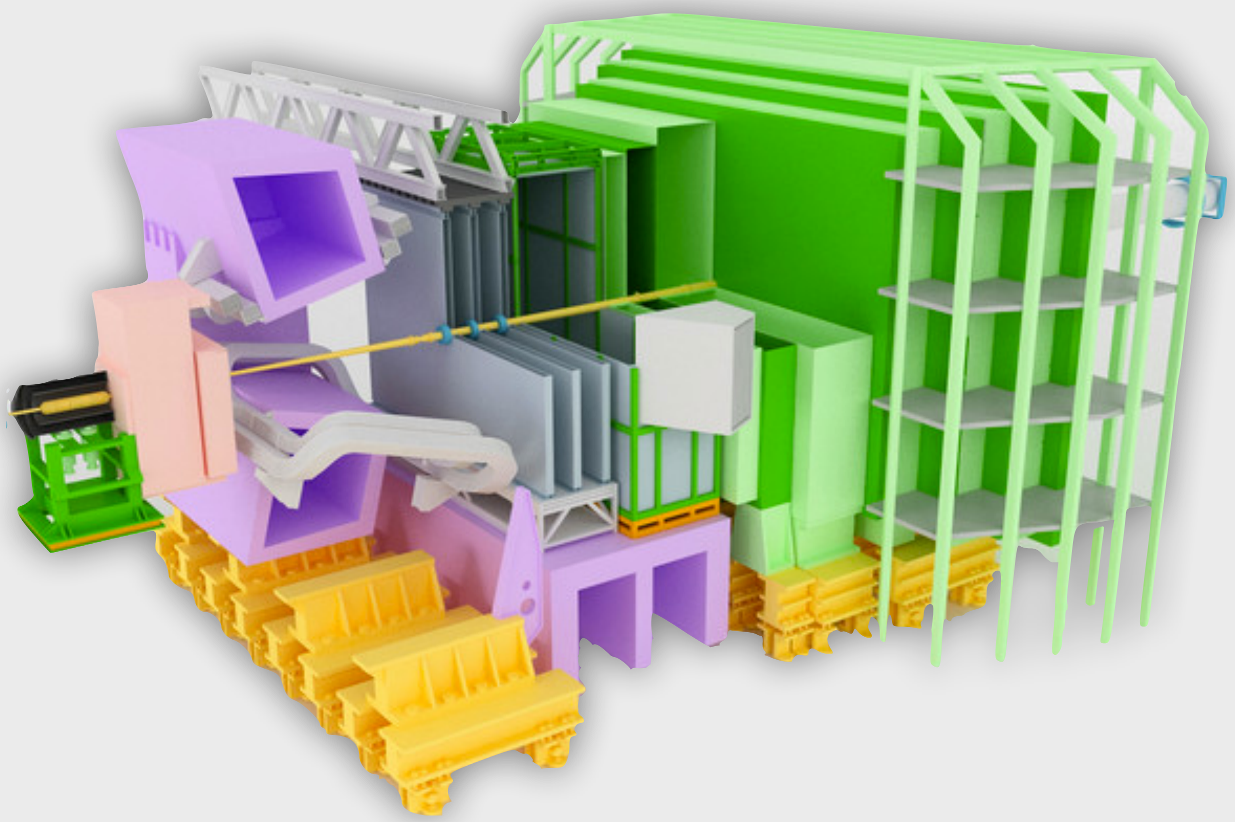


LHCb & LHCb upgrade

Marco Gersabeck (The University of Manchester)
on behalf of the LHCb-UK groups

PPAP Community meeting - Birmingham - 26 July 2016

MANCHESTER 1824
The University of Manchester

Antimatter Matters

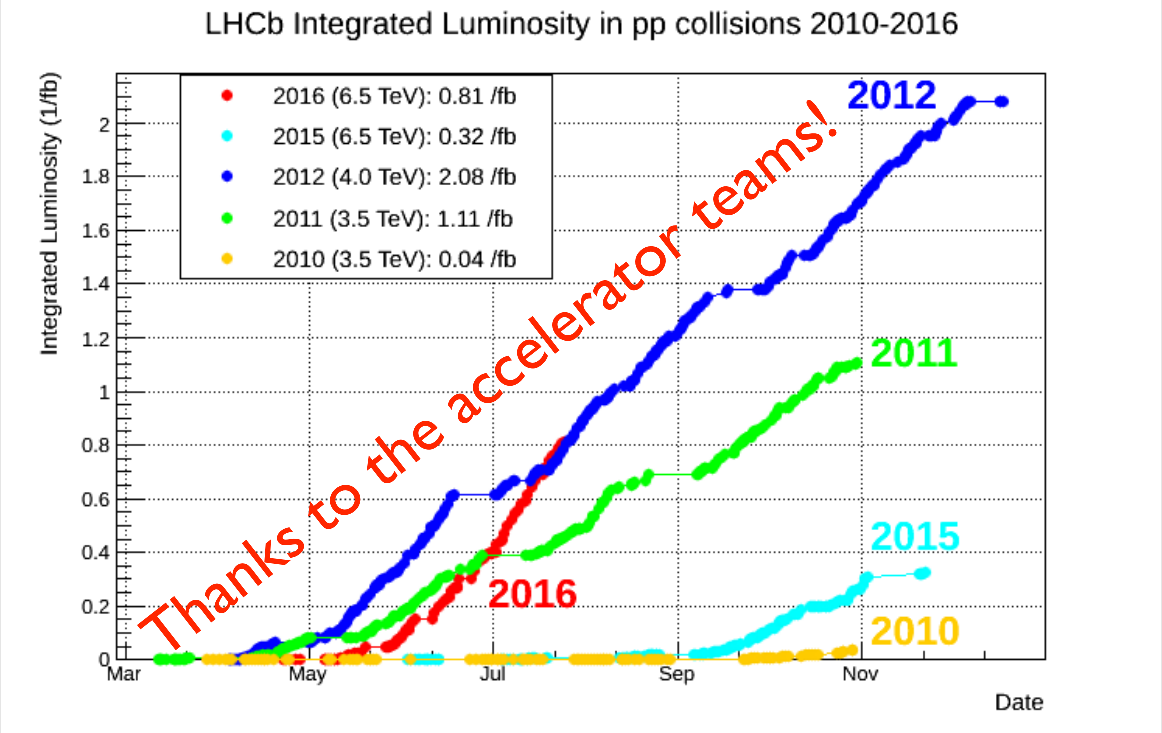
~10'000 visitors

60% got more interested,
38% already interested in physics

LHCb & ALPHA @ Royal Society Summer Science Exhibition 2016

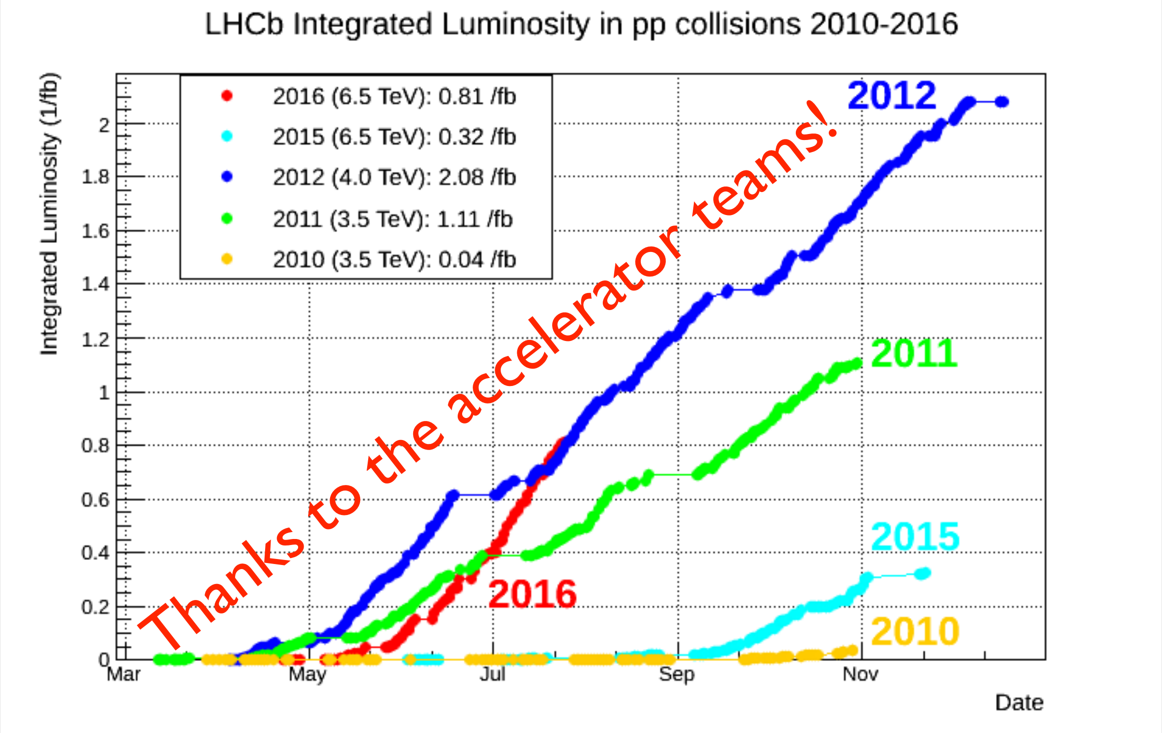
Introduction

- News
  - ➡ Tim Gershon took over from Chris Parkes as LHCb-UK spokesperson
  - ➡ Chris will remain PI for the LHCb-upgrade project

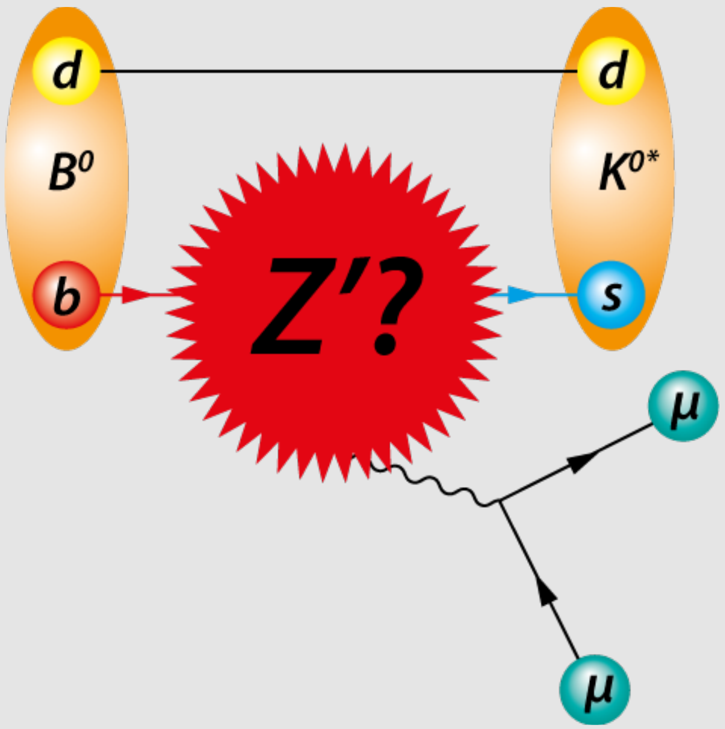


Introduction

- News
  - ➡ Tim Gershon took over from Chris Parkes as LHCb-UK spokesperson
  - ➡ Chris will remain PI for the LHCb-upgrade project

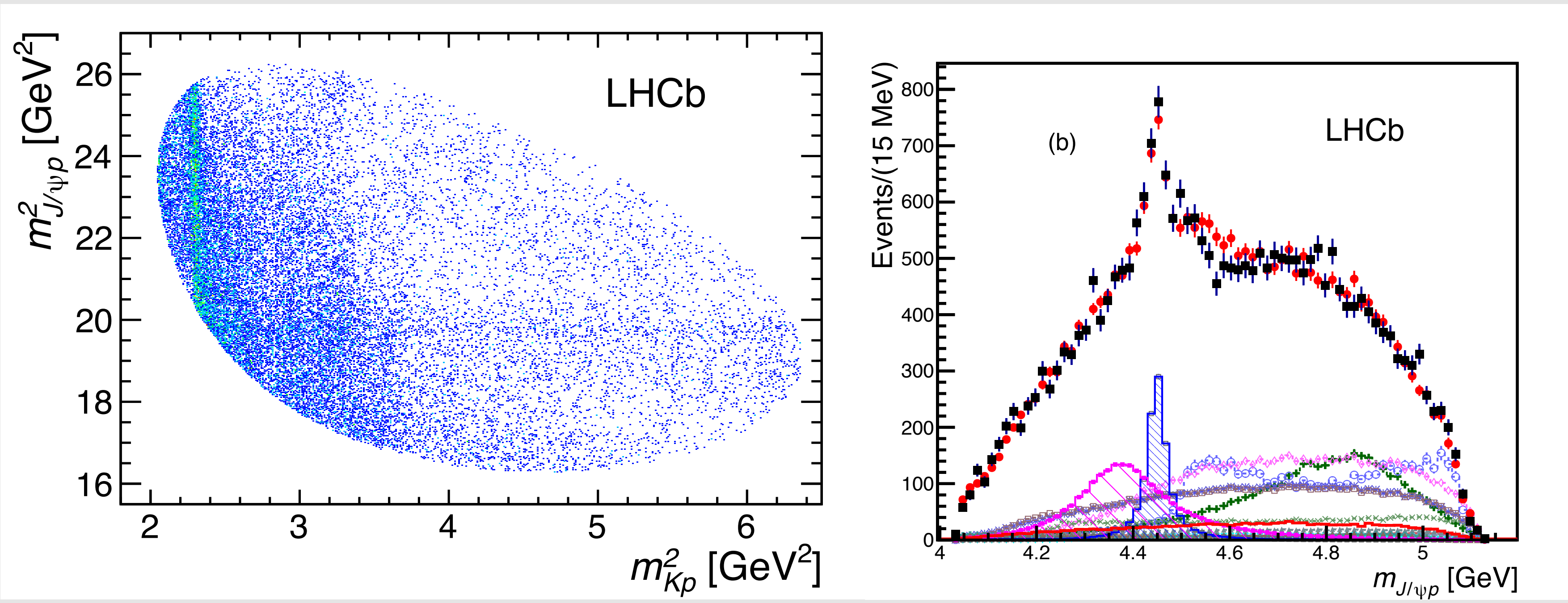


- Flavour physics and much more
  - ➡ Precision measurements
  - ➡ New particles can enter in quantum loops
  - ➡ Looking for deviations from SM behaviour

