CMS Highlights

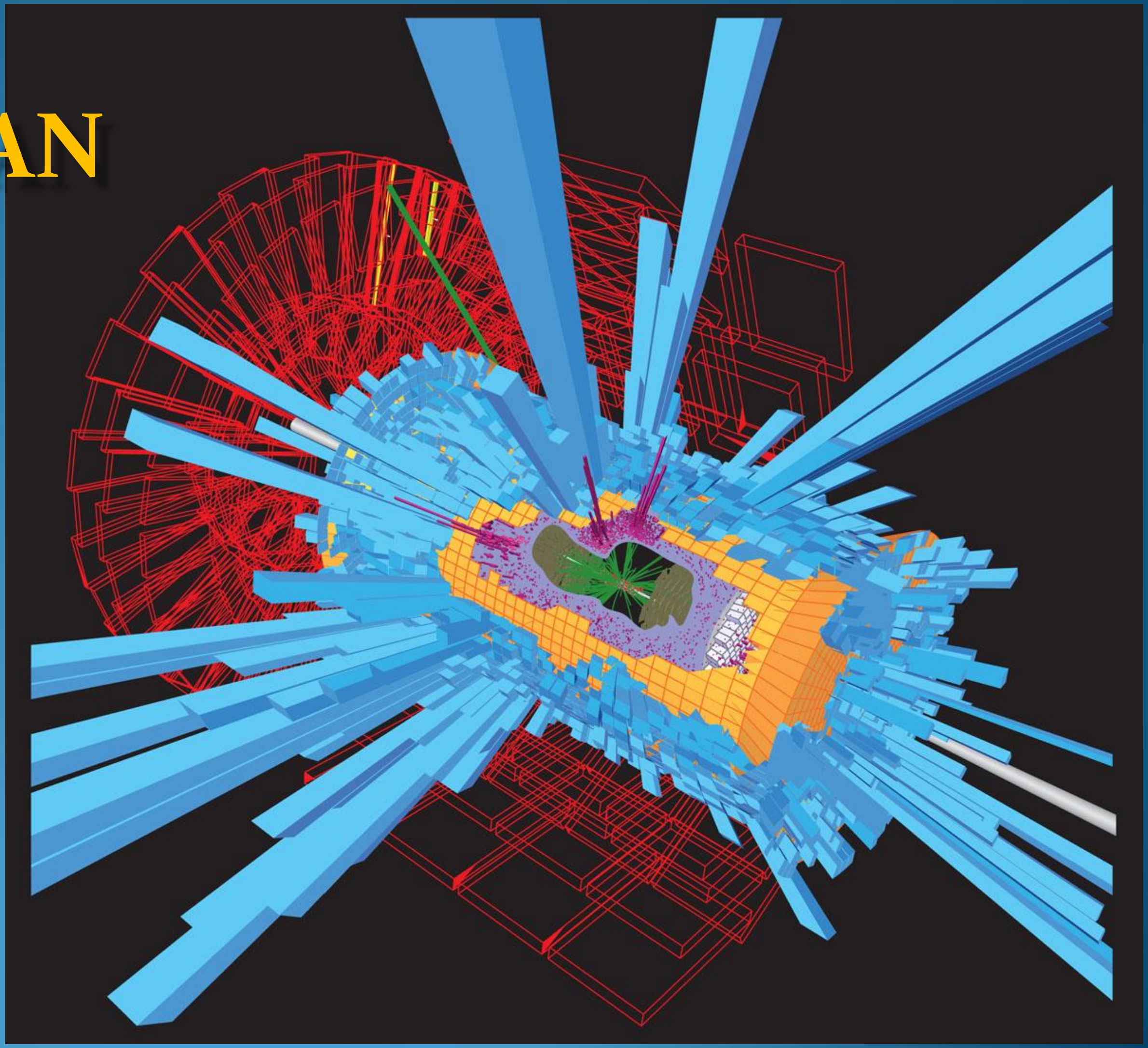
III Jornadas CPAN

Barcelona
November 2-4, 2011

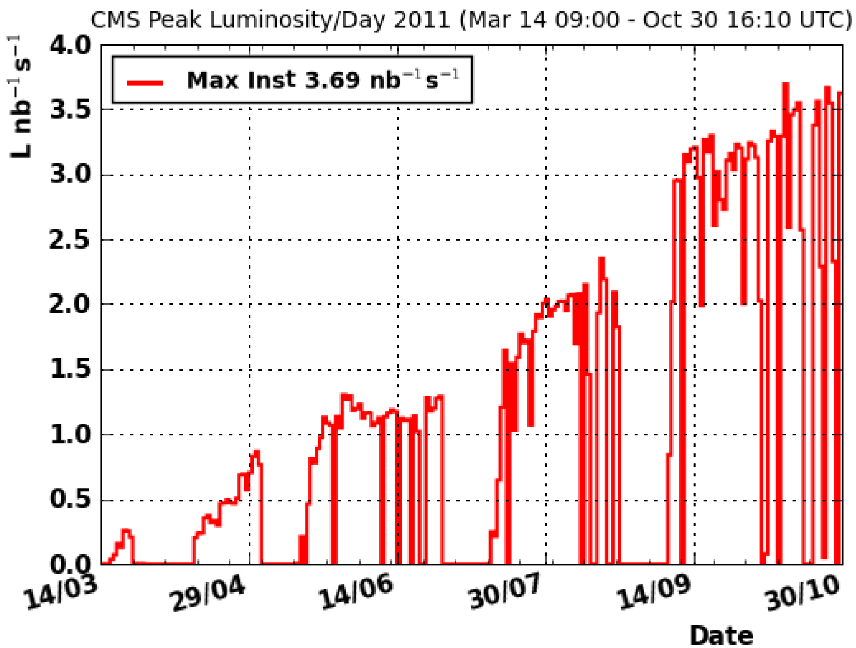
Gervasio Gómez

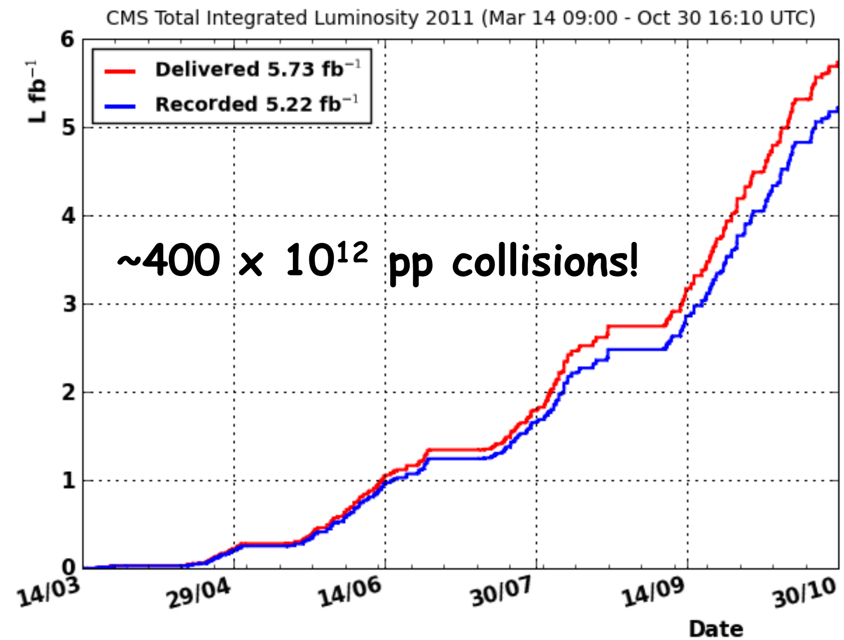
Instituto de Física de Cantabria

for the CMS Collaboration



LHC in 2011





Rapid increase in *L*:
collecting per (good) day more data than 4 x entire 2010 run

pp collisions at $\sqrt{s} = 7$ TeV

peak $L \approx 3.69 \times 10^{33}$ cm^{-2} s^{-1}

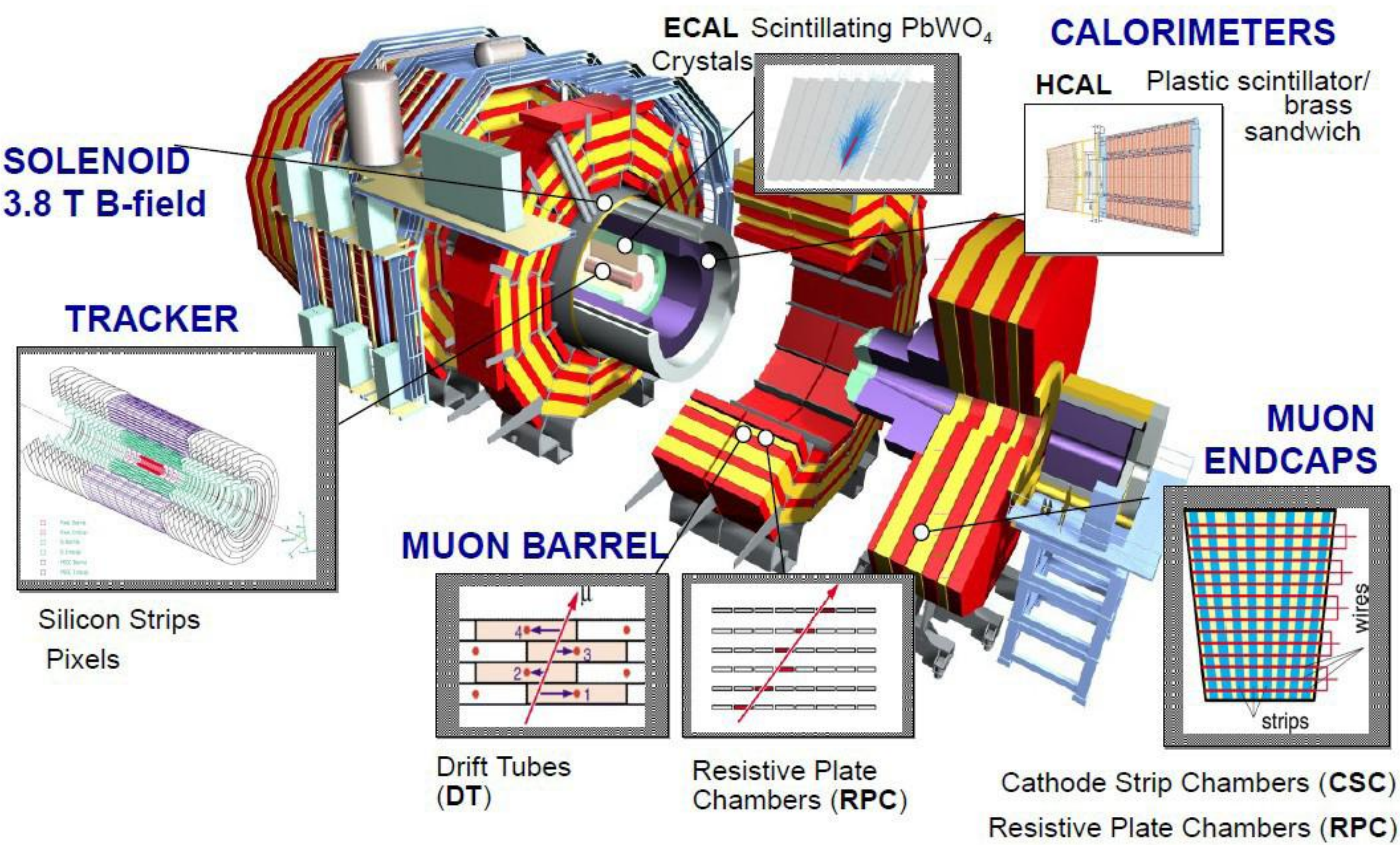
$\int L dt \approx 5.73\,(5.22)$ fb^{-1} delivered(recorded)

1380 bunches/beam ; 2.7×10^{11} p/bunch

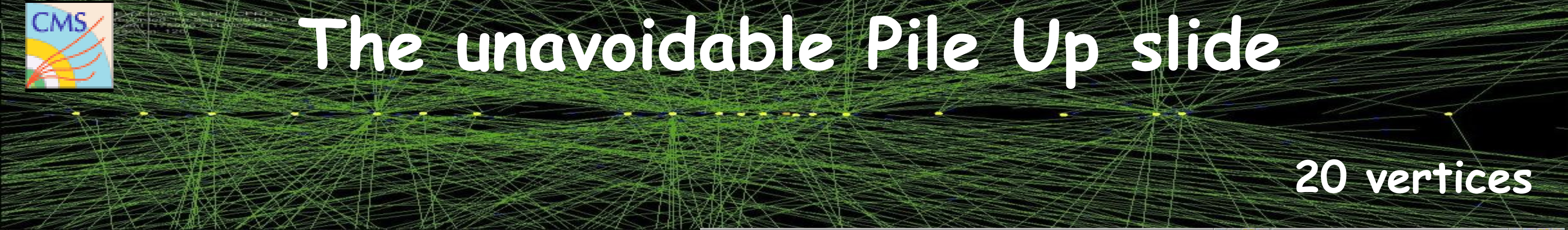
50 and 25 ns bunch spacing

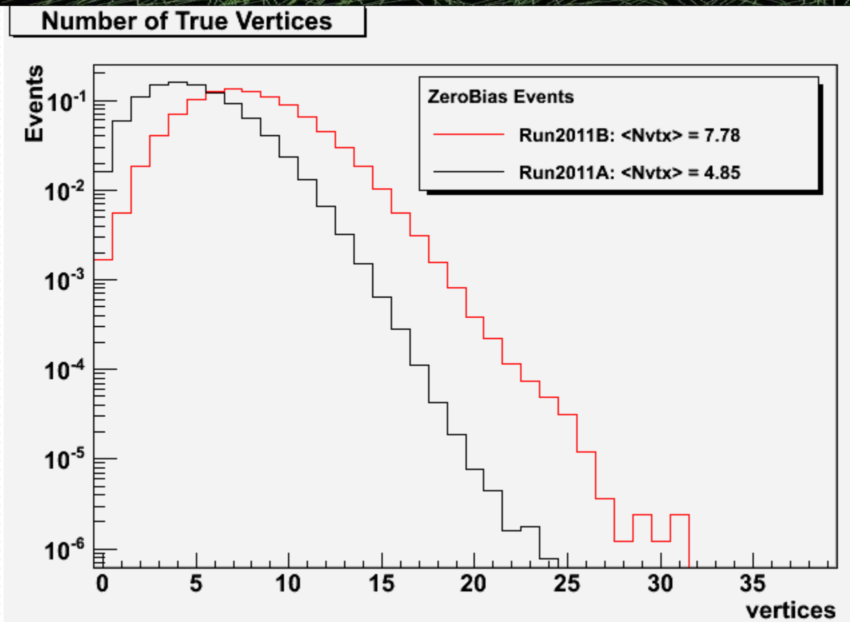
LHC is performing very well

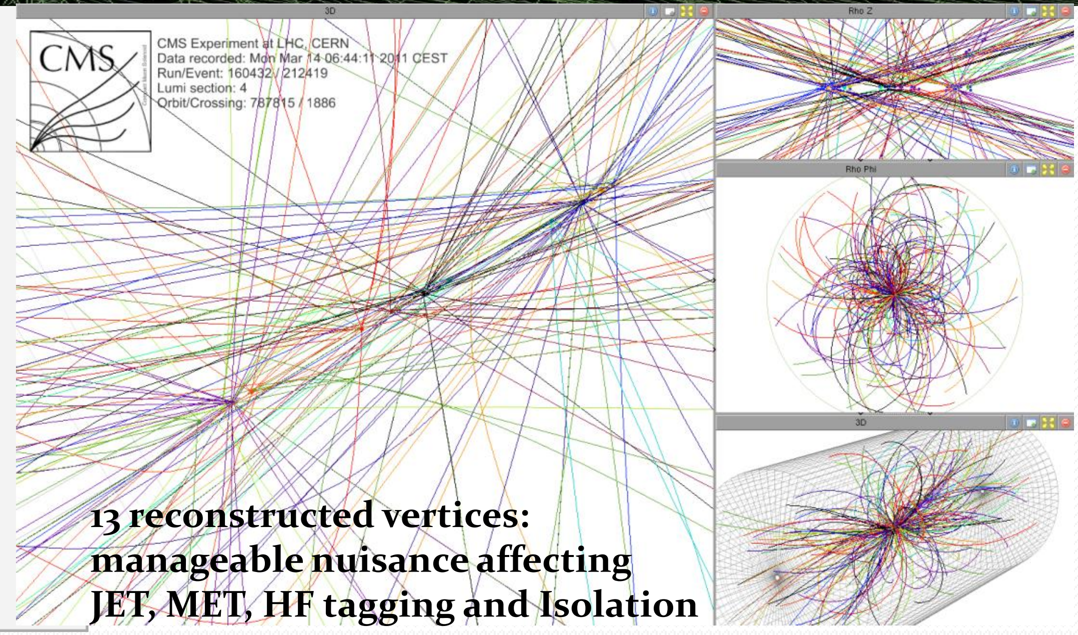
CMS Detector



The unavoidable Pile Up slide

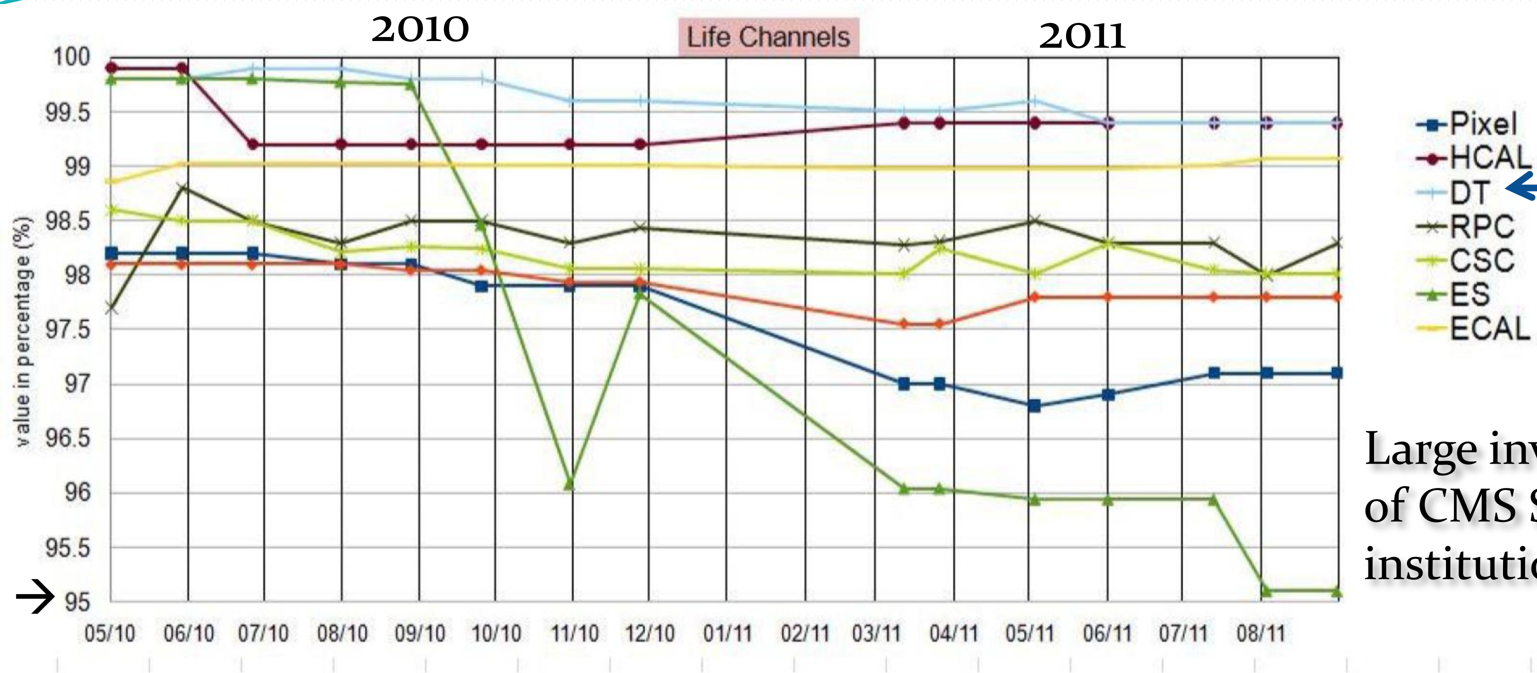






- High multiplicity of interactions in a single collision of two p-bunches
- Number of reconstructed vertices after the August Technical Stop increased by factor 1.5 (β^*=1.5 m → 1 m)
  - Fills start with ~15 pile-up interactions
  - CMS can deal with this: high granularity → relatively low occupancies
  - Vertex reconstruction still quite linear with luminosity
- Triggers able to cope with this **challenging** data taking conditions
- Offline algorithms subtract activity not coming from event primary vertex

CMS Detector Performance I



95% →

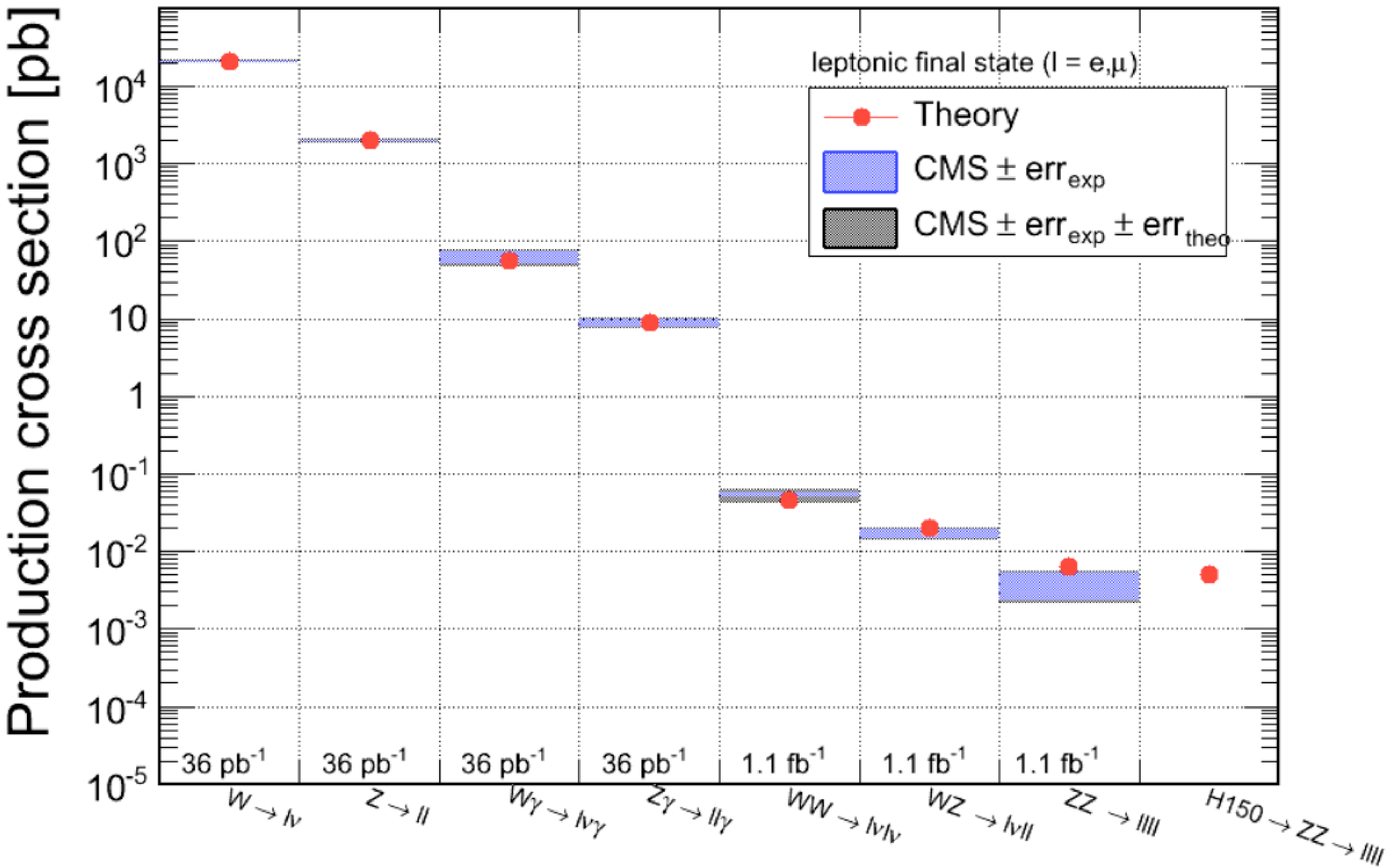
Large involvement of CMS Spanish institutions

- High % of live detector channels and stable over time
  - slight drop in Preshower due to leakage current in one sensor type
- **5.7 fb^{-1}** delivered by LHC and **5.2 fb^{-1}** collected by CMS: ~91% data taking ε
- Data Certification for Analysis
  - 84% for all CMS systems
  - 91% for μ analysis

CMS performing very well

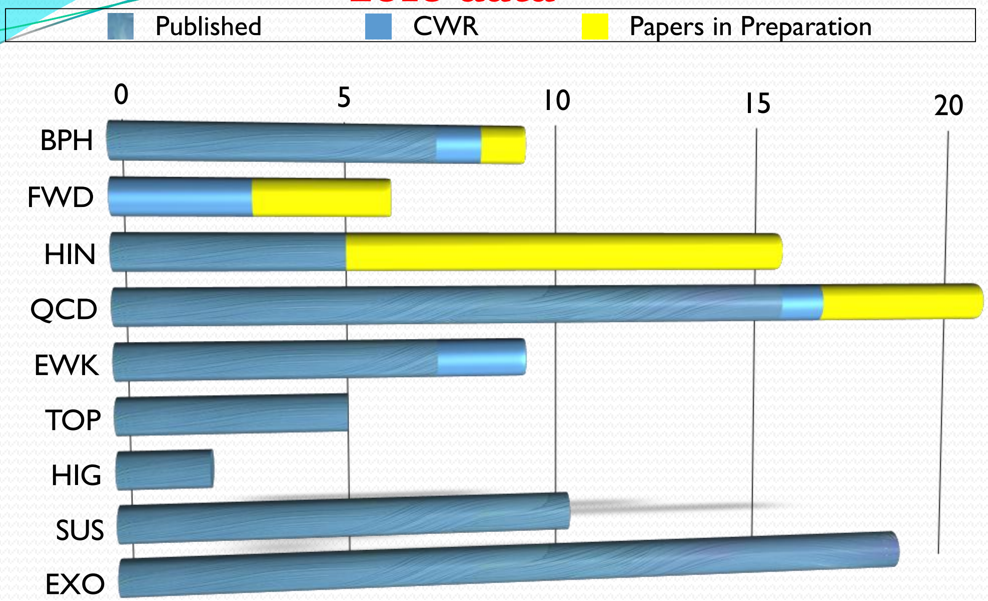
CMS Detector Performance II

Measuring EW processes down to σ comparable to SM Higgs

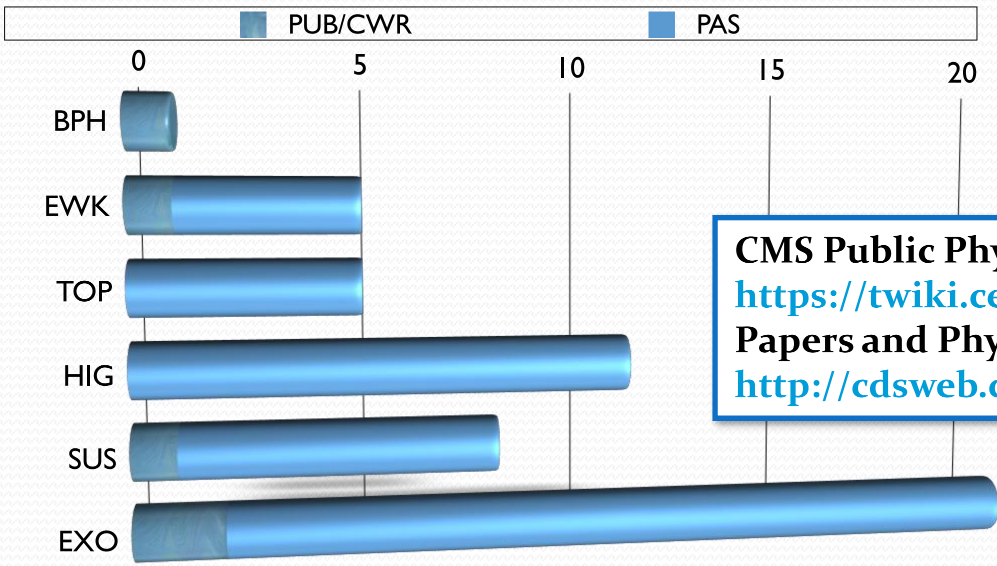


CMS Publications

2010 data



2011 data



- Reached 100 publications on 3-Aug-2011
- As of 28-September
  - 105 publications
  - 161 PAS
- The rest of this talk is (hopefully) indicative of the quality of the CMS physics program and results

