LHCb status report

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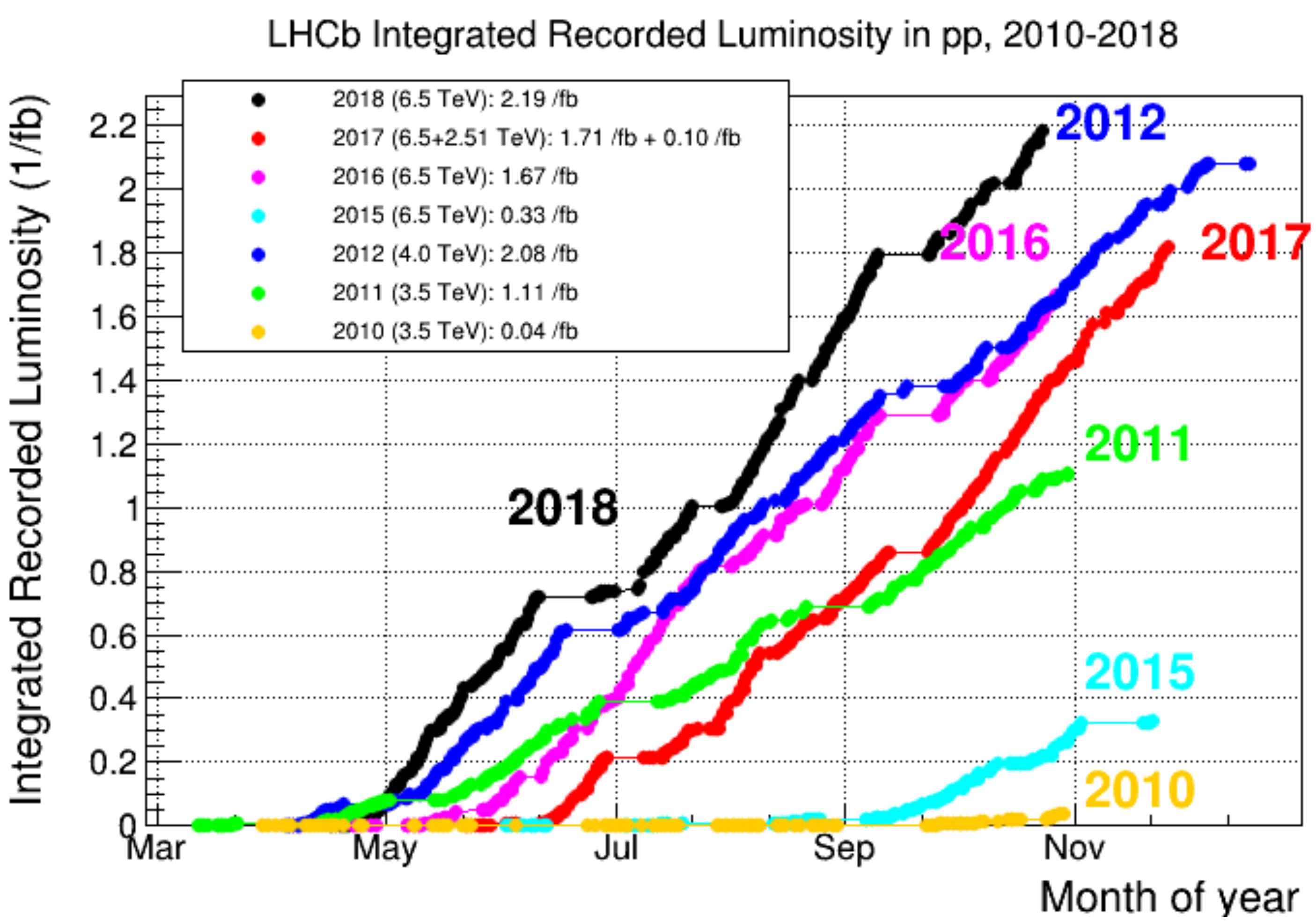
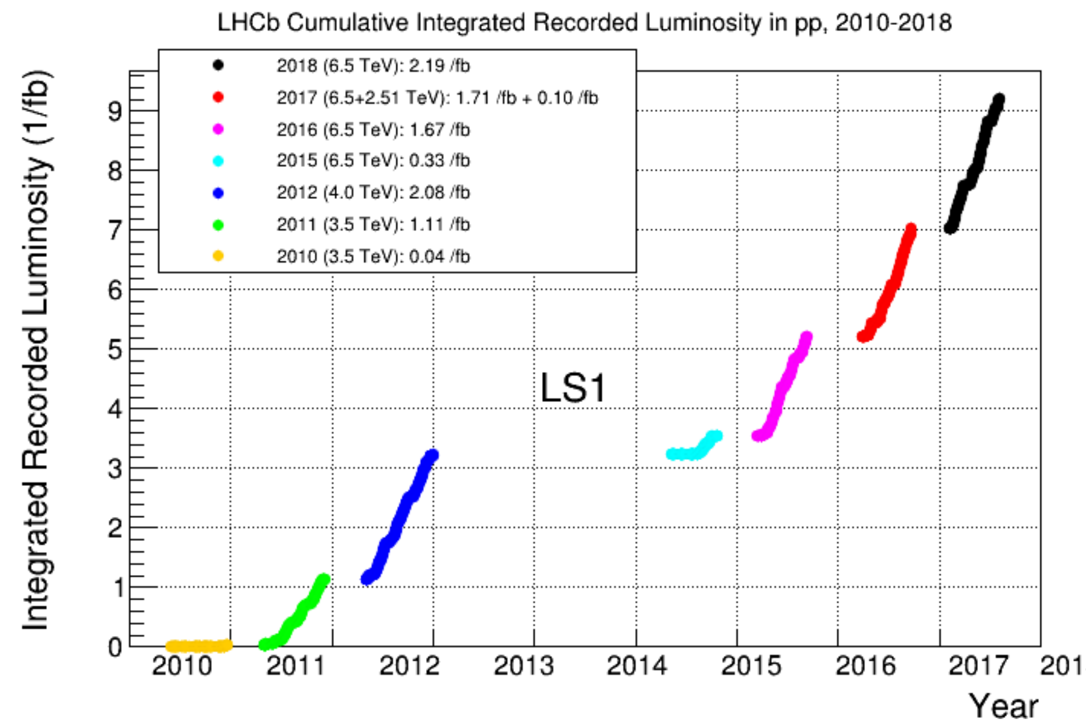
on behalf of the LHCb collaboration

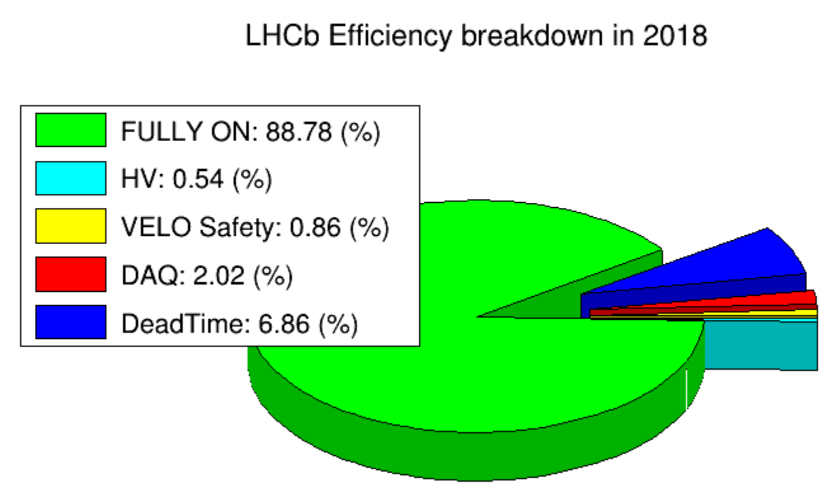
LHCC open session
28/11/2018
CERN

Operations in 2018

- 2018 has been an exceptional year.
  - Record in delivered and recorded luminosity.
  - Thanks to the LHC for the fantastic performance.







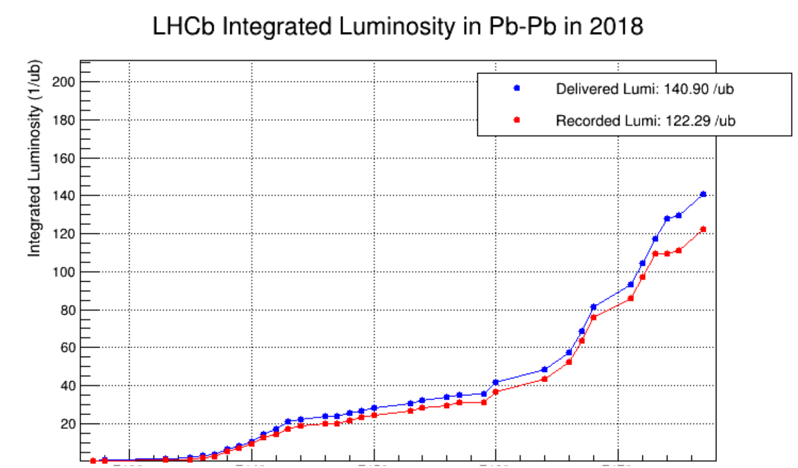
Since the start of LHCb

>10 fb^{-1} delivered, >9 fb^{-1} collected

Matches the aim of the Technical Proposal (1998)

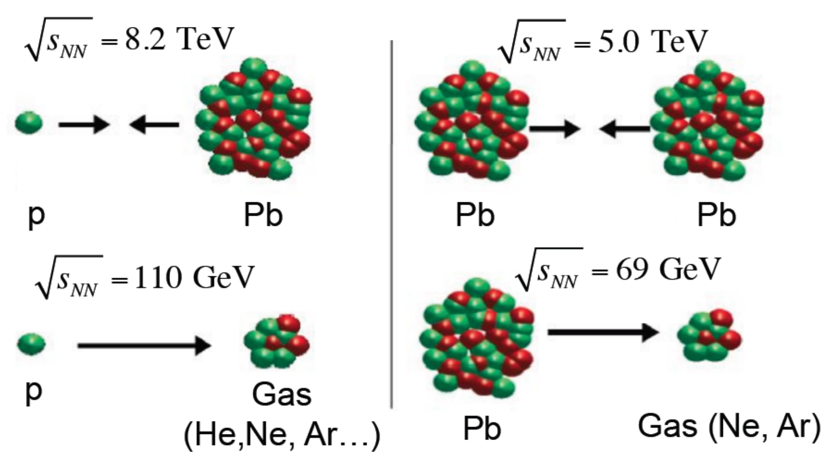
Operations in 2018

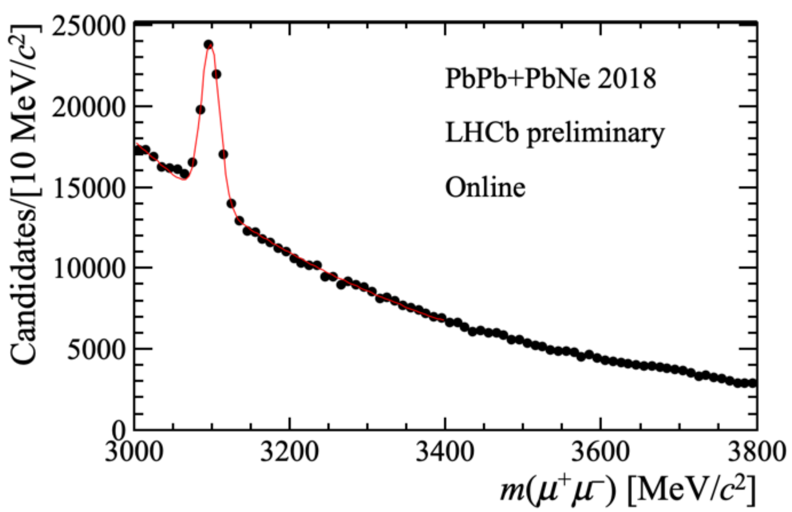
- 2018 has been an exceptional year.
  - Record in delivered and recorded luminosity.
  - Thanks to the LHC for the fantastic performance.
- Heavy ion run still ongoing. Take data in PbPb and PbNe configuration simultaneously thanks to the SMOG system.



