LHCb status report

Manuel Schiller
on behalf of LHCb

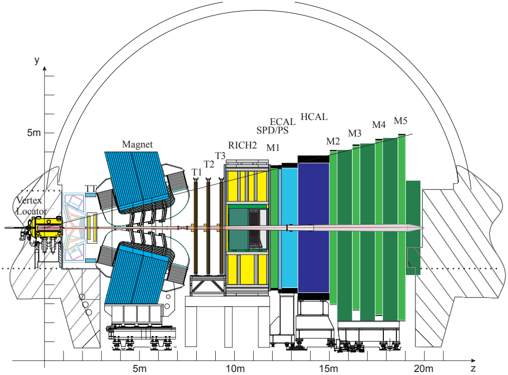
CERN

May 25th, 2016

outline

- new physics results
  - a_{sl}^{s}, Δm_d, γ, (no) tetraquark, …
- 2016 startup and first data
- heavy ion plans
- upgrade

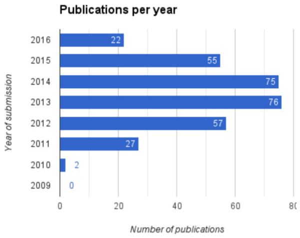
LHCb experiment

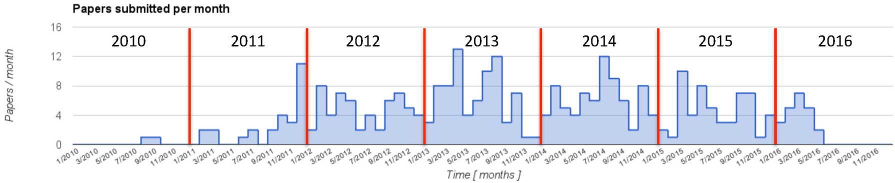


- originally designed to study CPV in rare *b* and *c* decays, nowadays GPD in forward region
  - tracking efficiency $> 96\%$
  - excellent vertexing: decay time resolution ~ 45 fs
  - very good momentum resolution: $dp/p \sim 0.5 - 1.0\%$
  - software trigger (HLT) input rate: 1 MHz

overview

- 314 papers submitted
- 9 further papers in preparation
- 41 new analyses under review





overview

- 13 papers submitted since last LHCC week:
  - 5 JHEP
  - 3 PLB
  - 3 PRL
  - 1 EPJC
  - 1 PRD
- 4 conference notes since last LHCC

- Measurement of the CKM angle γ using $B^0 \to DK^{*0}$ with $D \to K^0_S\pi^+\pi^-$ decays
- Measurement of forward W and Z boson production in association with jets in proton-proton collisions at $\sqrt{s} = 8$ TeV
- Model-independent evidence for $J/\psi p$ contributions to $\Lambda_b \to J/\psi pK^-$ decays
- Measurement of the properties of the Ξ_b^{*0} baryon
- A precise measurement of the B^0 meson oscillation frequency
- Model-independent measurement of the CKM angle γ using $B^0 \to DK^{*0}$ decays with $D \to K^0_S\pi^+\pi^-$ and $K^0_S K^+K^-$
- Measurement of the mass and lifetime of the Ω_b^- baryon
- Measurement of CP observables in $B^\pm \to DK^\pm$ and $B^\pm \to D\pi^\pm$ with two- and four-body D meson decays
- Search for B_c decays to the $p\bar{p}\pi$ final state
- Observation of $\Lambda_b^0 \to \psi(2S)pK^-$ and $\Lambda_b^0 \to J/\psi\pi^+\pi^-pK^-$ decays and a measurement of the Λ_b^0 baryon mass
- Search for violations of Lorentz invariance and CPT symmetry in $B^0_{(s)}$ mixing
- Observation of the $\Lambda_b \to \Lambda\phi$ decay
- Observation of $B_s^0 \to \overline{D}^0 K_S^0$ and evidence for $B_s^0 \to \overline{D}^{*0} K_S^0$ decays

CP violation in mixing

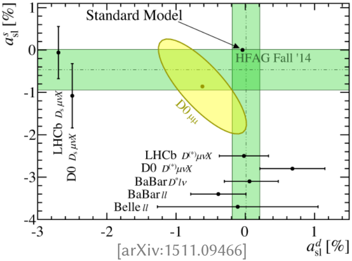
- CPV in mixing: $\Gamma(B_q \to \overline{B}_q) \neq \Gamma(\overline{B}_q \to B_q)$ $(q = d, s)$
- asymmetry sensitive to CPV in mixing:

$$A_{raw} = \frac{N(D_q^- \mu^+) - N(D_q^+ \mu^-)}{N(D_q^- \mu^+) + N(D_q^+ \mu^-)} \approx \frac{a_{sl}^q}{2} + \text{corrections...}$$

