CMS

2.5 Experiments:

Still active on Run1 analysis

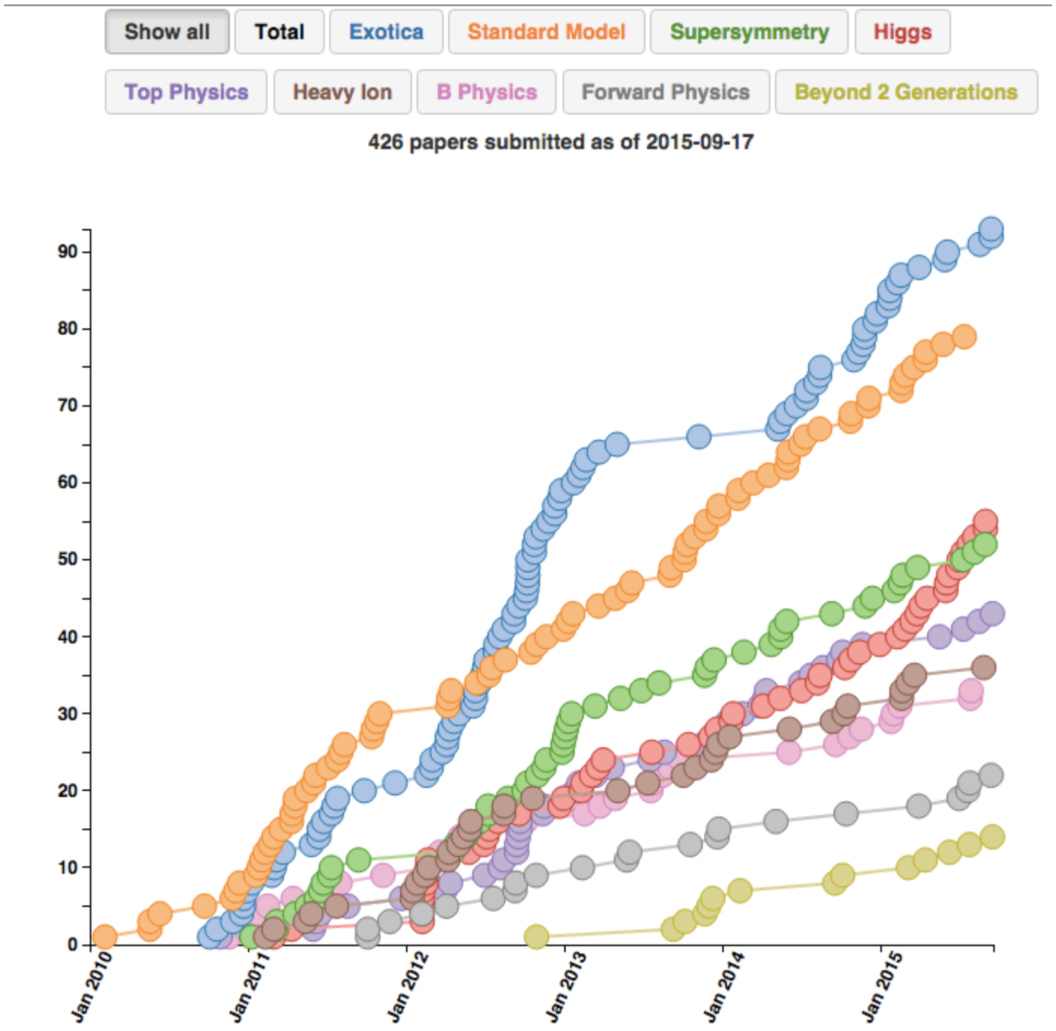
Working on upgrades of the present detector (completed in 2018)

Defining the future CMS to explioit the High Lumi LHC after 2025

Summary of last 6 months

- Steady production of Run1 results
  - rate ~ 3 papers/week
- Preparations for Run2 and start of data taking: HW, SW and physics program exercised in Computing and analysis challenges; CMS was ready at LHC restart.
- However, problems in the Cryogenics systems have been affecting operation of the magnet.
- Progress in installation/execution of Phase1 upgrade
- Definition of the Phase 2 upgrade technical proposal : the LHC resource Review Board agreed with the recommendation from the CERN management to **approve our Upgrade program**

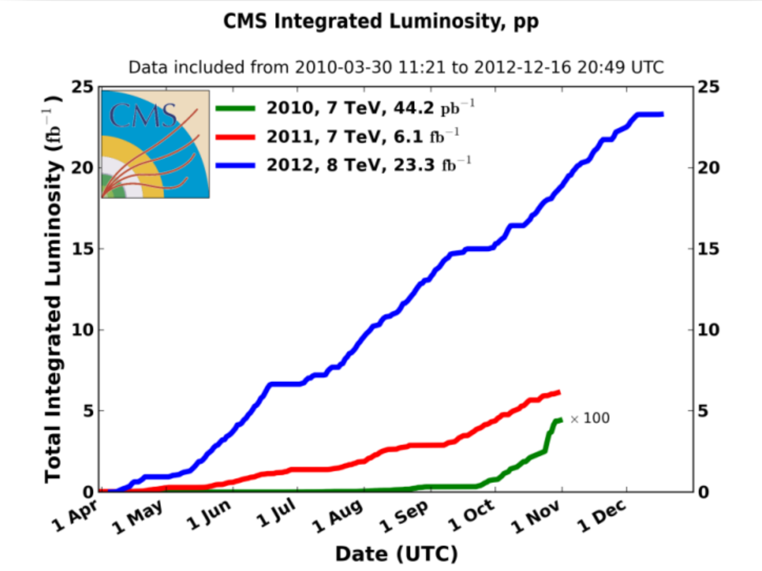
Run 1 data exploitation

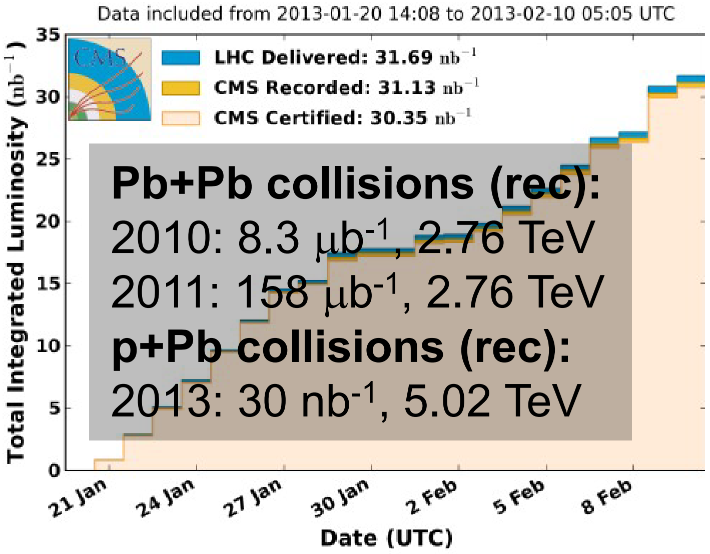


- Rate at ~3 papers /week
- 449 papers published
- Several new precision analyses: QCD, EWK, Top, B-Physics

The CMS experiment in Run I

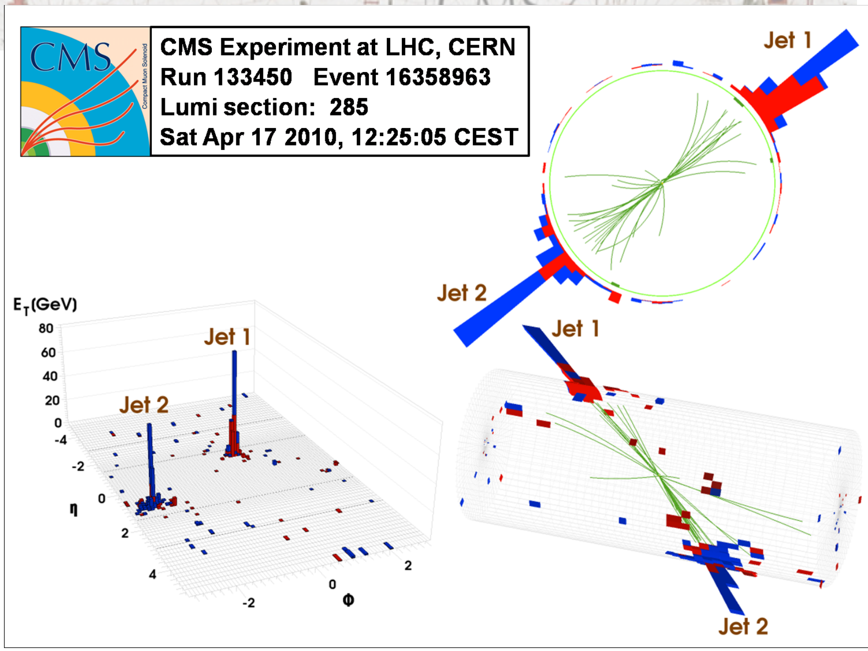
- An immense crop of Standard Model measurements
- Brout-Englert-Higgs mechanism: a historical achievement
- A leading role in Heavy Ion research

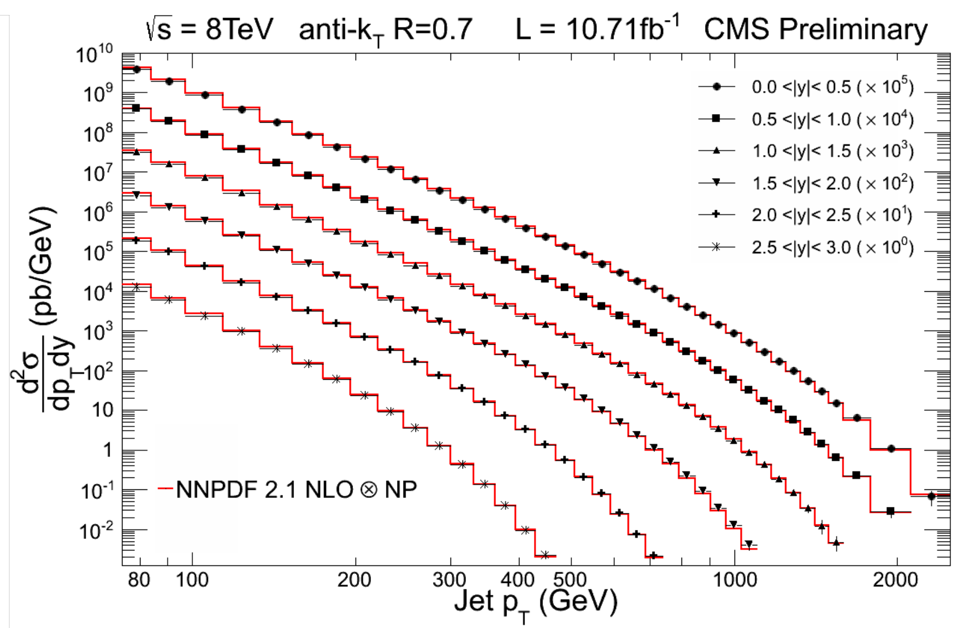




Pb+Pb collisions (rec):
2010: 8.3 μb^{-1}, 2.76 TeV
2011: 158 μb^{-1}, 2.76 TeV
p+Pb collisions (rec):
2013: 30 nb^{-1}, 5.02 TeV

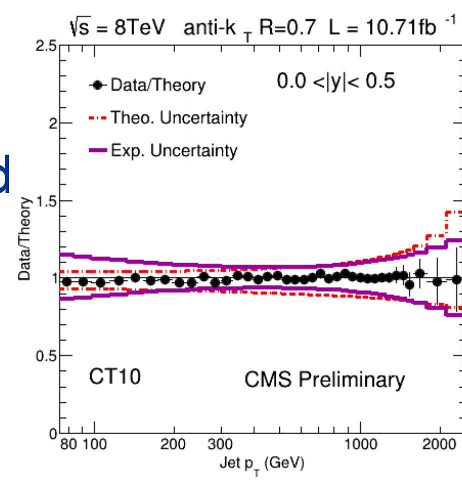
Jets





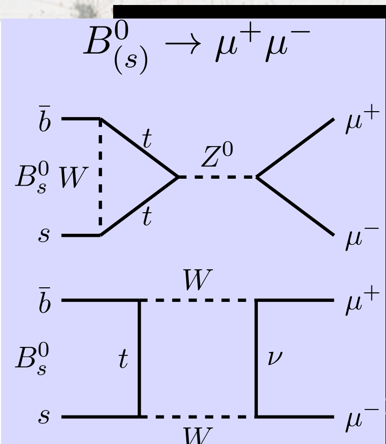
- **Probe the hard scatter:**
  - The hard scatter: jet P_T and η, dijet correlations, dijet mass,…

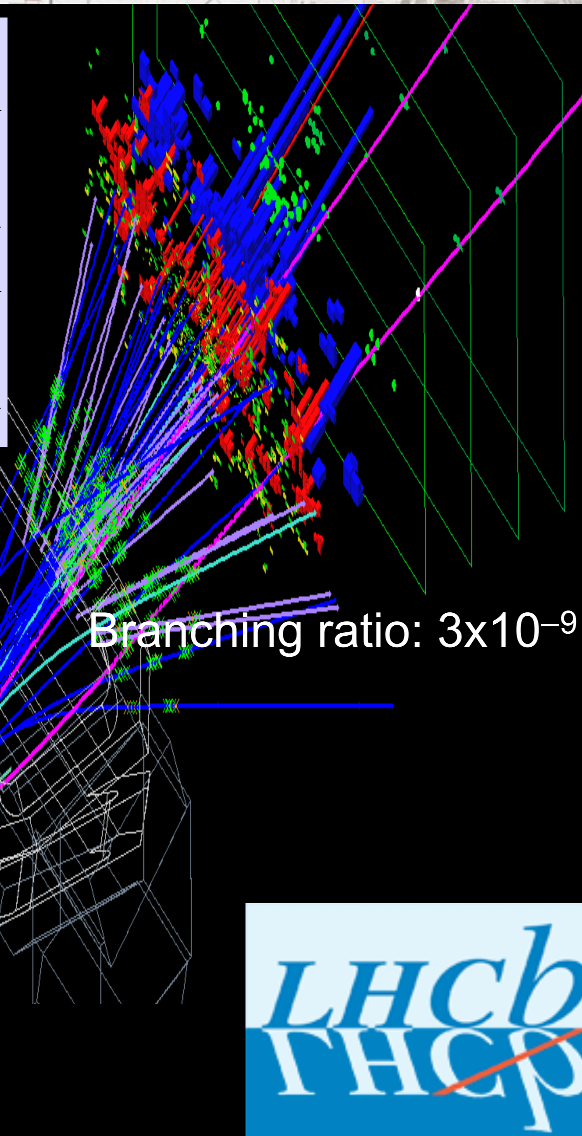
Excellent agreement with QCD up to 2 TeV



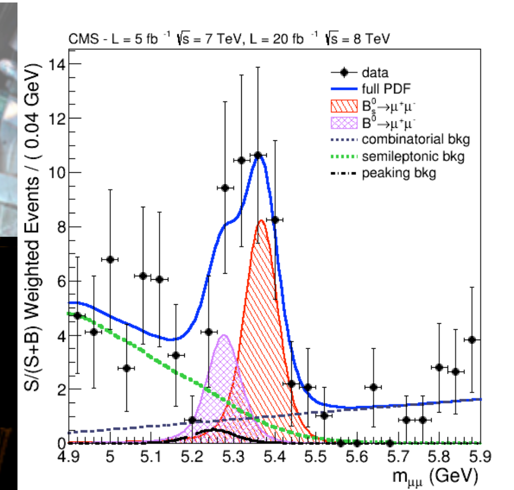
Syst. Unc. (~10%)
Dominated by JetEnergyScale (1-2%) & PDFs

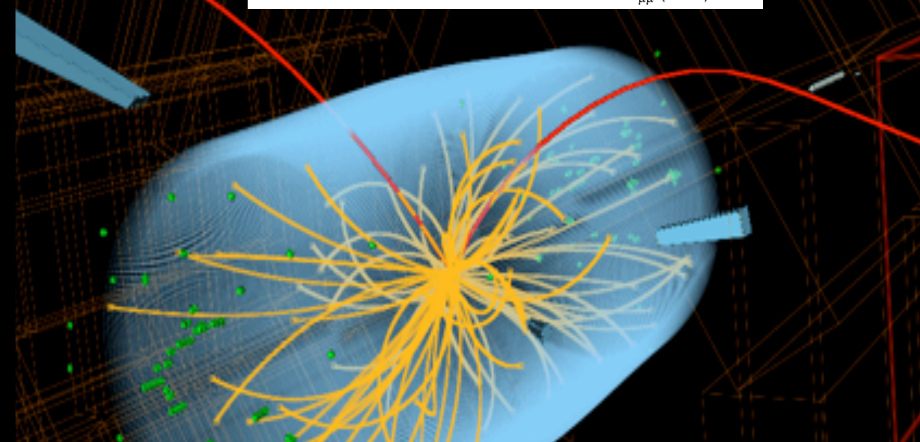
$B_s \to \mu\mu$

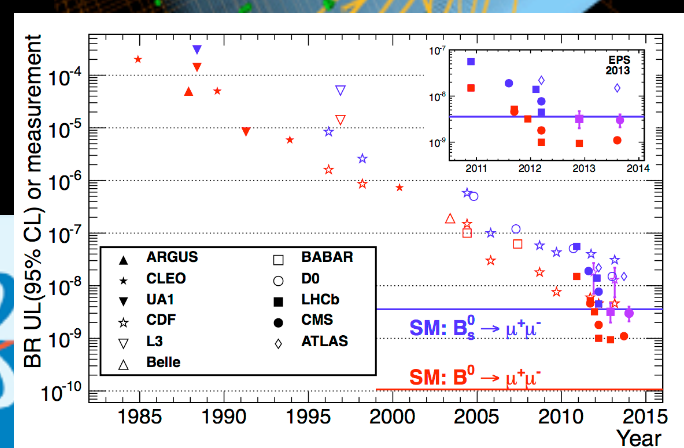




Branching ratio: 3×10^{-9}!

