Recent Results from CMS

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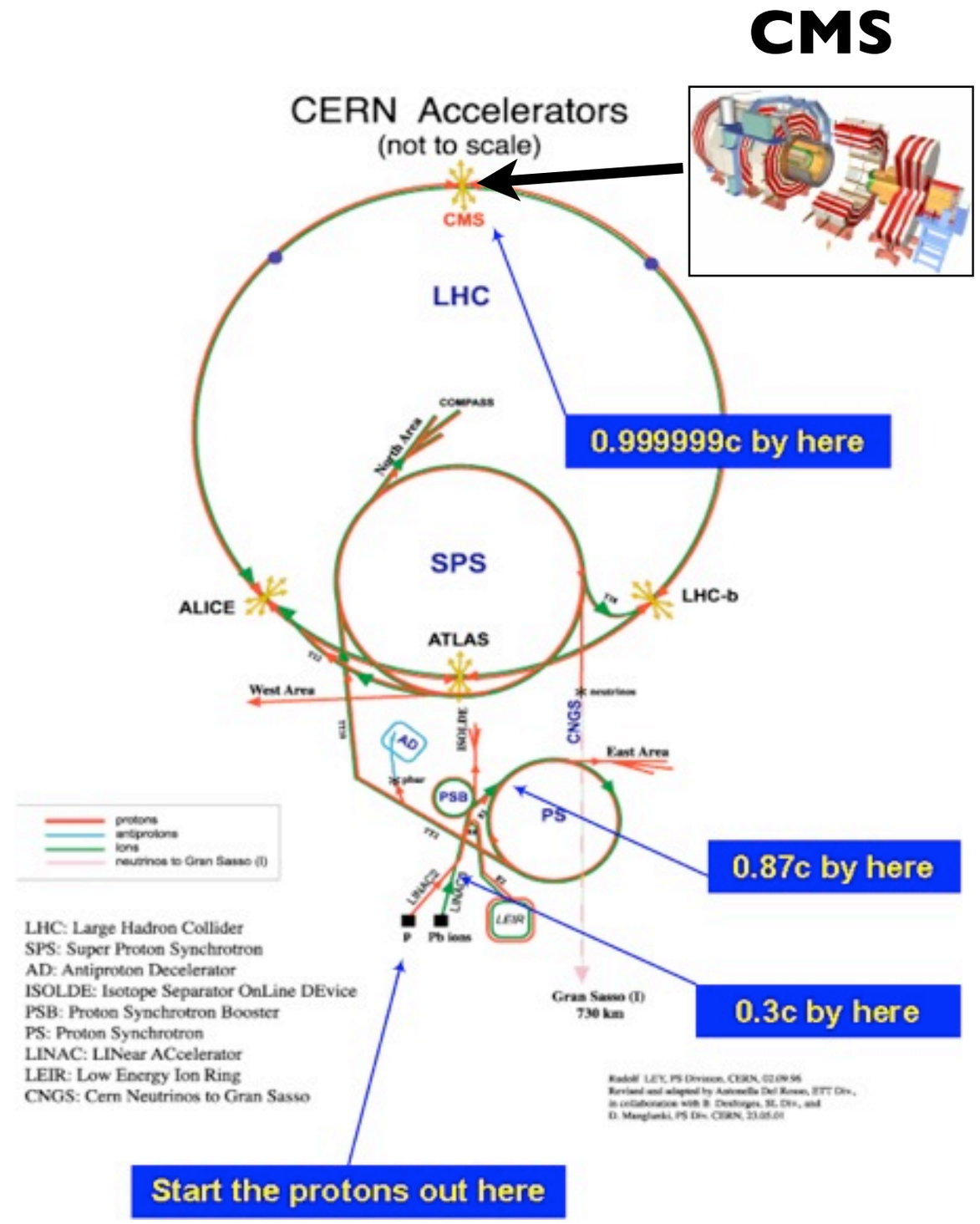
Outline

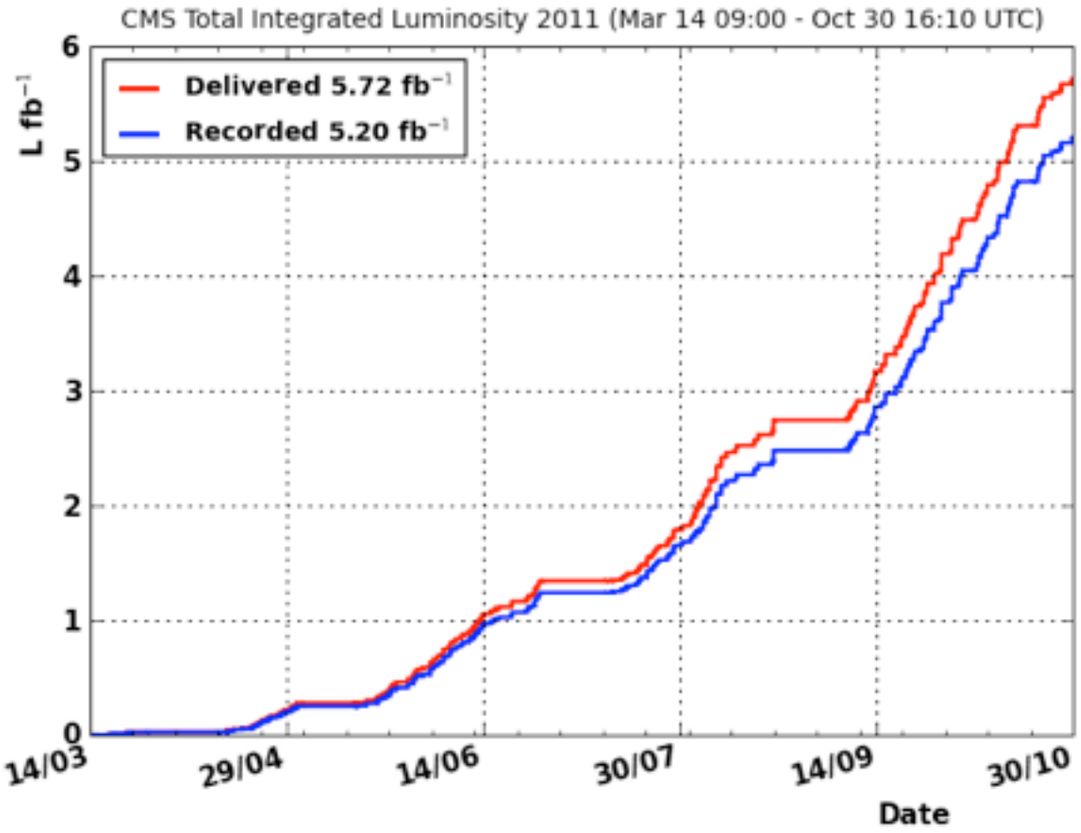
- Introduction: LHC & CMS
- Standard Model Measurements
  - EWK: W-asymmetry, W+jj, Z→4l
  - QCD: jet & dijet cross sections
  - TOP: top mass, single-top, FCNC, charge asymmetry

A **very incomplete** list of results, due to time limitations, and according to my **personal bias** !!!

- SM Higgs Searches
  - HWW, HZZ, Hττ, Hbb, Hγγ
  - CMS Higgs Combination
- Beyond the Standard Model
  - Exotics: quark compositeness, dijet resonances, monojets, dilepton resonances/Z', W'
  - SUSY: razor framework

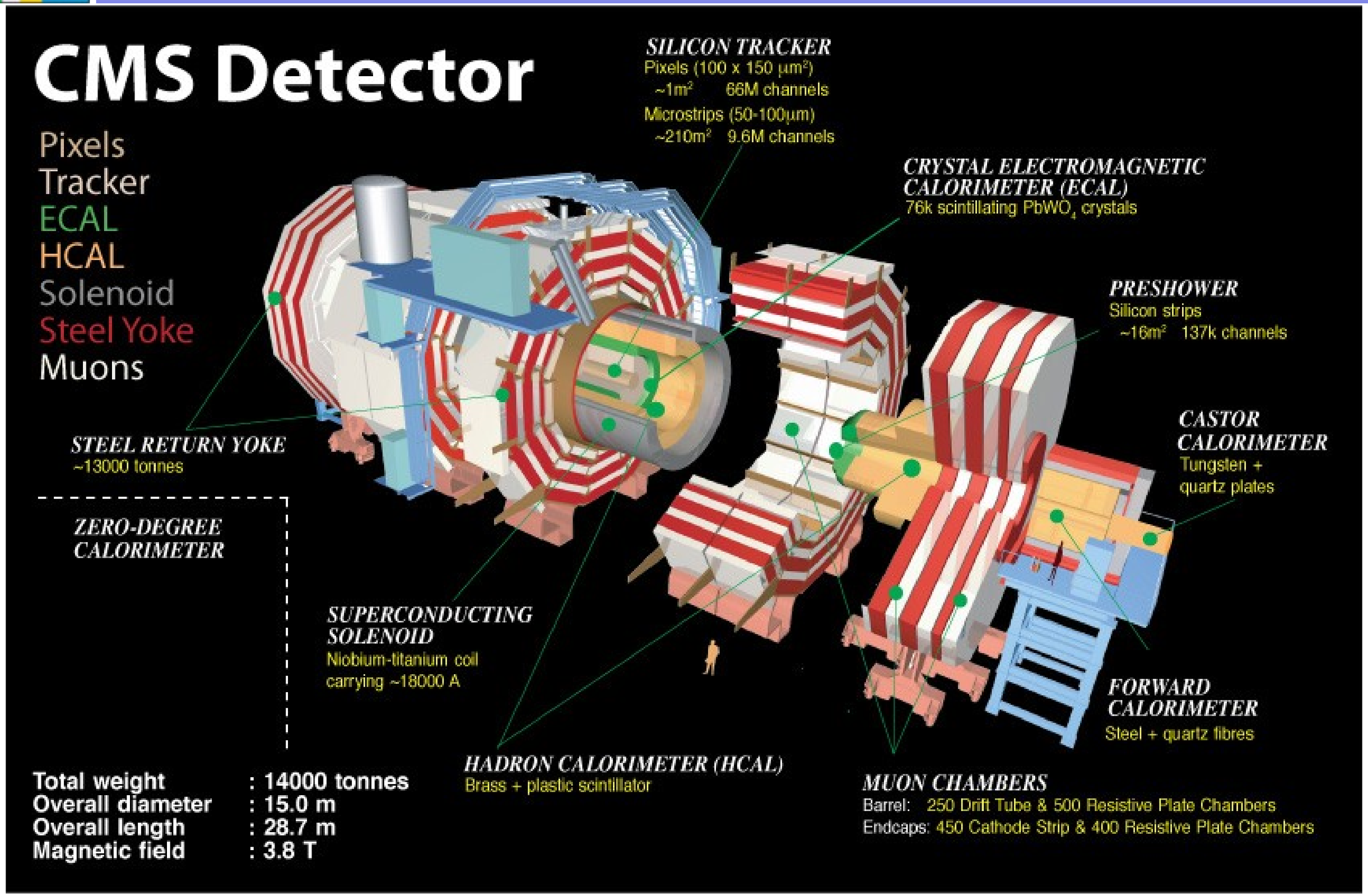
Large Hadron Collider



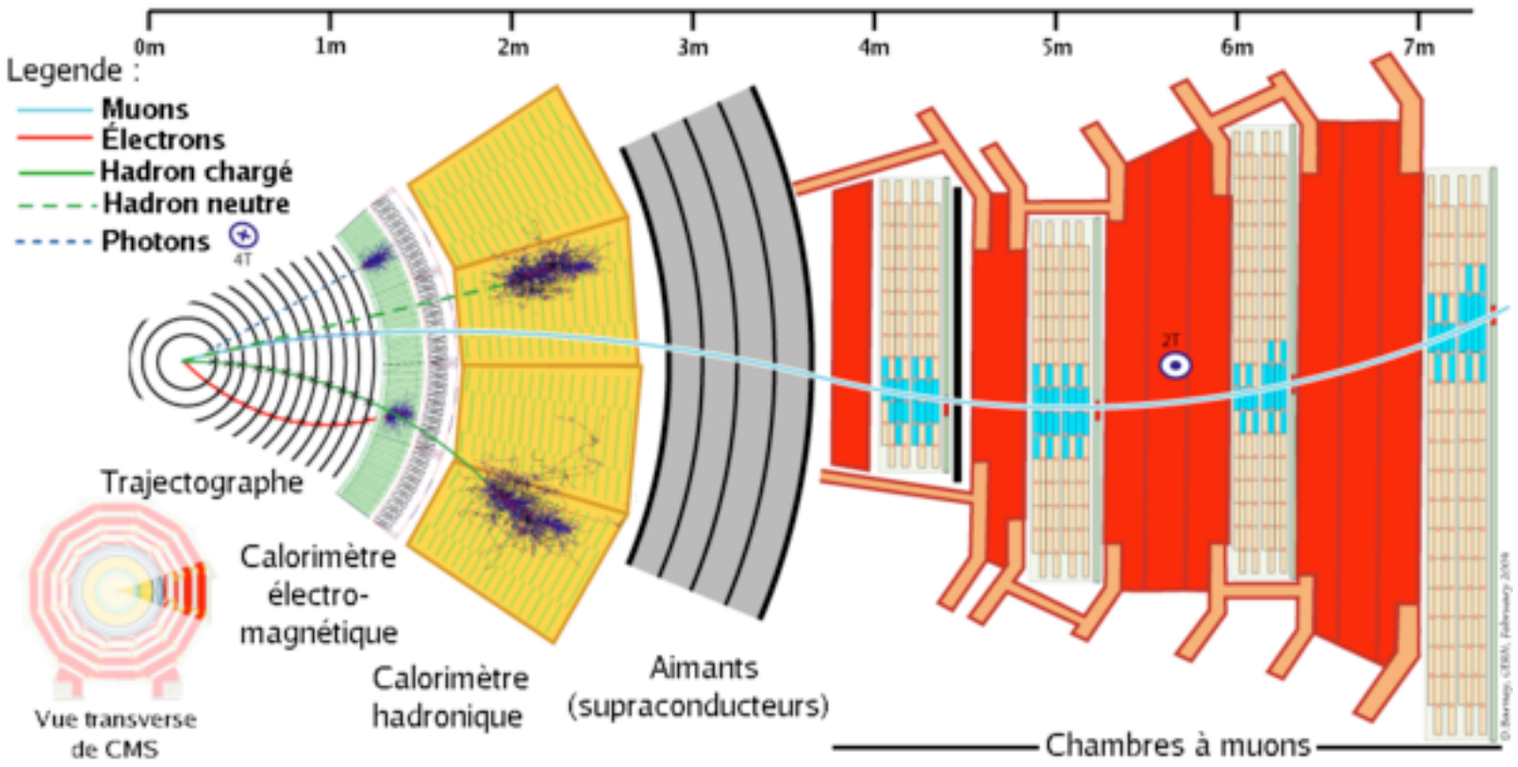


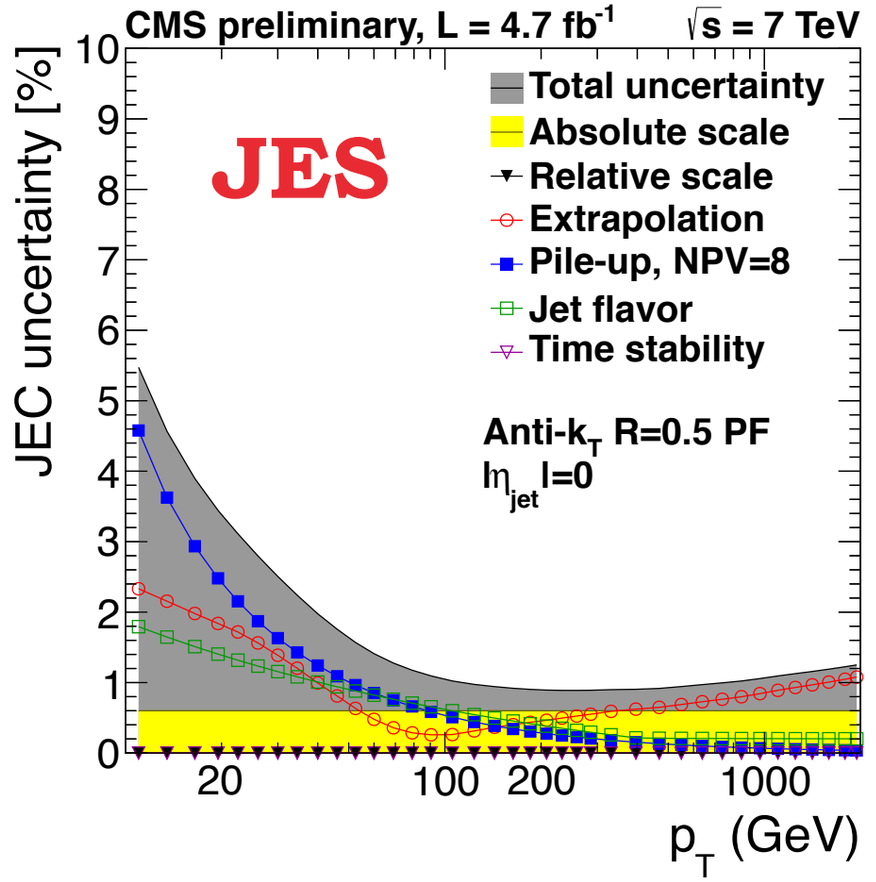
- **pp collisions @ 7 TeV**
- delivered luminosity: **5.72 fb^{-1}**
- peak luminosity: **3.5 x 10^{33} cm^{-2}s^{-1}**
  - bunch spacing 50 ns, $\beta^* = 1$ m, bunch intensity 1.35 x 10^{11} ppb
  - 10 pileup events on average
- data taking efficiency: **90%**
  - more than **90%** of the recorded data suitable for analysis

Compact Muon Solenoid

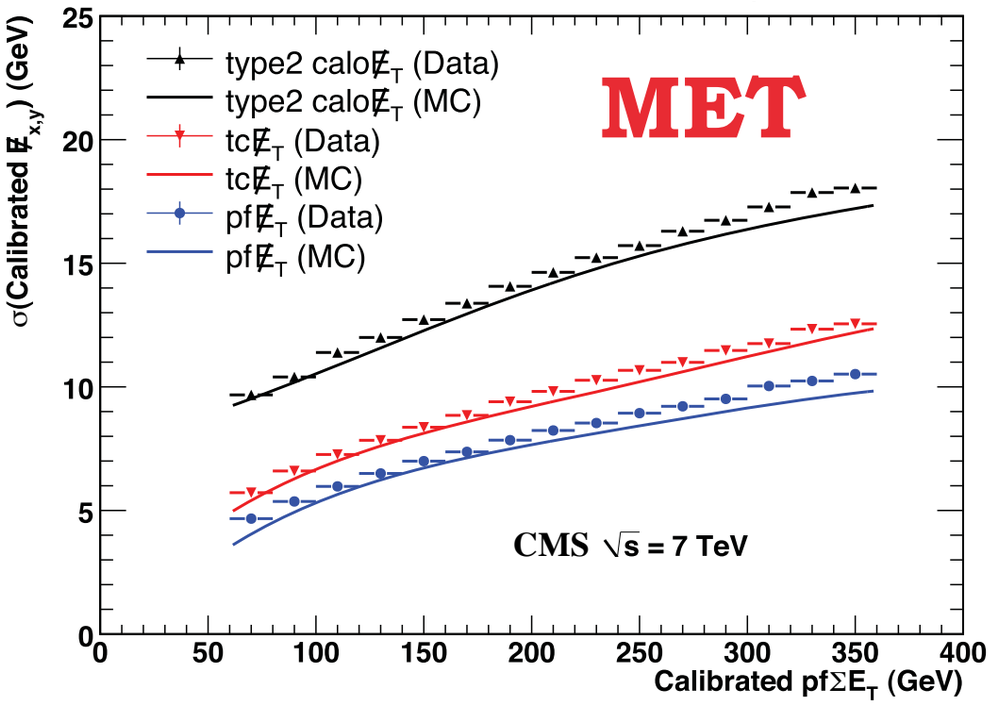


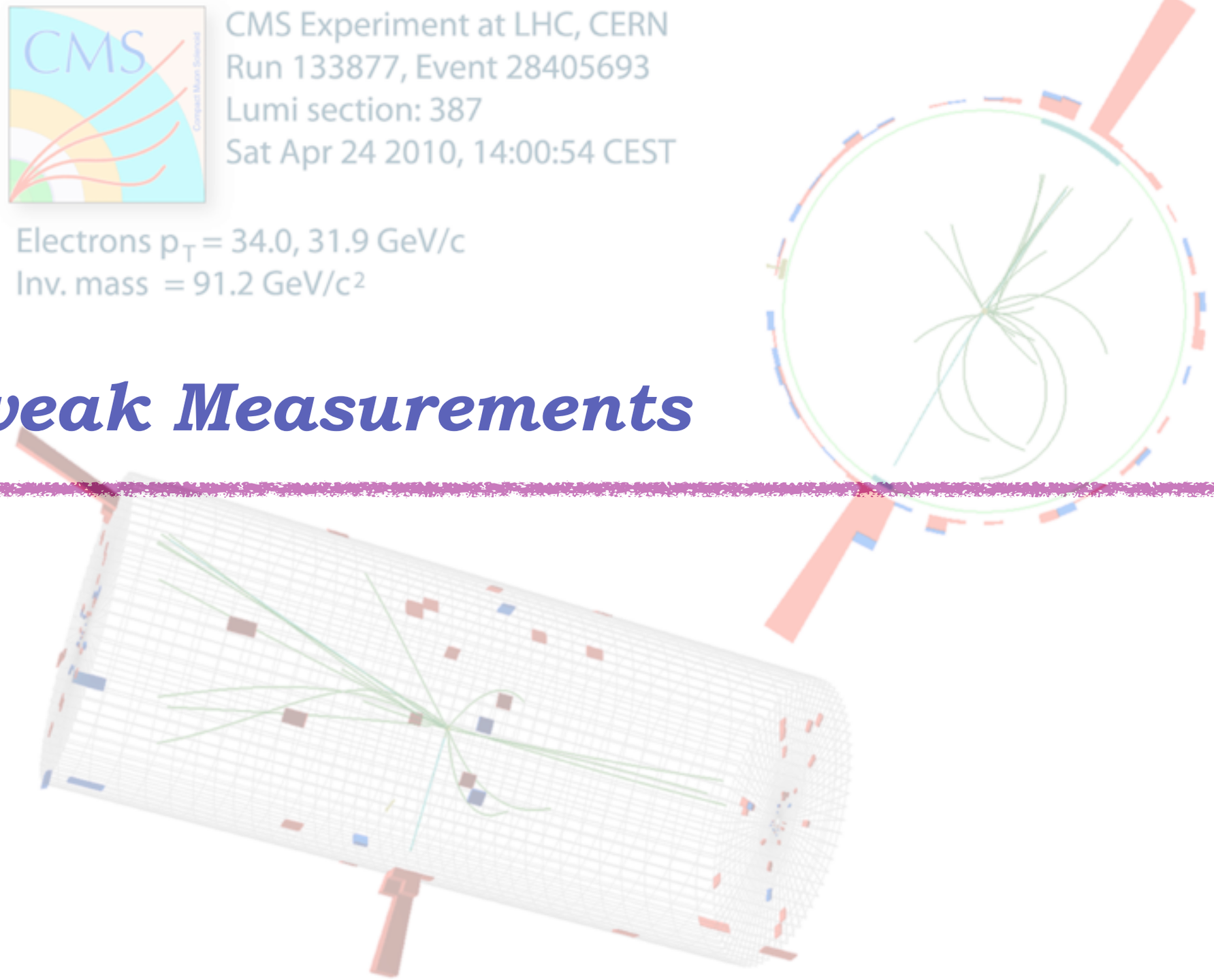
Object Reconstruction





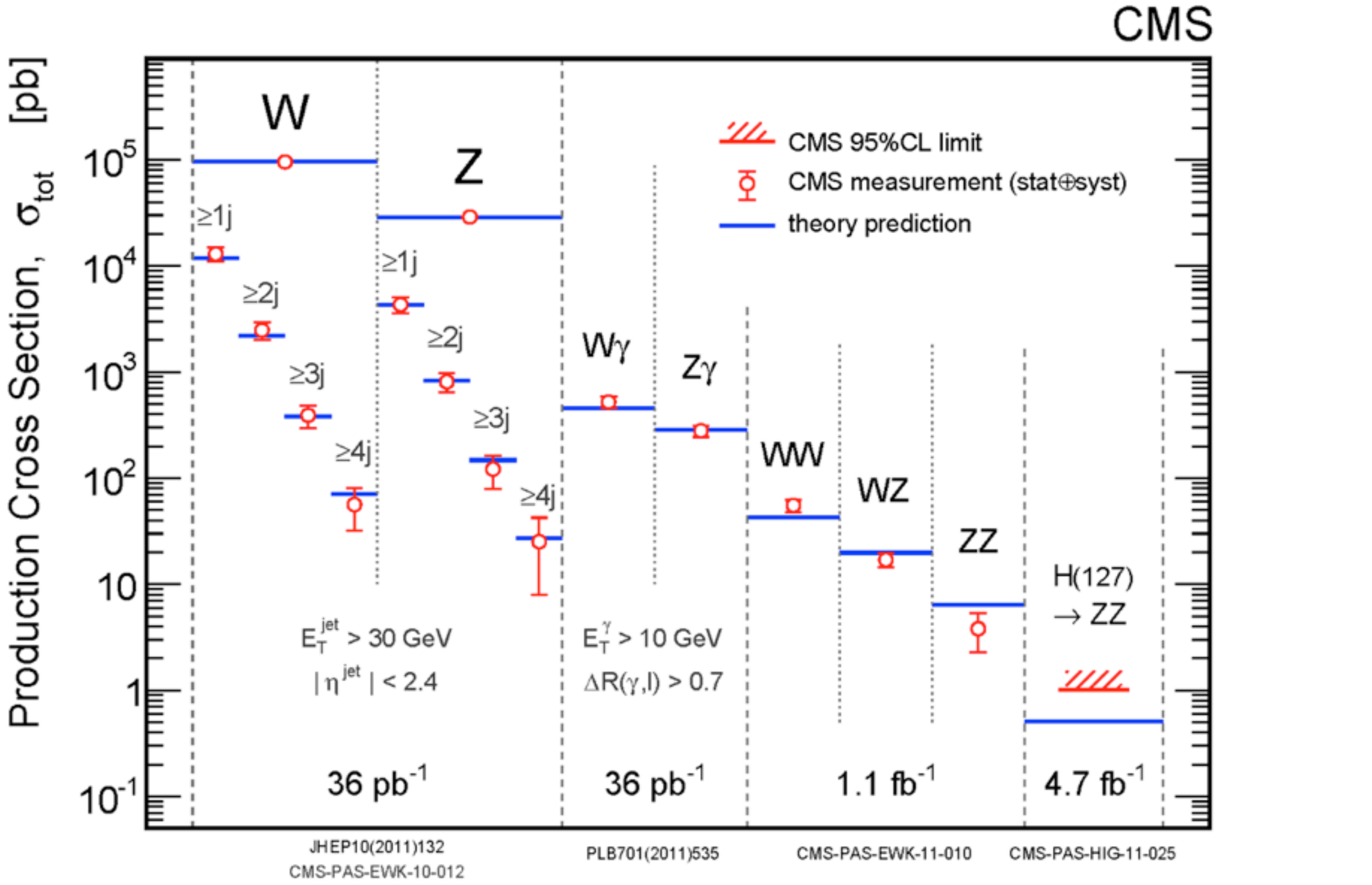
- excellent lepton reconstruction
- ECAL: photon reconstruction with 1% energy resolution in the barrel
- global event description through a **particle-flow algorithm**
  - great improvement on jet, MET, and tau reconstruction



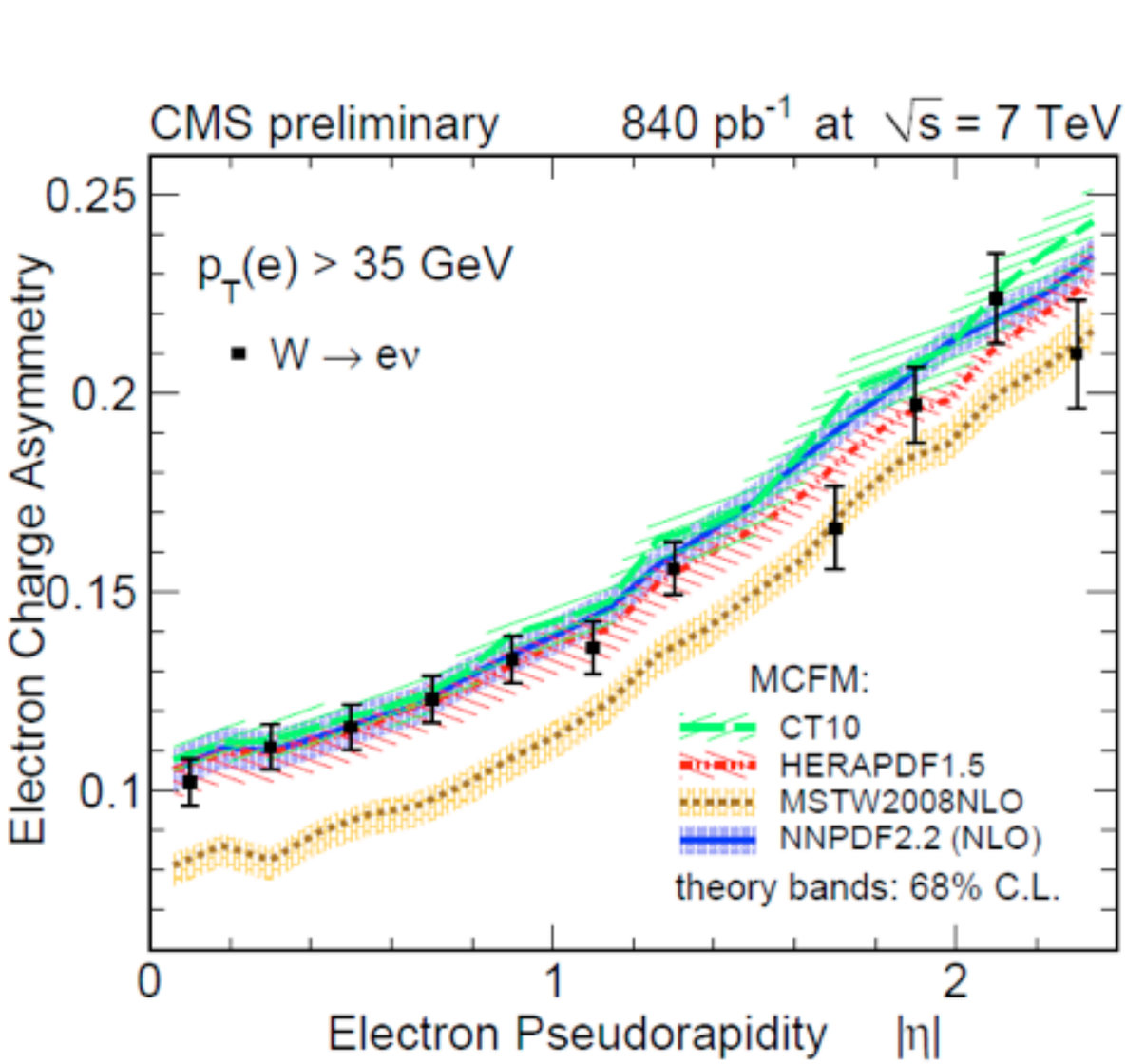


Electroweak Measurements

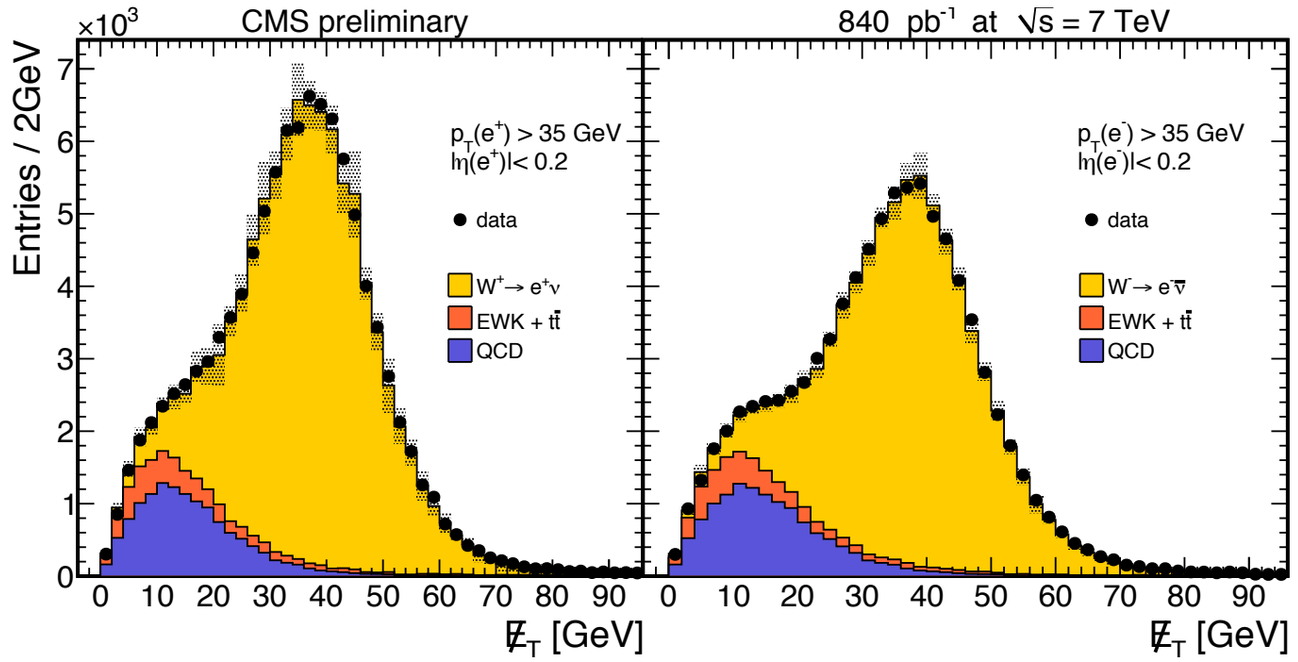
Overview


CMS
Production Cross Section, σ_{tot} [pb]
10^5
10^4
10^3
10^2
10
1
10^{-1}
W
Z
Wγ
Zγ
WW
WZ
ZZ
H(127) → ZZ
≥1j
≥2j
≥3j
≥4j
≥1j
≥2j
≥3j
≥4j
CMS 95%CL limit
CMS measurement (stat⊕syst)
theory prediction
E_T^{jet} > 30 GeV
$|\eta^{jet}|$ < 2.4
E_T^{γ} > 10 GeV
ΔR(γ,l) > 0.7
36 pb^{-1}
36 pb^{-1}
1.1 fb^{-1}
4.7 fb^{-1}
JHEP10(2011)132
CMS-PAS-EWK-10-012
PLB701(2011)535
CMS-PAS-EWK-11-010
CMS-PAS-HIG-11-025

