Search for $\tau \longrightarrow 3\mu$ LFV decay @Belle II

On behalf of the Belle II collaboration

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OUTLINE

- Introduction to Belle II
- Motivations
- Analysis strategy
- Results and future prospects

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..

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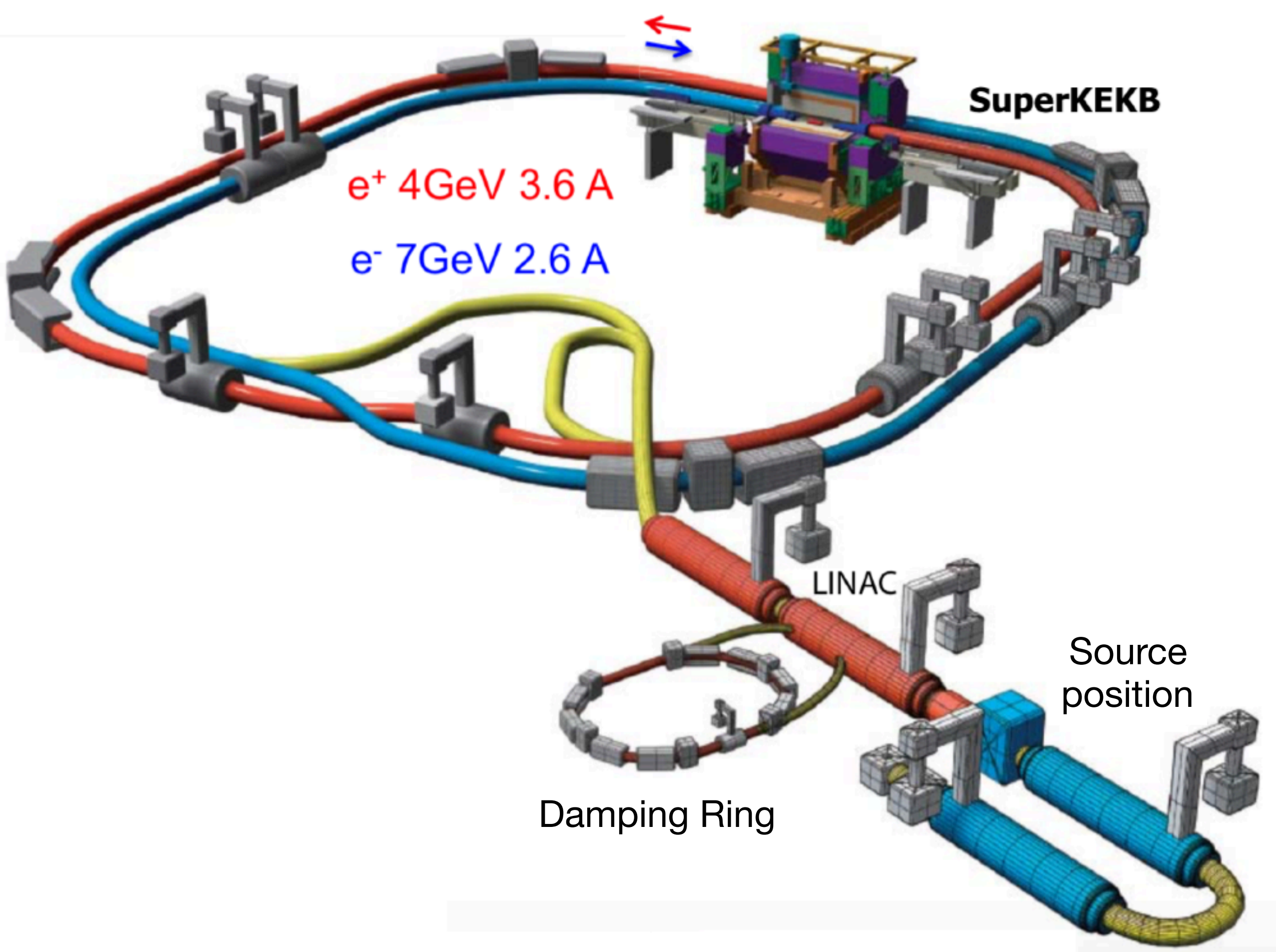
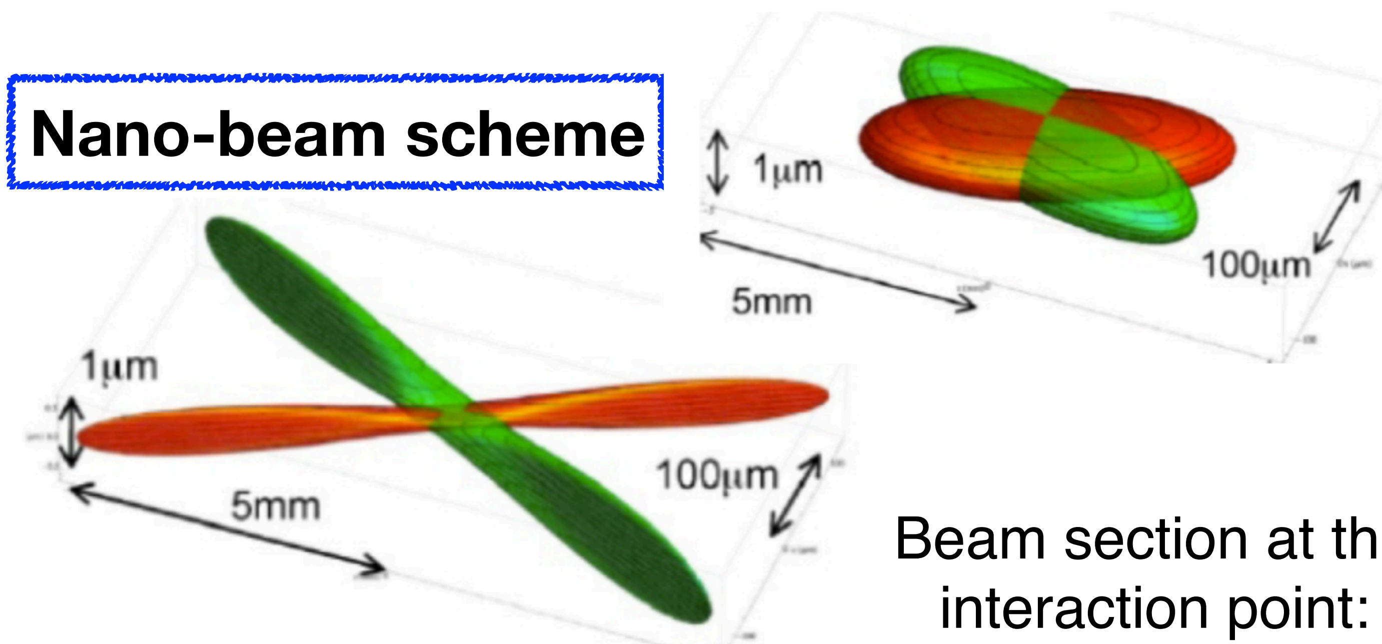


