INTENSE annual workshop

(Charged) Lepton Flavor Violation searches

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Outline

- CLFV limits
- Mu2e competitors
- Tau rare decays
- Higgs LFV searches

Flavor Violation

- We've known for a long time that quarks mix

  ✓**Mixing strengths parameterized by V_{CKM}**

$$\mathrm{V_{CKM}} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

- In last 15 years also neutrinos (neutral leptons) mixing was measured

  ✓**Mixing strengths parameterized by PMNS matrix**

- **Is there violation for charged leptons?**

CLFV limits

Process	Experiment	Limit	C.L.
$\mu^+ \to e^+\gamma$	MEG	4.2×10^{-13} [99]	90%
$\mu^\pm \to e^\pm e^- e^+$	SINDRUM	1.0×10^{-12} [133]	90%
$\mu^- N \to e^- N$	SINDRUM-II	$6.1(7.1) \times 10^{-13}$ Ti (Au) [47,134]	90%
$\mu^- N \to e^+ N'$	SINDRUM-II	5.7×10^{-13} [135]	90%
$\tau\pm \to e^\pm\gamma$	BaBar	3.3×10^{-8} [136]	90%
$\tau^\pm \to \mu^\pm\gamma$	BaBar	4.4×10^{-8} [136]	90%
$\tau \to eee$	Belle	2.7×10^{-8} [137]	90%
$\tau \to \mu\mu\mu$	Belle	2.1×10^{-8} [137]	90%
$\tau \to \mu ee$	Belle	1.8×10^{-8} [137]	90%
$\tau \to e\mu\mu$	Belle	2.7×10^{-8} [137]	90%
$\tau \to \pi^0 e$	Belle	8.0×10^{-8} [138]	90%
$\tau \to \pi^0 \mu$	BaBar	1.1×10^{-7} [139]	90%
$\tau \to \eta e$	Belle	9.2×10^{-8} [138]	90%
$\tau \to \eta\mu$	Belle	6.5×10^{-8} [138]	90%
$\tau \to \rho^0 e$	Belle	1.8×10^{-8} [140]	90%
$\tau \to \rho^0 \mu$	Belle	1.2×10^{-8} [140]	90%
$h \to \mu e$	ATLAS	6.1×10^{-5} [66]	95%
$h \to \tau e$	CMS	2.2×10^{-3} [67]	95%
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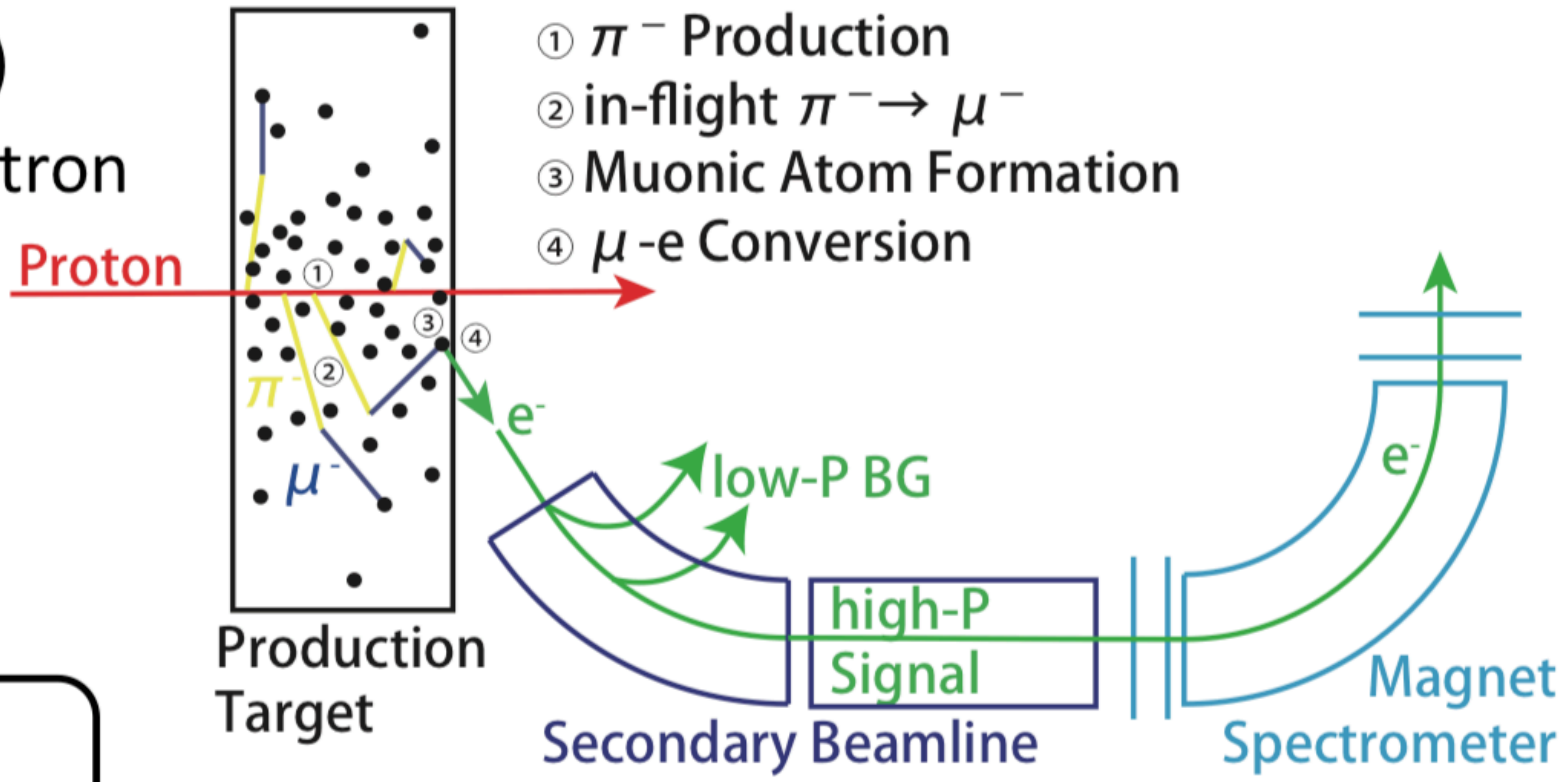
Already reviewed

Mu2e competitors

DeeMe experiment

- Process : $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - A single mono-energetic electron
    - 105 MeV
    - Delayed：~1μS
- No accidental backgrounds
- Physics backgrounds
  - Muon Decay in Orbit (DIO)
    - $E_e > 102.5$ MeV (BR:10^{-14})
    - $E_e > 103.5$ MeV (BR:10^{-16})
  - Beam Pion Capture
    - $\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$
      $\gamma \rightarrow e^+ e^-$
    - Pulsed Proton beam
      - Prompt timing

