Recent results from CMS

Selected topics presented at EPS2011

Slava Krutelyov (UCSB)

CMS Collaboration

seminar in series of *The first year of the LHC*

KITP

July 26, 2011

Outline

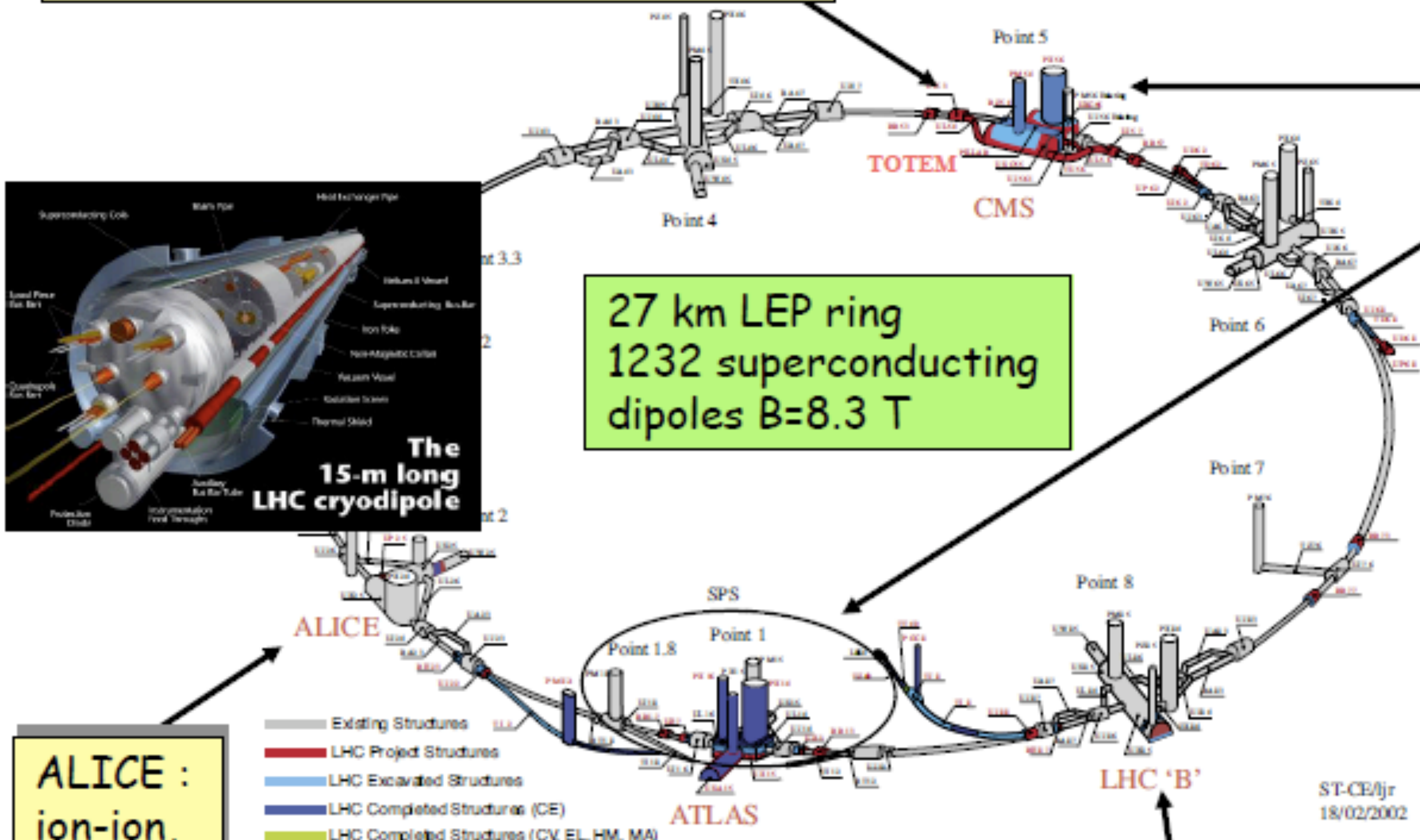
- LHC and CMS
- One year of rediscovering the Standard Model
- Highlights from EPS 2011, 1 fb^{-1} of data
  - ➡ Searches for SuperSymmetry
  - ➡ Varia: Z', $B_s \to \mu\mu$
  - ➡ Searches for the Higgs boson: WW, other modes, and combination
- Summary

Acknowledgements go to my CMS collaborators from whom I took a number of slides
Most slides are taken from EPS2011 presentations
This is not a comprehensive summary of all analyses
Apologies for skipping some of your favorite analyses

LHC

TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
general purpose



27 km LEP ring
1232 superconducting
dipoles B=8.3 T

ALICE :
ion-ion,
p-ion

LHCb :
pp, B-physics, CP-violation

<u>Design parameters:</u>

pp collisions at $\sqrt{s}$ = 14 TeV

L = 10^{34} $cm^{-2}s^{-1}$ ≈ 100 fb^{-1}/year

<u>Current:</u>

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

L = 2 10^{33} $cm^{-2}s^{-1}$ = 2 nb^{-1} s^{-1}

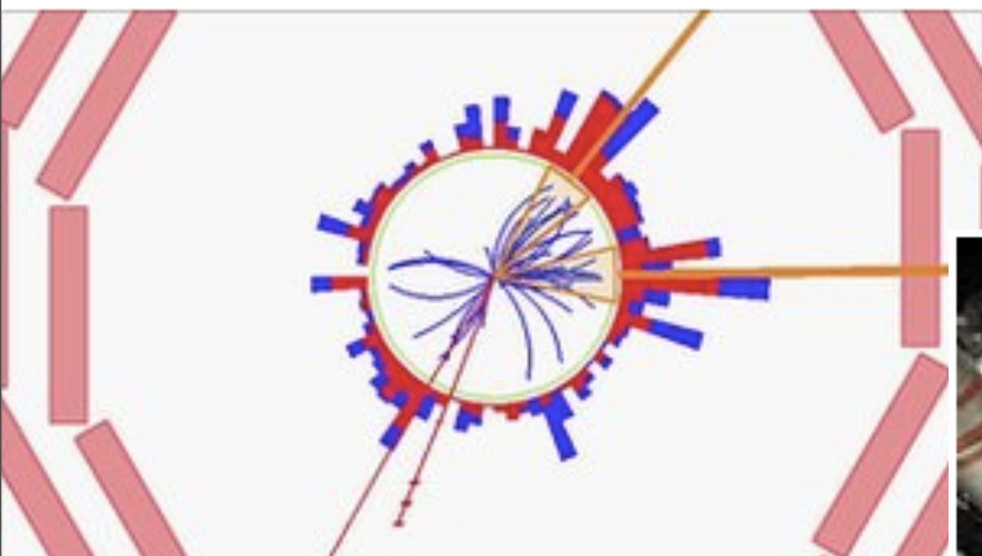
expect 5 10^{33} $cm^{-2}s^{-1}$ by Fall

- Design parameters yet to be reached
- Impressive progress in 2011 is a step to it …

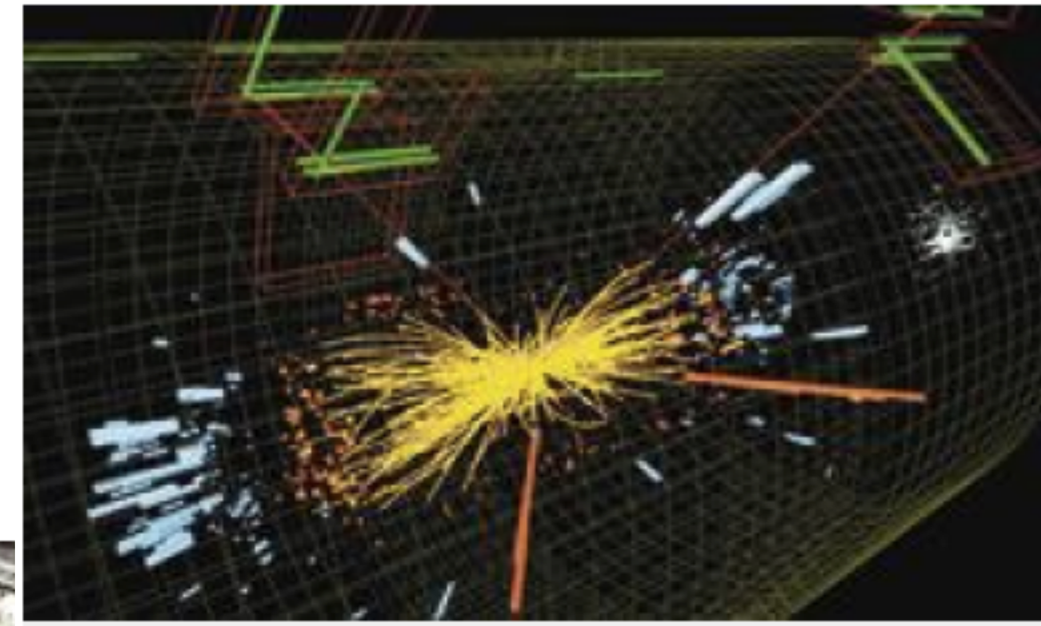
LHC: one year in the news

Just a few days more than a year ago

http://www.bbc.co.uk/news/science-environment-10746900



CMS saw a potential top quark "decay" into two other particles



Particle collisions at the Large Hadron Collider — including this smash-up observed by the Compact Muon Solenoid detector — are not yet giving physicists many surprises.

CERN

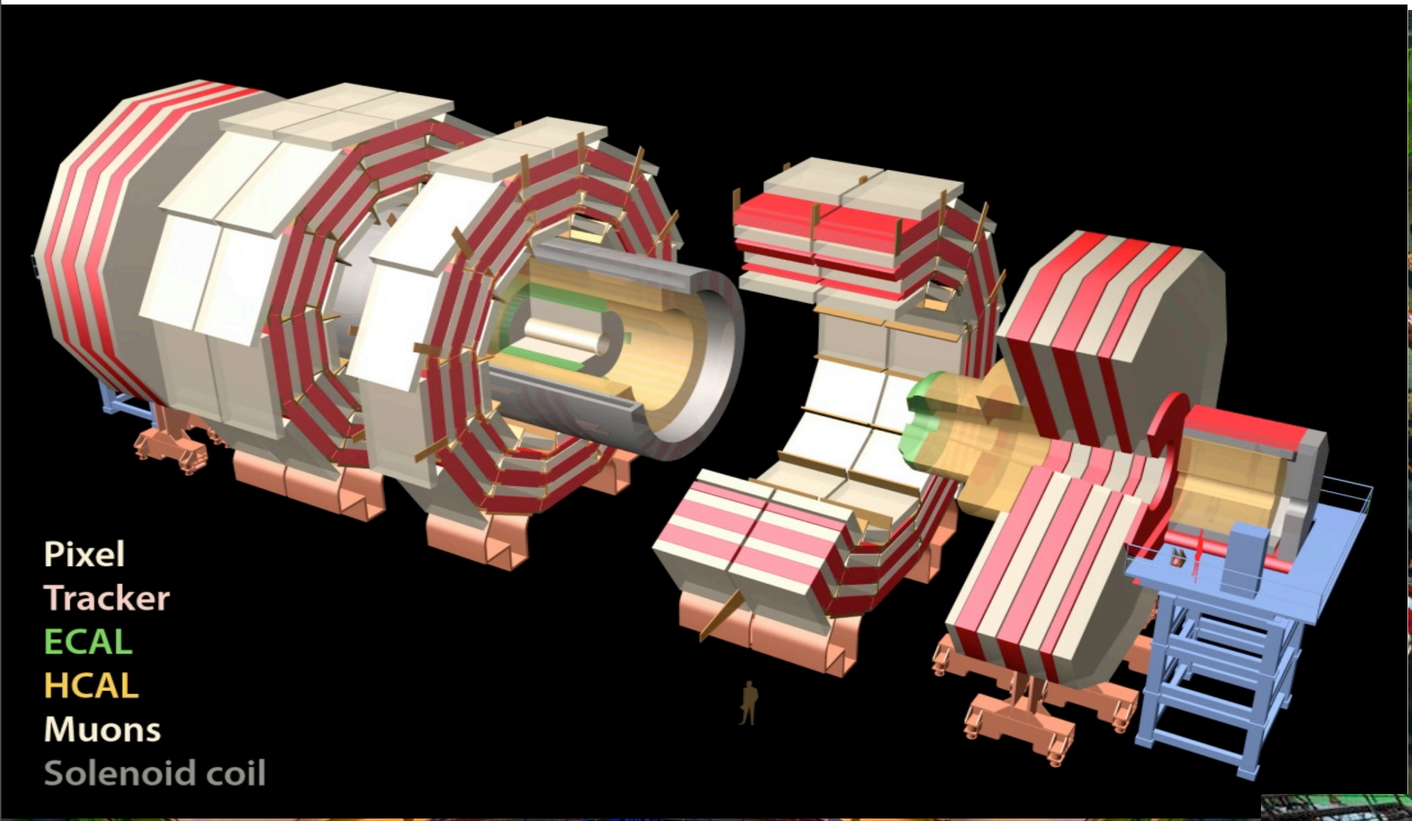
Researchers at the Large Hadron Collider say they could confirm the existence of the Higgs boson within a matter of months.

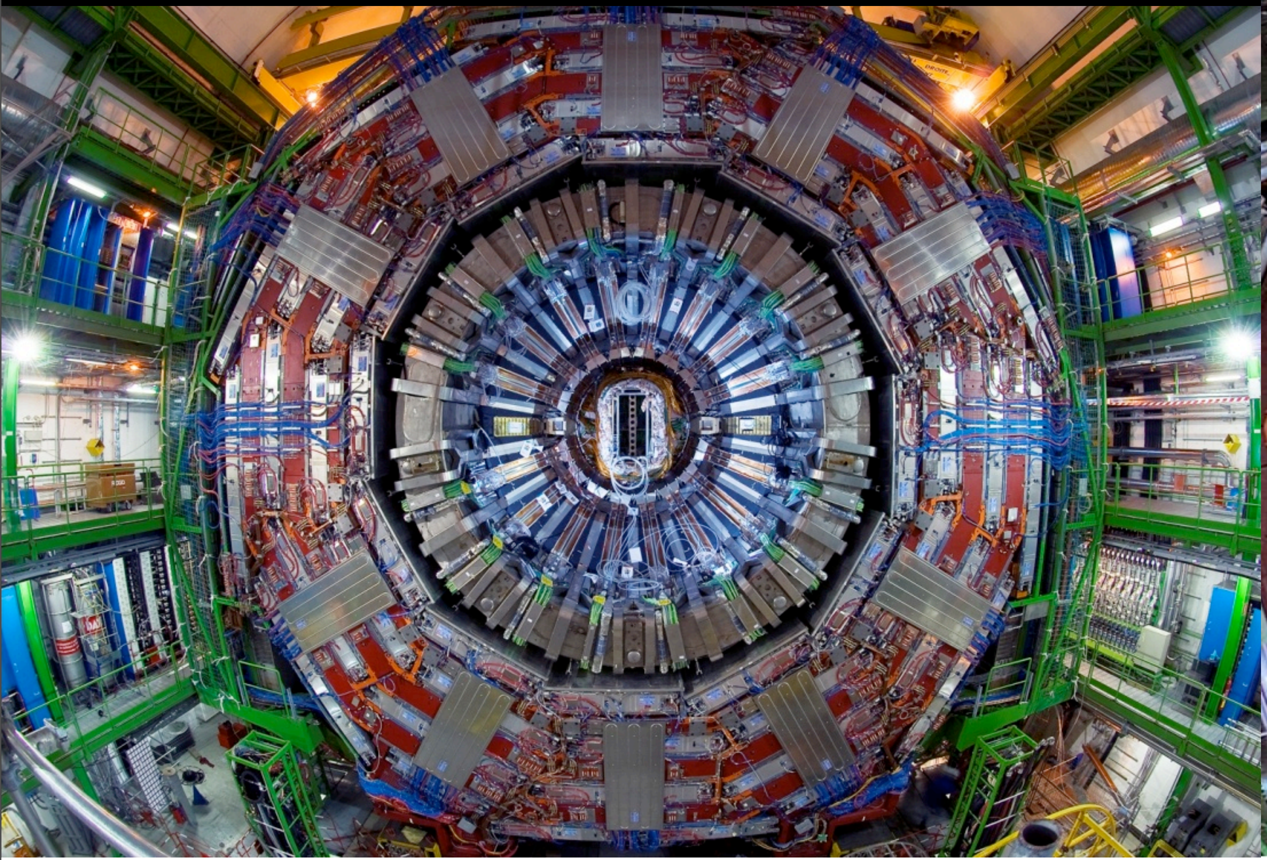
Claudia Marcelloni/CERN

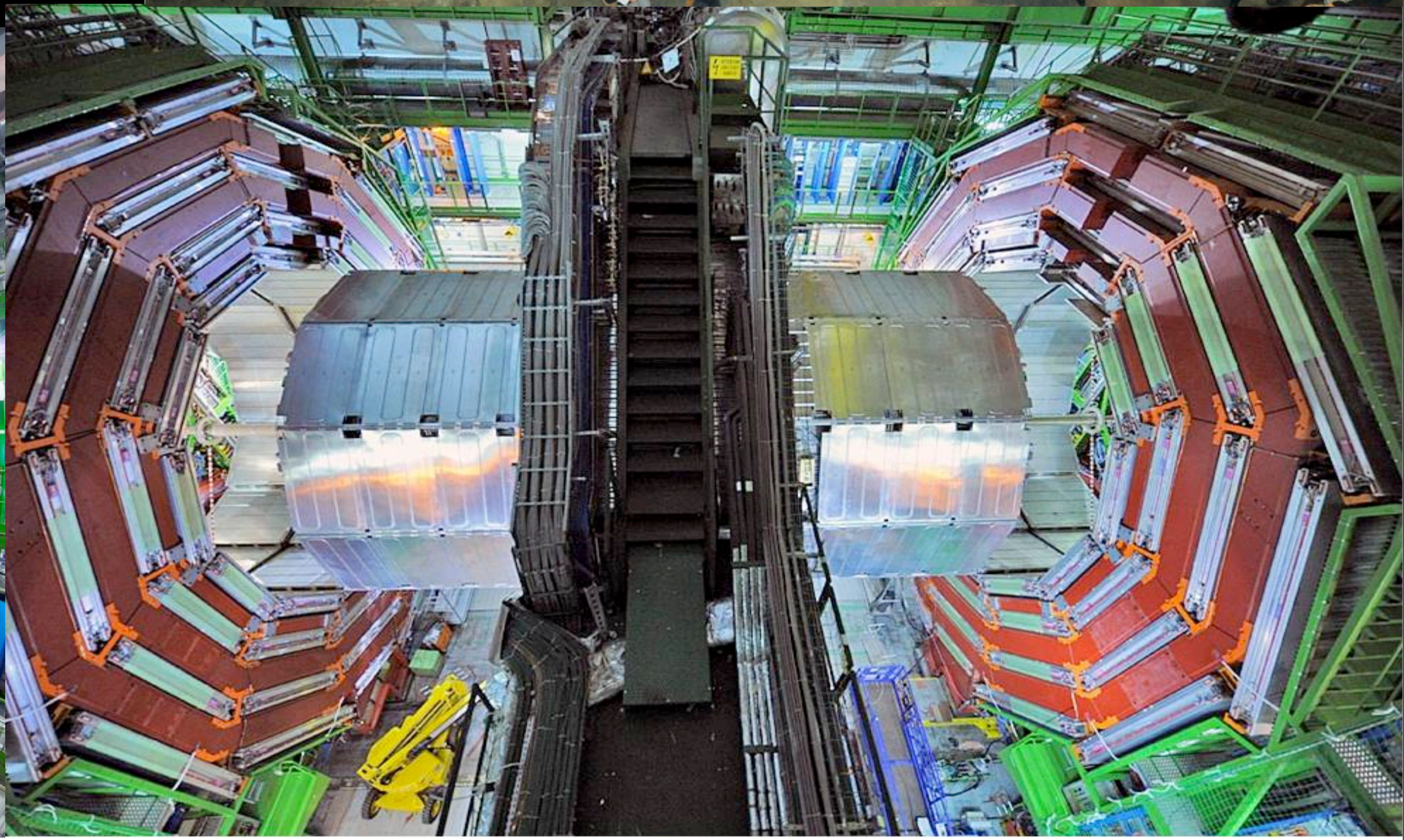
http://www.nature.com/news/
Just from the past 5 days

- We all had a good press coverage

CMS collaboration





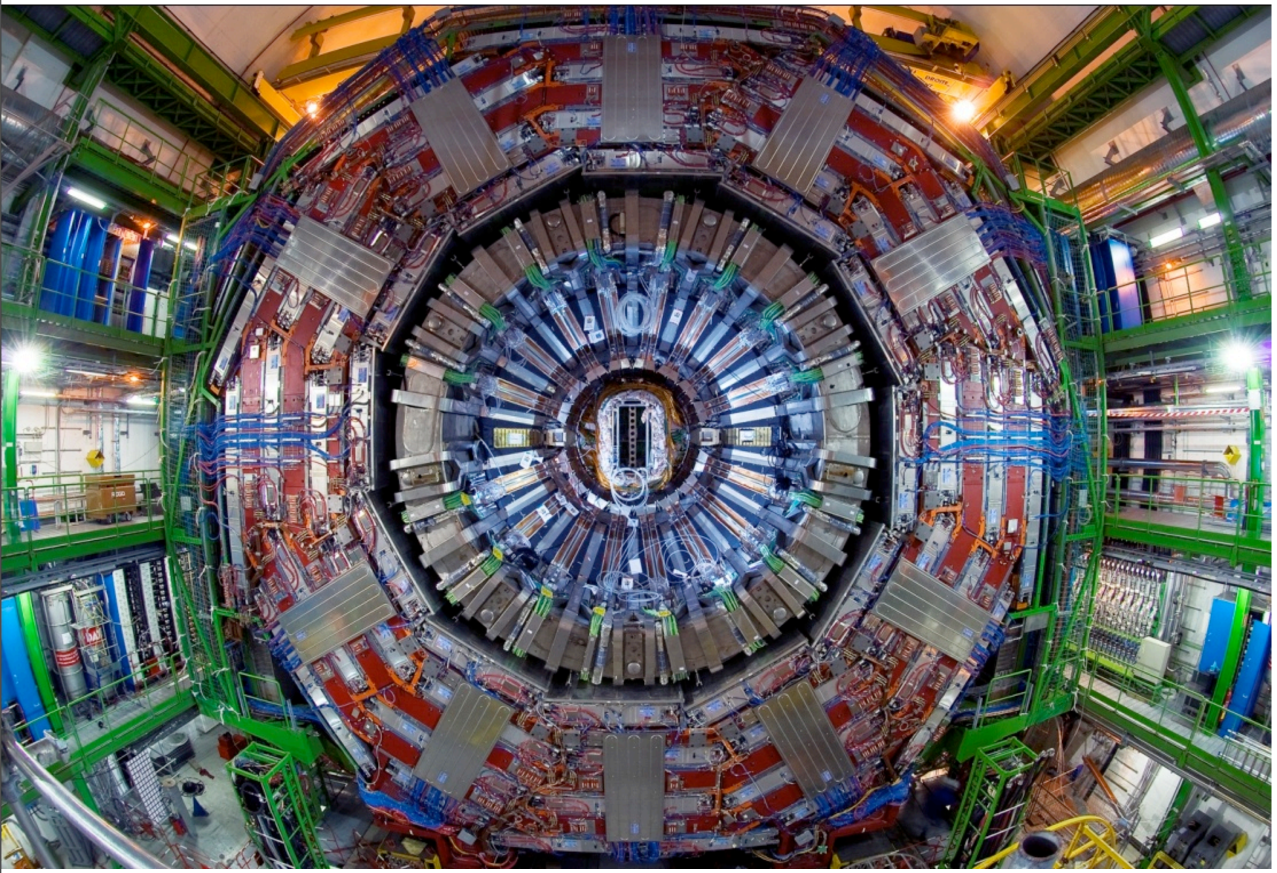


CMS collaboration and UCSB

3381 scientists and engineers (including ~840 students) from 173 institutes in 40 countries

UCSB group has ~25 members (new students not yet in author list)

Our group has a significant hardware and physics impact in CMS



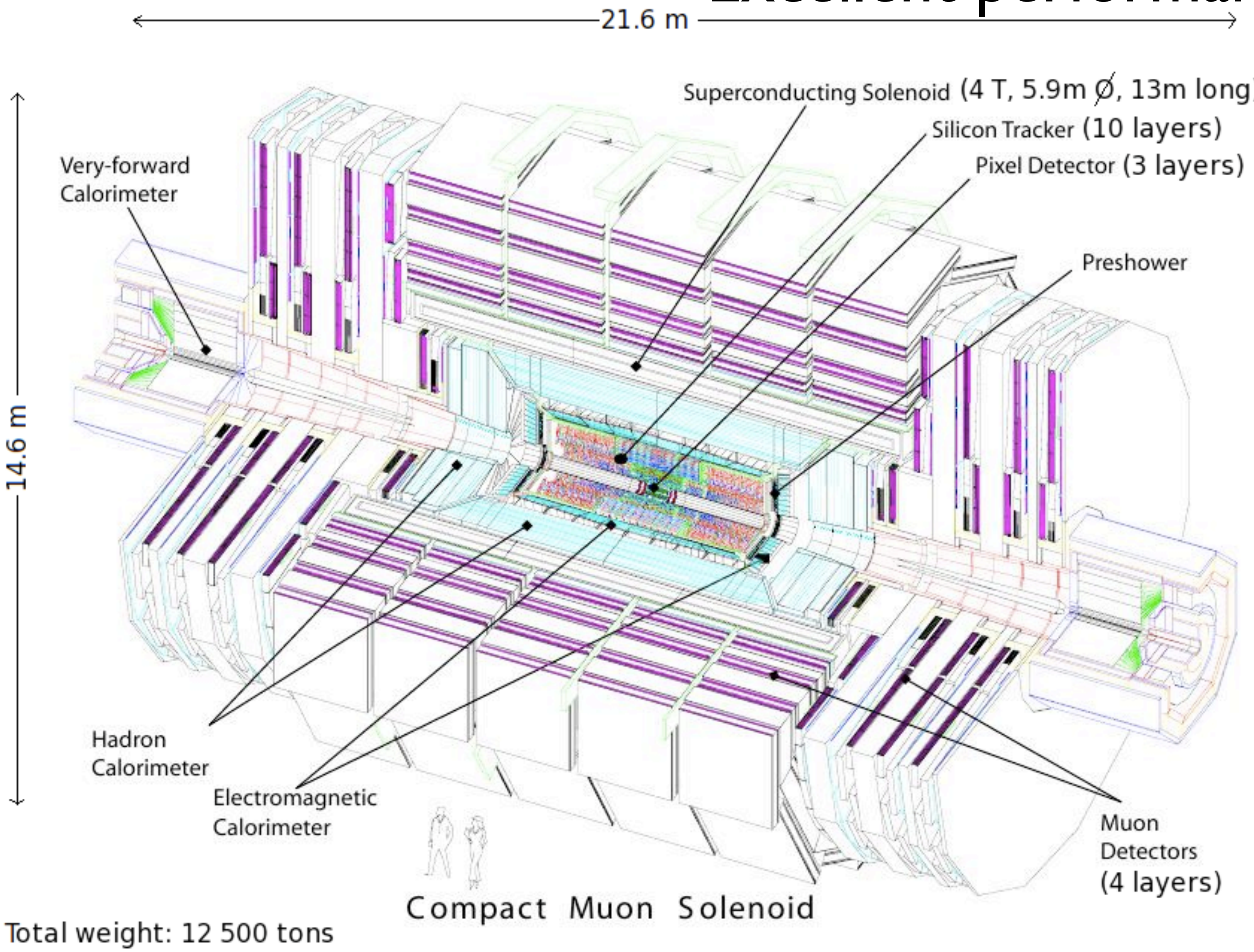
Joe Incandela is the CMS spokesperson starting 2010

Incandela is the first U.S. scientist to be elected spokesperson for an experiment at the LHC.

