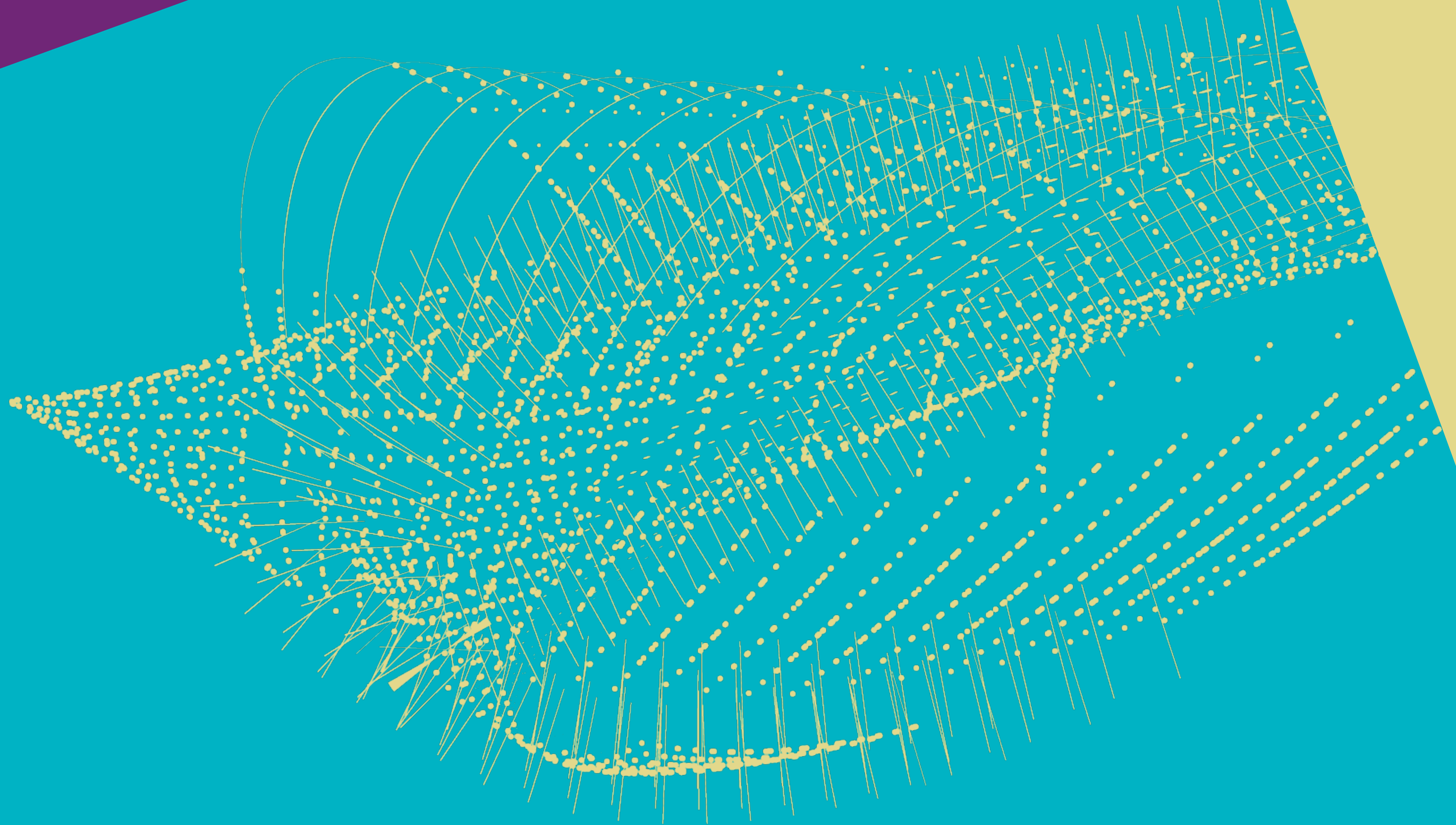
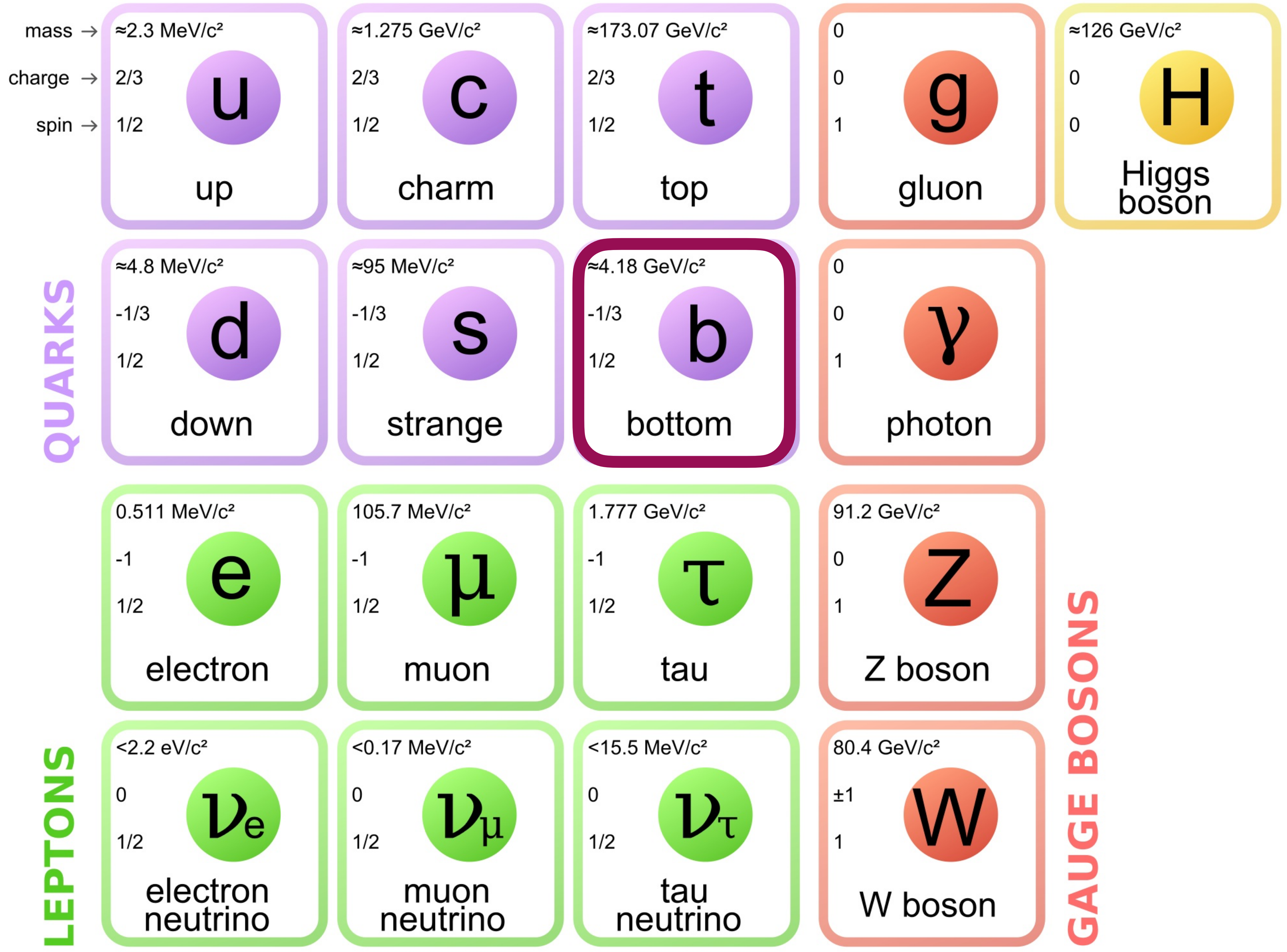
NIKHEF QUSOFT WORKSHOP
14-09-2021



