Status of LHCb

- Collaboration matters
- Run 1 + Run 2 summary
- Physics output and selected physics results
- The LHCb upgrade
- Conclusions and outlook

G. Passaleva
INFN – Florence and CERN
*On behalf of the LHCb collaboration*

RRB – 29/04/2020
Collaboration matters

• The collaboration keeps growing. Four new groups joined the collaboration as associate members:
  - Helmholtz-Institut für Strahlen-und Kernphysik (HISKP) at Bonn University (Bonn, Germany)
  - La Salle-Universitat Ramon Llull (Barcelona, Spain)
  - Maastricht University (Maastricht, The Netherlands)
  - INFN and University of Perugia (Perugia, Italy).

• The new LHCb Spokesperson elect is Prof Chris Parkes (Manchester University, UK). He will take over in July for three years.

• The new Physics Coordinator elect is Dr Niels Tuning (Nikhef, The Netherlands). He will take over in August for two years.
Run 1 + Run 2 summary

At work on our legacy data
Run 1 + Run 2: a lot of data to analyse...

- A lot of data to analyse
- High statistics implies stricter control of systematics
- Calibration, reprocessing, control samples...

- Different c.o.m. energies
- Collider mode
- Fixed target mode
- Combined
- p-p, Pb-Pb, p-Pb, p-A, Pb-A (A= He, Ne, Ar)
Operations: offline computing

- Intense and complex operation activities during LS2
  - Monte Carlo productions are using ~90% of the computing power
  - Using the online farm for MC production: ~40% of the sample.
  - About a factor 2 more MC events produced in 2019, thanks to fast simulation (~75% of the Monte Carlo events).

MC events in last 365 days
- 65% of the events produced with fast simulation
- 40% of the events produced on the online farm

- Fast simulation (ReDecay)
- Full simulation
- Fast simulation (Tracker only)
- Fast simulation (Particle gun)

Running jobs in all sites
28 Weeks from Week 39 of 2019 to Week 15 of 2020

- ~90% of running jobs are Simulation jobs @ > 98%
- CPU/Wall time efficiency

MC events in last 365 days
- 65% of the events produced with fast simulation
- 40% of the events produced on the online farm

- Fast simulation (ReDecay)
- Full simulation
- Fast simulation (Tracker only)
- Fast simulation (Particle gun)

Running jobs on the HLT farm
32 Weeks from Week 16 of 2019 to Week 10 of 2020

- Max: 46.7, Min: 1.01, Average: 16.5, Current: 21.5

Striping Campaign
- pp Run1 and Run 2
- Stripping Campaign
- MC re-construction
- User jobs

3 Physics
Since the last RRB report, the LHCb collaboration has submitted 23 new papers, for a total of 515 publications at the time of writing. LHCb has also submitted one conference note. A summary of these is given in Table 1. A further 7 papers are being processed by the LHCb Editorial Board and are close to submission. In the following, some selected results from recent publications are highlighted.

3.1 CP violation and CKM studies
The existence of direct CP violation in the charm system is now established. However, mixing-induced CP-violation in charm decays remains an open question. In the SM, it is predicted to be considerably smaller, at the level of few $\times 10^{-5}$, and is under better theoretical control than direct CPV. It therefore serves as a sensitive probe for new physics. In [14], LHCb published the results of a search for time-dependent CP violation using the $A$ observable. Experimentally, this is accessed as $A_{CP}(D_0 \rightarrow f;t)=A_{dir}+A(t)$ for a final state $f$, where $A_{dir}$ is the direct CP asymmetry, and $t$ is the average lifetime of $D_0$ mesons. Thus, by measuring the asymmetry as a function of decay time $t$, the indirect component can be separated from time-independent effects (which include the direct CP asymmetry but also nuisance effects such as the production asymmetry and most detector effects). This analysis uses secondary $D_0$ mesons (i.e., those produced in semileptonic decays of $B$ mesons), for which the decay time acceptance is easier to model than promptly produced charm, and includes the 2016–18 dataset. A precision of better than $10^{-3}$ is obtained for each decay mode. Combined with results from Run 1, these yield $A_{CP}(K_0^+ + K_0^-) = (4.4 \pm 2.3 \pm 0.6) \times 10^{-4}$ and $\delta \theta_{CP} = (2.5 \pm 0.8)$ deg.
Operations: Run 1 + Run 2 data reprocessing campaign

- Full Run 1 + Run 2 reprocessing. Up to date calibrations and pre-selectons ("Stripping")*
- Reprocessing of full pp Run1 and Run2 data for the legacy measurements completed.
- Reprocessing of heavy ion and fixed target data samples ongoing.
- A monumental work that engaged our operation and computing teams for ~2 years

