technische universität
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LHCb Status Report

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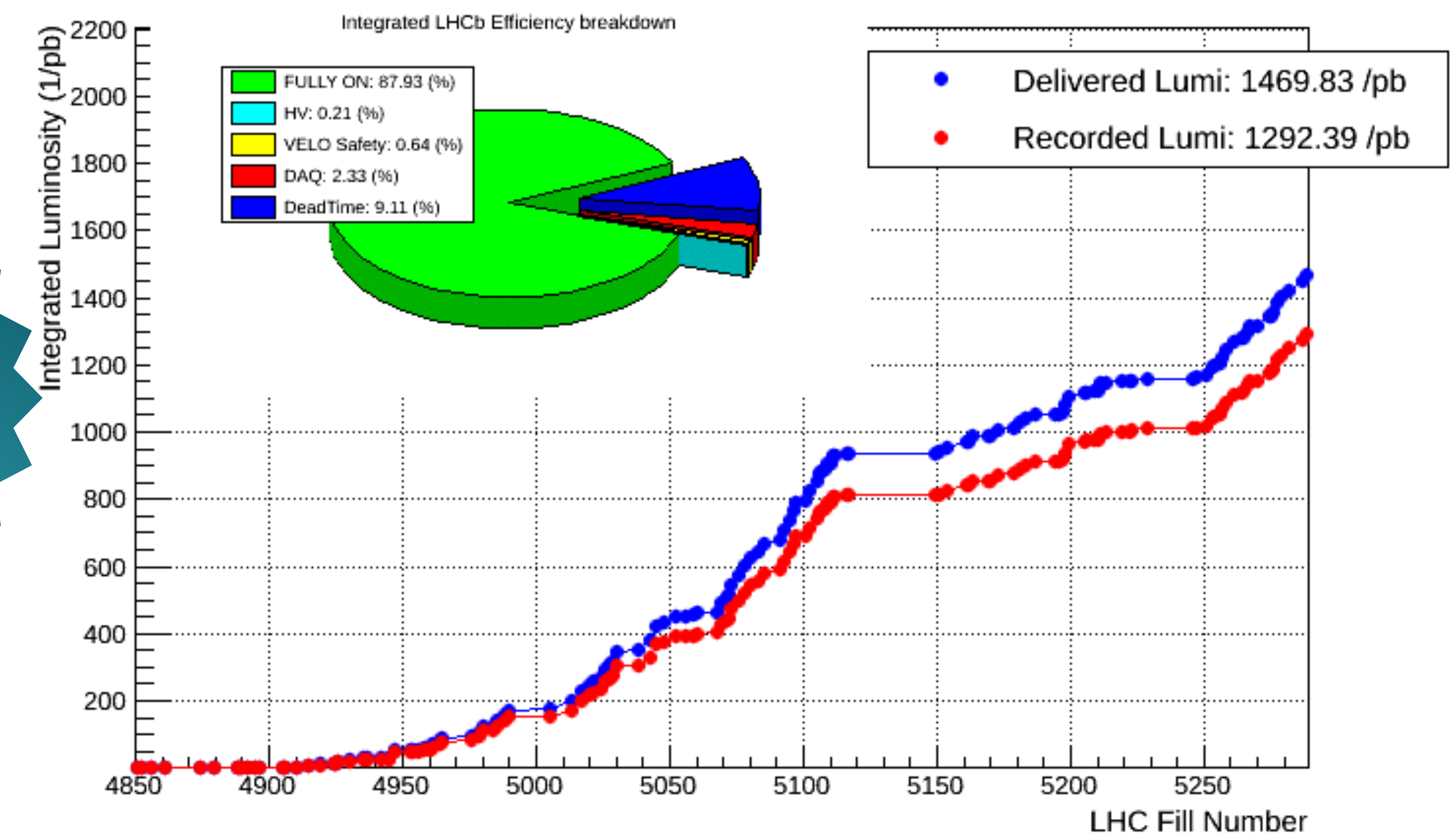
127th LHCC Meeting, 21st of September 2016, CERN

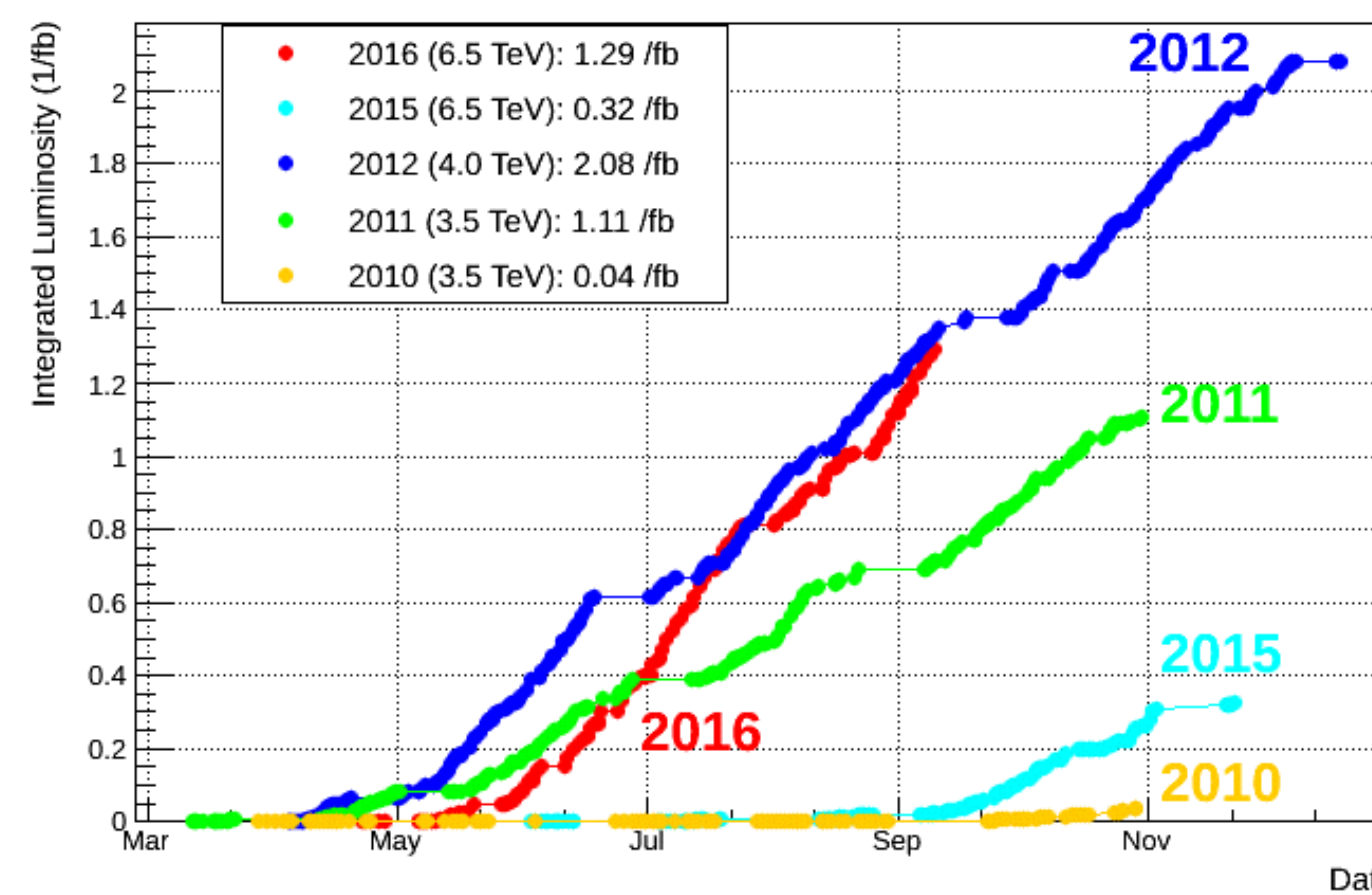
Operations

Data taking status

- amazing LHC performance
  - 80% peak efficiency
  - >50% in stable beams
- great LHCb performance
  - all sub-detectors in good shape
  - data accumulation with ≈90% efficiency
  - collected ≈1.3 fb^{-1} in 2016
  - more *bb*-pairs than in 2012 dataset
- working hard to exploit LHC's record-crunching!
  - originally assumed ≈30% efficiency

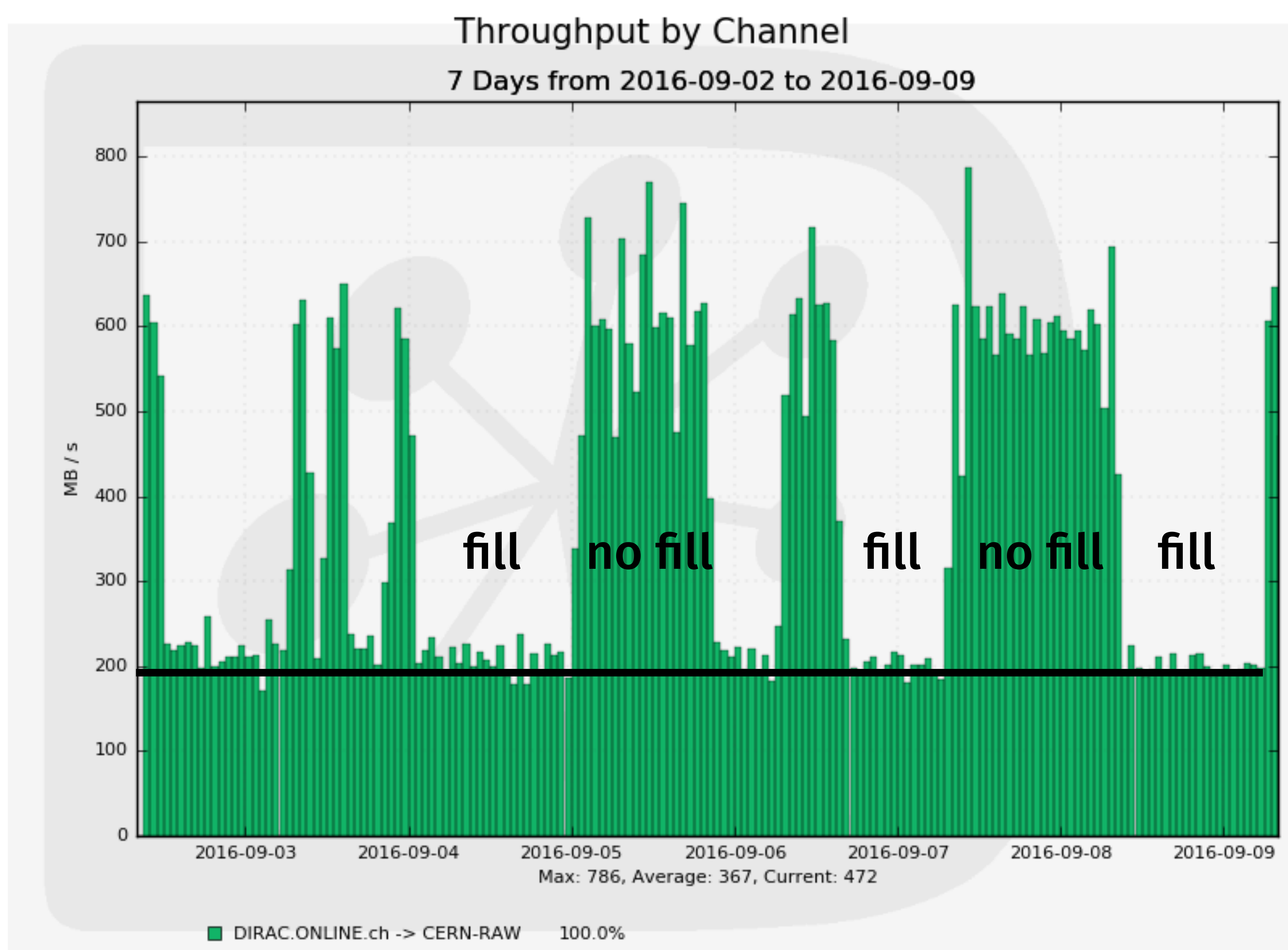
thanks to the accelerator teams!

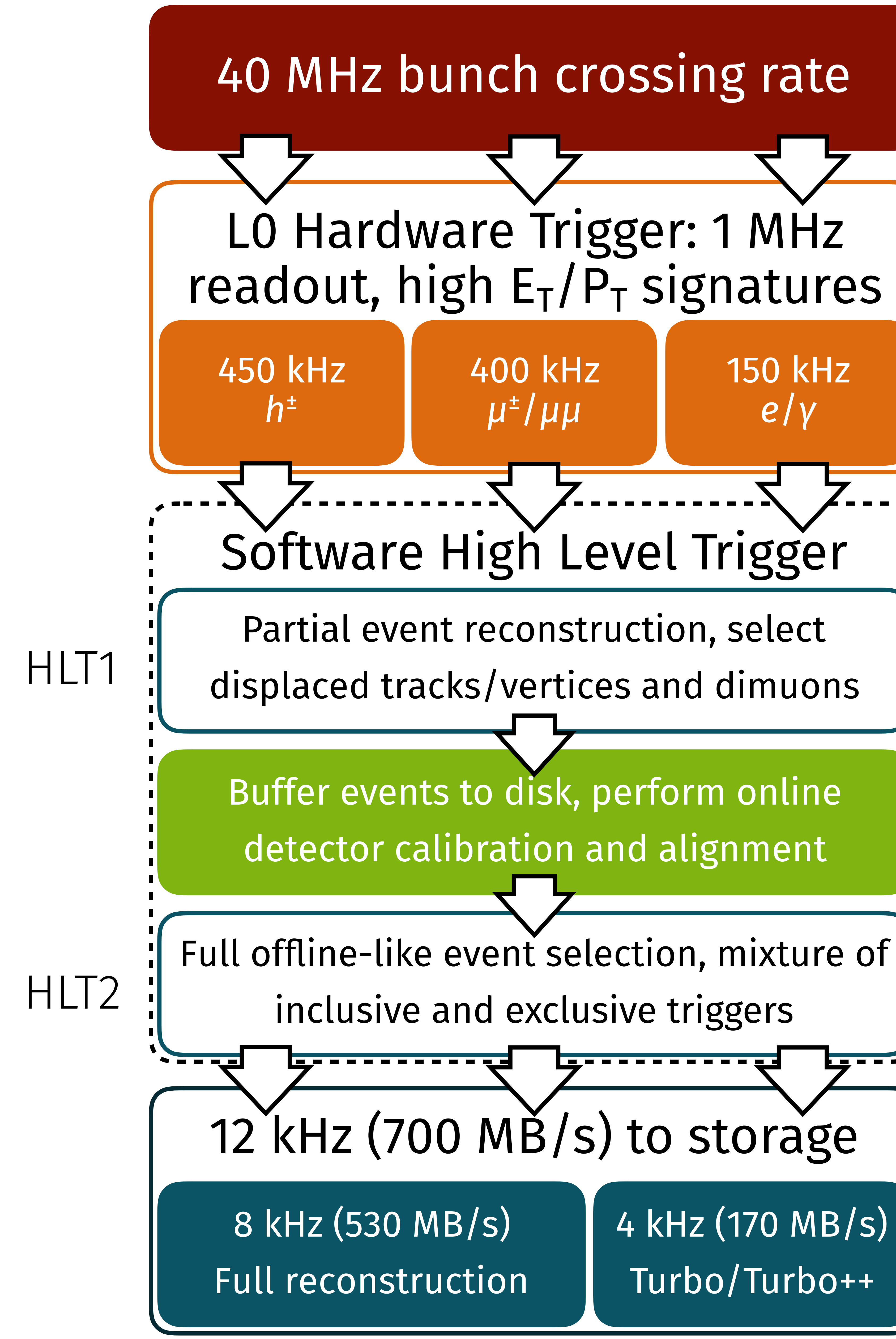




Data taking in Run II – Reminder

- trigger w. split HLT and automatic alignment
  - buffer data after HLT1
  - perform alignment
  - HLT2 processes data continuously and asynchronously
- HLT1 and HLT2 run on the same farm
- strategy is working very well





Data taking in Run II – Buffers

- trigger w. split HLT and automatic alignment
  - buffer data after HLT1
  - perform alignment
  - HLT2 processes data continuously and asynchronously
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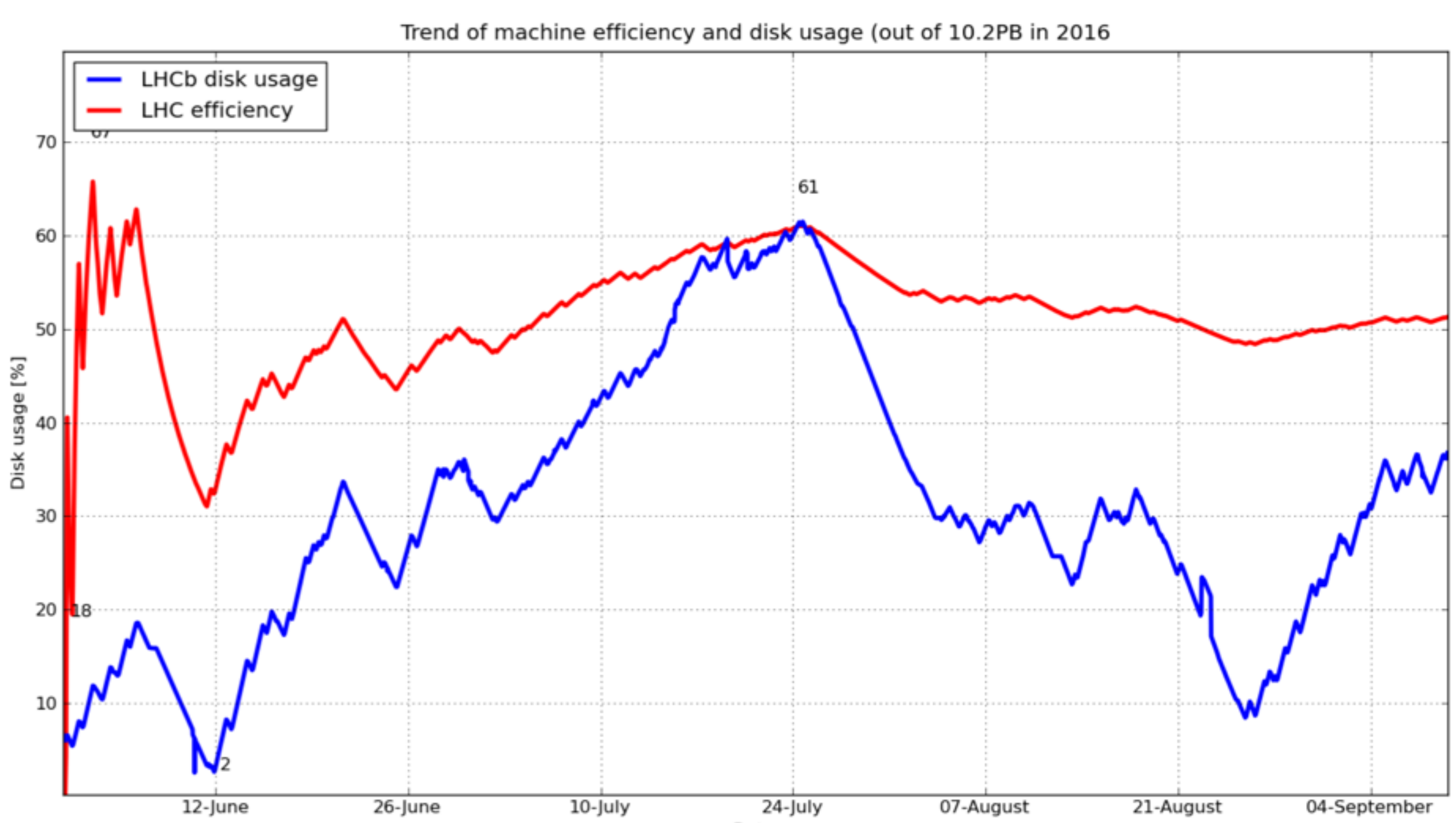
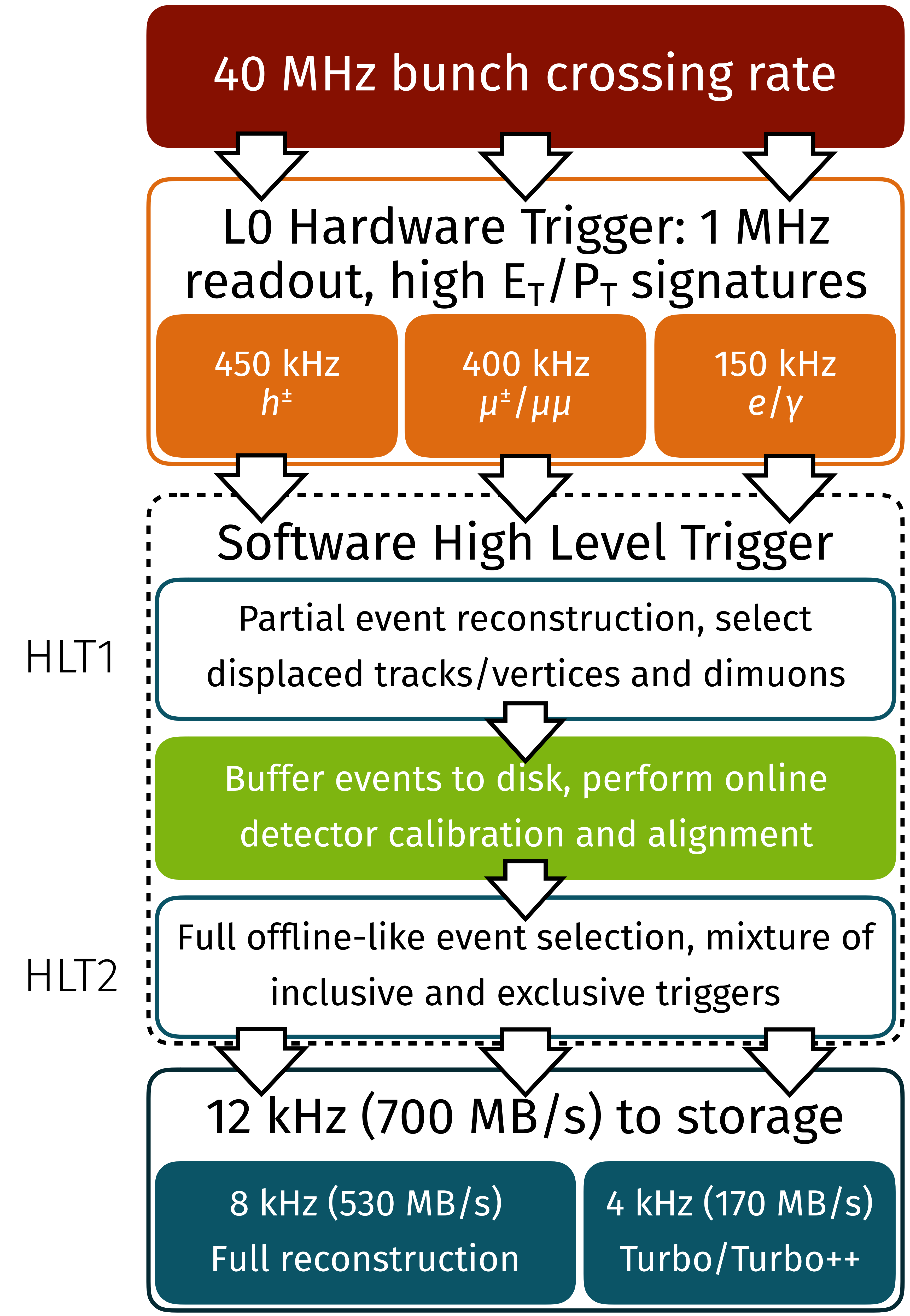
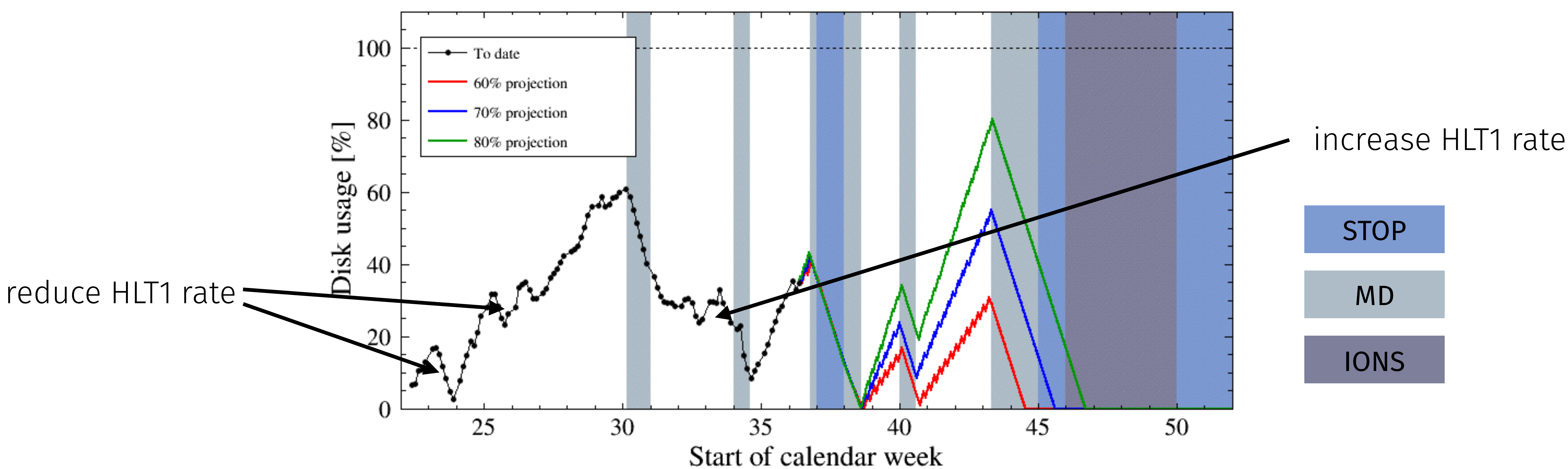




