ICNFP 2015 – Κολυμπάρι, 27/8/2015

CMS Overview

Tommaso Dorigo

INFN, Sezione di Padova

on behalf of the CMS Collaboration

Contents

- Recent Run 1 results
  - Precision **Higgs physics**
  - **Top quarks**: a probe of electoweak theory and new physics
  - **Electroweak precision tests**
- The detector upgrades and the start of LHC Run 2
  - Rediscovering resonances
  - Remarkable events at 13 TeV
  - Top quark pair production cross section at 13 TeV
- Summary and outlook

The CMS collaboration has produced a large number of important results using 2011-2012 data, and very recently has started to use the new 13-TeV collisions for new measurements.

In this talk I can only provide a quick summary of the most interesting new measurements, according to my personal taste

- For detailed results of all CMS searches and measurements, you are welcome to visit the public page of physics results at

  http://cms.web.cern.ch/news/cms-physics-results

- And of course follow the many interesting talks in plenary and parallel sessions by CMS speakers:
  - Ludvine Ceard: SM physics (25/8, parallel 6)
  - Paolo Gunnellini: Forward & QCD (25/8, parallel 6)
  - Claudia Wulz: Exotica (25/8, parallel 1)
  - Kerstin Hepfner: Future of CMS (26/8, parallel 1)
  - Georgios Anagnostou: Beyond 2 generations (parallel 2)
  - Francesco Romeo: tau ID (26/8, parallel 6)
  - Shervin Nourbakhsh: CMS detector (26/8, plenary)
  - Mario Masciovecchio: SUSY (26/8, parallel 6)
  - Rainer Mankel: Higgs (27/8, plenary)
  - Niladribihari Sahoo: B physics results from CMS (27/8, plenary)

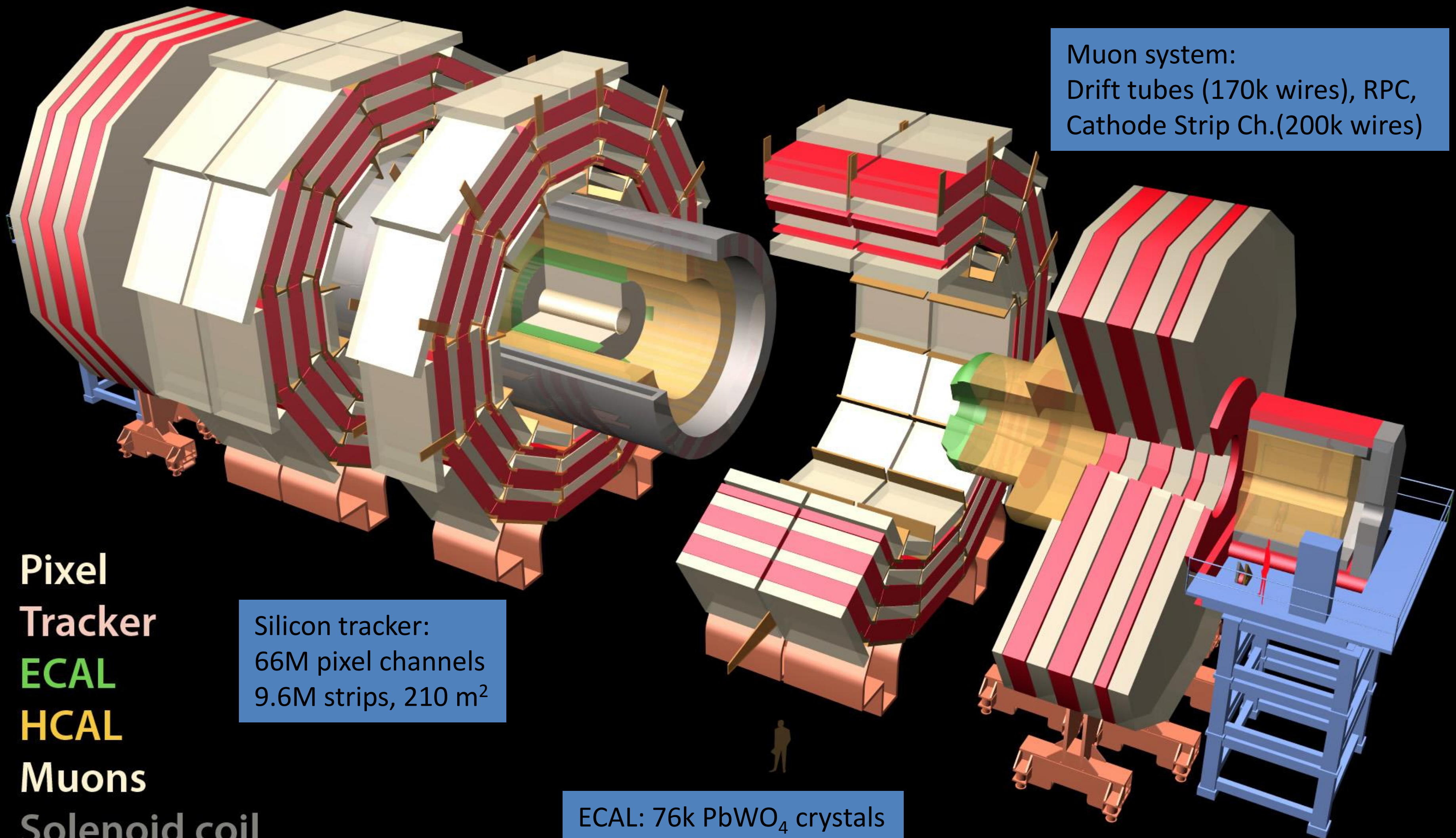
The CMS Collaboration

5000 among scientists, engineers, students from 200 institutions around the world

The CMS Detector

10k CPU cores,
2M lines of code

Muon system:
Drift tubes (170k wires), RPC,
Cathode Strip Ch.(200k wires)



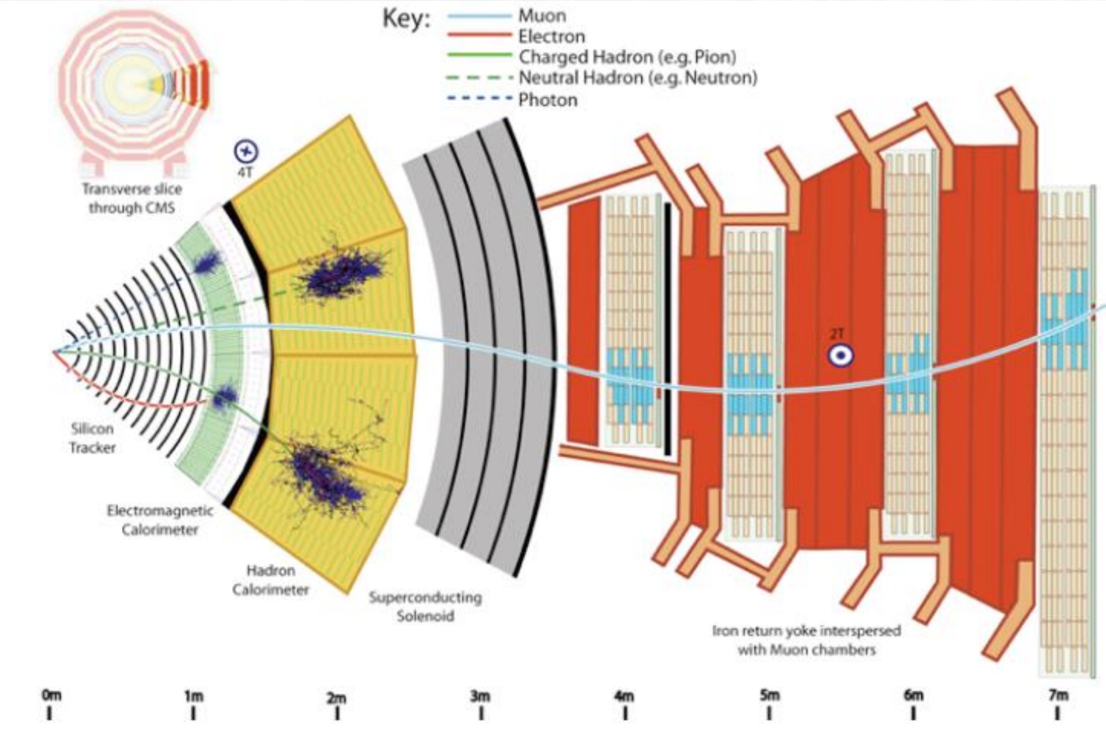
Silicon tracker:
66M pixel channels
9.6M strips, 210 m^2

ECAL: 76k $PbWO_4$ crystals
HCAL: 15k scint/brass ch.

Total weight 12500 t, Overall diameter 15 m, Overall length 21.6 m, Magnetic field 4 Tesla

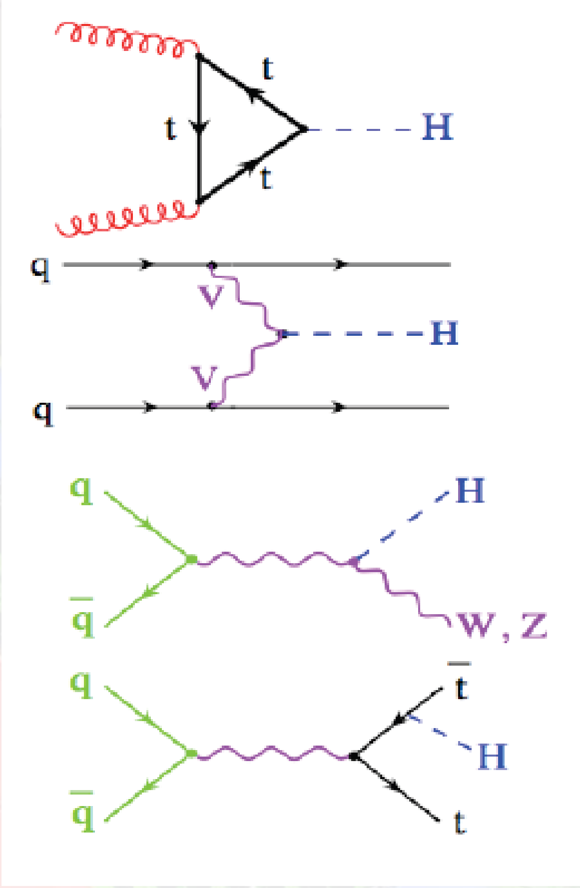
The CMS Detector

- CMS: A Compact Muon Solenoid
- Actually much more than that:
  - a redundant, all-silicon tracking (210 m^2)
  - a 4-Tesla solenoid for high-resolution momentum measurements
  - a Lead tungstate crystal calorimeter for high-resolution EM shower measurements
  - hermetic hadron calorimetry
  - redundant muon coverage up to $|\eta|<2.4$

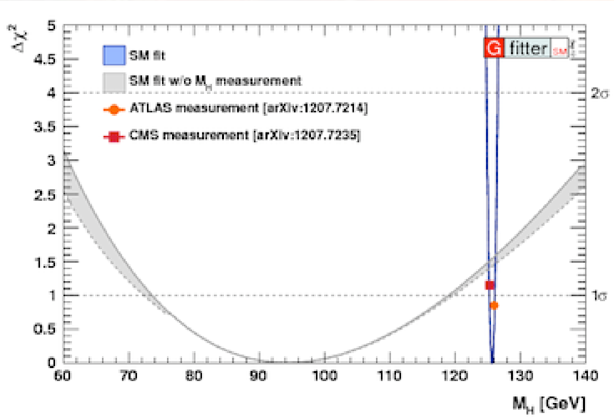


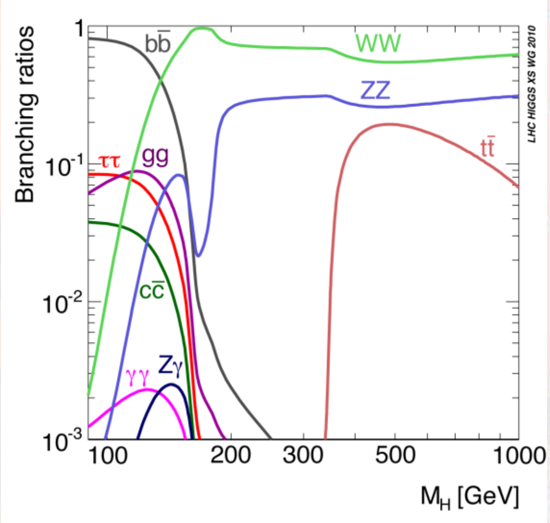
An all-purpose electronic eye for subatomic physics

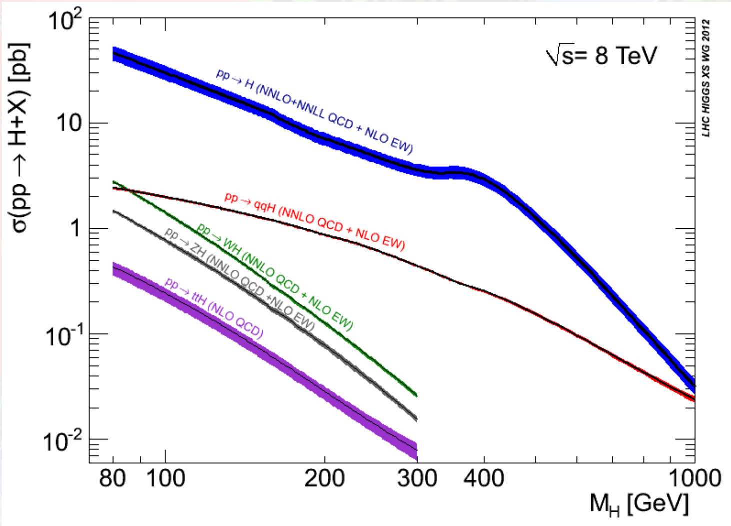
Higgs Physics



- The SM makes very precise predictions for many properties of the Higgs boson:
  - production modes
  - branching fractions
  - spin and parity
- No prediction for H mass, but indirect experimental input connecting M_H to EW observables via quantum loops constrain it loosely
- Here I will only show some selected results of my liking
- **For a more complete overview see this morning's talk by R.Mankel**

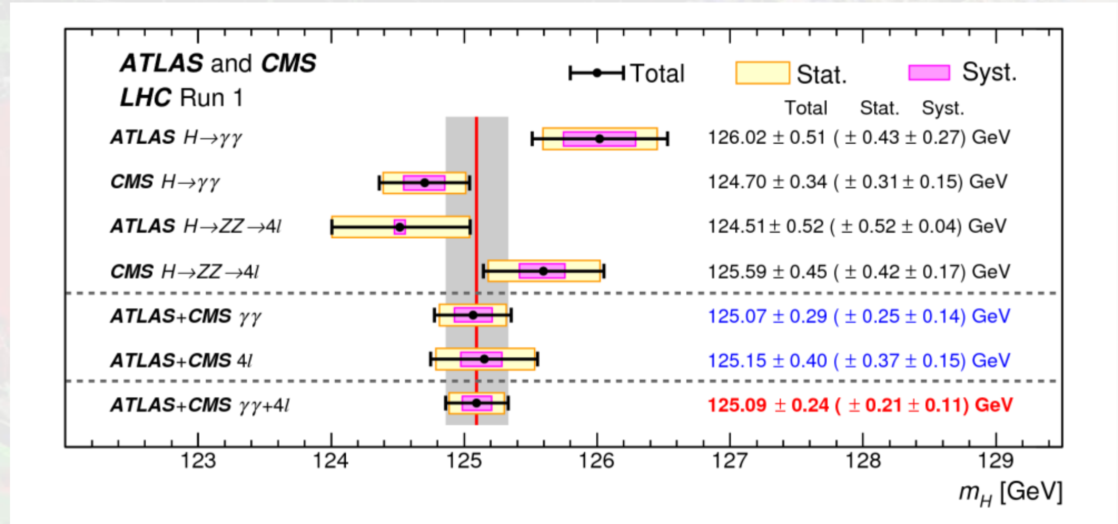


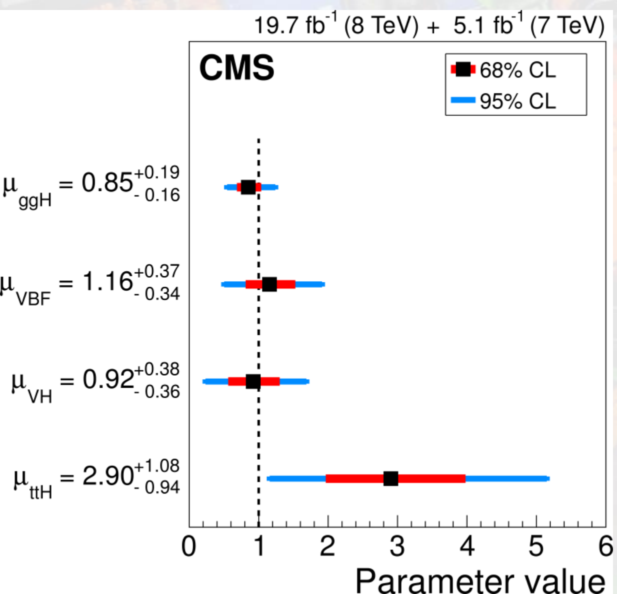




CMS Higgs measurements summary

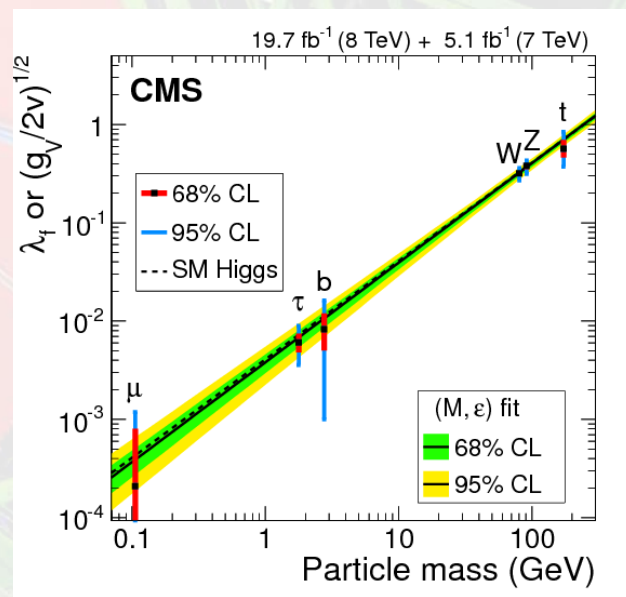
- Mass:
  M_H=125.02 ± 0.27 ± 0.15 GeV
- Cross section:
  μ = 1.00 ± 0.09 (stat) $^{+0.08}_{-0.07}$ (theo) ± 0.07 (syst)
- **J^P: 0^+**
- Couplings: **As the SM predicts!**





Left: fits to the signal strength μ from measurements in different final states allow to disentangle the contribution of different production modes

Right: coupling of Higgs boson to different particles is compared to SM predictions



Higgs boson: going differential

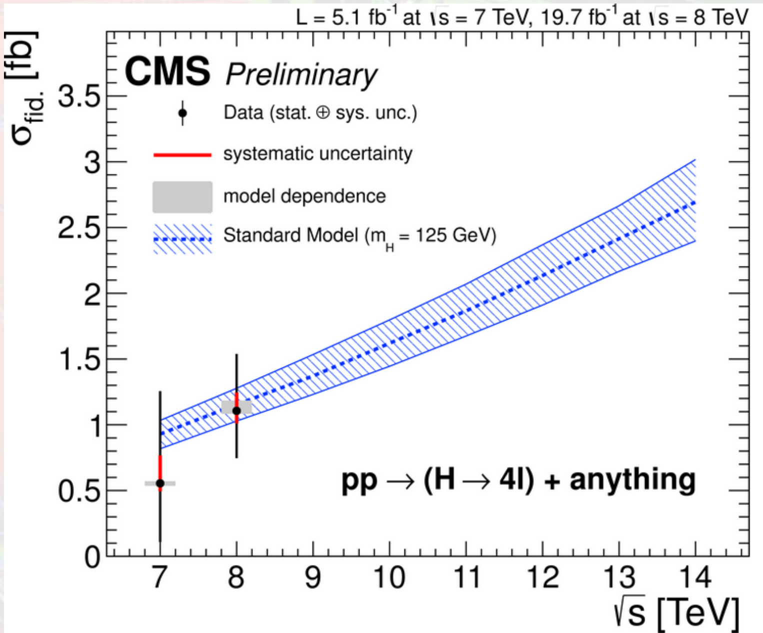
In the old days of hadron spectroscopy, people used to say that **with one event you could measure a cross section, and with two you could publish differential distributions...**

CMS collected many Higgs events in the Run 1 data, so it was due time to start studying fiducial differential distributions.

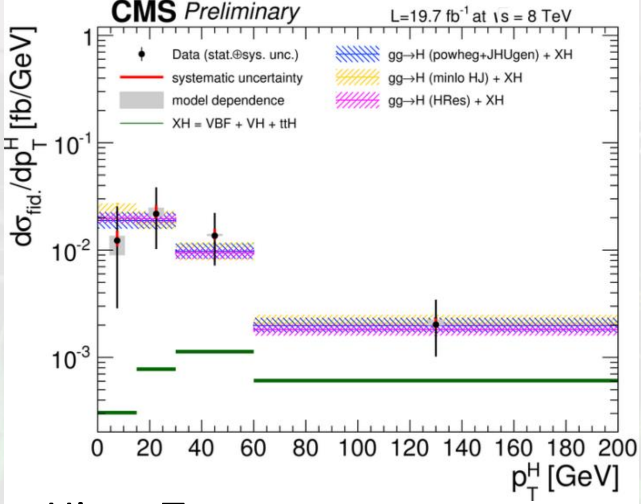
Fiducial == the measurement is performed in a region of phase space matching the detector acceptance. This reduces model systematics

Requirements for the $H \to 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
leading lepton p_T	$p_T > 20$ GeV
next-to-leading lepton p_T	$p_T > 10$ GeV
additional electrons (muons) p_T	$p_T > 7(5)$ GeV
pseudorapidity of electrons (muons)	$\|\eta\| < 2.5(2.4)$
p_T sum of all stable particles within $\Delta R < 0.4$ from lepton	less than $0.4 \cdot p_T$
Event topology	
existence of at least two SFOS lepton pairs, where leptons satisfy criteria above	
inv. mass of the Z_1 candidate	$40\,\text{GeV} < m(Z_1) < 120\,\text{GeV}$
inv. mass of the Z_2 candidate	$12\,\text{GeV} < m(Z_2) < 120\,\text{GeV}$
distance between selected four leptons	$\Delta R(\ell_i \ell_j) > 0.02$ for any $i \neq j$
inv. mass of any opposite sign lepton pair	$m(\ell^+ \ell'^-) > 4\,\text{GeV}$
inv. mass of the selected four leptons	$105\,\text{GeV} < m_{4\ell} < 140\,\text{GeV}$
the selected four leptons must originate from the $H \to 4\ell$ decay	

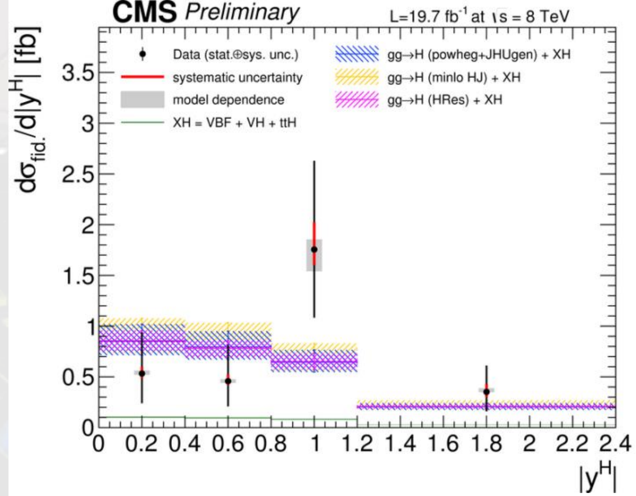
The cross section is derived in the fiducial volume at 7 and 8 TeV independently, by maximum likelihood fits to the data assuming M_h=125 GeV. They are compared to predictions at NNLO+NNLL performed with Hres, MinLOHJ, and POWHEG+JHUGEN.