<table>
<thead>
<tr>
<th>Data set</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp Runs</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>completed</td>
</tr>
<tr>
<td>2011 and 2012</td>
<td>completed</td>
</tr>
<tr>
<td>2015 and 2016</td>
<td>completed</td>
</tr>
<tr>
<td>2017</td>
<td>completed</td>
</tr>
<tr>
<td>Ions Runs</td>
<td></td>
</tr>
<tr>
<td>2017 pNe</td>
<td>completed</td>
</tr>
<tr>
<td>2018 PbPb</td>
<td>Under test</td>
</tr>
<tr>
<td>2018 PbNe</td>
<td>Under preparation</td>
</tr>
</tbody>
</table>

*Stripping sorts the data into streams and applies a dedicated offline selection for each analysis

29/04/2020
Physics: paper production

- 519 papers (submitted + published) total – 49 in 2019, 13 in 2020
- +4 Conference Notes
- +23 papers since Oct ‘19 RRB
- 7 more being processed by Editorial Board
- 39 further under collaboration review, several more under working group review

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Physics: paper production

- Analysis of full Run 2 data in full swing!
- Substantially growing number of Run 1+ Run 2 analyses
- Several with full Run 1+ Run 2 dataset
Selected physics results

An overview of recent physics highlights
Recent physics highlights

- Many new results published this year
- Increasing number exploiting the full Run 1 + Run 2 data set (9 fb⁻¹)
- Will show only a few of them
Rare decays

- Test of lepton flavour universality in baryon decays
- Angular analysis of $B^0 \rightarrow K^* \mu^+ \mu^-$ decays
Test of lepton universality with $\Lambda^0_b \rightarrow pK^-\ell^+\ell^-$ decays

- First test of LFU with baryons
- Measure the ratio $R_{pK}^{-1} = \frac{\mathcal{B}(\Lambda^0_b \rightarrow pK^-e^+e^-)}{\mathcal{B}(\Lambda^0_b \rightarrow pK^-J/\psi(\rightarrow e^+e^-))}/\frac{\mathcal{B}(\Lambda^0_b \rightarrow pK^-\mu^+\mu^-)}{\mathcal{B}(\Lambda^0_b \rightarrow pK^-J/\psi(\rightarrow \mu^+\mu^-))}$

- Dilepton mass-squared range: $0.1 < q^2 < 6 \text{ GeV}^2$

\[
R_{pK}^{-1} = 1.17^{+0.18}_{-0.16} \pm 0.07
\]

For comparison with other LFU tests:

\[
R_{pK} = 0.86^{+0.14}_{-0.11} \pm 0.05
\]

Results compatible with the SM within 1σ

Intriguingly again on the low side...
Angular analysis of $B^0 \rightarrow K^* \mu^+ \mu^-$ decays

- Rare decay strongly suppressed in the SM $\Rightarrow$ very sensitive to new physics
- A set of optimised observables can be extracted from the angular distributions (the $P^i$ variables)
- Distinctive local tension in $P'_5$ seen by LHCb and other collaborations
- New analysis with $x^2$ statistics with respect to the previous.
- Results compatible with previous analysis. Interpretation within an effective theory favours a deviation from the SM at the level of $3.3\sigma$ (caution: model-dependent)
CP violation measurements

- Search for additional CP violation sources in charm ($A_f$)
Now that direct CP violation is established, look for additional CPV sources

\( A_\Gamma \) is the “holy grail” – sensitive to new physics

It can be extracted from time-dependent CPV measurements

\[
A_{CP}(f, t) \equiv \frac{\Gamma(D^0 \to f, t) - \Gamma(\bar{D}^0 \to f, t)}{\Gamma(D^0 \to f, t) + \Gamma(\bar{D}^0 \to f, t)}
\]

\[
\approx a_{CP}^{dir}(f) - \frac{t}{\tau_{D^0}} A_\Gamma(f) \quad (f = \pi\pi/K^+K^-)
\]

\[
A_\Gamma = (-2.9 \pm 2.0 \pm 0.6) \times 10^{-4}
\]

Still statistically limited

Need Upgrade II to reach sensitivity to SM

\[
\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}
\]
Spectroscopy

- First observation of excited $\Omega_b^-$ states
First observation of excited $\Omega_b^-$ states

- Great interest on LHCb observation of five new $\Omega_c^0$ resonances (css) [Phys. Rev. Lett. 118 (2017) 182001]
- Search for excited $\Omega_b^-$ (bss – $b$ counterpart or the $\Omega_c^0$ resonances) states particularly interesting
- Four narrow peaks seen for the first time, two of them with large statistical significance

