Update from LHC

Yuri Gershtein

Very, very CMS-centric Update from LHC

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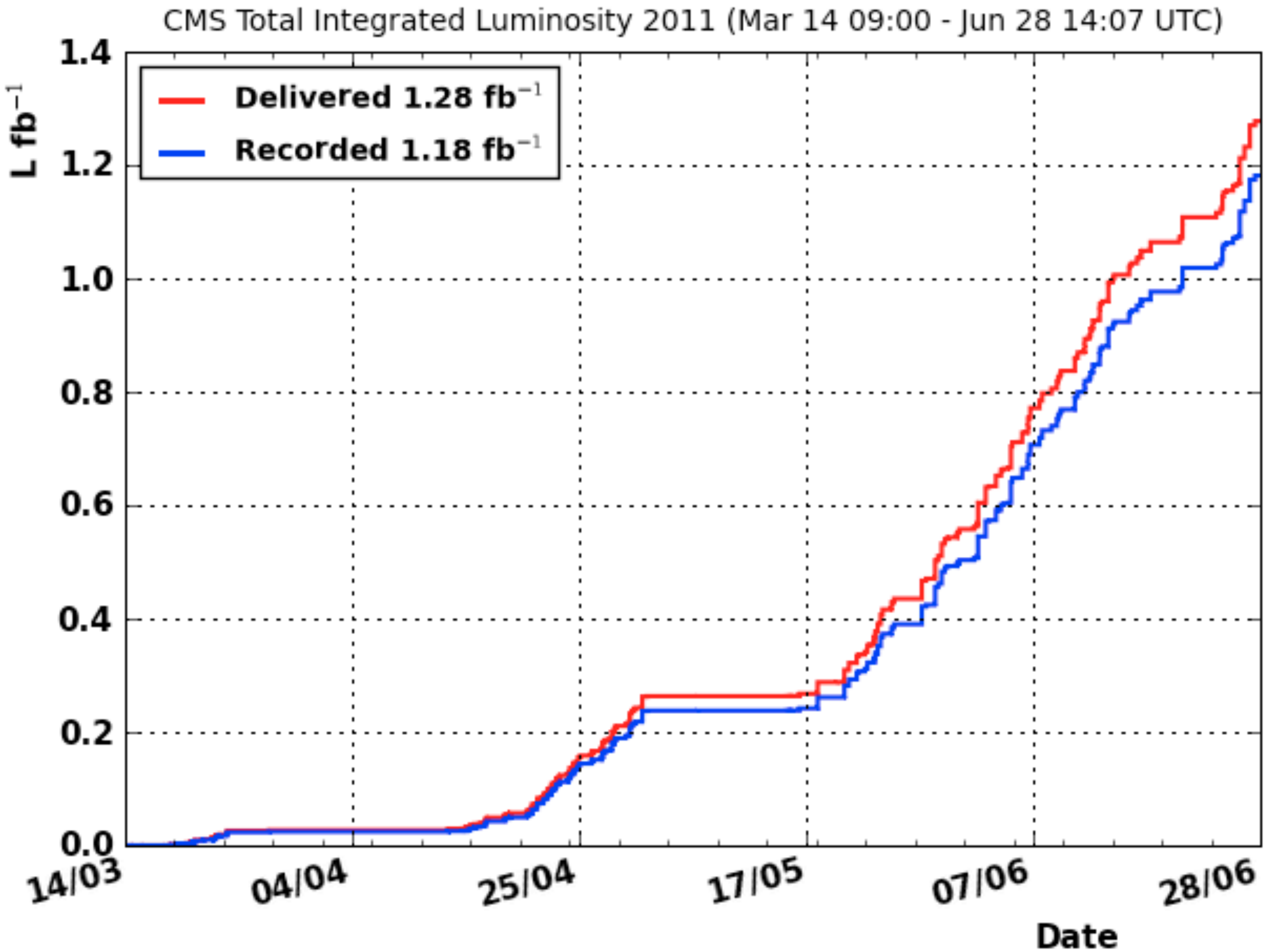
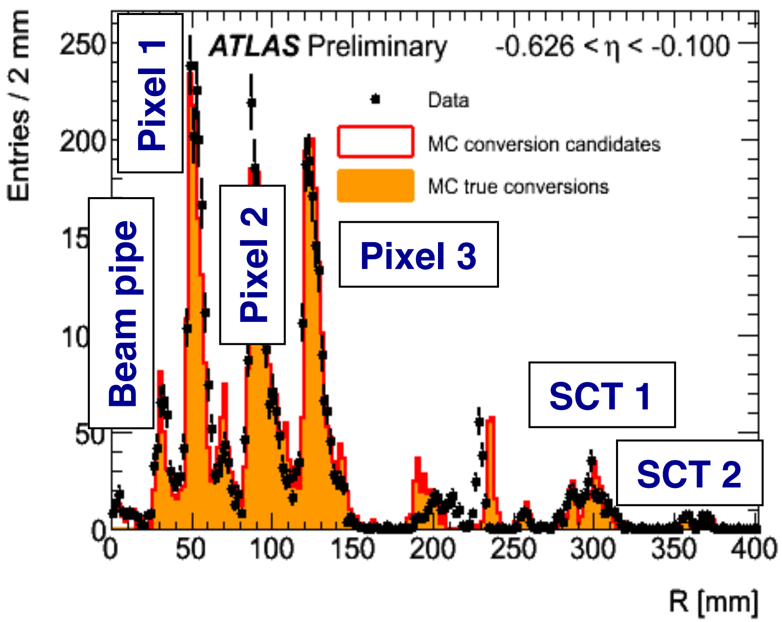
Luminosity

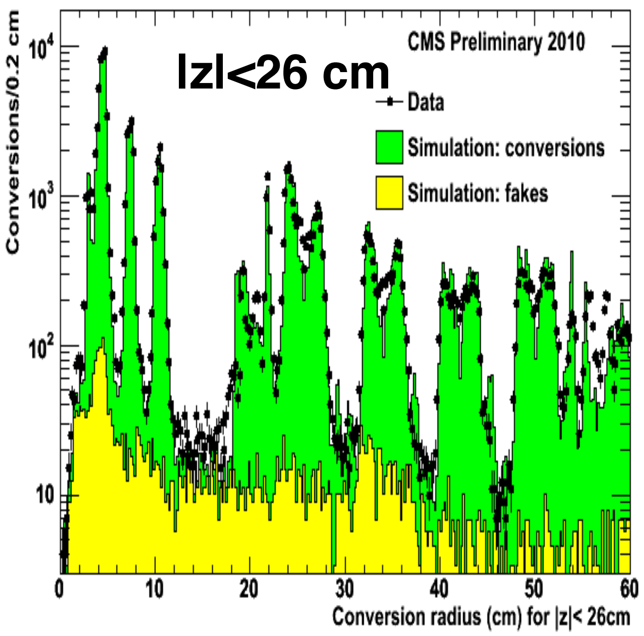
- LHC has been working really well
  - Talk about 10^{34} this year and 20-25 fb^{-1} by the end of 2012



Experiments are amazingly well-described in simulation

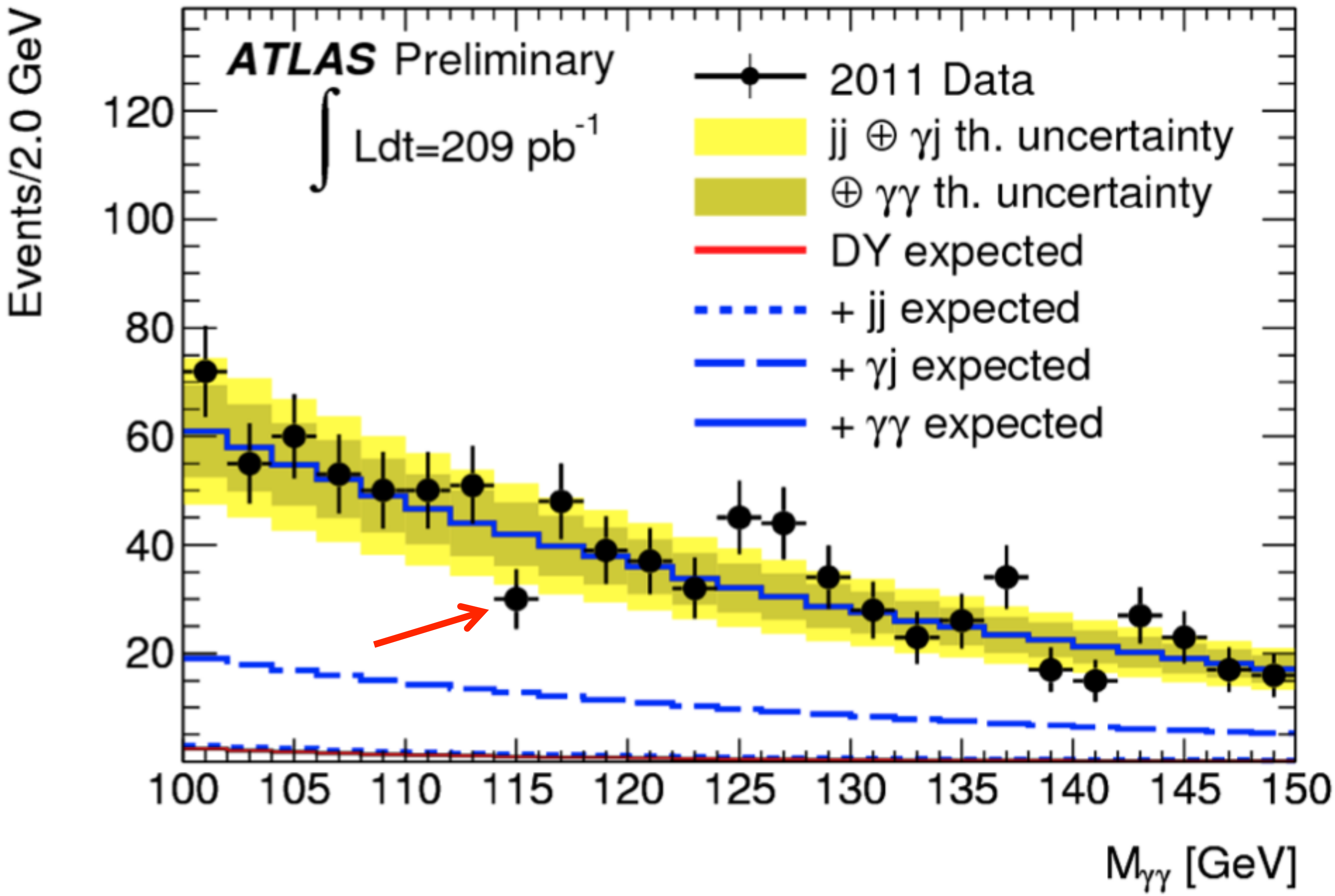
e.g. Material Budget of Trackers:





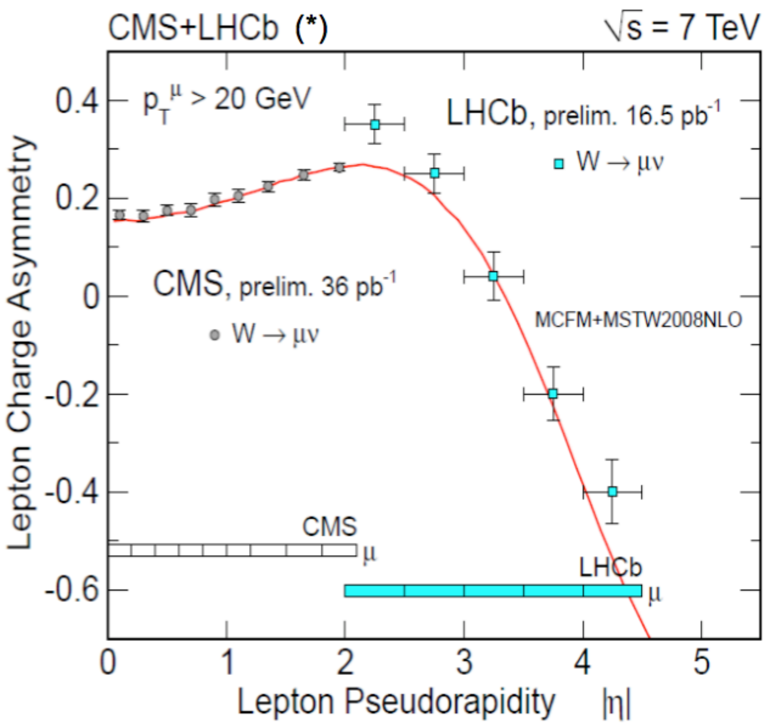
So, what have we learned so far?

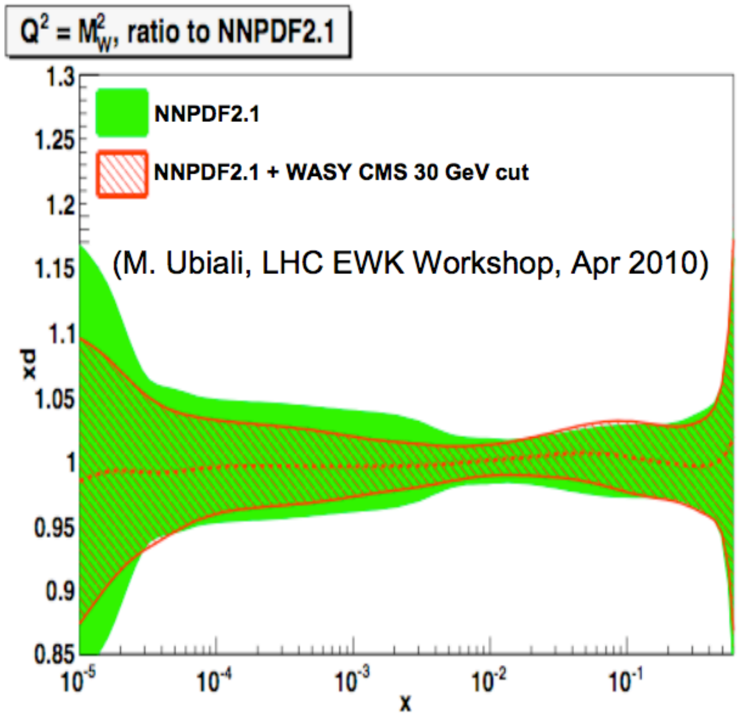
The Anti-Higgs



The Standard Model

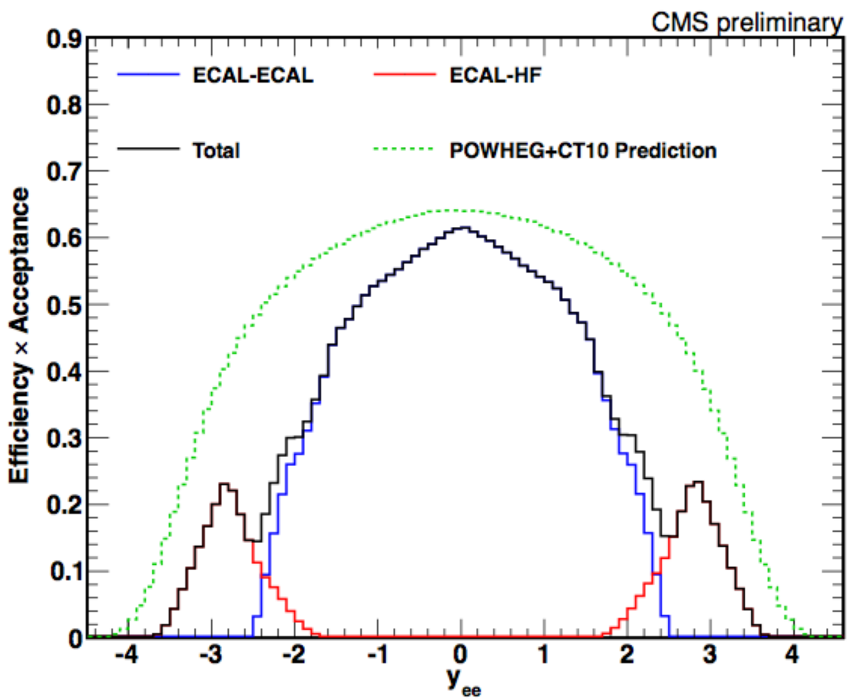
W, Z properties

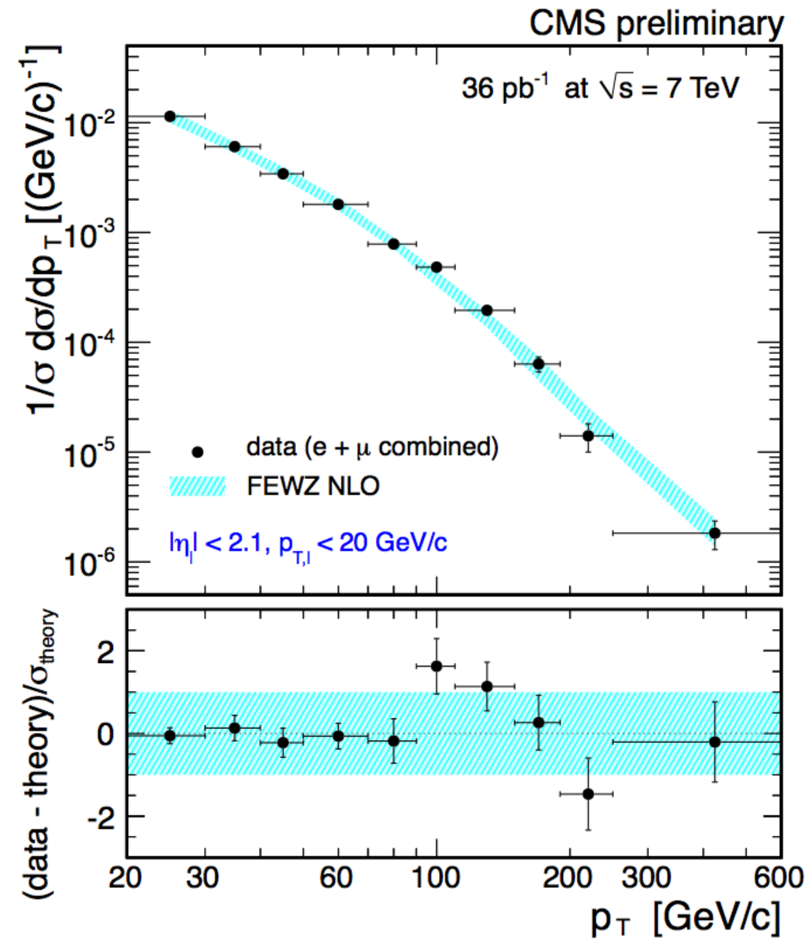




- W asymmetry measurement
  - 36 pb^{-1} is enough to start constraining PDF's

W, Z properties

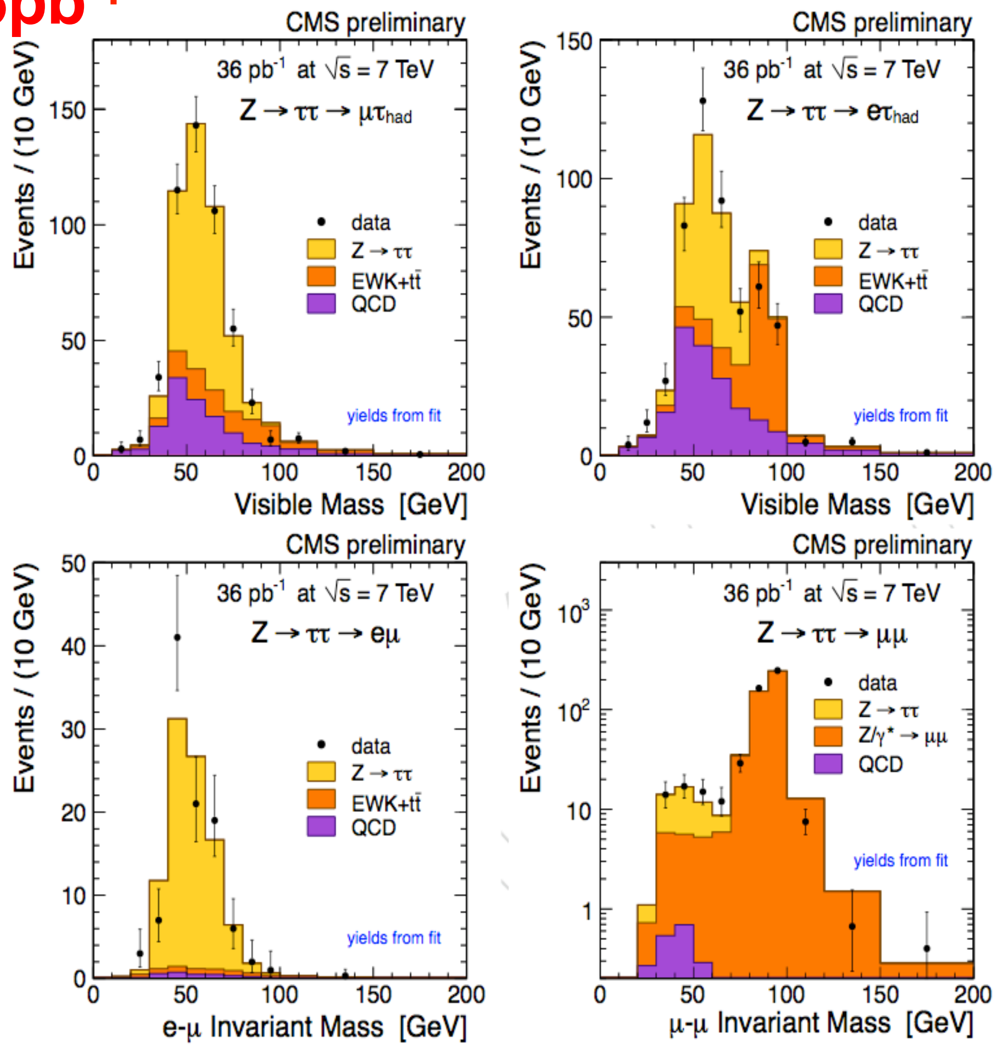


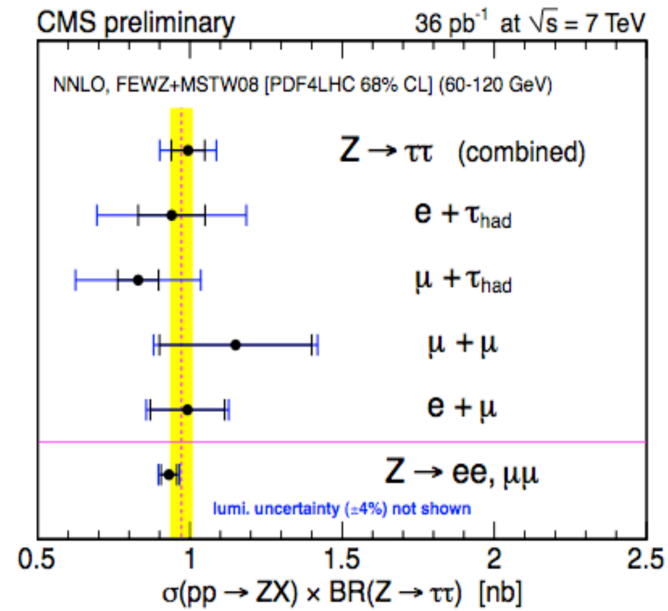


- Z rapidity measurement
  - Note how far forward CMS can measure the Z!!
- Z transverse momentum
  - 36 pb^{-1} is enough to have experimental error much smaller then theory