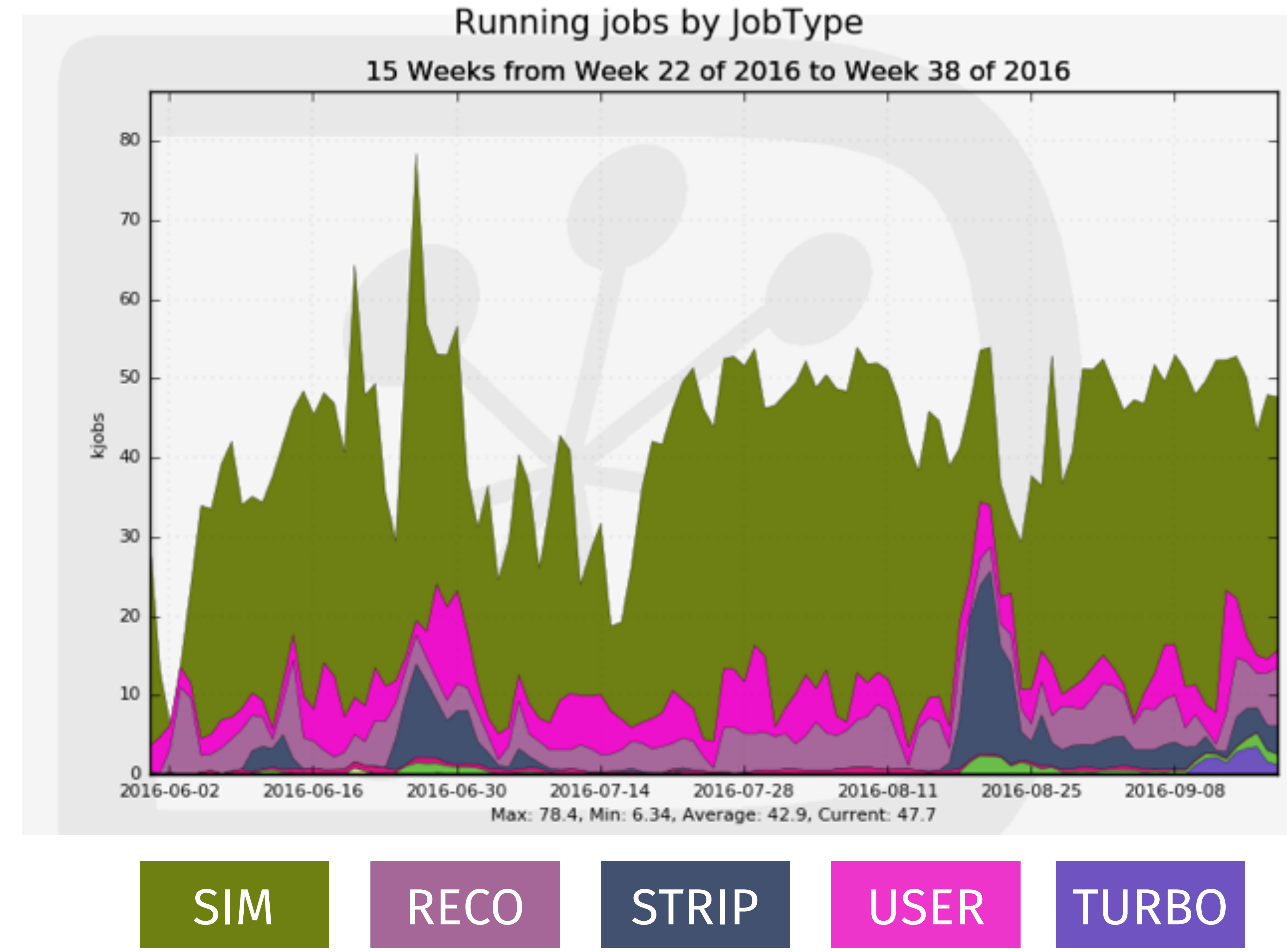
LHC efficiency and LHCb HLT

- defined various scenarios depending on LHC efficiency and luminosity increase
- monitor status of buffer disks and speed-up the HLT
- small set of trigger configurations for different LHC setups
  - ≈3%/day of disk occupancy decrease when HLT2 running at max
  - increase originally ≈5%/day, can be adjusted by tightening/loosening trigger requirements



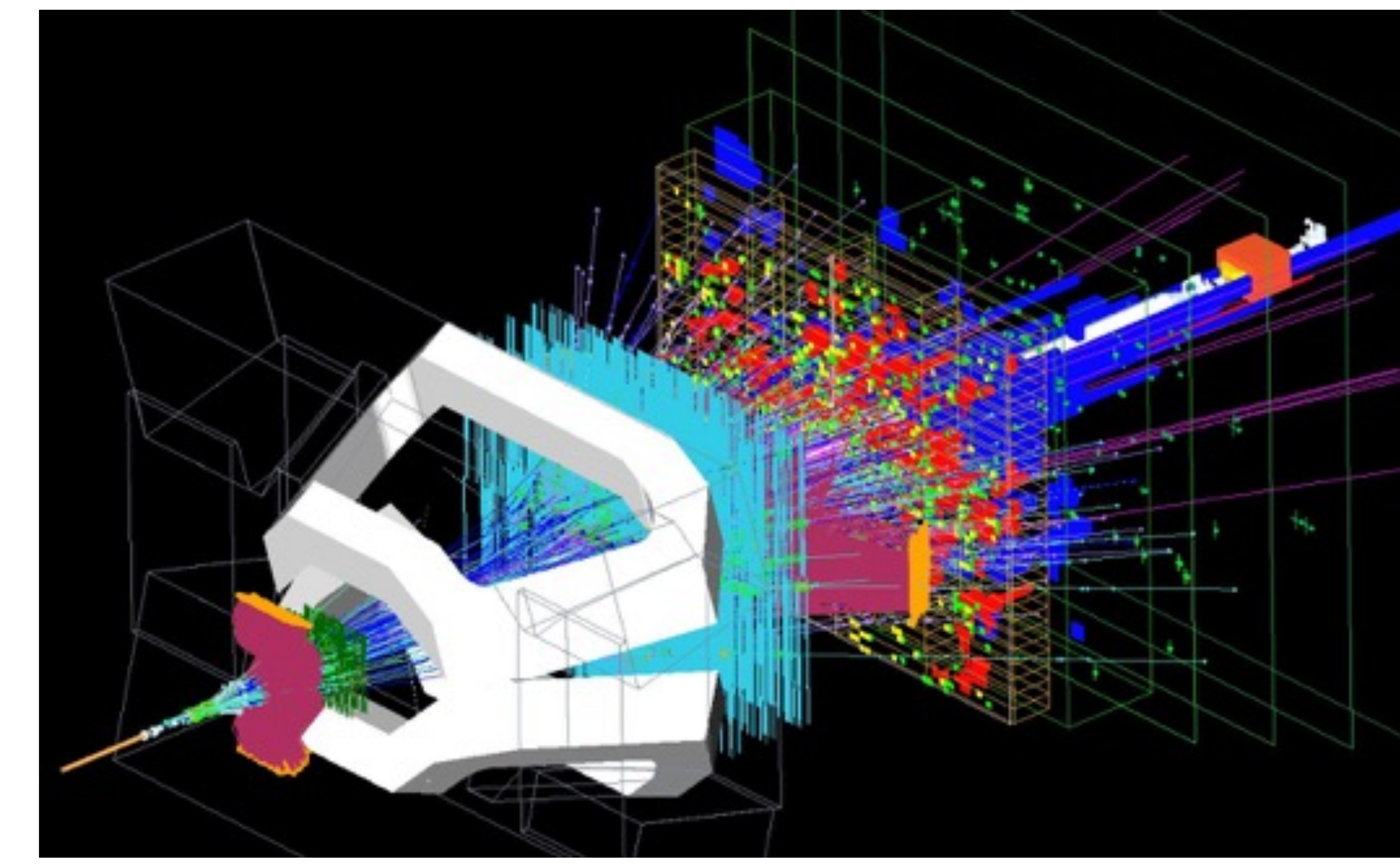
Distributed Data Processing in 2016

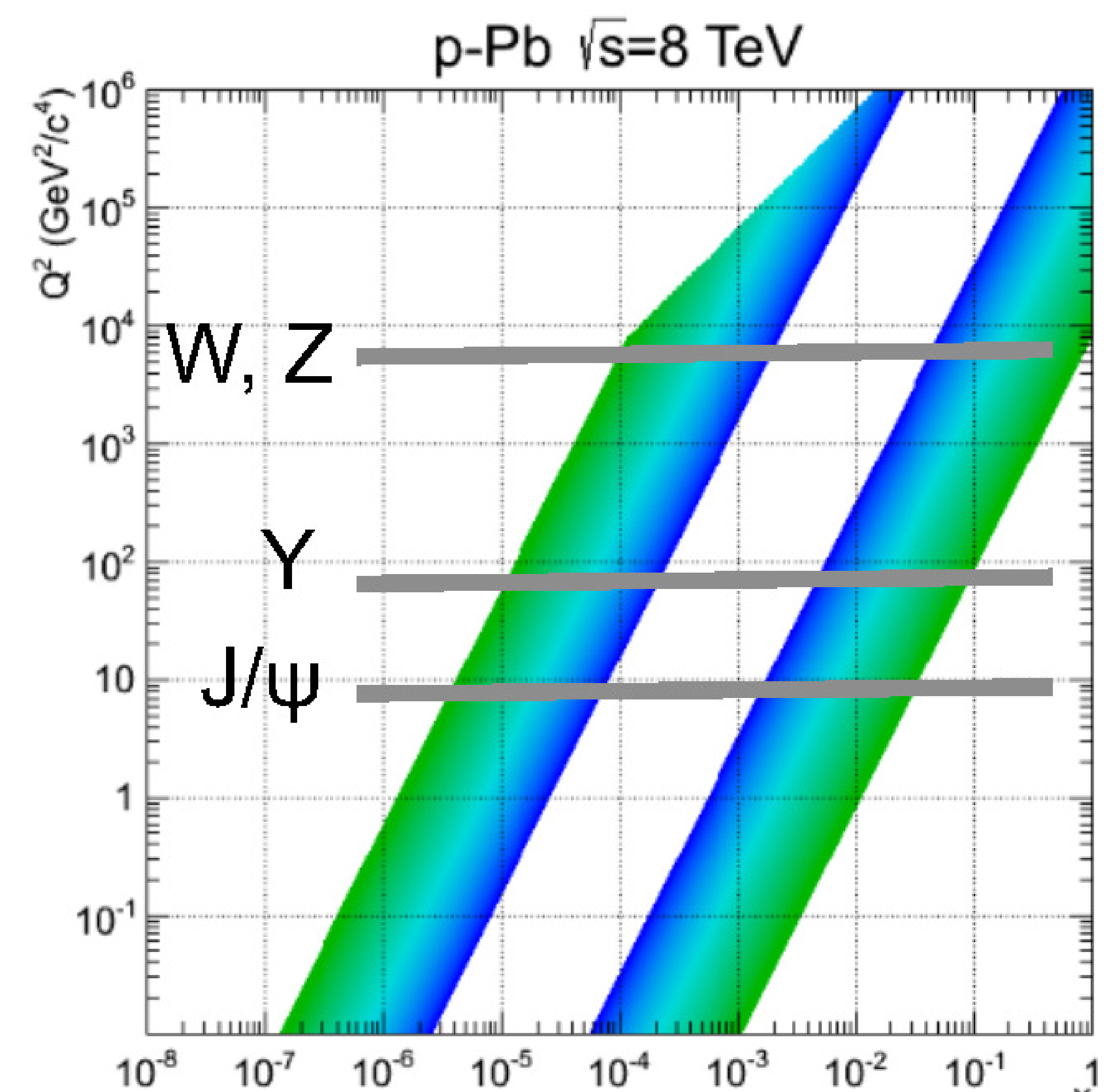
- increased LHC efficiency also affects CPU/disk and tape needs
  - required adaptation of data processing workflows
  - all offline data processing workflows now operational and backlogs processed
- additional strain due to changes in "Turbo"
  - now also contains reconstruction information
  - reduced offline CPU needs
  - increased disk requirements
- additional disk needs mitigated by
  - reduction of disk replicas
  - data popularity to remove unused datasets
  - parking of 1/3 of the Turbo data on tape
- using resources well above pledges



Preparations for the 2016 pPb run

- LHCb will take part to the pPb run at the end of the year
  - it will represent a big step forward for heavy ion physics at LHCb
  - work ongoing to optimise trigger and event reconstruction
  - we aim to get an integrated luminosity of 20 nb^{-1} at $\sqrt{s_{NN}}$ = 8 TeV
  - pPb and Pbp configurations split 50/50
- main physics targets
  - J/ψ, $\psi(2S)$, $\Upsilon(nS)$, and Drell-Yan production
    - 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

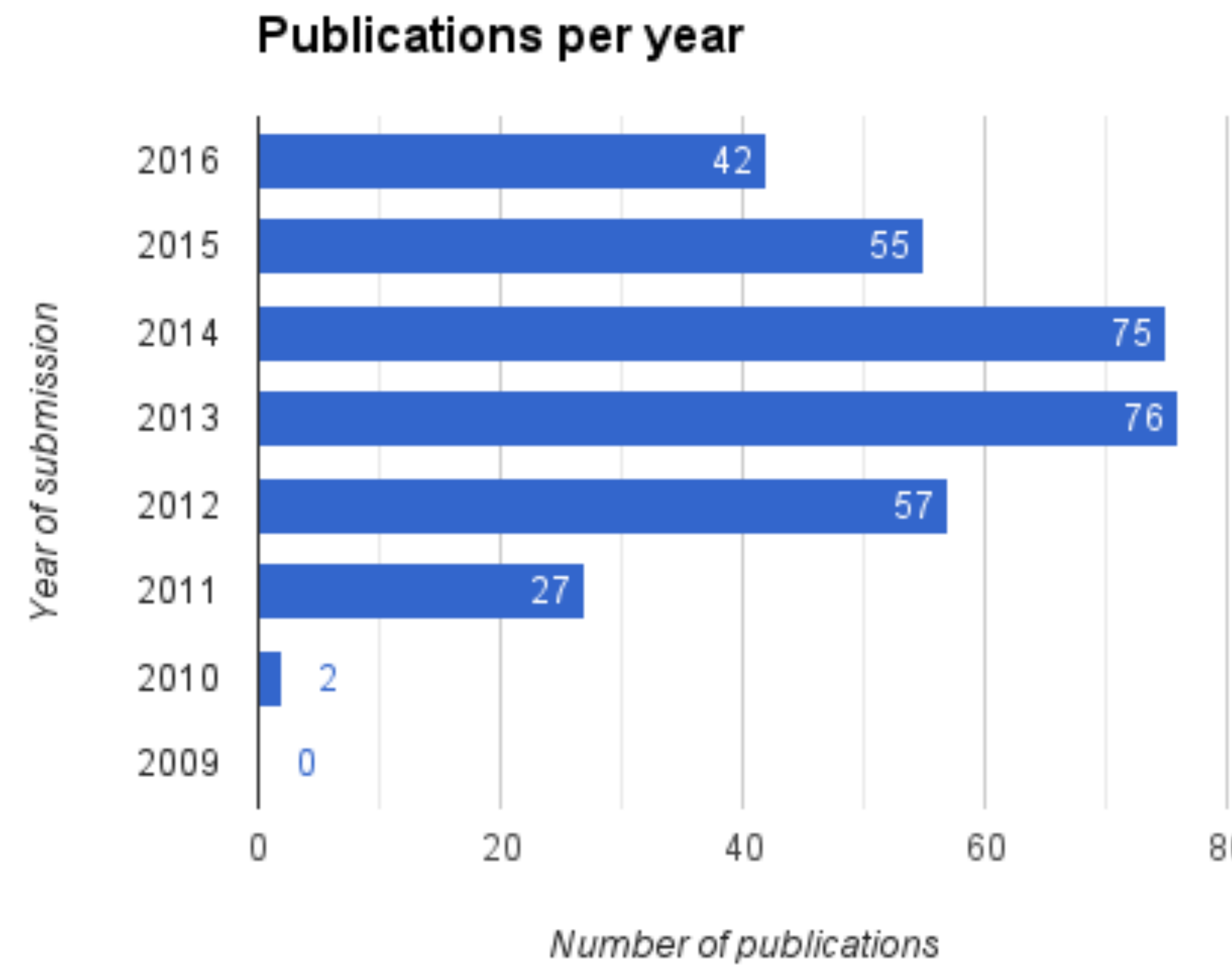


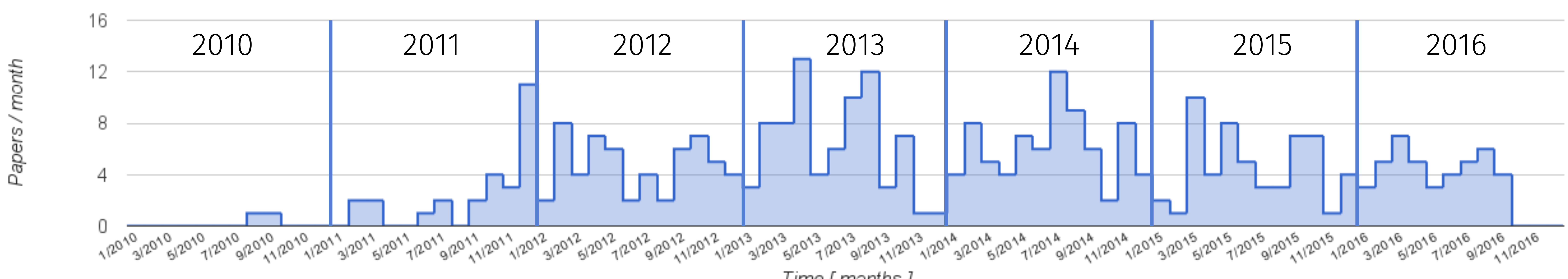


New results

Publication status

- 334 papers submitted
  - +20 papers w.r.t. last LHCC
  - 7 PRL, 5 JHEP, 4 PLB, 2 PRD, 1 EPJC, 1 Nature Physics
- 15 papers in preparation
- 47 analyses under review





