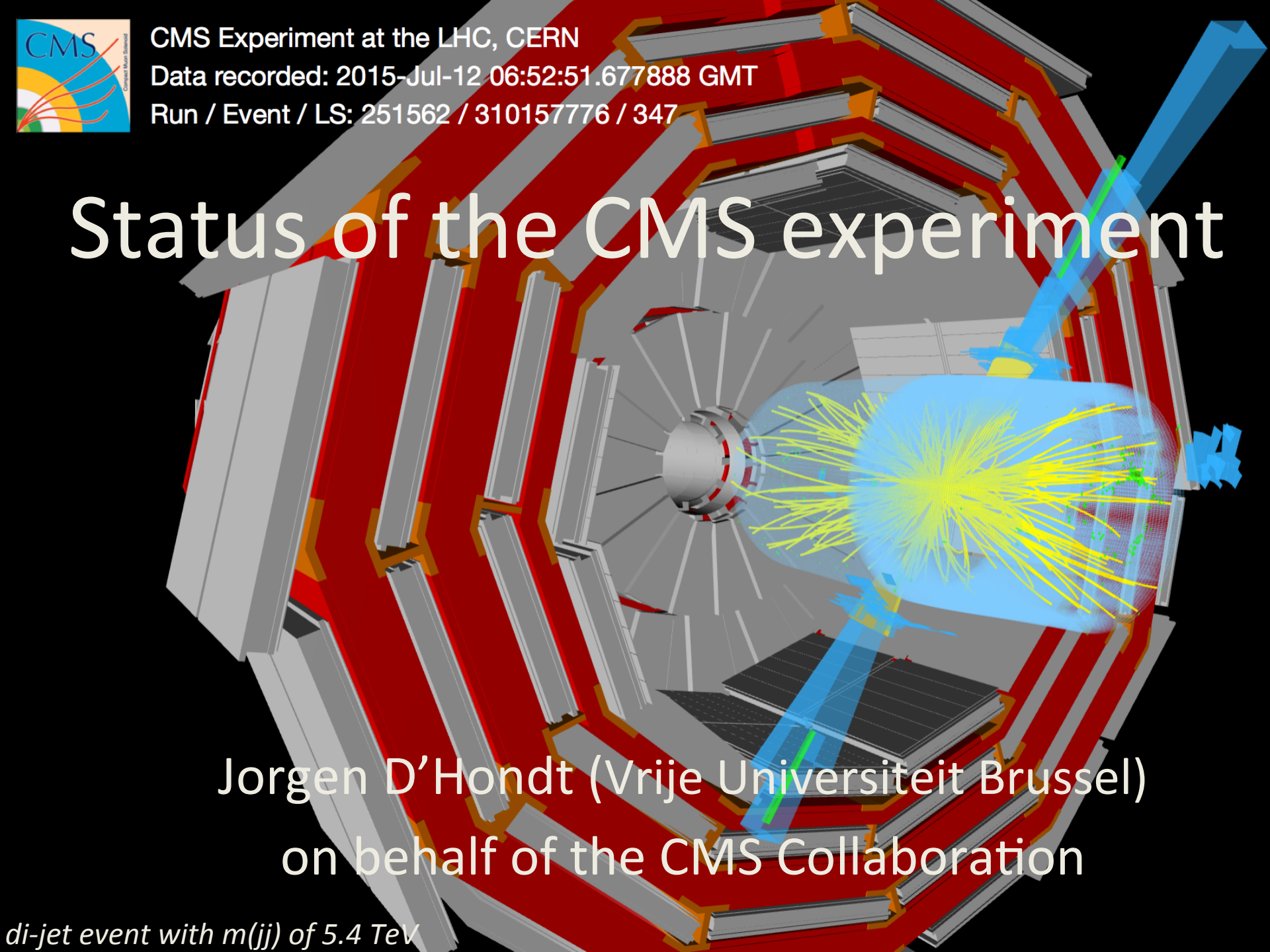
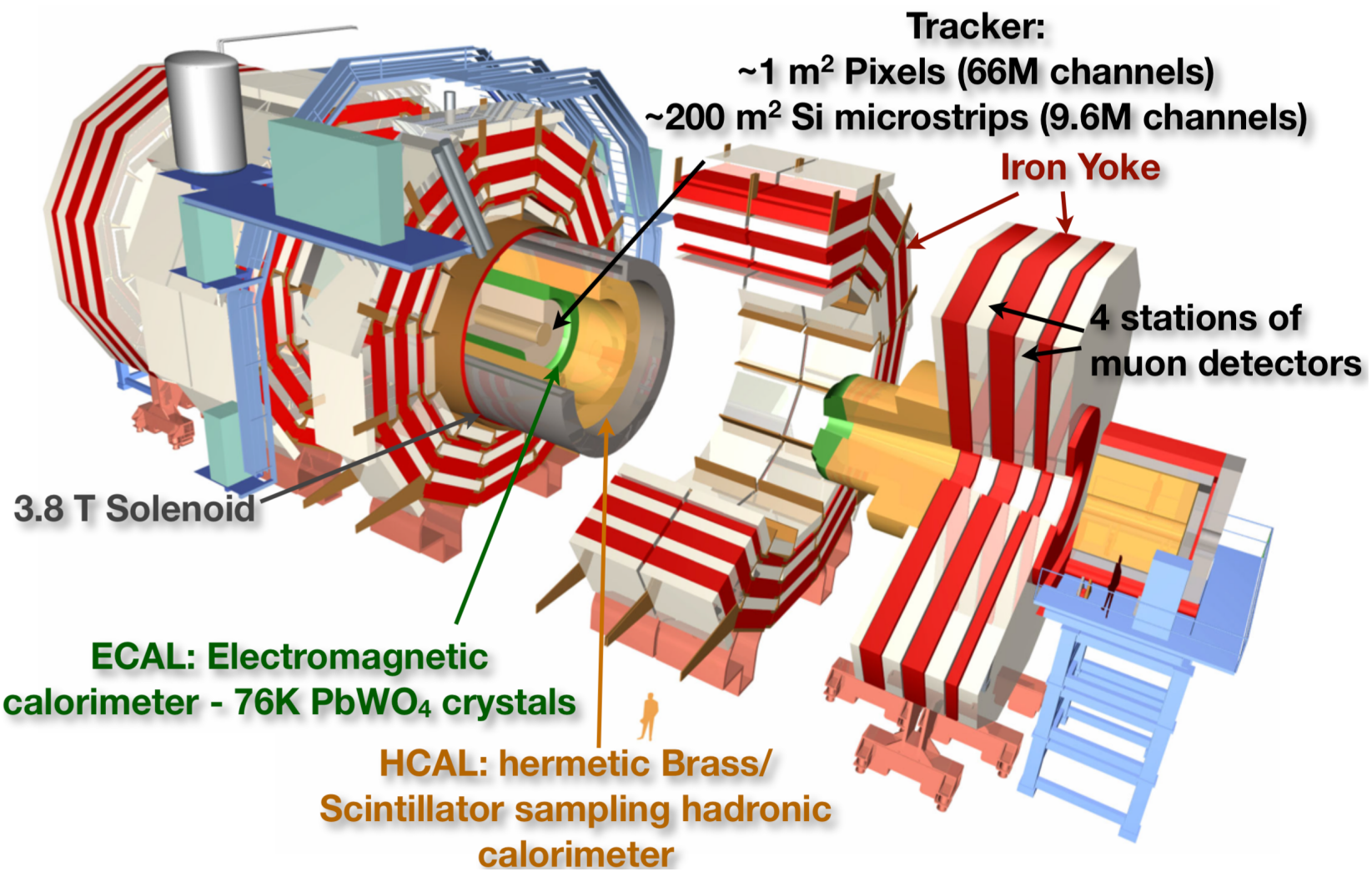


Status of the CMS experiment

Jorgen D'Hondt (Vrije Universiteit Brussel)
on behalf of the CMS Collaboration

di-jet event with m(jj) of 5.4 TeV

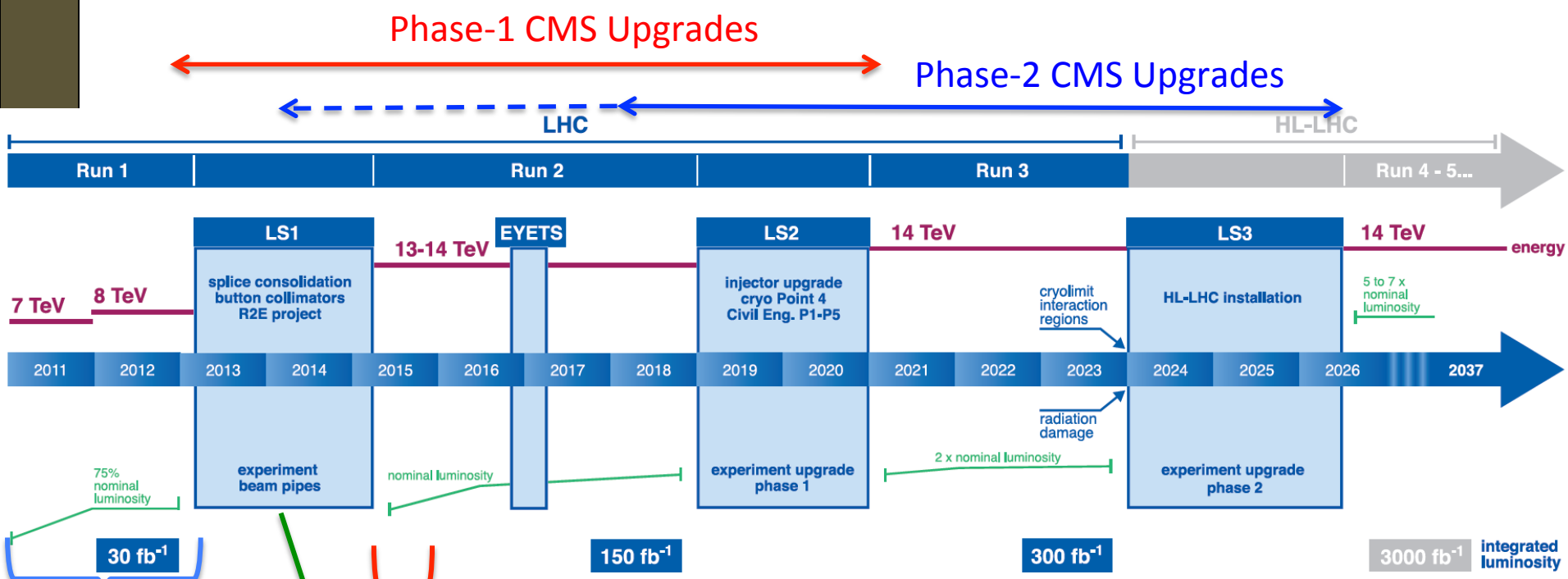
The CMS experiment @ LHC



The CMS Collaboration

Applications from in total 10 new institutions in 2015 from Russia, Ecuador, Hungary, China, Belgium, Korea

Timeline



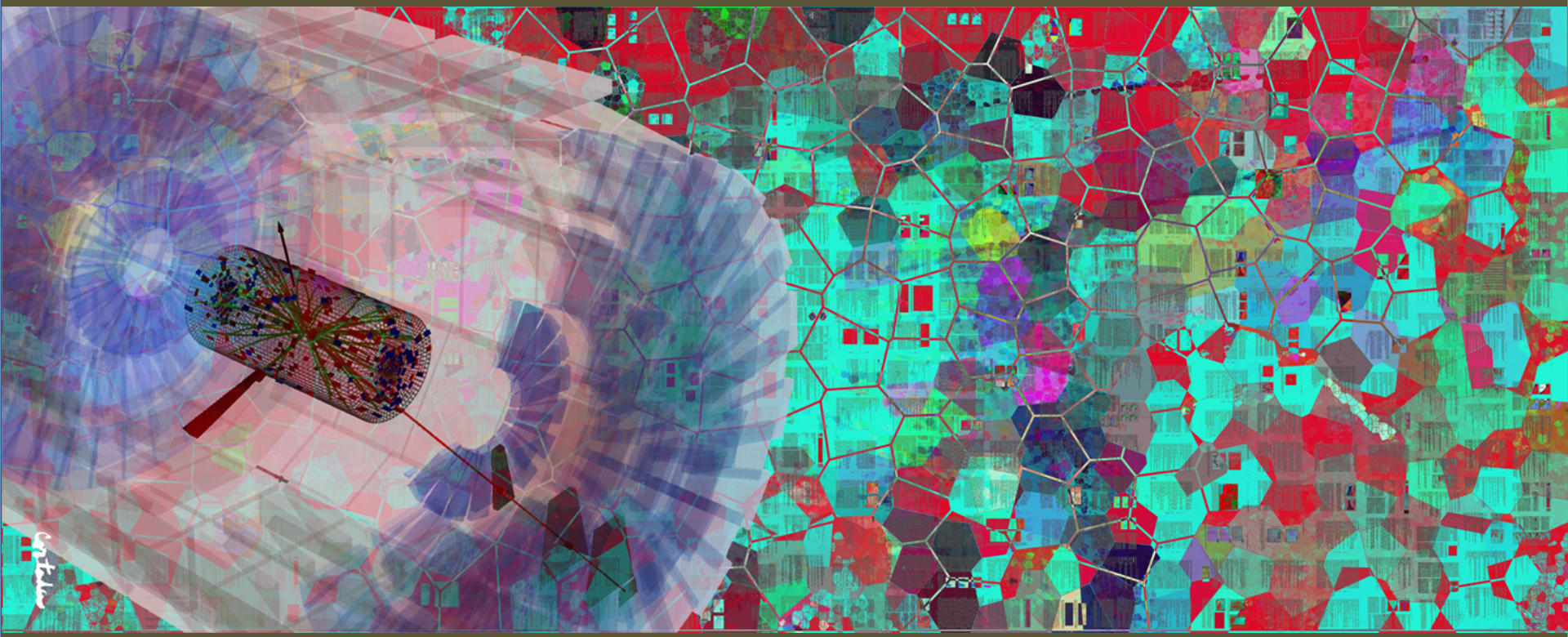
Run-1 highlights

Early Run-2 results

Long Shutdown 1 (LS1) activities

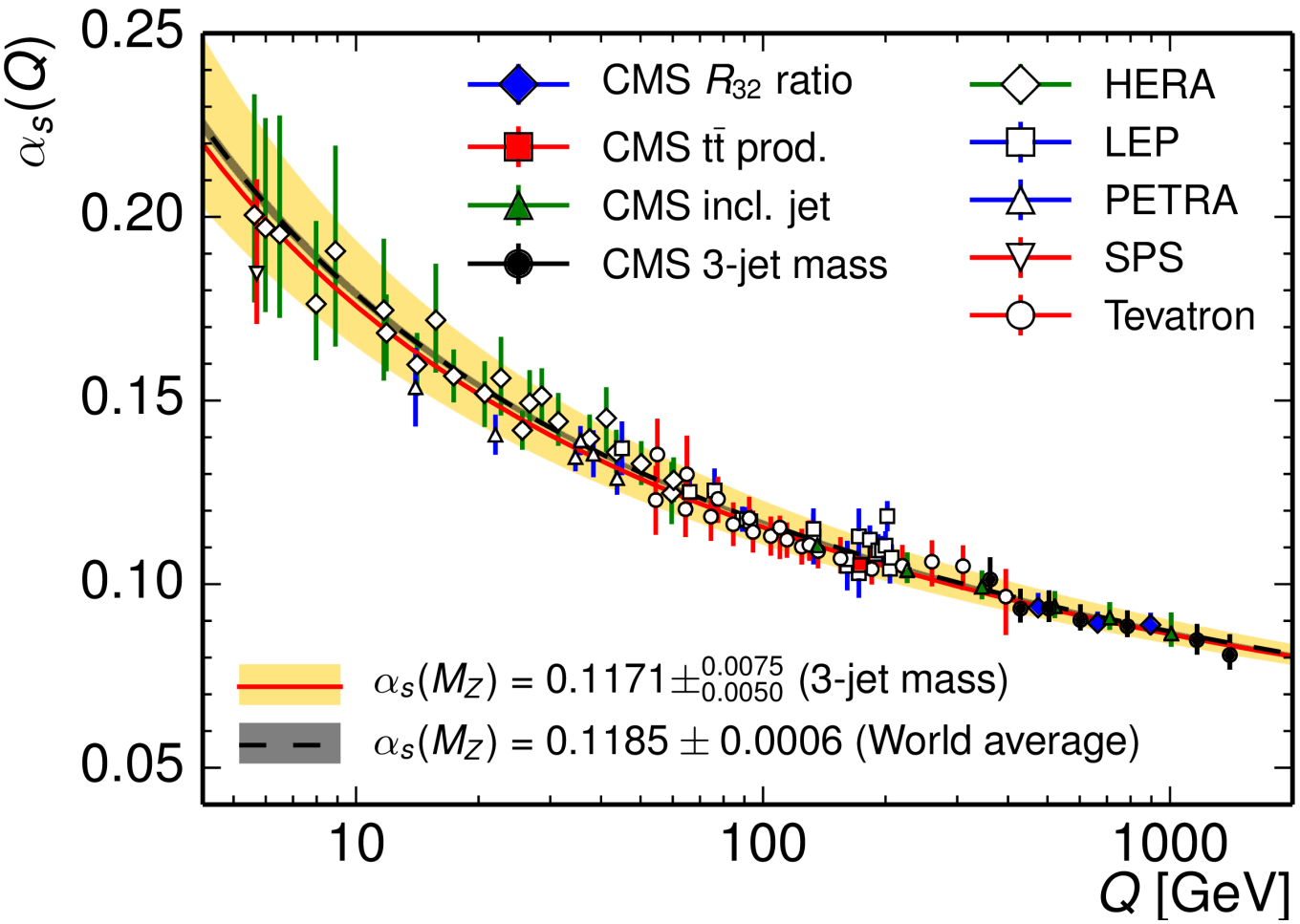
CMS is active on many fronts

Run-1 results at 7 and 8 TeV



Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> WW", digital art, 2013.

The LHC is a QCD machine

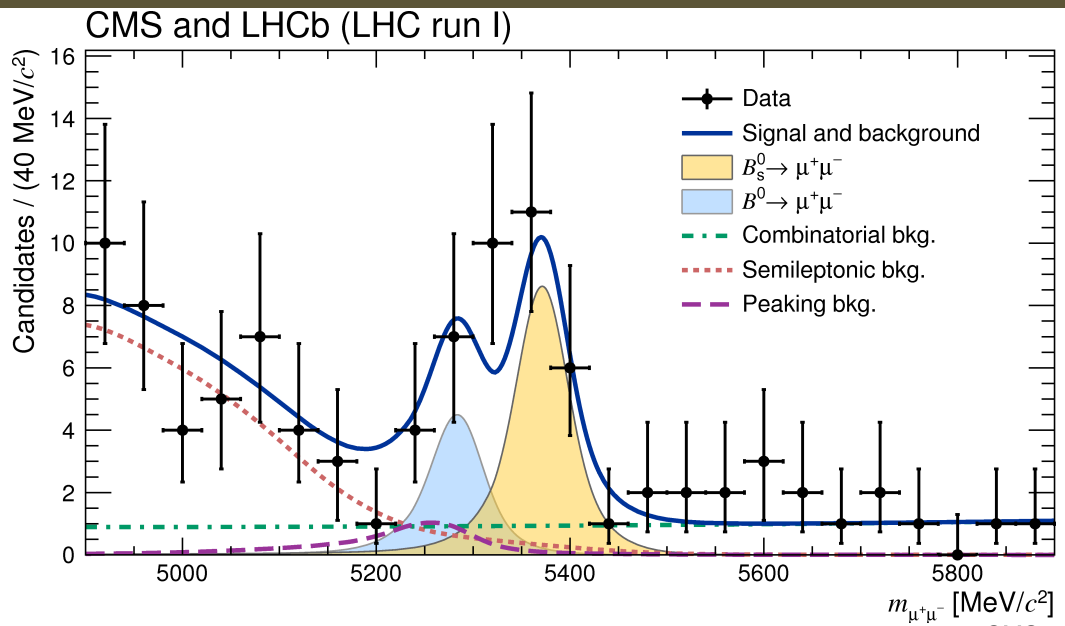


$$\alpha_S(M_Z) = 0.1171 \pm 0.0013\,(\text{exp}) \pm 0.0024\,(\text{PDF}) \pm 0.0008\,(\text{NP}) \,^{+0.0069}_{-0.0040}\,(\text{scale})$$

Eur. Phys. J. C 75 (2015) 186

renormalisation & factorisation

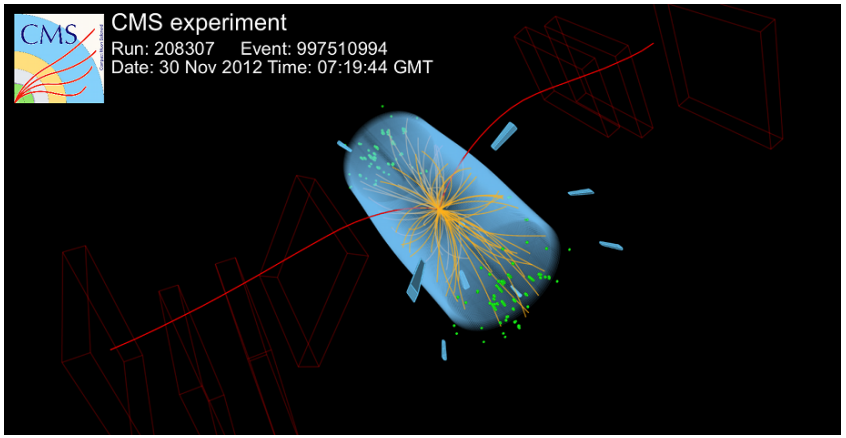
… a B-physics machine

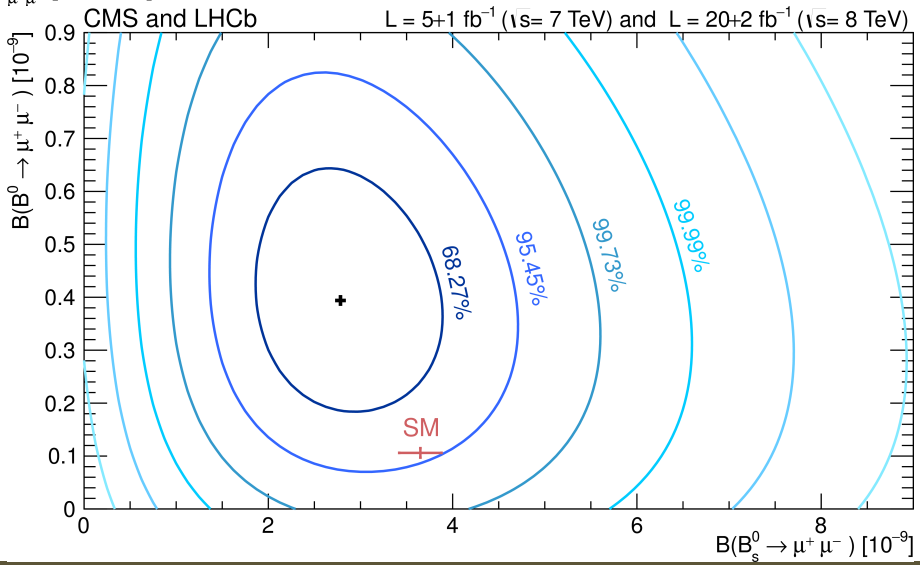


After 3 decades of experiments:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.8\,^{+0.7}_{-0.6}\right) \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(3.9\,^{+1.6}_{-1.4}\right) \times 10^{-10}$$



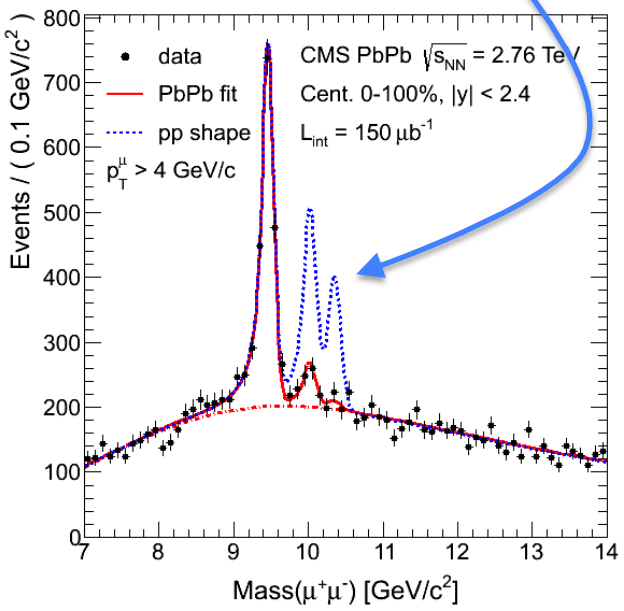


CMS & LHCb, Nature (2015) 14474

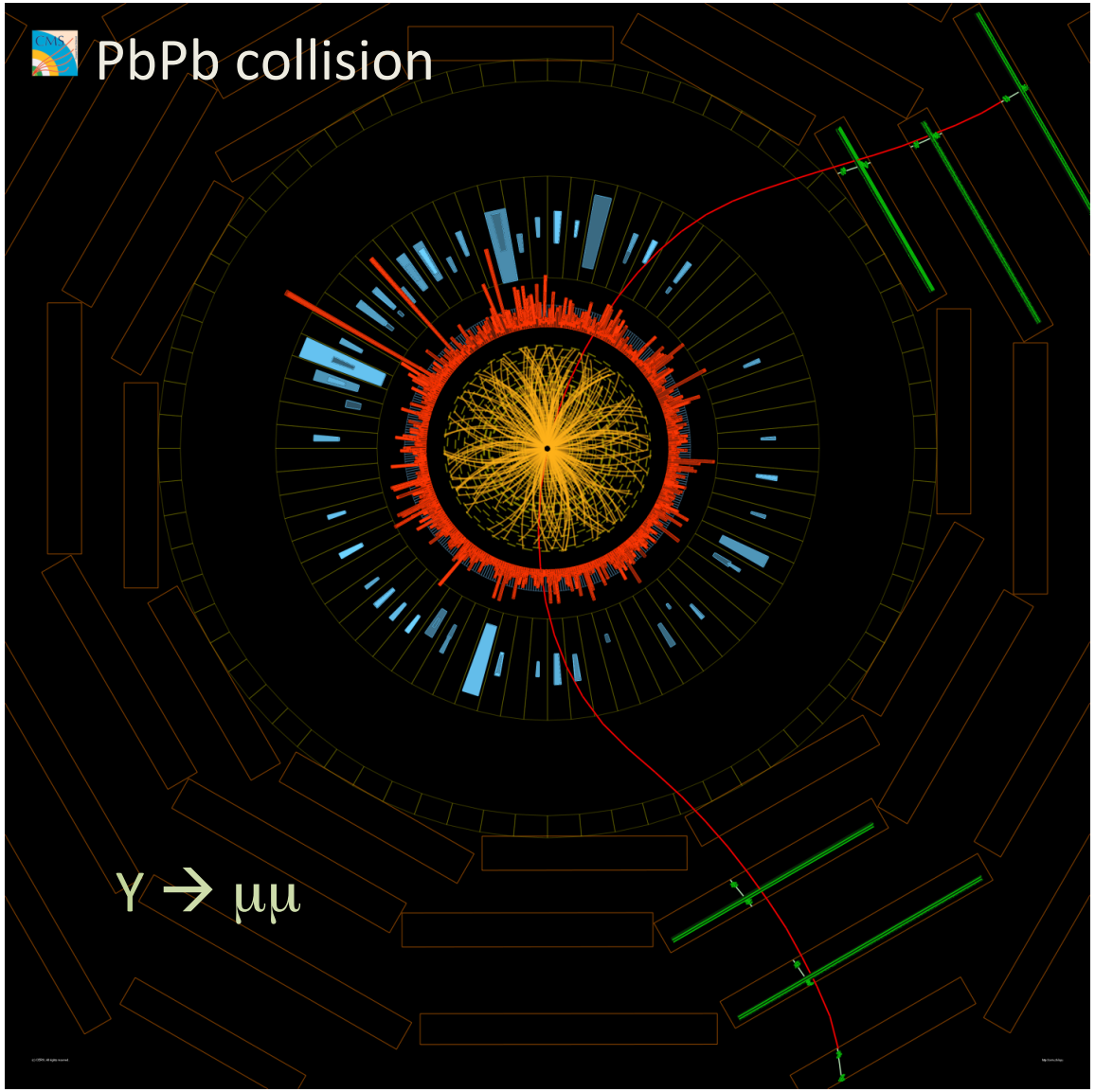
… a Heavy Ion machine

Understanding the properties of the quark-gluon plasma.

