Beauty is back:

Belle II status and how we (hopefully) will find New Physics

Heavy Quarks through the Looking Glass

UNIVERSITÄT SIEGEN

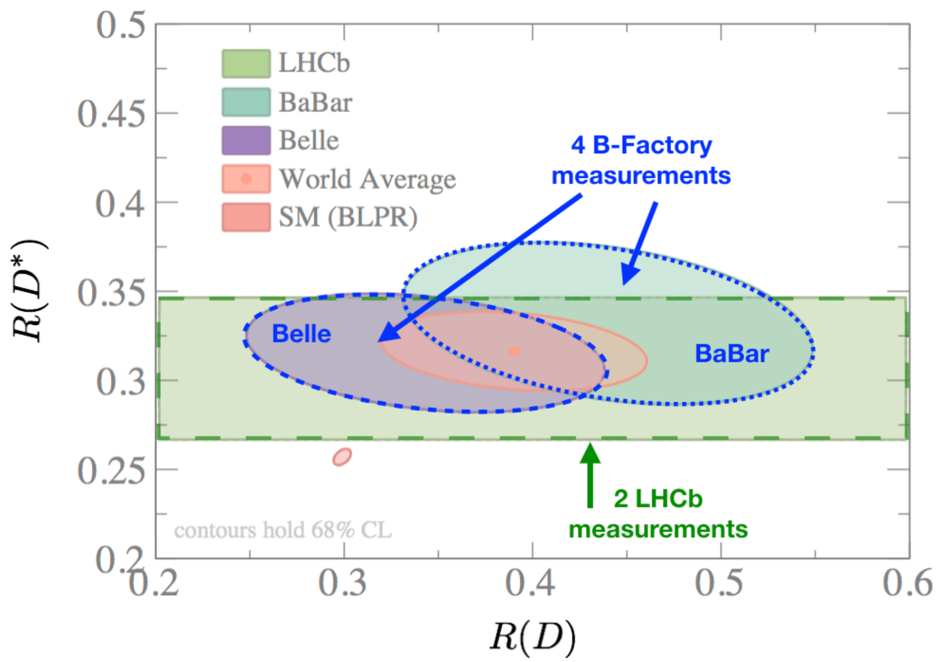
October 4-5, 2018

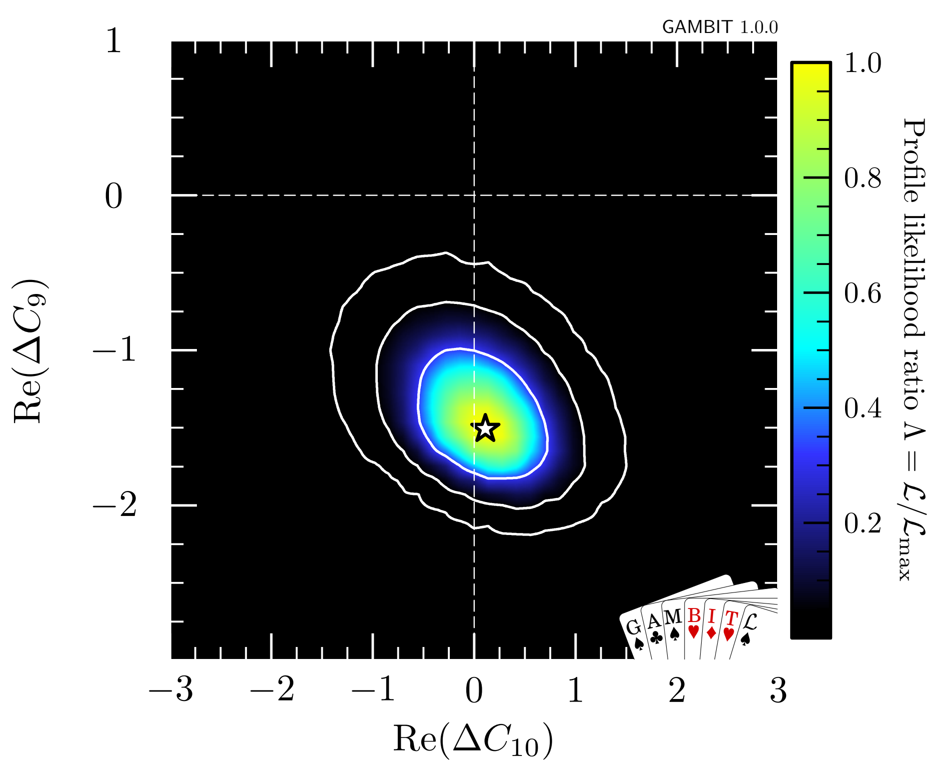
Emmy-Noether Campus (ENC)
University of Siegen

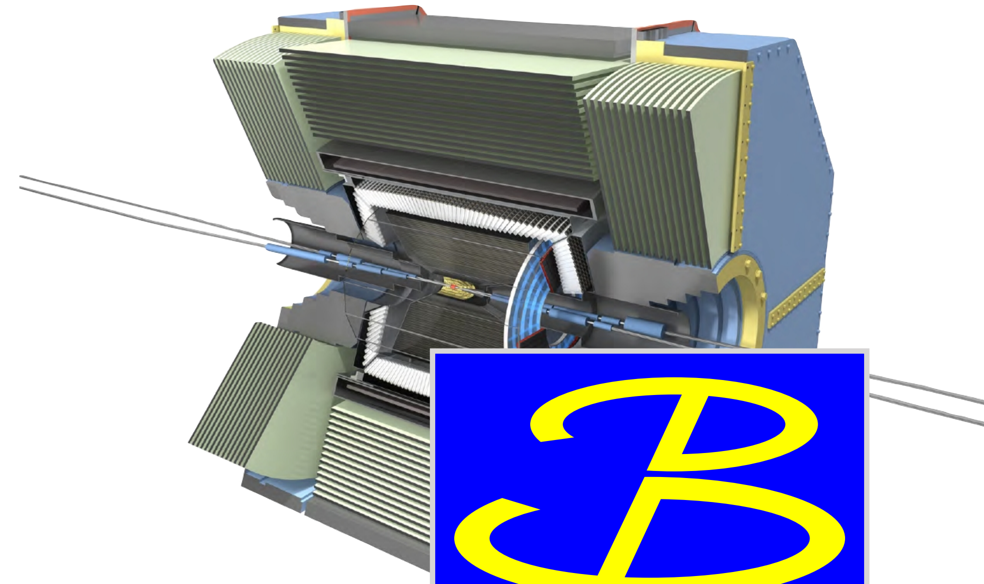
Belle II

Why is beauty back in our minds?

Two reasons







A next-generation Super-B-Factory in the making

- Integral idea: **nano-beams** P. Raimondi for SuperB
  - **50 nm** vertical spot size
  - Major upgrade of existing facilities needed

Groundbreaking Ceremony — 2011

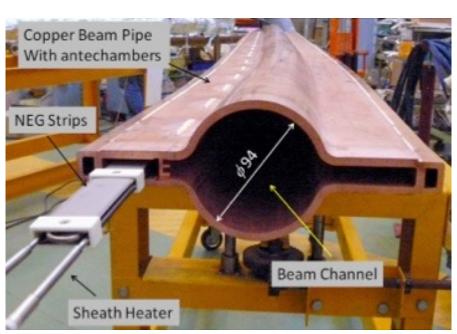
Construction Positron damping ring finished — 2014

First Beams circulating — 2016

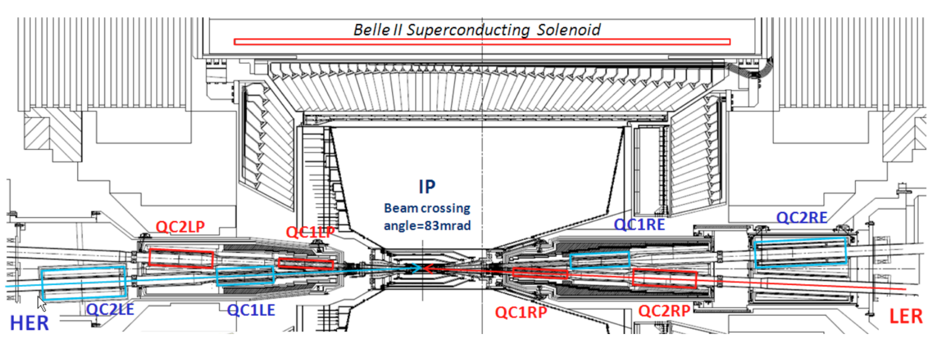
Installation Superconducting final focusing magnets — 2017

First Collisions — 2018

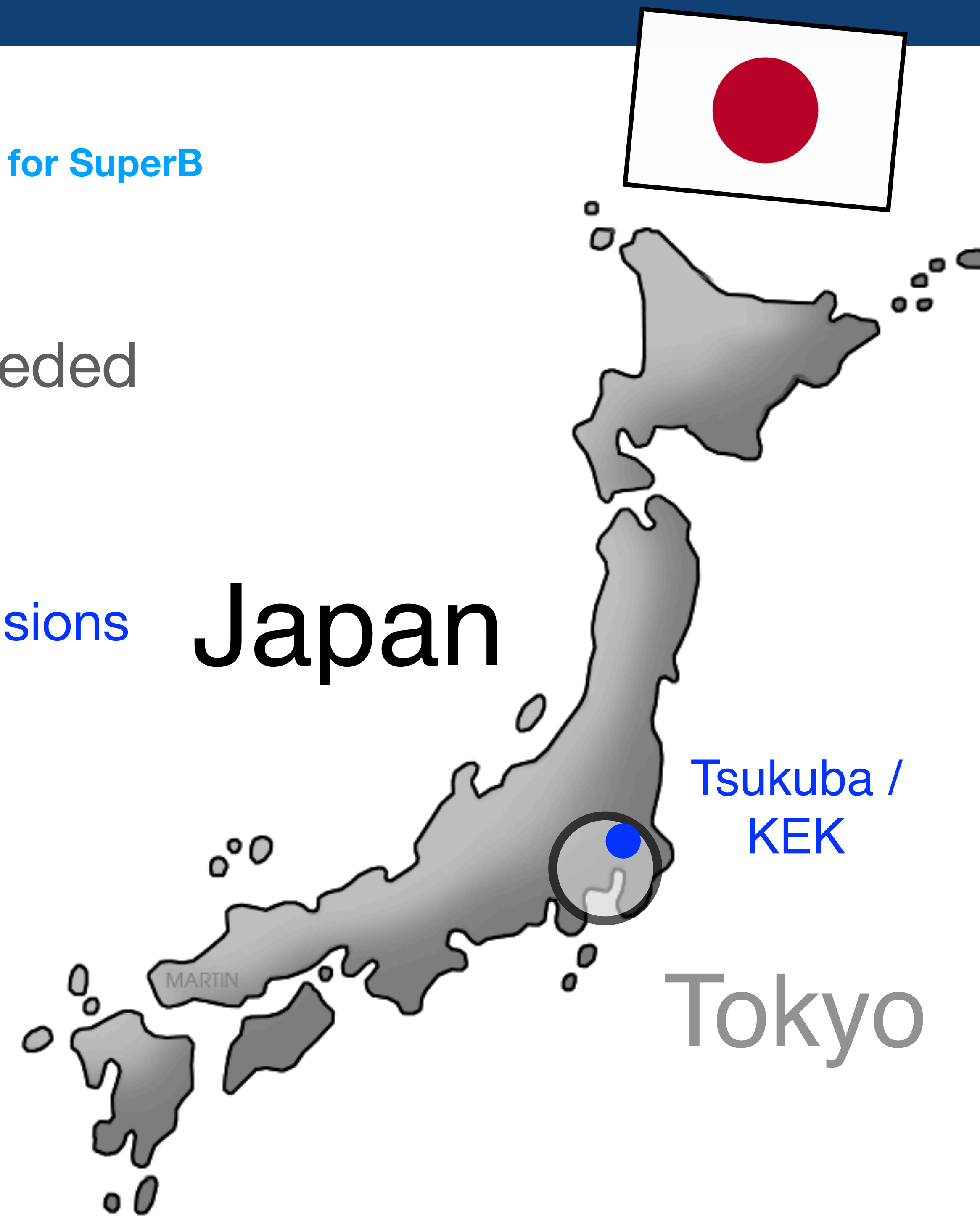
2011 2012 2013 2014 2015 2016 2017 2018



Replaced old beam pipes with TiN coated beam pipes with antechambers

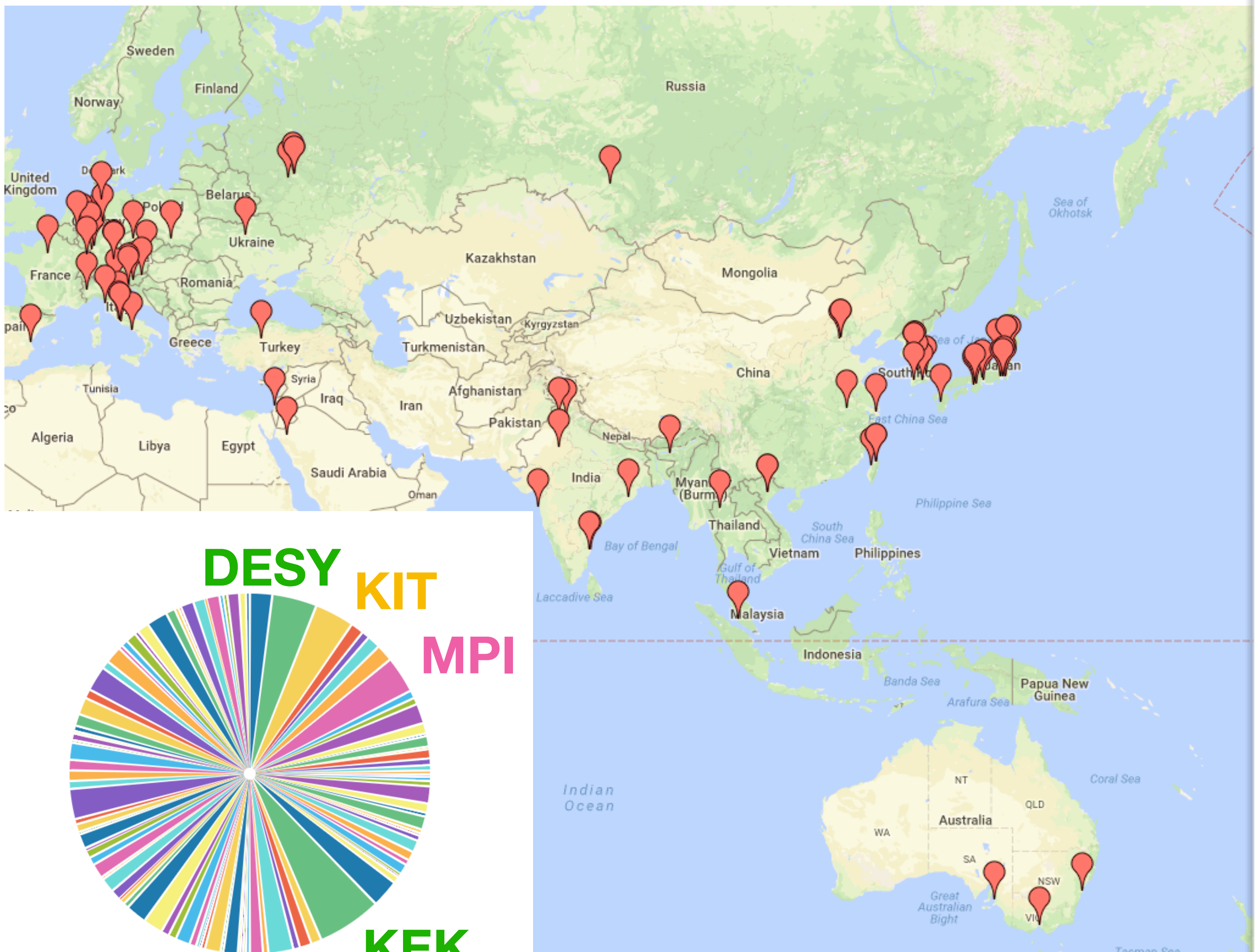


New superconducting final focusing magnets near the IP



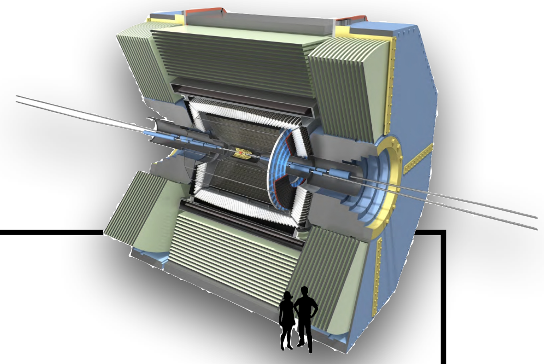
A next-generation Super-B-Factory in the making

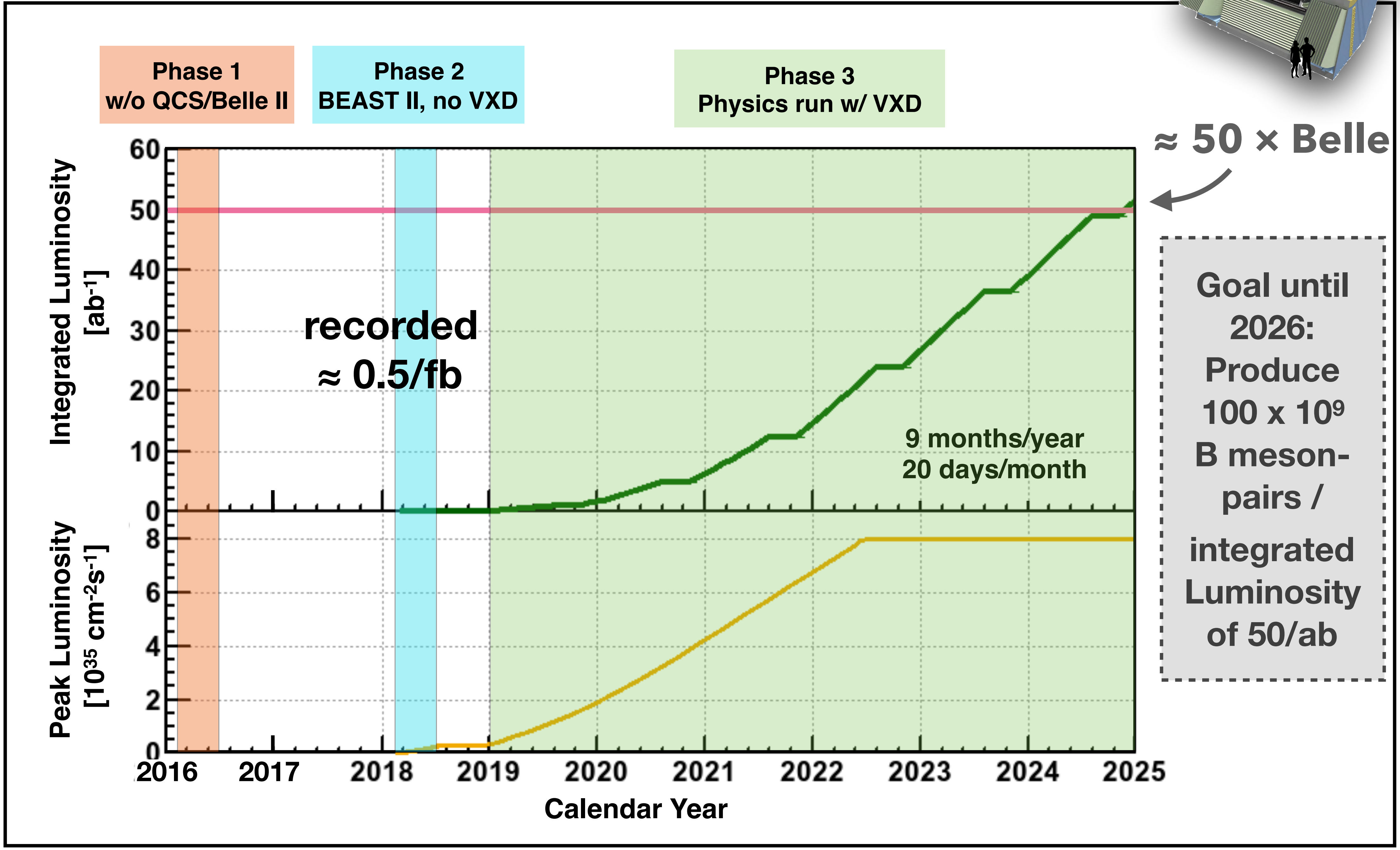
850 Physicists
109 Institutes
25 countries



