Status Report on Experiments and Computing

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CERN Council Session 193, June 21, 2019

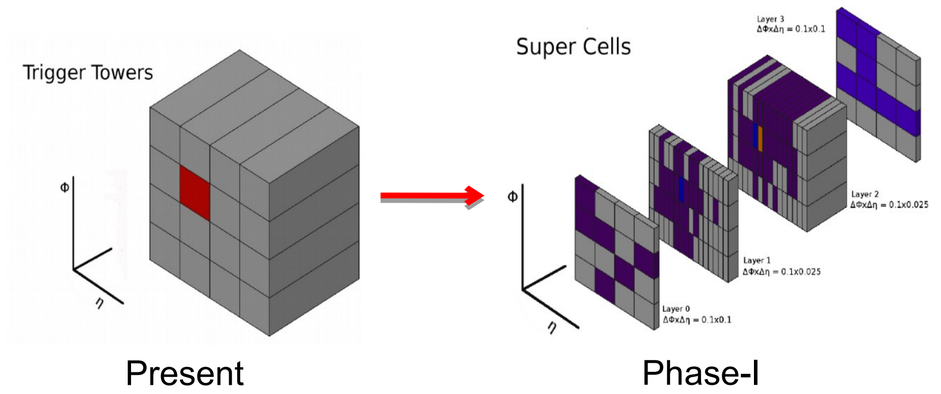
LS2 goals
– rebuilt of ALICE and LHCb
– conclusion of Phase I upgrades for ATLAS and CMS
– and preparation of Phase 2 upgrade

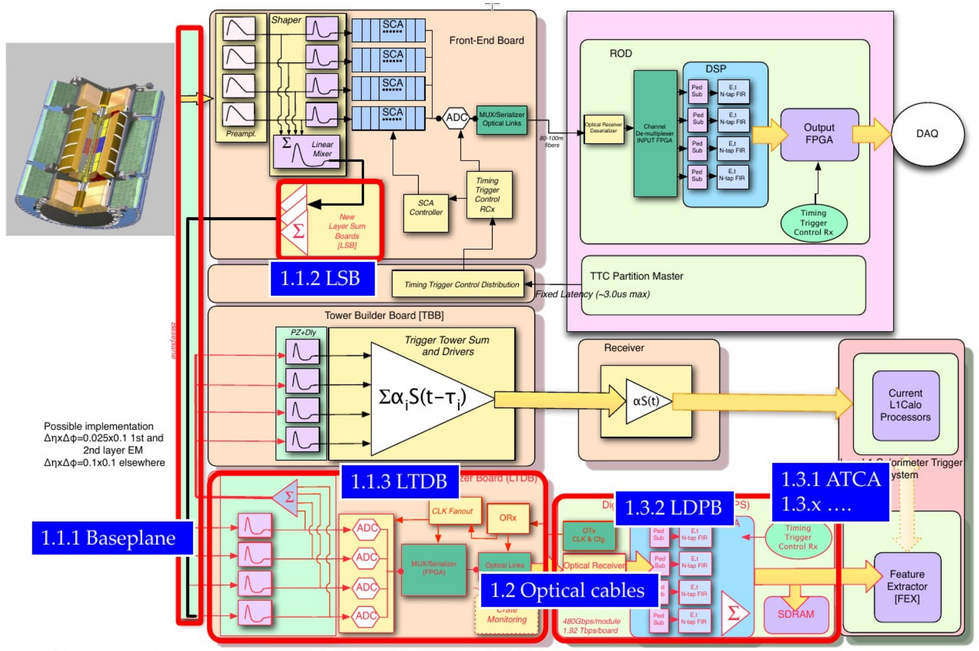
LS2 Activities

Overall very good progress

LAr Trigger

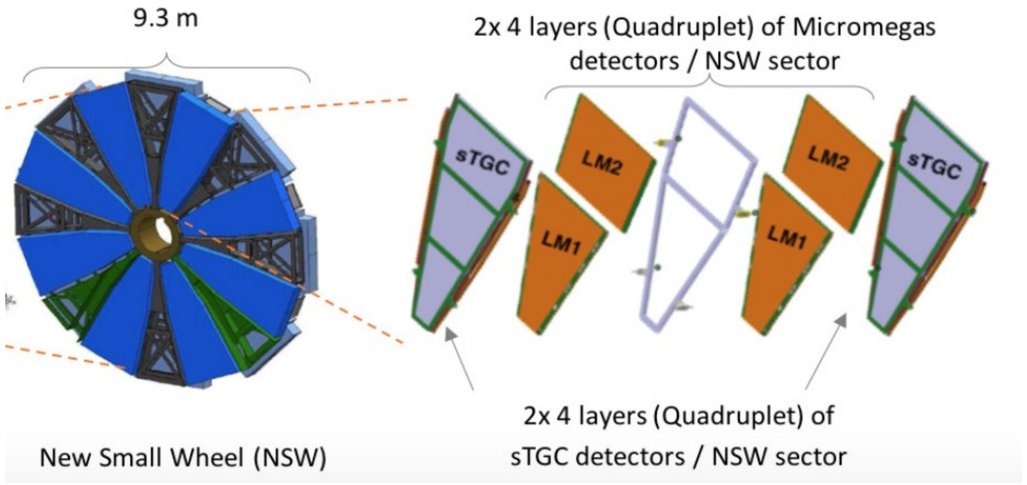
- Installation of new trigger data path for liquid argon calorimeter
  - synergistic with “regular” maintenance
- Front-end board rework, crate baseplane replacement proceeding well
  - 50 FEB/wk achieved (1524 total)
- Commissioning of new crates ongoing
  - validate old trigger path first, then new path when possible





- *New elements are highlighted in RED*

Muon New Small Wheel

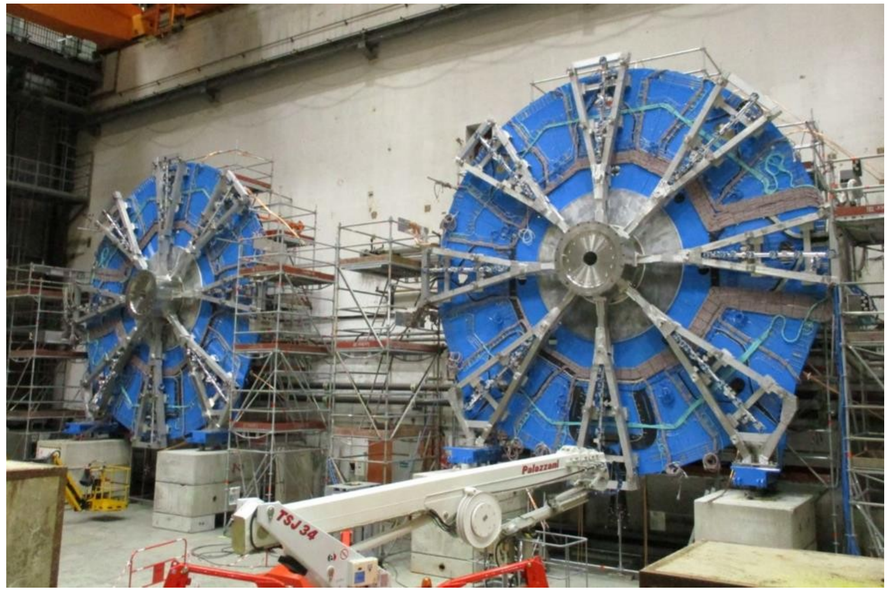


Assembled sTGC wedges, waiting for services and electronics

Electronics test on sTGCs

First complete Micromegas double wedge in cosmic ray test stand for electronics studies

Status NSW



- NSW structure ready to receive detector sectors: installation of 1st sector planned in summer
  - Services installation on A-side wheel is complete
- sTGC:
  - Production is progressing according to schedule, 27 chambers shipped to CERN. Wedge assembly ongoing, first 5 wedges completed
- Micromegas:
  - Production is ongoing. Some remaining HV stability issues
  - Wedge assembly PRR was passed in April
  - 1st double wedge assembled successfully, further wedge integration driven by chamber availability
- Electronics:
  - 50% of front end ASIC (VMM) series production wafers received → packaging next
  - All electronics cards are either in pre-production or production, with some delays on the Micromegas frontend board (MMFE8)

Overview of CMS 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

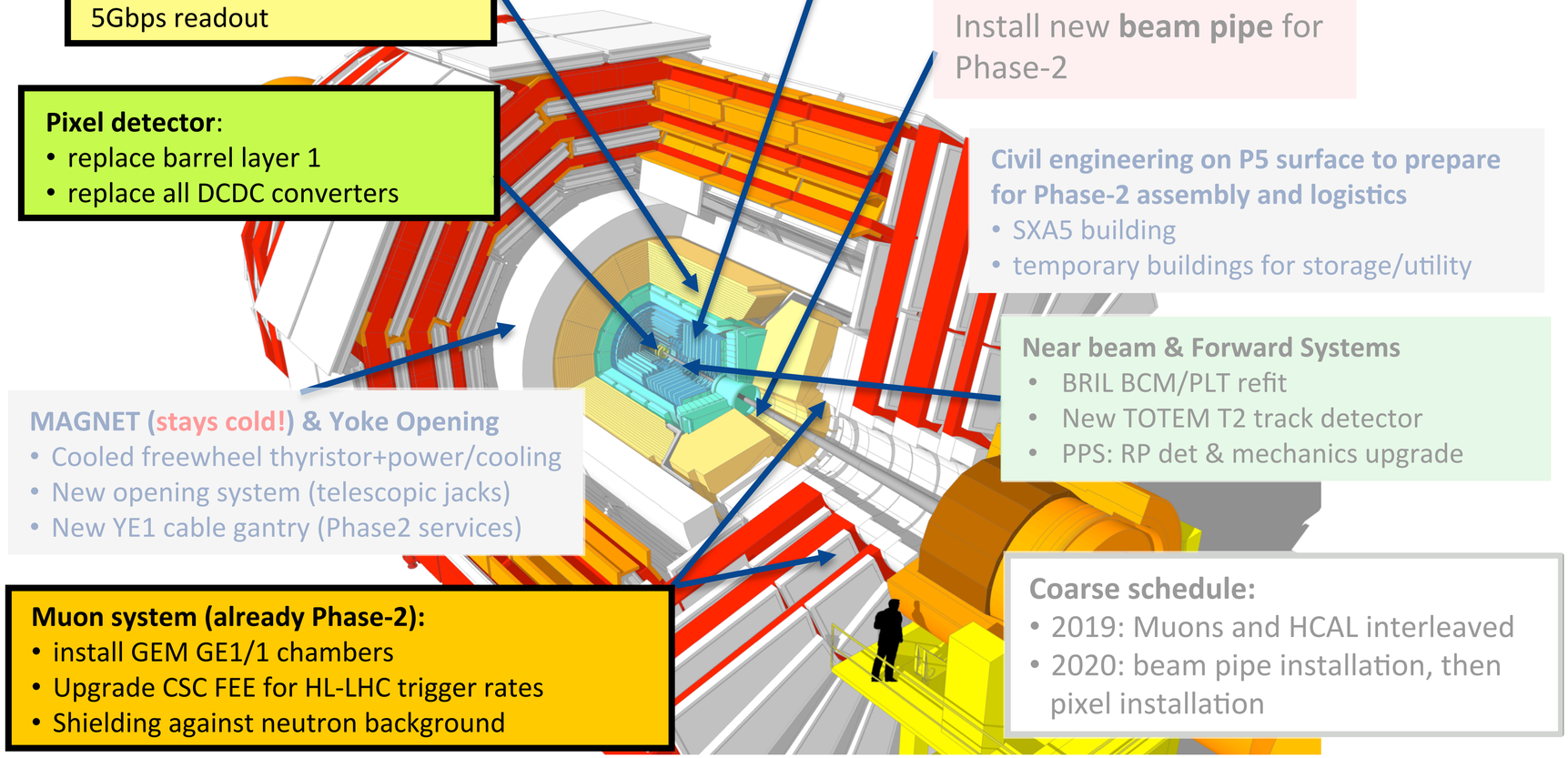
Keep **strip tracker** cold to avoid reverse annealing

