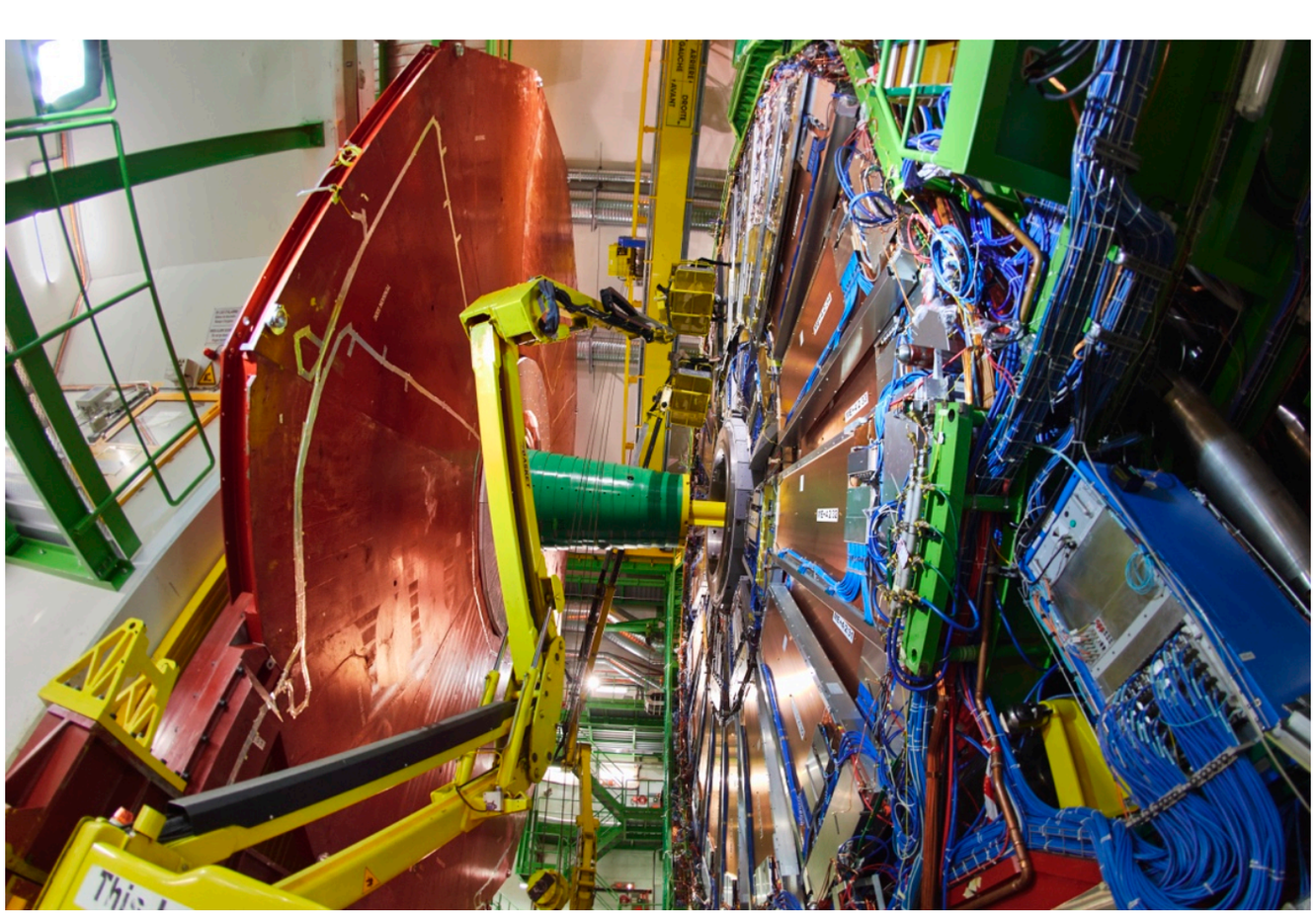
CMS Status Report

Louise Skinnari (Northeastern University)
on behalf of the CMS Collaboration

138th LHCC Open Meeting, June 5, 2019

Outline

- Activities during LS2
- Subsystem status
- Planning toward Run-3 & HL-LHC
- Physics highlights
- Conclusions



Activities during LS2

Good progress on planned work @ P5

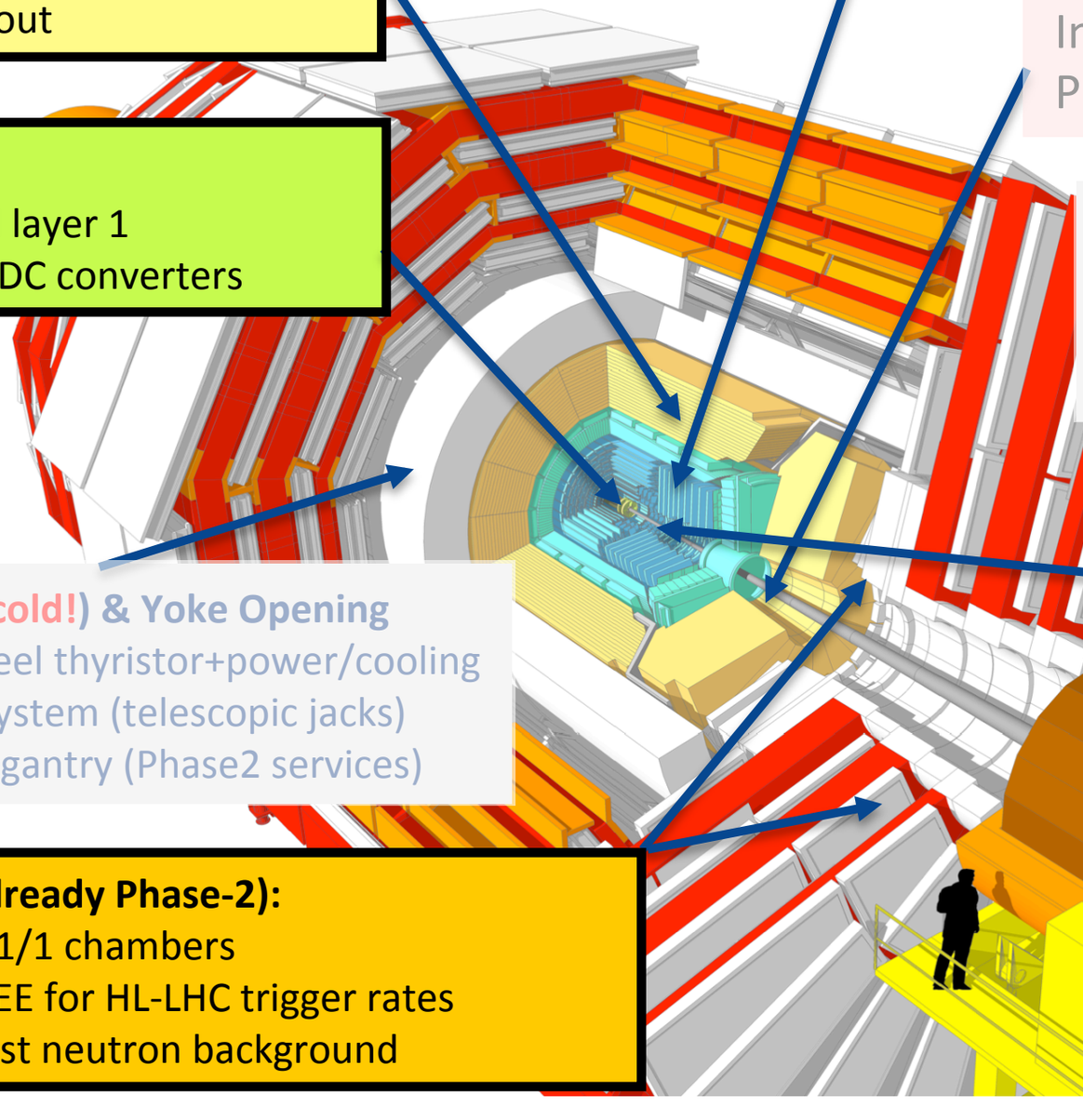
Completed Phase-1 upgrades
- new L1 trigger
- new pixel detector
- HCAL endcap
- muon electronics & detector upgrades

Keep **strip tracker** cold to avoid reverse annealing

HCAL barrel (last Phase-1): install SiPM+QIE11-based 5Gbps readout

Install new **beam pipe** for Phase-2

Pixel detector:
- replace barrel layer 1
- replace all DCDC converters



highlighted → discussed in next slides

Civil engineering on P5 surface to prepare for Phase-2 assembly and logistics
- SXA5 building
- temporary buildings for storage/utility

Near beam & Forward Systems
- BRIL BCM/PLT refit
- New TOTEM T2 track detector
- PPS: RP det & mechanics upgrade

MAGNET (stays cold!) & Yoke Opening
- Cooled freewheel thyristor+power/cooling
- New opening system (telescopic jacks)
- New YE1 cable gantry (Phase2 services)

Muon system (already Phase-2):
- install GEM GE1/1 chambers
- Upgrade CSC FEE for HL-LHC trigger rates
- Shielding against neutron background

Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

Pixel

- New barrel layer 1
  - ✦ Received all wafers of readout ASICs (PROC600 + TBM10)
    - Latest version of PROC600 to be validated before summer closure of company: last but one version is already production ready
  - ✦ *Sensor module production will start soon after company summer closure*

Radiation tolerance through Run-3 (+ improved readout ASICs)

- Replace all DCDC converters
  - ✦ Received (by CERN EP-ESE) latest version of ASIC (FEAST v2.3)
    - To be validated by end of August
  - ✦ *DCDC converter modules will be produced in Fall/Winter 2019*

Issue with chip in DCDC converters (2017)

- **On track for detector ready for installation in Fall 2020**

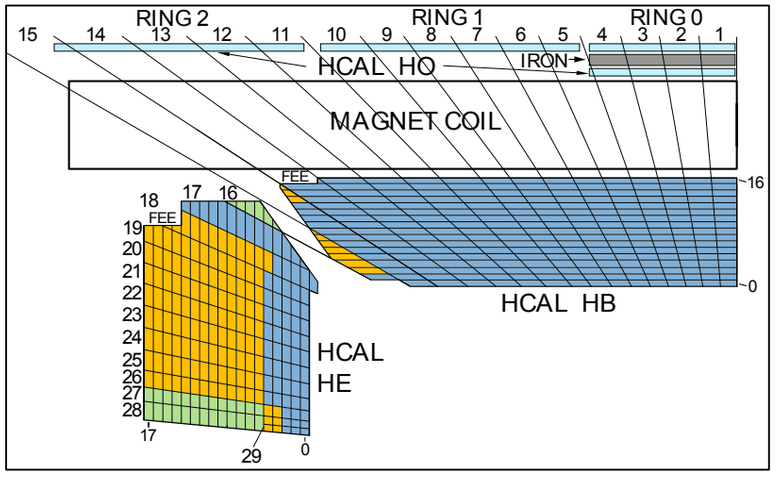
1/2 CMS Phase-1 barrel pixel

HCAL

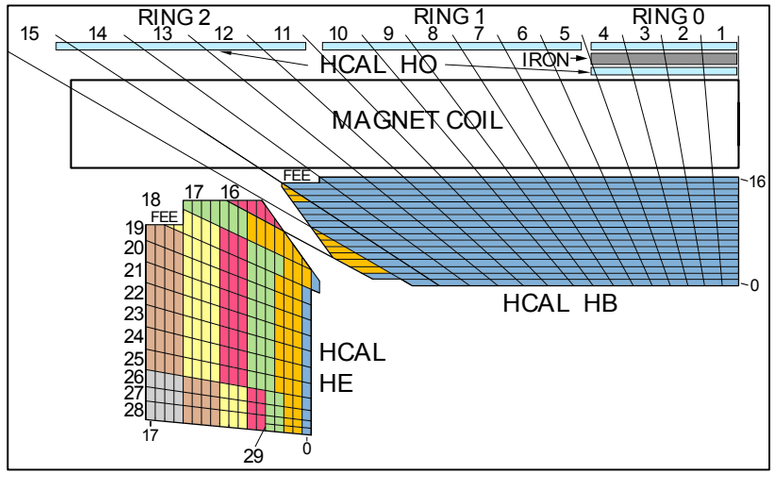
- Barrel electronics upgrade, last Phase-1 upgrade
  - ✦ Corresponding endcap upgrade completed in 2018
- Replacement of HPDs with SiPM
  - ✦ Improve noise levels, light yield & radiation tolerance
  - ✦ Maintain physics performance for jets & MET

HPD=Hybrid PhotoDetectors
SiPM=Silicon Photo-Multipliers

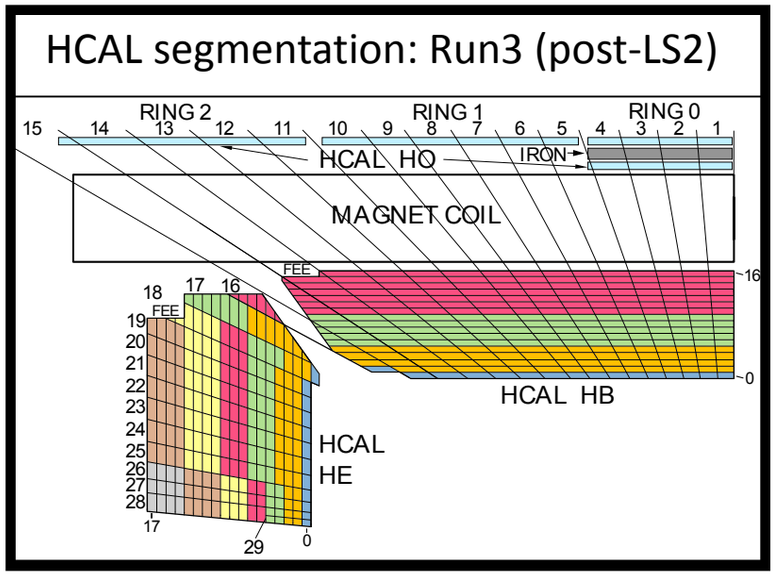
HCAL segmentation: pre-2018



HCAL segmentation: 2018

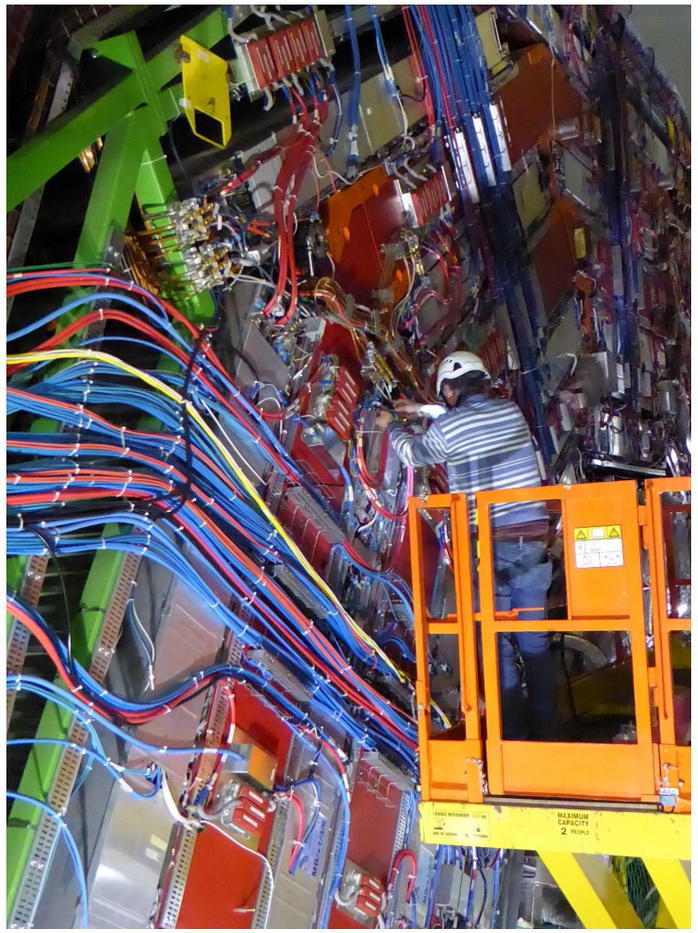


HCAL segmentation: Run3 (post-LS2)



- **On track to complete installation & commissioning before Dec 2019**

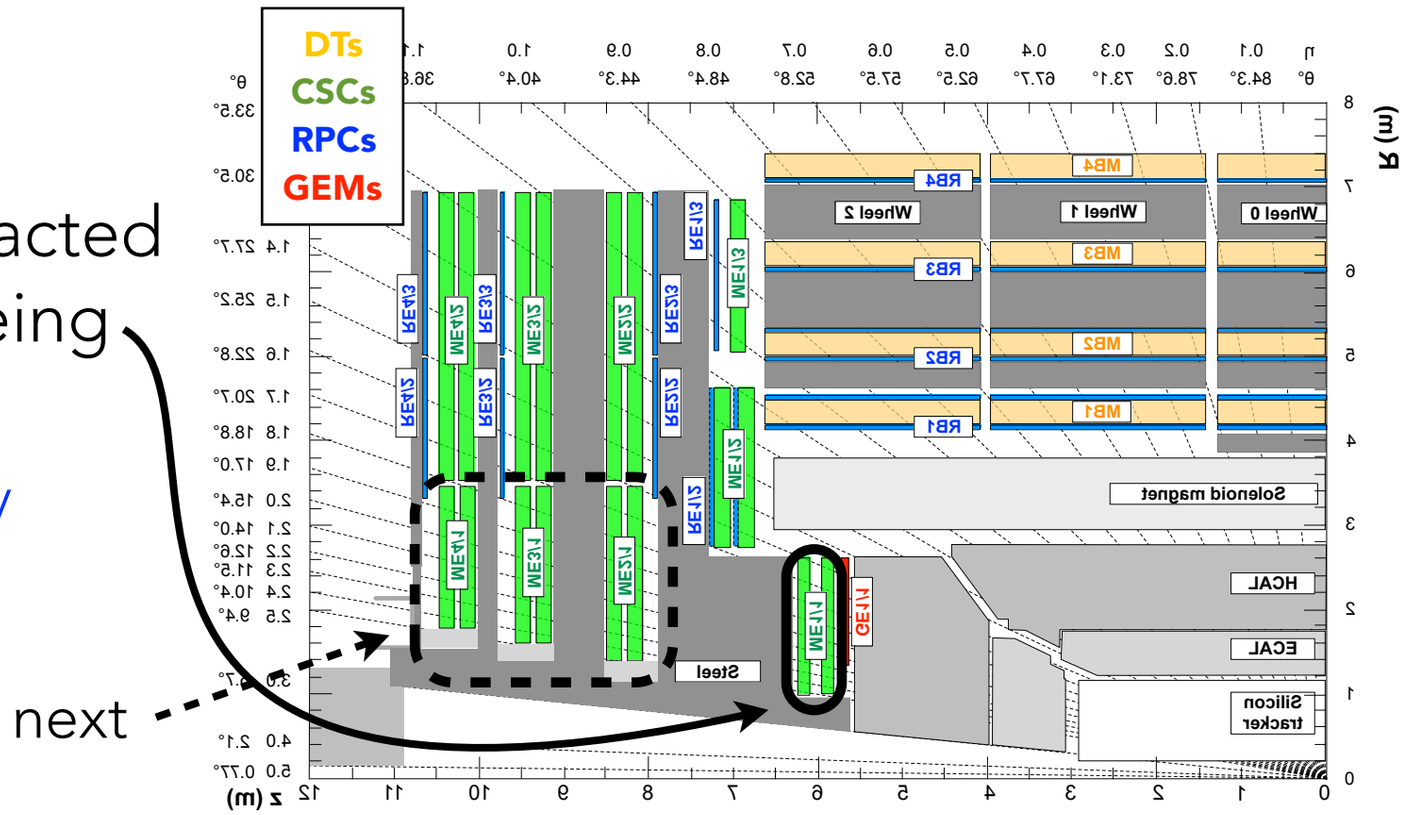
Muons (1)



- Maintenance work
  - RPC gas leak repair campaign ongoing
  - Shielding to reduce background on top part of detector
  - **Progressing well & according to schedule**

Phase-2 upgrade!