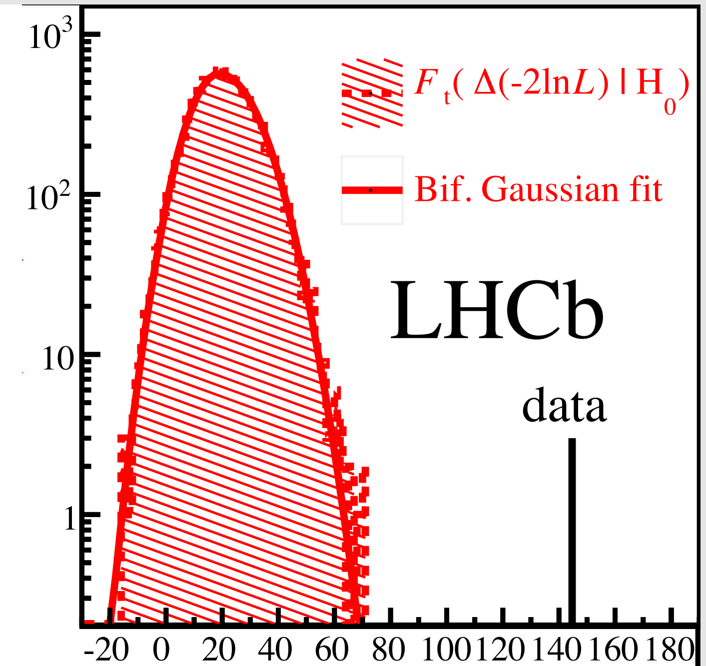


Tetraquarks and Pentaquarks

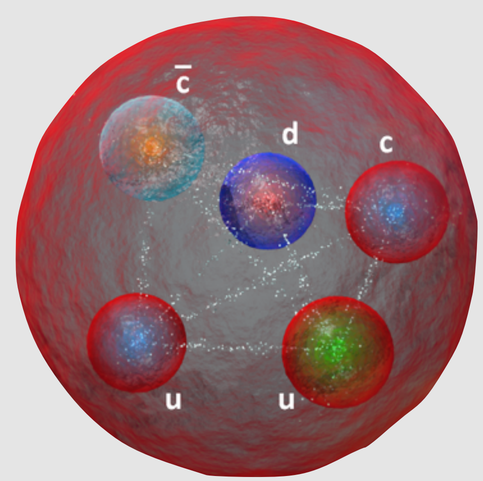
Phys. Rev. Lett. 115 (2015) 072001



arXiv:1604.05708

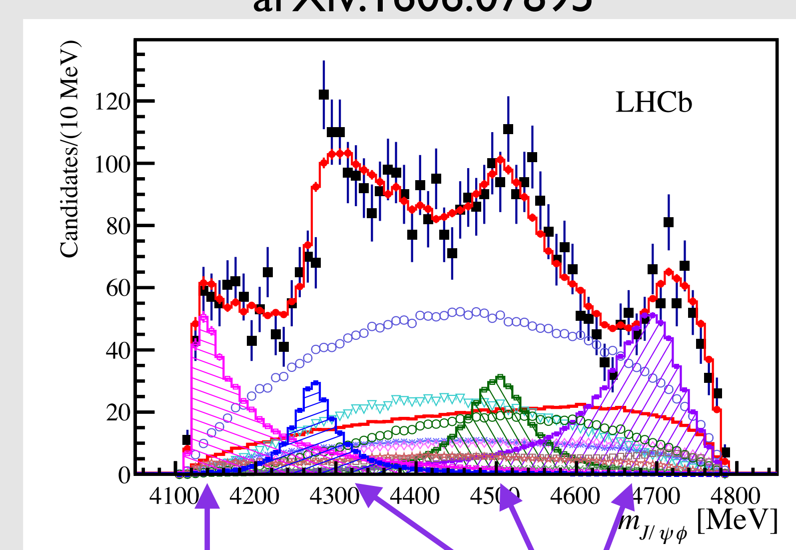


- Two pentaquark candidates discovered in 2015
  - ➡ Model-independent confirmation in 2016



- Four tetraquark candidates observed decaying to J/ψϕ
  - ➡ First full amplitude analysis
  - ➡ Three new states plus one known suspect