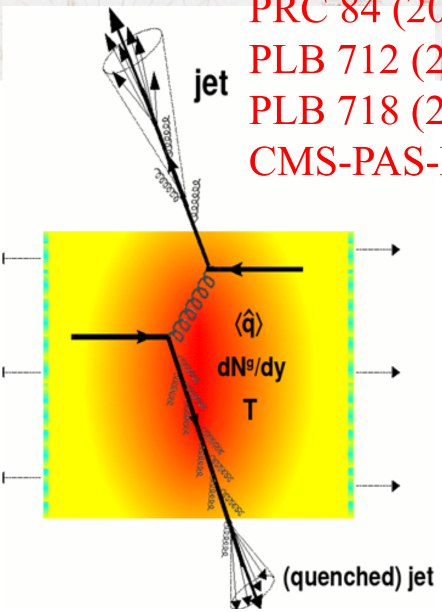




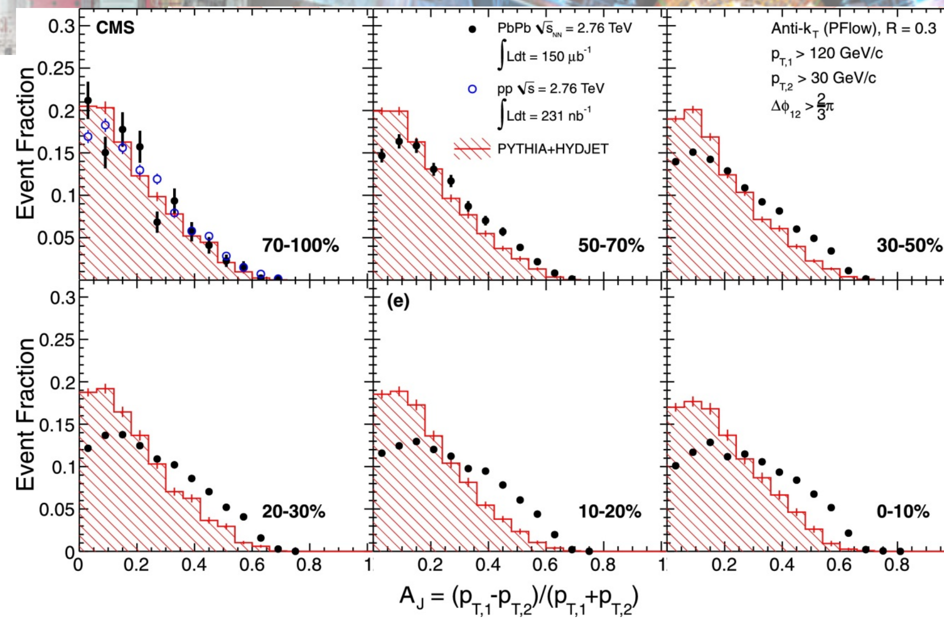


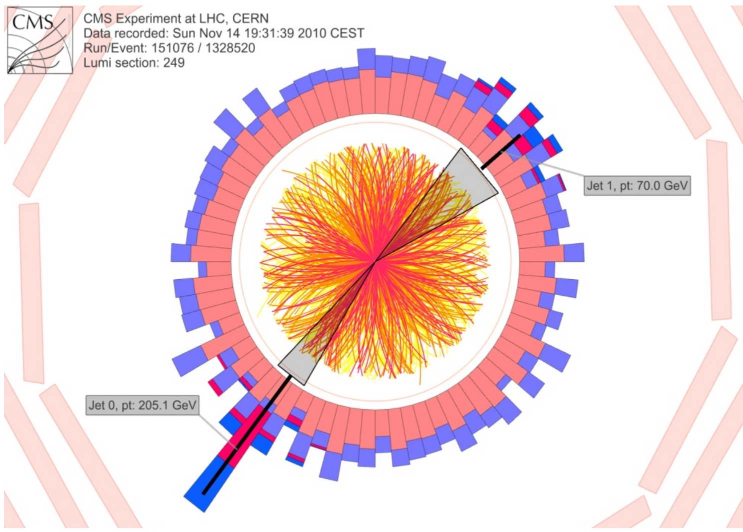
The ultimate CMS: heavy-ion detector

PRC 84 (2011) 024906
PLB 712 (2012) 176
PLB 718 (2013) 773
CMS-PAS-HIN-12-003

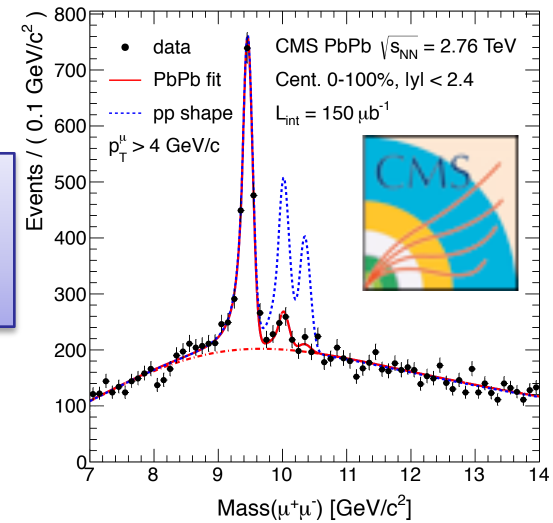


Jet Quenching



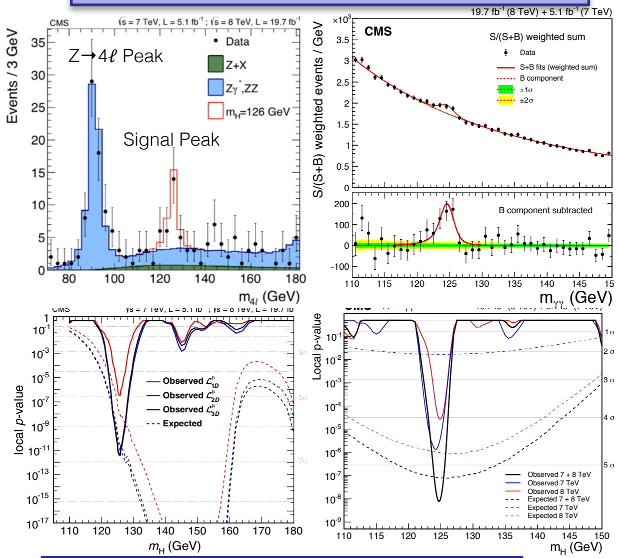


+ Melting Upsilons…

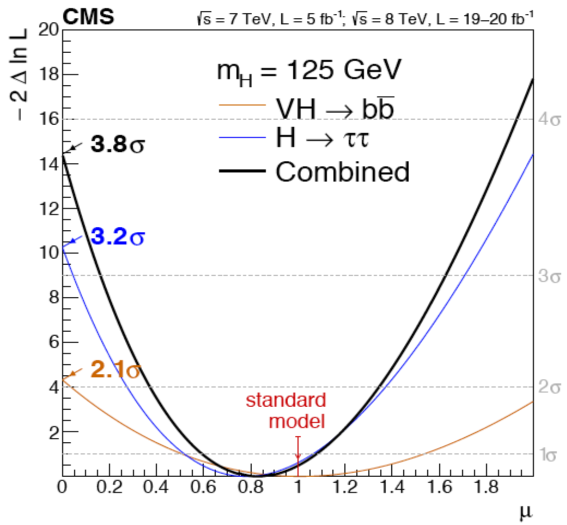


The new boson: looks like the expected one

Significance: huge

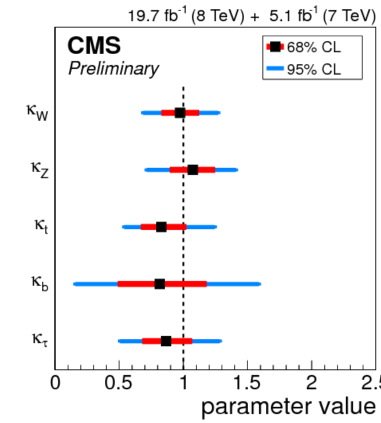


H→ττ + H→bb

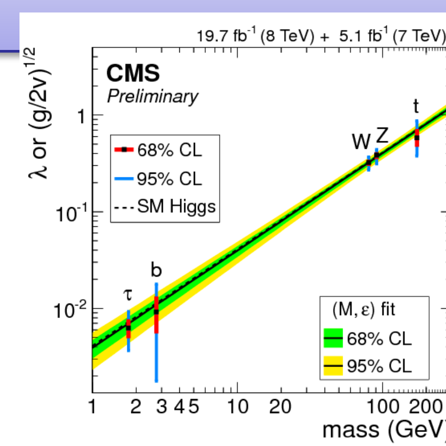


Significance	Exp	Obs
CMS (ττ)	3.4 σ	3.2 σ
CMS (bb)	2.1 σ	2.1 σ

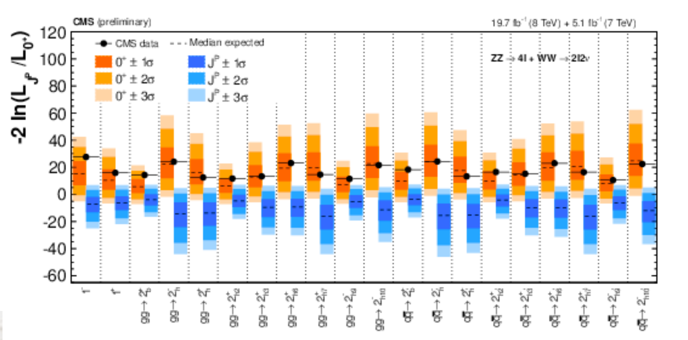
Couplings wrt SM



$g \sim m^2$ non-universality As expected by SM

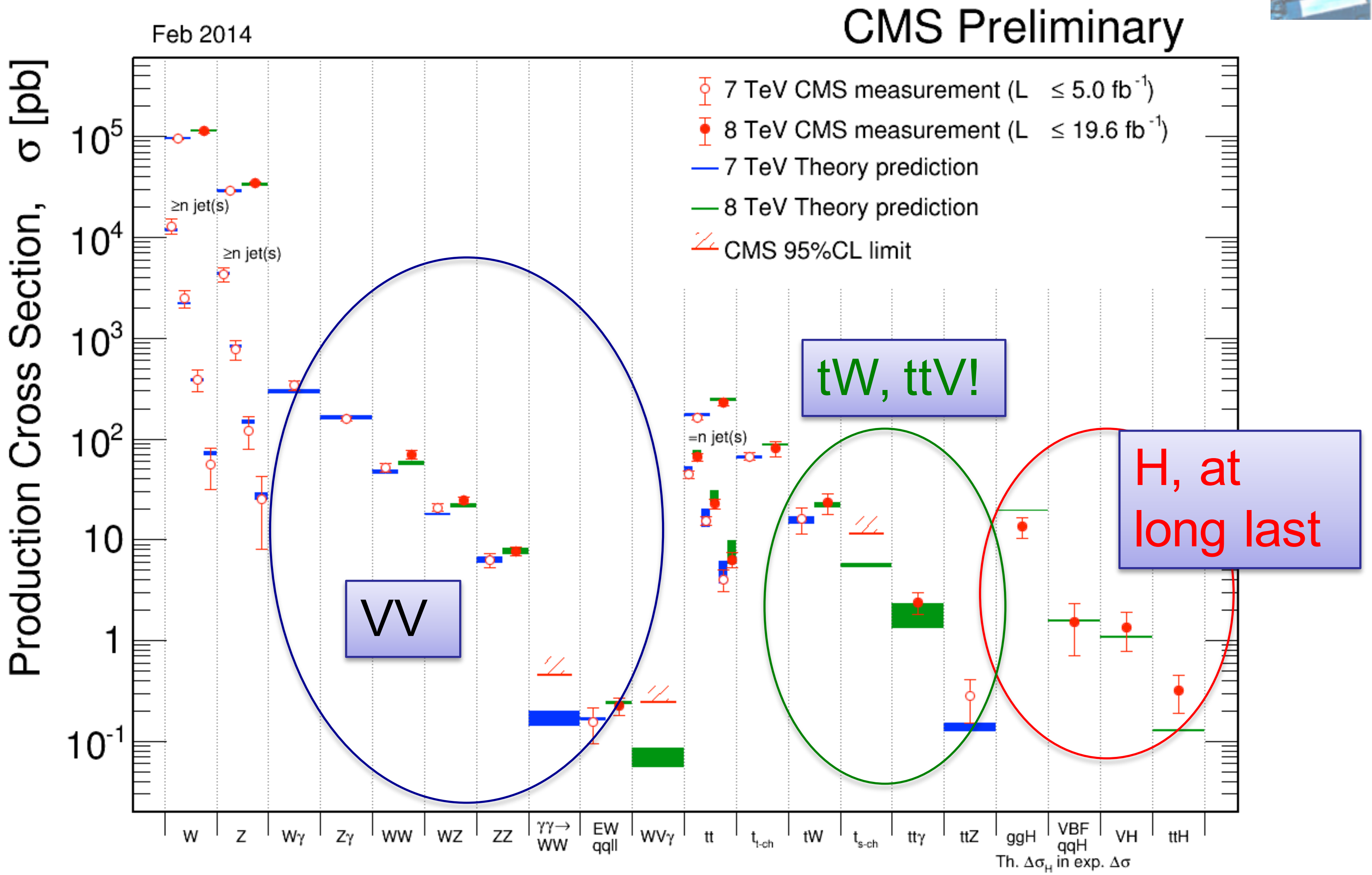


Spin-parity: 0^+ As expected by SM



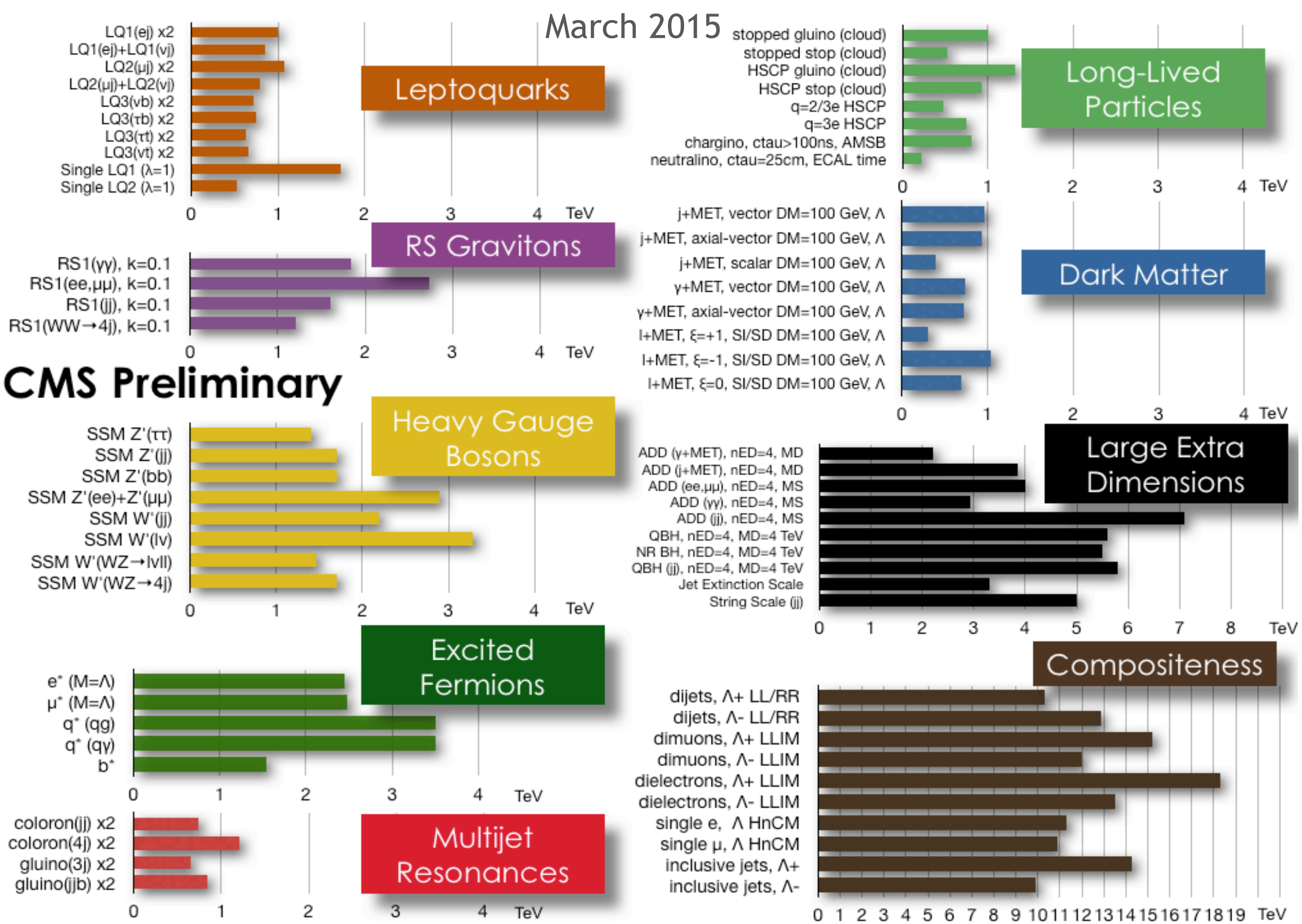
Put simply: it couples also to fermions

SM: a new standard for "success"



Nothing unusual found: e.g. exotics

Mass scale limits

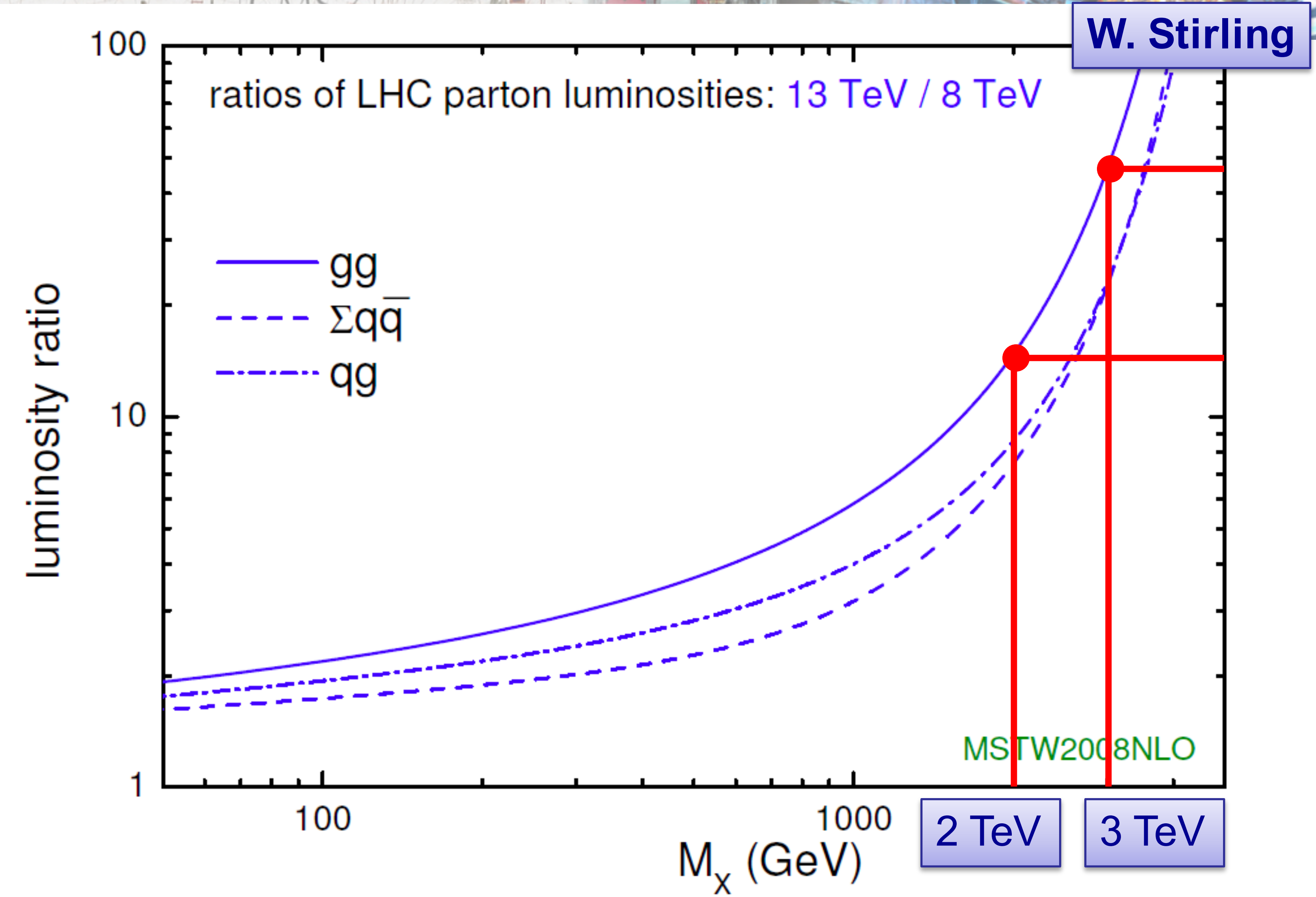


CMS Exotica Physics Group Summary – Moriond, 2015

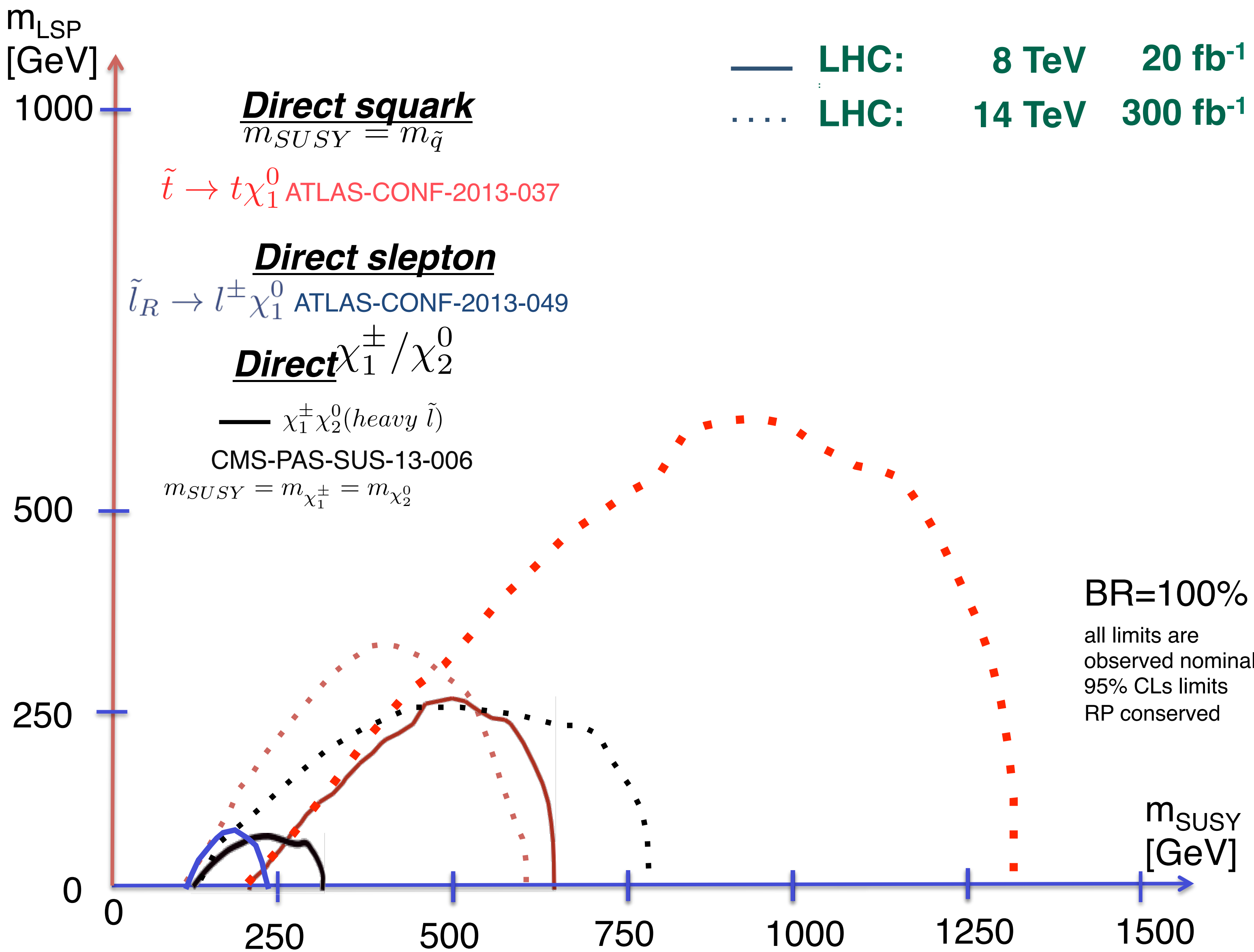
The present CMS

Run2

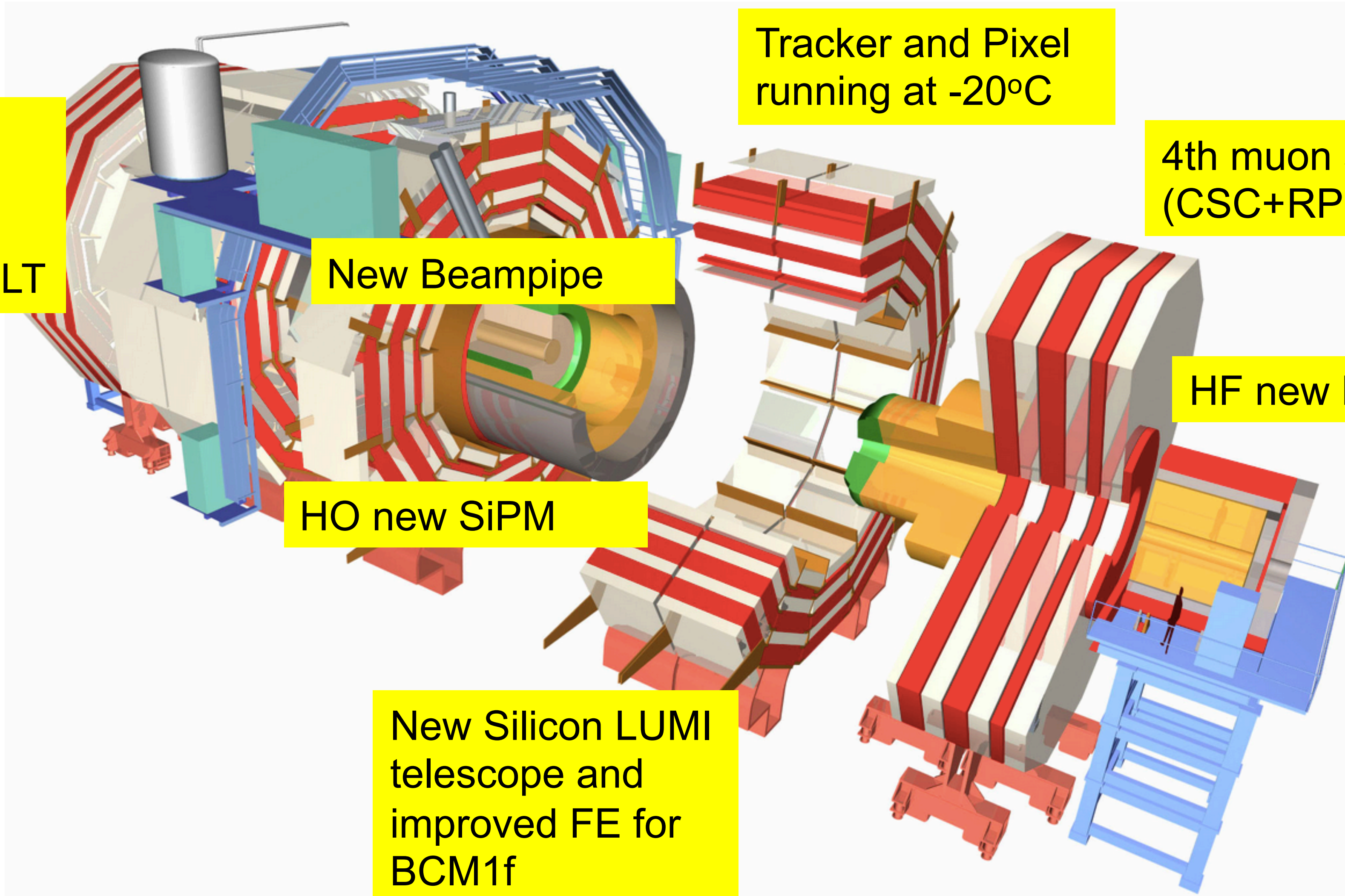
The promise of High Energy: 13Tev vs 8TeV



