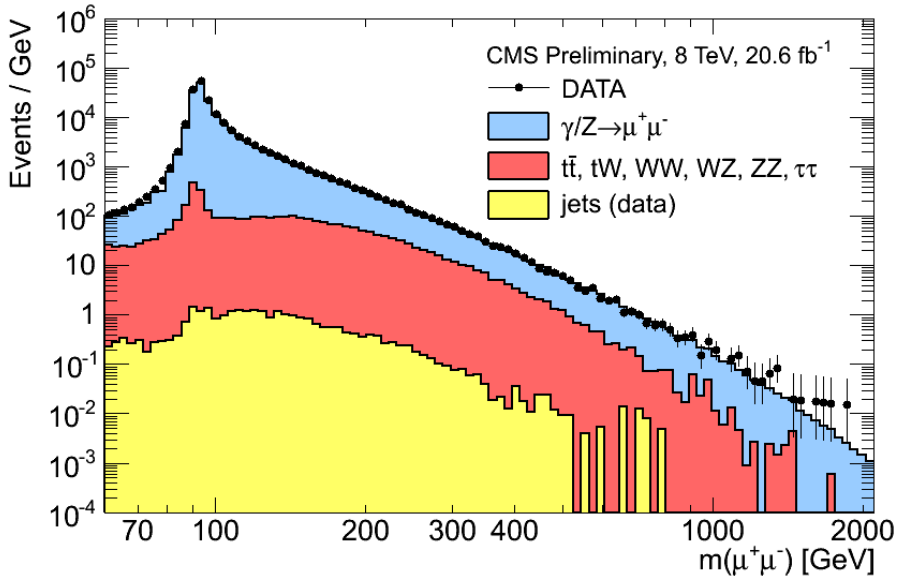


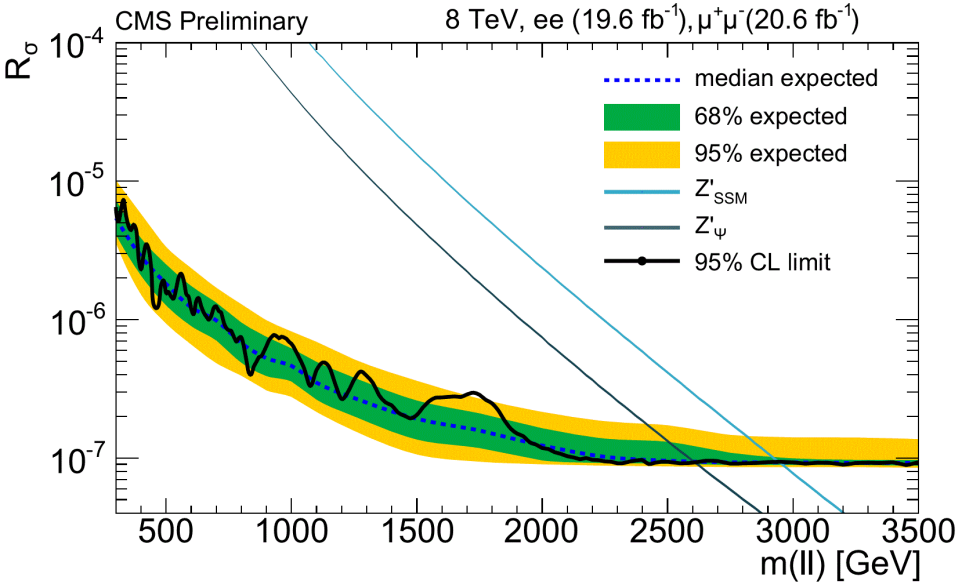
Selections on e and μ similar to W' (lower ele p_T thanks to DoubleEle trigger).

DY bkgd from POWHEG MC . Other bkgd with genuine $\ell\ell$ pairs from eμ control region. Fake ele bkgd from QCD control region (fake μ negligible).

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

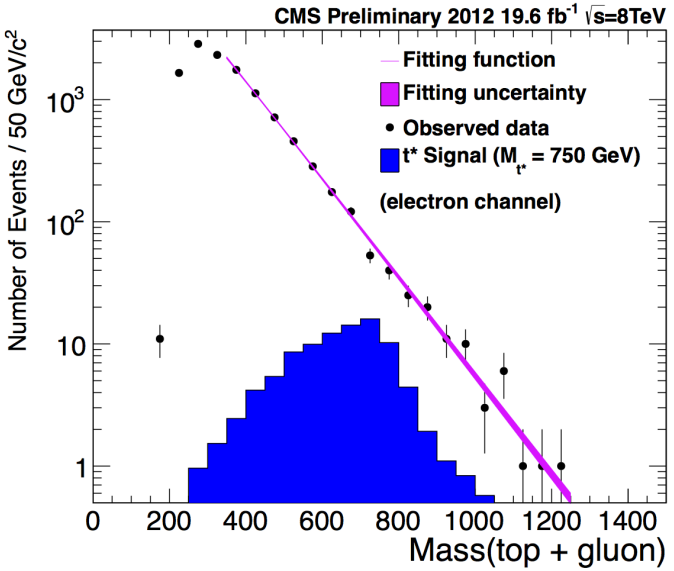
Description by MC is just amazing...