- CSC electronics upgrade
  - Longest LS2 work for CMS
  - First station (minus side) extracted & brought to surface, now being tested+reinstalled
    - 26/36 already reinstalled, 3 fully commissioned
  - **Work on schedule!**



next

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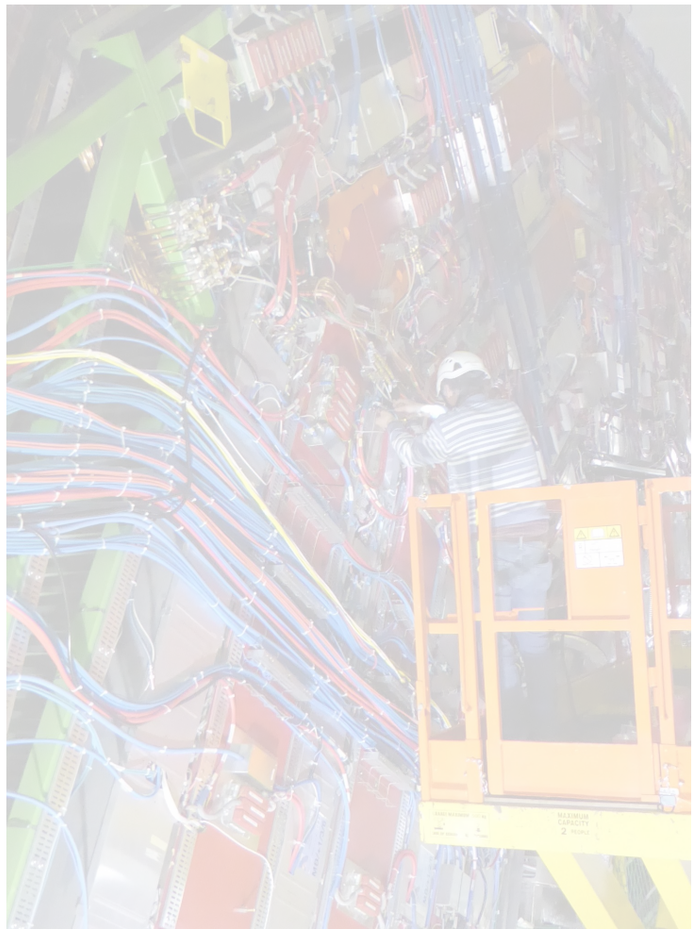

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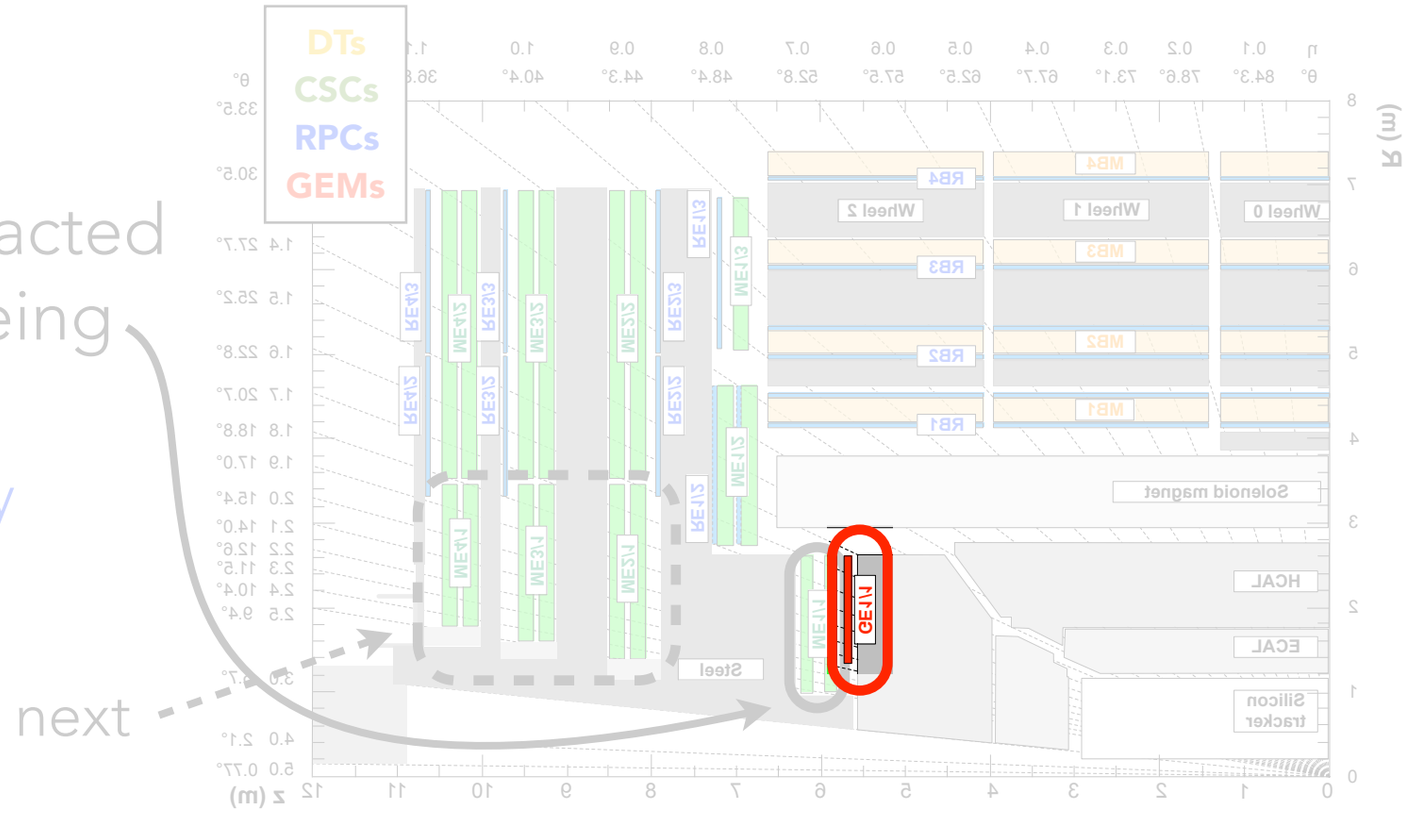


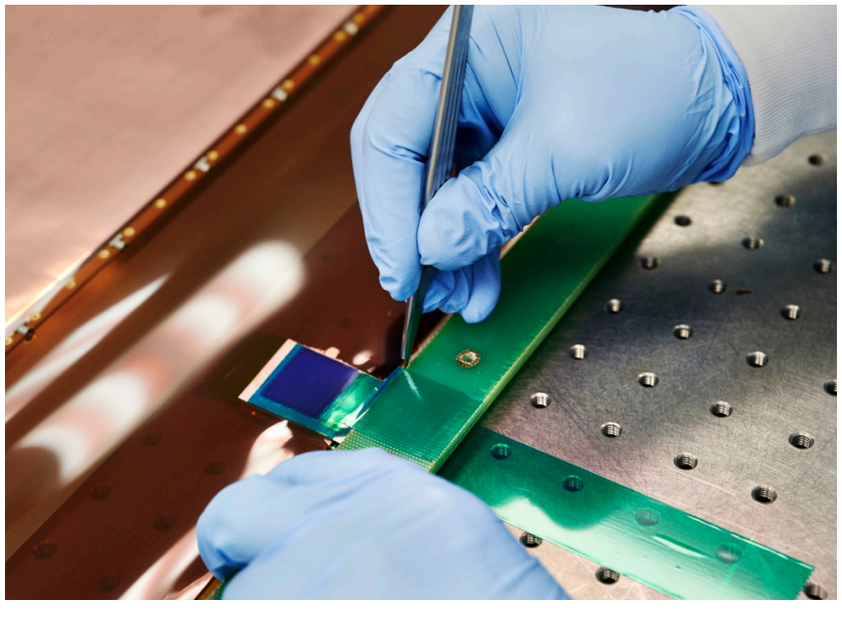
Muons (2)

First full Phase-2 detector, installing already now

- Install GEM GE1/1 chambers
  - Chambers
    - All built & validated
  - FE electronics
    - Design change to improve spark protection, production underway
  - Two chamber assembly (super chamber=SC)
    - 7/72 assembled with final electronics: cooling, gas, etc. OK
    - Final validation on cosmic test stand - expect to test 10 SC per month
- Services (power, gas, cooling, cables)
  - Production on schedule

- **On schedule to start installation in July**

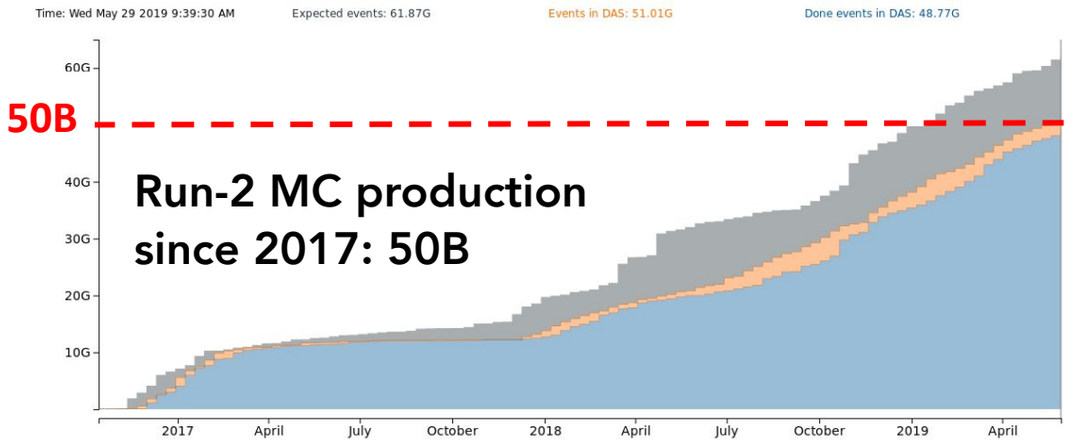
GEMs to improve muon capabilities around 1.5<|η|<2.0



Computing & PPD

← **P**hysics **P**erformance and **D**ataset

- Since last LHCC, focus on ...
  - ✦ MC production for full Run-2 analyses
  - ✦ Preparation for ultra legacy full Run-2 processing & MC with best possible alignments, calibrations, performance
  - ✦ Also started processing B-parking dataset



- Preparations for Run-3 & Phase-2
  - ✦ MC production
    - ... to study physics performance with luminosity/PU/aging detectors corresponding to end of Run-3
    - ... for Phase-2 L1 trigger TDR (PU=200)
  - ✦ Upgrade infrastructures for Run-3
    - New Run Registry, monitoring systems, ML integration to DQM, ...
  - ✦ Phase-2: Adapt to GPUs, FPGAs, via a heterogeneous framework

L1 trigger plans for Run 3

No major upgrades planned for Run 3, but significant improvements foreseen

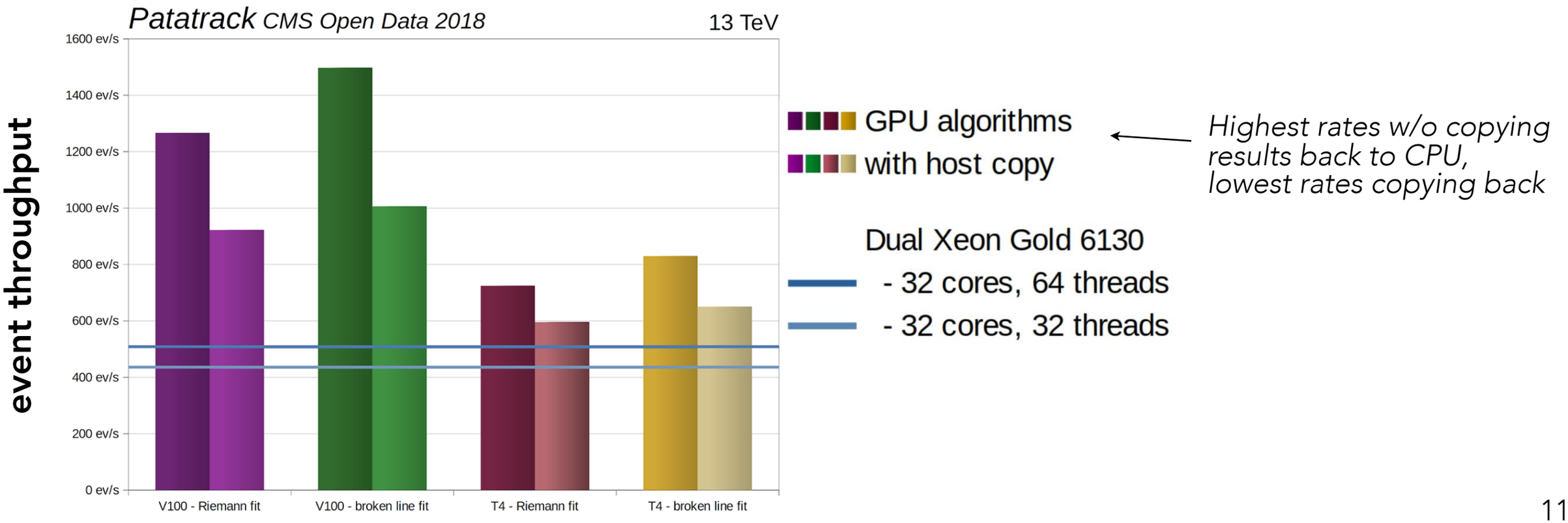
Phase-1 upgrades already completed
Continue exploiting these to improve algorithms

- **Algorithms and menu**
  - ✦ Preserve core trigger menu while creating new seeds for unexplored physics
    - New displaced muon trigger in barrel, develop targeted multi-object paths
  - ✦ Use upgraded detector inputs to reduce rate in high-pileup conditions
    - e.g. depth segmentation in HCAL, extra GEM muon detectors in endcap

- **Operations and monitoring**
  - ✦ With HLT, overhaul trigger menu editor to enable fast modifications
  - ✦ Integrate monitoring data from trigger systems with central monitoring
  - ✦ Build automated tests for monitoring data, pointing to appropriate actions

HLT plans for Run 3

- Trigger strategy in Run 2 worked well, review & improve for Run 3
  - ✦ Main challenge: control rate/CPU time, while ensuring physics perf.
  - ✦ GPU-based HLT reconstruction may help in this direction
    - First tests on pixel tracking, ECAL/HCAL local reconstruction promising
- Reconstruction performance on GPUs (pixel tracking)
  - ✦ A single Tesla T4 GPU has better performance than a full HLT node (dual Xeon Gold 6130 with a total of 32 cores) at a fraction of the cost



HL-LHC upgrade overview

Technical proposal CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886
Scope Document CERN-LHCC-2015-019 https://cds.cern.ch/record/2055167/files/LHCC-G-165.pdf

