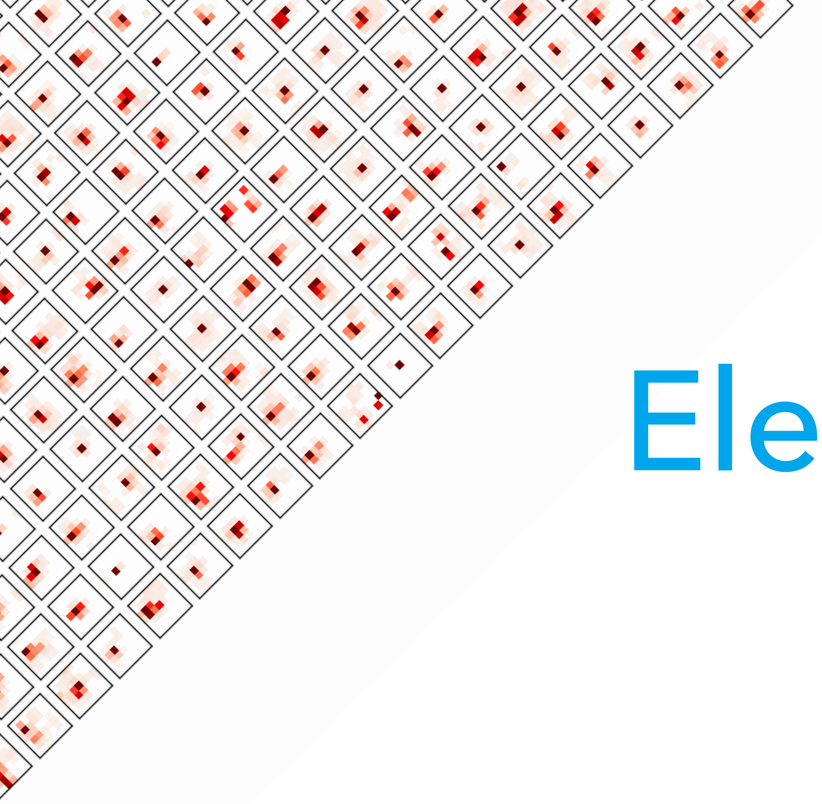


Electromagnetic calorimeter reconstruction in Belle II.

2019-03-12, ACAT, Saas-Fee

Torben Ferber (torben.ferber@desy.de) for the Belle II ECL group

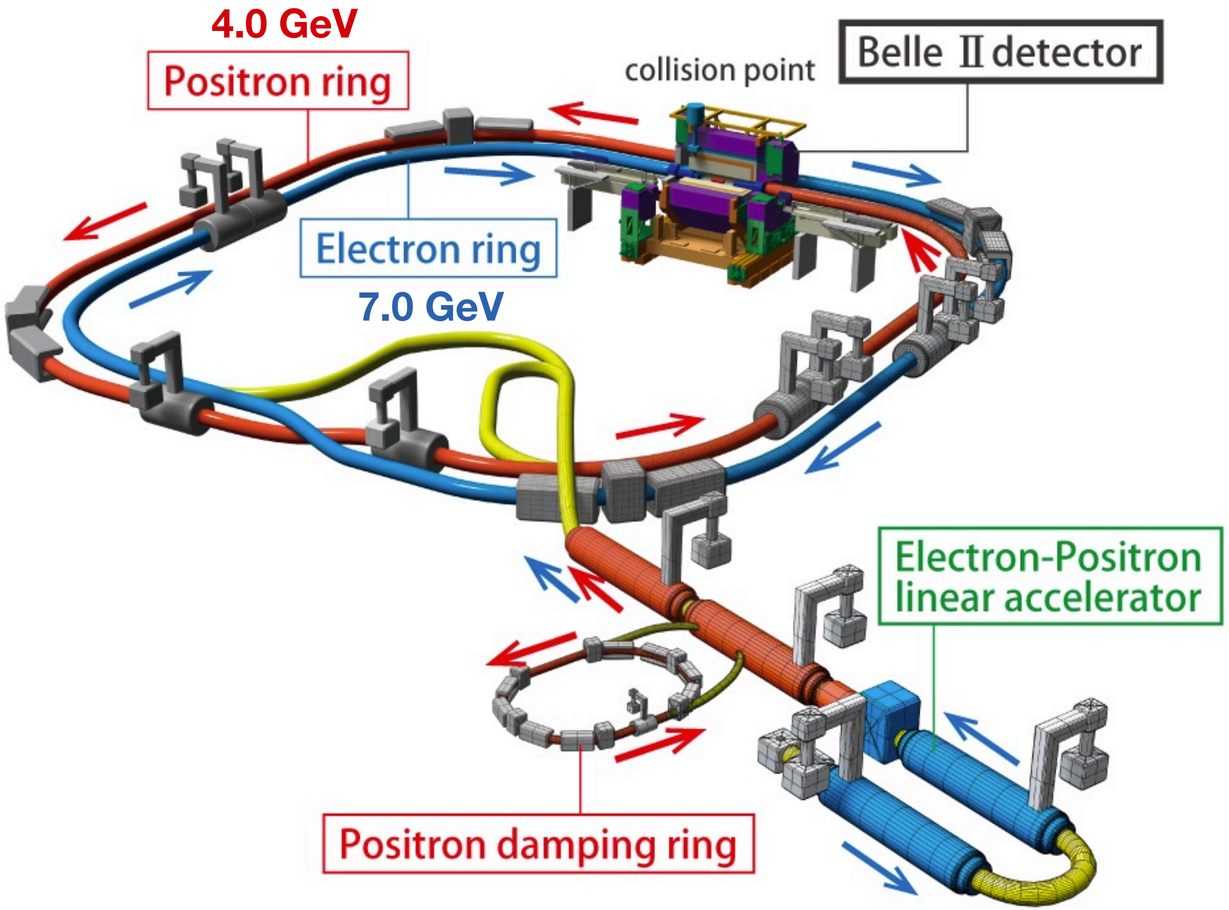
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

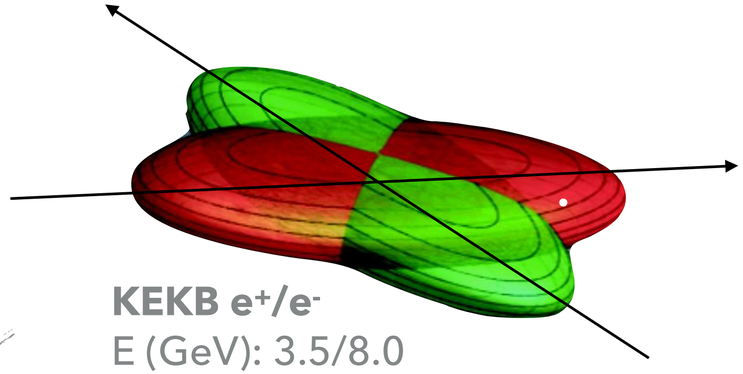
Belle II

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

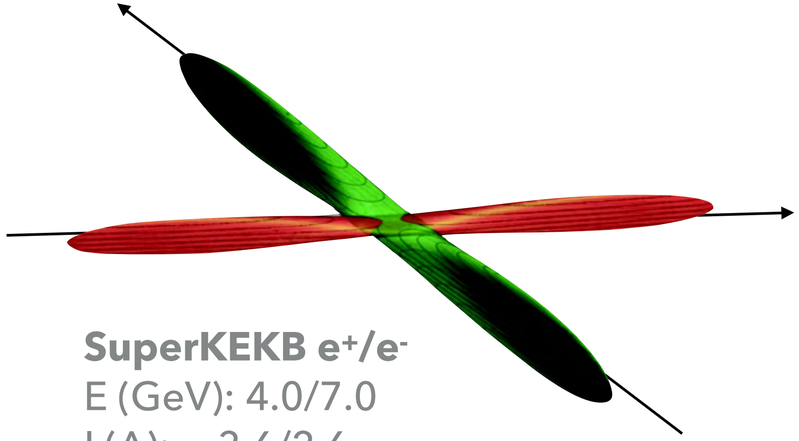
DESY.