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

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)

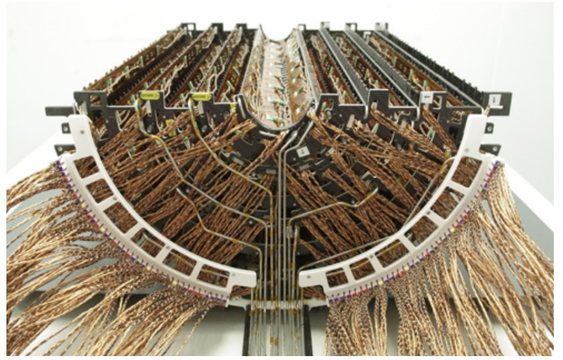
Coarse schedule:
- 2019: Muons and HCAL interleaved
- 2020: beam pipe installation, then pixel installation

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

CMS Pixel Detector

- New barrel layer 1 ← *Radiation tolerance through Run-3 (+ improved readout ASICs)*
  - 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*
- Replace all DCDC converters ← *Issue with chip in DCDC converters (2017)*
  - 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*

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



1/2 CMS Phase-1 barrel pixel

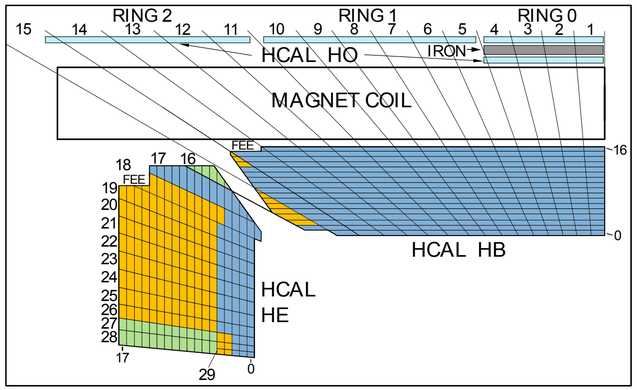
HCAL

- 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

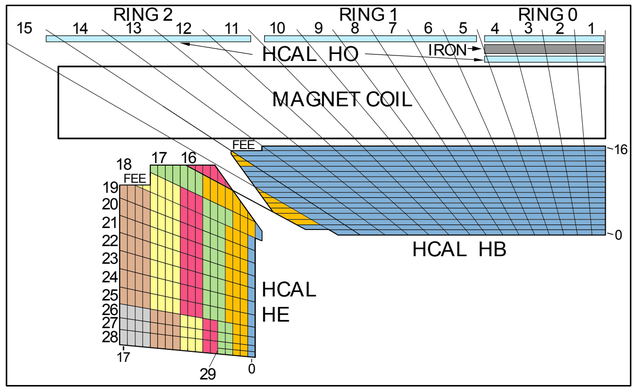
HPD=Hybrid PhotoDetectors
SiPM=Silicon Photo-Multipliers

on track for completion before end 2019

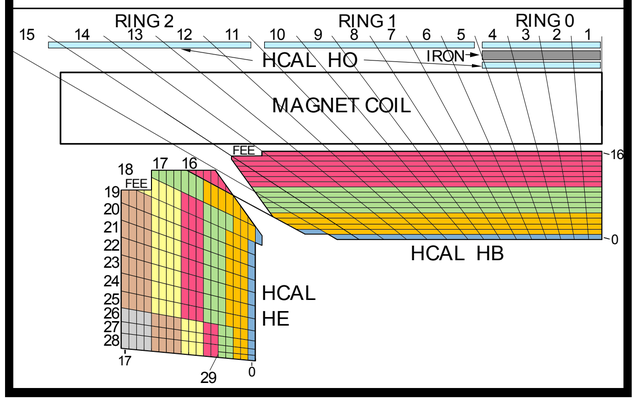
HCAL segmentation: pre-2018



HCAL segmentation: 2018



HCAL segmentation: Run3 (post-LS2)



Muon system upgrade (Phase II)

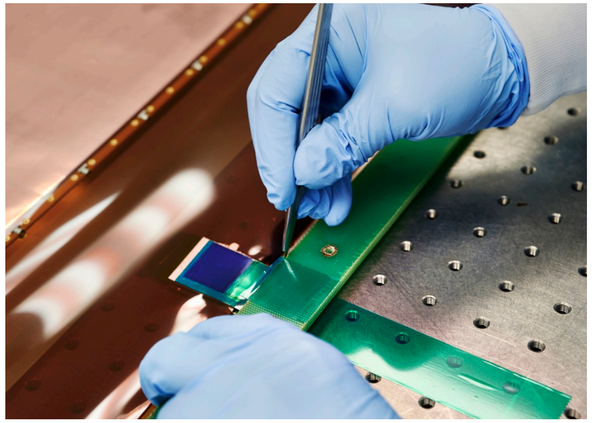
CMS

- Install GEM GE1/1 chambers

installing already now

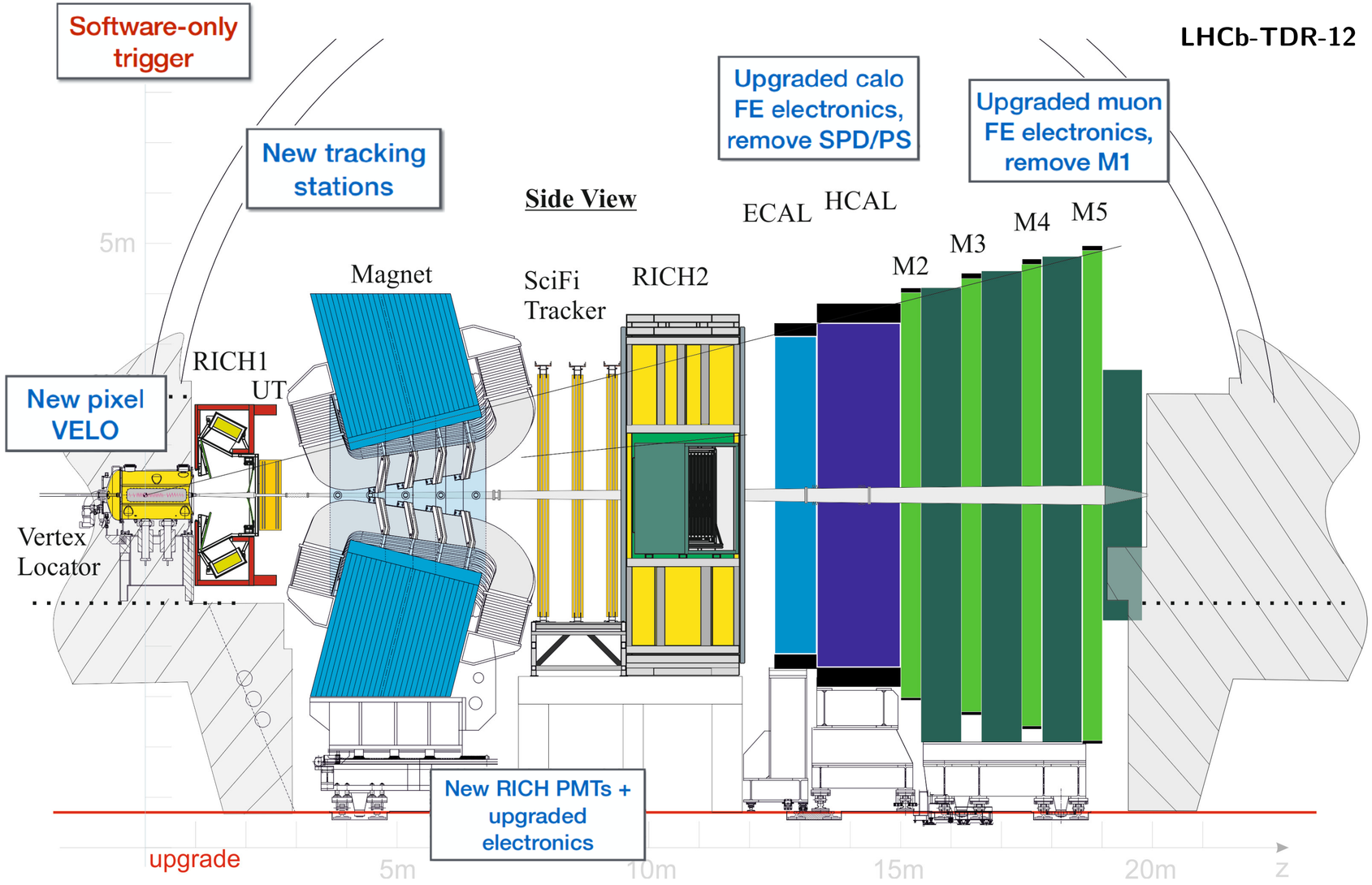
  - Chambers
    - All built & validated
  - FE electronics
    - Design change to improve spark protection, production underway
  - Two chamber assembly (super chamber=SC)
    - 7/72 assembled with final electronics: cooling, gas, etc. OK
    - Final validation on cosmic test stand - expect to test 10 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