Nano-beam scheme



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

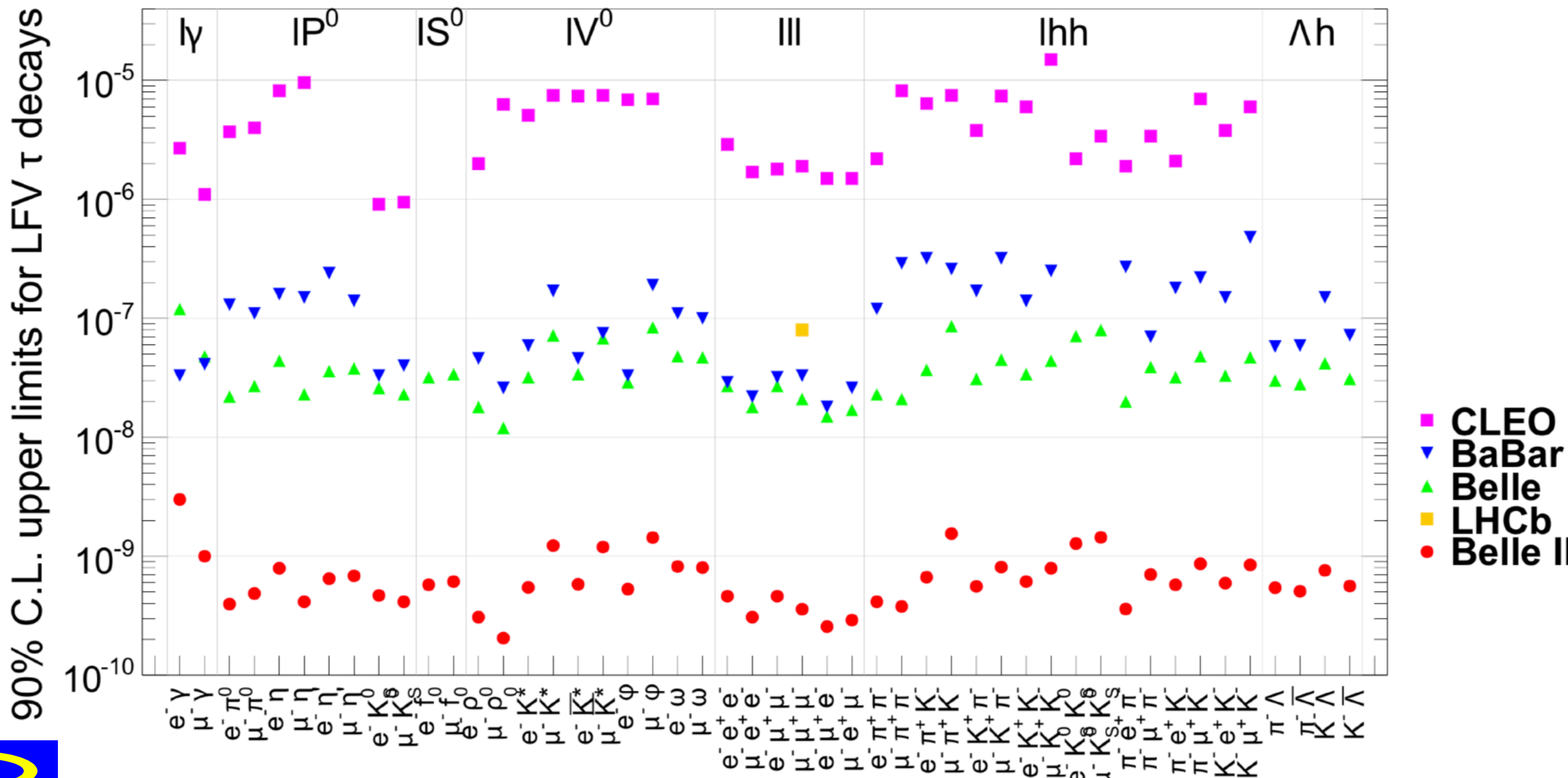
Expected improvement of integrated luminosity of a factor ~50 w.r.t. Belle: **50 ab^{-1}**

$\tau \to 3\mu$ motivations

Status of the τ LFV @Belle II

Belle II expectations:

Improvement of ≲2 order of magnitude w.r.t. the actual limits

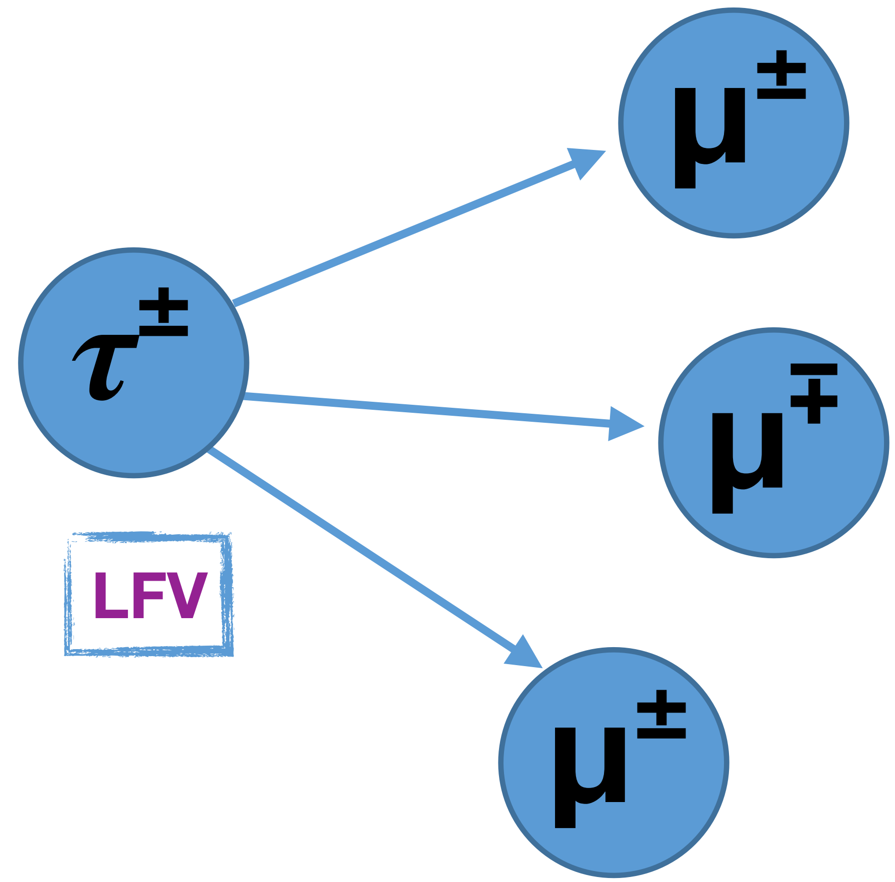


Analysis motivations: $\tau \to 3\mu$

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

$\tau^{\pm} \to \mu^{\pm}\mu^{\pm}\mu^{\mp}$ decay is predicted to be non vanishing by New Physics (NP) models:

- Supersymmetric models;
- Models with Higgs/little Higgs;
- Non-universal Z'
- Left-right symmetric models;
- …



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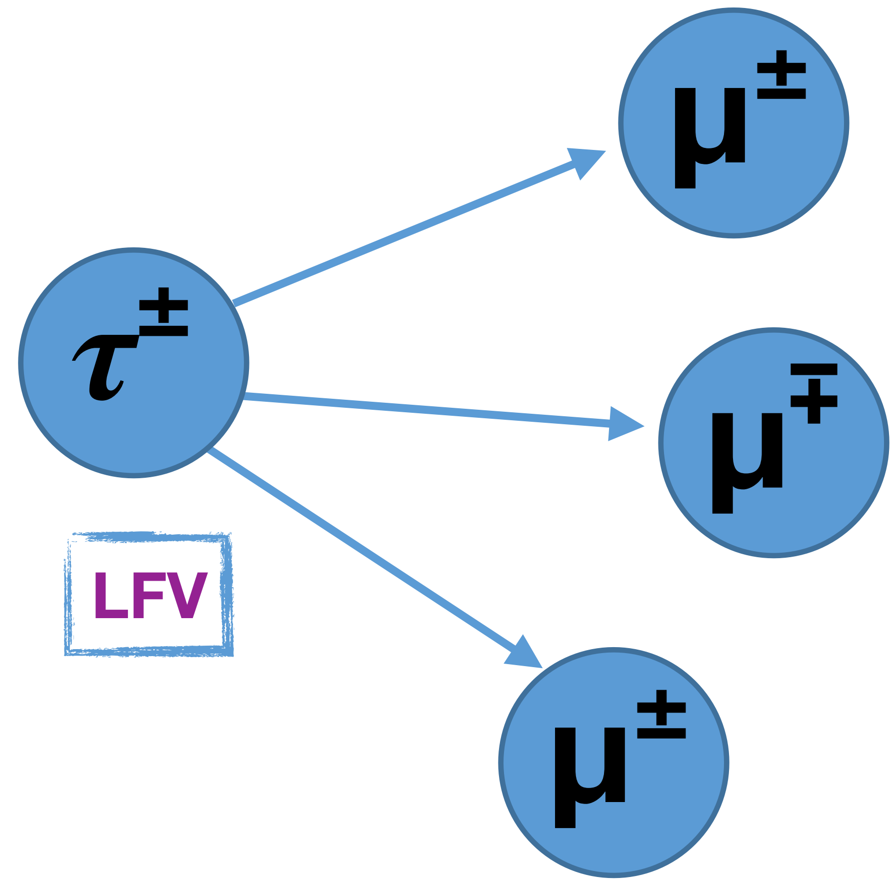
Branching Fraction predictions down to $\sim 10^{-10}$
↓
accessible by Belle II



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

- Belle: $\mathbf{2.1 \times 10^{-8}}$ @90% confidence level
- BaBar: $\mathbf{3.3 \times 10^{-8}}$ @90% confidence level