Publications since last LHCC

- Probing matter-antimatter asymmetries in beauty baryon decays
- Search for Higgs-like bosons decaying into long-lived exotic particles
- First experimental study of the photon polarization in radiative B_s decays
- Differential branching fraction and angular moments analysis of the decay $B^0 \to K^+ \pi^- \mu^+ \mu^-$ in the $K^*_{0,2}(1430)^0$ region
- Measurement of CP violation in $B^0 \to D^+ D^-$ decays
- Measurement of the CP-violating phase and decay-width difference in $B_s \to \psi(2S)\varphi$ decays
- Measurement of forward $W \to e\nu$ production in pp collisions at $\sqrt{s}$=8 TeV
- Search for the suppressed decays $B^+ \to K^+ K^+ \pi^-$ and $B^+ \to \pi^+ \pi^+ K^-$
- Amplitude analysis of $B^- \to D^+ \pi^- \pi^-$ decays
- Search for structure in the $B_s \pi^\pm$ invariant mass spectrum

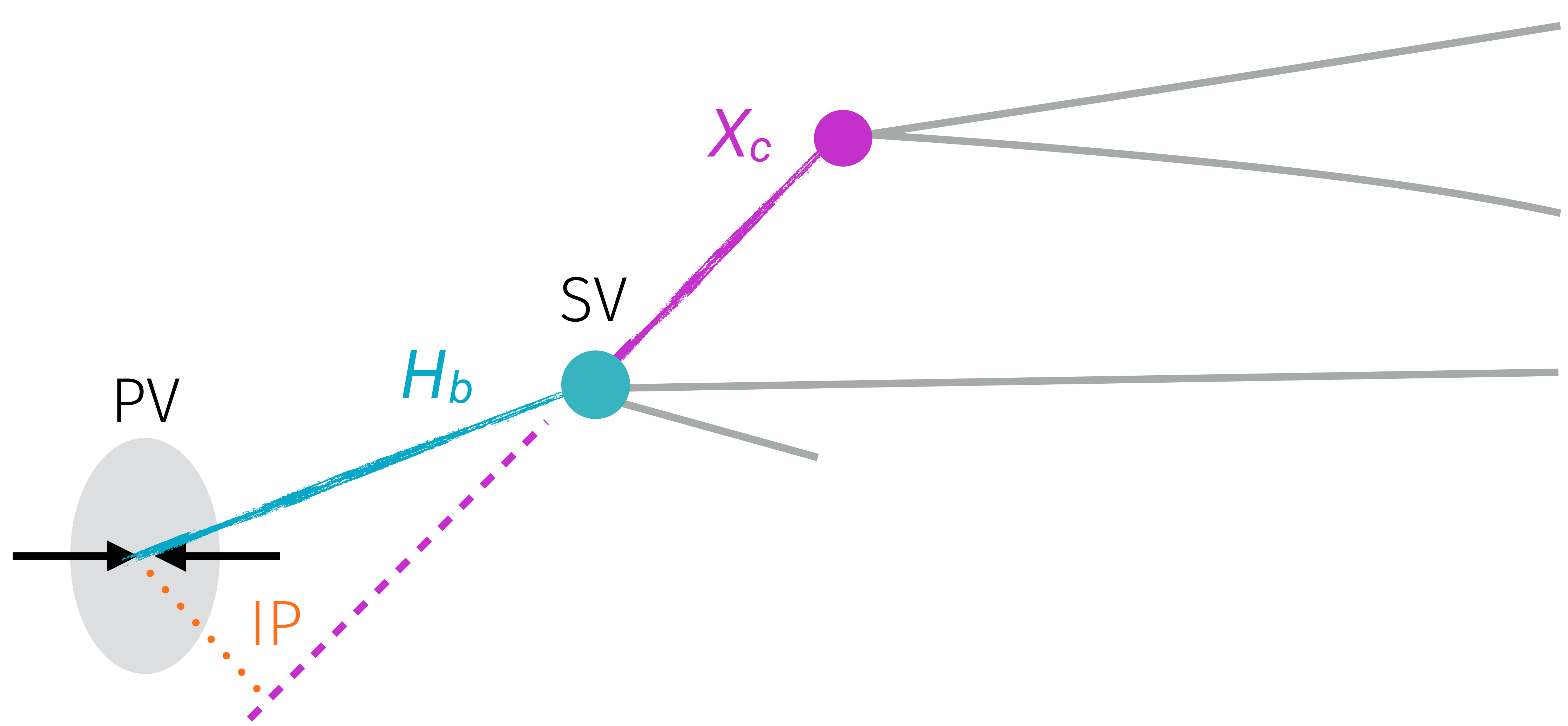
Publications since last LHCC (cont.)

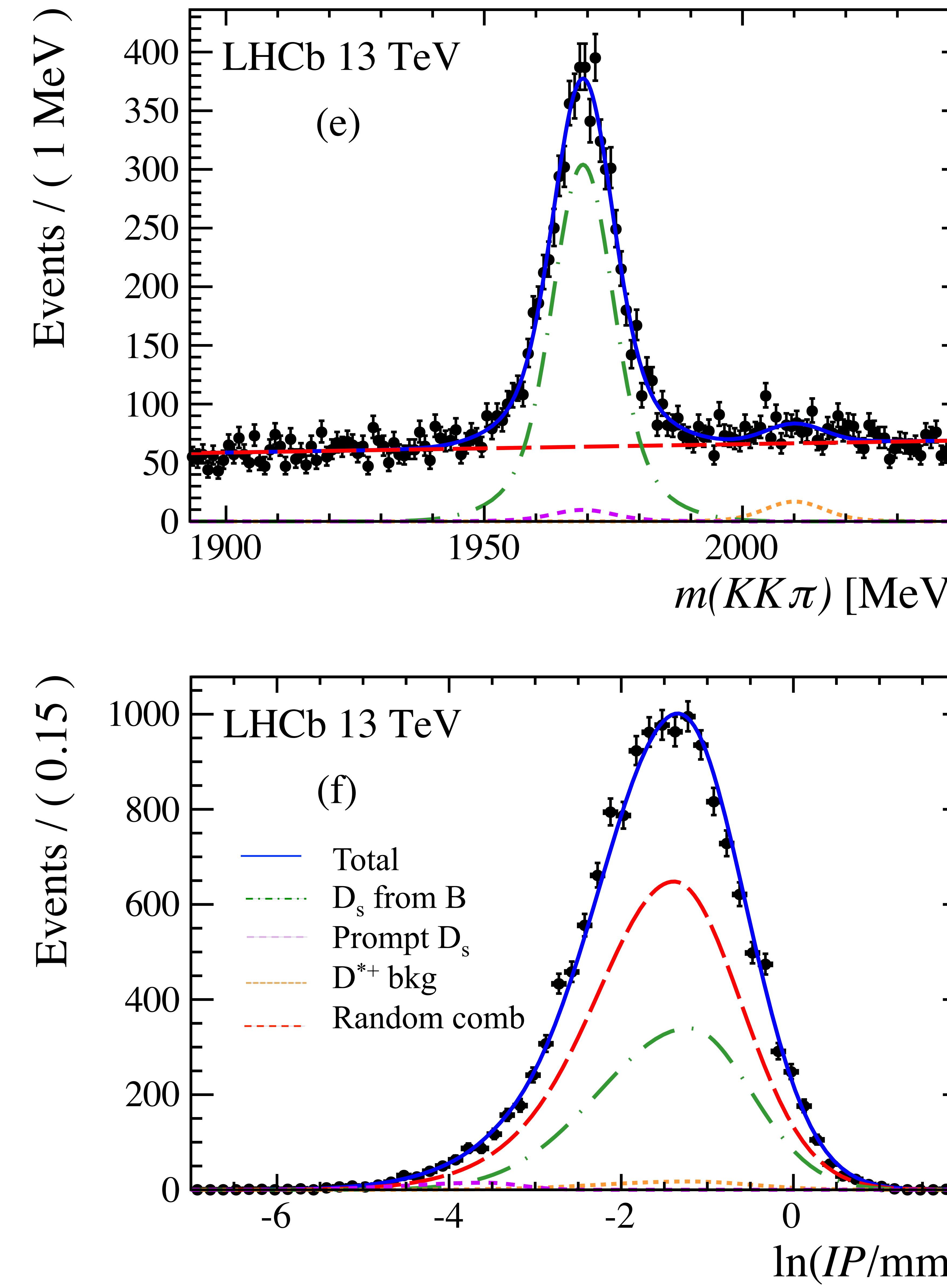
- Measurement of the ratio of branching fractions $\mathrm{Br}(B_c \to J/\psi K^+)/\mathrm{Br}(B_c \to J/\psi \pi^+)$
- Measurement of the forward Z boson production cross-section in pp collisions at $\sqrt{s}$=13 TeV
- Observation of $\eta_c(2S) \to pp$ and search for $X(3872) \to pp$ decays
- Measurement of the $B_s \to J/\psi \eta$ lifetime
- Study of B_c decays to the $K^+K^-\pi^+$ final state and evidence for the decay $B_c \to \chi_c^0 \pi^+$
- Amplitude analysis of $B^+ \to J/\psi \varphi K^+$ decays
- Observation of $J/\psi\varphi$ structures consistent with exotic states from amplitude analysis of $B^+ \to J/\psi \varphi K^+$ decays
- Evidence for exotic hadron contributions to $\Lambda_b \to J/\psi p \pi^-$ decays
- Measurements of the S-wave fraction in $B^0 \to K^+\pi^-\mu^+\mu^-$ decays and the $B^0 \to K^*(892)^0\mu^+\mu^-$ differential branching fraction
- Measurement of the CP asymmetry in B_s mixing

Run II

b-quark production cross-section @13 TeV

- strategy: measure inclusive $b \to X_c \mu \nu X$ decays
  - right-sign μX_c combinations, $X_c = \{D^0, D^+, D_s, \Lambda_c\}$
    - form a good secondary vertex (SV)
    - do not point back to the primary vertex (PV)
  - 2D fit to m and ln(IP) distribution to identify non-prompt X_c

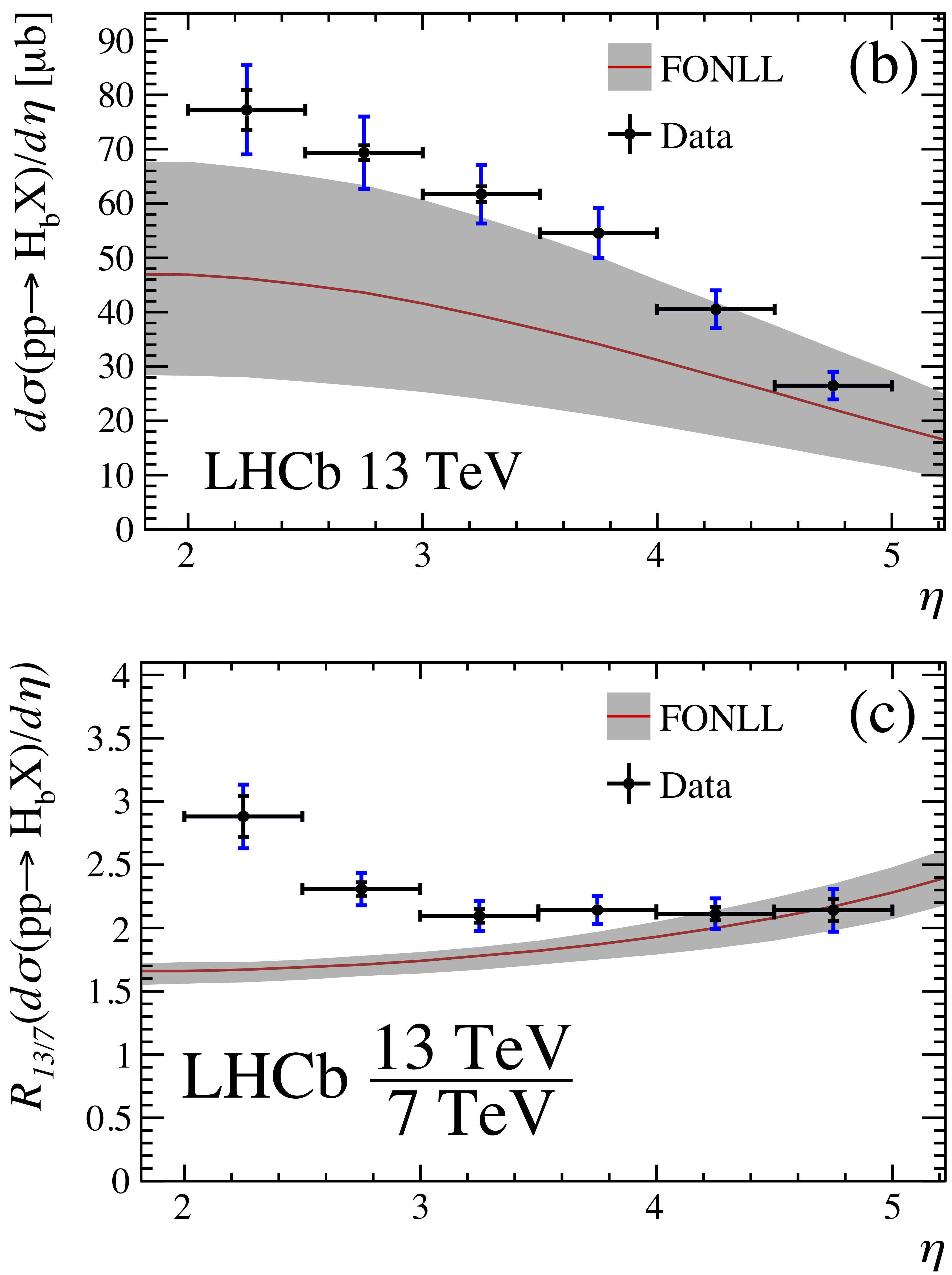




LHCb-PAPER-2016-030, in preparation

Run II

b-quark production cross-section



- cross-section in LHCb acceptance
  - σ_{bb} = (164.9 ± 2.3 ± 14.6) μb
  - theory prediction 111^{+51}_{-44} μb from FONLL [arXiv:1507.06197]
- measured ratio
  - σ_{bb}(13 TeV)/σ_{bb}(7 TeV) = 2.30 ± 0.25 ± 0.19
  - theory FONLL predicts $1.70^{+0.21}_{-0.15}$
  - tensions at low η

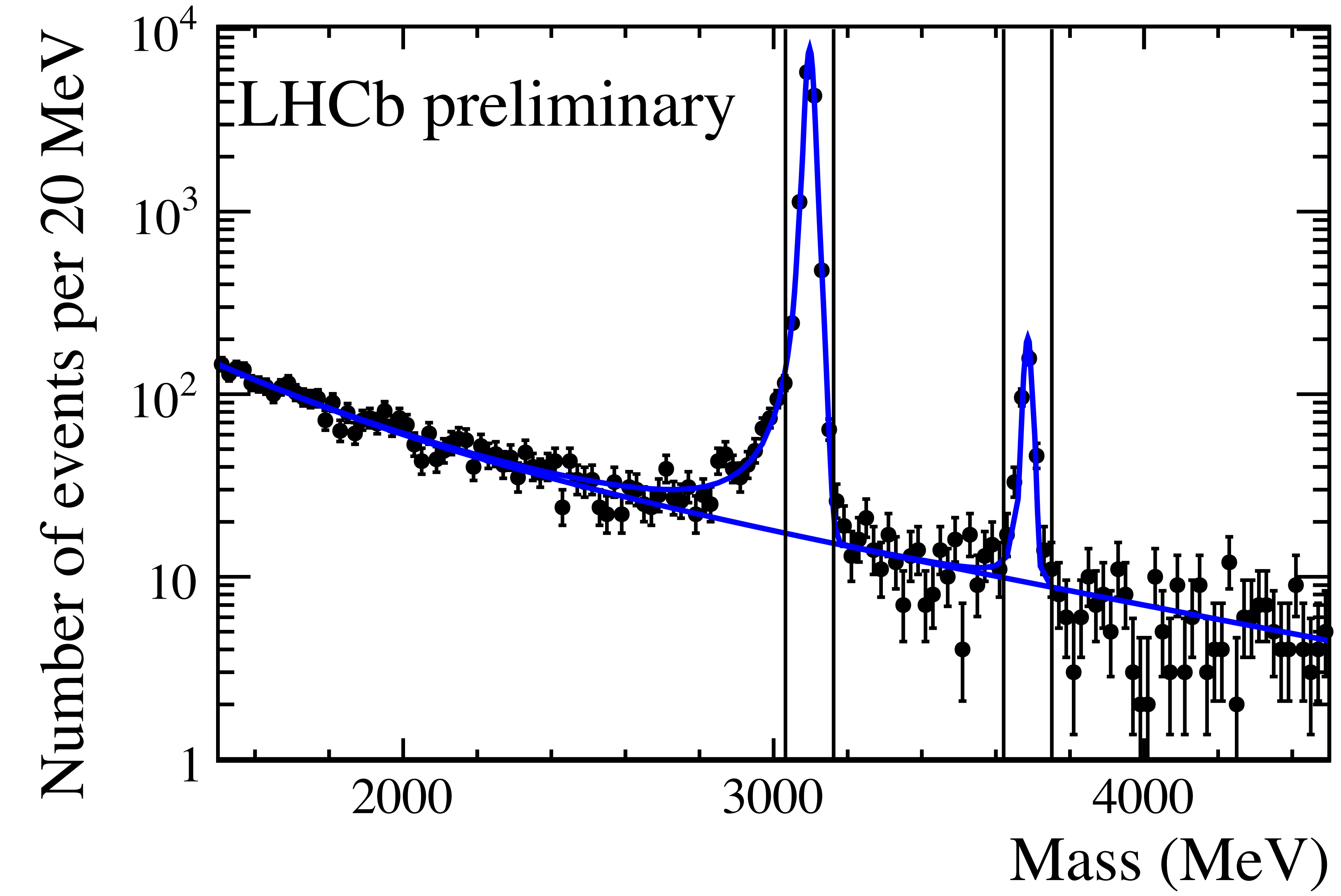
LHCb-PAPER-2016-030, in preparation

Run II

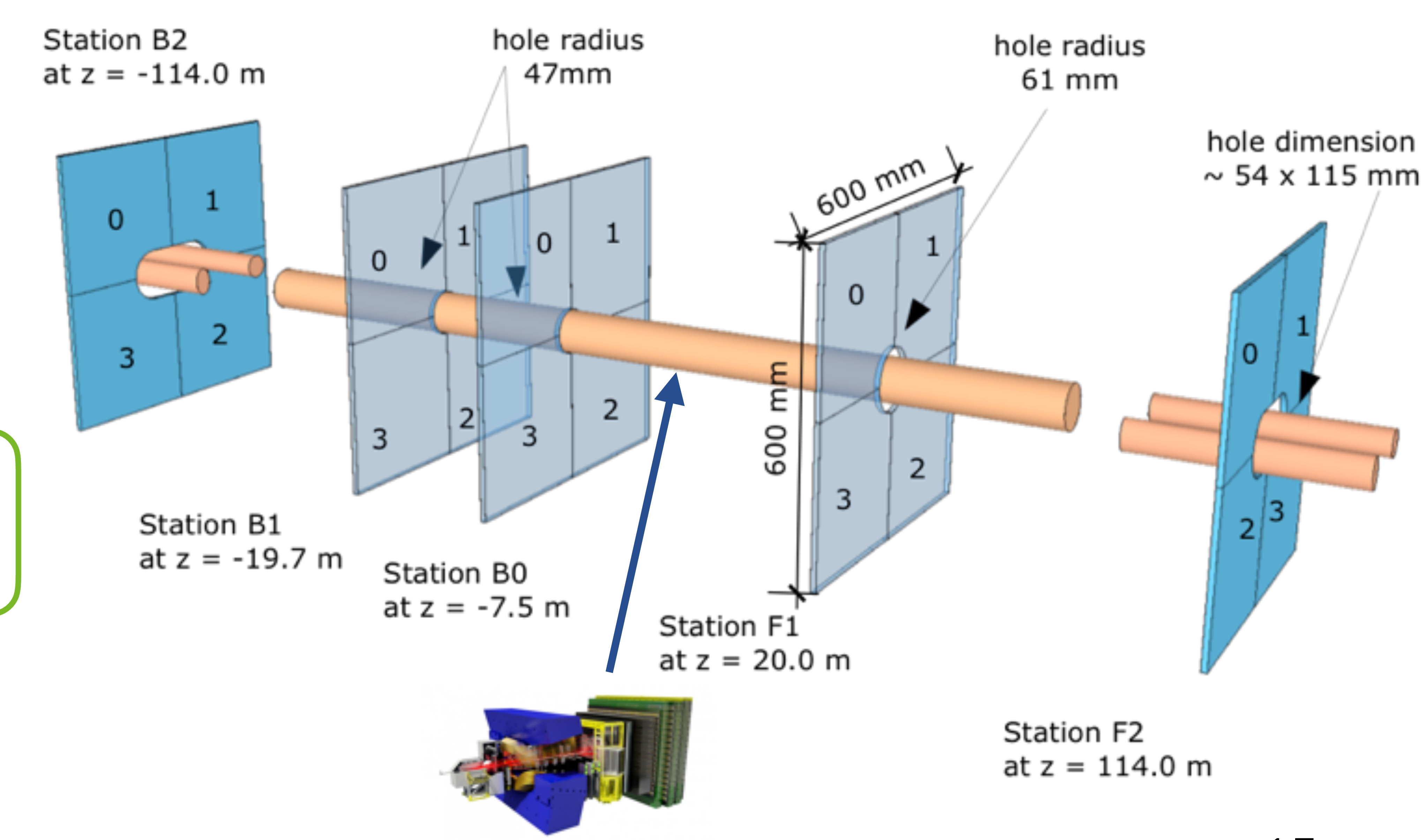
J/ψ and $\psi(2S)$ production @13 TeV

- central exclusive production
  - diffractive process, protons remain intact
  - interaction mediated by pomerons
- cross-section measurements useful for
  - testing QCD
  - description of pomerons
  - probing the gluon PDF, down to $x = 2 \times 10^{-6}$
- first result with the inclusion of HeRSChel!

