Findings in a heartbeat

Vladimir V. Gligorov

LPNHE, February 12th 2015

Research career summary

2003-2008 : PhD, University of Oxford, LHCb experiment

-- Measurement of the CKM angle γ in $B \to DX$ decays

-- Emulation of the L1 displaced vertex hardware trigger and measurement of B meson lifetimes

2007-2009 : Research Associate, University of Glasgow, LHCb

-- Implemented first inclusive software triggers and offline selections for the $B \to DX$ family of decays

-- Data-Driven approach to correction of trigger lifetime biases in time-dependent B/D measurements fully commissioned within the LHCb simulation framework

2009-2012 : CERN Marie Curie Fellow, LHCb

-- Deputy convener of Gamma-With-Trees WG of LHCb

-- Responsible for Hadronic/Radiative LHCb software triggers

-- Co-author of trigger section of LHCb upgrade LOI

-- Analysis : measurement of B-hadron fractions

-- Analysis : measurement of $B_s \to KK$ lifetime

-- Analysis : mixing and CPV in $D^0 \to hh$ decays

2012-2017 : CERN Staff, LHCb

-- Co-convener, B2OpenCharm WG of LHCb

-- HLT project leader

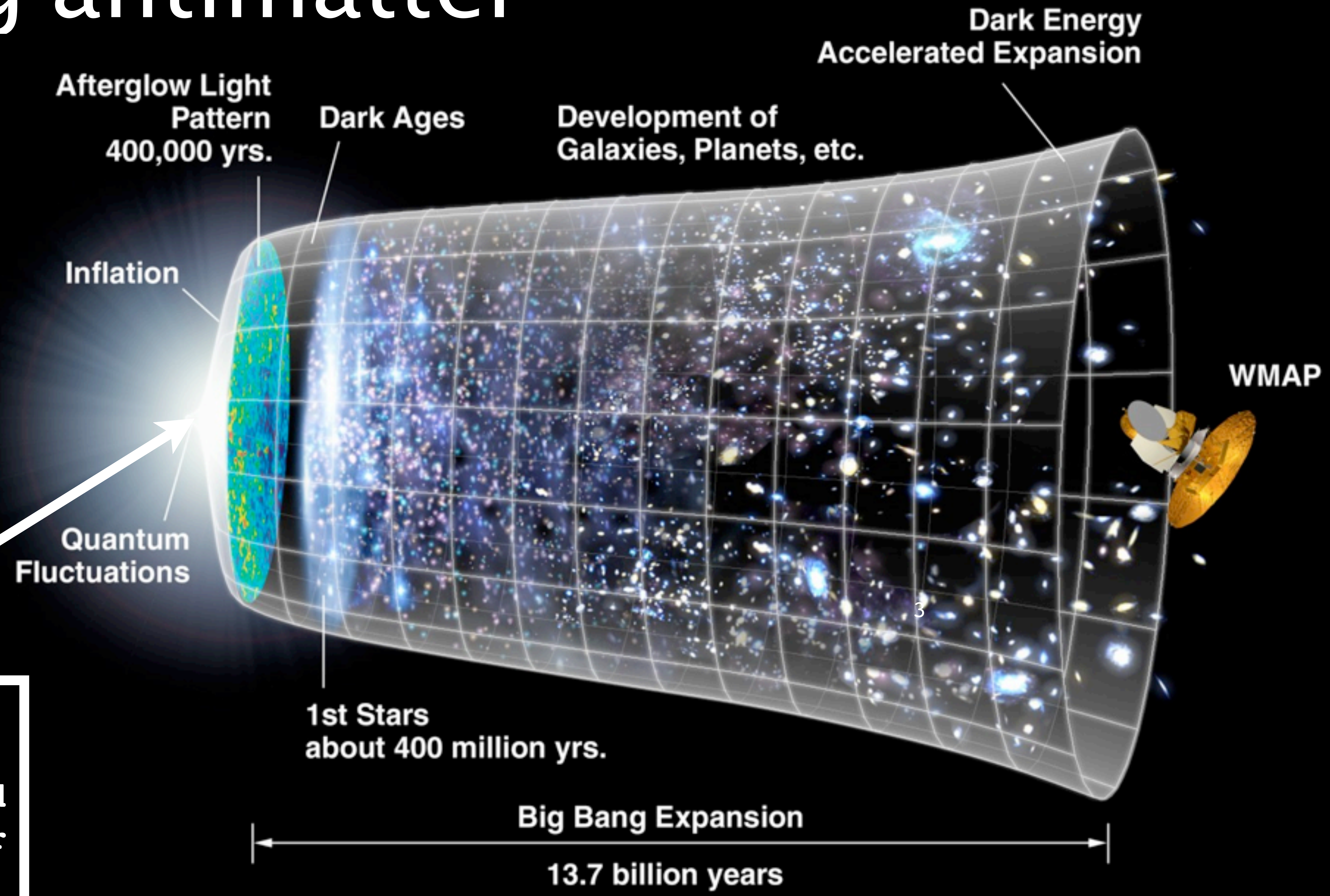
-- Analysis : first observations of $X_b \to X_c X_c$ decay modes

-- Analysis : measurement of CKM angle γ in $B_s \to D_s K$

-- Analysis : precise measurements of excited B hadrons

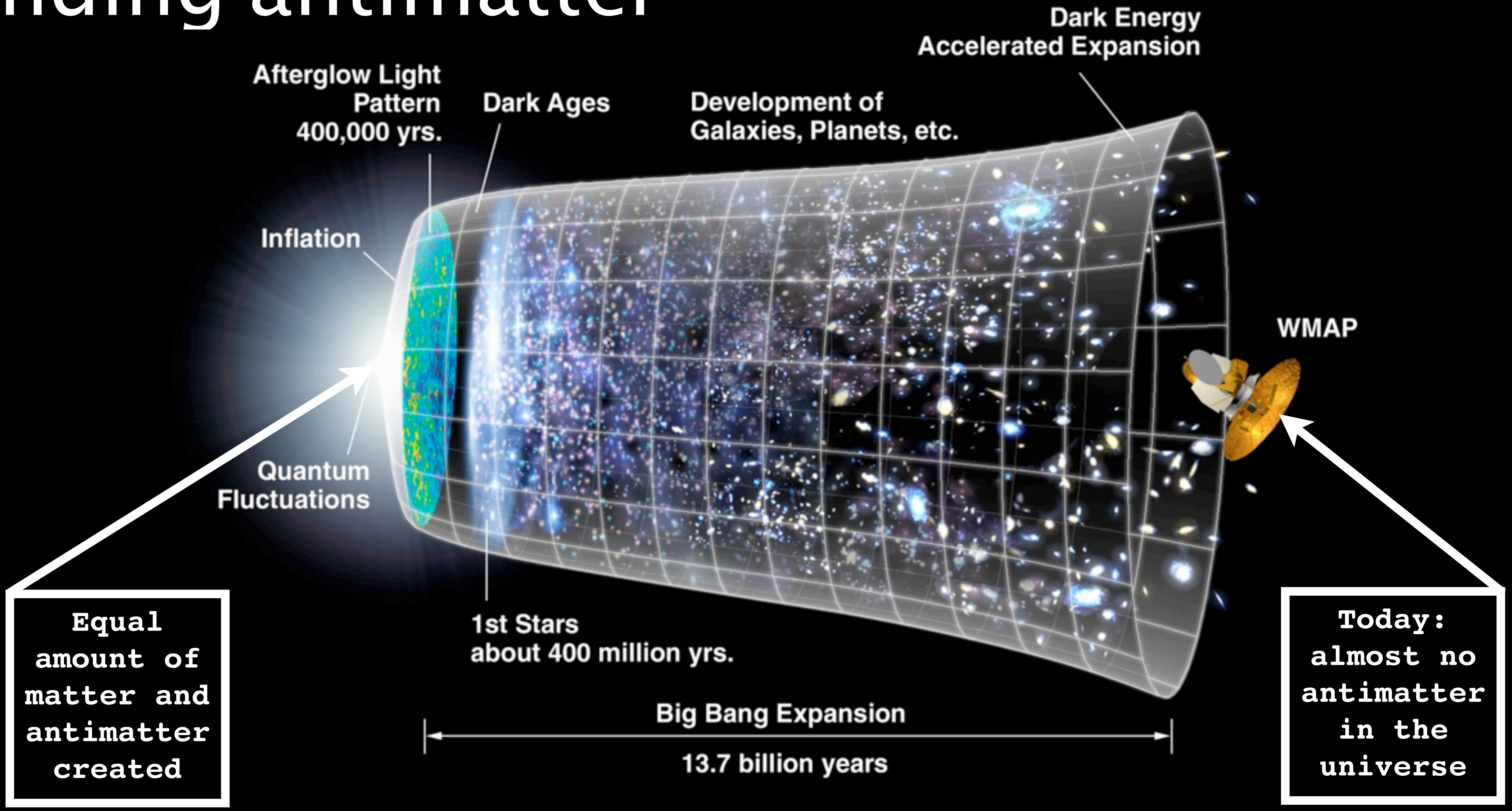
Shift leader & Trigger Piquet
>150 shifts/piquet days in Run I

Finding antimatter

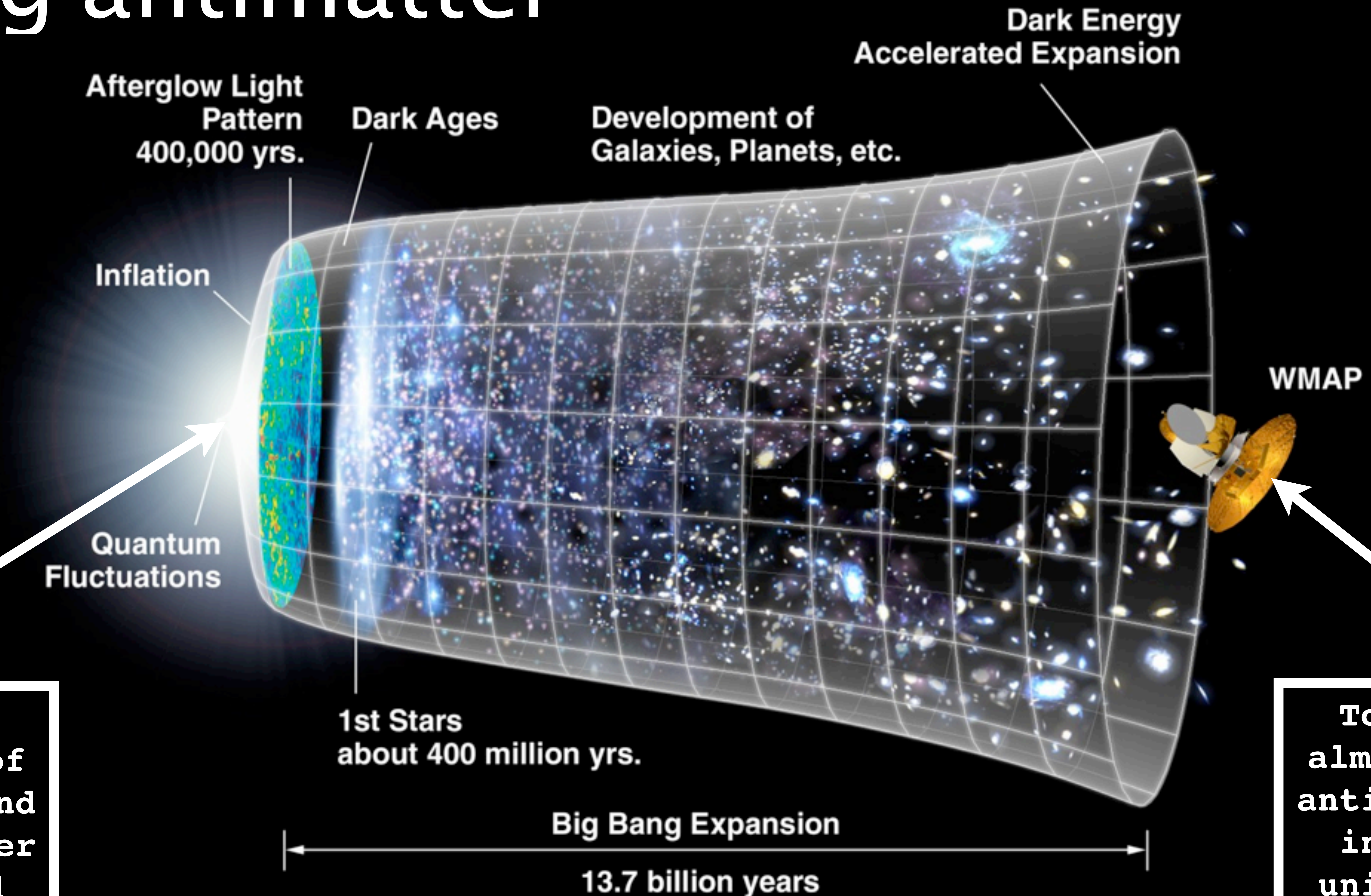


Equal amount of matter and antimatter created

Finding antimatter



Finding antimatter



Equal amount of matter and antimatter created

Today: almost no antimatter in the universe

So where did all the antimatter go?

The standard model…

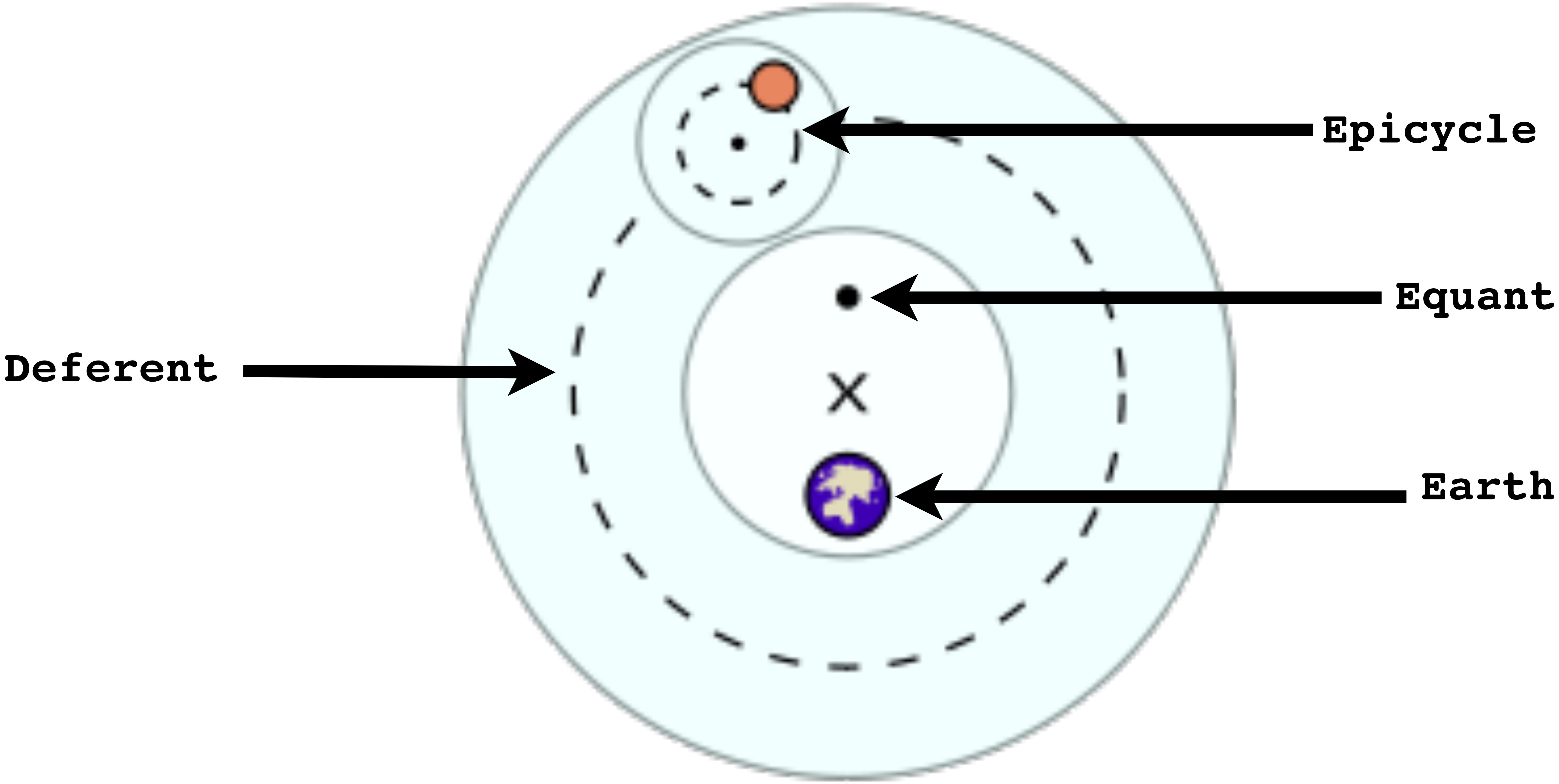
Electromagnetic force

Strong force

Weak force

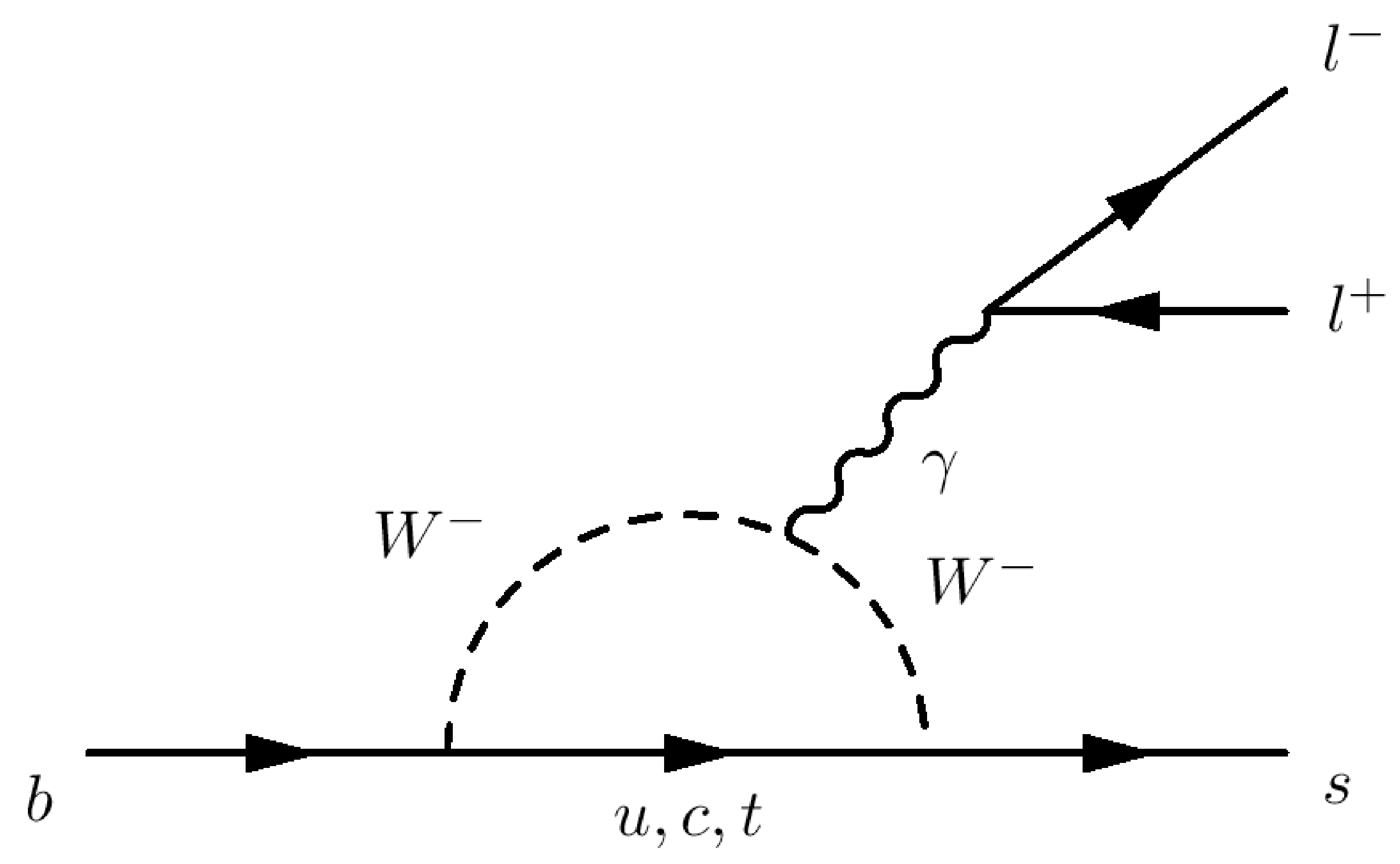
Very predictive, wonderfully accurate, and wholly incompatible with cosmology!

…ptolemaic model?



A sometimes forgotten property of the Ptolomeic model : it was very predictive and accurate. One just had to some epicycles (particles?)...

Indirect detection



Particles which are too heavy to produce can affect processes virtually

Indirect detection

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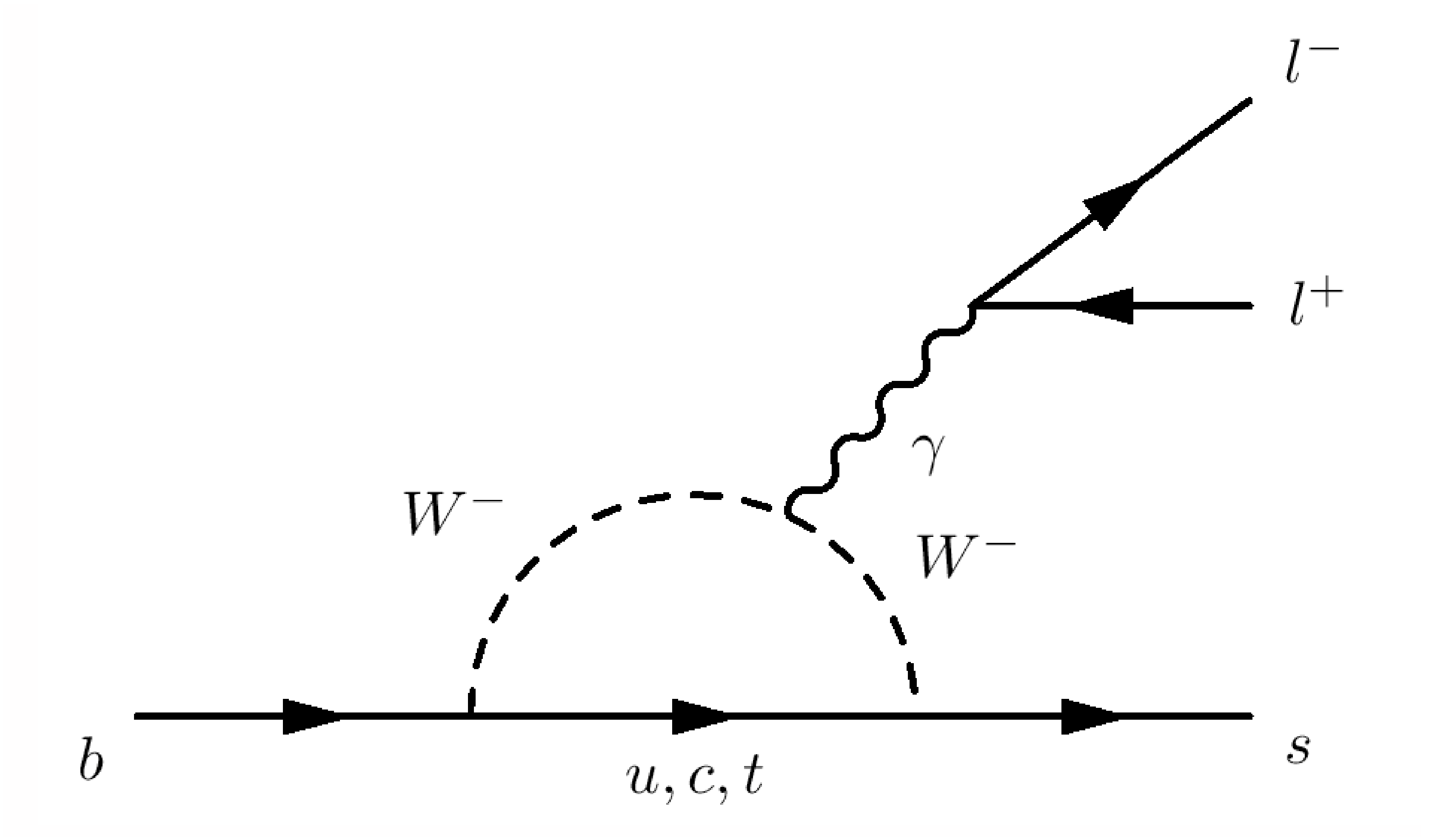
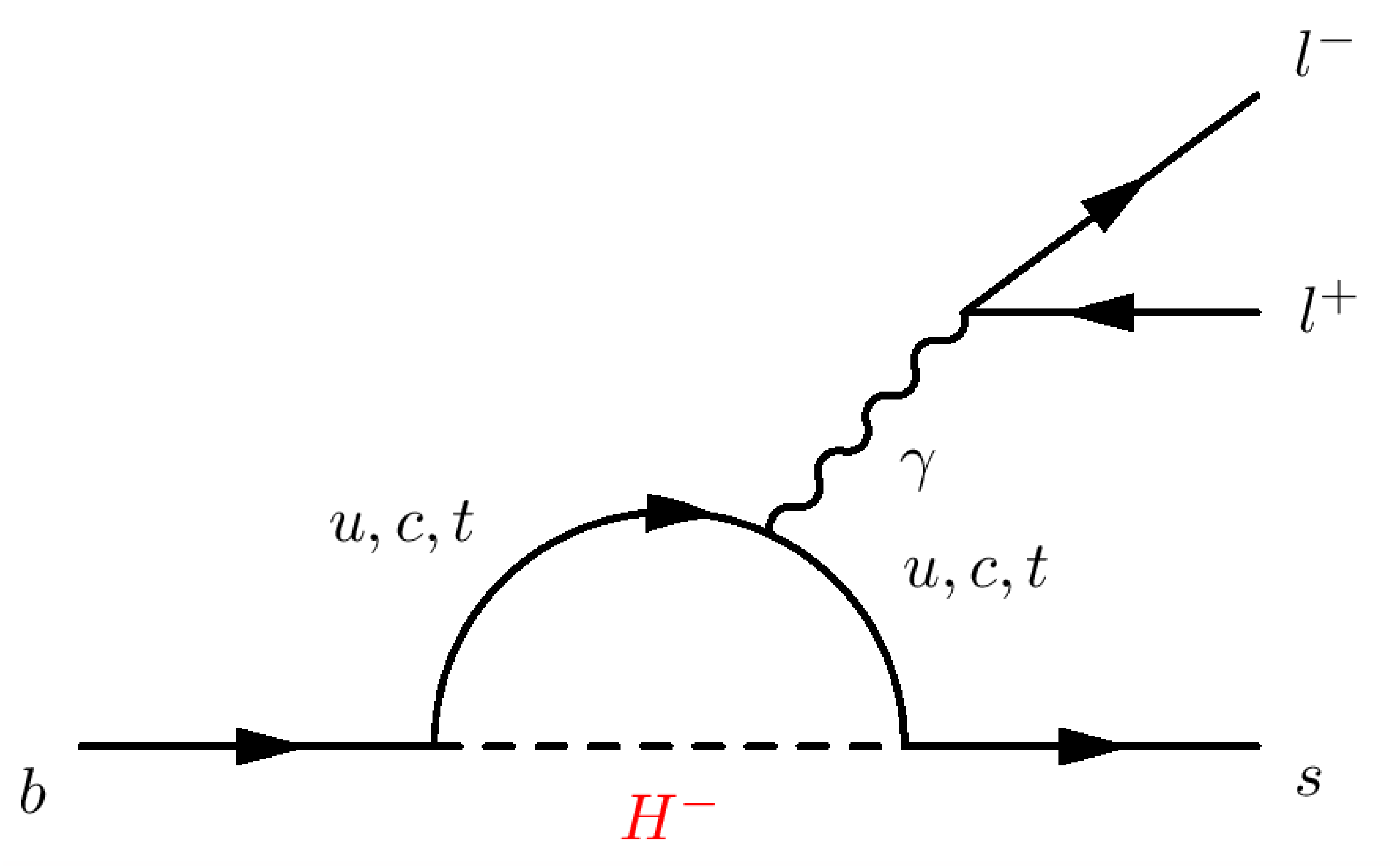
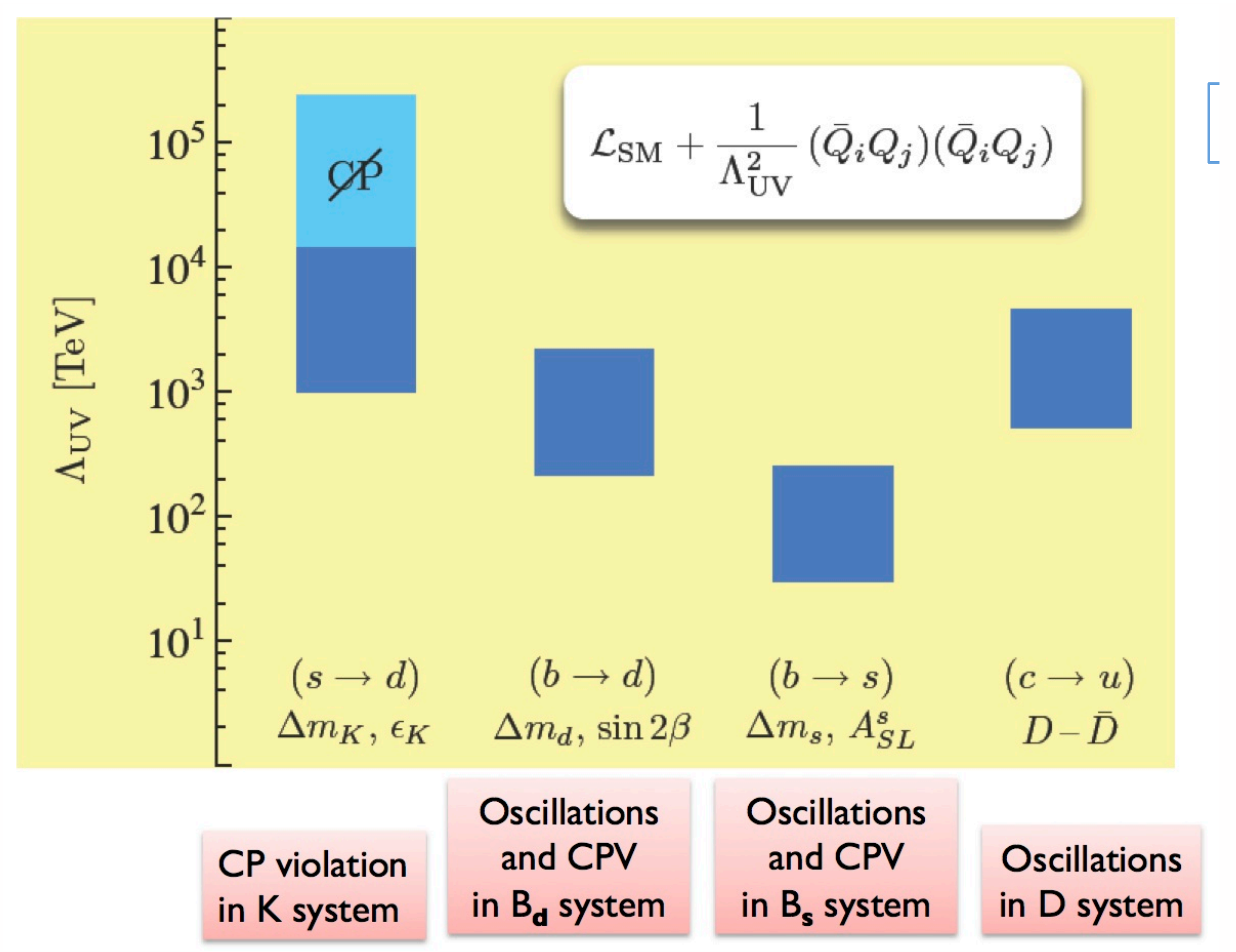
Indirect detection