SuperKEKB



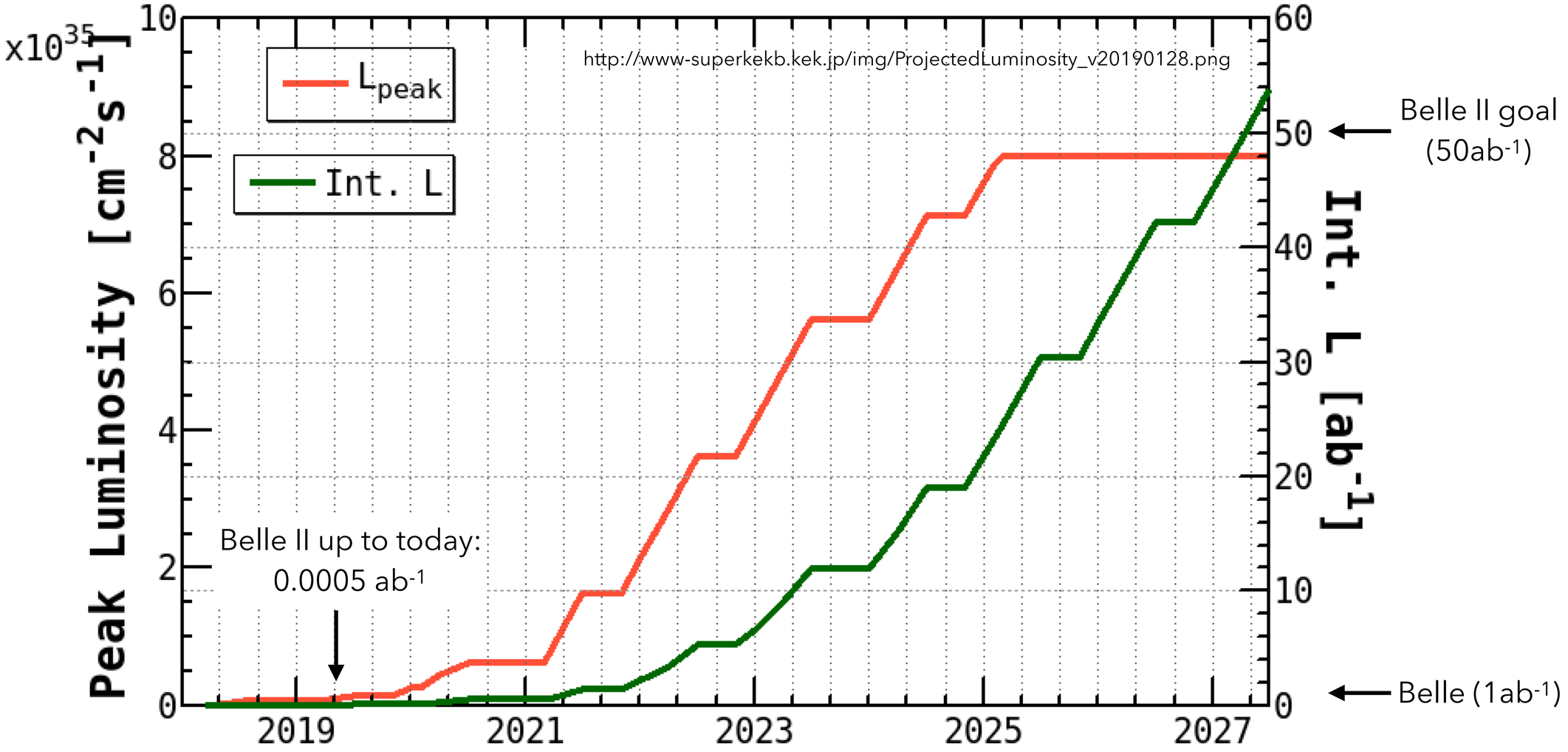


KEKB e^+/e^-
E (GeV): 3.5/8.0
I (A): ~ 1.6/1.2
β^*_y (mm): ~5.9/5.9
Crossing angle (mrad): 22

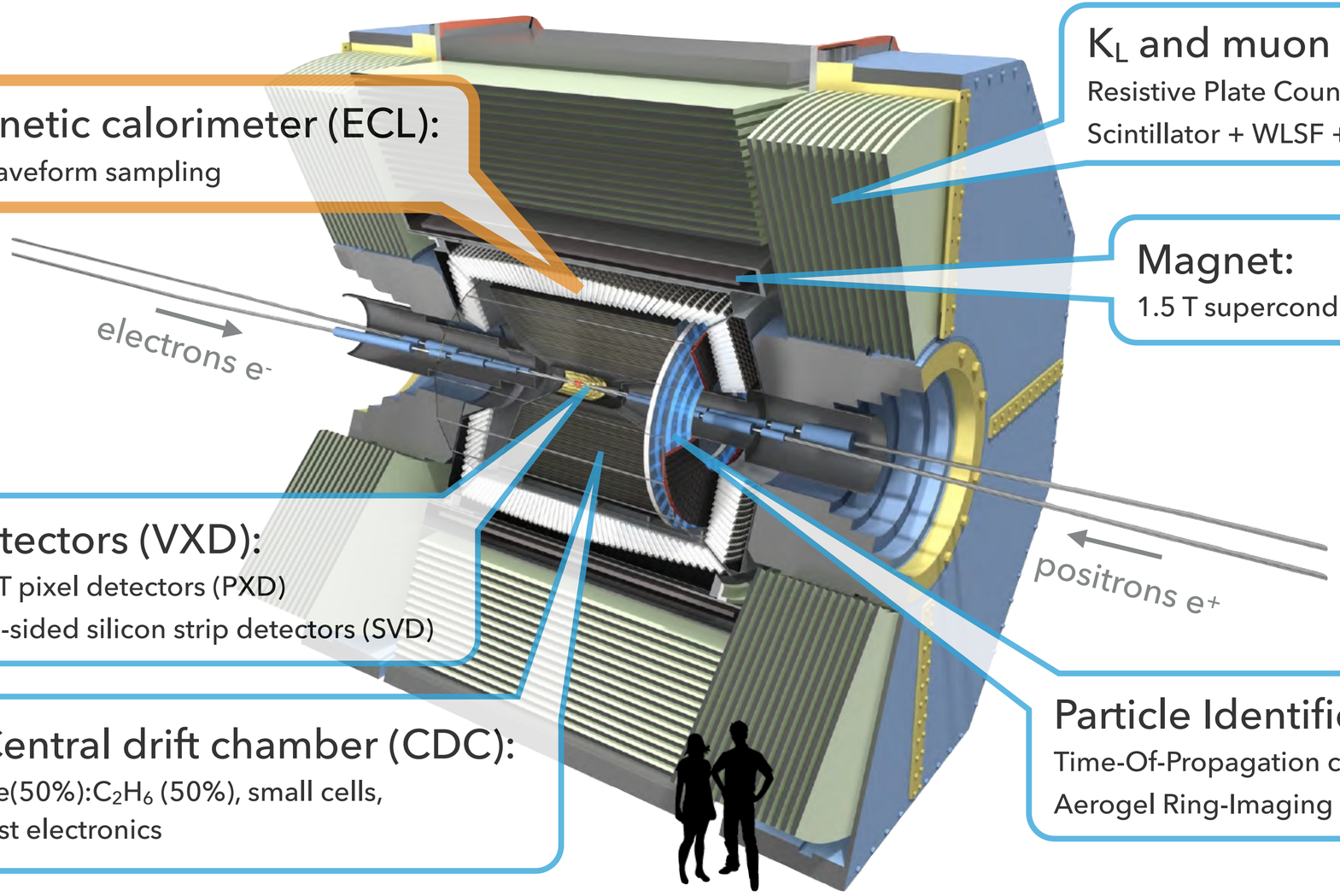


SuperKEKB e^+/e^-
E (GeV): 4.0/7.0
I (A): ~ 3.6/2.6
β^*_y (mm): ~0.27/0.3
Crossing angle (mrad): 83
→ **Luminosity increase x40**

Belle II at SuperKEKB



Belle II at SuperKEKB



Electromagnetic calorimeter (ECL):
CsI(Tl) crystals, waveform sampling

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

Trigger:
Hardware: < 30 kHz
Software: < 10 kHz

Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD)
4 layer double-sided silicon strip detectors (SVD)

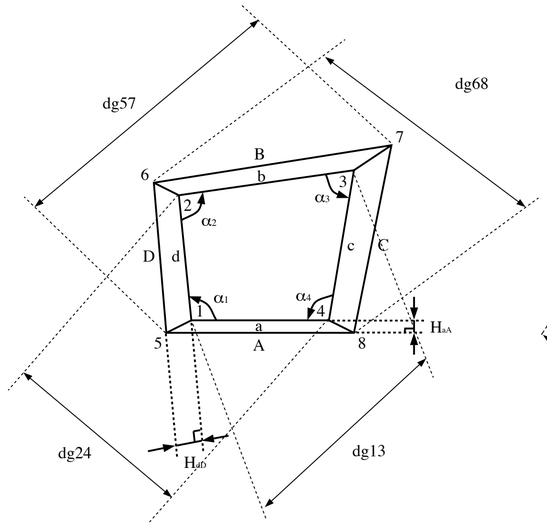
Central drift chamber (CDC):
He(50%):C_2H_6 (50%), small cells,
fast electronics

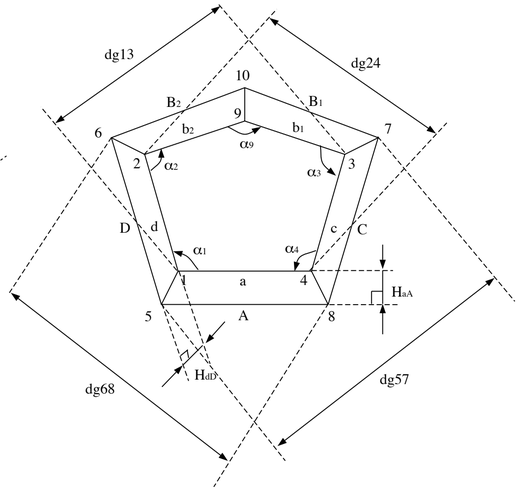
Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

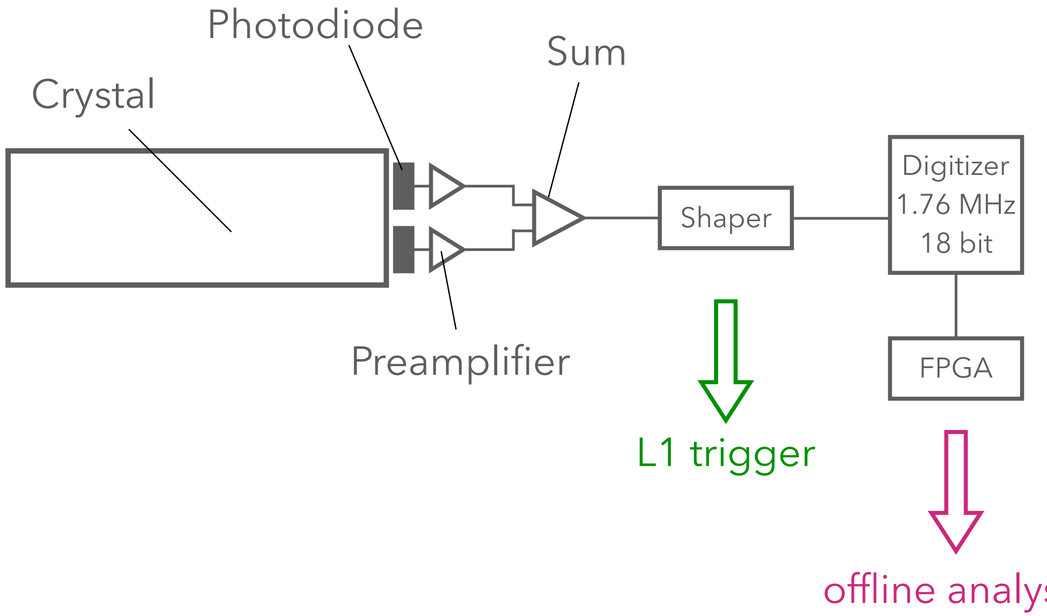
DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

