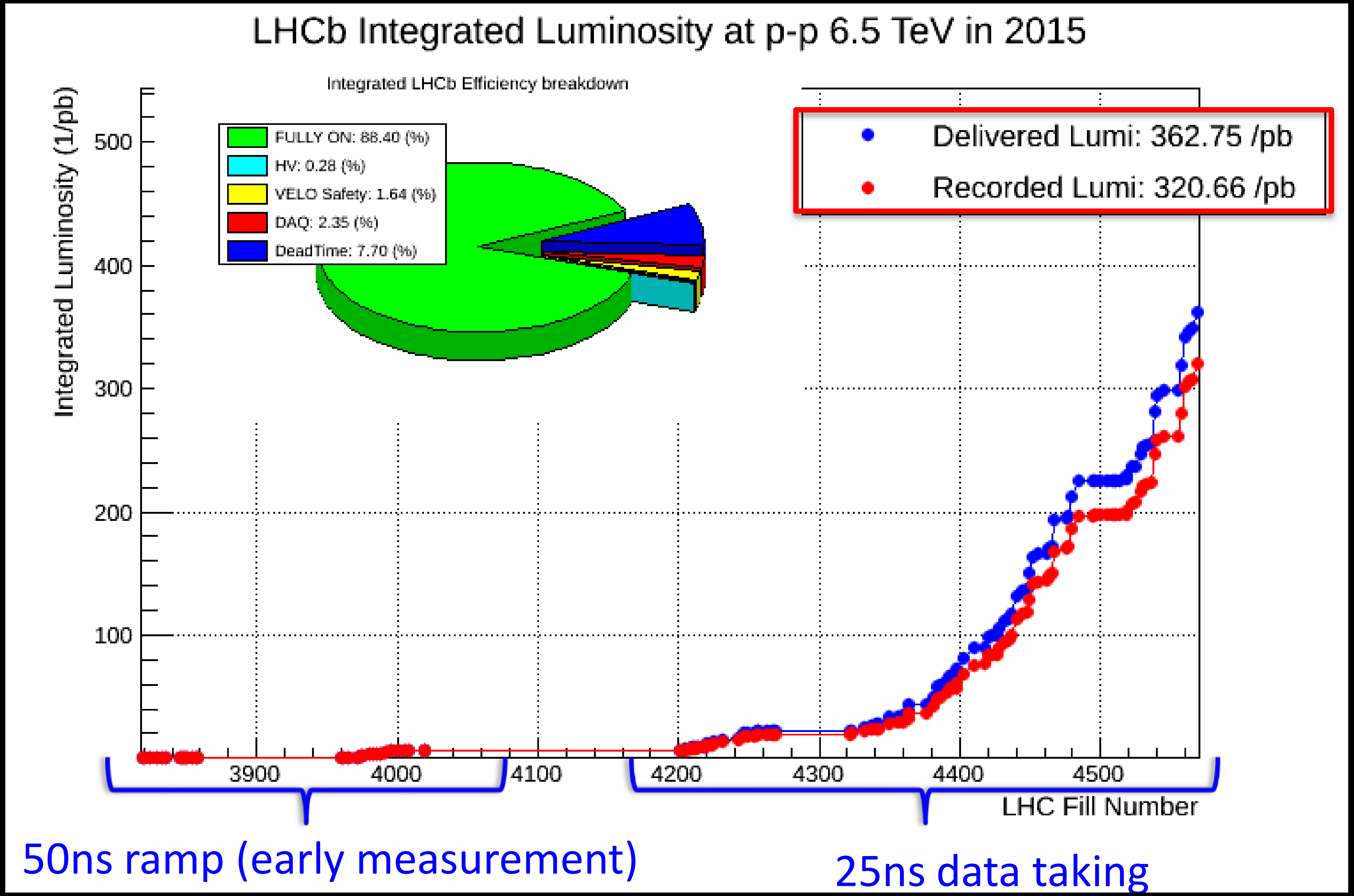
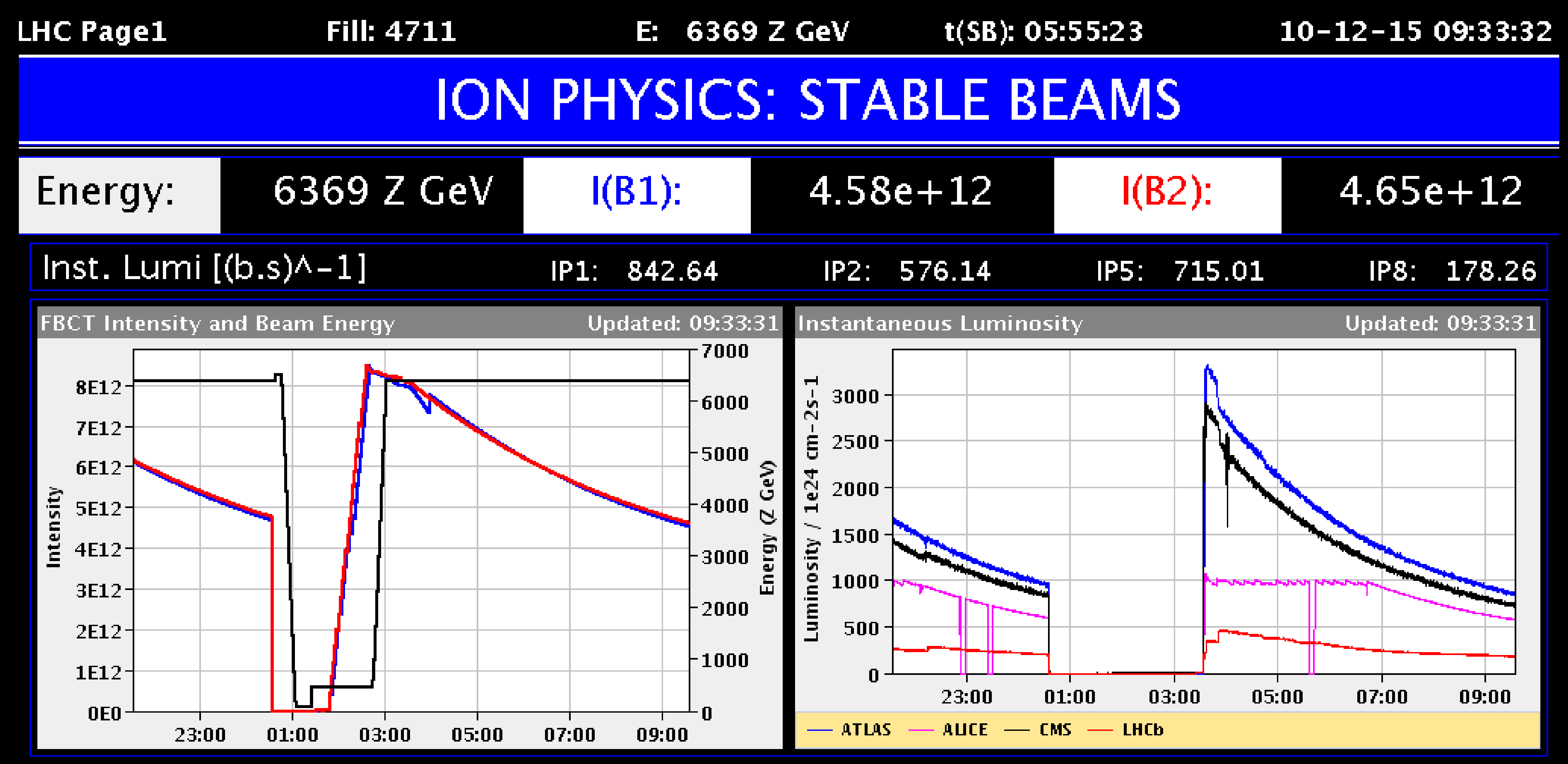
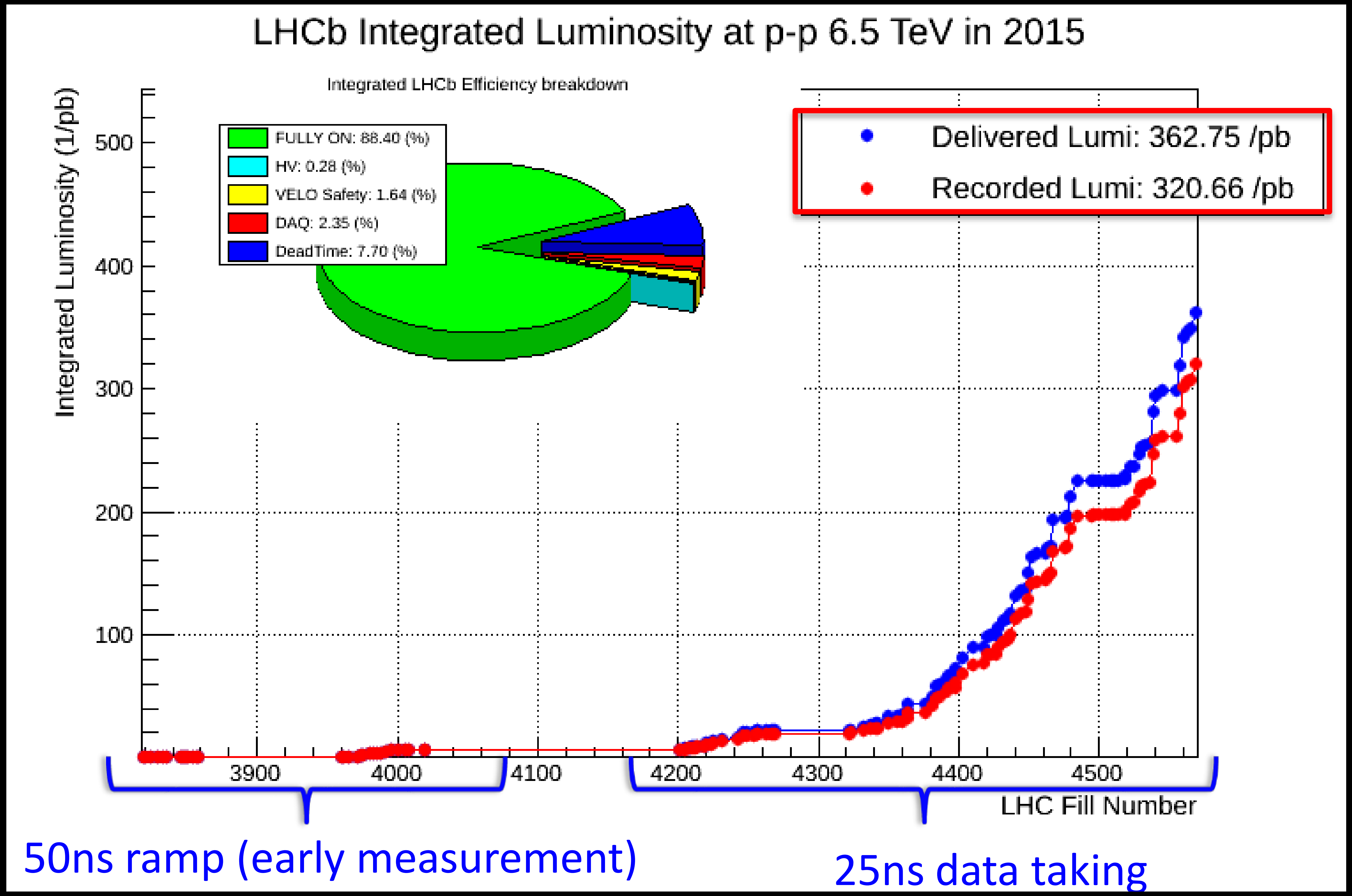
Run 2 Data Taking