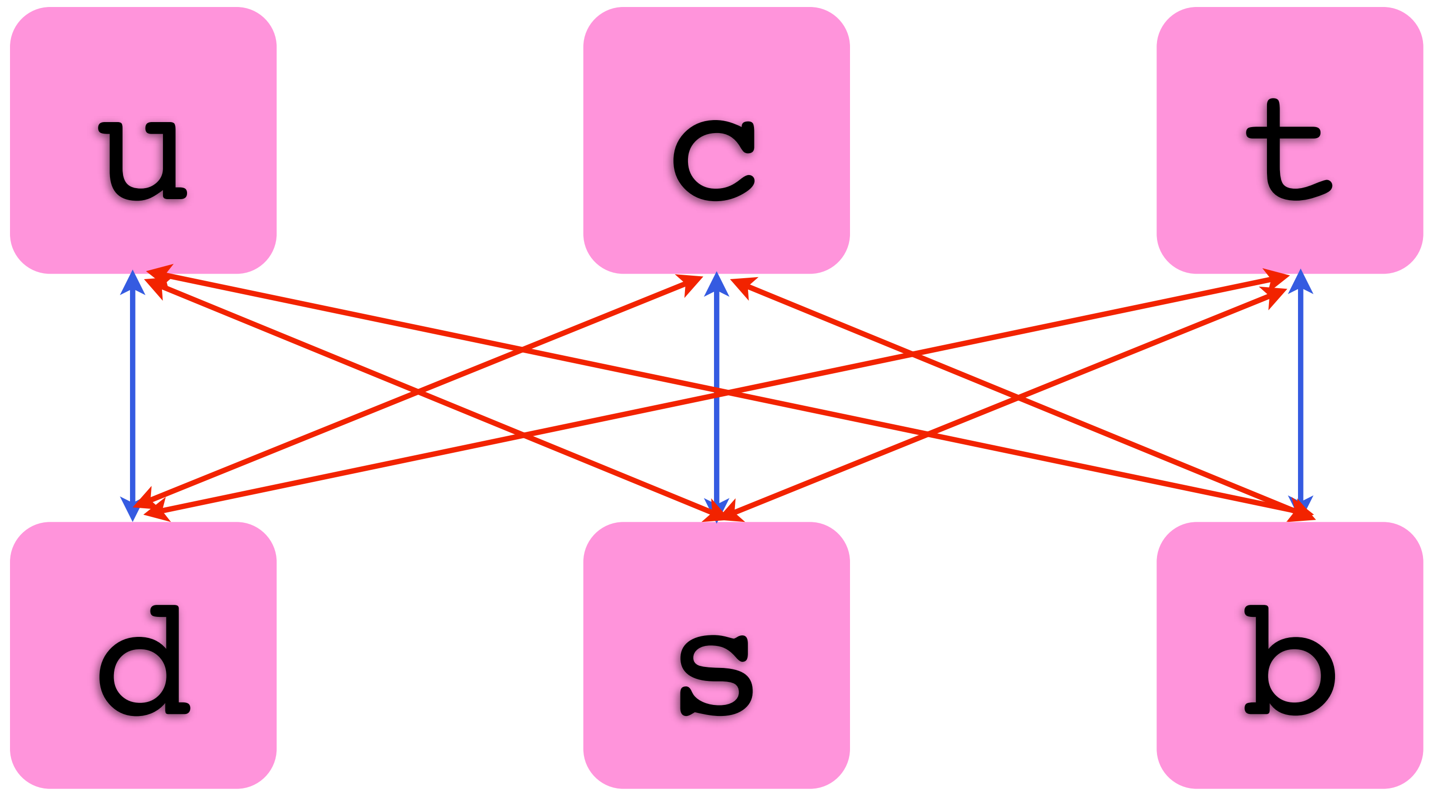


(Fig. Neubert, EPS-HEP'11)

Isidori, Nir, Perez, Ann. Rev. Nucl. Part. Sci. 60 (2010) 355 [arXiv:1002.0900],
Isidori, arXiv:1302.0661

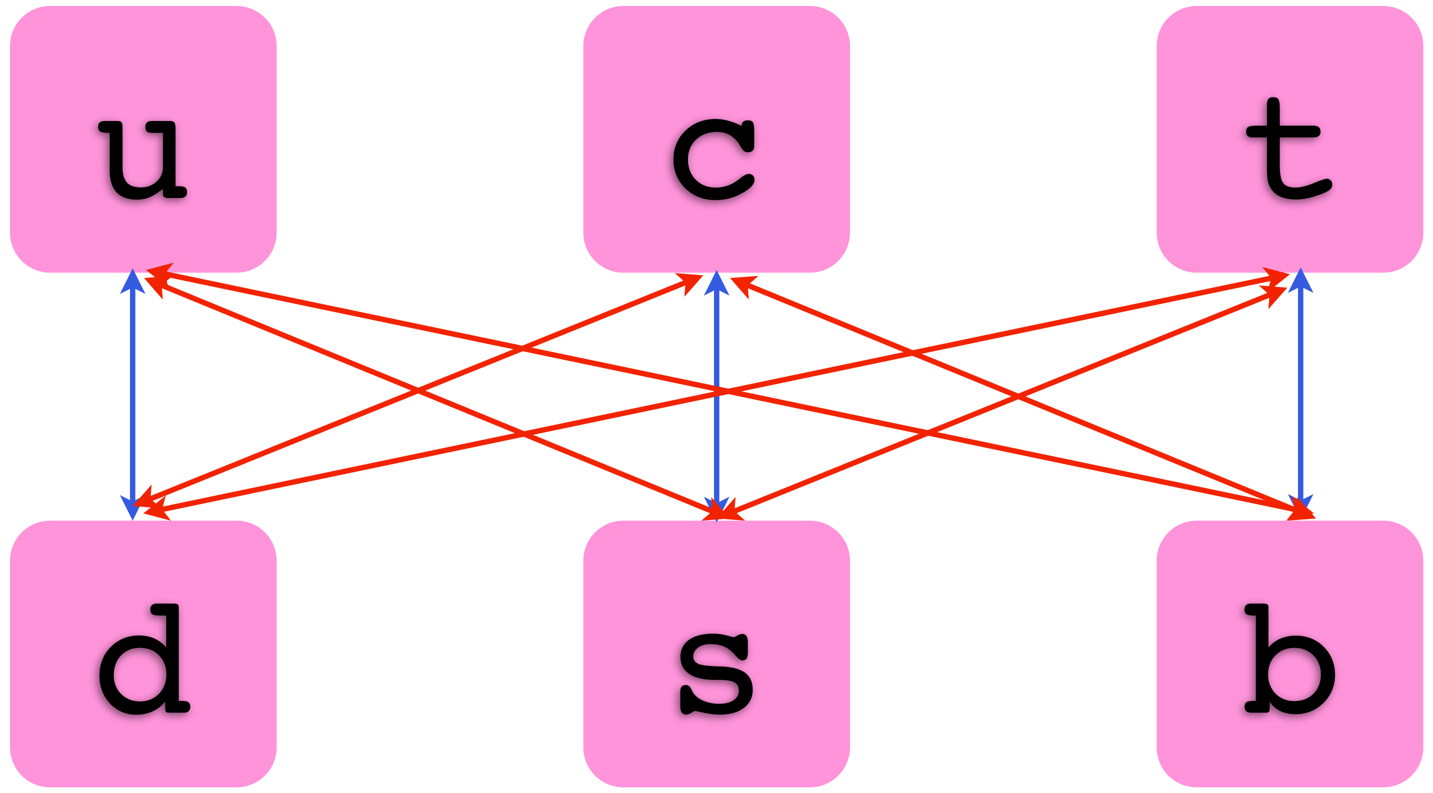
Flavour physics constrains new particles at TeV scale => complements direct detection!

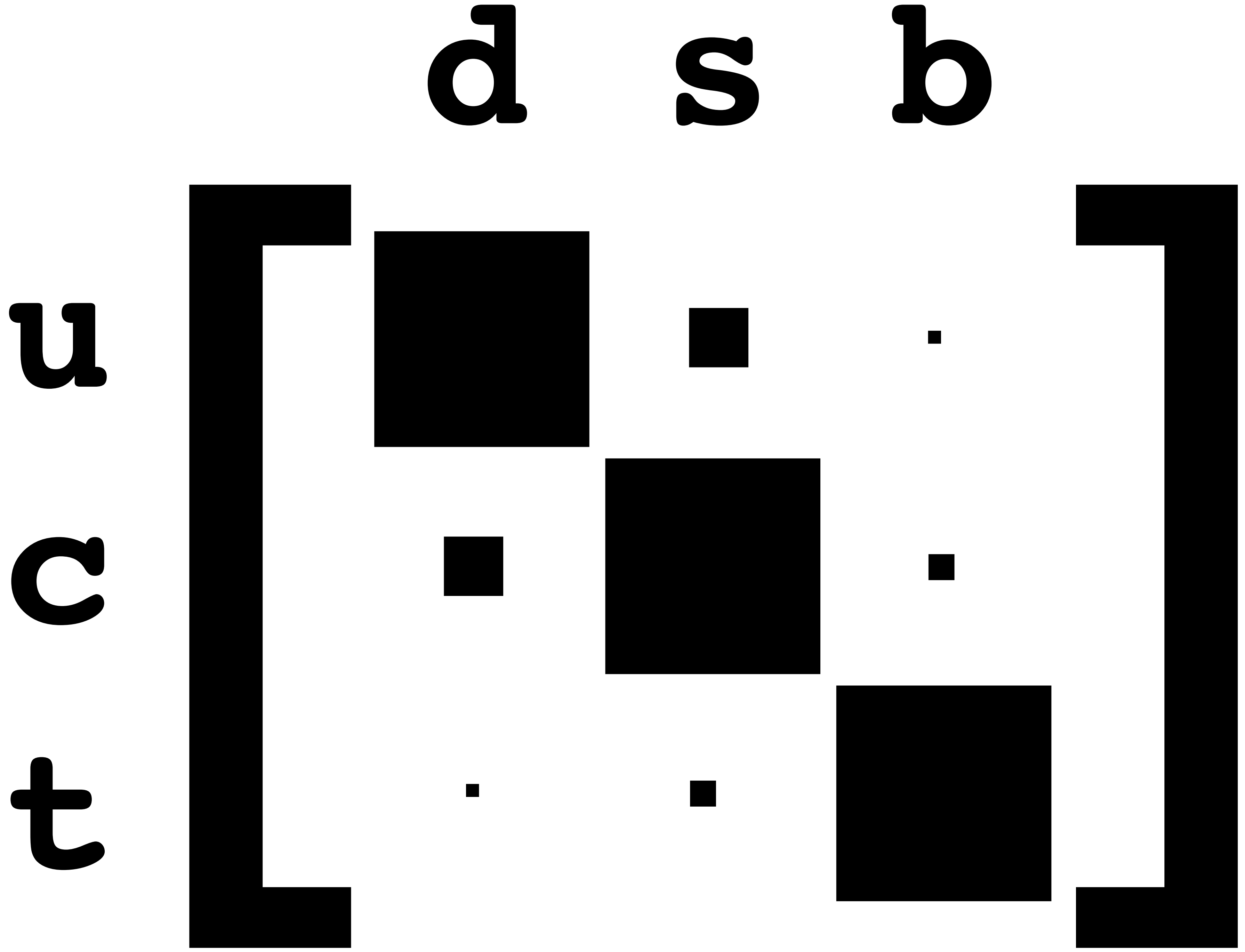
Quark mixing in the Standard Model



Transformations between up and down type quarks can be arranged in a 3x3 matrix

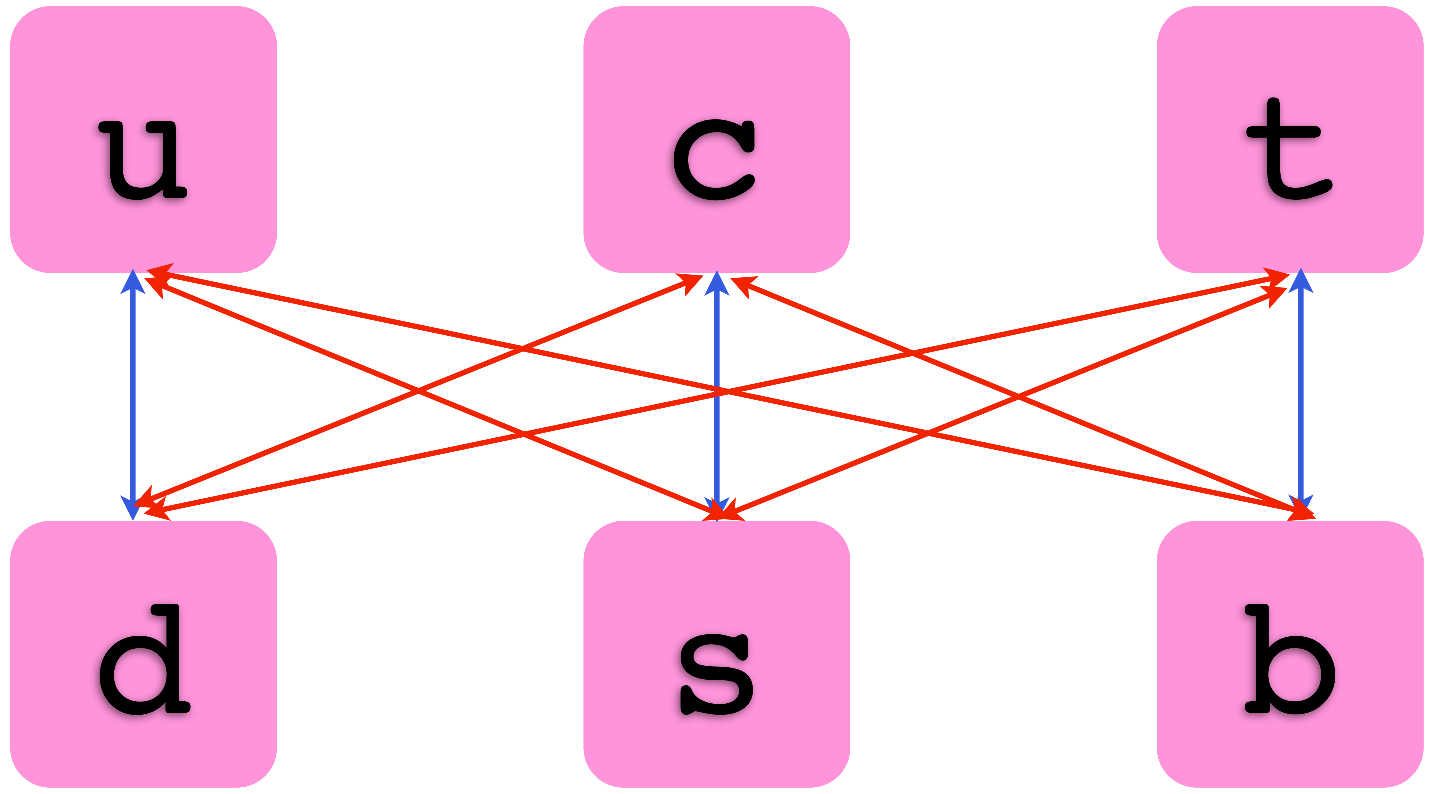
Quark mixing in the Standard Model





These transitions are very hierarchical, quarks in the same column mix almost maximally

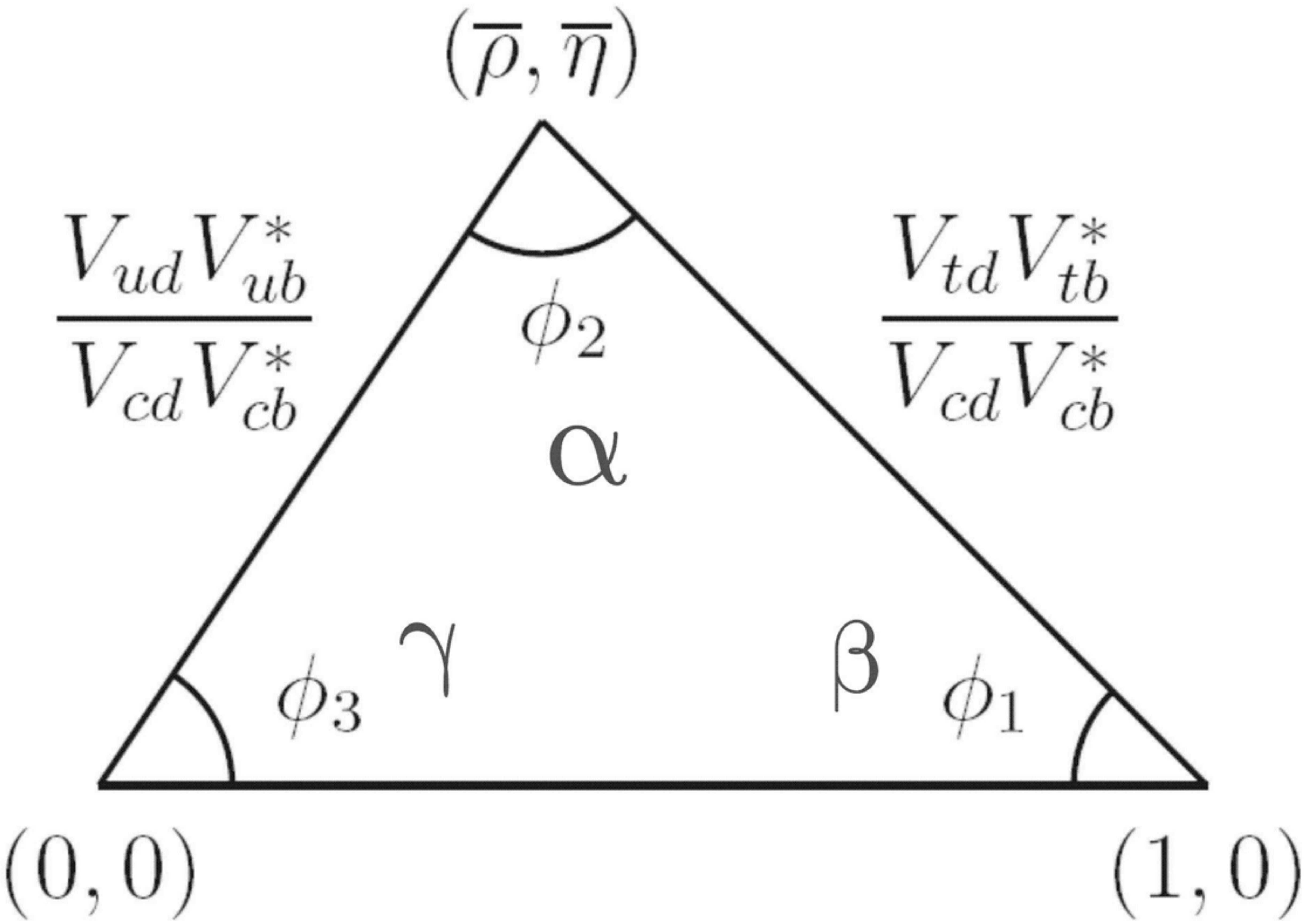
Quark mixing in the Standard Model



$$\mathbf{V_{CKM}} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & \boxed{A\lambda^3(\rho - i\eta)} \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ \boxed{A\lambda^3(1-\rho-i\eta)} & -A\lambda^2 & 1 \end{pmatrix} + \sum_{n=4}^{N} O(\lambda^n)$$

Imaginary component gives rise to matter-antimatter asymmetry (CP violation)

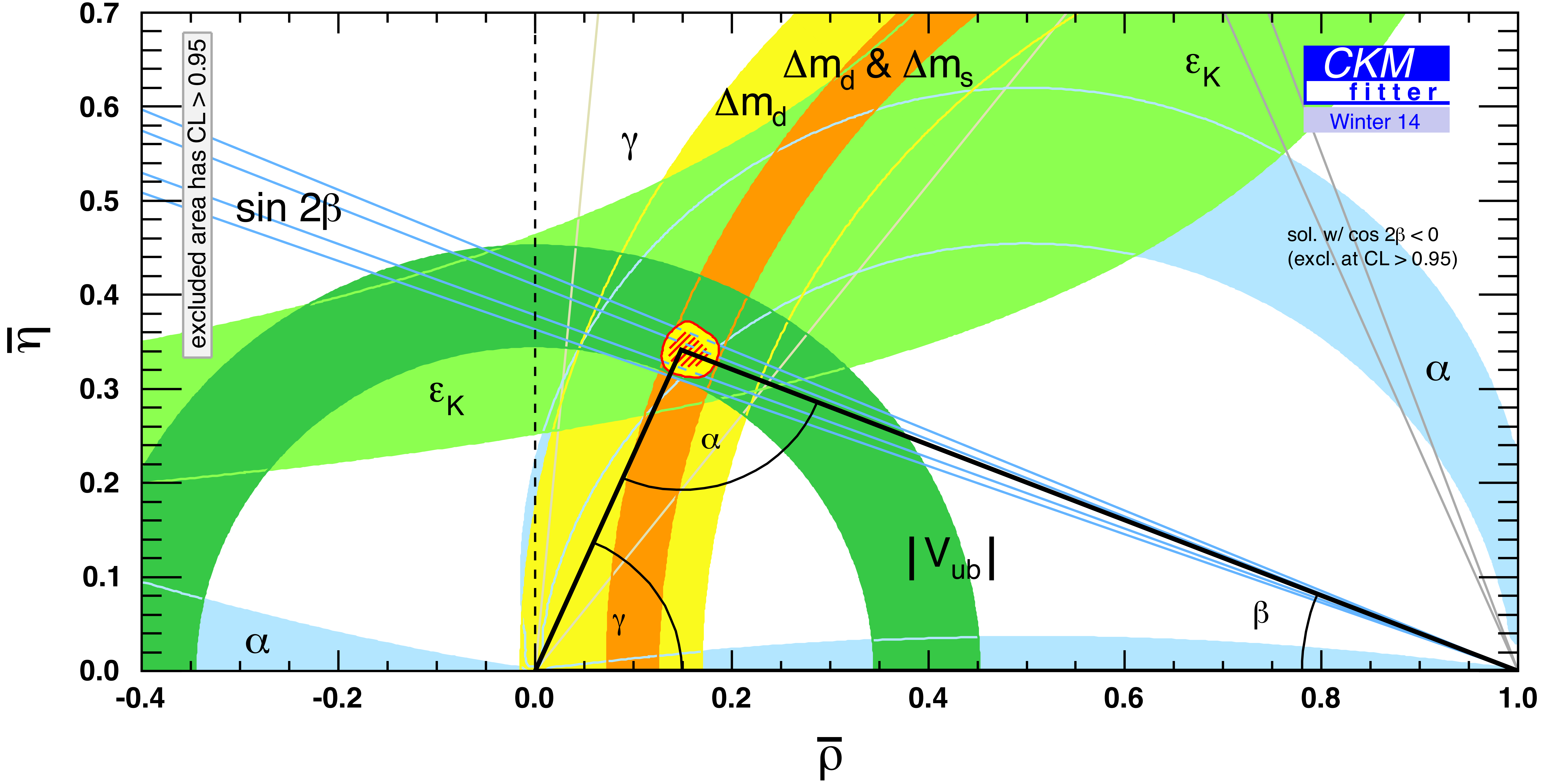
The unitarity triangle



Unitary matrix => 6 triangles in imaginary plane, one experimentally convenient

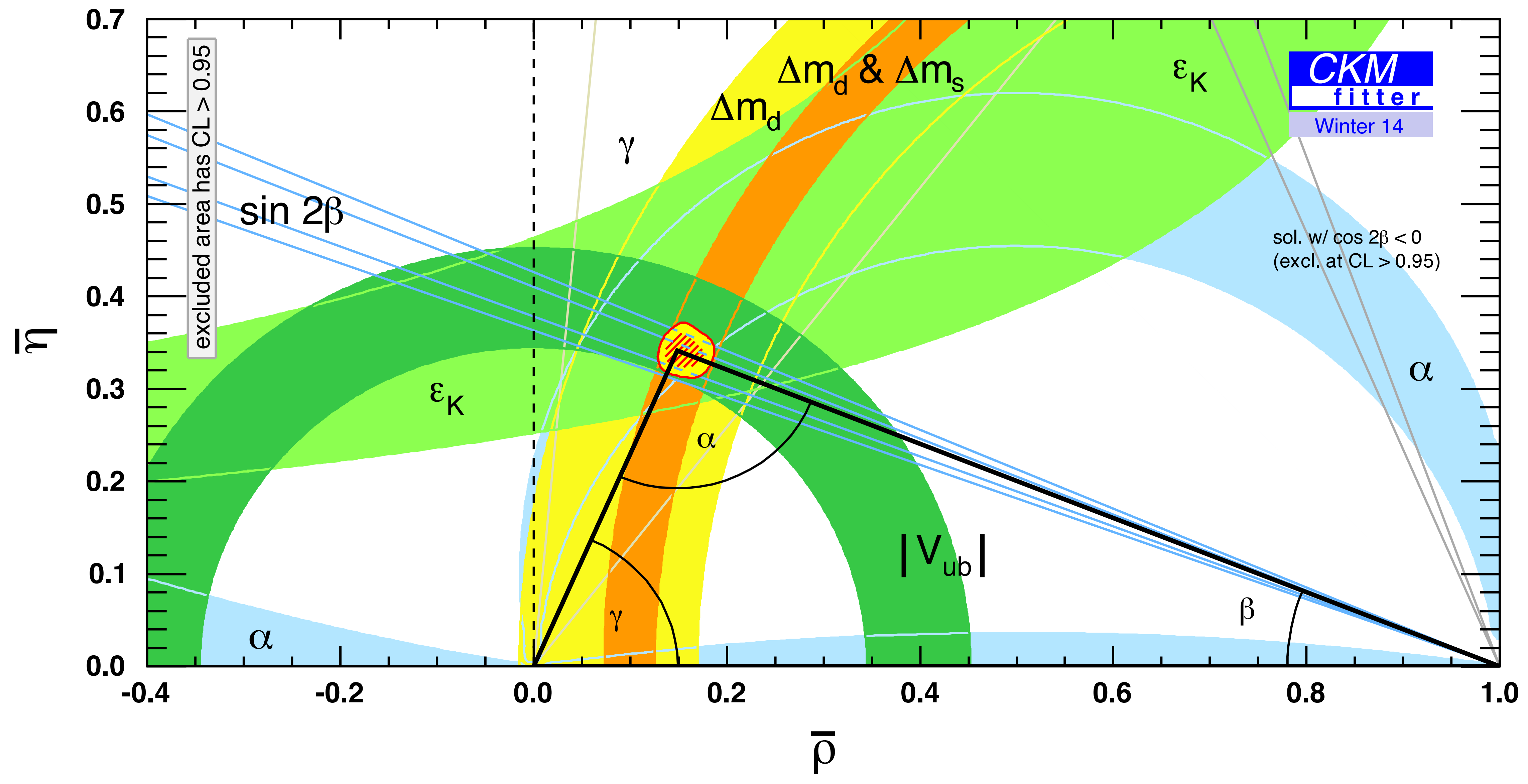
The apex of the triangle

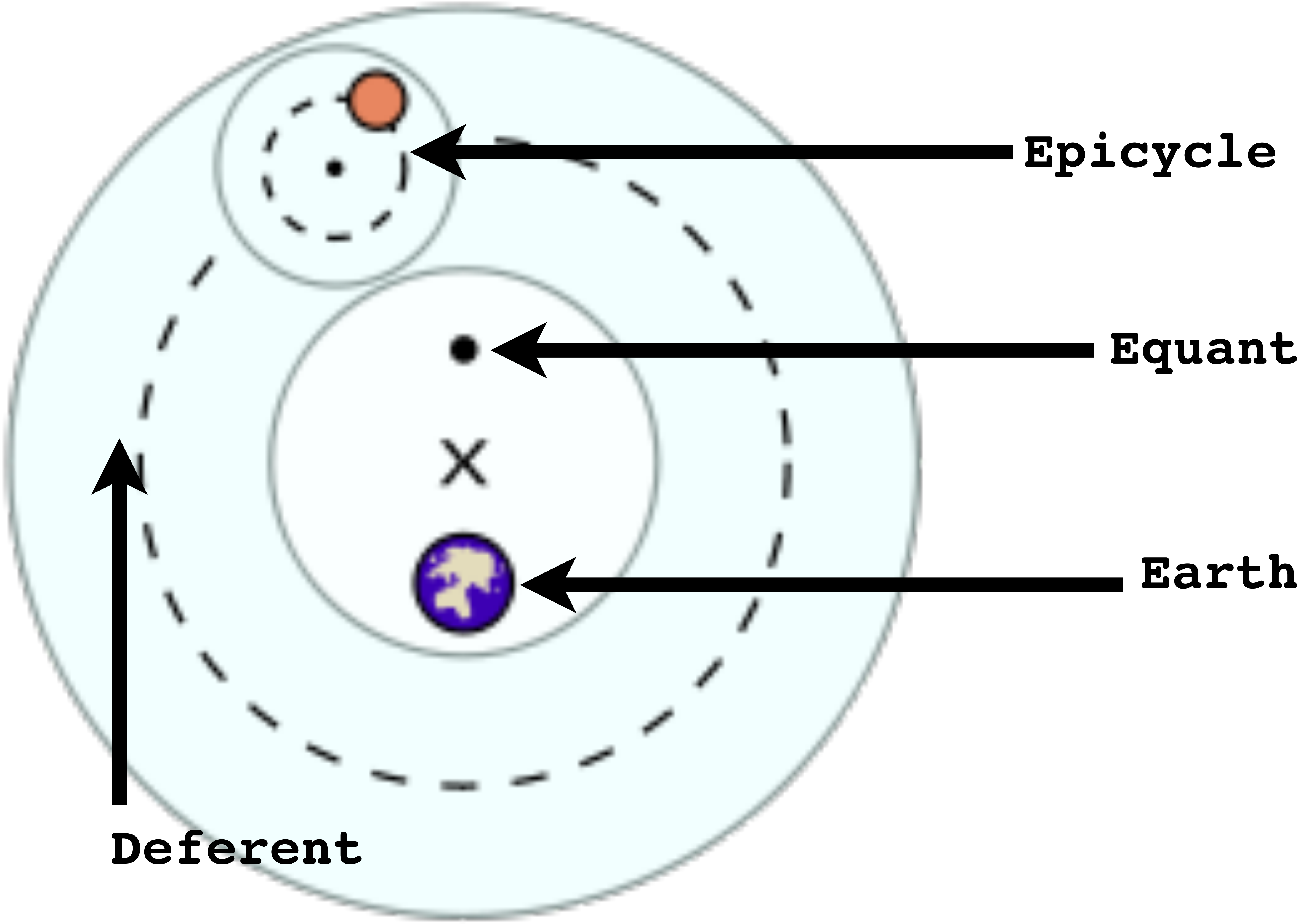
http://ckmfitter.in2p3.fr
Similar plots with Bayesian treatment available at www.utfit.org