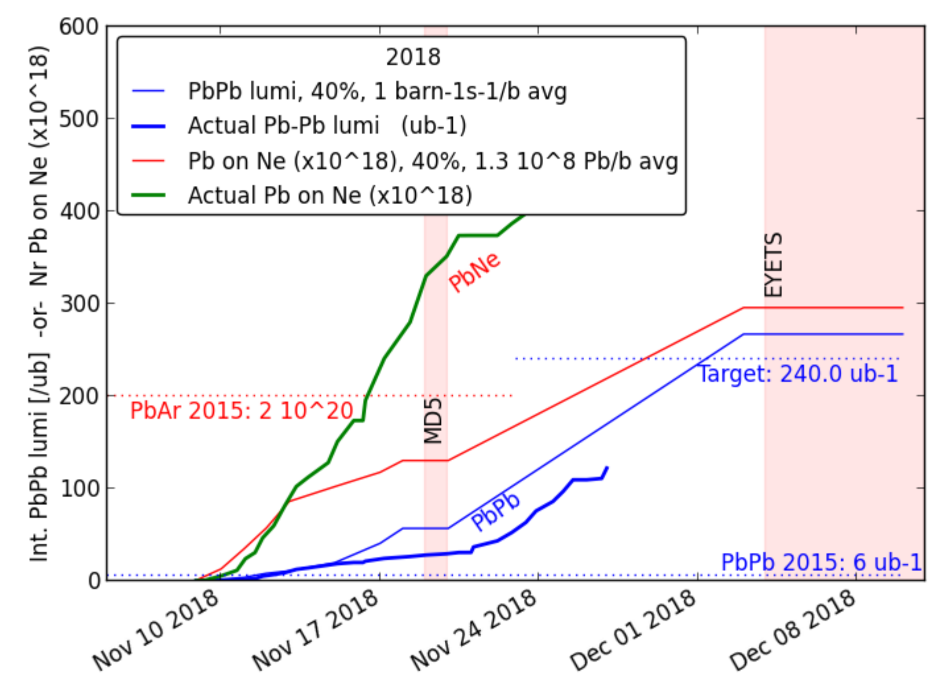
Collider mode

Fixed target mode





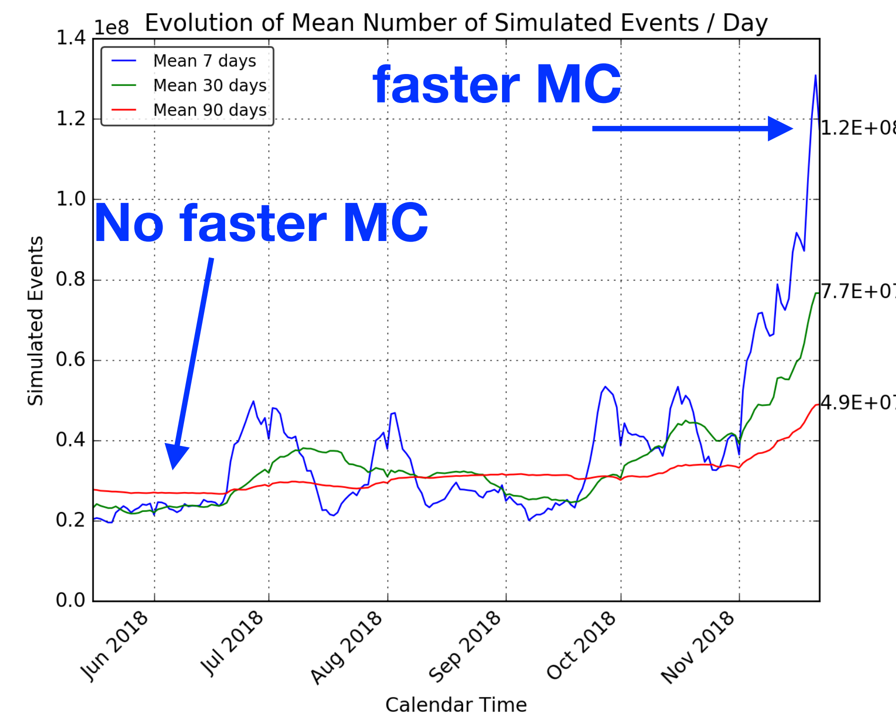
J/ψ→μμ candidates from PbPb and PbNe after HLT1 (only a fraction of data)

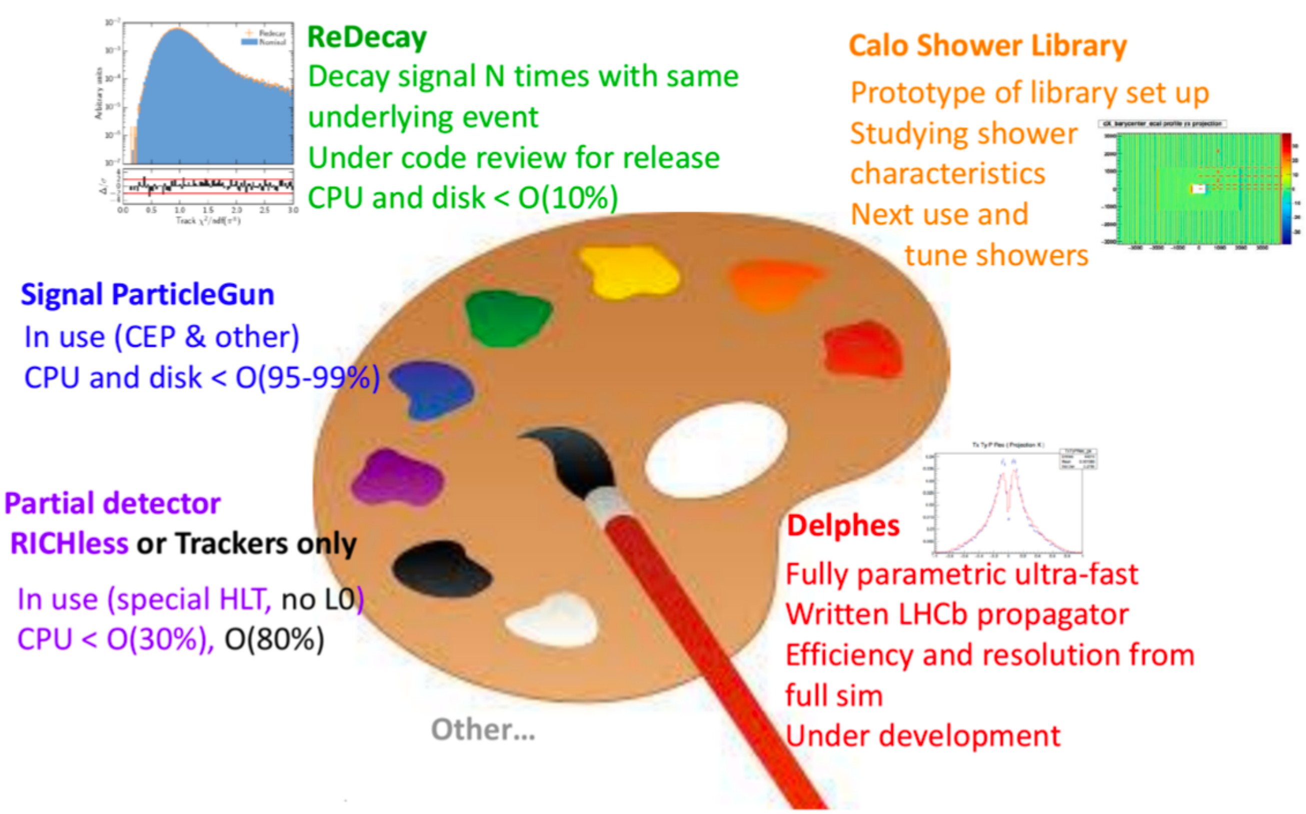


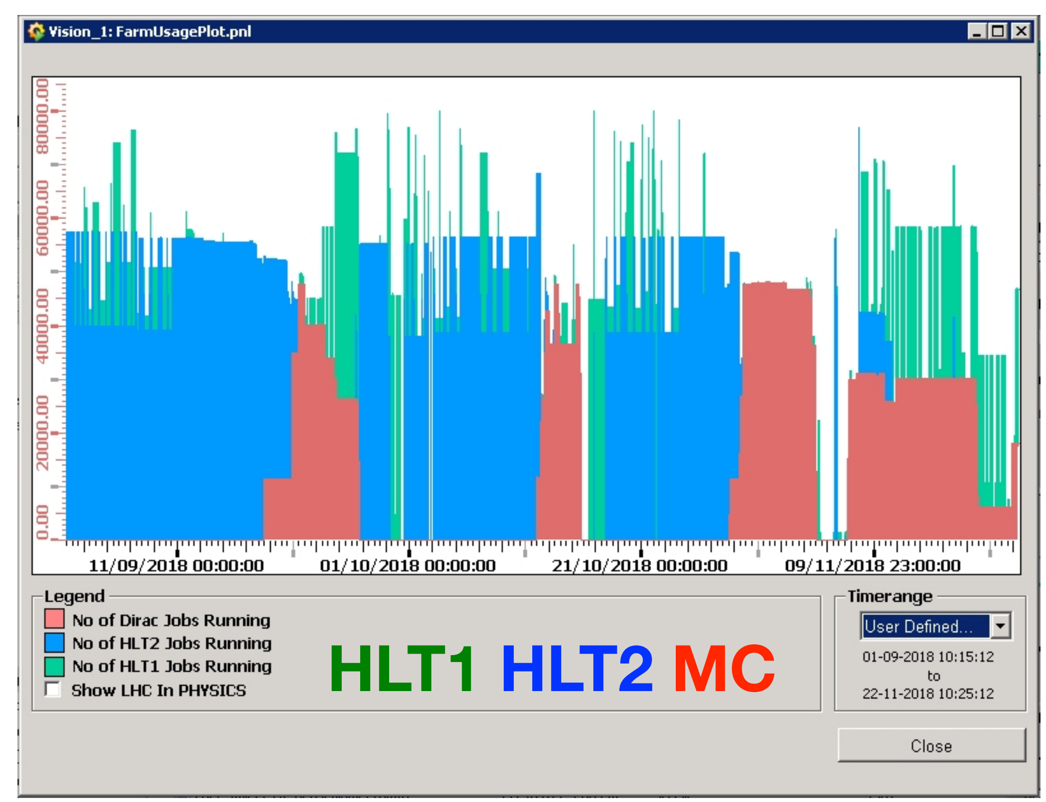
Operations in 2018

- Very stable running conditions through the year.
- Extensive palette of faster simulation options.
    - Current MC productions are heavily using them.
- Gain a factor 6 in number of produced events when used.