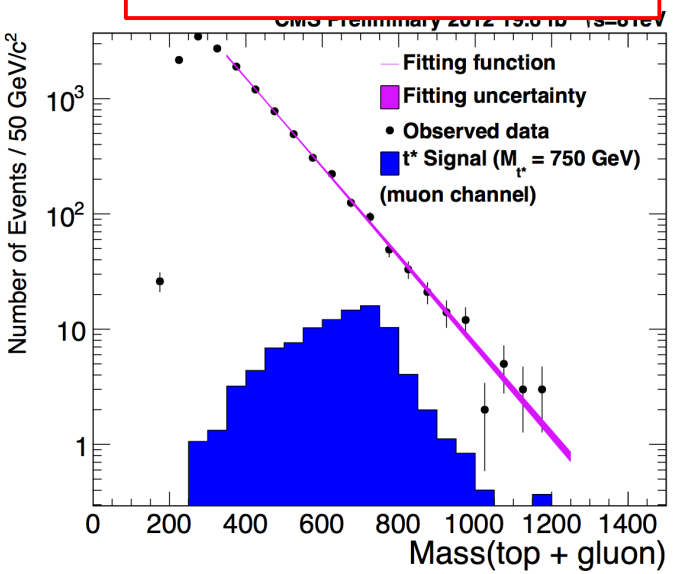




Excited top

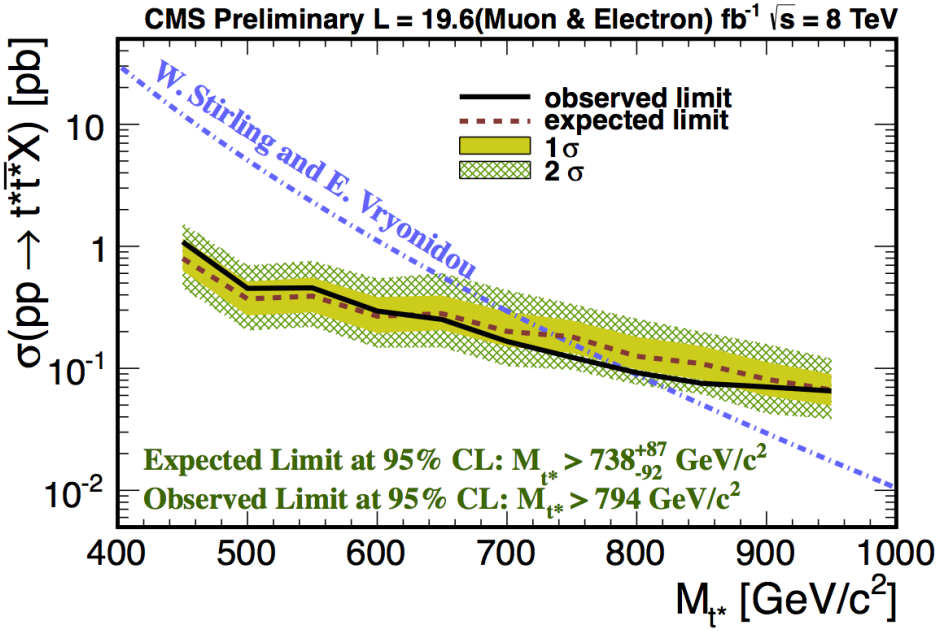
CMS-PAS-B2G-12-014



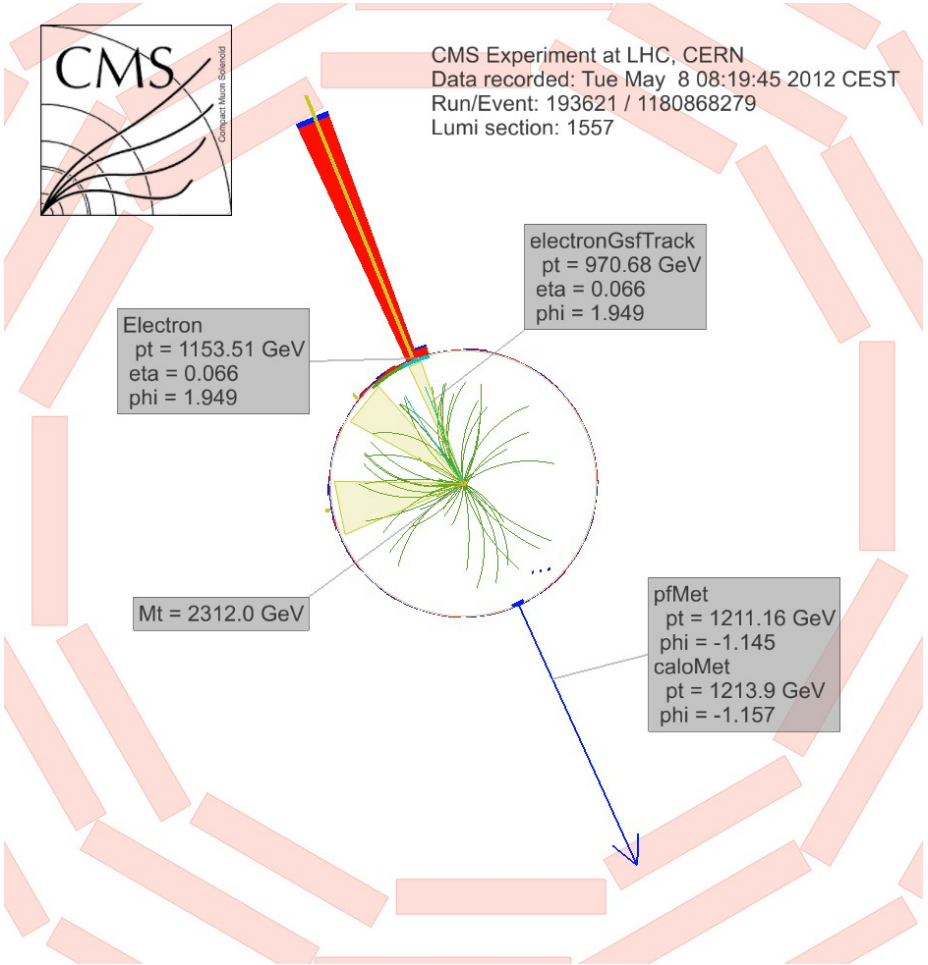


Pair production of spin 3/2 excited top : $t^* \rightarrow tg$

- first measurement of this type !
- one t decays semi-leptonic, the other full hadronic
- one isolated lepton with p_T > 26 (30) GeV, six AK5 jets (p_T> ~45 GeV, at least one b-tagged)
- several constraints on the invariant masses of the system for reducing combinatorics and background from $t\bar{t}$ background
- limits set on prediction based on RS model
- open to inputs on more interpretations for exploiting these results !