W Asymmetry



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

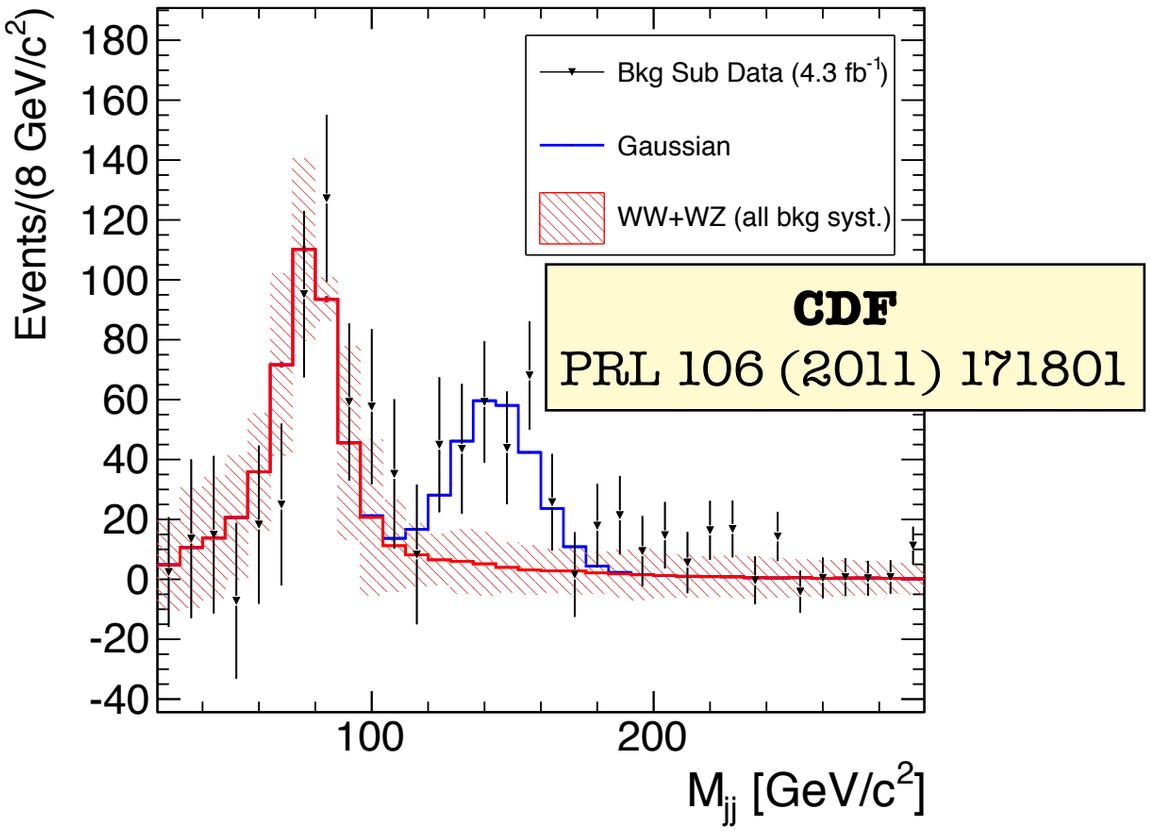


$$u\bar{d} \to W^+$$

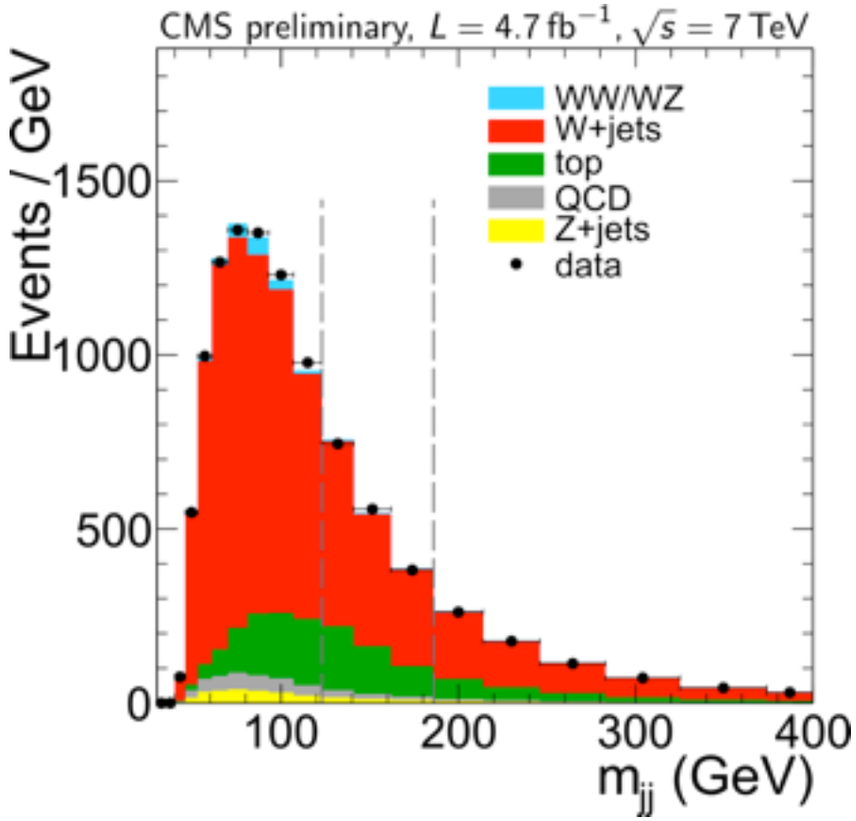
$$d\bar{u} \to W^-$$

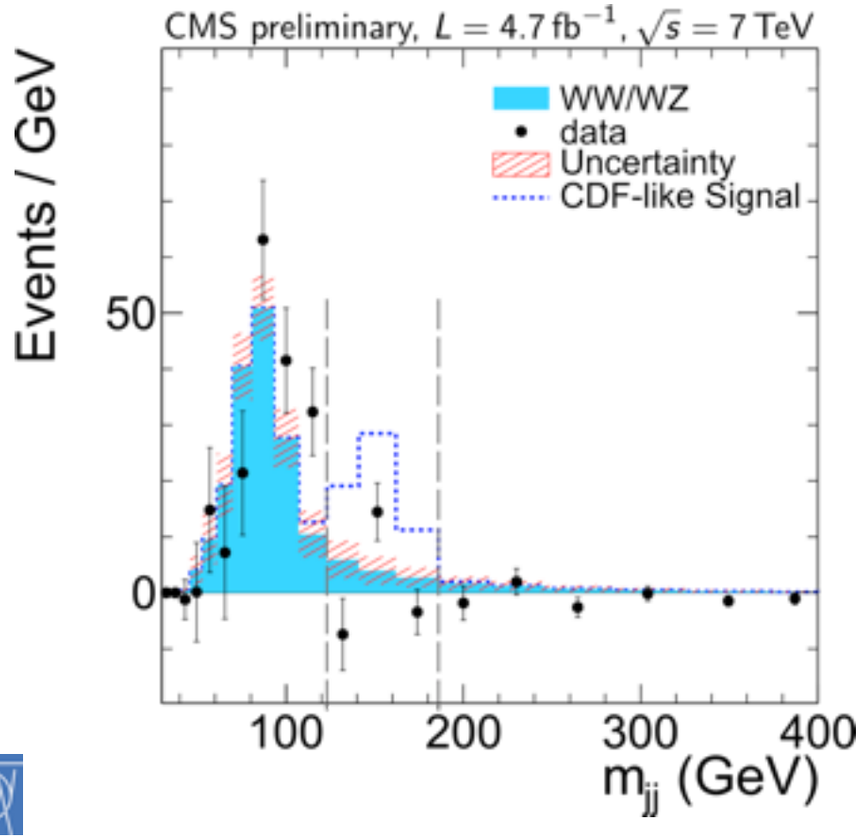
- two valence u quarks in the proton: surplus of W^+
- stringent test of PDFs: u/d ratio and sea-quark densities
- electron p_T > 35 GeV
- W yield extracted by MET template
- result expected to be used in PDF fits

W+2j



CDF
PRL 106 (2011) 171801

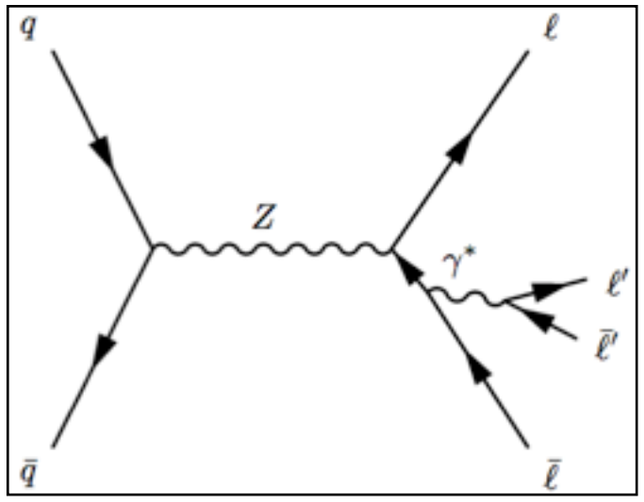


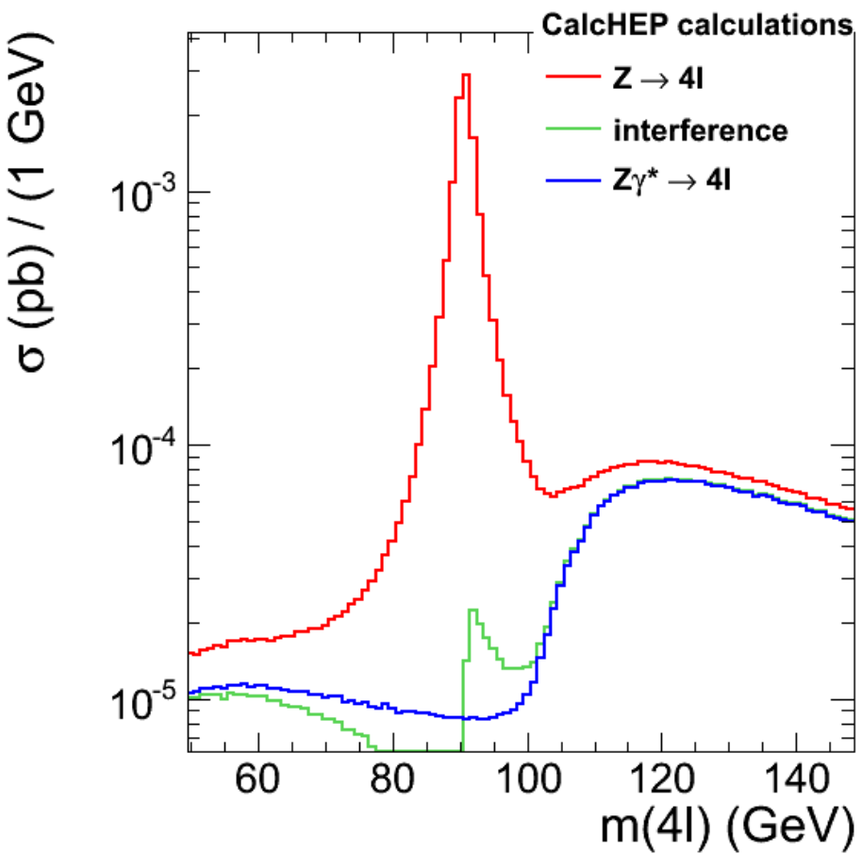


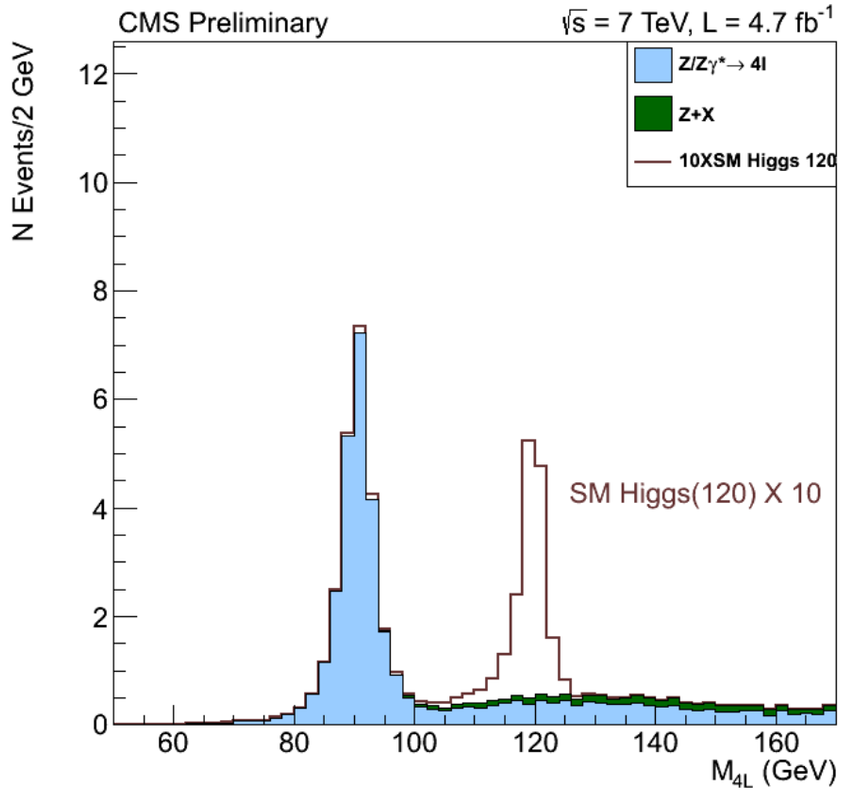
- CDF reported a "bump" in the dijet mass spectrum produced in association with a W boson
- CMS performed a similar analysis
  - W+jets background is dominant: uncertain modeling
  - **excluded: 1.5 pb** @ 95 C.L. (**CDF** projected cross section @ 7 TeV = **3.4 pb**)
  - no irregularity found: **CDF "bump" not confirmed**

Observation of Z→4l Decays (I)

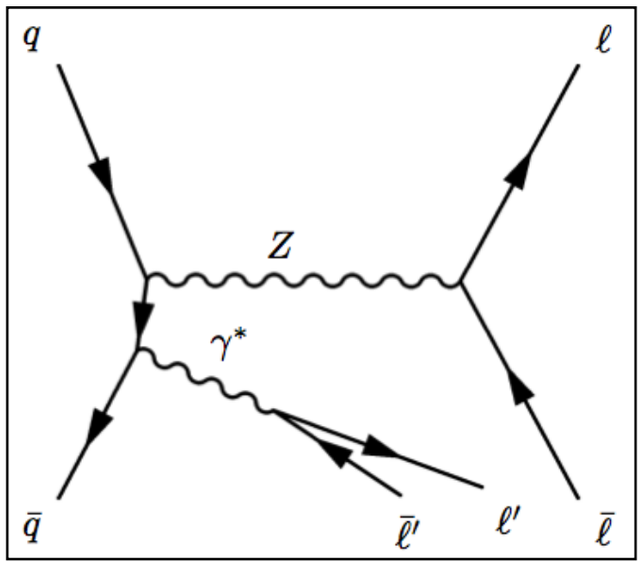
signal







background

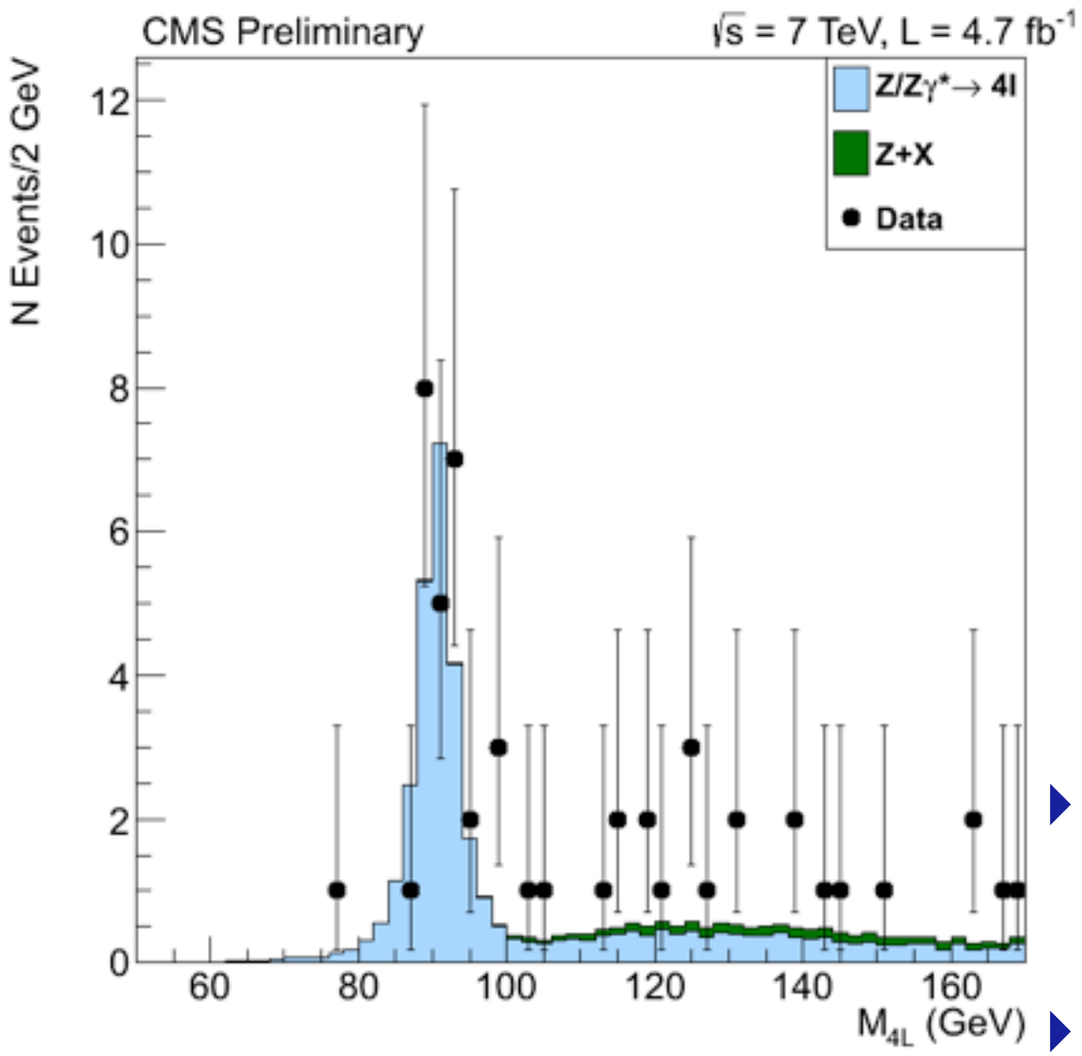


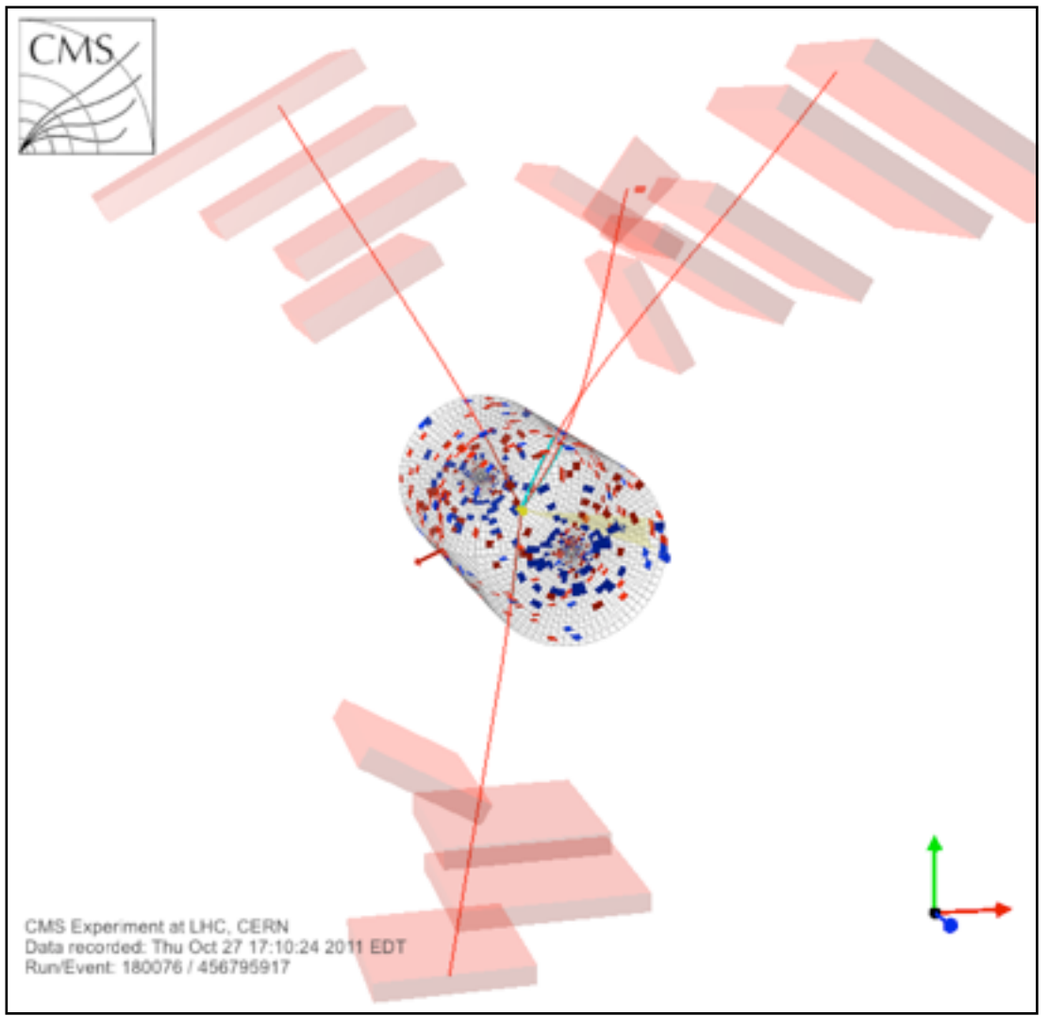
- signal: Z boson production with γ* radiation from one lepton
- very important "candle" for the H→ZZ
  - in situ calibration of m_{4l}

Observation of Z→4l Decays (II)

$$\sigma \times BR(Z \to 4\ell) = 125^{+26}_{-23}(\text{stat})^{+9}_{-6}(\text{syst})^{+7}_{-5}(\text{lumi})\ \text{fb}$$

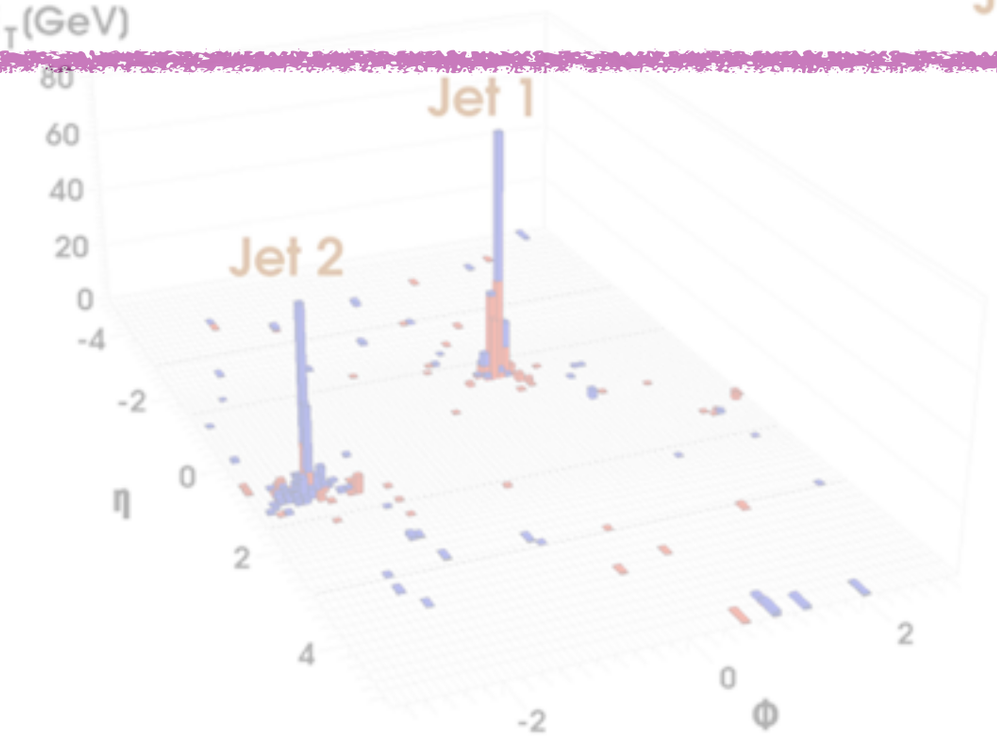
$$\sigma_{TH} = 120 \pm 4.92\ \text{fb}$$