Besides the cross section at 7 and 8 TeV, the considered variables for differential production cross section studies are the transverse momentum and rapidity of the four leptons in H→ZZ*→4l, and its kinematics WRT the leading jet.

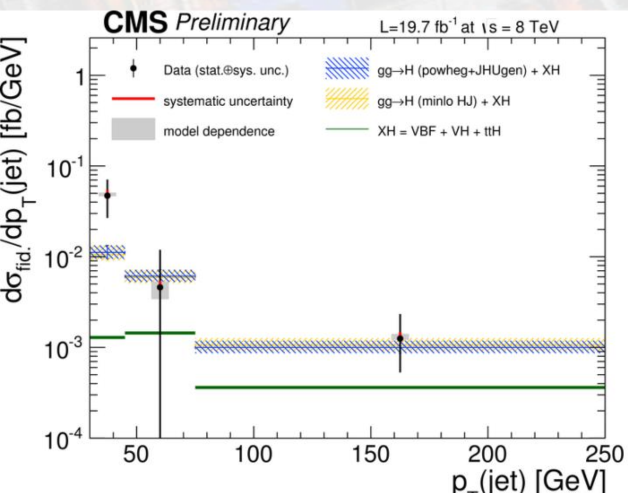


Higgs Transverse momentum

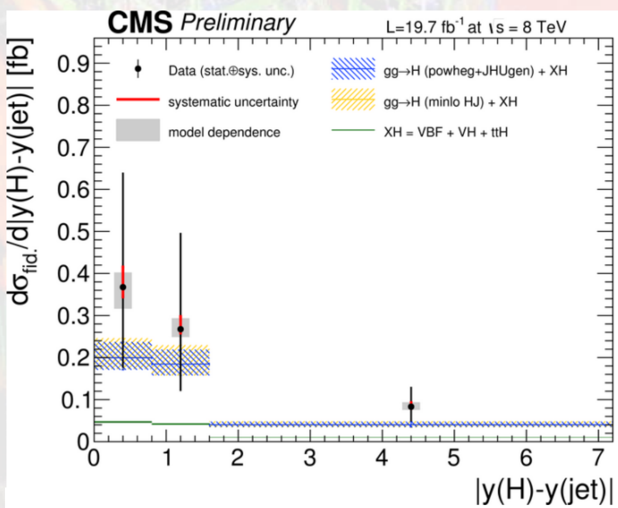


Higgs rapidity

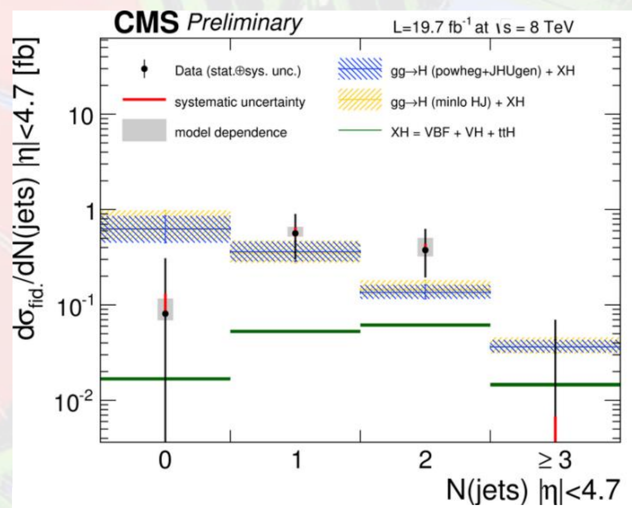
Results match nicely the precise theoretical predictions at NNLO in all considered distributions



Jet transverse momentum



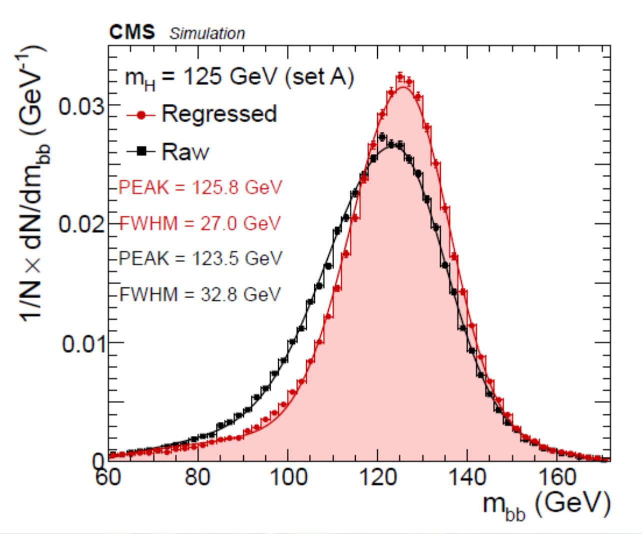
Jet-H rapidity difference



Number of jets in H events

A Higgs signal in all-jet final states ?!

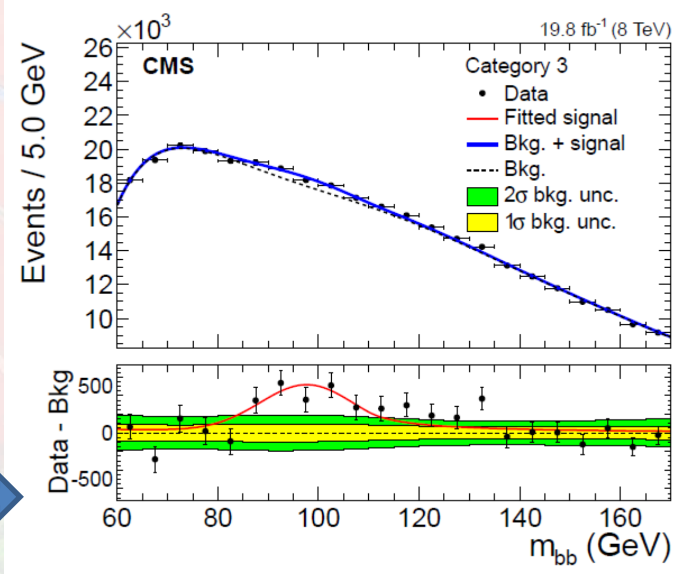
When searching for rare processes, the all-jet final state is usually anathema at hadron colliders. Now for the first time a meaningful Higgs physics result is extracted from 4-jet events



CMS sought for the **VBF production of Higgs bosons with decay to b-quark pairs** in Run 1 data. The signal yields two forward jets of large energy, and a b-quark jet pair which has no colour connection to those "tag" jets

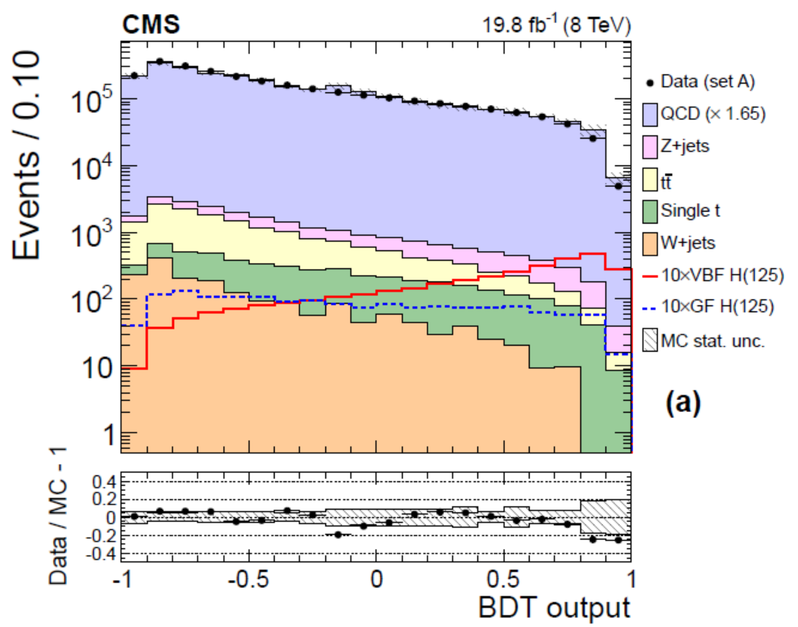
A **jet energy regression technique** is applied to improve the resolution on the dijet invariant mass, employing jet variables (p_T, η, mass, charged fraction), vertex variables, soft lepton characteristics (if present), and missing E_T and other event information. It improves mass resolution by 20%

A simplified version of the technique employed for the signal discrimination is proven to work to **extract Z→bb events in the same dataset**



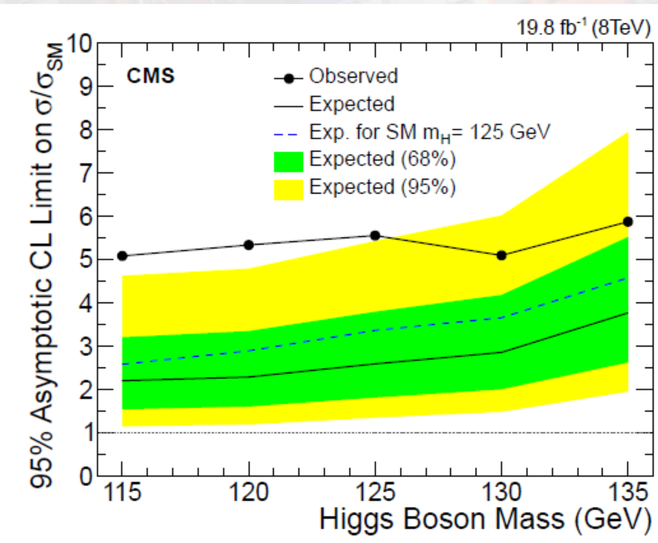
To extract a Higgs signal, a BDT discriminant is used to reduce the huge background from QCD; it uses variables with little or no correlation with m_{bb}

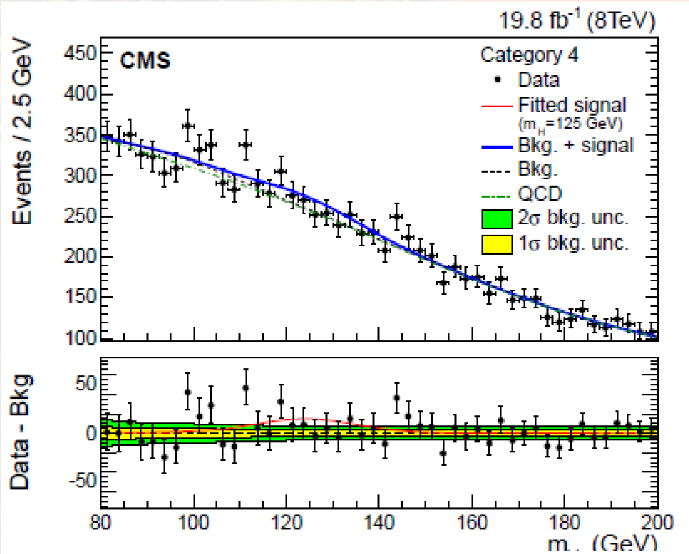
- VBF kinematics: $\Delta\eta$, $\Delta\phi$, m_{jj}
- b-tagging variables: CSV of two central jets
- jet shapes (quark-gluon discriminant output)
- soft radiation pattern using tracks
- cosine of angle between the two dijet systems



Then a fit to the dijet mass distribution of the b-quark candidates is performed simultaneously on 4+3 different categories of BDT output

The result on the signal strength (in SM expectation units) is **μ=2.8+1.6-1.4**, with a significance of **2.2 σ** (0.8σ expected).





Mass distribution in high-BDT category

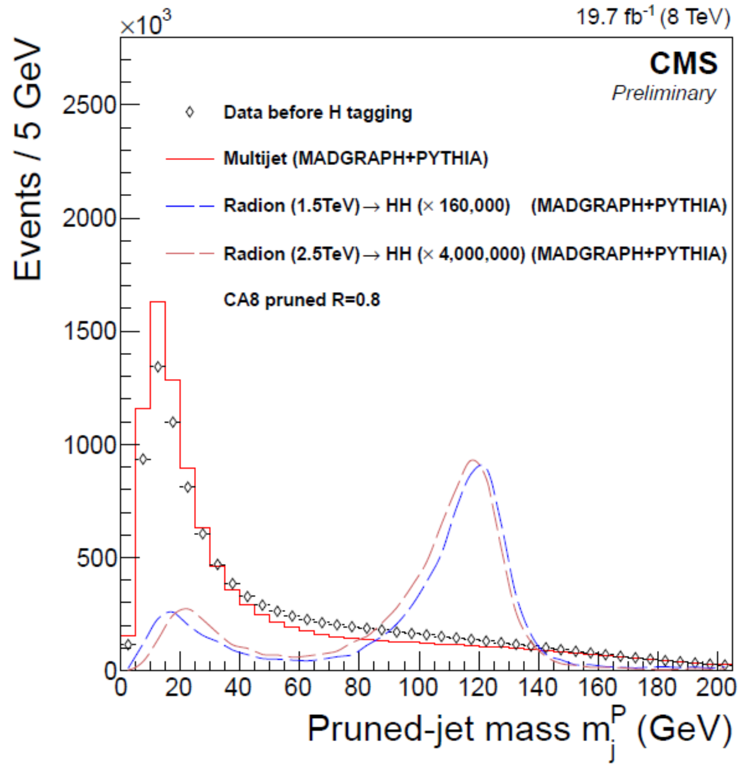
The signal strength is finally combined with previous measurements of the Higgs cross section in the bb final state, yielding **μ=1.03+0.44-0.42** (total significance = 2.6σ).

Using Higgs bosons in searches

- New physics objects may decay to Higgs boson pairs → the Higgs can be used as a probe of exotic new models
  - Example: models inspired by warped extra dimensions predict the existence of spin-0 Radions X, or spin-2 Kaluza-Klein excitations of the graviton, G_{RS}.
- Due to small cross sections of predicted phenomena, the only practical Higgs decay mode to exploit in these searches is currently the H→bb one

Searches for resonant HH production and decay to bbbb final states have been performed by ATLAS and CMS in the non-boosted regime (M_X<1 TeV) Decays of heavy objects into HH pairs will result in highly boosted b-quark jets that merge in a single "fat jet"

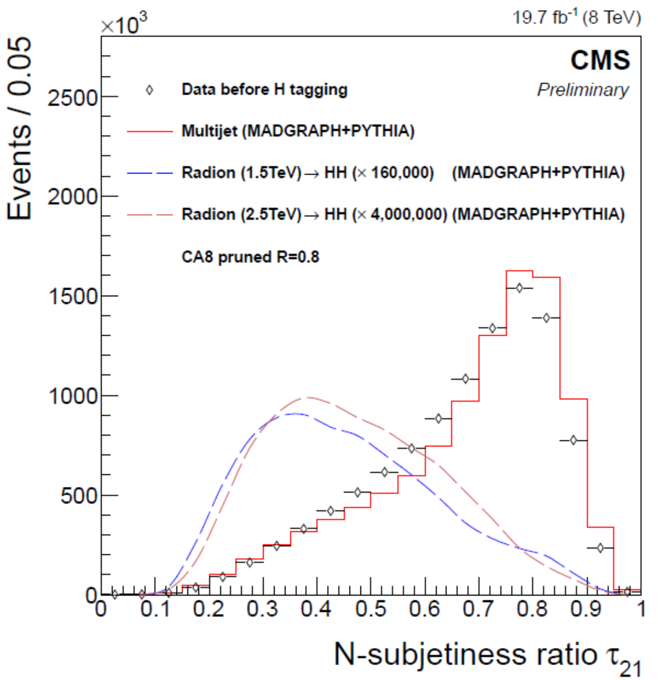
These topologies can now be spotted and separated from backgrounds using jet substructure techniques



The 2-subjet mass can be effectively used to distinguish H decays from generic jets.

- B-tagging is also used – secondary vertices are sought in the sub-jets (or in the fat jet if the sub-jets are at $\Delta R<0.3$).
- H-jets have mass in the 110-135 GeV range and are b-tagged. Events are retained if both jets are “H-jets”, and at least one of the two leading jets is tight b-tagged (both subjets are tagged, or the fat jet is)

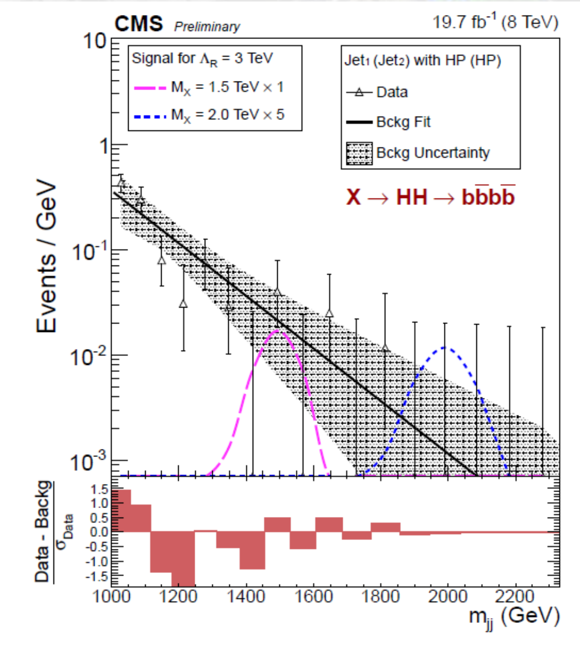
- To further reduce backgrounds, the τ_{21} variable is used to distinguish H-jets in “high-purity” and “low-purity” ones. Three categories are created: HPHP, HPLP, and LPLP.

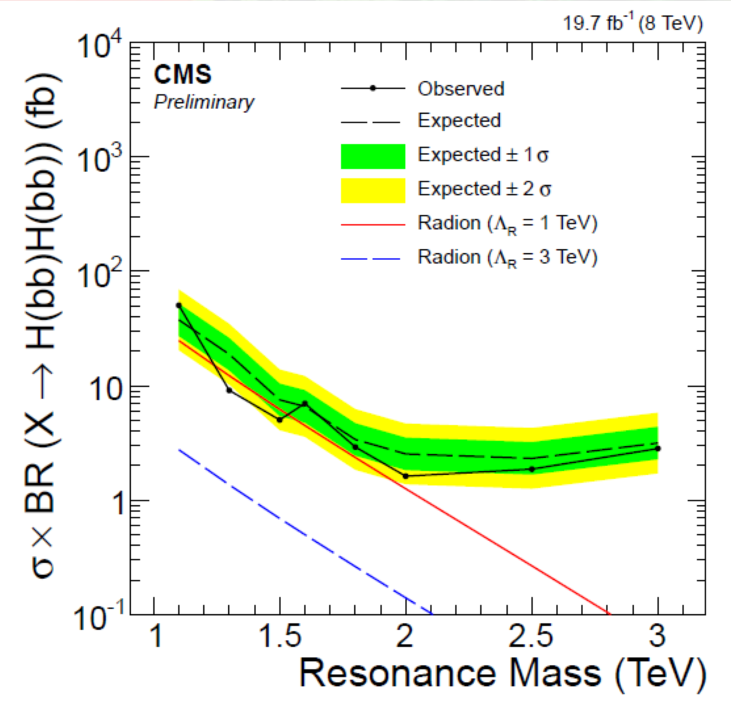


A data-driven fit cross-checked in control samples and MC is used to extract the signal contribution and set upper limits.