Phases of a Super-B-Factory

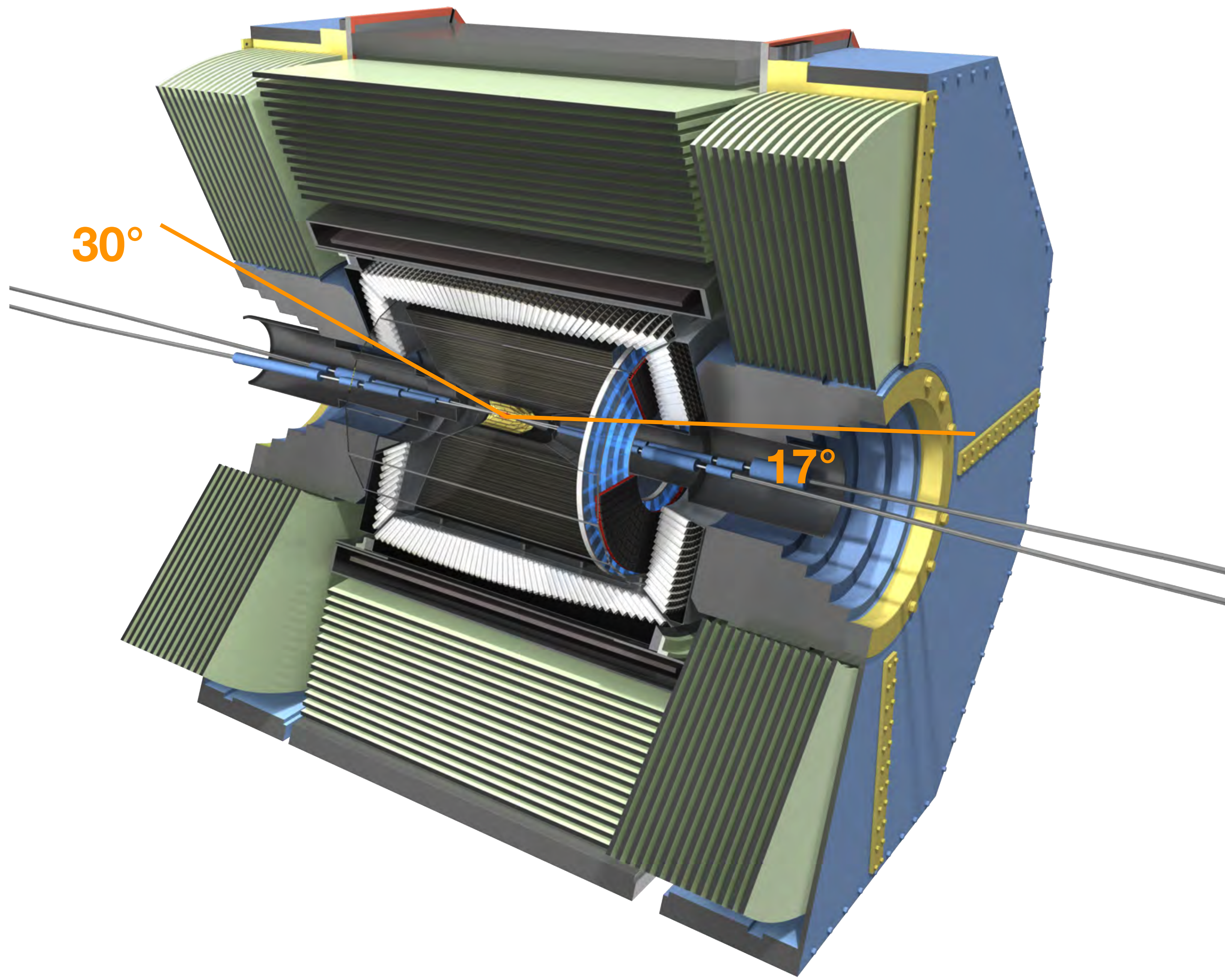
- Belle II start progresses in **three** phases

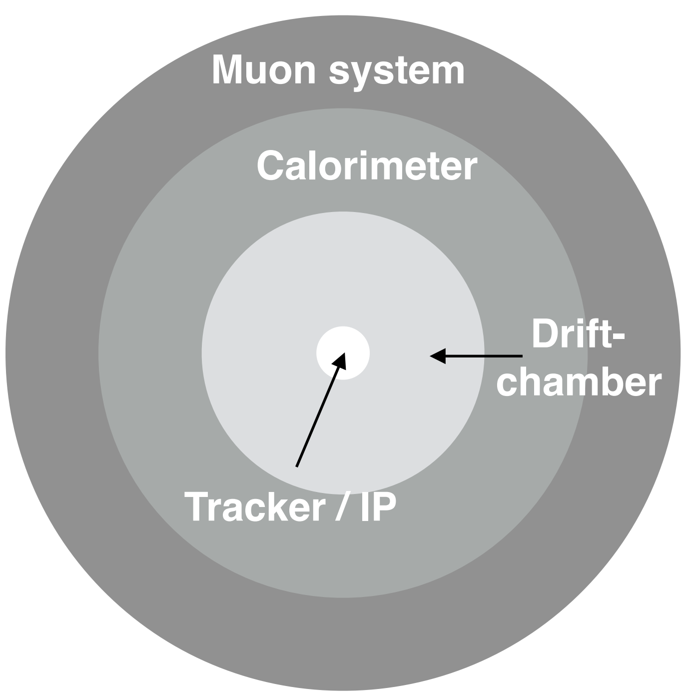




The Belle II Detector

Direction of boost
Direction of electron beam
“Forward”





The Belle II Detector

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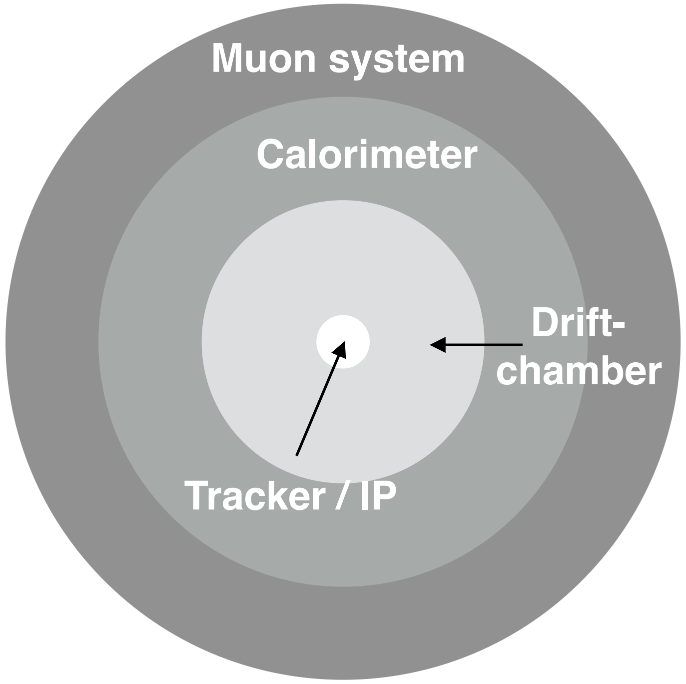
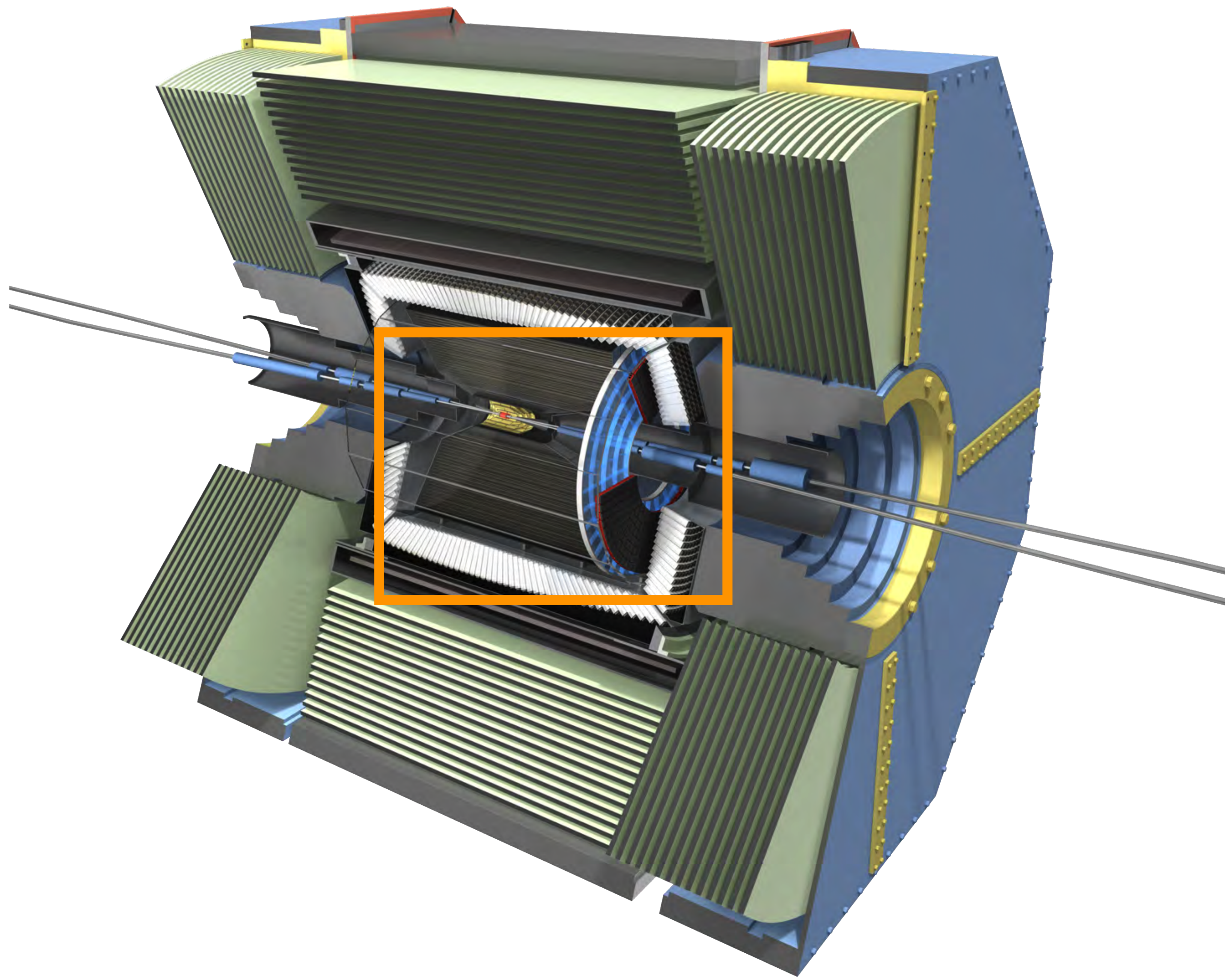
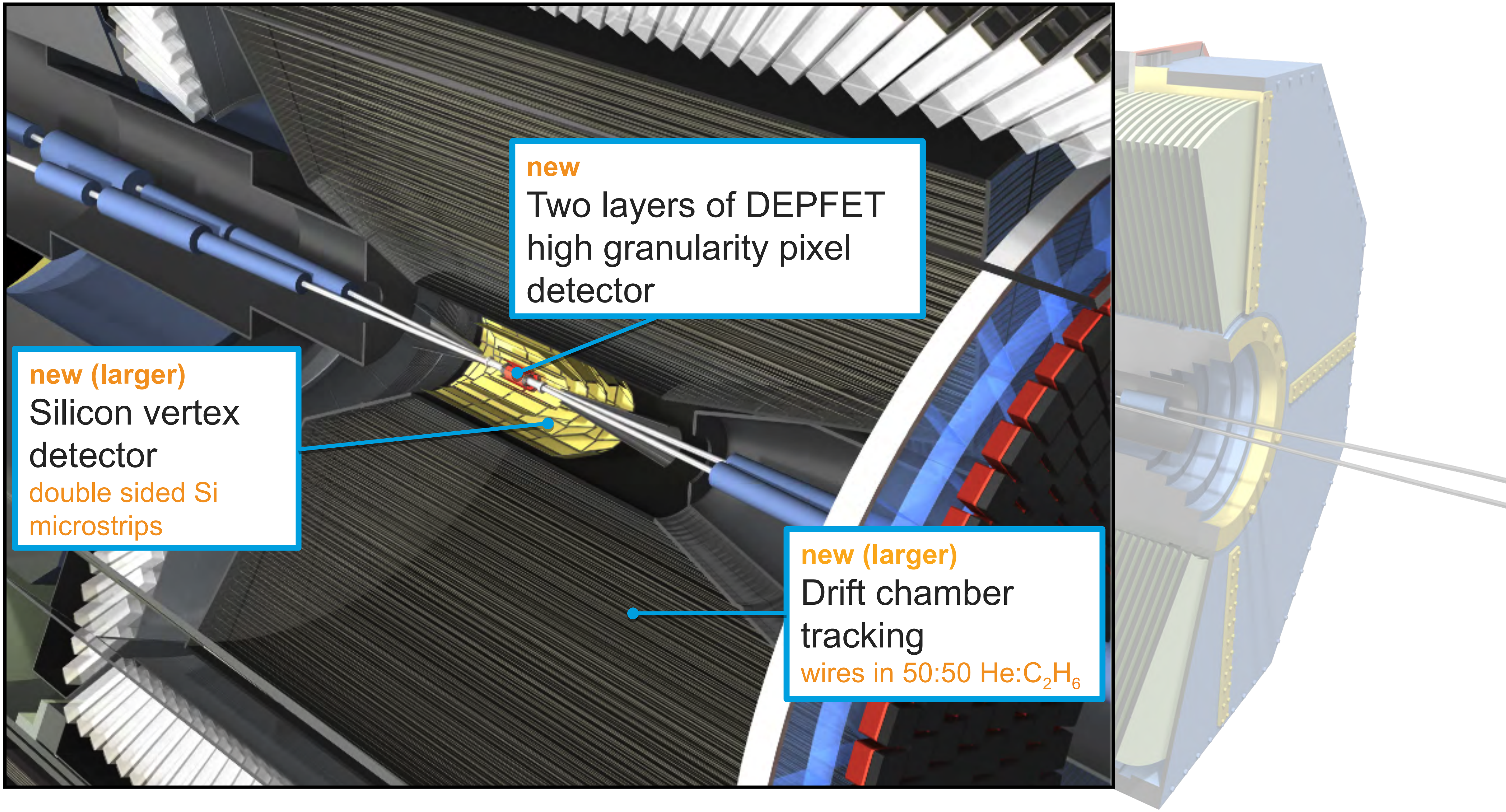
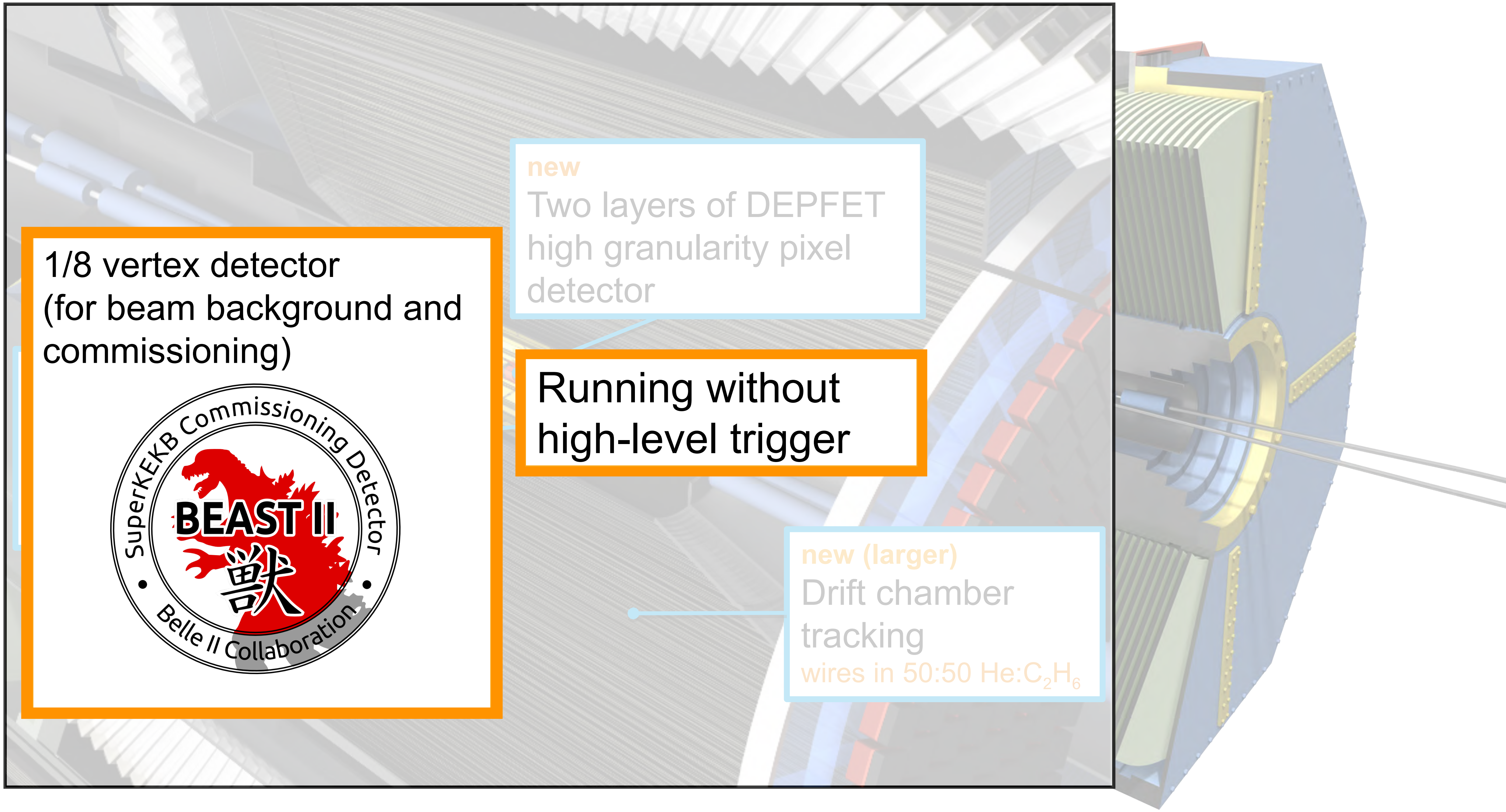