Belle II Calorimeter (ECL)

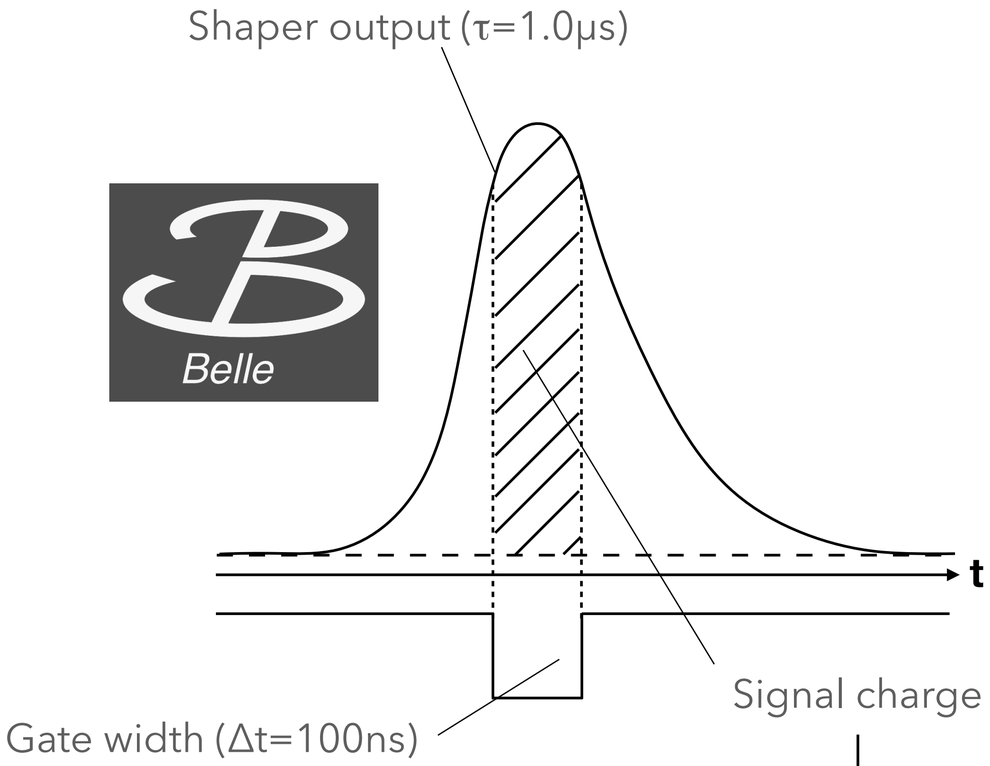
- 8736 crystals
  - ~5×5×30 cm^3 CsI(Tl) → 16.1 X_0
  - Crystals, photodiodes and preamplifiers reused from Belle experiment
- New shapers and digitizers/FPGAs







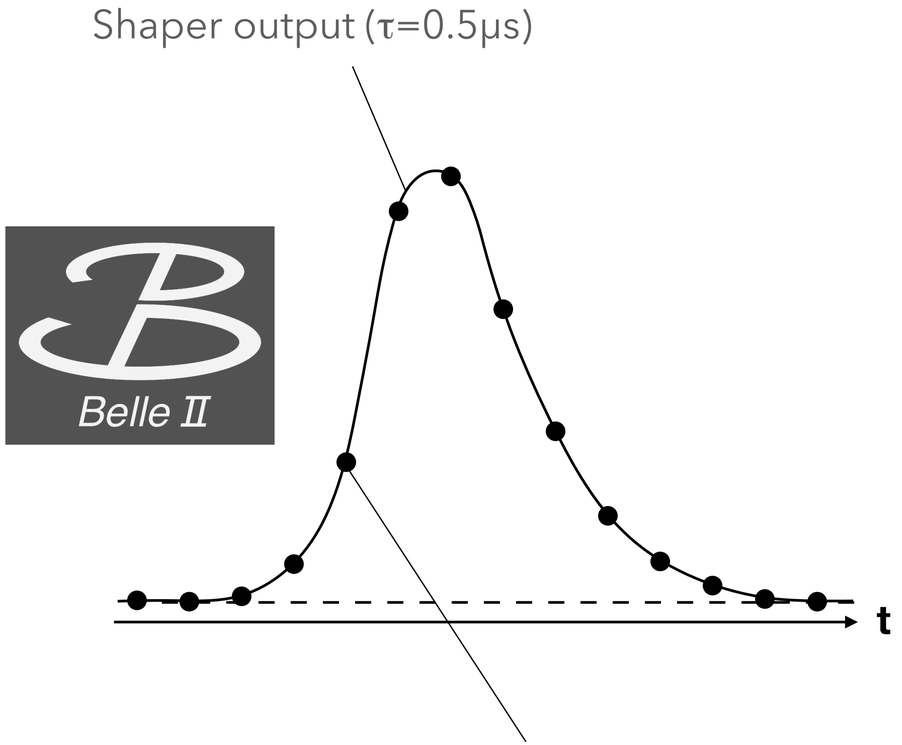
Signal processing: Belle and Belle II



Charge-to-time converter (QTC)

Digitizer (TDC)

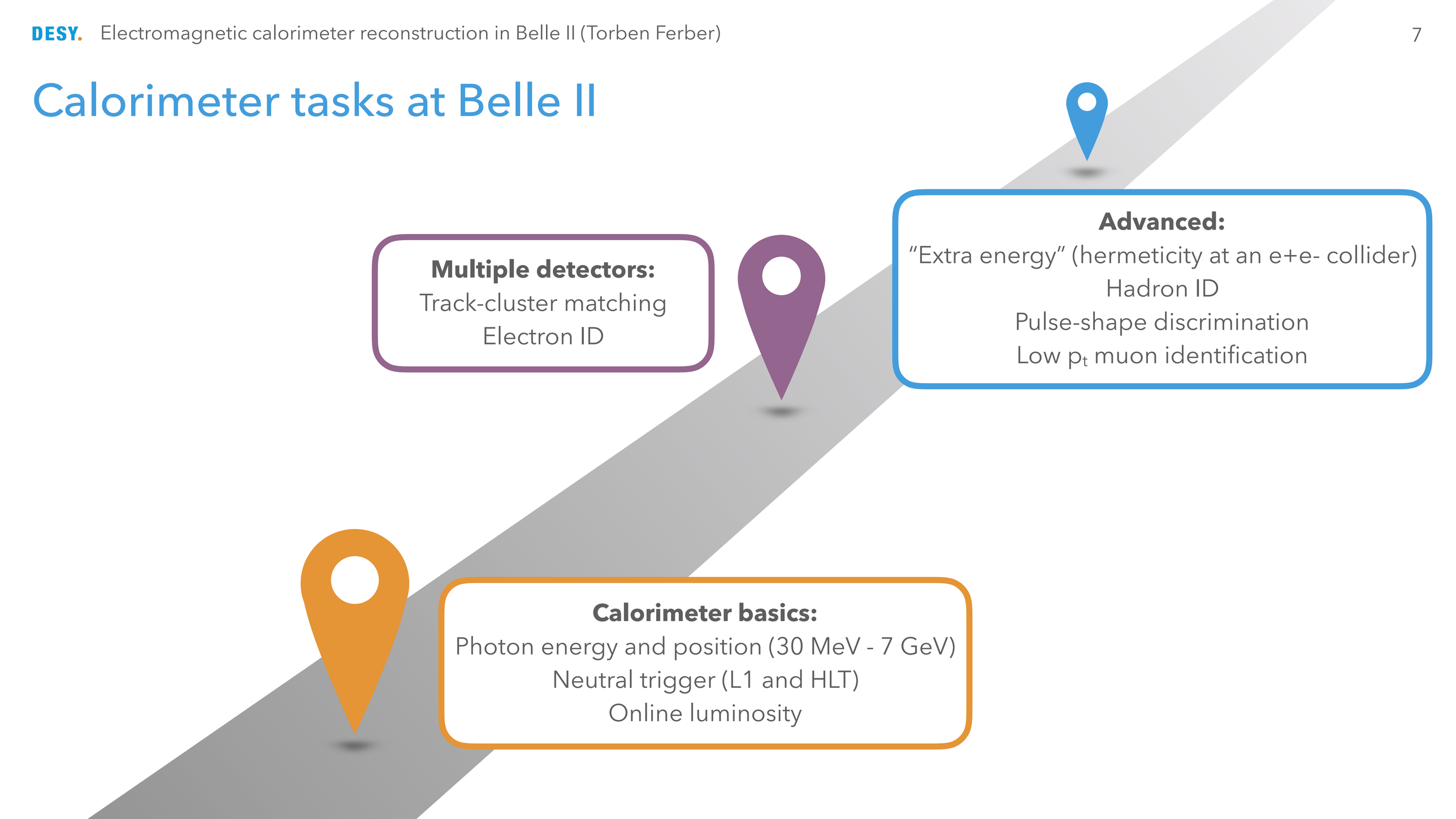
Amplitude



Waveform Digitizer, 1.76 MHz, 18 bit

FPGA fits to extract **Amplitude** and **Time**

Calorimeter tasks at Belle II



Advanced:
"Extra energy" (hermeticity at an e+e- collider)
Hadron ID
Pulse-shape discrimination
Low p_t muon identification