Left: fit to HPHP events

Right: combined limit on radion cross section from the combination of three categories





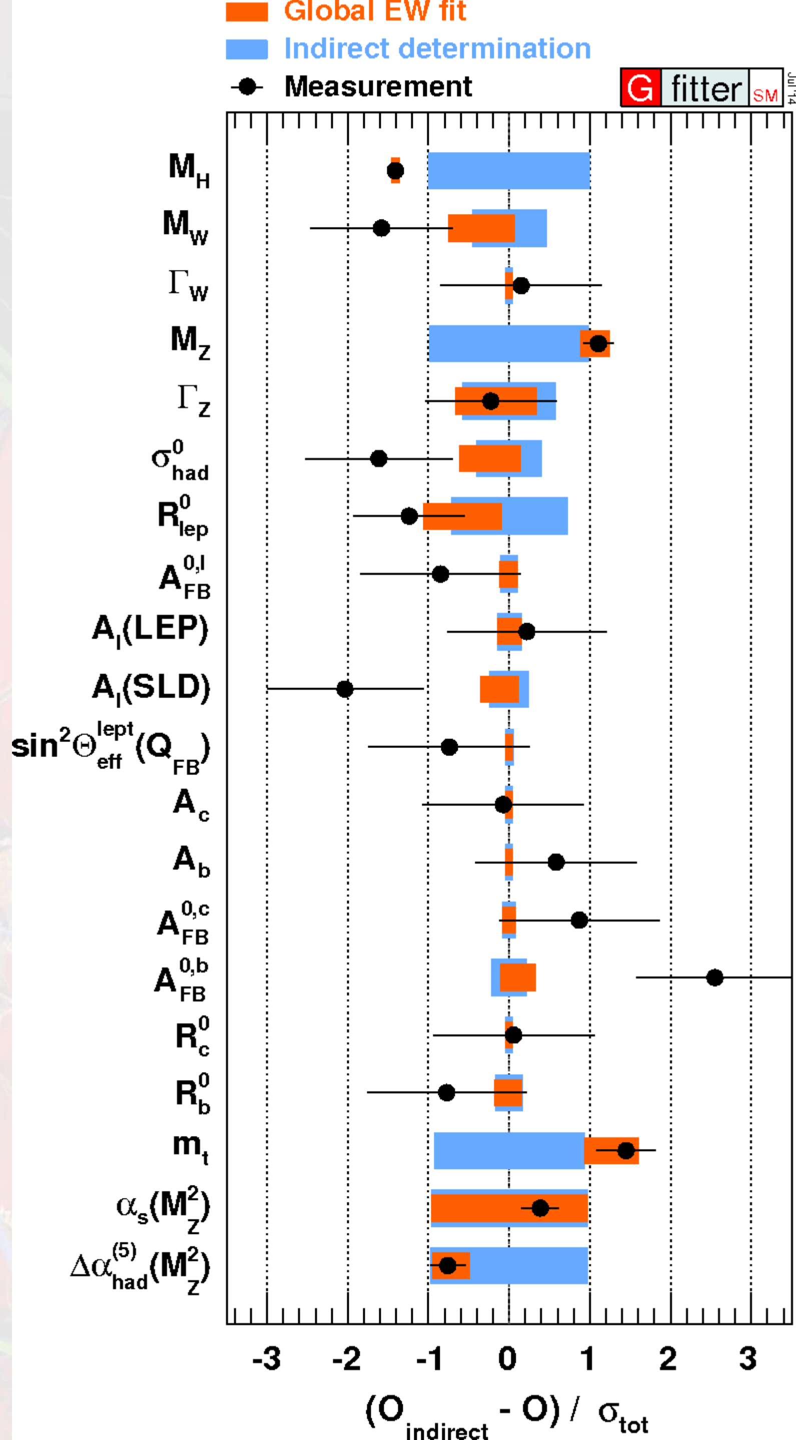
How is the SM doing ?

- With new experimental input from the Higgs mass, top and W masses, as well as other re-evaluations of EW observables, the global fit to the SM shows overall a good consistency
  (**p-value=21%**)

- What is important to realize is that most of these parameters are still better constrained by the theory than by measurements! → the game of precision measurements has not become an idle one just yet.

- Clearly the **masses** of top, Z, and H **are not** the parameters most urgently **in need of a more precise experimental determination**

- effort on M_W continuing ... LHC alone ultimately will get to O(5 MeV)



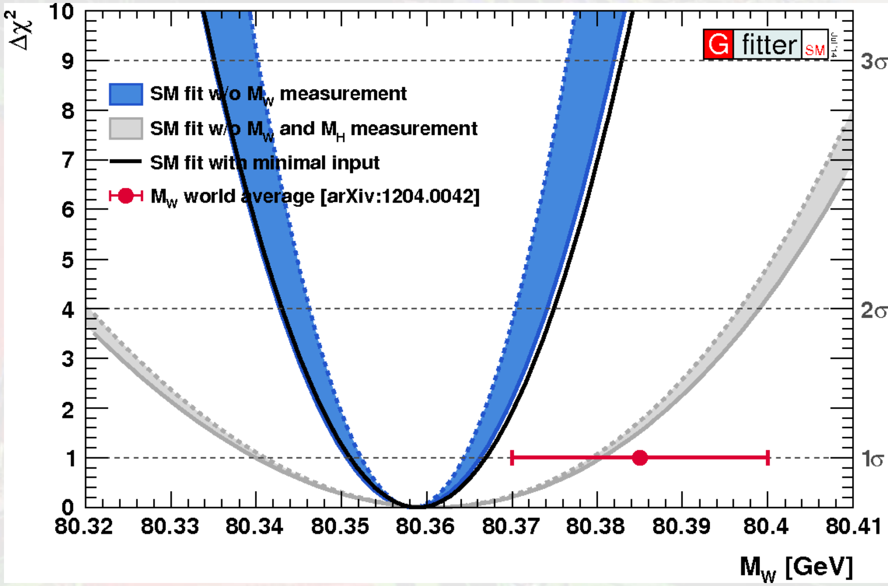
Two more nice plots from Gfitter

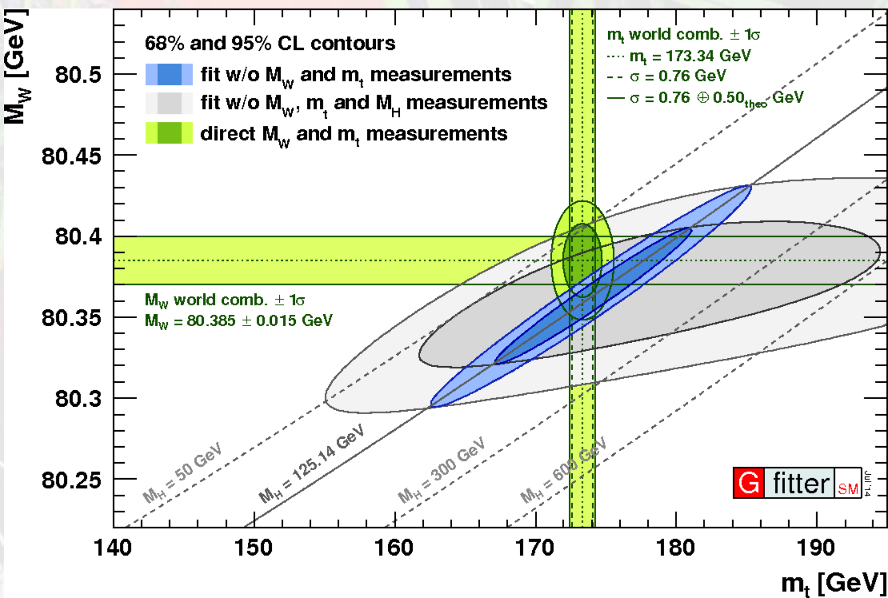
- The combination of SM measurements has considerably improved in power now that we have a 0.2% measurement of the Higgs mass

- The indirect M_W measurement is the best example of the improvement, with an uncertainty of 8 MeV (0.01%!), twice as good as direct ones:

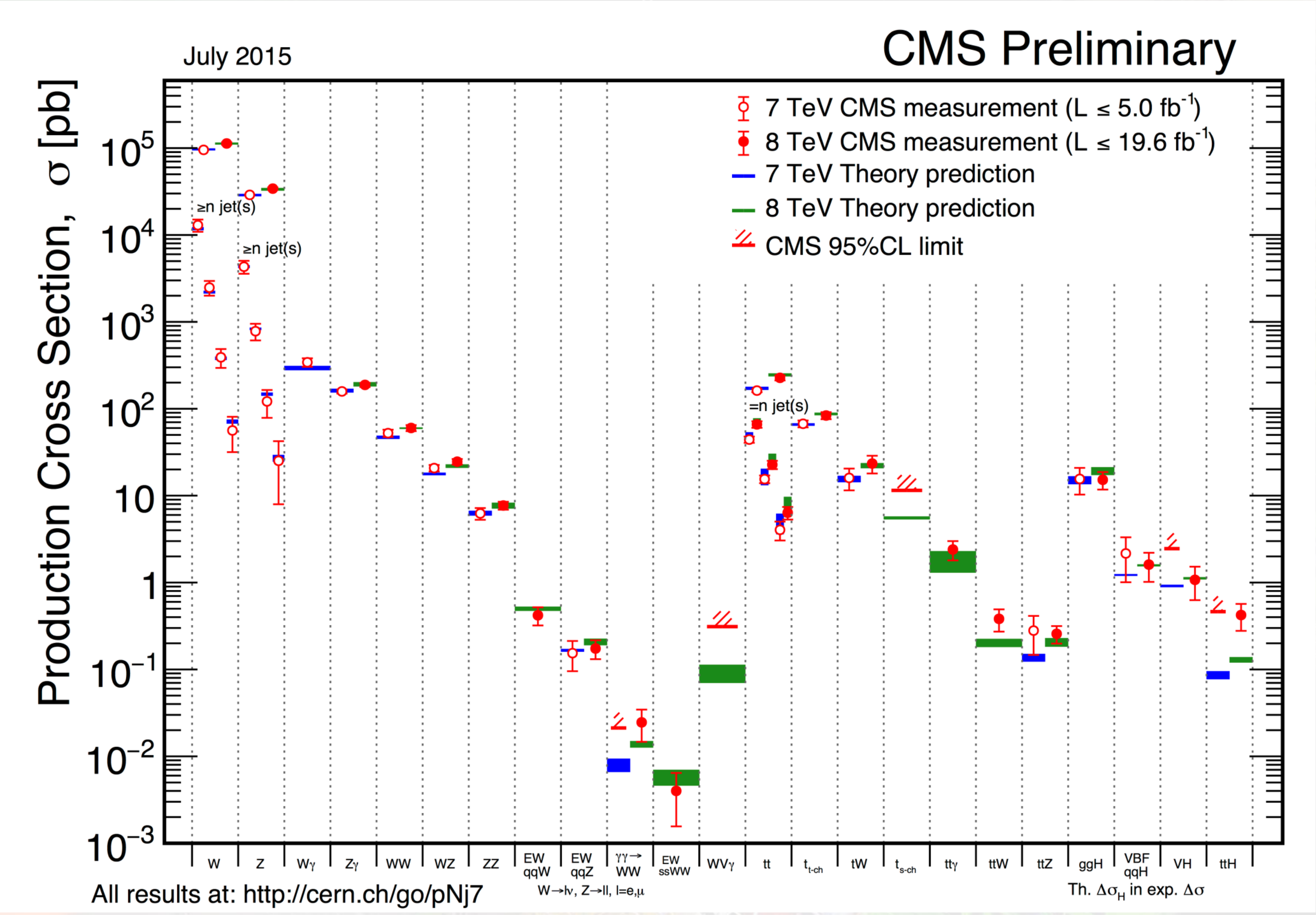
  M_W=80358+-8 MeV

- The usual M_t-M_W plane graph is now as impressive as ever, with all-around consistency of theory and experiment (direct and indirect)

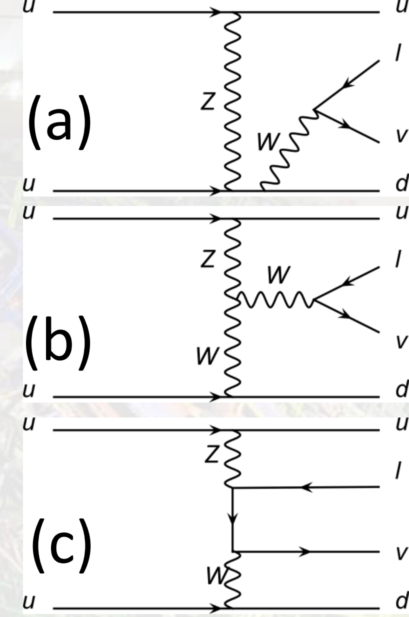




One quick summary of EW cross sections



Electroweak production of W



t-channel exchange of EW bosons may result in the production of EW bosons

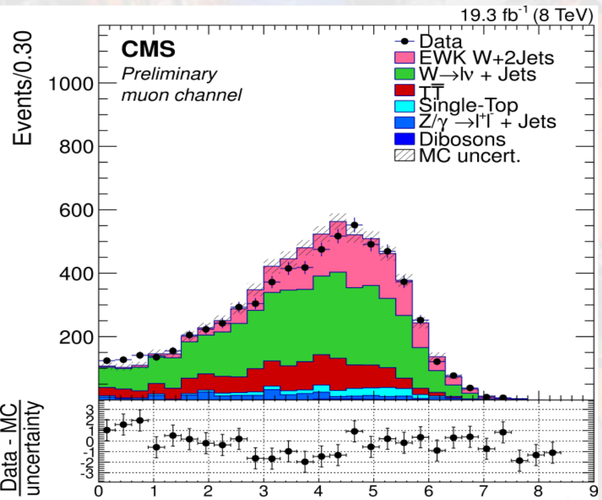
- Rare process, of importance for Higgs physics as well as for studies of rapidity gaps and as a test of the SM and triple-boson couplings
- Three classes of diagrams: (a) bremsstrahlung, (b) VBF, and (c) multiperipheral collisions. Large interference exists among (a) and (b)

CMS used 19/fb of 8 TeV data to search for this process. W→eν,μν events with two jets with m_{jj}>1000 GeV must be present. Δη of W and dijet syst <1.2 reduces backgrounds.

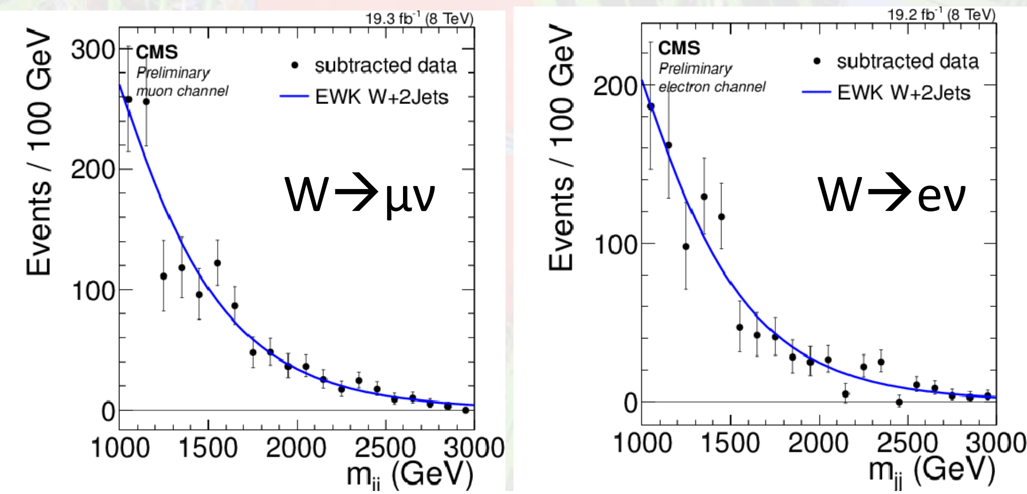
A BDT using lepton and jets kinematics is trained to distinguish the signal from backgrounds

Bgr-subtracted rate in e and μ channels are combined with BLUE:

σ=0.49+-0.04+-0.09+-0.01 pb, compatible with SM prediction of 0.50+-0.03 pb (MG+P6)



Δη of jets in μ channel

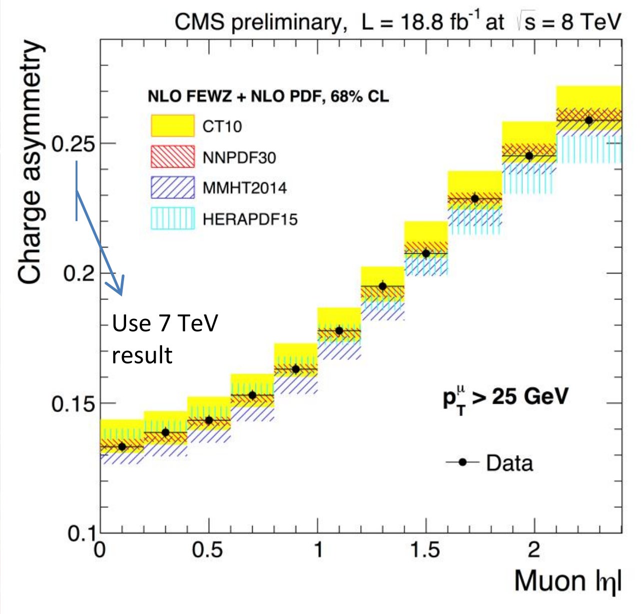


Background-subtr. M_{jj} spectra of EW W production

Muon charge asymmetry in W decay

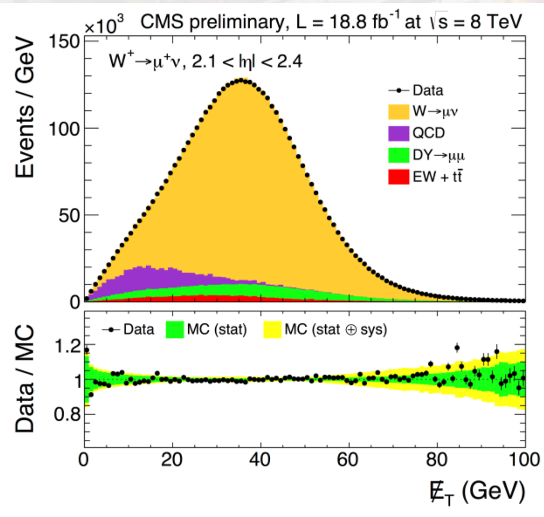
106 million W→μν decays from 18.8/fb of 8-TeV data have been used to measure the charge asymmetry in W production and decay:

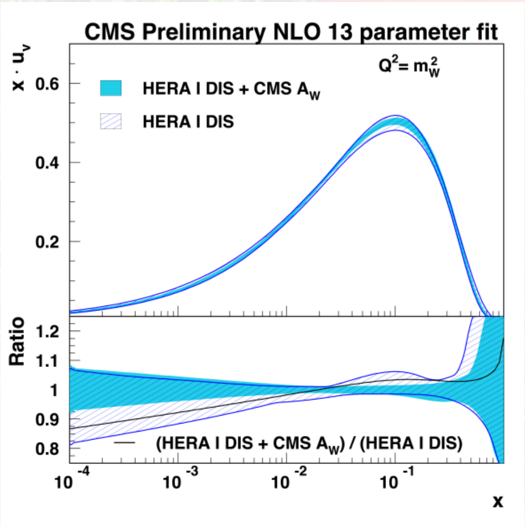
$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\bar{\nu})}$$

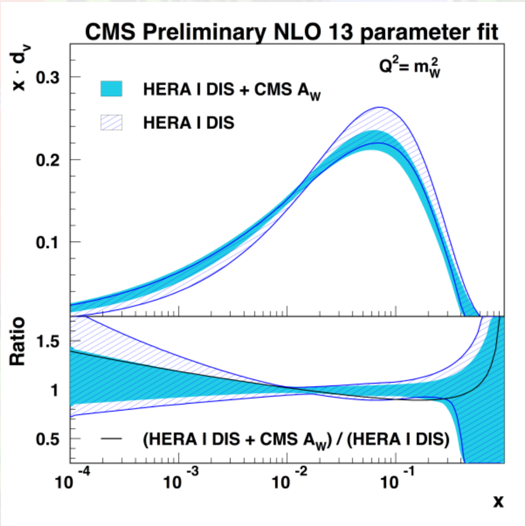


The asymmetry can be used to constrain the valence quarks PDF. A NLO QCD analysis is performed by simulating W decays with MCFM and PDF functions are determined using the HERAFITTER package and the HERA cross section measurements.

→ CMS data significantly reduces PDF uncertainties of u_V, d_V in the 0.001-0.1 range







Top Quark Studies

- LHC is a top factory – **in Run 1 produced** N=(2xσ_{tt}+σ_{tb}+σ_{tW}+σ_{tbq})*L = **15M top quarks** in CMS, and In Run 2 cross sections are growing by a factor of 3

- Interest of top physics driven by several factors
  - heaviest known SM particle
  - Yukawa coupling = 1
  - top decays free of QCD effects – can study production mechanisms and polarization in ideal conditions
  - top mass important for model building
  - rare top decays and FCNC tests might lead to surprise discoveries

- CMS has new results shedding light on these issues

  E.g. <1y old paper submissions:

  - **TOP-13-013 Measurement of the charge asymmetry in top quark pair production in pp collisions at s√= 8 TeV using a template method, submitted to PRD Aug 2015**
  - **TOP-12-033 Inclusive and differential measurements of the tt¯ charge asymmetry in pp collisions at s√= 8 TeV, submitted to PLB Jul 2015**
  - **TOP-12-028 Measurement of the differential cross section for top quark pair production in pp collisions at s√ = 8 TeV, submitted to EPJC May 2015**
  - **TOP-13-010 Measurement of the cross section ratio σtt¯bb¯/σtt¯jj in pp collisions at s√ = 8TeV, PLB 746 (2015) 132**
  - **TOP-12-020 Measurement of the W boson helicity in events with a single reconstructed top quark in pp collisions at s√ = 8 TeV, JHEP 01 (2015) 053**
  - **TOP-13-012 Search for standard model production of four top quarks in the lepton + jets channel in pp collisions at s√ = 8 TeV, JHEP 11 (2014) 154**

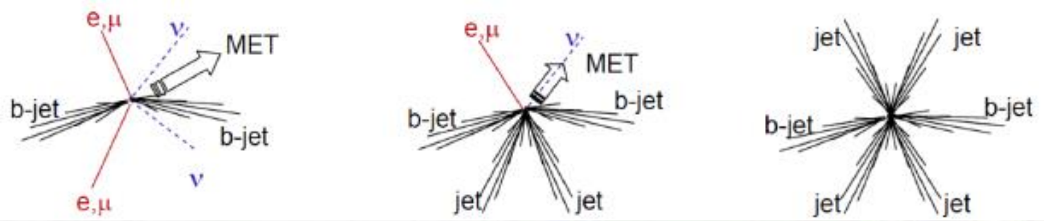
CMS Preliminary results <1y old

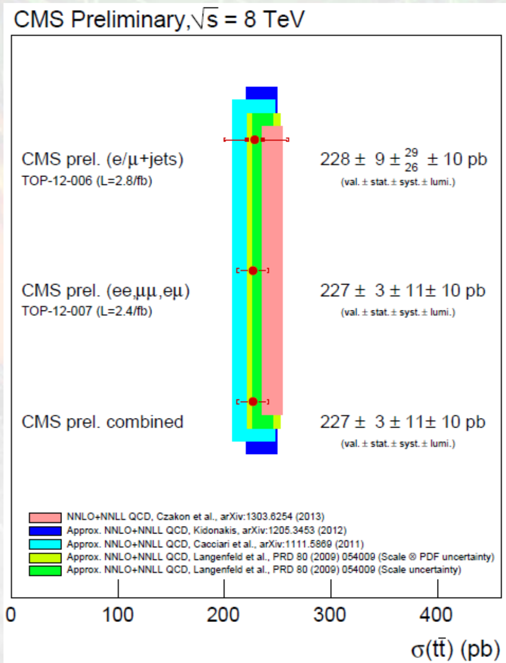
CMS-PAS-TOP-14-012	Measurement of the differential $t\bar{t}$ production cross section for high-p_T top quarks in e/μ+jets final states at 8 TeV		August 2015
CMS-PAS-TOP-15-003	Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV with the CMS detector		August 2015
CMS-PAS-TOP-13-016	Measurement of the $t\bar{t}b\bar{b}$ cross section and the ratio $t\bar{t}b\bar{b}/t\bar{t}jj$ in the lepton+jets final state at 8 TeV with CMS detector		July 2015
CMS-PAS-TOP-14-021	Measurement of top quark pair production in association with a W or Z boson using event reconstruction techniques		July 2015
CMS-PAS-TOP-14-017	Measurement of the W boson helicity using $t\bar{t}$ events in the dilepton final state at $\sqrt{s} = 8$ TeV		July 2015
CMS-PAS-TOP-14-019	Search for top quark decays $t \to qH$ with $H \to \gamma\gamma$ in pp collisions at $\sqrt{s} =$ 8 TeV		July 2015
CMS-PAS-TOP-13-015	Measurement of spin correlations in top pair events in the lepton+jets channel with the matrix element method at 8 TeV		June 2015
CMS-PAS-TOP-13-017	Search for top quark decays via Higgs-boson-mediated flavor changing		March 2015
CMS-PAS-TOP-14-014	Determination of the top-quark mass from the m(lb) distribution in dileptonic ttbar events at sqrt(s) = 8 TeV		2014
CMS-PAS-TOP-14-004	Single top t-channel differential cross section at 8 TeV		2014