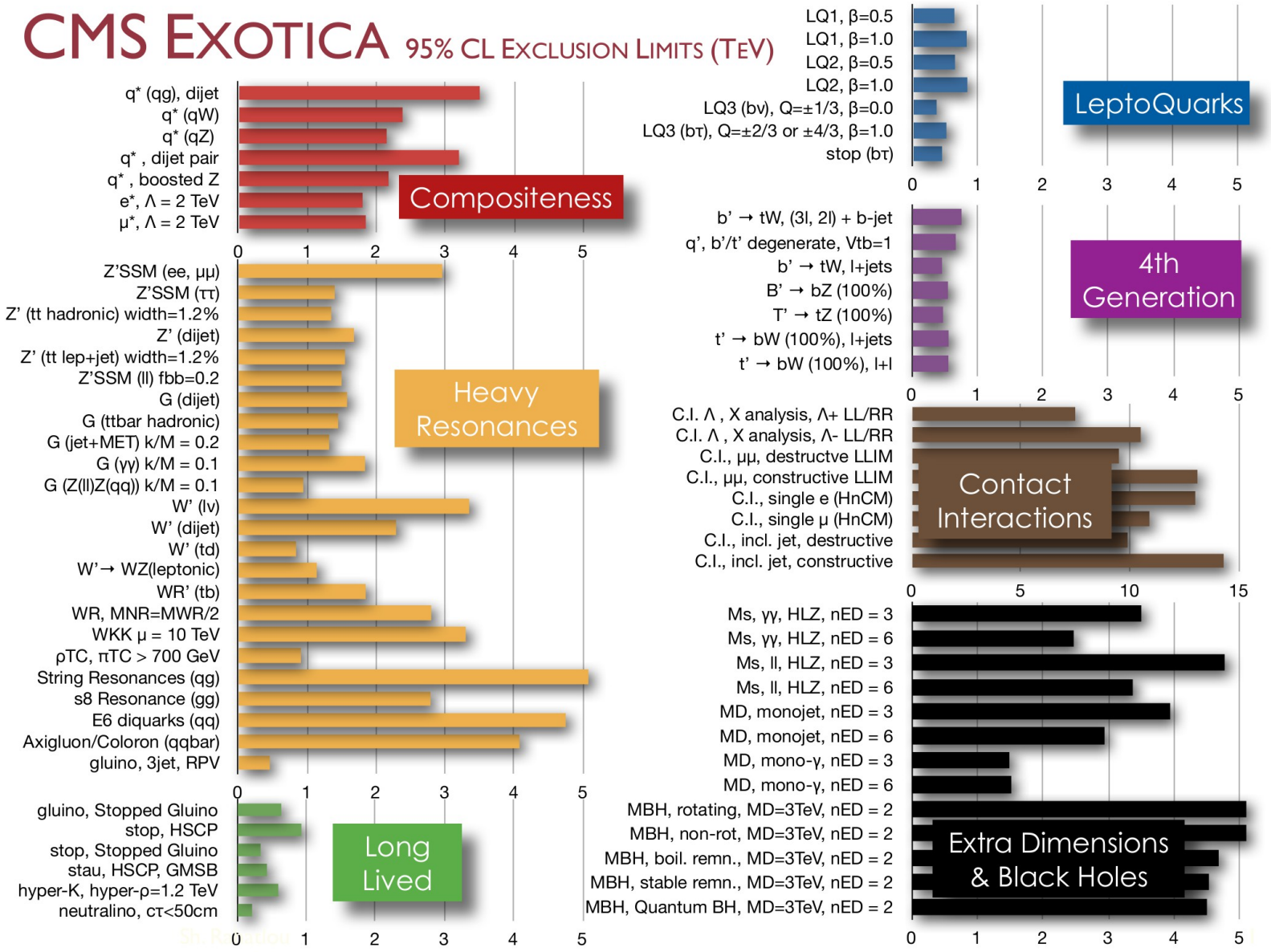


Summary



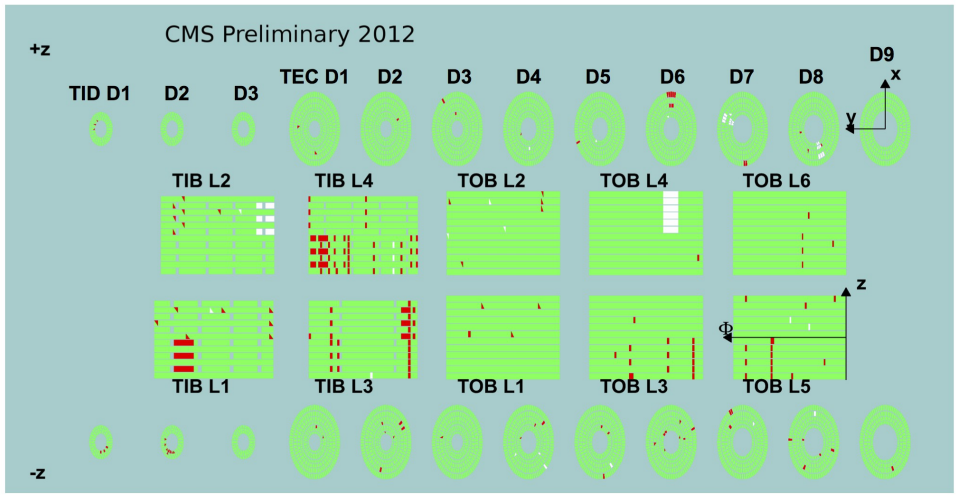
$W' \rightarrow e\nu$ cand with highest M_T

- Intense program of exotic searches at CMS:
  - I could focus only on few highlights, but physics program is huge
  - 61 public results released with 7TeV data, already 12 new ones with 8TeV
- No sign of new physics, but we keep searching
  - sensitivity and limits keep improving thanks to lumi and new analysis techniques
- Plan for 2013 is to update a substantial fraction of analyses with full statistics at $\sqrt{s}$=8 TeV

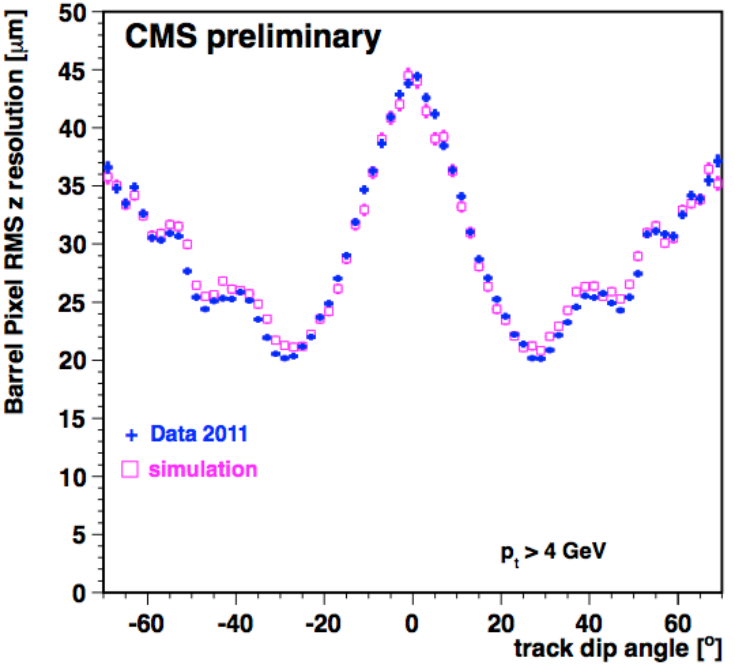

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lν)
W' (dijet)
W' (td)
W'→ WZ(leptonic)
WR' (tb)
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Heavy Resonances
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
neutralino, cτ<50cm
Long Lived
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bν), Q=±1/3, β=0.0
LQ3 (bτ), Q=±2/3 or ±4/3, β=1.0
stop (bτ)
LeptoQuarks
b' → tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' → tW, l+jets
B' → bZ (100%)
T' → tZ (100%)
t' → bW (100%), l+jets
t' → bW (100%), l+l
4th Generation
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
Contact Interactions
Ms, γγ, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 3
Ms, ll, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-γ, nED = 3
MD, mono-γ, nED = 6
MBH, rotating, MD=3TeV, nED = 2
MBH, non-rot, MD=3TeV, nED = 2
MBH, boil. remn., MD=3TeV, nED = 2
MBH, stable remn., MD=3TeV, nED = 2
MBH, Quantum BH, MD=3TeV, nED = 2
Extra Dimensions & Black Holes