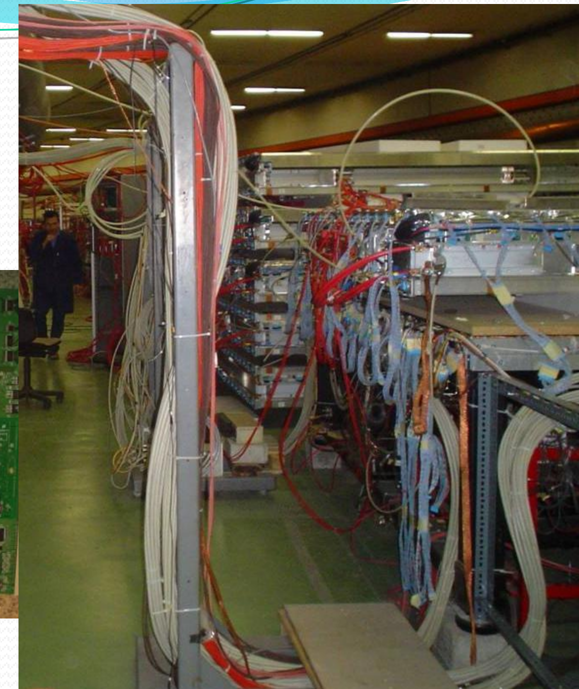
CMS Public Physics Results
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
Papers and Physics Analysis Summaries (PAS):
http://cdsweb.cern.ch/collection/CMS

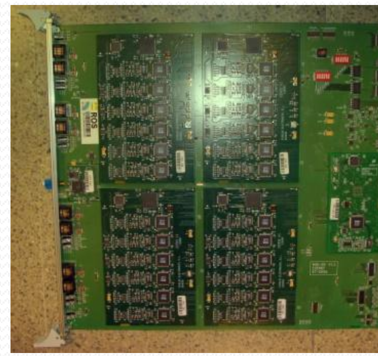
Spain in CMS

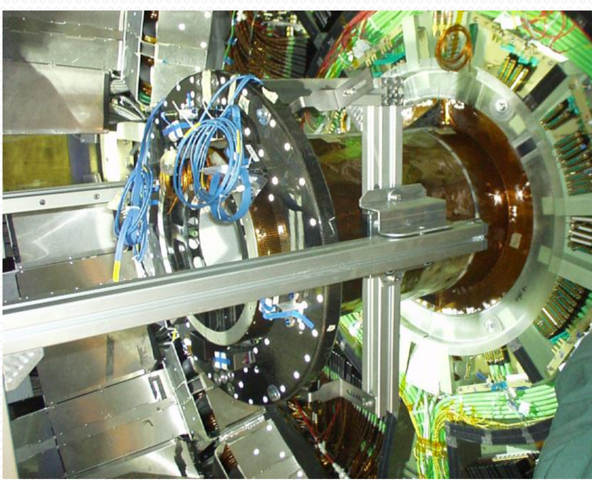
- Spanish institutions in CMS:
  - CIEMAT-IFCA-Oviedo-UAM
- Large Spanish contribution in detector construction, installation, calibration, commissioning, maintenance, running and physics analysis:
  - DT, Trigger, Alignment, computing, software, analysis
- Spanish "presence" in CMS leadership
  - CMS Collaboration Board chairperson: T. Rodrigo (IFCA)
  - Run coordinator: M. Chamizo (CIEMAT)
  - Muon alignment coordinator: G. Gómez (IFCA)
  - Barrel alignment contact: L. Scodellaro (IFCA)
  - DTTF Project Leader: J. Fernández de Trocóniz (UAM)
  - DT Upgrade Project and Electronics coordinator: C. F. Bedoya (CIEMAT)
  - DT Upgrade RO: A. Navarro (CIEMAT)
  - Muon Physics Object Coordinator: S. Goy (CIEMAT)
  - Muon High Level Trigger Coordinator: S. Goy (CIEMAT)
  - DT operations: I. Redondo (CIEMAT)
  - DT DPG Technical coordinator: C. Battilana (CIEMAT)
  - DT Prompt analysis: M.C. Fouz (CIEMAT)
  - DT DPG Validation/PVT: J. Santaolalla (CIEMAT)
  - DTTF operations: G. Codispoti (UAM)
  - H→WW task coordinator: J. Cuevas (UO)
  - VBTF group: J. Alcaraz (CIEMAT)

Spain contribution to detector

- CIEMAT:
  - Construction, installation, commissioning of DTs
    - 60 MB2 (entire station) + 10 MB4
  - DT readout electronics
- UAM
  - DTTF (DT track finder) trigger
- IFCA+CIEMAT+Oviedo
  - Muon alignment

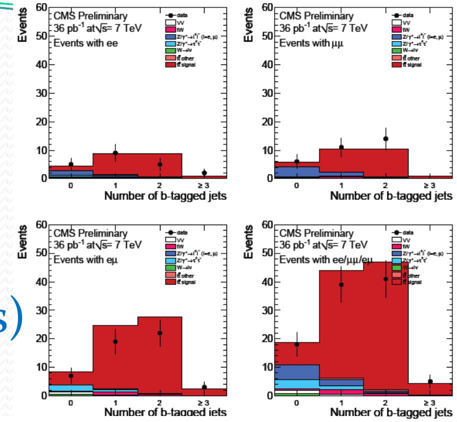


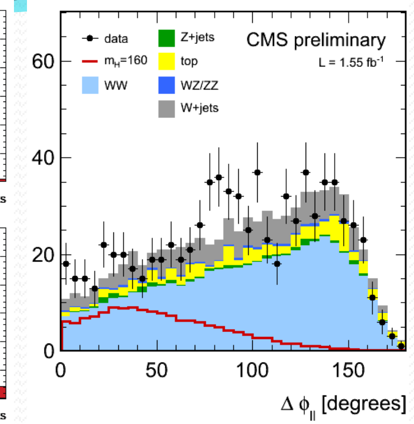


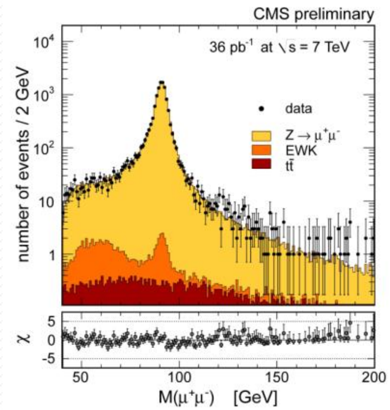


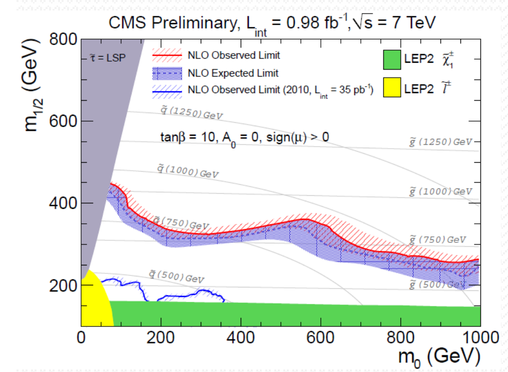
Spanish contribution to analysis

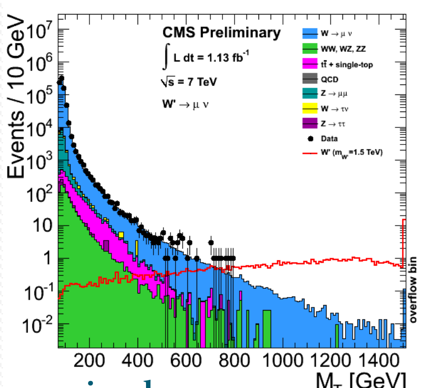
- IFCA+Oviedo (dilepton final states):
  - WW cross section
  - H→WW
  - ttbar→dileptons + btag + MET
  - SUSY searches in SS dileptons (+ jets + MET)
- CIEMAT+UAM (single and di-lepton final states)
  - H→ZZ→llbb
  - Inclusive W/Z xsec
  - W+charm
  - W polarization for Ws from top decay
  - W' search
  - Excited lepton search
  - W→μν production in Pb-Pb (H.I.) collisions
- Tools
  - Lepton fake rates
  - B-tagging

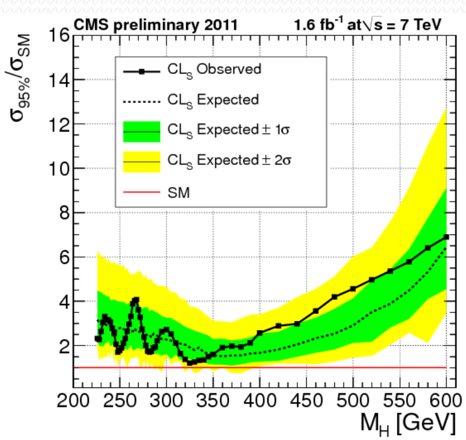


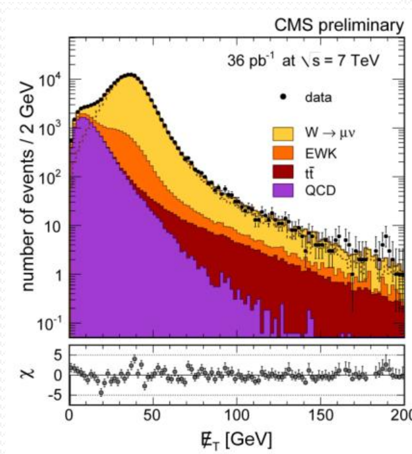


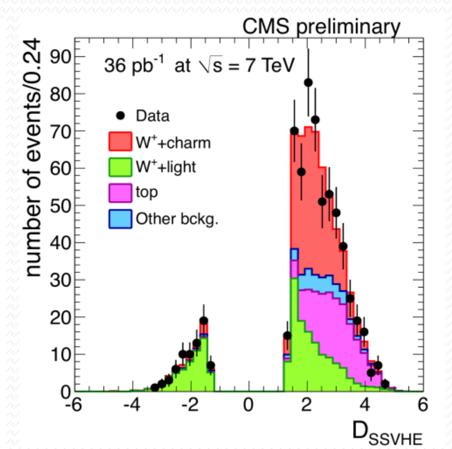










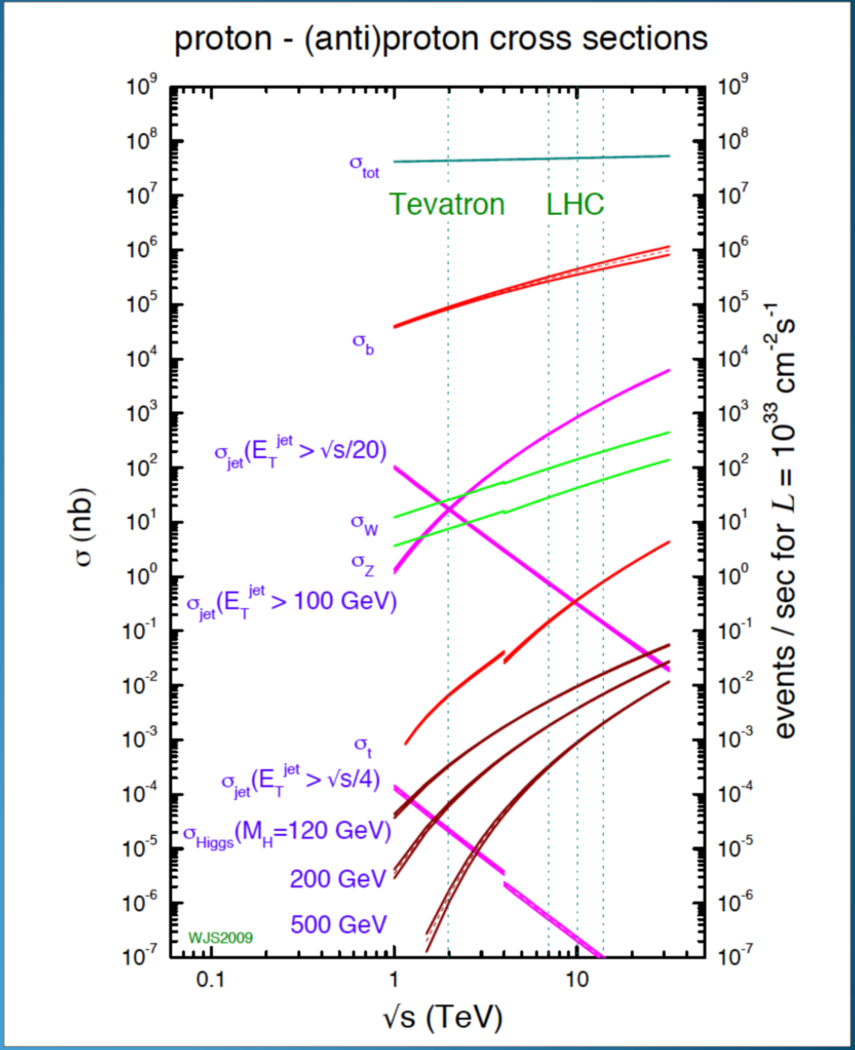


CMS Physics Results

Rich physics program covering processes with production cross sections that span several orders of magnitude

- over 160 physics analyses (PAS) and counting
- cannot cover all results in 30’

This talk concentrates on Higgs and SUSY searches



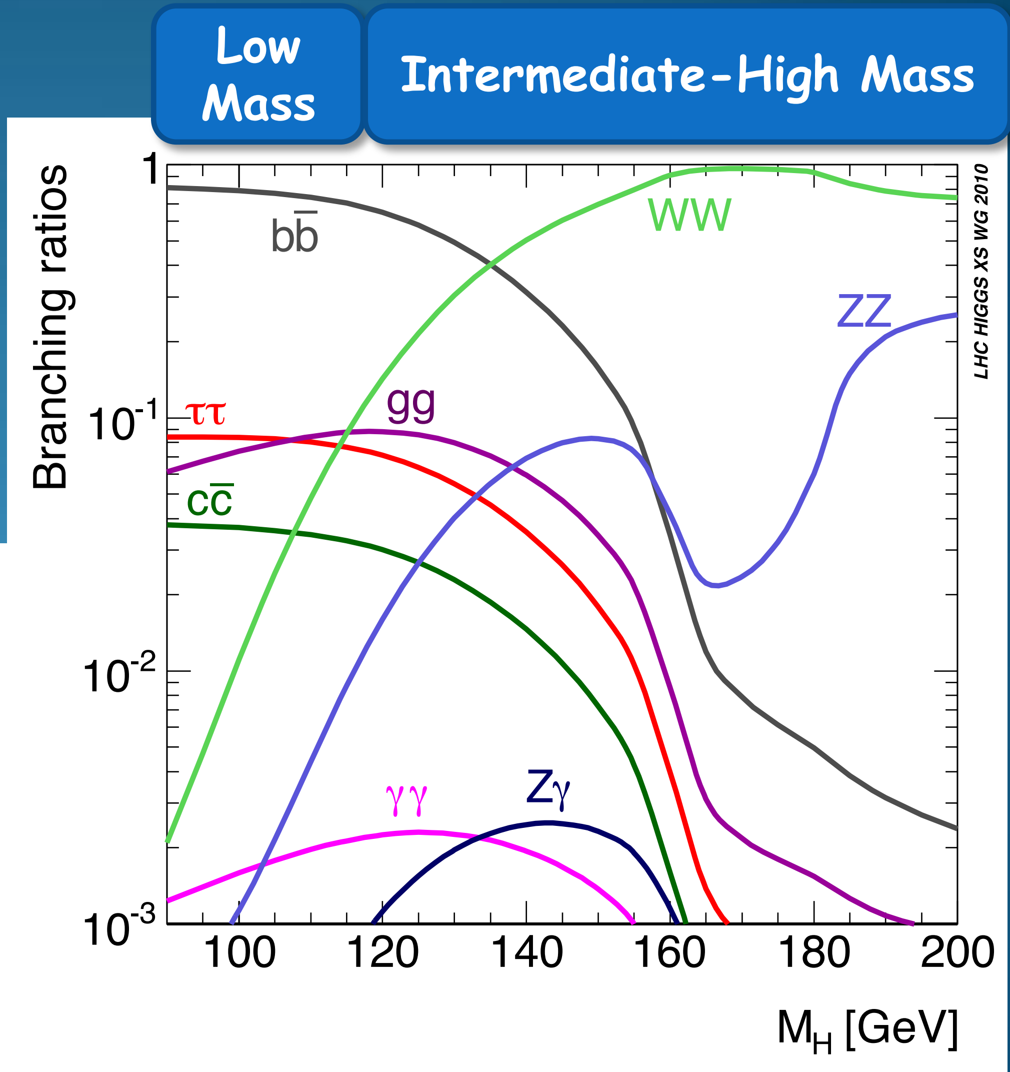
Specialized CMS talks in parallel sessions:

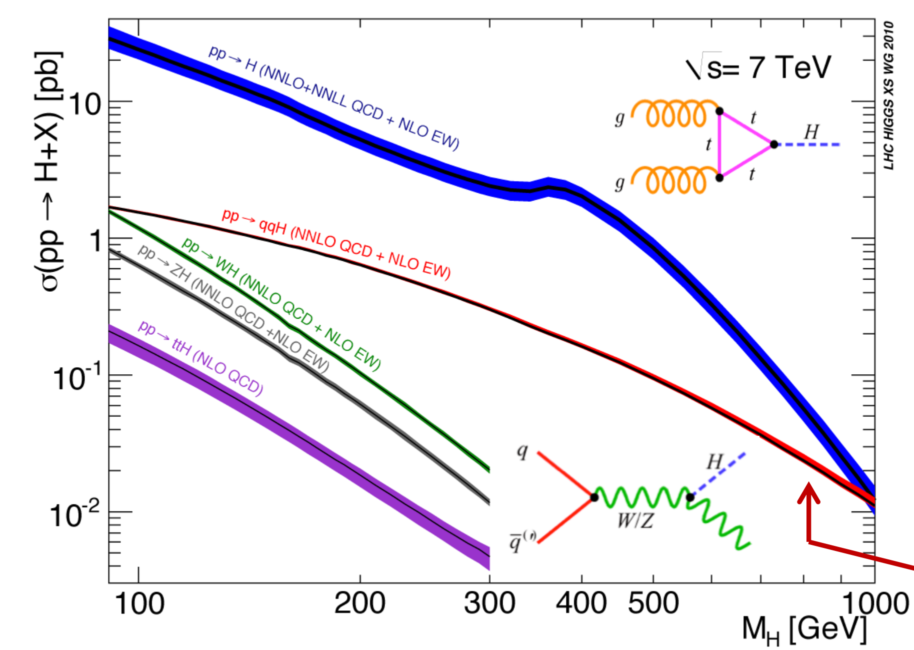
- EWK Physics: W/Z, W/Z + jets
  - See talk by Javier Santaolalla
- Exotica (non-SUSY) searches
  - See talk by Carmen Diez
- Higgs Searches
  - See talk by Patricia Lobelle

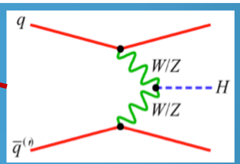
All public results in:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Higgs Searches

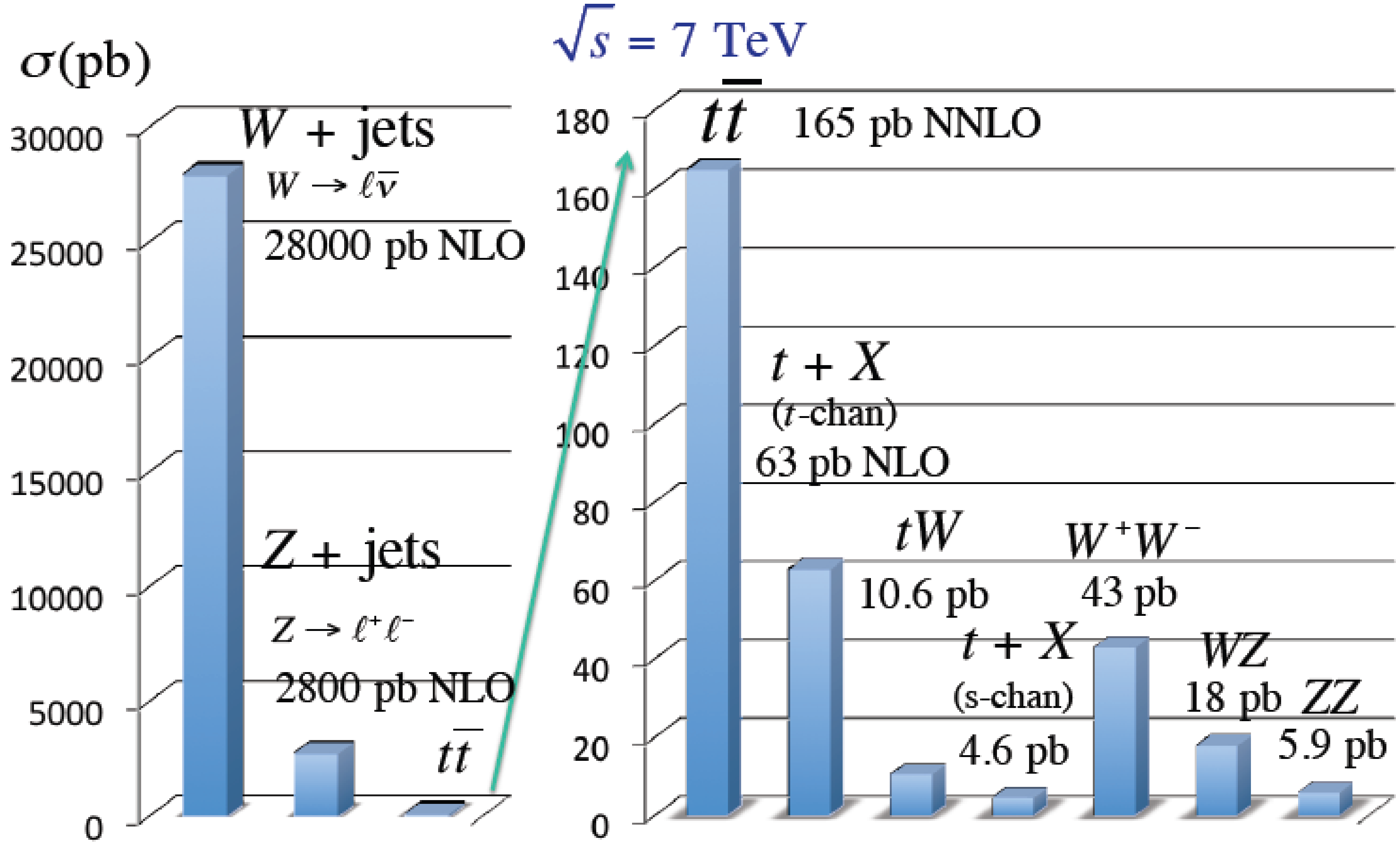
- Higgs searches
  - H→γγ
  - H→bb
  - H/ϕ→ττ
  - H→WW
  - H→ZZ
- CMS 2011/2012 prospects



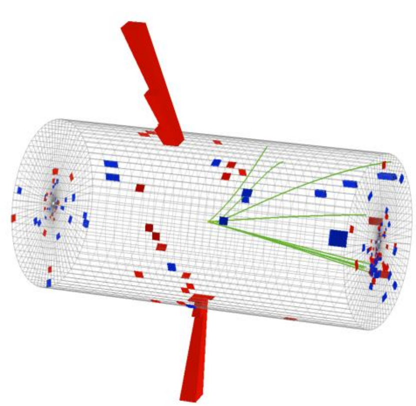


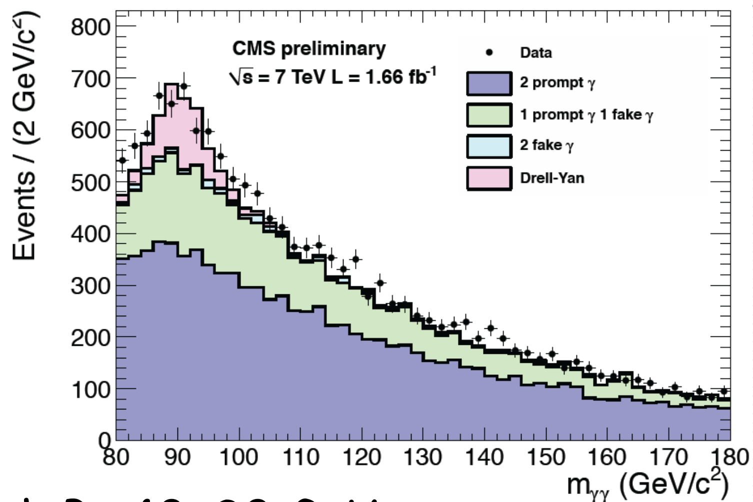


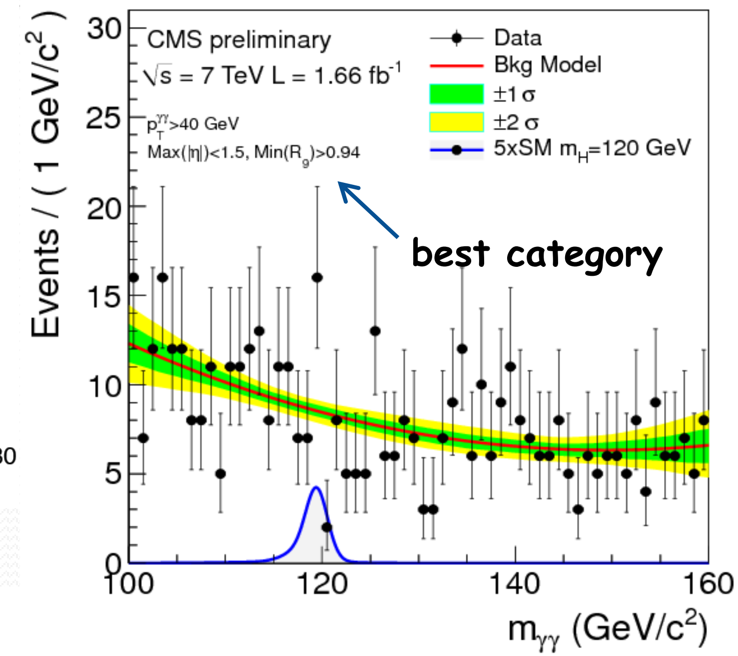
Dominant SM Backgrounds



H→γγ, 1.66 fb^{-1}

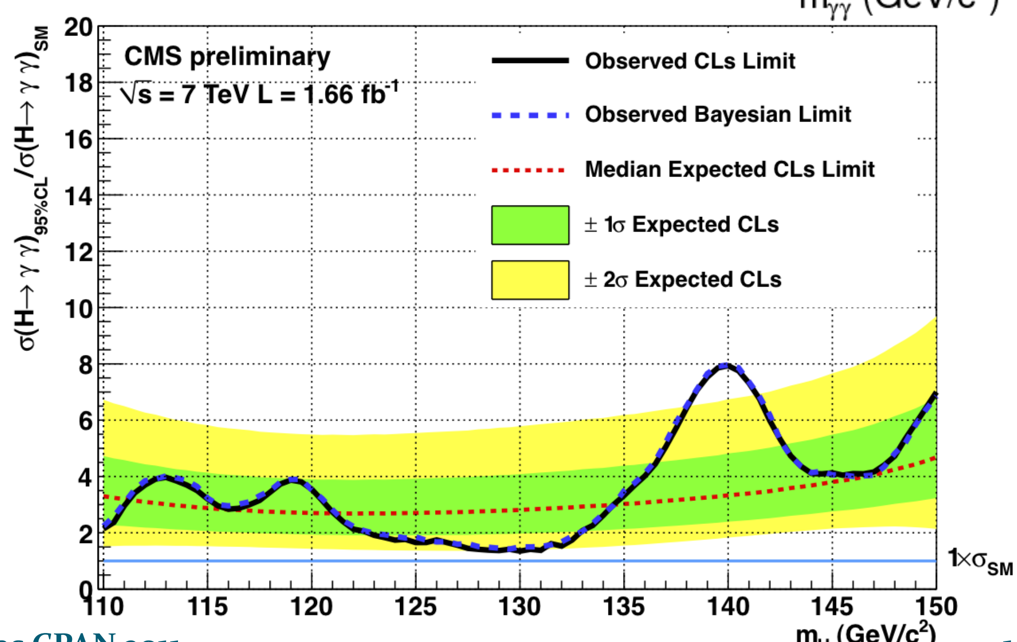


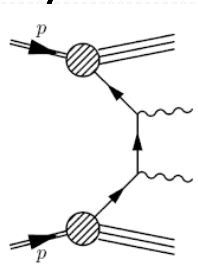


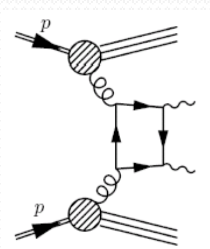


Strategy

- 2 isolated γ's with P_T>40, 30 GeV
- Data divided into 8 categories depending on γ quality and $p_T(H)$
  - σ_{eff}(mass) varies from 1.4 – 7.9 GeV
  - Signal energy resolution extracted from Z→ee data
- Final discriminant: $m_{\gamma\gamma}$
- Background shape (QCD) from sidebands, fitted by 2nd order polynomial in each category