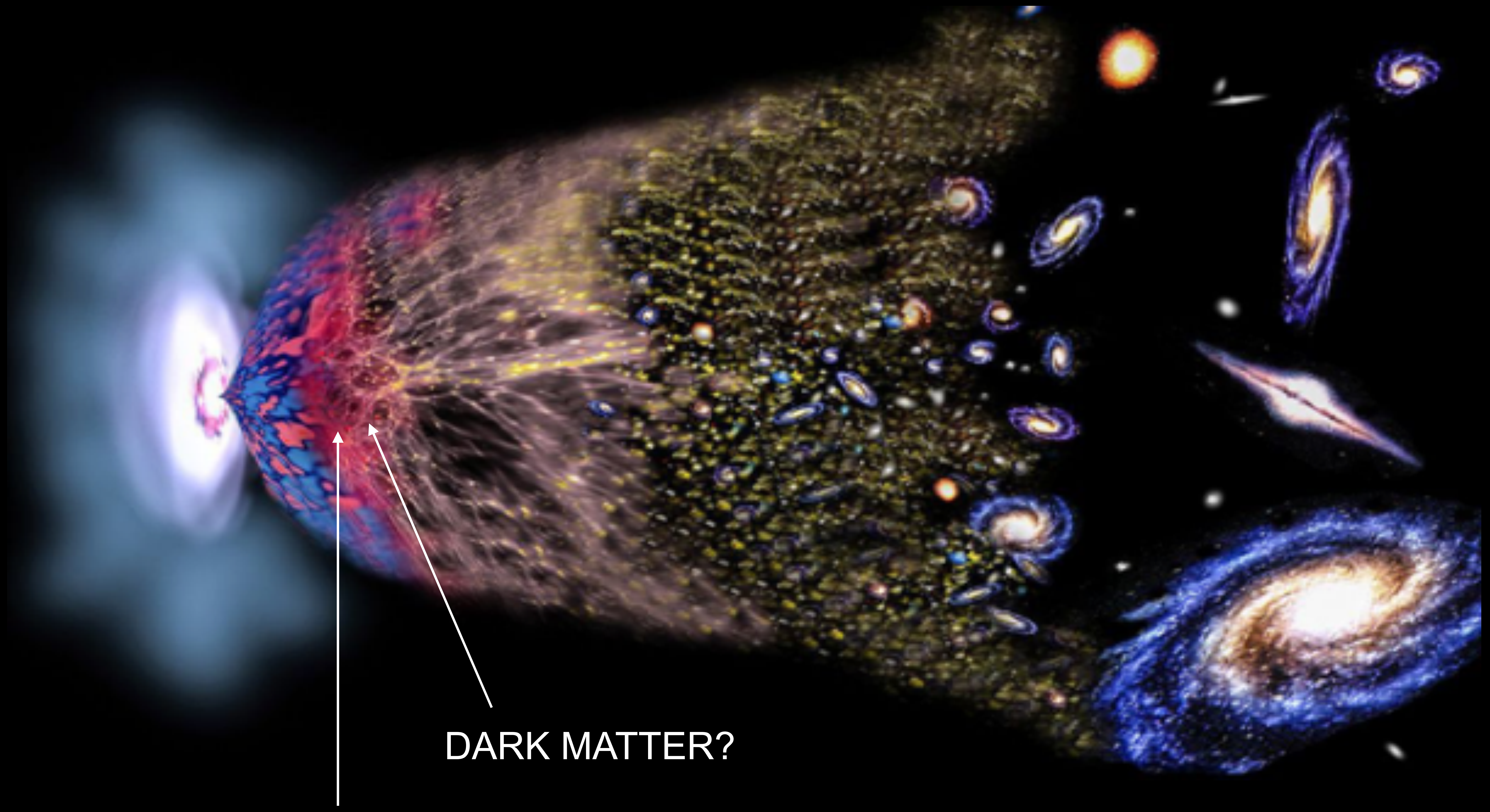
QUANTUM COMPUTING FOR HEP - LHCB

Jacco de Vries &
Daniel Campora

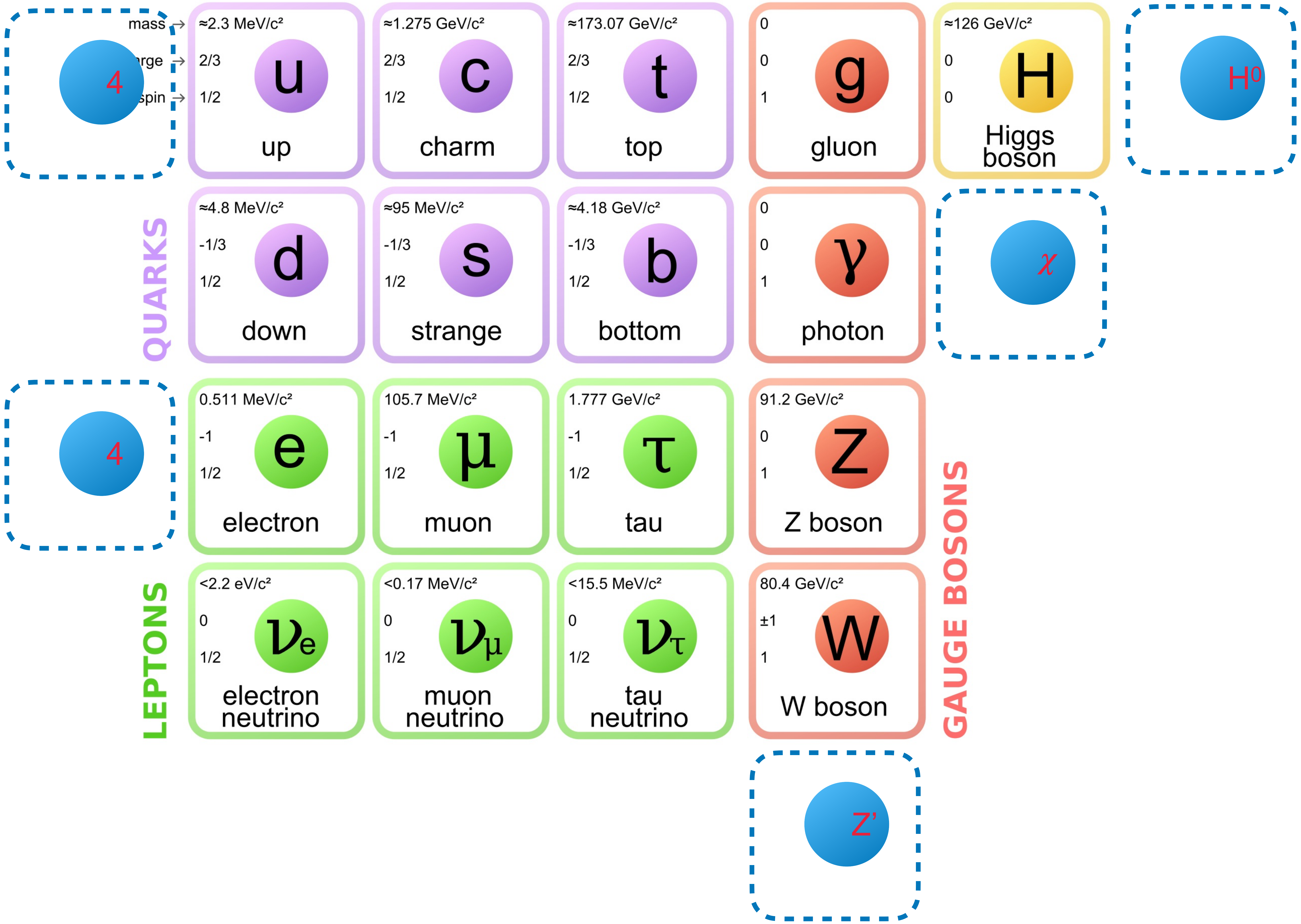
THE STANDARD MODEL



THE EARLY UNIVERSE



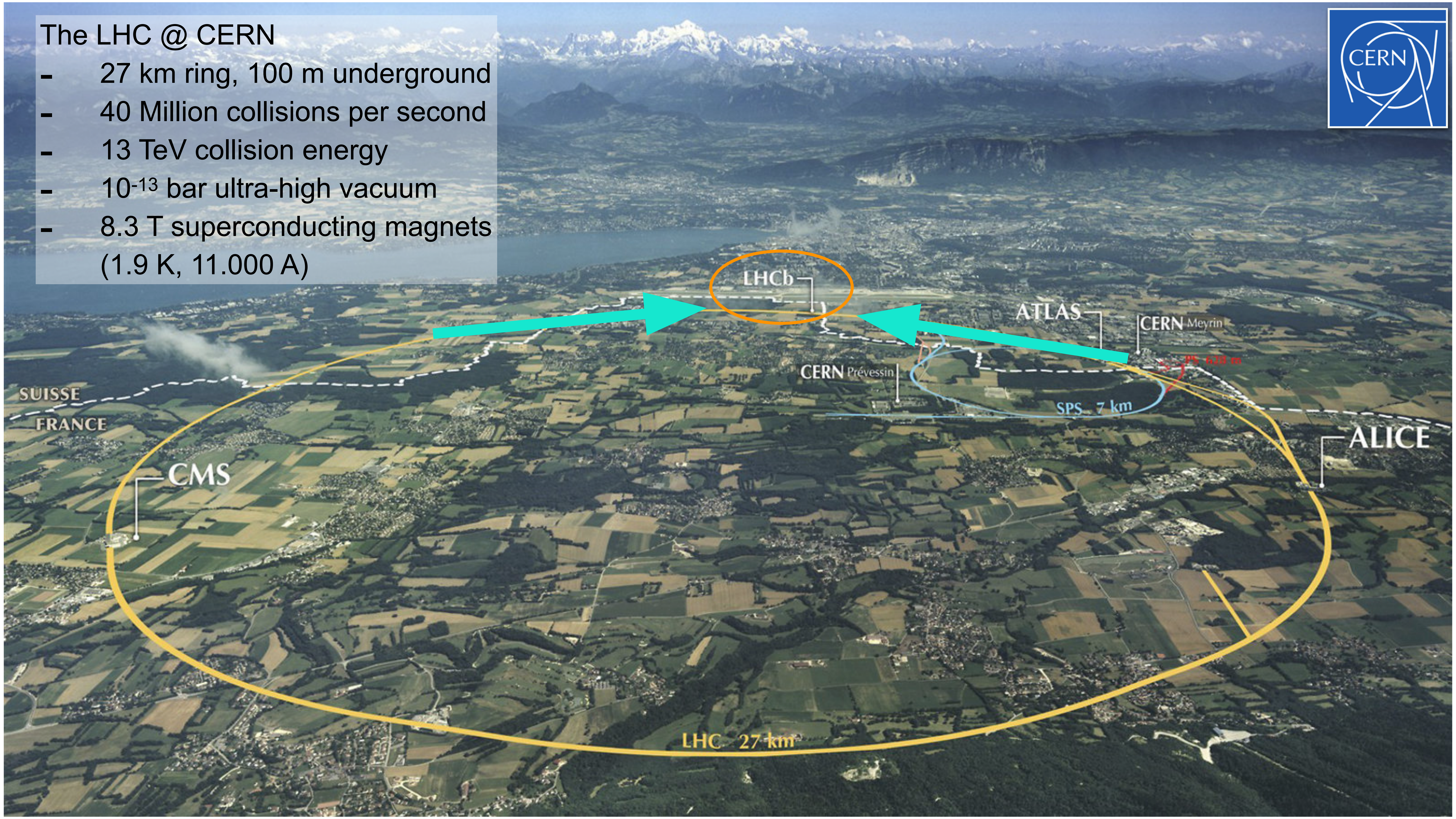
THE STANDARD MODEL IN 2030?



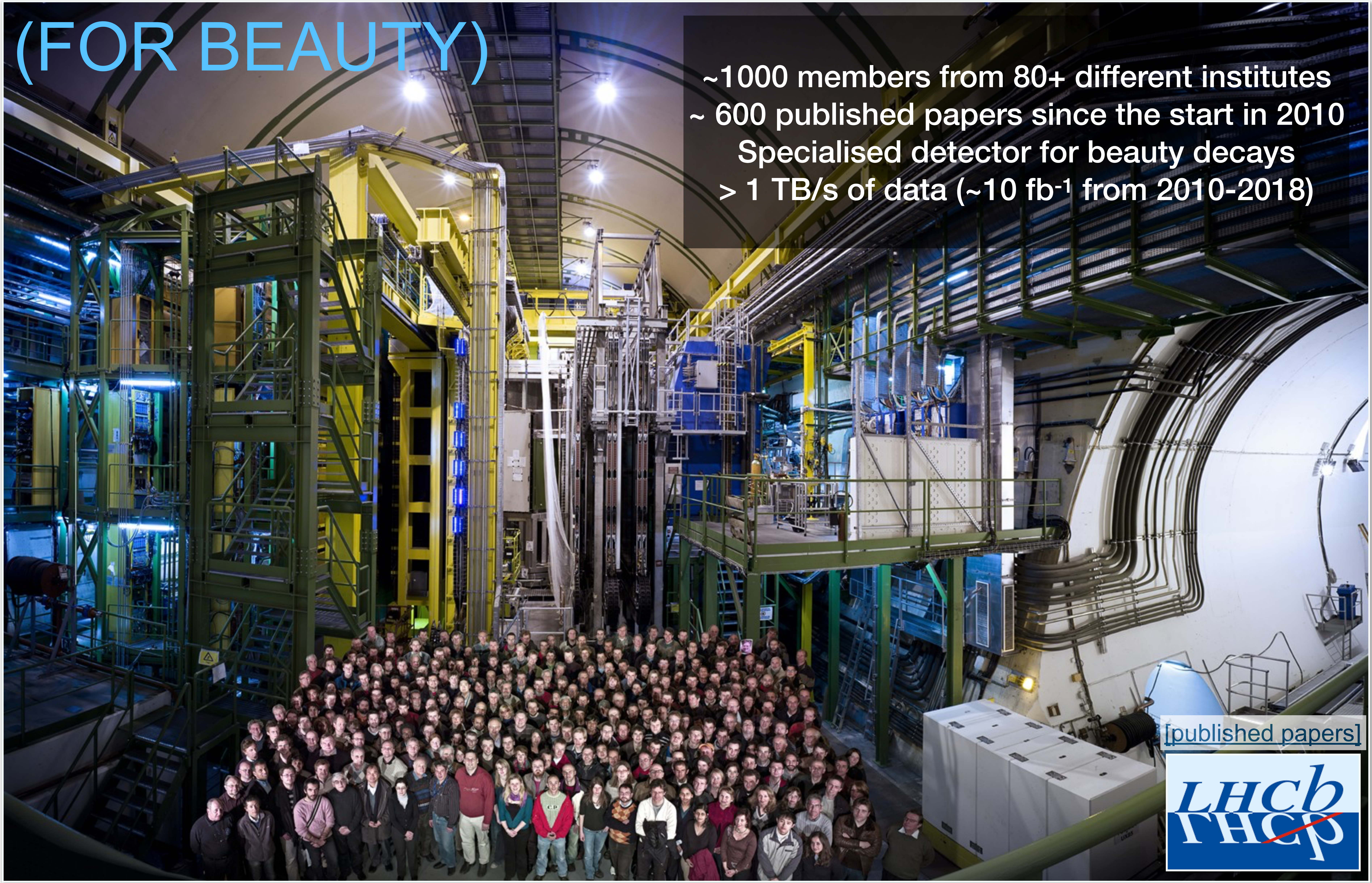
Nikhef

LARGE HADRON COLLIDER

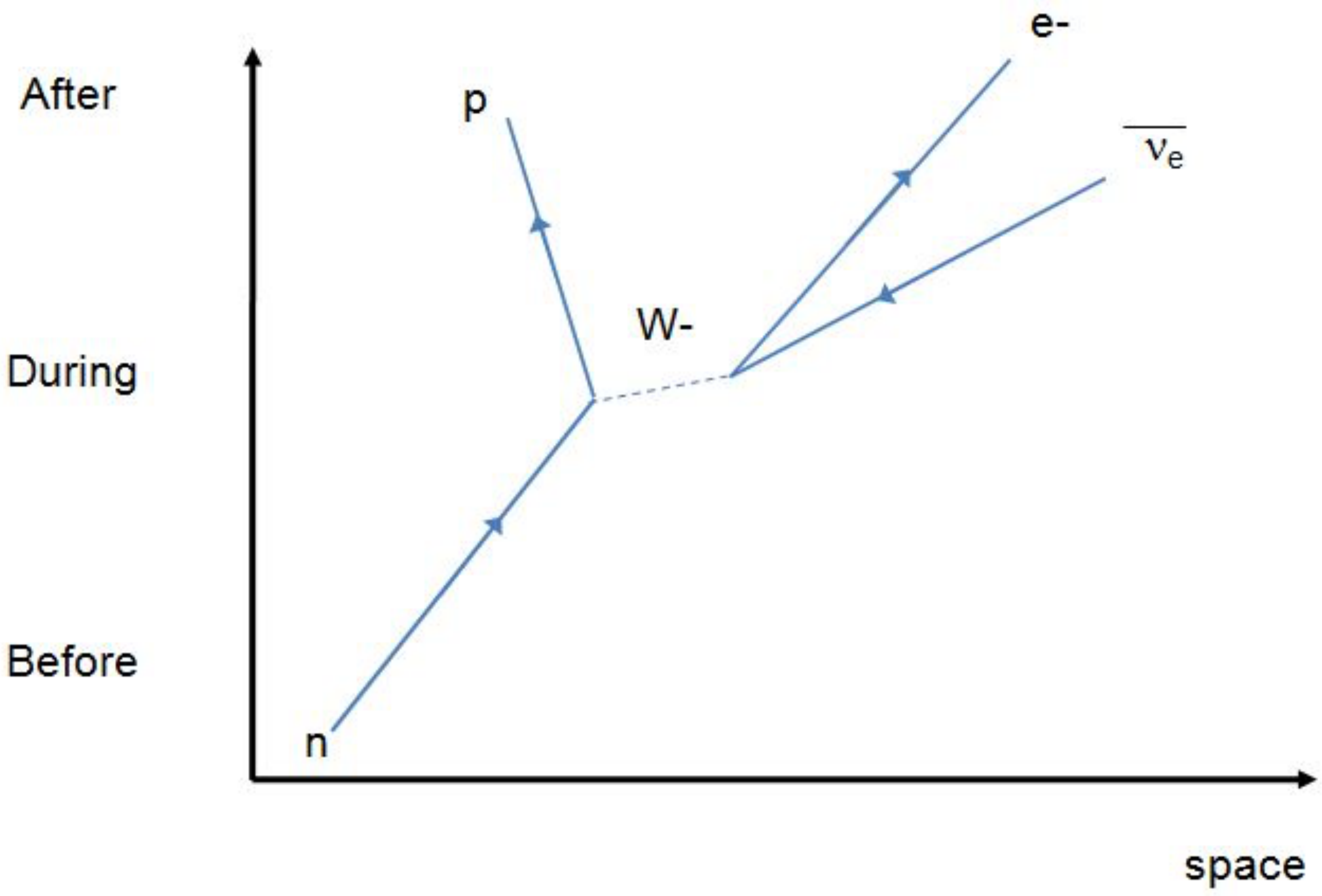
The LHC @ CERN
- 27 km ring, 100 m underground
- 40 Million collisions per second
- 13 TeV collision energy
- 10^{-13} bar ultra-high vacuum
- 8.3 T superconducting magnets (1.9 K, 11.000 A)



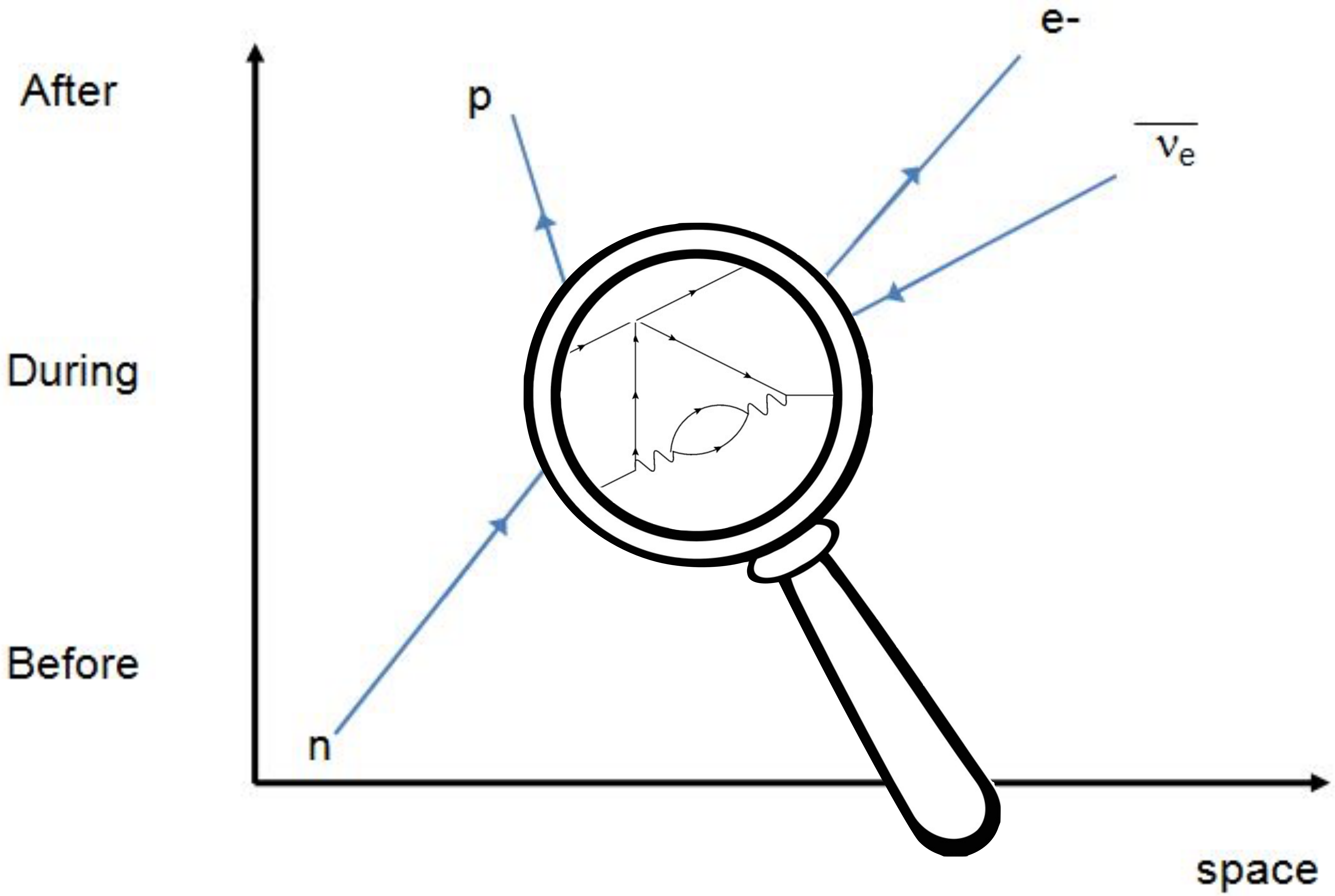
LHCB (FOR BEAUTY)



