Higgs Boson Searches
With The Early LHC Data

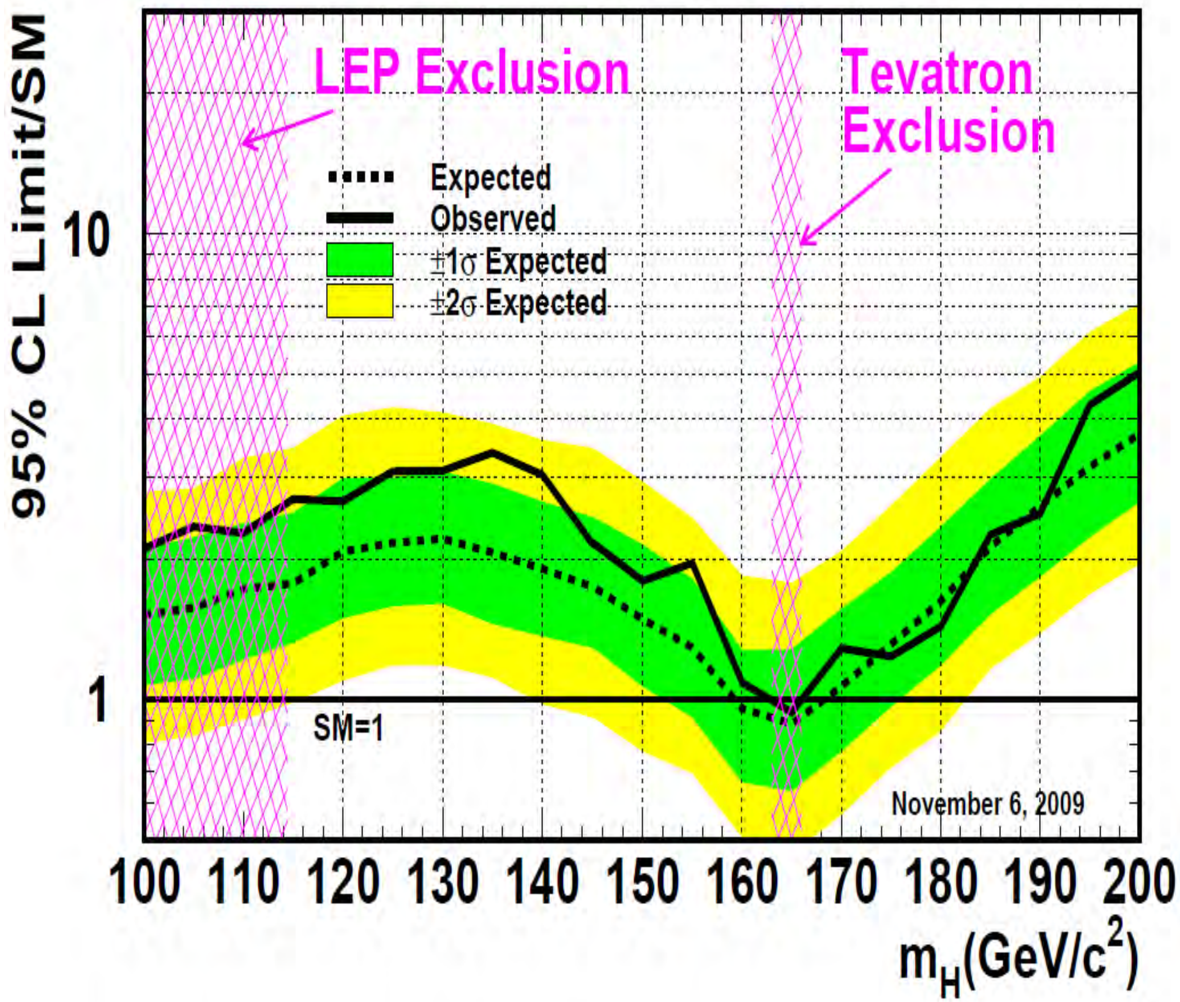
Vivek Sharma

University of California, San Diego

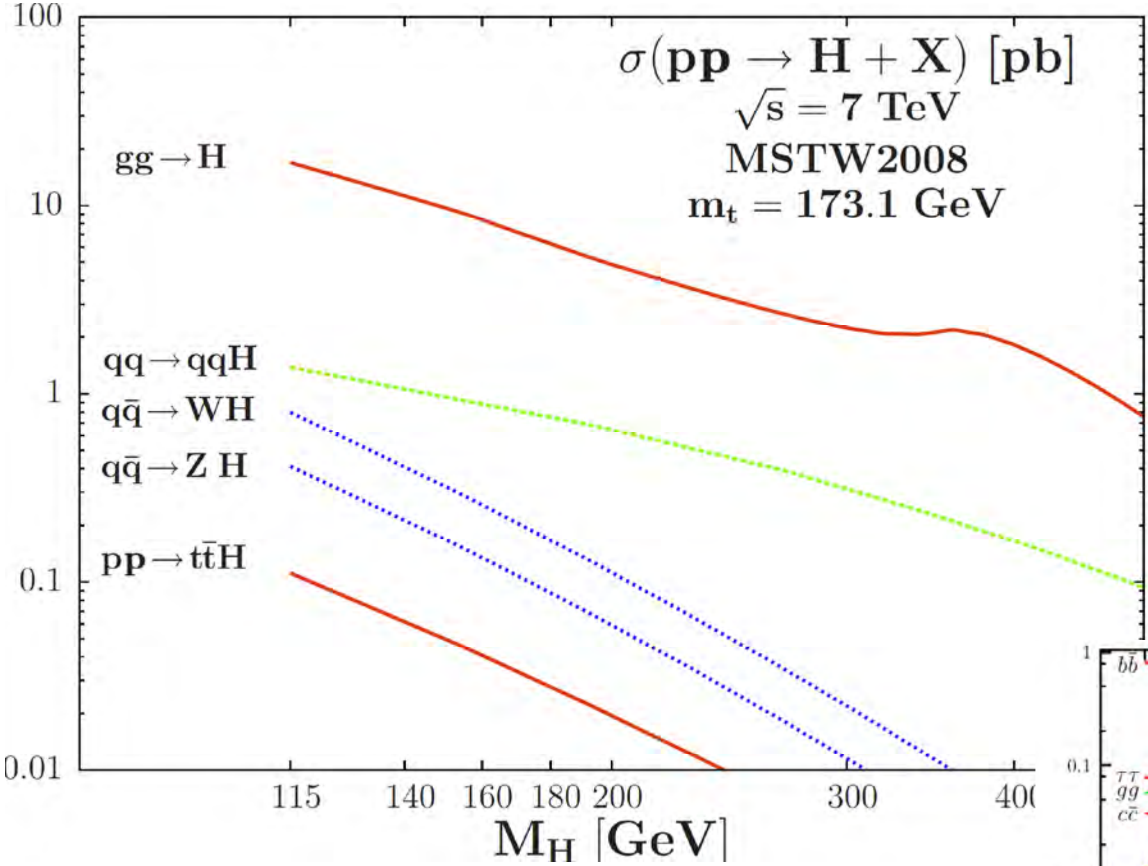
(On behalf of ATLAS & CMS Experiments)

Story So Far: Direct Searches For Higgs

arXiv:1001.4162



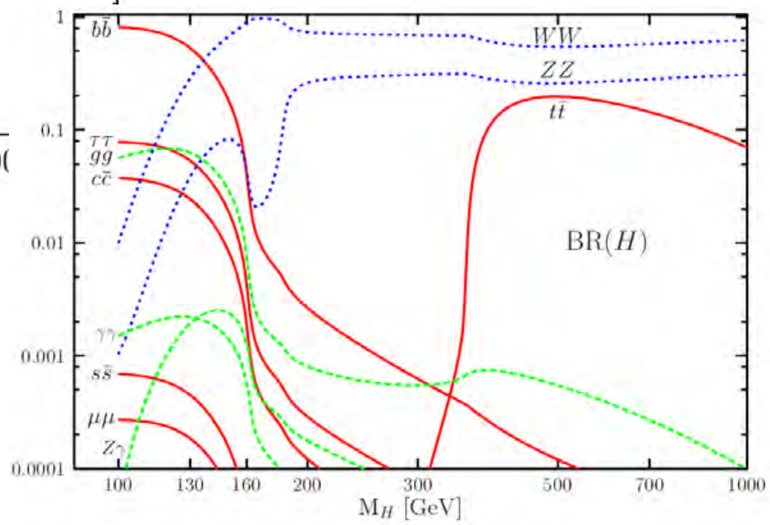
Higgs Production in 7 Tev pp Collsions



Dominant production:
gg→ H

Dominant decay mode
At high H mass

H→ WW, ZZ



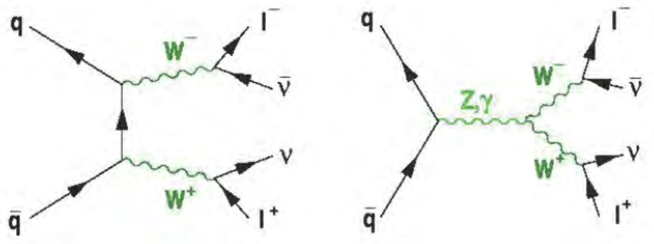
LHC & Tevatron : A Basic Comparison

For M_X > 140:

gg σ at 7 TeV > 15x that at Tevatron

Higher rate for Higgs production

Irreducible backgrounds (WW, ZZ)



originate from qqbar which rises relatively slowly

⇒ S/N rises , ⇒ LHC competitive with $1fb^{-1}$

For M_X < 140: slow rise in qqbar σ

Compared to at Tevatron, Higg-sstrahlung (pp → VH) rate @ 7 TeV not much larger

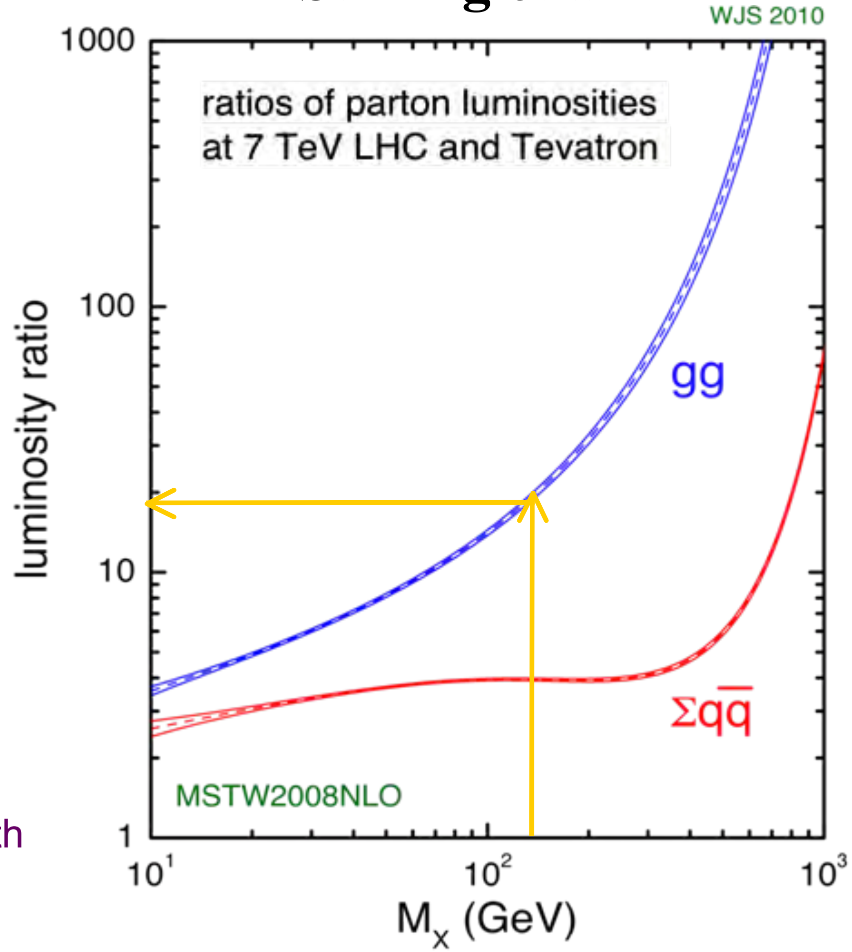
Major backgrounds are W/Z+bbbar & ttbar which rise sharply due to rapid rise in gg σ ⇒ small signal rate & poor S/N

gg → H →γγ favored in production and even with Br(H →γγ) ≅ 0.2%

large QCD γγ background

⇒ Poor S/N

Stirling et al



Higgs Sensitivity @ 7 TeV with 1 fb^{-1}

- **Predicting future is dodgy business !**
  - but one tries nevertheless
- Projections based on published 14 TeV studies (2008 and earlier)
  - Based on analyses constructed to **discover** Higgs, not set **best limits**
  - 7 TeV simulation studies ongoing but not completed
- Projections not rigorous: Indicative not predictive ! ….& designed to be conservative
- Will mostly show today projections from CMS
  - ATLAS projections in public domain "soon", expected to be similar to CMS
  - CMS Event reconstruction and analysis methodology as of 2008, not the current (improved) state-of-the-art
  - Projection method verified, in CMS, on complete analyses of 10 TeV pp simulations (but without pileup; which is important)

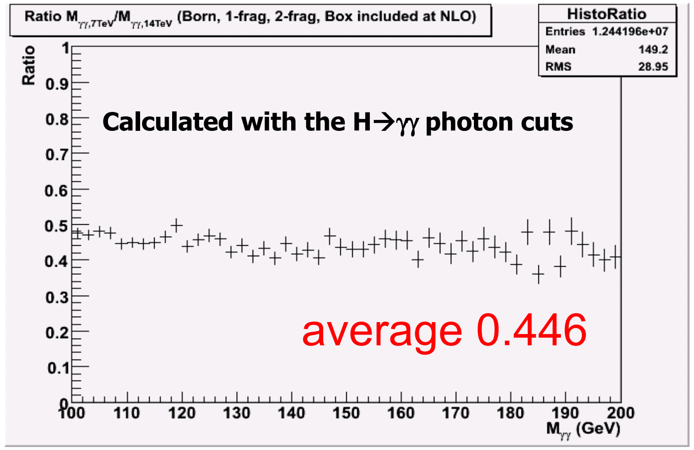
CMS 7 TeV Projections Workflow

- Start with results at 14 TeV (int. luminosity used varies: 1-30 fb^{-1})
- Re-scale signal and bkgd event counts by the ratio of 7 to 14 TeV cross sections and project for an integrated luminosity of 1 fb^{-1}
- **Use NNLO σ for $gg \rightarrow H$ (30% gain) , NLO for VBF & VH**
- Apply no correction for higher acceptance at smaller sqrt(s), which can be **up to 20%**
- Scaled systematic errors:
  - **for backgrounds derived from control samples $\Rightarrow$ scale as** 1/sqrt(N)
  - **other errors: assess whether to keep as is (e.g. theoretical errors) or inflate to correspond to the smaller data set**
  - **take into account correlations in systematic uncertainties**
- Statistical analyses of Sensitivities:
  - **Use re-scaled event counts and re-evaluated systematic errors**
  - **Exclusions:** Modified Frequentist (CL_s), **Significance:** Profile Likelihood