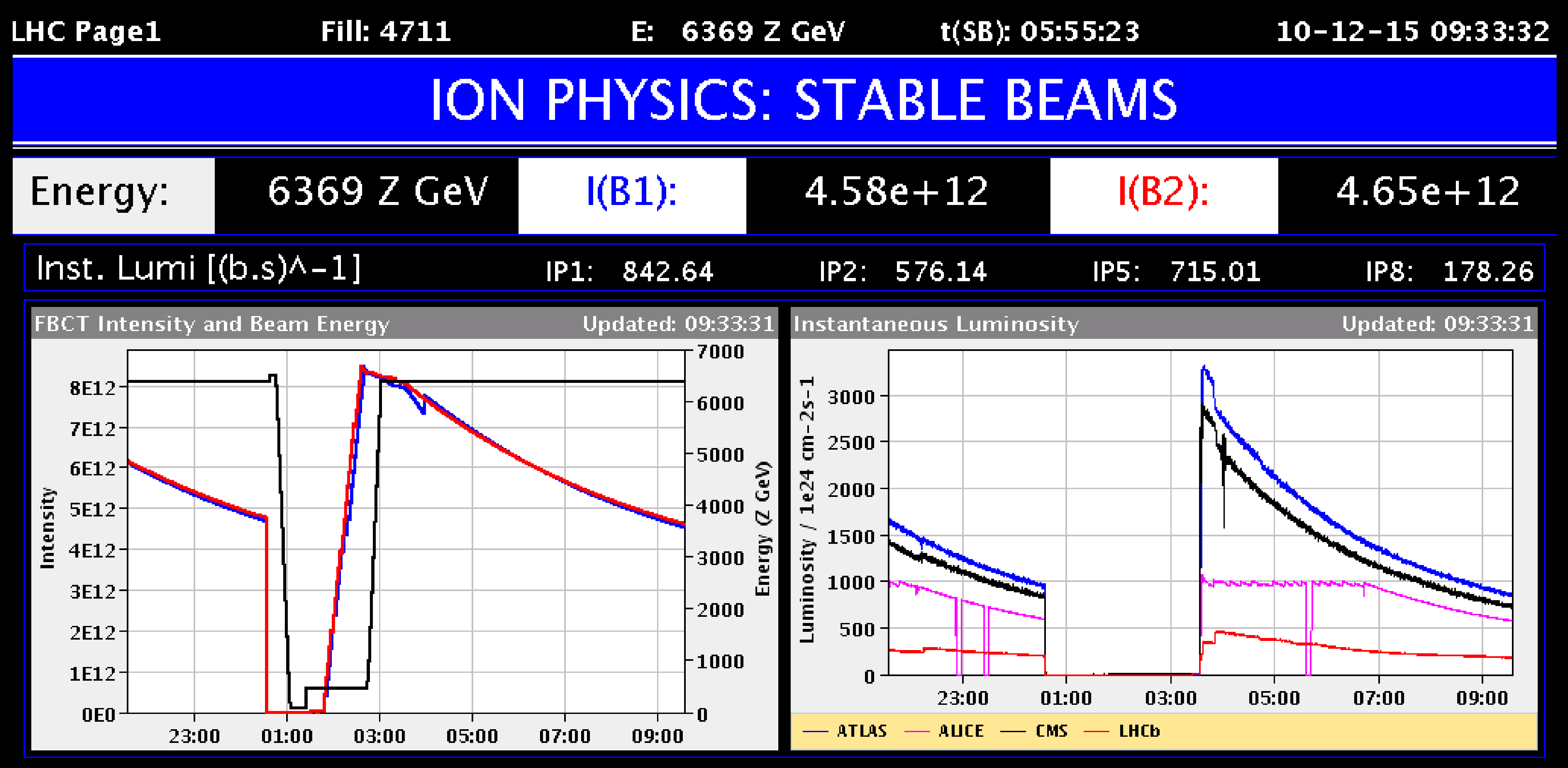
Run 2 Data Taking





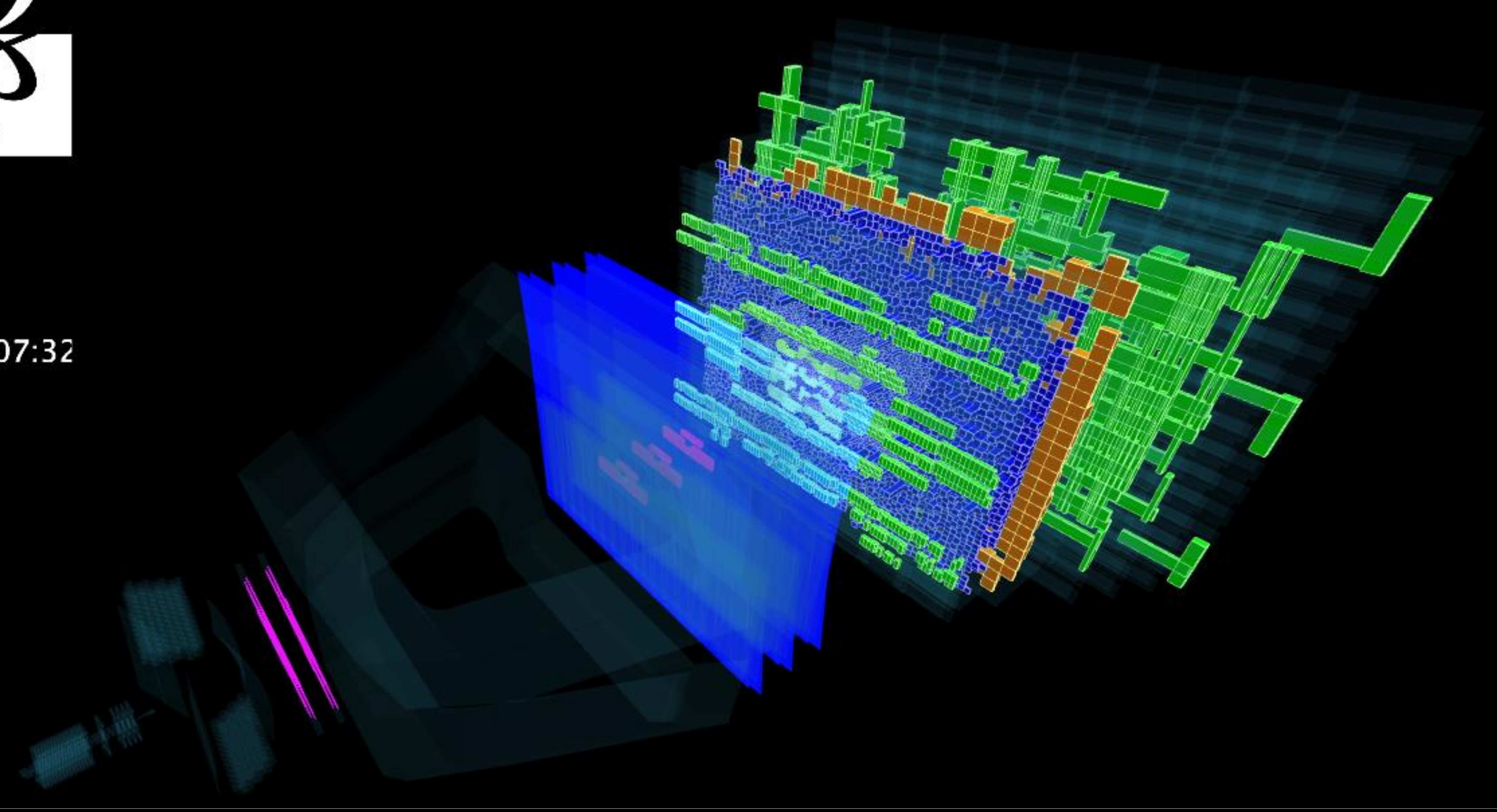
Run 2 Data Taking

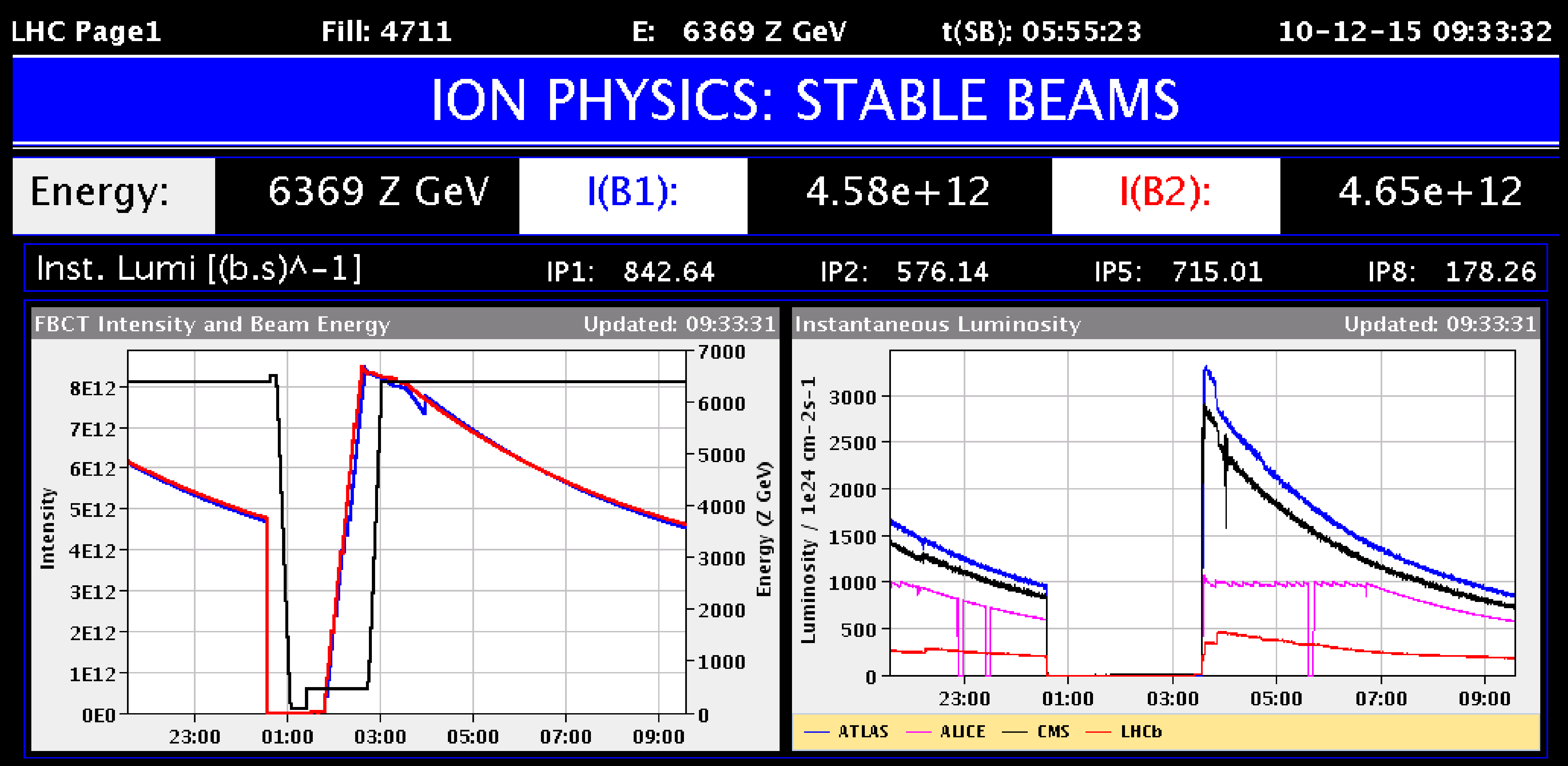




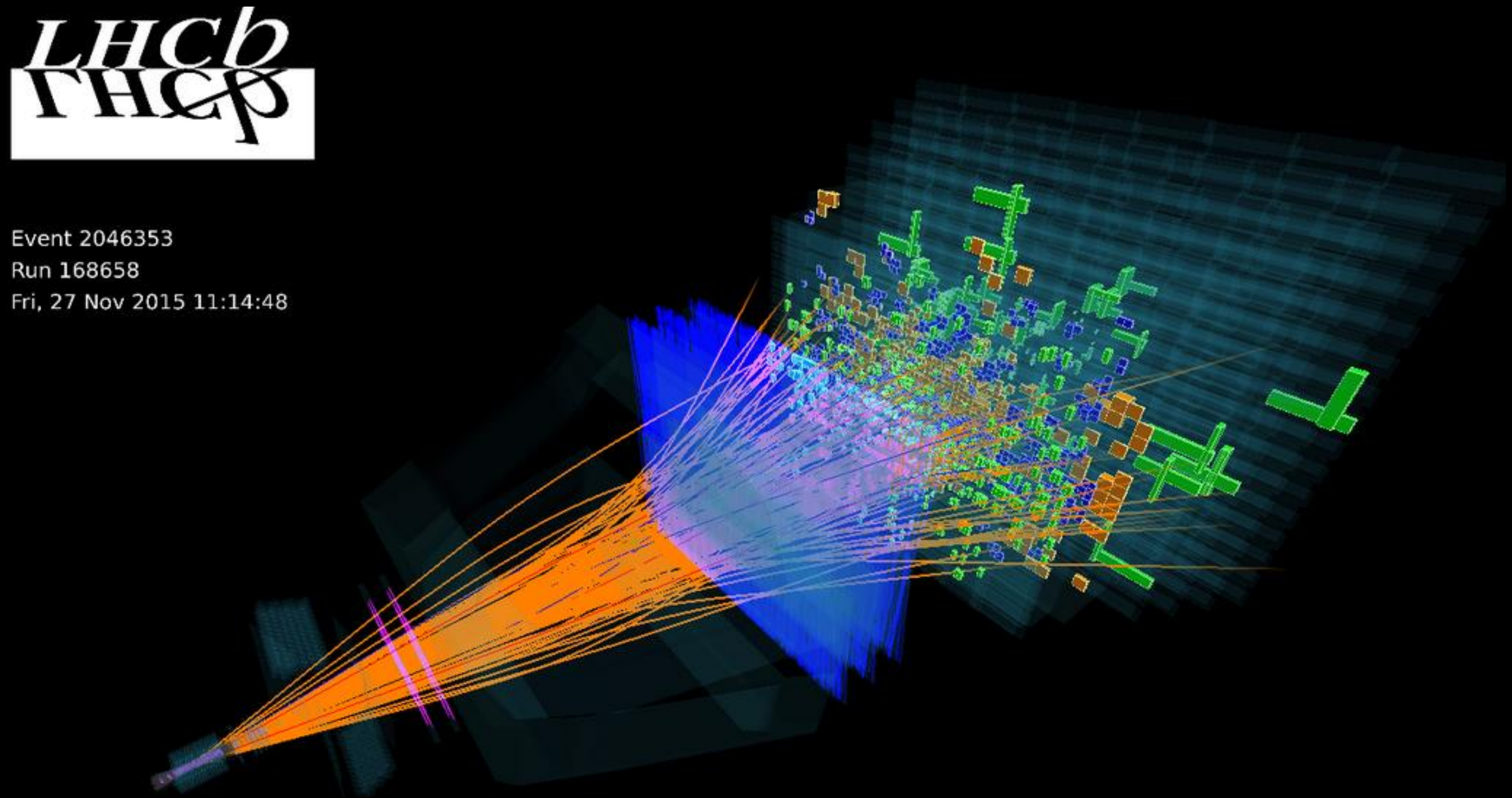
Run 2 Data Taking

Event 28006
Run 168487
Wed, 25 Nov 2015 13:07:32



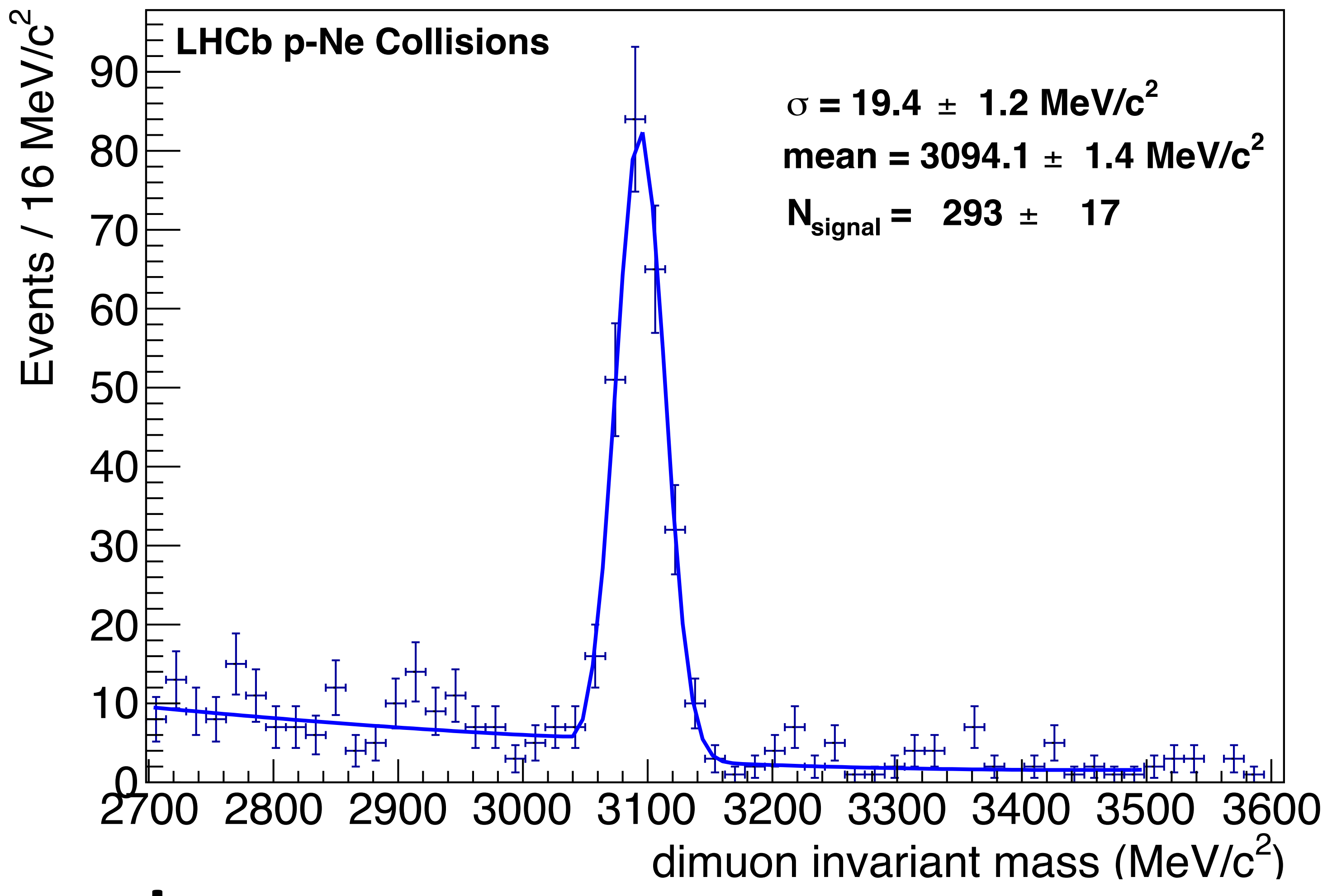


Run 2 Data Taking



Run 2 Data Taking

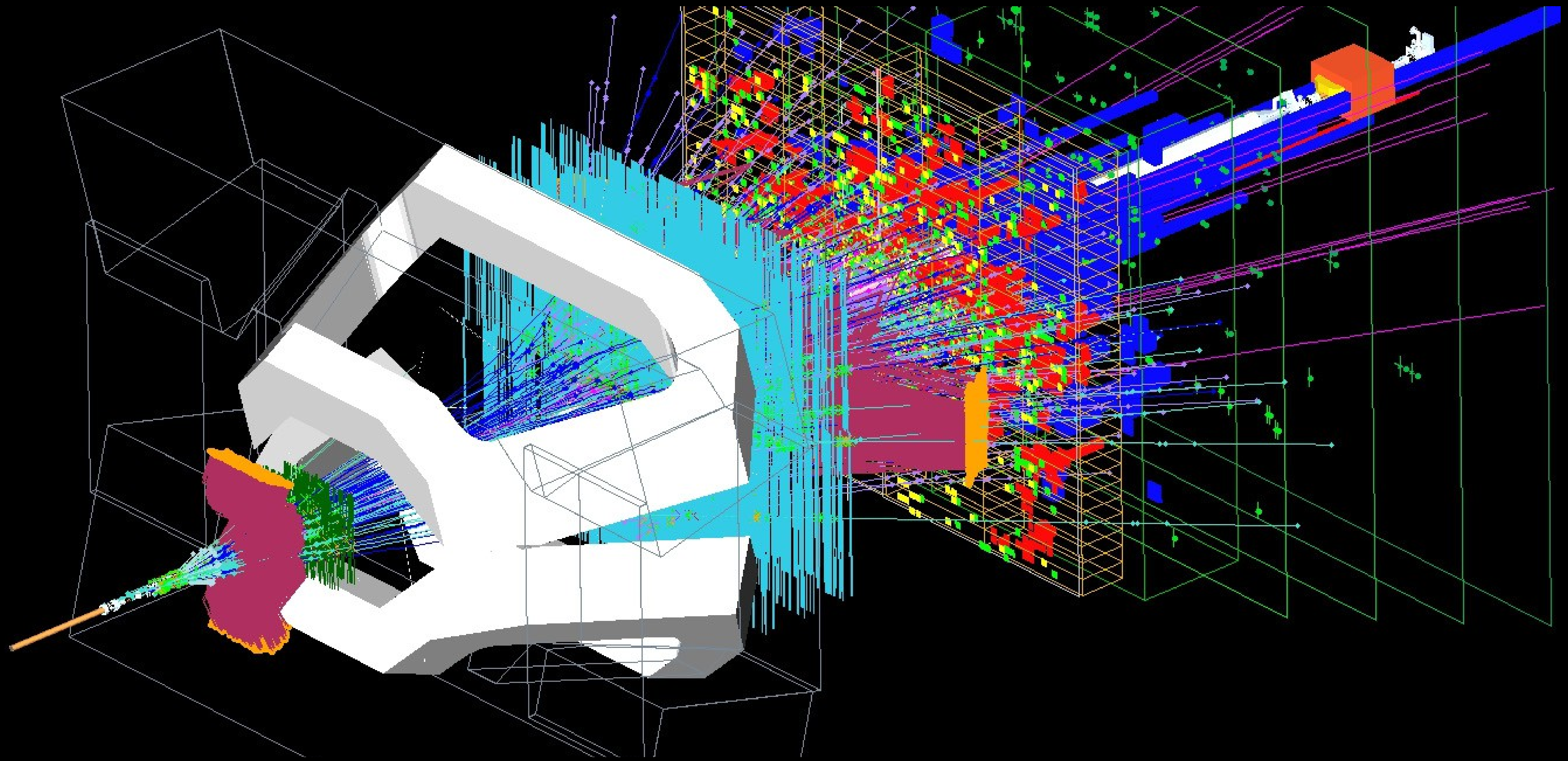
- p (6.5 TeV) – ***Neon***: 20h
- p (6.5 TeV) – ***Helium***: 20h
- p (6.5 TeV) – ***Argon***: 3 days
- p (2.51 TeV) – ***Argon***: 9 h
- Pb (6.37Z TeV) – ***Argon***: ongoing



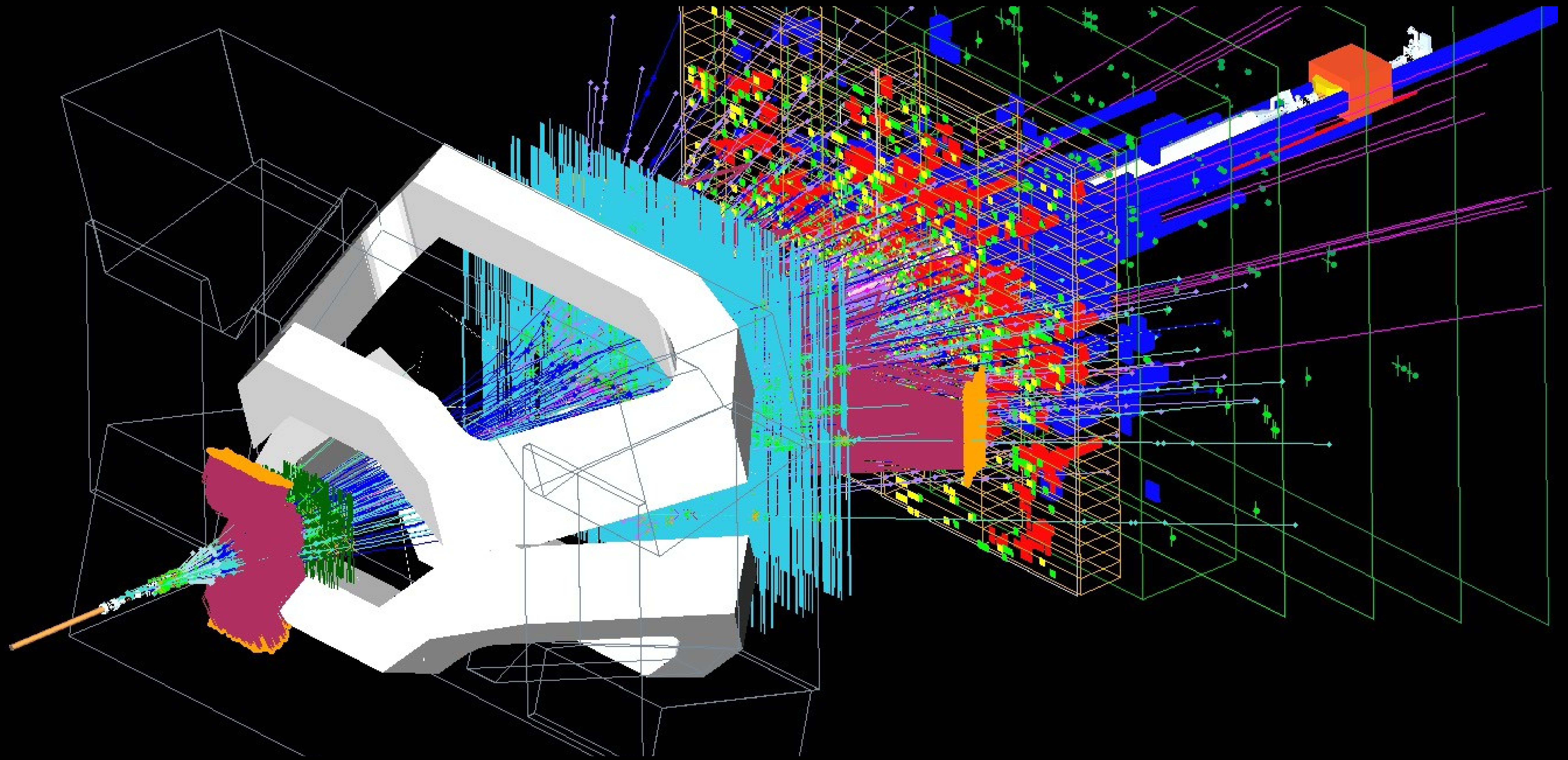
"Success is a journey, not a destination."

— Arthur Ashe

The evolution of LHCb in 2015



The evolution of the LHCb trigger in 2015



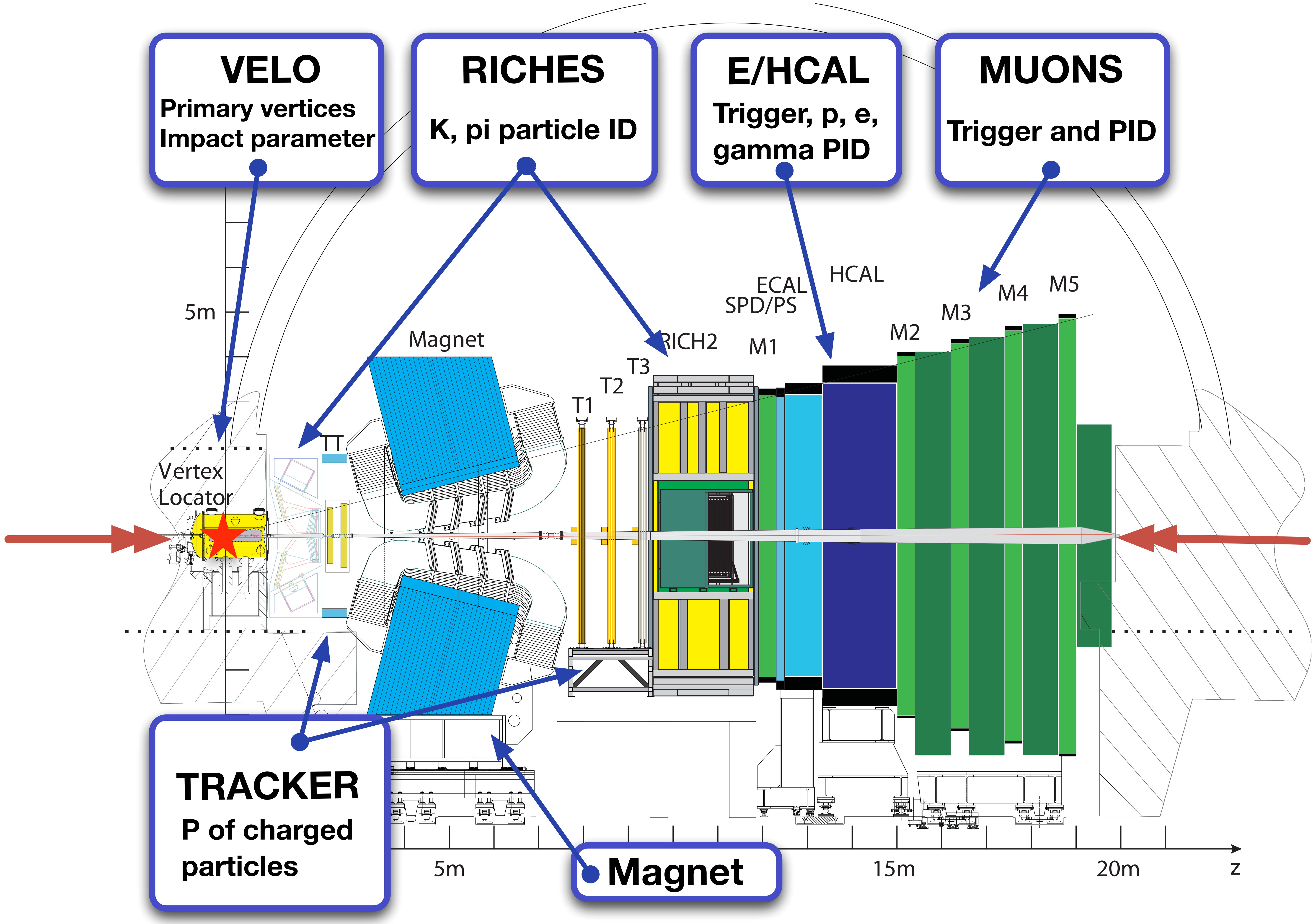
The Challenge

At 13 TeV & L = 4 × 10^{32} $cm^{-2}s^{-1}$:

~45 kHz bb pairs produced
~ 1 MHz cc pairs produced

Can only readout @ 1 MHz
(must decide within 4 μs)

Can only store O(10kHz)
(decide using ~50K cores)



Run 1 Trigger

40 MHz bunch crossing rate

⇩

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz	400 kHz	150 kHz
$h^{\pm}$	$\mu/\mu\mu$	e/γ

⇩

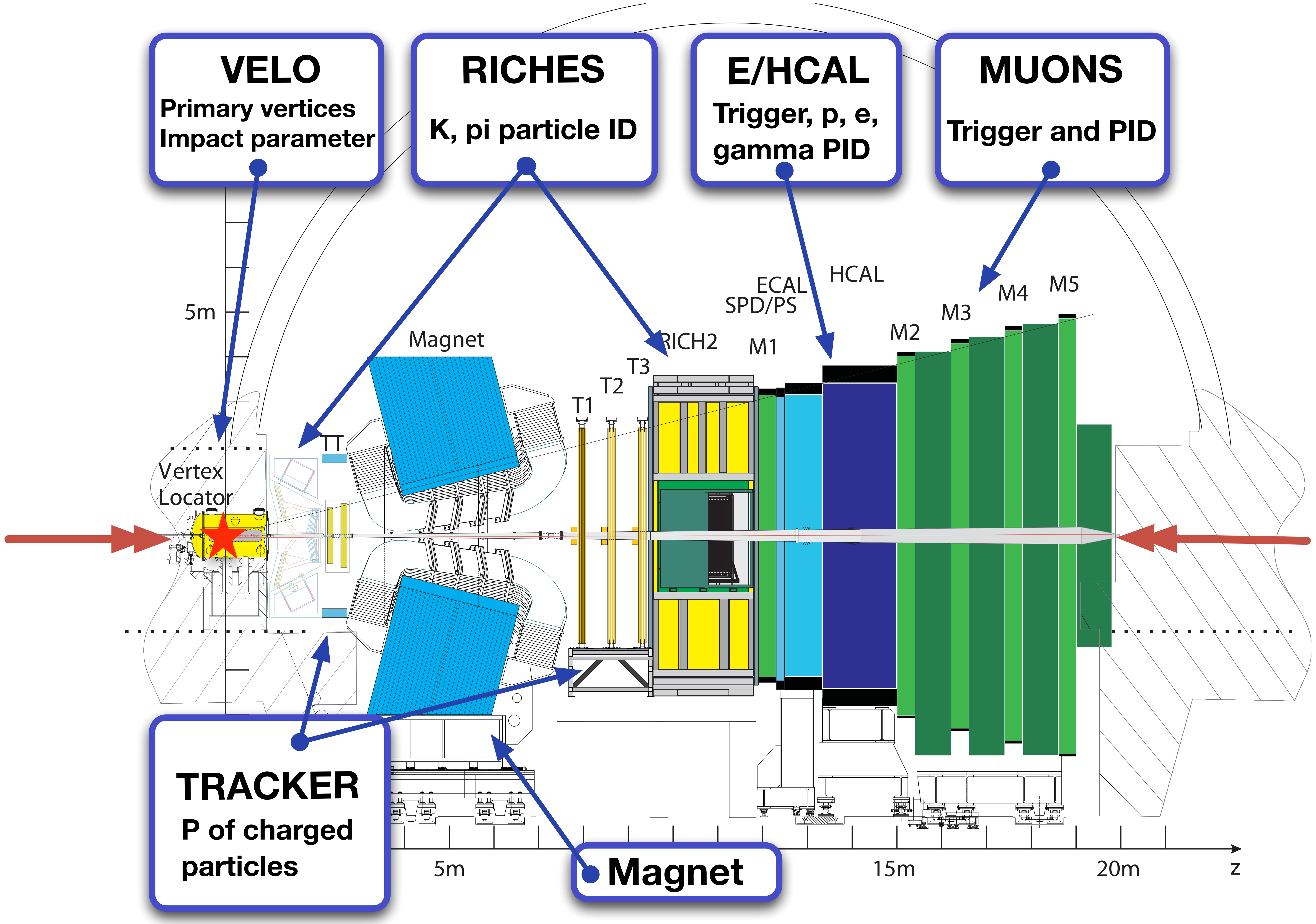
Software High Level Trigger

- 29000 Logical CPU cores
- Offline reconstruction tuned to trigger time constraints
- Mixture of exclusive and inclusive selection algorithms

⇩

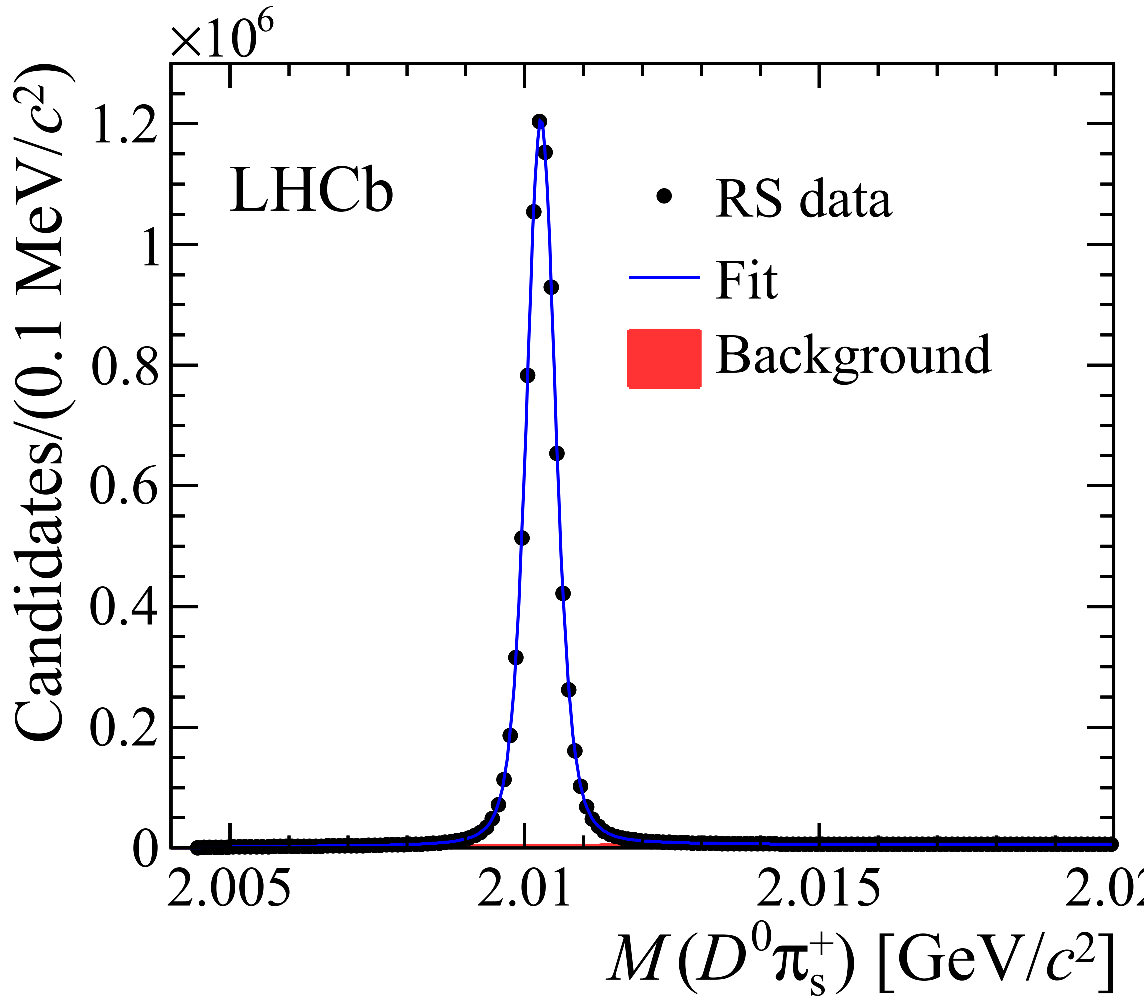
5 kHz Rate to storage

2 kHz	2 kHz	1 kHz
Inclusive Topological	Inclusive/ Exclusive Charm	Muon and DiMuon

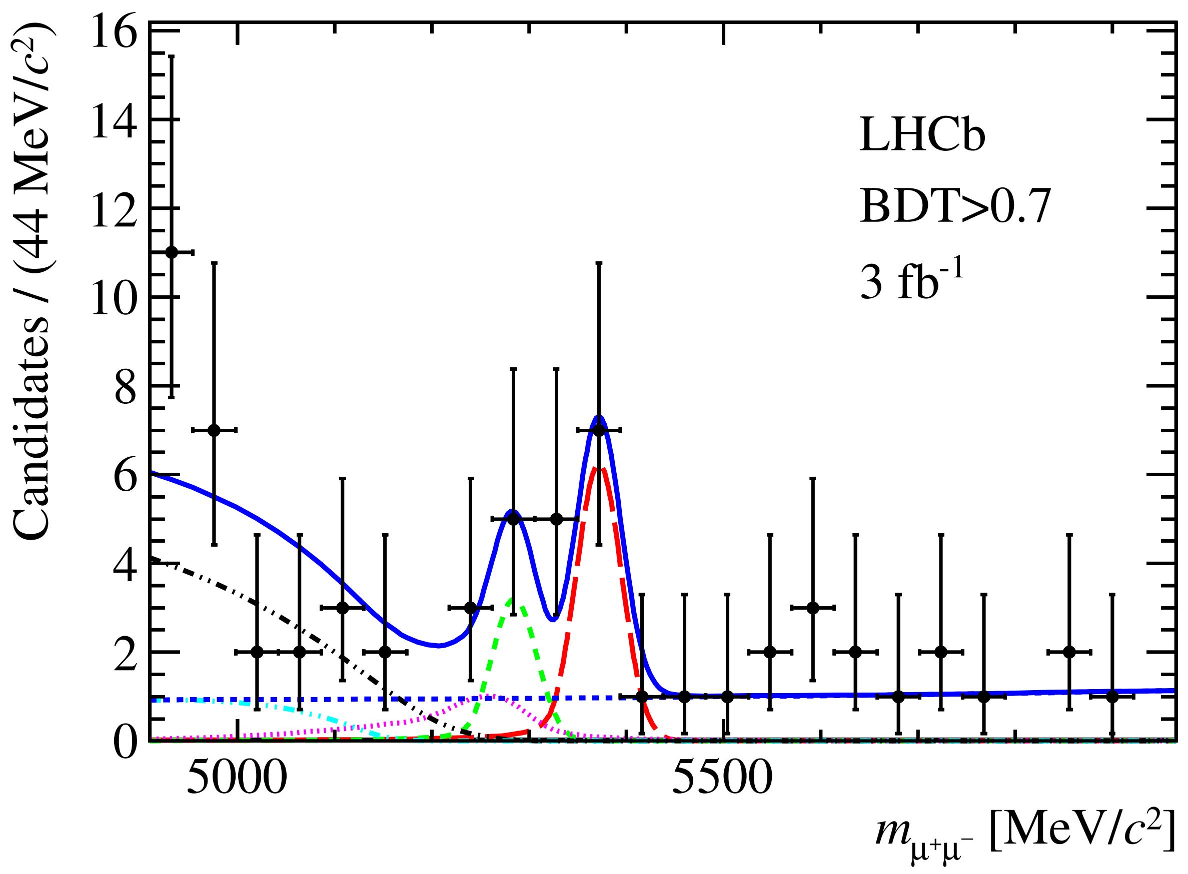


Run 1 Performance

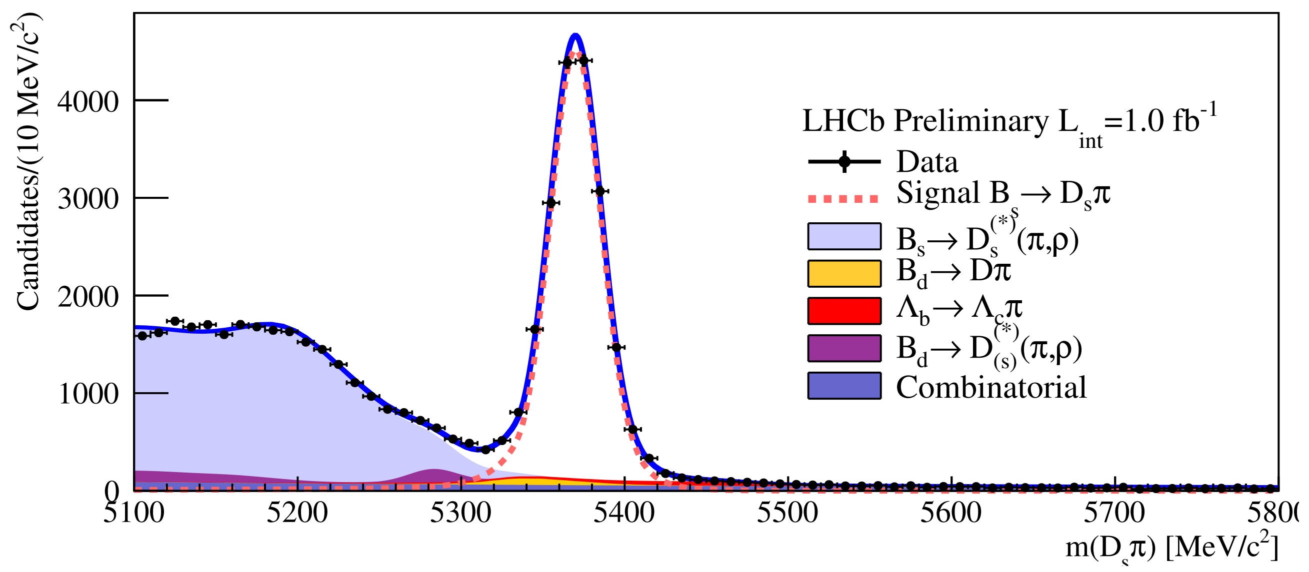
$D^* \to D^0\pi$ [1211.1230]



$B^0_s \to \mu\mu$ [1211.2674]

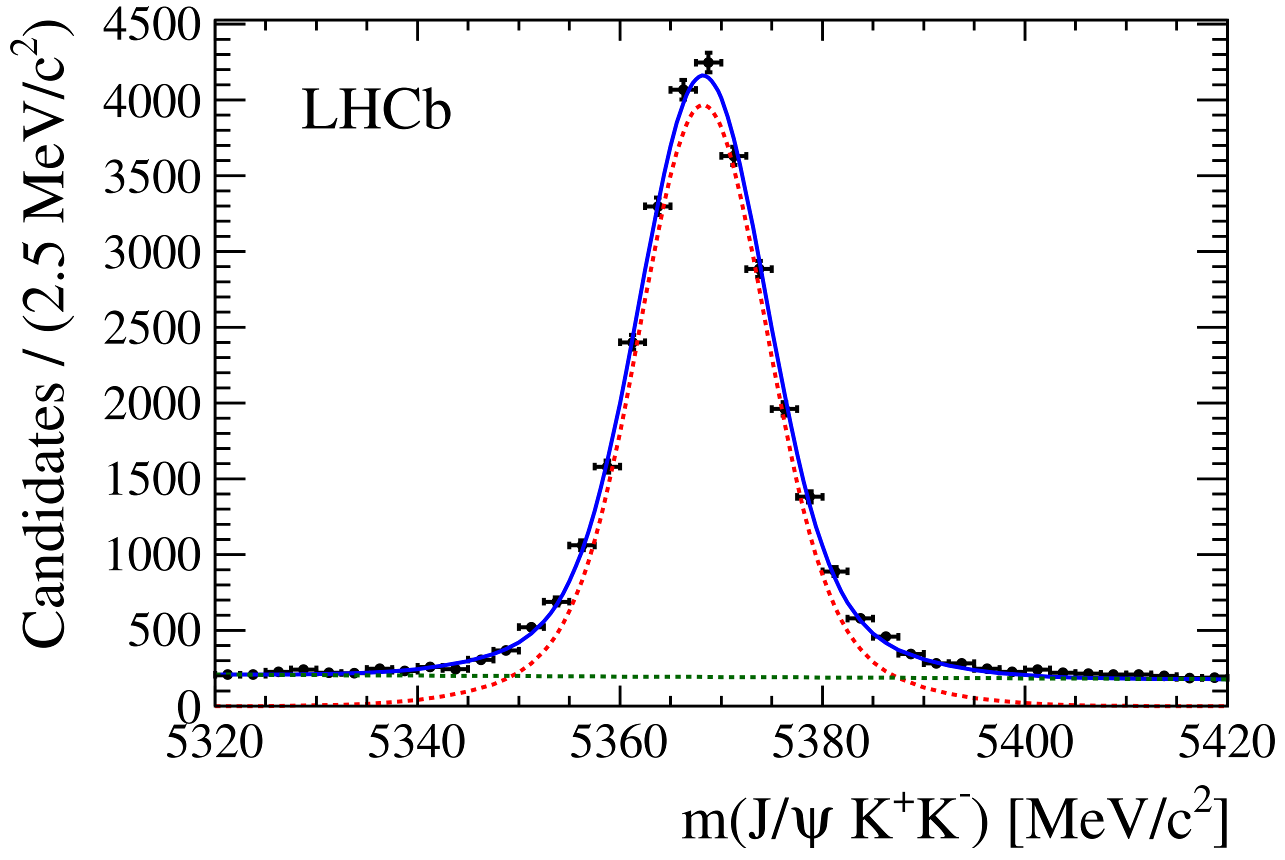


$B^0_s \to D_s\pi$ [1304.4741]



