CMS searches for new physics

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On behalf of the CMS Collaboration
(CIEMAT – Madrid)

Workshop on Discovery Physics at the LHC
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CMS searches for new physics: outline

Where

The CMS detector

What is in the CMS program

Exotic particles, SUSY, Higgs
and its challenges

How are we takling

Understanding the detector
Physics of Standard Model (SM)
commissioning

Overview on search strategies

Focusing on the experimental aspects rather than on the models

Incomplete list, only highlights -- not enough time to mention all searches

Results on CMS searches with 2010 data presented in dedicated talks in this conference

See bibliography at the end

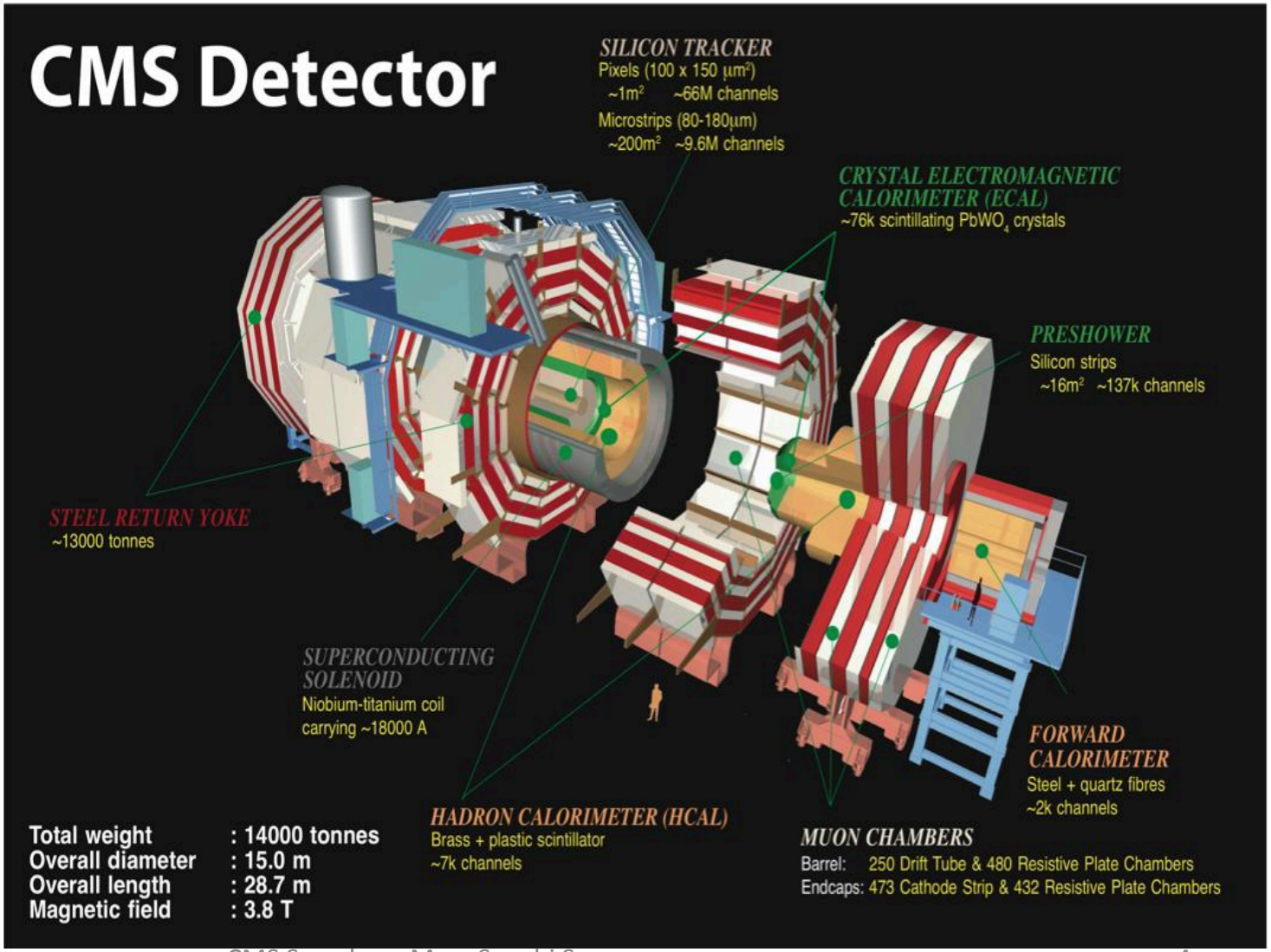
Where: the CMS detector

The experiment: CMS detector

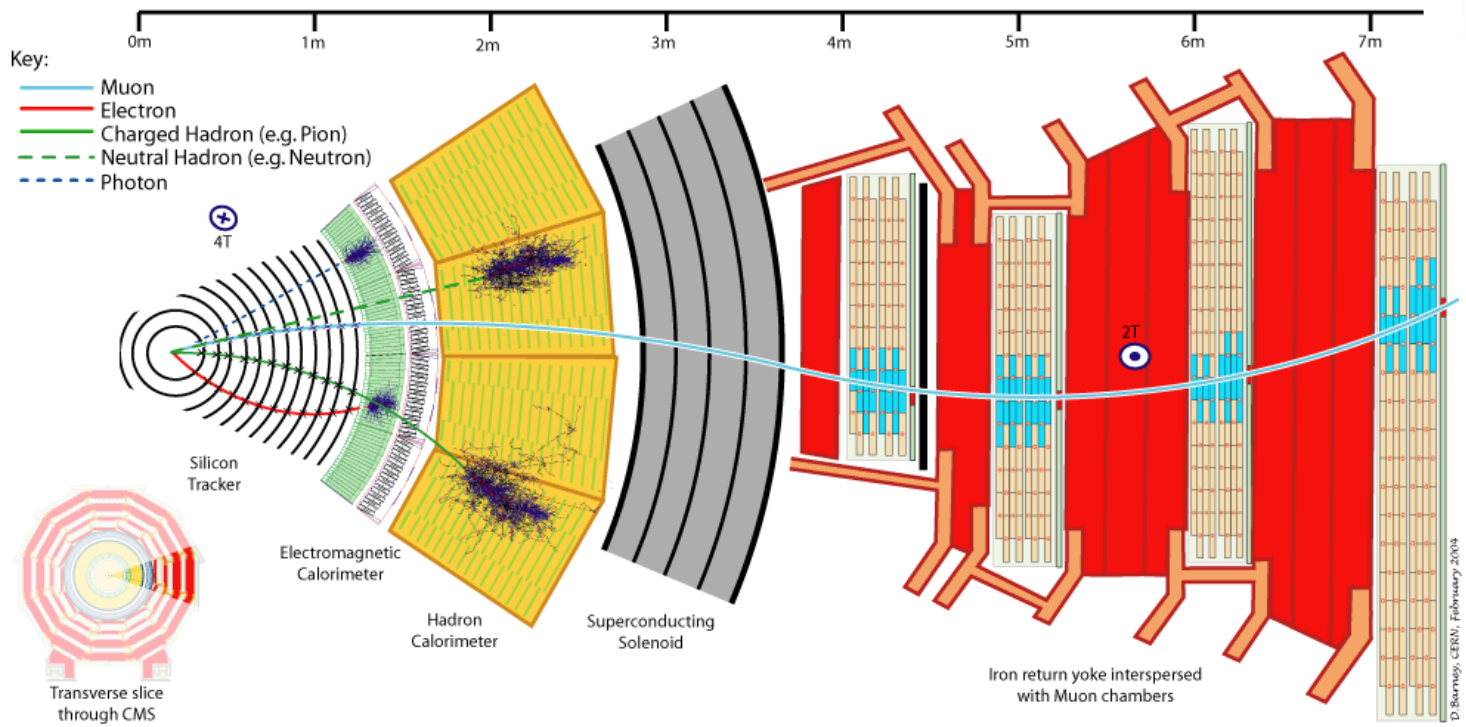
Magnet: Solenoid 3.8T, comprises calorimeters

Inner Tracking: Pixels and Si-strips

excellent resolution



The experiment: CMS detector

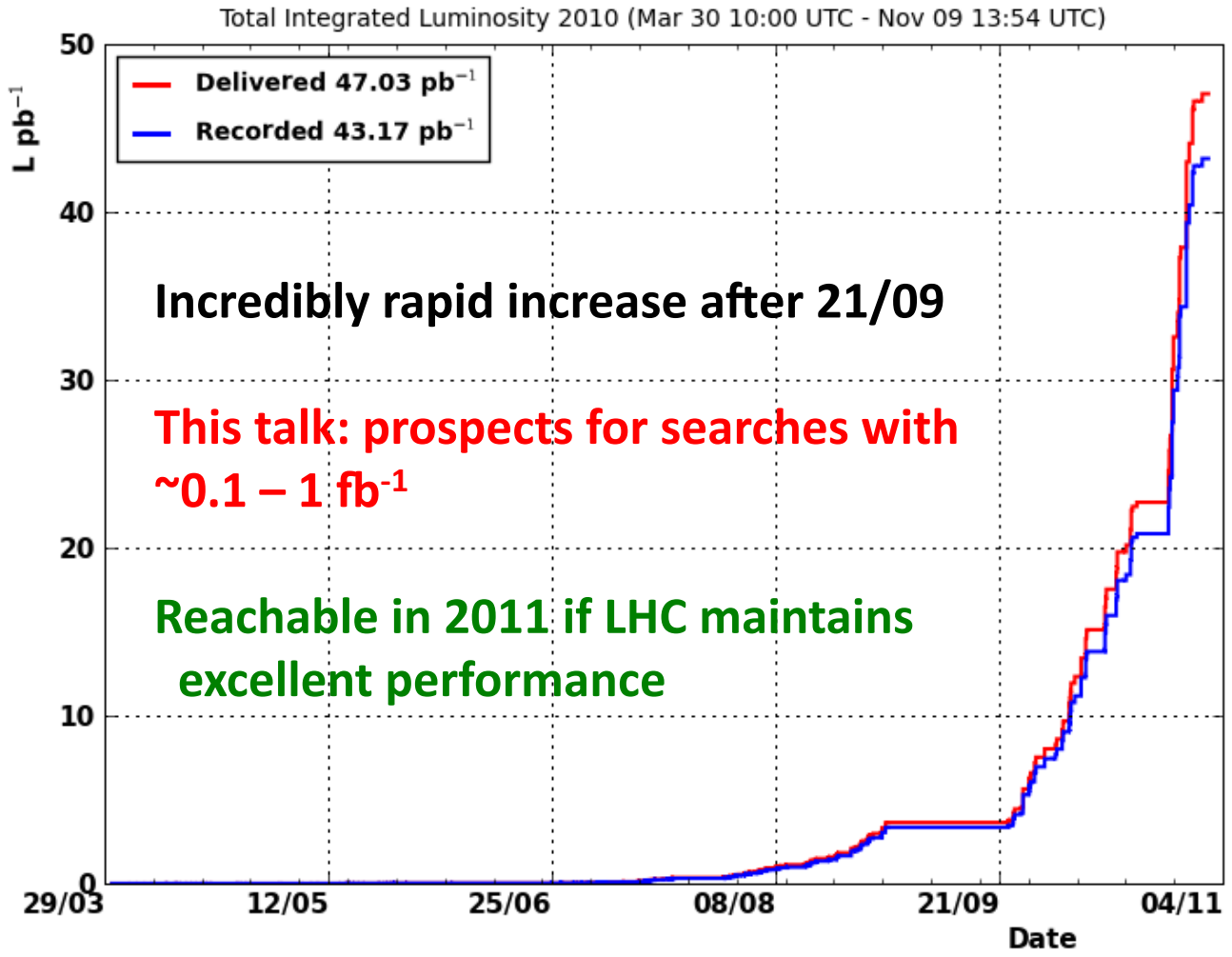


Muon Spectrometer System: Instrumented Iron return yoke
(resolution muons (spectr+tracker): ~1% for pT ~100 GeV, ~10% for 1 TeV)

