INFN ROMA TRE
Istituto Nazionale di Fisica Nucleare
Sezione di Roma Tre

ROMA TRE
UNIVERSITÀ DEGLI STUDI

LFV searches at Belle II: $\tau \to 3\mu$ analysis expectations

On behalf of the Belle II collaboration

Alberto Martini
University & INFN Roma Tre

58th International Winter Meeting on Nuclear Physics — 24 January 2020, Bormio, Italy

Belle II

OUTLINE

- Introduction to Belle II
- LFV motivations in $\boldsymbol{\tau}$ sector
- $\tau \to 3\mu$ analysis strategy
- Expected results @ Belle II

The Belle II experiment

Main experiments at B-factories of the past:

- Belle (KEK Laboratory, Japan)
- BaBar (SLAC Laboratory, California)

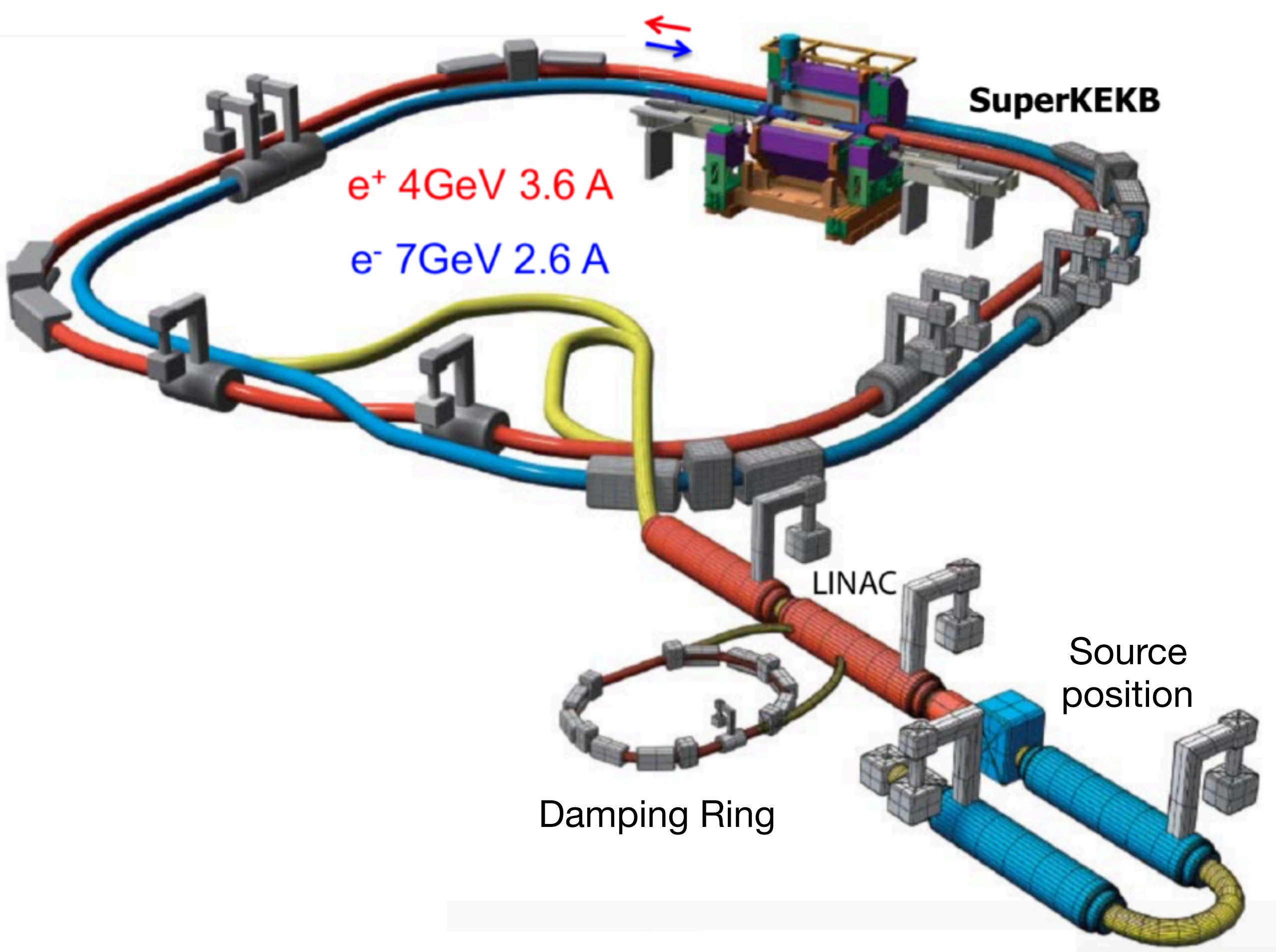
→ Important results: confirmation of the CKM mechanism in the SM, CP violation observation in the B meson system etc..

The Belle II experiment

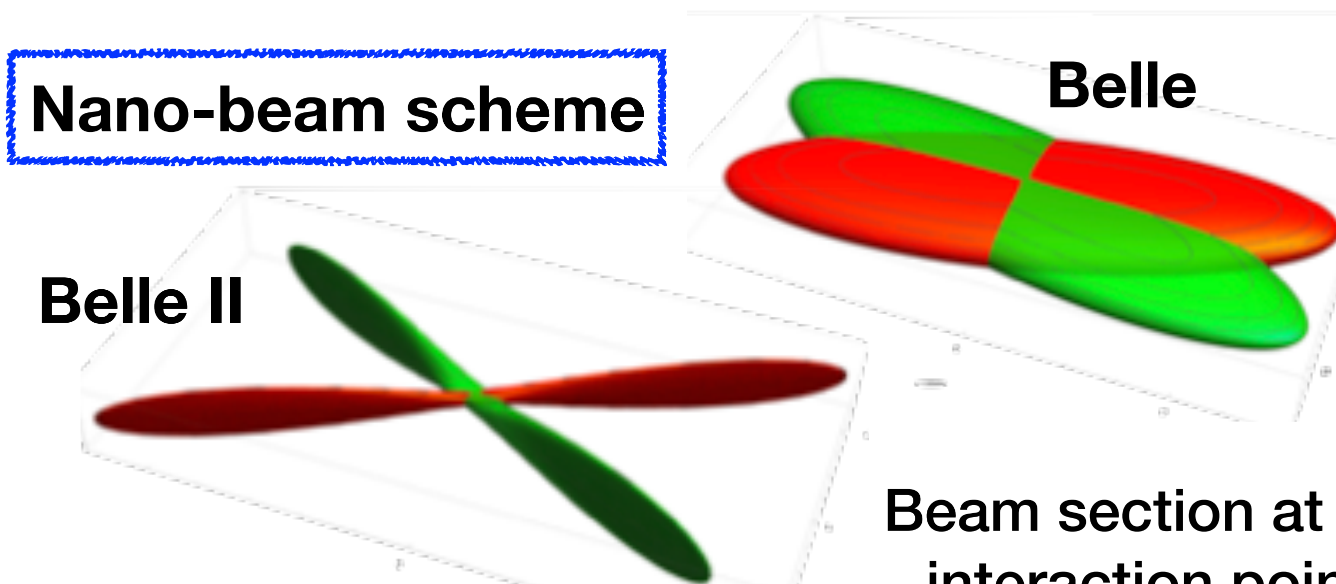
Main experiments at B-factories of the past:

- Belle (KEK Laboratory, Japan)
- BaBar (SLAC Laboratory, California)

→ Important results: confirmation of the CKM mechanism in the SM, CP violation observation in the B meson system etc..



Nano-beam scheme



Beam section at the interaction point:
~42 nm in y
~6 µm in x

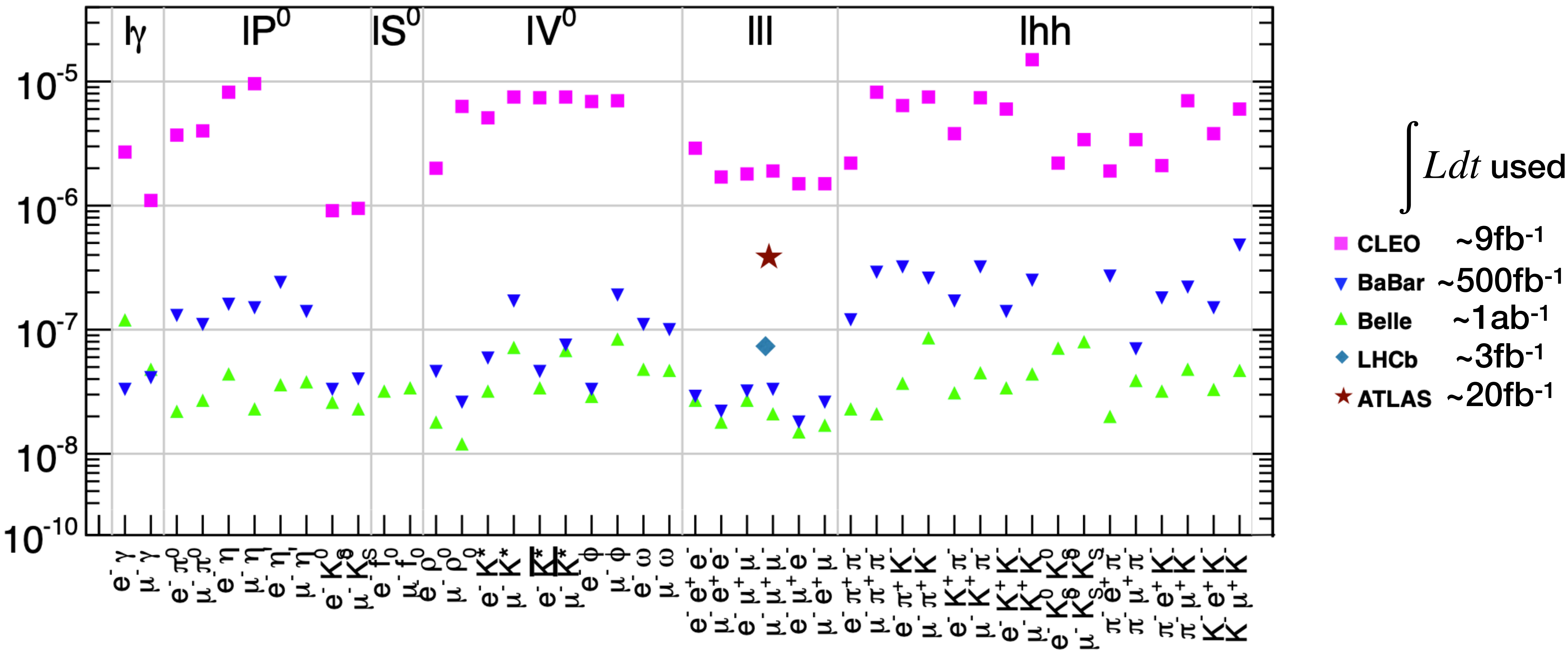
Expected improvement of integrated luminosity of a factor ~50 w.r.t. Belle: **50 ab^{-1}**

LFV motivations in τ sector

Status of the τ LFV

Lepton Flavor Violation (LFV) are allowed in various extensions of the Standard Model (SM) but it has never been observed

Many τ channels studies have been done at the B-factories



Belle II advantages

Analysis involving τ are challenging for most of the experiments for different reasons:

- **missing energy → difficult to reconstruct**
- pions in the final state → **lot of background** sources from qcd

Belle II has several advantages to exploit

- Initial state energy is well defined (B-factory feature) → good measurement of missing momentum
- τ produced in pairs → backgrounds reduction
- Clean environment → background free wrt hadron machines
- High hermeticity of the detector → advantages in studies with missing energies

CM Energy $\simeq$ 10.58 GeV

Belle II

τ LFV searches

Search various decay modes:

- $\tau \to \ell\ell\ell$
- $\tau \to \ell K_s, \Lambda h$
- $\tau \to \ell V_0(\to hh')$
- $\tau \to \ell P^0\ (\to \gamma\gamma)$
- $\tau \to \ell hh'$
- $\tau \to \ell\gamma$

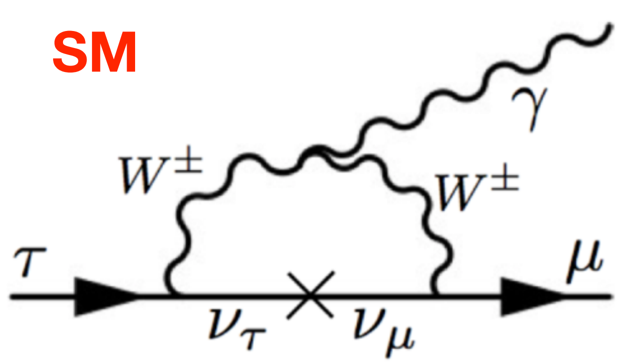
τ LFV searches

Search various decay modes:

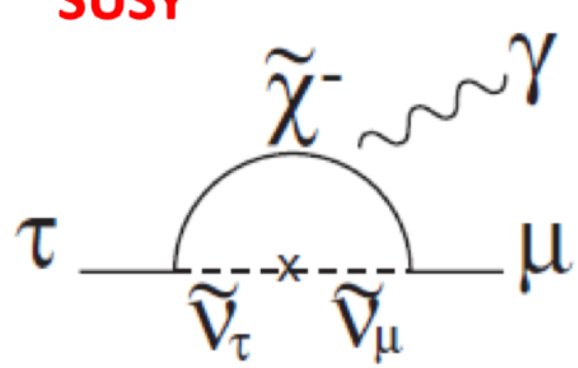
- $\tau \to \ell\ell\ell$
- $\tau \to \ell K_s, \Lambda h$
- $\tau \to \ell V_0(\to hh')$
- $\tau \to \ell P^0\ (\to \gamma\gamma)$
- $\tau \to \ell hh'$
- $\tau \to \ell\gamma$