arXiv:1810.10362

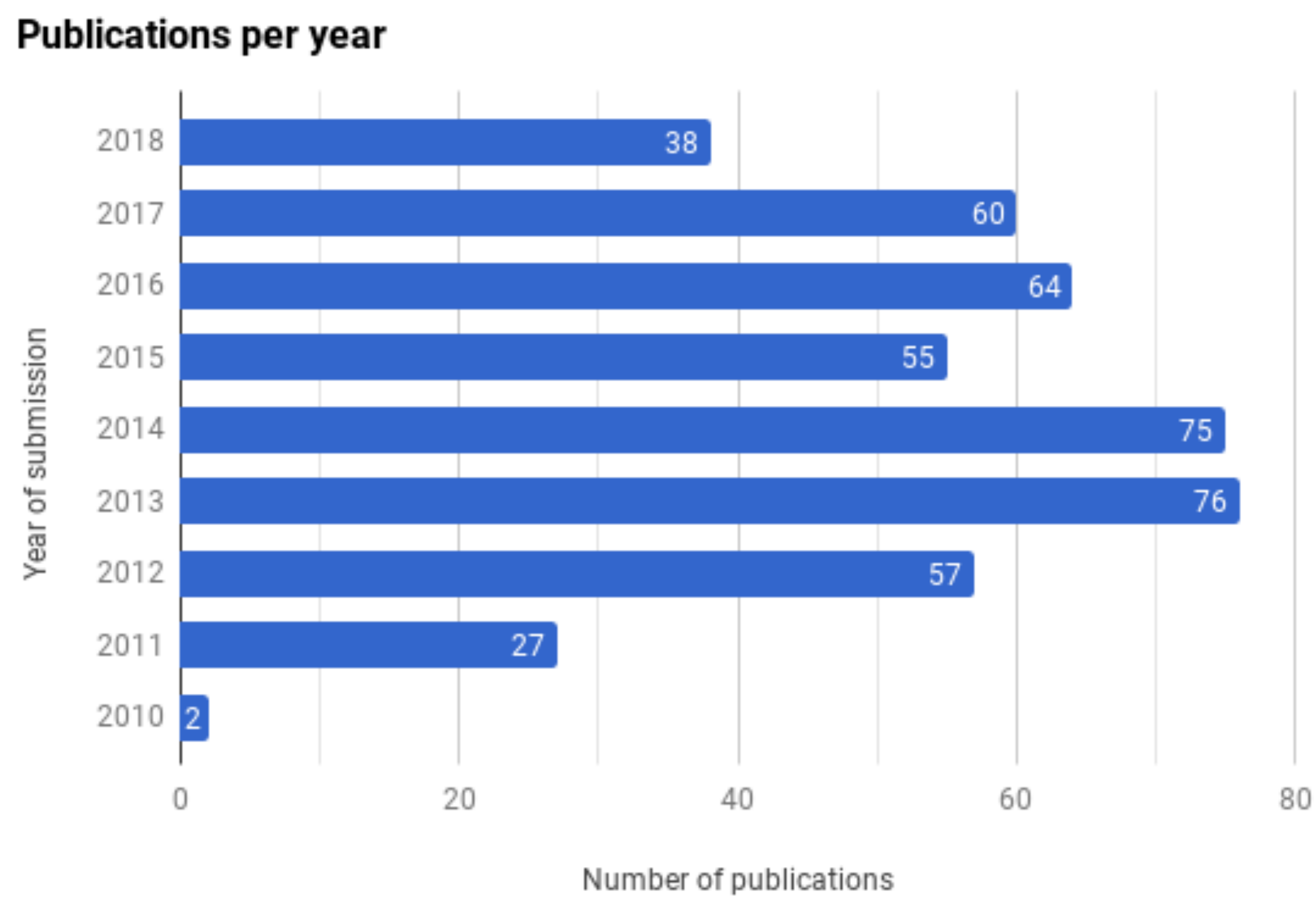


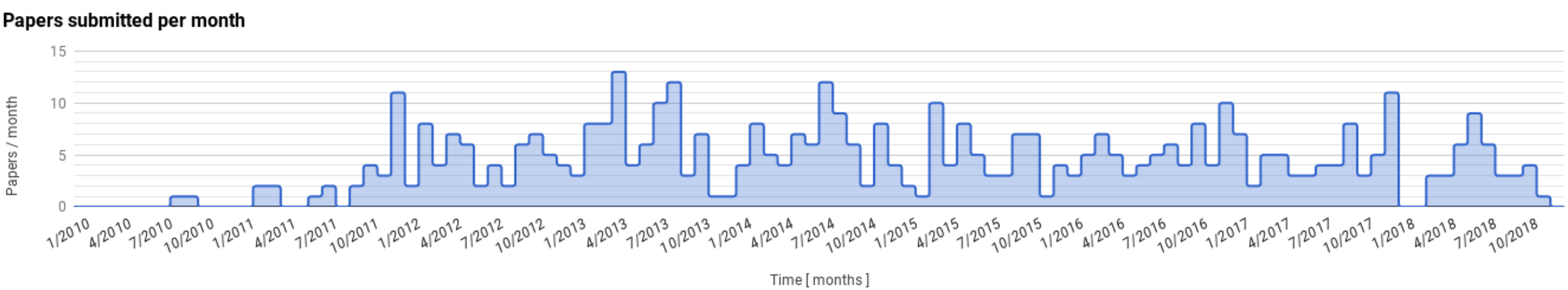




Physics analysis

- 454 papers in total
    - 38 published in 2018
- Additional 34 analyses in review





Physics papers and conference reports since last LHCC

Published

PAPER-2018-023	First measurement of charm production fixed-target configuration at the LHC.
PAPER-2018-032	Observation of two resonances in the $\Lambda^0_b\pi^\pm$ systems and precise measurement of $\Sigma^\pm_b$ and $\Sigma^{*\pm}_b$ properties.
PAPER-2018-033	Measurement of the branching fractions of the decays $D^+\to K^-K^+K^+$, $D^+\to\pi^-\pi^+K^+$ and $D^+_s\to\pi^-K^+K^+$.
PAPER-2018-034	Evidence for an $\eta_c(1S)\pi^-$ resonance in $B^0\to\eta_c(1S)K^+\pi^-$ decays.
PAPER-2018-035	Study of $\Upsilon(nS)$ production in pPb collisions at $\sqrt{s_{NN}}$=8.16 TeV.
PAPER-2018-038	Measurement of the charm-mixing parameter y_{CP}.
PAPER-2018-041	Search for CP violation through an amplitude analysis of $D^0\to K^+K^-\pi^+\pi^-$ decays.

Preliminary

PAPER-2018-036	Measurement of the branching fraction and CP asymmetry in $B^+\to J/\psi\rho^+$ decays.
PAPER-2018-037	Search for the rare decay $B^+\to\mu^+\mu^-\mu^+\nu_\mu$.
PAPER-2018-039	Dalitz plot analysis of the $D^+\to K^-K^+K^+$ decay.
PAPER-2018-042	Study of the $B^0\to\rho(770)^0K^*(892)^0$ mode and amplitude analysis of $B^0\to(\pi\pi)(K\pi)$ decays.
PAPER-2018-043	Model-independent evidence for exotic contributions to $B^0\to J/\psi K^+\pi^-$ decays.

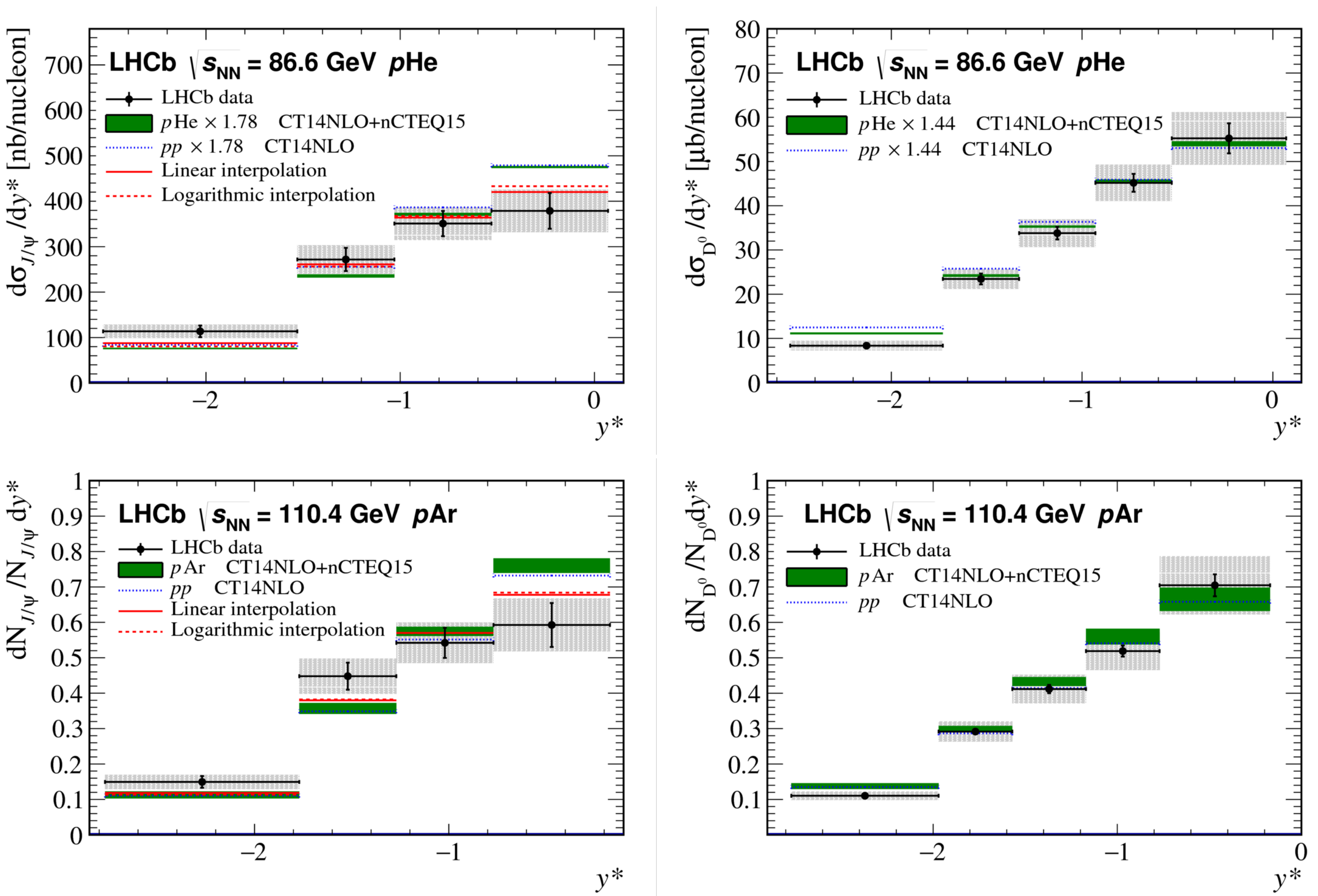
Charm production in fixed-target mode

LHCb-PAPER-2018-023 (7.6 nb^{-1})

- First measurement of heavy flavour production in fix target mode at the LHC.
- Measurement of the production of J/ψ and D^0 mesons at $\sqrt{s_{NN}}$=86.6 GeV and $\sqrt{s_{NN}}$=110.4 GeV in pHe and pAr collisions.
  - Reconstructed as $J/\psi \to \mu^+\mu^-$ and $D^0 \to K^+\pi^-$

$\sigma_{J/\psi}$ = 1225.6±100.7 nb/nucleon
σ_{D^0} = 156.0±13.1 μb/nucleon

- Theory predictions underestimate measured cross-sections.
  - In the plot, predictions are rescaled by 1.78 (1.44) for J/ψ(D^0) to check the shape.
- At large Bjorken-x (up to 0.37 for D^0) intrinsic charm contribution can be large.
- No deviations with respect to theoretical predictions (that do not include charm contribution) are observed.



Y(nS) production in pPb collisions

LHCb-PAPER-2018-035 (31.8 nb^{-1})

- Measure suppression of Y(nS) due to cold nuclear matter effects in pPb collisions at $\sqrt{s}$=8.16 TeV. Use nuclear modification factor. Should be unity in absence of modifications.

$$R_{p\mathrm{Pb}}(p_\mathrm{T}, y^*) = \frac{1}{208}\frac{\mathrm{d}^2\sigma_{p\mathrm{Pb}}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}{\mathrm{d}^2\sigma_{pp}(p_\mathrm{T}, y^*)/\mathrm{d}p_\mathrm{T}\mathrm{d}y^*}$$

- Suppression can be due to collision with comoving particles (comovers) with similar rapidities.