EM Calorimeter: Lead-Tungstate Crystals ***(ΔE/E < 0.5% for E > 100 GeV, good resolution Mγγ)***

HAD Calorimeter: sampling, dense absorber (brass or steel) + layers of dense absorber and tiles of plastic scintillator

Luminosity x time in 2010



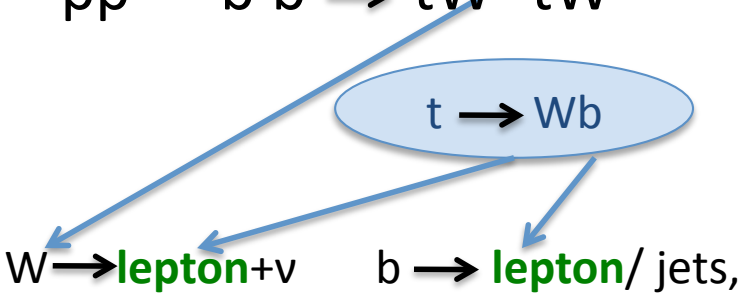
What: search strategy for new exotic states

MC based studies

Fourth generation (b') quark

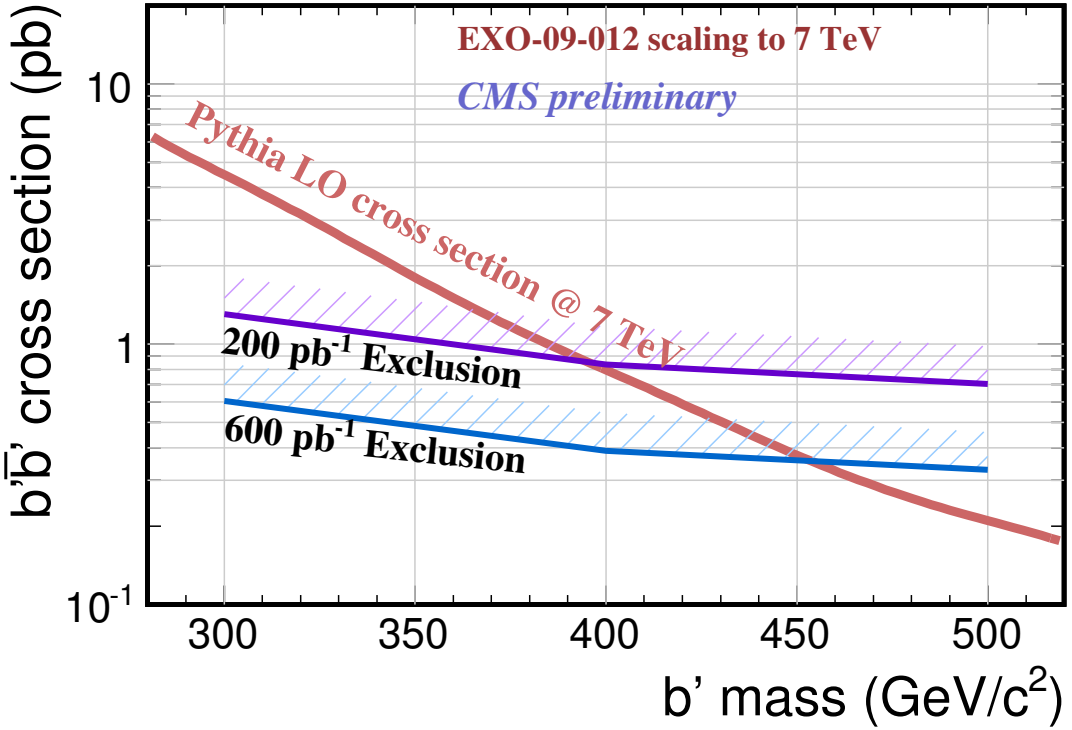
Search: pair production of bottom-like fourth generation quark

$pp \quad b'\bar{b}' \rightarrow \bar{t}W^+ tW^-$



Signature: same-sign dileptons or trileptons + jets + missing ET (MET)

Background: very small bkg from the Standard Model: ttbar+jets/W/Z



100 pb-1 of 7TeV CMS will surpass Tevatron limit of Mass(b')>325 GeV @ 95% C.L.

Large Extra Dimensions

In the SM: gravity scale M_{planck} ≈10^{19} GeV >> electroweak scale M_{EW} ≈ 10^{3} GeV
(hierarchy problem, strong implications on Higgs mass, due to radiative corrections)

AAD Model: constrain SM to space+time (3D) *(Arkani-Hamed,Dimopoulos,Dvali)*
allow gravity to propagate through entire multi-D space

Gravitational force diluted, **fundamental Planck scale** related to the apparent scale via **number** and **ratio of ED**:

$$M_D^{n_{\mathrm{ED}}+2} \approx \frac{M_{\mathrm{Planck}}^2}{R^{n_{\mathrm{ED}}+2}}$$

Virtual gravitons production: parameterization of ED effects in terms of M_S (ultraviolet cutoff scale) :

$$\eta_G = \frac{\mathcal{F}}{M_S^4} \qquad \mathcal{F} = \begin{cases} \log\frac{M_S^2}{\hat{s}}, & n_{\mathrm{ED}} = 2 \\ \frac{2}{n_{\mathrm{ED}}-2}, & n_{\mathrm{ED}} > 2 \end{cases}$$

Limits: in terms of n_{ED}, M_D (real G) or n_{ED}, M_S (virtual G)

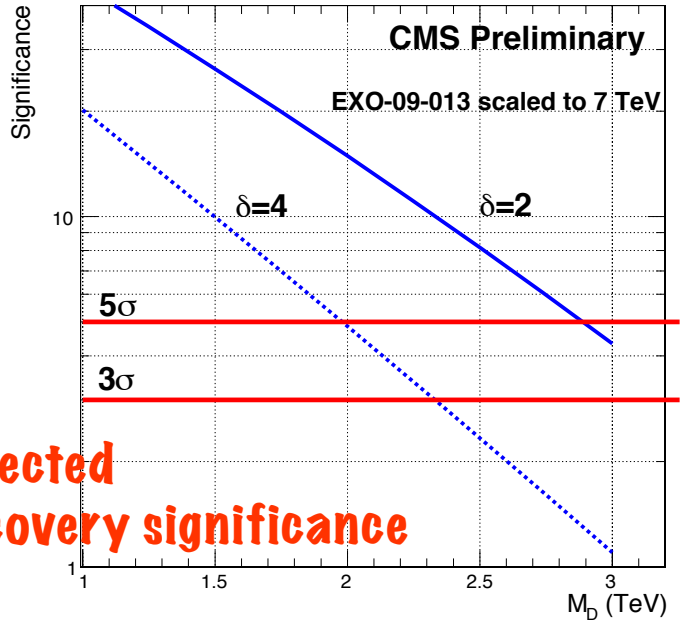
Large Extra Dimensions

Search 1: graviton production: $q\bar{q} \rightarrow gG$, $qg \rightarrow qG$, $gg \rightarrow gG$

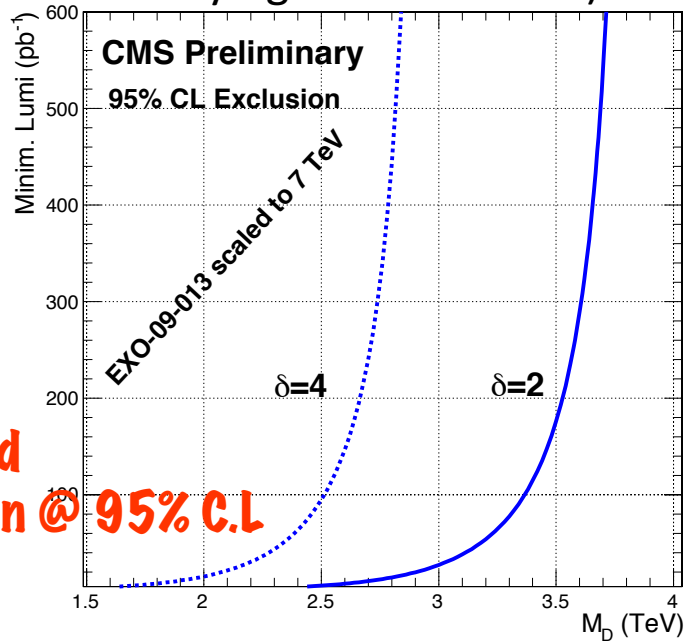
Limits in terms of M_D scale and number of extra dimensions ($n_{ED} = \delta$)

Signature: **Mono-jet production**: one single jet at very high-pT, compensated by same amount of MET back-to-back *(see also Data-Driven techniques)*

Background: $t\bar{t}$, W+jet and Z+jet production (bosons decaying into neutrinos)



Expected Discovery significance

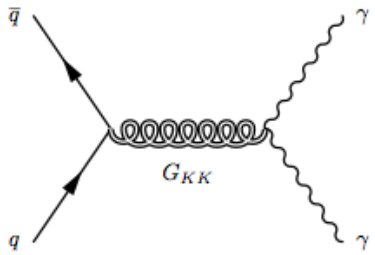


Expected exclusion @ 95% C.L

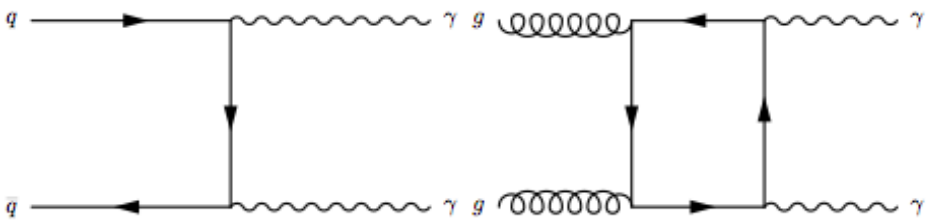
Searches limited by understanding the tail on MET distributions (discussed later)

Large Extra Dimensions

Search 2: virtual graviton production, decaying into two photons

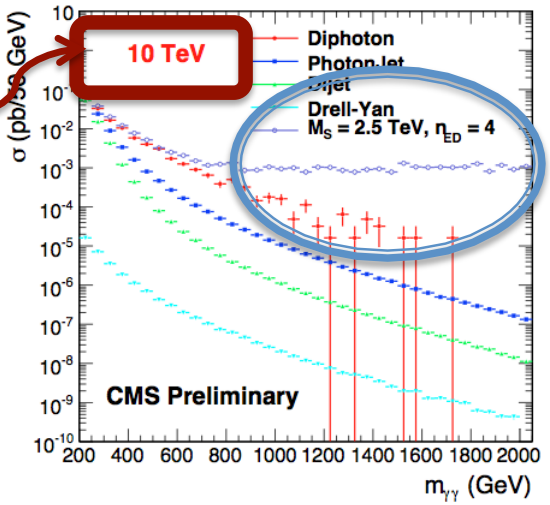


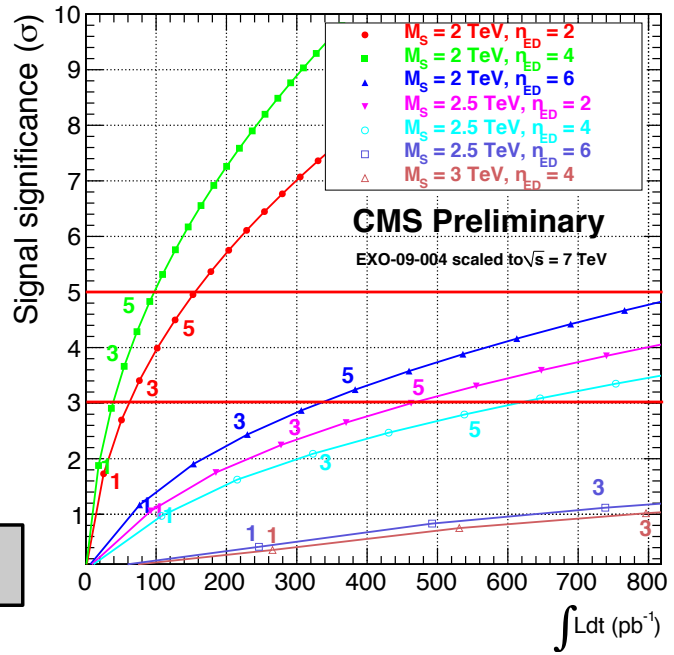
SM background: real diphoton production and electrons or jets faking photons



