MANCHESTER 1824
The University of Manchester

The Future of Charm Physics at LHCb

LHC Run II & the LHCb Upgrade

Chris Parkes
on behalf of the LHCb Collaboration

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LHCb

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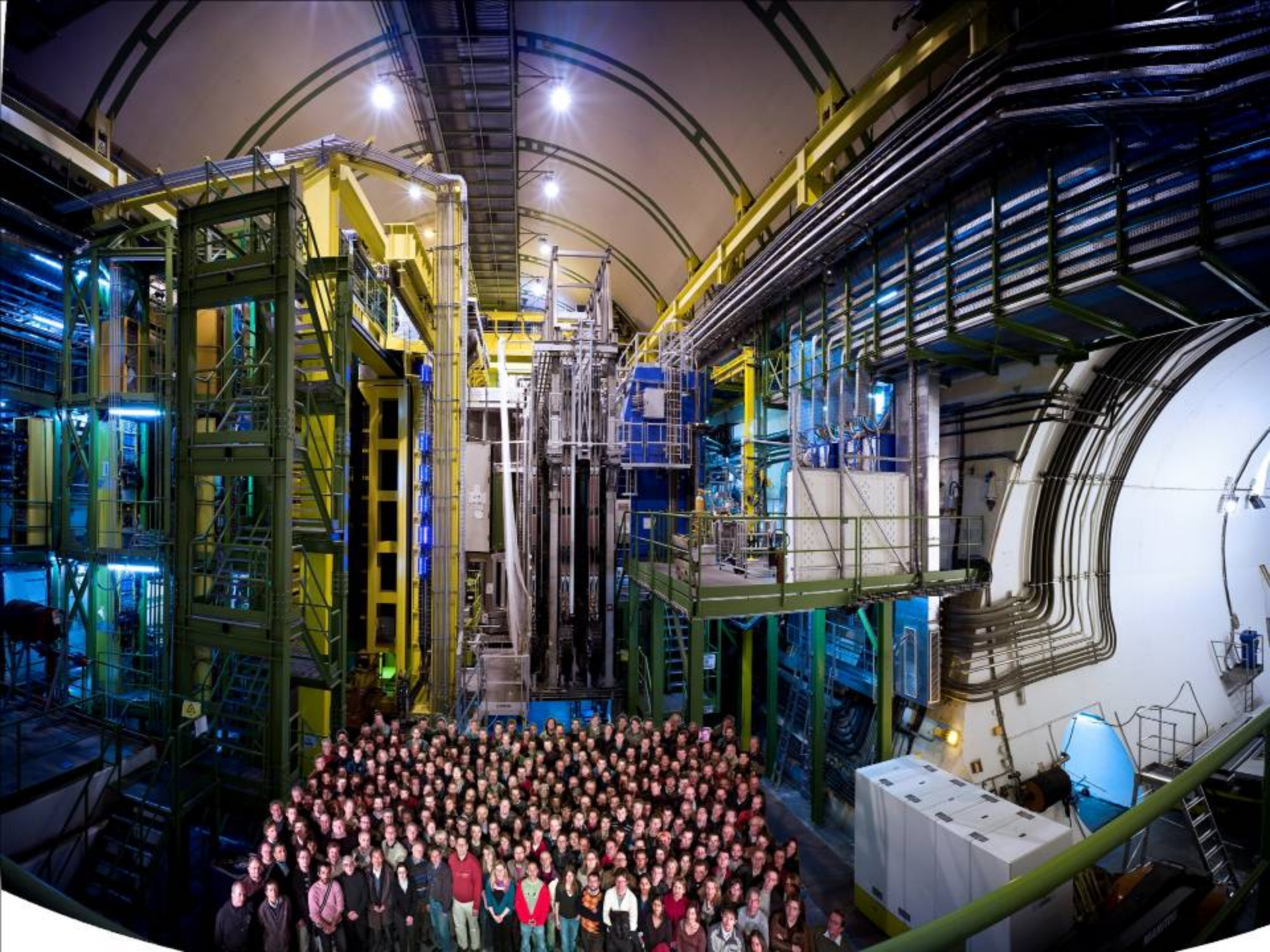
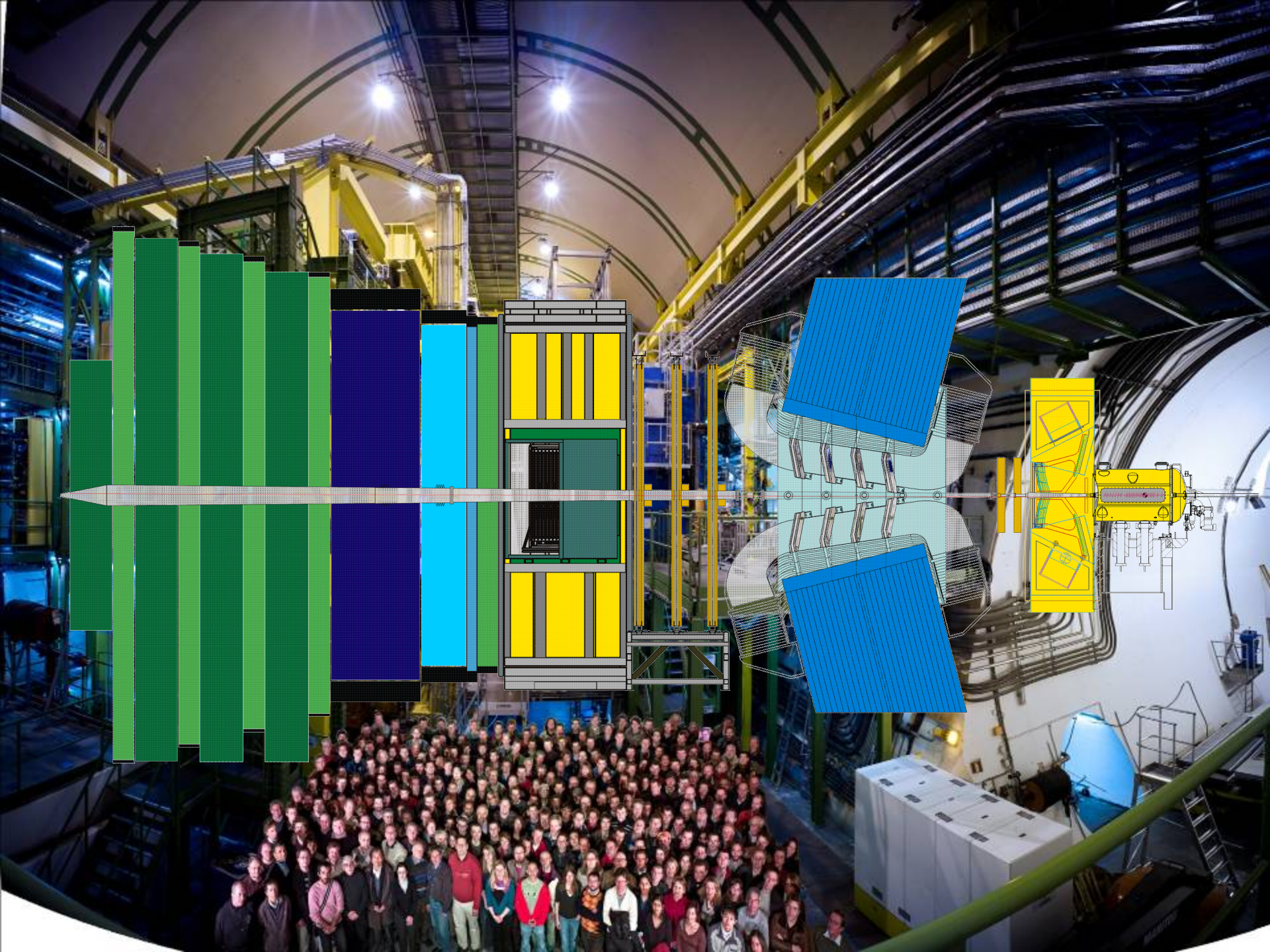
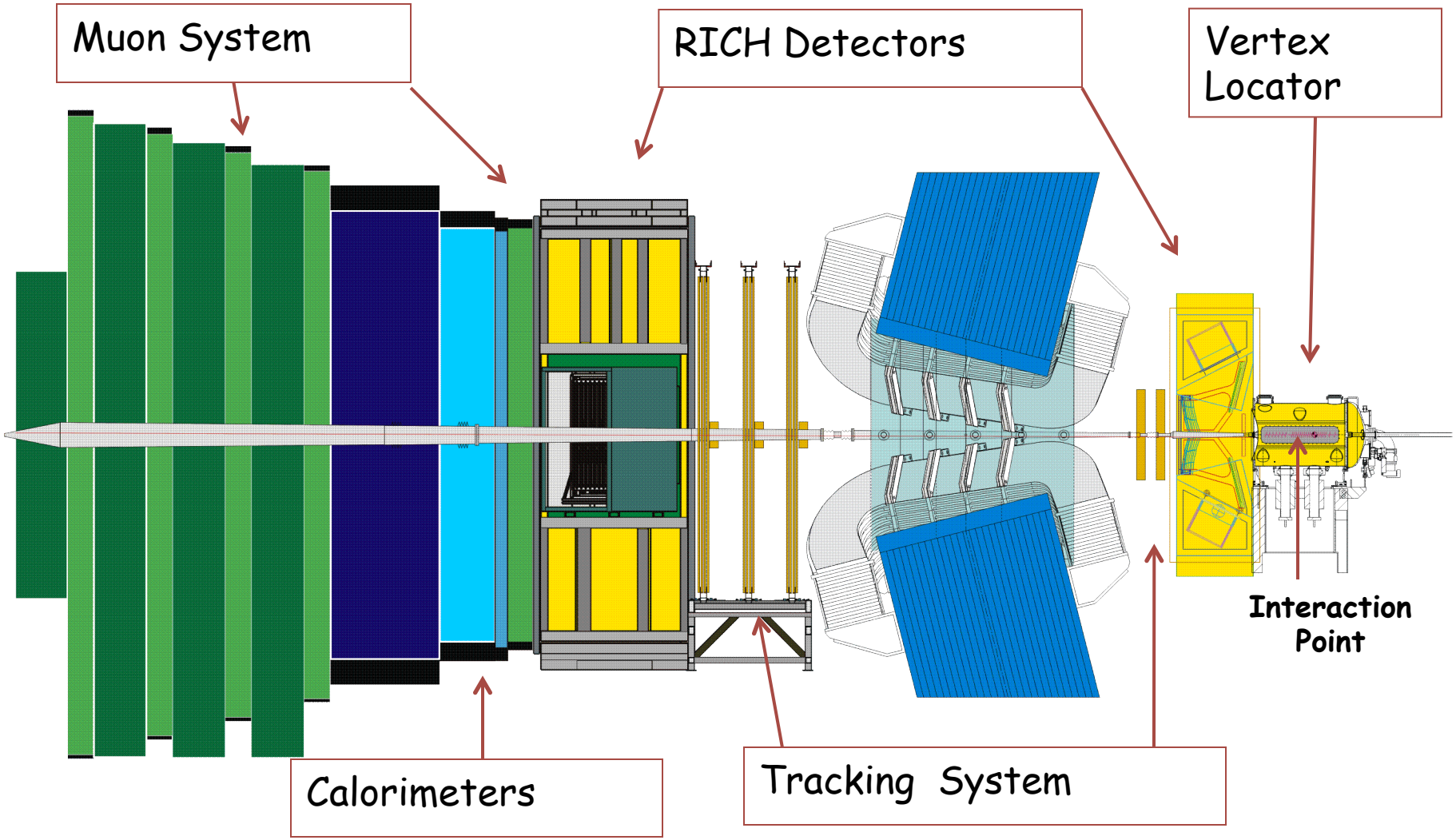
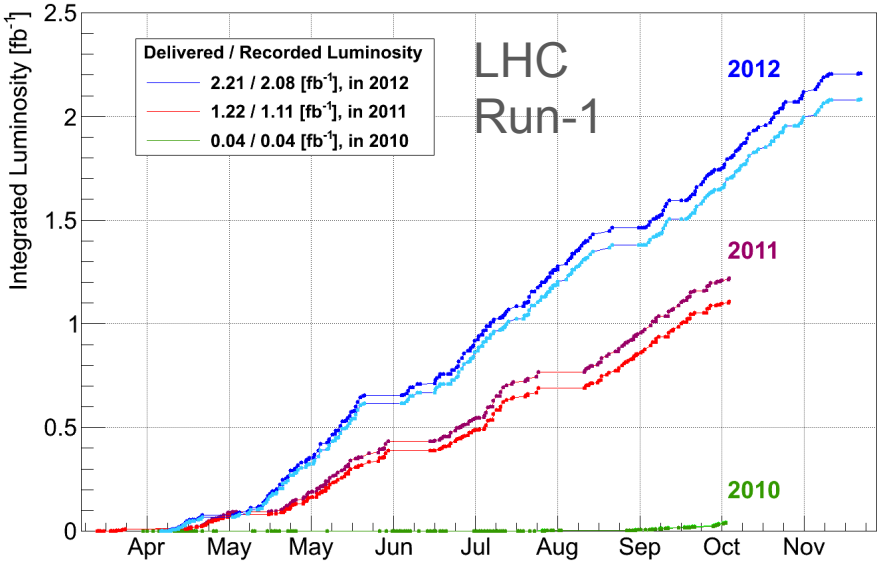