Overconstraining the apex tests the consistency of the SM picture of CP Violation

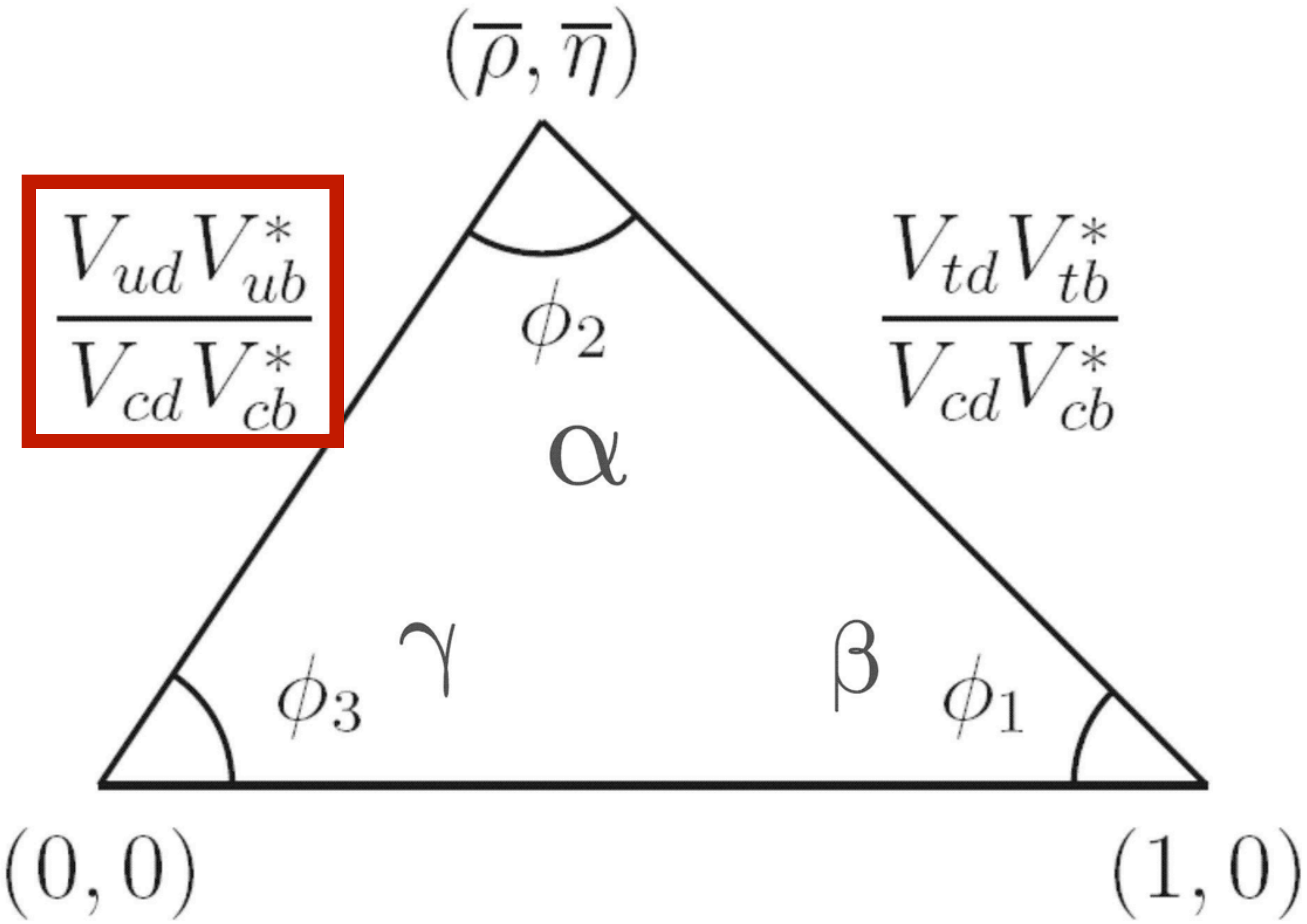
Overconstraining the epicycles





Any New Physics model must also exibit consistency in the triangle : a powerful experimental protection against further epicycles!

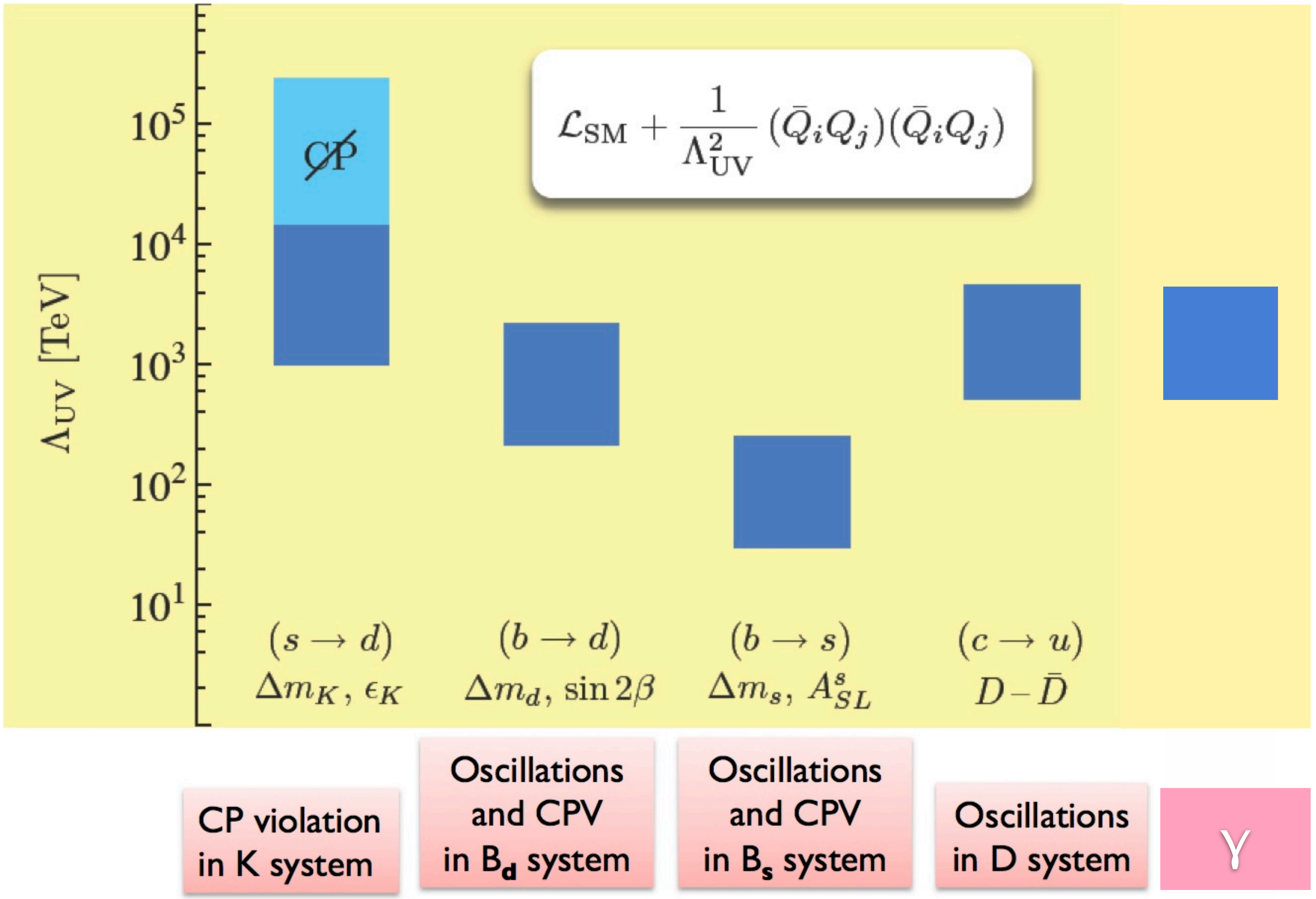
γ and matter–antimatter asymmetries



Because γ is the argument of this term which contains the imaginary V_{ub}, we measure it by observing matter–antimatter asymmetries

What scales does γ probe?

$$|\delta\gamma| \lesssim \mathcal{O}(10^{-7})$$



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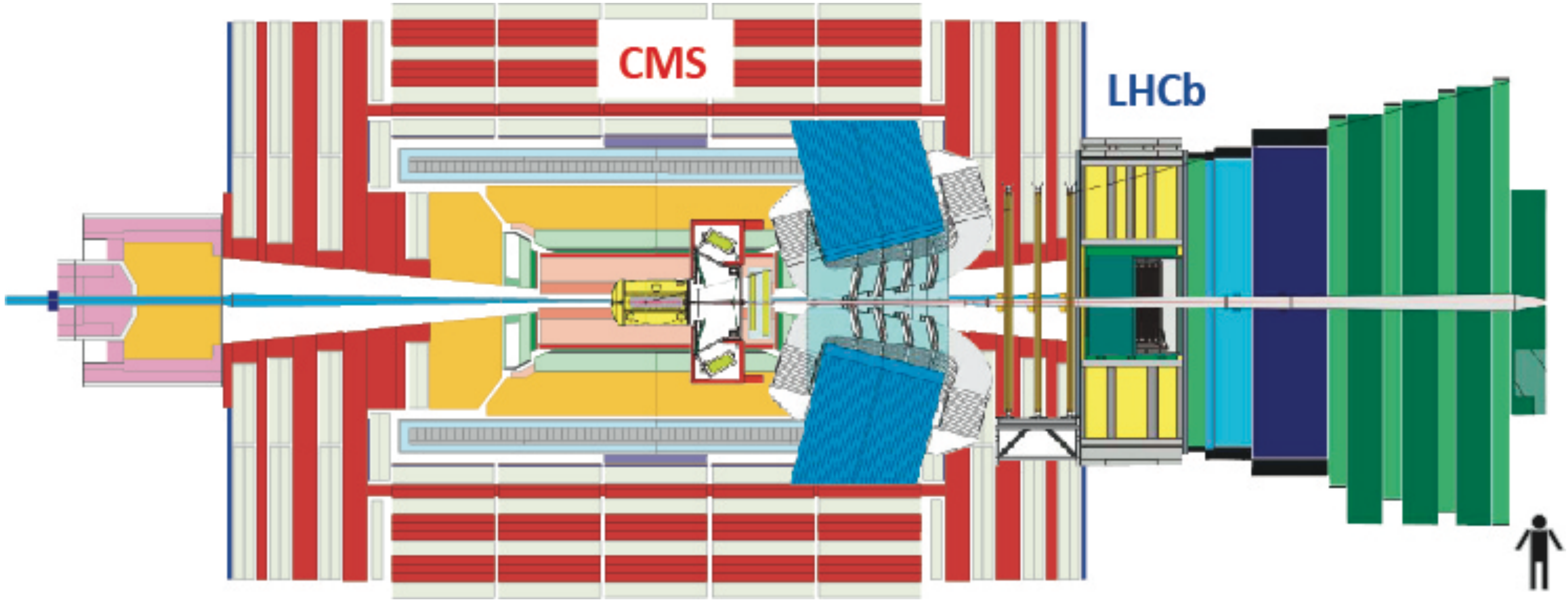
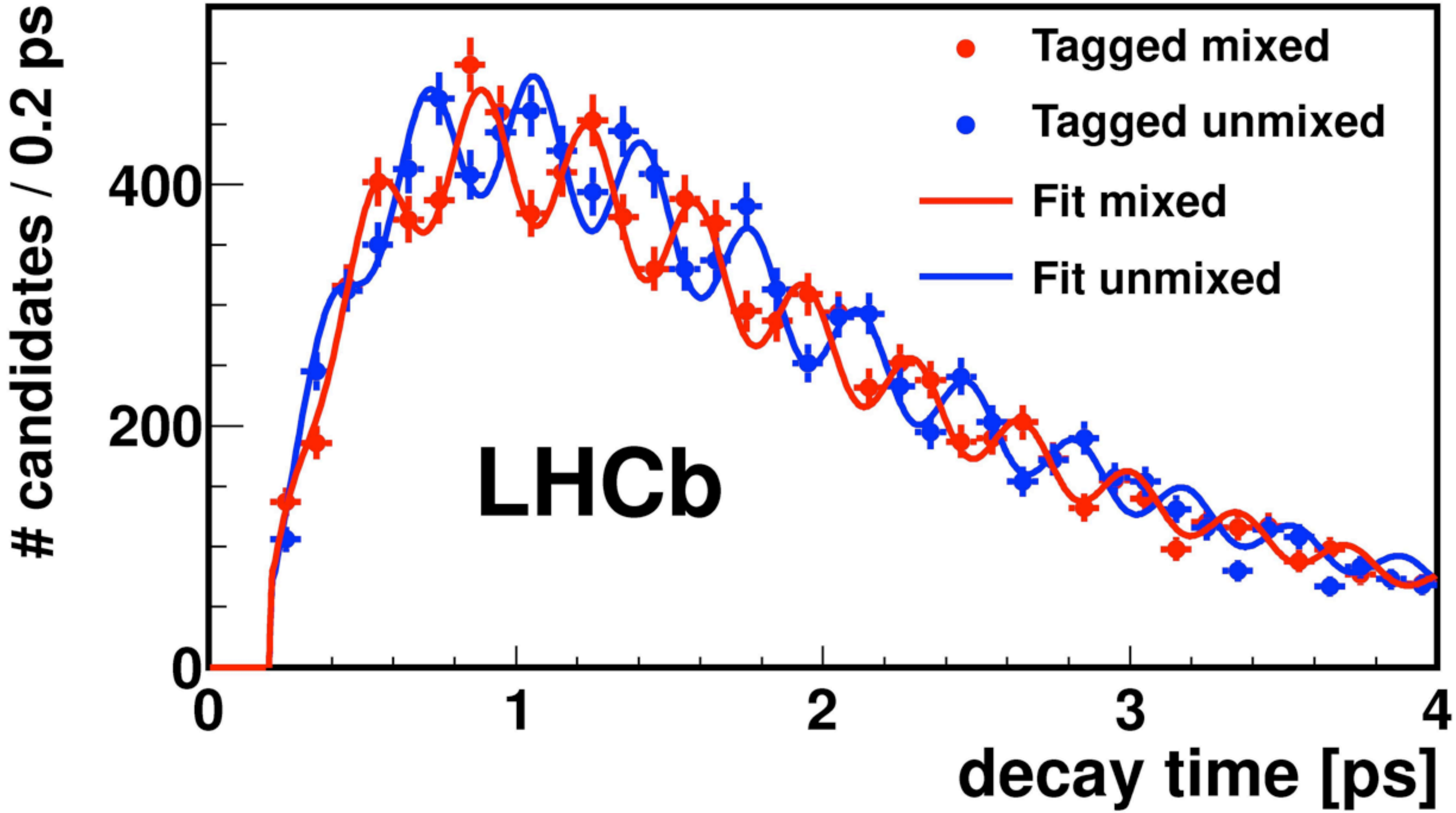
Zupan&Brod
http://arxiv.org/pdf/1308.5663.pdf

Dramatis personae



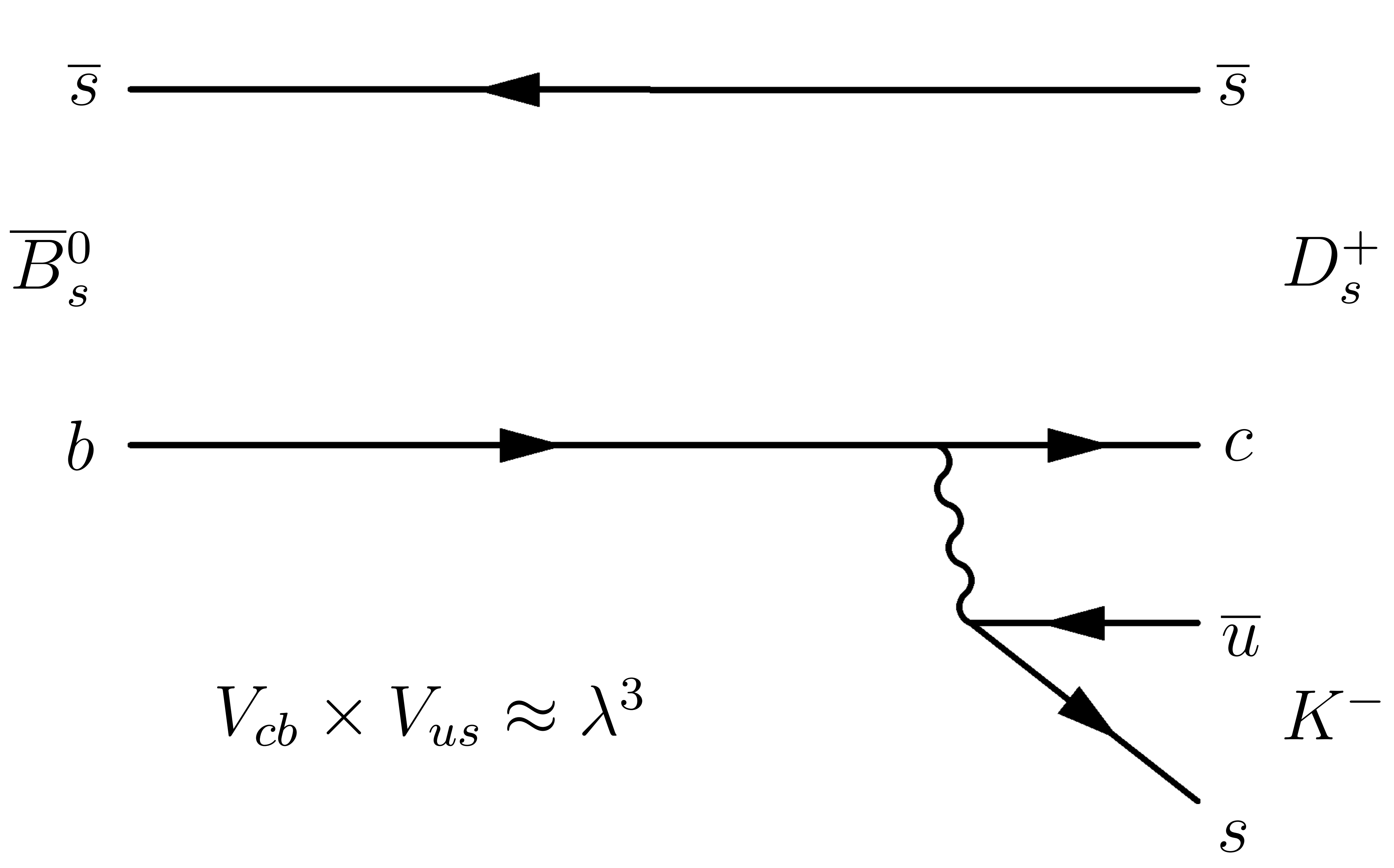
LHCb : forward spectrometer for flavour physics at LHC

Finding CPV in oscillations

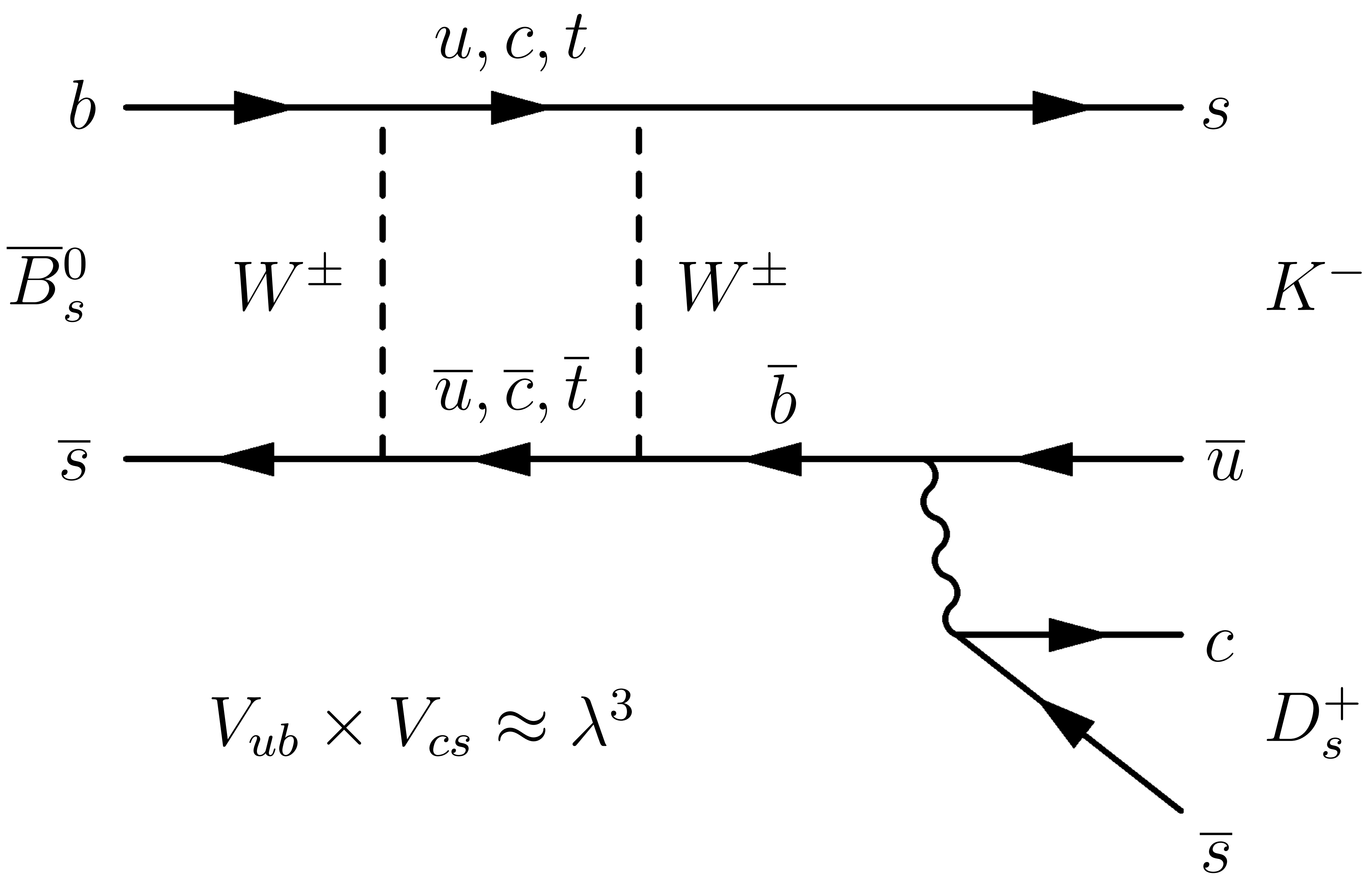


The physics of $B_s \to D_s K$

UNMIXED



MIXED



Interference in mixing and decay => CPV

We in fact have four decay rates

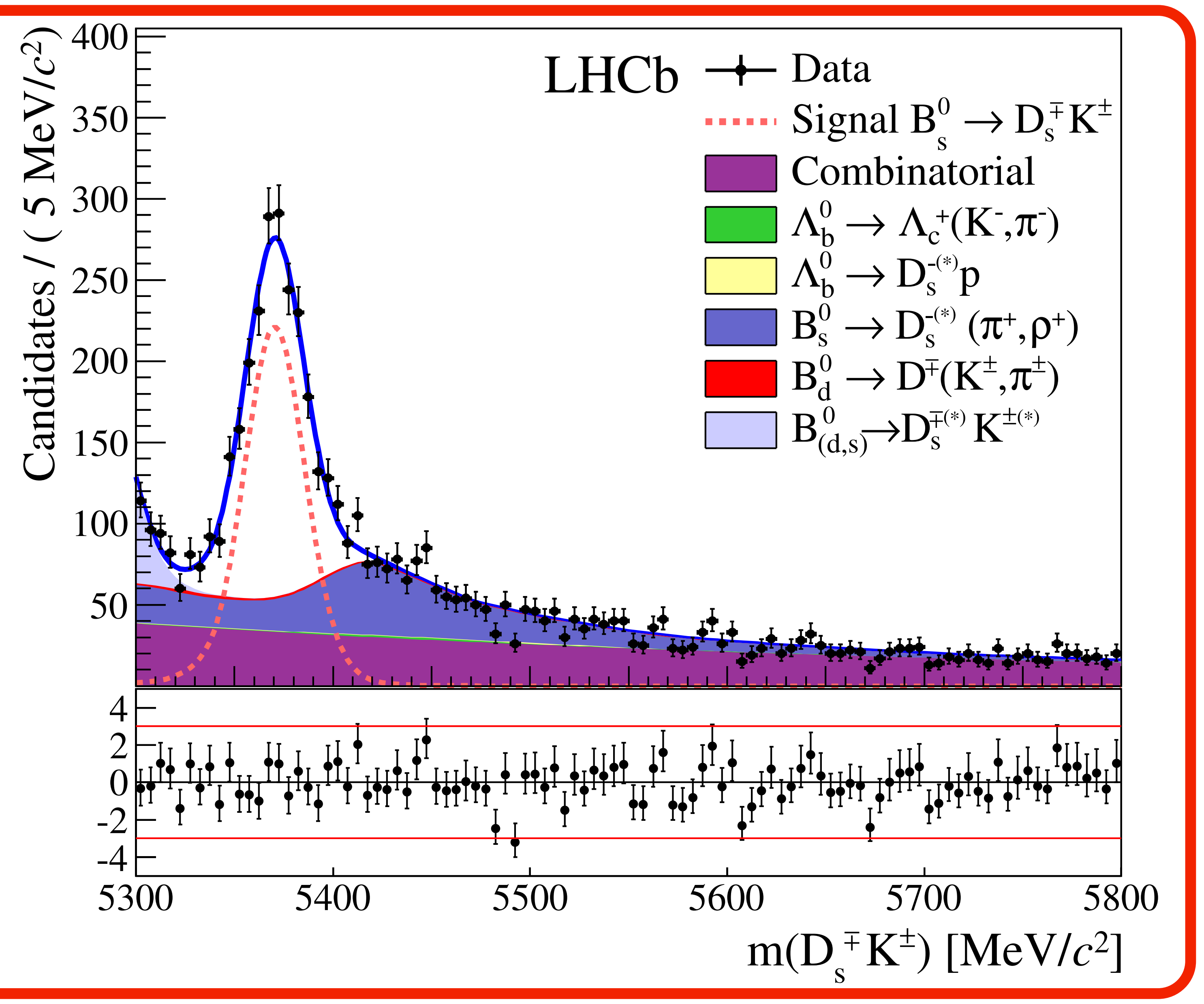
1. $B^0_s \rightarrow D^+_s K^-$
2. anti-$B^0_s \rightarrow D^+_s K^-$
3. $B^0_s \rightarrow D^-_s K^+$
4. anti-$B^0_s \rightarrow D^-_s K^+$

Each decay rate is a function of the decay-time of the B^0_s (anti)meson, and the parameters of that function depend on γ