Golden channel: $\tau \to \mu\gamma$

SM

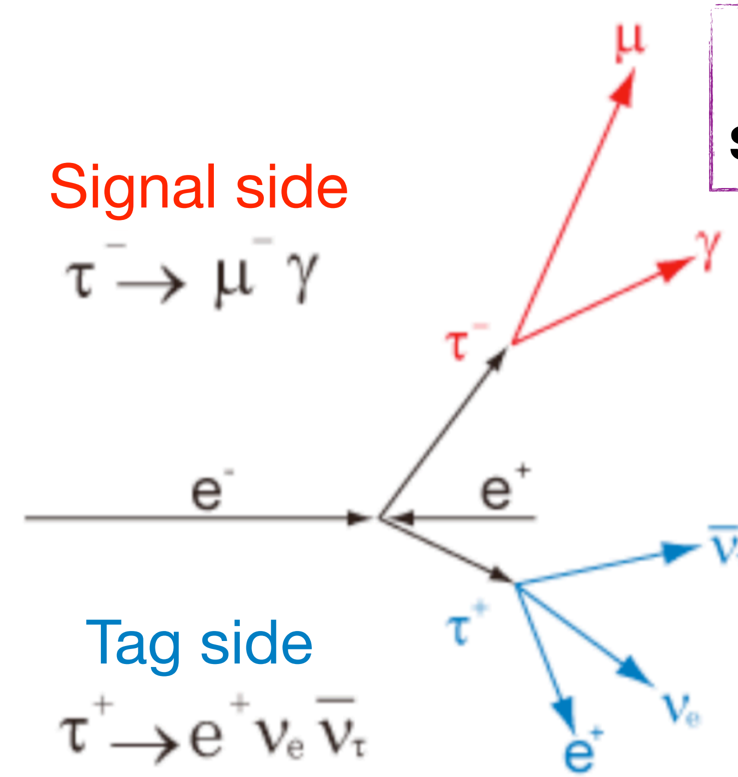


SUSY



Highest not-SM BF prediction

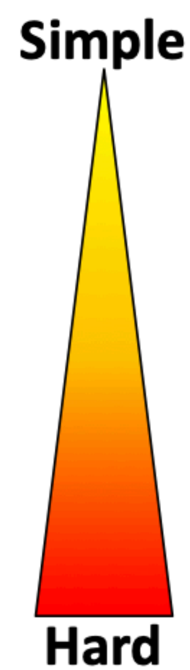
Decay scheme



τ LFV searches

Search various decay modes:

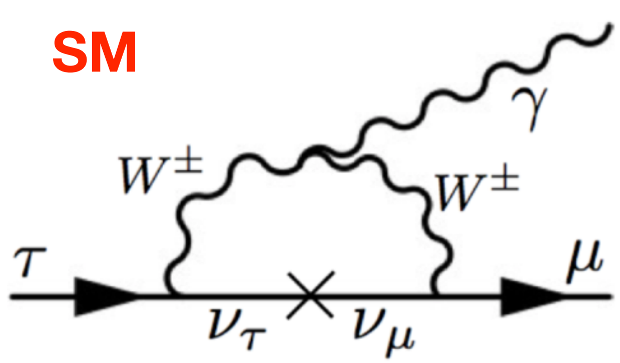
- $\tau \to \ell\ell\ell$
- $\tau \to \ell K_s, \Lambda h$
- $\tau \to \ell V_0(\to hh')$
- $\tau \to \ell P^0\ (\to \gamma\gamma)$
- $\tau \to \ell hh'$
- $\tau \to \ell\gamma$



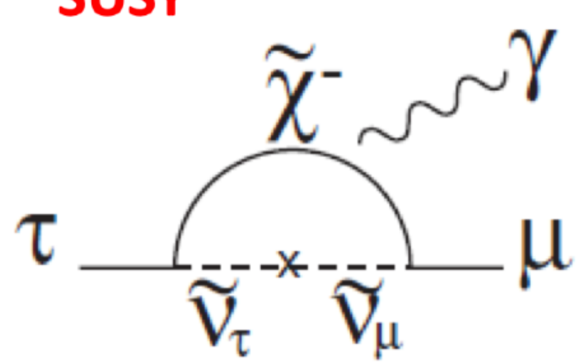
Difficulty of background reduction

Golden channel: $\tau \to \mu\gamma$

SM

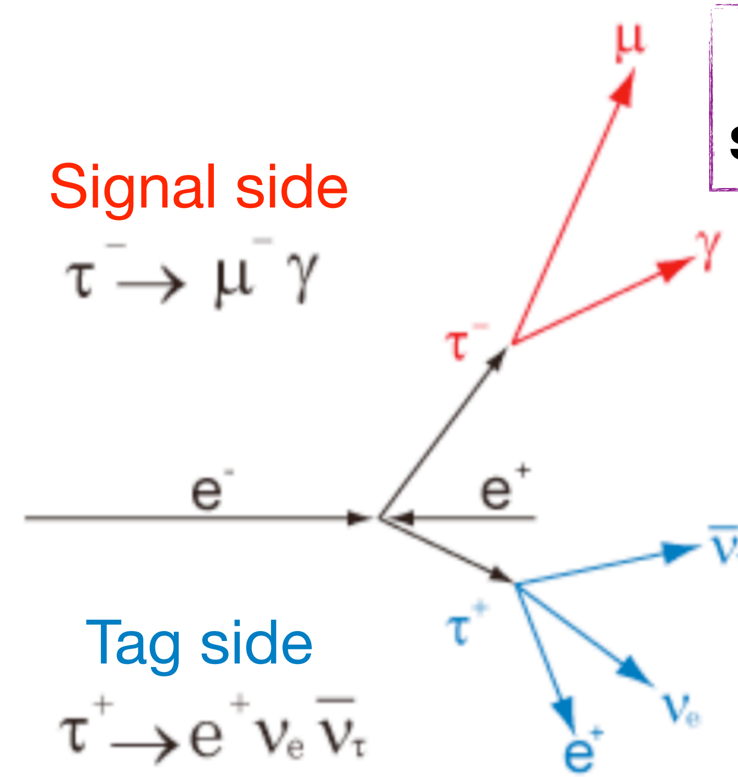


SUSY



Highest not-SM BF prediction

Decay scheme

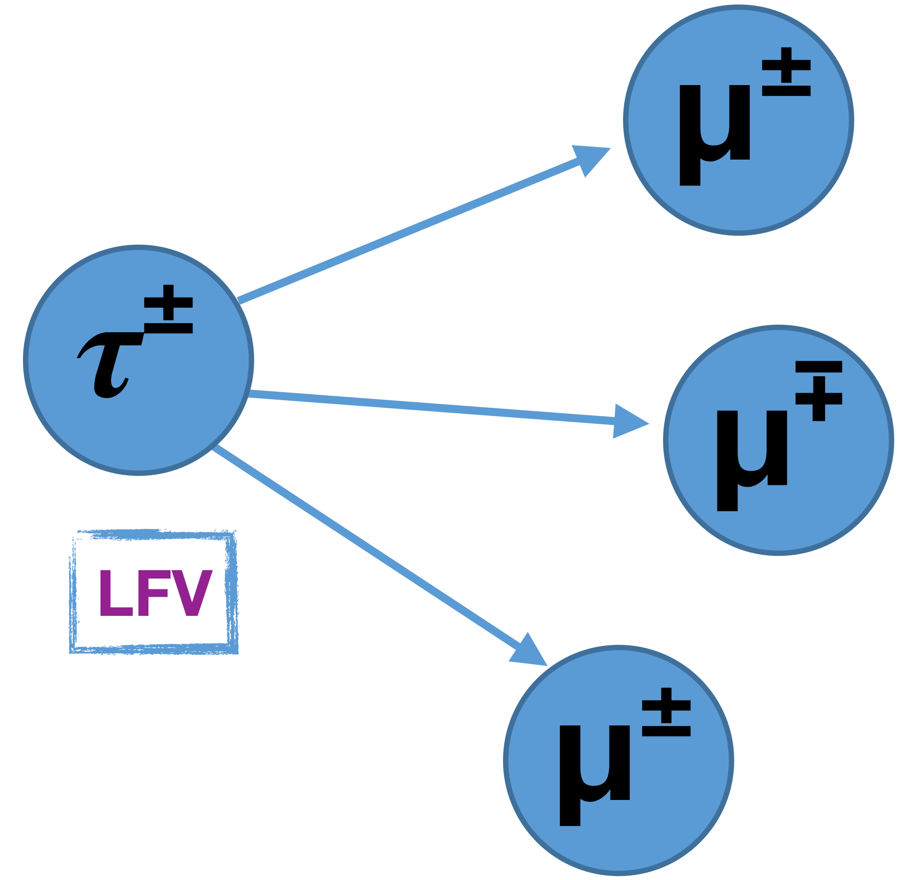


Analysis motivations: $\tau \to 3\mu$

BSM branching fraction predictions within $\sim 10^{-7}$ and $\sim 10^{-10}$

↓

accessible by Belle II

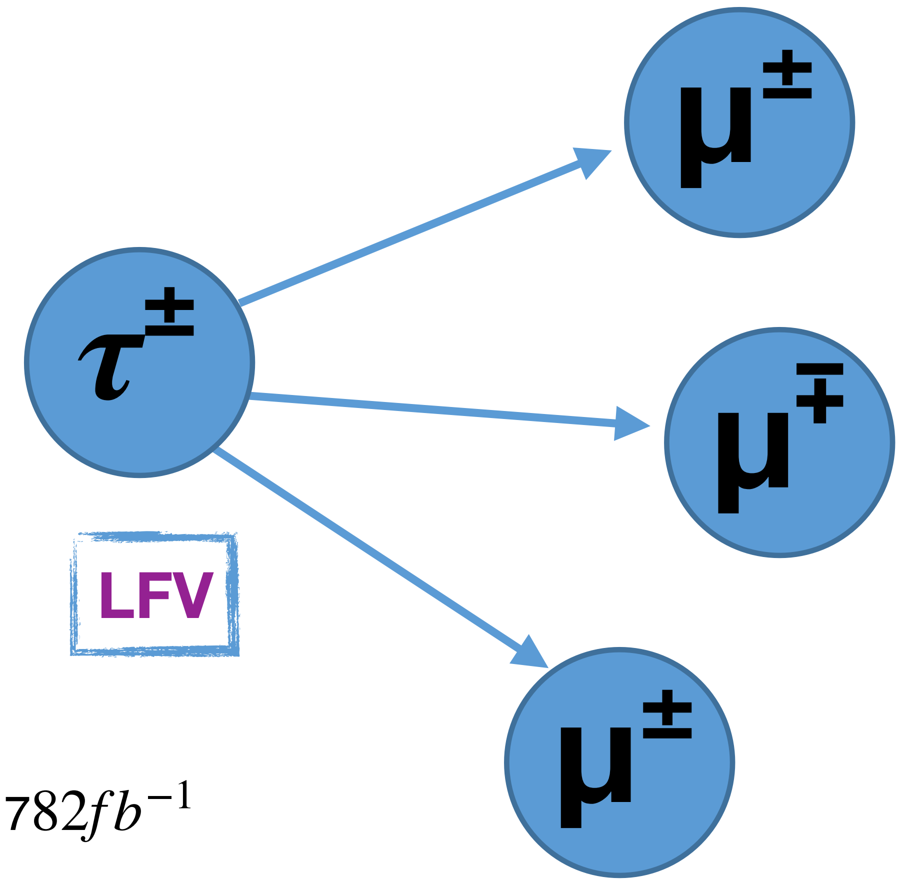


Analysis motivations: $\tau \to 3\mu$

BSM branching fraction predictions within $\sim 10^{-7}$ and $\sim 10^{-10}$

↓

accessible by Belle II



Experimental upper limits from **Belle** and **BaBar**:

- Belle: **2.1 x 10^{-8}** @90% confidence level using $\int L dt = 782 fb^{-1}$
- BaBar: **3.3 x 10^{-8}** @90% confidence level using $\int L dt = 468 fb^{-1}$

…improved limits would further constrain the phase space of parameters of the models.