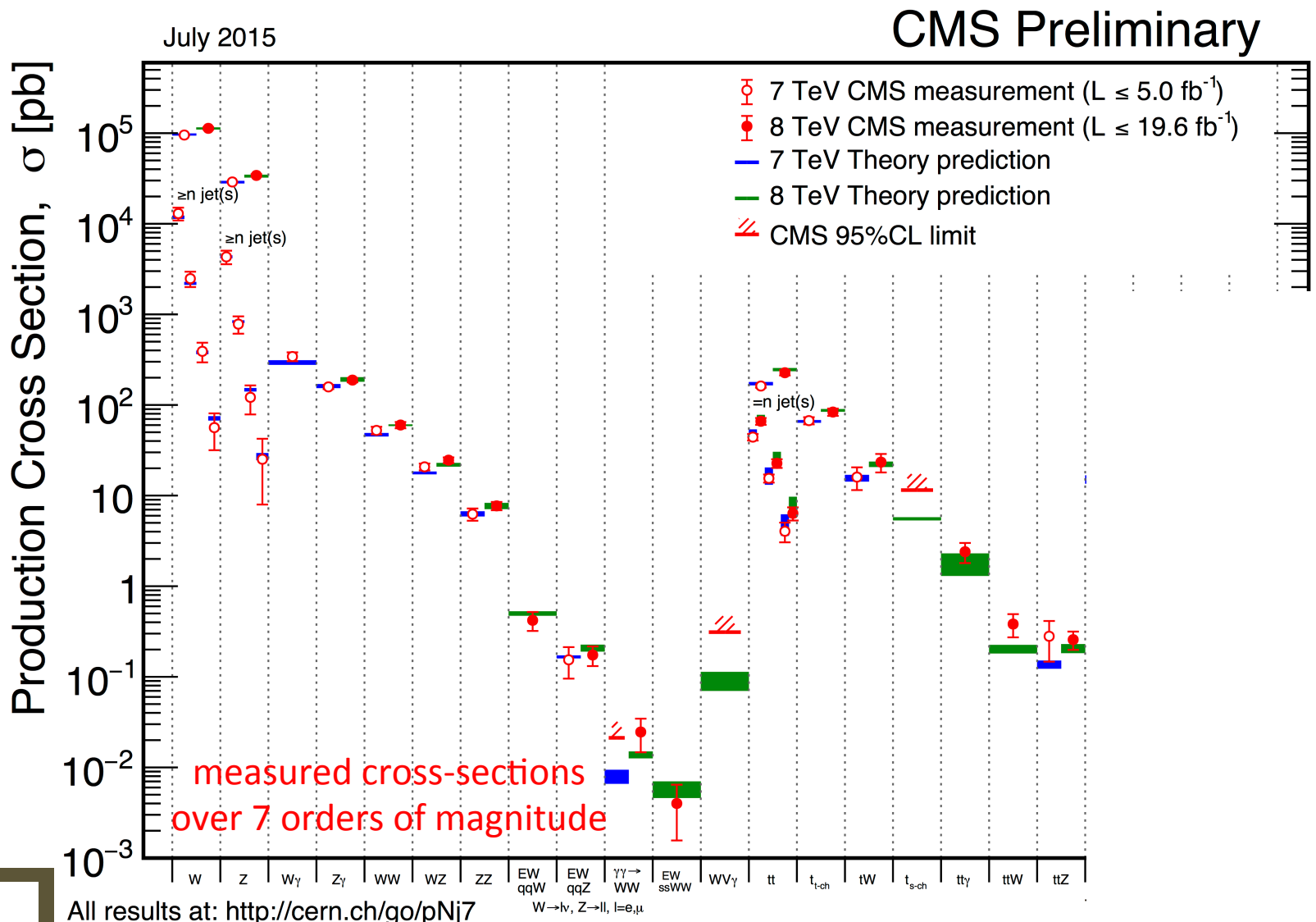
CMS observes melting of Upsilon (Y) particles in heavy-ion collisions.



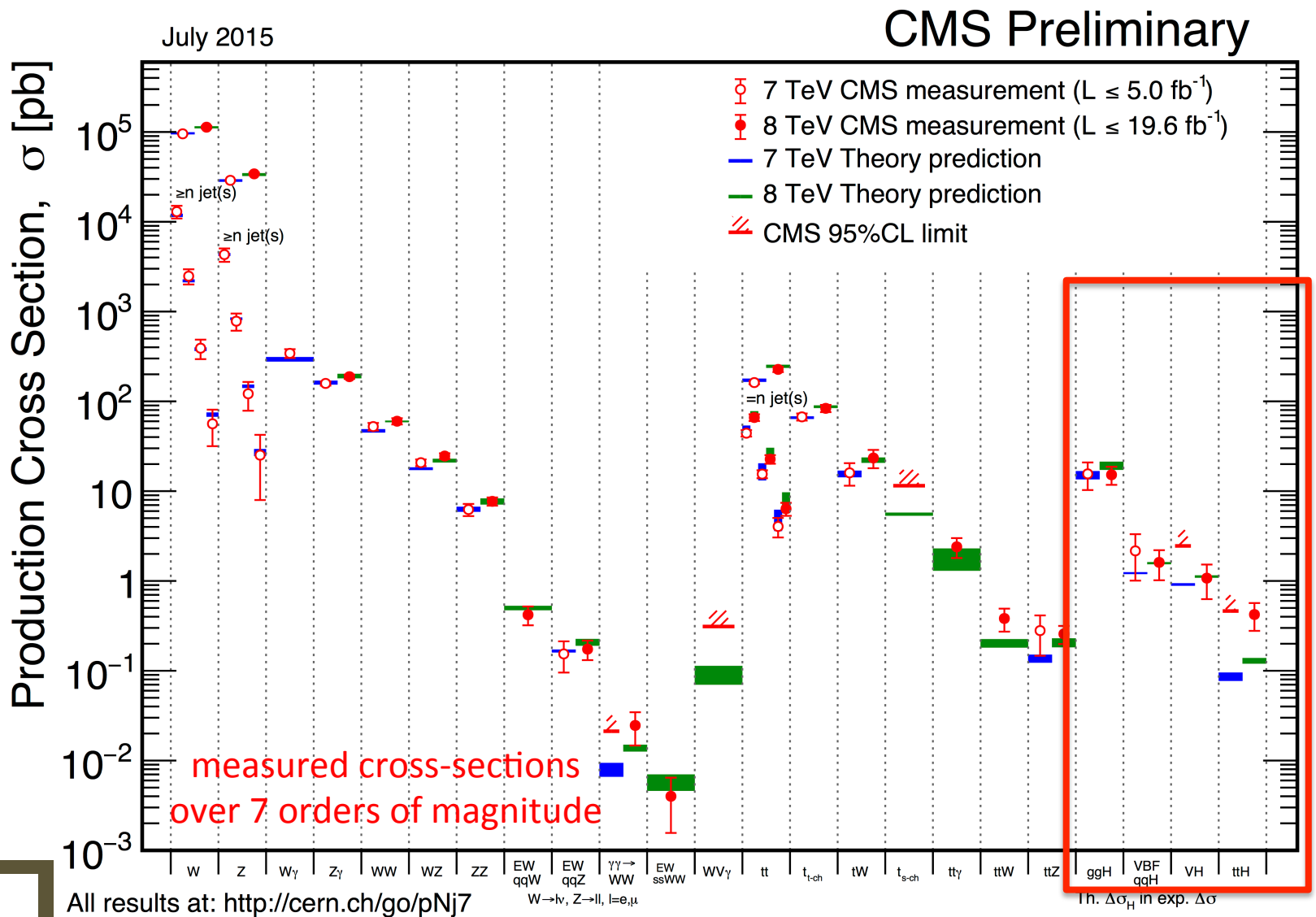
PRL 109 (2012) 222301



… a W/Z/top machine



… and a Higgs particle machine

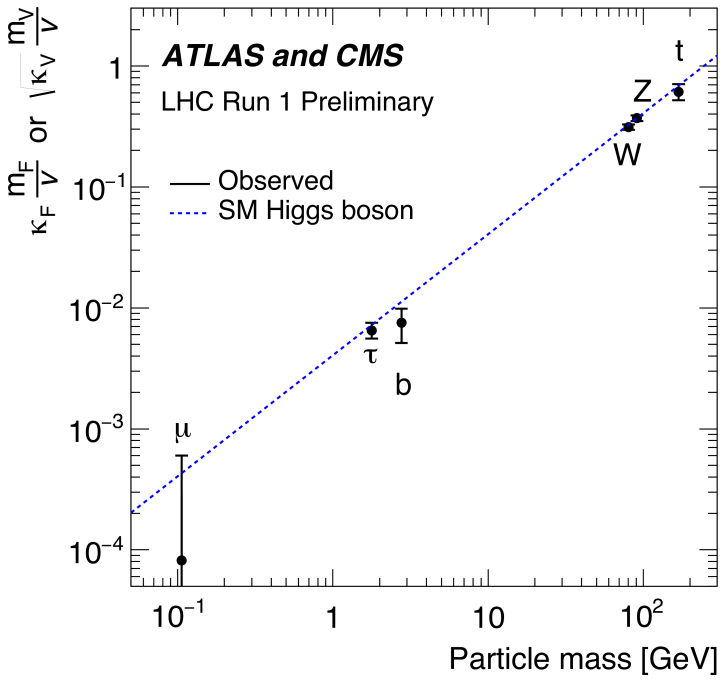


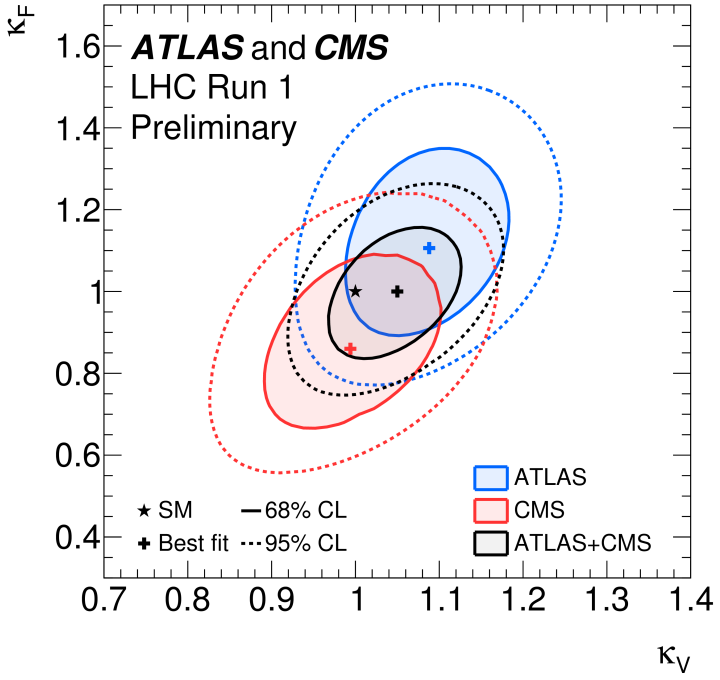
… and a Higgs particle machine

ATLAS/CMS combination: SM like couplings within the current precision
The combined signal yield relative to the SM expectation is:

$$\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\,(\text{stat})\,^{+0.04}_{-0.04}\,(\text{expt})\,^{+0.03}_{-0.03}\,(\text{thbgd})^{+0.07}_{-0.06}\,(\text{thsig})$$

ATLAS-CONF-2015-044; CMS-PAS-HIG-15-002



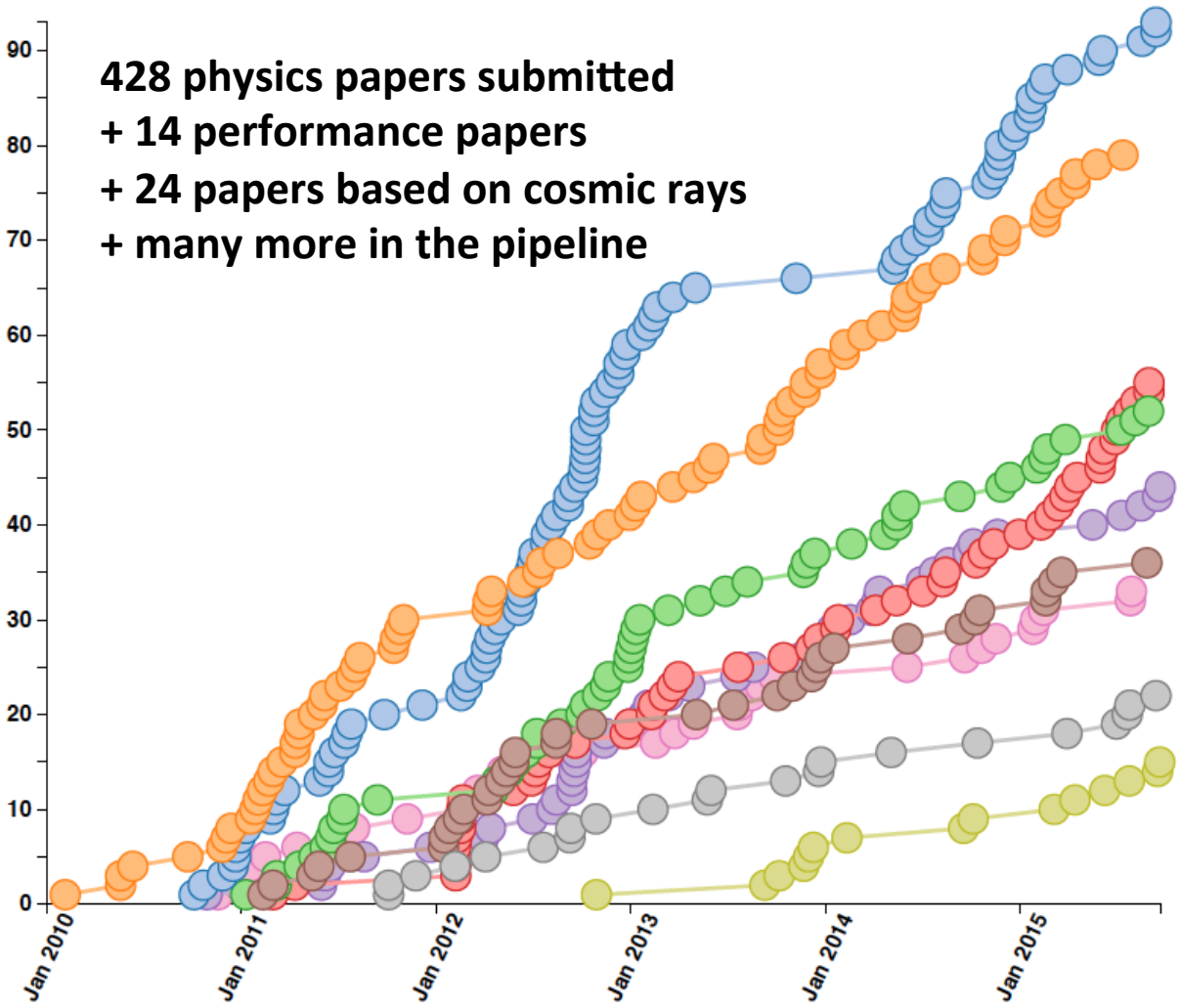


ATLAS/CMS combination of the mass : $m_H = 125.09 \pm 0.24$ GeV

PRL 114 (2015) 191803

$= 125.09 \pm 0.21\,(\text{stat.}) \pm 0.11\,(\text{syst.})$ GeV

… more CMS Publications



exotica

Standard Model

Higgs

Supersymmetry

Top quark physics

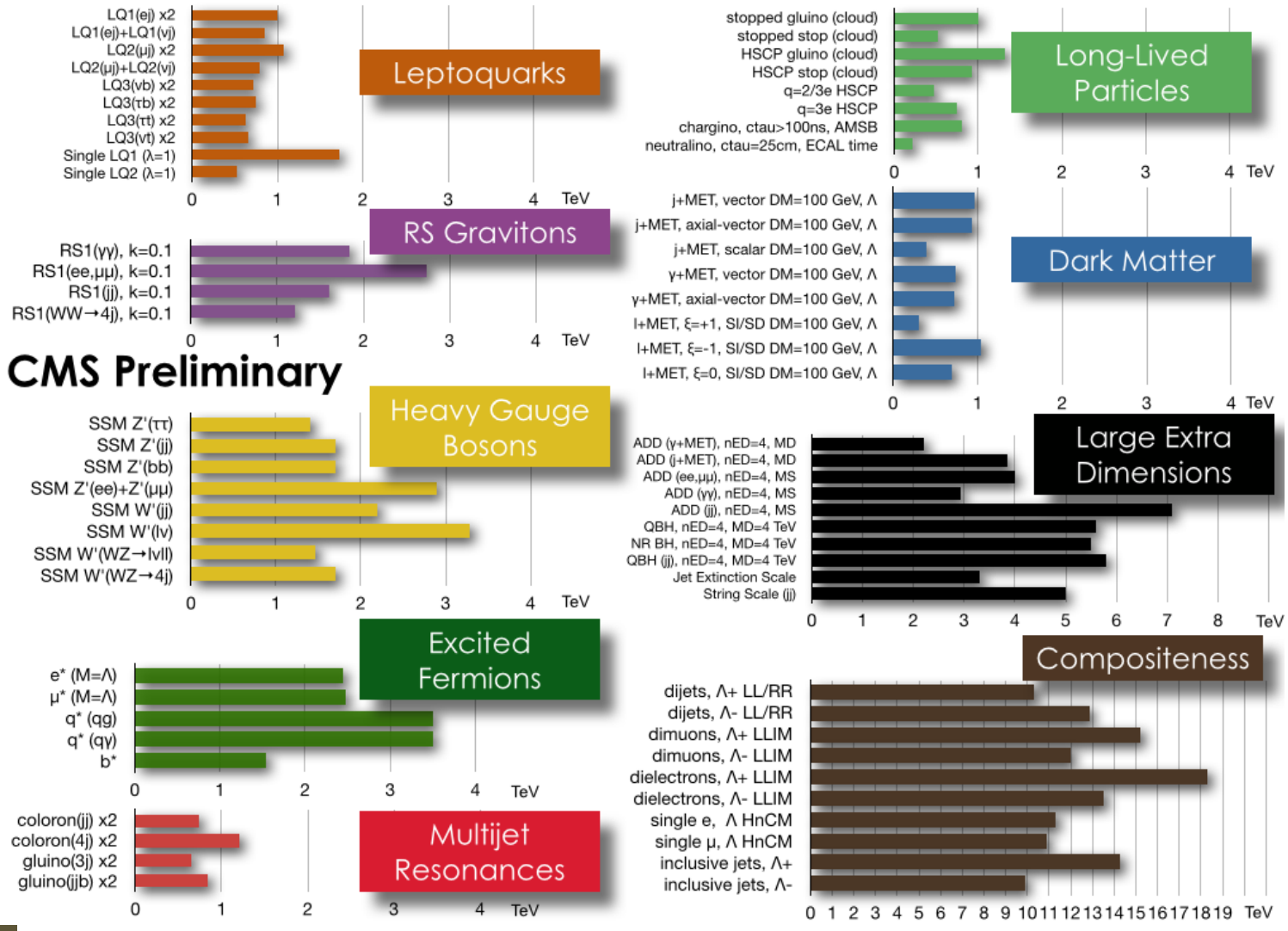
Heavy Ion physics

B physics

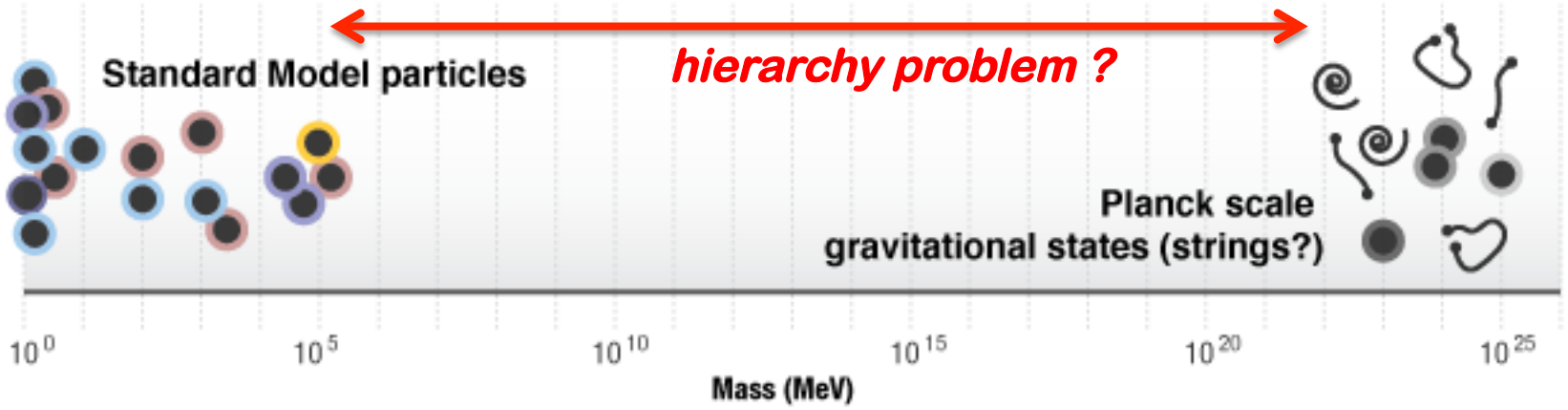
Forward physics

Beyond 2 Generations

Searches for new physics

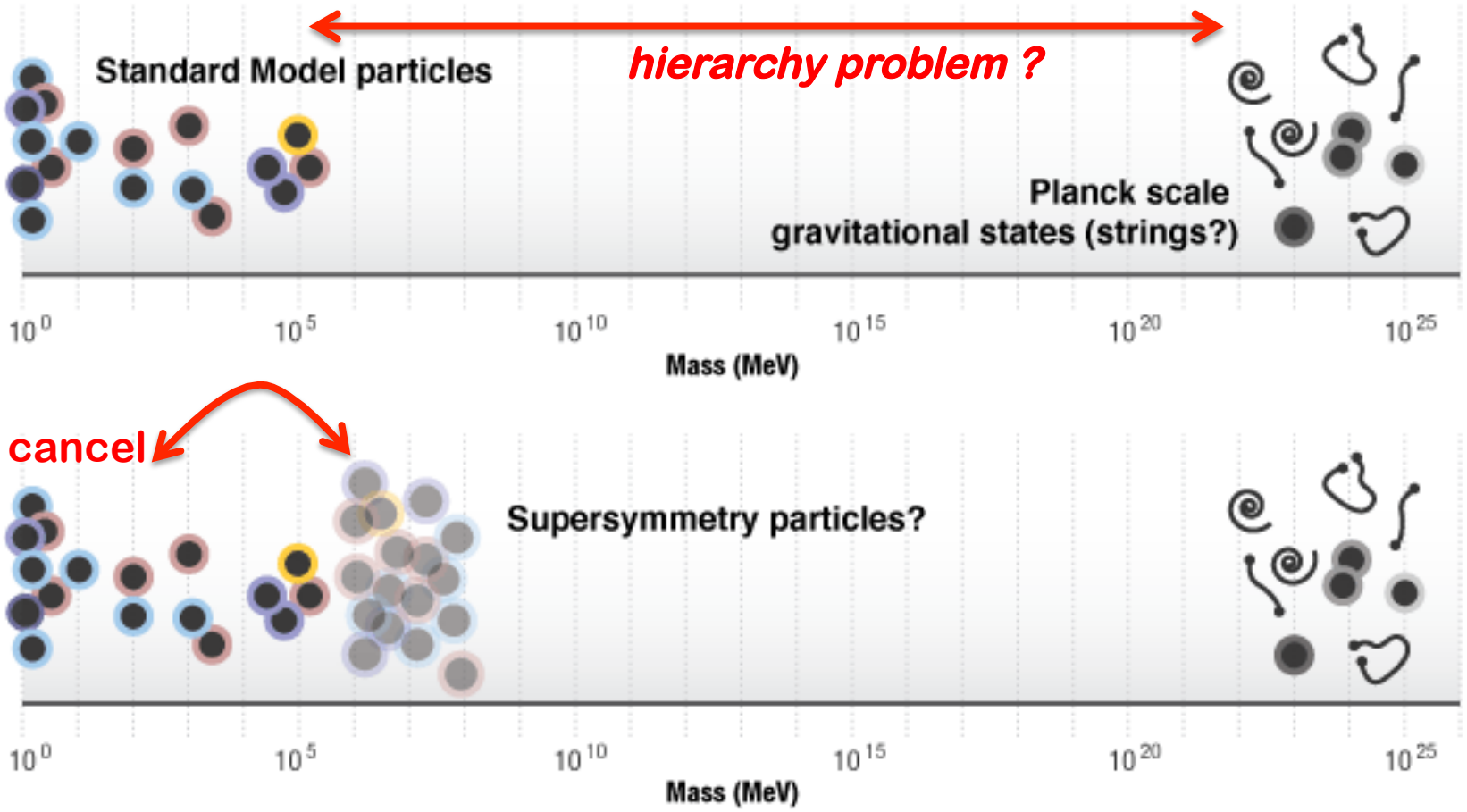


What should be out there…



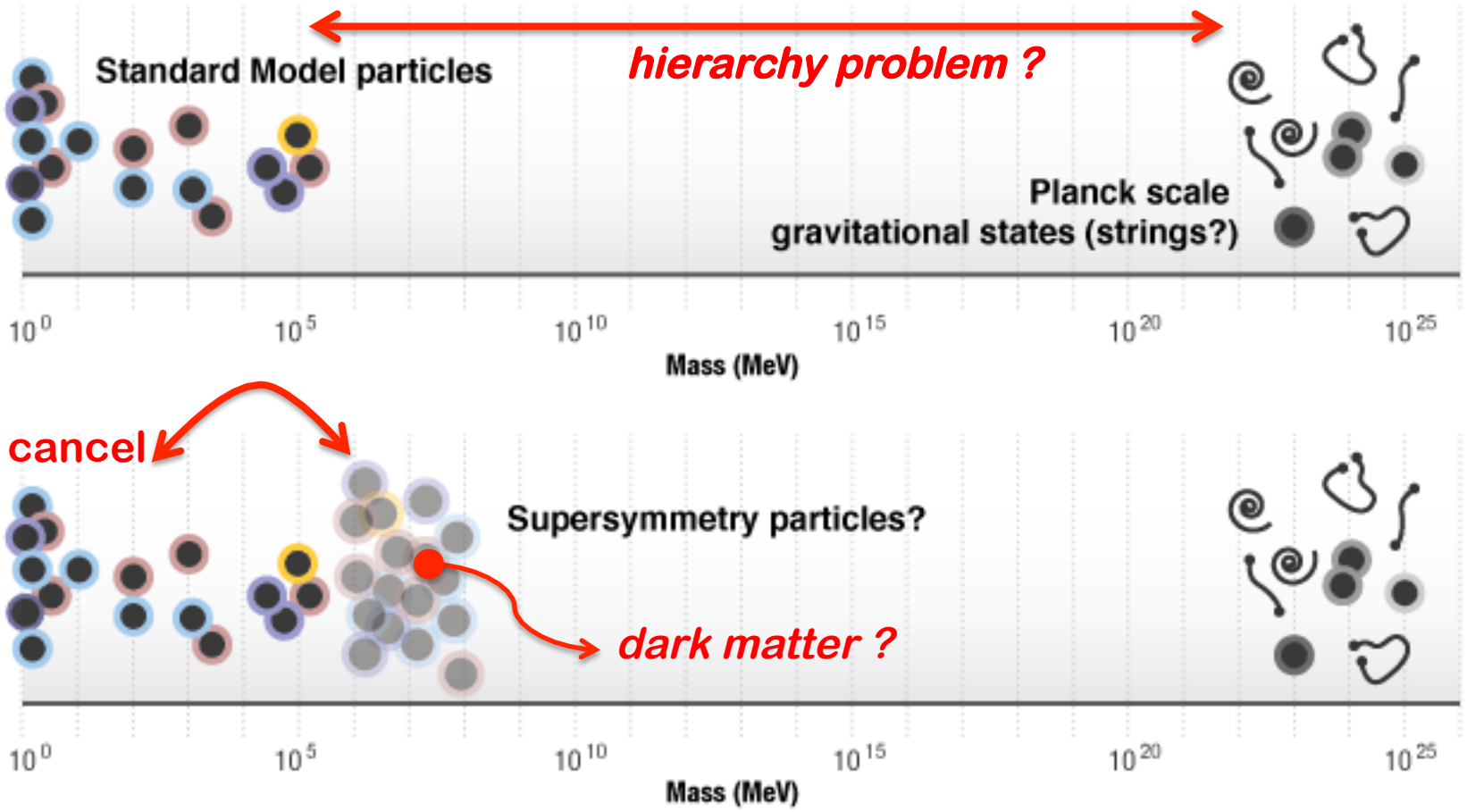
*Nelson Hsu drawings for Quanta Magazine (August 2014), "*At Multiverse Impasse, a New Theory of Scale*" by Natalie Wolchover*