Multidimensional fit

LHCb-PAPER-2014-038

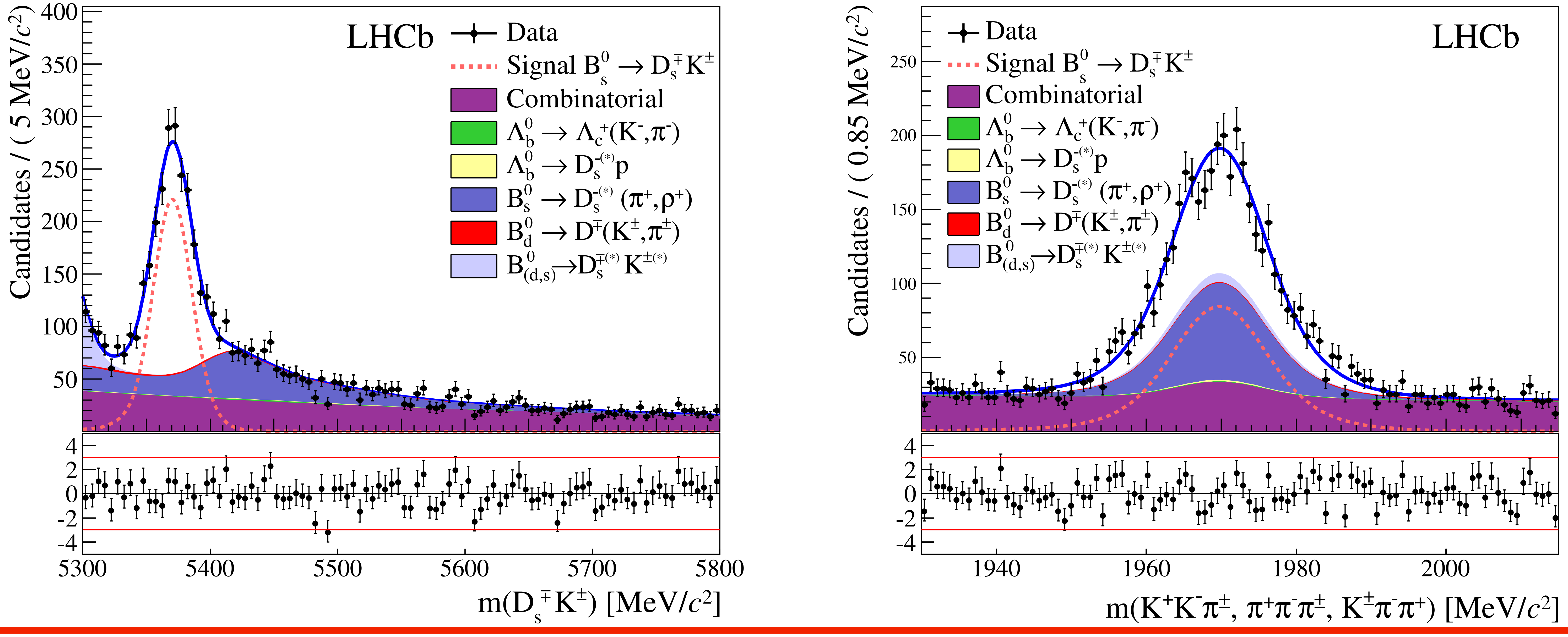
$B_s^0 \to D_s^\mp K^\pm$



Multidimensional fit

LHCb-PAPER-2014-038

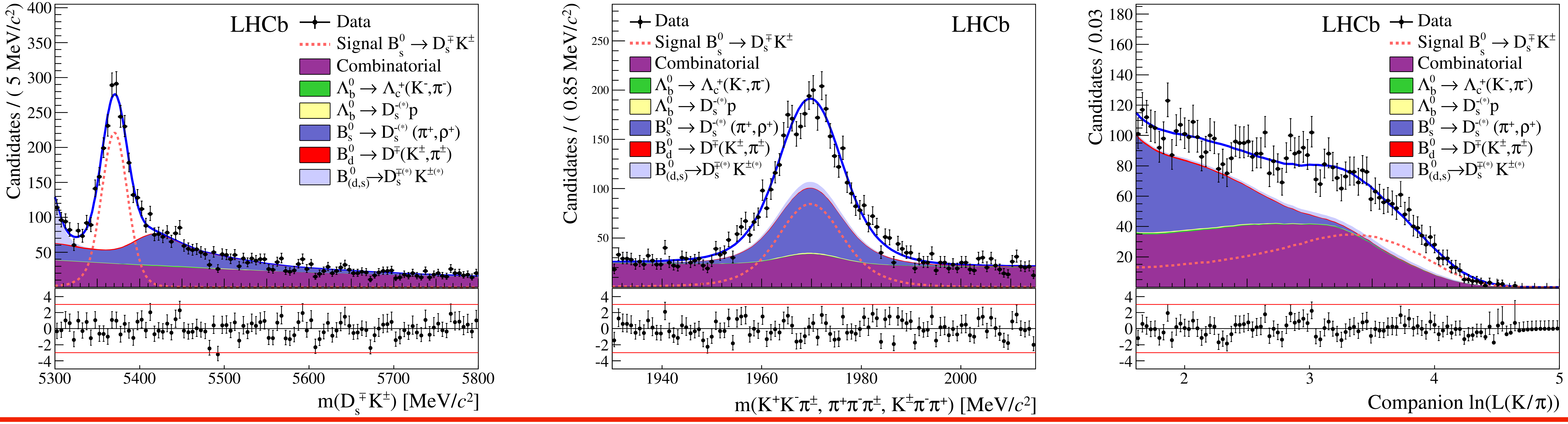
$B_s^0 \to D_s^{\mp} K^{\pm}$



Multidimensional fit

LHCb-PAPER-2014-038

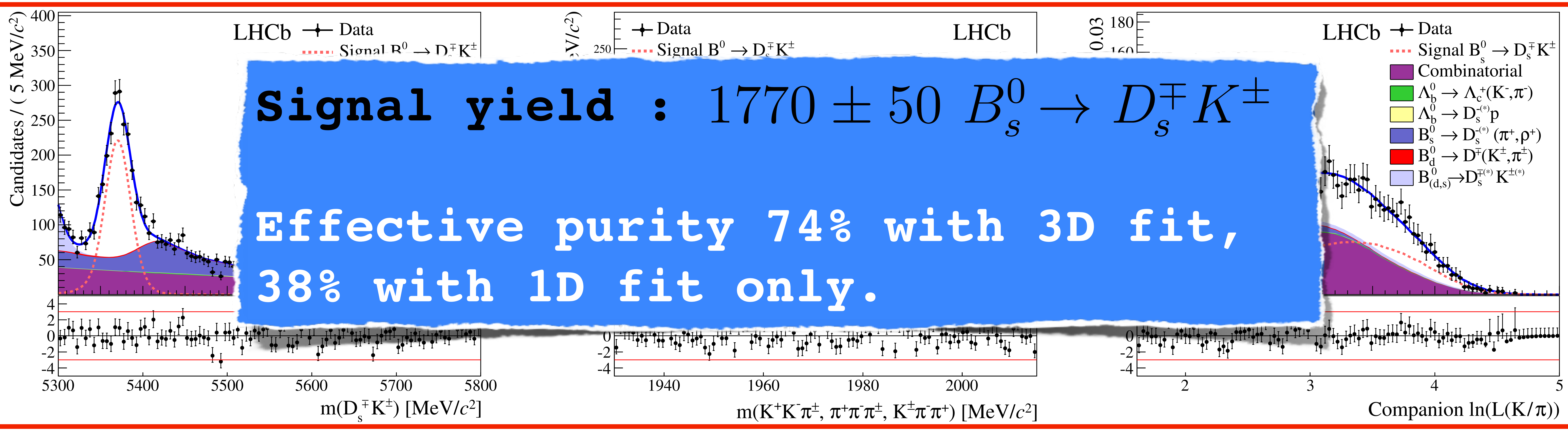
$B_s^0 \to D_s^{\mp} K^{\pm}$



Multidimensional fit

LHCb-PAPER-2014-038

$B_s^0 \to D_s^{\mp} K^{\pm}$

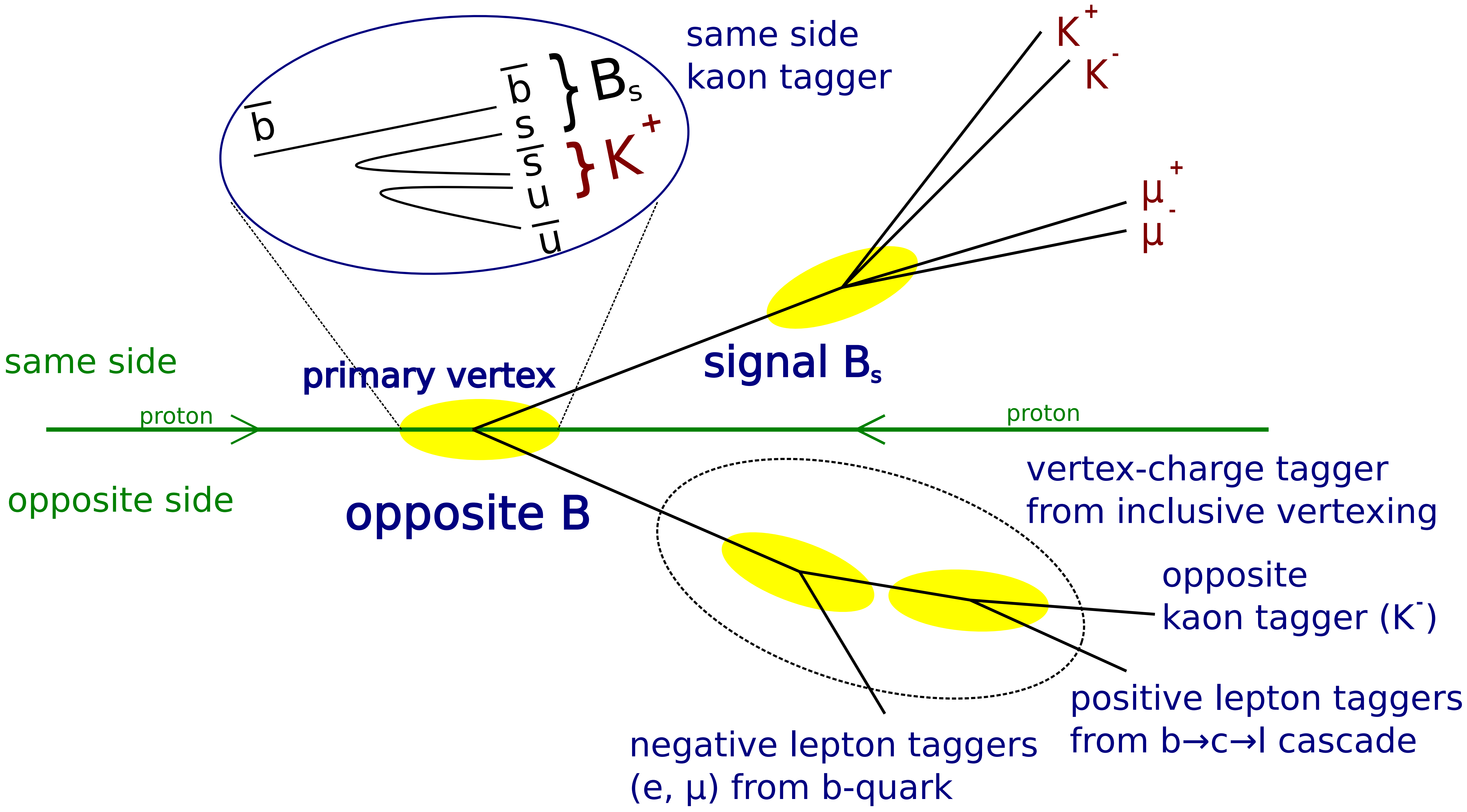


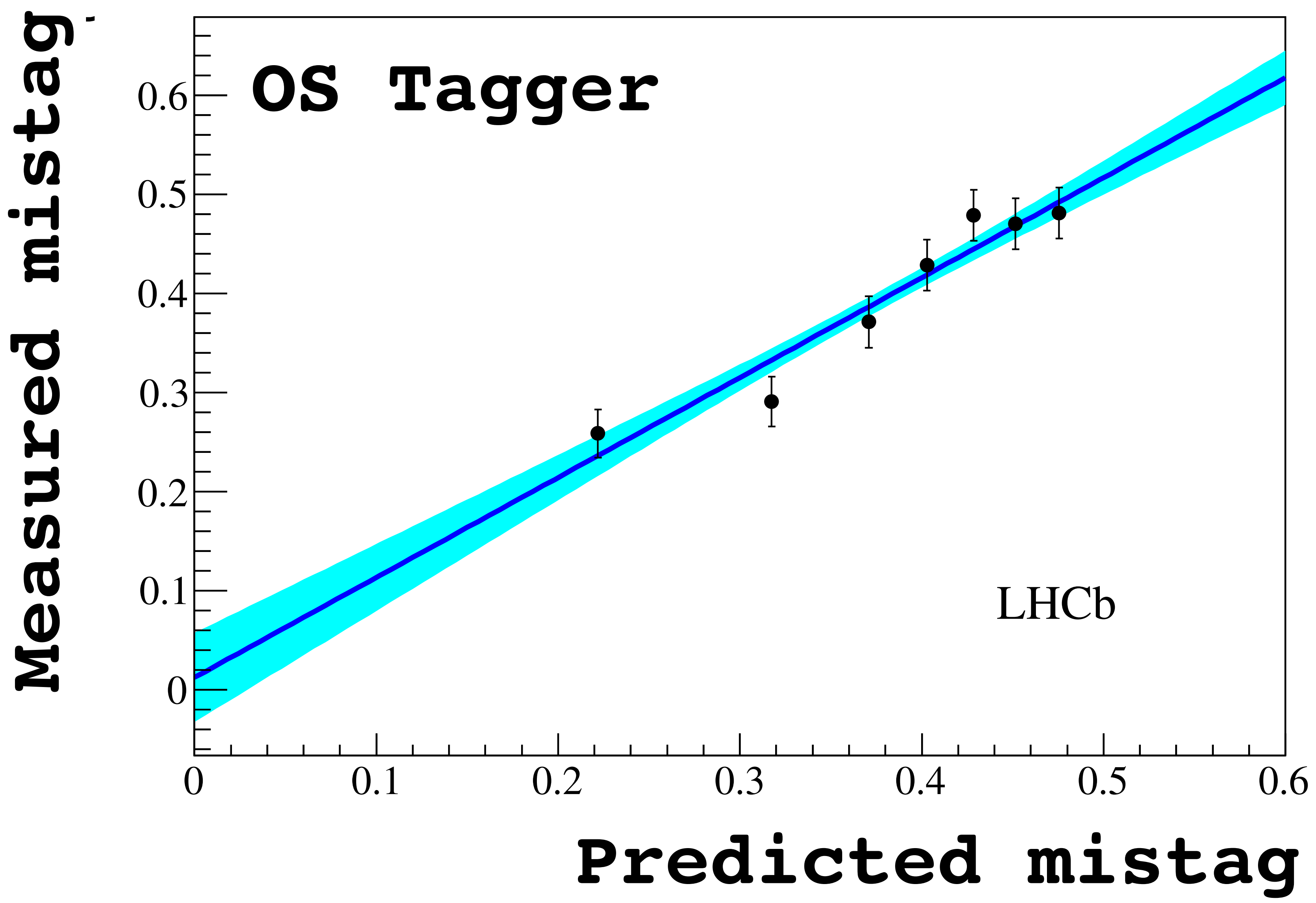
Signal yield : $1770 \pm 50\ B_s^0 \to D_s^{\mp} K^{\pm}$

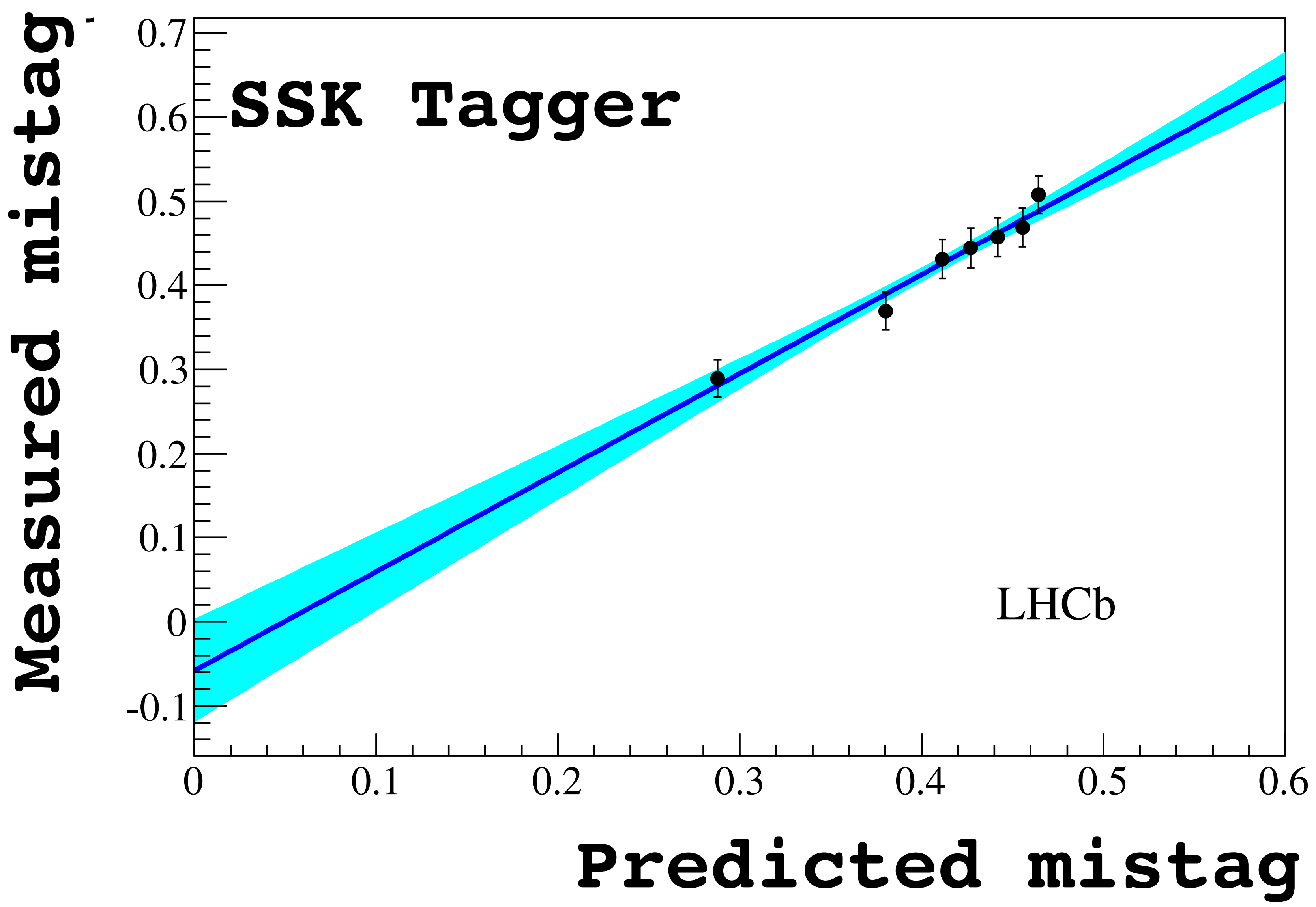
Effective purity 74% with 3D fit, 38% with 1D fit only.

Flavour tagging

LHCb-PAPER-2014-038

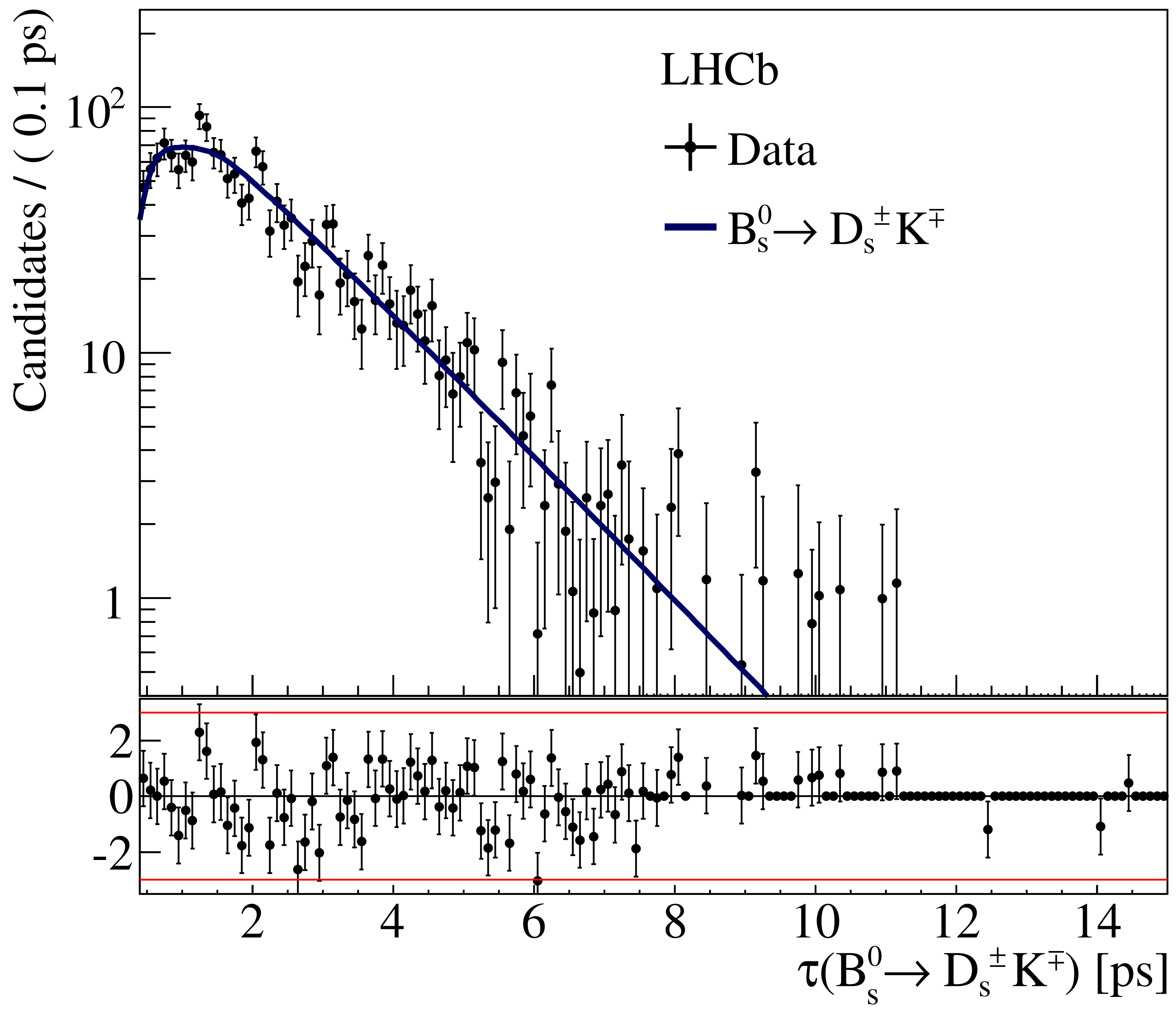






Event type	ε_{tag} [%]	ε_{eff} [%]
OS-only	19.80 ± 0.23	$1.61 \pm 0.03 \pm 0.08$
SSK-only	28.85 ± 0.27	$1.31 \pm 0.22 \pm 0.17$
OS-SSK	18.88 ± 0.23	$2.15 \pm 0.05 \pm 0.09$
Total	67.53	5.07

Time fit to D_sK



Time fit to D_sK

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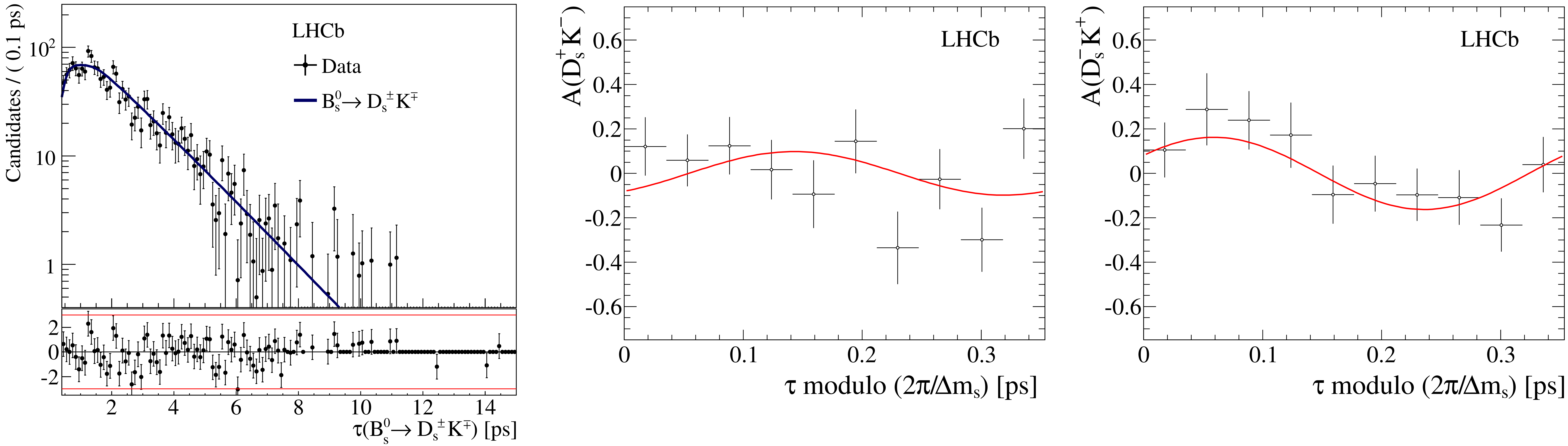
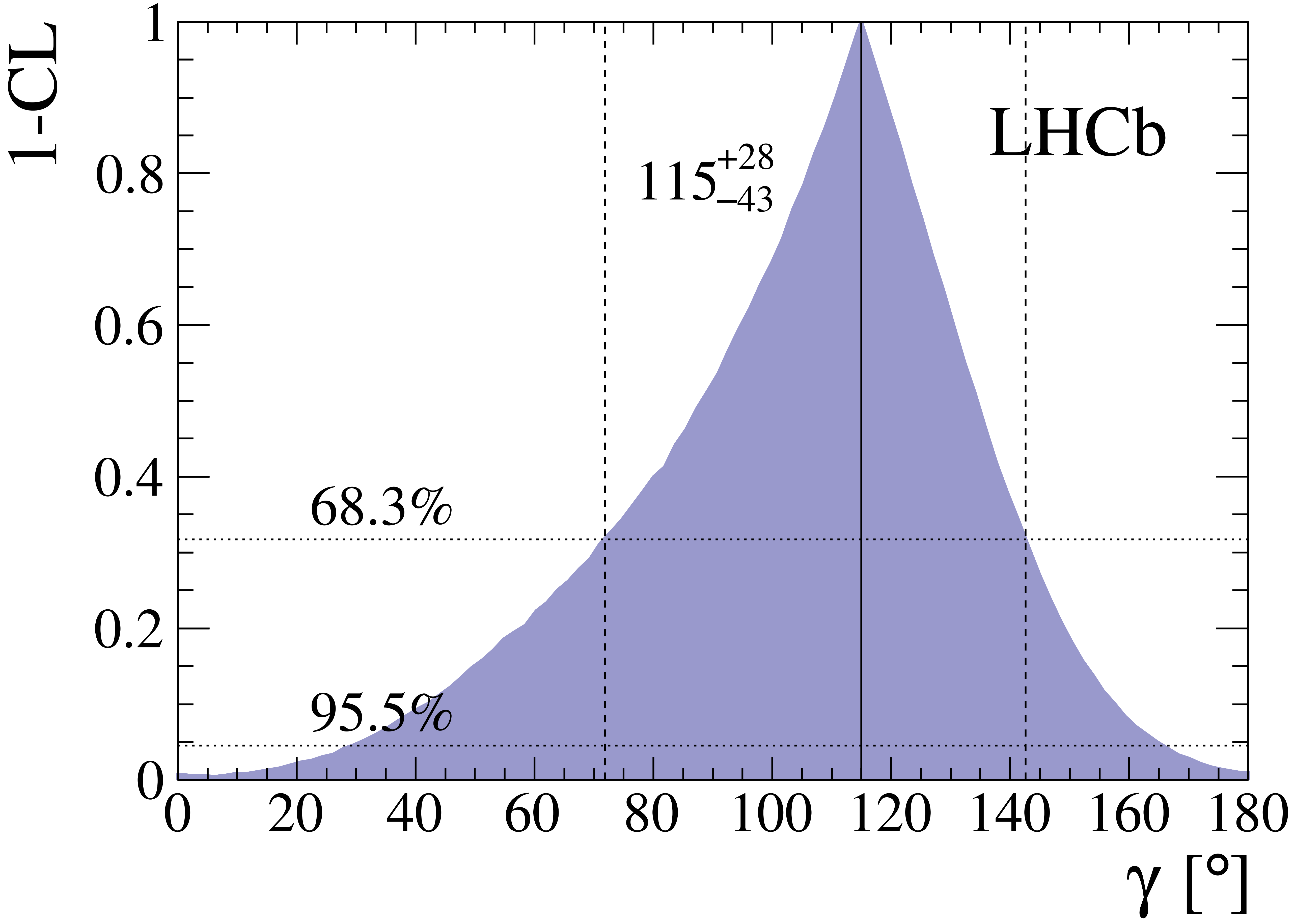


The measurement of γ

LHCb-PAPER-2014-038

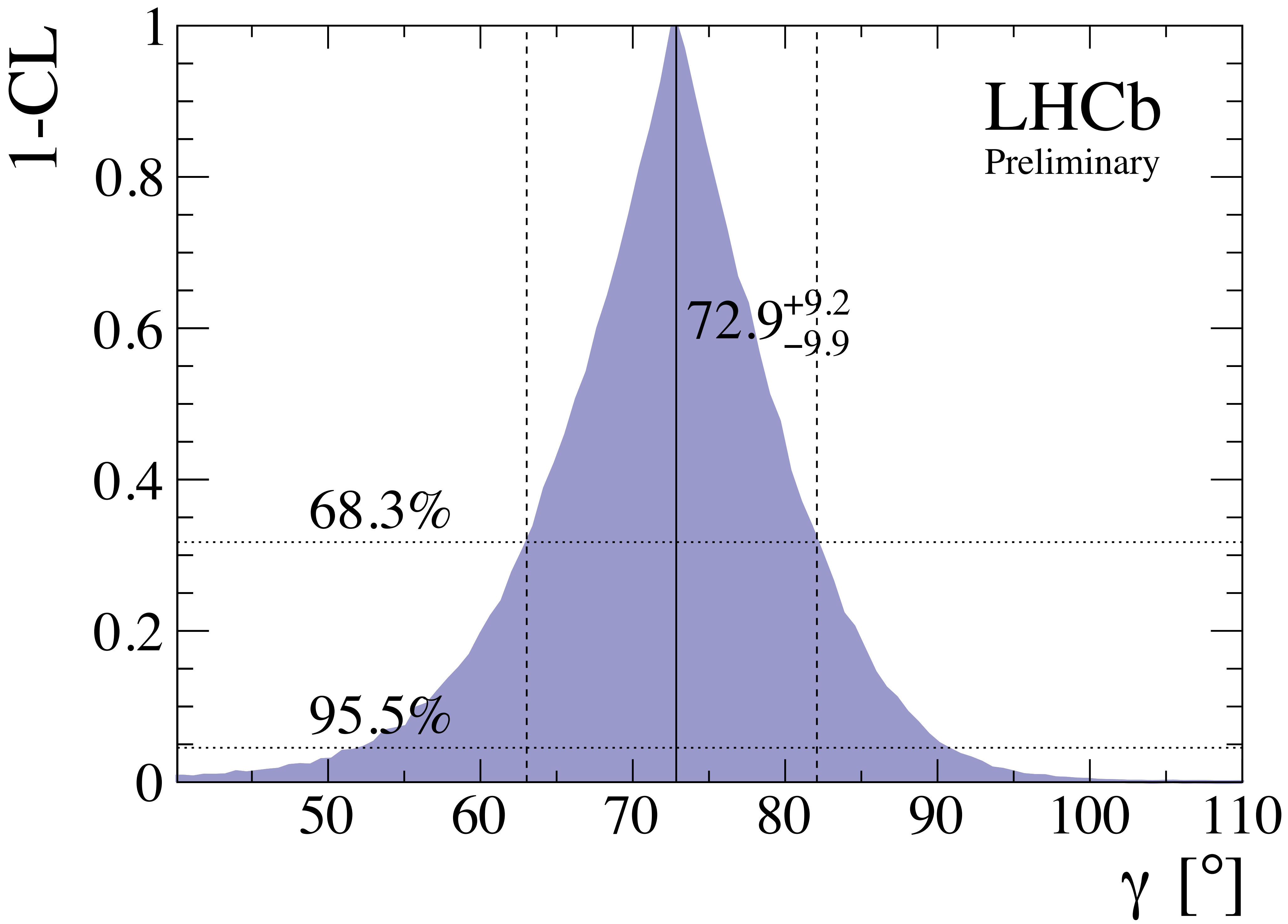
$$\gamma = (115^{+28}_{-43})^\circ$$



About 2.8 sigma away from no CP violation point...