$Z \rightarrow \tau^+\tau^-$

$36pb^{-1}$



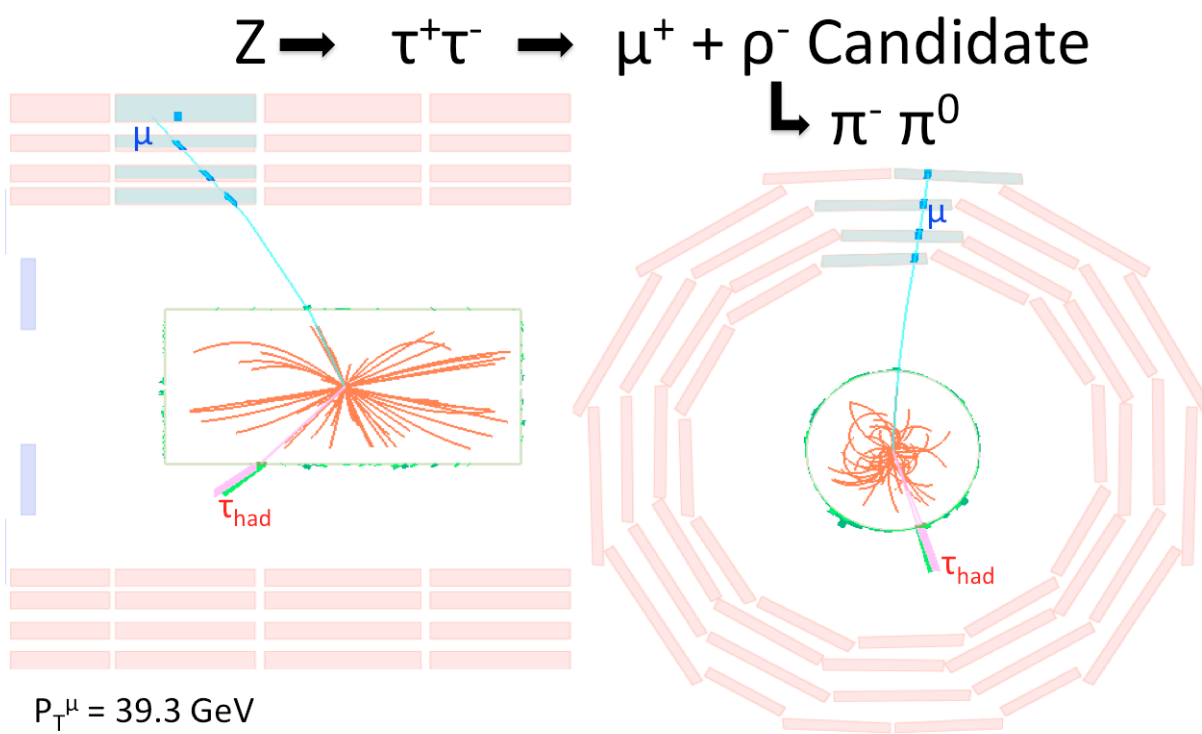


Measurement of the tau id efficiency → important to understand the tau as a discovery tool (Higgs, SUSY etc)

CMS-EWK-10-013; Submitted to the Journal of High Energy Physics

$Z \rightarrow \tau\tau$

- Done in four modes: e+had, μ+had, e+μ and $\mu+\mu$
- Re-assemble tau decay products with PFlow



P_T^{μ} = 39.3 GeV

P_T^{had} = 28.2 GeV, lead. Track P_T = 3.3 GeV

M_{vis} = 67.0 GeV, MET = 19.9 GeV, $M_{\tau\tau}$ = 90.3 GeV

$Z \rightarrow \tau\tau$

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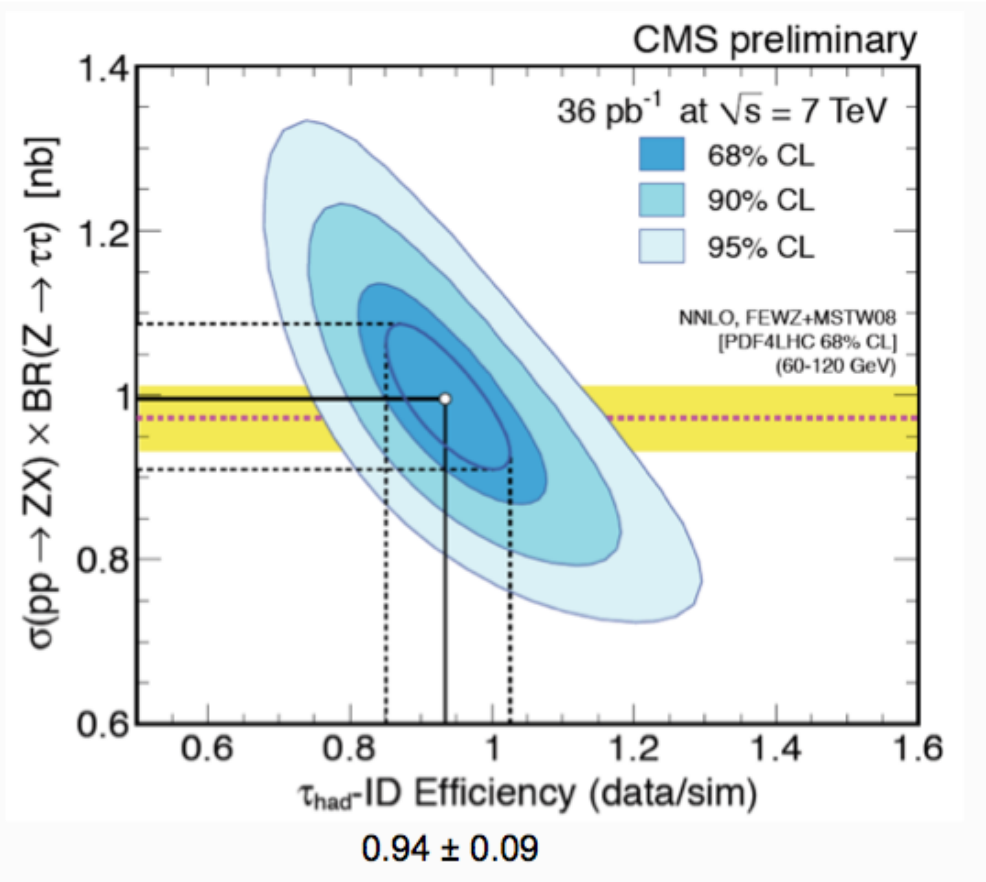
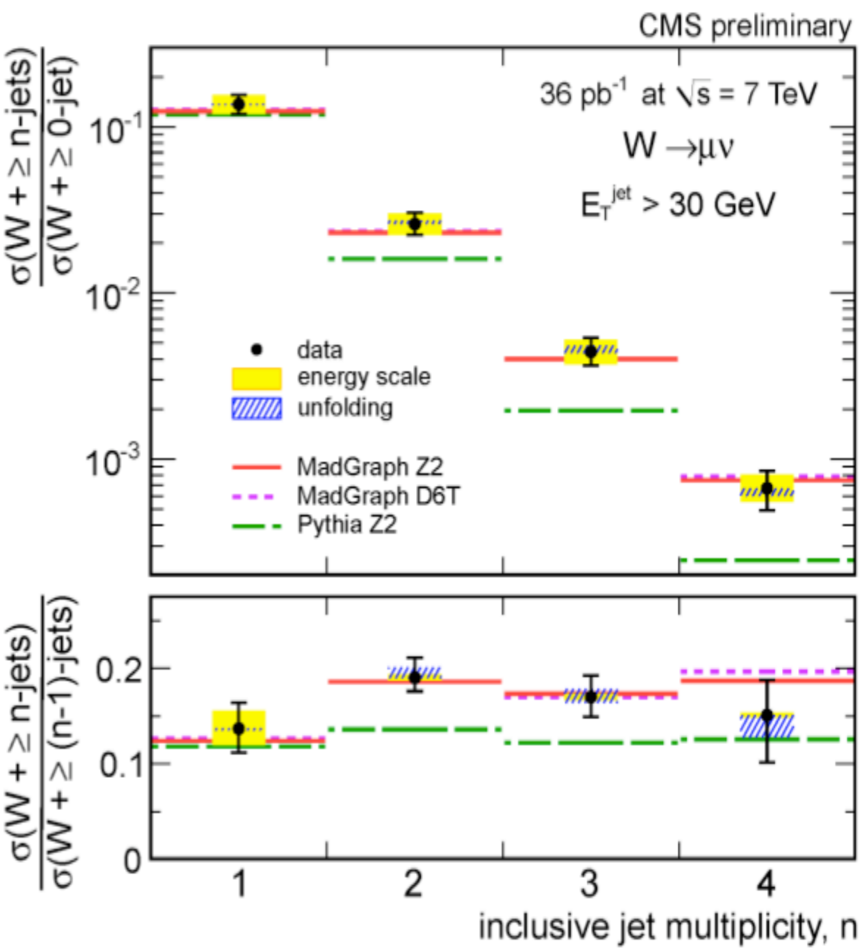
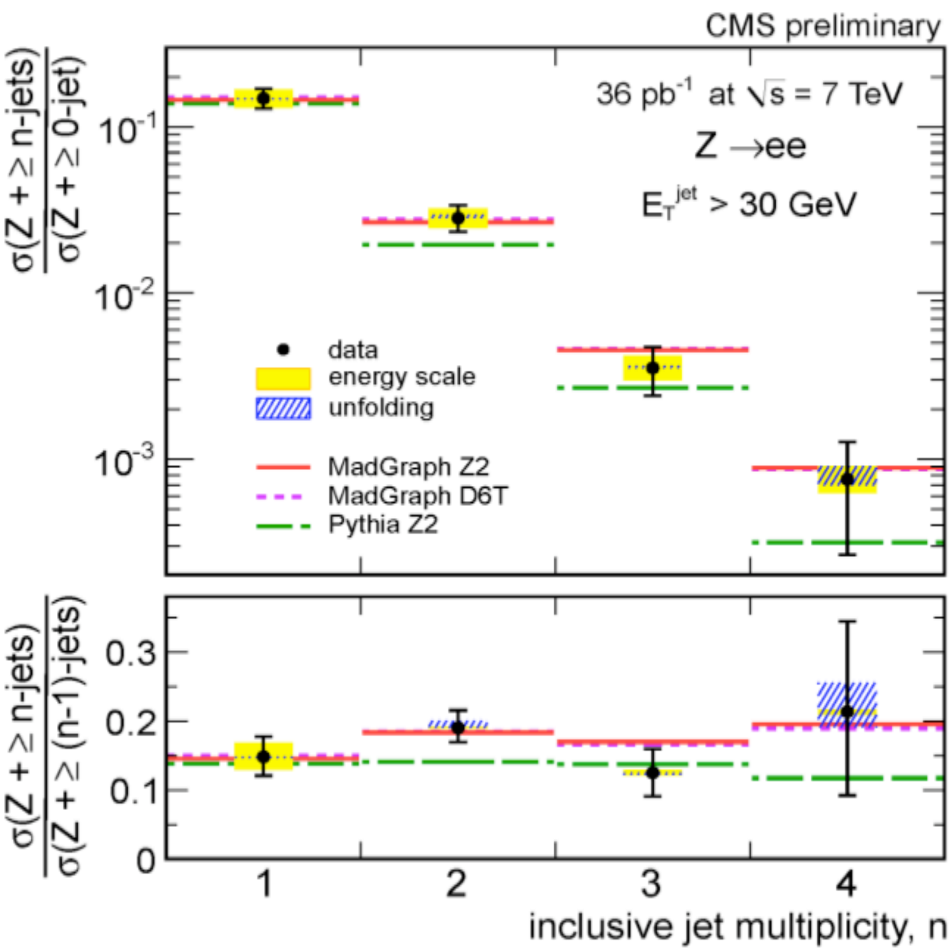
- Re-assemble tau decay products with PFlow



W, Z +jets


CMS preliminary
36 pb-1 at √s = 7 TeV
W →μν
E_T^jet > 30 GeV
σ(W + ≥ n-jets) / σ(W + ≥ 0-jet)
σ(W + ≥ n-jets) / σ(W + ≥ (n-1)-jets)
data
energy scale
unfolding
MadGraph Z2
MadGraph D6T
Pythia Z2
inclusive jet multiplicity, n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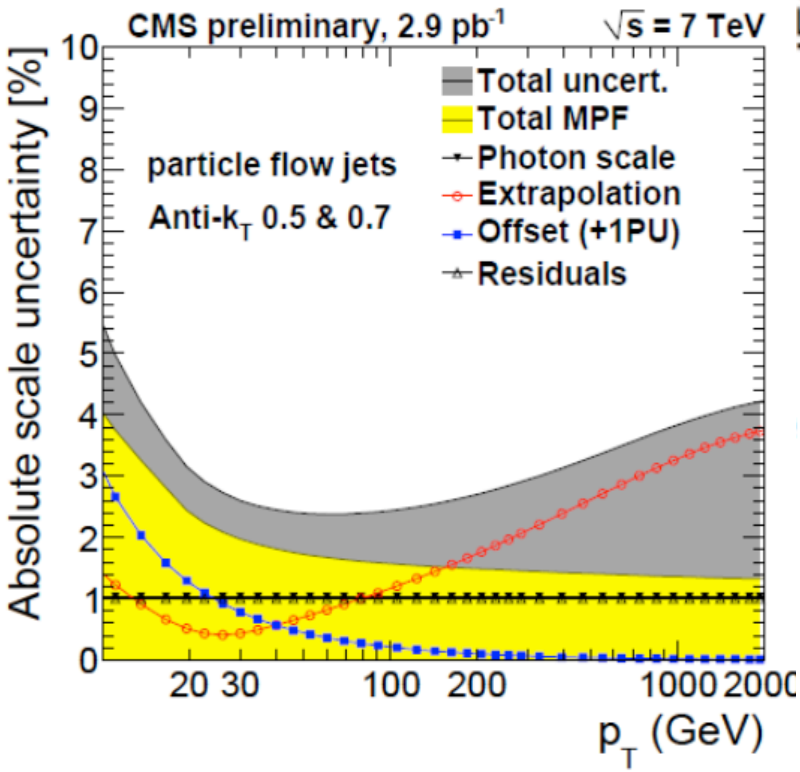
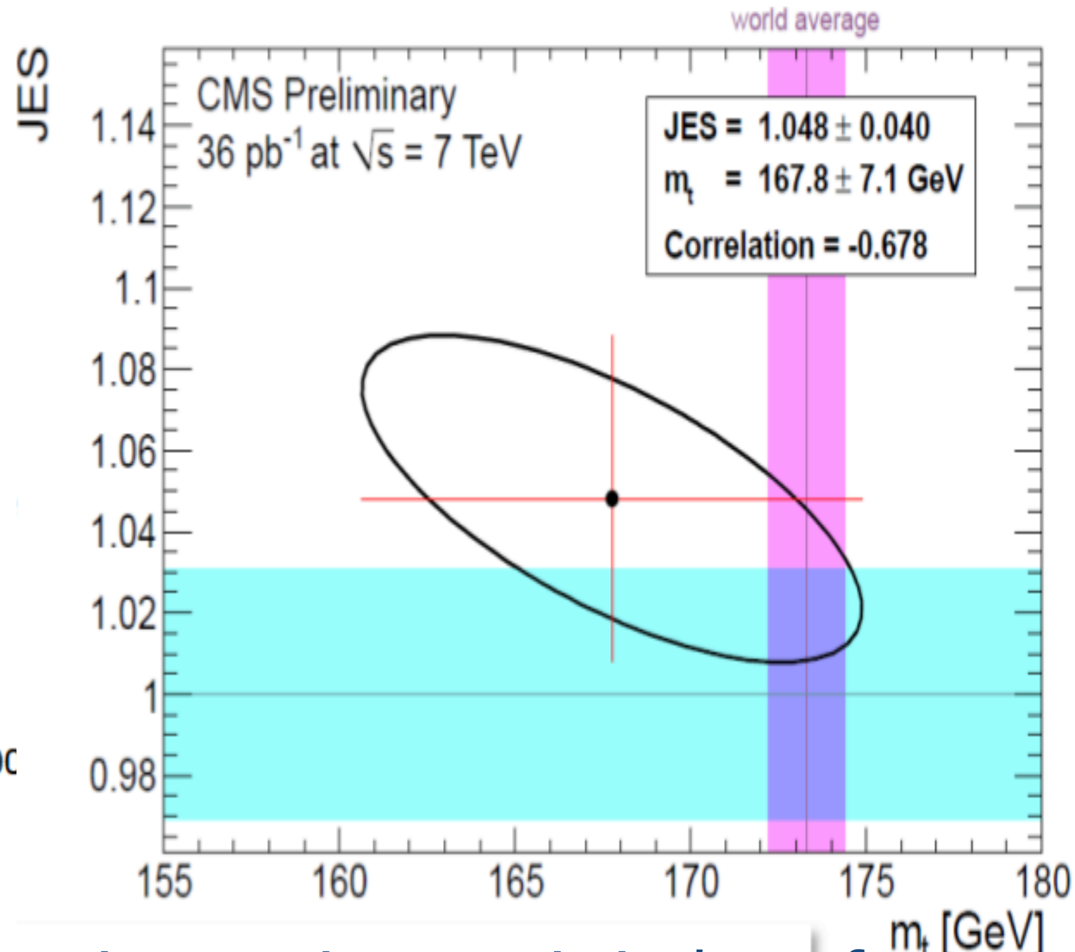
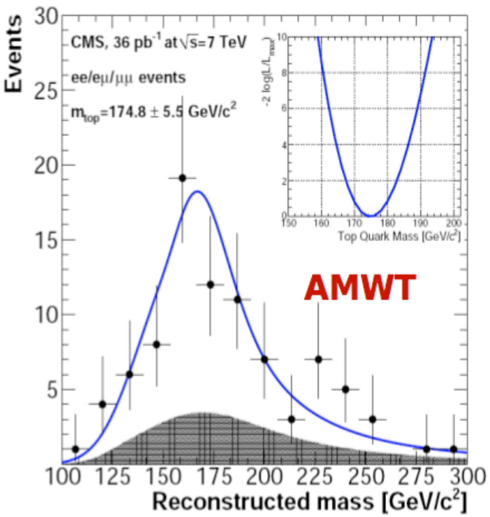
Top mass