L1-Trigger/HLT/DAQ

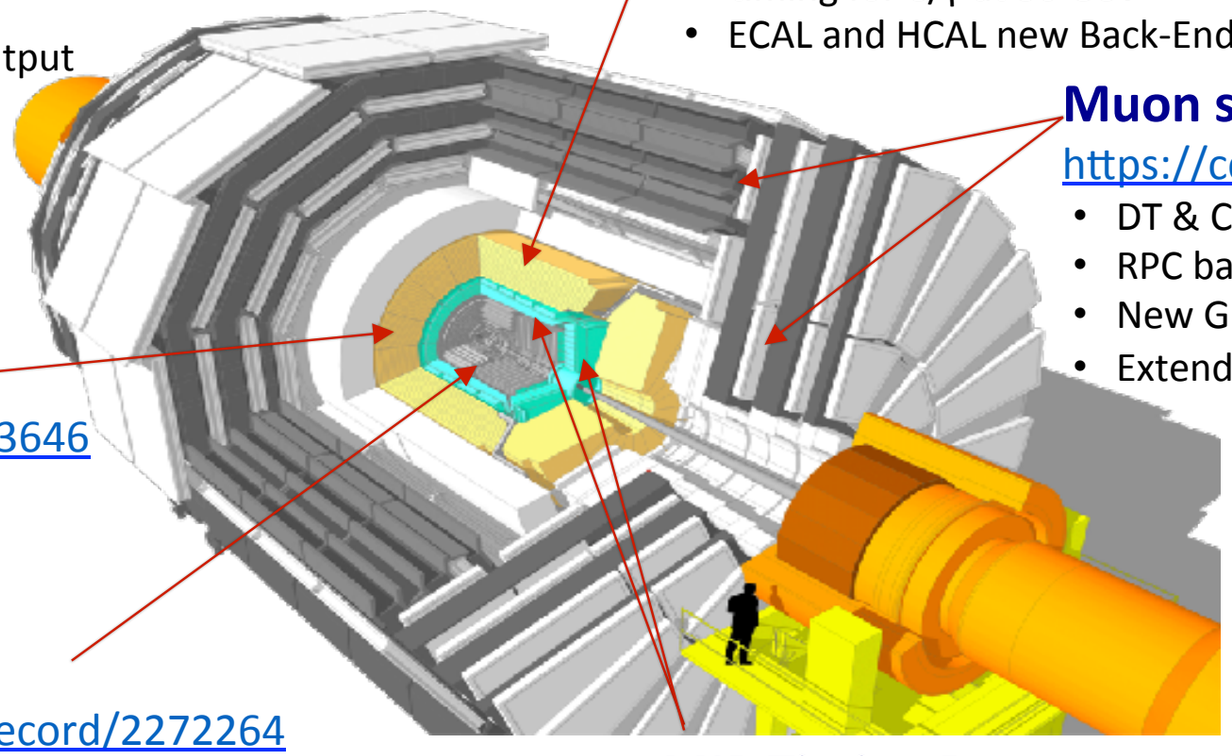
https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

Barrel Calorimeters

https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

https://cds.cern.ch/record/2020886

Tracker https://cds.cern.ch/record/2272264

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

MIP Timing Detector

https://cds.cern.ch/record/2296612

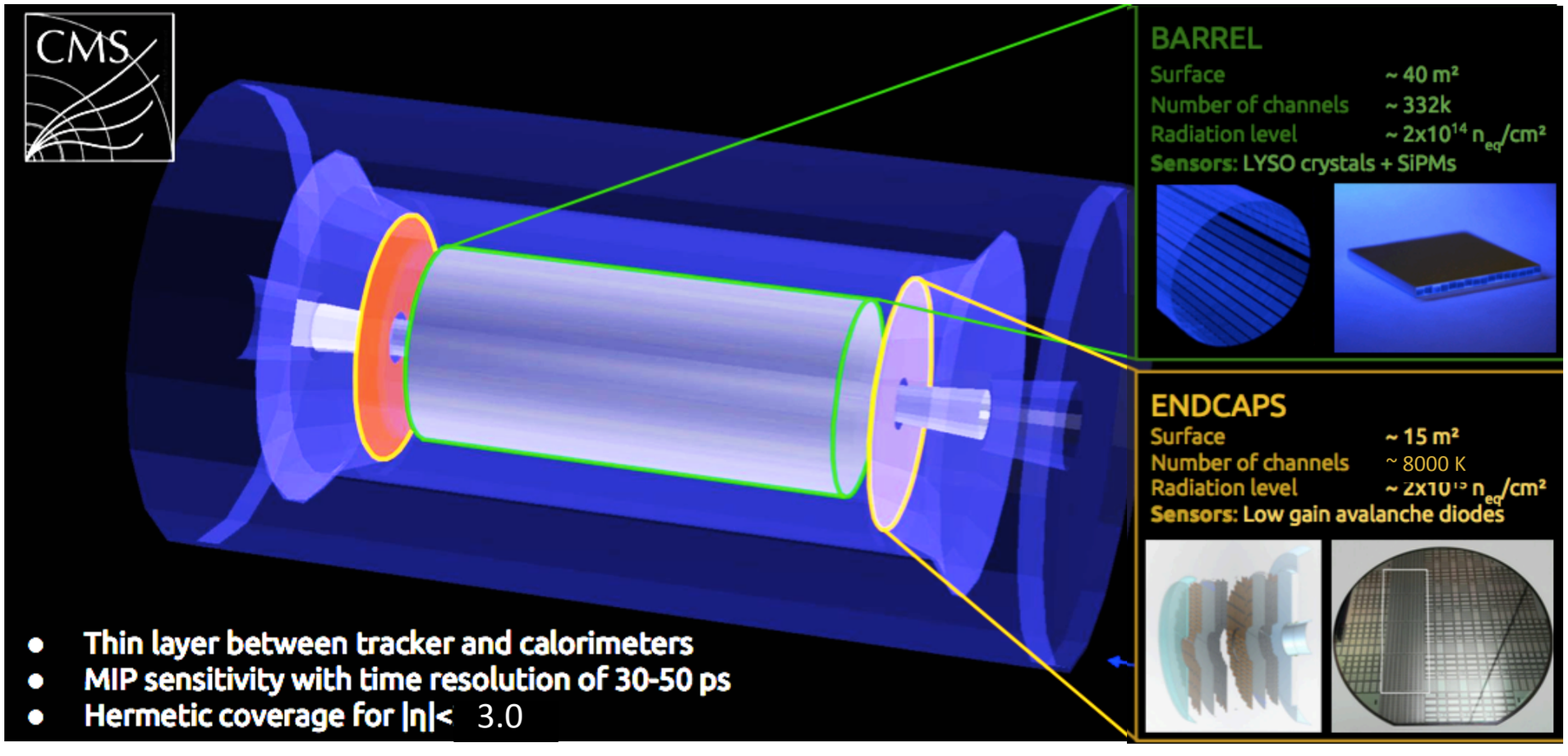
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

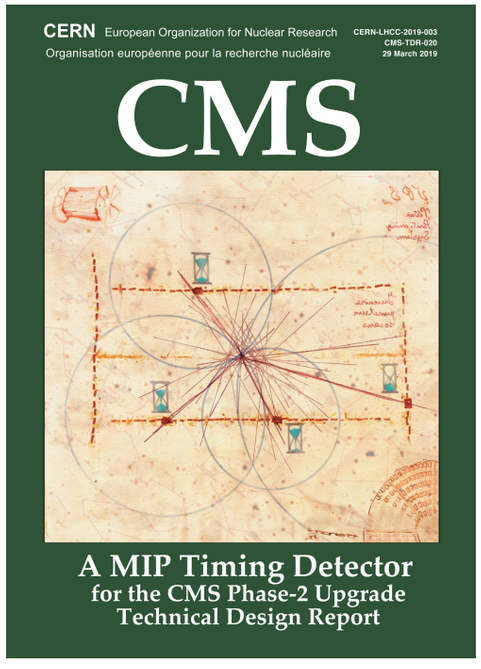
New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity

MTD: MIP Timing Detector

- High precision time measurement of MIP particles
  - 30-50 ps precision with nearly hermetic coverage (up to $|\eta|<3.0$)
  - ✦ Identify which pp interaction vertex track is coming from
  - ✦ Provide other unique features: sensitivity to slow particles, particle ID, etc

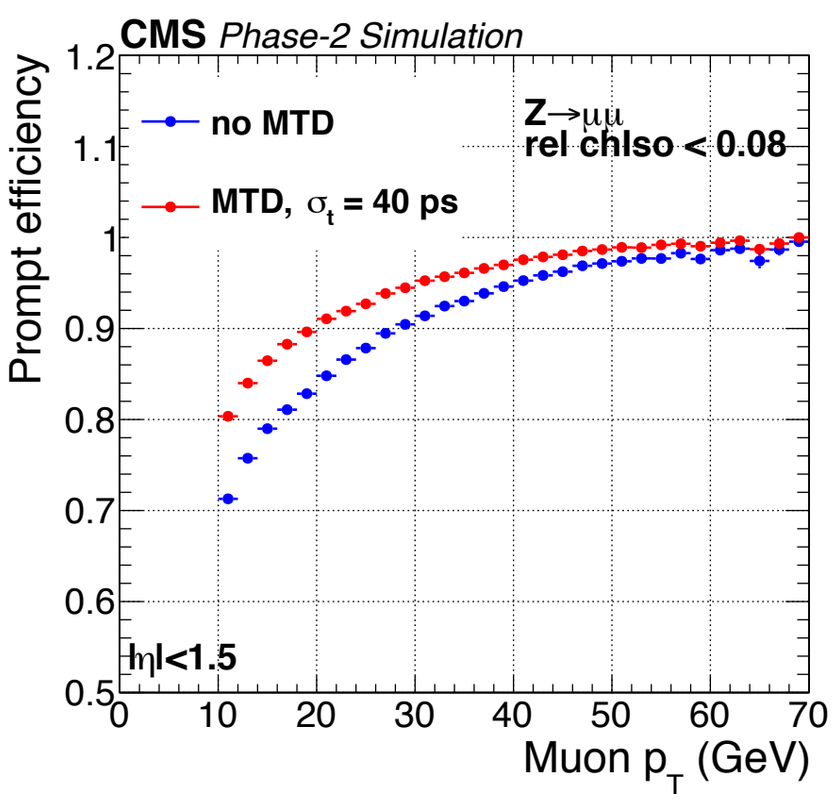


TDR submitted 29.03.2019
Scientific review June 3
Goal - full approval in 09/2019

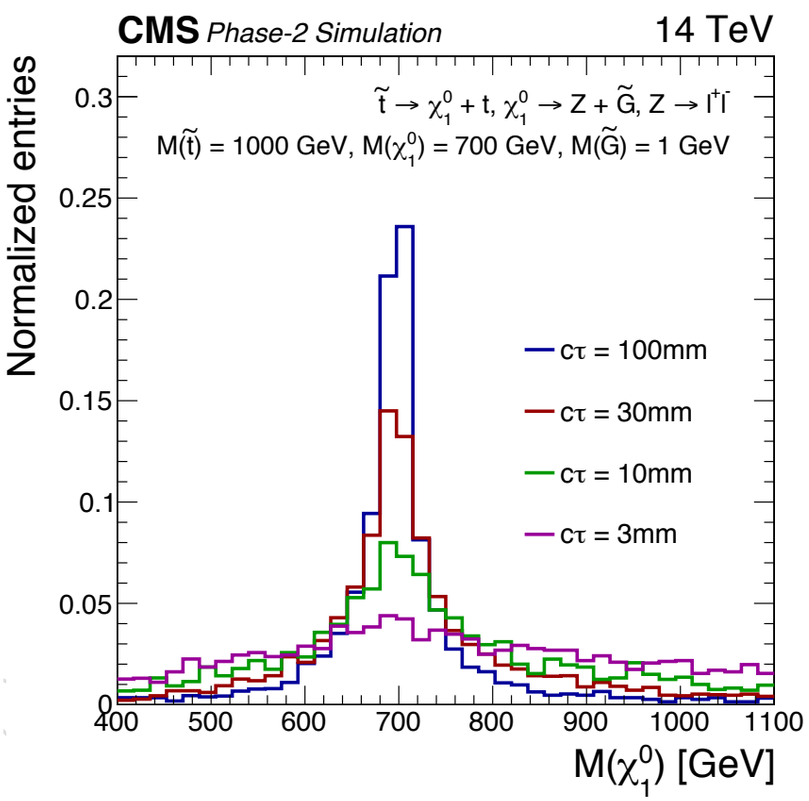


MTD performance studies

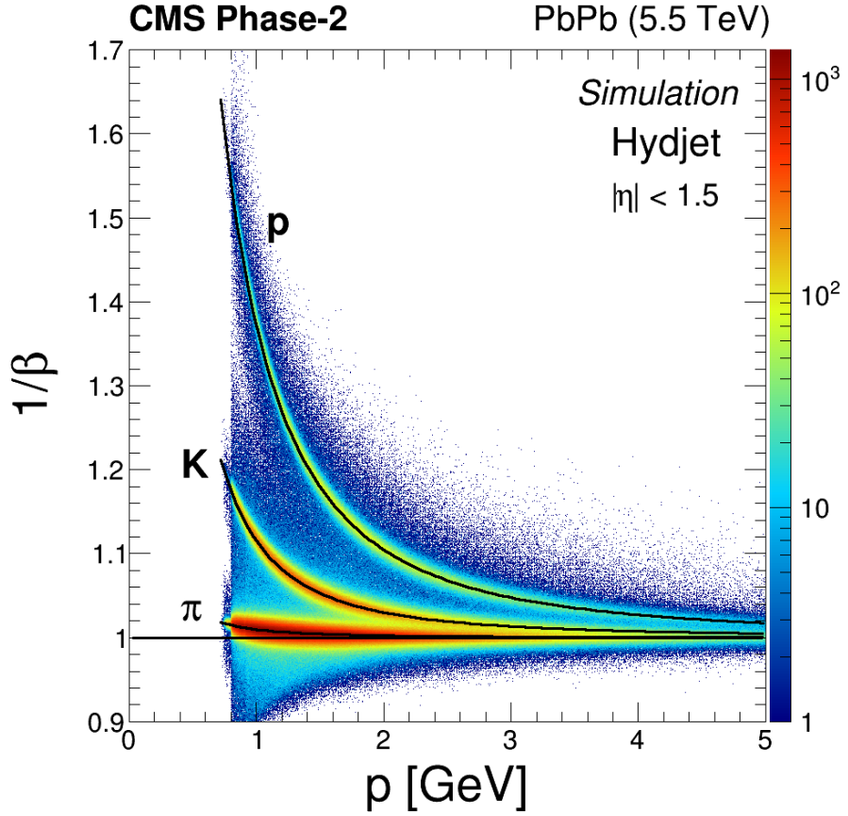
- Significant impact on the HL-LHC program from pileup reduction
  - 20-30% increase in effective integrated luminosity, leveraging gains over full pseudo-rapidity coverage and cross a wide range of observables
- Unique discovery potential for long-lived particles
- Extended potential for heavy-ion physics through particle ID



prompt muon isolation efficiency

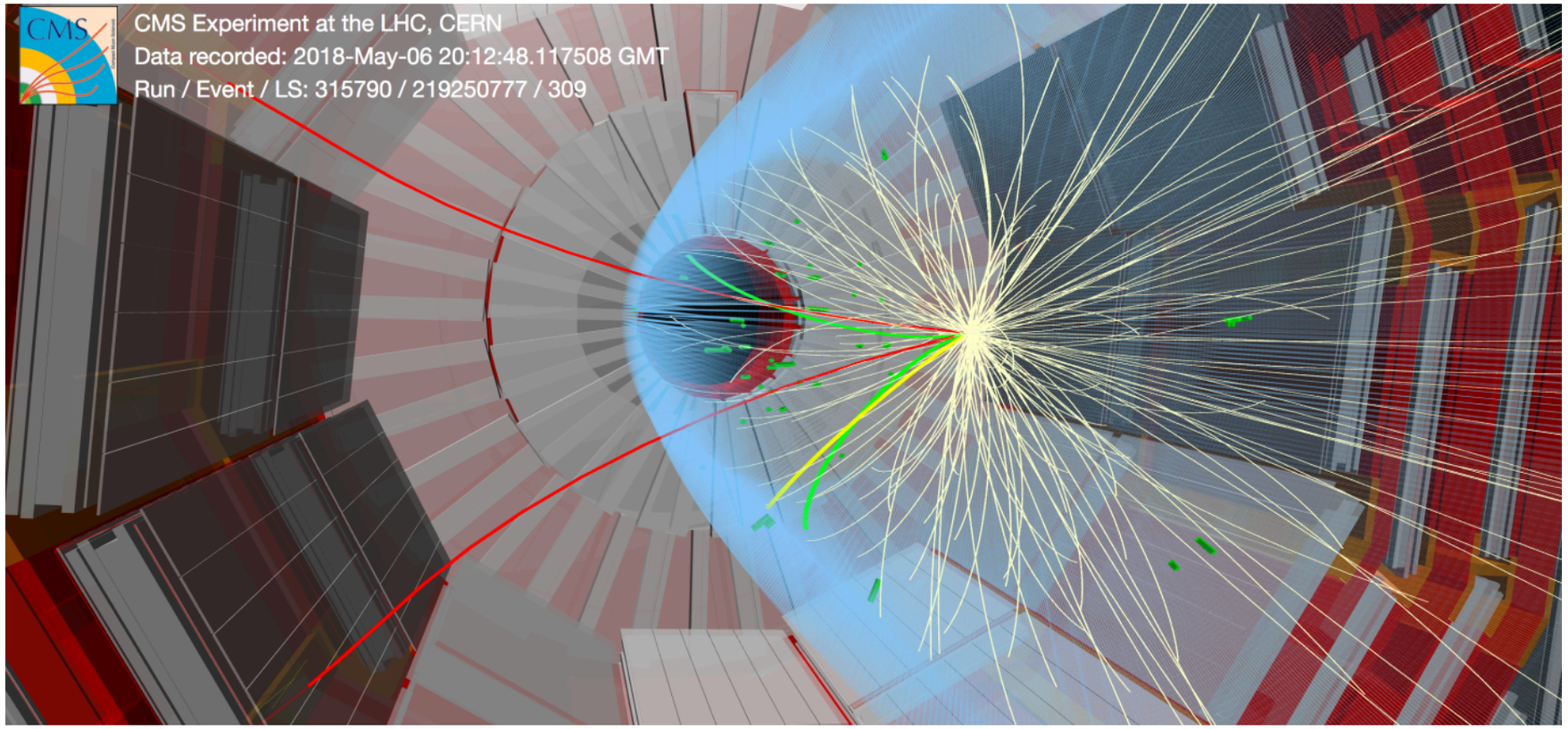


long-lived neutralino (GMSB)