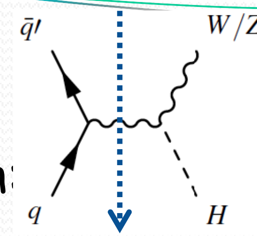




H→bb, 1.1 fb^{-1}

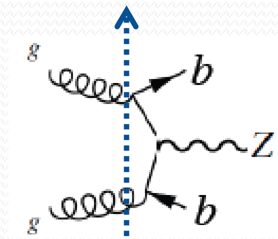
Challenging at LCH:

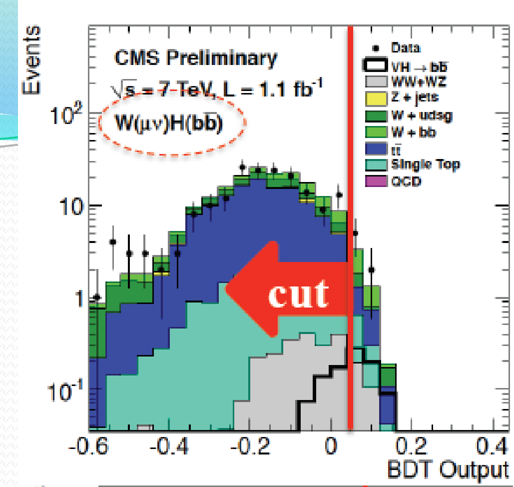
- gg and VBF overwhelmed by QCD
- VH best but S/B 3-4 worse than Tevatron

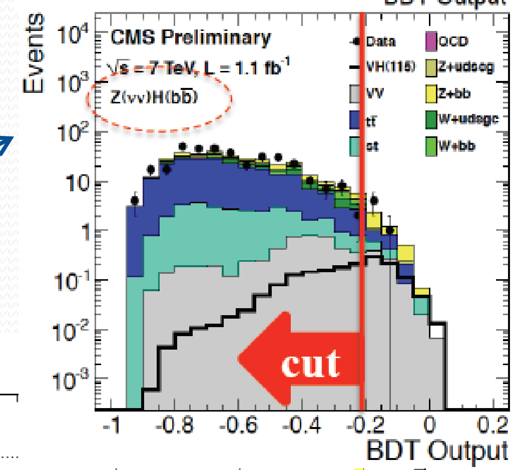


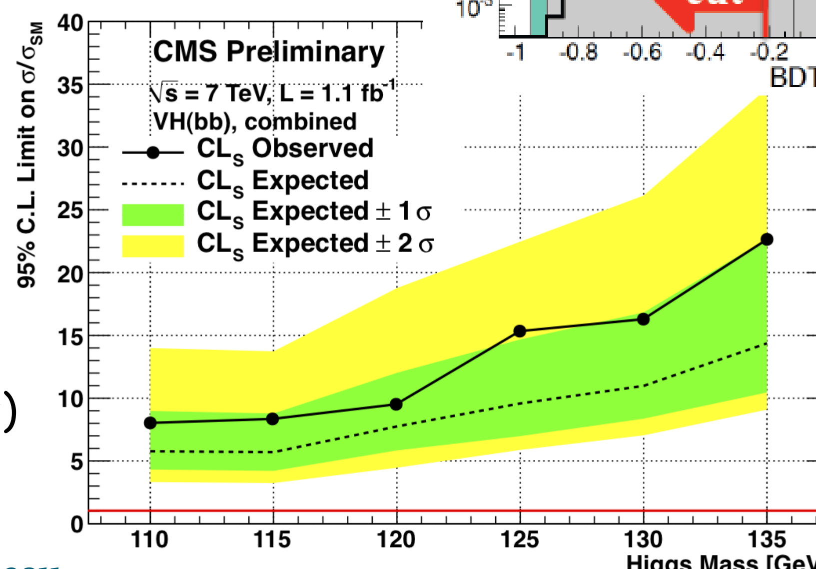
Search strategy:

- Boosted W/Z topology: $P_T(V)$>100-160 GeV
- High MET
- 2 tight tag b-jets with $P_T(bb)$>100-160 GeV
  - ~10% mass resolution
  - Aided by bb system boost
- H back-to-back with W/Z: $\Delta\phi(V,H)$>3
- 5 topologies:
  - WH → μνbb, eνbb
  - ZH → μμbb, eebb
  - ZH → ννbb
- Two complementary analyses:
  - Cut and count in M_{bb}
  - MVA with boosted decision tree
- Yields in good agreement with data-driven background estimates
  - Vbb: from data, invert $P_T(bb)$ boost
  - V+jets: from data, invert b-tag
  - Top: from data, require extra jet
  - QCD: from data, require small $\Delta\phi$(MET,jet)
  - W/Z + Z(bb) from MC

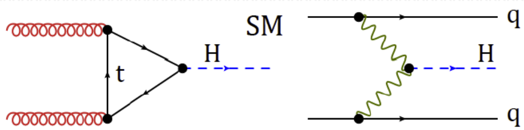


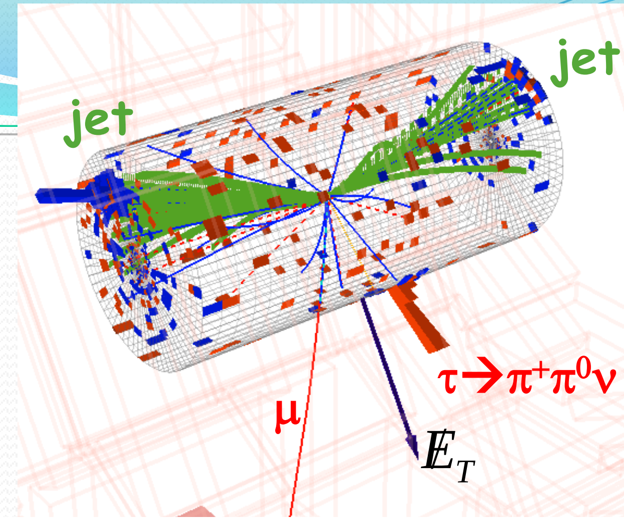






$H/\phi \rightarrow \tau\tau$, 1.6 fb^{-1}

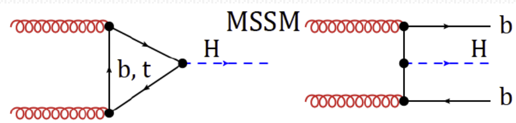




SM categories

- VBF: 2 jets with $\Delta\eta > 3.5$, $m_{jj} > 350$
- Non-VBF: <2 jets or 2j failing VBF tag

MSSM categories

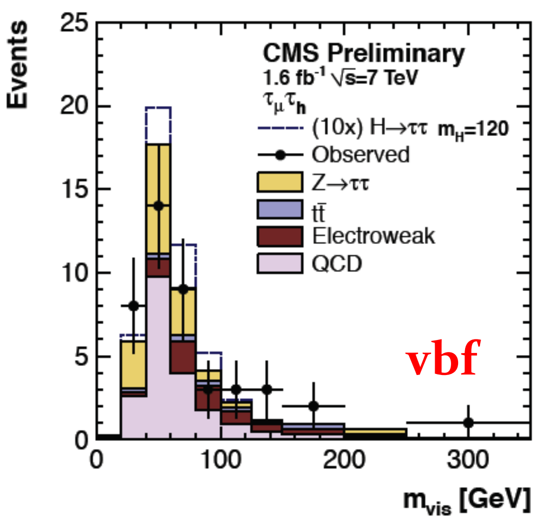


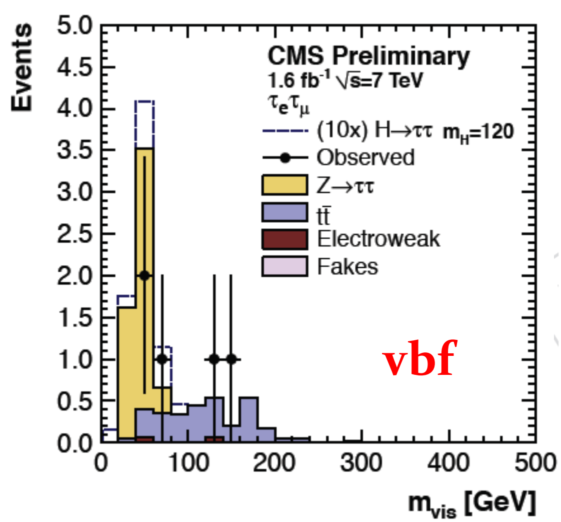
- B-tag: ≥1 b jet $p_T > 20$
- Non-b-tag: <2 jets and no b-tags

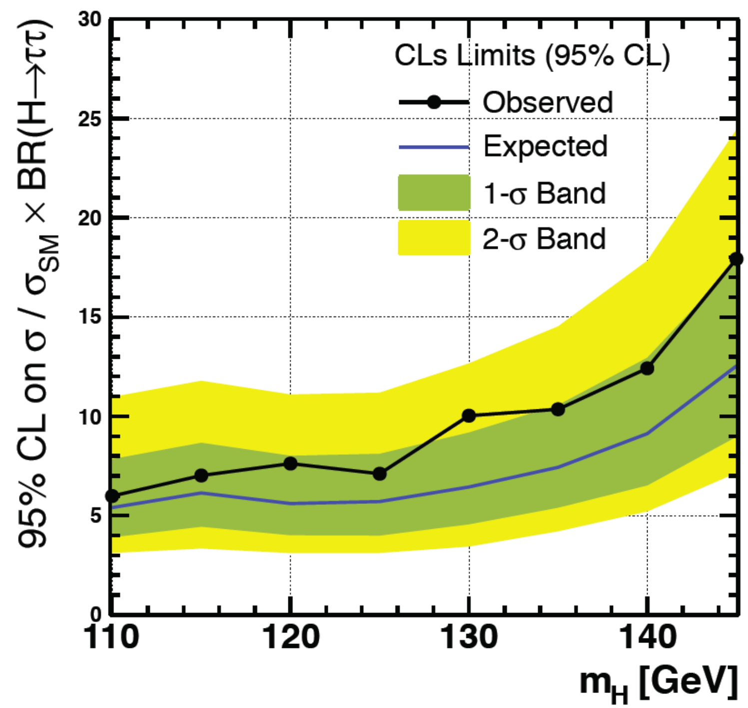
Topologies

- $\mu\tau_h$, $e\tau_h$, $e\mu$ (1.6 fb^{-1}), $\mu\mu$ (1.1fb^{-1})
- τ_h ID by "hadron plus strips", 6% efficiency uncertainty

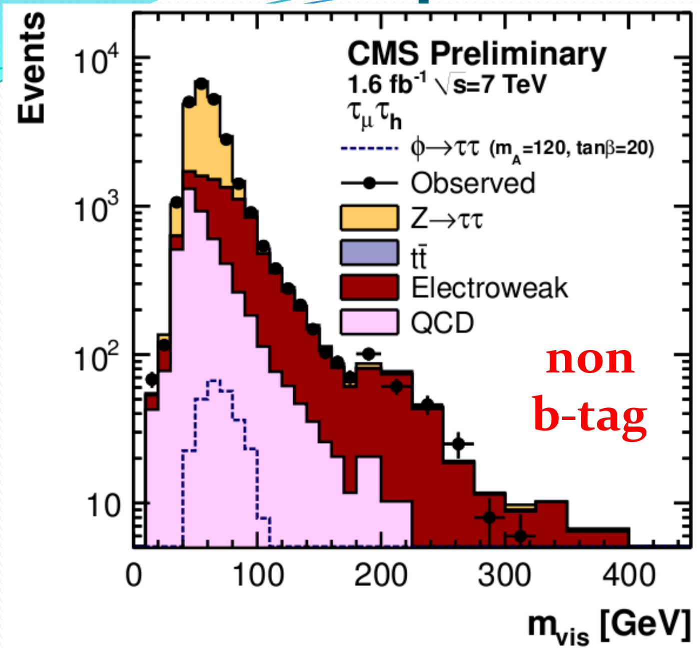
Fit $m_{\tau\tau}$ visible mass distribution

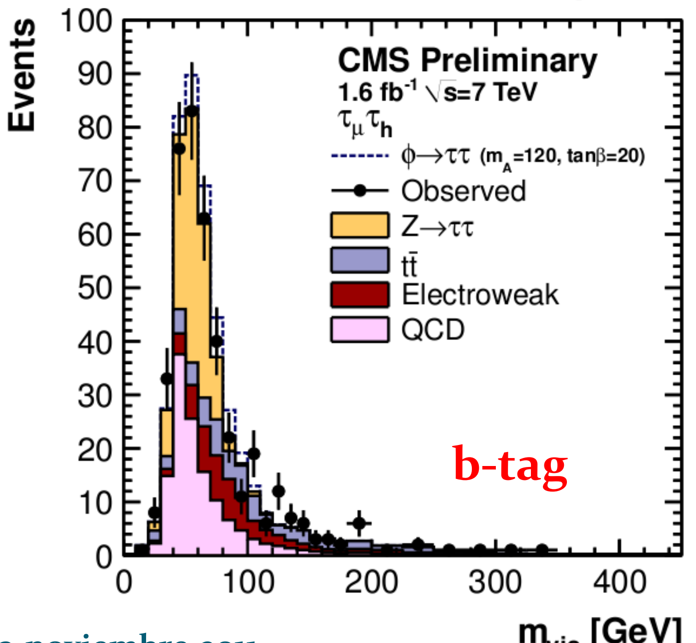






$\phi \rightarrow \tau\tau$ MSSM exclusion



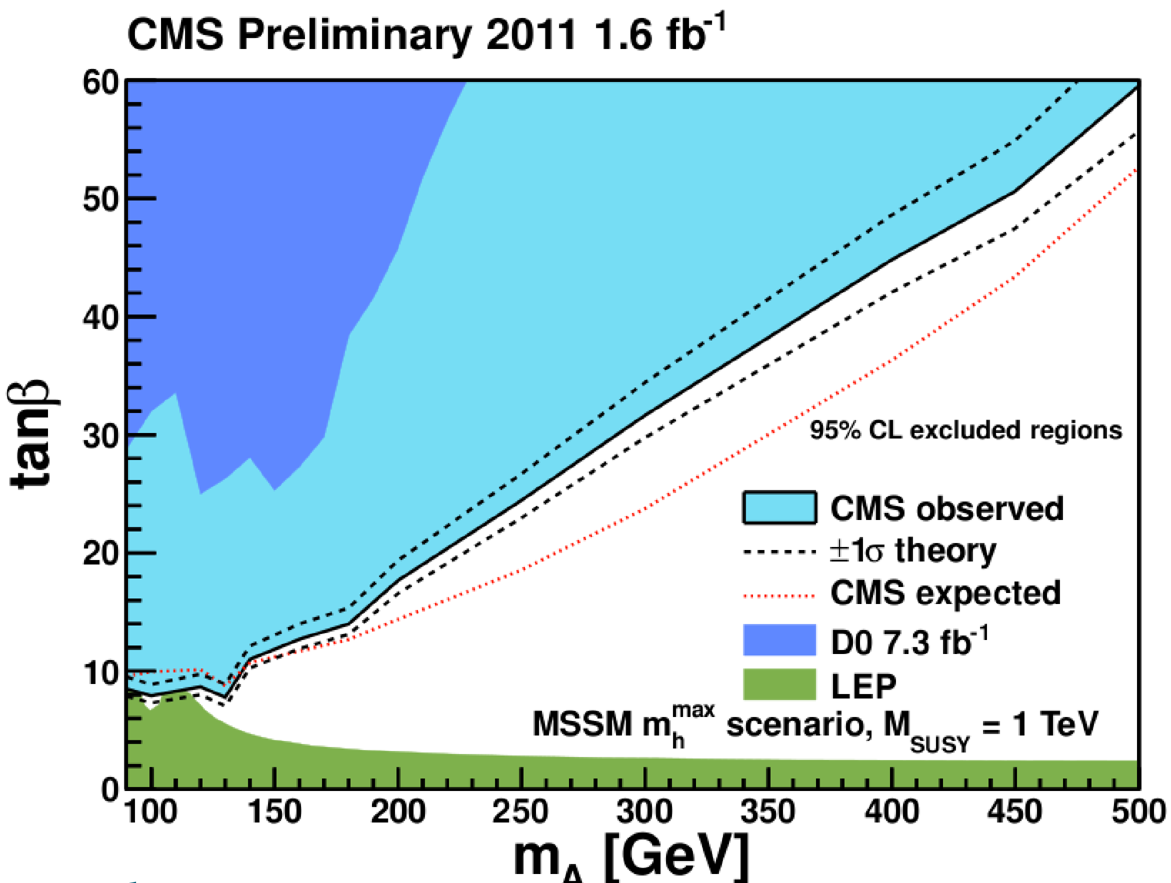


Final states used:

$\tau_\mu\tau_h+\tau_e\tau_h+\tau_e\tau_\mu+\tau_\mu\tau_\mu$

Cut on "CDF variable" P_ζ against W+jets

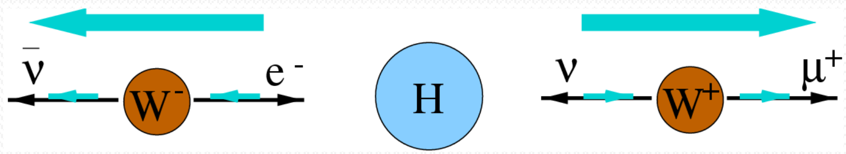
(topological variable formed from visible τ decay products and MET)

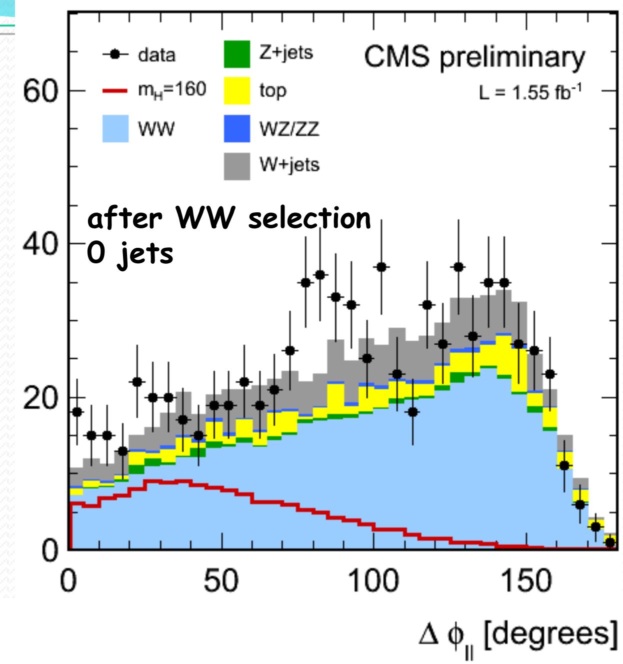


H→WW→2l2ν, 1.55 fb^{-1}

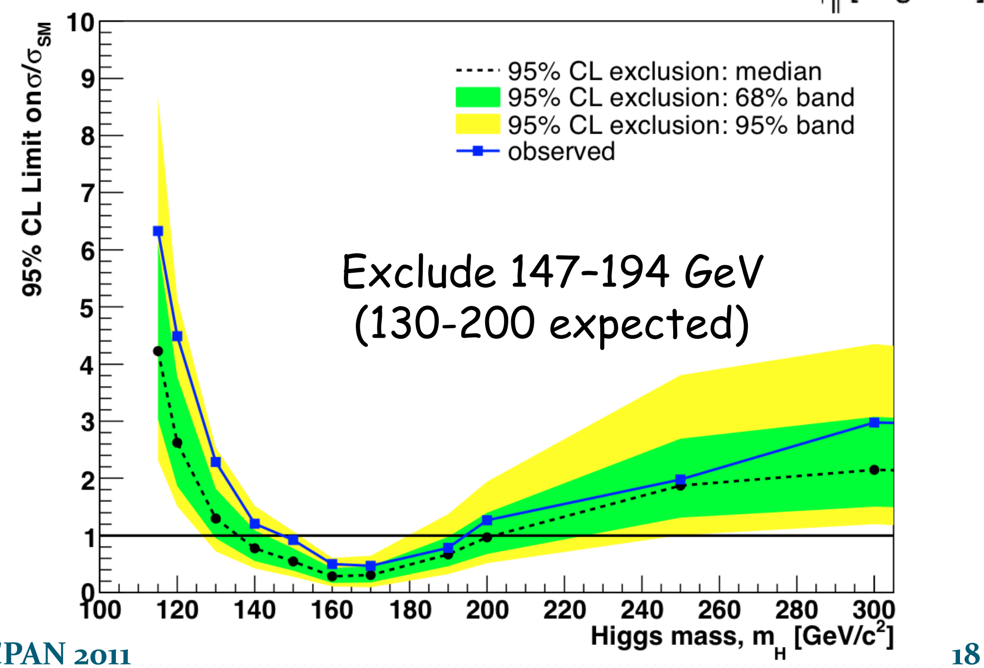
- 2 isolated, energetic leptons
- large MET
- no b-tags (anti-top),veto Zmass
- 0,1,2 (VBF) jets

Main challenge: separate H from direct WW production
How? Helicity conservation:
exploit spin 1 (Z*→WW) vs. spin 0 (H→WW)
For H, charged leptons tend to go in the same direction





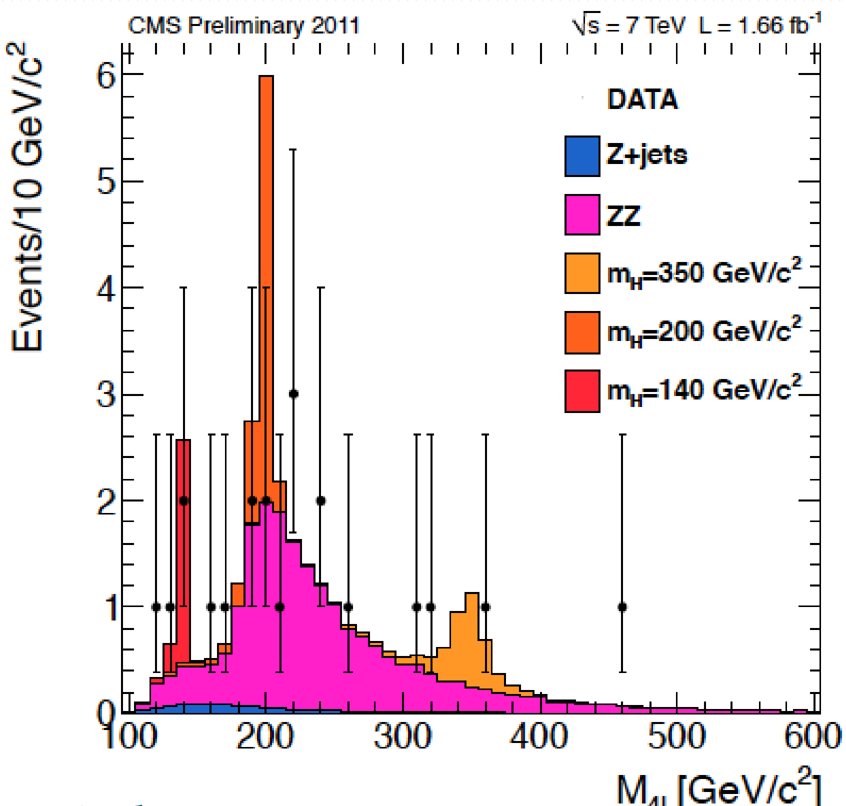
- Simple counting analysis
- MVA techniques (BDT)
  - $\Delta\phi_{ll}$ and m_{ll}
  - p_T of both leptons
  - $M_T(H)$
  - ΔR_{ll}, $\Delta\phi$(ll,MET), $\Delta\phi$(ll,maxJet)
  - train separately for 0,1,2 jets
  - train for SF/OF leptons
  - train for each M_H

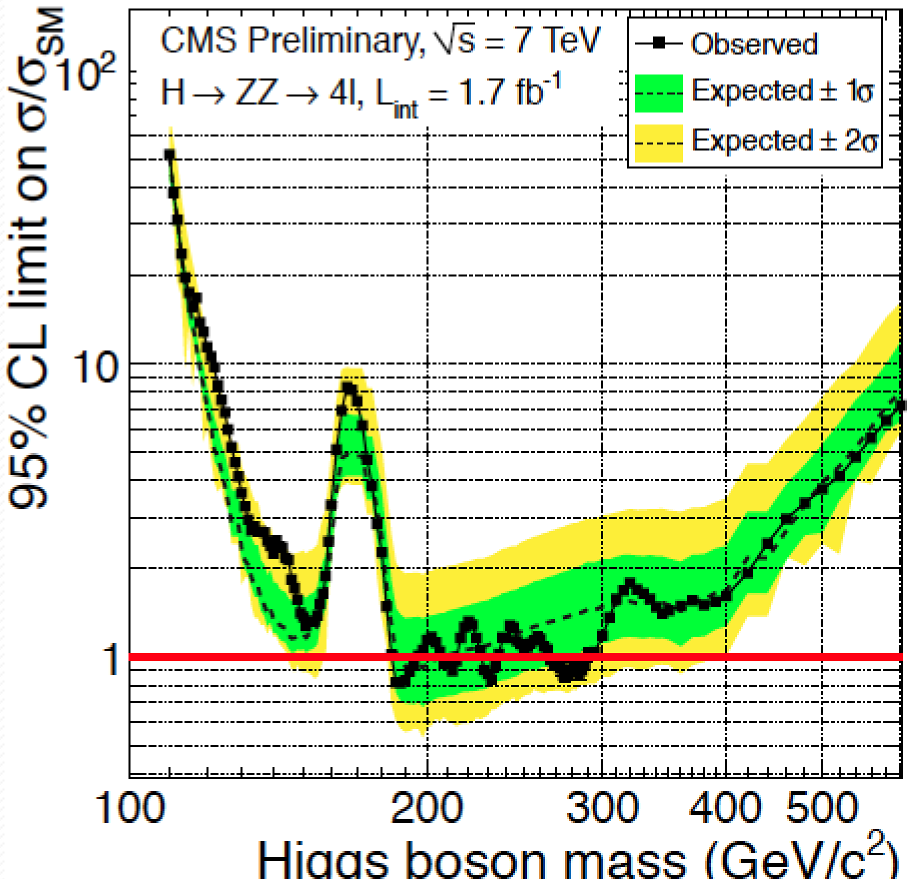


H→ZZ→4l, 1.66 fb^{-1}

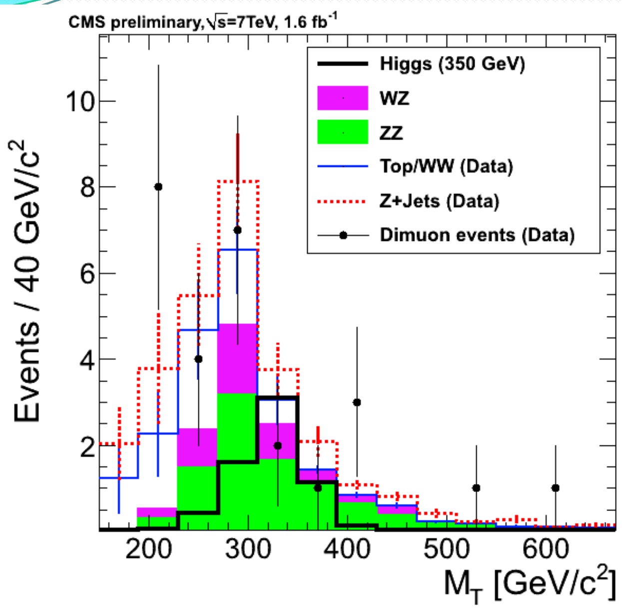
Golden channel:
- 4 isolated leptons from the same vertex
- fully reconstructed events: 4l mass resolution 2-3 GeV (1%)
- low backgrounds
- each event with low m(4l) is very significant!