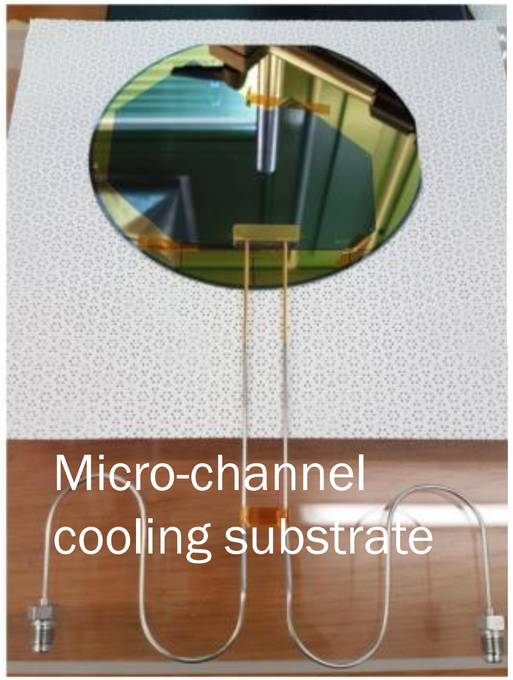
Critical path

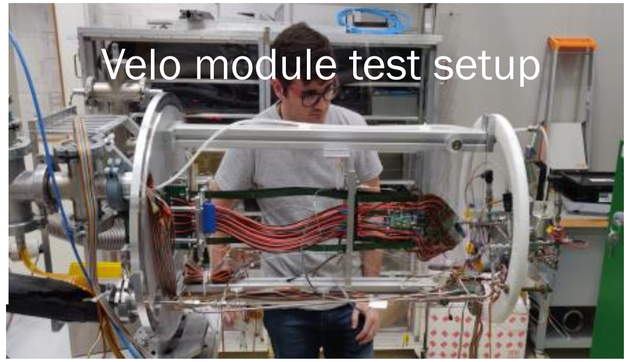
LHCb Phase I upgrades

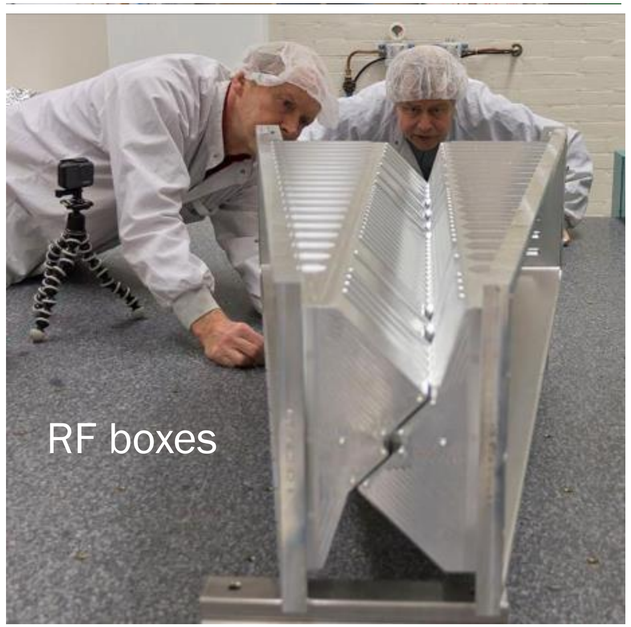


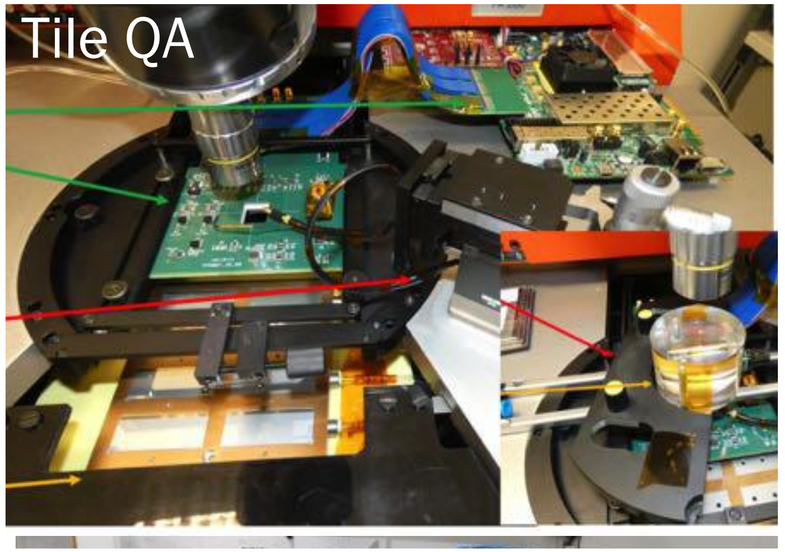
Assembly hall fully prepared

VELO

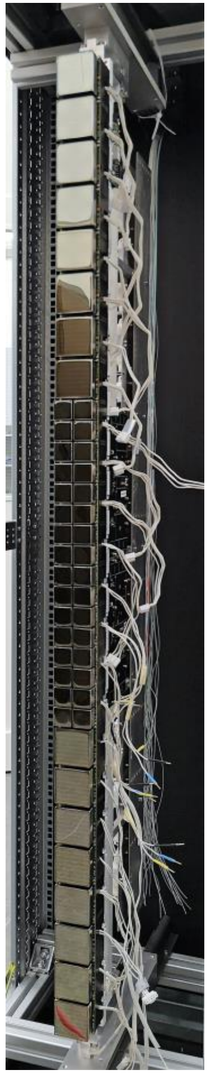

Micro-channel
cooling substrate


Velo module test setup


RF boxes


Tile QA

RICH



An assembled MaPMT column

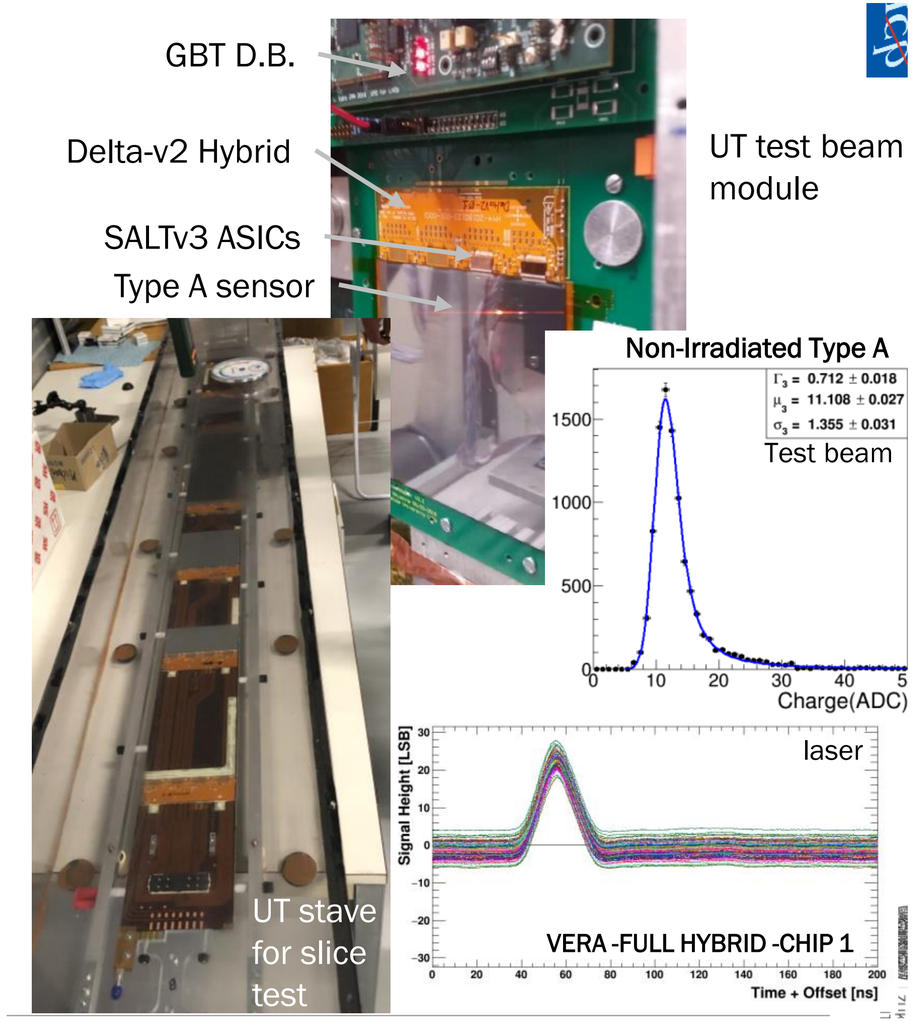
SciFi

Front-end tester at Point 8

C-Frame 1 with fibre modules

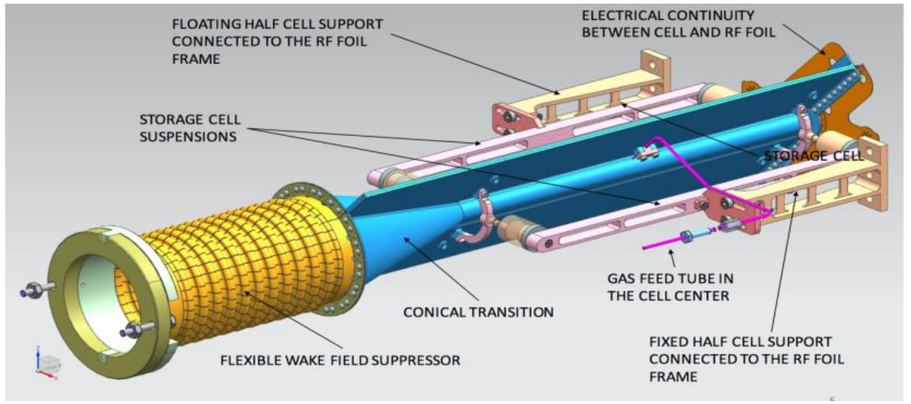
UT

- SALT v3 asic received and tested, v3.5 sent for production
  - Issues seen in the previous version largely fixed.
  - Test beam at Fermilab in March. Good results.
- Slice test setup in progress at Point 8
  - instrumented stave with realistic power, cooling and protomechanics
- Now to finalize the hybrid and start production
  - Hybrid production June 2019, QA and tools ready
- Sensors:
  - received all A-type, pre-series of B,C,D, prod. in Oct. 2019.
- Read out electronics: production started
  - Flex cables pre-series available, under test
- Bare staves: production finished
- Integration infrastructure progressing at full speed



SMOG 2

- LHCb has a unique fixed target physics programme at LHC [LHCb-PUB-2018-015]
  - Heavy ions
  - Cosmic ray physics
  - Useful for early measurements such as p/He cross-section
- New SMOG will increase by up to two orders of magnitude the effective target areal density [CERN-LHCC-2019-005 ; LHCB-TDR-020]
- significant increase of the luminosity for fixed- target collisions.
- Multiple gas capabilities being studied
  - Impact on accelerator



Technical drawing of the gas storage cell to be installed inside the VELO

Inner Tracker System ITS Installation

May 2019

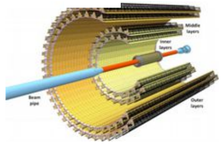
Jun 2019

Aug. 2019

Oct. 2019

June 2020

Feb. 2021



Detector Construction and Assembly

- **Module production: completed!** (May 2019)
- **Electronics production: done!**

→ testing till end of July 2019

- **Stave production: 85% done**

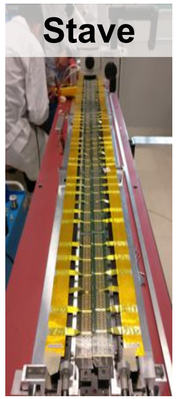
→ continues till Aug. 2019

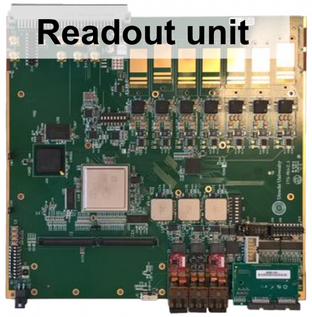
Commissioning on ground with final services ongoing (operation 24/7)