Multiple detectors:
Track-cluster matching
Electron ID

Calorimeter basics:
Photon energy and position (30 MeV - 7 GeV)
Neutral trigger (L1 and HLT)
Online luminosity

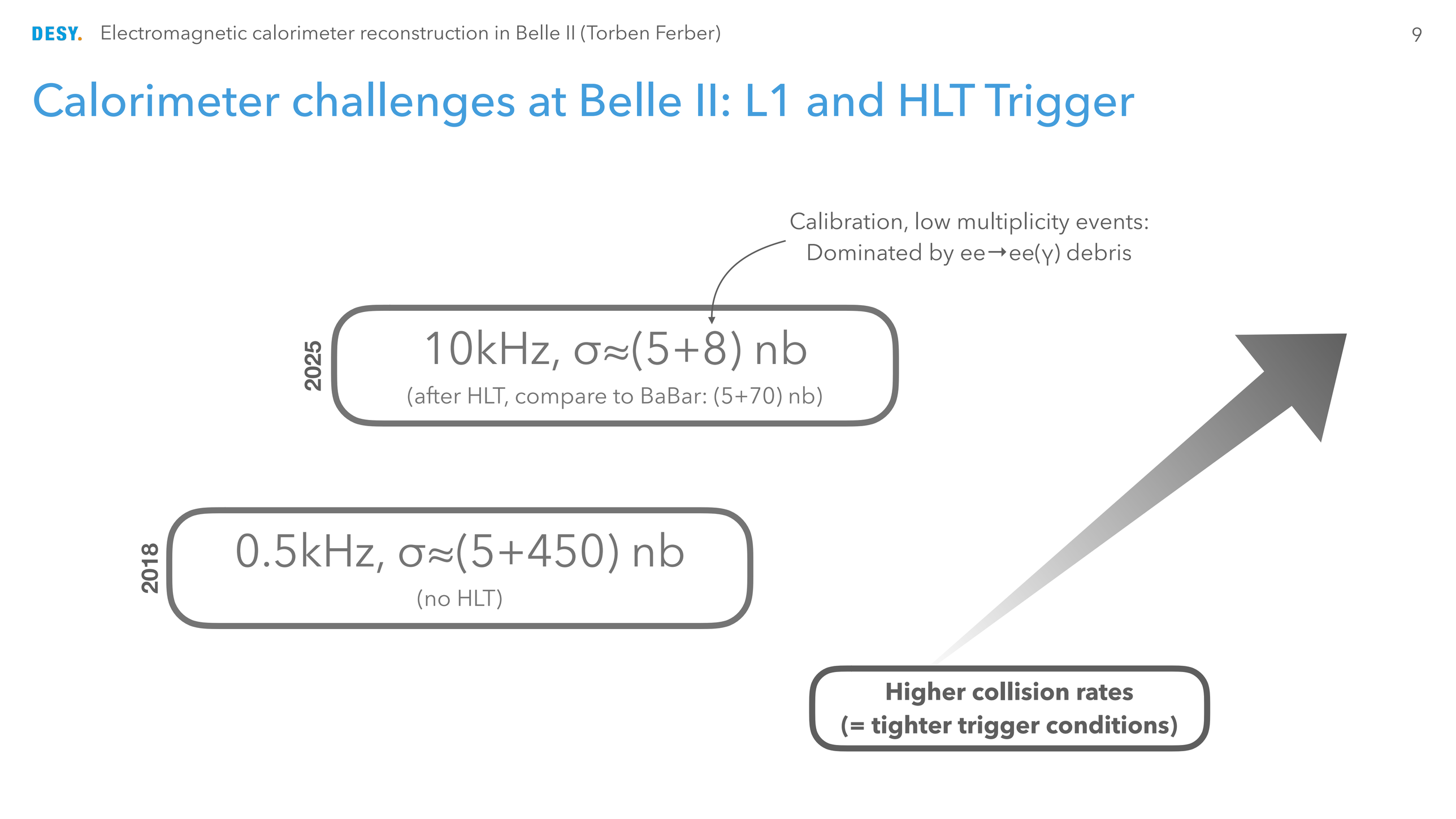
Calorimeter challenges at Belle II

Calorimeter challenges at Belle II: L1 and HLT Trigger

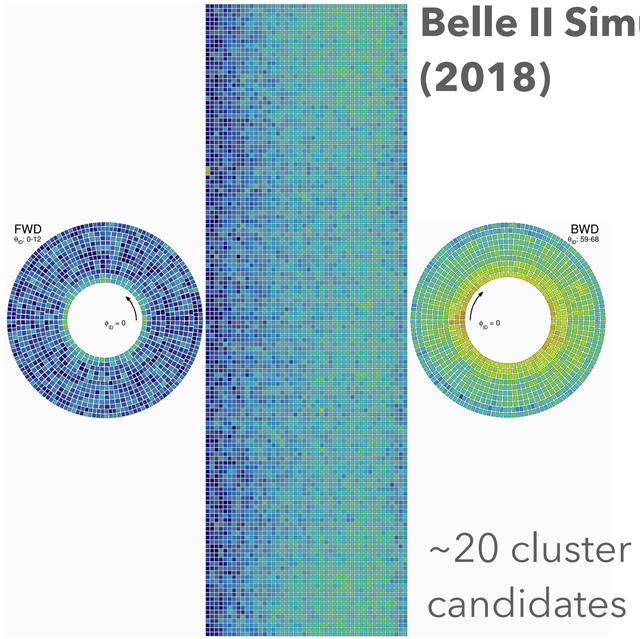
Calibration, low multiplicity events:
Dominated by ee→ee(γ) debris

2025: 10kHz, σ≈(5+8) nb
(after HLT, compare to BaBar: (5+70) nb)

2018: 0.5kHz, σ≈(5+450) nb
(no HLT)

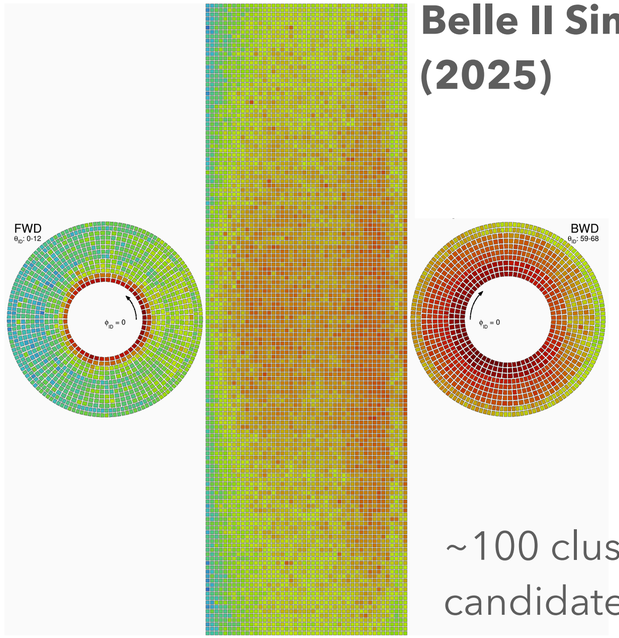


Calorimeter challenges at Belle II: Beam background



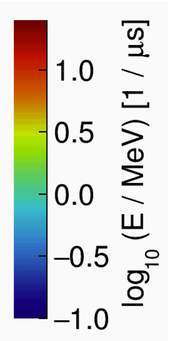
Belle II Simulation (2018)