Backgrounds:
- ZZ: from NLO MC ZZ/Z and measured Z
- tt and Z+jets: from data, loose leptons and shape extrapolation from MC



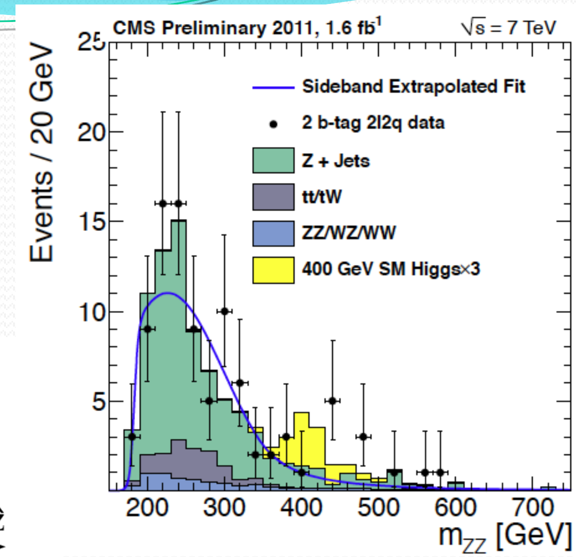


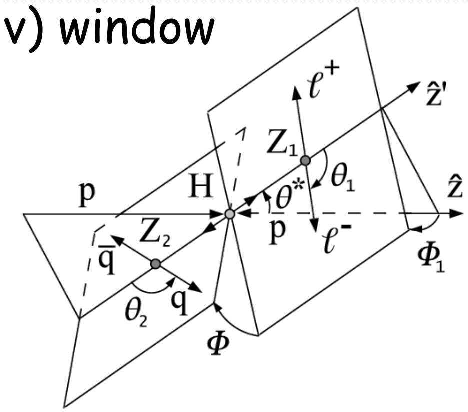
H→ZZ→2l2ν/2l2j, 1.6 fb^{-1}

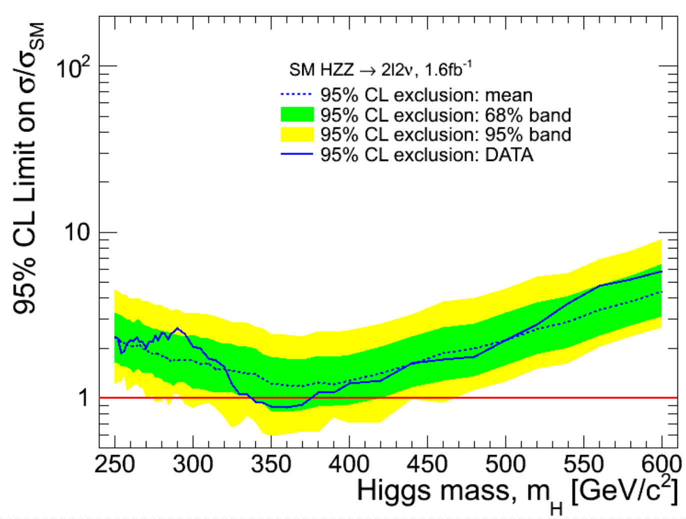


ZZ→2l2ν

- Z→ll
- Large MET
- No b-tag jets
- M_T (2l2ν) window

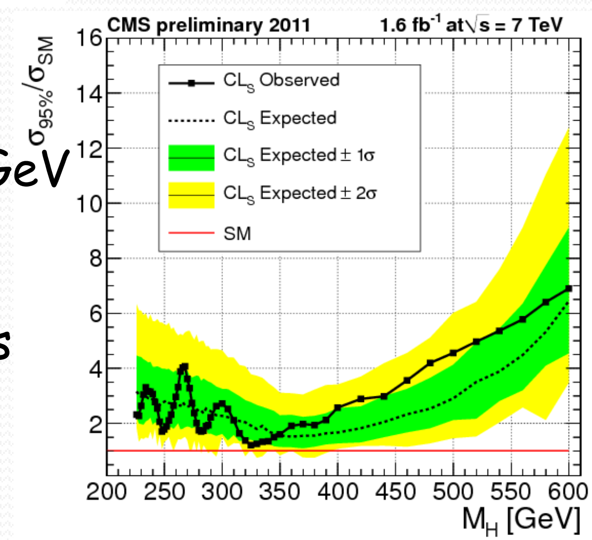




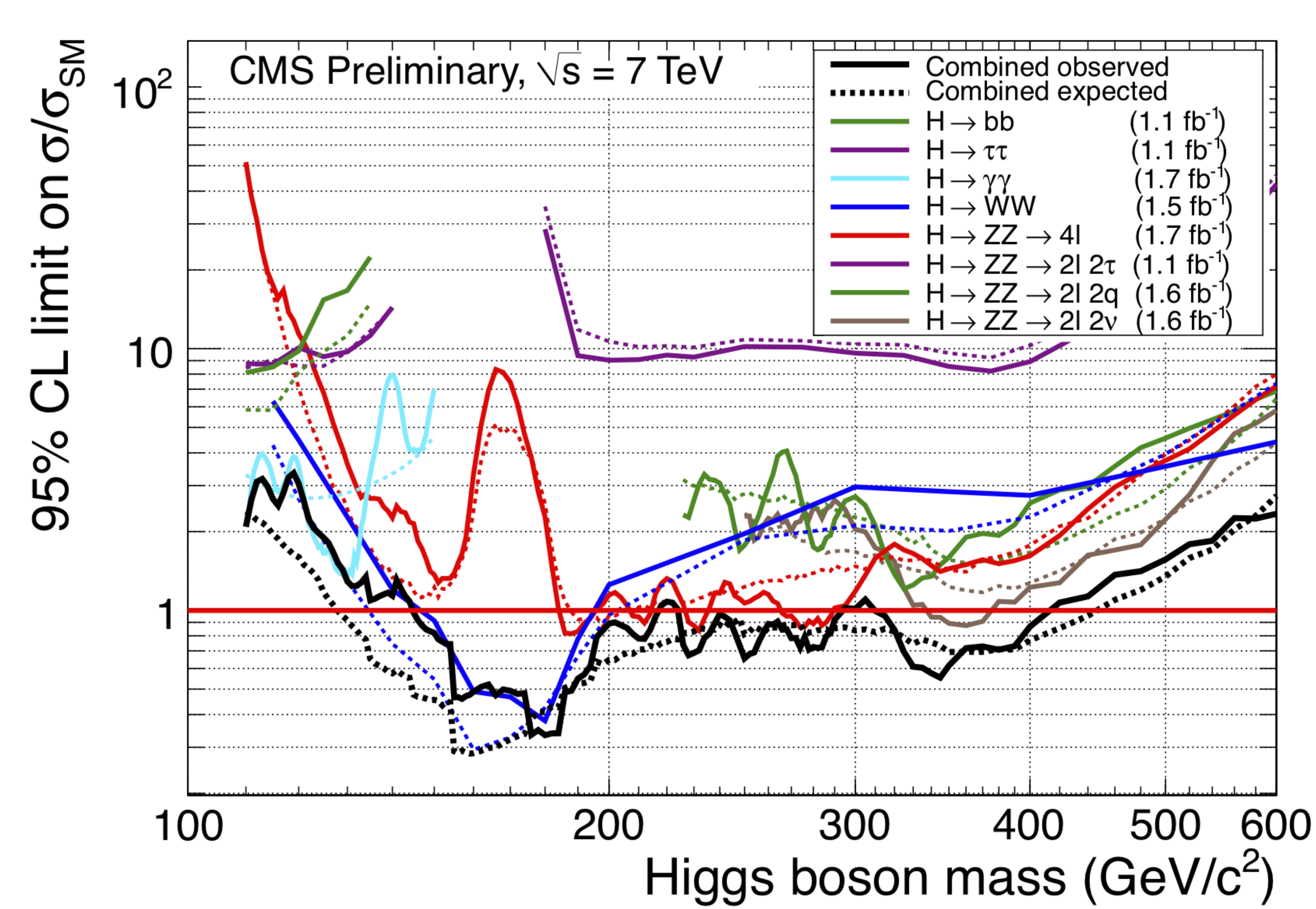


ZZ→2l2j

- highest (ZZ) rate
- peak in m(2l2j) res~10 GeV
- L discriminant based on angular correlations
- categorized by # b-tags

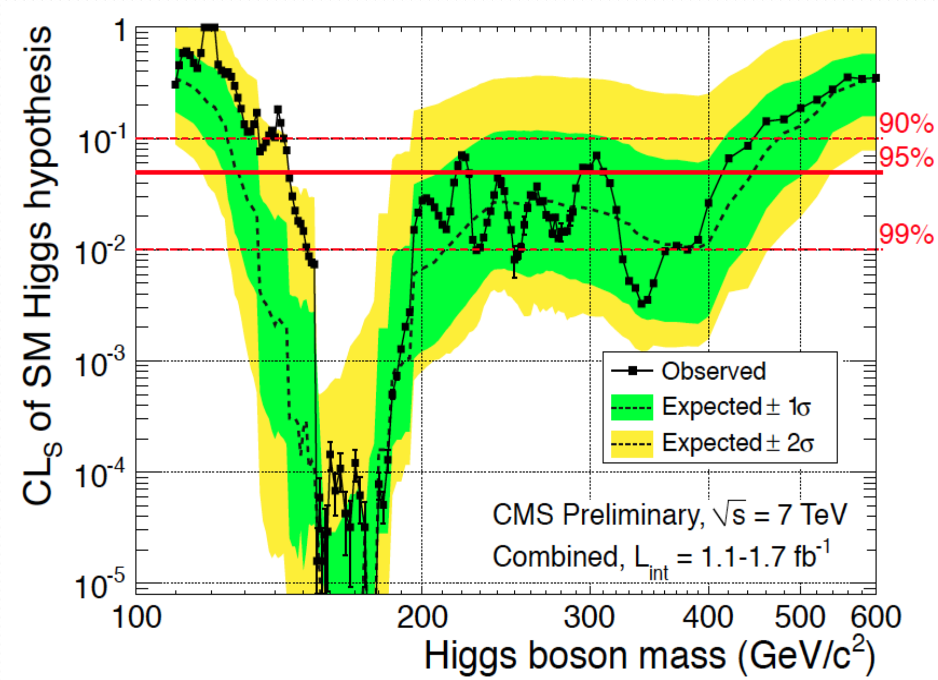


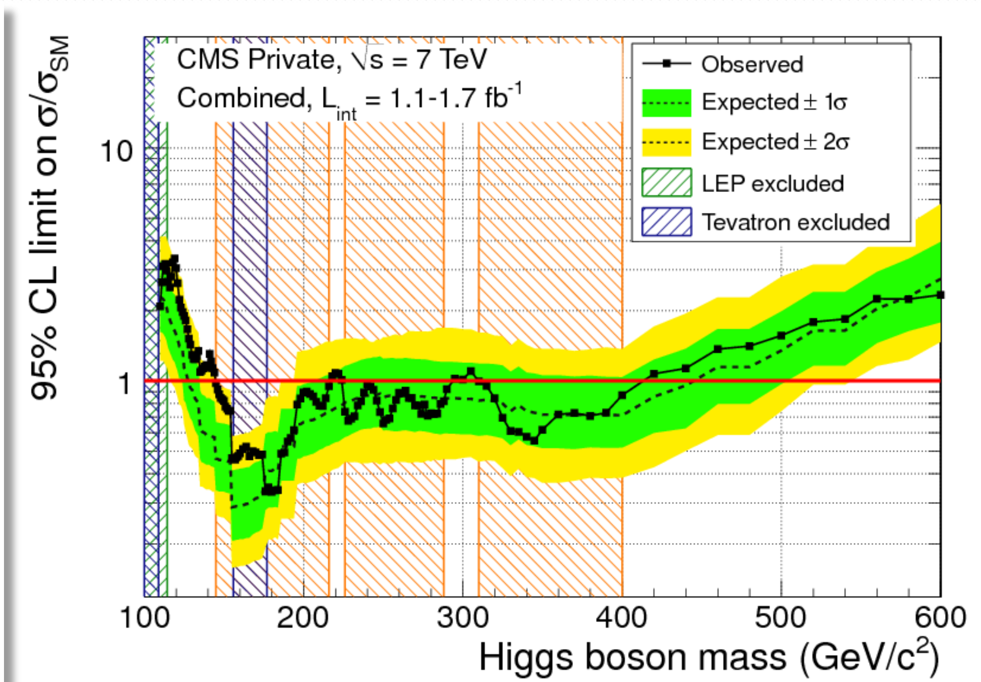
CMS Higgs: all channels



- Solid lines: observed limits @ 95% CL
- Dashed lines: expected limits

CMS Higgs: Combined

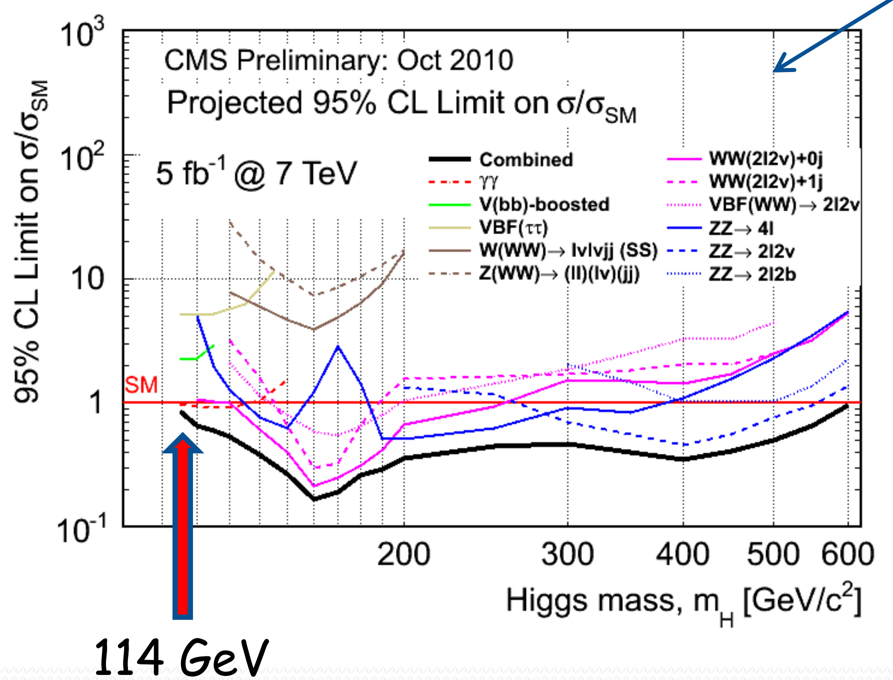


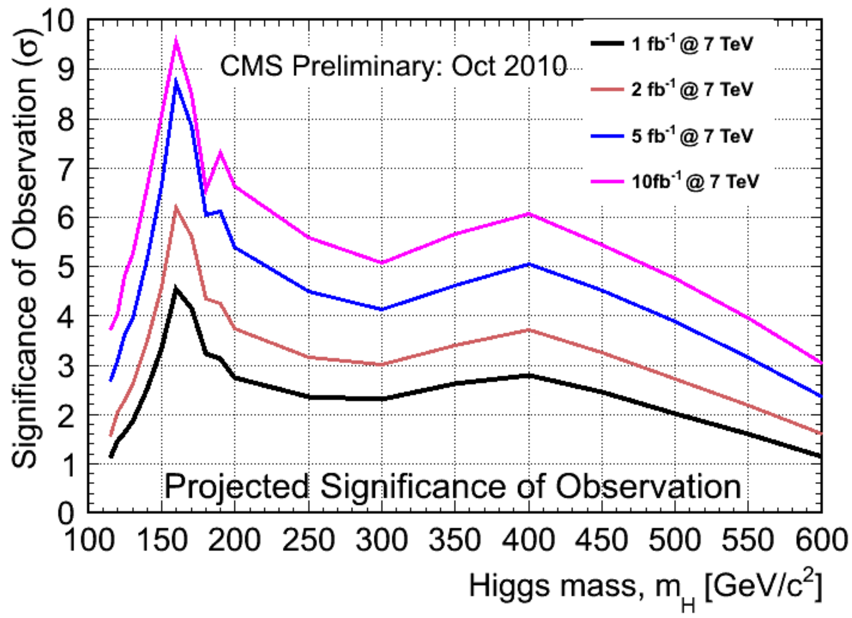


SM Higgs boson: expected exclusion mass range [130-440] GeV

Observed exclusion mass range: [145-216] [226-288] [310-400] GeV

Prospects for 2011 and 2012





SM Higgs boson will either be discovered or ruled out (by both CMS and ATLAS)

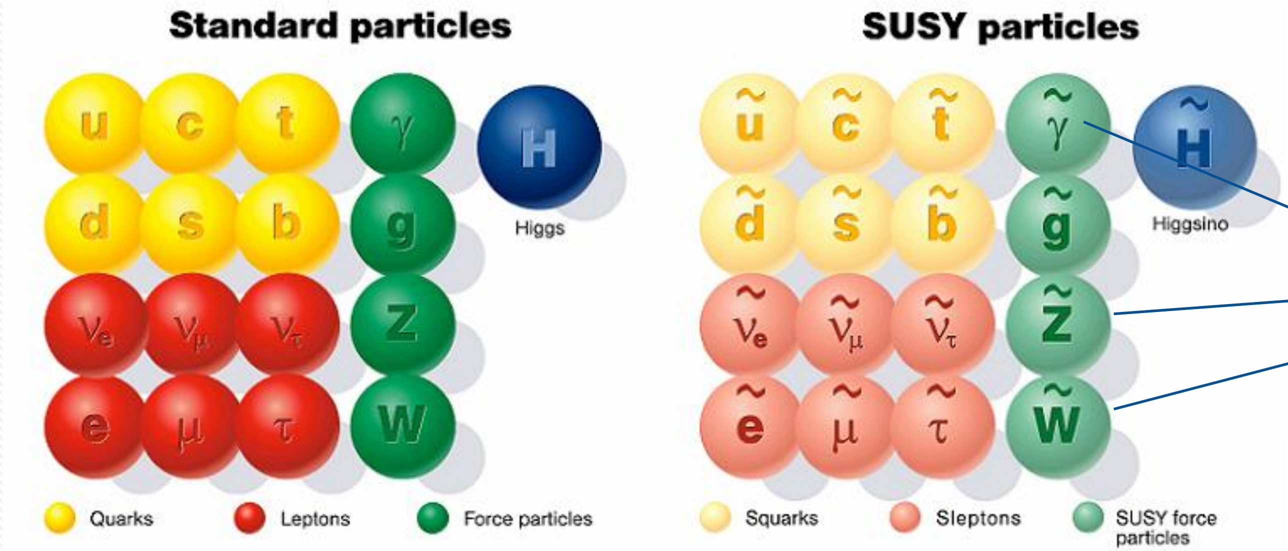
- perhaps as soon as entire current data sample is analyzed
- by end of 2012 run at the latest
  (if non-stat. significant upward fluctuations at low mass)

SUSY Searches

- SUSY
  - Hadronic search with MET
  - Lepton + jets search
  - Dilepton + jets search
  - $\gamma\gamma$ + jets + MET search (GMM)
- An indirect search from B-physics
  - Bs/Bd→$\mu\mu$

SUSY

SM extension: each boson(fermion) gets a fermion(boson) "superpartner" which differs only in spin



Gauginos mix to form charginos and neutralinos

$\tilde{\chi}_i^{\pm}$ $\tilde{\chi}_j^{0}$

Some advantages:

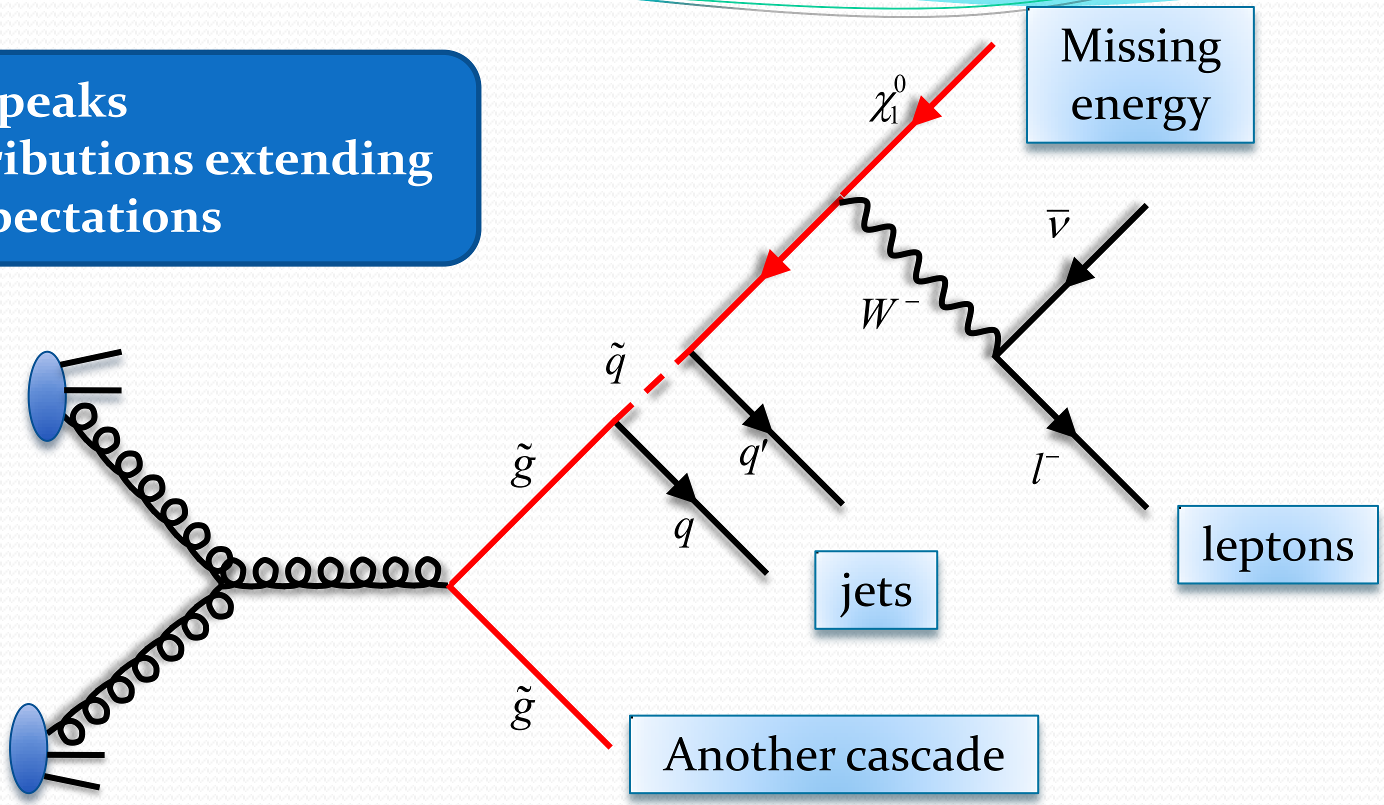
- Removes fine-tuning problem (large radiative corrections cancel)
- Offers dark-matter candidate (assuming LSP is stable)
- Offers possibility of force unification

Popular GUT-based SUSY model: CMSSM

- Assumes mass unification at GUT scale, reduces vast parameter space to just 5: m_o, $m_{1/2}$, A_0, tanβ, sign(μ)
- CMSSM is simply a "benchmark" for comparing limits across experiments
- Other scenarios (such as simplified models) are possible

SUSY Signatures

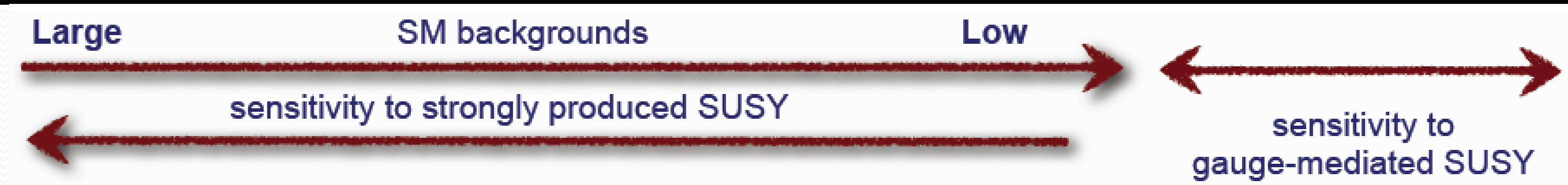
- No narrow peaks
- Broad distributions extending over SM expectations



- Strong production of squarks and gluinos
- Production rate depends on masses, ~ SUSY model independent
- Decay chain details depend on SUSY model (BRs, mass spectrum, ...)
- Long decay chains
- Signature has **MET** from LSPs (and νs), energetic **jets**, **leptons**
- General gauge-mediated models (GGM) also predict photons in final state

SUSY Search Strategy

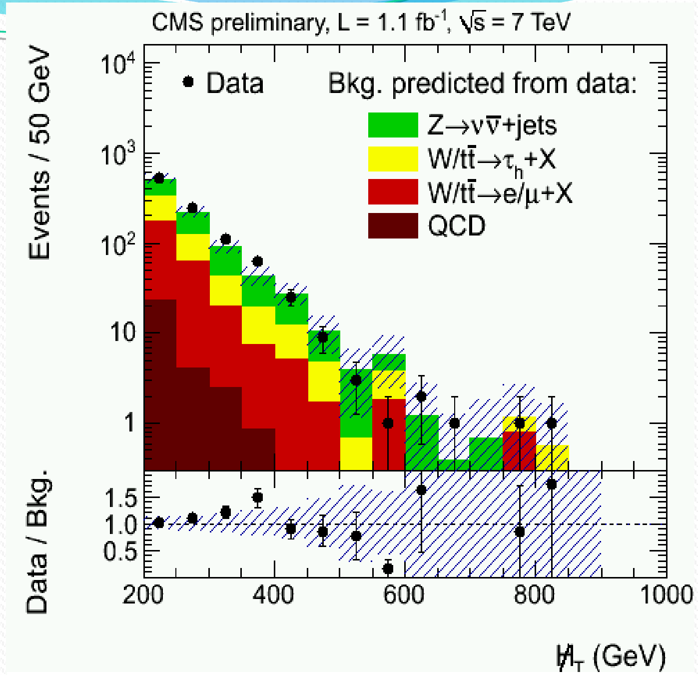
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

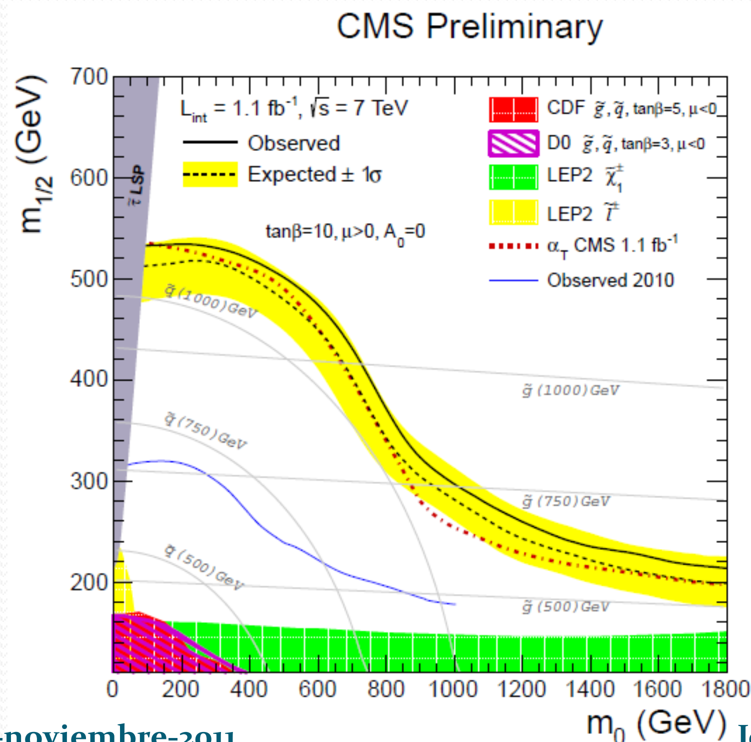


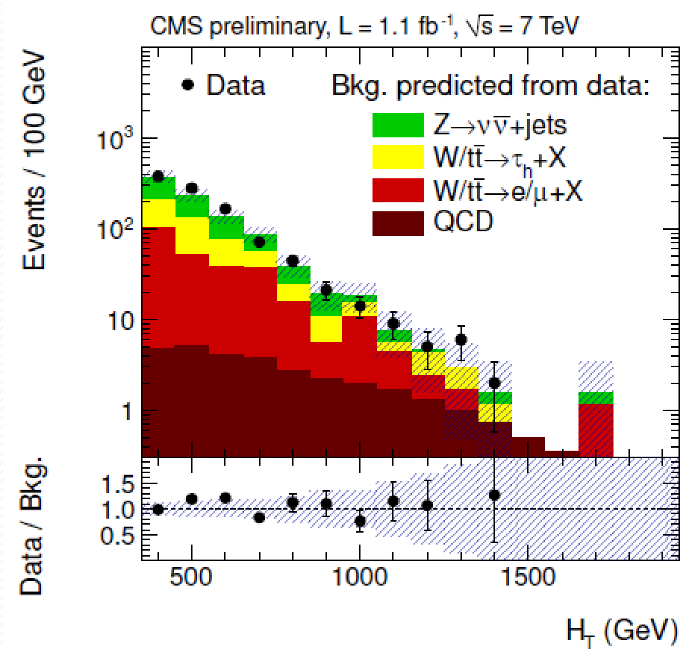
- **Basic analysis strategy:**
- **Focus on topology using different kinematic observables**
- Generic MET signatures
  - Categorize by number of leptons, photons or jets
- All counting experiments so far
  - not optimal for best exclusion limits
  - but easy and sharp for discovery
- Look for excess production of these signatures w.r.t. SM predictions
- No significant excess? Set limits to production rate
- Set model-dependent limits on parameters upon which production*decay rate depends (such as masses)