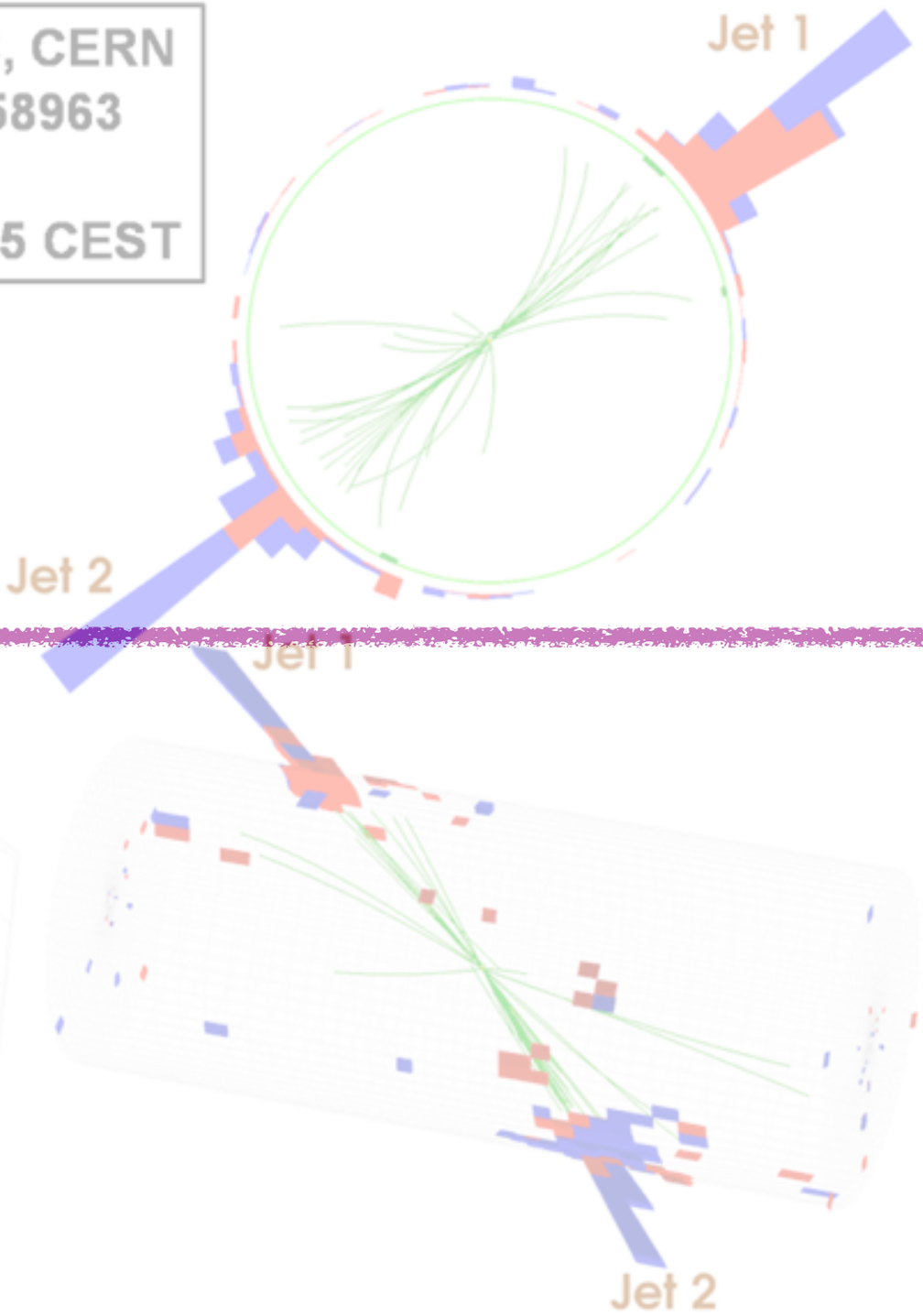




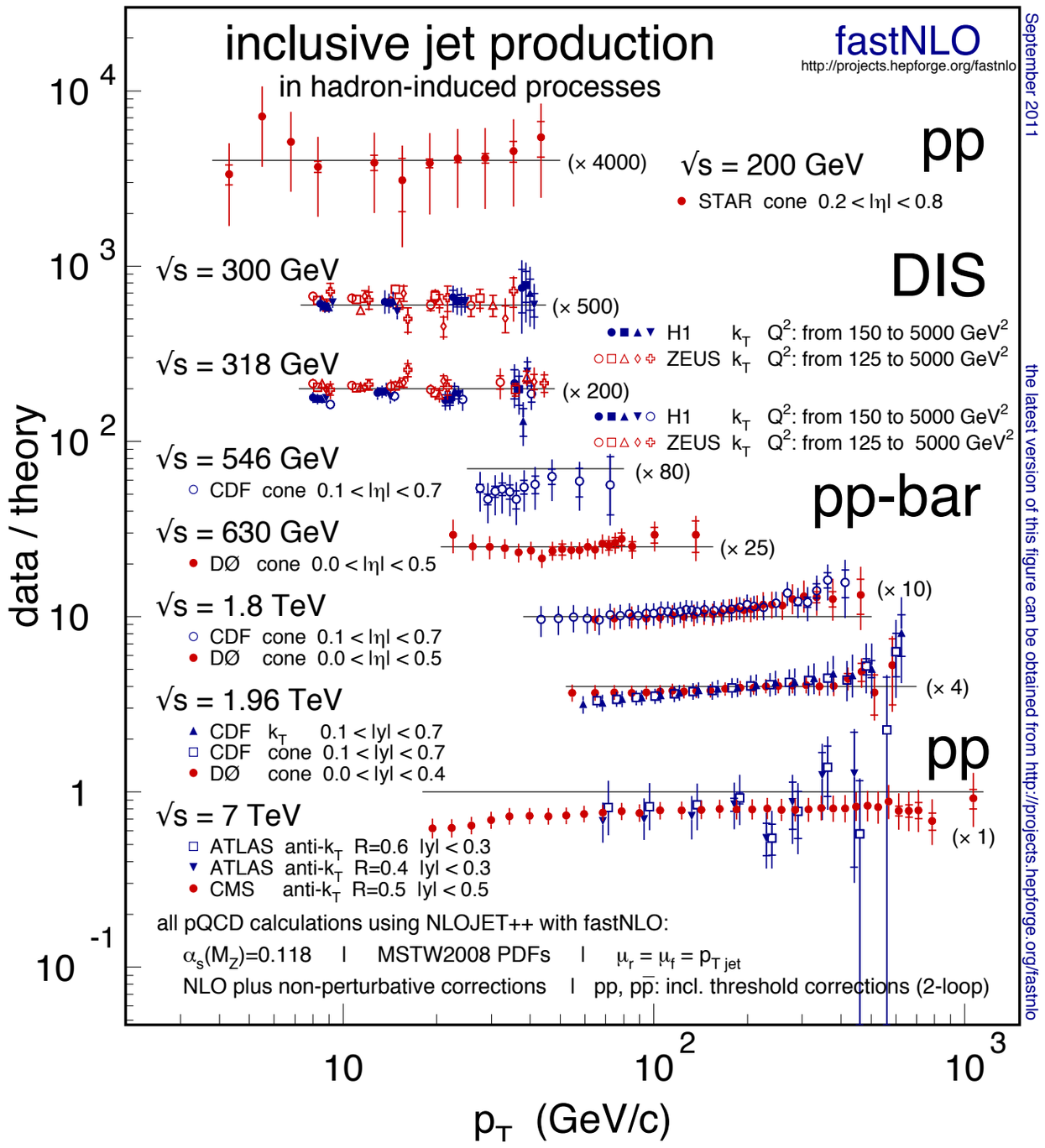
- first observation at hadron collider
  - possible in CMS thanks to low lepton p_T reconstruction
- $p_T(el) > 7$ GeV, $p_T(\mu) > 5$ GeV, $m_{ll} > 4$ GeV

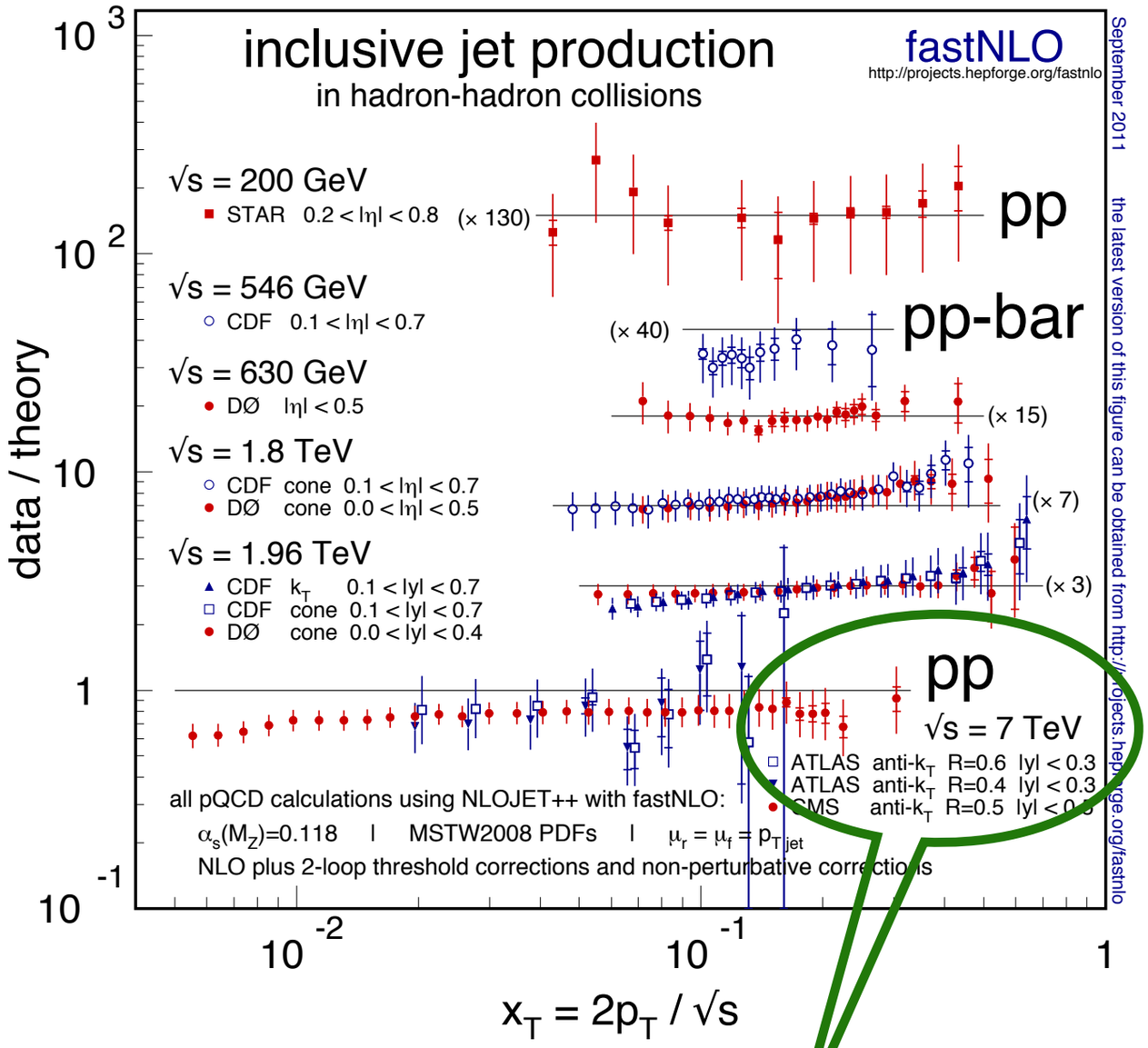
QCD Measurements





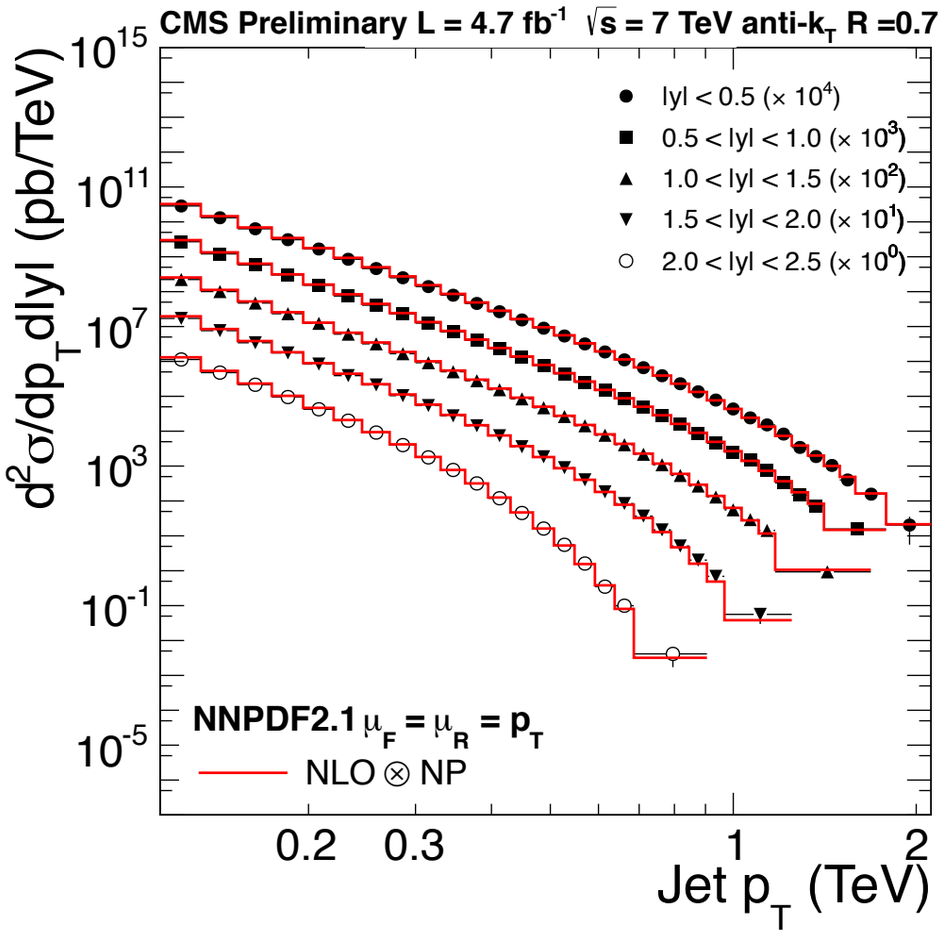
Inclusive Jet Production

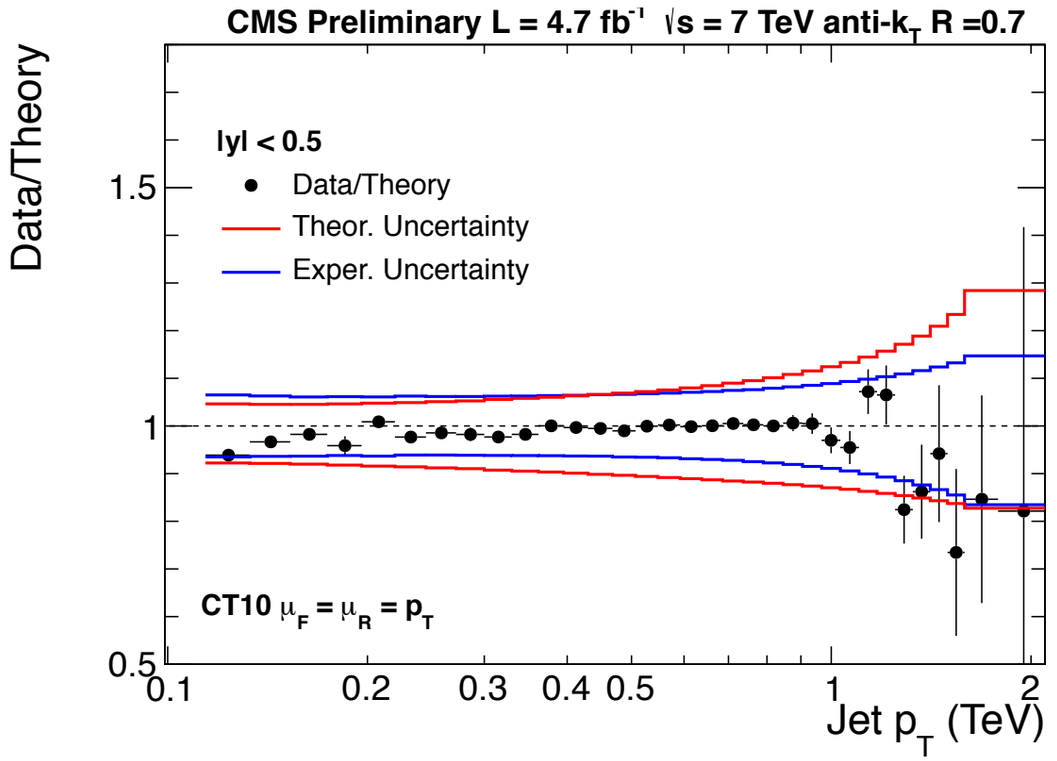


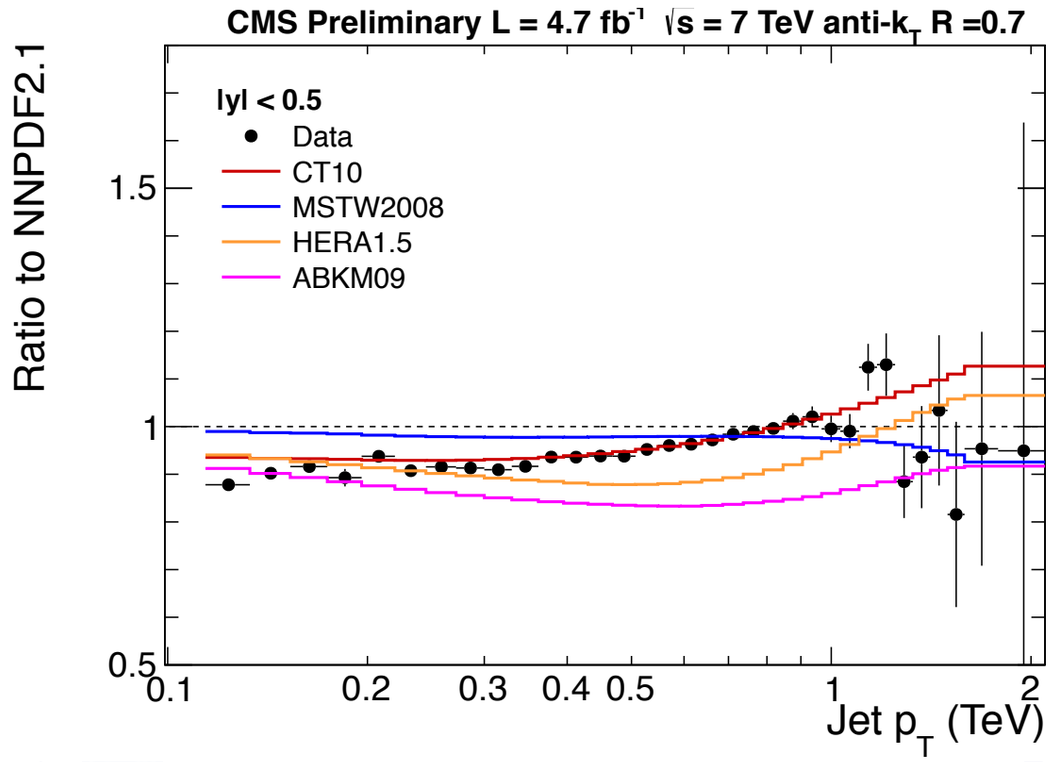


phase space covered by the 2011 measurement

Inclusive Jet Cross Sections

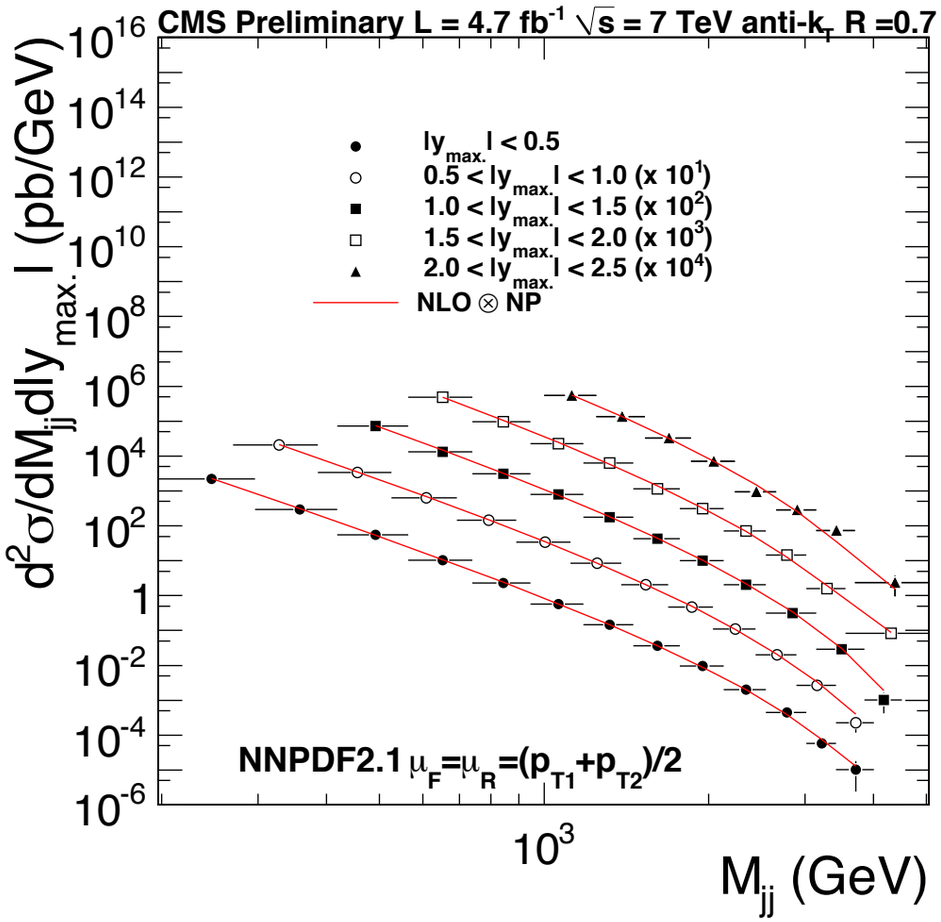


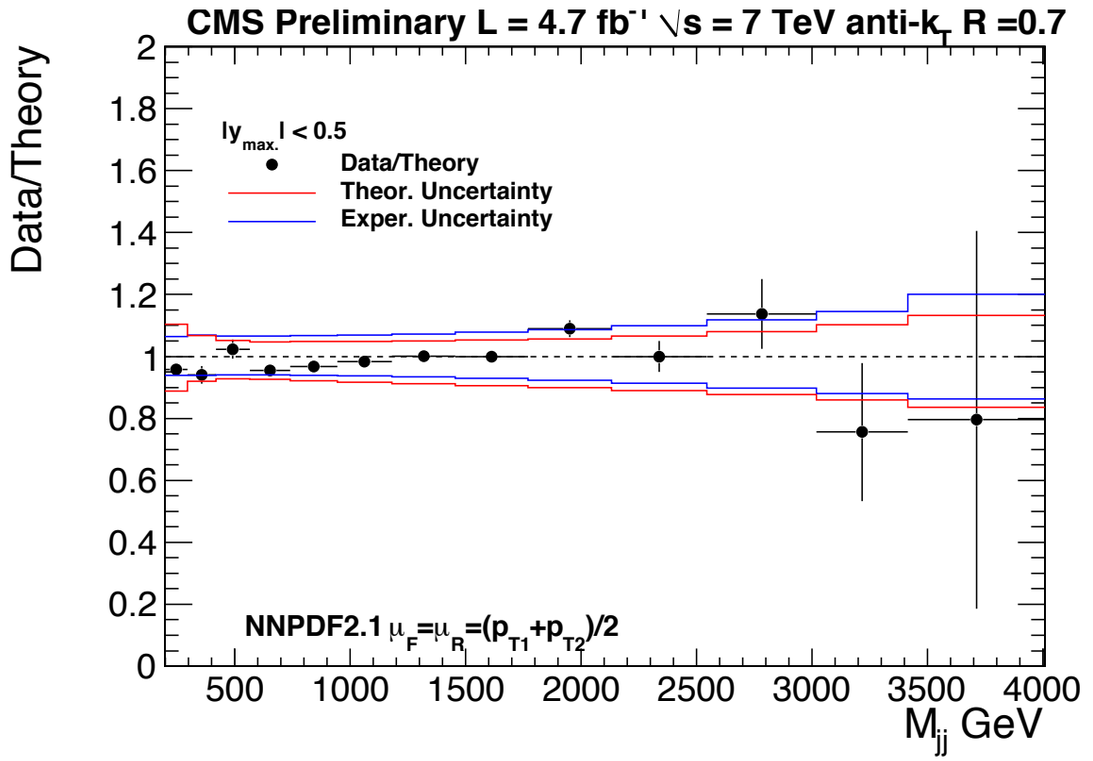




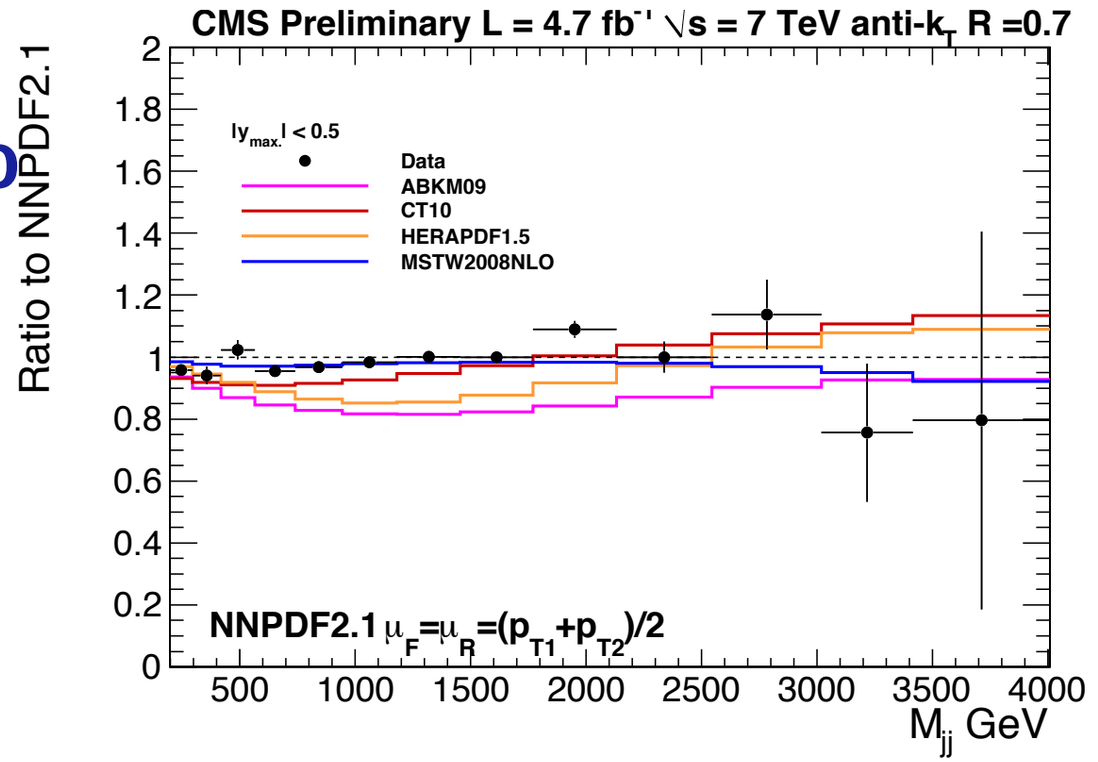
- inclusive jet cross section in the p_T range **0.1-2.0 TeV** and up to **|y|=2.5**
- experimental uncertainty comparable to the theory uncertainty
  - constraint of the gluon PDF at high x
- differentiation between PDFs
  - all PDFs compatible within uncertainties, but some are in better agreement

DiJet Cross Sections

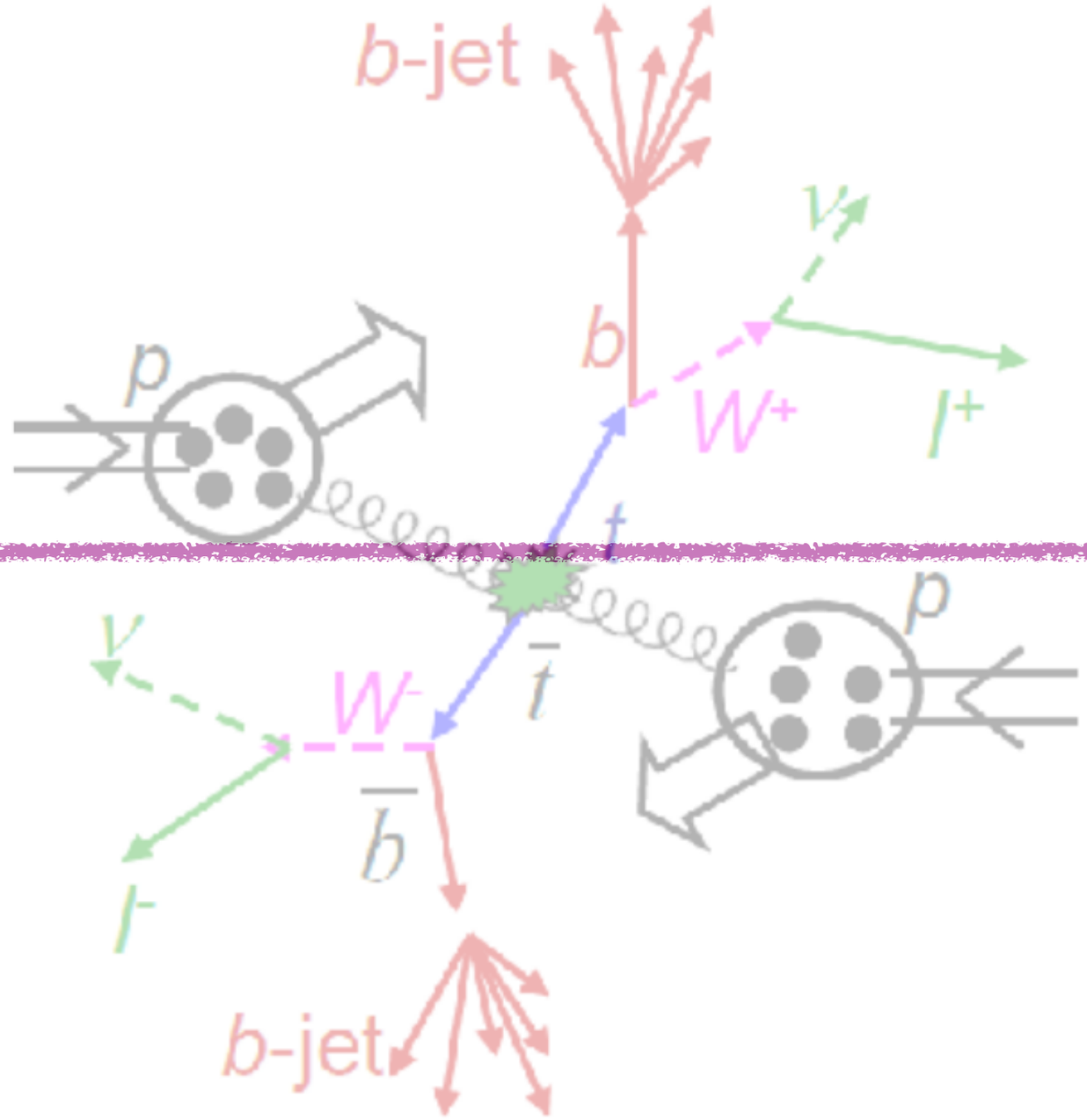




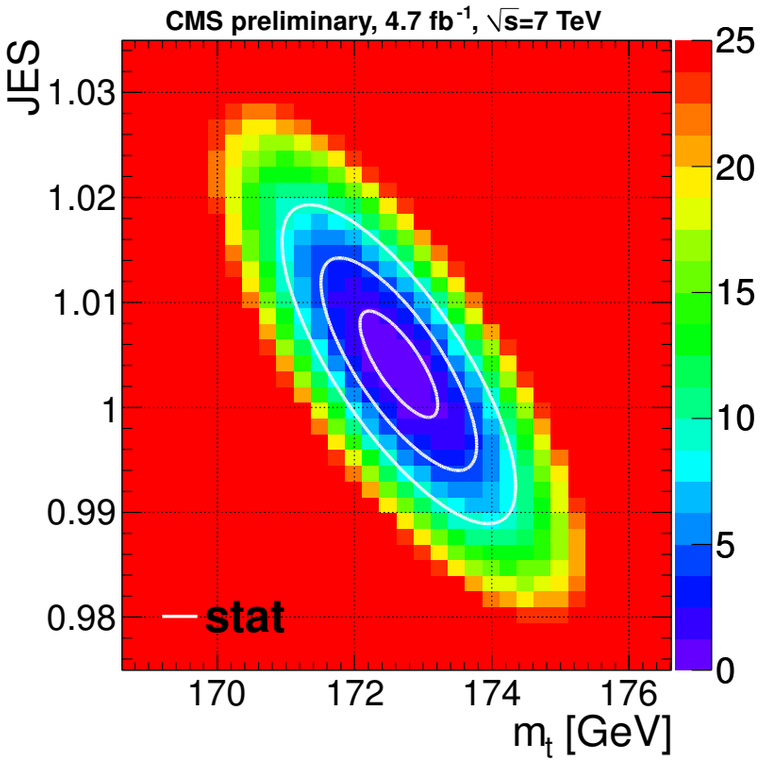
- dijet cross section in the mass range **0.2-4.0 TeV** and up to **|y|=2.5**
- experimental uncertainty comparable to the theory uncertainty
  - constraint of the gluon PDF at high x
- differentiation between PDFs
  - all PDFs compatible within uncertainties, but some are in better agreement