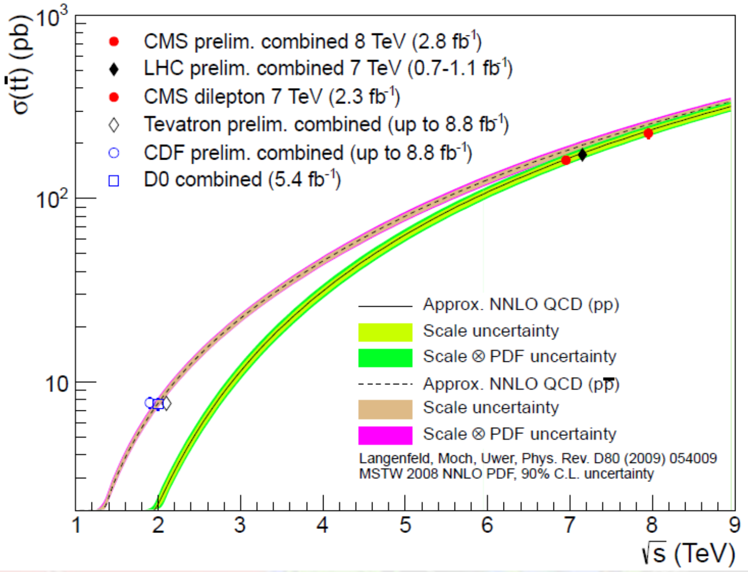
Full list and links to documentation at
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TOP/index.html

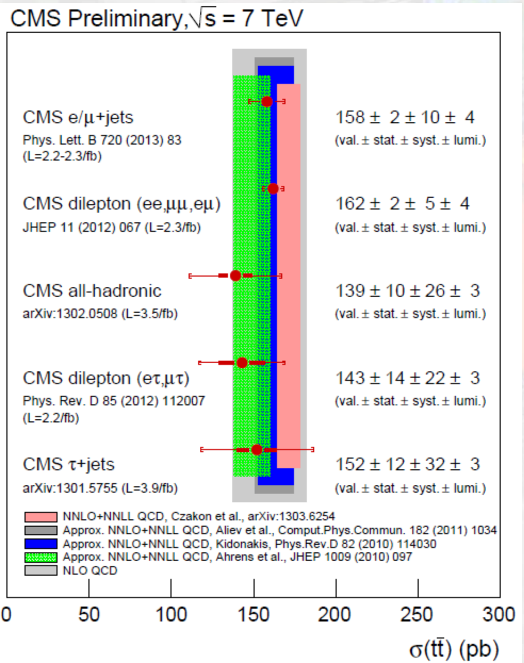
Top quark production cross sections

- Top is mainly produced in pairs by gluon-gluon collisions; also produced singly via EW processes (W*→tb, bg→tW, gW→tbq)
- Top pairs undergo three possible decay modes: dileptonic (e,μ: 5%), single lepton (e,μ+jets: 30%), hadronic (all jets: 45%); these channels have complementary issues and purity
- Results challenge NNLO+NNLL QCD calculations both at 7 and 8 TeV









Bottom line: Great agreement!

This is a true success of precision calculations of perturbative QCD

Top quark mass

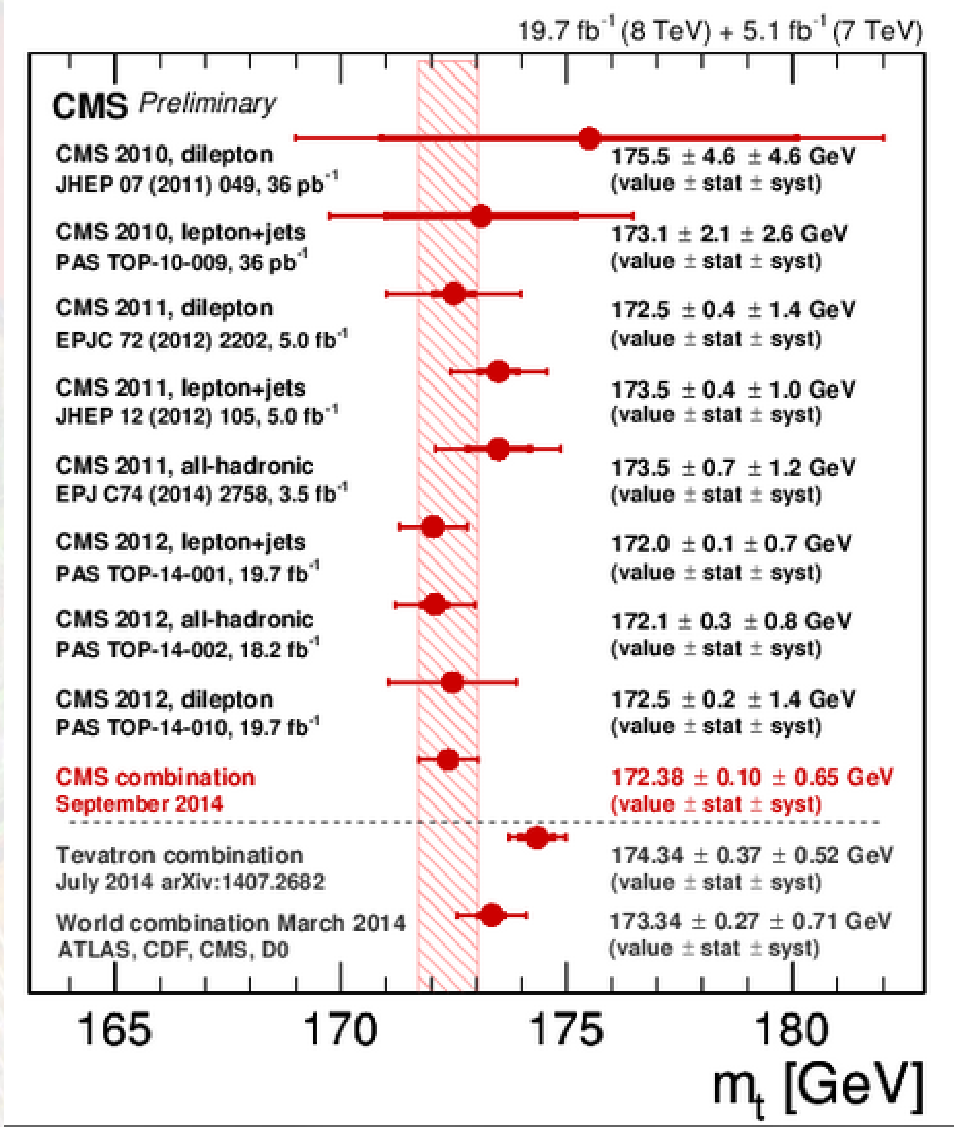
- CMS produced a number of top mass measurements in Run 1.
- A combination of those results yields

  M_t=172.38+-0.10+-0.65 GeV

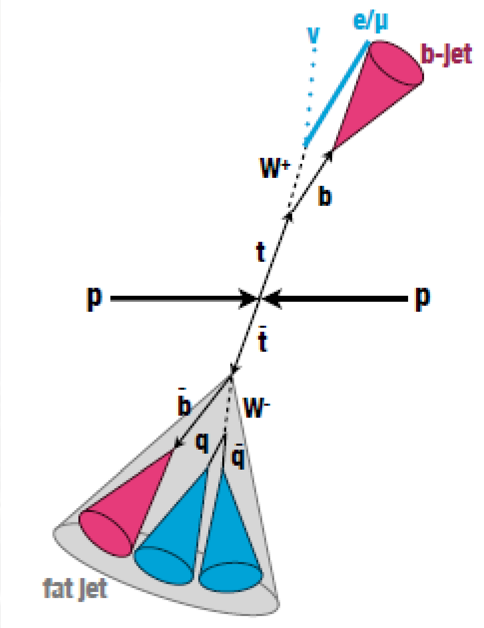
  → beats all other single-experiment results

  → matches combined precision of Tevatron measurements

- Small tension with TeVatron results, mainly due to high m_t D0 determination



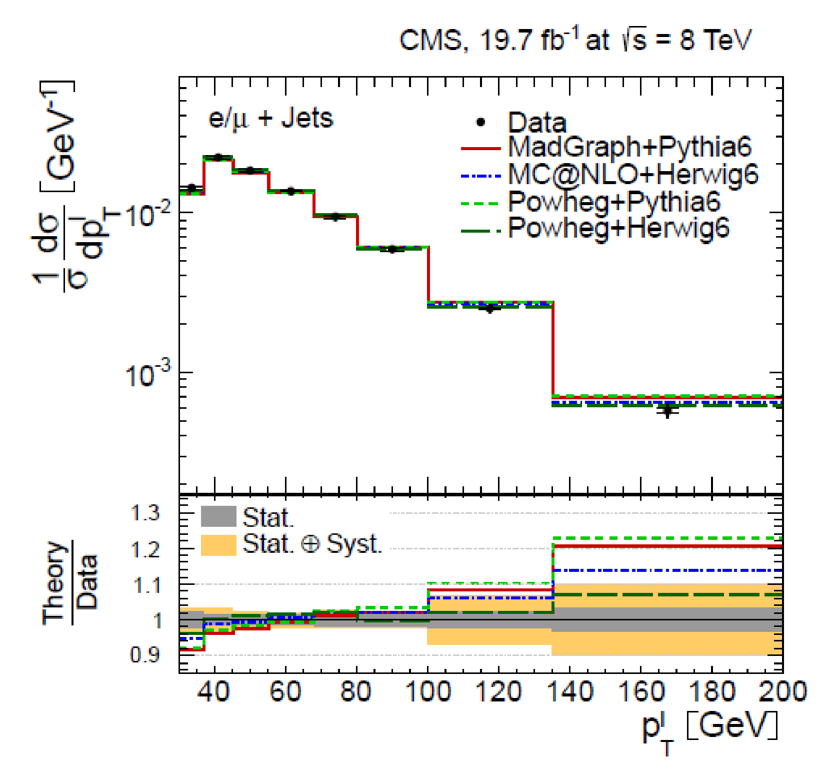
Top production cross section at high p_T with boosted tops



- At high-p_T, top decay products merge together just as b-decay products do, so special techniques are needed to identify pairs or triplet of "sub-jets" within wide jets

- This allows to measure the top pair production cross section in very boosted regimes, of special interest for new physics searches

- In particular, a differential measurement performed with non-boosted techniques found some deficit of top production WRT MG+P6 at high p_T → worth looking at in detail!
  - See arxiv:1505.04480

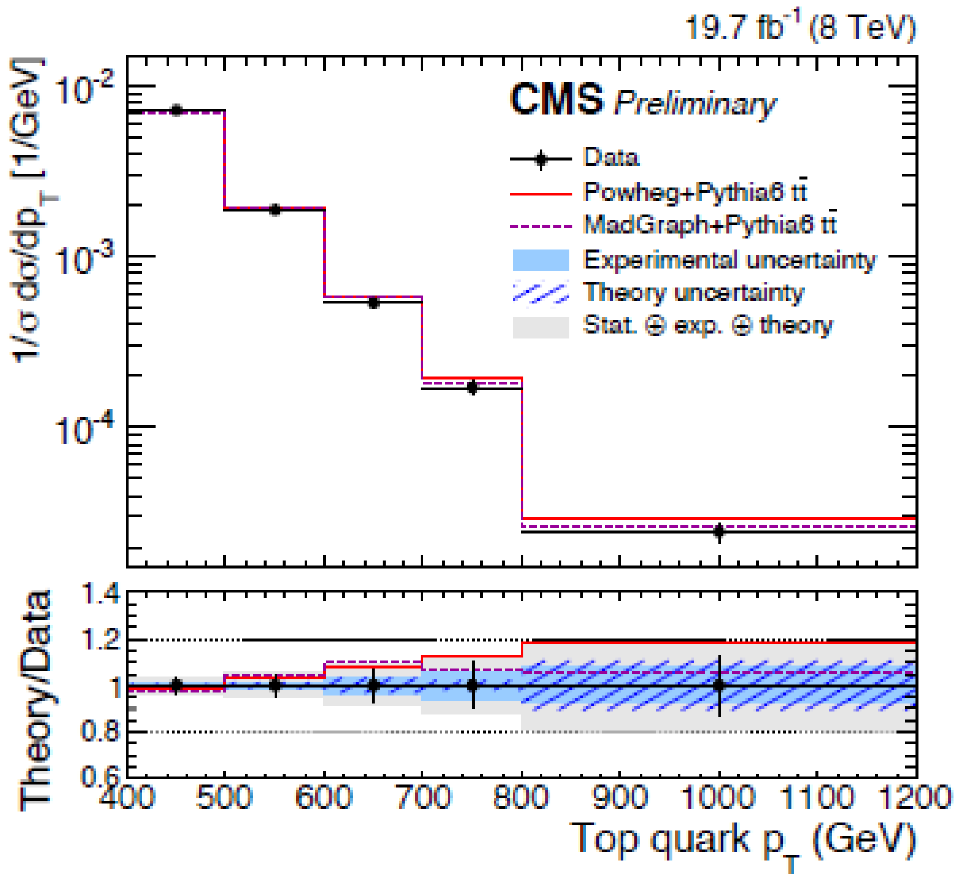


- The boosted top technique works for p_T>400 GeV → complementary regime
  - a wide jet (CA8) is the input of the top tagging
    - 3 subjets with M_{jk}>50 GeV, 3-mass 140-250 GeV
  - on the leptonic side (LS) a regular ak5 jet is used with lepton and neutrino signature

Fit employs both b-tagged and non-b-tagged LS jets

Use p_T templates: QCD data-driven from MET fit plus non-QCD (tt and t, W+jets) from MC

Simultaneous fit to 3x2 e/μ categories extracts normalization of signal, then study p_T distribution



Result in good agreement with MG and Powheg+P6

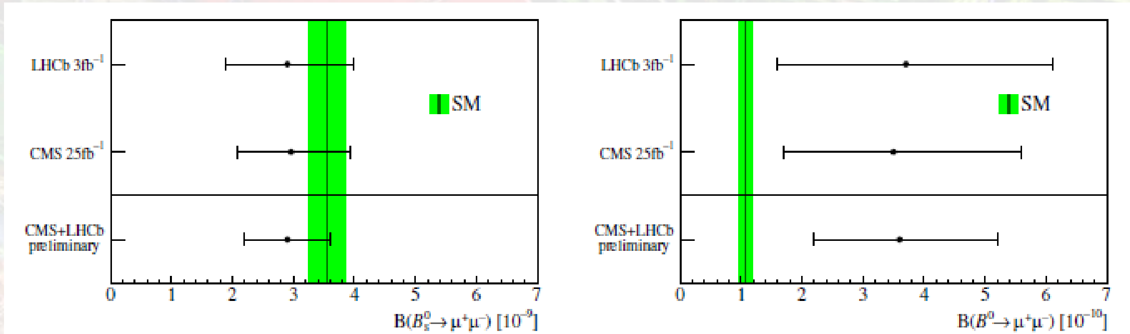
B Physics Results

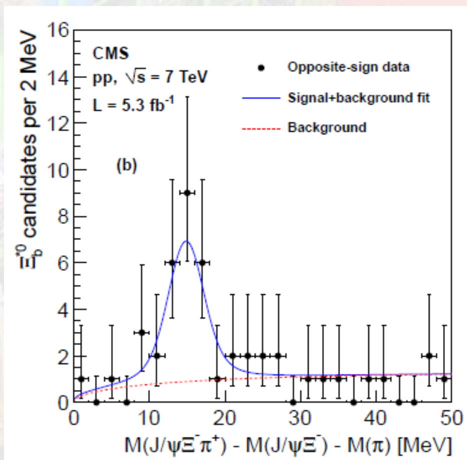
Recently submitted for publication:

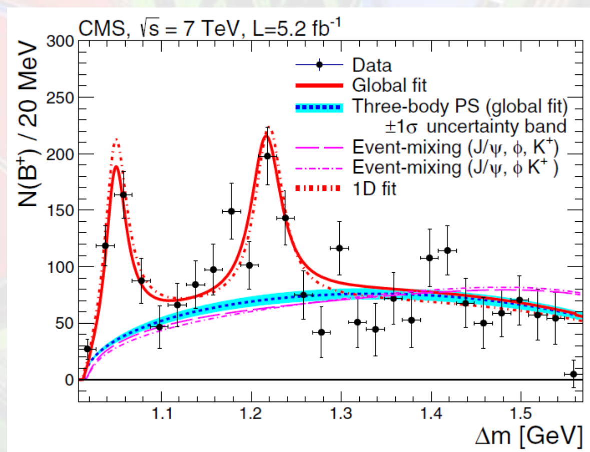
- CMS-PAS-BPH-14-001 , J/psi and psi(2S) prompt double-differential cross sections in pp collisions at 7 TeV, PRL 114 (2015) 191802
- CMS-PAS-BPH-13-012, Measurement of the CP-violating weak phase φ_s and the decay width difference $\Delta\Gamma_s$ using the $B_s \rightarrow J/\psi\varphi(1020)$ decay channel, submitted to PLB

Most notable results from Run 1:

- Measurement of B_s and B_d decays to muon pairs and combination with LHCb
- Observation of new resonances:
- new states in $B \rightarrow J/\psi\phi$
- New Ξ_b^* state







For more, see talk by S. Niladribihari later this morning

Searches for Supersymmetry

Before the 7-TeV run, **SUSY was thought by many as a very probable to certain discovery** in the very first few months of running...

That attitude has changed now

- yet hopes are still alive and expectations for 2015 run are still high
- some 2σ/3σ results focus the attention
  - trials factor very high → statistically quite insignificant
  - but SUSY is only in one place of the large param space, so believers can/should watch those with care

CMS has actively pursued all the most promising signatures of Supersymmetric particles in 7- and 8-TeV data

- dozens of new parameter space limits
- Executive summary: **NO HINT OF ANY SIGNAL**
- **No time for a summary -** I direct you to slides of talk by CMS speaker:
  - **M. Masciovecchio, 26/8 parallel session 6**

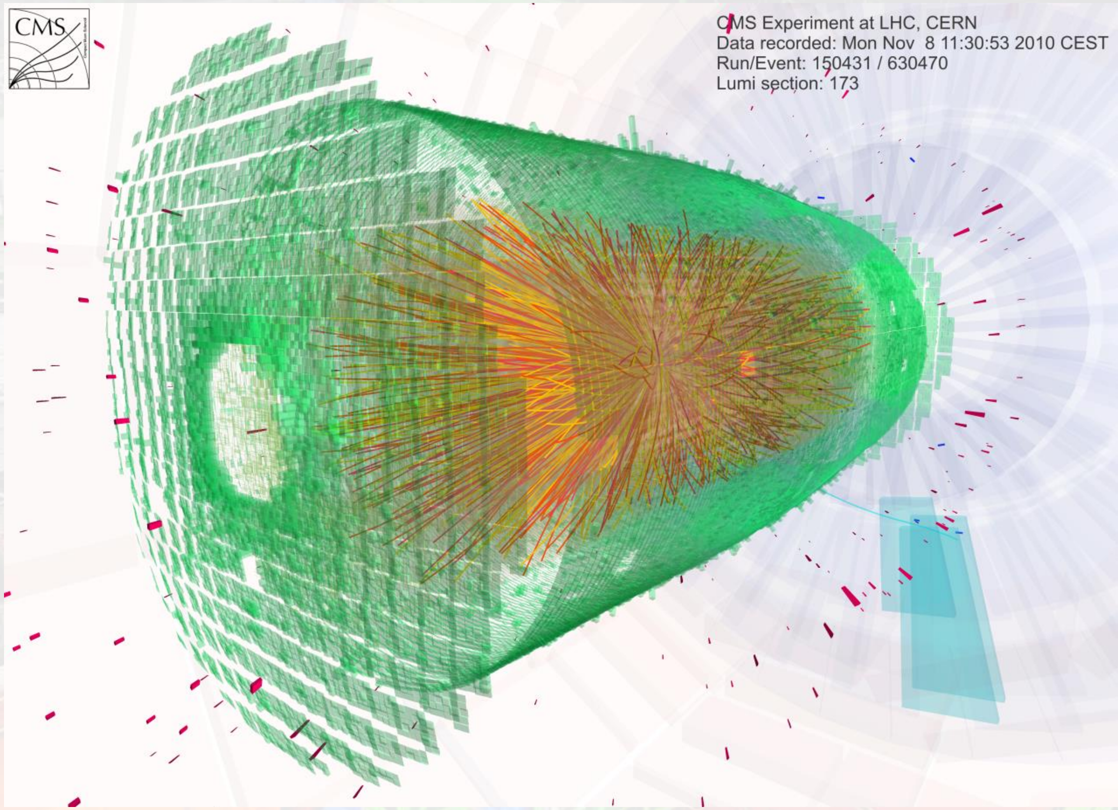
Other Exotica Searches

- **New physics fortunately does not mean just SUSY** ! CMS sought the 2011-2012 data for dozens of exotic new signatures of new physics:
  - large extra dimensions
  - gravitons
  - new resonances
  - heavy stable particles
  - dark matter candidates
  - black holes
  - new interactions
  - etcetera

- New searches have been concentrating on the less-than-straightforward exploitation of semi-hadronic and fully hadronic final states, once only yielding results for strongly-interacting new particles, but now competitive also due to groundbreaking new techniques with boosted objects

- For the most interesting recent CMS results, see slides of
  - **Claudia Wulz's talk (25/8, parallel 1)**
  - **Georgios Anagnostou (26/8, parallel 2)**