For Y(1S):

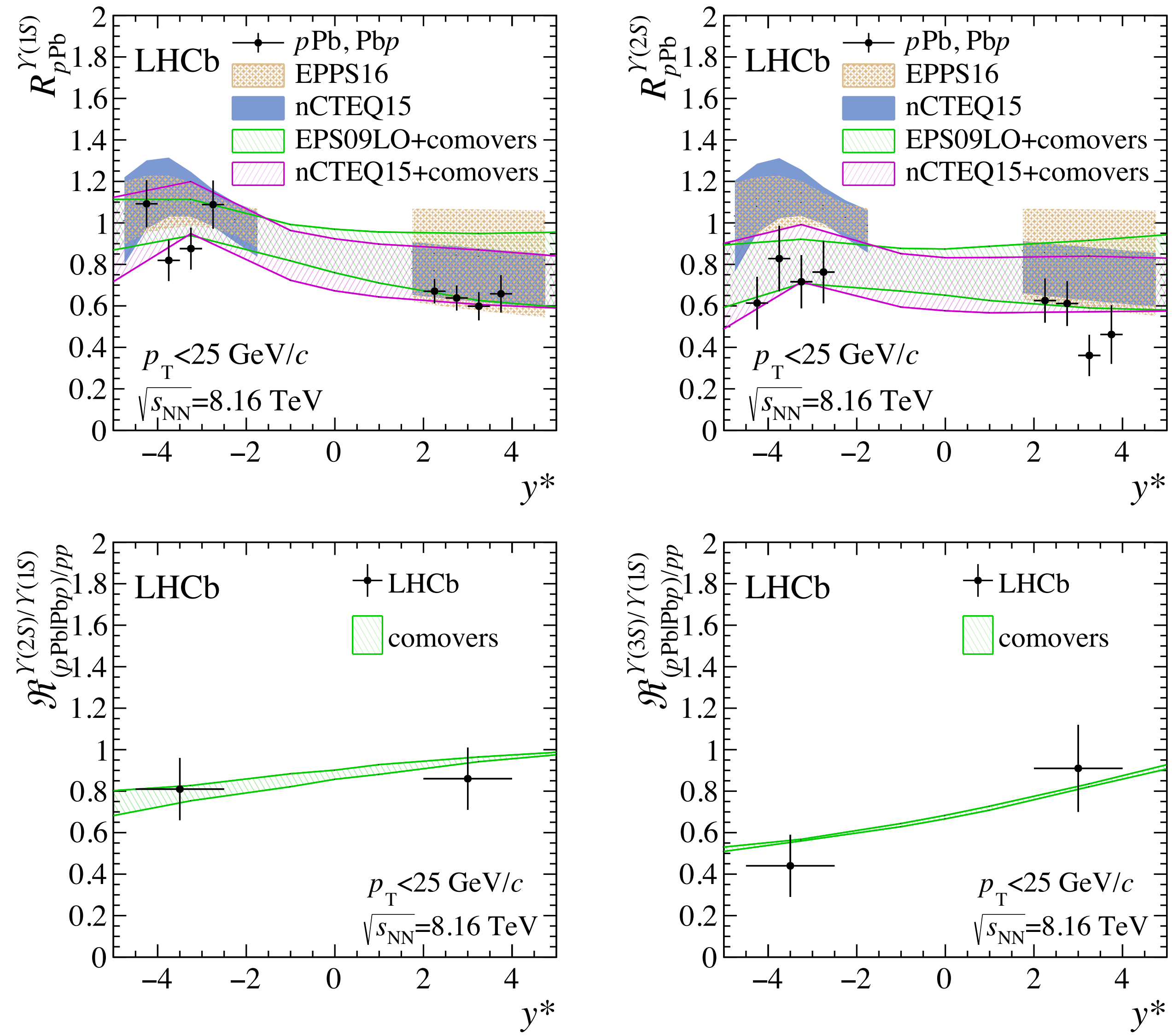
$R_{p\mathrm{Pb}}$ is consistent with unity in the Pbp region. Suppression in the pPb region.

For Y(2S):

Same behaviour as for Y(1S) with smaller values of $R_{p\mathrm{Pb}}$.

Measure the double ratio of excited to ground state in pPb vs pp. Stronger suppression for higher n compared with ground state.

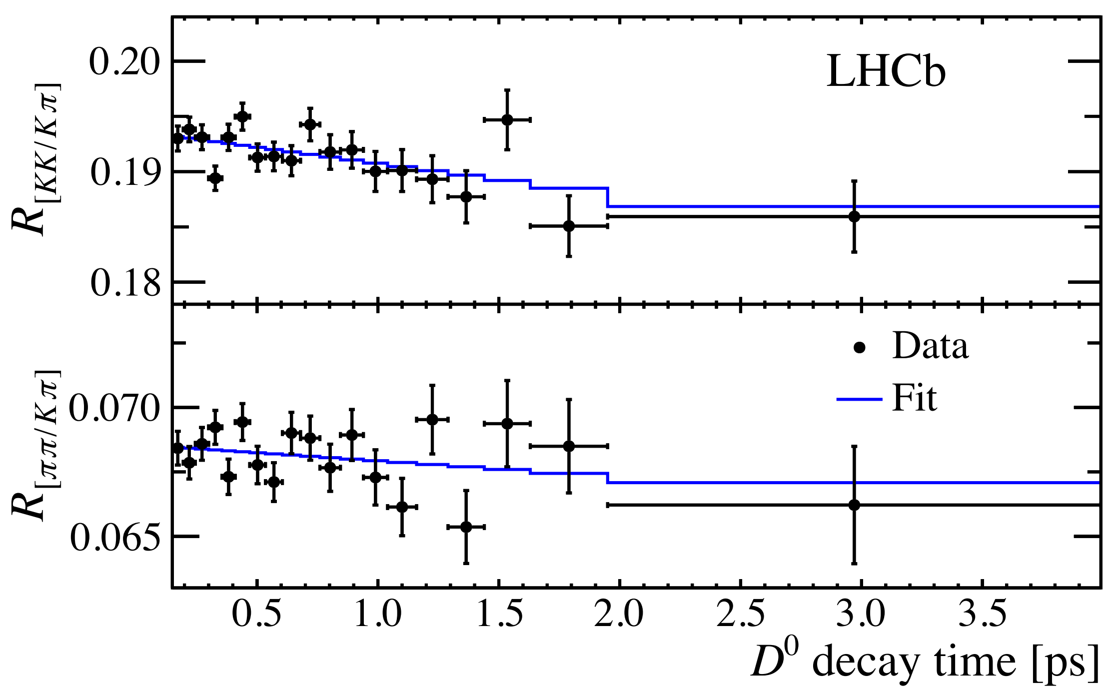
Well described by the comovers models.



Measurement of charm-mixing

LHCb-PAPER-2018-038
Run1 ($3fb^{-1}$)

- Mixing in D^0 mesons works as for other neutral mesons, **but it's tiny.** ($x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$).
- Effective D^0 lifetime to CP-even eigenstates (Γ_{CP+} from $D^0 \to \pi^+\pi^-$, $D^0 \to K^+K^-$) is different from lifetime to CP-mixed states (Γ from $D^0 \to K^+\pi^-$)
- **If no CP is present** the mixing parameter $y = \frac{\Delta\Gamma}{2\Gamma}$ is equal to $y_{CP} \equiv \frac{\Gamma_{CP+} - \Gamma}{\Gamma}$
- Measurement using time-dependent ratio between CP-even ($D^0 \to \pi^+\pi^-(K^+K^-)$) and CP-mixed ($D^0 \to K^+\pi^-$) final states.
- Use D^0 mesons from semileptonic B decays: $B \to D^0 \mu\nu X$. Reduce selection biases.
- First publication using faster simulation options.



y_{CP} = (0.57 ± 0.13(stat) ± 0.09(syst))%
consistent and as precise as world average.

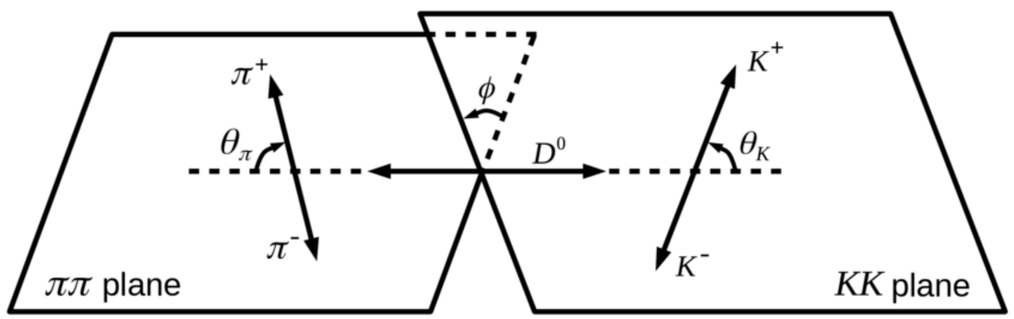
Result is consistent with y=(0.62±0.07)%

This shows no evidence of CP violation in charm mixing.

CP violation in $D^0 \to K^+K^-\pi^+\pi^-$

LHCb-PAPER-2018-041
Run1 ($3fb^{-1}$)

- Multibody decay with rich resonant structure. May provide enhanced sensitivity to CP violation due to variation of the strong phases → requires amplitude analysis.
  - Use isobar formalism to describe the amplitudes. Each amplitude is built as a series of two-body decays.
- Use D^0 from semileptonic B decays: $D^0\mu\nu X$. The muon charge tags the flavour of the D^0.
- Decay described by 5 dimensions.
  - $m(\pi^+\pi^-)$, $m(K^+K^-)$, θ_π, θ_K, ϕ



26 amplitudes have been identified to contribute. Most precise description of the decay.

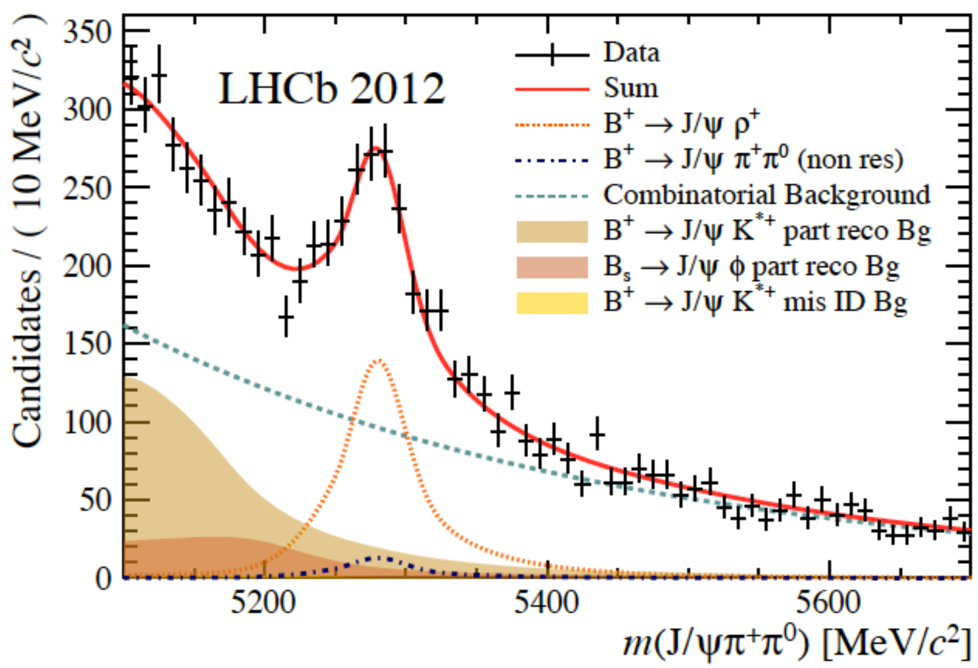
Fit CP asymmetries for each of the contributing amplitudes. **None of them show CP violation. Large non-SM effects are ruled out.**

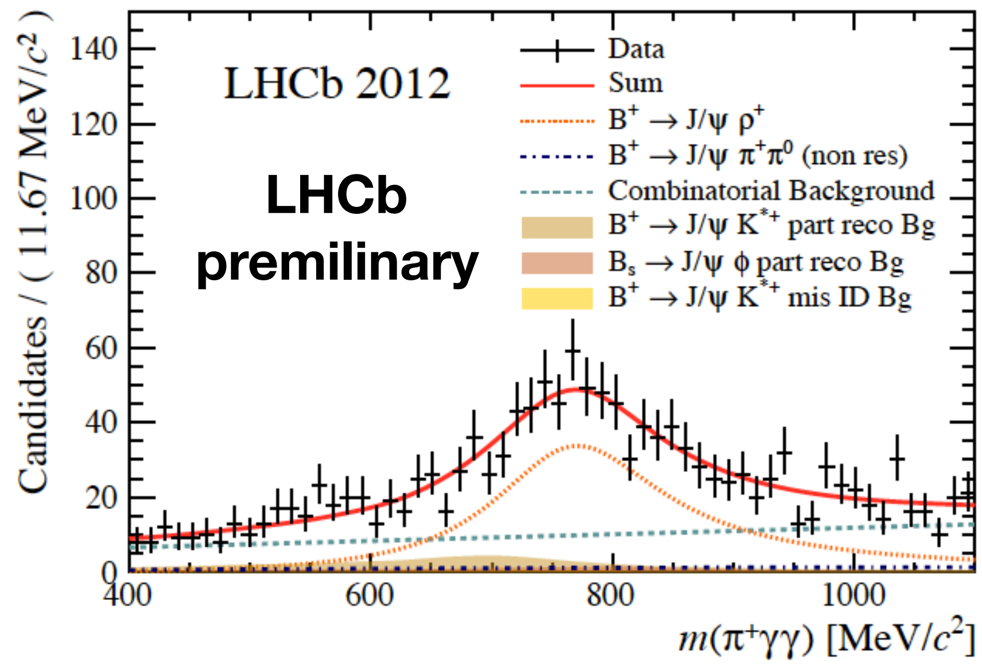
	KK	$\pi\pi$	$K\pi$	$KK\pi$	$K\pi\pi$
$J^P = 0^+$	$a_0(980)$ $f_0(980)$ $f_0(1370)$	$f_0(980)$ $f_0(1370)$	$K_0^*(1430)$		
$J^P = 1^+$				$a_1(1260)$	$K_1(1270)$ $K_1(1400)$
$J^P = 1^-$	$\phi(1020)$	$\rho(770)$ $\omega(782)$ $\rho(1450)$	$K^*(892)$ $K^*(1680)$		$K^*(1410)$ $K^*(1680)$
$J^P = 2^+$	$f_2(1270)$ $a_2(1320)$	$f_2(1270)$	$K_2^*(1430)$		$K_2^*(1430)$