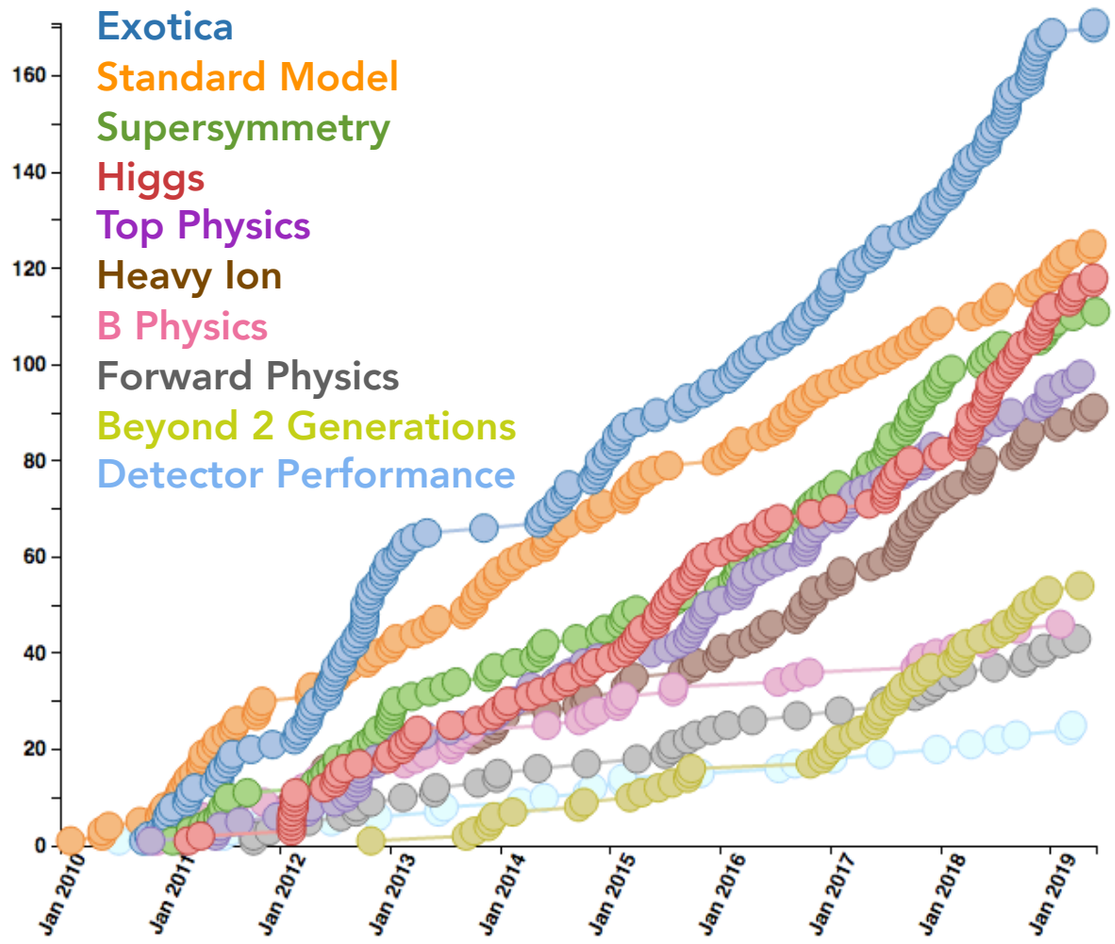
particle identification in PbPb

Recent physics highlights

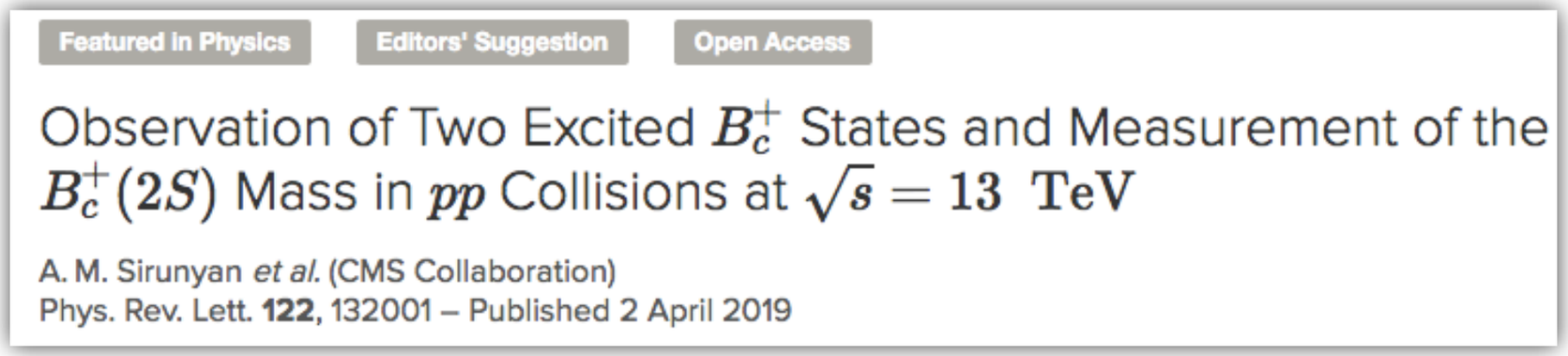


Publication status

- *CMS recently submitted its* ***900th*** *paper!!*
- Now at 907 submitted papers, of which 882 on collider data



- First full Run-2 paper published
  - ✦ Highlighted as **PRL Editors' suggestion**


Featured in Physics | Editors' Suggestion | Open Access

Observation of Two Excited B_c^+ States and Measurement of the $B_c^+(2S)$ Mass in pp Collisions at $\sqrt{s} = 13$ TeV

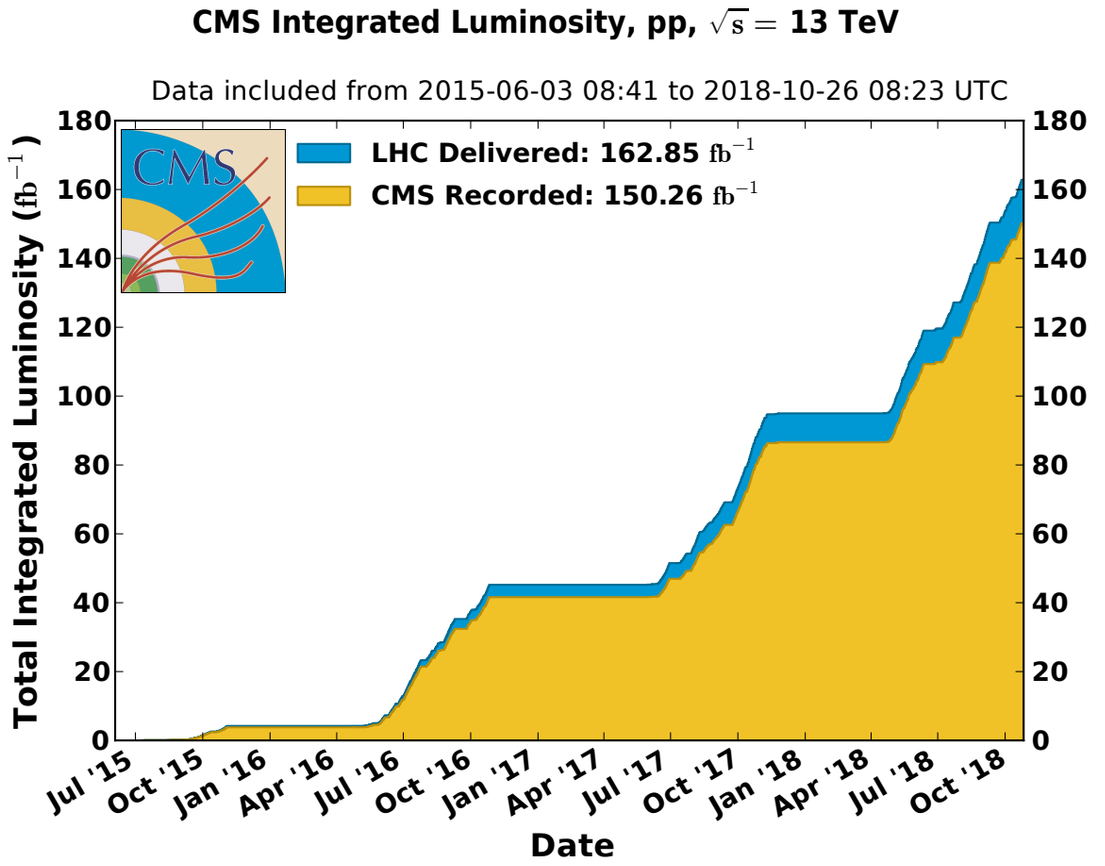
A. M. Sirunyan *et al.* (CMS Collaboration)
Phys. Rev. Lett. **122**, 132001 – Published 2 April 2019

- Full details: http://cms-results.web.cern.ch/cms-results/public-results/publications/

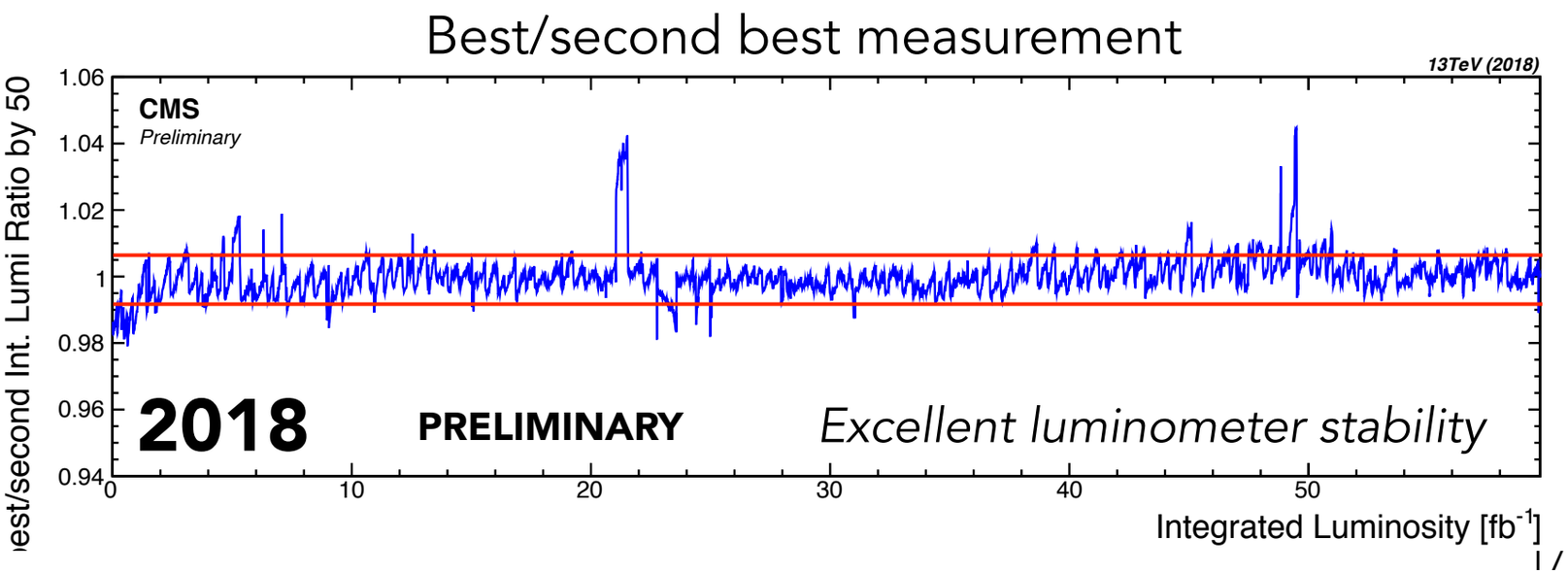
Run-2 luminosity

LUM-18-002

- Several results presented using full 2016-2018 dataset (**137 fb^{-1}**)
- *Thanks to the LHC for the excellent performance!*



- *Preliminary* uncertainties
  - ✦ 2.3-2.5% for pp collisions @ 13 TeV in single year
  - ✦ 2018 dominant systematics due to x-y correlation
    - Study ongoing to measure bias, expect improved uncertainty after correction



Physics highlights

- >50 new results since last LHCC, including 9 results with full Run-2 data

- *Next slides highlighting a few recent results*
  - ✦ Highlight from heavy ions
  - ✦ Precision EW measurement
  - ✦ SM ZZ & H→ZZ production
  - ✦ Update on ttH (with H→bb) & SM tt+bb production
  - ✦ Select new physics searches

  - ✦ Emphasis on maximizing physics potential through ...
    - Unconventional triggering
    - Innovative strategies & probing new topologies
    - Precision measurements with full Run-2 dataset

Highlight from heavy ion

HIN-18-009

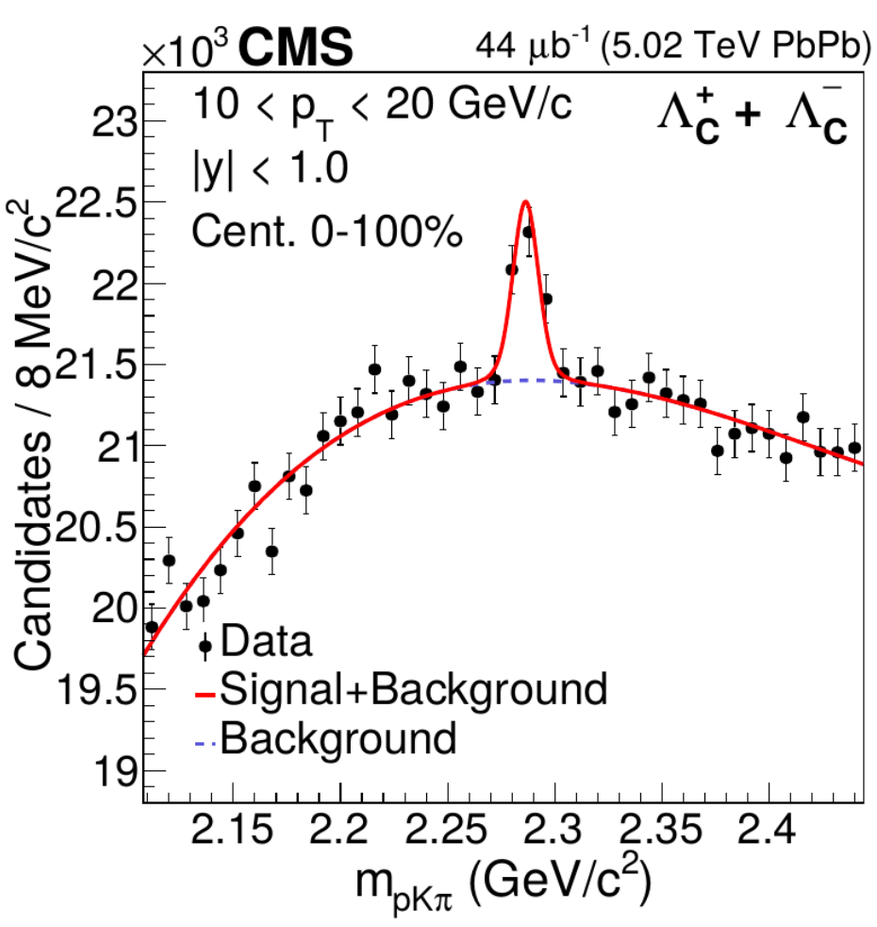
- Measurement of Λ_c baryons in pp & PbPb collisions at 5.02 TeV
  - ✦ Hint of suppression in central PbPb collisions compared to pp (R_{AA})
  - ✦ Λ_c/D_0 ratio consistent between pp & PbPb
    - Coalescence process may not play a significant role in Λ_c baryon production for $10<p_T<20$ GeV

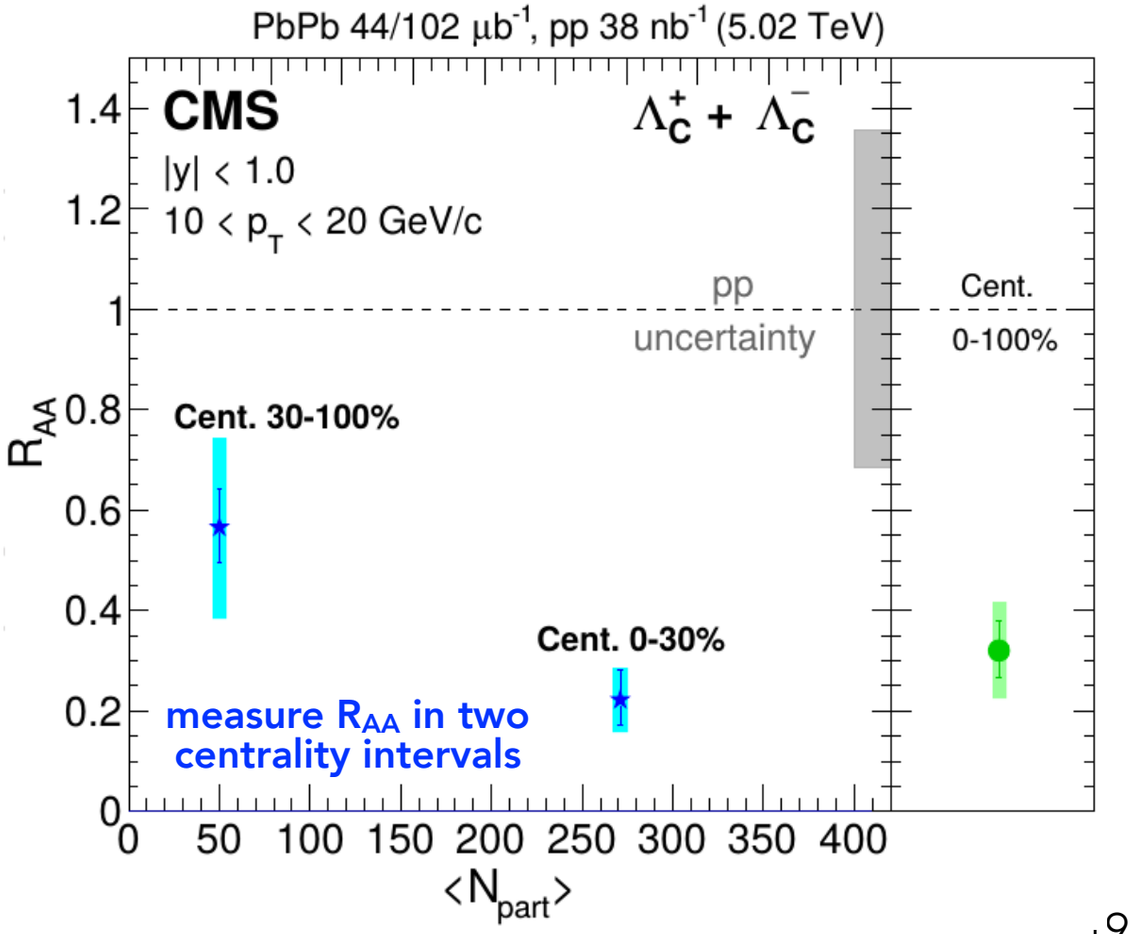
Decay: $\Lambda_c^+ \rightarrow pK^-\pi^+$

p_T range studied:
pp 5-20 GeV
PbPb 10-20 GeV

Hadron production via coalescence:

Partons combine while traversing QGP medium





R_{AA} = [yield in PbPb] / [yield in pp], scaled by number of nucleon-nucleon interactions

Precision EW

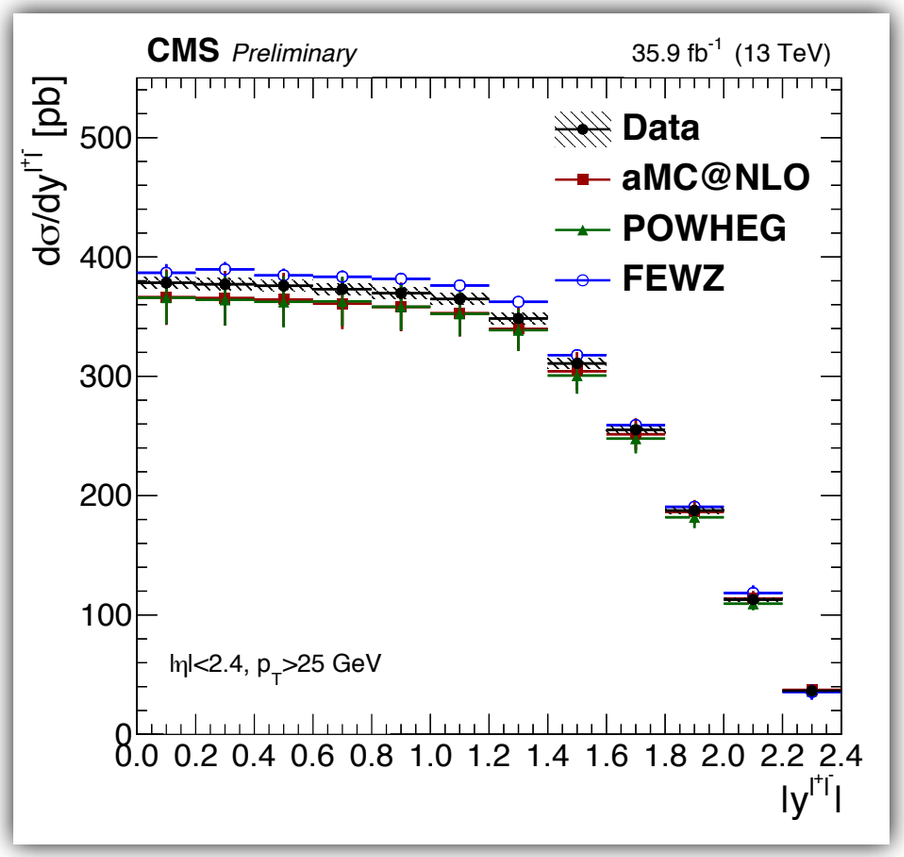
SMP-17-010

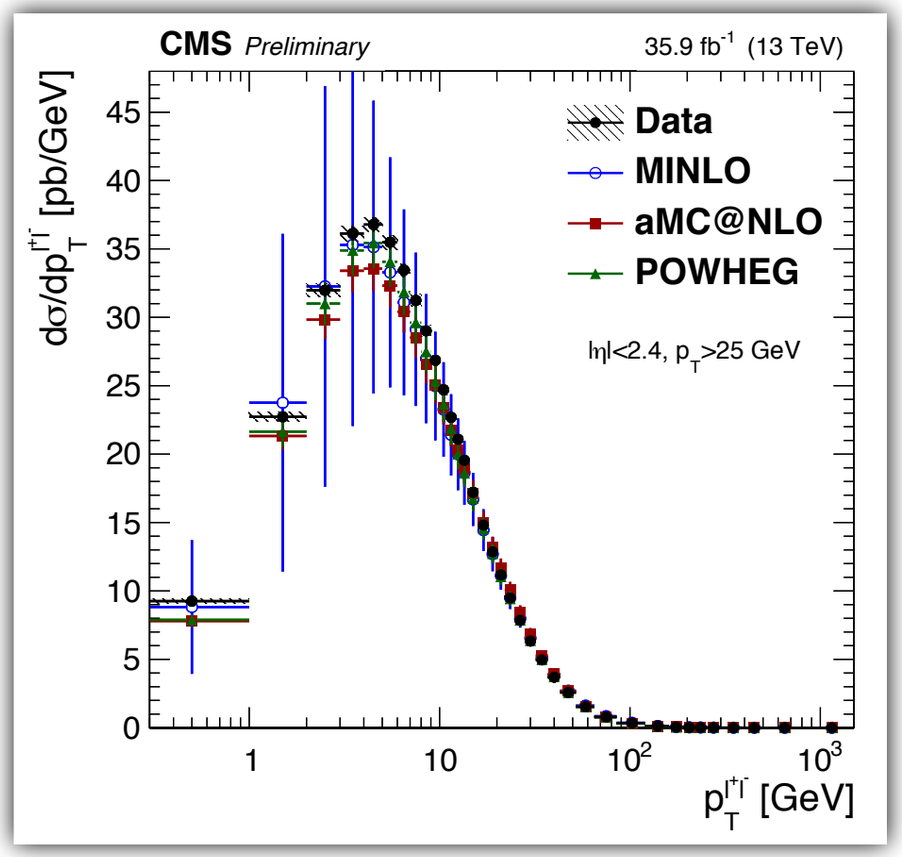
- Z/γ* production cross section @ 13 TeV
  - ✦ SM precision test, constrain PDFs, input to m_W
  - ✦ Fiducial + differential measurements vs p_T, y, ϕ^* (incl. double-diff!)
    - Systematic uncertainties: luminosity (2.5%) + lepton ID (ee 1.4%, μμ 0.8%)
    - Compare to state of the art (N)NLO calculations

Cross section	$\sigma\,\mathcal{B}$ [pb]
$\sigma_{Z\to\mu\mu}$	$694 \pm 6\,(\text{syst}) \pm 17\,(\text{lumi})$
$\sigma_{Z\to ee}$	$712 \pm 10\,(\text{syst}) \pm 18\,(\text{lumi})$
$\sigma_{Z\to\ell\ell}$	$699 \pm 5\,(\text{syst}) \pm 17\,(\text{lumi})$

$\sigma_{Z\to\ell\ell} = 682 \pm 55$ pb MADGRAPH5_AMC@NLO
$\sigma_{Z\to\ell\ell} = 719 \pm 8$ pb FEWZ

$$\phi^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin(\theta^*_\eta)$$
$$\cos(\theta^*_\eta) = \tanh(\frac{\eta^- - \eta^+}{2}),$$

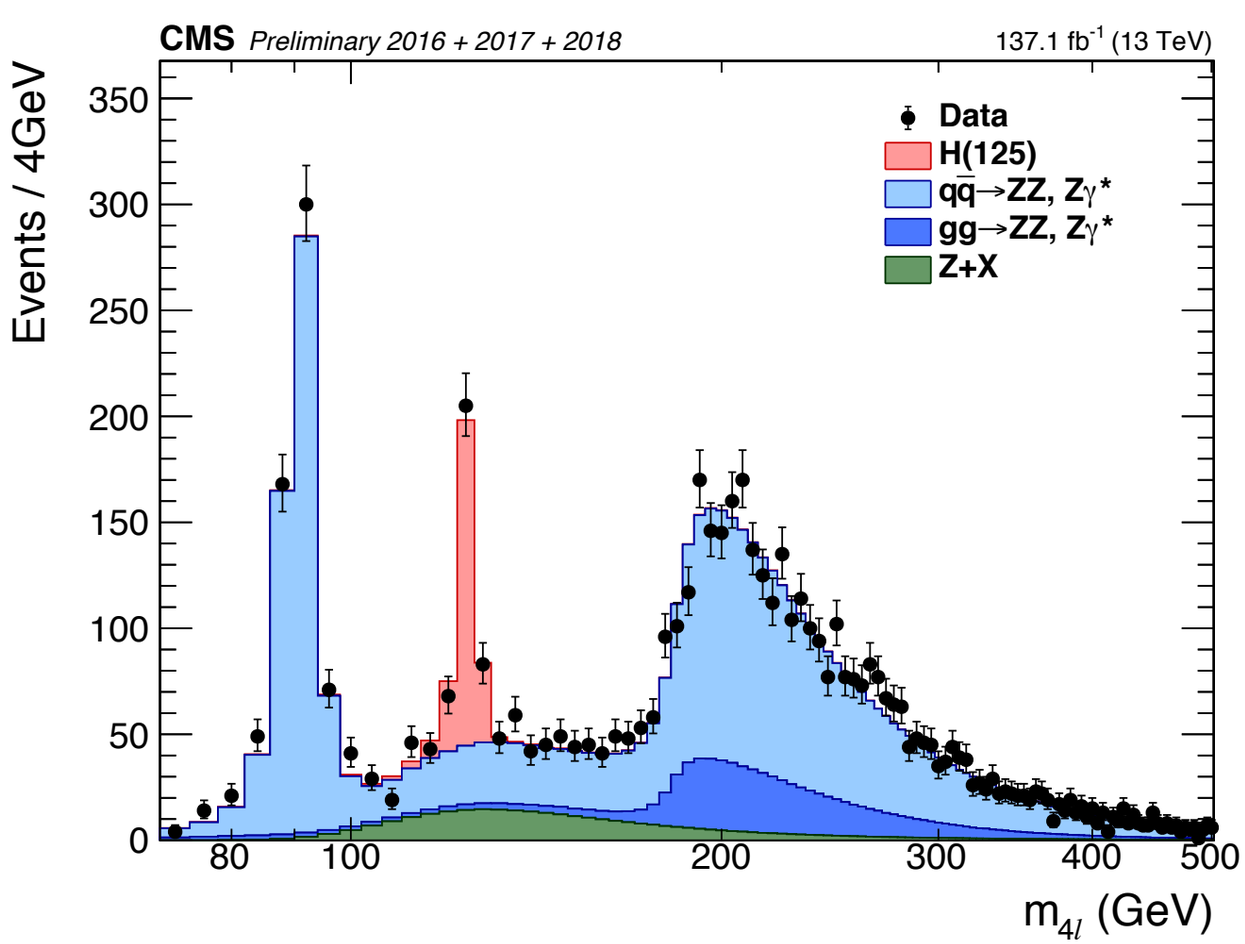


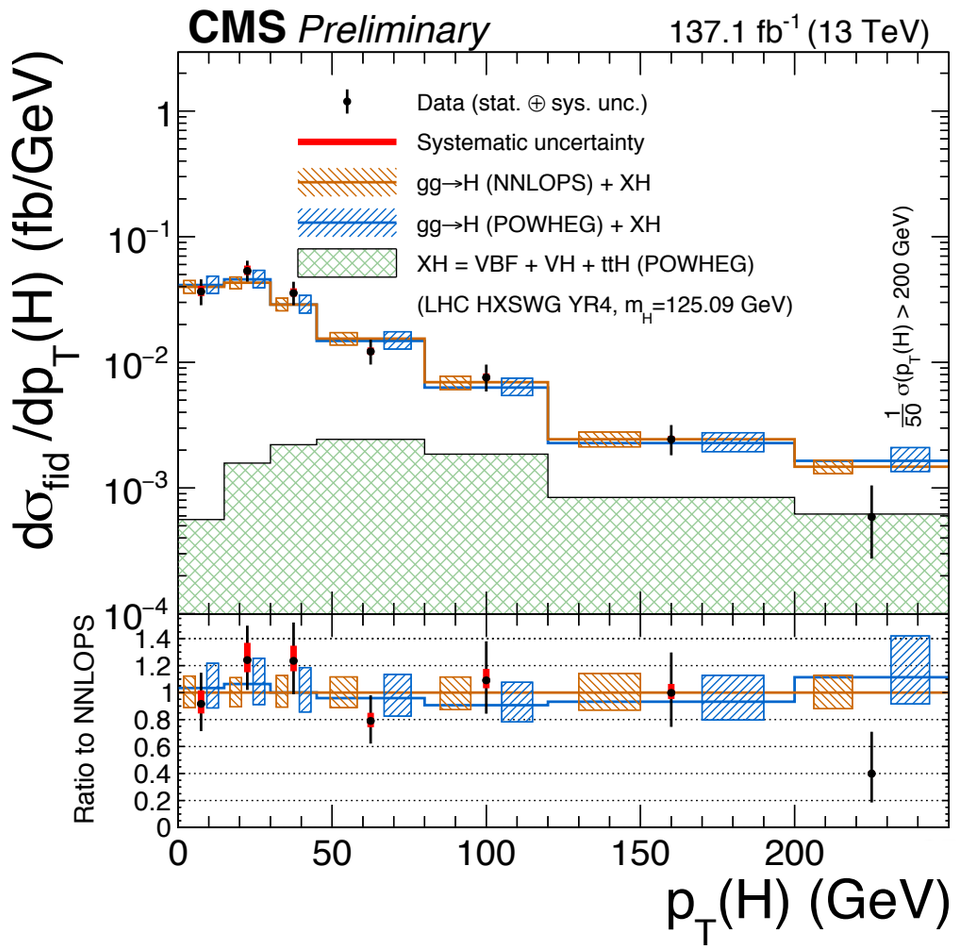


SM ZZ & H→ZZ

both: ZZ → 4 lepton

- *Measurements* utilizing 137 fb^{-1}
- SM ZZ production cross section — **SMP-19-001**
  - reduced from ~4.1% (2016) to ~2.3%
  - ✦ $\sigma_{tot}(pp \to ZZ) = 17.1 \pm 0.3(stat) \pm 0.4(syst) \pm 0.4(theo) \pm 0.3(lumi)$ pb
    - consistent with SM predictions, total measurement uncertainty of ~4%
- H→ZZ fiducial + differential measurements — **HIG-19-001**