![Data, Full fit, Signals, Background](image)

<table>
<thead>
<tr>
<th>$\Omega_b^-$</th>
<th>$\delta M_{\text{peak}}$ [MeV]</th>
<th>Mass [MeV]</th>
<th>Width [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_b^-$ ($6316^-)</td>
<td>$523.74 \pm 0.31 \pm 0.07$</td>
<td>$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$</td>
<td>$&lt; 2.8 \ (4.2)$</td>
</tr>
<tr>
<td>$\Omega_b^-$ ($6330^-)</td>
<td>$538.40 \pm 0.28 \pm 0.07$</td>
<td>$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$</td>
<td>$&lt; 3.1 \ (4.7)$</td>
</tr>
<tr>
<td>$\Omega_b^-$ ($6340^-)</td>
<td>$547.81 \pm 0.26 \pm 0.05$</td>
<td>$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$</td>
<td>$&lt; 1.5 \ (1.8)$</td>
</tr>
<tr>
<td>$\Omega_b^-$ ($6350^-)</td>
<td>$557.98 \pm 0.35 \pm 0.05$</td>
<td>$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$</td>
<td>$&lt; 2.8 \ (3.2)$</td>
</tr>
</tbody>
</table>

2.1$\sigma$, 2.6$\sigma$, >5$\sigma$ >5$\sigma$

With this and many other results LHCb keeps providing world-leading results in the domain of hadron spectroscopy.
LHCb Upgrades

Moving towards Run 3...

...or: the status before COVID-19
LHCb Upgrade I in a snapshot

All sub-detectors read out at 40 MHz for a **fully software trigger**

- New scintillating fibre tracker (SciFi)
- New silicon upstream tracker (UT)
- New RICH optics and photodetectors
- New PIXEL vertex detector (VELO)
- New electronics for muon and calorimeter systems

$L_{int} = 50 \text{ fb}^{-1}$
$L = 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
Very intense activity at LHCb site throughout LS2!

- All old detectors and obsolete equipment removed
- Installation of services nearly completed: ready to install and test detectors

Will discuss later on impact of covid-19 lockdown
Upgrade: construction

Working... (and preparing to restart full steam)
Upgrade: VELO

- Module production delayed due to assembly problem was resumed in February
- RF foil etched and coated, ready for installation
- All other parts of the project progressing well

RF foil treatment: etching to 150μm, torlon internal coating, NEG outer coating preparation

Preparation of μ-channel cooling plates

VELO modules

Vacuum Feed Through being assembled

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preparation @P8 for RF foil installation

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Upgrade: SMOG2

- New fixed target system (SMOG2): based on a gas storage cell connected to VELO
  - Significant increase of the luminosity for fixed-target collisions
- SMOG2 system ready to be installed together with VELO RF foil
Upgrade: Upstream Tracker

- Mass production of staves started ⇒ soon shipments to CERN for assembly
- Installation delayed due to known issues with ASIC, tight schedule

staves construction chain: mechanical support, cooling pipes, flex cables

wire-bonded modules mounted on staves

stave installation in assembly hall at CERN

detail of the 10x10 cm$^2$ UT sensors
Upgrade: SciFi

- Installation of first C-frame was completed early this year
- 3/12 C-frames well advanced – need to install 6/12 before beam pipe installation – Tight schedule!

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Upgrade: RICH

New quartz window developed and installed on a new supporting frame
More work on the gas enclosure needed before installation

Production and qualification of photon detectors completed
Production and testing of electronics almost finished
Commissioning of photon detector columns well advanced

Spherical mirrors have been coated at CERN and ready
Upgrade: Calorimeters, Muon system

- Both systems progressing well

Production of MUON electronics boards completed

Installation of patch panels for both ECAL and HCAL

MUON commissioning ongoing at CERN: population of M4 and M5

CALO FEB and control boards under production and test

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• Construction and commissioning of common DAQ boards (PCle40) almost completed.
• Event builder technology chosen (dedicated network)

New data centre constructed, commissioned and connected to cavern via long distance fibres, old farm moved

Servers for Event Builder identified, order placed

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Upgrade: full software trigger

- Development under the responsibility of the Real-Time Analysis Project (RTA)
- Development advancing – several HLT2 selections already in place.
- Two technology options for HLT1 – Review completed, final decision imminent.

Technical design and performance of a GPU HLT1
Impact of COVID-19 crisis
Impact of COVID-19 crisis

- Analysis activities still going on very well: ~50 analyses in final or review phase!
  - Experience on video-only workshops and large meetings positive – e.g. workshop on future upgrades

- Following closely CERN management guidelines to prepare for the restart
  - Preparation for cautious resumption of very selected high-priority activities
  - Few people, maintain physical distance – use of adequate PPEs – apply hygienic precautions.