CMS Detector: 2008 JINST 3 S08004

CMS Detector

Excellent performance from first days of collisions



Tracker: $\sigma/p_T \simeq 1.5\times10^{-4}\times p_T \oplus 0.005$

Muon standalone @ 1 TeV: $\sigma/p_T \simeq 0.10$

Electromagnetic energy resolution

$$\frac{\sigma(E)}{E}=\frac{3\%}{\sqrt{E}}+0.3\%$$

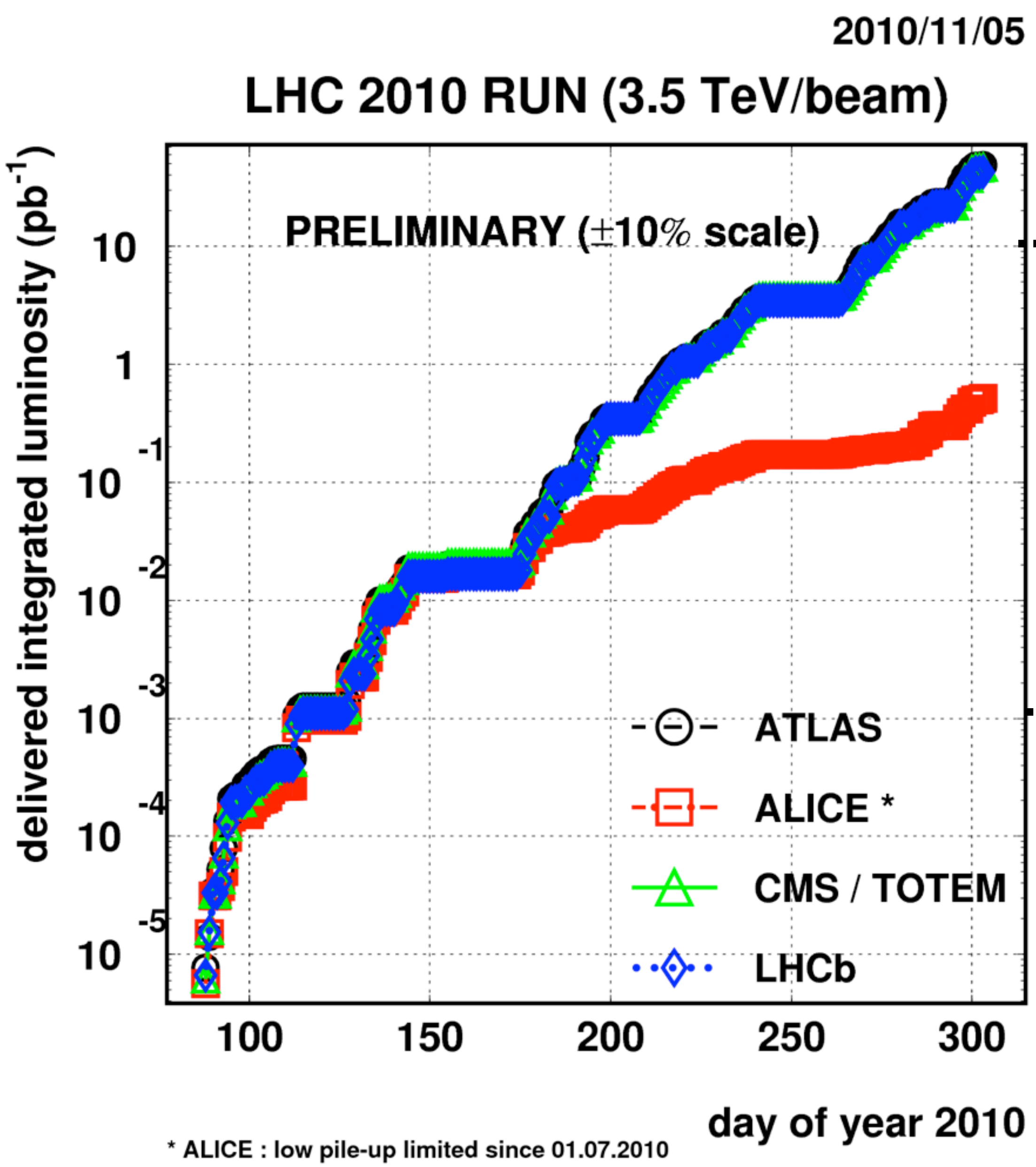
Hadronic energy resolution

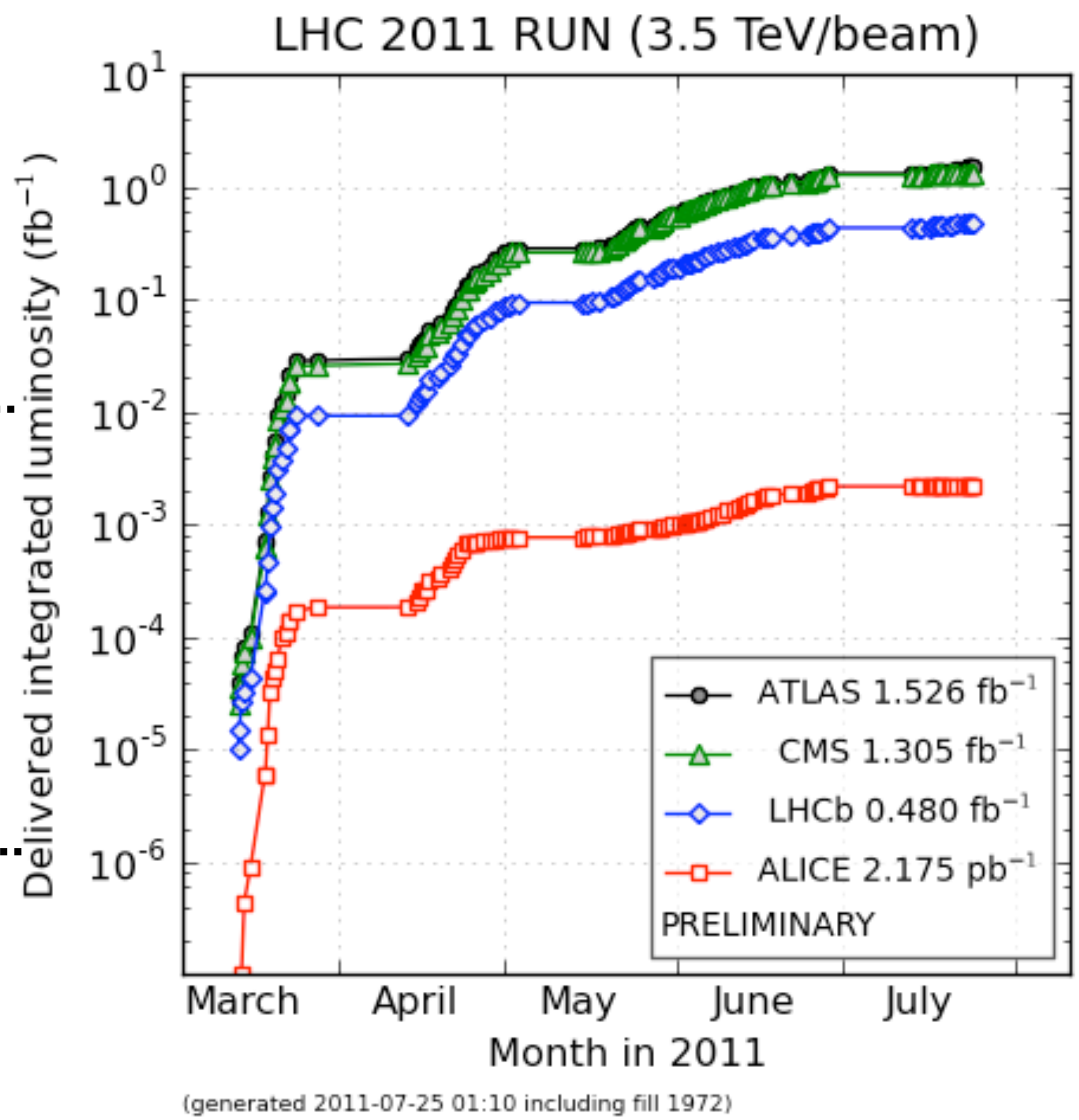
$$\frac{\sigma(E)}{E}=\frac{100\%}{\sqrt{E}}+5\%$$

- Trigger system setup to reduce input rate of 40MHz down to 100-200 Hz
  - ✓ Hardware level-1 40MHz → 100 kHz followed by PC farm with near-final reconstruction resolution
  - ➡ No triggering on inner tracks at L1 (available only in a couple of years)
  - ➡ Final trigger stage can select muons, electrons, photons, jets, MET, displaced vertices

LHC in 2010→ 2011

http://lpc.web.cern.ch/lpc/lumiplots.htm





- 40 pb^{-1} delivered in 2010; now have 1.5 fb^{-1} in 2011
- results today with ~1fb^{-1}

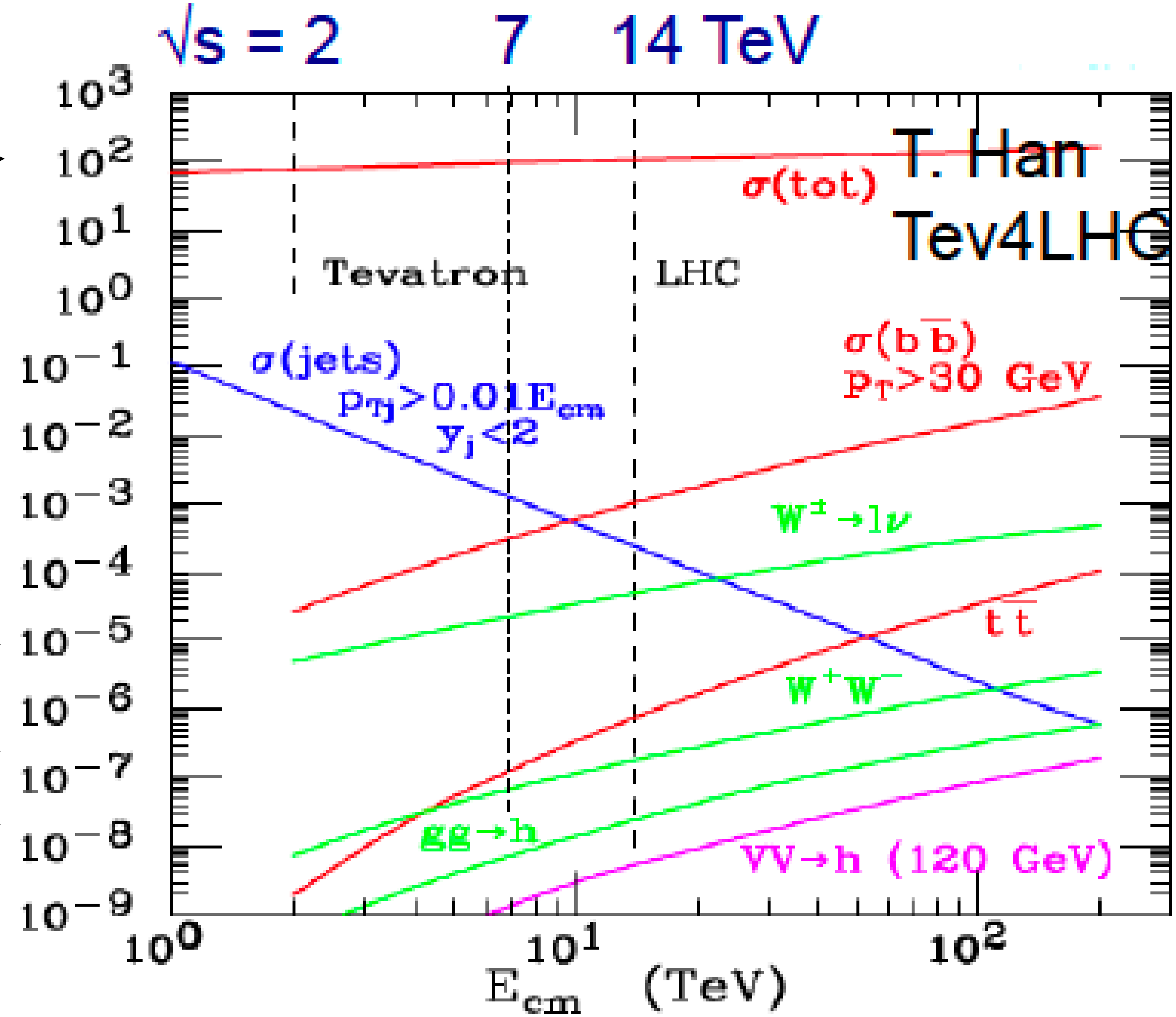
LHC rediscovering the SM

April 2010 →

May 2010 →

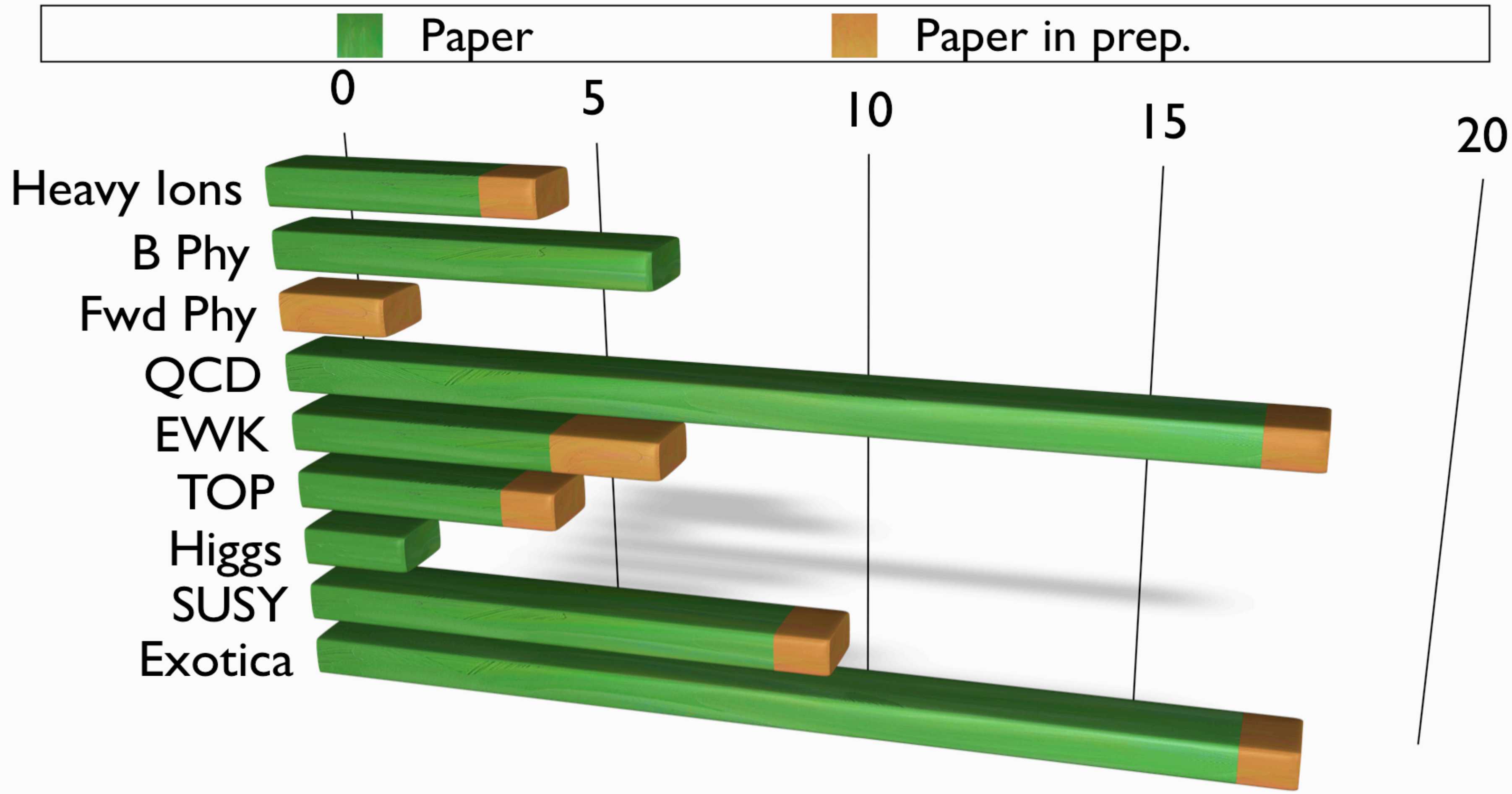
July 2010 →

Nov 2010 →



Most previously known processes observed within just under a year of data taking

Publications



In total : **65** papers on physics analyses, submitted, accepted or published
9 papers close to submission

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

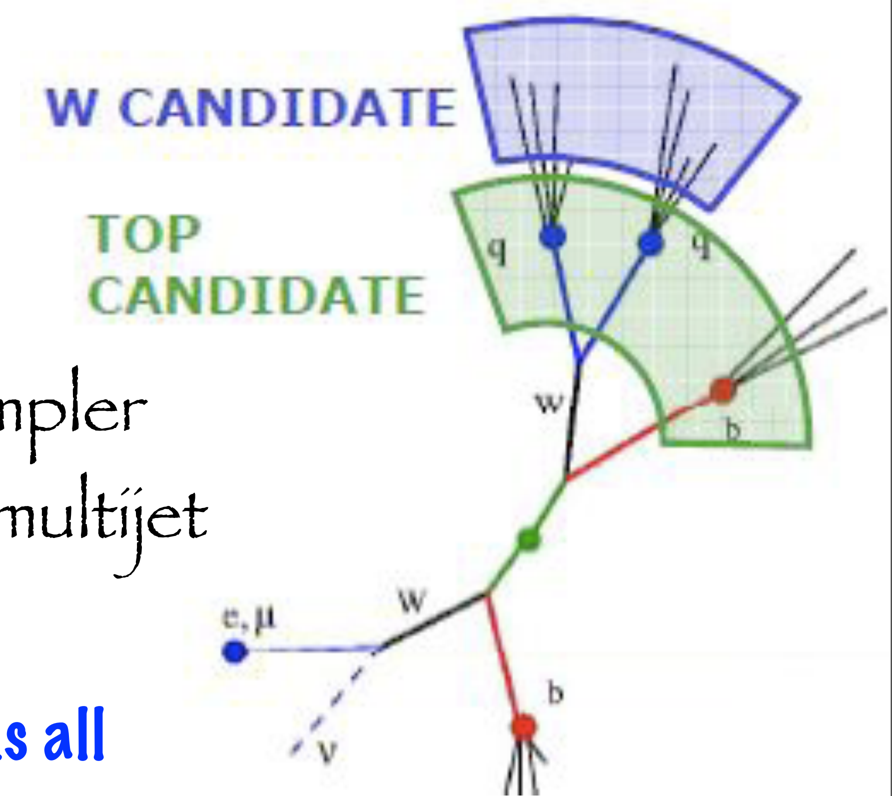
- Impressive progress over about one year
- Many more to appear later this year

Ingredients in physics analyses

- Objects we use to select events
  - ✓ leptons (electrons, muons, taus), most importantly isolated
  - ✓ photons
  - ✓ jets, including ones from b-quarks
- Commissioning of performance and selections has been successfully accomplished with 2010 data
- A great physics "candle" here was the top pair production
  - ✓ The final state naturally includes all important objects
    - ⊙ Sorry, not photons.
  - ✓ The production is quite abundant

➡ All objects were commissioned separately using simpler standard candles, like Z/W decaying leptonically, multijet QCD events, photon+jet events

  - ✓ Showing that it all works combined in top events confirms all pieces work

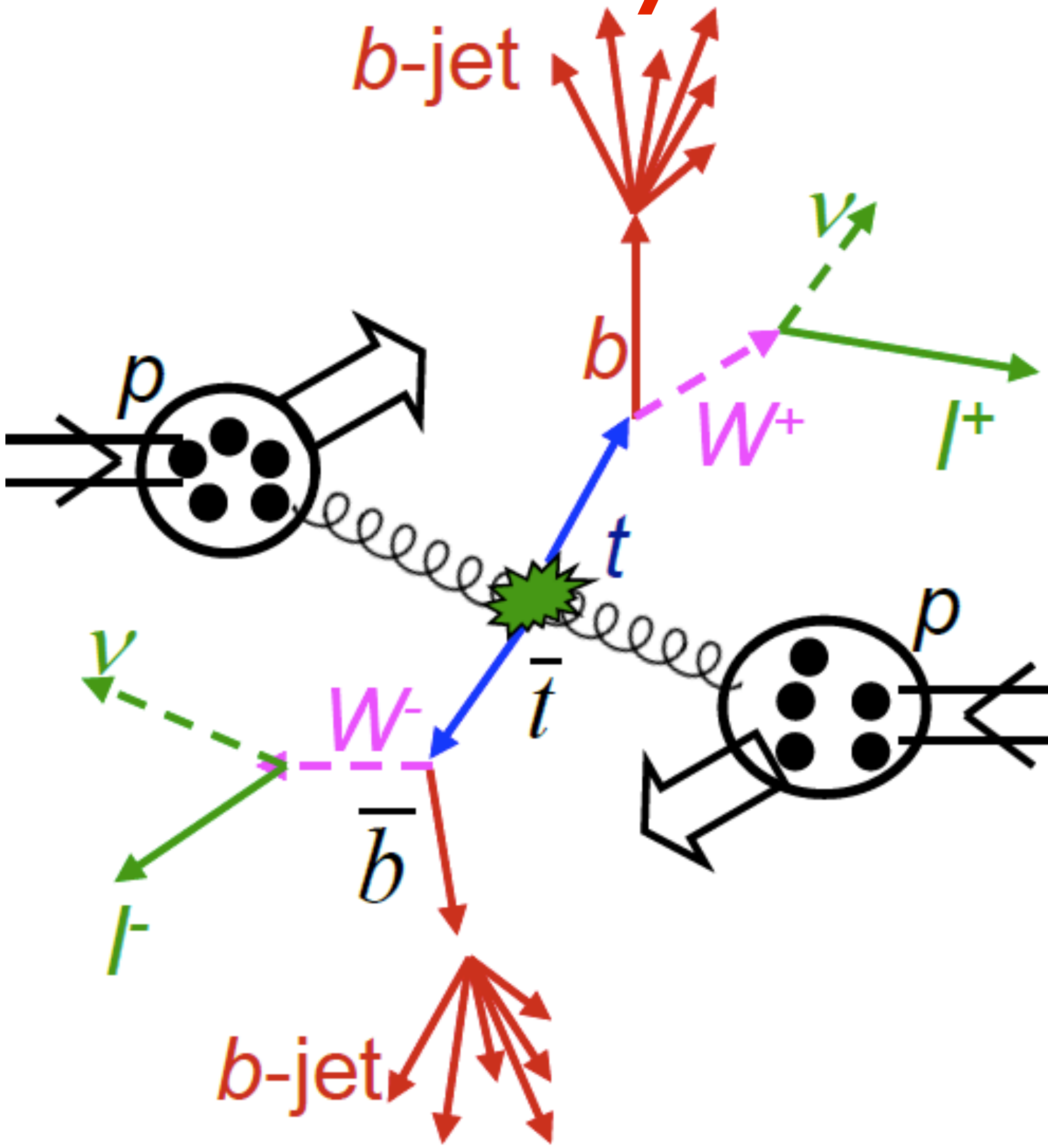


3 pb^{-1} : Phys. Lett. B 695 (2011) 424-443

36 pb^{-1}: JHEP07 (2011) 049

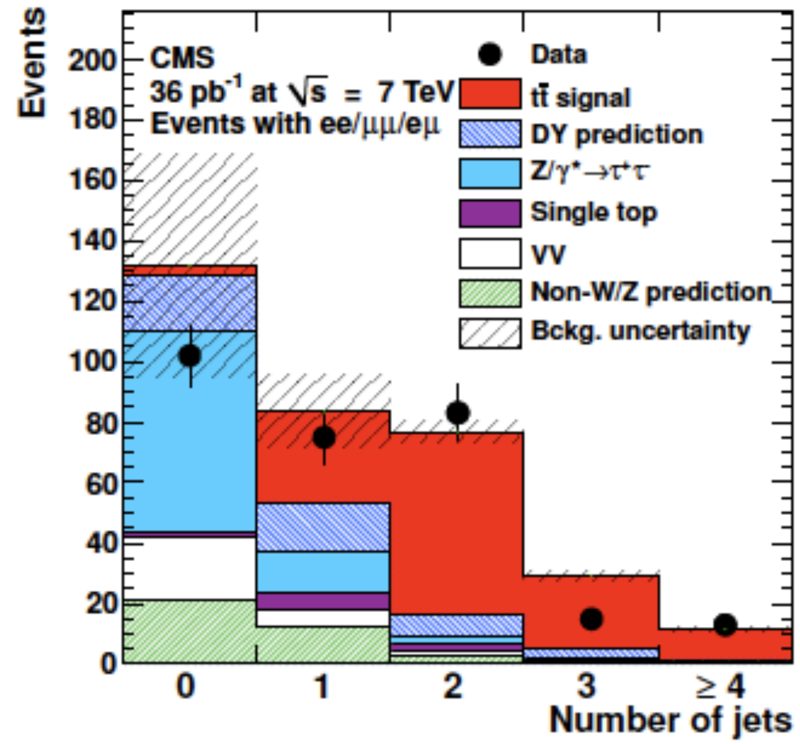
Physics commissioning: top quarks

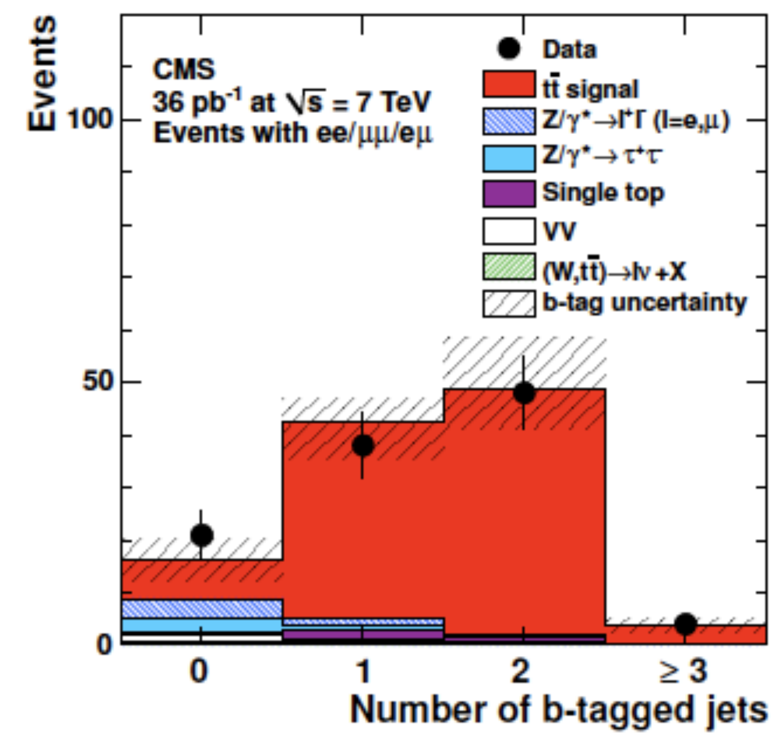
- Using 3 pb-1 data sample, then repeated and improved with 36 pb-1
  - ✓ First 10 events; the update is based on 100 signal
- **Similar selections and methods used in other analyses**
- Dilepton final state has low backgrounds
  - ✓ eμ the cleanest
- Cut and count method
- Selection
  - ✓ Two opposite-charge leptons pT>20 GeV
  - ✓ Lepton isolation
  - ✓ Two or more jets (anti-Kt 0.5) with pT>30 GeV
  - ✓ MET > 30(20) GeV ee,μμ (eμ)
  - ✓ Veto M near Z in ee,μμ: |Mass-91| > 15GeV
- Backgrounds
  - ➡ Non-W/Z e/μ from j→ l rate in QCD dijets
  - ➡ DY in ee/μμ normalized to events near Z
  - ➡ MC for the rest: dibosons, tW, DY→ ττ



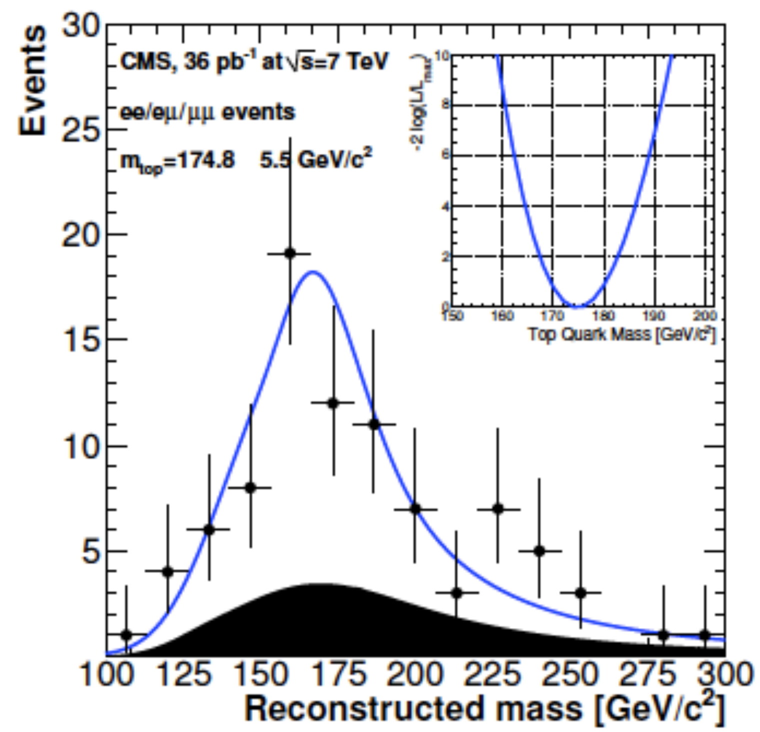
Rediscovering the SM: top quarks

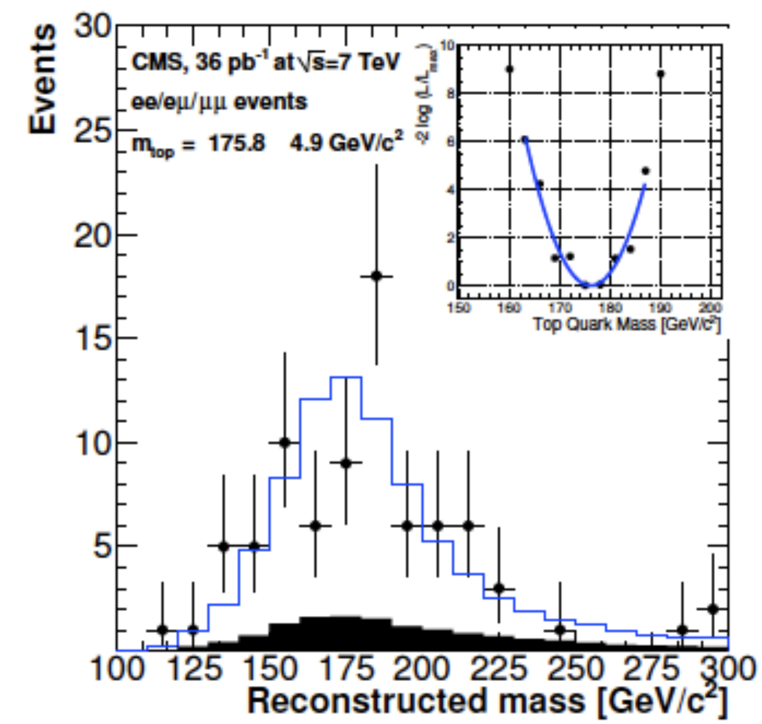
- Measured cross section in agreement with the SM
  - ✓ NLO: 157 pb
  - ✓ measured 168±24 pb