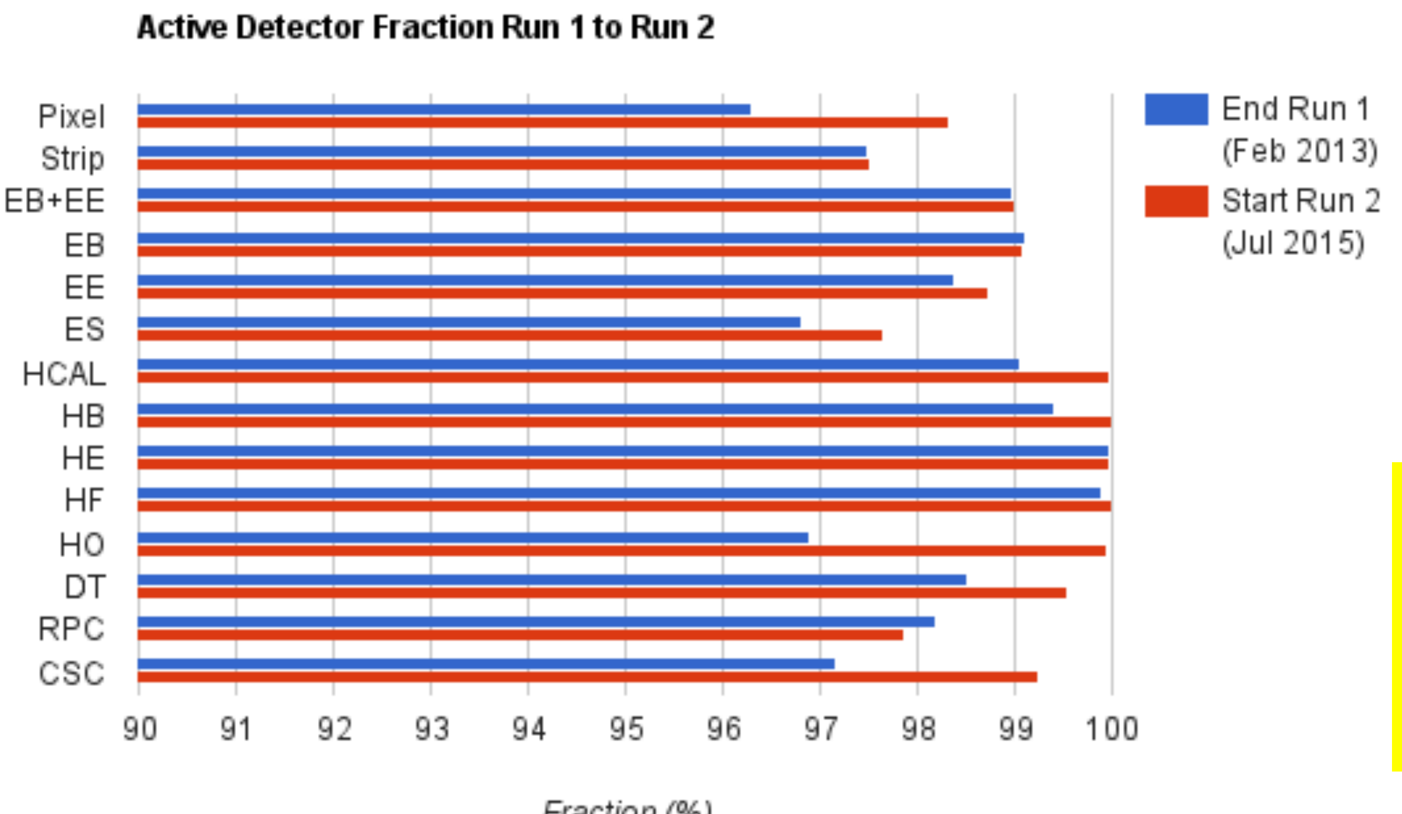
The promise of high energy



Run2 CMS


New DAQ fabric and HLT
Tracker and Pixel running at -20°C
4th muon station (CSC+RPC)
New Beampipe
HF new PMT
HO new SiPM
New Silicon LUMI telescope and improved FE for BCM1f

Detector and SW in great shape

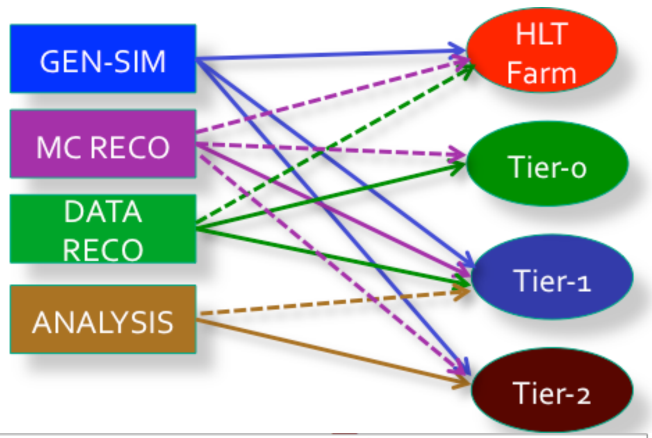


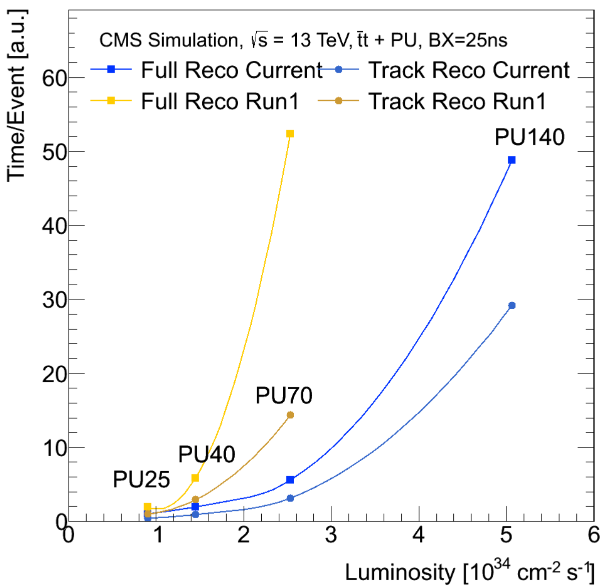
Active channel fraction better than in Run1

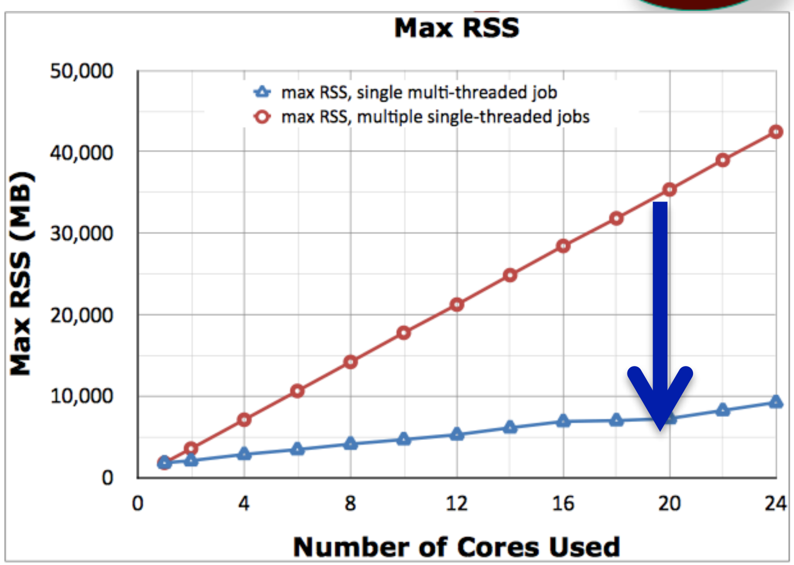
Run II Software and computing: LS1 improvements fully deployed

LS1 developments concentrated on increasing flexibility of our workflows to improve our resource usage efficiency

- Monte Carlo DIGI-RECO workflows routinely running on a large set of Tier-2s
- Data Federation: AAA (Anydata Anytime
- Anywhere) in widespread use
- Multithreaded CMSSW framework and algorithm deployed
- Major Improvement of Reconstruction code efficiency







But … Cryogenics problem

- Since March the "Cold Box" (CB) that produces Liquid He for the operation of the CMS magnet has shown problems, following a compressor oil pollution of the CB circuit.
- For a definitive recovery, the system requires an overall cleanup which takes several months.
- Meanwhile, the CERN cryo group, in collaboration with the CMS Technical Coordination, has been trying to find a way to operate the CB with a reasonable Duty Cycle (> 70%) that would allow operation of the magnet synchronized with physics operation of the LHC until the Year end technical stop

Cold Box: present status

- Since then: numerous investigations and attempts to understand the problem and arrive at a solution have been carried out; several false alarms, equally many false hopes.
- More recent finding: a special regeneration cycle of the first heat exchanger seems to allow longer periods between downtimes. This would give CMS an "acceptable" duty cycle for the remainder of 2015 (until the deep clean during the End-Year Technical Stop).
- In the recent Technical Stop a number of other technical interventions* that should allow a longer period of operation in between regenerations have been made.
- The improvements of the CB done during the technical Stop have clearly allowed a more stable CB operation: presently we hope to have a cycle 8-10 days up/18 hours regeneration until the Extended stop at the year end when a complete cleanup will be done

*[new filters (factor 40, 100 in surface respectively) have been installed in the CB for the Active Charcoal 80K adsorber post filter and before the first turbine]

Fine collaborative work:
CMS
EN-MME
TE-VSC

‘Find the welder’ game

Many thanks to the TE technical teams & the ace welders from CERN main shop!!

Magnet cryo: longer term

Primary Oil Removal System (PORS)

-ordered, delivery 1 Jan 2016

(coalescers will be later – mid March), but can be installed in parallel

300m warm He transfer line (surface to underground)

-surface pipe done, work started in PM 54 shaft

80K Ads tank spares

- first one ready in CERN shops
- second one in order from Air lIquide

Cold box cleaning

-cleaning machine ordered, delivery Dec 2015

-selecting solvent –

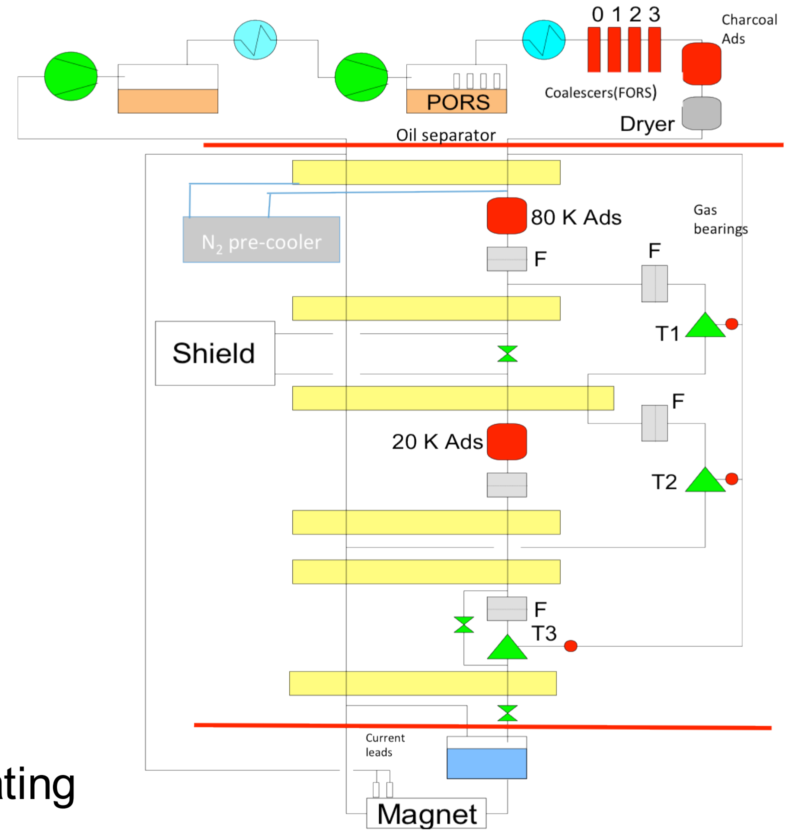
-and defining cleaning sequence

Direct contacts with other victims:

-“Elbe” plant in Dresden, “ALICE” in UK, investigating “Cello” at PETRA (not documented).

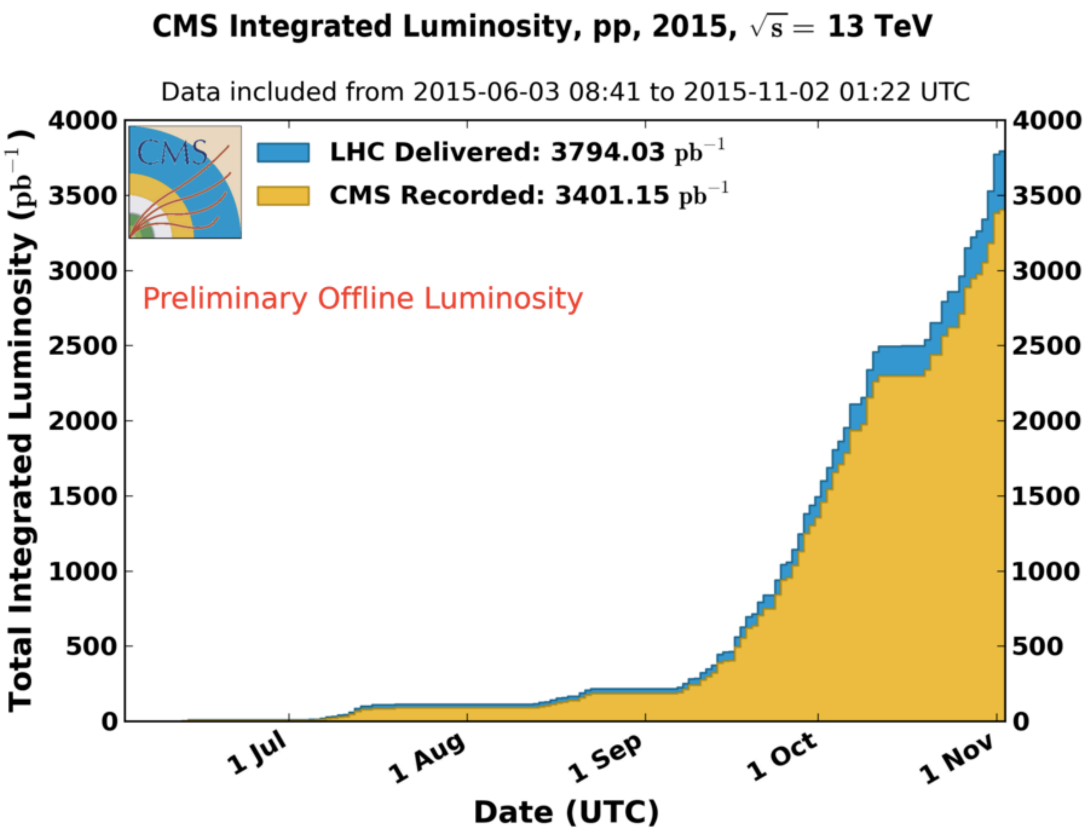
Risk analysis review (all risks to magnet)

- started



Lumi delivered/collected so far at √s=13 TeV

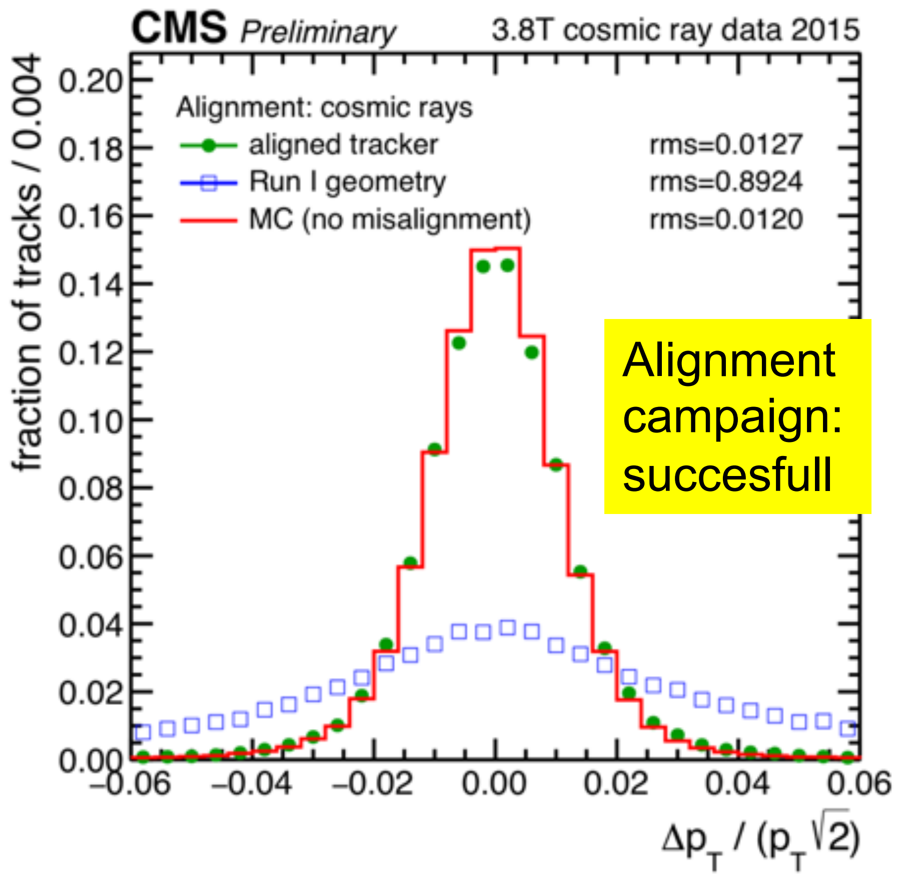
https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults



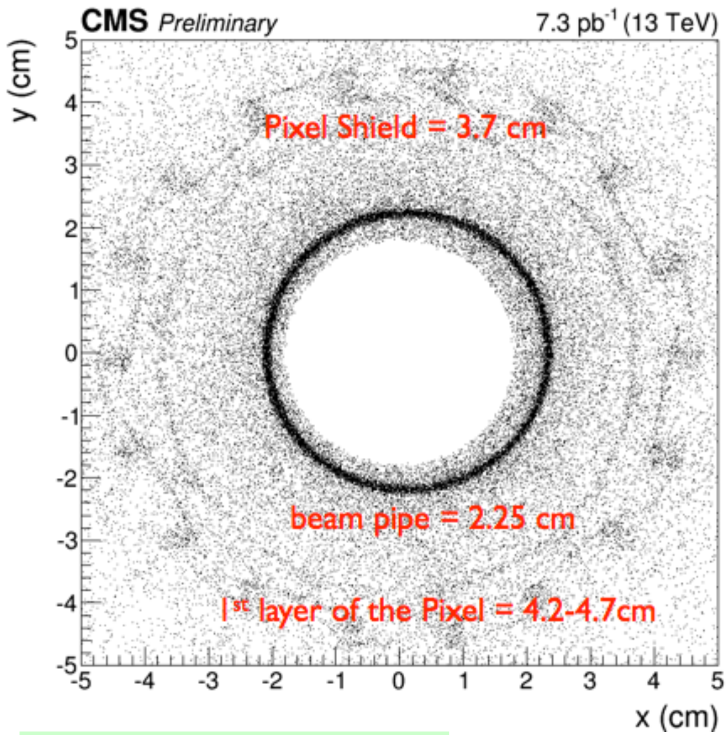
B = 3.8T: 2.8 fb^{-1} delivered
B ≠ 3.8T: 1 fb^{-1} delivered

Data taking efficiency >92%

Run2 : excellent performance



Alignment campaign: succesfull

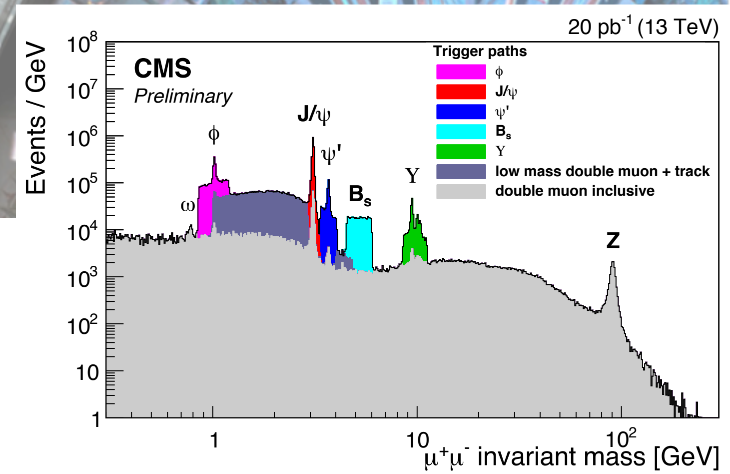


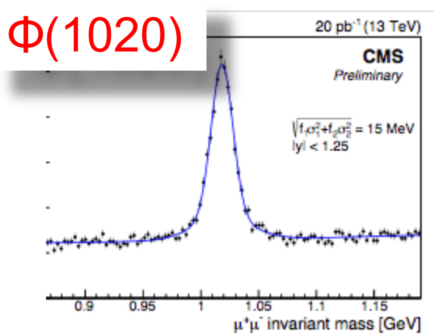
New beam pipe

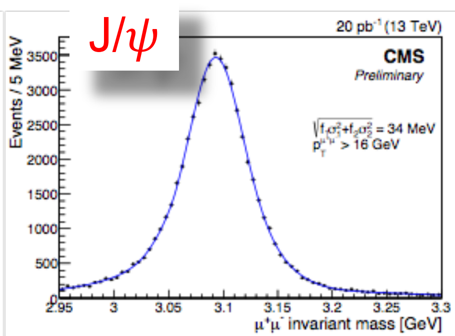
Beam spot displaced wrt to CMS(0,0)

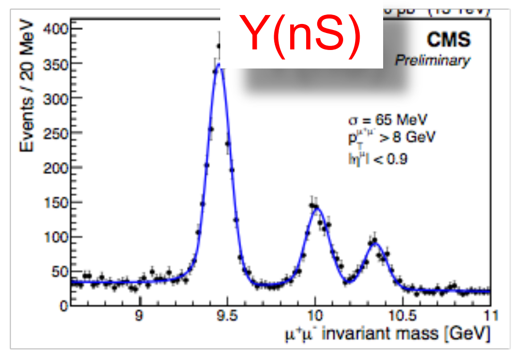
Run2 performance: Di-muon spectroscopy

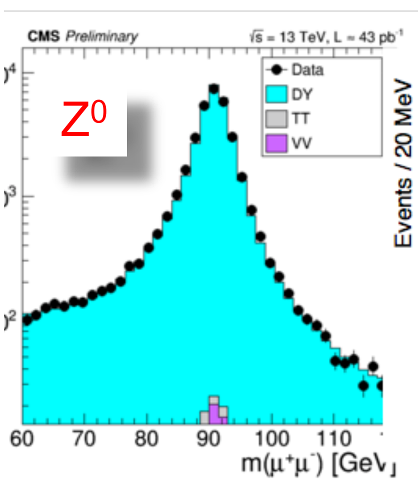
Maintaining a CMS Hallmark: trigger flexibiltity