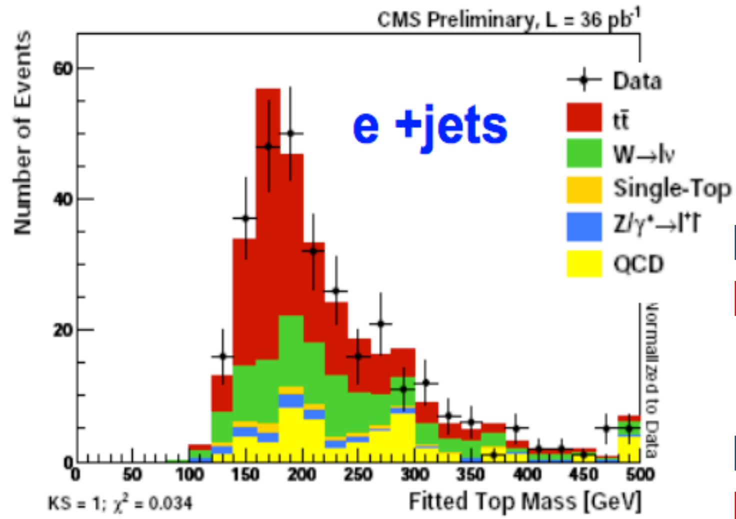


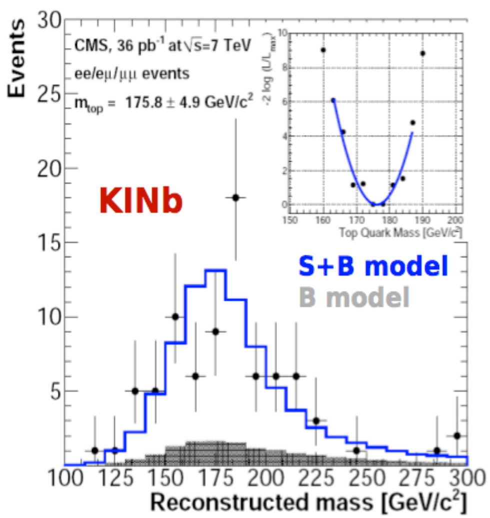


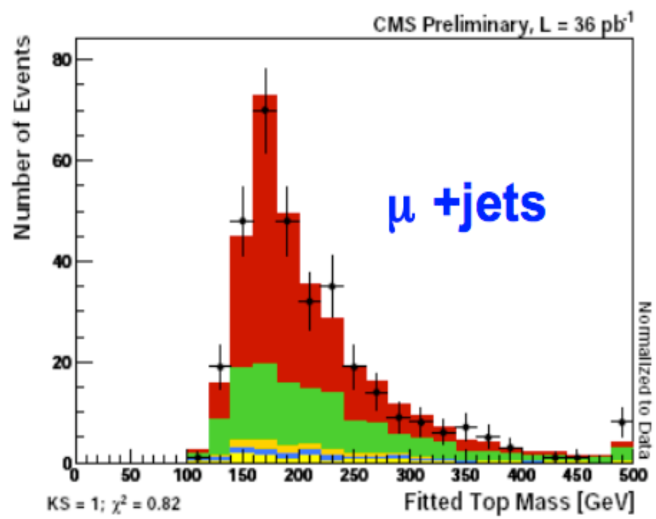
Old DØ trick: transfer systematic error into statistical: perform simultaneous fit of m_{top} and JES and bring the uncertainty from 3-5% down to 1%

Top mass









Dilepton channel

M_{top}=175.5±4.6±4.6 GeV

Lepton+jets channel

M_{top}=173.1±2.1±2.8 GeV

CMS combination

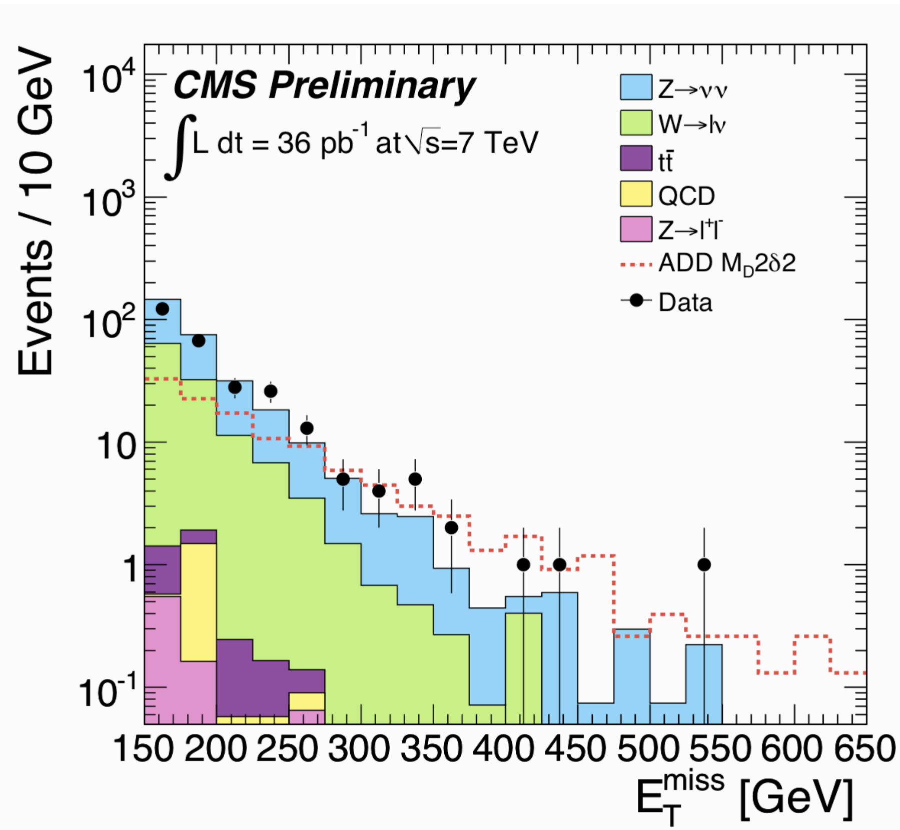
M_{top}= 173.4±1.9±2.7GeV

arXiv:1105.5661 ; CMS-TOP-11-002 ; CERN-PH-EP-2011-055

Beyond SM

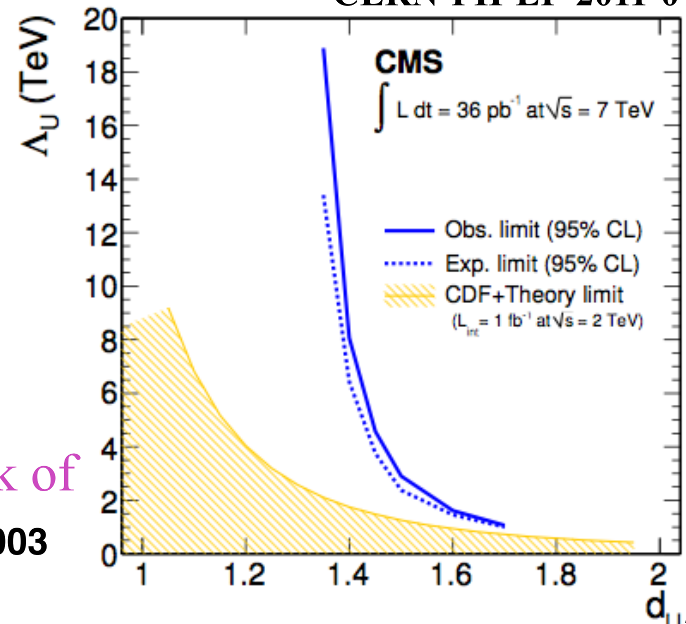
Monojets

- Classic signature of producing invisible states at hadron collider: ISR jet + MET



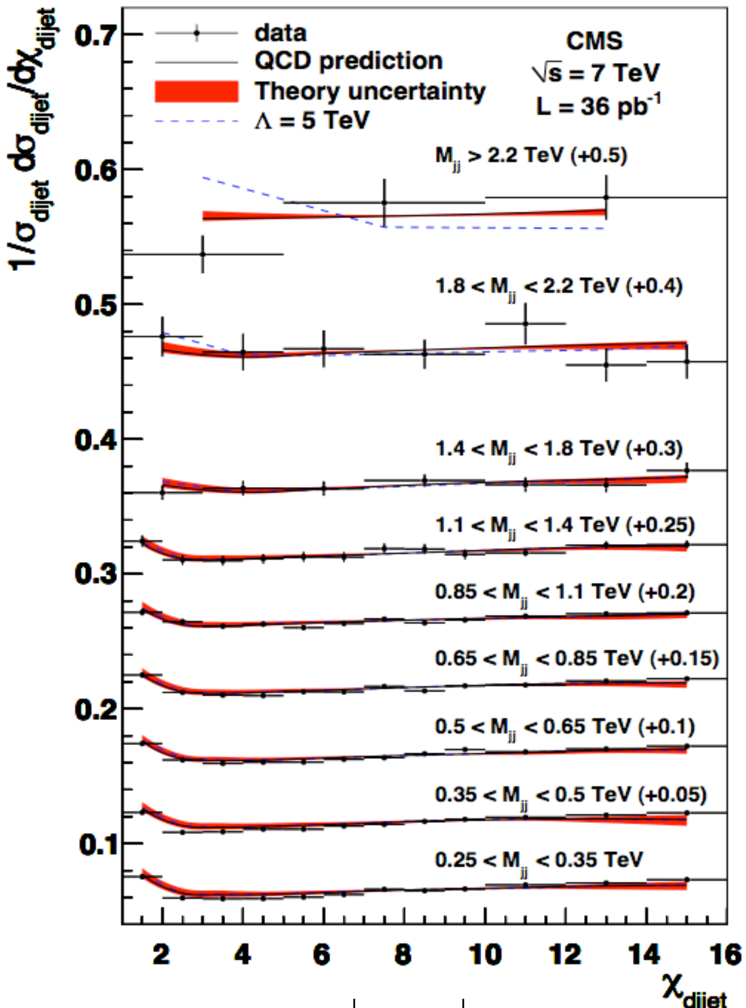
- Leading jet above 110 GeV $|\eta|<2.4$
- Second jet above 30 GeV is allowed if $\Delta\phi<2$ radians
- No third jet above 30 GeV
- For ADD with M_D=3 TeV and δ=3:
  - Acceptance = 10%
  - X-section limit 19 pb

CERN-PH-EP-2011-070



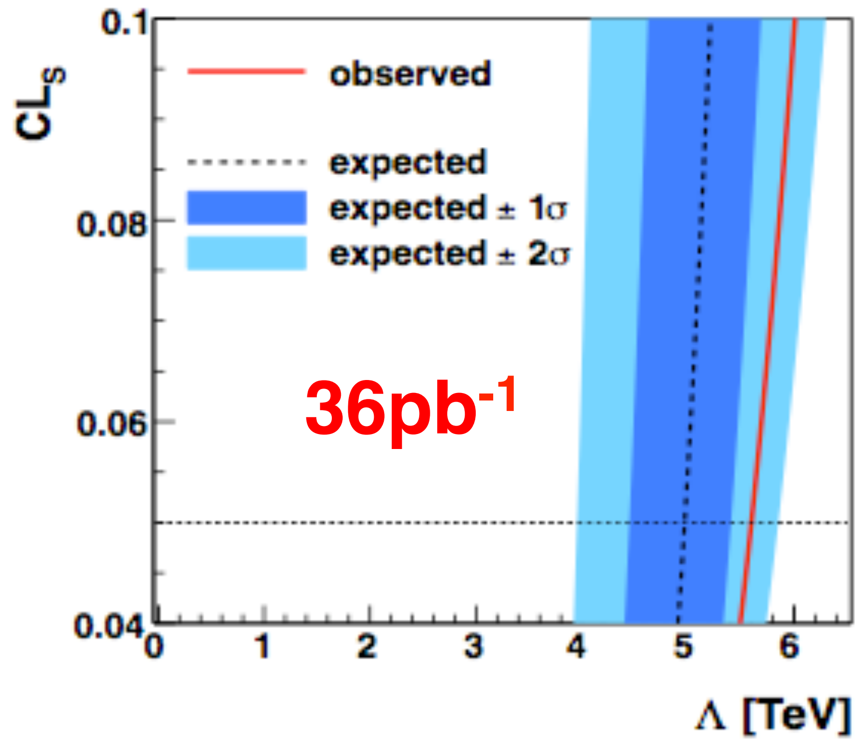
Also, first limit on unparticles in framework of Delgado & Strassler **Phys. Rev. D 81 (2010) 056003** arXiv:1102.2020

Di-jets



$$\chi = e^{|y_1 - y_2|}$$

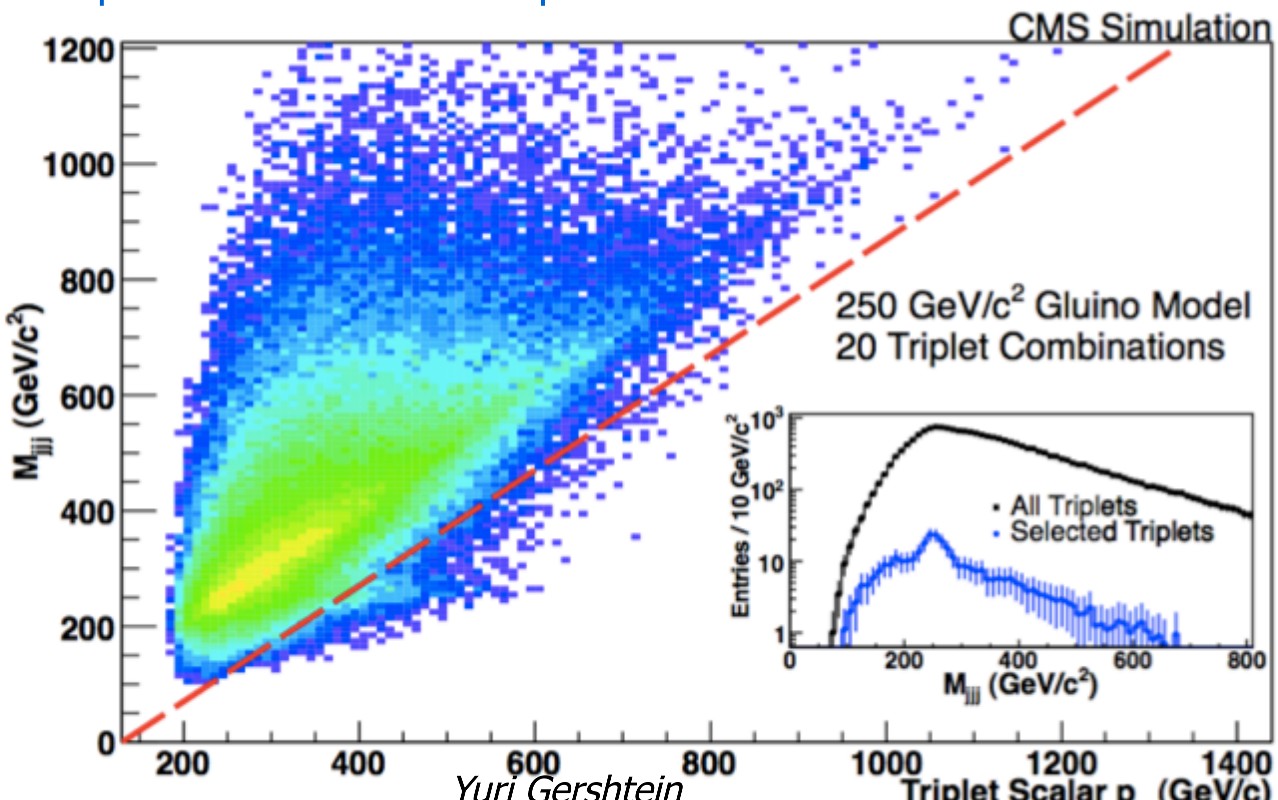
The dijet angular distributions are sensitive to compositeness (+ extra dimensions, etc, etc).



We put a lower limit on the contact interaction scale of Λ =5.6 TeV at 95% CL.

Multijets: pp→XX→ 6 jets

- Multi-jet final states are very tricky at hadron colliders (ISR!!)
- Energy resolution is not very good, and when the number of jets is large the combinatorics is huge. Chances of picking the correct combination are very small.
- Idea: do not try reconstructing the entire event. Just find a small region of parameter space where you can correctly identify just one of the jet triplets
  - Plot ALL triplet combinations on a plane Mass vs. Sum ET



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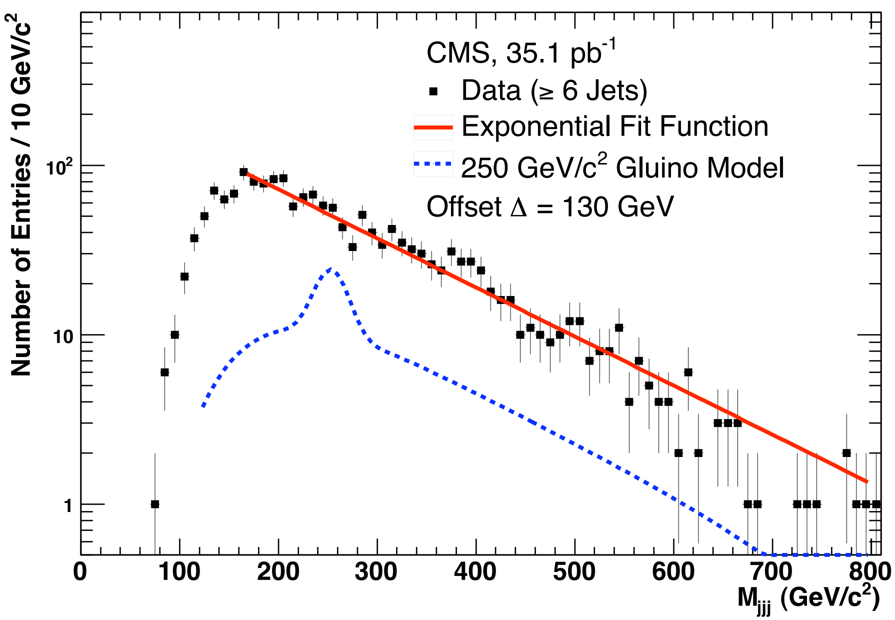
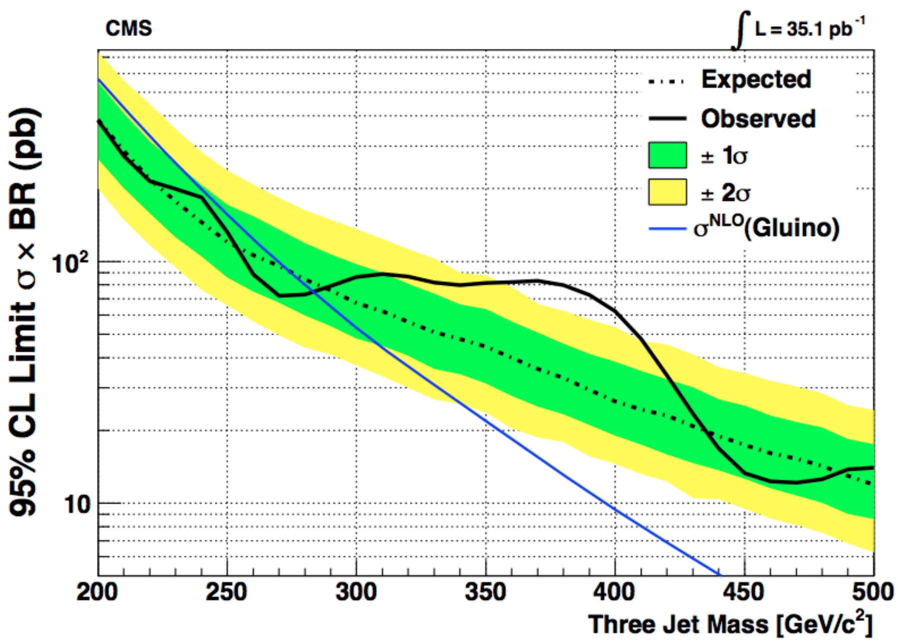
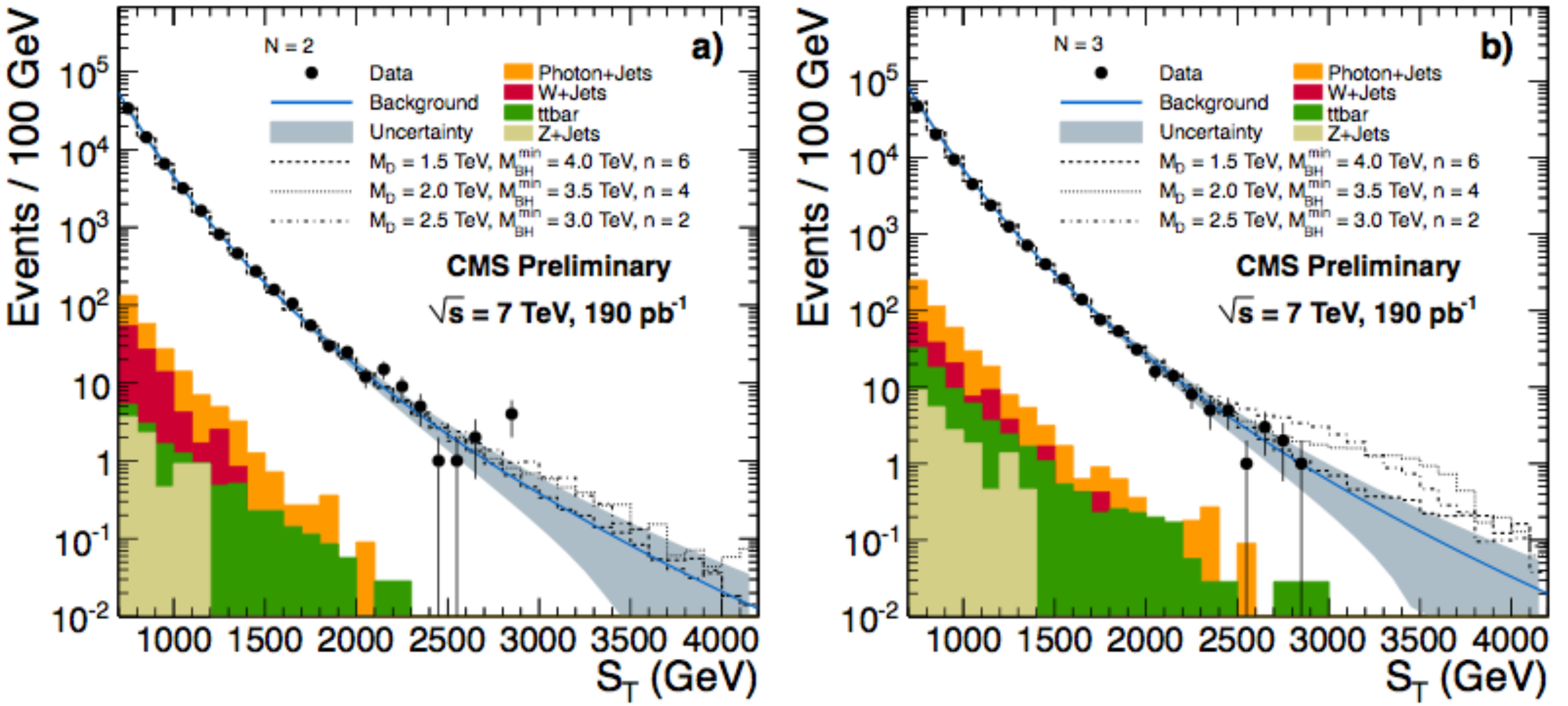