An observation of LFV in τ decays would be a clear signature of NP

Belle II

LFV new physics models

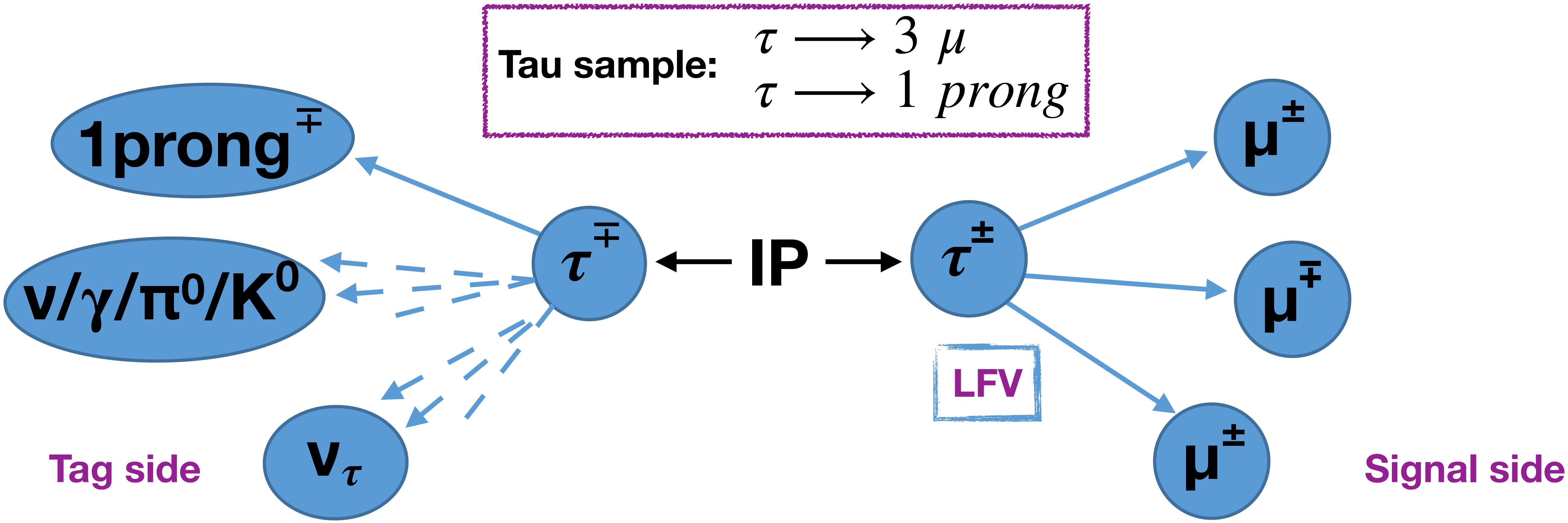
BF limits on τ LFV decays allow to discriminate NP models!

Physics models	$B(\tau \to \mu\gamma)$	$B(\tau \to \mu\mu\mu)$
SM + ν mixing	$10^{-49} \sim 10^{-52}$	$10^{-53} \sim 10^{-56}$ [1]
SM+heavy Majorana ν_R	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY SO(10)	10^{-8}	10^{-10}
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY Higgs	10^{-10}	10^{-7}

Ref.
M. Blanke, et al., Charged Lepton Flavour Violation and (g – 2)μ in the Littlest Higgs Model with T-Parity: a clear Distinction from Supersymmetry, JHEP 0705, 013 (2007).

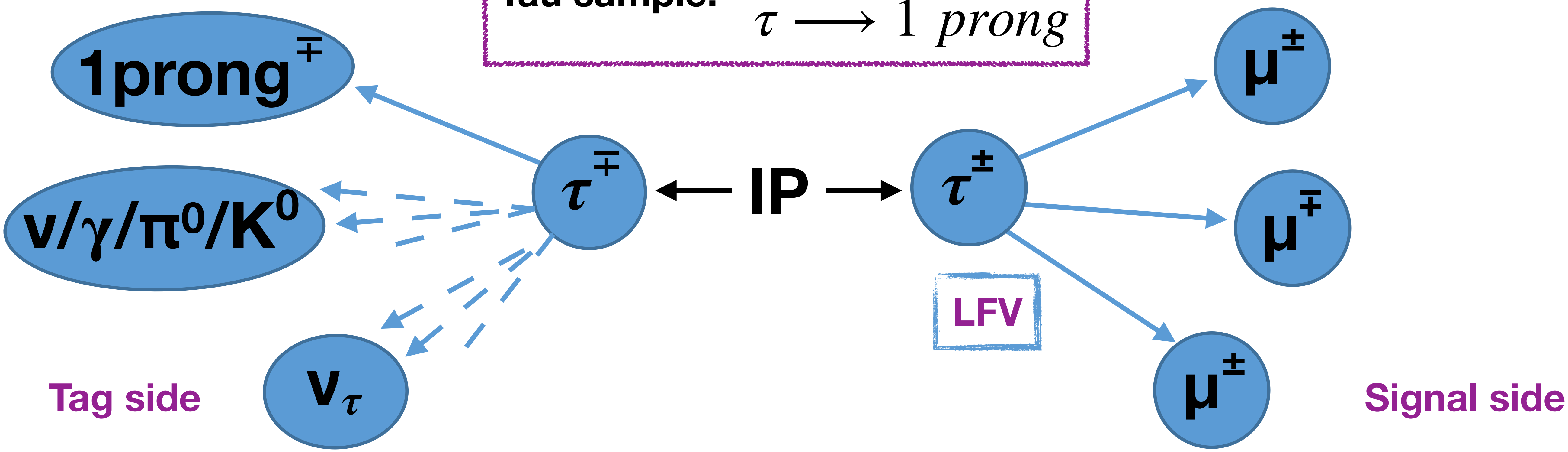
$\tau \rightarrow 3\mu$ analysis strategy

Belle II advantages and decay description



Belle II advantages and decay description

Tau sample:
$$\tau \longrightarrow 3\ \mu$$
$$\tau \longrightarrow 1\ prong$$



Signal side completely reconstructed

↓

good measurement of τ **mass and energy**

Strong signal side signature

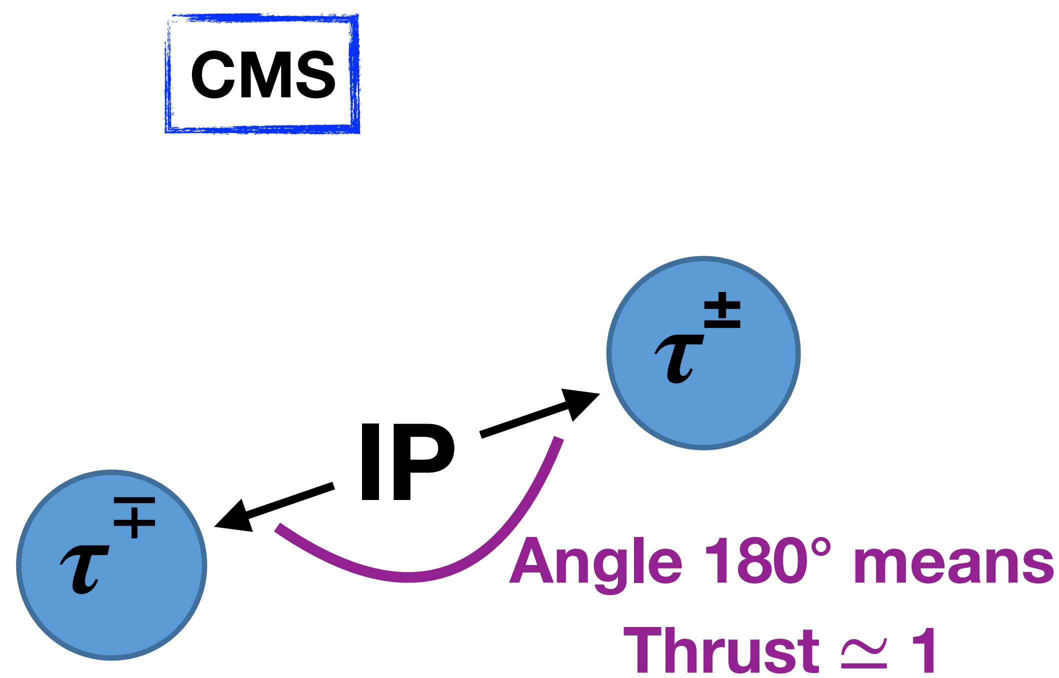
↓

few physical background sources

Signal preselection

Requirement adopted to reconstruct the decay:

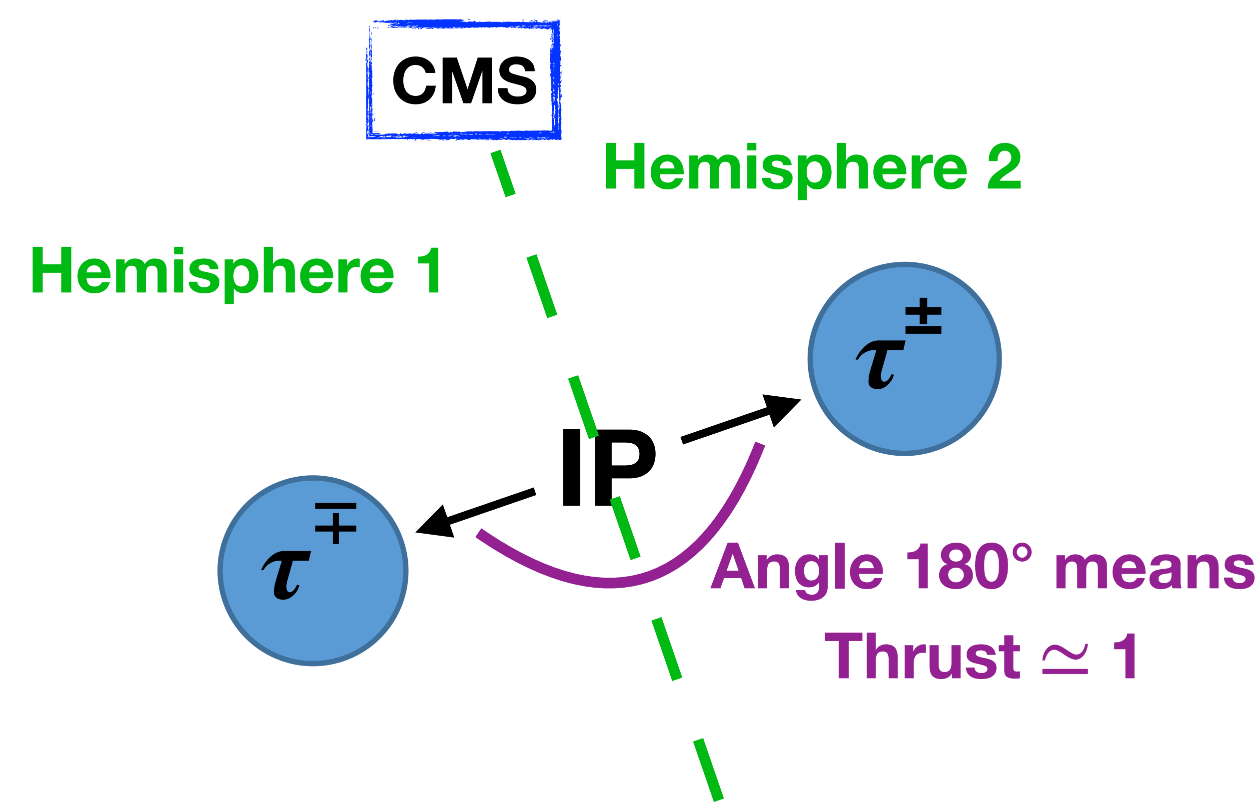
- **thrust**: discriminate between spherical and boosted events;



Signal preselection

Requirement adopted to reconstruct the decay:

- **thrust**: discriminate between spherical and boosted events;
- the two τ point to opposite **hemispheres**;

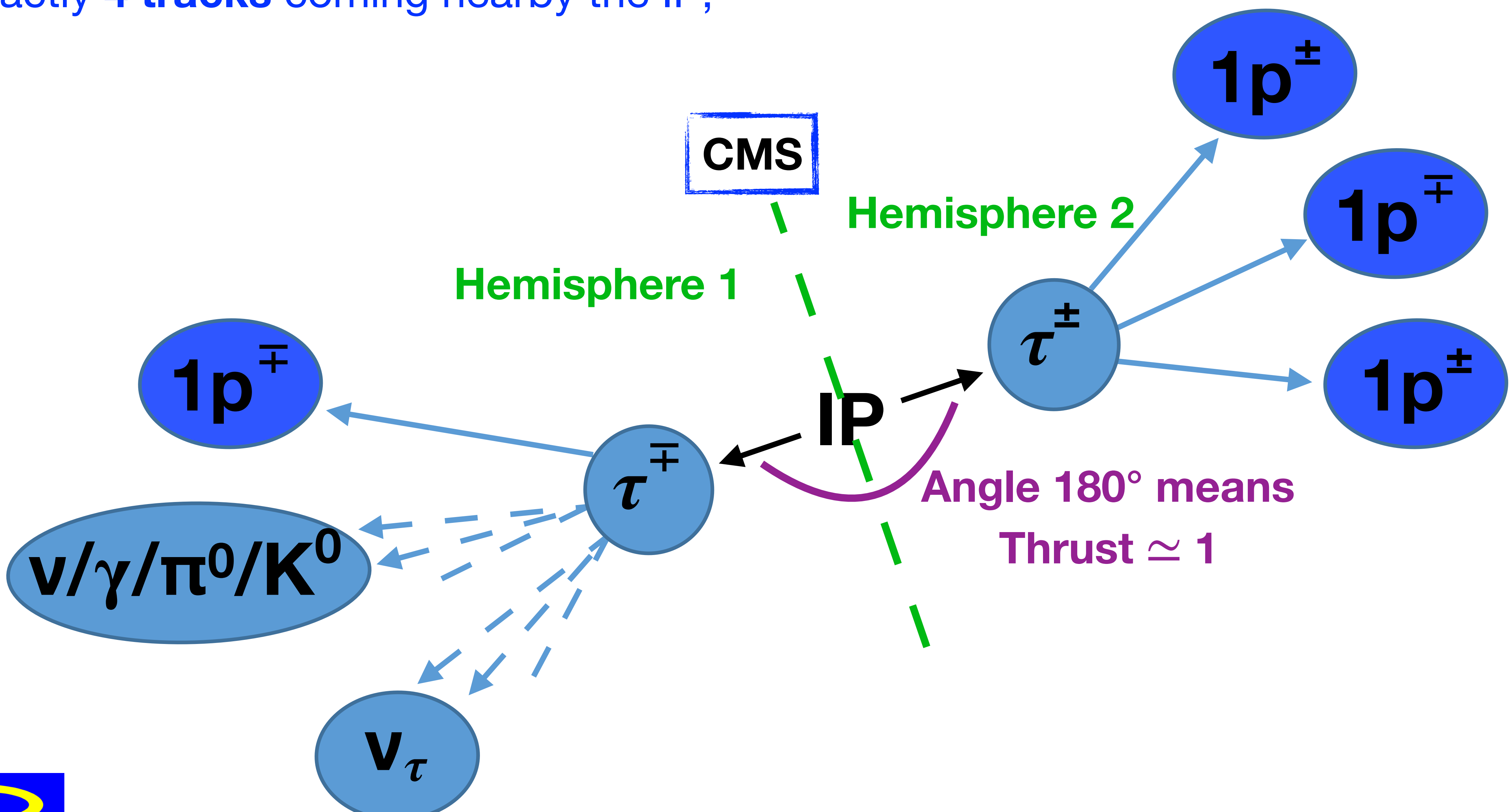


Signal preselection

Requirement adopted to reconstruct the decay:

1p=1prong

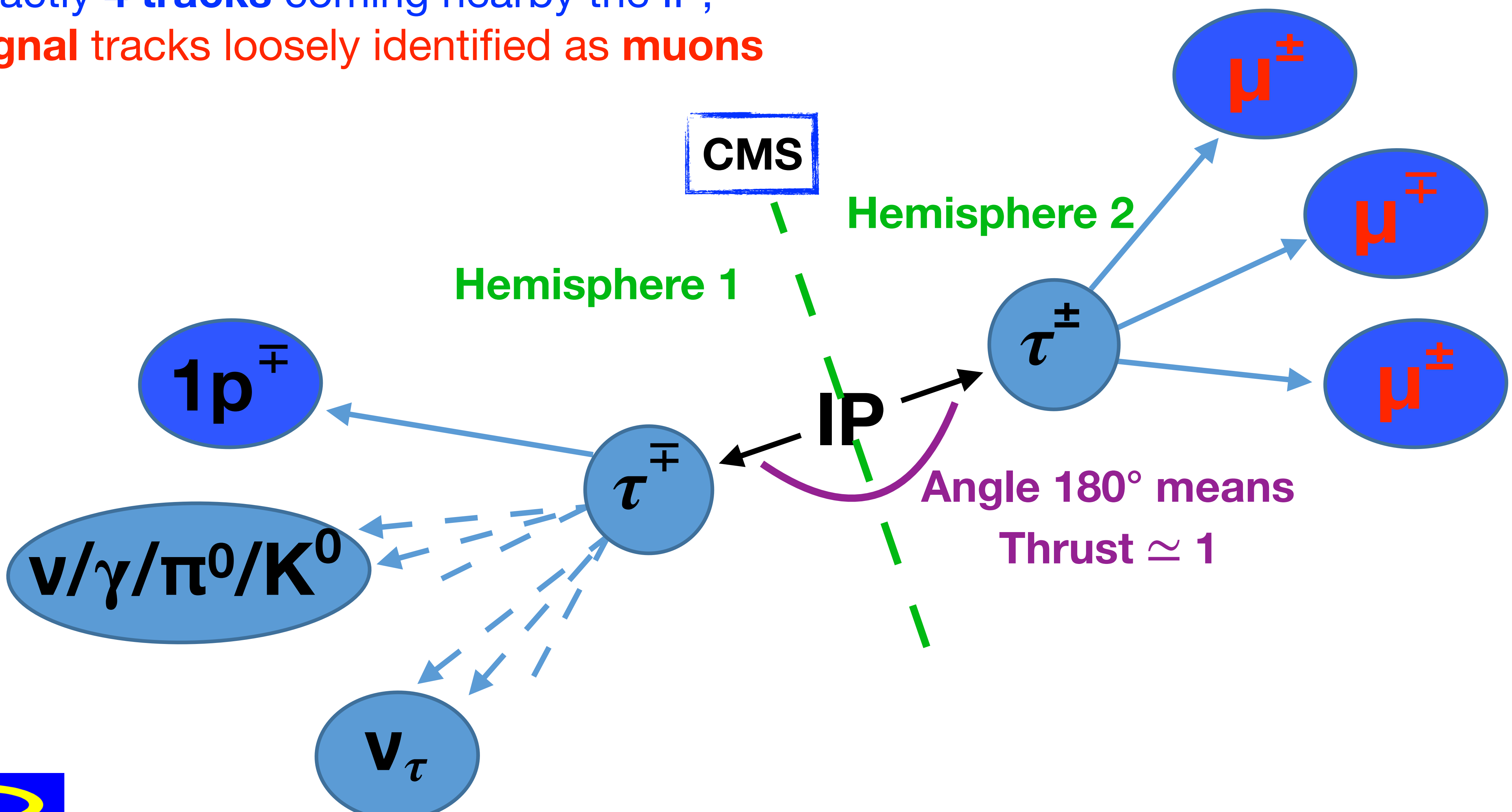
- **thrust**: discriminate between spherical and boosted events;
- the two τ point to opposite **hemispheres**;
- Exactly **4 tracks** coming nearby the IP;



Signal preselection

Requirement adopted to reconstruct the decay:

- **thrust**: discriminate between spherical and boosted events;
- the two τ point to opposite **hemispheres**;
- Exactly **4 tracks** coming nearby the IP;
- **Signal** tracks loosely identified as **muons**



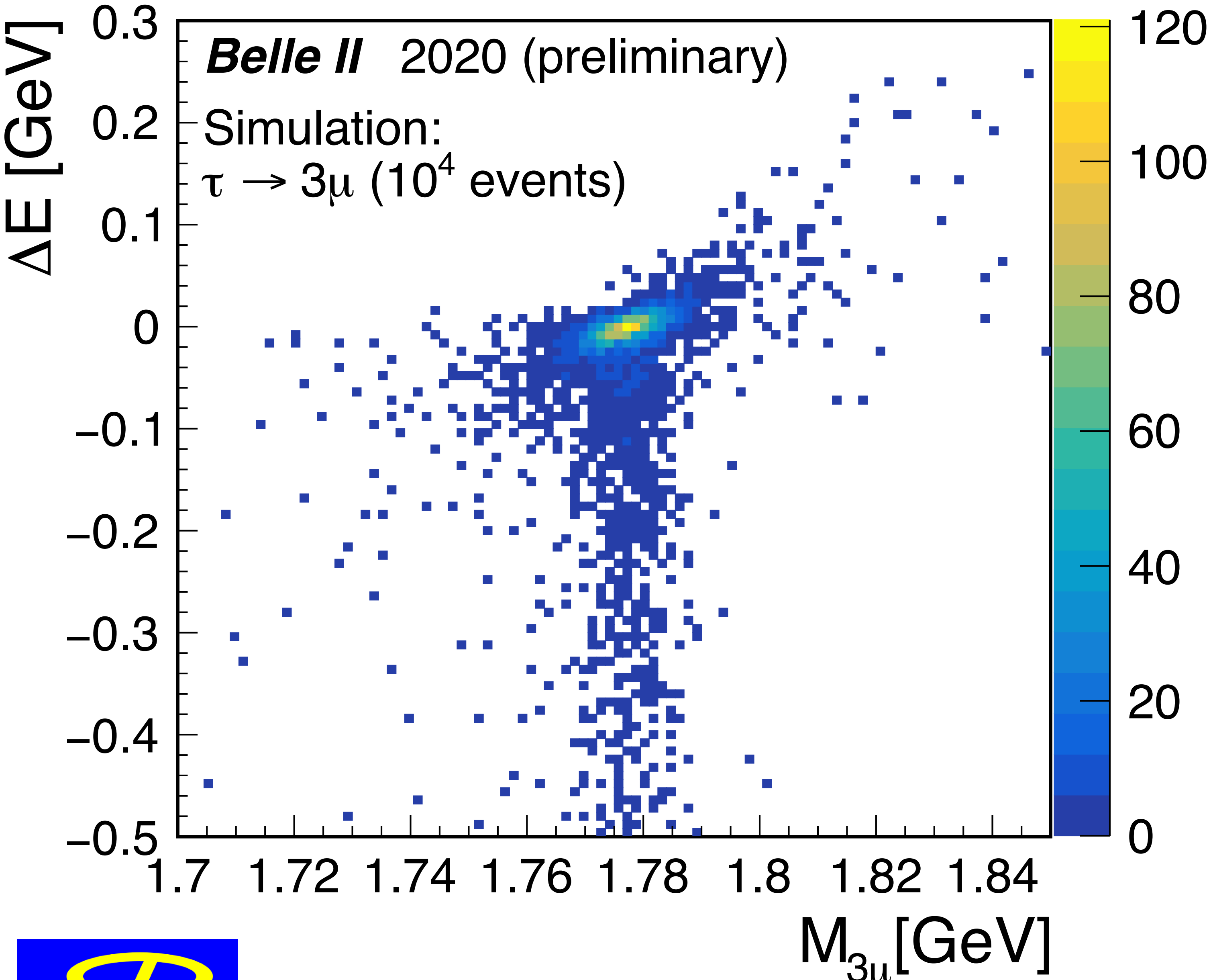
Signal determination: signal region

Signal identification in LFV τ analysis is usually done using a τ mass and ΔE selection

$$\Delta E \equiv E_\tau - E_{beam}$$

$E_\tau \rightarrow E_{3\mu}$, $E_{beam} \rightarrow \sqrt{S}/2$

ΔE VS M of signal τ



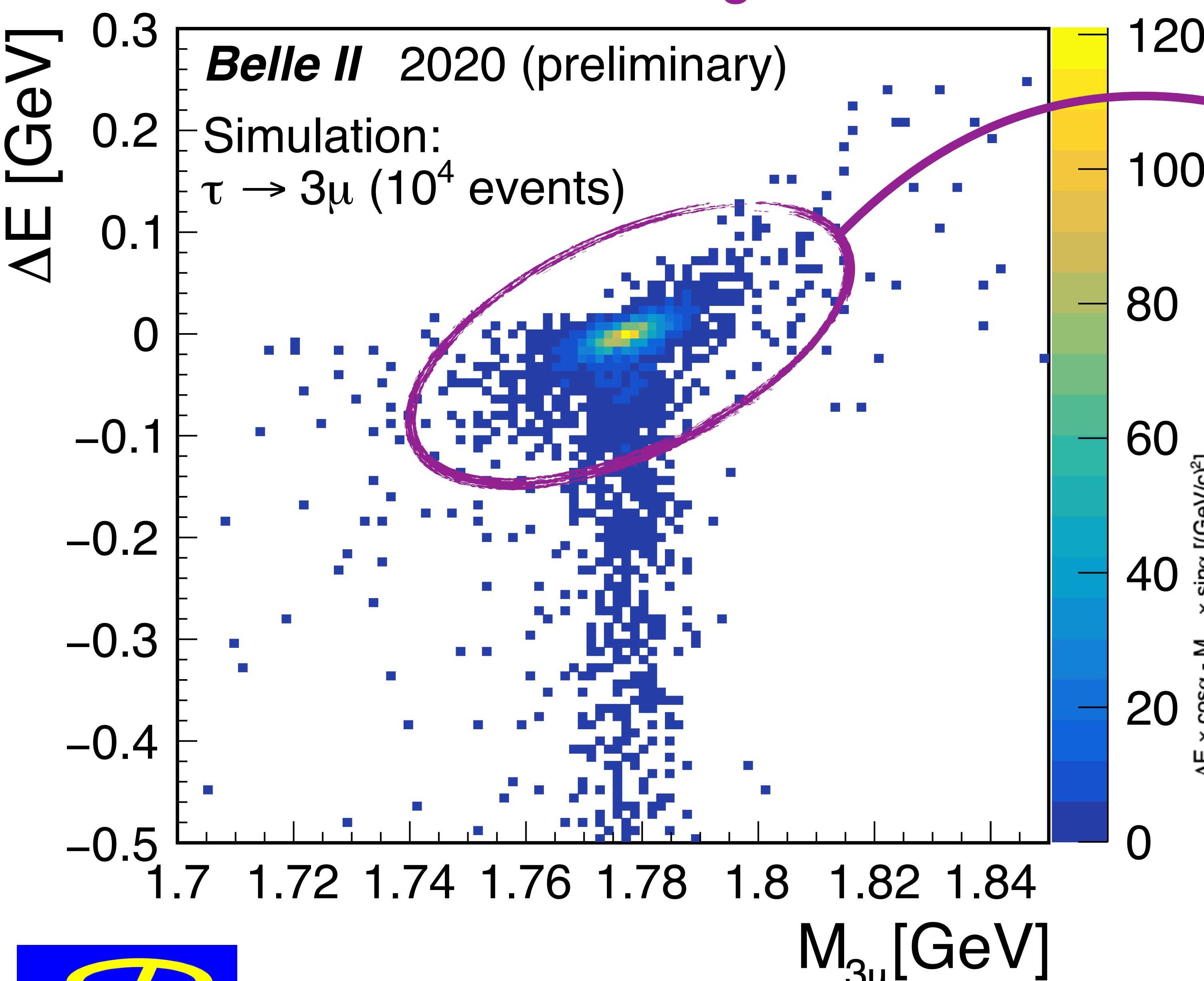
Signal determination: signal region

Signal identification in LFV τ analysis is usually done using a τ mass and ΔE selection