- sensitive to potential NP entering in the mixing

the story so far:

- SM:
  $a_{sl}^d = (-4.7 \pm 0.6) \cdot 10^{-4}$
  $a_{sl}^s = (2.22 \pm 0.27) \cdot 10^{-5}$
  [arXiv:1511.09466]
- HFAG:
  $a_{sl}^d = (0.01 \pm 0.20) \cdot 10^{-2}$
  $a_{sl}^s = (-0.48 \pm 0.48) \cdot 10^{-2}$
  [arXiv:1412.7515], excl. D∅ $\mu\mu$ result
- LHCb: (3 fb^{-1}/1 fb^{-1})
  $a_{sl}^d = (-0.02 \pm 0.19 \pm 0.30) \cdot 10^{-2}$
  $a_{sl}^s = (-0.06 \pm 0.50 \pm 0.36) \cdot 10^{-2}$
  [PRL 114, 041601 (2015)]
  [PLB 728C (2014) 607]



[arXiv:1511.09466]

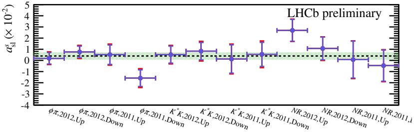
CP violation in mixing

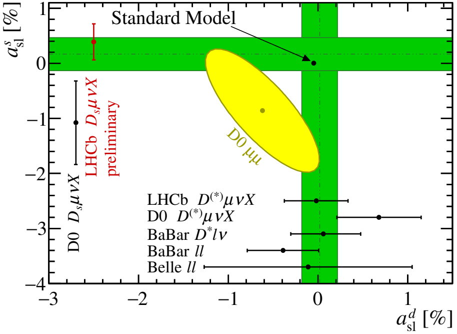
- new untagged, time-integrated, inclusive analysis of $\overline{B}_s \to D_s^- \mu^+ \overline{\nu}_\mu^- X$
  - using full run 1 data set (3 fb^{-1})
  - using full $D_s^- \to KK\pi$ Dalitz space

$$A_{raw} = \frac{N(D_q^- \mu^+) - N(D_q^+ \mu^-)}{N(D_q^- \mu^-) + N(D_q^+ \mu^+)} \approx A_D + \frac{a_{sl}^q}{2} + (A_P - \frac{a_{sl}^q}{2}) \frac{\int dt \, \cos(\Delta m_q t)\varepsilon(t)}{\int dt \, \cosh(\Delta\Gamma_q t/2)\varepsilon(t)}$$

A_D: detection asymmetry, A_P: production asymmetry

- formerly dominant systematics: tracking asymmetry
  - was 0.13% in prev. LHCb measurement, down to 0.03% for K and 0.04% for μ
  - much improved: J/ψ tag-and-probe, D^* partially reconstructed methods + simulation
- $a_{sl}^s = (0.45 \pm 0.26 \pm 0.20)\%$



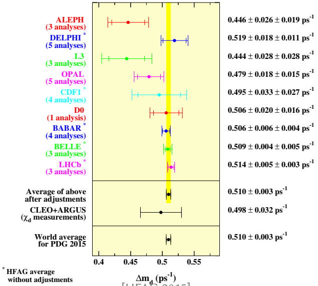


[LHCb-PAPER-2016-013, preliminary]

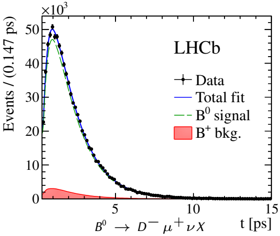
Δm_d from $B^0 \to D^{(*)-}\mu^+\nu X$

- measure mixing frequency Δm_d with full run 1 sample ($3\,\text{fb}^{-1}$)
  - use flavour specific decays:
    - 1.6 M $B^0 \to D^-(K^+\pi^-\pi^-)\mu^+\nu X$ decays
    - 0.8 M $B^0 \to D^{*-}(\overline{D}^0(K^+\pi^-)\pi^-)\mu^+\nu X$decays
  - need flavour tagging (4 categories)
  - reconstruct decay time (k-factor corrected), fit $N_\pm(t) = e^{-t/\tau}(1 \pm (1-2\omega)\cos(\Delta m_d t))$