Multi-jets/photons/leptons: Black Holes



Parametrize the background using exclusive low-multiplicity bins
Then fix the S_T shape and look at high multiplicities

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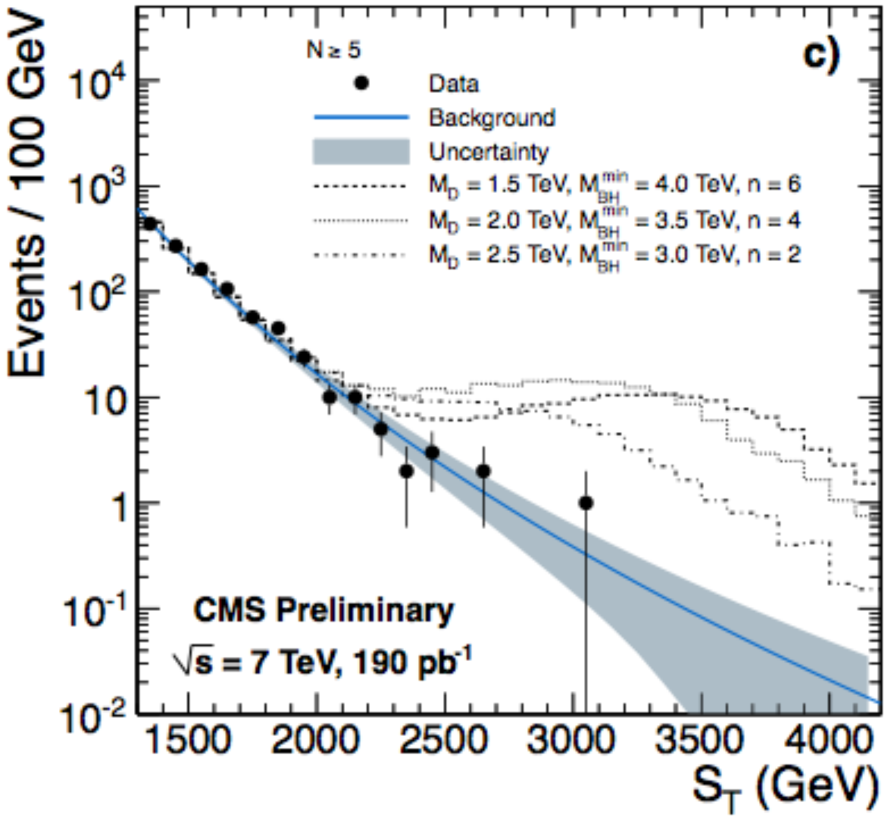

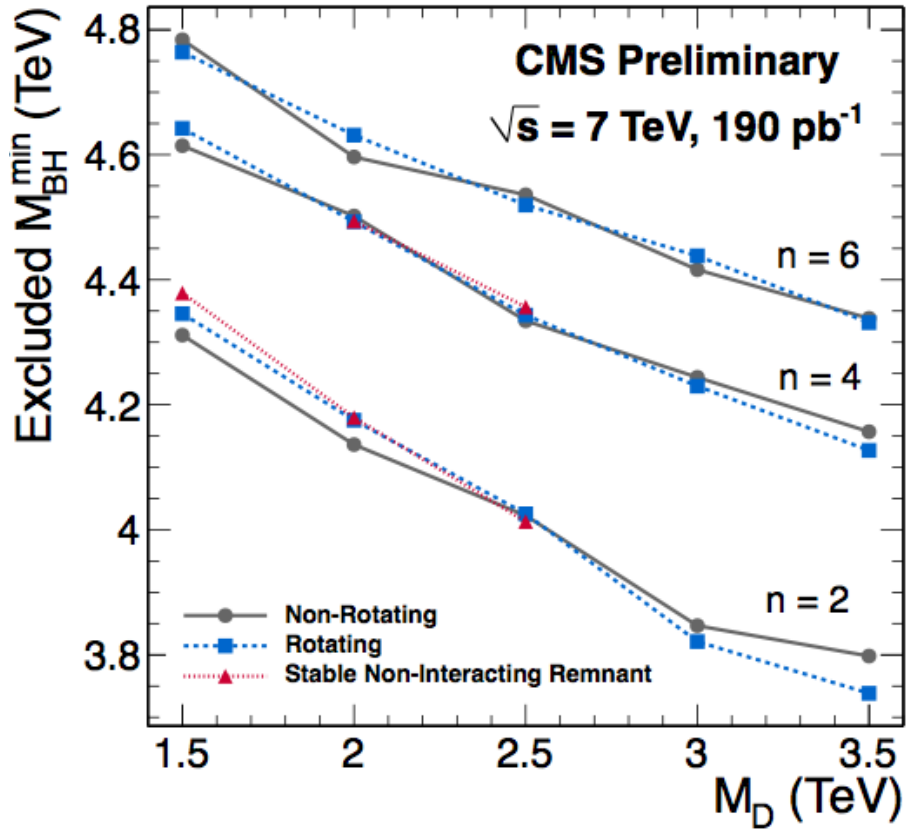

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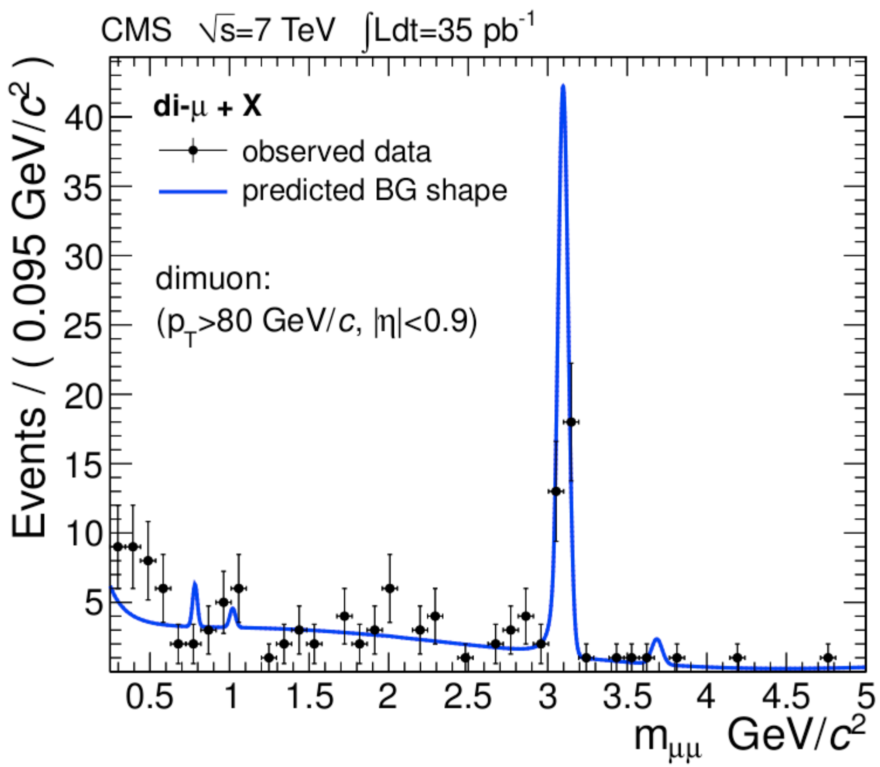
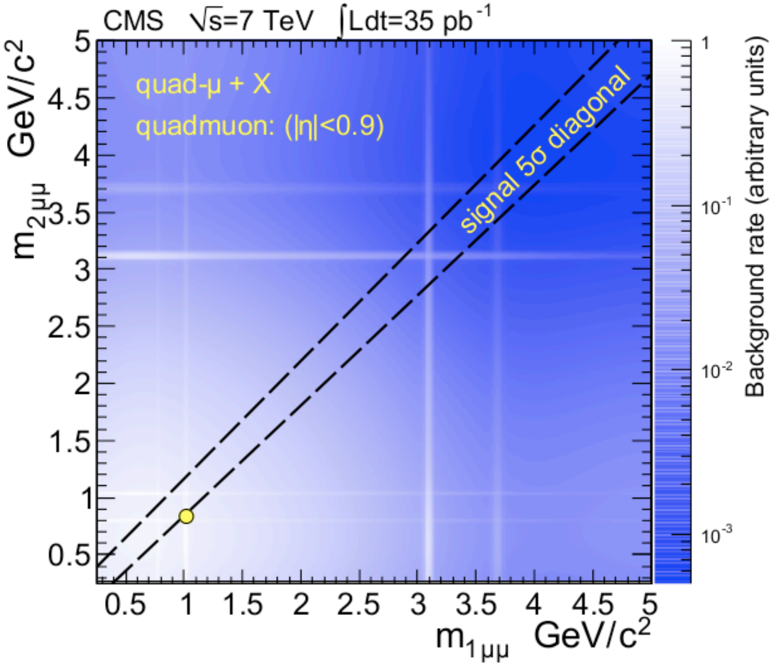
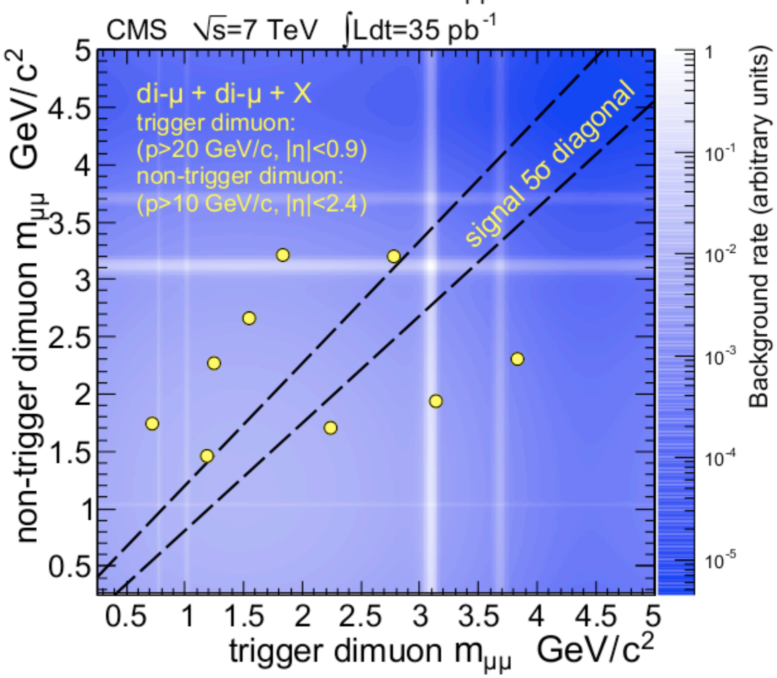
Leptonic Jets

- Only muons are considered
- Muons are clustered in jets based on invariant mass
- No isolation or MET requirements
- Search for di-muon invariant mass peaks
- Three “signal areas”
  - Single di-muon jet
  - Single 4-muon jet
  - Two di-muon jets

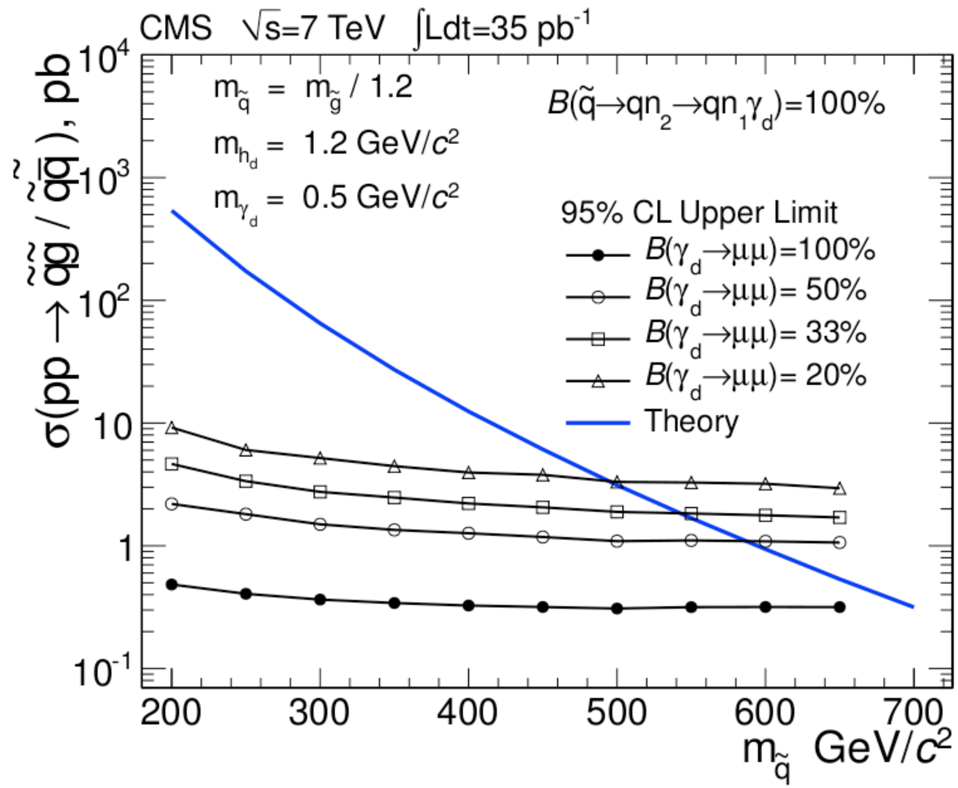


Leptonic Jets



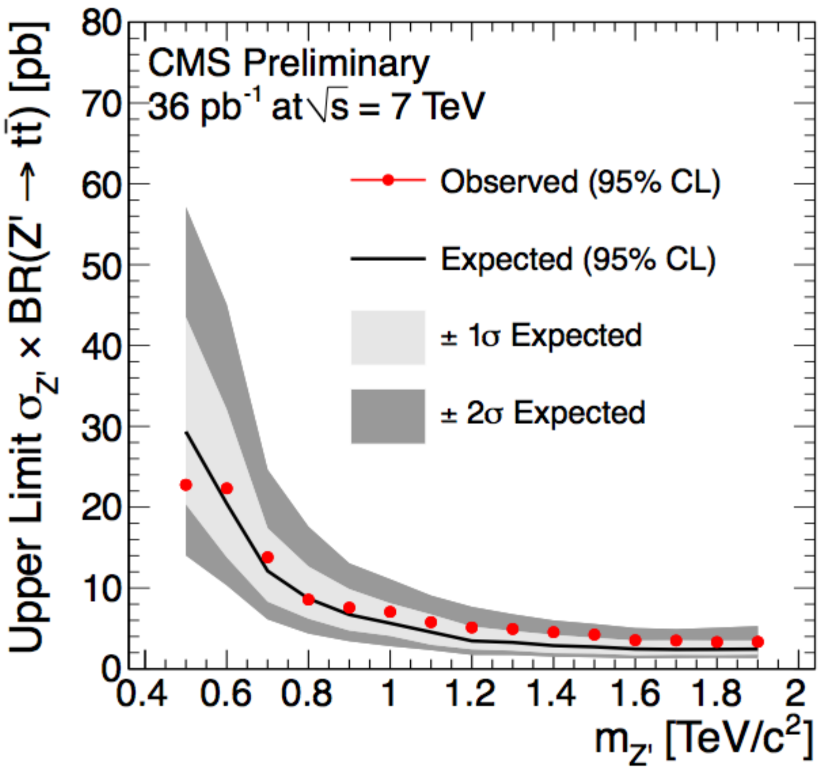


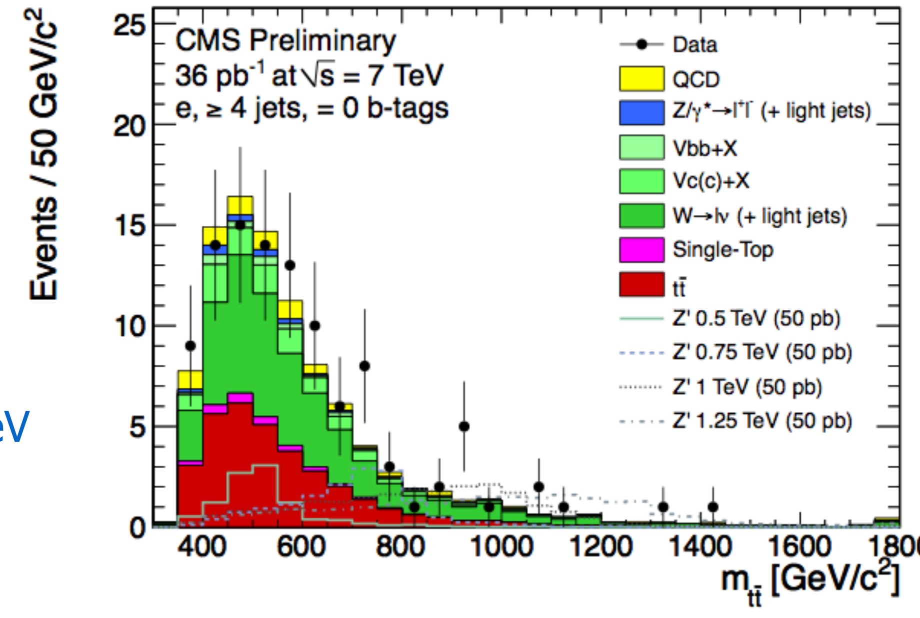
- Limits in simplified SUSY models

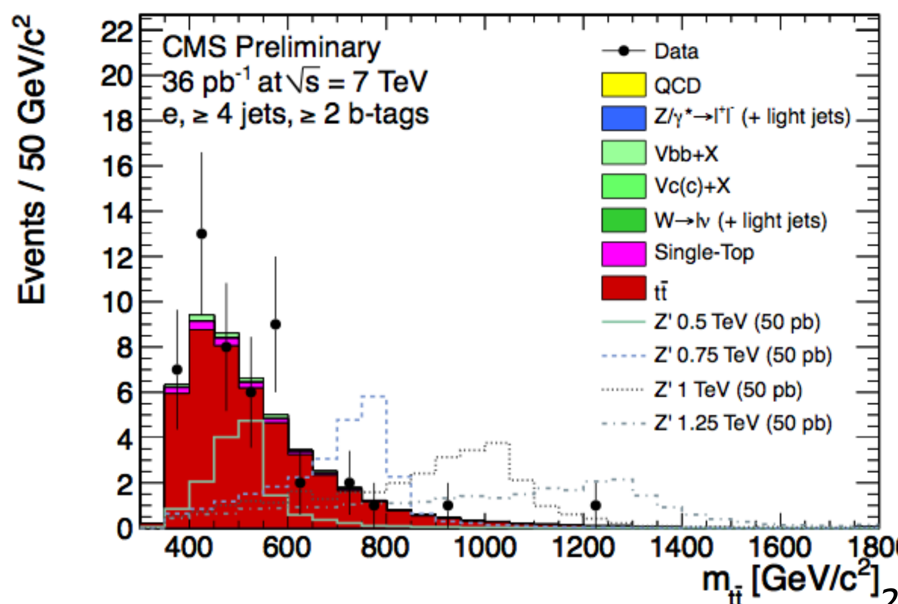


Z′ → ttbar

- Lepton + jets final state
  - Exclusive 3j (1b), >3j(0b, 1b, 2b)
- Find "best combination" using χ^2 to ttbar hypothesis, and make a constrained fit (fix top and W mass)
  - Improves resolution by ~40% at low mass, makes little difference above 1.5 TeV