$D_s\pi$

$B^0_s \to J/\psi\phi$ [1304.2600v3]



	Hadronic		Dimuon
Mode	$D \to hhh$	$B \to hh$	$B^+ \to J/\psi K^+$
ϵ(L0) [%]	27	62	93
ϵ(HLT | L0) [%]	42	85	92
ϵ(HLT $\times$ L0) [%]	11	52	84

Very clean signals

Large “dynamic range”

Good trigger efficiencies

…. except for charm
…. but there is a lot of charm

Run 2

- Energy: 8 TeV → 13 TeV

- Bunch spacing: 50 ns → 25 ns

Run 2

- Energy: 8 TeV → 13 TeV

  + σ_{bb} x 1.6

  - $\sigma_{inelastic}$ x 1.2

  - multiplicity x 1.2

- Bunch spacing: 50 ns → 25 ns

  + constant lumi → pileup / 2

  - 1 MHz L0/readout limit: 1/20 → 1/40

  - spillover

Run 2 Challenge

- Energy: 8 TeV → 13 TeV

  + σ_{bb} x 1.6

  - $\sigma_{inelastic}$ x 1.2

  - multiplicity x 1.2

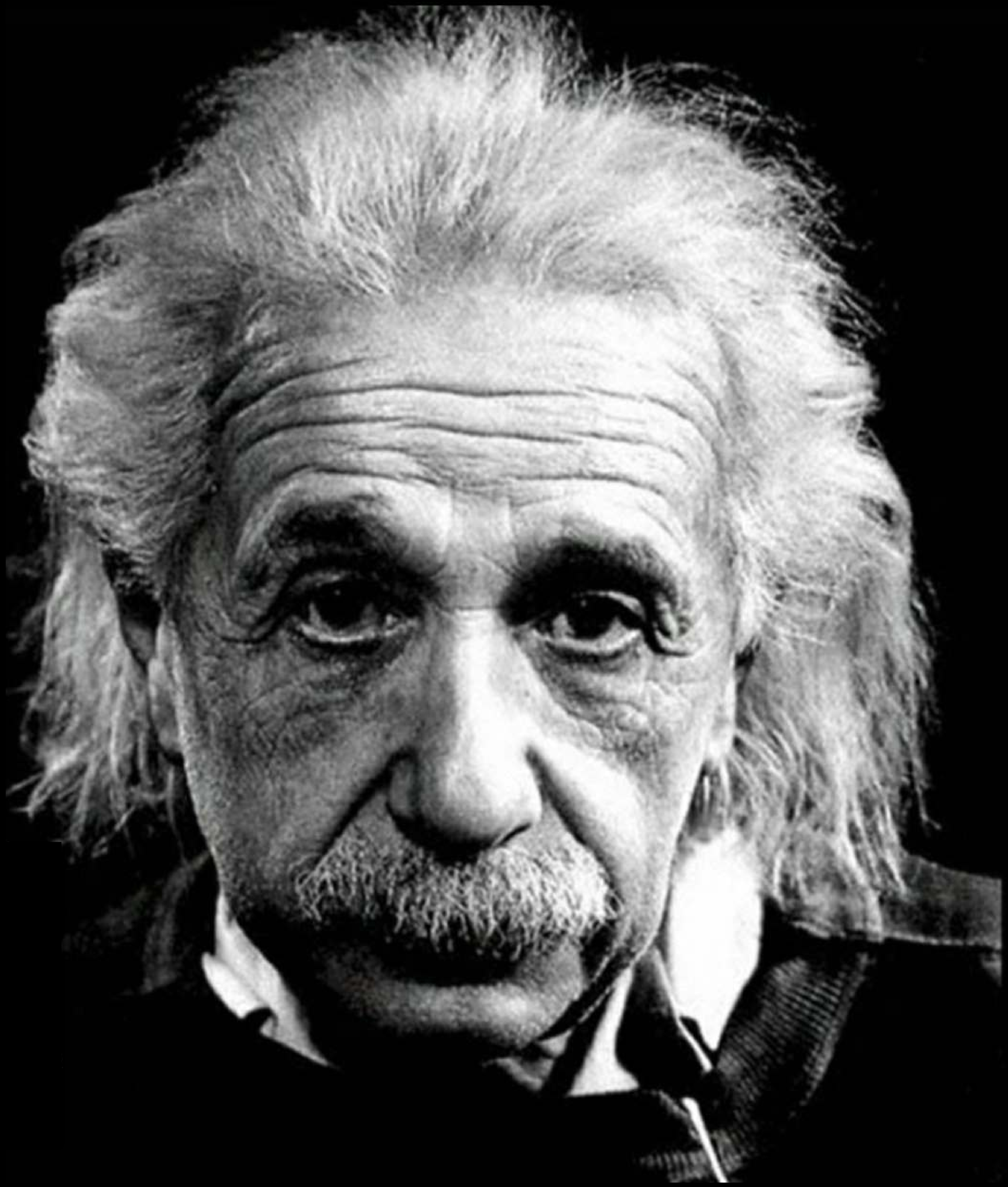
- Bunch spacing: 50 ns → 25 ns

  + constant lumi → pileup / 2

  - 1 MHz L0/readout limit: 1/20 → 1/40

  - spillover

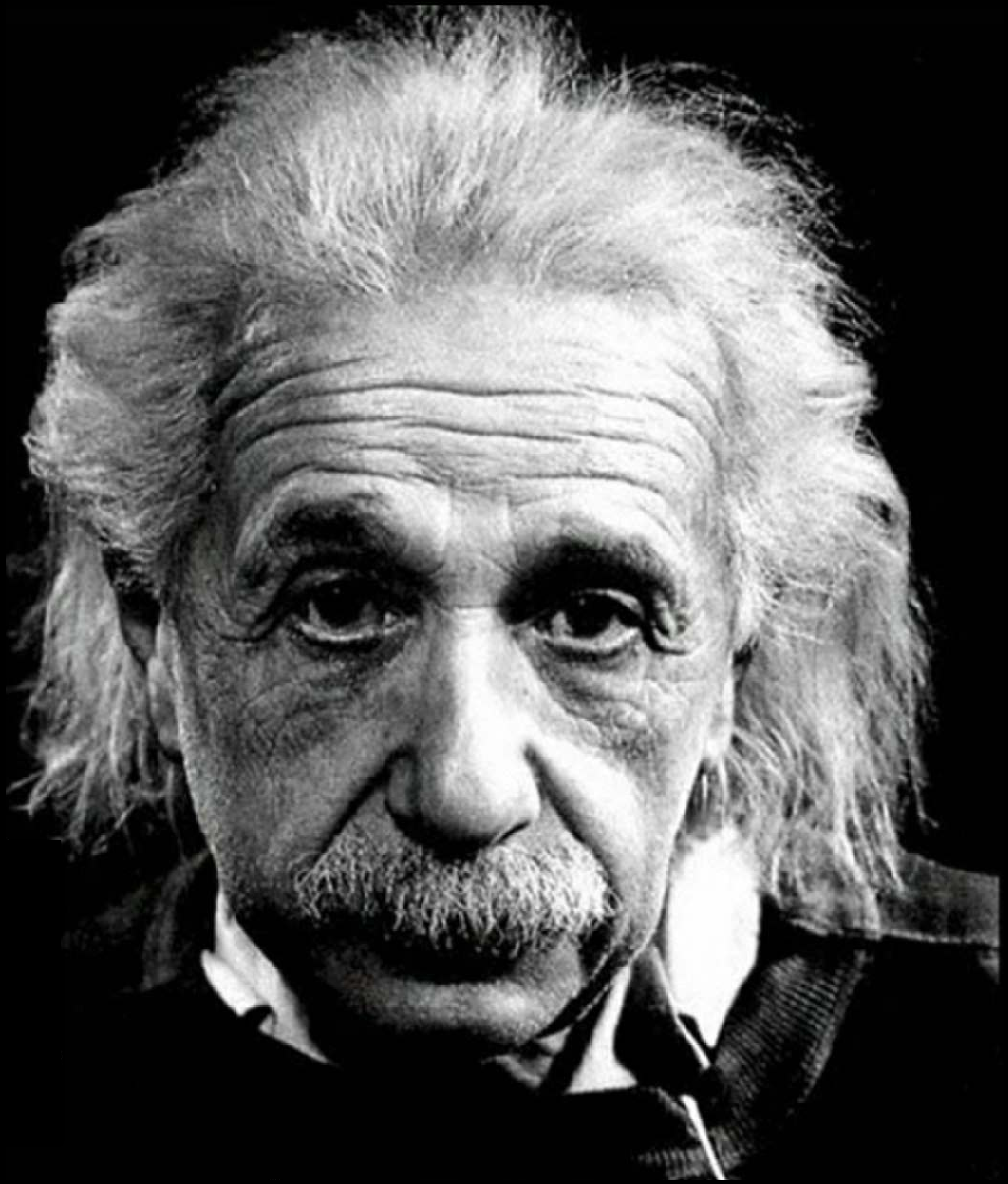
Can we ~~maintain~~ *improve* performance under more challenging conditions?



"The formulation of the problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill."

"To raise new questions, new possibilities, to regard old questions from a new angle requires creative imagination and marks real advances…"

— Albert Einstein



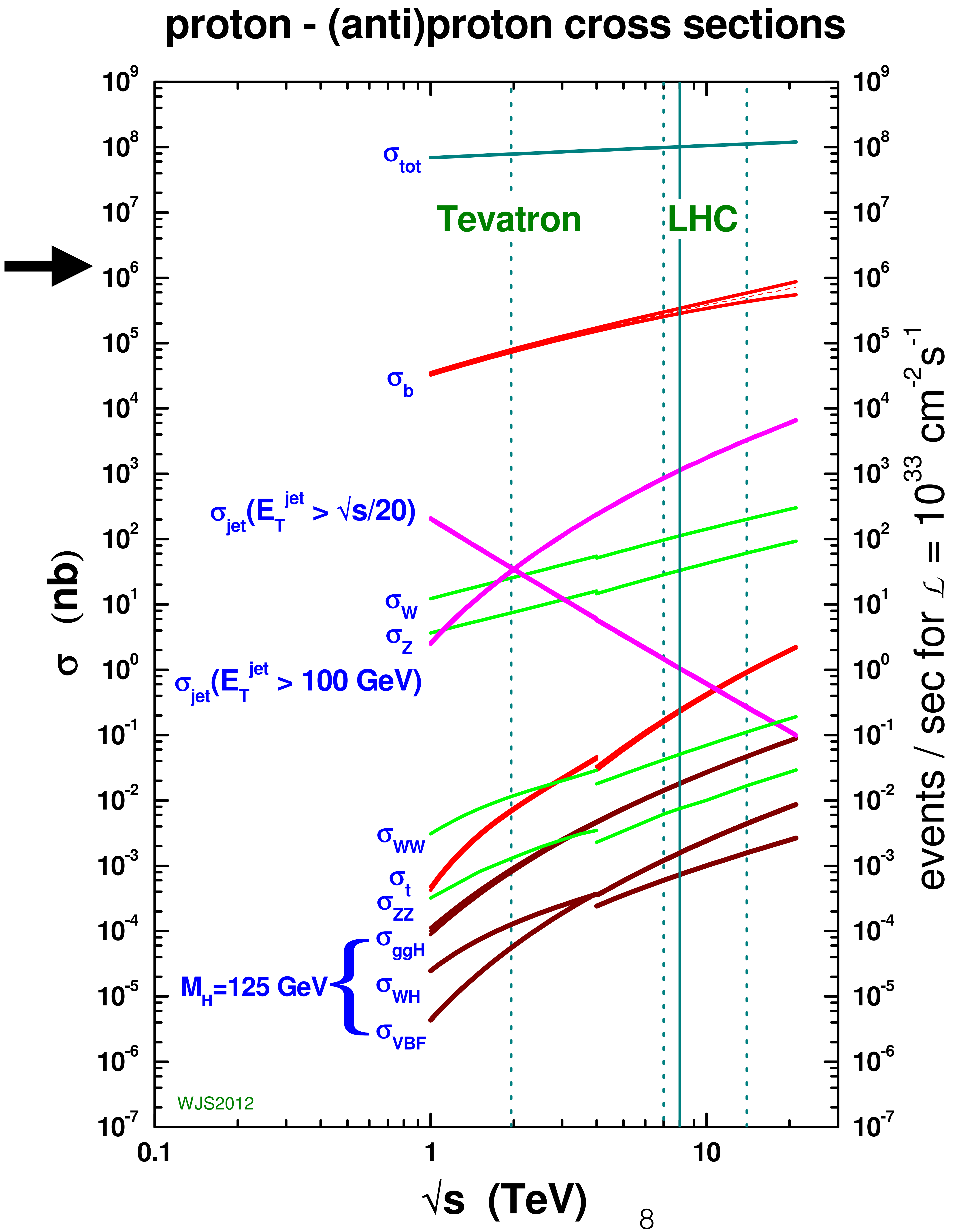
"The formulation of the problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill."

"To raise new questions, new possibilities, to regard old questions from a new angle requires creative imagination and marks real advances…"

— Albert Einstein

What is the problem?

Some things are not rare…



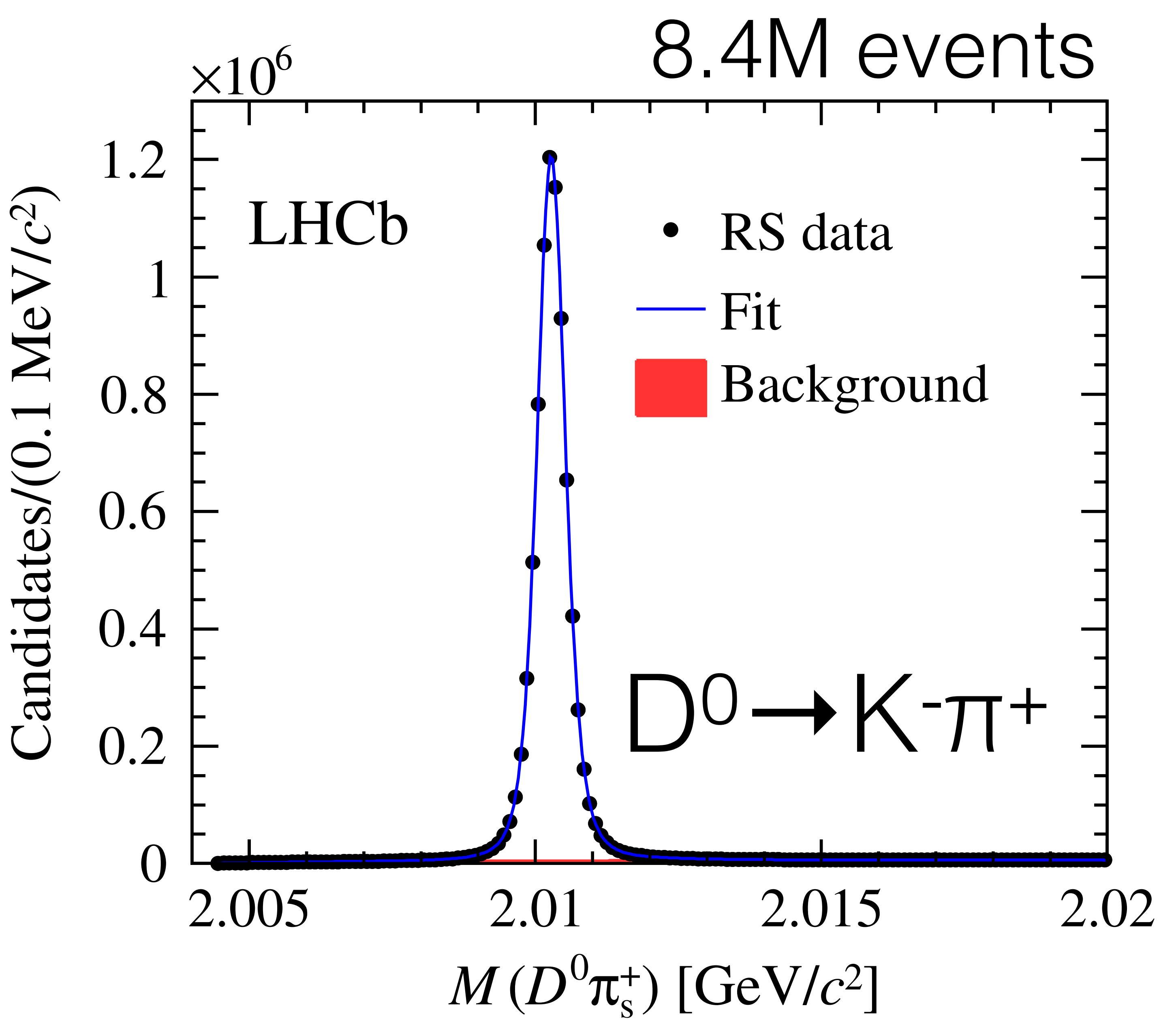
Some things are not rare…

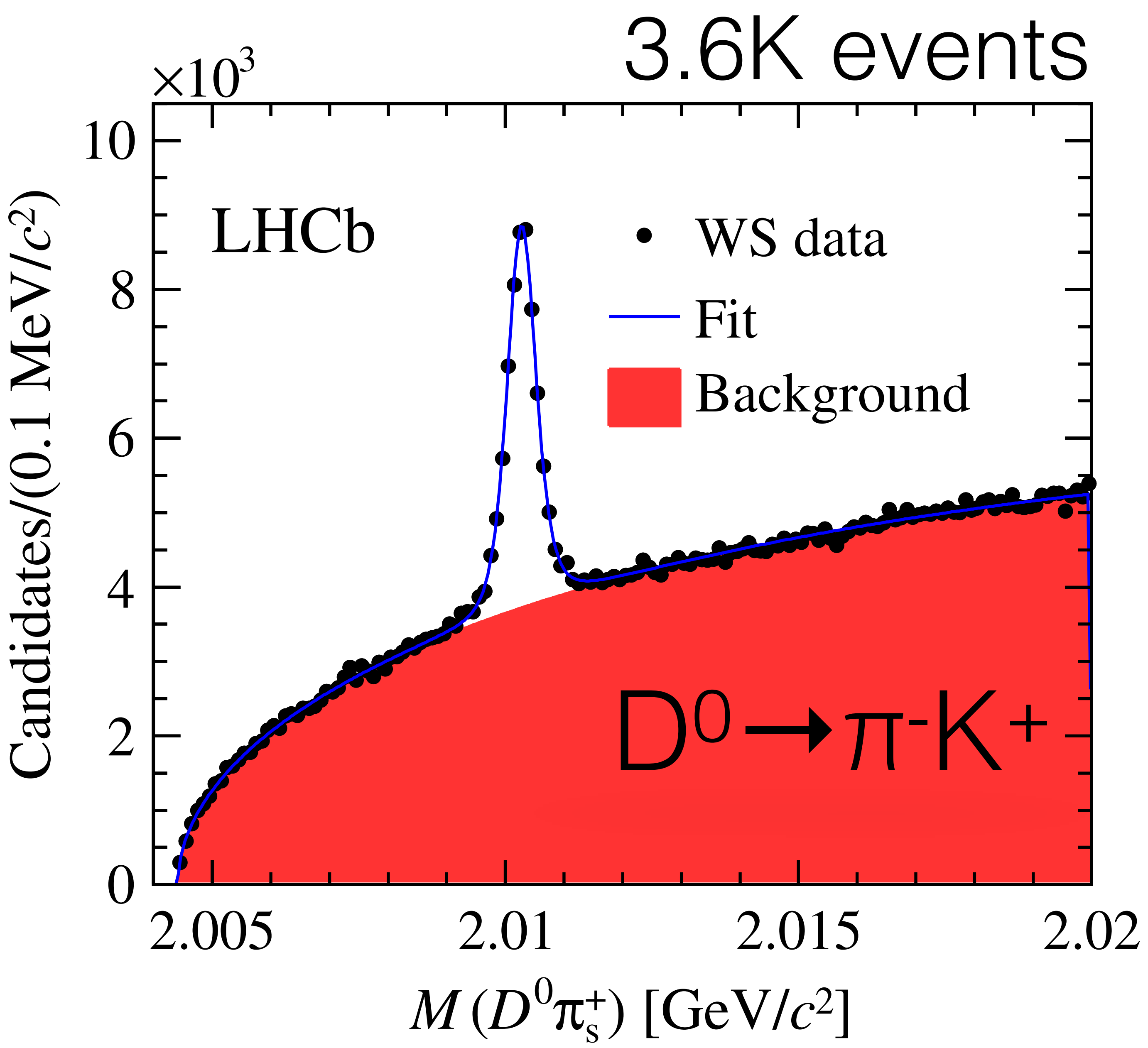
Selected for a Viewpoint in *Physics*
PRL **110,** 101802 (2013) PHYSICAL REVIEW LETTERS week ending 8 MARCH 2013

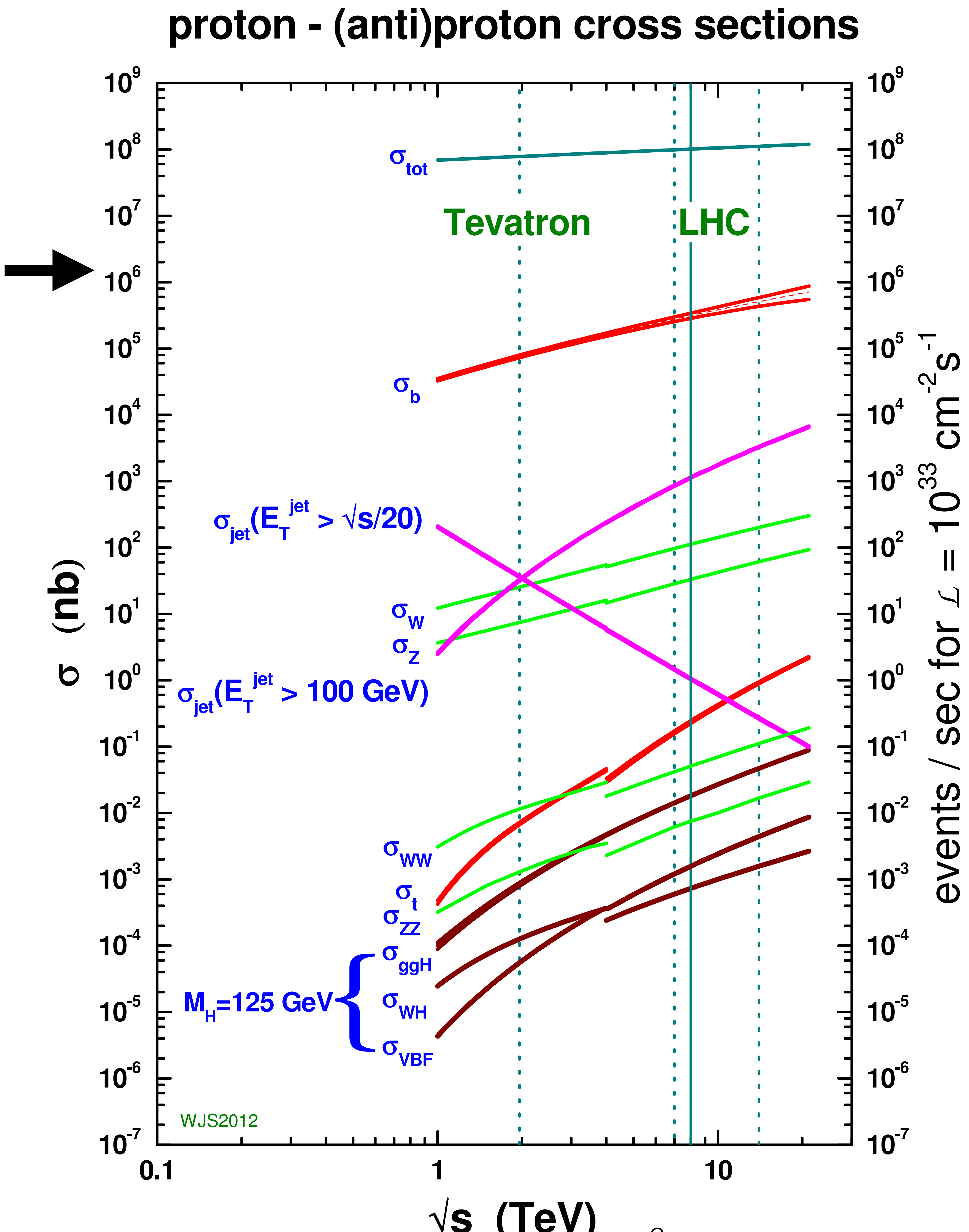
Observation of $D^0 - \bar{D}^0$ Oscillations

R. Aaij *et al.**
(LHCb Collaboration)
(Received 6 November 2012; published 5 March 2013)

We report a measurement of the time-dependent ratio of $D^0 \to K^+\pi^-$ to $D^0 \to K^-\pi^+$ decay rates in D^{*+}-tagged events using 1.0 fb^{-1} of integrated luminosity recorded by the LHCb experiment. We measure the mixing parameters $x'^2 = (-0.9 \pm 1.3) \times 10^{-4}$, $y' = (7.2 \pm 2.4) \times 10^{-3}$, and the ratio of doubly-Cabibbo-suppressed to Cabibbo-favored decay rates $R_D = (3.52 \pm 0.15) \times 10^{-3}$, where the uncertainties include statistical and systematic sources. The result excludes the no-mixing hypothesis with a probability corresponding to 9.1 standard deviations and represents the first observation of $D^0 - \bar{D}^0$ oscillations from a single measurement.





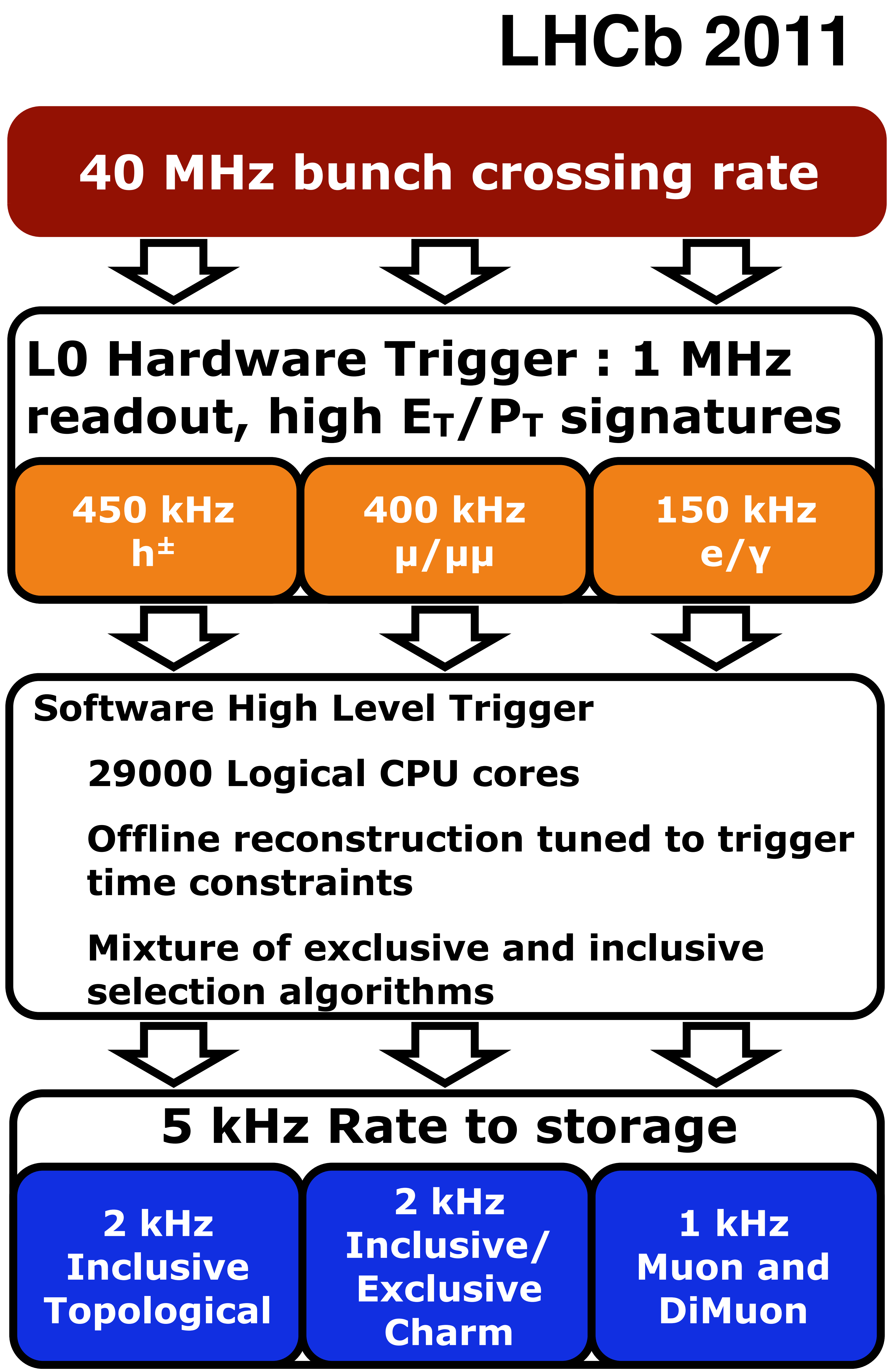



"The problem is not the problem.
The problem is your attitude
about the problem"

Offline → Online!