Jets + MET Search: traditional

- ≥3 jets with E_T>50 GeV and |η|<2.5
- 3 (H_T,MH_T) search regions
  - H_T>500 GeV and MH_T>350 GeV
  - H_T>800 GeV and MH_T>200 GeV
  - H_T>800 GeV and MH_T>500 GeV
- No electrons or muons
- Veto events where MH_T aligned with j1,j2 or j3
- Backgrounds from data-driven techniques
  - Z→νν + j, QCD, W+jets and top
- No excess of events observed → set limits in CMSSW

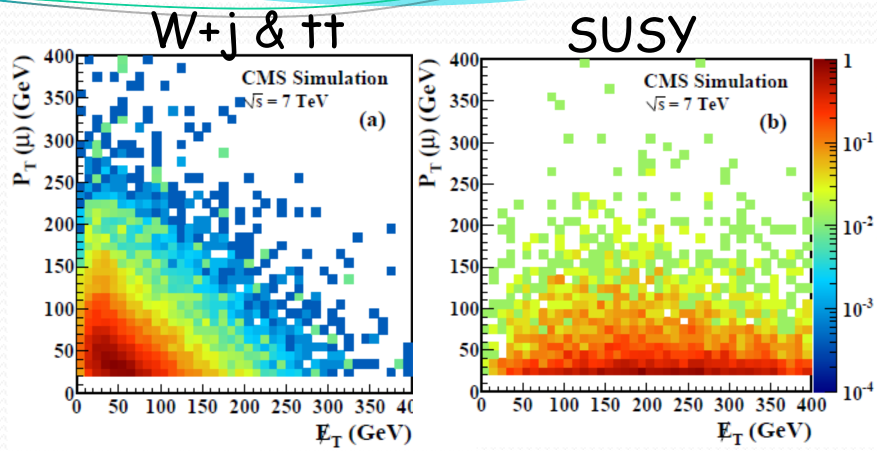






Single lepton + jets + MET

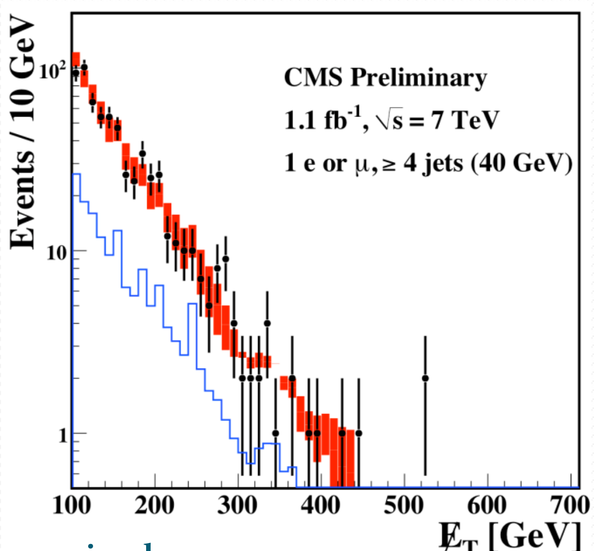
- Exactly one isolated e or μ with p_T>20 GeV/c
- H_T>500 GeV and MET>250 or 350 GeV
- ≥3-4 jets with E_T>40 GeV and $|\eta|$<2.4
- Backgrounds from data-driven techniques
- Lepton spectrum
  - Exploit fact that in W+jets events l and ν have similar p_T spectra
  - Use μ spectrum to predict background for events with H_T>500 GeV
- Lepton projection
  - Use helicity structure of V-A coupling to W
  - Well understood from W polarization analysis

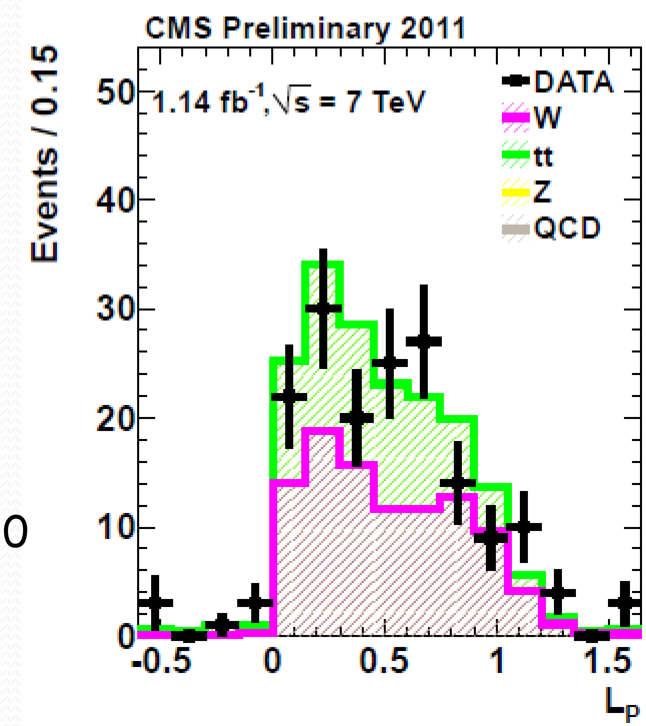


$$L_P = \frac{\vec{p}_T(\ell)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

SUSY signal: Lp < 0.15

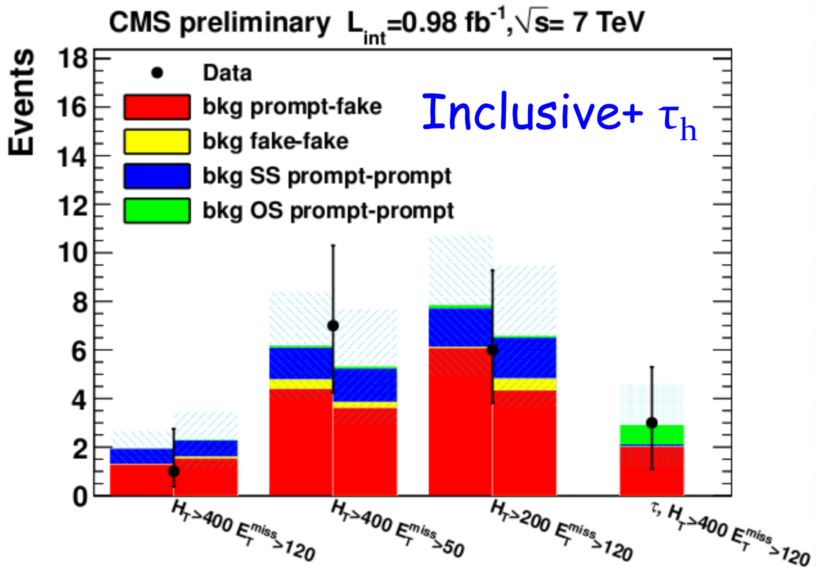
W+j, tt control: Lp > 0.30

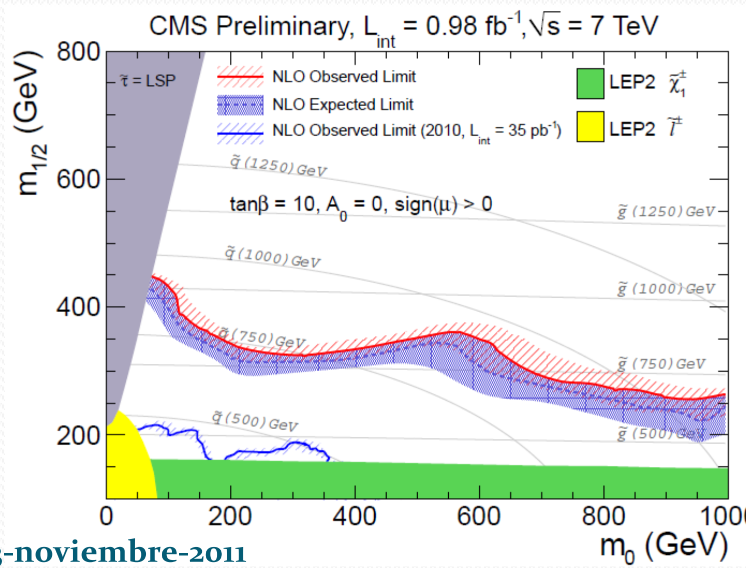


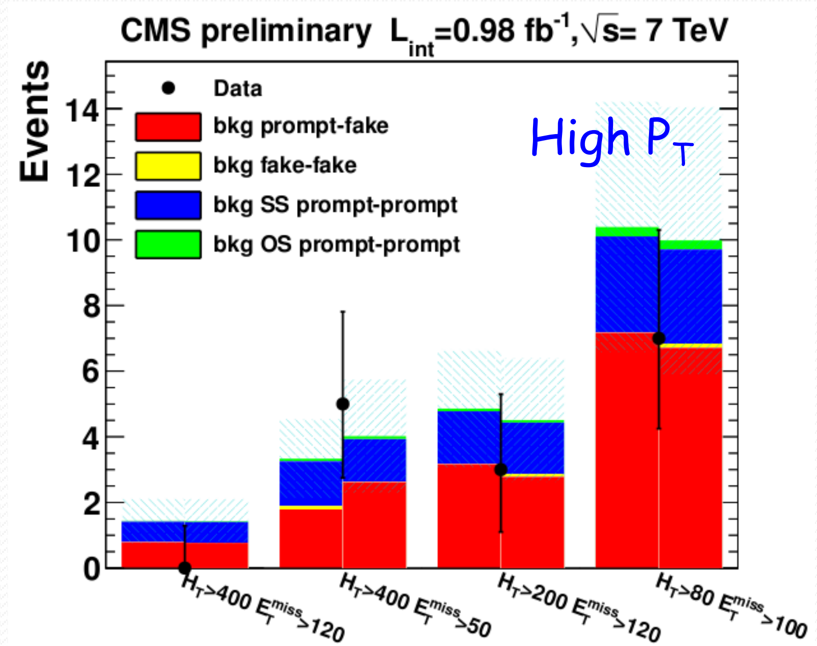


Same-sign dileptons + jets + MET

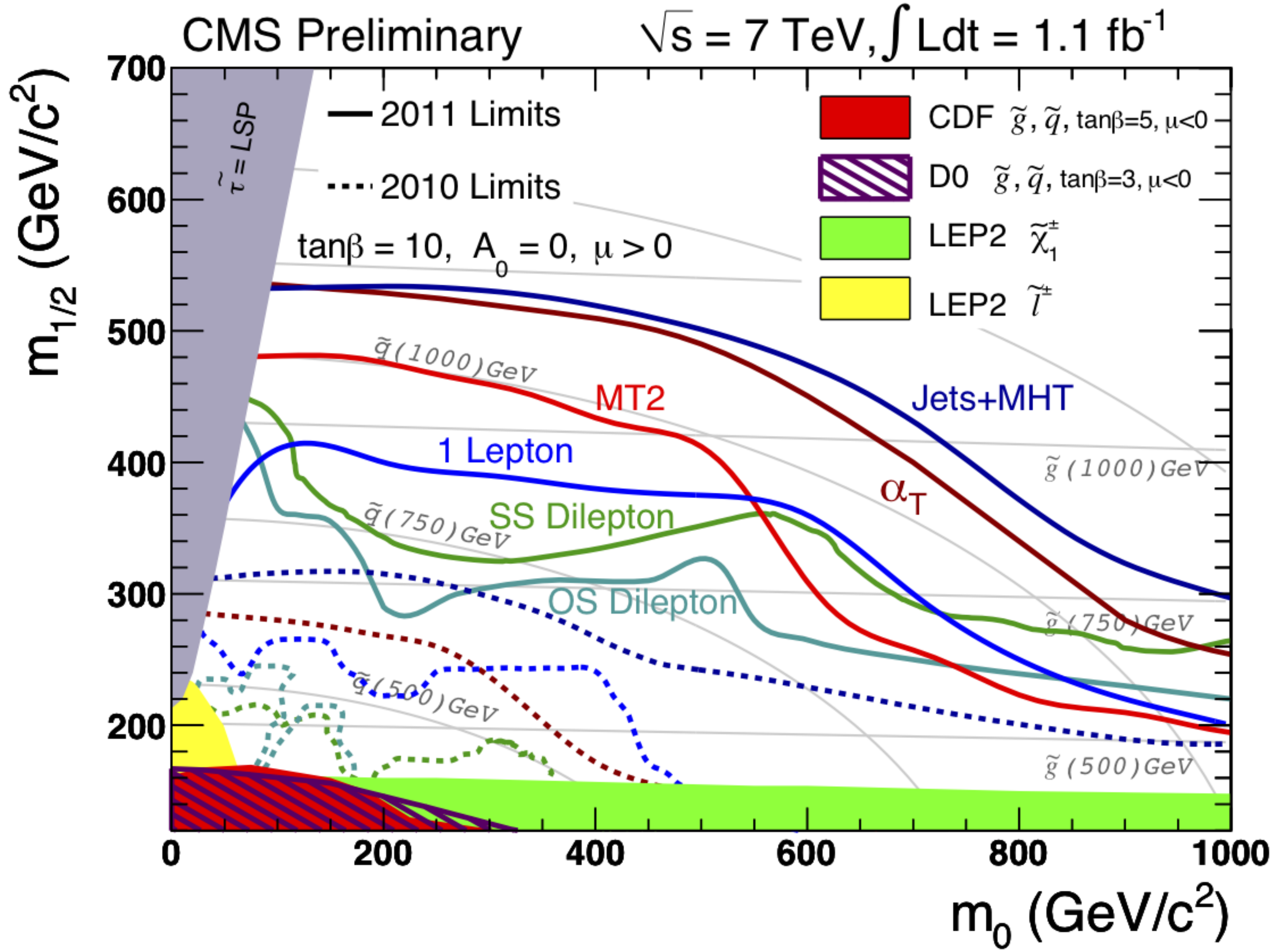
- 2 SS leptons with Pt as low as 5/10/15 GeV for $\mu/e/\tau$
  - Consider ee, $e\mu$, $\mu\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$
- ≥2 jets with E_T>40 GeV and $|\eta|$<2.4
- MET>30 GeV
- Complementary baseline selections, used to check bkgnd predictions
  - Inclusive SS dileptons with H_T>200
  - Dileptons with τ_h and H_T>350, MET>80
  - High P_T SS dileptons with H_T>80
- 4 search regions with varying H_T and MET cuts
- Clean signature: very low SM backgrounds
  - QCD, W/Z+jets, top with jets faking leptons (data-driven)
  - Electron charge mis-reco (data-driven)
  - $W\gamma \rightarrow \gamma$ conversion, WZ/ZZ/ttW (small, from MC)







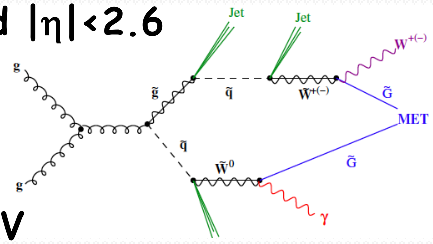
CMS Exclusion Plot: all searches



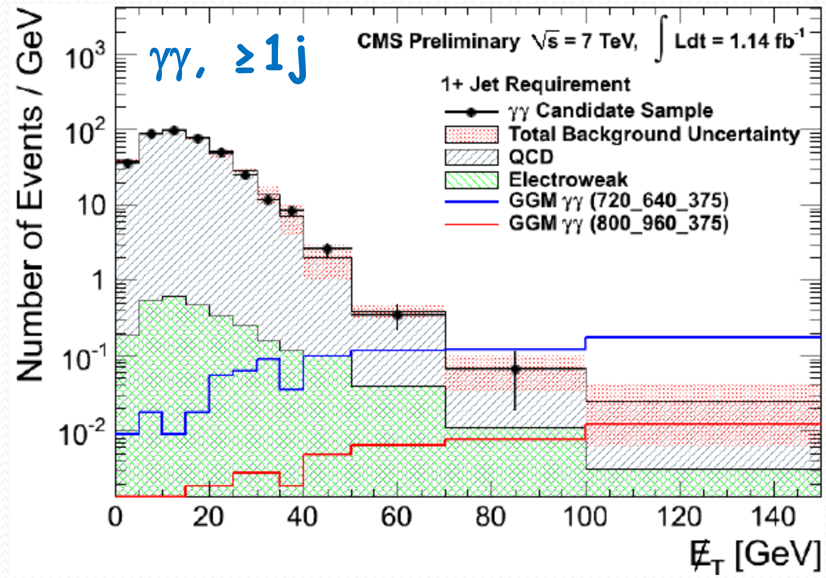
Limits extend well beyond Tevatron reach and well beyond 2010 limits

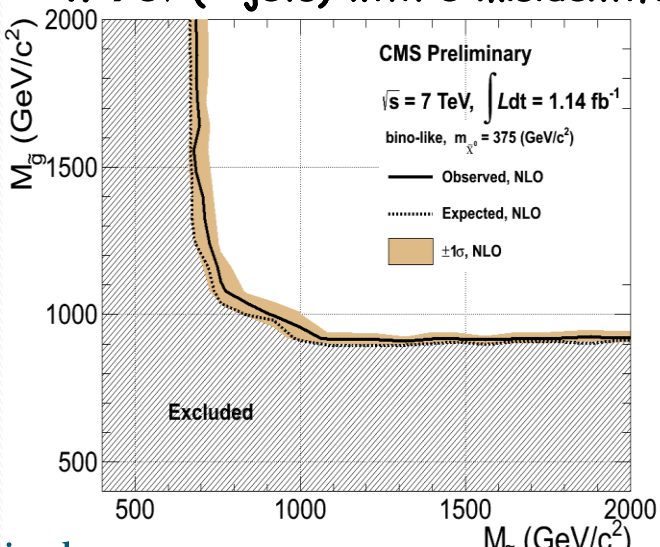
GGM SUSY: $\gamma(\gamma)$ + jets + MET

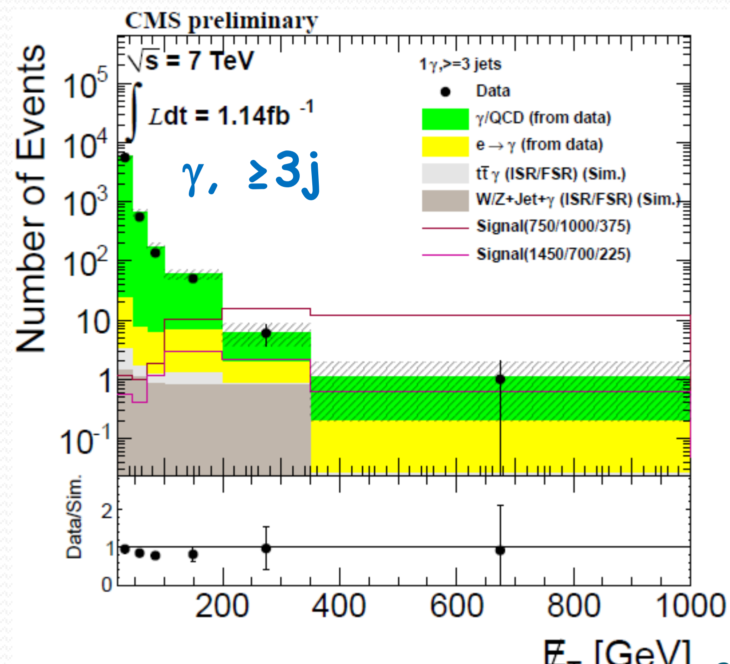
- General Gauge Mediated SUSY breaking (GGM)
  - Neutralino or wino (NLSP) → Gravitino (LSP) + γ
- Topology 1
  - ≥2 isolated γ with E_T>45,30 GeV and $|\eta|$<1.4
  - ≥1 jet with E_T>30 GeV and $|\eta|$<2.6
  - $\Delta R j\gamma$ > 0.5
  - MET > 100 GeV



- Topology 2
  - 1 isolated γ with E_T>75 GeV
  - ≥3 jets (with same requirements as top. 1)
  - MET> 200 GeV
- Backgrounds from data-driven techniques
  - QCD dominant background
  - W→eν (+ jets) with e misidentified as γ





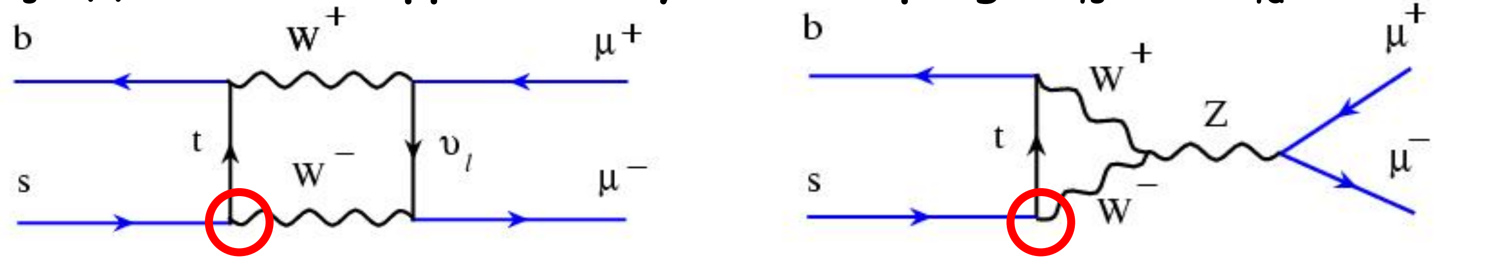


Indirect search: Bs/Bd → μμ

FCNC decay $B \to \mu\mu$ heavily suppressed in SM

- can only occur via higher order loop diagrams
- helicity suppressed by factors $(m_\mu/m_B)^2$

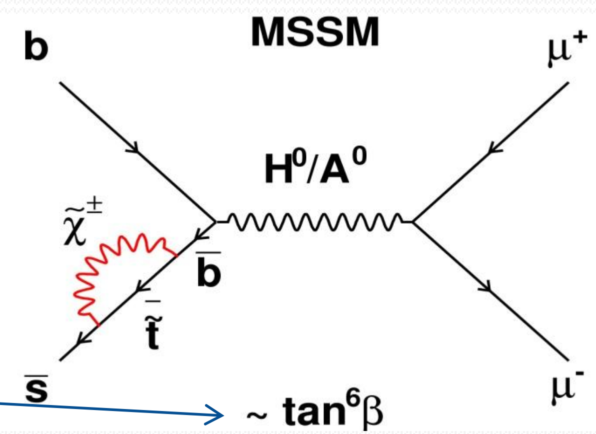
$B_d/B_s \to \mu\mu$ further suppressed by CKM coupling $|V_{ts}|^2 / |V_{td}|^2$



SM:

$$BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$BR(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

SUSY scenarios (MSSM,RPV,mSUGRA) can significantly boost the BR

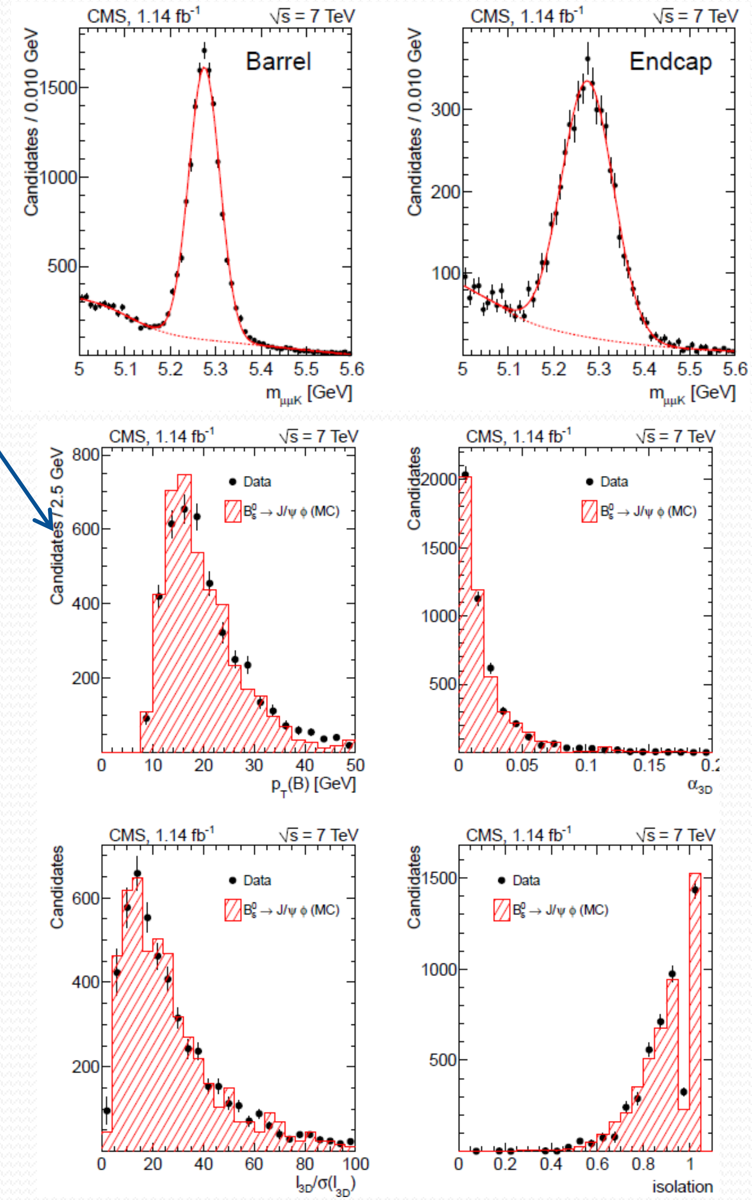


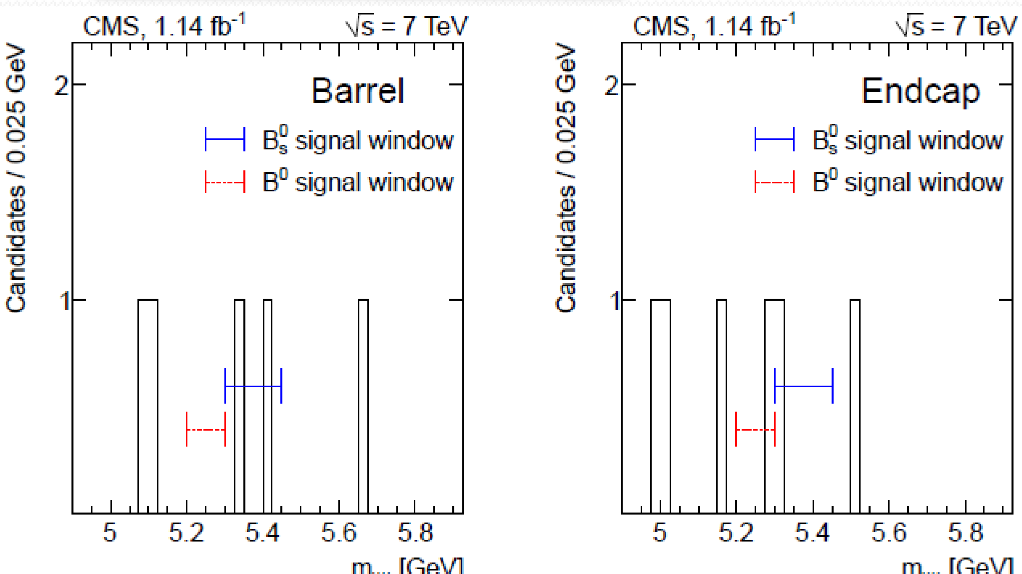
Observe no excess of events ⇒ set limits on new physics
Observe excess of events ⇒ clear evidence for new physics