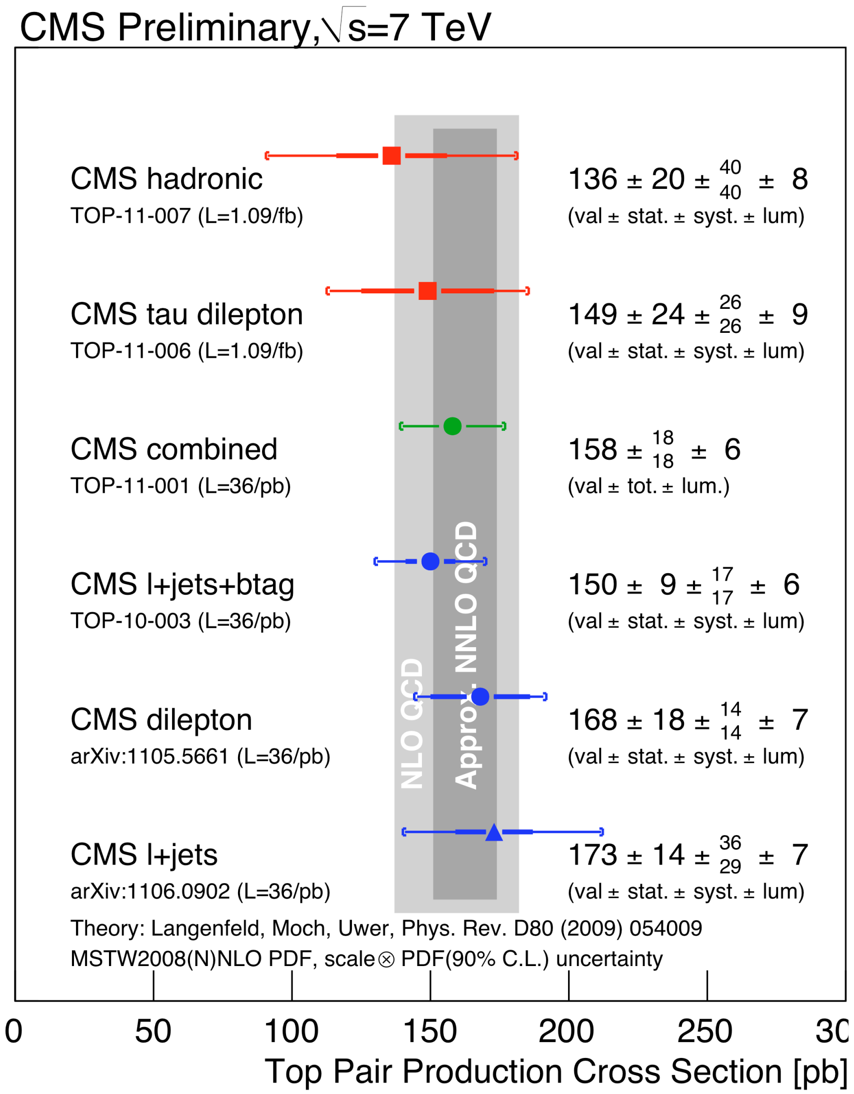


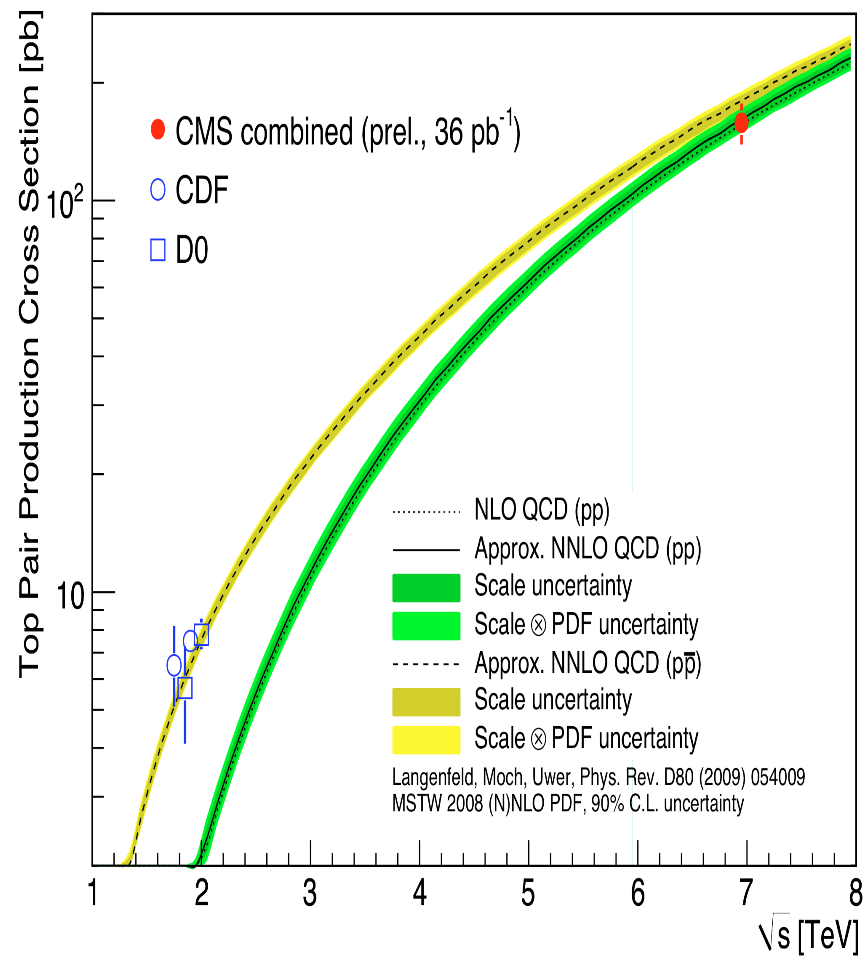
- Additionally, use full event kinematics to fit for the top quark mass
  - ✓ Two methods to constrain kinematics
  - ✓ Consistent measurements
  - ✓ Combined: 175.5±6.5
    - This was the first top-quark mass measurement at LHC
  - ✓ cf Tevatron: 173.2±0.9

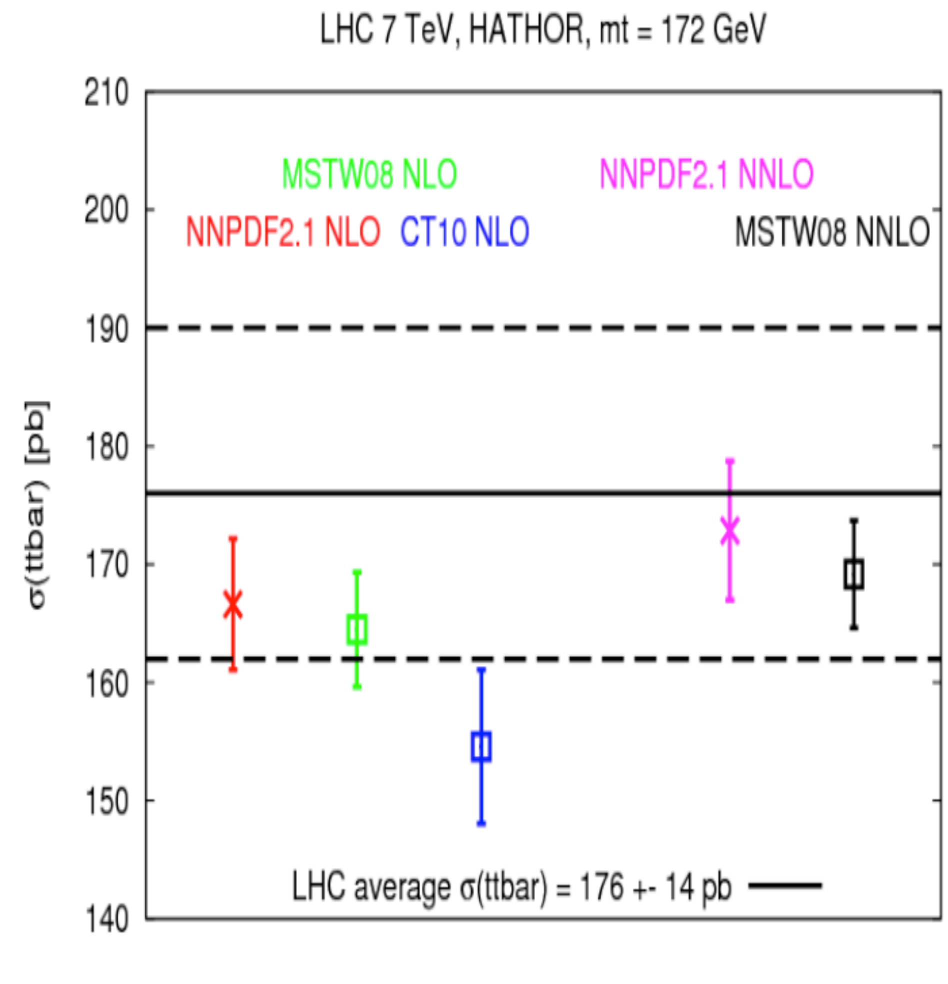




Rediscovering the SM: top quark



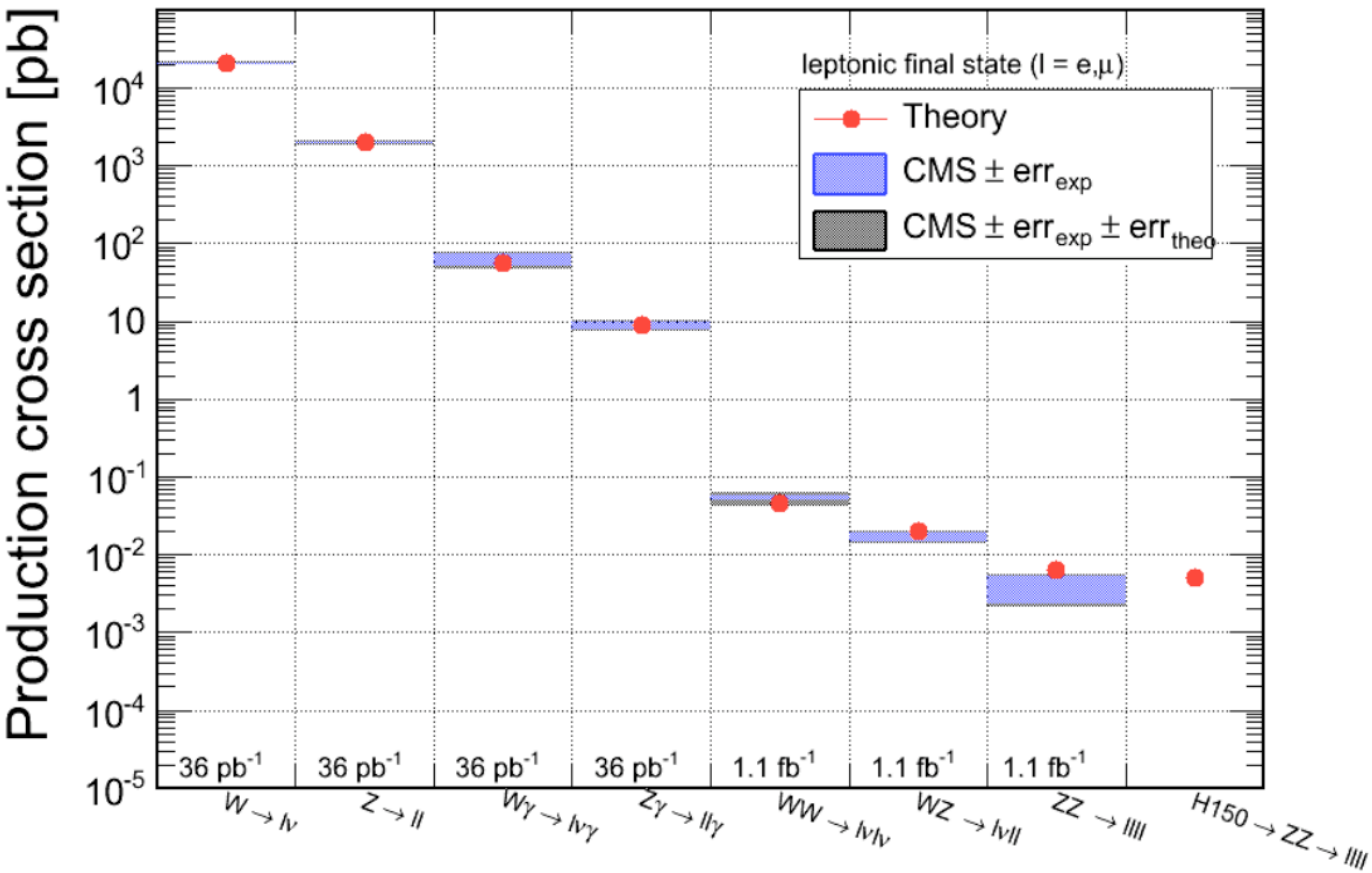




NNLO (Juan Rojo)

- This combines measurements in dilepton, lepton+jets, and all-hadronic final states. Each shows consistent values

Rediscovering the SM: dibosons



- We have confirmed what we expect from the standard model
  - ✓ NB: the first measurement of WW production was done with 36 pb^{-1}
- **... it's time to search for something new**

Estimating backgrounds from data

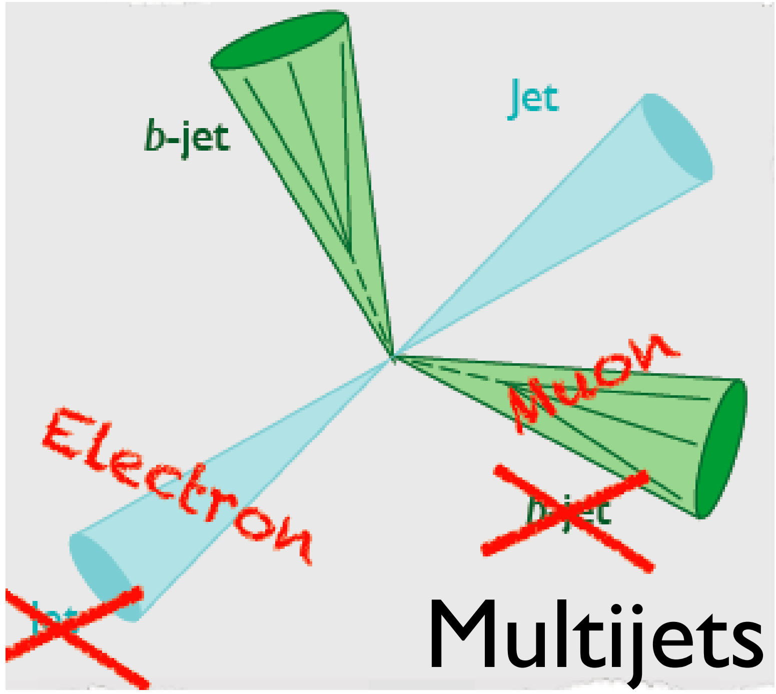
- … before jumping to details on searches, it's important to mention our analyses rely on data as much as possible.
  - ✓ We only trust simulation to the extent where it can be tested on data where important
- Misidentified leptons
  - ✓ These come mostly from generic QCD jets misidentified as good isolated leptons
    - controlled by looking at leptons failing selections and extrapolating to good region
- (Mis)measured missing ET
  - ✓ One of the biggest sources is mismeasured hadronic part of the event (jets)
    - a) controlled by MET measured in QCD-dominated events with jets
    - b) in dilepton searches with Z-boson veto use events near Z for control
  - ✓ $Z \to \nu\nu$ has a special place, important in multijet+MET searches
    - control Z recoil distribution in photon+jets and dilepton+jets events
- Smart physics-based ideas
  - ✓ Neutrino (MET) spectrum prediction using lepton spectrum [$W \to (l \leftrightarrow \nu)$]
- Empirical relationships
  - ✓ Discriminating variables are often uncorrelated: two variables can be used to define a control region and extrapolation to the signal region

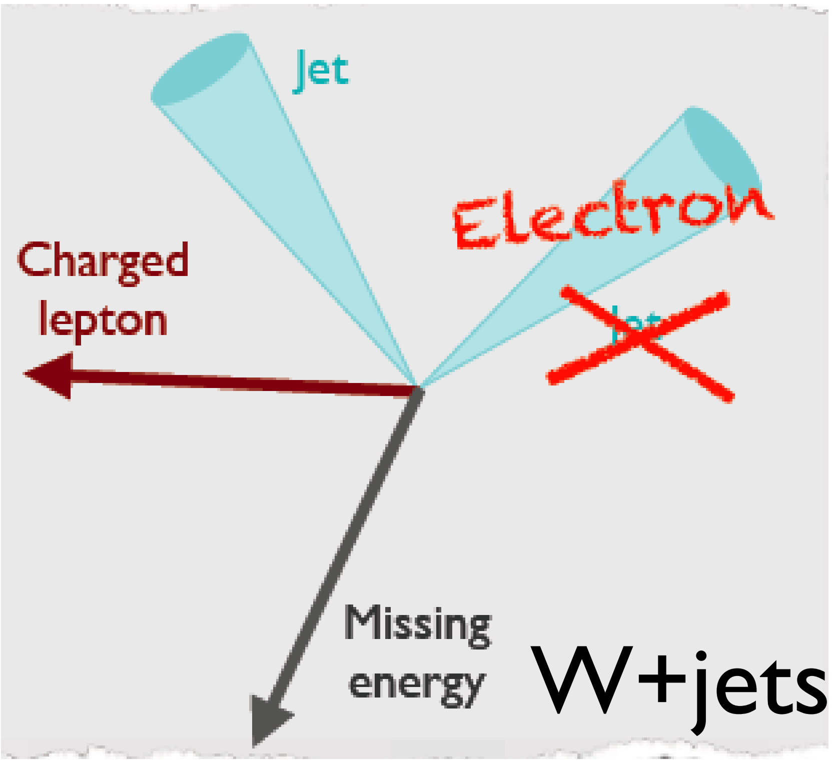
Misidentified leptons (jet->e/μ)

- Backgrounds arising from jets faking one or more leptons
  - ✓ Multijet: 2 fake leptons
  - ✓ W+jets: one fake and one real

- Rate of jets faking leptons extracted from jet sample dominated by QCD
  - ✓ R=(pass lepton ID&Isolation)/(pass loose cuts)
  - ✓ Use lepton-like objects (not any jet) in denominator to be more similar to signal

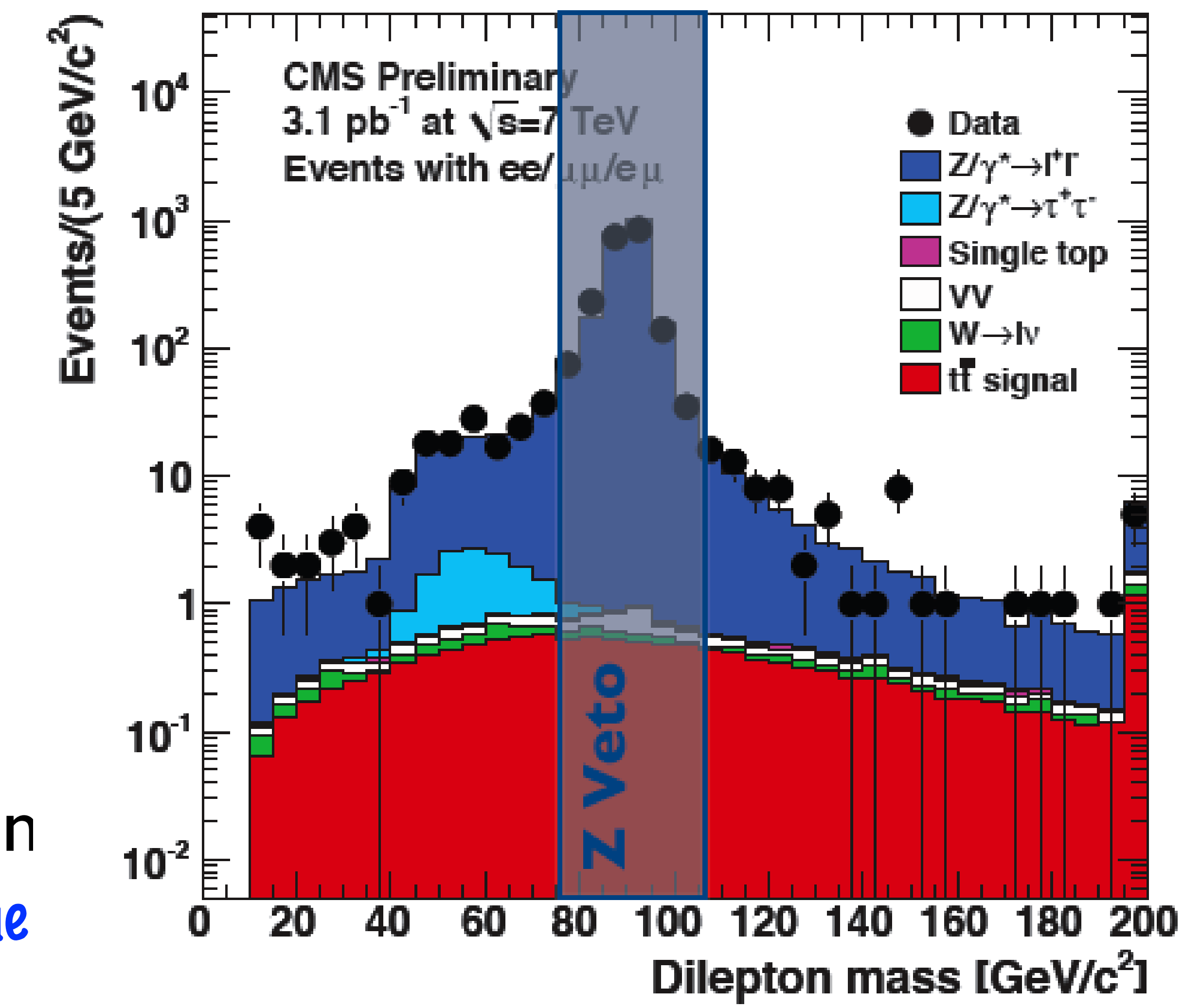
- Fake rate applied to data control sample to predict background
  - ✓ The control samples are dilepton events passing all other selections and failing (one or both) lepton ID&Isolation requirements





Mismeasured MET: predict using Z

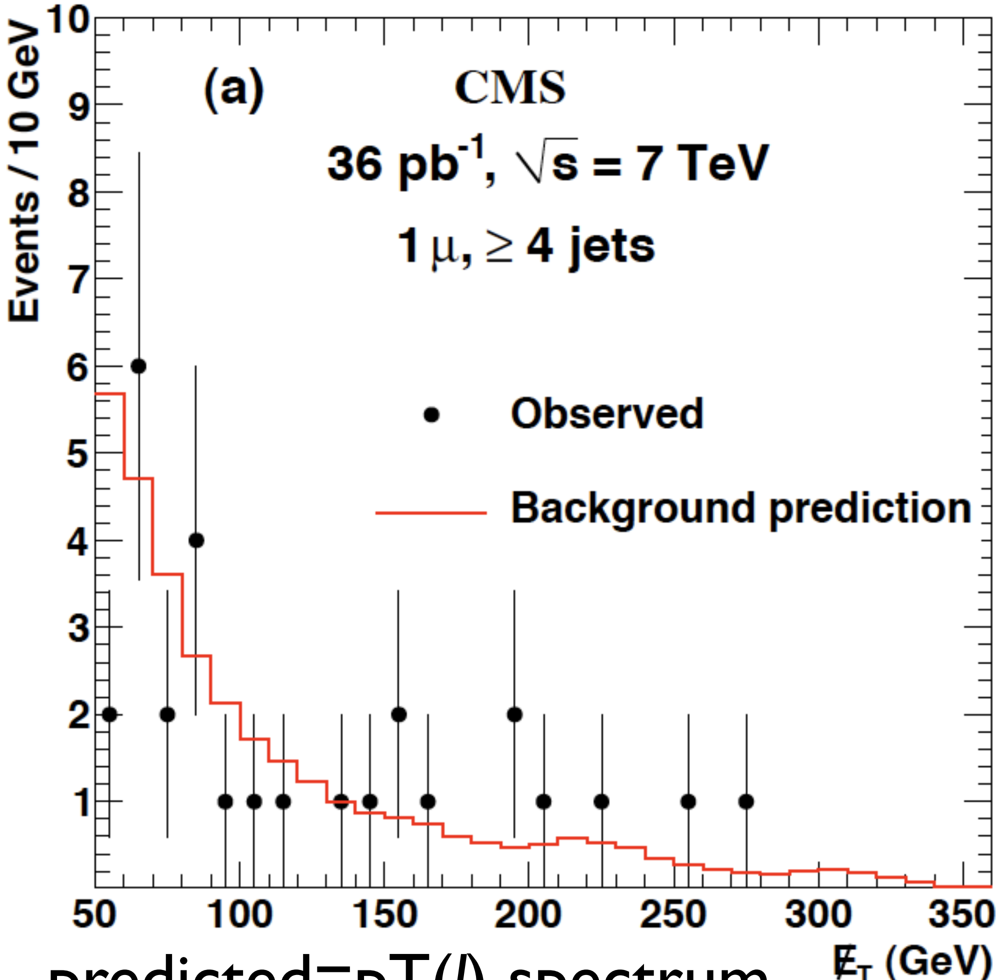
- Z-boson veto removes most DY background in dilepton analyses (e.g. ttbar, WW)
  - ✓ Close to a factor of 10 suppression
- Residual background estimated from data in Z veto region
  - ✓ Use events with $|mass - 91| < 15$ GeV/c^2
- Data corrected for non-DY contribution
  - ✓ Mostly WW here: use eμ events passing same selections near Z mass
- Scale counted Z inside veto region to that outside using MC



Physics-based: MET shape from leptons

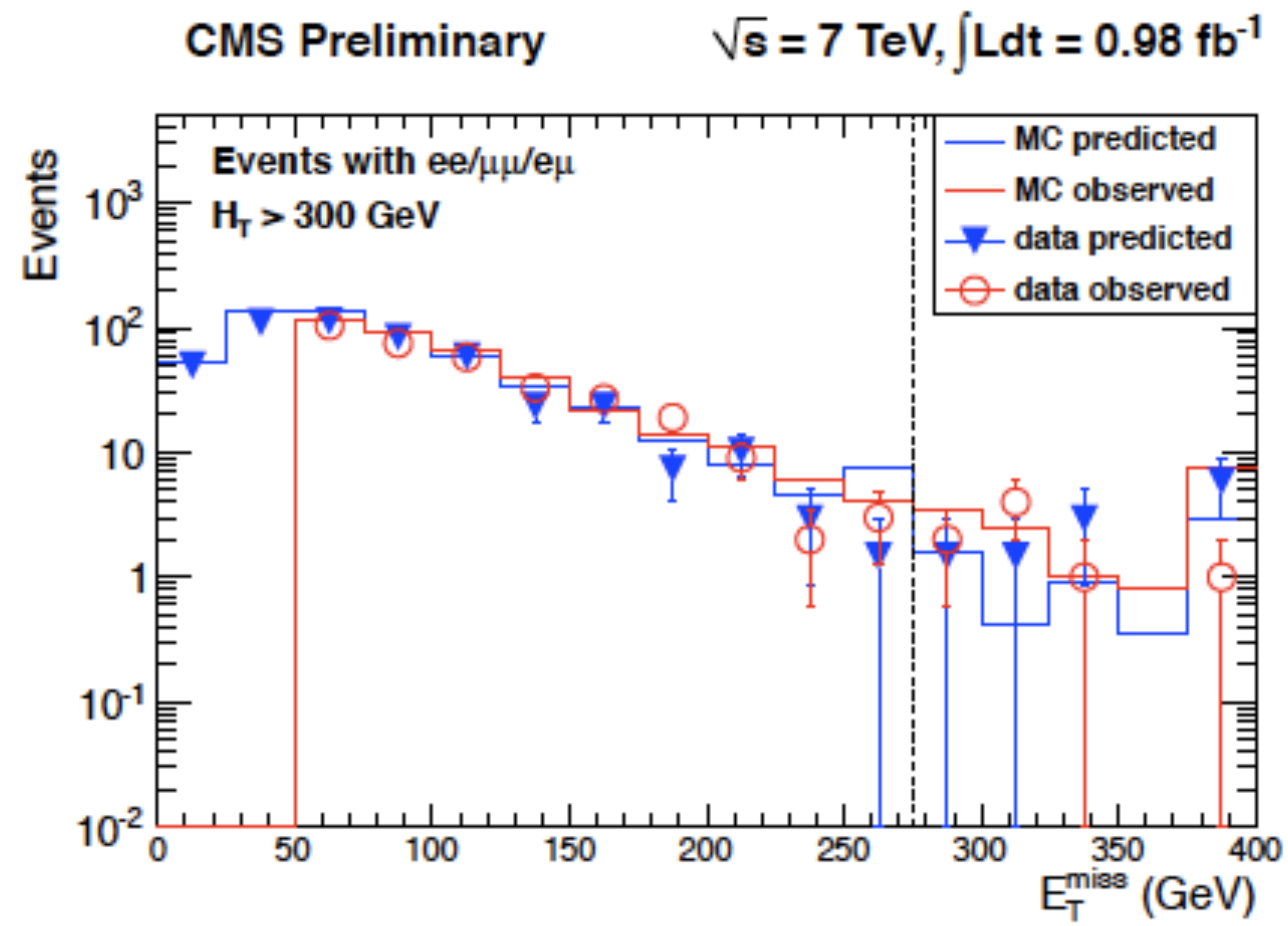
SUS-10-006, sub to JHEP

search in lepton+jets+MET



predicted=pT(*l*) spectrum smeared for jet resolution

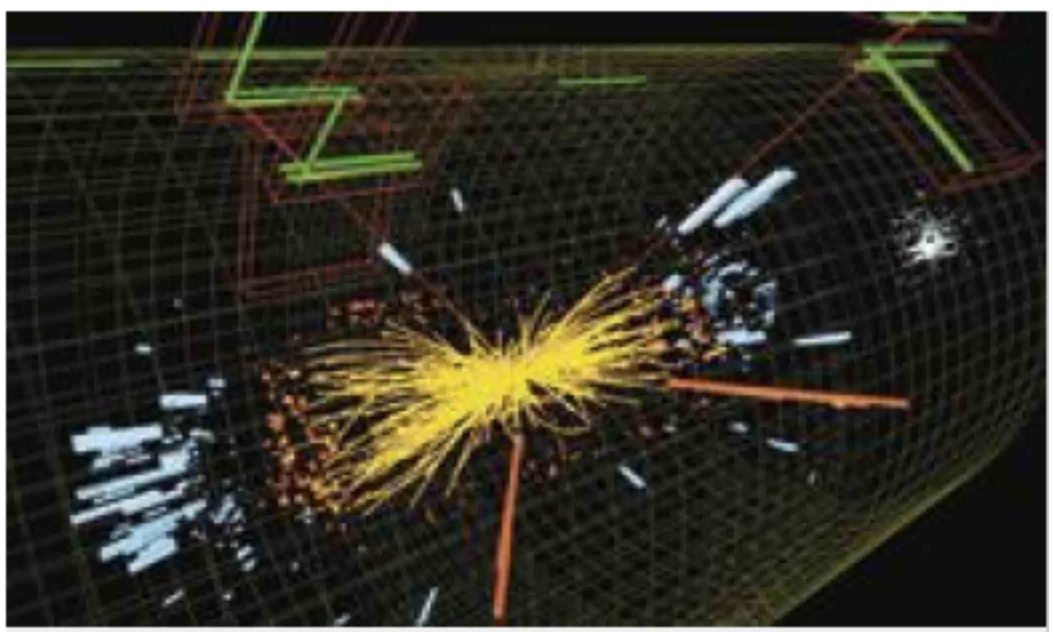
SUS-11-011 Search in OS dileptons, jet, MET



predicted=scaled pT(*ll*) spectrum

- In a leptonic W → lν decay a lepton and a neutrino can be swapped ==> a lepton pT distribution can approximate the neutrino pT distribution
  - ✓ Corrections to this approximation can be applied using simulation, or, if small enough, treated as an uncertainty

Now, to the searches ...