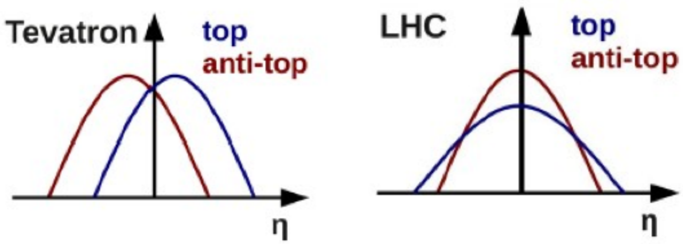






Top quark charge asymmetry

- Can not measure A_{FB} at pp collider
- But – quarks have higher x then anti-quarks
  - A_{FB} will result in different rapidity distributions for top and anti-top
  - Diluted by dominant gg production, unfortunately…

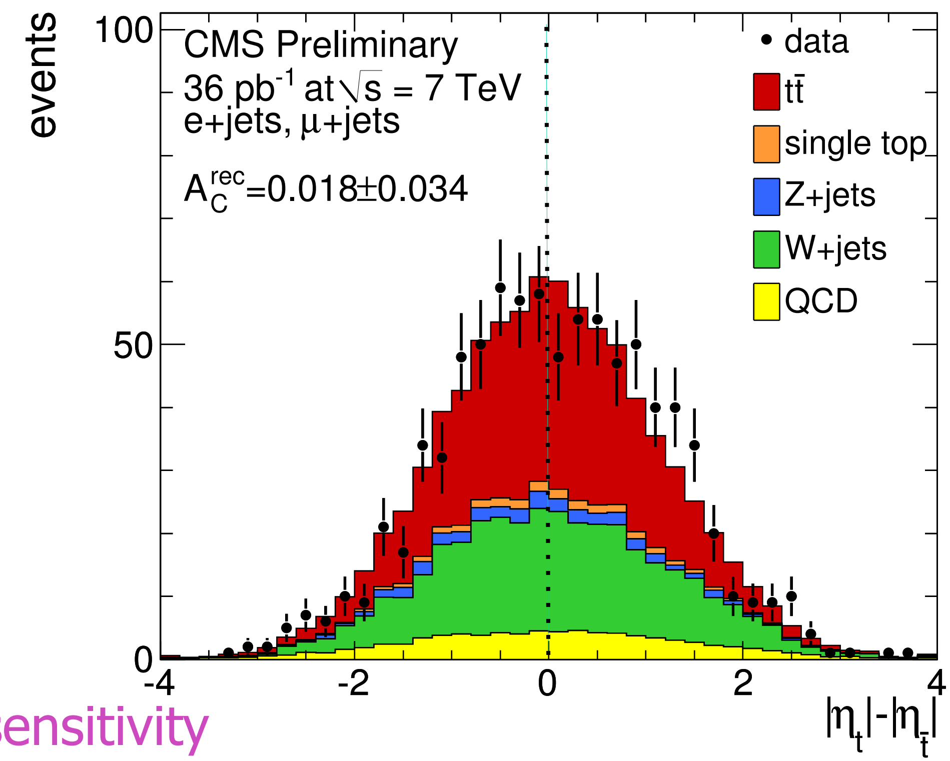


- Sensitive variable is

  $A_C = (N^+ - N^-)/(N^+ + N^-)$

$A_C(SM) = 0.013 \pm 0.001$

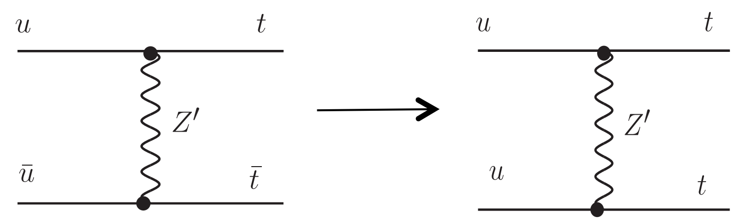
$A_C = 0.06 \pm 0.12 \pm 0.03$



Need ~1fb to get close to Tevatron sensitivity

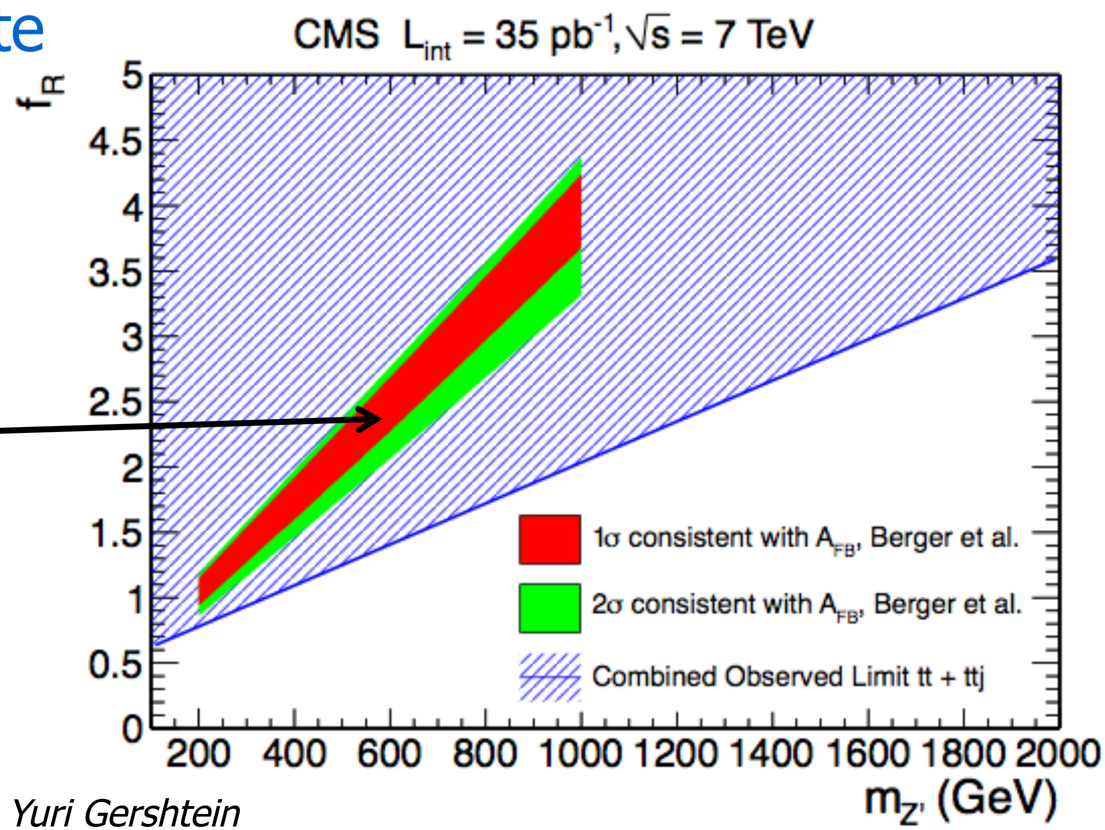
Same Sign tops

- Can be produced by the same physics that causes t-tbar asymmetry at the Tevatron



- Pretty much the same analysis as SUSY search in the same-sign leptons final state
  - 2 observed events
  - 0.9±0.6 expected

"Favored" region for Tevatron A_{FB} from Berger *et al*
arXiv:1101.5625v2



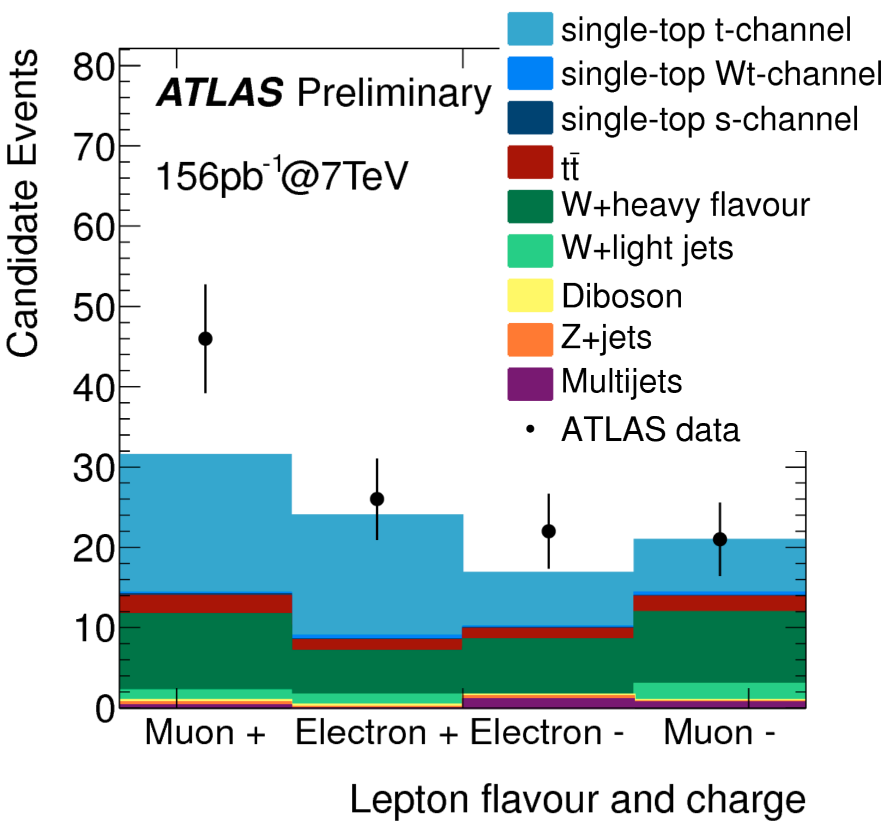
Single Top

- Increased production rate at the LHC is also one of possible signals motivated by ttbar asymmetry at the Tevatron
- MVA trained on SM single top may suppress anomalous signals
- ATLAS has attempted most simple cut based analysis

- |untagged jet η |>2.0
- 140 GeV < top mass < 190 GeV
- | $\Delta\ \eta$ (lepton, b-tagged jet)| < 1.5
- |b-taggedjet η |<2.0
- HT>180GeV

Observed cross section:
$\sigma_t = 97\ ^{+54}_{-30}$ pb

Observed (expected) significance:
6.3 (4.5) σ



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To be compared with NN analysis result:

Observed cross section:
$\sigma_t = 76\,^{+41}_{-21}$ pb

Observed (expected) significance 6.2 (5.7) σ

Single Top

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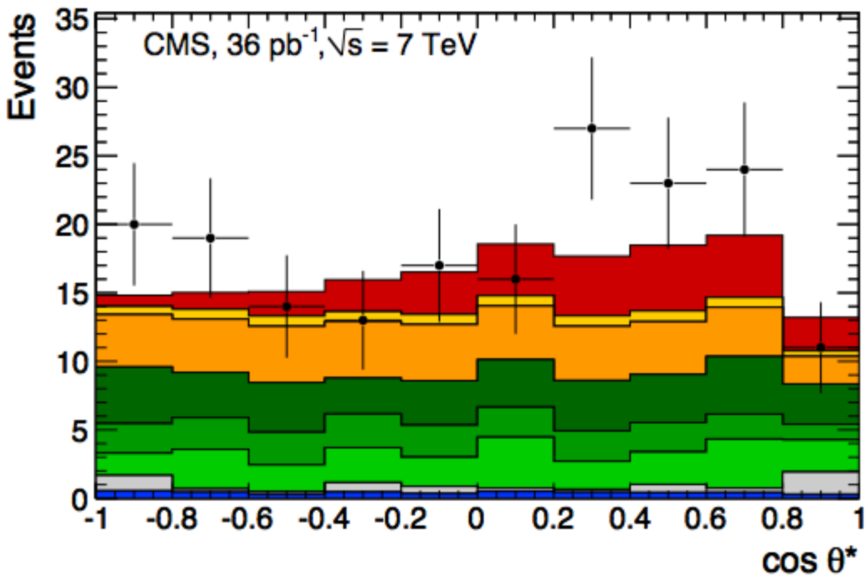
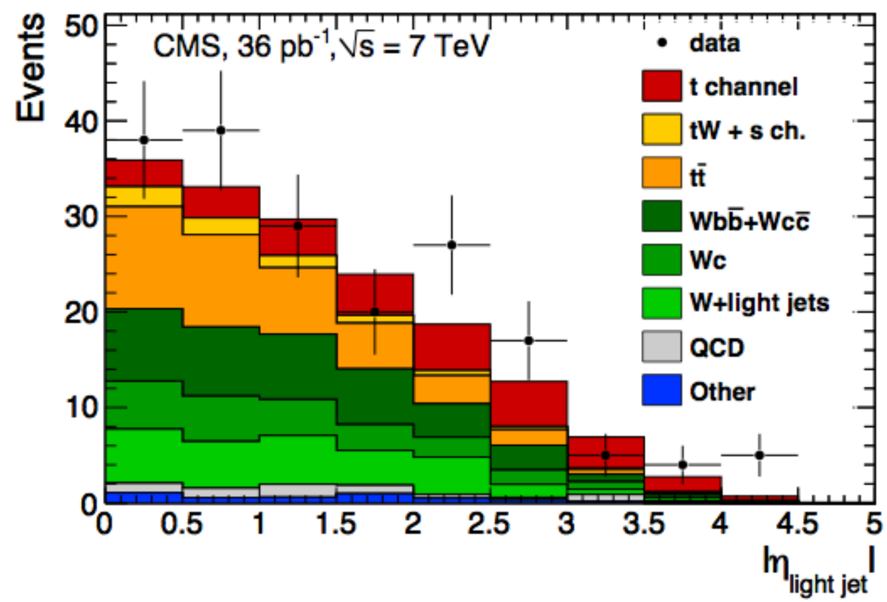
- MVA trained on SM single top may suppress anomalous signals
- CMS did 2-D likelihood fit as a “simple” analysis



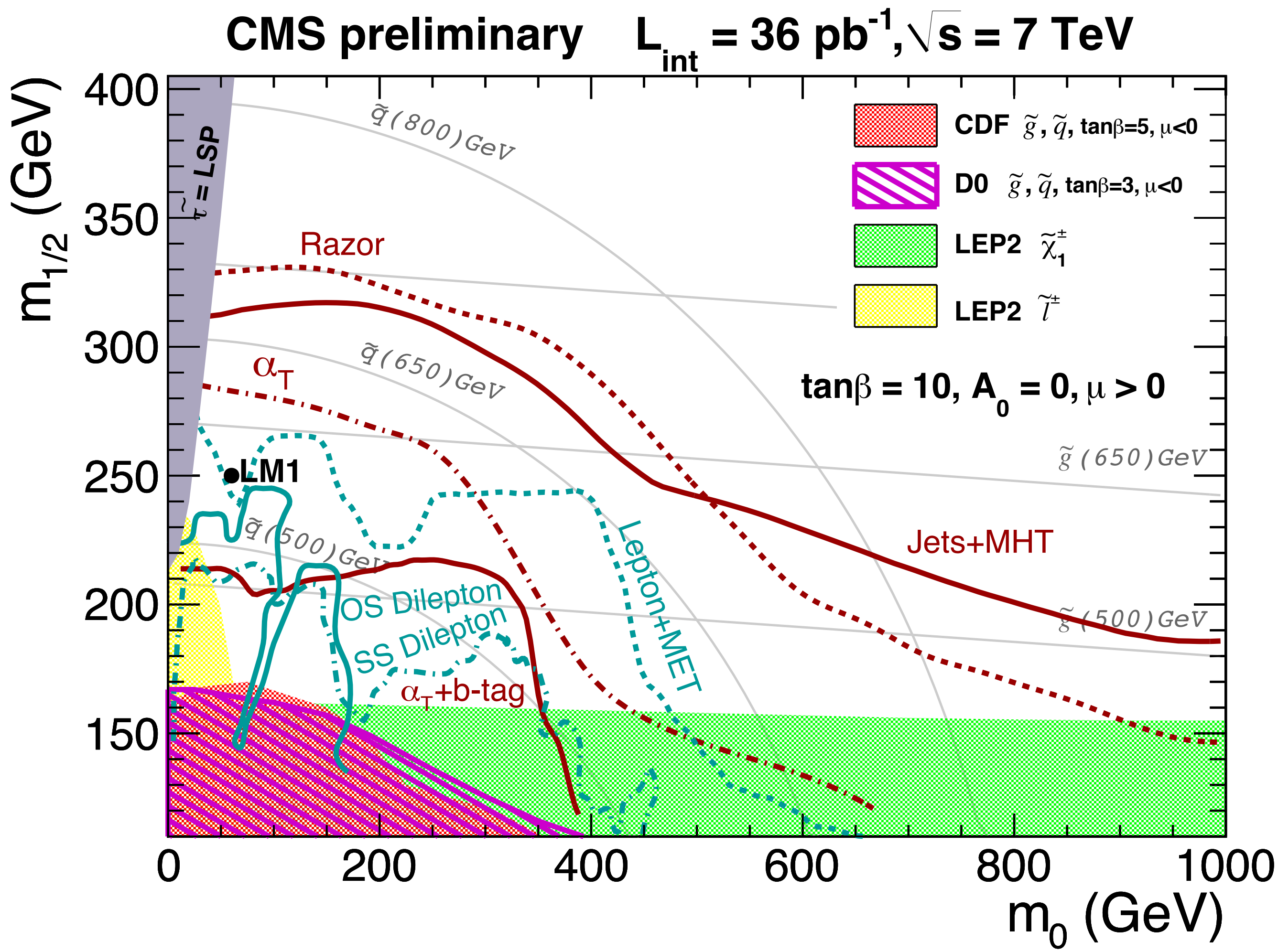


Channel	2D analysis	BDT analysis
$\mu + \mathrm{e}$	$124.2 \pm 33.8\,^{+30.0}_{-33.9}$ pb	$78.7 \pm 25.4\,^{+13.2}_{-14.6}$ pb

SUSY

SUSY

- Or absence thereof



SUSY

- Final states studied so far:
  - Jets + MET (several incarnations)
  - B-jets + MET
  - 2 photons + jet + MET (GM)
  - Photon + lepton + MET (GM)
  - 1 lepton + jets + MET
  - 2 SS leptons + jets + MET
  - 2 OS leptons + jets + MET
  - Z + jets + MET
  - >= 3 leptons + X

Tiny cross-sections

3 and 4 body production

- σ x Br (ttW) →3l ~ 1fb, →2l ~ 5 fb
- σ x Br (ttZ) →3l ~ 0.3 fb
- σ x Br (WWW) →3l ~ 1fb
- σ x Br (ttWW) → (3+)l ~0.05 fb
- σ x Br (WWWW) ~ (3+)l ~0.01 fb

Double parton scattering

- σ x Br (WW) →2l (same sign) 0.4 fb

How reliable are these numbers?