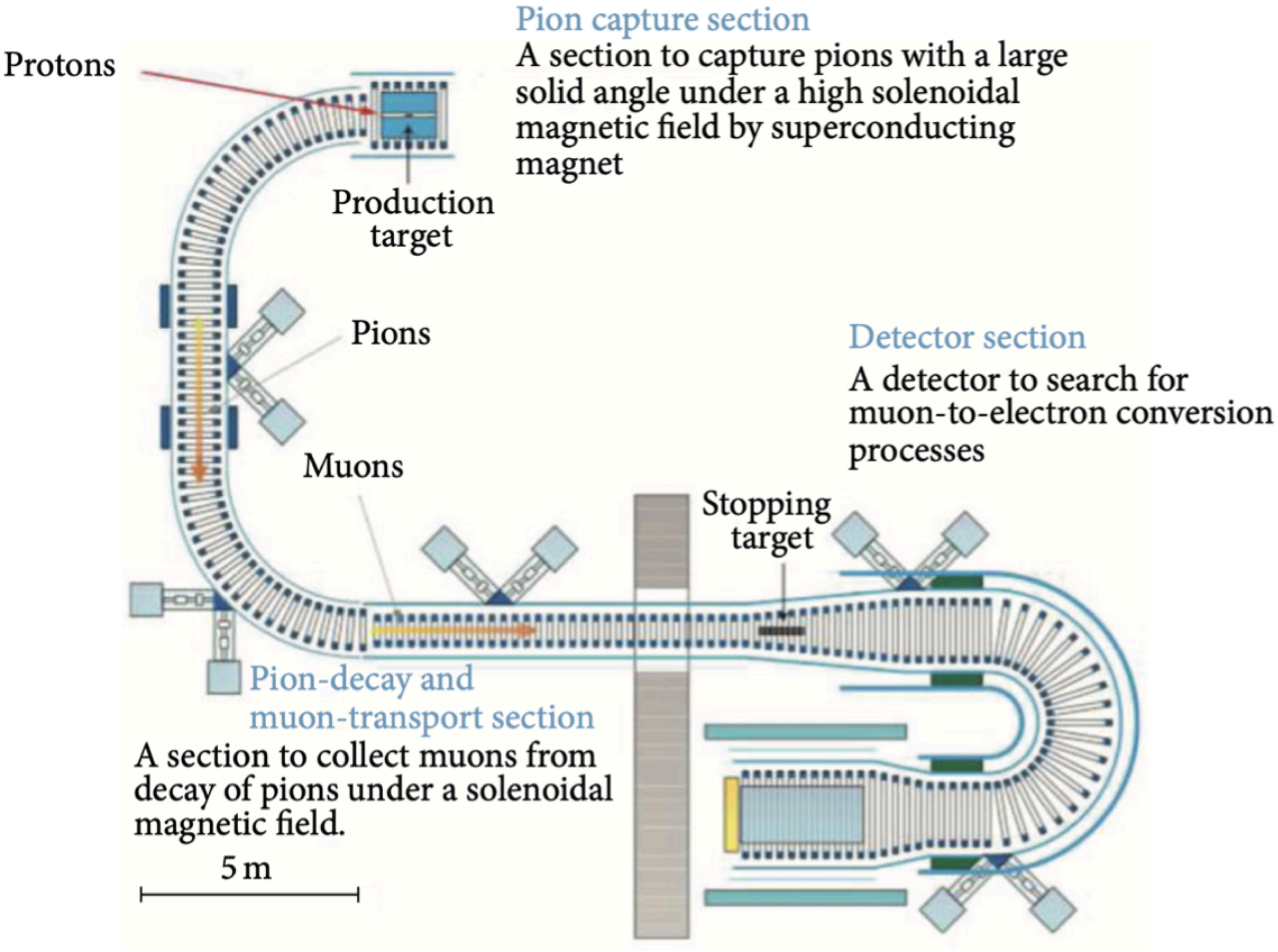


- Low Energy main part: suppressed by the beamline.
- High Energy tail: Magnet Spectrometer (Δp < 0.5%)

- Main pulse burst: State-of-the-art MWPC that becomes operational quickly after a burst.
- Delayed-protons: Suppressed owing to the extremely small after-protons from RCS -- $R_{DP} << 10^{-17}$.

M. Aoki, Presentation @ CLFV2019

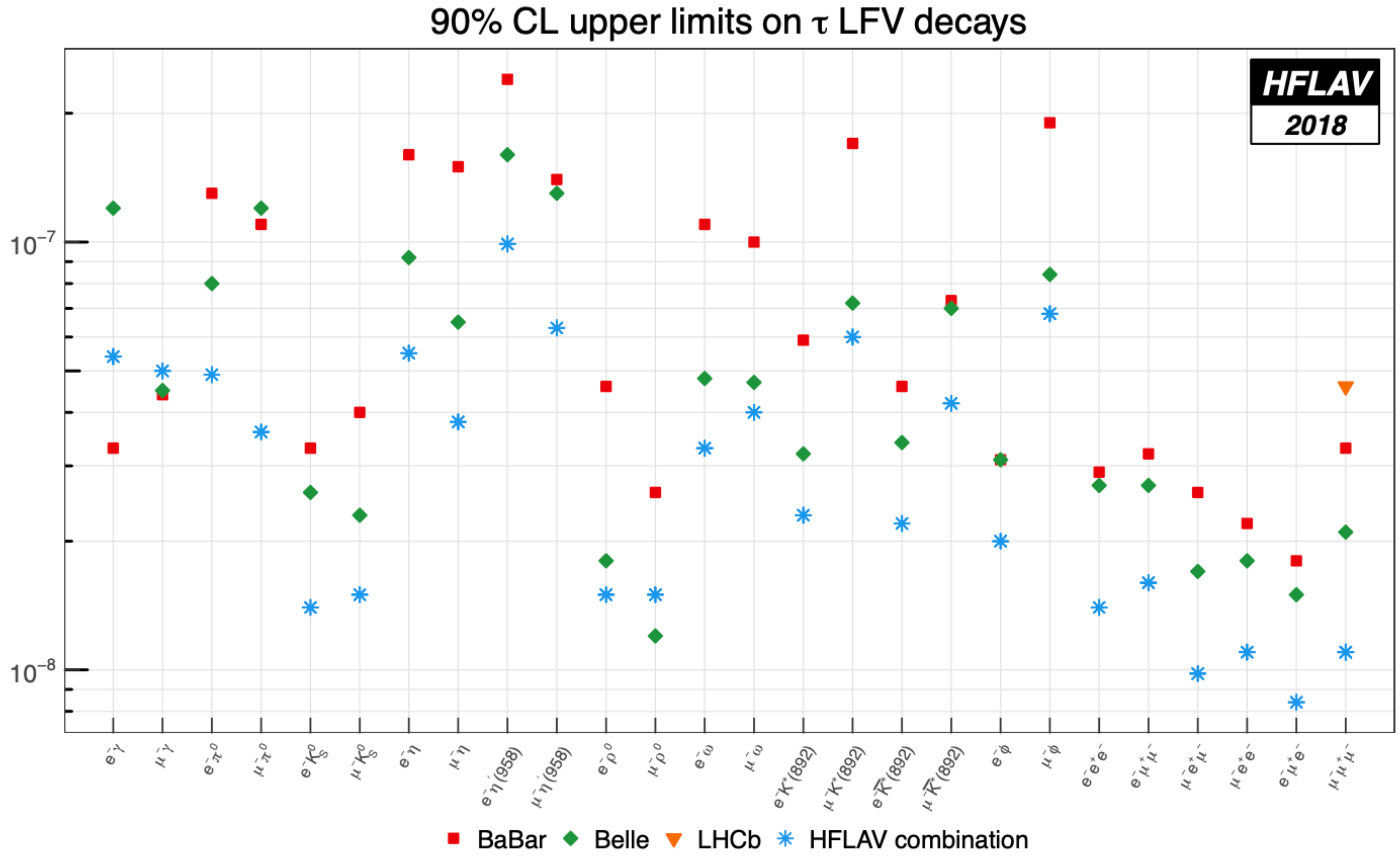
COMET


Pion capture section
A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting magnet
Protons
Production target
Pions
Muons
Detector section
A detector to search for muon-to-electron conversion processes
Stopping target
Pion-decay and muon-transport section
A section to collect muons from decay of pions under a solenoidal magnetic field.
5 m