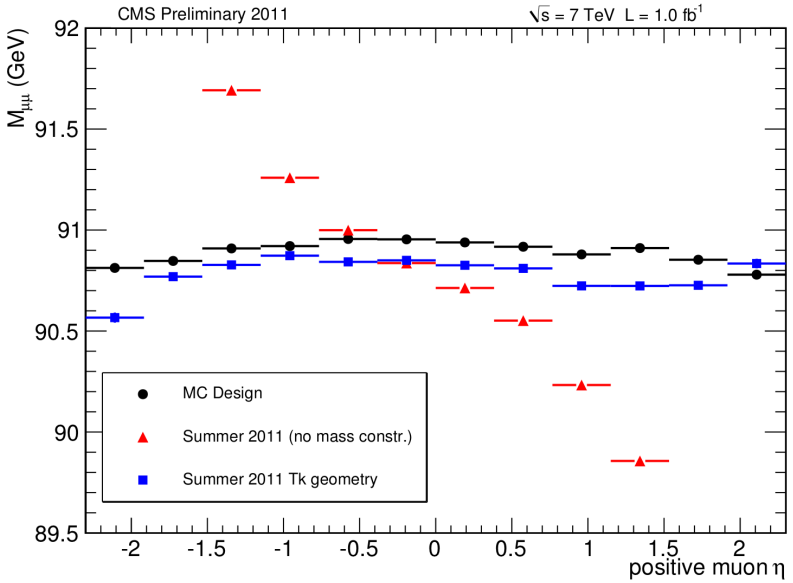
Backup slides

Commissioning of Si Tracker



Active, Masked, Not Commissioned

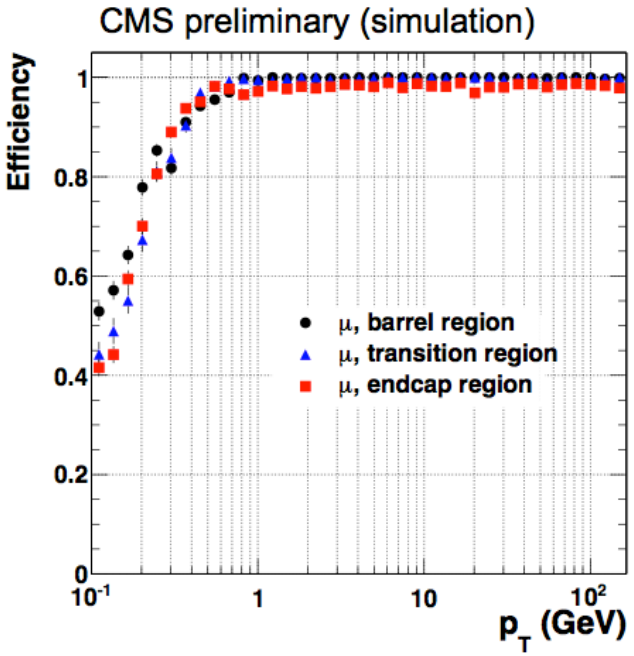




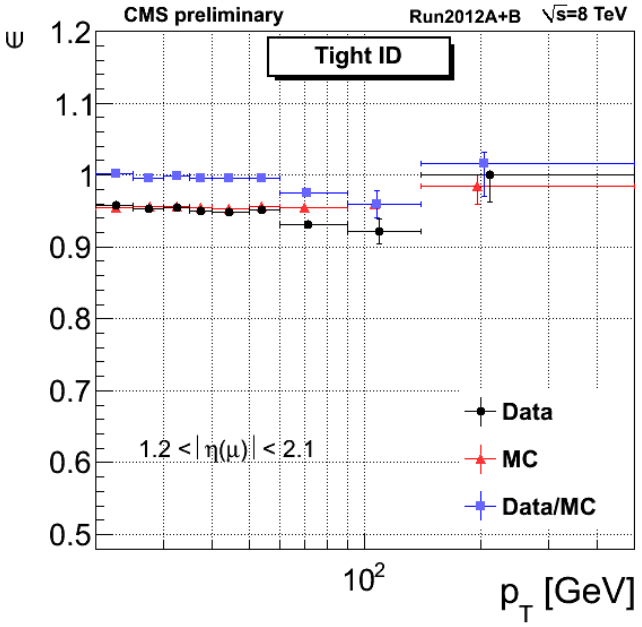
Excellent level of understanding of the Si Tracker:

- High fraction of active modules in both pixel and micro-strip trackers (>98%), high hit efficiency
- Hit resolution within specifications, well described by simulation
- Alignment monitored over time, using several types of tracks for constraining systematic deformations. $Z \rightarrow \mu\mu$ is one of the main handles