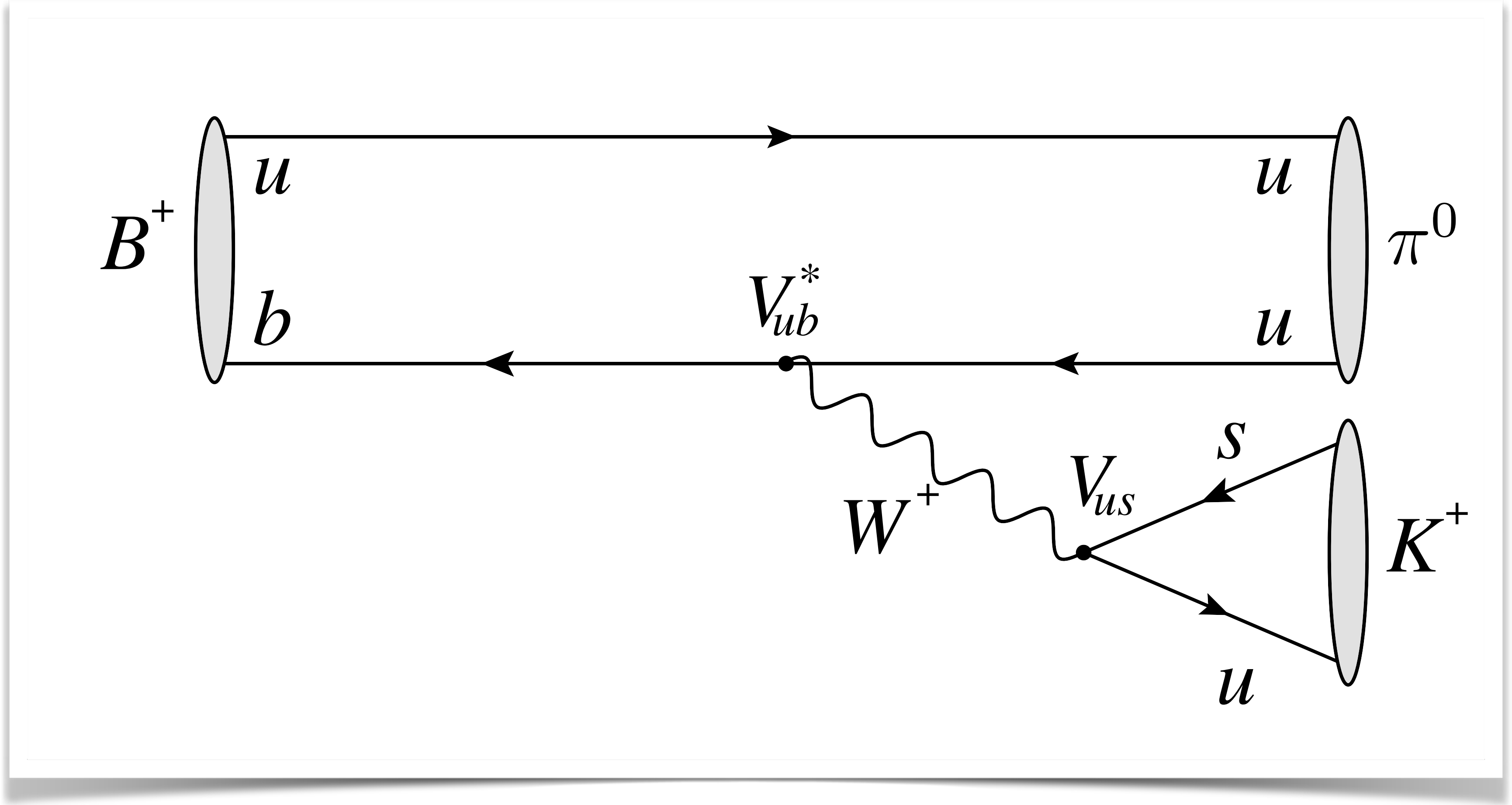
FLAVOUR PHYSICS

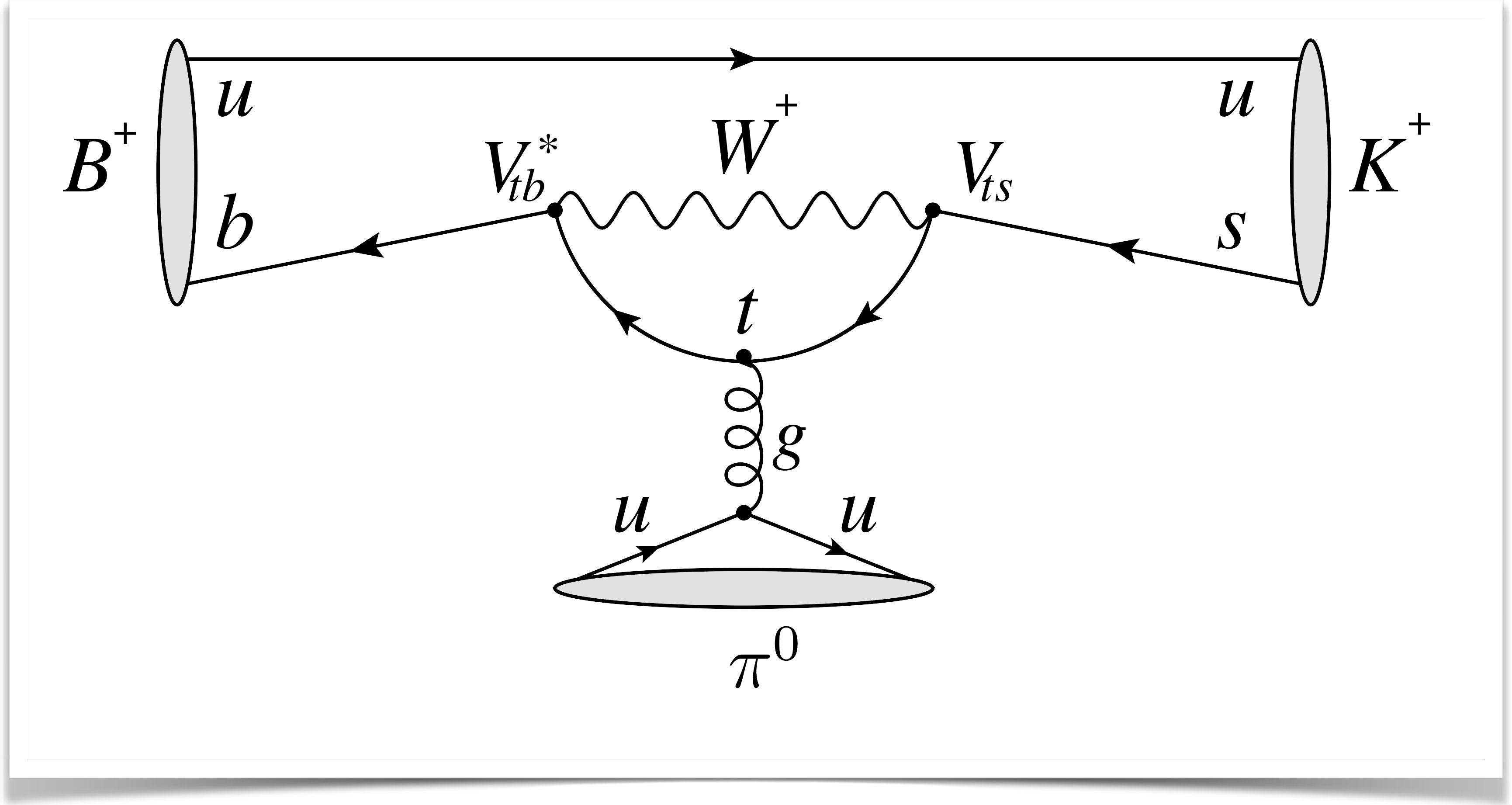


FLAVOUR PHYSICS

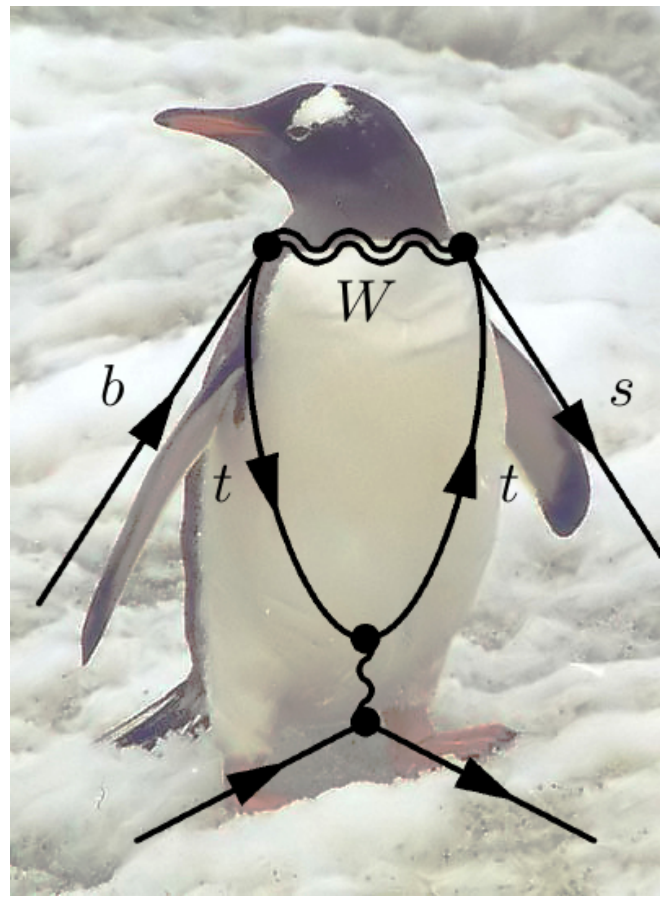


FLAVOUR PHYSICS - CP VIOLATION

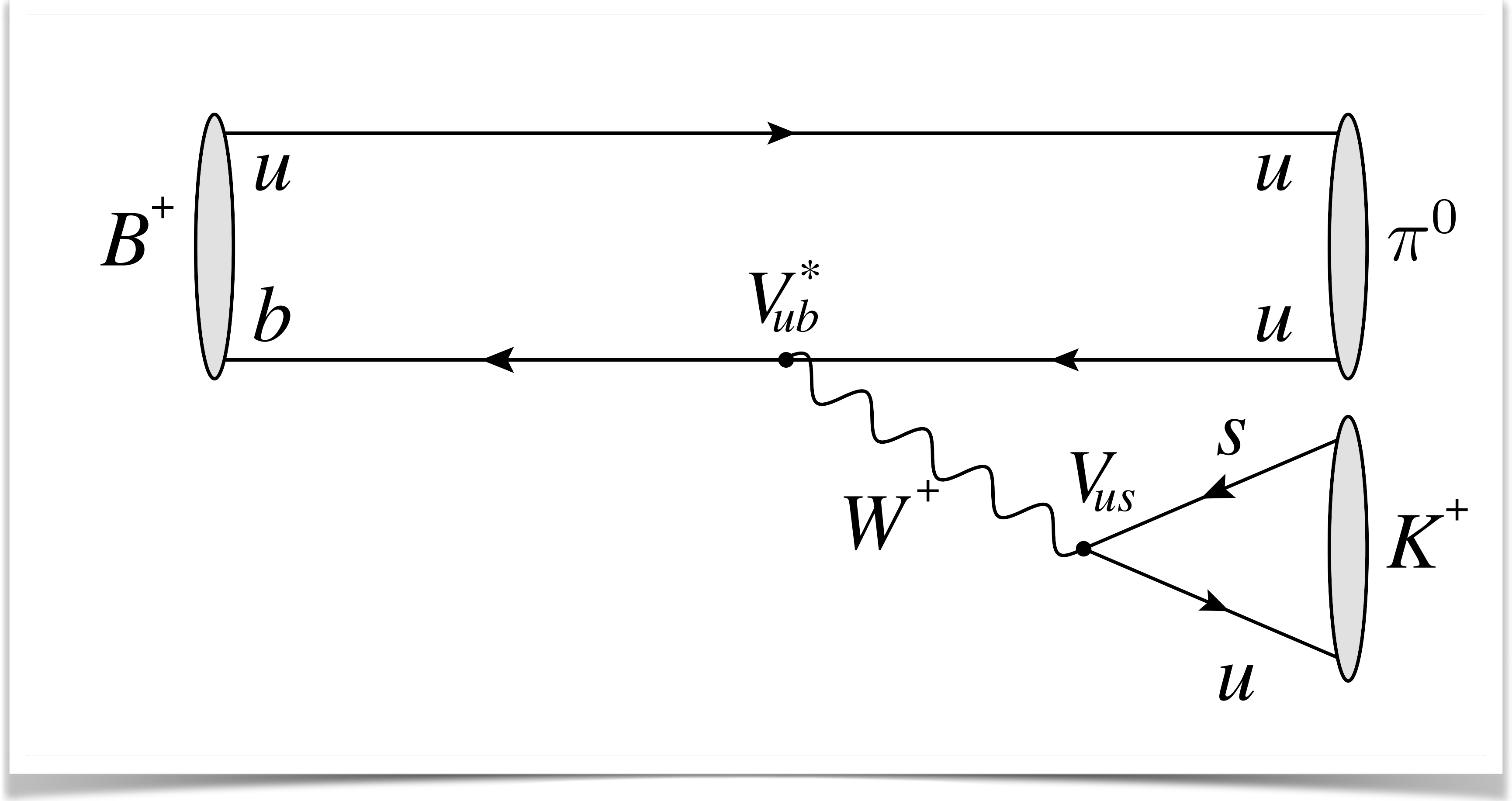


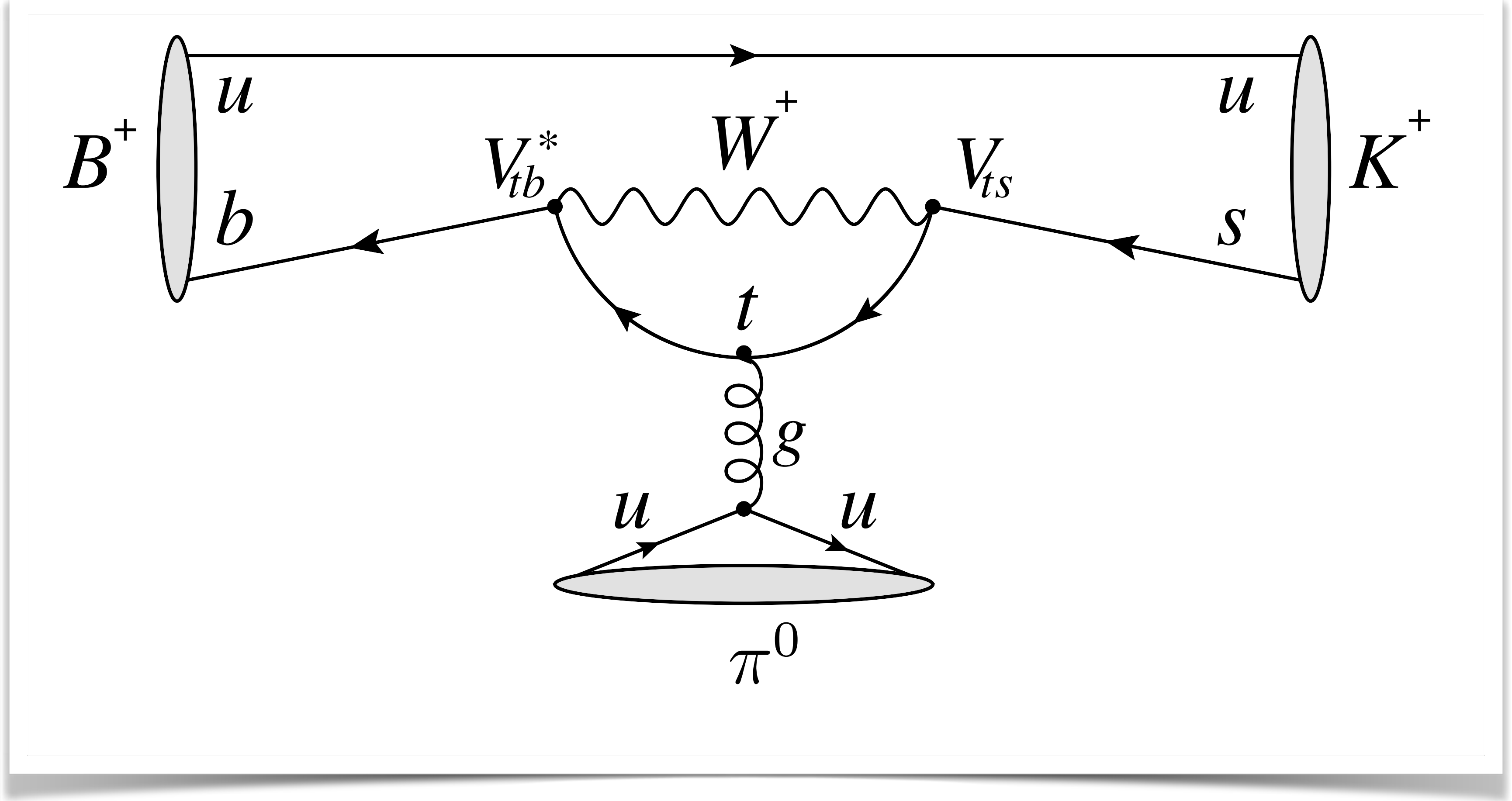


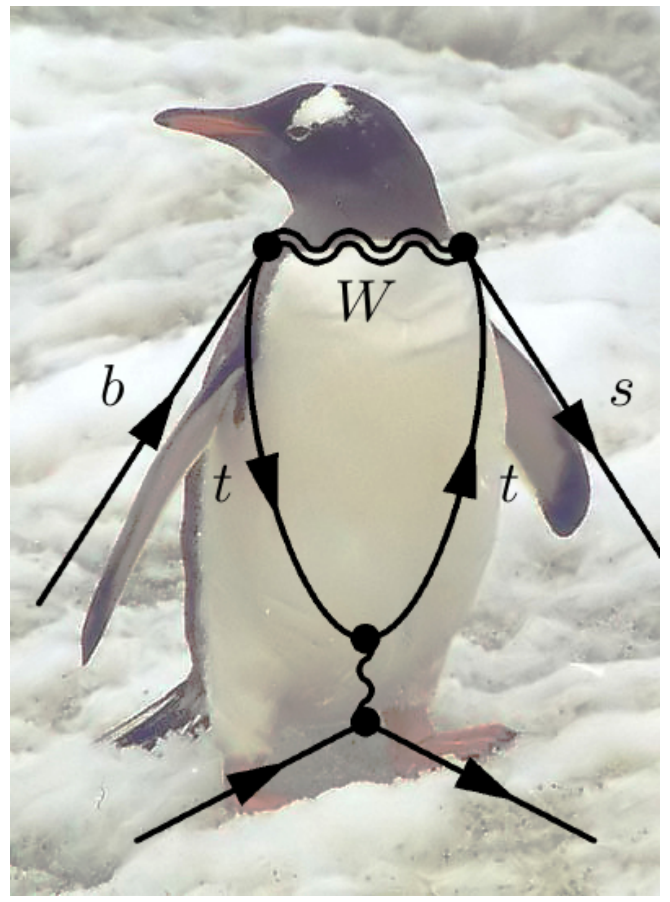
$$|\mathcal{A}|^2 = |\mathcal{A}_1 + \mathcal{A}_2|^2 = |\mathcal{A}_1|^2 + |\mathcal{A}_2|^2 + 2|\mathcal{A}_1||\mathcal{A}_2|\cos(\Delta\delta + \Delta\phi)$$