The Belle II Tracking Detectors

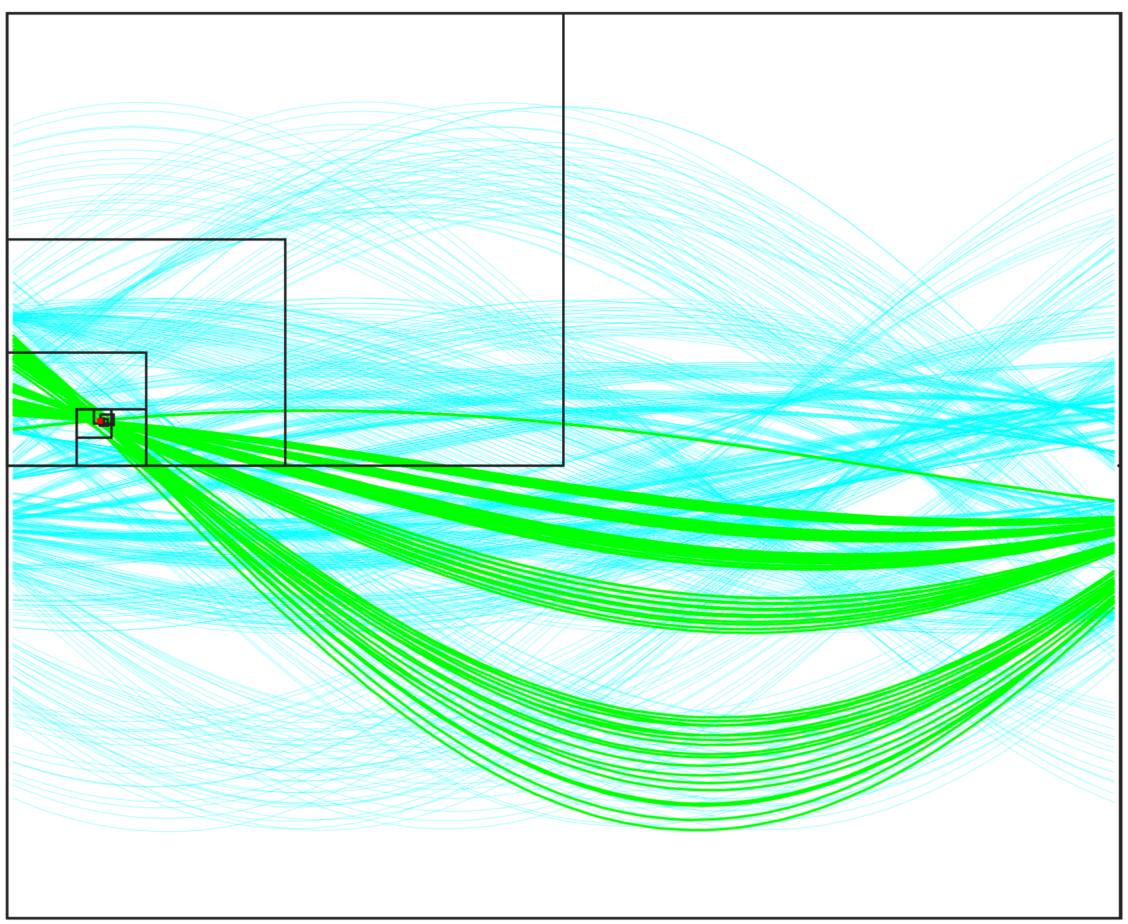


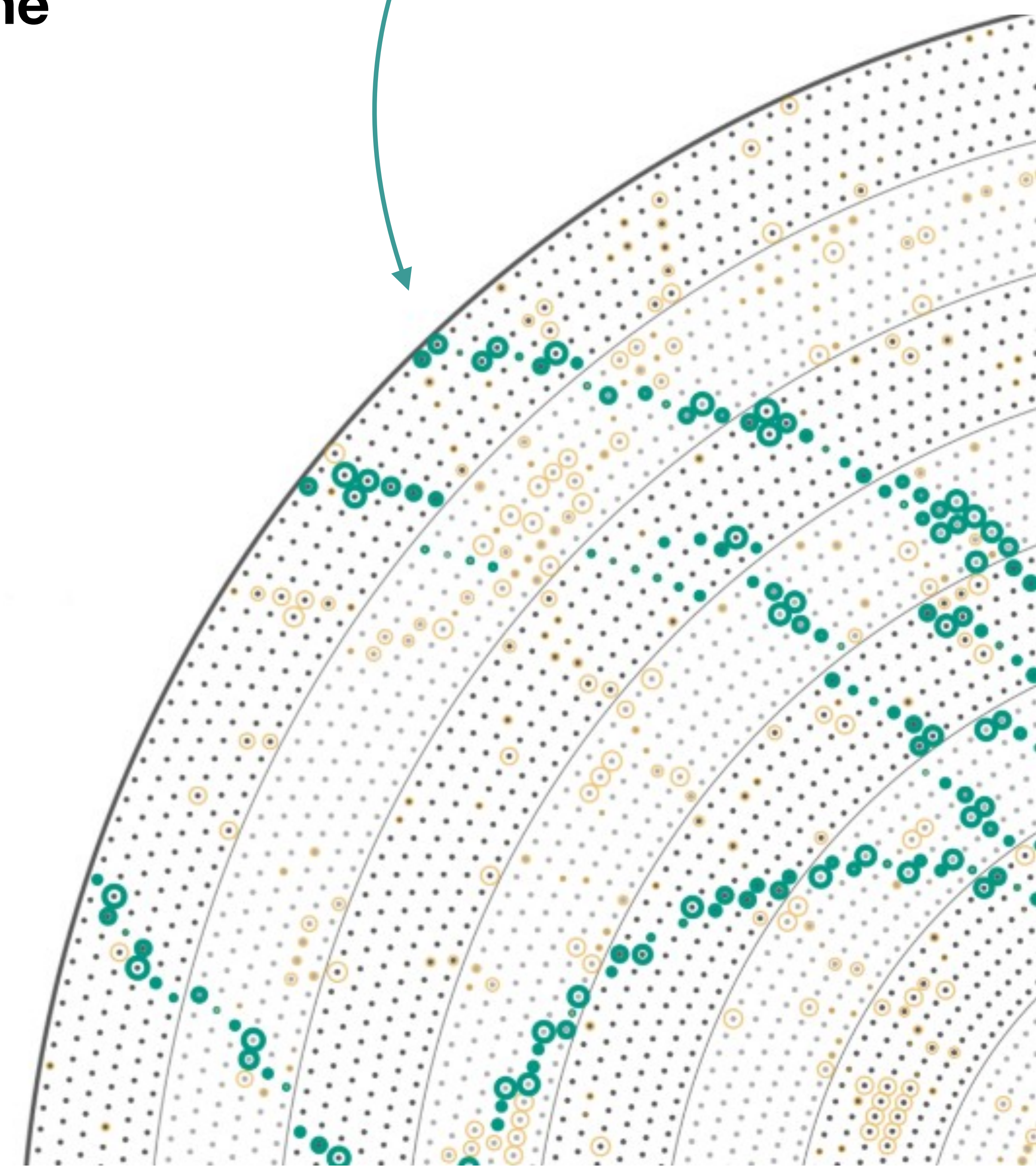
The Belle II Phase II Tracking Detectors



Tracking details

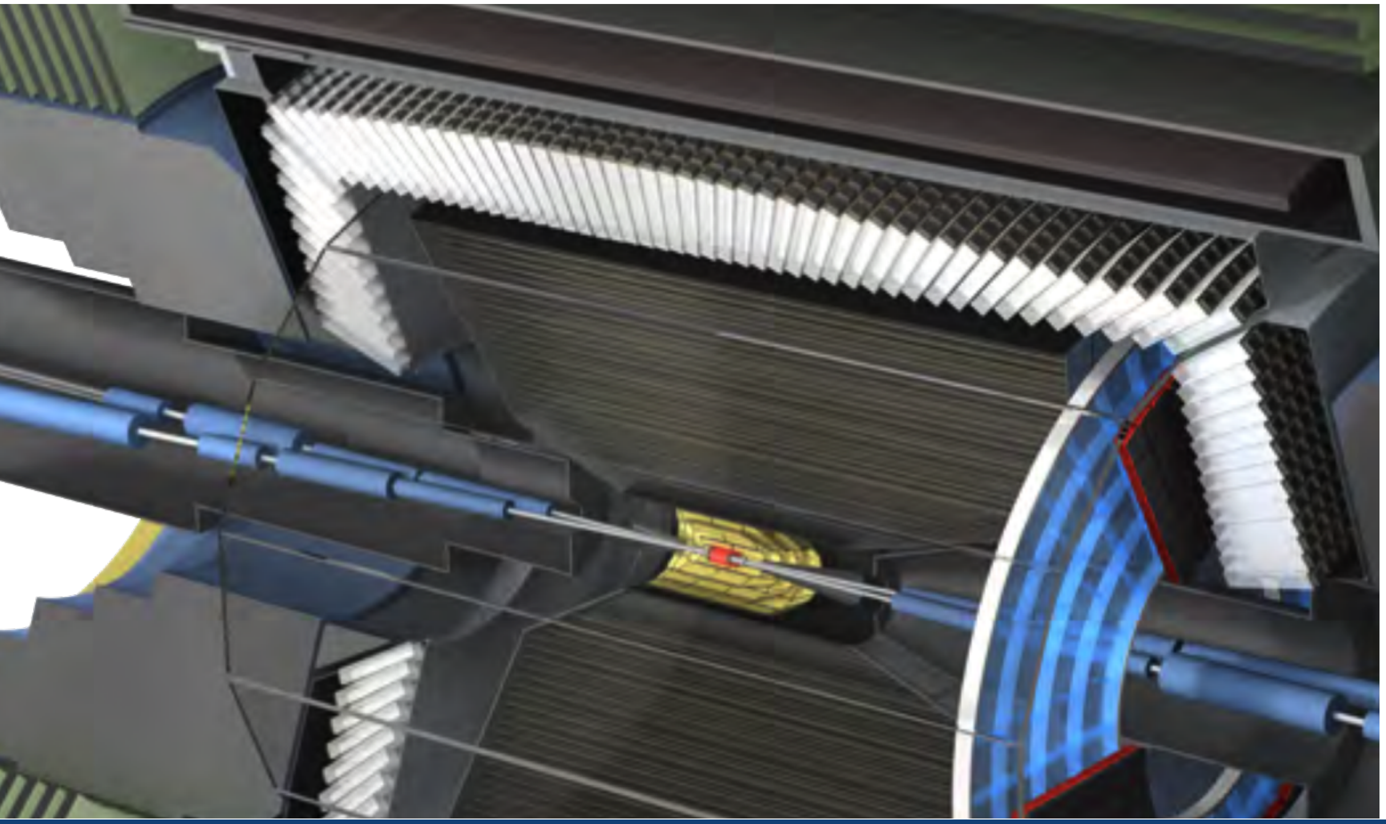
- Newer, larger wire drift chamber. Improvements from Belle
- High luminosity: **40% of wire hits** from **machine background**.
  - **Multivariate methods used to suppress**
- **Legendre based** tracking for wire chamber.

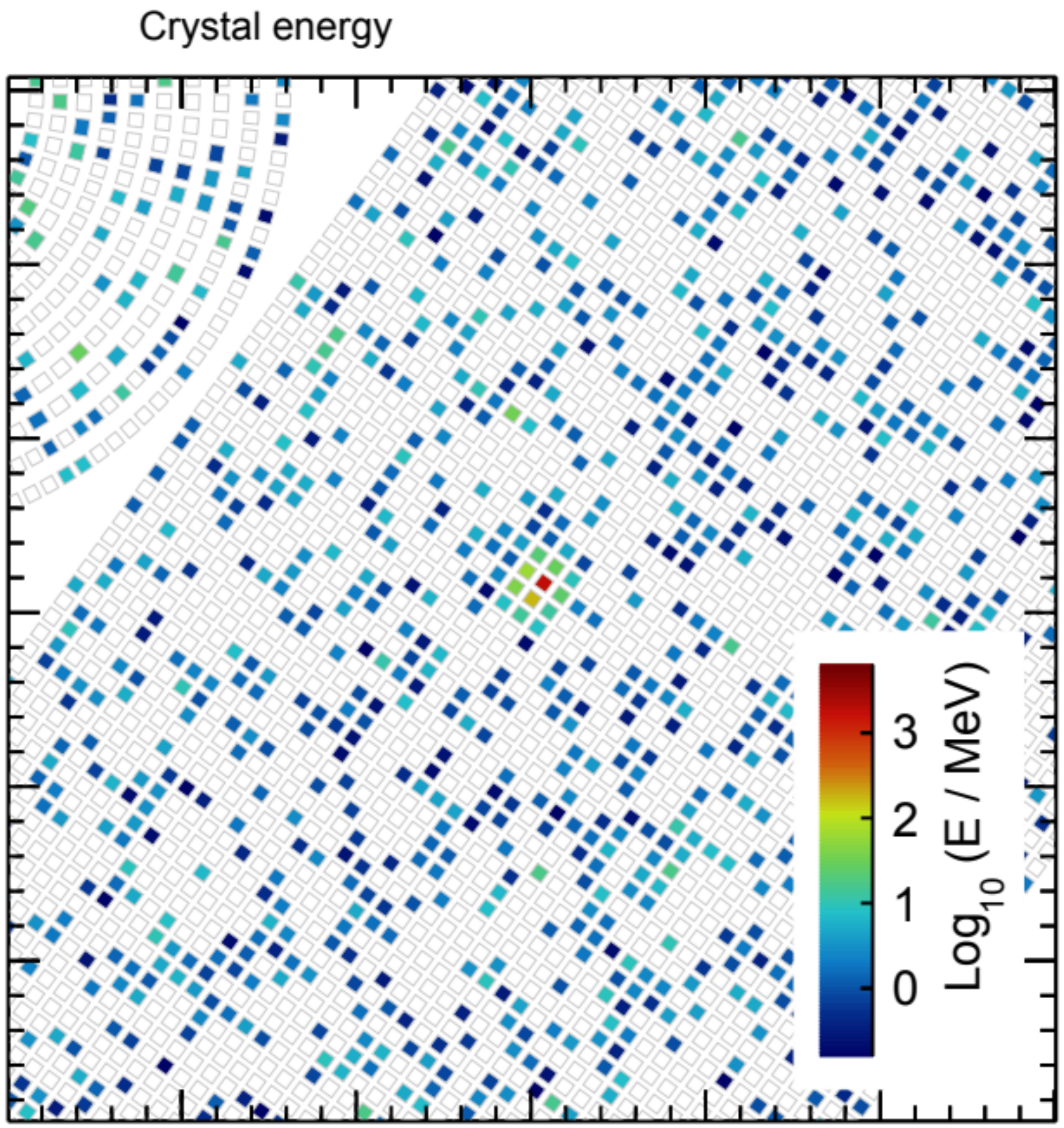




Calorimeter details

- Belle II **calorimeter crystals** are **reused from Belle**
  - **8736 CsI(TI) crystals**
  - **New readout electronics**
- New clustering → **high luminosity environment**





Nominal backgrounds
+ single 2.5 GeV photon

Calorimeter details

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  - 8736 CsI(TI) crystals
  - New readout electronics
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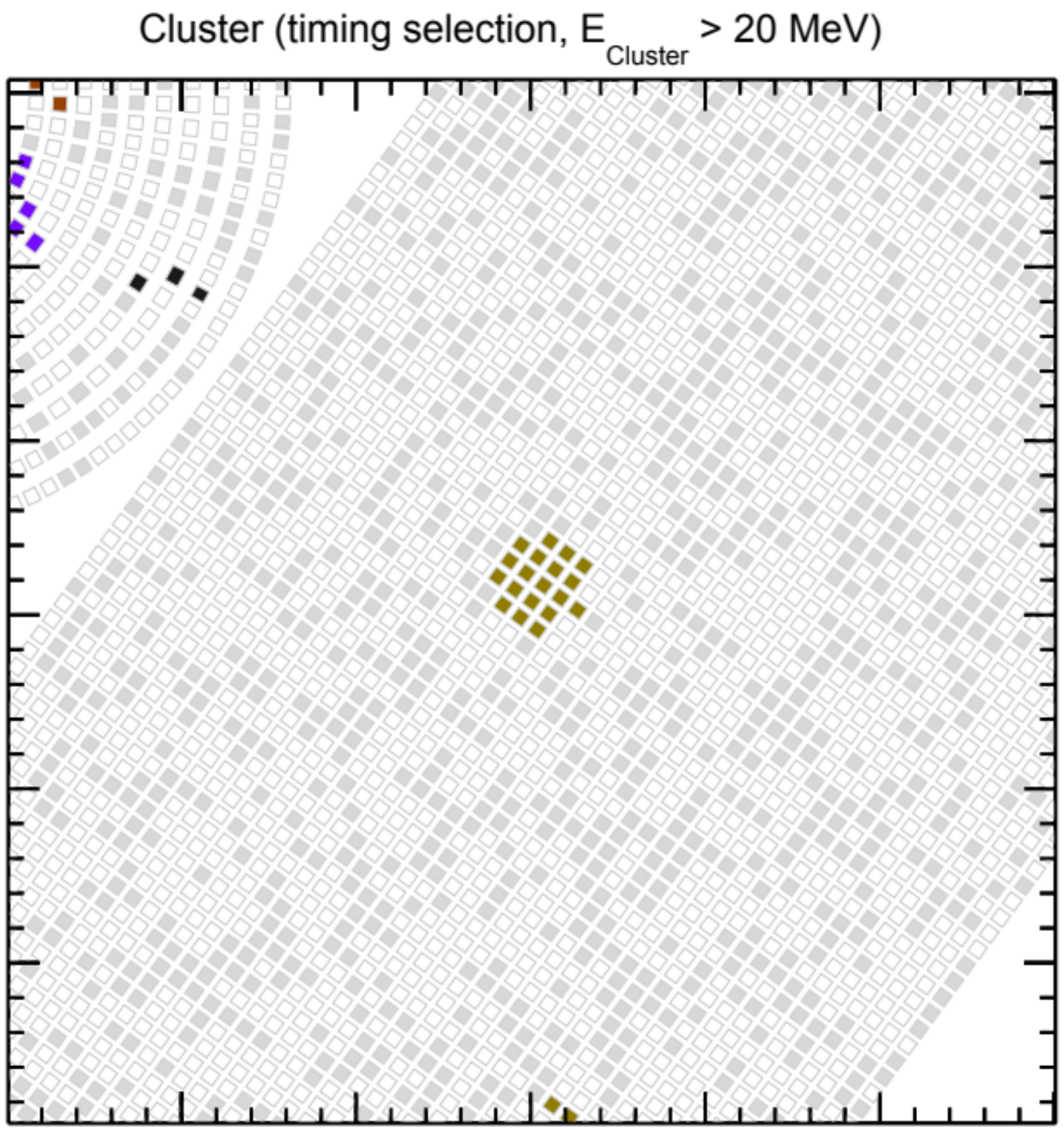
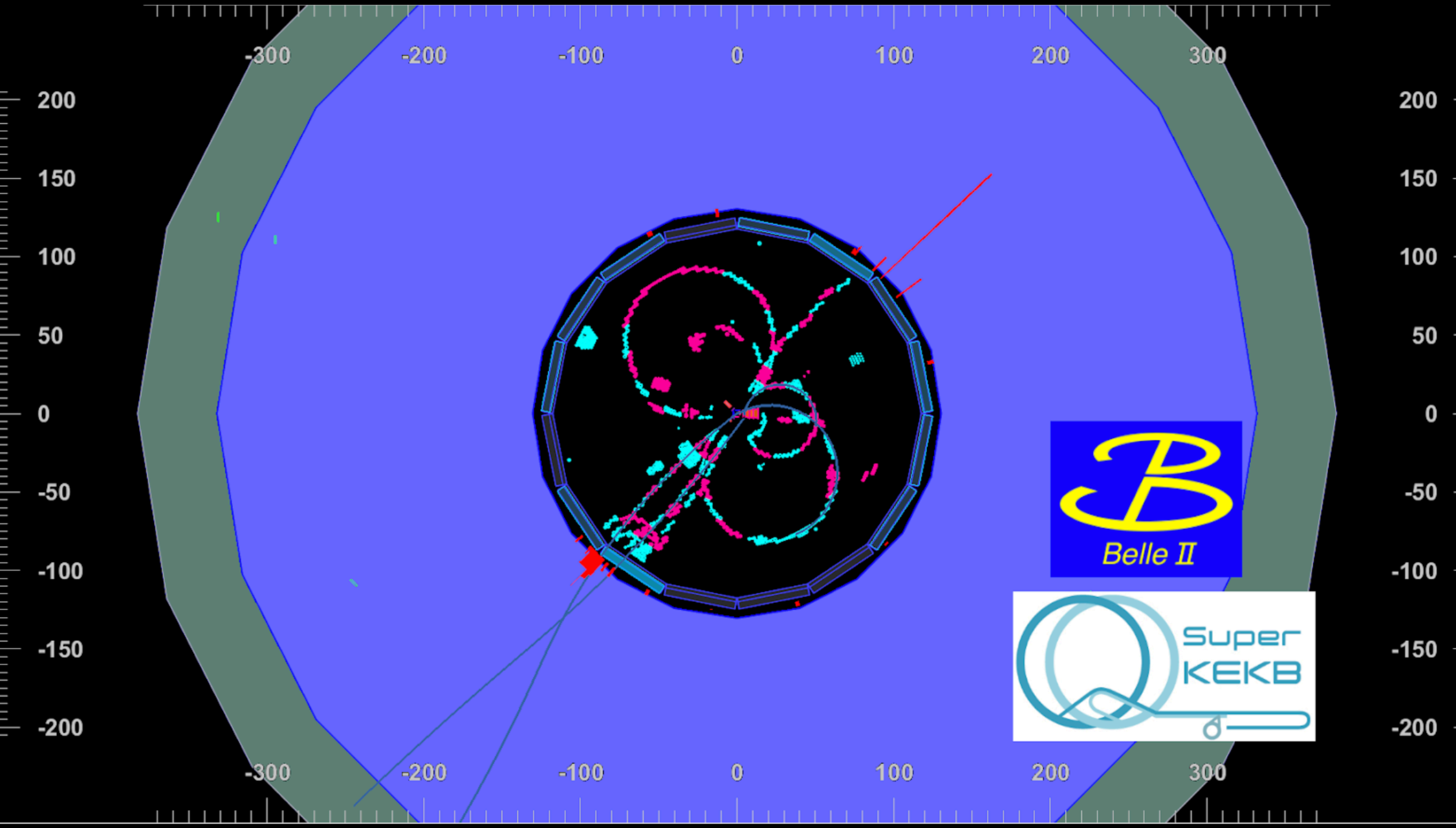