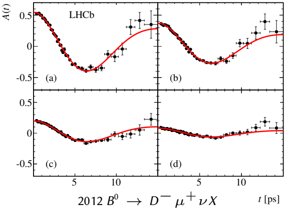
→ world's most precise single measurement: $\Delta m_d = (505.0 \pm 2.1(\text{stat.}) \pm 1.0(\text{syst.}))\ \text{ns}^{-1}$



[HFAG 2015]

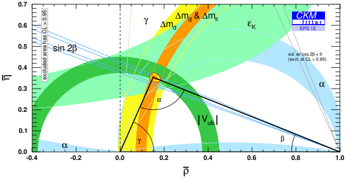


[arXiv:1604.03475]

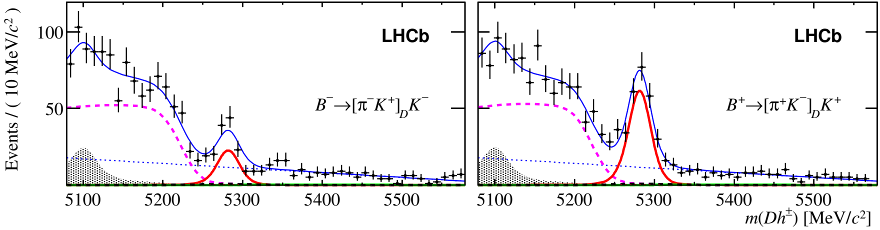


CKM angle γ

- $\gamma = \arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$ least well-known angle in the UT
- measurable in interference between 2 amplitudes to same final state
  - one has a weak $b \to u$ transition, the other not
  - plenty of possible channels
- interference causes different decay rates, e.g. in $B^\pm \to D(\pi^+K^-)K^\pm$



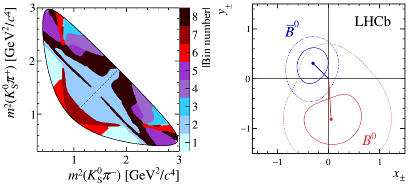
[EPS-HEP 2015]



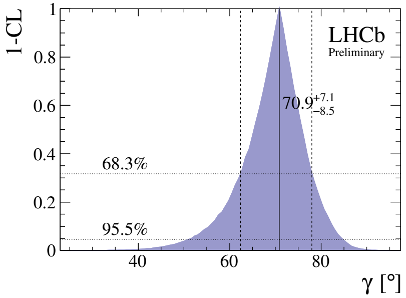
[arXiv:1603.08993]

CKM angle γ

- plenty more $B_{(s)} \to D_{(s)} K^{(*)}$ results from run 1 available:
  - another recent result: $B^0 \to D^0(K^0_S h^+ h^-) K^{*0}$ alone: $\sigma_\gamma \sim 20^\circ$
  - [arXiv:1603.08993], [arXiv:1504.05442], [arXiv:1408.2748], [arXiv:1402.2982], [arXiv:1602.03455], [arXiv:1407.8136], [arXiv:1605.01082], [arXiv:1505.07044], [arXiv:1407.6127]
- perform LHCb-wide statistical γ combination of DK modes: $\gamma = (70.9^{+7.1}_{-8.5})^\circ$ is most precise measurement by single experiment



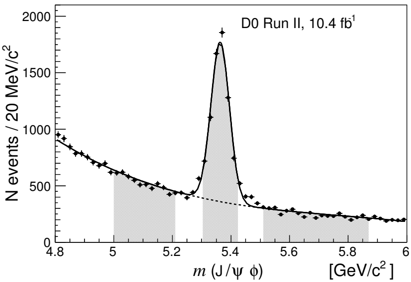
[arXiv:1604.01525][arXiv:1605.01082]



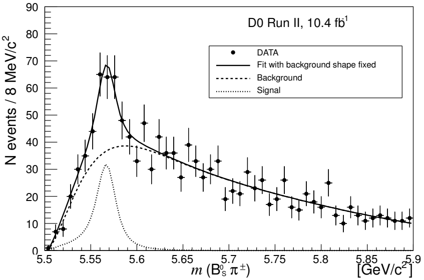
[LHCb-CONF-2016-001]