OB stave Assembly End:> 50% done

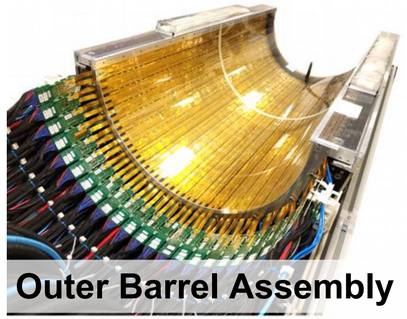
Installation

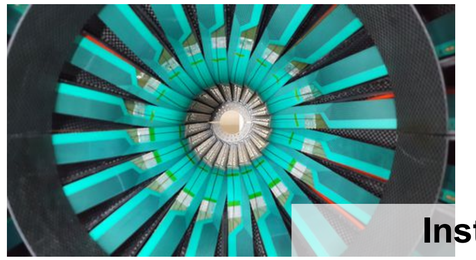
6-month Global Commissioning


Stave

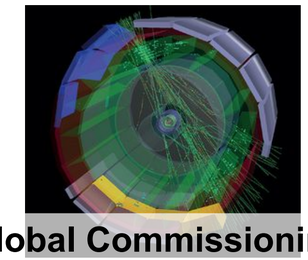

Readout unit


Inner Barrel Assembly

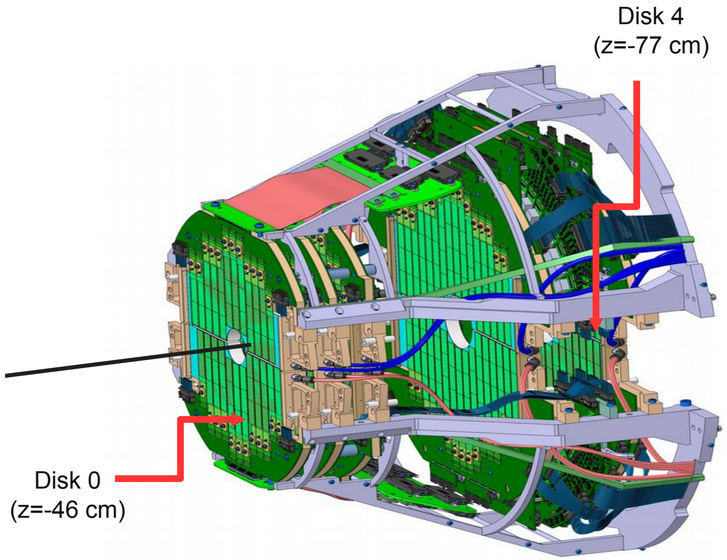

Outer Barrel Assembly




Installation

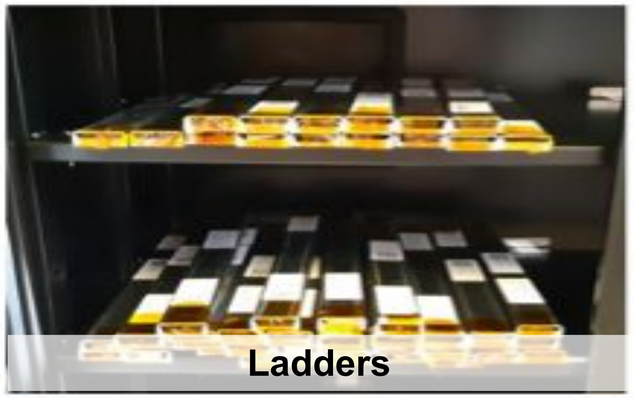

Global Commissioning

Muon Forward Tracker

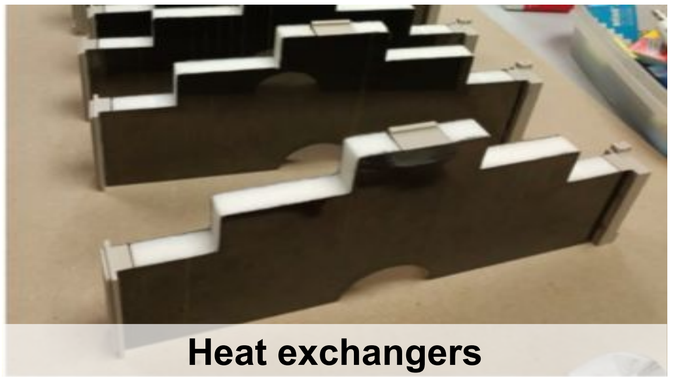


Mechanical disk fully equipped

Support barrels



Ladders



Heat exchangers

TPC in cleanroom

- **TPC moved to the cleanroom on 5th April**
- Field cage X-ray irradiation - positive
- **Multi-wire proportional Chamber (MWPC) removal on A-side accomplished**
- TPC Field Cage adaptation for operation in RUN 3 and 4 **ongoing**
- **Next step: install GEM chambers**

Moved to the cleanroom 5th April

Multi-wire proportional chamber (MWPC) removal

LS2 Brief Summary

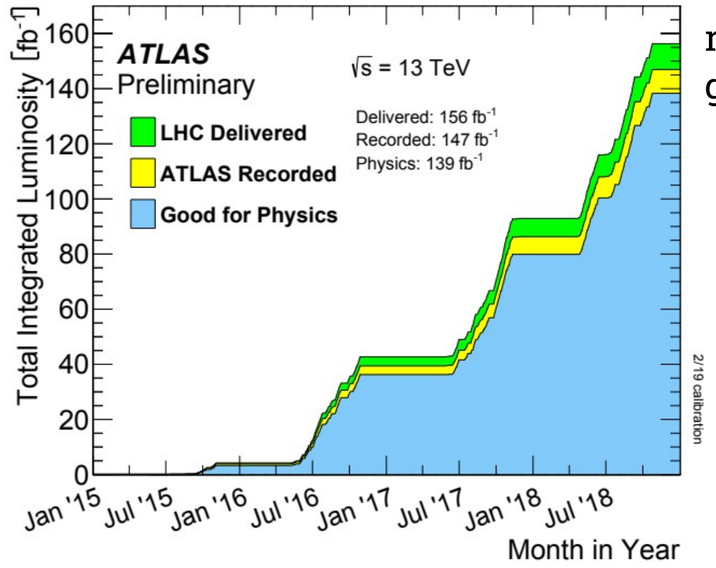
Excellent Progress everywhere, but…

- ATLAS
  - NSW installation on critical path even for one wheel
  - FTK: manpower not available to produce full-fledged system; discussing whether to install down-scoped FTK (higher p_T-cutoff)
- CMS
  - Muon detector installation GE1 time critical
- LHCb
  - Upstream Tracker electronics (SALT-chip) resolved; UT installation remains on critical path
- ALICE
  - CRU electronics order for TPC in India delayed; way forward will have to be settled by end of June

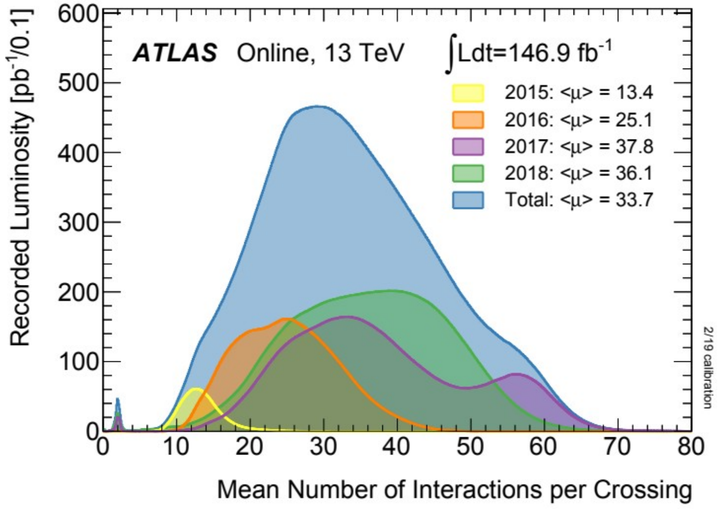
Selected Physics Results

ATLAS

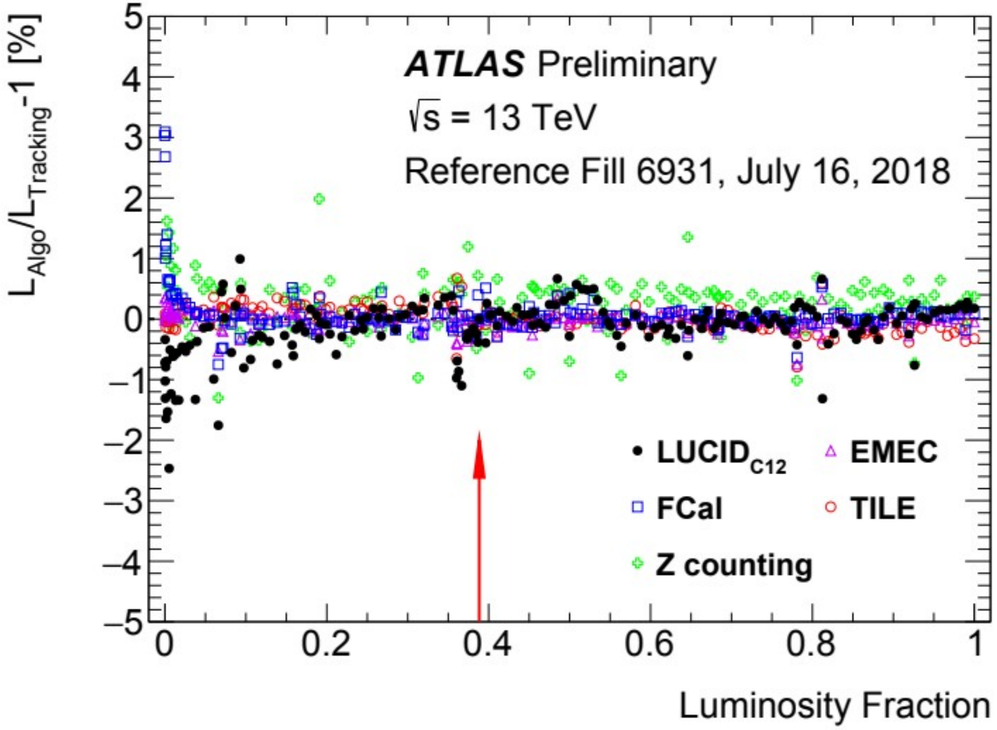
Status of 13 TeV data sample



recording eff ~ 94%
good for physics ~ 95%



comparative stability of different lumi measurements in 2018



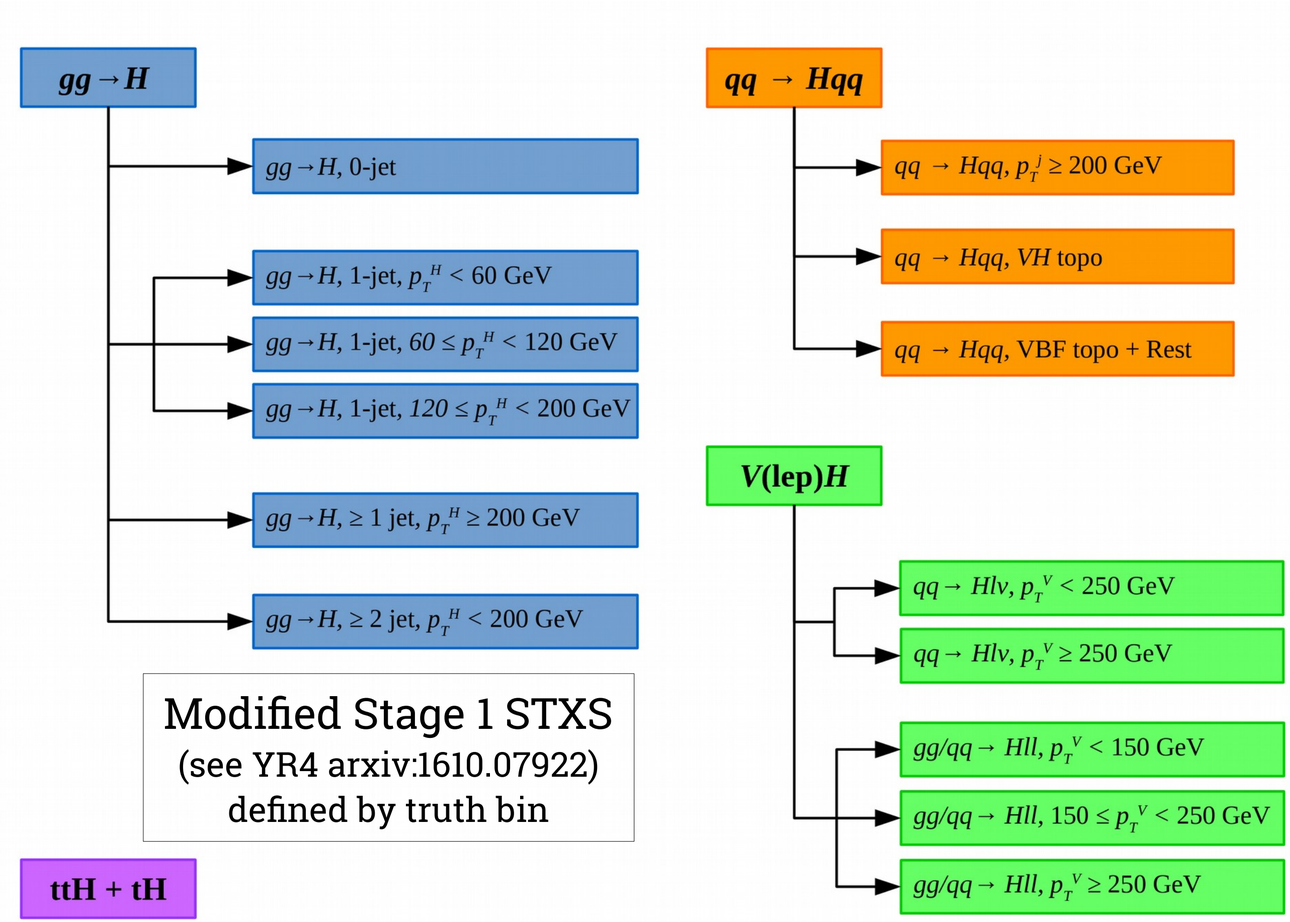
2018 prelim lumi uncertainty 2.0%
(of which stability 0.8%)