Timing and minimal cluster energy requirement

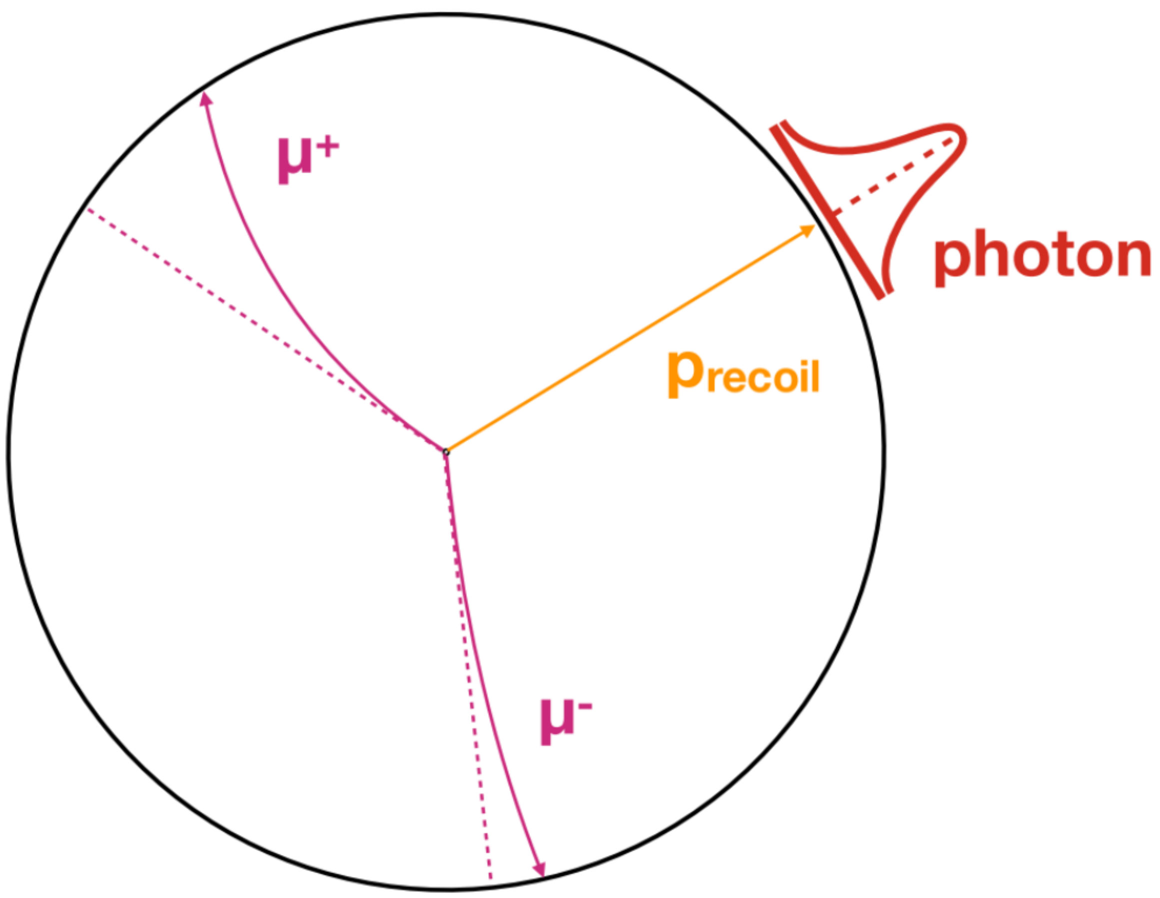
First Belle II collision: 26 April 2018 00:38 GMT+09:00

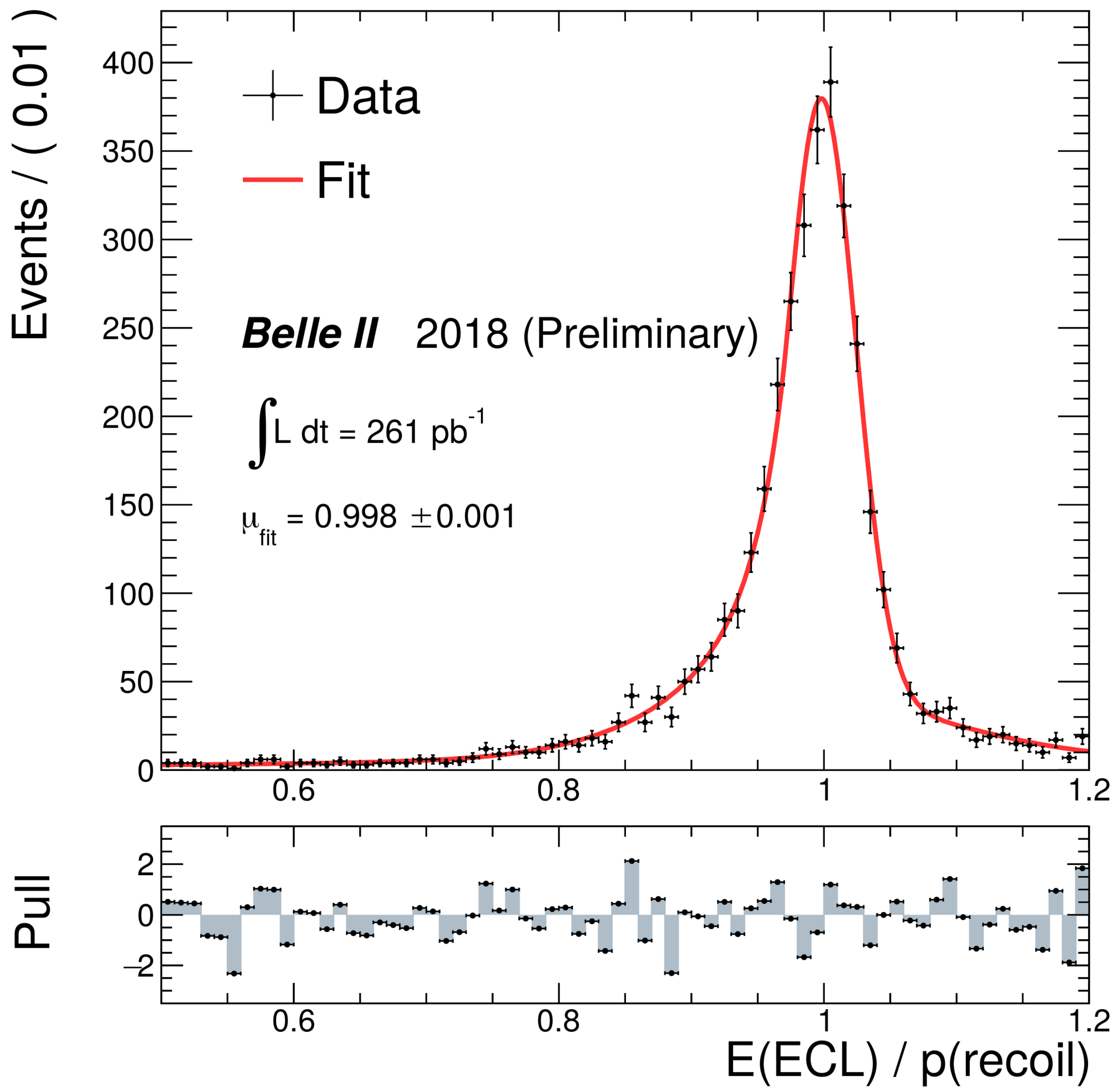
First Belle II collision



Tracking and ECL work well

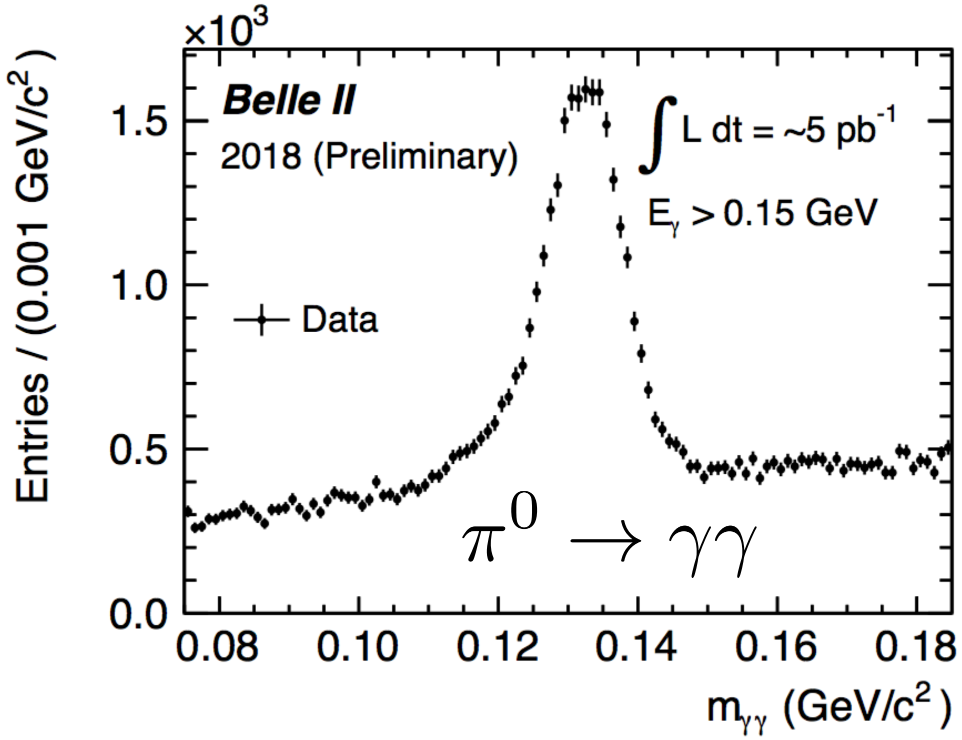
Radiative dimuon events in first data

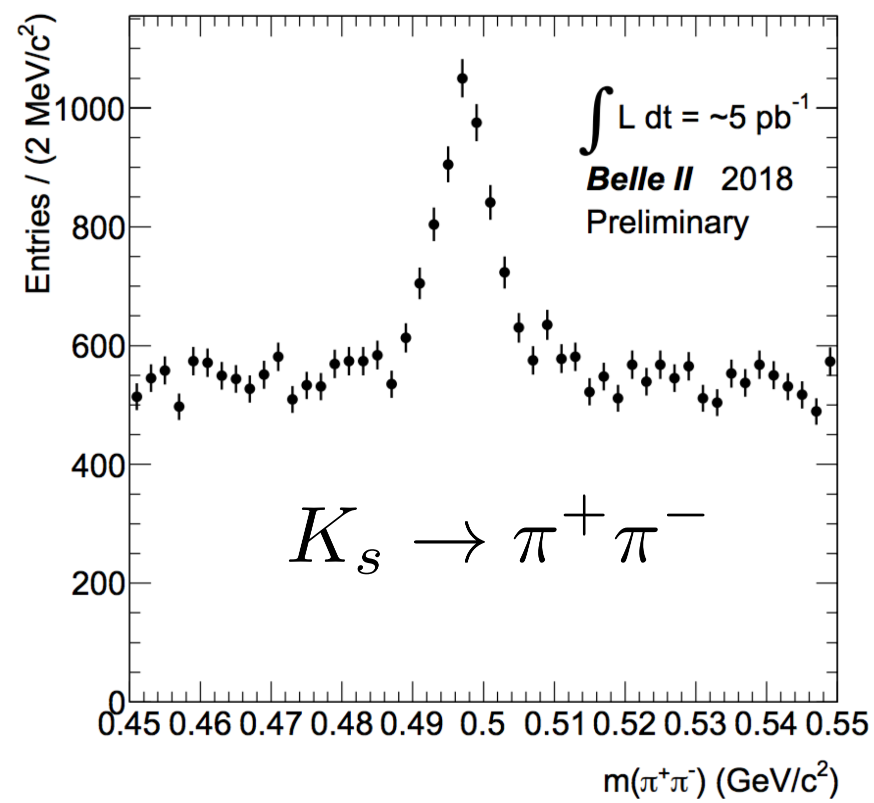


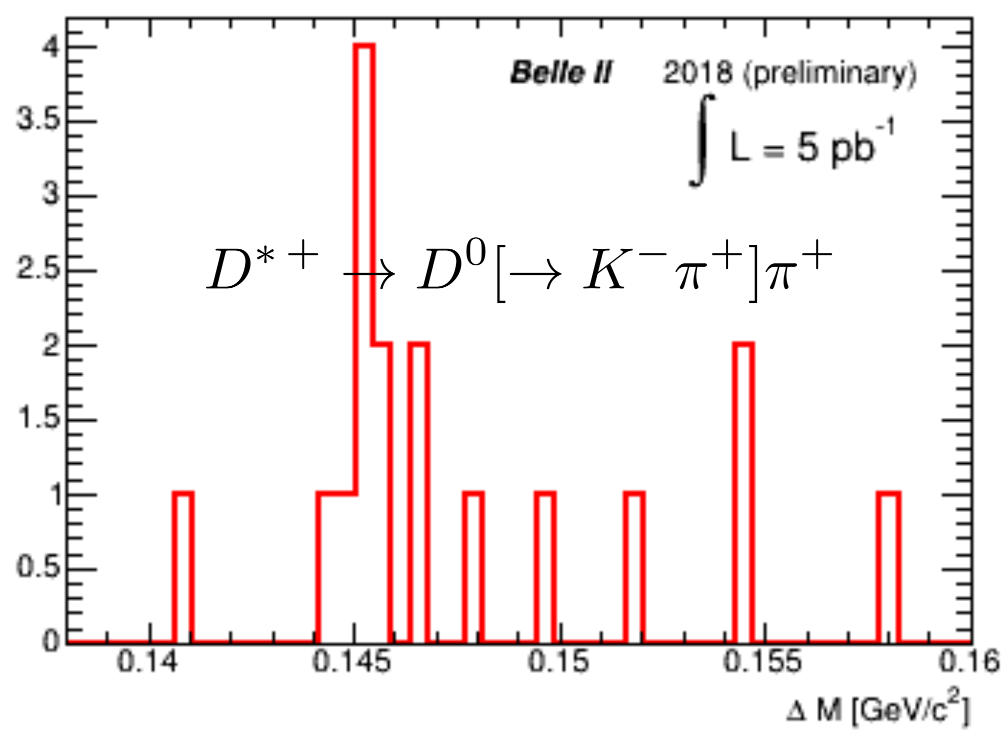


“rediscovery of the Photon”

More Phase II “rediscovery plots”



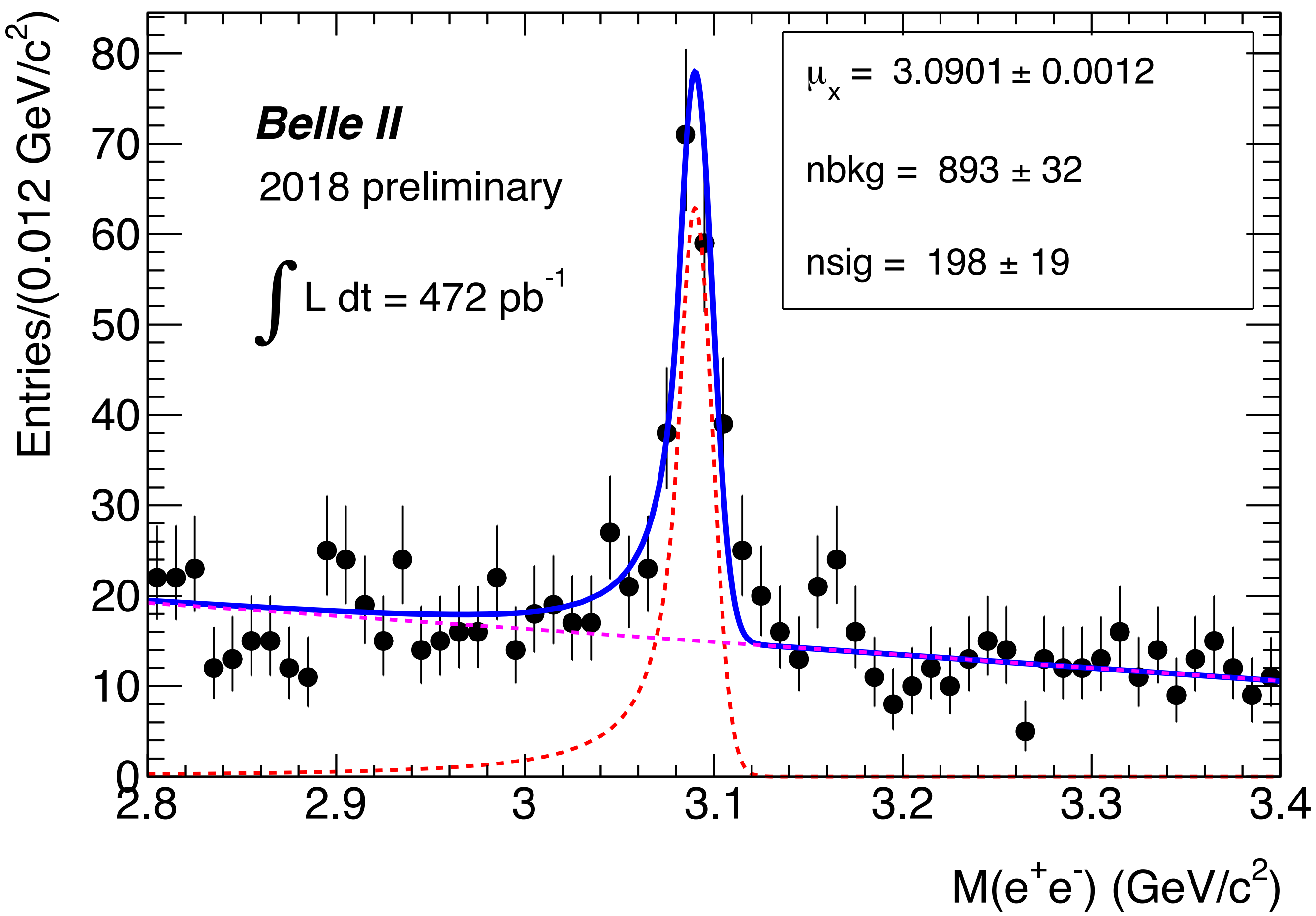




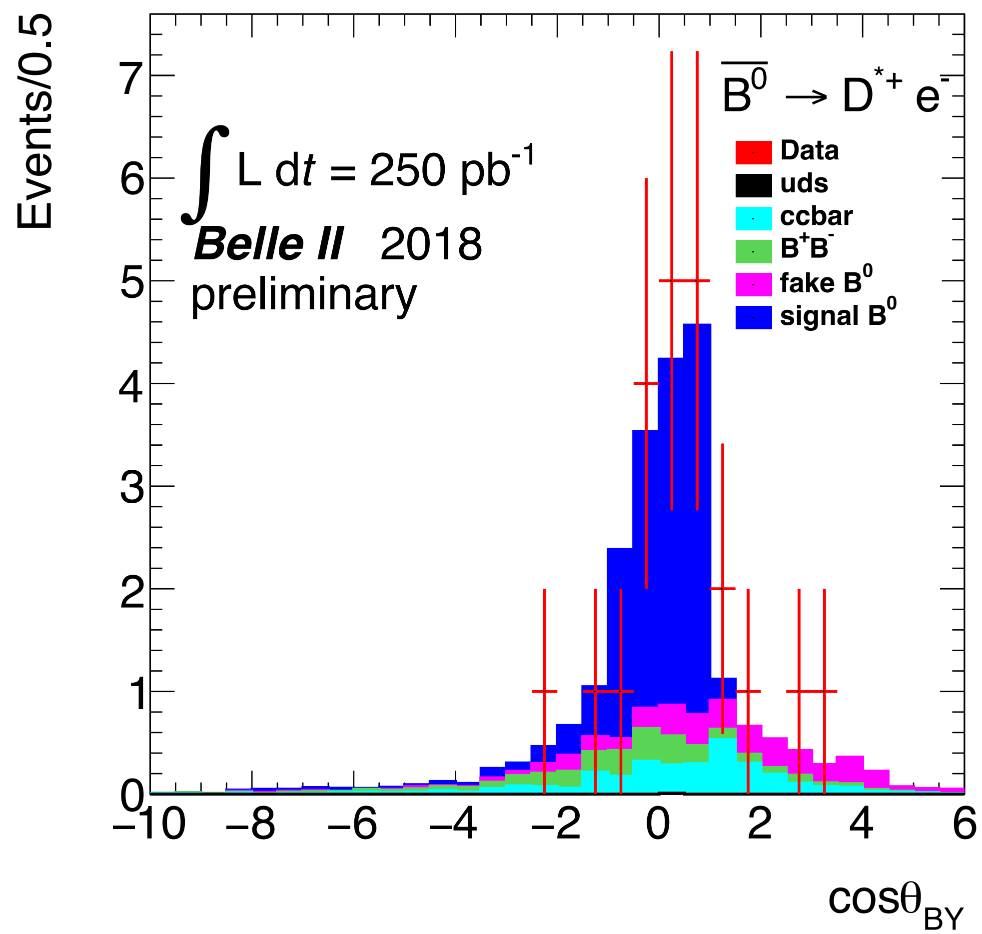
$$\Delta M = m_{D^{*+}} - m_{D^0}$$

Charmonium and SL B-Meson decays

$$J/\Psi \to e^+e^-$$



$$\bar{B}^0 \to D^{*\,+} e^- \,\bar{\nu}_e$$



$$\cos\theta_{BY} = \frac{2E^*_B E^*_Y - M^2_B - m^2_Y}{2p^*_B p^*_Y}$$

Tools, Tools, Tools

- In order to carry out the Belle II physics program, many tools had to be reinvented
  - Completely new software framework: BASF2 arXiv:1809.04299
  - Completely new tagging algorithms: FEI arXiv:1807.08680
  - Flavour Tagging with Deep Learning: DFT
  - Practice makes perfect: B2BII arXiv:1810.00019