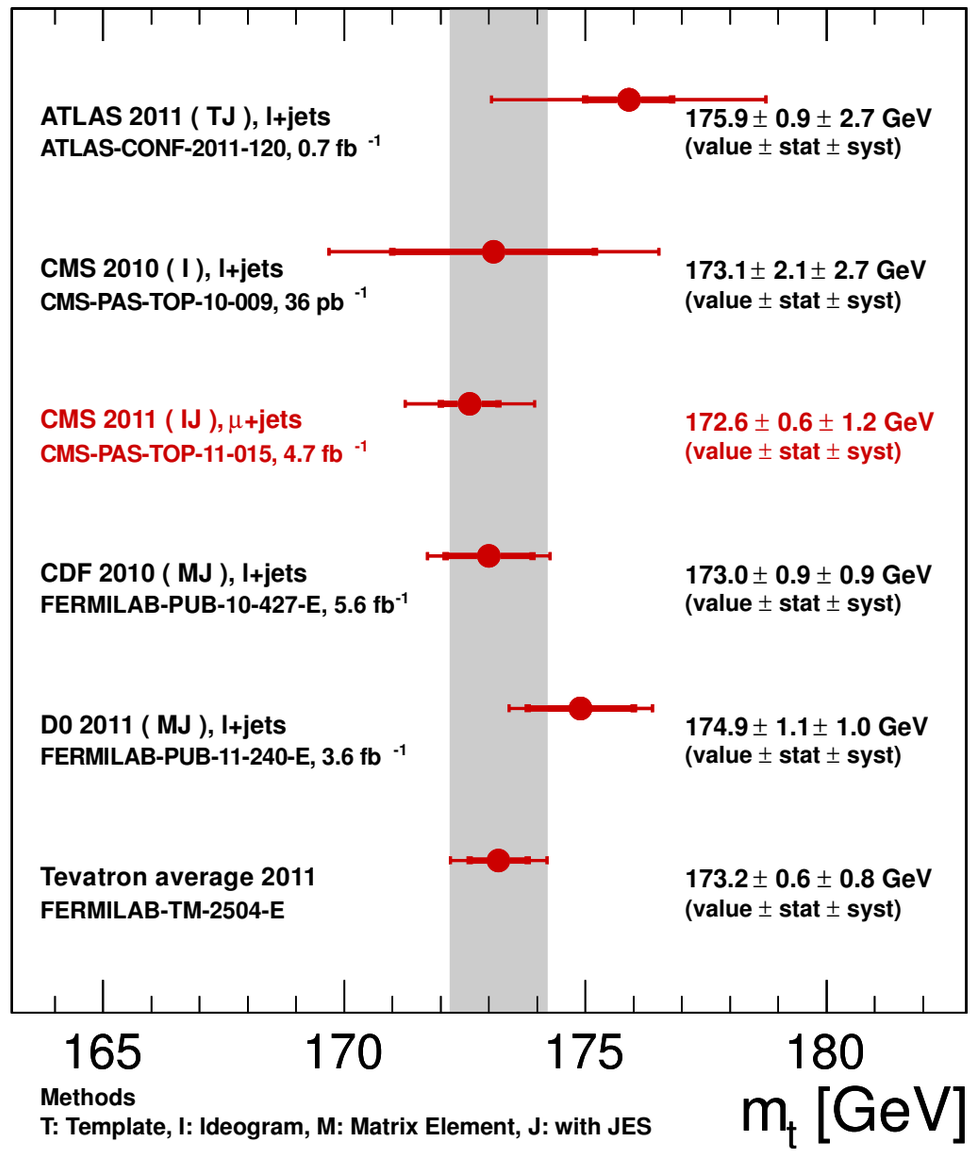
Top Measurements



Top Mass (μ + jets)



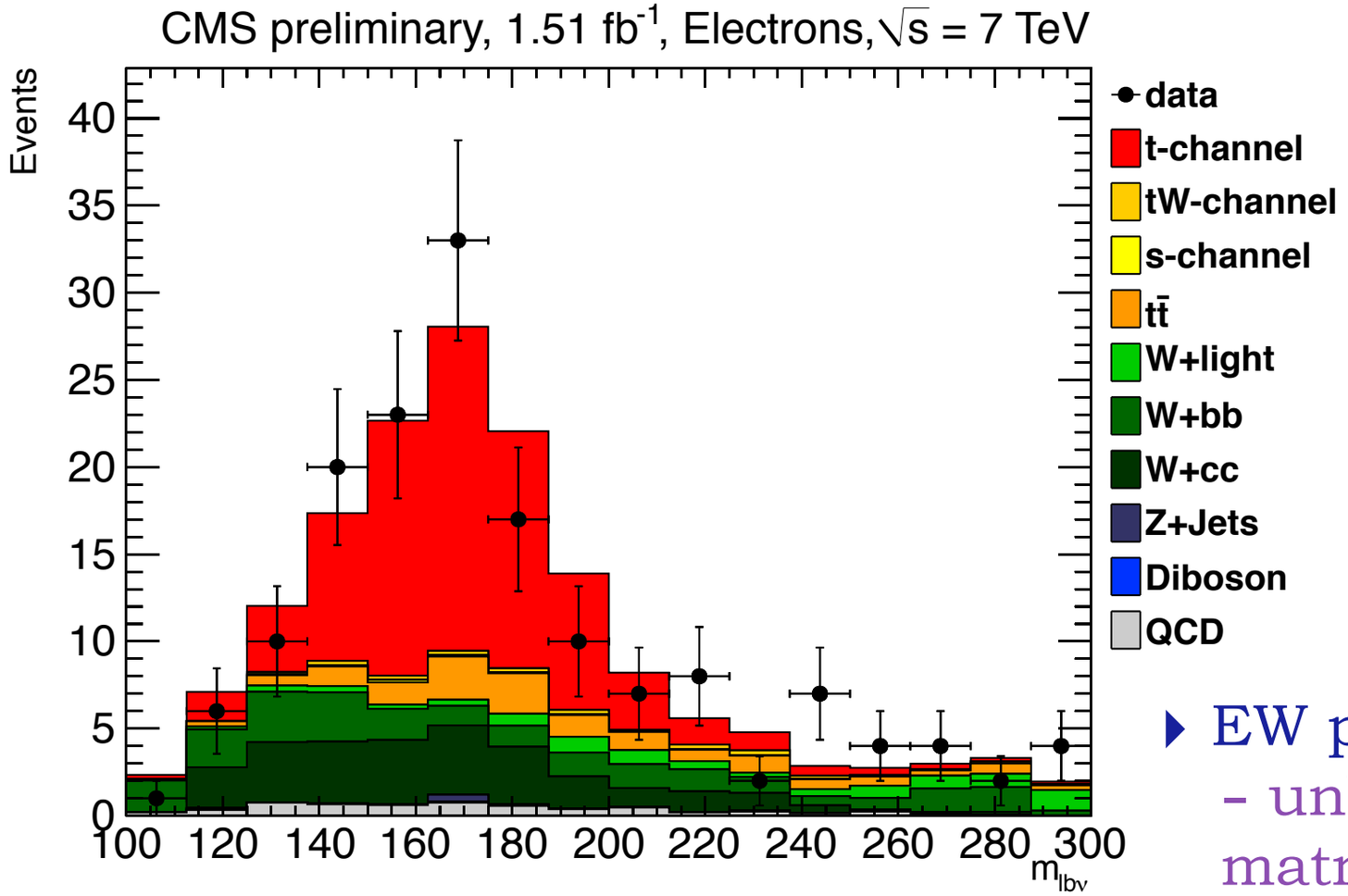
	δ_{m_t} (GeV)
Calibration	0.15
b-tagging	0.17
b-JES	0.66
p_T- and η-dependent JES	0.23
Jet energy resolution	0.21
Missing transverse energy	0.08
Factorization scale	0.76
ME-PS matching threshold	0.25
Non-$t\bar{t}$ background	0.09
Pile-up	0.38
PDF	0.05
Total	1.18

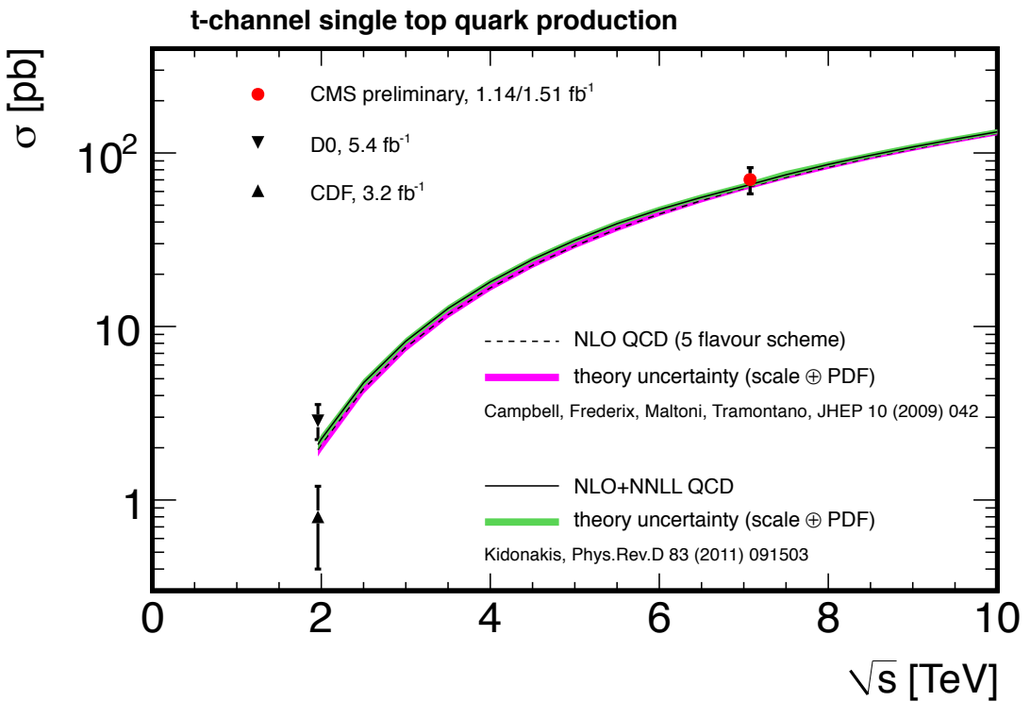


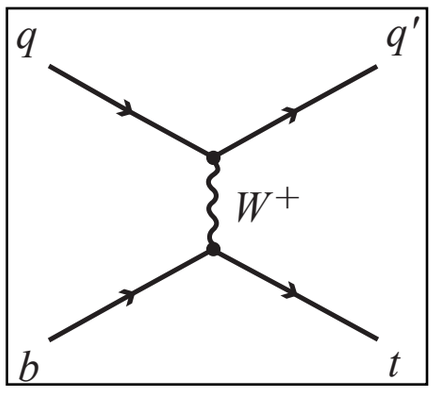
- top mass: fundamental SM parameter
- ideogram method
  - event-by-event 2D likelihood fit (m_{top}, JES)
  - kinematic fit of the entire event
  - m_W constraints (leptonic, hadronic) + top mass constraint ($m_t^{lep} = m_t^{had}$)
- most precise LHC measurement, **but**:
  - some systematics (color connection, UE) not included yet (up to 0.6 GeV contribution each)

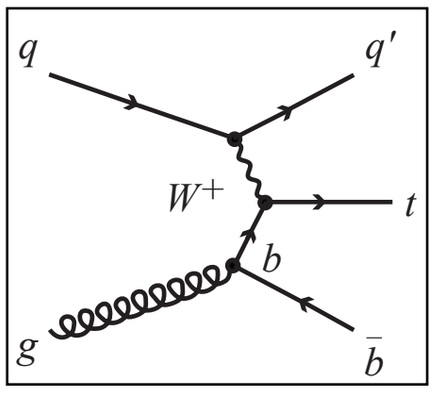
$$m_t = 172.64 \pm 0.57\,(\text{stat+JES}) \pm 1.18\,(\text{syst})\ \text{GeV}$$
$$\text{JES} = 1.004 \pm 0.005\,(\text{stat}) \pm 0.012\,(\text{syst})$$

Single Top (t-channel)







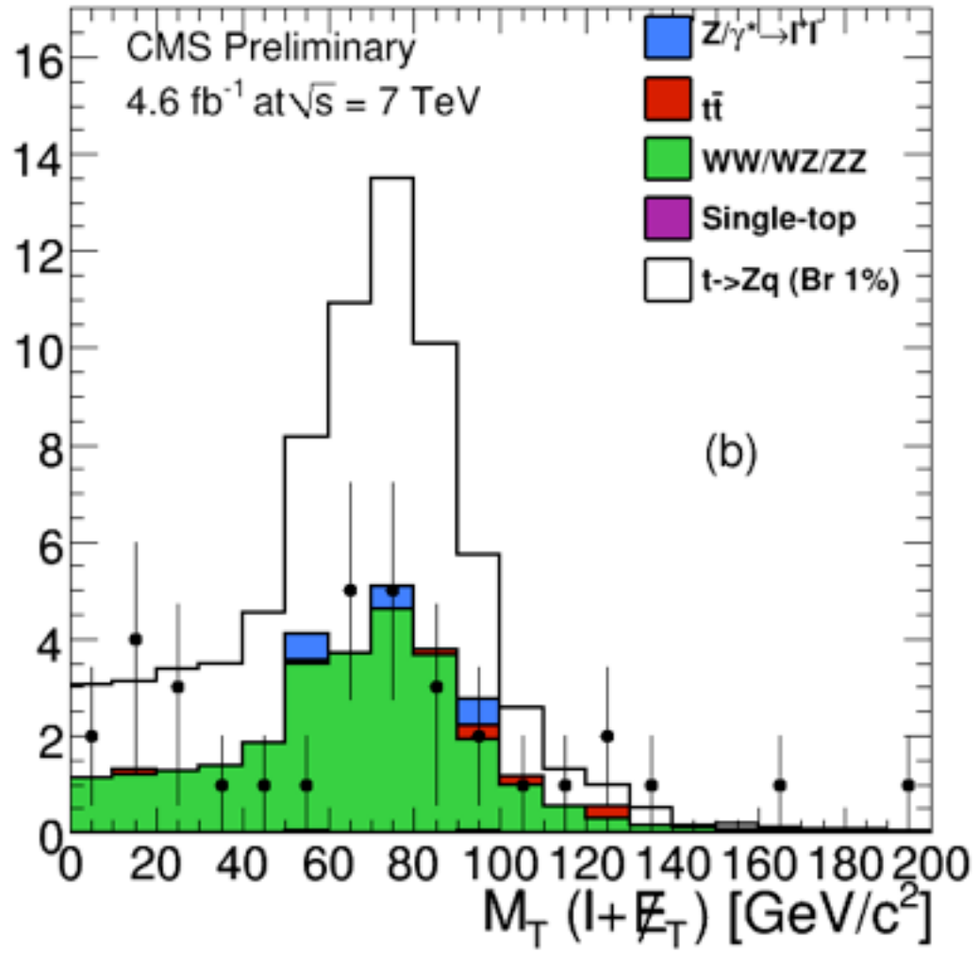


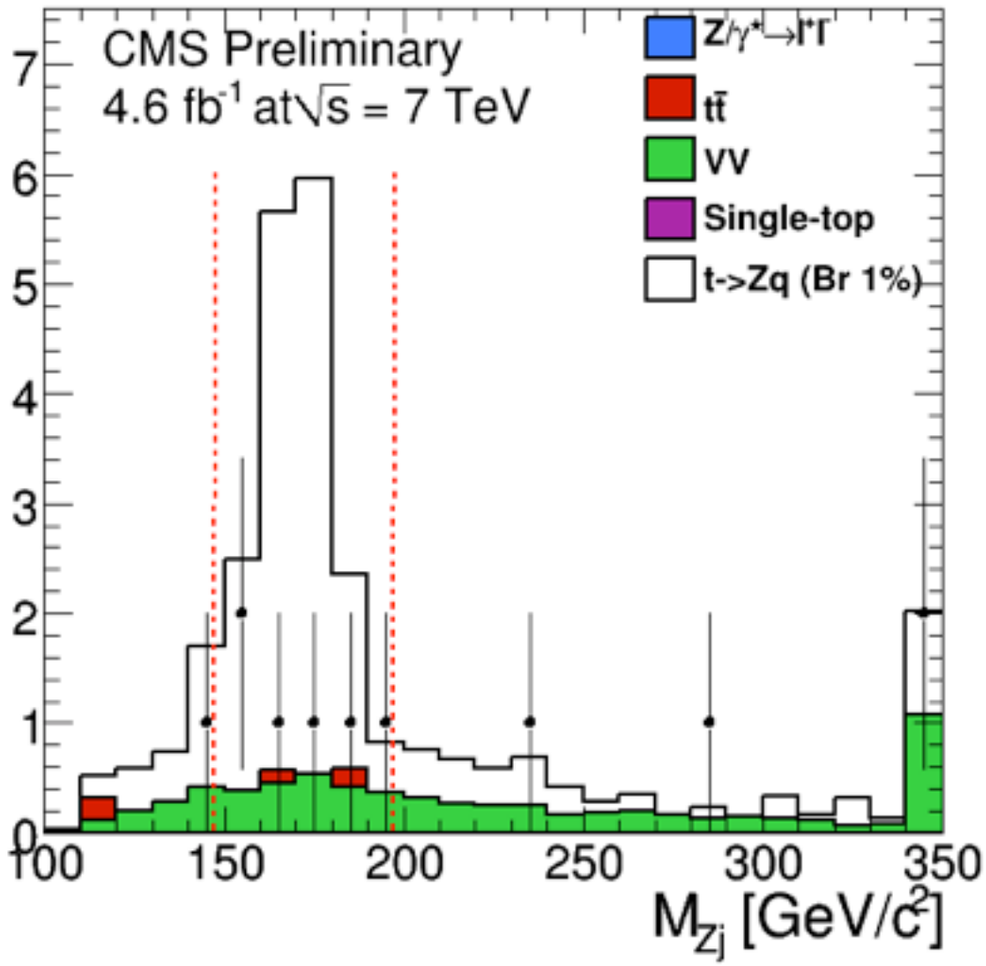
- EW production of top quark
  - unbiased measurement of CKM matrix element V_{tb}
  - sensitivity to BSM physics
- t-channel: dominant production
- experimental signature: one isolated lepton + MET + 1 central b-jet + 1 jet

$$\sigma_{t-\mathrm{ch.}} = 70.2 \pm 5.2(\mathrm{stat.}) \pm 10.4(\mathrm{syst.}) \pm 3.4(\mathrm{lumi.})\ \mathrm{pb}$$

$$|V_{tb}| = \sqrt{\frac{\sigma_{t-\mathrm{ch.}}}{\sigma^{\mathrm{th}}_{t-\mathrm{ch.}}}} = 1.04 \pm 0.09\,(\mathrm{exp.}) \pm 0.02\,(\mathrm{th.})$$

Flavor Changing Neutral Currents

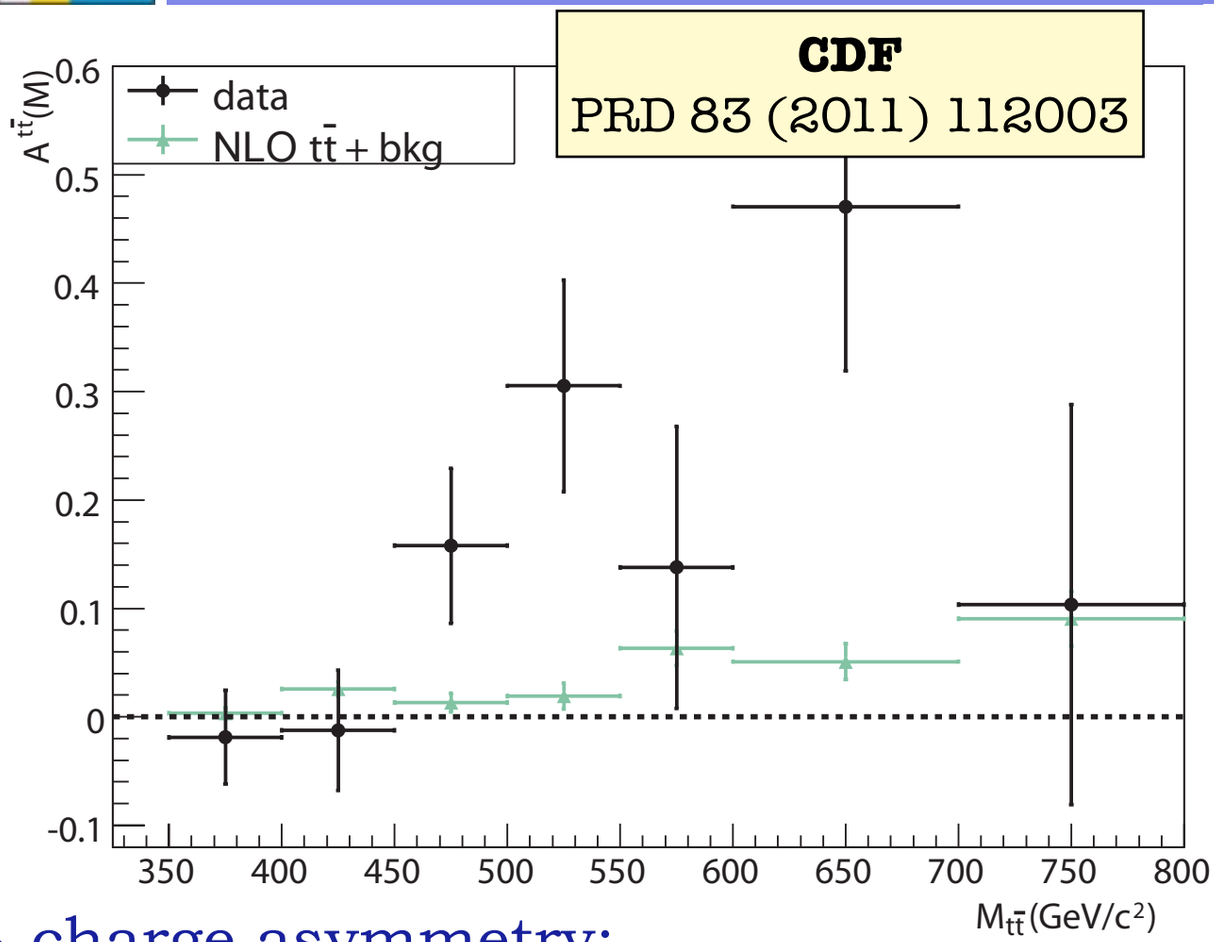


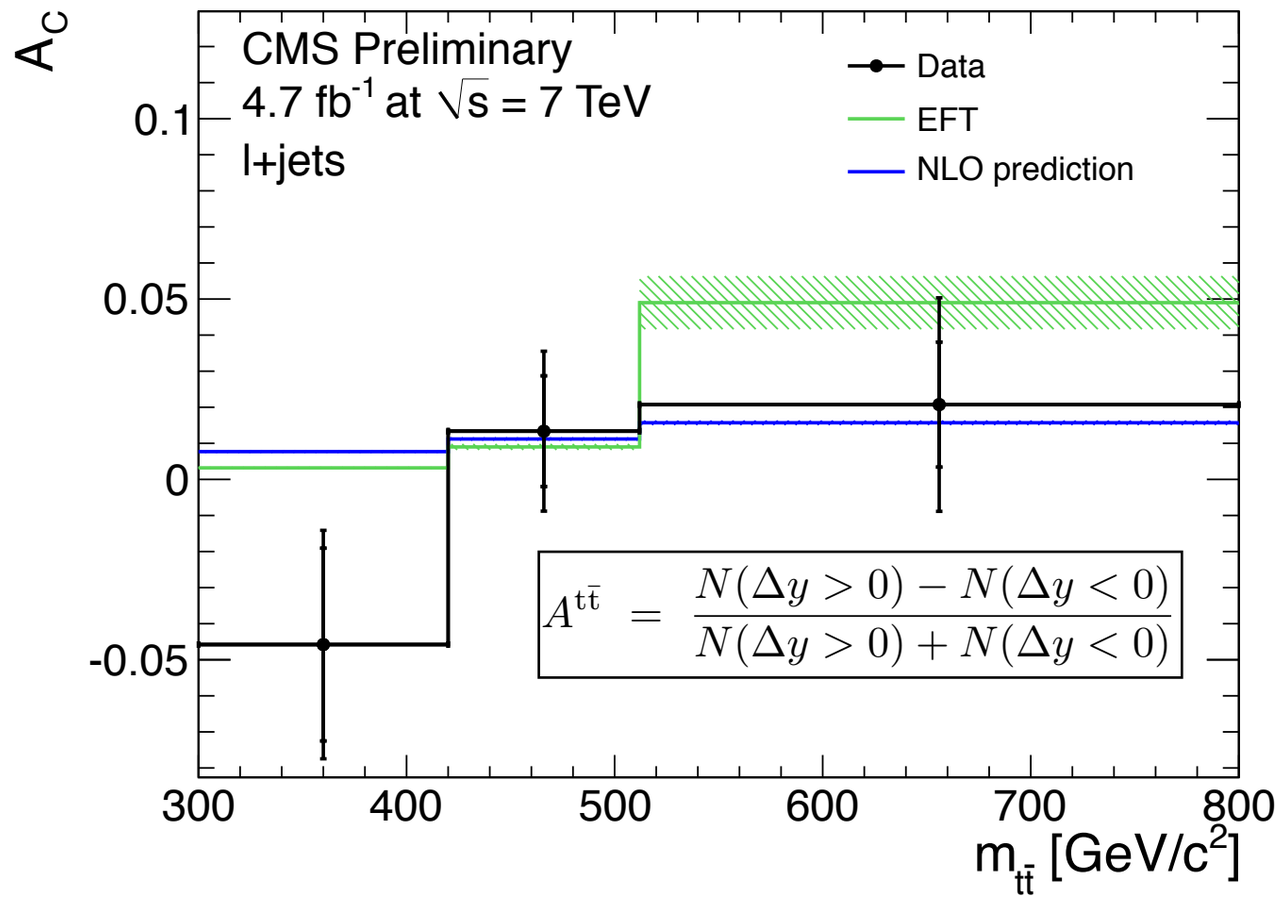


$$t\bar{t} \rightarrow Wb + Zq \rightarrow l\nu b + llj$$

- in SM: t→Wb, while t→Zq (q=u,c) through loop corrections with BR~10^{-14}
- beyond SM: BR~10^{-4}
- final state: 3 leptons + MET + 2 jets
- measurement consistent to the SM expectations
  - exclude FCNC with BR(t→Zq) > 0.34% @ 95 CL