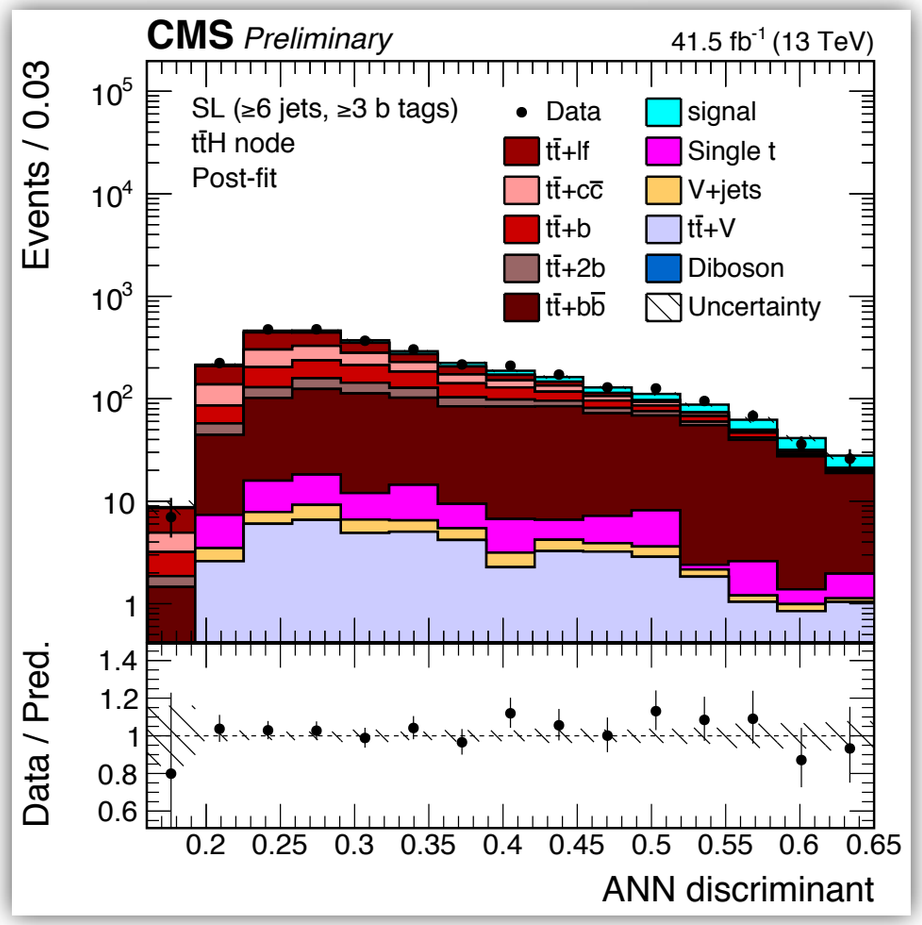




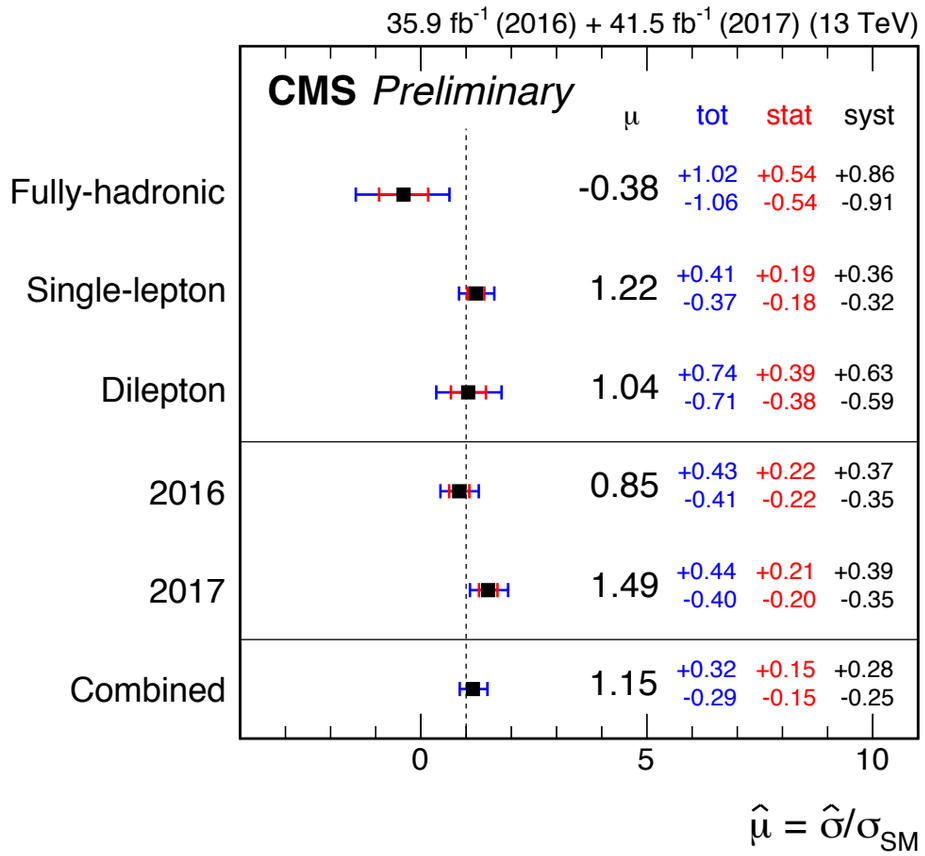
ttH, H→bb

HIG-18-030

- ttH production with H → bb, challenging final state **0/1/2 lep channels**
  - ✦ Sophisticated MVA techniques to distinguish signal from background
    - Several improvements in 2017 data analysis w.r.t. previous result (2016 data): new b-tagging, refined analysis methods, ...
  - ✦ Main systematic: tt+HF modeling, QCD background, b-tagging
- Best-fit signal strength (combining 2016+2017): $\hat{\mu} = 1.15\,^{+0.15}_{-0.15}(\text{stat})\,^{+0.28}_{-0.25}(\text{syst})$



Obs (exp) significance 3.9σ (3.5σ)



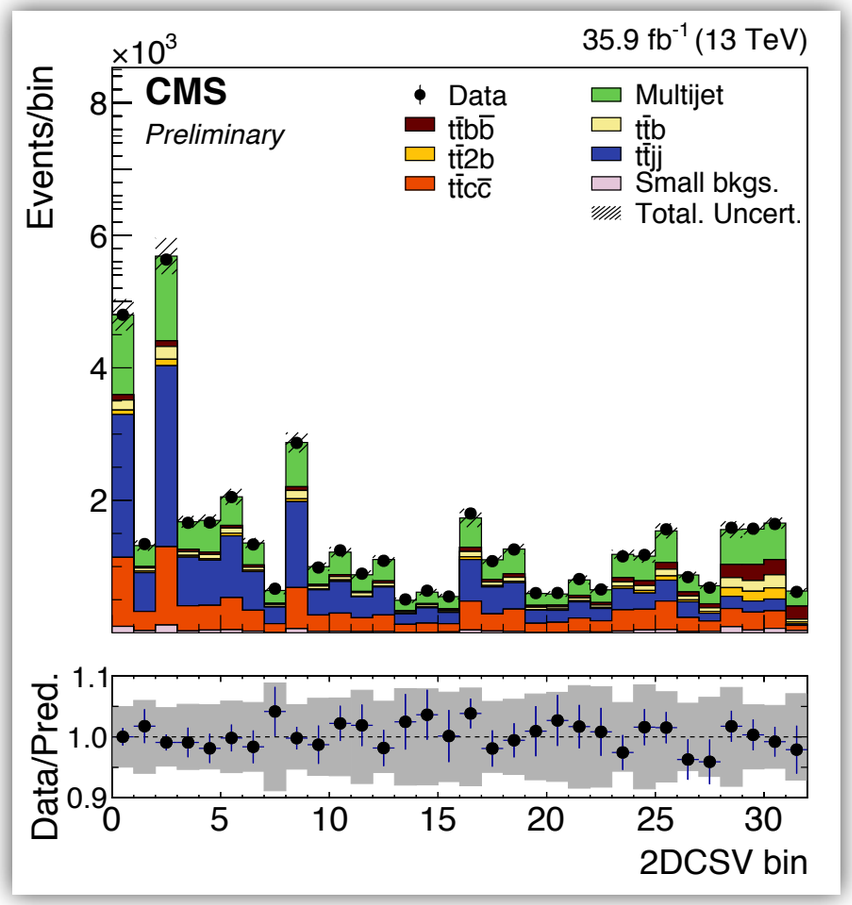
SM ttbb

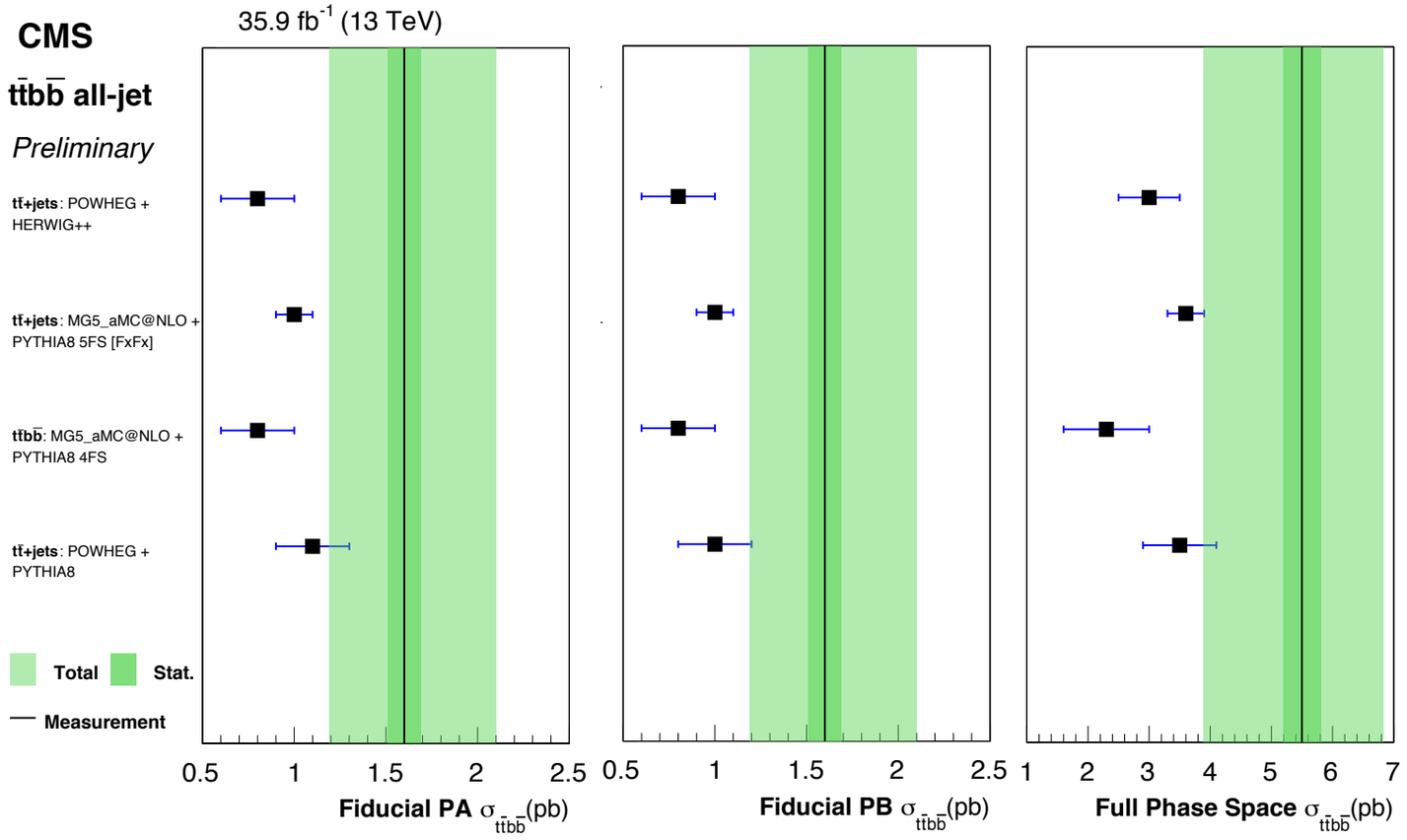
TOP-18-011

- Measurement of SM ttbb production
  - Important background to ttH(bb) & tttt, test QCD predictions
  - Fully hadronic final state (35.9 fb^{-1})

1st measurement in this channel!

    - Various MVA techniques to reduce multijet background & identify signal
    - 2D fit to b-tagging discriminator scores to extract cross section
    - Measurement high w.r.t. theory predictions -- input needed from theory community to improve modeling



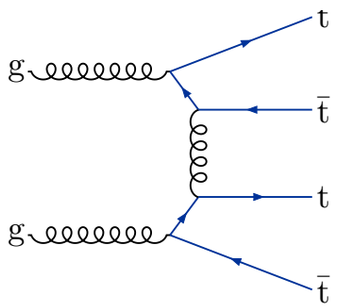


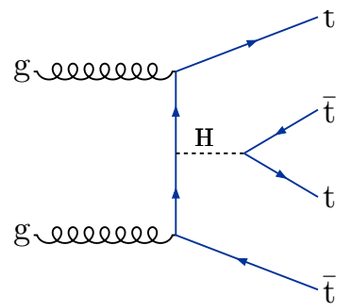
w/o parton info *closer to ttH(bb) def.*

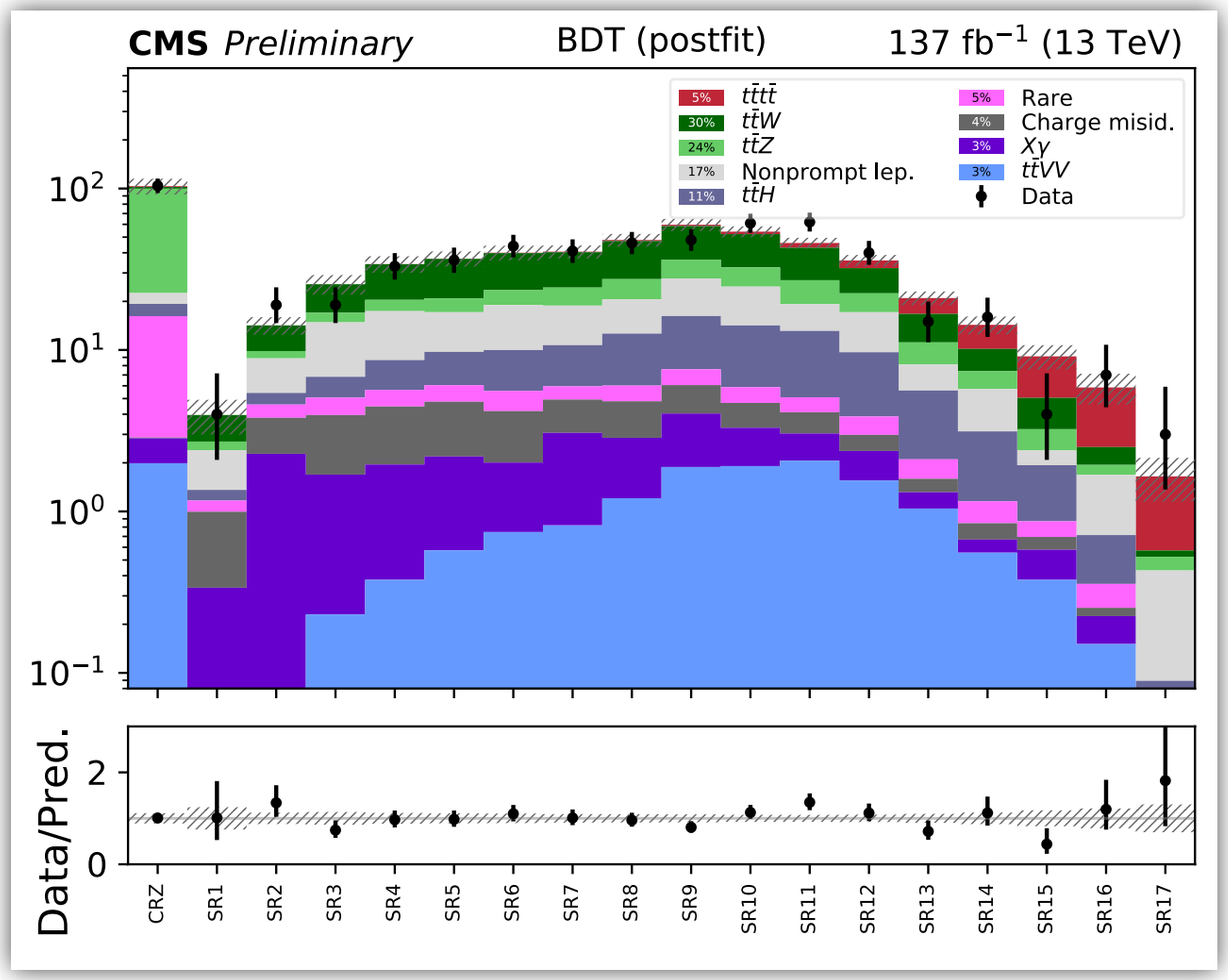
Probing the very rare

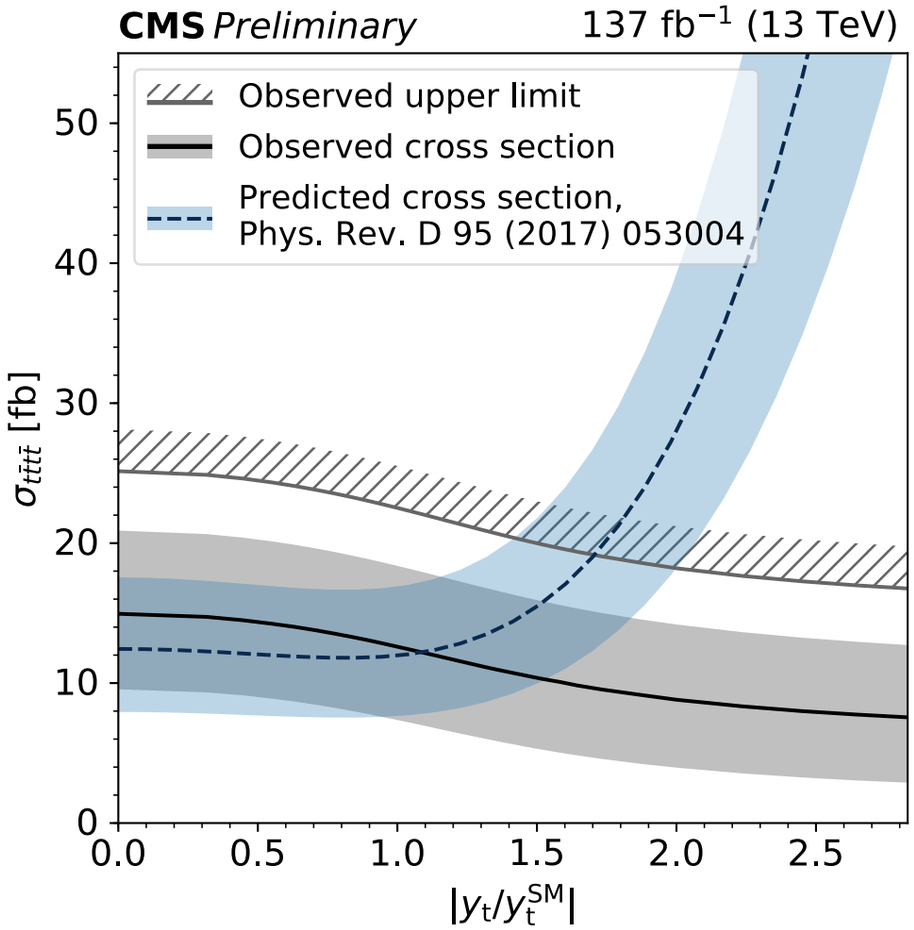
TOP-18-003

- **SM four top production**, yet unobserved process (σ_{SM}~0.01pb)
  - Same-sign + multileptons with 137fb^{-1}, highest LHC sensitivity search
  - Observed (expected) significance of 2.6σ (2.7σ)
    - Measure σ = 12.6 +5.8/-5.2 fb
    - Constrain top Yukawa coupling: $|y_t / y_t^{SM}| < 1.7$