Particle collisions at the Large Hadron Collider — including this smash-up observed by the Compact Muon Solenoid detector — are not yet giving physicists many surprises.

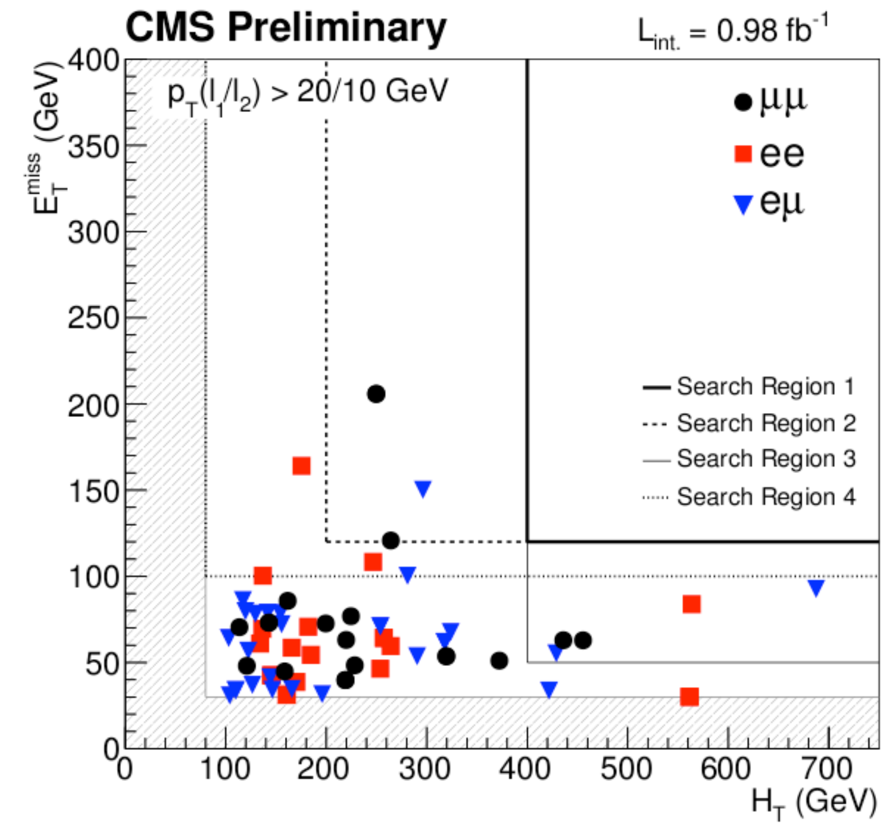
CERN

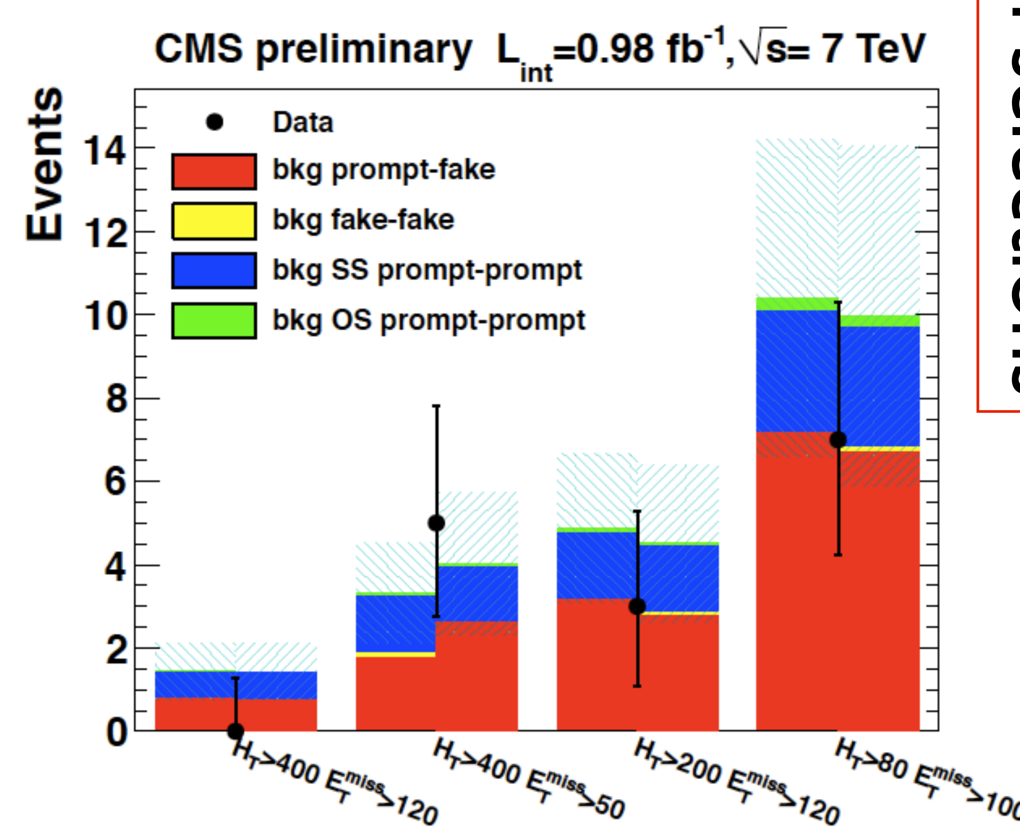
You could guess from p4 that we don't find anything

SUS-11-010

SUSY search: SS leptons, jets MET

- Preselections
  - ✓ Two isolated leptons
    - Inclusive: pt>5/10 GeV
    - High-pt: pt>10/20 GeV
  - ✓ MET> 50 GeV
  - ✓ At least two jets pt>40 GeV
- Use preselection to test bgd predictions
- Main backgrounds
  - ✓ Fake/misidentified leptons
  - ✓ Real SM same-sign (multiboson) contributions significant at tighter selections
- Look at selections with tighter sum-Jet-pt, MET
  - ➡ Report limits for HT>400 GeV, MET>120 GeV



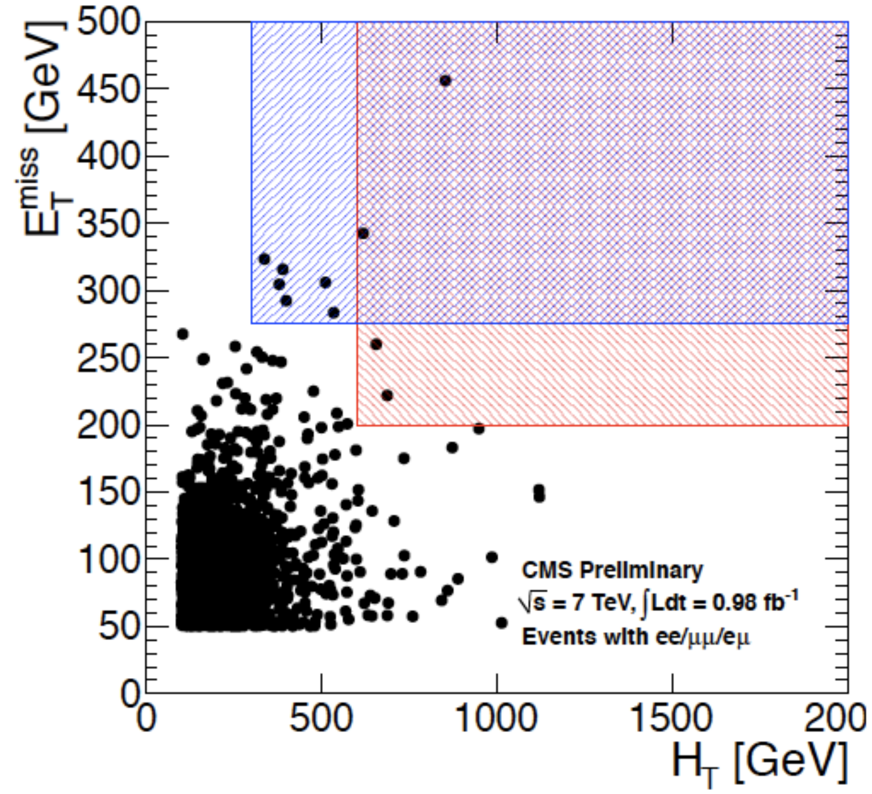


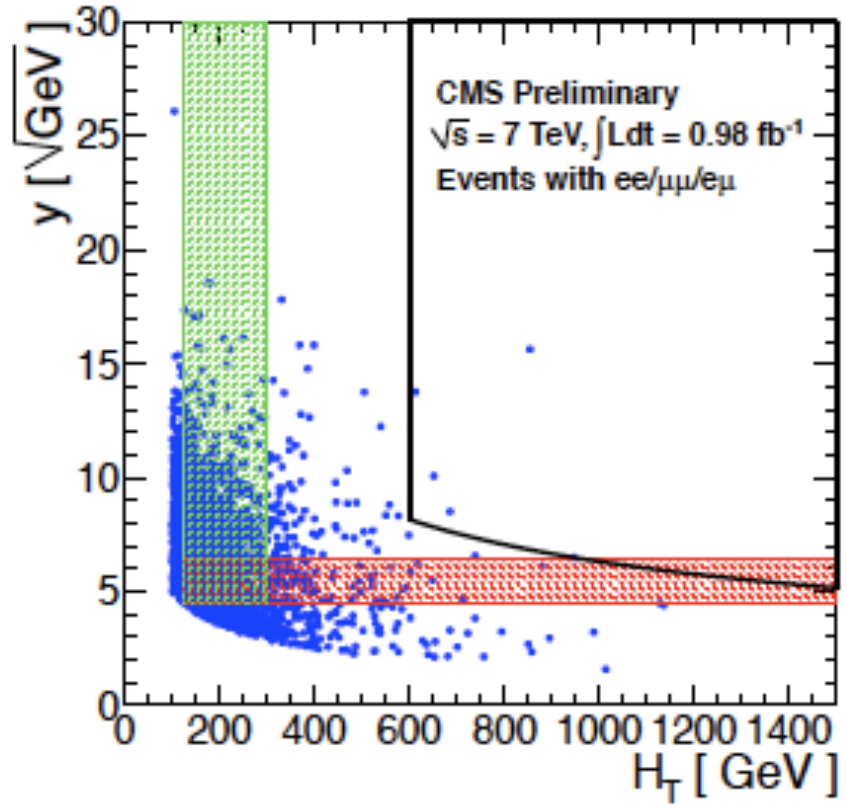
high-pt, search selections

SUS-11-011

SUSY search: OS leptons, jets MET

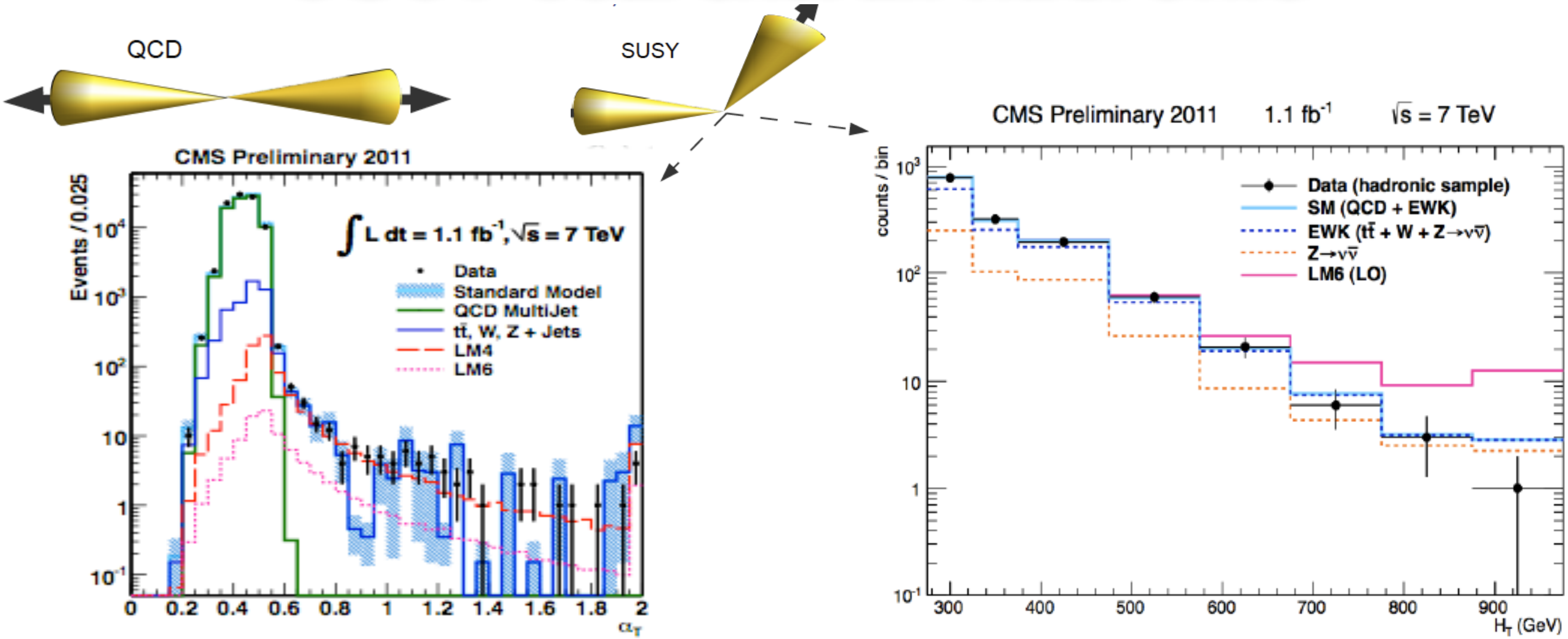
- Preselections
  - ✓ Two isolated leptons pt>10/20 GeV
  - ✓ MET> 50 GeV
  - ✓ At least two jets pt>30 GeV
  - ✓ Reject Z-boson in 76--106 GeV mass
- Main backgrounds
  - ✓ Top-pair production
- Seacrh with tighter HT, MET
  - ✓ Report limits for HT>600 GeV, MET>200 GeV
- Several methods to predict backgrounds
  - ✓ Predict MET from dilepton pt
    - See results p19
  - ✓ Use HT, y=MET/sqrt(HT) roughly uncorrelated variables
    - Extract functional shape as X(HT)*Y(y)





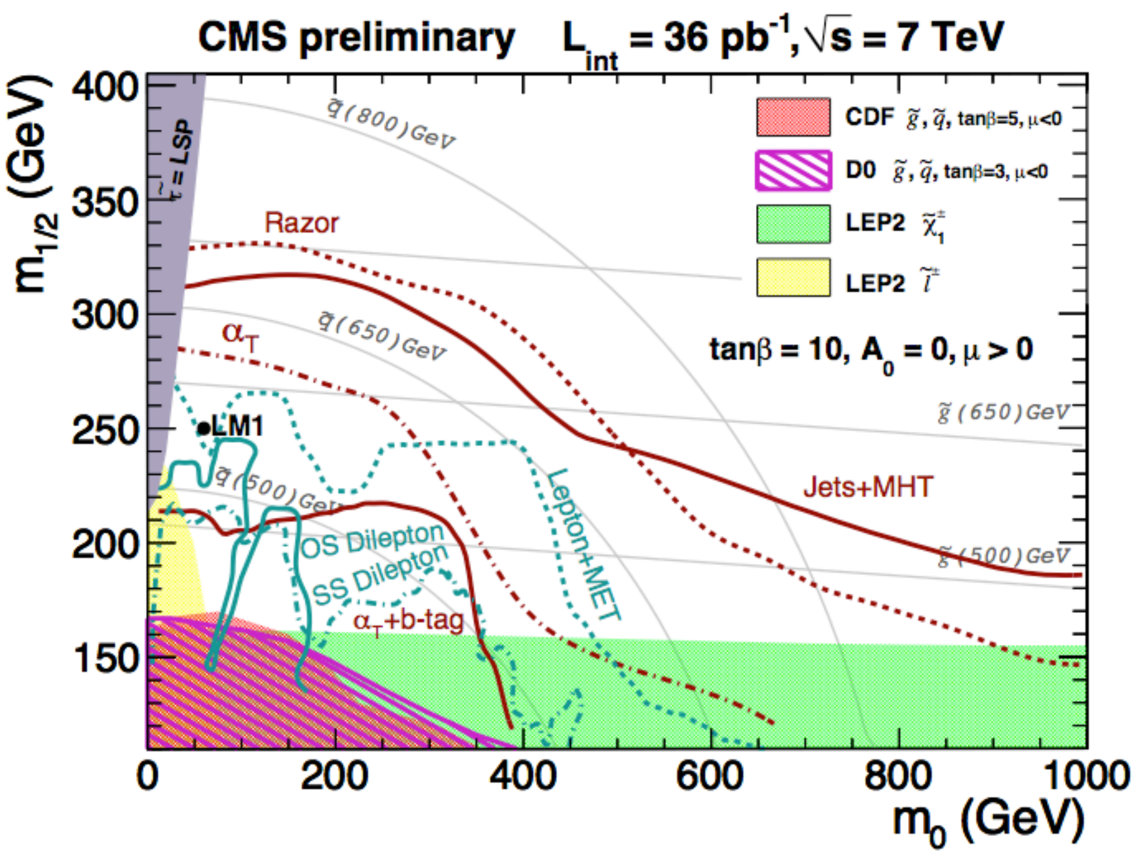
SUS-11-003

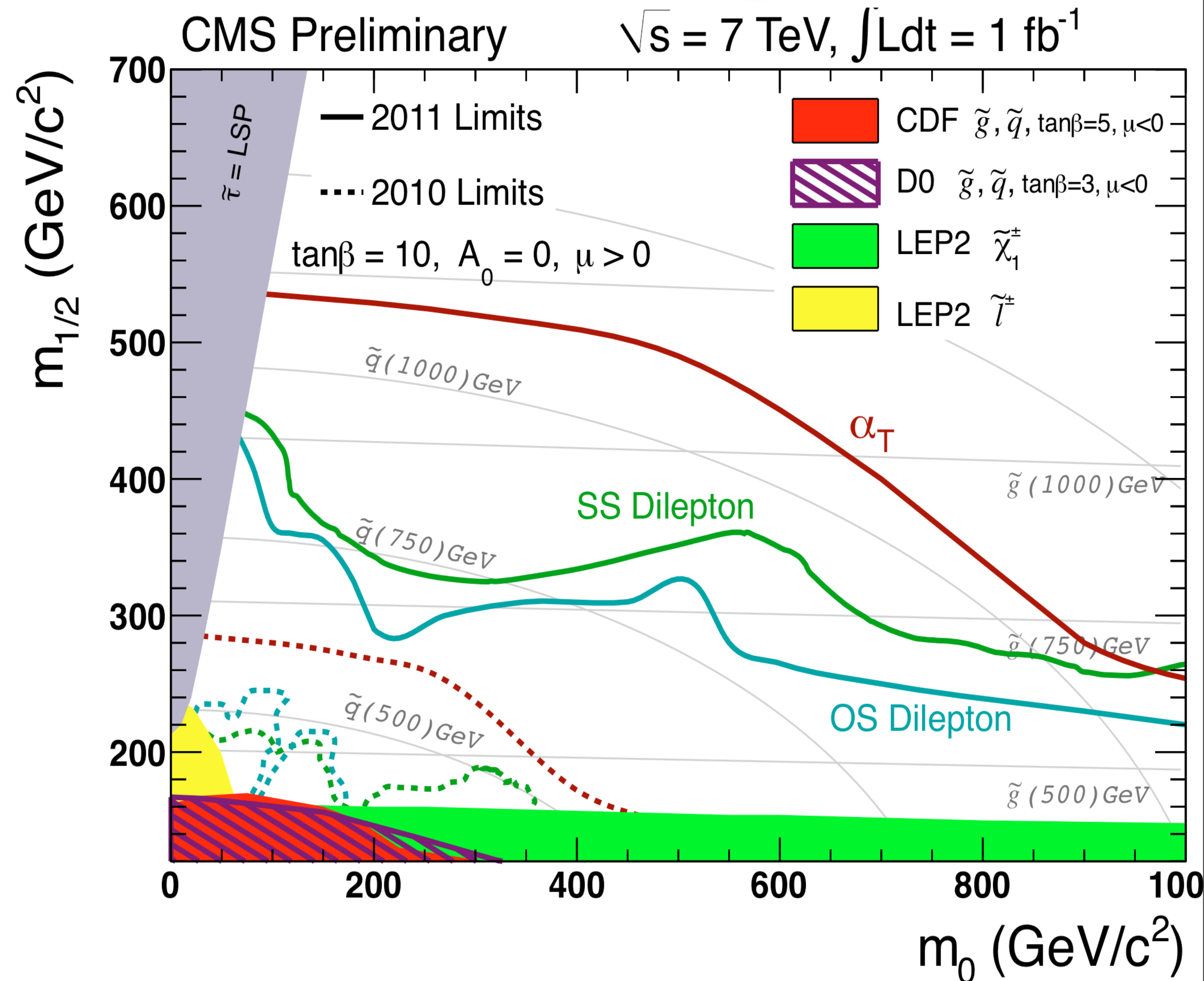
SUSY searchs: all hadronic



- A number of searches in multijet+MET signature
- Show here only the one with 2011 dataset: α_T analysis
- Main discriminant is α_T variable
  - ✓ 1) combine jets into two pseudo-jets
  - ✓ 2) $\alpha_T = p_{T,jet2}/M_T$, where M_T= sqrt[2 pt1 *pt2 * {1 - cos (ϕ1-ϕ2)}]
- Set limit based on observation of counts with α_T >0.55 in HT bins

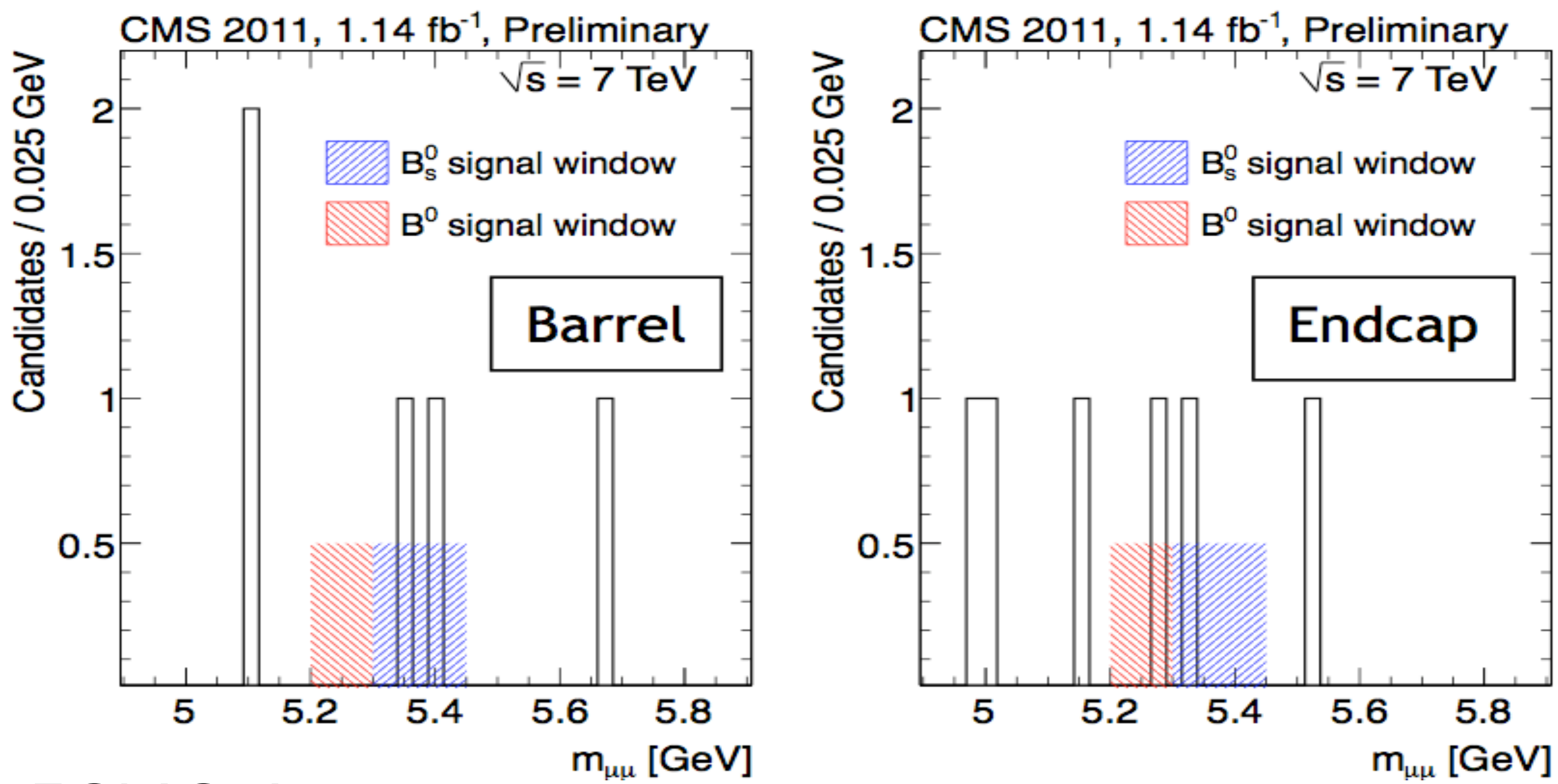
SUSY searches: summary





- No SUSY here
- Excluded squark/gluino masses around 1 TeV
- Observed limits agree with expected

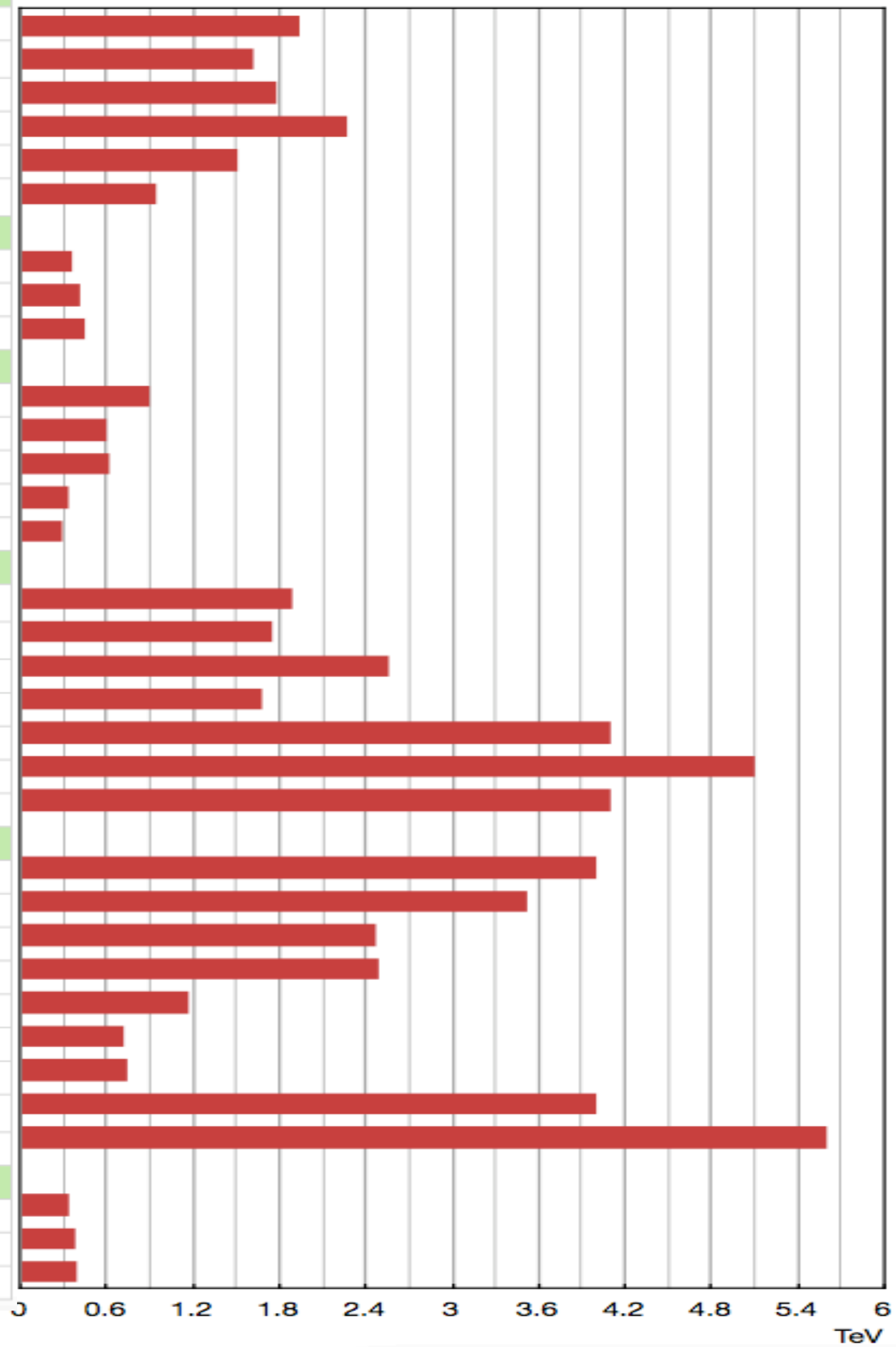
SUSY-related: Bs→ μμ



- Rare FCNC decays
  - ✓ SM: $Bs \to \mu^+\mu^- = (3.2 \pm 0.2) \times 10^{-9}$; $Bd \to \mu^+\mu^- = (1.0 \pm 0.1) \times 10^{-10}$
  - ✓ Large enhancements possible in MSSM with large tan β
- Observed limits in agreement with expectations
  - ✓ $Bs \to \mu^+\mu^- < 1.9 \times 10^{-8}$ (95% CL) $Bd \to \mu^+\mu^- < 4.6 \times 10^{-9}$ (95% CL)
- Very timely result in view of (~2 sigma) excess reported by CDF
  - ✓ Bs from CDF $1.8^{+1.1}_{-0.9} \times 10^{-8}$