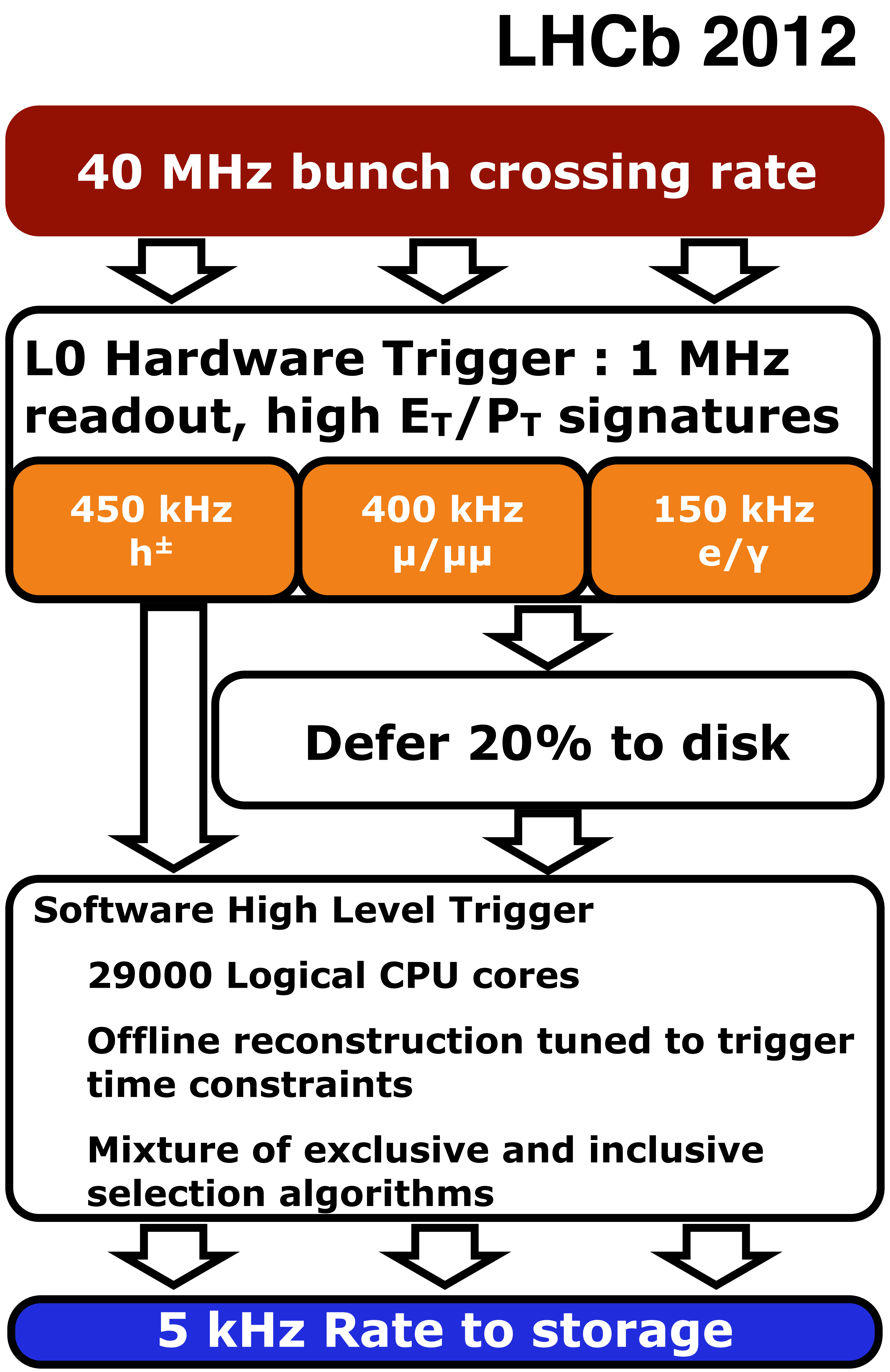
- Do "Online" what used to be done "Offline"
  - Calibrate in "Real Time"
  - Run offline reconstruction online
  - Skip offline reconstruction / skimming
  - Don't store events / information that you won't really use…

Trigger Evolution

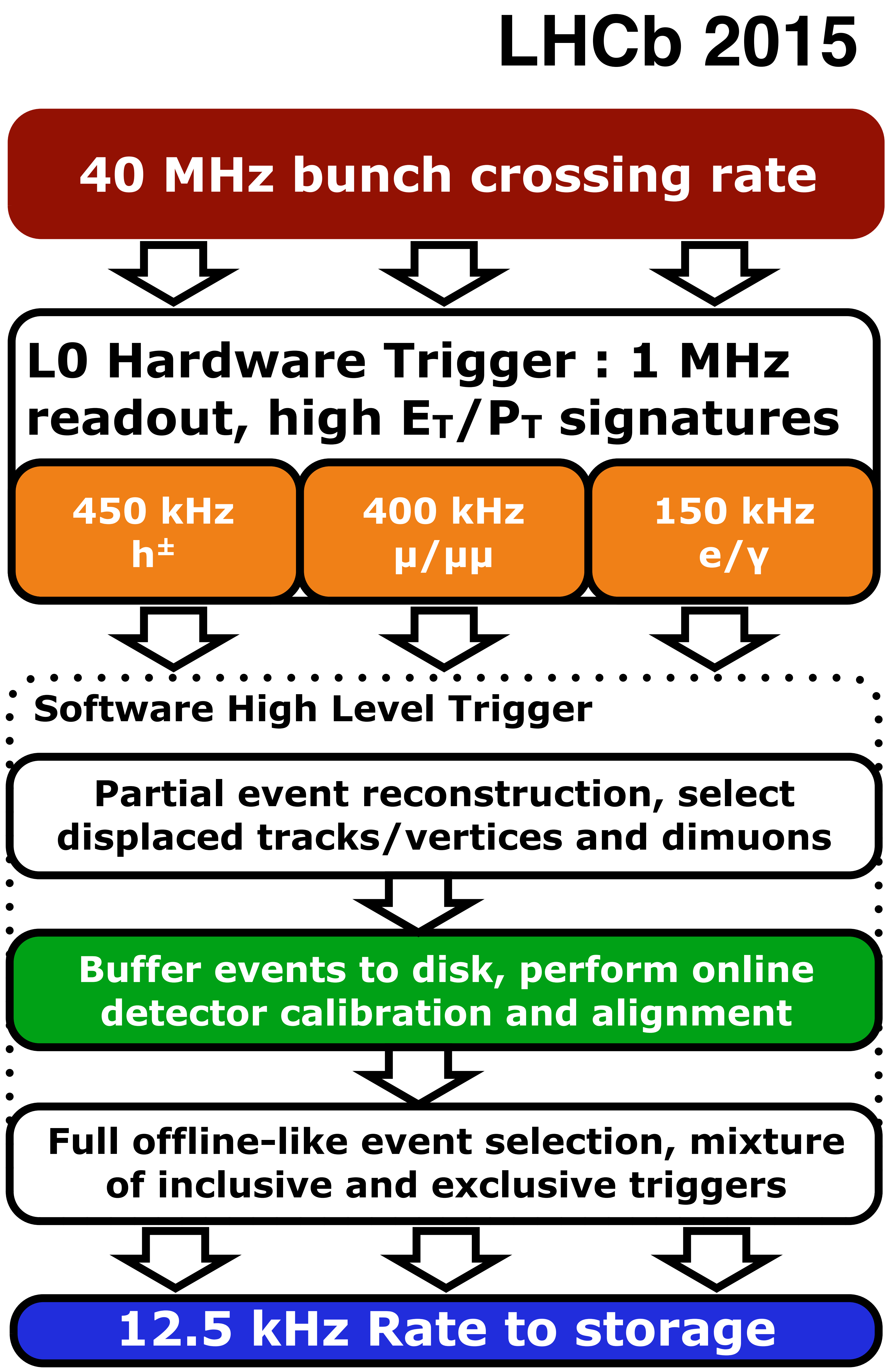


- 2011: increased bandwidth
  - 2 kHz → 5 kHz to accommodate charm
  - 29K CPU cores

Trigger Evolution



- 2011: increased bandwidth
  - 2 kHz → 5 kHz to accommodate charm
  - 29K CPU cores
- 2012: add *deferred* triggering to utilize farm between fills
  - 20% deferral → 25% extra capacity



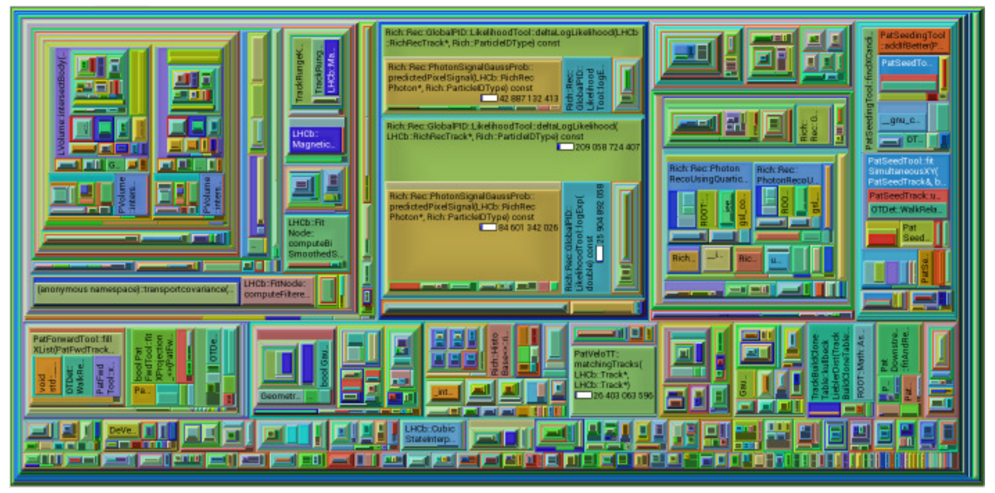
Trigger Evolution

- 2011: increased bandwidth
  - 2 kHz → 5 kHz to accommodate charm
  - 29K CPU cores
- 2012: add *deferred* triggering to utilize farm between fills
  - 20% deferral → 25% extra capacity
- 2015: split HLT
  - 50K CPU cores
  - buffer full HLT1 output (150 kHz) to 5PB of disk
  - HLT2 uses “offline quality” calibrations

Software Improvements

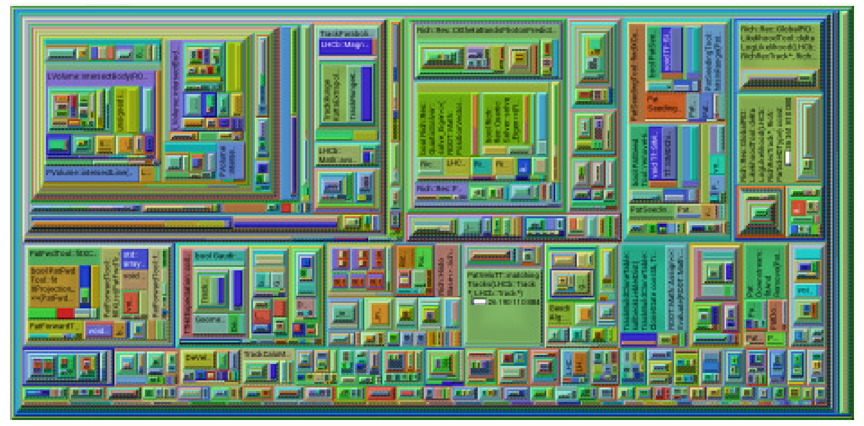
- Equivalent to 'a few MCHF' of hardware
- Unified online and offline reconstruction!

Area ∝ cycle count



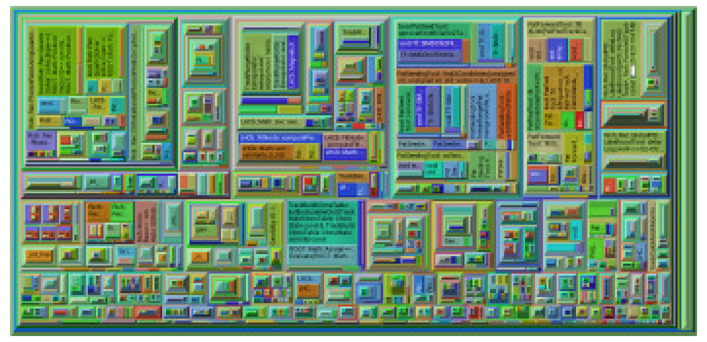
v45r1

Run 1 software
Run 1 configuration



v48r1

Run 2 software
Run 1 configuration



v48r1 (2015 reco)

Run 2 software
Run 2 configuration

"Start where you are. Use what you have. Do what you can." — Arthur Ashe

Software Improvements

- Equivalent to ‘a few MCHF’ of hardware
- Unified online and offline reconstruction!

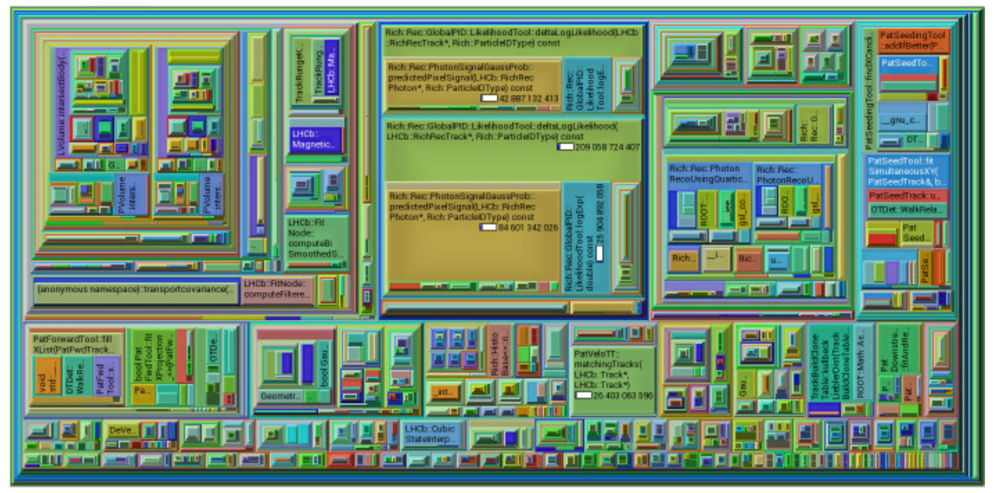
⇓

- P_T threshold: 1.3 GeV/c → 0.5 GeV/c
- Drop (IP | muon match) requirement in HLT1

⇓

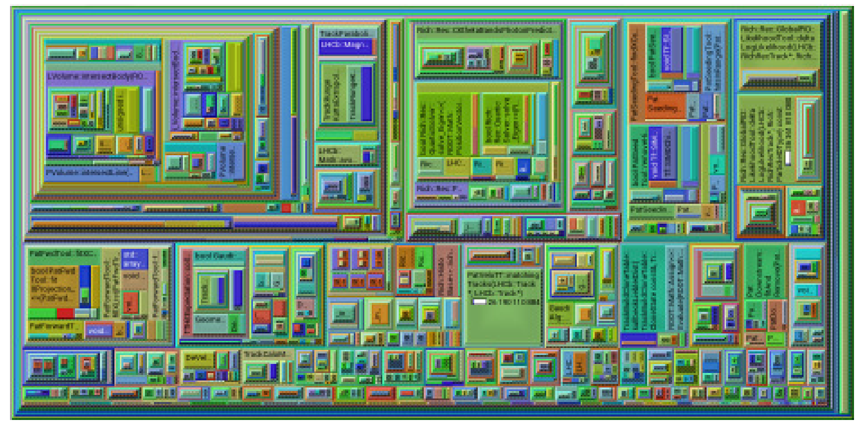
- ε_{HLT}(charm): +50%
- $\varepsilon_{HLT}(B^+ \rightarrow D^0\pi^+)$: +20% (75% → 90%)

Area ∝ cycle count



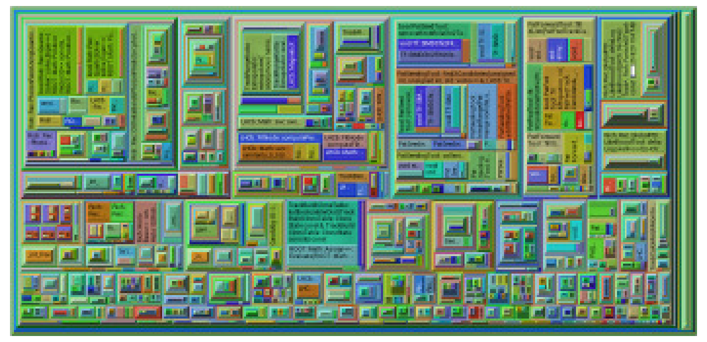
v45r1

Run 1 software
Run 1 configuration



v48r1

Run 2 software
Run 1 configuration

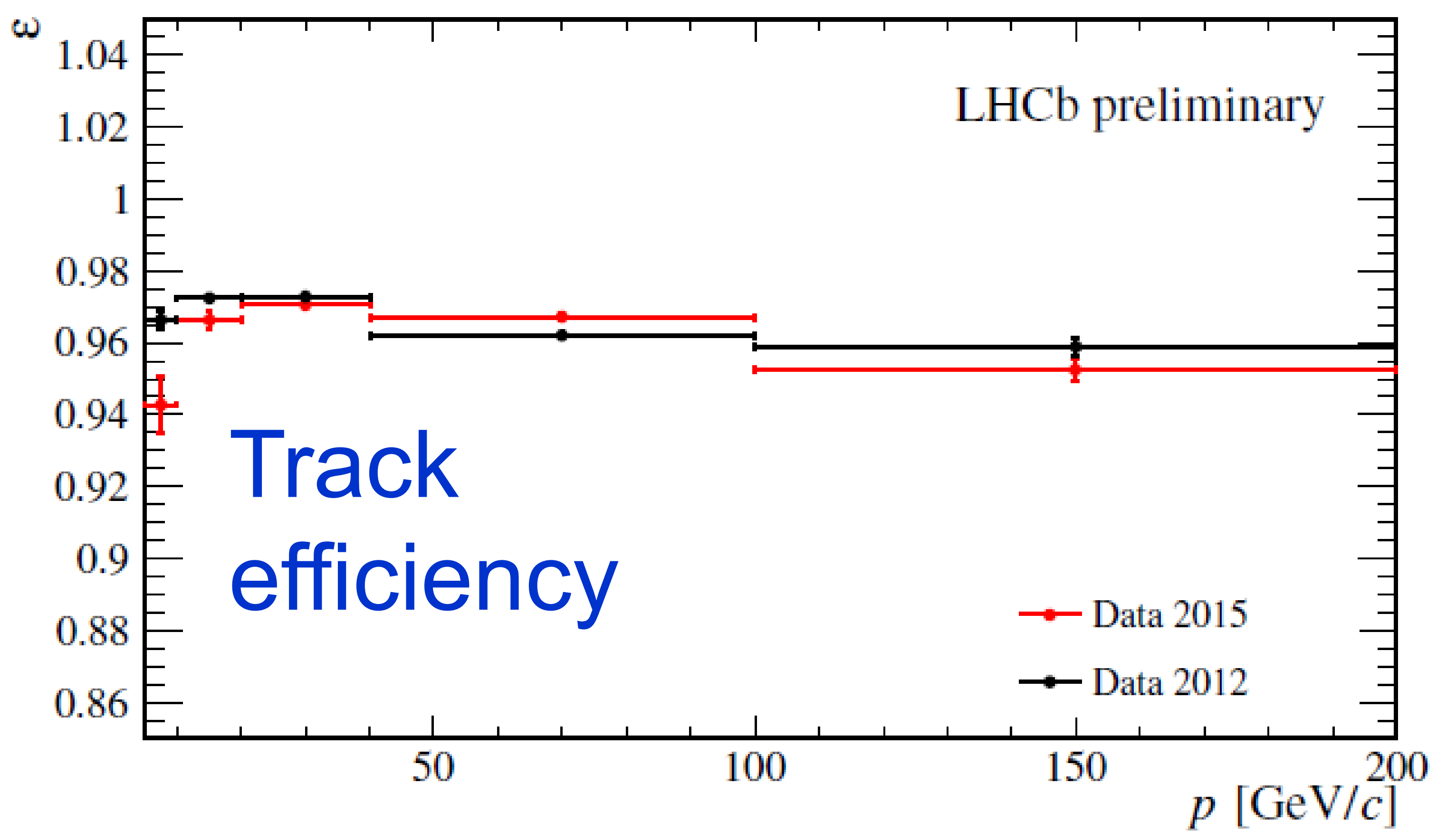


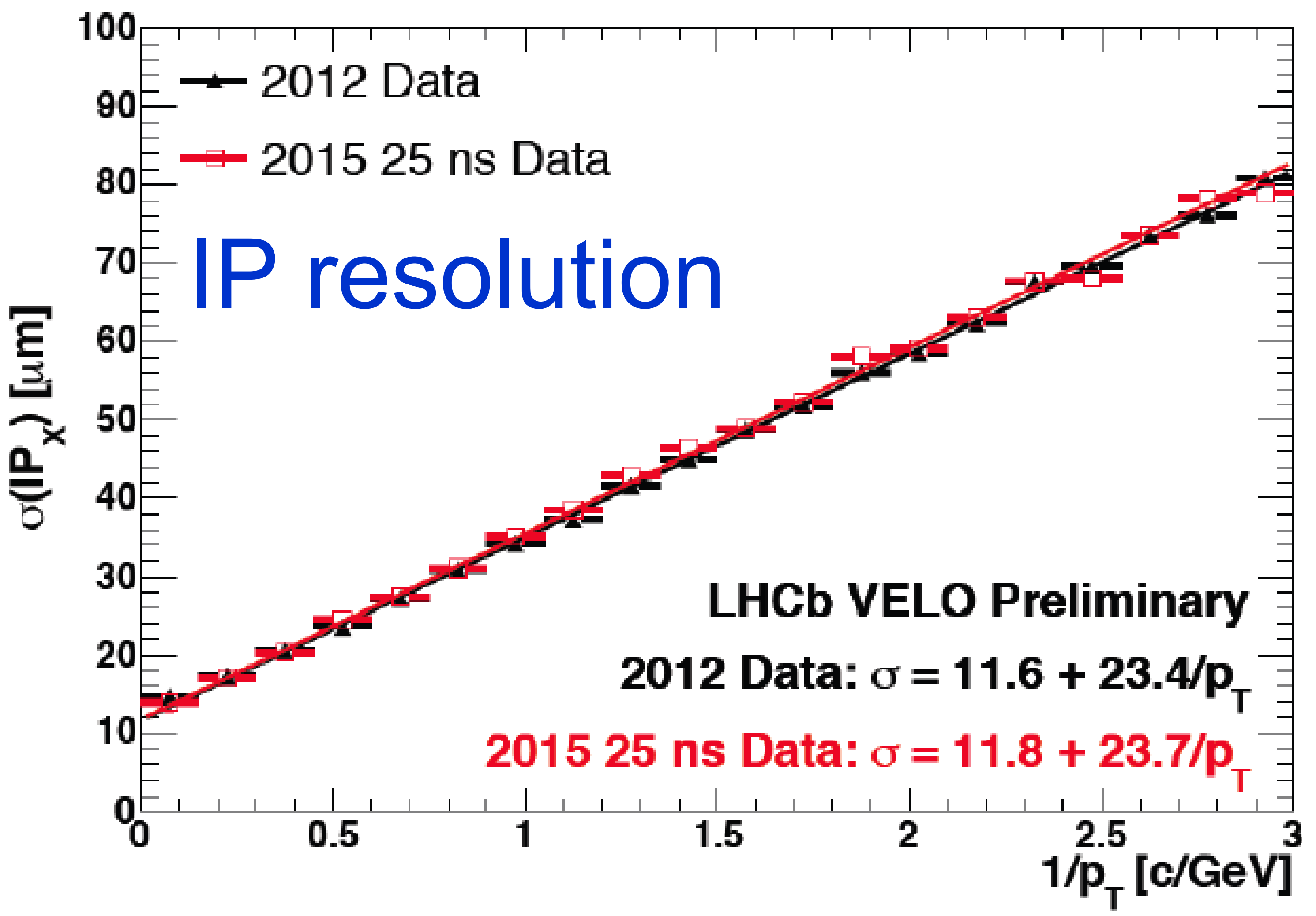
v48r1 (2015 reco)

Run 2 software
Run 2 configuration

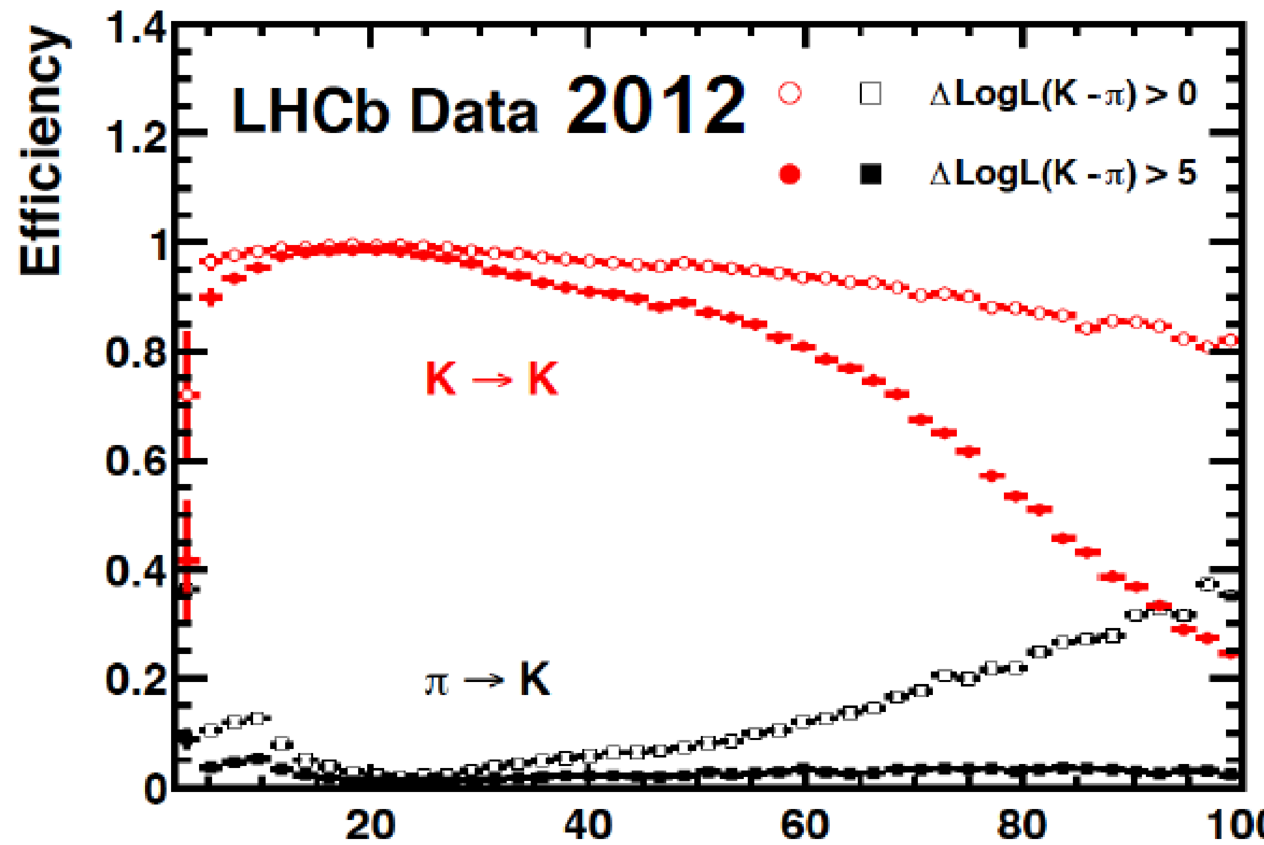
“Start where you are. Use what you have. Do what you can.” — Arthur Ashe