Details of top production kinematics

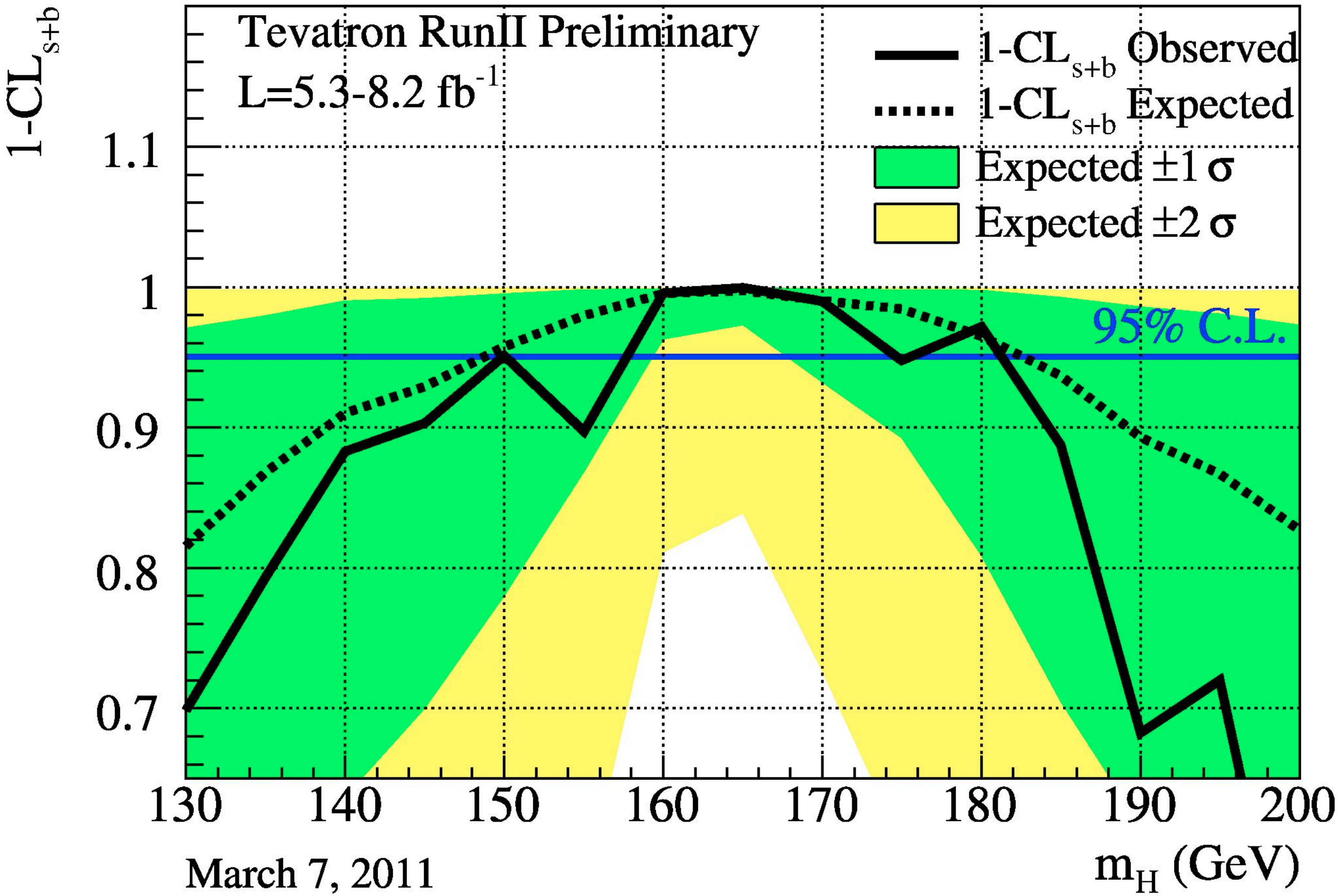
- $\sigma \sim 1.6 \times 10^5$ fb – do we understand its kinematics to 10^{-5}?

Anomalous jet fragmentation

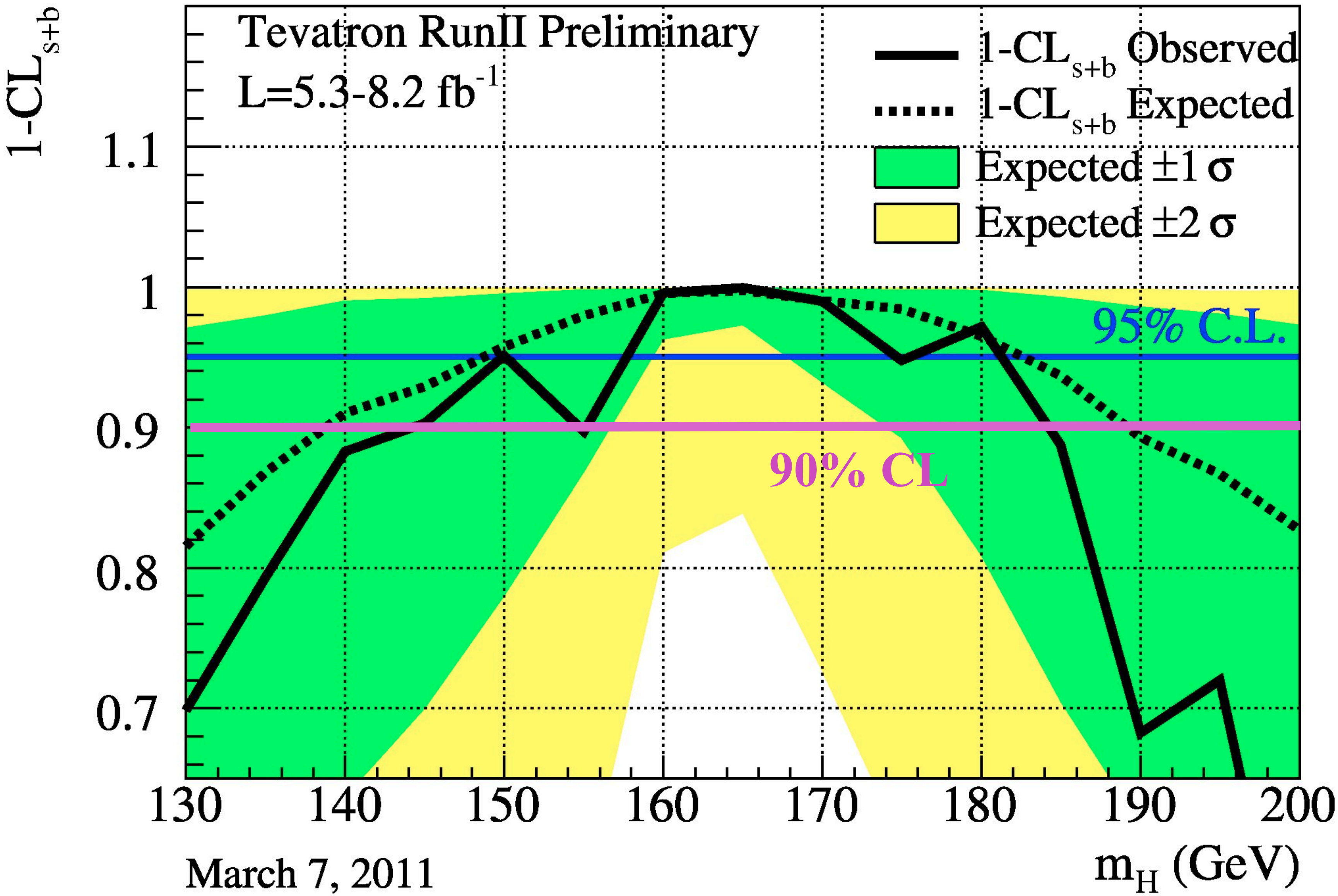
- W cross section is 10^8 fb (+30 GeV jet: 10^7 fb) – are we sure we can control subtle jet fragmentation effects to so many orders of magnitude? (q vs. g vs. Q, for instance)

Higgs

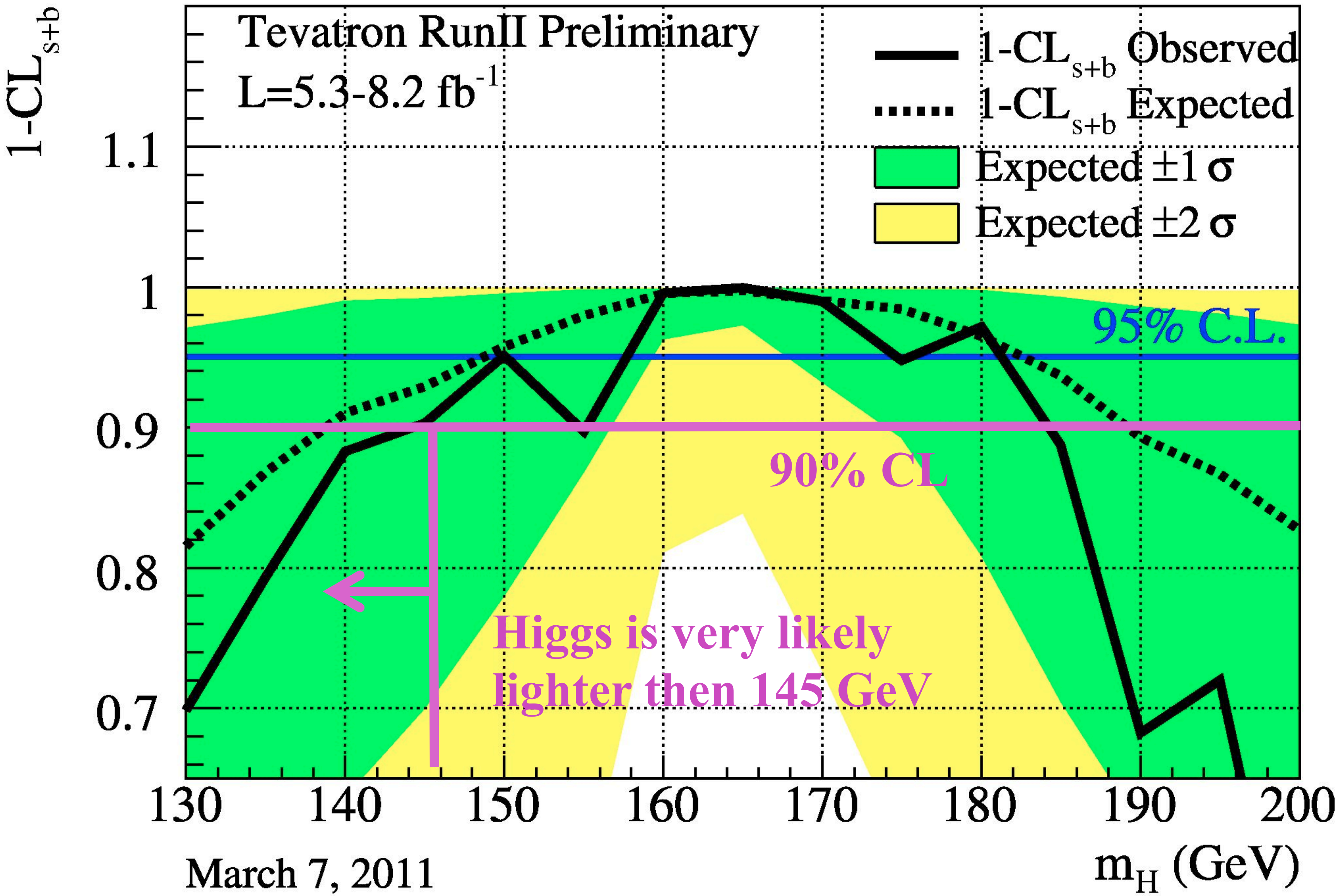
Tavatron limits



Tavatron limits



Tavatron limits



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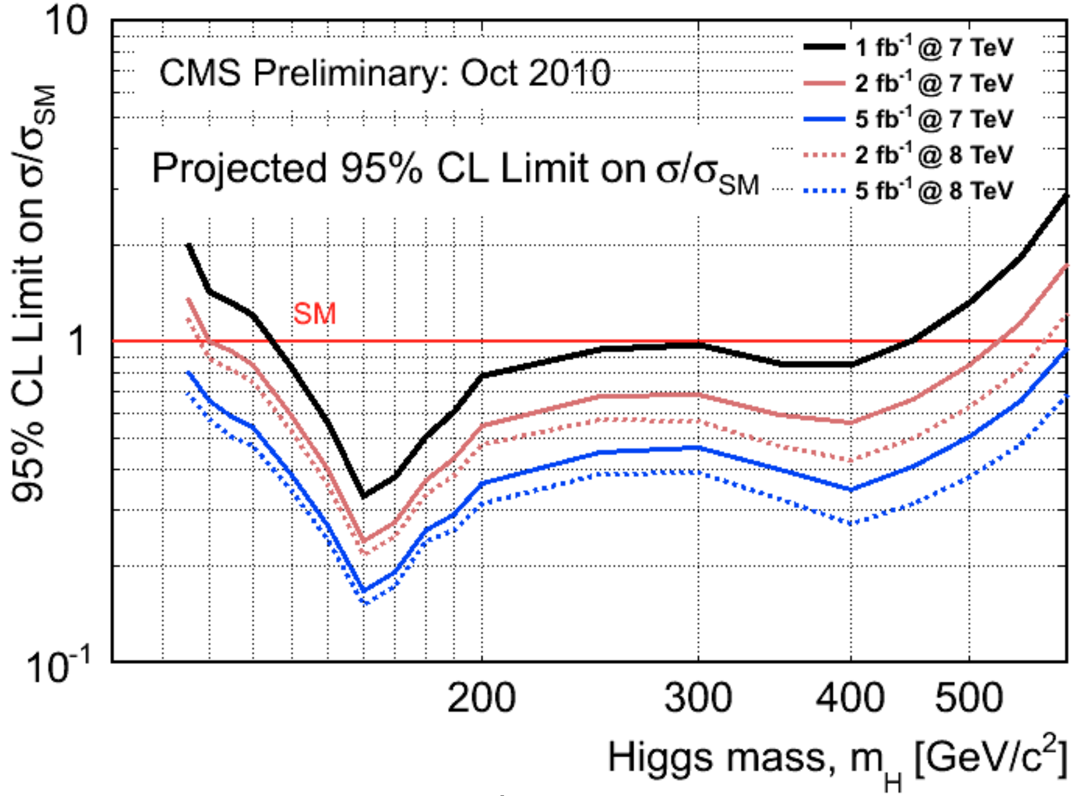

Note how close are 8 and 7 TeV curves

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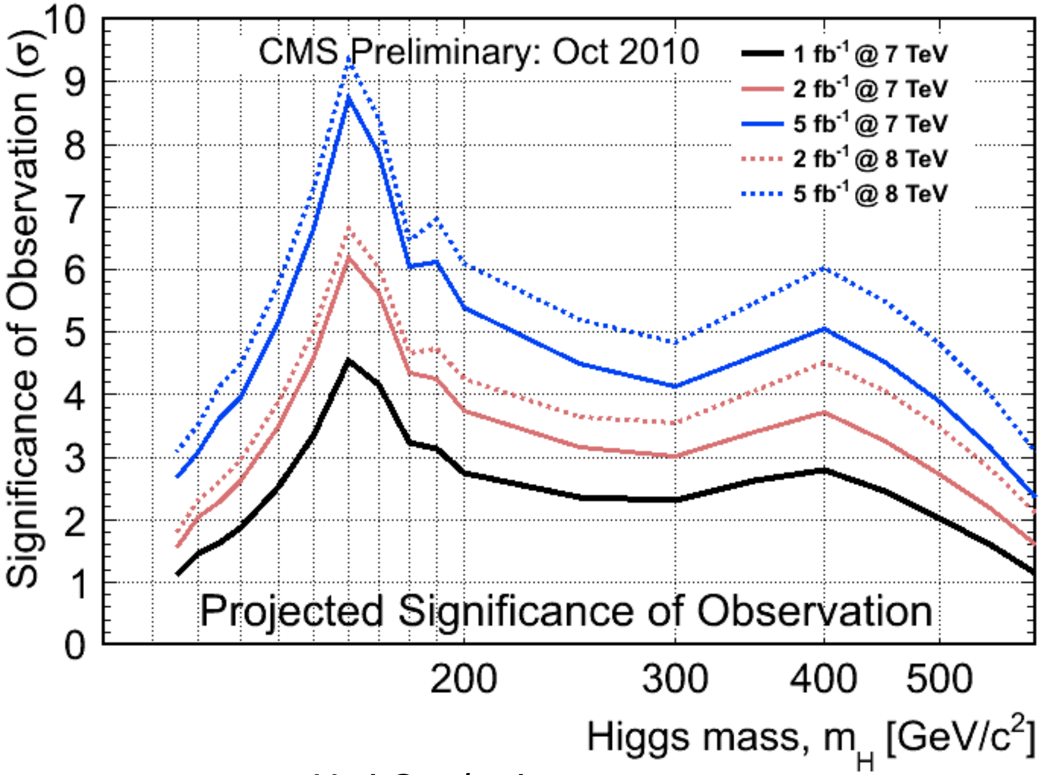