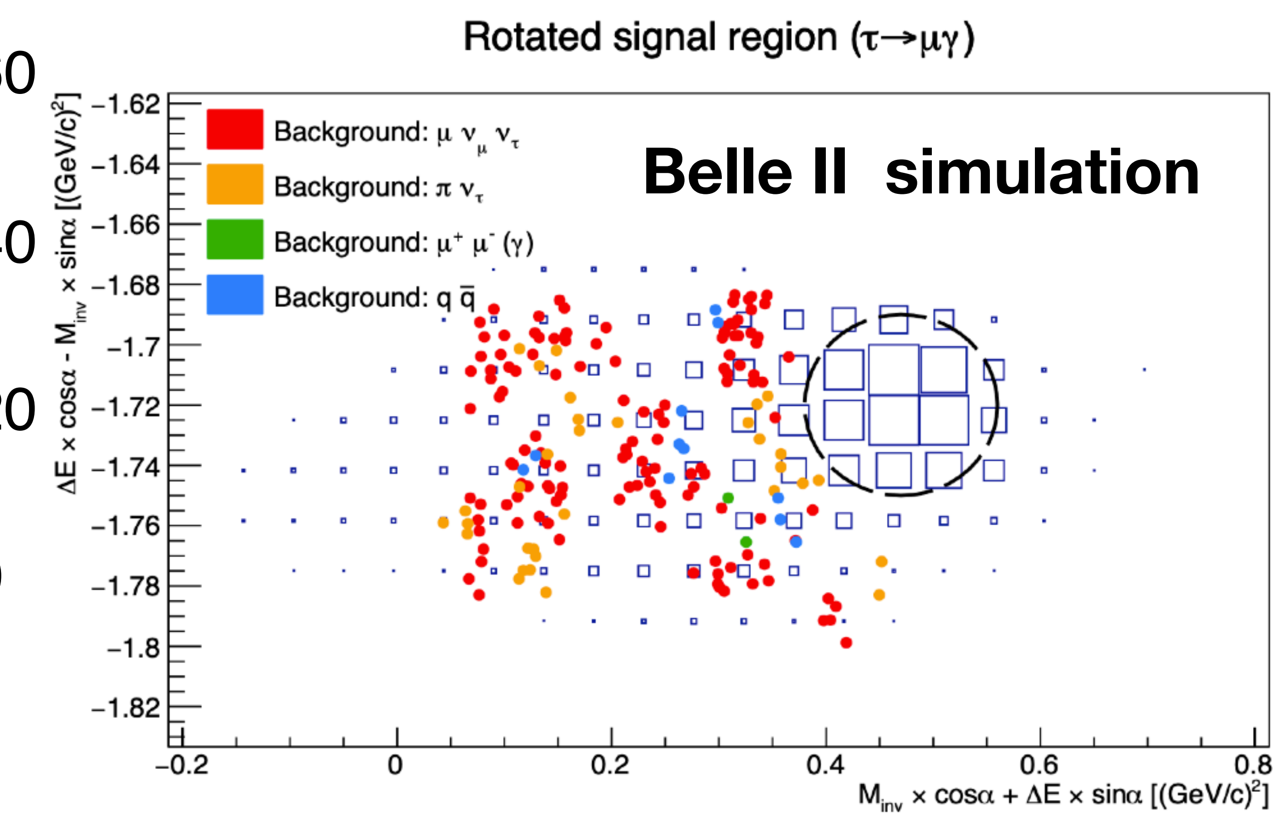
$$\Delta E \equiv E_\tau - E_{beam}$$

$E_\tau \rightarrow E_{3\mu}$, $E_{beam} \rightarrow \sqrt{S}/2$

ΔE VS M of signal τ



$$\begin{pmatrix} M'_{3\mu} \\ \Delta E' \end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} M_{3\mu} \\ \Delta E \end{pmatrix}$$



The Belle II Physics Book arXiv:1808.10567v2

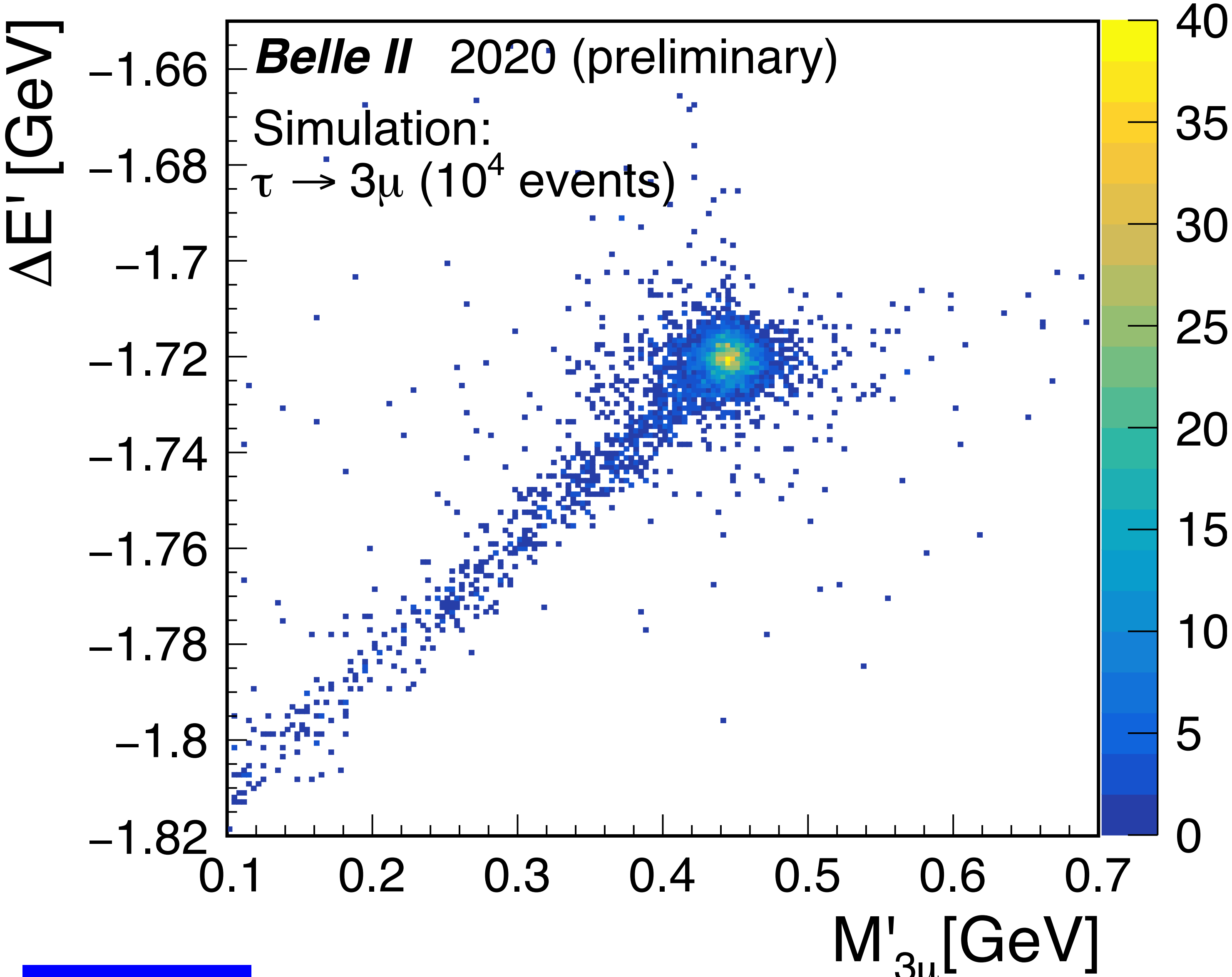
Signal determination: signal region

Signal identification in LFV τ analysis is usually done using a τ mass and ΔE selection →

$$\Delta E \equiv E_\tau - E_{beam}$$

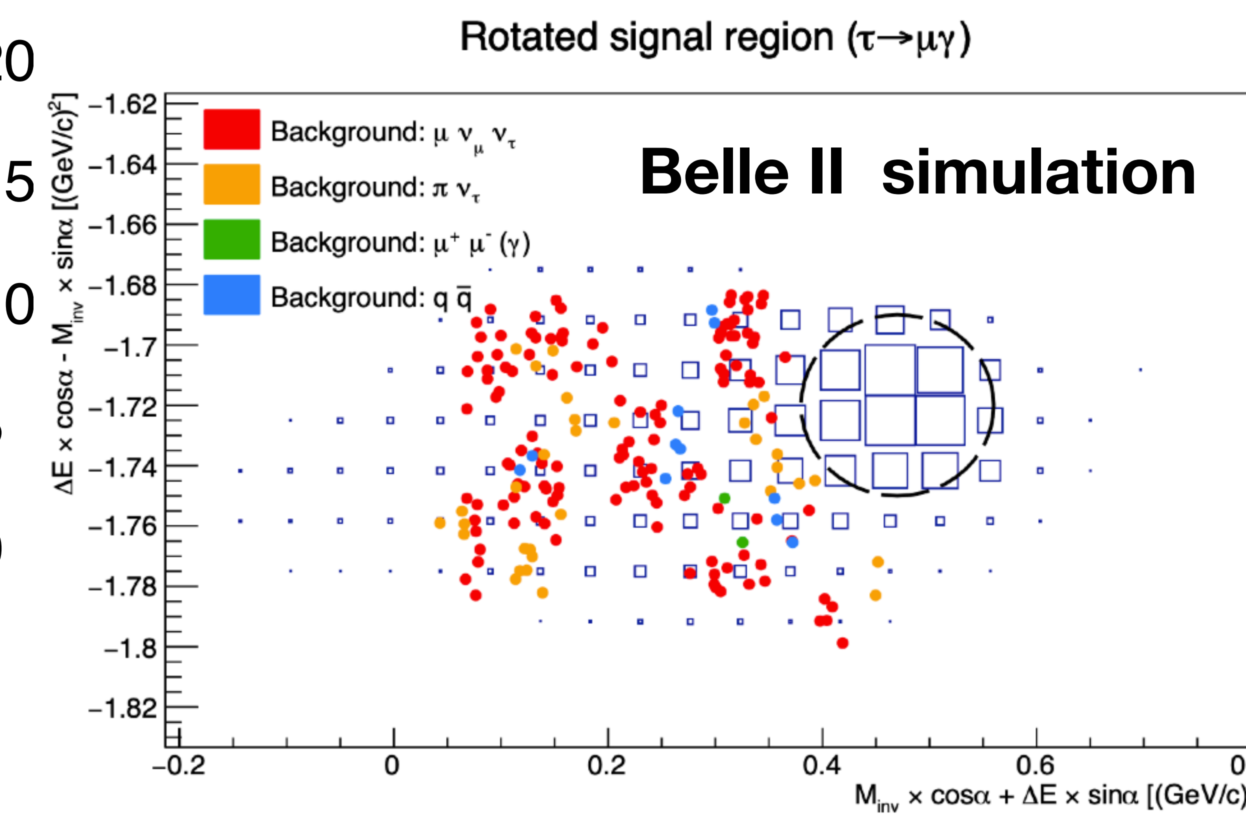
$E_\tau \to E_{3\mu}$, $E_{beam} \to \sqrt{S}/2$

ΔE VS M of signal τ



$$\begin{pmatrix} M'_{3\mu} \\ \Delta E' \end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} M_{3\mu} \\ \Delta E \end{pmatrix}$$