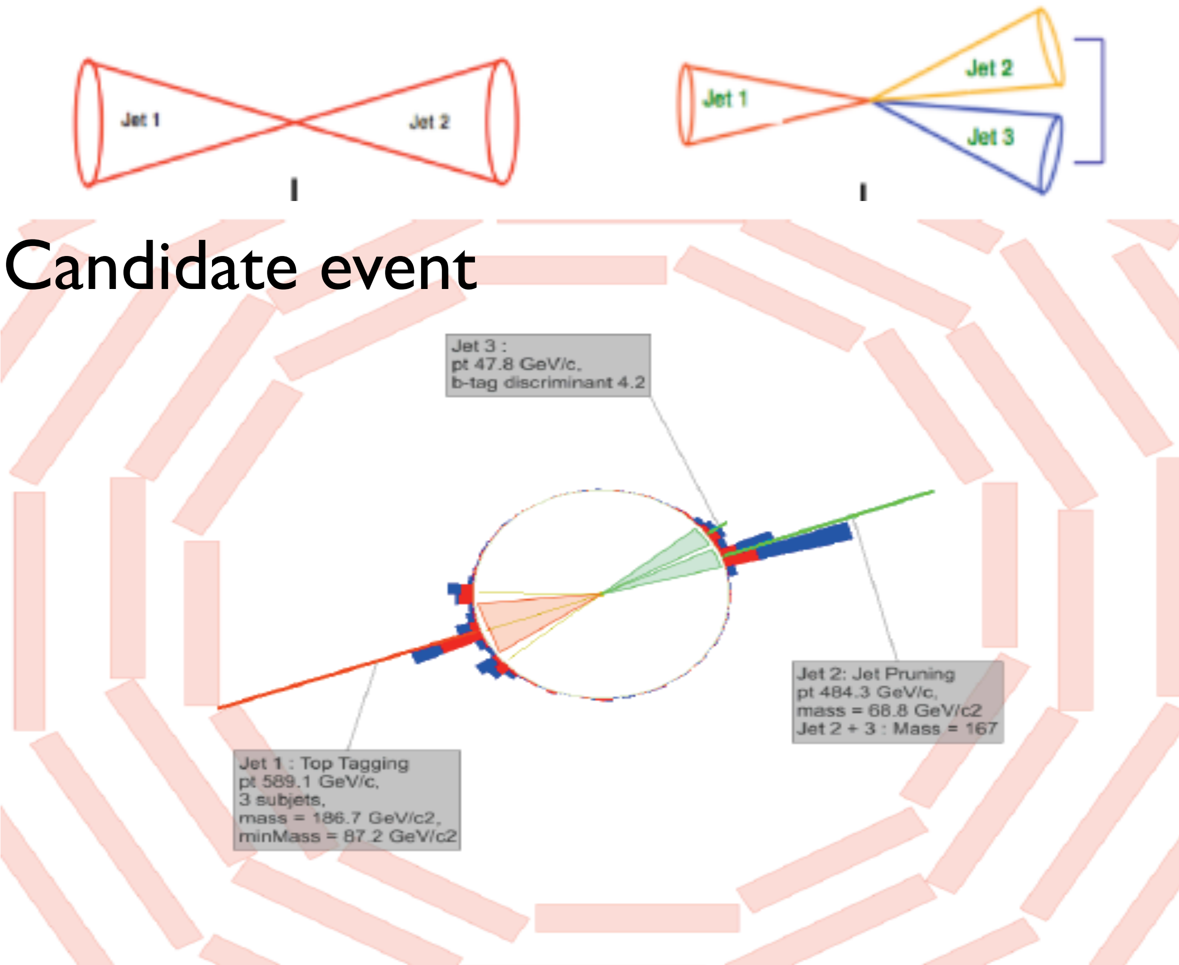
Other exotic searches: summary

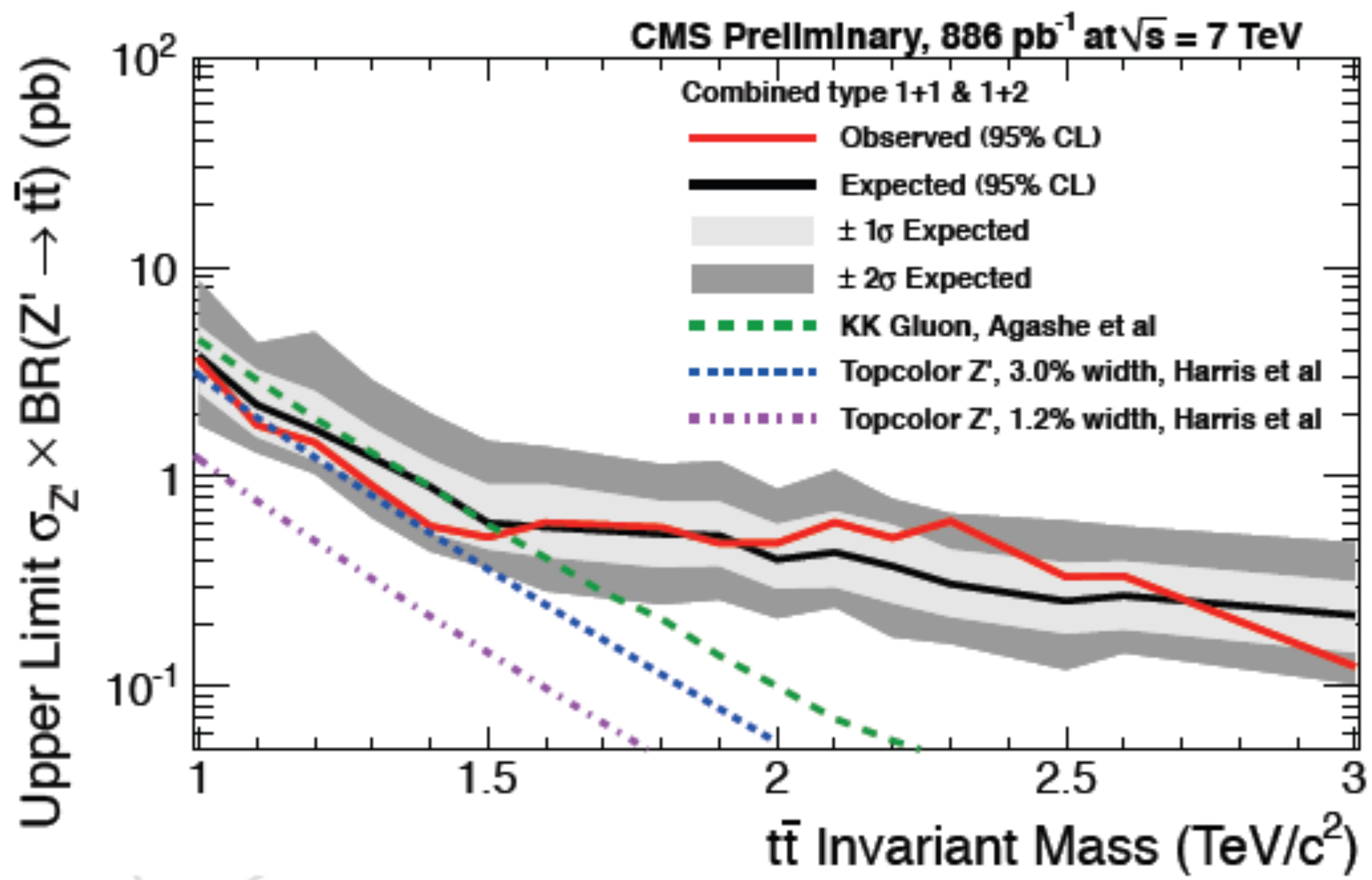
	Limits in TeV	
	Heavy Bosons	
Z'_{SSM} ll	1.94	2011
Z'_{Ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lν	2.27	2011
W' dijet	1.51	2011
G_{KK} γγ k/M = 0.1 (2010)	0.945	2010
	4th Generation	
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
	Heavy Stable Particles	
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
	Large Extra Dimensions	
M_s, γγ, GRW (2010)	1.89	2010
M_s, μμ, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
	Compositeness and Contact Interactions	
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q* , dijet	2.49	2011
q* , boosted Z	1.17	2010
e*, Λ = 2 TeV	0.720	2010
μ*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , X analysis	5.6	2010
	LeptoQuark	
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010



(EXO) Z'→ tt all hadronic

Candidate event

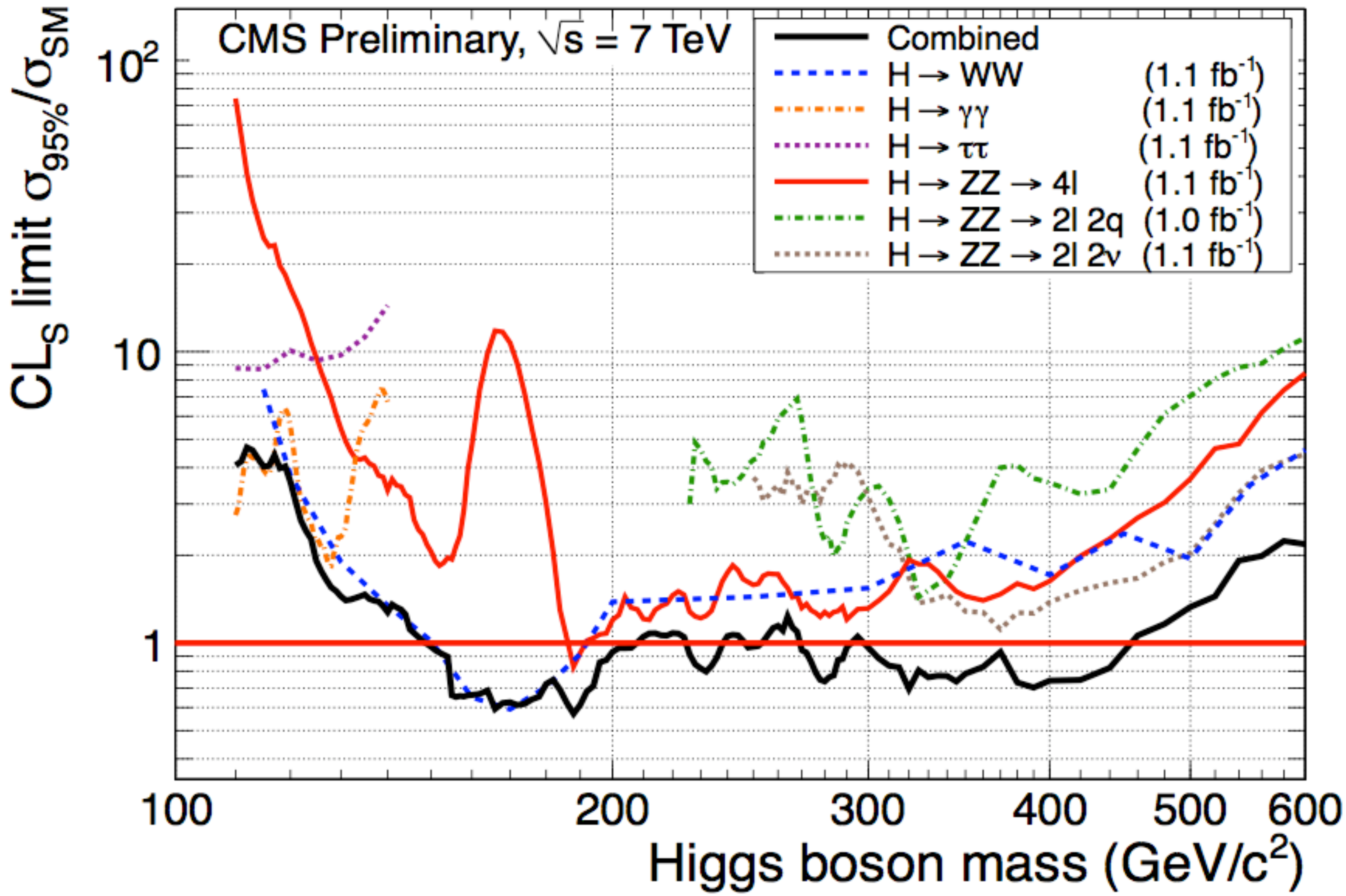




- Random-picked analysis from the summary on prev page
- Features successful analysis using jet reconstruction with jet substructure
  - ✓ Top-tagging, reconstructs boosted top→ 3 subjets inside a fat jet
  - ✓ (Jet pruning), reconstructs boosted W→ 2 subjets inside a fat jet
- Main background is QCD, estimated from events with jets failing tagging requirements

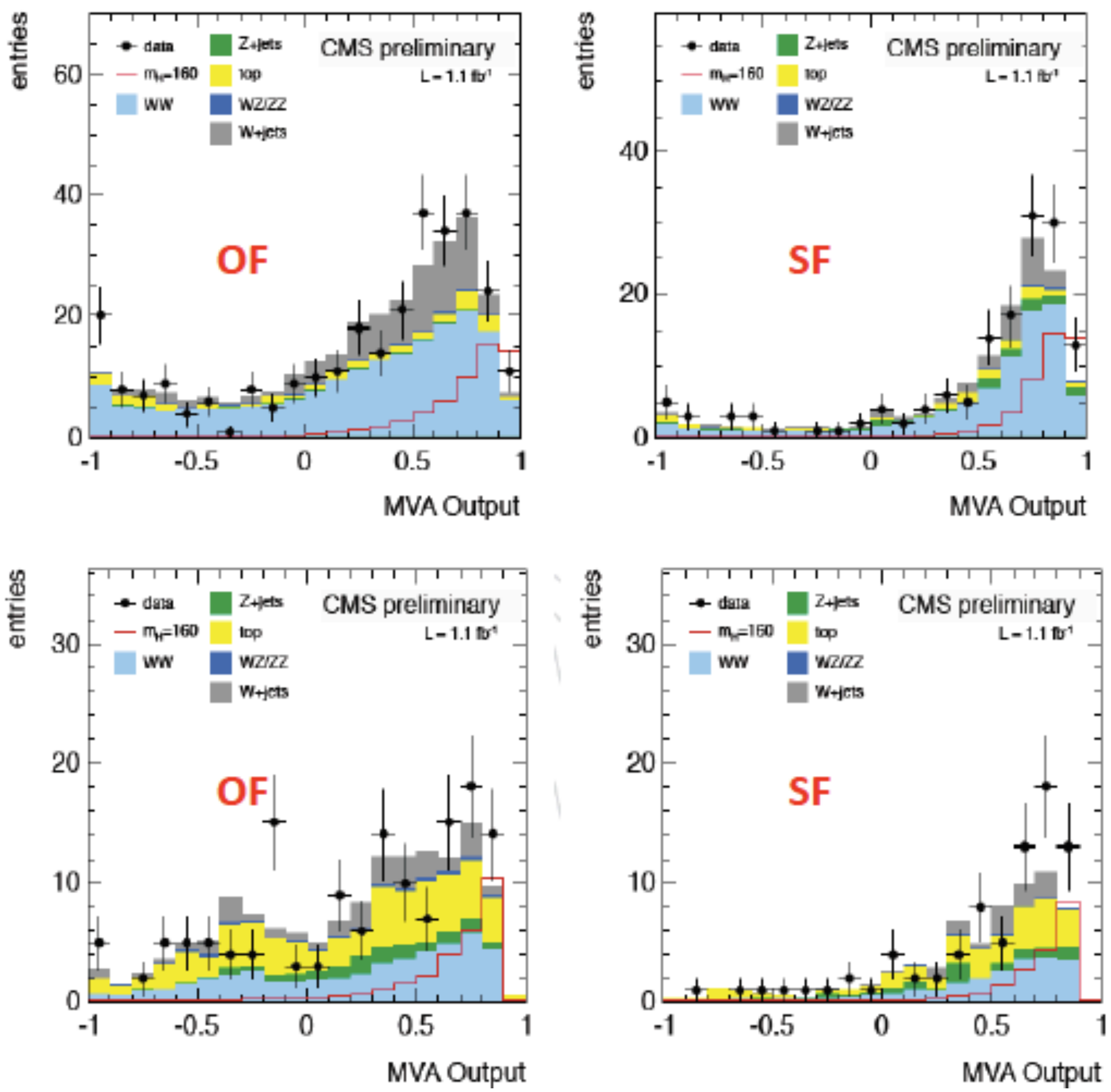
Almost verbatim copy from G.Tonelli at EPS2011

Search for the SM Higgs Boson



- Significant contributions from many channels
  - ✓ H->WW has probably the most significant contribution in the range m 120--300 GeV

H→ WW → 2l2ν



0 jets

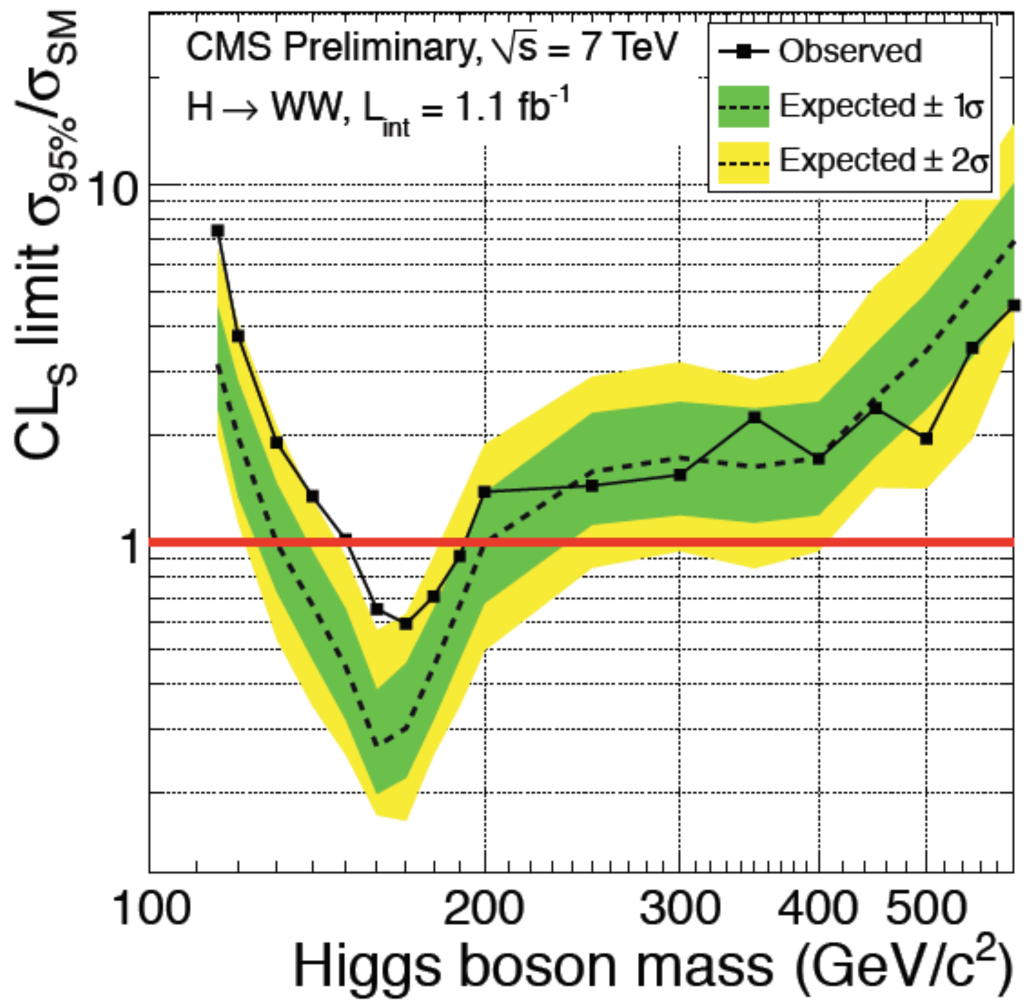
1 jet

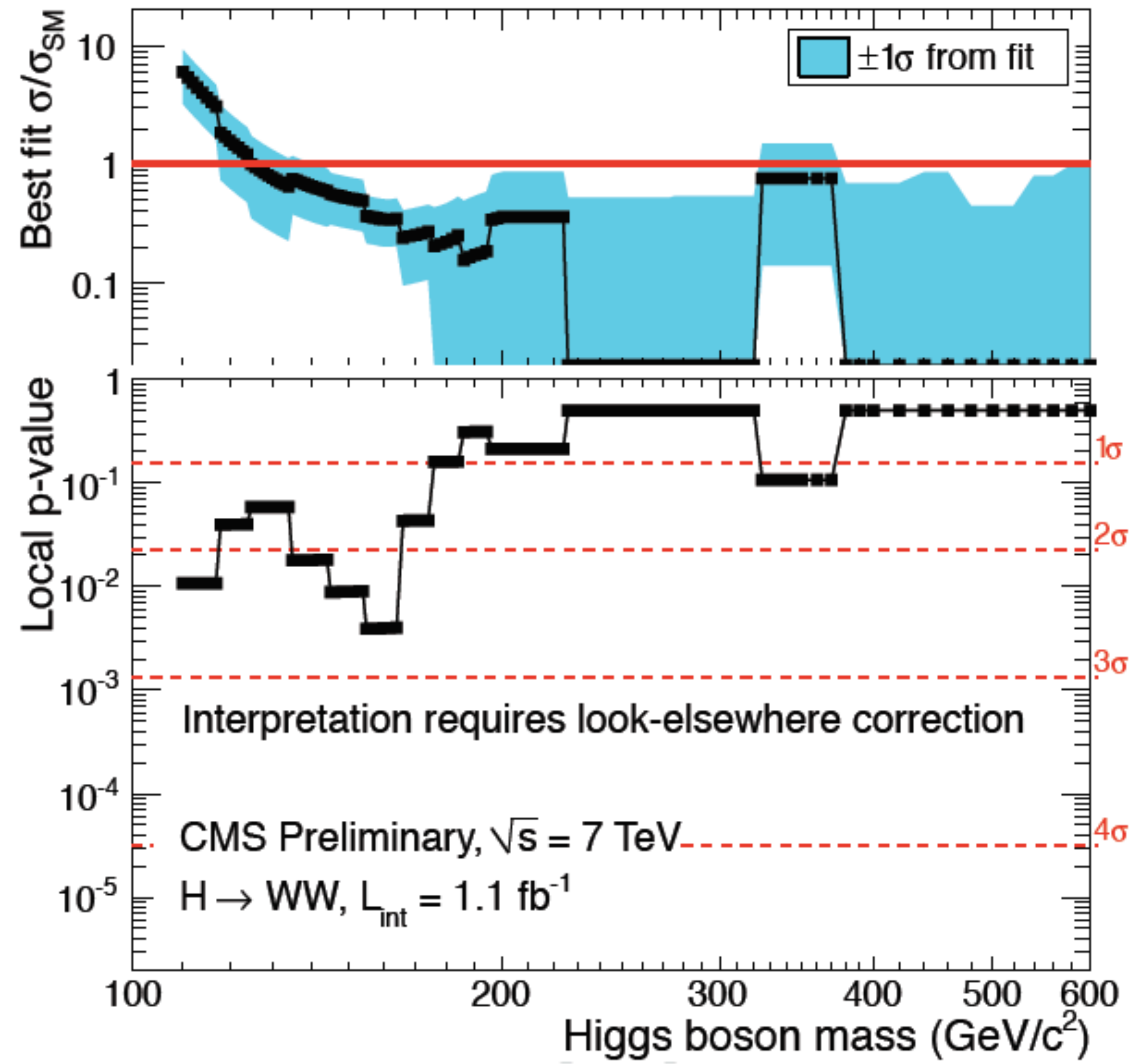
CMS PAS-HIG-11-003

- Preselections
  - ✓ Two isolated leptons pt>10/20 GeV
  - ✓ MET>40 GeV ee/μμ; >20 GeV in eμ
  - ✓ Veto Z-mass in ee/μμ
- Cut-based and multivariate (BDT) analyses
  - ➡ Cut-based used as cross-check
  - ✓ Higgs-mass-dependent requirements on dilepton mass
- Main backgrounds
  - ✓ Wjets
  - ✓ top-pair production
  - ✓ Drell-Yan
  - ✓ WW continuum

CMS PAS-HIG-11-003

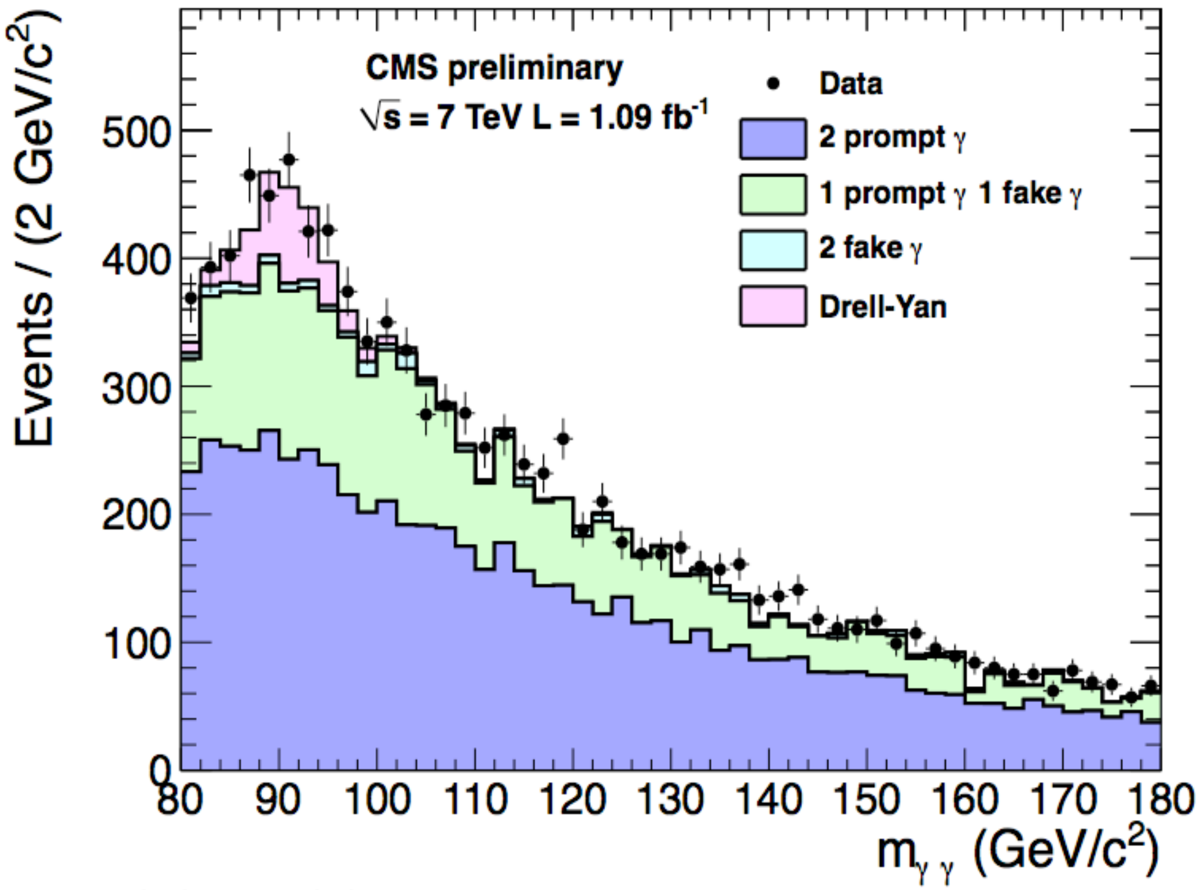
H → WW → 2l2ν



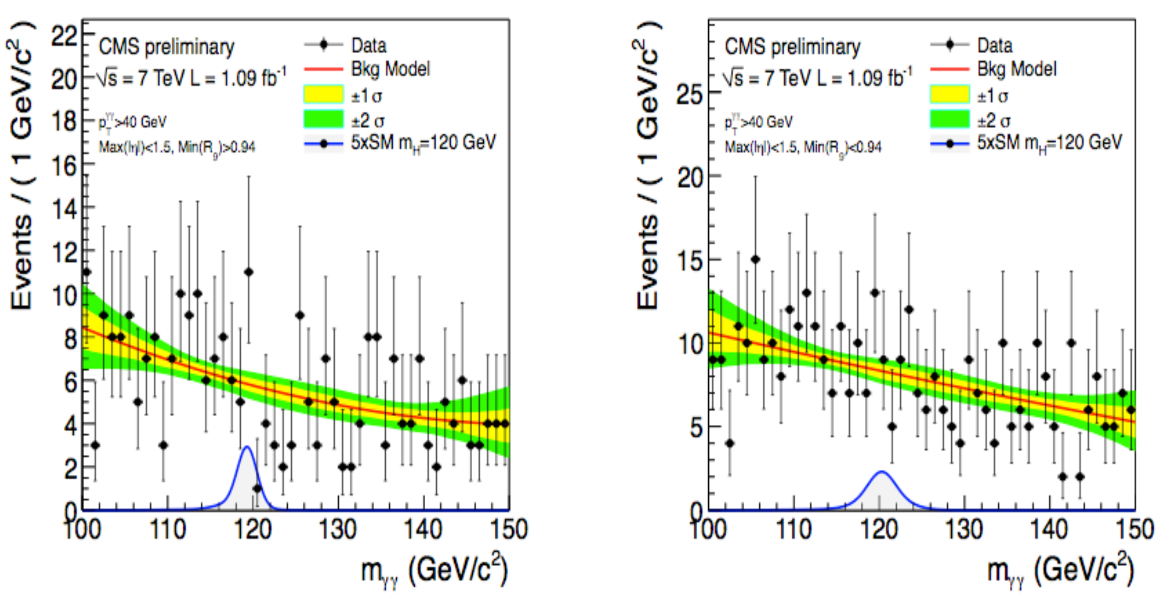


- Poor mass resolution
  - ✓ *Higgs would appear as a broad excess*
  - ✓ *Some background excess will affect a broad range of Higgs masses as well*
  - ✓ *Correlation "length" at low-mass is ~30 GeV (distance of the effect)*
- Observed exclusion 150-193 GeV
  - ✓ *For m<200 GeV the limit is not as strong as expected due to +2σ deviation*
  - ✓ *Good agreement exp/obs at high masses*