…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

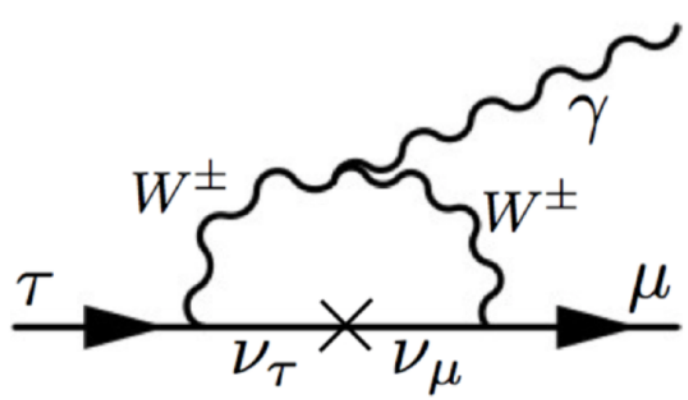
LFV new physics models

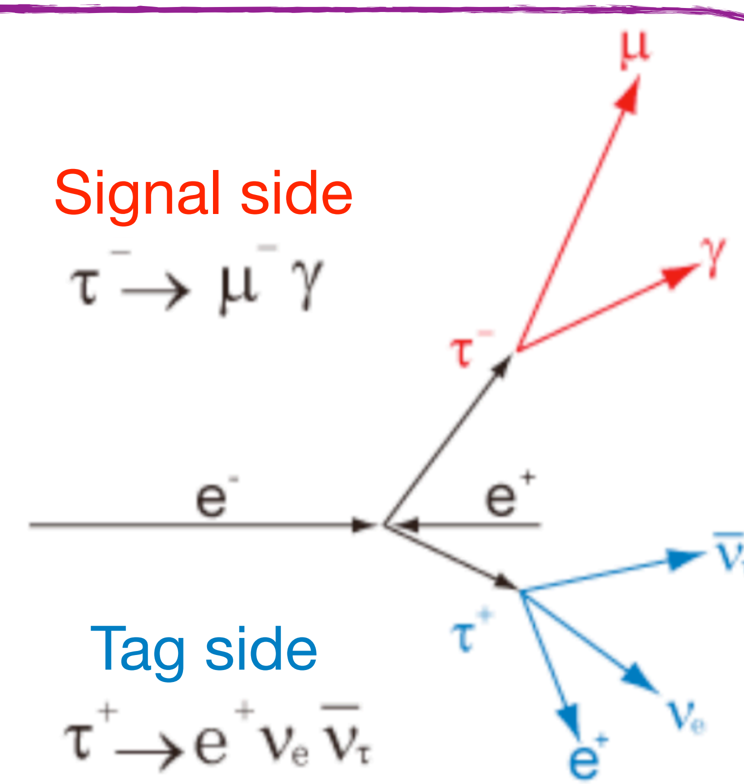
Ratios of BFs of τ LFV decays allow to discriminate NP models!

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).

Decay reference





Analysis strategy

Decay description and advantages

Analysis involving τ in Belle II are challenging because of:

- lot of **missing energy**
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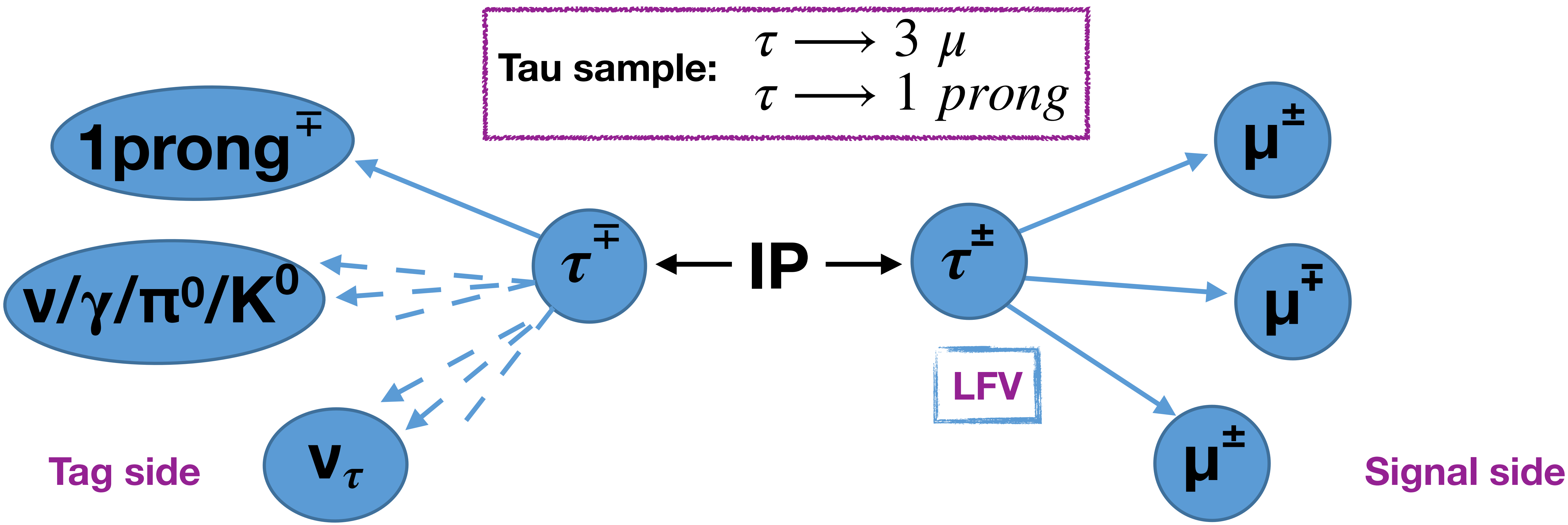

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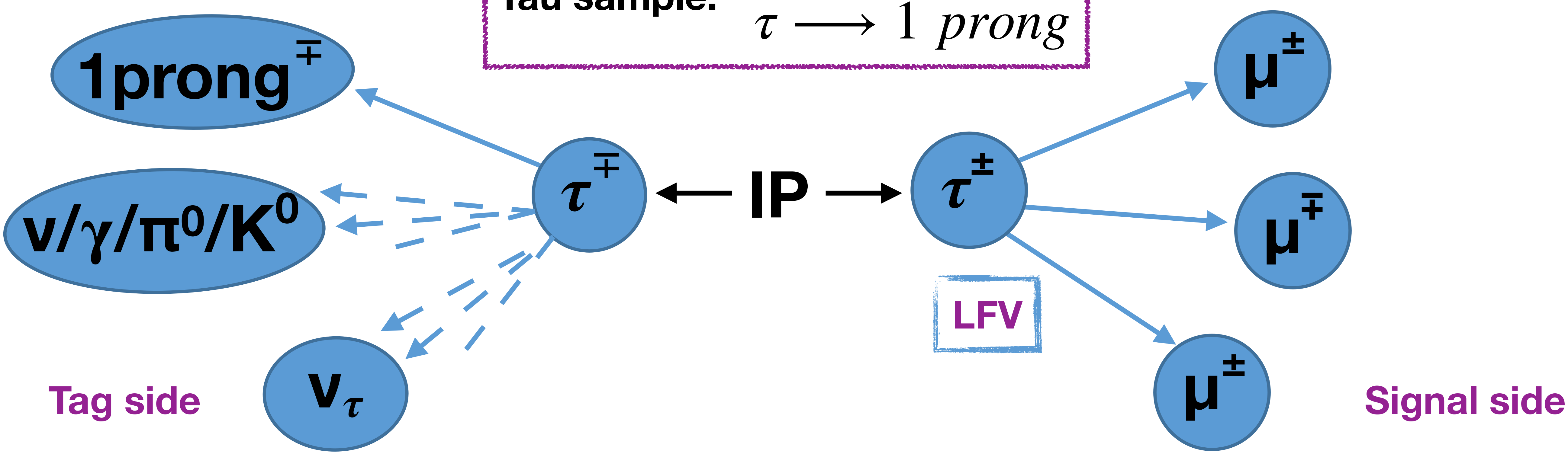
Tau sample: $\tau \longrightarrow 3\ \mu$
$\tau \longrightarrow 1\ prong$



Signal side completely reconstructed

↓

good measurement of **τ mass and energy**

Strong signal side signature

↓

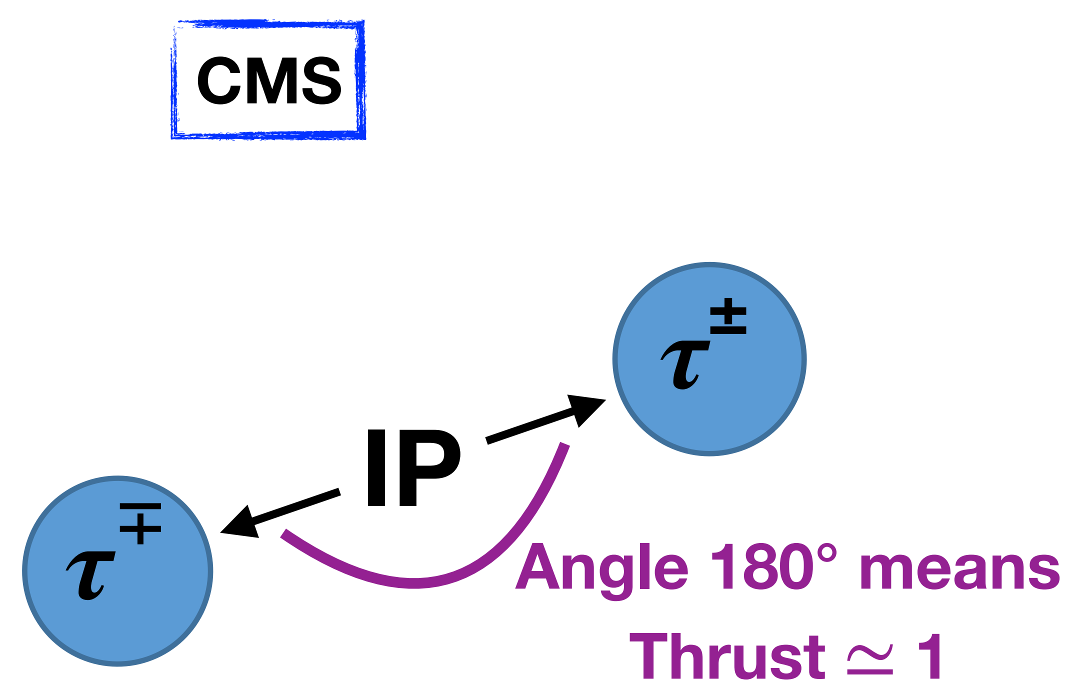
few physical background sources

Signal preselection

Requirement adopted to reconstruct the decay:

1p=1prong

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



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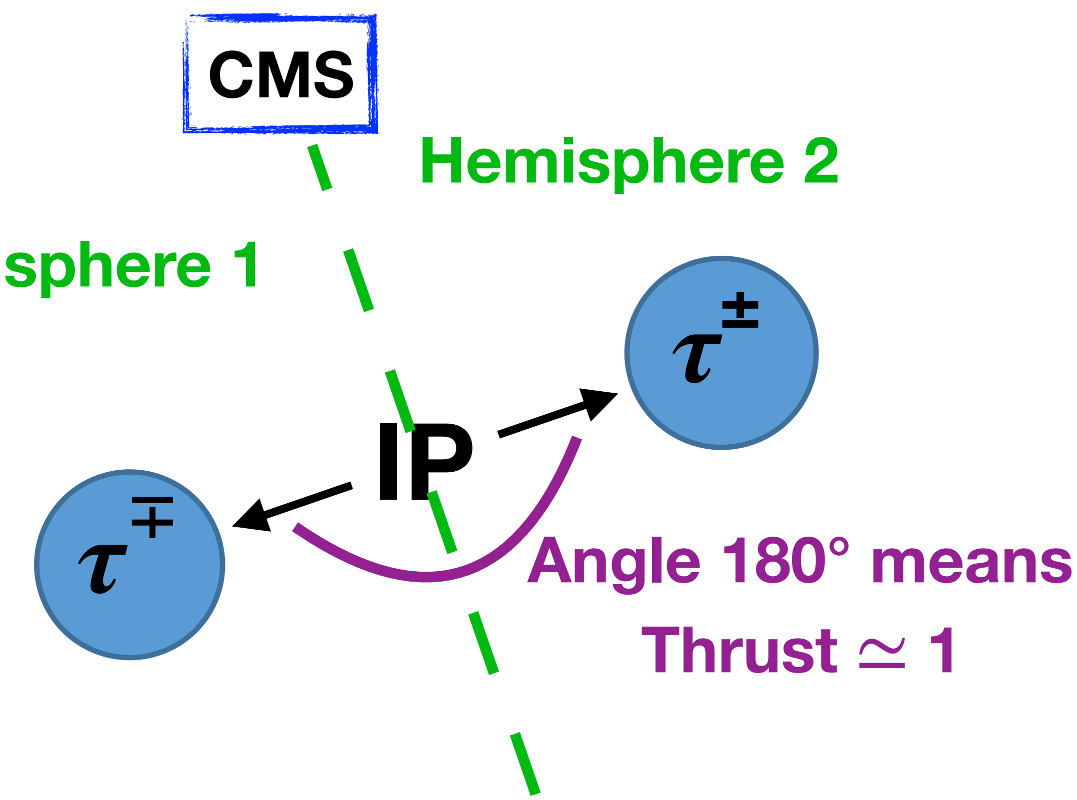

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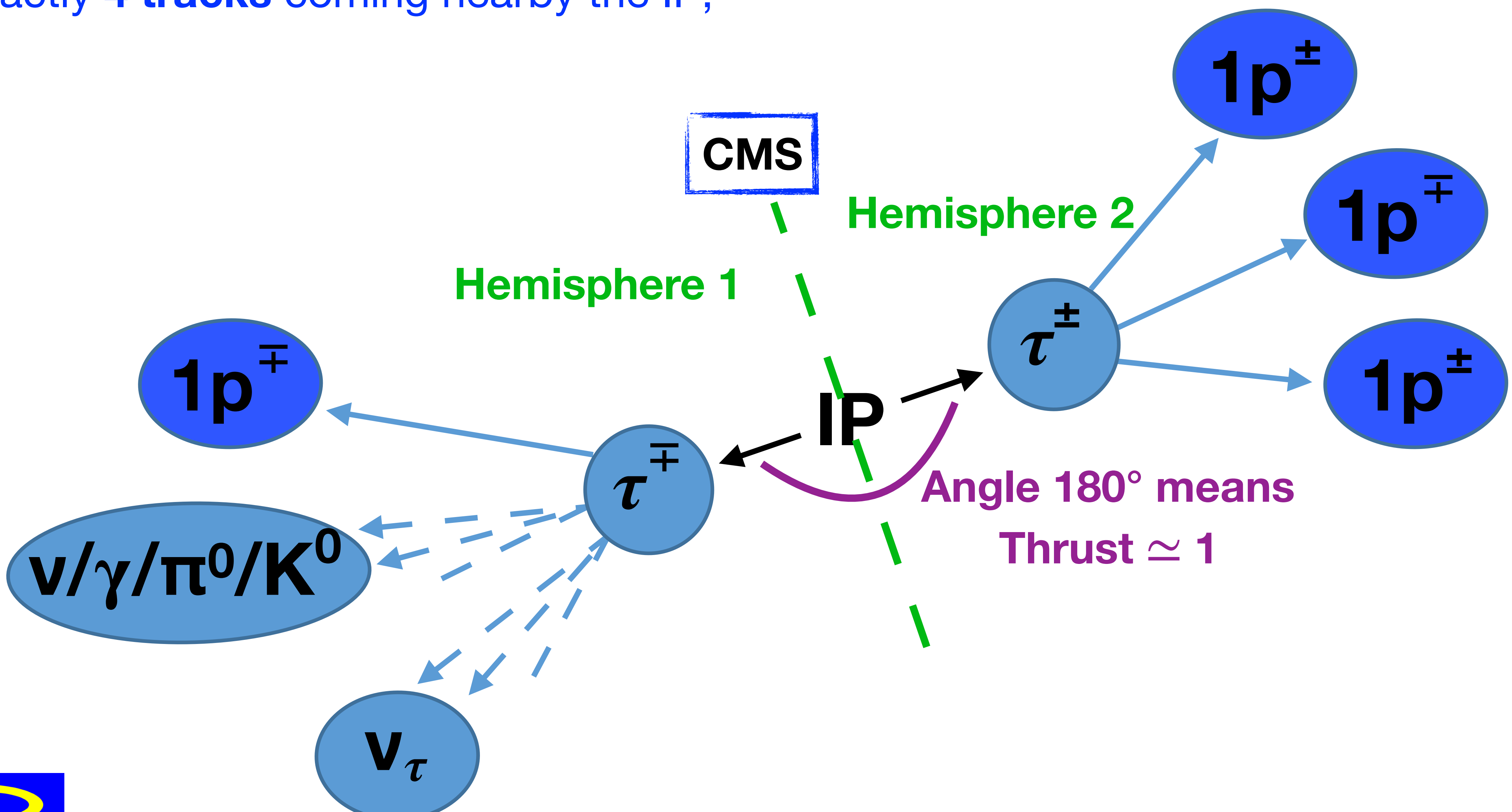