What should be out there…



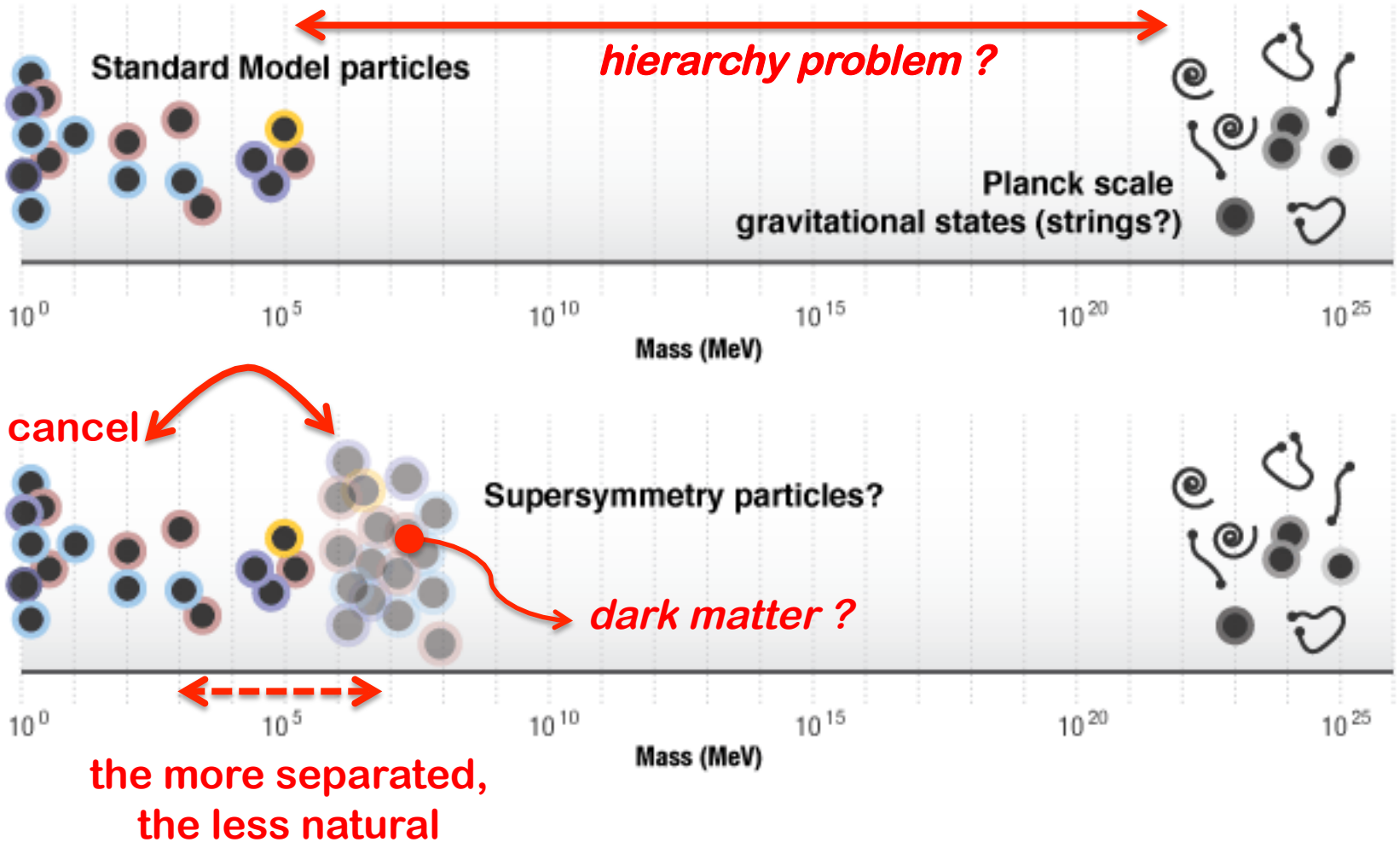
*Nelson Hsu drawings for Quanta Magazine (August 2014), "*At Multiverse Impasse, a New Theory of Scale*" by Natalie Wolchover*

What should be out there…



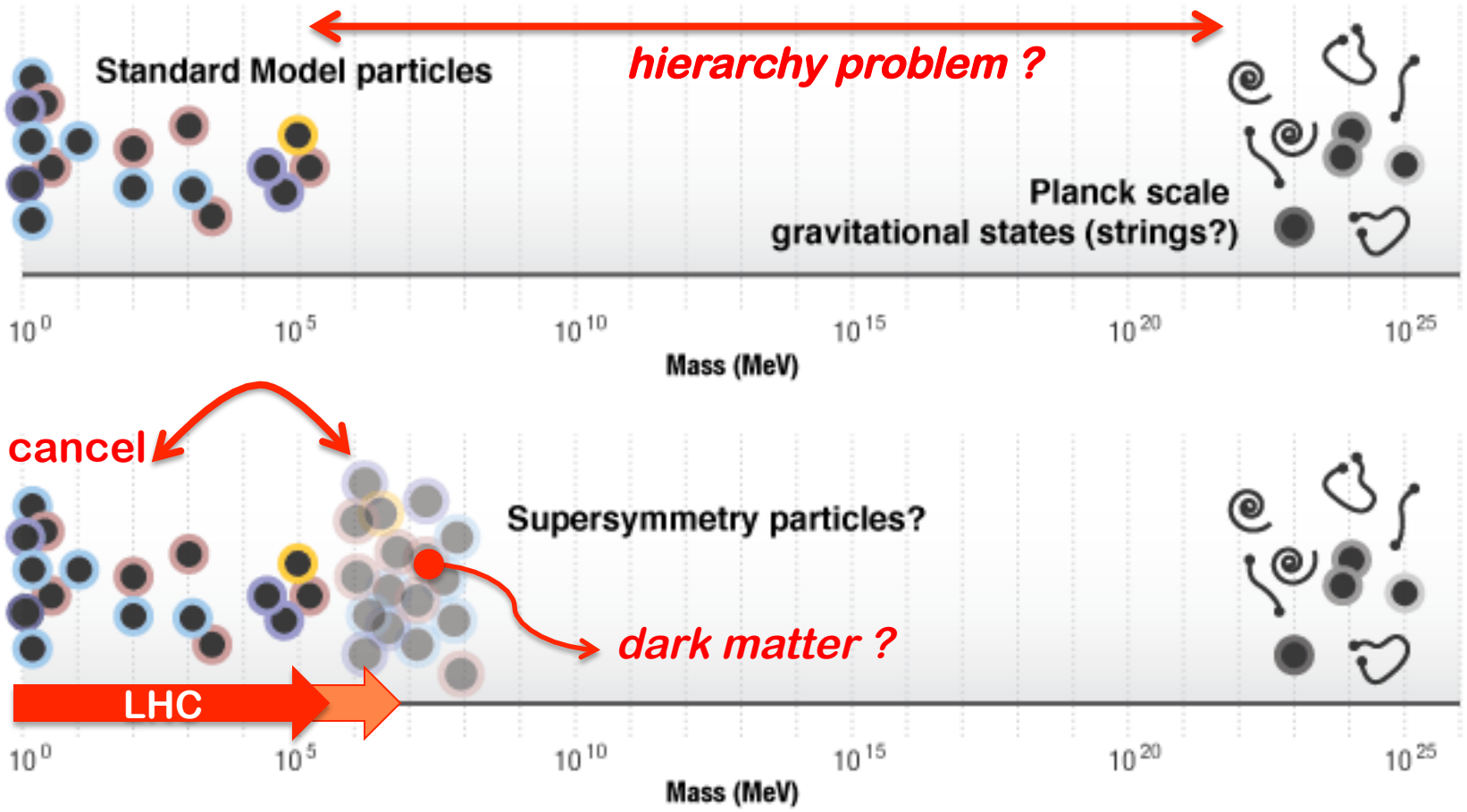
*Nelson Hsu drawings for Quanta Magazine (August 2014), "*At Multiverse Impasse, a New Theory of Scale*" by Natalie Wolchover*

What should be out there…



*Nelson Hsu drawings for Quanta Magazine (August 2014), "*At Multiverse Impasse, a New Theory of Scale*" by Natalie Wolchover*

What should be out there…

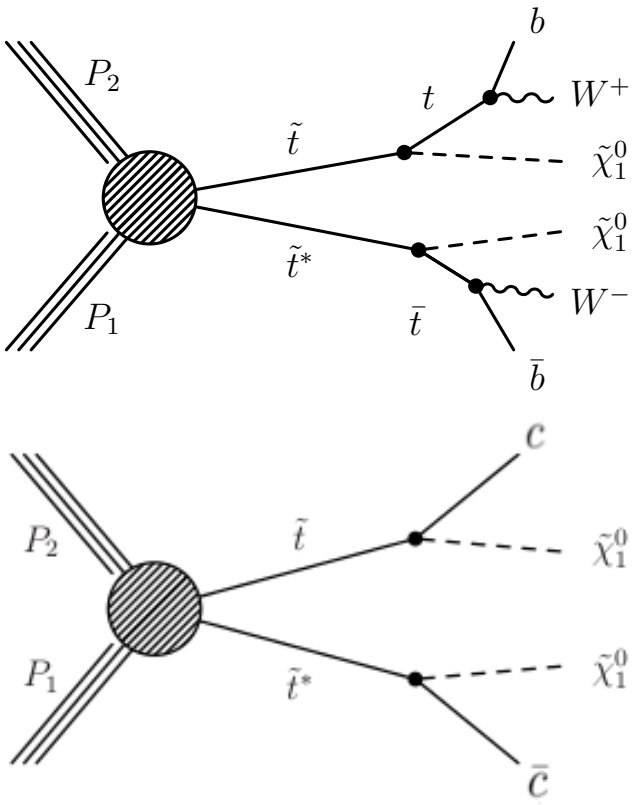


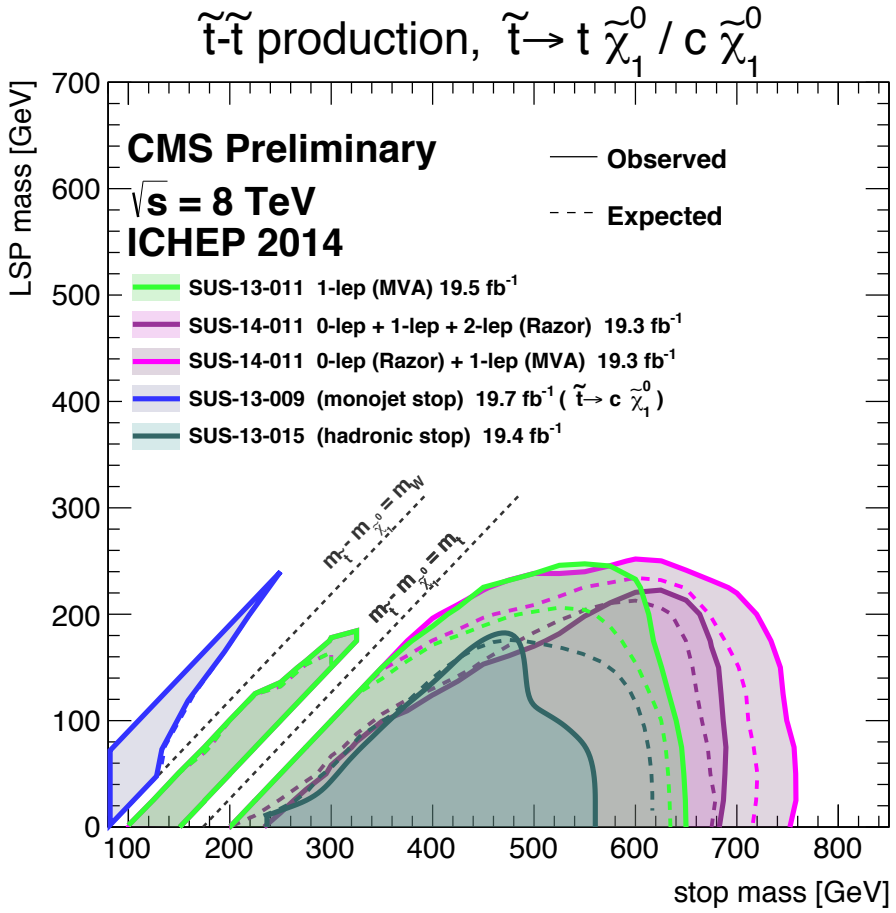
*Nelson Hsu drawings for Quanta Magazine (August 2014), "*At Multiverse Impasse, a New Theory of Scale*" by Natalie Wolchover*

Will the LHC become a SUSY machine?

The signal can hide in a >100 dimensional parameter space

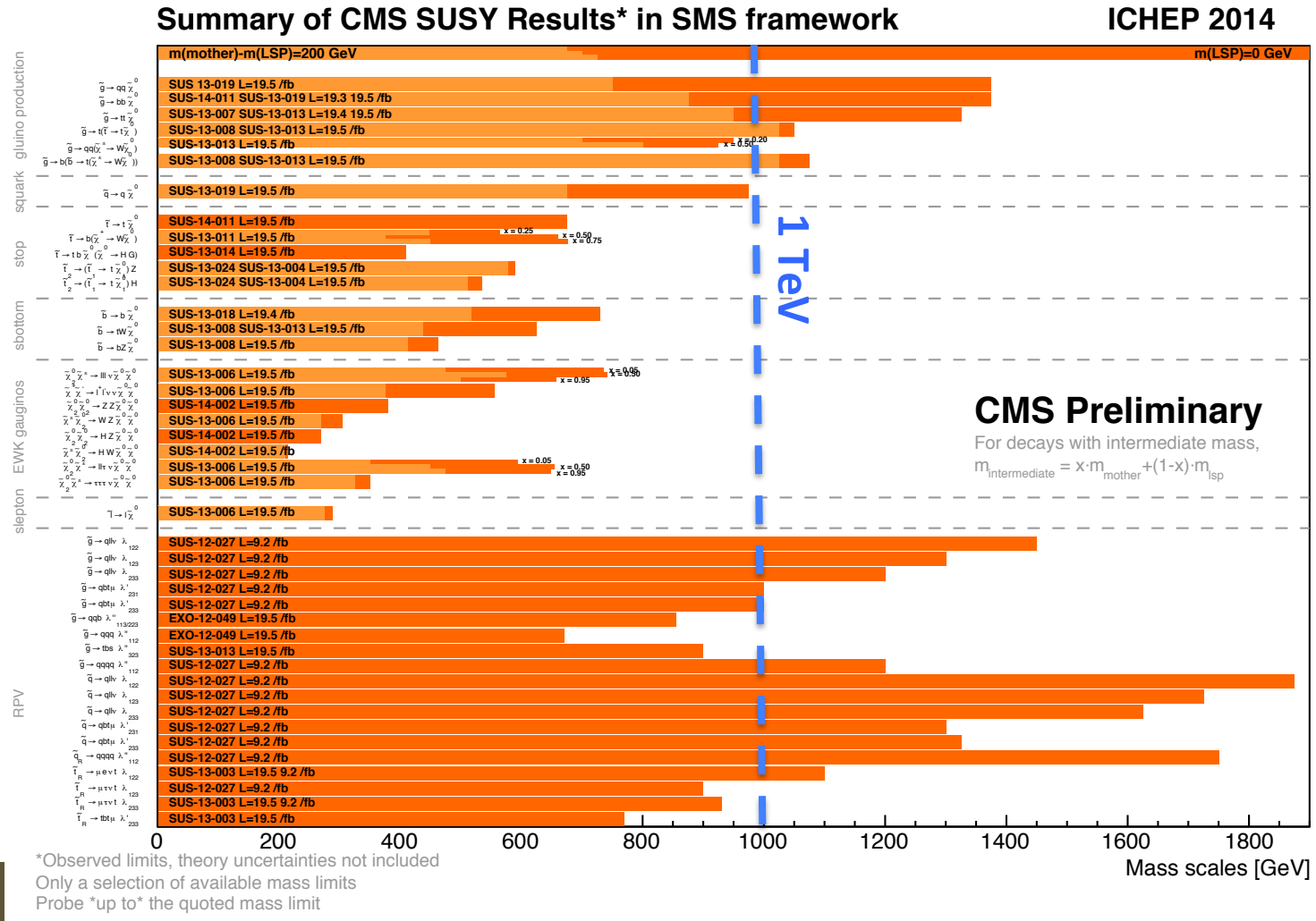
here only one (simplified model) example





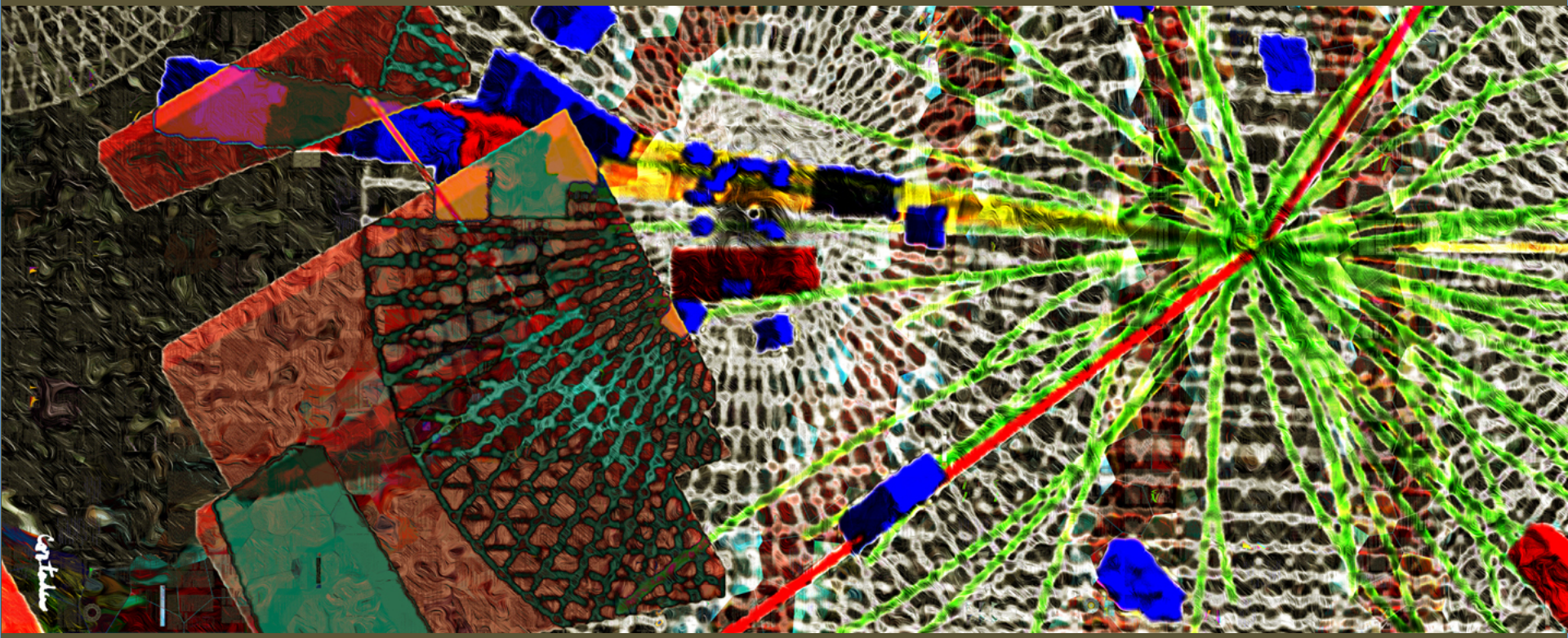
Key challenge for Run-2

we need to turn each stone in the search for supersymmetry



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Towards Run-2: Long-shutdown 1



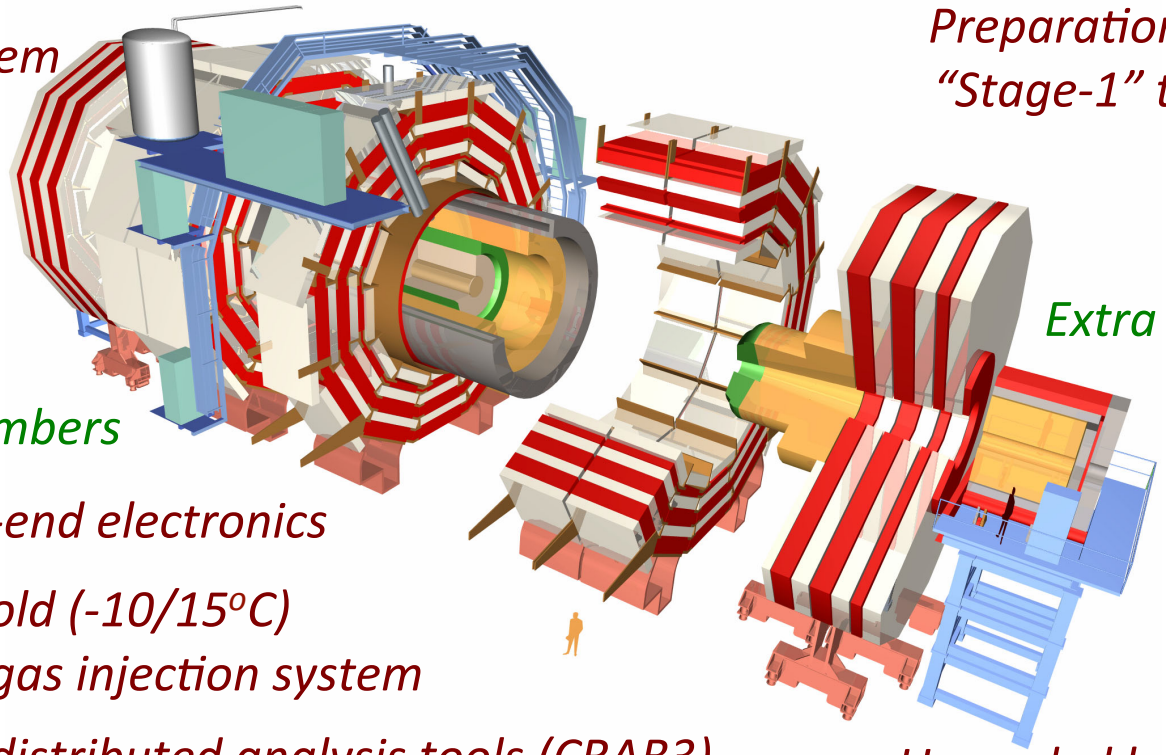
Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> gamma gamma", digital art, 2013.

LS1 program

Installation of new detector systems and extension of existing ones. Repair and maintenance after 3 years of Run-1 operation, and consolidation for the long-term future. CMS closed for physics on March 29th.

New DAQ system

Preparations for the new "Stage-1" trigger system



Extra CSC chambers

Extra RPC chambers

HF μTCA back-end electronics

Tracker cold (-10/15°C)

New dry-gas injection system

New distributed analysis tools (CRAB3)

Data federation deployed (AAA)

Upgraded beam monitors

New Pixel Luminosity Telescope

New reconstruction software & miniAOD format & pile-up mitigation

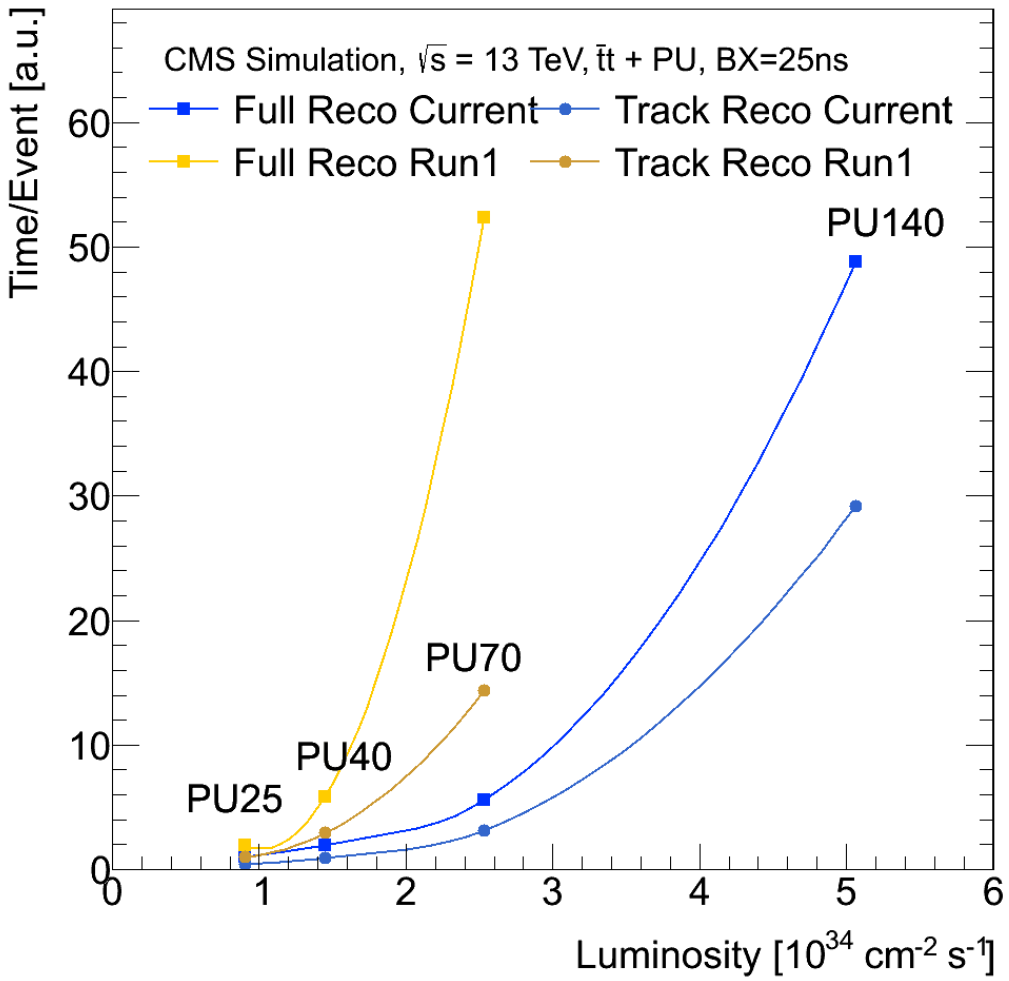
Computing & Offline evolution

Increased pile-up imposes important challenges to our computing and software parts

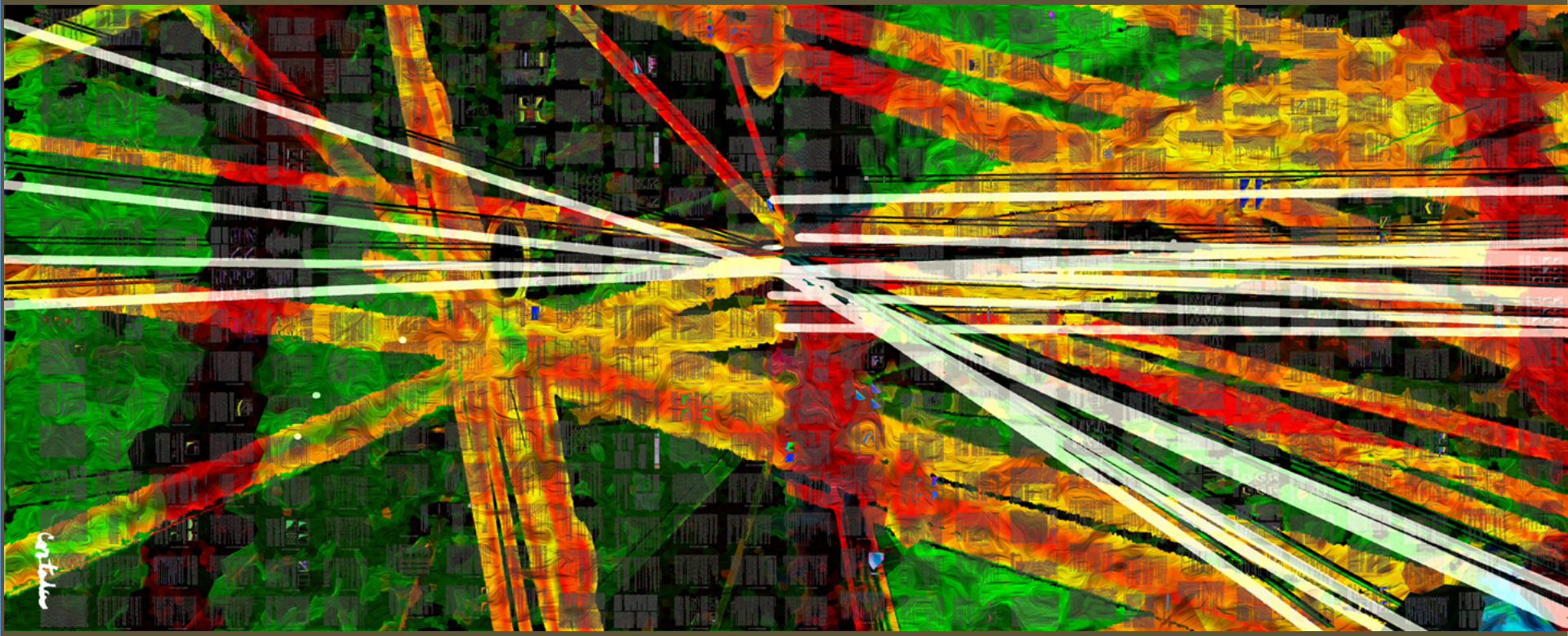
CMS achieved major improvements in the efficiency reconstruction code

→ also deployment of multi-threaded algorithms

These challenges are also essential towards the HL-LHC settings



Run-2 at 13 TeV

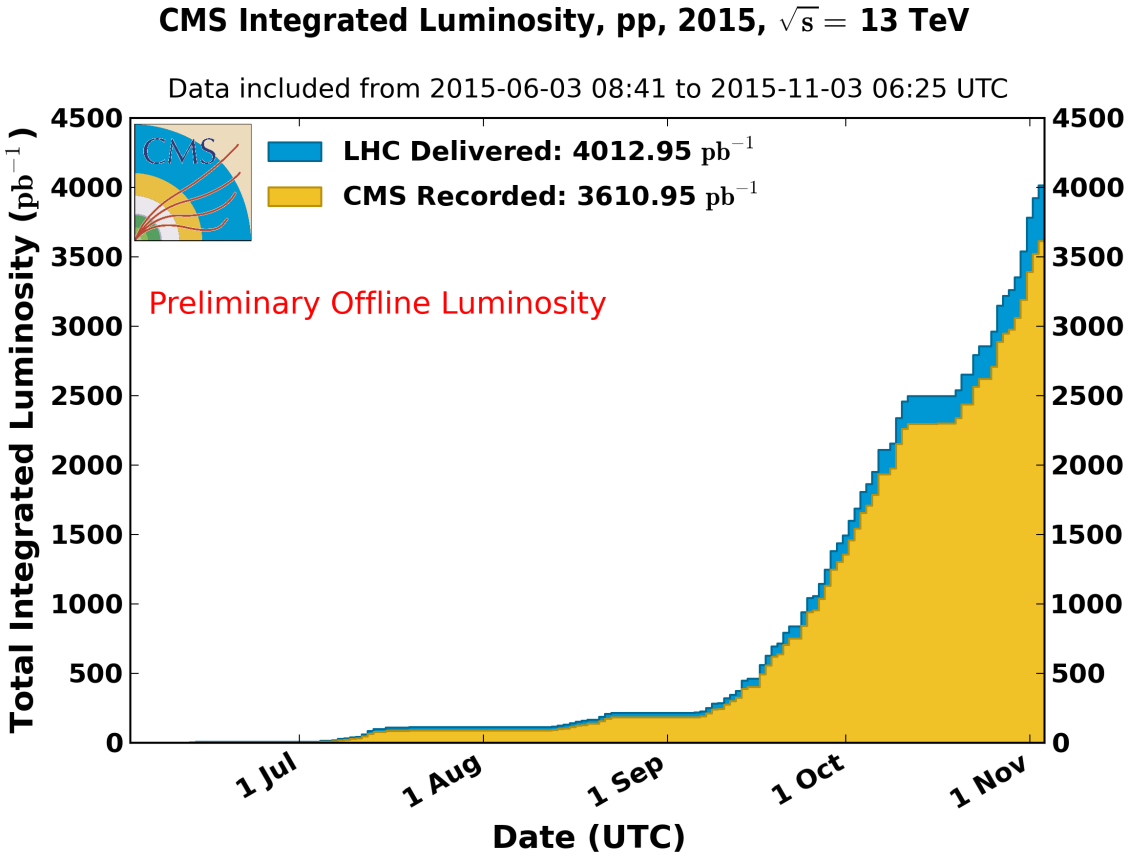


General reference: http://cms-results.web.cern.ch/cms-results/public-results/publications/

Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> bottom bottom", digital art, 2013.