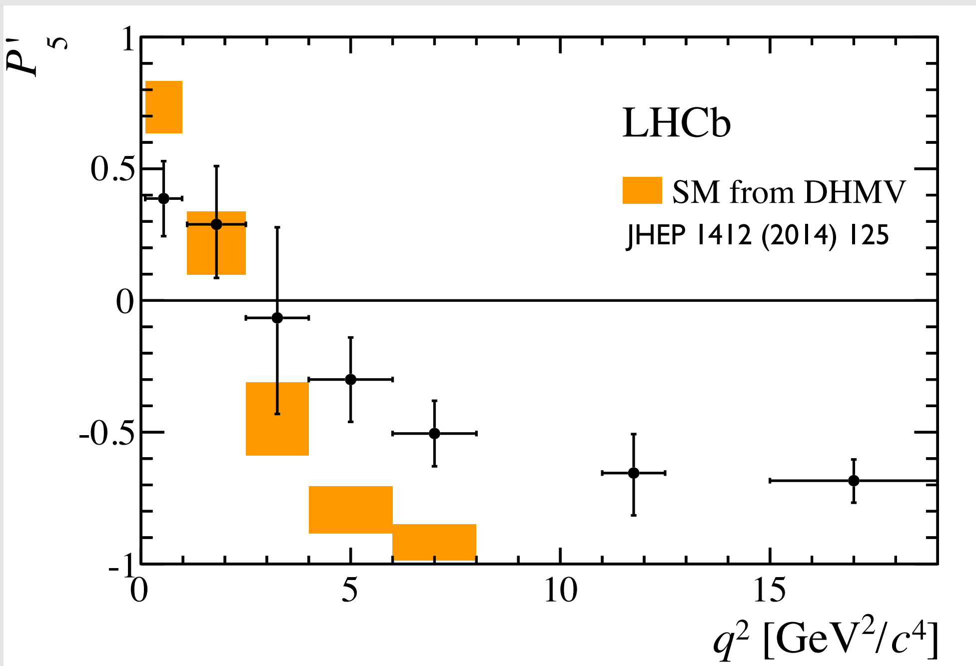
arXiv:1606.07895



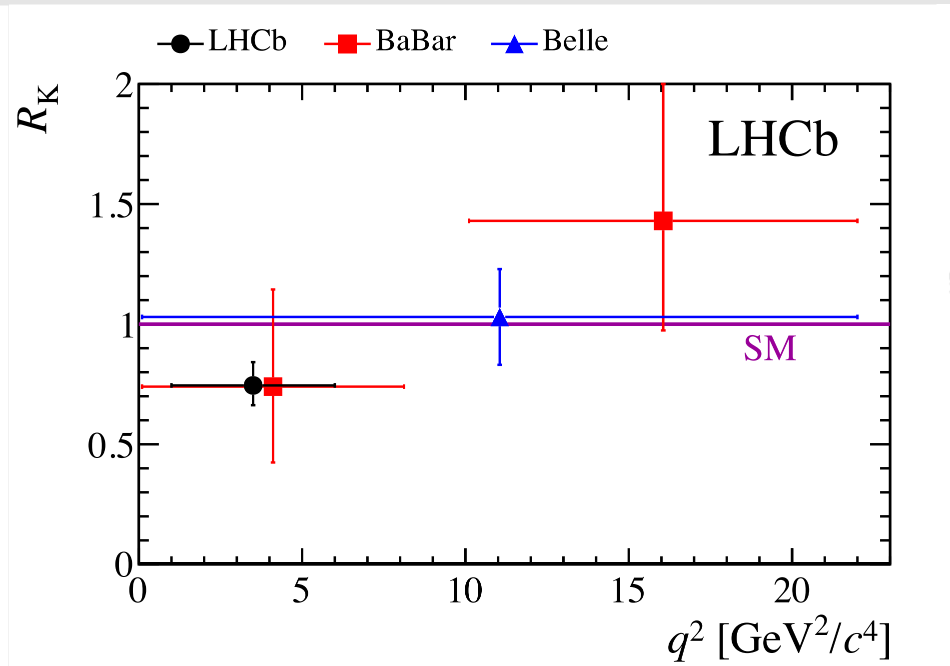
$D_sD_s^*$ cusp? NEW

Rare gems

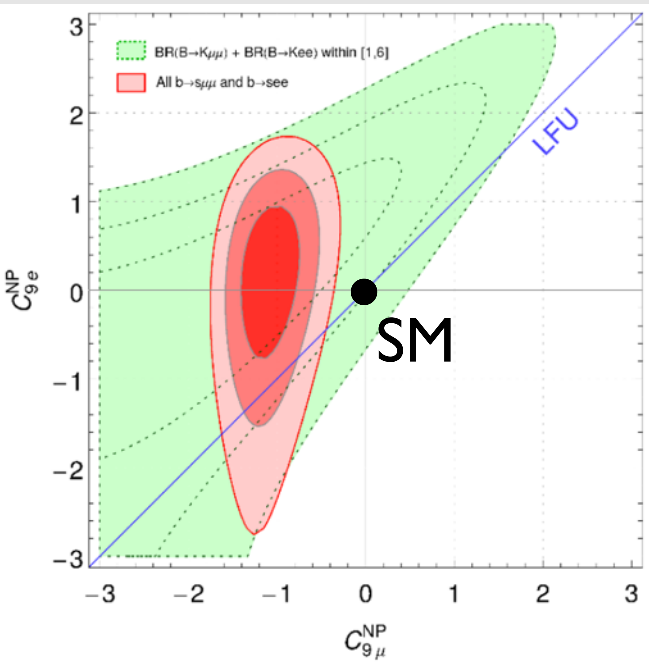
JHEP 02 (2016) 104



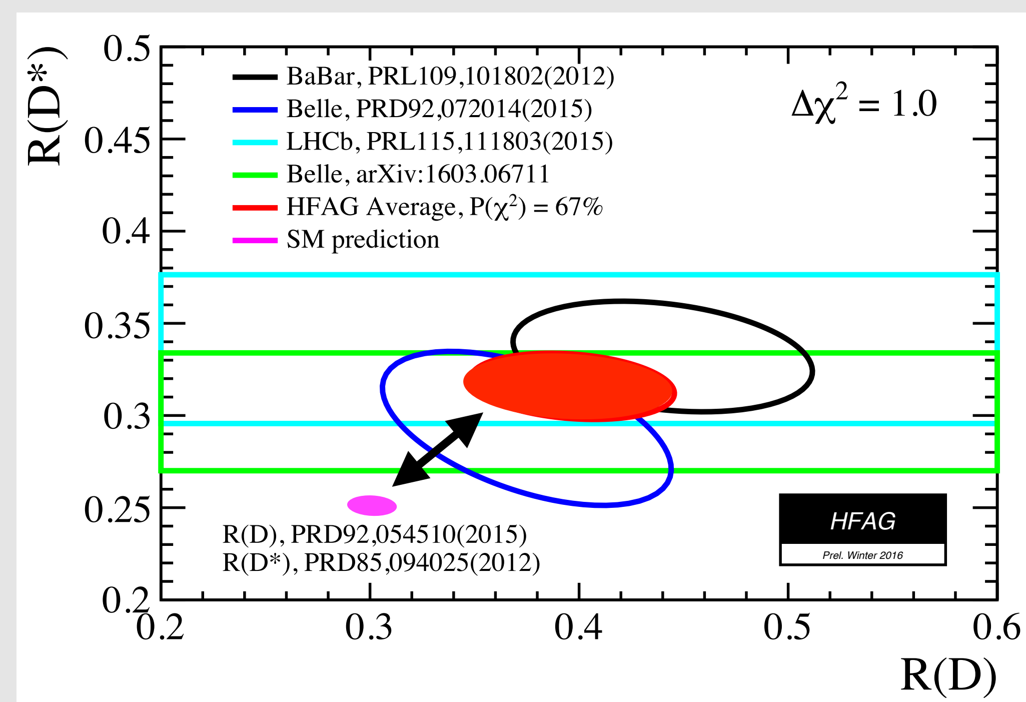
PRL 113 (2014) 151601



Descotes-Genon et al.,
JHEP 06 (2016) 092

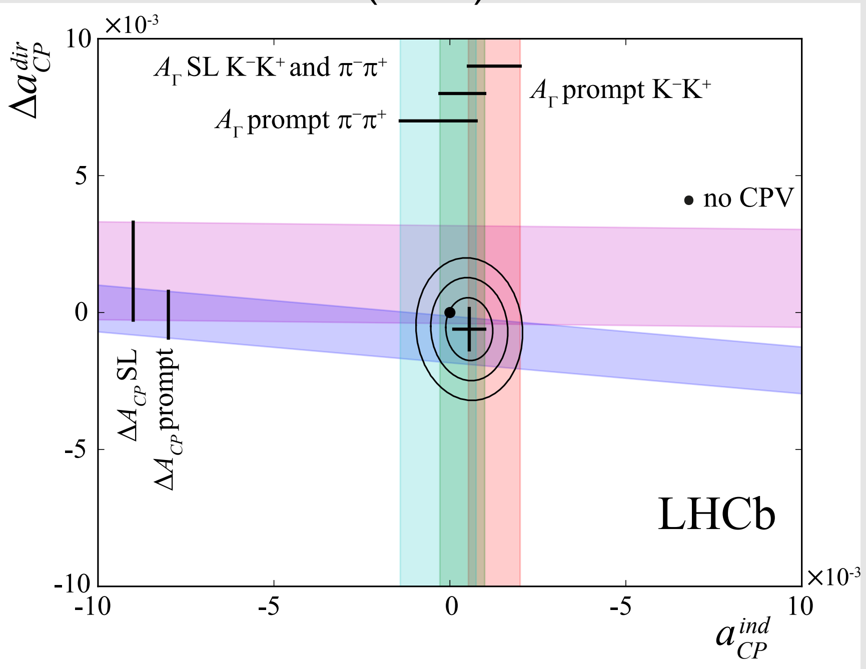


- Several SM tensions
  - ➡ B→K*μμ angular observables, lepton-universality in B→Kll
- Global analysis of b→sll observables points at
  - ➡ New Physics contribution to C_9 Wilson coefficient
  - ➡ C_9 different for electron and muon modes
- Also observed tension in B→D*τν/B→D*μν ratio
- Also checking in charm sector: D→eμ constraining NP models
- Run 2 and upgrade
  - ➡ Higher precision measurements to achieve better significance
  - ➡ Add more electron and tau final states to challenge LU



B+D CP violation

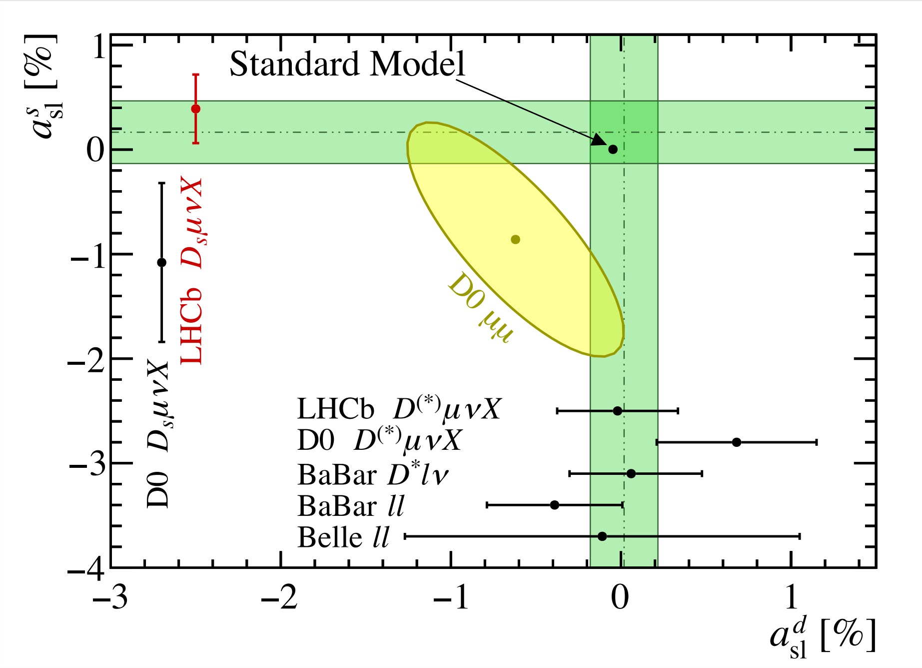
PRL 116 (2016) 191601



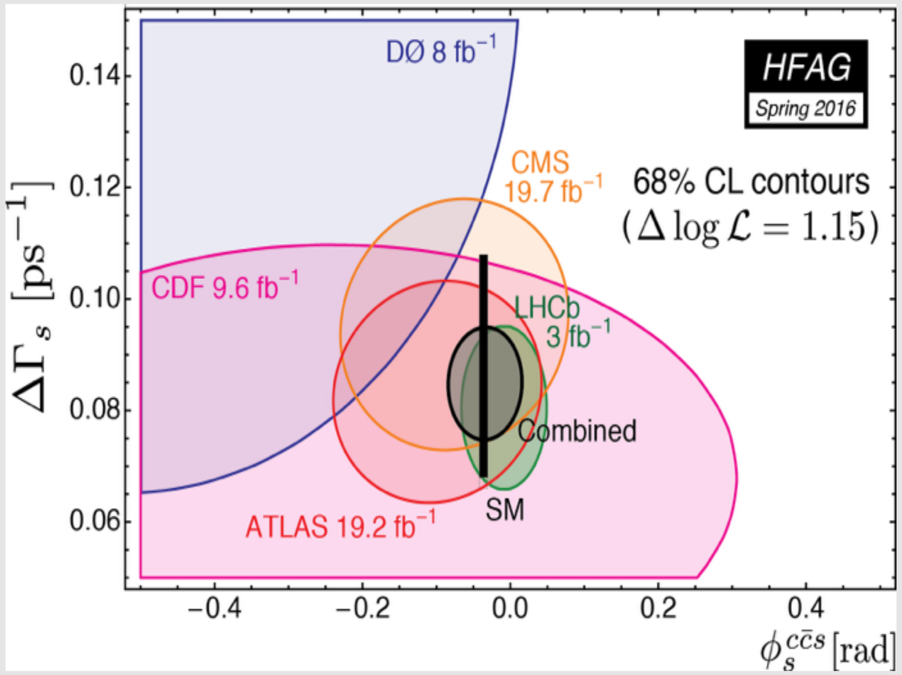
Charm CP violation constrained to sub-10^{-3} precision

Will approach SM sensitivity with upgrade

arXiv:1605.09768

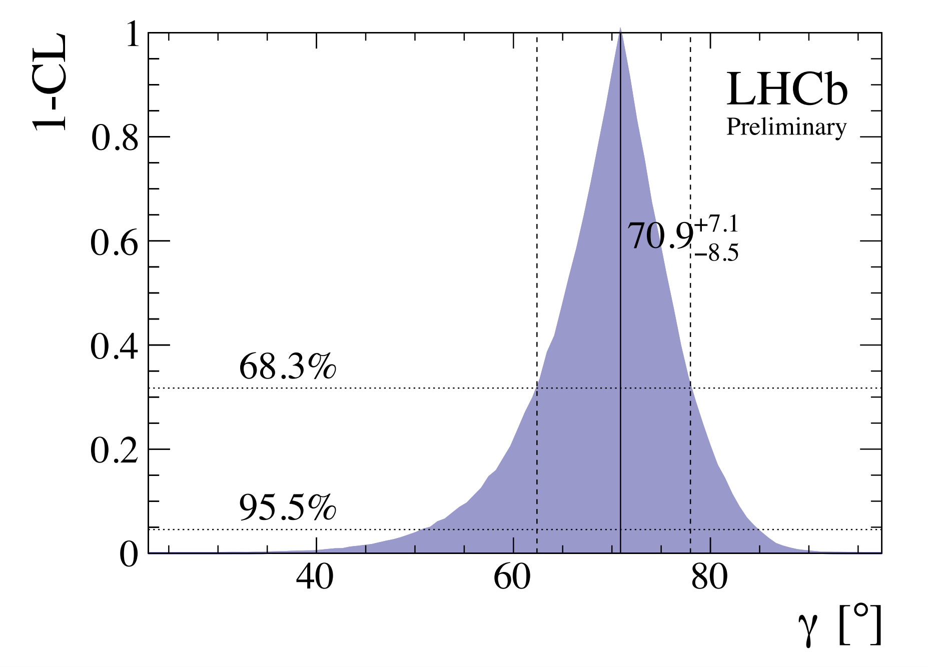


No sign for CPV in B mixing



CKM angle γ now constrained to 8° by LHCb

LHCb-CONF-2016-001



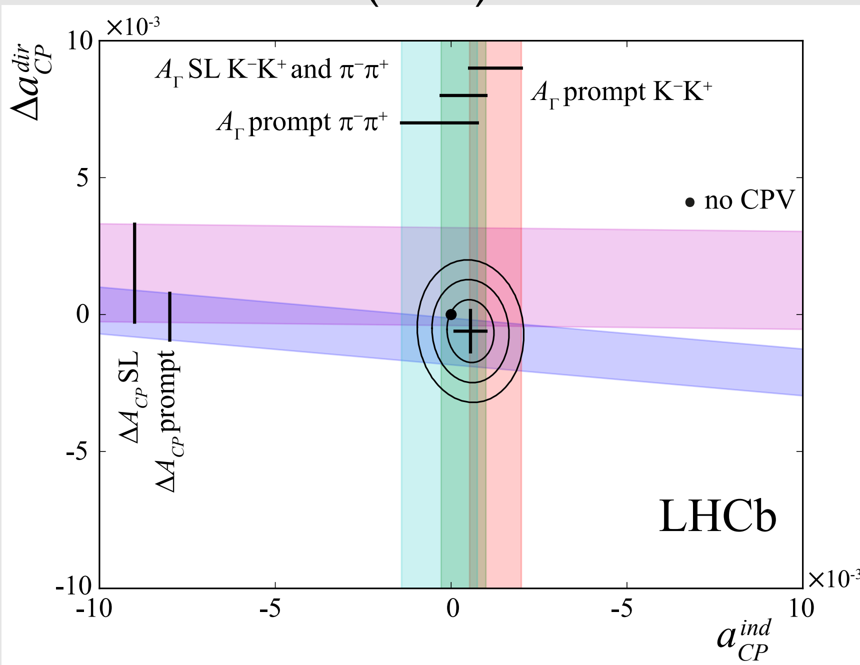
Still room for NP in ϕ_s

Upgrade will allow adding $B_s \to \phi\phi$

B+D CP violation

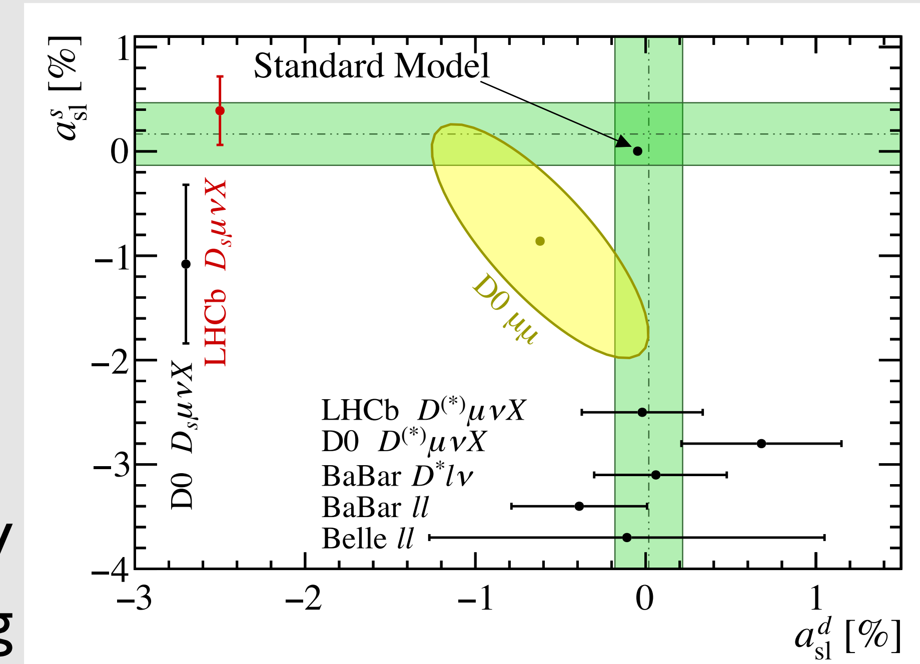
MANCHESTER 1824
The University of Manchester

