Performance and highlights from LHCb & Moedal

Carla Marin
on behalf of the LHCb & Moedal collaborations

LHC Jamboree 2018
LHCb: Large Hadron Collider Beauty experiment

- Precision measurements heavy flavor physics
- Core physics: matter-antimatter asymmetry (CPV) and rare decays
- Much more: spectroscopy, QCD, heavy ions...

- 848 authors, more than 40 nationalities
- 78 institutes from 18 countries
LHCb operations in 2018

Most productive data-taking year, target accomplished with almost 90% efficiency

Also recorded PbPb collisions, x20 existing sample (from 2015)

Huge thanks to the LHC!
CPV: constraining CKM angle $\gamma$


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$\gamma \equiv \arg\left[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*\right]$$

$\gamma = (74.0^{+5.0}_{-5.8})^\circ$

Most precise from single experiment
Rare Decays: searches and asymmetries

First evidence for $B_s \rightarrow K^* \mu \mu$ [JHEP 07 (2018) 020]:

Best limits:

PAPER-2018-037

Phys.Rev.D97,091101

Angular and CP asymmetries in $D^0 \rightarrow h h \mu \mu$

(BR $\sim 1.9 \times 10^{-7}$):

$A_{FB}(D^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (3.3 \pm 3.7 \pm 0.6)\%$,

$A_{2\phi}(D^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (-0.6 \pm 3.7 \pm 0.6)\%$,

$A_{CP}(D^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-) = (4.9 \pm 3.8 \pm 0.7)\%$,

$A_{FB}(D^0 \rightarrow K^+ K^- \mu^+ \mu^-) = (0 \pm 11 \pm 2)\%$,

$A_{2\phi}(D^0 \rightarrow K^+ K^- \mu^+ \mu^-) = (9 \pm 11 \pm 1)\%$,

$A_{CP}(D^0 \rightarrow K^+ K^- \mu^+ \mu^-) = (0 \pm 11 \pm 2)\%$.

Angular analysis of $\Lambda_b \rightarrow \Lambda^0 \mu \mu$ (BR $= 1 \times 10^{-6}$):

$B(B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_\mu) < 1.6 \times 10^{-8}$

$B(A_c^+ \rightarrow p \mu^+ \mu^-) < 7.7 (9.6) \times 10^{-8}$ at 90% (95%) CL

JHEP 07 (2018) 020

Phys. Rev. Lett. 121, 091801

JHEP 09 (2018) 146
$\Xi_{cc}^{++}$: understanding doubly charmed baryons

LHCb observed last year for the first time a baryon with 2 heavy quarks (ucc):


Next step: study its properties
Not only pp physics

The SMOG system:

- Can inject different gas species

Charm production in pHe and pAr:

- Also first direct antiproton production in pHe
LHCb lifetime

1995

LHC-B

LETTER OF INTENT

A Dedicated LHC Collider Beauty Factory for Precision Measurements of CP Violation and Rare B Decays

Abstract

The LHCb Collaboration proposes to build a forward detector as part of the LHC at CERN in order to study CP violation and rare B decays. The detector will be located at a distance of 280 m away from the LHC. It will measure the lifetime of the tau lepton and the CP violation parameter by measuring the decay time of the tau lepton. The detector will be equipped with excellent tracking and calorimetry capabilities. The LHCb detector is designed to be modular and scalable, allowing for future upgrades and extensions.

1998

Technical Proposal

A Large Hadron Collider Beauty Factory for Precision Measurements of CP Violation and Rare B Decays

Abstract

The LHCb Collaboration proposes to build a forward detector as part of the LHC at CERN in order to study CP violation and rare B decays. The detector will be located at a distance of 280 m away from the LHC. It will measure the lifetime of the tau lepton and the CP violation parameter by measuring the decay time of the tau lepton. The detector will be equipped with excellent tracking and calorimetry capabilities. The LHCb detector is designed to be modular and scalable, allowing for future upgrades and extensions.