Tau channels

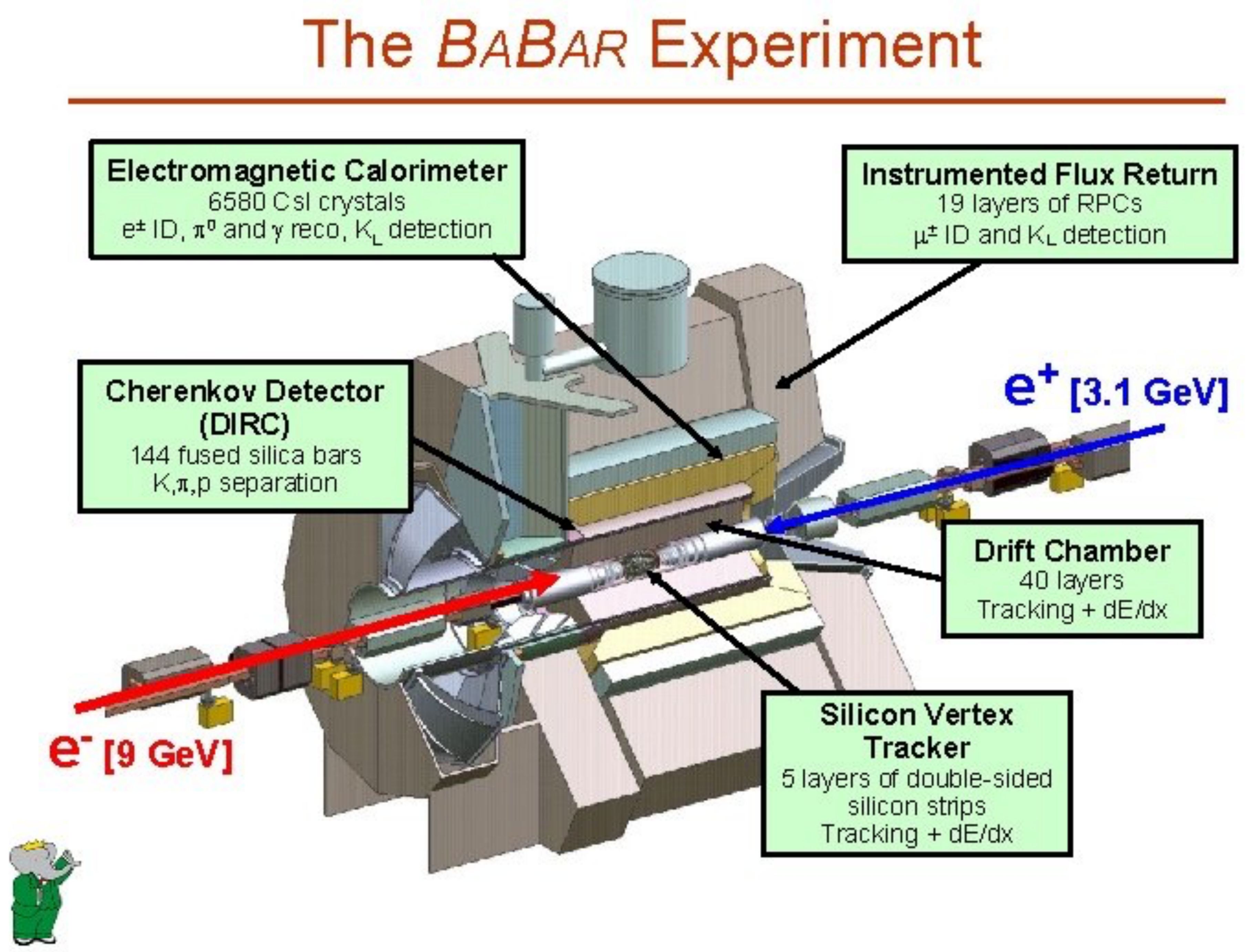
Tau channels

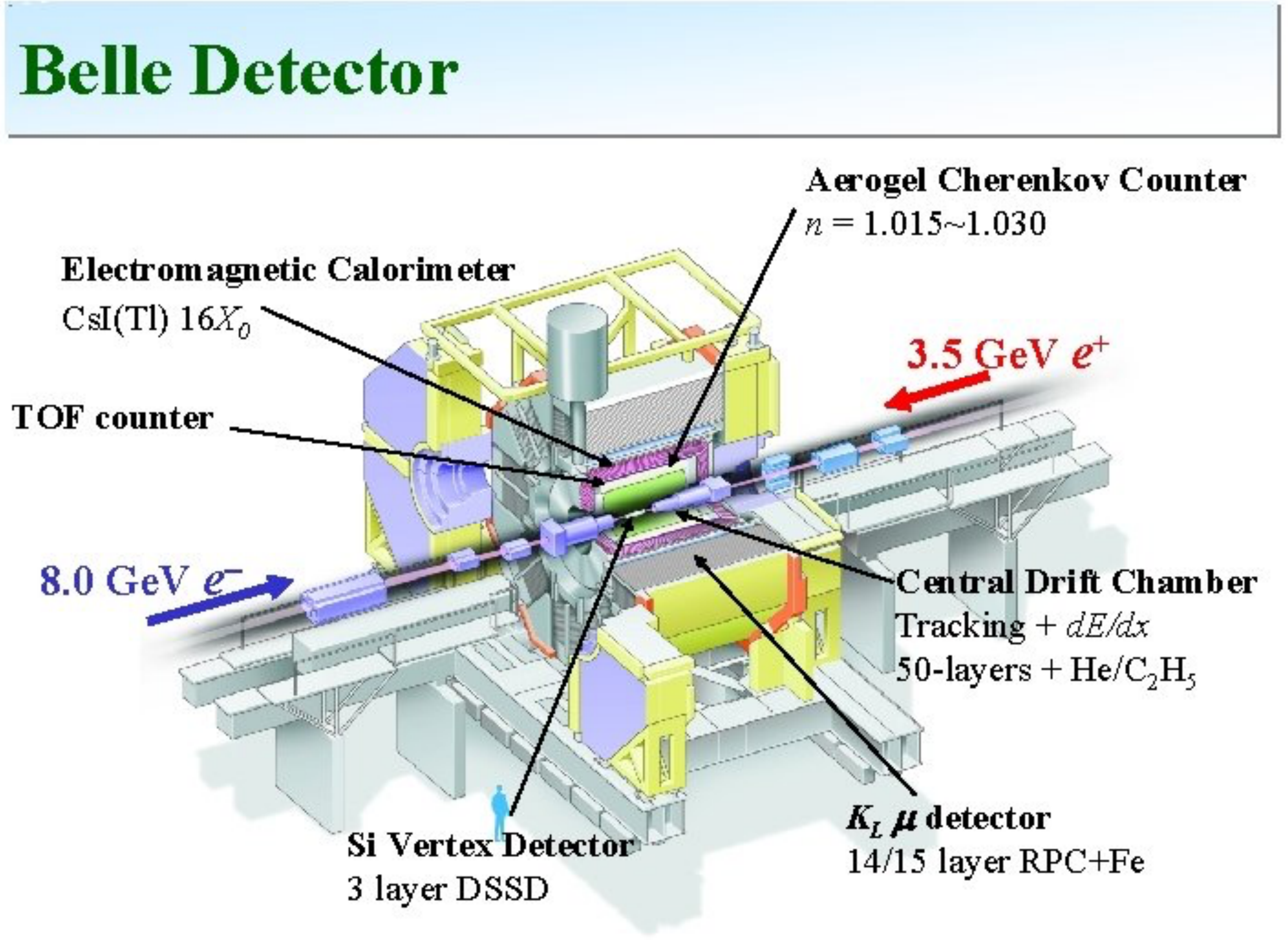
- The tau lepton is in principle a very promising source of CLFV decays. Thanks to the large tau mass ($m_\tau \approx 1.777$ GeV), many CLFV channels can be investigated