H→ γγ

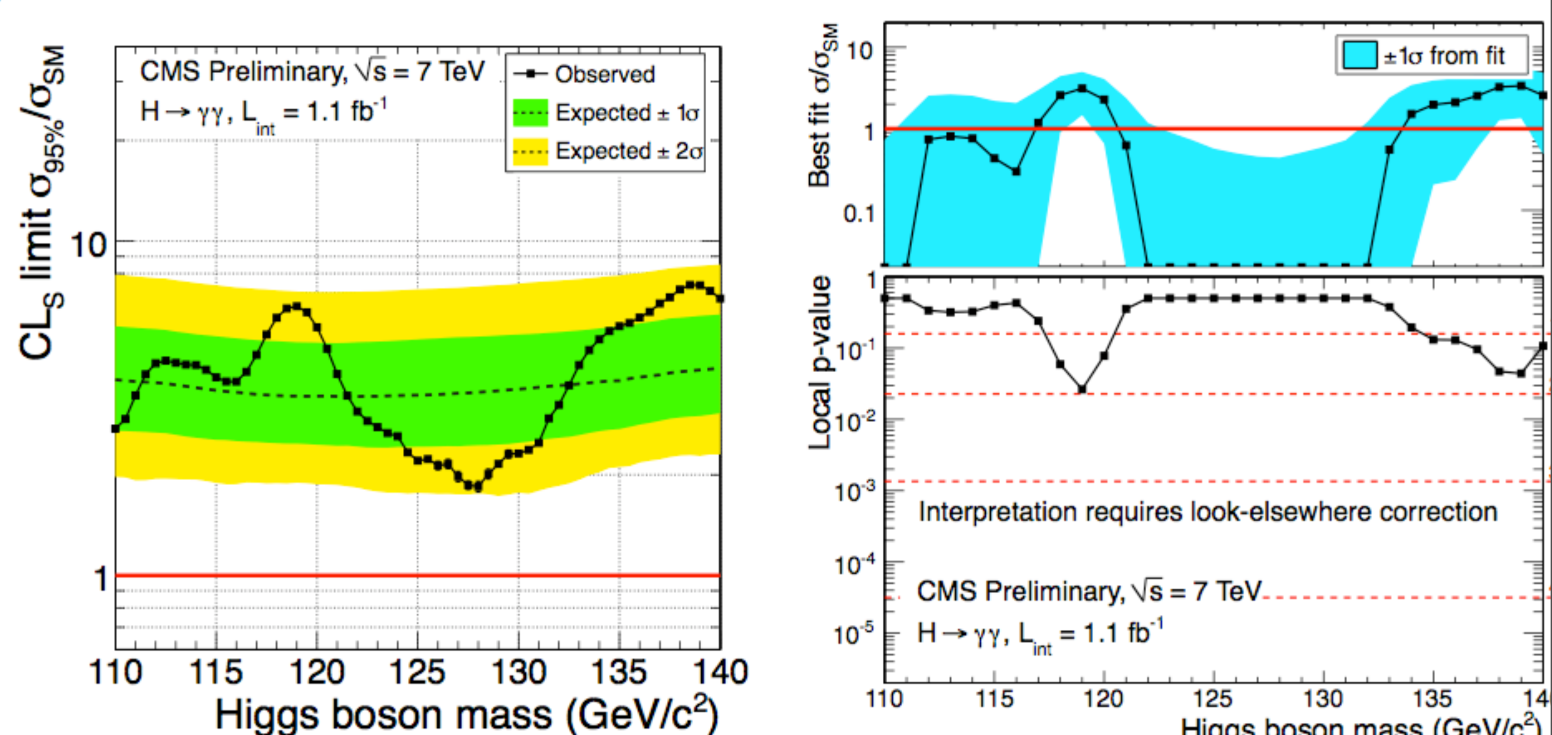


- Selection: two isolated photons pt>40/30 GeV
- Observed limit (2-7)XSM
  - ✓ *Excursions are in agreement with expectations*
- 1-2GeV mass resolution expected to improve later this year
  - ✓ *The main challenge is calibration and selection of correct pp collision vertex*



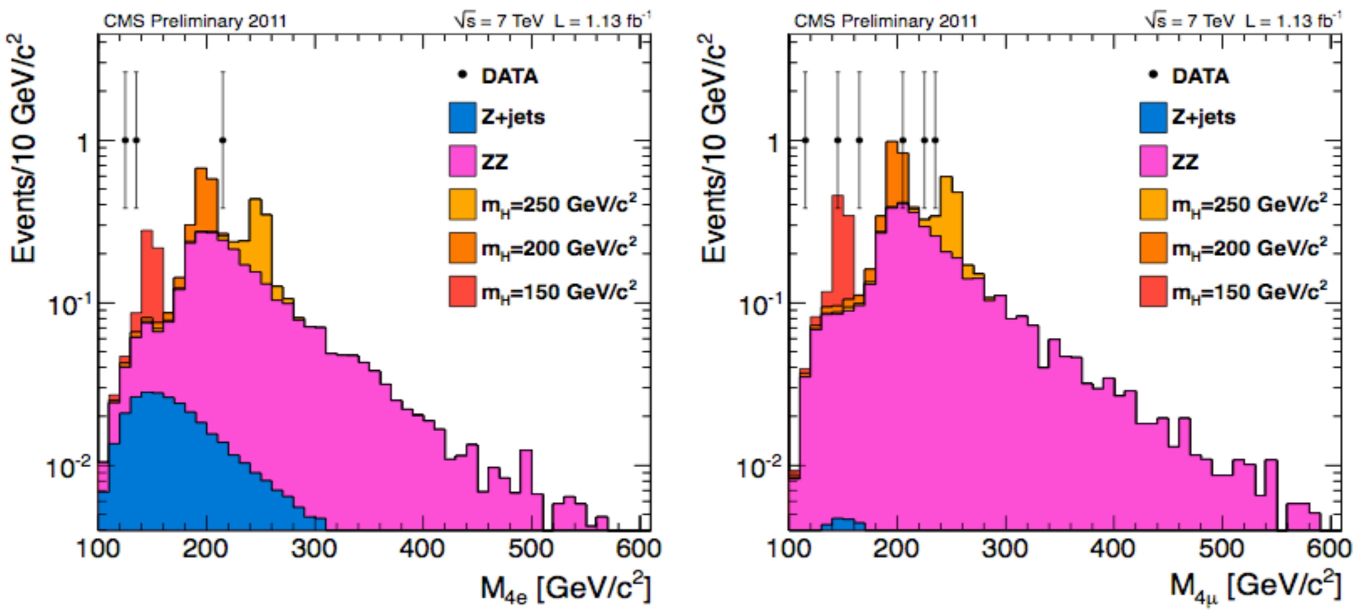
(a) (b)

CMS PAS-HIG-11-010



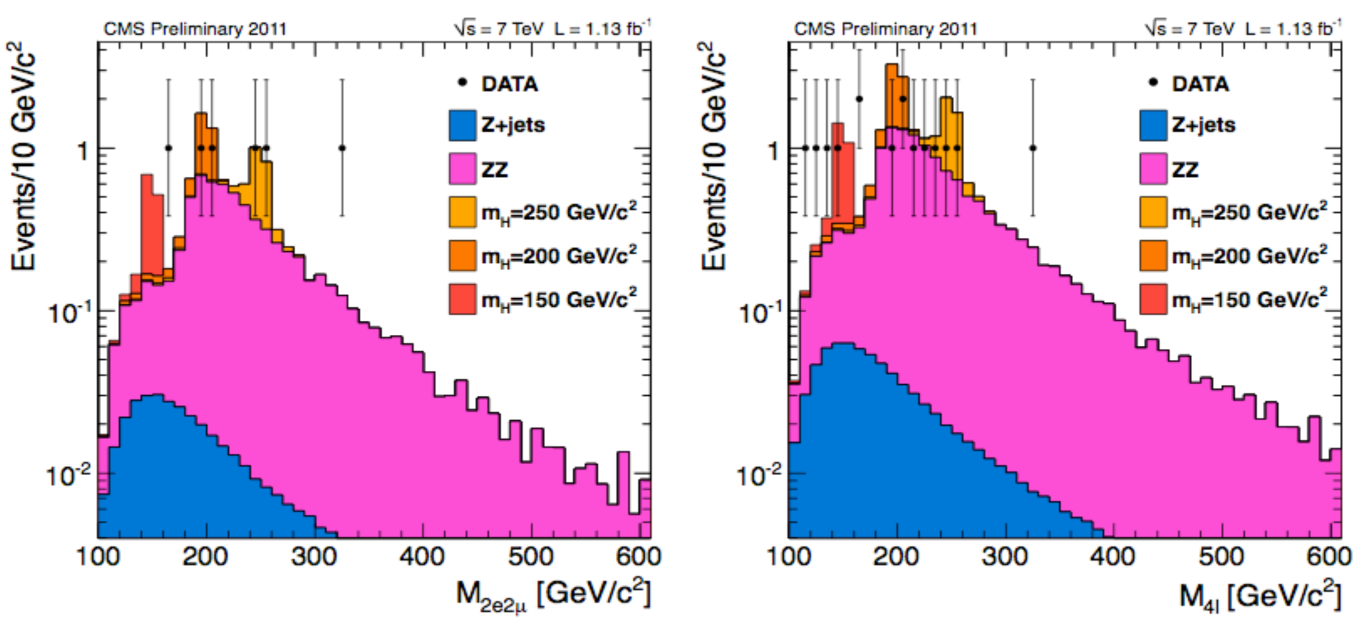
(a) (b)

H→ ZZ→ 4leptons

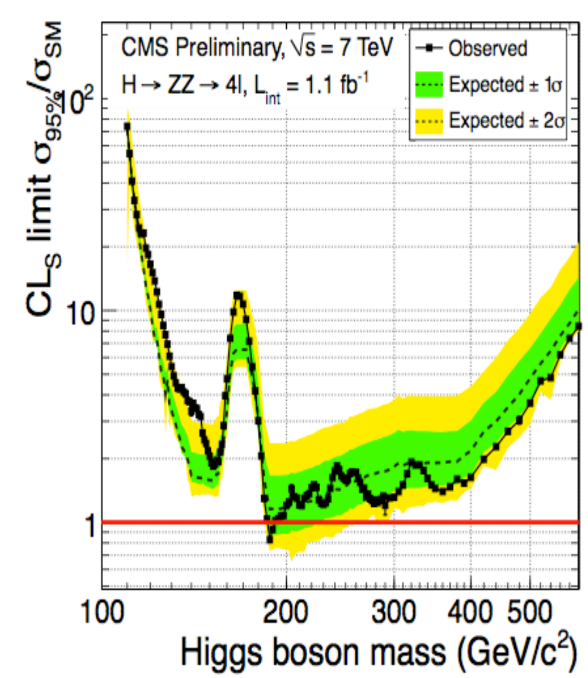


(a) (b)

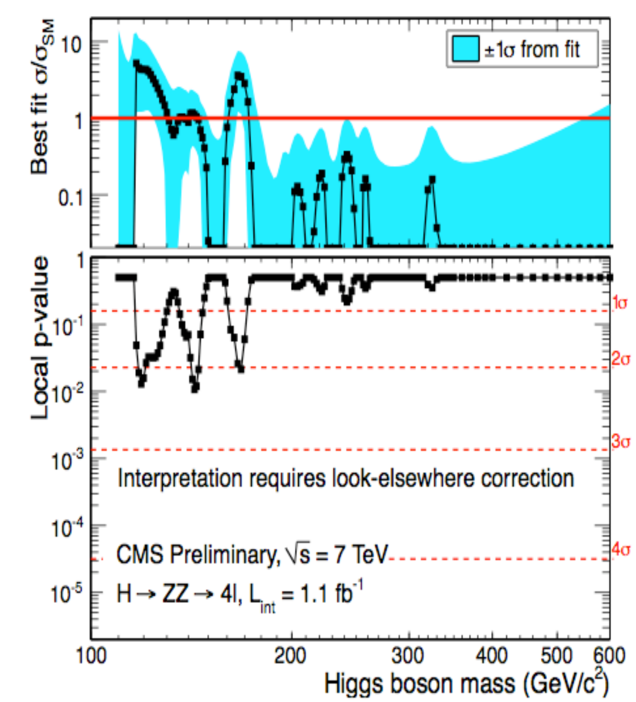
m(4l), GeV	flavor	dm(4l), %	dm(4l), GeV	compatibility (sigma)	expected SM H events
119	4m	0.9%	1.1	2.5	0.25
124	4e	1.4%	1.7		0.49
139	4e	0.9%	1.3	2.1	1.6
144	4m	1.4%	2.0		1.8
163	2e2m	1.1%	1.8	1.8	0.61
168	4m	1.3%	2.2		0.45



(c) (d)



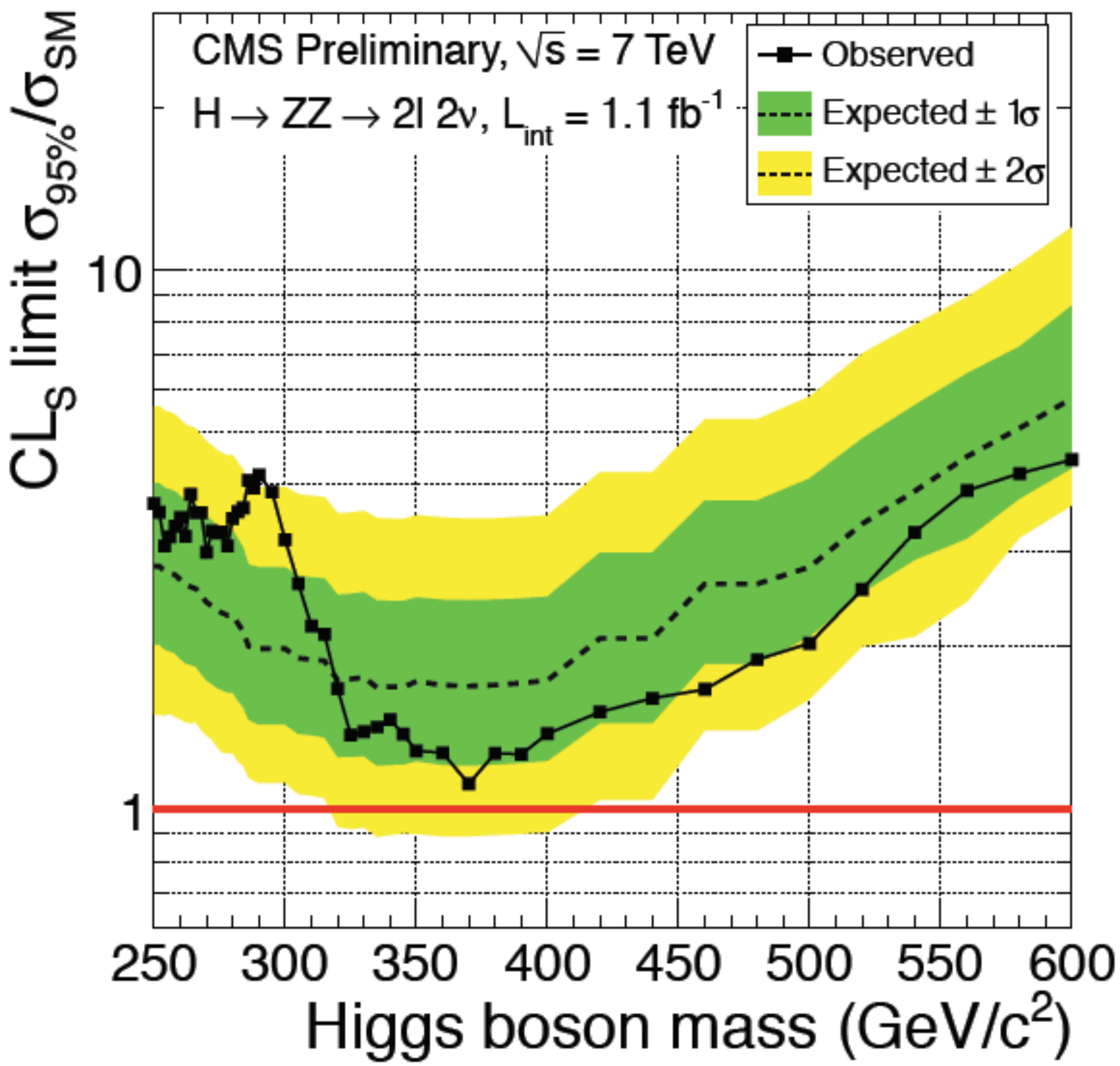
(a)

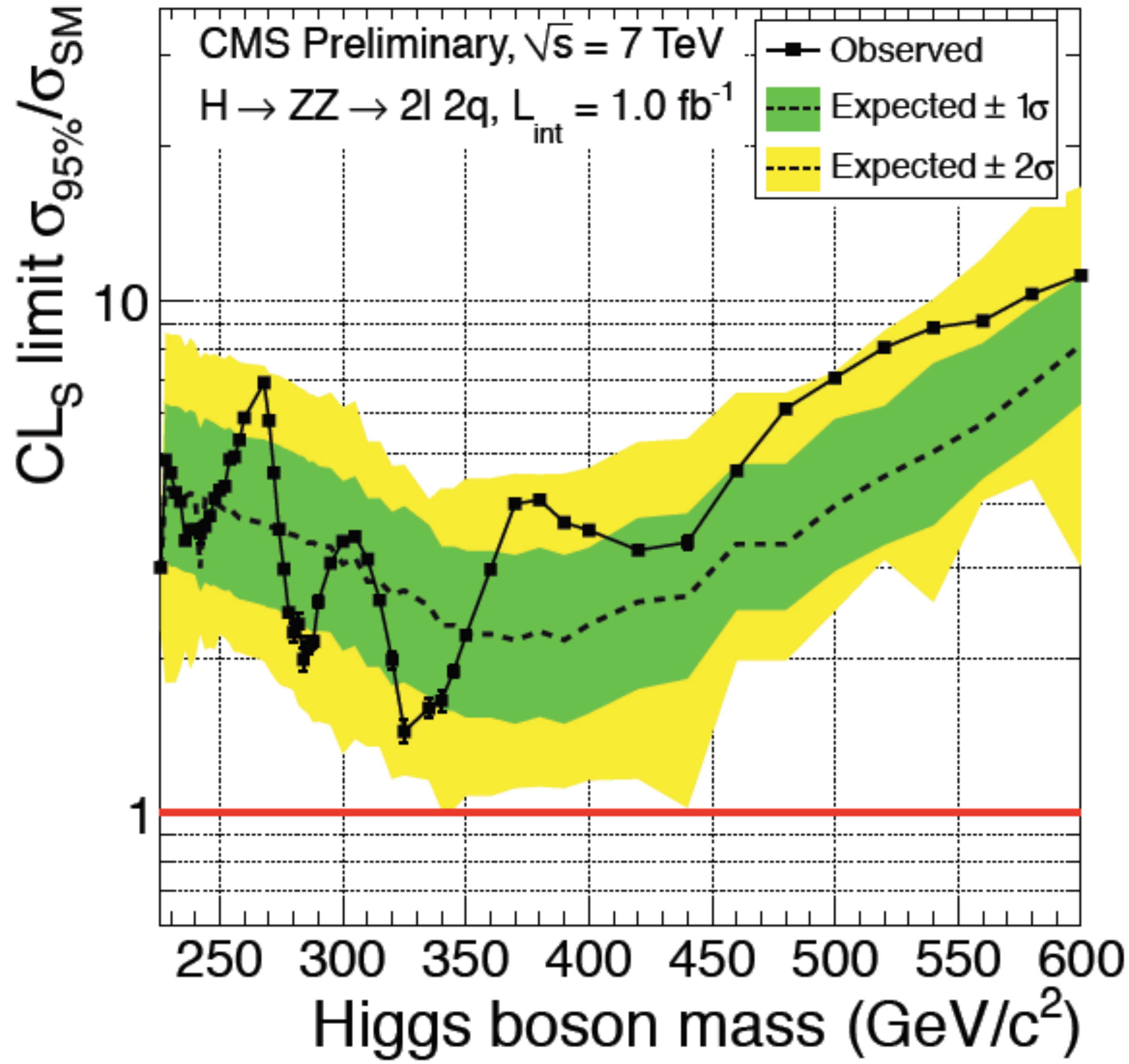


(b)

- Low sensitivity, high resolution
- Look-elswhere-effect (LEE) ~100 washes out significance of excesses
- Pairs of events at 120 and 160 GeV imply too large signal

H→ ZZ→ 2l2ν, 2l2q

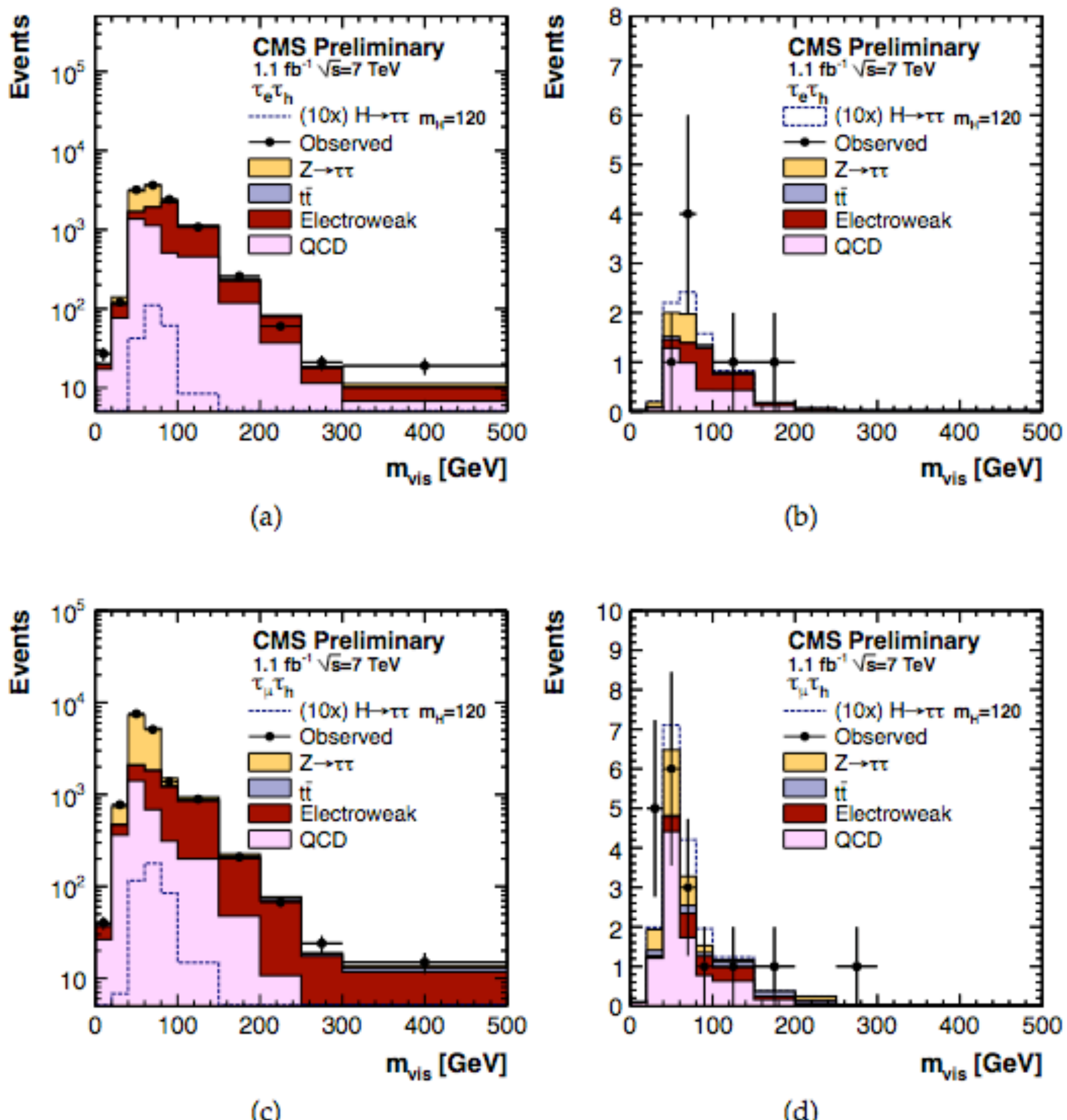


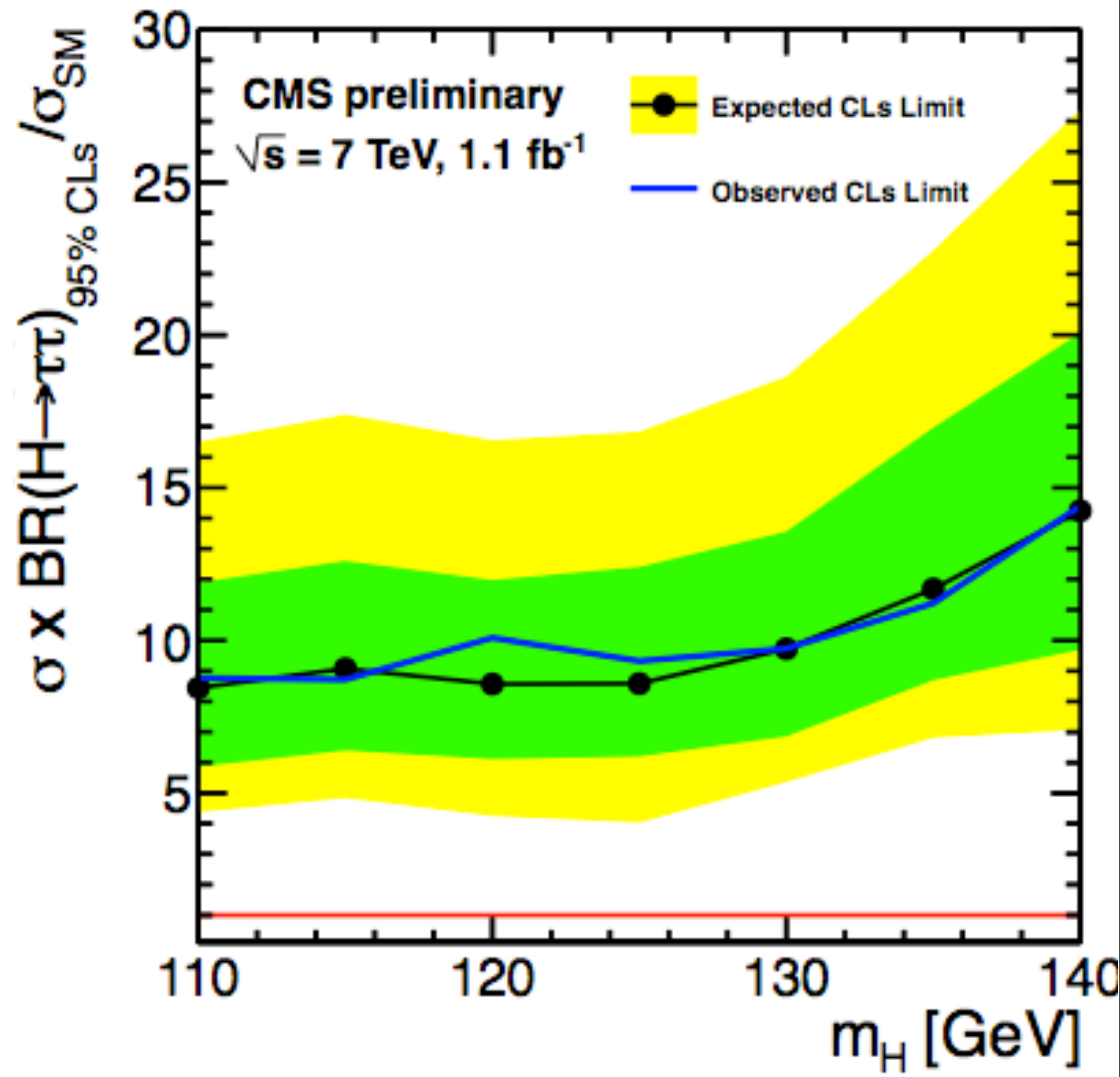


- H→ ZZ→ 2l2ν has low mass resolution 50 (200) GeV for low (high) m_H
- H→ZZ → 2l2q mass resolution ~3% (6%) for masses 250 (500) GeV
- No significant excess in either of the channel