DØ tetraquark observation

- Feb. 26th: DØ claims exotic state $X(5568) \to B_s^0 \pi^\pm$ with 5.1 σ significance
  (with $B_s^0 \to J/\psi\phi$, $J/\psi \to \mu^+\mu^-$ and $\phi \to K^+K^-$)
  - $M = 5567.8 \pm 2.9^{+0.9}_{-1.9}$ MeV$/c^2$, $\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}$ MeV$/c^2$
  - fraction of B_s^0 from $X(5568)$ decay: $\rho_X^{D\emptyset} = (8.6 \pm 1.9 \pm 1.4)\%$
- at least 4 quarks with u, d, s, b flavours, theory community buzzing with models to explain state



$N_{B_s} \sim 5500$, $\sigma_m \sim 30\text{MeV}/c^2$

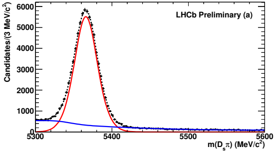


$N_X \sim 133 \pm 31$

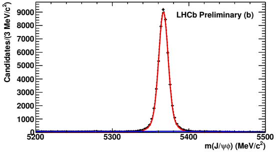
[arXiv:1602.07588]

LHCb tetraquark non-observation

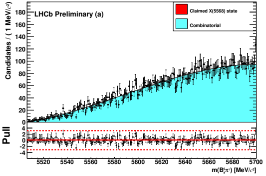
- Mar. 20th: LHCb looks in 3 fb^{-1} of data
  - exploit experience from previous analyses
  - $\sim$110k ultra-clean B_s (in $D_s\pi$ and $J/\psi\phi$ modes)



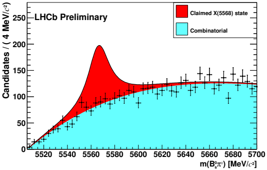
65k $B_s^0 \to D_s\pi$, $\sigma_m \sim$ 15 MeV/c^2, S/B=10



45k $B_s^0 \to J/\psi\phi$, $\sigma_m \sim$ 6 MeV/c^2, S/B=50



$p_T(B_s) > 5$ GeV/c^2



$p_T(B_s) > 10$ GeV/c^2, DØ signal superimposed

[LHCb-CONF-2016-004]

- X(5568) not seen by LHCb:

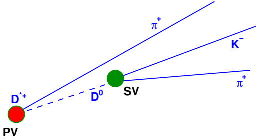
  $\rho_X^{LHCb}(p_T(B_s) > 5GeV) < 0.9(1.0)\%$ @ 90(95)% CL

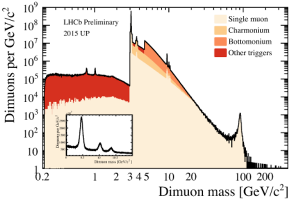
  $\rho_X^{LHCb}(p_T(B_s) > 10GeV) < 1.6(1.8)\%$ @ 90(95)% CL
- bottom right plot: LHCb data with claimed X(5568) at $\rho_X = 8.6\%$ superimposed
- looking forward to hearing from other experiments
- publication in preparation

- 13 papers, 4 conference notes released since last LHCC
- many interesting results in the pipeline:
  - run 1 lepton universality
  - W and Z cross-sections
  - CP violation in charm
  - exotic particles and states
  - spectroscopy
  - ...
- stay tuned for the summer conferences – there are exciting times ahead!

2016 startup and first data

- 2016 data taking has started
  - we thank the machine for a smooth experience!
  - well, there's the occasional "weasel" (literal and other)
  - generally smooth experience, problems are resolved quickly and effectively
- reminder: new in run 2:
  - real-time calibration and alignment in the software trigger
  - software trigger has offline reconstruction (and quality!)
  - TURBO stream: save trigger candidates at $\frac{1}{10}$ size

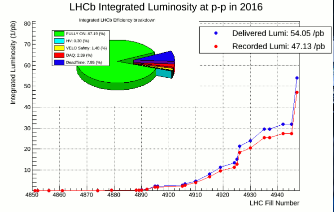


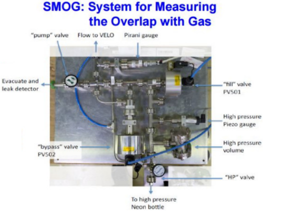


- 2016 is like 2015, only better…

2016 startup and first data

- data are being taken successfully, all detectors work
- new control room ready just in time