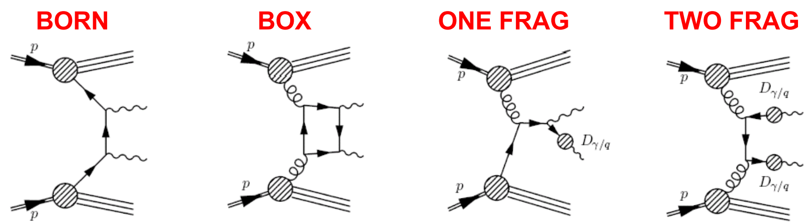
Background Cross Sections used

General background sources

process	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 10$ TeV	$\sqrt{s} = 7$ TeV	comment
$W \to \ell\nu$	3*20283.7	3*14253.7	3*9679.9	MCFM NLO
$DY(20-\infty) \to \ell\ell$	3*3259.7	3*2323.6	3*1606.6	MCFM NLO
WW	112.5	71.4	42.9	MCFM NLO
WZ	51.0	31.4	18.3	MCFM NLO
ZZ	15.6	9.9	5.9	MCFM NLO
$t\bar{t}$	918	415	165	MCFM NLO
Wt	56.1	26.0	10.5	MCFM NLO
tq-t channel	244.6	130.5	62.8	MCFM NLO
tq-s channel	11.9	7.6	4.6	MSTW 2008 NNLO
$W(\to \ell\nu) + \gamma$	54.7*1.8	35.4*1.8	23.2*1.8	NLO k-Factor from Bauer
$Z(\to \ell\ell) + \gamma$	17.5*1.8	11.3*1.8	7.3*1.8	NLO k-Factor from Bauer



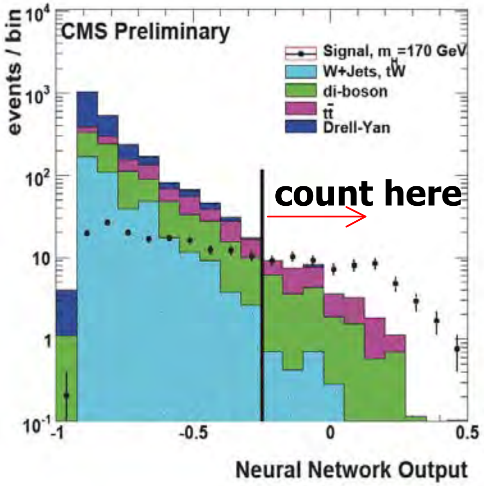
Background Estimate for H→γγ mode



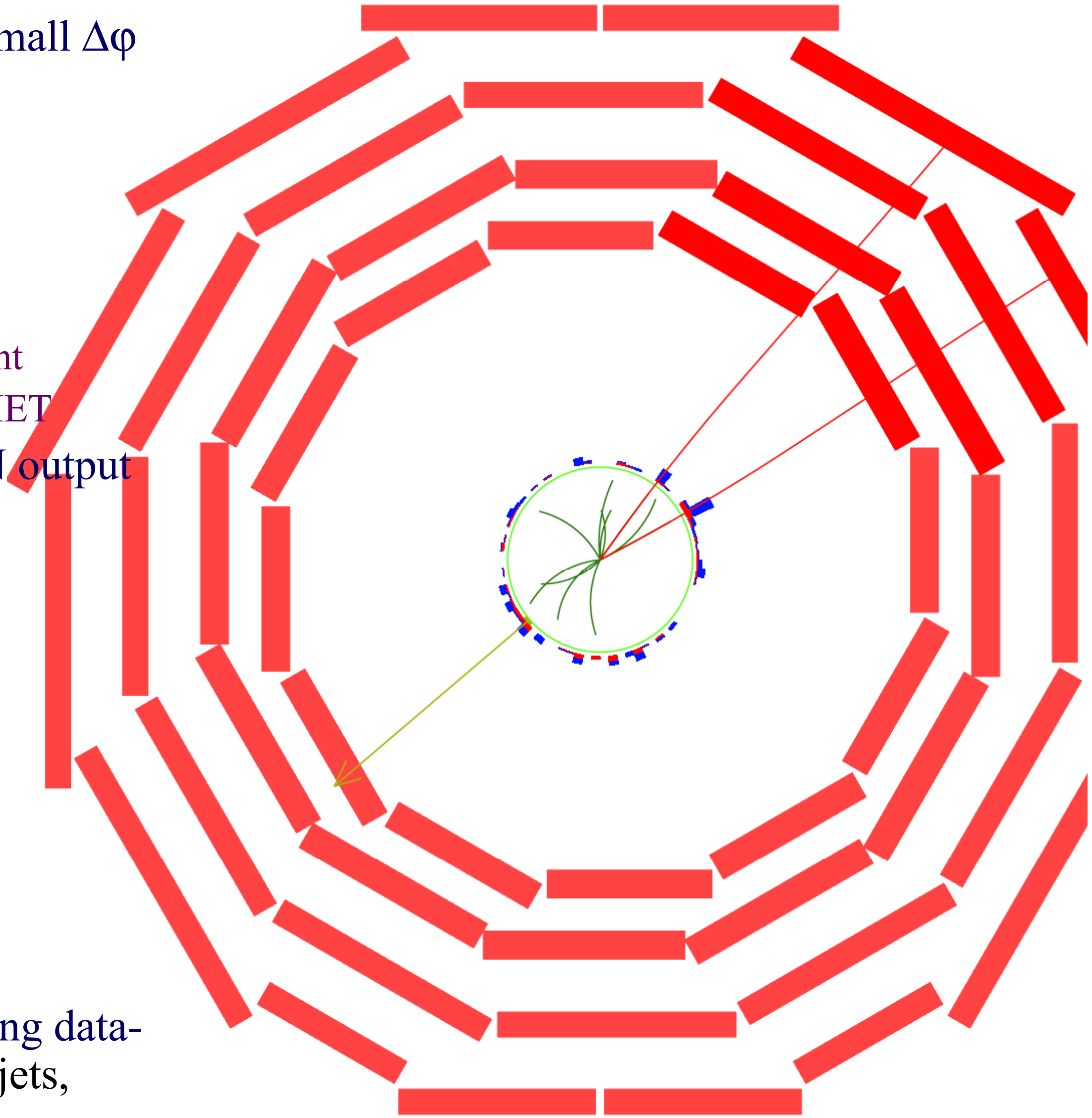
Diphox, Gamma2MC:
born+1frag +2frag + box **[all at NLO]**

$H \rightarrow WW$: Most Prolific Decay mode

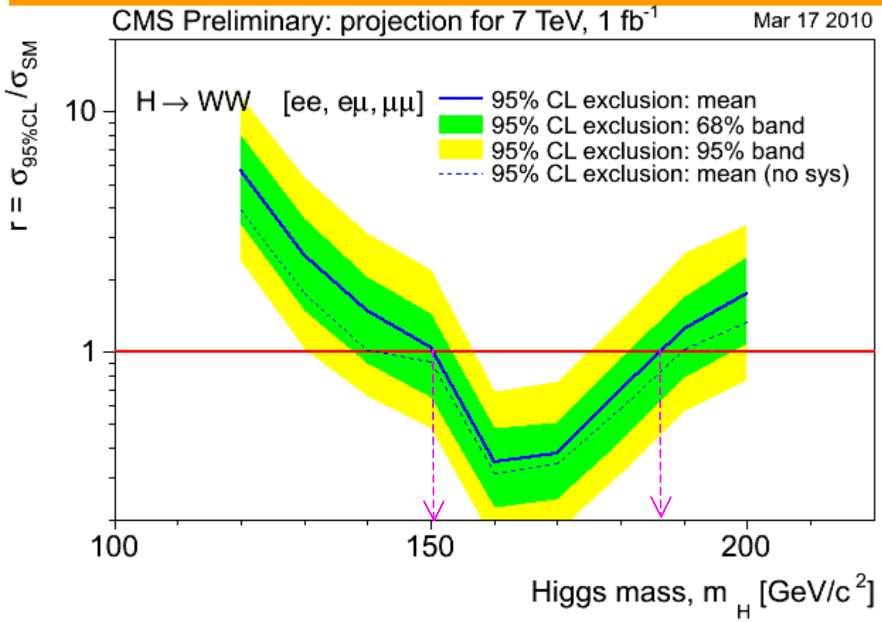
- Signal: two isolated leptons with small $\Delta\varphi$ + MET + no central jets (jet veto)
- Backgrounds reduction:
  - WW: $\Delta\varphi$ & m_{ll}
  - ttbar: cental jet veto, $\Delta\varphi$ & m_{ll}
  - W+jets: lepton id
  - DY alleviated by MET requirement
  - WZ/ZZ: 2 leptons in final state, MET
- look for excess above a cut on NN output

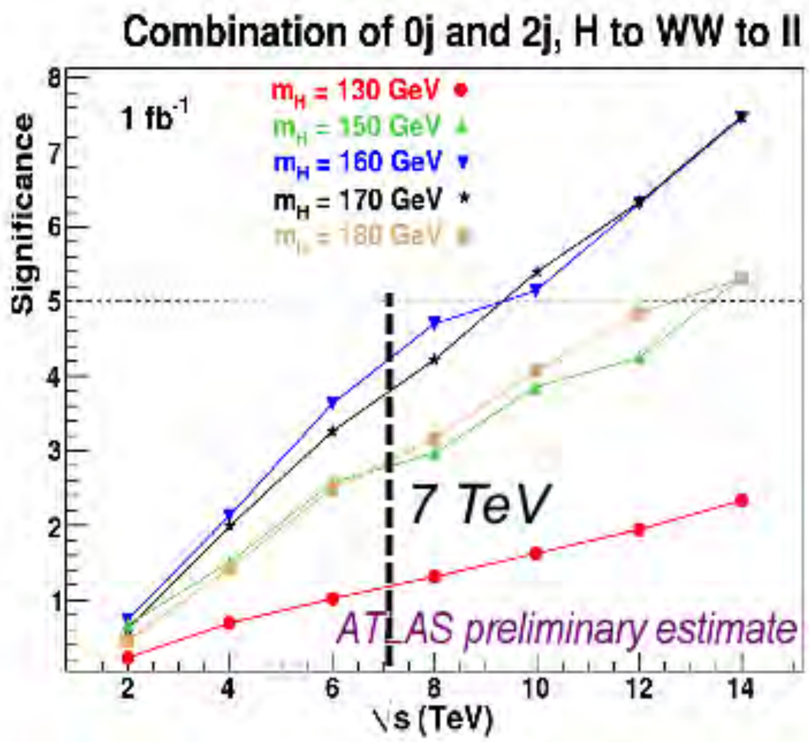


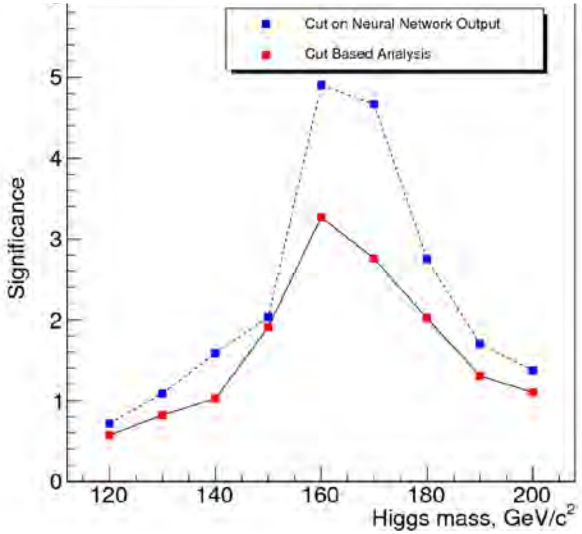
- main backgrounds are assessed using data-driven techniques: WW, ttbar, W+jets, Drell-Yan



SM $H \to WW \to 2l2\nu$





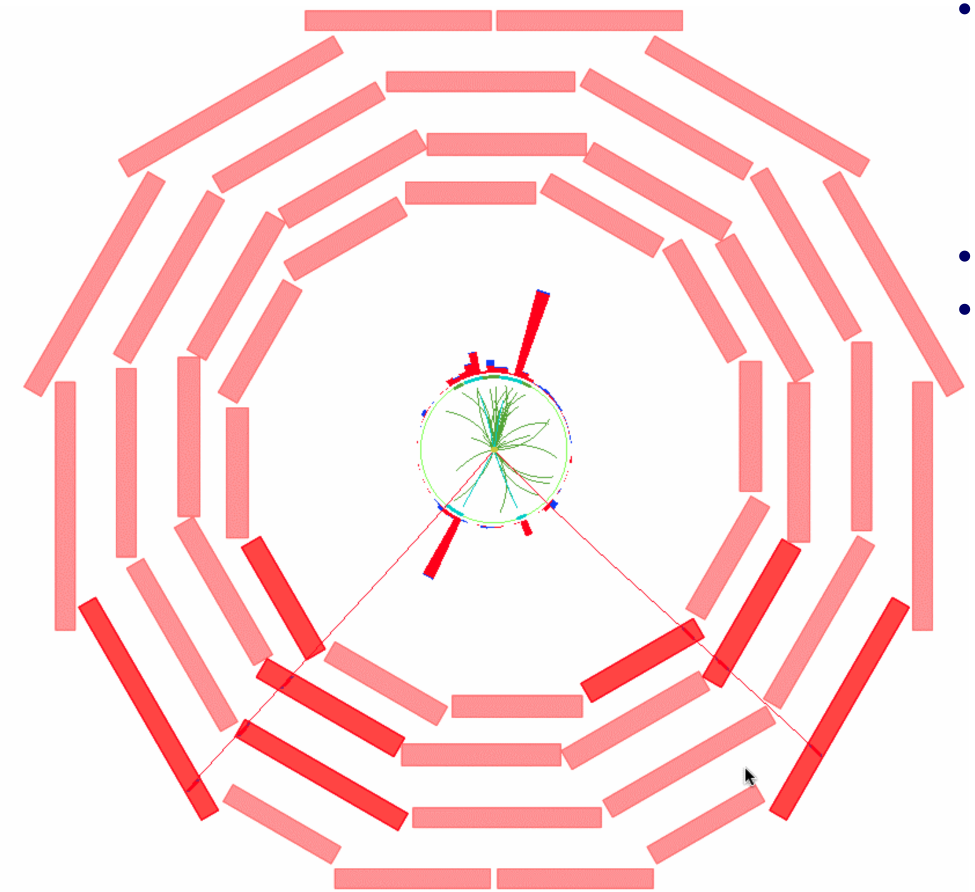


CMS expected exclusion range :[150-185]
ATLAS expected exclusion range : [140-185]