FLAVOUR PHYSICS - CP VIOLATION

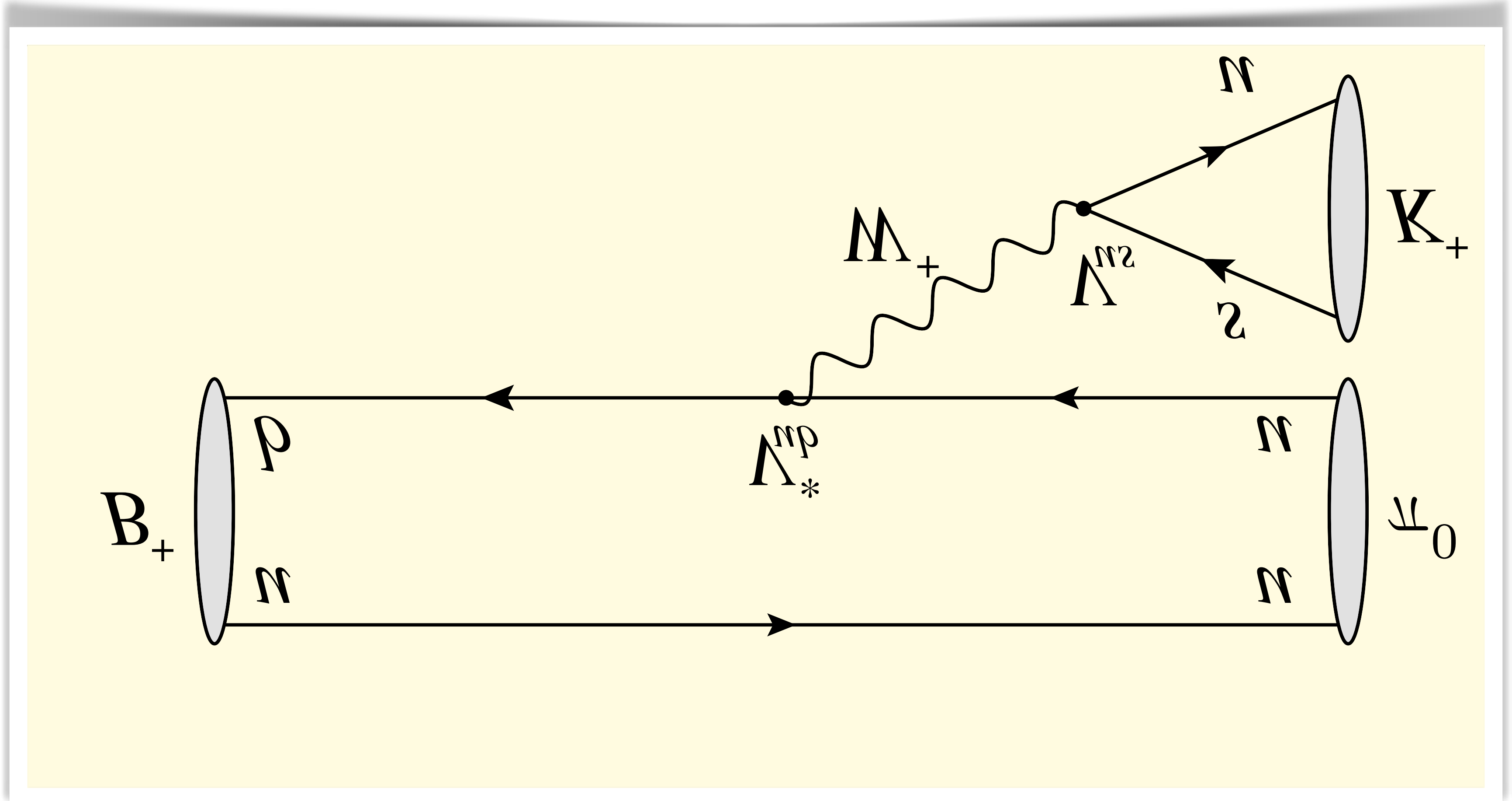


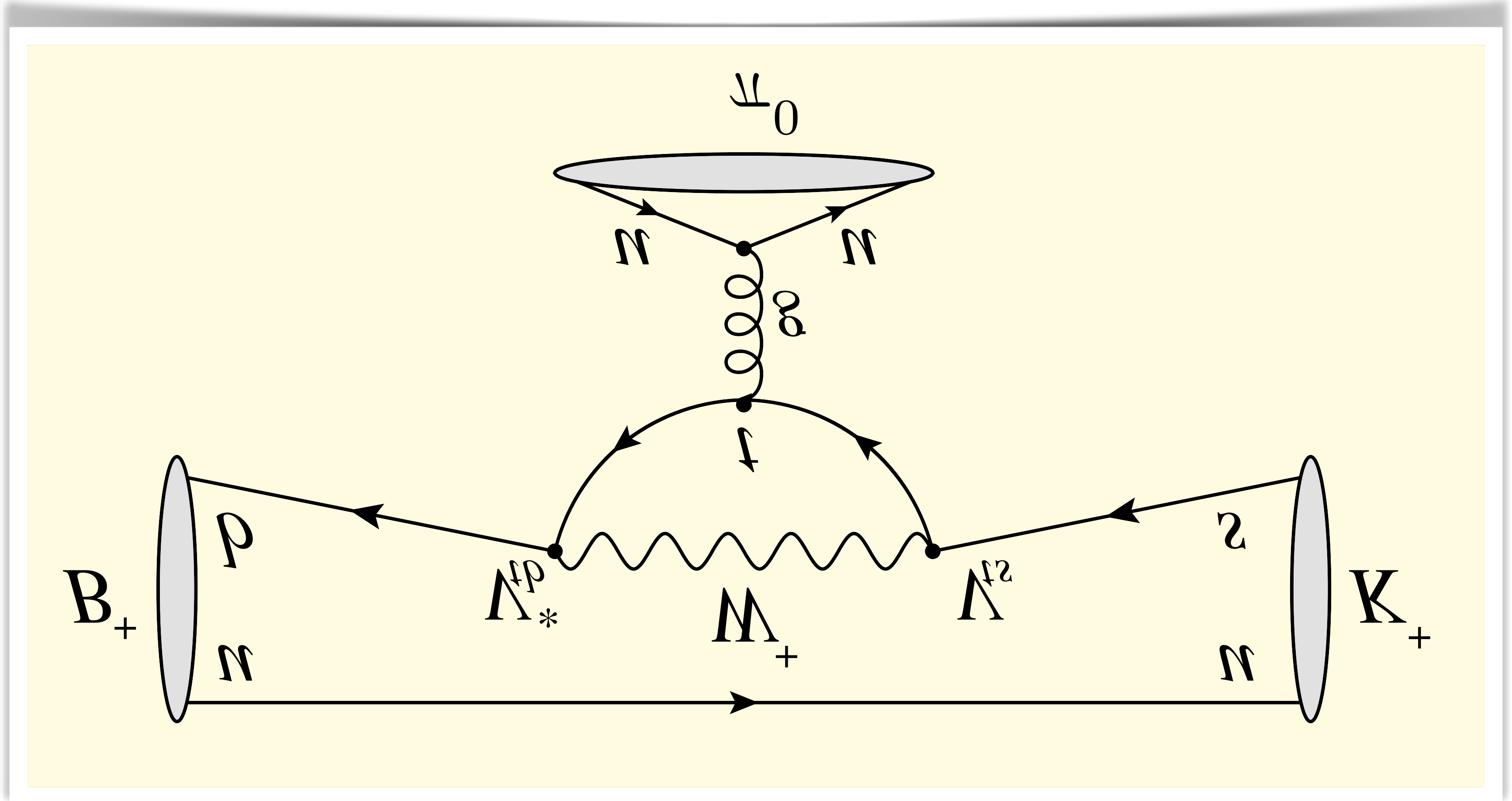




$$|\mathcal{A}|^2 = |\mathcal{A}_1 + \mathcal{A}_2|^2 = |\mathcal{A}_1|^2 + |\mathcal{A}_2|^2 + 2|\mathcal{A}_1||\mathcal{A}_2|\cos(\Delta\delta + \Delta\phi)$$

$$|\overline{\mathcal{A}}|^2 = |\overline{\mathcal{A}}_1 + \overline{\mathcal{A}}_2|^2 = |\mathcal{A}_1|^2 + |\mathcal{A}_2|^2 + 2|\mathcal{A}_1||\mathcal{A}_2|\cos(\Delta\delta - \Delta\phi)$$





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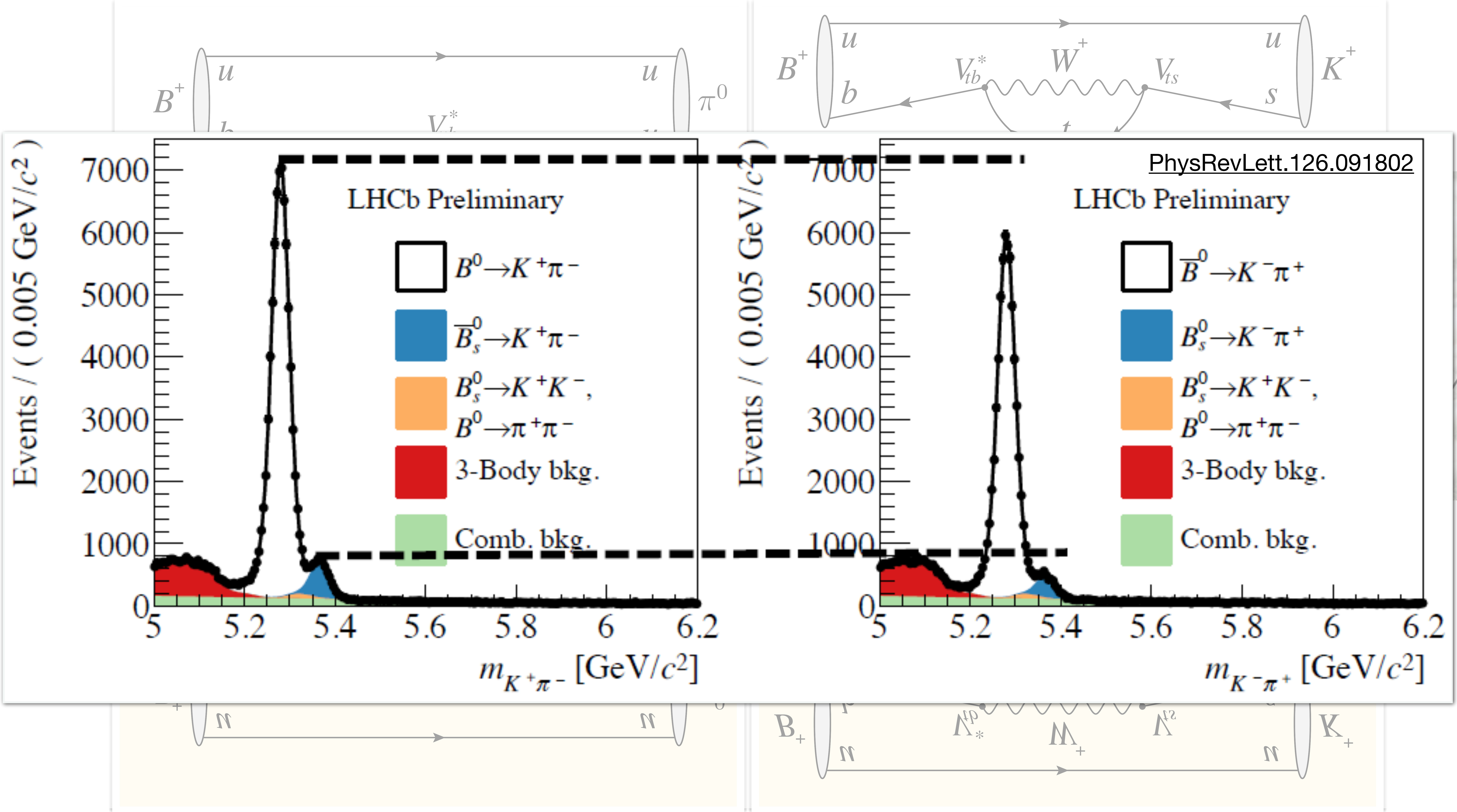
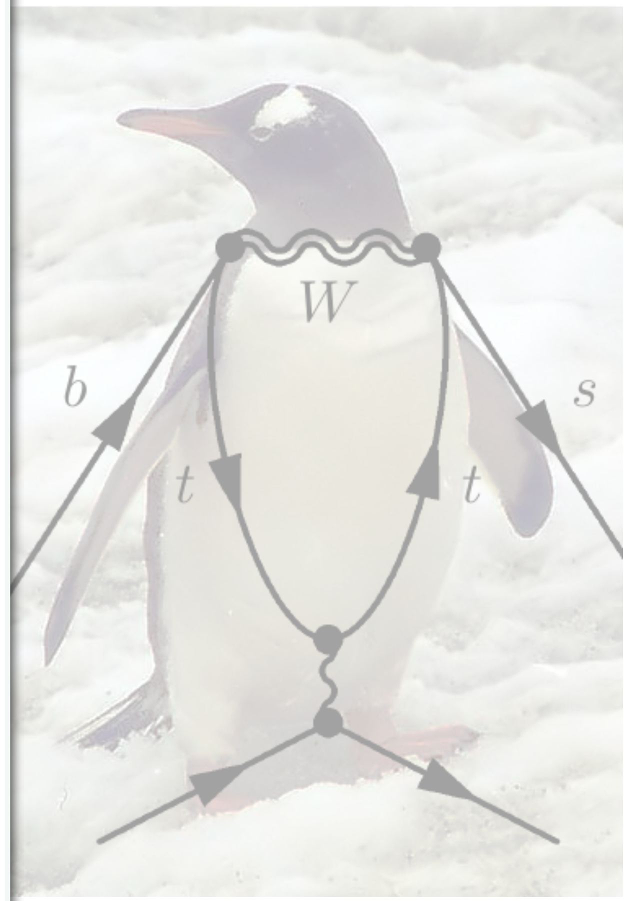
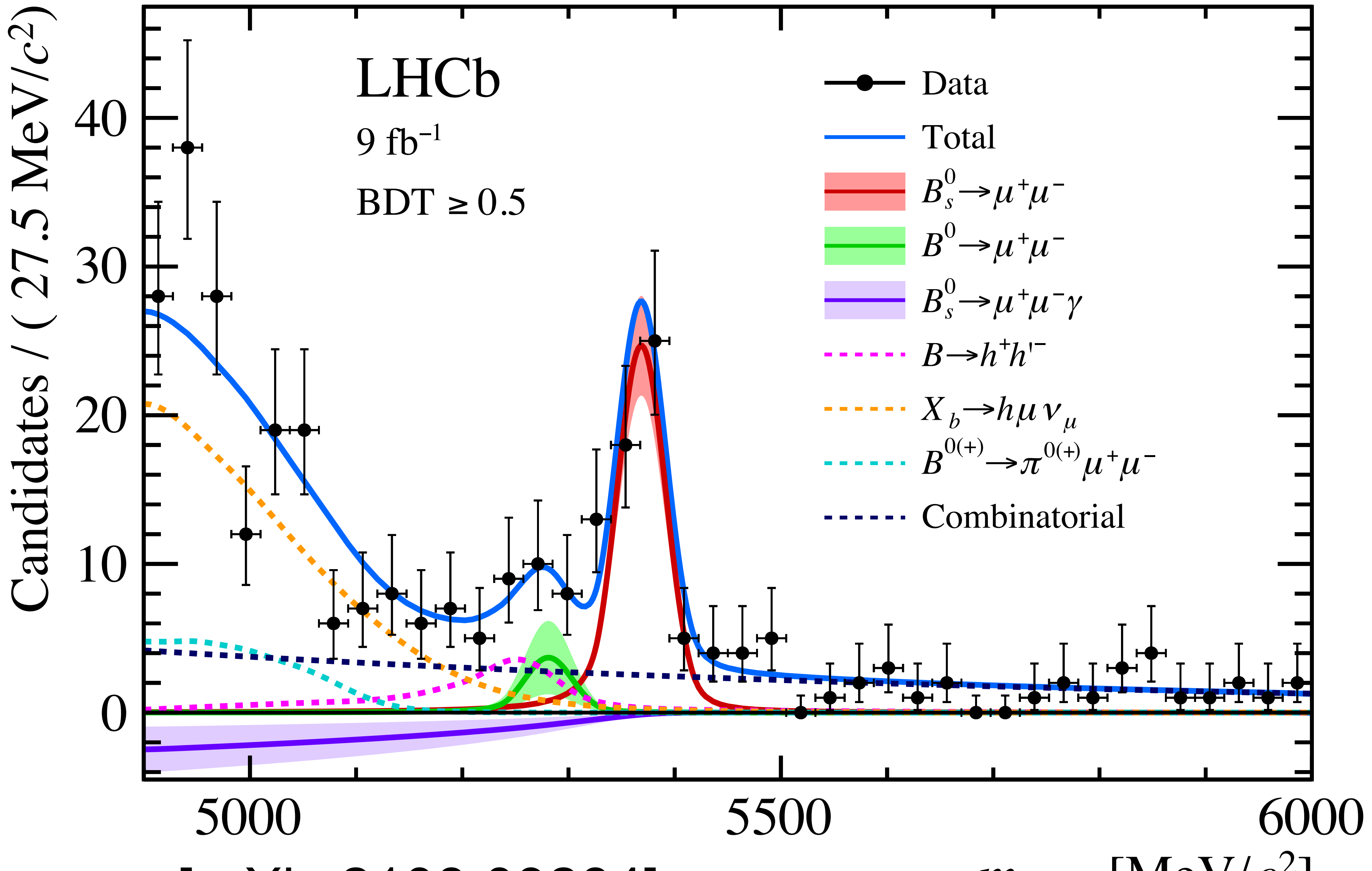
FLAVOUR PHYSICS - CP VIOLATION