$\tau \to l\gamma$

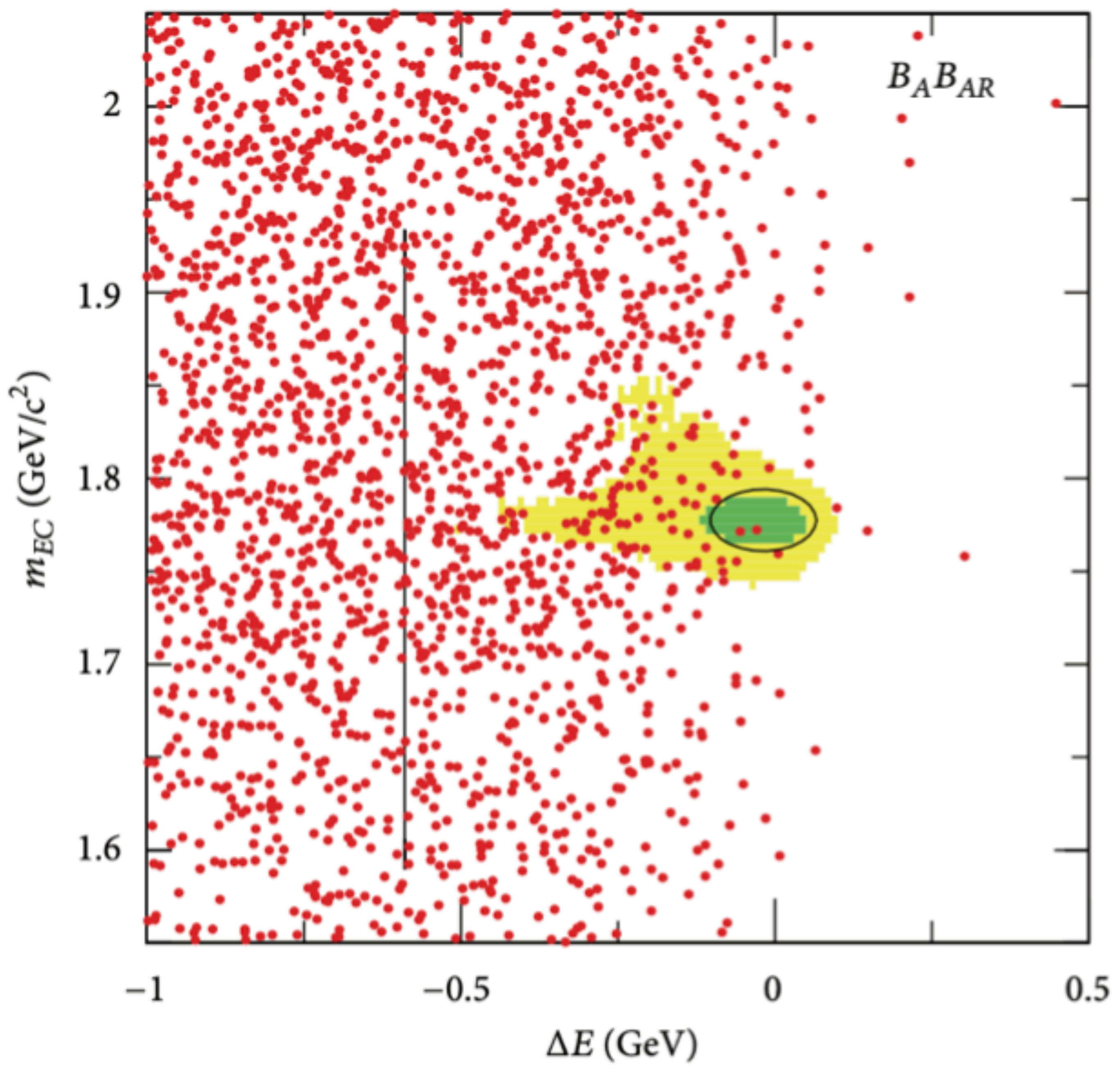
- Final state: pair of light lepton and a photon, with minv = tau_mass
- Searches implemented at B-factories: Belle and BaBar
- Main background: $e^+e^- \to e^+e^-\gamma$, $e^+e^- \to \mu^+\mu^-\gamma$, tau mis-identification