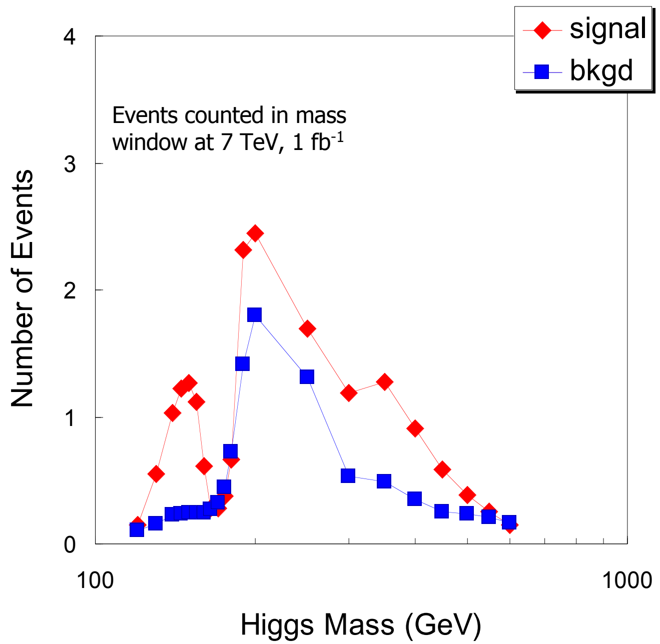
CMS discovery 3-5σ sensitivity : near 160 GeV

$H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons

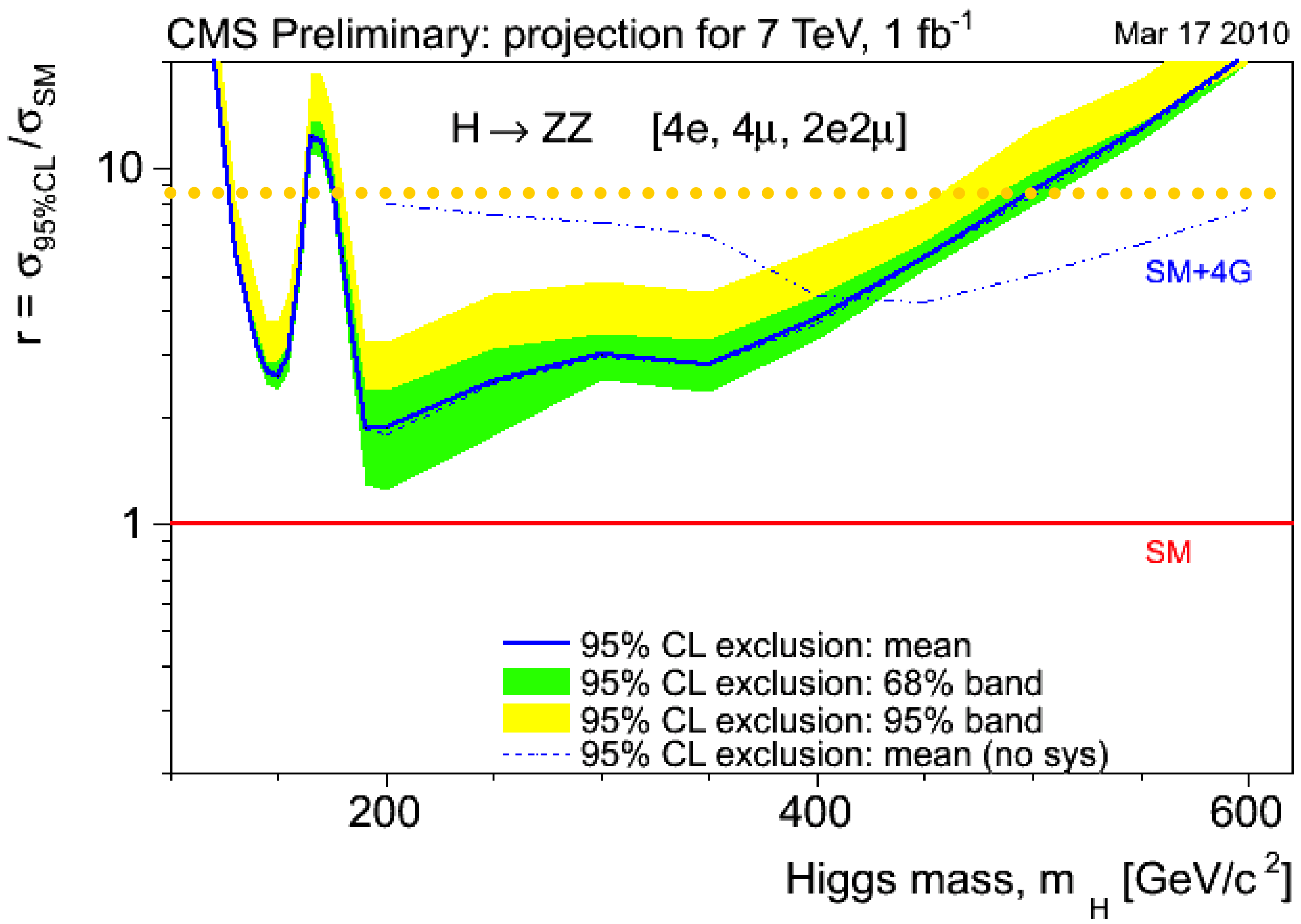
$H \rightarrow ZZ^{*} \rightarrow e^{+}e^{-}\mu^{+}\mu^{-}$



- Signal: four isolated leptons, look for 4l-mass peak [count in sliding mass window]
- Backgrounds:
  - ZZ : irreducible background, [rate assessed from data—Z events]
  - ttbar & Zbbbar removed by lepton isolation & impact parameter veto
- Narrow mass peak, low background
- But low yield ⇒ need to push lepton id

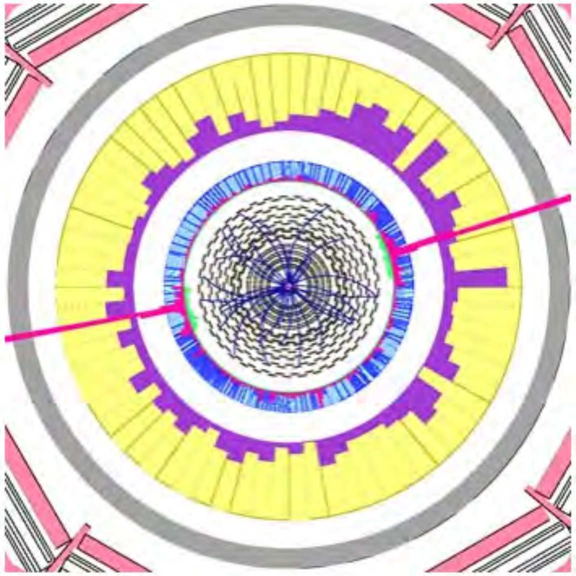


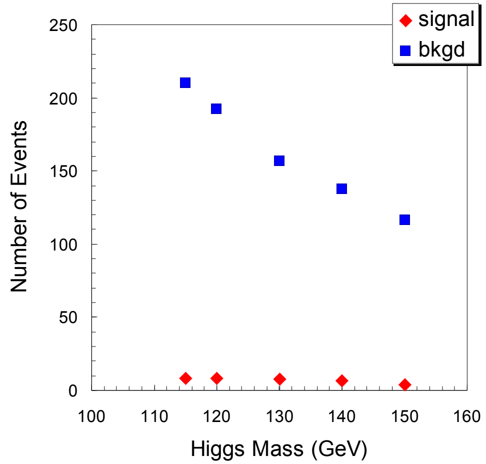
$H \rightarrow ZZ$



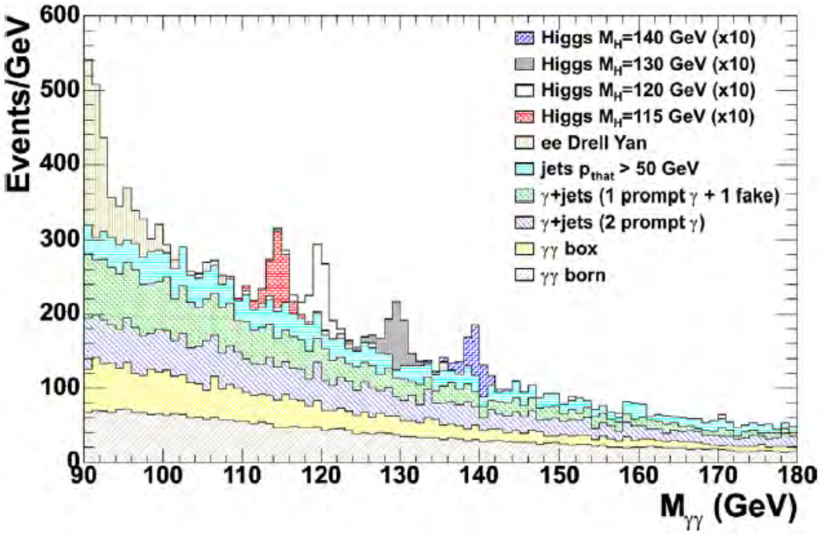
For SM Higgs with 4 fermion generations
- gg→H cross section increases naively by a factor ~ $3^2=9$
- Less naive exclusion limit (based on Kribs et al) ➔ **~ 420 GeV**

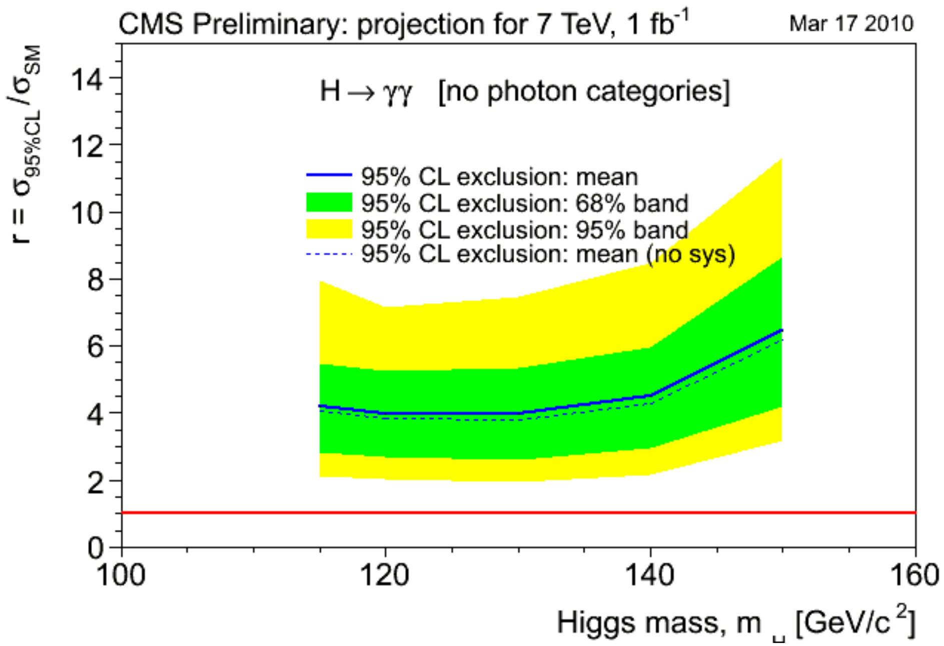
H → γγ





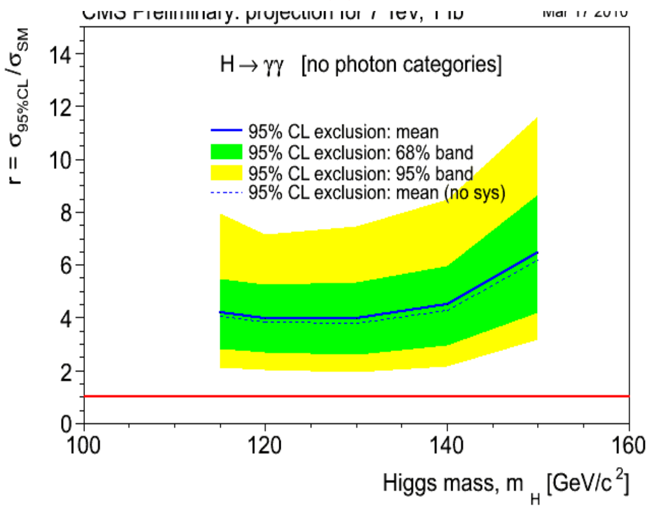
- two isolated photons, search for mass peak
- QCD bkgd is large and partly irreducible,
  - measured from sidebands
- Not a viable mode of low mass SM Higgs in 7 TeV/ 1fb^{-1} run