Signature: : excess of diphotons above SM, tail of Mγγ distribution (no resonance)

For 10 TeV (illustrative)





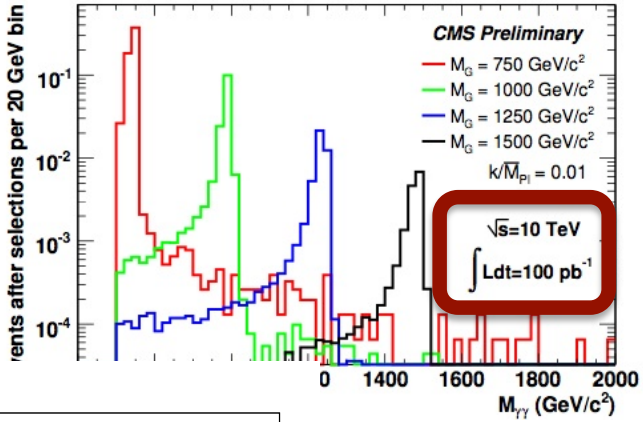
Limits in terms of cut-off scale M_S and n_{ED}

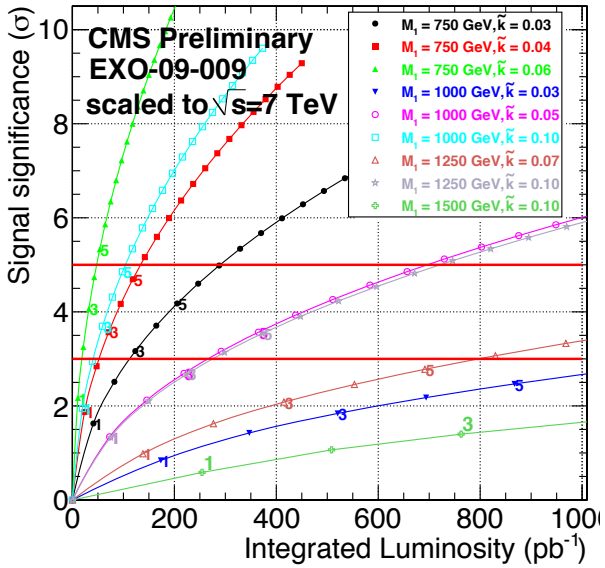
Large Extra Dimensions

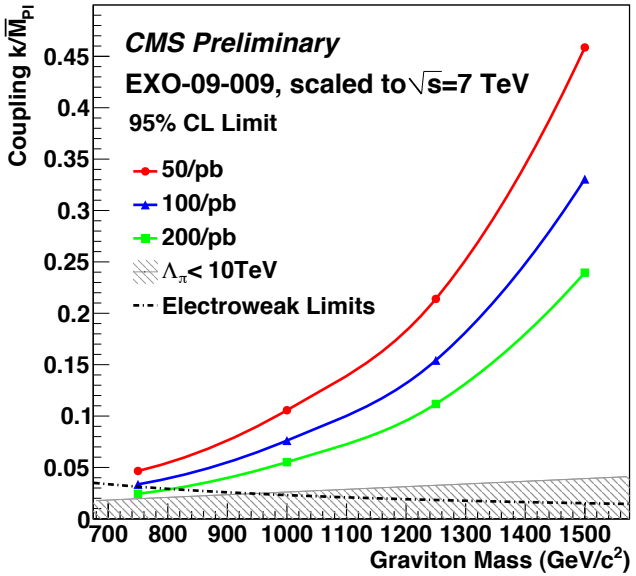
Search 3: same γγ data sample allows limits to be imposed also to graviton production in the **Randall-Sundrum** model

Signature: : expected resonant states of Kaluza-Klein gravitons

(careful: for 10 TeV, illustrative)







Leptoquarks

Standard Model: striking symmetry between leptons and quarks

is there a fundamental relationship between them?

Leptoquarks: proposed in several models (GUT, compositeness, Technicolor, superstring…)
carry both baryonic and leptonic numbers

LQ's coupling to SM fermions **(β)**: only chiral, **only within the same generation**

Allowing mixing of generations . violation of lepton-family numbers
. flavor-changing neutral currents

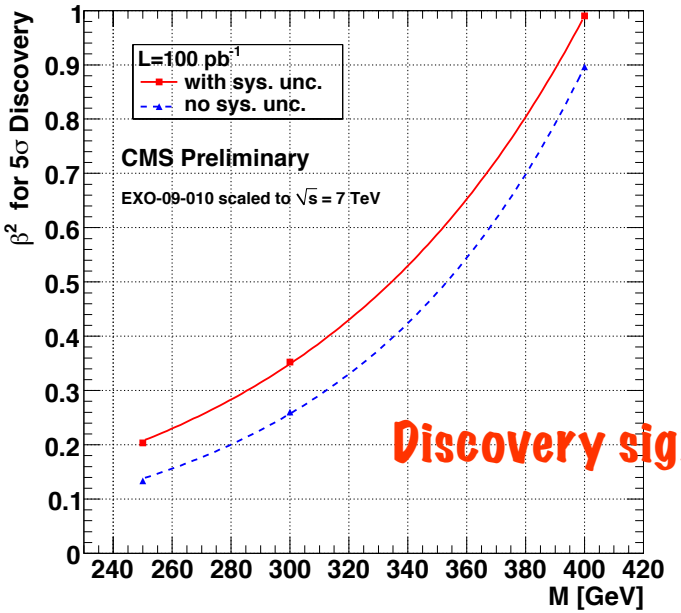
Searches on First Generation of Leptoquarks: see dedicated talk

Leptoquarks

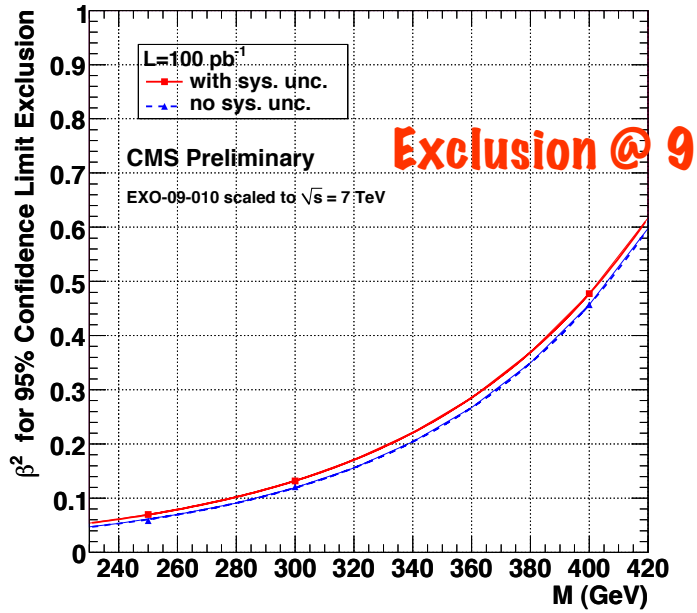
Search : pair of leptoquarks decaying to muon+quark ($q\bar{q}$ anihilation or gg fusion)

Signature: : two high-p_T isolated muons and two high-pT jets

Background: $t\bar{t}$+jets, Drell-Yan+jets (Z/γ* mediated), VV+jets (V=W or Z)



Discovery significance



Exclusion @ 95% C.L

Limits in terms of the LQ Mass and coupling β

Prospects for Higgs discovery

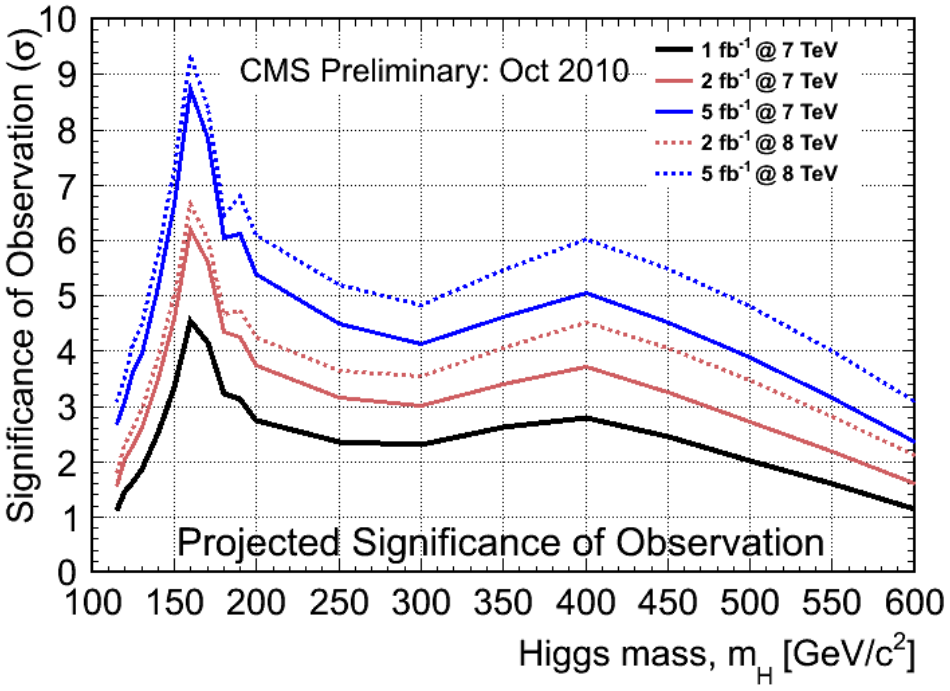
Higgs: the only Standard Model search

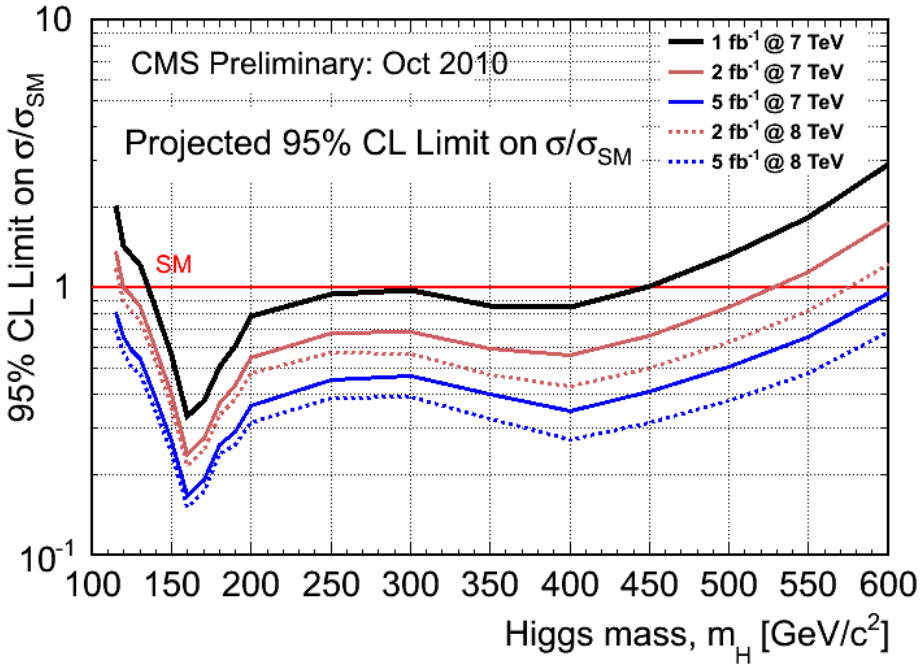
Channels included	Higgs mass range used in analyses (GeV)
$H \to \gamma\gamma$	115-150
VBF $H \to \tau\tau$	115-145
VH, H→bb (highly boosted)	115-125
VH, H→WW→lvjj	130-200
H→WW→2l2v + 0/1 jets	120-600
VBF H→WW→2l2v	130-500
H→ZZ→4l	120-600
H→ZZ→2l2v	200-600
H→ZZ→2l2b	300-600