Performance: Run 1 vs. Run 2

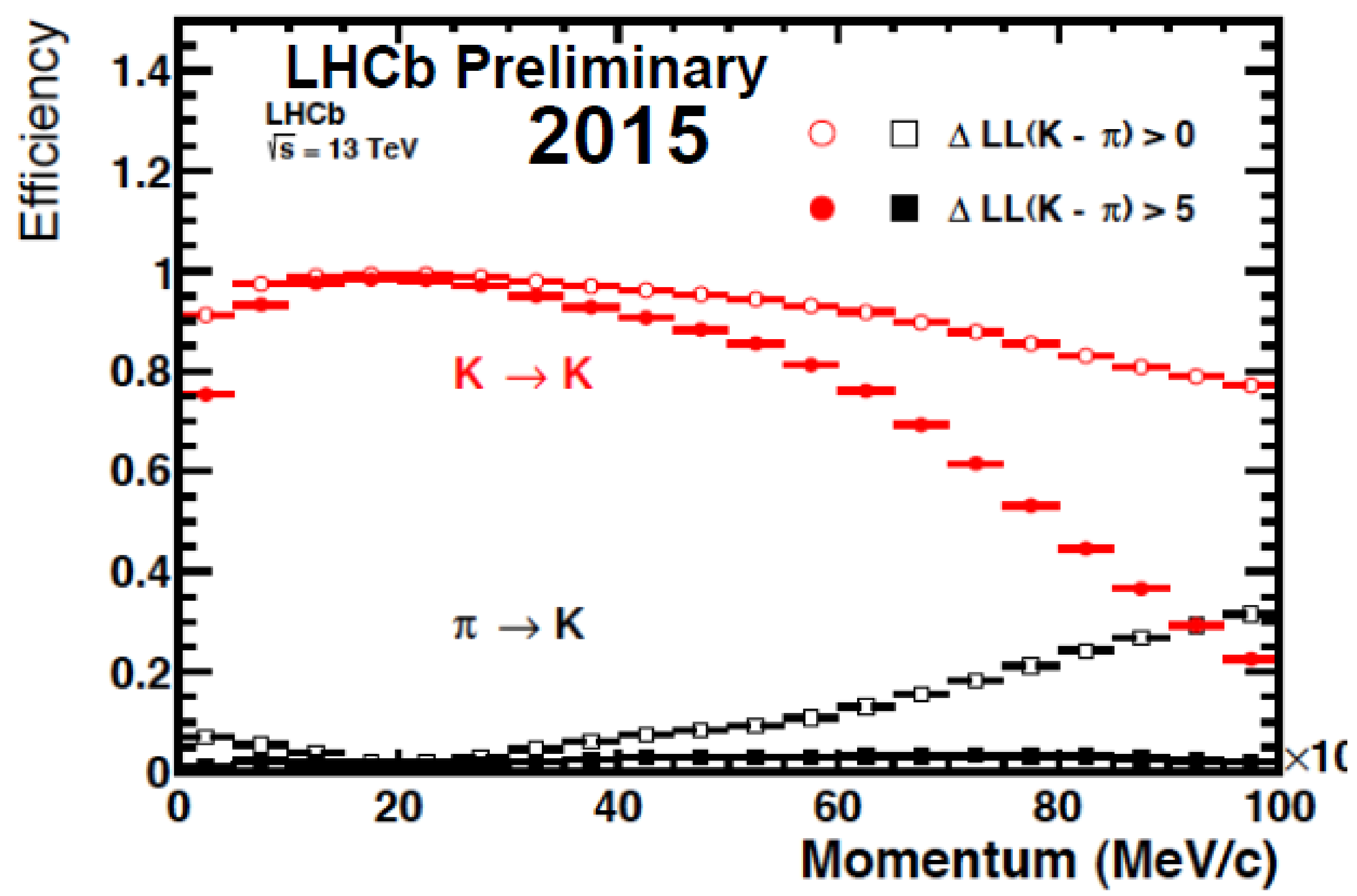


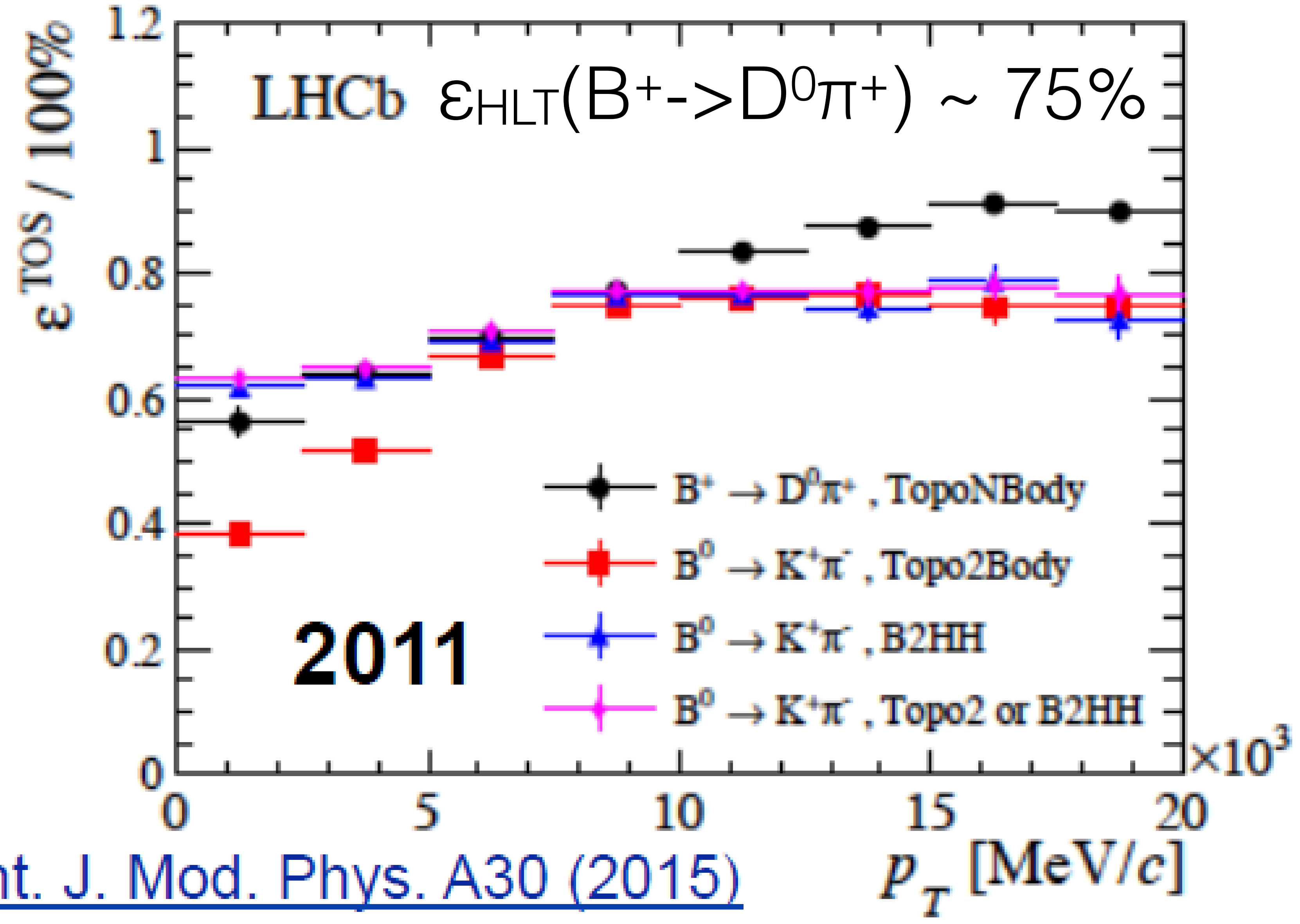


RICH PID



Int. J. Mod. Phys. A30 (2015)





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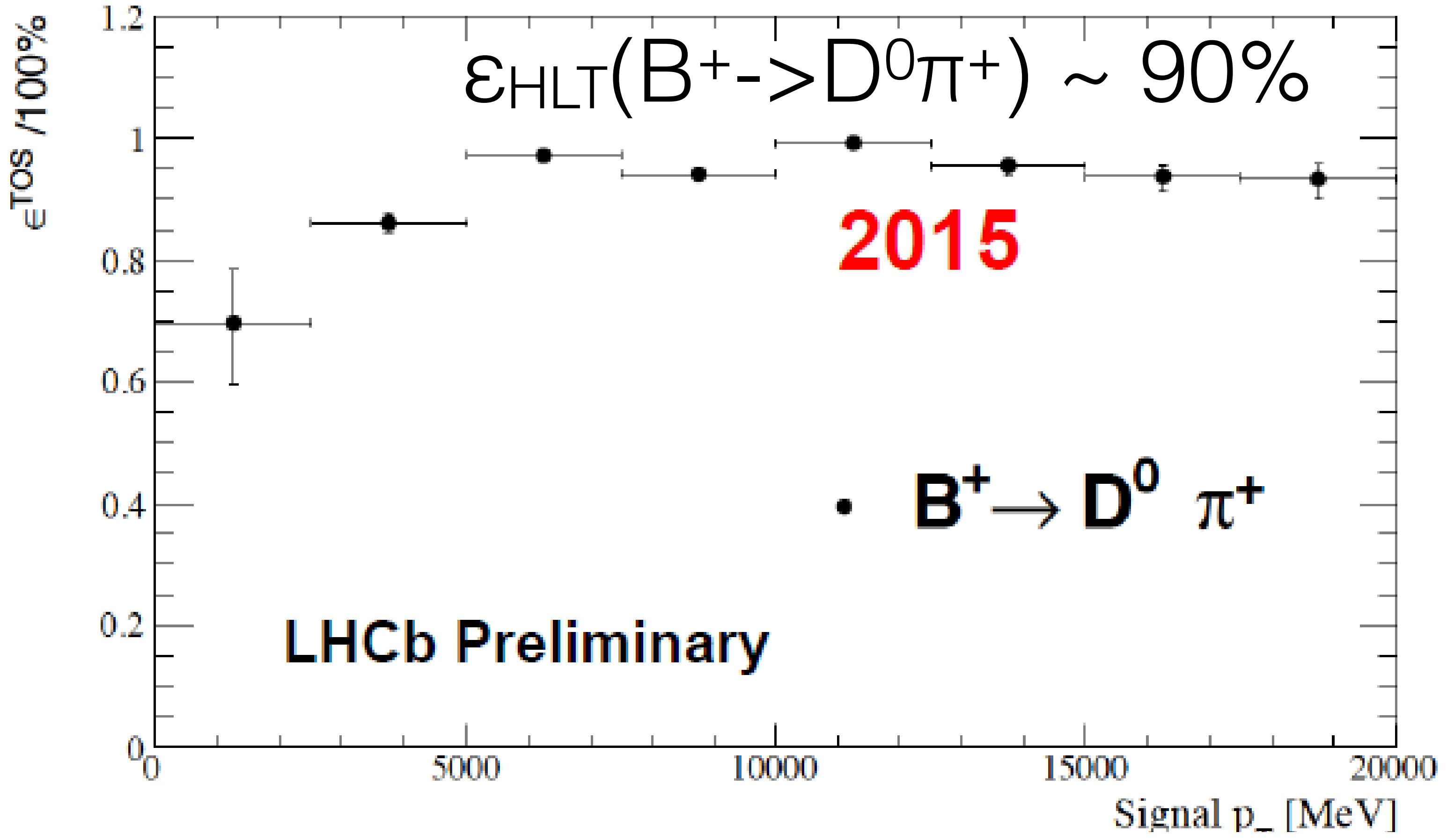
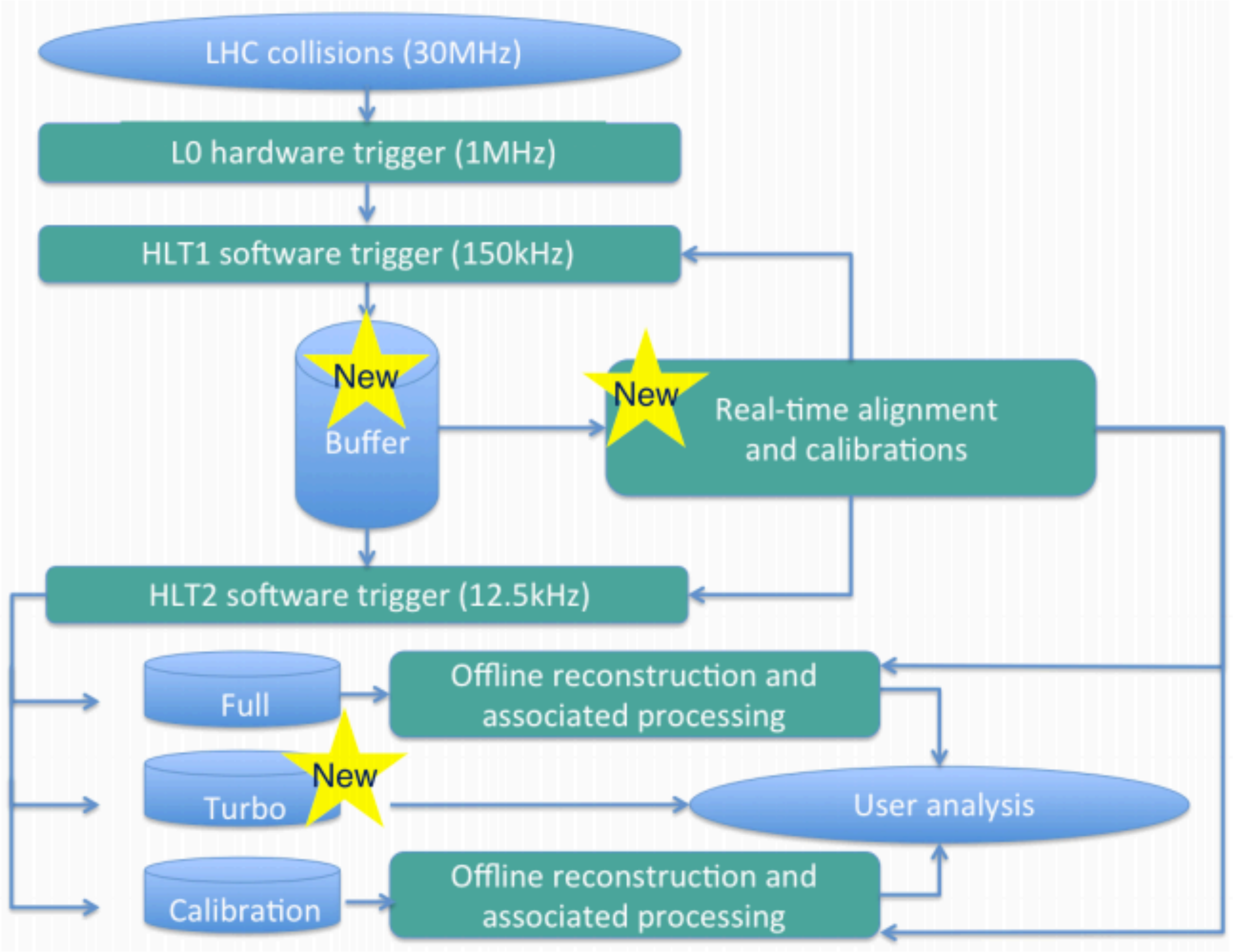


“Turbo” Output

- Online reconstruction == Offline reconstruction
- Online calibration == Offline calibration

⇓

- Turbo: store Trigger Data *only*
  - For a given bandwidth, increases the event rate by an order of magnitude
  - Ideal for high-yield analysis
- 185 out of 374 HLT2 selections go to “Turbo”



“Turbo” Charm

$D^0 \to K^-\pi^+$ $\quad$ $D^+ \to K^-\pi^+\pi^+$ $\quad$ $D_s^+ \to K^-K^+\pi^+$

Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s} = 13\,\text{TeV}$

The LHCb collaboration†

Abstract

Production cross-sections of prompt charm mesons are measured with the first data from pp collisions at the LHC at a centre-of-mass energy of 13 TeV. The data sample corresponds to an integrated luminosity of $4.98 \pm 0.19\,\text{pb}^{-1}$ collected by the LHCb experiment. The production cross-sections of D^0, D^+, D_s^+, and D^{*+} mesons are measured in bins of charm meson transverse momentum, p_{T}, and rapidity, y, and cover the range $0 < p_{\text{T}} < 15$ GeV/c and $2.0 < y < 4.5$. The ratios of the integrated cross-sections between charm mesons agree with previously measured fragmentation fractions. The inclusive $c\bar{c}$ cross-section within the range of $0 < p_{\text{T}} < 8$ GeV/c is found to be

$$\sigma(pp \to c\bar{c}X) = 2940 \pm 3 \pm 180 \pm 160\,\mu\text{b},$$

where the uncertainties are due to statistical, systematic and fragmentation fraction uncertainties, respectively.

The prompt atmospheric neutrino flux in the light of LHCb

Rhorry Gauld,[a] Juan Rojo,[b] Luca Rottoli,[b] Subir Sarkar[b,c] and Jim Talbert[b]

[a] *Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, UK*
[b] *Rudolf Peierls Centre for Theoretical Physics, 1 Keble Road, University of Oxford, OX1 3NP Oxford, UK*
[c] *Niels Bohr International Academy, Copenhagen University, Blegdamsvej 17, 2100 Copenhagen, Denmark*

E-mail: rhorry.gauld@durham.ac.uk, juan.rojo@physics.ox.ac.uk, luca.rottoli@physics.ox.ac.uk, subir.sarkar@physics.ox.ac.uk, jim.talbert@physics.ox.ac.uk

Abstract: The recent observation of very high energy cosmic neutrinos by IceCube heralds the beginning of neutrino astronomy. At these energies, the dominant background to the astrophysical signal is the flux of 'prompt' neutrinos, arising from the decay of charmed mesons produced by cosmic ray collisions in the atmosphere. In this work we provide predictions for the prompt atmospheric neutrino flux in the framework of perturbative QCD, using state-of-the-art Monte Carlo event generators. Our calculation includes the constraints set by charm production measurements from the LHCb experiment at 7 TeV, recently validated with the corresponding 13 TeV data. Our result for the prompt flux is a factor of about 2 below the previous benchmark calculation, in general agreement with other recent estimates, but with an improved estimate of the uncertainty. This alleviates the existing tension between the theoretical prediction and IceCube limits, and suggests that a direct direction of the prompt flux is imminent.

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Received: September 3, 2015
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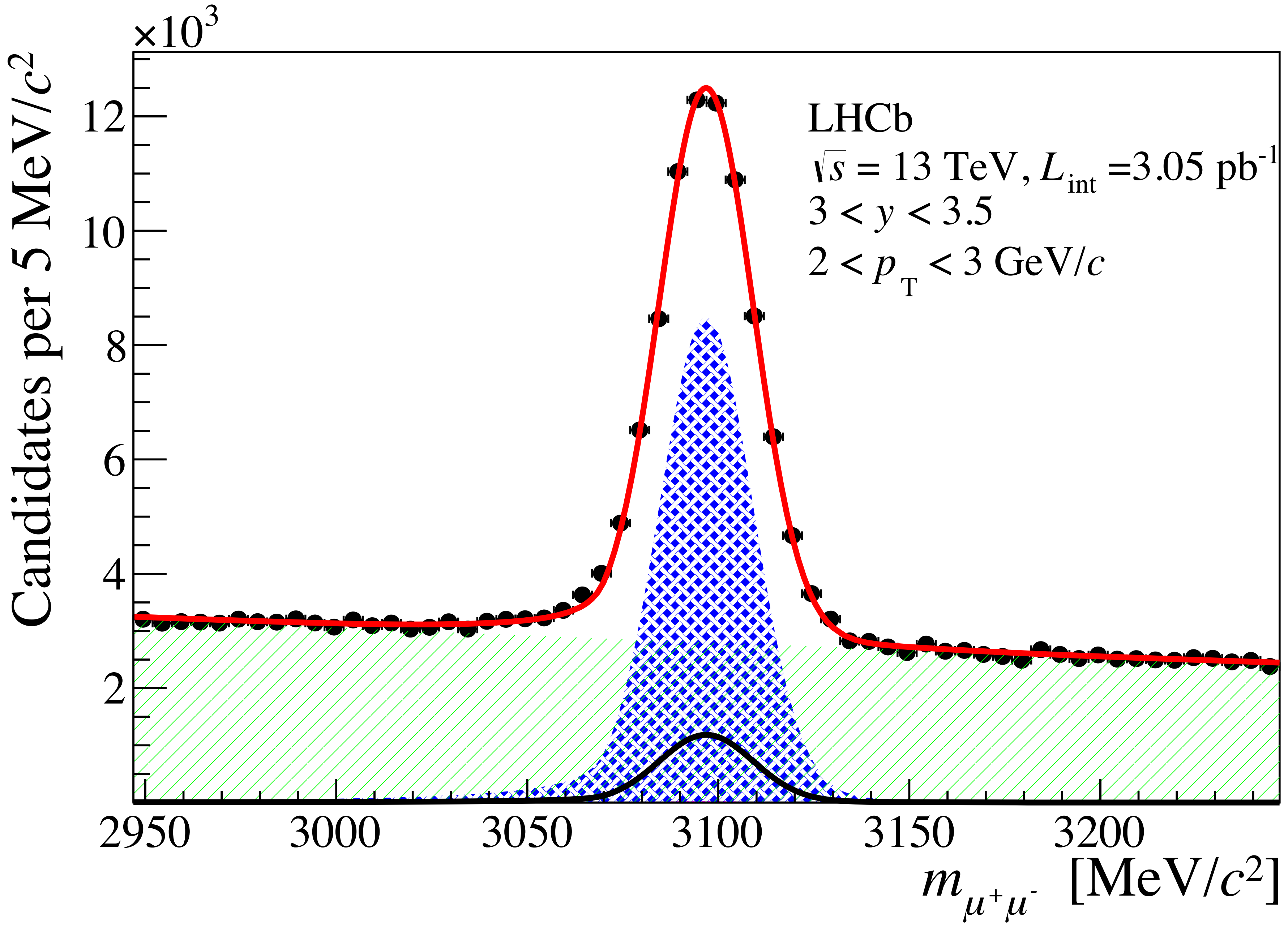
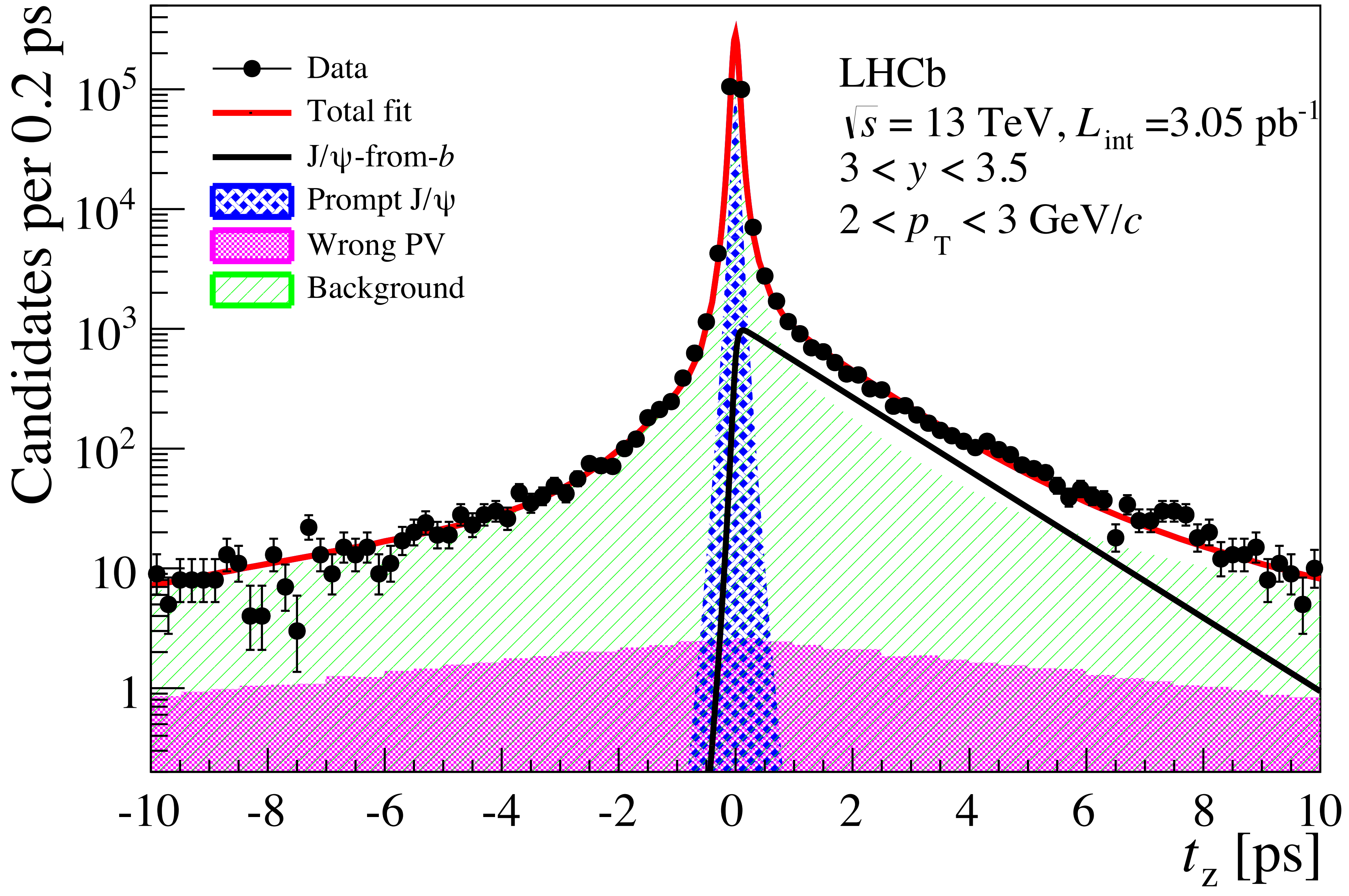
Published: October 26, 2015

Measurement of forward J/ψ production cross-sections in pp collisions at $\sqrt{s} = 13$ TeV

The LHCb collaboration

Abstract: The production of J/ψ mesons in proton-proton collisions at a centre-of-mass energy of $\sqrt{s} = 13$ TeV is studied with the LHCb detector. Cross-section measurements are performed as a function of the transverse momentum p_T and the rapidity y of the J/ψ meson in the region $p_T < 14\,\text{GeV}/c$ and $2.0 < y < 4.5$, for both prompt J/ψ mesons and J/ψ mesons from b-hadron decays. The production cross-sections integrated over the kinematic coverage are $15.30 \pm 0.03 \pm 0.86\,\mu\text{b}$ for prompt J/ψ and $2.34 \pm 0.01 \pm 0.13\,\mu\text{b}$ for J/ψ from b-hadron decays, assuming zero polarization of the J/ψ meson. The first uncertainties are statistical and the second systematic. The cross-section reported for J/ψ mesons from b-hadron decays is used to extrapolate to a total $b\bar{b}$ cross-section. The ratios of the cross-sections with respect to $\sqrt{s} = 8$ TeV are also determined.





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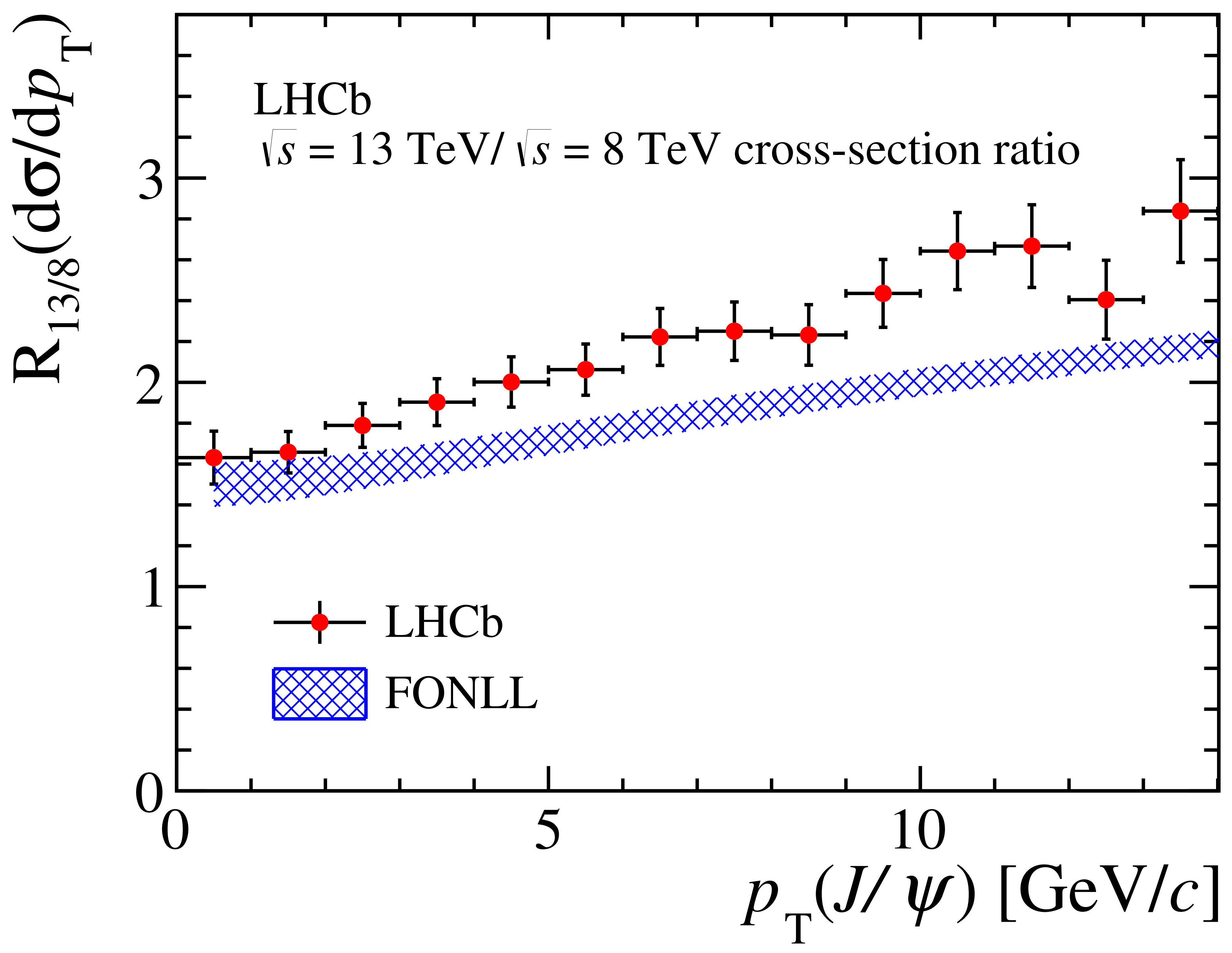
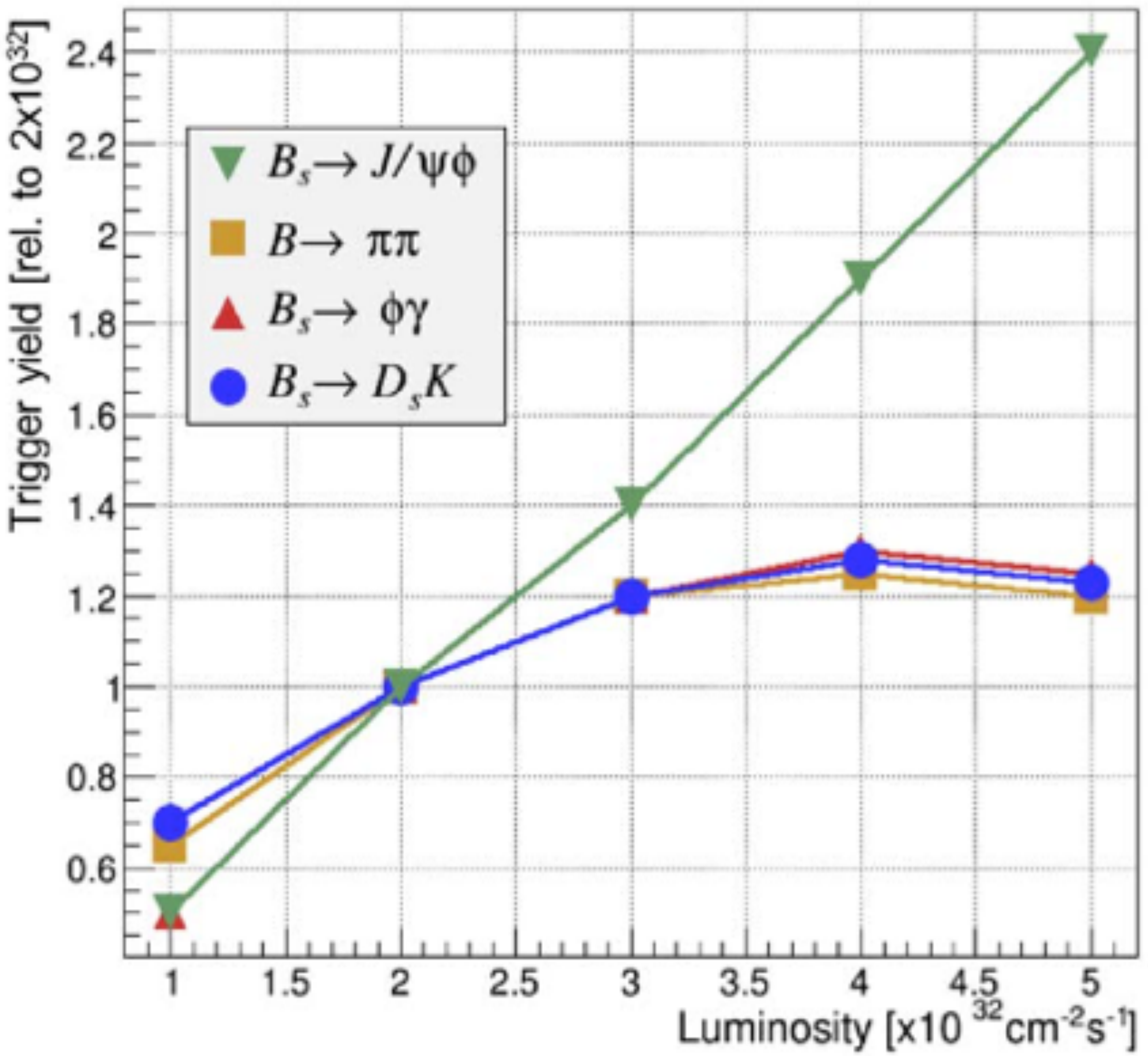
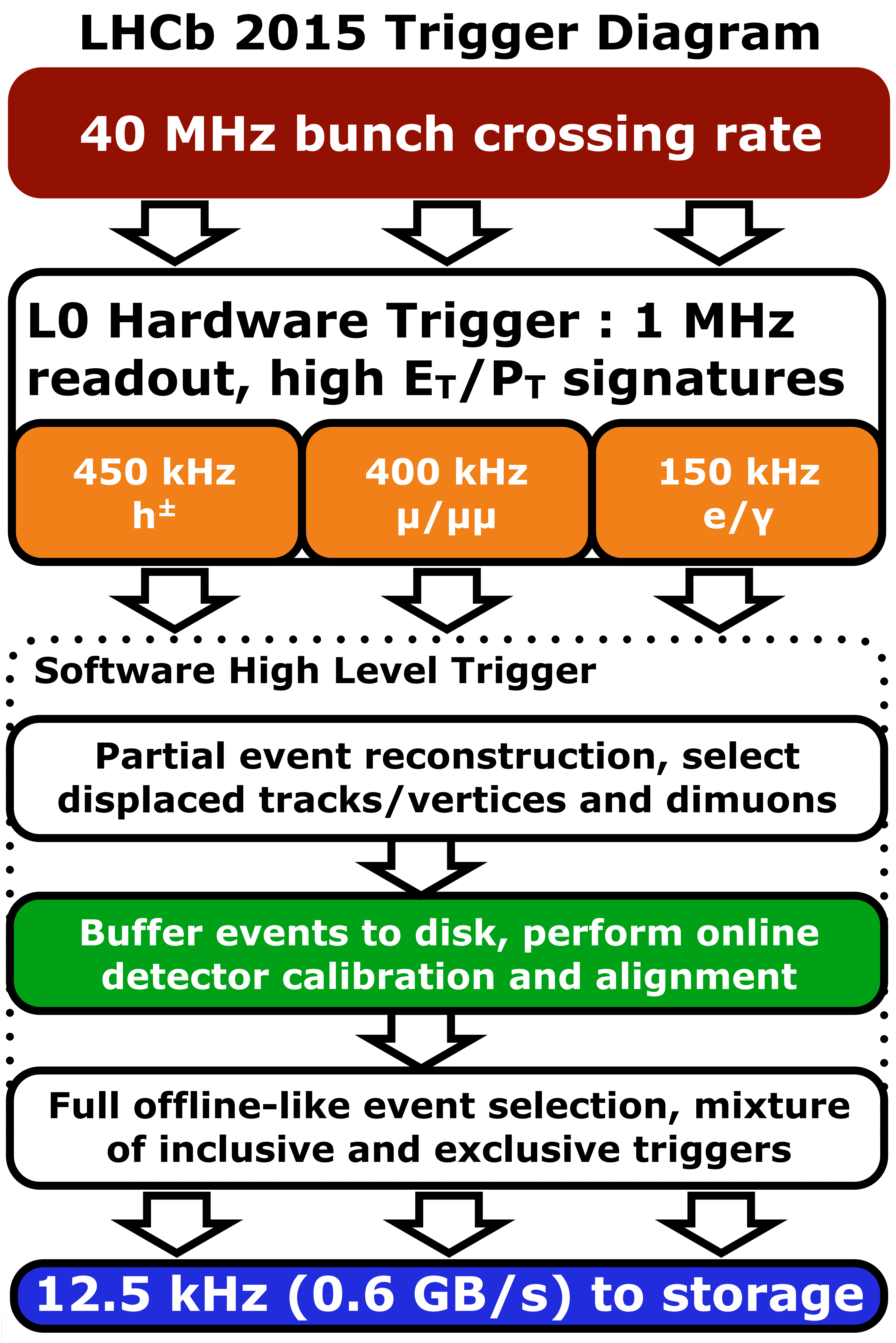