PRL 116 (2016) 191601



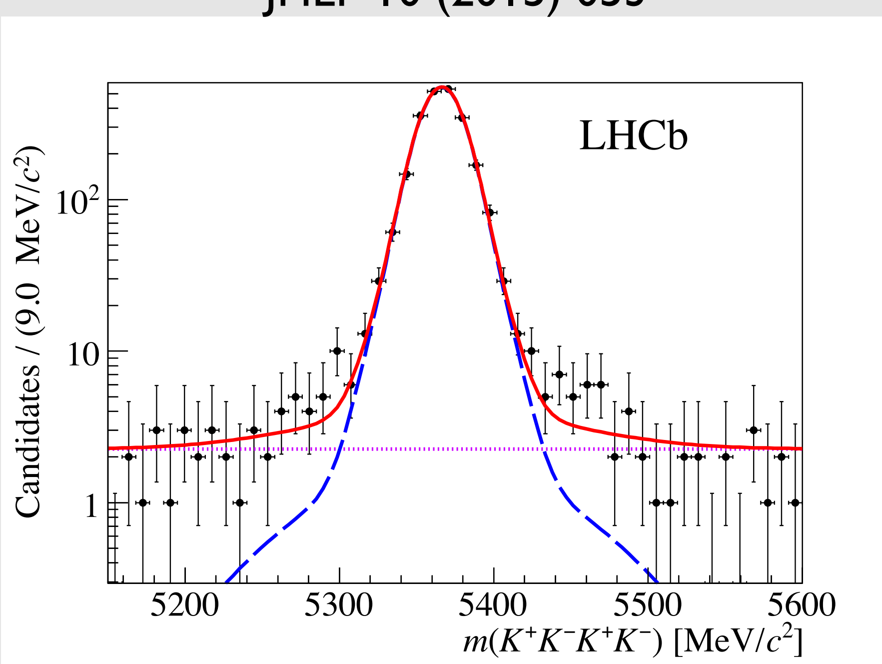
Charm CP violation constrained to sub-10^{-3} precision
Will approach SM sensitivity with upgrade

arXiv:1605.09768



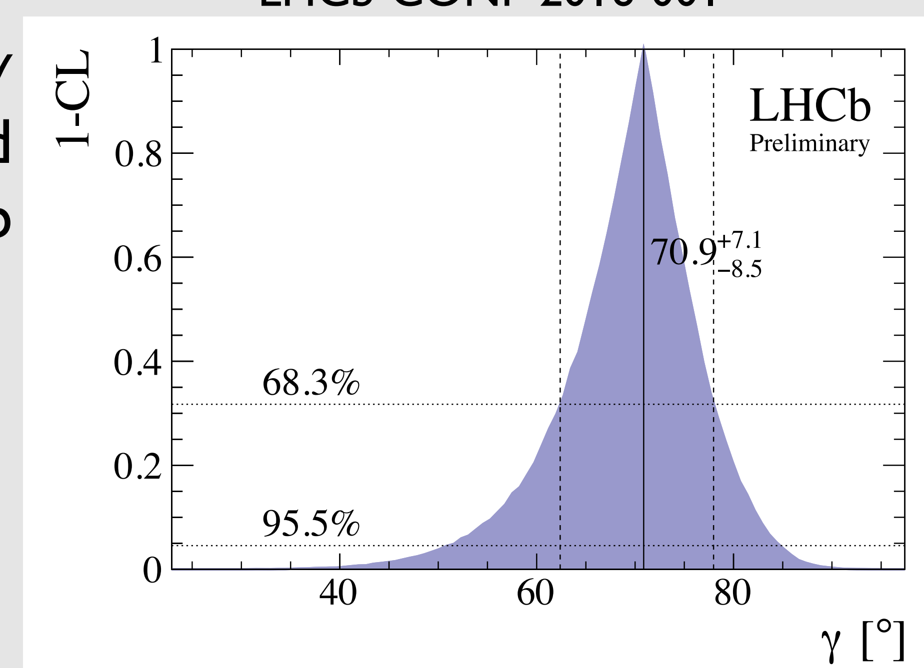
No sign for CPV in B mixing

JHEP 10 (2015) 053



CKM angle γ now constrained to 8° by LHCb

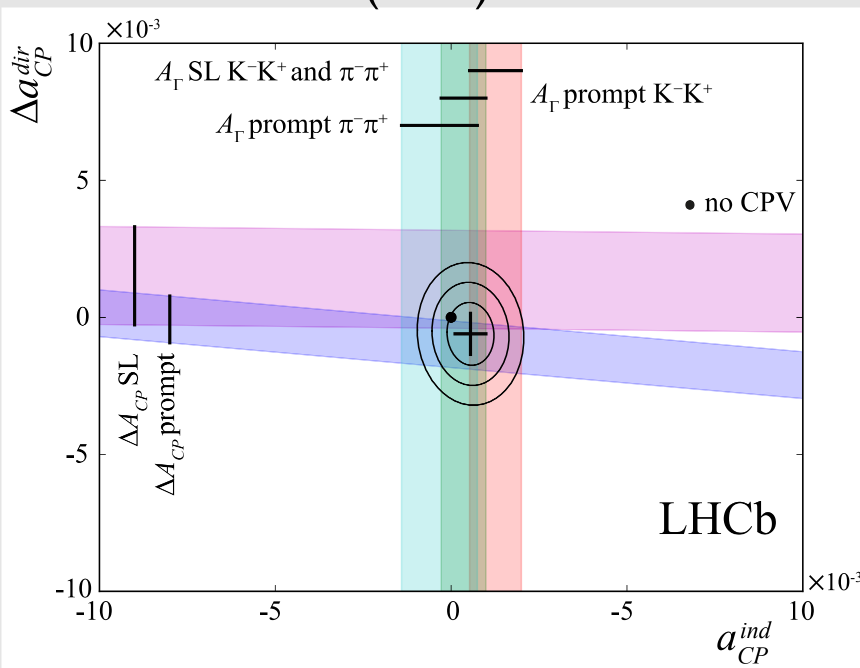
LHCb-CONF-2016-001



Still room for NP in ϕ_s
Upgrade will allow adding $B_s \to \phi\phi$

B+D CP violation

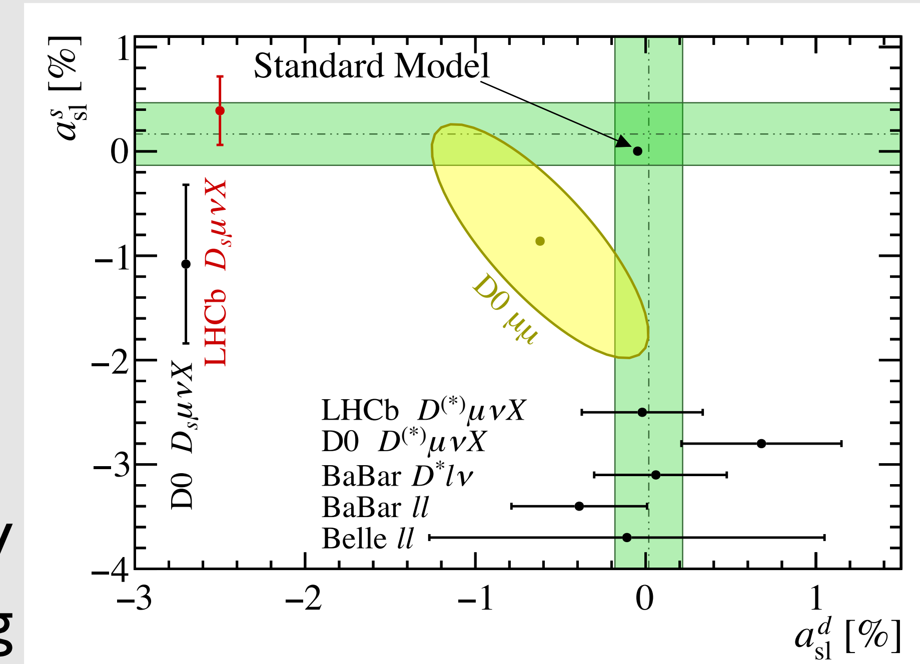
PRL 116 (2016) 191601



Charm CP violation constrained to sub-10^{-3} precision

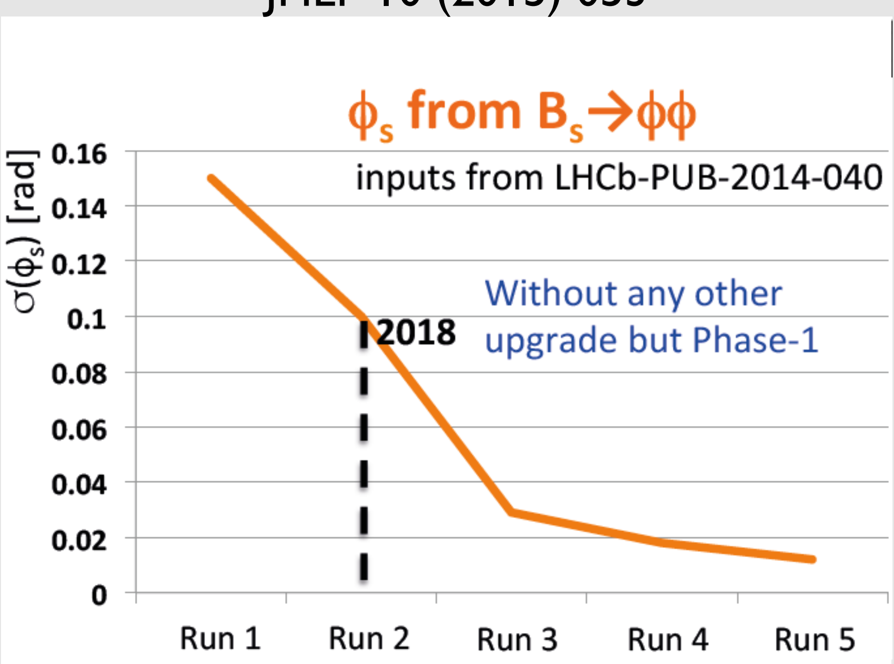
Will approach SM sensitivity with upgrade