Bs/Bd → μμ

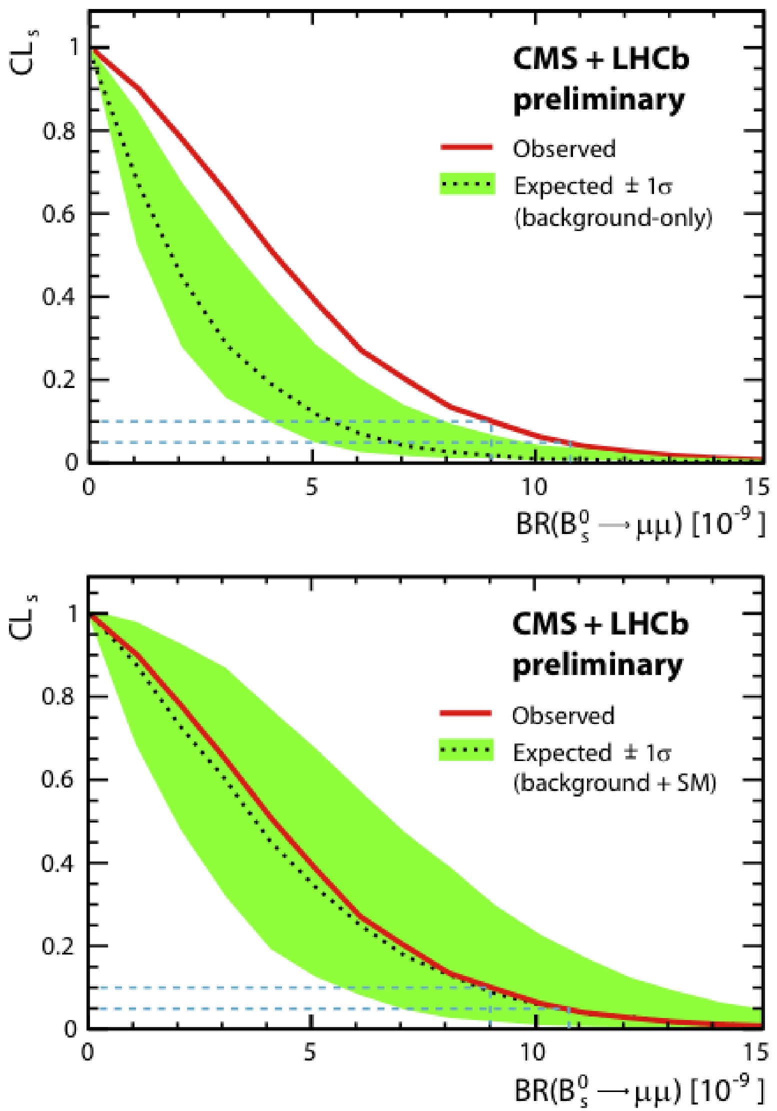
- Simultaneous search for $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$
- Blind analysis
  - $B^+ \to J/\psi K^+$ used for normalization
    - Minimize uncertainty from $\sigma(bb)$ and luminosity
  - $B^0 \to J/\psi\, \phi$ used as control regions for efficiencies
- Events observed in the unblinded windows consistent with bkg. plus SM expectations
- CMS BR Limits at 95% CL

$B_s \to \mu^+\mu^- < 1.9\times10^{-8}$
$B_d \to \mu^+\mu^- < 4.6\times10^{-9}$





Bs→ μμ : CMS+LHCb



- CMS BR Limit
  - $B_s \to \mu^+\mu^- < 1.9 \times 10^{-8}$
- LHCb BR limit
  - $B_s \to \mu^+\mu^- < 1.5 \times 10^{-8}$
- Combination of LHCb+CMS:

$B_s \to \mu^+\mu^- < 1.08 \times 10^{-8}$
(best existing limit)

- Value of CLs in good agreement with background + SM
- Enhancement of BR by more than 3.4 x SM excluded at 95% C.L.
  - There remains (a little) room for a contribution from BSM physics

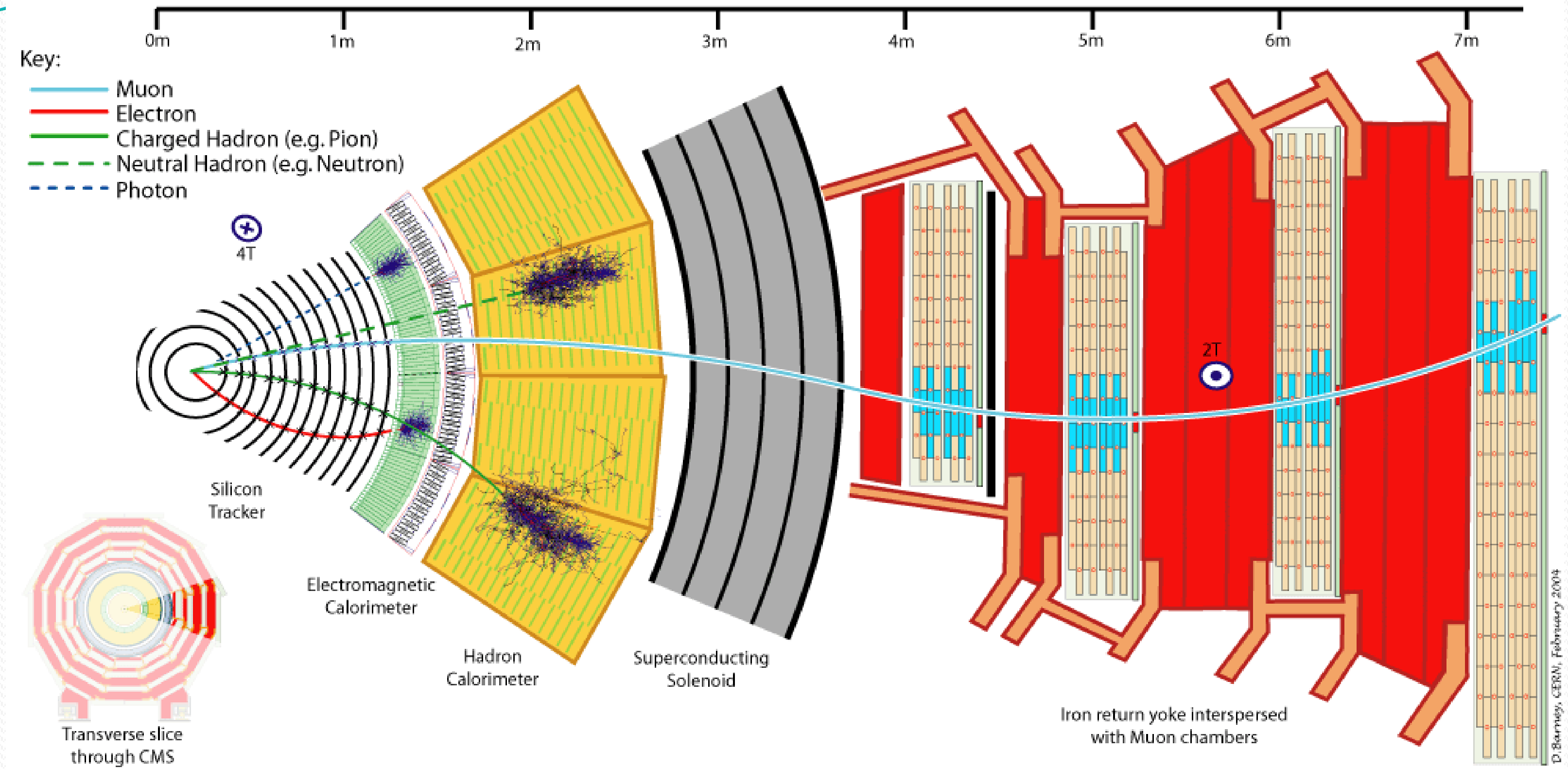
Conclusions

- ✓ The LHC accelerator is performing very well
  - ❑ Entered the 1/fb era and accumulating data fast
- ✓ CMS is in excellent shape
  - ❑ Operation, Performance, Detector understanding, Analysis tools
- ✓ CMS has performed a comprehensive set of SM measurements at 7 TeV
  - ❑ impressive amount of physics analyses in a very short time scale
  - ❑ broad set of tools and strategies have been developed
- ➢ The search for new physics is now the main activity
  - ❑ Several new limits exceed previous Tevatron and 2010 limits
  - ❑ Accessing new, unexplored territory in BSM searches
  - ❑ Imposing new, stringent constrains on several BSM models
- ✓ Higgs prospects very promising for 2011-2012
  - ❑ SM Higgs will be discovered at the latest by 2012 if it exists
  - ❑ SM Higgs will be ruled out between 2011-2012 if it does not exist
- ✓ SUSY searches with sensitivity to squark/gluino masses in the range 0.5-1 TeV

CMS is ready for discoveries
More exciting results to come in 2012

Backup Slides

CMS Detector: basic parameters

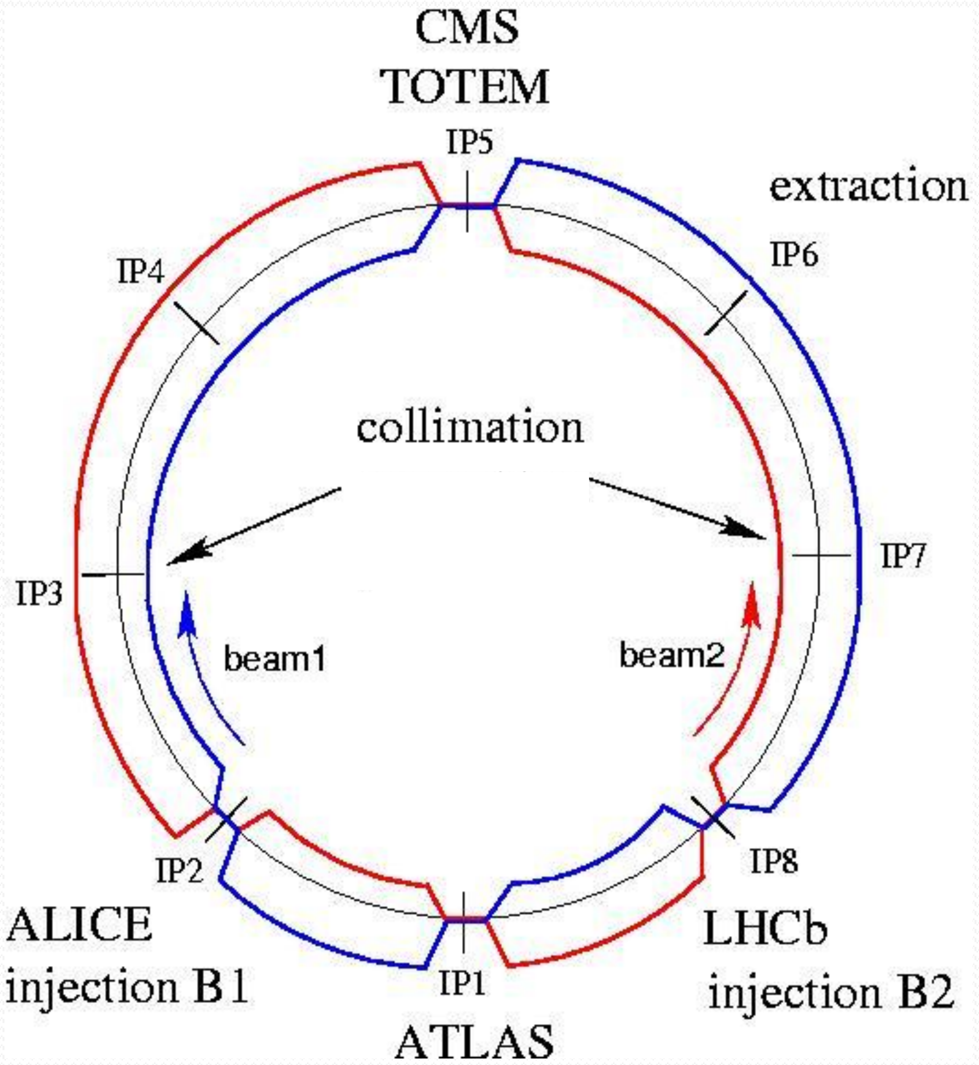


- **Momentum / charge of tracks and secondary vertices (e.g. from b-quark decays) are measured in central tracker (Silicon layers).**
- **Energy and positions of electrons and photons measured in high resolution electromagnetic calorimeters. (~ 0.5% @ ET ~ 50 GeV)**
- **Energy and position of hadrons and jets measured mainly in hadronic calorimeters**
- **Muons identified and momentum measured in external muon spectrometer (+central tracker) dp/p<1% @ 100GeV and <10%@1 TeV**
- **Neutrinos "detected and measured" through measurement of missing transverse energy in calorimeters (hermeticity; good Missing ET resolution)**

LHC: basic parameters

- 8 arcs (sectors), ~3 km each
- 8 long straight sections (700 m each)
- beams cross in 4 points
- 2-in-1 magnet design with separate vacuum chambers → *p-p* collisions

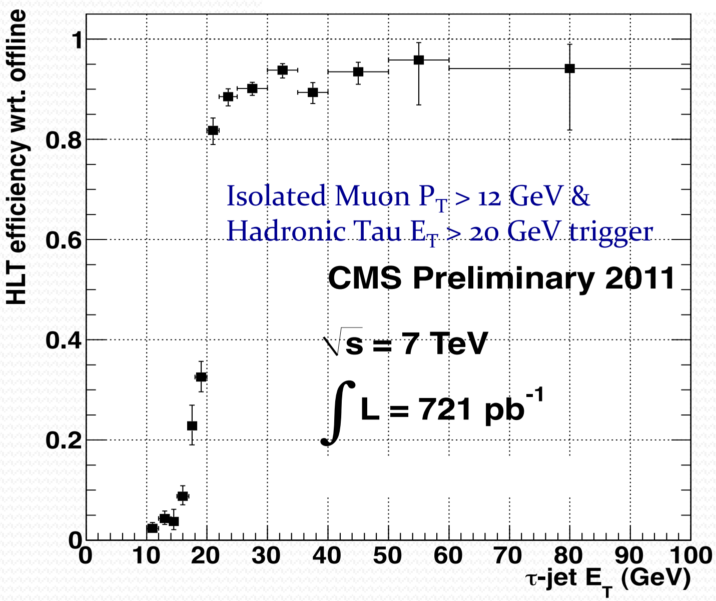
Nominal LHC parameters	
Beam energy (TeV)	7.0
No. of particles per bunch	1.15×10^{11}
No. of bunches per beam	2808
Stored beam energy (MJ)	362
Transverse emittance (μm)	3.75
Bunch length (cm)	7.6
Luminosity (*cm^{-2} s^{-1}*)	*10^{34}*



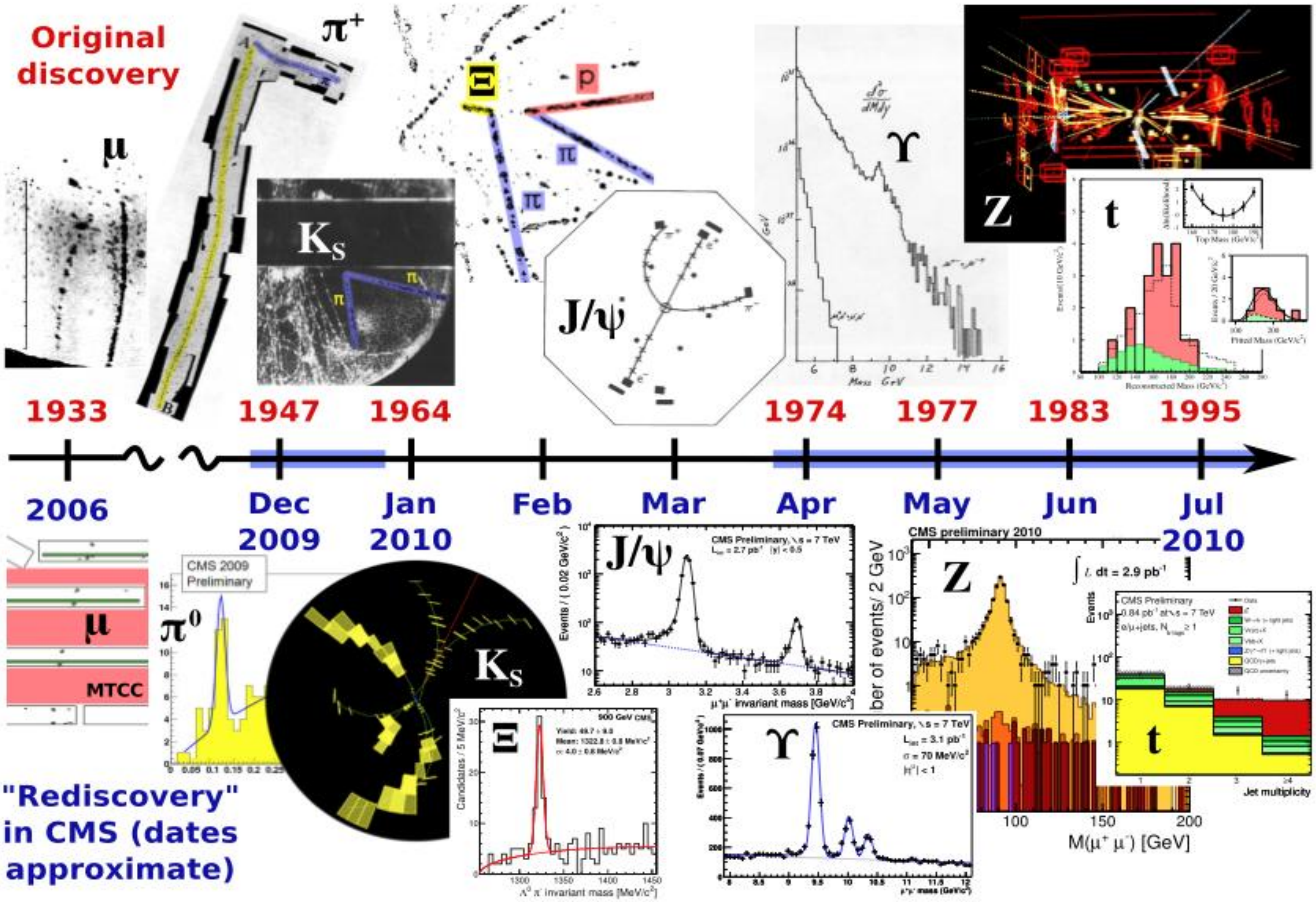
CMS High Level Trigger Performance

- The CMS HLT is performing well in the high luminosity environment
- Trigger algorithms and menus have increased in complexity
  - Over 200 multi-object triggers including tau and b-jet triggers, in addition to single object triggers for electrons, photons, muons, jets, total energy, & missing transverse energy (400 total paths)
  - Successfully using algorithms such as Particle Flow tau reconstruction

TAU + MUON

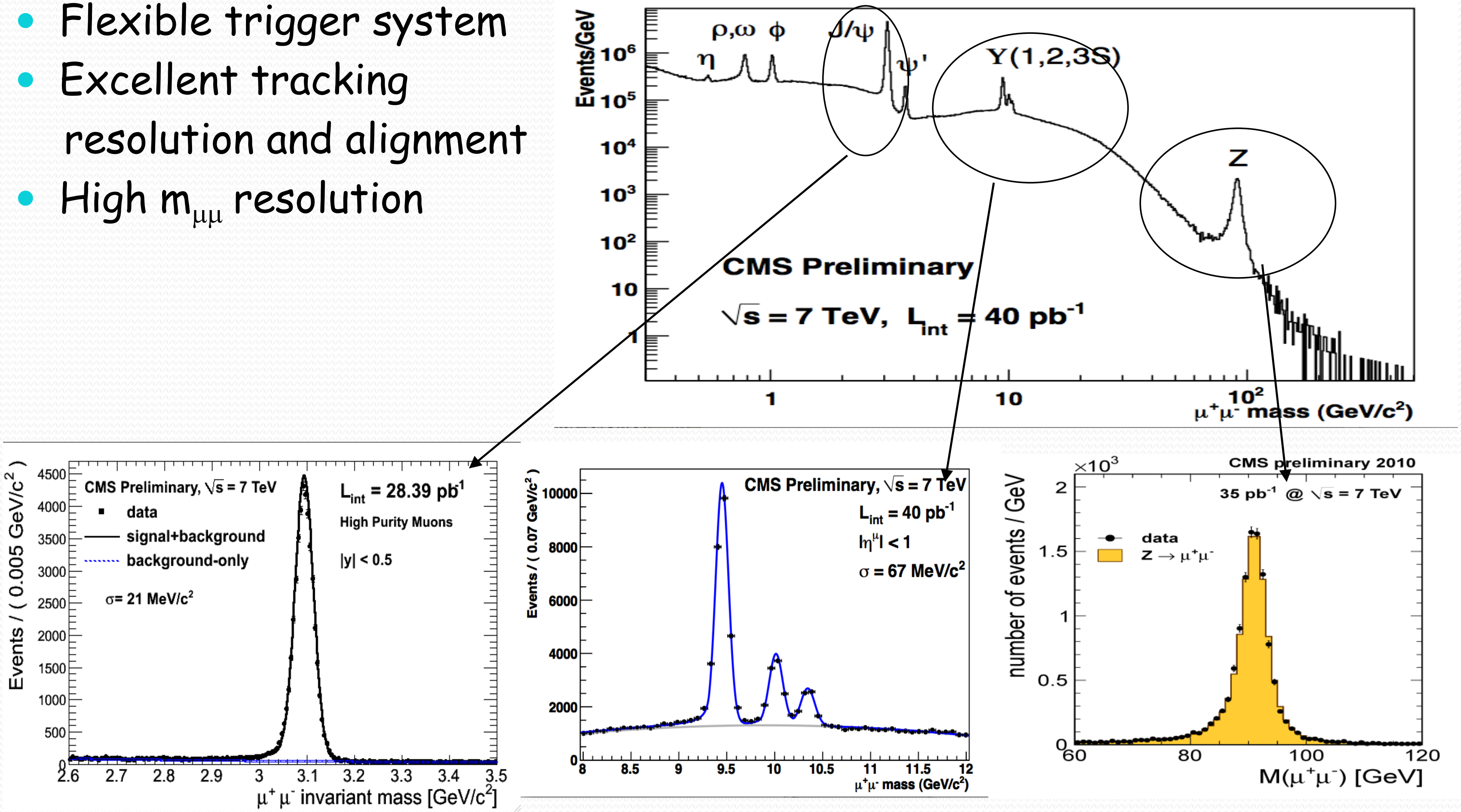


SM: "rediscovered" at 7 TeV



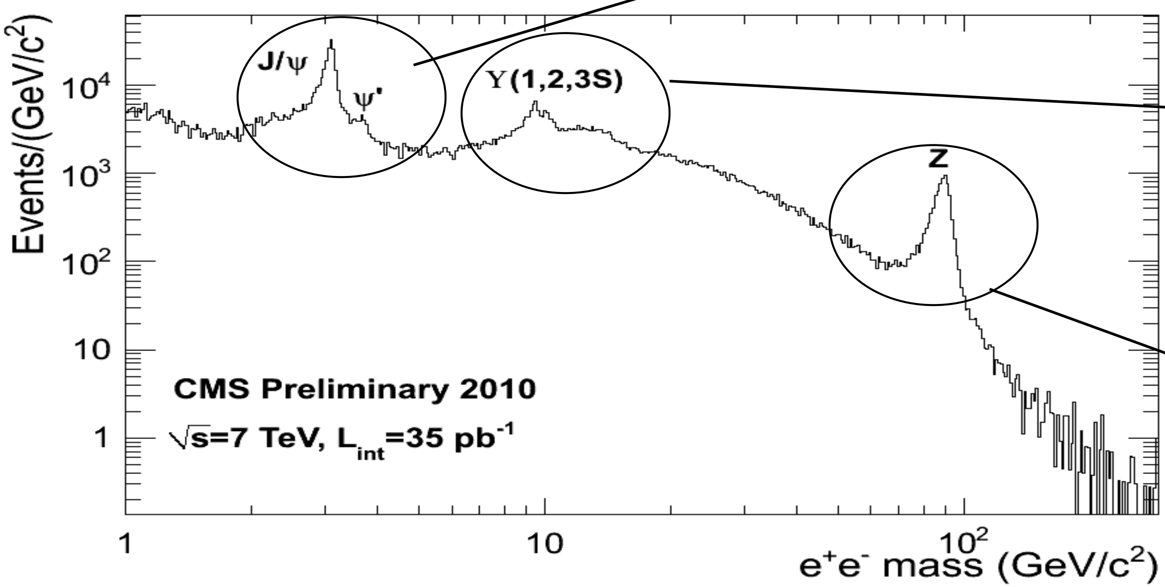
μ Performance

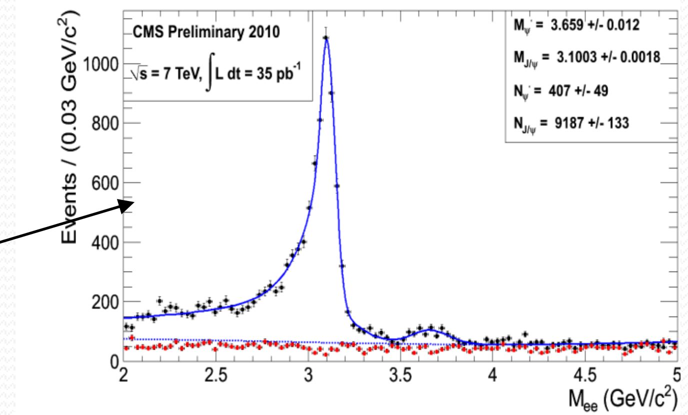
- Flexible trigger system
- Excellent tracking resolution and alignment
- High $m_{\mu\mu}$ resolution

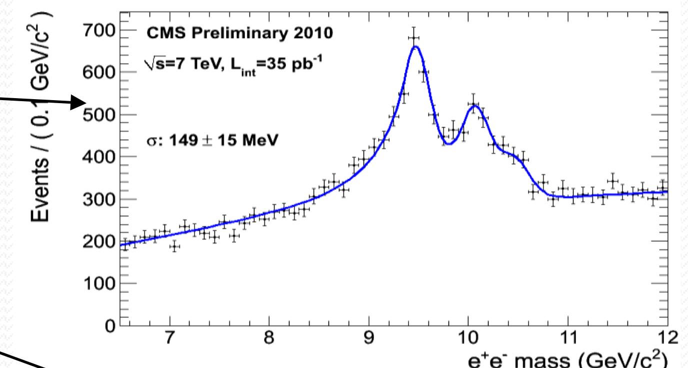


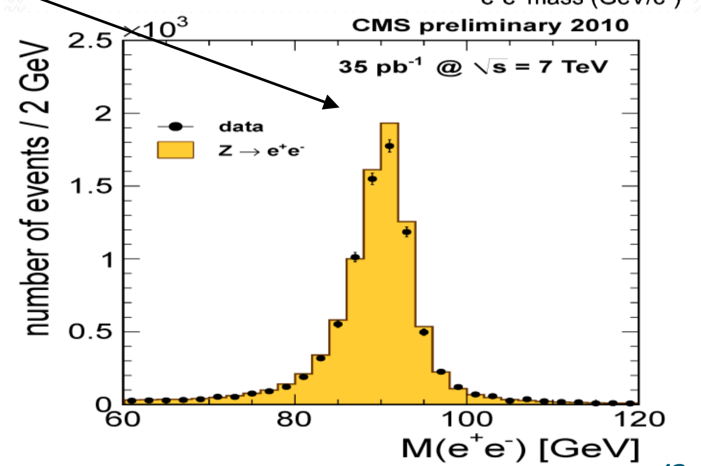
e/γ Performance

- High $m_{\mu\mu}$ resolution also in dielectron mass spectrum



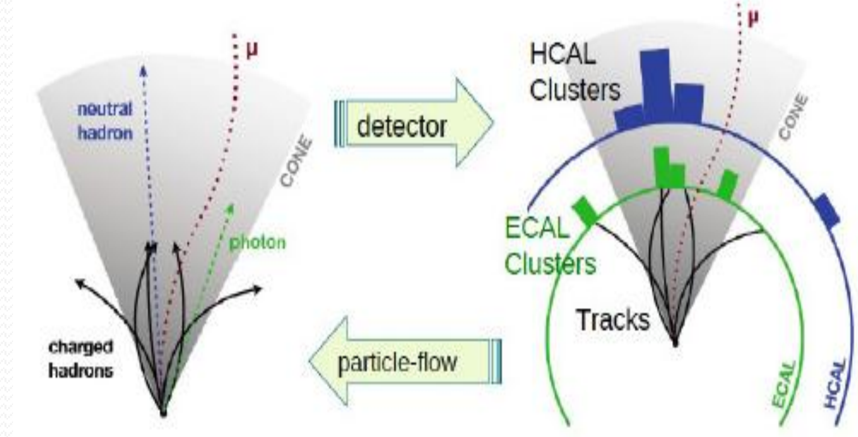




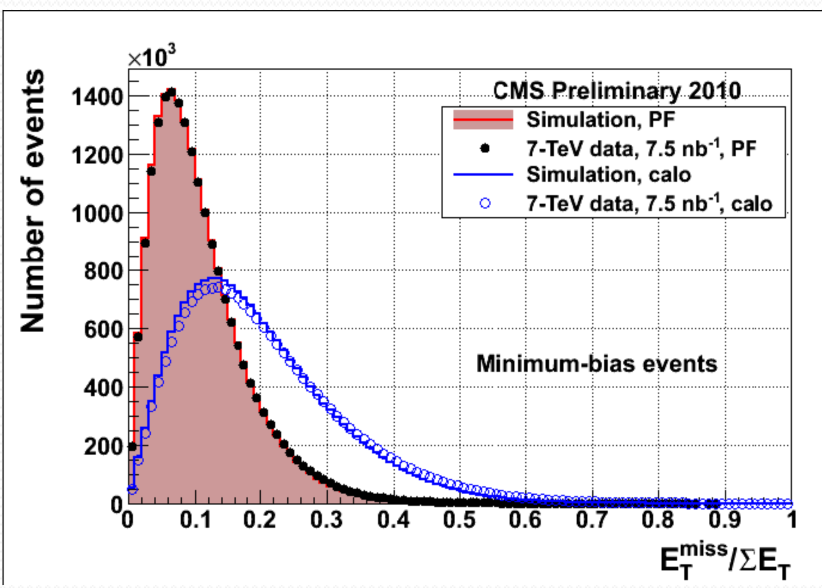


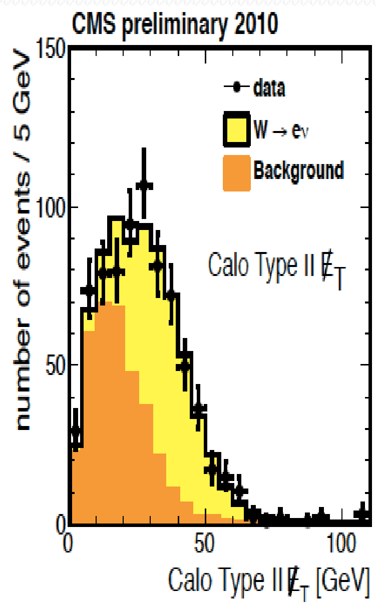
Particle Flow

- Charged particles get well separated due to the huge tracker volume and high magnetic field
- CMS has an excellent tracking resolution, able to go to down to very low momenta (~few hundred MeVs)
- CMS has also an excellent electromagnetic calorimeter with good granularity
- In multijet events, only 10% of the energy corresponds to neutral (stable) hadrons
- Big improvement in energy resolution and identification using particle-flow techniques
- Factor of two improvement in energy resolution w.r.t. measurements using calorimeter information only