The impact of LHCb on γ

LHCb-CONF-2014-014



$$\gamma = (72.9^{+9.2}_{-9.9})^\circ \quad @\,68\%\ \mathrm{CL}\,,$$

$$\gamma \in [63.0, 82.1]^\circ \quad @\,68\%\ \mathrm{CL}\,,$$

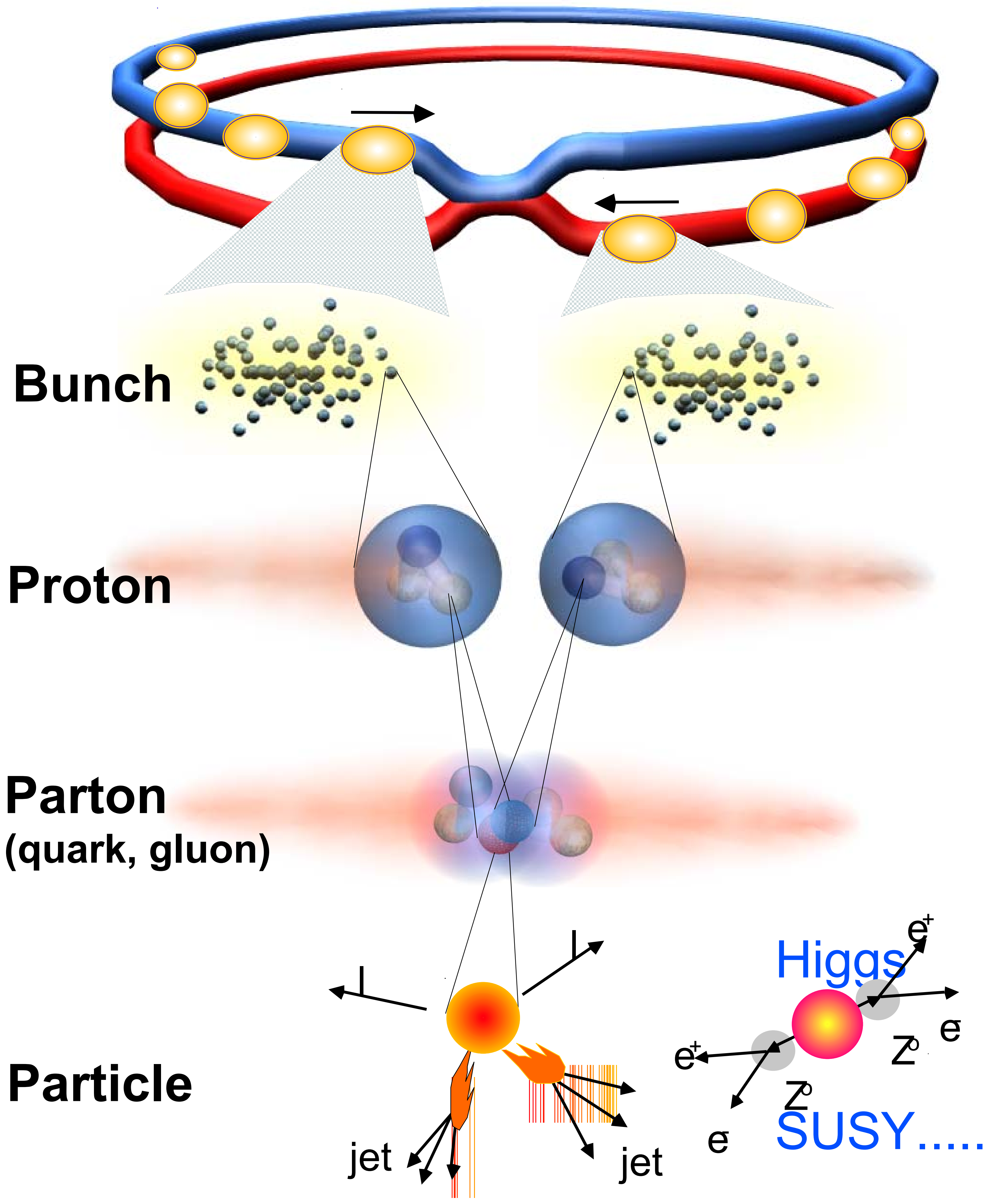
$$\gamma \in [52.0, 90.5]^\circ \quad @\,95\%\ \mathrm{CL}\,.$$

Combining all channels, LHCb has the world's most precise measurement of γ. The world average is now approximately ±6.5°, so we still have a way to go to catch up with α/β.

Finding particles at 40 MHz

The heartbeat of the LHC

Collisions at the LHC: summary

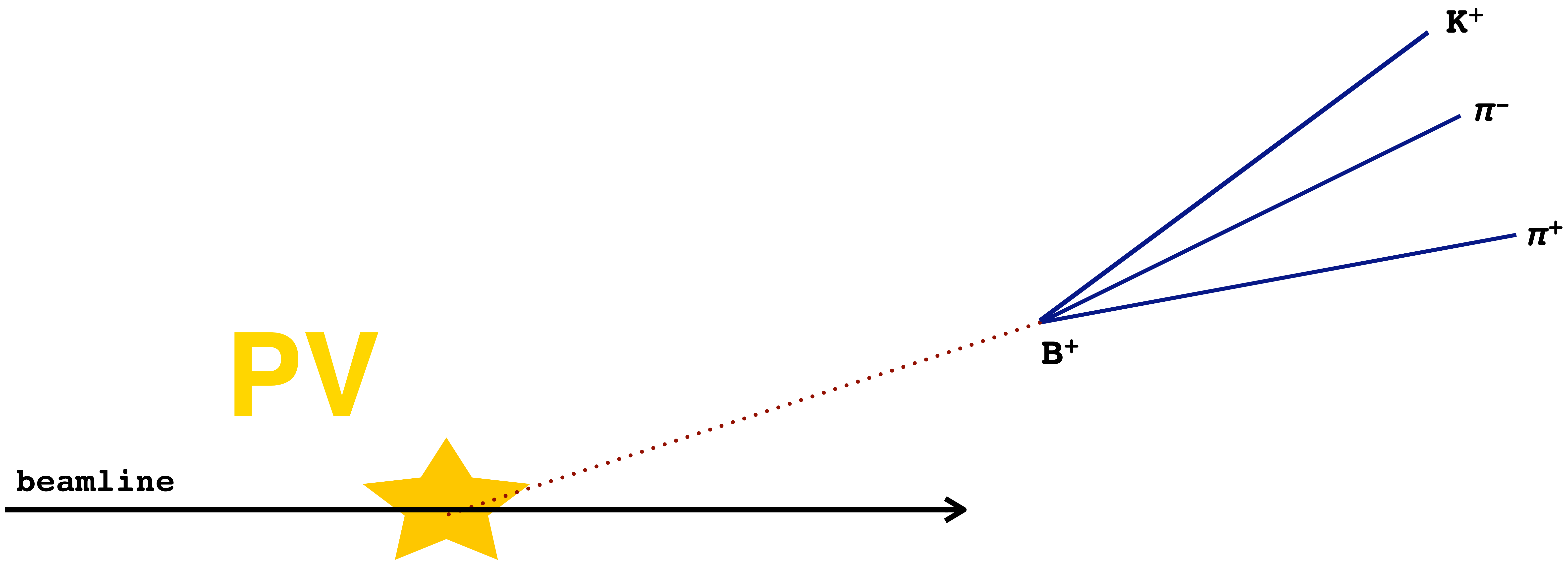


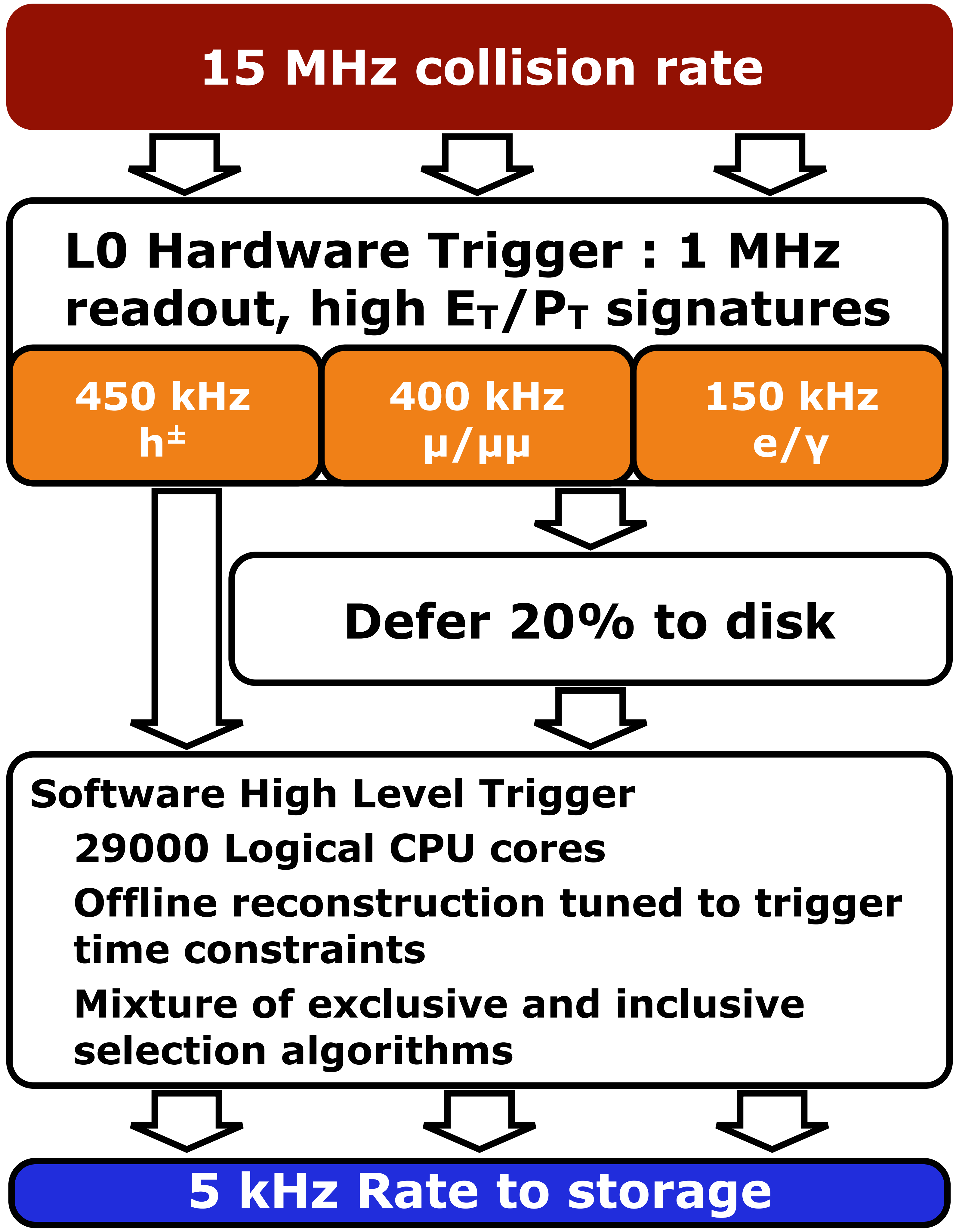
Proton - Proton	2804 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	$10^{34} cm^{-2}s^{-1}$
Crossing rate	40 MHz
Collision rate ≈	10^7-10^9

New physics rate ≈ .00001 Hz

Event selection:
1 in 10,000,000,000,000

A good approach in Run1





LHCb-PUB-2011-003

In Run I, this was a good approach : only 0.5% of bunch crossings contain bbar, so we can use simple inclusive criteria to distinguish bbar from the rest and save them

Real time event selection

1.

Information gathering
("reconstruction") stage

Real time event selection

1. Information gathering
("reconstruction") stage ⇒ 

Real time event selection

1. Information gathering (“reconstruction”) stage ⇒ 

⇓

2. Event selection stage

Real time event selection

1. Information gathering (“reconstruction”) stage ⇒ 

⇓

2. Event selection stage ⇒ Selected | Rejected

Real time event selection

1. Information gathering ("reconstruction") stage ⇒ 

⇓

2. Event selection stage ⇒ Selected | Rejected

⇓

3. Next reconstruction stage ⇒  

⇓

Displaced track trigger

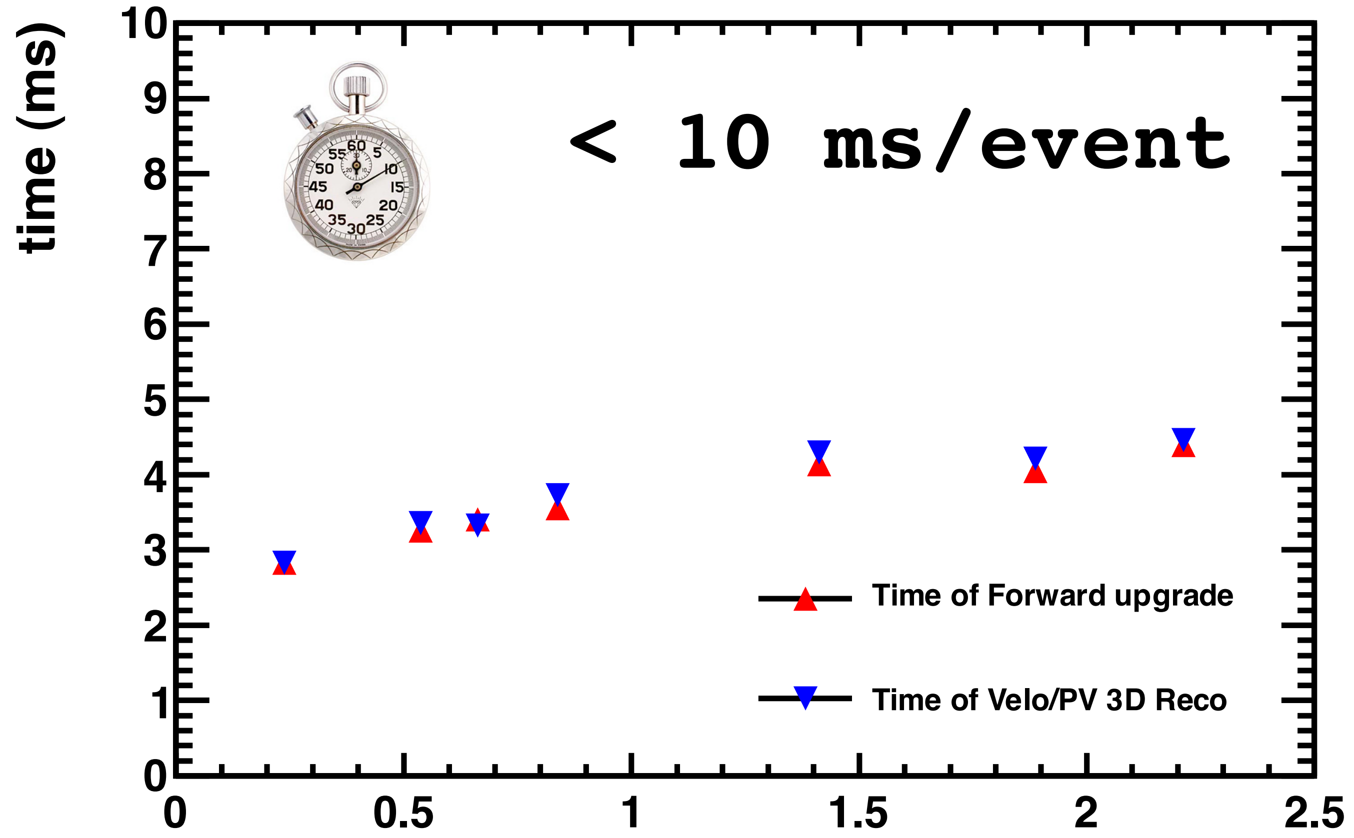
1. Full reconstruction of tracks in vertex locator

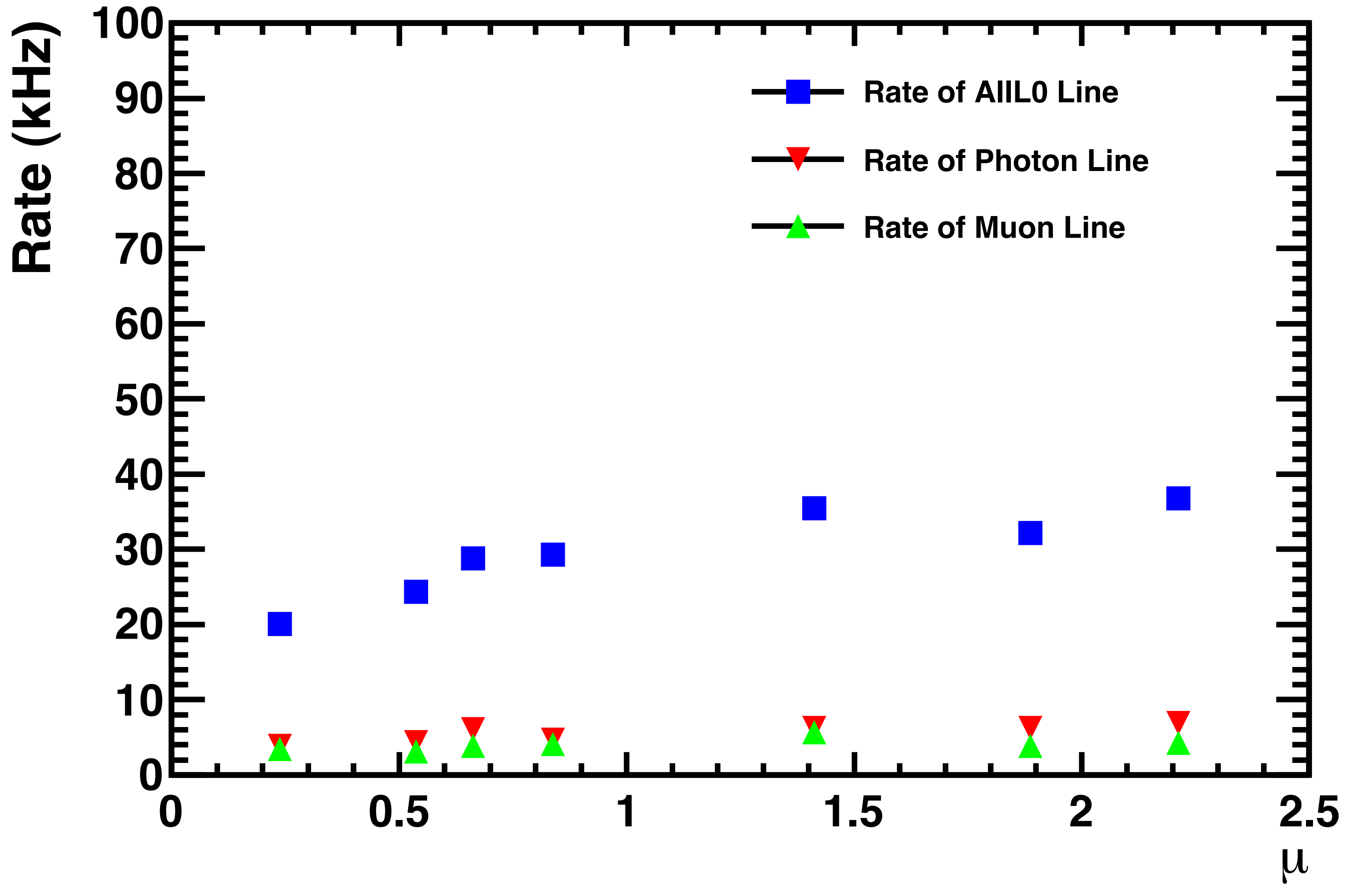
⇓

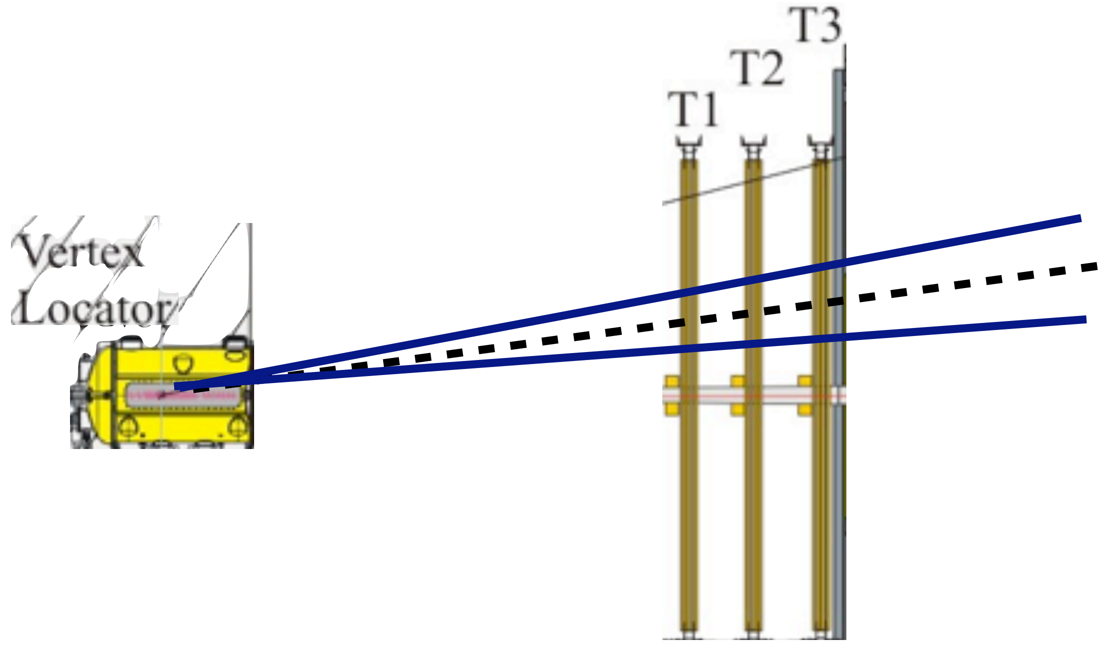
Select displaced tracks

⇓

2. Reconstruction of displaced tracks in regions of interest

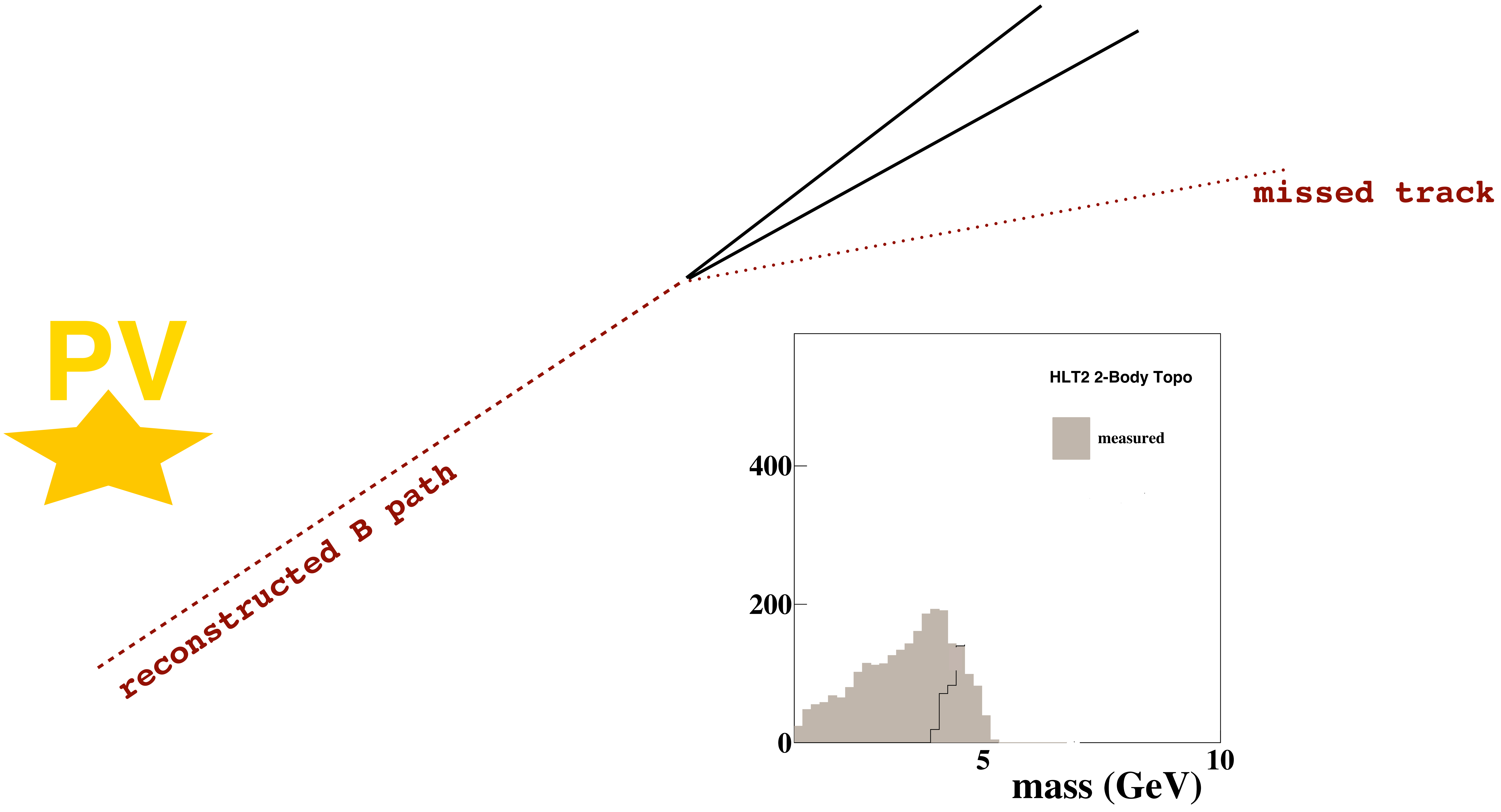






Region of interest defined by assumed track P&P_T

A topological decision tree trigger



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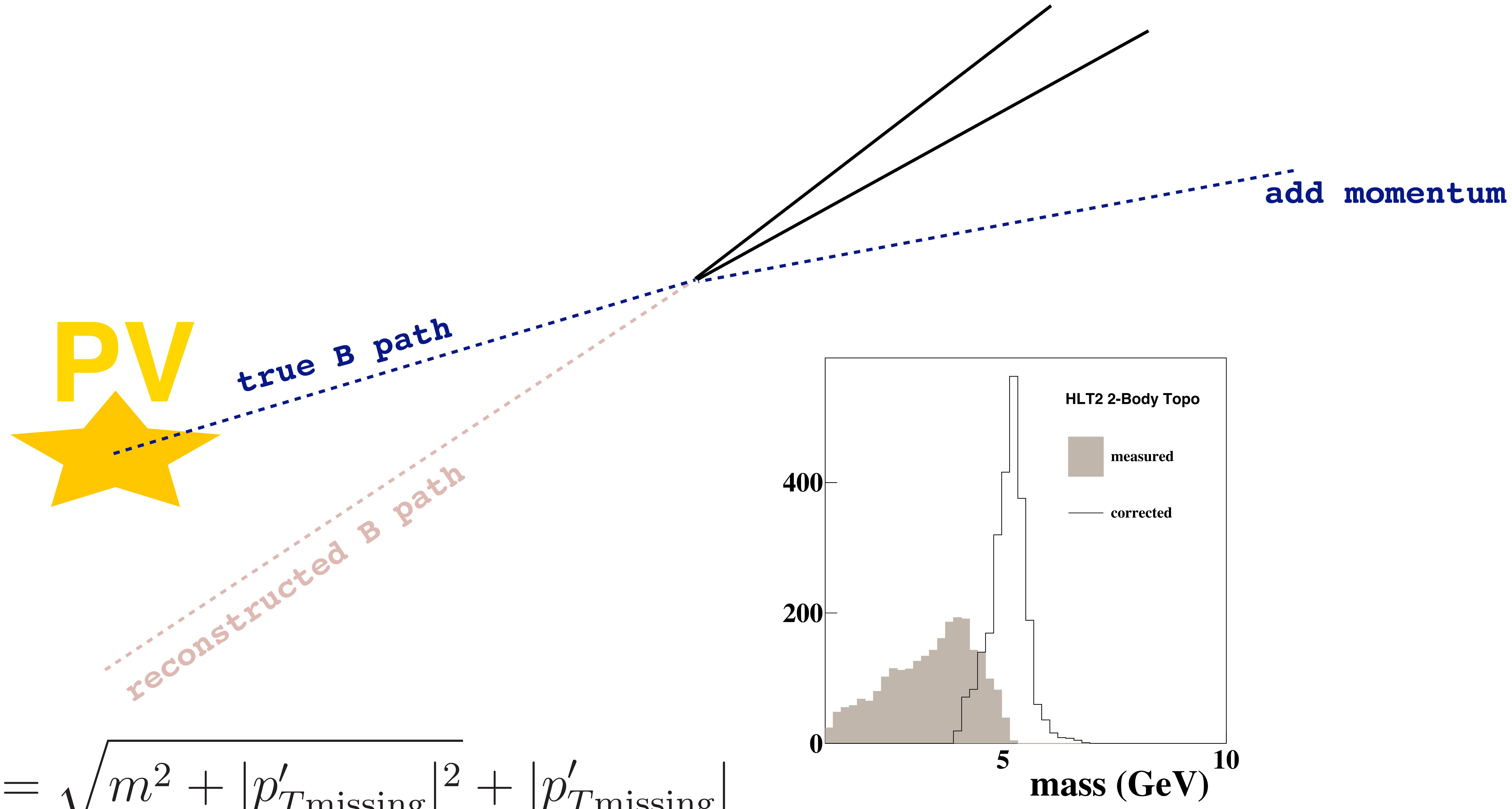
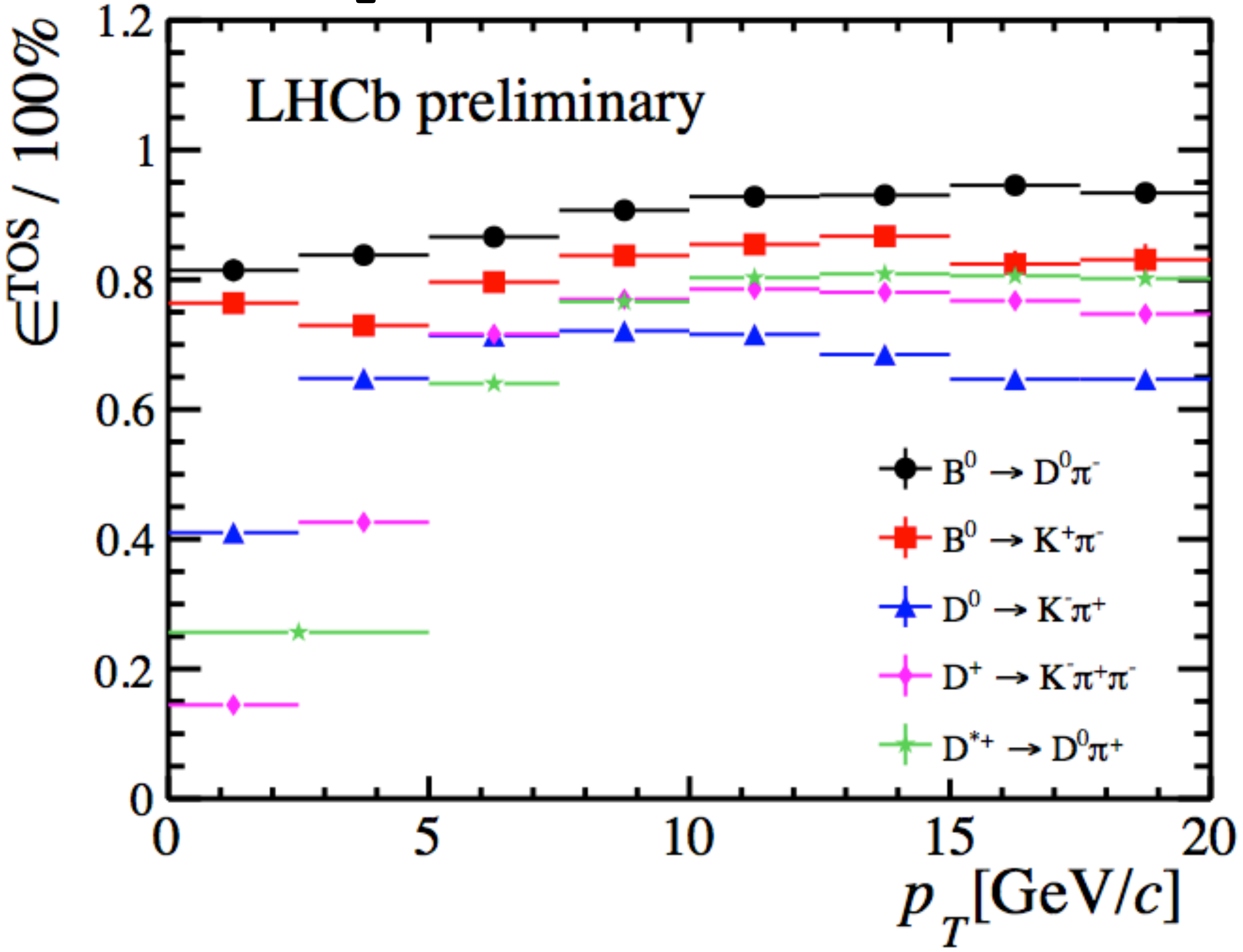


$$m_{\text{corrected}} = \sqrt{m^2 + |p'_{T\text{missing}}|^2} + |p'_{T\text{missing}}|$$