Data collected by CMS

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



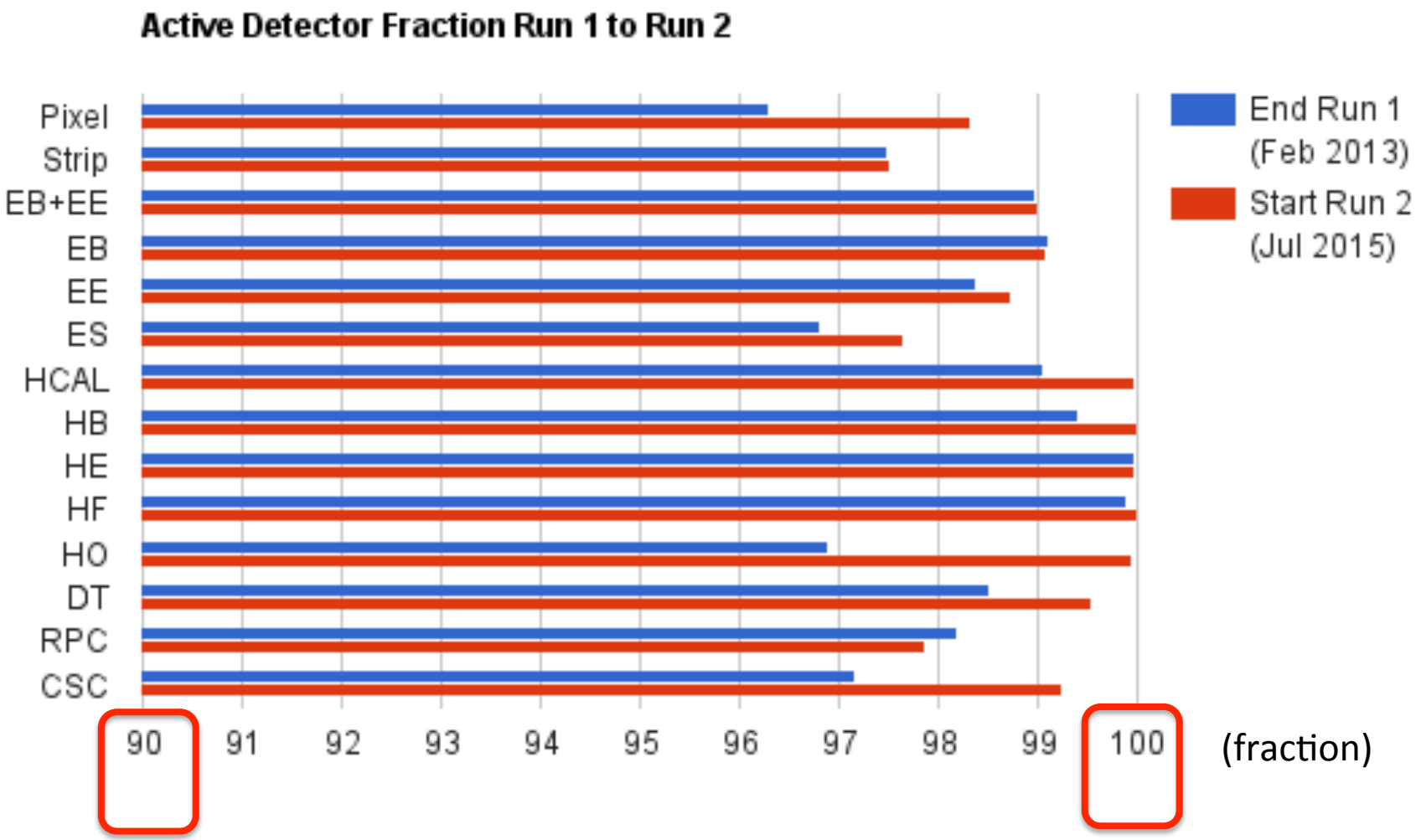
TOTAL in 2015: 4.1 fb^{-1} / 3.7 fb^{-1} (delivered/recorded)

- B = 3.8T: 3.1 fb^{-1} / 2.9 fb^{-1} (93%)
- B ≠ 3.8T: 1.0 fb^{-1} / 0.8 fb^{-1} (80%)

Cryogenic system for CMS magnet

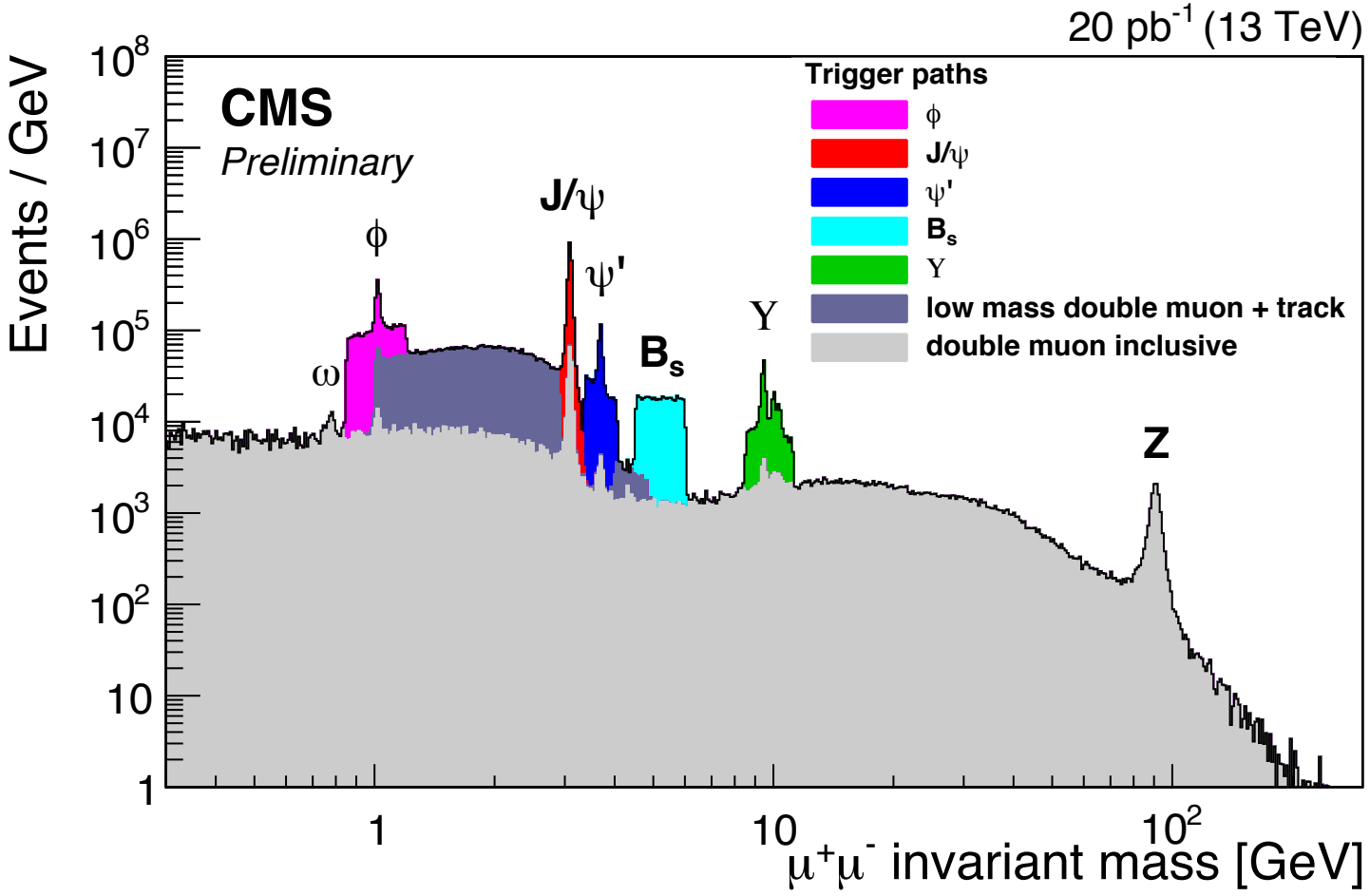
- The restart of the CMS magnet after LS1 was more complicated than anticipated due to problems with the cryogenic system in providing liquid Helium.
- These problems are consistent with clogging effects due to contaminants in the “Cold box” that provides liquid Helium.
- Currently the magnet can be 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 being organized for the end-of-the-year technical stop.

Performance of the experiment



Di-muon mass spectrum

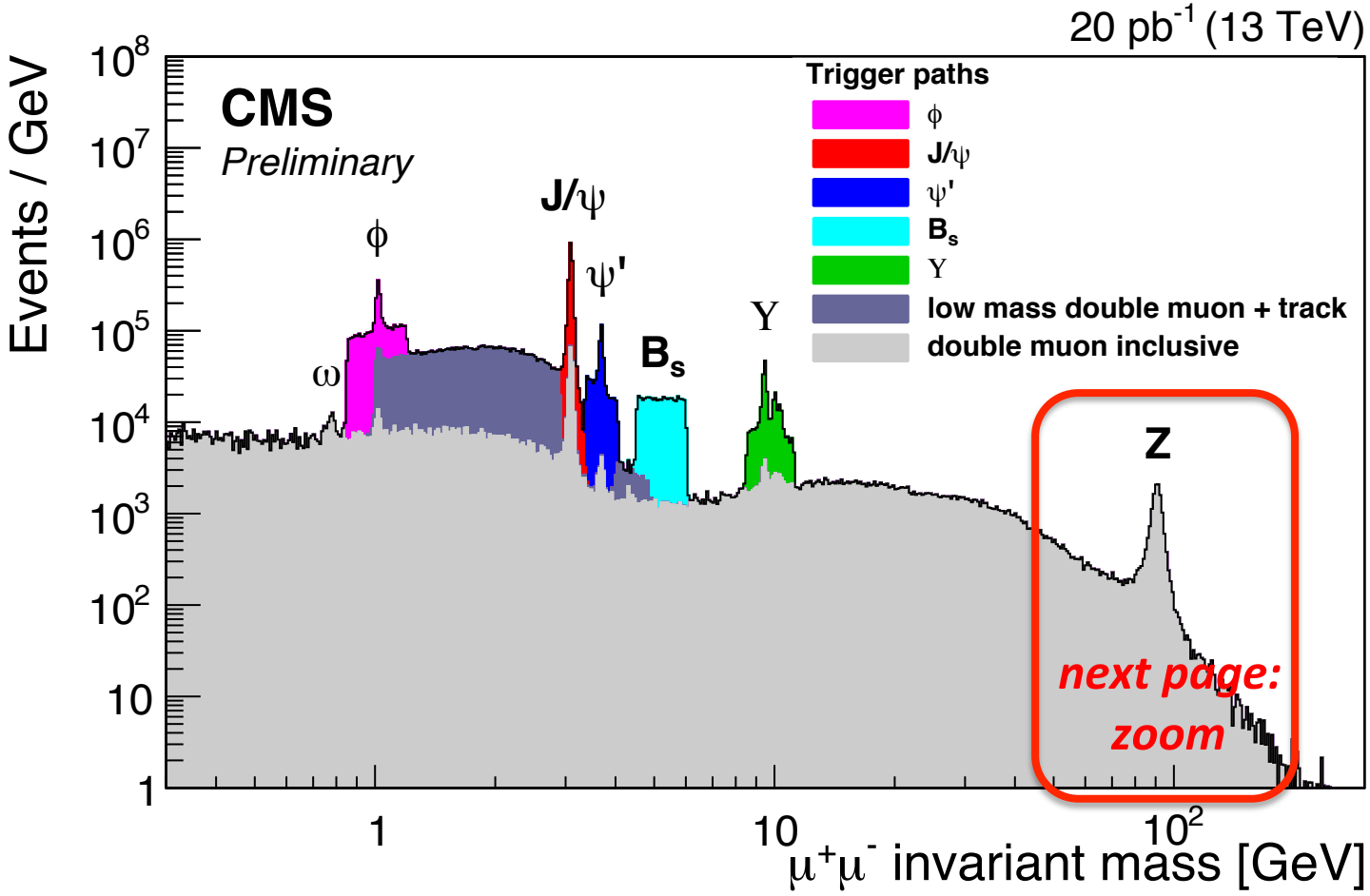
Collected with various di-muon triggers, from inclusive di-muons triggers at high p_T and low-mass non-resonant di-muon triggers, to specialized triggers.



CERN-CMS-DP-2015-018

Di-muon mass spectrum

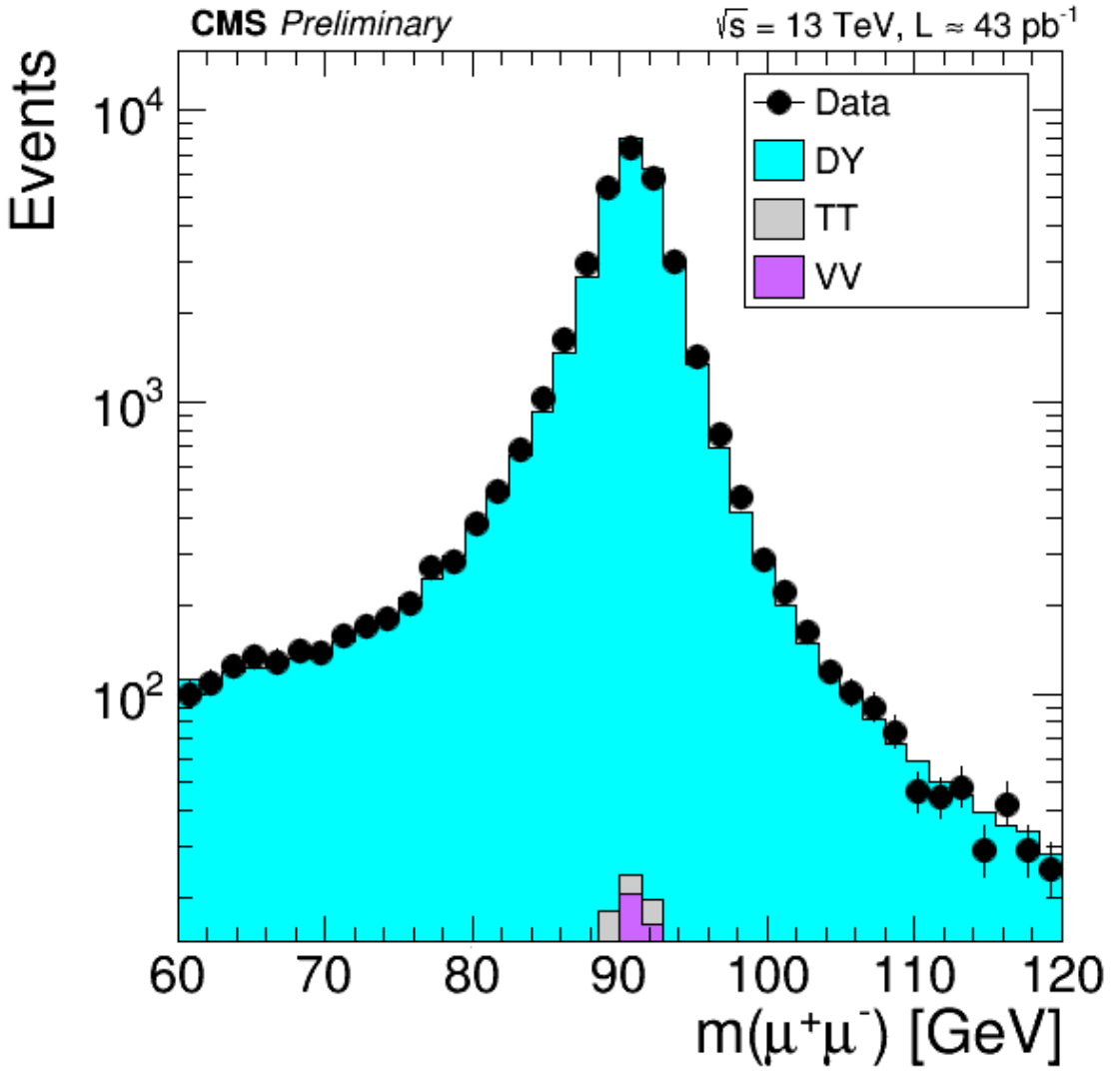
Collected with various di-muon triggers, from inclusive di-muons triggers at high p_T and low-mass non-resonant di-muon triggers, to specialized triggers.



CERN-CMS-DP-2015-018

Di-muon mass spectrum

Very good agreement of our simulation with the collision data.

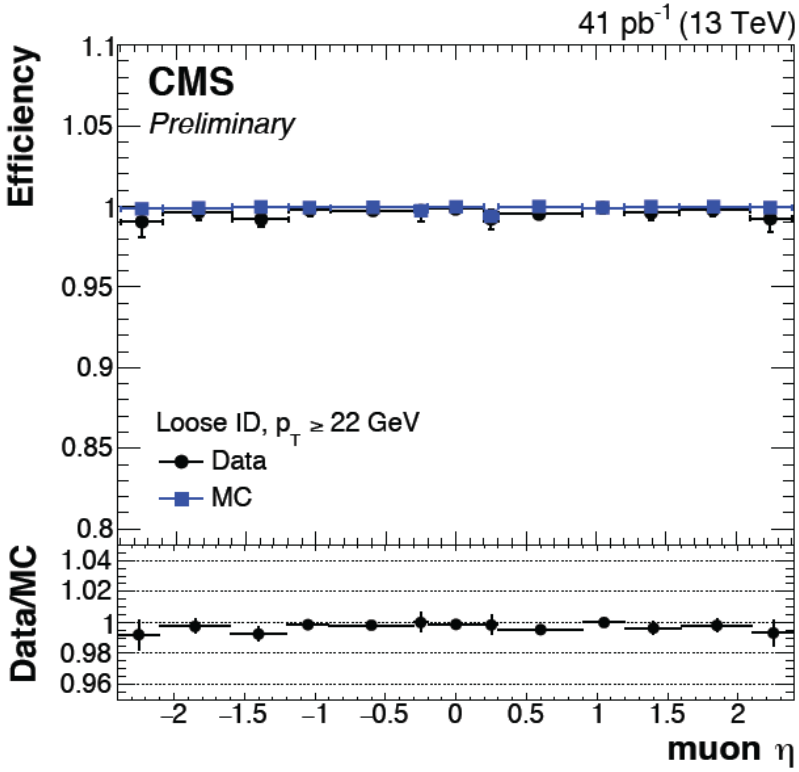


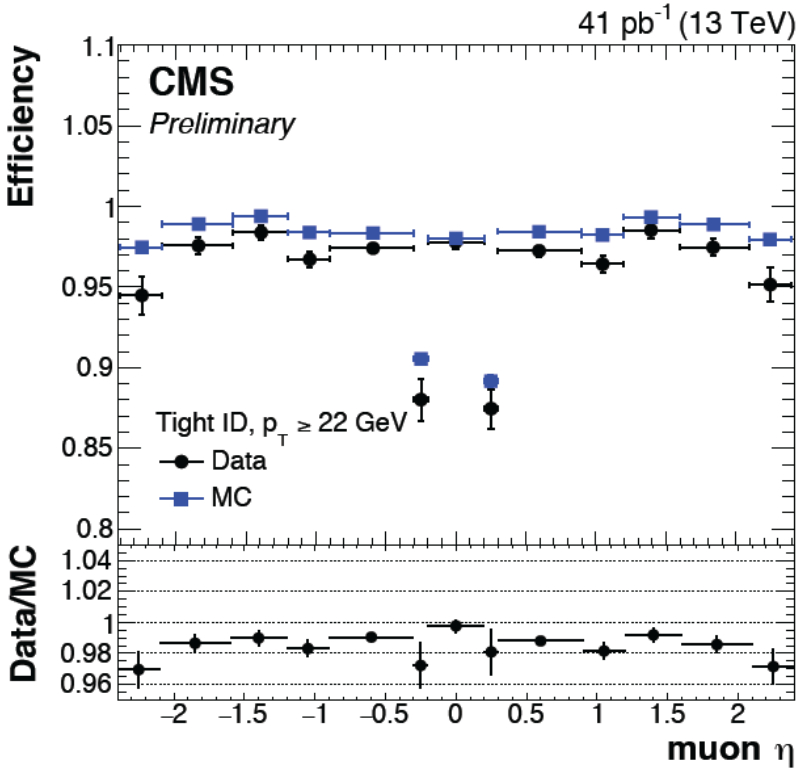
CERN-CMS-DP-2015-015

Muon reconstruction

Using Tag-and-Probe methods on Z events

→ *using certified data & MadGraph_aMC@NLO Drell-Yan+jets samples*

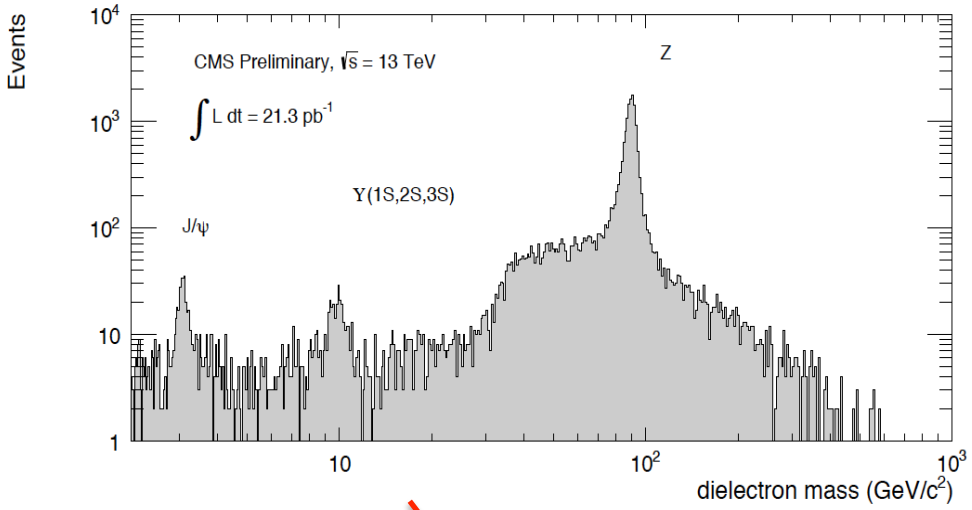




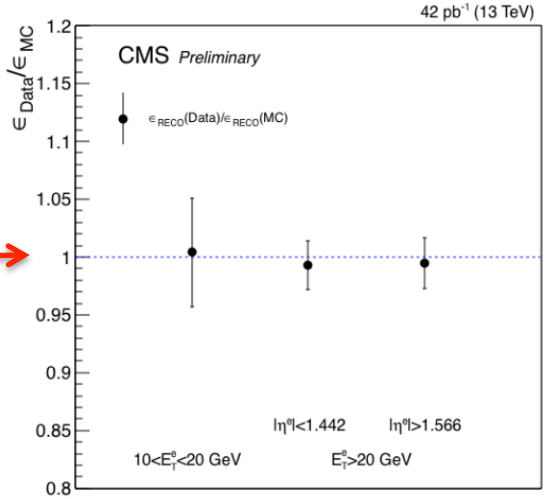
CMS DP-2015/047

Electron reconstruction

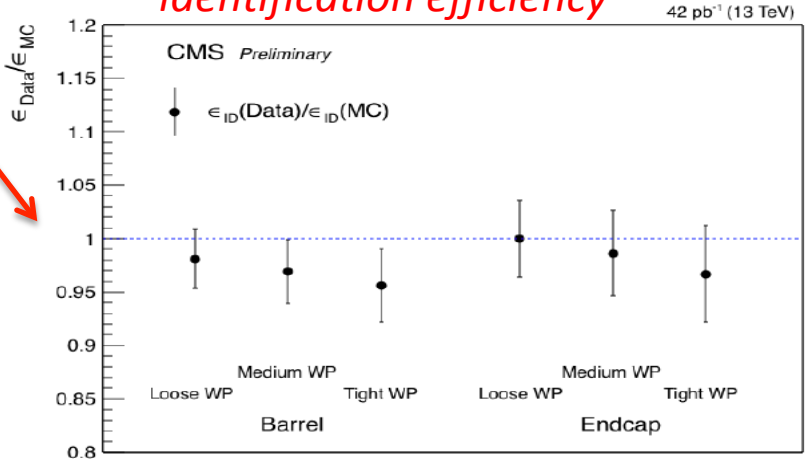
Using Tag-and-Probe methods on Z events



reconstruction efficiency



identification efficiency



CMS DP-2015/013

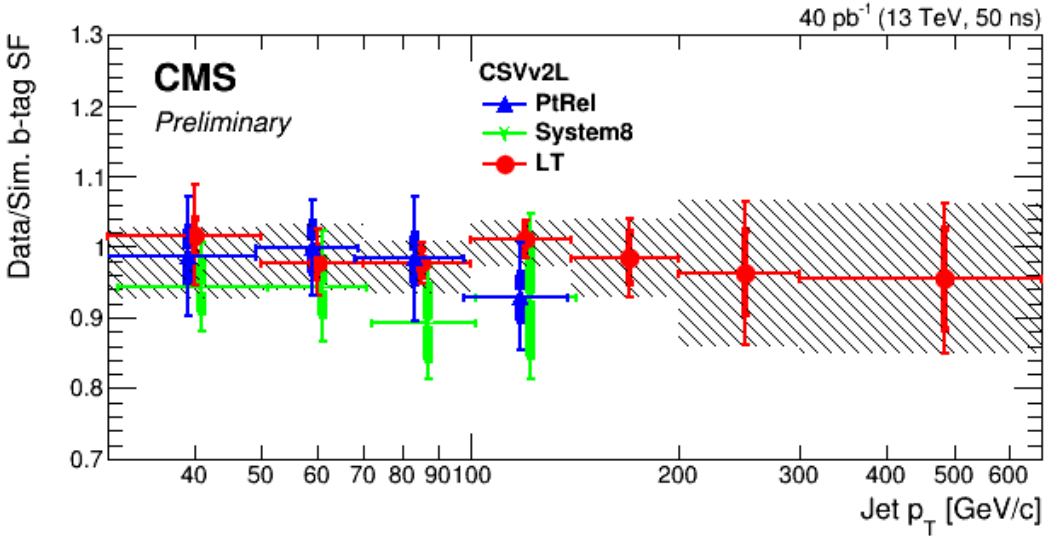
B-tagging performance

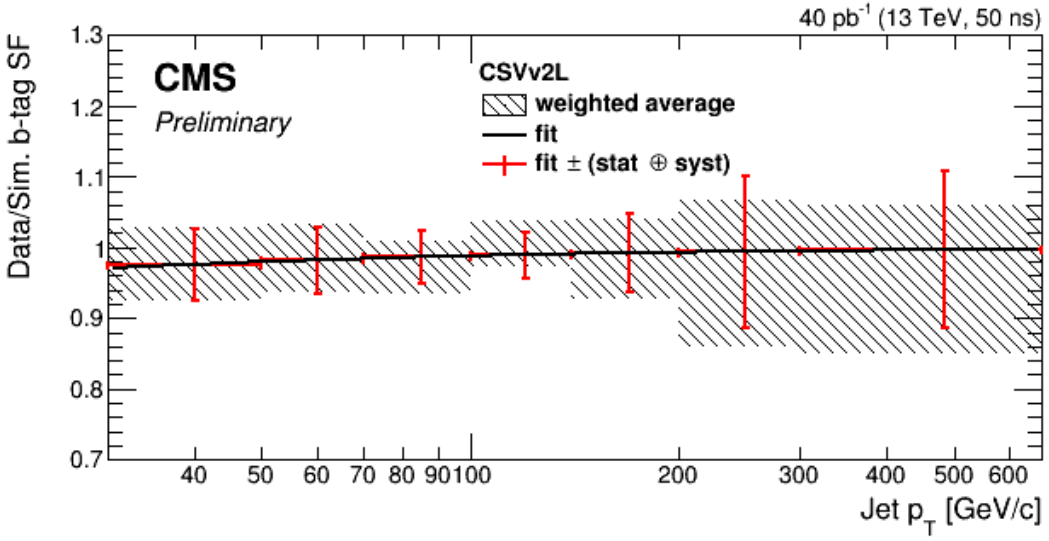
Data driven estimation of the tagging performance

→ *using certified data & multi-jet events*

Individual and combined measurements of the ratio of b-tagging efficiencies of data to that in simulation.