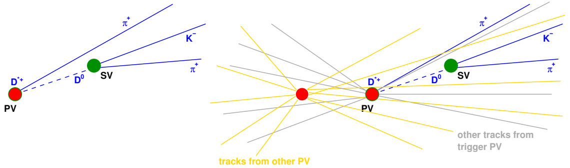




- huge effort to validate incoming data: done on day 2 after start of data taking
- successfully took VdM scan, also SMOG data (fixed target p-He collisions)
- improvements for this year numerous:
  - TURBO++ stream (next slide)
  - retuning to optimise performance

HLT improvements: TURBO++ stream

- already in 2015: TURBO stream: fully reconstructed HLT candidate for analysis at a fraction of the event size



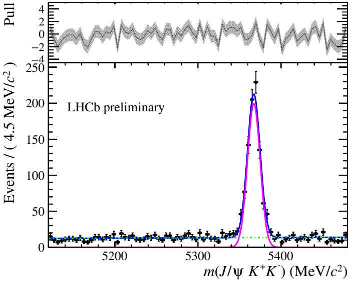
TURBO TURBO++

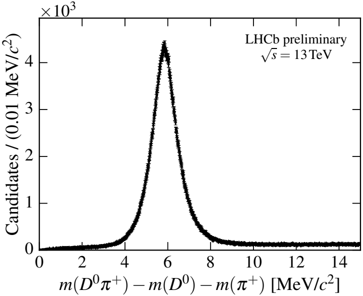
- new: TURBO++ stream is TURBO plus:
  - persist arbitrary variables like isolation with HLT candidate
  - can now save HLT candidate + any reconstructed particles

  → can do qualitatively new things (at higher rate & statistics per storage space) on HLT output
    - entire analysis can be done on trigger output, incl. flavour tagging
    - e.g. in charm spectroscopy: $D^* \to D^0(K^-\pi^+)\pi^+$

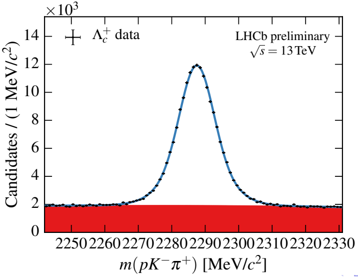
HLT improvements: TURBO++ stream

$B_s \to J/\psi K^+ K^-$





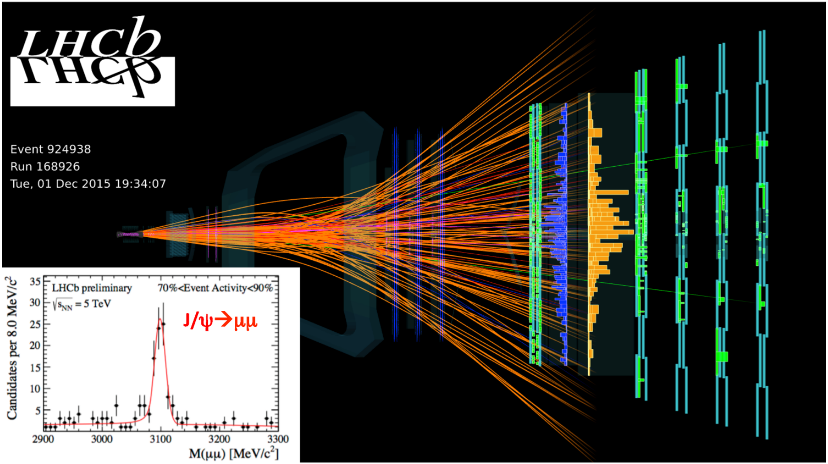
$D^{*+} \to D^0(K\pi)\pi^+$



$\Lambda_c^+ \to pK^-\pi^+$

heavy ions

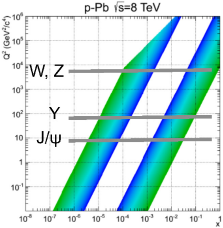
Event display with a $J/\psi \to \mu\mu$ candidate from PbPb data



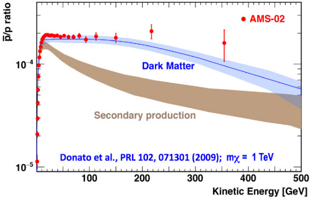
- LHCb has become a player in heavy ion physics, too