arXiv:1605.09768



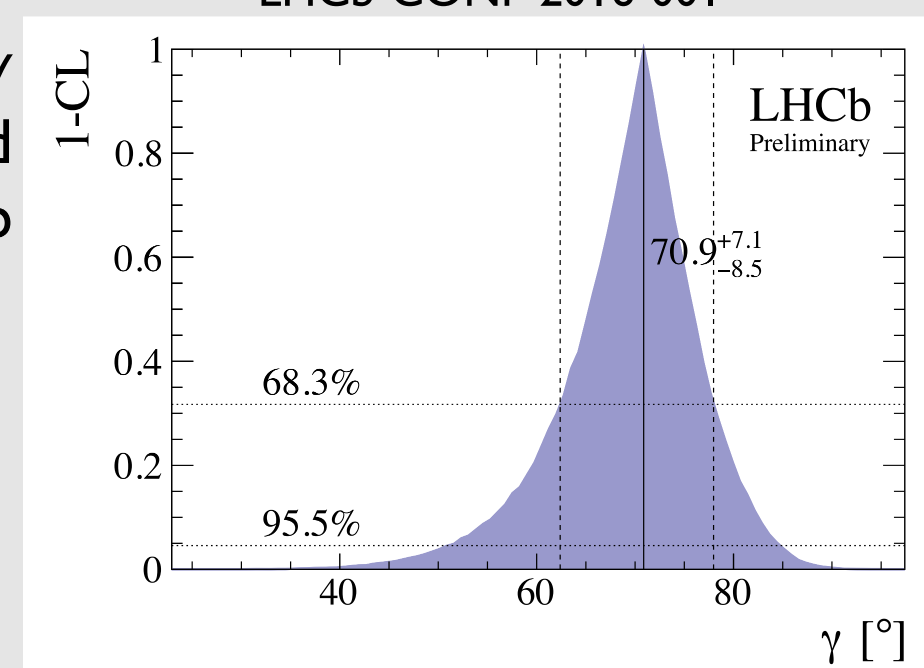
No sign for CPV in B mixing

JHEP 10 (2015) 053



CKM angle γ now constrained to 8° by LHCb

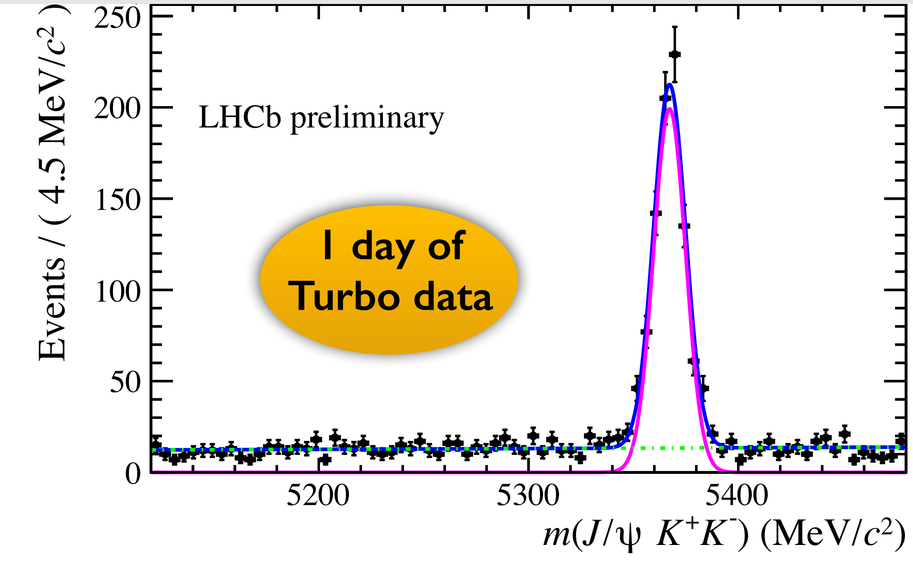
LHCb-CONF-2016-001



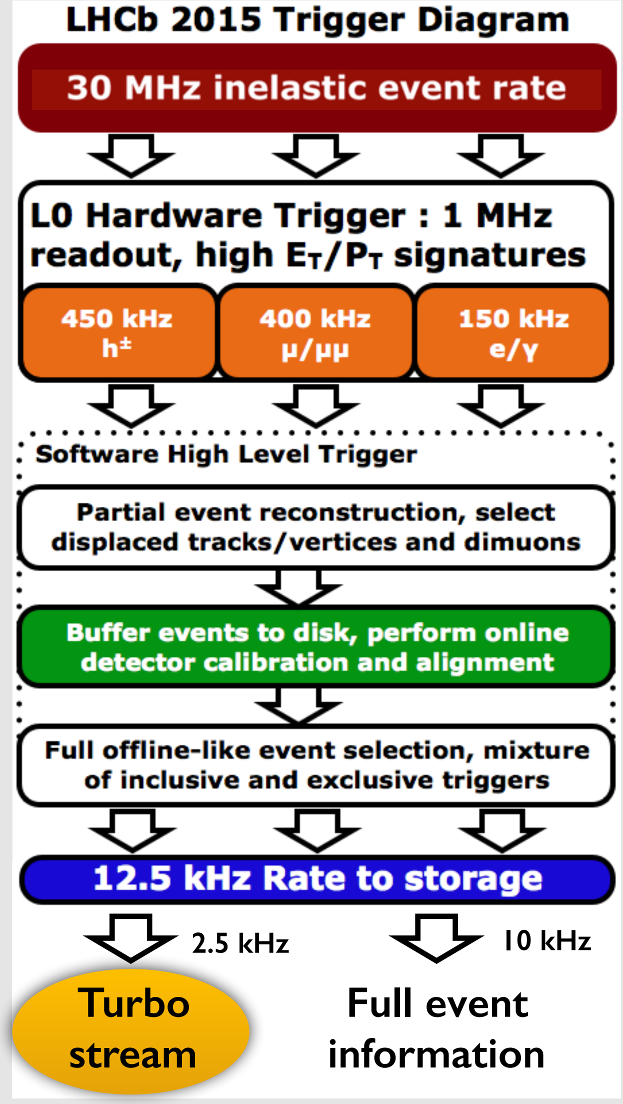
Still room for NP in ϕ_s

Upgrade will allow adding $B_s \to \phi\phi$

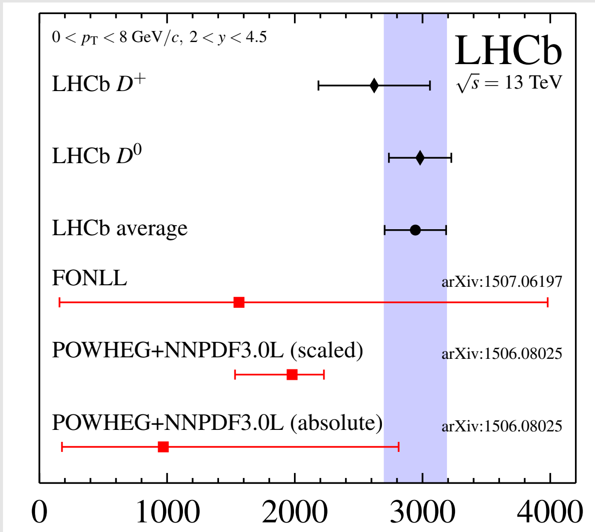
Run 2



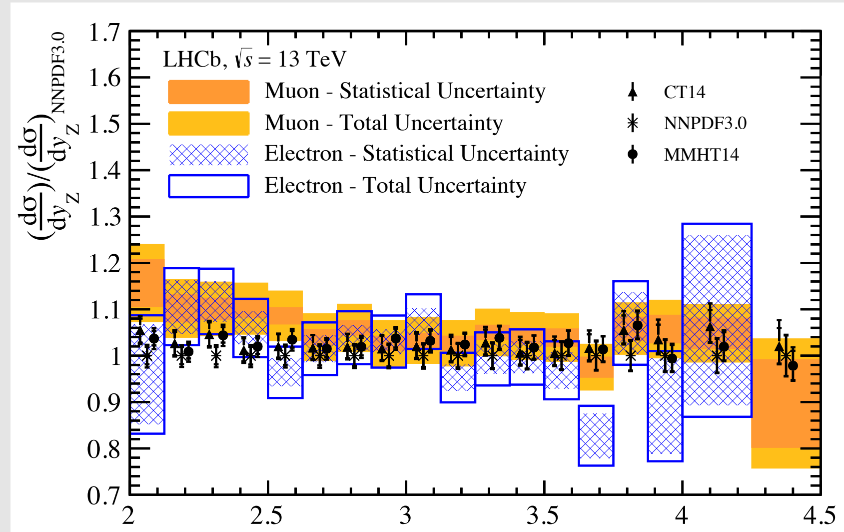
- Paradigm shift in data flow
  - ➡ Online calibration, analyses with trigger candidates
    - Turbo stream
  - ➡ Gaining experience with upgrade data flows
- Production measurements confirm expected rise in cross-section
  - ➡ D, J/ψ, Z: Impact on PDFs
- New very forward scintillators (HERSCHEL) open new opportunities for central exclusive production
- SMOG gas injection allows production studies with a range of nuclei (Ne, Ar, He)
  - ➡ Constrains neutrino production in atmosphere



Run 2

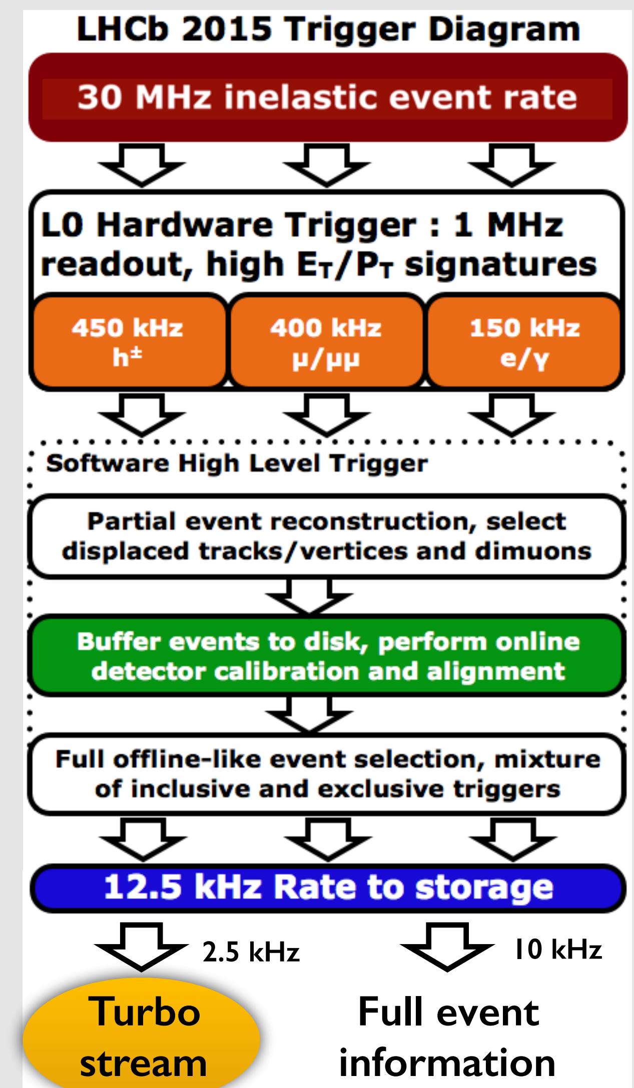


JHEP 03 (2016) 159



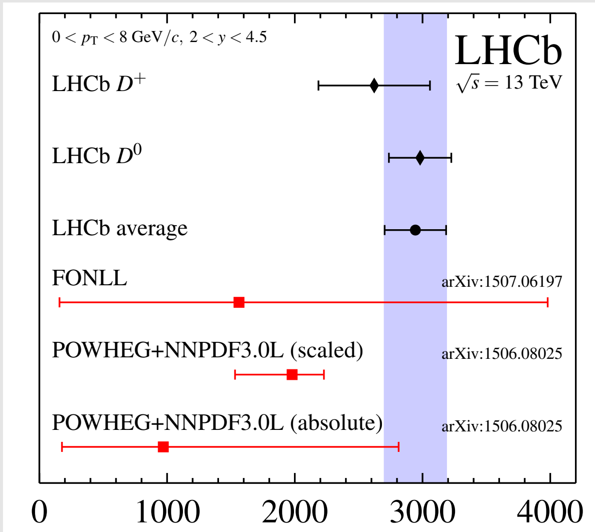
arXiv:1607.06495

- Paradigm shift in data flow
  - ➡ Online calibration, analyses with trigger candidates
    - Turbo stream
  - ➡ Gaining experience with upgrade data flows
- Production measurements confirm expected rise in cross-section
  - ➡ D, J/ψ, Z: Impact on PDFs
- New very forward scintillators (HERSCHEL) open new opportunities for central exclusive production
- SMOG gas injection allows production studies with a range of nuclei (Ne, Ar, He)
  - ➡ Constrains neutrino production in atmosphere