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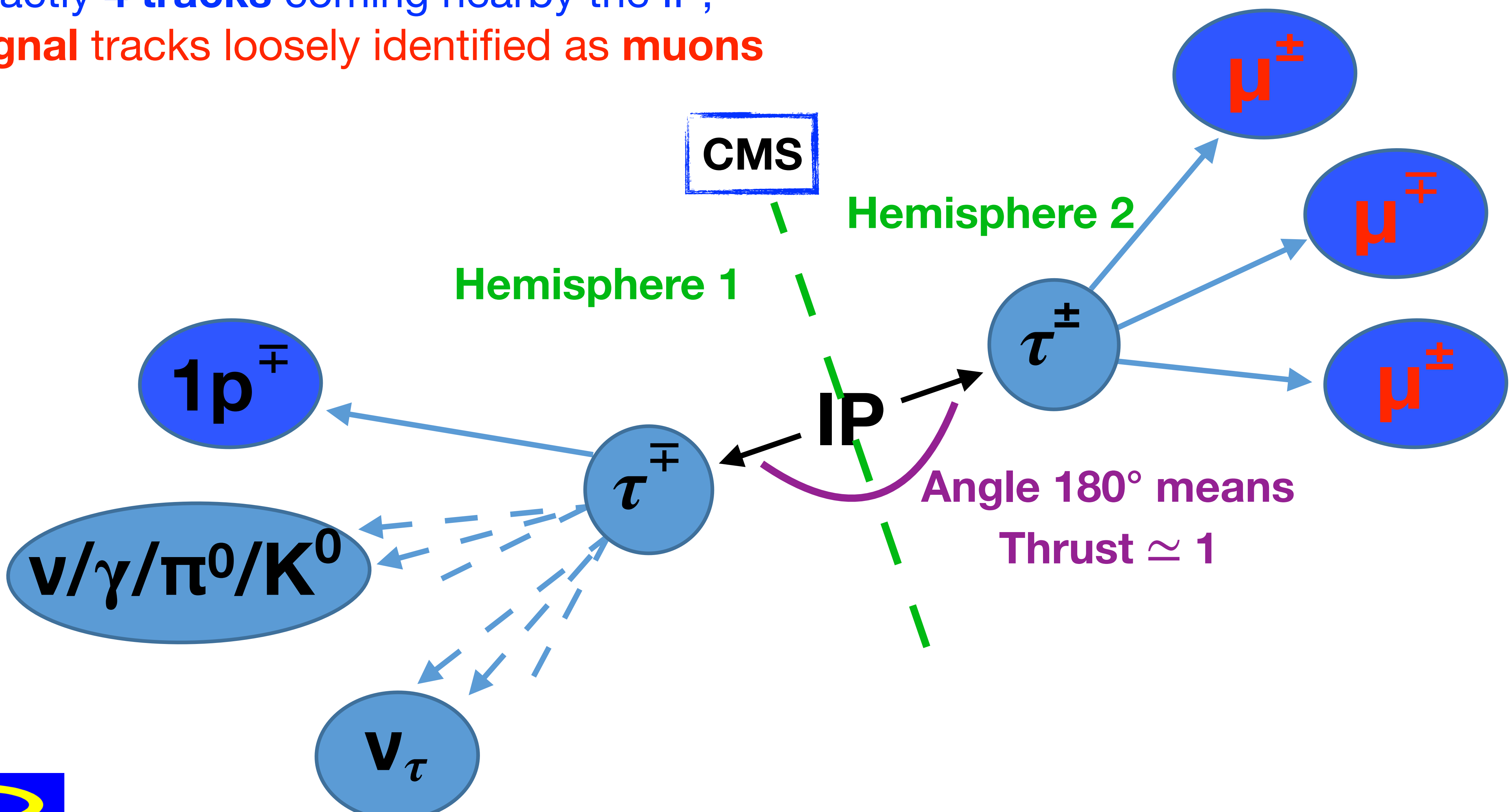
- the two τ point to opposite **hemispheres**;
- Exactly **4 tracks** coming nearby the IP;
- **Signal** tracks loosely identified as **muons**



Signal determination: signal region

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

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

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

$$\begin{matrix}\tau\ mass' \\ \tau\ \Delta E'\end{matrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} \tau\ mass' \\ \tau\ \Delta E' \end{pmatrix}$$

with $\theta \simeq 75°$

Belle II

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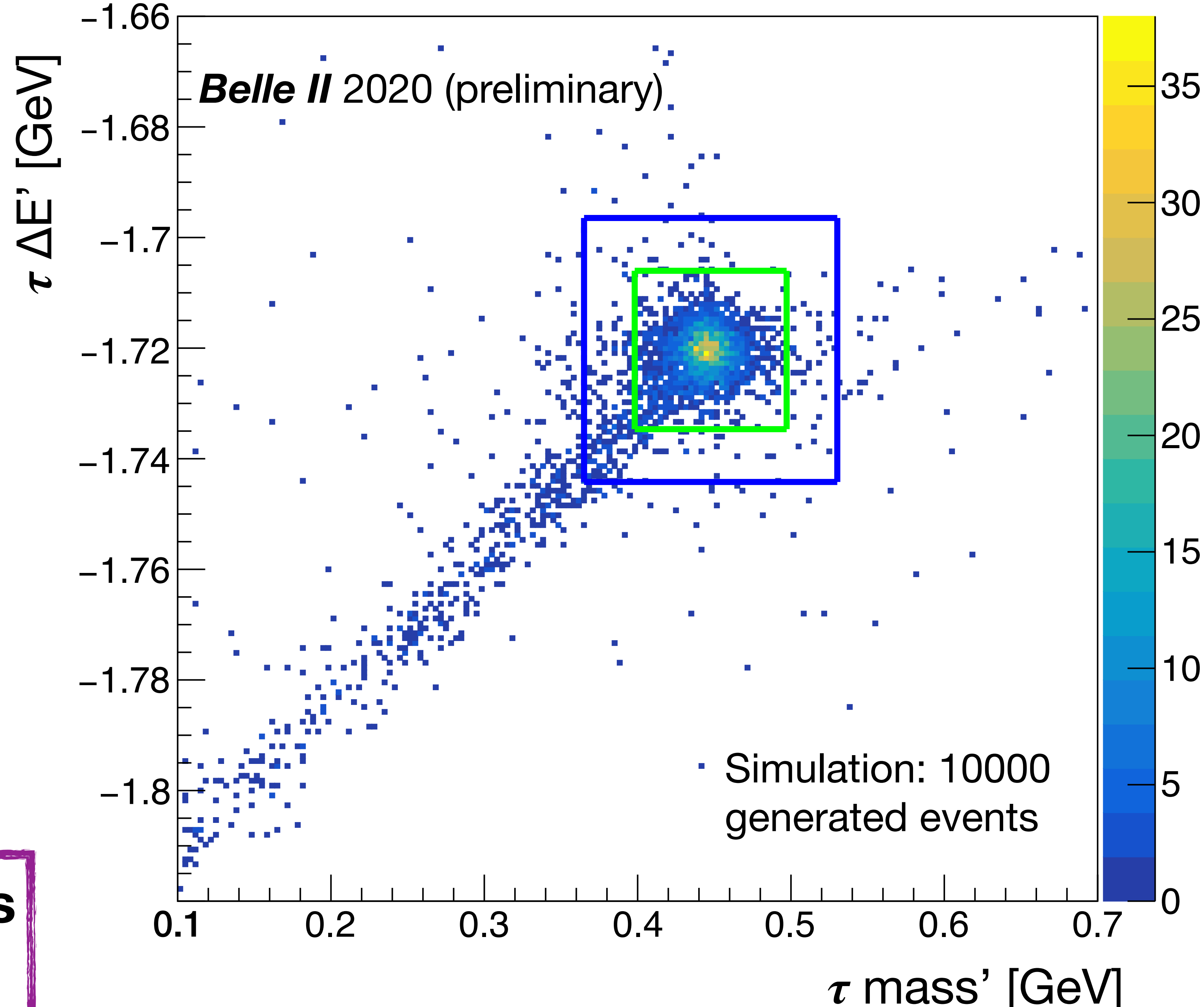
5σ window