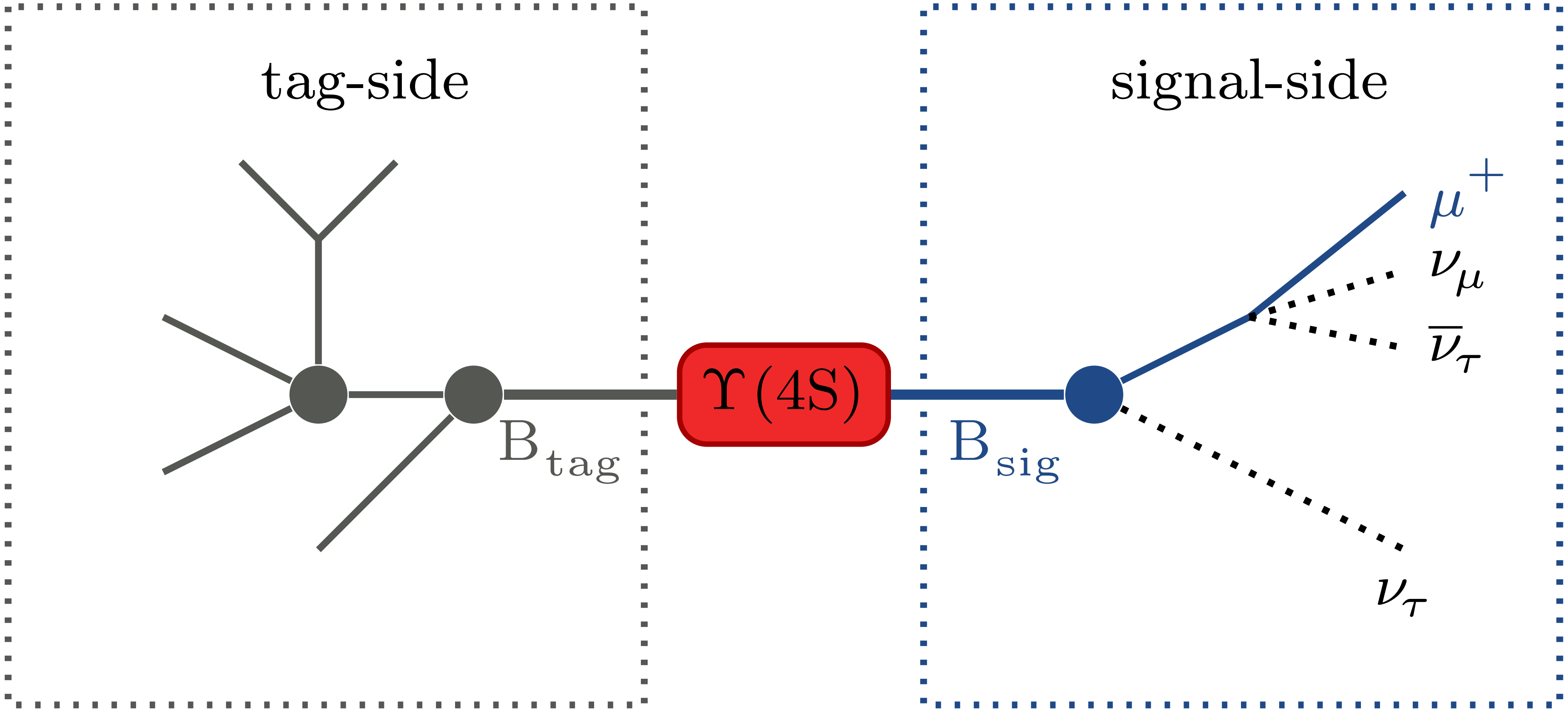
```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-

# Generate 100 events with event numbers 0 to 99↩
      that contain only the event meta data.

import basf2
main = basf2.create_path()
main.add_module('EventInfoSetter', evtNumList↩
     =[100])
basf2.process(main)
```

Full Event Interpretation

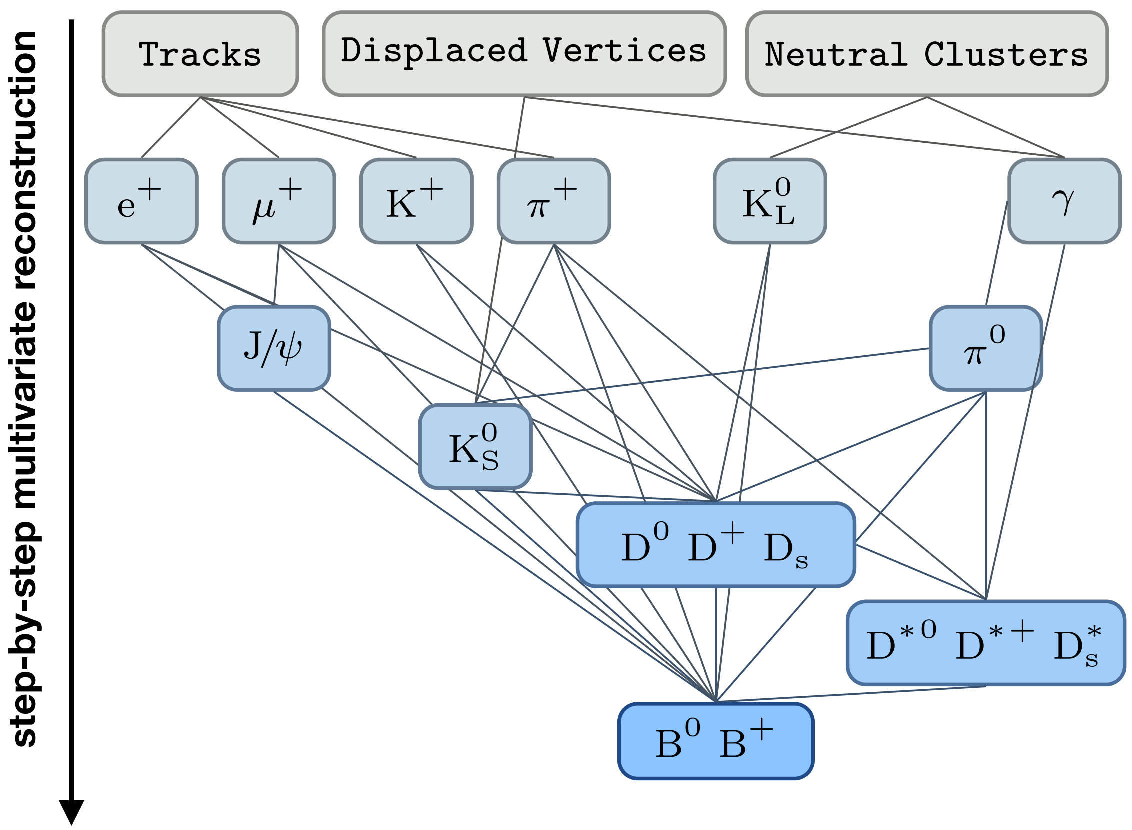
- **Key idea:** reconstruct second B-Meson in collision
  - Allows to constrain properties of signal decay (kinematic and others)



E.g. hadronic: $p_{\text{invisible}} = p_{\text{beam}} - p_{\text{tag}} - p_{\text{visible}}$

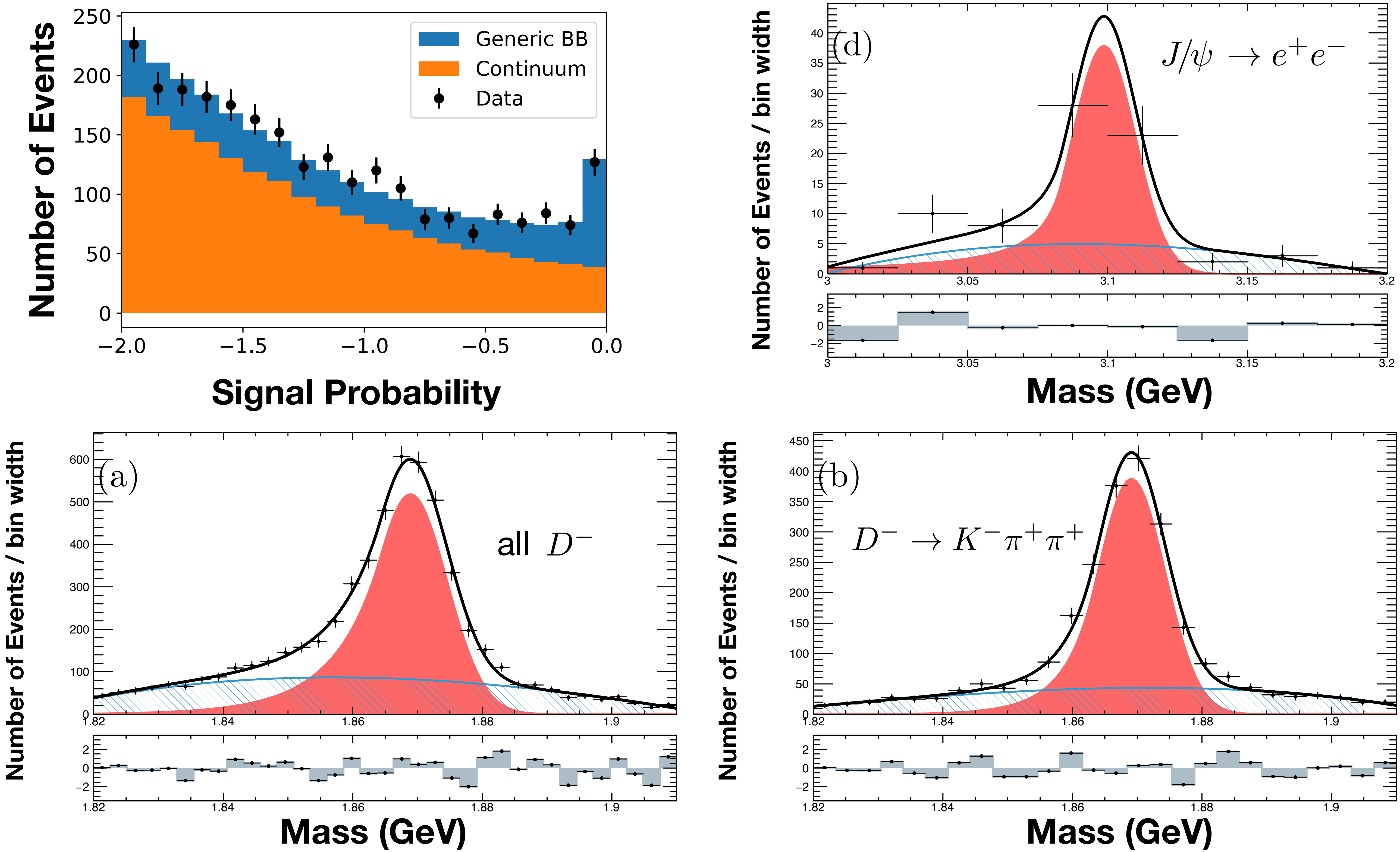
Full Event Interpretation

- **Key idea:** reconstruct second B-Meson in collision
  - Allows to constrain properties of signal decay (kinematic and others)

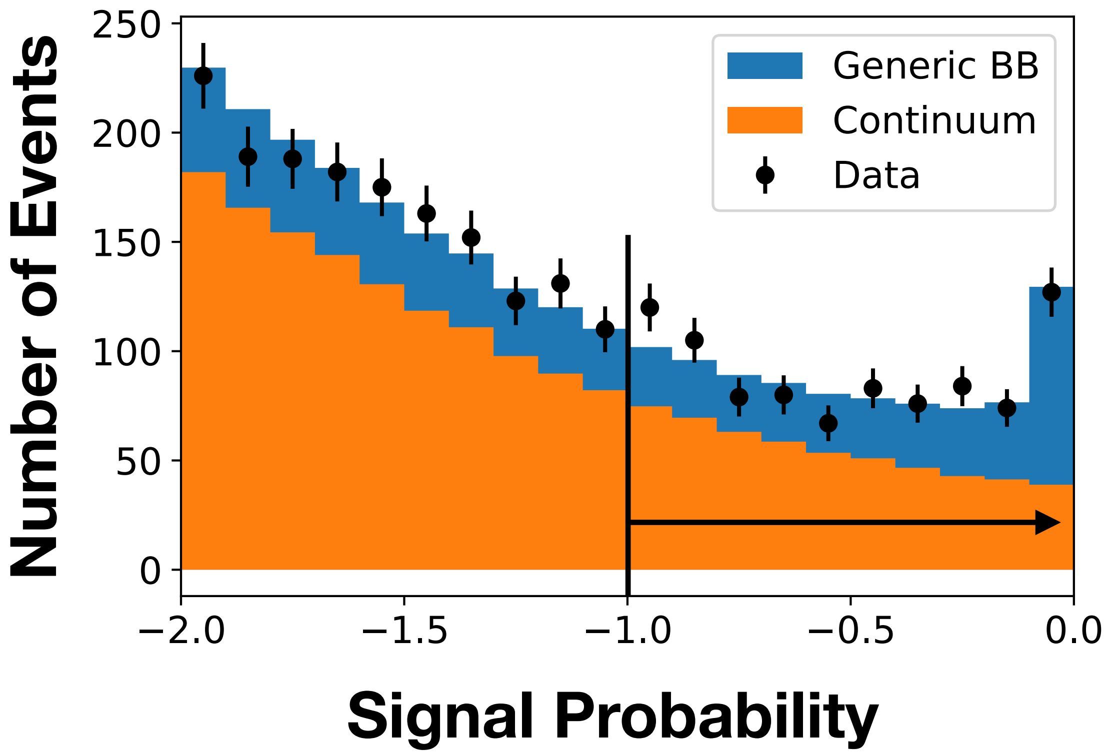


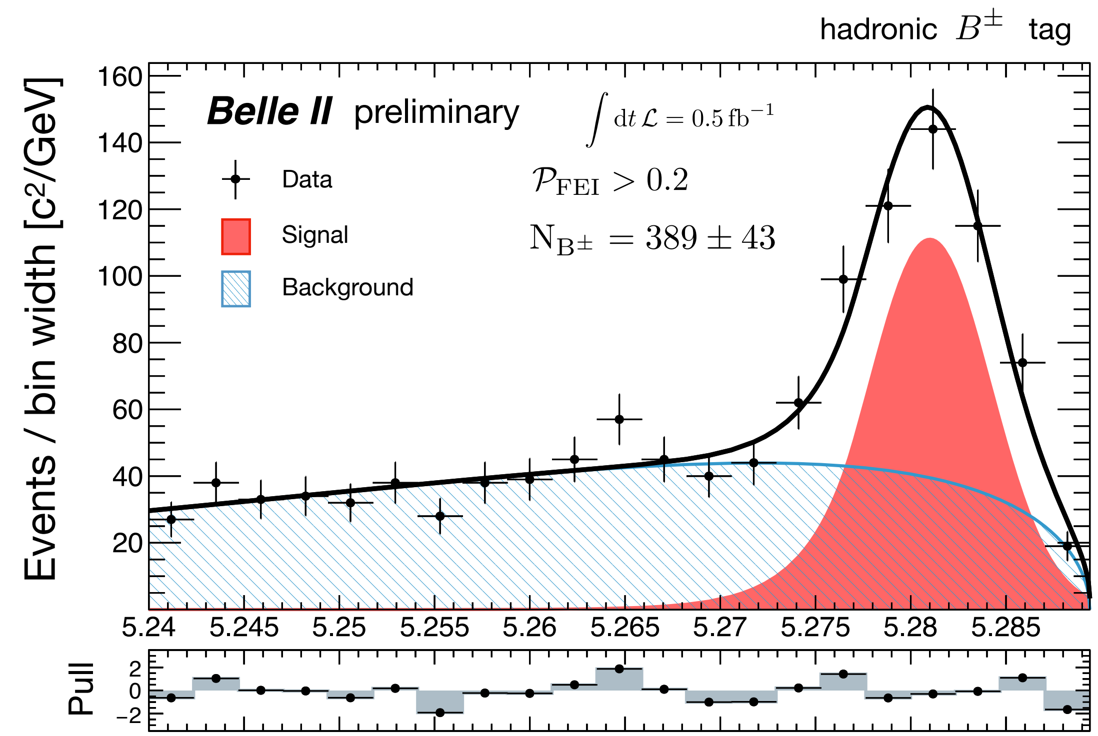
	FEI			old algorithms	
	$B^\pm$	B^0		$B^\pm$	B^0
Hadronic			Hadronic		
FEI with FR channels	0.53 %	0.33 %	FR	0.28 %	0.18 %
FEI	0.76 %	0.46 %	SER	0.4 %	0.2 %
Semileptonic			Semileptonic		
FEI	1.80 %	2.04 %	FR	0.31 %	0.34 %
			SER	0.3 %	0.6 %