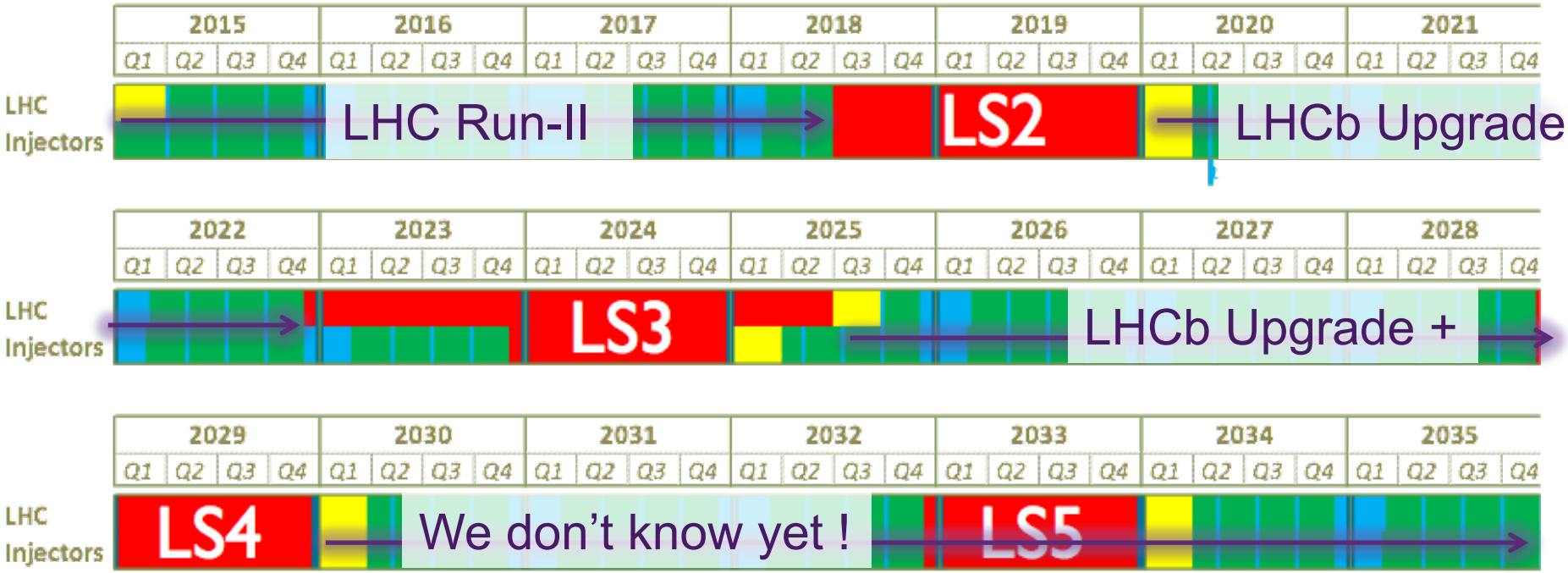

Muon System
RICH Detectors
Vertex Locator
Interaction Point
Calorimeters
Tracking System

LHCb Timeline

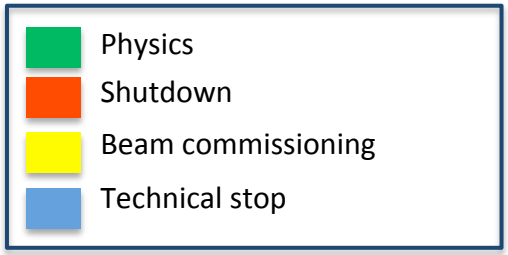
- LHC Run-I (2010-2012)
  - Many results shown this week, more to come
- LHC Run-II (2015-2018)
  - Trigger computing increased, strategy evolved
- LHC Run-III (2020-2023)
  - LHCb Upgrade
- LHC Run-IV (2025-)
  - LHCb Upgrade (+ additions ?)



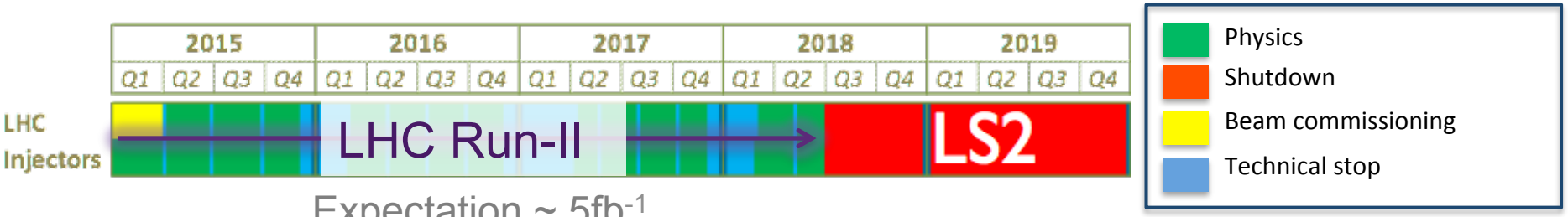
LHC Schedule & LHCb



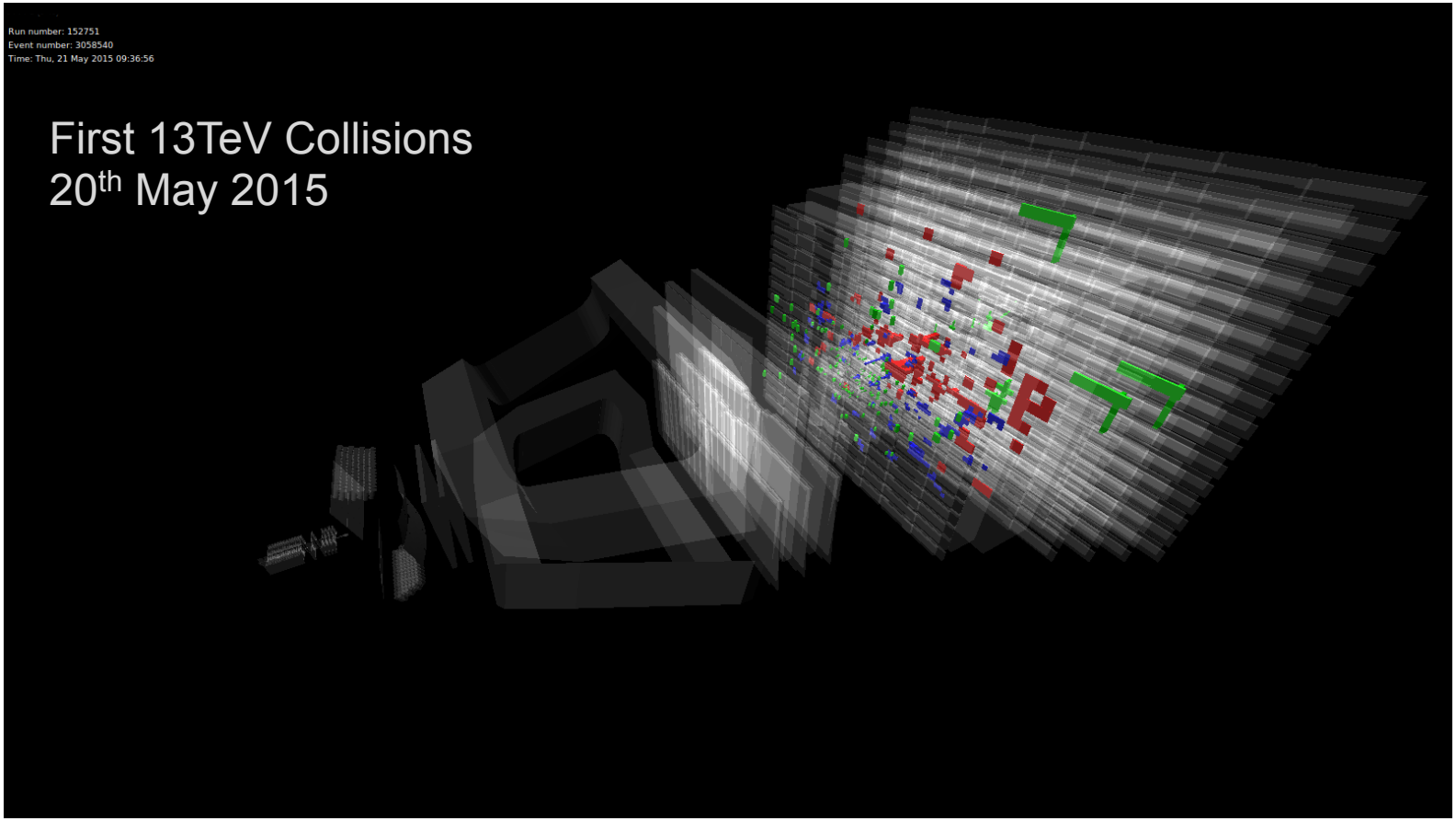
- Schedule till 2020 reasonably firm
- HL-LHC upgrade in LS3
- GPD main upgrades (phase II) scheduled for LS3