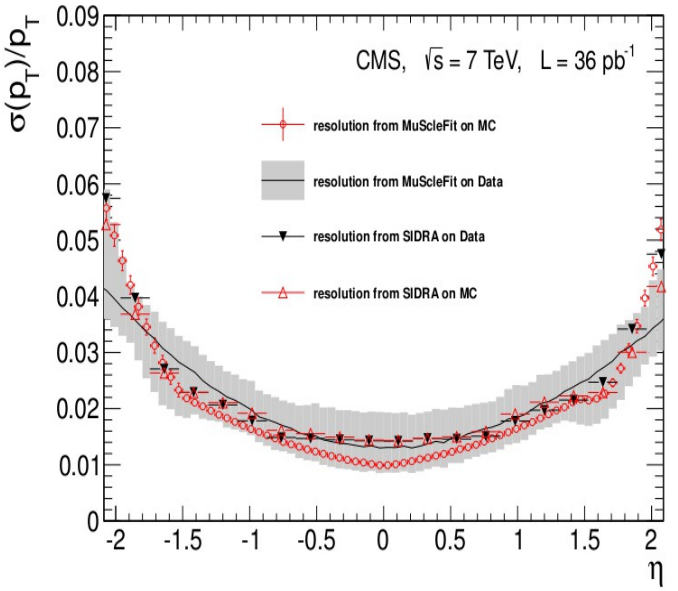
Muon performances



Tracking efficiency(all η)

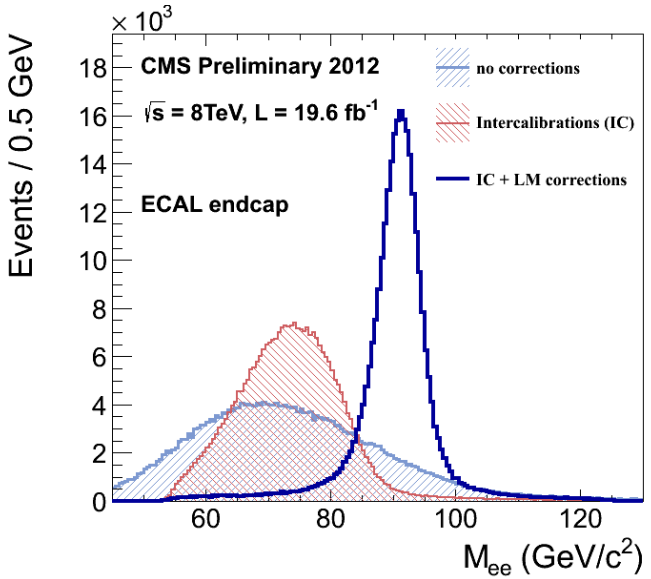


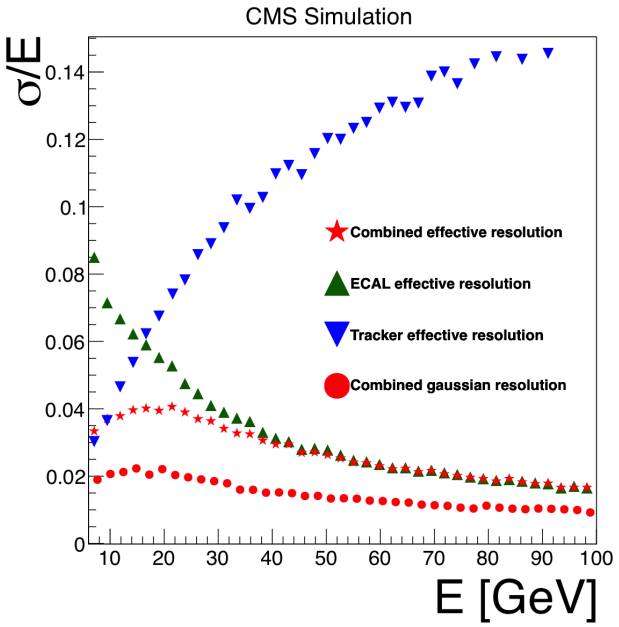
Tight ID efficiency (endcaps)