BR and CP asymmetries in $B^+ \to J/\psi\rho^+$

LHCb-PAPER-2018-036
Run1 ($3fb^{-1}$)

- A_{CP} in this decay can be used to place constraints on penguin pollution in measurements of ϕ_s from $B_s \to J/\psi\phi$ assuming SU(3) flavour conservation.
- Simultaneous fit to $B^+ \to J/\psi\rho^+$ and $\rho^+ \to \pi^+\pi^0$.
- Use $B^+ \to J/\psi K^{*+}$ to assess the π^0 reconstruction efficiency from data.





$$\mathcal{B}(B^+ \to J/\psi\,\rho^+) = (3.81^{+0.25}_{-0.24} \pm 0.35) \times 10^{-5}$$

$$\mathcal{A}^{CP}(B^+ \to J/\psi\,\rho^+) = -0.045^{+0.056}_{-0.057} \pm 0.008$$

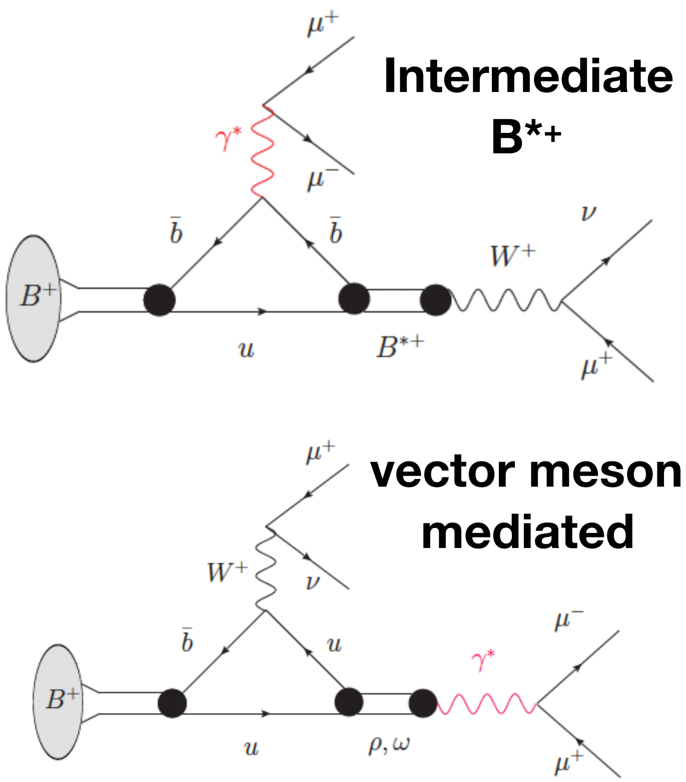
Most precise measurements and consistent with isospin symmetric channel $B^0 \to J/\psi\rho^0$

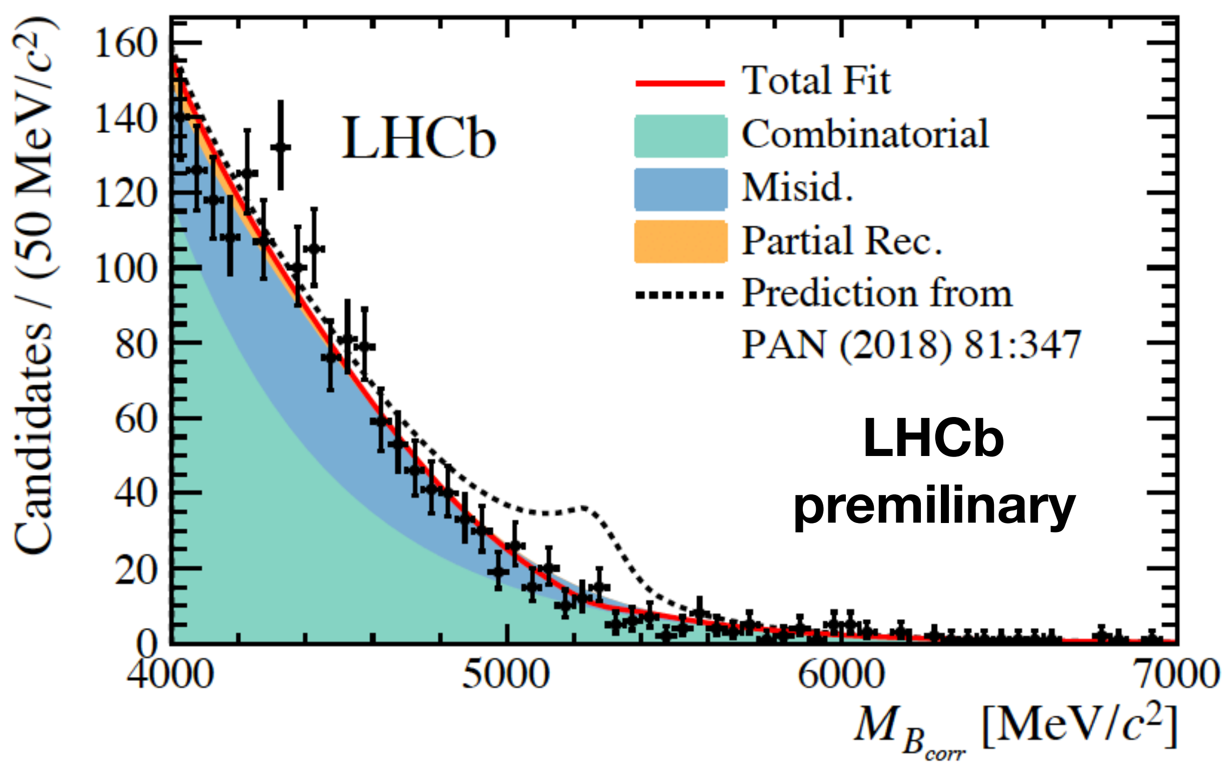
Phys. Lett. B742 (2015) 38

Search for $B^+ \to \mu^+\mu^-\mu^+\nu_\mu$

LHCb-PAPER-2018-037
Run1 + Run2 ($4.7 fb^{-1}$)

- Similar to $B^+ \to \mu^+\nu_\mu$ but with 3 charged particles in the final state.
- Rare decay with twofold interest.
  - Helicity suppressed → sensitive to non-SM particles.
  - Purely leptonic decay → is sensitive to V_{ub}
- Only prediction available based on vector meson dominance
  - $BR(B^+ \to \mu^+\mu^-\mu^+\nu_\mu) \simeq 1.6 \times 10^{-7}$
- Set limit as no events are observed.





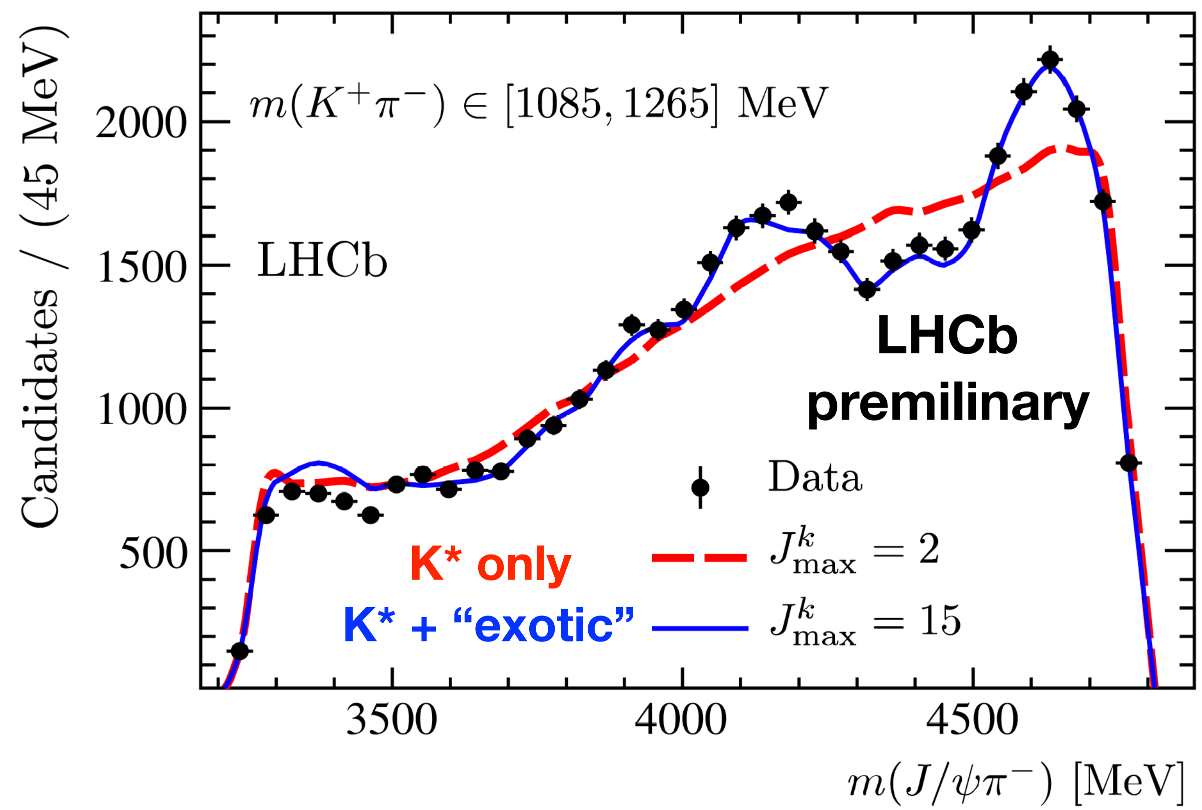
$BR(B^+ \to \mu^+\mu^-\mu^+\nu_\mu) < 1.6 \times 10^{-8}$ @ 95% CL

Tension with predictions based on purely vector meson dominance.
Active discussion with theory community.
Expect revised calculations.