Optimal performance : real-time MVA

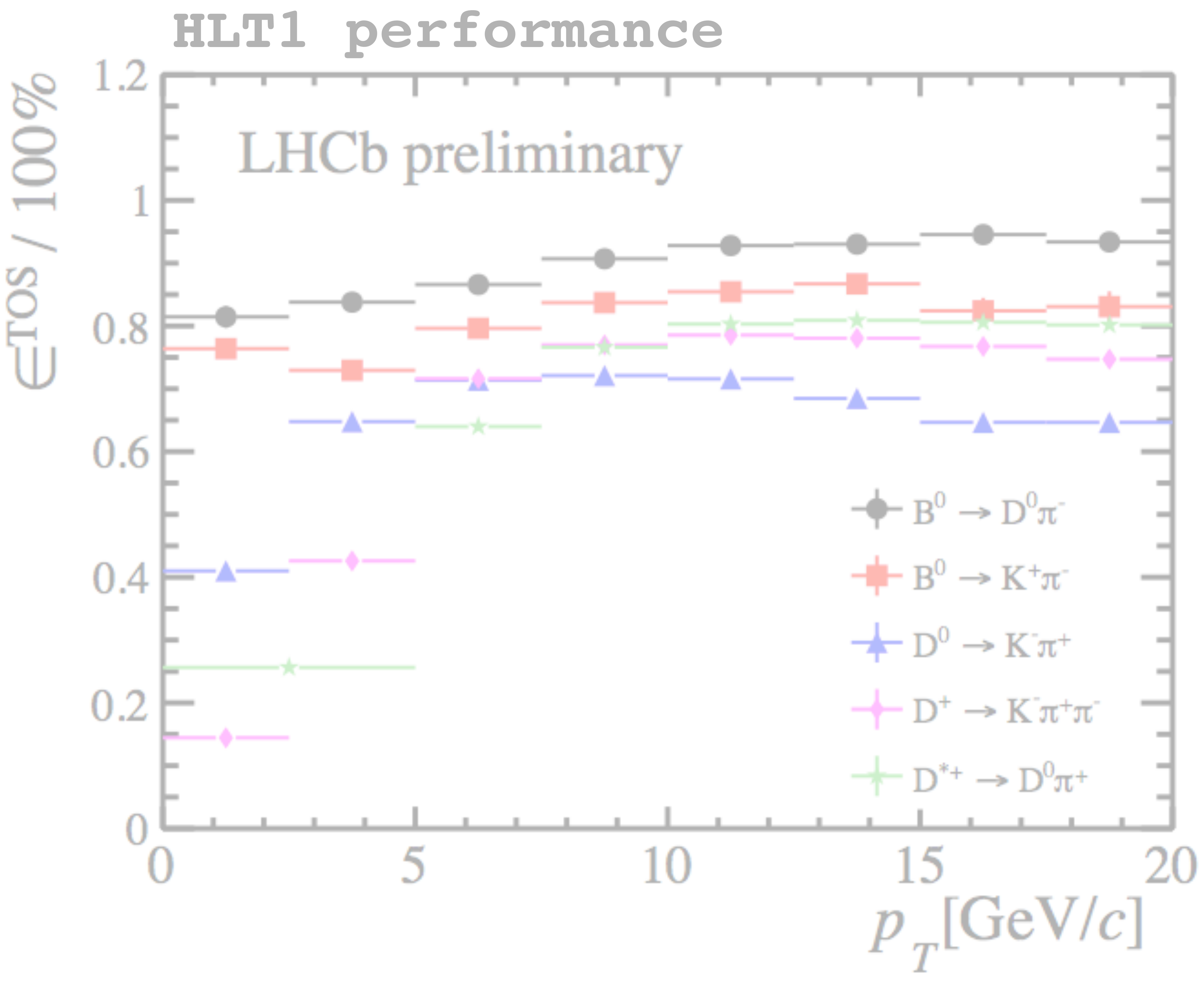
HLT1 performance

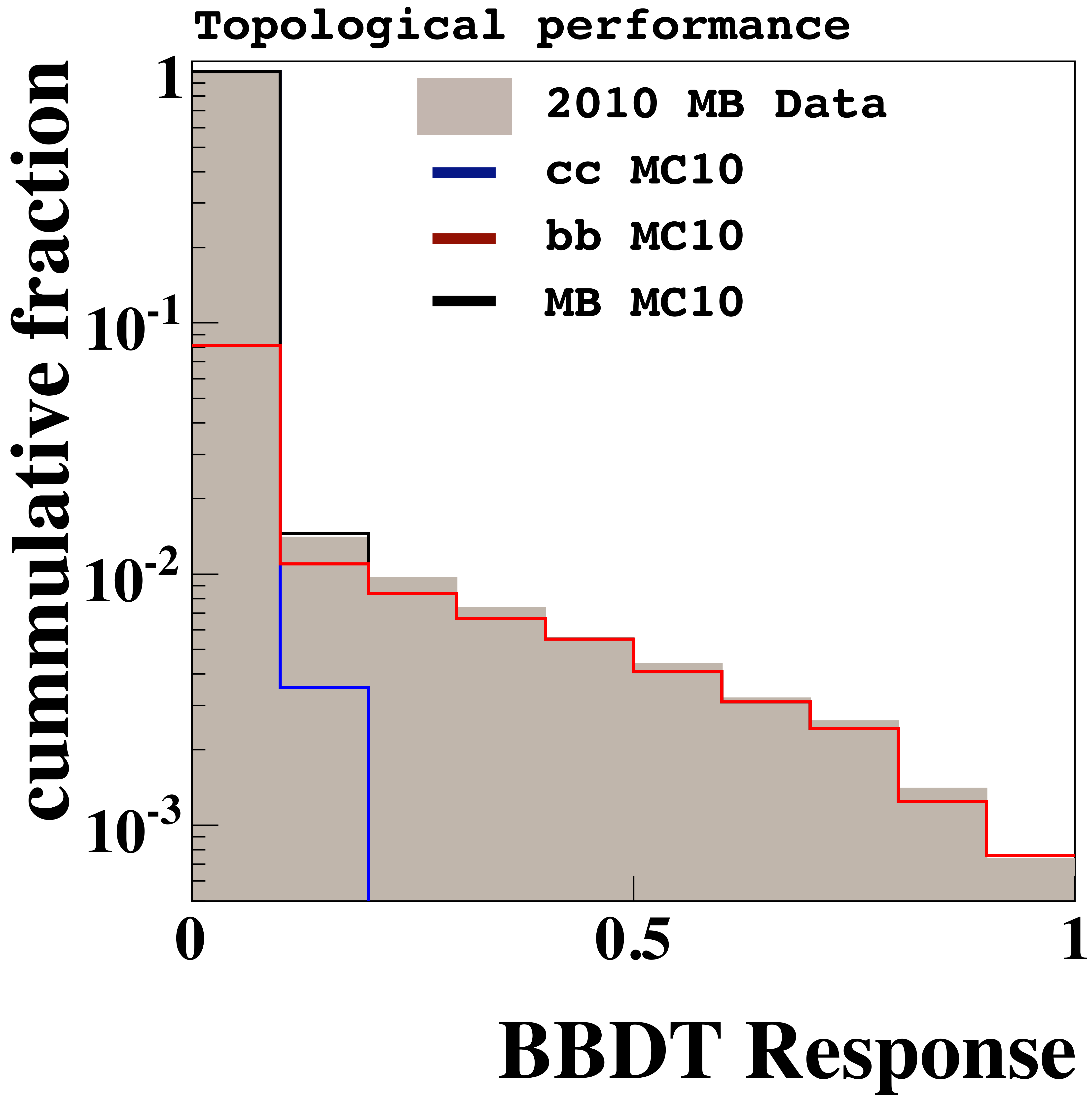


See also LHCb-PUB-2011-002,003,016
http://arxiv.org/abs/1310.8544
http://arxiv.org/abs/1211.3055

Gligorov&Williams http://arxiv.org/abs/1210.6861

Optimal performance : real-time MVA





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http://arxiv.org/abs/1211.3055

Gligorov&Williams http://arxiv.org/abs/1210.6861

Triggers today

Why do we need triggers at the LHC?

Input data rate of the LHCb experiment = 1.5 TB/second

NB : ATLAS/CMS about a bit more than one order of magnitude above LHCb

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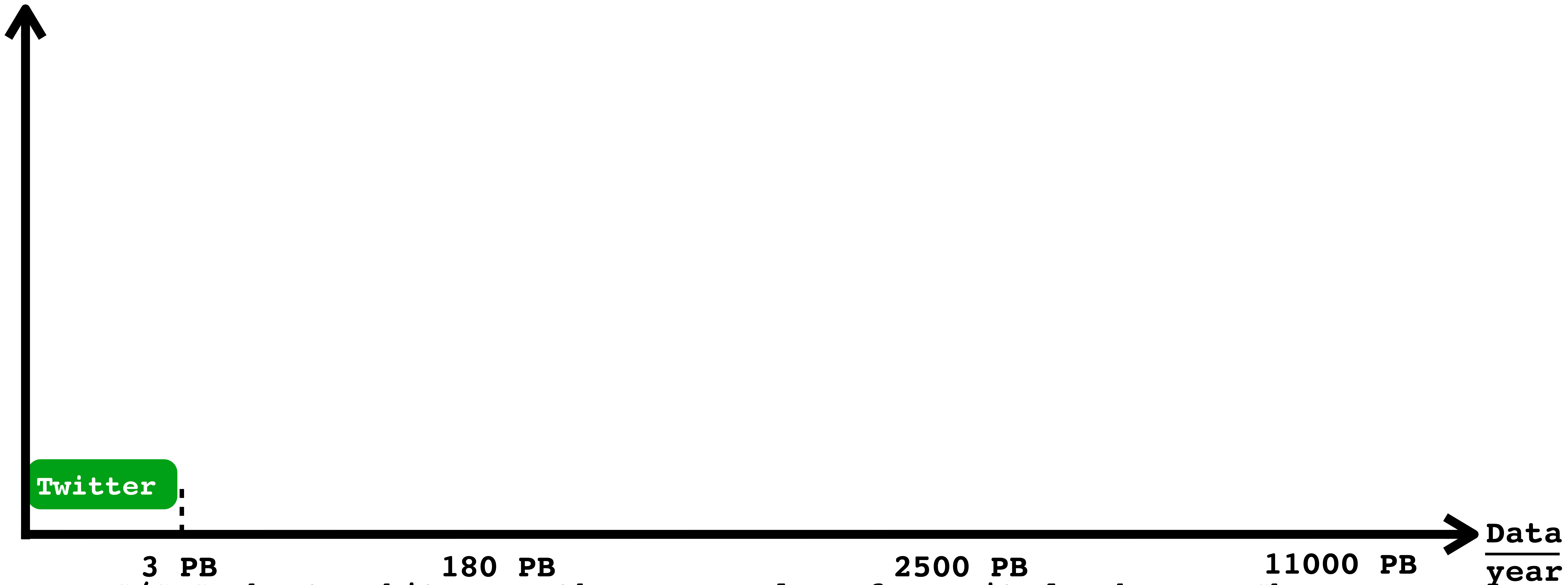

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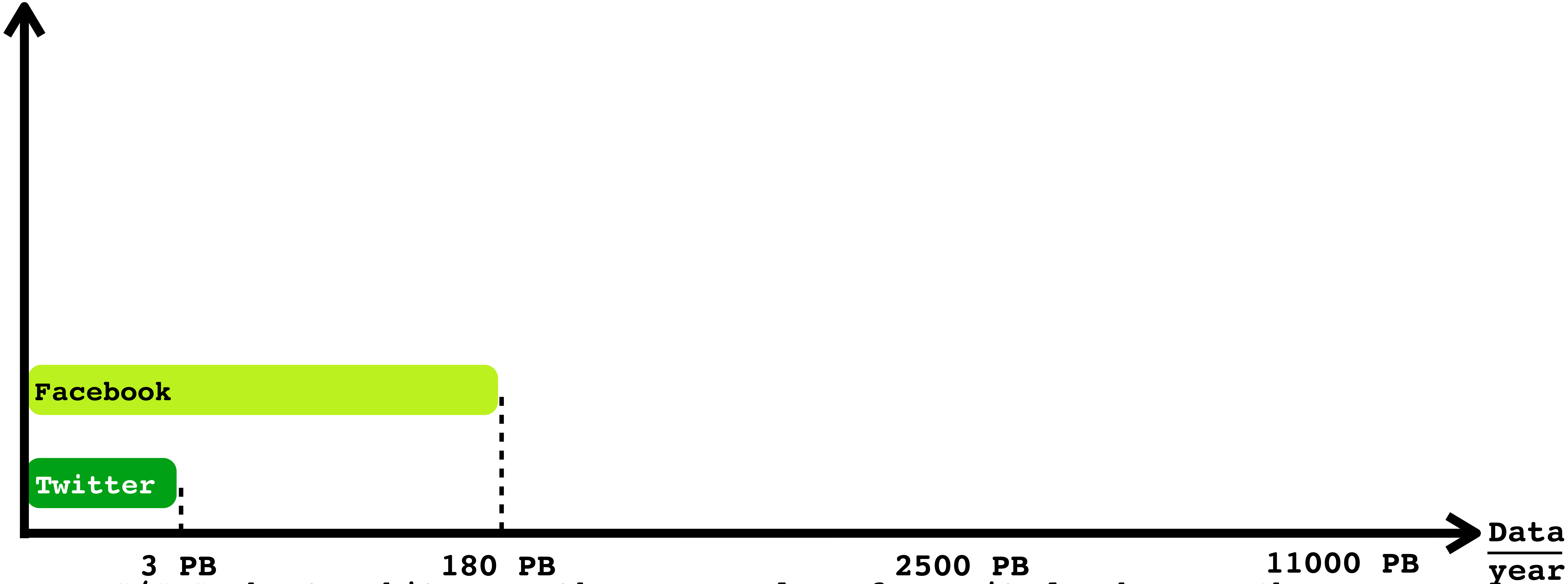

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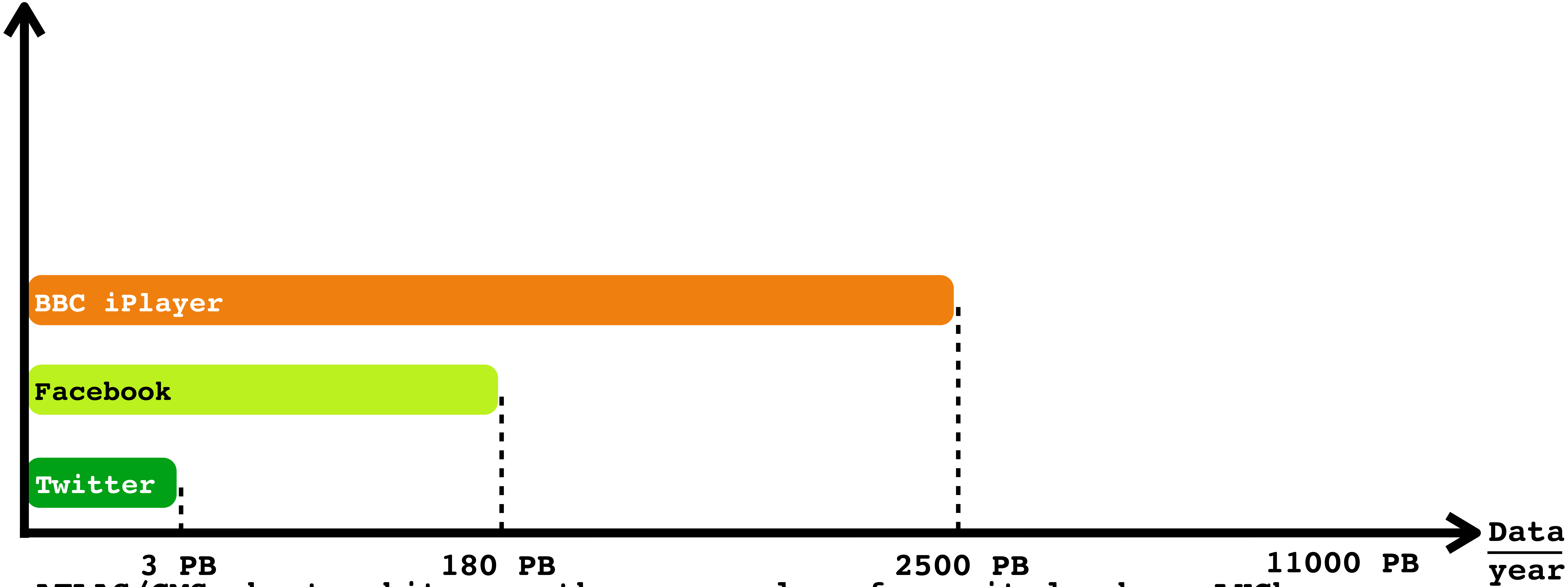

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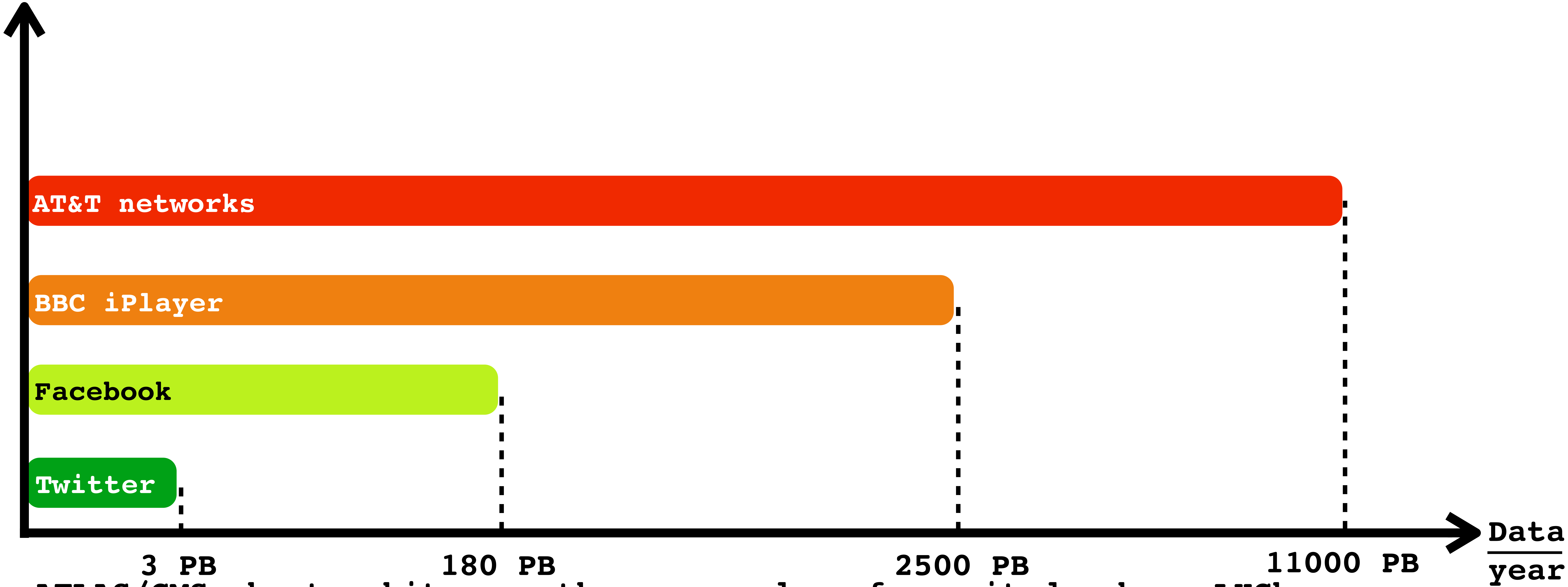

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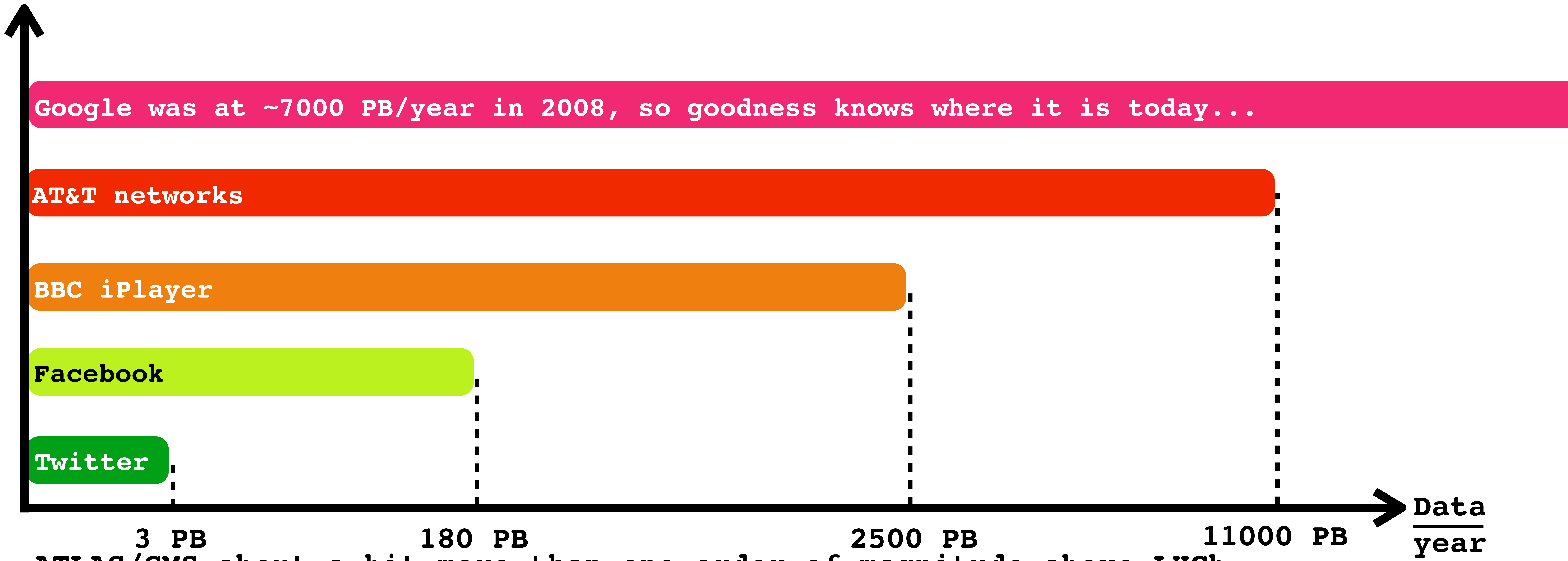

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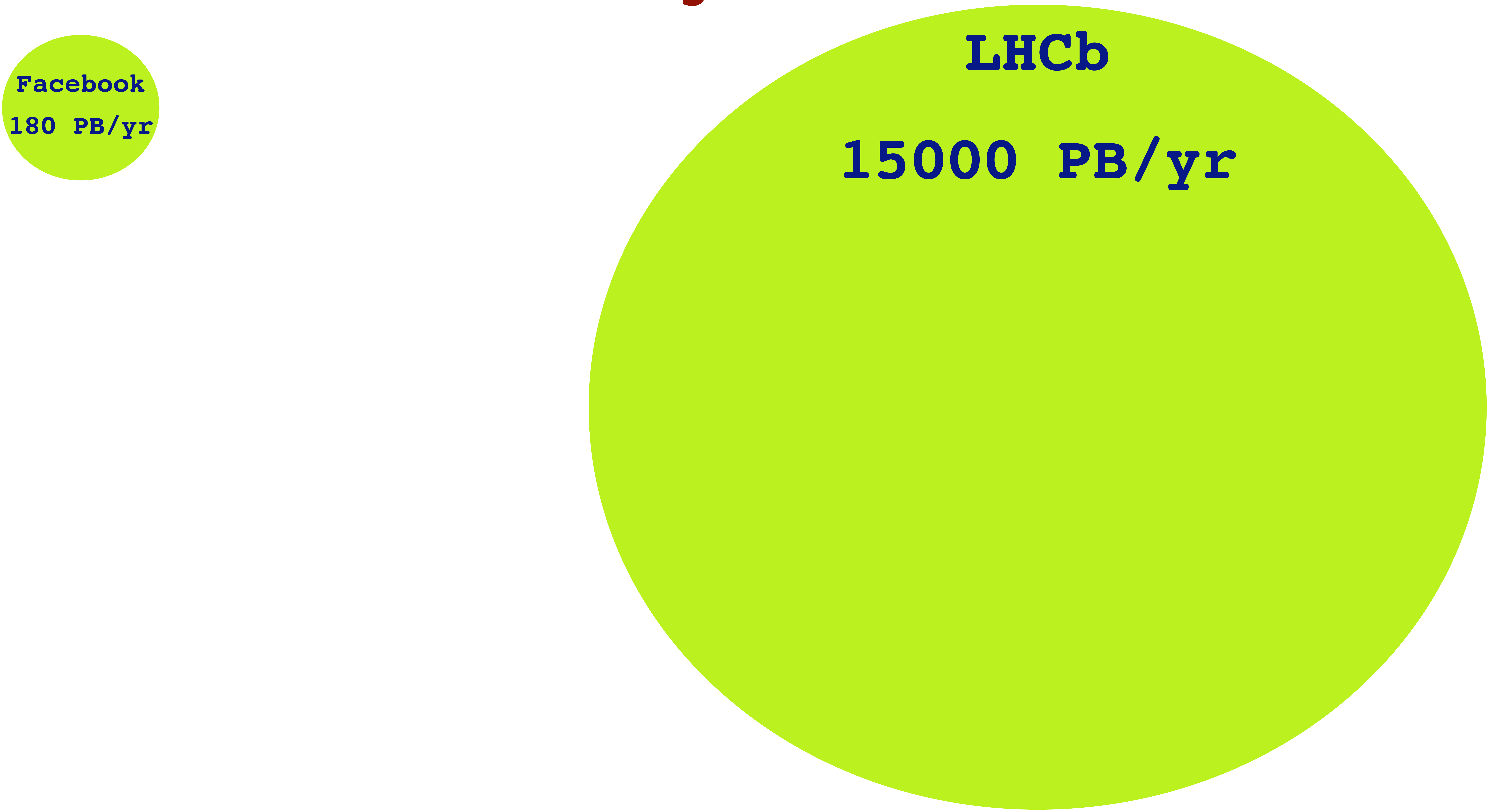
It’s all about the benjamins