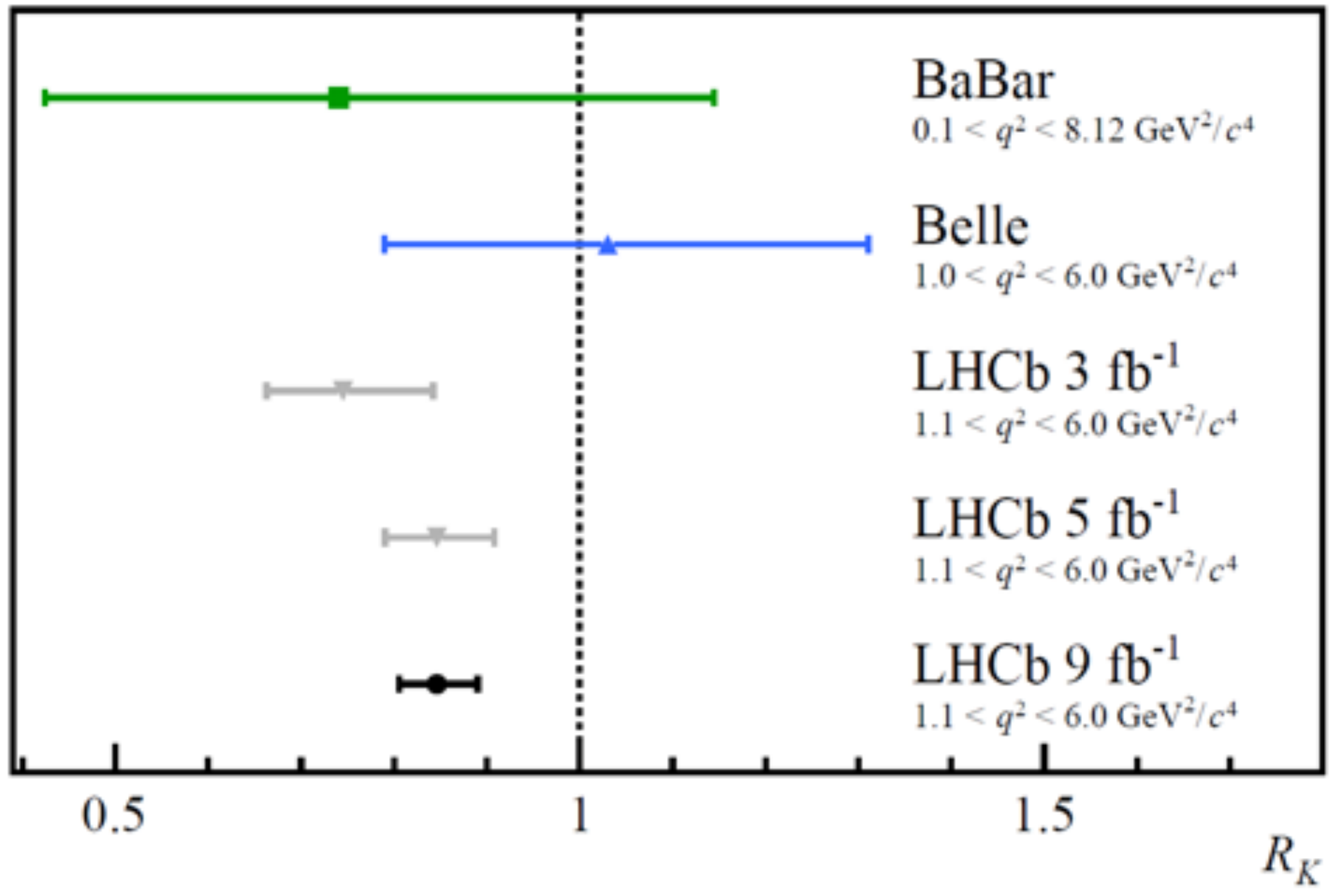


FLAVOUR PHYSICS - RARE DECAYS

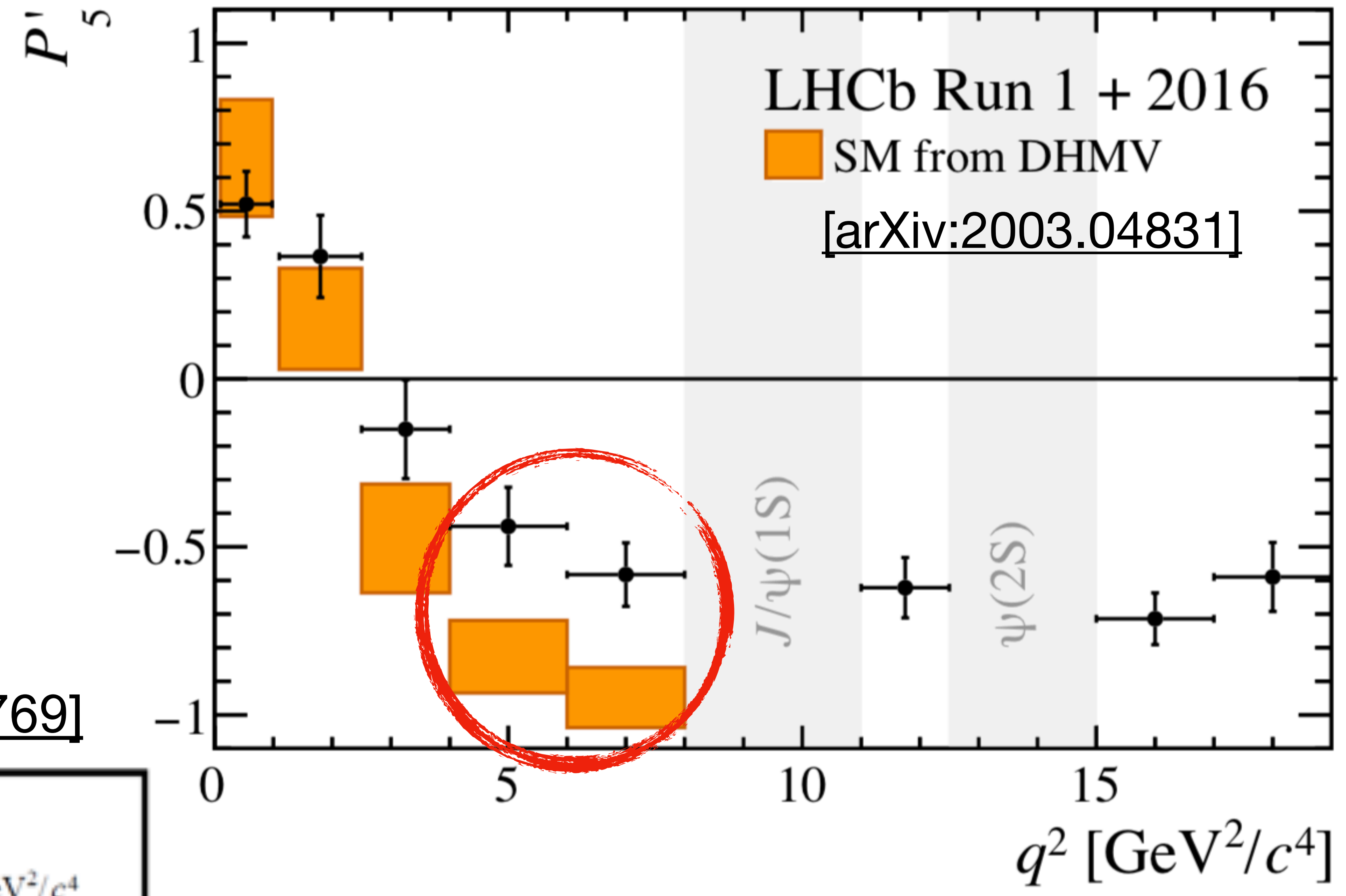


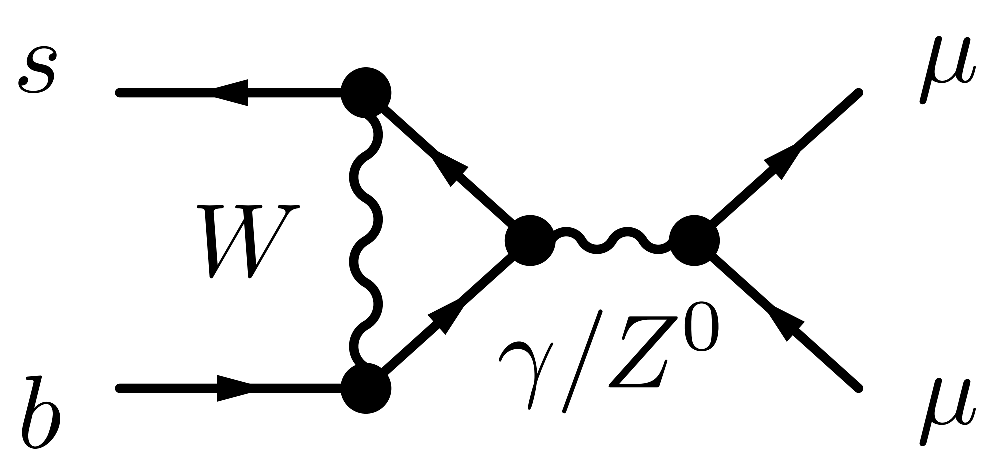
[arXiv:2108.09284]

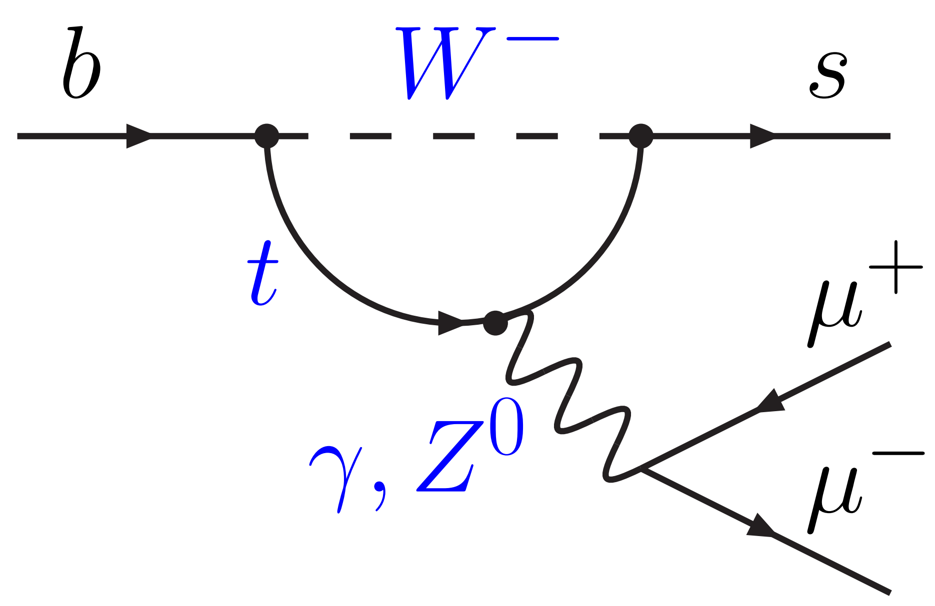
[arXiv:2103.11769]