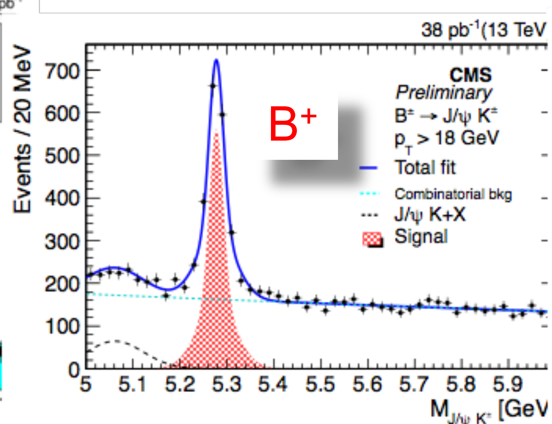


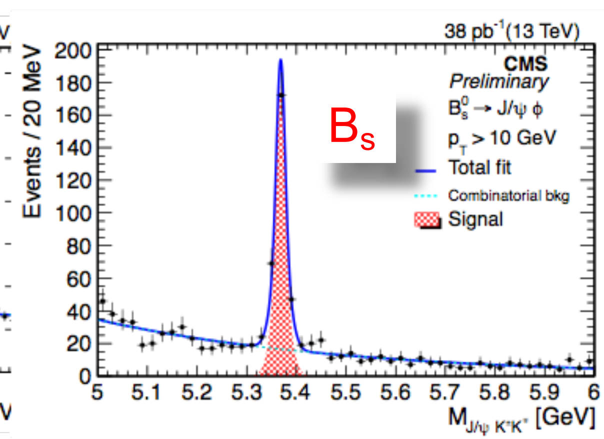




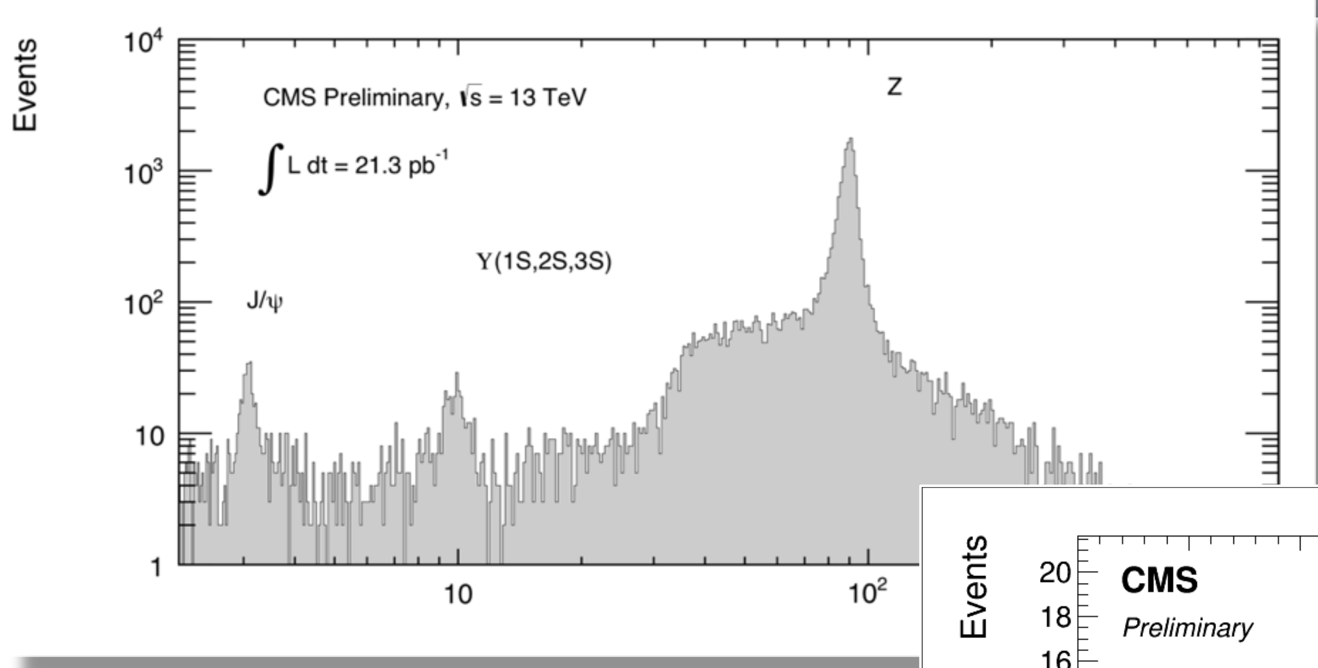






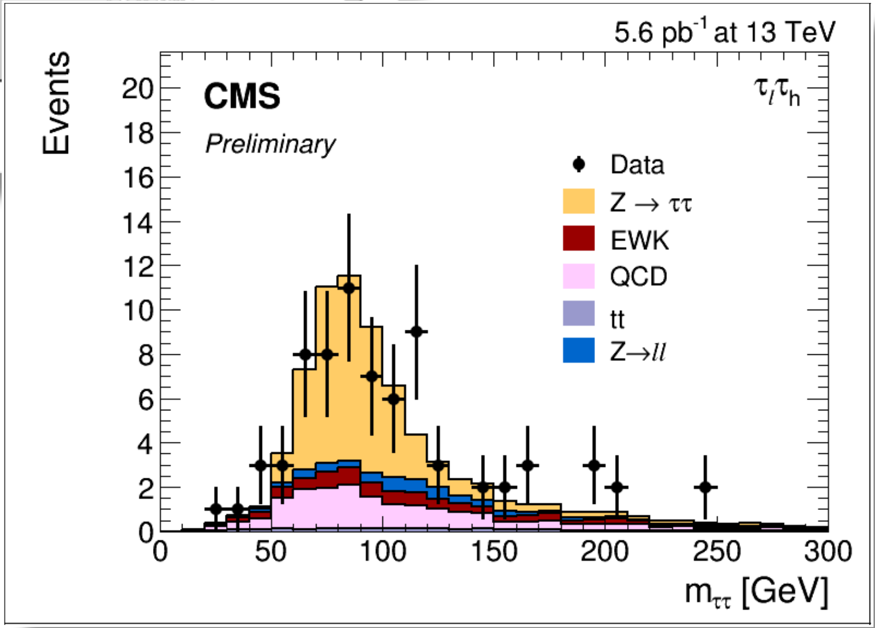


...and electrons and taus



Di-electrons

Di-taus

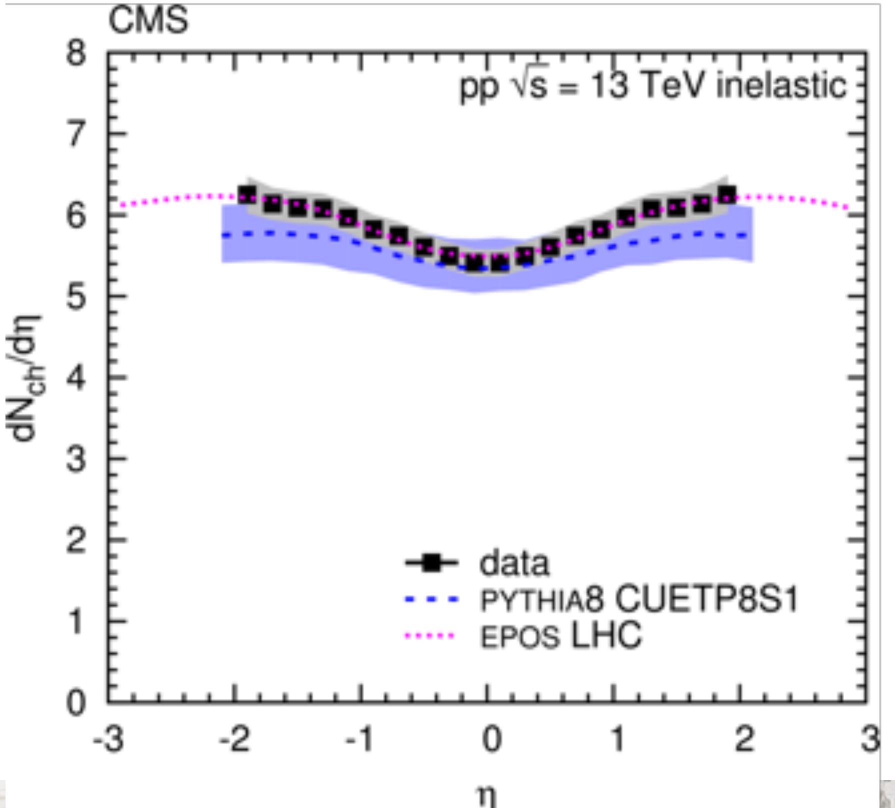


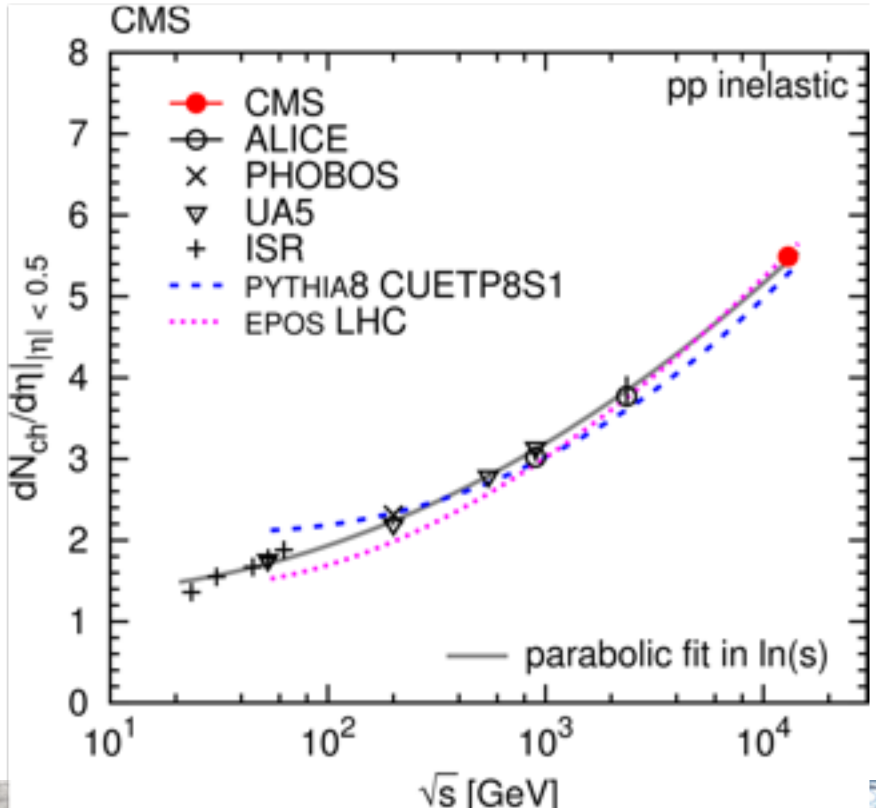
First LHC publication

Lack of B field has not prevented us from exploiting the first runs taken at low luminosity

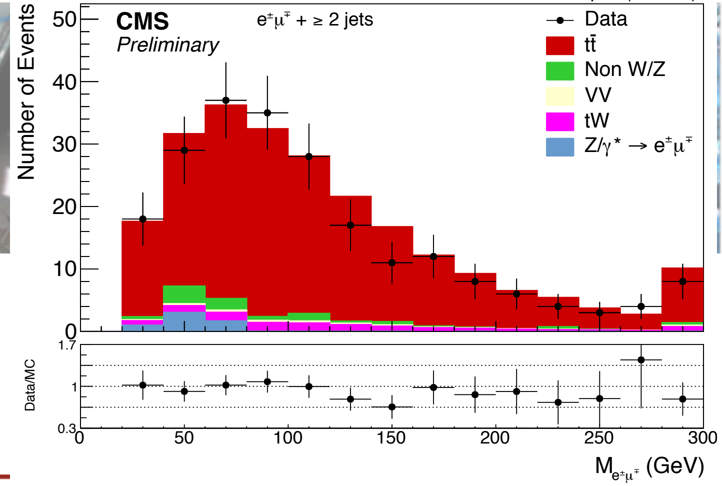
Submitted to PLB
http://arxiv.org/abs/1507.05915

$dN_{ch}/d\eta||\eta|<0.5 = 5.49 \pm 0.01$ (stat) $\pm$ 0.17 (syst)



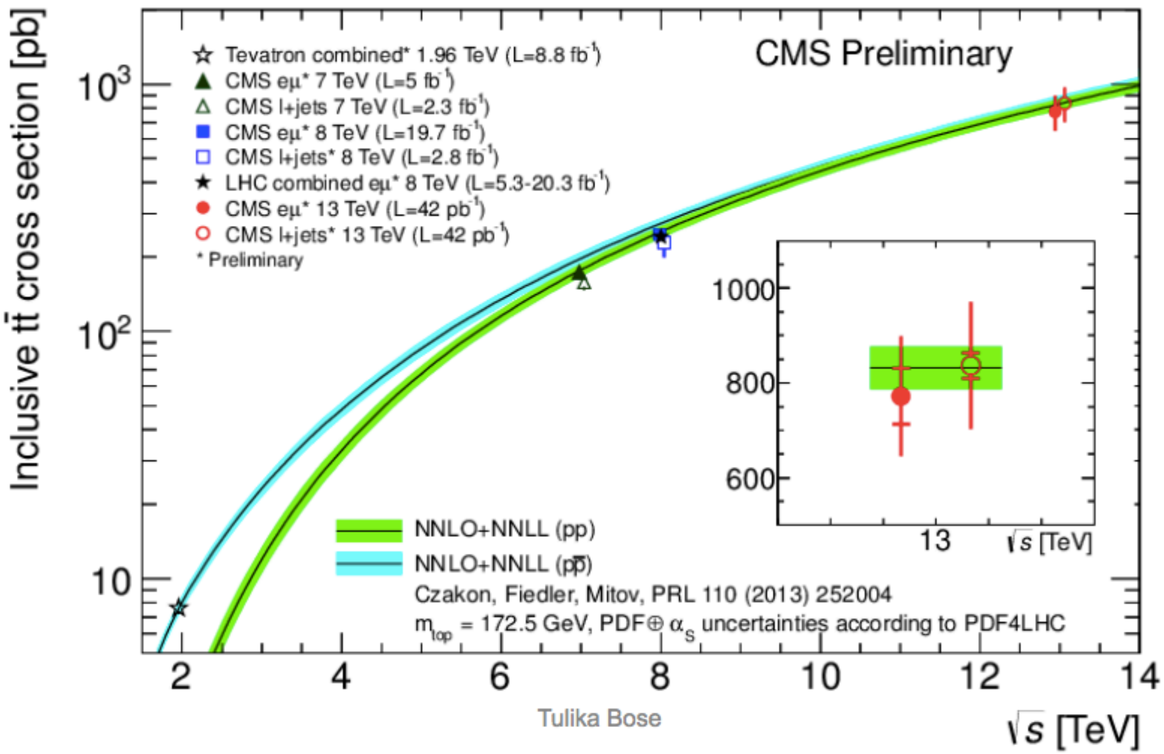


t-tbar cross section



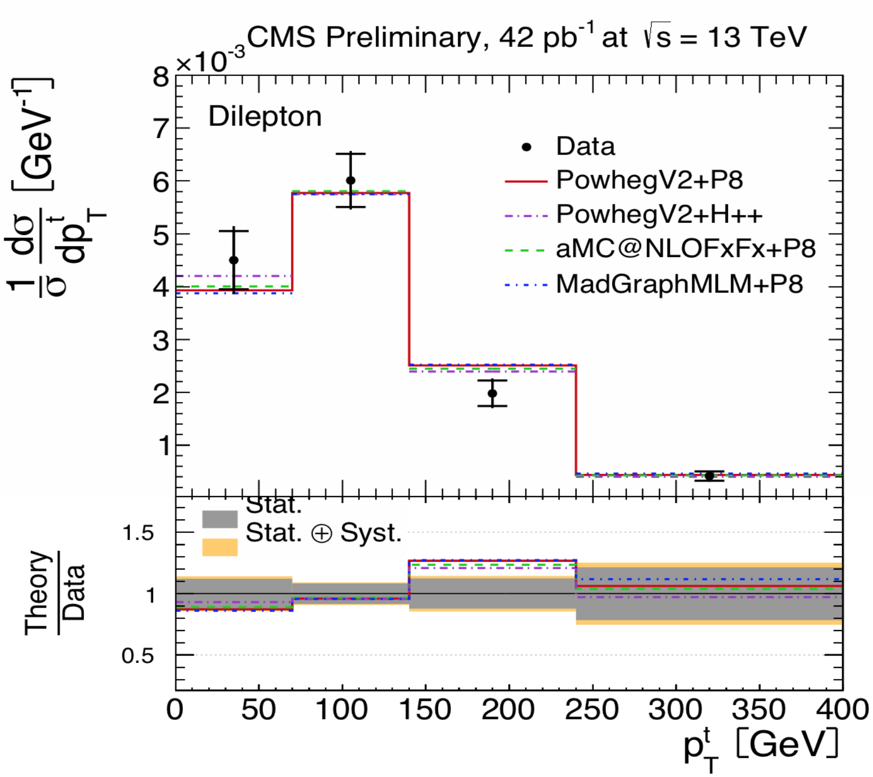
- Inclusive ttbar cross section @13 TeV measured:
  - eμ and semi-leptonic channels

TOP-15-005
TOP-15-003

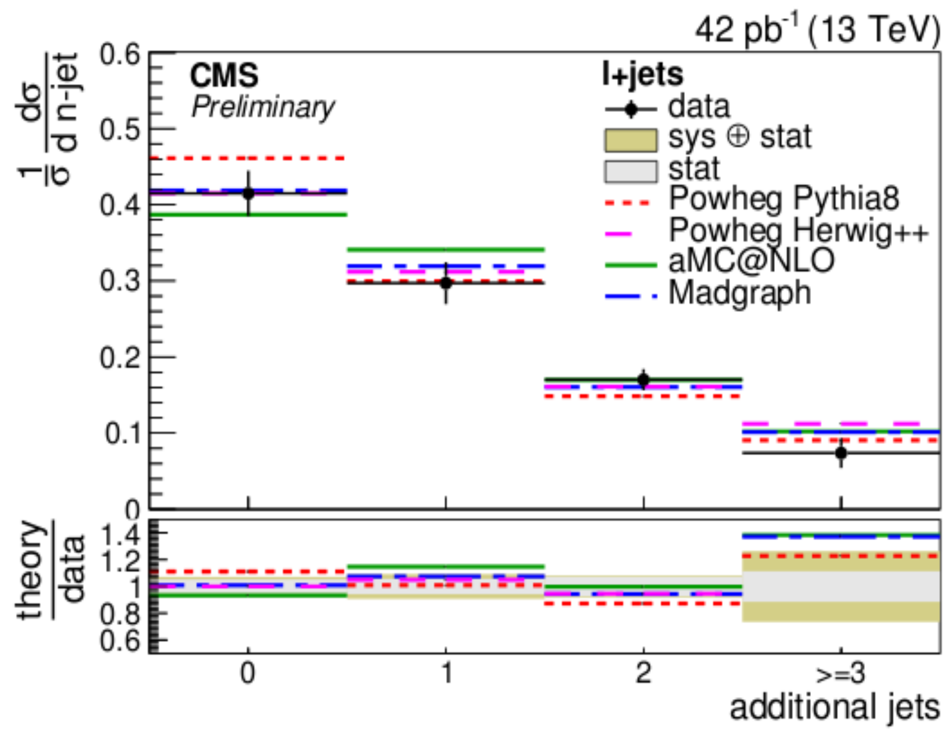


t-tbar differential cross section

- ttbar differential cross sections at 13 TeV measured:
  - di-lepton (ee, eμ, μμ) and semi-leptonic channels
  - Good agreement with NLO MC within uncertainties



TOP-15-010

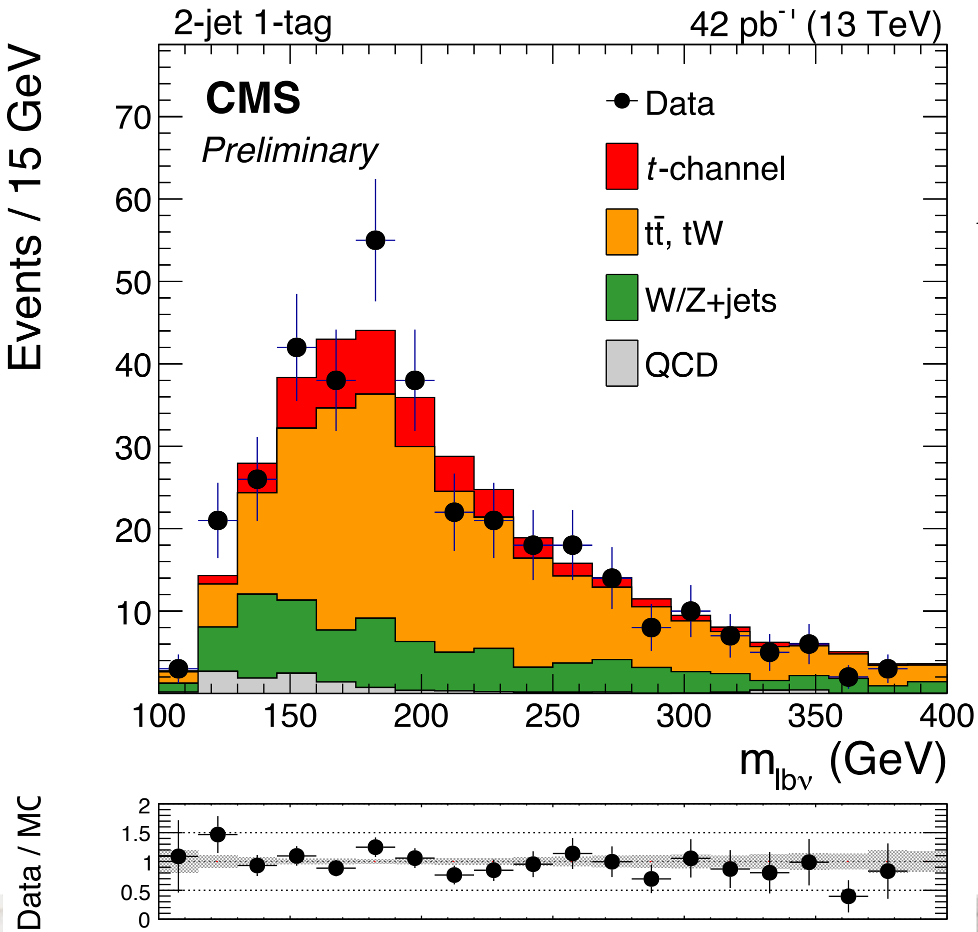


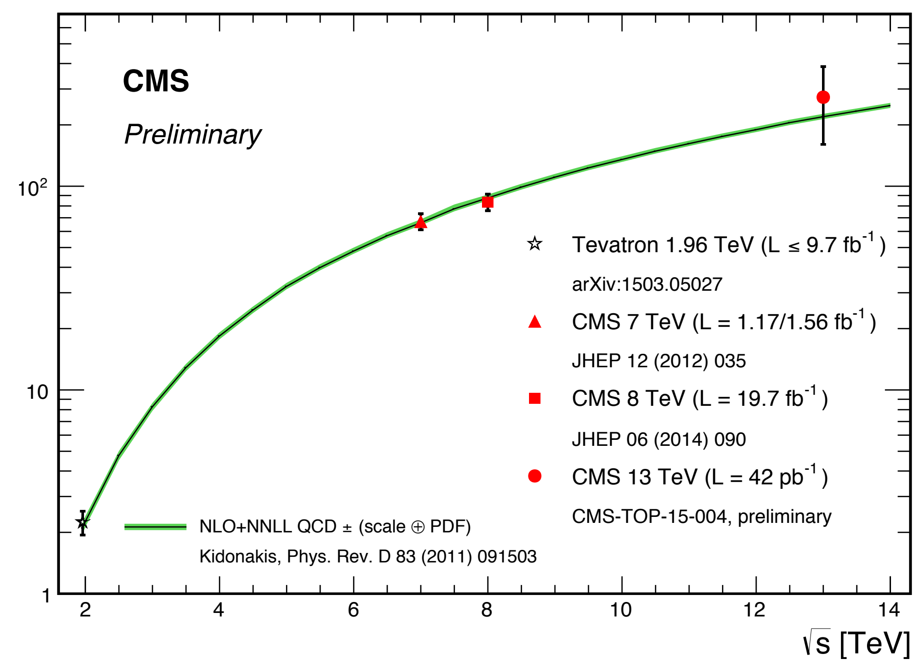
TOP-15-005

Single top cross section

- t-channel single top cross section @13 TeV measured:
  - μ + jet channel

$$\sigma_{t\text{-ch.}} = 274 \pm 98\,(\text{stat.}) \pm 52\,(\text{syst.}) \pm 33\,(\text{lumi.})\,\text{pb},$$