LHC Run II

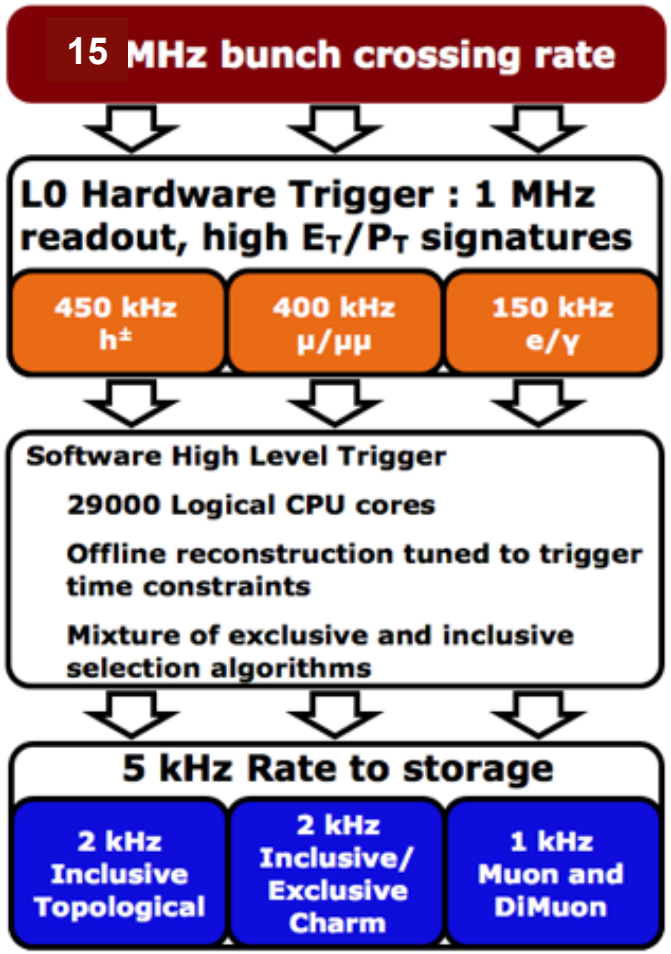


Expectation ~ $5fb^{-1}$

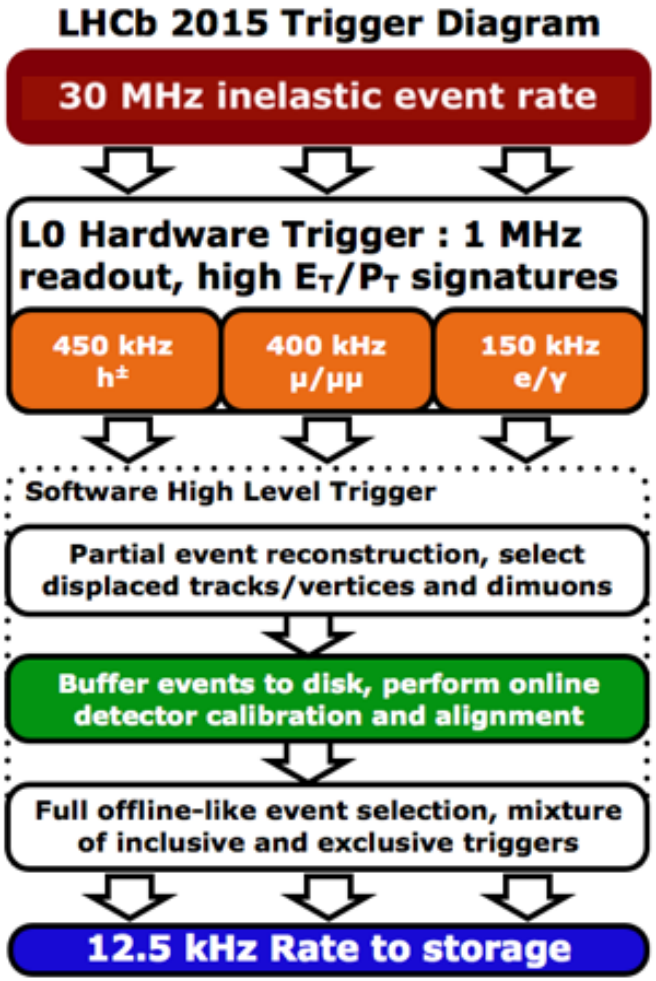


Trigger Evolution – Run II

Run I



Run II

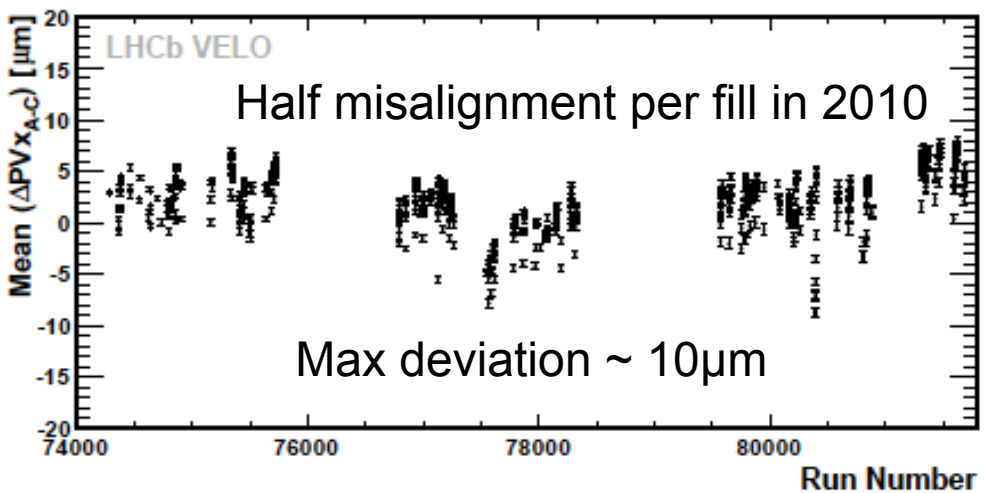


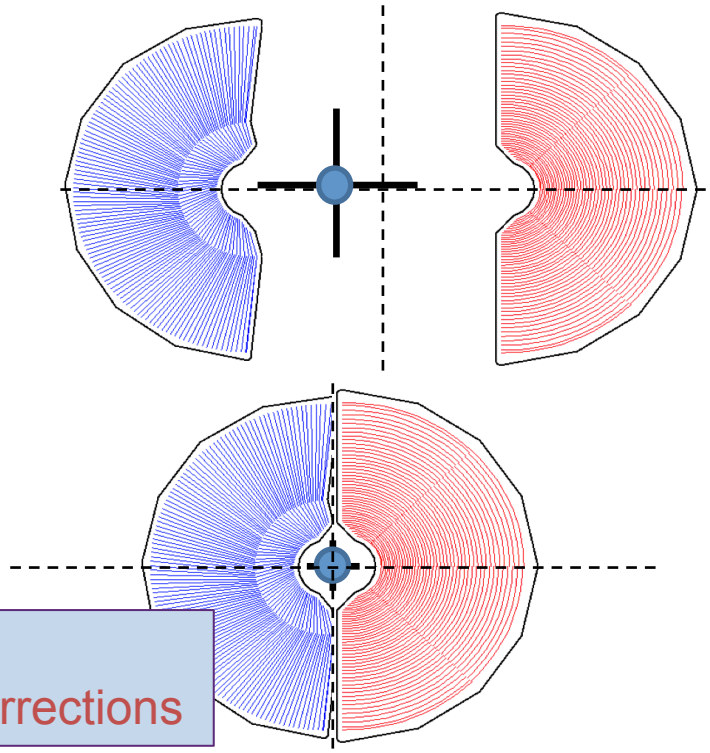
(assuming currrent event size)

Reference: G. Dujany, CHEP '15

Online: Automatic Alignment & Calibration

- Minimise Online / Offline differences
  - Improve effective trigger performance
- Automatic evaluation at regular intervals
  - Vertex Locator (VELO) alignment as example
  - $\mathcal{O}$(1 min) CPU, update immediately





- **Tracking**: spatial & time alignment
- **RICH**: mirror alignment, photon detector image corrections

Turbo Stream

Reference: S. Benson, CHEP '15, LHCb-TALK-2015-066

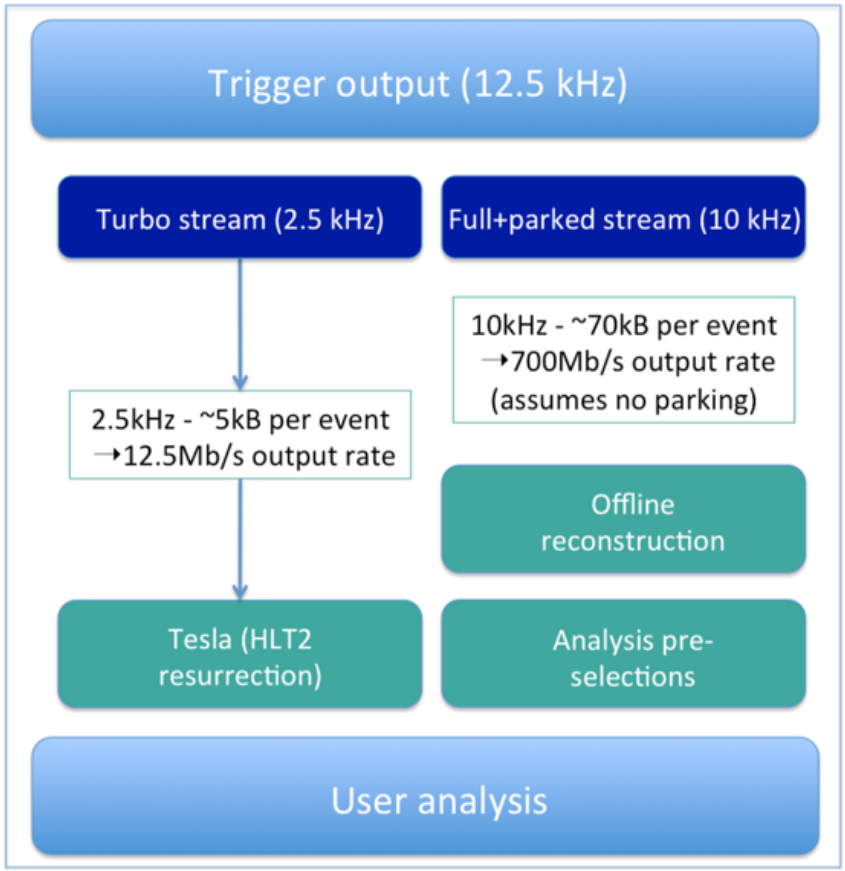
Raw data: electronic signals recorded from detector

Analysis level: information of signal candidate tracks

- Analyse directly on trigger output ?
  - Online calibration

    a critical first step

- Maximise number of events for user analysis
  - Output rate is a limit
- Testing mode
  - Raw events will be kept



Physics Programme

Limited by Detector

But **NOT** Limited by LHC

- Upgrade to extend Physics reach
  - Exploit advances in detector technology
    - Displaced Vertex Trigger, **40MHz readout**
  - Better utilise LHC capabilities

- Collect >50 fb^{-1} data
- Modest cost compared with existing accelerator infrastructure

Independent of LHC upgrade
- HL-LHC not needed
- But compatible With HL-LHC phase