The Future…



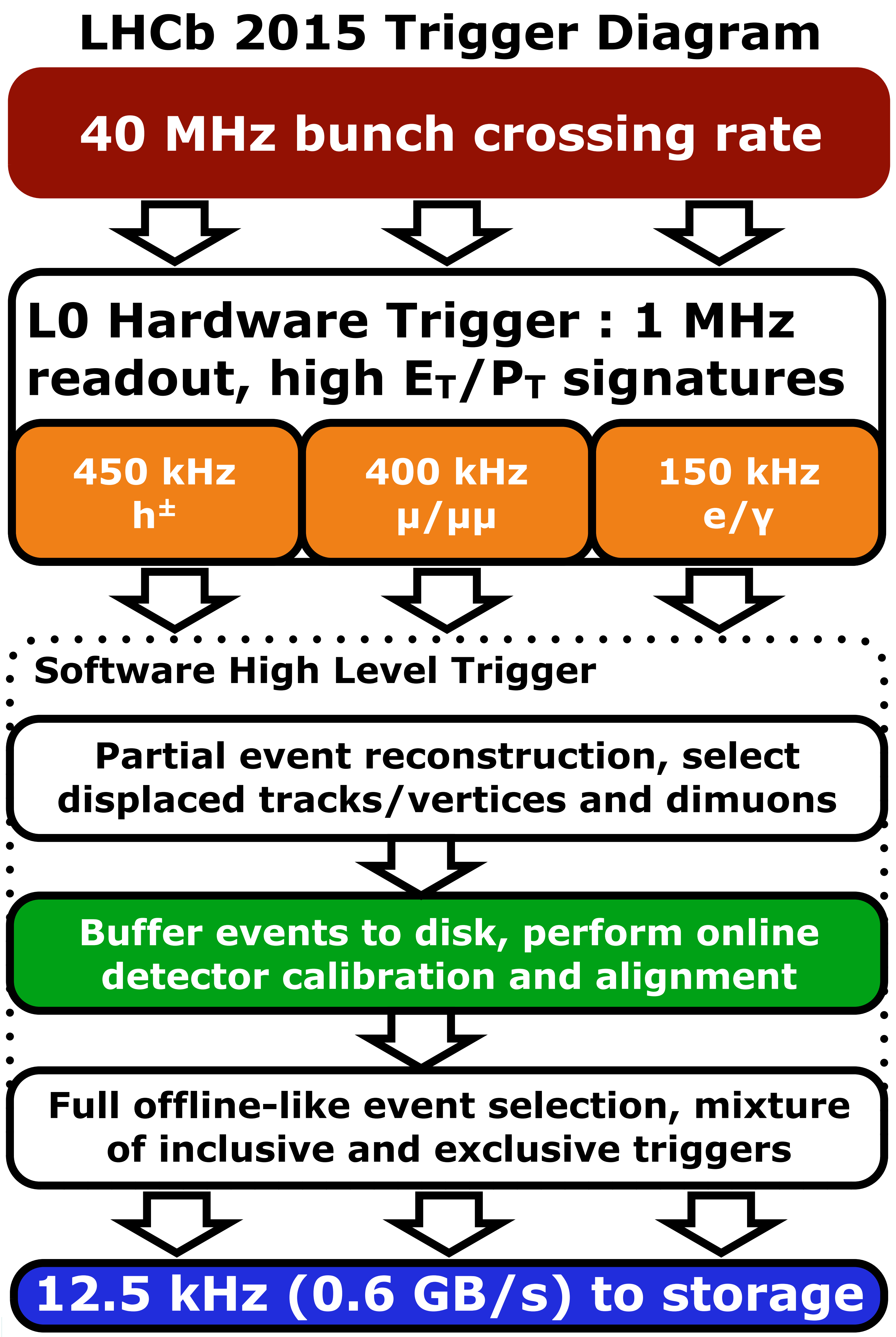
L0/Readout limit @ 1 MHz

The Future…

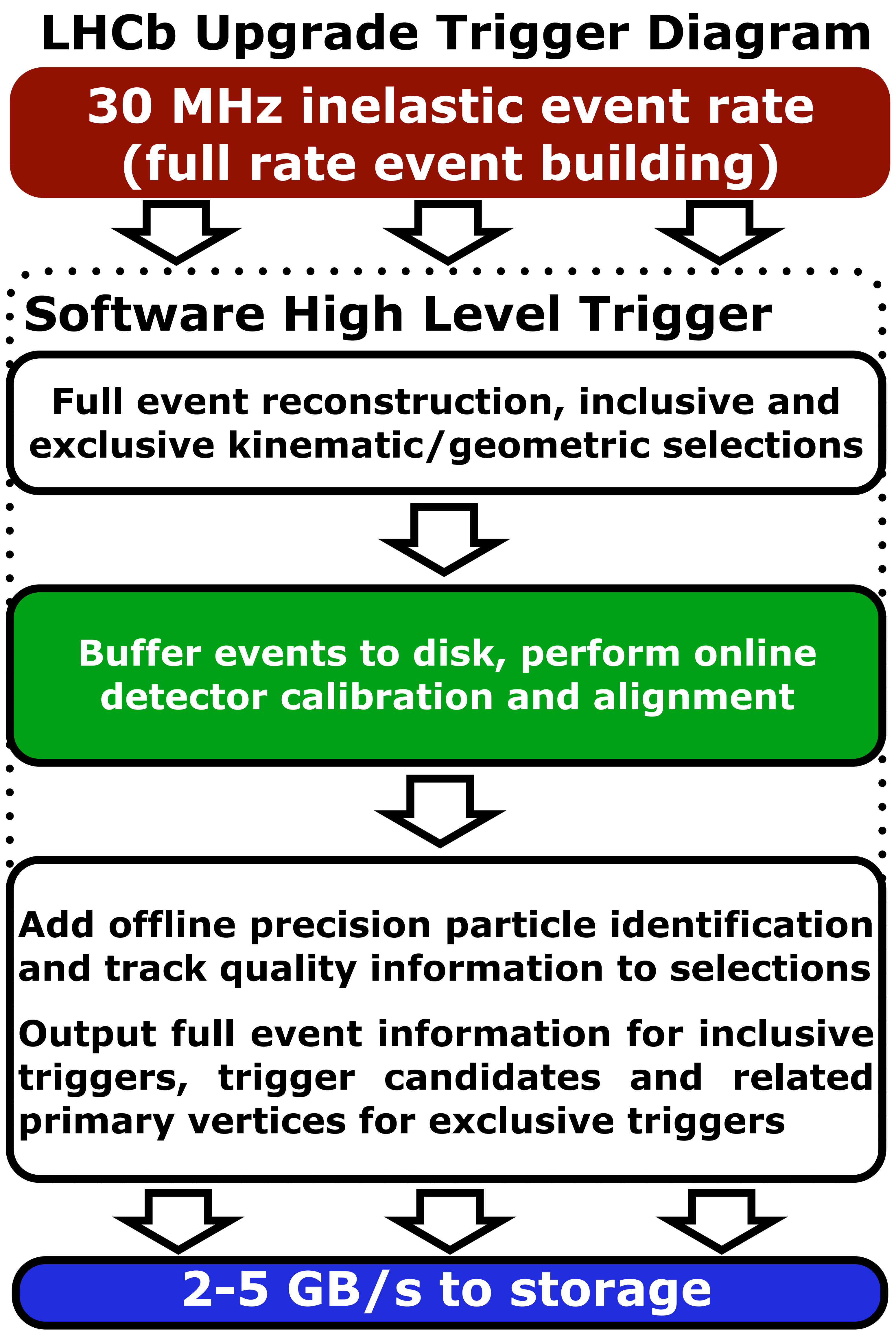


L0/Readout limit @ 1 MHz

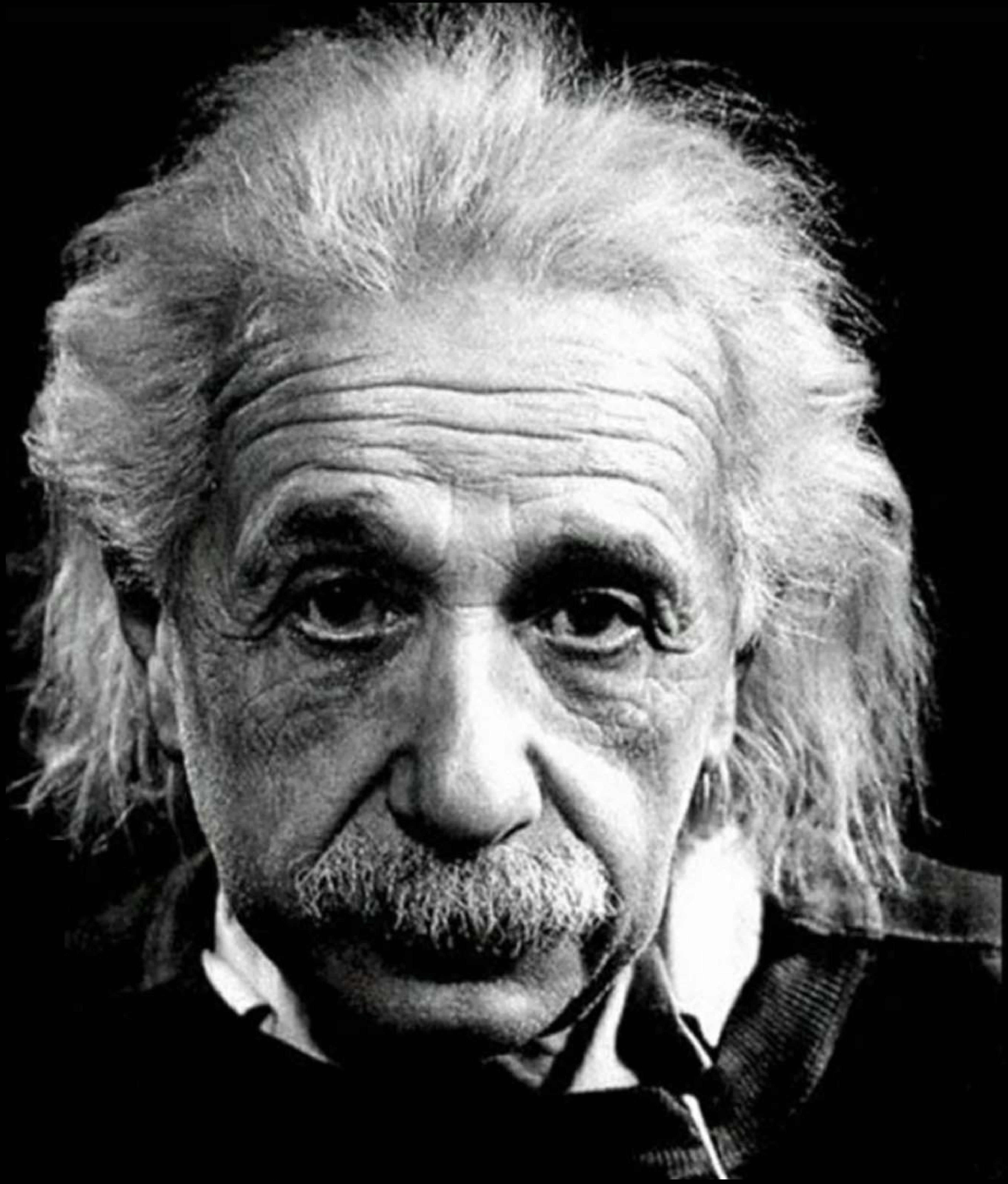
The Future…



Take what ye can!
— Jack Sparrow



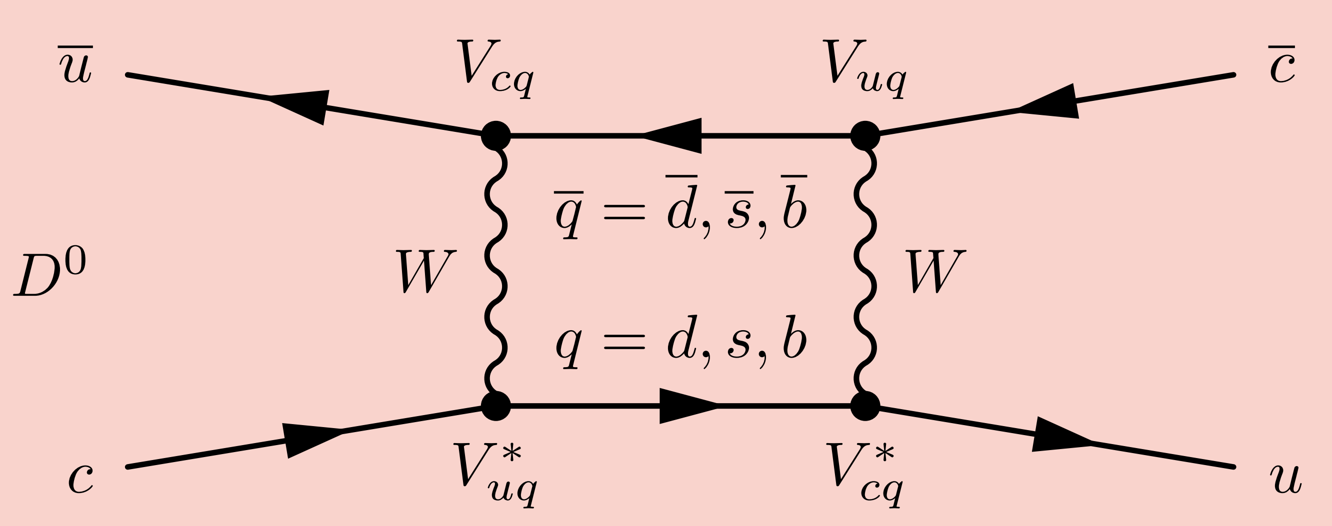

"The Journey of a thousand
miles begins with a single step"
— Lao Tzu



"If you cannot explain it simply, you do not understand it well enough"

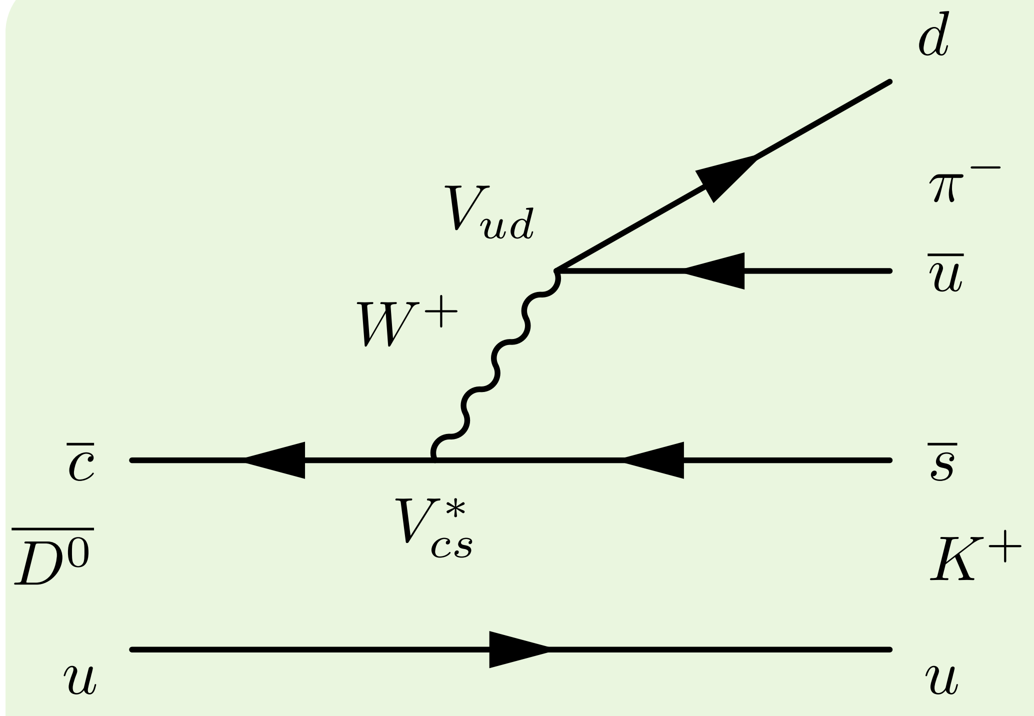
— Albert Einstein

D^0 mixing



d,s,b 'in the loop' instead of u,c,t

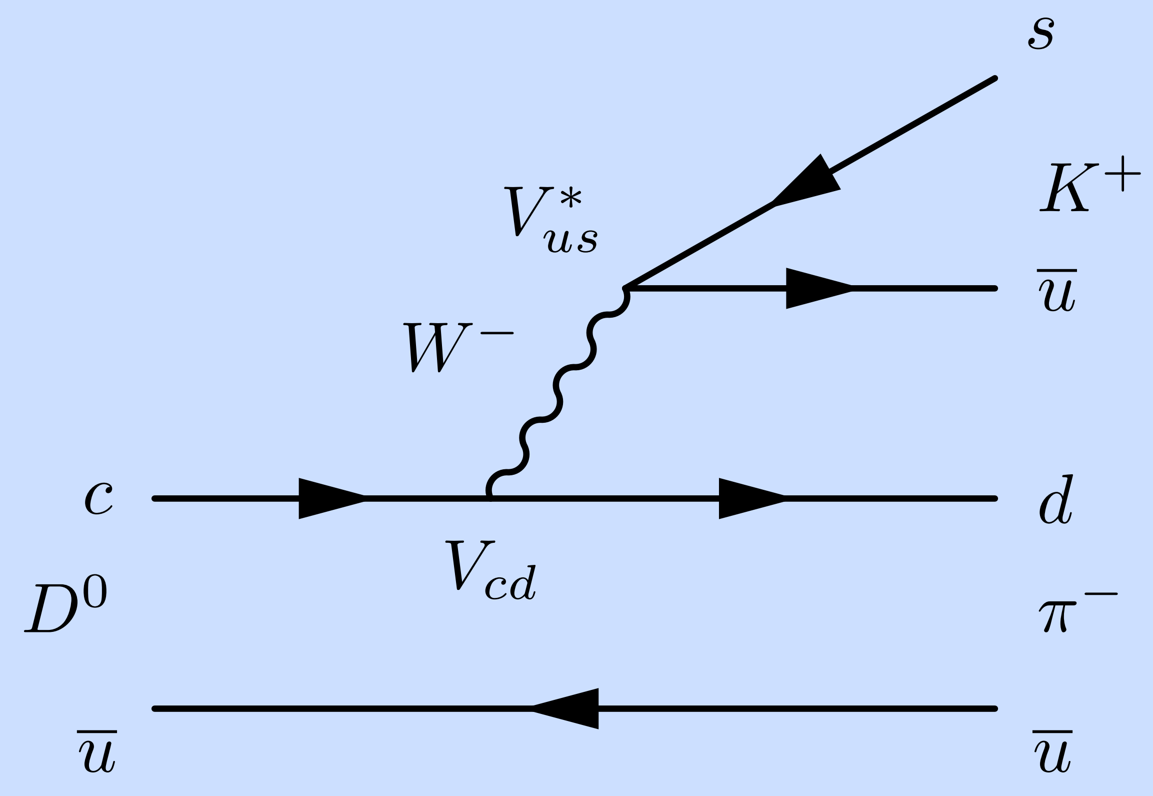
⇒ GIM (almost) kills this amplitude...



$$|V_{cs}^* V_{ud}| = \mathcal{O}(1)$$

Look for 'wrong sign' D^0 decays

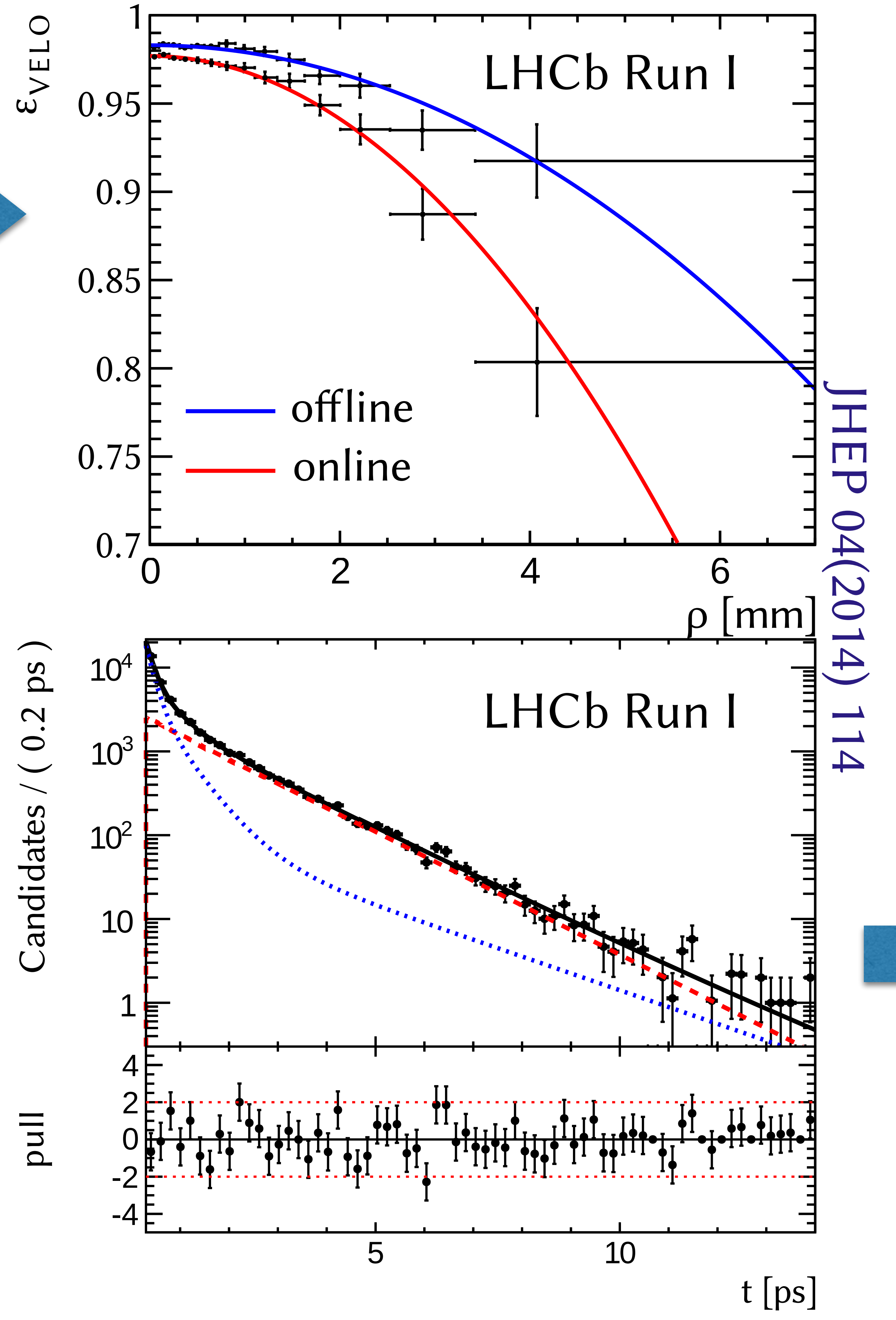
$$D^0 \rightarrow \overline{D^0} \rightarrow K^+\pi^-$$