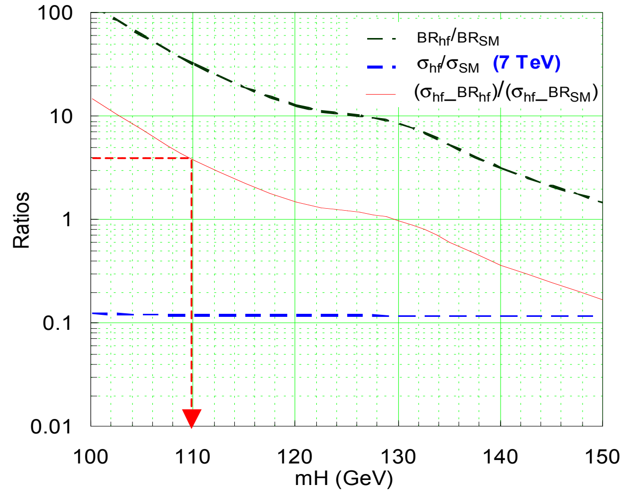


Fermiophobic Higgs: Back-of-Envelope

CMS SM H→γγ exclusion r~4



Fermiophobic/SM ratios



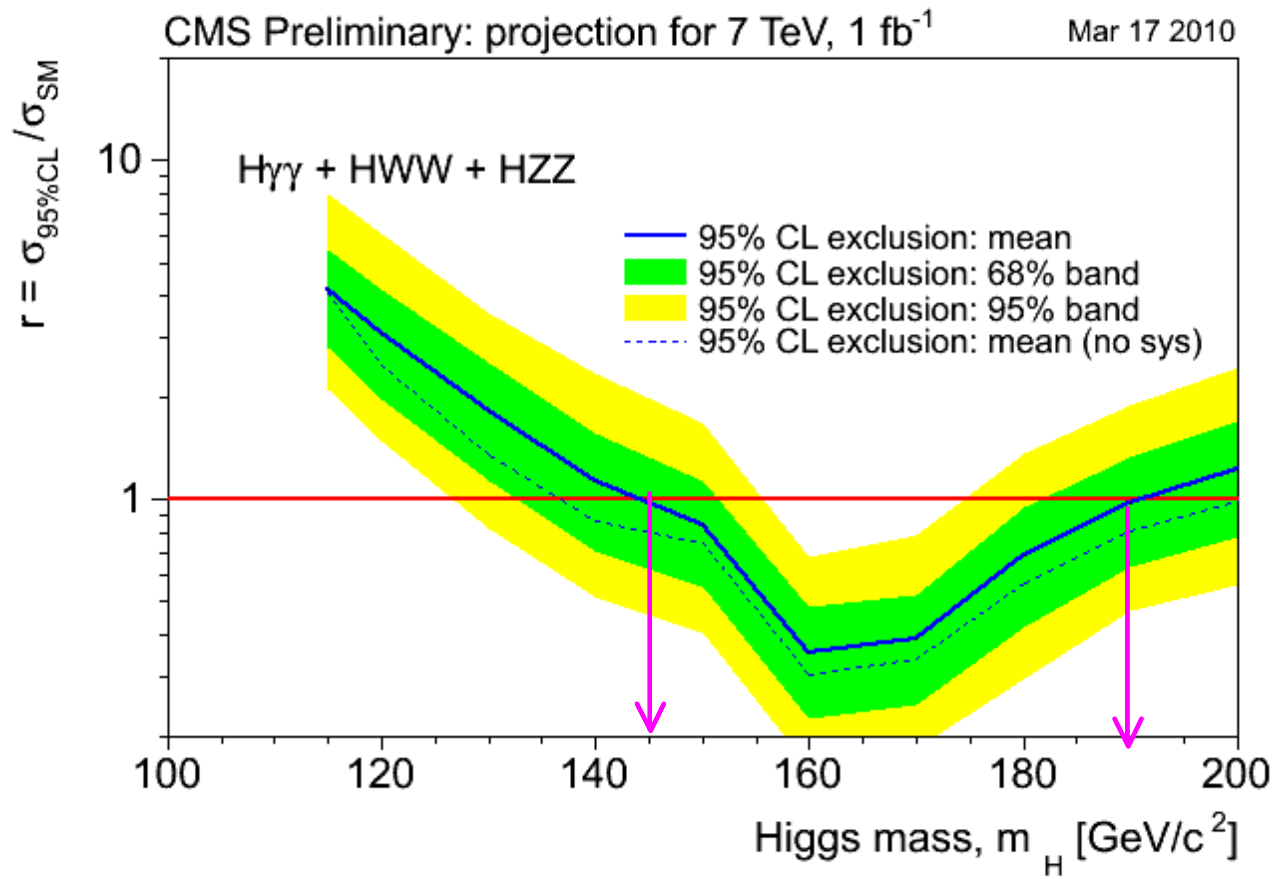
Fermiophobic/SM (see plot on the right)

- gg→H disappears ⇒ loss of a factor of 10 in H cross section [blue line]
- Gain a large factor in BR(H→γγ) [black line]
- CS x BR larger than that of SM up to 130 GeV

If do <u>nothing</u> special (charateristic kinematics) for fermiophobic Higgs,

- r~4 for SM Higgs (see left plot) implies that
- Possibly exclude fermiophobic Higgs with m~110 GeV (see right plot), which is better than Tevatron, comparable to LEP limit

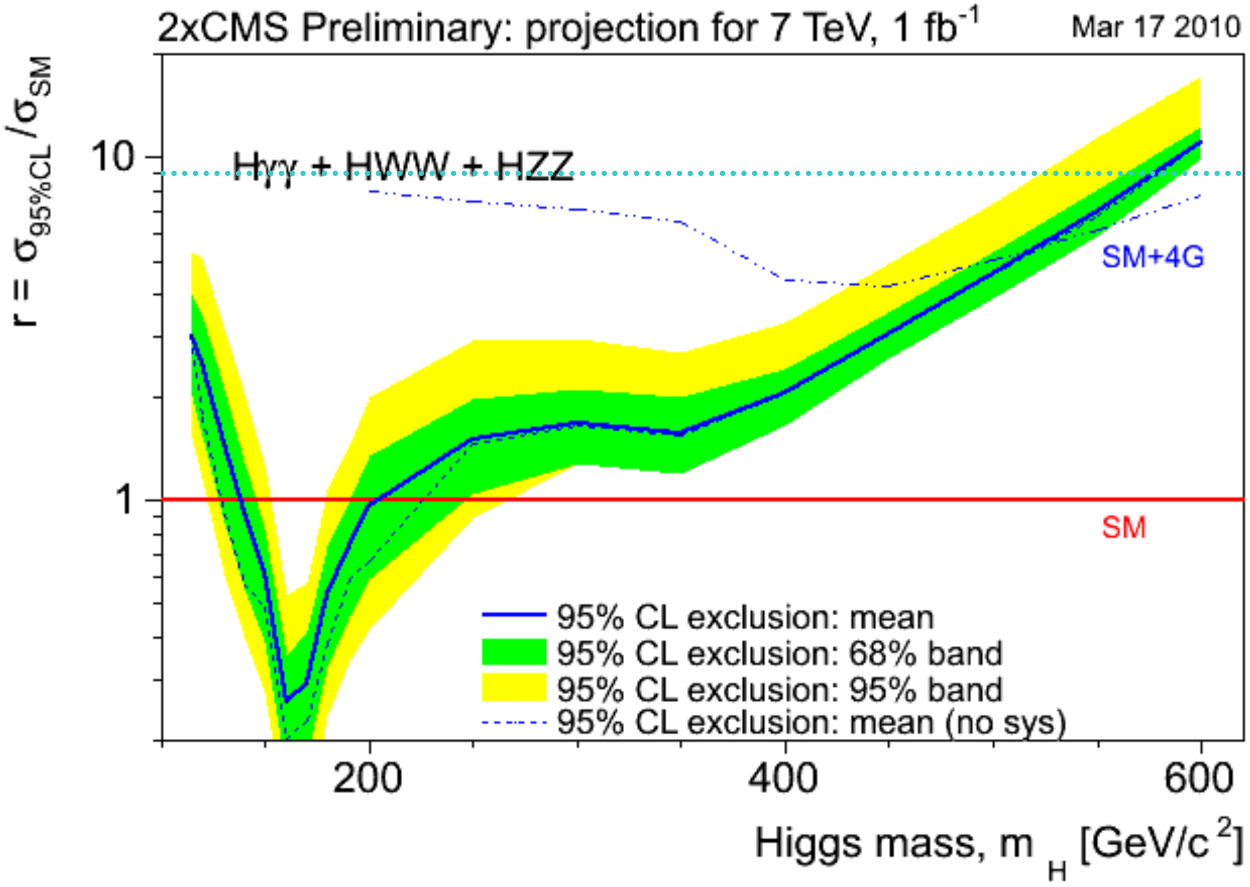
CMS: All Modes Combined



SM Higgs expected excluded range: **145-190 GeV**

SM Higgs with 4 fermion generations: **< ≈ 420 GeV**

[CMS x 2 Projection] ≈ ATLAS+CMS

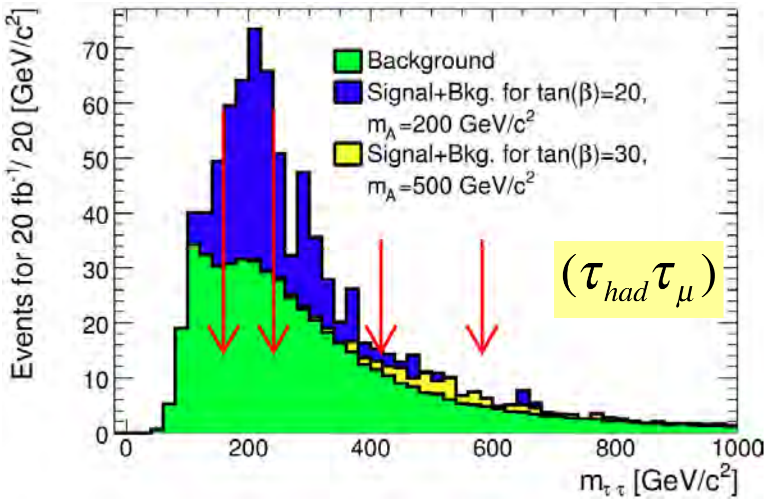


SM Higgs expected excluded range approx: **140-200 GeV**

discovery range approx: **160-170 GeV**

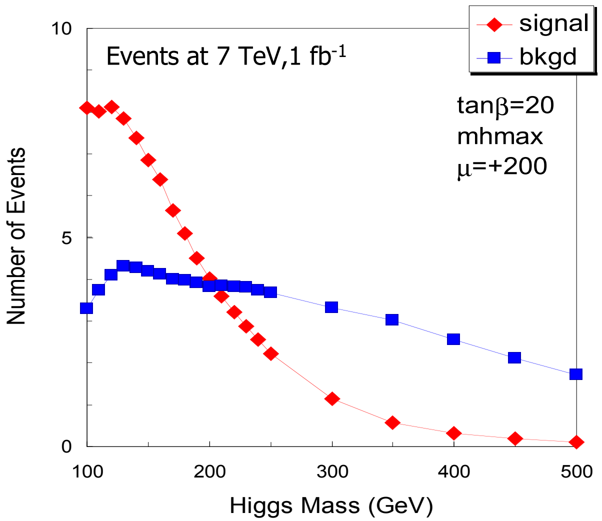
SM Higgs with 4 generations can be ruled out to $M_H \approx$ 530 GeV

MSSM Higgs In pp→bbΦ; Φ→ τ⁺ τ⁻

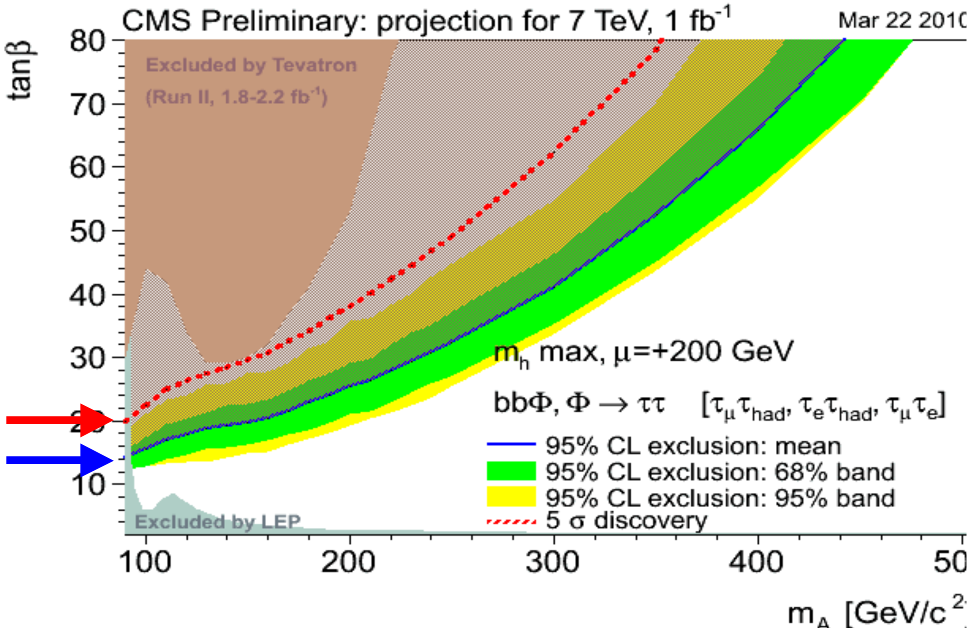


- – – Isolated pairs of $(\tau_{had}\tau_{\mu}),(\tau_{had}\tau_{e}),(\tau_{\mu}\tau_{e})$
- – – With MET, 1 tagged bjet, veto extra jets
- – – Build $\tau\tau$-mass using collinear approx
- – – Count events in sliding $\tau\tau$-mass window
- – – Dominant backgrounds: $t\bar{t}$, Z+$b\bar{b}$ & Z+$c\bar{c}$