QCD, Heavy Ions, and Forward Physics



- No time to even mention it!
  - **Please see talk slides by Paolo Gunnellini, 25/8 (parallel session 6)**

RUN 2 RESULTS

- The LHC started operations at 13 TeV last June
  - Since then it delivered 106/pb of proton-proton collisions
  - CMS recorded a total of 83.5/pb
  - Of these, 62/pb were recorded with the solenoid at 3.8 Tesla
  - Results so far have been produced using 42/pb

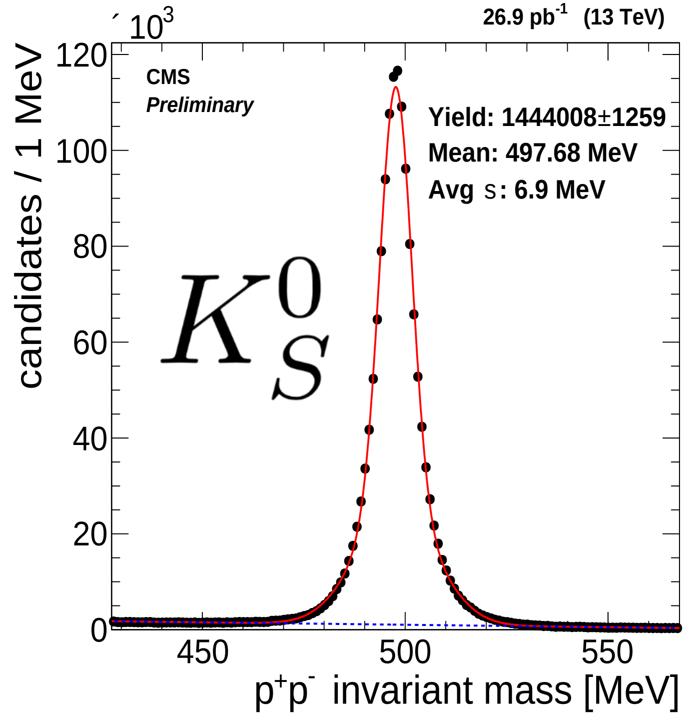
- In the following I will show a few "advertisement" plots and some of the nicest event displays collected with the above luminosity
- plus one full-fledged new analysis

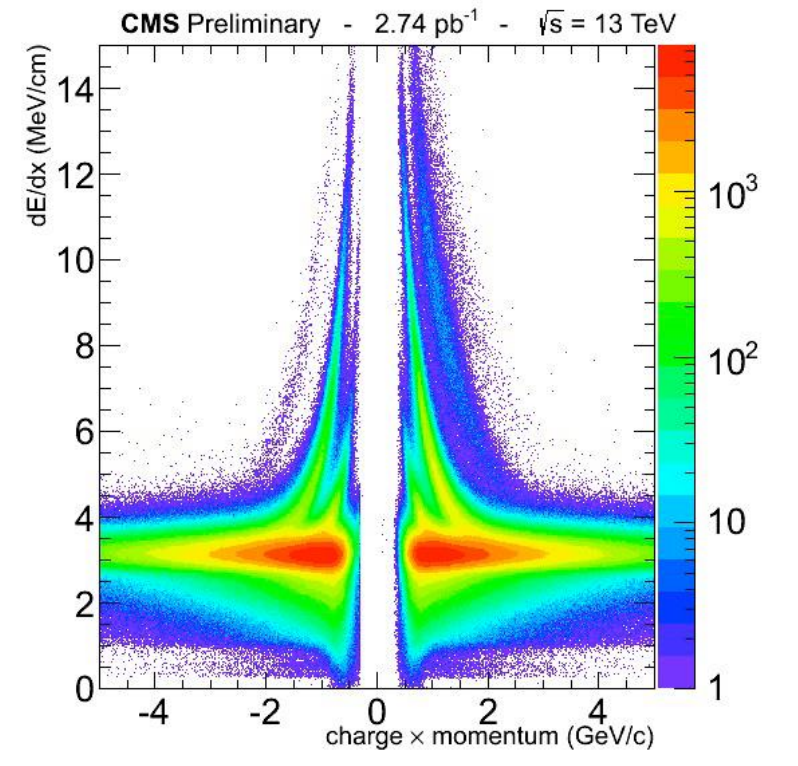
How CMS prepared for Run 2

- Main challenge: mitigate the effects of radiation on the performance of the Tracker
  Addressed by equipping it to operate at low temperatures (down to -20°C). Cooling plant and cooling distribution were modified to prevent condensation.
- Planning ahead: Central beampipe was replaced by a narrower one in preparation for the installation in 2016-'17 of a new Pixel Tracker that will better measure the momenta and points of origin of charged particles.
- Better muon system: A fourth measuring station was added to each muon endcap, in order to maintain discrimination between low-momentum muons and background as the LHC beam intensities increase. This was complemented by two 125-ton shielding at each end of detector, reducing neutron backgrounds.
- Better luminosity measurement: A luminosity-measuring device, the Pixel Luminosity Telescope, was installed on either side of the collision point around the beam-pipe.
- Other improvements:
  - Photo-detectors in the hadron calorimeter were replaced by better-performing designs, moving the muon readout to more accessible locations for maintenance; a first stage of a new hardware triggering system was installed.
  - The software and computing systems underwent a significant overhaul during the shutdown to reduce the time needed to produce analysis datasets.

Tracker Performance

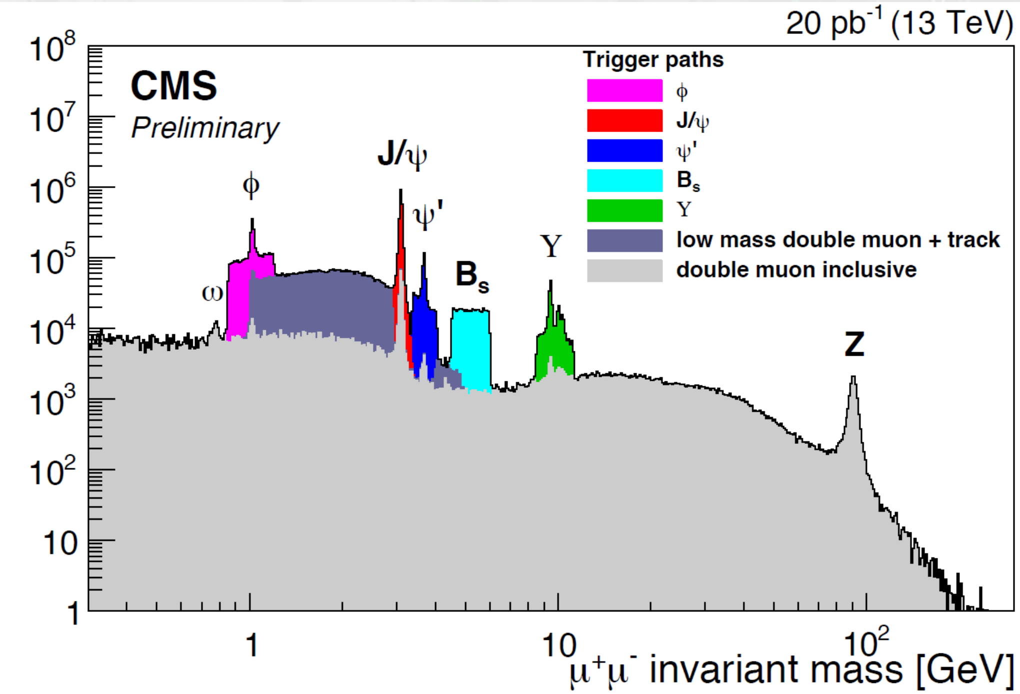
Deuteron, proton and Kaon bands can be distinguished by dE/dx in silicon. Note asymmetry in charge due to +2 initial state





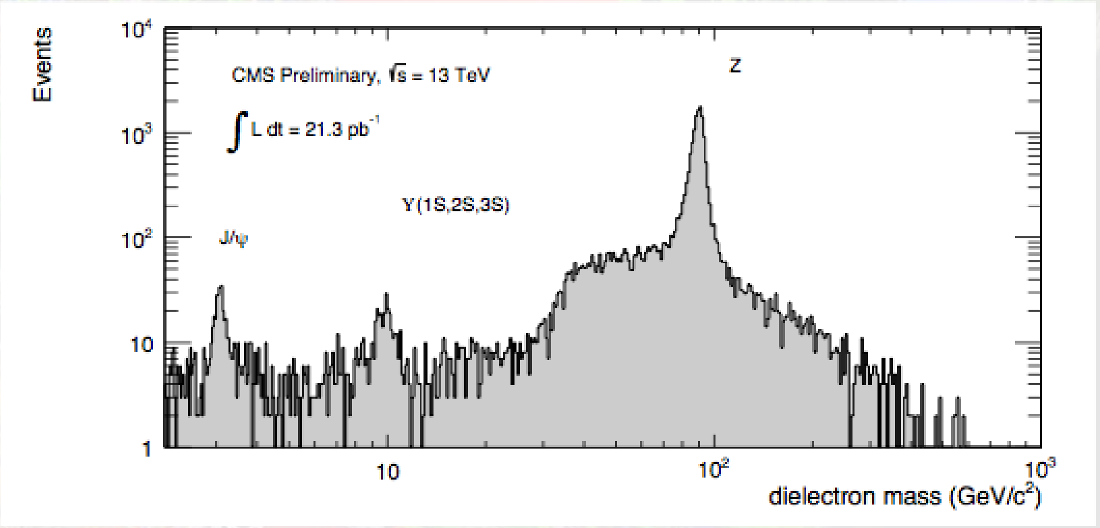
The mass of tagged pion pairs fitted with a double Gaussian gives m=497.68 MeV
→very good calibration
[PDG: 497.614 ± 0.006 MeV]

Dilepton resonances



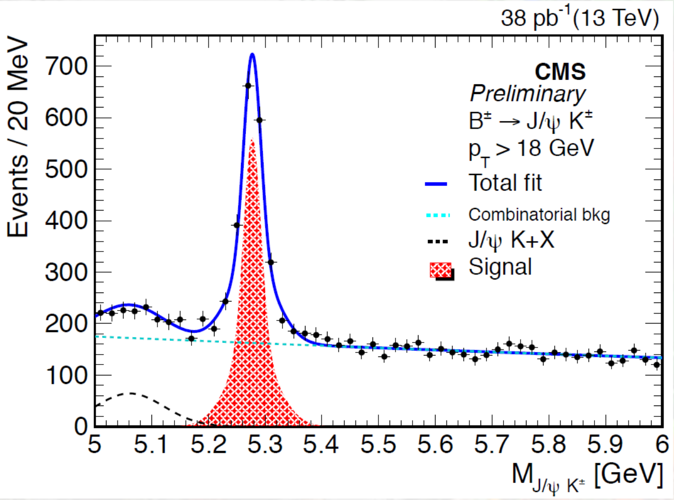
The dimuon mass spectrum shows the usual spectacular landscape of resonances and it also describes the special triggers we will use for B physics measurements

The dielectron mass spectrum comes from electron triggers requiring p_T>10 GeV



Other resonances

CMS has already restarted its rich B physics program. J/ψ triggers provide the usual avenue to clean and well-understood B signals

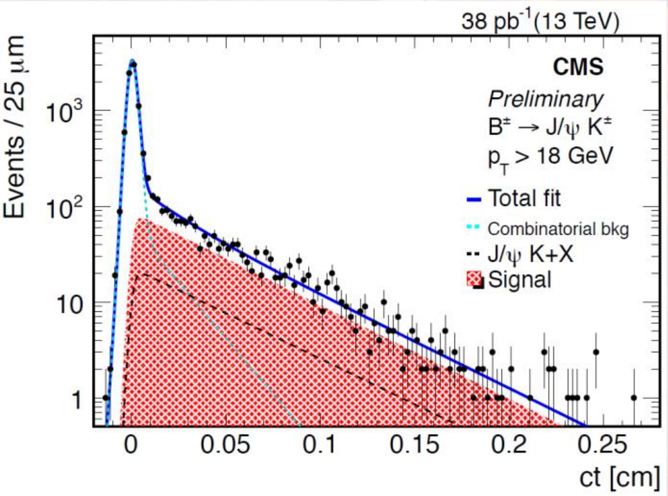


A $B^{\pm} \to J/\psi K^{\pm}$ signal is obtained from an inclusive $J/\psi \to \mu\mu$ trigger

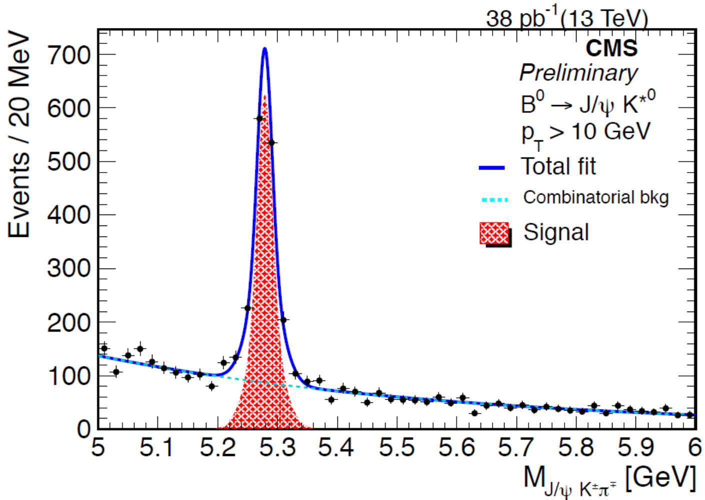
3-body mass: 5.277 ± 0.001(stat.) GeV

[PDG: M_B=5279.26 ± 0.17 MeV]

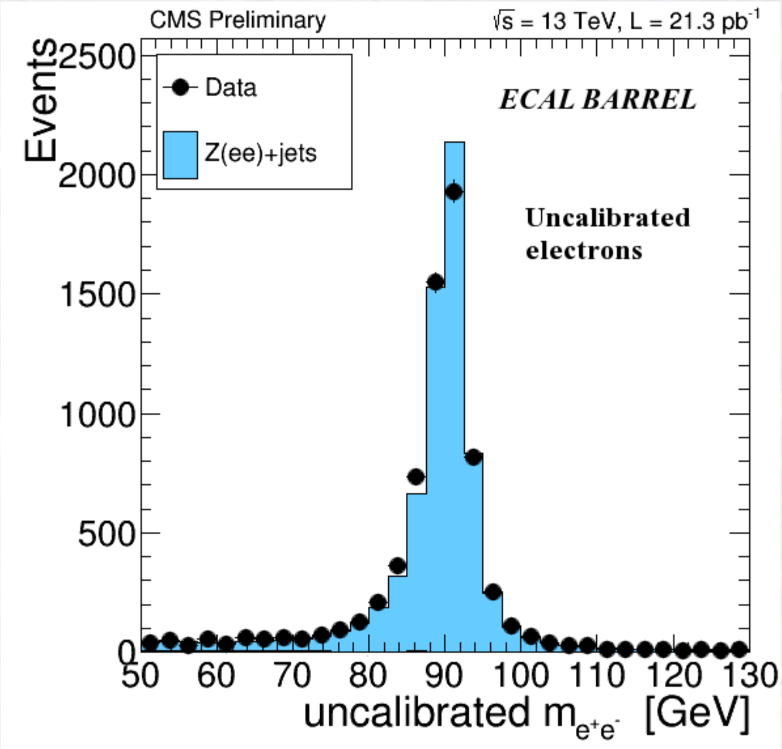
A $B^0_s \to J/\psi\phi$ signal can be reconstructed from a displaced J/ψ plus track trigger



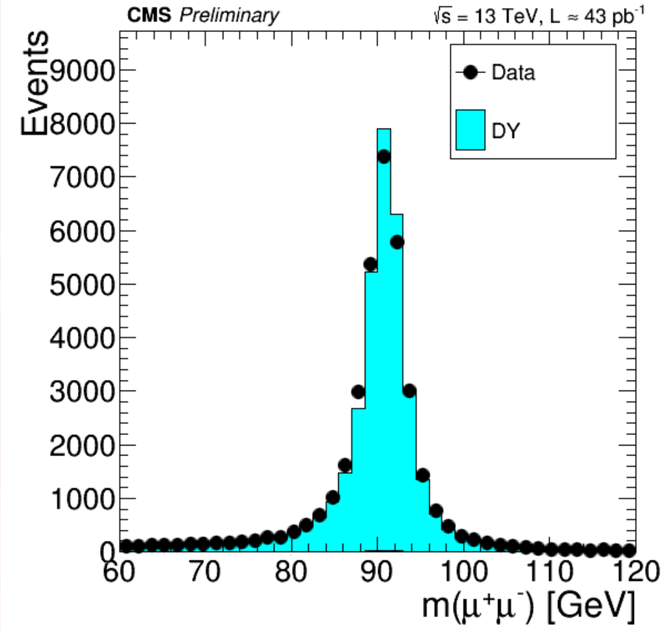
4-body mass: 5369 ± 1(stat.) MeV [PDG: 5366.7 ± 0.4 MeV]