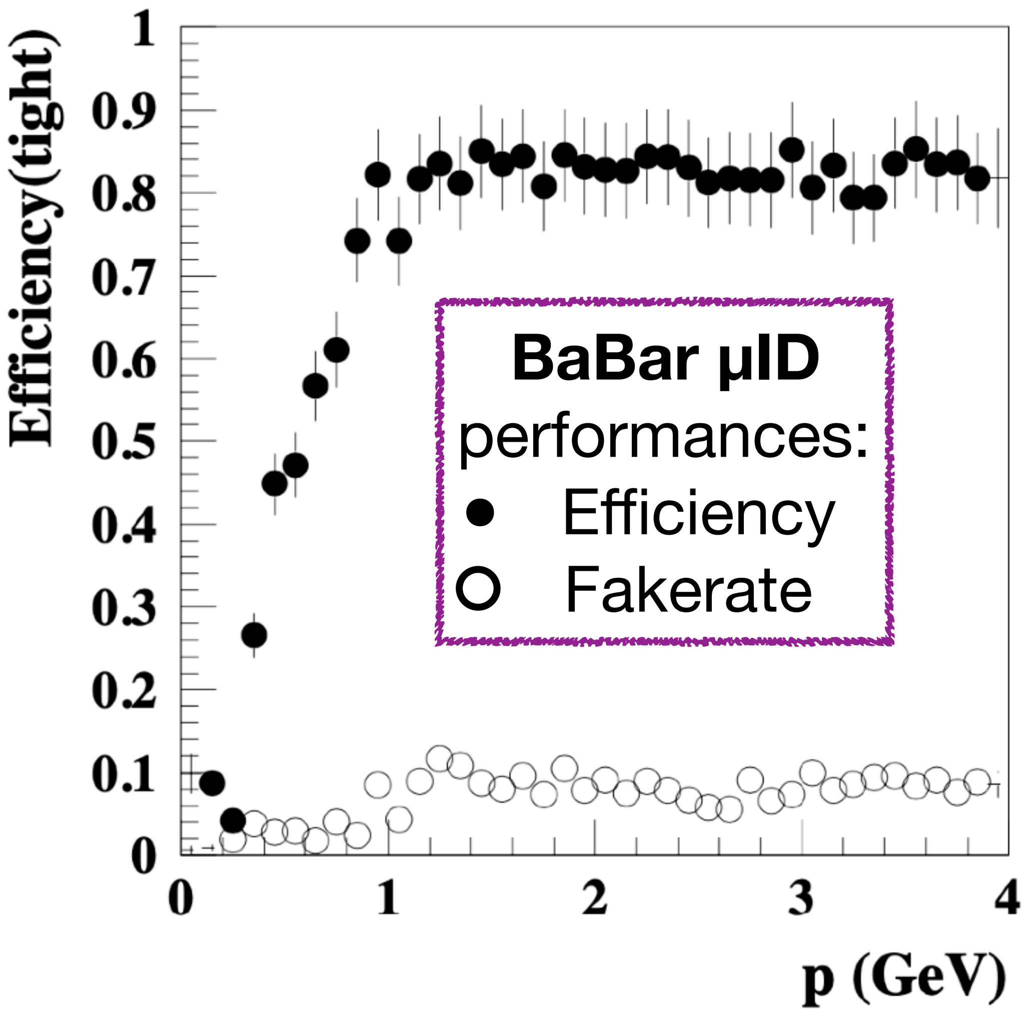
with $\theta \simeq 75°$



The Belle II Physics Book arXiv:1808.10567v2

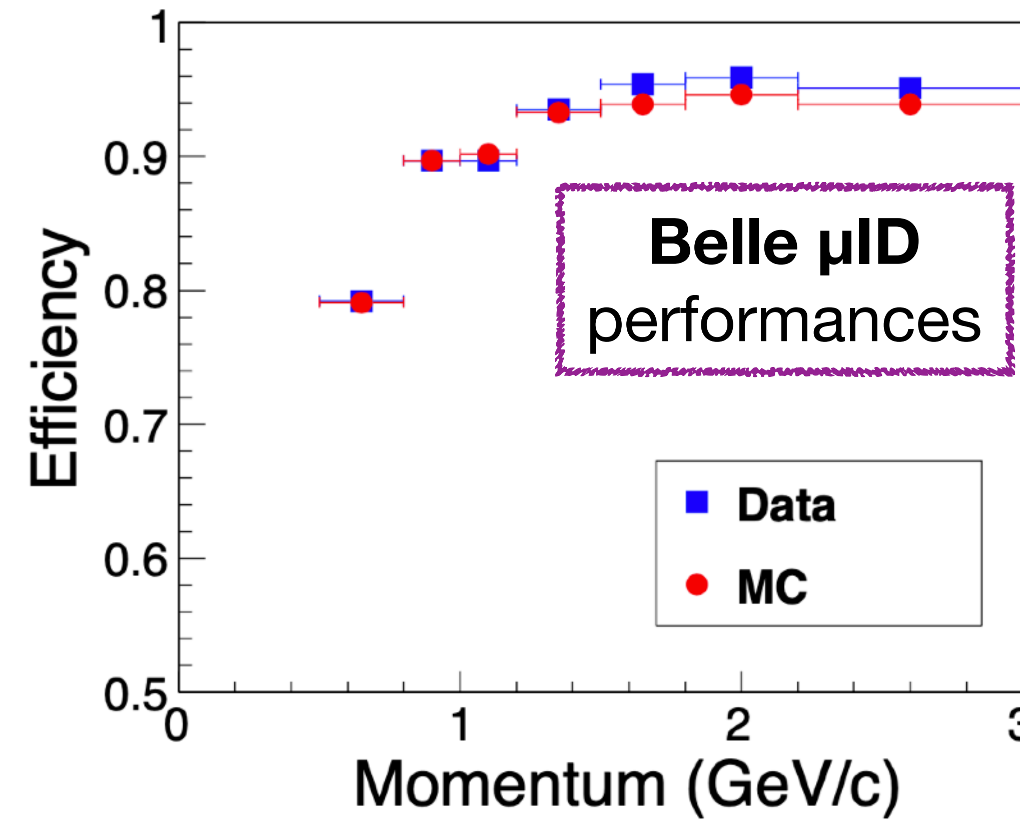
Background rejection: signal side

The most powerful discriminating variable between signal and background is the μID



μID efficiency *in τ → 3μ analysis*:

BaBar: 77%
Belle: 85%



μID algorithm in Belle II is expected to be better → possible analysis improvement

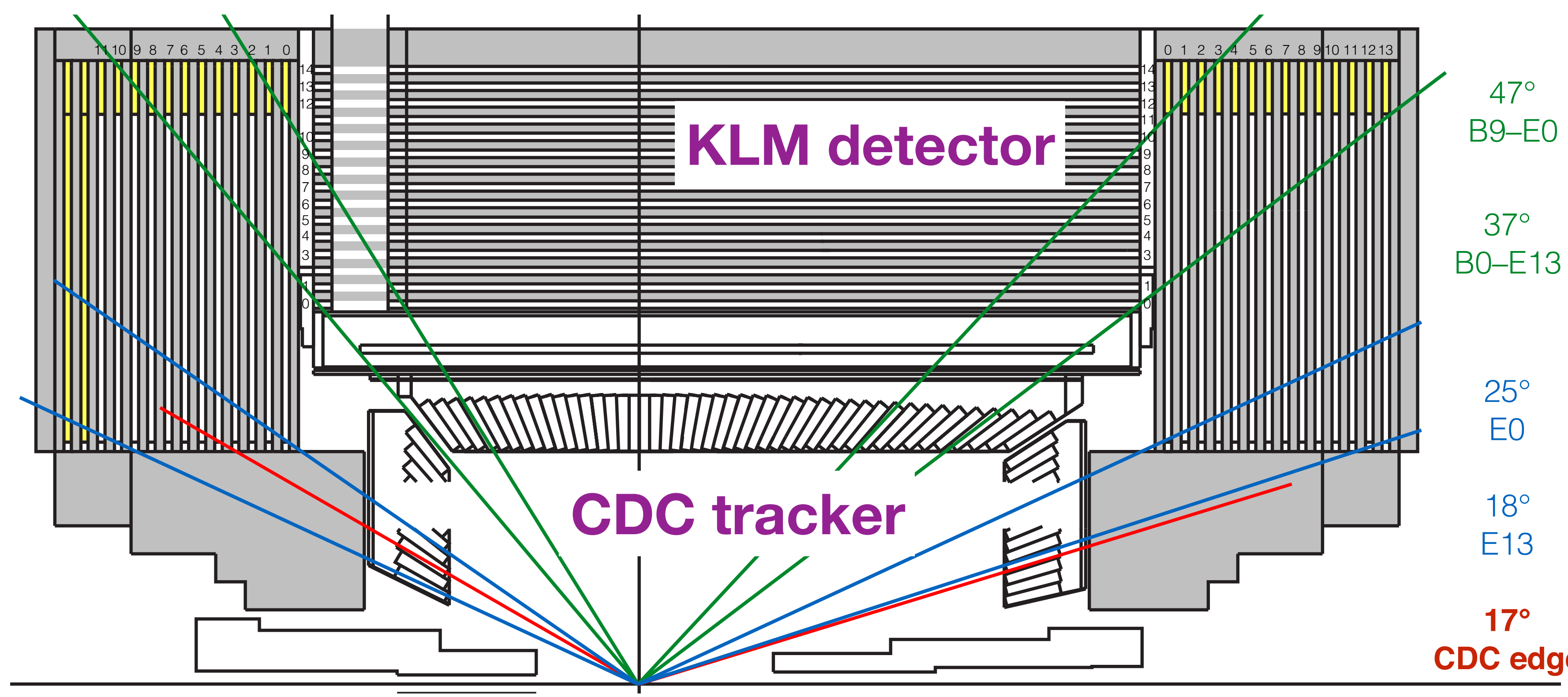
Background rejection: signal side

Usage of a different&optimised cut-based approach → improve analysis results

Momentum ranges:

- Pμ<0.7 GeV: μ do not reach the μ detector (KLM)
- 0.7<Pμ<1 GeV: μ reach KLM but not many layers are crossed
- Pμ>1 GeV: μ reach KLM and many layers are crossed

New improved Belle II μID algorithm using KLM will be crucial



Belle II

Background rejection: signal side

Usage of a different&optimised cut-based approach → improve analysis results

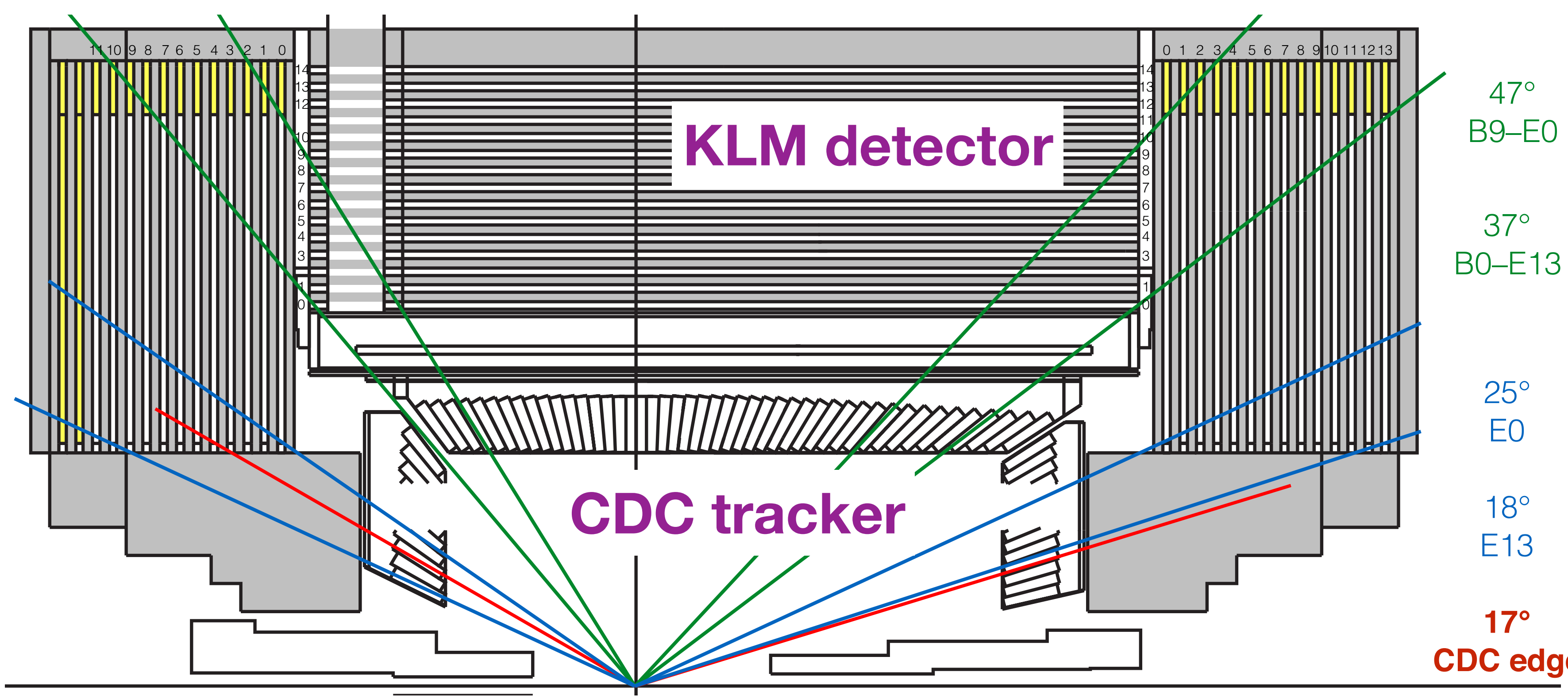
Momentum ranges:

- **Pμ<0.7 GeV**: μ do not reach the μ detector (KLM)
- **0.7<Pμ<1 GeV**: μ reach KLM but not many layers are crossed
- **Pμ>1 GeV**: μ reach KLM and many layers are crossed

Optimization of the μID cuts on 3 momentum ranges

↓

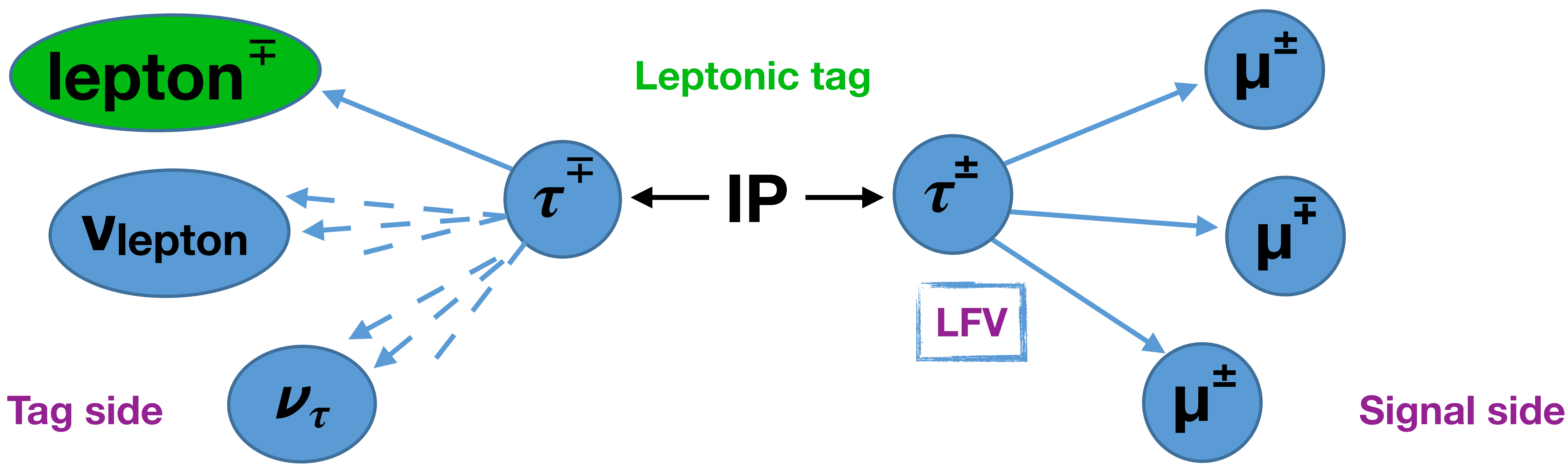
Extract the best combination of tight cuts for the analysis also at low momentum (*<u>not used by Belle/BaBar</u>*)