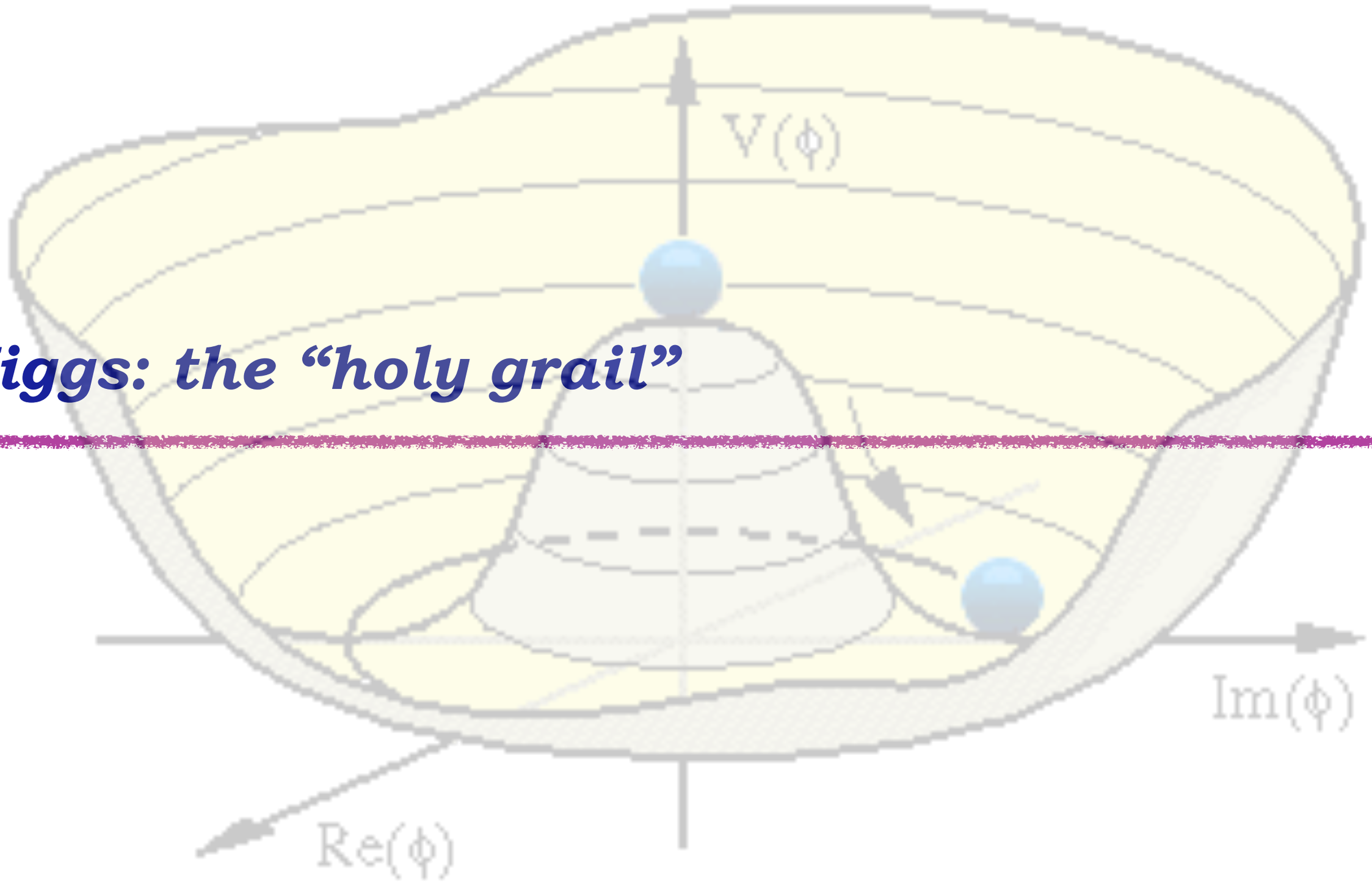
Charge Asymmetry



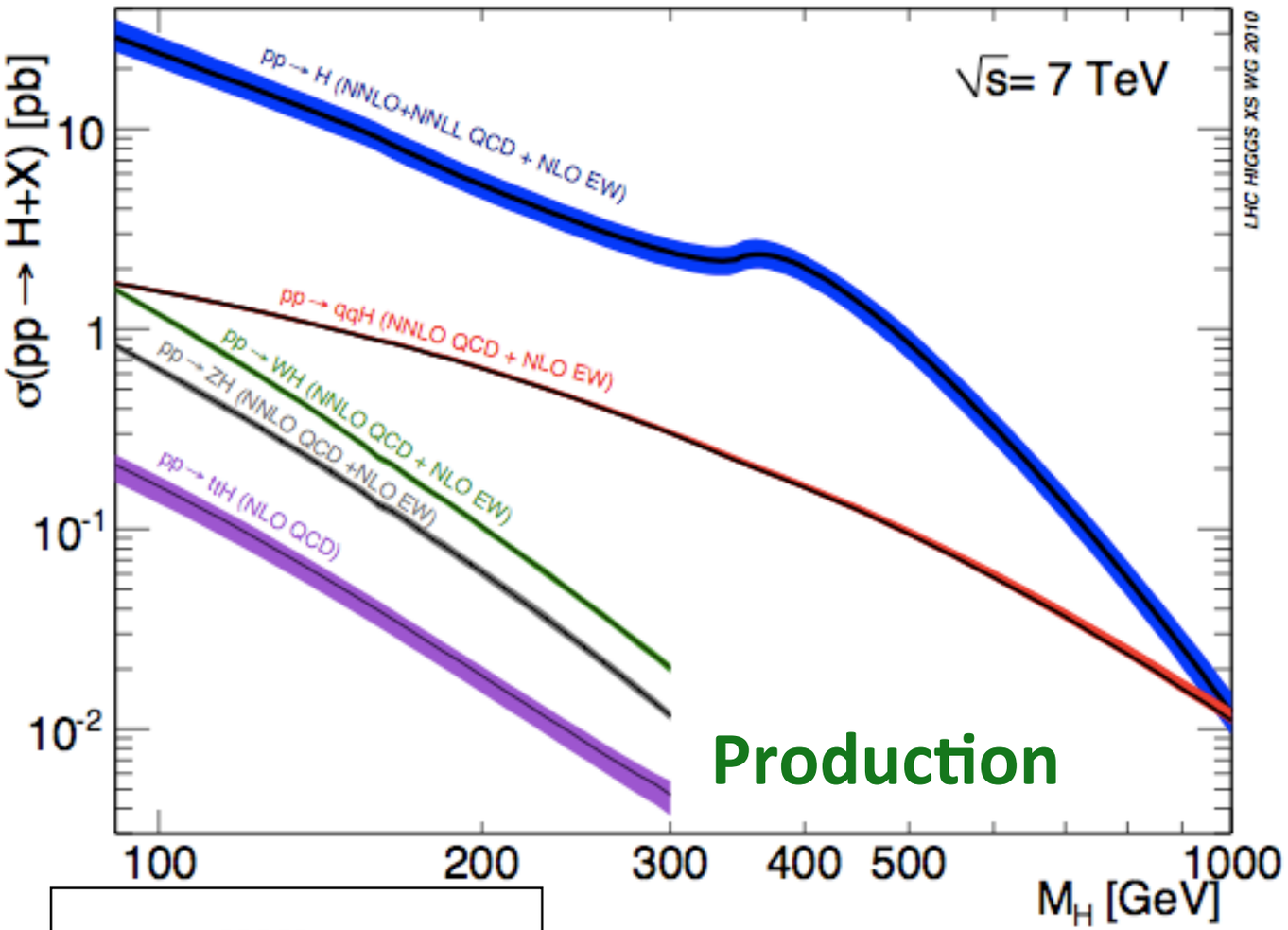


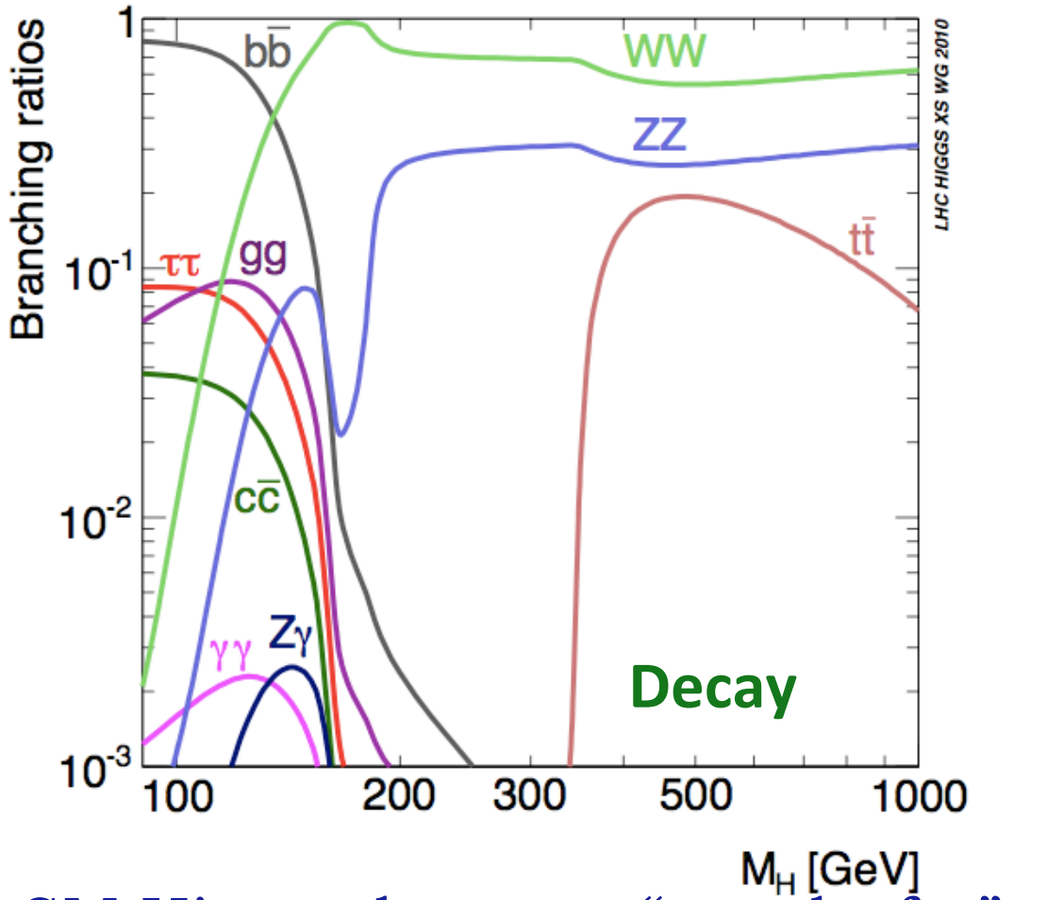
- charge asymmetry:
  - occurs in quark-antiquark initial states
  - in pp collisions, IS quarks are mostly valence, while IS antiquarks are always sea quarks
  - quarks have larger momentum fraction: excess of top quarks at forward directions
  - $\Delta y = |y_{top}| - |y_{antitop}|$
- experimental signature: lepton + jets
- **CMS measurement in agreement with the theory predictions**

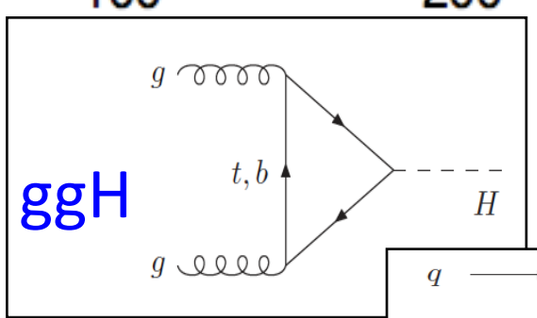
Higgs: the "holy grail"

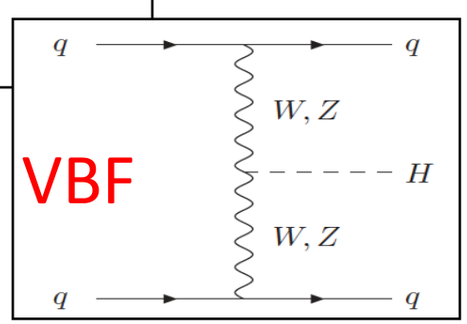


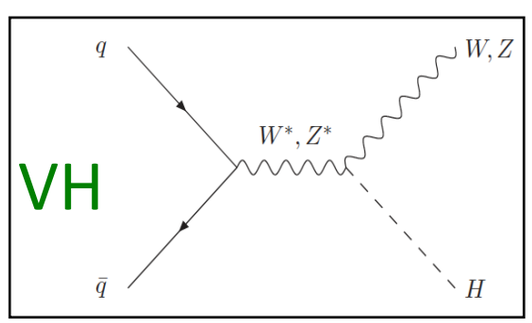
SM Higgs





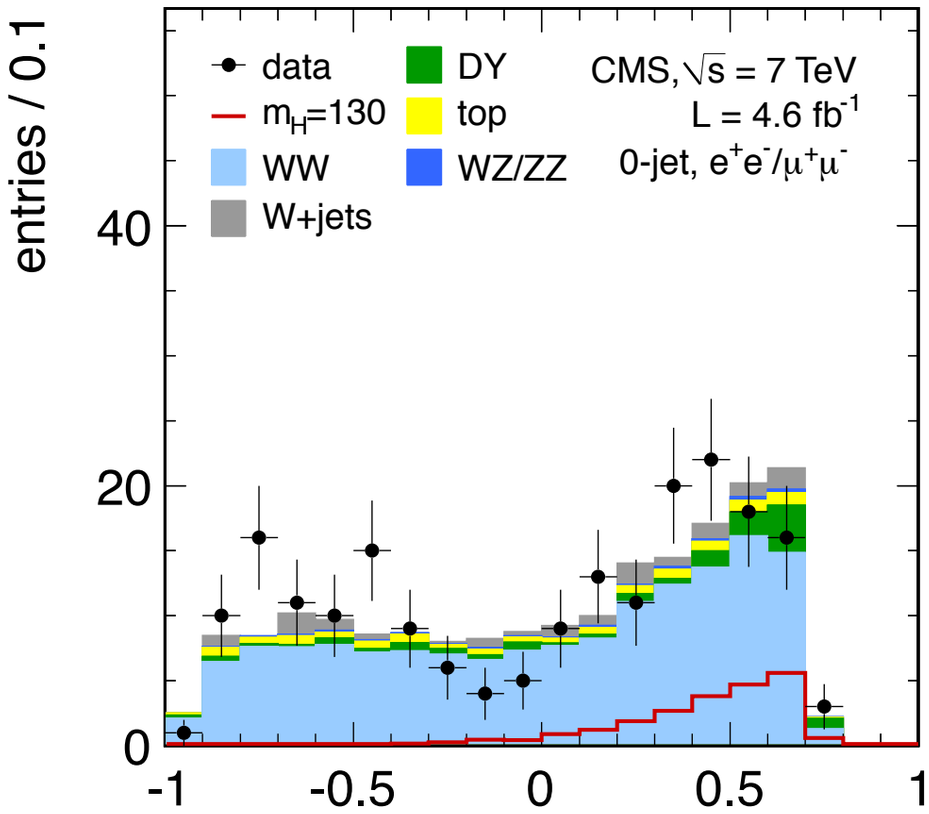


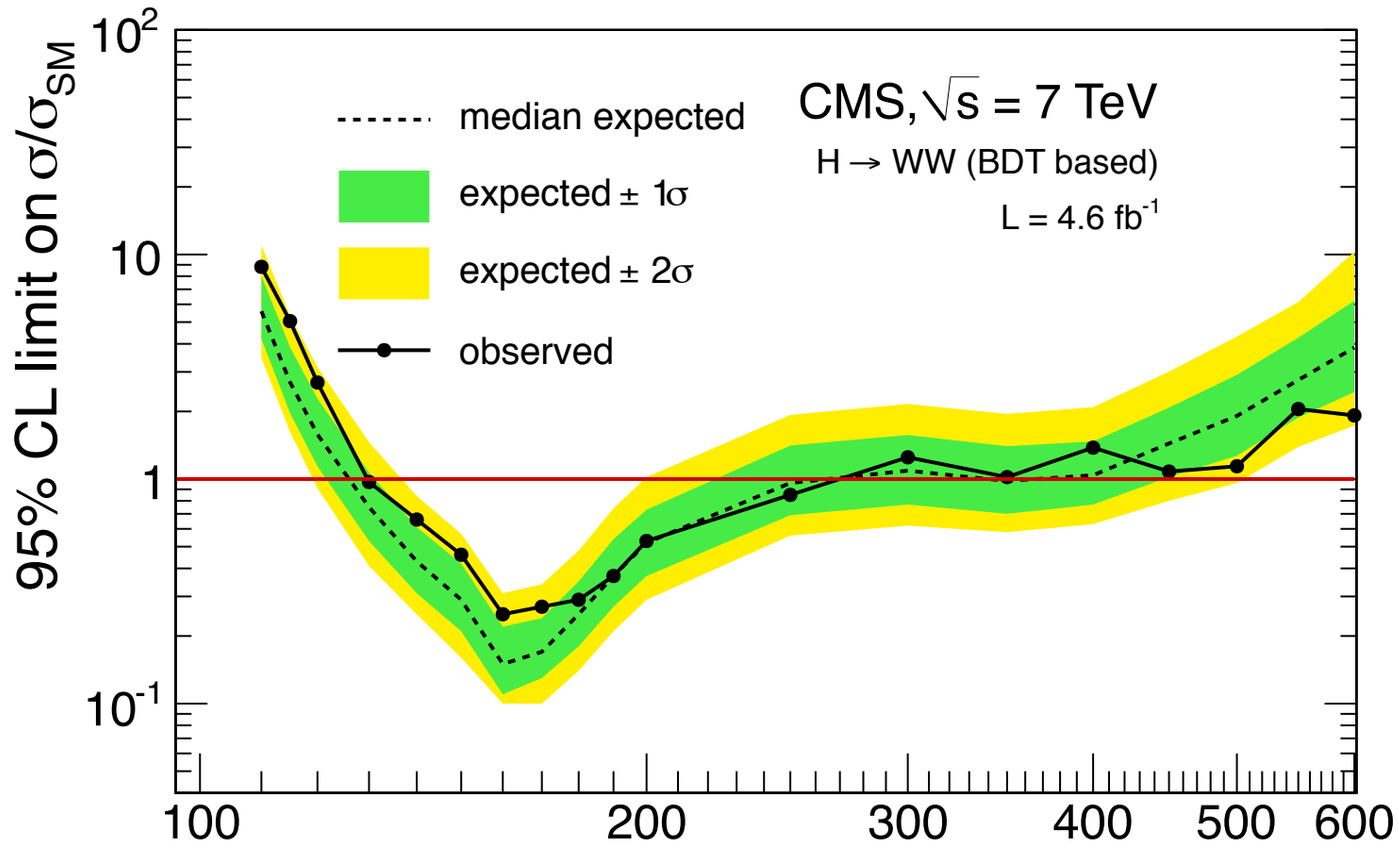




- SM Higgs: the most "sought for" particle
  - global EW fits favor low masses
- production mechanisms
  - gluon-gluon fusion
  - vector-boson fusion
  - associated production
- decay modes strongly dependent on the Higgs mass

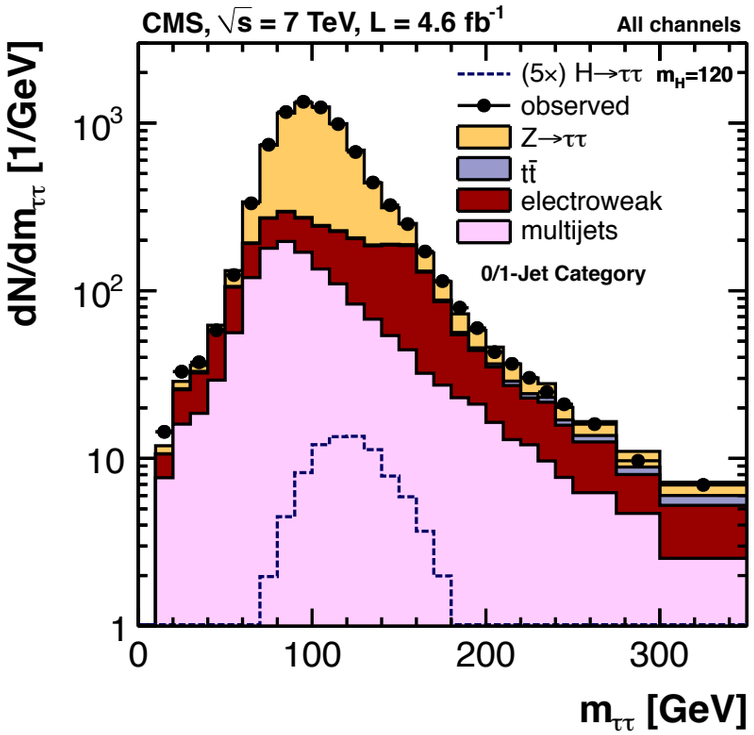
$H \rightarrow WW \rightarrow 2l+2\nu$

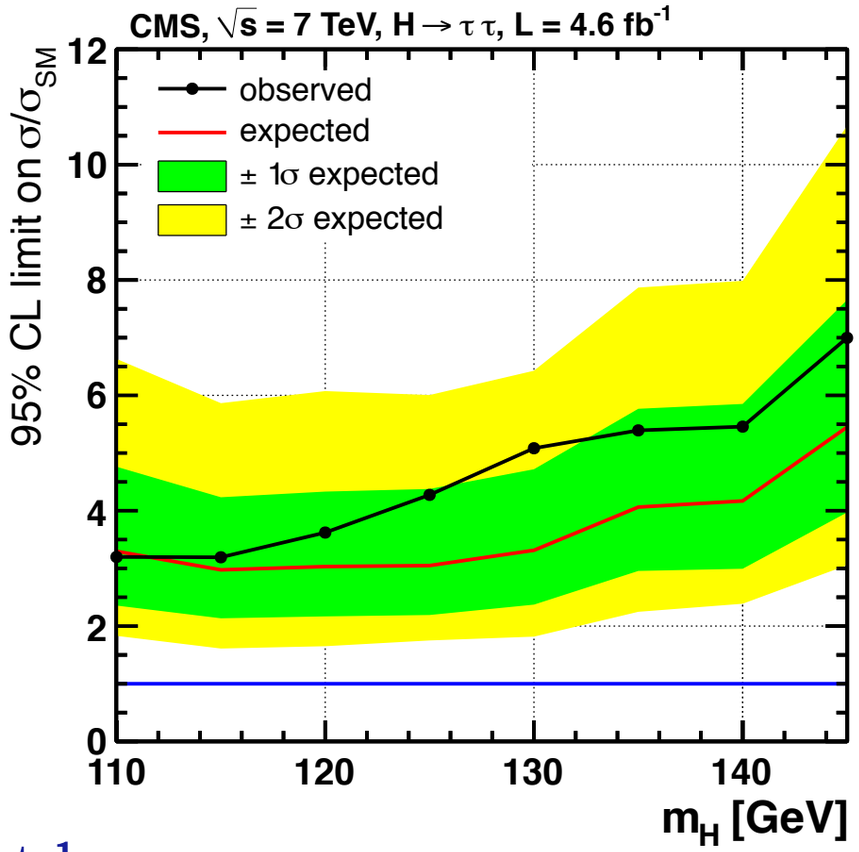


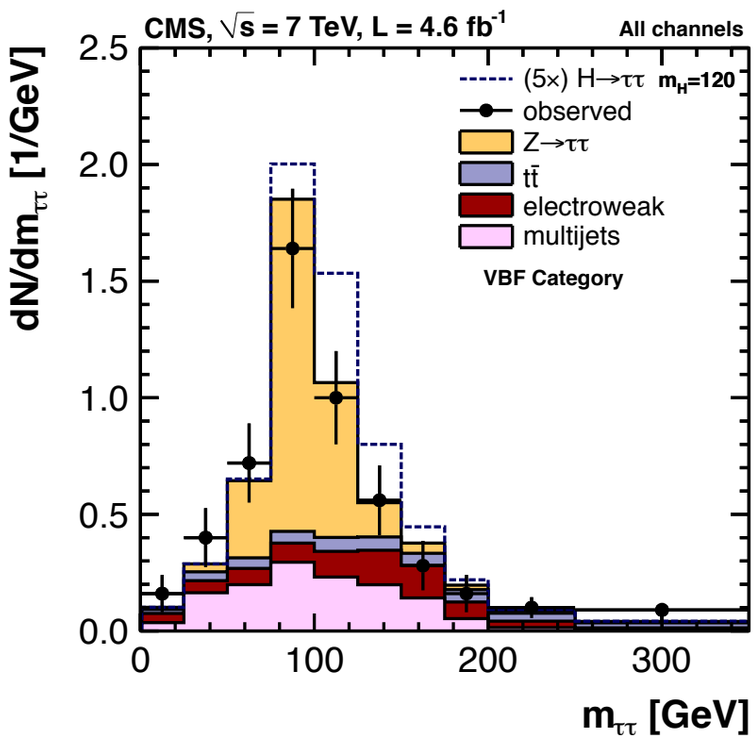


- **most sensitive channel in the range ~125 - 200 GeV**
- experimental signature: two high p_T isolated leptons + MET
  - no narrow mass peak
- two parallel analyses
  - cut based in the 0,1,2 jet bins
  - multivariate in the 0,1 jet bins
- data-driven estimates of the main backgrounds
- **no significant excess found**

$H \to \tau\tau$

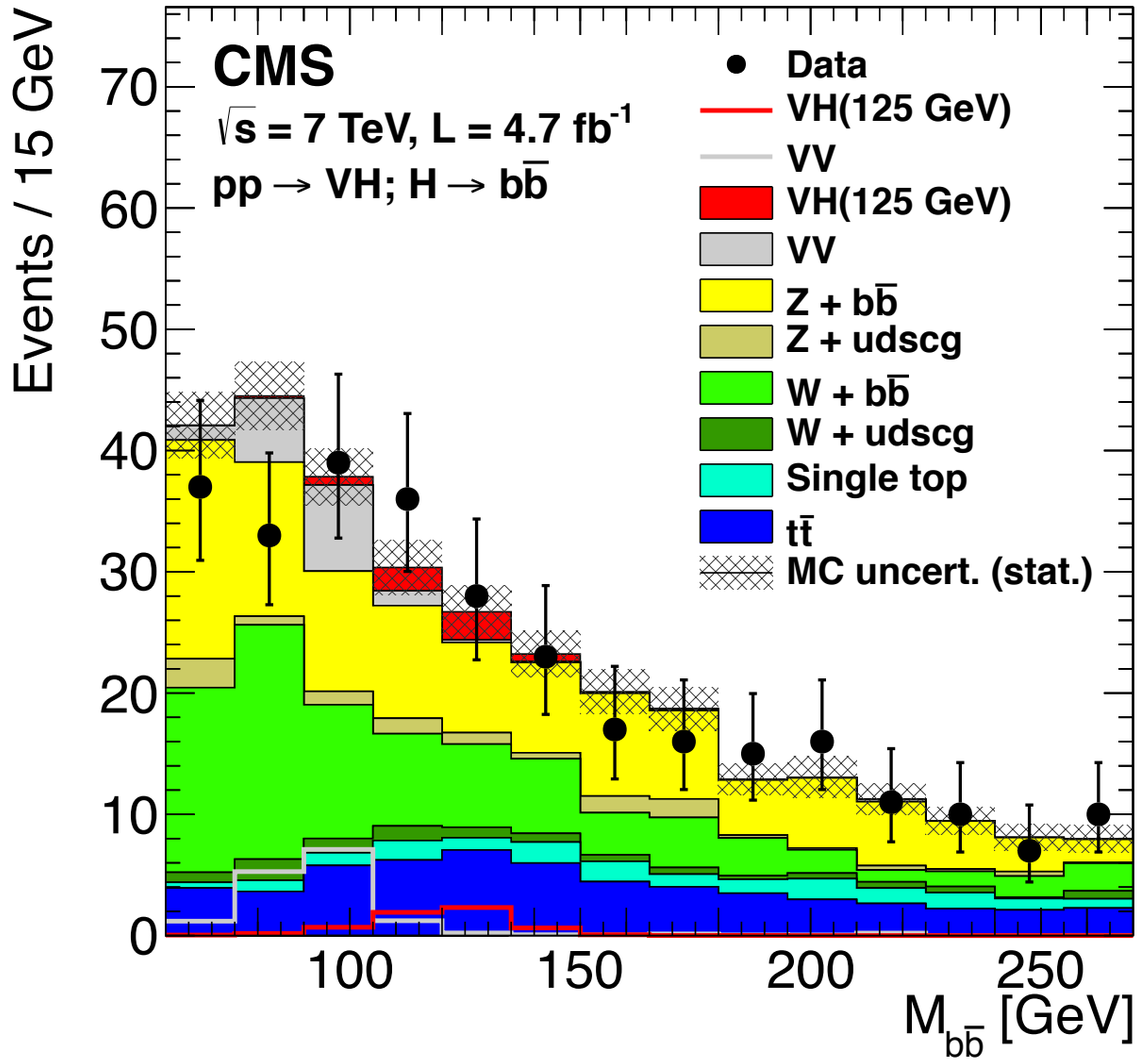


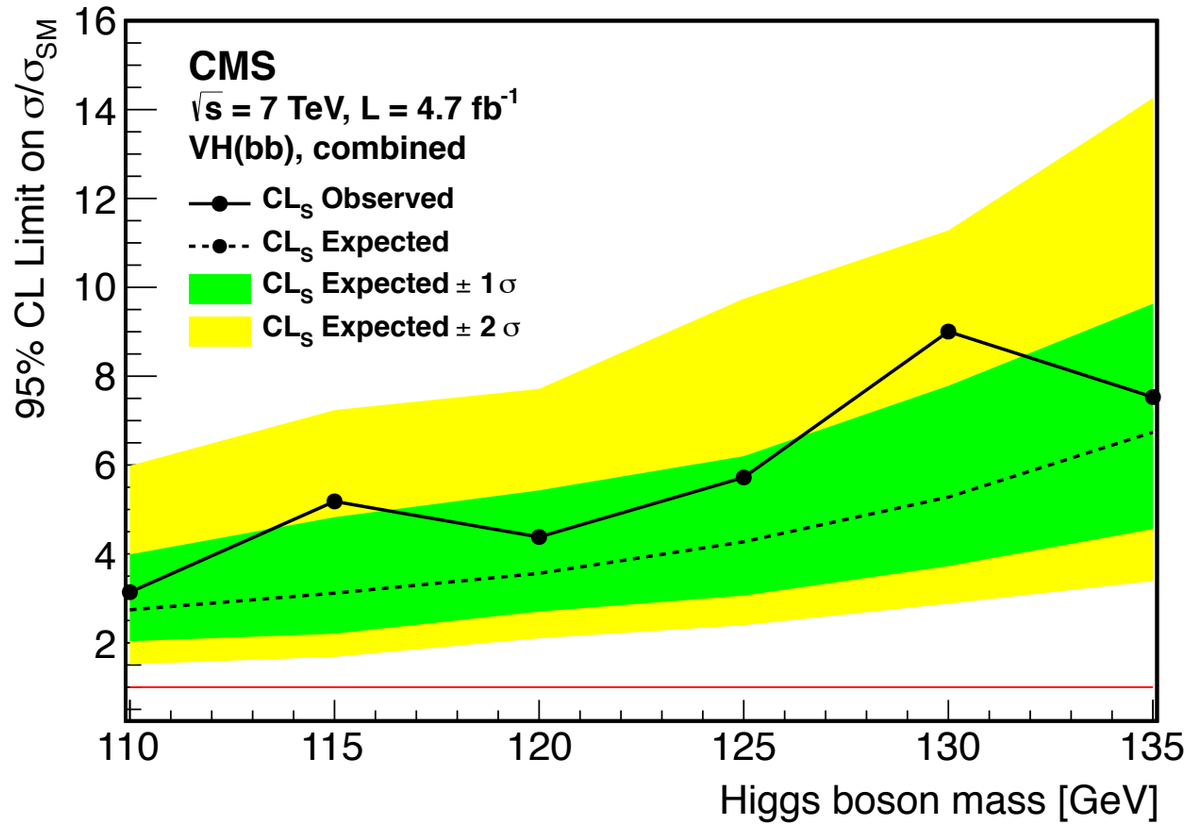




- sensitivity at low masses
- no narrow mass peak
  - 20% resolution
  - irreducible background: Z
- 3 sub-channels
  - gg fusion with 0 or 1 jets
  - VBF production with 2 forward jets
  - boosted (one high p_T jet)
- sensitivity: 3-5 σ_{SM} in the range 110-150 GeV for the 2011 dataset

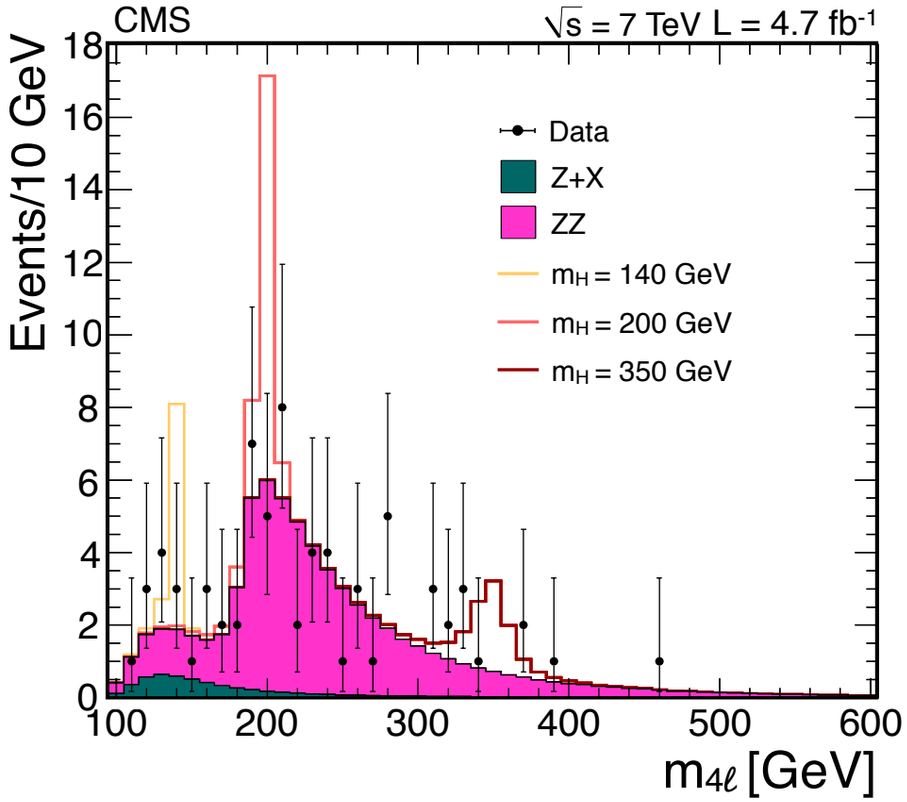
VH→Vbb

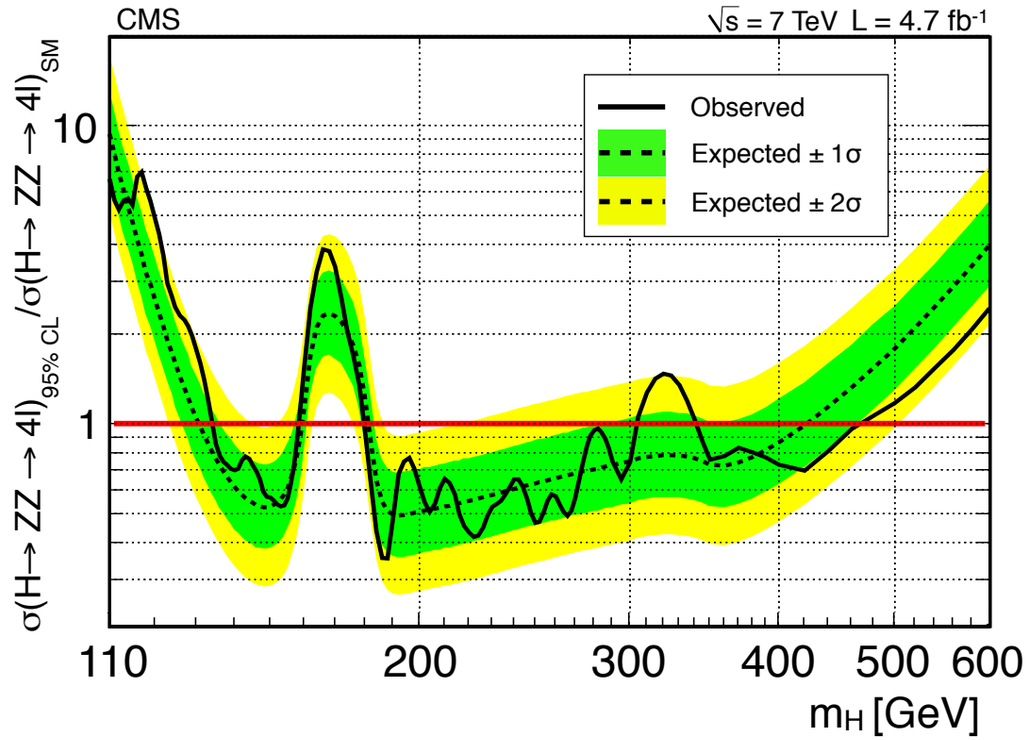




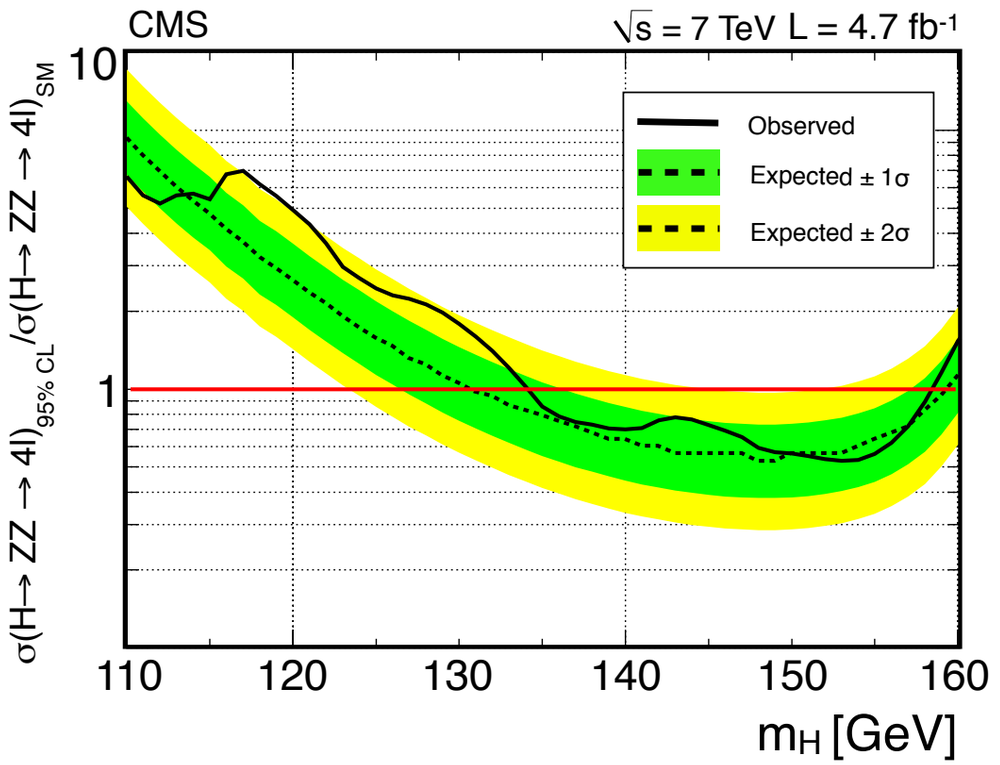
- Hbb decay has the largest BR but QCD background is huge
  - need additional tag: associated production of vector bosons decaying to leptons
- 10% mass resolution
- sensitivity: 3-5 σ_{SM} in the range 110-135 GeV for the 2011 dataset