LHCb Upgrade Approved

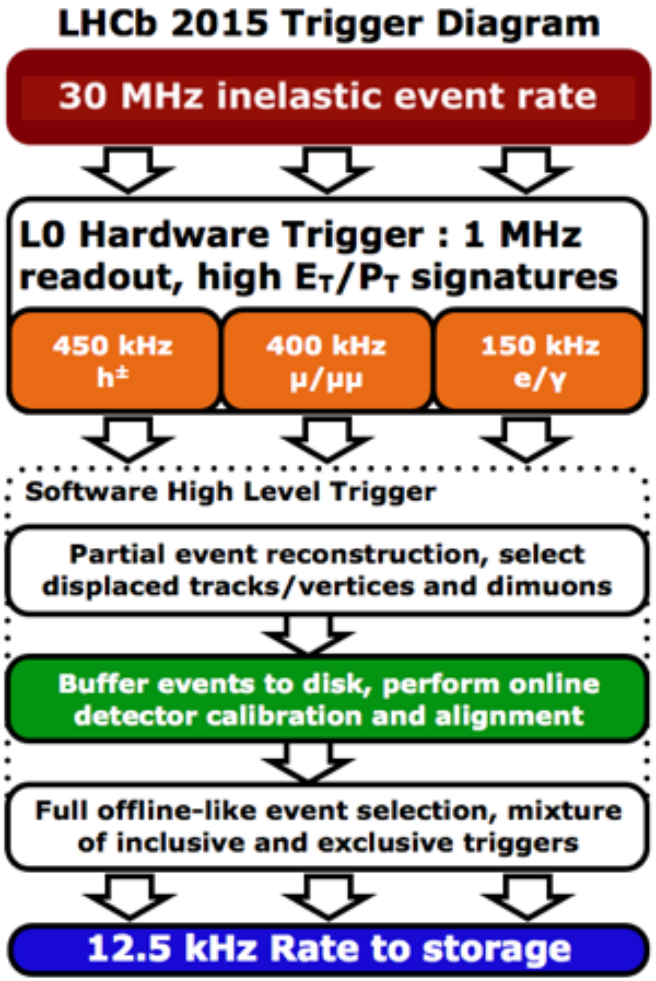
- Letter Of Intent 2011
- Framework Technical Design Report 2012
- Subsystem TDRs 2014

- Funding largely in place from end 2014

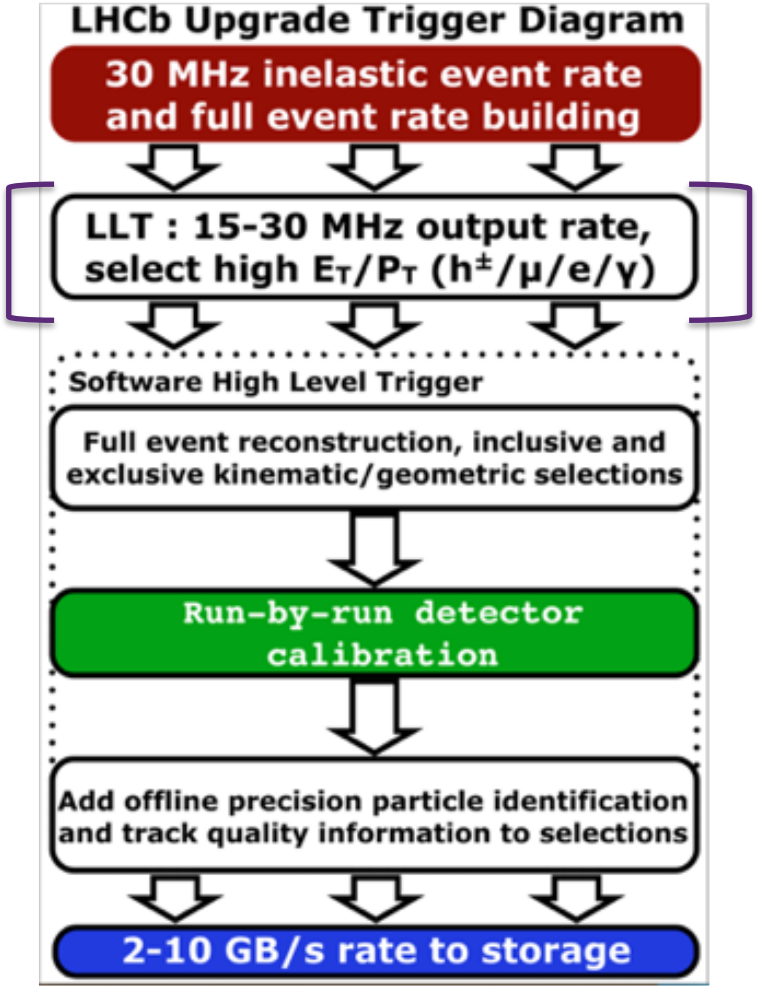
CERN-RRB-2014-105

Trigger Evolution - Upgrade

Run II

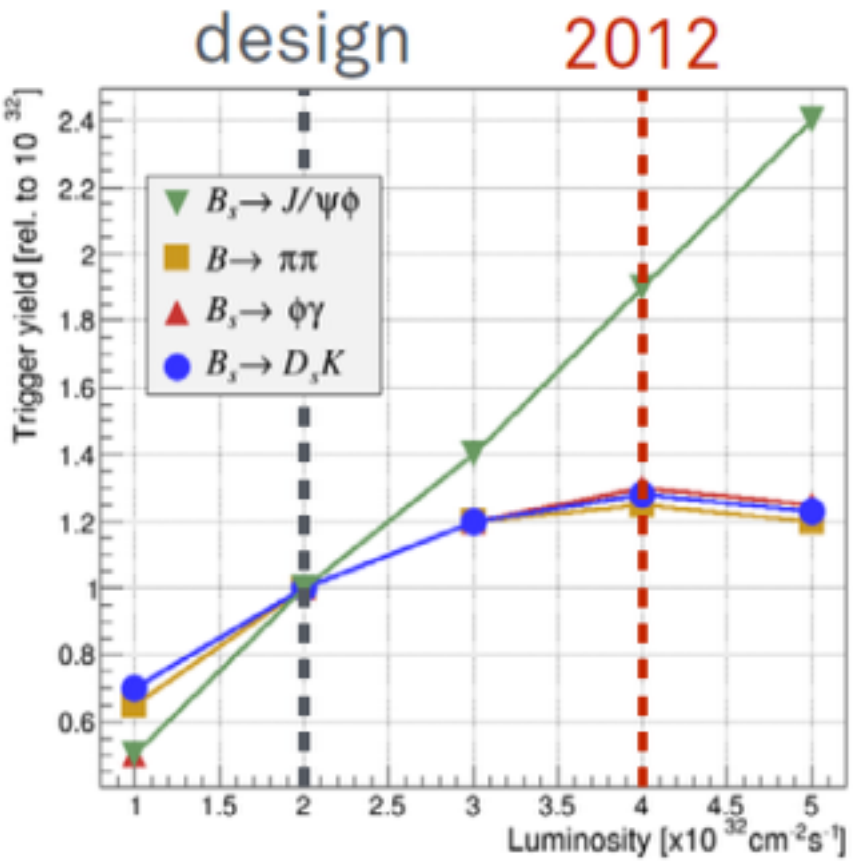


Upgrade



LHCb Trigger: the key to higher Lumi

- Aim: Increase integrated luminosity from 2 fb^{-1} to 5 fb^{-1} per year
  Increase instantaneous luminosity to $2x10^{33}$ cm^{-2} s^{-1}



Current First Trigger Level:
Hardware Muon/ECAL/HCAL
1.1 MHz readout

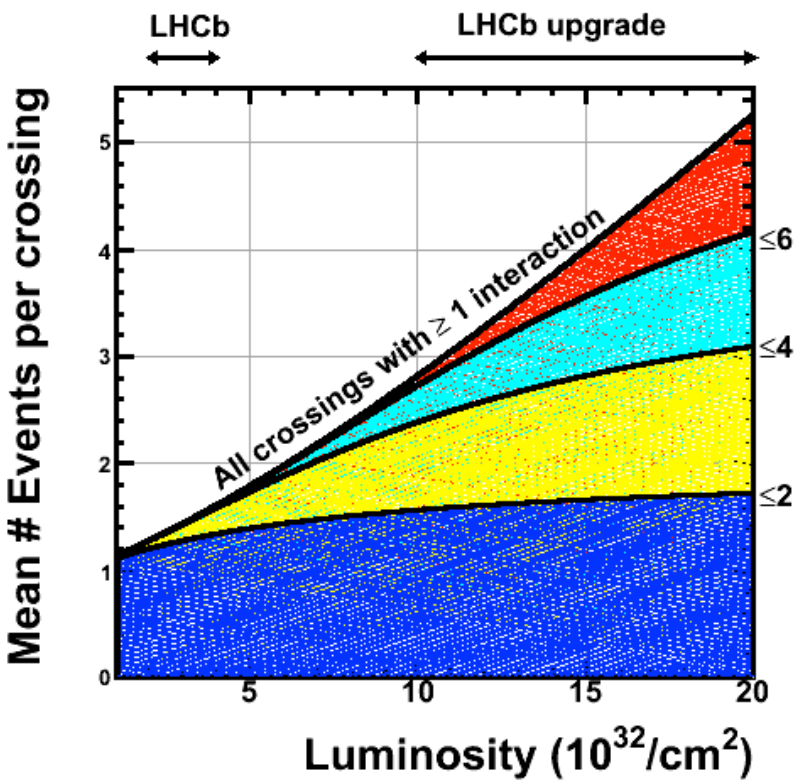
Performance:
Muon channels scale
Hadronic channels saturate bandwidth

Hardware trigger particularly poorly suited to lower momentum of charm

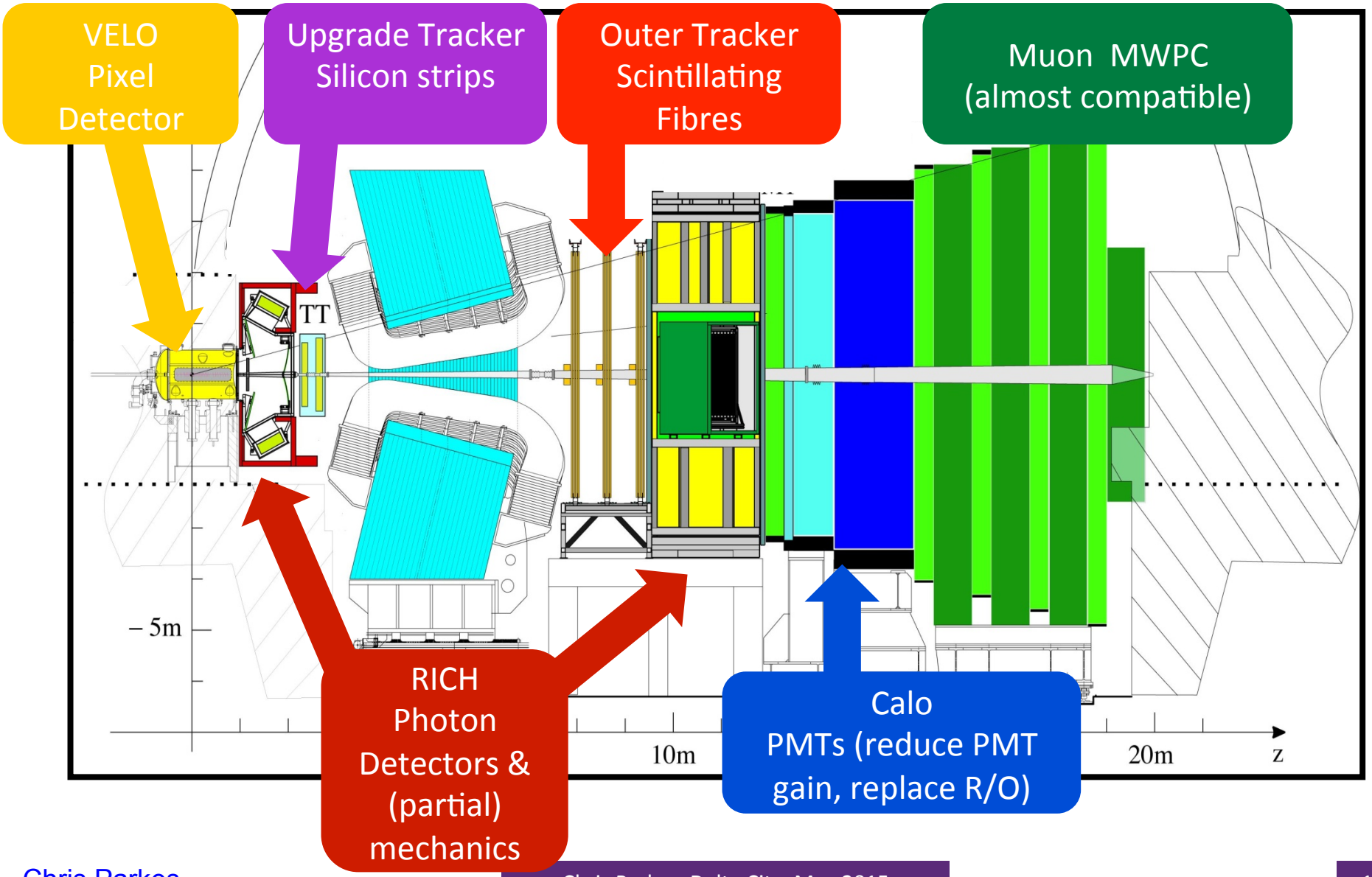
- No gain in hadronic channels with current trigger