1998

MEMORANDUM

From: The Director General

Subject: Recommendations of the LHCb committee

Evaluation of the LHCb Technical Proposal and Recommendation to the Research Board

The LHCb has completed the scientific, technical, and cost review of the LHCb Technical Proposal (LHCb-96-48), and the subsequent documentation, including the plan with milestones for further development of the project.

5. Recommendations to the Research Board

The LHCb recommends the approval of the LHCb project, together with the plan, including milestones, leading to the Subsequent Year.

2008

Expression of Interest for an LHCb Upgrade

The LHCb Collaboration

Abstract

There is a growing international understanding that future frontier physics can be pursued at the LHC and at high luminosity. At the time of this meeting, the LHCb Collaboration expressed interest in an upgrade of the LHCb detector to explore physics at even higher luminosity. This paper discusses the motivations for the upgrade, the technical and scientific goals, and the potential impact on future physics. The LHCb Collaboration presented recommendations for the design and development of the upgraded detector, which was later approved by the CMS Tier-1 Tier-2 conference.

2011

Letter of Intent for the LHCb Upgrade

The LHCb Collaboration

Abstract

The success and scale of the LHCb is in large part due to the efforts of the scientific community. The LHCb Collaboration expressed interest in an upgrade of the LHCb detector to explore physics at even higher luminosity. This paper discusses the motivations for the upgrade, the technical and scientific goals, and the potential impact on future physics. The LHCb Collaboration presented recommendations for the design and development of the upgraded detector, which was later approved by the CMS Tier-1 Tier-2 conference.

The installation of the LHCb upgrade takes into consideration the present long-term planning of LHC and will start with the long shutdown (LS2) in 2018. The overall time for the installation and commissioning of the LHCb upgrade amounts to 18 months (Fig. 8). It is mandatory that the new detector systems are assembled as much as possible before the installation. Some systems will be integrated in the existing supports and infrastructure.
LS2 = end of current detector!!
LHCb operations overview

Huge thanks to the LHC!

Target delivered lumi as of Lol achieved!
LHCb farewell: did we achieve our goals?

From the Roadmap document [LHCb-PUB-2009-029]:

1 Introduction
   1.1 Key measurements .............................................
   1.2 The LHCb trigger .............................................

2 The tree-level determination of $\gamma$

3 Charmless charged two-body $B$ decays

4 Measurement of mixing-induced CP violation in $B_0^\pm \rightarrow J/\psi \phi$

5 Analysis of the decay $B_0^0 \rightarrow \mu^+ \mu^-$

6 Analysis of the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

7 Analysis of $B^0_s \rightarrow \phi \gamma$ and other radiative $B$ decays
LHCb farewell: did we achieve our goals?

From the Roadmap document [LHCb-PUB-2009-029]:

LHCb

B_s \rightarrow J/\psi \Phi

B_s \rightarrow K\pi

B \rightarrow K^*\mu\mu

B \rightarrow \phi\gamma

Candidates / ps

Candidates / (10 MeV/c²)

B_s \rightarrow J/\psi \Phi

CPV in B_s \rightarrow K\pi

Phys.Rev.Lett.118 191801
LHCb-CONF-2018-002
Phys.Rev.Lett.108 101803
Phys.Rev.Lett.118 021803
Phys.Rev.Lett.110 221601
LHCb farewell: did we achieve our goals?

From the Roadmap

DONE

\[ B_s \rightarrow J/\psi \Phi \]

\[ B_{s} \rightarrow B_{s} \rightarrow K\pi \mu\mu \]

\[ B^0 \rightarrow K^\pm \pm \]

\[ B^0 \rightarrow \pi^+\pi^- \mu^+\mu^- \]

\[ B^+ \rightarrow K^+\pi^+ \mu^+\mu^- \]

\[ B_s \rightarrow \mu^+\mu^- \]

\[ B^+ \rightarrow K^+\pi^+ \mu^+\mu^- \]

\[ B_s \rightarrow K^+\pi^- \mu^+\mu^- \]