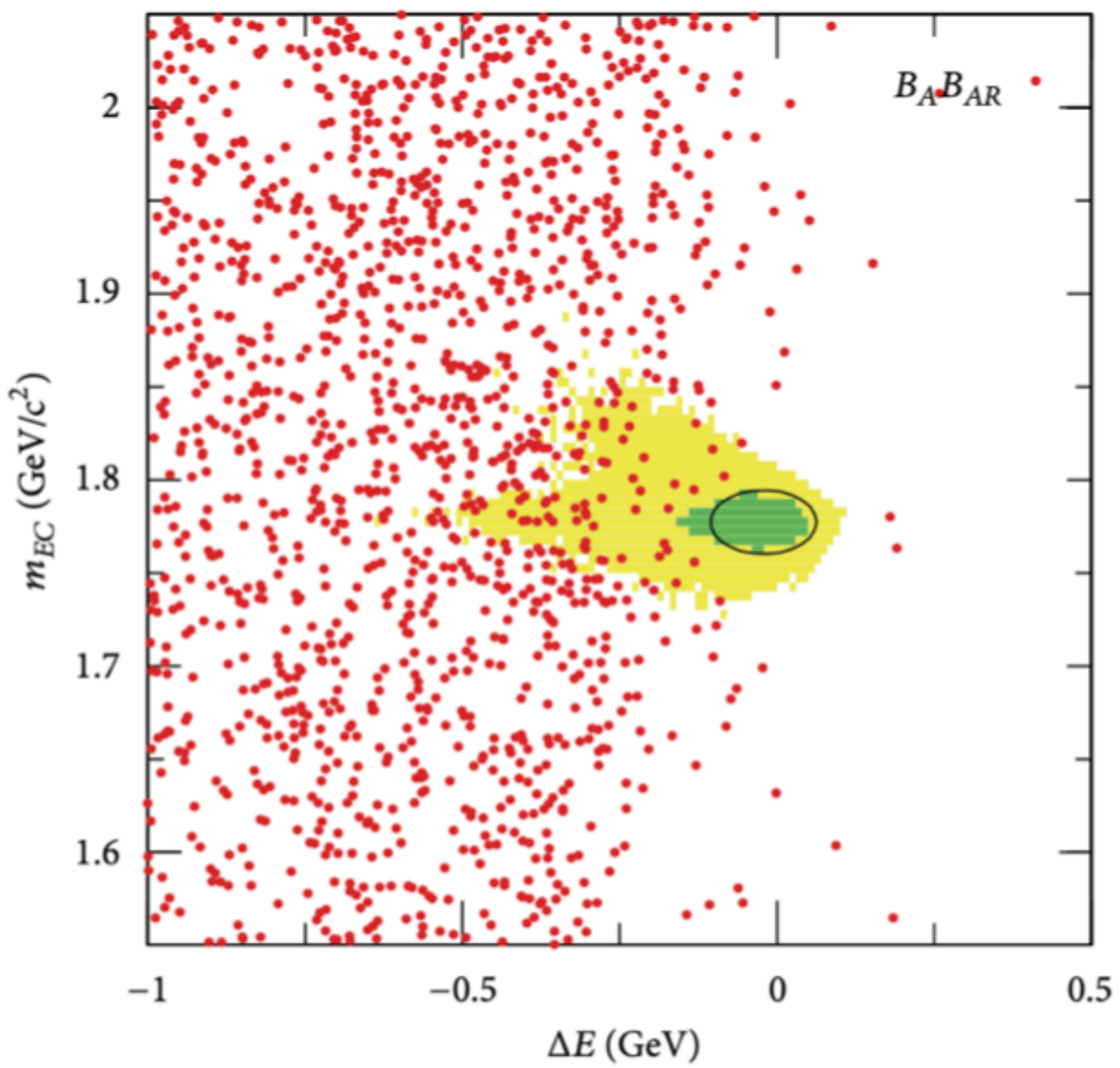




$\tau \to l\gamma$ @ BaBar

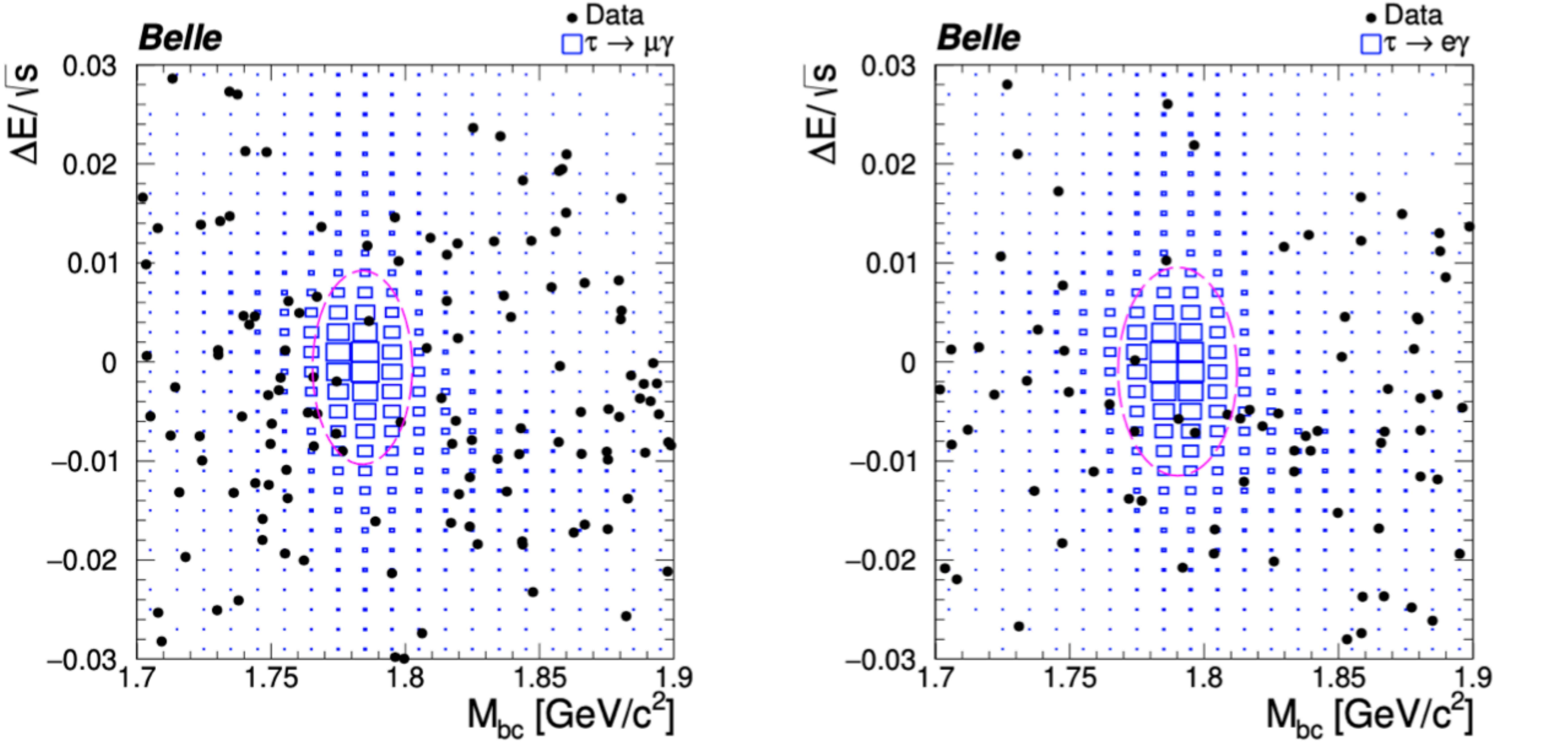
- BaBar collected $(963 \pm 7) \times 10^6 \tau$ decays near the Υ(4S), Υ(3S) and Υ(2S) resonances
- Signal decays are identified by two kinematic vars: (i) the energy difference $\Delta E = E - \sqrt{s}/2$ and the beam energy constrained τ mass obtained from a kinematic fit
- **Limits**: $3.3(4.4)\times10^{-8}$ for the electron (muon) channel