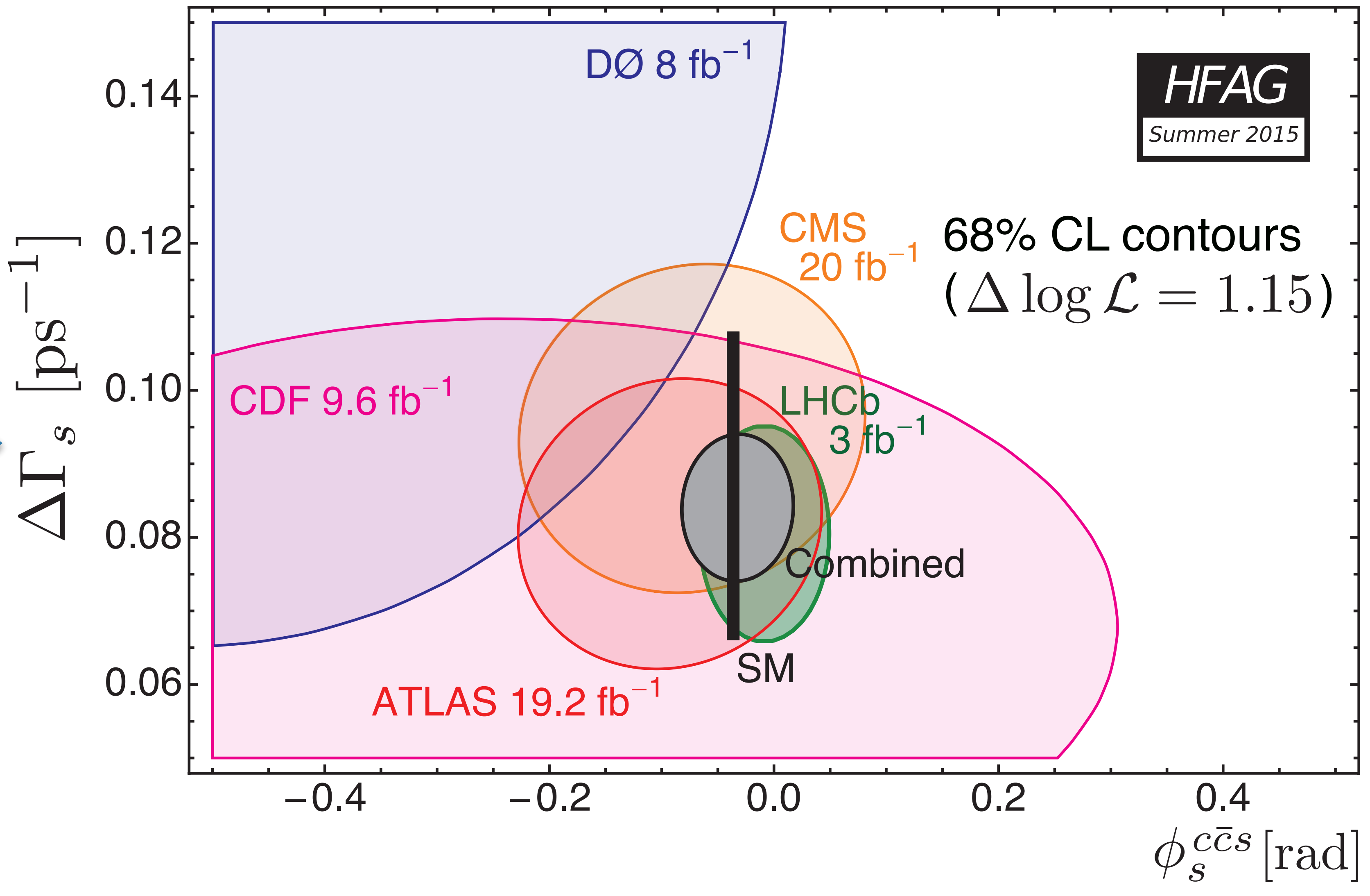


$$|V_{cd} V_{us}^*| = \mathcal{O}(\lambda^2) \approx 0.04$$

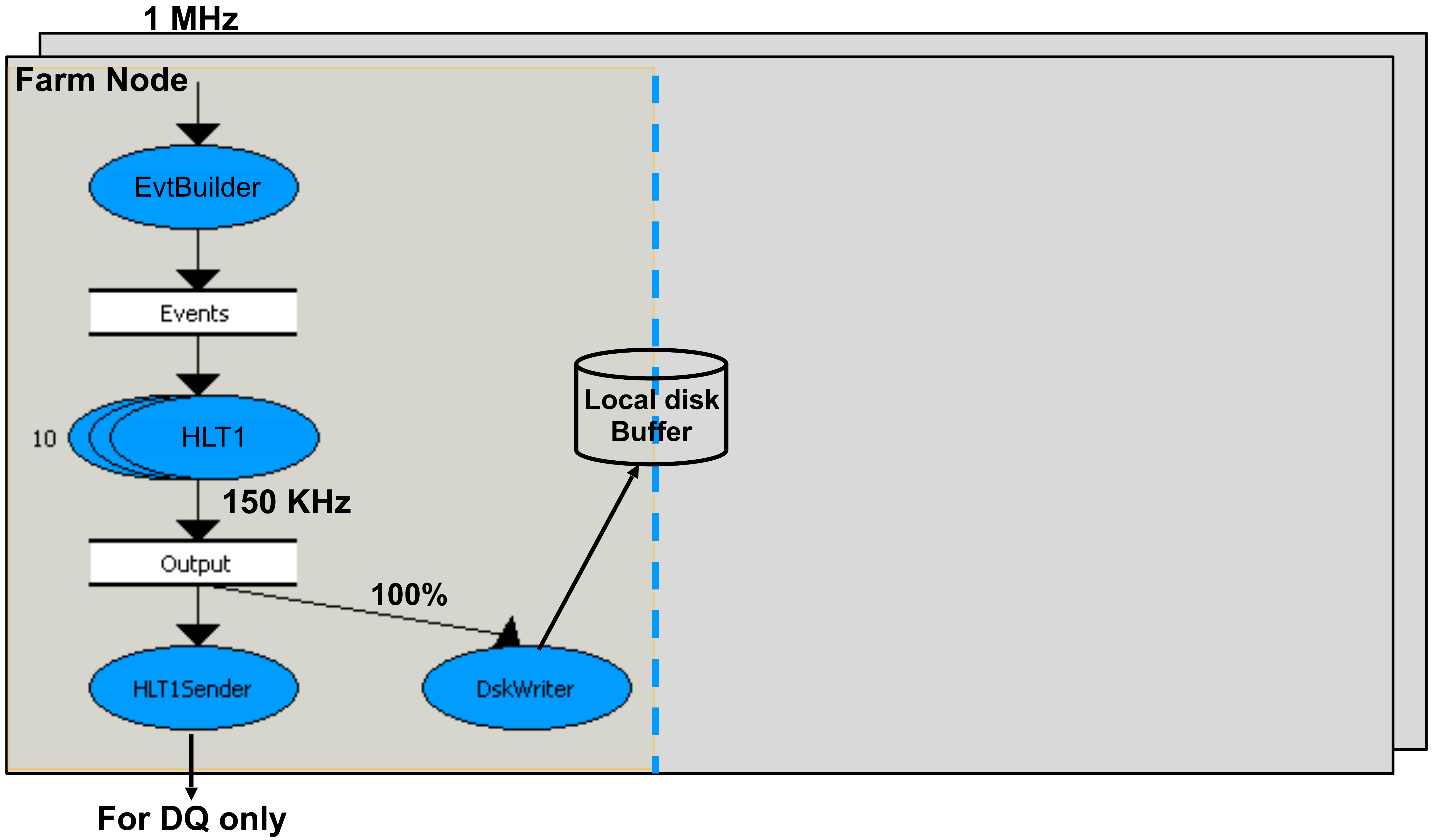
What needs to be improved?

- Tracking:
  - faster/better algorithms
  - More CPU time
  - Real-time calibration
- Particle ID:
  - Faster algorithms
  - More CPU time
  - Real-time calibration

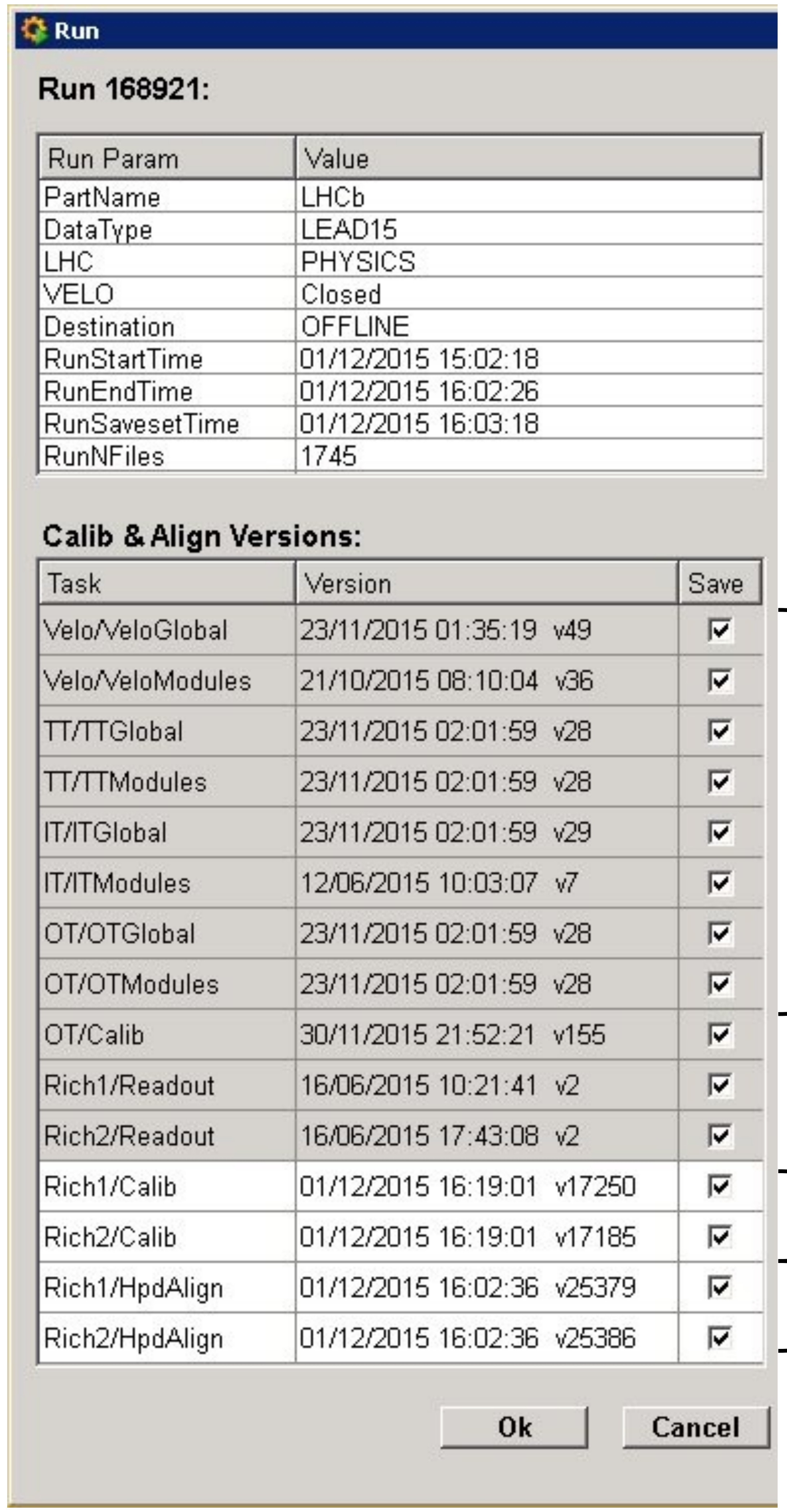




Online “Real-Time” Calibration



Online “Real-Time” Calibration



Run

Run 168921:

Run Param	Value
PartName	LHCb
DataType	LEAD15
LHC	PHYSICS
VELO	Closed
Destination	OFFLINE
RunStartTime	01/12/2015 15:02:18
RunEndTime	01/12/2015 16:02:26
RunSavesetTime	01/12/2015 16:03:18
RunNFiles	1745

Calib & Align Versions:

Task	Version	Save
Velo/VeloGlobal	23/11/2015 01:35:19 v49	☑
Velo/VeloModules	21/10/2015 08:10:04 v36	☑
TT/TTGlobal	23/11/2015 02:01:59 v28	☑
TT/TTModules	23/11/2015 02:01:59 v28	☑
IT/ITGlobal	23/11/2015 02:01:59 v29	☑
IT/ITModules	12/06/2015 10:03:07 v7	☑
OT/OTGlobal	23/11/2015 02:01:59 v28	☑
OT/OTModules	23/11/2015 02:01:59 v28	☑
OT/Calib	30/11/2015 21:52:21 v155	☑
Rich1/Readout	16/06/2015 10:21:41 v2	☑
Rich2/Readout	16/06/2015 17:43:08 v2	☑
Rich1/Calib	01/12/2015 16:19:01 v17250	☑
Rich2/Calib	01/12/2015 16:19:01 v17185	☑
Rich1/HpdAlign	01/12/2015 16:02:36 v25379	☑
Rich2/HpdAlign	01/12/2015 16:02:36 v25386	☑