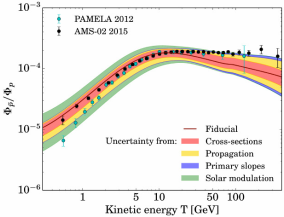
heavy ion plans

- pPb run at $\sqrt{s_{NN}} = 8$ TeV
  - high lumi run for all experiments
  - LHCb asks for 20 nb^{-1}, pPb and Pbp split 50/50
  - J/ψ, $\psi(2S)$, $\Upsilon(nS)$, and Drell-Yan production to study cold nuclear matter effects
  - Z, J/ψ, Υ production to improve nuclear PDFs
  - associated heavy flavour production to study contributions from single and double parton scattering
  - details in LHCb-PUB-2016-011
- pPb run at $\sqrt{s_{NN}} = 5$ TeV (prefer p as beam 1)
  - low pile-up minimum bias data for ALICE
  - can use SMOG system to study p-He collisions at this beam energy
  - $\bar{p}$ production valuable input for cosmic ray physics in light of AMS-02's $\bar{p}$ excess



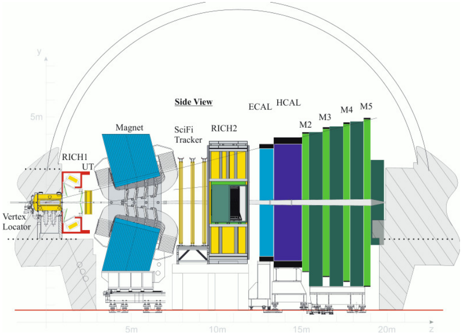
[AMS Coll., CERN 15. 04. 2015]





[arXiv:1504.04276]

overview of the detector upgrade



- LS 2 activity!
- 40 MHz readout of all sub-detectors; data processed with software trigger
  - VELO: new pixel detector
  - Upstream Tracker (UT): silicon strips
  - Fibre tracker (FT): scintillating fibres
  - RICH: new PMTs, readout electronics
  - CALO: reduced PMT gain, new electronics
  - MUON: more shielding, upgraded readout electronics

in-depth review of the LHCb upgrade

LHCb upgrade just had an in-depth review...

Executive Summary: DAQ& Trigger for Run3

- All software trigger requires unprecedented DAQ of 40 Tbit/s, built from commercially available network and server technology
- Compact physical layout of entire Online system in new data-centre → minimizes cost (driven by high-speed interconnects)
- One common, custom-made, generic high-performance PCIe board for data acquisition, slow and fast control (adopted by ALICE)
- Encouraging results with small scale tests give confidence on the feasibility of the 40 MHz readout system
- Continuation of proven, universal Experiment Control System
- Close collaboration with industry partners to maximize performance of upcoming technologies
- All mile-stones so far met in time, on good track to meet upcoming ones

NIKO NEUFELD, DAQ & TRIGGER LHCC IN-DEPTH REVIEW, 23/05/16 21

Executive summary

- LHCb is undertaking an ambitious and novel event selection strategy for the upgrade
- Run 2 is serving as a demonstrator for several crucial ingredients
  - Real-time alignment and calibration
  - Real-time analysis without the need for offline processing
- We have identified areas missing expertise in the upgrade reconstruction sequence and are addressing them
- Several improvements to core parts of the sequence since the TDR using the present framework
- These can be ported to the upgrade framework as it evolves

C. Fitzpatrick, May 22, 2016

Conclusion

- Rather precise programme of work has emerged from brainstorming in the last few months
  - Very ambitious, but necessary
- On the short term:
  - Individual tasks described
  - First software hackathon scheduled on May 26-27th
  - Review progress in forthcoming computing workshops
    - Weeks of May 30th and November 14th
- 2016 is a crucial year
  - We must use it to define what changes are needed
    - Can we afford to put them in place (effort)
    - Can we afford to NOT put them in place (physics performance)
  - Any technology not demonstrated for the TDR will almost certainly not be adopted
    - In particular where changes are intrusive and require long lead times for implementation, integration, commissioning.
- Finding (and retaining) effort is the weakest aspect

C. Bozzi - 23/05/2016 20

Summary

- simulation, reconstruction and understanding of the upgrade performance significantly advanced
- detector optimization finalized
- first complete reconstruction sequence will be ready these days
  → input to tune trigger strategy and study physics performance
- b-daughter reconstruction efficiency for long tracks > 94%
- PID performance expected to be comparable to Run-II
- demonstrated that alignment framework works for the upgrade for the VELO expect to work similarly smoothly for UT & SciFi

Stephanie Hansmann-Menzemer 14

Executive SUMMARY

- LHCb-LS2 program is very challenging: 2y will be needed for removal and installation of detectors and services, without much room for contingency.
- The activities related to VELO, UT, RICH1, and the first section of the beam pipe are correlated in time (sequence to respect) and space.
- LHCb has set up a dedicated organization for LS2 to address the challenges of the upgrade project
- LHCb is finalizing the specifications and requirements for detector services and infrastructure.
- The drafting of work packages with other support teams is in progress.
- Work is already proceeding full speed at P8, to prepare for detector assemblies and tests.