Facebook

180 PB/yr

It’s all about the benjamins

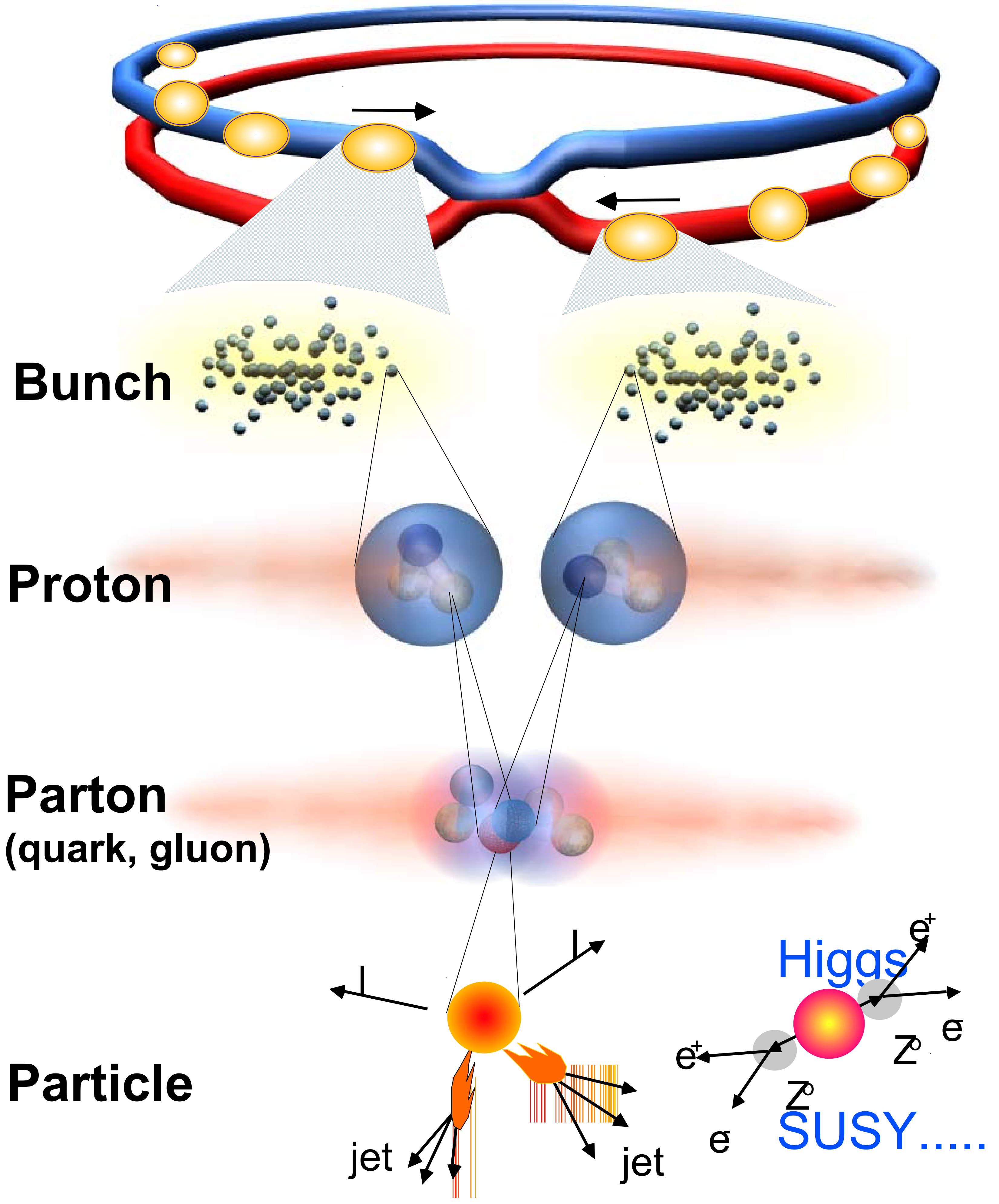


It’s all about the benjamins

It’s all about the benjamins

Back to our traditional outreach slide…

Collisions at the LHC: summary



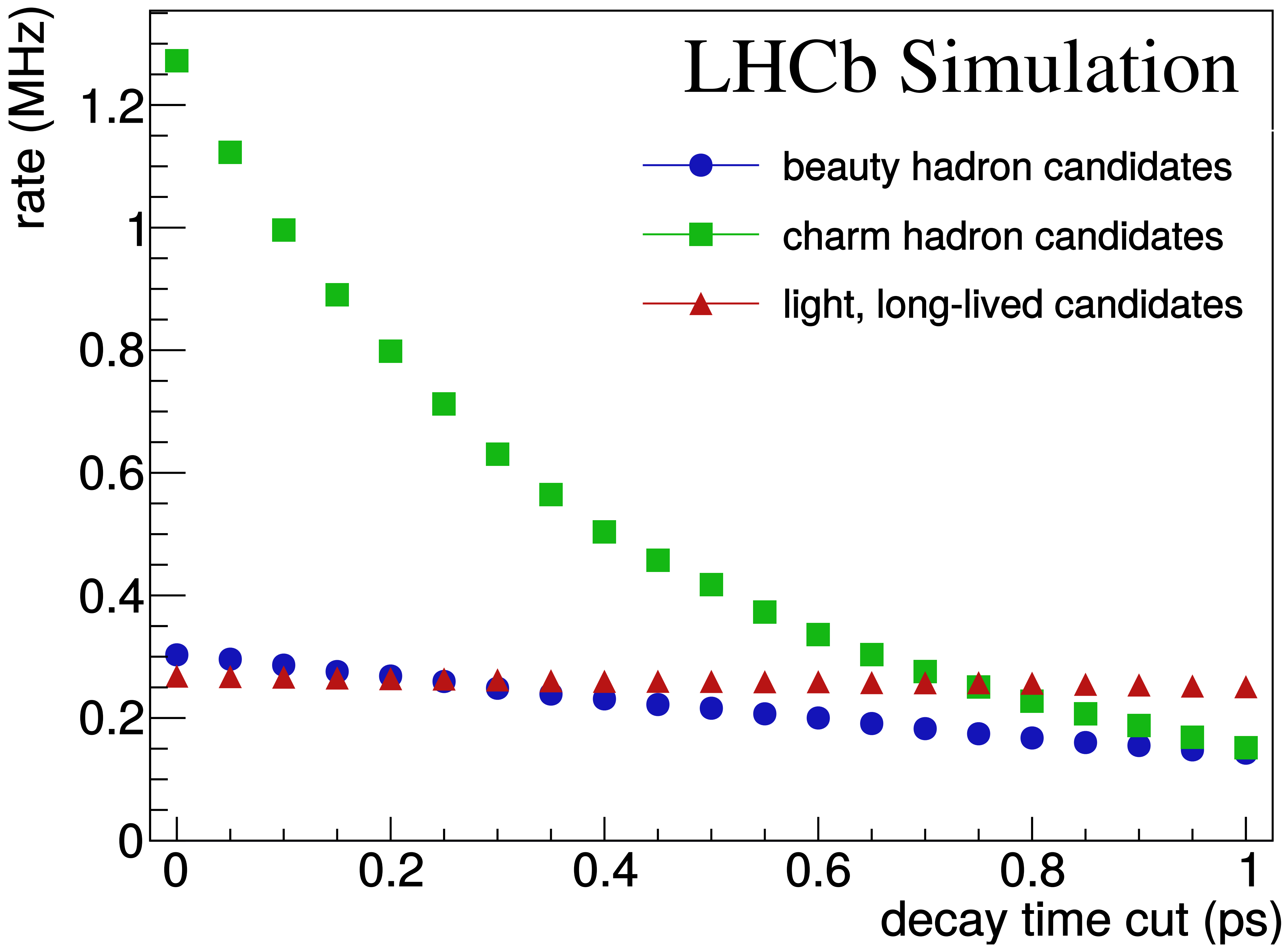
Proton - Proton	2804 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	$10^{34}cm^{-2}s^{-1}$
Crossing rate	40 MHz
Collision rate ≈	10^7-10^9

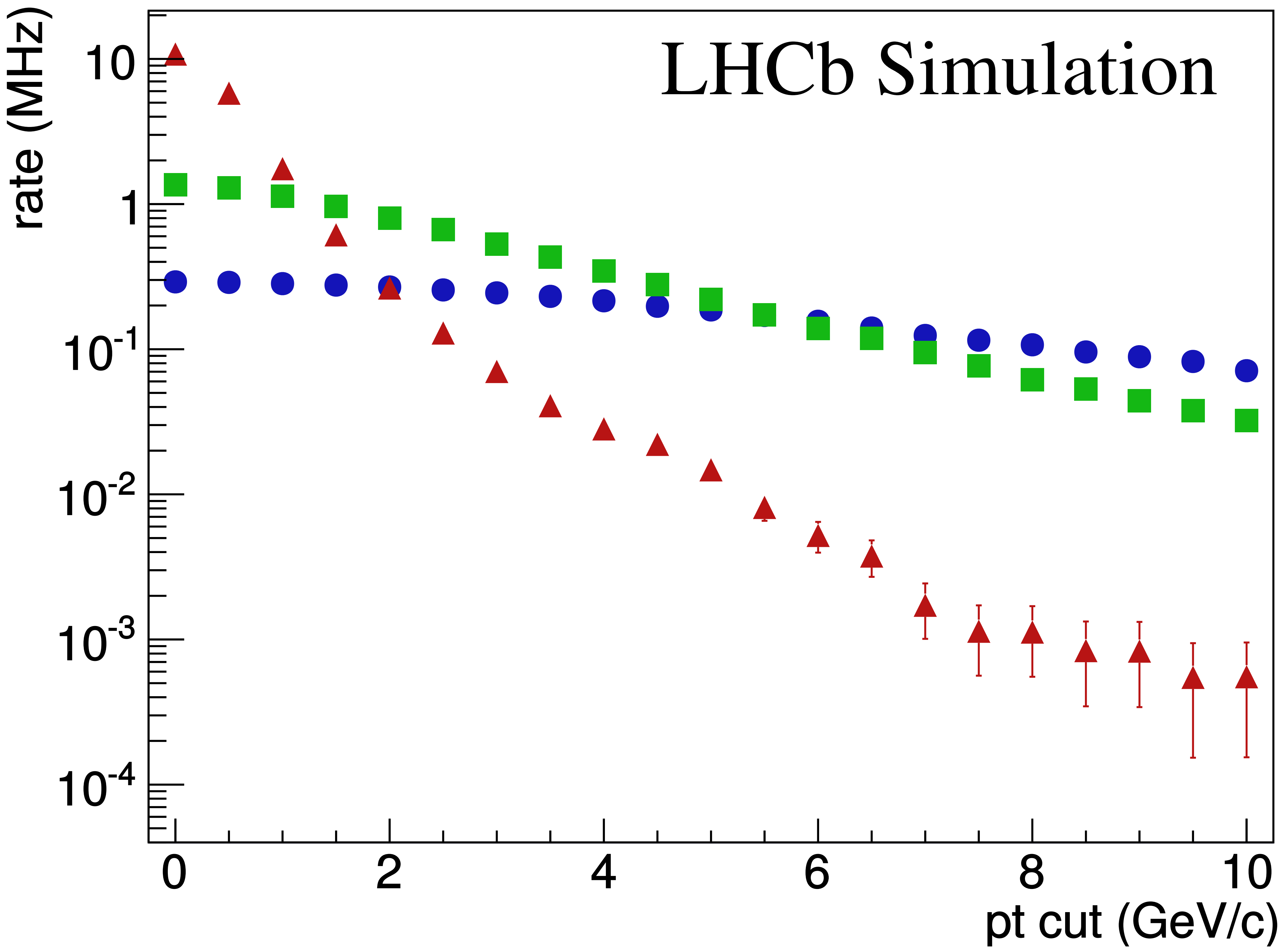
New physics rate ≈ .00001 Hz

Event selection:
1 in 10,000,000,000,000

Enter the MHz signal era

Fitzpatrick&Gligorov
LHCb-PUB-2014-027



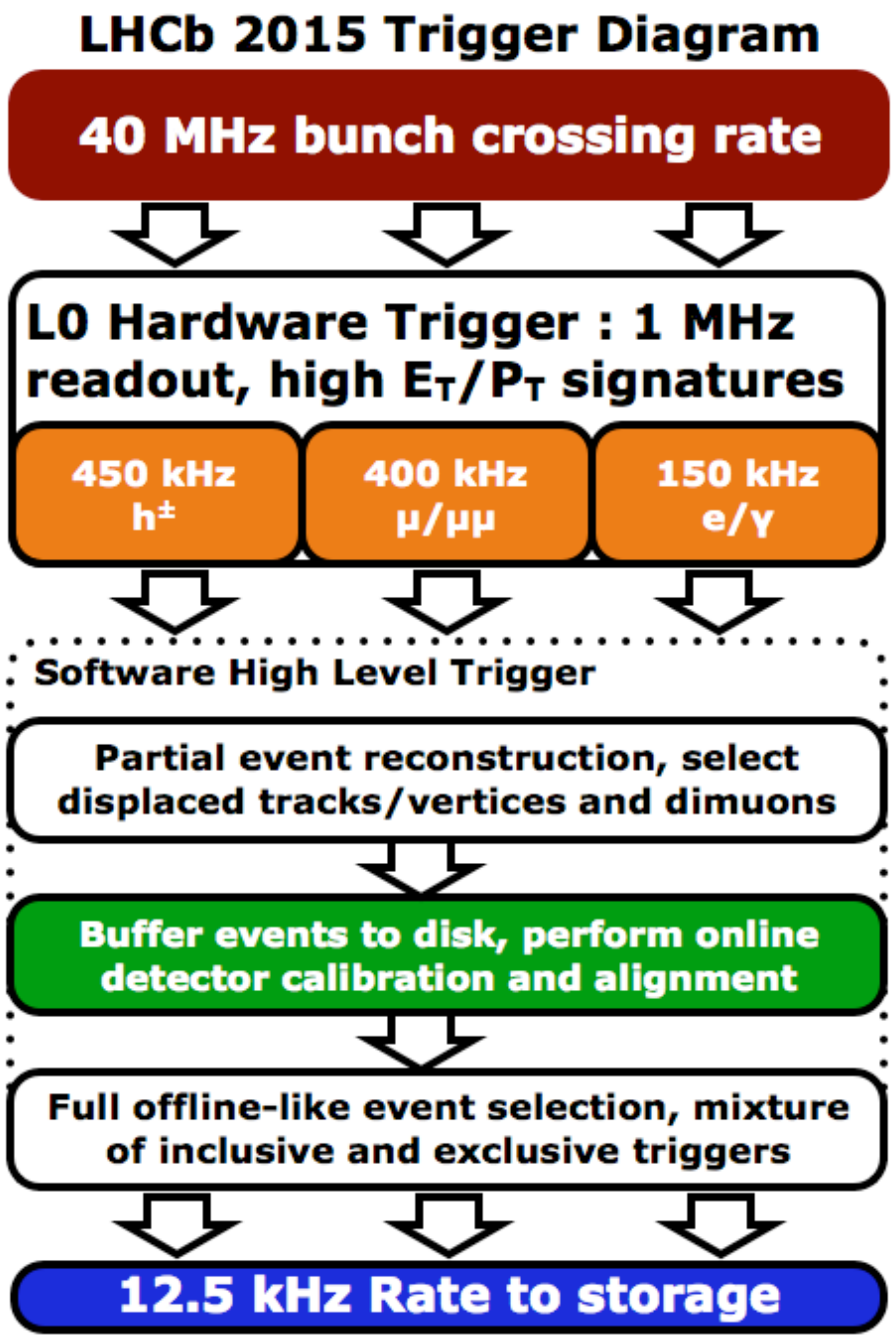


In the HL-LHC era triggers will discriminate between different signal classes!

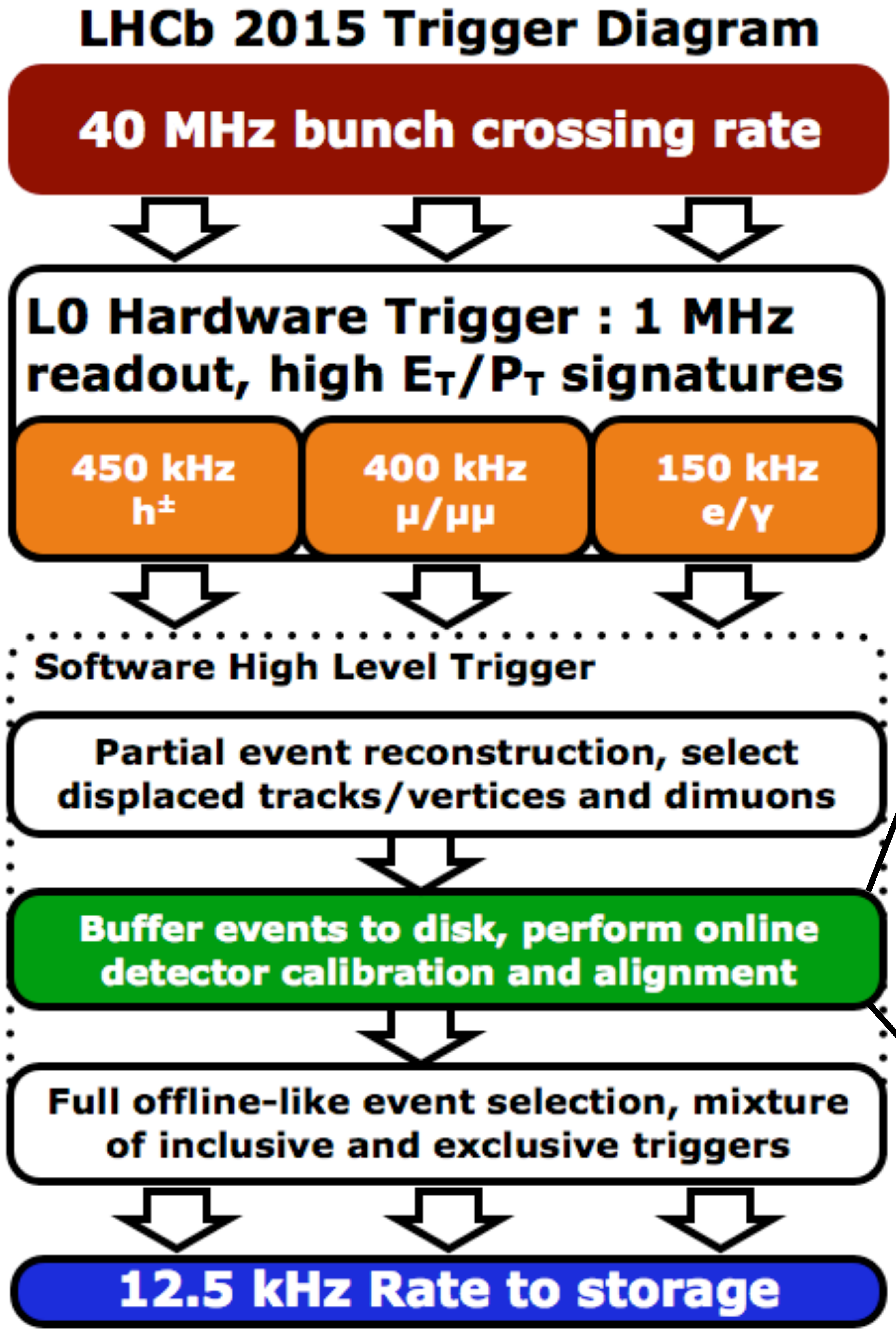
Triggers today

Triggers in the future

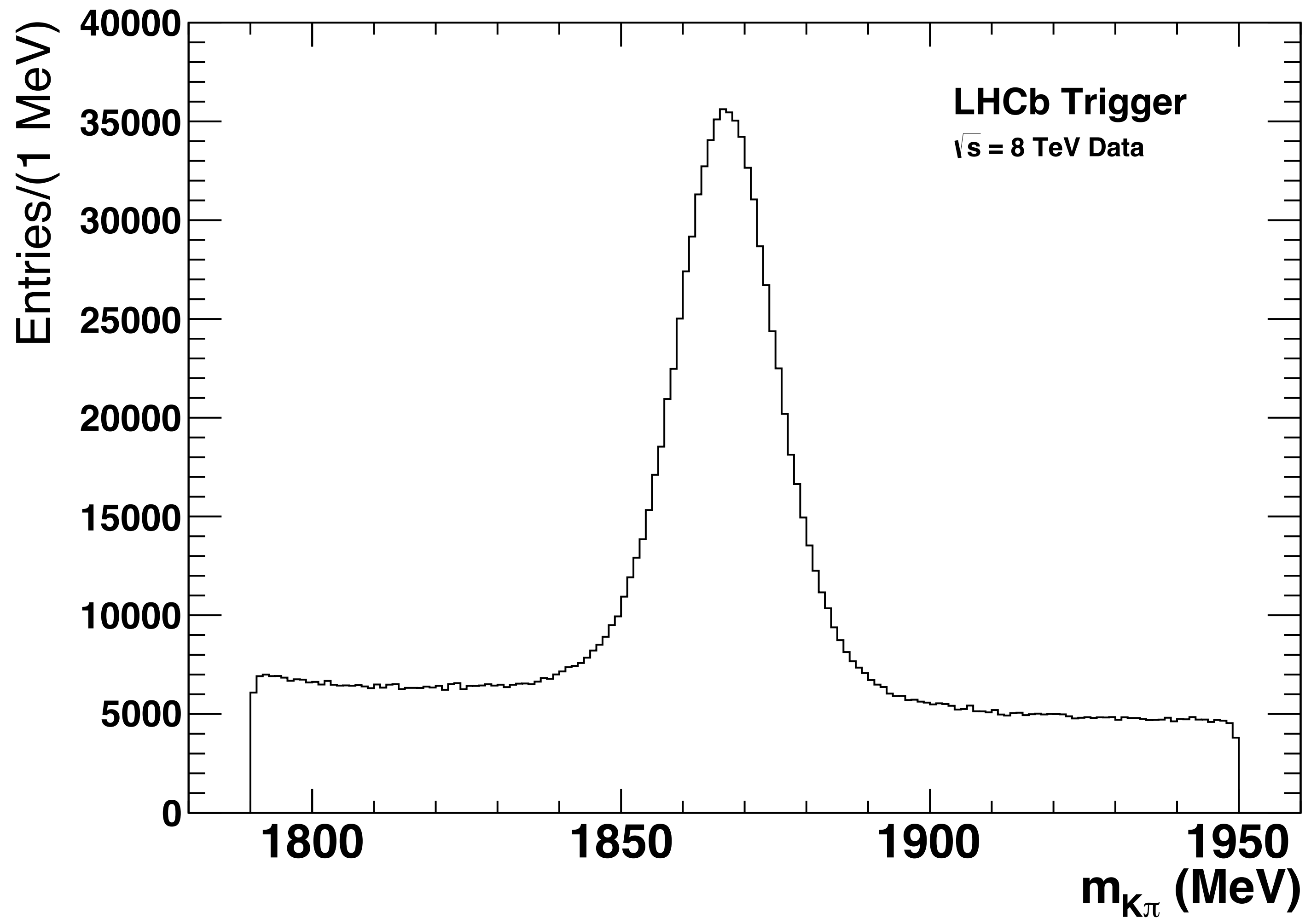
More precision ⇒ real time analysis



More precision ⇒ real time analysis

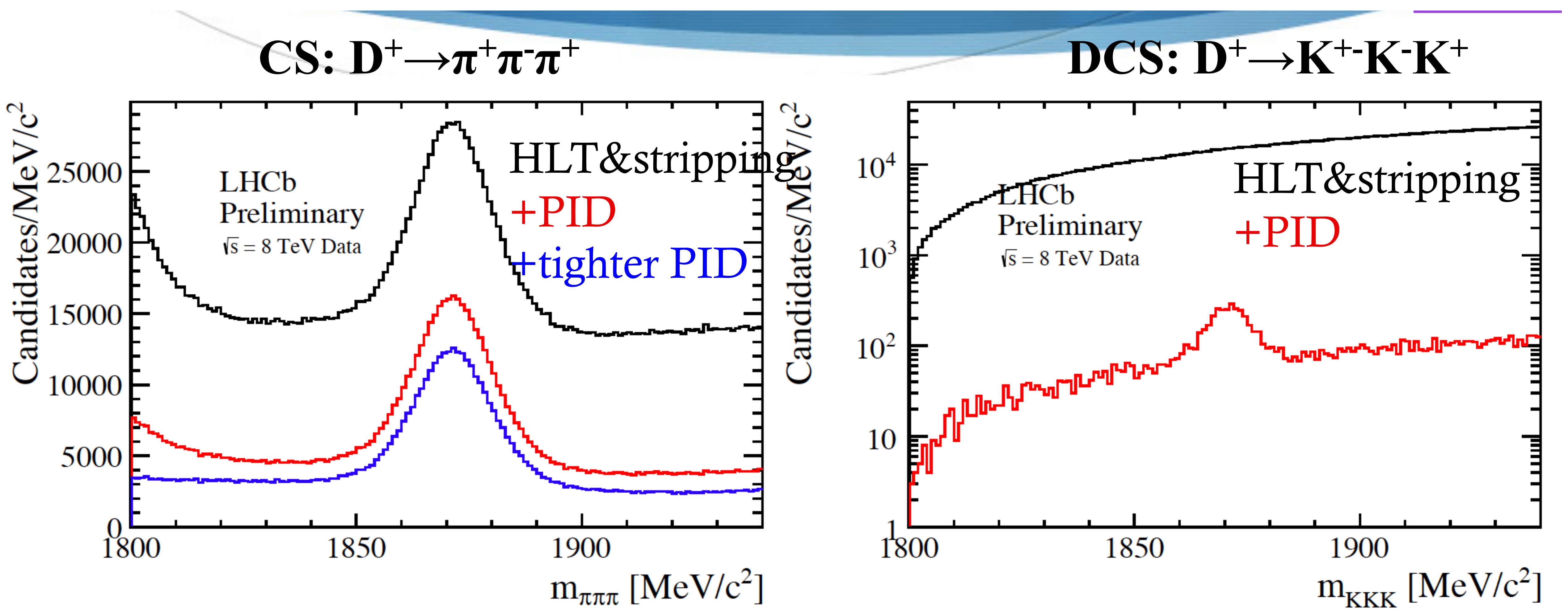


Align tracker with D^0 decays tagged in HLT

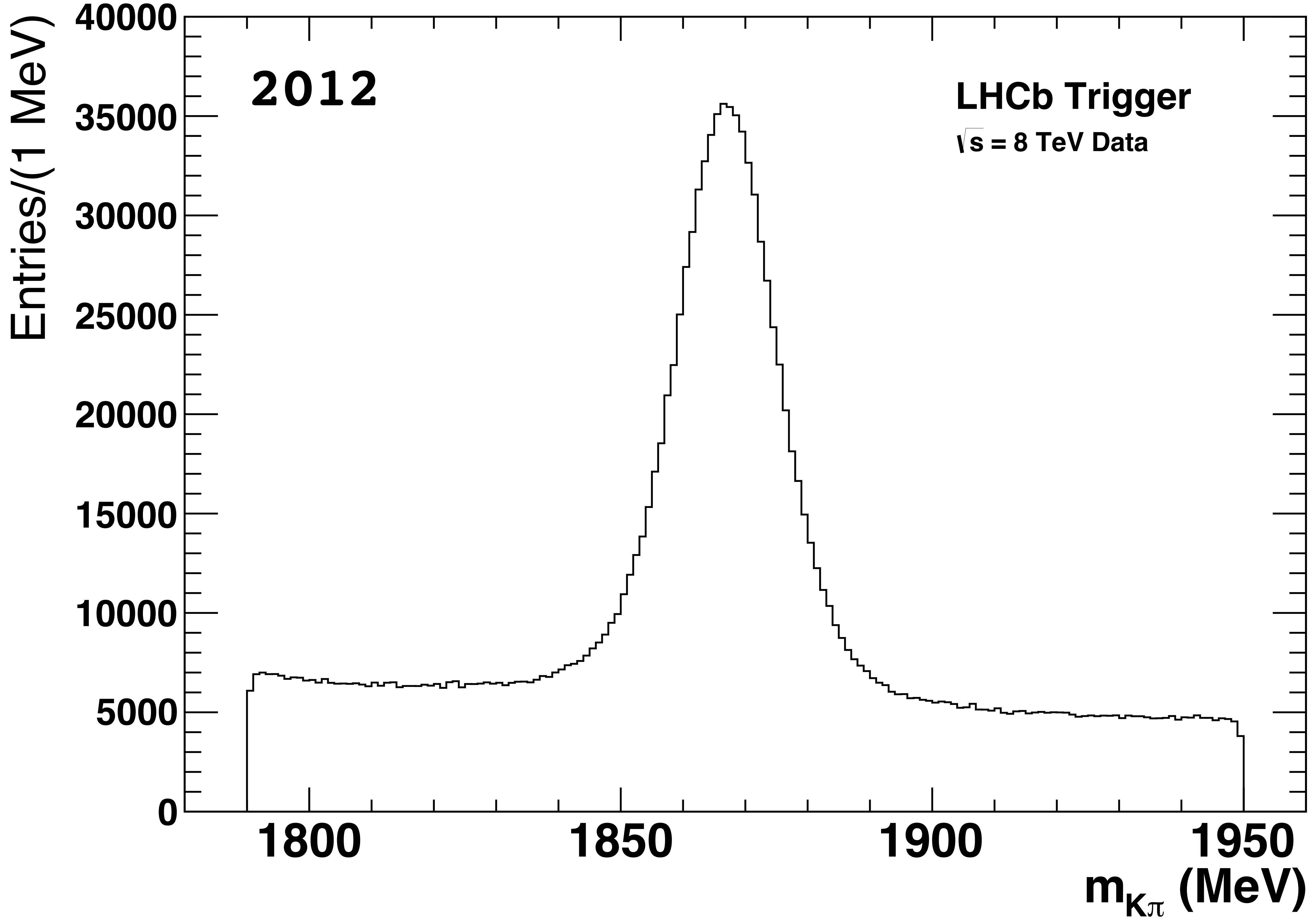


HLT2 $D^0 \to K^- \pi^+$

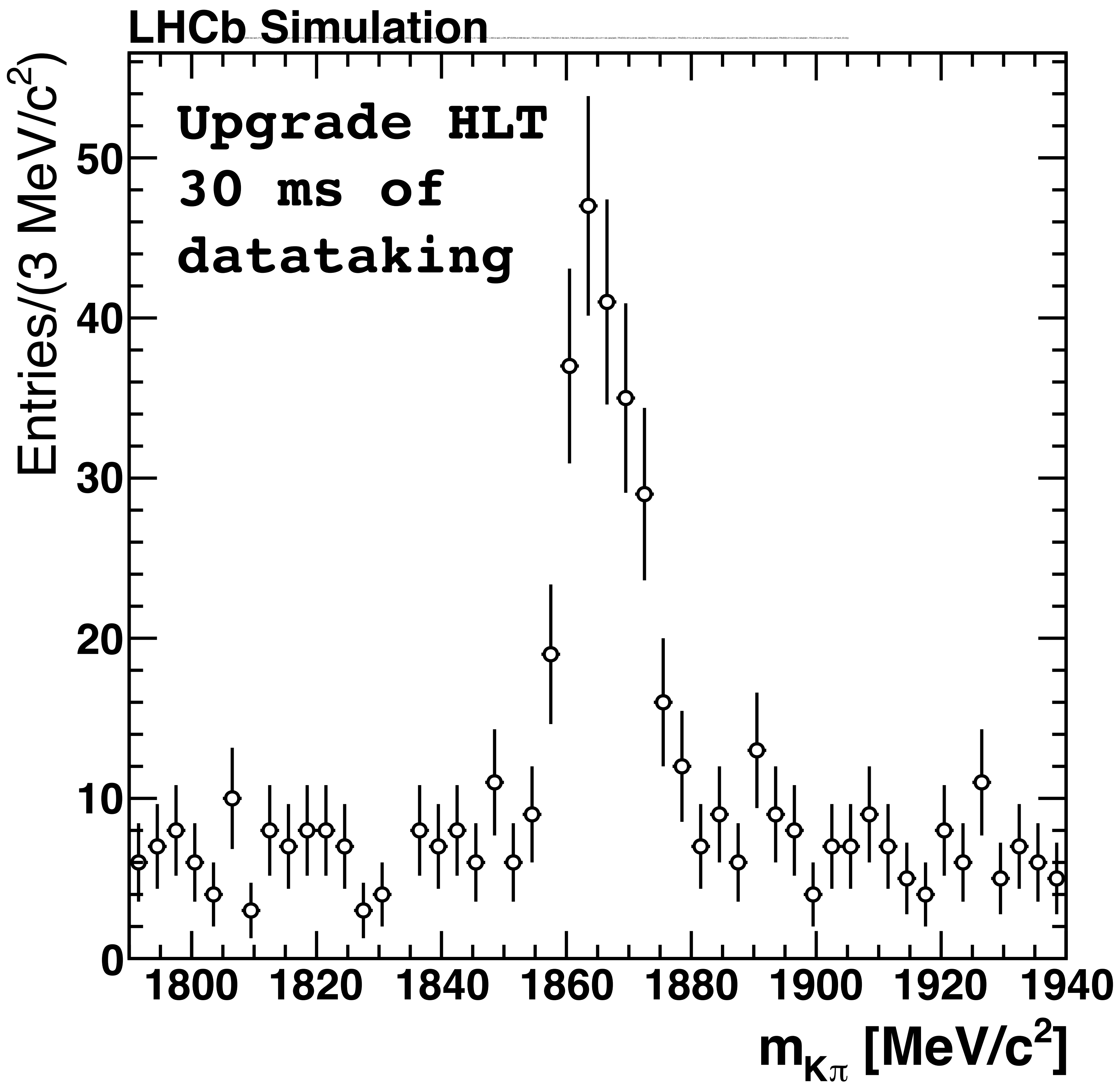
Calibrate particle identification run-by-run