~20 cluster candidates per event



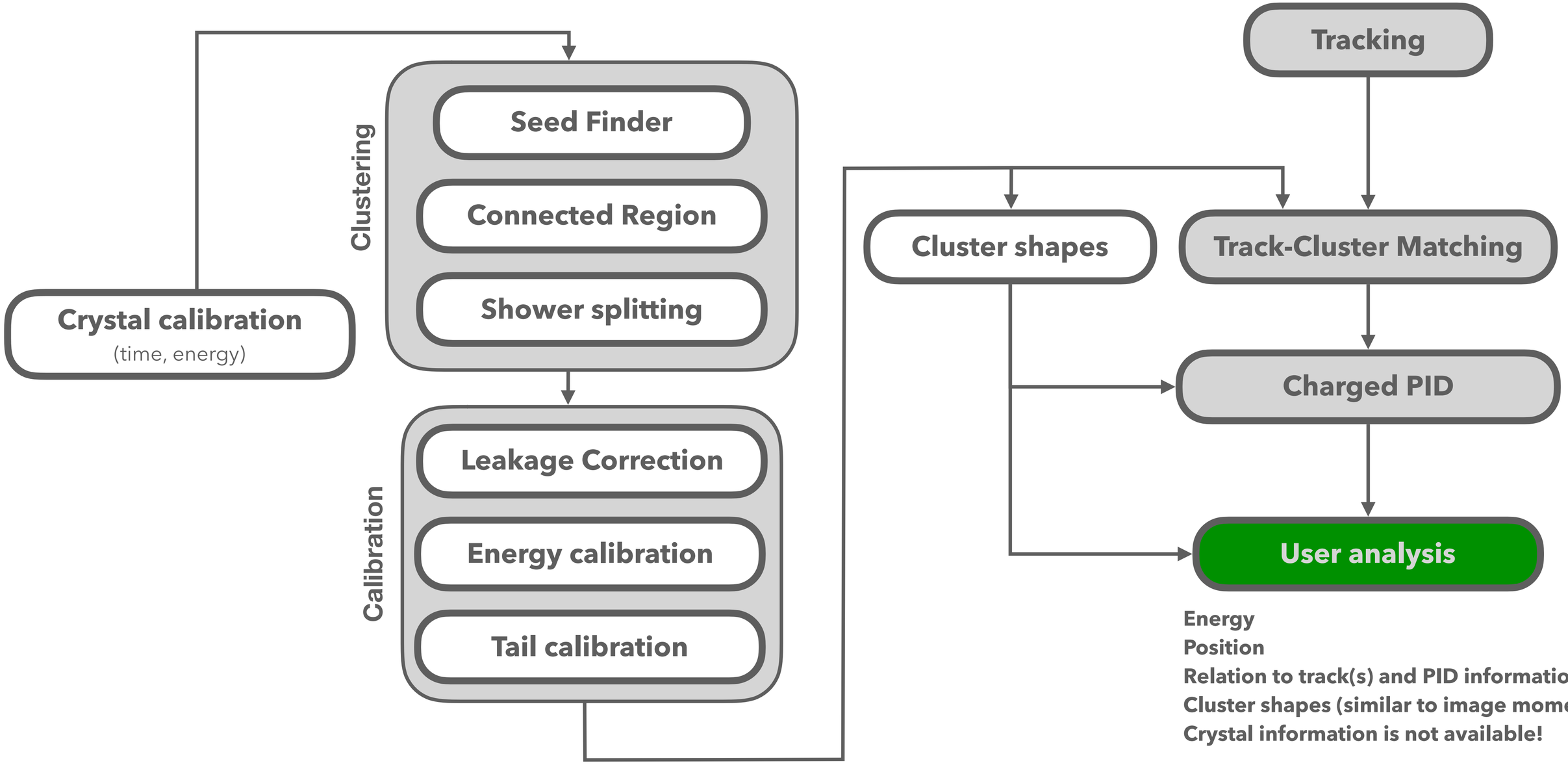
Belle II Simulation (2025)