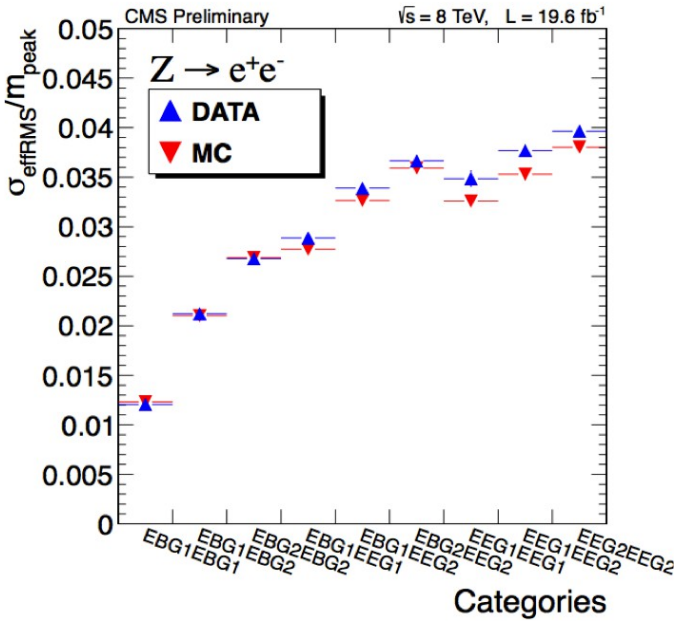


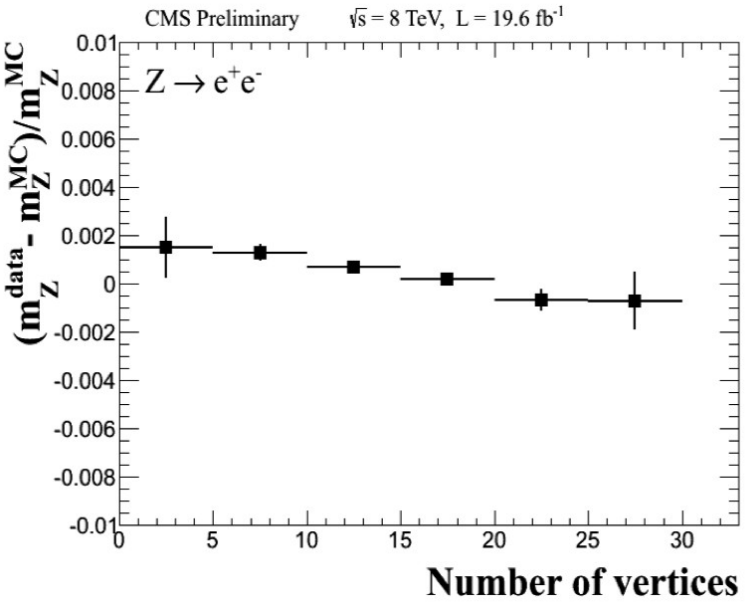
Resolution vs η from $Z \rightarrow \mu\mu$

More about electrons









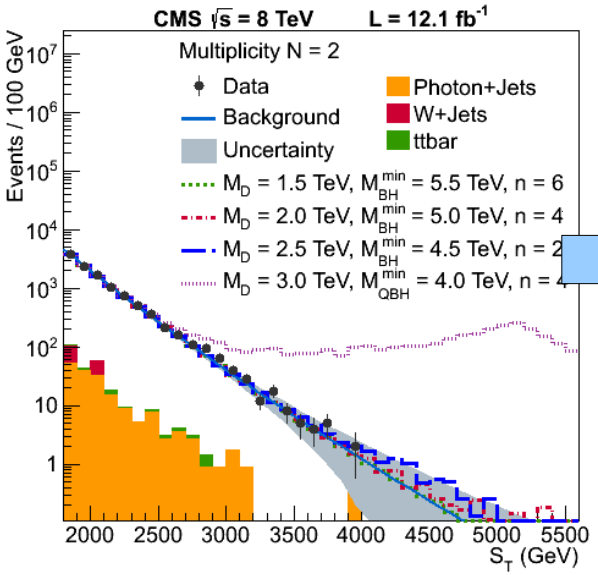
Black Holes with 8TeV data

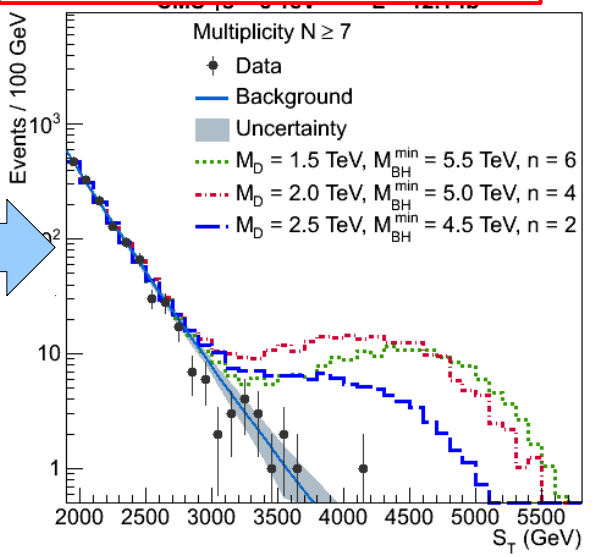
CMS-PAS-EXO-12-009

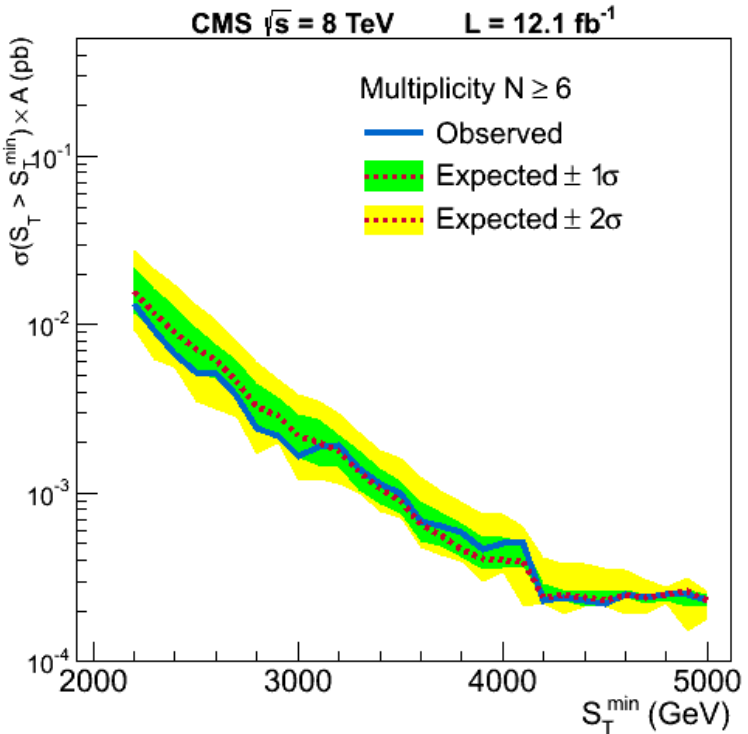
Updated with 12.1 fb^{-1} at 8 TeV.