Exotic contributions in $B^0 \to J/\psi K^+\pi^-$

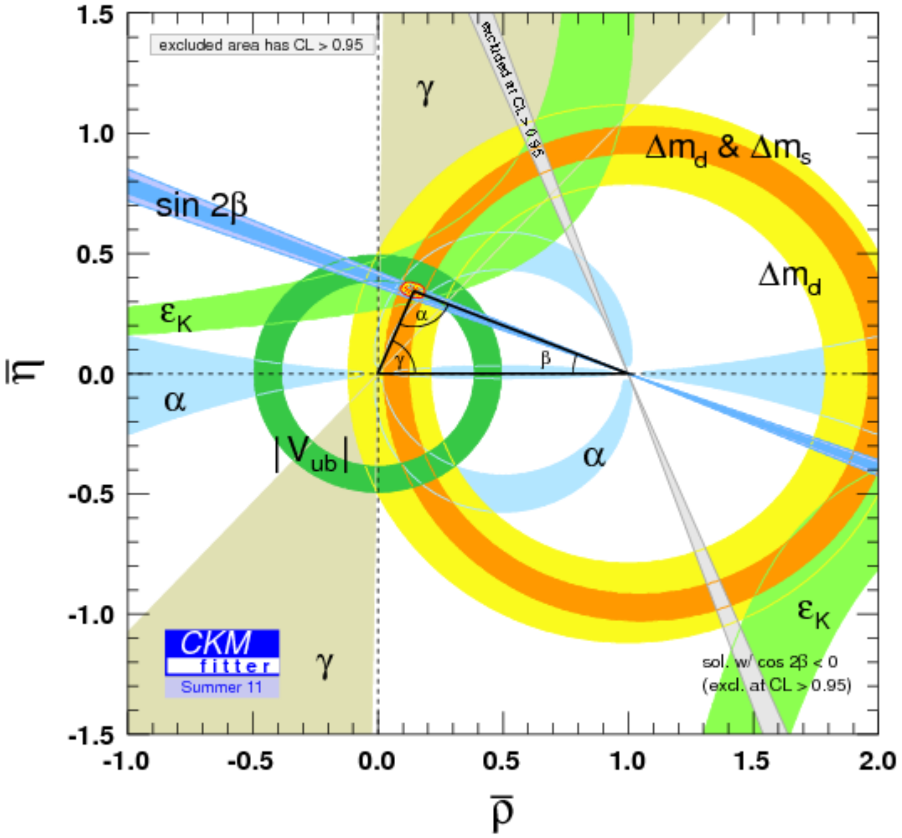
LHCb-PAPER-2018-043
Run1 ($3 fb^{-1}$)

- Belle claimed a new exotic resonance $Z_c(4200)^-$ together with evidence of $Z_c(4430)^-$ in $B^0 \to J/\psi K^+\pi^-$ decays. PRD 90 (2014) 112009
- General concern about these broad exotic states is to disentangle contributions from non-exotic components.
- Describe full angular distribution using only K* resonances. Will help in establishing the presence of any exotic structure in a model independent way.
- Structures around 4200 and 4600 MeV cannot be described by only K* resonances.
  - Significances are >>5 standard deviations.
- A model dependent analysis is ongoing to understand their origin.

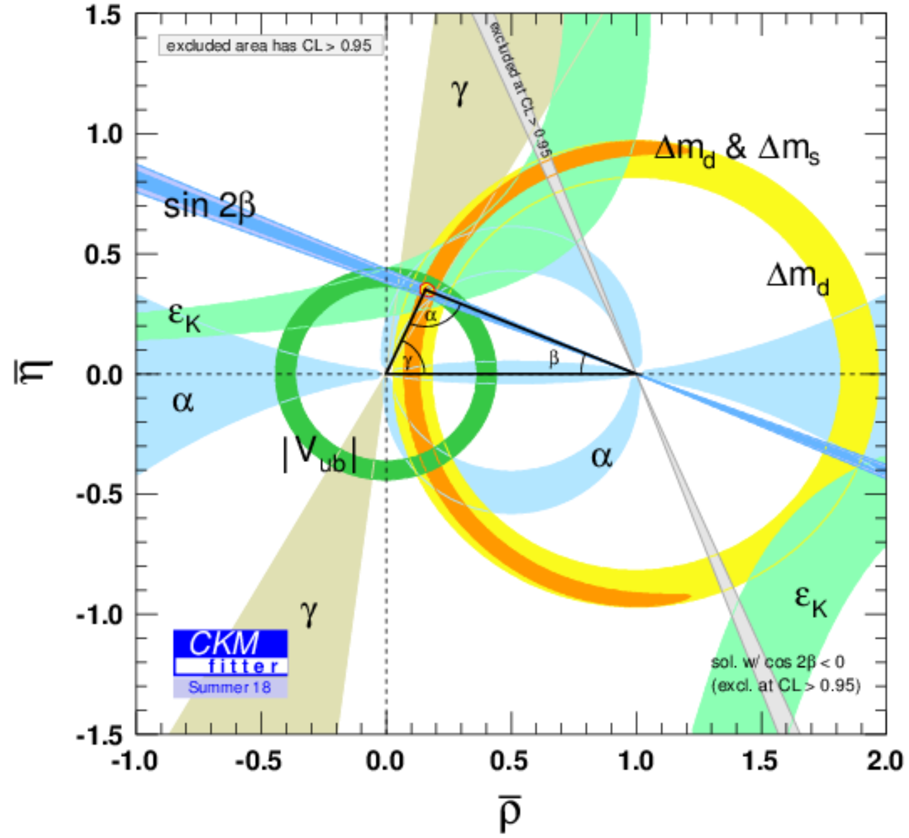


What we have achieved with Run1 + Run2 harvest

CKM unitary triangle as of summer 2011



CKM unitary triangle as of summer 2018



Great reduction of parameter phase space in the CKM triangles.

Not everything is due to LHCb, but it's certainly a major contributor. e.g: **γ, $\Delta m_{s/d}$, ϕ_s**

- On non CKM measurements.
  - Observation of $B_s \to \mu^+\mu^-$; anomalies in EWP: R(K), R(K*); anomalies in semileptonic decays: R(D*), observation of exotic states: pentaquarks; …

What to expect from Run1+Run2 harvest: new measurements

- More data will allow to inspect new decays and/or observables that did not offer sensitivity in the past. e.g: **$B_s \to \mu^+\mu^-$ lifetime**.
- More data helps in understanding better the detector. e.g: increased trigger efficiencies, improved analysis tools.

- With Run1 + Run2 data we can expect (some selected measurements):
  - Evidence for $B_d \to \mu^+\mu^-$
  - Precision on γ of ~3 degrees
  - If central values stay, anomalies can reach 5σ
  - Precision on charm mixing few x 10^{-4}
  - Precision on ϕ_s ~30 mrad (SM is less than 1 mrad).

Predicting the future is not always easy

- LHCb did projections for Run1 + Run2 in CERN-PH-EP-2012-334.
- None of the anomalies were present at the time.

Refers to analyses done with 2011 data sample (→ Current precision)

What we thought we could do with Run1 + Run2 data (→ LHCb 2018)

Type	Observable	Current precision	LHCb 2018
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [138]	0.025
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [214]	0.045
	$a_{\rm sl}^s$	6.4×10^{-3} [43]	0.6×10^{-3}
Gluonic penguins	$2\beta_s^{\rm eff}(B_s^0 \to \phi\phi)$	–	0.17
	$2\beta_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$	0.17 [43]	0.30
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.08 [67]	0.025
	$s_0\ A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [67]	6 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.25 [76]	0.08
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [85]	8 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–12° [244, 258]	4°
	$\gamma\ (B_s^0 \to D_s K)$	–	11°
	$\beta\ (B^0 \to J/\psi\ K_S^0)$	0.8° [43]	0.6°
Charm *CP* violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}

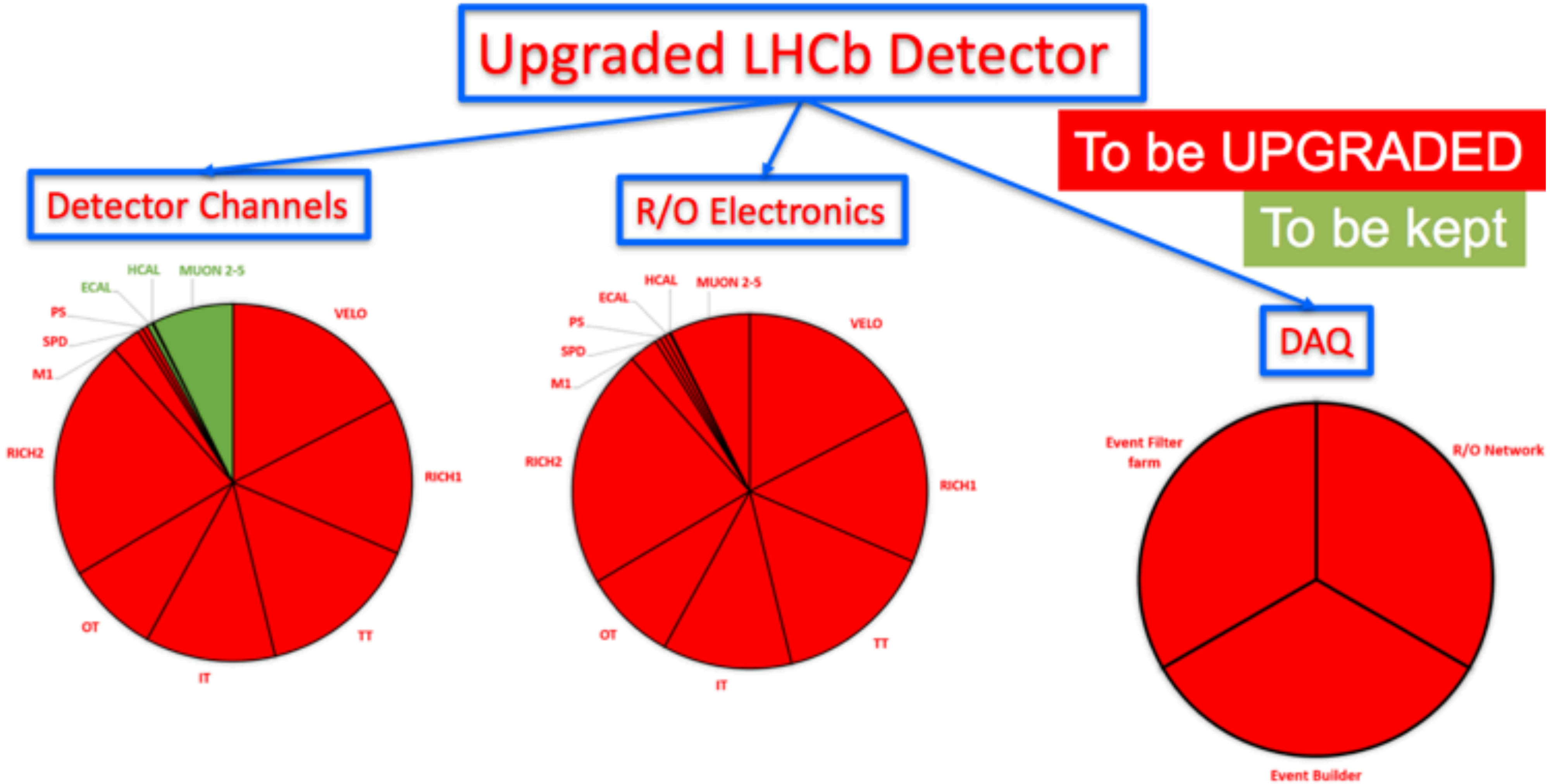
Already better with full Run1.

Still far away from SM precisions.