- Planning a few “pilot” activities, for example:
  - Installation of event-builder nodes (first batch, just arrived at CERN)
  - Installation of RF foil
  - Commissioning of RICH2 photon detector columns

- Impact on upgrade activities still to be fully evaluated
  - Roughly, the time of lock down until full resumption of work translates into a linear delay in all those areas that depend on physical intervention, i.e. all the upgrade construction work.
  - Lockdown and travel restrictions in the various countries makes it difficult to re-build the construction and installation teams at CERN. Presumably this will restart slowly over summer
  - For example: SciFi, VELO, UT rely heavily on personnel from US, UK, Germany, NL to be at CERN
“CERN against COVID-19” and LHCb

- Some LHCb members strongly involved in “CERN against COVID-19” initiative
  - HEV ventilator – aimed at milder cases of the disease, design based on components that are cheap and easy to obtain

  Folding@home – LHCb trigger farm computing resources devoted to this worldwide initiative to study protein folding, including COVID-19. Mainly old HLT farm nodes
Conclusions and outlook
Conclusions and outlook

• The march towards the Upgrade I is continuing
  ★ All subsystems progressing - installation ongoing
  ★ Impact of COVID-19 to be fully assessed
  ★ Preparing for the restart

• LHCb continues to provide a wealth of excellent physics results
• This is my last RRB meeting as LHCb spokesperson
• Let me wholeheartedly thank all the Funding Agency delegates and the CERN management for the strong support given to LHCb throughout my mandate

Thank you!
Angular analysis of $B^0 \rightarrow K^*\mu^+\mu^-$ decays

- 3-body FCNC decays strongly suppressed in the SM very sensitive to new physics
- Final state containing a vector meson very rich angular structure, allows to extract several observables that can be compared with SM predictions
- A set of optimised observables can be defined where form factor uncertainties cancel at first order (the $P'$ basis)
- Distinctive local tension in $P'_5$ seen by LHCb and other collaborations
- Interpretation of these results within an effective theory favours certain new-physics scenarios

N.B. deviations from SM could be reabsorbed assuming large hadronic uncertainties, see e.g. JHEP06(2016) 116

Non-exhaustive list of global fit examples:

Upgrade II

*LHCb Upgrade II: the ultimate exploitation of LHC for flavour physics*
Aim to fully exploit HL-LHC for flavour physics and other opportunities in the forward direction

Aim to collect > 300 fb\(^{-1}\) at \(L = 2 \times 10^{34}\), x10 with respect to Upgrade I

Expression of Interest issued in 2017

Feasibility study performed by LHC experts

Physics case document released

Support for project in the “Physics Briefing Book : Input for the European Strategy for Particle Physics Update 2020” – “The LHCb Upgrade II... will enable a wide range of flavour observables to be determined at HL-LHC with unprecedented precision”

Green light from LHCC and RB to proceed to a Framework TDR (expected 2021)
Measurement of $|V_{cb}|$ with $B_s^0 \to D_s^{(*)-} \mu^+\nu_\mu$ decays

- Fundamental parameter of SM
- Need to measure it precisely to (over-) constrain the CKM Unitarity Triangle and spot possible new physics effects
- Problem: different measurement approaches (“inclusive” vs “exclusive”) and parametrizations of hadronic effects (form-factors) used to give different results
- LHCb uses $B_s^0 \to D_s^{(*)-} \mu^+\nu_\mu$ decays to measure $|V_{cb}|$ and constrain hadronic contributions (form-factors)
  - ★ Some advantage in using $B_s^0$ vs $B^0$ e.g. easier lattice-QCD calculations
- First determination of $|V_{cb}|$ from exclusive decays at a hadron collider and the first using $B_s^0$ decays:
  
  $|V_{cb}|_{CLN} = (41.4 \pm 0.6{\mathrm{stat}} \pm 0.9{\mathrm{syst}} \pm 1.2{\mathrm{ext}}) \times 10^{-3}$
  
  $|V_{cb}|_{BGL} = (42.3 \pm 0.8{\mathrm{stat}} \pm 0.9{\mathrm{syst}} \pm 1.2{\mathrm{ext}}) \times 10^{-3}$

- Results obtained using two different parametrizations of form-factors are compatible
...in a range of running modes!

- Different c.o.m. energies
- Collider mode
- Fixed target mode
- Combined
- p-p, Pb-Pb, p-Pb, p-A, Pb-A (A= He, Ne, Ar)