Full Run 2 prelim uncertainty 1.7%

L ~1.7%

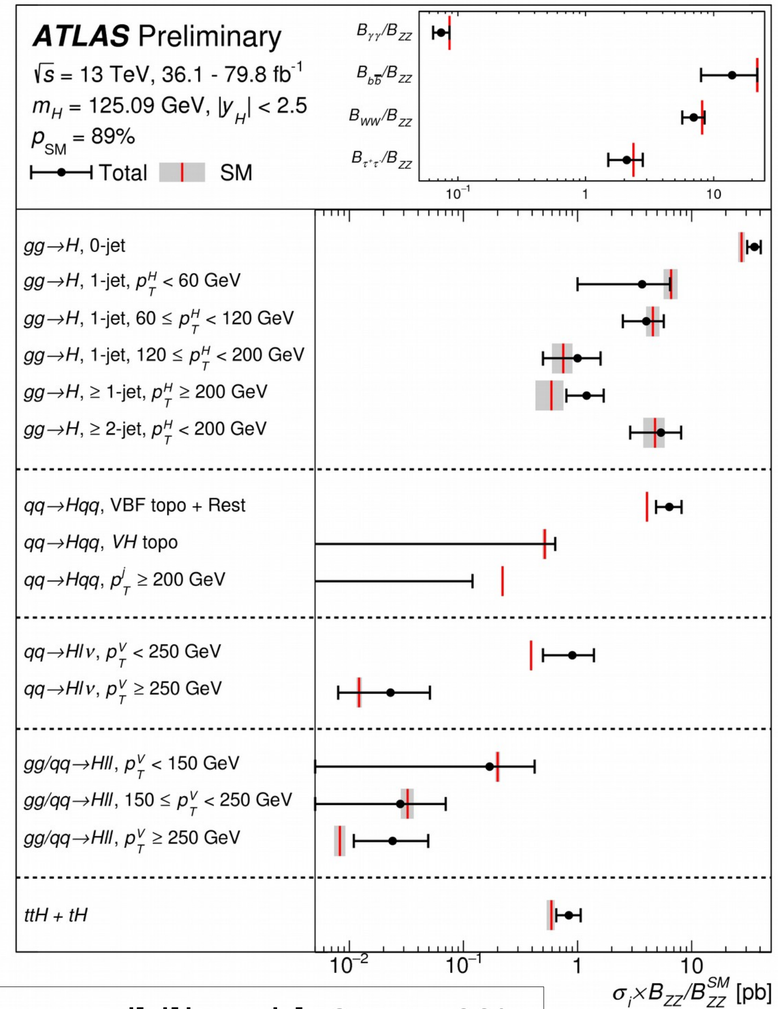
Simplified Template Cross Sections: Higgs Combination

ATLAS



Modified Stage 1 STXS
(see YR4 arxiv:1610.07922)
defined by truth bin

ATLAS-CONF-2019-005



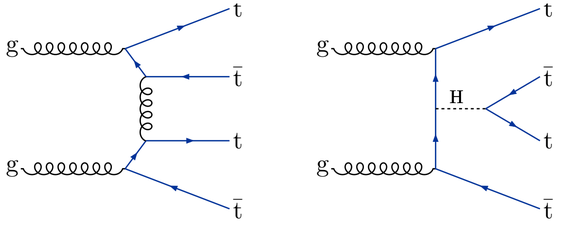
compatibility with SM p = 88%

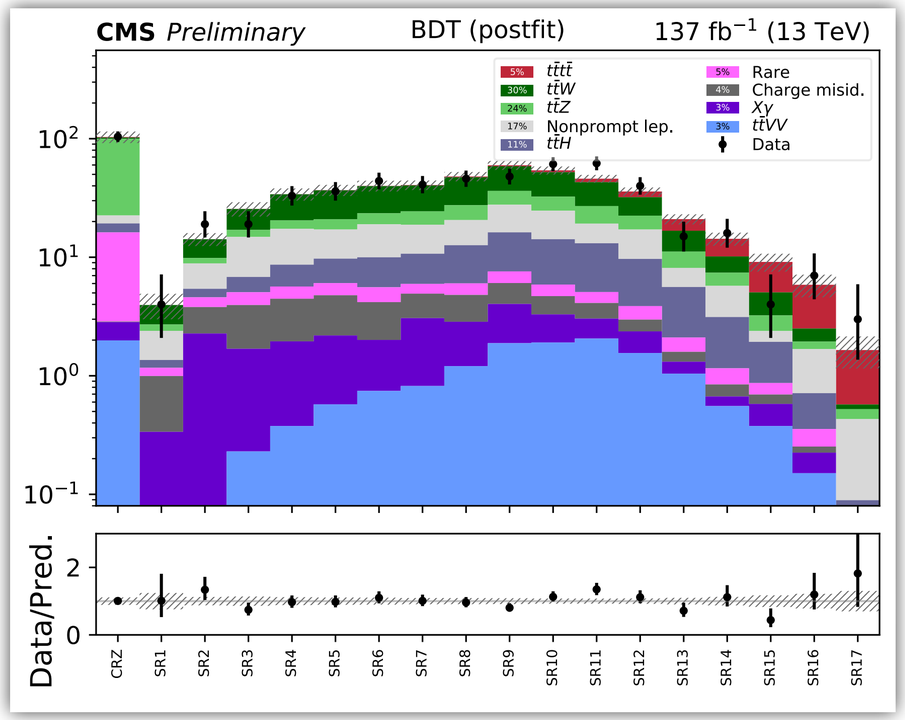
CMS

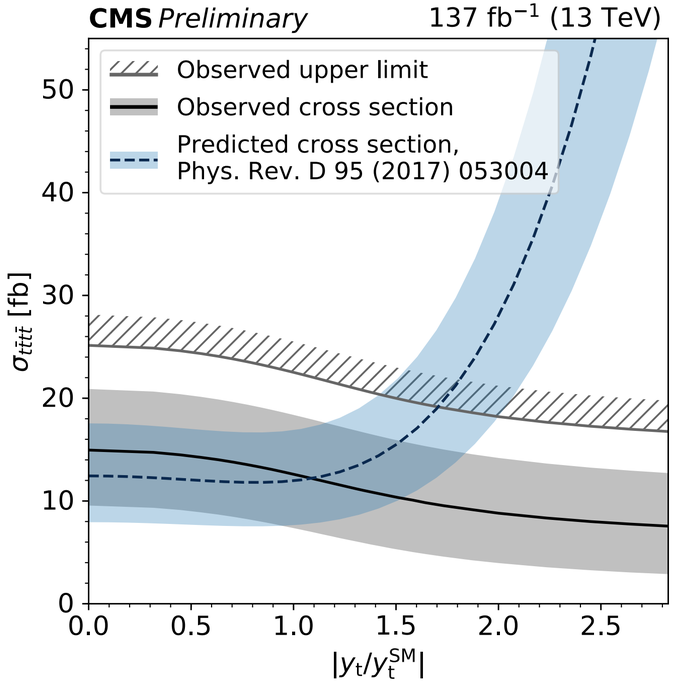
$pp \rightarrow t\bar{t}t\bar{t}$

CMS

- 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: $|y_t / y_t^{SM}| < 1.7$



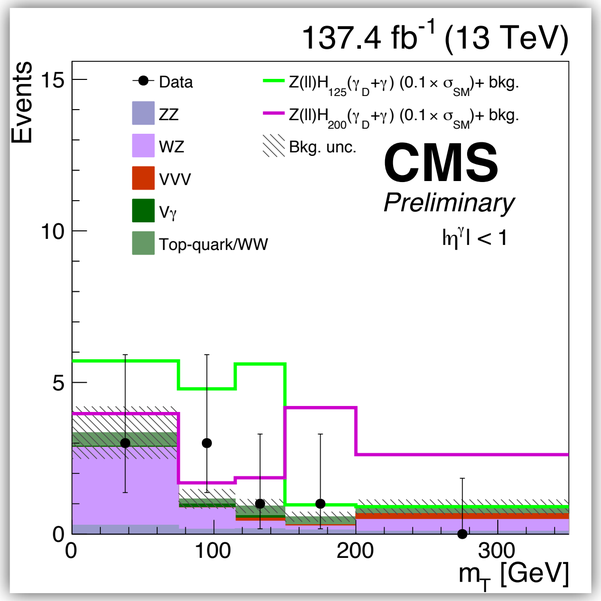


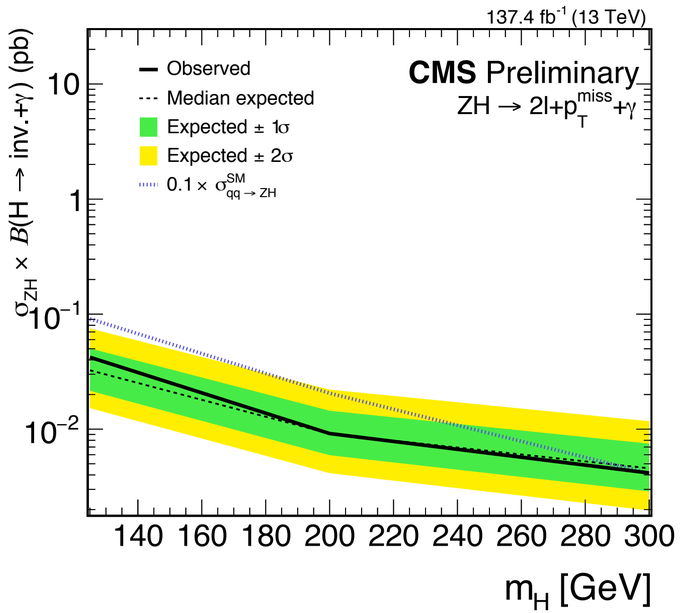


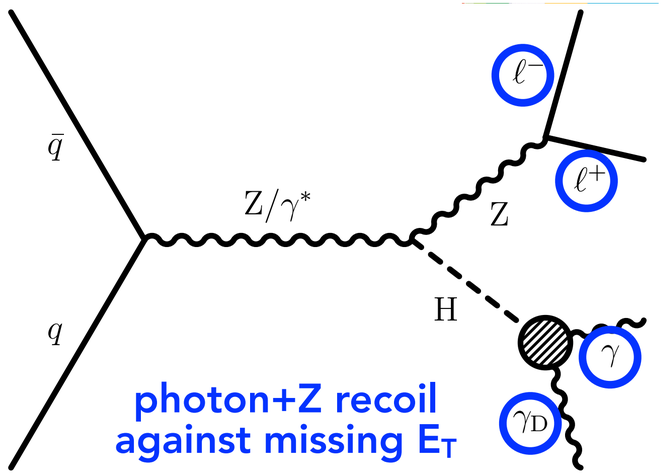
Dark Photons

- Massless dark photons coupling to a Higgs boson through charged dark sector particles
- 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