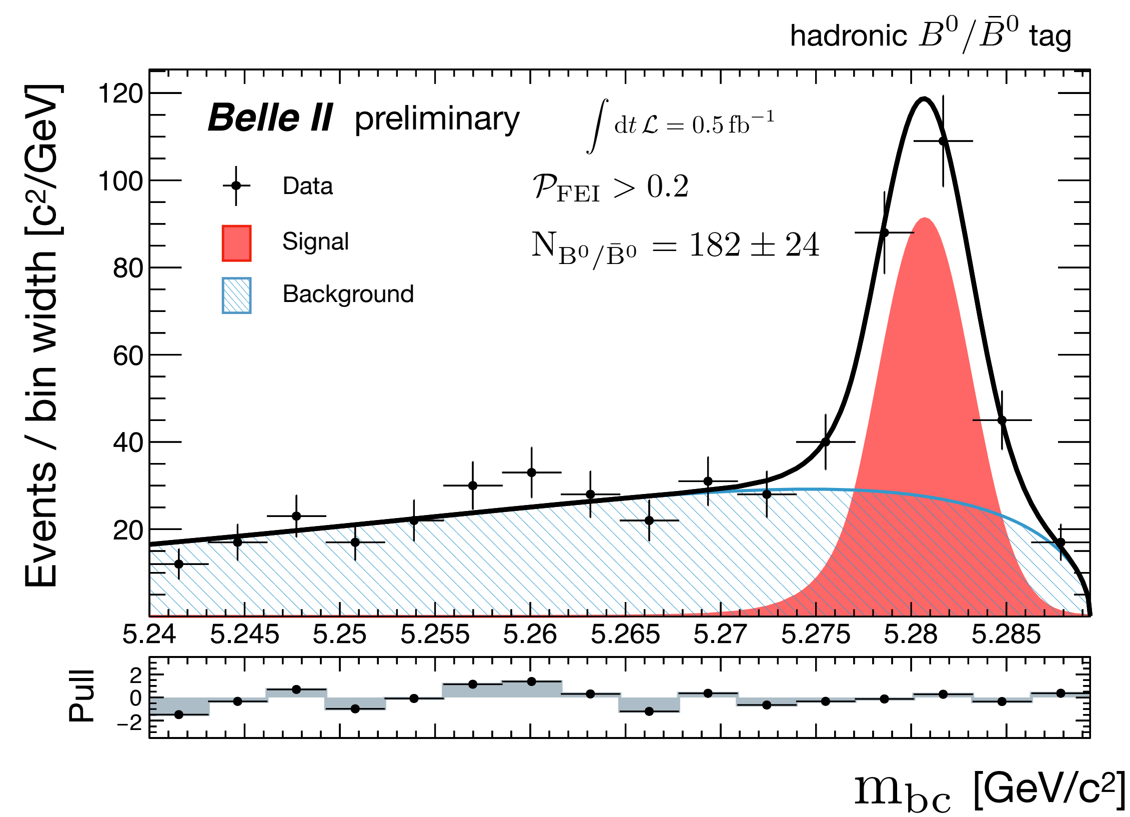
Full Event Interpretation in Phase II



Full Event Interpretation in Phase II







Cut on Signal probability to improve purity and fit in

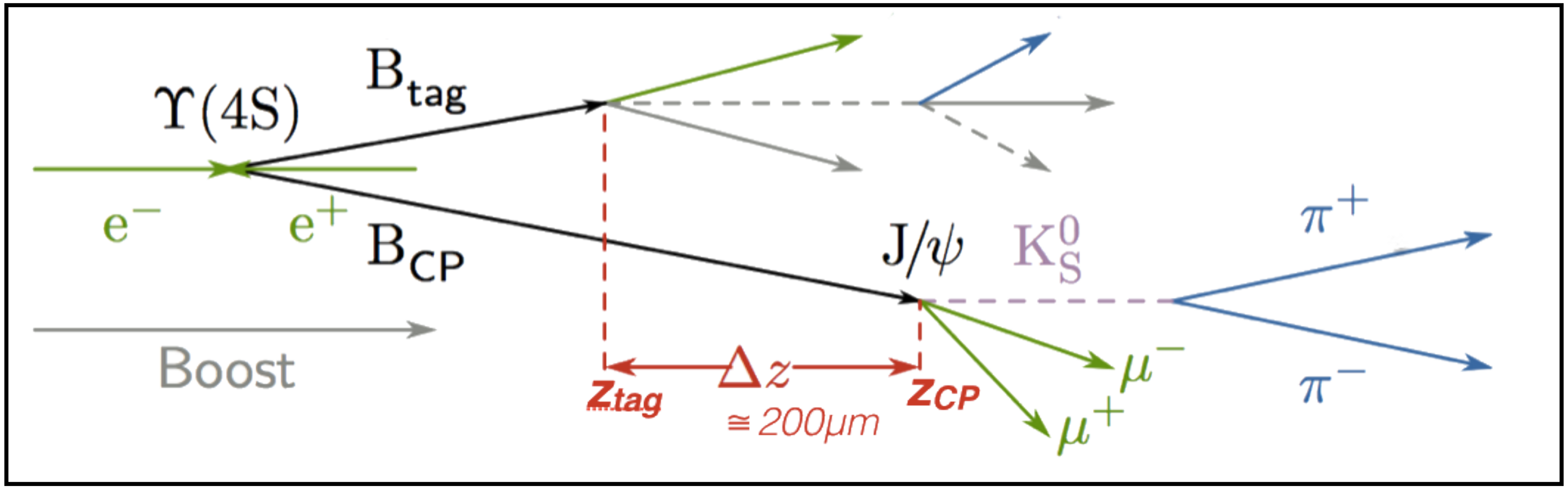
$$m_{bc} = \sqrt{s/4 - |\vec{p}^{\,*}_{B_{\mathrm{tag}}}|^2}\,,$$

Flavour Tagger with Deep Neural Networks

- Flavour tagging:
  - important tool for time-dependent and time-integrated CPV measurements

$\sin 2\beta$

Golden mode



- Current approaches use categories

flavor-specific categories	decay processes
Primary Leptons	$\bar{b} \to \bar{c}\, \ell^+ \nu$
Secondary Leptons	$\bar{b} \to \bar{c} \to \bar{s}\, \ell^- \bar{\nu}$
Slow Pion	$B^0 \to D^{*-} X, D^{*-} \to \bar{D}^0 \pi^-$
Fast Strange Particles	$B^0 \to K^+ X_{c\bar{c}}$
Slow Strange Particles	$\bar{b} \to \bar{c} \to \bar{s}$

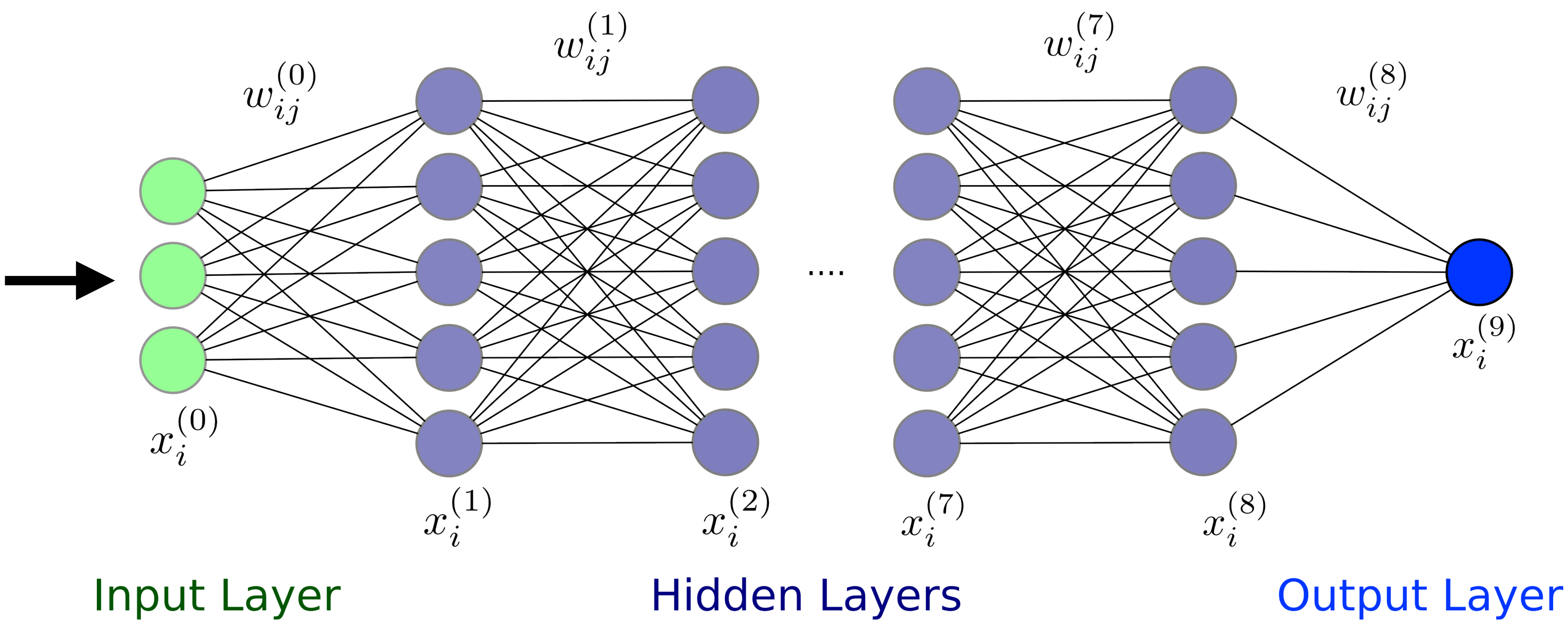
Flavour Tagger with Deep Neural Networks

- Great playground for deep learning:
  - **Human** made **high-level categories** versus **full set of input observables**

Features

- 10 charged tracks at maximum
- sorted by momentum, grouped by charge
- p_{CMS}, $\cos(\theta_{CMS})$, ϕ_{CMS}
- electron, pion, muon, kaon, proton ID
- hit count of the Belle II-tracking detectors (3)
- track perigee (dr, dz)
- pValue
- overall 140 input features

DNN



8 layers with 300 nodes each

Flavour Tagger with Deep Neural Networks

- Great playground for deep learning:
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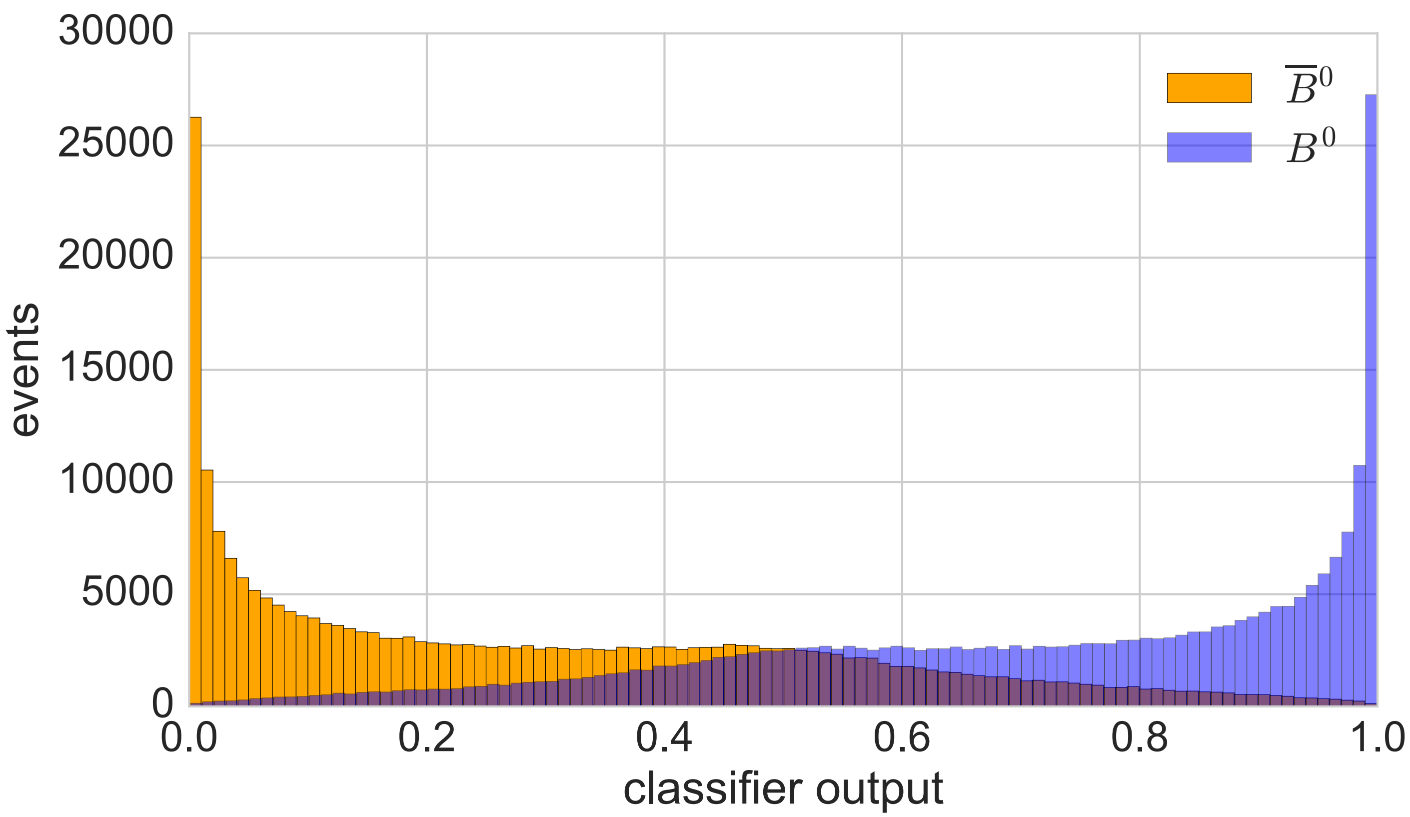
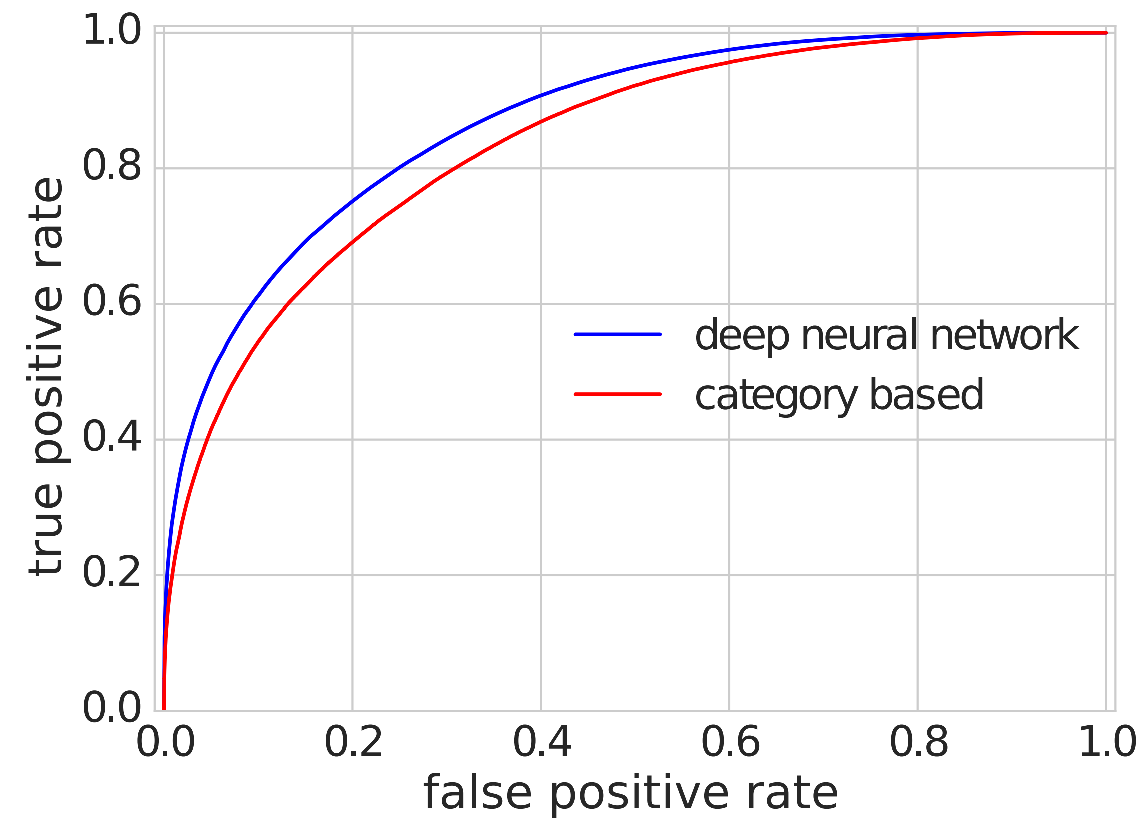
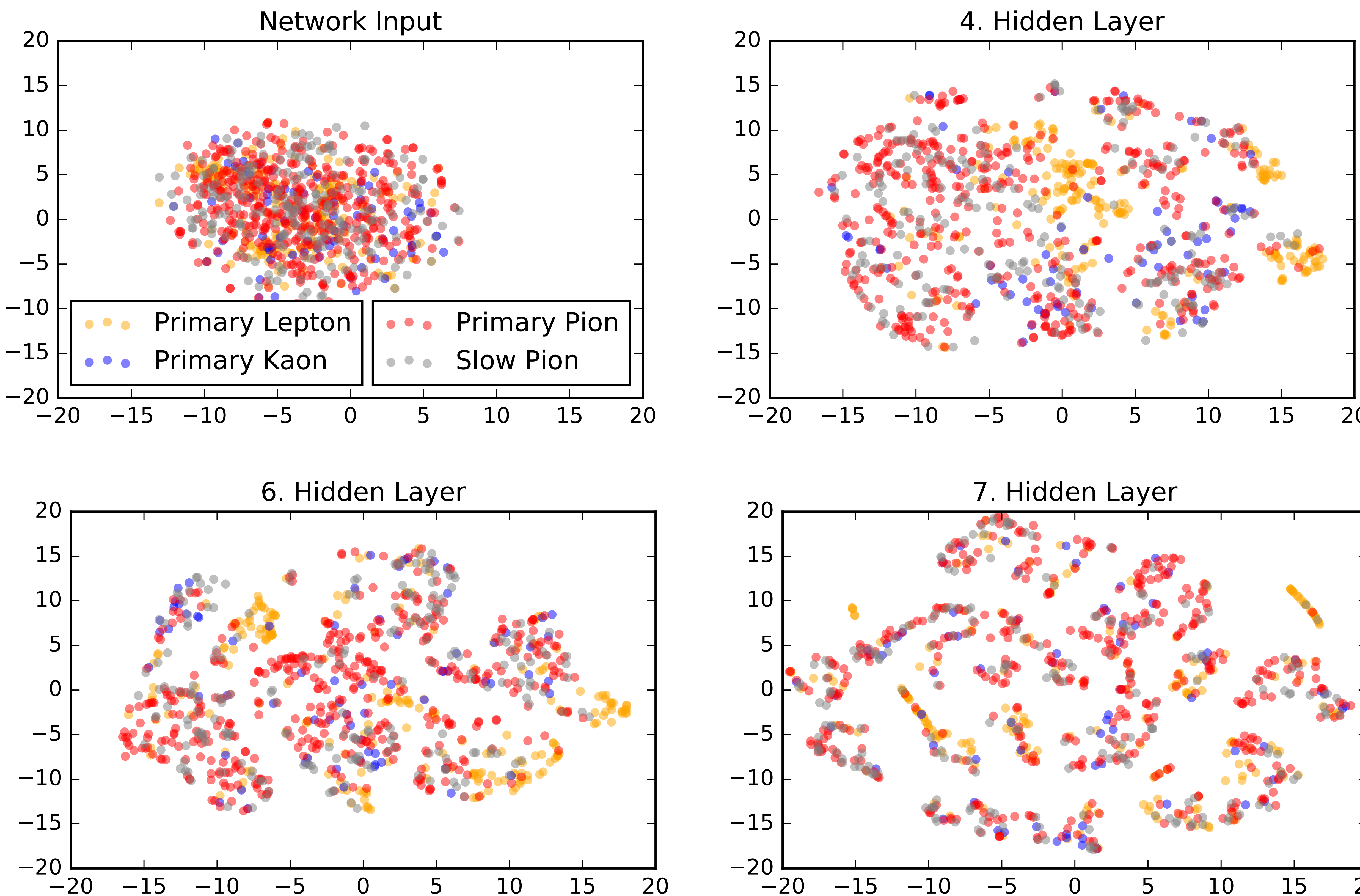
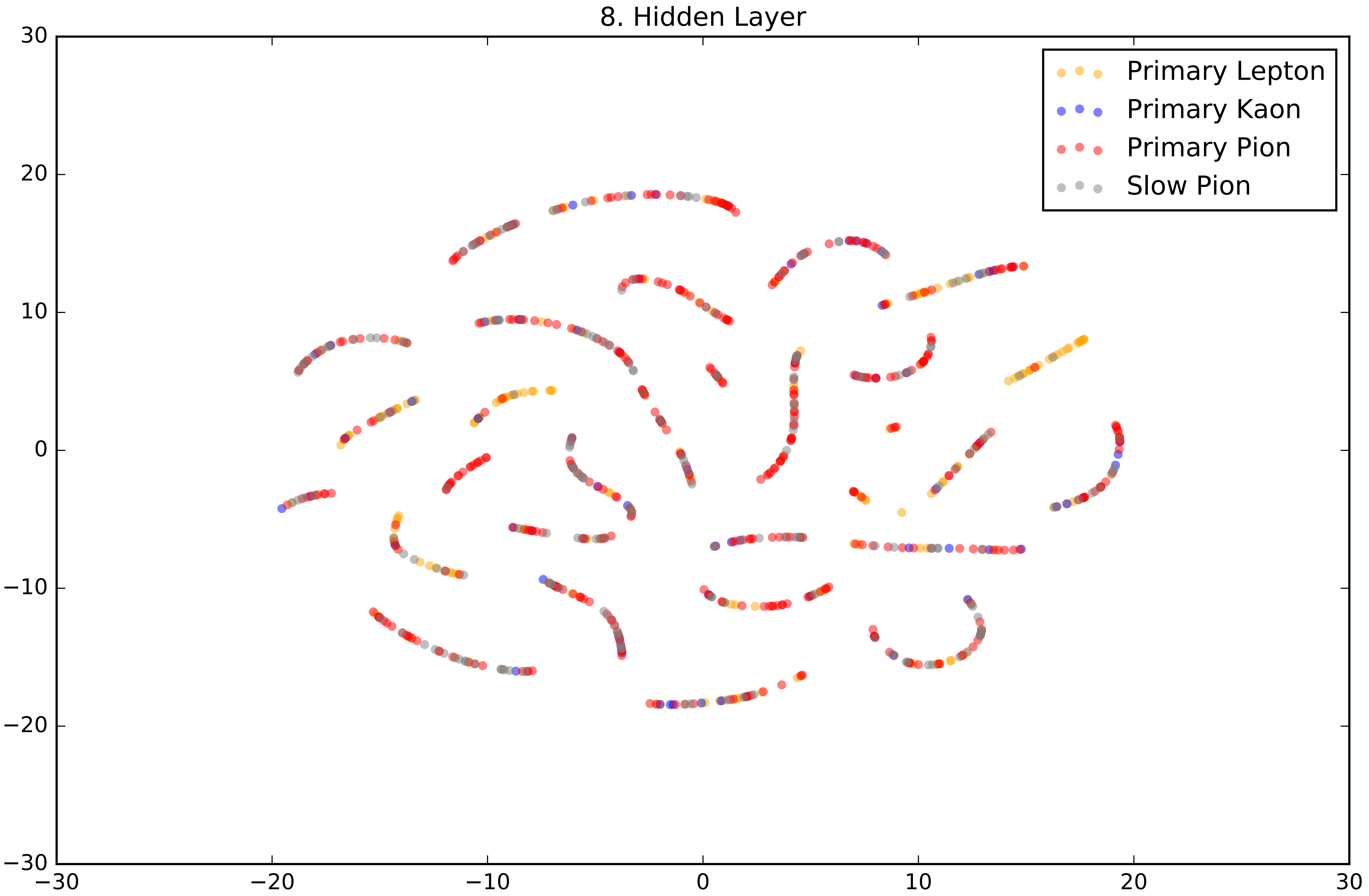