Belle II

Background rejection: tag side

Signal-background discrimination depends on the tag-side track

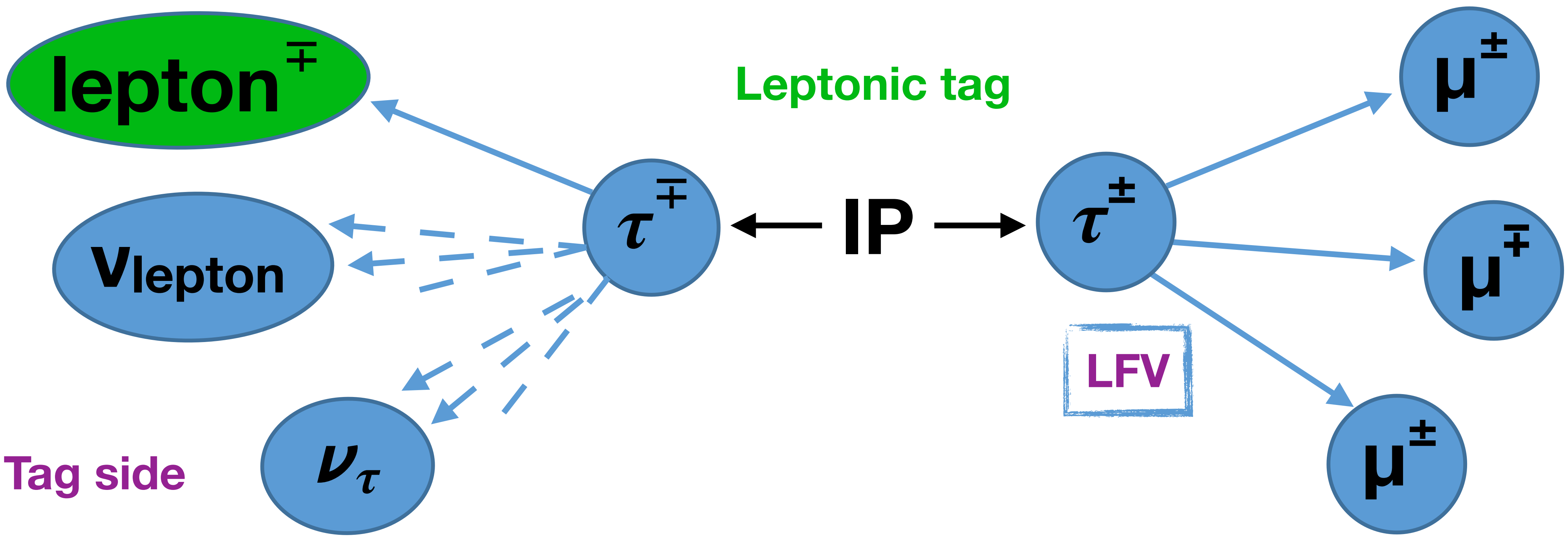


In case of leptonic tag the missing energy on the tag side is high (2 neutrinos) and leptonID performances come into play

Background rejection: tag side

Signal-background discrimination depends on the tag-side track

μ veto applied by Belle/BABar → **No veto by Belle II → gain efficiency**

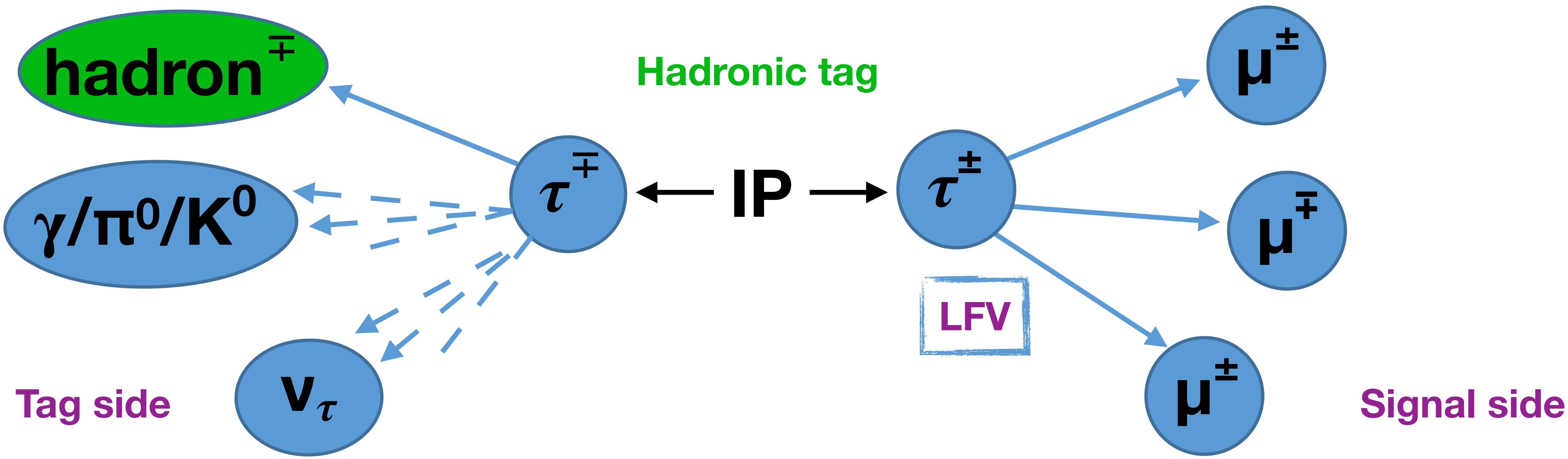


Tag side **Signal side**

In case of leptonic tag the missing energy on the tag side is high (2 neutrinos) and leptonID performances come into play

Background rejection: tag side

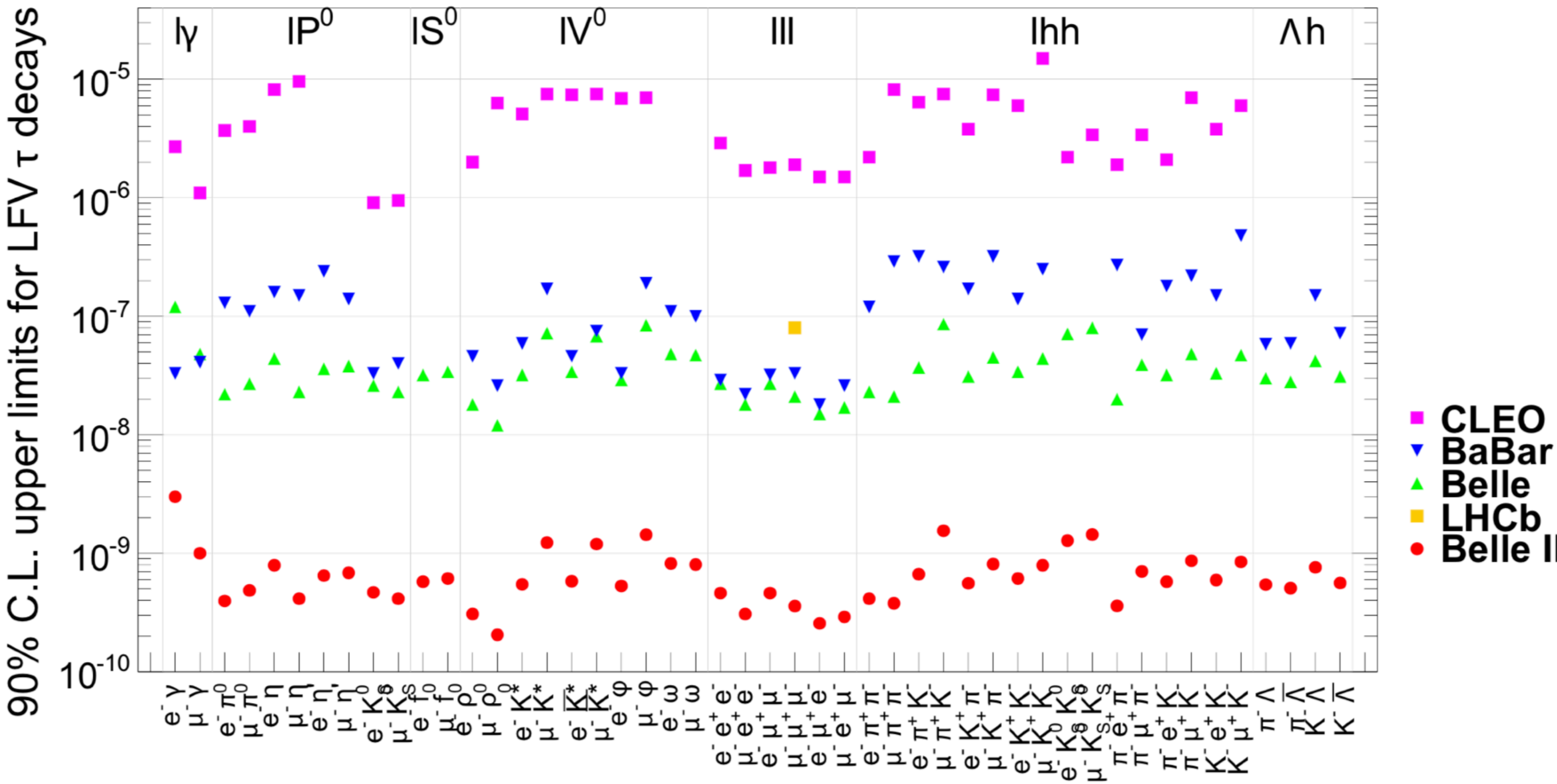
Signal-background discrimination depends on the tag-side track



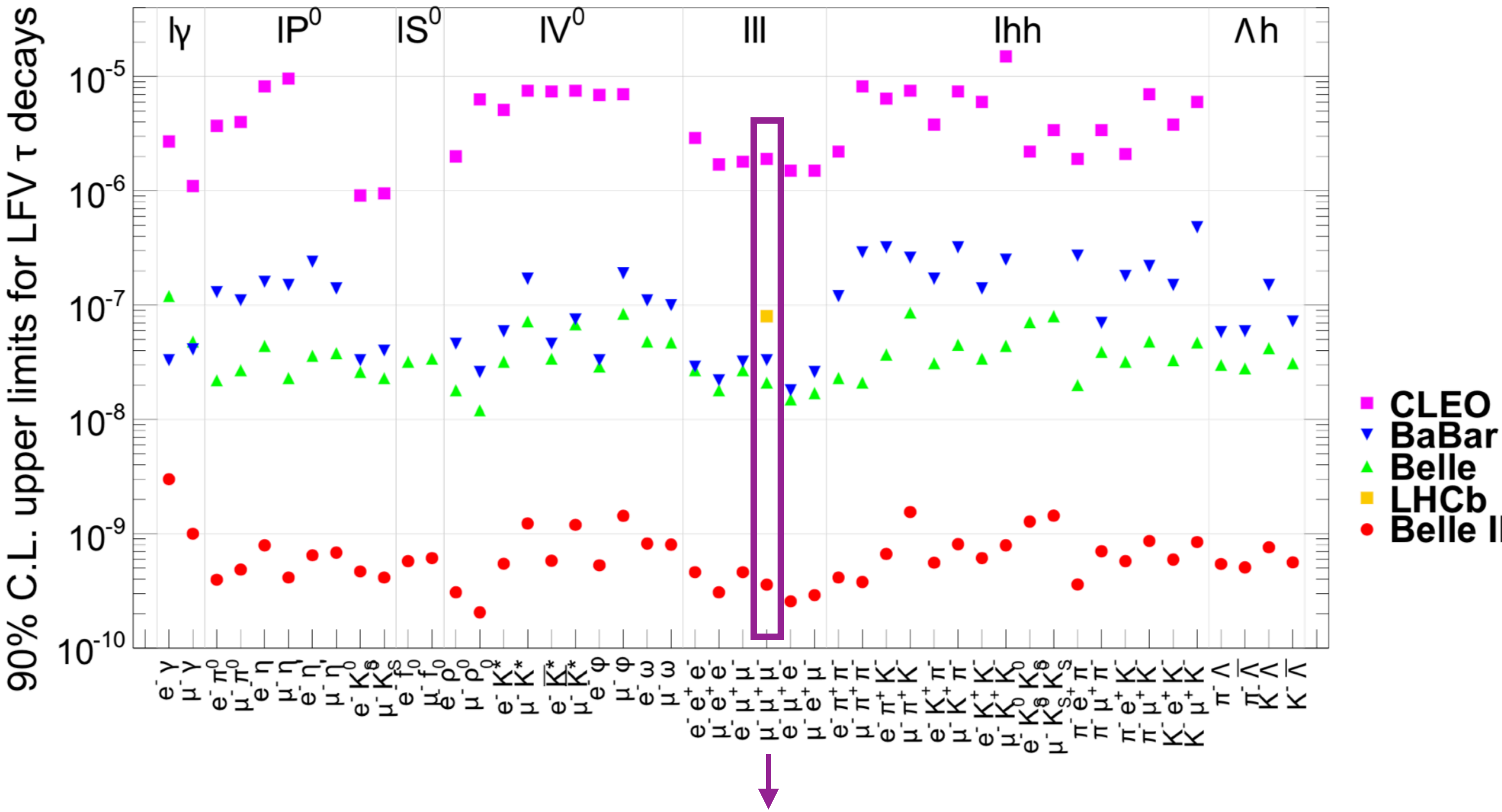
In case of hadronic tag the missing energy on the tag side is lower (1 neutrino) and hadronID performances come into play

Expected results @ Belle II

Expected limits results



Expected limits results



Belle II is expected to improve the results of previous B-factory by a factor ~100

With a better analysis strategy the results can be even better…
and they are coming soon!