Eric Thomas PH-LBO 26

Executive Summary

The VELO will be upgraded to a 40 MHz readout pixel detector situated at a closest approach of 5.1 mm from the LHC beams

Pre-production sensors and Timepix3 prototypes have shown excellent performance; PRRs moving ahead with small delays

Electronics, readout and DAQ Integration proceeding on schedule
RF foil is a very challenging project on track

VeloPix ASIC is .... (submitted?)

Mechanics faces a challenge to be ready for the EDR. Extra effort has been identified to boost this part of the project

Microchannel cooling plates which form the cooling backbone of the modules is delayed, schedule is being compressed to accommodate

Module design and production in all other aspects is on track.

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Conclusions

- We have achieved significant progress & we are poised to transition to construction of all the important components of the upstream tracker in 2016
- Some schedule delays (mostly driven by electronics components) but well on-track to be ready for installation in July 2019

5/23/2016 M. Artuso LHCC 'in-depth' review 24

Conclusions/executive summary

- New set of dates for RICH Milestones has been presented to LHCb and LHCC.
- Pre-series of MaPMTs (50 + 20 pieces) received and being evaluated, first results in line with expectations. QA Centres ready for production validation.
- A complete demonstration system (SysLab@CERN) is operational since ~2 years and open to all RICH collaborators: four successful Test Beam Sessions in 2014-15, high event-rates system-tests, electrical and thermal studies, environmental monitoring and controls, compliant software development, etc.
- 2015 radiation tests indicated issues with some On-detector Electronics:
  - New RHBD CLARO version submitted and recently received (first functional tests OK, rad. tests starting shortly);
  - Radiation tests on DEB FPGA ongoing, results second half of 2016.
- Final (we expect) components for our opto-electronic chain will arrive in our labs in 3 weeks.
- Intensive Lab activities and Test Beams will be required before and after PRRs and production phase (from 2nd half 2016); test beams starting end-June.
- Challenging goal of sticking all the needed elements and functionalities inside RICH 1 and 2 demonstrated! EDRs for RICH 1 and 2 Mechanics/Optics held on 18th of May successfully passed.

Thank you!

Carmelo, LHCC, 23 May 2016 34

Executive summary

- SciFi project is at the transition to fibre mat and module series production
- Test beam results validate 6L and 8L mat design
- Fibre order placed, pre-series delivery has started. End of delivery in January 2018.
- Fibre bump problem solved. 6L mat remains baseline.
- Successful PRR for fibre mats at one centre. Other 3 centres rapidly advancing.
- SiPMs from 2 vendors. Viable solution in hand, however expect further improvement. EDR passed.
- Full electronics readout chain prototyped. EDR passed.
- PACIFIC3 ASIC works, but requires improvements (as anticipated). PACIFIC4 submission in June.
- Good progress on Readout/cold box. EDR this summer.
- Large efforts on interfaces, integration, infrastructure.
- Project has so far been able to follow the planning.
- The incompressible fibre delivery schedule will entail delays in the completion of fibre mats and modules (due to the), however those are not on the critical path and should not delay the completion and installation of the detector.

C. Joram / CERN LHCC In-Depth Review 22 23/05/2016

Executive summary

- Analog electronics
  - EDR passed, PRR beginning Autumn
  - Production should start Nov. 2016
- Front-end boards for the ECAL/HCAL (digital part)
  - FEB design well advanced (EDR this summer)
  - Production should start mid 2017
- Control board (3CU) - HV/Calibration/Monitoring systems
  - Prototyping level
  - Schedule follows approximately FEB planning
- Readout (TELL40 calo specific code)
  - Optical link path well defined (number of links, patch-panels, etc...)
  - Already an important activity on TELL40 microcode
- Installation/Dismantling/Commissioning
  - Prepare operations and define tools (new and recuperated ones)