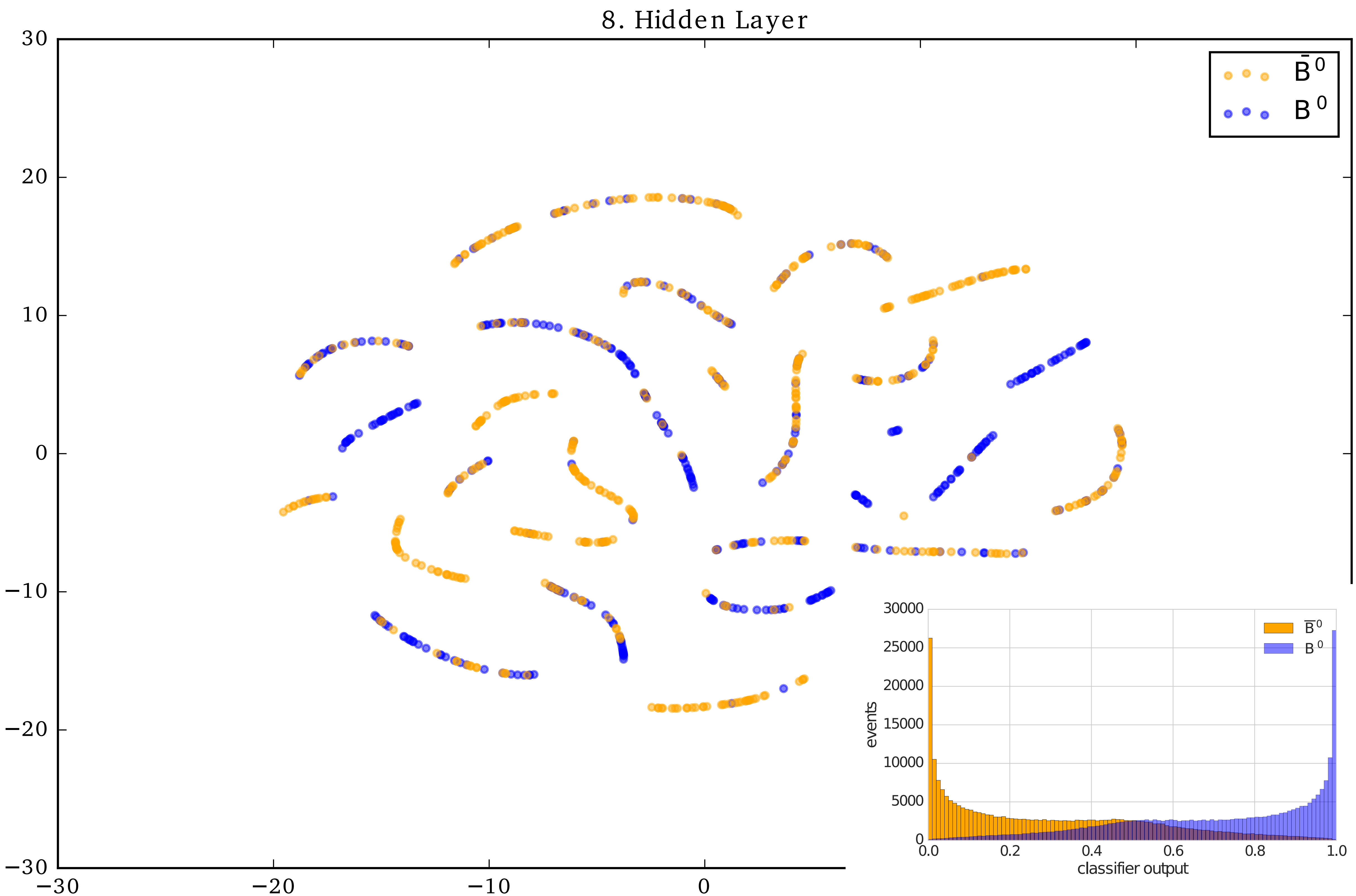
		Category Based	Deep Neural Network
Belle	$J/\Psi K_S^0$	0.293 ± 0.01 [1]	0.3442 ± 0.0009



T-distributed Stochastic Neighbour Embedding (TSNE)



8. Hidden Layer
Primary Lepton
Primary Kaon
Primary Pion
Slow Pion
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30



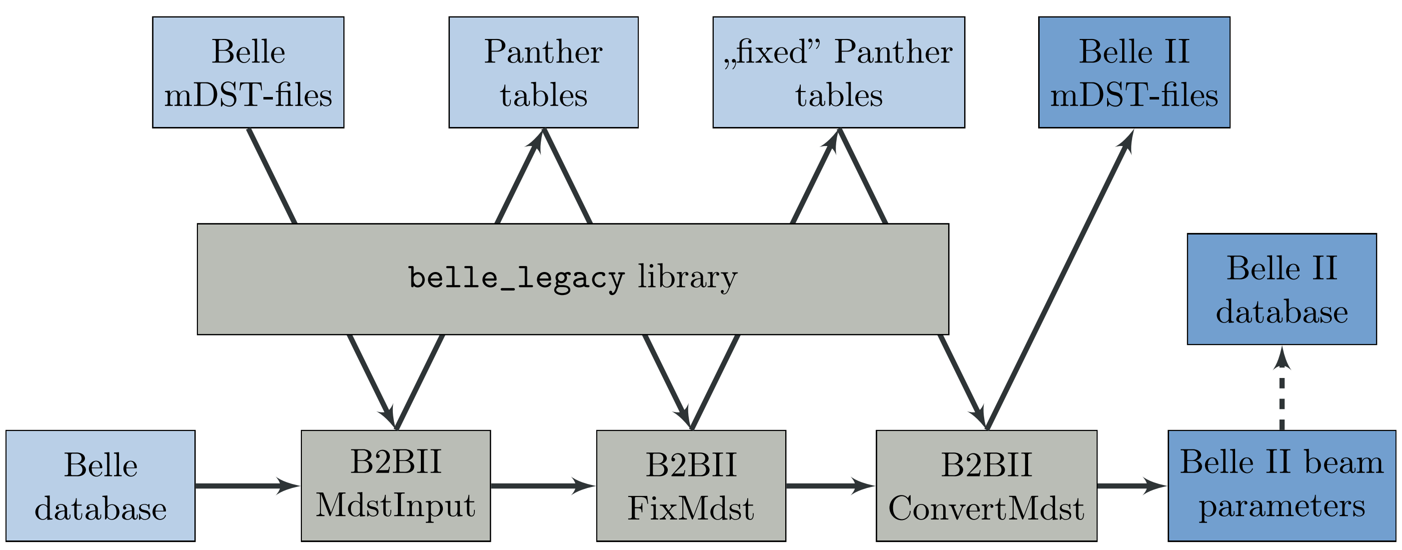
8. Hidden Layer
$\bar{B}^0$
B^0
30
20
10
0
−10
−20
−30
−30
−20
−10
0
30000
25000
20000
15000
10000
5000
0
events
0.0
0.2
0.4
0.6
0.8
1.0
classifier output

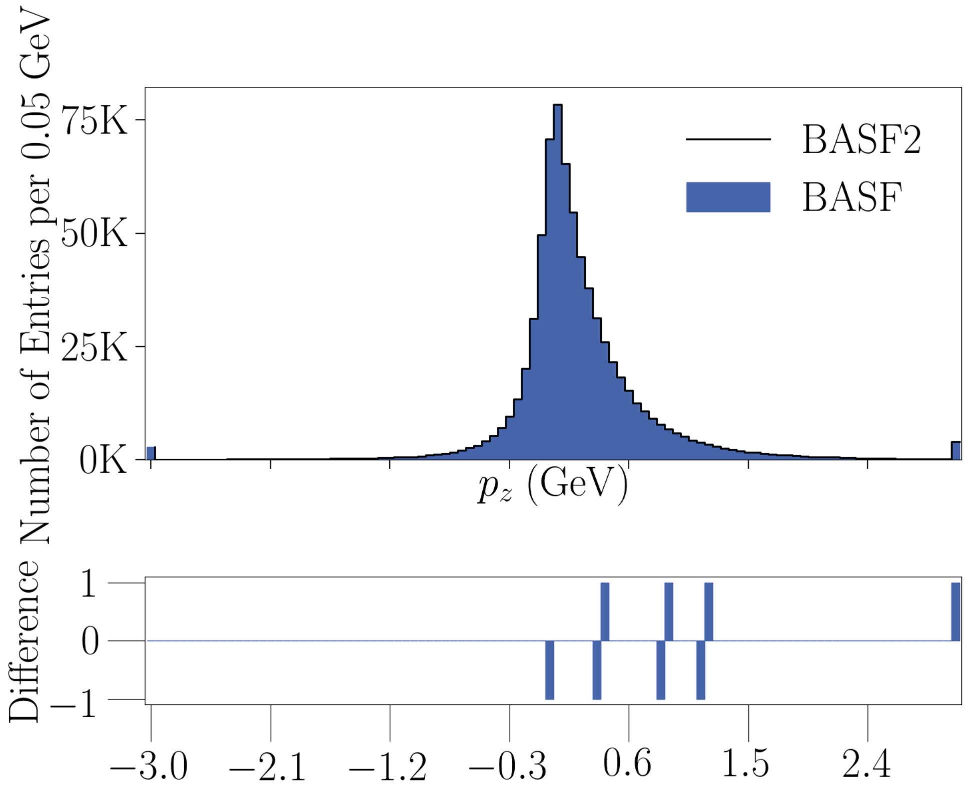
Practice makes perfect: B2BII

- Imagine you build a new experiment, but you have plenty of similar data lying around from a previous run.
    - But computing system completely changed; but old data invaluable tool to train PhD students and Postdoc

- Imagine you build a new experiment, but you have plenty of similar data lying around from a previous run.
  - But computing system completely changed; but old data invaluable tool to train PhD students and Postdoc
- B2BII: Belle to Belle II conversions made easy
  - Converts Belle files into Belle II format

Conversion flow





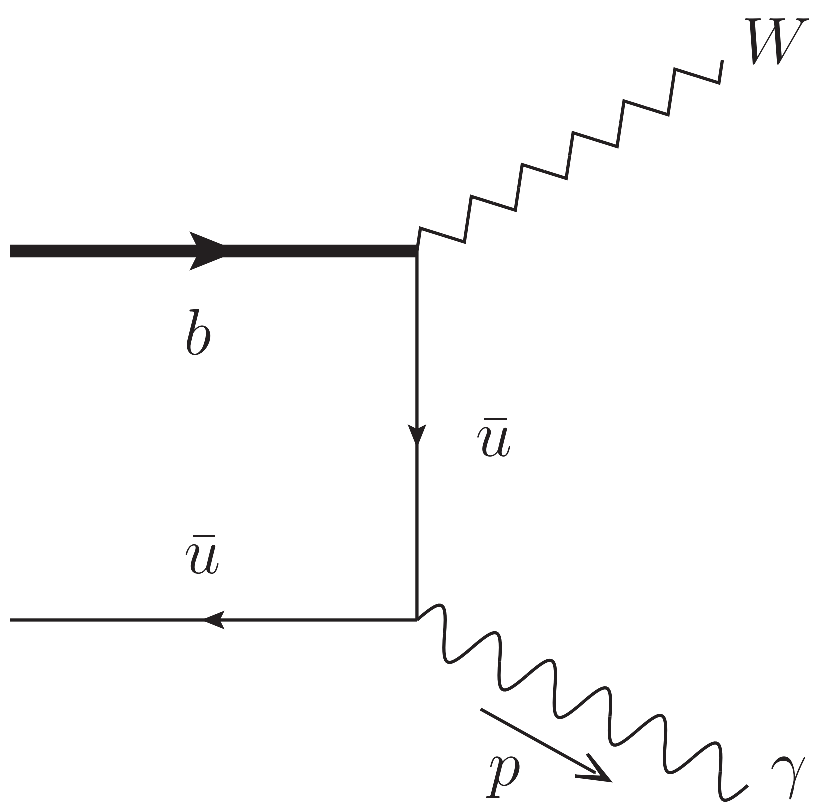
p_z of charged tracks

Search for the rare decay of $B \to \ell \nu \gamma$ using B2BII & FEI

- Rare decays excellent testing ground for B2BII & FEI
  - $B \to \ell \nu \gamma$ with $E_\gamma > 1$ GeV is expected to have BF of $O(10^{-6})$
  - **Incredibly difficult** signature for **LHCb**
    (Single Photon, Lepton and missing energy)

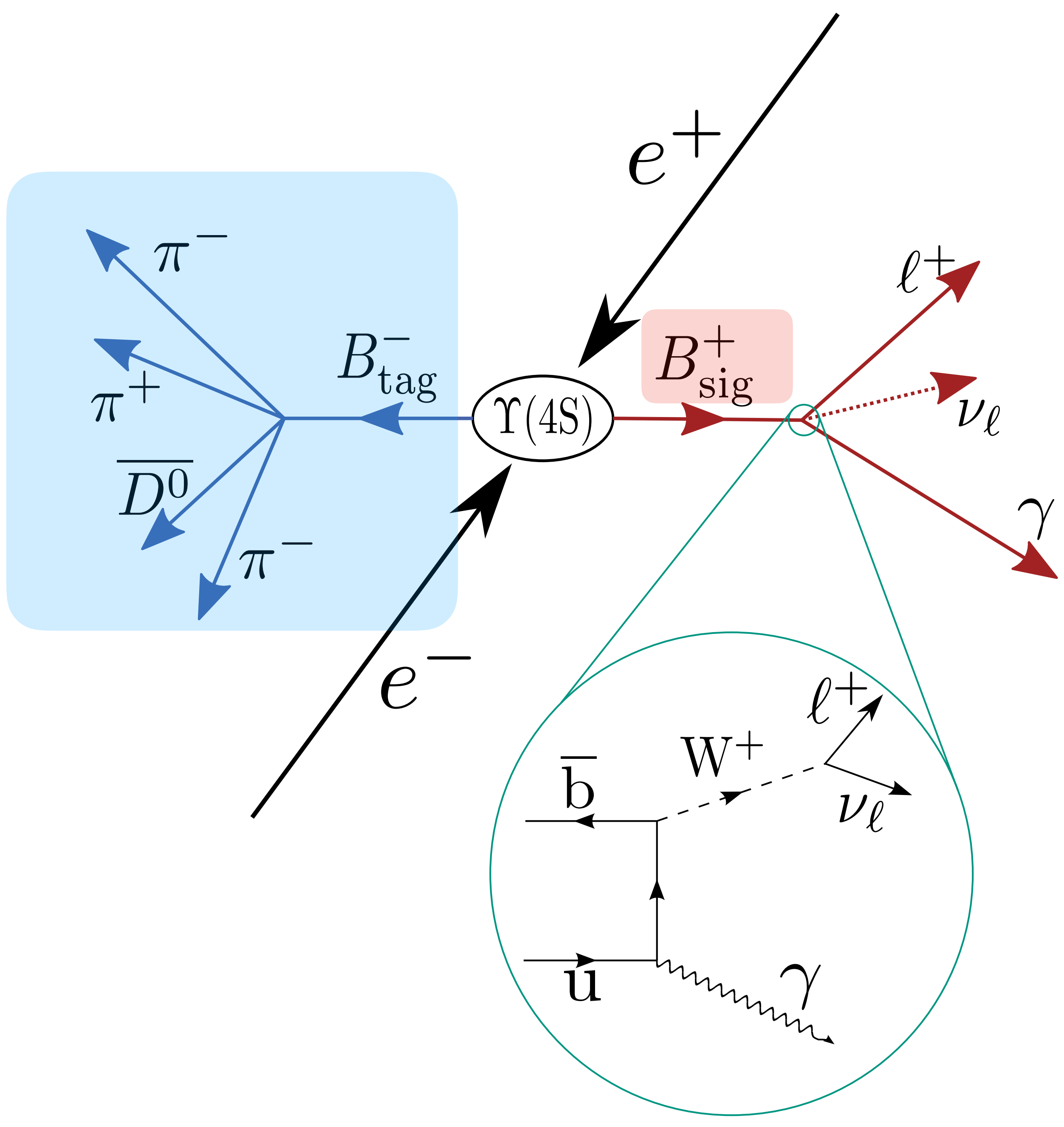
- **Partial BF proportional** to first **inverse moment** of **leading** twist **B-Meson** light-cone **distribution function**

$$\lambda_B^{-1} = \int_0^\infty \mathrm{d}w \, \phi_+(w)$$



  - **Important** input for **non-leptonic** factorisation predictions

Search for the rare decay of B →ℓνɣ using B2BII & FEI



- First reconstruct signal side. Then use hadronic FEI to reconstruct rest of event
- Allows reconstruction of neutrino four-momentum

$$p_{B_{\rm sig}} = \begin{pmatrix} \sqrt{s}/2 \\ -\vec{p}_{B_{\rm tag}} \end{pmatrix} \quad \text{and} \quad p_\nu = \left(p_{B_{\rm sig}} - p_\ell - p_\gamma \right)$$

- **Major background:** charmless semileptonic decays with π^0 or η

⟶ Suppressed via dedicated MVA

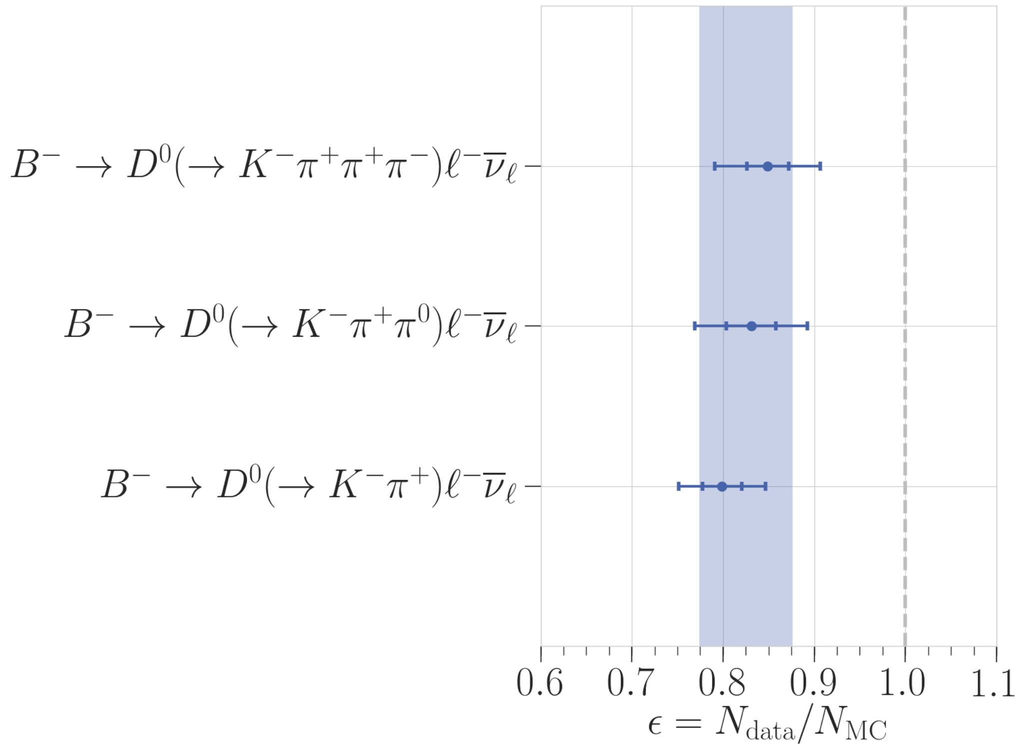
Three times larger signal efficiency

Search for the rare decay of B →ℓνɣ using B2BII & FEI

- FEI efficiency different in data and simulation
  - Needs to be calibrated using a standard candle process

$$B^- \to D^0\,\ell\,\bar{\nu}_\ell$$

- Calibration Factor(s):



The calibration pamphlet

Why calibration?
Difference in tagging efficiency on data and MC:

- Hadronic branching ratios
- Dynamics of hadronic decays
- Detector simulation
- ...