$$\begin{aligned}\sigma_{J/\psi\to\mu^+\mu^-}(2.0 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) &= 407 \pm 8 \pm 24 \pm 16 \text{ pb} \\ \sigma_{\psi(2S)\to\mu^+\mu^-}(2.0 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) &= 9.4 \pm 0.9 \pm 0.6 \pm 0.4 \text{ pb}\end{aligned}$$



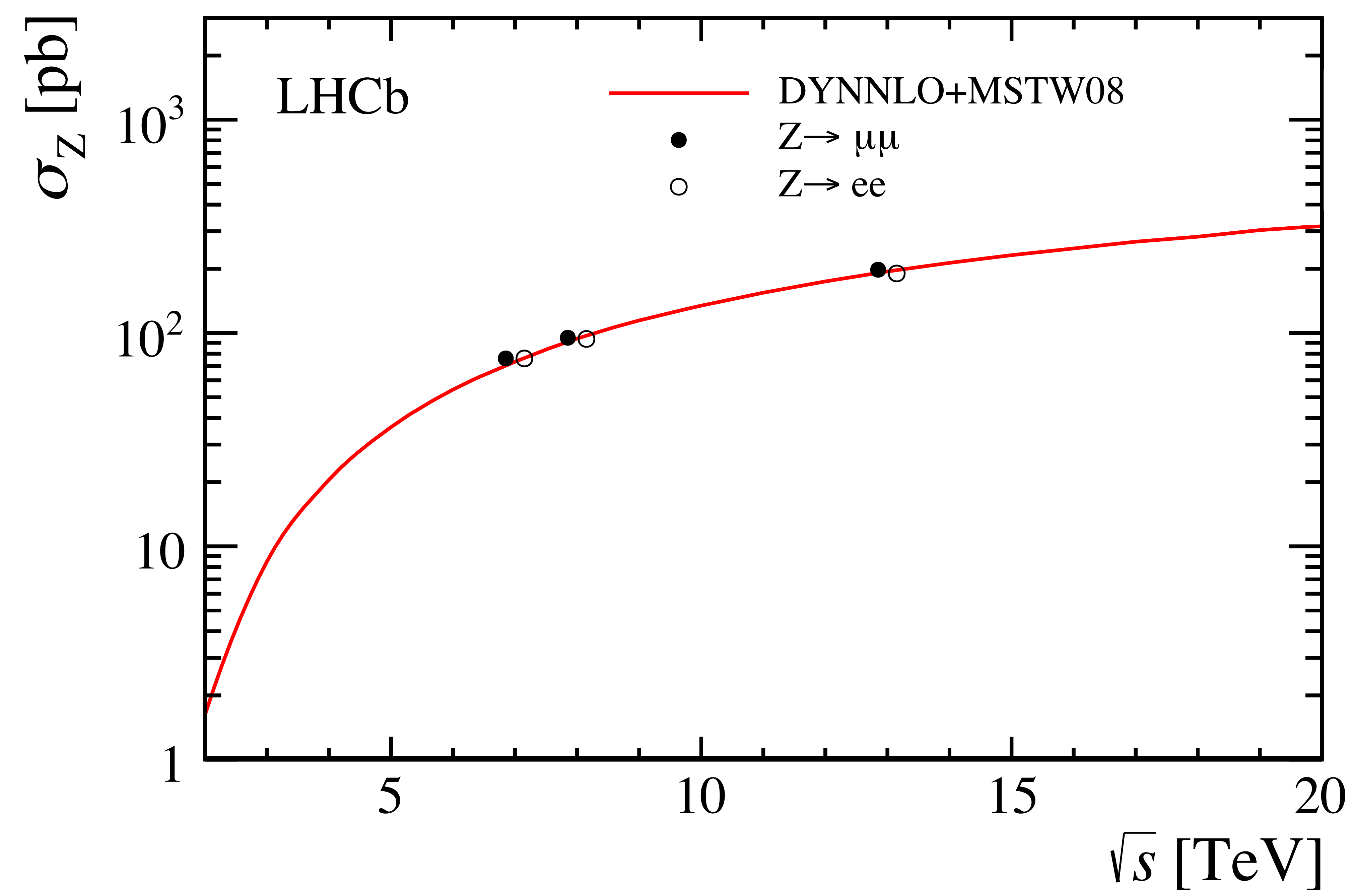
LHCb-CONF-2016-007



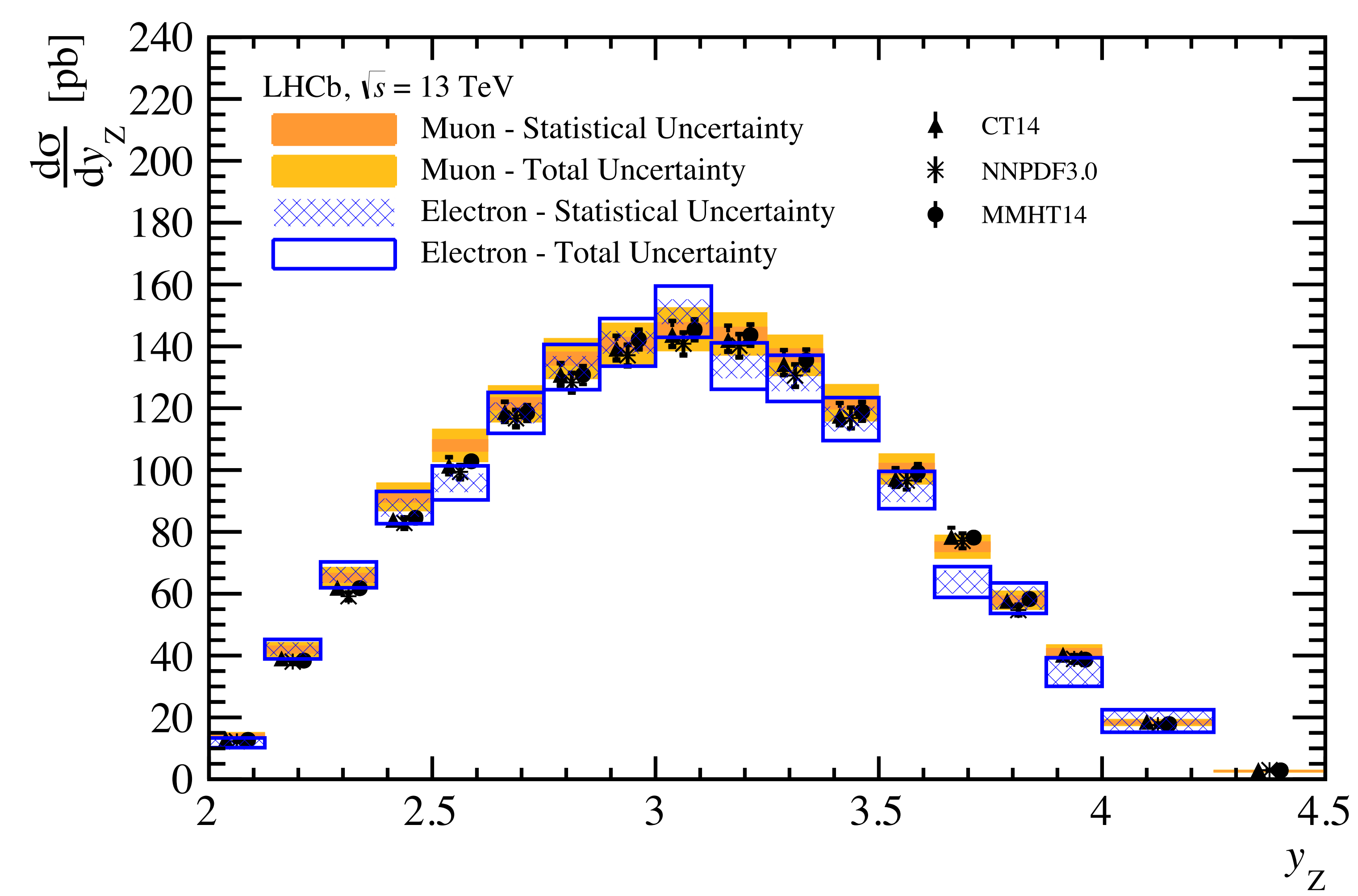
Run II

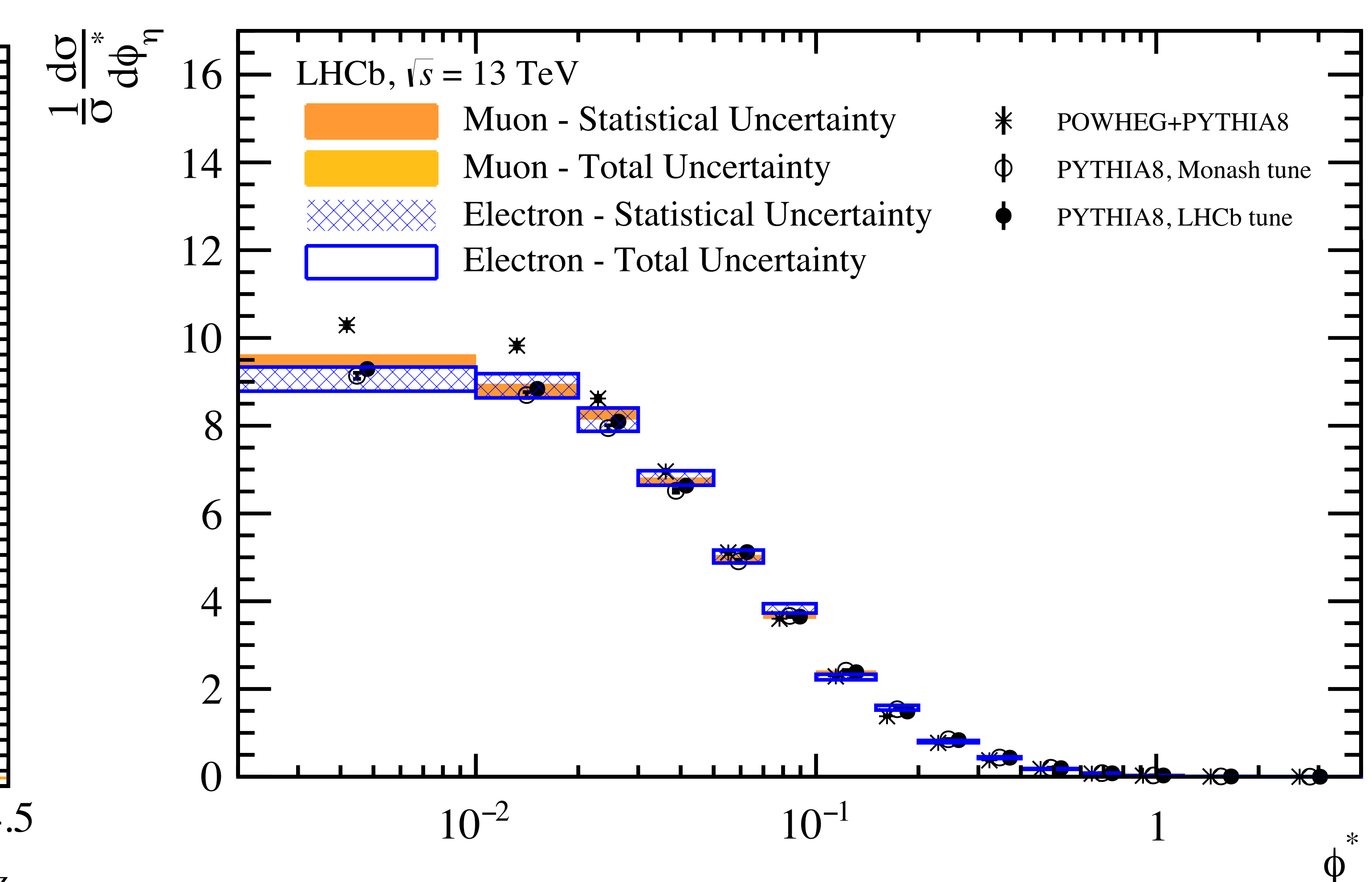
Forward Z boson production at $\sqrt{s}$=13 TeV

- measure $\sigma(Z \to l^+ l^-)$ with $l^\pm = e^\pm, \mu^\pm$
- probe lower Bjorken-x than in Run I
- good agreement
  - between the two final state cross-sections
  - differential cross-section distributions vs. theory
- first step towards further Run II studies
  - great potential for LHCb's electroweak programme



LHCb-PAPER-2016-021, arXiv:1607.06495





Photon polarisation in $B_s \to \varphi\gamma$

- decay-time dependent decay rate

$$\Gamma_{B_s^0 \to \phi\gamma}(t) \propto e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) - \mathcal{A}^{\Delta}\sinh(\Delta\Gamma_s t/2)\right]$$

  - photon polarisation parameter

$$\mathcal{A}^{\Delta} \approx \sin 2\psi \cos\varphi_s$$

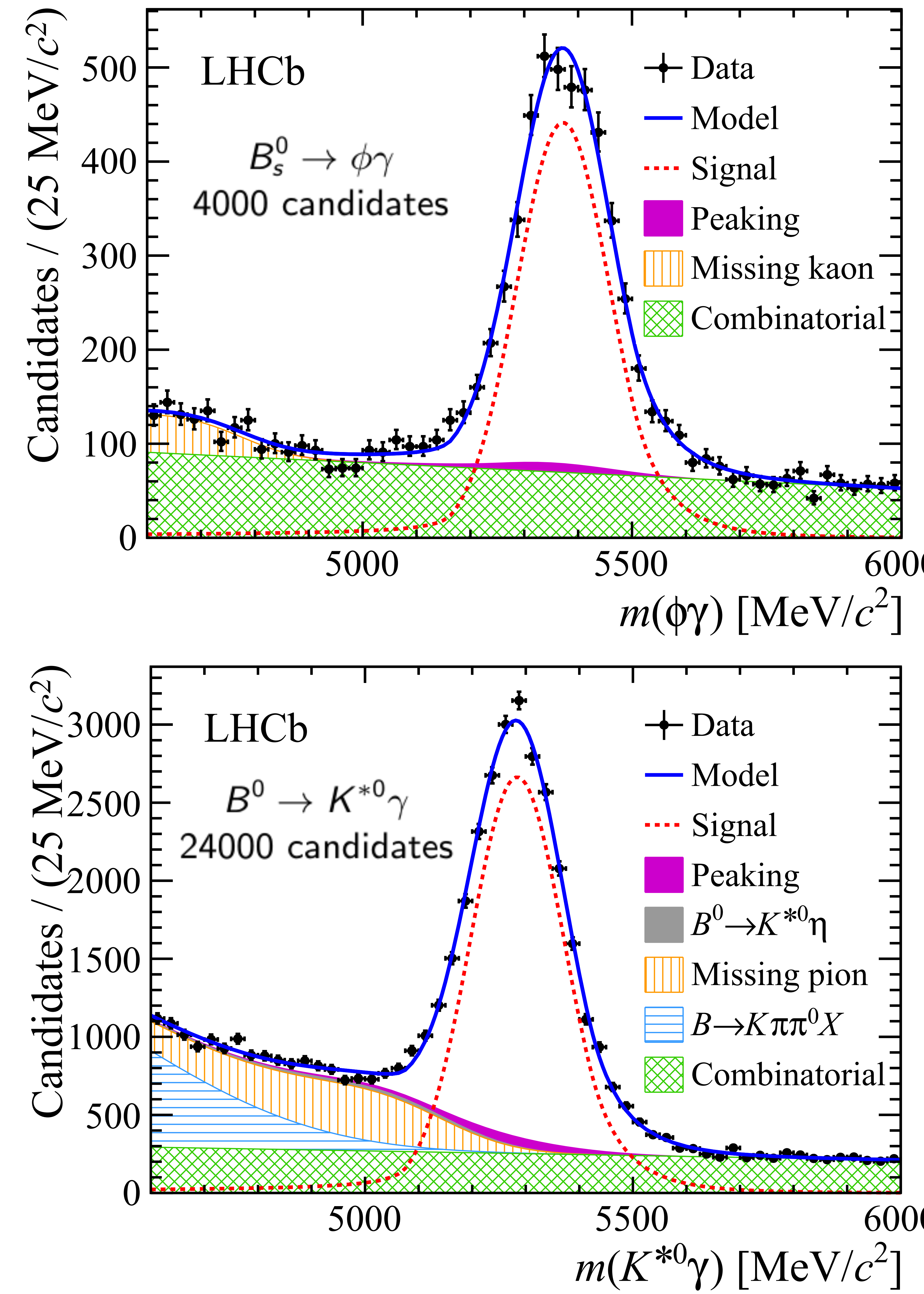
mixing phase

$$\mathcal{A}^{\Delta}_{\mathrm{SM}} = 0.047^{+0.029}_{-0.025}$$

$$\tan\psi \equiv \frac{|A(\bar{B}_s^0 \to \phi\gamma_R)|}{|A(\bar{B}_s^0 \to \phi\gamma_L)|}$$

dominant left-handed polarisation expected

    - angular observables in $B^0 \to K^{*0}e^+e^-$ also sensitive
  - well measurable due to large decay width difference $\Delta\Gamma_s$ = 0.083 ± 0.006 ps^{-1}
- use $B^0 \to K^{*0}\gamma$ as control channel
  - here $\Delta\Gamma_d \approx 0$, thus can determine decay-time related effects