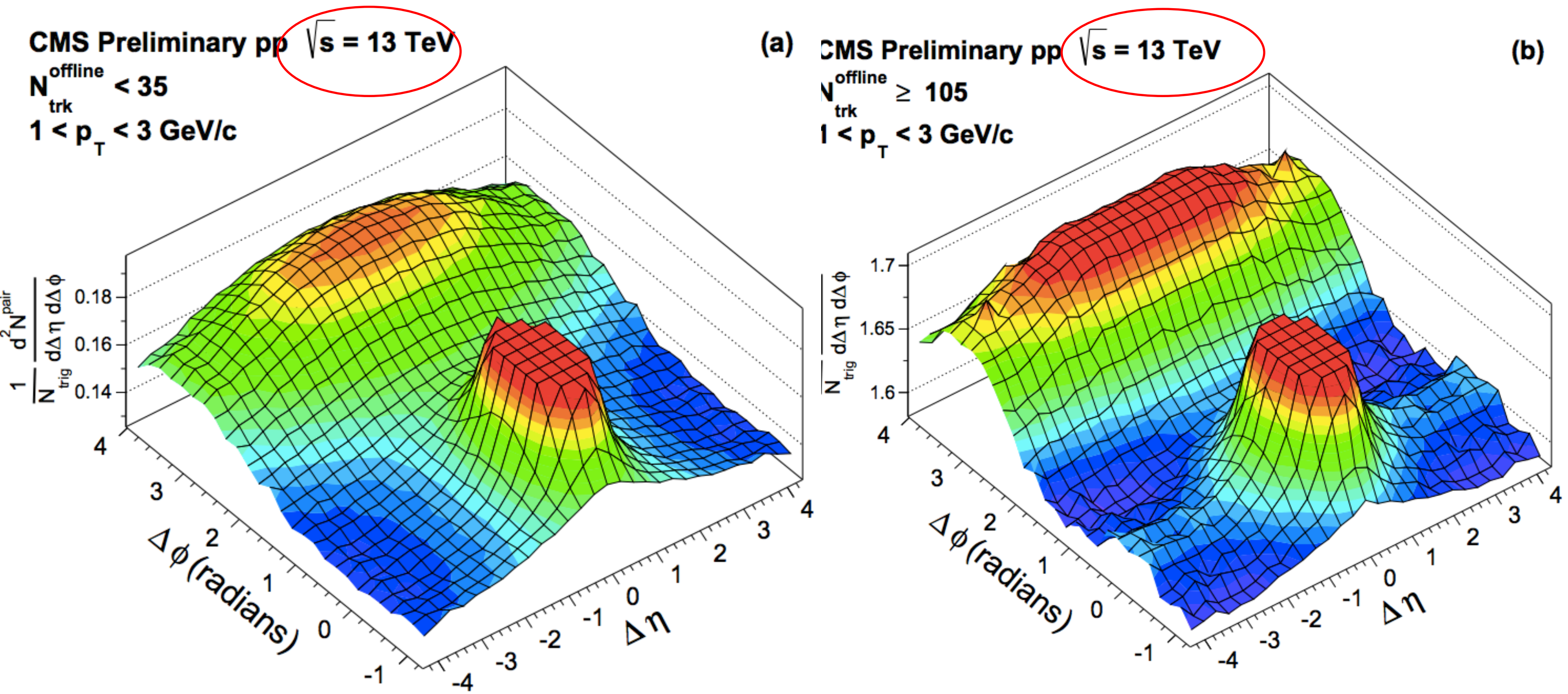


$$|V_{tb}| = 1.12 \pm 0.24\,(\text{exp.}) \pm 0.02\,(\text{theo.})$$

TOP-15-004

The 'ridge'

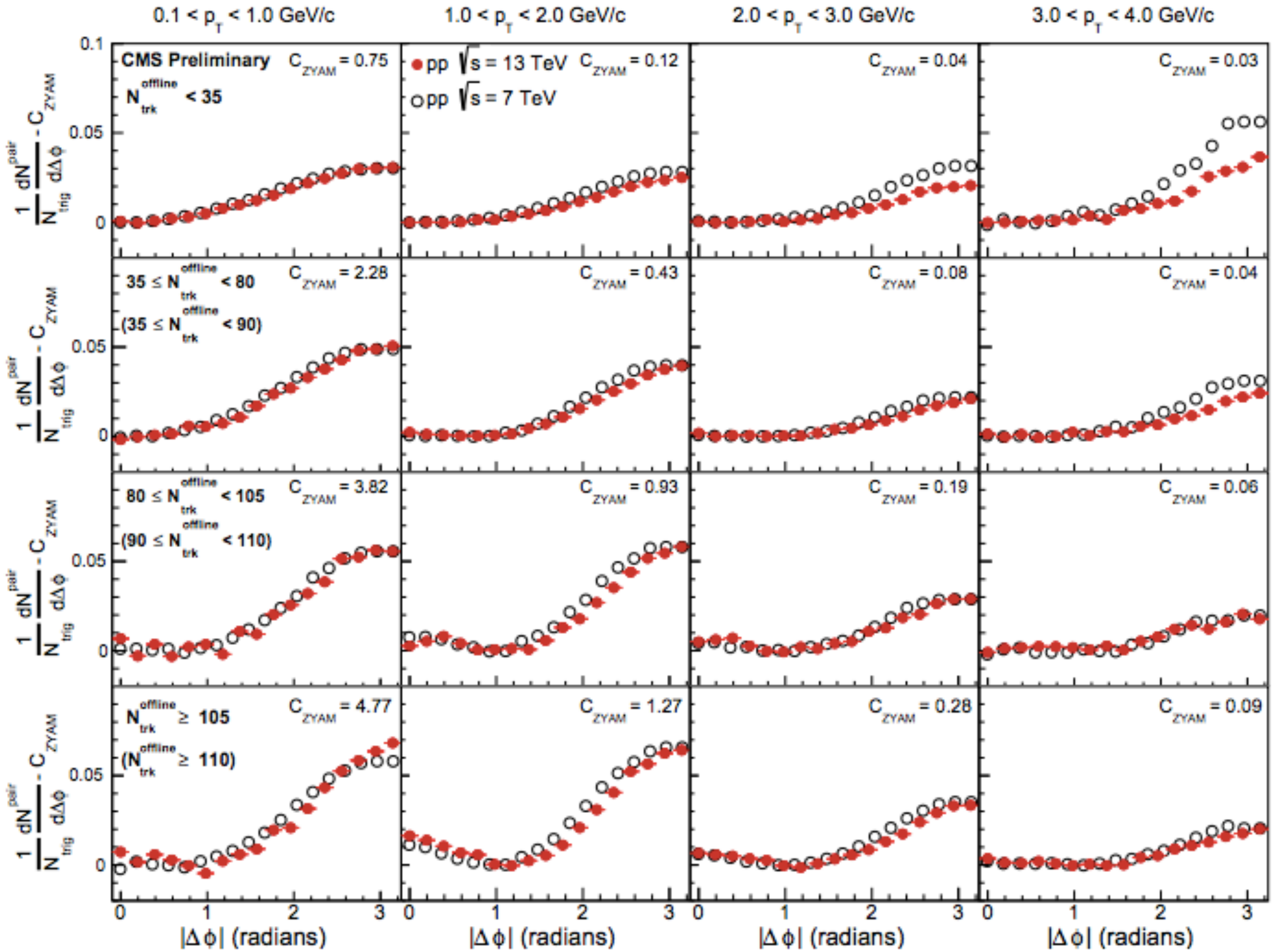
Paper being submitted



At 13 TeV we find the same long range correlation, on the side of the tagging jet, which was discovered by CMS at 7 TeV when selecting high multiplicity events

The ridge looks the same at 7 and 13 TeV

After subtraction of the opposite side correlated portion

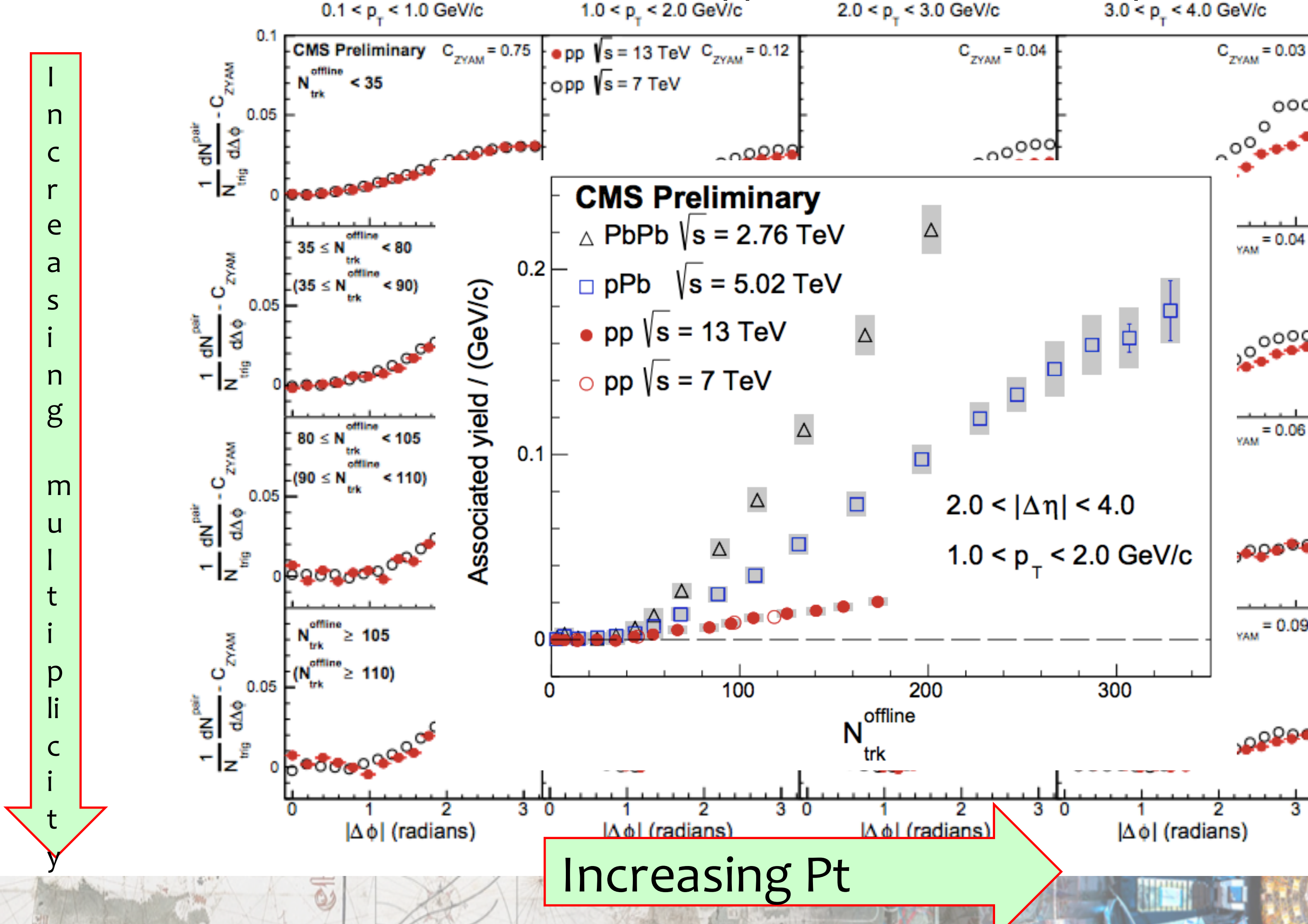


Increasing multiplicity

Increasing Pt

The ridge looks the same at 7 and 13 TeV

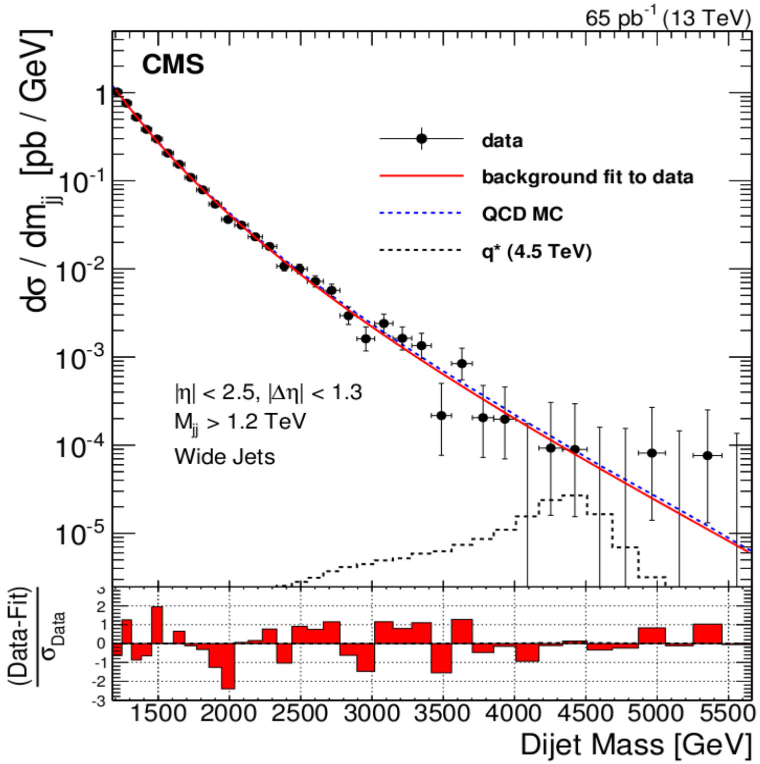
After subtraction of the opposite side correlated portion

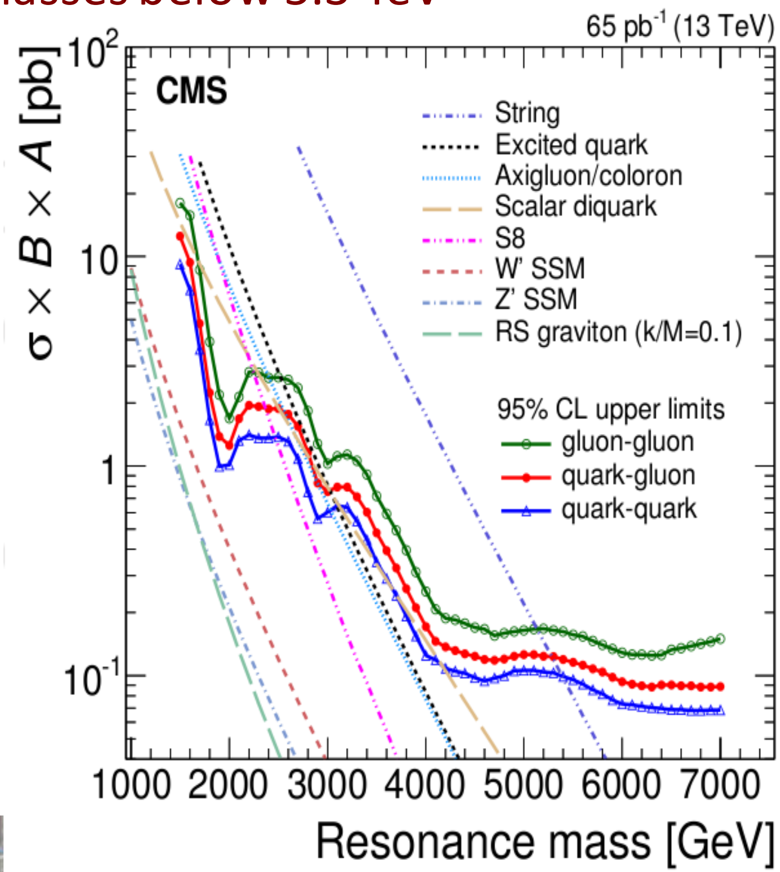


Di-jet resonance search

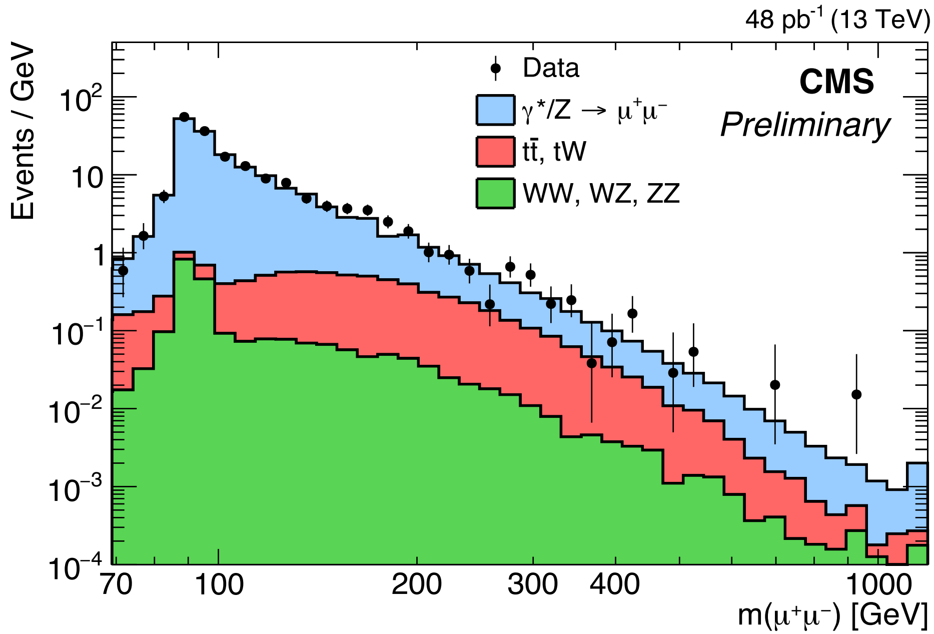
- Model independent search applicable to any model with narrow qq, qg, or gg resonances
  - Surpass Run 1 limits for string models & resonances above 5TeV in general

We exclude string resonances with masses below 5.3 TeV



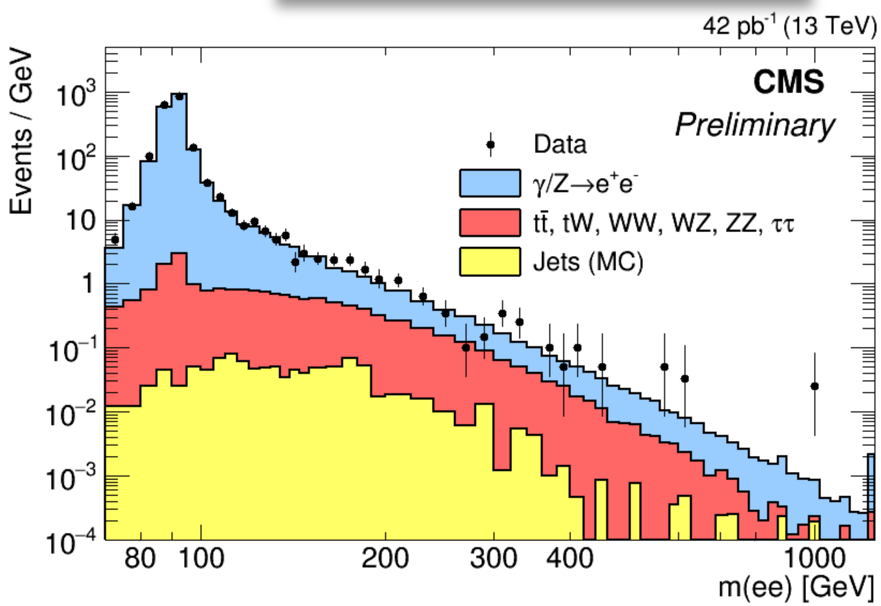


Di-leptons search

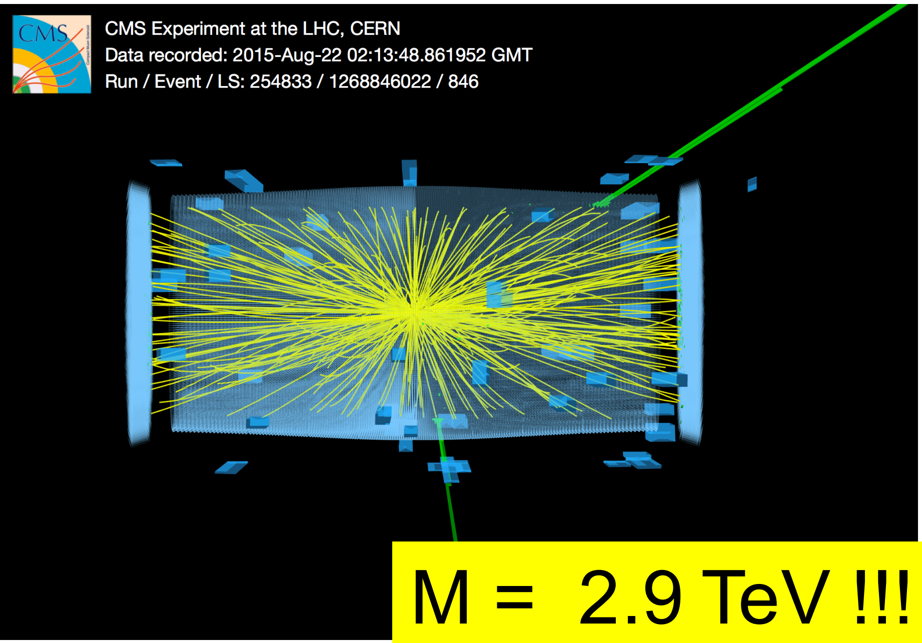


Di-muons: highest mass
920 GeV

Di-electrons
Highest mass…
see next



High mass di-electron event



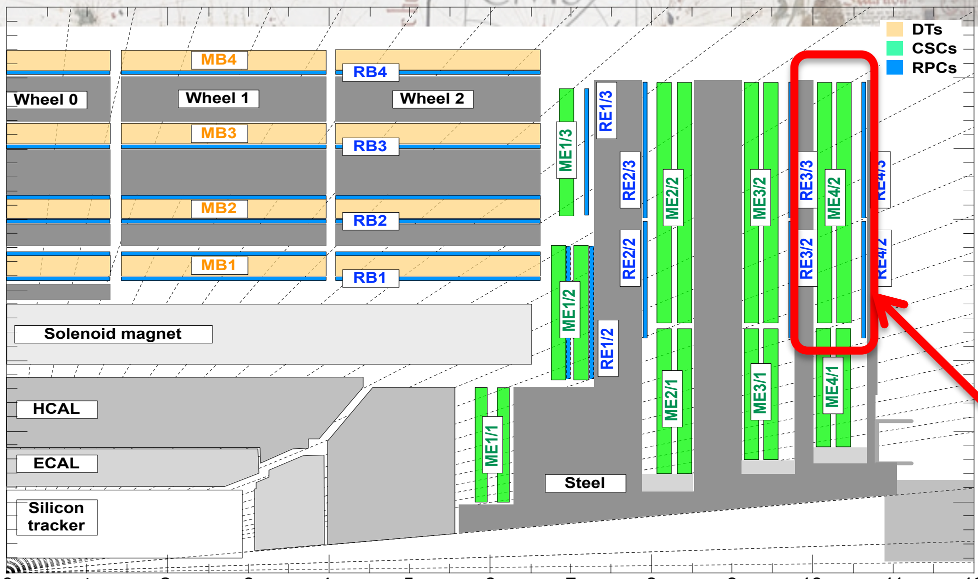
M = 2.9 TeV !!!

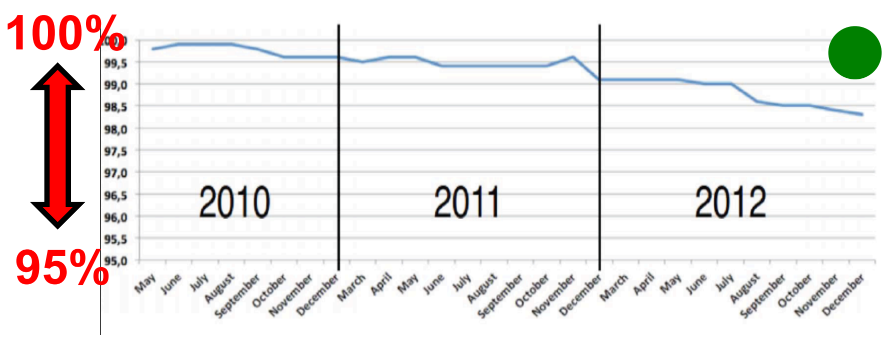
	electron 0	electron 1
E_T	1260 GeV	1280 GeV
η	-0.24	-1.31
ϕ	-2.74 rad	0.42 rad
charge	-1	+1
mass	2.91 TeV	
$\cos\theta^*_{CS}$	-0.49	
y	-0.78	

"Collins-Soper" angle, $\cos\theta_{CS}$, negative while DY bkg peaks at positive $\cos\theta_{CS}$.
The rapidity of the di-electron is rather large
Background is very low but not negligible ~ 0.002 events for M>2.5
Background uncertainty studies are ongoing (theory uncertainties expected to dominate)

The new CMS
Phase 1 upgrades

Muons: (done in LS1!)