Spans Higgs mass range from 115 to 600 GeV

Higgs: the only Standard Model search

Combination of all channels: prospects for observation / exclusion

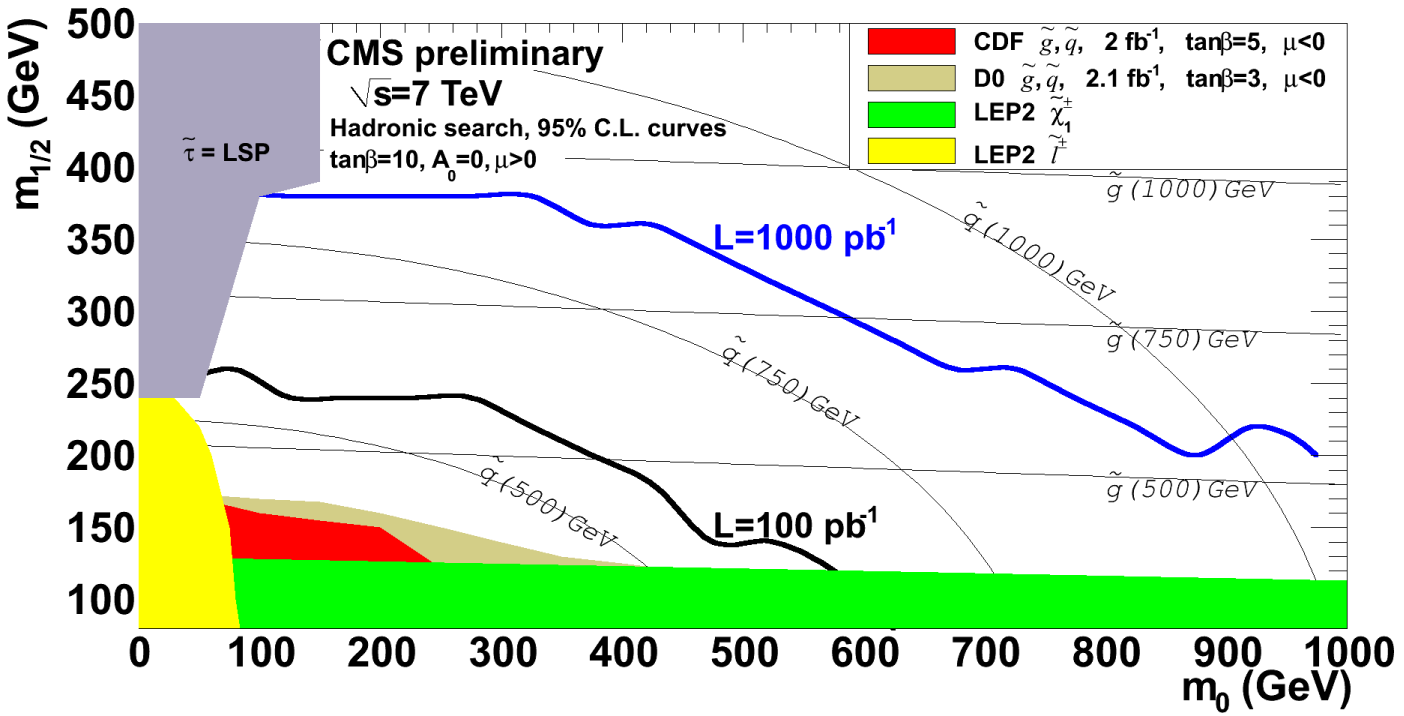




With L=5 fb^{-1}, CMS is expected to reach an exclusion sensitivity in the mass range from the LEP limits (114 GeV) to 600 GeV.

Super symmetry

SUSY



- mSUGRA : at ~100 pb^{-1} sensitivity to SUSY parameter space well beyond the current limits (Tevatron and LEP)
- BUT… sensitivity reach strongly dependent on the SM background control and experimental uncertainties AND…

SUSY

CMS approach:

- keep searches as generic as possible
- do not confine to one/a set of specific models

Expected Signals:

- Final states with large MET, jets, leptons, photons above the Standard Model

Background:

- SM cross sections usually orders of magnitude larger than SUSY signals

With first data collected in 2010:

- Derive data-driven methods to control background
- Control/reduce experimental uncertainties

How: data-driven methods for background and experimental uncertainties control

QCD background reduction: α_T

Important variable in SUSY searches: **$H_T = \Sigma\ p_T$(jets)**

- **Define a new variable:** $\alpha_T \equiv \frac{p_{T2}}{M_T}$ **(for dijets, can be redefined for multijets)**
- M_T= dijet system transverse mass
- Jet numbering: 1, 2 ordered in p_T
- Can be re-written as $\alpha_T = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-\cos\Delta\phi)}}$ ΔΦ=the angle between 1,2

⌘ Well measured back-to-back di-jet system with no real MET: $\alpha_T = 0.5$

⌘ Di-jet system with no real MET, but one jet mismeasured: $\alpha_T < 0.5$

⌘ If 3 jets in the event, but one is lost: $\alpha_T > 0.5$

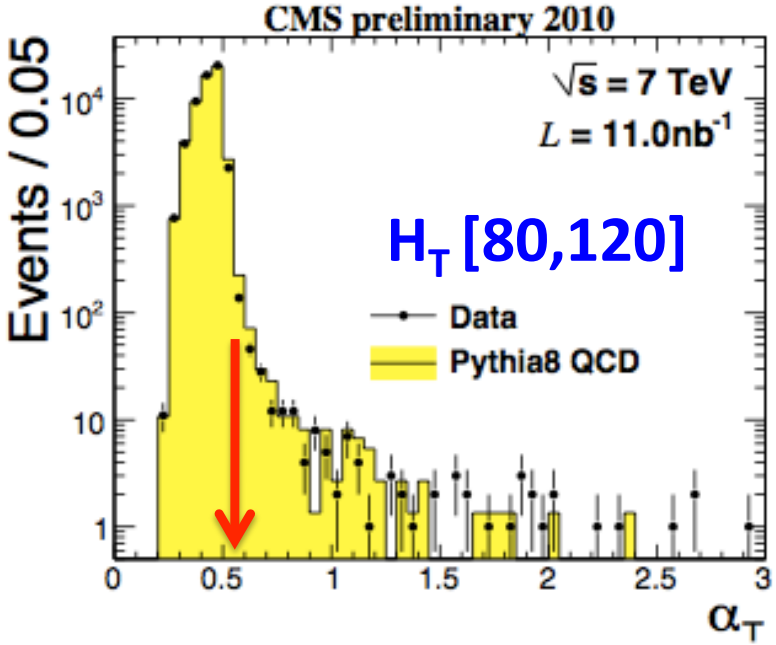
QCD background reduction: α_T

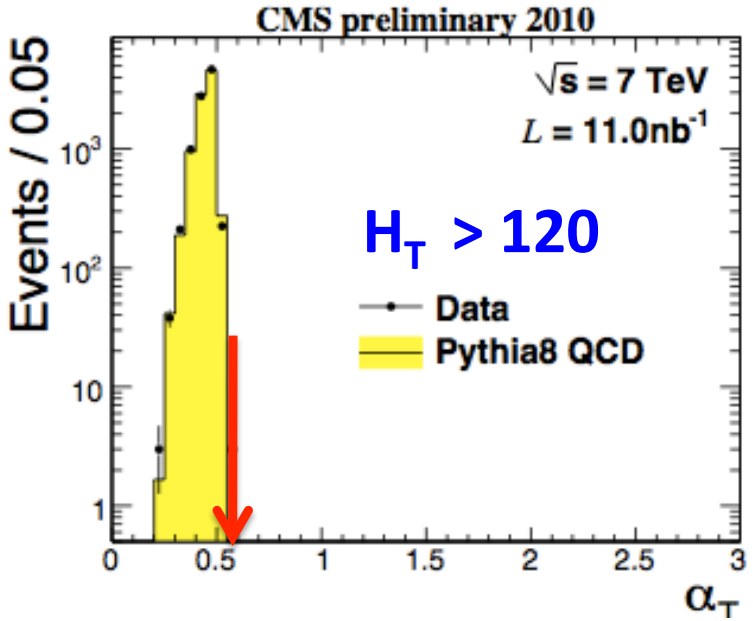
QCD events : Mainly confined at $\alpha_T < 0.5$

SUSY candidates sample: selected with cut $\alpha_T > 0.55$

QCD background to SUSY searches: remaining tail of QCD evt with $\alpha_T > 0.55$

Method: measure QCD bkg **(at moderate H_T)** and extrapolate to **high-H_T region**



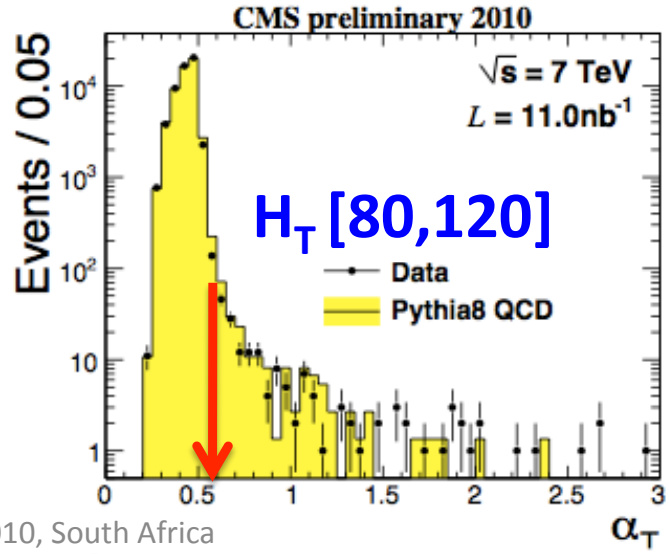


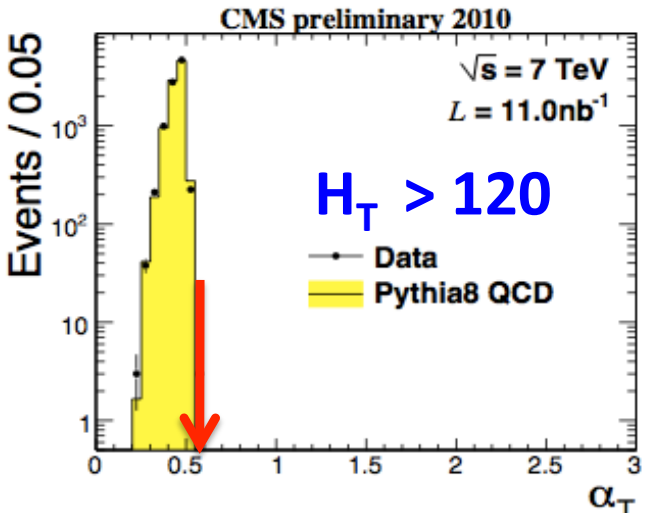
QCD background reduction: α_T

Dependence with H_T : α_T tail in QCD decreases as H_T increases

Excellent discriminant for SUSY searches (expected high H_T)

Fraction of events with	= **upper limit** to QCD bkg
α_T >0.55 in **a given H_T**	**on a higher-H_T sample**
(pure QCD JET sample)	*(containing SUSY candidates)*