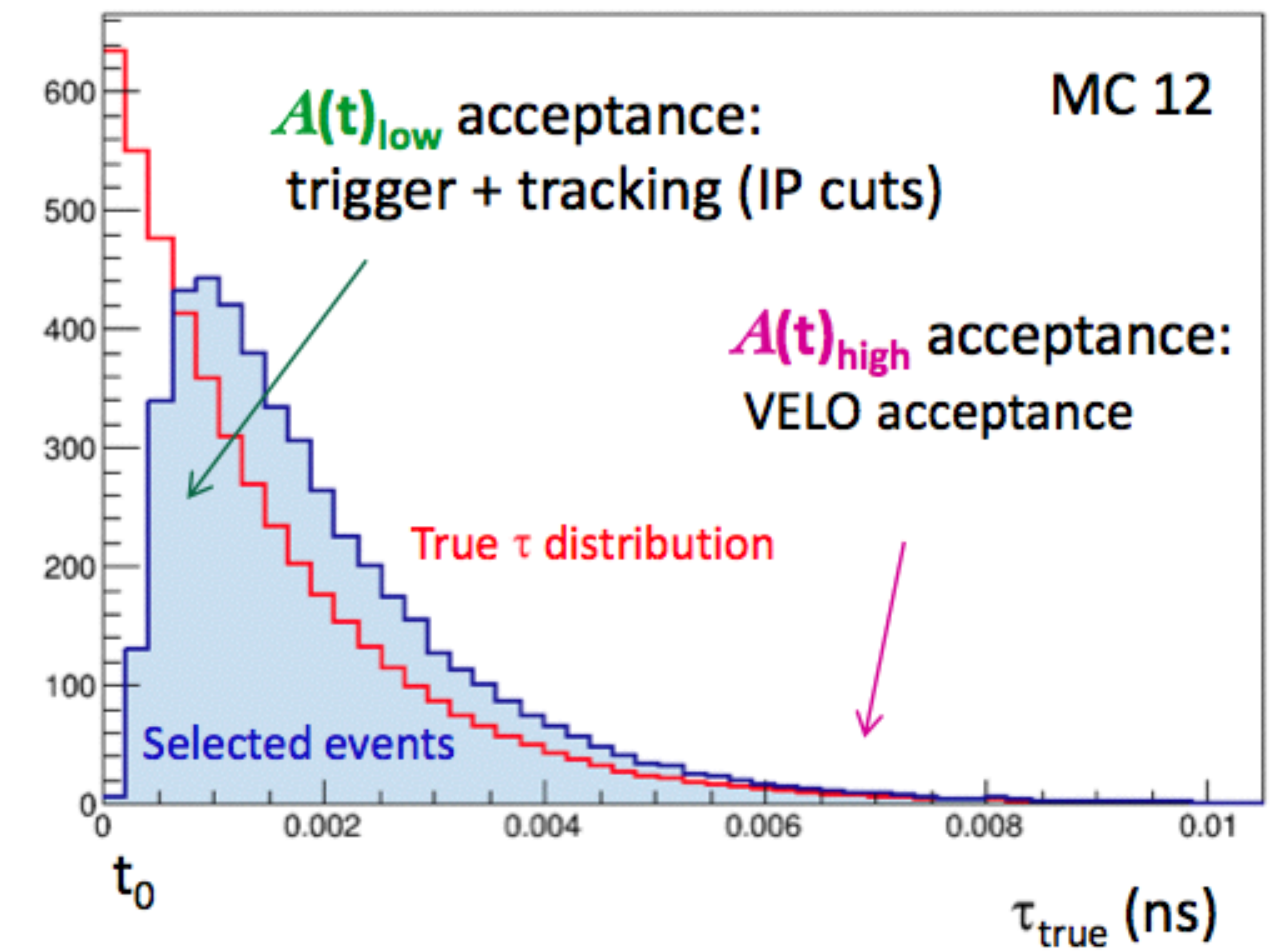


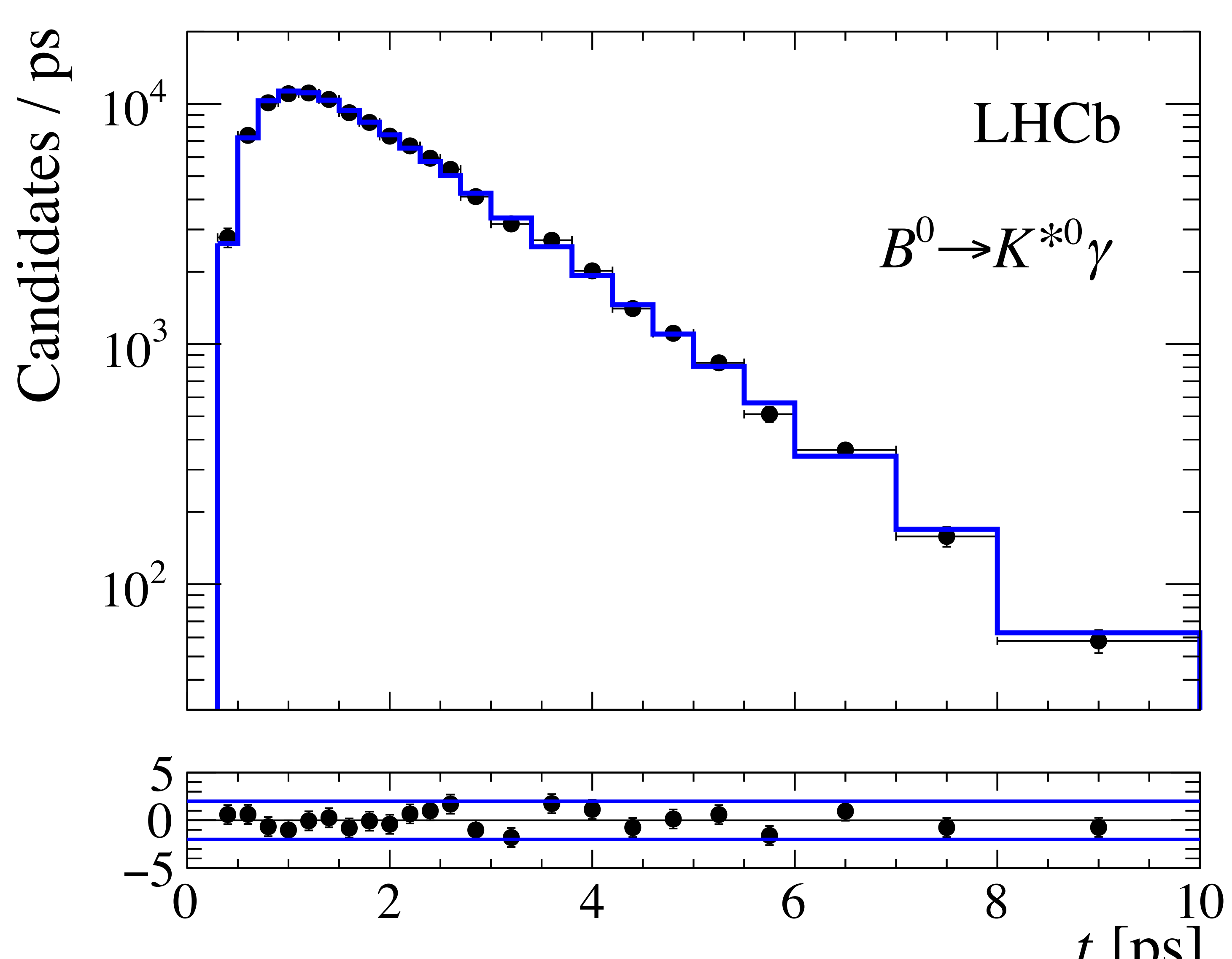
LHCb-PAPER-2016-034, arXiv:1609.02032

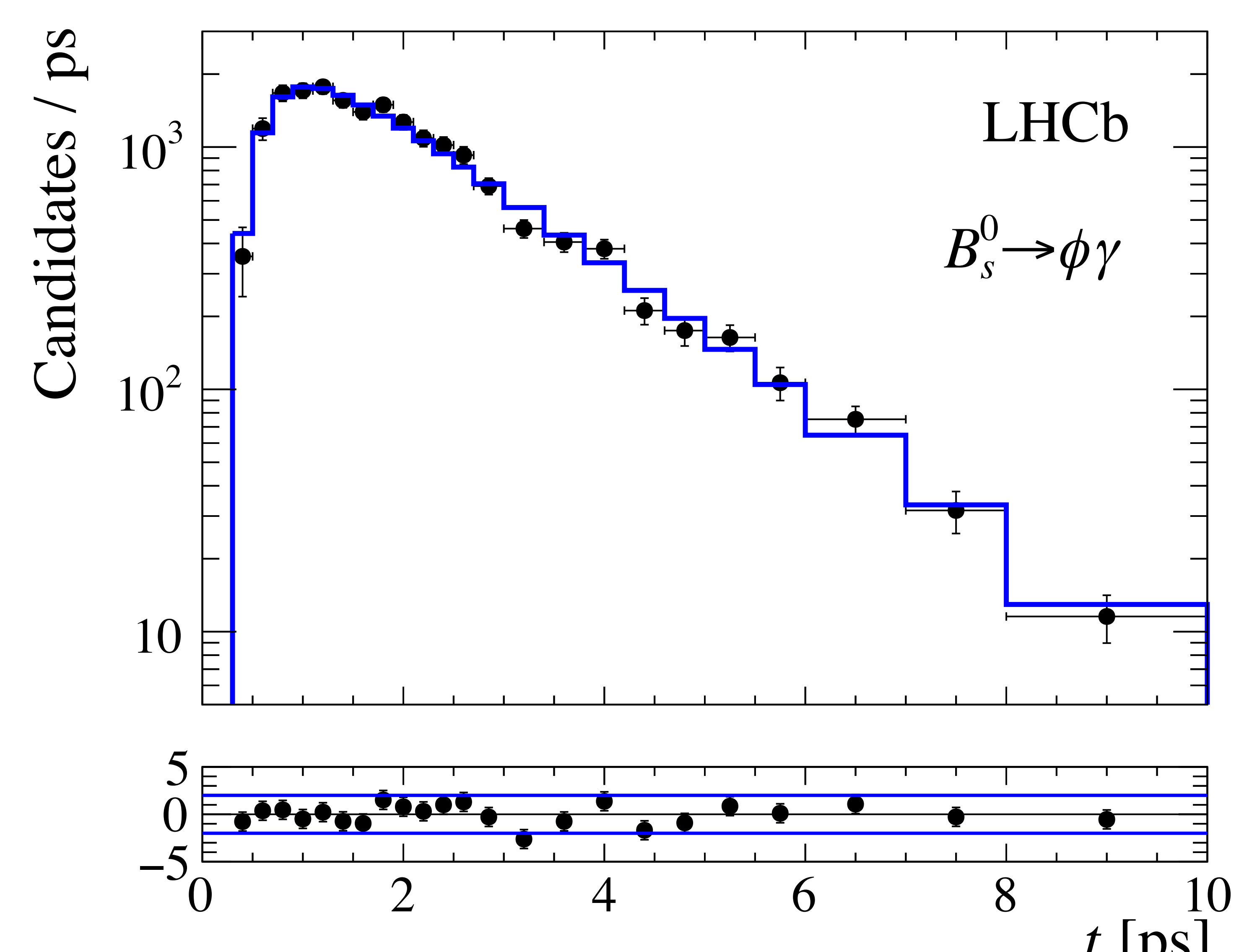
Run I

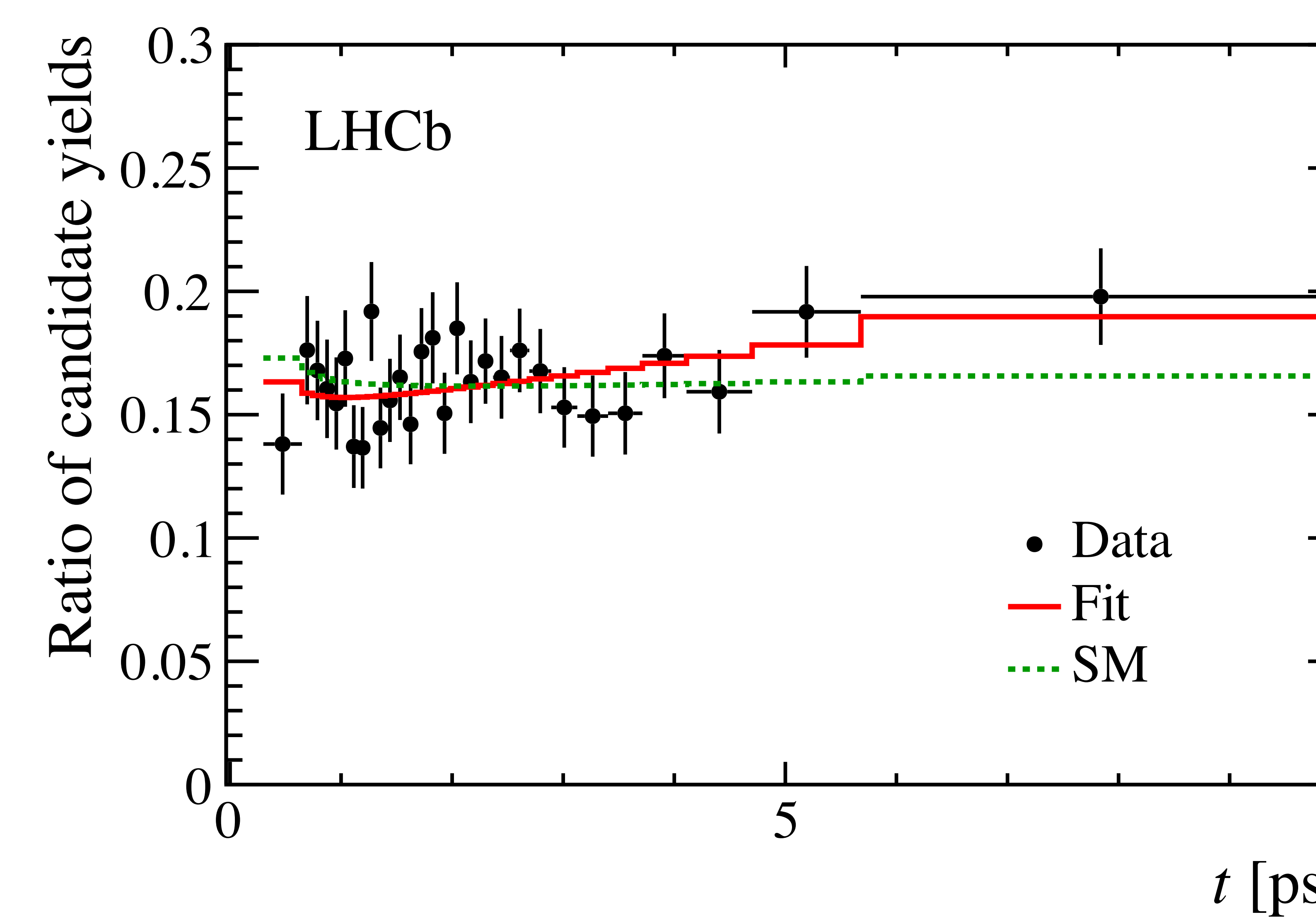
Photon polarisation in $B_s \to \varphi\gamma$

- experimental challenges
  - $\mathcal{P}(t) = [\text{Physics} \times \text{Acceptance}] \otimes \text{Resolution}$
    - resolution from simulations
    - control acceptance by using $B^0 \to K^{*0}\gamma$
  - comb. & partially reconstructed backgrounds
  - peaking backgrounds







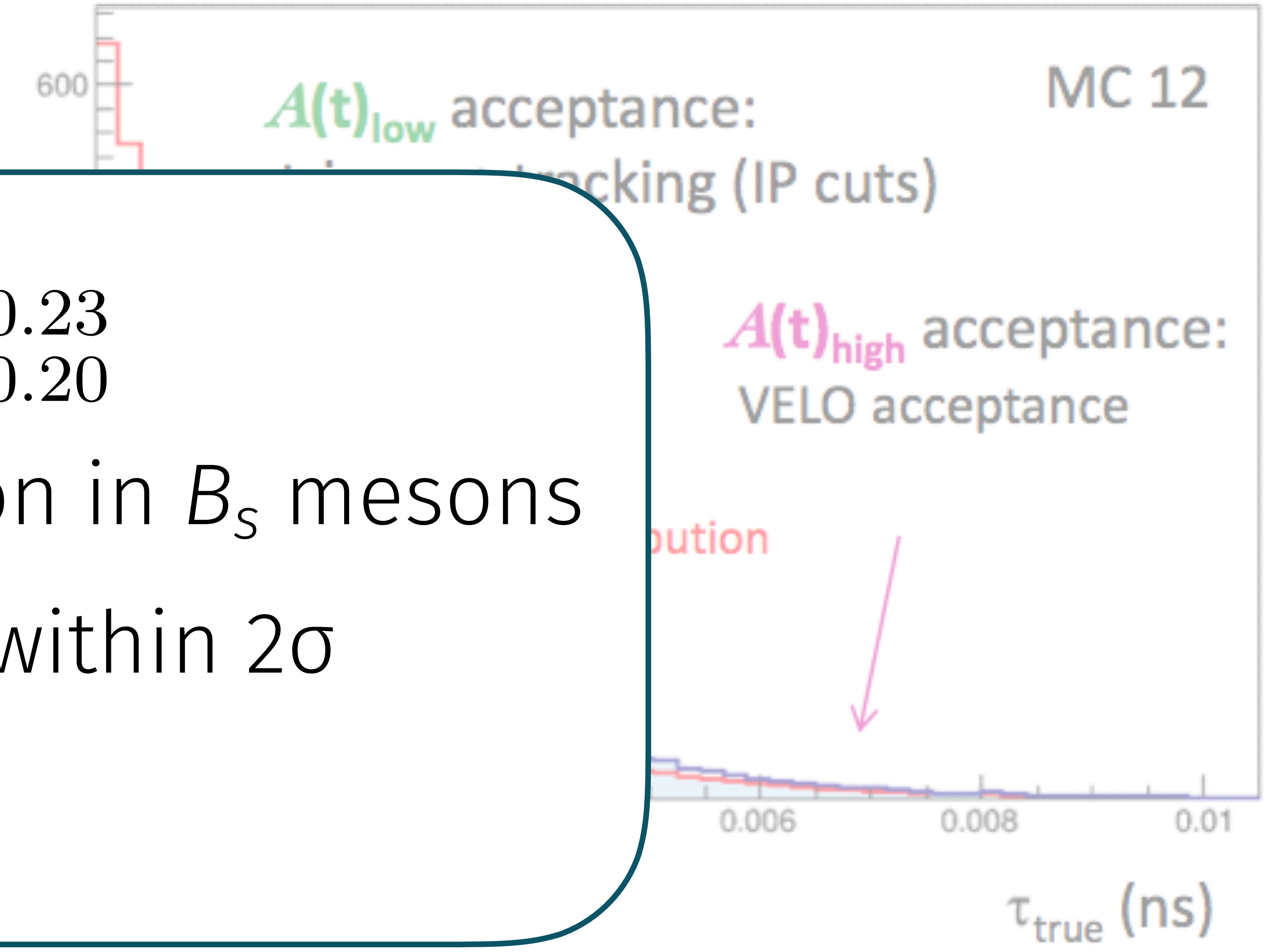


LHCb-PAPER-2016-034, arXiv:1609.02032

Run I

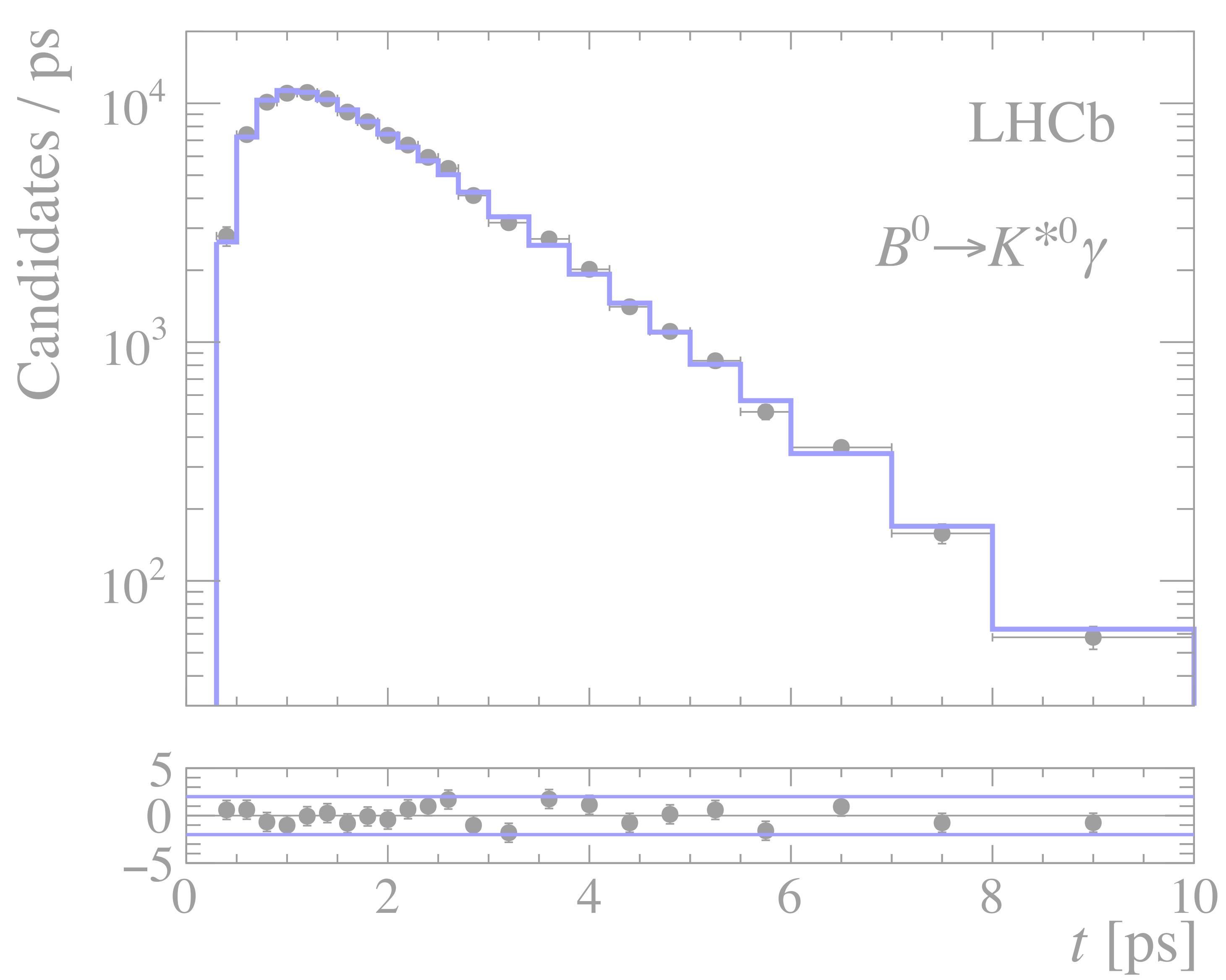
Photon polarisation in $B_s \to \varphi\gamma$