  -- assessed from data



discover
exclude

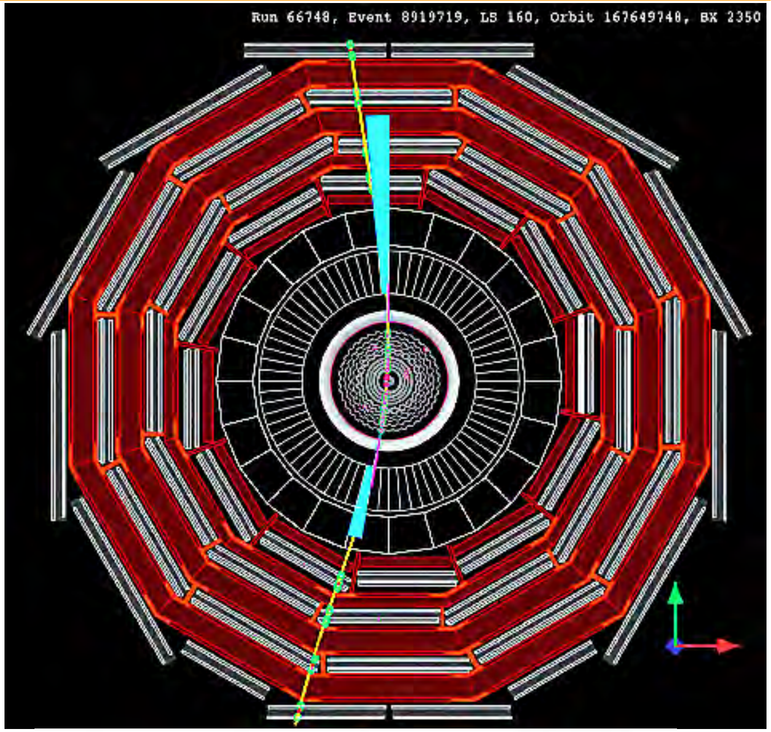


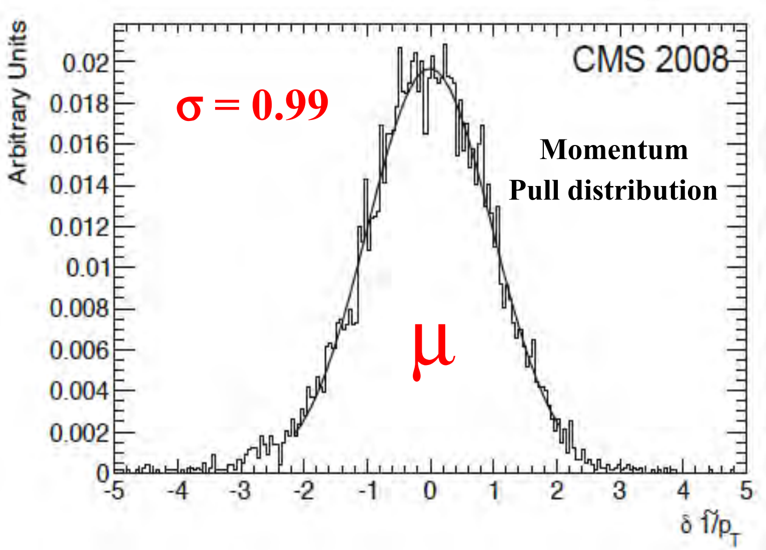
From Projections to Reality

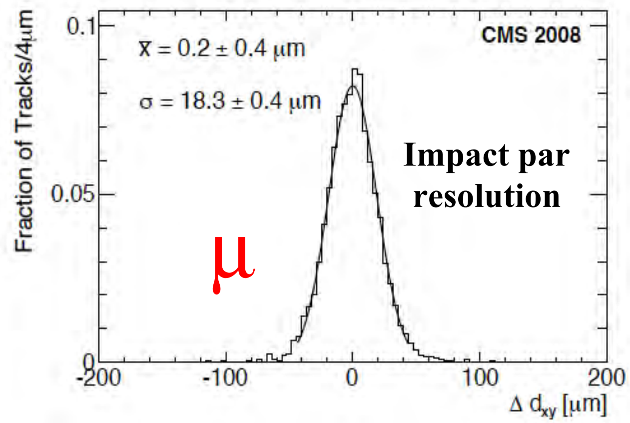
Early ATLAS & CMS
Performance in
LHC Collision data

Key Preparation Before LHC Collisions

- Several Cosmic ray data campaigns prior to LHC collisions
  - ~ 1 Billion cosmics analyzed
  - Has led to well understood detector **<u>in advance</u>** of pp collisions in 2009
    - **Timing, alignment, resolution, coherent running, trigger, DAQ etc**

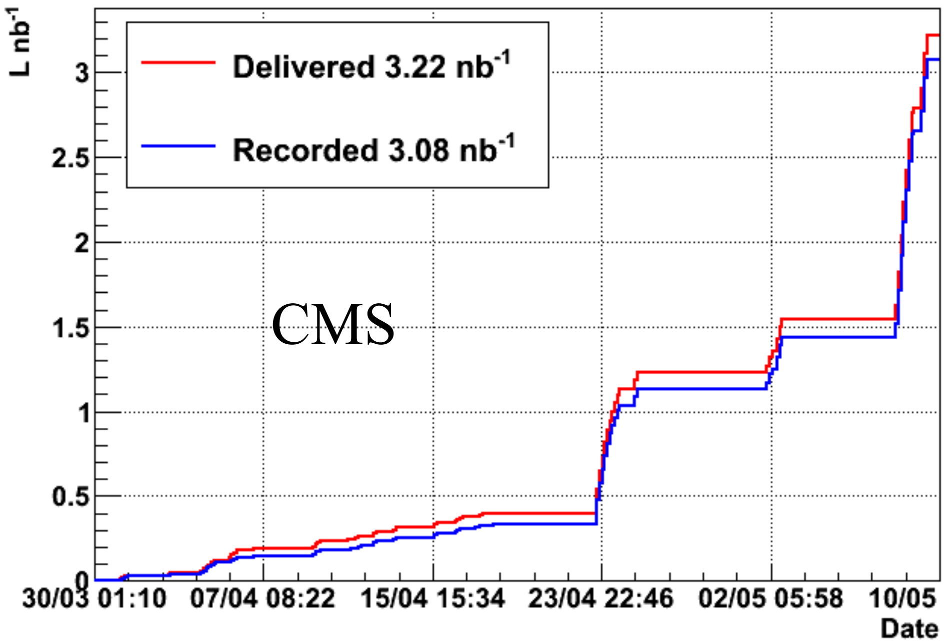


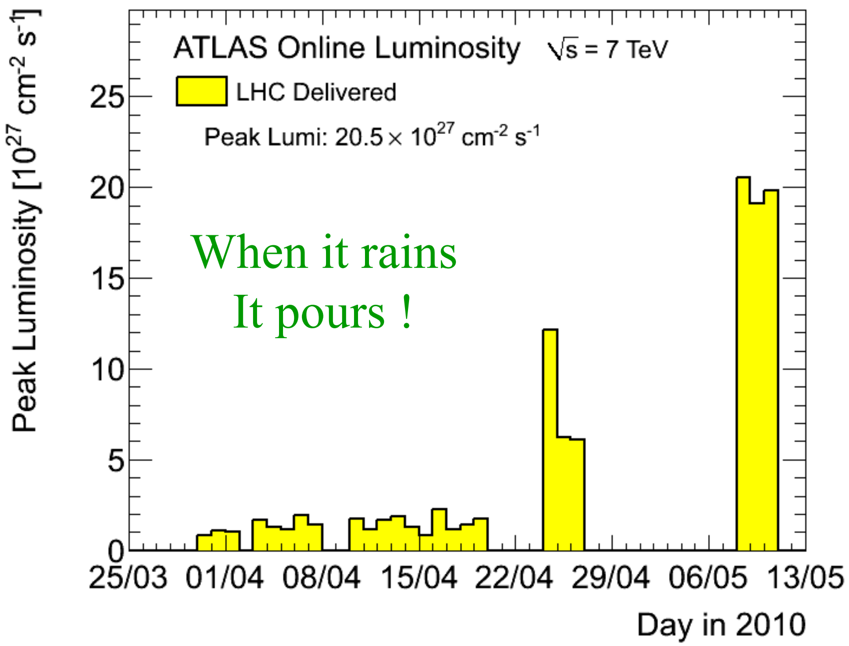




7 TeV Run So Far

More than 4.5 nb^{-1} accumulated so far





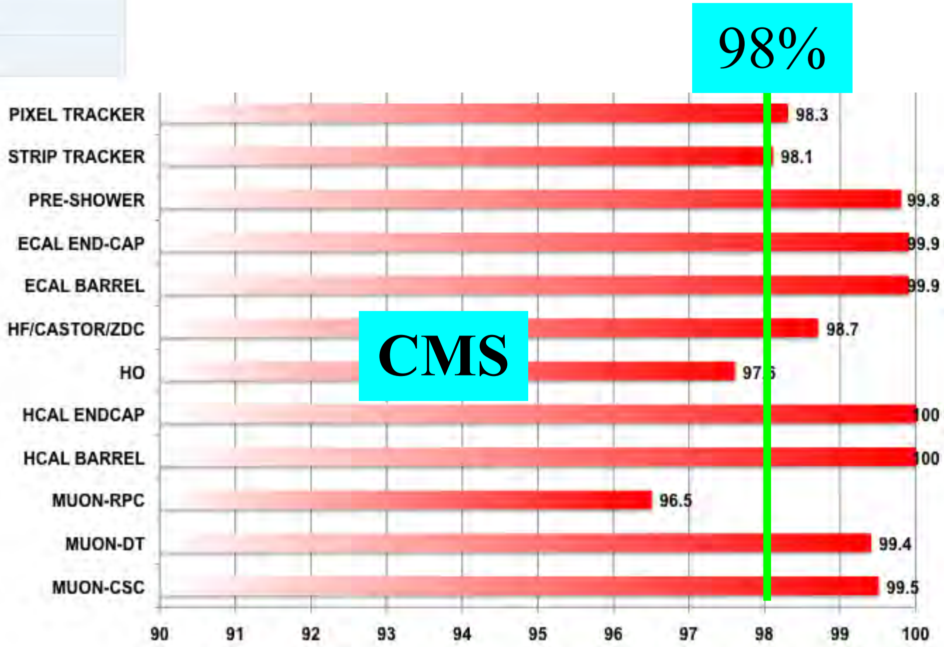
ATLAS & CMS data taking efficiency ≈ 96%
under stable 7 TeV beam conditions

Excellent Hardware Performance

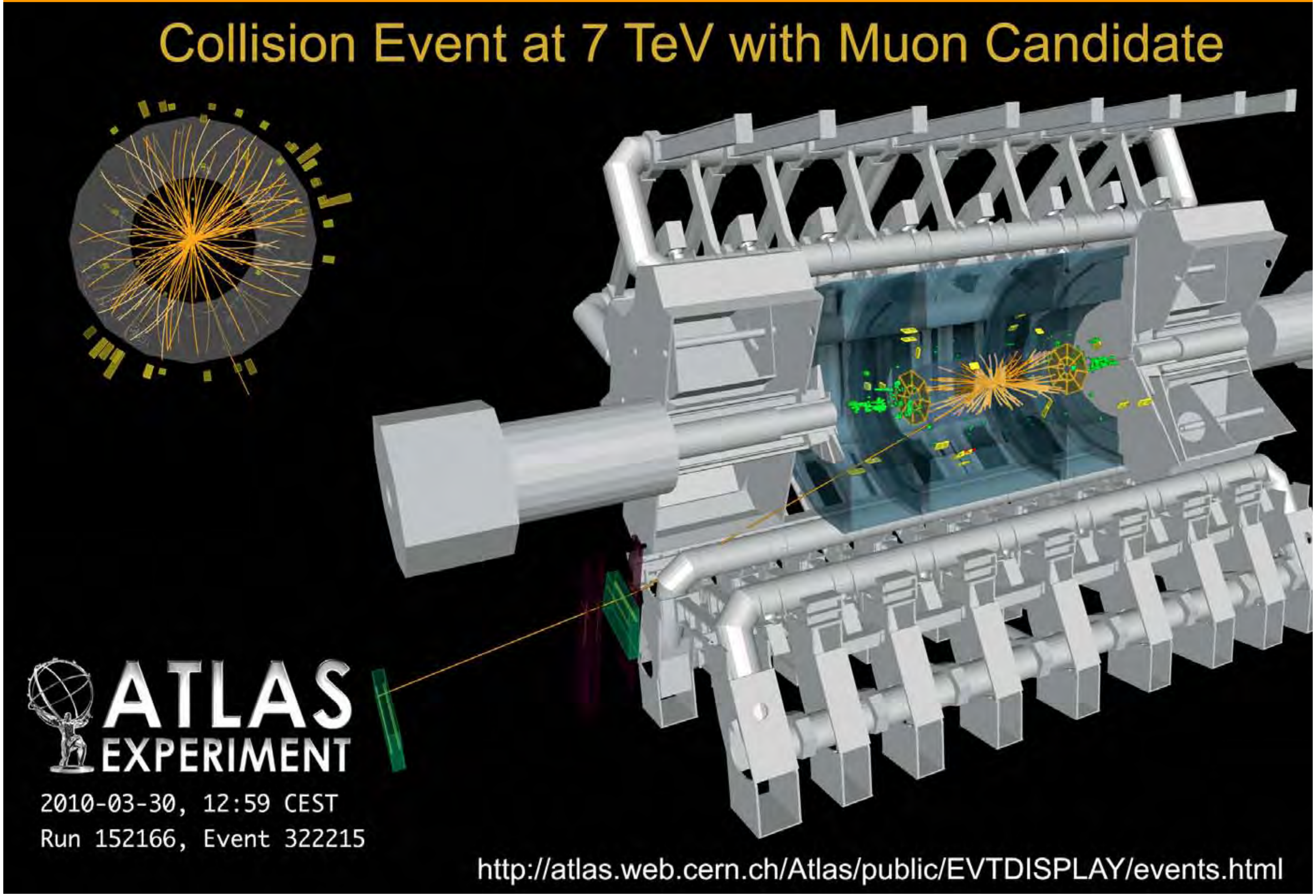
ATLAS

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.5%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.8%
LVL1 Muon RPC trigger	370 k	99.7%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.3%
TGC Endcap Muon Chambers	320 k	98.8%