Real time data analysis…

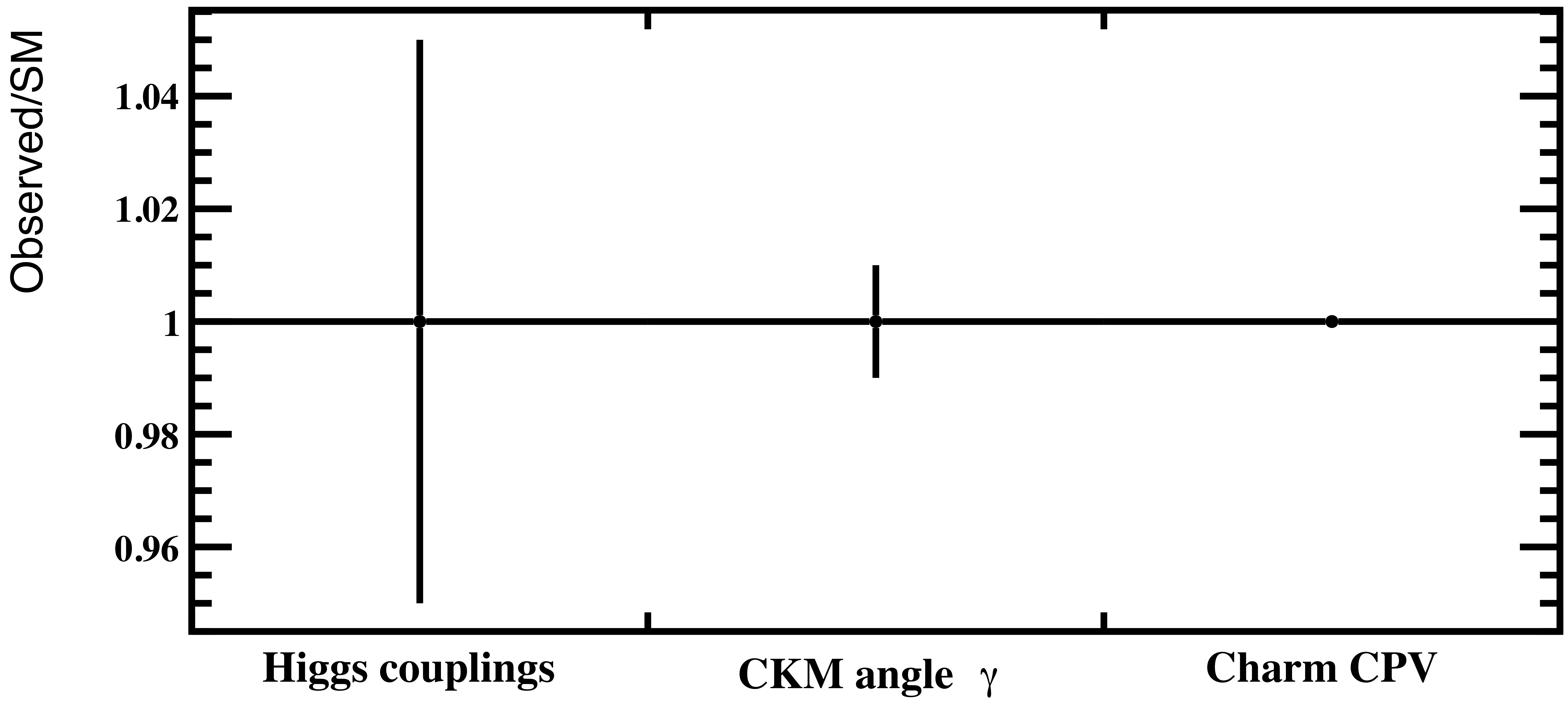


HLT2 $D^0 \to K^- \pi^+$

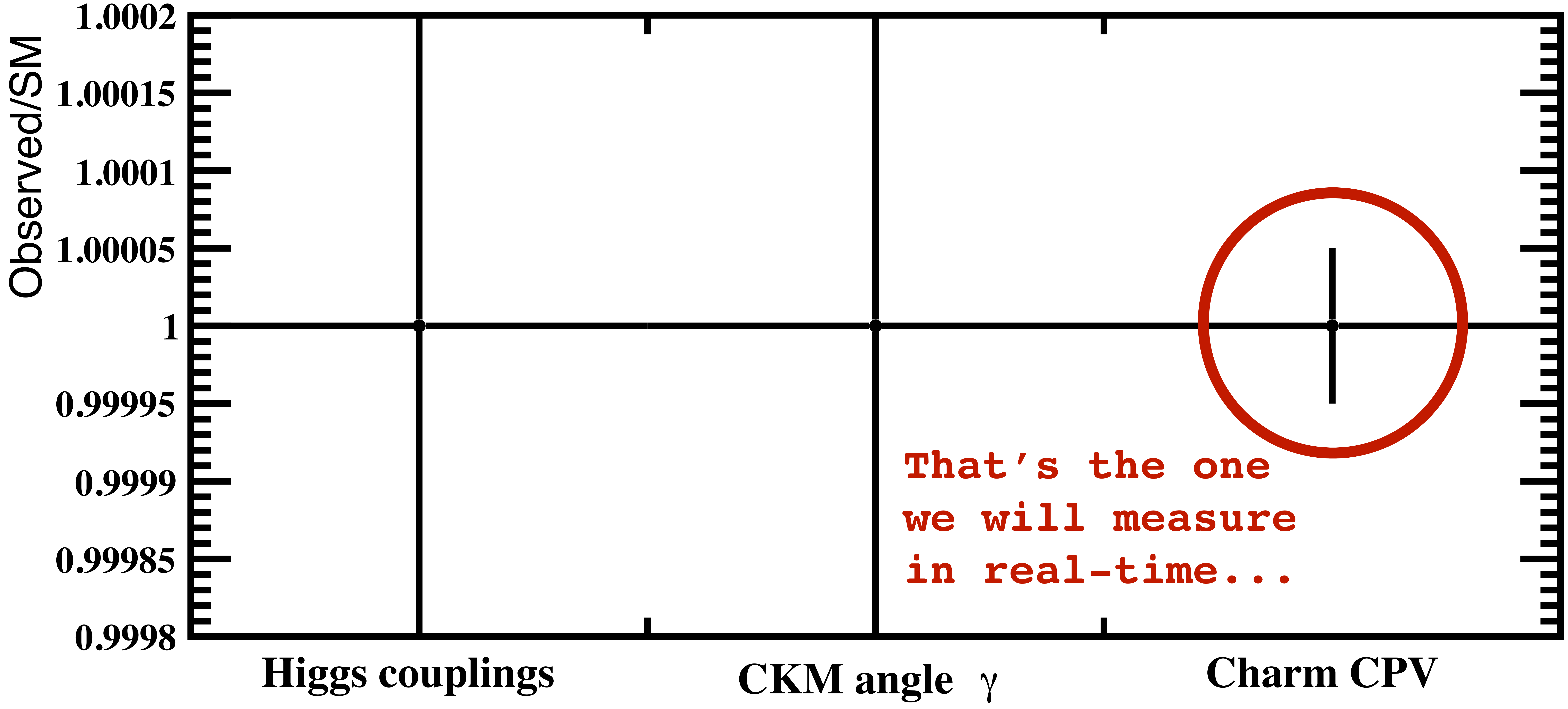


Solve disk space problem by performing analysis online : no going back if we make mistakes.

…at 10^{-5} precision?



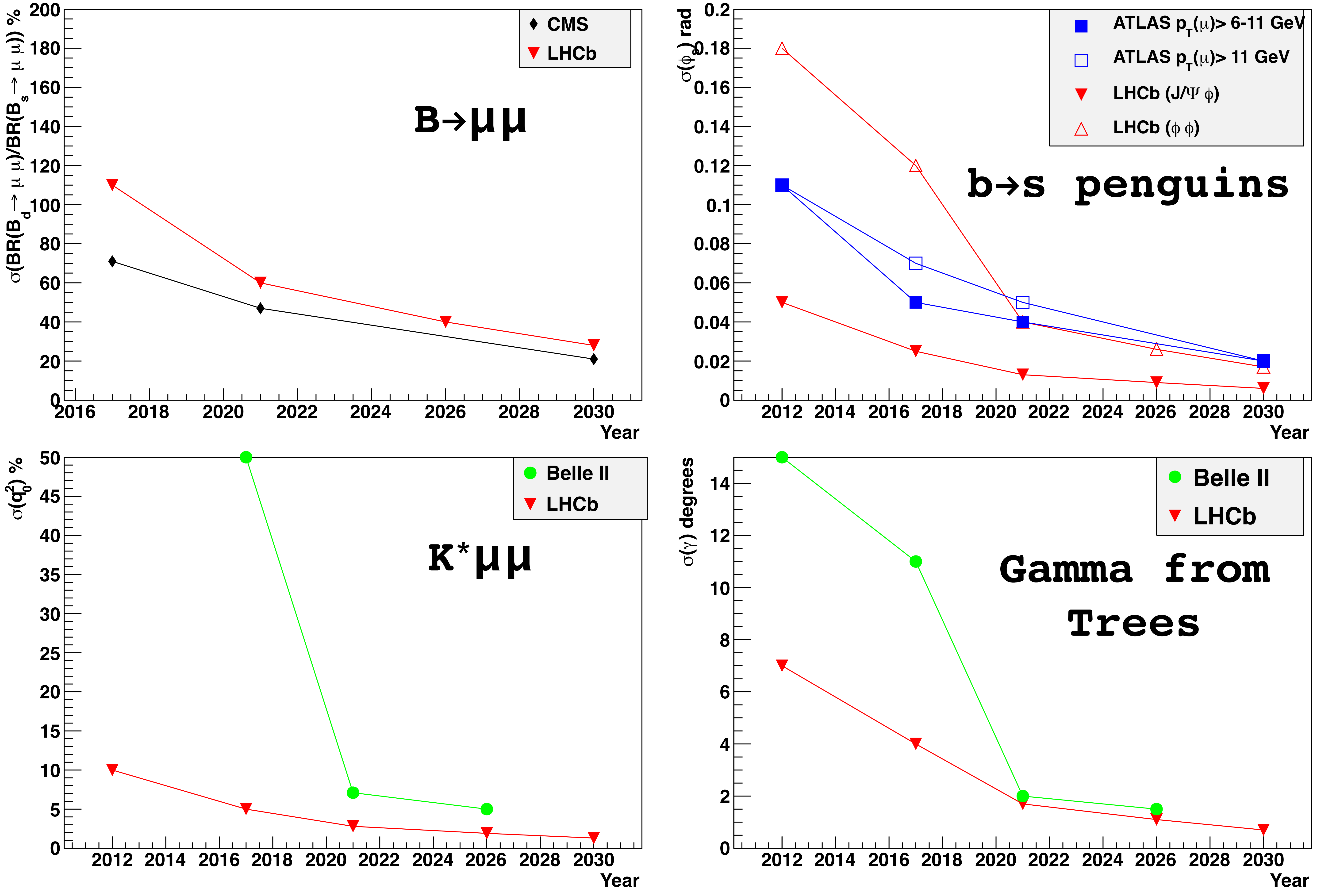
…at 10^{-5} precision?



The future is sub-permille measurements in real time. I hope you are scared.

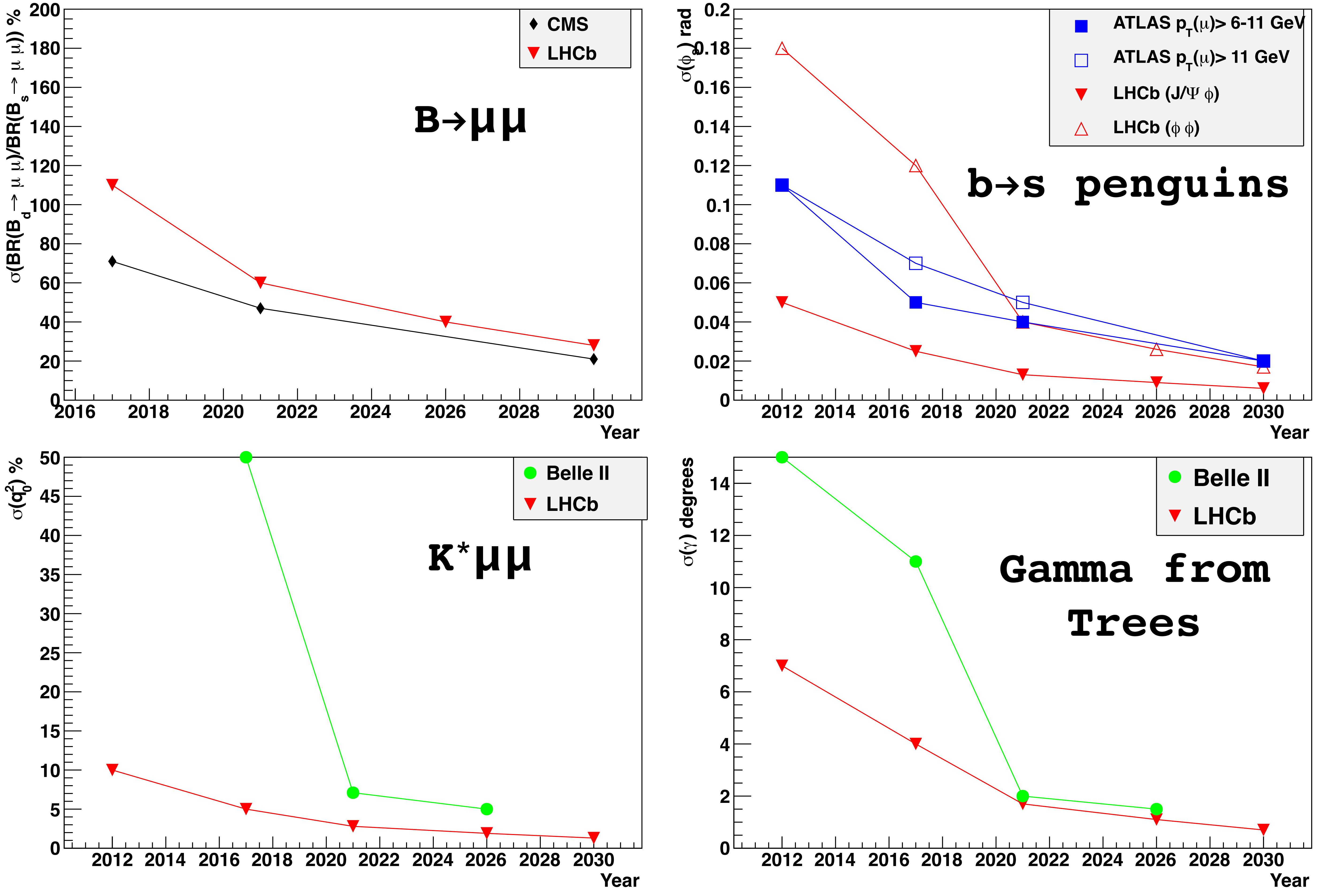

The Future Is Now!

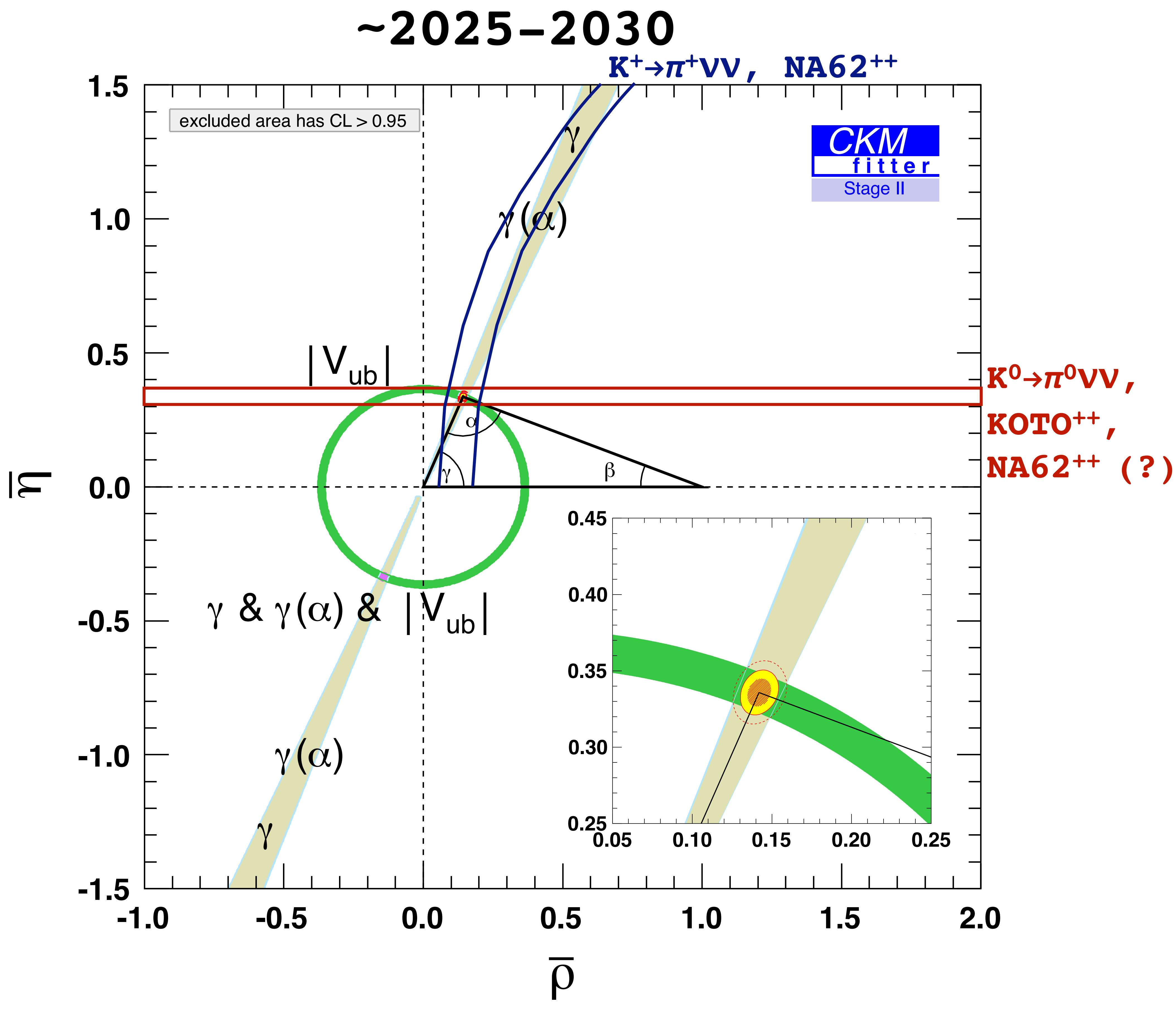
A few key observables



https://twiki.cern.ch/twiki/bin/view/ECFA/PhysicsGoalsPerformanceReachHeavyFlavour

Let’s add a bit of wishful thinking

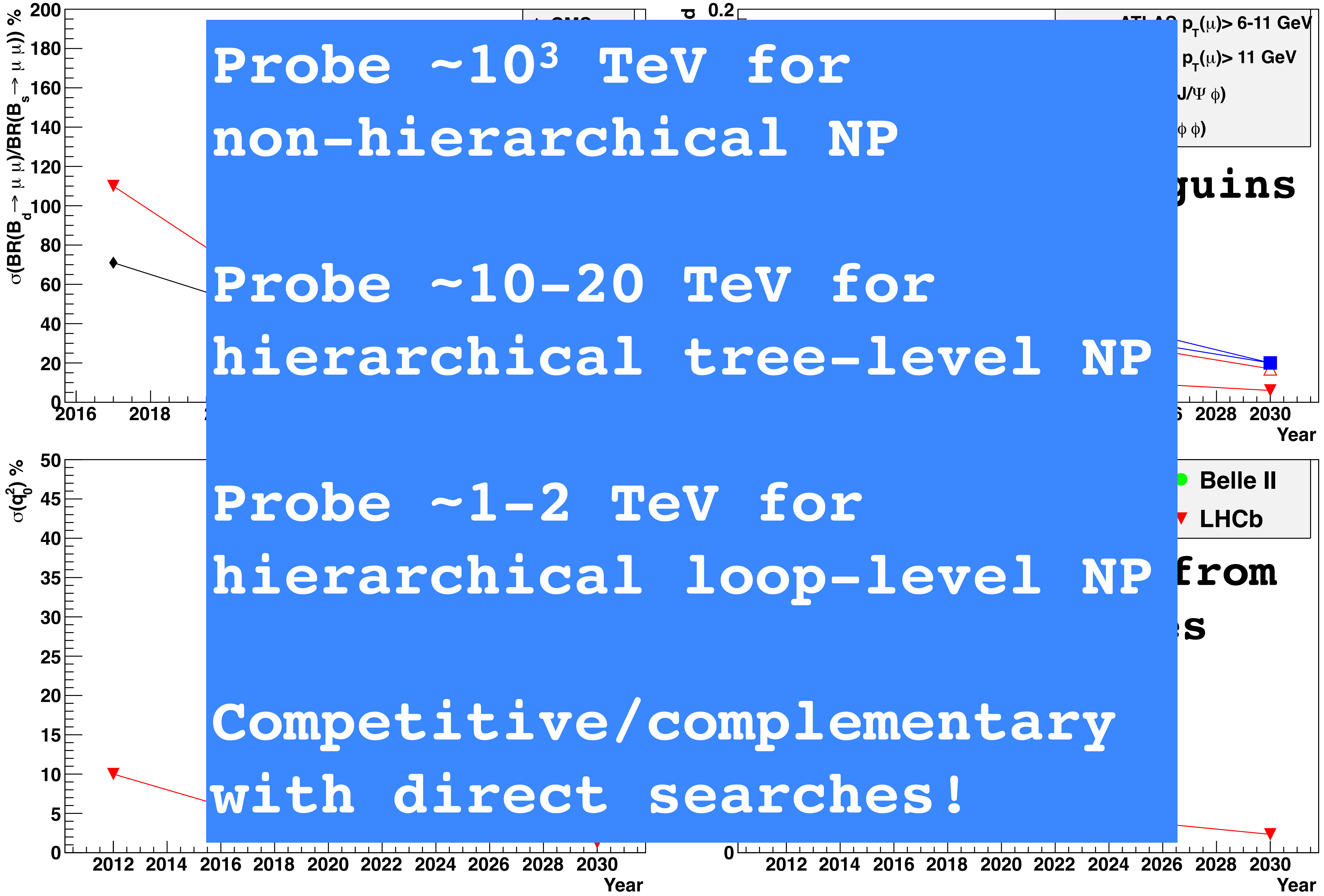




https://twiki.cern.ch/twiki/bin/view/ECFA/PhysicsGoalsPerformanceReachHeavyFlavour

J. Charles et al. http://arxiv.org/abs/1309.2293

Flavour will continue to constrain NP

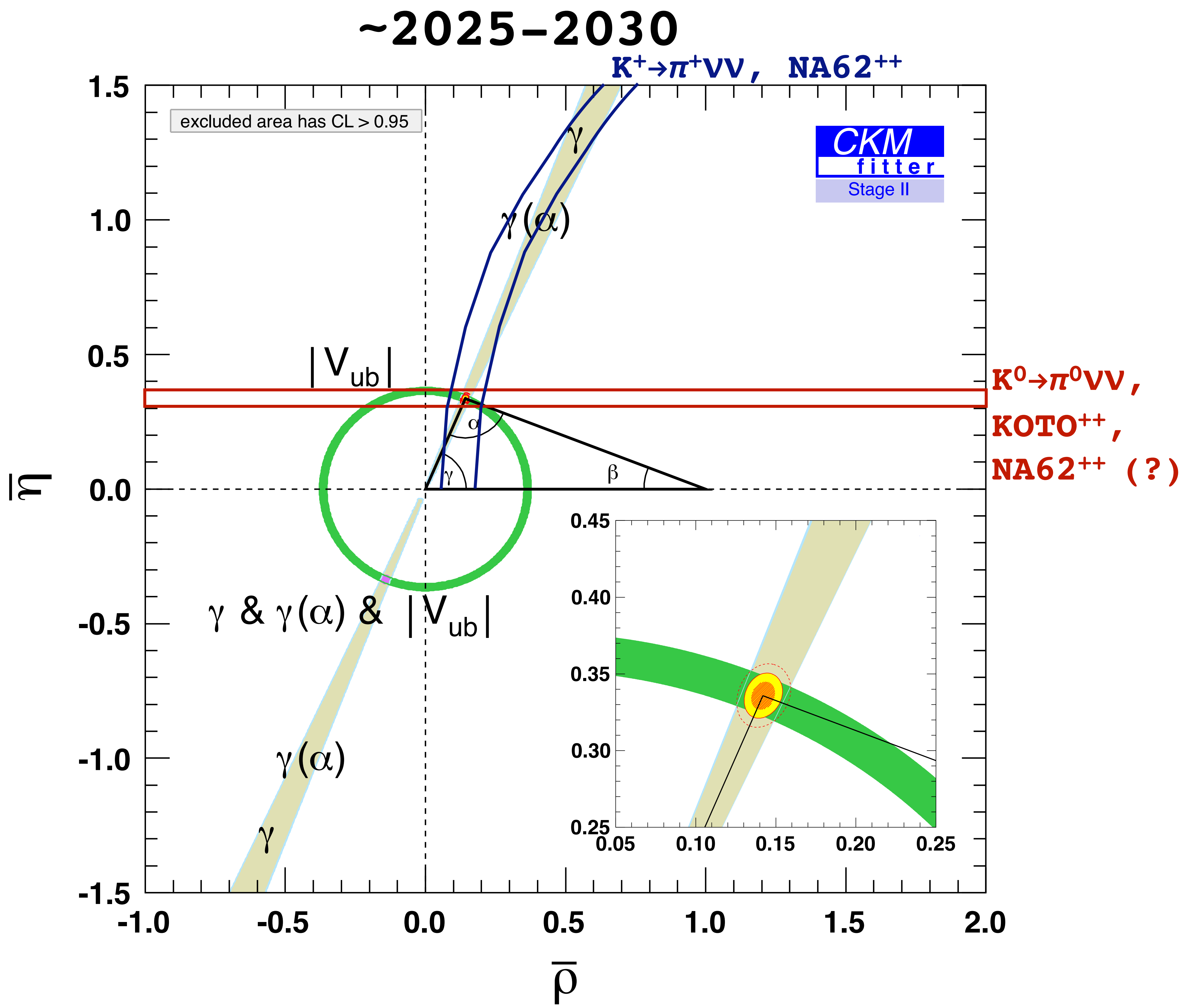


Probe ~10^3 TeV for non-hierarchical NP

Probe ~10-20 TeV for hierarchical tree-level NP

Probe ~1-2 TeV for hierarchical loop-level NP

Competitive/complementary with direct searches!



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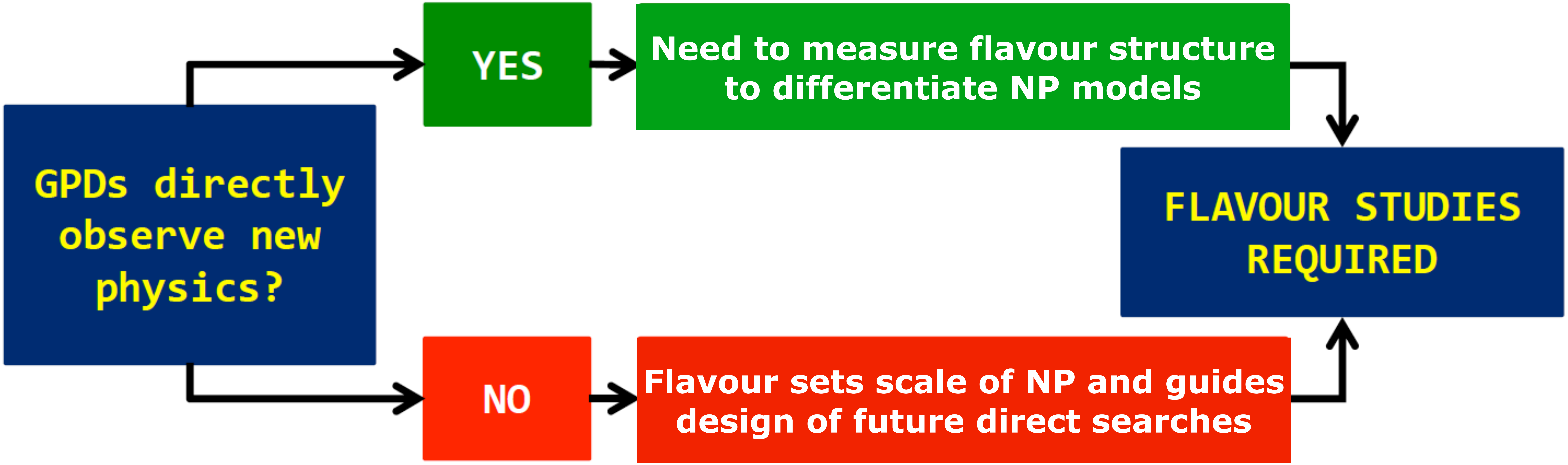
GPDs directly observe new physics?
YES
NO
Need to measure flavour structure to differentiate NP models
Flavour sets scale of NP and guides design of future direct searches
FLAVOUR STUDIES REQUIRED