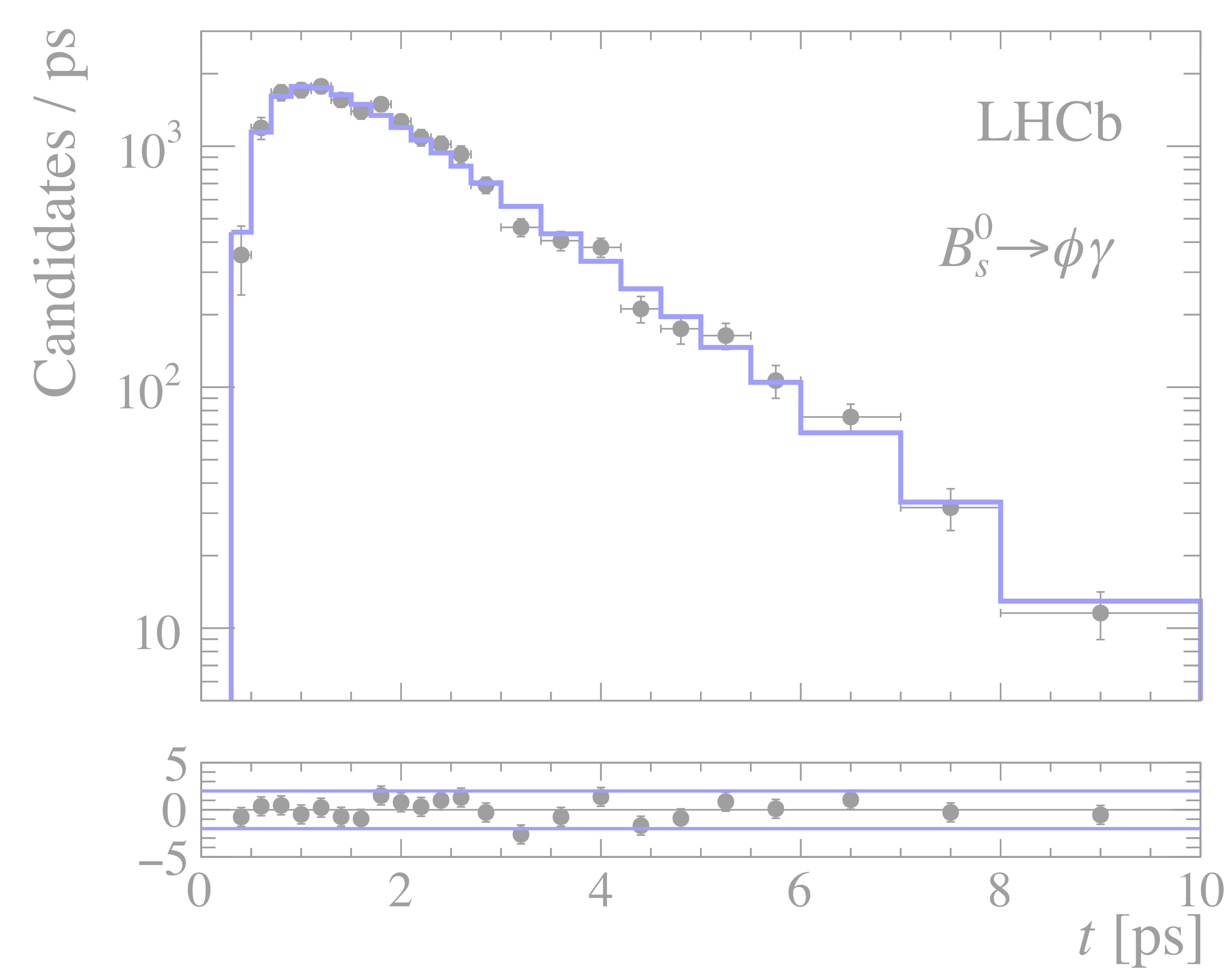
- experimental challenges
  - $\mathcal{P}(t) = [$Ph
    - resolution
    - control acc
  - comb. & pa
  - peaking bac

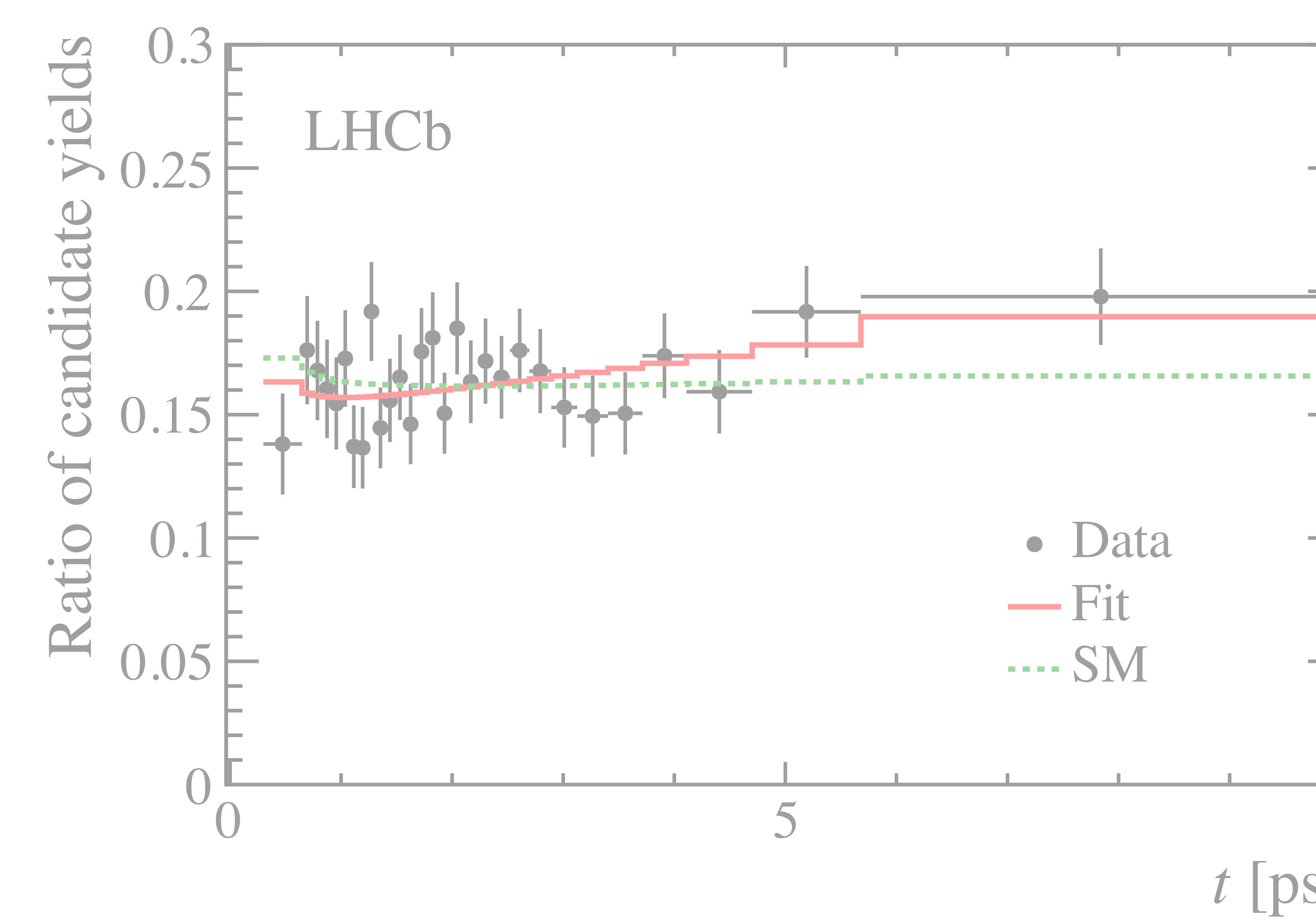


result: $\mathcal{A}^{\Delta} = -0.98 \,{}^{+0.46}_{-0.52}\,{}^{+0.23}_{-0.20}$

- first measurement of polarisation in B_s mesons
- consistent with SM expectation within 2σ
- statistically limited





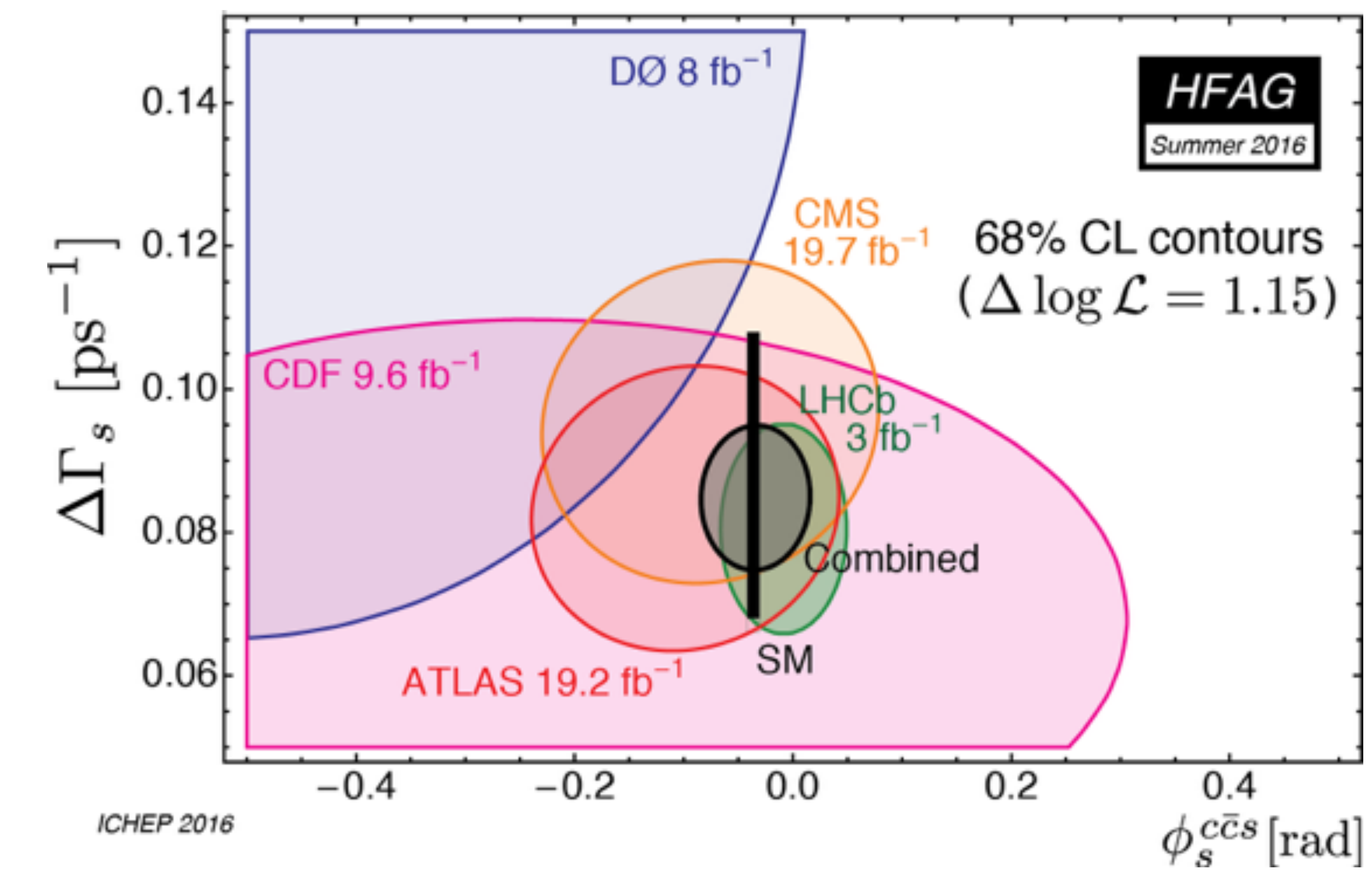


LHCb-PAPER-2016-034, arXiv:1609.02032

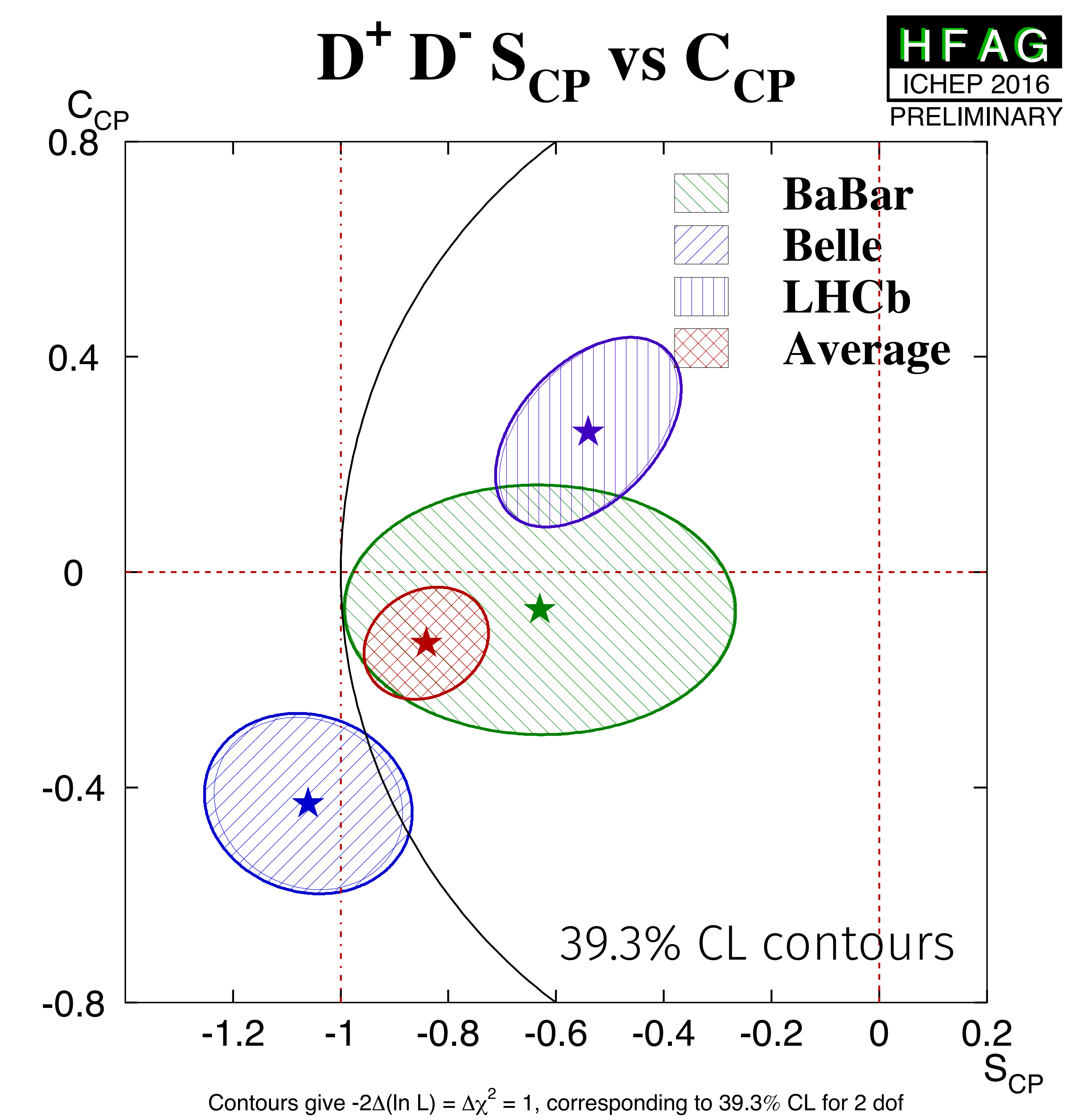
Run I

Flavour tagged analyses

- decay-time dependent *CP* analyses
  - require the knowledge of the initial *B* production flavour
  - flavour tagging algorithms exploit event information
- recent analyses
  - "Measurement of the *CP*-violating phase and decay-width difference in $B_s \to \psi(2S)\varphi$ decays"
    - tagging power of 3.9%
  - "Measurement of *CP* violation in $B^0 \to D^+ D^-$ decays"
    - precision on CPV significantly improved w.r.t. *B* factories
    - exploiting new tagging algorithms
    - tagging power of 8.1%!



LHCb-PAPER-2016-027

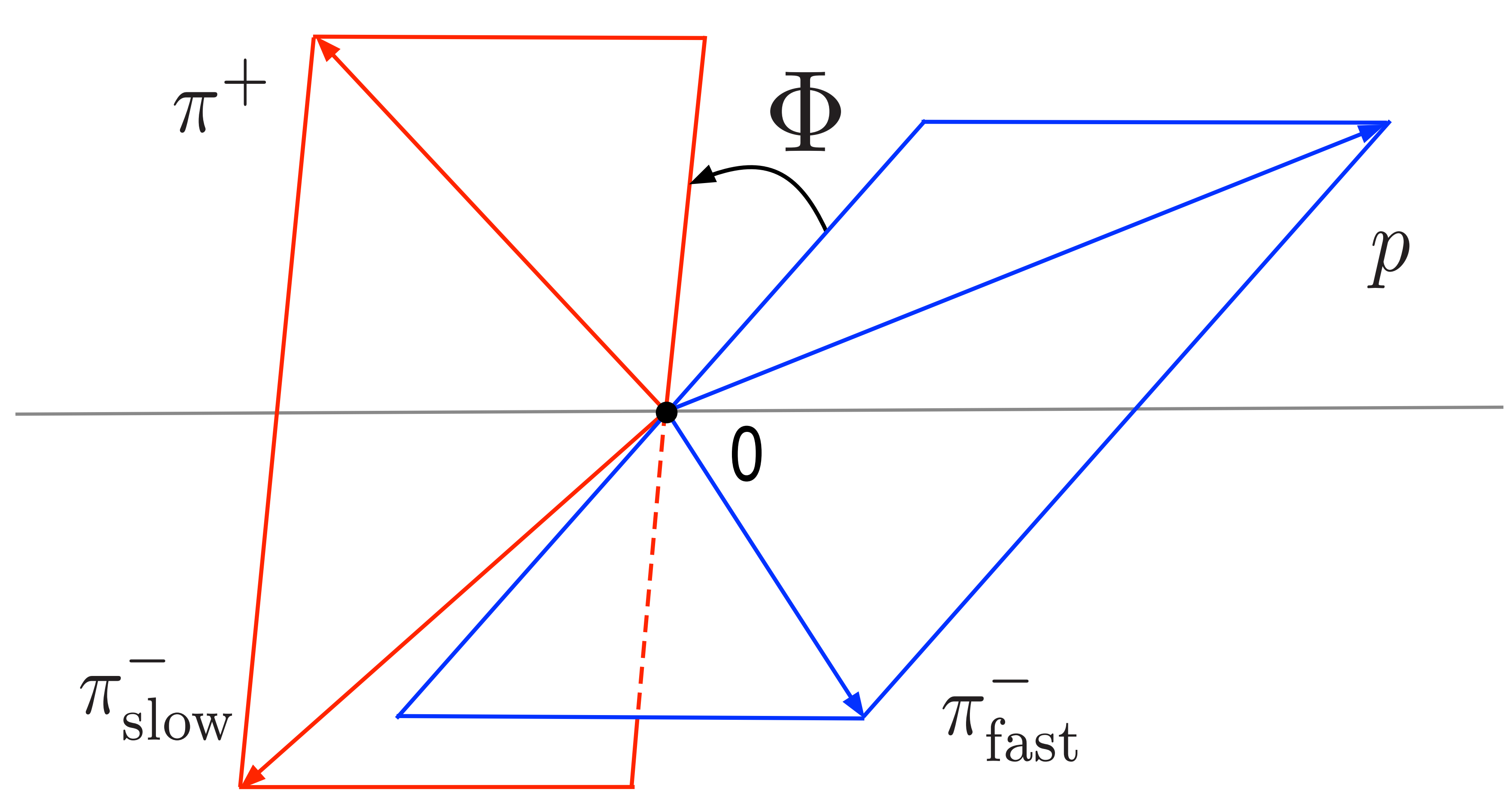


LHCb-PAPER-2016-037

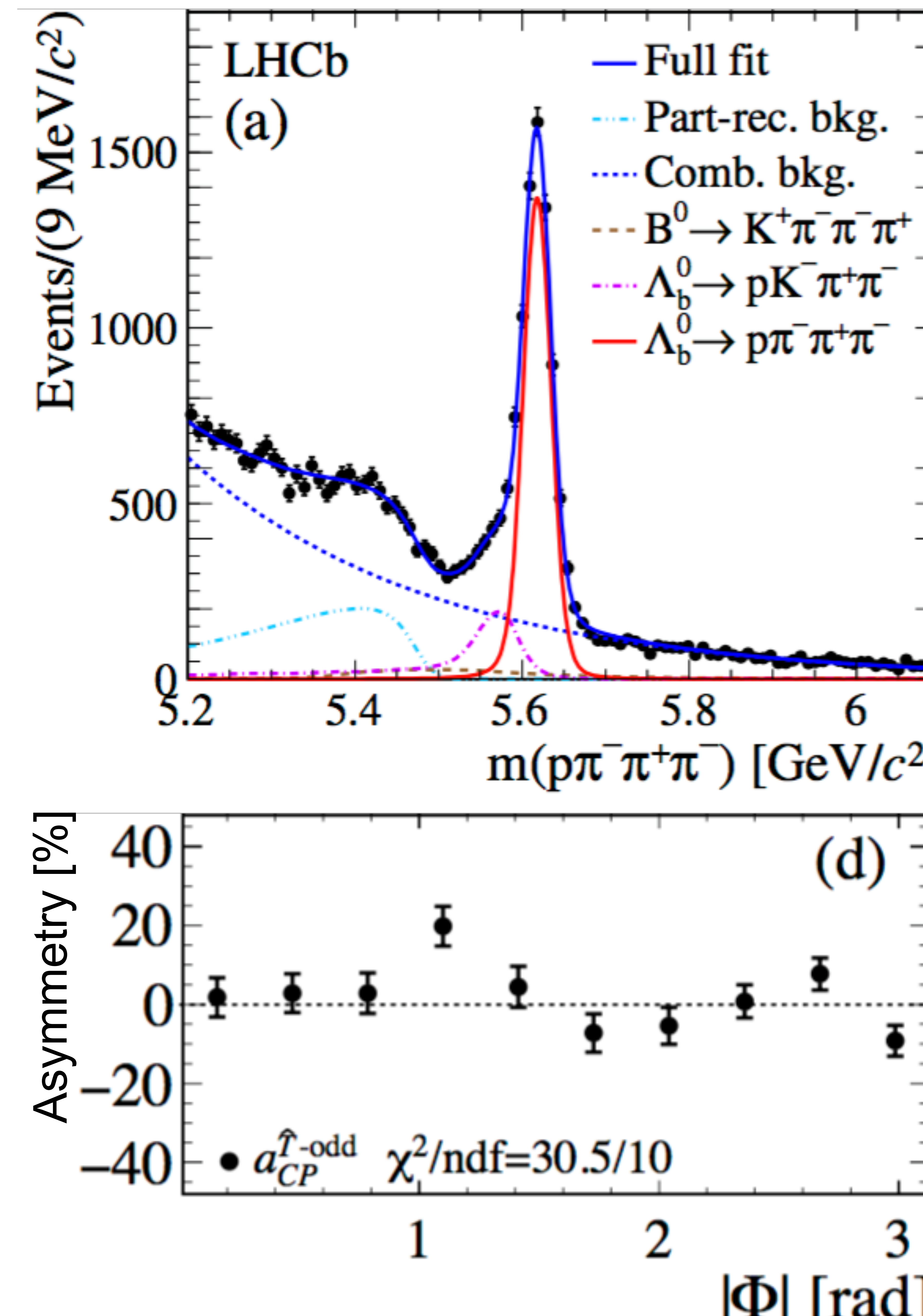
Run I

CP violation in *b*-baryons

- strategy: use $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays
  - search for *CP*-violating asymmetries in triple-products of final-state momenta
  - study local CPV as a function of the angle Φ between the $p\pi^-$ and $\pi^+\pi^-$ decay planes



- evidence for *CP* violation at 3.3σ
- first evidence for *CP* violation in baryons!