≈ 100M channels
≈ 98% channels operational

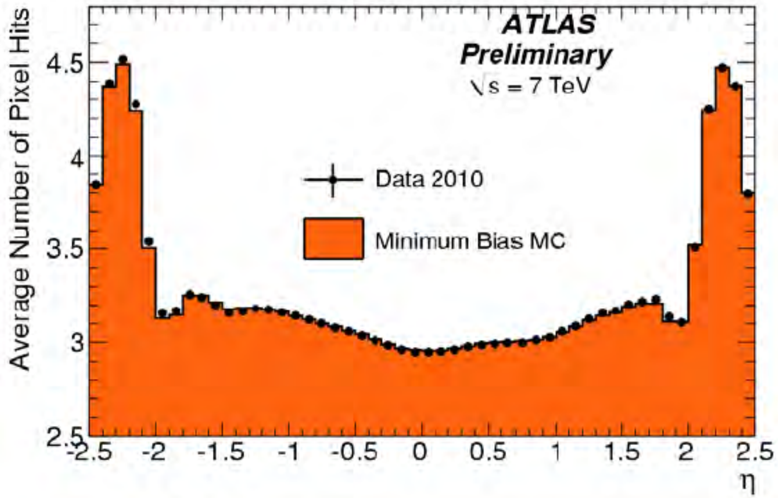


Performance With Collision Data

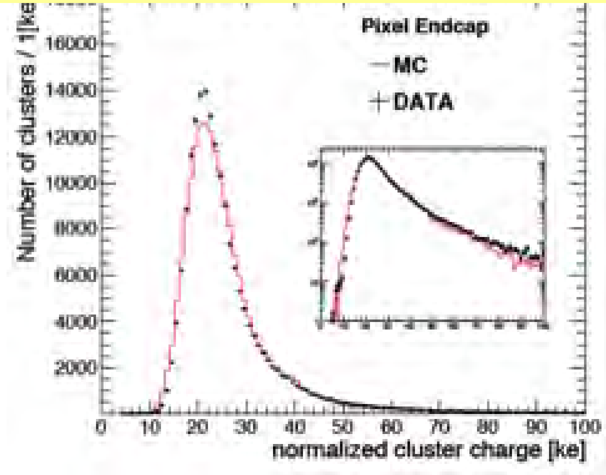


Pixel & Silicon Strip Tracker Performance

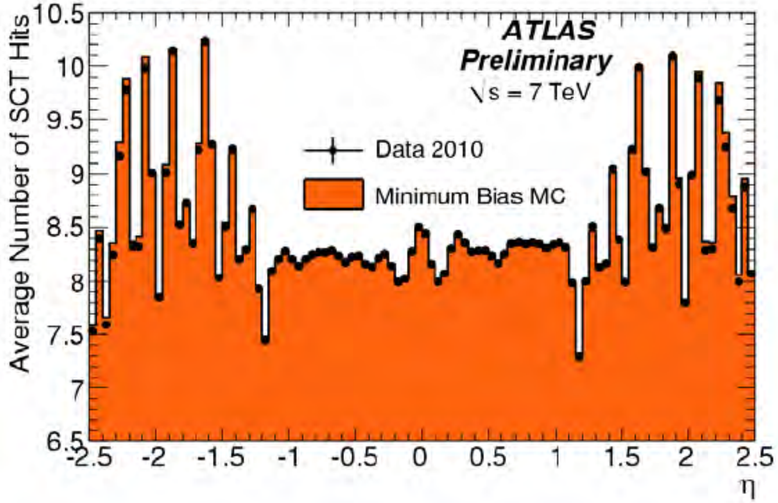
Pixel Det.



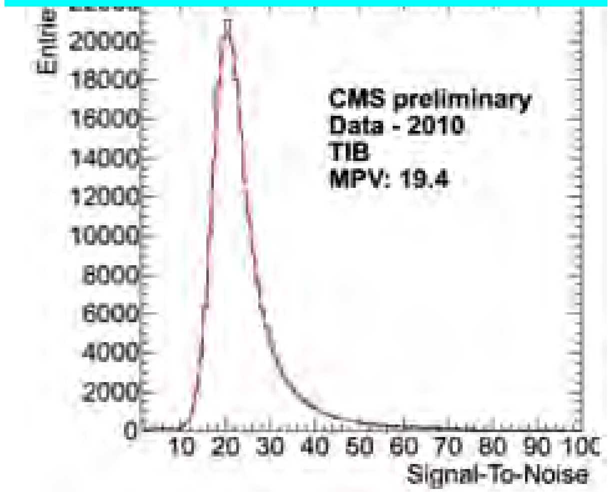
CMS Pixel cluster charge



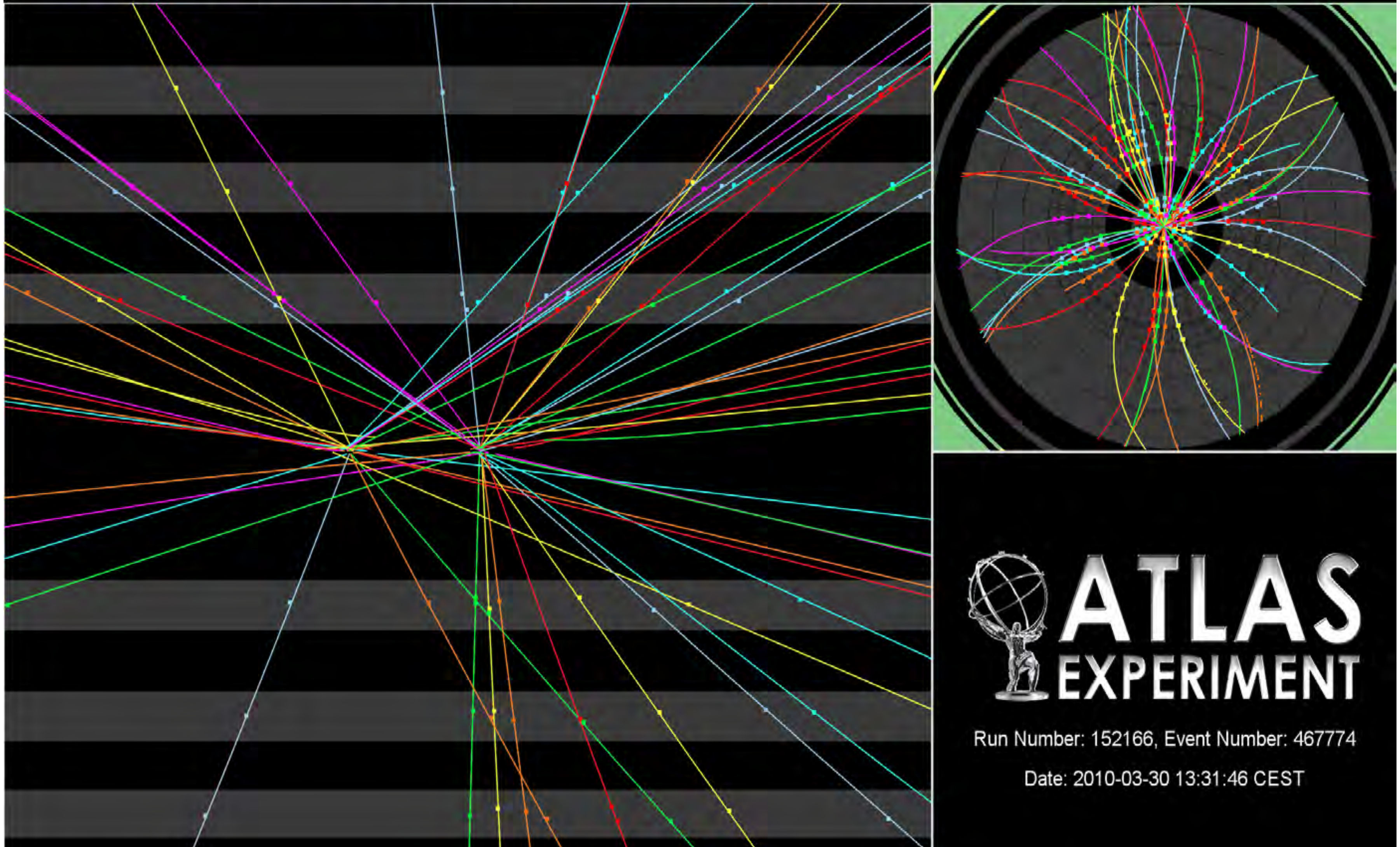
SCT Det.



CMS SST Signal/Noise



Collision Event at 7 TeV with 2 Pile Up Vertices



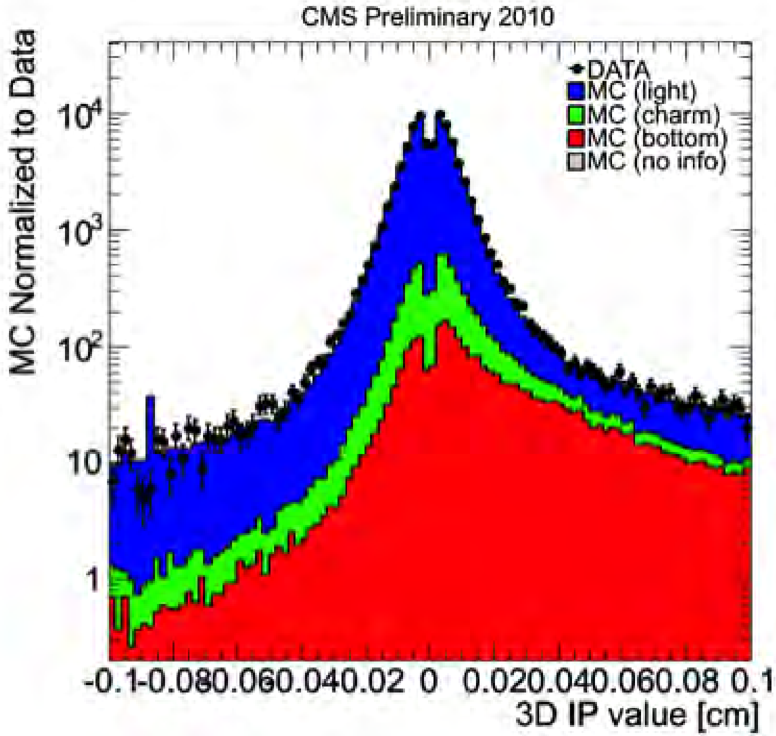
Similar Pileup events also reconstructed in CMS

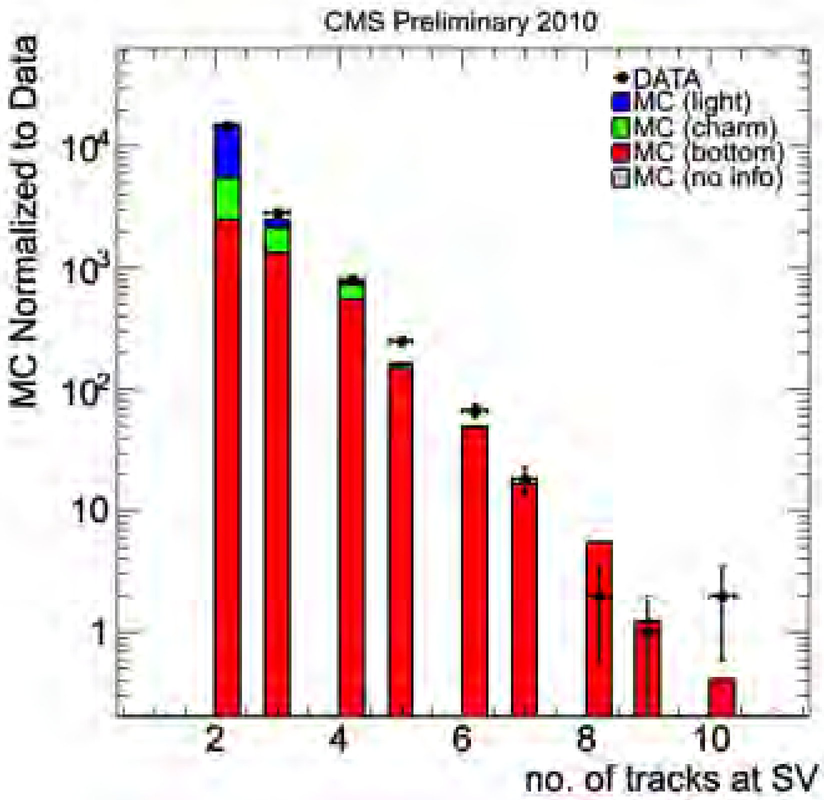
B-tagging: Works straight out of the box

Basic variables relevant for B-tagging compare well in data Vs MC

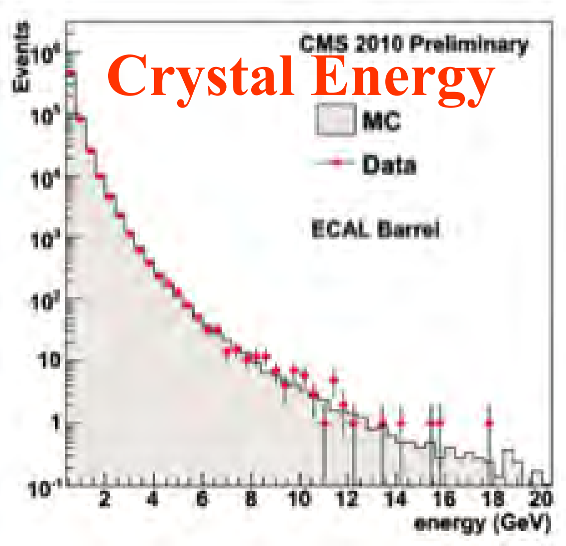
Signed 3D impact parameter for all tracks selected for b-tagging in jets with pT > 40 GeV and |η|<1.5

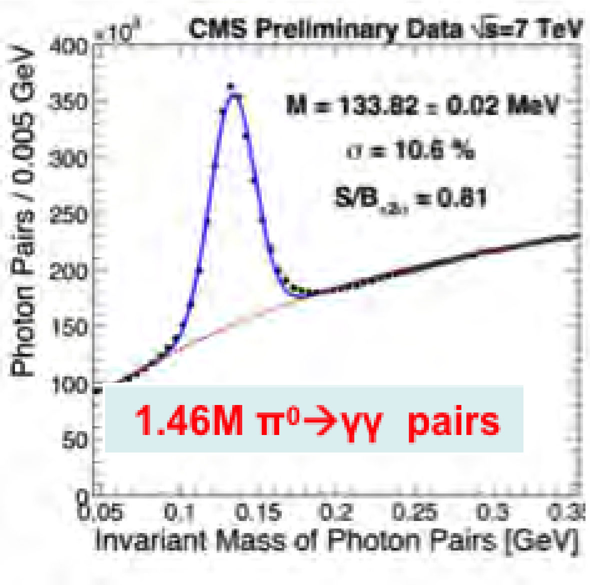
Track multiplicity in reconstructed secondary vertices