Z bosons – our standard candles

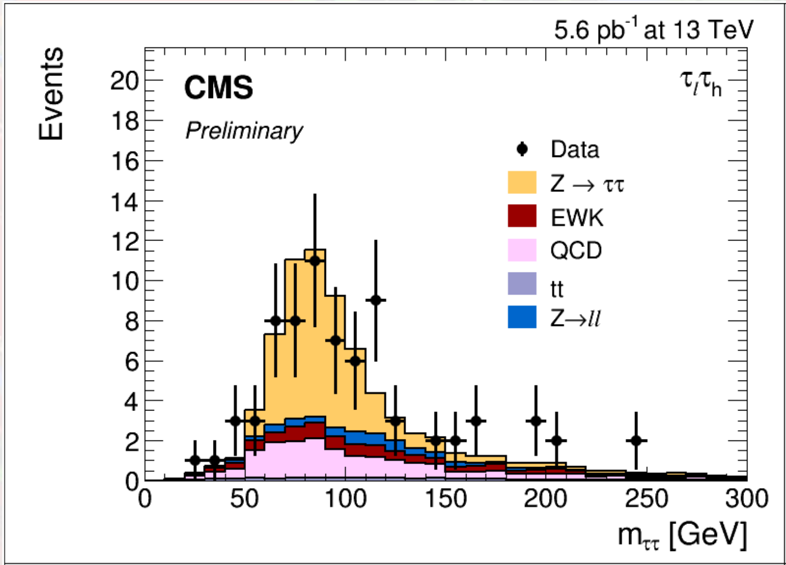


Z → μμ

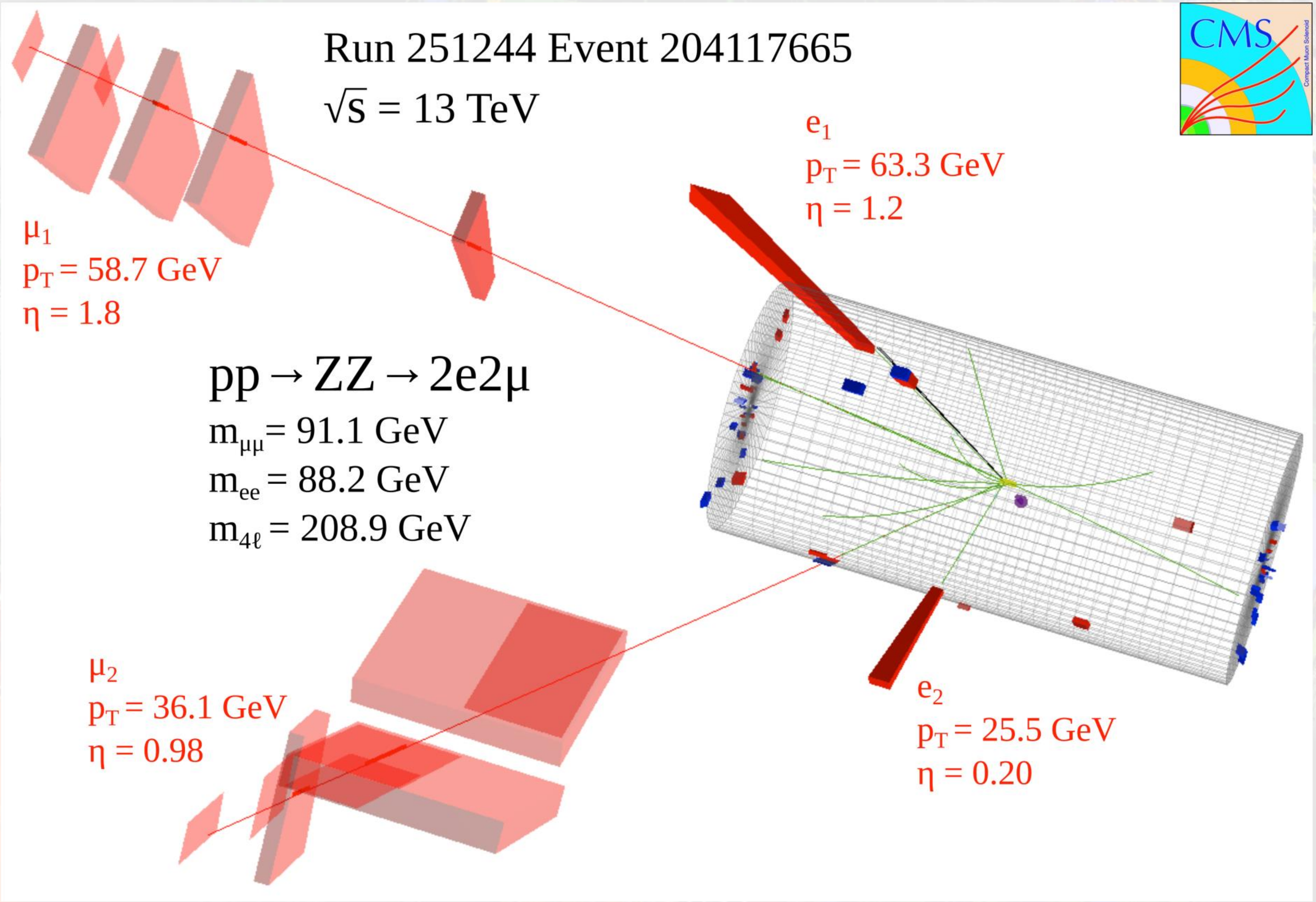


Z → ee data nicely match MC shape

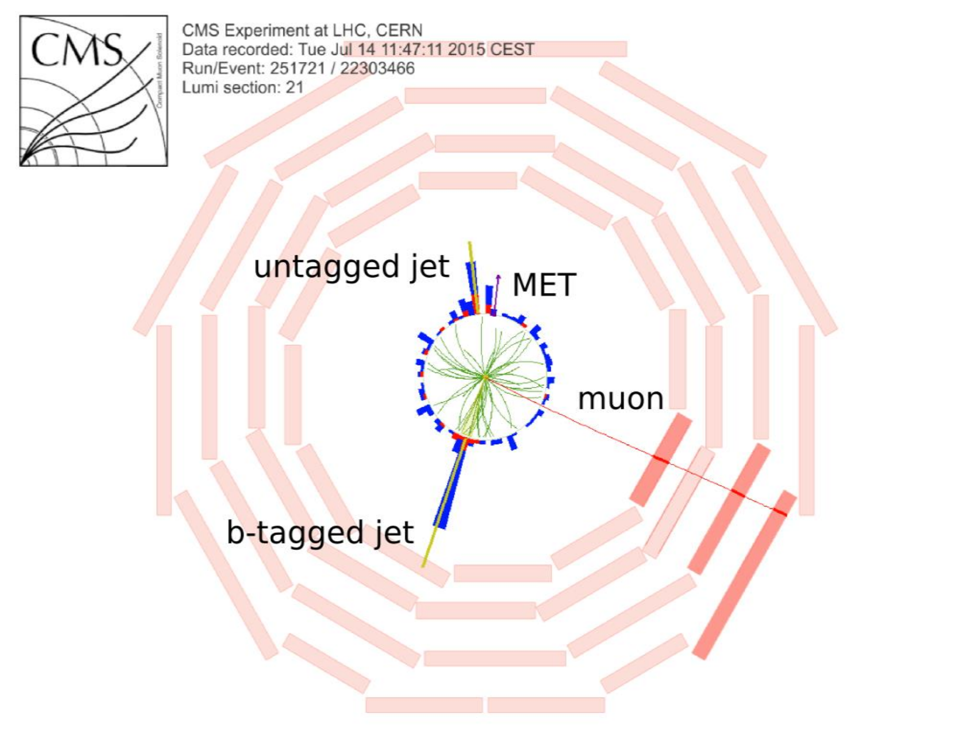
Z → ττ easily seen with standard cuts

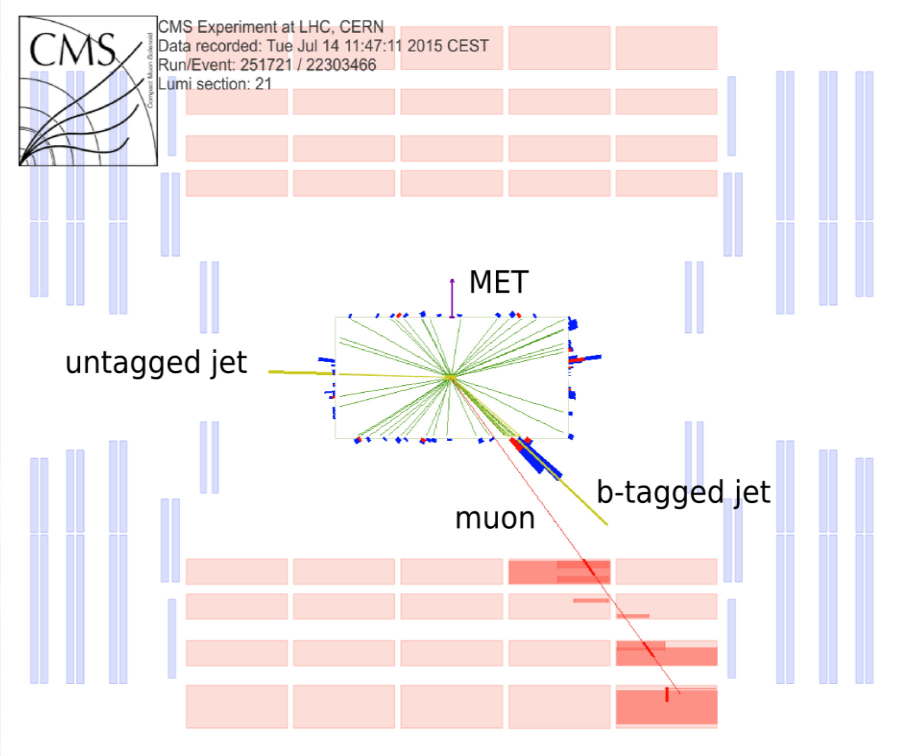


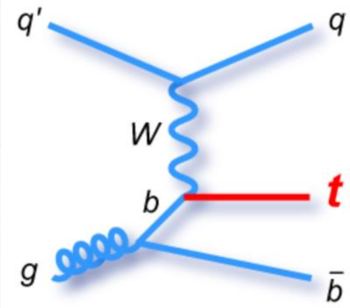
First diboson signals: a ZZ → eeμμ



Towards Single Top (t-channel)





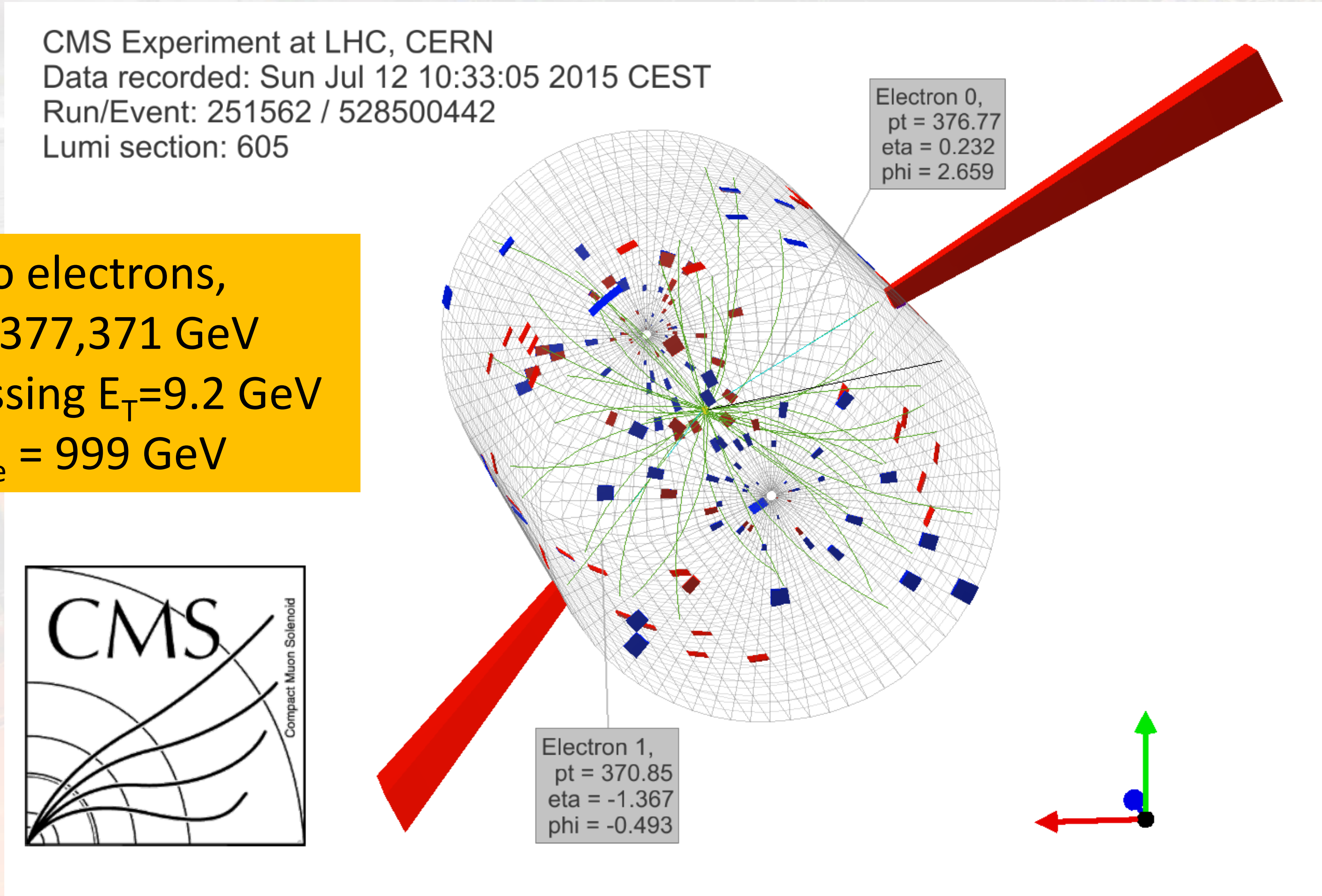


The event has one isolated muon, missing E_T, and one b tagged central jet, plus one further forward jet

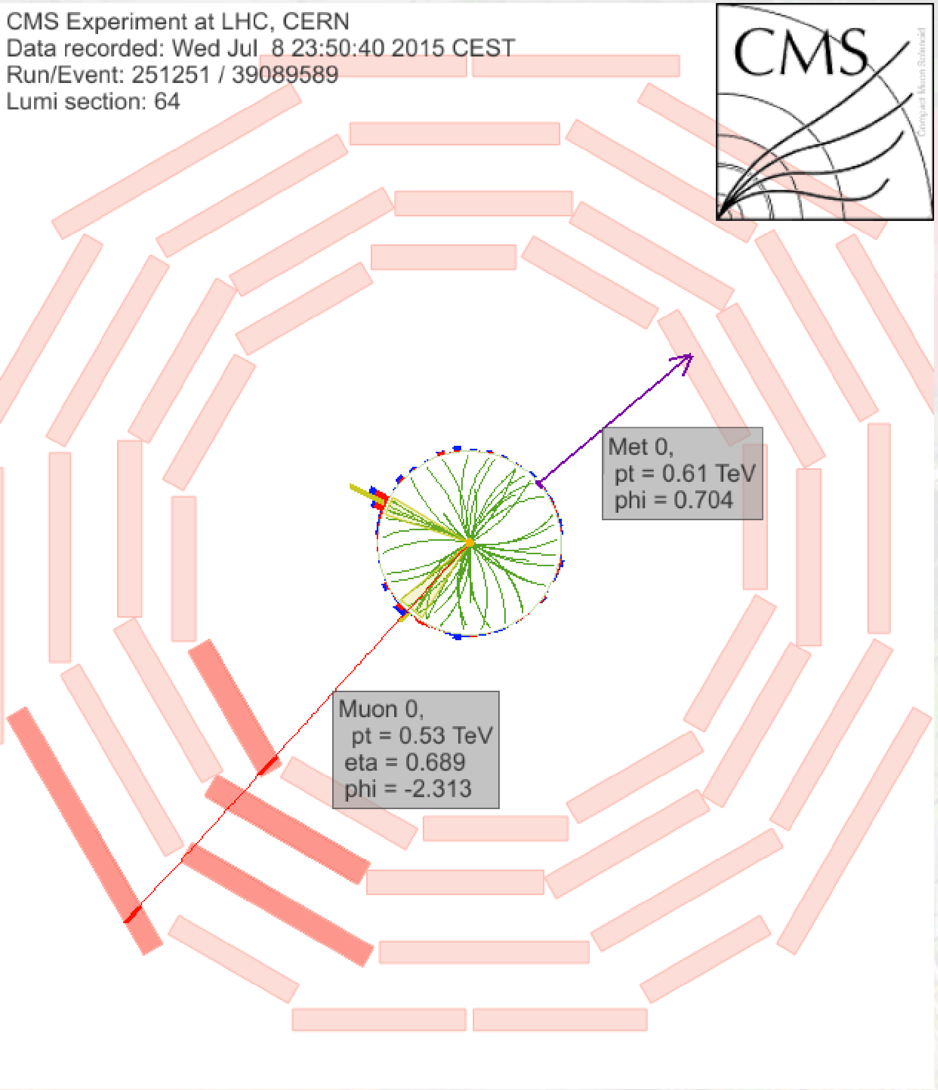
3-body mass compatible with top decay (m= 177 GeV)

A 1-TeV Electron - Positron Candidate

Two electrons,
p_T=377,371 GeV
Missing E_T=9.2 GeV
M_{ee} = 999 GeV



M_T=1.1 TeV μν event



Here is a nice event which will end up in every W' search set:

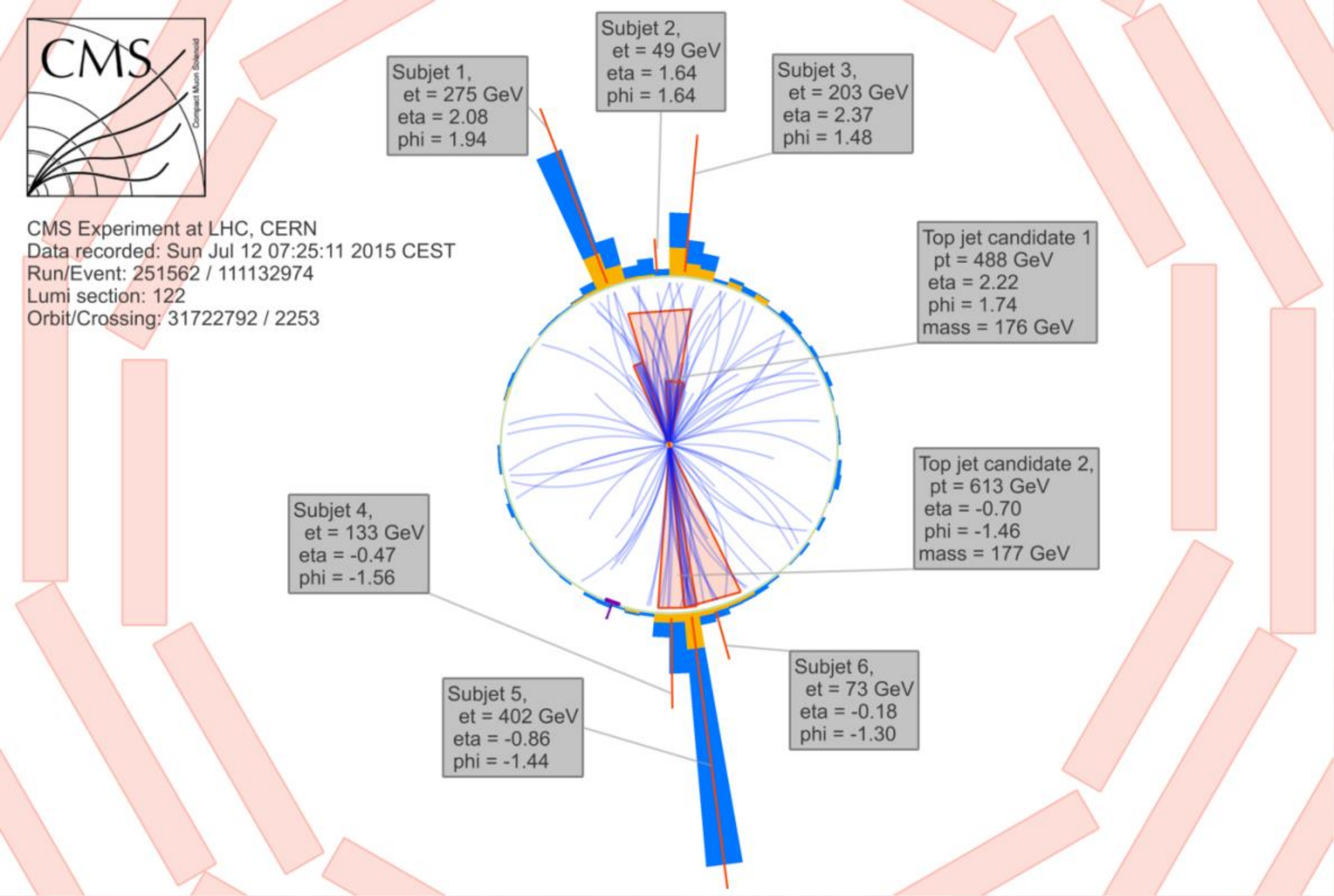
Muon p_T = 530 GeV

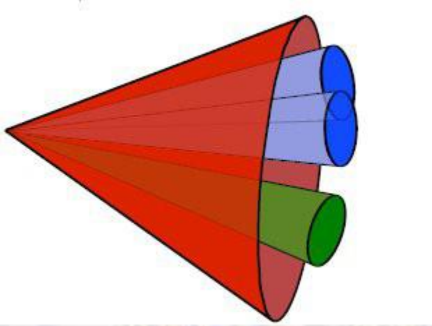
Missing E_T = 620 GeV

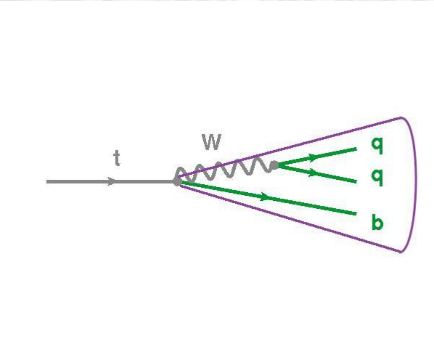
Transverse mass =1.1 TeV

One such event is expected by SM sources with m_T>700 GeV in the data analyzed so far

Boosted Top Pair Candidate





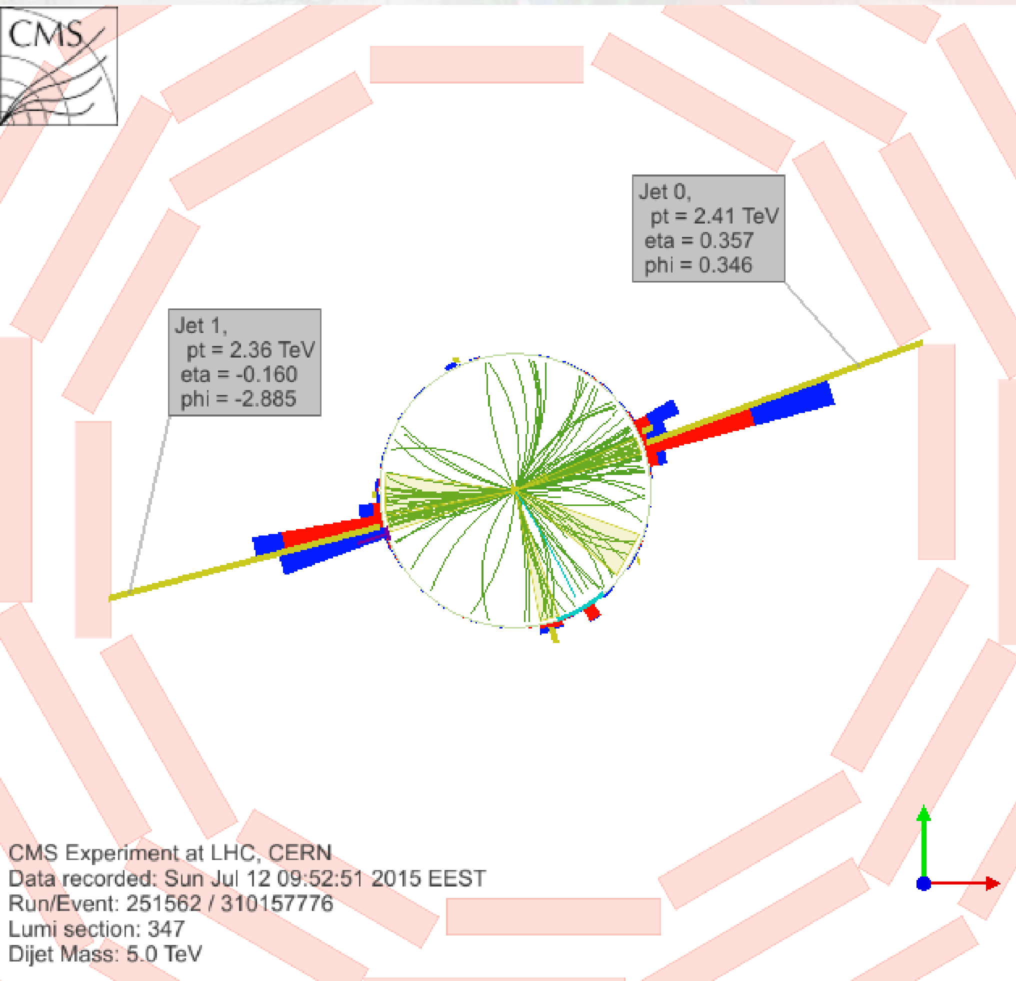


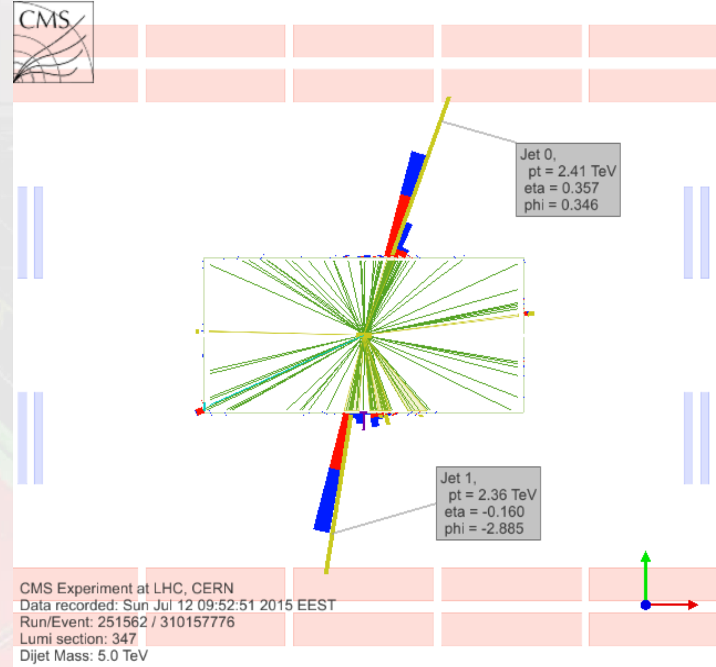
Top jet 1: m = 177 GeV, p_T = 613 GeV

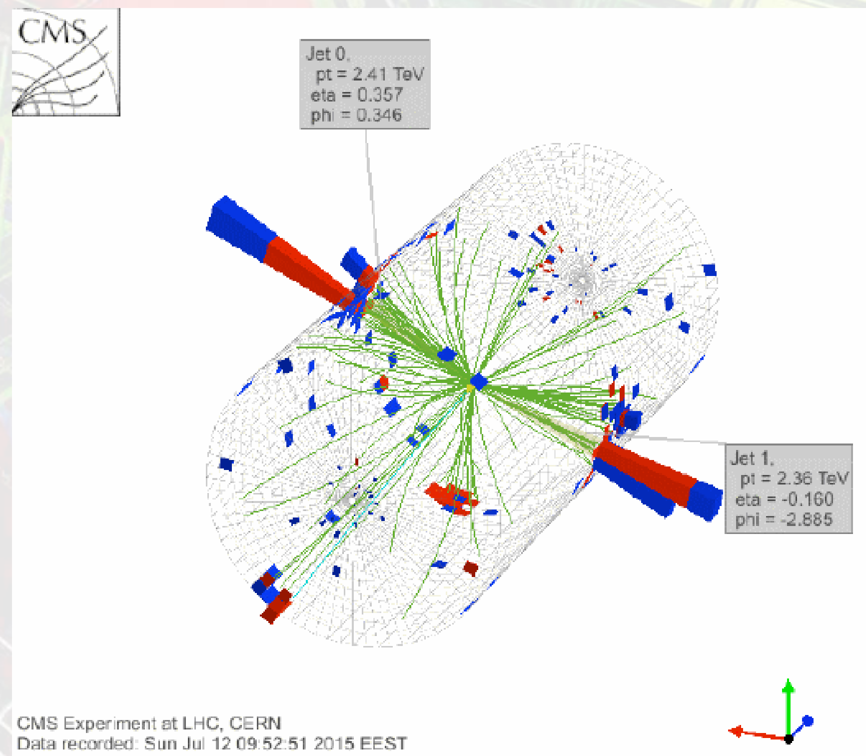
Top jet 2: m = 176 GeV, p_T = 488 GeV

Combined top pair mass 2491 GeV

A dijet event with M_{jj} = 5.4 TeV







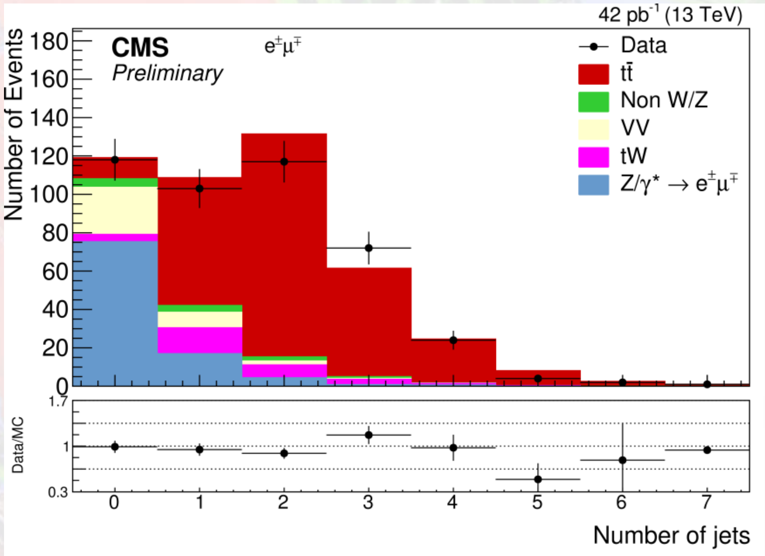
Top production cross section at 13 TeV

- The top pair production cross section has been measured with 42/pb of Run 2 data at 13 TeV by using dilepton candidates in the **eμνν+jets** final state collected by a eμ trigger