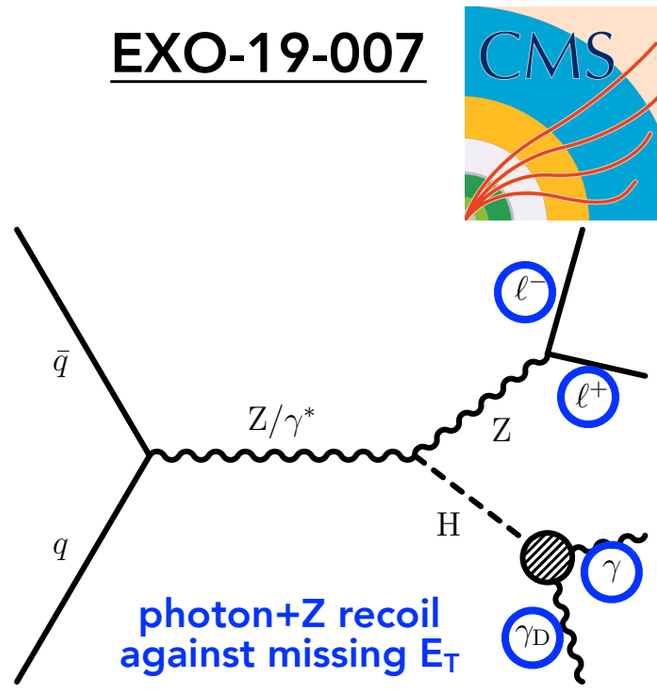






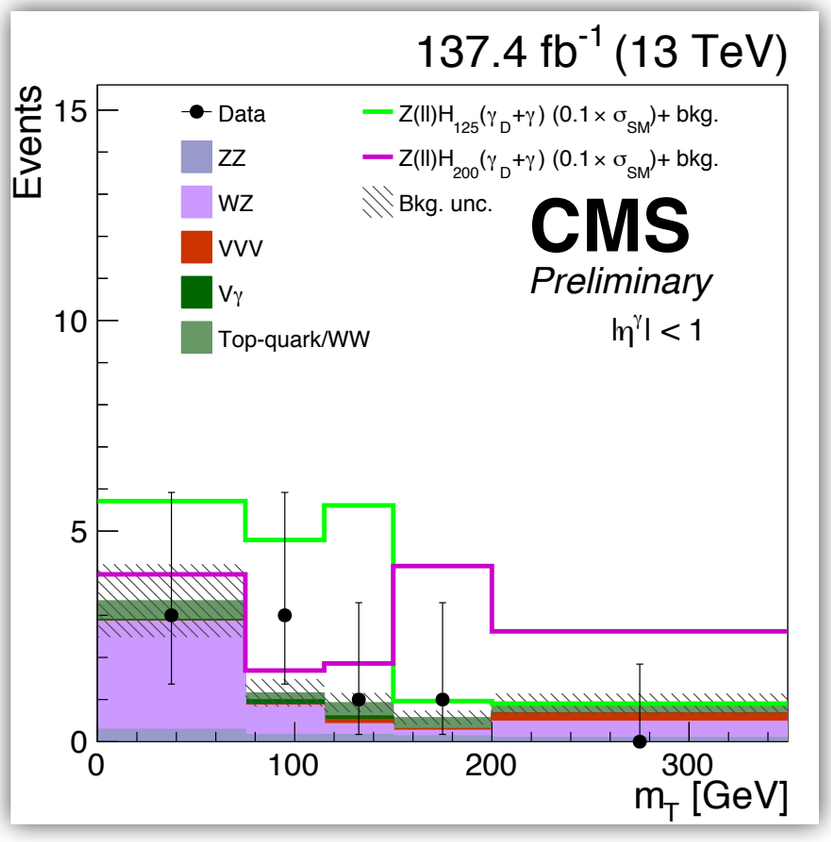
Searches with 137 fb^{-1}

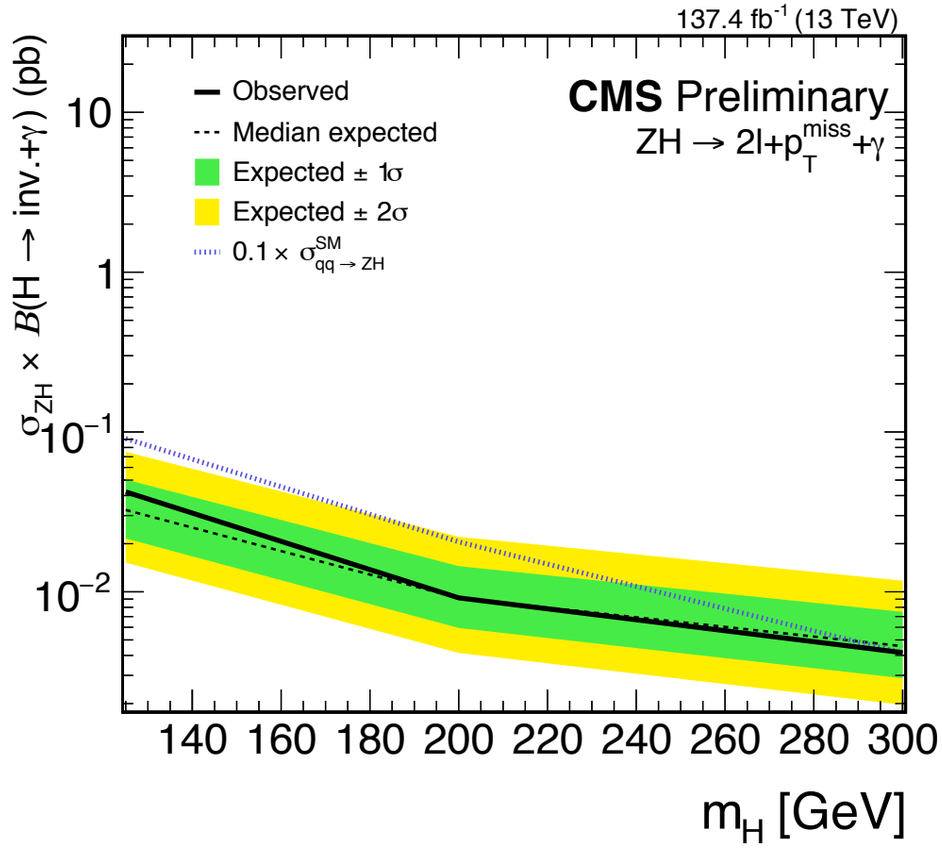
EXO-19-007



Dark photons

- Massless dark photons coupling to a Higgs boson through charged dark sector particles
  - Signal extraction from fitting m_T in $|\eta^\gamma|$ regions + background control regions
  - No excess observed
- For $m_H = 125$ GeV: BR(H→inv+γ) < 4.6% ($3.6^{+2.0}_{-1.2}$ % expected) at 95% CL, vs m_H



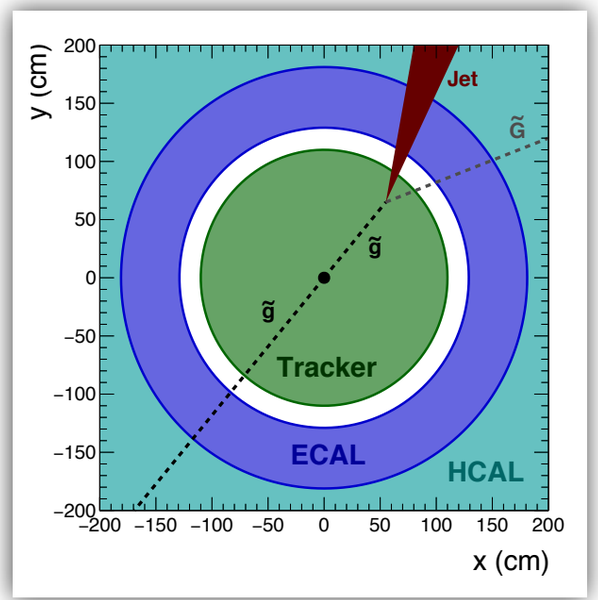


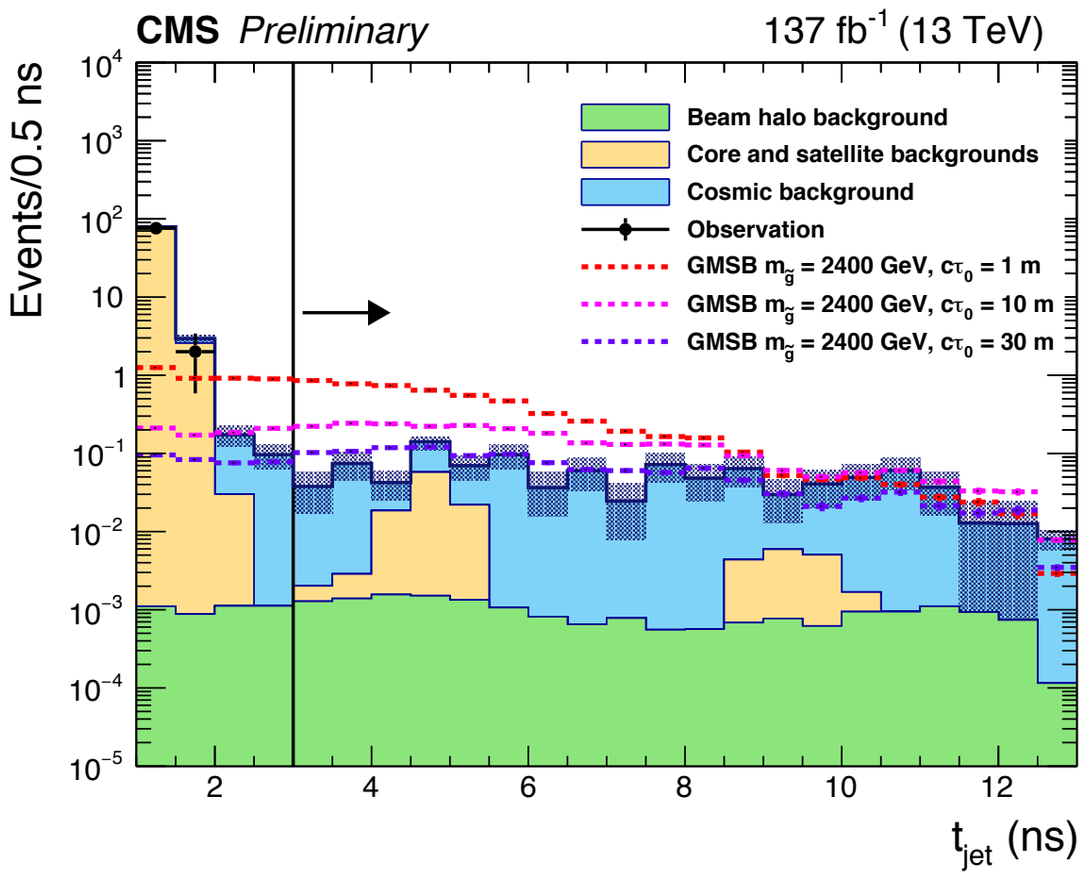
Searches with 137 fb^{-1}

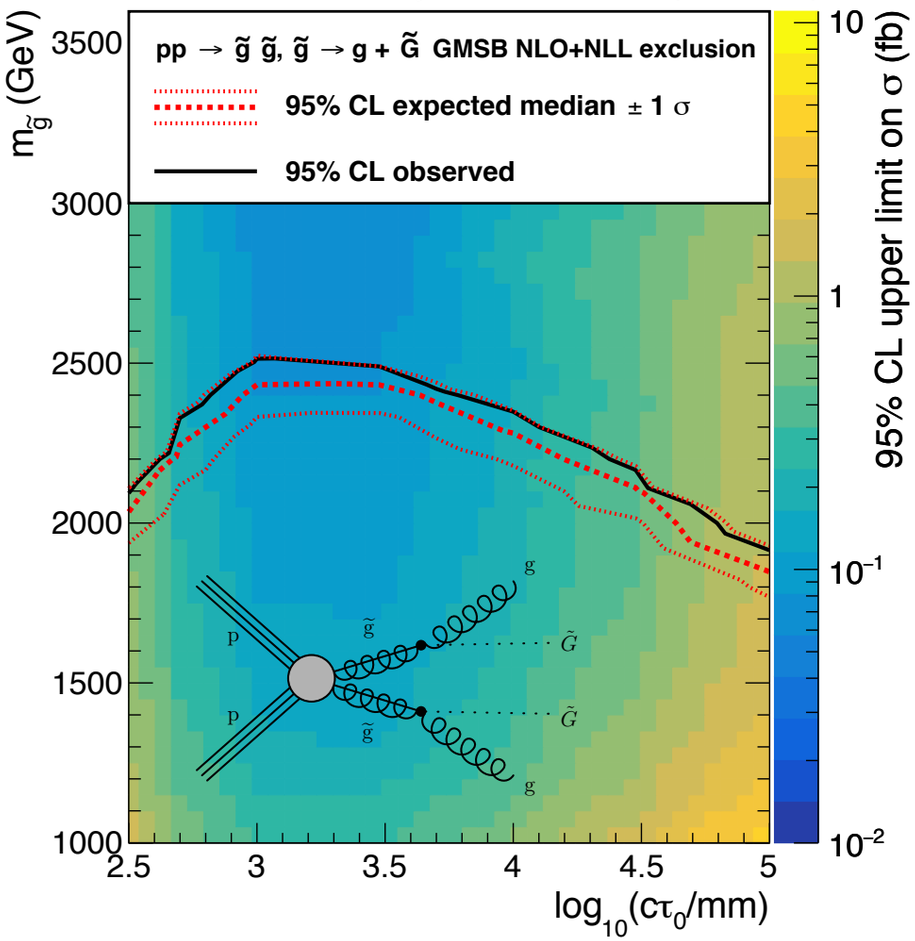
EXO-19-001

Delayed jets

- BSM scenarios (SUSY, hidden valley, ...) with long-lived particles may result in "delayed" jets
  - ✦ First search for such jets using ECAL timing!
    - Dedicated reconstruction to extract jet timing
    - "Unusual" backgrounds
    - No excess, interpret in context of **GMSB**







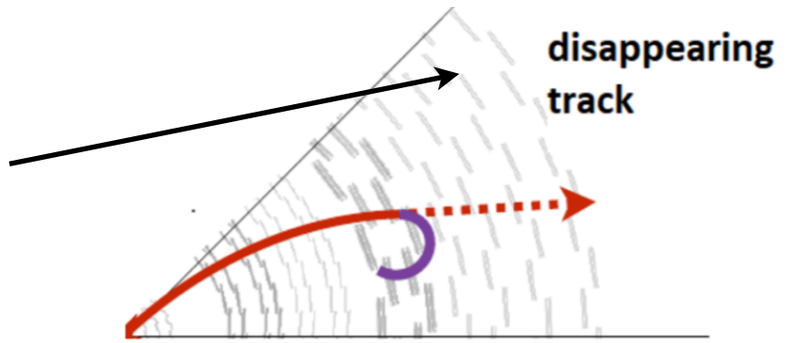
Searches with 137 fb^{-1}

SUS-19-005

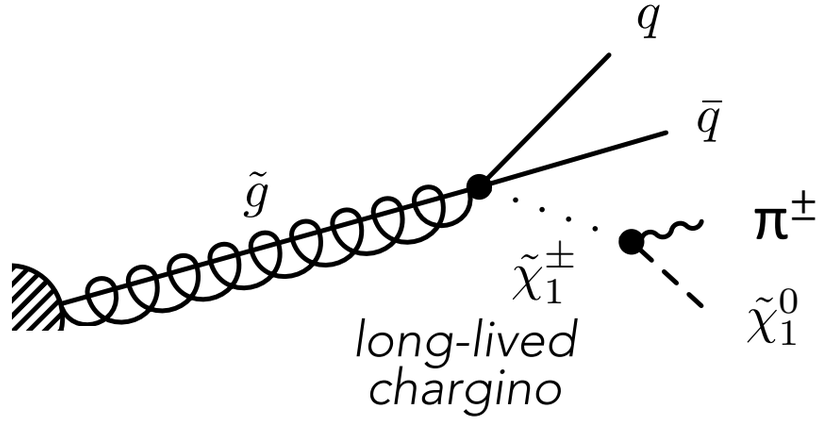
Disappearing tracks

$$M_{T2} = \min_{\vec{p}_T^{\,miss\,X(1)} + \vec{p}_T^{\,miss\,X(2)} = \vec{p}_T^{\,miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

- Search for prompt & long-lived SUSY particles
  - Exploit p_T imbalance w. M_{T2} in jets+MET events
  - *Long-lived particle that decays in tracker volume*



- No excess, constrain:
  - Displaced: gluinos ~2.5 TeV
  - Prompt: gluinos ~2.1 TeV,
    stop/sbottom ~0.9 TeV



... and more

SUS-19-008

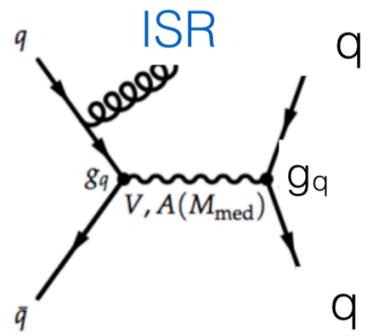
- Search for SUSY with two same-sign dileptons or ≥3 leptons & jets
- Search for new physics in multilepton final states (≥3 leptons)