All ingredients ready for installation by the end of 2018

Monday May 23rd, 2016 Frédéric Machefert - LHCC in-depth review 17 / 17

Executive Summary

- The muon system readout electronics will be upgraded to allow a 40 MHZ readout; the control electronics will also be upgraded to allow a faster detector control/monitoring using the new LHCb communication protocols
- The shielding upstream of M2 will be redesigned and tungsten components will be used
- Spare MWPCs will be built to guarantee the required spare detectors for the LHCb upgrade phase
- Many important achievement in the last 6 months: electronics EDR, nSYNC ASIC prototype submission, nODE and nSB board in preparation, new shielding design ongoing, muon-specific TELL40 firmware in development
- In the next 6 months: ASICs test and final chip design, new electronics full-chain tests, start production of new shielding components
- Board production is expected to start in 2017
- The material procurement is in a well advanced state
- Activities are proceeding according to schedule and there are no important delays or items on the critical path

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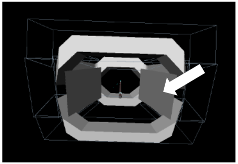
LHCb upgrade

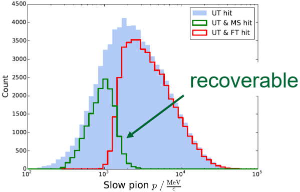
…so I will have to pick a few points to summarise

- good progress on all subsystems
  - entering production phase for many subprojects
  - where possible, perform work proactively (LS2 is short!):
    - installation of CO_2 cooling lines, optical fibres (for DAQ), shielding in MUON during EYETS
    - software, HLT in particular, is employing some of the techniques needed for upgrade: nice demonstator!
  - progress monitored through milestones

beyond the phase 1 (LS2) upgrade

- began discussion about evolution beyond current upgrade
  - plans discussed in a recent workshop in Manchester
- LS3 is ideal opportunity to
  - consolidate existing improvements
  - further modest developments
  - → could significantly enhance LHCb's capabilities in specific areas
  - example: side chambers in magnet to improve acceptance of low momentum tracks (e.g. slow π from D^* and high multiplicity decays)





- longer term (LS4): phase 2 upgrade, allowing operation at high lumi ($\sim 2 \cdot 10^{34}\ \mathrm{s}^{-1}\mathrm{cm}^{-2}$)
  - physics case under development
  - machine aspects being studied (thanks to HiLumi LHC team!), and so far are promising
- more information will be presented to LHCC in near future

summary and conclusion

- LHCb physics programme continues to yield new results
  - a^s_{sl}, Δm_d, exotic states, UT angle γ
  - plenty more, stay tuned for the summer conferences
- successful startup in 2016
  - 2016 will be like 2015, only better…
  - we're taking data successfully
  - 2016 HLT has become even better, allowing qualitatively new analyses
- heavy ion run is being planned with exciting physics objectives
- LHCb upgrade is progressing well
  - many subprojects entering construction phase
  - test new technologies and prepare where possible already during run 2
  - thinking about the upgrade beyond LS2

backup

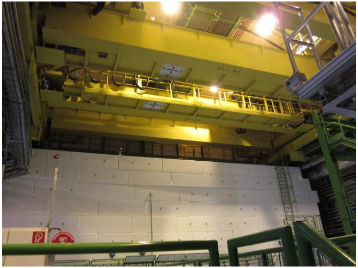
backup slides

EYETS: replacement lift and cranes

Replacement of Lift (AS713) and overhead cranes (P720-721)

- both inherited from DELPHI, 30 years old
- not compliant with modern standards (e.g. EN80-20)
- electrical components no longer available

→ increased maintenance and repair cost



- baseline: proceed with both in parallel
- provisional planning: 9 weeks (from 07/02/17 to end of TS)

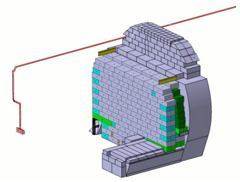
→ work on detectors shall be completed by end of January 2017

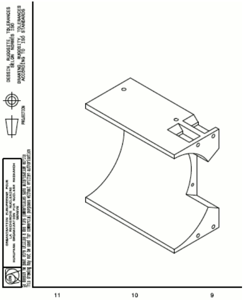
EYETS: upgrade preparation, standard work

- preparation for the LHCb upgrade

  aim: reduce as much as possible LS2 workload

  - installation of CO_2 cooling transfer lines for UT and VELO
    - from UXA to UXB, through shielding wall
    - will allow early commissioning of cooling plants
  - installation of additional shielding for MUON
    - at M2 beam plug, replace iron by tungsten
    - expect 60% rate reduction in M1
  - installation of optical support path
    - fibres from US/UX border to patch panels at detector





+ standard EYETS workload:
  - maintainance and test of all infrastructure, detector services and safety systems