- Offline, events are retained if leptons have p_T>20 GeV and $|\eta|$<2.4, and are isolated ($I^{e}_{0.3}$<0.11, $I^{\mu}_{0.3}$<0.12)
- Anti-k_T clustered jets are counted if they have p_T>30 GeV and $|\eta|$<2.4
- The event selection includes a requirement N_{jets}>=2

The signal is modeled with the POWHEG 2.0 NLO generator interfaced with PYTHIA 6 for hadronization.

The signal to noise ratio for events with N_{jets}>=2 is already good enough that no b-tagging is necessary to further reduce backgrounds



Results

Systematic uncertainties include the knowledge of integrated luminosity (12%, from beam-beam scans), trigger (5%) and lepton ID (4%), and jet energy scale (3%)

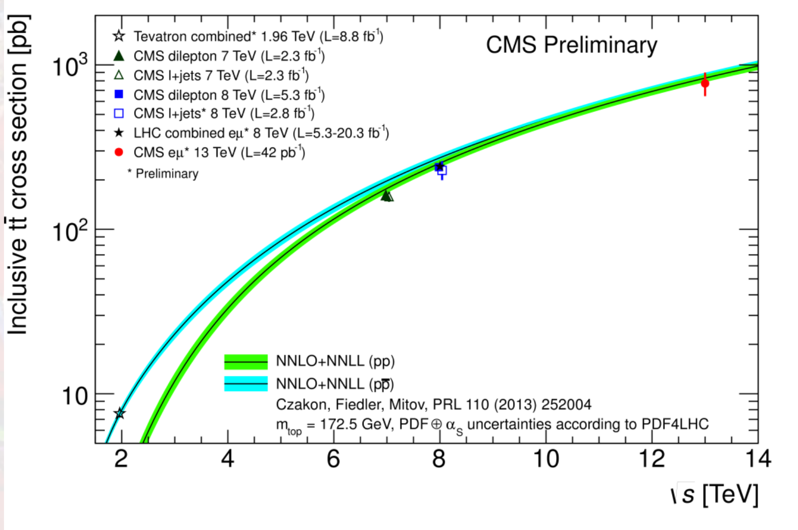
Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	60	7.7
Trigger efficiencies	39	5.0
Lepton efficiencies	33	4.3
Lepton energy scale	<1	≤ 0.1
Jet energy scale	20	2.6
Jet energy resolution	<1	≤ 0.1
Pileup	2.8	0.4
Scale (μ_F and μ_R)	1.5	0.2
$t\bar{t}$ NLO generator	15	1.9
$t\bar{t}$ hadronization	14	1.8
PDF	12	1.5
Single top quark	14	1.8
VV	3.5	0.5
Drell–Yan	3.9	0.5
Non-W/Z leptons	8	1.0
Total systematic (no integrated luminosity)	62	8.0
Integrated luminosity	93	12
Total	126	16.4

Source	Number of events $e^{\pm}\mu^{\mp}$
Drell–Yan	6.4 ± 1.2
Non-W/Z leptons	8.5 ± 4.3
Single top quark	10.6 ± 3.4
VV (V = W or Z)	2.6 ± 0.9
Total background	28.1 ± 5.7
$t\bar{t}$ dilepton signal	206.7 ± 16.0
Data	220

The tt cross section is extracted from the event counts, once backgrounds are accounted for.

Result: **σ_{tt}= 772 ± 60 (stat) ± 62 (syst) ± 93 (lumi) pb**, with a total relative uncertainty of 13.5%.

This measurement is consistent with the SM prediction ($\sigma^{NNLO+NNLL}_{tt} = 832^{+40}_{-46}$ pb), valid for a top quark mass of 172.5 GeV



Concluding Remarks

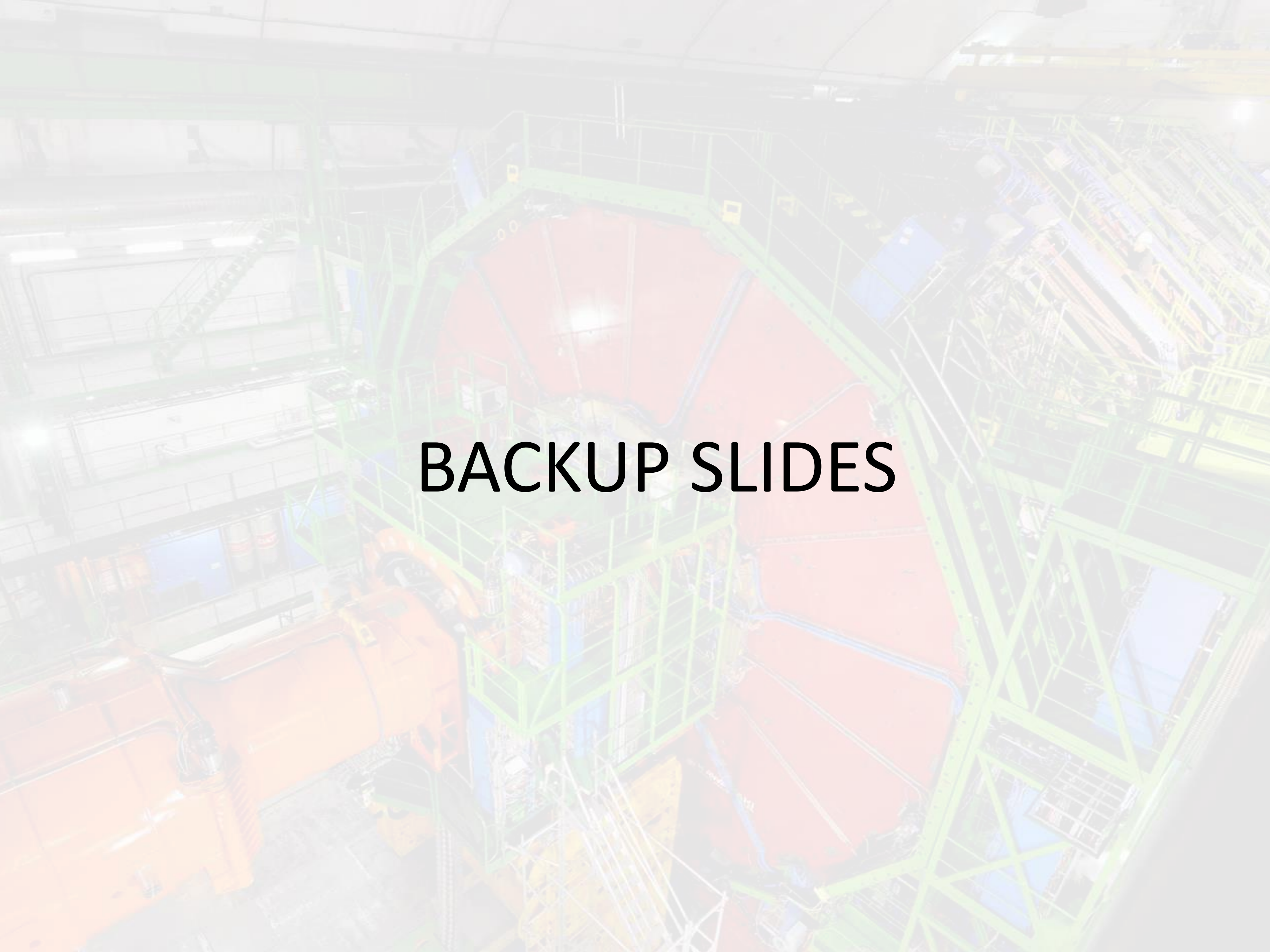
- Still many very interesting results are being published by CMS using data from the 2011-2012 LHC Run 1
  - **Higgs boson:** detailed studies
  - **Top physics:** precise measurements break new ground
  - **Electroweak physics**: SM tests have moved to multi-boson production and to very detailed properties
  - And more:
    - Constraints to a large number of NP models have come from a long list of searches
    - B physics, Exotica, Heavy Ion Physics, QCD – not discussed here

- After the long shutdown the new energy and luminosity of LHC are going to yield sensitivity to higher energy scales in Run 2

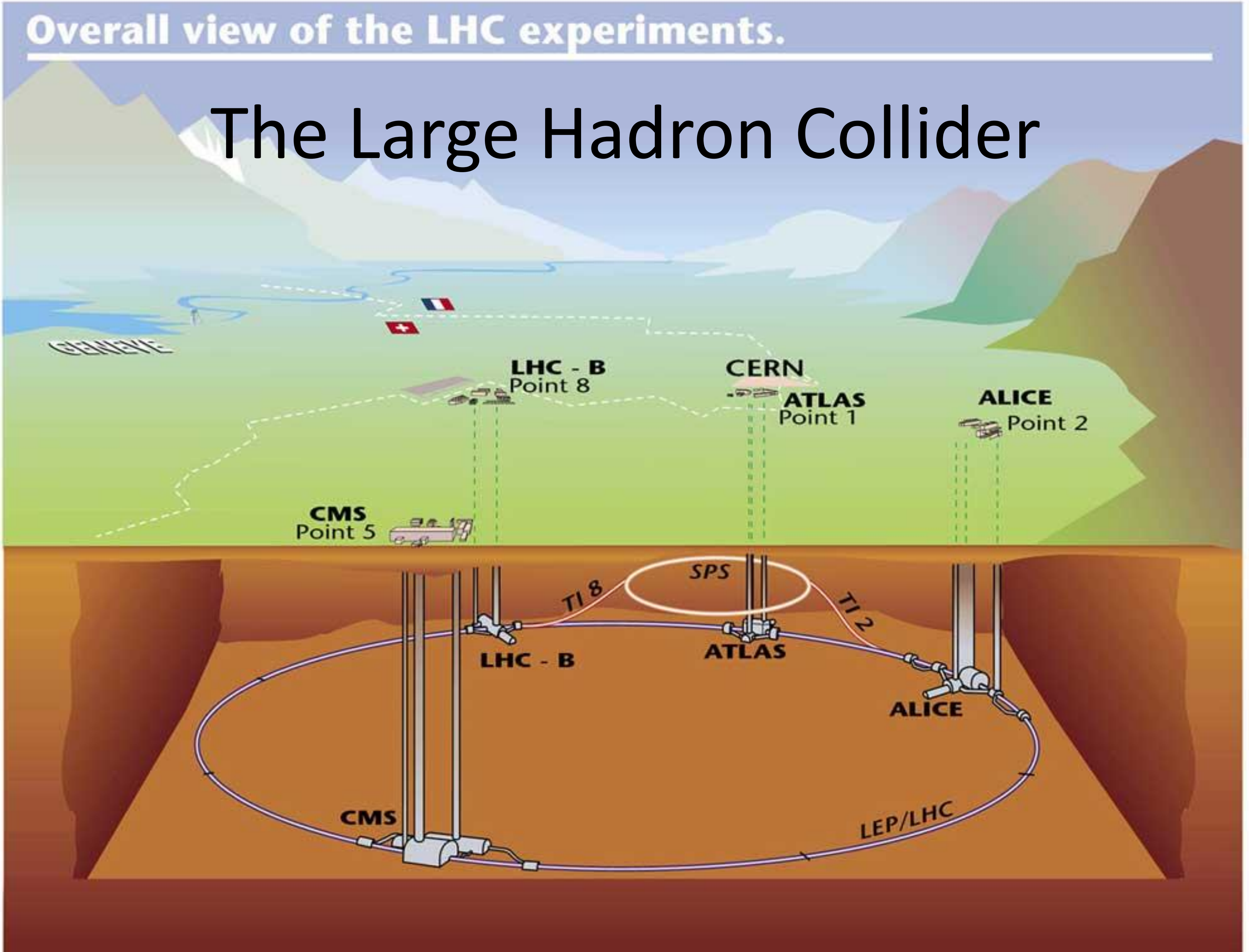
- **CMS is ready and first results at 13 TeV have already started to trickle out**

- The next step is to collect enough luminosity to improve our measurements of the Higgs properties and couplings, and to search for previously unaccessible resonances.

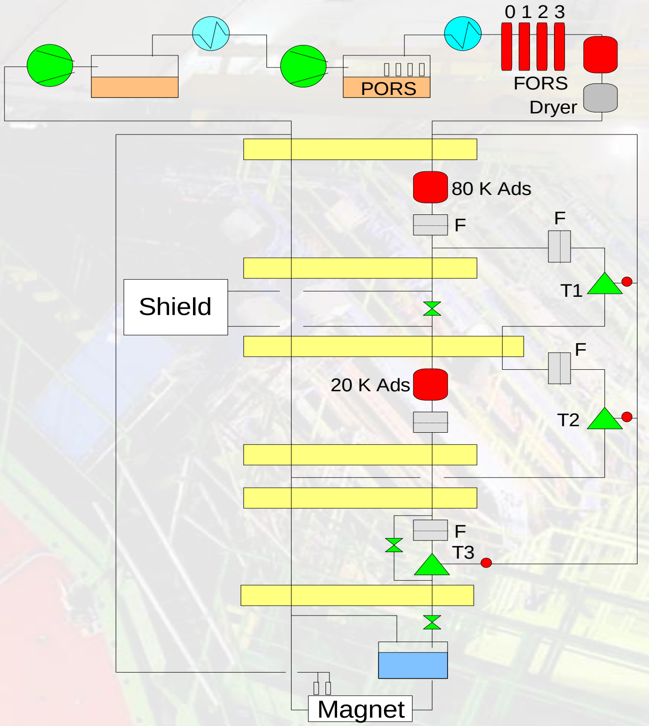
BACKUP SLIDES



The Large Hadron Collider



Magnet Cryogenics

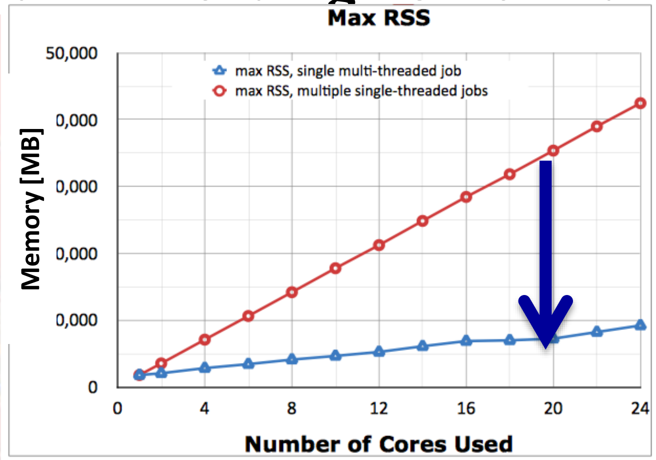


- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.
- Inefficiencies of the oil separation system of the compressors for the warm Helium required several interventions and delayed the start of routine operation of the cryogenic system.
- The data delivered during the first two weeks of LHC re-commissioning with beams at low luminosity have been collected with B=0
- Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual.
- A comprehensive program to re-establish its nominal performance is underway. These recovery activities for the cryogenic system will be synchronized with the accelerator schedule in order to run for adequately long periods.

DAQ & Computing & Offline

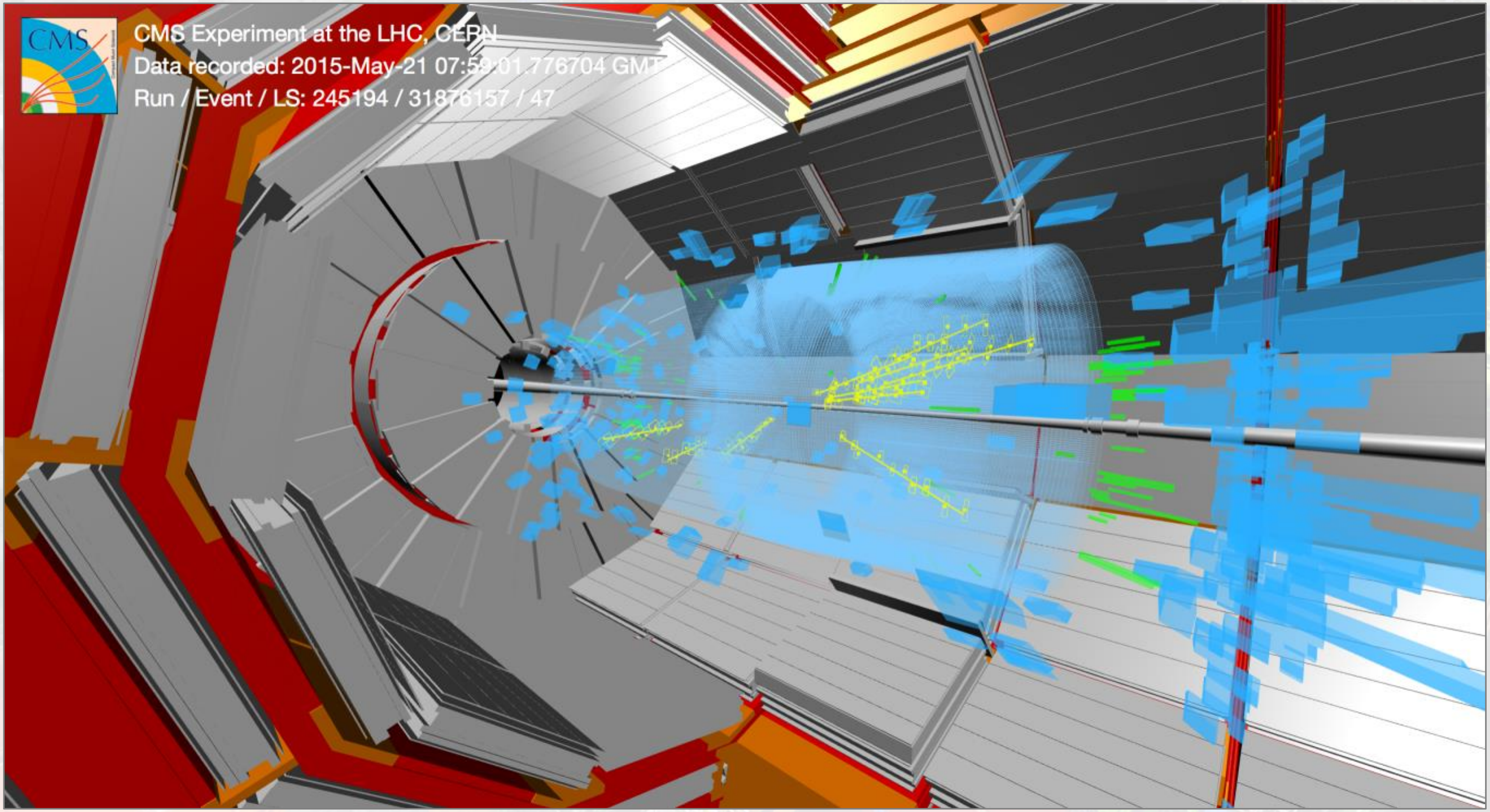
- New DAQ2 concept realized for the online part
- Replaced all 500 DAQ Computers, and 1/2 of the High Level Trigger (HLT) CPUs → increase budget to 0.3s/event from 0.2s/event
- HLT Farm now also used for production and other offline tasks
- Move to multi-threading with multi-core queues at CERN and Tier-1 centers
- New, more flexible and efficient workflow and data management systems

Multi-threading now standard



- Improvements in Distributed Analysis
- Faster event reconstruction
- New miniAOD data format for many physics object improvements:
  - compact high level data objects (30-50 kb/event) → gain factor ~10
  - covering needs of mainstream analyses → avoid duplications

First Physics Collisions @ 13 TeV !