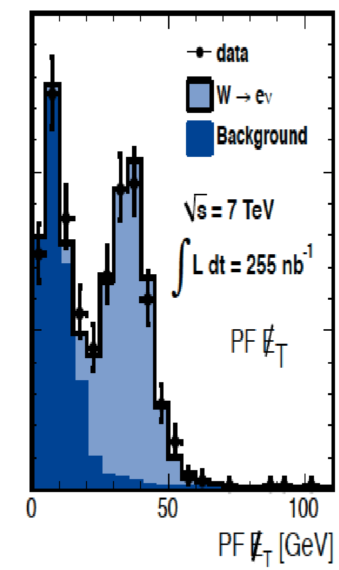
PF: full event reconstruction



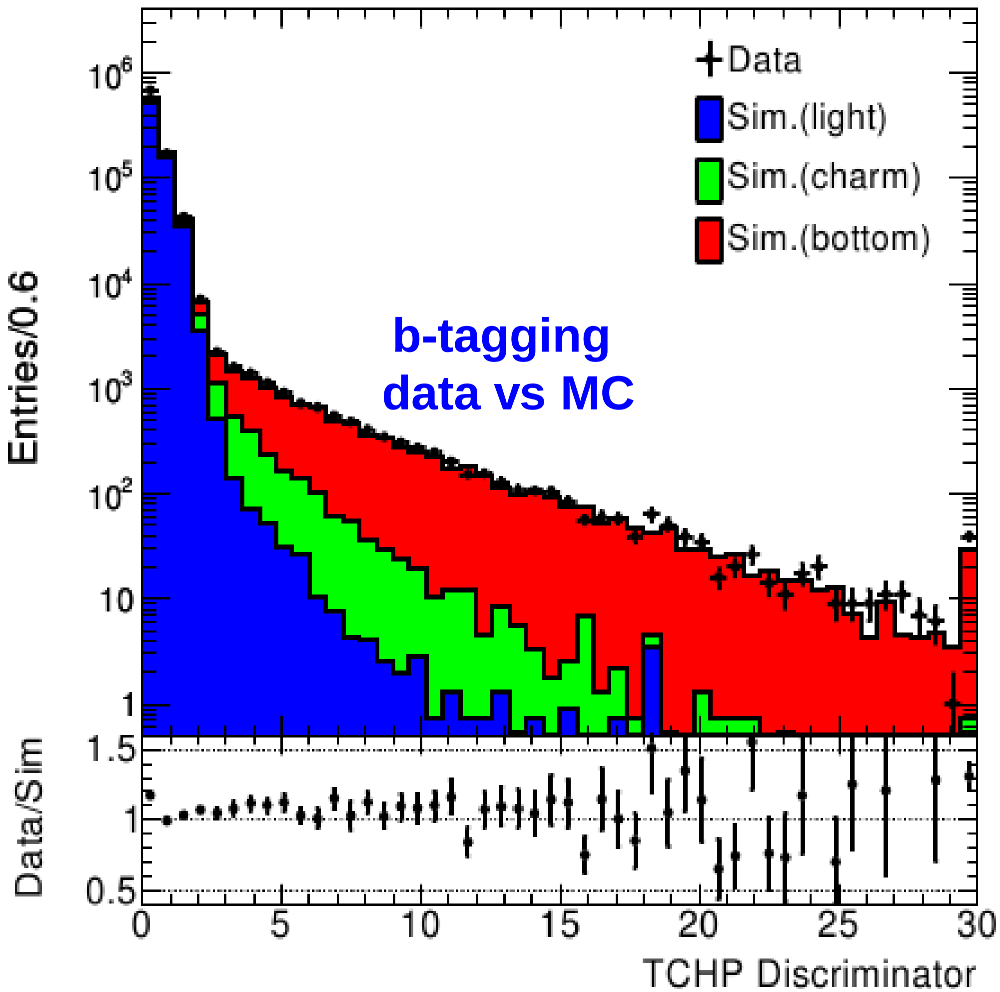


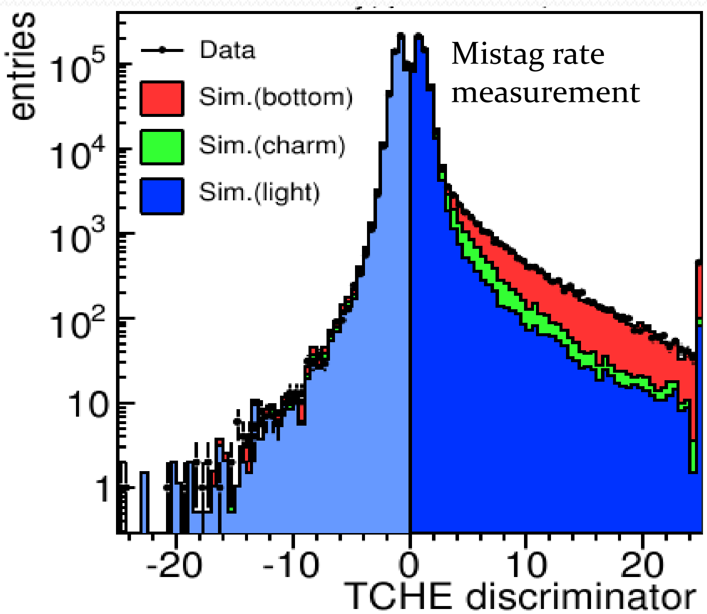
Calorimeter MET

PF MET



B-tagging





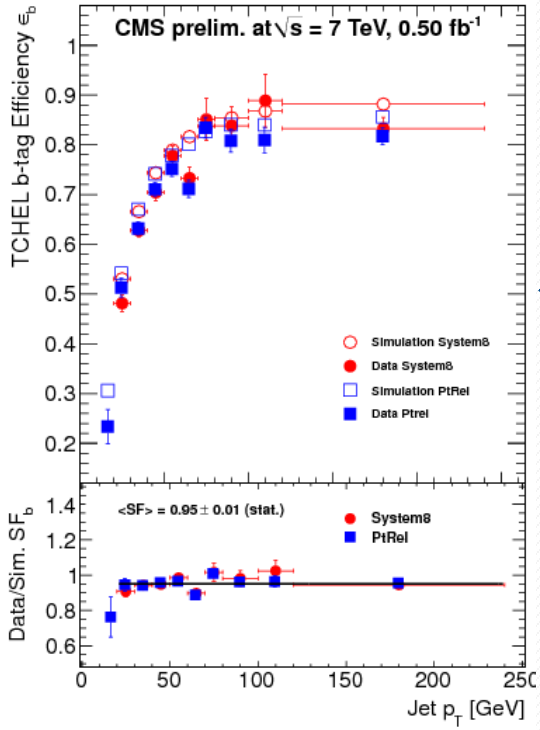
Efficiency and mis-tag rate evaluated from data.
Agreement with MC simulation within few %

2 taggers:
- Track counting high efficiency
- Track counting high purity

Both based on IP significance of tracks within jet

Heavily used in several EWK, TOP measurements & searches already

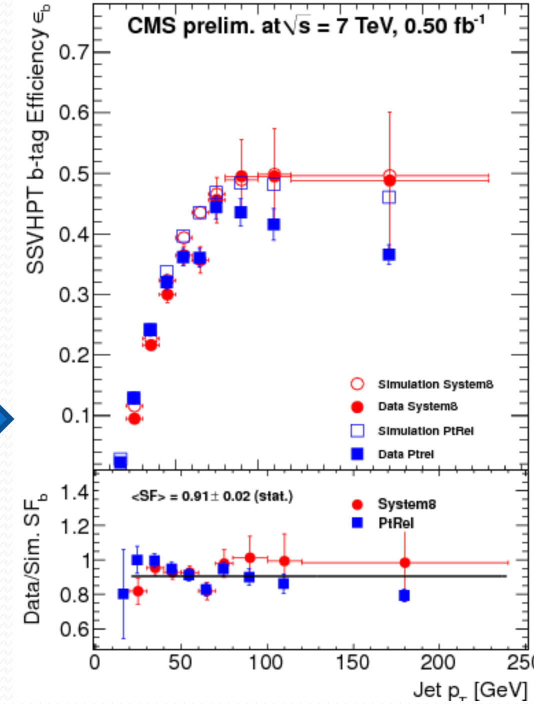
B-tagging performance

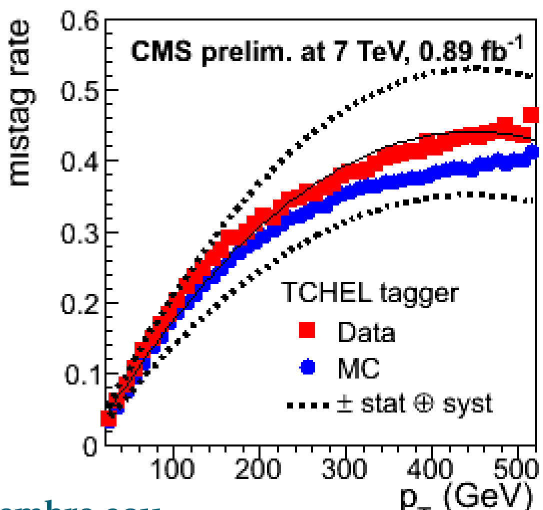


Efficiency

High efficiency

High purity

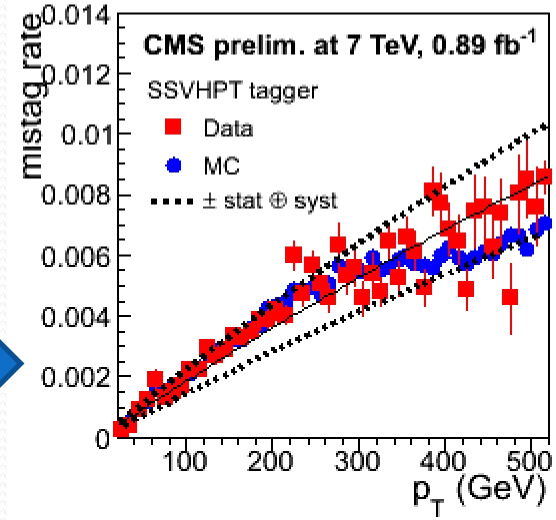




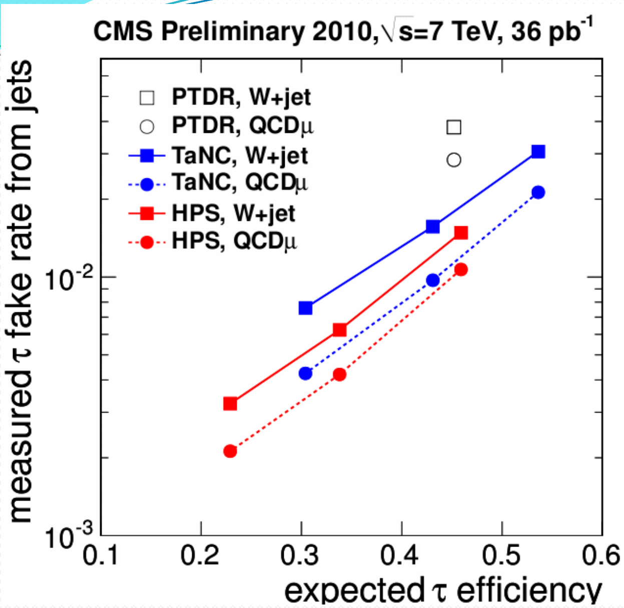
Fake rate

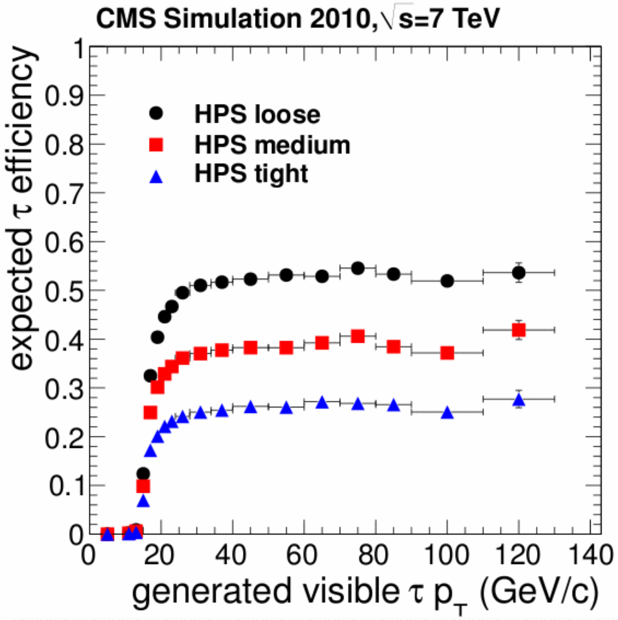
High efficiency

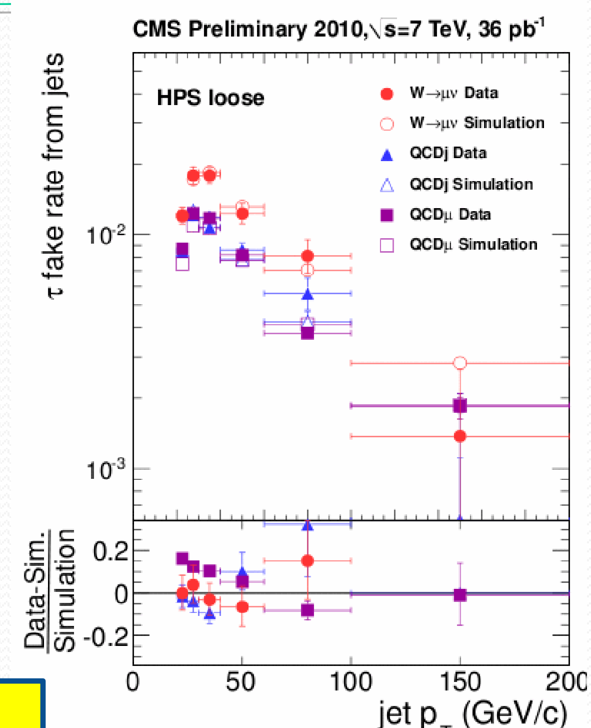
High purity

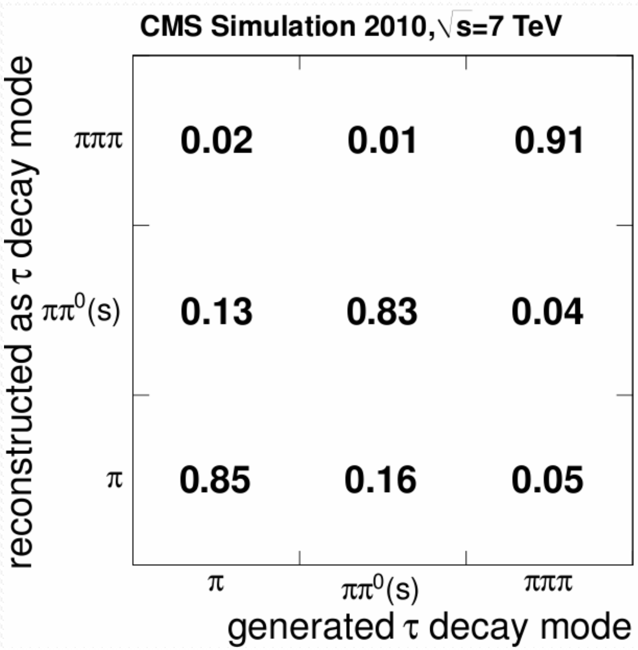


τ ID

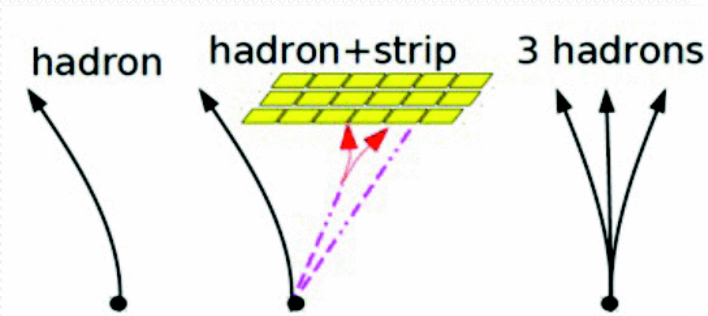


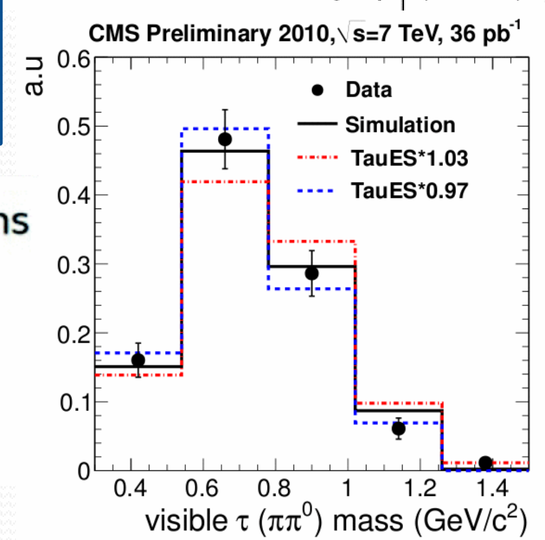




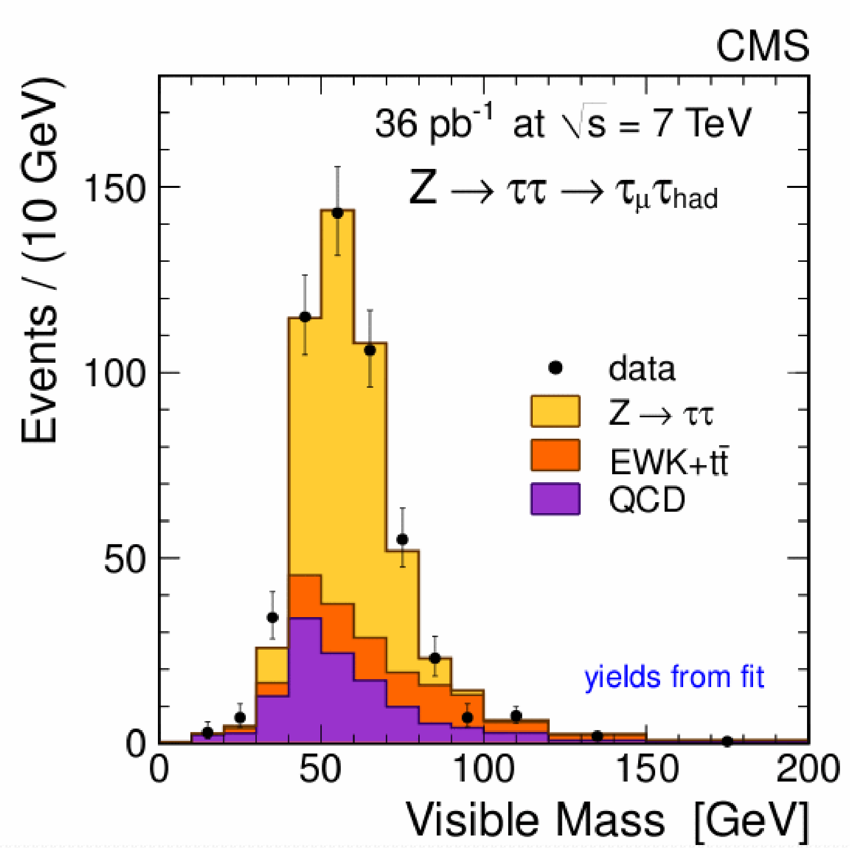


τ ID uncertainty – 6 %
τ jet energy scale unc. < 3 %

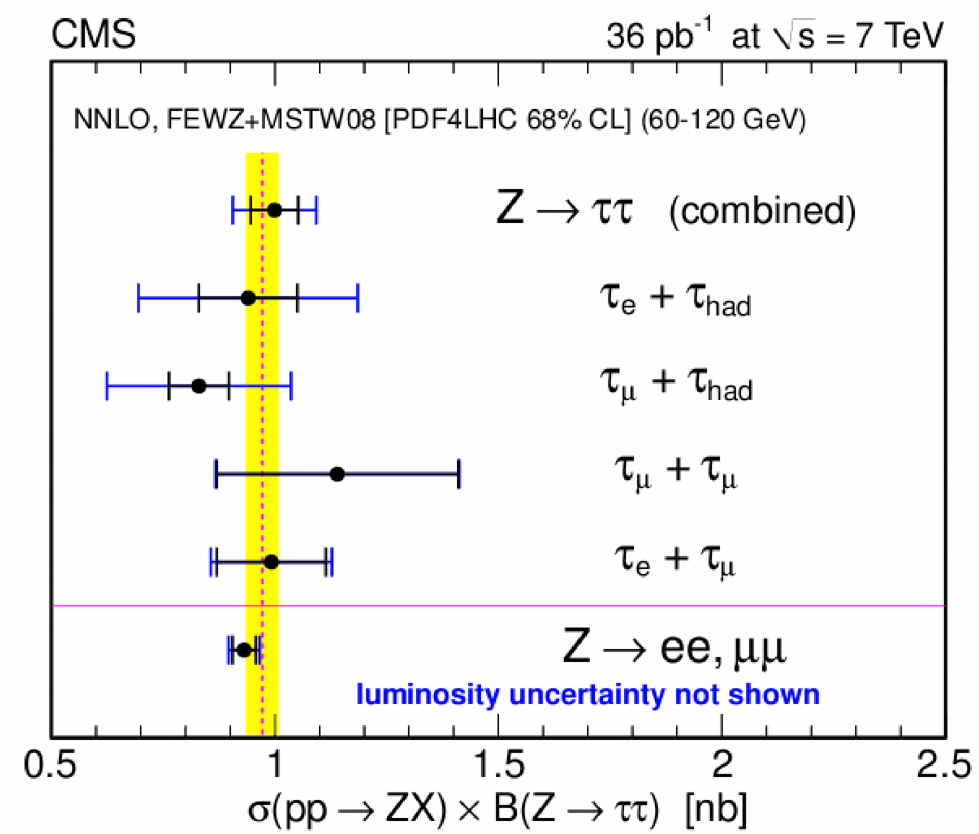




Z→ττ



CMS
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
$Z \to \tau\tau \to \tau_\mu \tau_{had}$
Events / (10 GeV)
data
$Z \to \tau\tau$
EWK+$t\bar{t}$
QCD
yields from fit
Visible Mass [GeV]

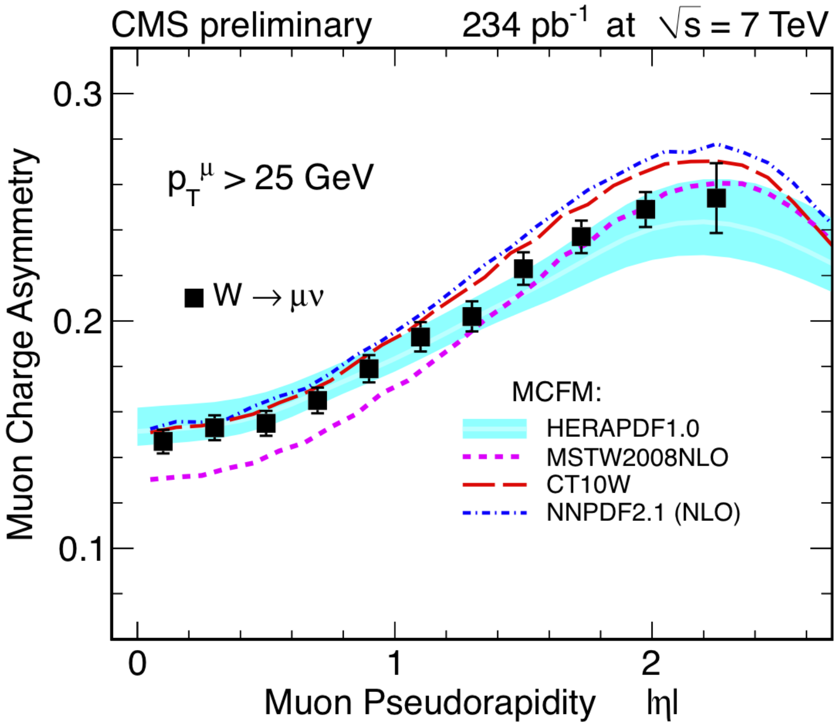


CMS
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
NNLO, FEWZ+MSTW08 [PDF4LHC 68% CL] (60-120 GeV)
$Z \to \tau\tau$ (combined)
$\tau_e + \tau_{had}$
$\tau_\mu + \tau_{had}$
$\tau_\mu + \tau_\mu$
$\tau_e + \tau_\mu$
$Z \to ee, \mu\mu$
luminosity uncertainty not shown
$\sigma(pp \to ZX) \times B(Z \to \tau\tau)$ [nb]

W lepton charge asymmetry

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\overline{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\overline{\nu})}$$

- More W^+ than W^- due to excess of u over d in pp collisions
- Asymmetry = f(η) since u carries higher fraction of proton momentum
- Charge asymmetry in e and μ agree with each other
- Precision of the measurement good enough to provide new inputs to the PDF global fits



$\phi \rightarrow \tau\tau$ background

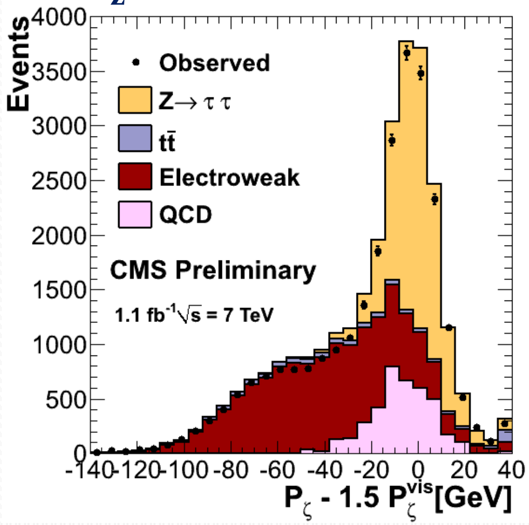
- **QCD multi-jets**
  - **normalization from Same Sign (SS) events**