Solution: Upgrade to 40MHz readout

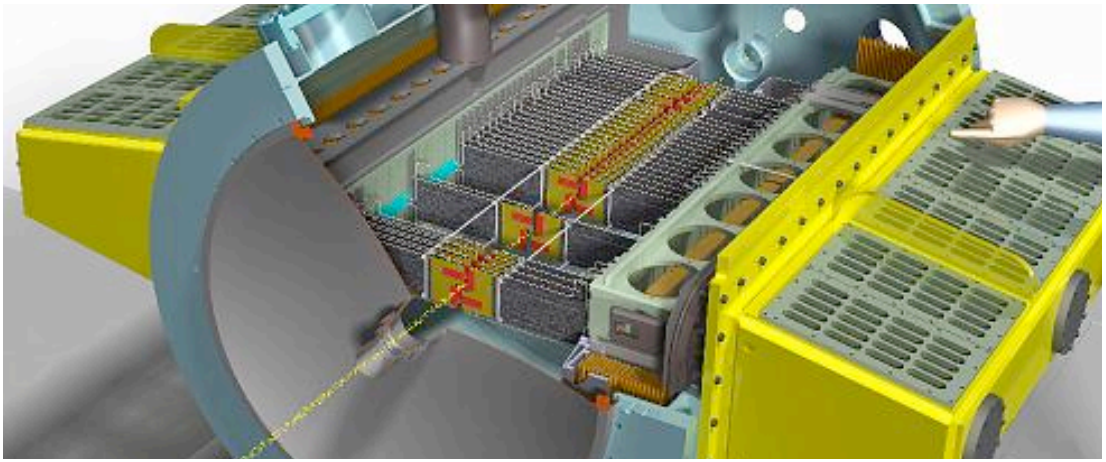
- Read out full detector at 40MHz
  - Major detector changes
  - Front-end electronics must change
- Use fully software trigger
  - Increased flexibility
- Maintain (improve) current detector performance
  - At increased multiple Interactions
    - – Occupancies – Radiation Damage

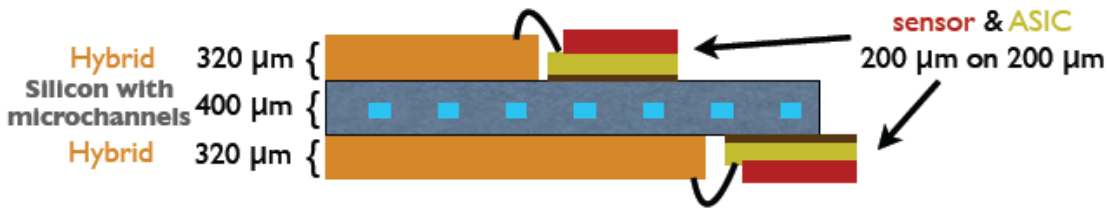


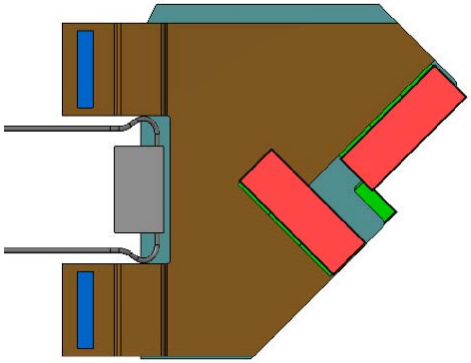
LHCb Upgrade to 40 MHz



LHCb Vertex Locator Upgrade

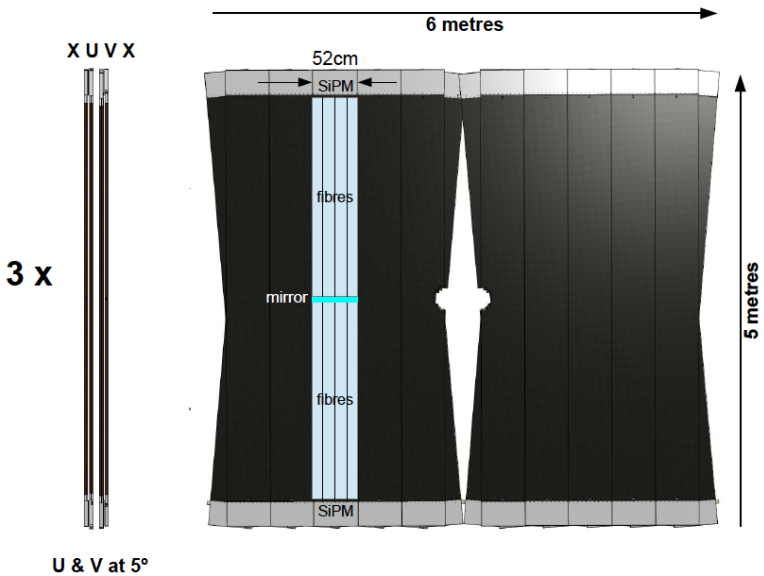




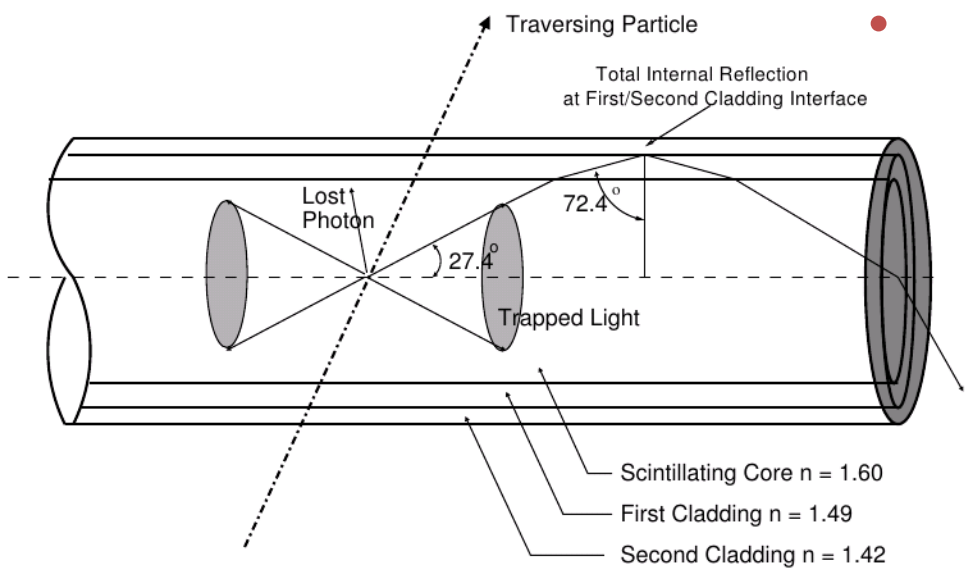


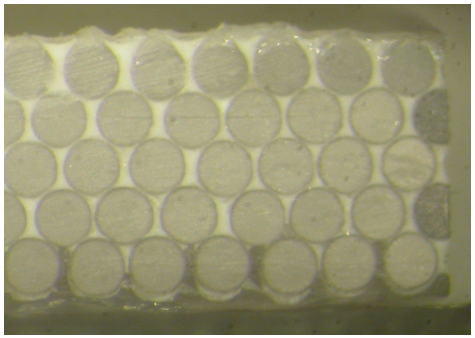
- Pixel Detector
  - 55x55µm
- In vacuum
- 5mm from LHC beam
  - 10^{16} n_{eq}/cm^2
  - Retracted for filling
- Silicon with Micro-channel
  - Bi-phase CO_2 cooling

LHCb Scintillating Fibre Tracker



- Mat made from
  - 250μm diameter fibres
  - SiPM readout
- Radiation hardness challenge
  - Fibres & SiPMs
- Defects (bumps) in fibres
  - 10,000 km fibre !



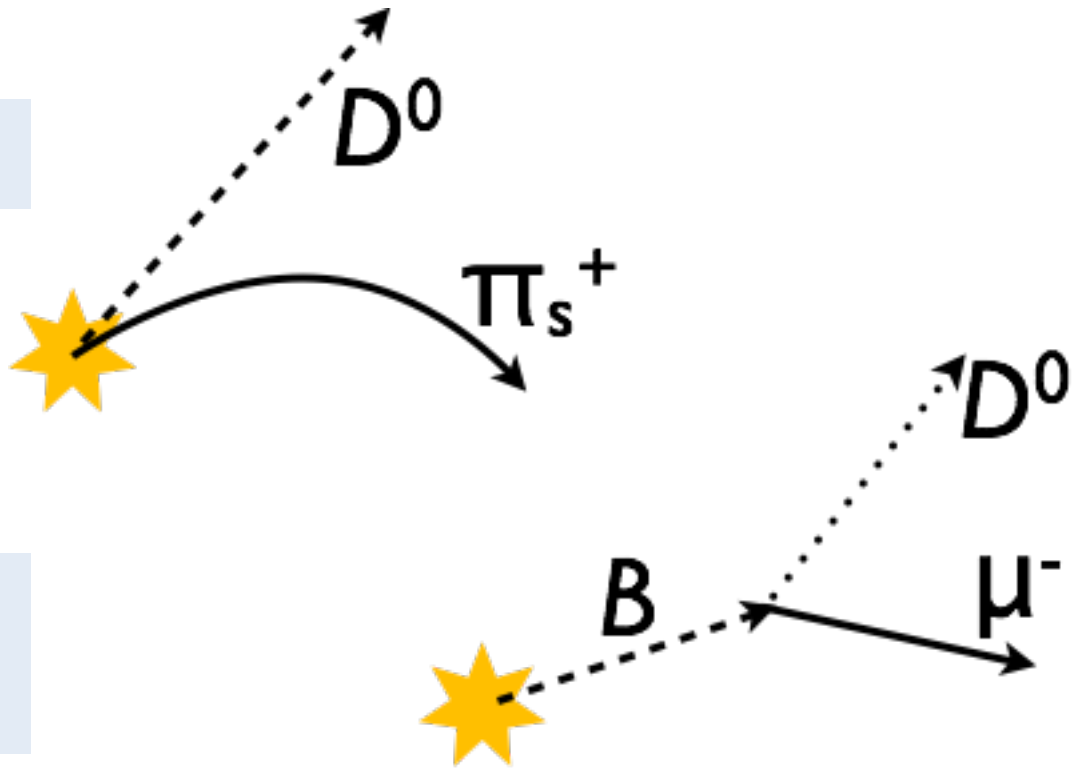


Sources of Charm

Prompt charm

Run I D➔Kπ: 100M

Offline selected D* tagged (x5 untagged)