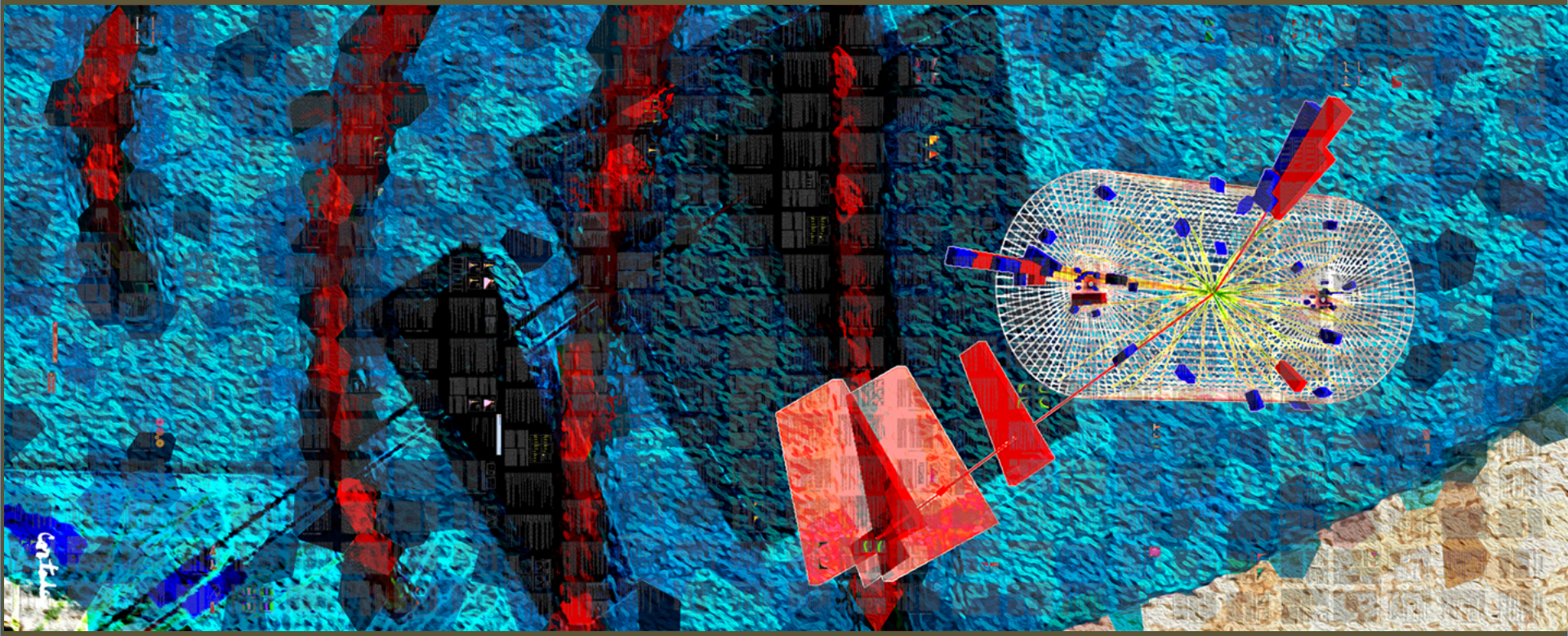
The grey hatched areas represent the combined measurement which is parameterized as a function of jet p_T.





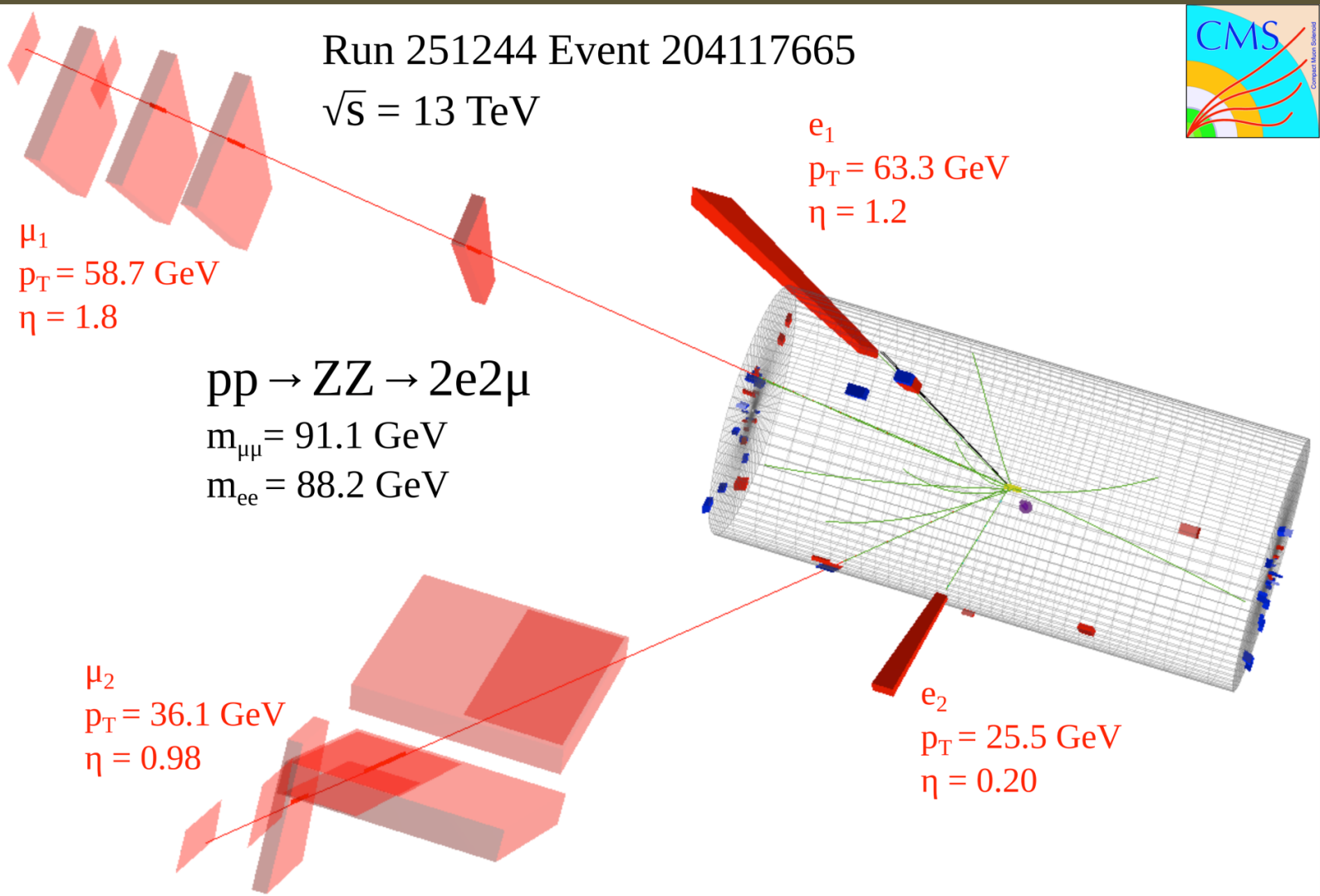
CMS DP-2015/045

Spectacular events at 13 TeV



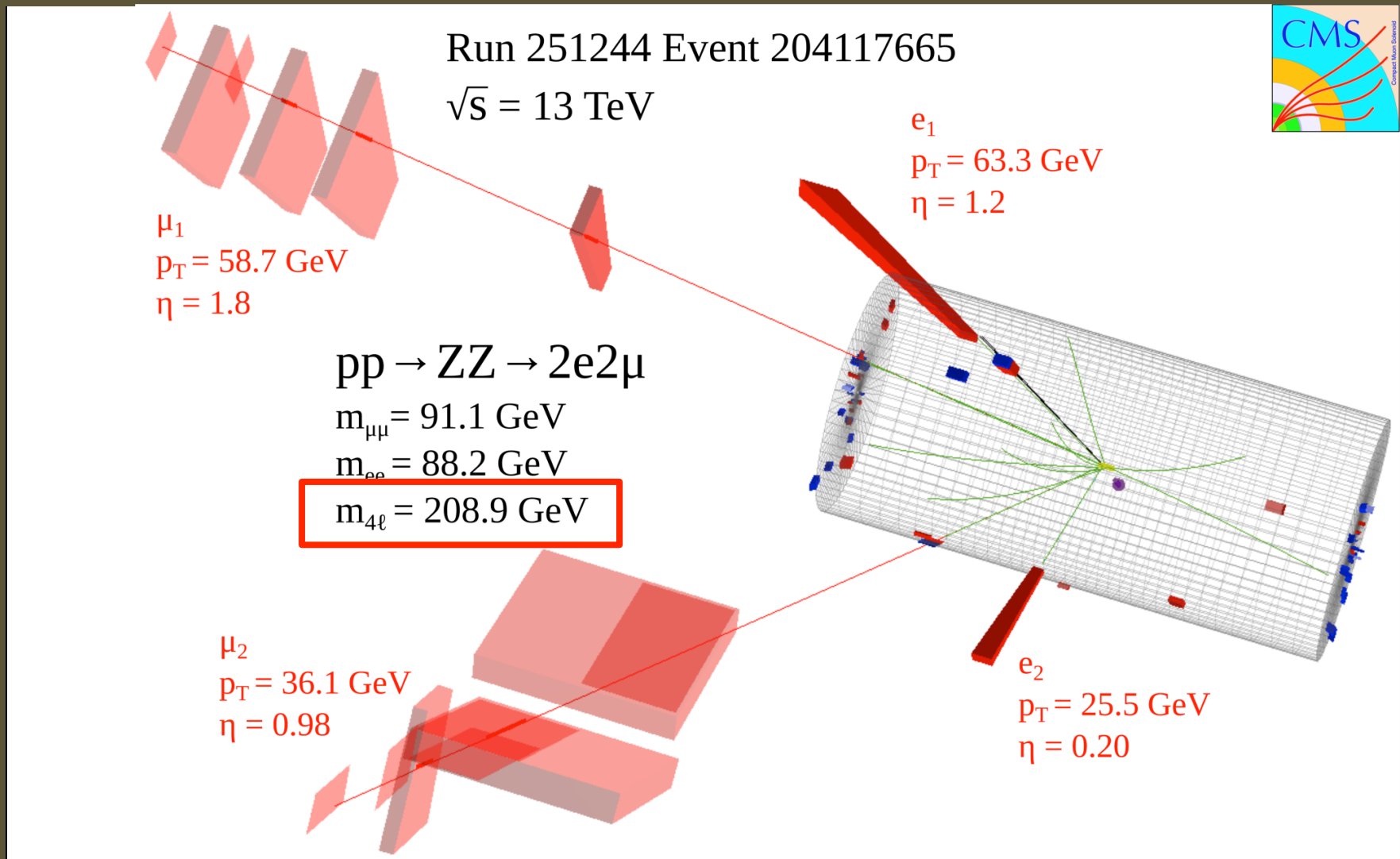
Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> tau tau", digital art, 2013.

A very nice 4-lepton event

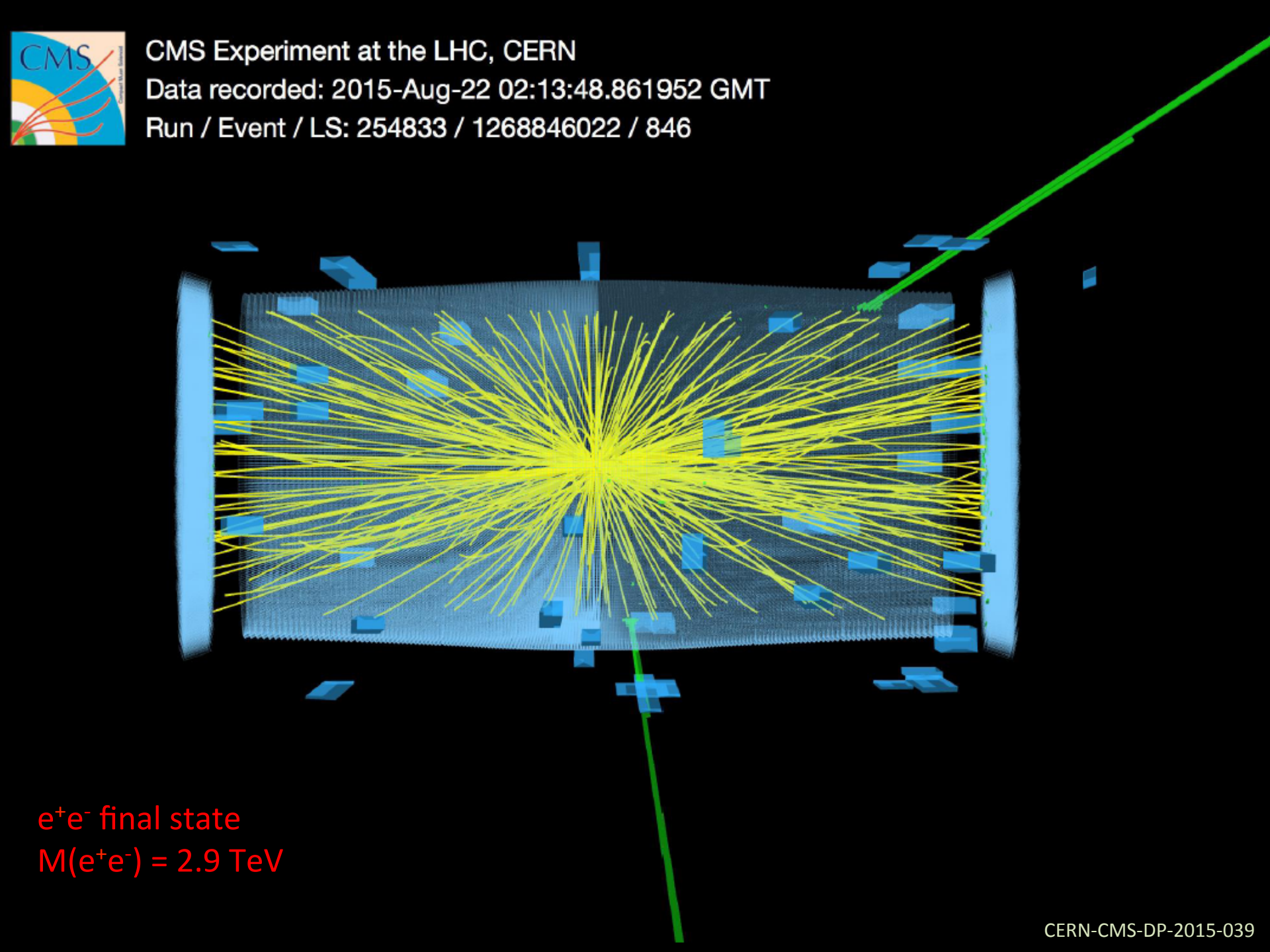


CERN-CMS-DP-2015-016

A very nice 4-lepton event: Higgs?

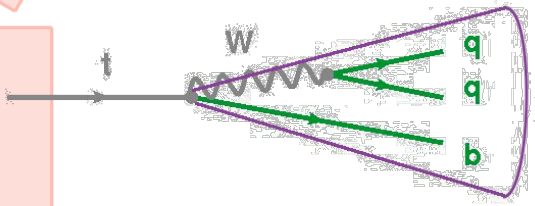


CERN-CMS-DP-2015-016


CMS Experiment at the LHC, CERN
Data recorded: 2015-Aug-22 02:13:48.861952 GMT
Run / Event / LS: 254833 / 1268846022 / 846
e+e- final state
M(e+e-) = 2.9 TeV
CERN-CMS-DP-2015-039

CERN-CMS-DP-2015-020

CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253



Subjet 1,
et = 275 GeV
eta = 2.08
phi = 1.94

Subjet 2,
et = 49 GeV
eta = 1.64
phi = 1.64

Subjet 3,
et = 203 GeV
eta = 2.37
phi = 1.48

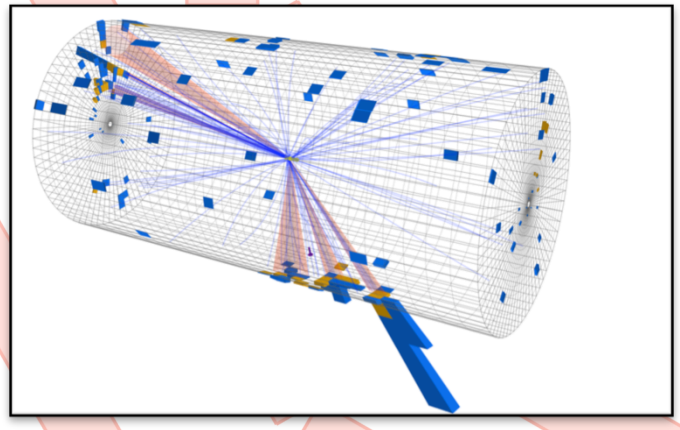
Top jet candidate 1
pt = 488 GeV
eta = 2.22
phi = 1.74
mass = 176 GeV

Top jet candidate 2,
pt = 613 GeV
eta = -0.70
phi = -1.46
mass = 177 GeV

Subjet 4,
et = 133 GeV
eta = -0.47
phi = -1.56

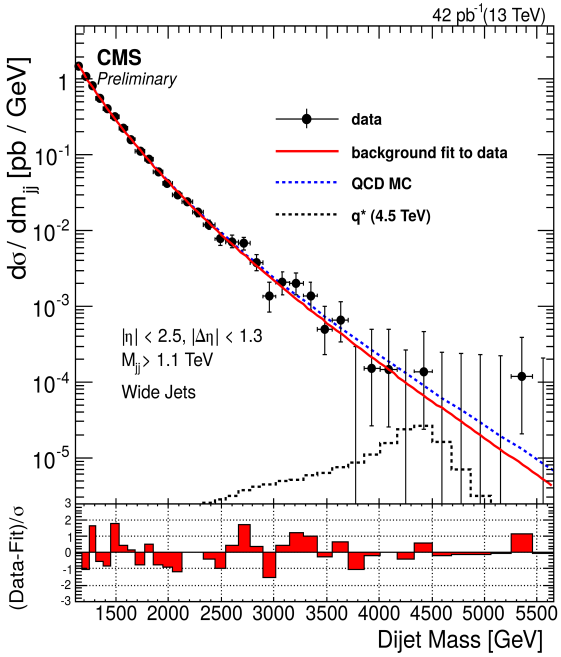
Subjet 5,
et = 402 GeV
eta = -0.86
phi = -1.44

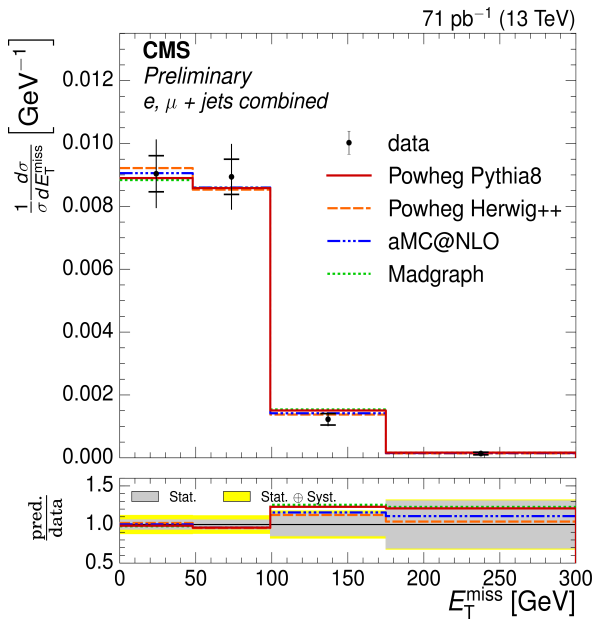
Subjet 6,
et = 73 GeV
eta = -0.18
phi = -1.30

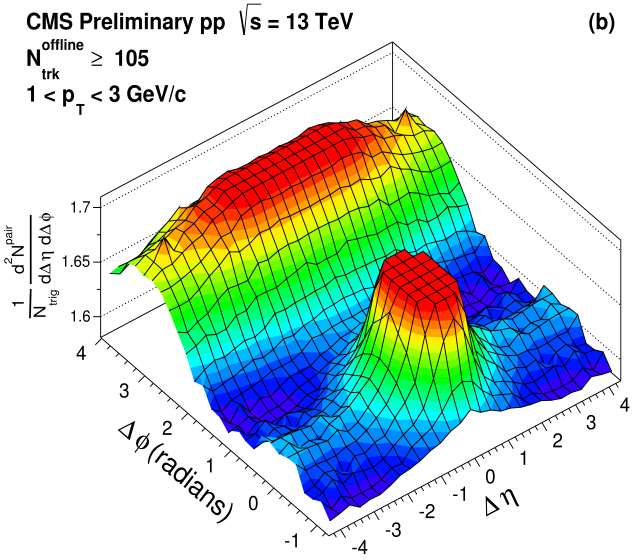


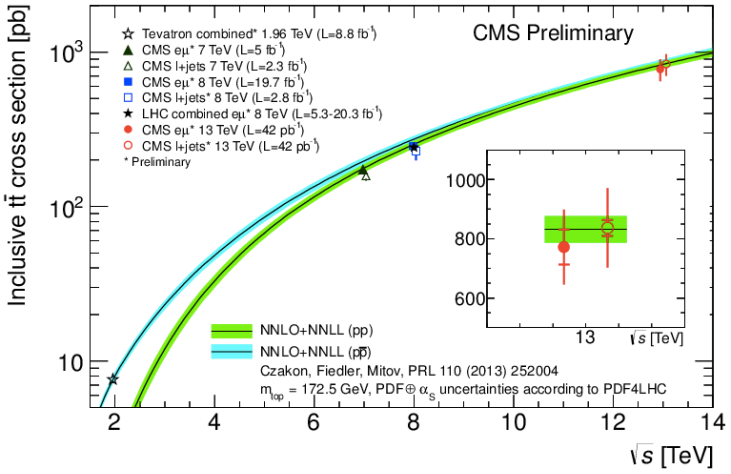
Two top-tagged objects
M(top-tagged 1) = 176 GeV
M(top-tagged 2) = 177 GeV
M(top-antitop) = 2.5 TeV

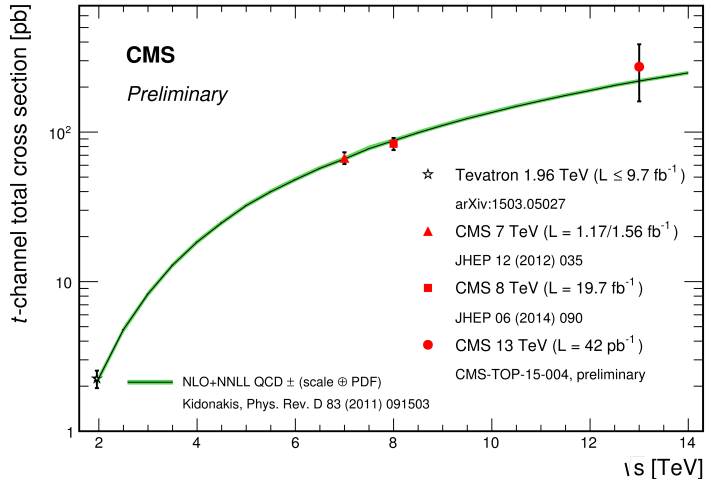
More physics in talk of G. Dissertori



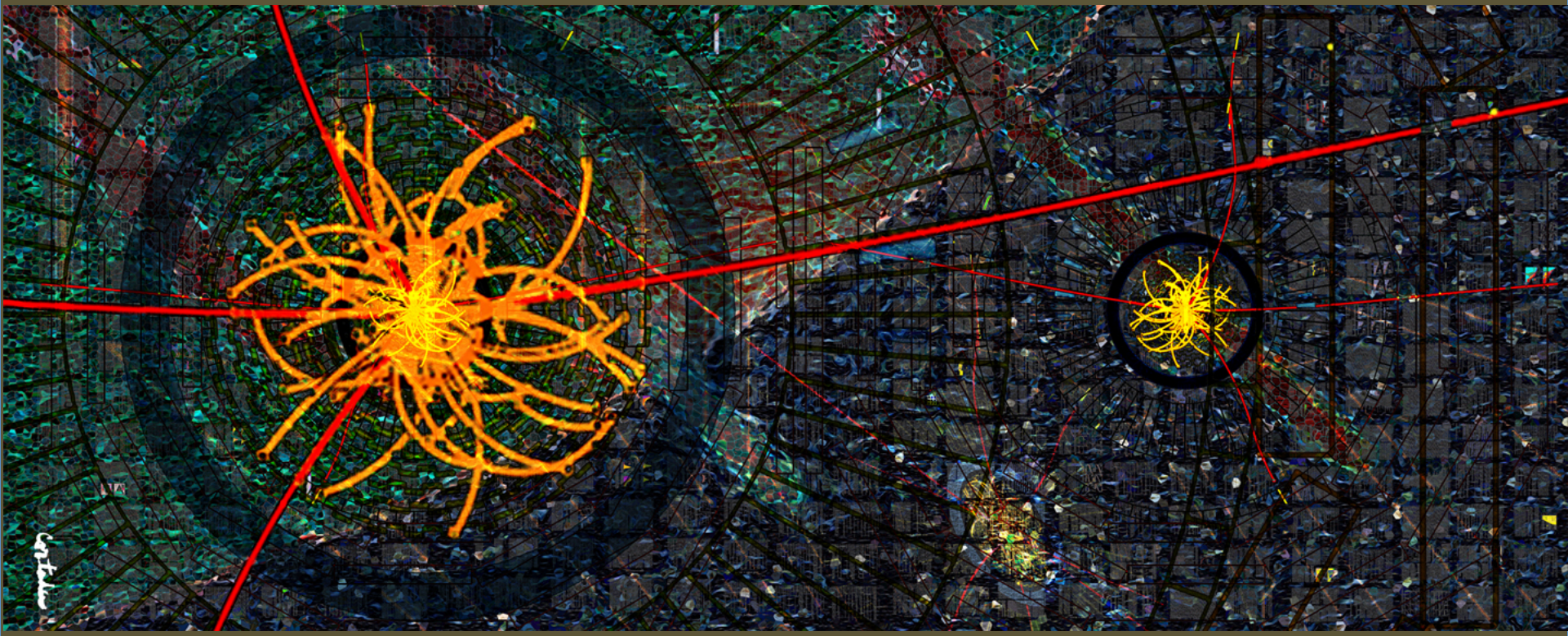






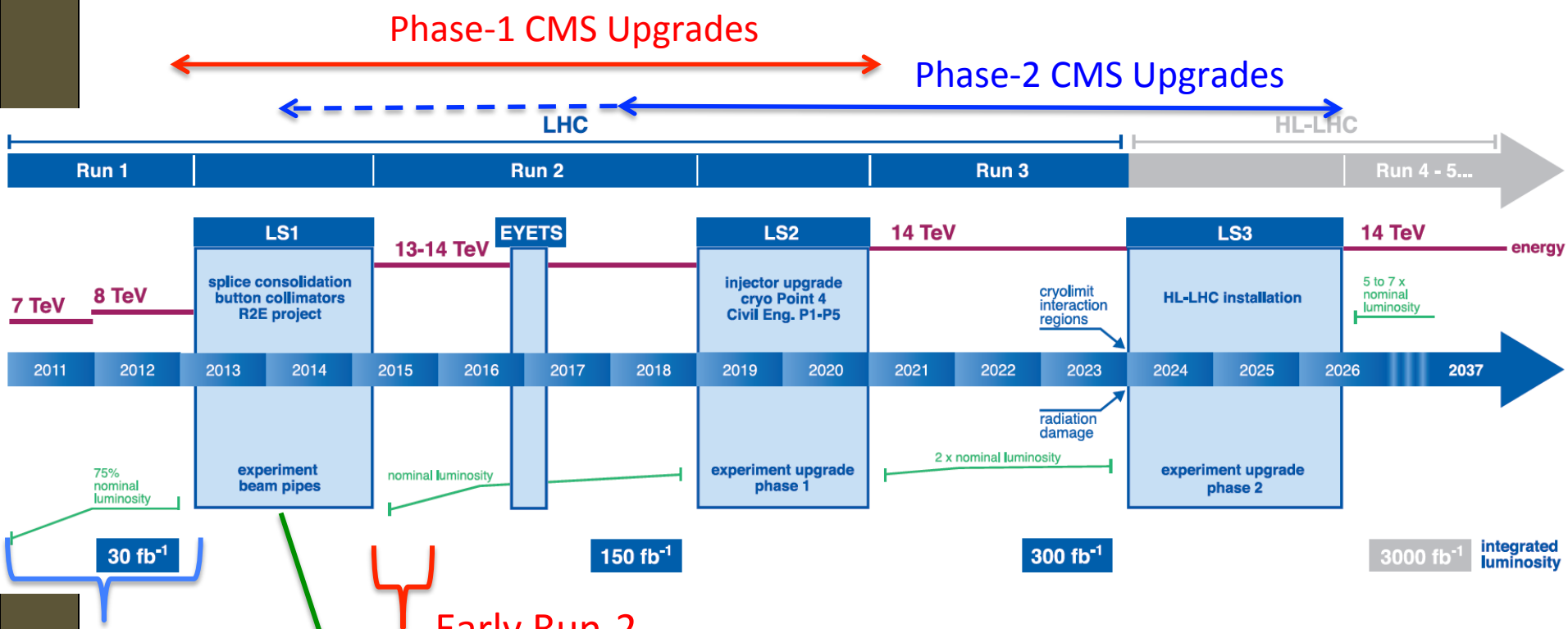


Upgrades: Towards improved detectors



Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> ZZ", digital art, 2013.