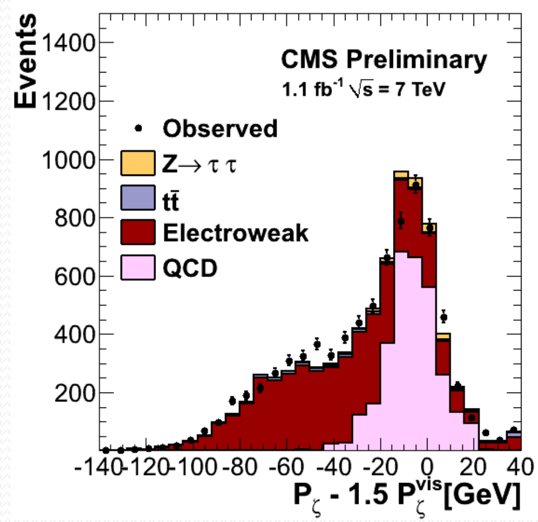
$$QCD^{OS}_{signal} = f^{OS/SS} \cdot QCD^{SS}_{signal} = f^{OS/SS} \cdot (N^{SS}_{signal} - W^{SS}_{signal} - Z^{SS}_{l+jet} - Z^{SS}_{ll})$$

$$f^{OS/SS}_{\mu\tau} = 1.06 \pm 0.02$$

$$f^{OS/SS}_{e\tau} = 1.06 \pm 0.05$$

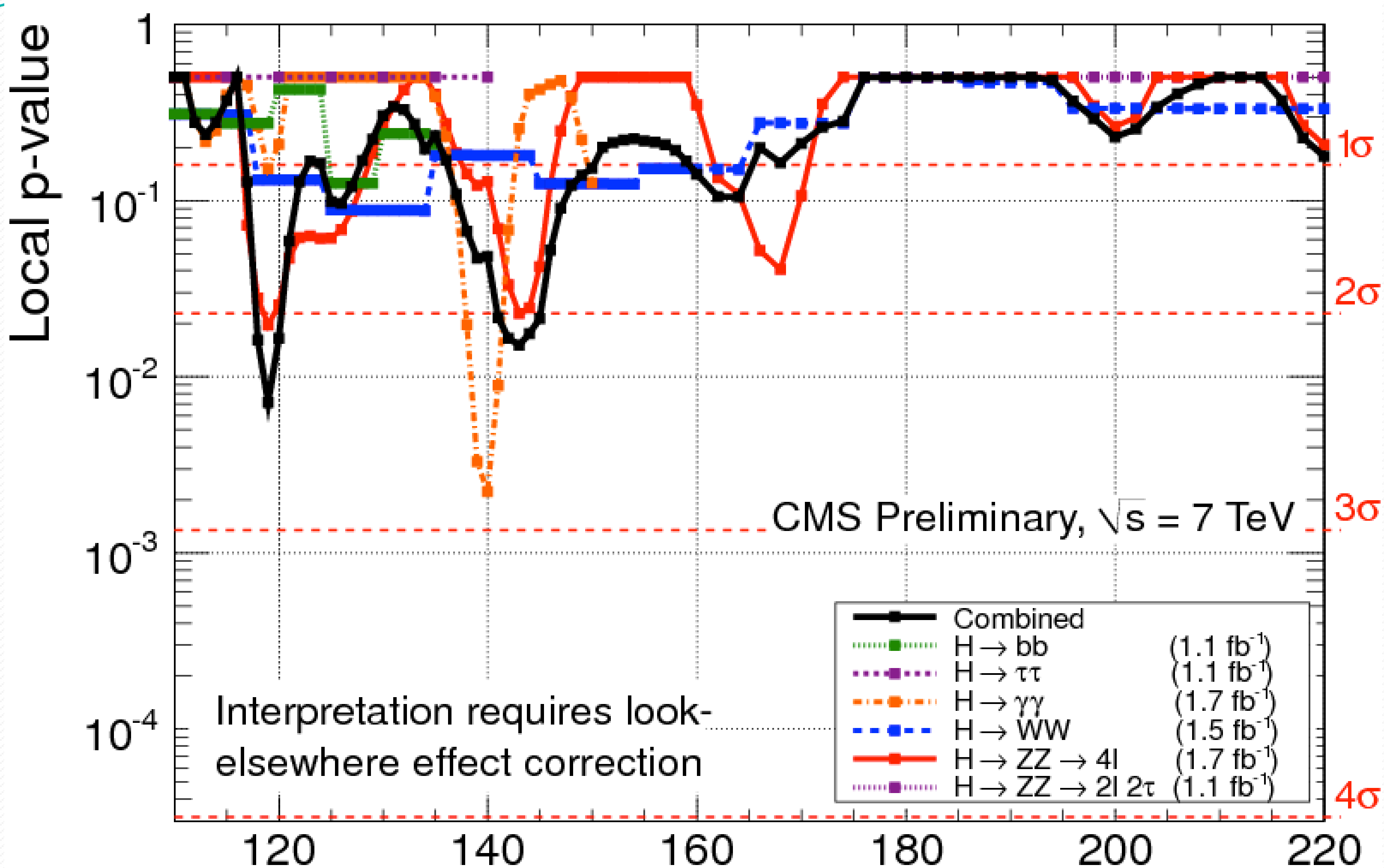
  - **shape – from SS events with relaxed isolation**
- **W+jets – extrapolation from the control region $P_z^{cut} < -40$ GeV to the signal region $P_z^{cut} > -20$ GeV**





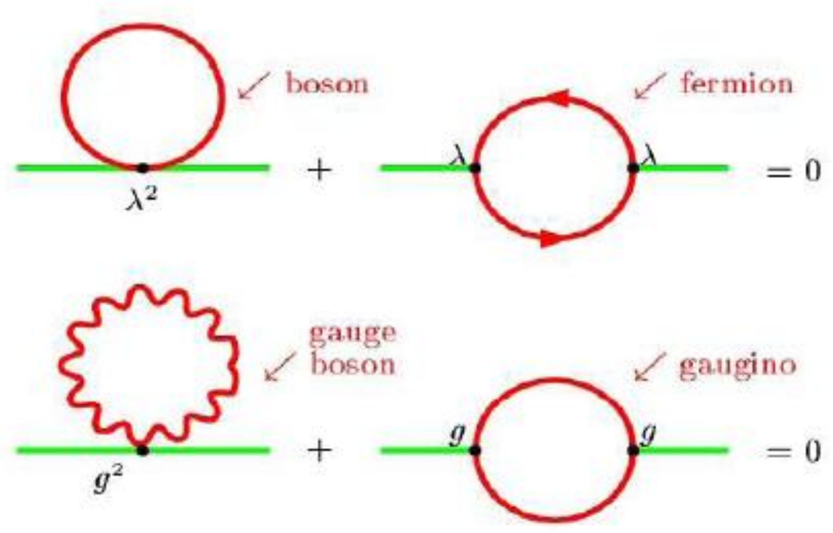
- **Z->ee,μμ, ττ from MC corrected by data/MC scale factors**

Quantifying excesses in Higgs searches



Probability of upward background fluctuation as high or higher than excess observed in data

SUSY



Quantum corrections to m_H

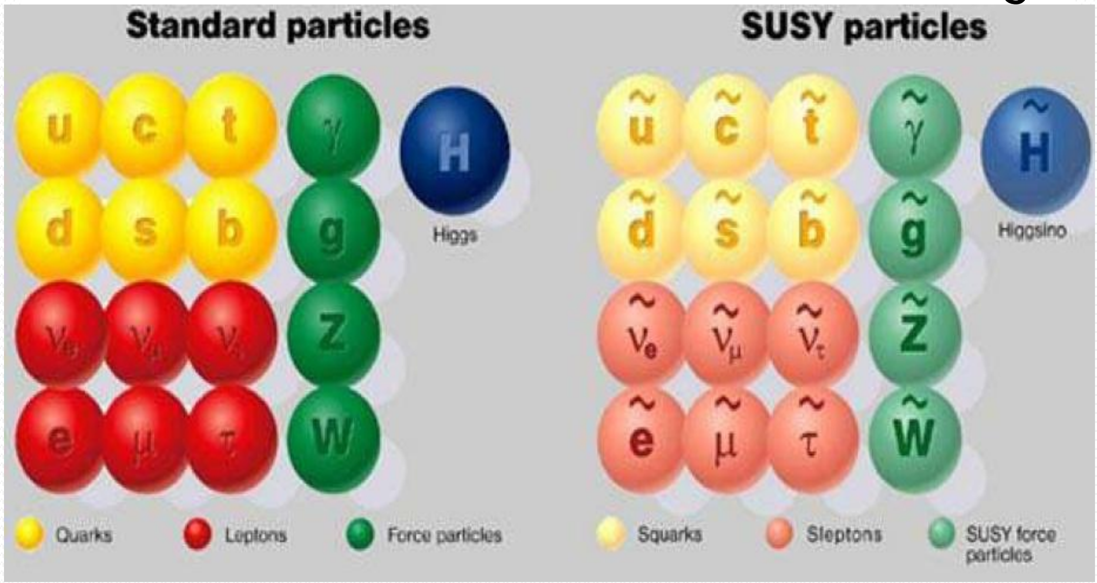
$$\Delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}[-2\Lambda_{UV}^2 + 6m_f^2 \ln(\Lambda_{UV}/m_f) + \ldots]$$

$$\text{if } \Lambda_{UV} \approx M_{planck} \rightarrow \text{fine tuning in } 10^{30} \text{ !!}$$

Exact cancellation between fermion & boson loops for Higgs cures the hierarchy problem

Higgs sector with 2 doublets

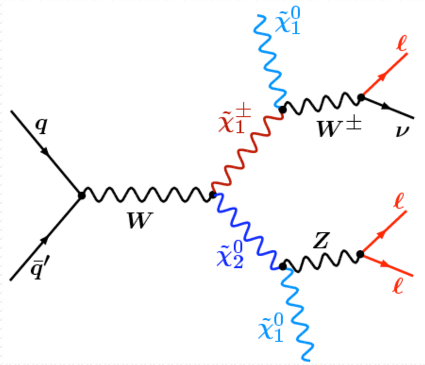
$$H_u, H_D \longrightarrow h, H, A, H^{\pm}$$

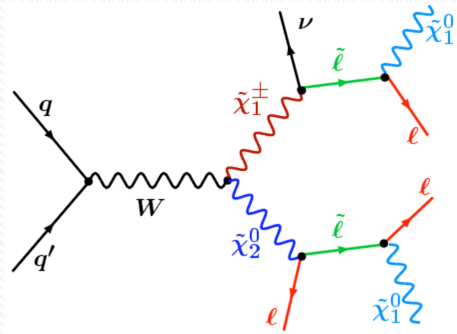


SUSY must be broken: model-dependent phenomenology

SUSY Signatures

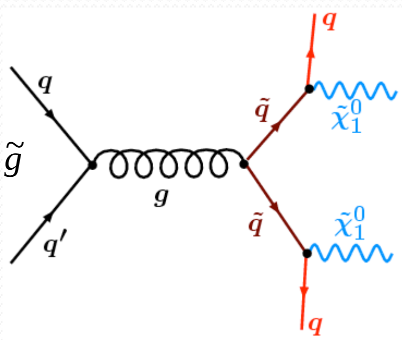
Charginos-Neutralinos: trileptons + MET



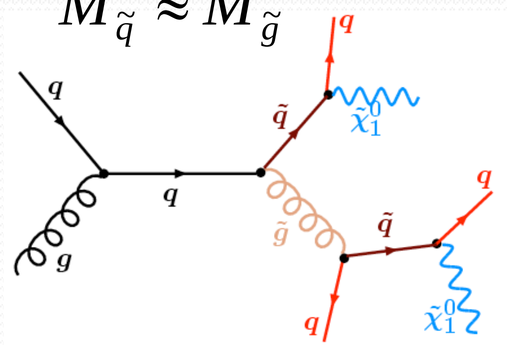


Squarks-Gluinos: jets + MET

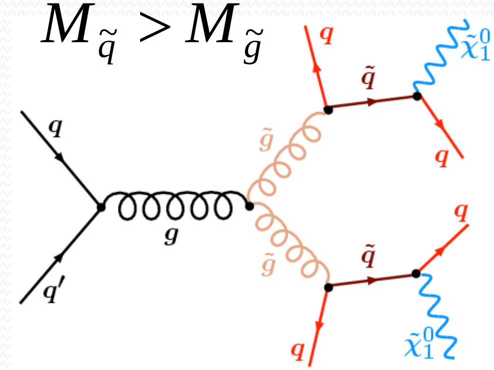
$M_{\tilde{q}} < M_{\tilde{g}}$



$M_{\tilde{q}} \approx M_{\tilde{g}}$



$M_{\tilde{q}} > M_{\tilde{g}}$

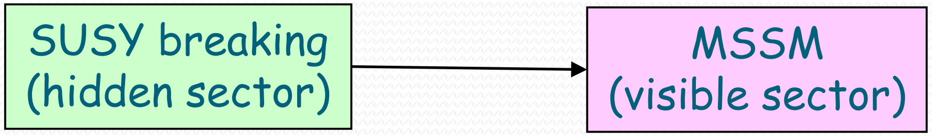


Basic analysis strategy:

- Look for excess production of this signatures w.r.t. SM predictions
- No significant excess? Set limits to production rate
- Set model-dependent limits on parameters upon which production rate depends (such as masses)

CMSSM & mSUGRA

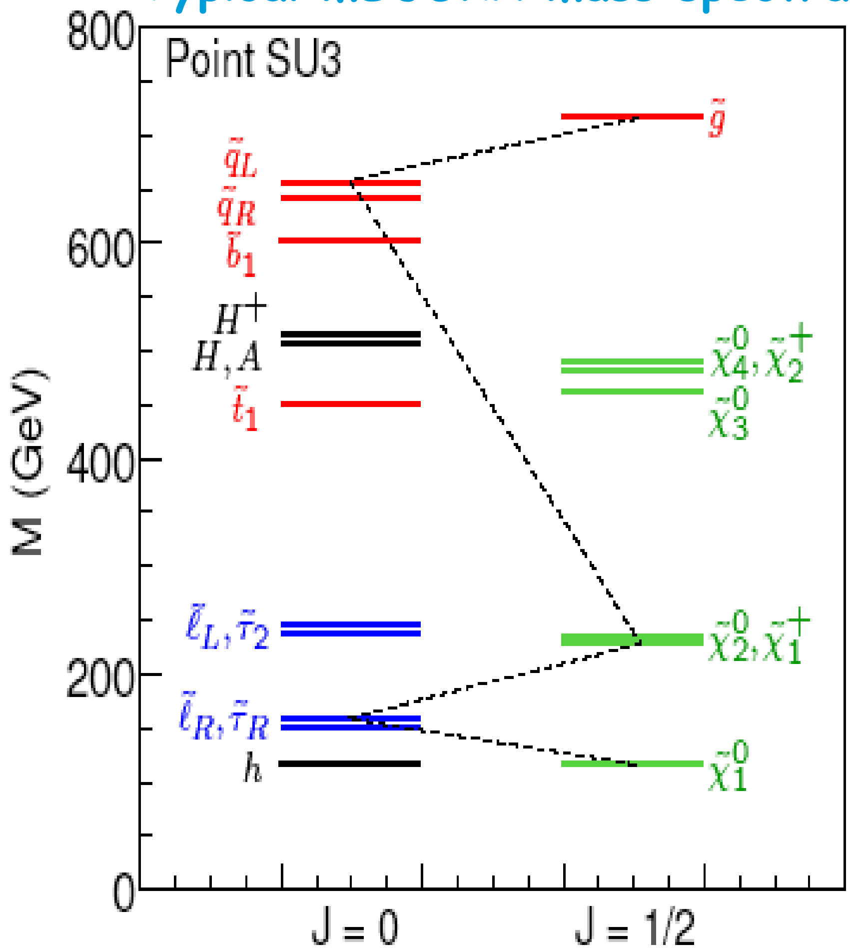
gravity-mediated SUSY breaking



L_{soft} terms introduce huge number (up to 105) of new parameters

Assuming unification of masses at GUT scale allows to reduce it to 5

Typical mSUGRA mass spectra



m_0: common scalar mass GUT

$m_{1/2}$: common gaugino mass at GUT

$\tan\beta$: <HU>/<HD> at EWK scale

A_0: common (scalar) coupling (soft trilinear SUSY breaking parameters)

Sign(μ): sign of Higgsino mass term (Higgs mixing parameter)

Squarks and Gluinos are heavy

mixing of third generation leads to light stop/sbottom and stau

$\tilde{\chi}_1^0$ **is the LSP (stable if Rp conserved)**

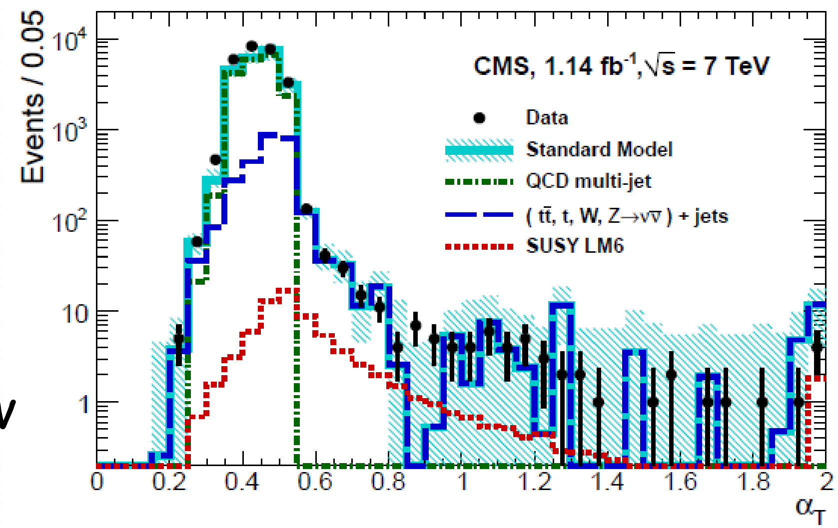
one higgs is very light (< 135 GeV)

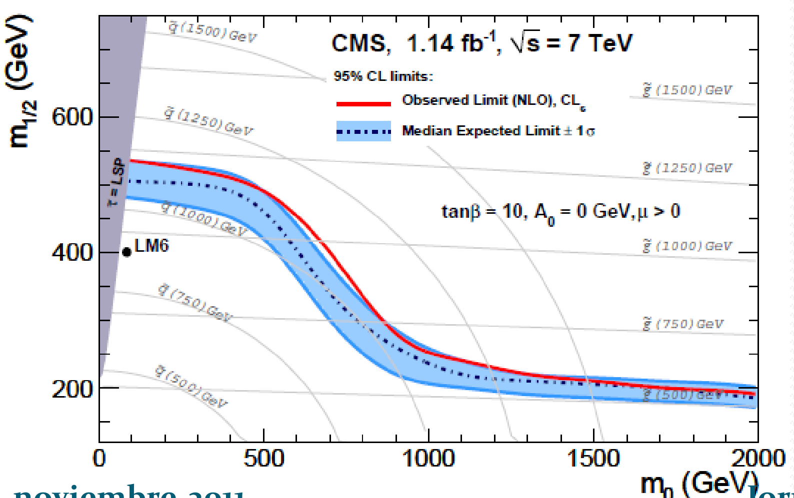
Jets + MET Search: α_T

$$\alpha_T = E_T^{j2} / M_T = \frac{E_T^{j2}}{\sqrt{H_T^2 - \not{H}_T^2}} = \frac{\sqrt{E_T^{j1} / E_T^{j2}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

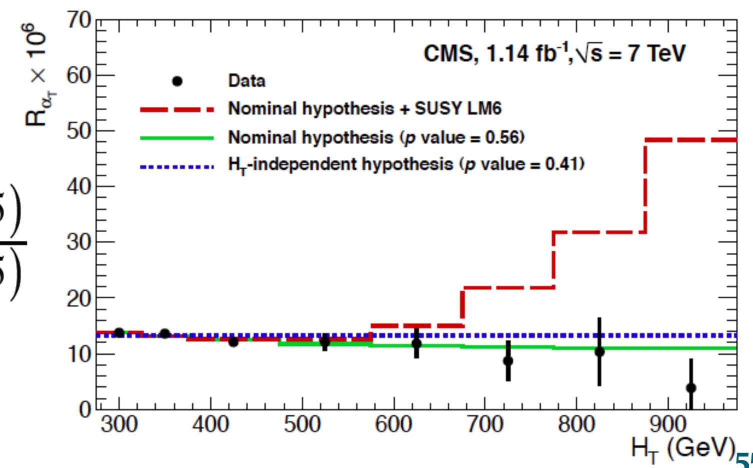
- perfectly measured di-jet: $\alpha_T = 0.5$
- mismeasured di-jet: $\alpha_T < 0.5$
- jets balancing genuine MET: $\alpha_T > 0.5$

- ≥2 jets E_T>50 GeV and $|\eta|<3$
- j1,j2 E_T>100 GeV and j1 $|\eta|<2.5$
- H_T>275 GeV
- No electrons or muons
- α_T>0.55
  - In nj>2, cluster into 2 pseudo-jets
  - Minimizing ΔE_T
- Backgrounds from data-driven techniques
  - $Z \rightarrow \nu\nu$ + j, QCD, W+jets and top
- No excess of events observed → set limits in CMSSW
- Perform shape analysis of $R_{\alpha T}$ vs H_T

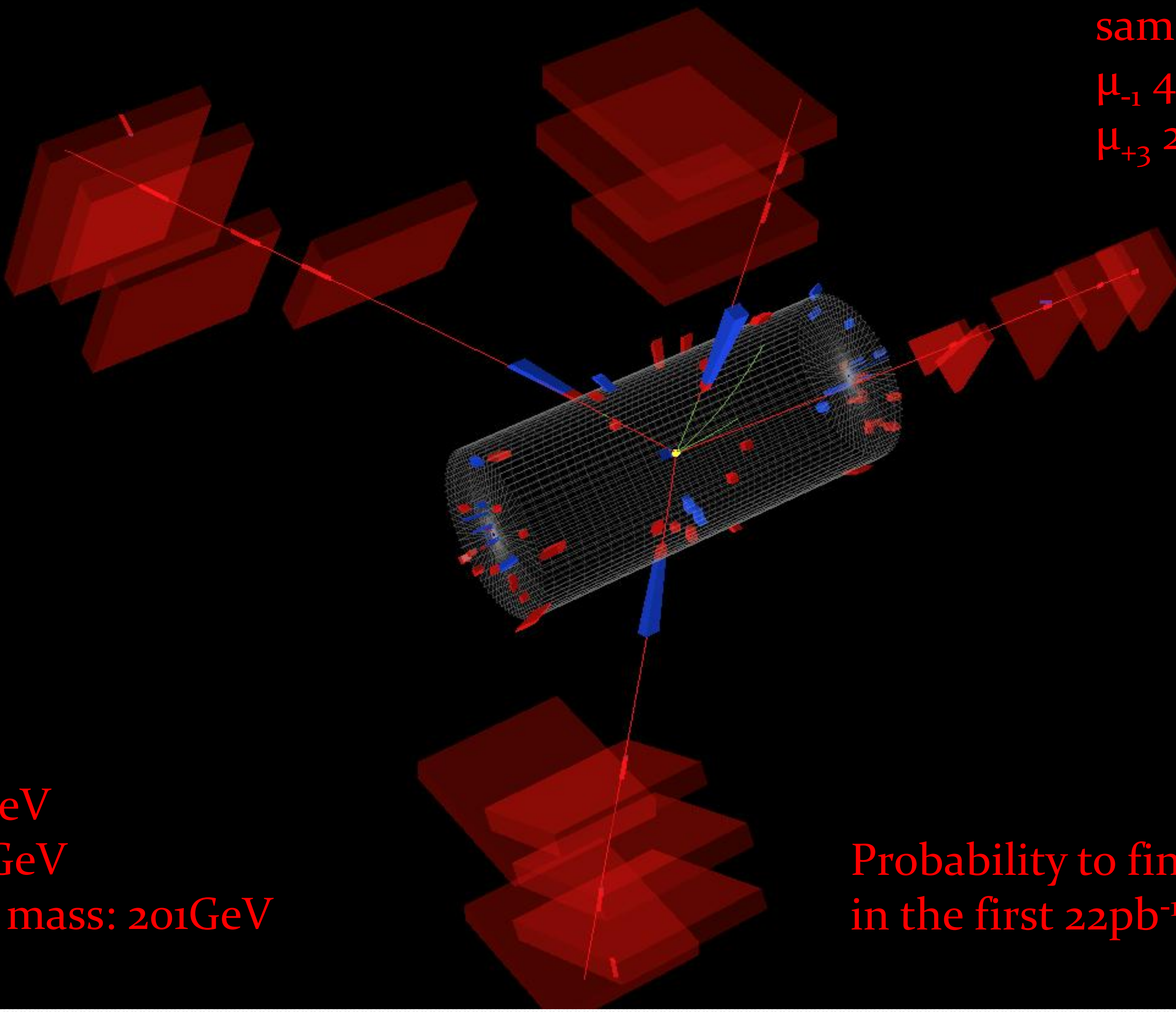




$$R_{\alpha T} = \frac{N(\alpha_T > 0.55)}{N(\alpha_T < 0.55)}$$



First ZZ→4μ event



All 4 muons from the same vertex:
μ_{-1} 48.1; μ_{+2} 43.4 GeV
μ_{+3} 25.9; μ_{-4} 19.6 GeV

Z_1= 92.15 GeV
Z_2= 92.24 GeV
Combined mass: 201GeV

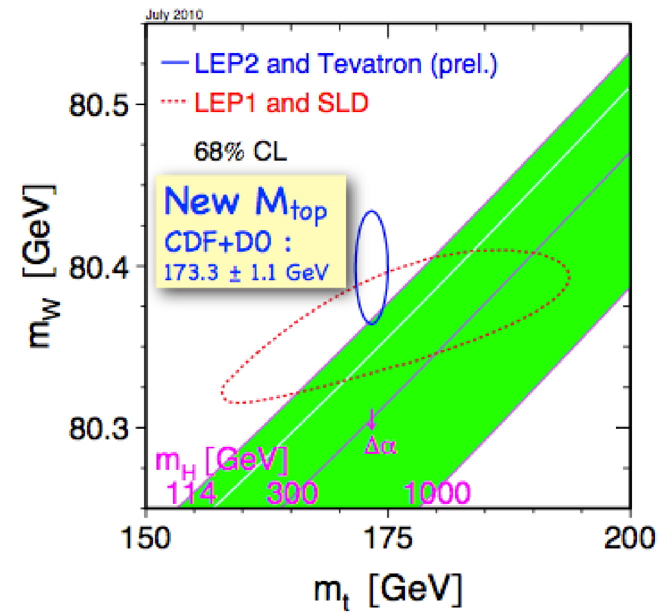
Probability to find such an event in the first $22pb^{-1}$ of data: 16%.

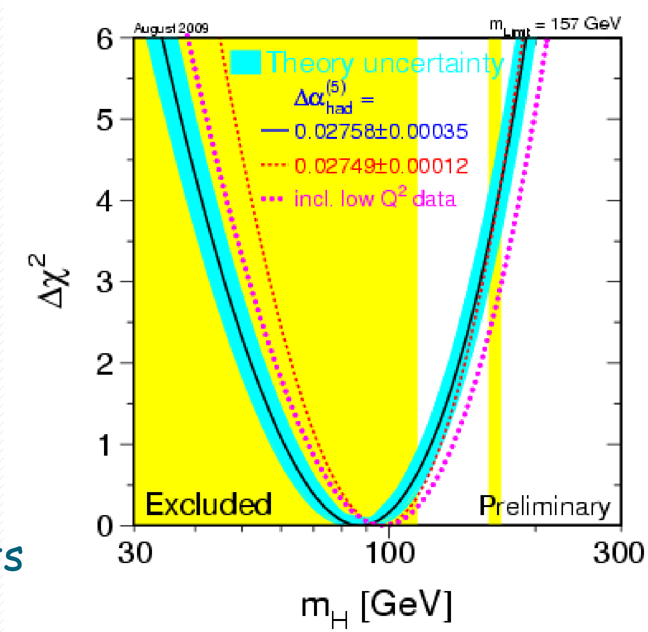
Constrains on Higgs Mass

- M_H not predicted by SM, but can be inferred:
  - From EWK precision data through radiative corrections

  - Direct searches at LEP
    - M_H>114.4 GeV/c² @ 95% C.L.
  - Direct searches at Tevatron
  - **Direct searches at LHC join the game!**

Precision Fit finds
m_H = 89.0 $^{+35}_{-26}$ GeV
m_H < 158 GeV @ 95% CL





Non-SM scenarios can weaken both direct and indirect limits