JHEP 02 (2016) 104
Phys.Rev.Lett.118 191801
LHCb-CONF-2018-002
Phys.Rev.Lett.108 101803
Phys.Rev.Lett.118 021801
Phys.Rev.Lett.110 221601
What was not in the roadmap

**Pentaquarks**

**LFU with e**

**LFU with τ**

**CPV in Charm**

**New charm baryon resonances**

**Dark photons**

**Charm production in pPb**
LHCb revival (or Upgrade I)

LHCb Upgrade Trigger Diagram

- **30 MHz inelastic event rate (full rate event building)**

  - **Software High Level Trigger**
    - Full event reconstruction, inclusive and exclusive kinematic/geometric selections
    - Buffer events to disk, perform online detector calibration and alignment
    - Add offline precision particle identification and track quality information to selections
    - Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

  - 2-5 GB/s to storage
LHCb revival (or Upgrade I)
LHCb revival (or Upgrade I)

LS2 = birth of a new detector!!
“The LHCC commends the LHCb collaboration for successfully preparing the physics case report for running beyond LS4 and supports the activities of the LHCb collaboration in planning for HL-LHC running through the preparation of TDRs.”
The MoEDAL Experiment

- The MoEDAL detector is only sensitive to highly ionizing avatars of new physics like the magnetic monopole
- There are no physics backgrounds from Standard Model processes
- The MoEDAL detector provides a permanent record of Discovery – where we track, “photograph” and/or trap new particles for further study.
MoEDAL’s First Results

- **Papers in active progress:**
  - Limits on highly electrically charged particles
  - DY & $\gamma - \gamma$ monopole search using full MMT detector
  - Detector Paper
- **We are just starting**

World’s best limits on multiply charged monopole production

- **PL. B782 (2018) 510**
- **PRL. 118 (2017), 061801.**
- **JHEP 1608 (2016) 067**

James L. Pinfold        MoEDAL        CERN Jamboree
The Next Steps

• Complete analyses using Run-2 data, for example:
  • The search for massive stable and pseudo electrically charged particles eg. sleptons, D-particles, R-hadrons, blackhole remnants, etc.
  • Monopole production via the Schwinger mechanism using heavy-ions, etc.

• MoEDAL plans to continue data-taking (to ~30 fb\(^{-1}\)) in Run-3
  • MoEDAL is planning to install the MAPP (MoEDAL Apparatus for Penetrating Particles ) subdetector for Run-3 data taking
  • MAPP will expand MoEDAL’s physics reach to include mini-charged particles and new long-lived neutrals
Merry Christmas and happy LS2

**LHCb:**
- Run 1-2 have been excellent, plenty of data & exciting results
- LS2 = new detector with much more data & physics
- Looking further into the future with Upgrade II

**MoEDAL:**
- Fully running during Run 2, first papers published and more to come
- Will extend capacities in Run 3
BACK-UP
### $\gamma$ combination

<table>
<thead>
<tr>
<th>$B$ decay</th>
<th>$D$ decay</th>
<th>Method</th>
<th>Ref.</th>
<th>Dataset</th>
<th>Status since last combination</th>
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<td>$B^+ \to DK^+$</td>
<td>$D \to h^+h^-$</td>
<td>GLW</td>
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<td>Run 1 &amp; 2</td>
<td>Minor update</td>
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<td>$B^+ \to DK^+$</td>
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<td>ADS</td>
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<td>Run 1</td>
<td>As before</td>
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<td>As before</td>
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<td>Run 1</td>
<td>As before</td>
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<td>As before</td>
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<td>$D \to h^+h^-$</td>
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<td>Minor update</td>
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<td>22</td>
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<td>New</td>
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</table>
Time-dependent decay rate in $B_s \to \phi \gamma$

Unbinned fit to background-subtracted decay-time distribution:

$$\mathcal{A}^\Delta = -0.98^{+0.46+0.23}_{-0.52-0.20}$$