H→ZZ→4l

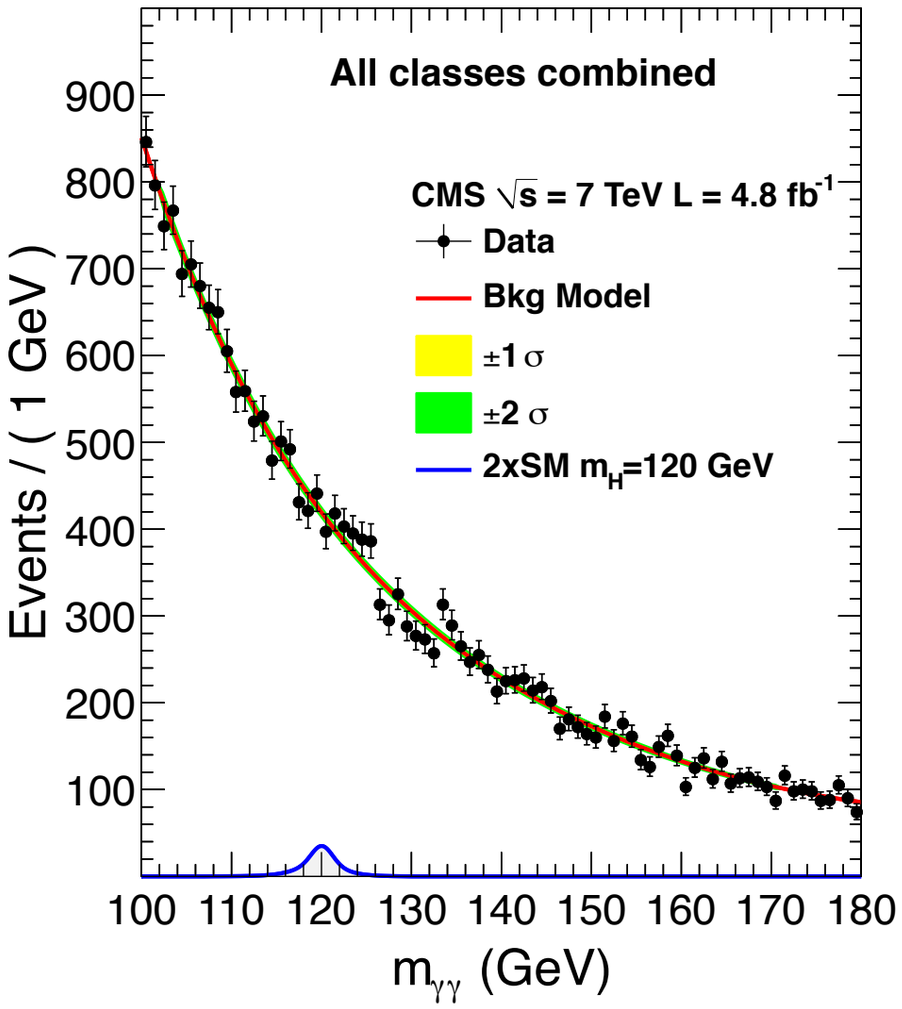


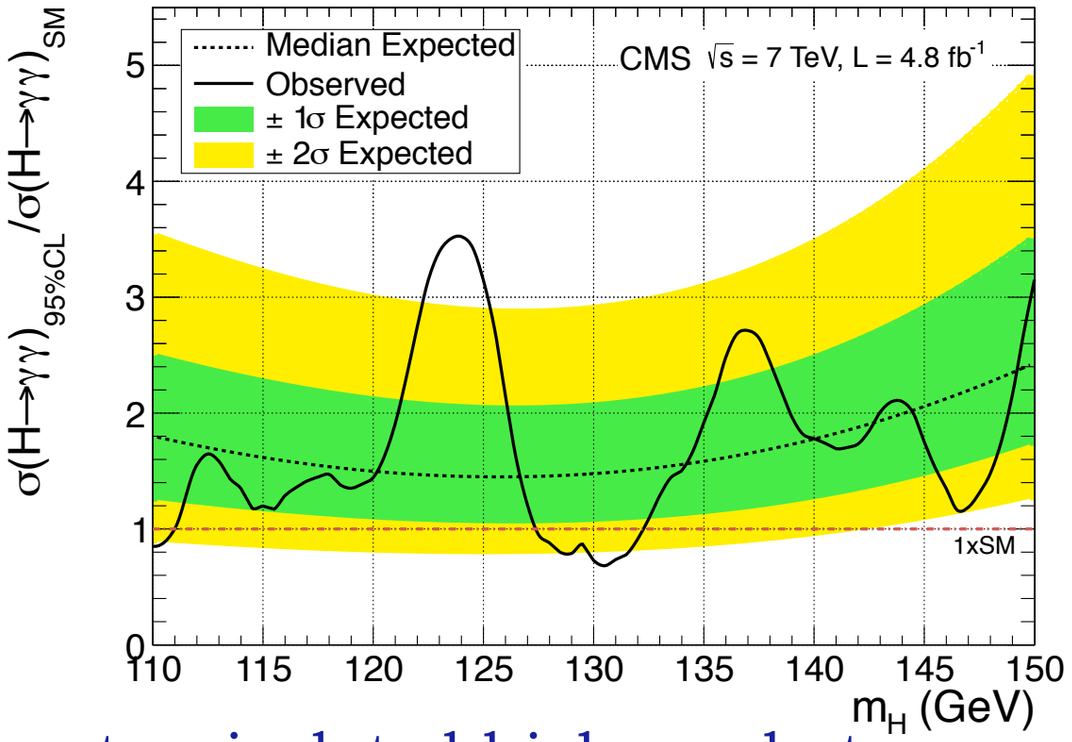


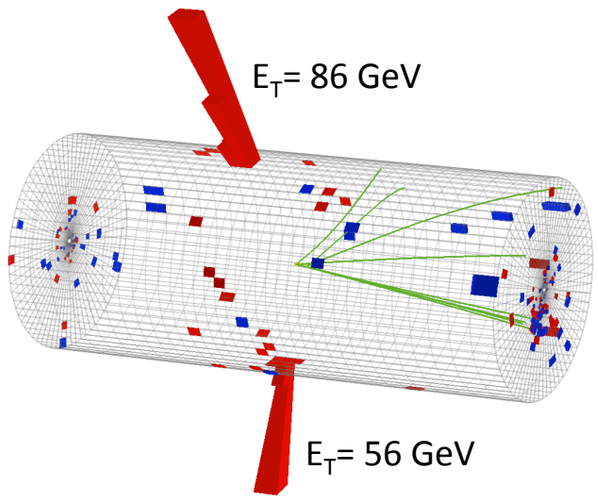
- experimental signature: two high-mass pairs of isolated leptons
  - very clean channel
  - narrow mass peak (1-2% resolution)
  - **critical to reconstruct low p_T leptons with high efficiency**
- **upper fluctuation observed at 119.5 GeV**
  - 2.5σ local significance
  - 1.0σ in the full mass range, 1.6σ in 100-160 GeV



$H \rightarrow \gamma\gamma$

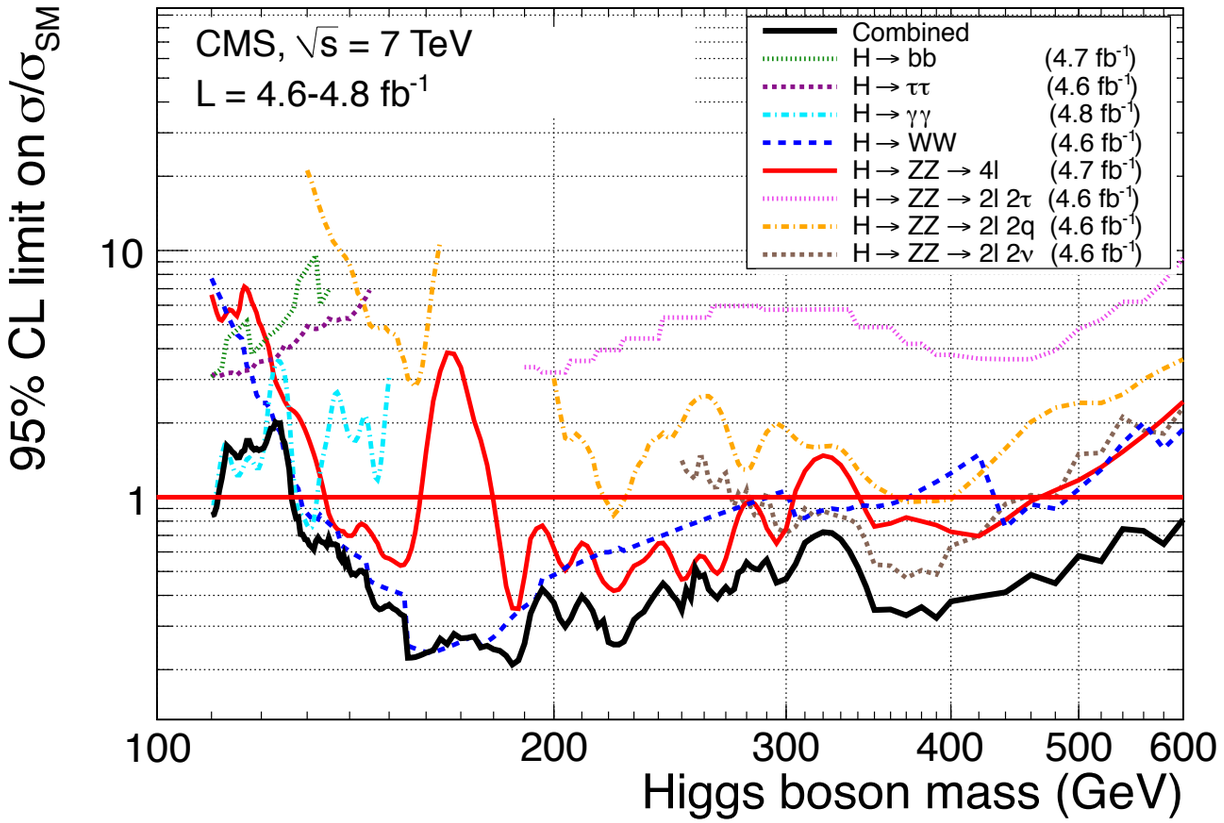


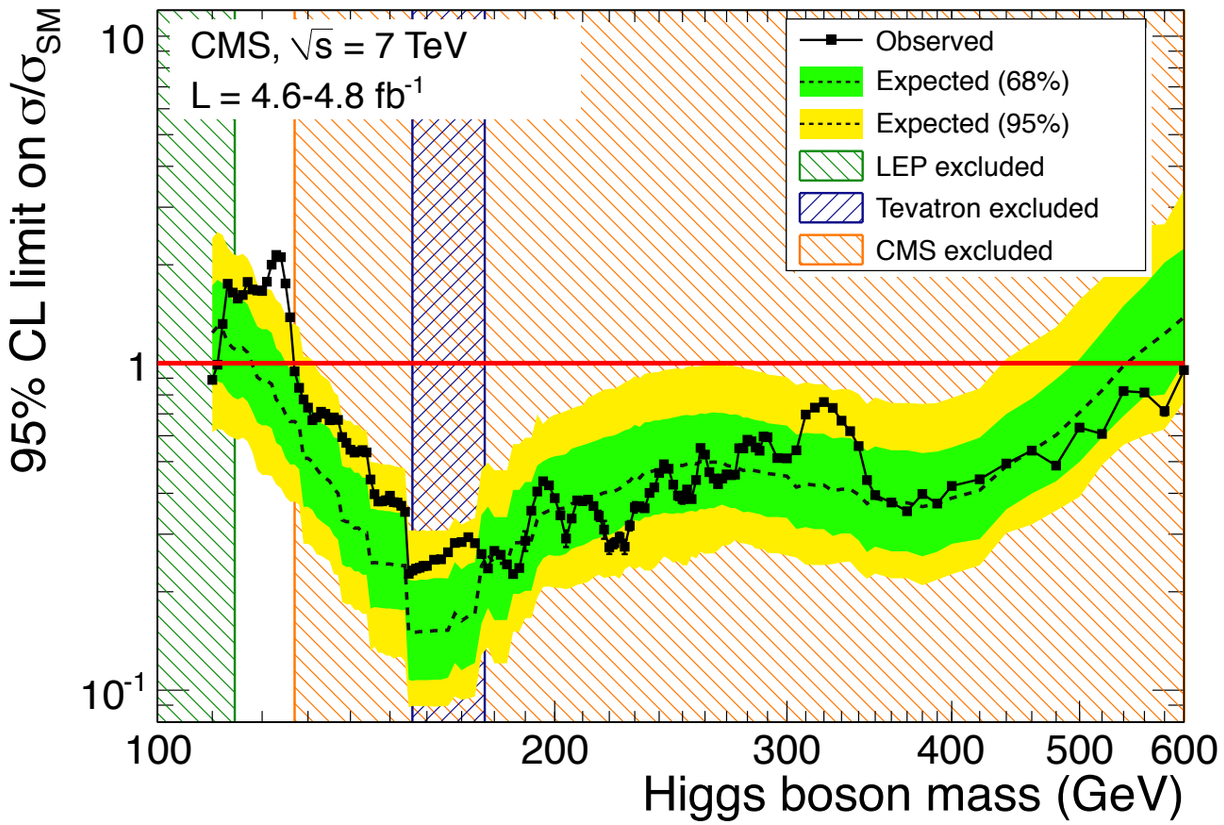




- signature: two isolated high p_T photons
- **excellent mass resolution: 1-2% (CMS ECAL designed for this channel !!!)**
  - narrow mass peak on top of large, smoothly falling, QCD background
- analysis strategy
  - cut based in categories (4 event classes + VBF)
  - MVA (improvement equivalent to 50% more luminosity)
- **largest upper fluctuation at ~125 GeV (2.9σ local significance, 1.6σ global significance)**

Combined Higgs Result (I)

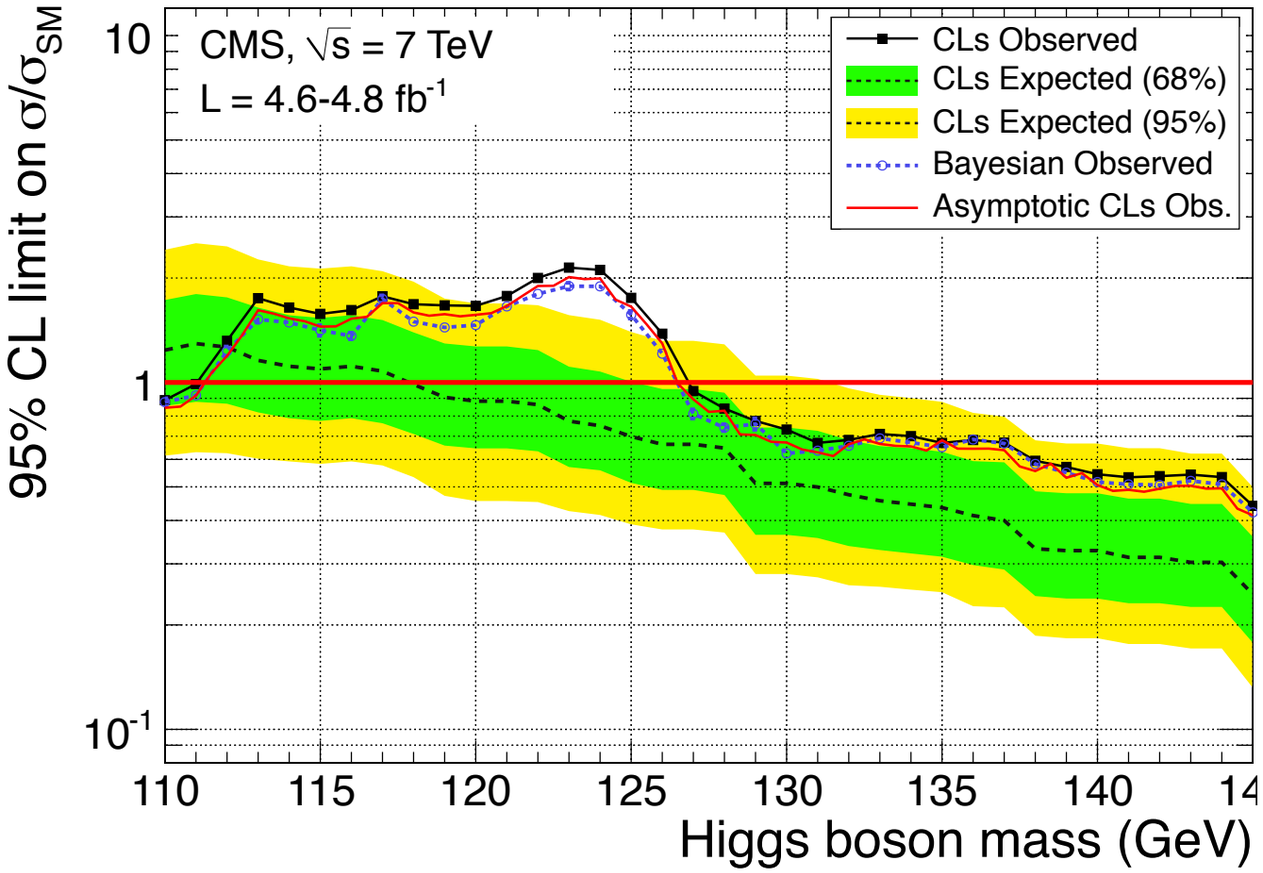


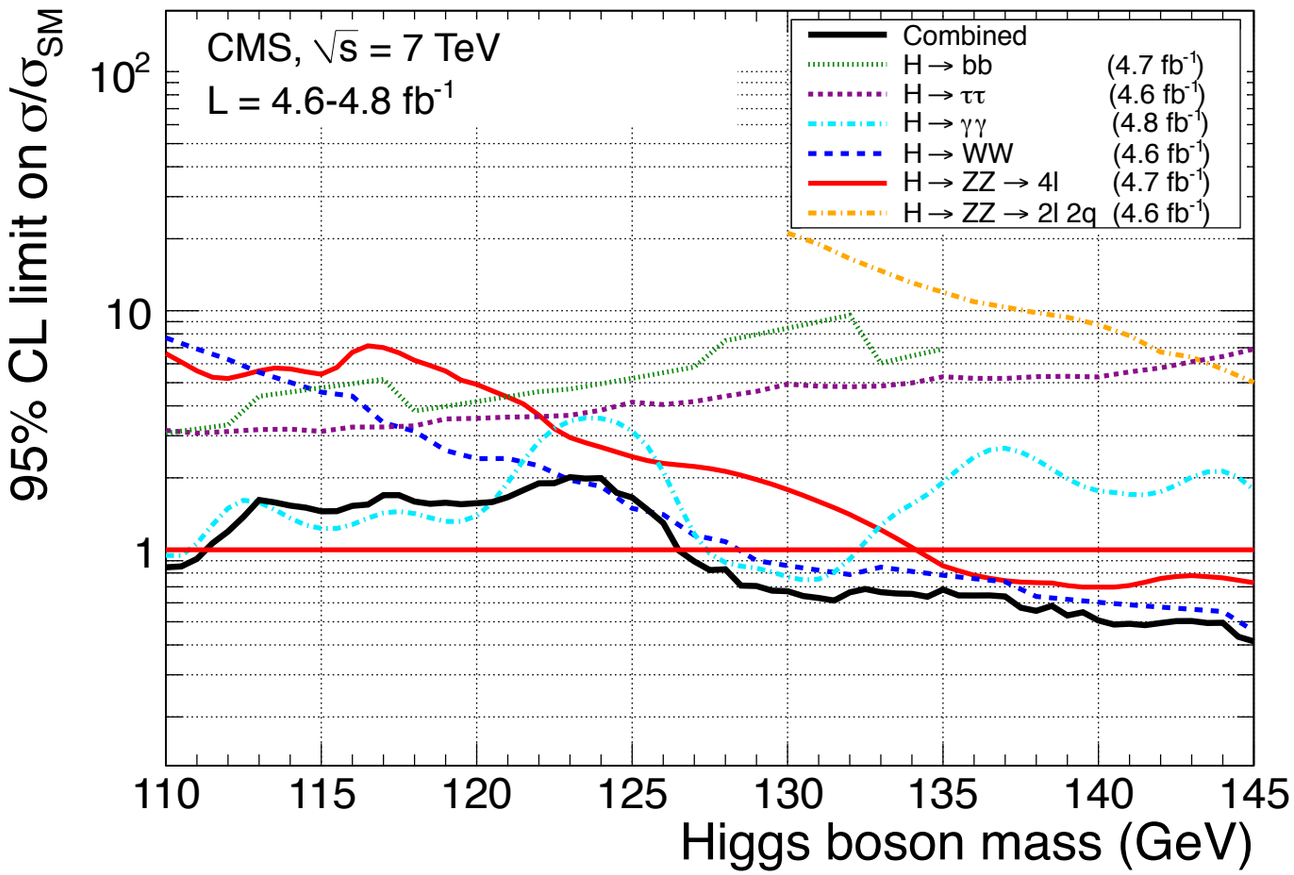


- expected 95% CL exclusion: 114.5 - 543 GeV
- **observed 95%(99%) CL exclusion: 127.5 - 600 GeV (129 - 525 GeV)**
  - upper fluctuation at low mass
- **allowed mass range: 114.5 - 127.5 GeV**

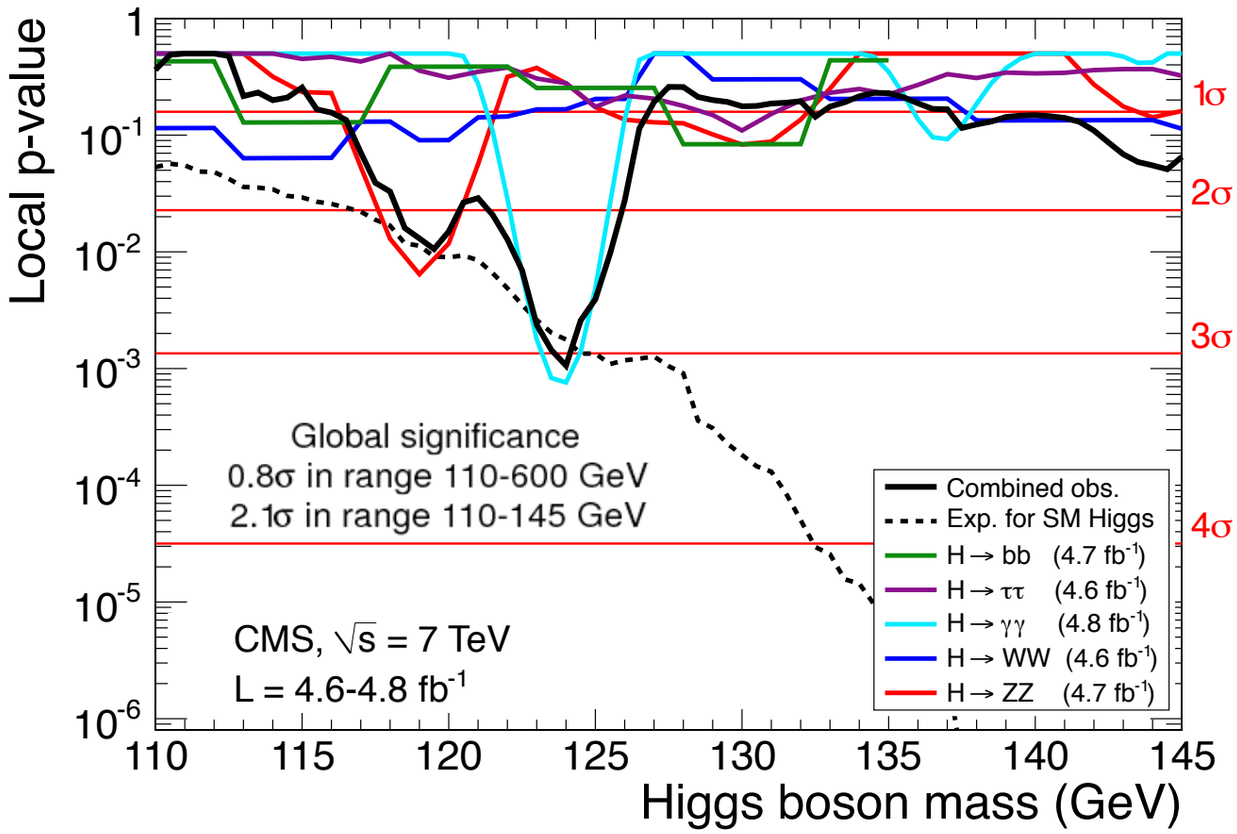
Combined Higgs Result (II)

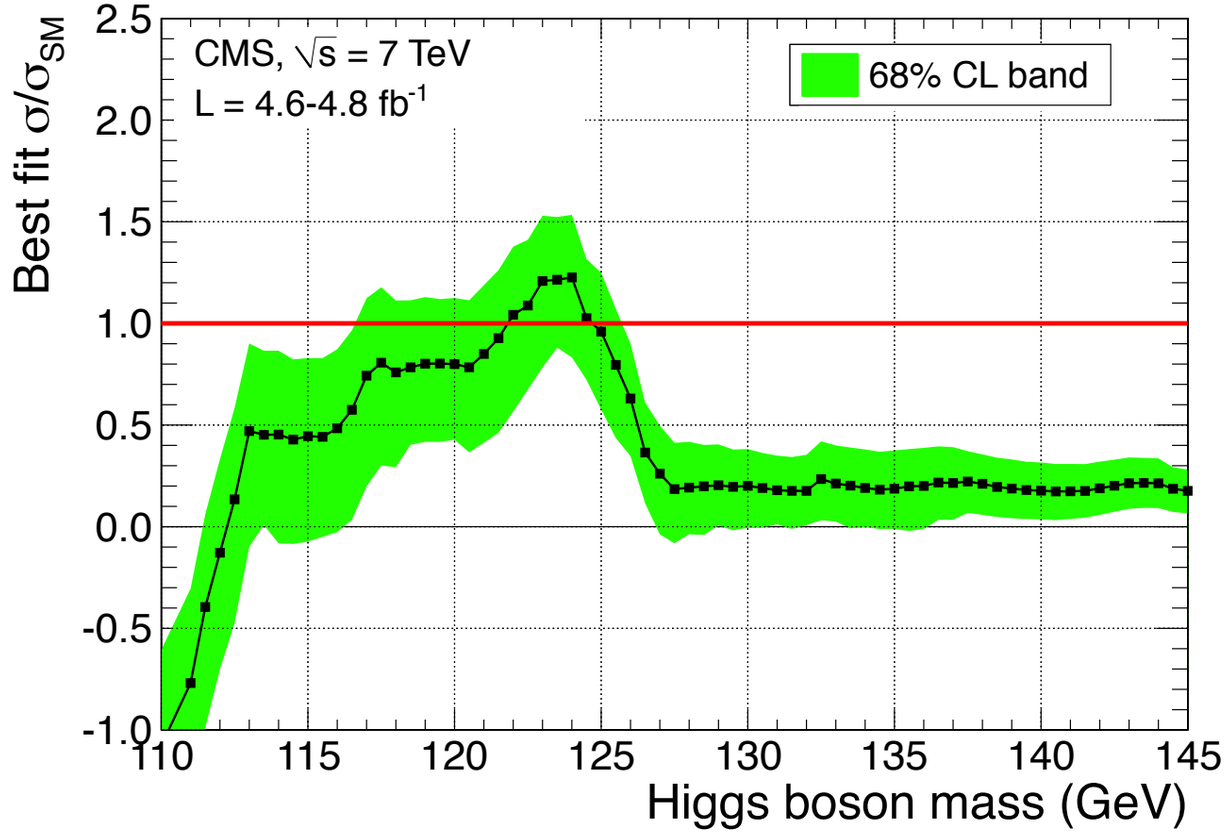
zoom at low mass



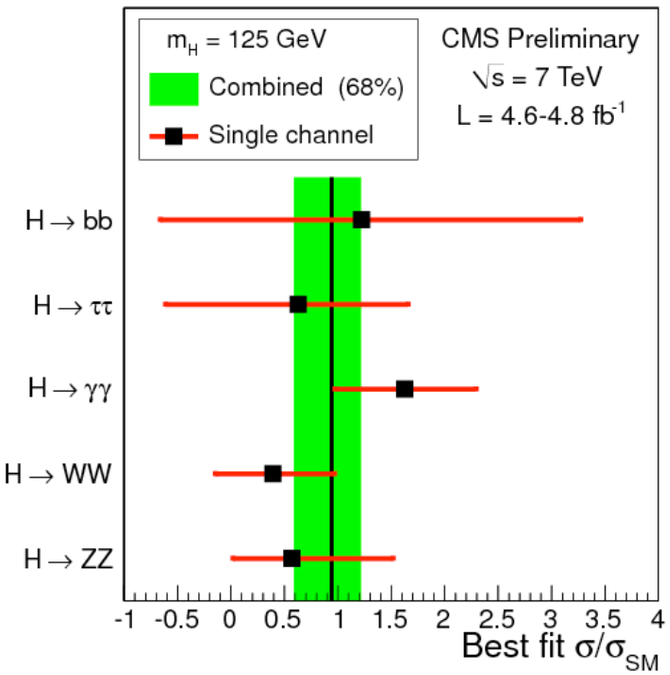


Combined Higgs Result (III)