Theory predictions from JHEP 12 (2014) 125, JHEP 09 (2010) 089,





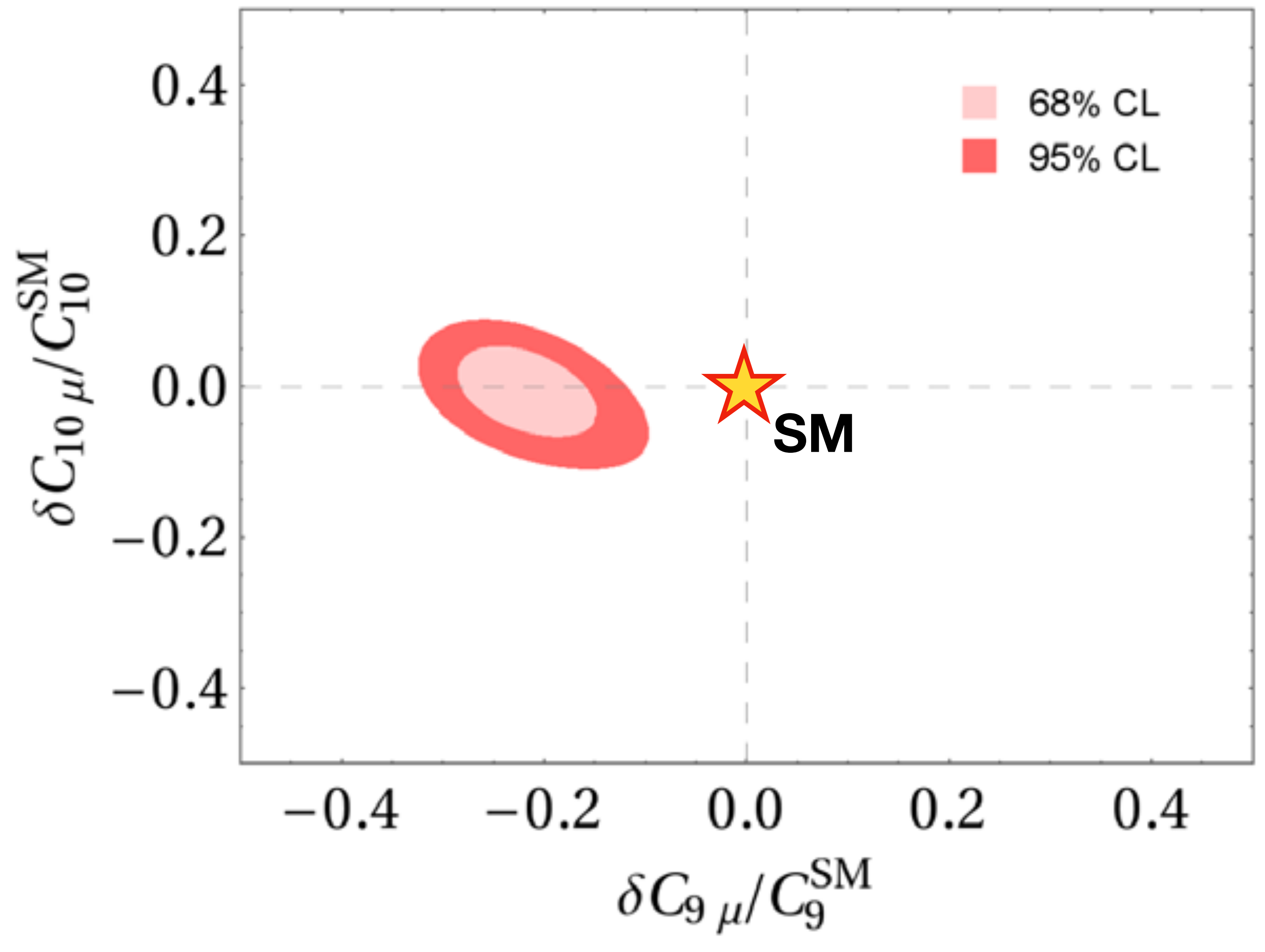


EFFECTIVE THEORY & THE FLAVOUR ANOMALIES

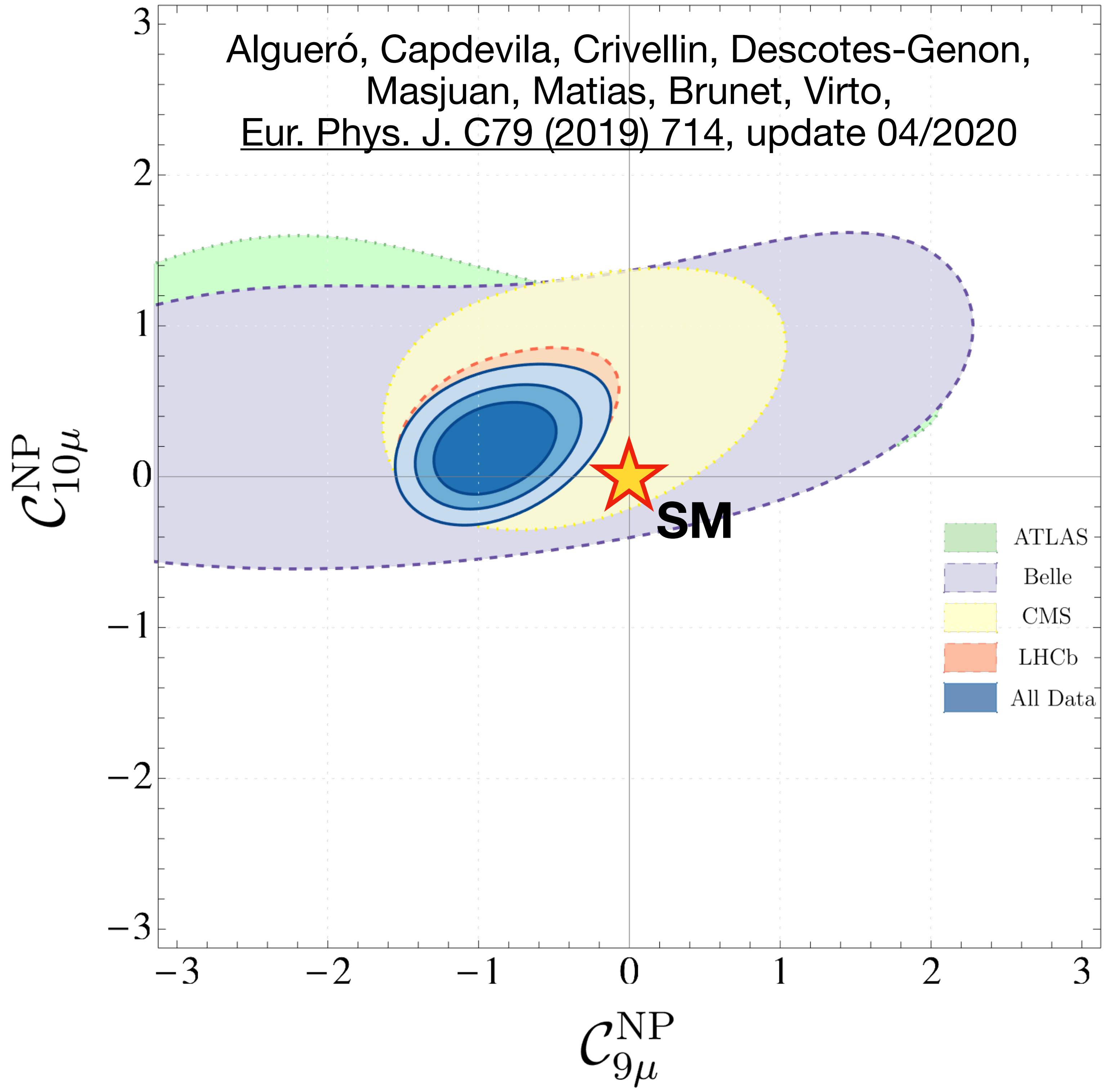
Model independent fits to O(170) measurements

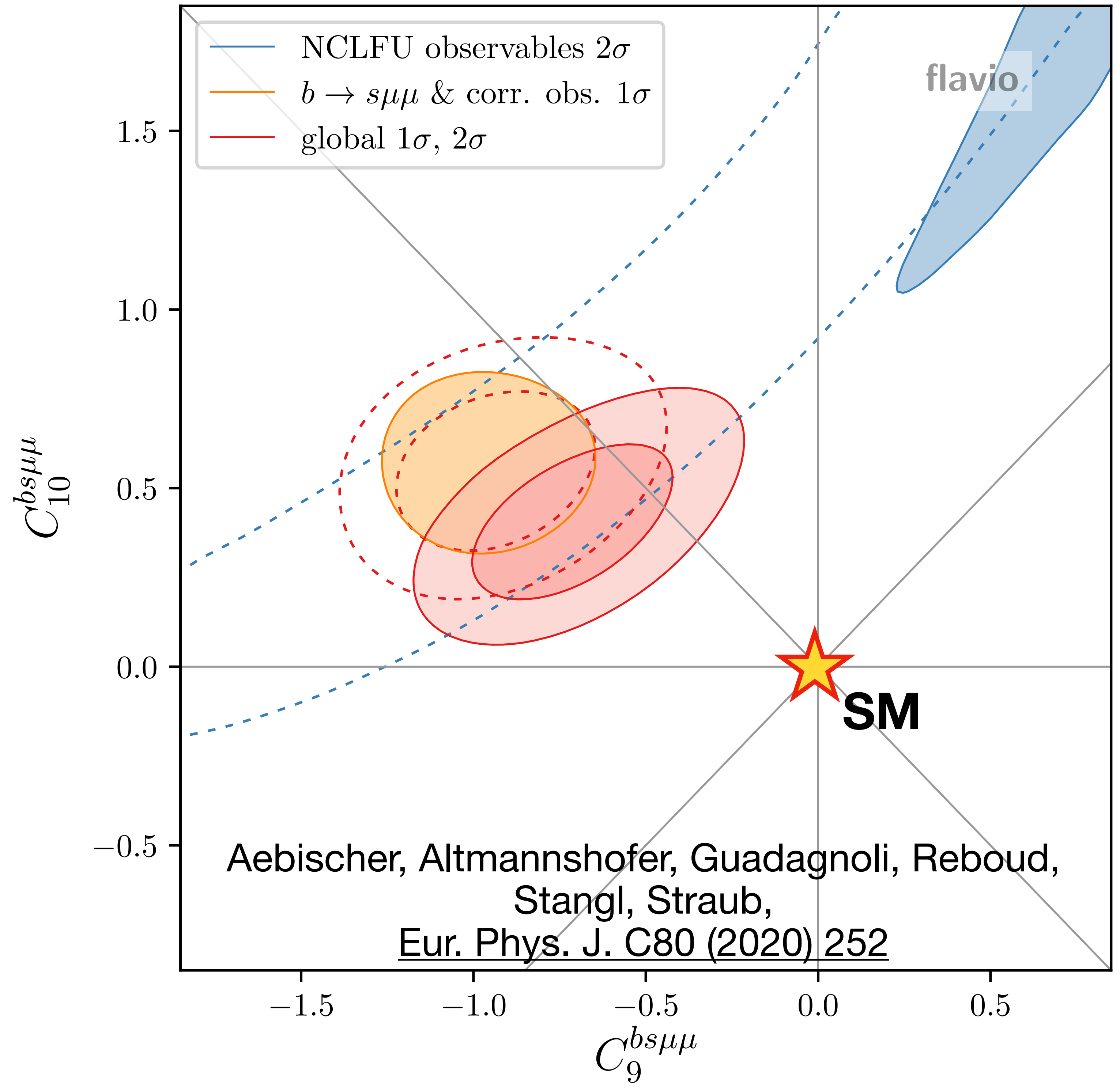
- C_9^{NP} deviates from 0 by > 4σ
- Many independent fits seem to favour C_9^{NP} = -1
- Vector Leptoquarks? Z'?

Arbey, Hurth, Mahmoudi, Martínez Santos, Neshatpour, Phys. Rev. D100 (2019) 015045



Algueró, Capdevila, Crivellin, Descotes-Genon, Masjuan, Matias, Brunet, Virto, Eur. Phys. J. C79 (2019) 714, update 04/2020





Aebischer, Altmannshofer, Guadagnoli, Reboud, Stangl, Straub, Eur. Phys. J. C80 (2020) 252

THE LHCB DETECTOR

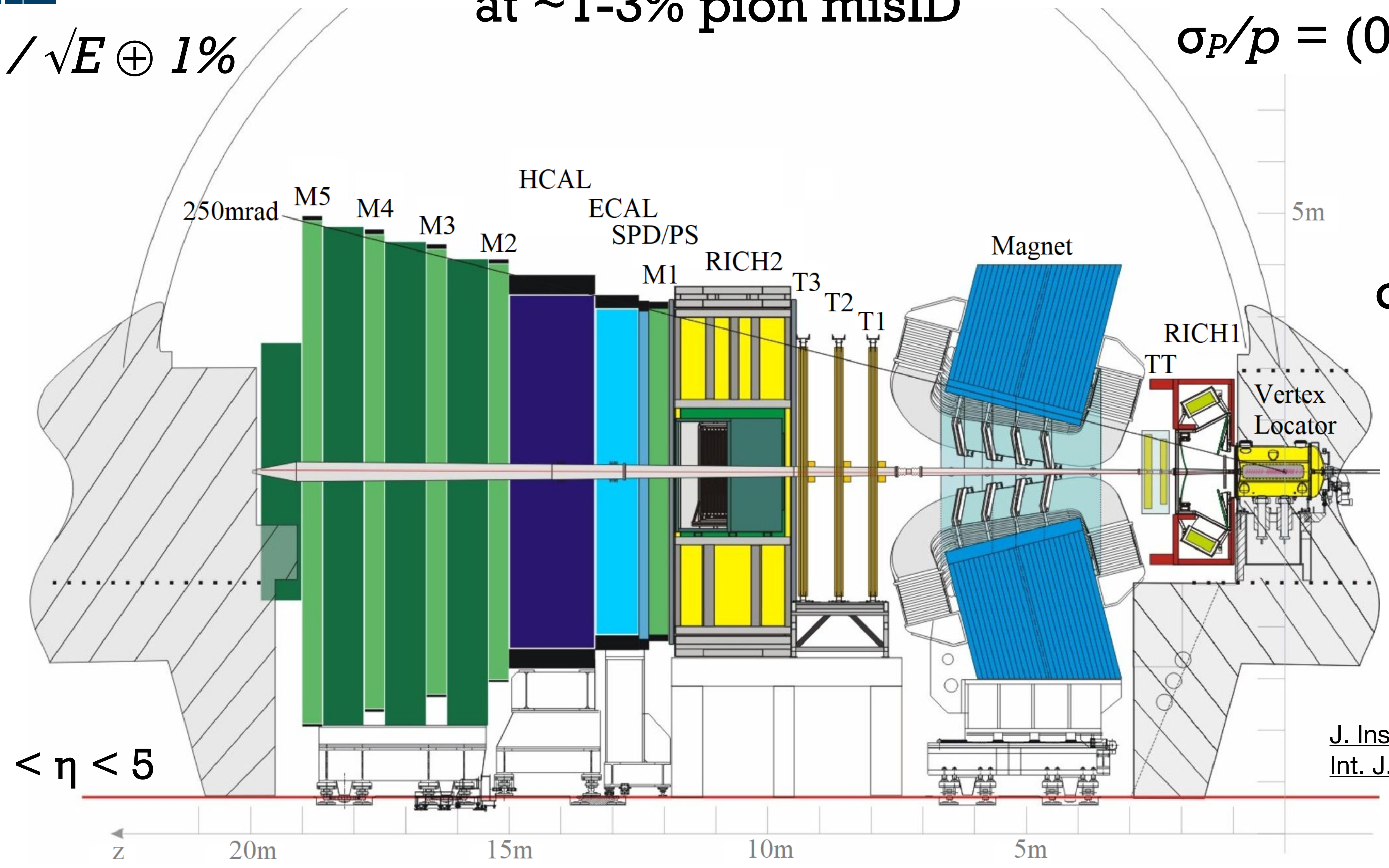
Particle ID
~97% lepton ID rate
at ~1-3% pion misID

ECAL
$\sigma_E/E \sim 10\% / \sqrt{E} \oplus 1\%$

Tracking
$\sigma_P/p = (0.4\text{-}0.6)\%$

MUON
trigger eff. > 90%
for $p_T > 5\ GeV/c^2$

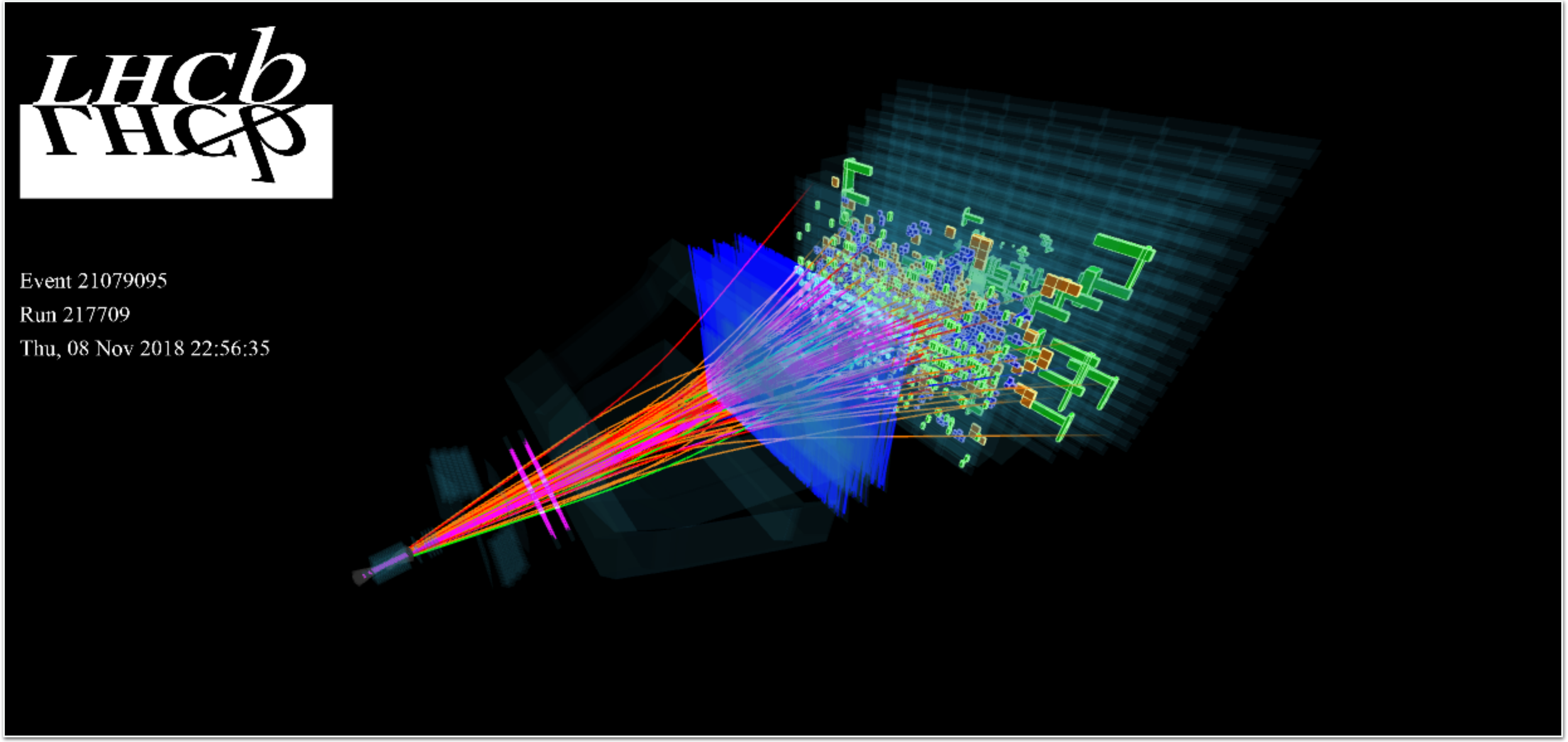
VELO
$\sigma_{IP} = (15 + 29/p_T)\ \mu m$