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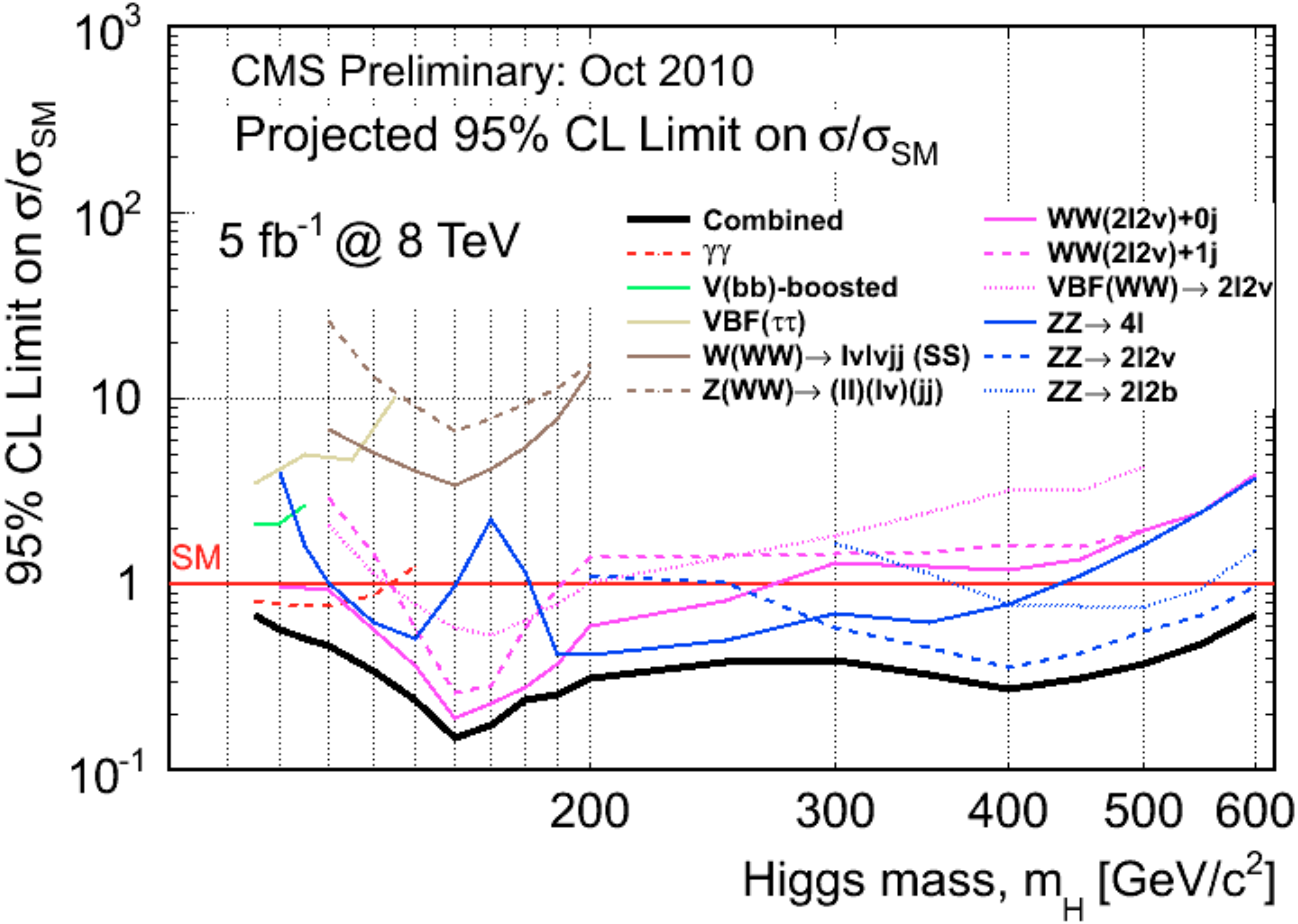
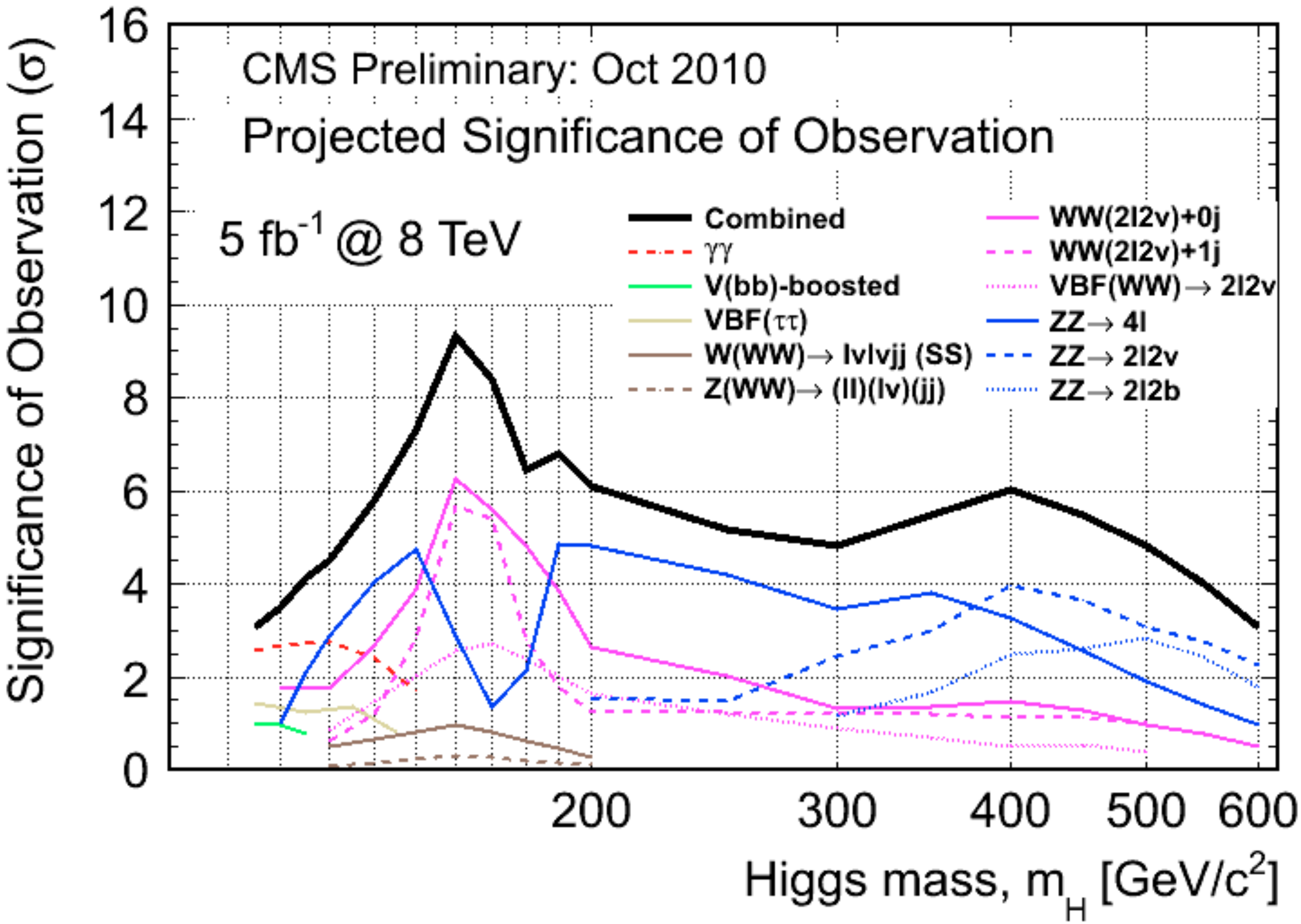
The Channels



The Channels

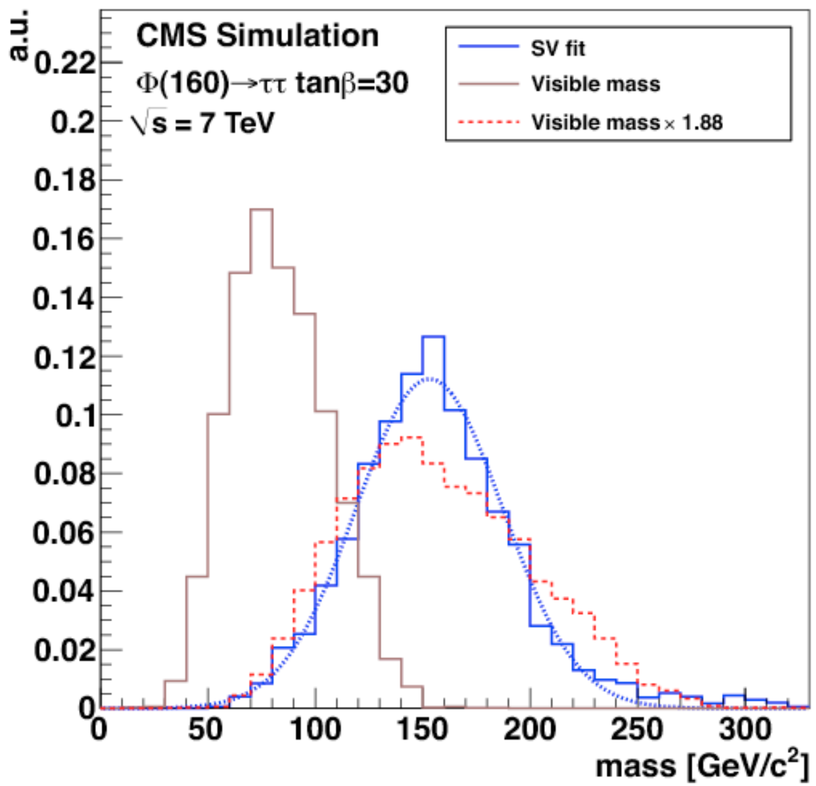


The Channels

- Concentrating on masses below 150
- For exclusion:
  - $\gamma\gamma$, WW, ZZ
- For discovery:
  - $\gamma\gamma$, ZZ
  - WW takes over for m>150
- Plus $\tau\tau$, boosted *bb*, VBF, Vh
- A lot of room for analysis optimization
  - Have to get into Tevatron's "squeeze blood out of stone" frame of mind

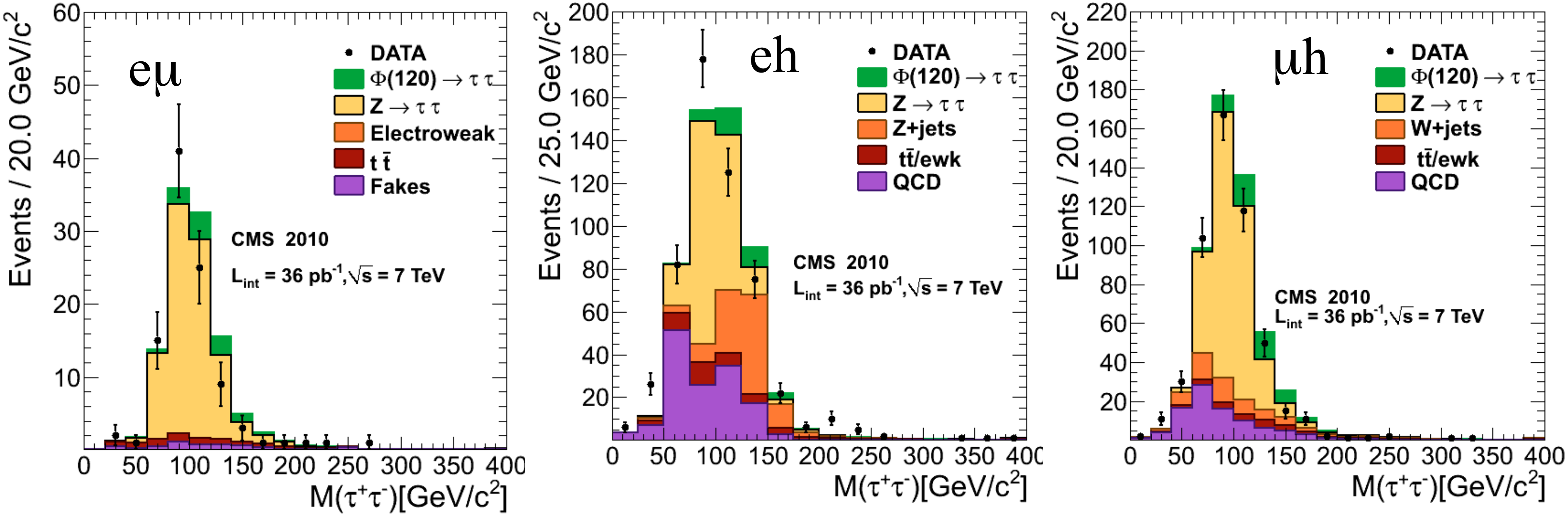
MSSM h→ττ

- Beyond collinear approximation:
  - Use all knowledge of tau decays
  - Use all experimental information (including tau decay vertex)
  - Arrive to the most likely value for the di-tau mass

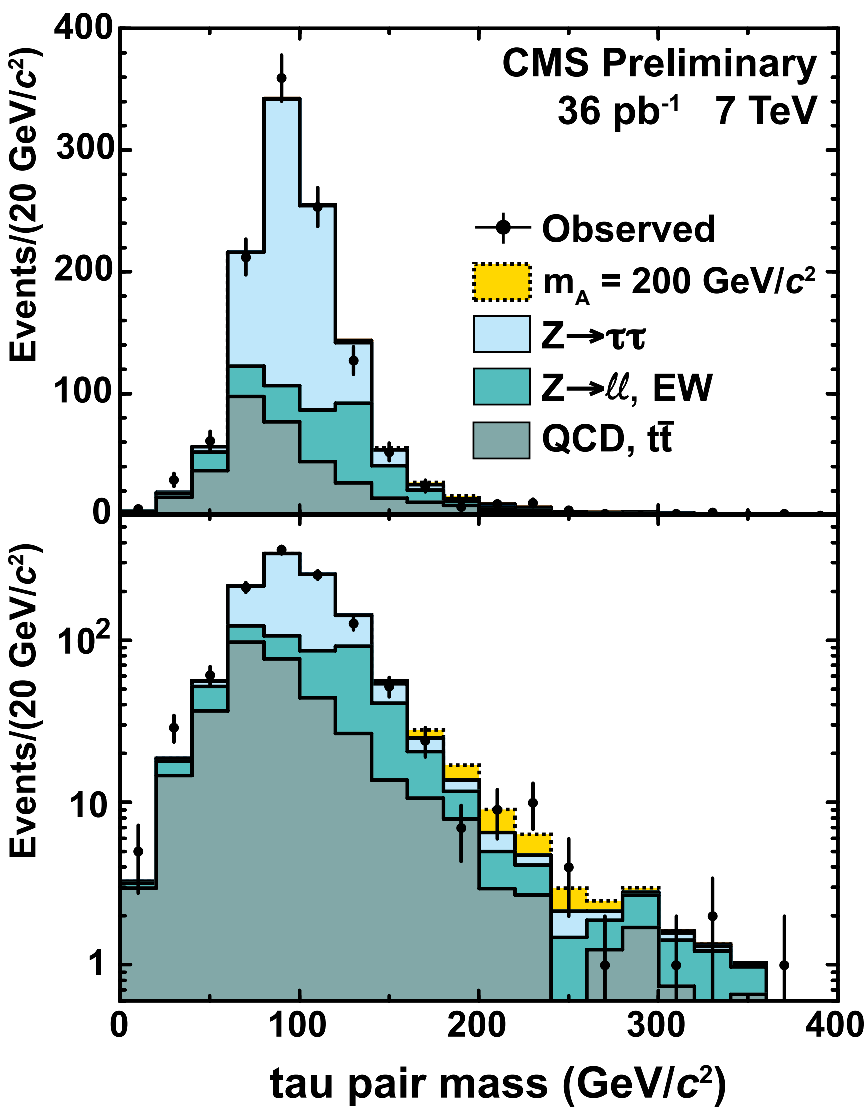


MSSM h→ττ

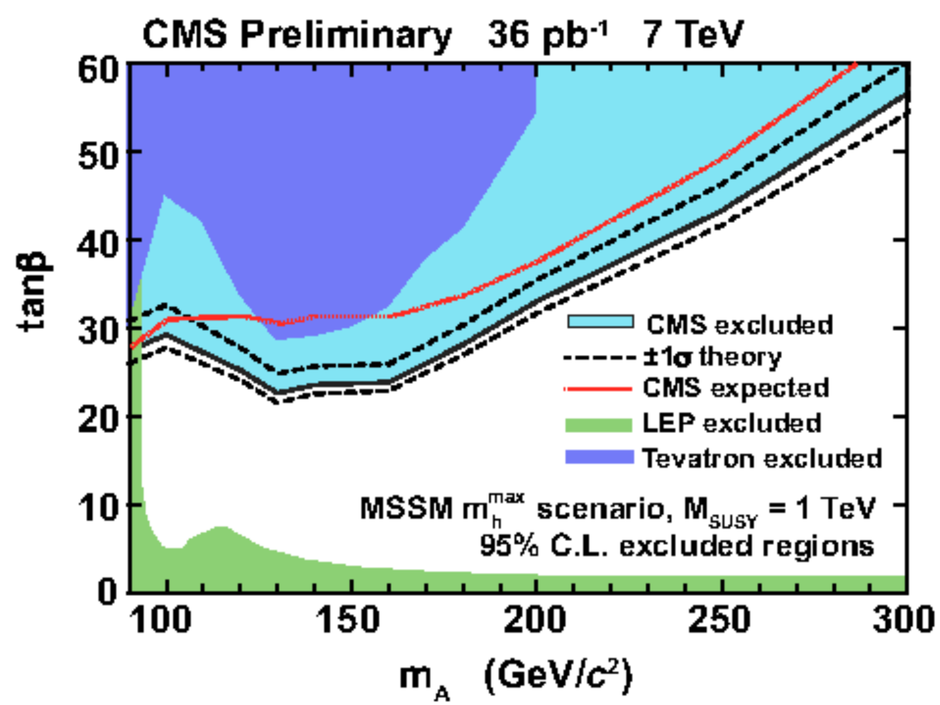
- Main backgrounds are
  - Z→ττ (irreducible)
  - W+j and QCD
- For QCD: isolated/non-isolated leptons vs SS/OS
  - Small corrections from MC
- W+j: control region M_T > 60 GeV



MSSM h→ττ



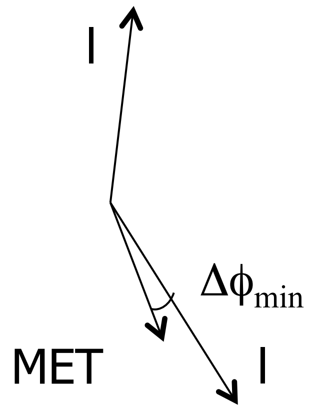
- Beat Tevatron!
- Coming improvements: require a b-jet



h→WW→2l2ν

- One of the main discovery modes (LHC & Tevatron)
- Two leptons + missing ET
- <u>Familiar challenges:</u>
  - Drell-Yan with mis-measured recoil (Z veto)
    - e+mu channel is cleanest
  - Drell-Yan with MET from mis-measured leptons or real neutrinos from tau decays
    - Projected missing ET

$$= \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{min} > \frac{\pi}{2}, \\ E_{\mathrm{T}}^{\mathrm{miss}} \sin(\Delta\phi_{min}) & \text{if } \Delta\phi_{min} < \frac{\pi}{2} \end{cases}$$



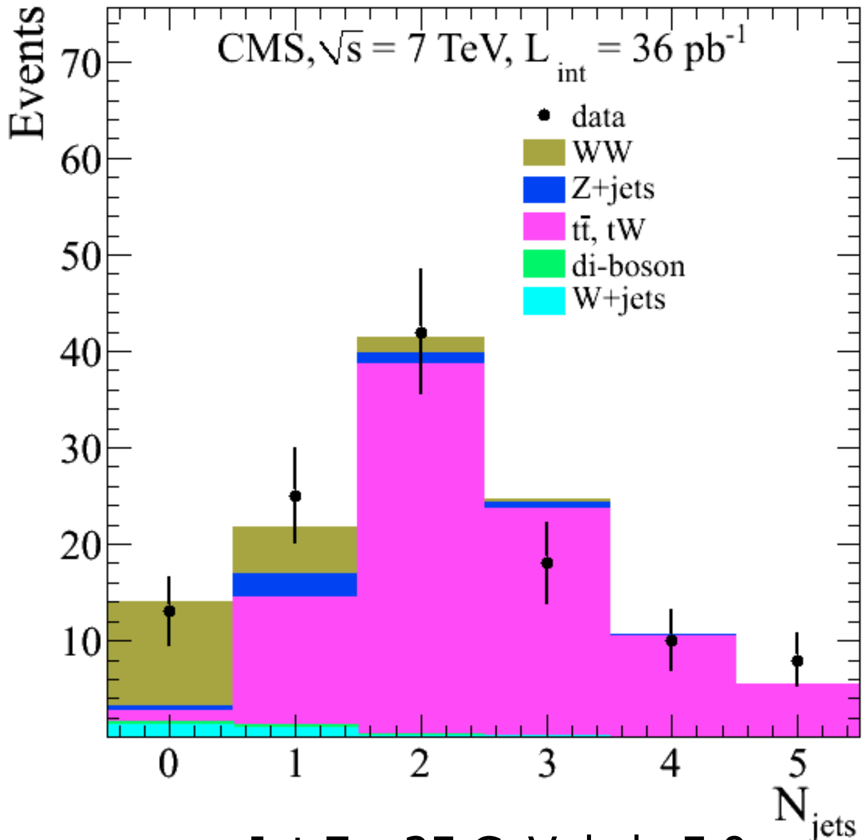
> 20 GeV for eμ and >35 GeV for ee/μμ

  - asymmetric early photon conversions - Wγ

$h \rightarrow WW \rightarrow 2l2\nu$

- One of the main discovery modes (LHC & Tevatron)
- Two leptons + missing ET
- Plus, some new one: top
- Two leptons
  - pT > 20 GeV
  - $|\eta|<2.4$ (2.5) for μ (e)
- MET and projected MET cuts

- Anti-top:
  - Jet veto
  - Top veto (low pT muons or b-jets below 25 GeV)