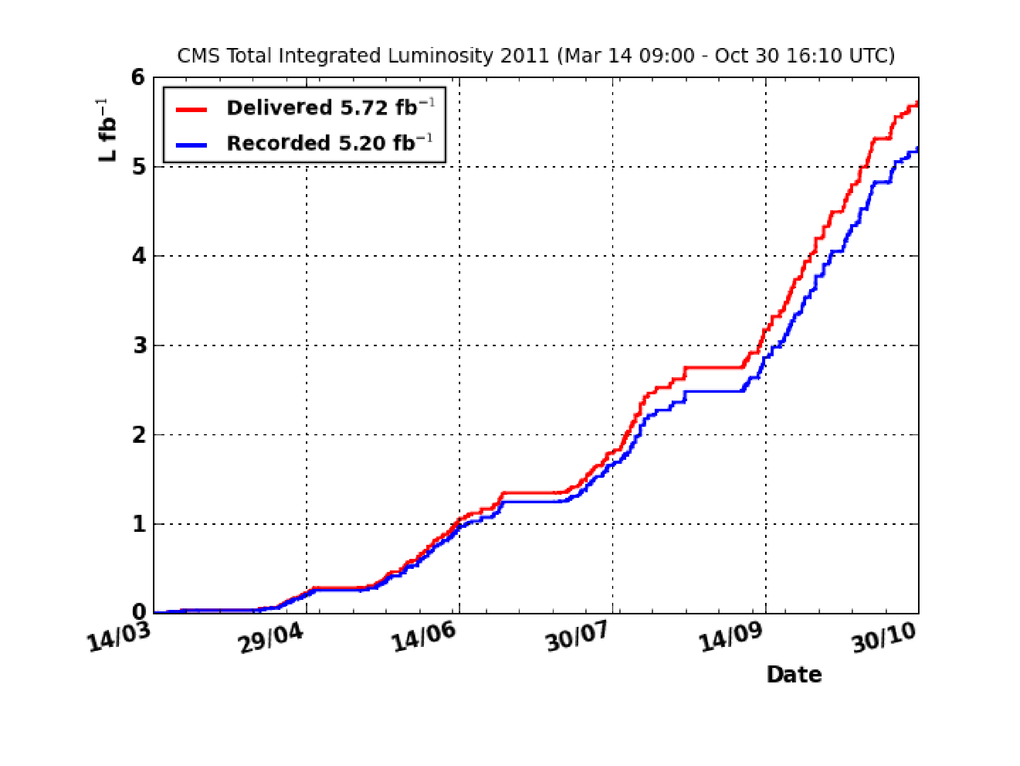
Review of the 2011 Run

- LHC delivered high-quality, high-intensity data in 2011
- Smooth running conditions, smooth curve in instantaneous luminosity
  - Allowed experiments to gradually understand triggers / tune them / tighten thresholds
  - Optimal turnaround in terms of studies of high-xs phenomena, then "rediscovery" of known EW physics, and finally searches of rare processes
  - Also collected small dataset of pp collisions at 2.76 TeV for xs comparisons to PbPb data
  - End-of-year heavy-ion running (Pb-Pb, 2.76 TeV/nucleon, 150/µb) allowed to extend measurements in high-energy nuclear collisions

5.72 fb^{-1} delivered by LHC

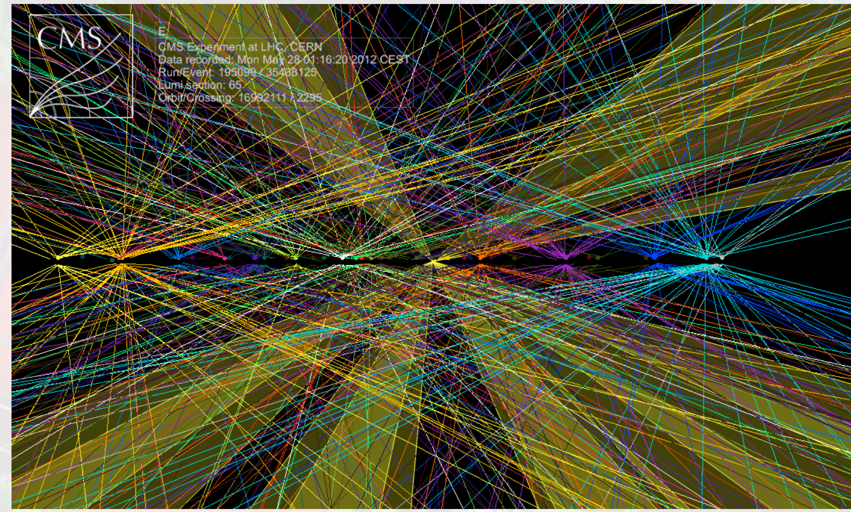
5.2 fb^{-1} recorded by CMS.

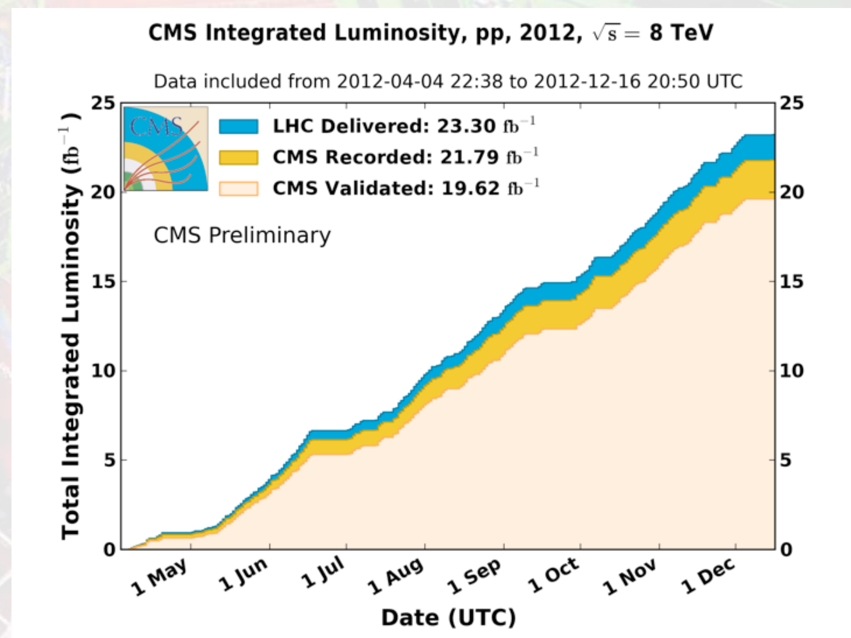
Average fraction of operational channels per subsystem >98.5% in CMS



The 2012 Run

- Following the 5/fb collected at 7 TeV in 2011, CMS recorded 21.8/fb of 8-TeV proton-proton collisions in 2012
  - running with max number of filled bunches (1380) at 50 ns spacing
  - LHC delivered luminosity: 23/fb → surpassed 15/fb goal by 50%
- The high instantaneous luminosity results in 20-50 pp interactions per bunch crossing
  - Affects jet reconstruction and energy measurement, missing Et resolution, tracking efficiency, lepton ID
  - All these effects are mitigated by smart algorithms that exploit the detector redundancy
  - Pile-up effects always included in simulation and accounted by reweighting methods
- During first months of 2013, 18/nb of asymmetric 4+1.58TeV/N p-Pb collisions also collected for HI studies

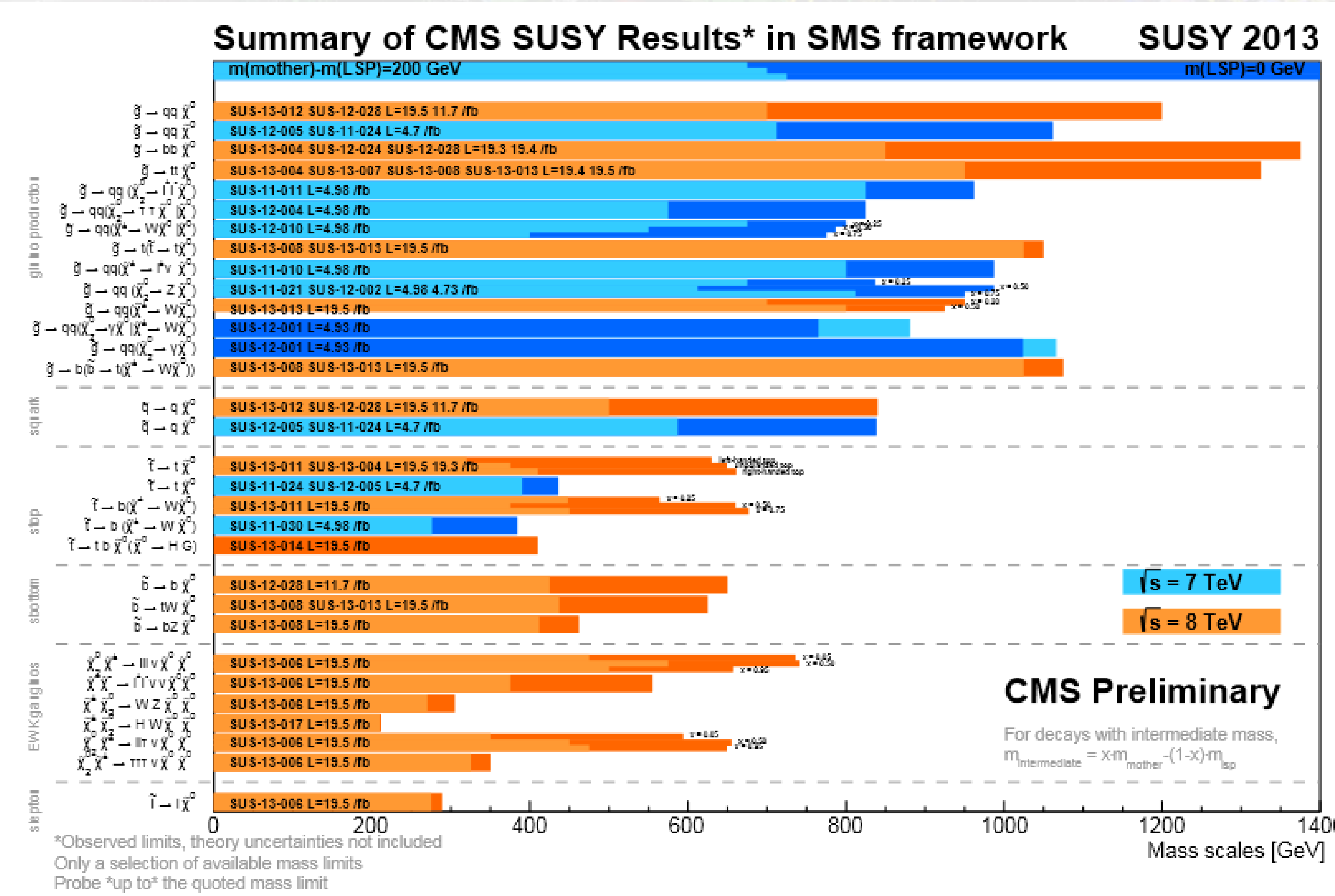




In the summary below, some of the searched signatures are compared in the mass scale they reach to, in simplified models with RPC

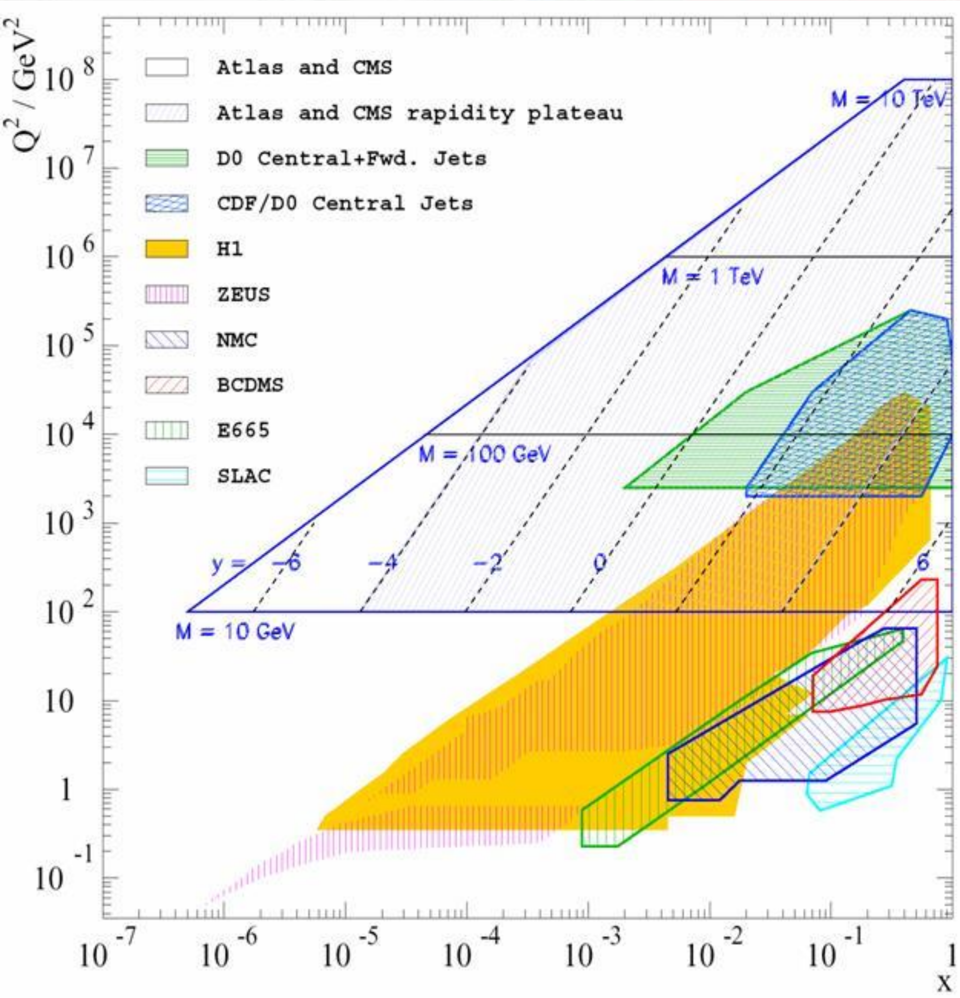
M(LSP)=0 (dark shading), M-M(LSP)=200 GeV (light shading)

Note: Theory uncertainties not included here



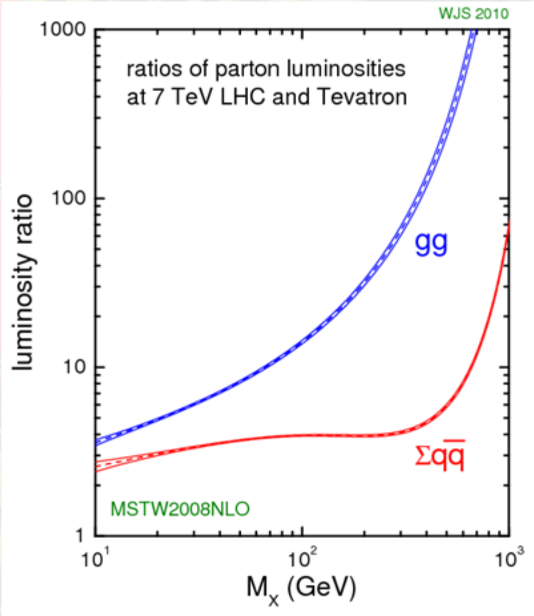
PDF and Parton Luminosities

Kinematical range spans largely unknown regions of (x,Q^2) → PDF uncertainties



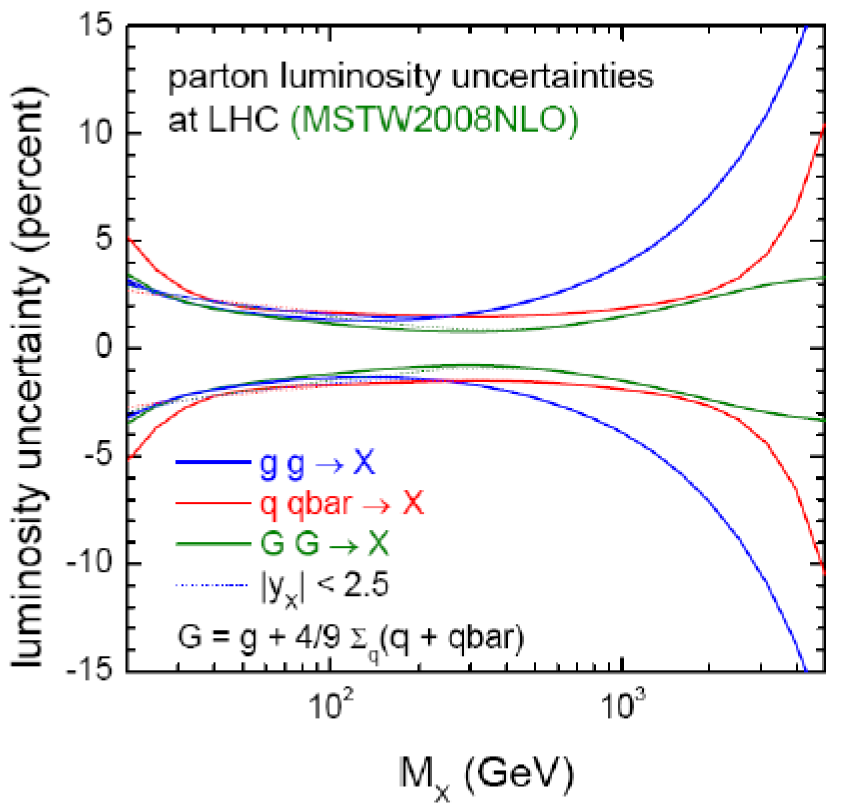
Gluon luminosity grows much faster than quark luminosity below effective masses of 500 GeV

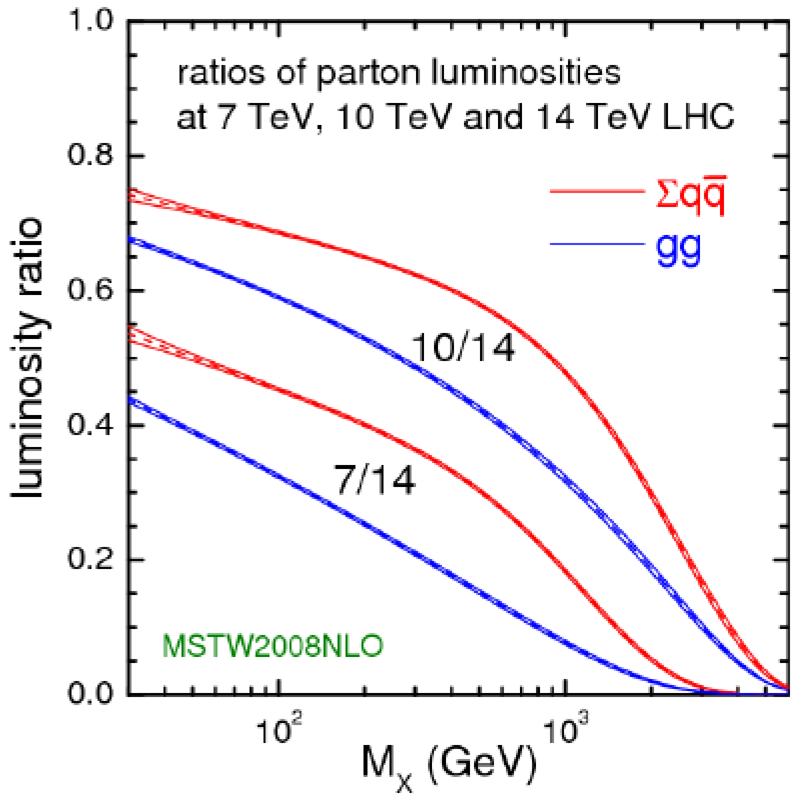
The implication for searches is generally a strong advantage WRT lower-energy machines (TeVatron) in production of massive particles, particularly at high end



Parton Luminosities

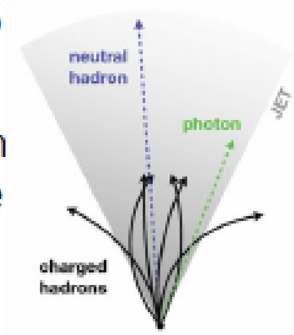
- The PDF uncertainties have a large impact in the prediction of cross sections in the low- and high- “effective mass” domains
- Running at higher energy rapidly improves the reach – at M=1 TeV the improvement of 10 over 7 TeV cms energy is already a factor of two for q-qbar annihilation processes





Jet Reconstruction & Energy Scale Calibration

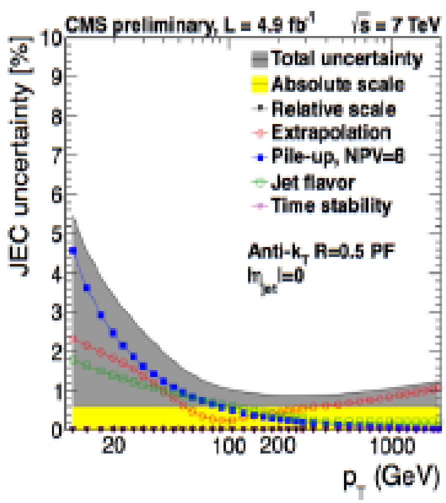
- **Anti-k_T clustering algorithm** : Infrared and collinear safe. Used with R=0.5 and 0.7.
- **Particle Flow Jets (PF Jets)** : The CMS global event reconstruction (PF) is an event reconstruction technique which reconstructs and identifies all stable particles in the event, through the optimal combination of all CMS sub-detectors. PF Jets are the output of anti-k_T on the reconstructed particles.

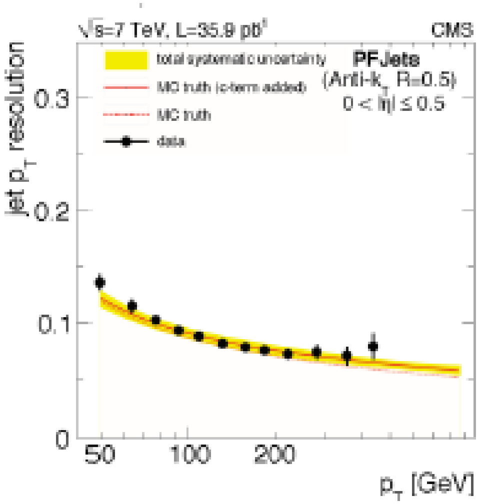


- For the Jet energy scale calibration CMS adopted a Factorized approach.

Calibrated Jet = Raw Jet × Offset Correction (pile-up) × Relative Correction (vs η) × Absolute Correction (vs p_T)

CMS :
JME-10-003
JME-10-010
JINST 6 2011
DP2012-006





Jet p_T resolution: ≈9% at 100 GeV

The Future of the LHC