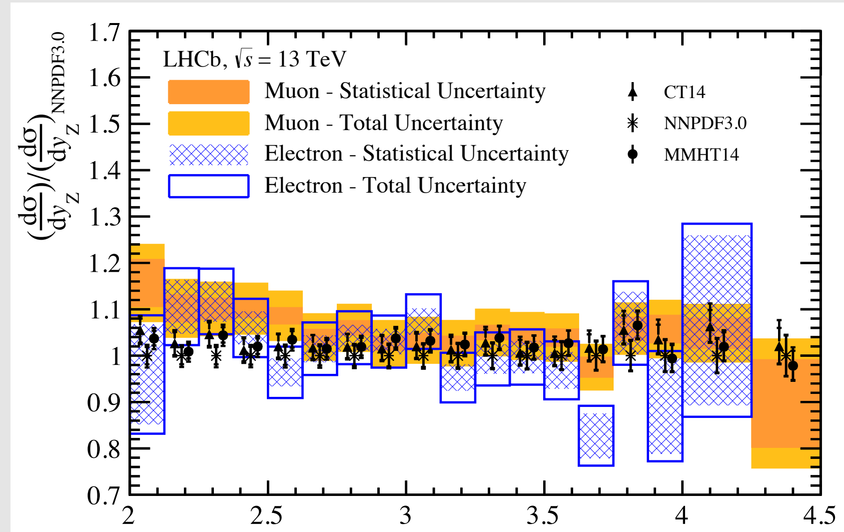


MANCHESTER 1824
The University of Manchester

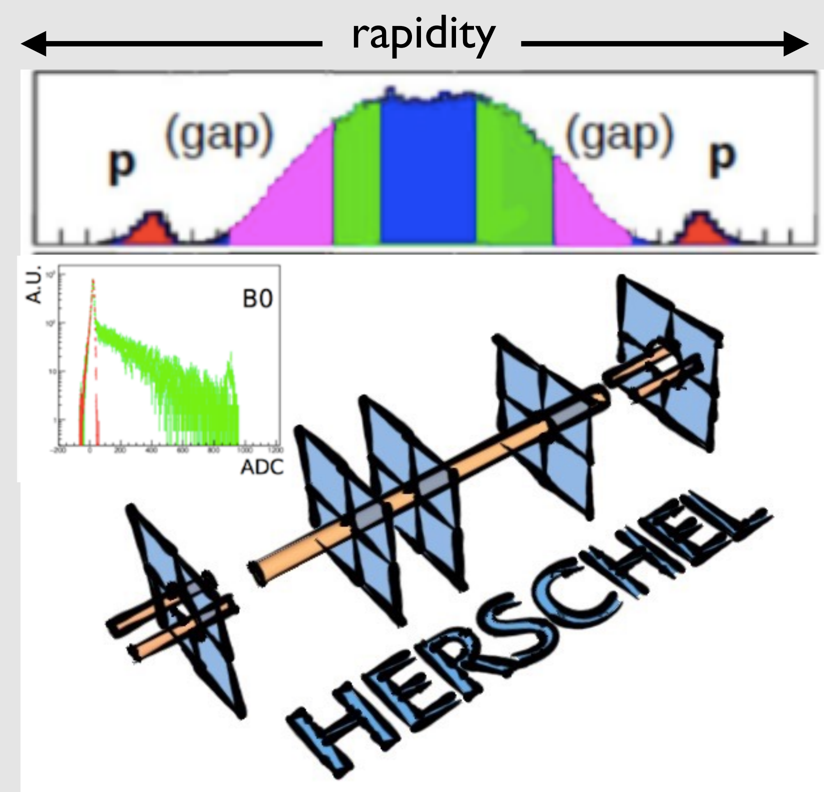
Run 2



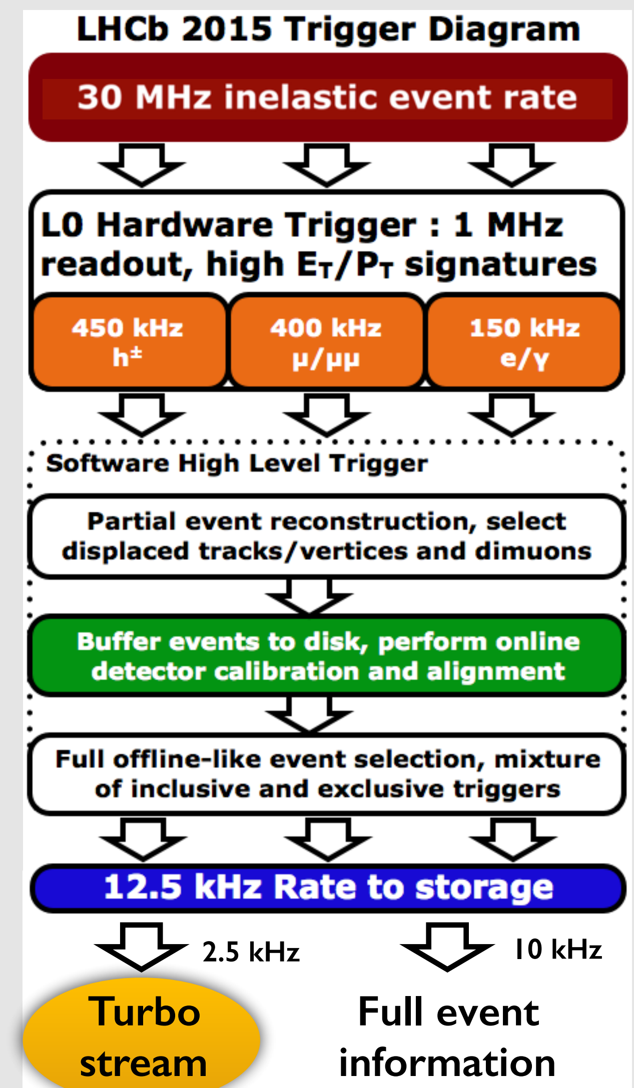
JHEP 03 (2016) 159



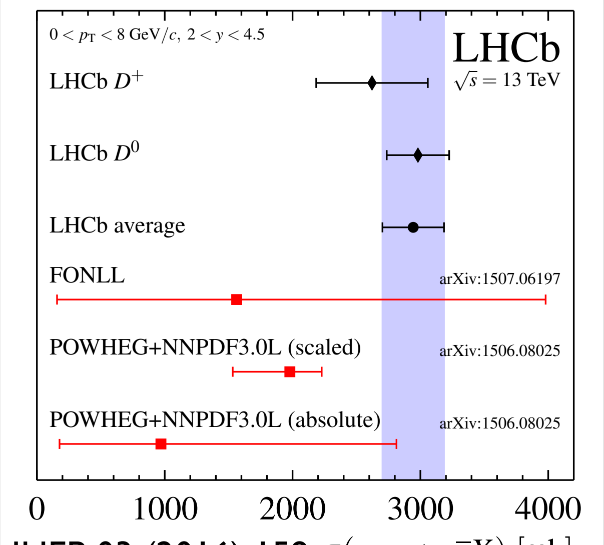
arXiv:1607.06495



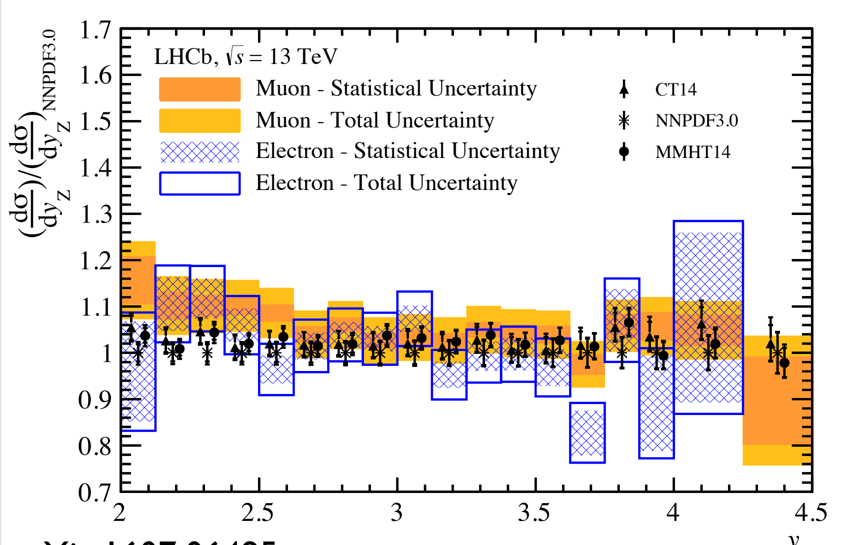
- Paradigm shift in data flow
  - ➡ Online calibration, analyses with trigger candidates
    - Turbo stream
  - ➡ Gaining experience with upgrade data flows
- Production measurements confirm expected rise in cross-section
  - ➡ D, J/ψ, Z: Impact on PDFs
- New very forward scintillators (HERSCHEL) open new opportunities for central exclusive production
- SMOG gas injection allows production studies with a range of nuclei (Ne, Ar, He)
  - ➡ Constrains neutrino production in atmosphere



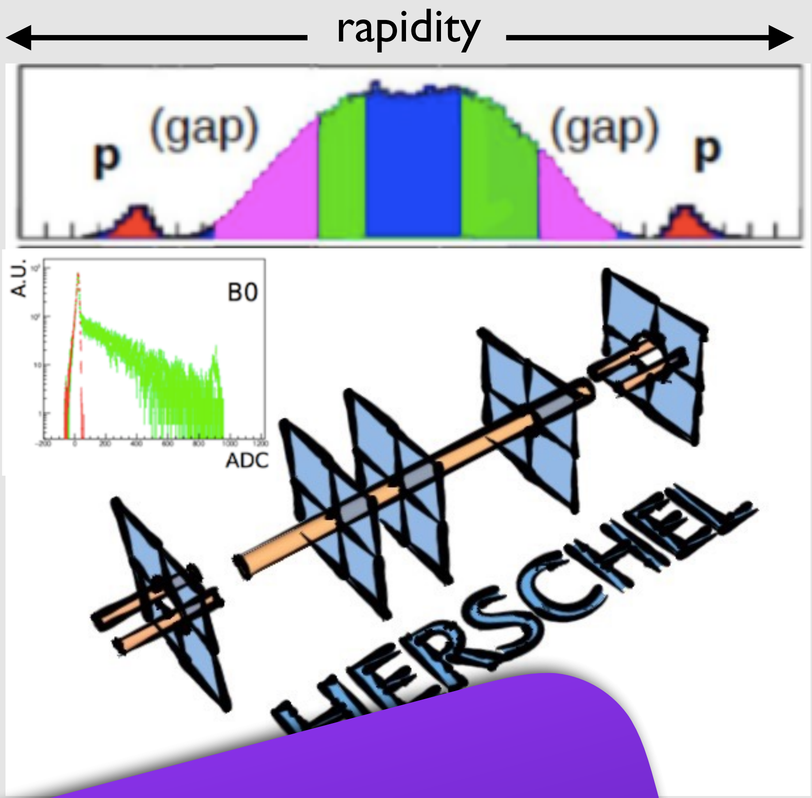
Run 2



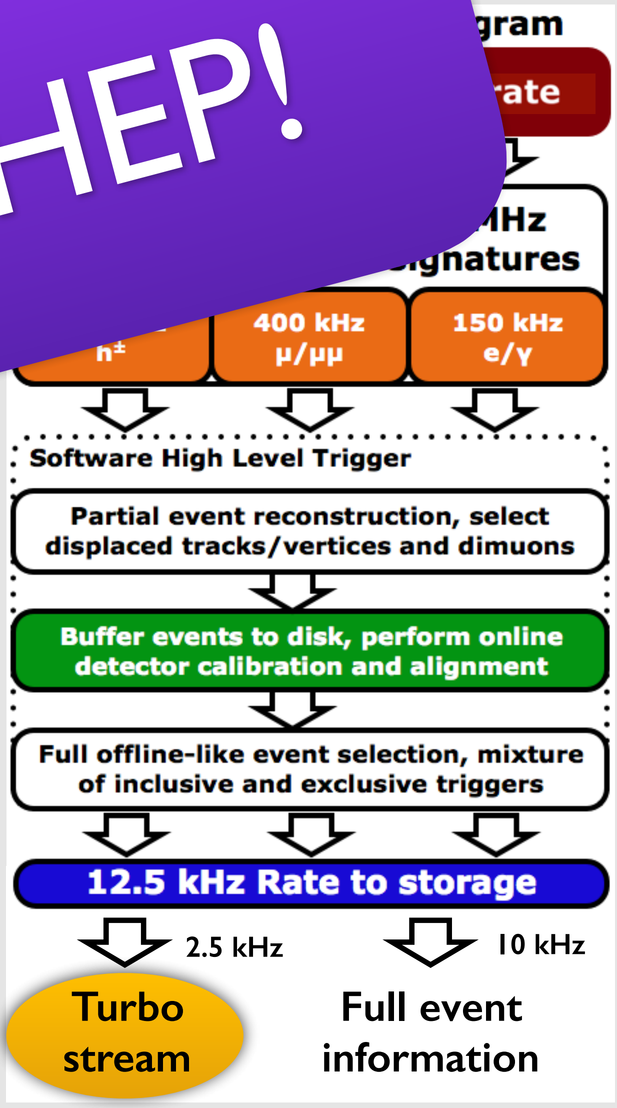
JHEP 03 (2016) 159



arXiv:1607.06495



- Paradigm shift in data flow
  - ➡ Online calibration, analyses with tri
    - Turbo stream
  - ➡ G
- oss-section
- ntillators (HERSCHEL) open new o ies for central exclusive production
- SMOG gas injection allows production studies with a range of nuclei (Ne, Ar, He)
  - ➡ Constrains neutrino production in atmosphere



And much more at ICHEP!

LHCb upgrade

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024-26 | 2027 | …

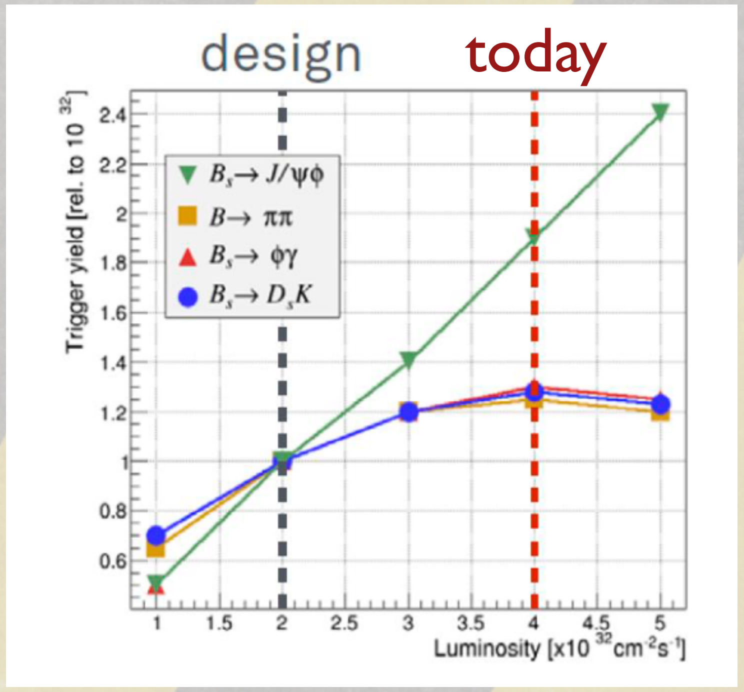
LHC run-1 — LHC run-2 — LHC run-3 — LHC run-4

LHCb — LHCb upgrade

Jul 2016

Belle 2

- With increased luminosity hadron channels would saturate
  - ➡ Limited by hardware trigger
- Upgrade to allow full detector readout at 40 MHz and increased luminosity: collect ~8fb^{-1} per year
  - ➡ Requires several new detectors (all tracking plus RICH) and new readout electronics otherwise
- Full software trigger
  - ➡ Massively improved trigger efficiencies
  - ➡ Offline quality reconstruction in trigger
- Major construction project
  - ➡ Vertex Locator and RICH built in UK
- Maintain/improve current level of detector performance