3σ window:
0.4GeV < m < 0.5GeV
-1.734GeV<ΔE<-1.706GeV

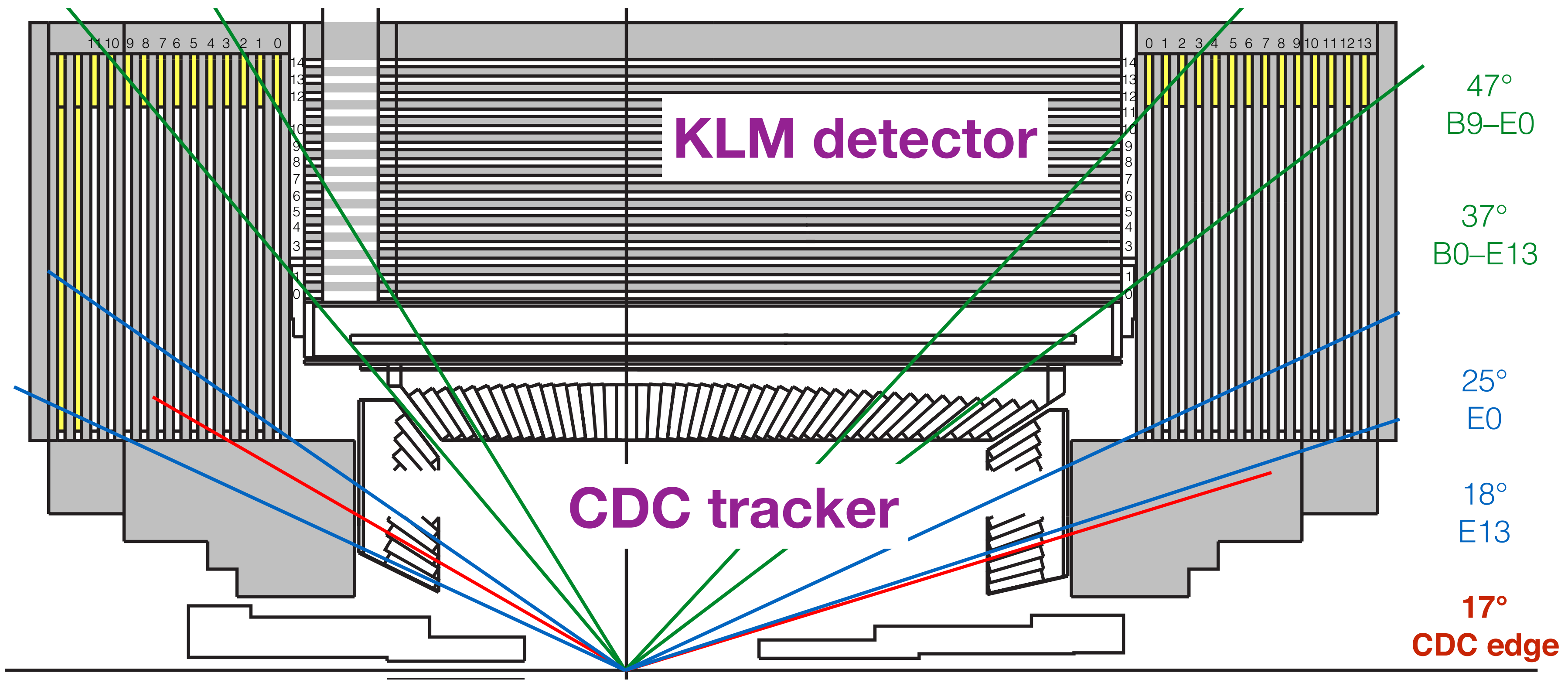
3σ window chosen as signal region

ΔE' VS τ mass' of signal τ



Signal-background rejection: signal side

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



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Momentum ranges:

- Pμ<0.7 GeV: μ do not reach the μ detector (KLM)
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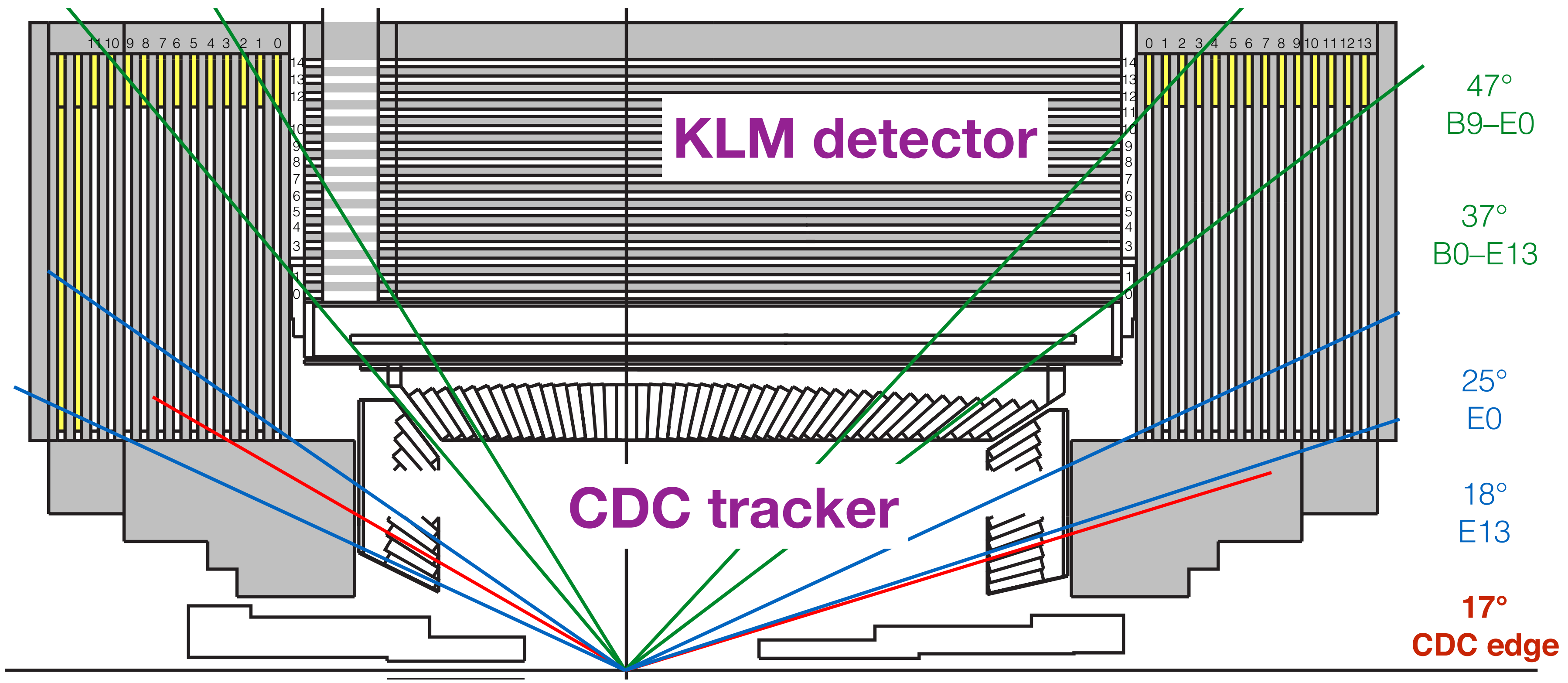

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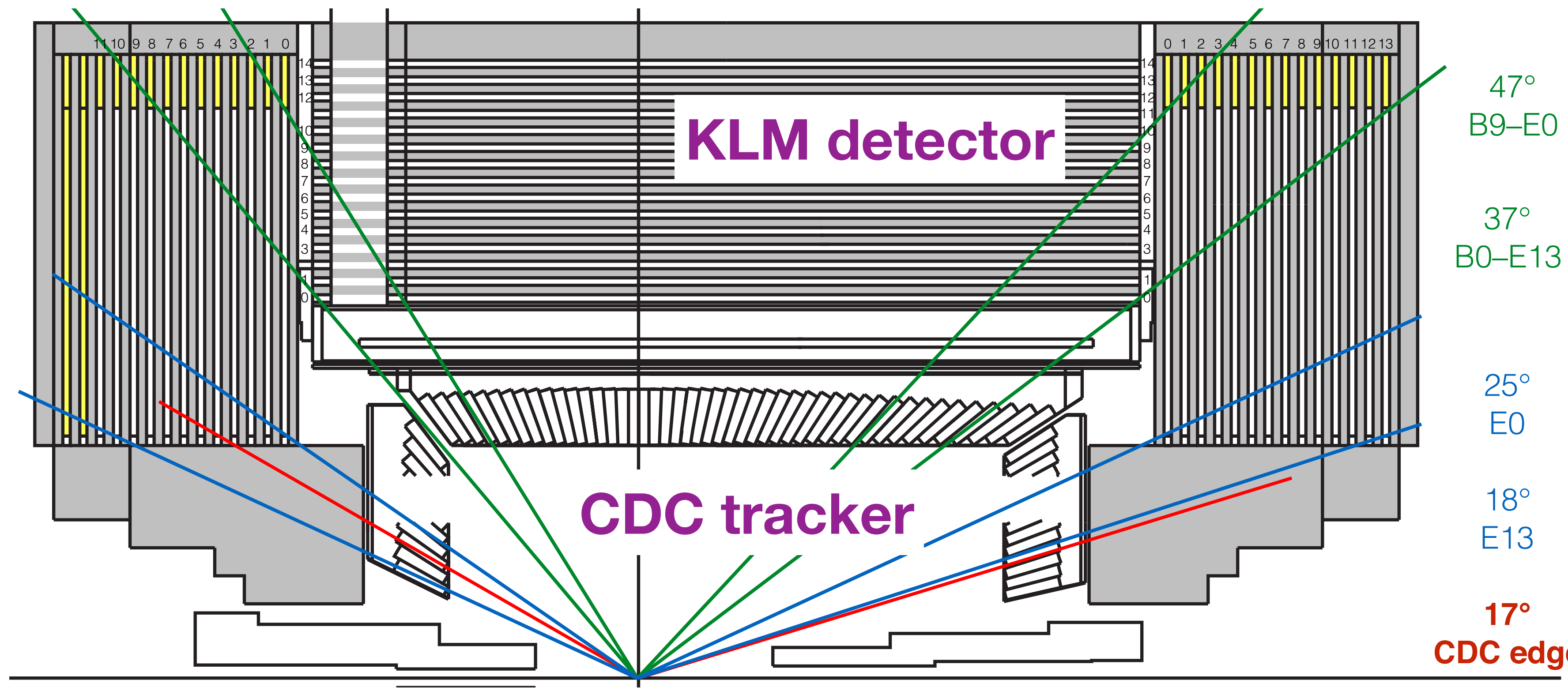