~100 cluster candidates per event

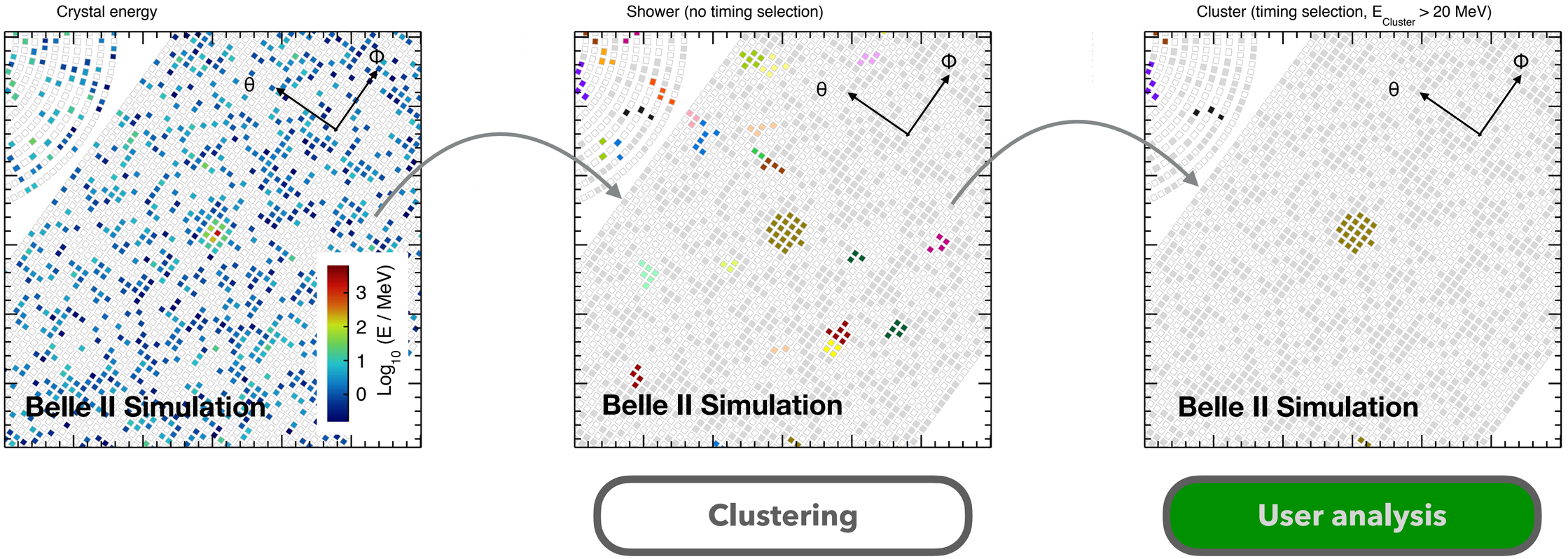


Higher beam backgrounds

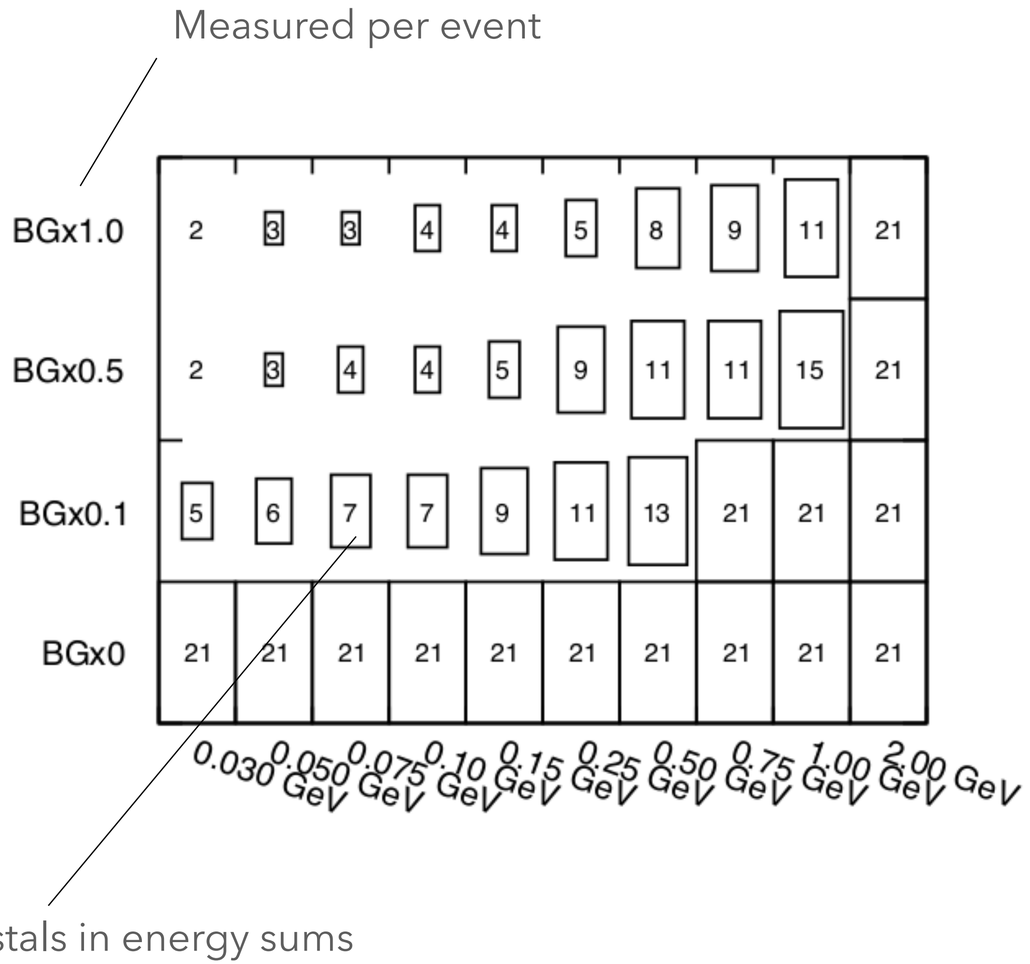
Offline reconstruction flow

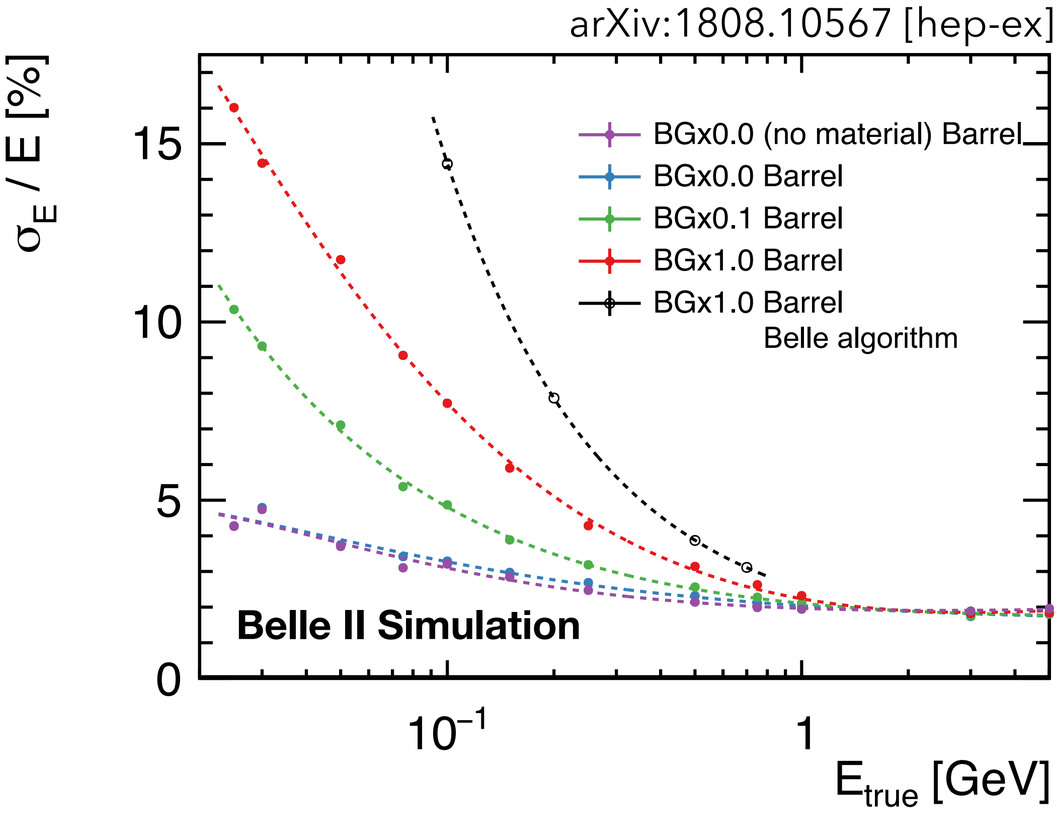


Offline reconstruction in pictures

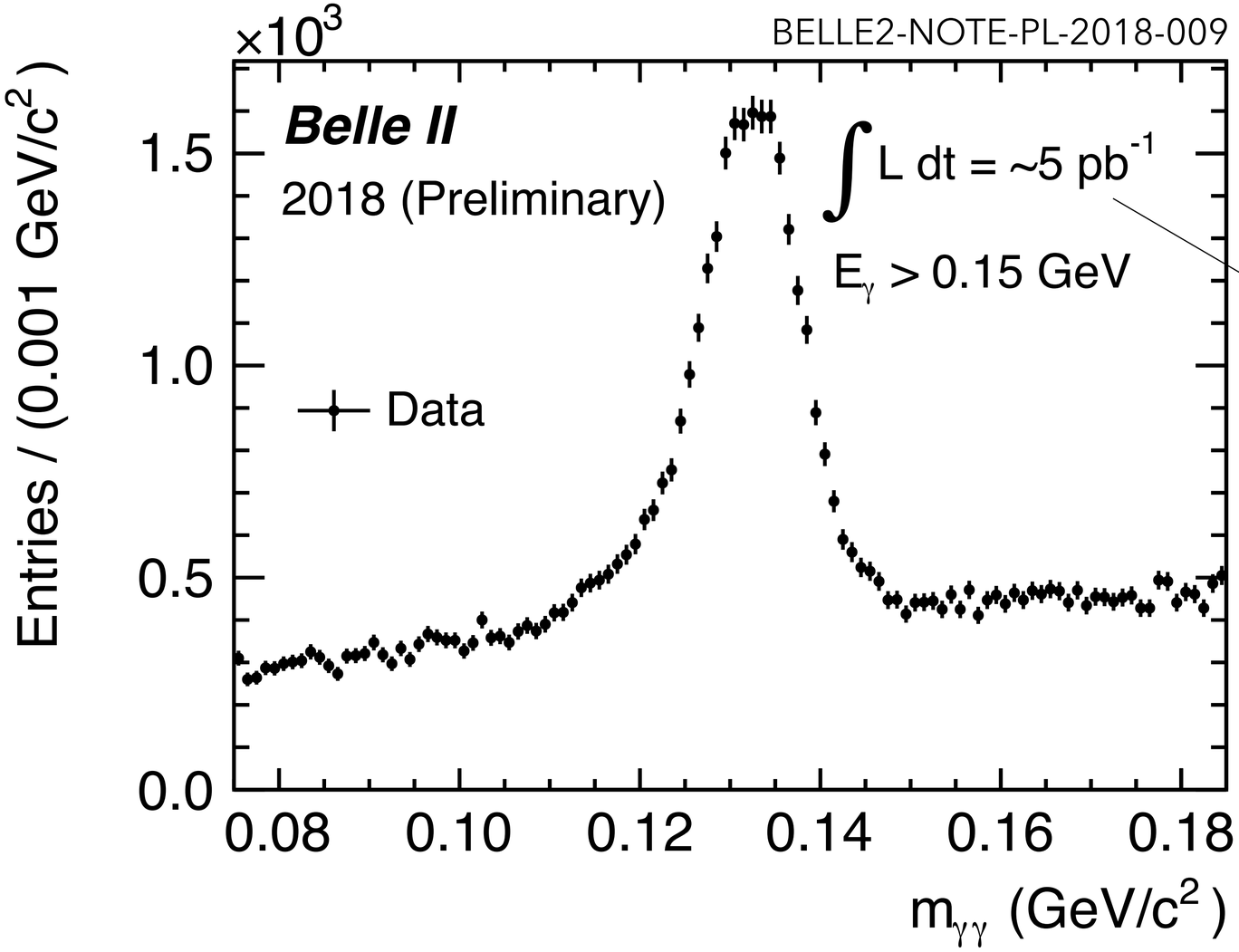


Offline reconstruction



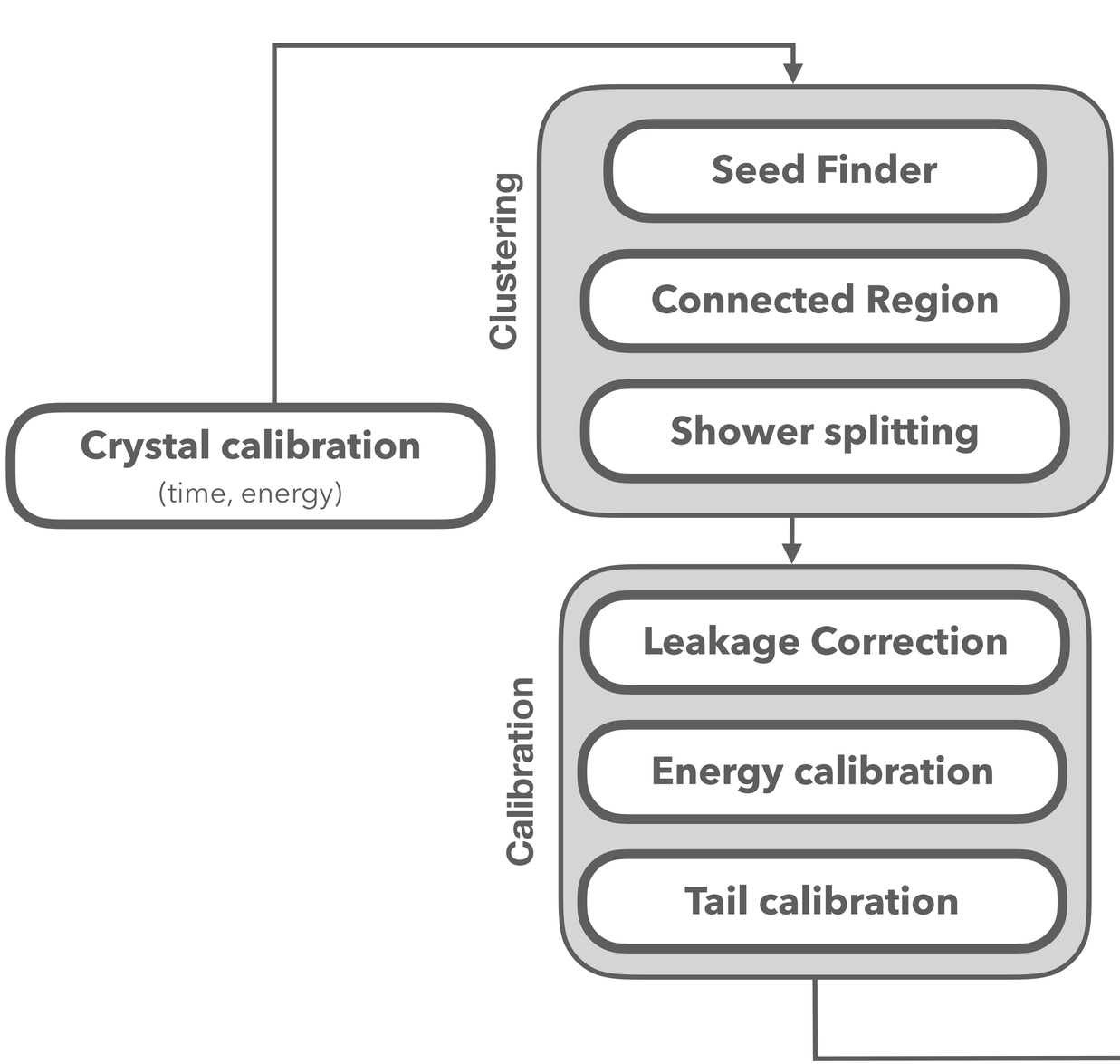


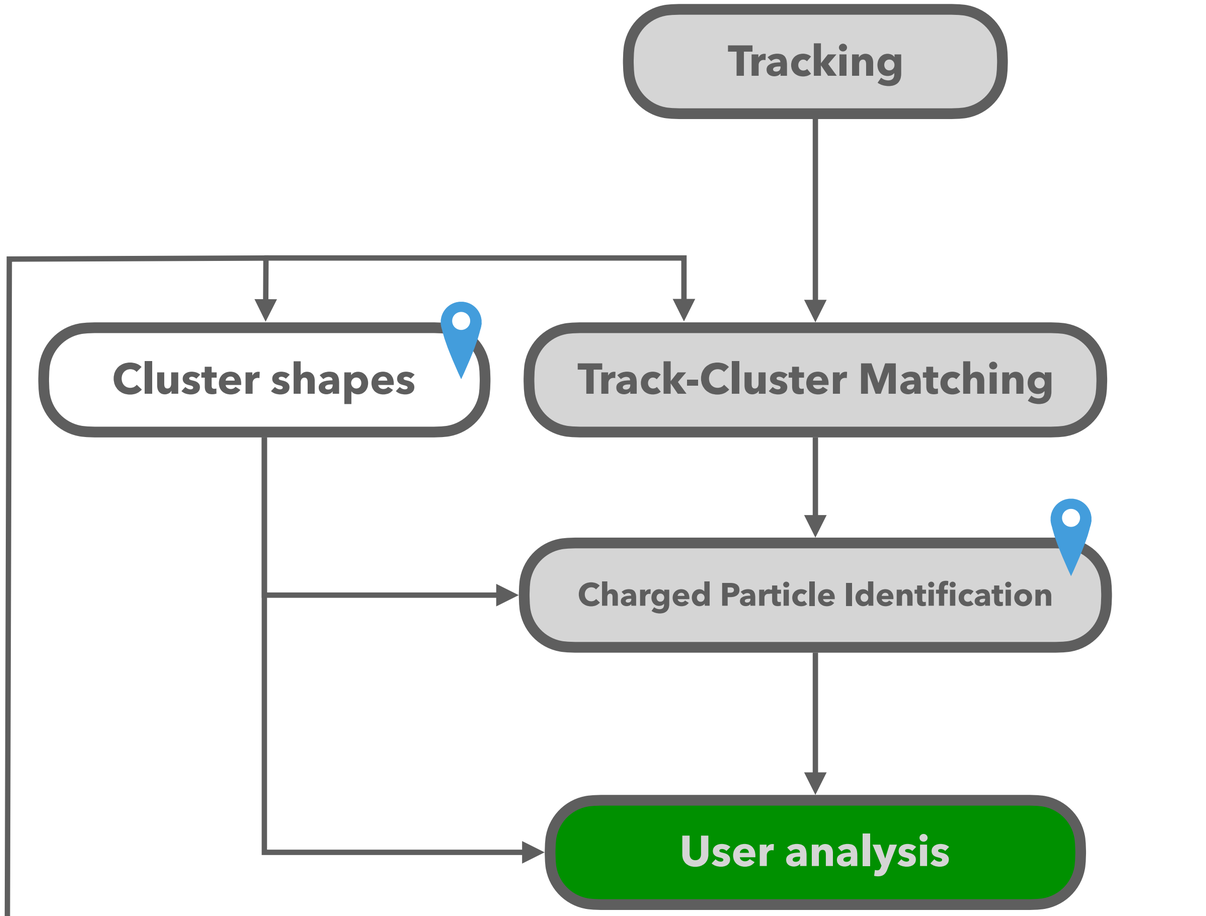
Performance: π^0



Few days after the start of data taking.

Offline reconstruction flow



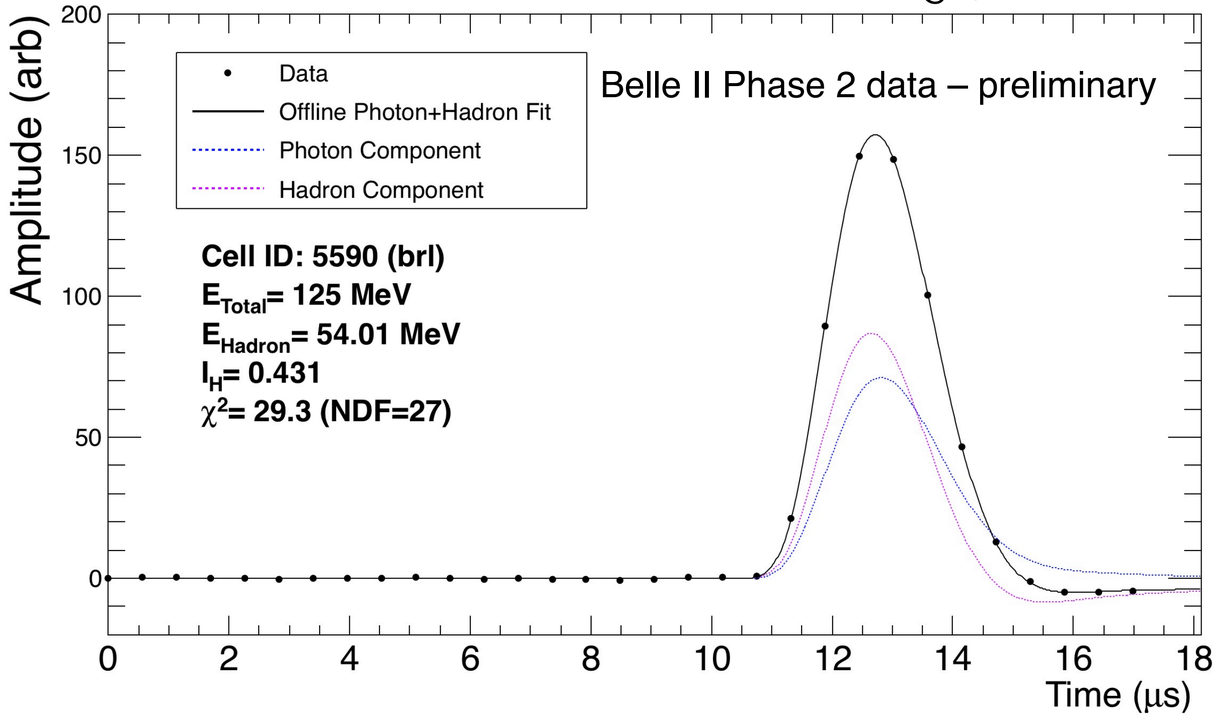


Energy