QCD background reduction: α_T

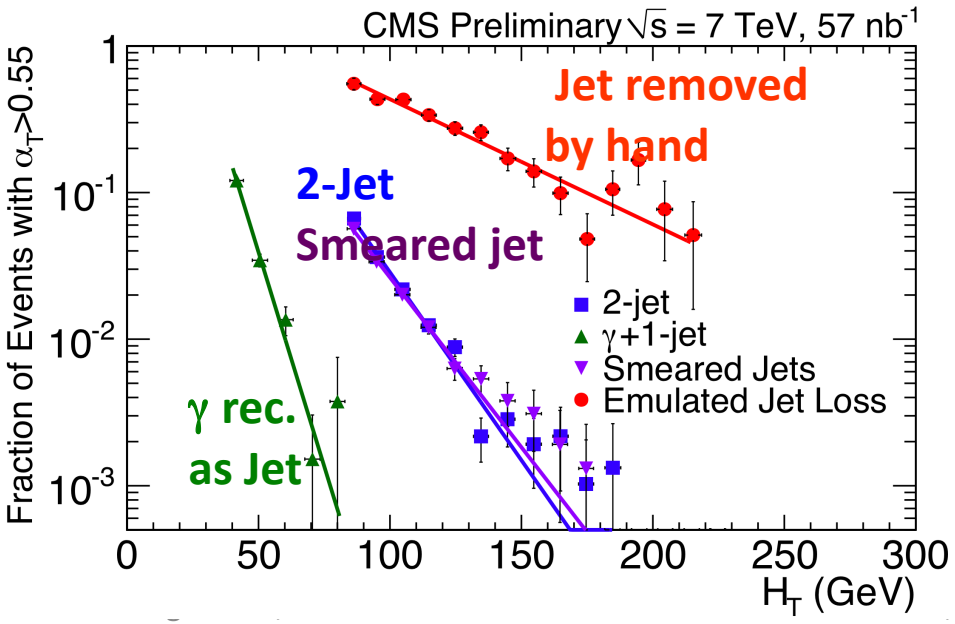
Decrease on QCD bkg does not depend on how well the jets are measured

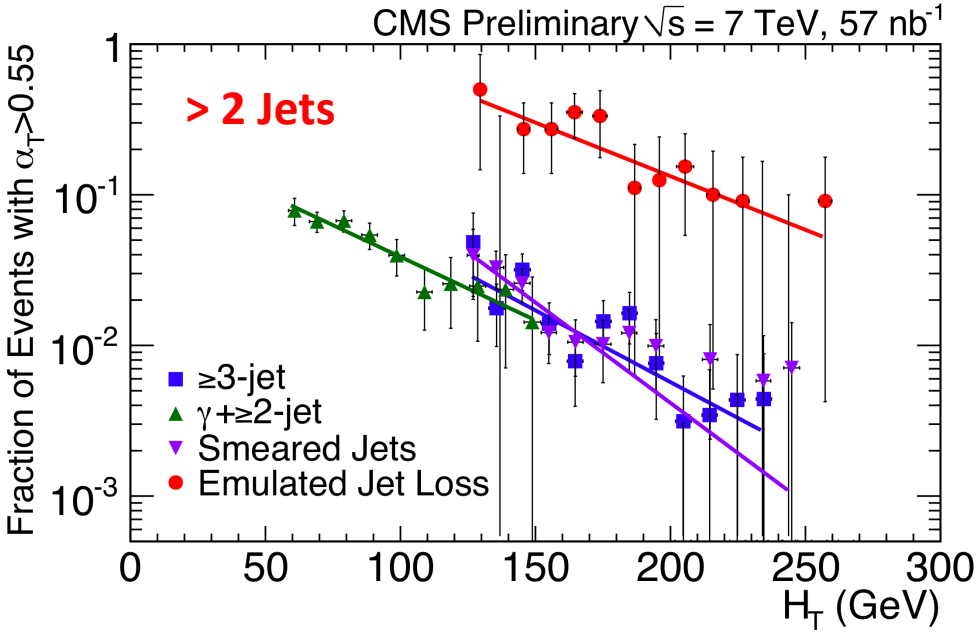
"Spoil the measurement" as much as you want:

- Use γ+jet(s) events (treat the photon is as a jet)
- Emulate extreme jet losses
- Smear jet energies …

(way worse than expected in real data)

Very stable method: fraction still decreases w. H_T





Measuring MET correctly: artificial MET in QCD

Also very important in Exotic searches with MET (e.g. graviton in MonoJet channel)

Artificial MET: **tail from mismeasurement**

* detector effects * spurious signals in the calorimeter * reconstr. software * …

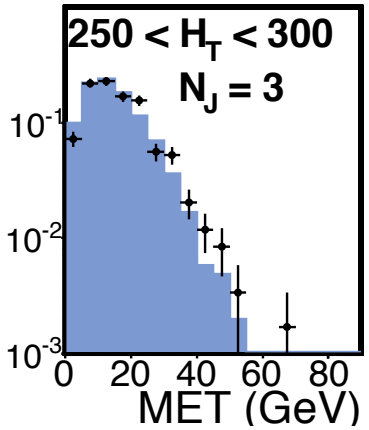
The method:

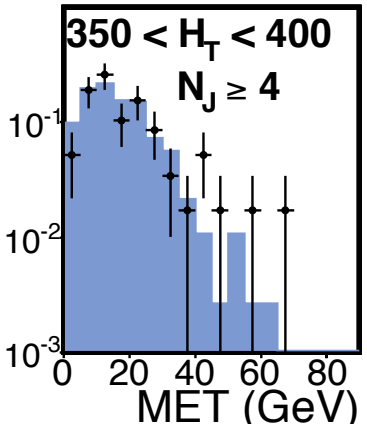
. **model** artificial MET in sample of QCD multi-jet events ➔ no real MET present

. **test** the model in a different sample

Build "templates" in QCD sample: measured MET in (H_T, N_{JETS}) bins

…





… several (H_T, N_{JETS}) bins

Area normalized to 1

+ CMS data

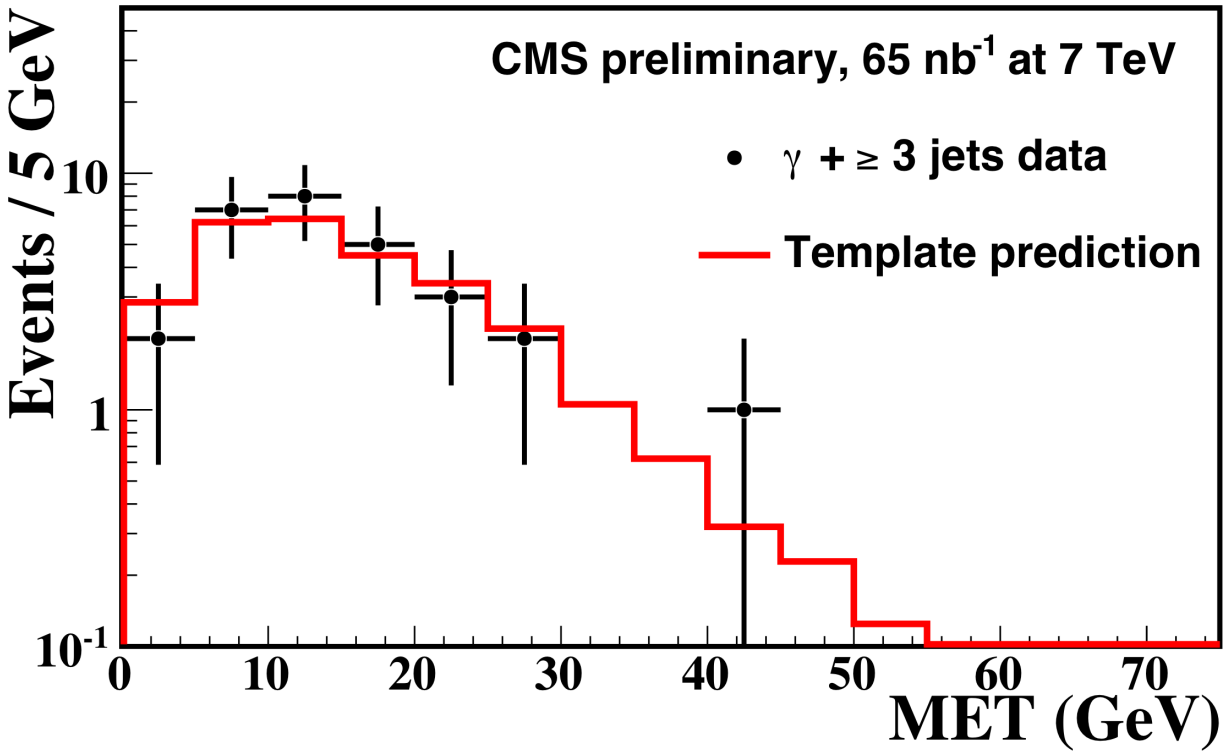
Blue: Pythia MC

Measuring MET correctly: artificial MET in QCD

Use "templates" (from QCD-jet) sample to predict MET tail in **another sample:**

Photon+Jets sample: collected with a different trigger, also **no real MET**

- **template prediction:** according to ($H_{T,}$ N_{JETS}) bin in Photon+Jets
- compare with the MET **actually measured** in Photon+Jets sample:



Remarkable agreement

Data-driven method to control MET tails from fakes established

(exercise @ very low statistics)

Measuring e, μ, γ correctly: control fake objects

Also very important in Exotic searches (e.g. searches with photons, multi-leptons)

Measured objects not always ``signal" objects we are looking for **(fakes)**

Case for electrons, easily extendable for muons, photons

Measured electrons may not be ``prompt electrons":

- products of heavy-flavor decays
- QCD jets mis-identified as electrons
- products of photon conversions

Background control with templates:

Isolation: sum of E_T within a hollow cone ($\Delta R<0.3$) around the electron

Relative Isolation: Isolation/p_T *(<0.3 ➔ cut for prompt electrons selection)*

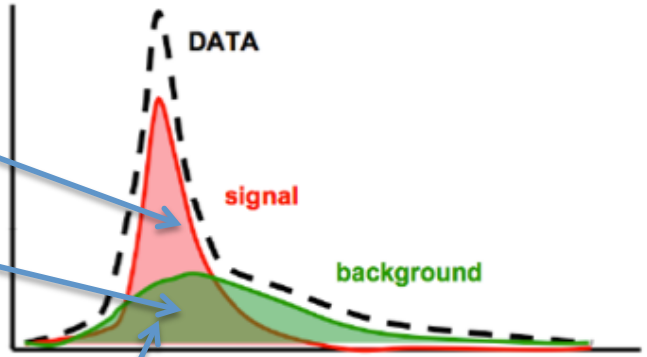
Measuring e, μ, γ correctly: control fake objects

Templates in a sample containing electron + MET

Whole sample = sum of signal.or.bkg enriched subsamples

RelIso shape very different each subsample:

- **Signal:** isolated electrons from **W → e ν** , peaked at small RelIso
  (signal shape taken from MC)



- **Bkg electrons from photon conversion**:
  ``almost same'' cuts for electron identification, BUT
  demand a partner track consistent with $\gamma \rightarrow e^+e^-$