Conclusions

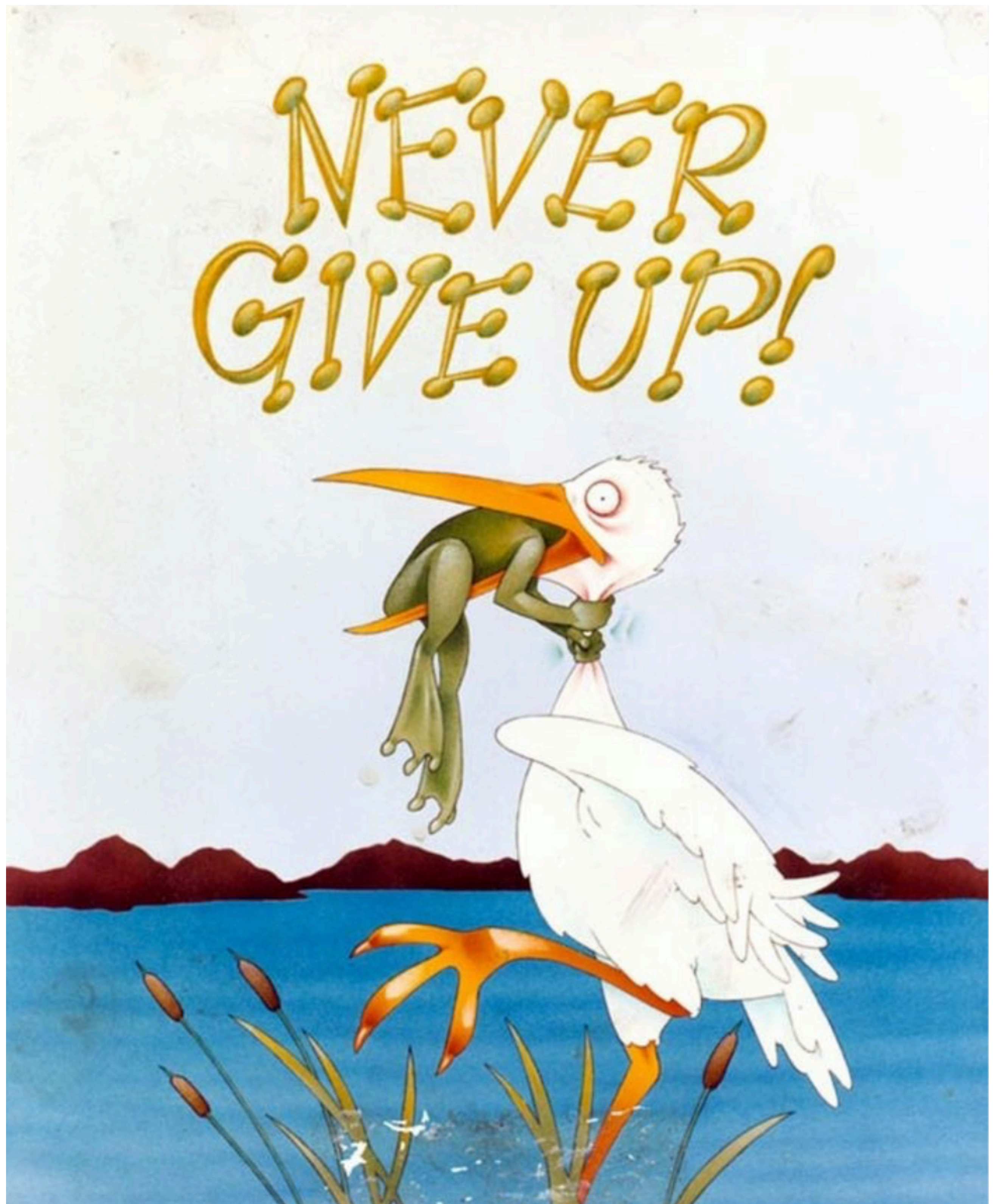
- **The Belle II experiment will be able to search for many LFV τ decays** within the next years **thanks to several advantages** as a B-factory

- Several NP contributions are accessible by Belle II → the aim is to further **improve existing limits and search for NP hints**

- **$\tau \rightarrow 3\mu$ channel is very promising** (together with $\tau \rightarrow \mu\gamma$)
  - New optimised analysis is being performed @ Belle II
  - Improved μID algorithm is expected to improve previous results

- **MC results are on the way & let's wait for more data to come!**

Emergency slides!!



Signal region

The best way to identify the signal is to look at the τ mass and ΔE

$$\Delta E \equiv E_\tau - E_{beam}$$

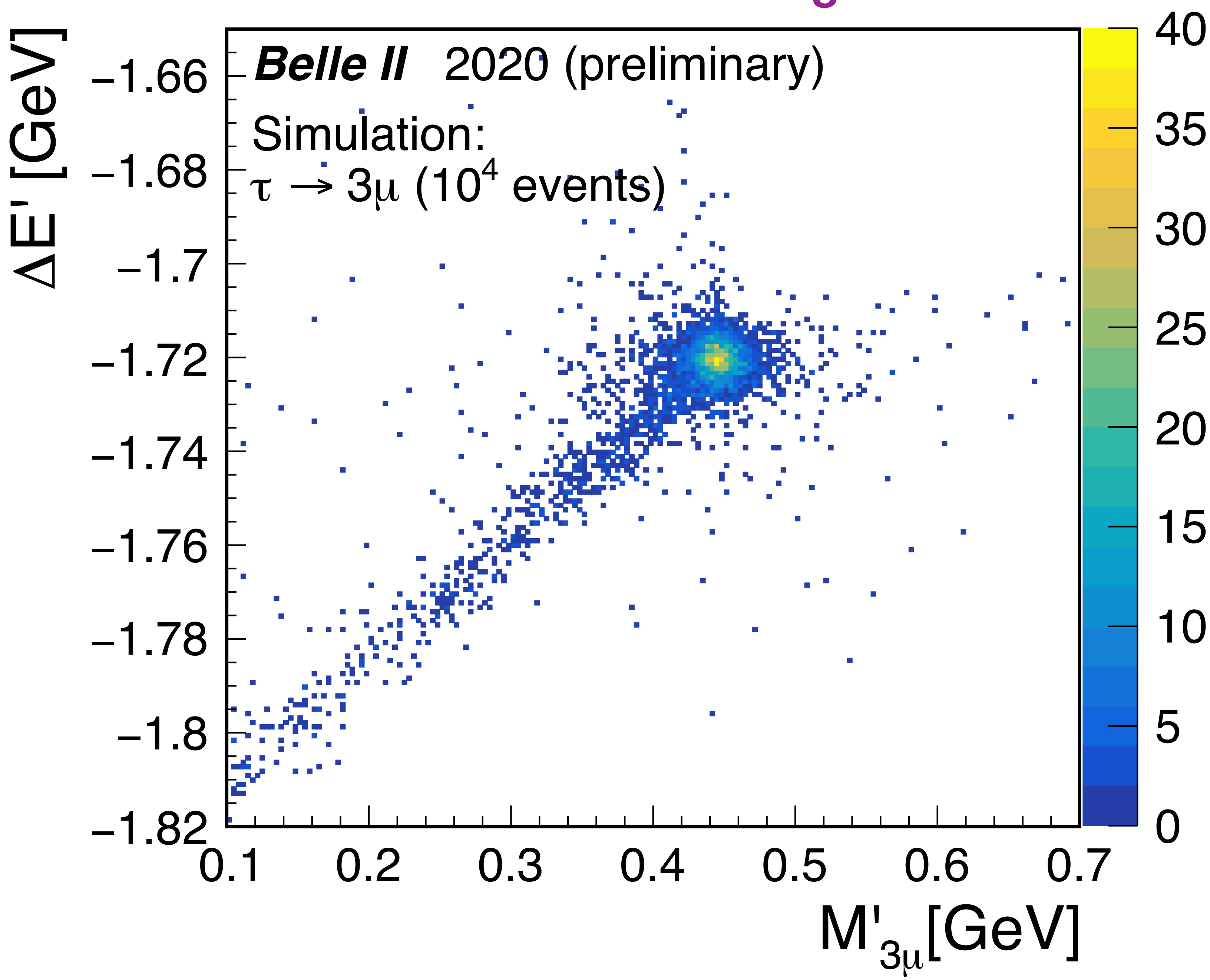
$E_\tau \rightarrow E_{3\mu}$, $E_{beam} \rightarrow \sqrt{S}/2$

$$\begin{pmatrix} M'_{3\mu} \\ \Delta E' \end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} M_{3\mu} \\ \Delta E \end{pmatrix}$$

with $\theta \simeq 75^\circ$

Removed correlation between the variables

ΔE' VS τ mass' of signal τ

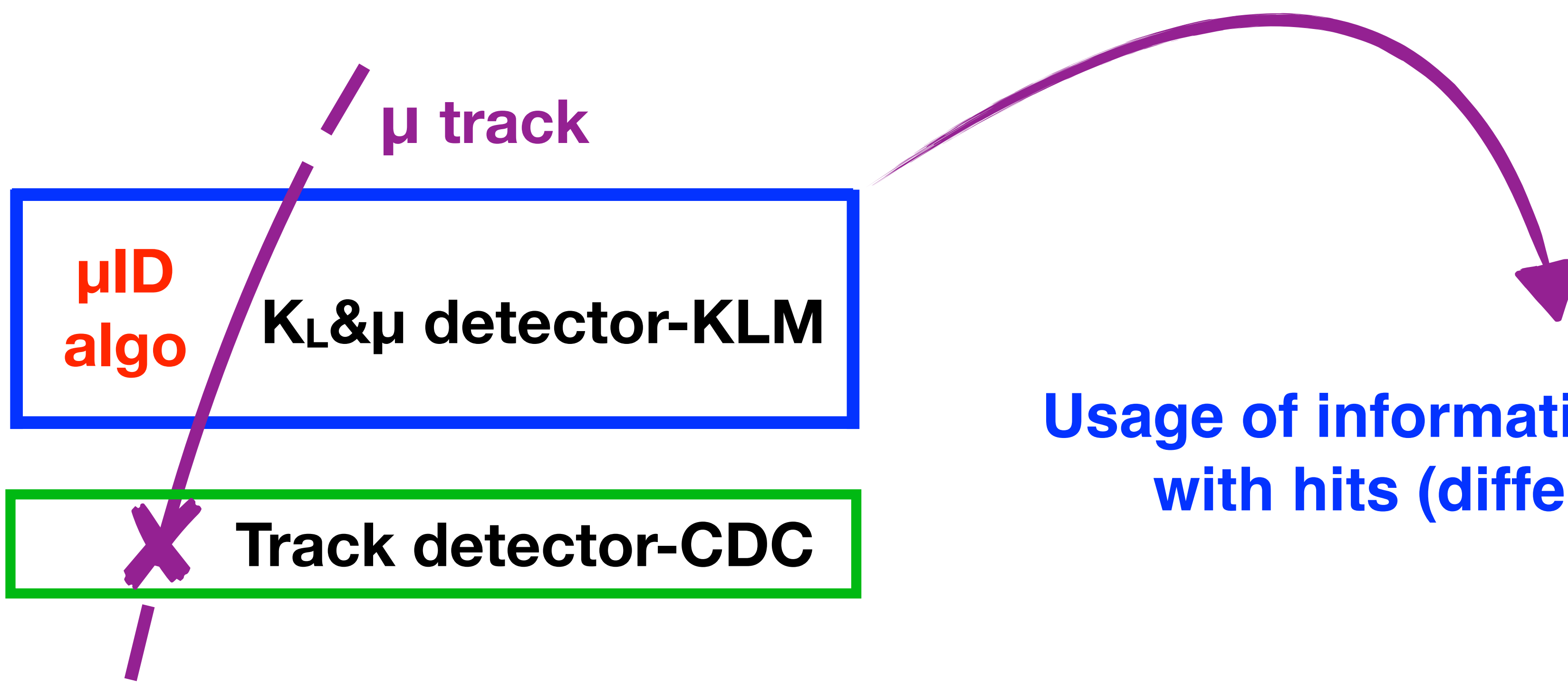


μ identification

Muon identification process

Geant4 is used to extrapolate tracks reconstructed from the inner detectors by the tracking software

When the track reaches the KLM layers the μID algorithm provides the probability of the track to be a μ.



Usage of informations from KLM layers with hits (differently from Belle)