Procedure

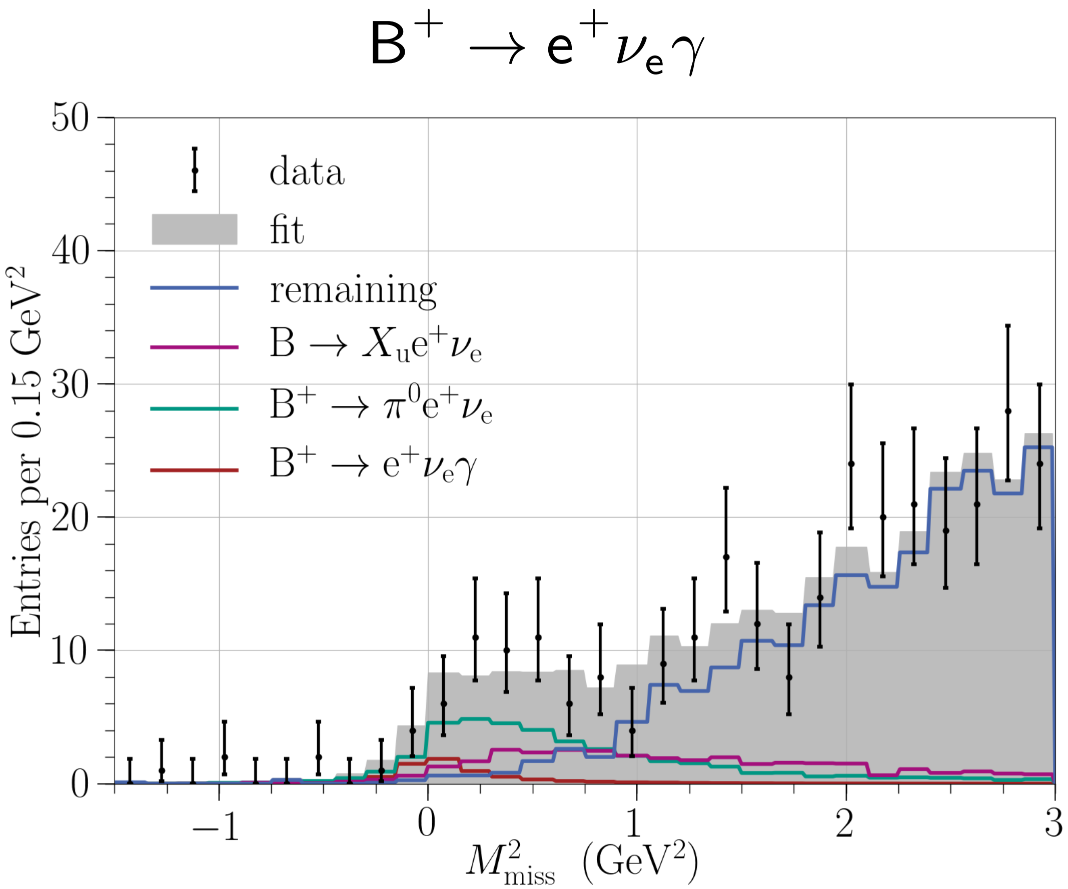
1) Reconstruct B_{sig} in well-known channel
2) Apply tagging algorithm
3) Extract the number of events on MC and data via a fit on M^2_{miss}
4) Calculate the correction factor for calibration channel:

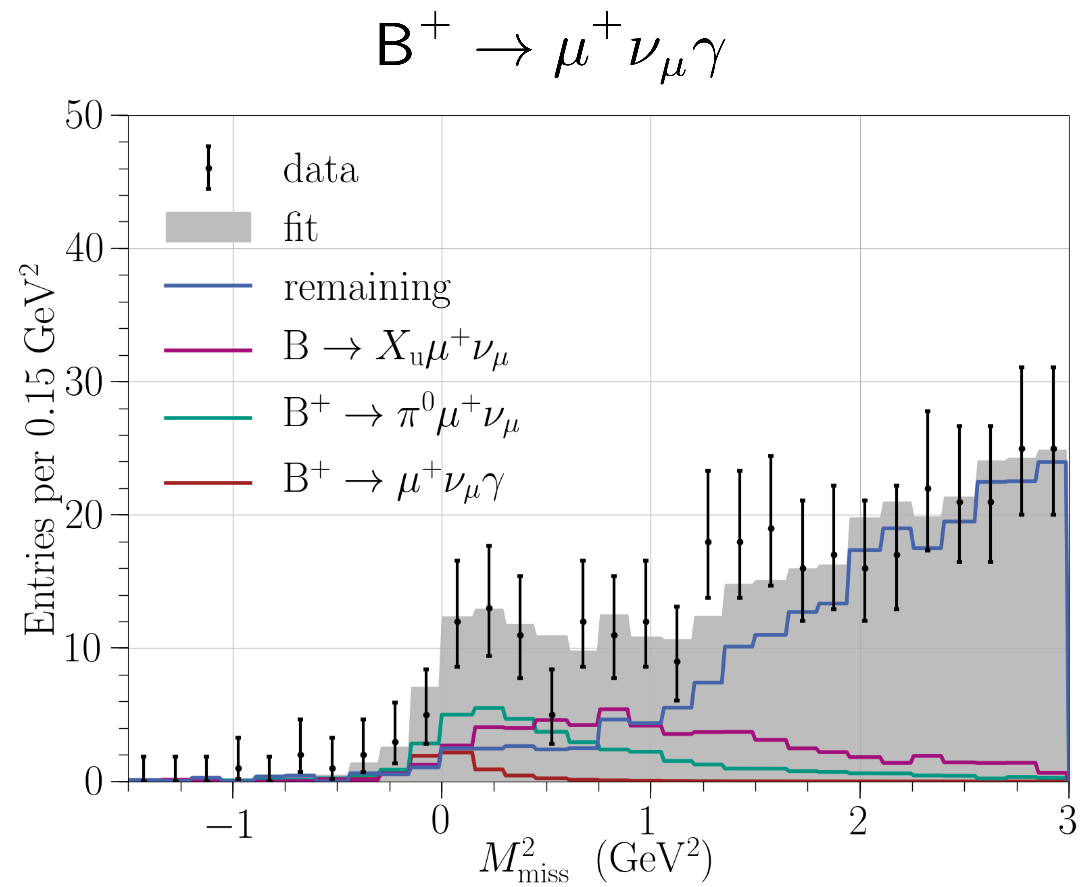
$$\epsilon = \frac{N_{\mathrm{Data}}}{N_{\mathrm{MC}}}$$

$$\boxed{\epsilon = \mathbf{0.825 \pm 0.014 \ \pm 0.049}}$$

Missing mass squared

$$M^2_{\text{miss}} = p^2_\nu = (p_{\text{beam}} - p_{\text{tag}} - p_\ell - p_\gamma)^2$$

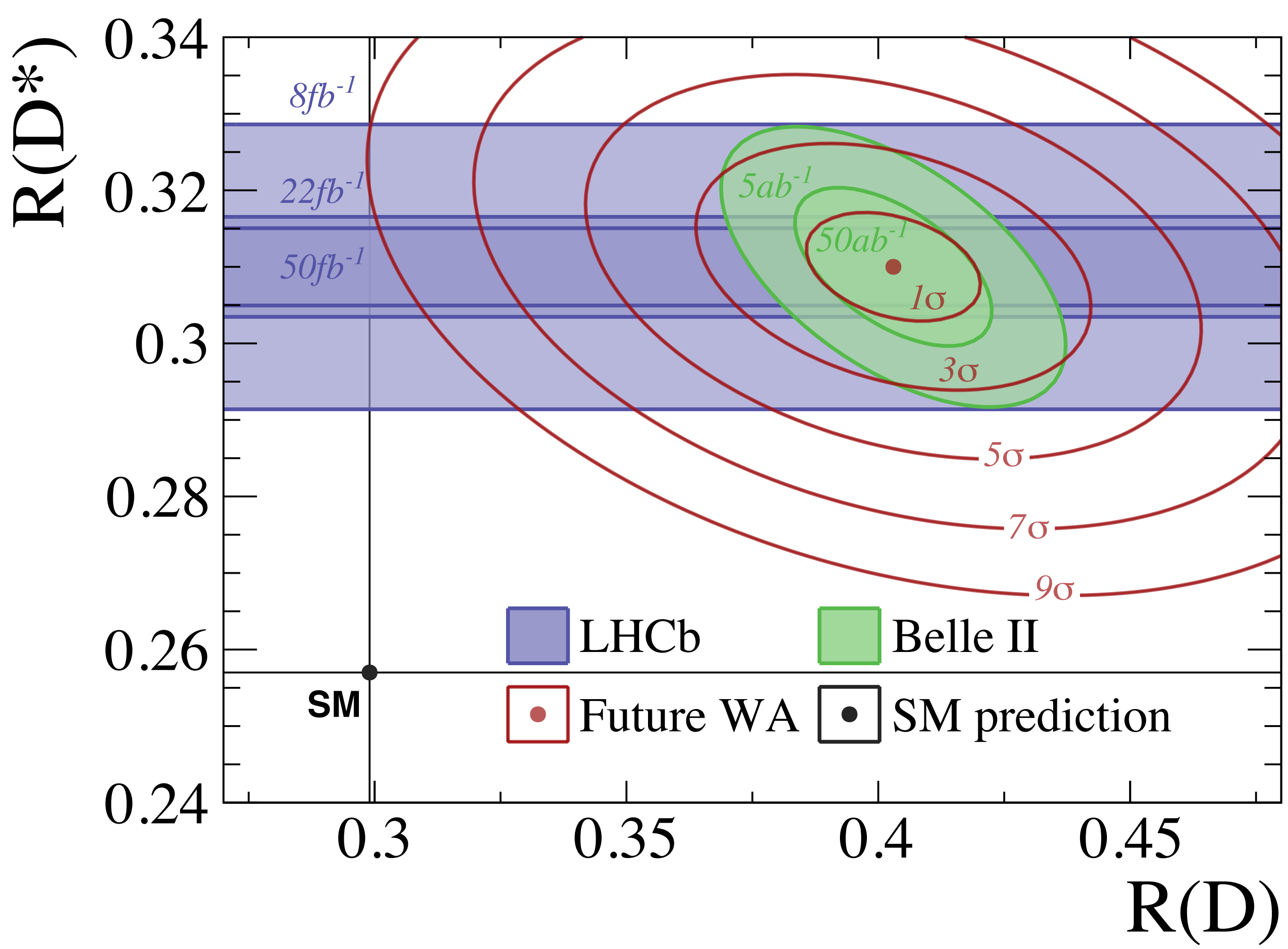




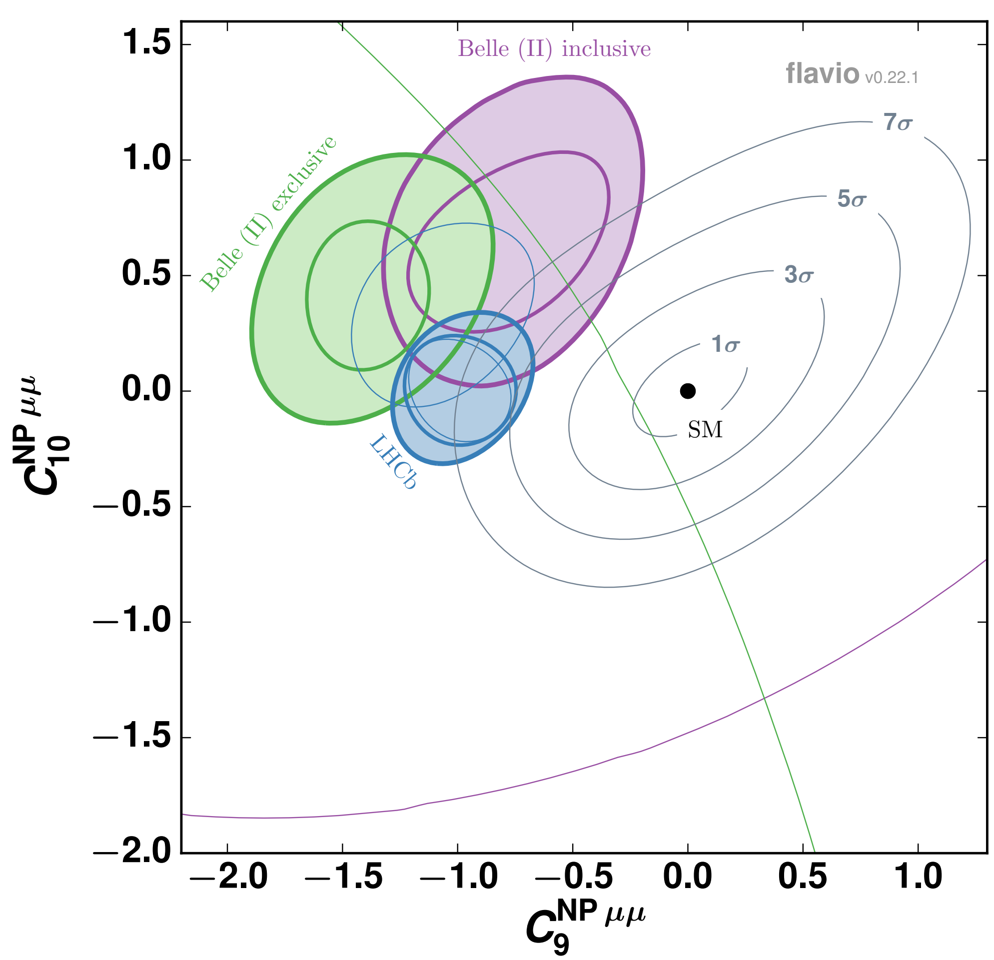
ℓ	$\mathcal{B}(B^+ \to \pi^0\ell^+\nu_\ell)$ (10^{-5})	σ	$\Delta\mathcal{B}(B^+ \to \ell^+\nu_\ell\gamma)$ (10^{-6})	σ
e	$8.3^{+0.9}_{-0.8} \pm 0.9$	8.0	$1.7^{+1.6}_{-1.4} \pm 0.7$	1.1
μ	$7.5 \pm 0.8 \pm 0.6$	9.6	$1.0^{+1.4}_{-1.0} \pm 0.4$	0.8
e, μ	**$7.9 \pm 0.6 \pm 0.6$**	**12.6**	**$1.4 \pm 1.0 \pm 0.4$**	**1.4**

Back to physics: Breaking out of the SM

- Preparations for next years physics run ongoing.
- It's clear that with the data recorded in the next years by Belle II and LHCb we will confirm or rule out the present day anomalies
  - Belle II tools ready; only thing missing is data :-)



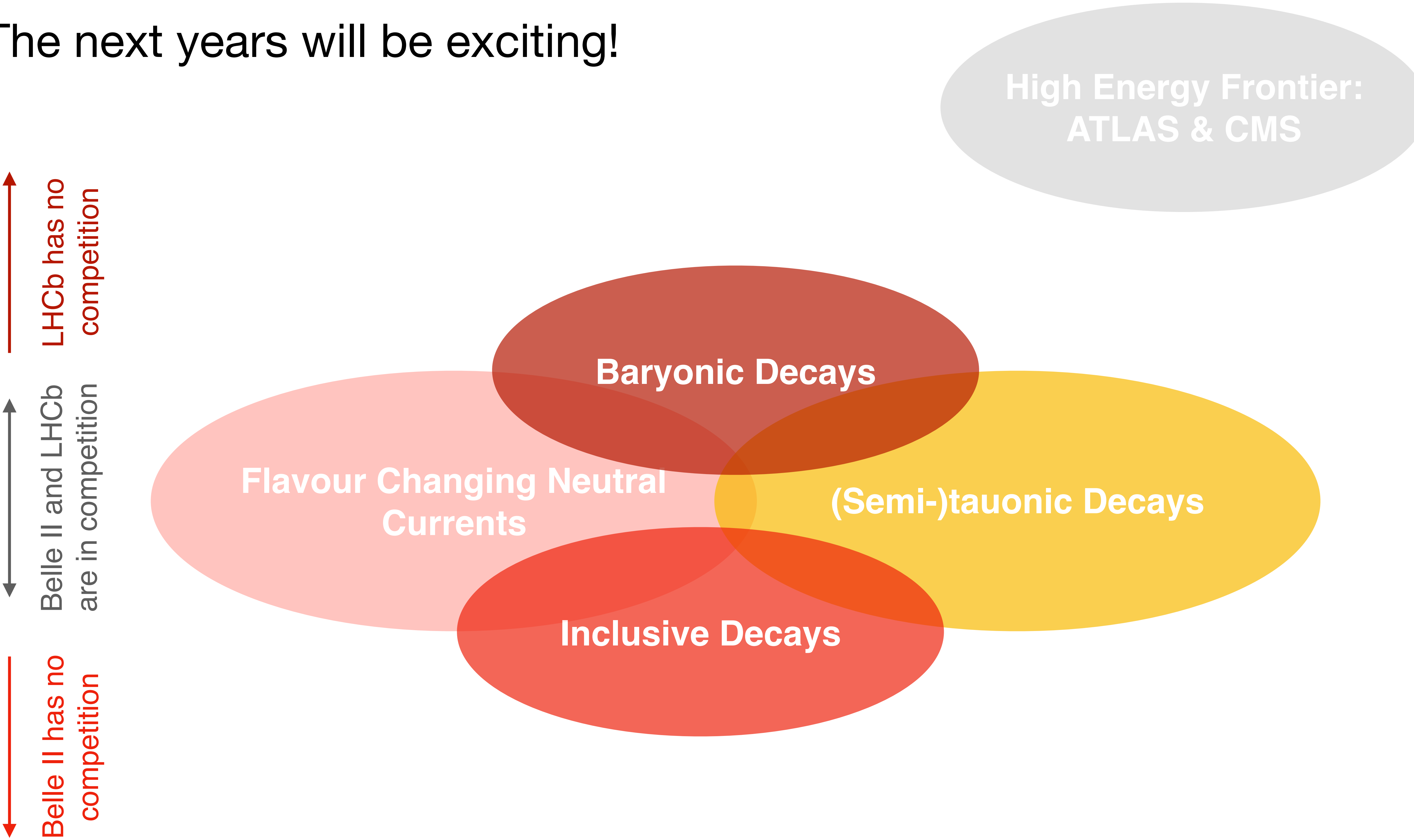
arXiv:1709.10308



b-Quark momentum dist.

Back to physics: Breaking out of the SM

The next years will be exciting!



b-Quark momentum dist.