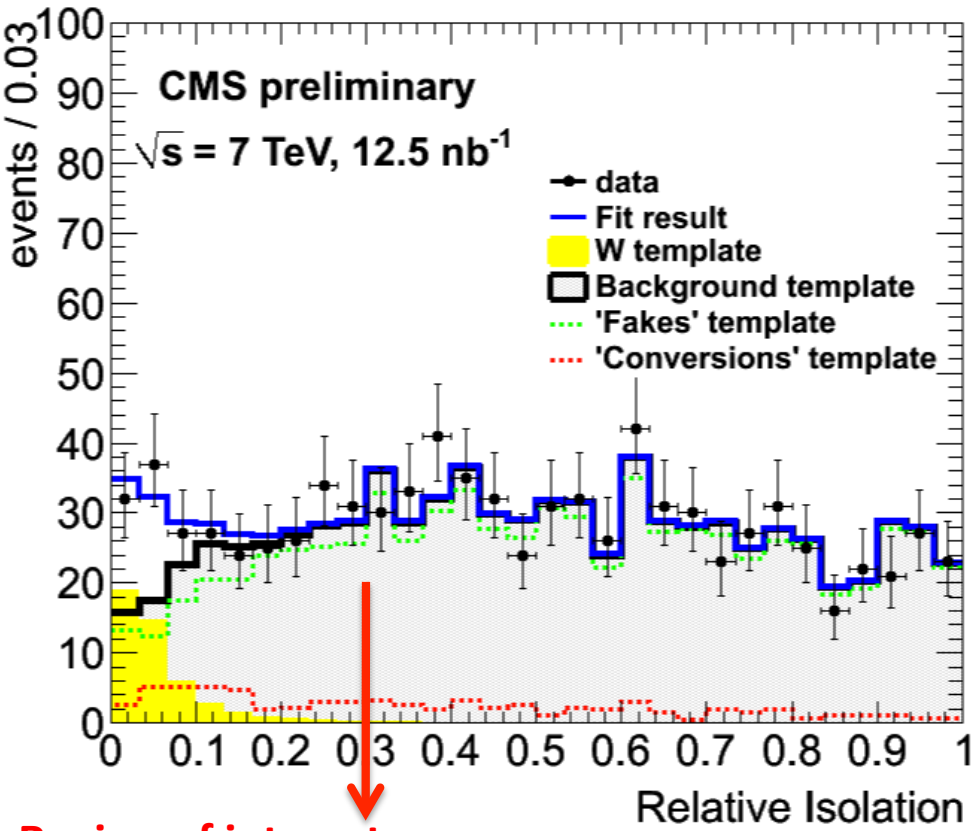
- **Bkg from fakes:**
  QCD jets mireconstructed as electrons and **electrons from heavy flavor decays**:
  ``almost same'' cuts for electron identification, BUT
  no matching track expected from electrons produced at primary vertex

(`matching trk' = propagated from pixel detector to the position of the electron calorimeter cluster)

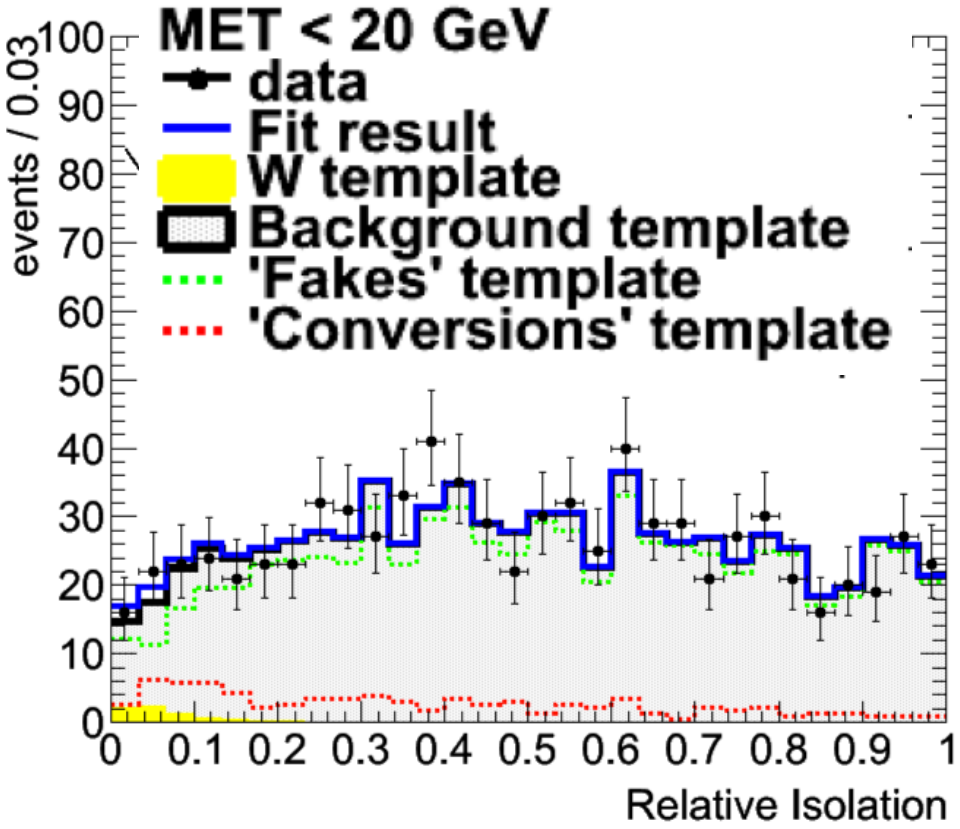
see figure in page 5

Measuring e, μ, γ correctly: control fake objects

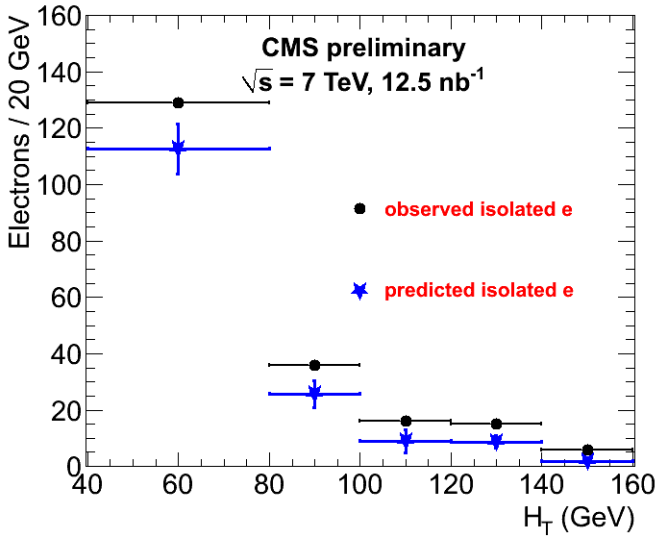
Allow fit to data determine best proportion signal + background : data well described



Region of interest



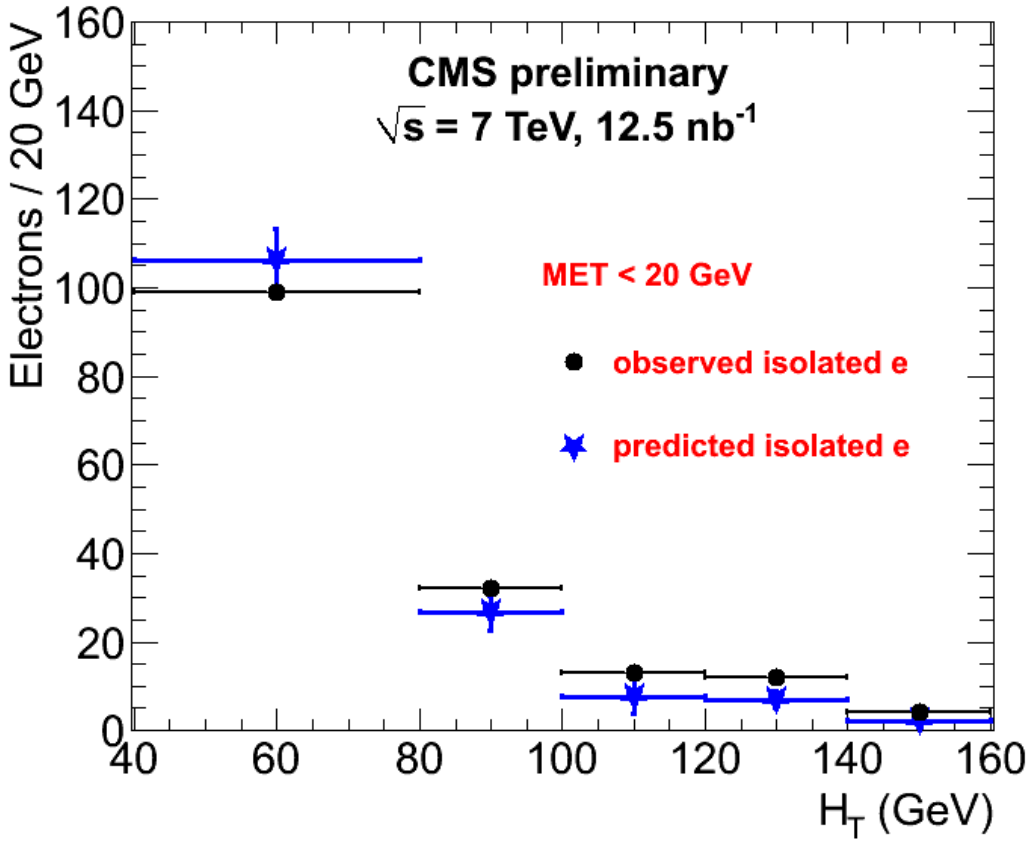
Measuring e, μ, γ correctly: control fake objects



Predicted : 224 ± 13 events

Observed : 263

Events predicted/observed within RelIso<0.3 (prompt e signal region)



Removing W events:

Predicted : 215 ± 13

Observed : 215

Measuring e, μ, γ correctly: control fake objects

Same method for object fake rate determination can be:

. applied for muons, photons

. cross-checked with other discriminating variables
(e.g. Isolation, shower shape variables for photons)

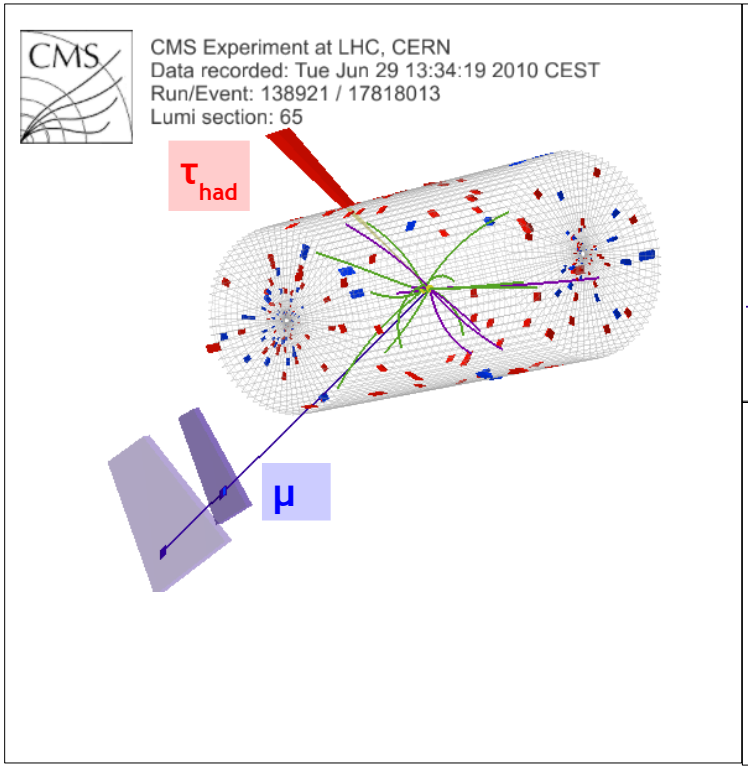
. applied on a sample of ``fakeble objects" with looser selection (L)
and transferred to the sample of interest with tight selection (T)
via ratio T/L
(important gain of statistics in some cases)