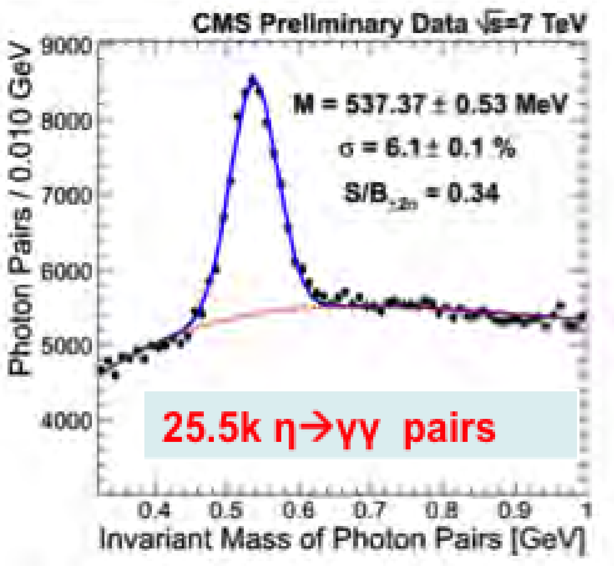




Performance of EM Calorimeters





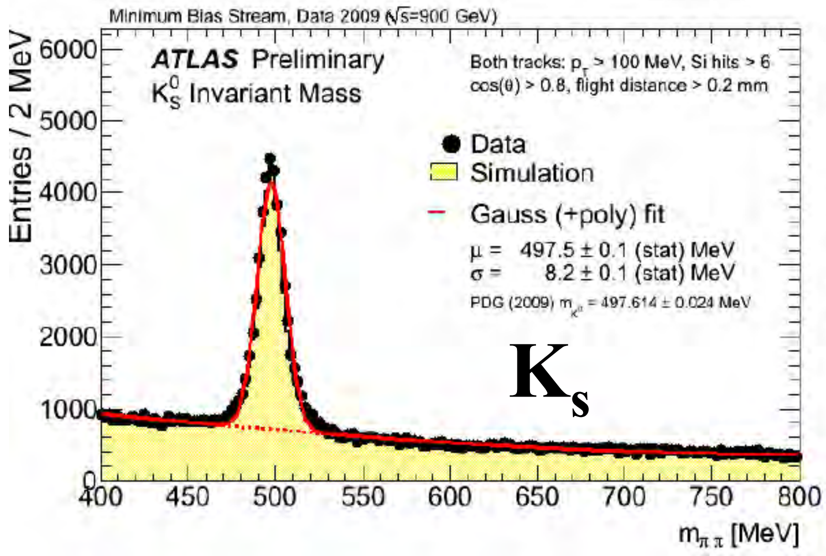


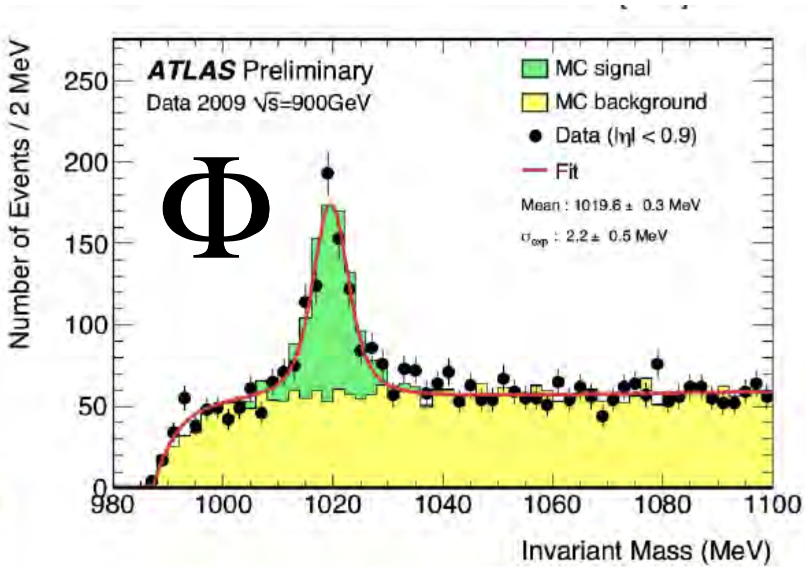
inter-crystal calibration in full swing

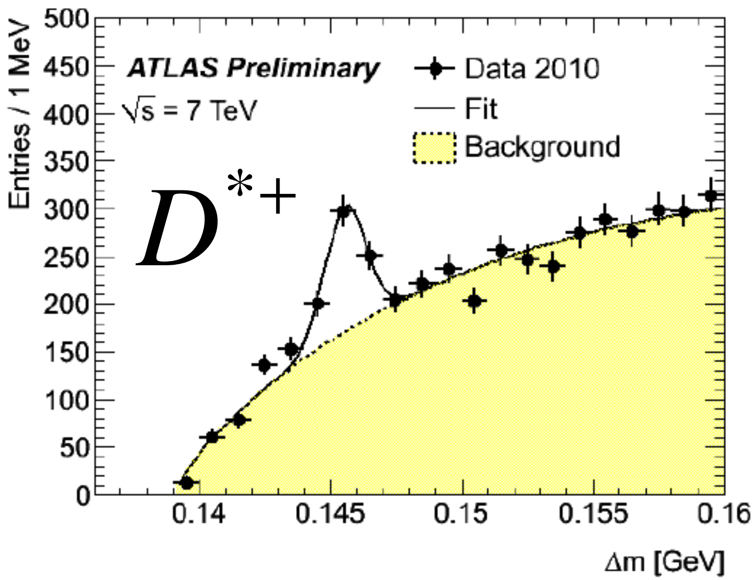
Next Step: Rediscovering the Standard Model

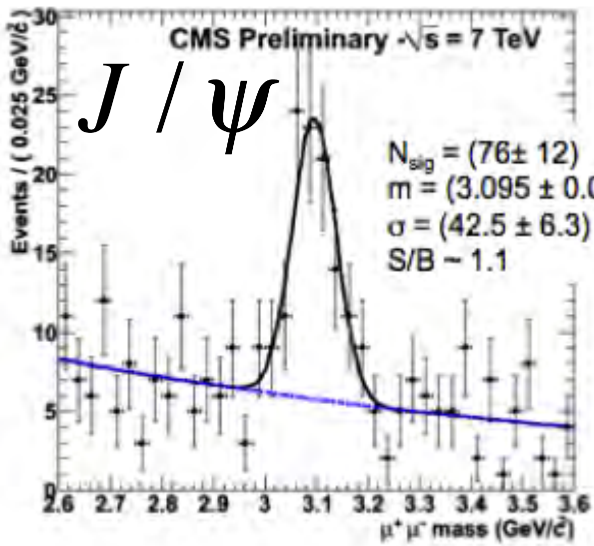
Precondition to searches for new particles and BSM phenomena

Strange, Charm and all that

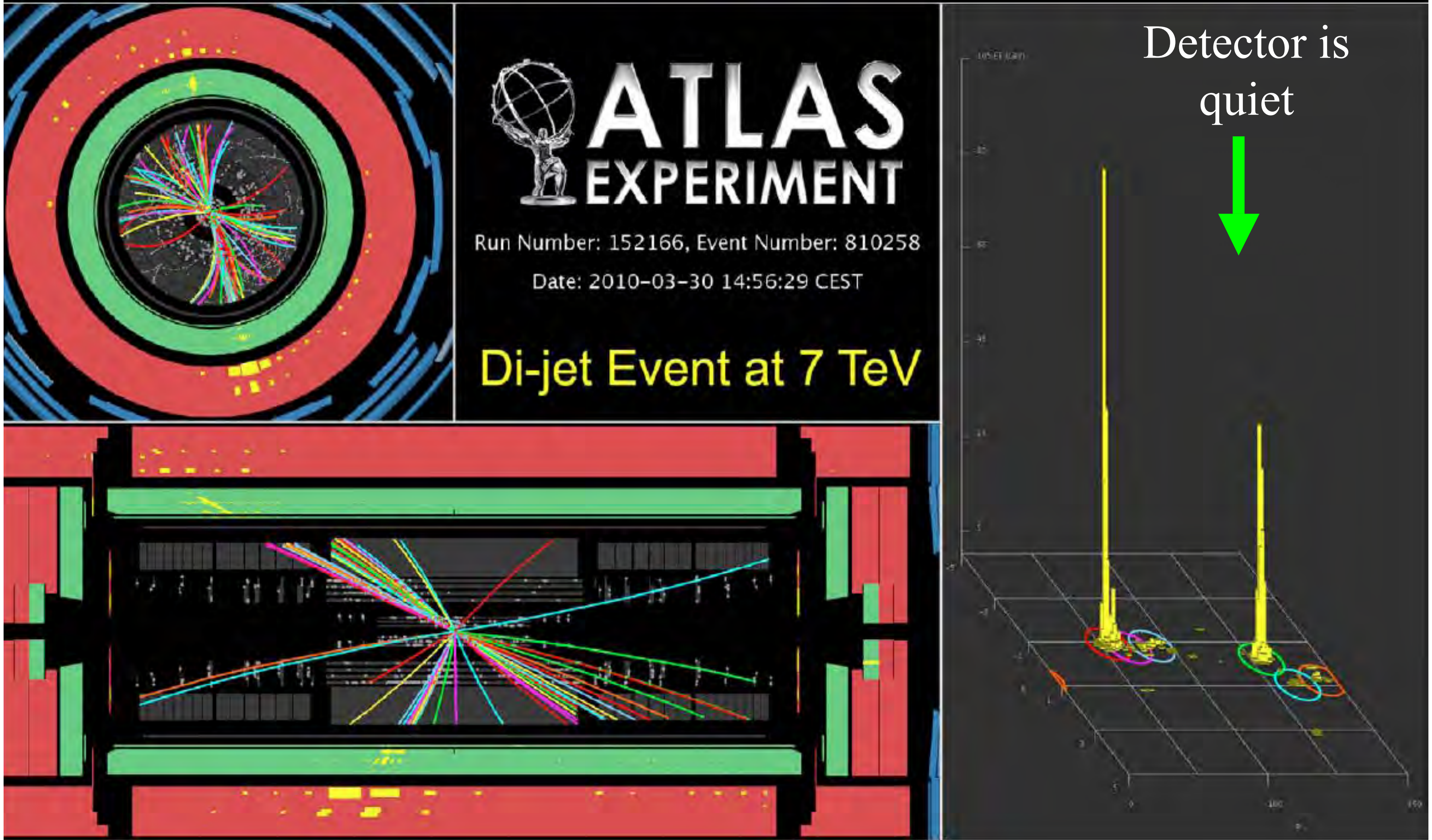




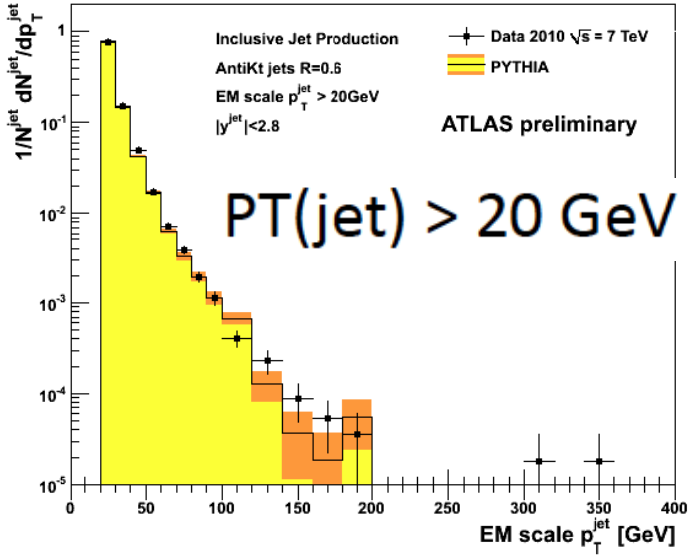


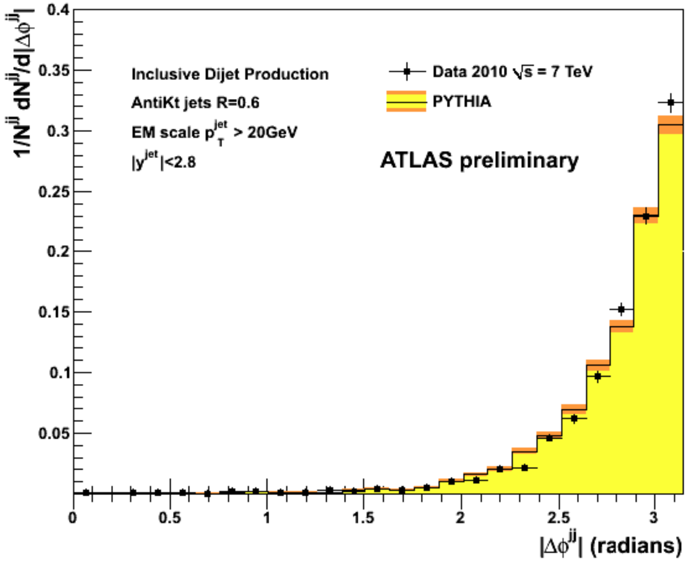


Jets are 310 GeV and 350 GeV at EM scale – highest PT di-jet event so far !