Semileptonic B-hadron decays

Run I D➔Kπ: 20M

Offline selected muon tagged

Hadronic B decays
Not only useful to measure CKM γ
Also revealed first spin-3 charm state

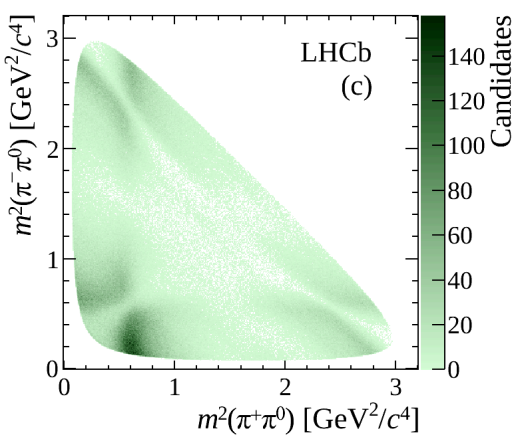
→ LHCb collaboration, Phys. Rev. Lett. 113 (2014) 162001

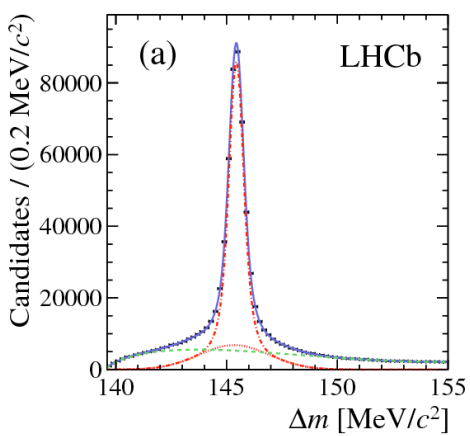
Physics Coverage / Limitations

- Inclusive charm trigger selections are not feasible
  - Upgrade will produce **800 kHz** of analysable charm-hadron events
  - **80 GB/s** with current data format
    - can keep **2-10 GB/s** for ALL LHCb physics
- Have to decide in advance what to keep
  - Cabibbo favoured modes prescaled ?
  - Purely exclusive selection – trigger is offline selection
- Limits of physics programme not yet reached
  - Use of neutrals
  - understanding production/detection asymmetries