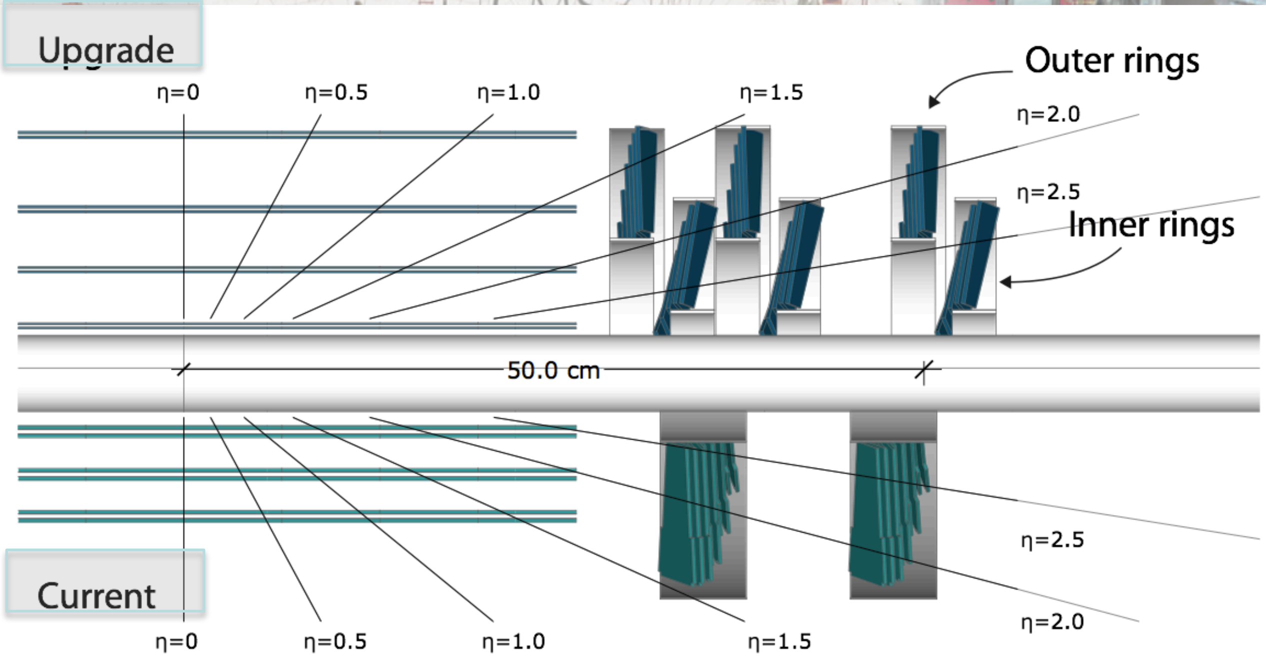
Muons:

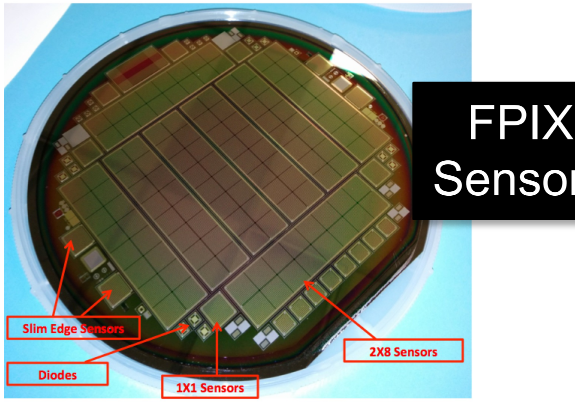
removal, revision, re-installation of ME1/1 chambers

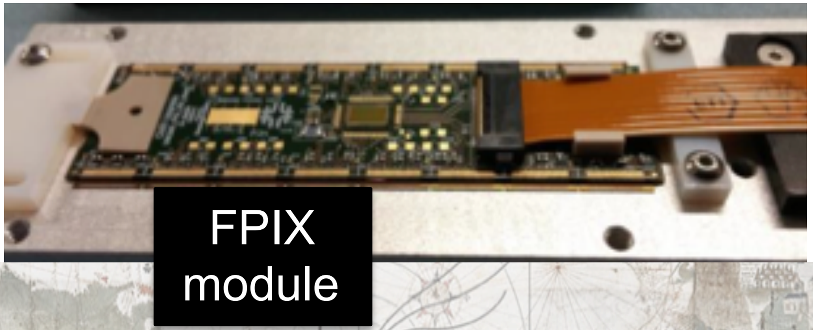
Fourth muon station added: 72 (144) new CSC (RPC) chambers

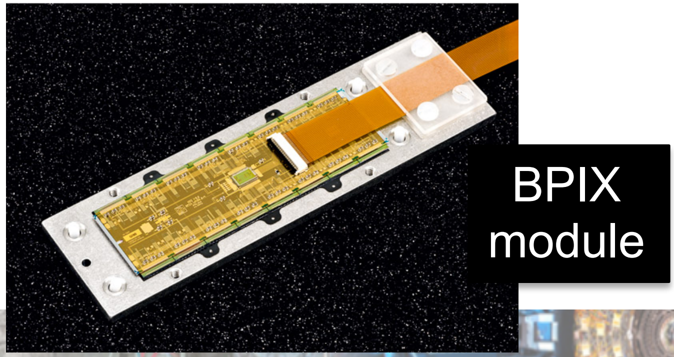
Accessibility to electronics: installed 3500 optical links, 20 new crates, for relocating part of the electronics out of the experimental cavern

Pixel upgrade : to install end 2016



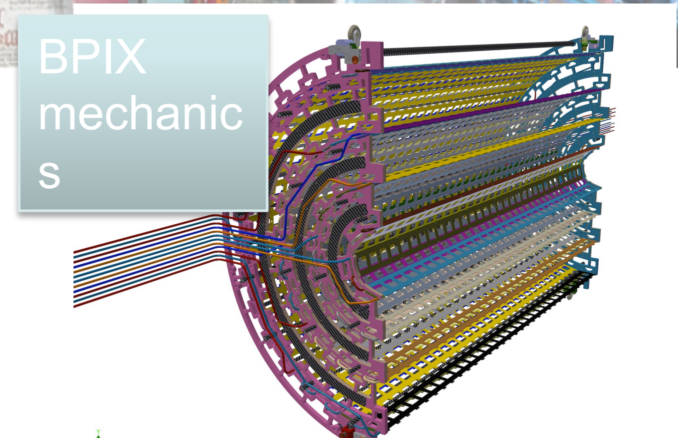


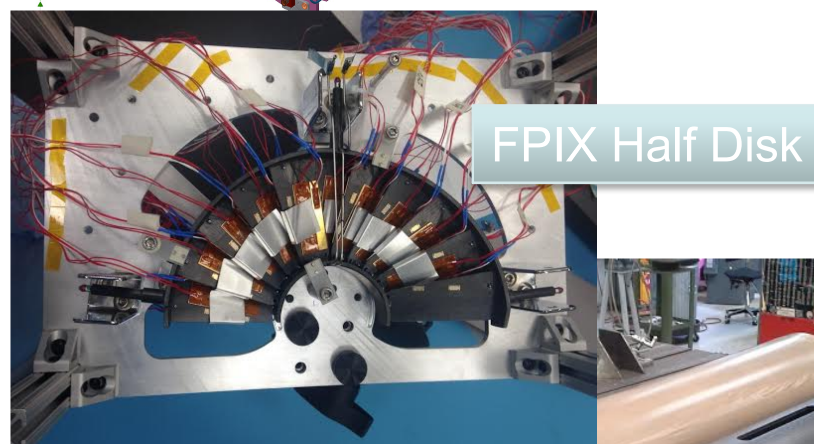


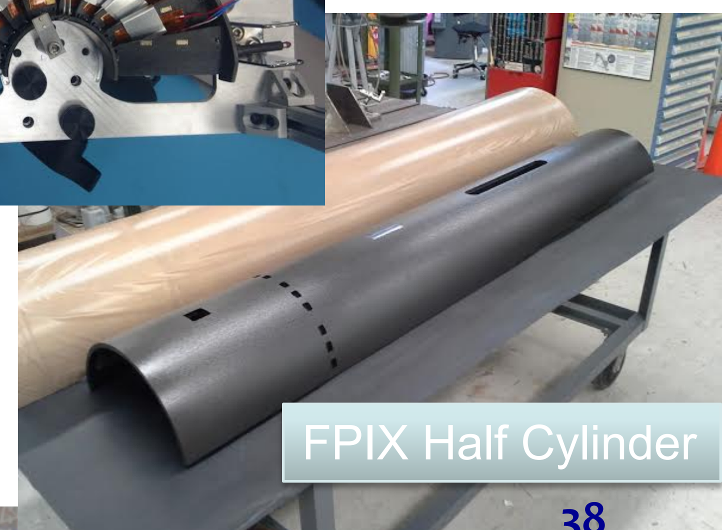


Pixel upgrade

- BPIX (2 half shells, 4 layers each)
  - ~20% of modules ready
  - First shell ready for module installation mid/end March 2016
  - Electronic boards ready to be produced or already produced
  - First supply tube incl. electronics: end of January 2016
- FPIX (4 half cylinders, 3 disks each)
  - First half cylinder disks ready in November.
  - First half cylinder mechanics ready in December
  - First fully equipped HC (modules + electronics) at CERN in May
- Pixel FWD blades installed now and taking data to commission Readout and online infrastructure



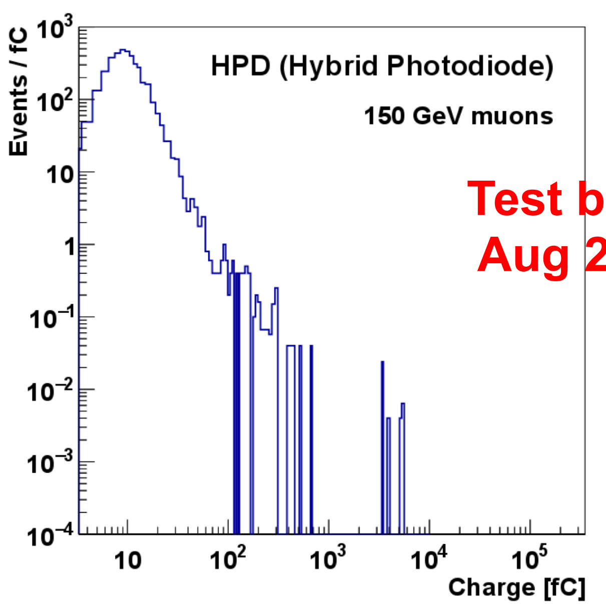




HCAL Phase 1 upgrade

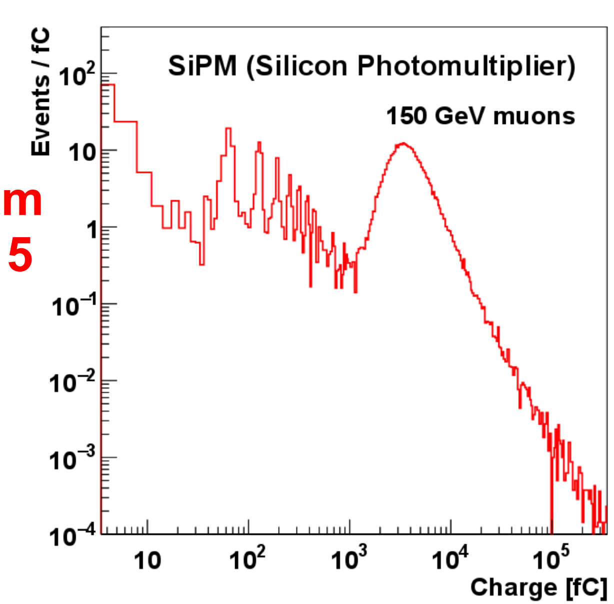
- Replacement of Photo-detectors :
  - HF new thin window multicathode PMT,
  - HPD replaced by SiPM everywhere else (done for HO, to be done in Year end Tech Stops 2016 –HE- and 2018 –HB-)
- New frontend (to complete in 2018)and Backend electronics (new mTCA based is already installed and being used in trigger)

HPDs (12 layers)



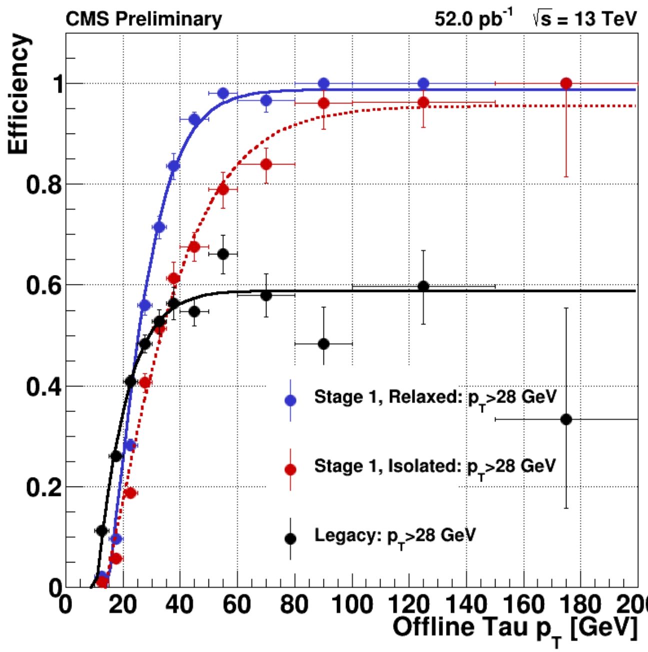
Test beam Aug 2015

SiPM (4 layers)



Level-1 Calorimeter Trigger Upgrade – 2015

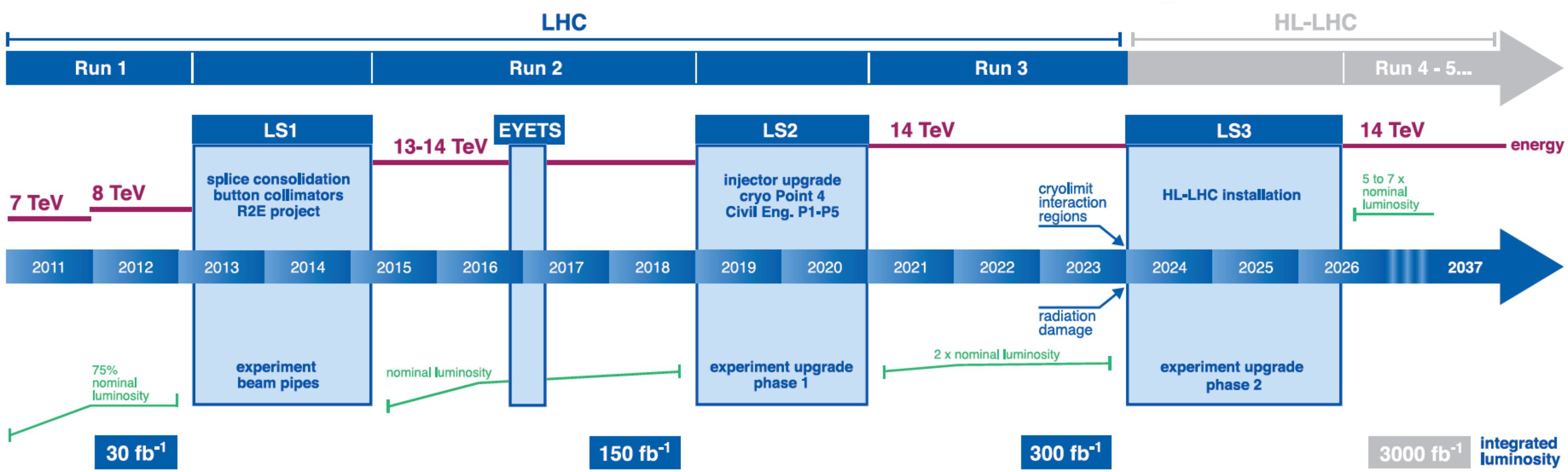
- Since the start of the 25ns running period, we have switched to the "Stage-1" calorimeter upgrade
- Full trigger upgrade (muon and calo + global trigger to operate at start of 206 run: being tested now in parallel to legacy trigger



New Tau trigger efficiency with and without isol. compared to legacy

The Future CMS

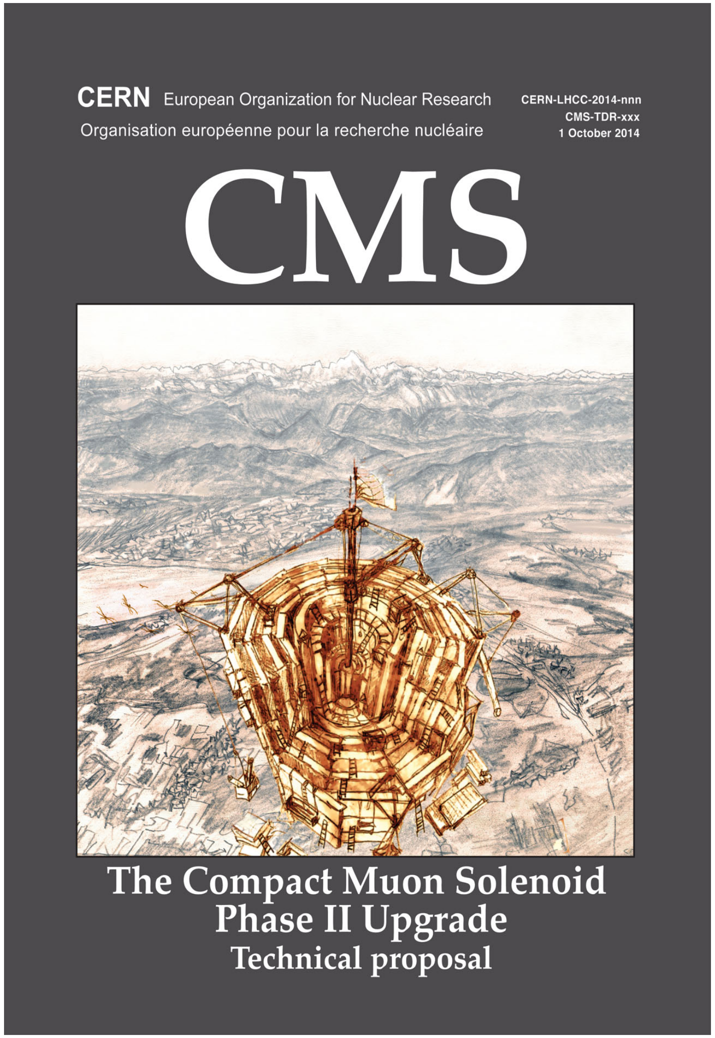
High Luminosity LHC (phase II)



- HL-LHC "baseline" peak luminosity 5×10^{34} cm^{-2} s^{-1} ; average number of collisions per bunch crossing ("pileup", PU): 140
- "Ultimate" peak luminosity is 7.5×10^{34} cm^{-2} s^{-1} → <PU>=200 (potentially increasing integrated luminosity per fill by 30%)

Long–term future: Phase 2 upgrade

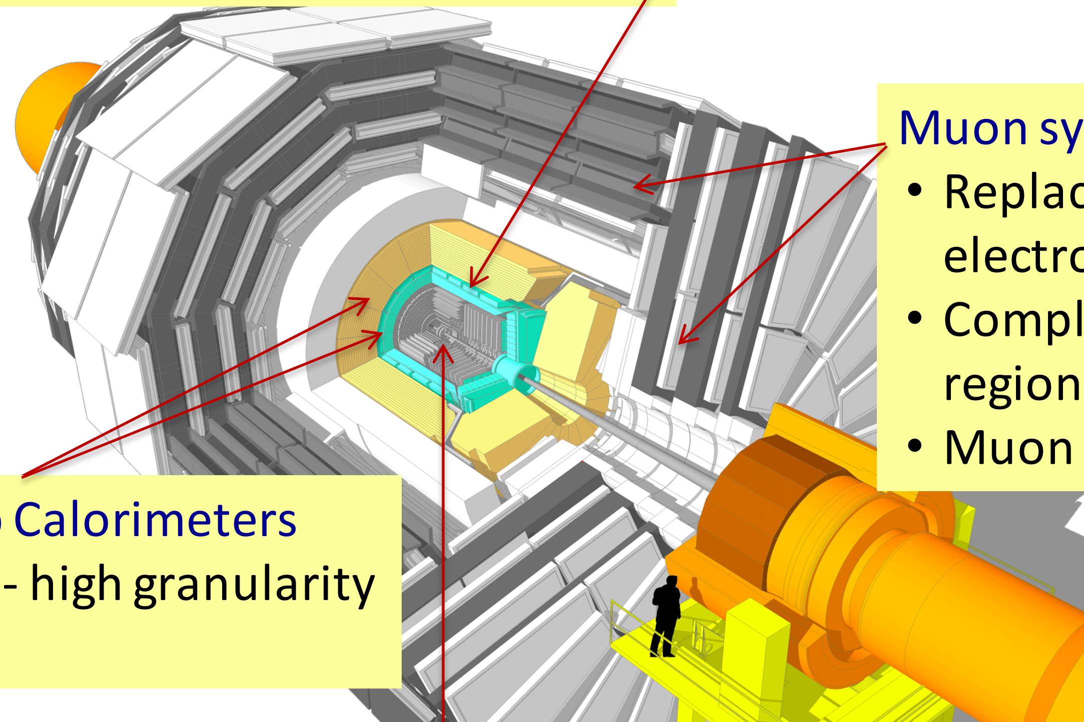
- Full Technical Proposal documenting $3ab^{-1}$ physics, need for upgrades, conceptual design, and detailed performance studies, submitted to LHCC in June 2015.
- And extensive studies of detector performance at 200PU
  Including detailed simulations and evaluation of costs
- Approved at last Week Resource Review Board: **our upgrade is now a project**



Summary of the CMS upgrades for Phase-II

Trigger/HLT/DAQ
- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≃7.5 kHz

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperature (8◦)

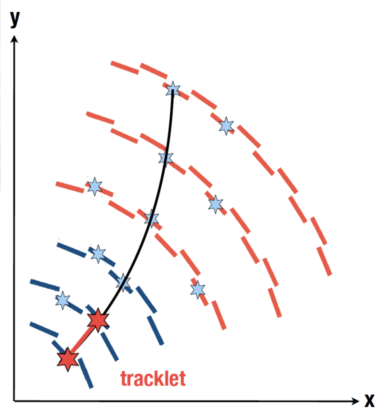


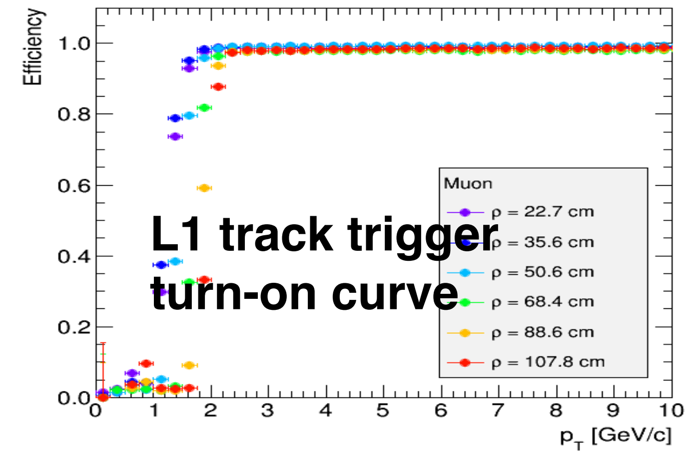
Muon systems
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region 1.5 < η < 2.4
- Muon tagging 2.4 < η < 3

Replace Endcap Calorimeters
- Rad. tolerant - high granularity
- 3D capability

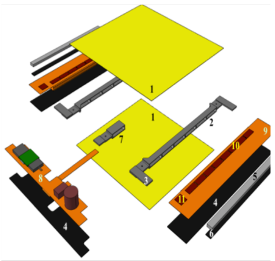
Replace Tracker
- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger
- Extend coverage to η = 3.8