Timeline



Run-1 highlights

Early Run-2 results

Long Shutdown 1 (LS1) activities

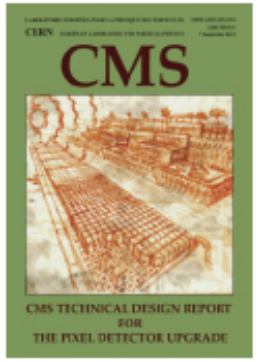
CMS is active on many fronts

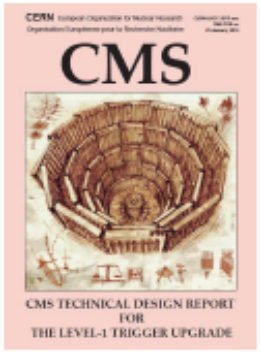
Overview of Phase-1 upgrades

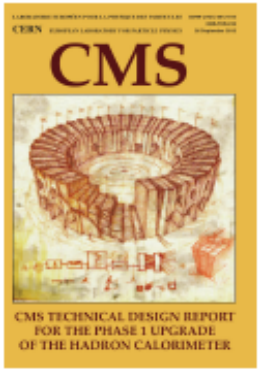
Since the initial construction of CMS the pile-up will increase to twice the design and new technology opportunities appeared.

Upgrades are ongoing for three areas:

- **New Pixel Tracker**: a barrel part with 4 layers and 3 forward disks, as well as a new readout chip
  → *installation E-YETS 2016-2017*
- **Level-1 Trigger**: to cope with the higher rate the calorimeter and muon L1 trigger system is being upgraded as well as the global trigger
  → *installation and commissioning in 2014-2016*
- **Hadron Calorimeter**: new electronics to be installed for the HF to allow timing based background rejection and new SiPM's for the barrel and endcap (HB/HE) readout
  → *installation HF electronics YETS 2015-2016*
  → *HCAL installation during LS2*



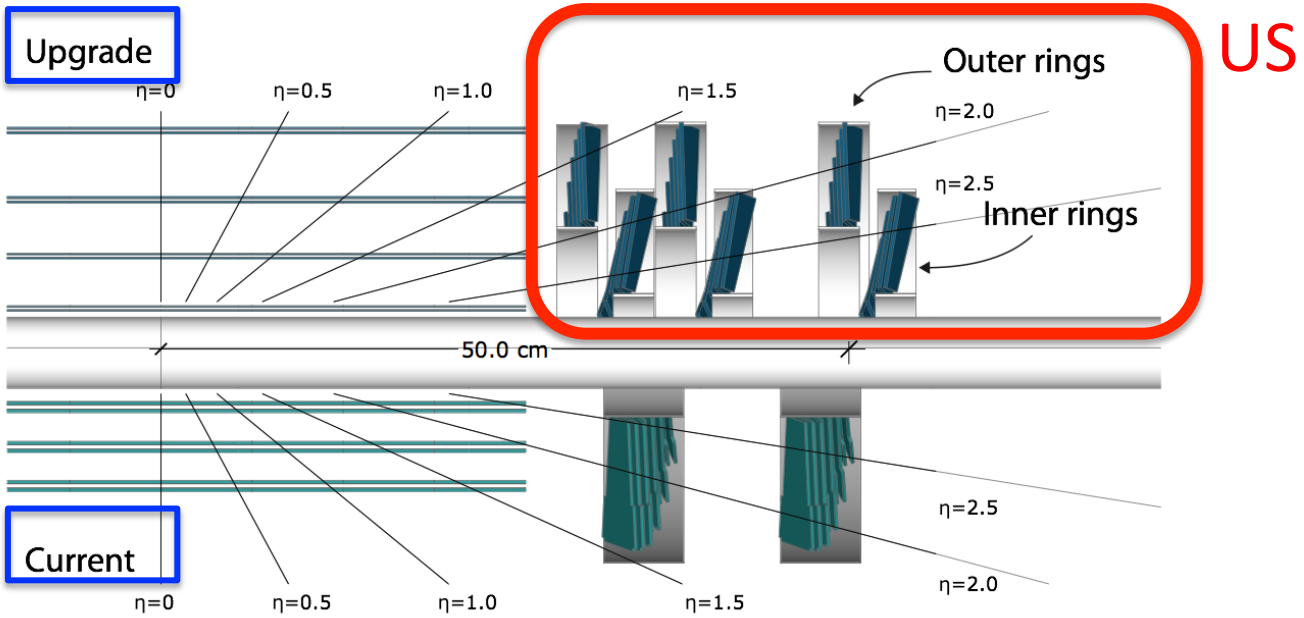




The US has a major role in all these upgrades

Pixel Phase-1 upgrade

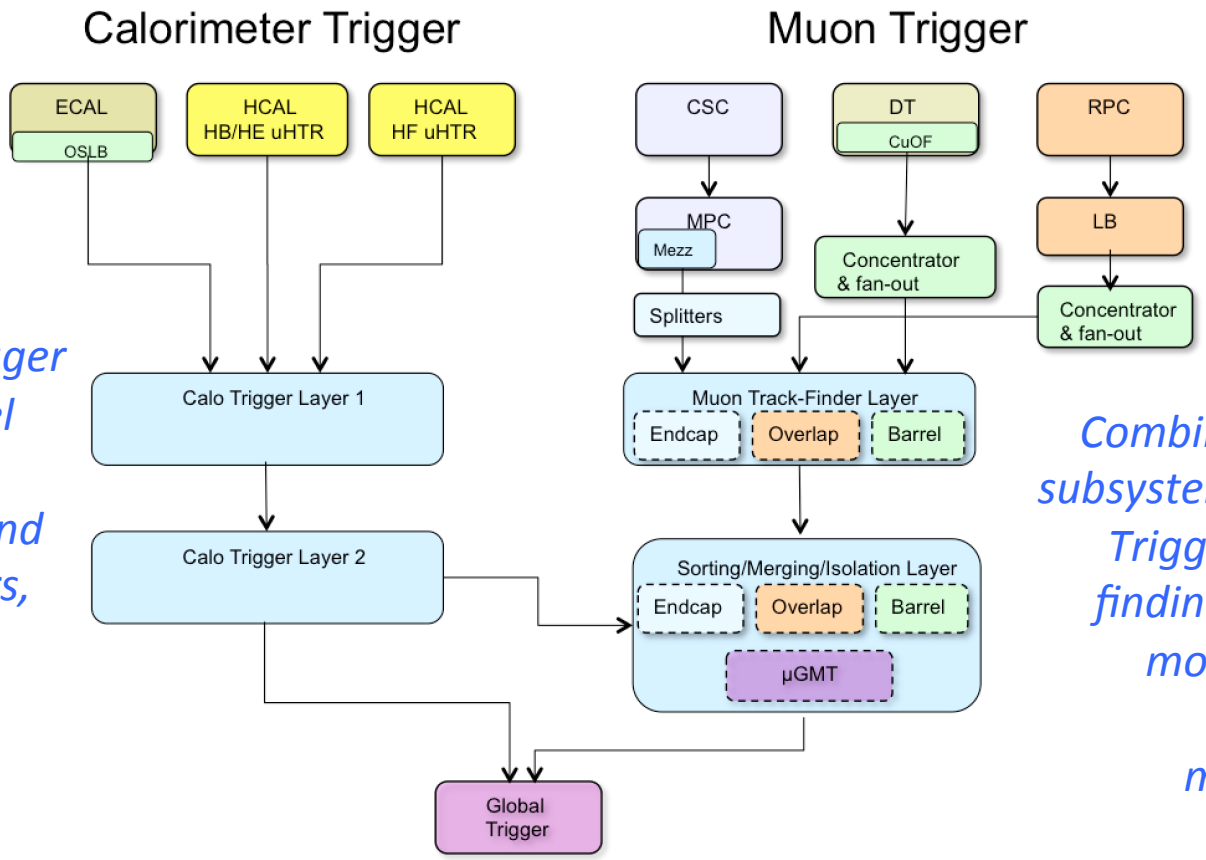
- More layers will be added in the barrel and endcap regions (most inner barrel layer with a *radius of 3cm*): will reduce fake rate and improve track resolution and efficiency
- New readout chip to operate at 50 pile-up and 100kHz, and tolerate rates up to 100 pile-up events
- 8 pilot modules are installed on forward blades for Run-2



L1 trigger Phase-1 upgrade

- Need to maintain the trigger performance of Run-1 towards Run-2&3
- Move to high-performance FPGA's and common use of the μTCA architecture
- Deployed from "legacy" to "upgrade" trigger system in two stages

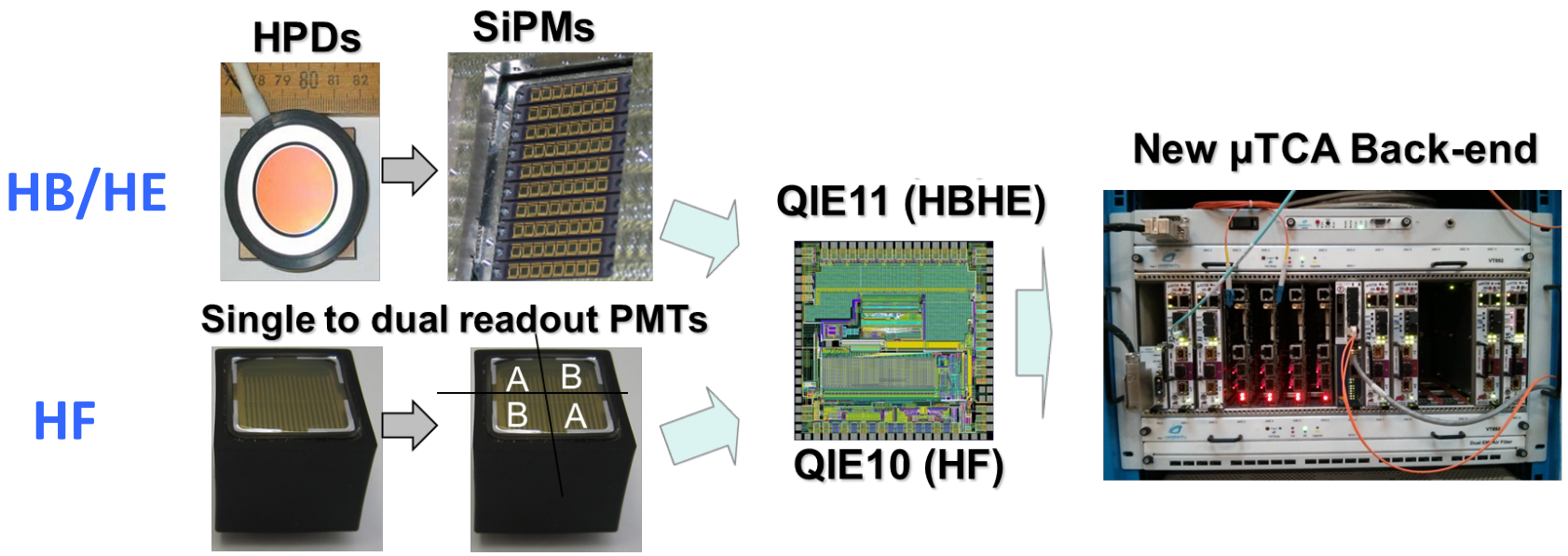
A two-layered calorimeter trigger with tower-level precision (i.e. improved tau and electron triggers, and pile-up subtraction)



Combining all muon subsystems in a Muon Trigger with track-finding options (i.e. more robust and improved p_T measurement)

HCAL Phase-1 upgrade

- New photodetectors to deal with radiation and anomalous signals: for HB/HE from HPD → SiPM, for HF from single-anode PMT → dual-anode PMT's
- New Front-End and Back-End electronics



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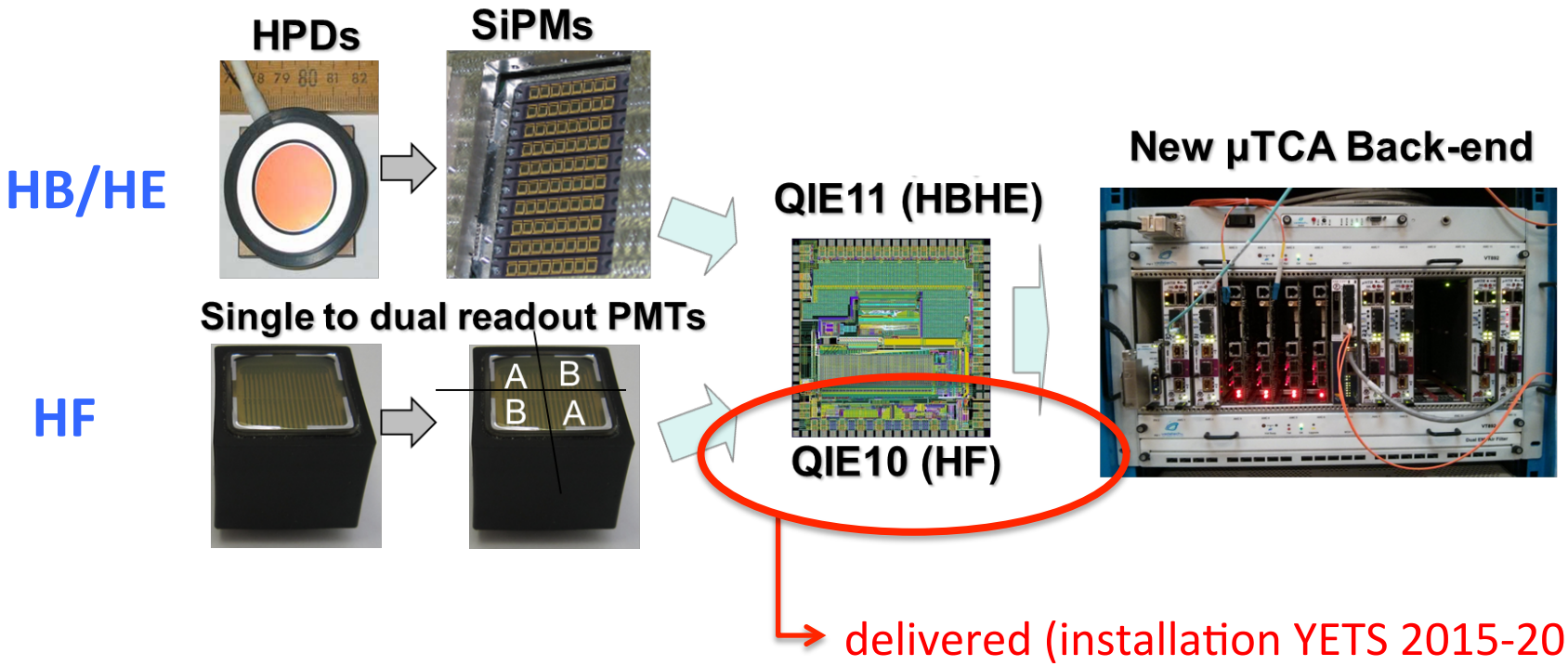

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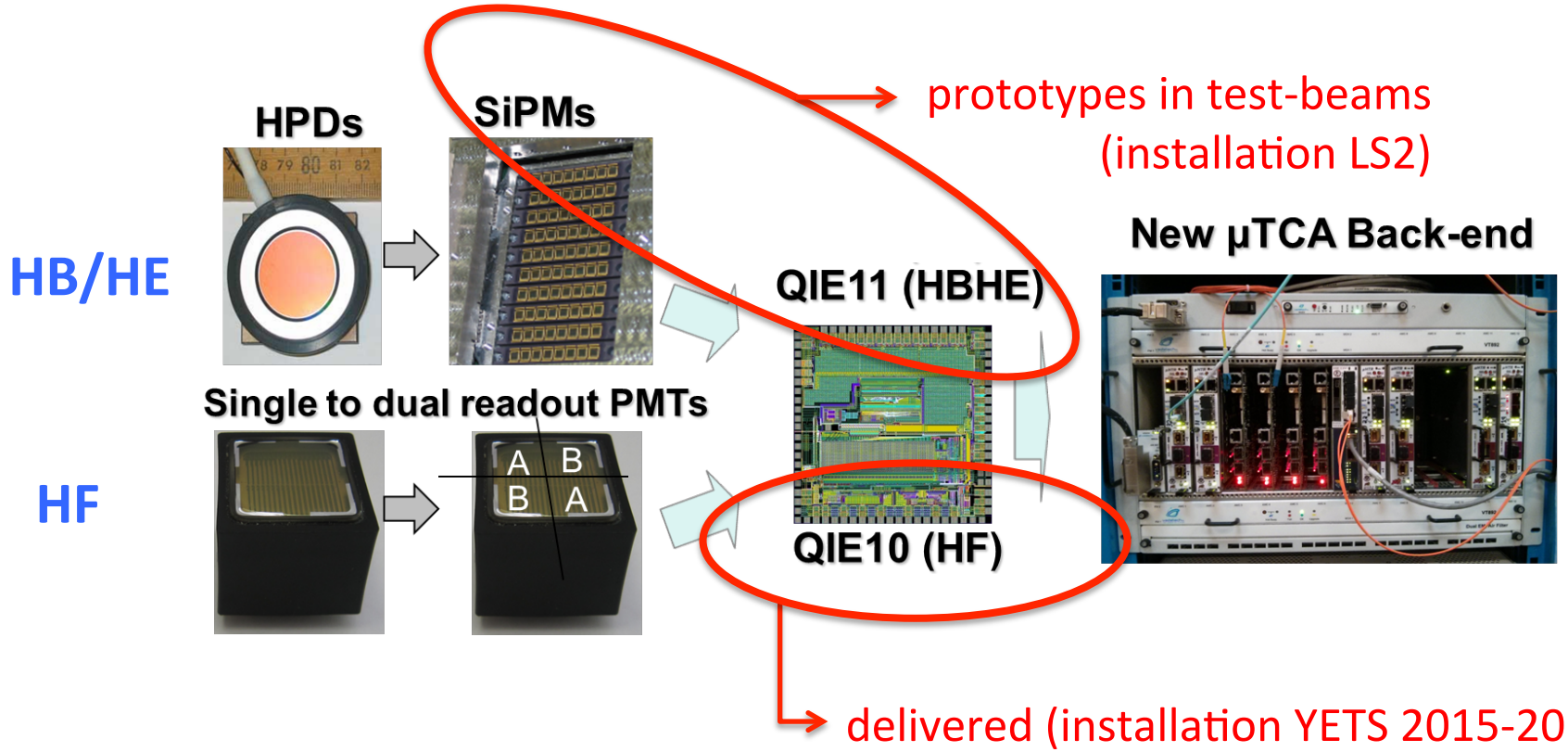
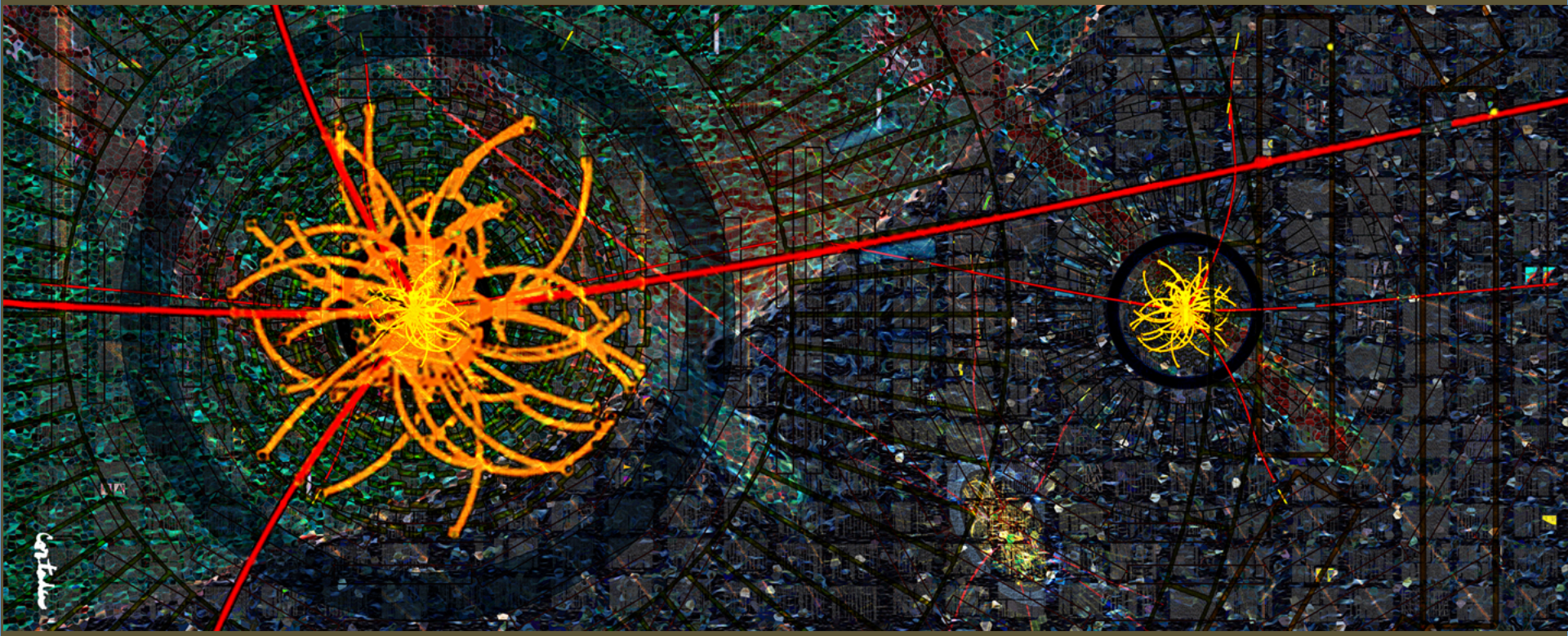


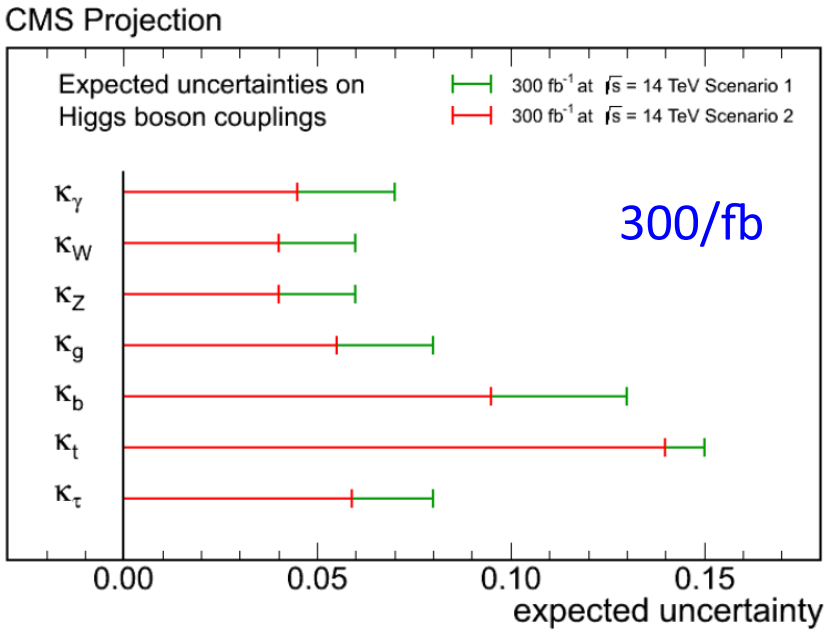
Upgrades: Towards HL-LHC

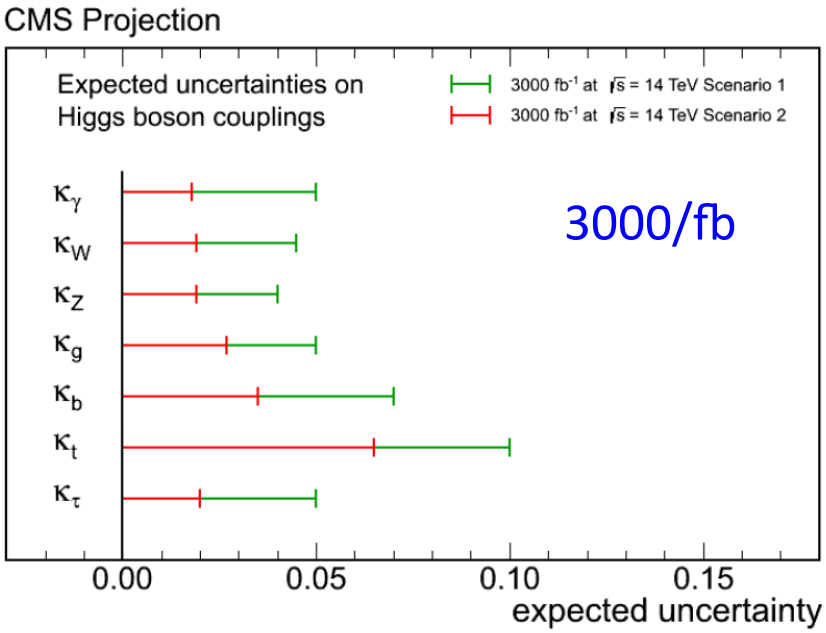


Xavier Cortada (with the participation of physicist Pete Markowitz), "In search of the Higgs boson: H -> ZZ", digital art, 2013.

More luminosity at HL-LHC

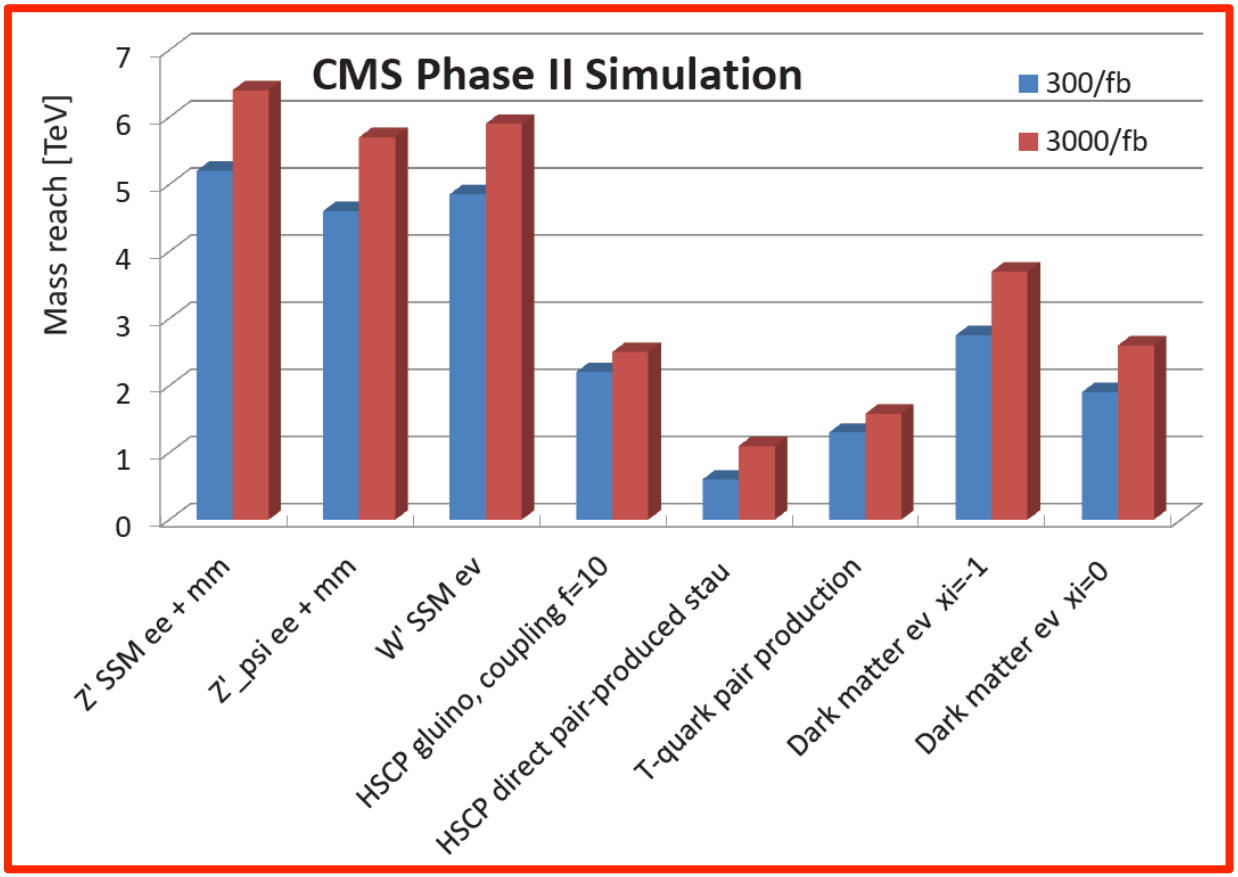
From full LHC dataset to full HL-LHC dataset a factor of >2 improvement in Higgs boson SM coupling precision (scaled from current measurements and assuming same detector performances with the full 300-3000/fb).