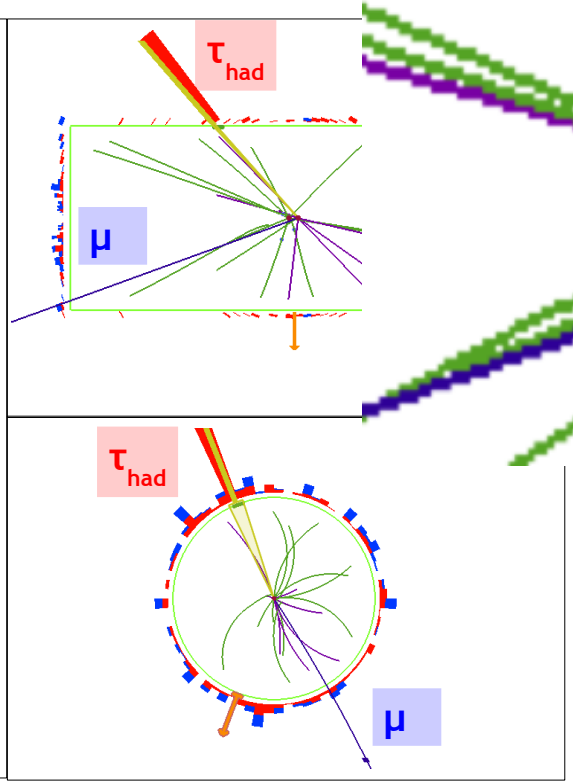
Standard Model commissioning

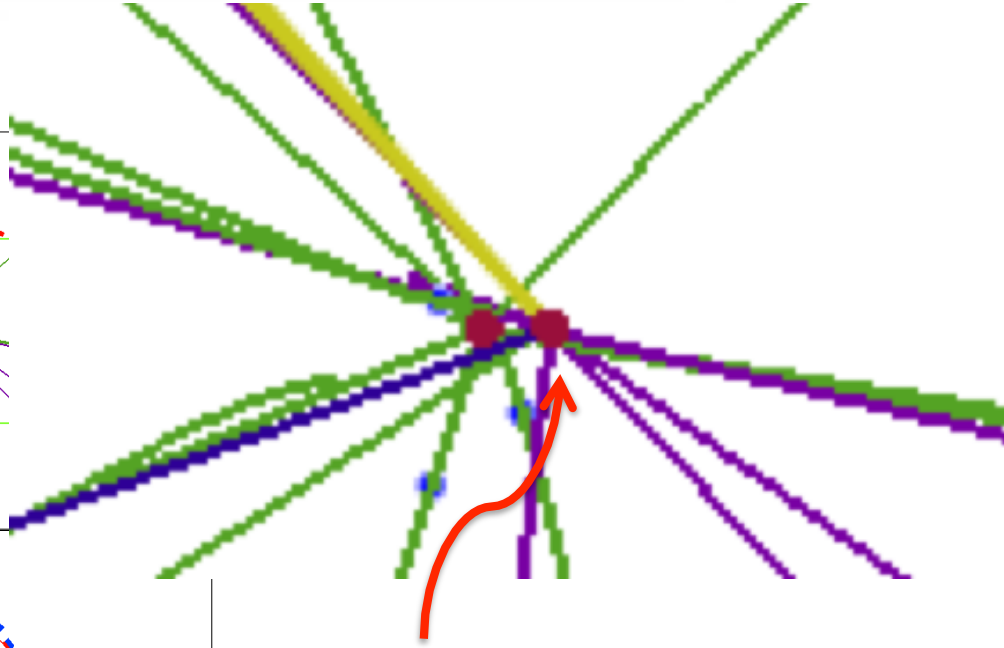
Couln't go for new physics if detector didn't perform well for ``known" physics

Z into taus: pile-up under control

$Z \rightarrow \tau\tau$







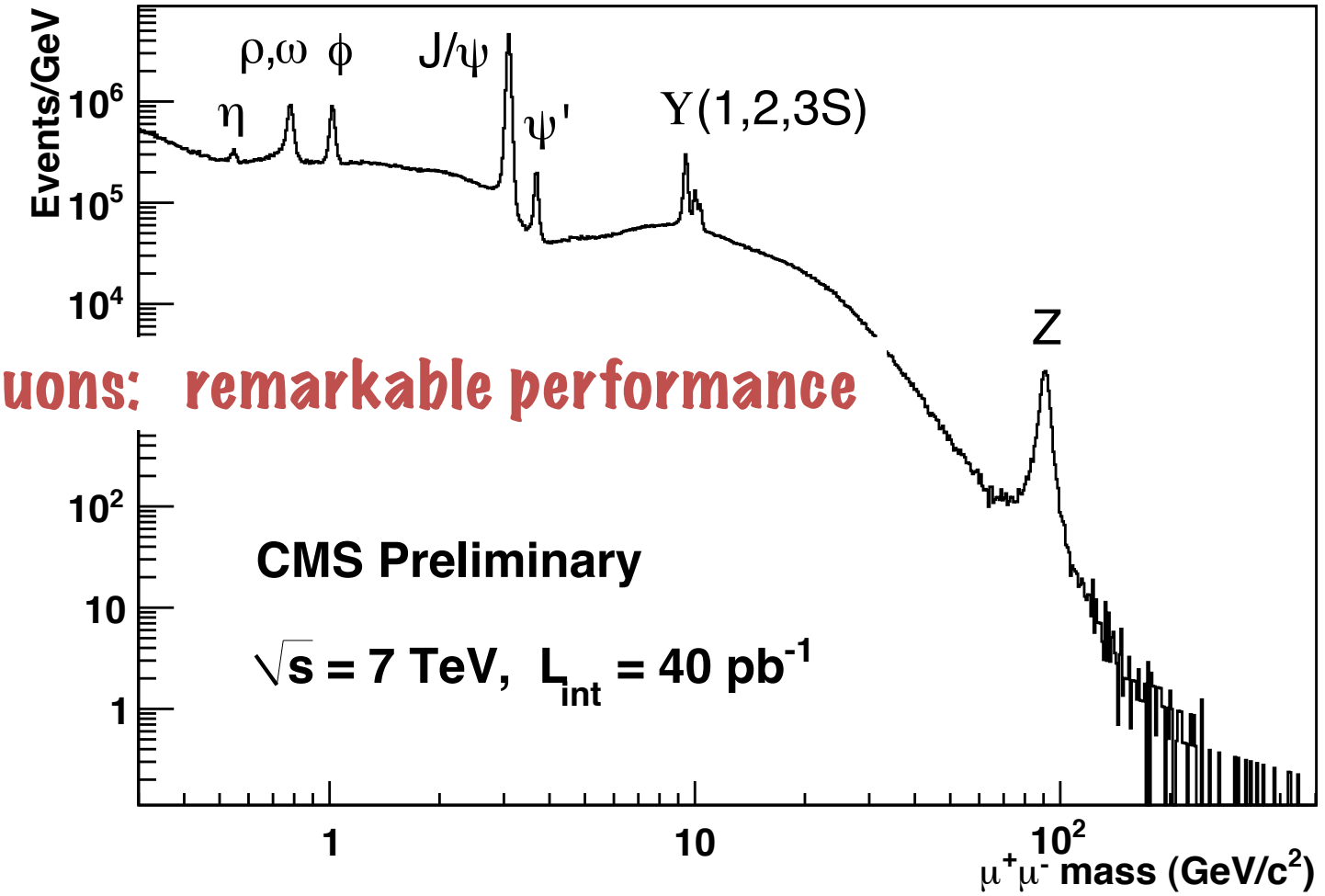
Second Primary Vertex (pile-up) clearly distinguished

μ p_T = 22.8 GeV/c

T_{had} E_T = 32.9 GeV

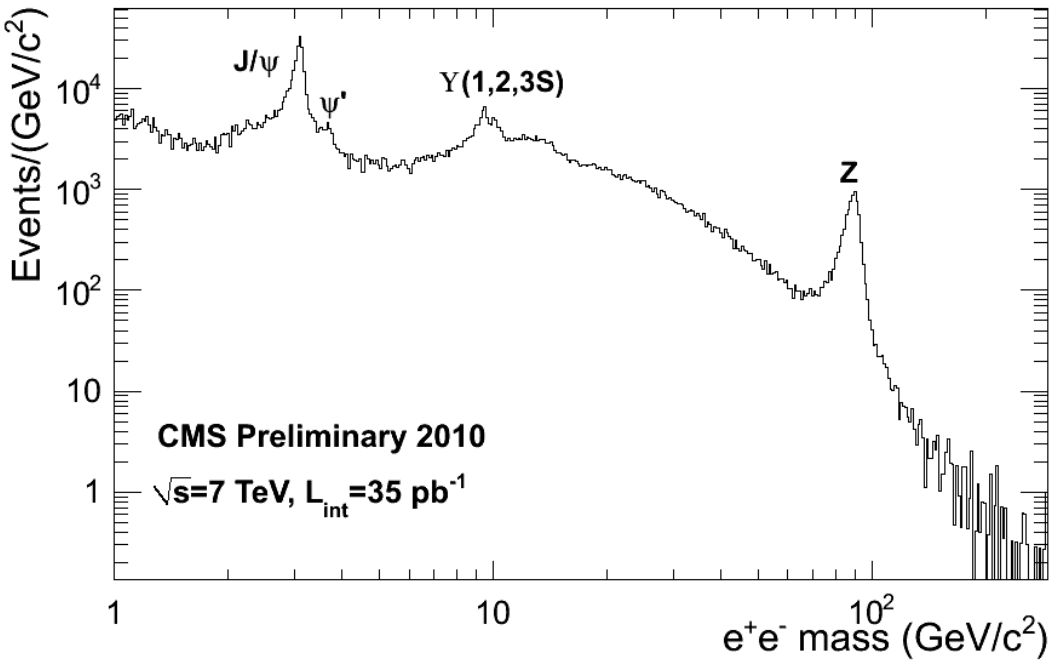
Vis. Mass = 60.8 GeV/c^2
M_T(μ,MET) = 10.1 GeV