Acceptance $2 < \eta < 5$

J. Instrum. 3 (2008) S08005
Int. J. Mod. Phys. A 30 (2015) 1530022

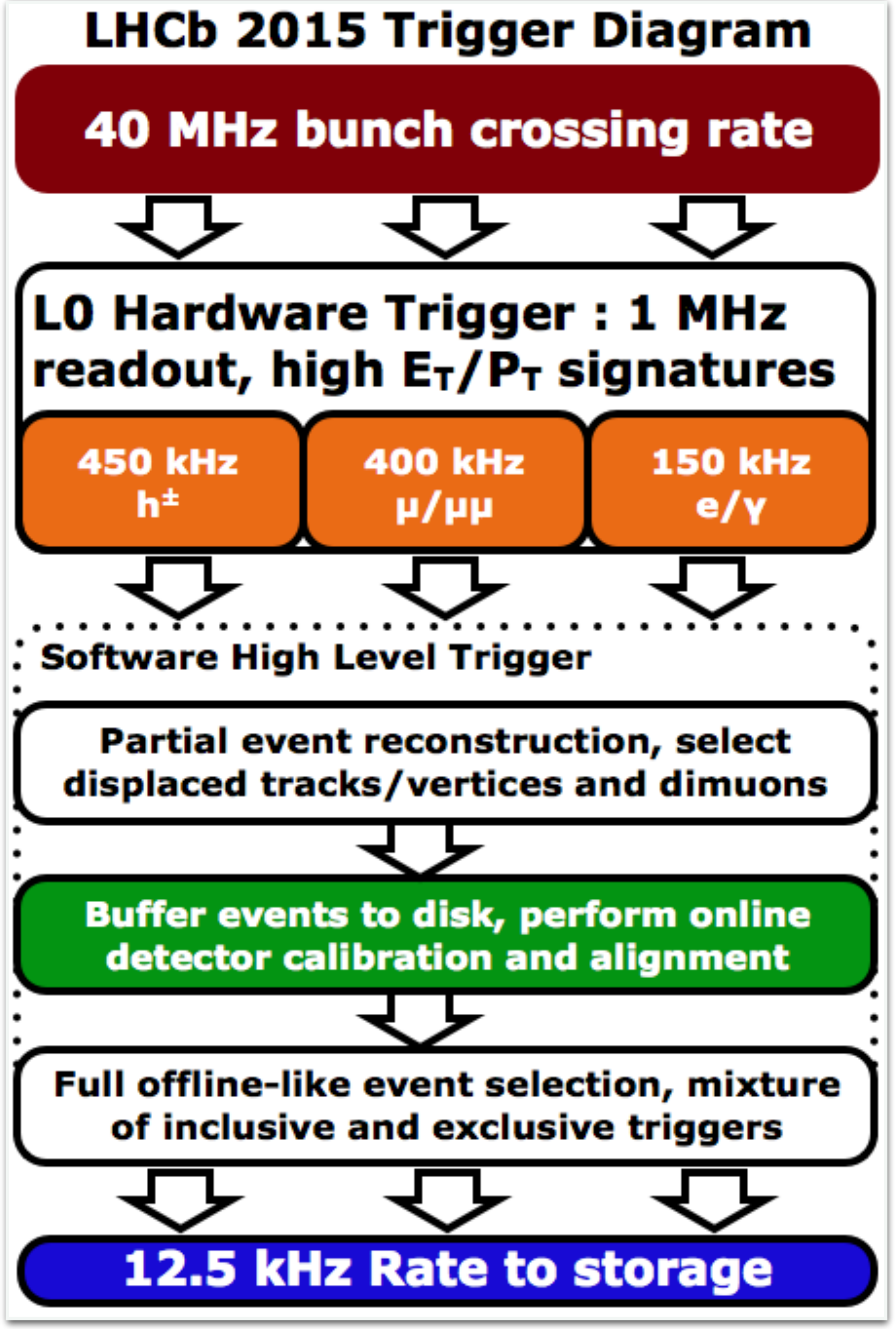
LHCB - EVENT DISPLAY



ONLINE DATA CHALLENGE

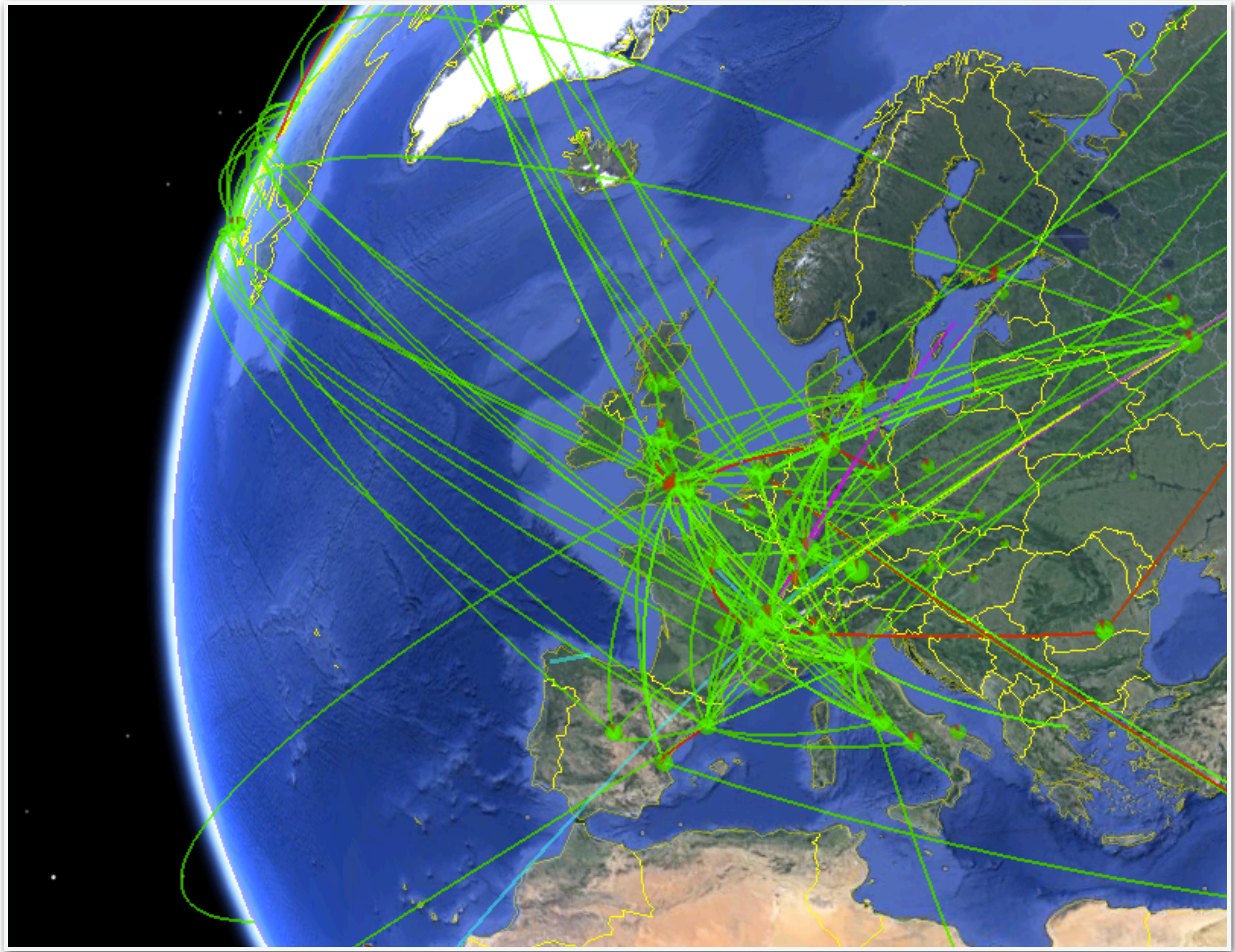
- Particle collisions at ~40 MHz, ~55 kB per collision
  —> select interesting events 'on-line': **trigger**
- Fast pattern recognition and reconstruction:
  —> **combinatorial** problem
- Most analysis limited by 'statistical error' —> more data!
- For 2022: **0.6 GB/s —> 10 GB/s** to storage
  —> Implemented first trigger level on GPUs

Beyond 2030: Further drastic increase in luminosity (x2-3?)



OFFLINE DATA CHALLENGE

https://wlcg.web.cern.ch



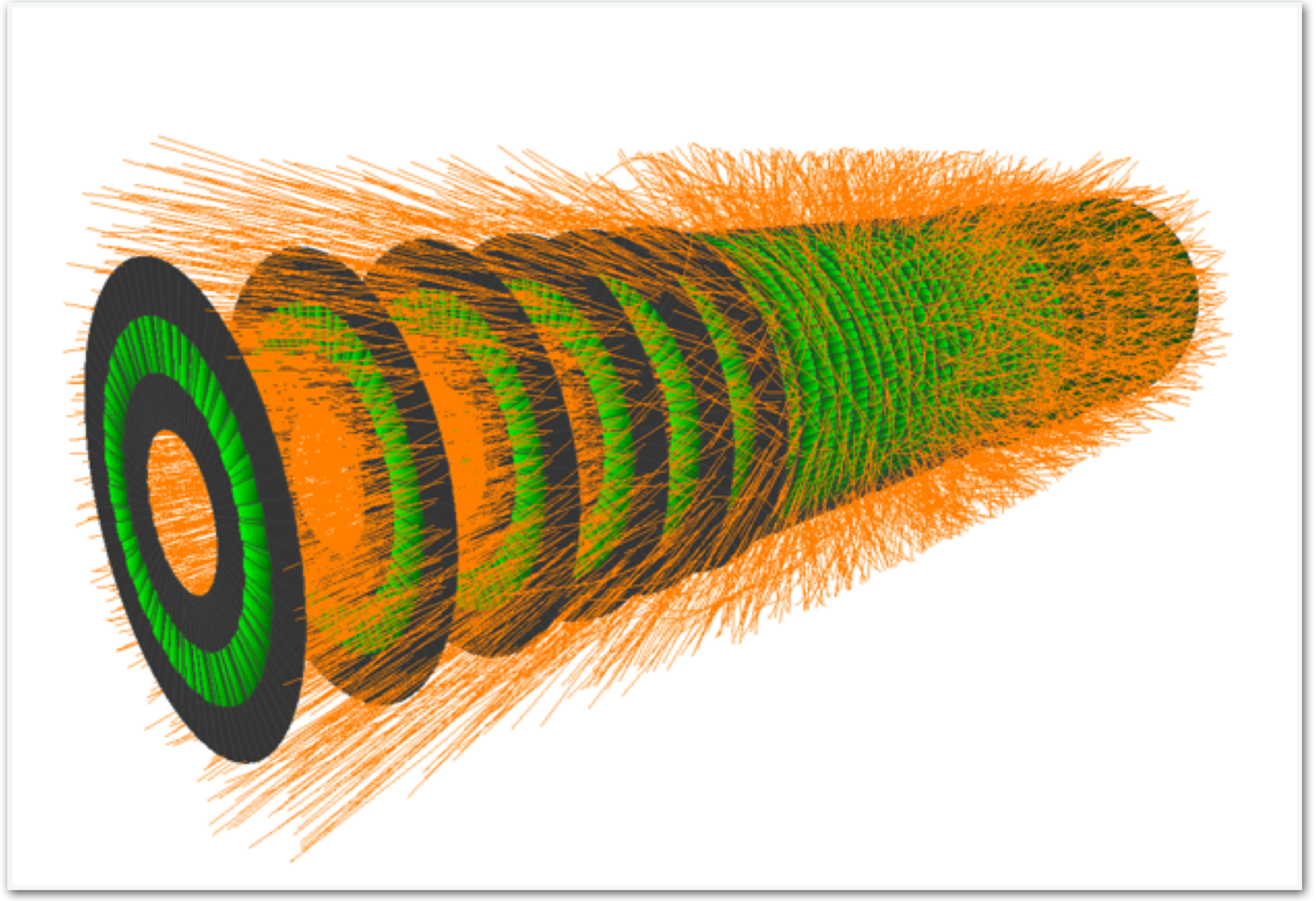
- Datasets of petabyte size.
  —> Demand simulated datasets of similar size

- Current infrastructure: 'The Grid'
  Tier 0 (CERN-Budapest), Tier-1 (13 Centres),
  Tier 2 (155 Universities)
- Addition of GPU clusters, Generative models, …

High-Luminosity LHC: ~10-15 years

—> Significant increase in multiplicity and event size

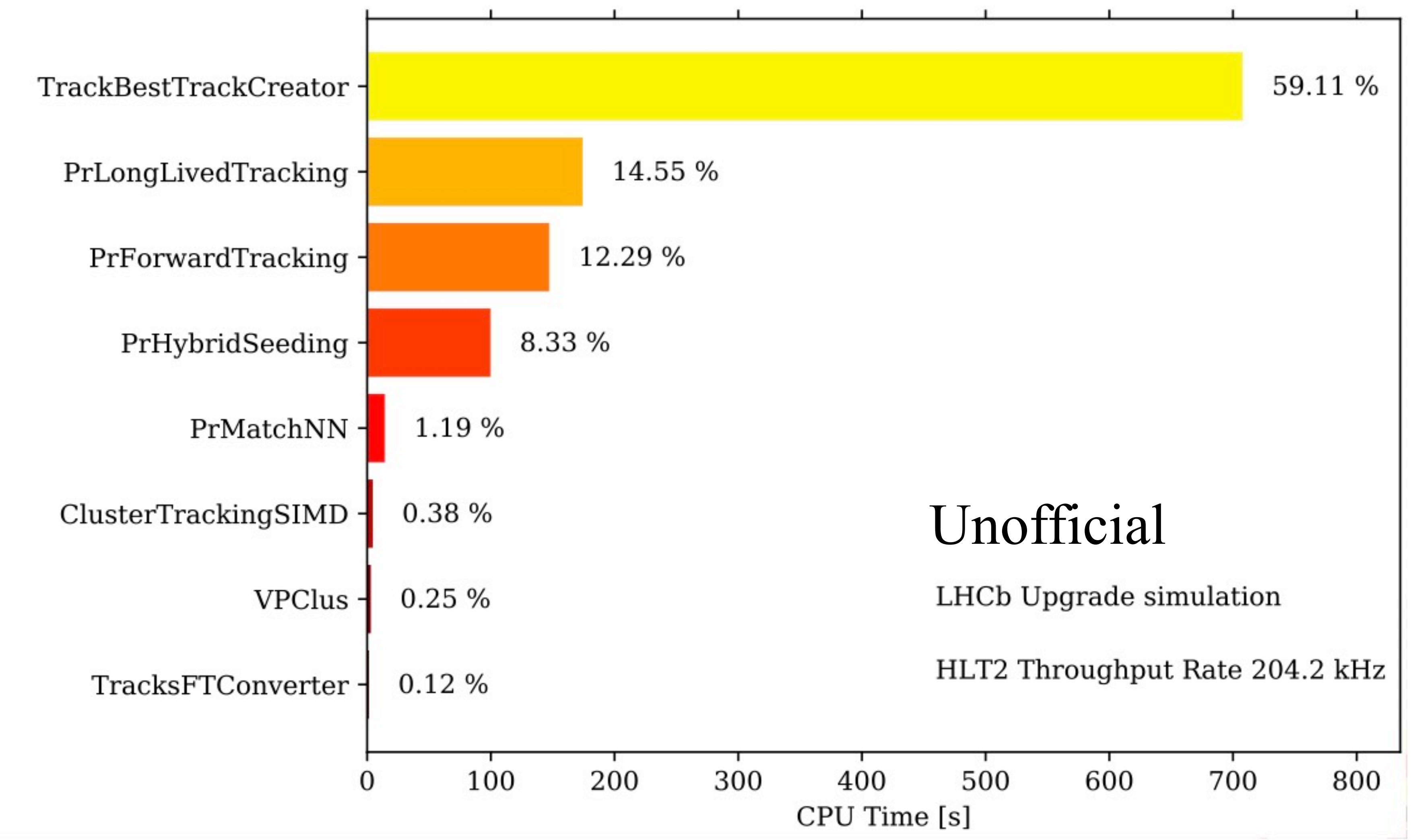
- Track reconstruction? Classification? Simulation?
- Rethink computing infrastructure!