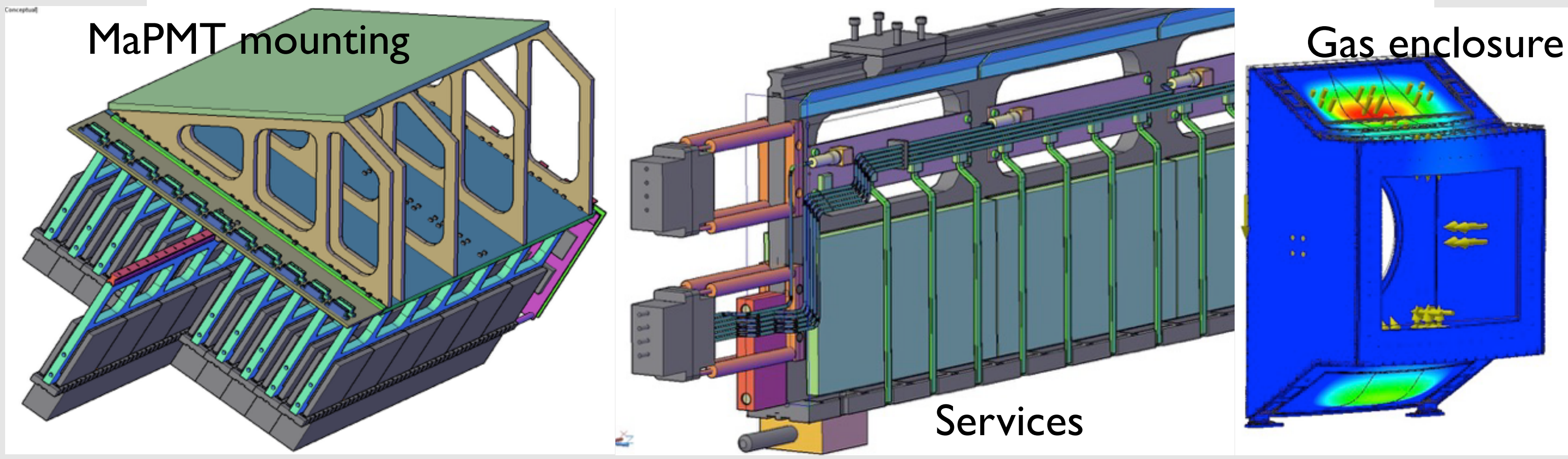


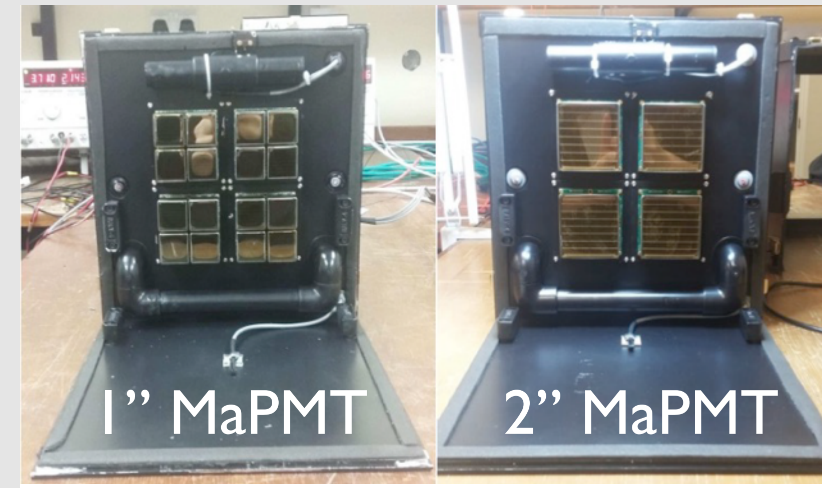
UNDER CONSTRUCTION

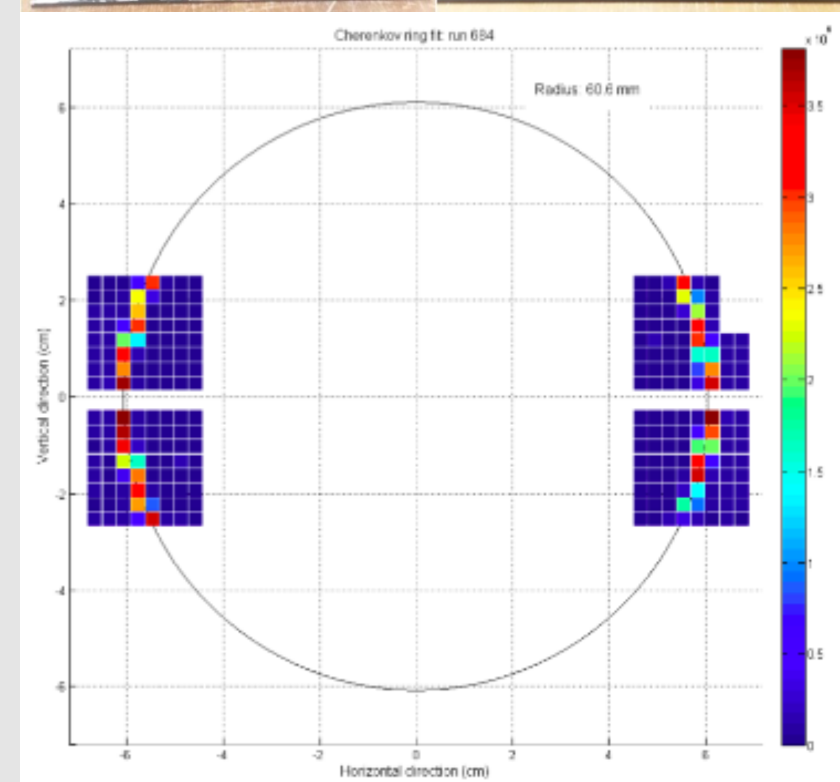
RICH


LHCb-PUB-2016-014
EDMS 1627005
3rd May 2016

LHCb Upgraded RICH 1
Engineering Design Review Report

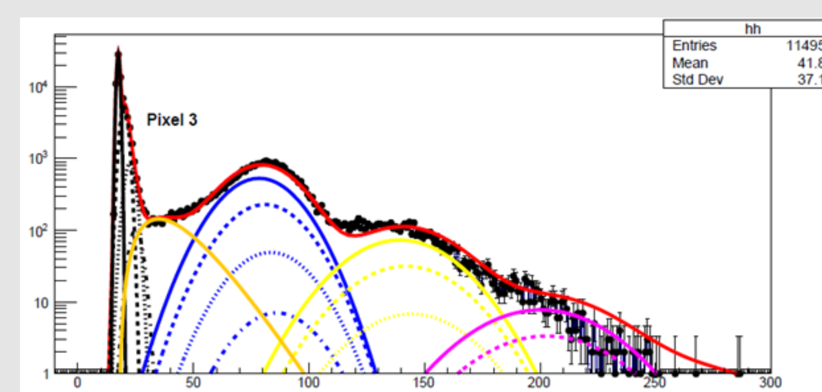






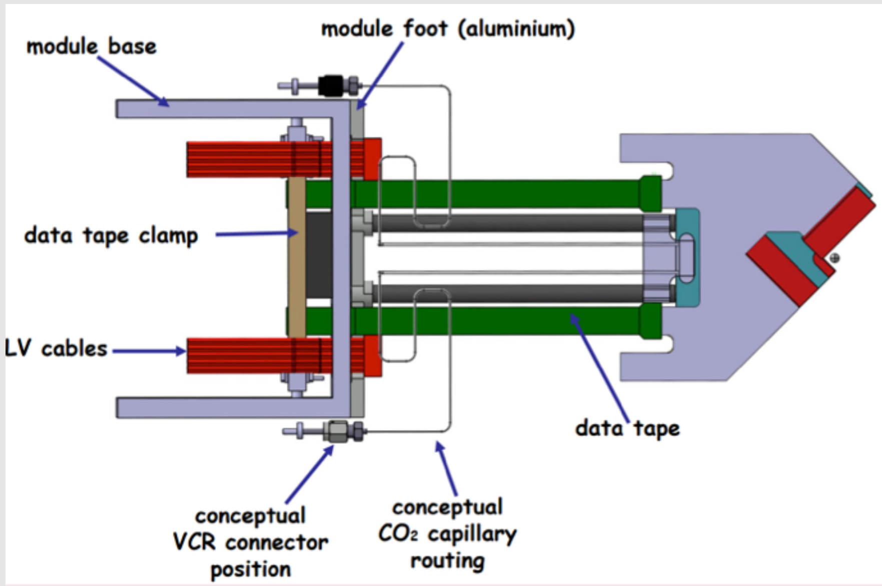
- Successful RICH1 mechanics EDR
- Optical geometry fully optimised
- Successful test-beam system test
- Photon detector pre-series MaPMTs delivered

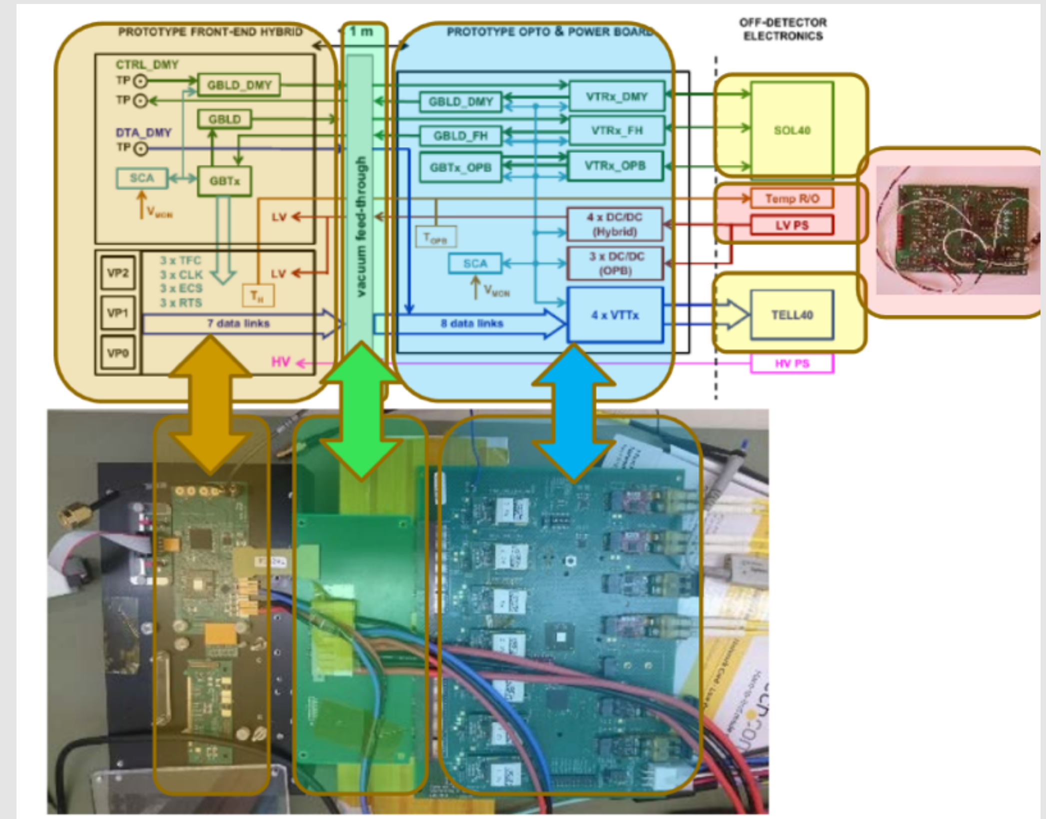
➡ Production testing underway



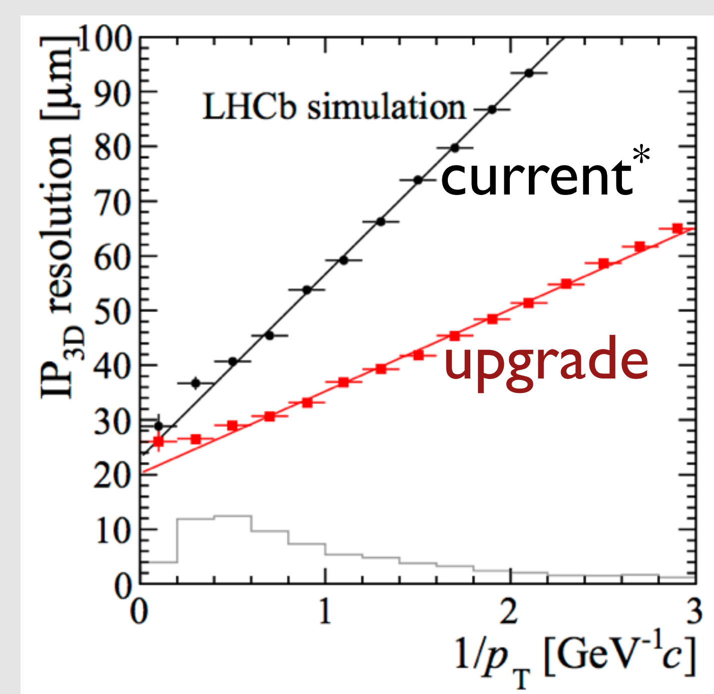
ADC counts

VELO





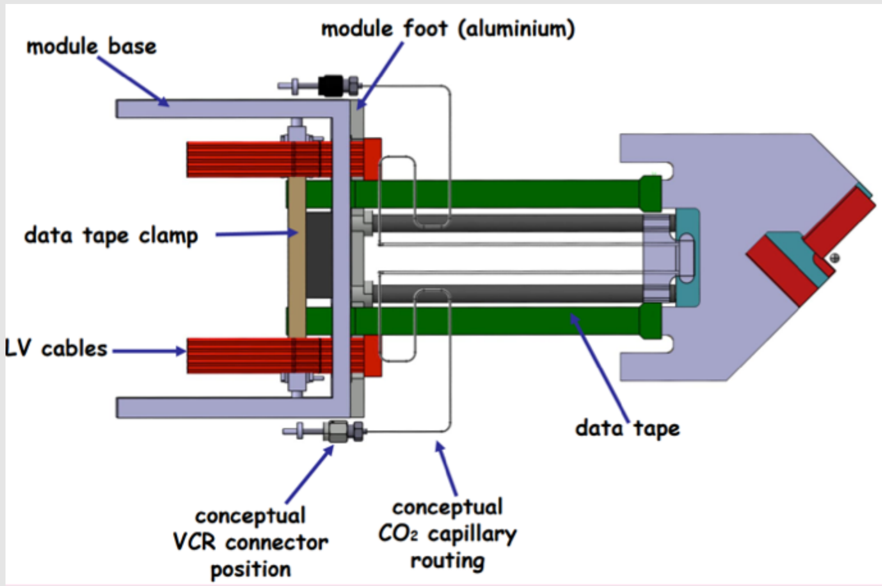
- Prototypes of the full electronics readout chain exist
  - ➡ ASIC submitted
  - ➡ Readout firmware close to completion
- Mechanical design exists
  - ➡ Assembly and transport being commissioned
- Micro-channel cooling substrate production challenging
  - ➡ Evaluating options including alternative design