CMS PAS-HIG-11-009

H→ ττ

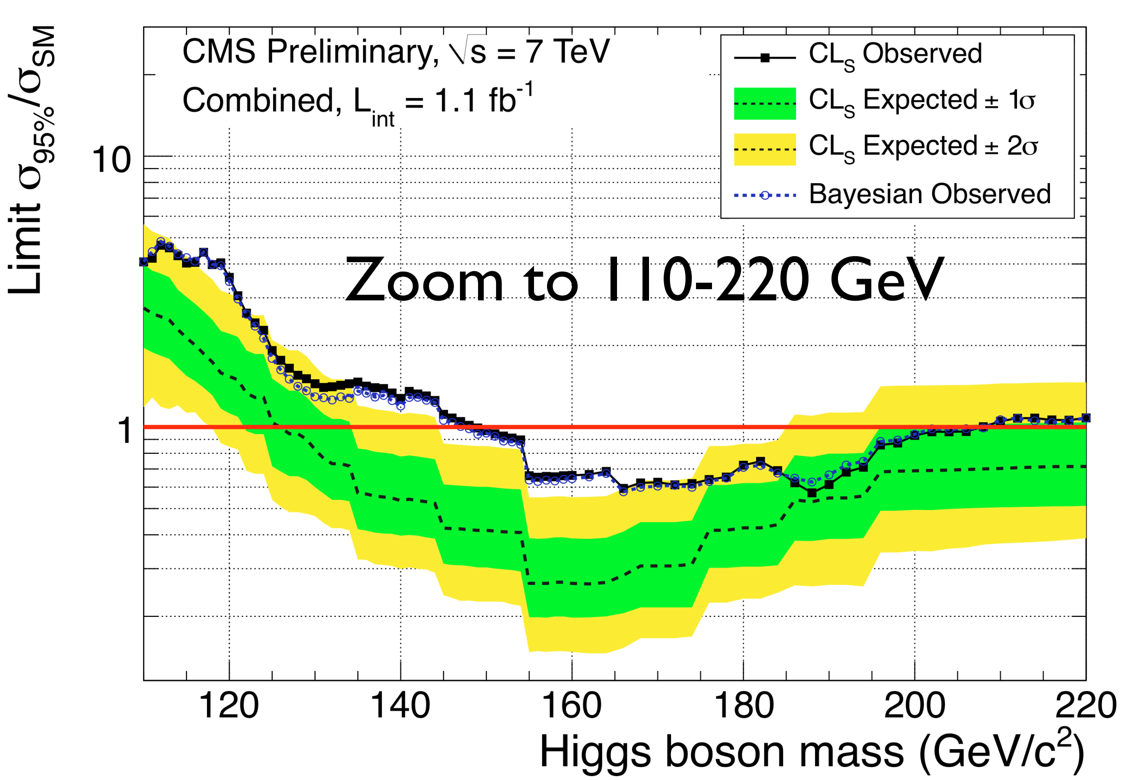


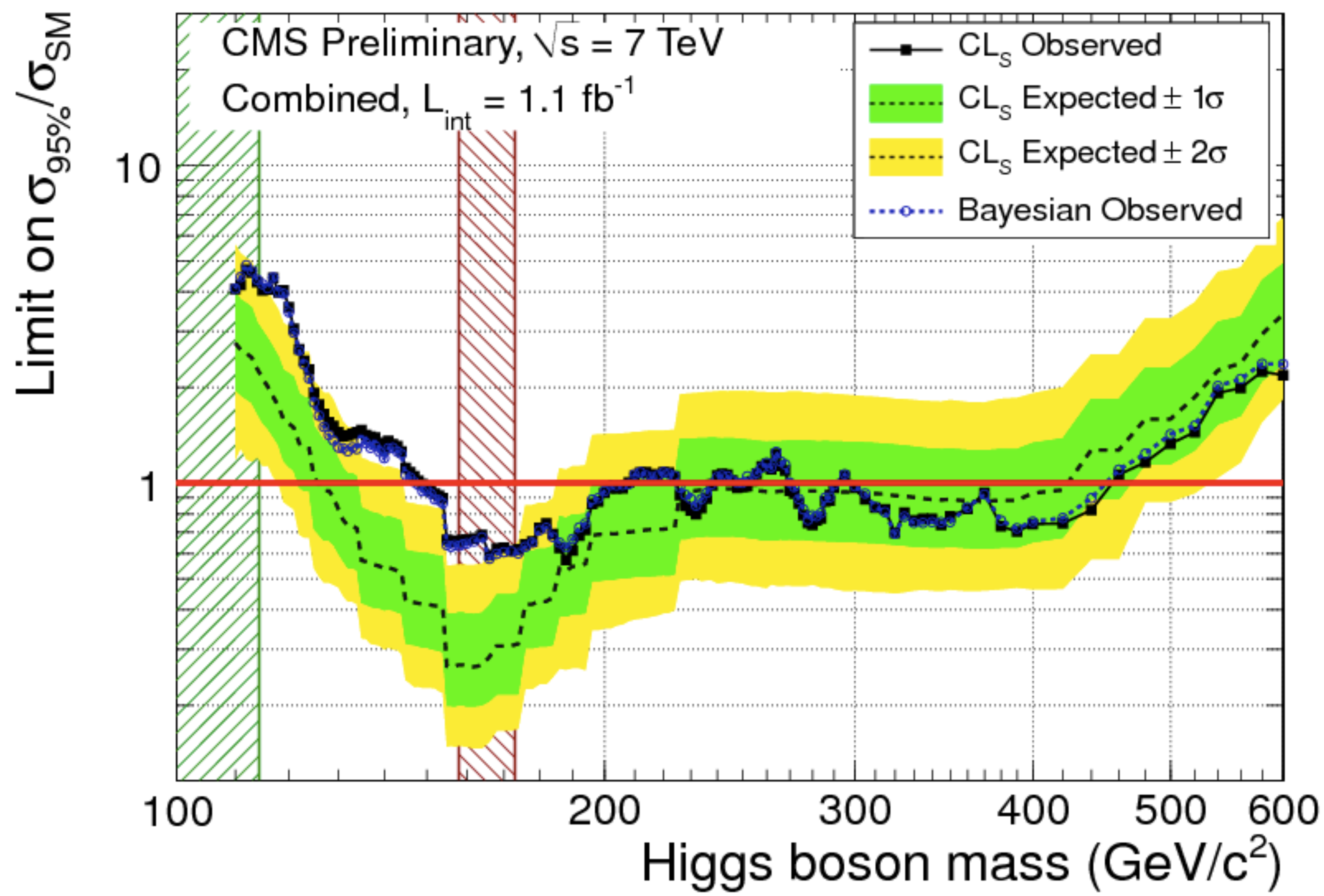


- Low sensitivity, medium resolution
- Challenging backgrounds
- Observed exclusion ~ expected

Combined limits on SM Higgs

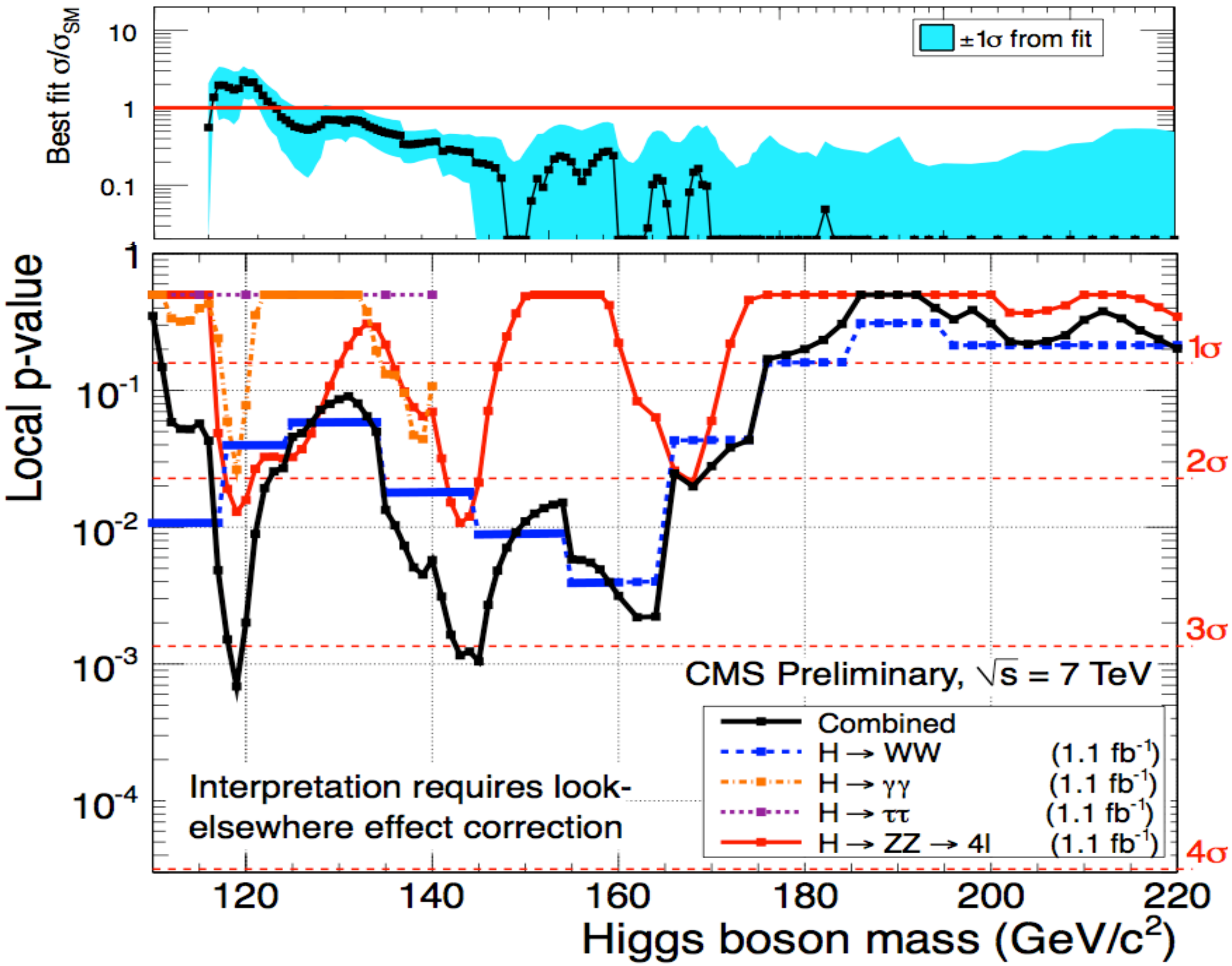
CMS PAS-HIG-11-011





- Expected exclusion: 127--420 GeV; observed 149--206 U 300-400
- Excesses seen show only local significance, without correction for LEE
- More data is needed to understand if these are fluctuations

p-value for Higgs combination

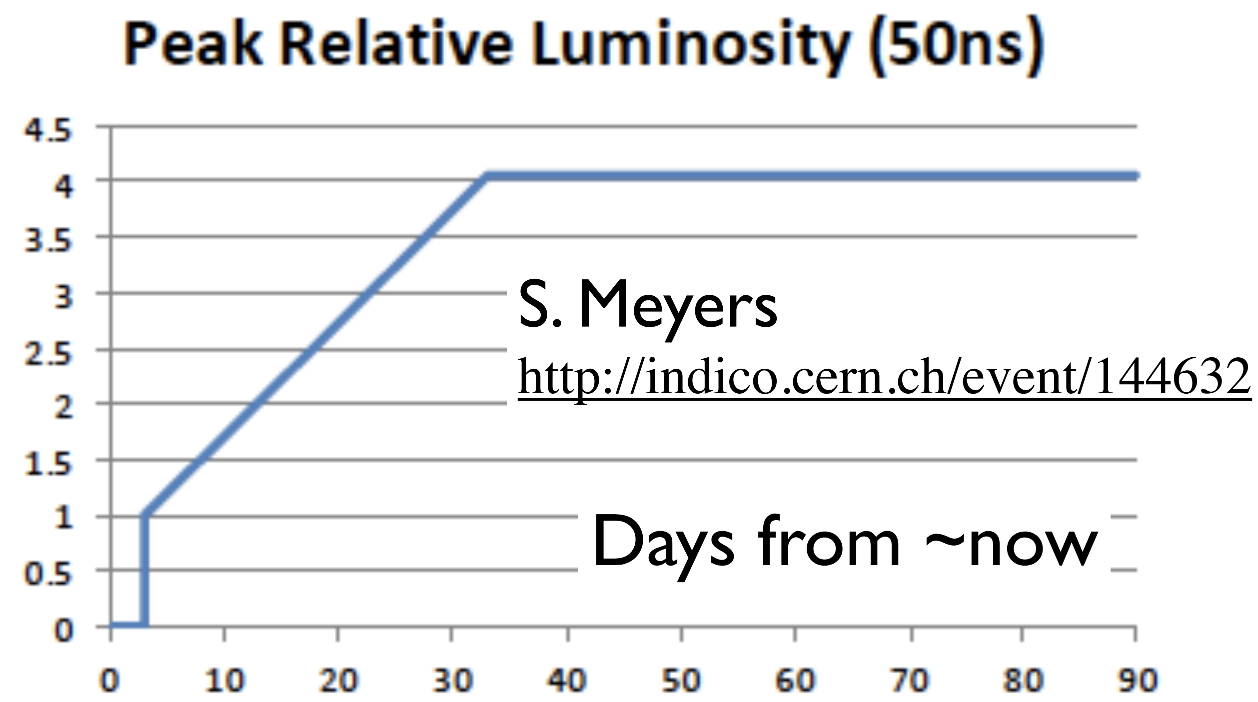


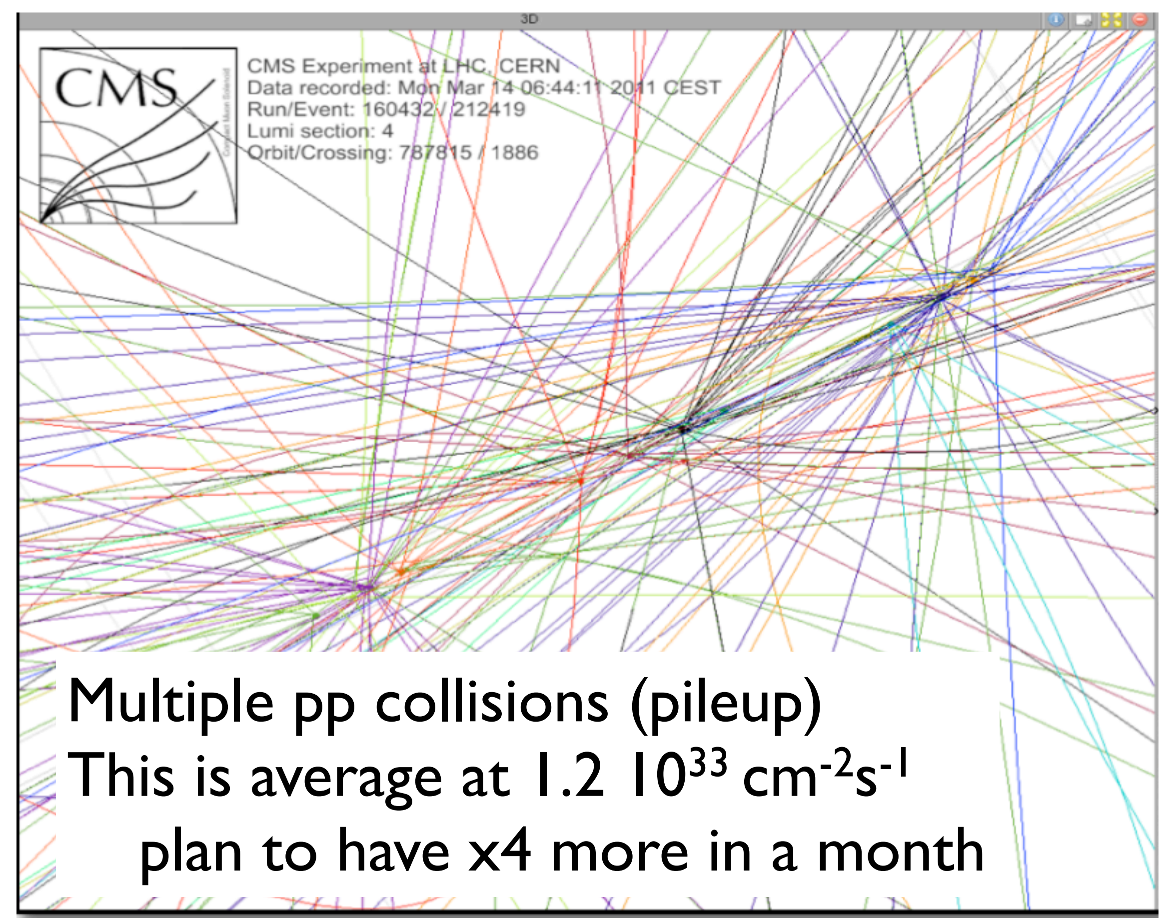
- Look-elswhere-effect is not included here
- These results will be updated with more data end of August

What's ahead: 2011

- Expect ~50 days at $5 \times 10^{33} cm^{-2} s^{-1}$
  - ✓ *This is about 0.1 fb^{-1} per day*
  - ➡ About x5 data to analyze
- Higher luminosity gives harsher environment for CMS
  - ✓ *More backgrounds from pileup*
  - ✓ *Higher trigger rates*
- More data gives more chance for discoveries, or at least better limits
  - ✓ *We'll be much more certain where the Higgs is not*

- Past 2011
  - ✓ *a) collect more data at same energy*
    - ◉ Maybe x3-5 of 2011 dataset
  - ✓ *b) increase the energy (up to 14 TeV)*
    - ◉ Still expected only in 2014





Multiple pp collisions (pileup)
This is average at $1.2 \; 10^{33} cm^{-2} s^{-1}$
plan to have x4 more in a month

Summary

- CMS is stepping forward confidently with analysis of data
- Excellent detector performance is established in all ingredients necessary to perform top physics analyses
- LHC run in 2010 brought almost 40 pb^{-1} of integrated luminosity, already analyzed and presented as early as at Moriond 2010
- LHC run in 2011 brings, excitingly, somewhat more data than expected. About 1 fb^{-1} of data has been analyzed and presented recently at EPS2011 in Grenoble.

- Sadly, we only know better where physics beyond the standard model is not
  - ✓ Higgs exclusion region by far surpasses that of the Tevatron
  - ✓ SUSY squark/gluino masses are pushed out to 1 TeV
  - ✓ Many more new particle scenarios are excluded as well

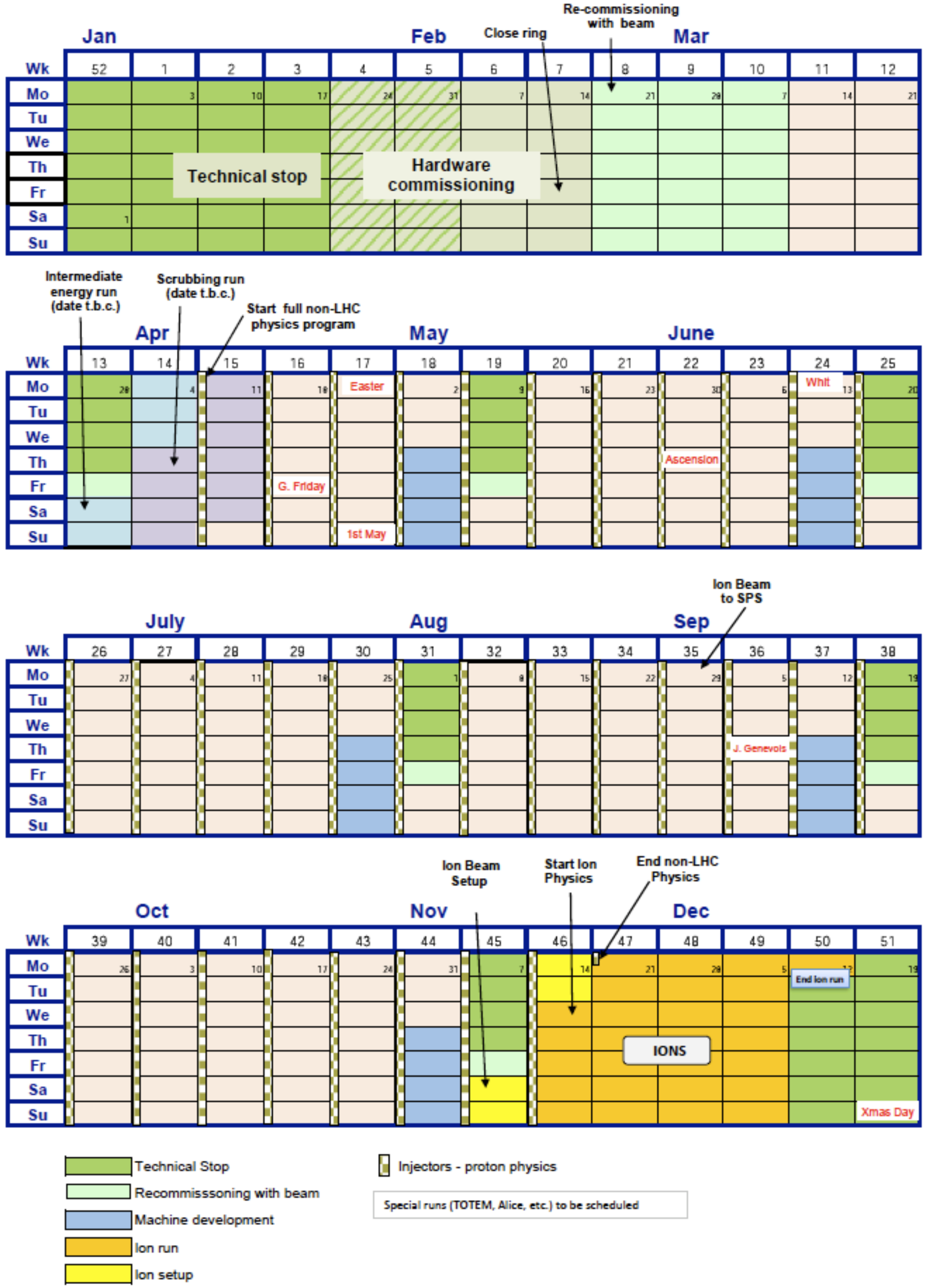
BACKUP SLIDES

ML

3/2/2011
V1.2

2011 LHC Schedule

Approved by the Research Board, December 2010



LHC Plans in 2011/2012

Geneva, 31 January 2011. CERN[1] today announced that the LHC will run through to the end of 2012 with a short technical stop at the end of 2011. The beam energy for 2011 will be 3.5 TeV.

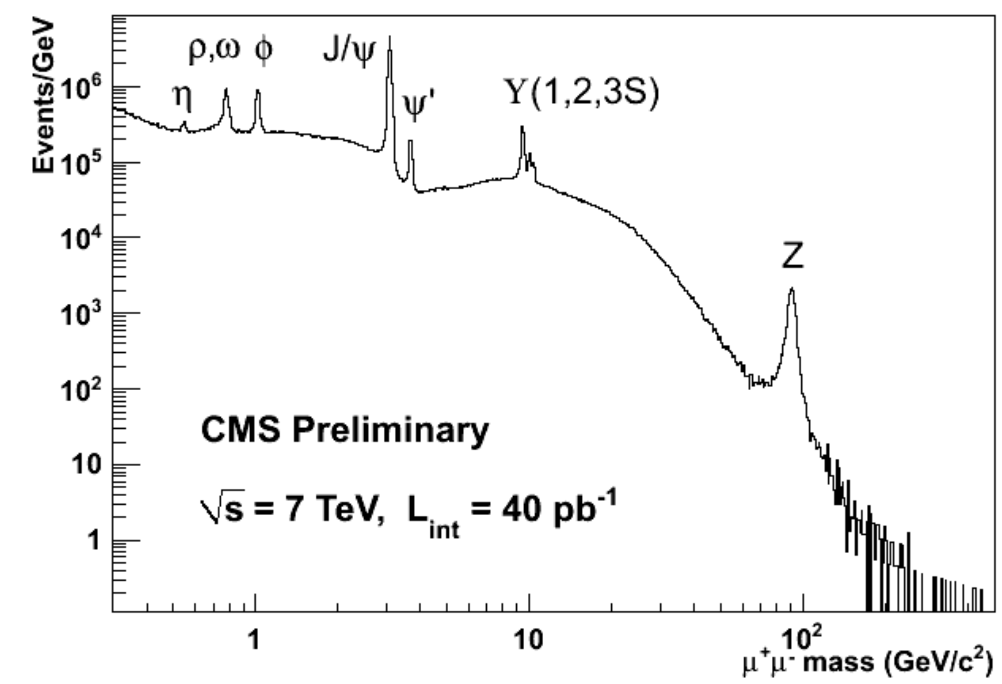
Summary of Chamonix 2011 Feb 9, 2011
http://indico.cern.ch/event/126218

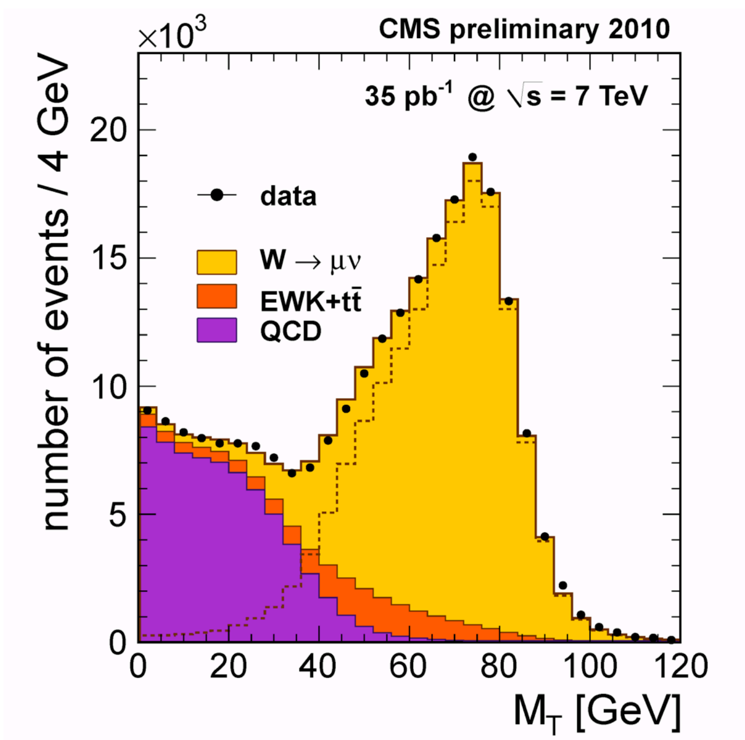
- 2011: collide at 7 TeV
- Baseline is 2×10^{32} cm^{-2} s^{-1} with 1 fb^{-1} delivered
- Following 2010 (closed at peak 2×10^{32} cm^{-2} s^{-1}), confident we will do better: possible integrated luminosity of 2-3 fb^{-1}
  - Running from 160 days @ 5E32 => 2 fb^{-1}; 125d@2E33 => 3 fb^{-1}

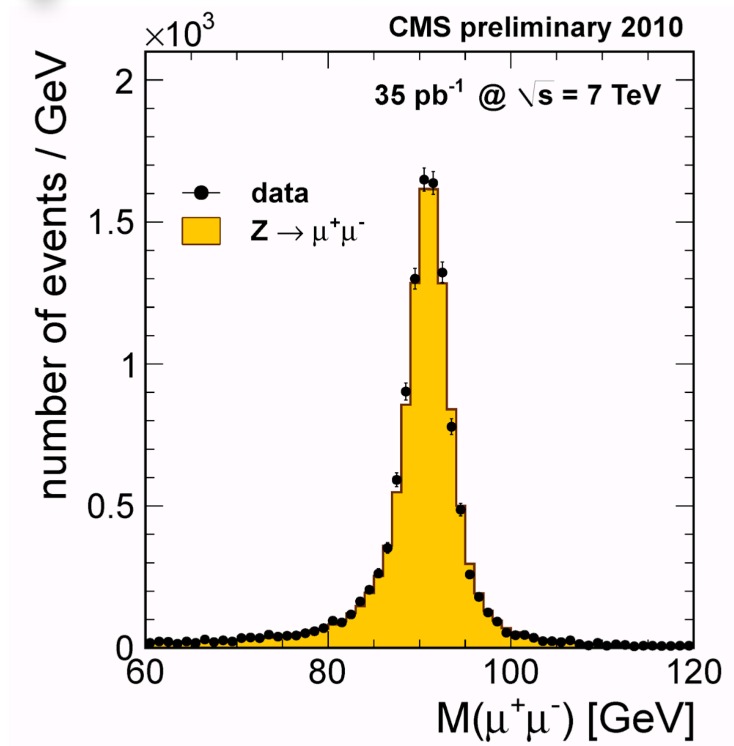
Thermal amplifier to be developped during 2011 to allow measurements during Christmas shutdown for a deterministic decision on a possible energy increase for 2012.