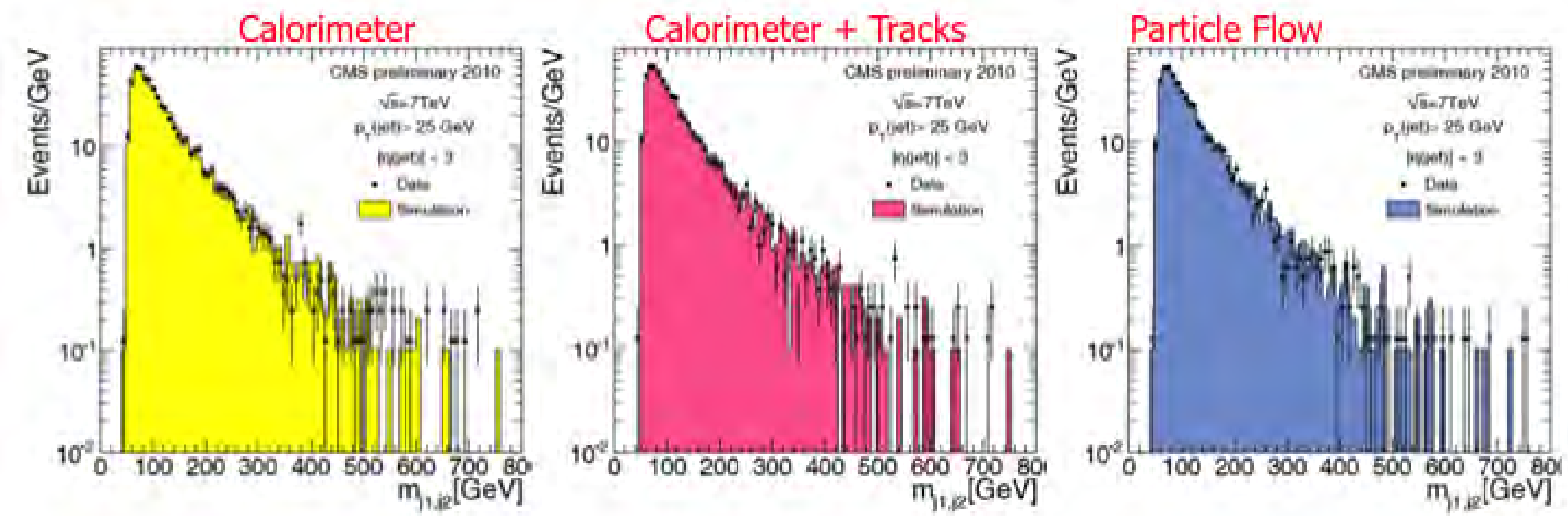


Jets & Dijets @ 7 TeV

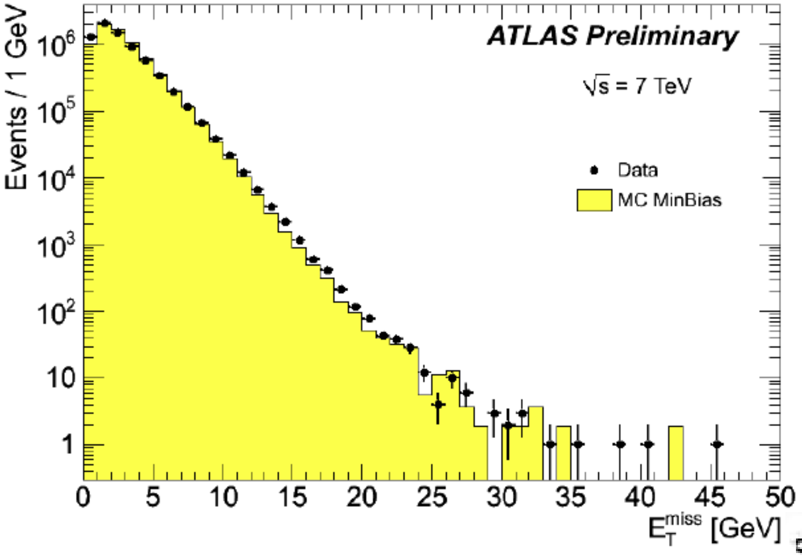




CMS: Dijet studies using several Jet reconstruction techniques



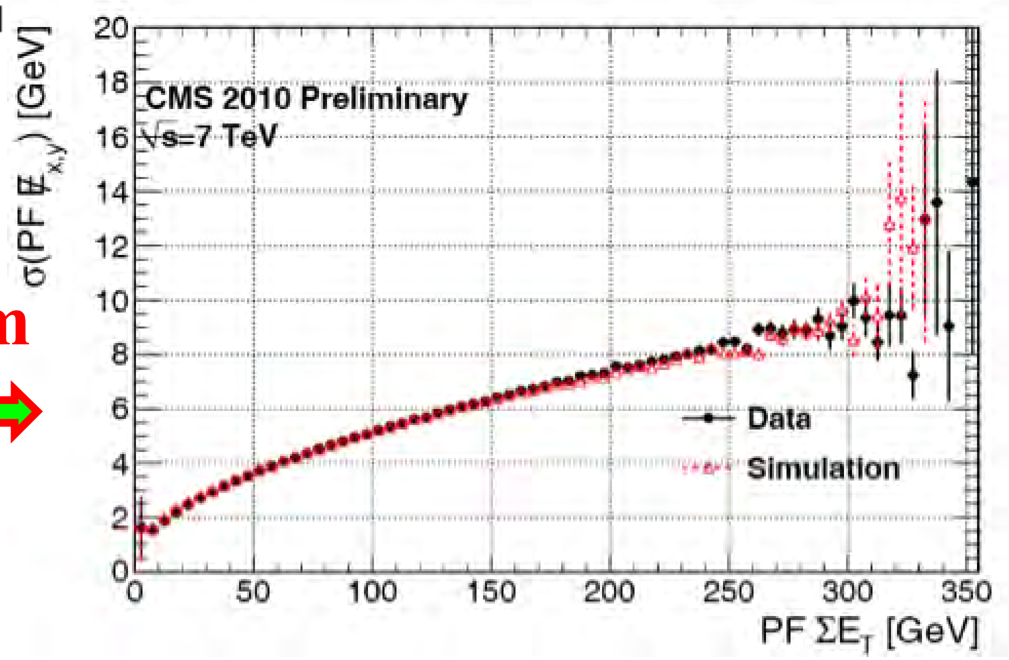
Transverse Missing Energy (MET)

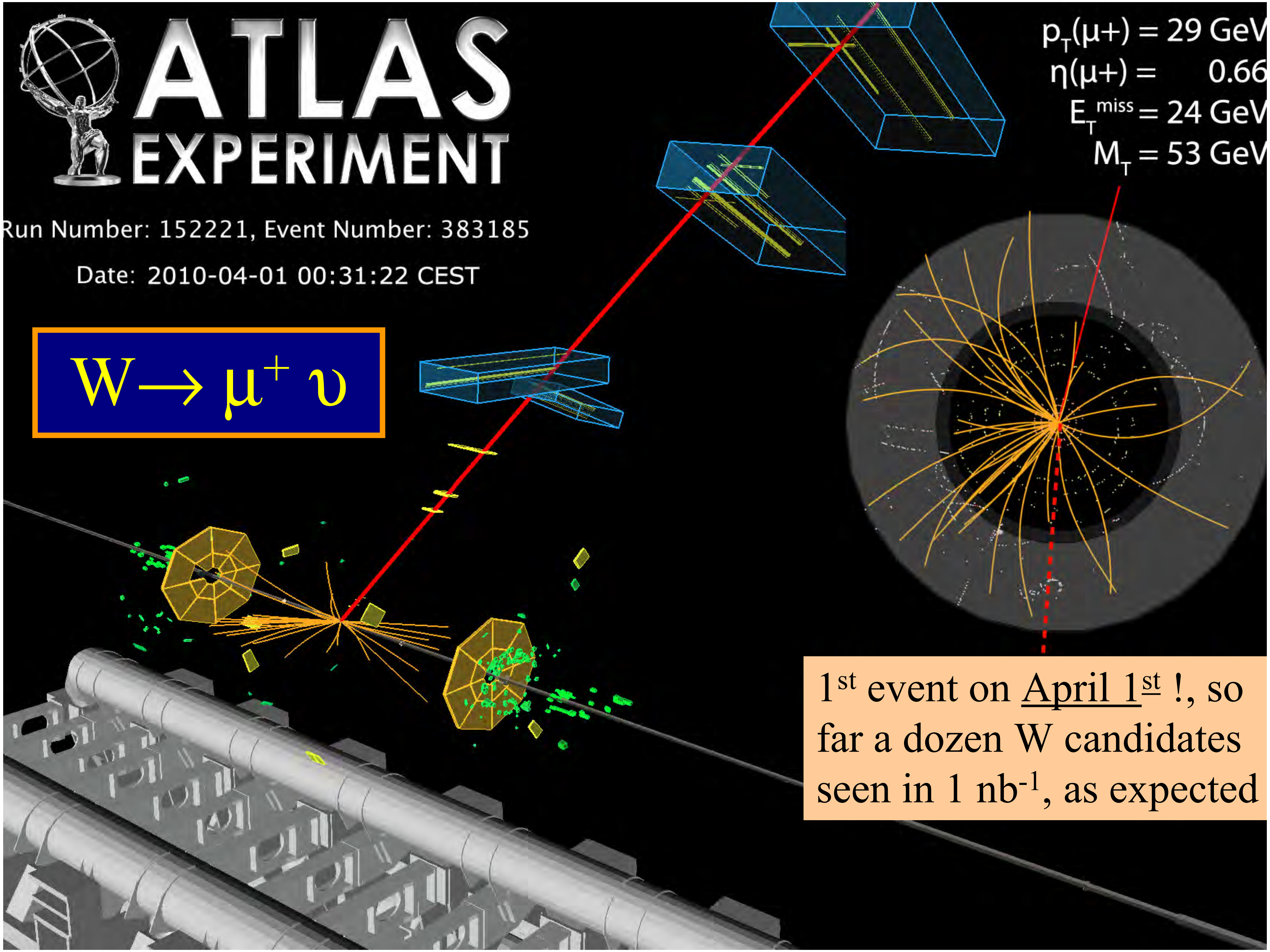


Excellent agreement between Data and simulations over more than **5 orders of magnitude**

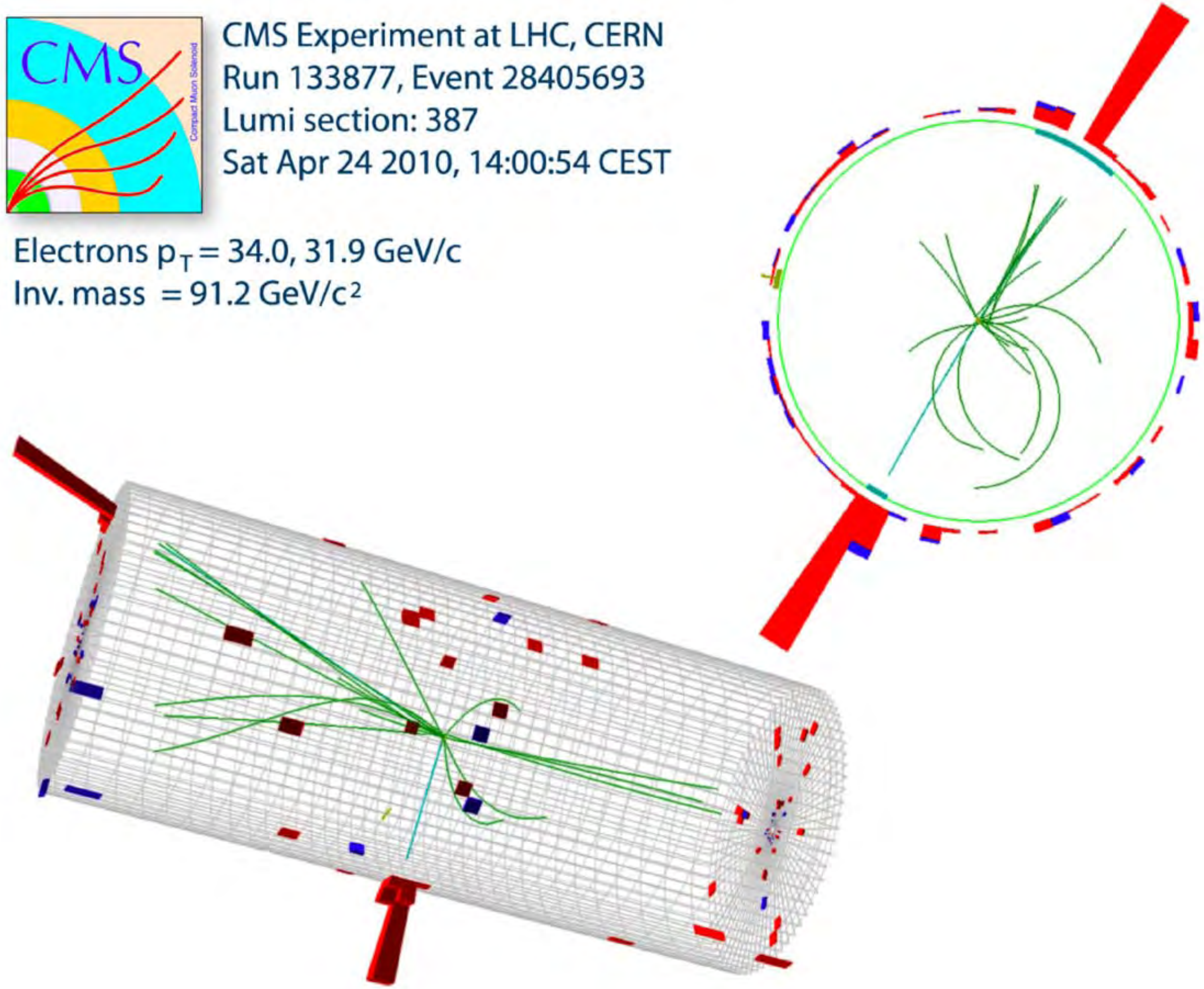
For Higgs searches, MET requirement is modest ~ [40-100] GeV

Particle Flow Algorithm MET Resolution ⇨




ATLAS EXPERIMENT
Run Number: 152221, Event Number: 383185
Date: 2010-04-01 00:31:22 CEST
W→ μ+ υ
pT(μ+) = 29 GeV
η(μ+) = 0.66
ET miss = 24 GeV
MT = 53 GeV
1st event on April 1st !, so far a dozen W candidates seen in 1 nb-1, as expected

$Z \rightarrow e^+e^-$



The Road Ahead at LHC

Summer 2010	End of 2010	Fall 2011
$\sim 1\ pb^{-1}$	$\sim 100\ pb^{-1}$	$\sim 1000\ pb^{-1} = 1\ fb^{-1}$

- QCD, b measurements
- W, Z cross sections
- Electroweak program
- Early ttbar observation
- Early searches, mainly Exotica

- + Higgs program

- + top physics program
- + broad search program:
  Mainly Exotica, SUSY

Higgs program starts With 250 pb^{-1} →

LHC Plans For Next Weeks

- Increase single bunch intensity to ~ $1x10^{11}$p/bunch
- To avoid risking safety of tertiary collimators, beams squeezed only to ß*=5m (a factor 2.5 lost)
- To compensate for this increase number of bunches up to 16 (total power of about 1MJ in the machine)
  - **Started with 2 → 4 → 6 bunches already**
- priority for LHC will be to give a sizeable amount of data to the experiments in time for the ICHEP
  - More than 300 nb^{-1}

Summary

- ATLAS & CMS well calibrated and have demonstrated agility in LHC data analyses : first results after few hour of data taking
  - First papers published
- Currently well on path of re-discovery of SM particles; hard work starts NOW !
- At 7 TeV & with 1 fb^{-1} data, ATLAS & CMS will begin to explore a sizable range of Higgs mass
  - SM Higgs discovery sensitivity : [160-170] GeV
  - SM Higgs exclusion range : [140-200] GeV
  - Low mass SM Higgs searches require 14 TeV & high lumi running
  - MSSM Neutral Higgs discovery range: down to $\tan\beta \sim 20$ for small m_A
  - MSSM Neutral Higgs exclusion range :down to $\tan\beta \sim 15$ for small m_A
  - **With large ttbar cross-sections, will be probing *terra incognita* in searches for H^+ (ttbar cross-section is 20x Tevatron)**
- Now awaiting luminosity promised, **stay tuned !**