LHCb-PAPER-2016-031, arXiv:1609.05216

Search for indirect CP violation in D^0 mixing

- decay-time dependent asymmetry in K^+K^- and $\pi^+\pi^-$ final states

$$A_{CP}(t) = \frac{\Gamma(D^0(t) \to f) - \Gamma(\overline{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\overline{D}^0(t) \to f)} \approx a_{CP}^{\mathrm{dir}} + \frac{t}{\tau_D} a_{CP}^{\mathrm{ind}}$$

$$A_\Gamma = -a_{CP}^{\mathrm{ind}} \qquad A_\Gamma = \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\overline{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\overline{D}^0 \to f)}$$

- analyses
  - use initial $D^{*\pm} \to D^0\pi^\pm$ for tagging the production flavour
  - challenge: avoid experimental biases
    - detector and reconstruction asymmetries
    - non-uniform decay-time acceptance

LHCb-CONF-2016-009, LHCb-CONF-2016-010

Run I

Search for indirect CPV in D^0 mixing

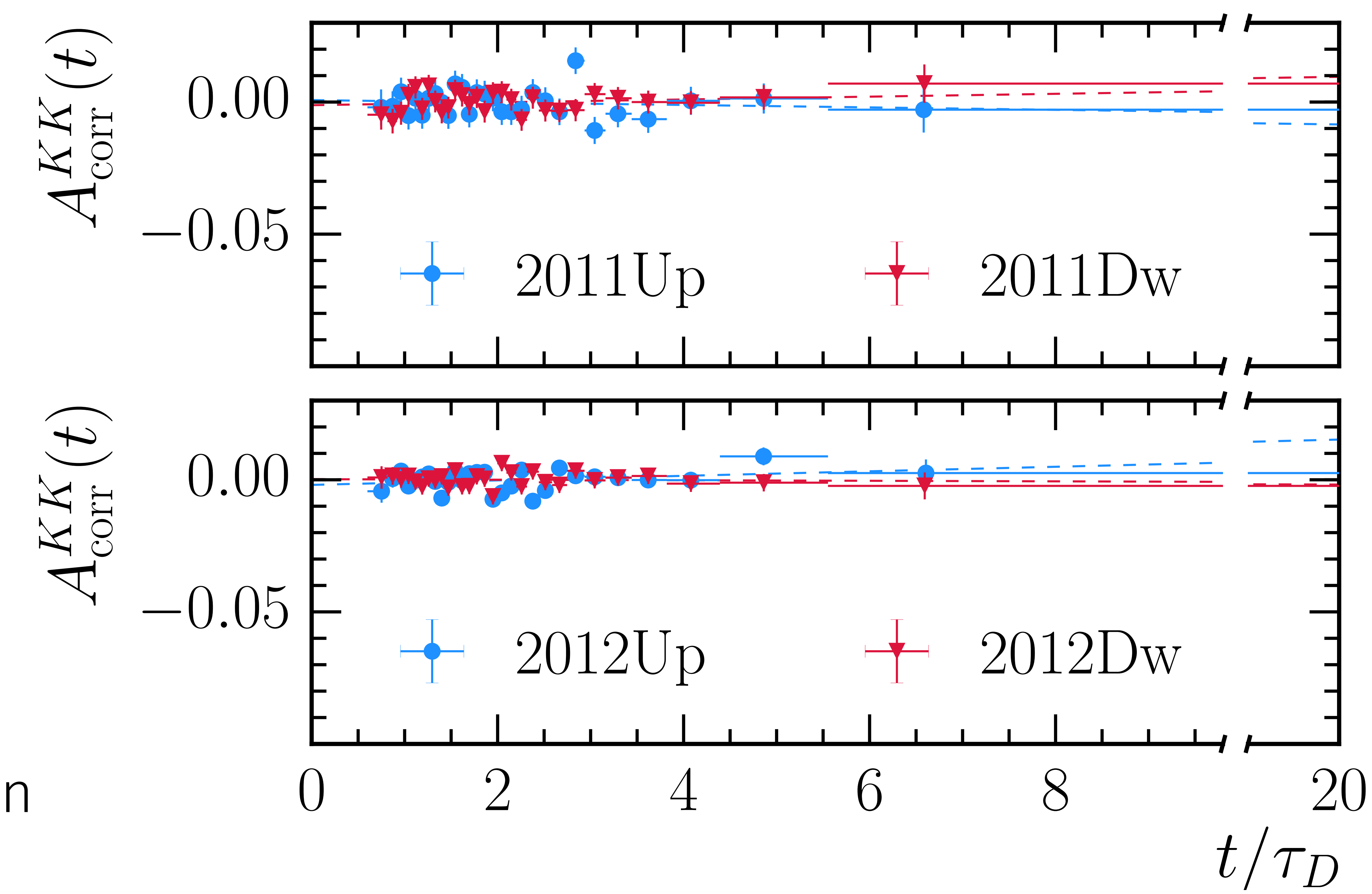
- two independent analyses
  - binned fit [LHCb-CONF-2016-009]
    - perform the analysis in bins of decay time
    - reduces effects from acceptance

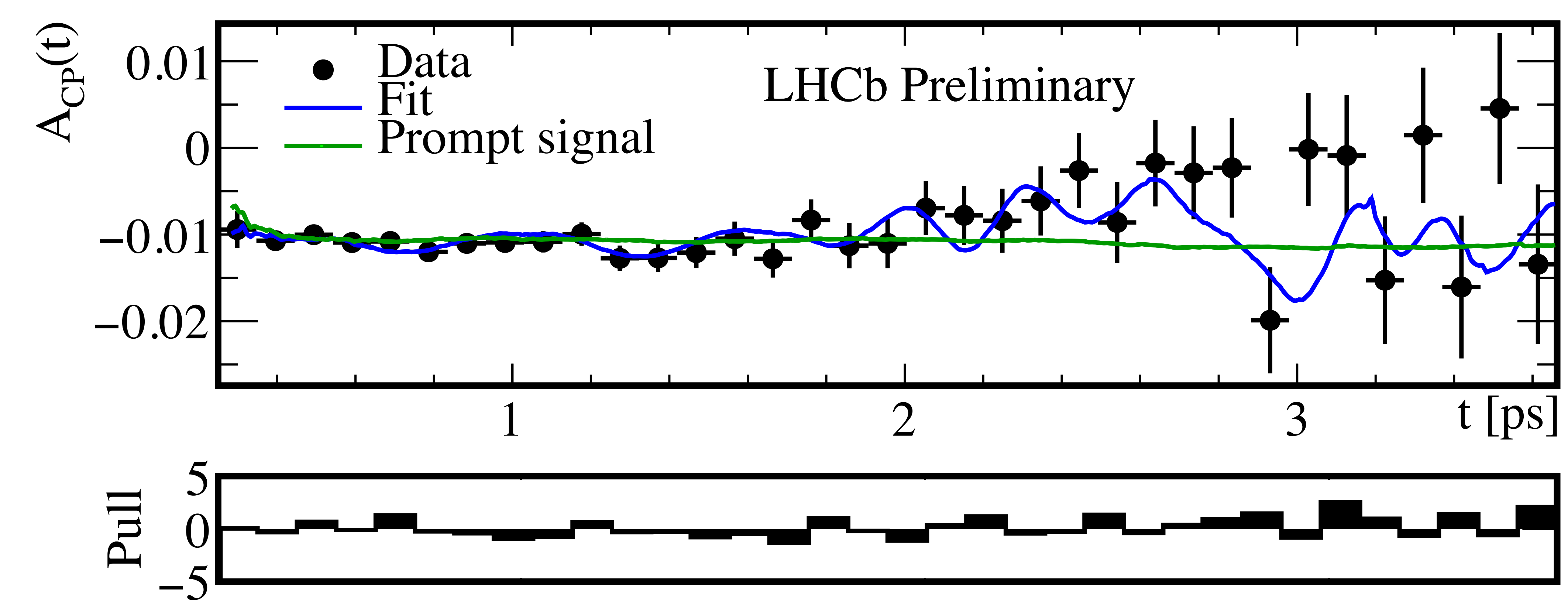
$$A_\Gamma = (-0.12 \pm 0.30) \times 10^{-3}$$

  - unbinned fit [LHCb-CONF-2016-010]
    - evaluate per-event decay-time acceptance function

$$A_\Gamma = (-0.07 \pm 0.34) \times 10^{-3}$$

- consistent within 1σ (incl. correlations)
- world's best measurements!





LHCb-CONF-2016-009, LHCb-CONF-2016-010

Run I

Direct *CP* violation in D^0 decays

- measure asymmetry of decay rate $A_{CP}(D^0 \to K^-K^+) \equiv \frac{\Gamma(D^0 \to K^-K^+) - \Gamma(\overline{D}^0 \to K^-K^+)}{\Gamma(D^0 \to K^-K^+) + \Gamma(\overline{D}^0 \to K^-K^+)}$

$$A_{raw}(D^0 \to f) = \frac{N(D^0 \to f) - N(\overline{D}^0 \to \overline{f})}{N(D^0 \to f) + N(\overline{D}^0 \to \overline{f})}$$

  - expect very small *CP* violation in the SM
  - determine experimental asymmetries from control channels

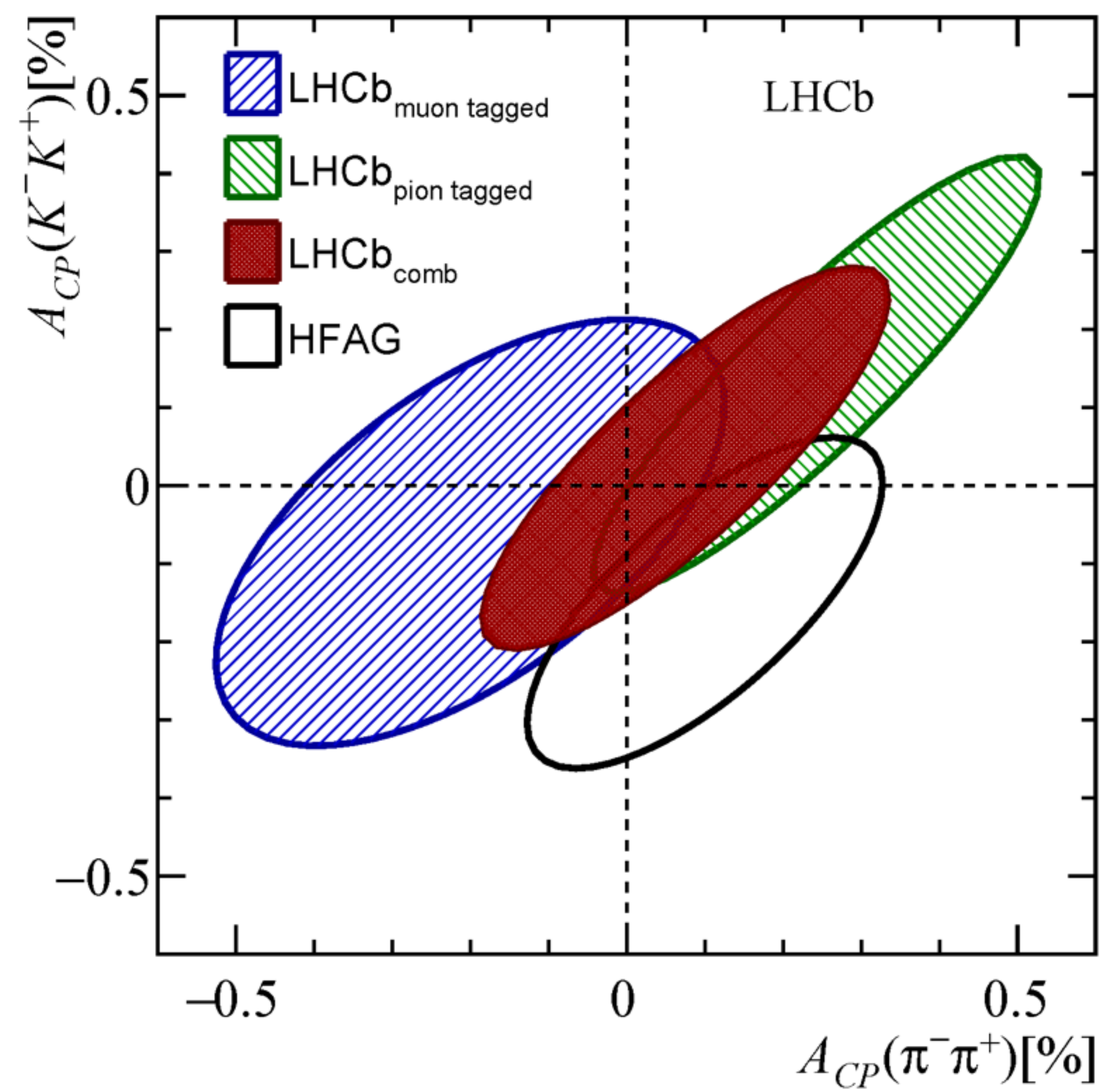
$$A_{CP}(D^0 \to KK) = A_{raw}(D^0 \to KK) - A_P(D^{*+}) - A_D(\pi_s^+)$$

- combined results w. previous analyses

$$A_{CP}^{comb}(KK) = (0.04 \pm 0.12 \pm 0.10)\,\%$$

$$A_{CP}^{comb}(\pi\pi) = (0.07 \pm 0.14 \pm 0.11)\%$$

no evidence for CPV

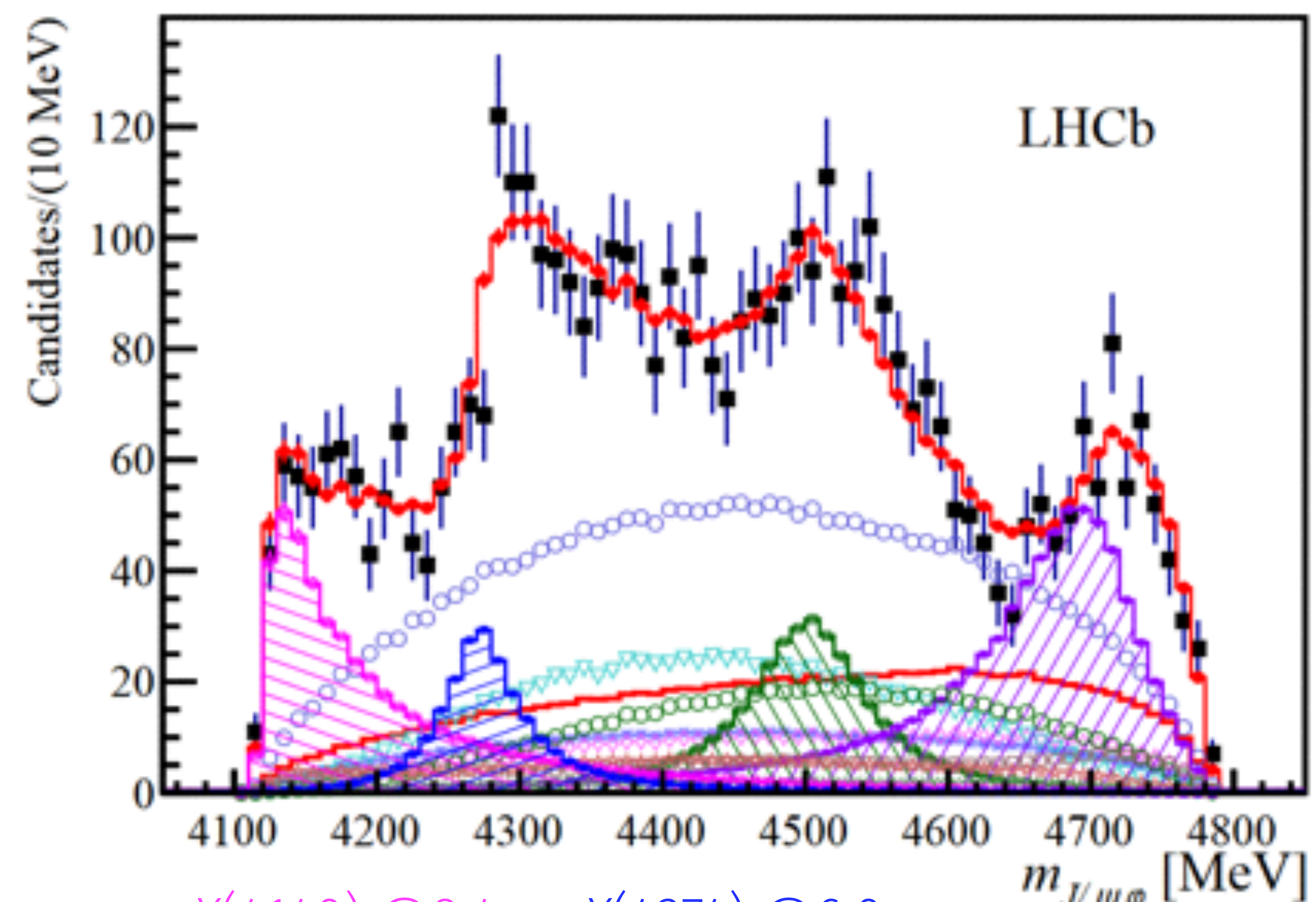


LHCb-PAPER-2016-035, in preparation

Run I

Observation of four exotic-like particles

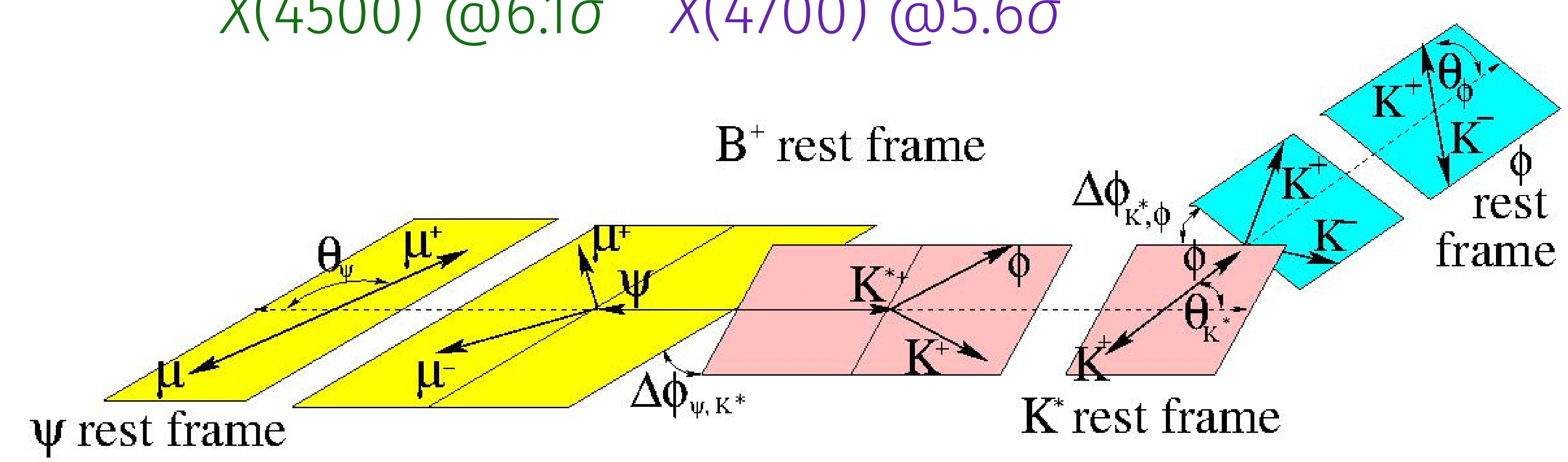
- $X \to J/\psi\varphi$ decays in $B^{\pm} \to J/\psi\varphi K^{\pm}$ decays
- "history"
  - CDF observed a narrow structure, $X(4140)$, and hint for another structure, $X(4274)$
  - exotic: narrow and above $D_s D_s$ threshold
  - also seen by D0 and CMS
- new, unique analysis by LHCb
  - first full amplitude analysis (6D likelihood fit)
  - measurement of quantum numbers
  - $X(4140)$ and $X(4274)$ seen (both $J^{PC}=1^{++}$)
    - $X(4140)$ described as $D_s^{+} D_s^{*-}$ cusp is preferred by fit
  - 2 additional structures, $X(4500)$ and $X(4700)$ (both $J^{PC}=0^{++}$)