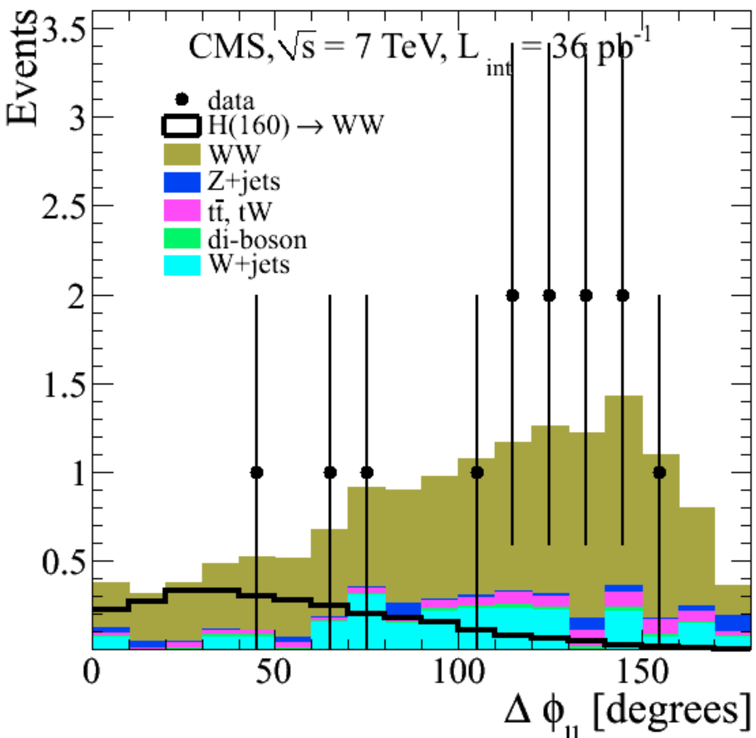


Jet E_T>25 GeV, $|\eta|$<5.0

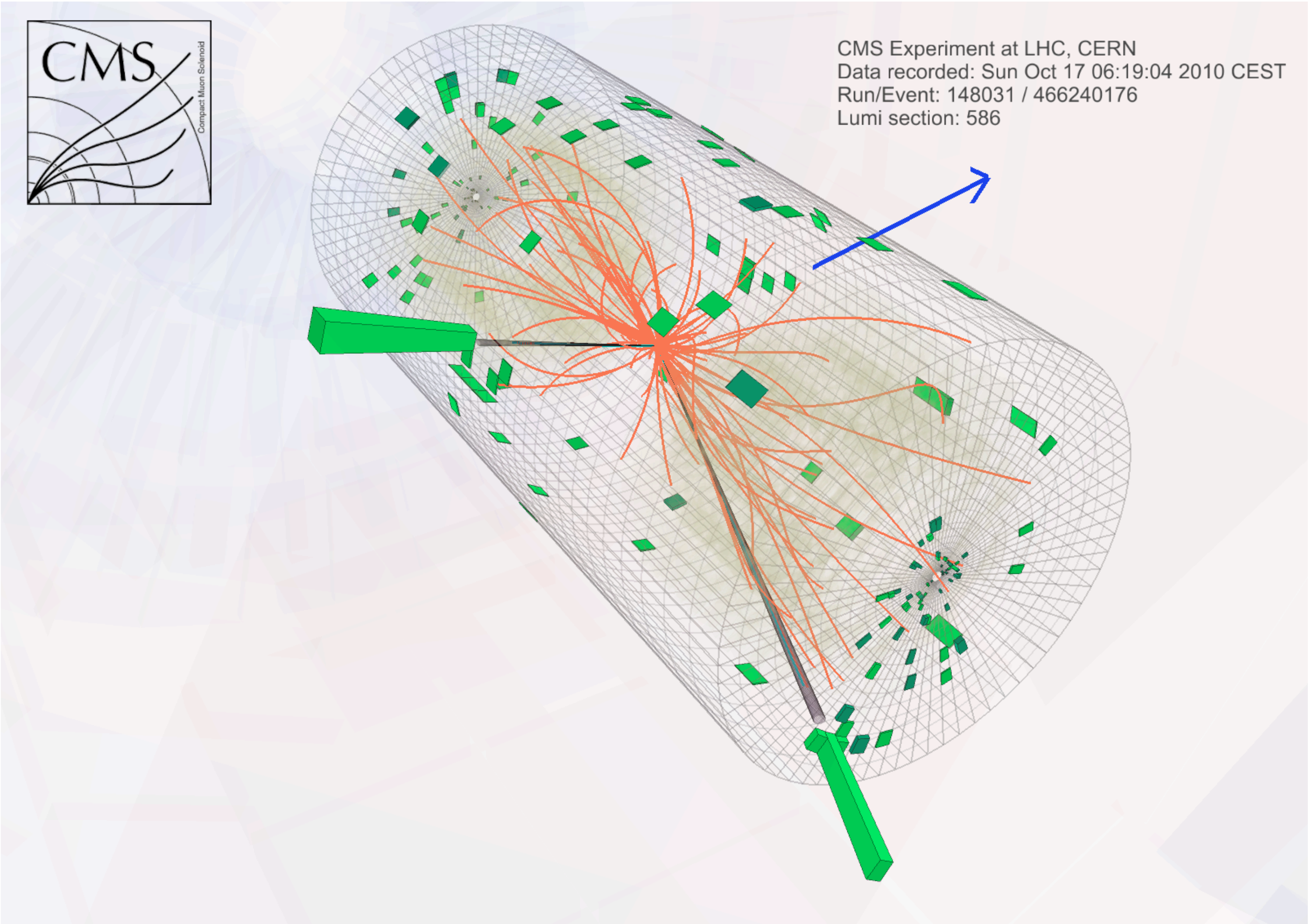
h→WW→2l2ν

- Higgs vs non-resonant WW: cut-based

m_H (GeV/c^2)	$p_T^{\ell,max}$ (GeV/c) >	$p_T^{\ell,min}$ (GeV/c) >	$m_{\ell\ell}$ (GeV/c^2) <	$\Delta\phi_{\ell\ell}$ (degree) <
130	25	20	45	60
160	30	25	50	60
200	40	25	90	100
210	44	25	110	110
400	90	25	300	175



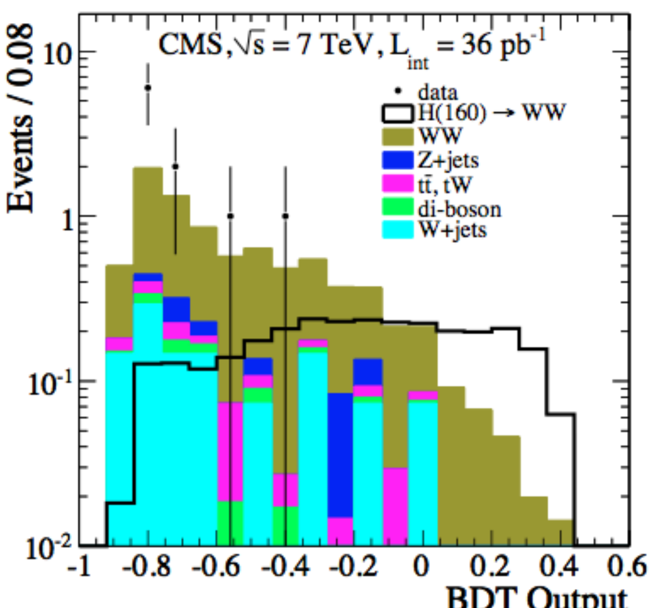
$h \rightarrow WW \rightarrow 2l2\nu$

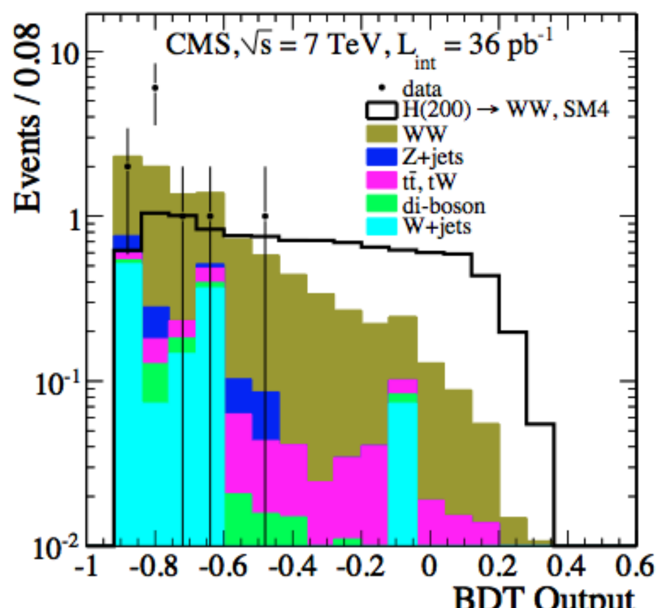


h→WW→2l2ν

- Higgs vs non-resonant WW: boosted decision trees
- Variables:
  - ΔR between leptons
  - Δφ between leptons and MET
  - Projected MET
  - MT for both leptons
  - Lepton flavors

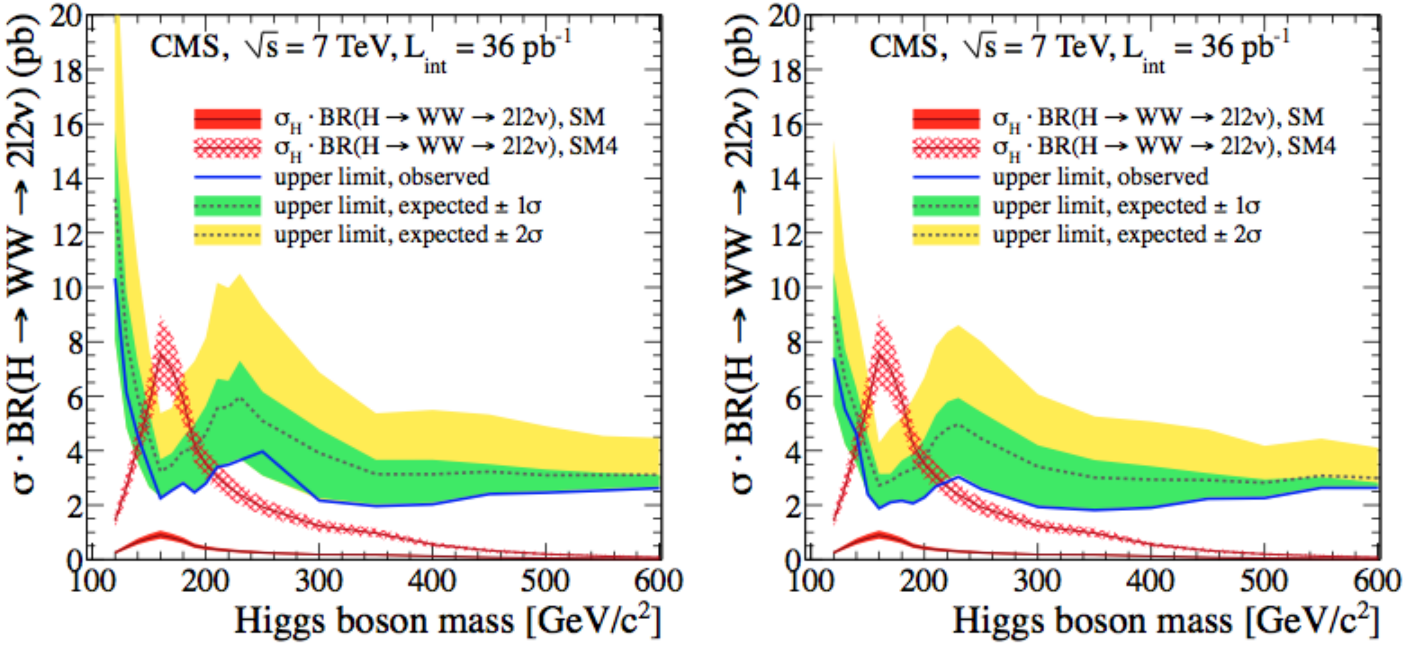
m_H (GeV/c^2)	data	SM $H \to W^+W^-$	SM with 4th gen. $H \to W^+W^-$	all bkg.
				cut-based approach
130	1	0.30 ± 0.01	1.73 ± 0.04	1.67 ± 0.10
160	0	1.23 ± 0.02	10.35 ± 0.16	0.91 ± 0.05
200	0	0.47 ± 0.01	3.94 ± 0.07	1.47 ± 0.09
210	0	0.34 ± 0.01	2.81 ± 0.07	1.49 ± 0.05
400	0	0.19 ± 0.01	0.84 ± 0.01	1.06 ± 0.03
				multivariate approach
130	1	0.34 ± 0.01	1.98 ± 0.04	1.32 ± 0.18
160	0	1.47 ± 0.02	12.31 ± 0.17	0.92 ± 0.10
200	0	0.57 ± 0.01	4.76 ± 0.07	1.47 ± 0.07
210	0	0.42 ± 0.01	3.47 ± 0.07	1.44 ± 0.07
400	0	0.20 ± 0.01	0.90 ± 0.01	1.09 ± 0.07



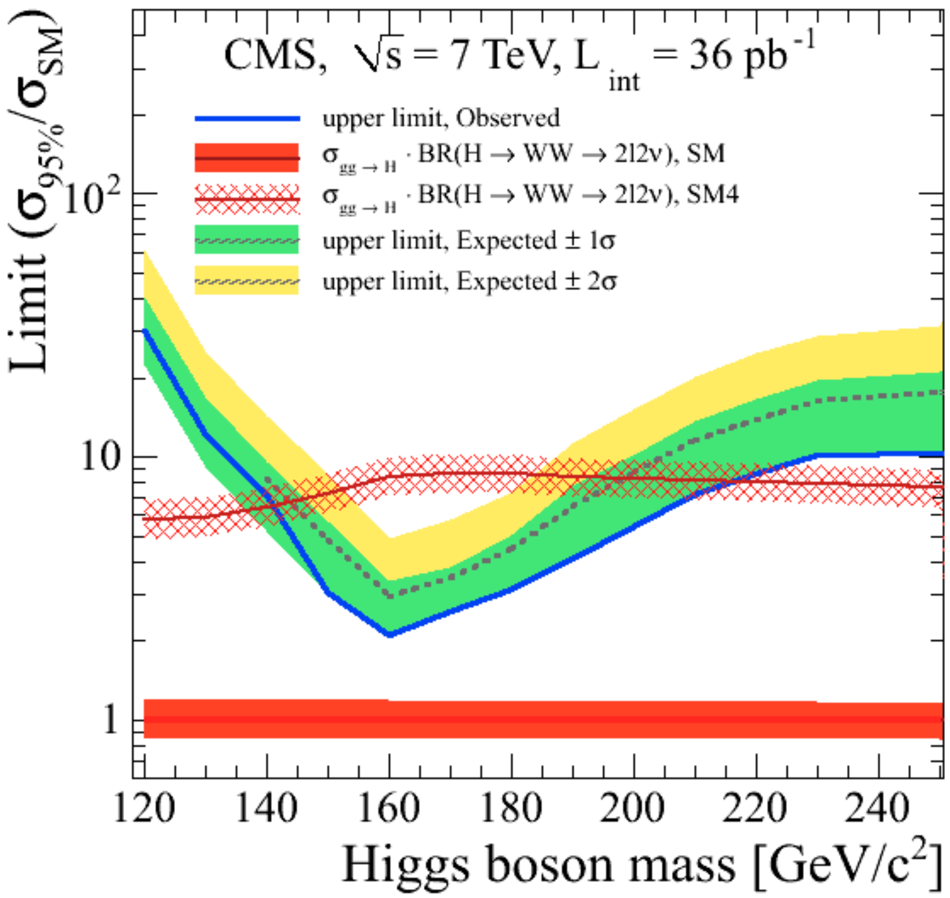


$h \to WW \to 2l2\nu$

- WW background
  - Normalize using data: for m(H)<200 GeV use m(ll)>100 GeV as the control region, for m(H)>200 GeV, use m(ll)<100 GeV
  - Results in large (50%) error
- Systematic uncertainty: jet veto is the main uncertainty
  - Use ratio of H->WW to Z->ll
- POWHEG vs NNLO with NNLL resummation
  - 14% difference in efficiency due to harder Higgs pT in POWHEG

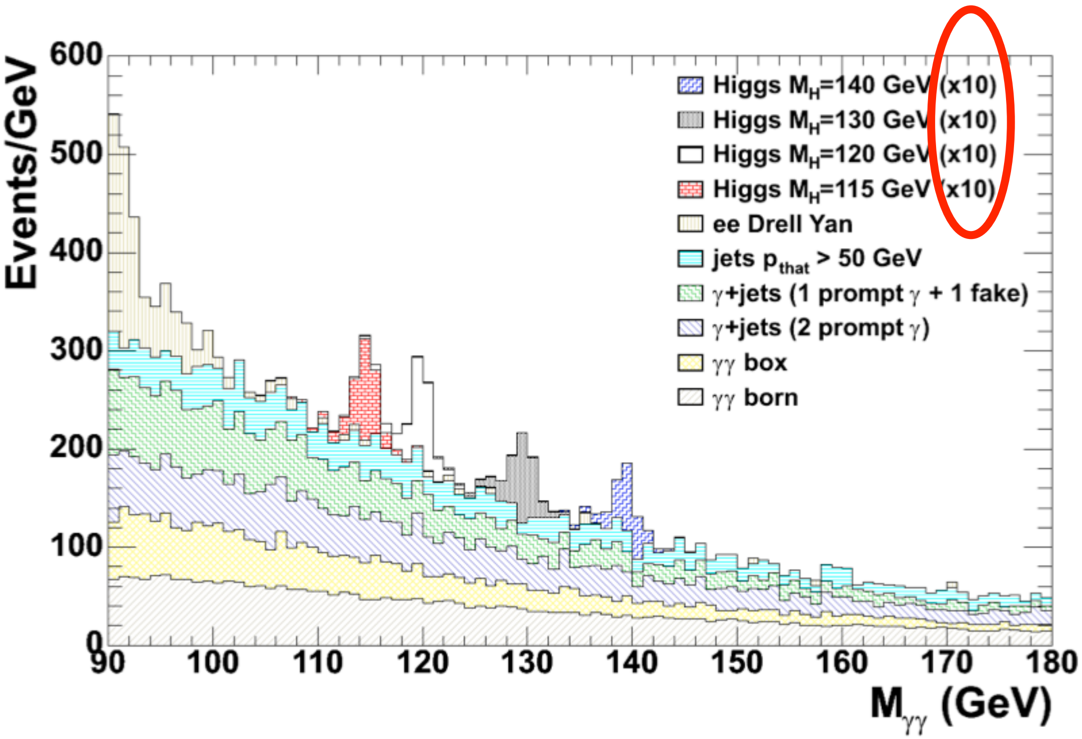


$h \to WW \to 2l2\nu$

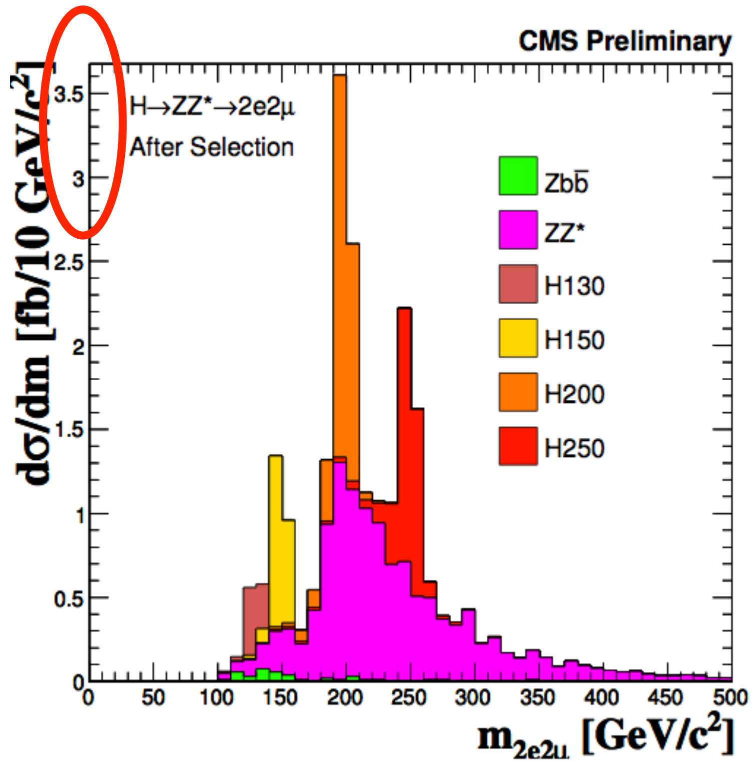


- Many improvements to come: exclusive jet bins, categorization instead of cuts, etc.

Challenges



Events/GeV
600
500
400
300
200
100
0
90
100
110
120
130
140
150
160
170
180
$M_{\gamma\gamma}$ (GeV)
Higgs M_H=140 GeV (x10)
Higgs M_H=130 GeV (x10)
Higgs M_H=120 GeV (x10)
Higgs M_H=115 GeV (x10)
ee Drell Yan
jets p_{that} > 50 GeV
γ+jets (1 prompt γ + 1 fake)
γ+jets (2 prompt γ)
$\gamma\gamma$ box
$\gamma\gamma$ born



CMS Preliminary
$d\sigma/dm$ [fb/10 GeV/c^2]
$H \to ZZ^* \to 2e2\mu$
After Selection
$Zb\bar{b}$
ZZ*
H130
H150
H200
H250
0
0.5
1
1.5
2
2.5
3
3.5
0
50
100
150
200
250
300
350
400
450
500
$m_{2e2\mu}$ [GeV/c^2]

Challenges

- For both $\gamma\gamma$ and ZZ channels mass resolution is the key
  - (boring things like calibration…)
- Energy resolution for electrons and photons
  - Take back the degradation from tracker material
  - Separate pile-up from showering electrons and photons
  - Multiple event classes based on measurement quality
- Primary vertex finding in $\gamma\gamma$
  - Both mass resolution and identification
- Take advantage of different S/sqrt(B) in sub-channels, especially in $\gamma\gamma$ – no shortage of events!
  - Exclusive jet bins
  - W/Z->jj, VBF, MET from associated Z
  - Leptons from associated W
  - Need to know relative contributions between the channels – wrong choices can lead to underestimated significance…

Outlook

- 1 fb^{-1} of data looked at with no grand surprises
  - If there is new physics in that data, it's more subtle then mSUGRA or low scale quantum gravity
- at least ten times more data is yet to come soon
  - Will get harder as we go along. Number of small background processes that need to be considered becomes large
    - recall the mono-jet discovery
- One thing for sure – by ~this time next year we will know whether the SM Higgs exists
  - This would be a great start for the next few decades of the LHC operation

J. Virdee PLHC summary

LHC Time-line

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

Already obsolete!

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

2030 — ILC, High energy LHC, ... ?