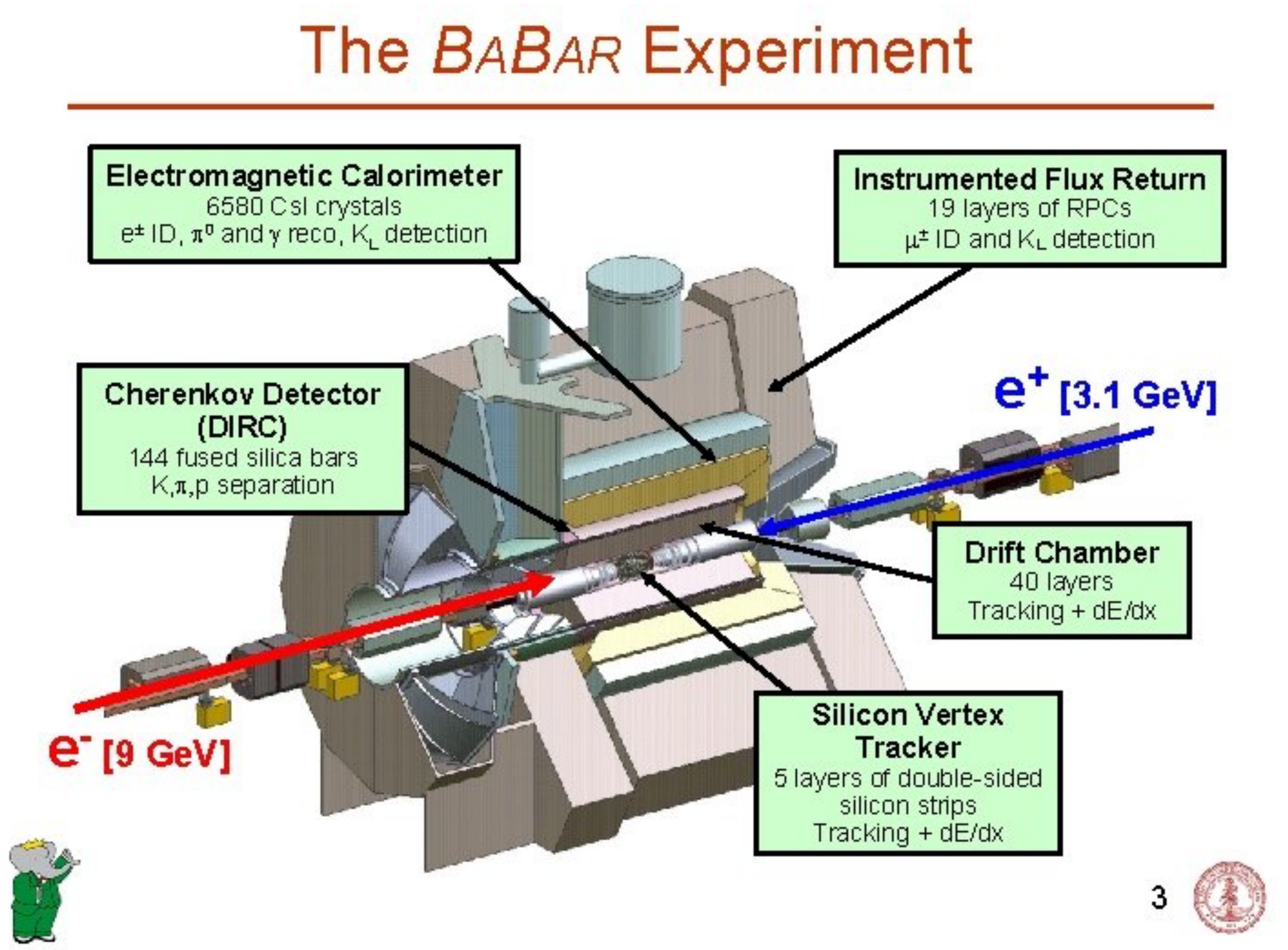
$\tau \to l\gamma$ @ Belle

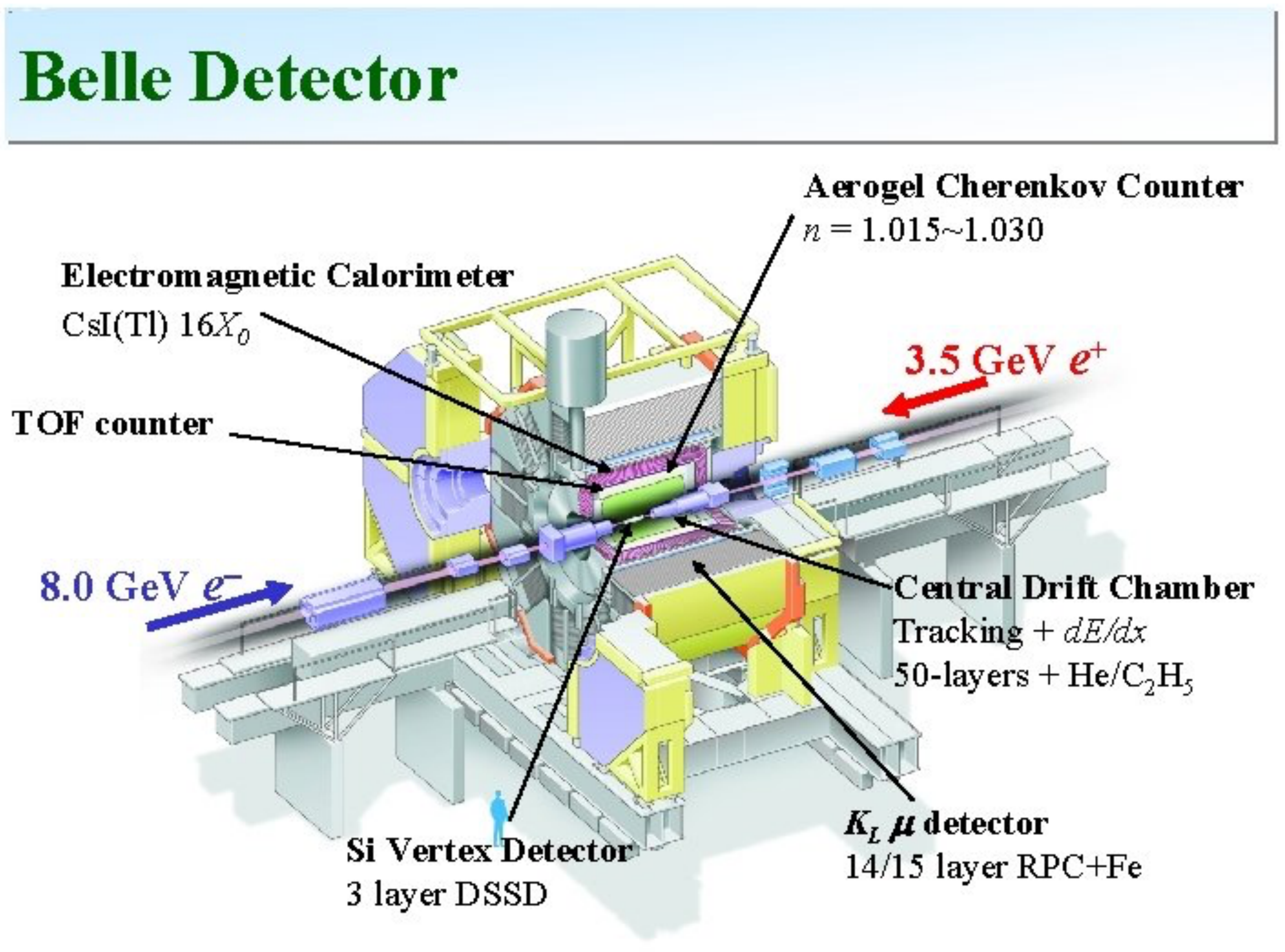
- The Belle experiment reported comparable limits using a data analysis based on 988 fb−1
- **Limits**: 5.6(4.2)x10^{-8} for the electron (muon) channel



$\tau \to 3l$

- Final state: three charged leptons with minv = tau_mass and sum_charge = 1
- Searches implemented at B-factories: Belle and BaBar in all the 6 combinations
- Events are selected looking for τ+τ− pairs in the final state (one tau i used as tag)





$\tau \rightarrow 3l$

- The polar angles of all four tracks in the laboratory frame are required to be within the calorimeter acceptance range, to ensure good particle identification
- The search strategy consists of forming all possible triplets of charged leptons with the required total charge and of looking at the distribution of events in the (mBC , ΔE) plane
- The backgrounds contaminating the sample can be divided in three broad categories:
  - low multiplicity $q\bar{q}$ events,
  - QED events (Bhabha or $\mu^+\mu^-$ depending on the specific channel)
  - SM $\tau^+\tau^-$ events
- Limits: at the level of $\sim 10^{-8}$

$\tau \to 3l$ @ LHC

- Experiments at the LHC also searched for the $\tau \to 3l$ decay in the case where l = μ
- The ATLAS experiment performed a search for the neutrinoless decay $\tau^- \to \mu^+\mu^-\mu^-$ using a sample of $W^- \to \tau^-\bar{\nu}\tau$ decays with 20.3 fb−1 collected in 2012 @ 8 TeV
- The LHCb experiment performed the same search using a sample of tau from b and c-hadron decays with 3.0 fb−1 collected in 2011(2) @ of 7(8) TeV
- The CMS experiment recently delivered the results for the same search using a sample of τ leptons produced in both W boson and heavy-flavor hadron decays using 33.2fb−1
- ATLAS, CMS and LHCb reported a 90% C.L. upper limit on the branching ratio of 3.76×10^{-7}, 8.0×10^{-7} and 4.6×10^{-7} respectively

Higgs searches

Constrains on Higgs

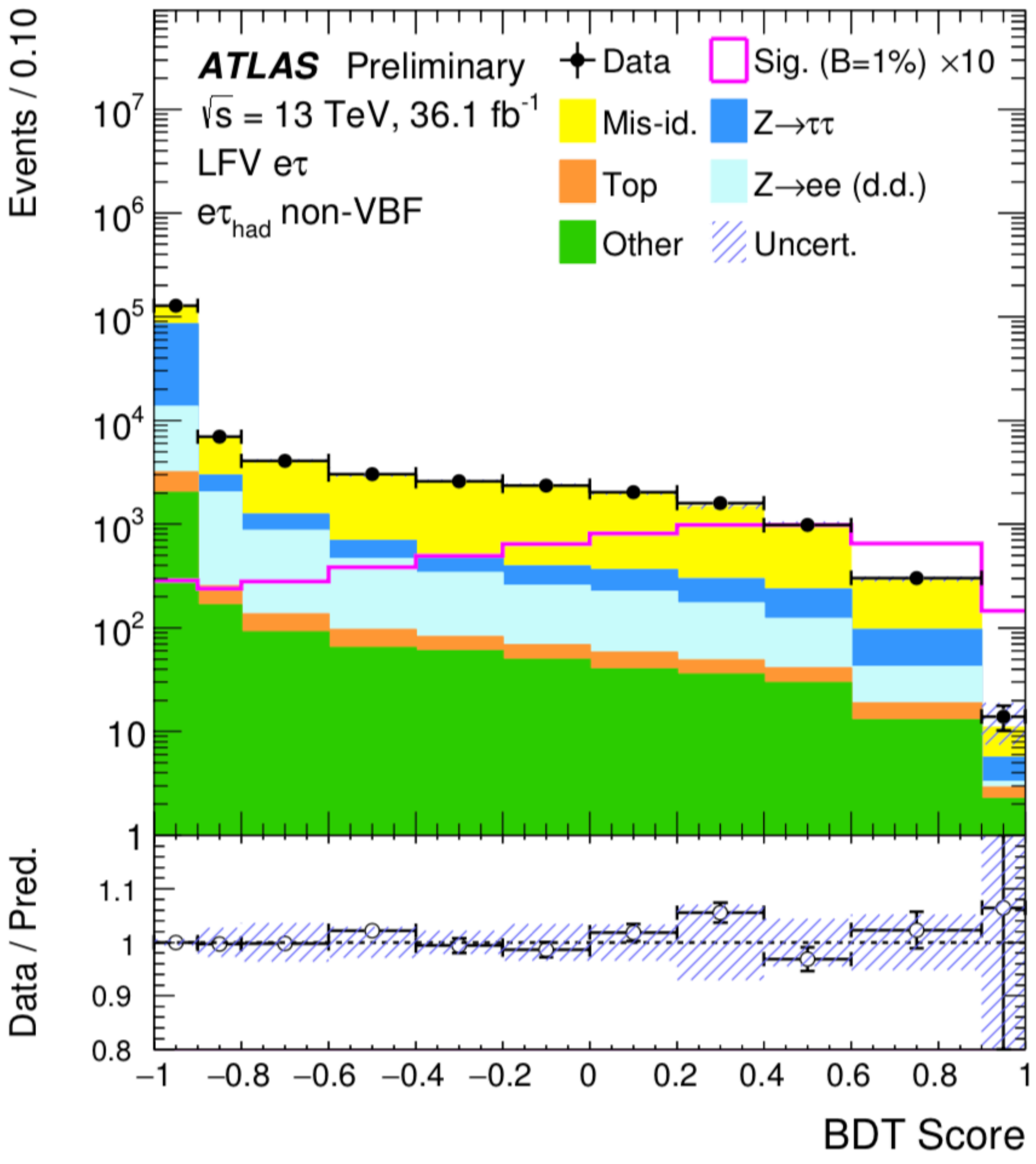
- **Muons** provide strong limits on LFV Higgs decays for 1st and 2nd generations
- **But not if tau involved:** 1st-3rd or 2nd-3rd

$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & Y_{\tau\tau} \end{pmatrix}$$