Muons : Drell Yan invariant mass

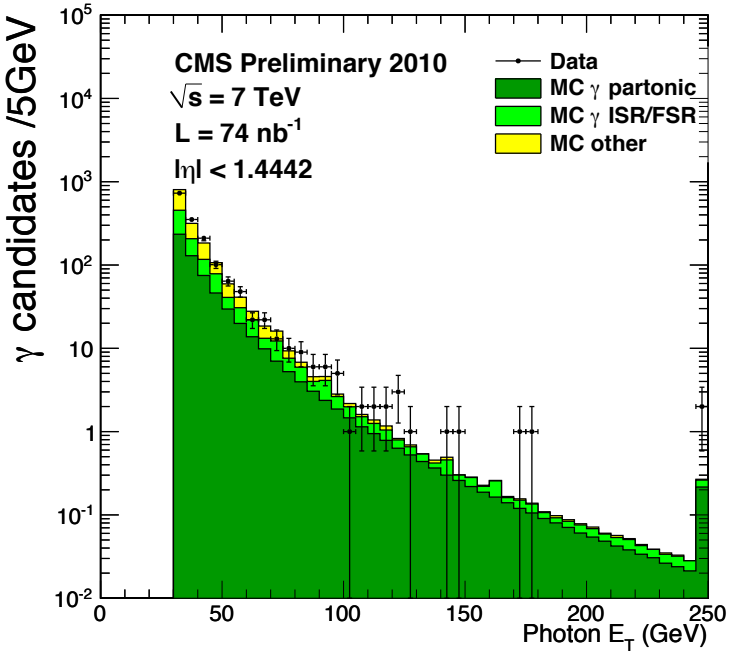


Dimuons: remarkable performance

Electrons and photons

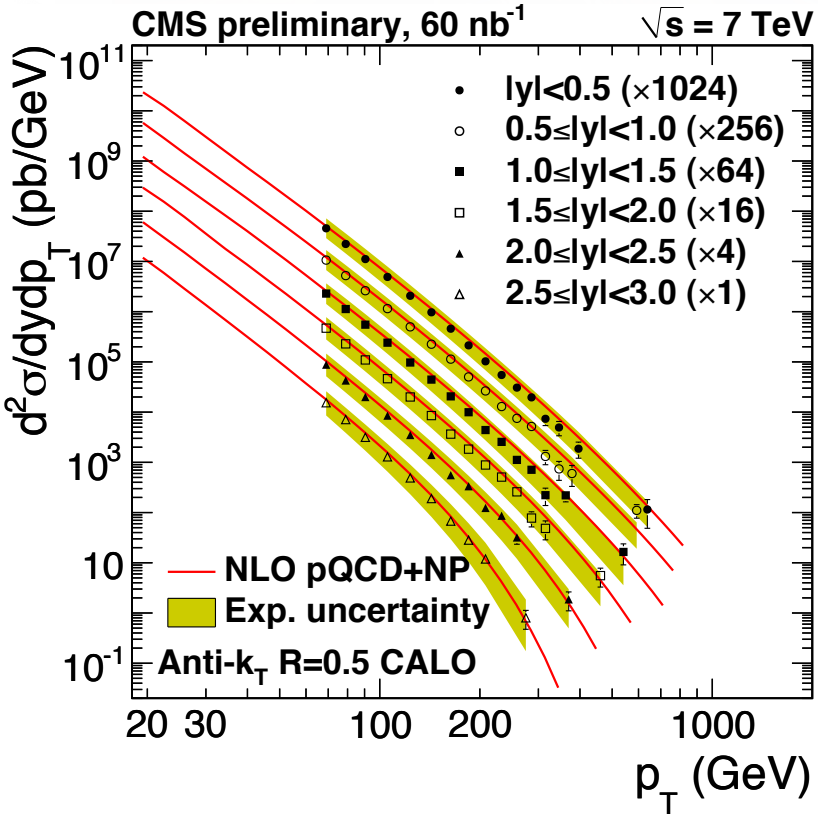


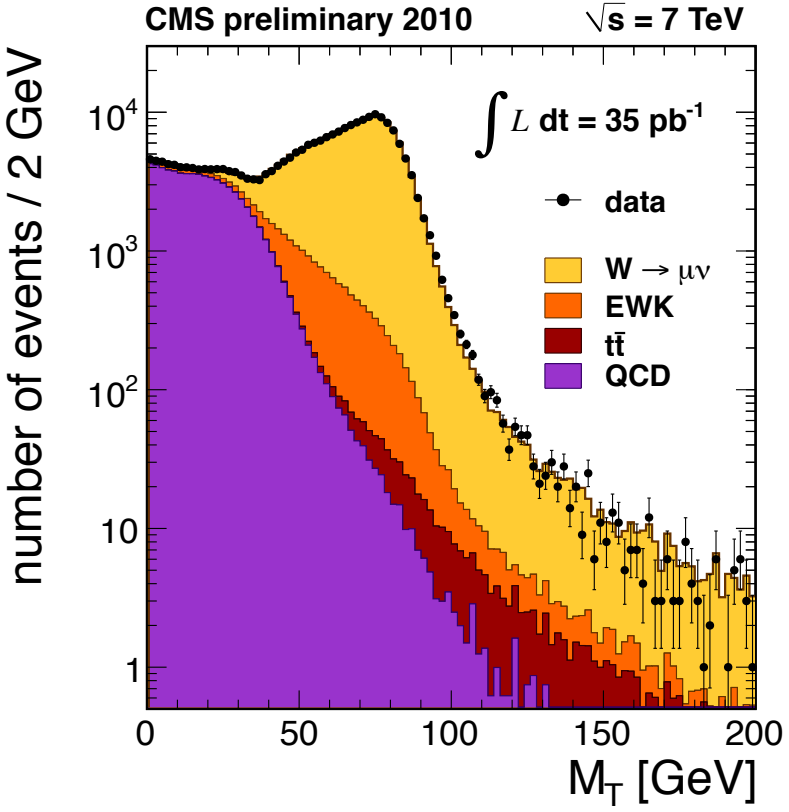
Dielectrons: DY invariant mass



Photons in perfect agreement with SM prediction

QCD jets, Electroweak W (MET)

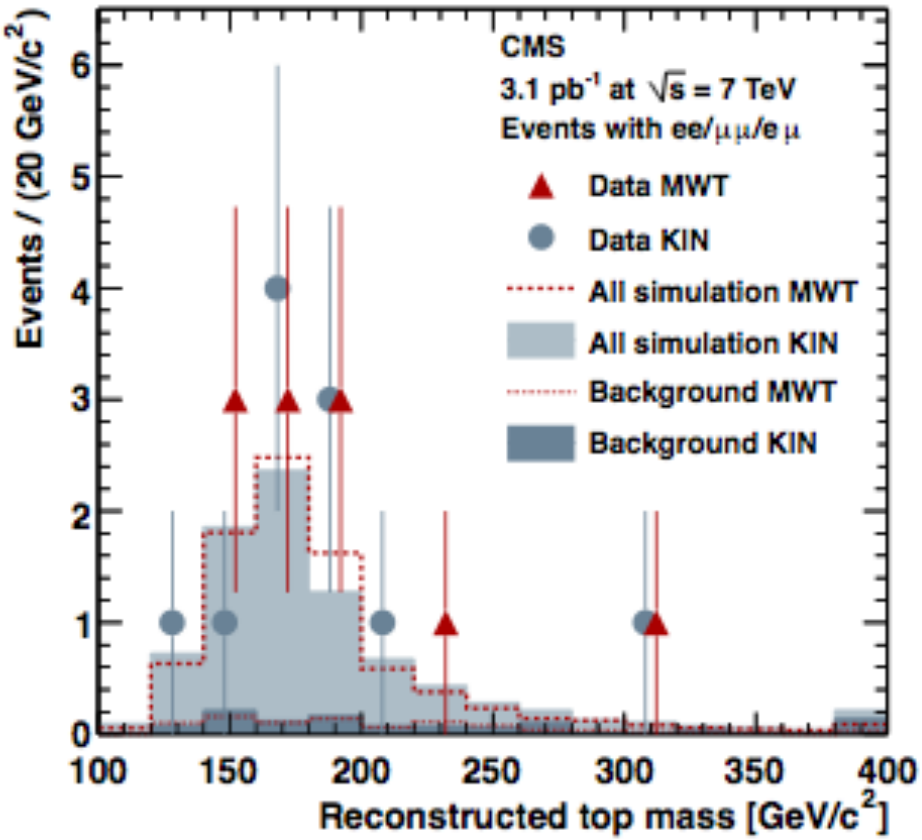




Jets in good agreement with SM from low to high p_T

W : SM process with MET under control, no tail

Top pair production



Top : important SM background for several signals of New Physics

So far, in very good agreement with SM predictions

Conclusions

2010

Excellent performance of the detector

Physics objects (leptons, jets, MET) well understood

SM processes commissioned

Limits on new physics surpassing previous generation of colliders being imposed

(see other CMS talks @ Kruger2010)

2011 and beyond

Higgs and SUSY searches taking place with SM background controlled

Large Extra Dimensions, gravitons, 4th-generation of quarks, leptoquarks, compositeness, Z', W', black holes… are part of the vast CMS program on searches for new physics

CMS detector is ready to impose new limits / discover new physics…

… and, of course to welcome the **Higgs**!

Bibliography

Accessible from CMS public results page:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

or from CERN server: http://cdsweb.cern.ch/?ln=en

The CMS physics reach for searches at 7 TeV CMS Note 2010/008

Photon reconstruction and identification at sqrt(s) = 7 TeV CMS-PAS-EGM-10-005

Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV CMS-PAS-QCD-10-011

First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at sqrt(*s) = 7 TeV* CMS-TOP-10-001

Measurement of the W and Z inclusive production cross sections at sqrts=7 TeV with the CMS experiment at the LHC CMS-PAS-EWK-10-002

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Search for Mono-Jet Final States from ADD Extra Dimensions CMS-PAS-EXO-09-013

Search for A Fourth Generation b' Quark in tW Final State at CMS in pp Collisions

at sqrt(s) = 10 TeV CMS-PAS-EXO-09-012

Search for Second Generation Scalar Leptoquarks with the CMS Detector CMS-PAS-EXO-09-010

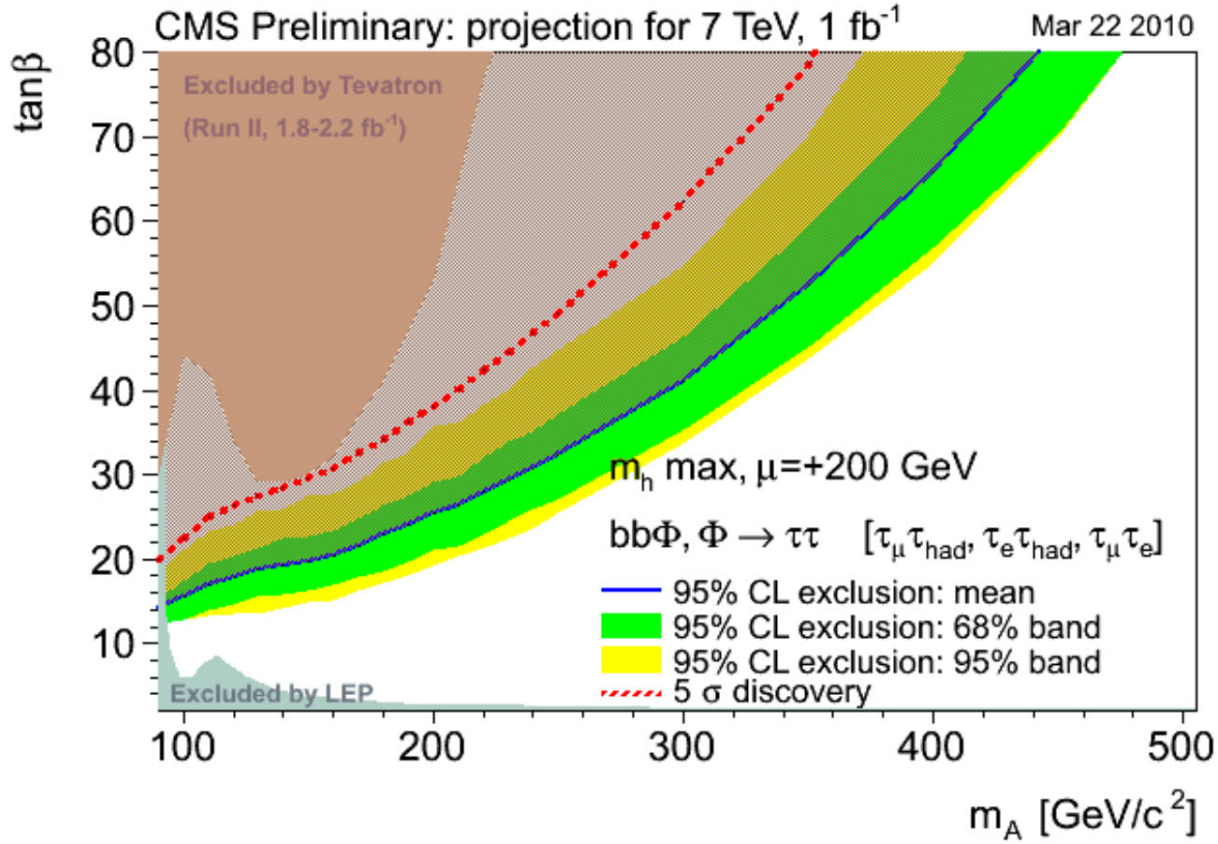
Search for Large Extra Dimensions in the Diphoton Final State CMS-PAS-EXO-09-004

Search for Randall-Sundrum Gravitons in the Diphoton Final State CMS-PAS-EXO-09-009

Performance of Methods for Data-Driven Background Estimation in SUSY Searches CMS-PAS-SUS-10-001

Backups

MSSM Higgs



Projection for 1fb-1: at low m_A~90 GeV, the discovery can be possible for tanβ>20 and the exclusion limit is expected to reach down to tanβ~15.

Measuring MET correctly: artificial MET in QCD

All bins, for completeness…