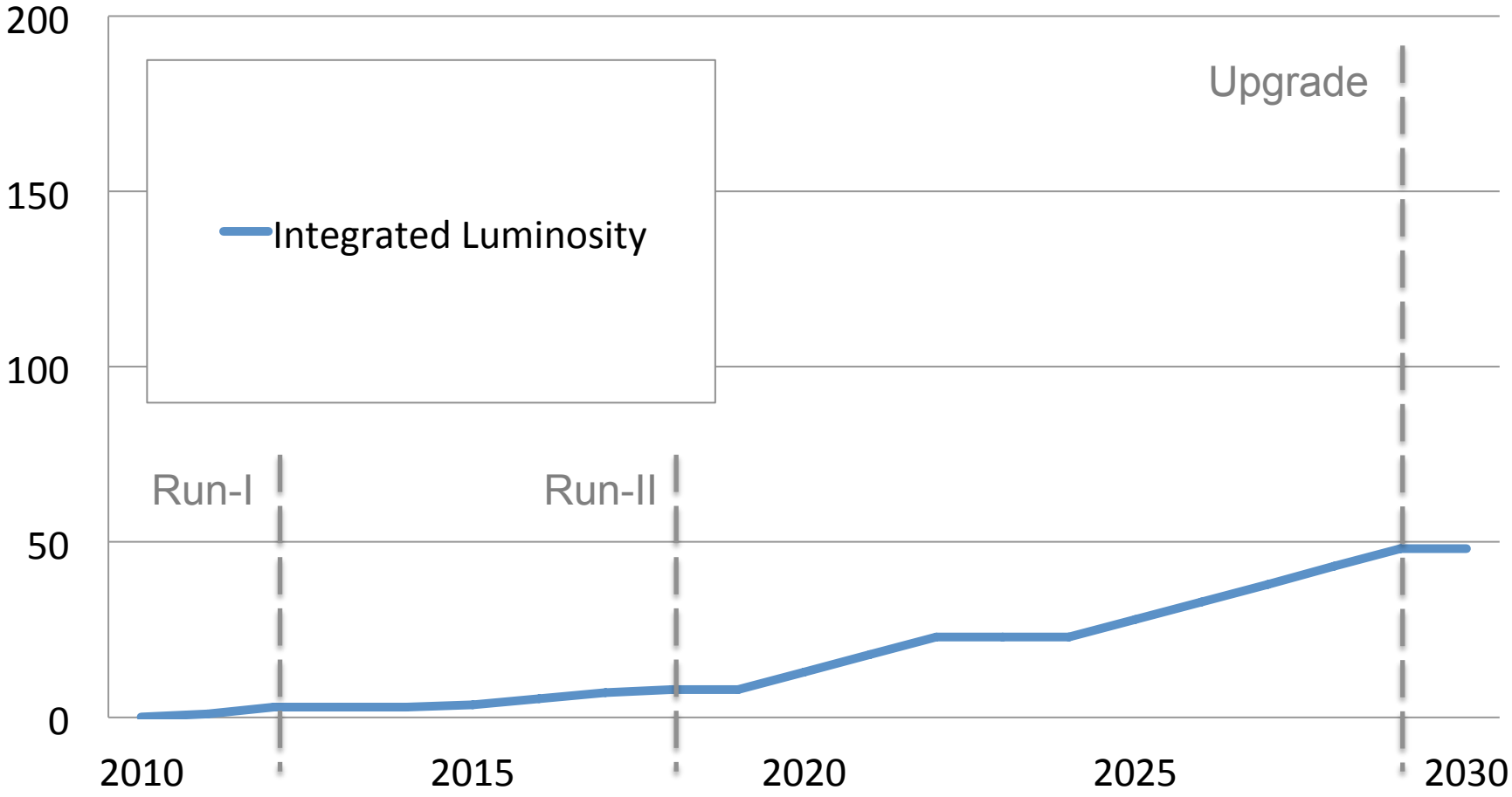
arXiv:1410.4170; LHCB-PAPER-2014-054

$D^0 \rightarrow \pi^+\pi^-\pi^0$: 1yr LHCb Run 1= 80 yrs B factory v1



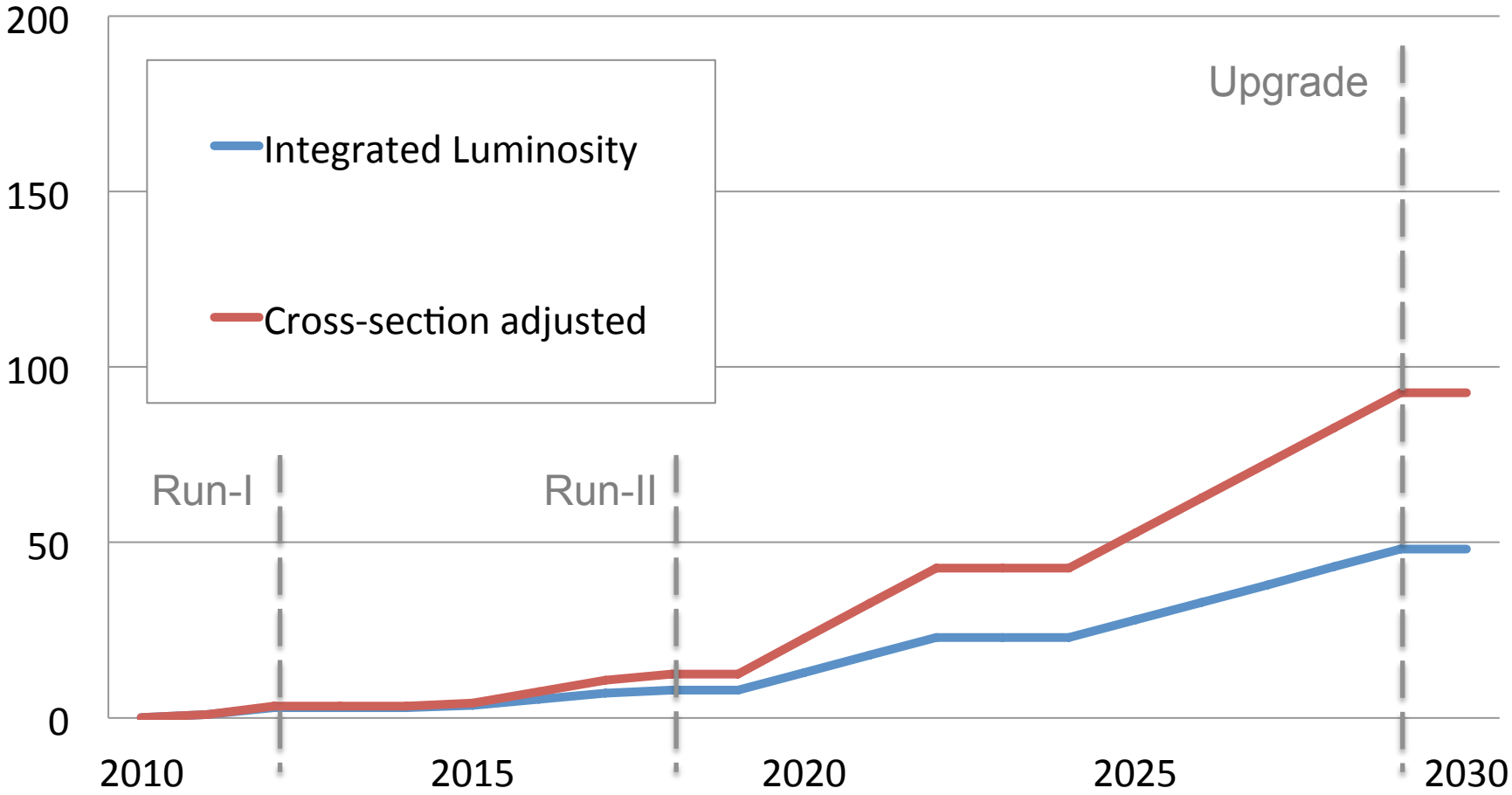


Statistics



- See backup slides for assumptions

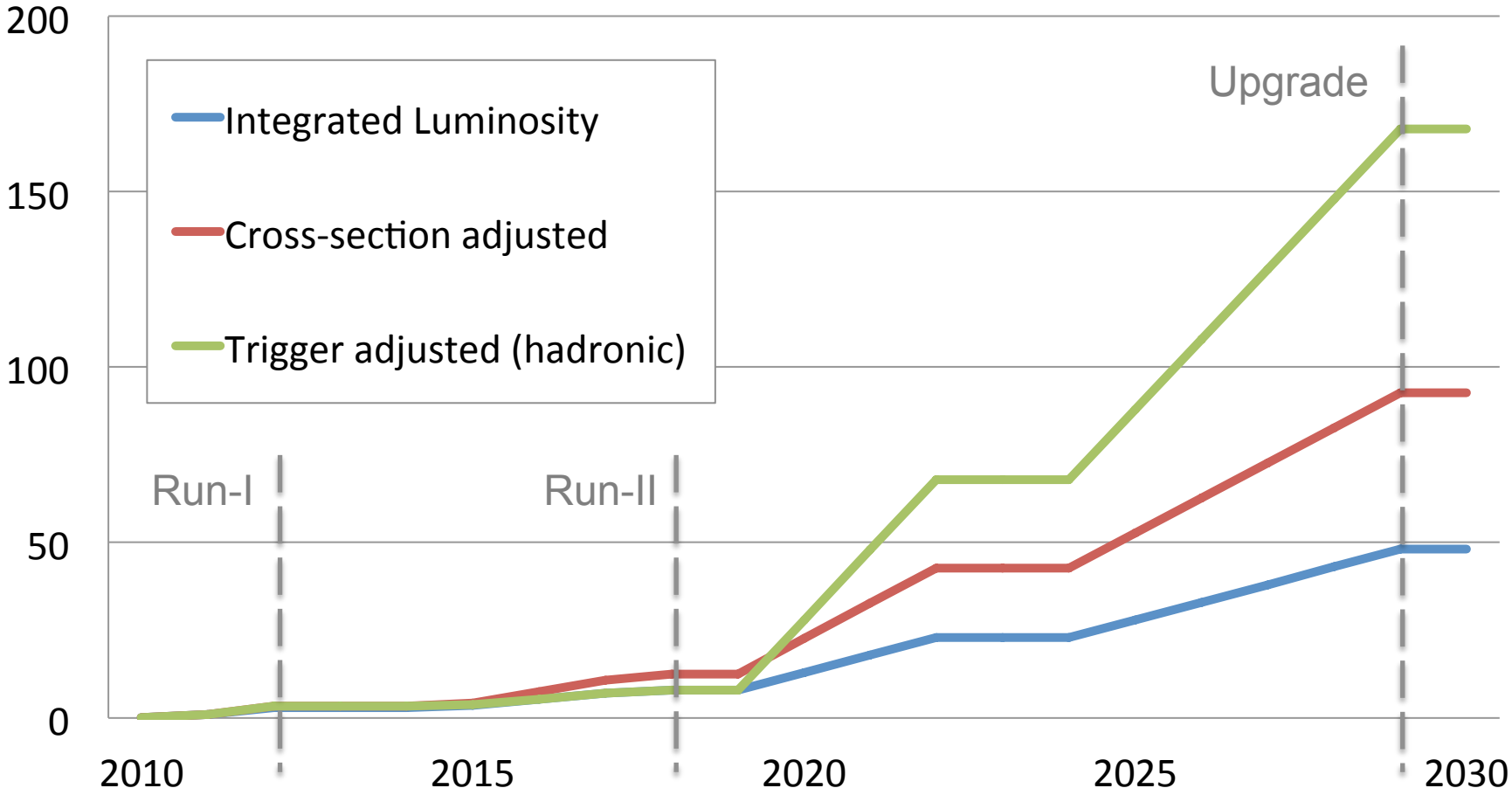
Statistics – Cross-section Adjusted



- 13 TeV cross-section

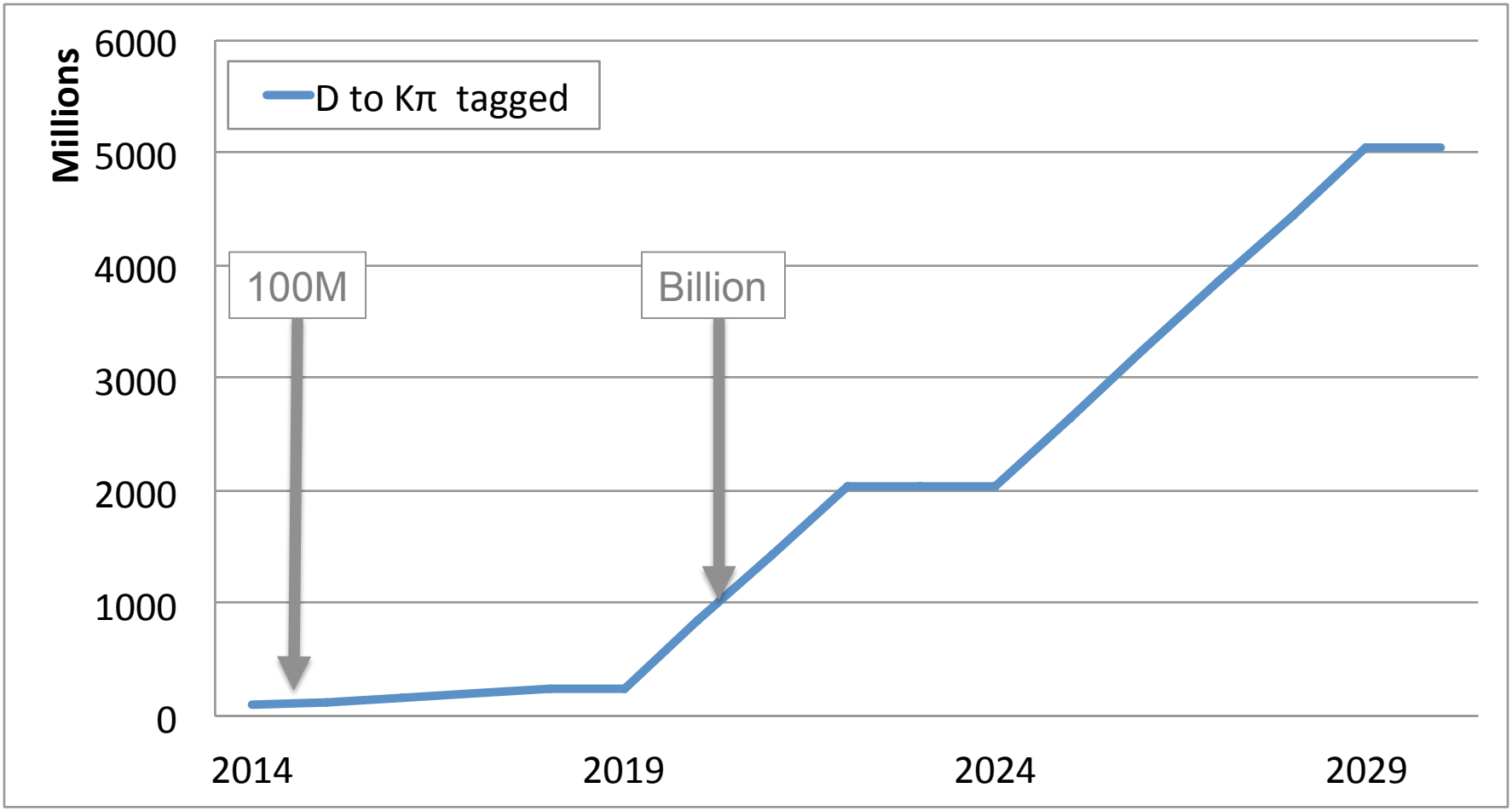
- See backup slides for assumptions

Statistics – Hadronic Trigger Adjusted



- 13 TeV cross-section
- Trigger efficiency adjusted for hadronic modes
  - See backup slides for assumptions

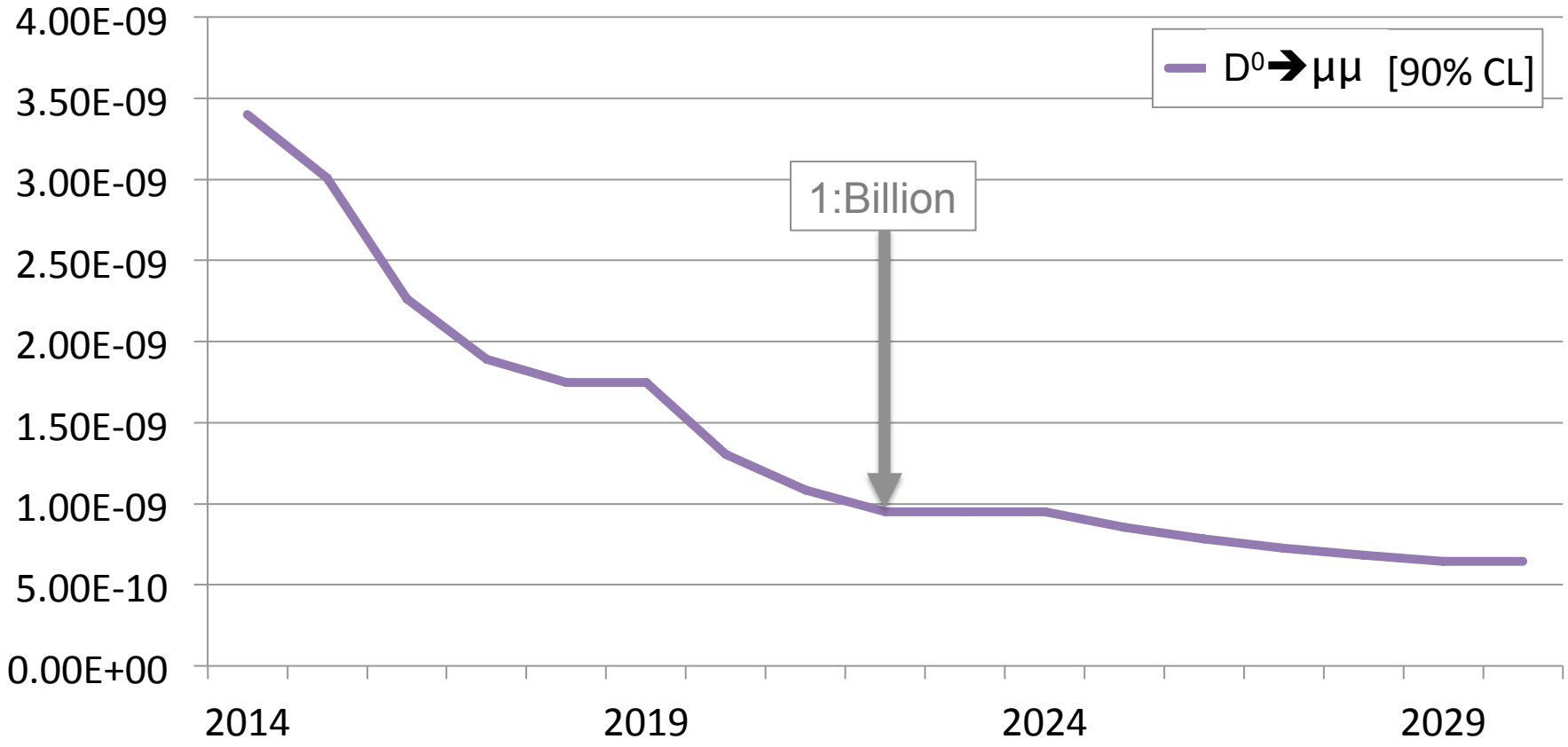
Statistics: $D^0 \rightarrow K\pi$ Events