Upgrade I

Goals:

- $L = 2 \times 10^{33}\ cm^{-2}s^{-1}$
- 5 interactions per bunch crossing
- $50fb^{-1}$ at the end of Run4



Less than 10% of detector channels will be kept
100% of R/O electronics will be replaced

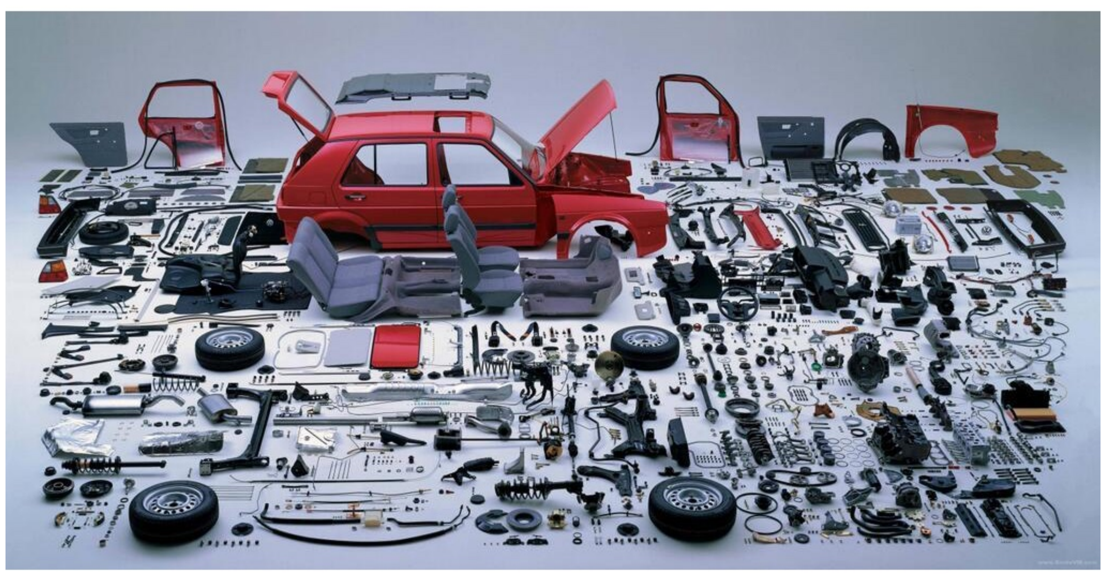
LS2 plans

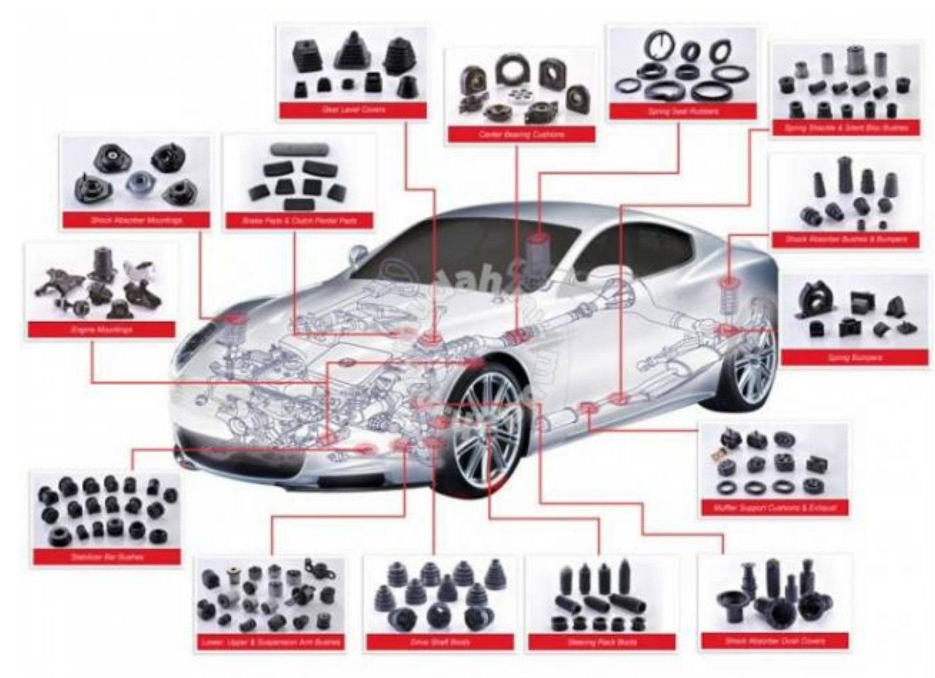
2018/2019 Dismantling current detector

2019/2020 Installation of new detector

2020 Global commissioning

2021 Commissioning with beam and data taking

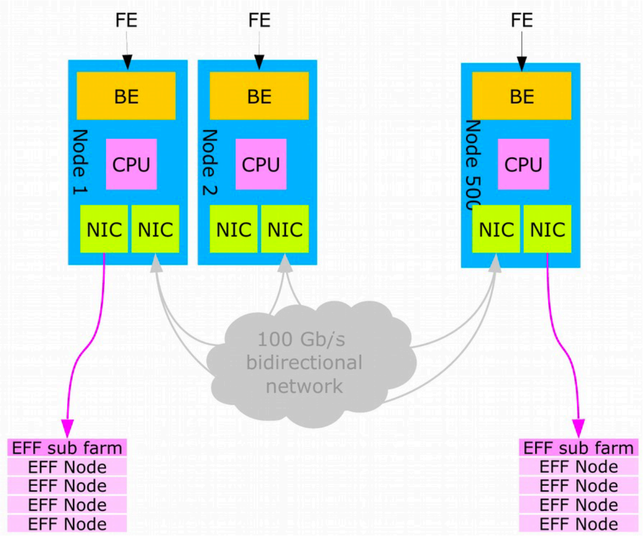




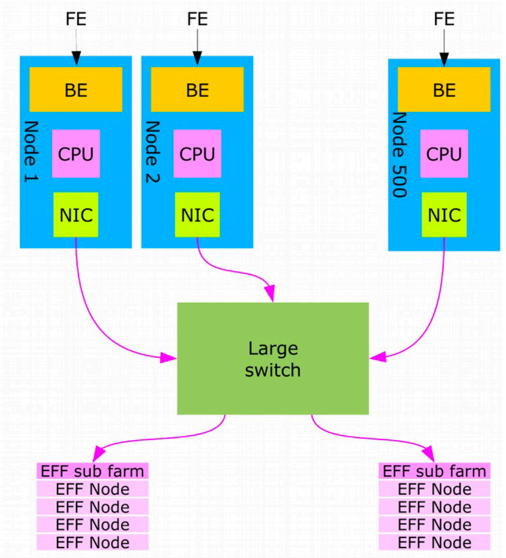
Upgrade I: Online

- First two containers for the Event Filter Farm were installed mid October.
  - Commissioning already started.
  - Share capacity with CERN-IT.
- 24 DAQ FPGA modules delivered.
- Production of long distance optical fibres and patch cords has been ordered.
- Alternative architecture for the event builder is being tested.

baseline architecture



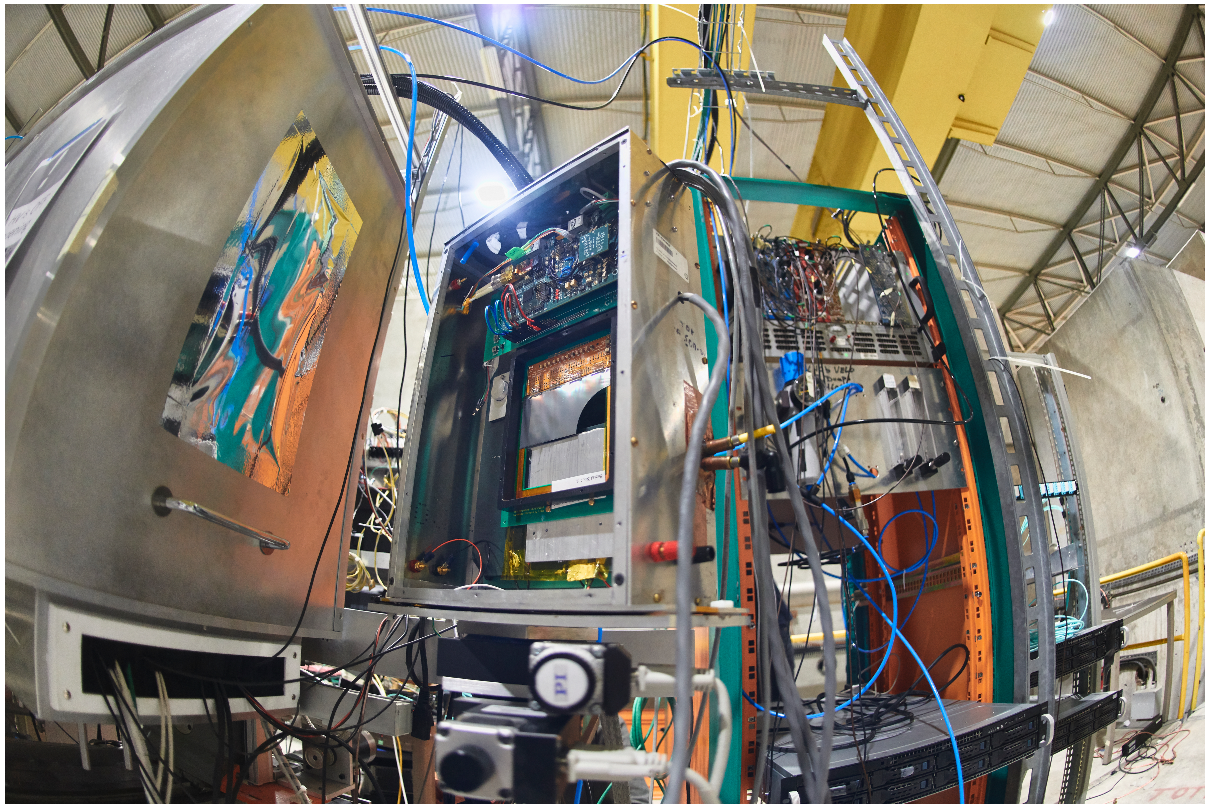
new architecture



Upgrade I: Velo Pixel and Upstream Tracker

Velo Pixel

- Prototype tested in testbeam.
- 3 full electrical modules readout with complete electronic chain.
- Sensors and chips produced and tested with >90% yield.
- Project reaching end phase: module serial production is about to start.

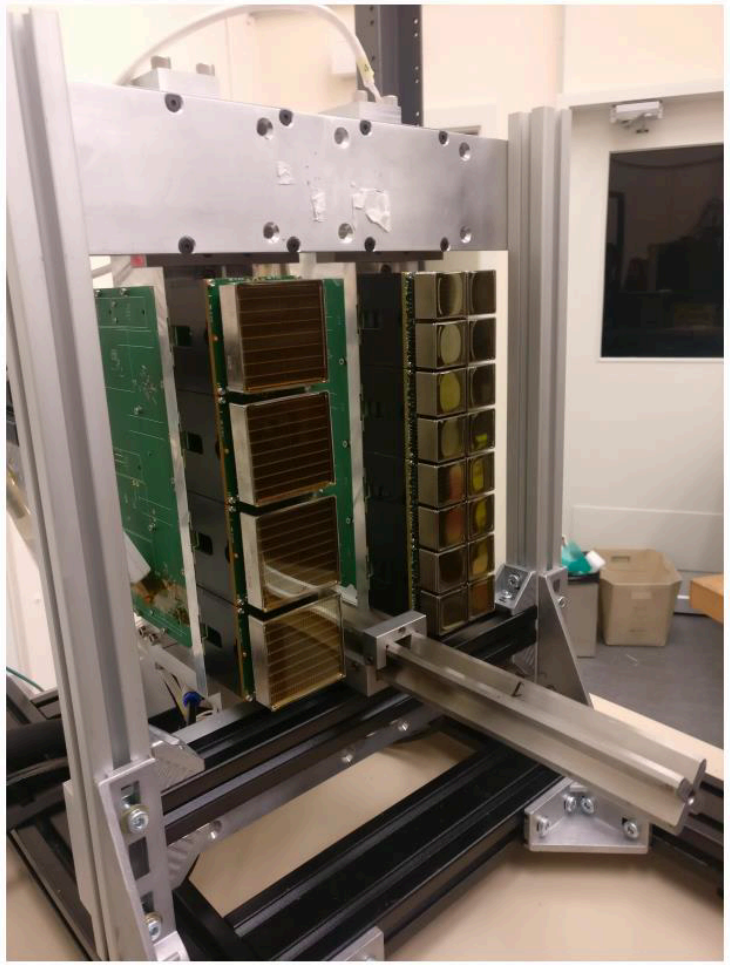


Upstream Tracker

- Front end ASIC (SALT) v3 submitted in October. Improved power distribution and front-end stabilisation.
  - Expect to test mid January.
- More than 50% of sensors delivered and tested.
- Test of special sensor that will surround the beam pipe done.