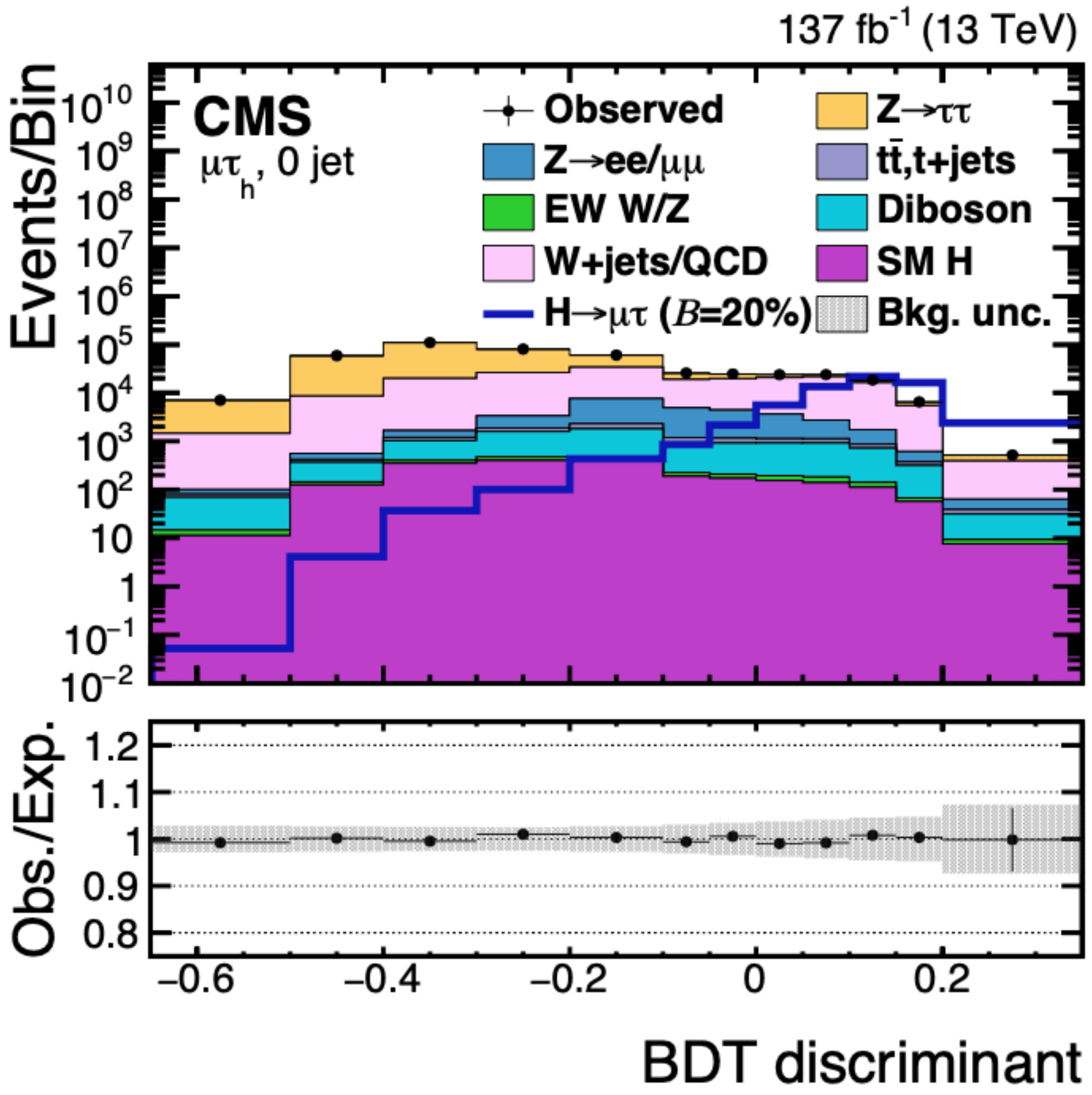
Hiroshi Okada, et al: arxiv.org/pdf/1604.01948.pdf

CLFV at CMS & ATLAS

- Similar final states as in $H \to \tau\tau$: search for $H \to e\tau$ and $H \to \mu\tau$
- 95% C.L. limits from likelihood fit are $Br(H \to e\tau) < 0.47\%$ and $Br(H \to \mu\tau) < 0.25\%$