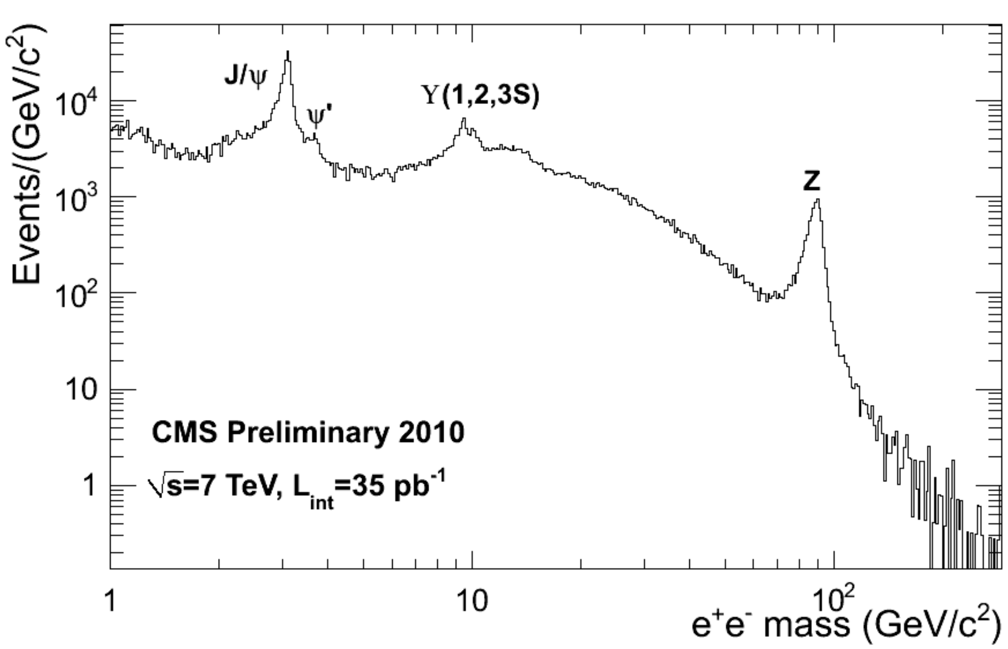
- Exciting times are up ahead

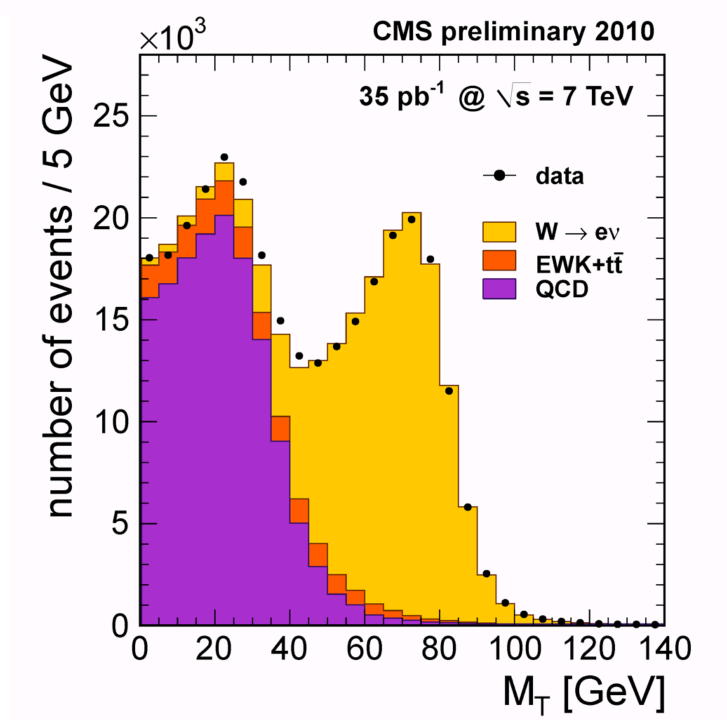
CMS performance: leptons

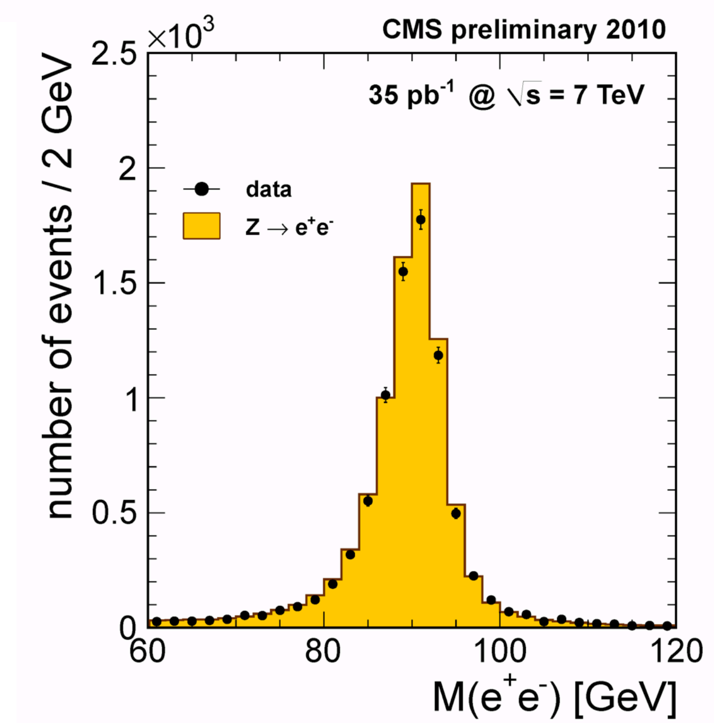








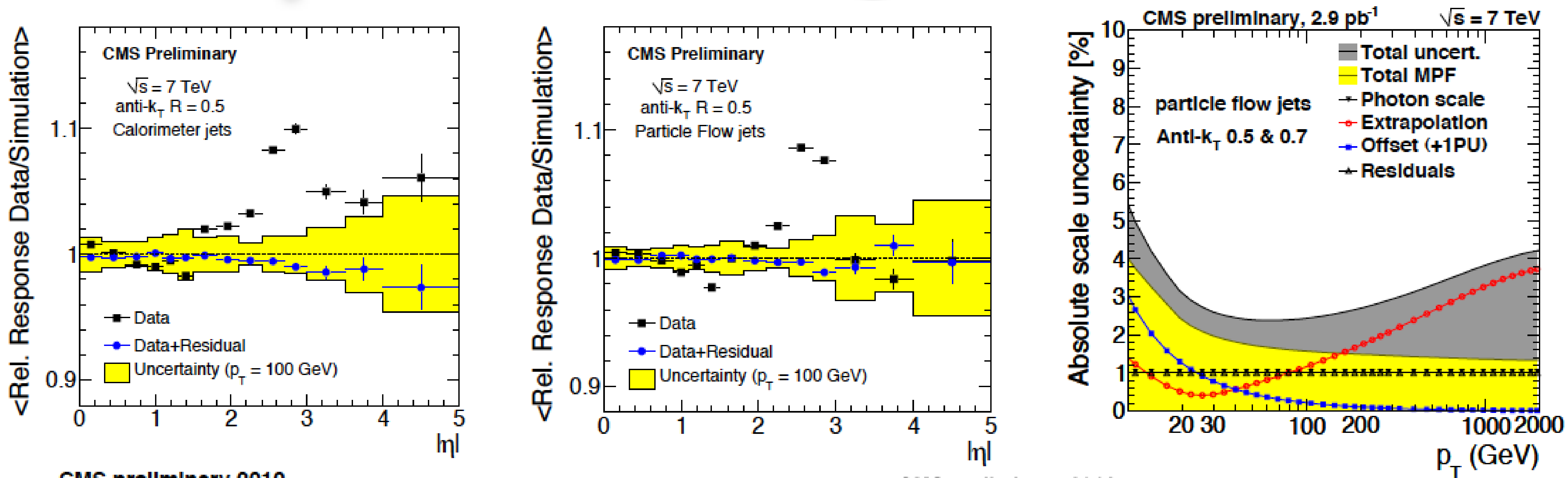




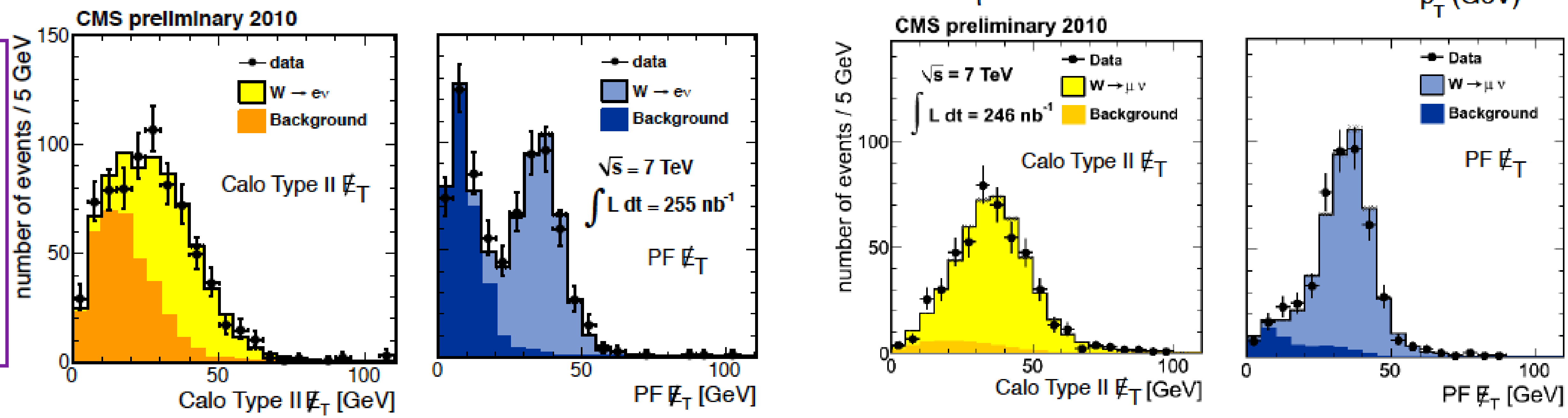
- Electron and muon performance matches expectations from simulation

CMS performance: jets and MET

PAS JME-10-010



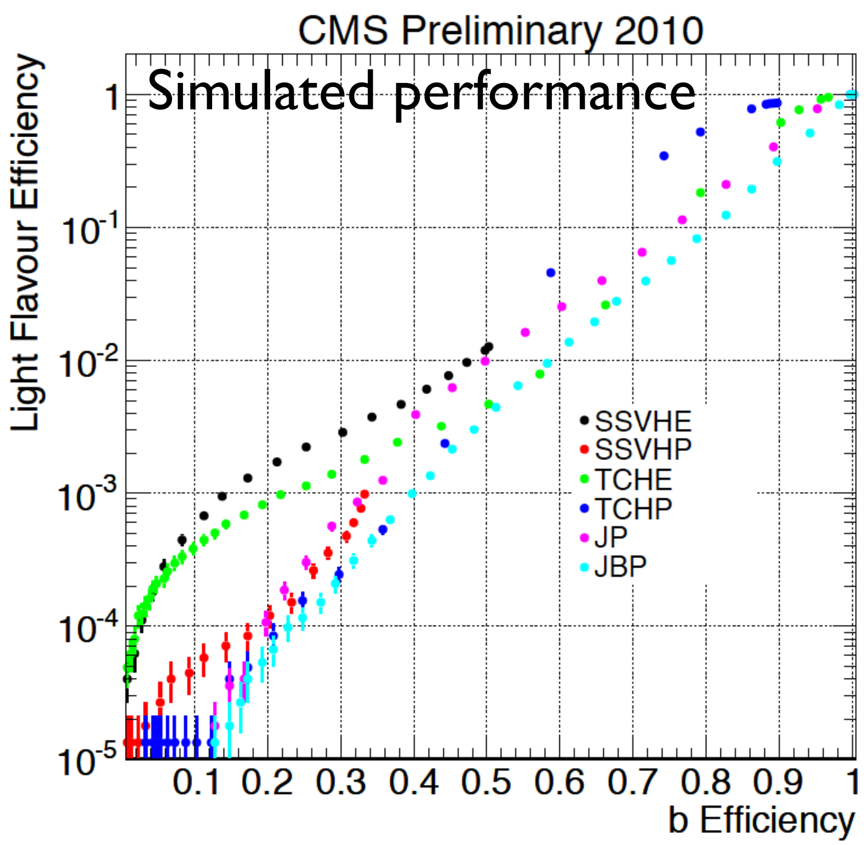
PAS JME-10-005

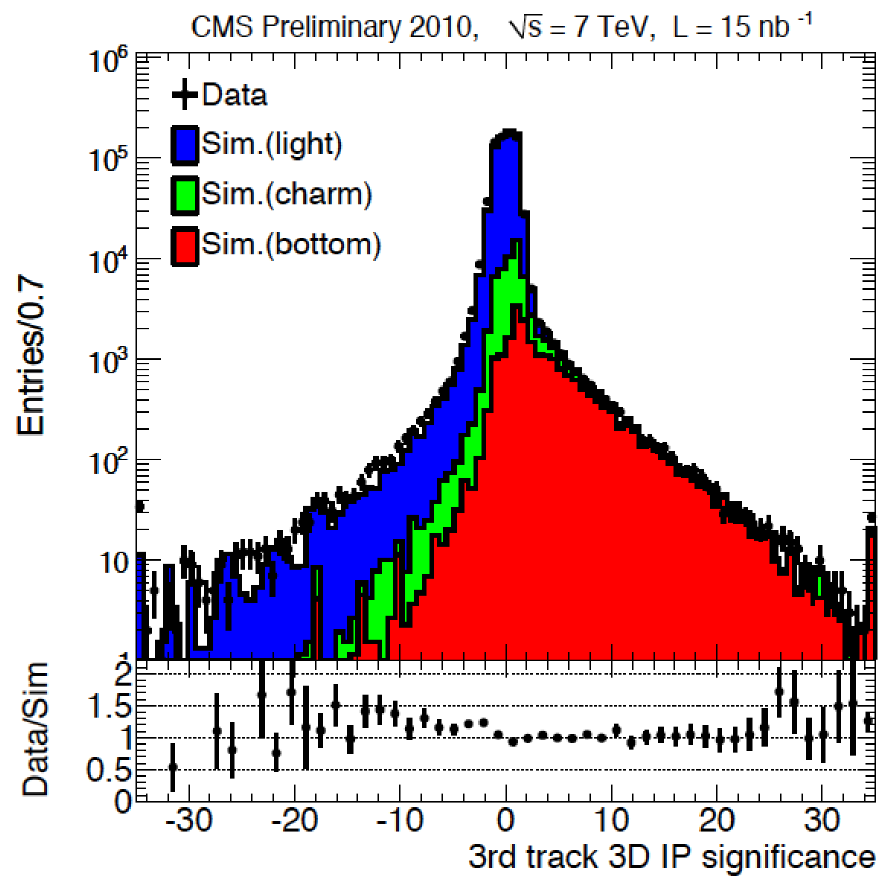


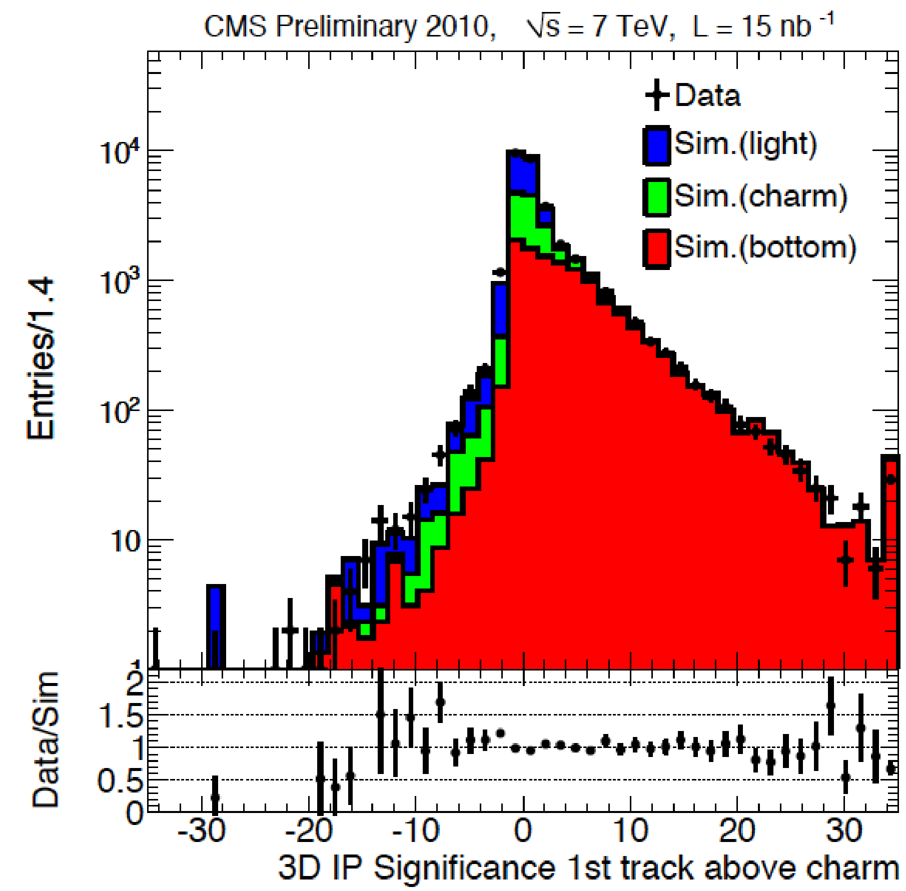
- Three algorithms: calorimeter only; corrected by tracks; particle flow
  - ✓ Best performance is from the particle flow algorithm
- Jet performance matches simulation very well

CMS performance: b-tagging

PAS BTV-10-001



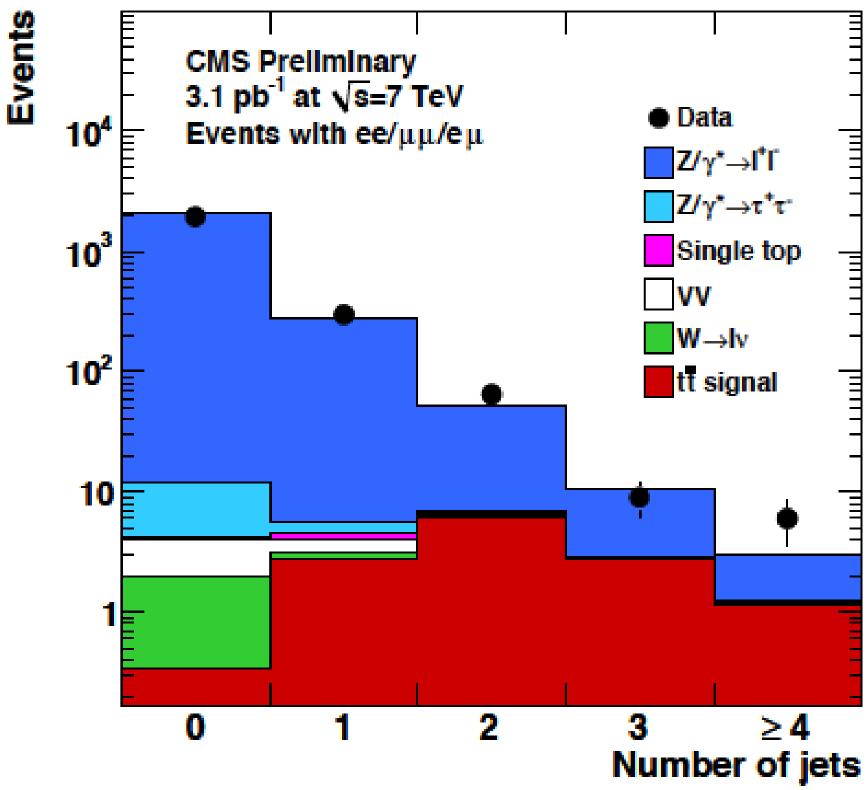


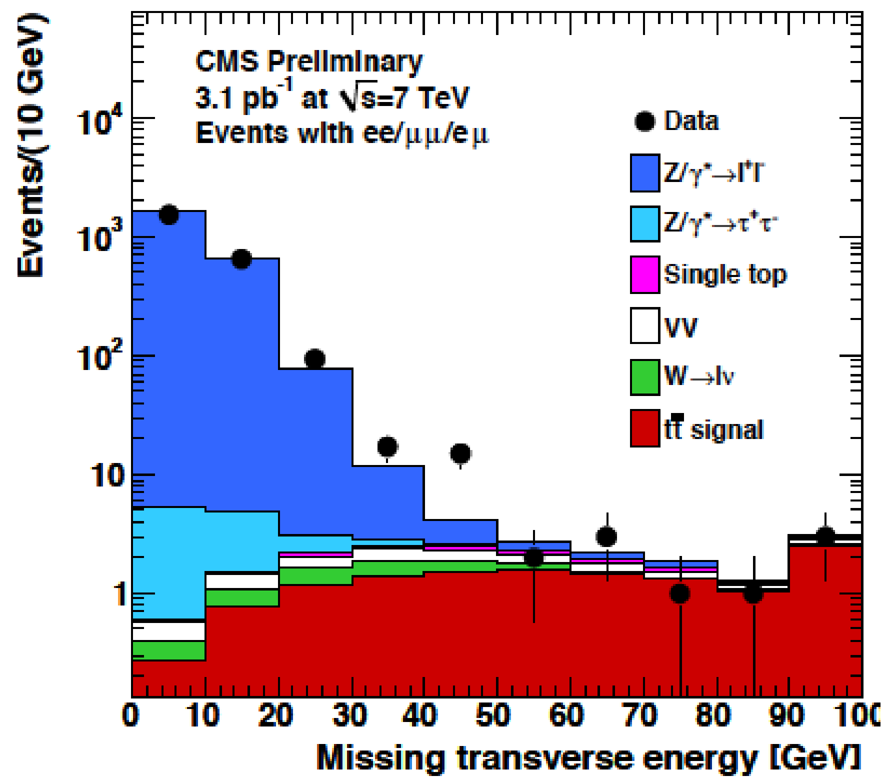


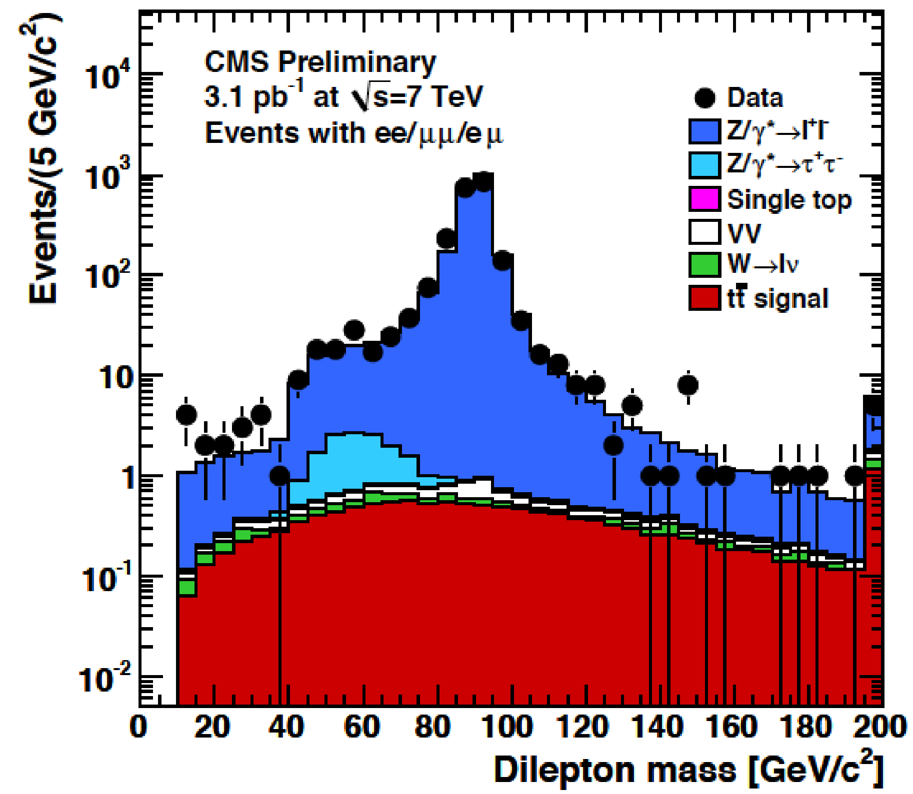
- Good performance from the start
- Taggers available in a range of efficiency:rejection performance points
  - ✓ Simple displaced track counting (TC***) — loose working point: $eff_b \approx 80\%$ at mistag 10%
  - ✓ Secondary vertex (SSV***)
  - ✓ jet-probability (JP***)

TTbar in dileptons: loose selection

Require only two opposite sign leptons passing ID and Isolation

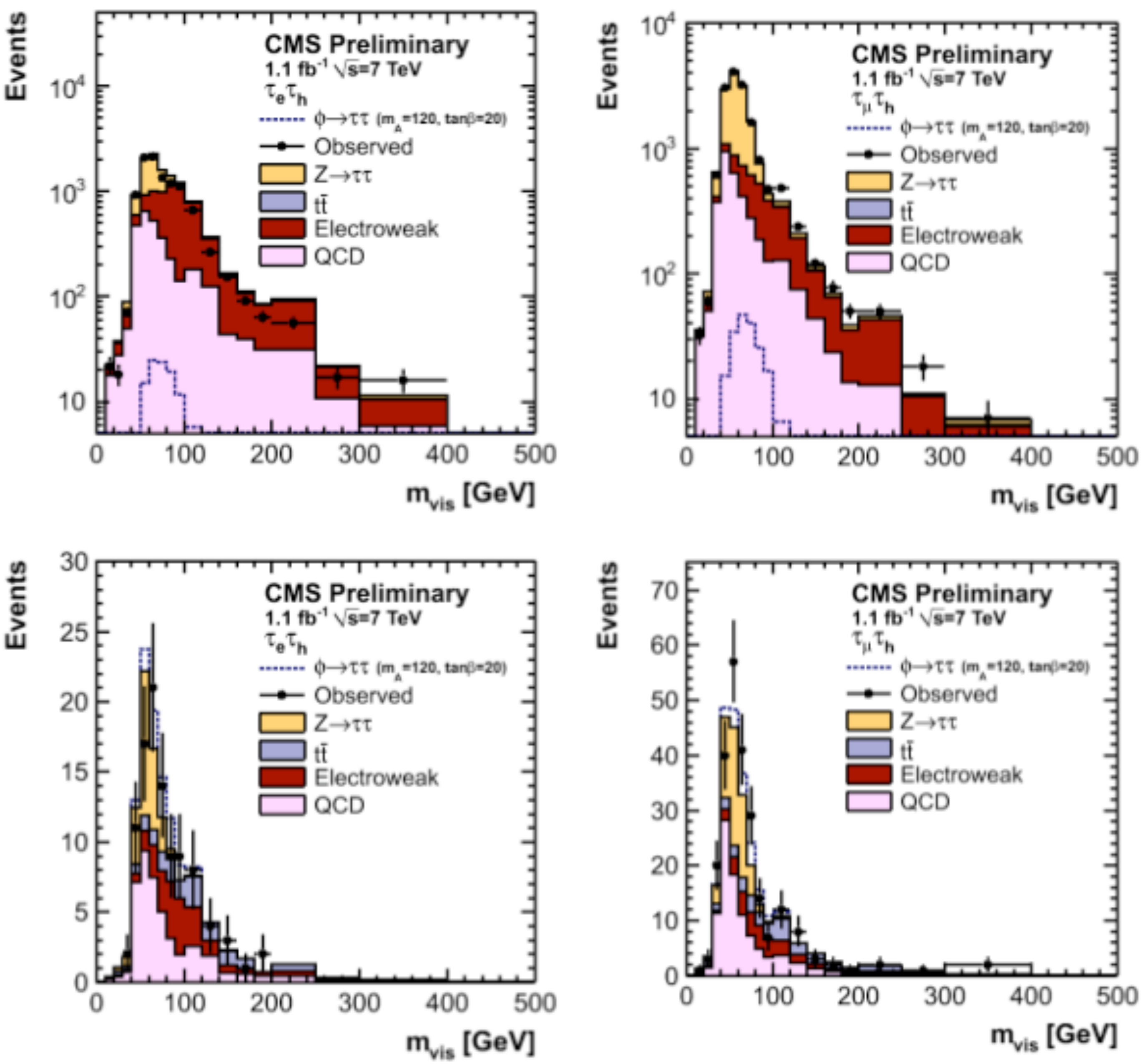


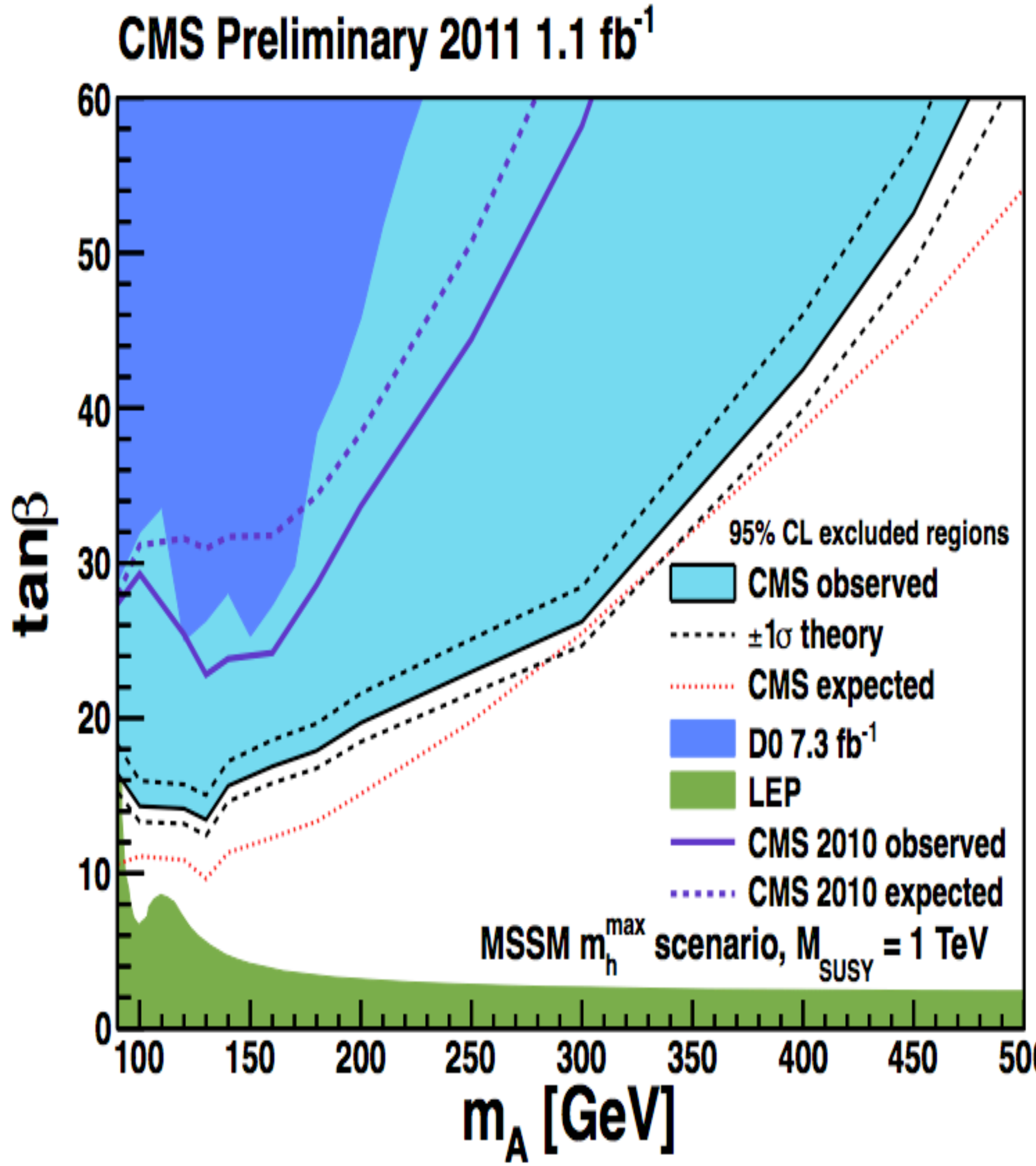




- Good agreement overall
- Some excess in missing energy due to extra pp collisions and not-so-perfect modeling. Not a problem: we rely on normalization to Z in data.

MSSM Higgs→$\tau^+\tau^-$





CMS PAS-HIG-11-009