Position
Relation to track(s)
Cluster shapes (similar to image moments)
Crystal information is not available!

Pulse-Shape Discrimination (PSD)

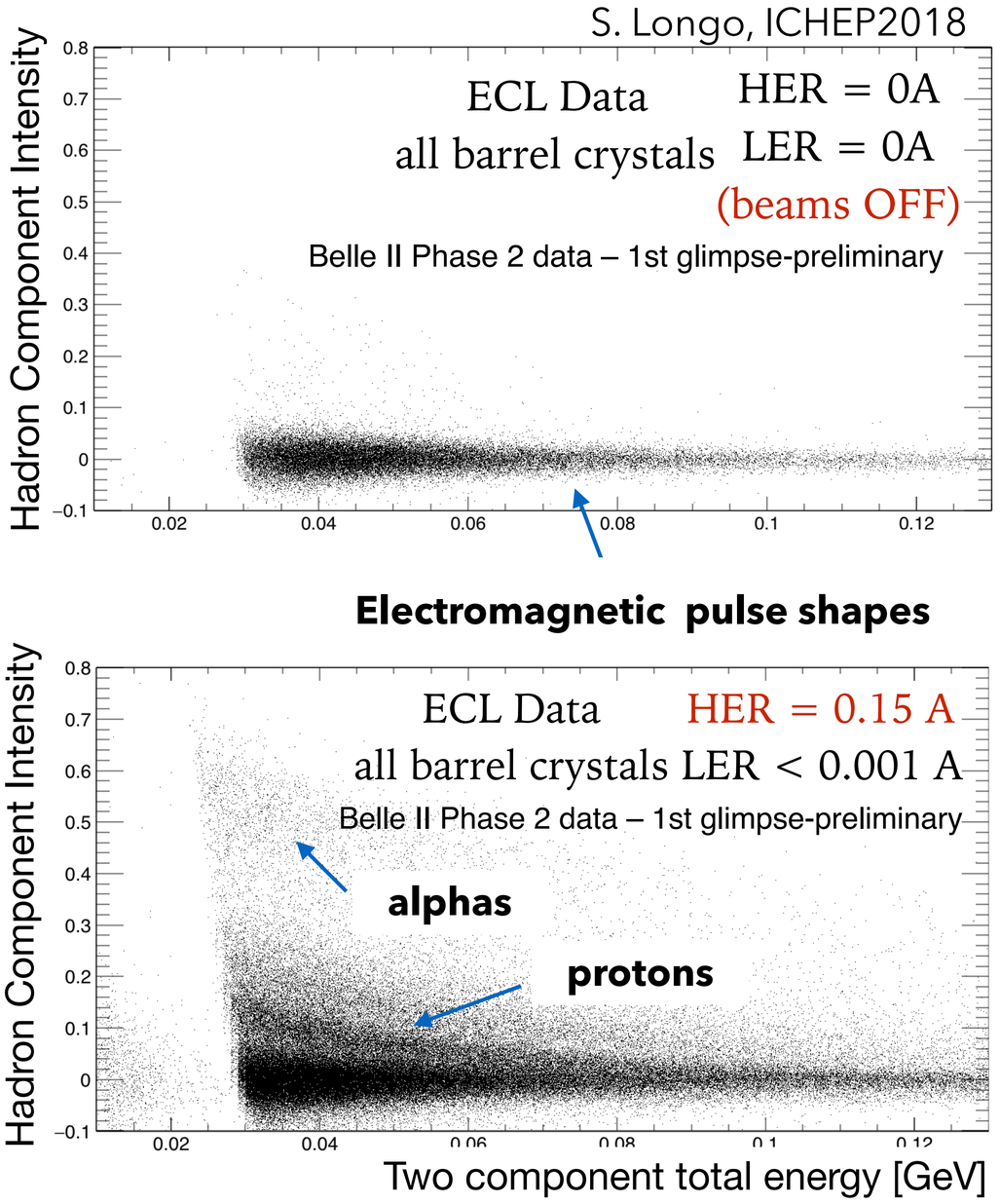
- Online FPGA waveform fits use photon templates only and provide time and amplitude fit results (2 variables)
- New: Exploit the fact that hadronic and electromagnetic scintillation components are different
  - If crystal energy E > 30 MeV: Store waveform data (31 variables) and repeat fit offline with different templates.
- Third information from a crystal: PSD