Main variable is S_T (scalar sum of p_T all particles with p_T > 50 GeV plus MET).

Shape of S_T from events with multiplicity of particles with p_T 50 > GeV, N==2. Normalization for each N bin from low S_T region.







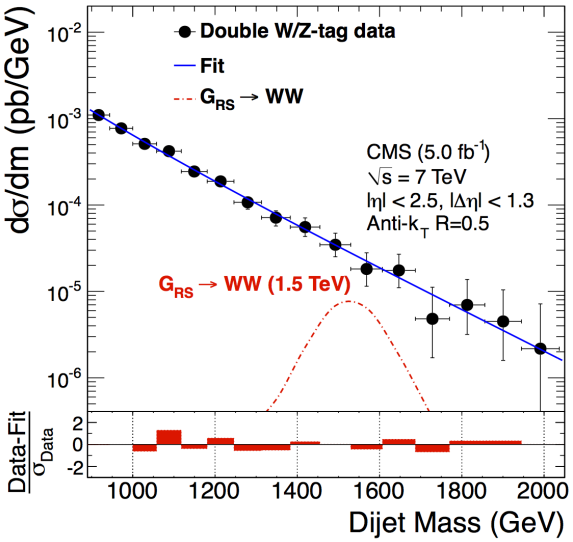
Limits set on BH production as a function of fundamental Planck scale (M_D) and # of extra-dim (N_D) for BlackHat and Charybdis MC.

Model-independent limit on # events with $S_T > S_T^{min}$, for different high-p_T multiplicities.

VV searches

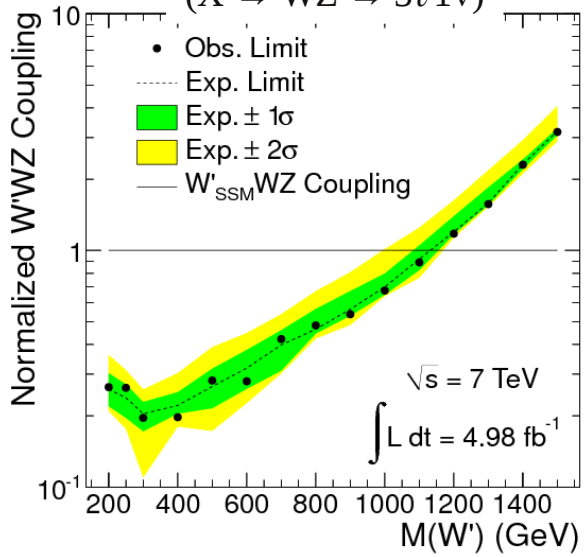
CMS-PAS-EXO-11-095

$(X \rightarrow VV \rightarrow 2J)$



CMS-PAS-EXO-11-041

$(X \rightarrow WZ \rightarrow 3\ell 1\nu)$

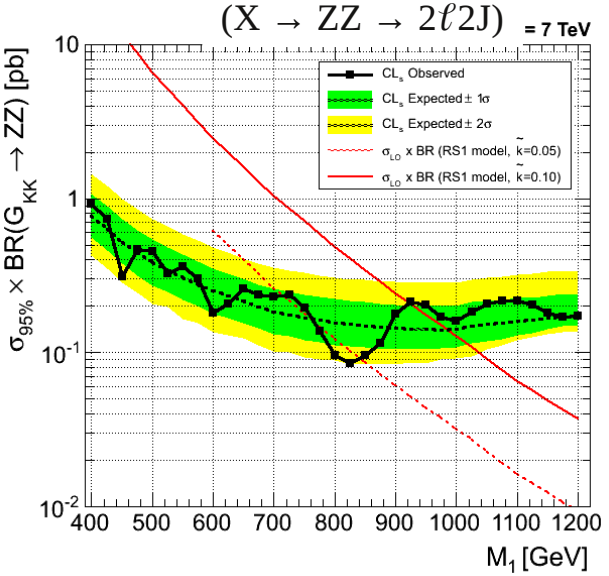


Several searches for resonances decaying to VV (V=W,Z):

- Gravitons, W', composite H
- VV scattering related to symmetry breaking, in general
- fully exploiting detector by probing different final states
- semi-leptonic and fully hadronic are most sensitive channels thanks to high BR(V → qq)
- at high pT of V, quarks very collimated: **jet merging**! Need ad-hoc analysis techniques
- all of this done at 7 TeV, preparing updates with full 8TeV stats

CMS-PAS-EXO-11-102

$(X \rightarrow ZZ \rightarrow 2\ell 2J)$



CMS-PAS-EXO-12-014

$(X \rightarrow ZZ \rightarrow 2\ell 1J + X \rightarrow ZZ \rightarrow 2\nu 1J)$