EXO-19-002

Low-mass resonances

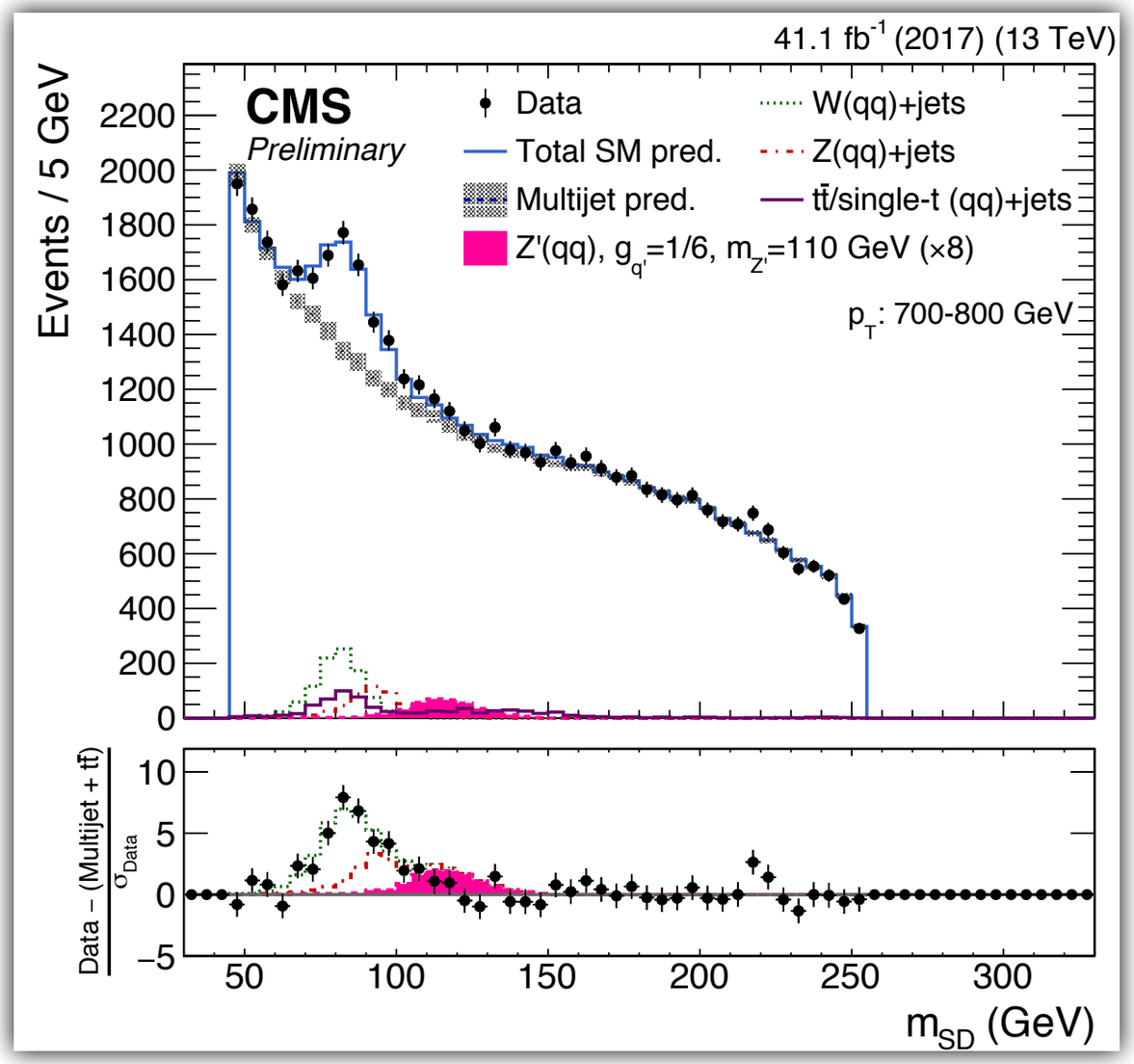
EXO-18-012

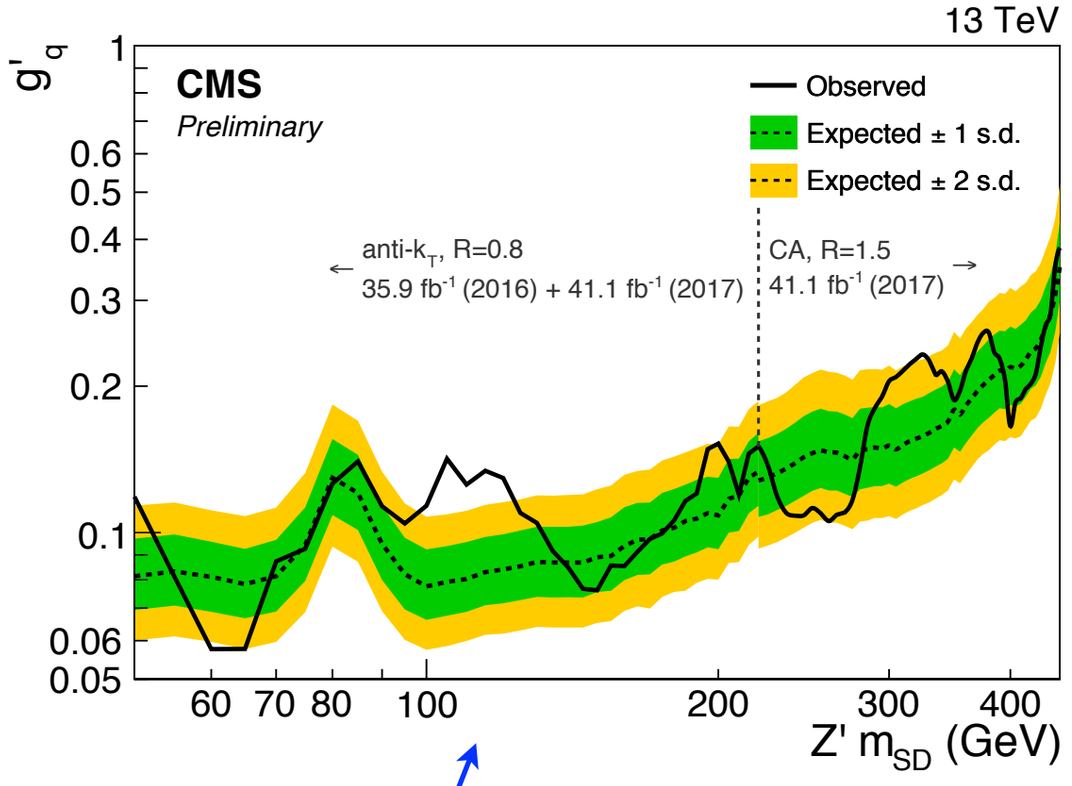
- Generic vector resonance coupling to quarks
  - ✦ Predicted in SM extensions, incl. DM models
  - ✦ Boosted dijet + ISR tag => trigger to probe low-mass



boosted resonance

- 95% CL upper limits on quark coupling g_q' vs resonance mass for leptophobic Z'

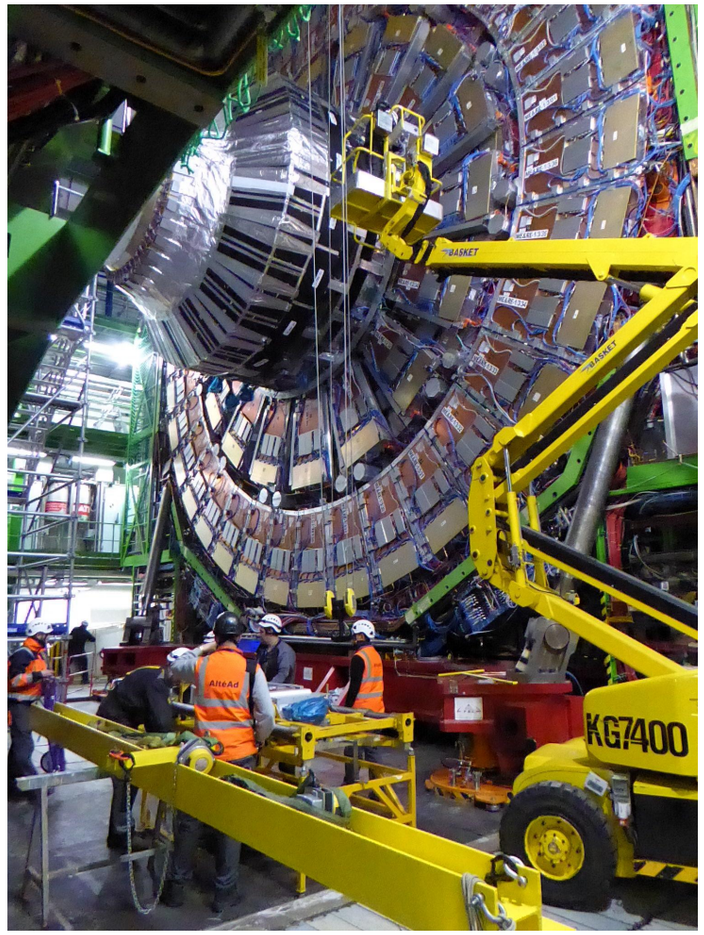




excess around 120 GeV from 2016 data, not confirmed in 2017 dataset

Conclusions

- Much work on different fronts for CMS!
  - ✦ LS2 activities
    - Ongoing work (pixel, HCAL, muons) progressing well
    - Detectors on track for re-installation as scheduled
  - ✦ Preparation for Run-3 underway
    - Both preparing detector & physics analysis
  - ✦ Installing first upgrades for HL-LHC



- ... and in parallel, analyzing Run-2 dataset!
  - ✦ Already several new physics results using full Run-2 data
  - ✦ Exploit innovative strategies, probe new topologies, ...

BACKUP

Control room UPS fire

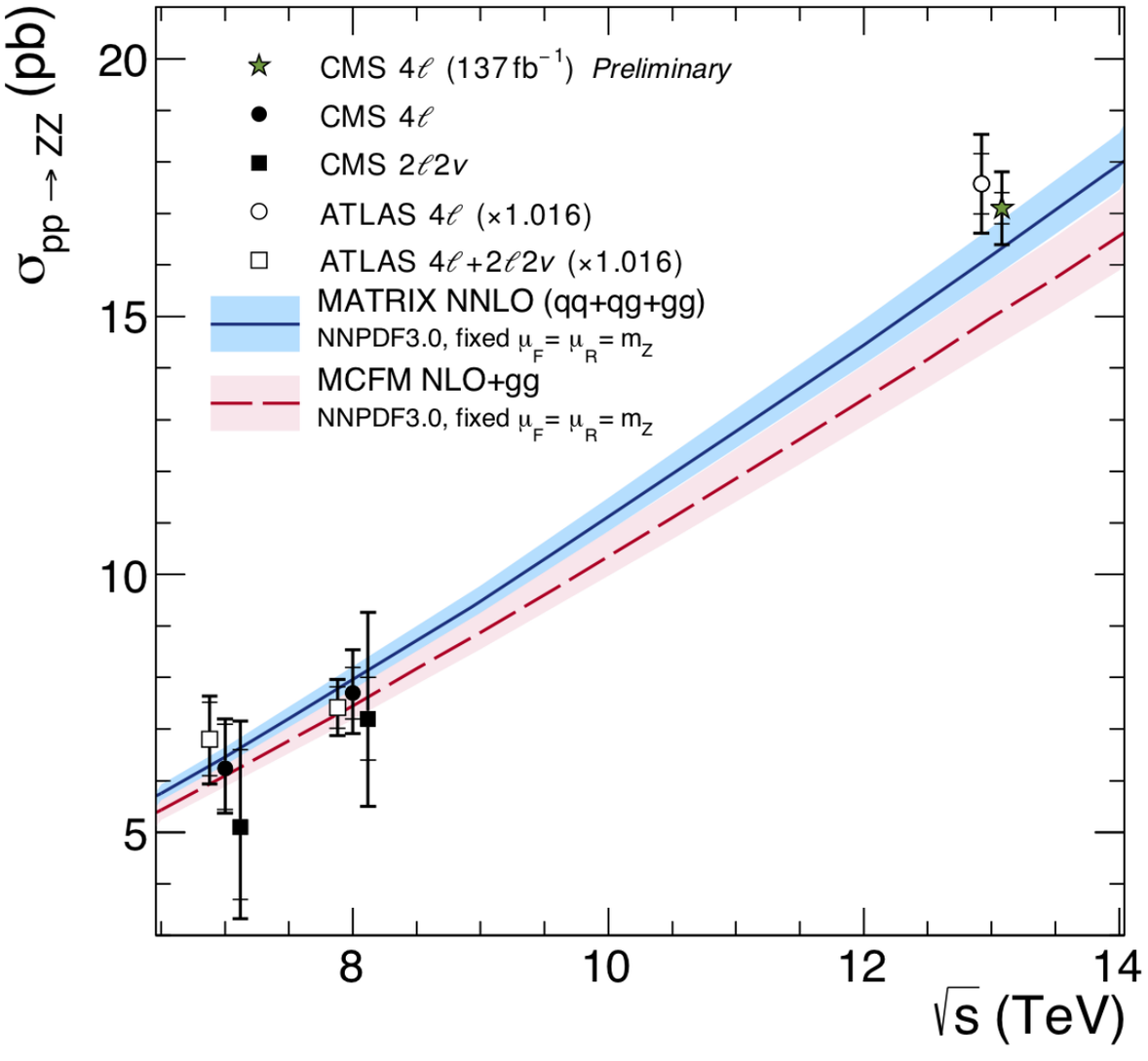
- Overnight between May 25-26, UPS battery rack providing assured power to CMS control room at P5 caught fire
  - ✦ On surface, in separate room adjacent to CMS control room
    - As consequence of fire, subsequent cut to DSS, etc, water mist system was triggered in control room & upstairs DAQ/server computer farm
    - Temporary fully-functional control room in place
- **Many thanks** to especially CERN Fire Brigade & EN-EL/CV for their prompt response & difficult work in extinguishing the fire

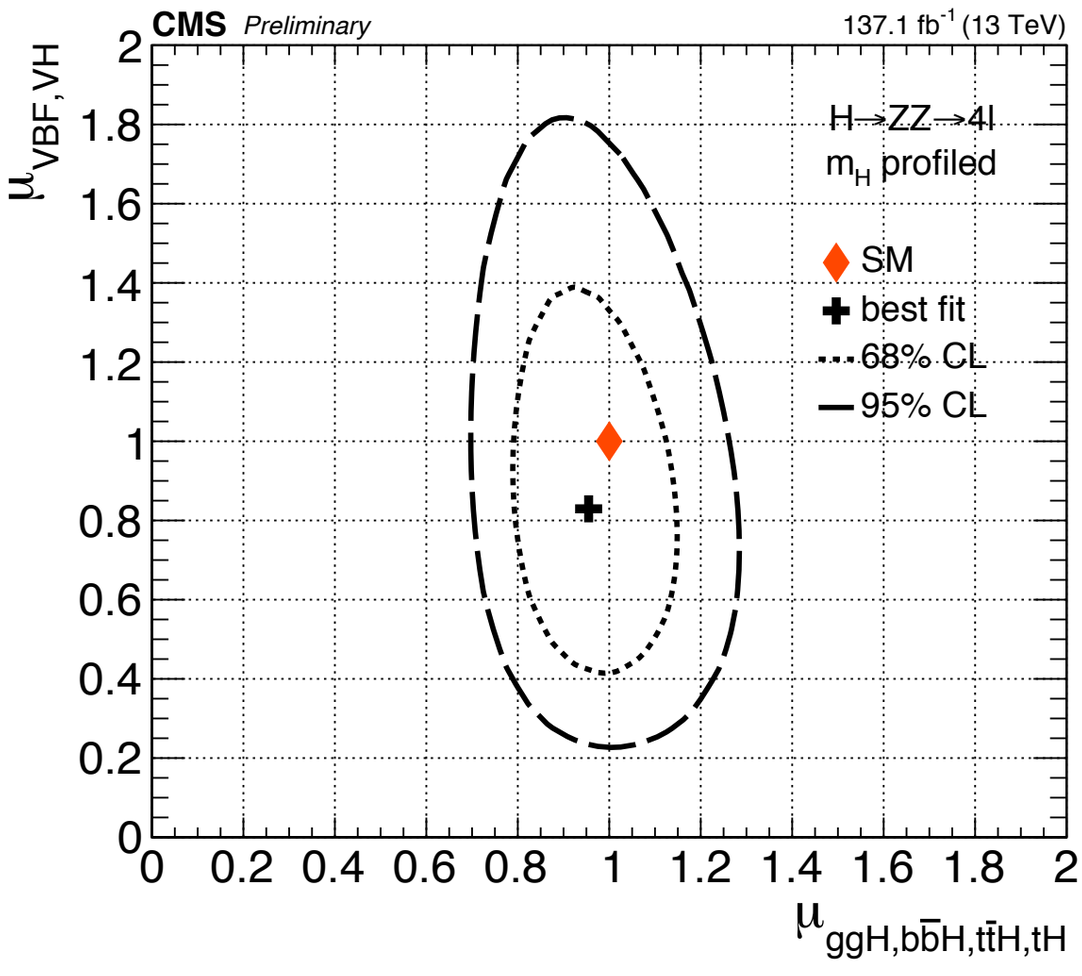
UPS = **U**ninterruptible **P**ower **S**upplies
SCX = **S**urface **C**ontrol e**X**periment building

- *CMS will fully recover from this incident within a few weeks*

  Impact on LS2 program will be very limited and mostly due to delays in test and commissioning activities inhibited while the SCX DAQ area is recovered

SM ZZ, H=>ZZ


CMS 4ℓ (137 fb^{-1}) Preliminary
CMS 4ℓ
CMS 2ℓ2ν
ATLAS 4ℓ (×1.016)
ATLAS 4ℓ+2ℓ2ν (×1.016)
MATRIX NNLO (qq+qg+gg)
NNPDF3.0, fixed $\mu_F = \mu_R = m_Z$
MCFM NLO+gg
NNPDF3.0, fixed $\mu_F = \mu_R = m_Z$
$\sigma_{pp \to ZZ}$ (pb)
$\sqrt{s}$ (TeV)


CMS Preliminary
137.1 fb^{-1} (13 TeV)
H→ZZ→4l
m_H profiled
SM
best fit
68% CL
95% CL
$\mu_{VBF,VH}$
$\mu_{ggH,b\bar{b}H,t\bar{t}H,tH}$

Run-2 luminosity

- *Preliminary* systematic uncertainties for 13 TeV pp luminosity measurement

	Systematic	Correction (%)	Uncertainty (%)
Normalization	Length scale	−0.8	0.2
	Orbit drift	0.2	0.1
	x-y nonfactorization	0.0	2.0
	Beam-beam deflection	1.5	0.2
	Dynamic-β^*	−0.5	
	Beam current calibration	2.3	0.2
	Ghosts and satellites	0.4	0.1
	Scan to scan variation	—	0.3
	Bunch to bunch variation	—	0.1
	Cross-detector consistency	—	0.5
	Background subtraction	0 to 0.8	0.1
Integration	Afterglow (HFOC)	0 to 4	$0.1 \oplus 0.4$
	Cross-detector stability	—	0.6
	Linearity	—	1.1
	CMS deadtime	—	<0.1
	Total		2.5