$X(4140)$ @8.4σ $X(4274)$ @6.0σ

$X(4500)$ @6.1σ $X(4700)$ @5.6σ

LHCb-PAPER-2016-019, arXiv:1606.07898

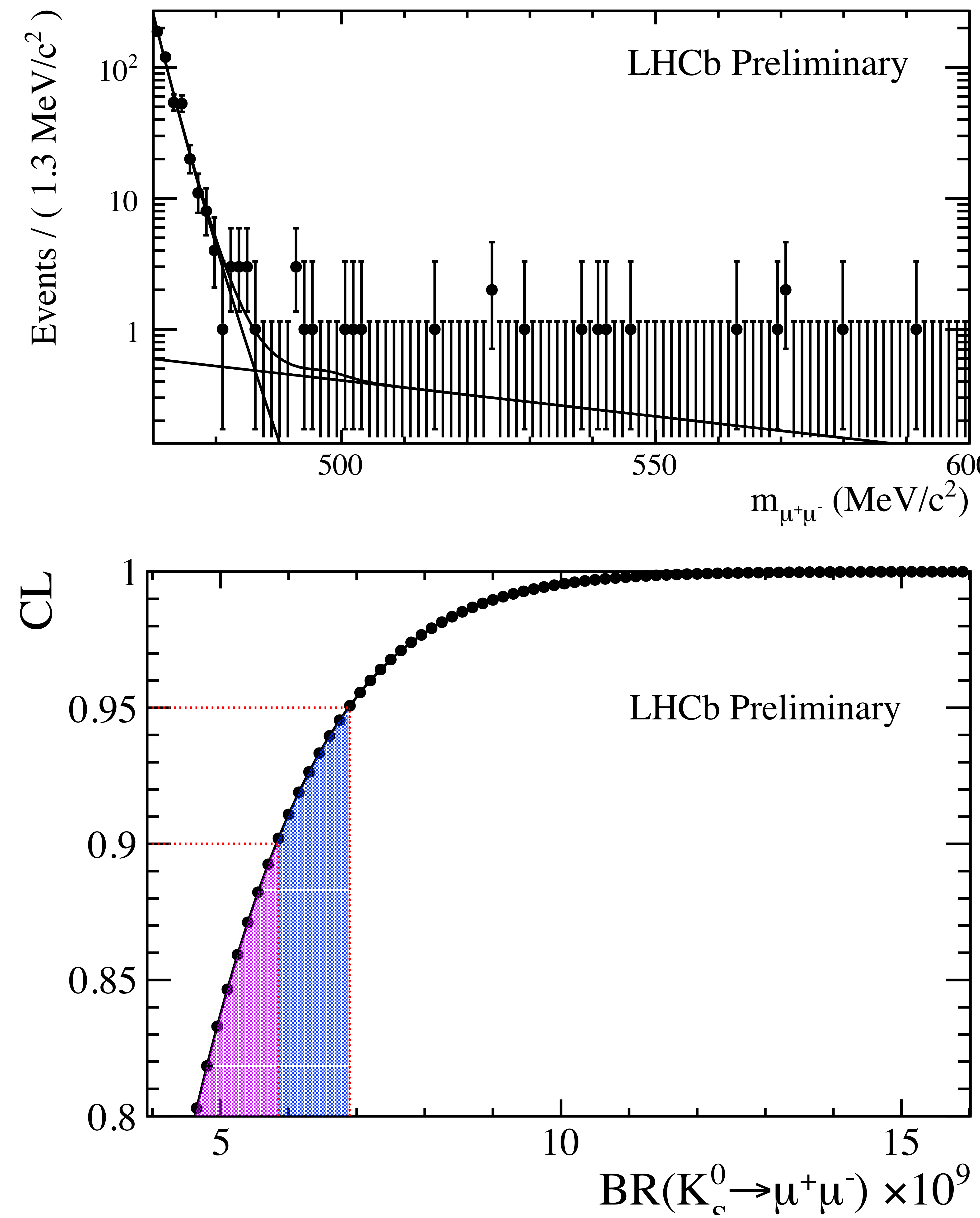


Run I

Search for $K_S \to \mu^+\mu^-$ decays

- $K_S \to \mu^+\mu^-$ has not been observed
  - in SM: FCNC transition with additional suppression due to small CPV
    - SM prediction: $BR(K_S \to \mu^+\mu^-) = (5.0 \pm 1.5) \times 10^{-15}$
    - experimental upper limit < 11×10^{-9} @95% CL
- analysis using 2 fb^{-1} of Run I
  - normalisation channel $K_S \to \pi^+\pi^-$
  - fit the kaon mass in bins of trigger selection and MVA output
- preliminary upper limit

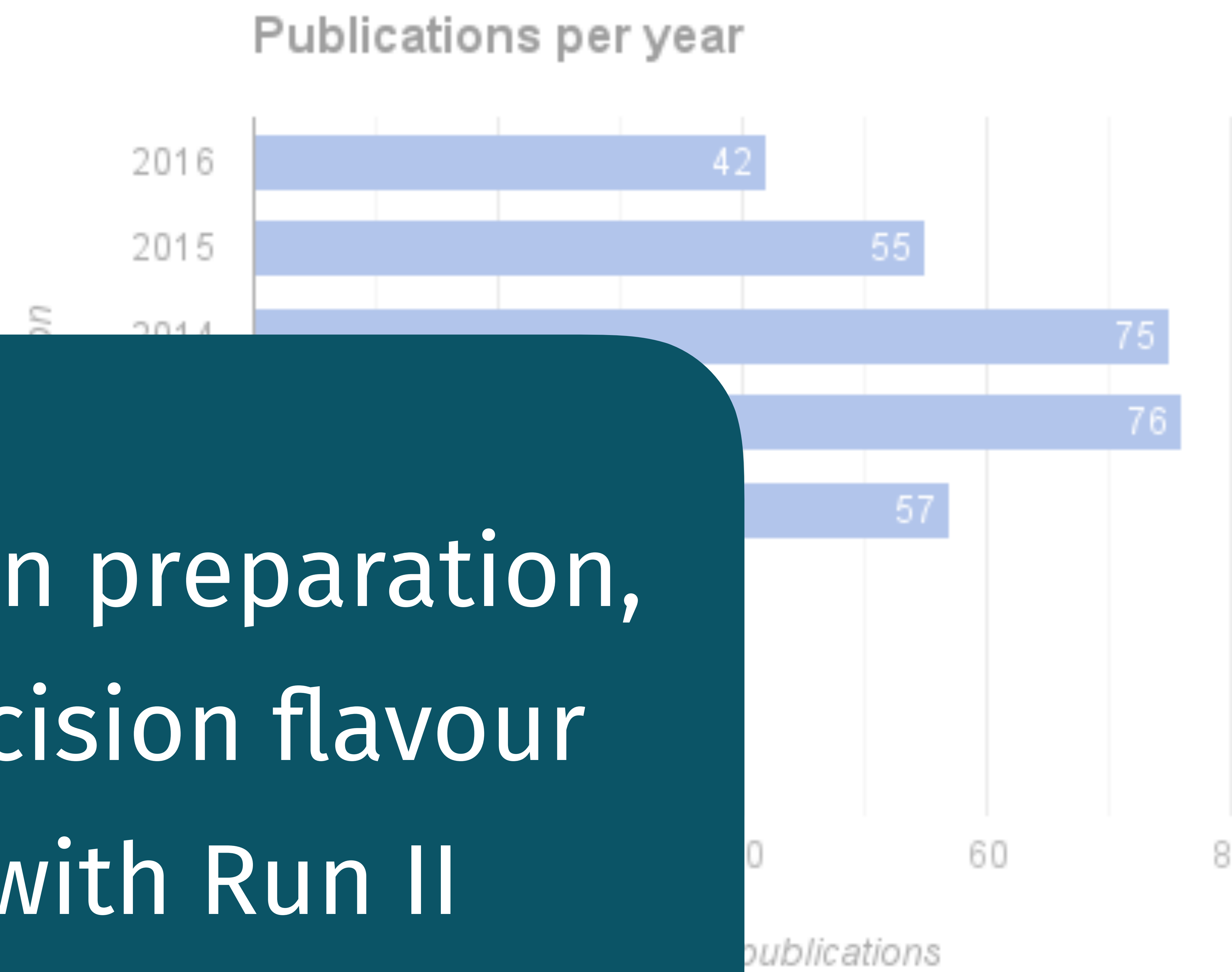
$$BR(K_S \to \mu^+\mu^-) < 6.9 \times 10^{-9} \text{ @95\% CL}$$



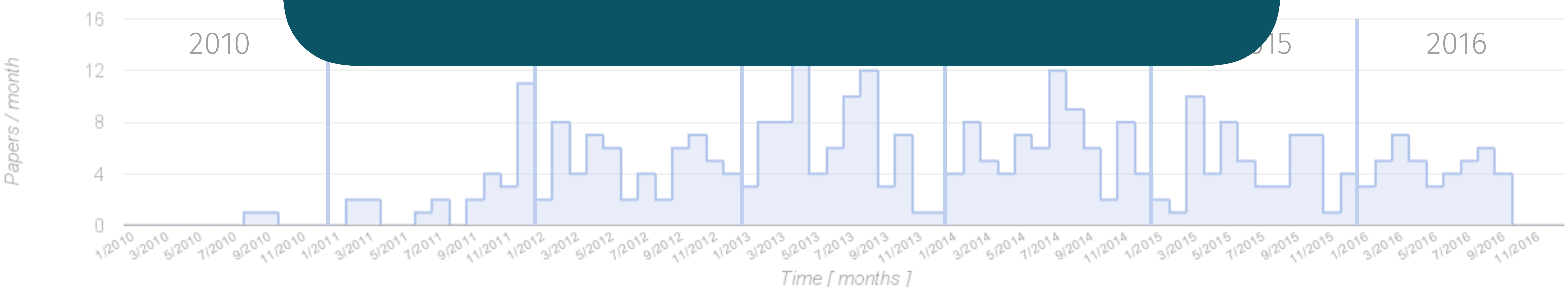
LHCb-CONF-2016-012

Publication status

- 334 papers submitted
  - +20 papers w.r.t. last LHCC
  - 7 PRL, 5 JHE
    1 EPJC, 1 Na
- 15 papers i
- 47 analyse

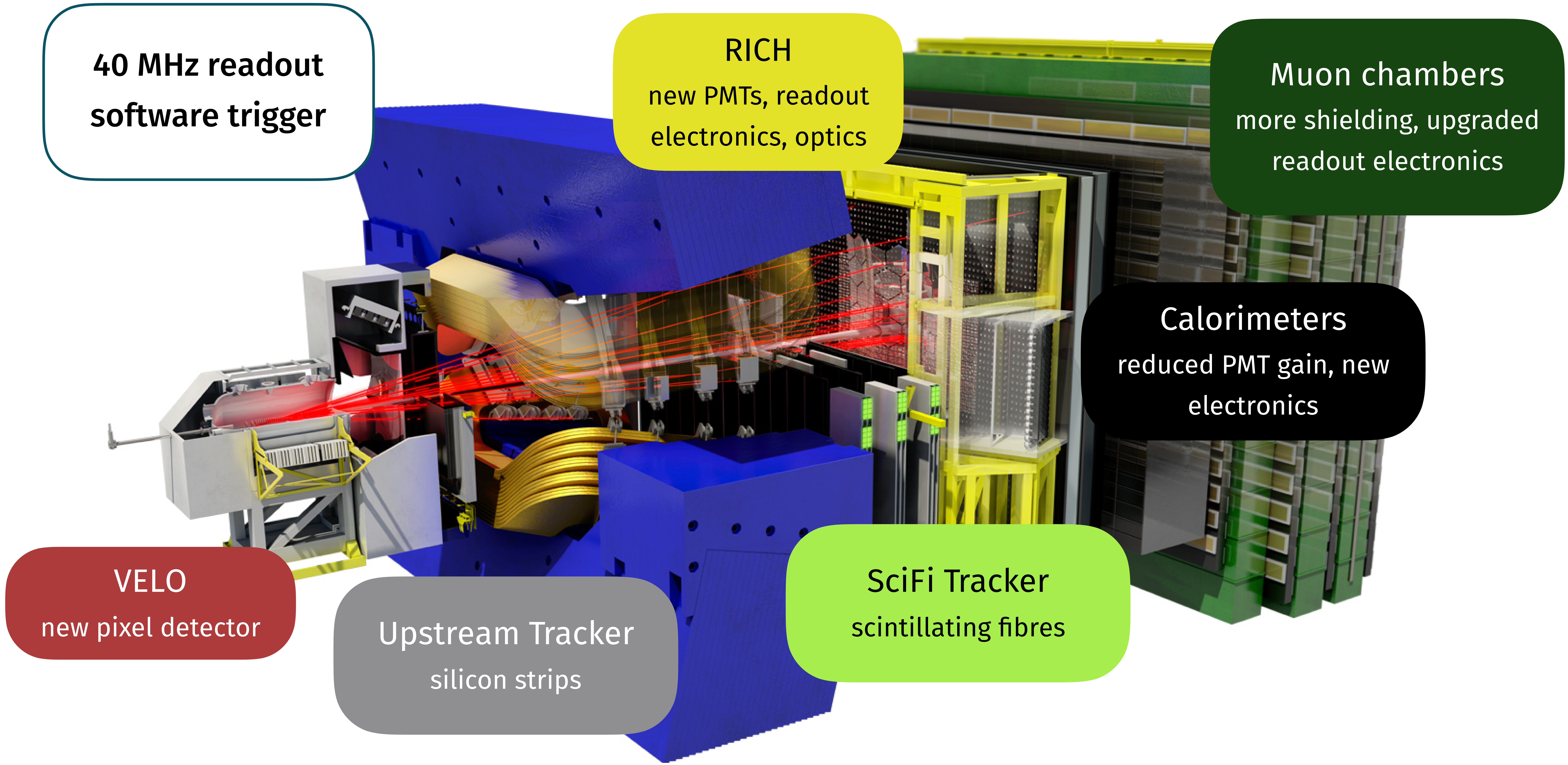


many more results in preparation, including high precision flavour physics results with Run II



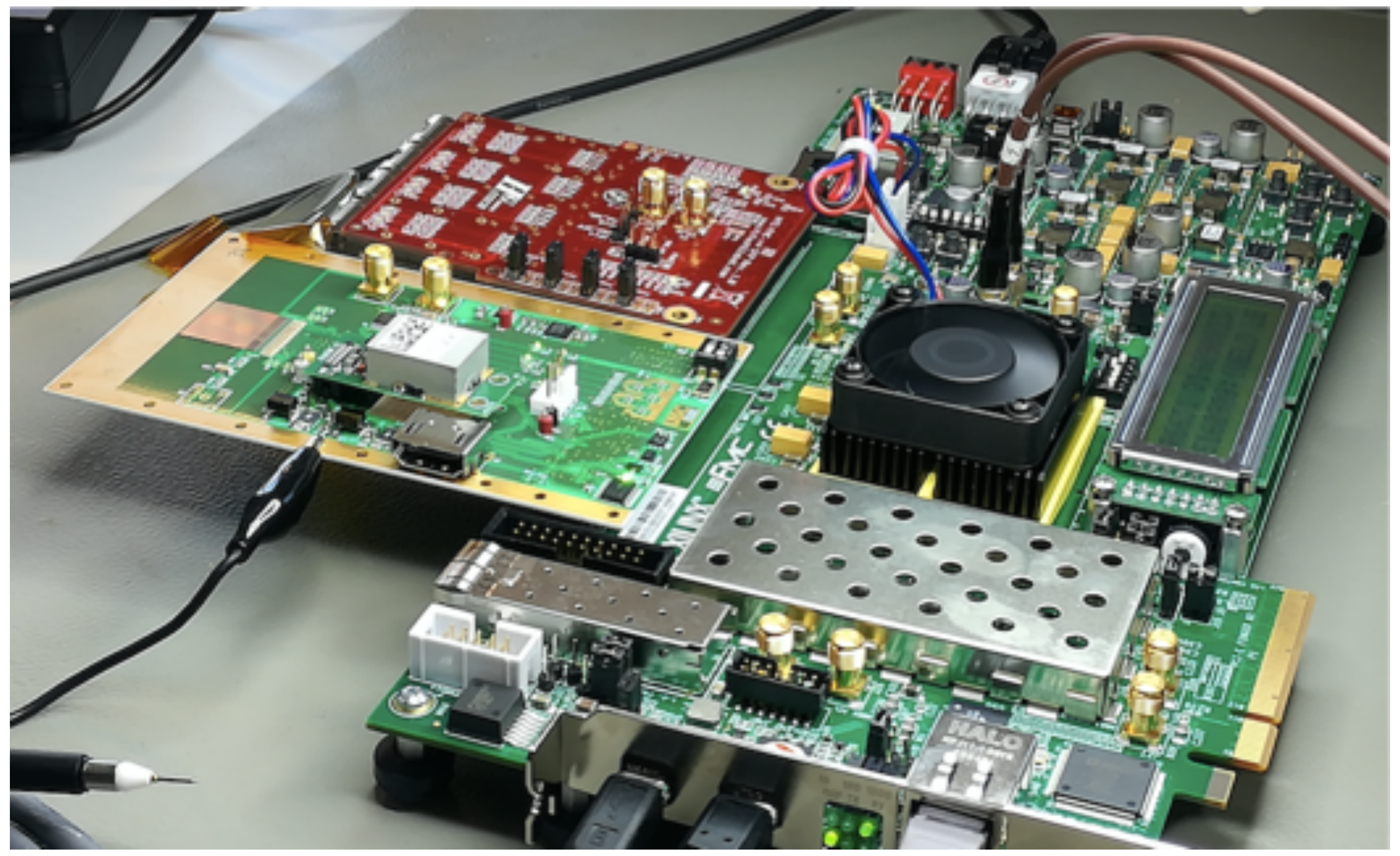
Upgrade

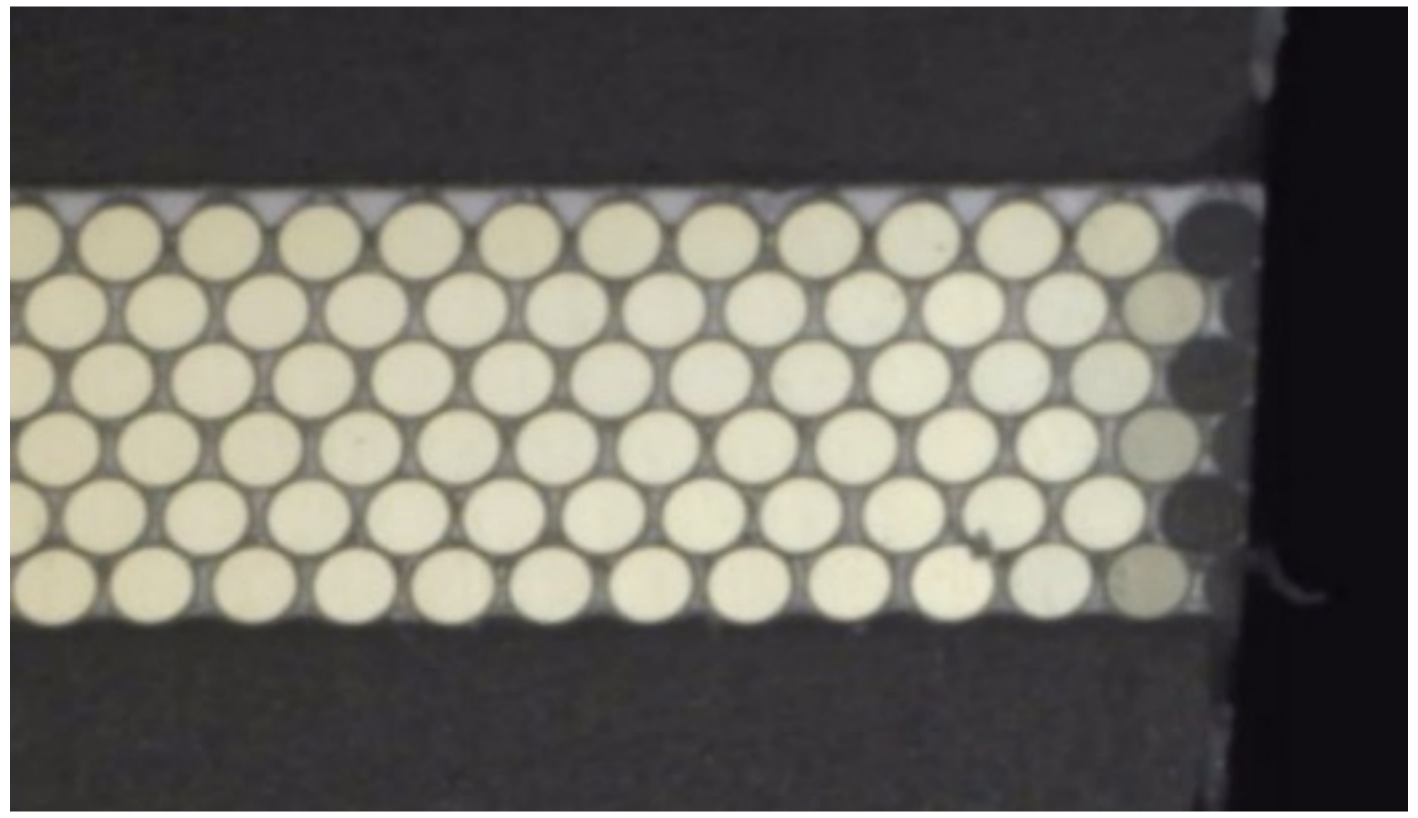
LHCb Upgrade in LS2 – Overview



LHCb Upgrade in LS2 – Status

- in general a good progress on all subsystems
  - many engineering design and production readiness reviews successfully completed during the summer
  - small delays for some of the milestones
- many detectors entering (pre-)production phase
  - several crucial front-end ASICS successfully submitted and under test
    - VELOPIX for VELO, SALT-128 for Upstream Tracker, CLARO for RICH
  - large component production started
    - delivery of MA-PMTs for RICH started
    - SciFi Tracker fibre delivery on schedule, fibre mat production started
- preparation of LS2 work and worksite organisation is ongoing, profit from EYETS





Conclusion

Summary & Conclusion

- LHCb's physics program
  - lots of new, diverse results over the summer
  - many long-expected results presented, and many more to come!
- LHCb operation = LHC's superb efficiency + LHCb's flexibility
  - optimal and dynamic use of resources to maximise the physics output
  - effects on computing are under control in 2016
  - already overtook 2012 data taking in terms of *bb*-pairs recorded
  - we are preparing for the *p*Pb runs
- LHCb upgrade is progressing well
  - huge progress over the past few months
  - working hard to keep up with our milestones