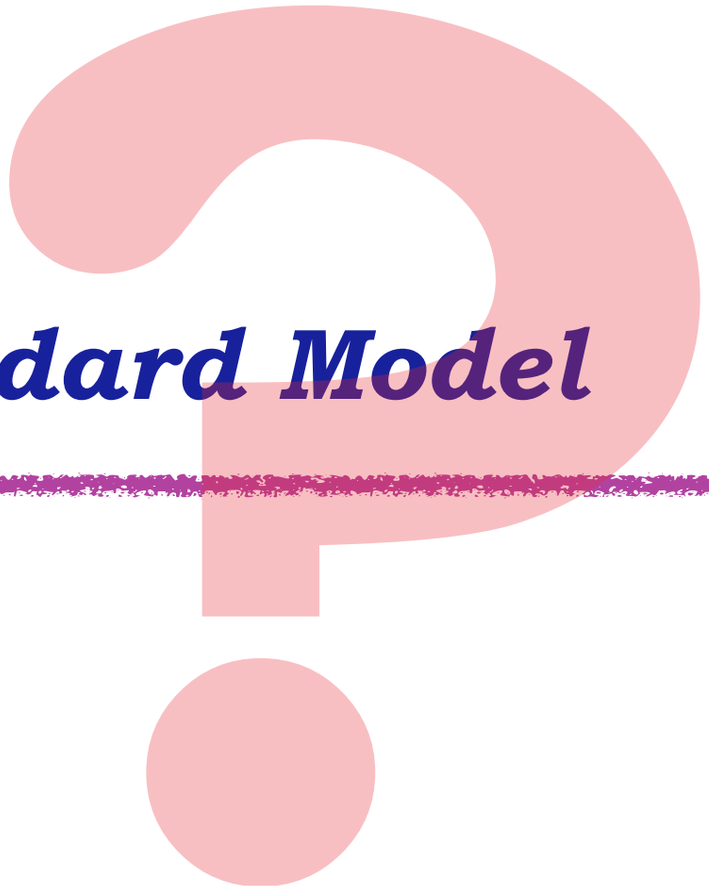




- local p-value: significance of fluctuations
  - global significance depends on the mass range
- **low-mass excess in data is consistent with signal expectations**
  - both in the local p-value and the signal best fit
- **more data are needed to investigate this excess**

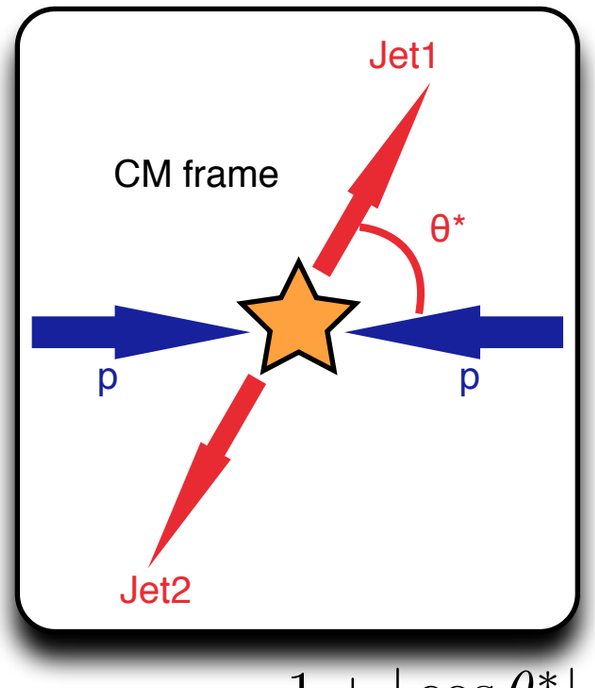


Beyond the Standard Model

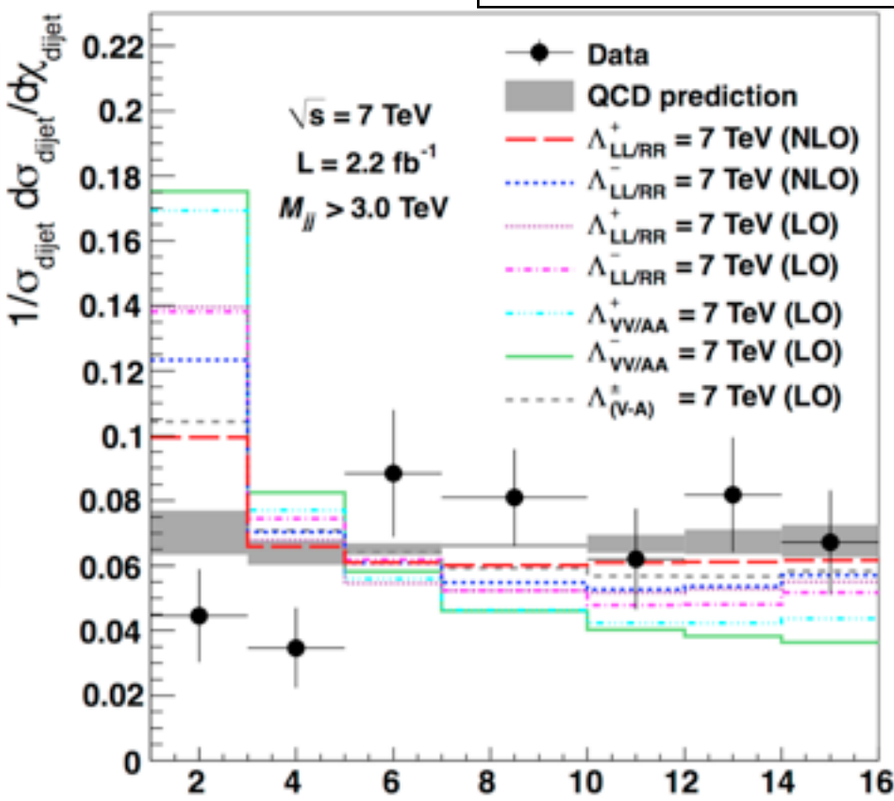


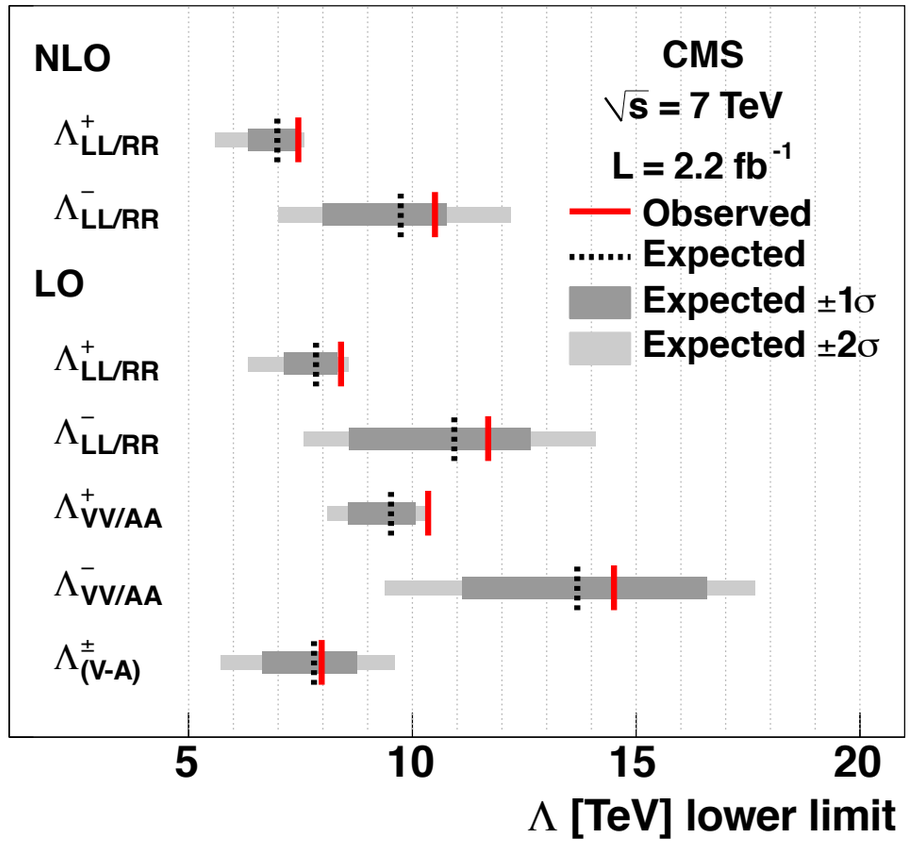
Quark Compositeness

$$L_{qq} = \frac{2\pi}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)\right]$$



$$\chi_{\text{dijet}} = \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

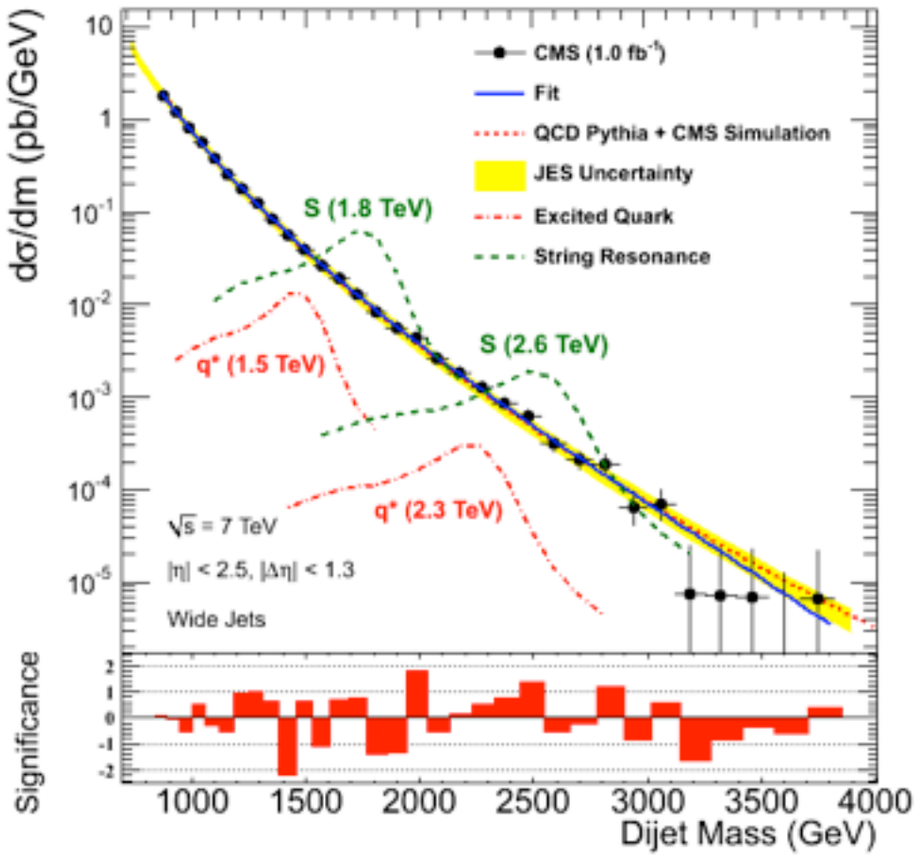


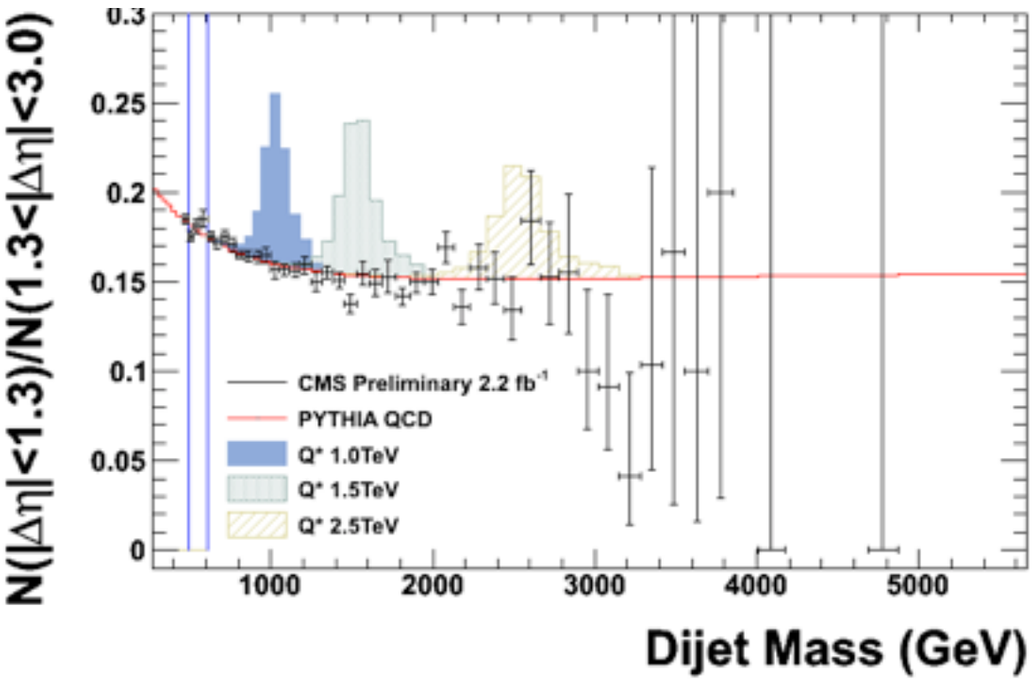


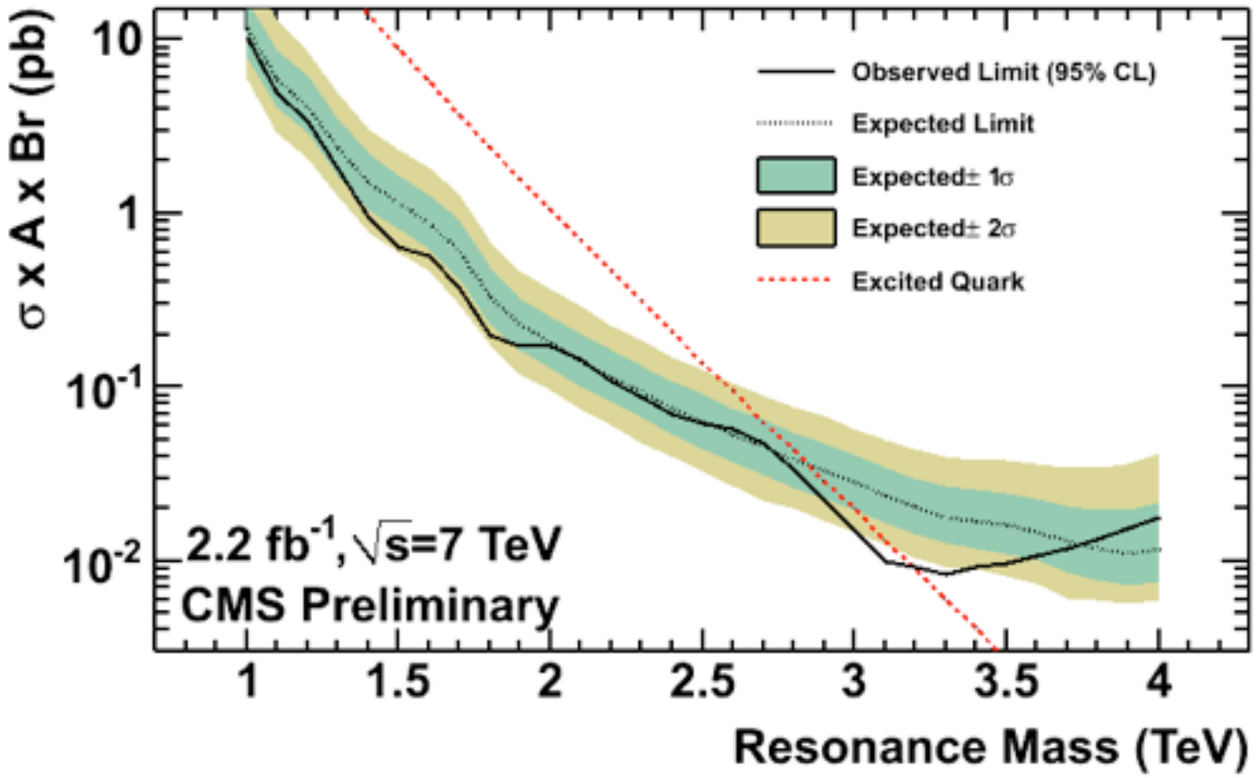
- quark substructure at scale Λ will appear as an effective 4-fermion interaction
  - enhancement of dijet production at large scattering angles (low χ)
- data compatible with NLO theory predictions
  - test of QCD dynamics
- **excluded scale Λ ranging from 7.5 to 14.5 TeV**
  - depending on the chiral structure of the effective lagrangian

$$\begin{aligned}
&\Lambda = \Lambda^\pm_{LL} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,0,0),\\
&\Lambda = \Lambda^\pm_{RR} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (0,\pm1,0),\\
&\Lambda = \Lambda^\pm_{VV} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,\pm1,\pm1),\\
&\Lambda = \Lambda^\pm_{AA} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (\pm1,\pm1,\mp1),\\
&\Lambda = \Lambda^\pm_{(V-A)} \text{ for } (\eta_{LL},\eta_{RR},\eta_{RL}) = (0,0,\pm1).
\end{aligned}$$

DiJet Resonances

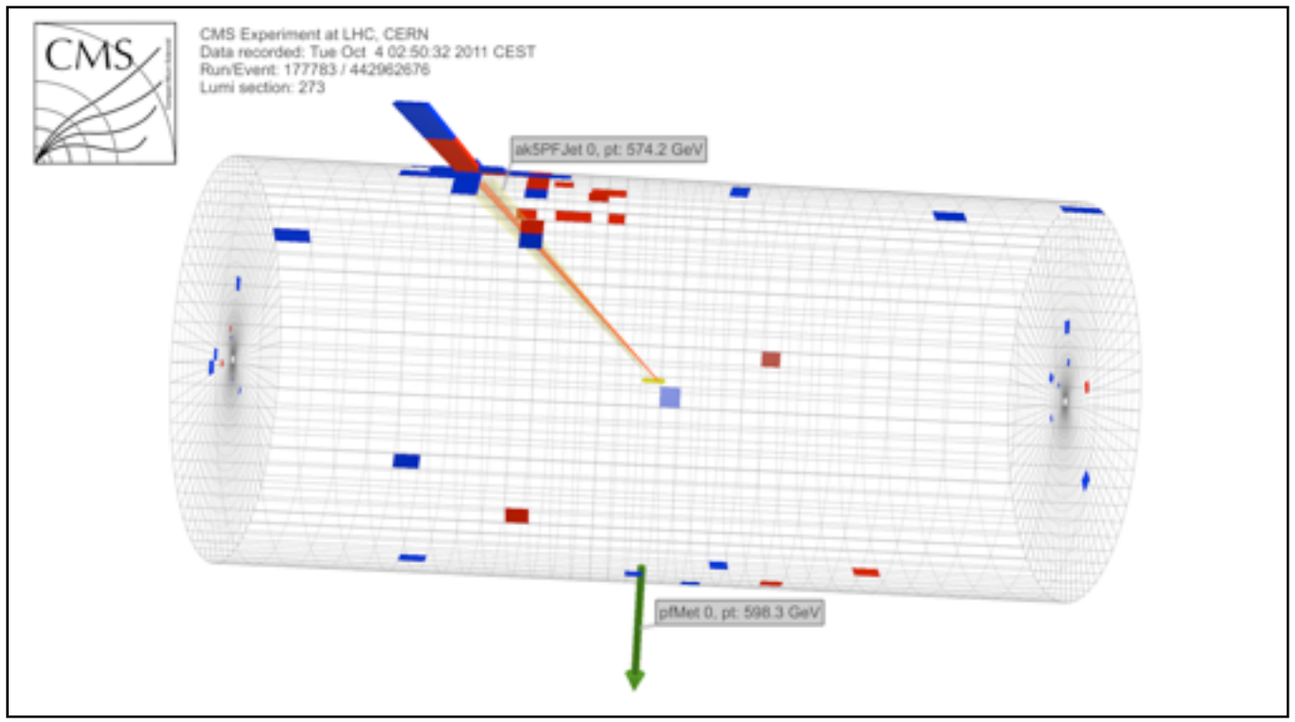


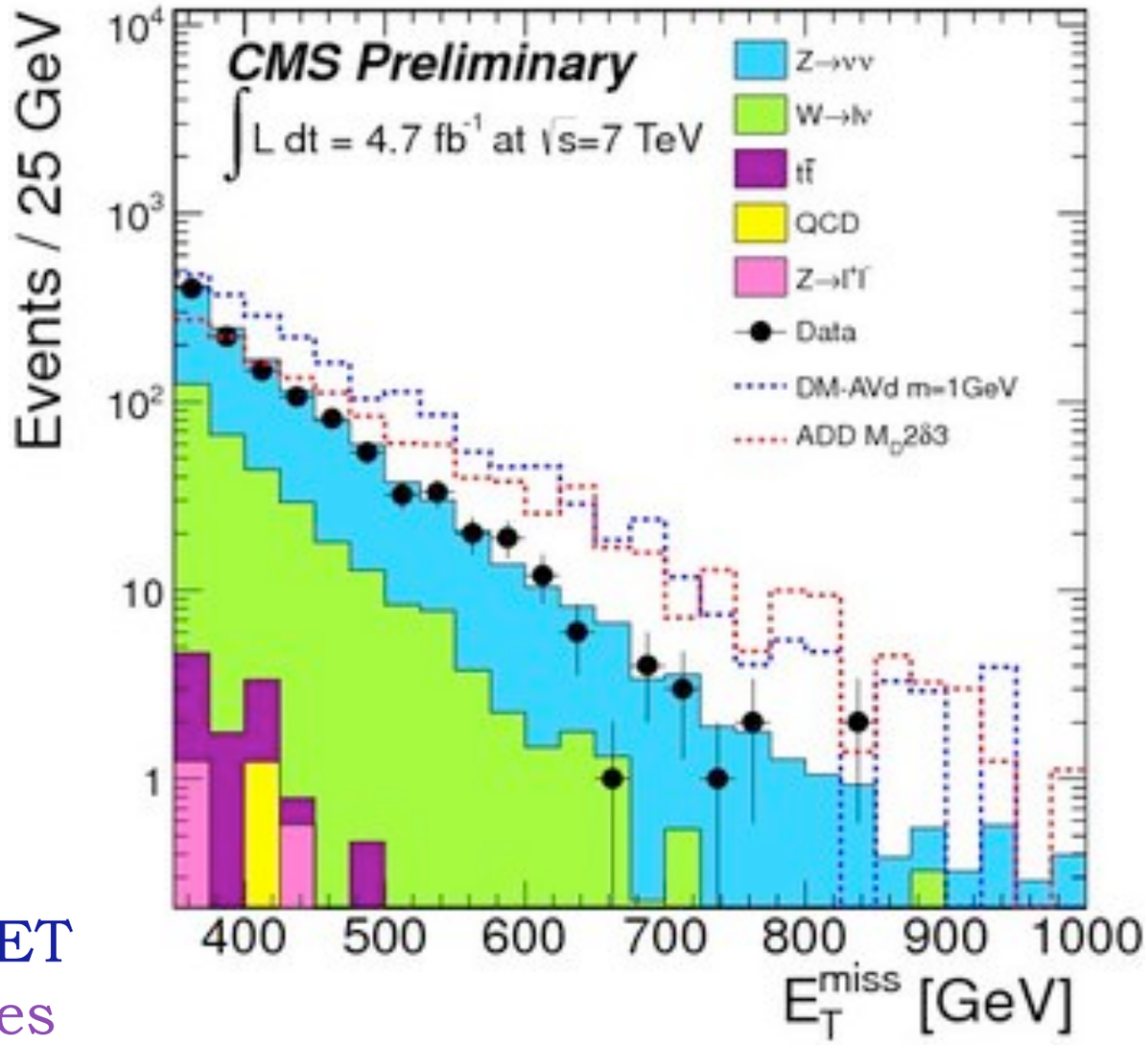




- search resonances decaying to dijets
  - exploit the mass spectrum
  - exploit the dijet angular ratio
- generic search for quark-quark, quark-gluon, gluon-gluon resonances
- limits (with 1 fb^{-1} and 2.2 fb^{-1})
  - excited quarks: 3.2 TeV
  - string resonances: 4 TeV
  - axigluon/colorons: 2.47 TeV
  - W': 1.51 TeV

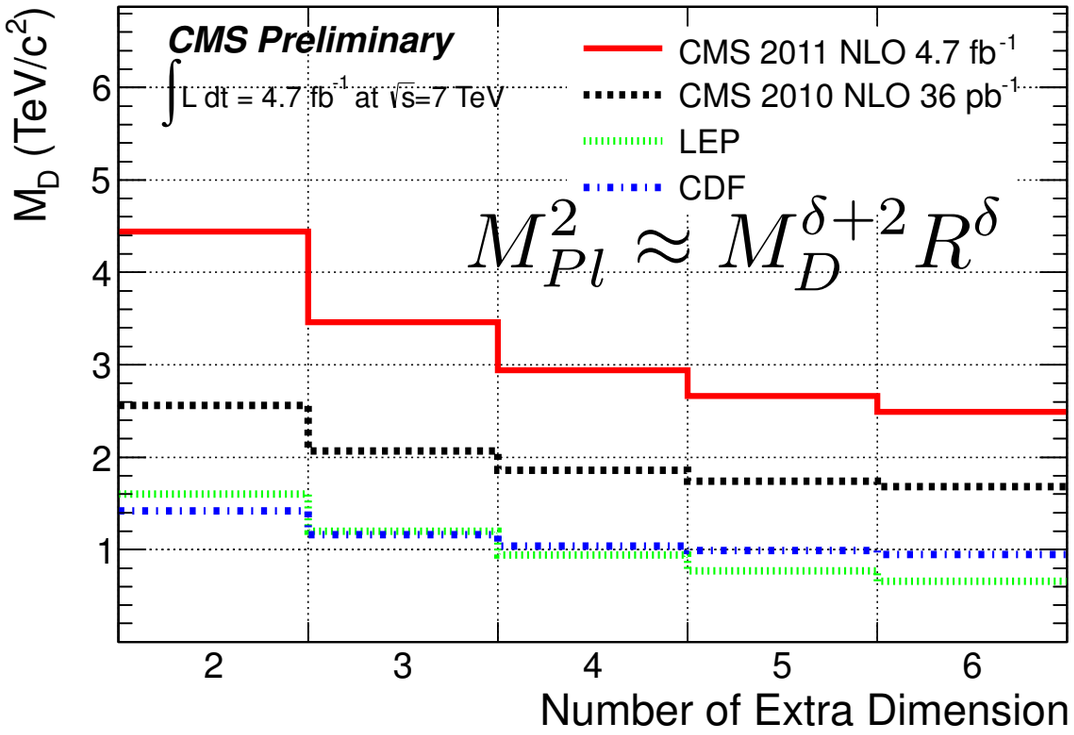
MonoJets (I)

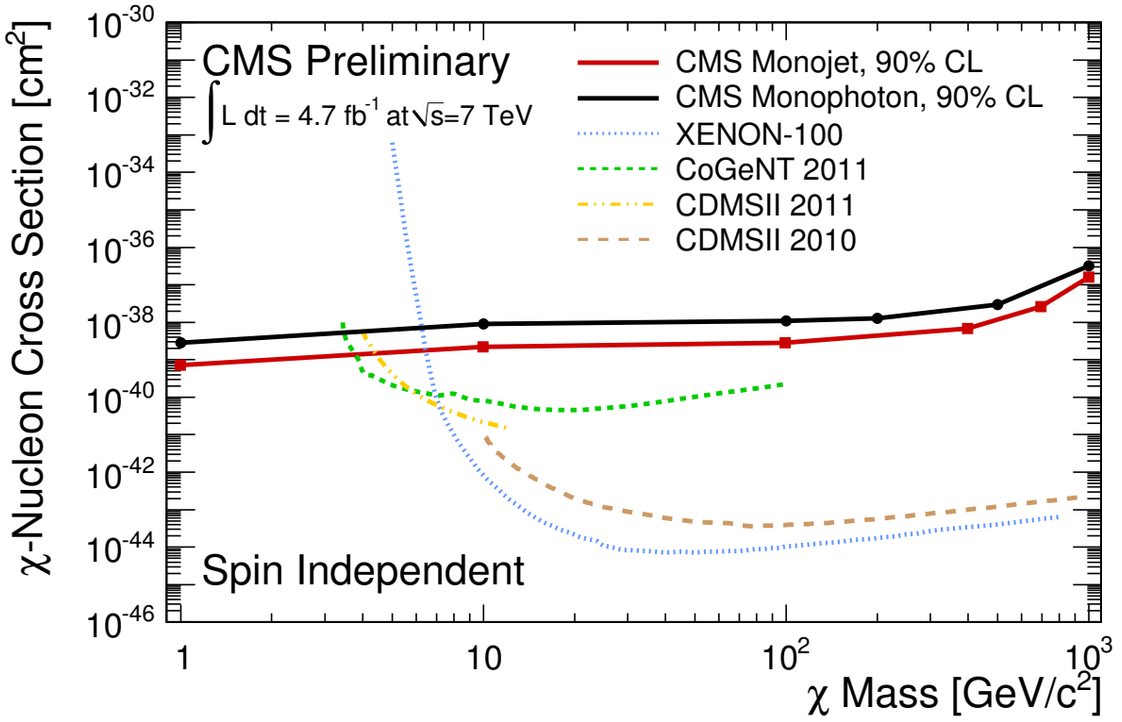




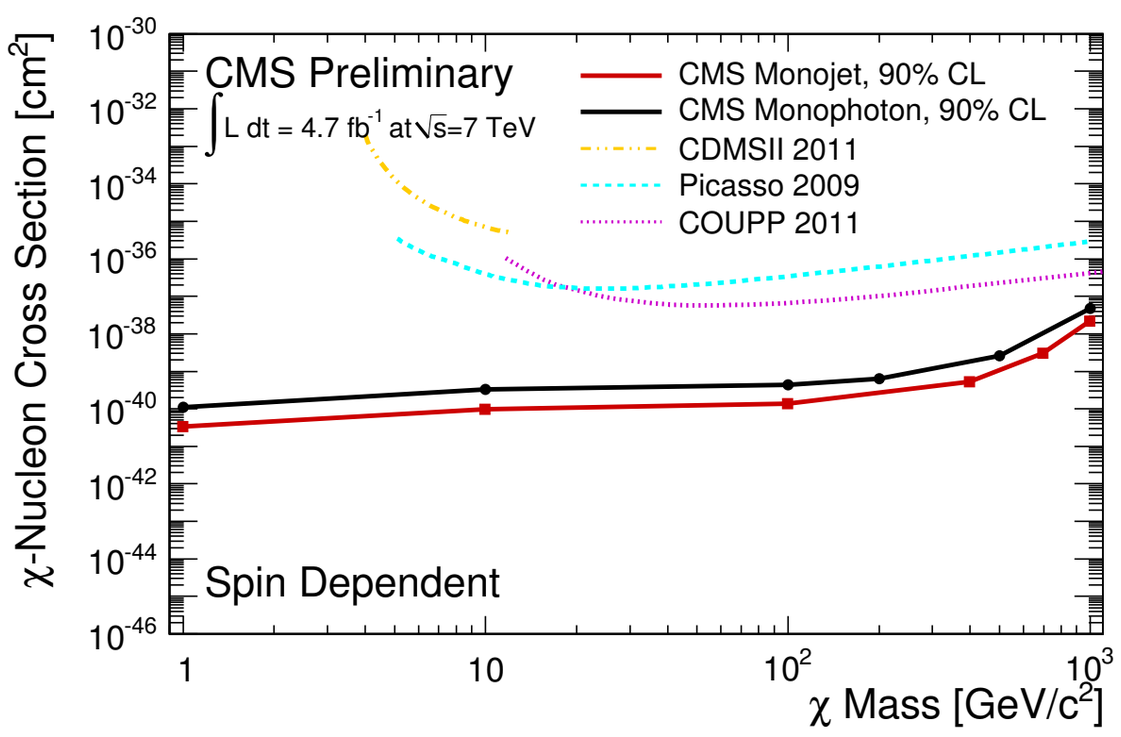
- search for **dark matter** and **large extra dimensions**
- signature: one energetic jet and large MET
  - pair production of dark matter particles (MET) with initial/final state radiation (jet)
  - associated production of a graviton (MET) and a jet
- dominant backgrounds: Z/W+jet