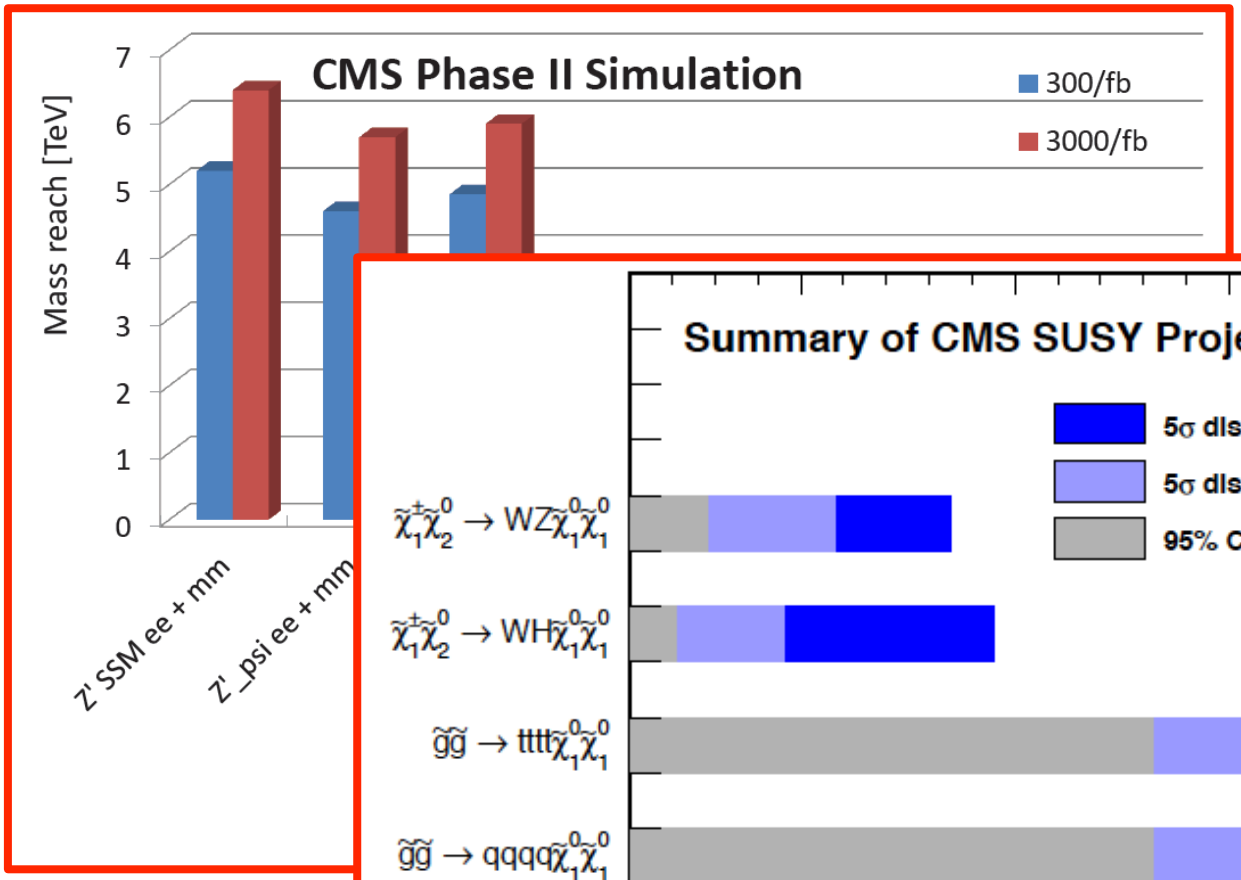
Two scenarios: (1) where systematic uncertainties do not scale with more integrated luminosity, and (2) where they do scale down with a factor of 2

More luminosity at HL-LHC



All plots from CMS Phase-2 Technical Proposal CERN-LHCC-2015-010

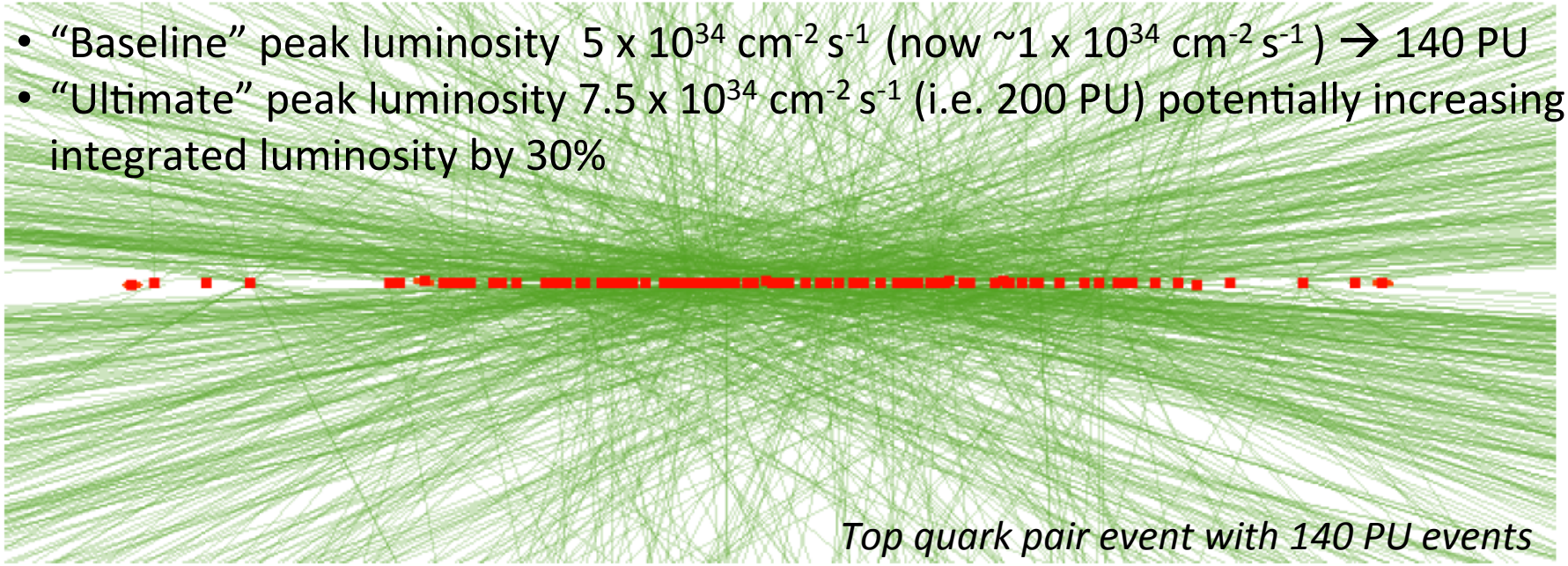
More luminosity at HL-LHC



All plots from CMS Phase-2 Technical Proposal CERN-LHCC-2015-010

HL-LHC: more luminosity

- "Baseline" peak luminosity 5 x 10^{34} cm^{-2} s^{-1} (now ~1 x 10^{34} cm^{-2} s^{-1}) → 140 PU
- "Ultimate" peak luminosity 7.5 x 10^{34} cm^{-2} s^{-1} (i.e. 200 PU) potentially increasing integrated luminosity by 30%

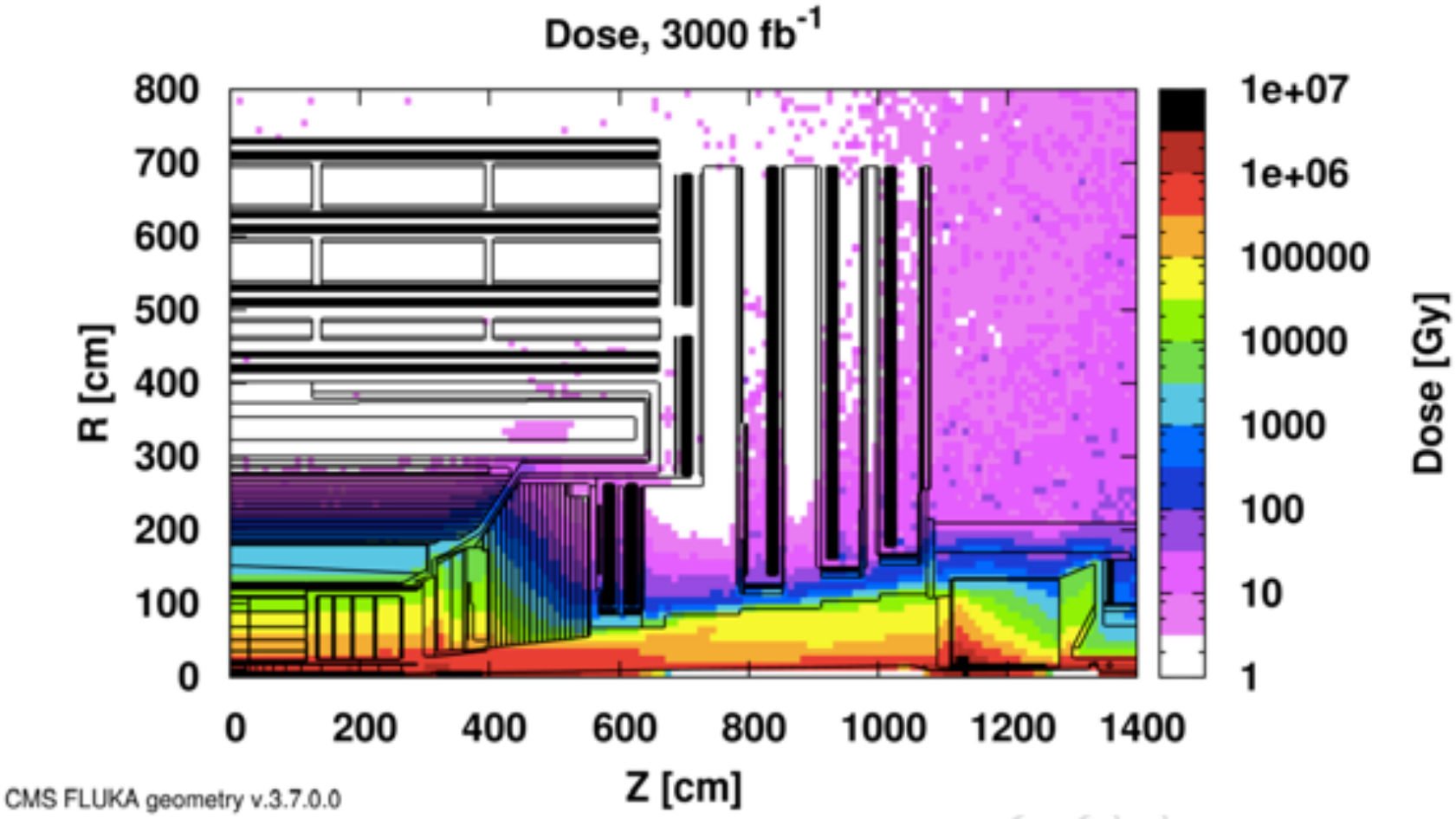


Top quark pair event with 140 PU events

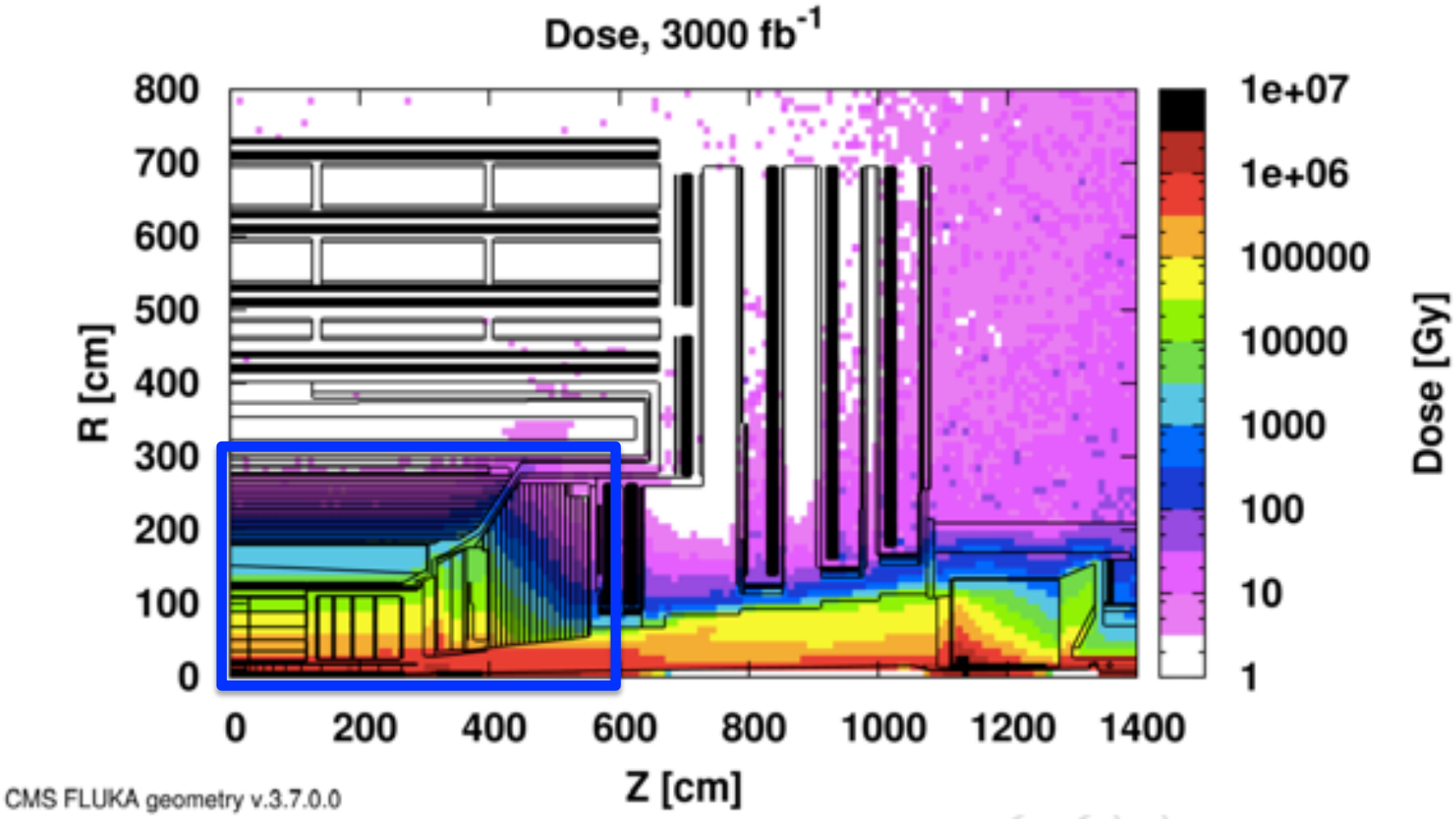
CMS Phase-II (i.e. HL-LHC) upgrade goals

- Maintain Phase-I detector performance, at 140 PU (baseline)
- Enable operation at 200 PU (ultimate), with moderate performance degradation
- Radiation tolerance 3000 fb^{-1} margin up to 4000 fb^{-1}

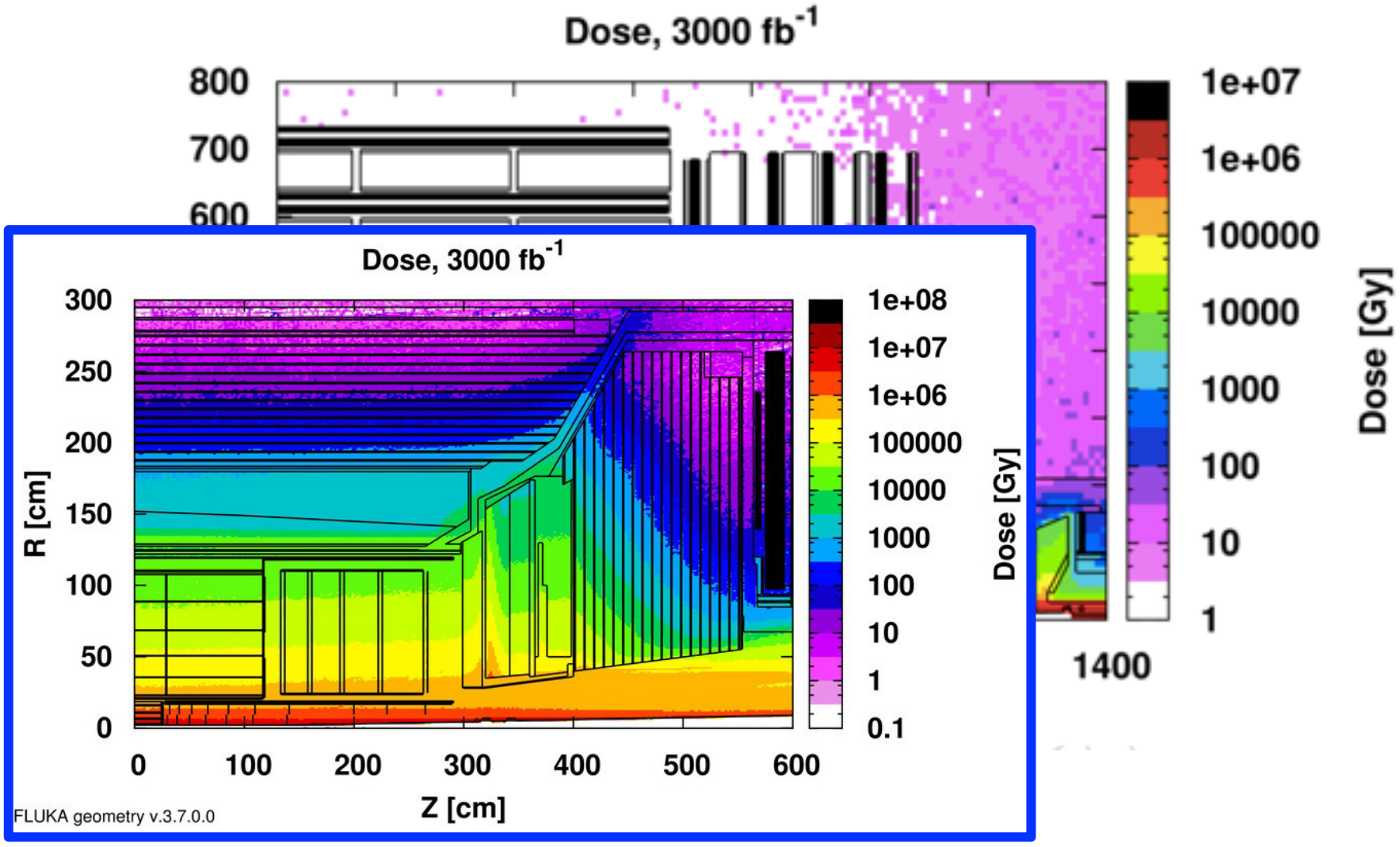
More luminosity, i.e. more radiation



More luminosity, i.e. more radiation



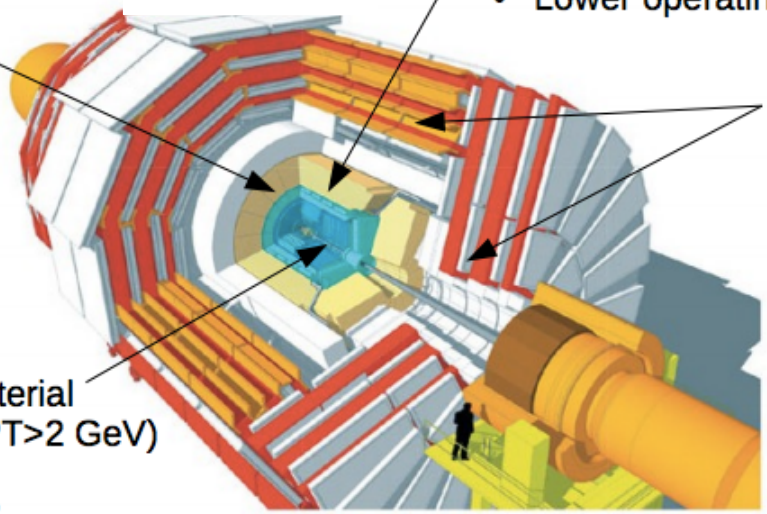
More luminosity, i.e. more radiation



Upgrades for the CMS experiment

New Endcap Calorimeter
- Radiation Tolerant
- High Granularity
- 3D capability

Barrel Calorimeter
- Replace FE/BE electronics
- Lower operating temperature(8°)

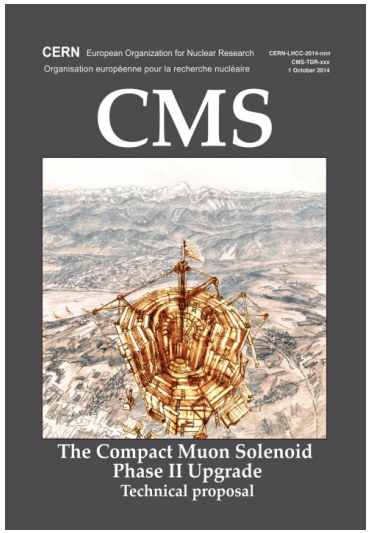


Muon system
- Replace DT/CSC FE/BE electronics
- Complete RPC coverage In region 1.5<η<2.4
- Muon tagging with GEMs for 2.4<η<3.0

New Tracker
- Radiation tolerant – less material
- 40 MHz selective readout (PT>2 GeV) for track trigger
- Extend to coverage of η~3.8

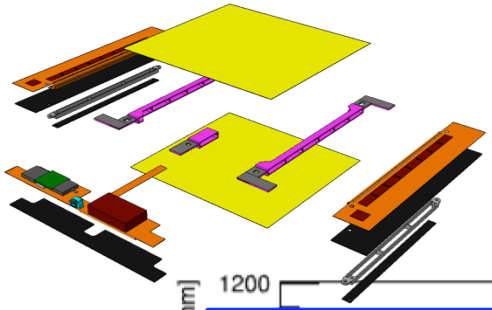
Trigger/HLT/DAQ
- L1 Track Trigger
- L1 Trigger: 12.5 μs latency, 750 kHz output
- HLT output of 7.5 kHz

These upgrades come with scientific/technical challenges and the CMS Collaboration is prepared to face them



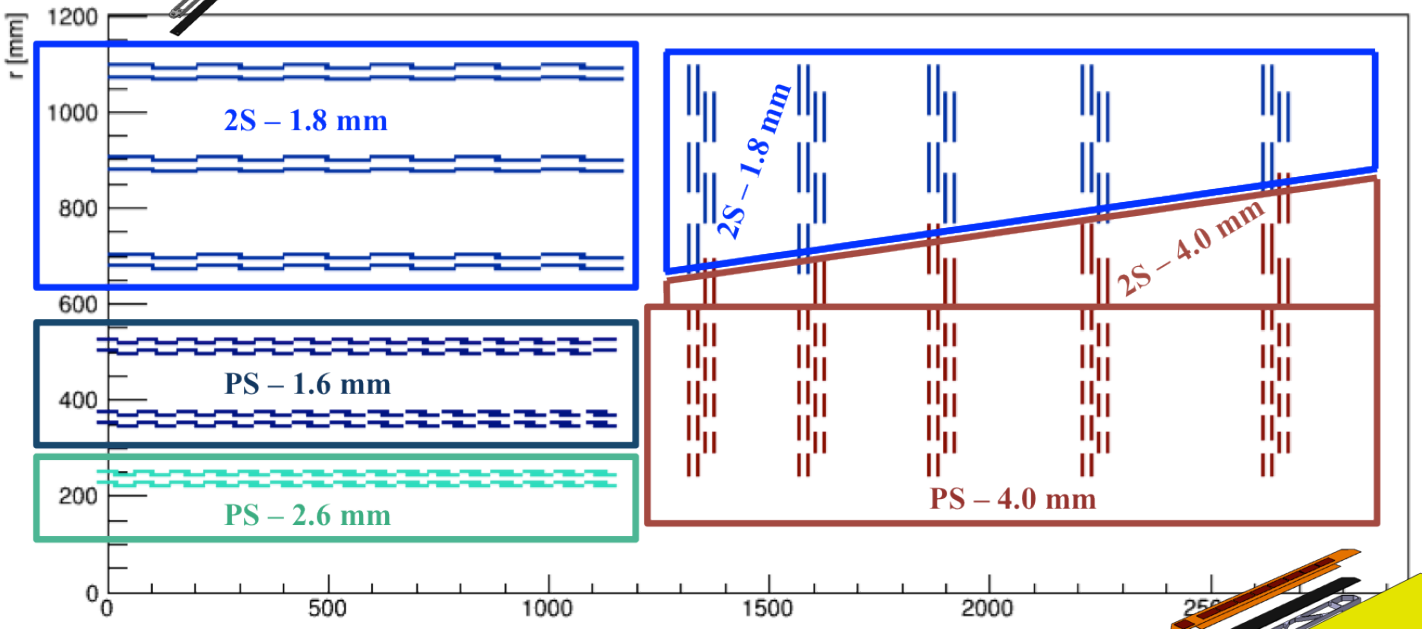
Technical Proposal: CERN-LHCC-2015-010, https://cds.cern.ch/record/2020886