S. Longo, ICHEP2018



Pulse-Shape Discrimination (PSD)

- First time pulse shape discrimination (PSD) is used in an e^+e^- collider experiment
- New variable based on a BDT trained (on MC) to separate photons and K^0_L using all pulse shapes in a cluster
- Will be included in charged particle identification to improve muon vs. pion separation

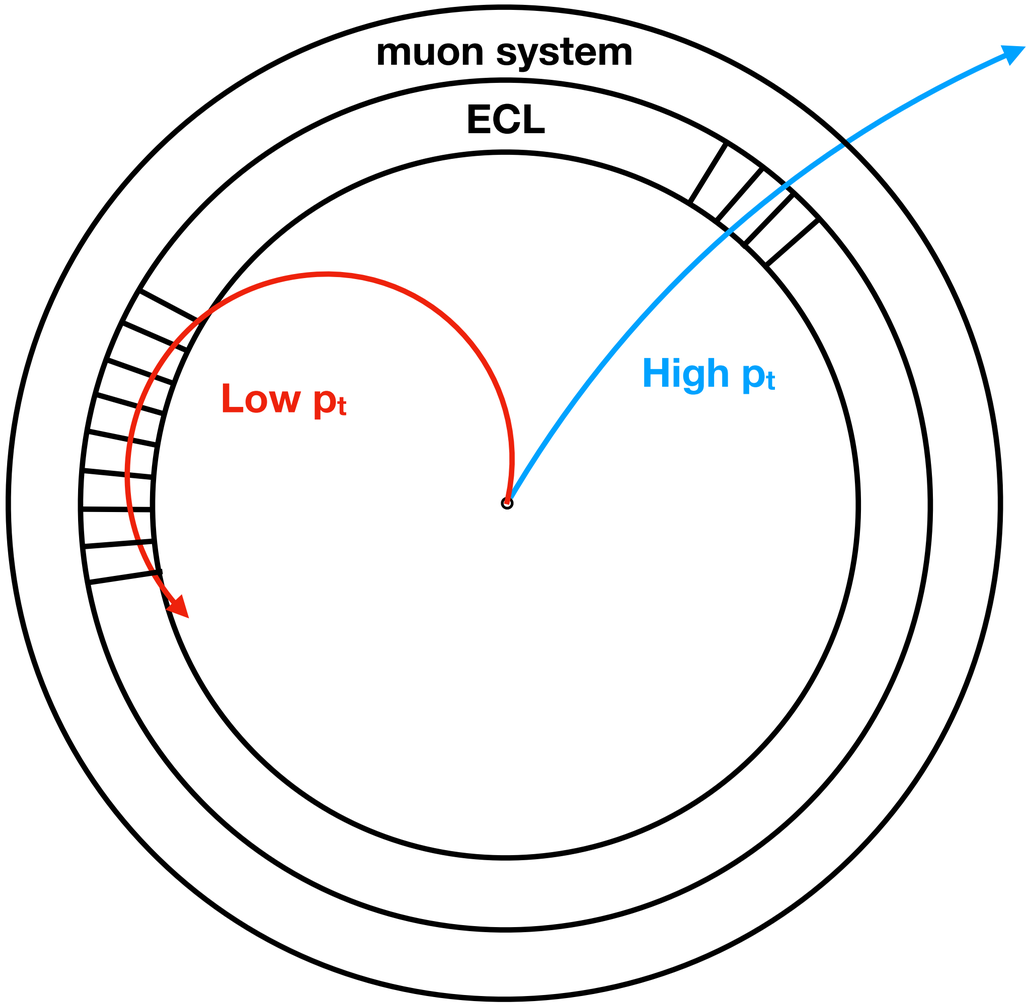


Low p_t Particle Identification plans: Muon vs Pion

- Particles with low transverse momentum (pt < 0.5 GeV/c) do not reach our muon system:

  → Baseline particle identification depends on E/p and is very poor

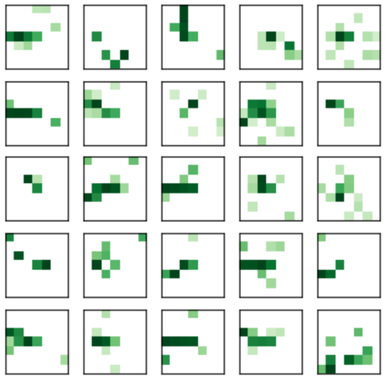
  → Clustering itself difficult, since these particles leave long, charge dependent, trails in the calorimeter



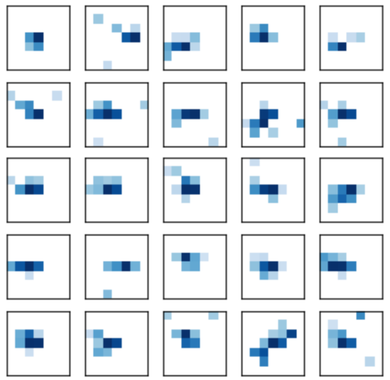
Low p_t Particle Identification plans

- Approach under study:
  - No clustering
  - Extrapolate tracks to calorimeter
  - Analyse 5×5 pixel calorimeter images around impact crystal using convolutional networks

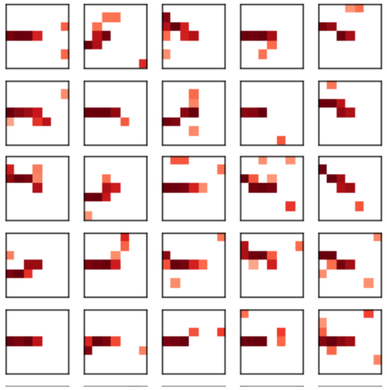
Pions

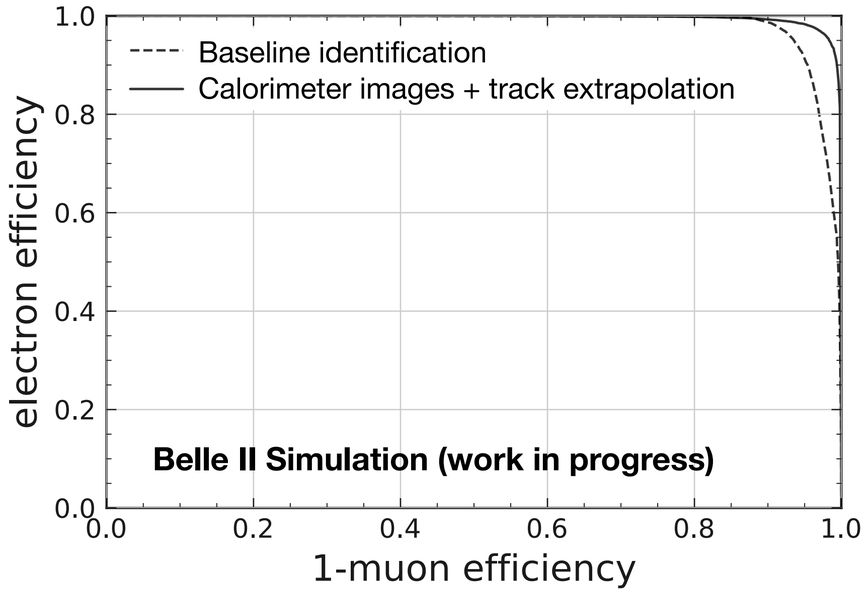


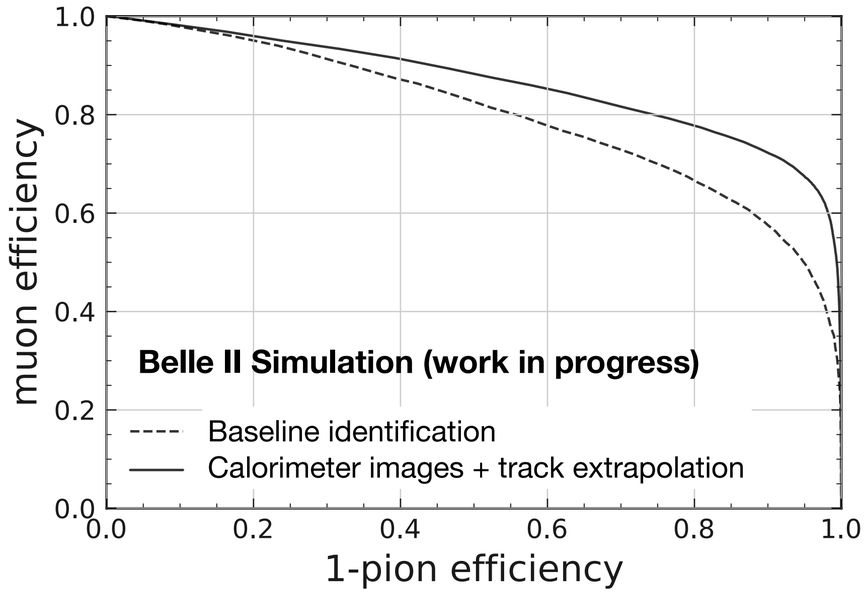
Electrons



Muons







Summary

- Belle II is starting physics runs in ~7 days
- Calorimeter reconstruction priorities so far: Robust reconstruction, calibration
- Calorimeter reconstruction priorities now: Getting ready for high and varying beam backgrounds, and complex physics analyses
- Bonus: The knowledge of the initial state at an e^+e^- collider and the huge event rate makes this a perfect playground to develop data-driven ML applications

Contact

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