MonoJets (II)

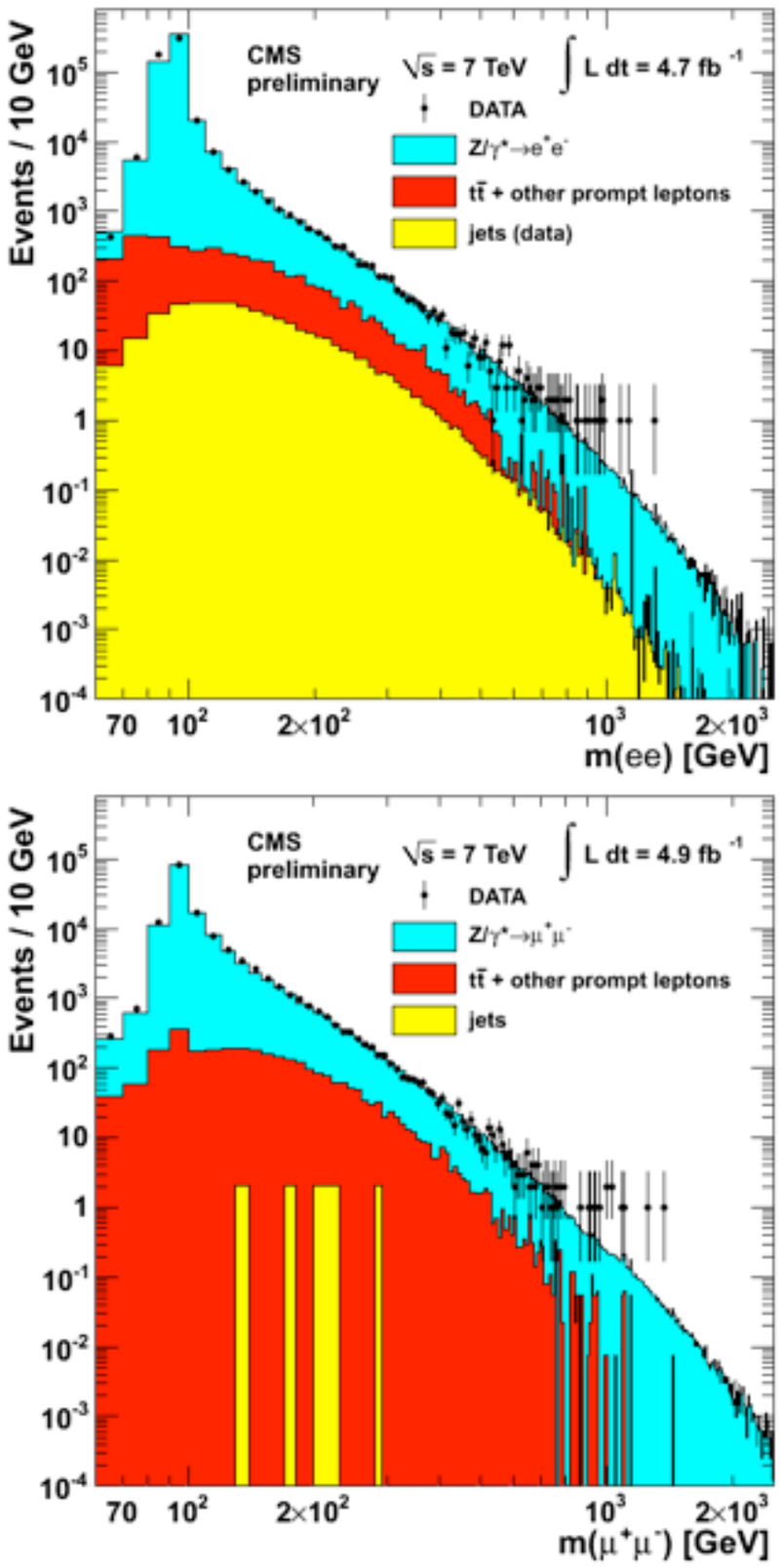


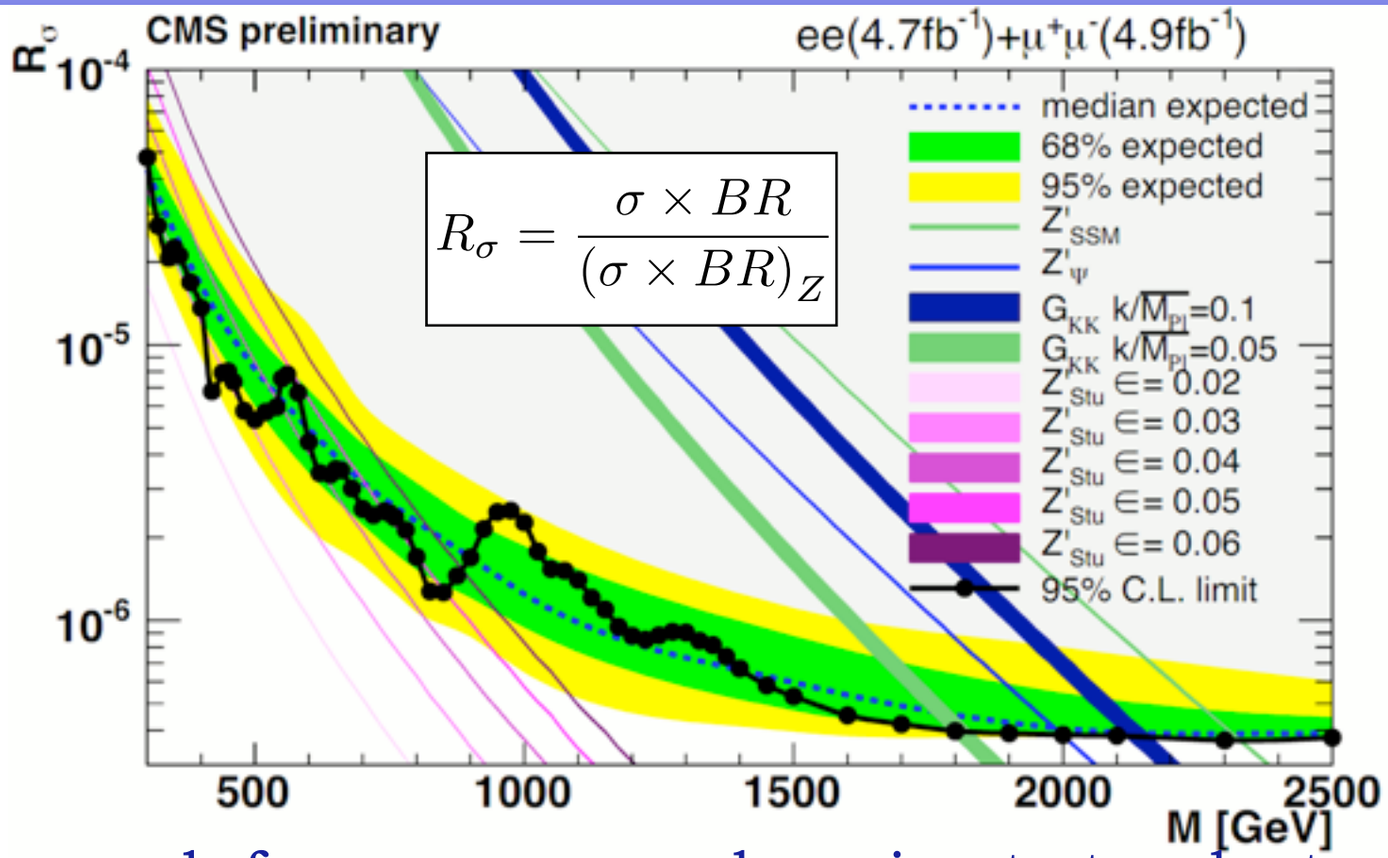


- constraints on **large extra dimensions** in the context of the **ADD model**
- constraints on **pair production of dark matter particles** (χ) in models with a heavy mediator
  - χ is assumed to be Dirac fermion
  - effective contact interactions with SM particles (scale Λ)
  - limits on Λ can be translated to limits on χ-nucleon cross sections



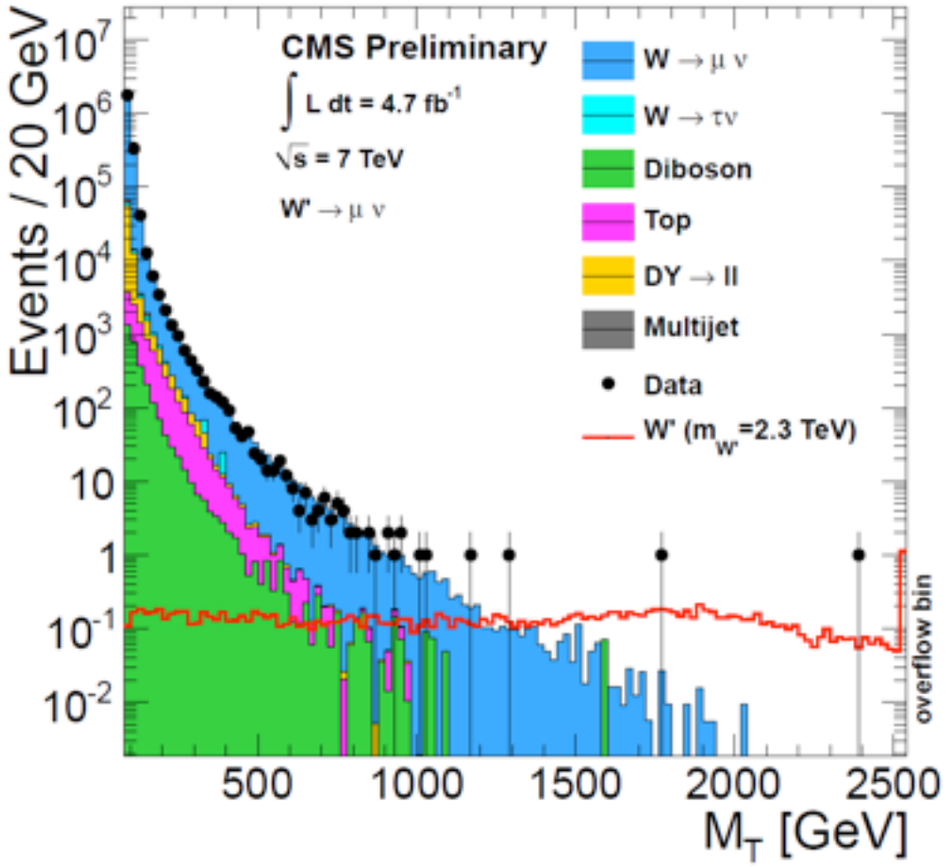
DiLepton Resonances

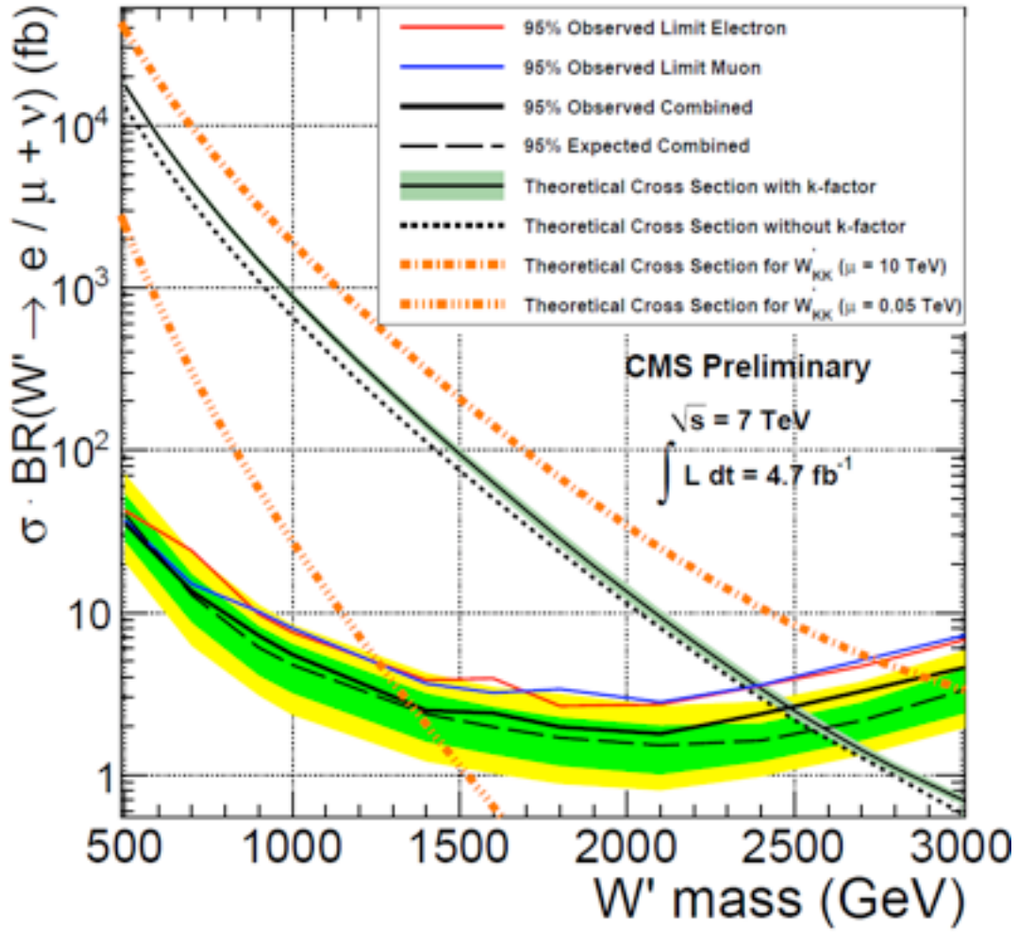




- search for resonances decaying to two leptons (Z', G_{KK})
- lepton selection
  - $p_T(e)$ > 35 (40) GeV in barrel (endcap)
  - $p_T(\mu)$ > 45 GeV
- mass resolution
  - di-muons: 6.5%(12%) @ 1 TeV (2 TeV)
  - di-electrons: 1-2% above 500 GeV
- no excess found: limits on R_σ
  - **excluded Z'_{SSM} < 2.32 TeV**

Search for W'→lν



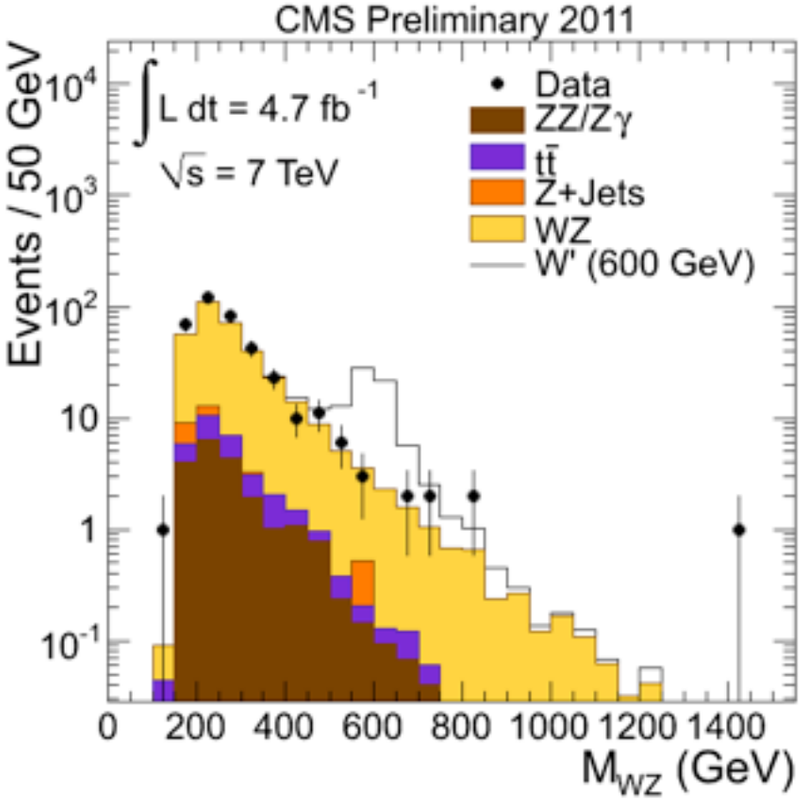


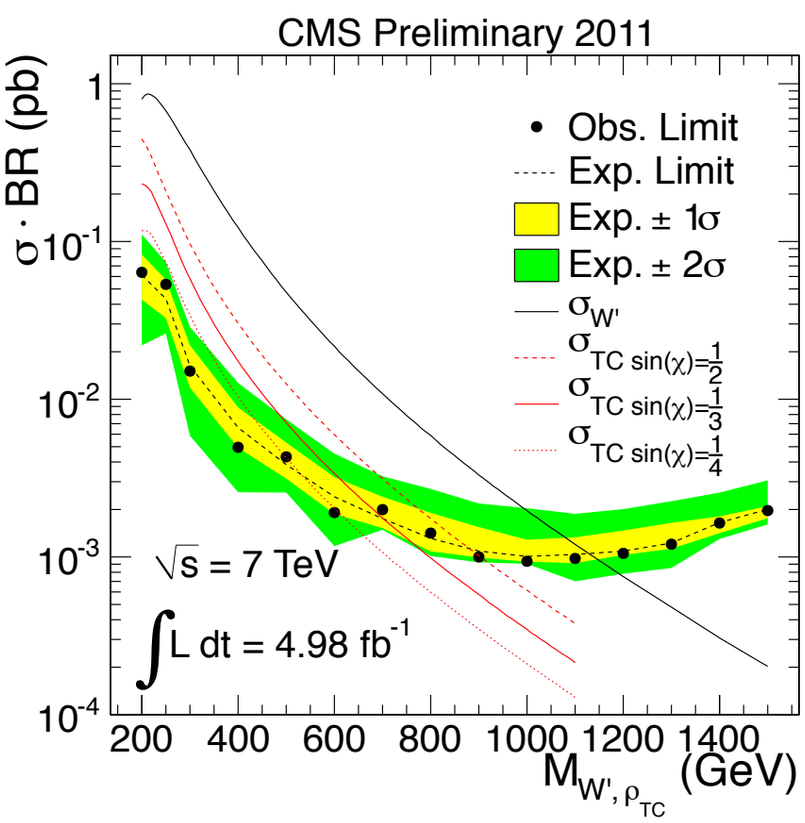
- W': a heavy analog of W boson
  - in SSM (sequential standard model) W' has similar couplings to W
- experimental signature:
  - one high p_T lepton
  - large MET (due to the escaping neutrino)
  - search conducted on the transverse mass variable

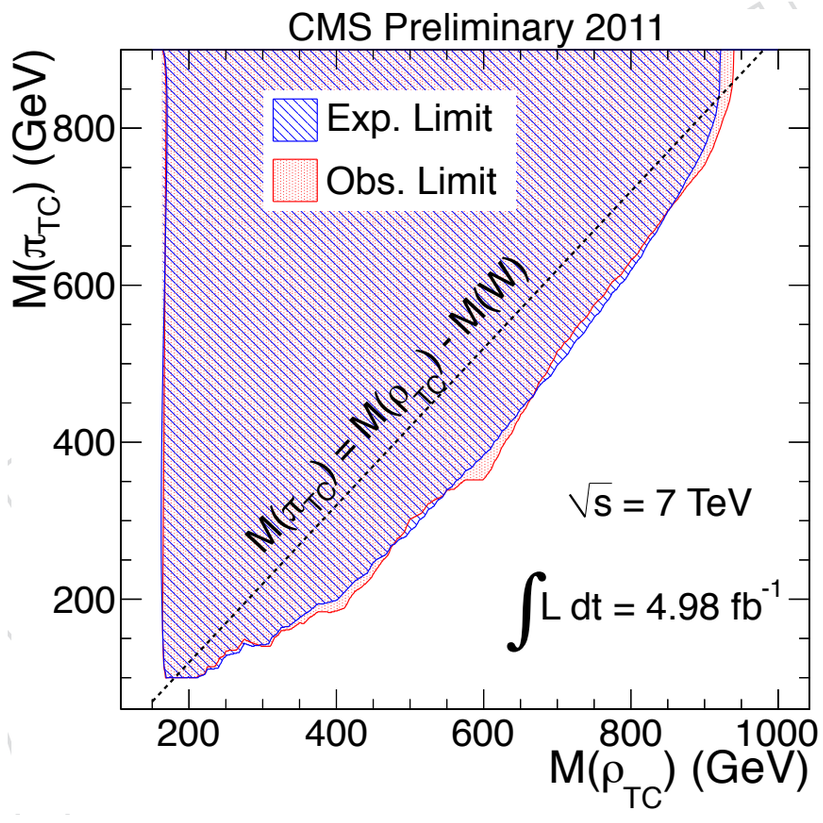
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

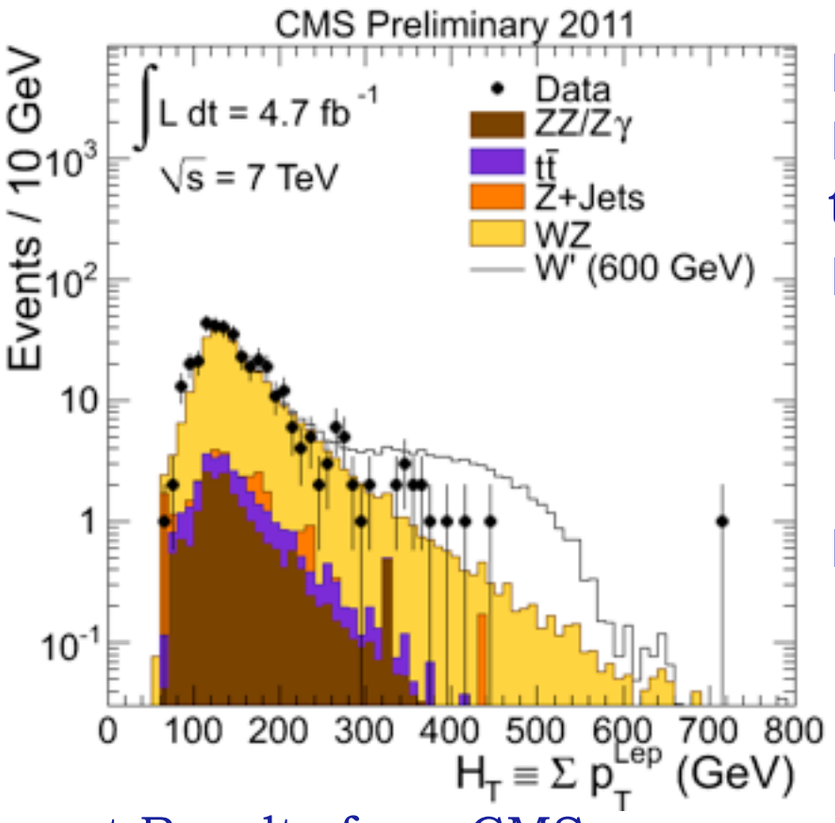
- no excess found. Excluded (SSM):
  - **W'_R M < 2.5 TeV**
  - **W'_L M < 2.63 (2.43) TeV** with constructive (destructive) interference to SM W

Search for W'→WZ



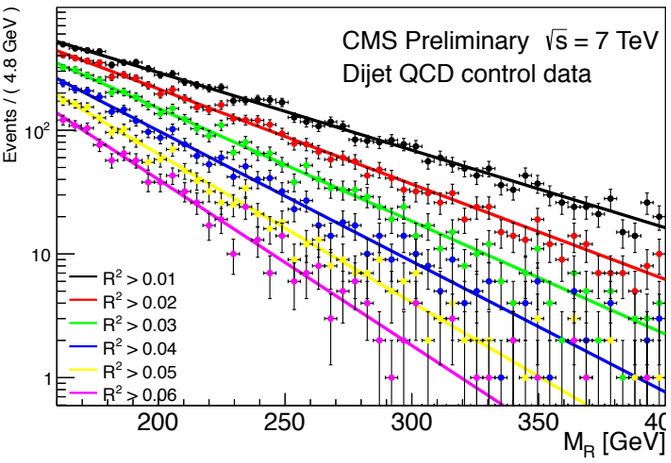


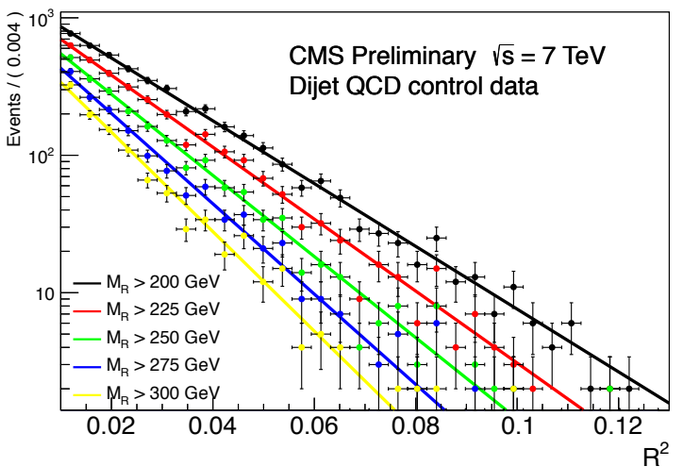


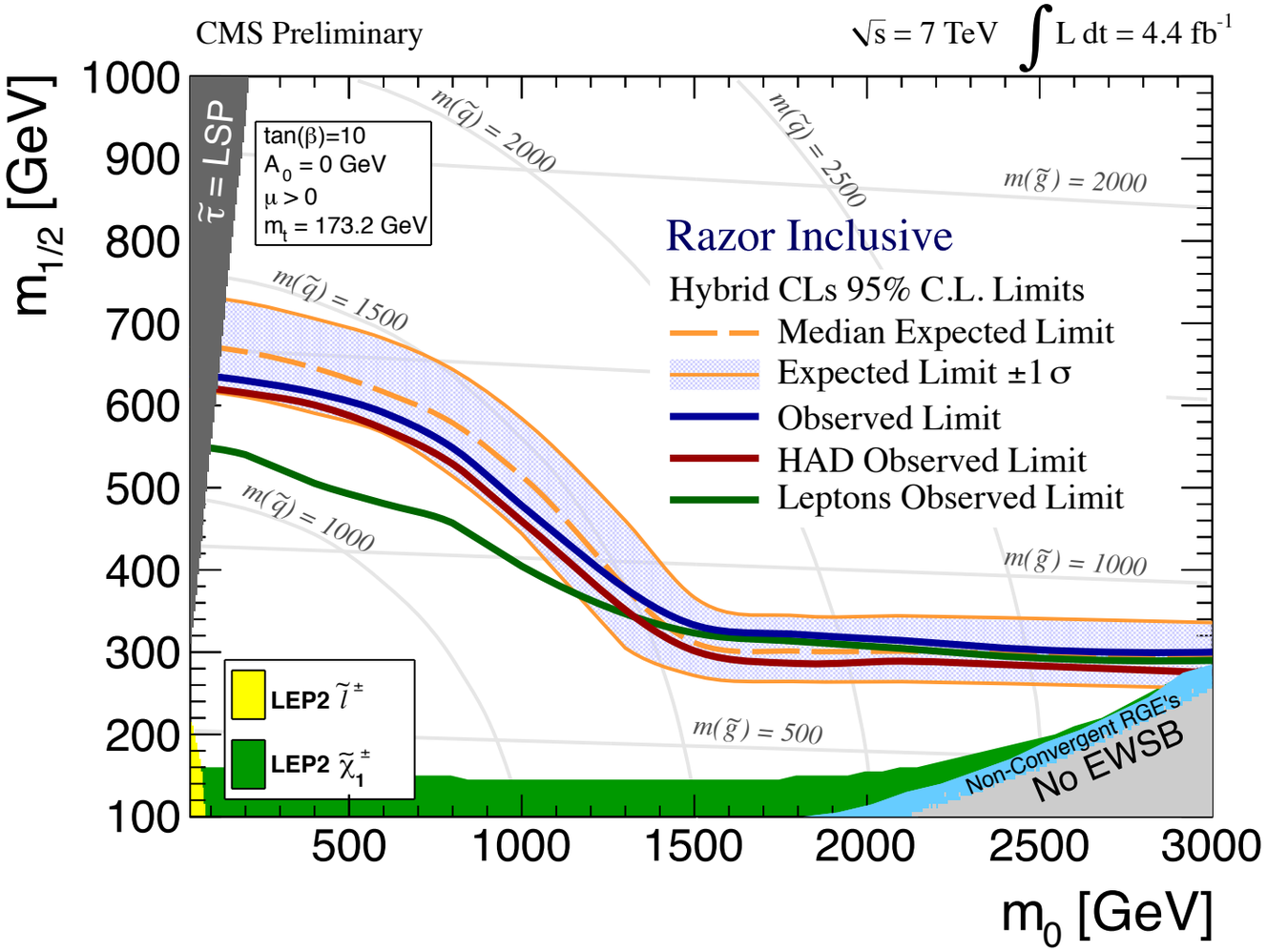


- fermiophobic W' with enhanced coupling to W/Z
- generic search for particles decaying to WZ (e.g technicolor hadrons)
- experimental signature:
  - 3 high p_T leptons (2 opposite charge, same flavor, consistent with M_Z)
  - large MET (due to the escaping neutrino from W)
- no excess found
  - exclude SSM W' **M < 1.143 TeV**
  - exclude ϱ_{TC} of **167-687 (180-938) GeV** under different model assumptions

SUSY: Razor Framework







- novice approach to generic search for pair production of heavy particles
  - no assumptions on the model details
  - complementary to MET-tail searches
- two or more reconstructed objects combined into "megajets"
  - event-by-event test of the hypothesis that the megajets arise from the decay chain of heavy particles
- razor variables
  - M_R sensitive to the scale of new physics
  - R discriminating S/B
- search strategy
  - M_R and R^2 falling exponentially
  - extrapolate to signal region
  - "boxes" based on number of leptons
- interpretation in the context of the CMSSM parameter space
  - **exclude squarks and gluinos up to 1.35 TeV ($m_{squark} \sim m_{gluino}$) and gluinos up to 800 GeV ($m_{squark} > m_{gluino}$)**

Summary

- **CMS has completed a very large number of analyses with pp collisions at 7 TeV**
  - more than **100 papers** published
  - more than **40 new results** shown at **Moriond 2012**
  - excellent understanding of the detector, even at high pile-up conditions
- **SM measurements of unprecedented precision**
  - important constraints on theory ingredients (e.g. PDFs) and backgrounds to searches
  - **Tevatron anomalies (W+2j, top charge asymmetry) not confirmed**
- **Fully deployed Higgs campaign**
  - **excluded @ 95% CL the mass range 127.5 - 600 GeV**
  - **interesting fluctuation at low masses** (anticipating the 2012 run at 8 TeV)
- **Intensive search for BSM physics**
  - **no sign of new physics so far**
  - impressive limits on model parameters