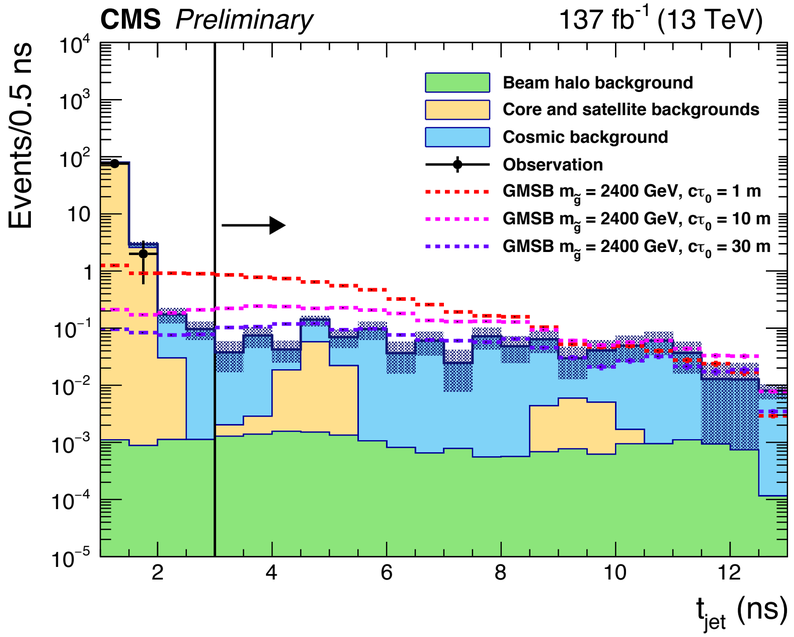


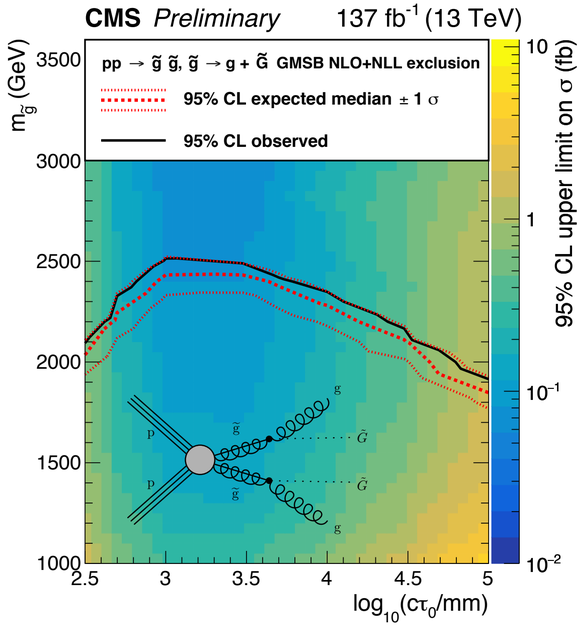


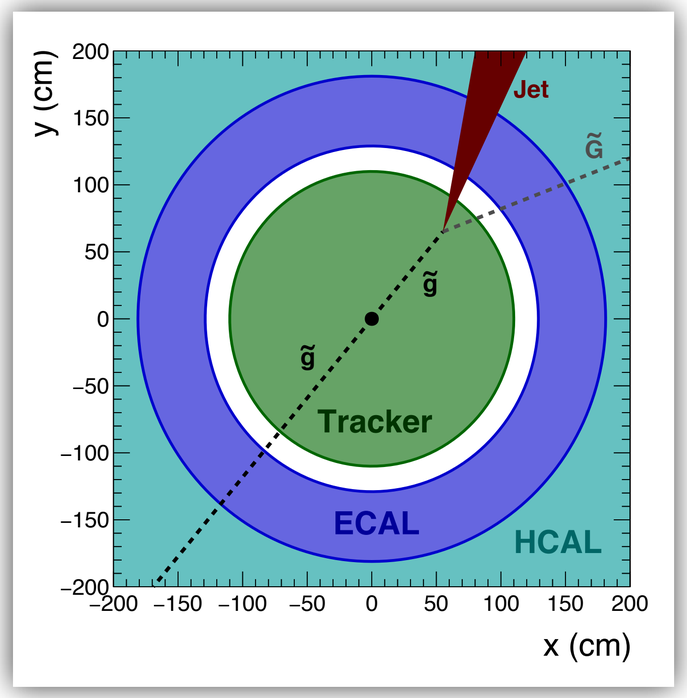


Delayed jets

- BSM scenarios (SUSY, hidden valley, ...) with long-lived particles may result in “delayed” jets
- First search for such jets using ECAL timing!
- No excess – interpret in terms of Gauge mediated Supersymmetry Breaking





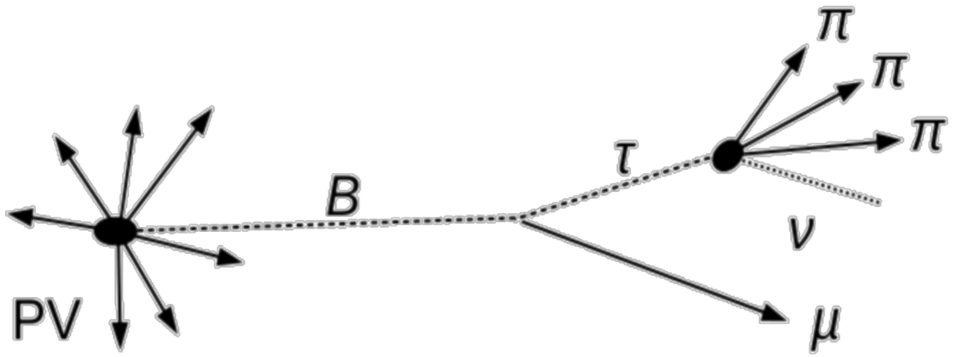


LHCb

Search for Lepton flavour violating decay $B^0_{(s)} \rightarrow \tau^{\pm}\mu^{\pm}$

LHCb

- Search for lepton-flavour violating decays $B^0_{(s)} \rightarrow \tau^{\pm}\mu^{\mp}$
- BR in SM very small: ~10^{-54}
- Can be strongly enhanced in NP models: up to O(10^{-9} – 10^{-5})
- Look for three prong τ decays



[LHCB-PAPER-2019-016, Run1 3 fb^{-1}] arXiv:1905.06614 Submitted to PRL

Mode	Limit	90% CL	95% CL
$B^0_s \rightarrow \tau^{\pm}\mu^{\mp}$	Observed	3.4×10^{-5}	4.2×10^{-5}
	Expected	3.9×10^{-5}	4.7×10^{-5}
$B^0 \rightarrow \tau^{\pm}\mu^{\mp}$	Observed	1.2×10^{-5}	1.4×10^{-5}
	Expected	1.6×10^{-5}	1.9×10^{-5}

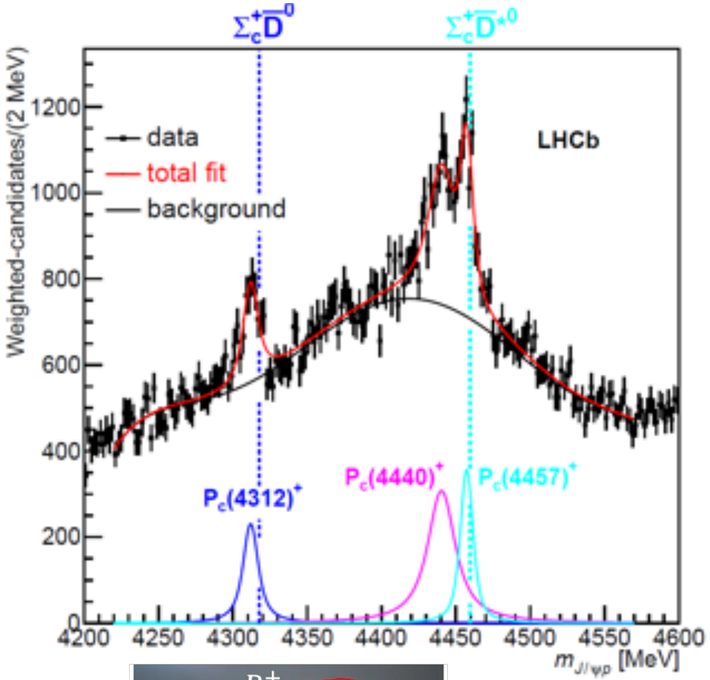
First limits

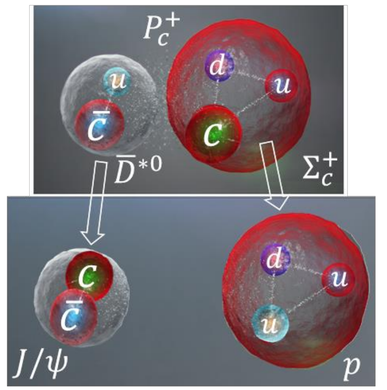
World Best limits (Factor of 2)

Observation of New Pentaquarks

LHCb

- A narrow peak from $\Lambda^0_b \to J/\psi\, pK$ – decays is observed near 4312 MeV with a width comparable to the mass resolution
  - Analysis uses full Run 1 and 2 data
  - statistical significance of 7.3σ.
- The structure at 4450 MeV is now resolved into two narrow peaks, at 4440 and 4457 MeV
  - statistical significance of this two-peak interpretation is 5.4σ
- Indication of a bound state
  - Full amplitude analysis required to better determine the nature of the states





[LHCB-PAPER-2019-014, Accepted by PRL]
arXiv: 1904.03947

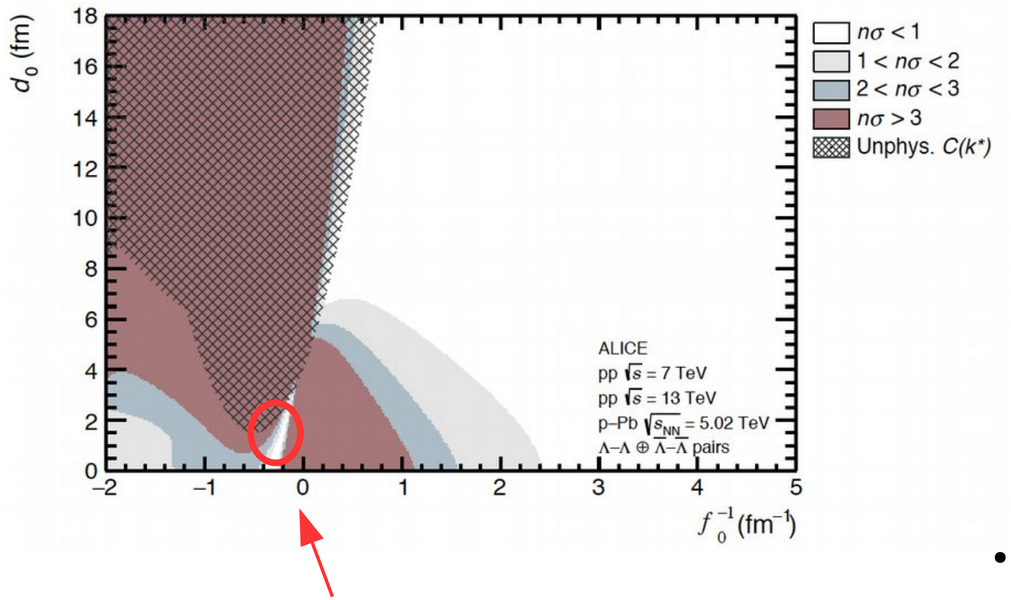
ALICE

Study of Baryon–(anti-)Baryon Interactions in pPb-collisions

ALICE

New paper arXiv:1905.07209

Exclusion plot for the Λ-Λ scattering parameters



Narrow allowed region compatible with a bound state

- **Use Λ-Λ momentum correlation to measure their interaction**

$$C(\vec{p}_1,\vec{p}_2) = \frac{P(\vec{p}_1,\vec{p}_2)}{P(\vec{p}_1)P(\vec{p}_2)}$$

$$C(\vec{q}) = \int S(\vec{r})\,|\Psi(\vec{q},\vec{r})|^2 d^3r$$

Measured correlation

Source size/shape known from pp

Two-particle wave functions Interaction unknown

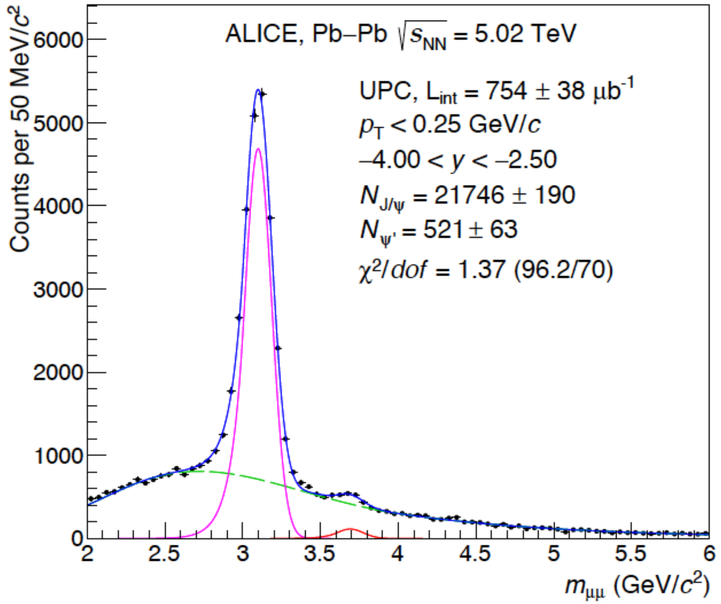
q: relative momentum
r: relative distance between the points of emission of the two kaons