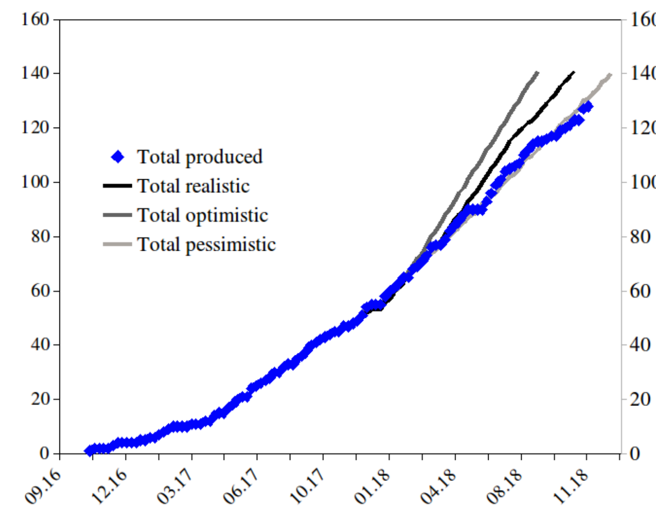
Upgrade I: RICH

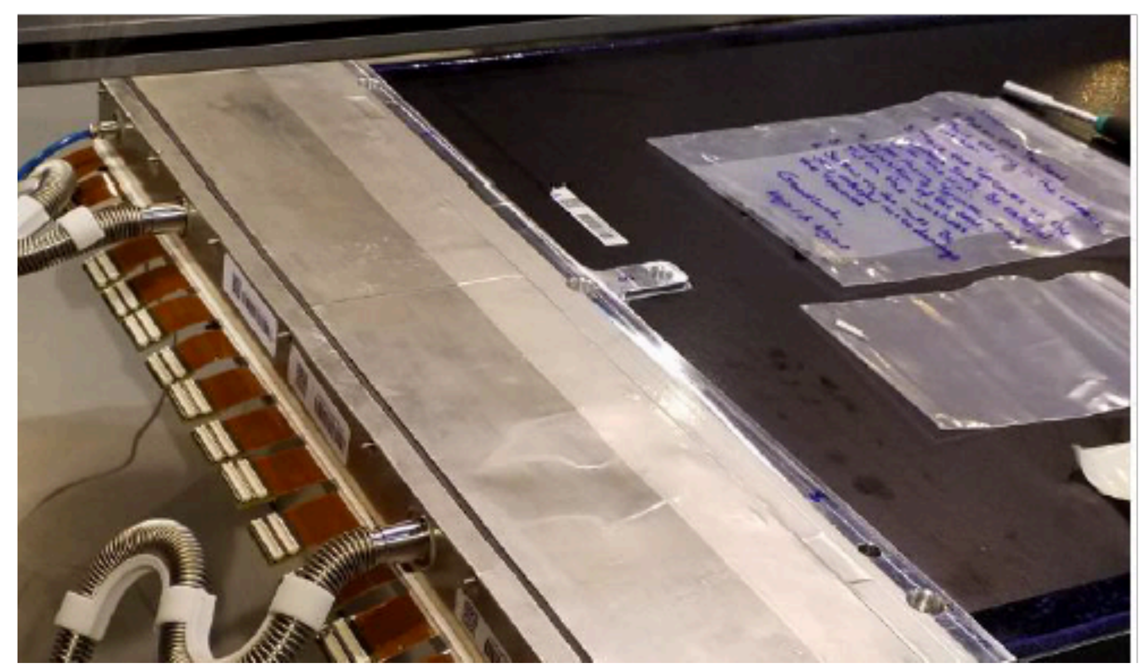
- Chassis + services ready for production. Will be first element to enter.
- Received full ASIC production.
- First serial Elementary Cells produced, column assembly to start soon.
- Preparing commissioning at ComLab@CERN with conditions as close to reality as possible.
- Test beam operation successfully achieved at SysLab@CERN
  - Includes complete DAQ/TELL40.



Upgrade I: SciFi

- Prototype frame partially equipped at LHCb pit.
- Bare module production is almost finished.
- First batch of cold boxes (28) has arrived to CERN.
- Started mounting module + cold-box at CERN.

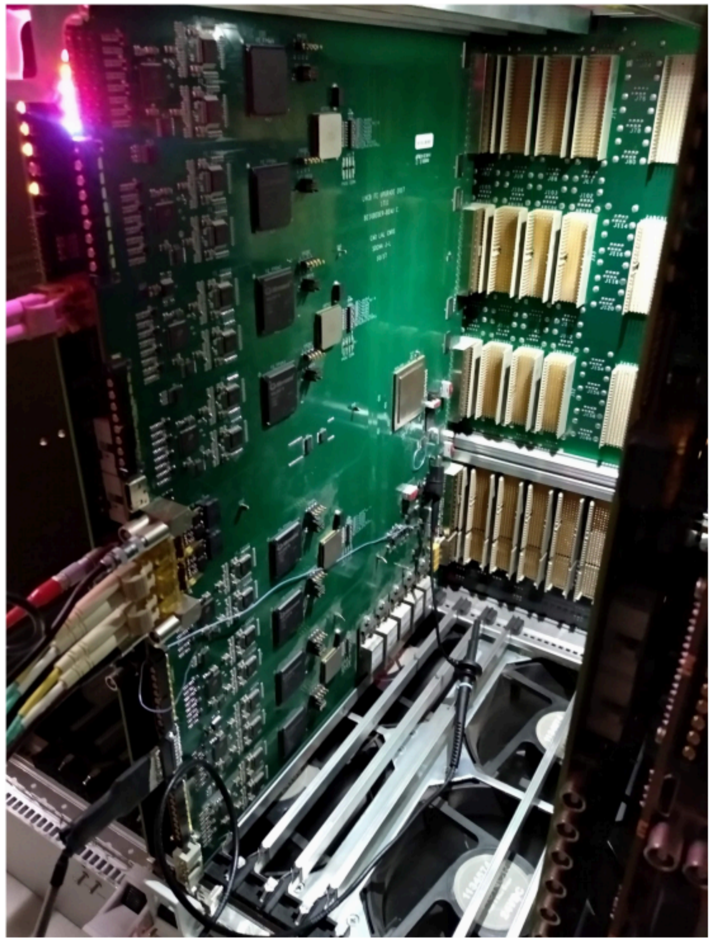




Upgrade I: Calo and Muon

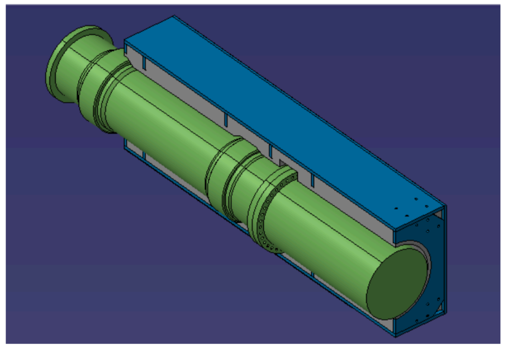
CALO

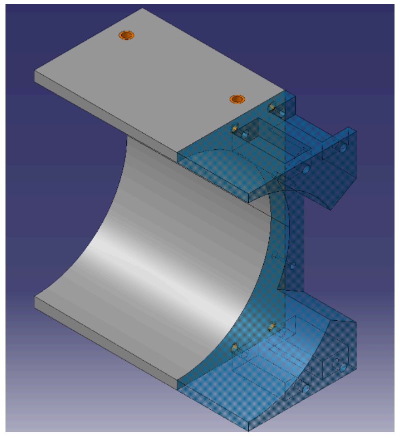
- Test of FEB production is completed.
- FEB tested on testbeam.
- FPGAs will arrive at the end of January.

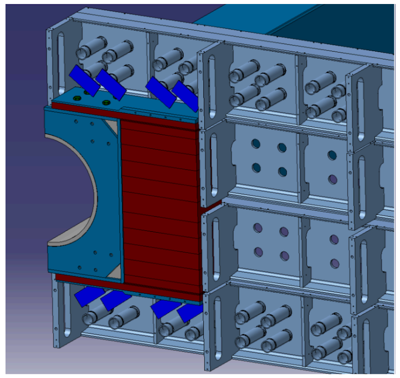


MUON

- ECR for new shielding is done. Plugs have been ordered.
- Production of electronics boards follows the schedule and will be ready for installation.







Upgrade I: Computing Model TDR

- Document describing offline computing model for LHCb from Run 3 onwards and related computing resources needs.

LHCb-TDR-018
is ready

Conclusions

- LHCb has operated extremely well in its 10 years -4 days of existence.
    - pp , pPb, PbPb, pA runs provide a unique dataset.
    - Many precise measurements of SM parameters and some anomalies.
    - Flavour structure and CP violation are still major pending questions.
- LHCb is ~~dead~~ (almost) retired, long live to LHCb!
    - Continue exploiting Run1 + Run2 datasets.
    - Upgrade preparations are proceeding well.
    - Extensive work in testbeams for different subsystems during the last month.
    - Computing model TDR is ready and will be discussed during this LHCC session.

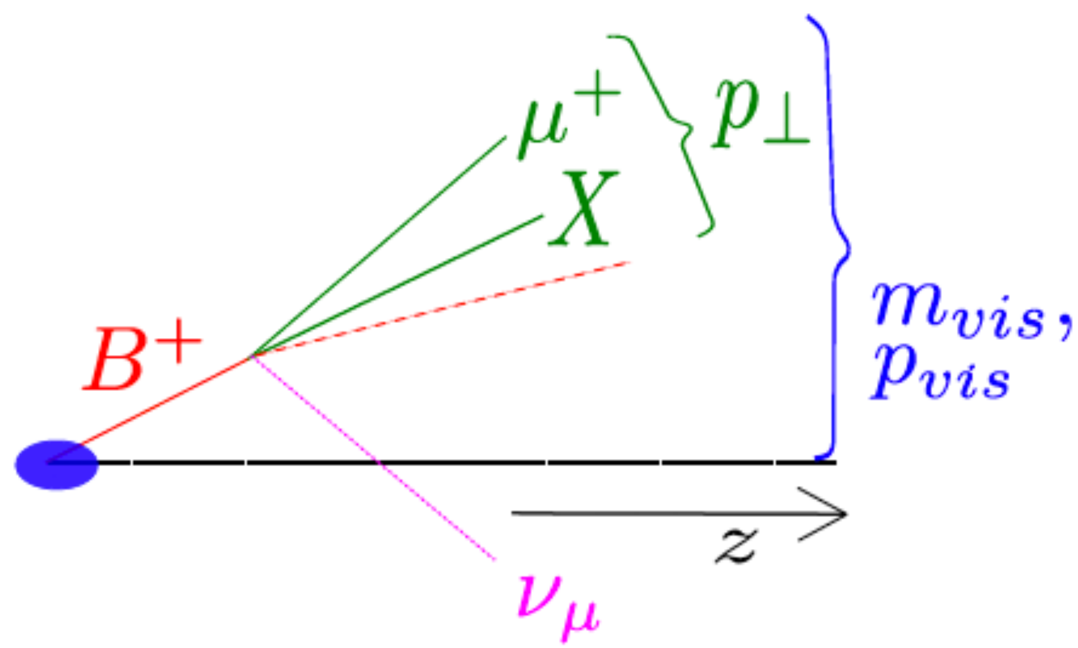
BACKUP

Velo Stepper motor

- Problem in fill 7474.
  - Broken while VELO was closing, took VELO open data. **Prevented next LHC injection.**
  - Fuse in power card blown, replacements blown too.
  - A bridge rectifier on the board found to be shorted.
  - Rectifier from spare boards removed and replaced the broken one.
  - Another blown fuse discovered and replaced => everything back to work.
- Successfully closed/opened in the next fill.

Corrected mass at LHCb

- Recover partially the momentum loss by the neutrino using the corrected mass.
- The visible transverse momentum with respect to the B flight direction is equal to the transverse momentum carried out by the neutrino.



$$m_{corr} = \sqrt{m_{vis}^2 + |p_T'|^2} + |p_T'|$$

What to expect from Run1+Run2 harvest

Observable	Current LHCb
EW Penguins	
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2 c^4)$	0.1 [274]
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2 c^4)$	0.1 [275]
R_ϕ, R_{pK}, R_π	–
CKM tests	
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]
ϕ_s, with $B_s^0 \to J/\psi \phi$	49 mrad [44]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]
a_{sl}^s	33×10^{-4} [211]
$\lvert V_{ub}\rvert / \lvert V_{cb}\rvert$	6% [201]
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$	
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]
$S_{\mu\mu}$	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**	
$R(D^*)$	0.026 [215, 217]
$R(J/\psi)$	0.24 [220]
Charm	
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]
$x \sin\phi$ from multibody decays	–

From CERN-LHCC-2018-027

Many of the analysis are based on Run 1 data only.

With the increase in energy, the integrated luminosity of Run 2 represents an six-fold increase relative to Run 1.

BEWARE: a simple scaling by sqrt(6) will give a wrong estimate due to systematic uncertainties.