Trackers

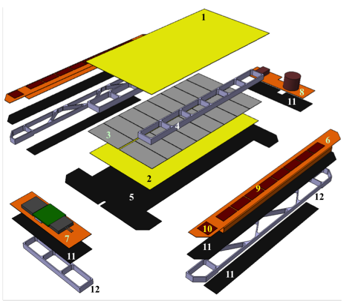


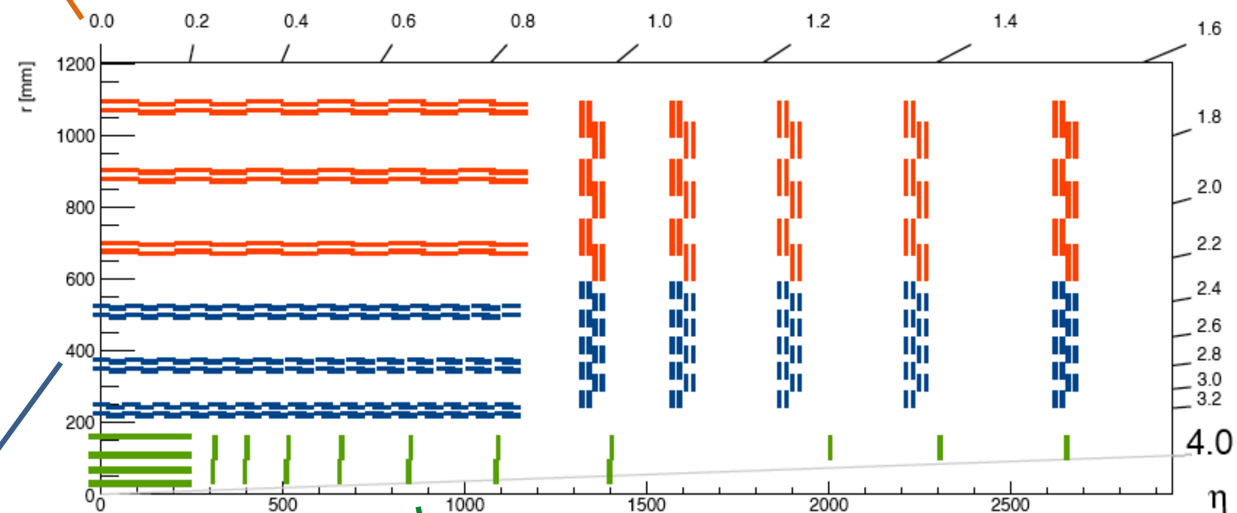


Strip/Strip Modules
90µm pitch / 5cm length



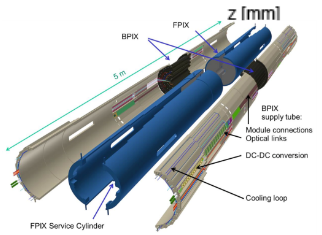
New: tracking triggering at first level (pt>2 GeV)





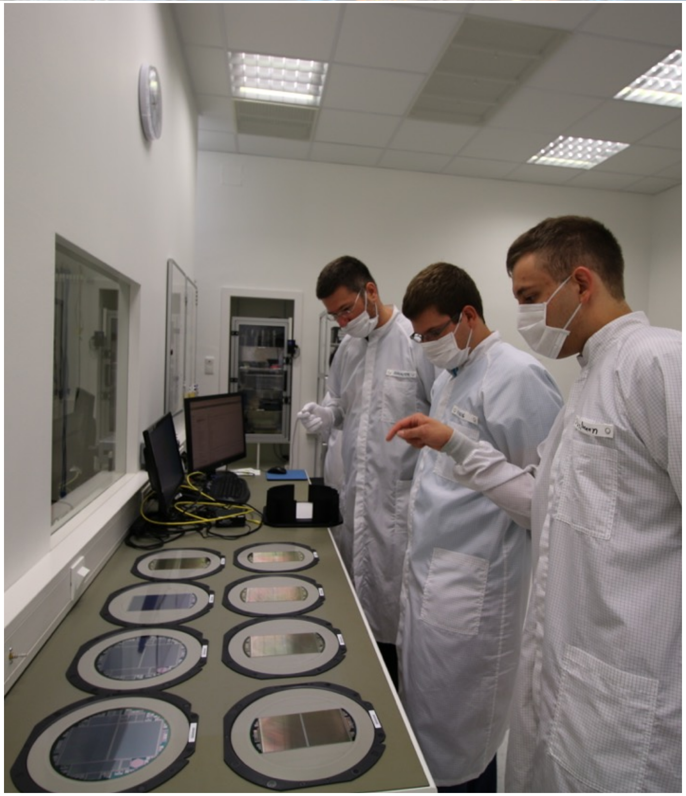
Strip/Pixel Modules
100µm pitch / 2.5cm length
100µm x 1.5 mm “macropixels”

Inner Pixel
Covers up to η=4.0



Phase 2 Tracker Upgrade

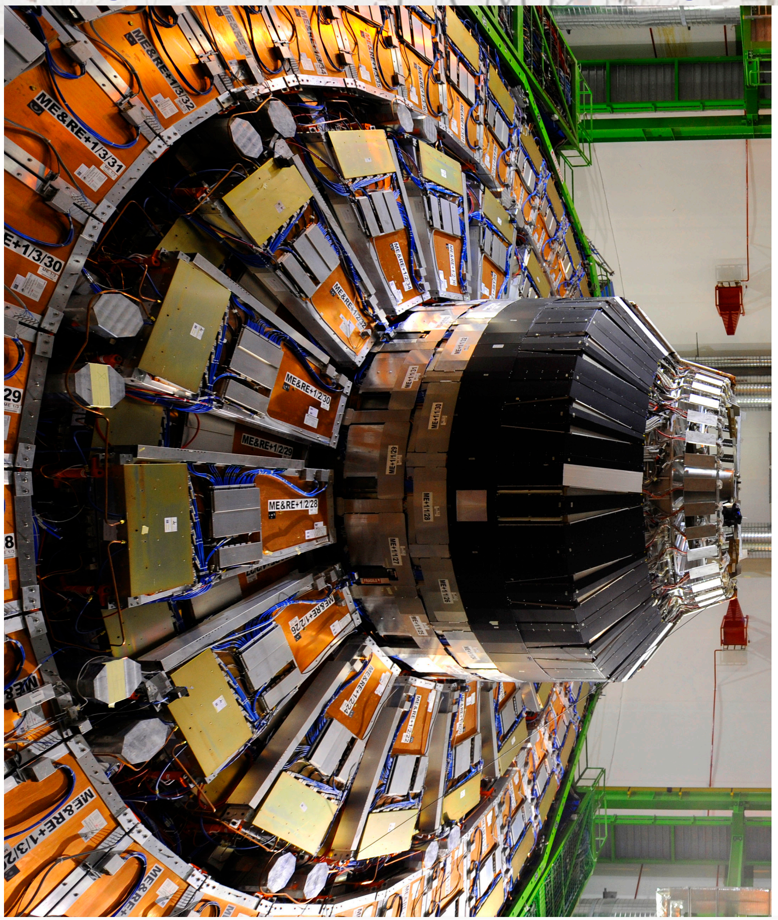
- 8 Inches wafer becoming a reality: a world first for Si trackers
- Second vendor is being qualified: the sensors are in Vienna being tested… first news are good
- HighGranularityCalo like diodes also on Wafer

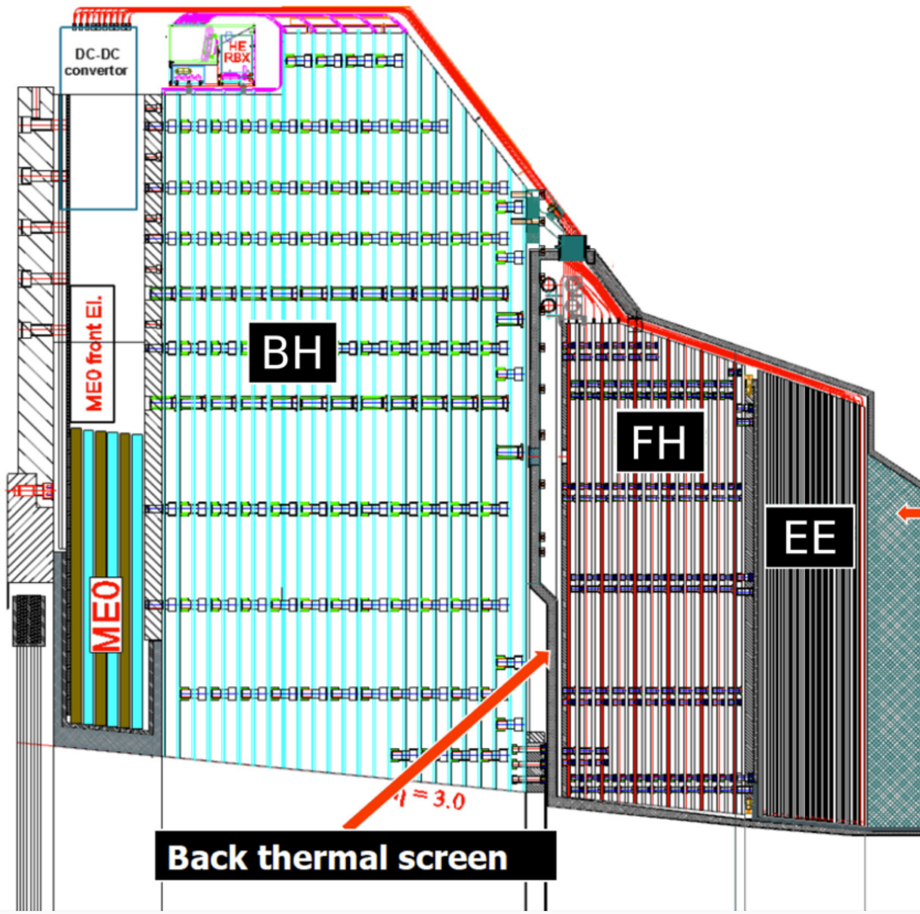


First batch of strip sensors on 200μm thin, 8-inch wafers is here!

Phase II Endcap Calorimeter Upgrade

High Granularity and Backing Calorimeter



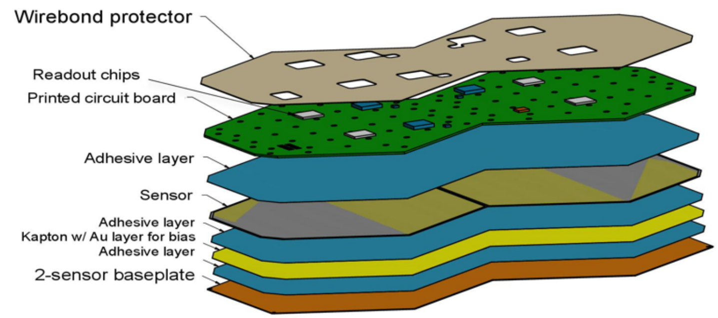


46 Institutions involved of which 20 are from the USA

University of Alabama, Baylor University, Boston University, Brown University, University of California – Davis, University of California – Santa Barbara, Carnegie Mellon University, University of Iowa, Fairfield University, University of Florida, Florida Institute of Technology, Florida International University ,FNAL, University of Maryland, Massachusetts Institute of Technology, University of Minnesota, University of Notre Dame, Northwestern University, University of Rochester, Texas Tech University

ENDCAP Calo:

Design with two 6” sensors



A challenging detector :

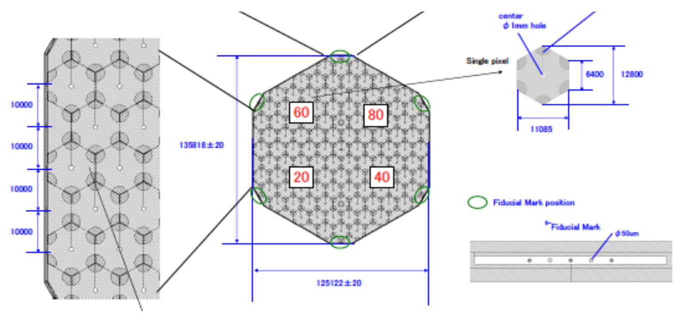
- Sensors and front-end electronics have to withstand fluxes of charged and neutrons in excess of 10^{15} /cm2
- Front end electronics power budget < 10 mWatts
- 660 m^2 of silicon

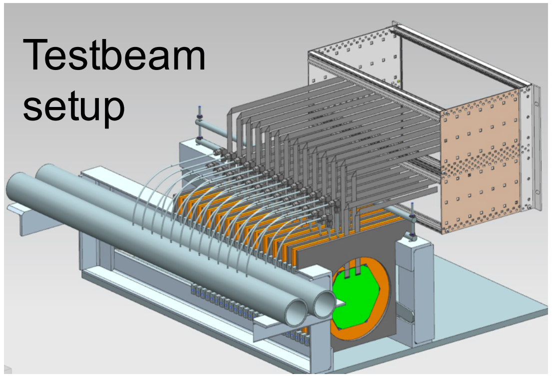
Test Beam: at FNAL and CERN during 2016

using Skiroc1 readout

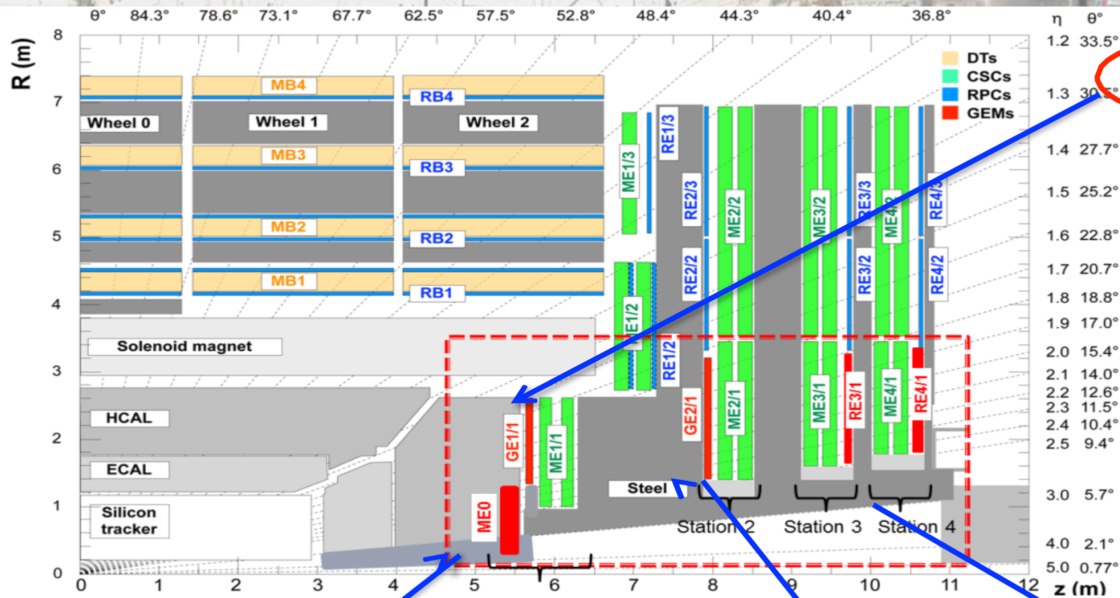
Front End : Final Design: progressing– plan to submit “test vehicles” Q1-16

Sensor design





Forward muon system enhancement



GE1/1:

Trigger and reconstruction

- 1.55 < |η| < 2.18
- **baseline detector for GEM project**
- 36 staggered super-chambers (SC) per endcap, each super-chamber spans 10°
- One super-chamber is made of 2 back-to-back triple-GEM detectors
- Installation: LS2 (2018-19)

ME0:

- **Muon tagger** at highest η
- **6 layers of Triple-GEM**
- each chamber spans 20°
- Installation: LS3 (2022-24)

GE2/1:

Trigger and reconstruction

- 1.55 < |η| < 2.45
- 18 staggered SC per endcap, each chamber covers 20°, **3.5 x GE1/1 area**
- Installation: LS3 (2022-24)

RE 3/1 –RE4/1 :

Trigger and reconstruction

- 1.8 < |η| < 2.4
- **Improved RPC (iRPC), finer pitch**
- 18 chambers per endcap, each chamber spans 20°
- Installation: LS3 (2022-24)

LHC High Luminosity:

aim is to reach beyond the standard model

Beyond the Std Model theories

Relations between theory and experiment (as seen by theorists)

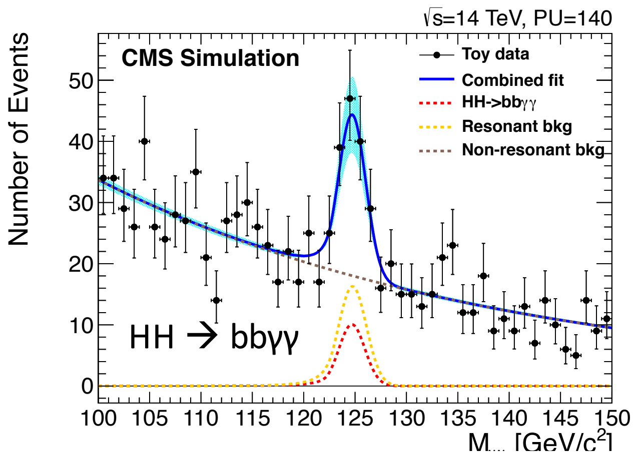
A defendable picture when you have very tight predictions: e.g. BEH boson, rare decays rate

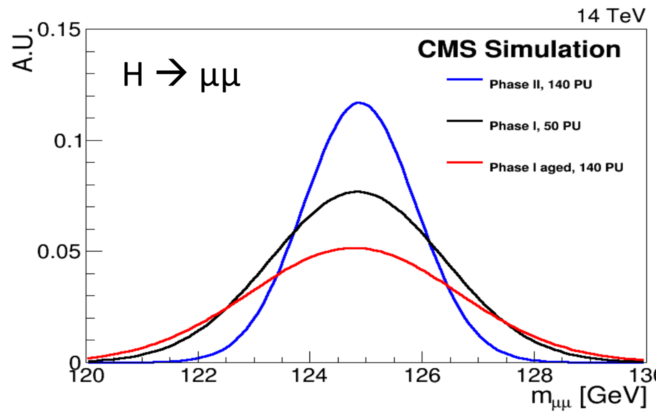
Courtesy of H. Yamamoto

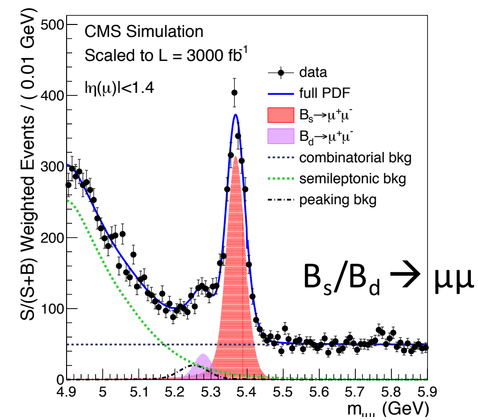
..as seen by experimentalists

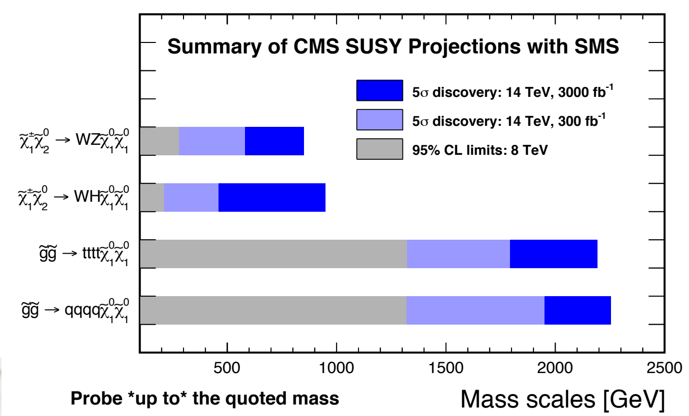
Phase II upgrade: physics reach examples

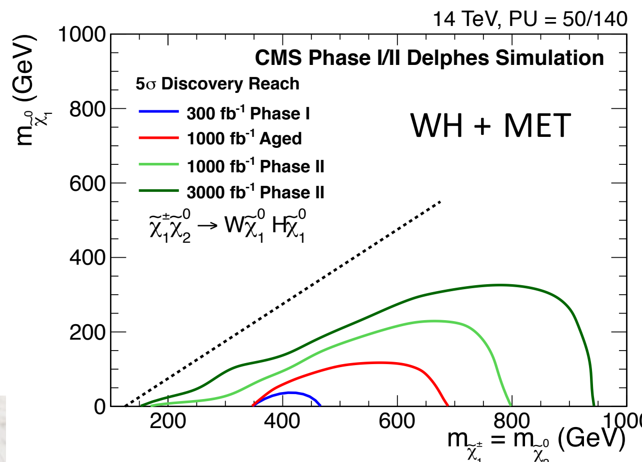
- Studies in TP establish upgrades required due to longevity issues or to the increased data rates
- TP presents physics reach with upgrades in several thematic areas of the physics program

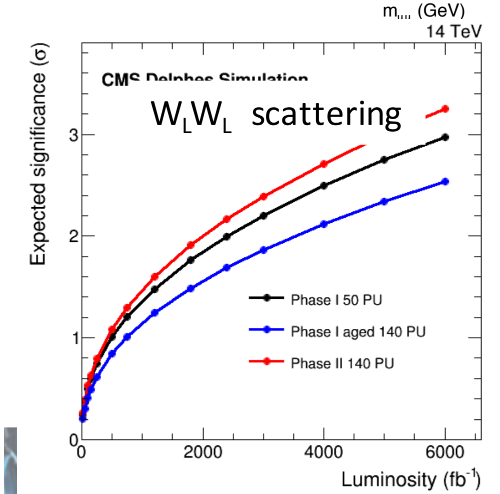












Phase II upgrade: physics reach examples

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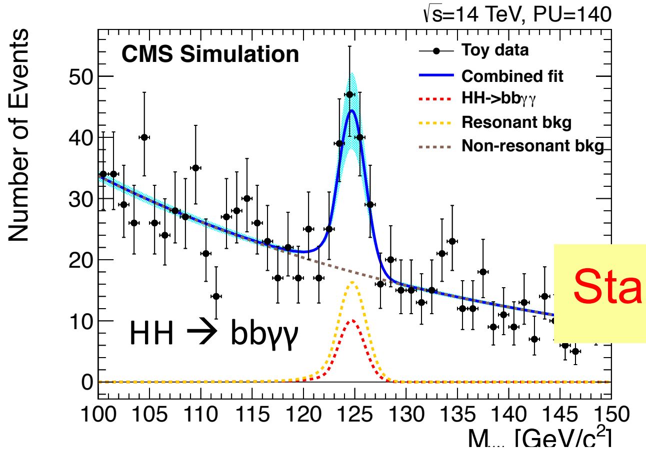
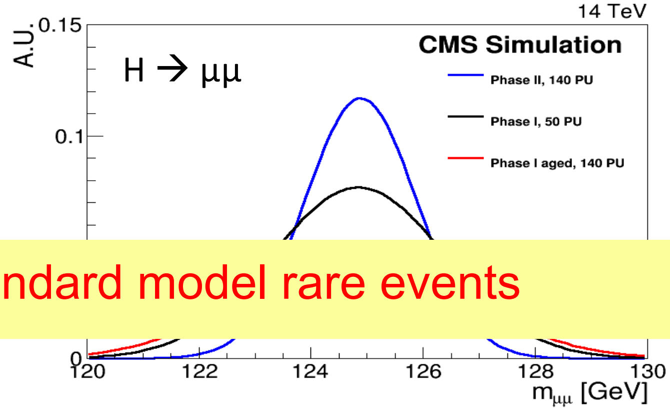
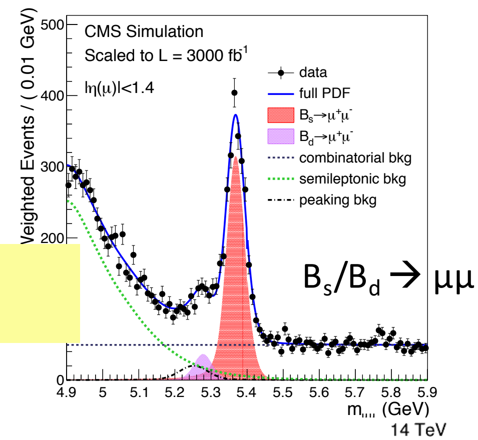
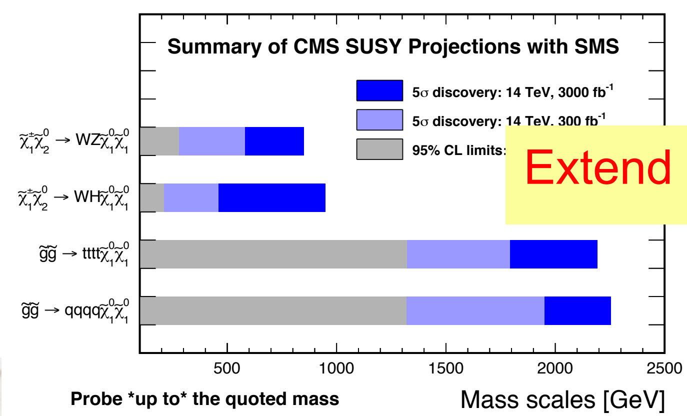
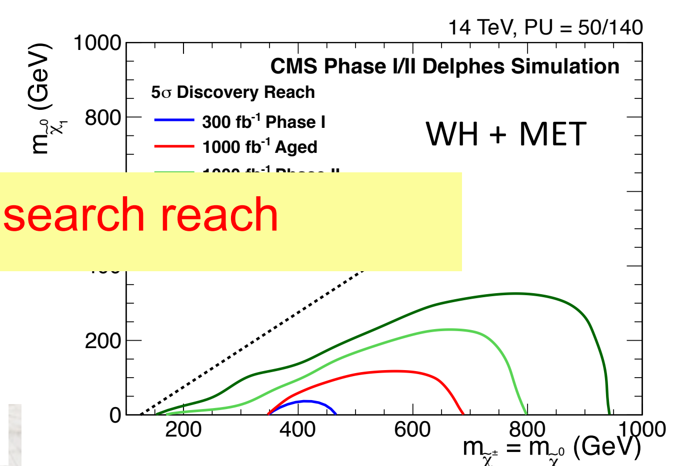