Future Charm Measurements – key channels

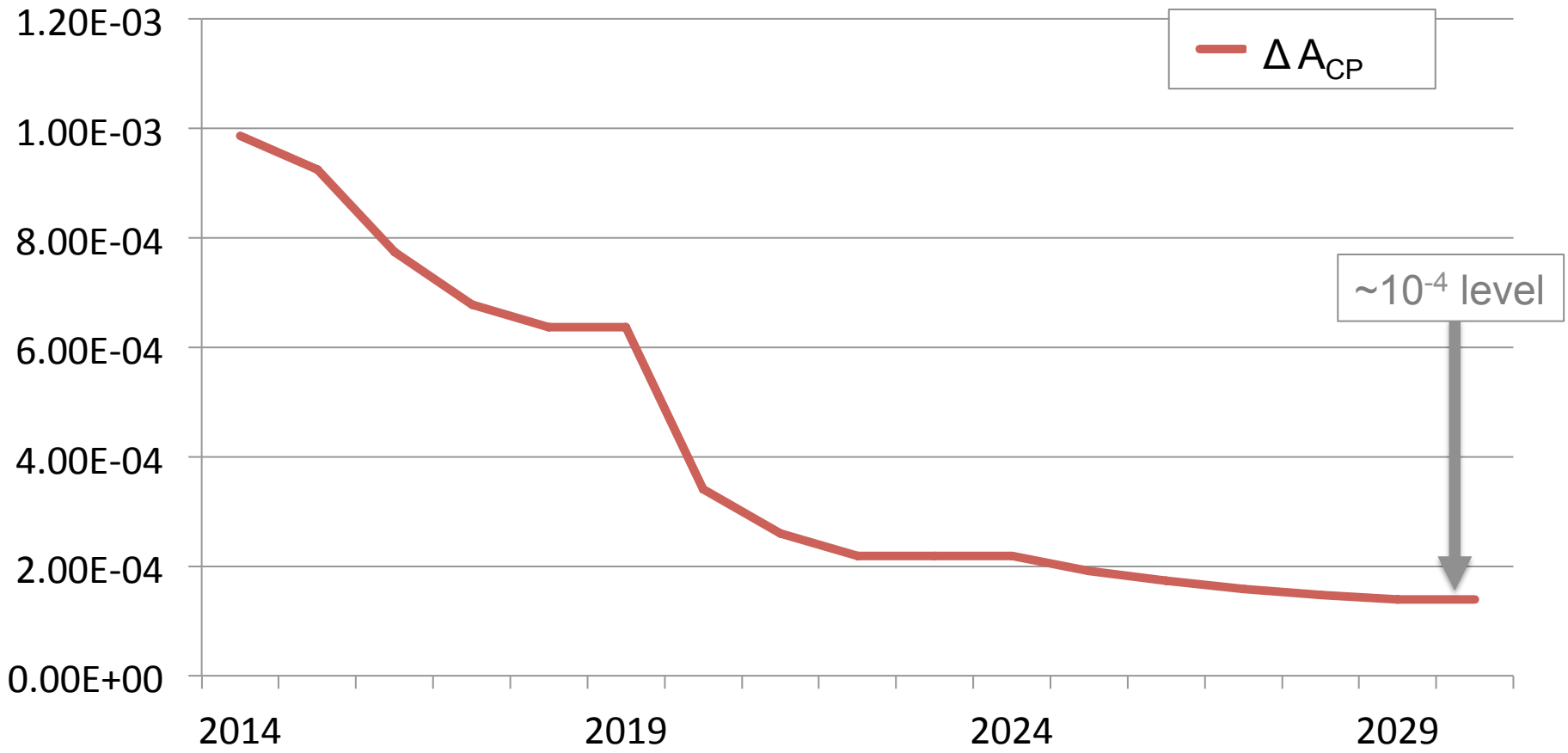
- A_Γ, WS $K\pi$, ΔA_{CP}
  - Inherently robust against systematics due to cancellations
  - Not all at the same level, but no limiting uncertainty known
- $y_{CP} \equiv \tau_{K\pi}/\tau_{KK} - 1 \approx y$
  - Comparison of two different final states
  - Less robust, key is controlling lifetime bias
- $K_S\pi\pi$
  - Leading systematics are either model uncertainties or measurements of CP content at threshold
  - Benefits from BESIII
- Rare Decays
  - Systematics unlikely to limit, no bandwidth issues
- Spectroscopy
  - Bandwidth limitations for Cabibbo favoured modes ?

Future Sensitivities: $D^0 \rightarrow \mu\mu$



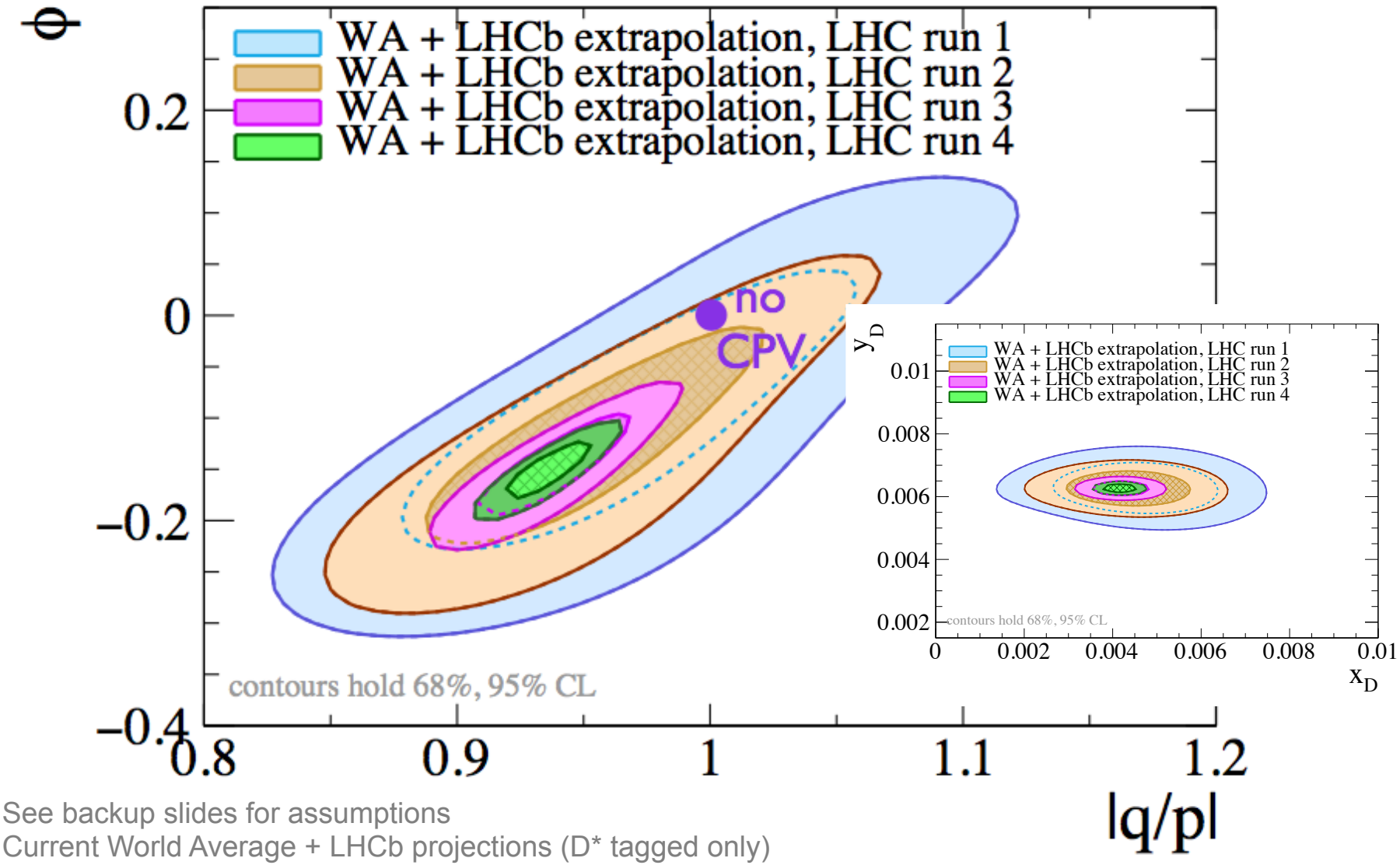
- Scaling sensitivities with √N from current LHCb results
  - Assumes scaling of systematic uncertainties
  - Ignores potential improvements in selections and analyses
- Shows data set collection date

Future Sensitivities: ΔA_{CP}



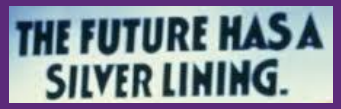
- Scaling sensitivities with √N from current LHCb results (D* tagged only)
  - Assumes scaling of systematic uncertainties
  - Ignores potential improvements in selections and analyses
- Shows data set collection date

Future Sensitivities: CPV & Mixing



- See backup slides for assumptions
- Current World Average + LHCb projections (D* tagged only)
- Central values of current world averages used

Conclusions



- LHCb Charm programme has exceeded expectations for LHC Run 1
- LHC Run II has begun
  - Novel trigger strategies are required to keep pace
- LHCb Upgrade
  - Approved, ~ financed
  - Significant technological challenges, fast timescale
  - Bandwidth key to charm prospects

V1

Upgrade ?

Probe SM level CPV at LHCb Upgrade

Backup Slides

Physics Performance Assumptions

Based on LHCb-PUB-2014-040

- Run-2
  - Cross-section increases linearly with $\sqrt{s}$
  - Non-muon trigger efficiency suffers from tighter thresholds and have a factor 2 lower efficiency
    - Does not assume Turbo Stream
  - $2fb^{-1}$ per year, $5fb^{-1}$ in total for run II

- Upgrade
  - Removal of hardware trigger brings factor 2 efficiency boost for non-muon triggered events
    - Charm factor may well be significantly higher
  - $\sim 5fb^{-1}$ per year

Sensitivity Prediction Assumptions

Based on M. Gersabeck, LHCb-Talk-2015-039, for IHEP 100 TeV workshop

- Mixing and CPV – A_Γ, $y_{cp,}$ WS $K\pi$, $K_S\pi\pi$
- Uses current WA central values from fit

- A_Γ : projection of LHCb 1fb^{-1} D* tagged
- WS $K\pi$: projection of LHCb 3fb^{-1}
- y_{cp}: projection of LHCb 0.03fb^{-1}
- $K_S\pi\pi$:assume same sensitivity per event as Belle

- $\Delta A_{CP:}$ projection of LHCb 1fb^{-1} prelim. result D* tagged only

- $D^0 \rightarrow \mu\mu$: projection of LHCb 1fb^{-1} , leptonic trigger – different scaling

In all CPV,mixing D* tagged only is used in extrapolations
Use of semileptonic B decays, muon tagged, will improve results, and is complementary in systematics

Extrapolations

M. Gersabeck, LHCb-Talk-2015-039, for IHEP workshop

Run	$\sqrt{s}$ in TeV	L in fb^{-1}	ε_{trig}	L_{eq}	ΣL_{eq}
1 (2011)	7	1	1	1	**1**
1 (2012)	8	2	1	2.3	**3.3**
2	13	5	0.5	4.6	**7.9**
3	14	15	2	60	**68**
4	14	25	2	100	**168**

- L_{eq} - Calculate equivalent luminosities to 7 TeV
- Extrapolate signal yields accordingly
- Based on existing Run-I measurements where available

Future Sensitivities

M. Gersabeck, LHCb-Talk-2015-039, for IHEP workshop

- Scaling sensitivities with $\sqrt{N}$
  - Assumes scaling of systematic uncertainties
  - Ignores potential improvements in selections and analyses

Run	x [10^{-3}]	y [10^{-3}]	$\lvert q/p \rvert$ [10^{-3}]	ϕ [mrad]
1	1.22	0.53	59	89
2	0.92	0.37	44	70
3	0.42	0.15	20	33
4	0.25	0.09	**12**	**20**