ATLAS_CONF Note 2019 013

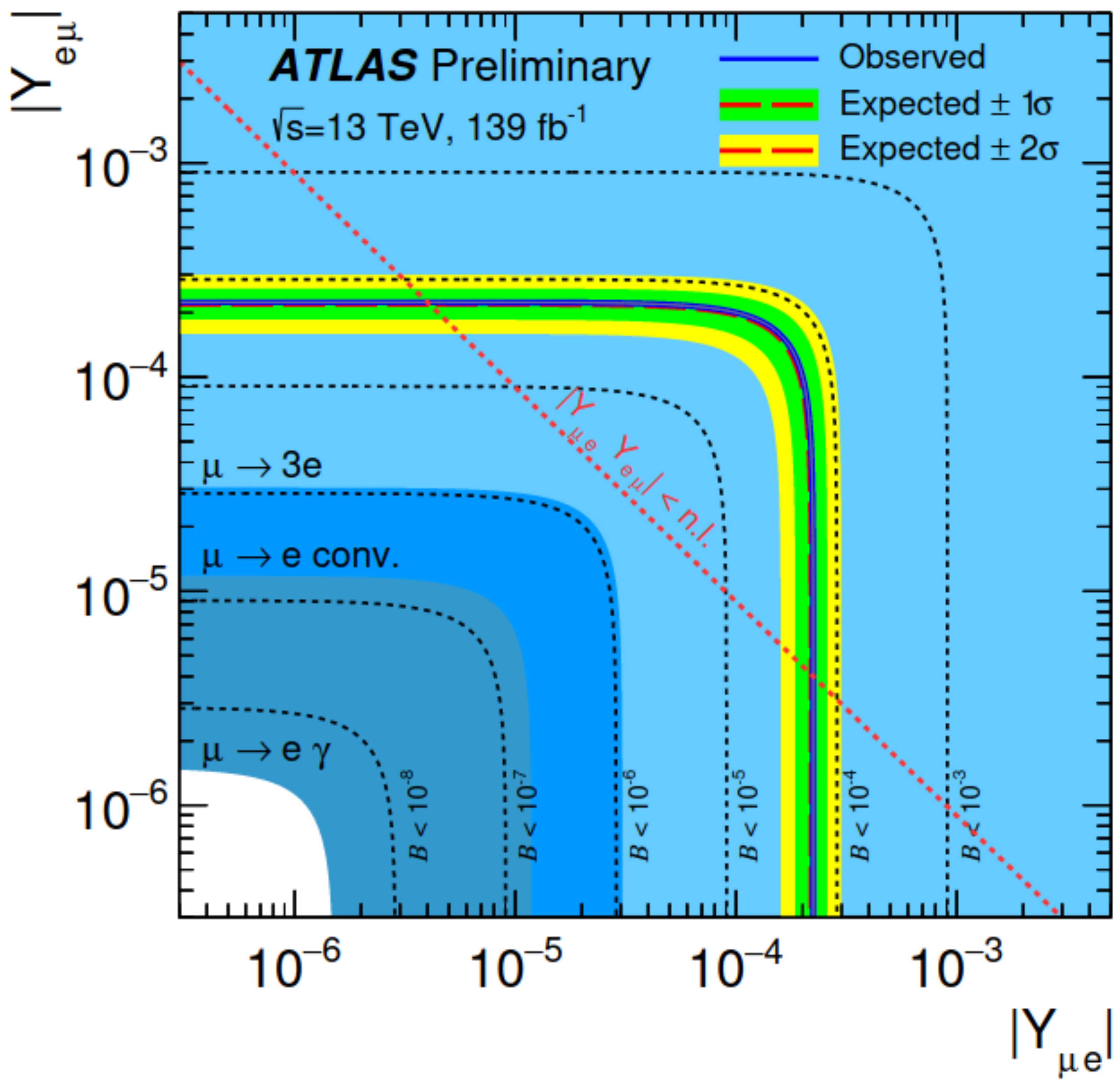


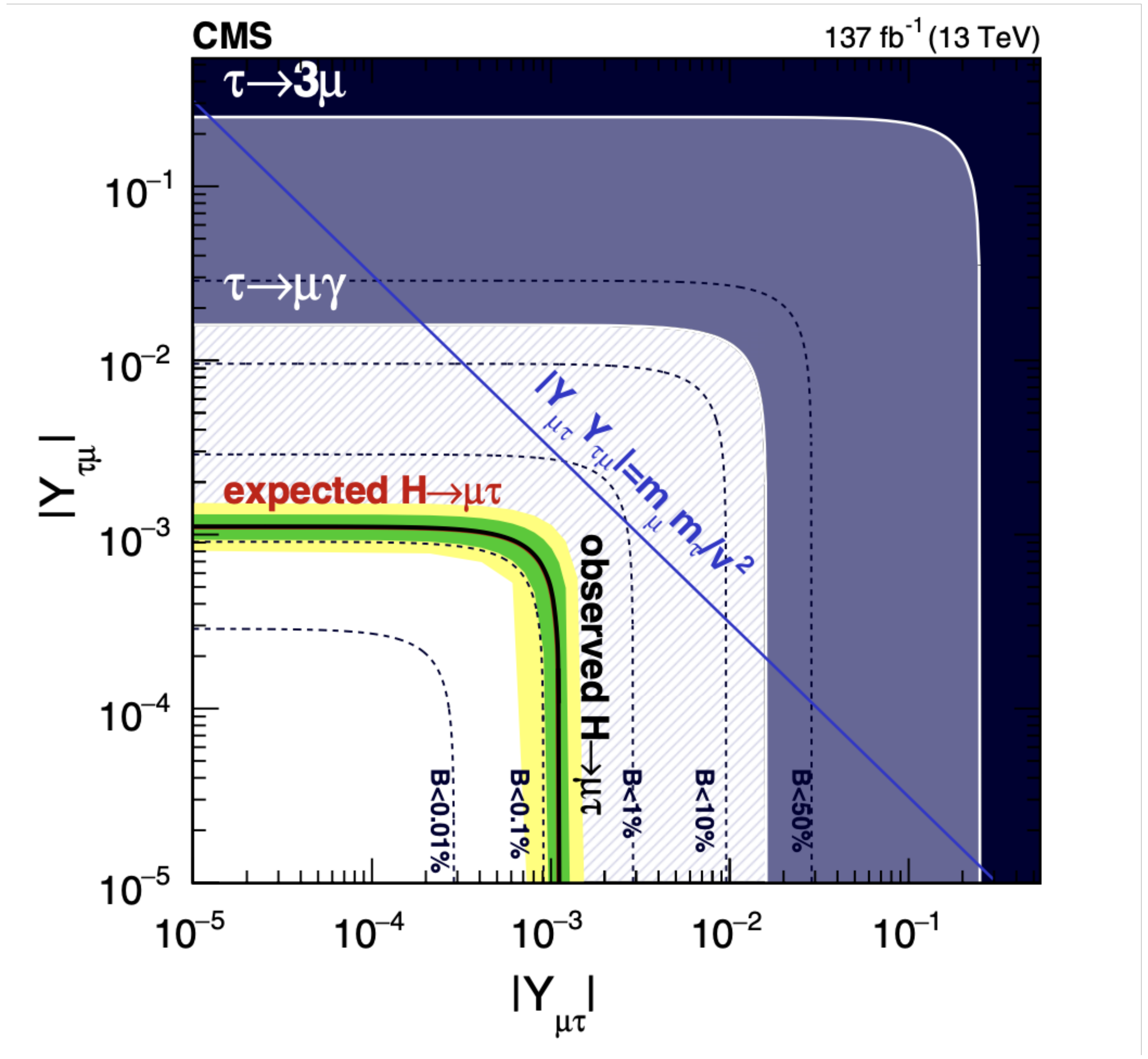
CMS, Sirunyan, A.M., Tumasyan, A. et al. J. High Energ. Phys. (2018) 2018: 1.

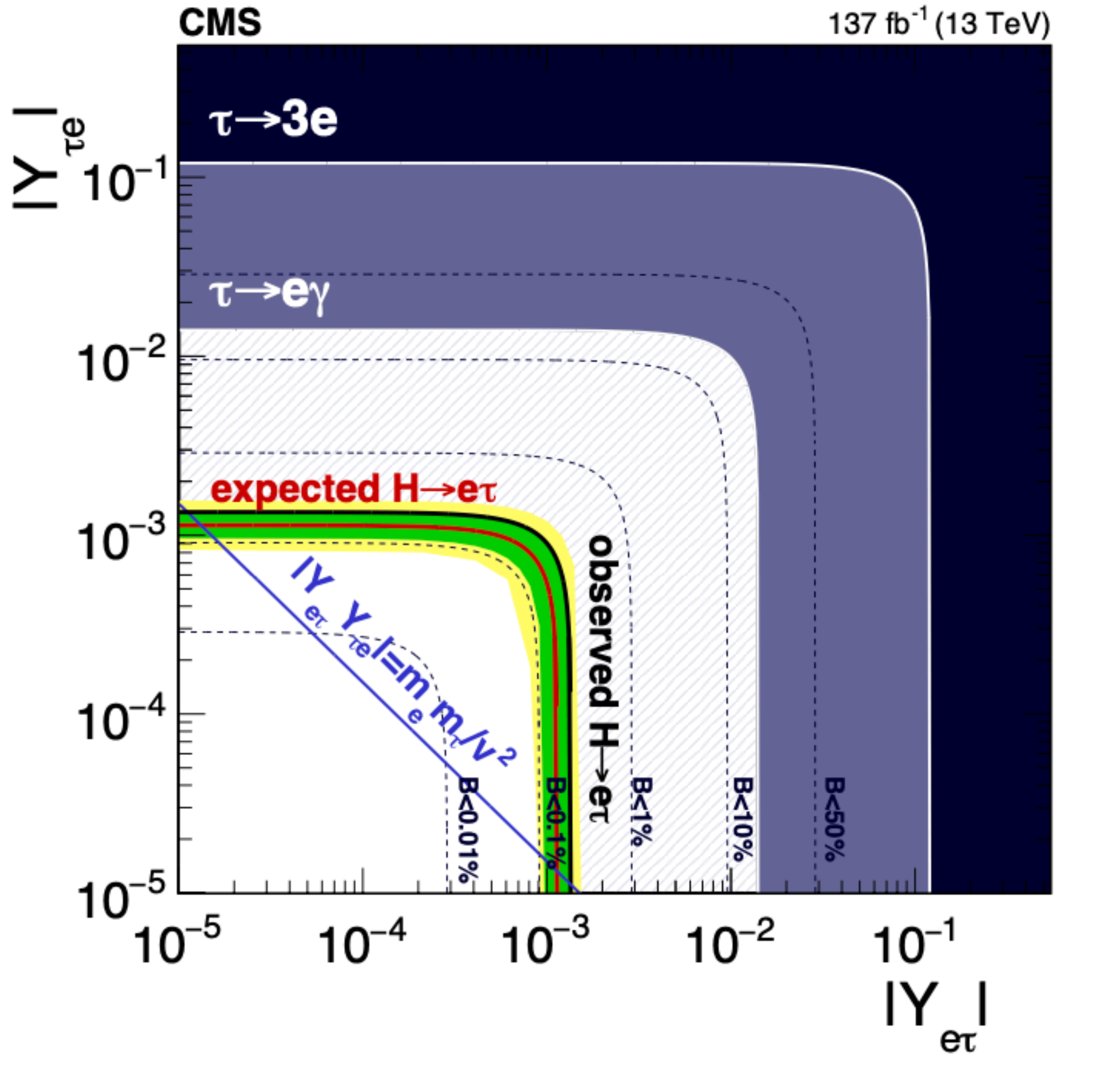
Intense

LHC/Direct searches

LUX ET VERITAS







- $H \to \mu e$ < 6.1 x 10-5 @ 95% C.L. (ATLAS)
- $H \to e\tau$ < (0.22)% @ 95% C.L. (CMS)
- $H \to \mu\tau$ < (0.15)% @ 95% C.L. (CMS)

Summary

- A short review of non-muonic LFV searches was given
- Tau rare decays and Higgs decays offer powerful tool to search for LFV processes
- The upgrade of the B-factories will enable an improvement in the tau->3 l search
  - LHC experiments are getting competitive in the pure muonic final state
- The Higgs portal provide powerful proves for LFV search in the (l, tau) final states