- **Determine the scattering parameters (f_0^{-1},d_0) defining the interaction**
  - **Scattering length: f_0**
  - **Effective range: d_0**

Lednicky Model

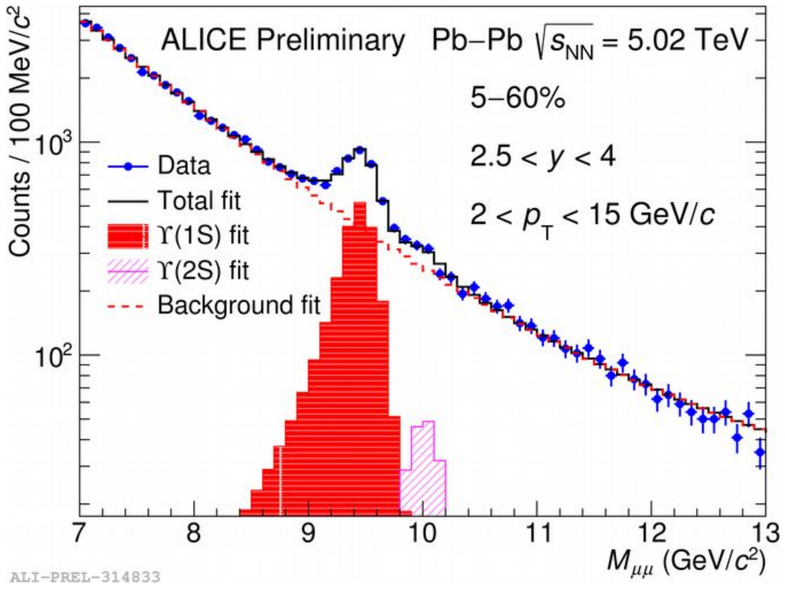
PbPb-run 2018

J/ψ
in ultra-peripheral Pb-Pb collisions



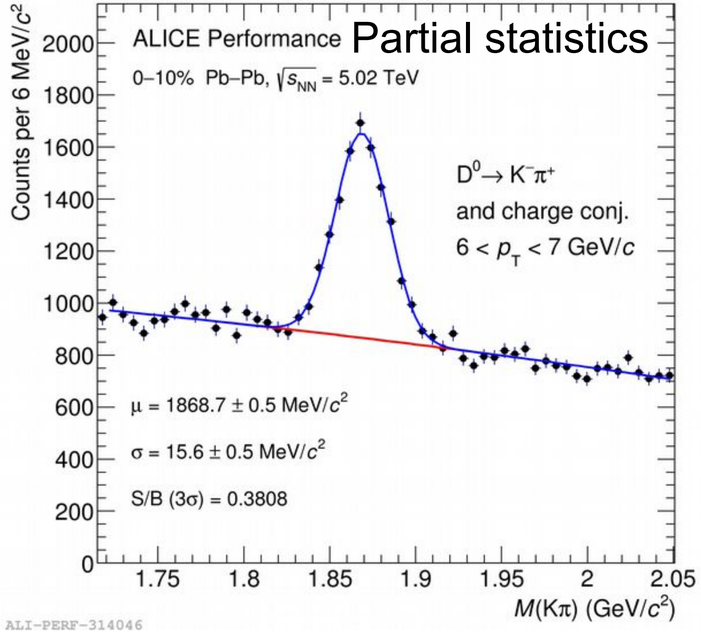
First paper submitted including 2018 data arXiv:1904.06272

ϒ
in 5-60% central Pb-Pb collisions



First preliminary results including 2018 data

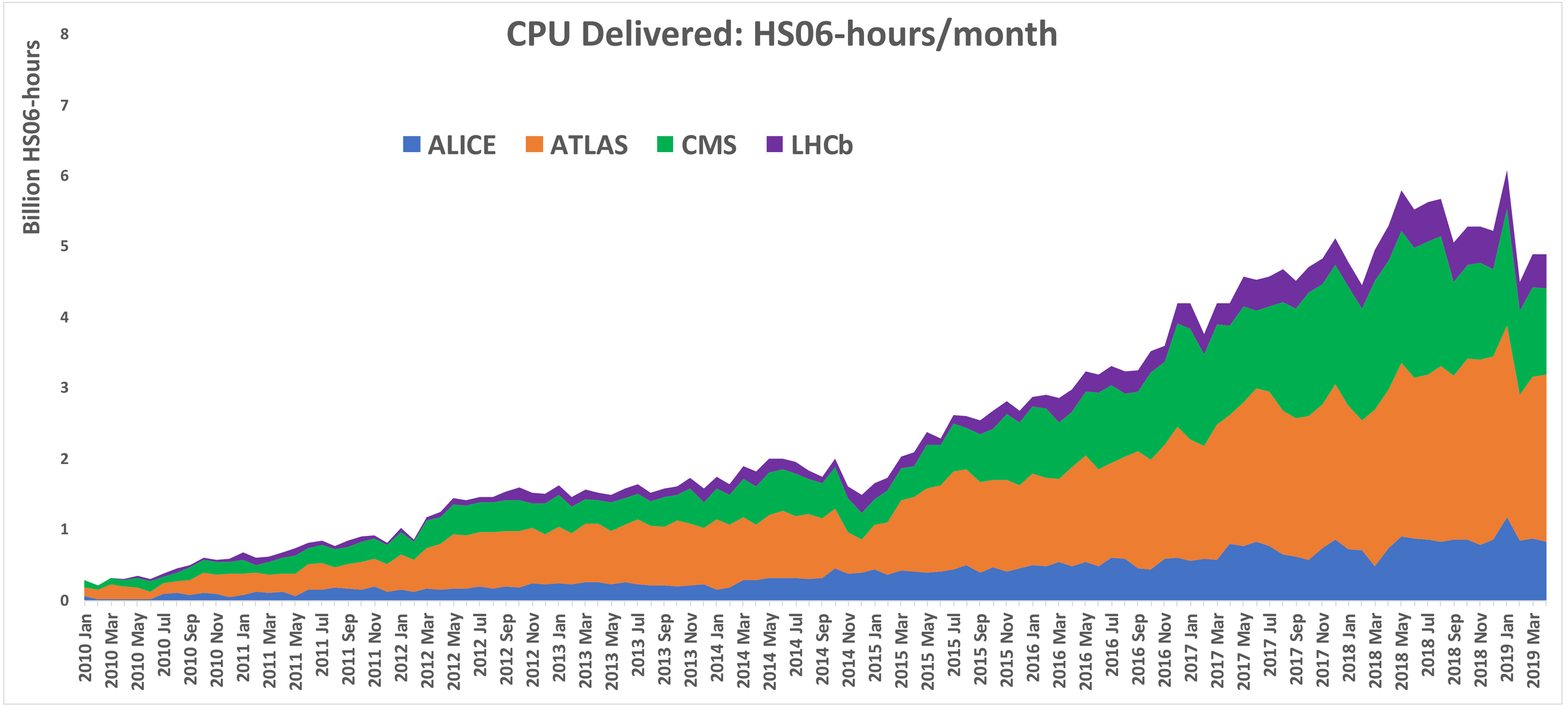
D^0
in 0-10% central Pb-Pb collisions



More results for Summer conferences

Status Computing

WLCG usage


CPU Delivered: HS06-hours/month
Billion HS06-hours
ALICE
ATLAS
CMS
LHCb
0
1
2
3
4
5
6
7
8
2010 Jan
2010 Mar
2010 May
2010 Jul
2010 Sep
2010 Nov
2011 Jan
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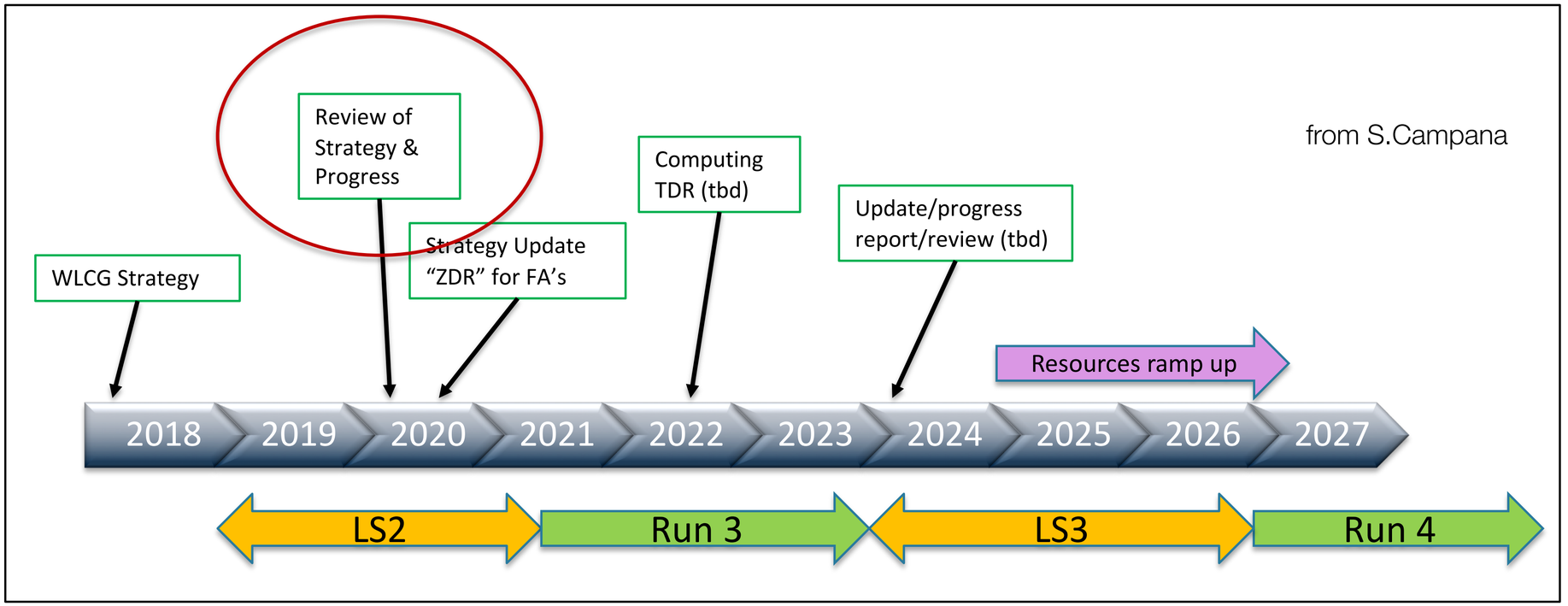
2019 Jan
2019 Mar

Towards HL-LHC Computing

- A team of computing experts is being put in place as part of the LHCC
- TDR for computing deferred to 2022 but intermediate assessment of developments