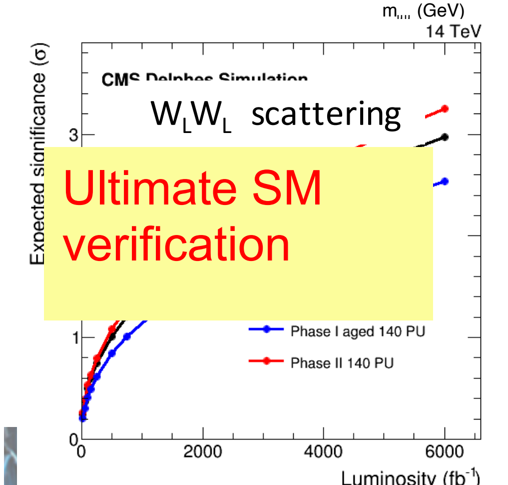


Standard model rare events





Extend search reach



Ultimate SM verification

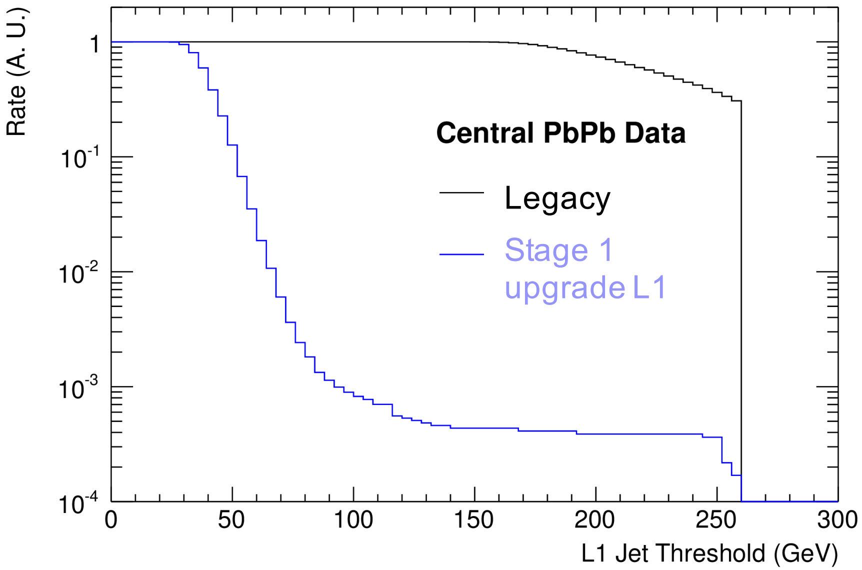
Discovery could come late

Analysis	luminosity (fb^{-1})	Model NM1	NM2	NM3	STC	STOC
all-hadronic (HT-MHT) search	300				$< 3\sigma$	$3-5\sigma$
	3000				$> 5\sigma$	$> 5\sigma$
all-hadronic (MT2) search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$		
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$		
all-hadronic $\tilde{b}_1$ search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$> 5\sigma$	$< 3\sigma$
	3000	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$> 5\sigma$	$< 3\sigma$
1-lepton $\tilde{g}/\tilde{t}_1$ search	300	$3-5\sigma$	$3-5\sigma$	$3-5\sigma$	$< 3\sigma$	
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$< 3\sigma$	
monojet $\tilde{t}_1$ search	300					$3-5\sigma$
	3000					$> 5\sigma$
$m_{\ell^+\ell^-}$ kinematic edge	300	$< 3\sigma$				
	3000	$> 5\sigma$				
tri-lepton search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	
	3000	$3-5\sigma$	$3-5\sigma$	$< 3\sigma$	$3-5\sigma$	
tri-leptons + b-tag search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	
EWKino WH search	300		$< 3\sigma$			
	3000		$3-5\sigma$			

$< 3\sigma$	$3-5\sigma$	$> 5\sigma$

Back to the present: the year is not over yet

- Heavy Ions: CMS presented six new results at Quark Matter 2015 (from quenching of charm-tagged jets to collective flow measurements)
- Even more, the upcoming Heavy Ion run will be very special: the increased capability of the new calorimeter trigger will allow CMS to continue its full exploitation of the HI beams at the higher luminosities expected.



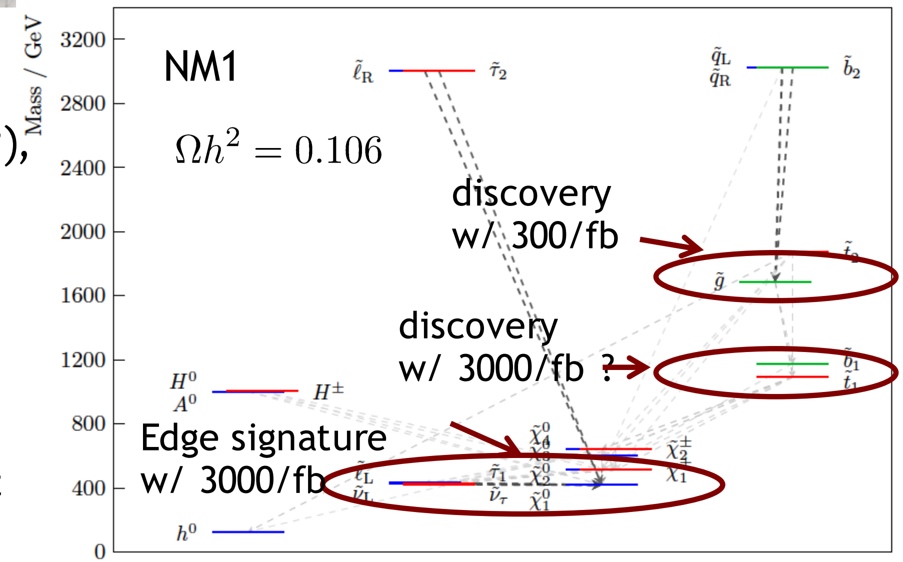
In Summary

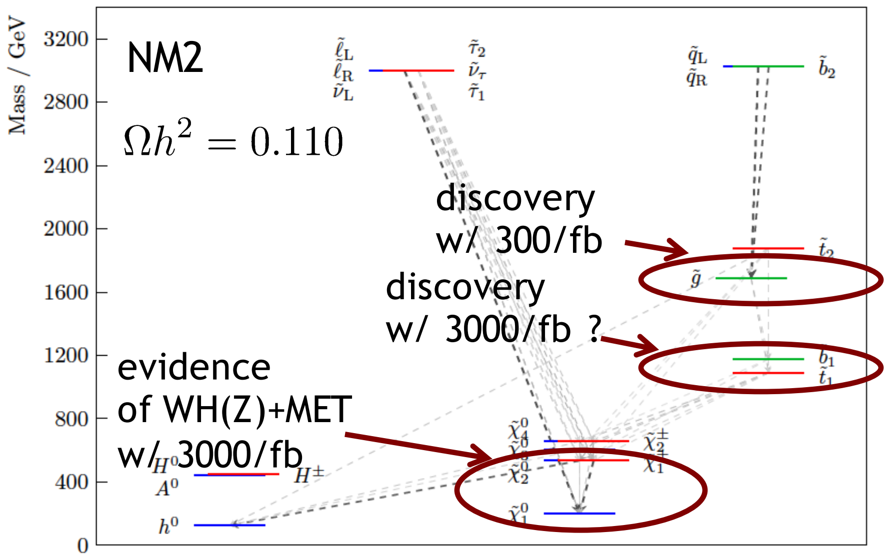
- Run I: an incredible feat. How often does one discover a fundamental aspect of Nature? **We did.**
- We are now in continuous improvement mode. Run II already required
  - A number of upgrades during LS1
  - PLUS Phase I upgrade
- A most exciting time, thanks to the 13 TeV
- Longer term: full exploitation of the LHC is the highest priority in HEP
  - It is necessary to upgrade CMS. Full upgrade program defined in Technical Proposal and we are approved now
- We "just" have to carry out these 2.5 experiments.
  - Run II our highest priority. Next: launch/secure Phase II.
  - Perhaps we'll find something.

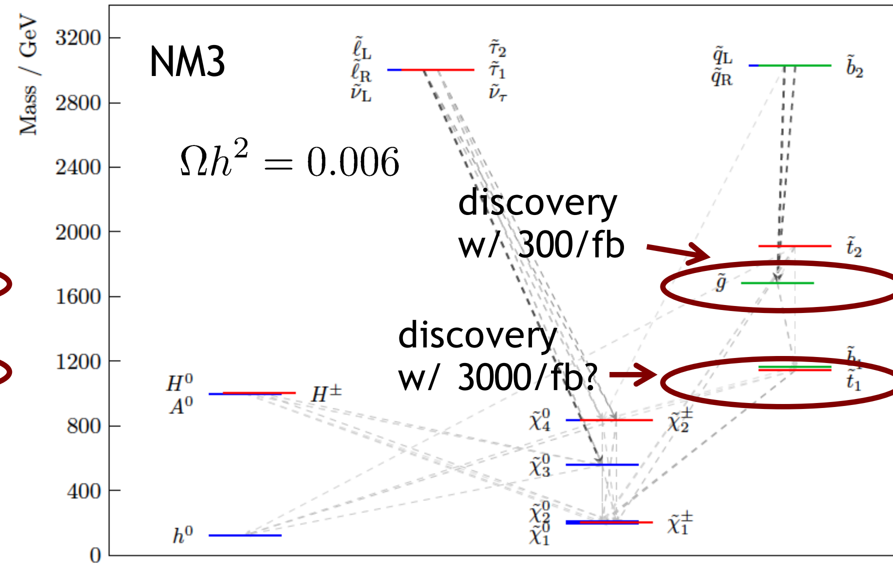
Backup

Possible discovery stories: Natural models

- Gluino mass 1.7 TeV (to be discovered with 300/fb)
- Stop mass 1.1 TeV (discovered with 3000/fb?), sbottom slightly higher
- Weakly interacting sector:
  - NM1: Bino-LSP, Wino-NLSP, sleptons inbetween N1 & N2 → edge signature; lepton-rich final states
  - NM2: Bino-LSP, Wino-NLSP, sleptons at high masses, WH(Z)+MET





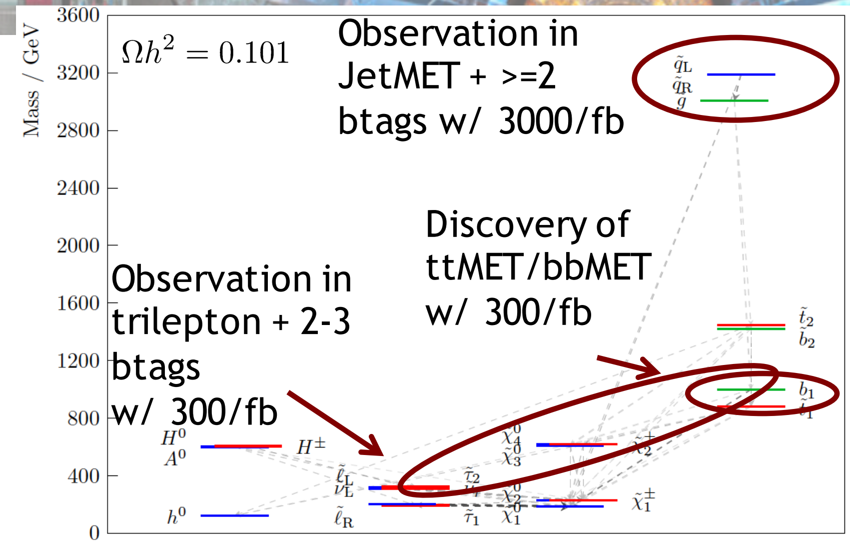


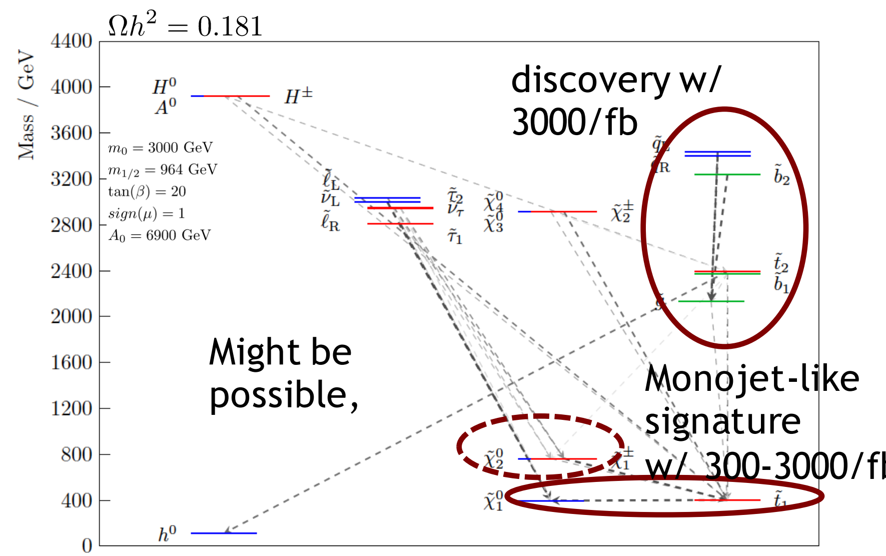
Possible discovery stories: Coannihilation Models

Coannihilation= almost degeneracy between LSP and NSLP

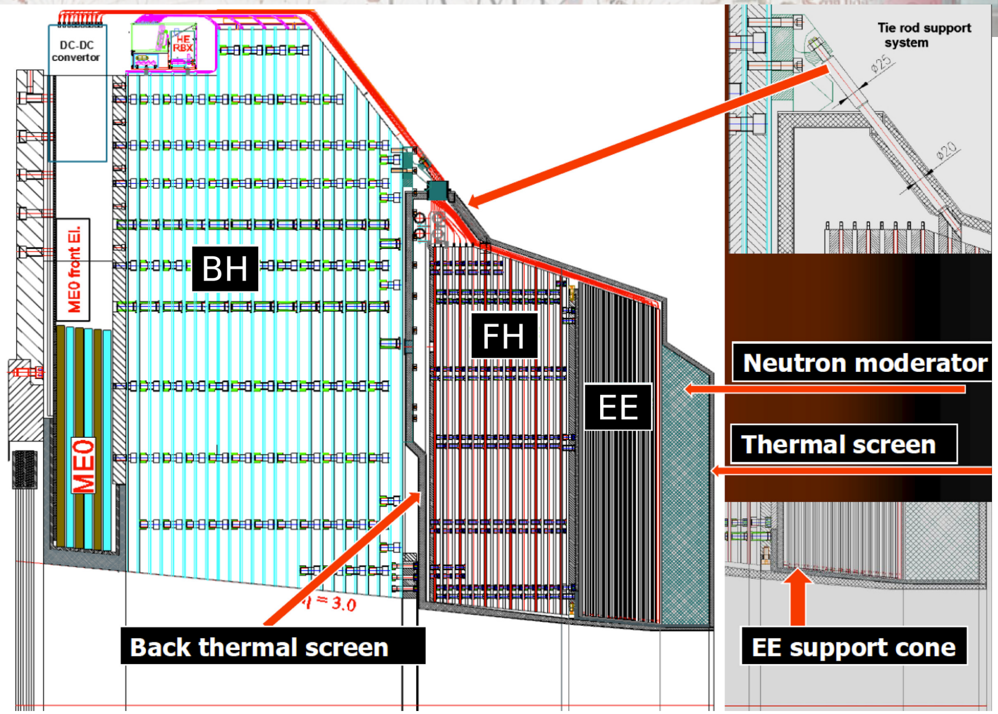
- Stau coannihilation model
  - Excess in tt+MET and bb+MET final states to be discovered with 300/fb
  - Observation of trileptons with 2-3 b-tags indicates the complex weakly interacting sector (produced in strong interaction)
  - >3 TeV gluino/squarks still discoverable with HL-LHC

- Stop coannihilation model
  - Compressed stop [$\Delta m(t_1, N1)$ =6 GeV], evidence in monojet search with 300/fb, growing to 5σ with 3000/fb
  - Jets+MET + btags: clear signal with 3000/fb
    - B-tag multiplicities → branching fraction of gluinos
    - Jet multiplicities suggest the existence of 1st and 2nd generation squarks





Conceptual Design



Construction:

- *Hexagonal Si-sensors built into modules.*
- *Modules with a W/Cu backing plate and PCB readout board.*
- *Modules mounted on copper cooling plates to make wedge-shaped cassettes.*
- *Cassettes inserted into absorber structures at integration site (CERN)*

Key parameters:

- *593 m^2 of silicon*
- *21,660 modules*
- *92,000 front-end ASICS.*
- *Power at end of life 115 kW.*

System Divided into three separate parts:

EE – Silicon with tungsten absorber – 28 sampling layers – 25 X_o + ~1.3 λ

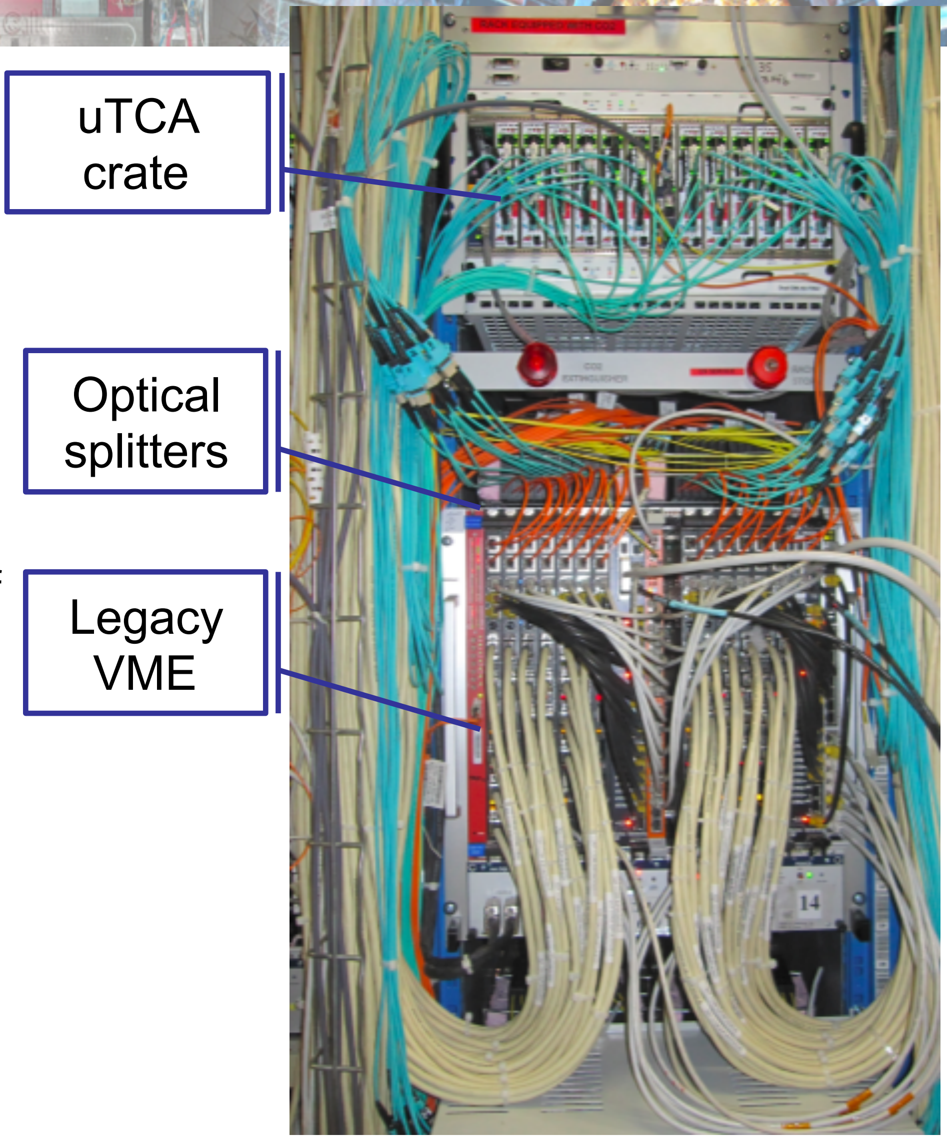
FH – Silicon with brass absorber – 12 sampling layers – 3.5 λ

BH – Scintillator with brass absorber – 11 layers – 5.5 λ

EE and FH are maintained at – 30°C. BH is at room temperature.

HCAL Phase 1 upgr: Back-end

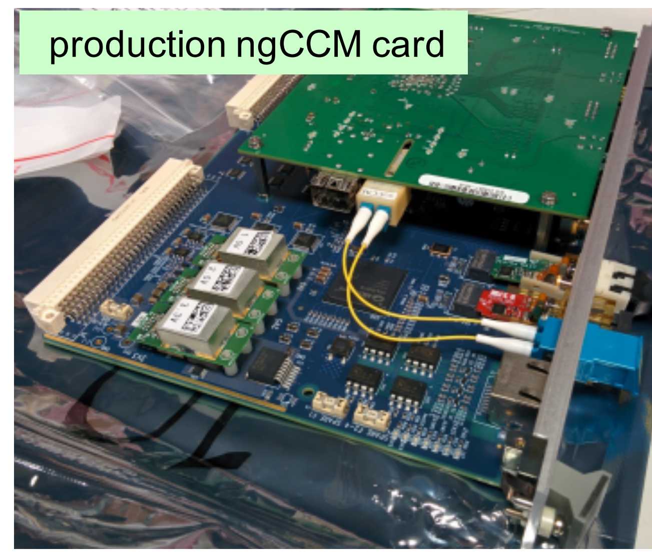
- Installation of Phase-1 uTCA back-end complete
  - 3 uTCA crates for HF, 9 for HBHE
  - Assembly of spares is being completed
- For HF, the uTCA is in use for data taking
- All HBHE frontend fibers are now split to feed both legacy VME and uTCA back-ends
  - VME used for CMS data taking until end of 2015
  - uTCA is used parasitically during the rest of 2015 to commission phase-1 L1 trigger (HBHE uHTR trigger firmware has been in use since July)
- Planning remaining commissioning steps for HBHE uTCA back-end to become the CMS data taking system of 2016
  - Work to be done together with L1 trigger and central DAQ over next few months



HCAL Phase 1 upgr: HF Front-end

- Hardware
  - Crates and backplanes (Brazil) production complete. All crates and backplanes are at CERN.
  - ngCCM (Maryland/Virginia) production complete, enough cards at CERN for entire system.
  - QIE cards (Turkey): Production <u>completed</u>.
  - Adapter cards (Fermilab): All received and tested.
- Facilities
  - Building 904 – Ready to do the front-end system burn-in.
  - P5 – A "Pilot" HFcrate, to test radiation environment and with the P5 TCDS system
  - CHARM facility - An irradiation test October 20.
- Potential Issue: VTTx (CERN)
  - 20 VTTx modules are now ready for us (as well as 25 SM VTRx).
  - Delivery of full pre-production quantity: mid-Nov seems feasible – this is the latest date to still allow installation
- Factorized Installation
  - Planning for full **electronics** installation during YETS 2015/16.
  - **PMT box rework** may be delayed into EYETS 2016/17: Parts are ready, but concern that work+commissioning may hamper early 2016 physics

production QIE card



production ngCCM card