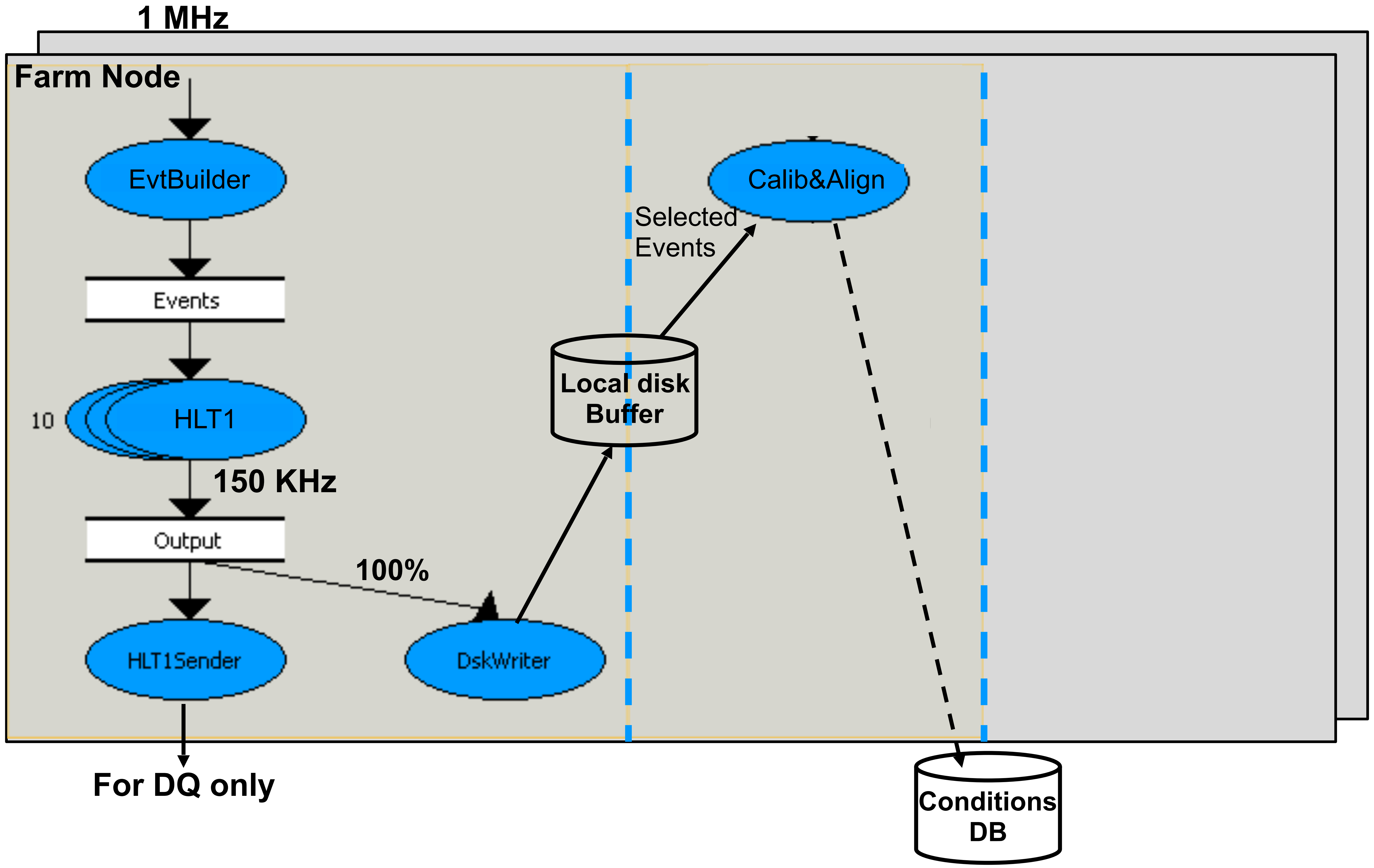
Ok Cancel

VELO & Tracker Alignment

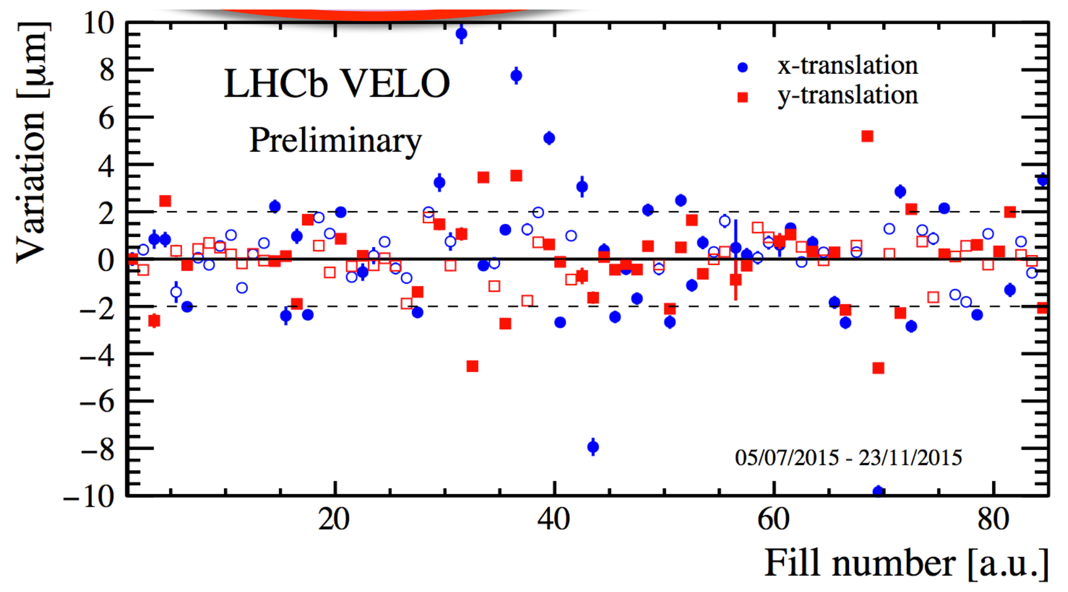
OT Timing

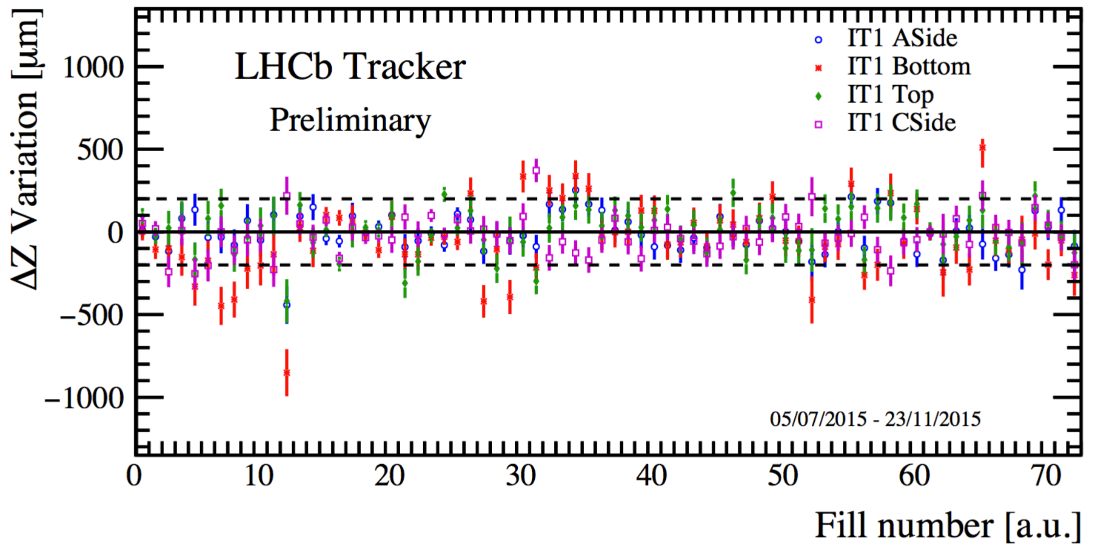
RICH refractive index

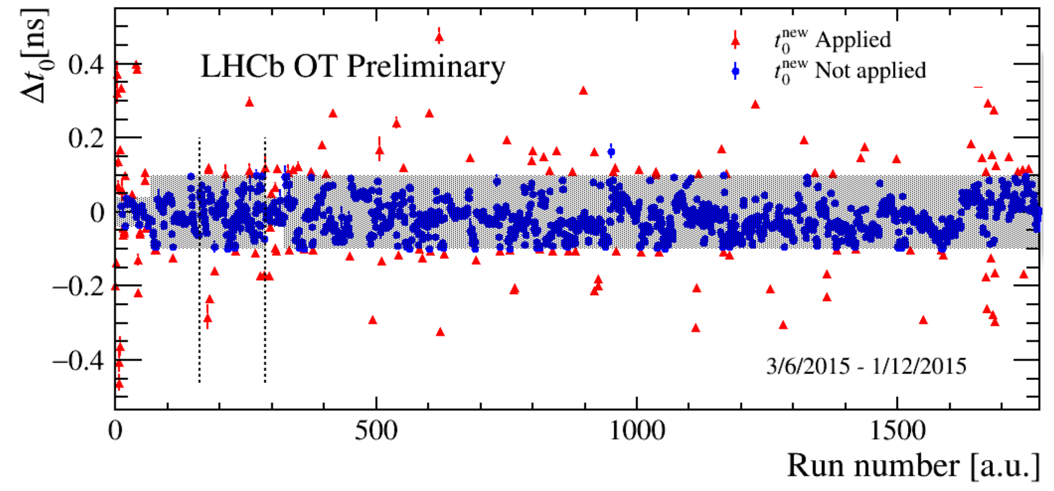
RICH image

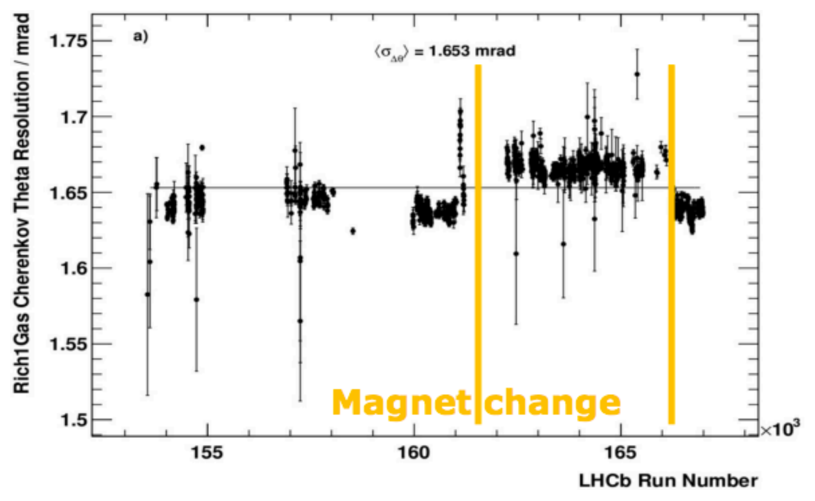


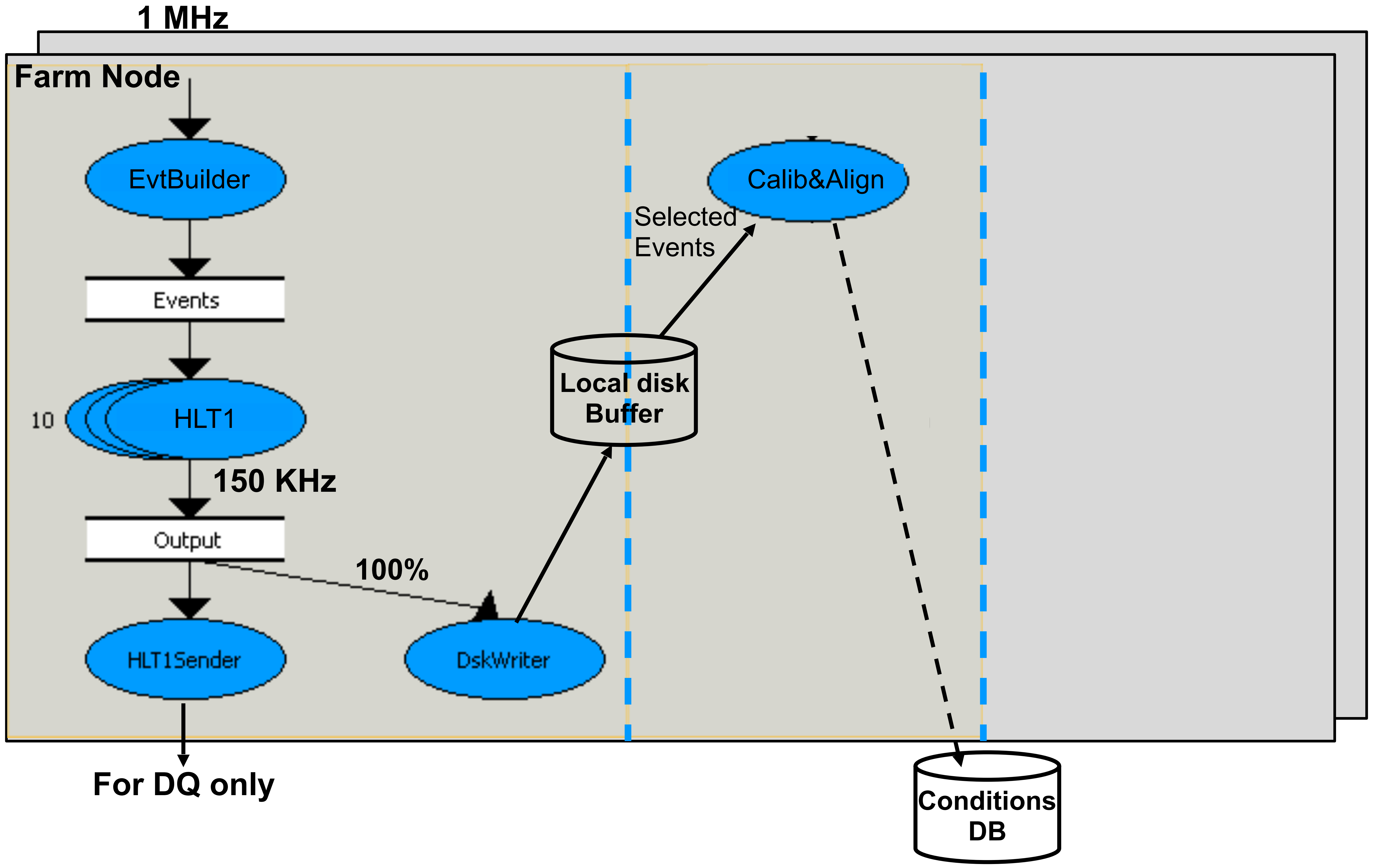
Online “Real-Time” Calibration



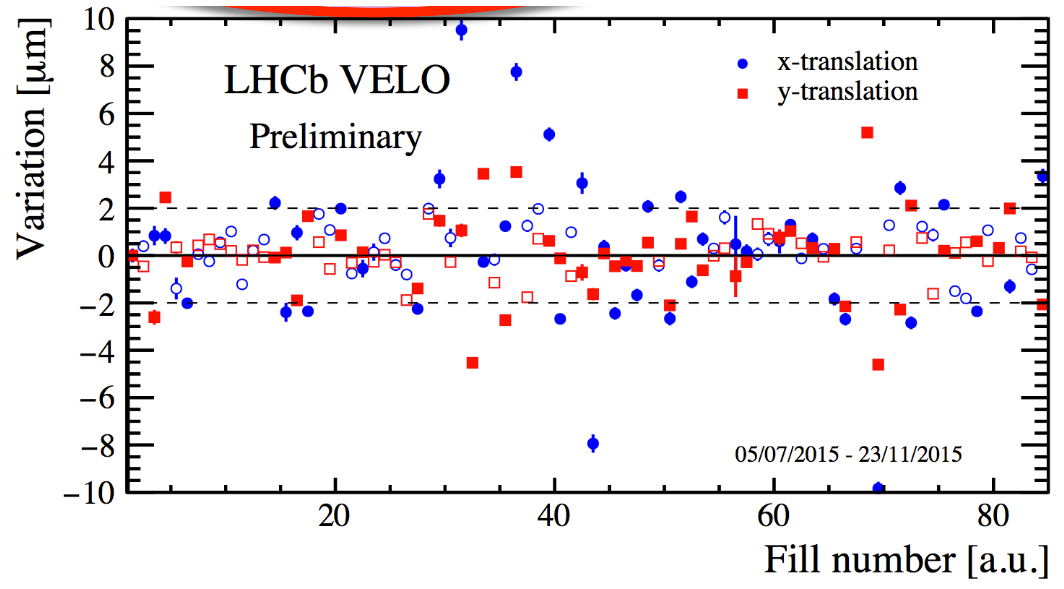


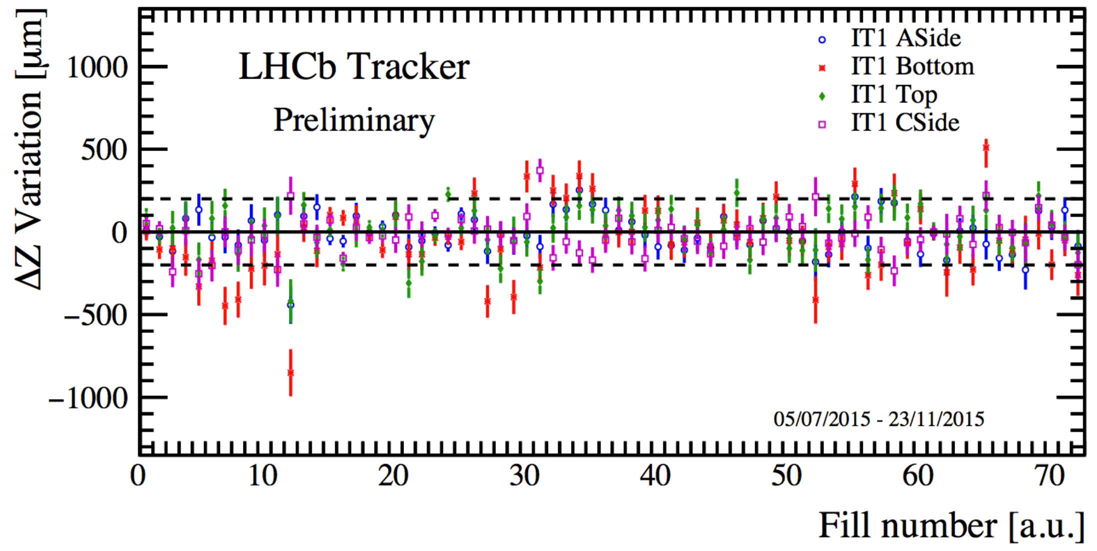


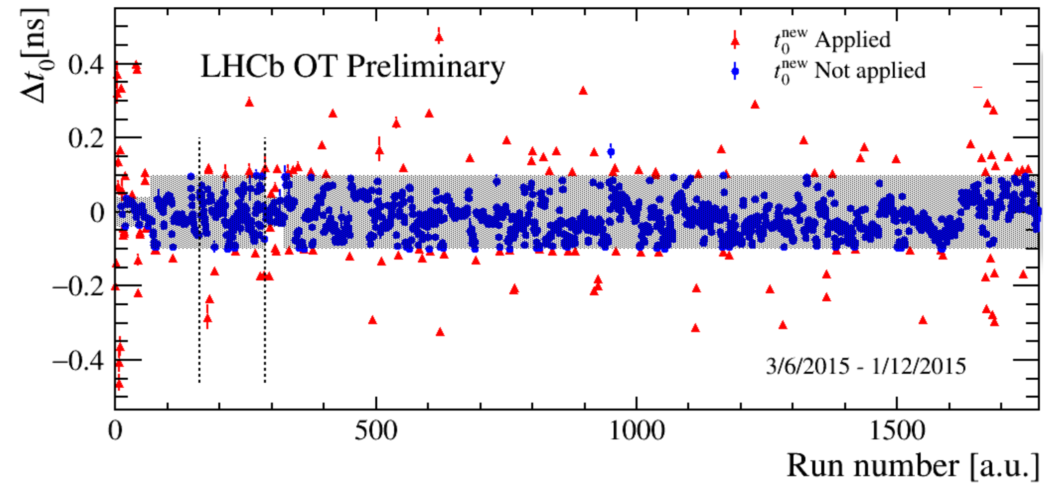


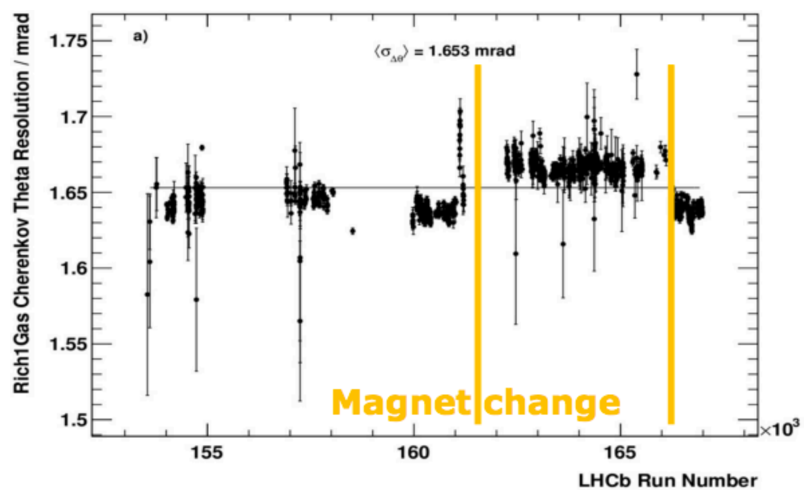


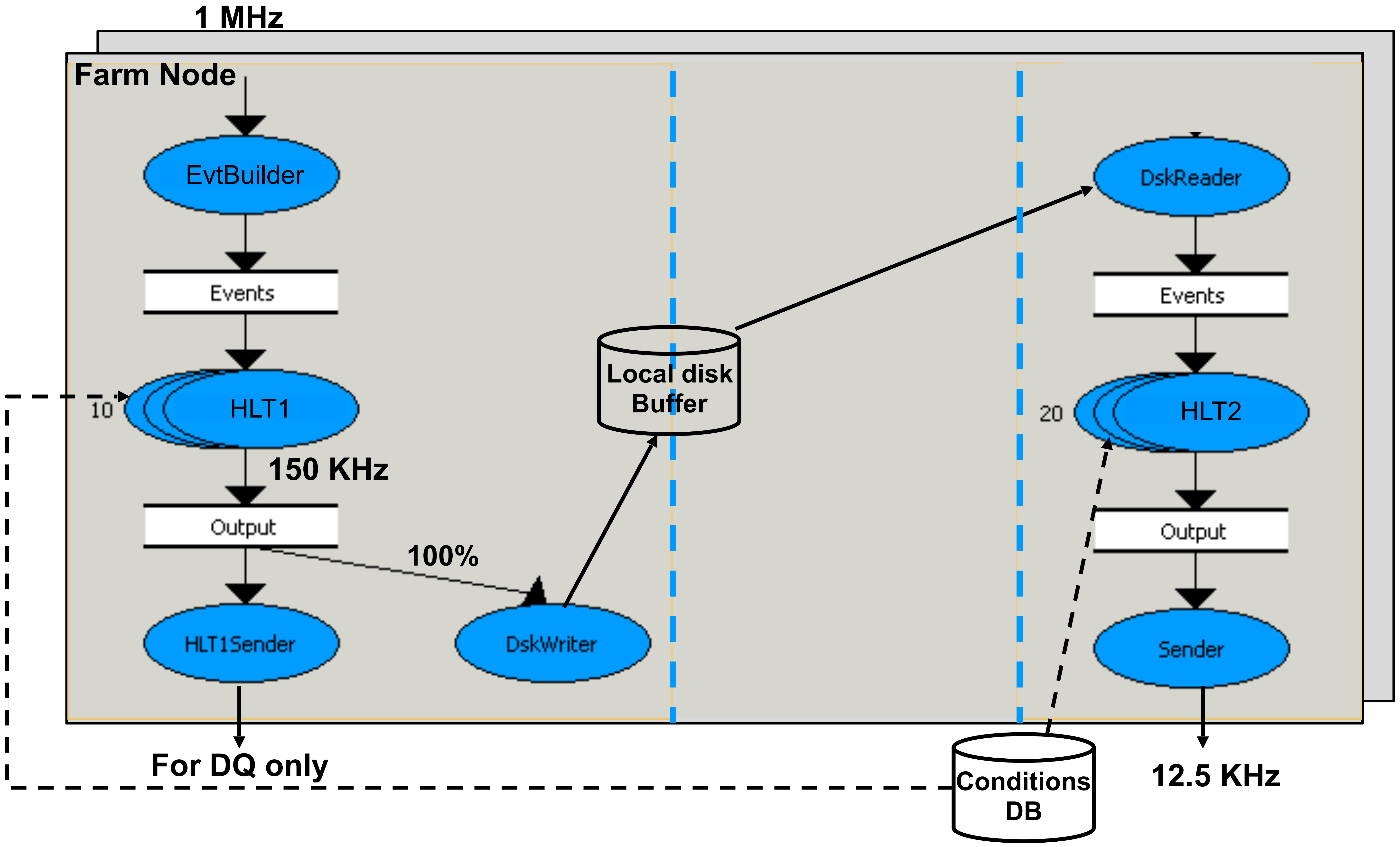
Online "Real-Time" Calibration







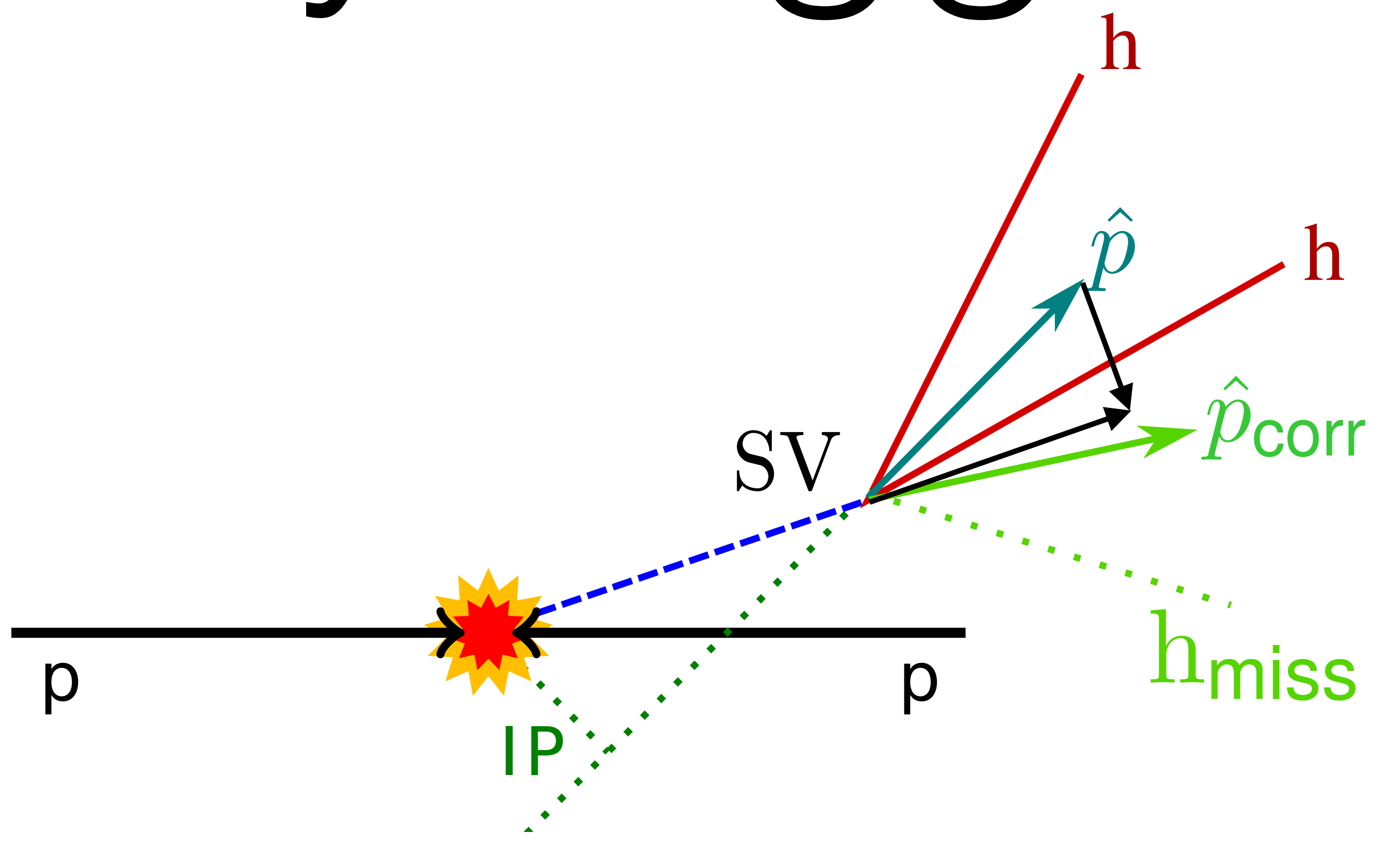


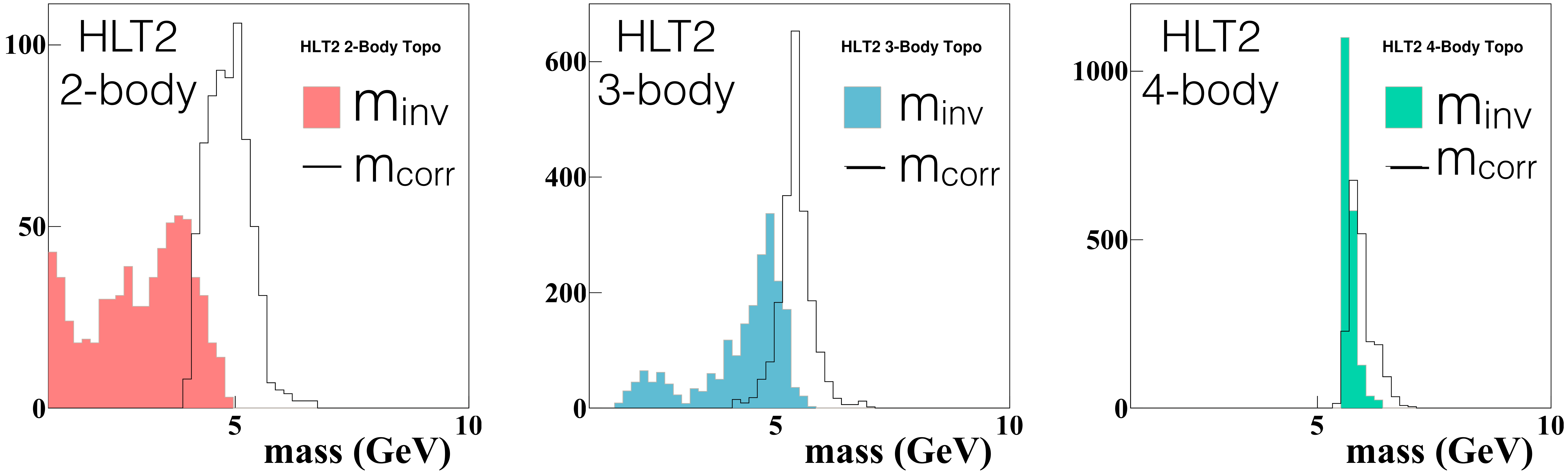


Topological N-body Triggers

- Utilizes excellent vertex and momentum resolution to compute:

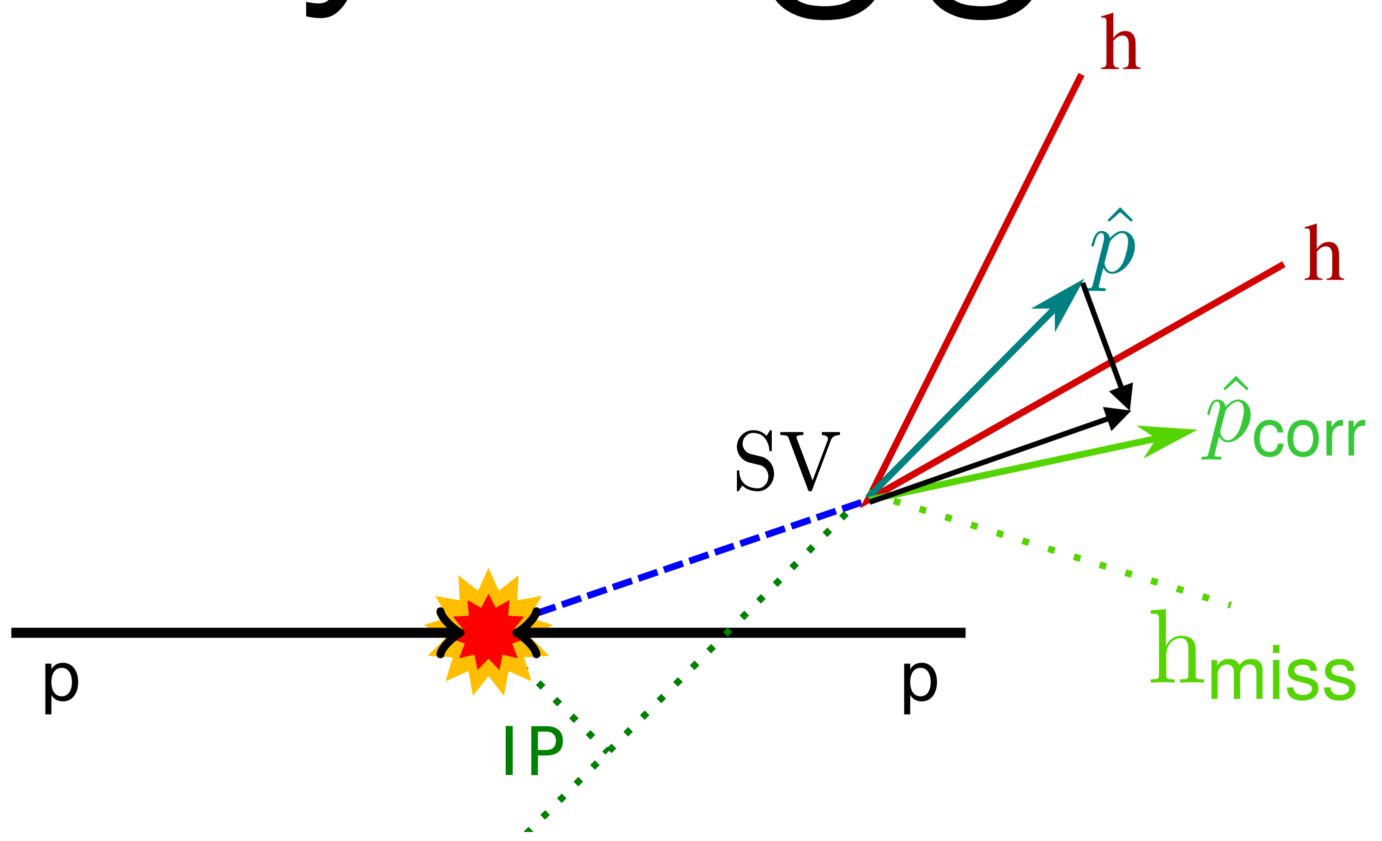
$$m_{\rm corr} \equiv \sqrt{m_{\rm inv}^2 + |P_{T\,\rm miss}|^2} + |P_{T\,\rm miss}|$$





Example: 4-body B decay, $m_{\rm inv}$ and $m_{\rm corr}$ for 2, 3 and 4 body selections

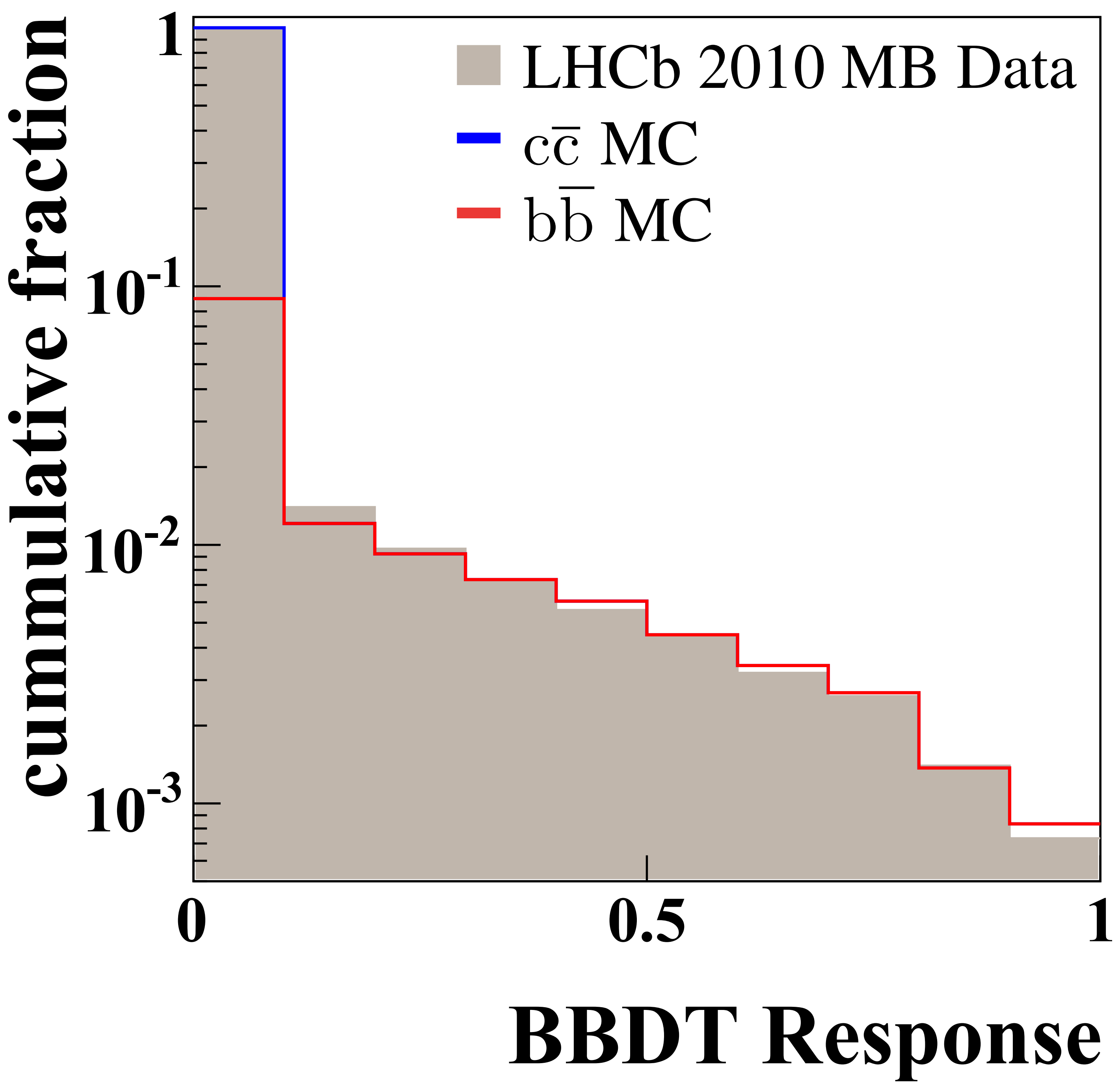
Topological N-body Triggers



- Utilizes excellent vertex and momentum resolution to compute:

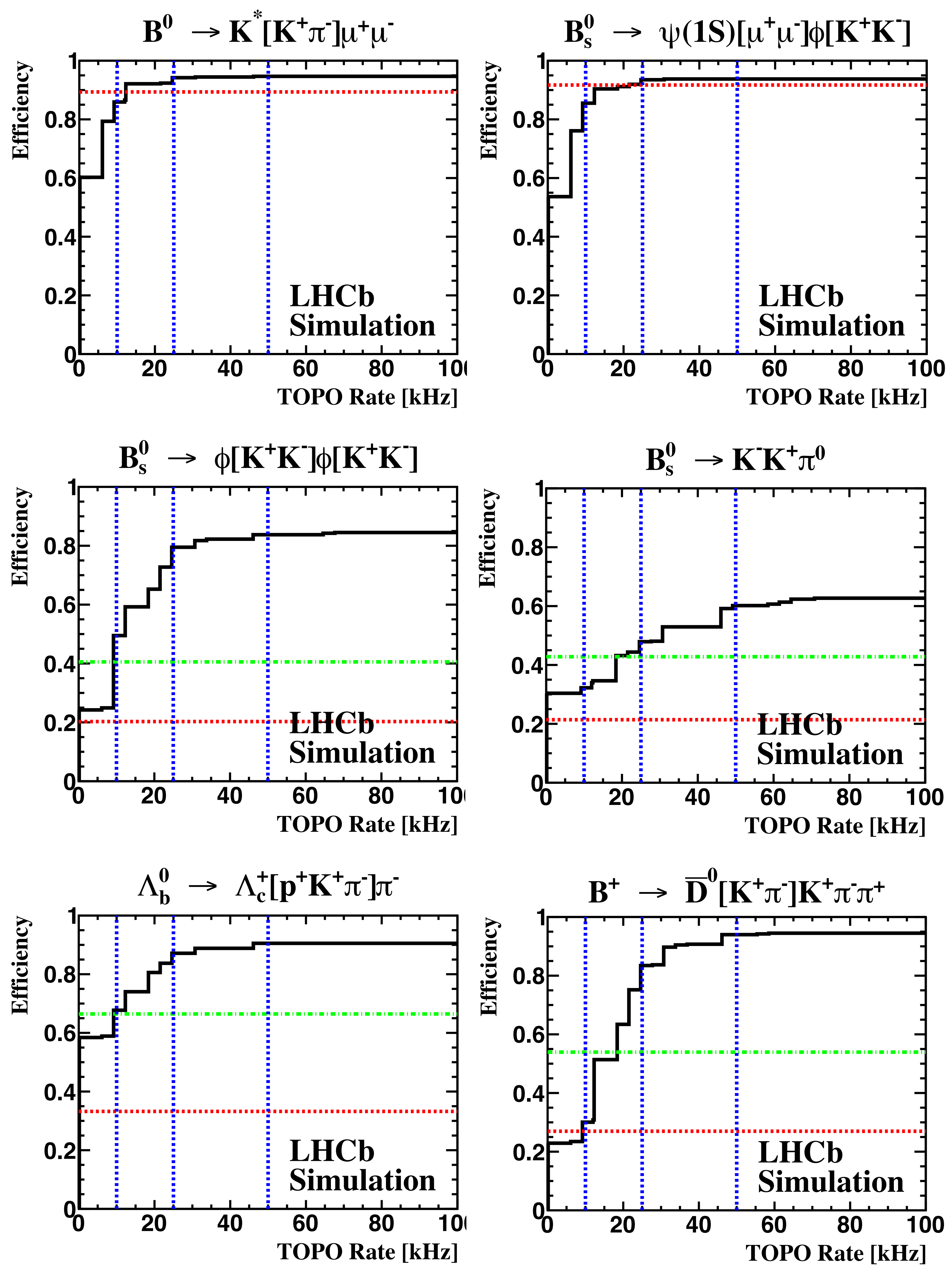
$$m_{corr} \equiv \sqrt{m_{inv}^2 + |P_{T\,miss}|^2} + |P_{T\,miss}|$$

- Uses a dedicated "Bonzai" Boosted Decision Tree [JINST 8 (2013) P02013] with
  - P_T, IPχ^2, FDχ^2, m_{inv}, m_{corr}
- Capable of filling its allotted bandwidth with ~100% pure generic $b\bar{b}$ events



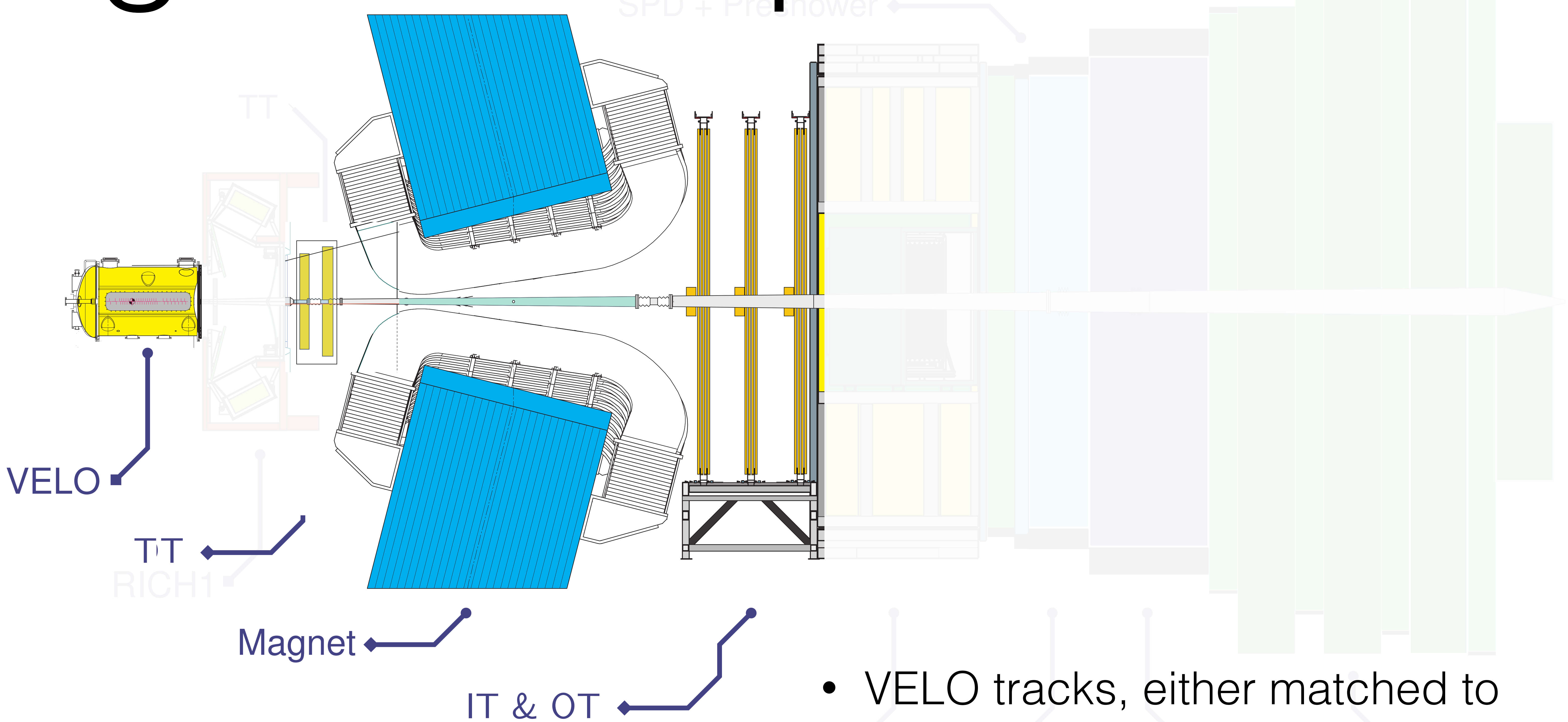
The Upgrade Trigger

- Same principle as Run 1 : preselect displaced tracks with $\sum P_T$, followed by BBDT
- Timing: <0.1 ms (*)
- At 25-50 kHz output rate, large efficiency gains over Run 1
  - red: run 1 efficiency
  - green: 2x run 1 efficiency
- LHCb-PUB-2014-031



(*) on our 2011 reference machine: Intel X5650 (Westmere) @ 2.67 GHz

Algorithm Optimizations



- HLT1 adds tracking in VErtex LOcator (VELO) and primary vertex reconstruction

- VELO tracks, either matched to muon hits, or with large IP are extended through the magnet

- P_T dependent search windows:

track	μ	$\mu\ \mu$	other
min. p_T [GeV]	1.0	0.5	1.6

Really bad for charm physics