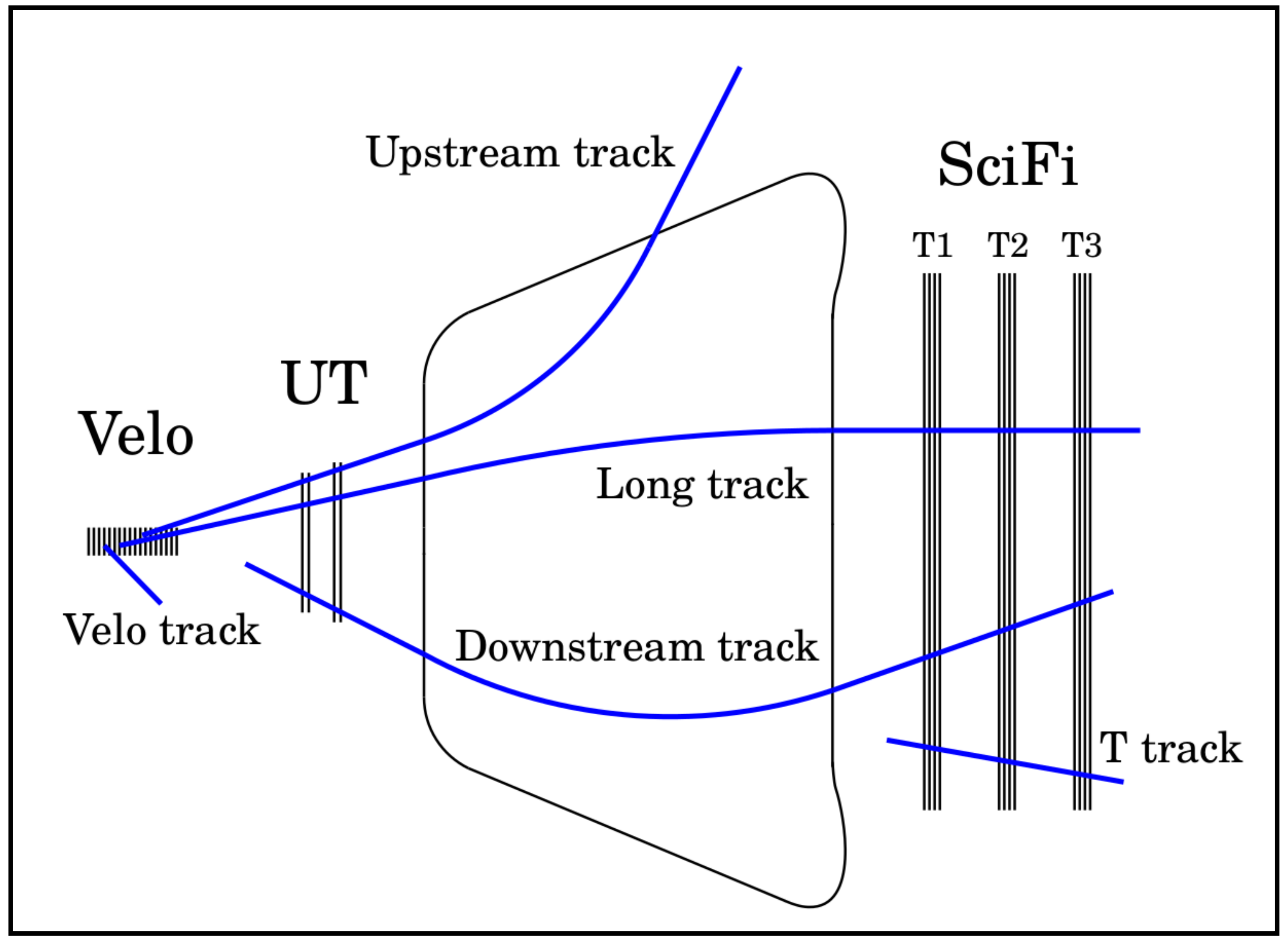


https://www.kaggle.com/c/trackml-particle-identification

TRACK RECONSTRUCTION

- LHCb is a 'single arm forward spectrometer'
  —> **reconstruct 'tracks' from 'hits'**, (then get momentum from curvature in B-field).
- At the core of LHCb's physics performance. Largest time component in trigger.
- Scales with $N_{hits}^{2\text{-}3}$, suffers drastically from luminosity increase beyond 2030.
  —> ?: How to reconstruct so many particles in 'real time'?





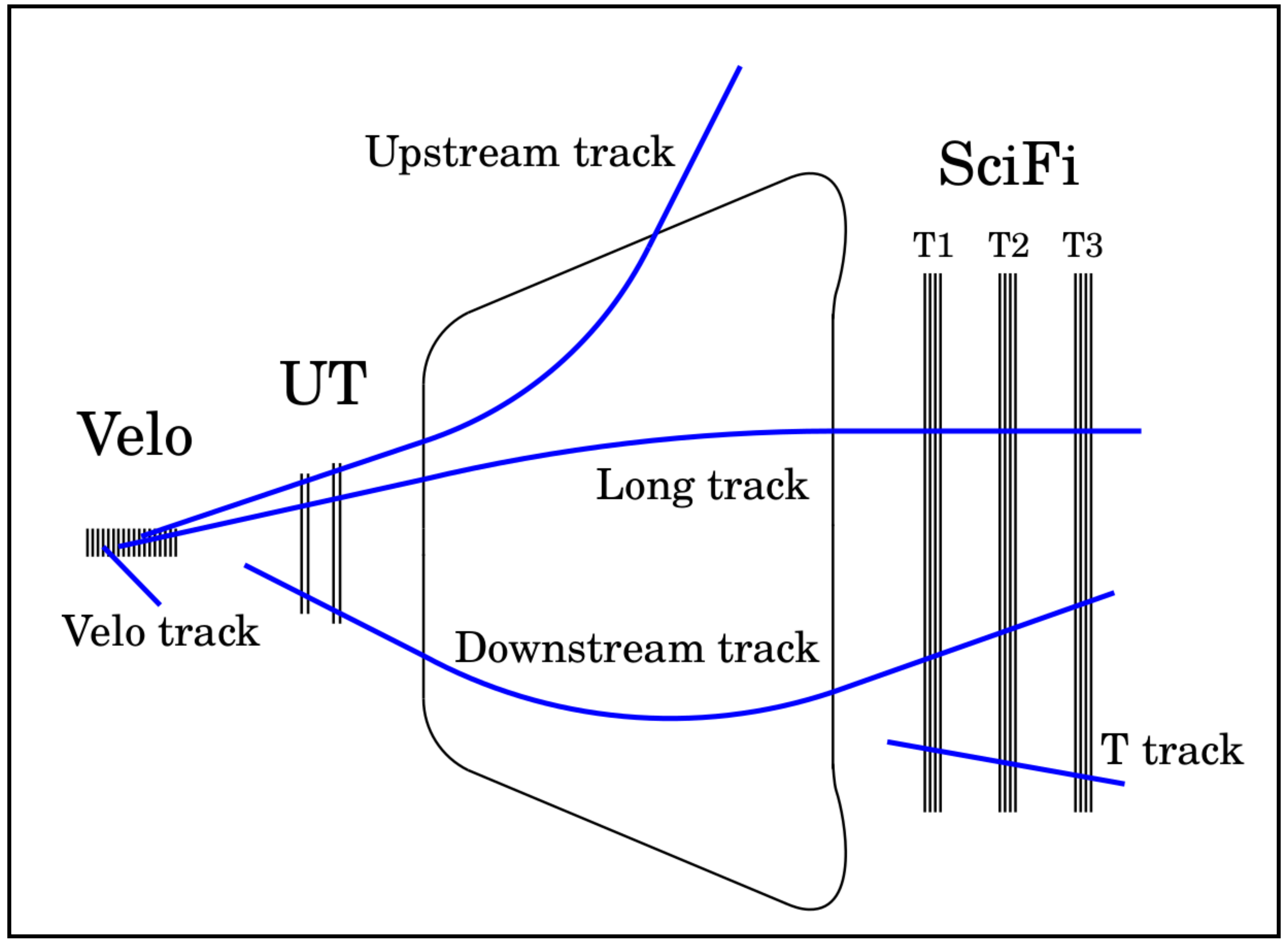
TRACK RECONSTRUCTION

Pattern recognition - finding hits belonging to one track

- Velo: ‘triplet search / track following’ *
- Project forward towards ‘UT’, and ’SciFi’ after magnet, search windows, Hough transform
- Match standalone ‘SciFi’ tracks with remaining Velo(-UT)
- Kill all double combinations (‘clones’)

Track fit: (extended) Kalman Filter - get optimal track parameters.

- Step-wise chi2 ‘fit’, projecting state onto next detector layers, filtering with measurement, and smoothing.
- Propagation in magnetic field: Runge-Kutta (5th order)
- Propagation through detector material: E-loss & scattering



https://indico.in2p3.fr/event/22193/contributions/86010/attachments/60141/81638/rquaglia_GDR_InF_Tracking_in_LHCb__lessons_learned.pdf

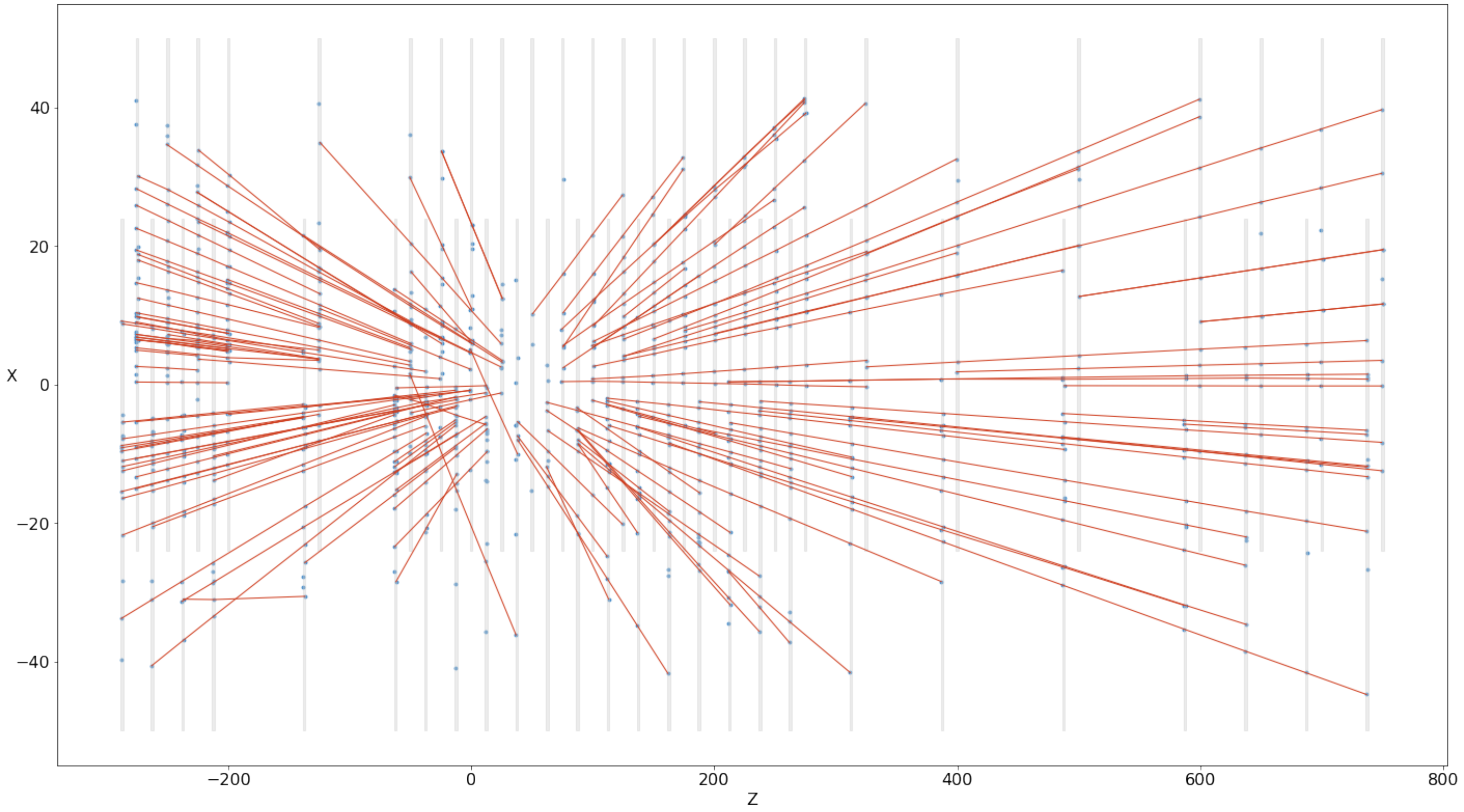
CASE STUDY: LHCB VELO

Pattern recognition in VELO detector

- 3D space points, straight line tracks
  Current implementation: ‘triplet search’ / ‘track following’
  See ‘toy’ at https://github.com/dcampora/velopix_tracking

- Performance figures:

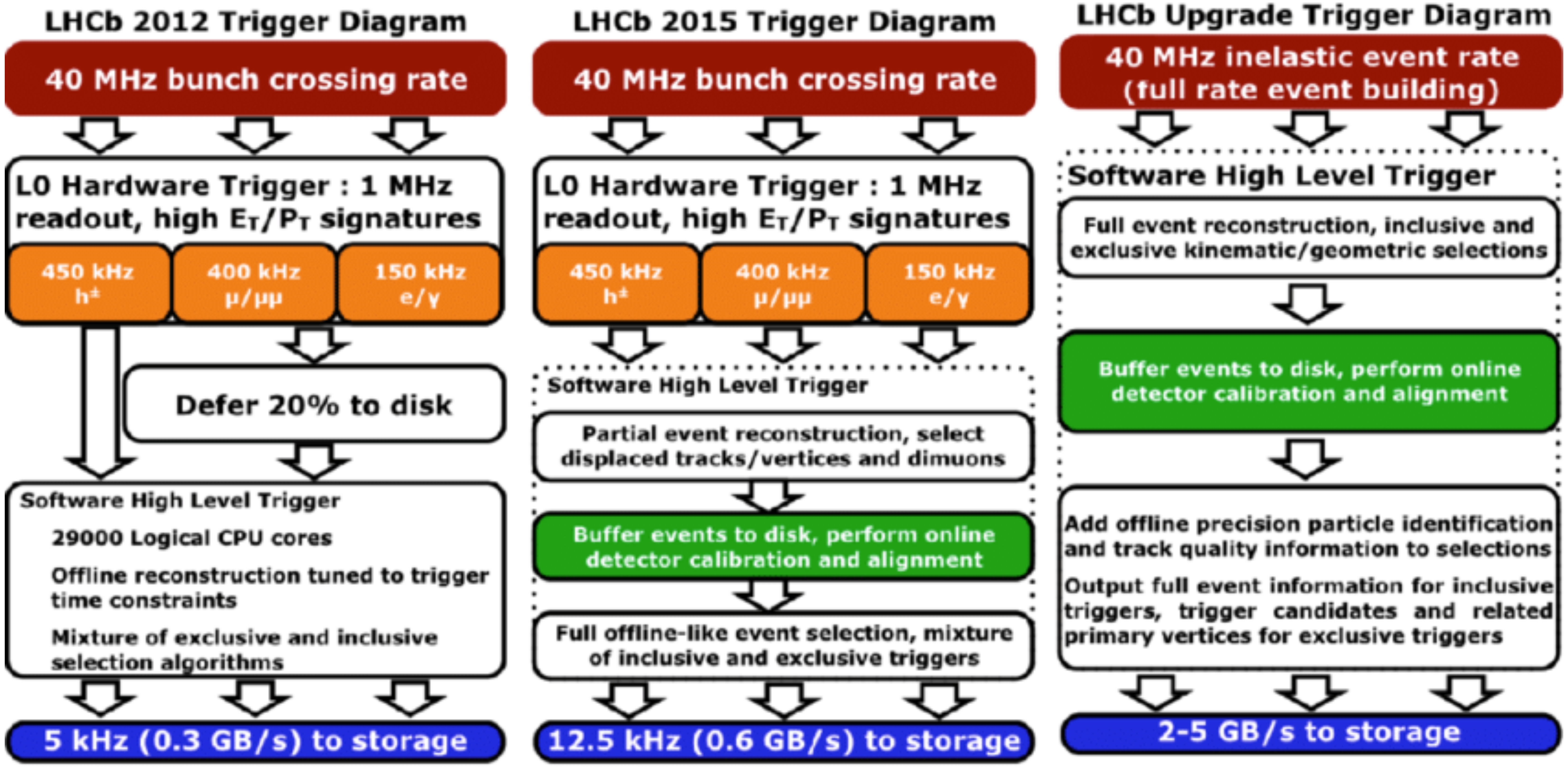
  - Efficiency (true found tracks)
  - Ghost rate (fake tracks)
  - Hit efficiency, purity, clone tracks




```
148 tracks including        8 ghosts (   5.4%). Event average    5.4%
                velo :       126 from      134 ( 94.0%,   94.0%)       3 clones (   2.38%), purity: ( 98.83%,   98.83%),  hitEff: ( 93.89%,   93.89%)
```

BACKUP

LHCB TRIGGER OVER THE YEARS



http://dx.doi.org/10.1088/1742-6596/762/1/012046