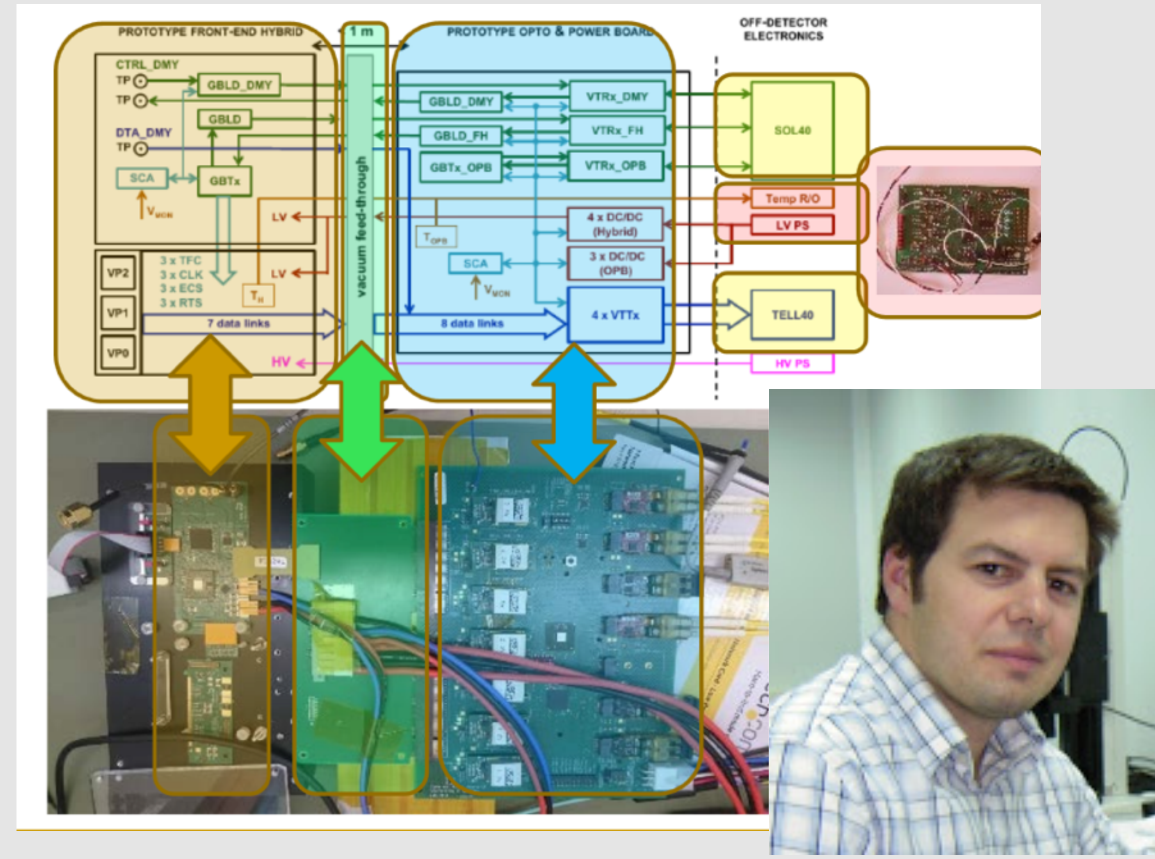


*current detector with upgrade luminosity

MANCHESTER 1824
The University of Manchester

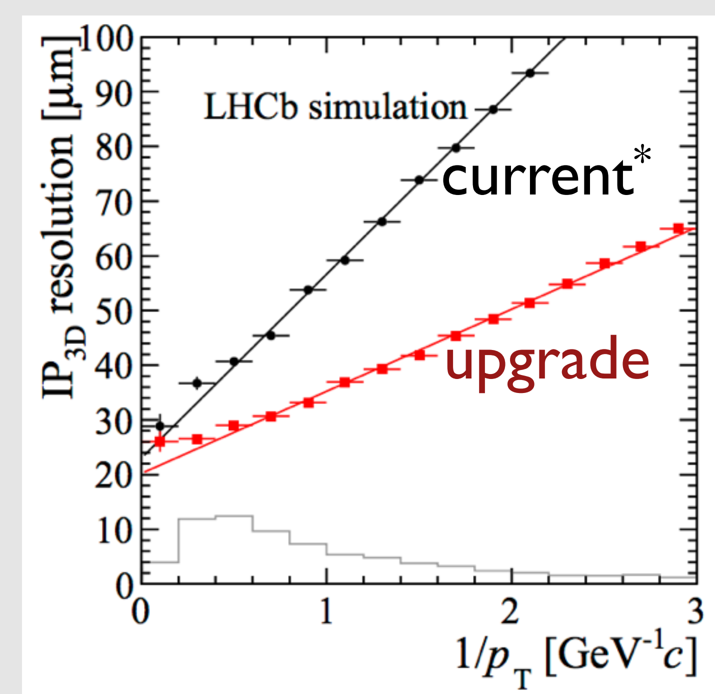
VELO





Pablo Rodriguez Perez
1976 - 2016

- Prototypes of the full electronics readout chain exist
  - ➡ ASIC submitted
  - ➡ Readout firmware close to completion
- Mechanical design exists
  - ➡ Assembly and transport being commissioned
- Micro-channel cooling substrate production challenging
  - ➡ Evaluating options including alternative design



*current detector with upgrade luminosity

Future physics impact

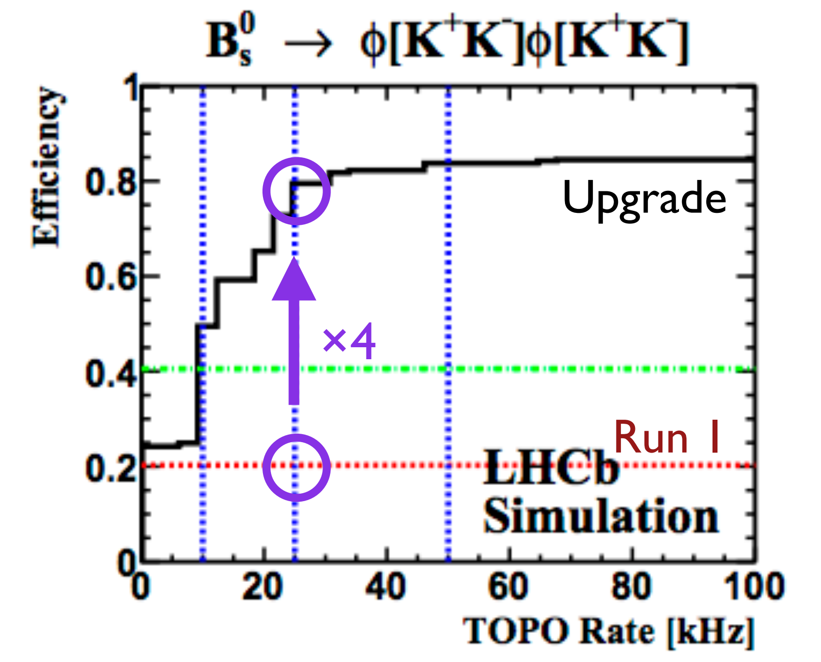
Eur. Phys. J. C (2013) 73:2373

Type	Observable	LHCb 2018	**Upgrade** (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.025	0.008	$\sim$0.003
	$2\beta_s(B_s^0 \to J/\psi\, f_0(980))$	0.045	0.014	$\sim$0.01
	a_{sl}^s	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	0.17	0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\overline{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$	0.09	0.02	$<$0.01
	$\tau^{eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	0.025	0.008	0.02
	$s_0 A_{FB}(B^0 \to K^{*0}\mu^+\mu^-)$	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	0.08	0.025	$\sim$0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	$\sim$10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\sim$100 %	$\sim$35 %	$\sim$5 %
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	0.65×10^{-3}	0.12×10^{-3}	–

Upgrade sensitivity impact:

Factor 3 (muonic) to 6 (hadronic)

CERN-LHCC-2014-016; LHCb-TDR-016



- Upgrade computing roadmap defined (LHCb-INT-2016-016)
  - ➡ TDR in Q4 2017
- Trigger efficiency key to upgrade success
  - ➡ Benefit from Run 2 experience

Future physics impact

Eur. Phys. J. C (2013) 73:2373

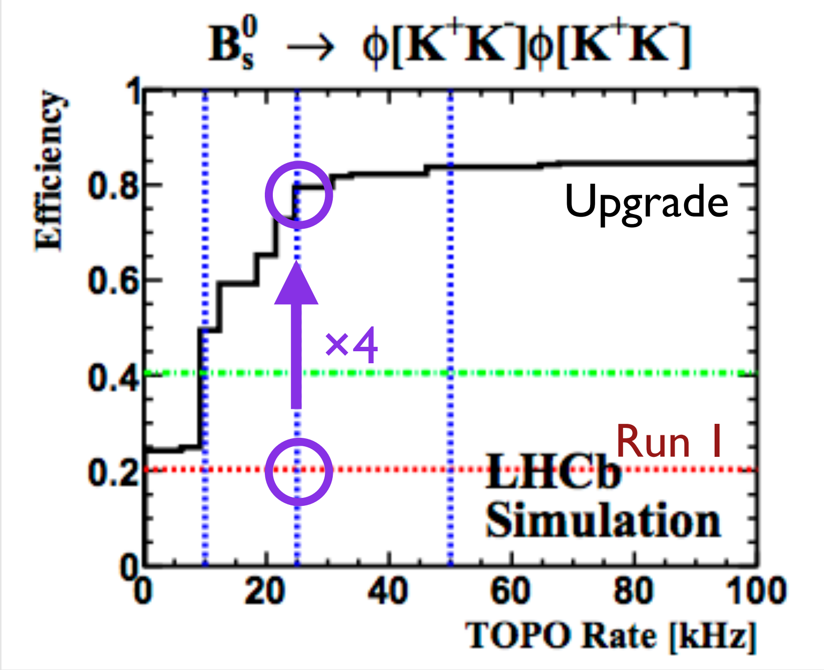
Type	Observable	LHCb 2018	Upgrade (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.025	0.008	$\sim$0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.045	0.014	$\sim$0.01
	a_{sl}^s	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	0.17	→ 0.03	0.02
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{eff}(B_s^0 \to \phi\gamma)$	0.09	0.02	<0.01
	$\tau^{eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.025	0.008	0.02
		6 %	2 %	7 %
	$\ldots V^2/c^4)$	0.08	0.025	$\sim$0.02
	$\ldots \to K^+\mu^+\mu^-)$	8 %	2.5 %	$\sim$10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	$\sim$100 %	→ $\sim$35 %	$\sim$5 %
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	4°	→ 0.9°	negligible
				negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
Charm CP violation	A_Γ	0.40×10^{-3}	→ 0.07×10^{-3}	–
	ΔA_{CP}	0.65×10^{-3}	0.12×10^{-3}	–

new observable: $\tau(B_s \to \mu\mu)$

Upgrade sensitivity impact:

Factor 3 (muonic) to 6 (hadronic)

CERN-LHCC-2014-016; LHCb-TDR-016



- Upgrade computing roadmap defined (LHCb-INT-2016-016)
  - ➡ TDR in Q4 2017
- Trigger efficiency key to upgrade success
  - ➡ Benefit from Run 2 experience

The University of Manchester

Conclusions

- LHCb Run 1 results have delivered a broad range of physics output beyond expectations
    - ➡ World best in all key areas
    - ➡ UK leading many headline analyses
    - ➡ Many more results at ICHEP
- Run 2 comes with major improvements
    - ➡ Trigger architecture evolving towards upgrade
- LHCb Phase-I upgrade (for LS2) has entered construction phase
    - ➡ Major UK involvement in RICH and VELO detectors

BACKUP