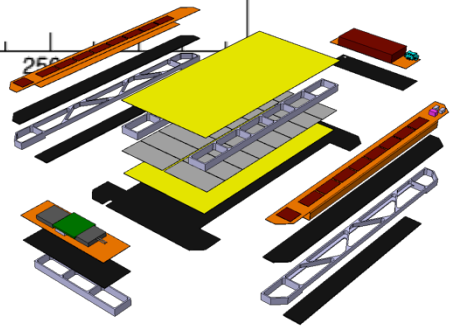
Tracker Upgrade: Outer Tracker



2S modules

90 μm pitch & 5 cm length



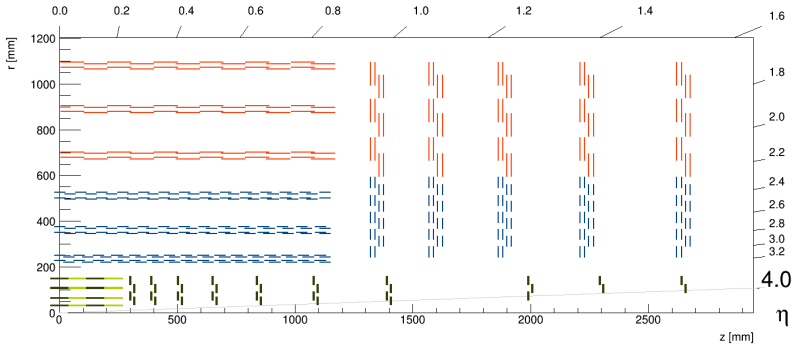


PS modules

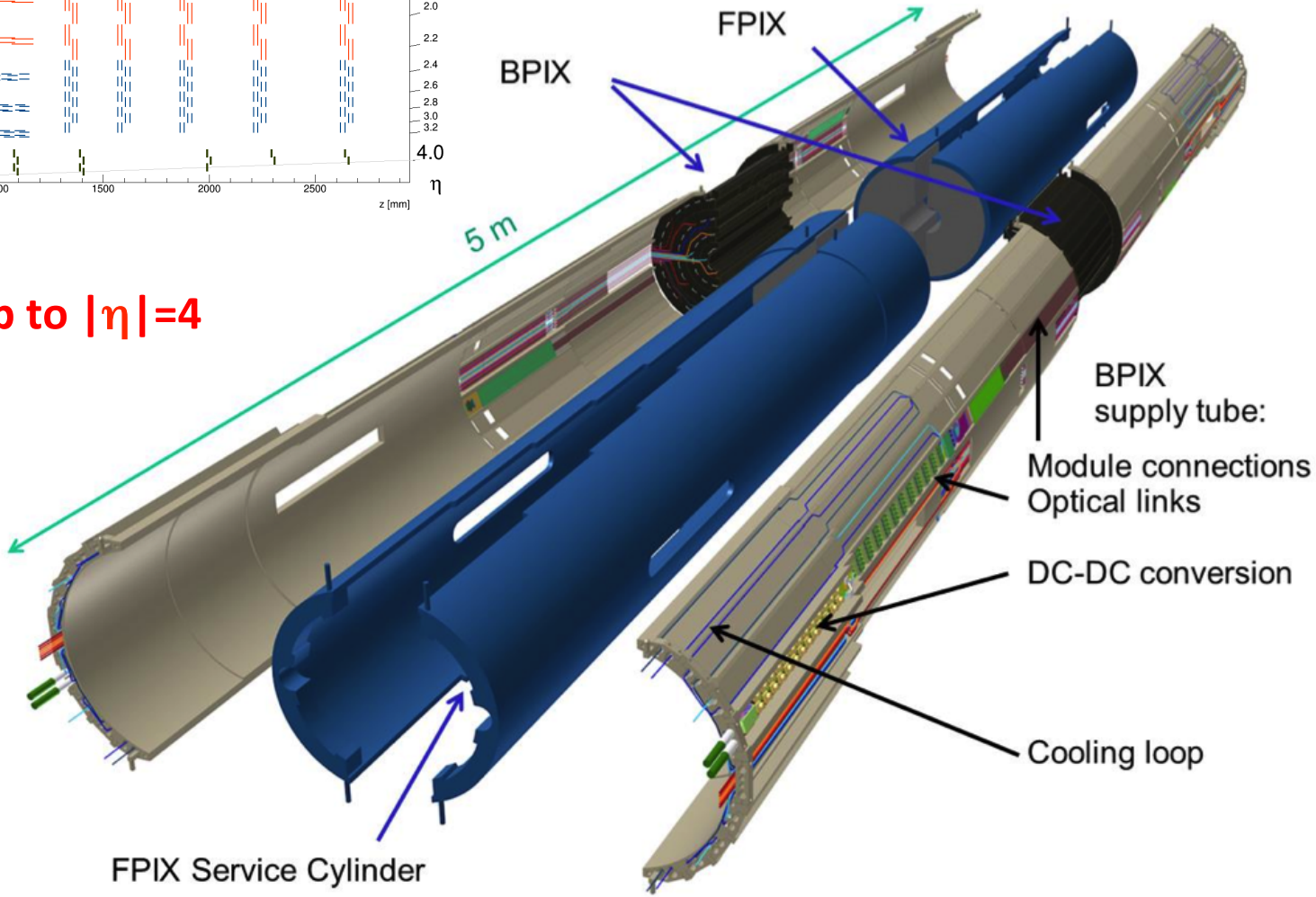
100 μm pitch & 2.5 cm length

100 μm x 1.5 mm macropixels

Tracker Upgrade: Inner (Pixel) Tracker



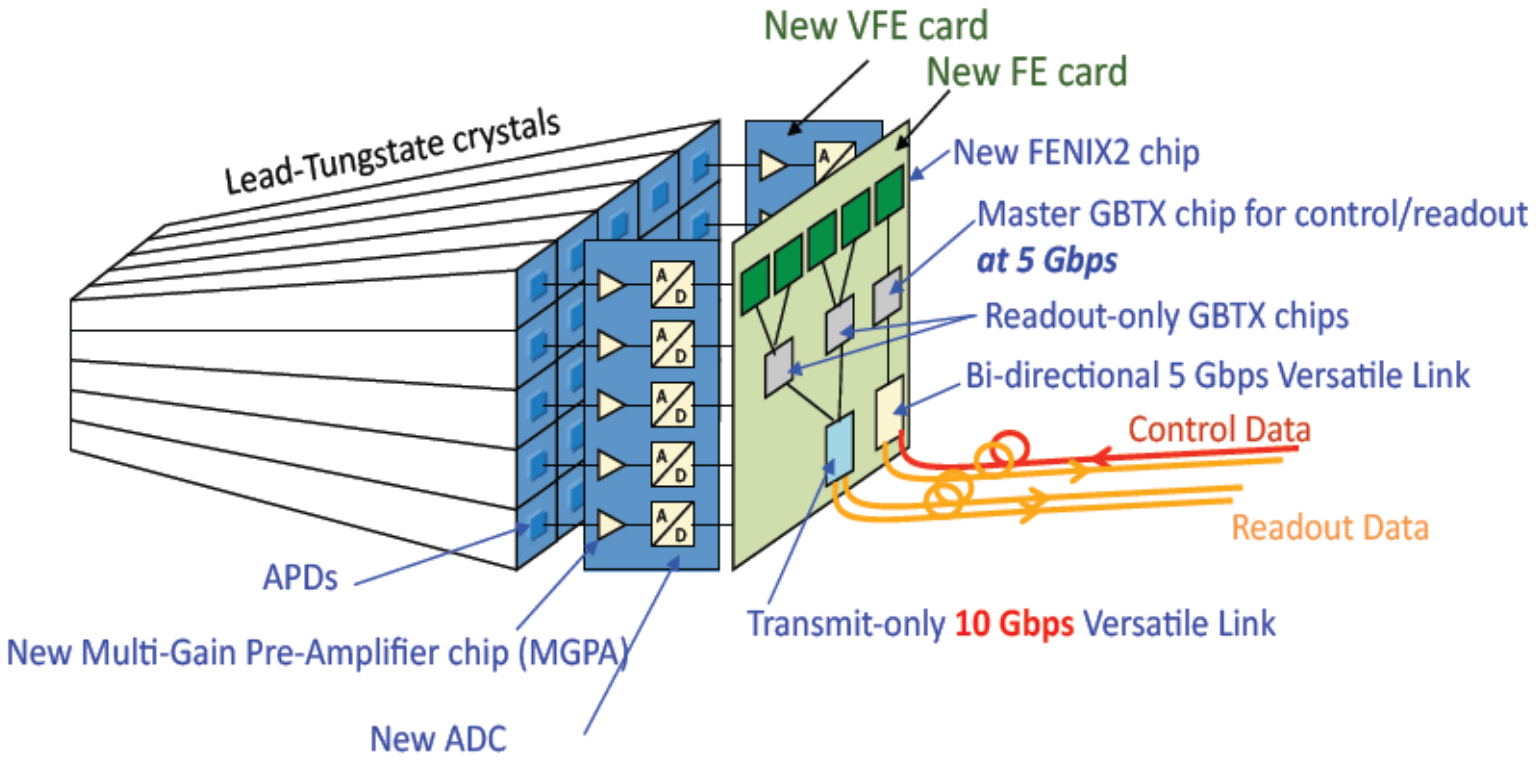
Covers up to |η|=4



Barrel Calorimeter Upgrade

Adapt to the trigger requirements & reduce radiation induced noise

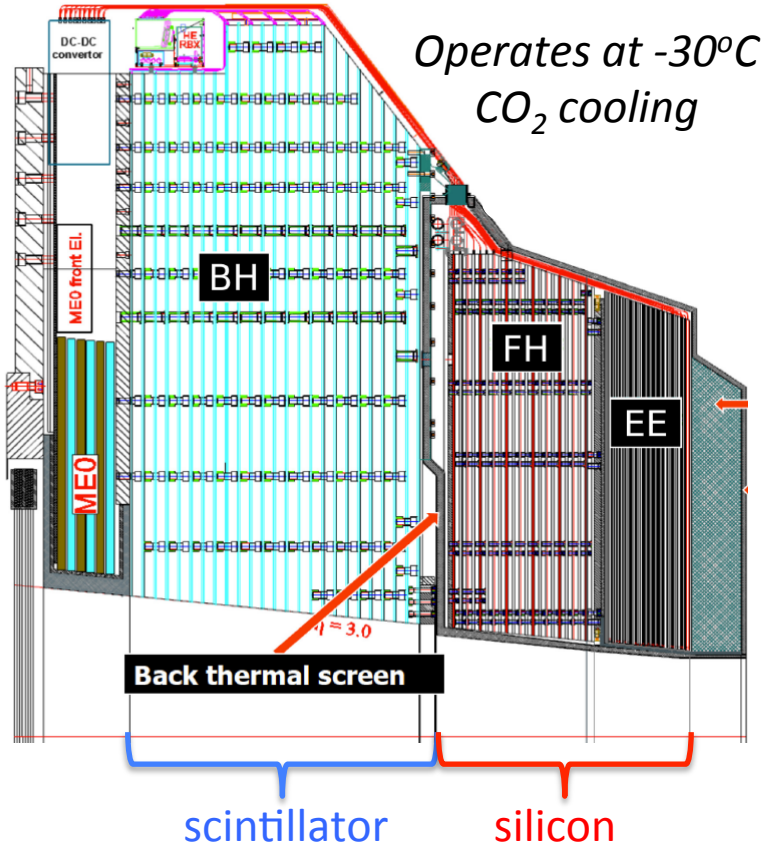
- New electronics to meet the trigger latency of 12.5 μs and L1 rate of 750 kHz
- Adjust operating temperature (8°C) to limit the noise in the APD's to 200 MeV



Forward Calorimeter Upgrade

3D shower measurement in a new High-Granularity Calorimeter (HGC) with high timing precision, will mitigate pile-up effects

$1.5 < |\eta| < 3.0$



Operates at -30°C
CO_2 cooling

ECAL section (**EE**): Tungsten/Silicon
Depth of $25X_0$, 1.5λ (28 layers)

HCAL section (**FH**): Brass/Silicon
Depth of 3.5λ (12 layers)

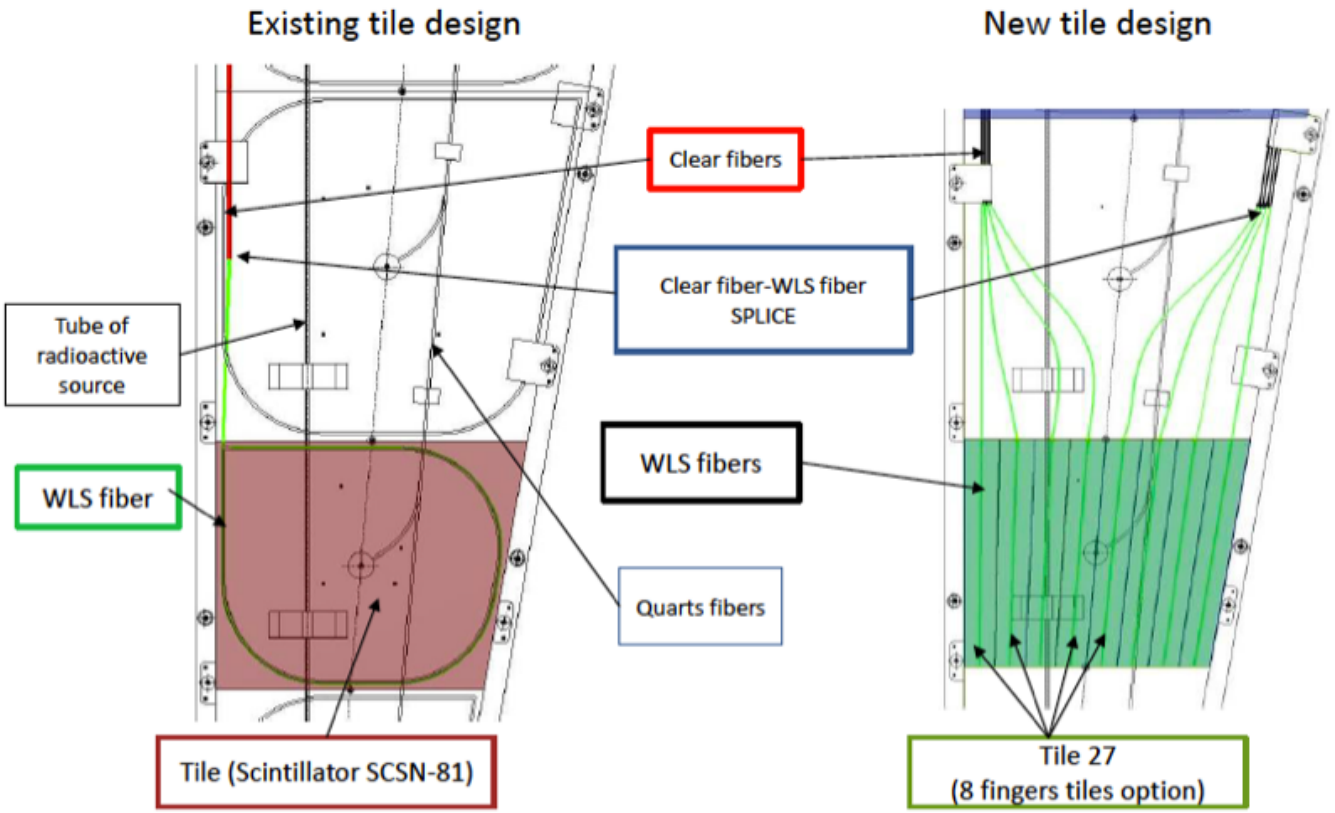
Backing HCAL section (**BH**): Brass/Scintillator
Depth of 5λ (12 layers)

Total depth of 10λ

Forward Calorimeter Upgrade

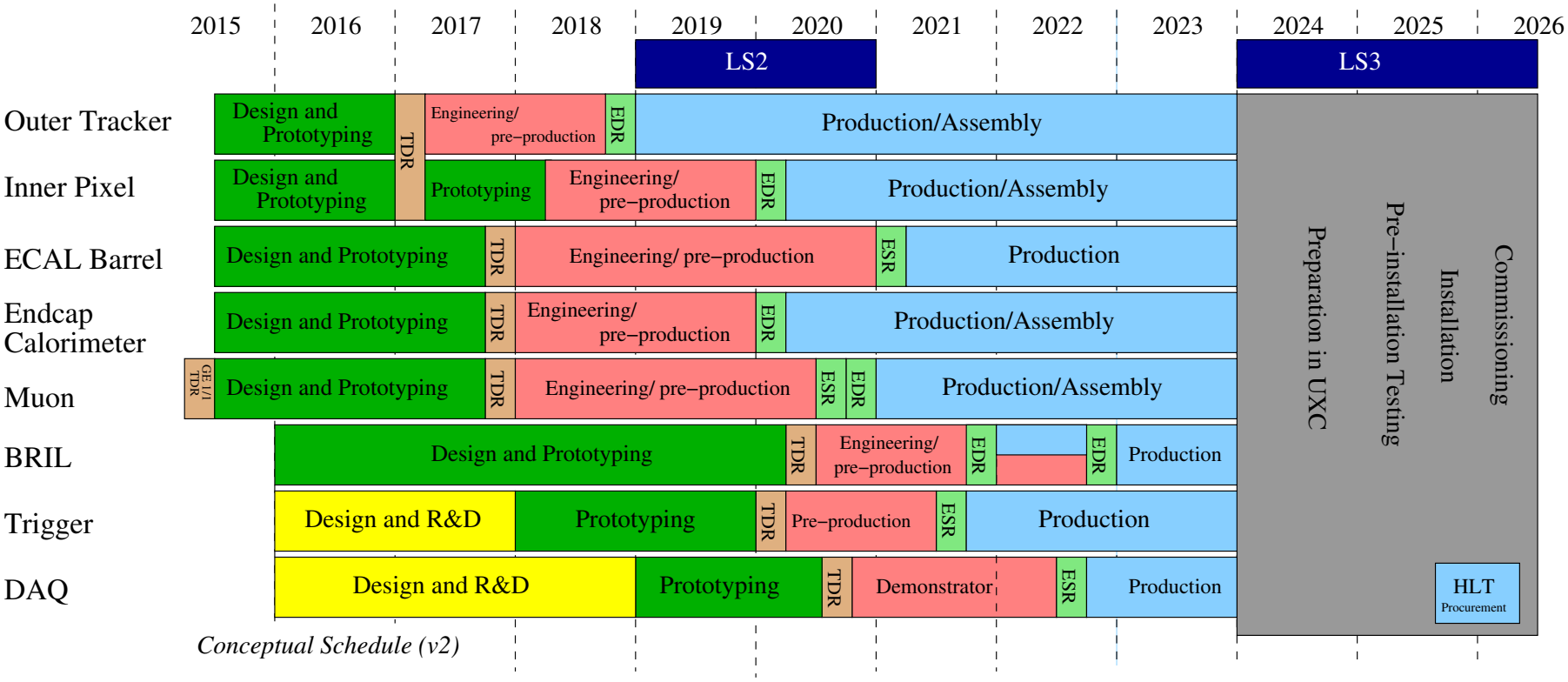
New Back Hadron calorimeter with scintillating tiles

- Similar to current HE but more radiation tolerant and higher granularity
  → *x2 in φ and x1.3 in η*
- Finger tile design with a shorter light path



Upgrades for the CMS experiment

- R&D is well defined and in progress
- Technical Design Reports (TDRs) to be delivered in 2017



Based on our successes and experiences, the CMS Collaboration is gearing up for its Phase-2 construction as well as its research program towards HL-LHC.

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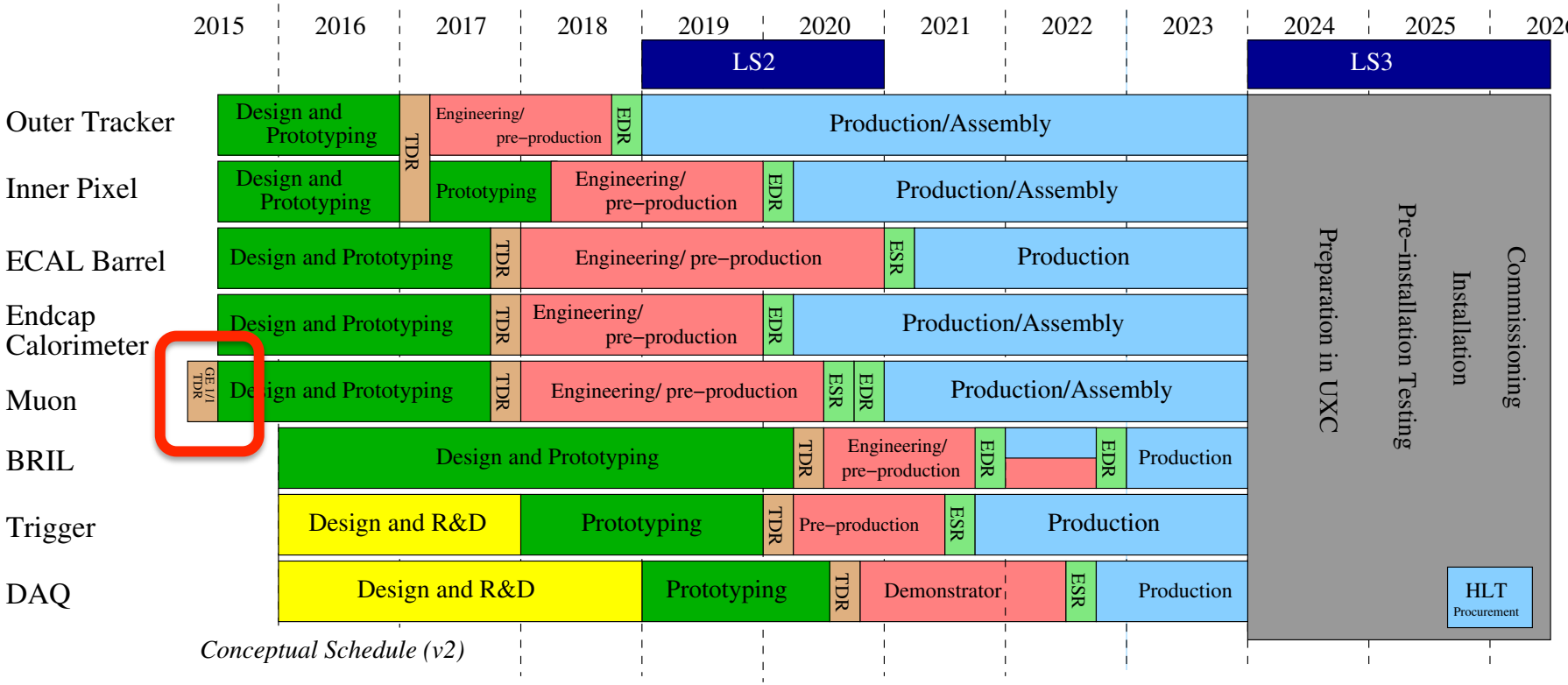
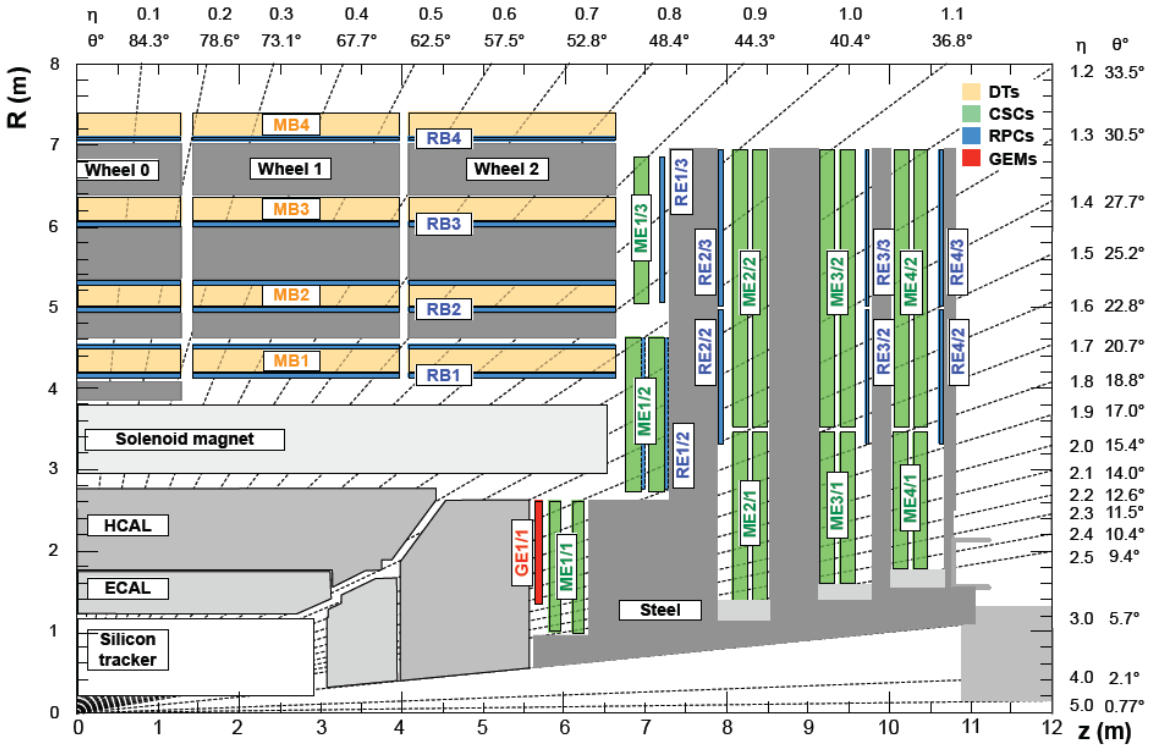
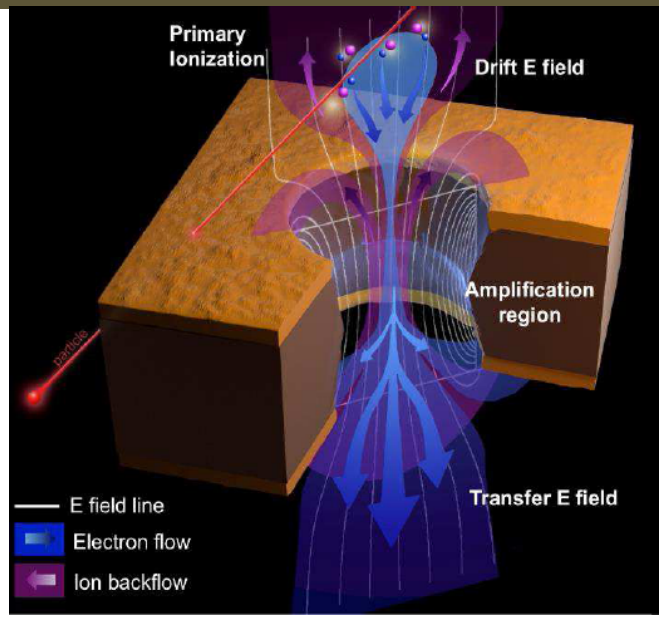


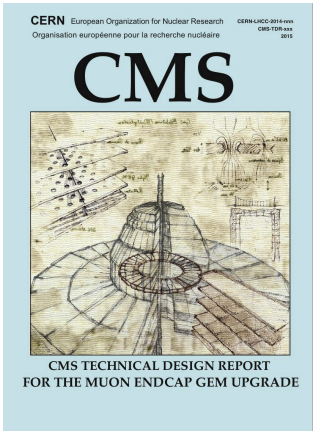
Based on our successes and experiences, the CMS Collaboration is gearing up for its Phase-2 construction as well as its research program towards HL-LHC.

LS2: installation of GEM detectors

- Triple-GEM in 1.5<|η|<2.2 region
- Improve L1 and HLT muon p_T resolution to reduce/maintain the global muon trigger rate
- Ensure 100% trigger efficiency in Run-3







Status of the CMS experiment

① Excellent detector performance during Run-1
② >400 journal papers, including a major discovery

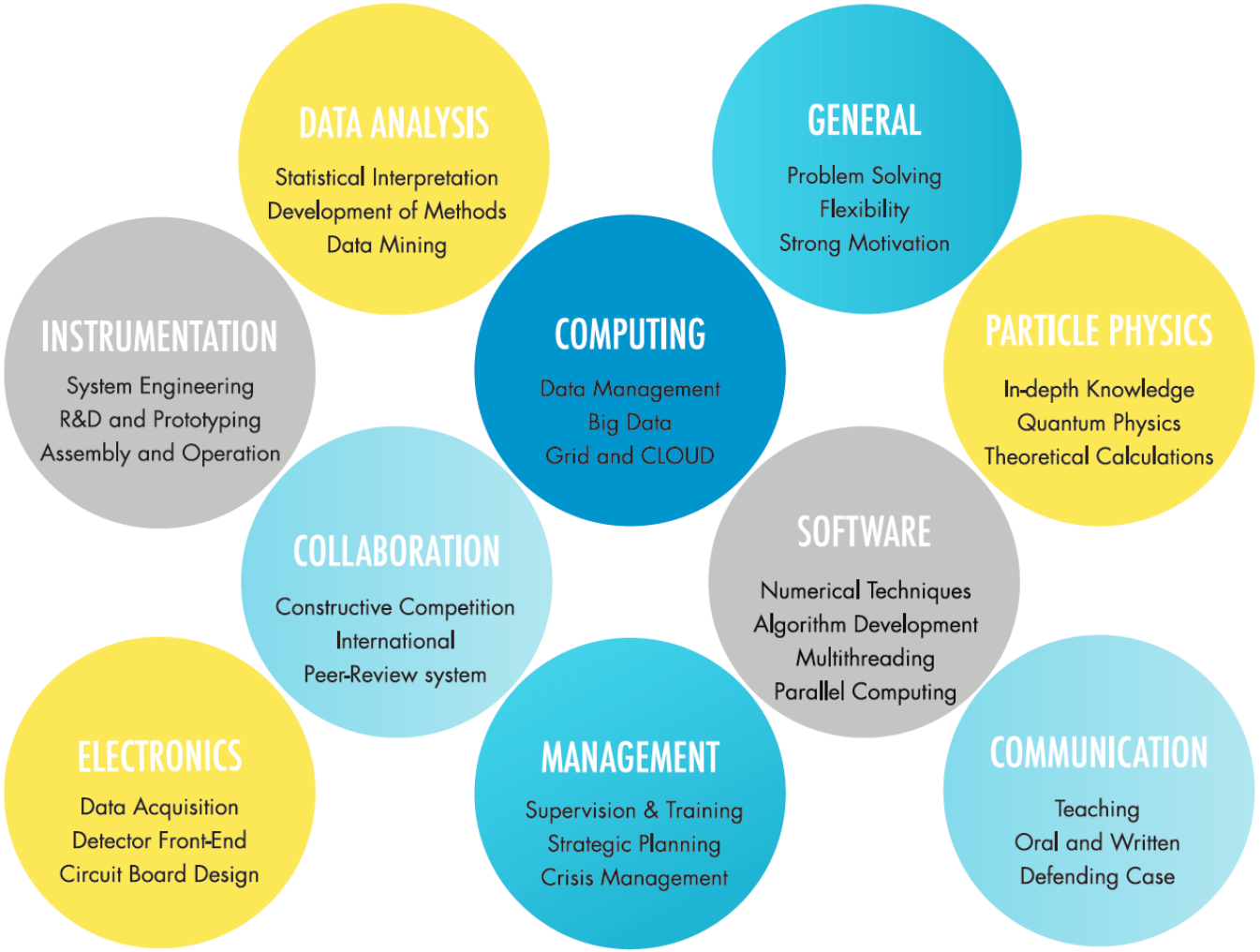
③ Successful program during LS1 (2013-2014)
④ Well prepared for 13 TeV collisions

⑤ First 13 TeV results appear
⑥ En-route for another long list of new physics insights

⑦ Preparing for our future research at the HL-LHC

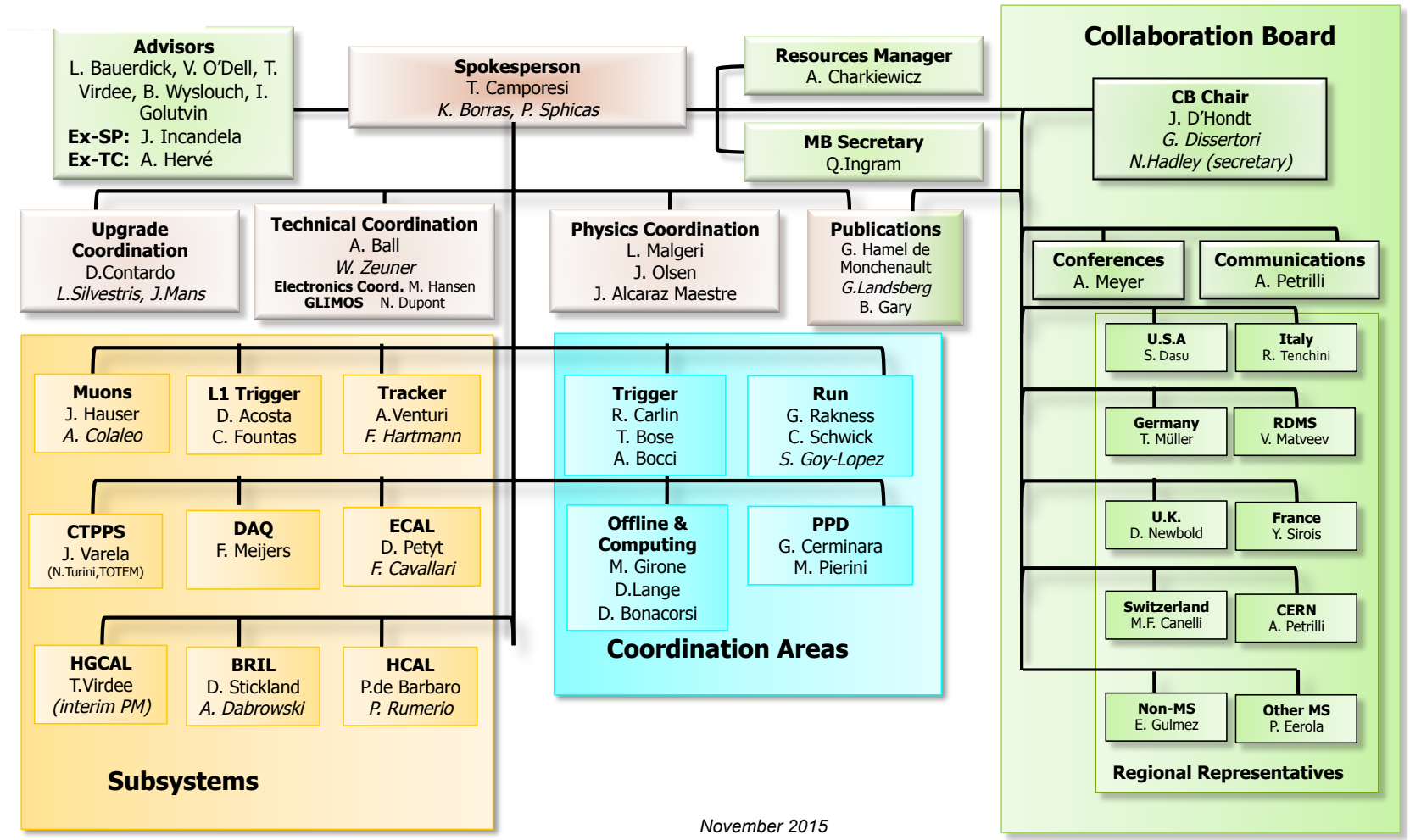
Many challenges ahead!

>4000 CMS members with excellent skills to face them



Back-up

The CMS Management



The Particle Physics Puzzle