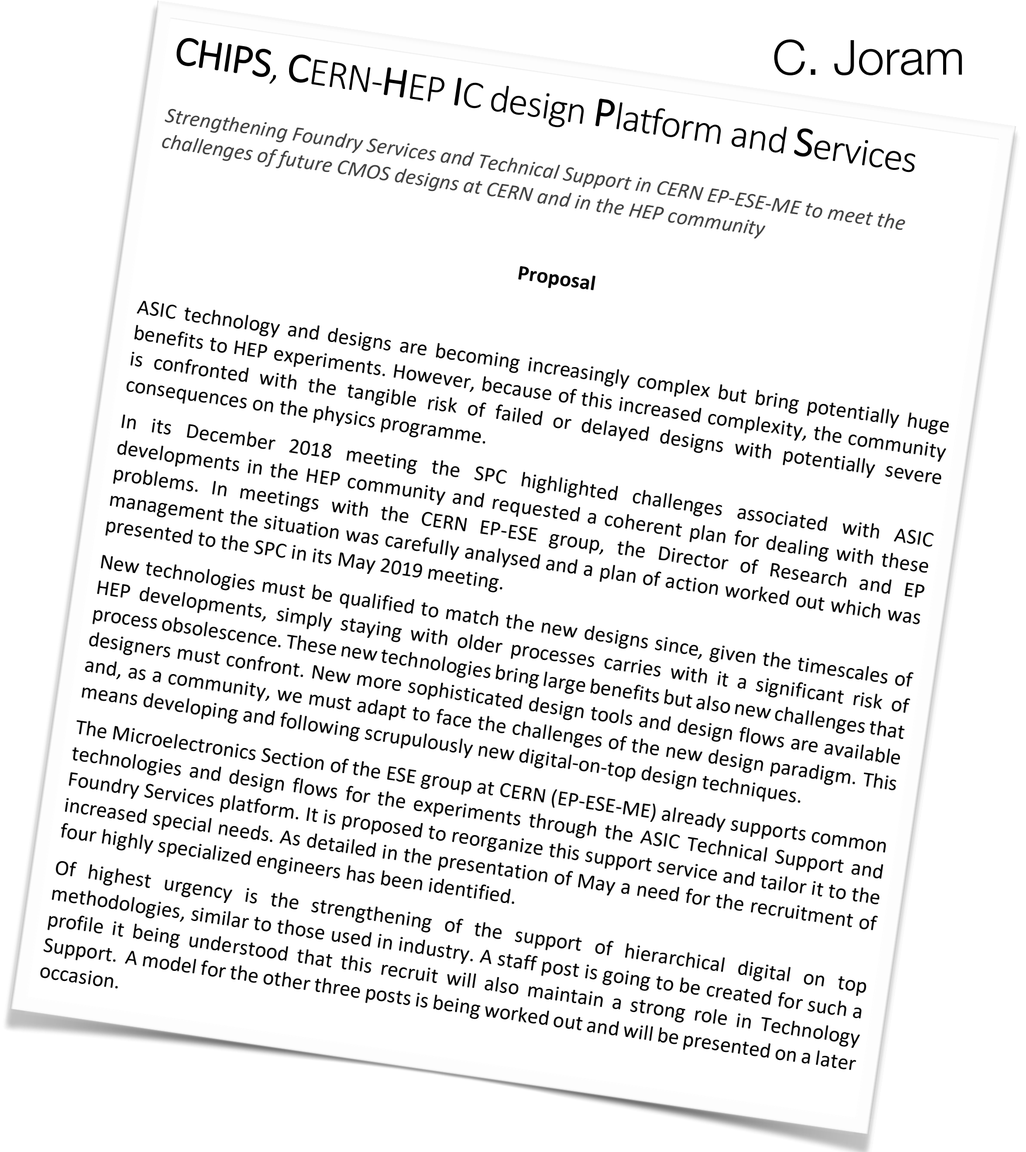
Phase II Upgrades

Phase II Upgrade Group (P2UG)

- Task is to monitor progress for Phase II upgrades of ATLAS and CMS
  - chaired by M. Morandin and M. Demarteau respectively
  - First in-depth meeting with the experiments and report to LHCC
- Overall schedule of HL-LHC will be reconsidered in Nov 27, 2019, when all information will be available

Follow-up on ASIC development at CERN

- Reminder of of M. Campbell's presentation im May SPC meeting
  - CHIPS (CERN-HEP IC design Platform and Services)
  - suggesting four FTE on the longterm to render ASIC developments more successful and shorten development cycles
    - One FTE will be hired for *hierarchical digital on top methodologies*, where the most urgent need has been identified



C. Joram

CHIPS, CERN-HEP IC design Platform and Services

Strengthening Foundry Services and Technical Support in CERN EP-ESE-ME to meet the challenges of future CMOS designs at CERN and in the HEP community

Proposal

ASIC technology and designs are becoming increasingly complex but bring potentially huge benefits to HEP experiments. However, because of this increased complexity, the community is confronted with the tangible risk of failed or delayed designs with potentially severe consequences on the physics programme.

In its December 2018 meeting the SPC highlighted challenges associated with ASIC developments in the HEP community and requested a coherent plan for dealing with these problems. In meetings with the CERN EP-ESE group, the Director of Research and EP management the situation was carefully analysed and a plan of action worked out which was presented to the SPC in its May 2019 meeting.

New technologies must be qualified to match the new designs since, given the timescales of HEP developments, simply staying with older processes carries with it a significant risk of process obsolescence. These new technologies bring large benefits but also new challenges that designers must confront. New more sophisticated design tools and design flows are available and, as a community, we must adapt to face the challenges of the new design paradigm. This means developing and following scrupulously new digital-on-top design techniques.

The Microelectronics Section of the ESE group at CERN (EP-ESE-ME) already supports common technologies and design flows for the experiments through the ASIC Technical Support and Foundry Services platform. It is proposed to reorganize this support service and tailor it to the increased special needs. As detailed in the presentation of May a need for the recruitment of four highly specialized engineers has been identified.

Of highest urgency is the strengthening of the support of hierarchical digital on top methodologies, similar to those used in industry. A staff post is going to be created for such a profile it being understood that this recruit will also maintain a strong role in Technology Support. A model for the other three posts is being worked out and will be presented on a later occasion.

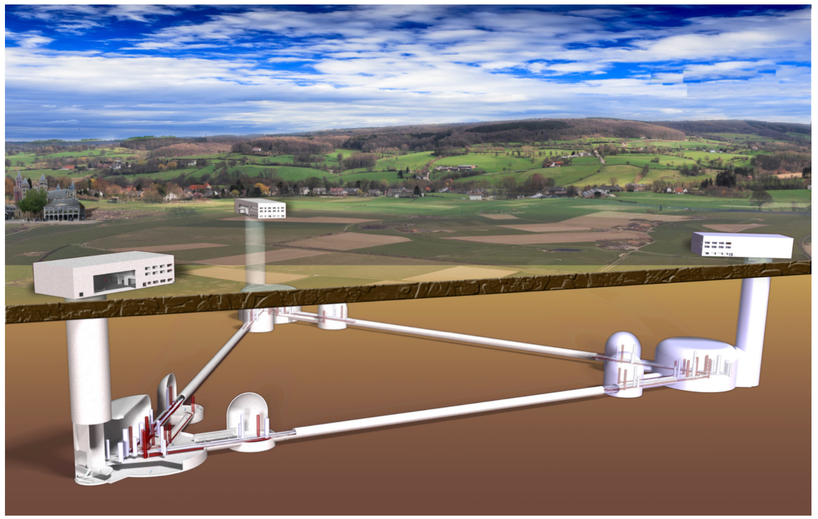
Emerging Collaboration Activities with ApPEC

EuCAPT – European Centre for Astroparticle and Particle Theory

- Astroparticle Physics European Consortium (ApPEC) has long wished to establish a joint Theoretical Centre; CERN is an Observer to ApPEC.
  - In 2018 the General Assembly of ApPEC asked CERN to found a European Centre for Astroparticle and Particle Theory (EuCAPT) for an initial period of five years:
    - CERN contributes 0.5 FTE from TH as part of the ongoing research in the group (no new position)
    - is ready to host meetings and provide (limited) secretarial support
    - a budget of up to 20 kCHF/a equally shared between CERN and ApPEC
- An external Director of EuCAPT has just been nominated (**Gianfranco Bertone** – NIKHEF) Kick-off at CERN on July 10, 2019

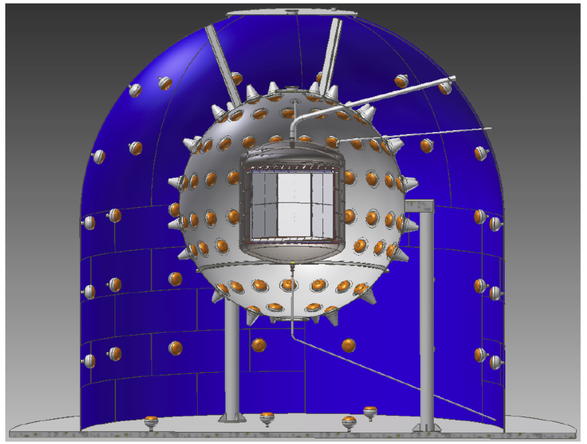
Consultancy for the Einstein Telescope

- The Gravitional Waves Community traditionally has maintained close contacts to particle physicists. All GW-experiments have CERN *Recognised Status*.
  - Many topics of common interest and expertise have long been identified (see e.g. Workshop at CERN 1.9.2017 https://indico.cern.ch/event/660772/timetable/)
- After several (uncoordinated) requests from site proponents the Steering Committee of the ET-Collaboration has now formally requested CERN to advise in matters of safety, civil engineering, vacuum technology and cryogenics
- CERN will explore the scope of such consultancy with the ET-collaboration and conclude appropriate Memoranda of Understanding

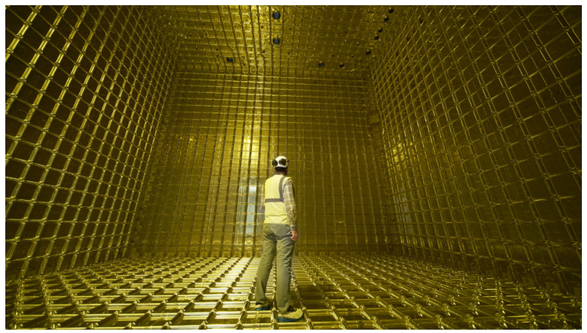


Technology of DarkSide-20k

- DarkSide-20k will be a 20 kt double phase LArTPC for Dark Matter searches at LNGS in Gran Sasso
- The original concept using a Liquid Scintillator veto will no longer be pursued because of environmental safety aspects at LNGS.
- Instead DarkSide-20k observed that imbedding a depleted LArTPC detector immersed in a standard LArTPC would provide an ideal active shield. In its work of support to the construction of the proto-DUNE detector and the cryostats of DUNE, CERN has developed unique expertise in cryogenics for LArTPC, in particular membrane cryostats (CERN/FC/6160/RA September 2017)
- DarkSide-20k is a Recognised Experiment at CERN which involves many CERN member states.



Original DarkSide-20k design



protoDUNE cryostat

Procurement *Cryogenics system for DarkSide-20k* KN4460/RCS

- INFN shall provide all funding required for the execution of this Collaboration Agreement and INFN shall be liable for any additional expenses incurred by CERN during the execution of the project.

- CERN will buy the components required for the DarkSide-20k project in accordance with CERN Financial Rules and in particular the Procurement rules for Recognized Experiments.

- **Technology transfer**: Taking into account its duty under the CERN Convention to make available the results of its work and resulting Knowledge Transfer programme, and the uniqueness of its experience in this matter, CERN gives the requested support, provided such support is on a best-effort basis, is funded by INFN and that CERN's Scientific Programme shall have priority over such support activities.

Summary

- Good physics harvest – often on full Run 2 dataset – as reported at Moriond and LHCP 2019 conferences
- Phase I upgrades on track
  - with remaining issues ATLAS NSW (only one in LS2)
- Phase II upgrades
  - P2UG has met for both ATLAS and CMS
  - Initial feedback shows the usefulness of these bodies and initial critical areas have been spotted