Optimization of the μID cuts depending on 3 momentum ranges

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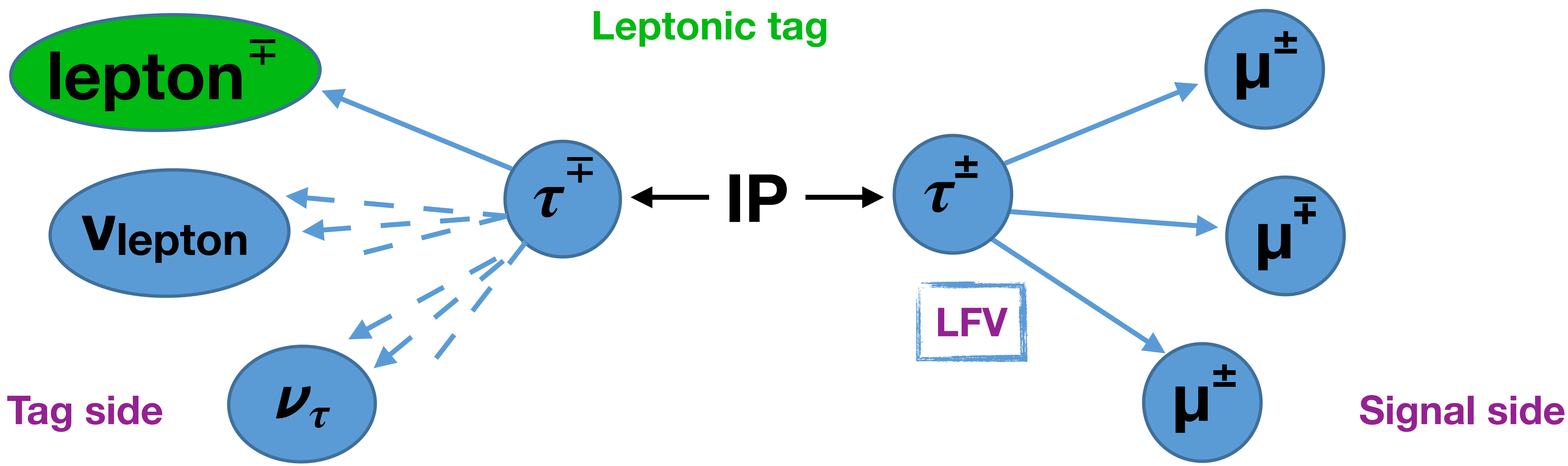
Extract the best combination of tight cuts for the analysis

Signal-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

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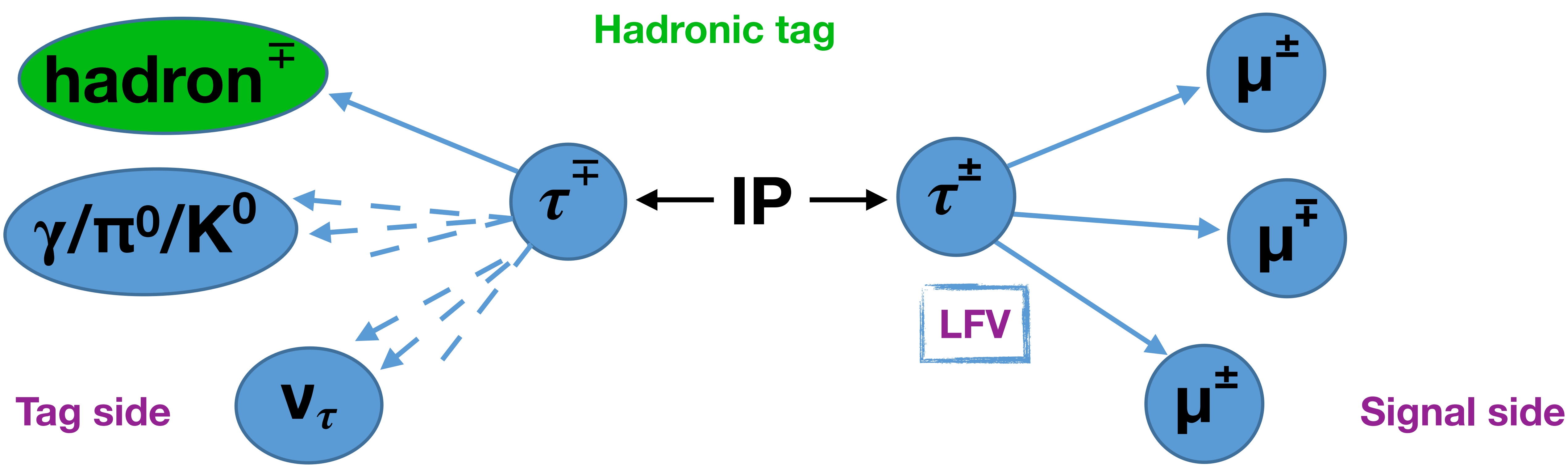

In case of hadronic tag the missing energy on the tag side is lower (1 neutrino) and hadronID performances come into play

Signal-background rejection: tag side

Backgroud sources: $u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$ (continuum) + $\tau\tau, \mu\mu\gamma, 4\mu, ee\mu\mu$

Most discriminating variables are:

- **Tag side** τ $\Delta E = E_{\tau_{tag}} - E_{beam}$ → suppress continuum background (mostly hadronic tag)
- **Missing momentum of the event** → suppress continuum background and $e^+e^- \to 4\mu$
- **Tag side τ mass** → suppress continuum background (mostly leptonic tag)
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Independently vary the last 3 variables (together with μID) to maximise a Figure Of Merit (fom) →

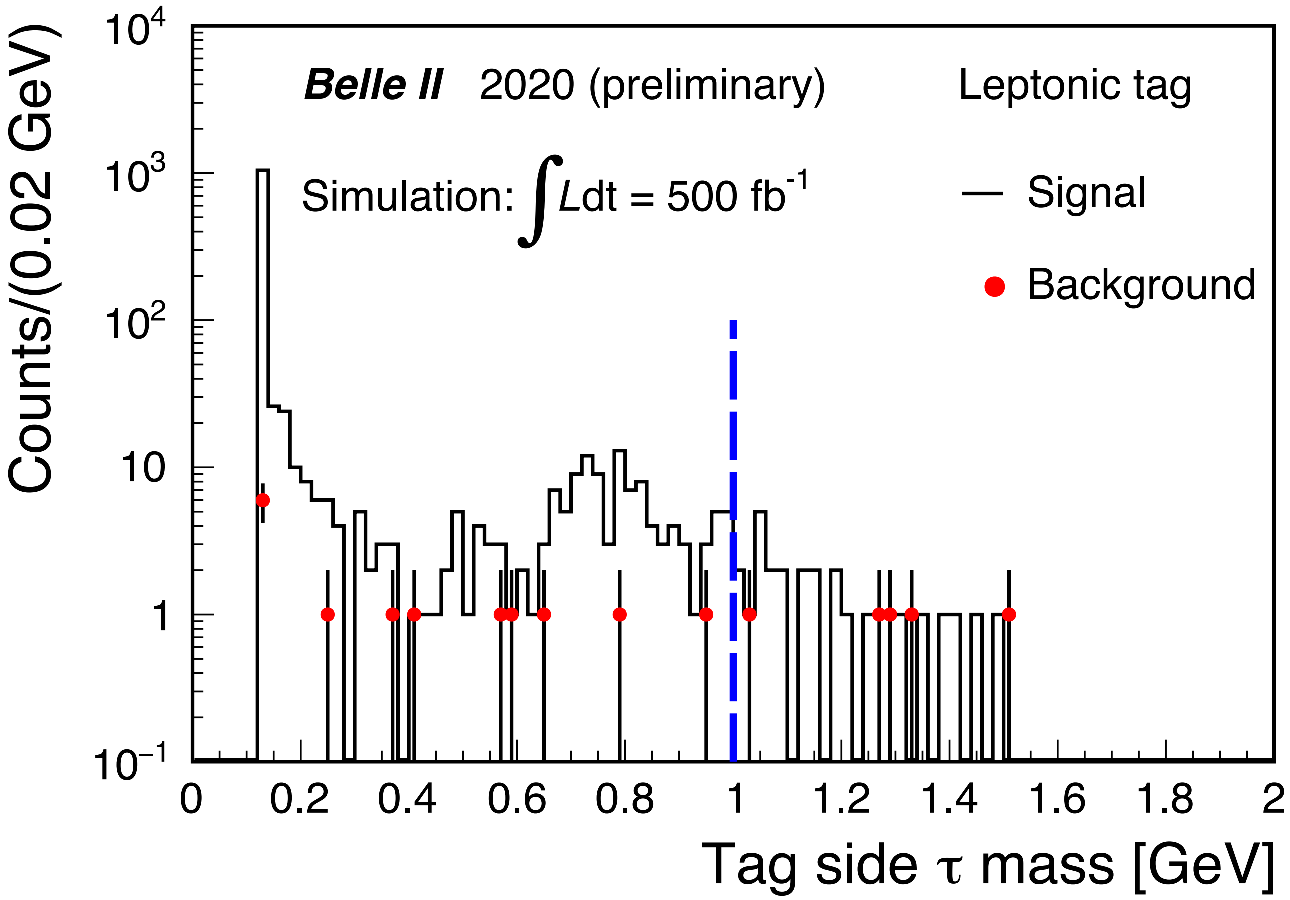
Punzi fom optimization:

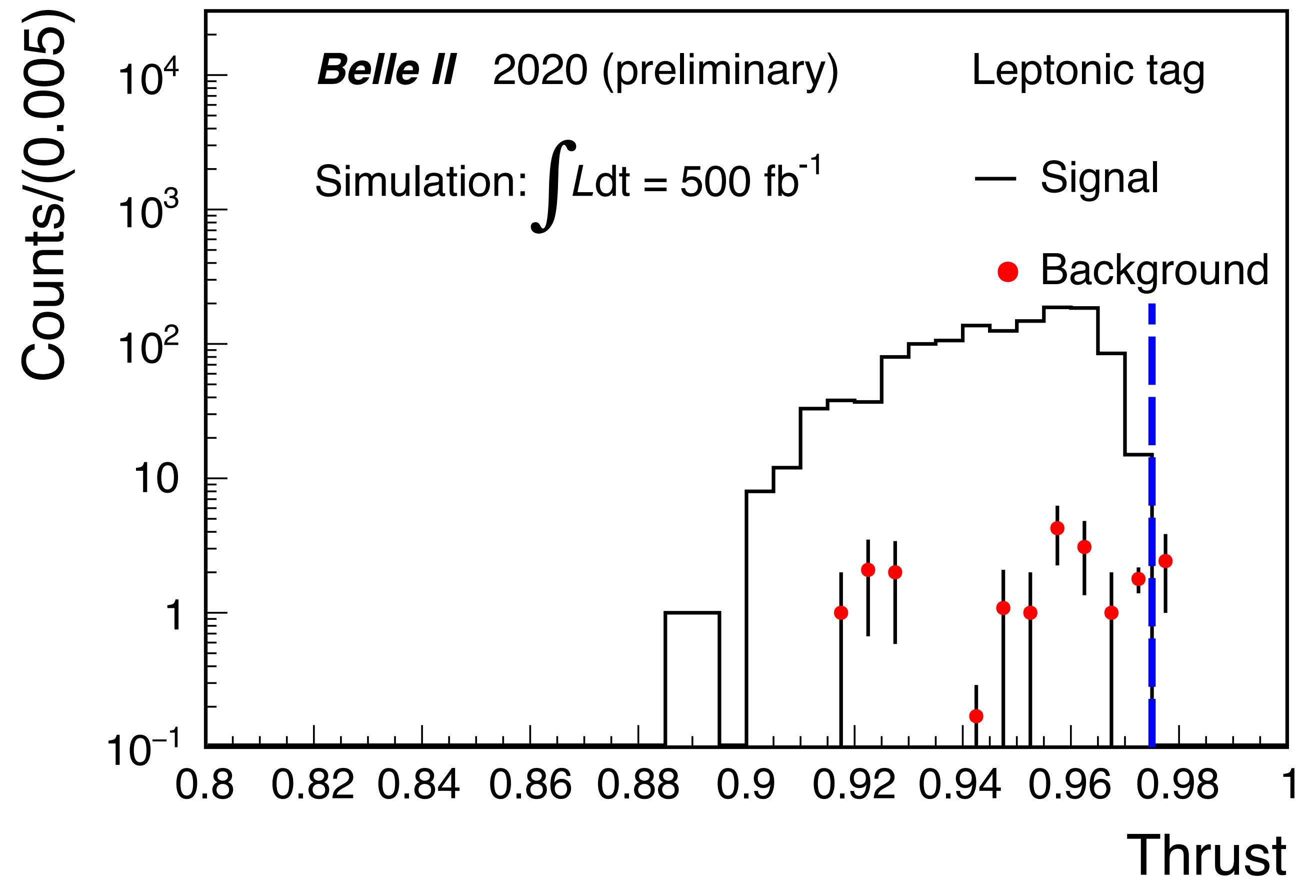
$$\mathbf{fom} = \frac{\mathbf{Sig_{eff}}}{\alpha/2 + \sqrt{\mathbf{\#Bkg}}}$$

α=1.64 at 90% CL

Final results and conclusions

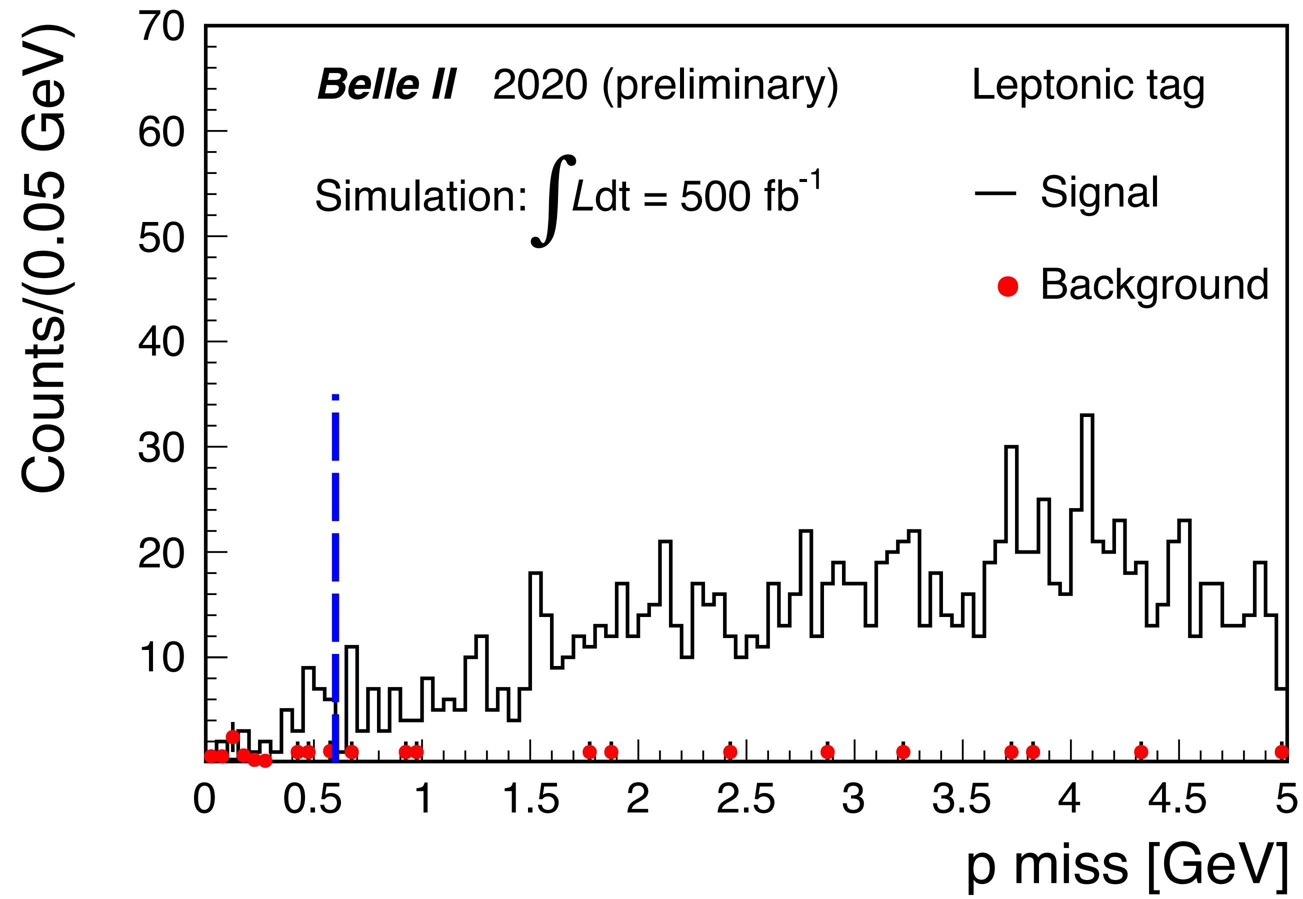
Optimized cut results





Leptonic tag

μID probability cuts:
p<0.7 GeV: μID>0.6
0.7<Pμ<1 GeV: μID>0.5
p>1 GeV: μID>0.7



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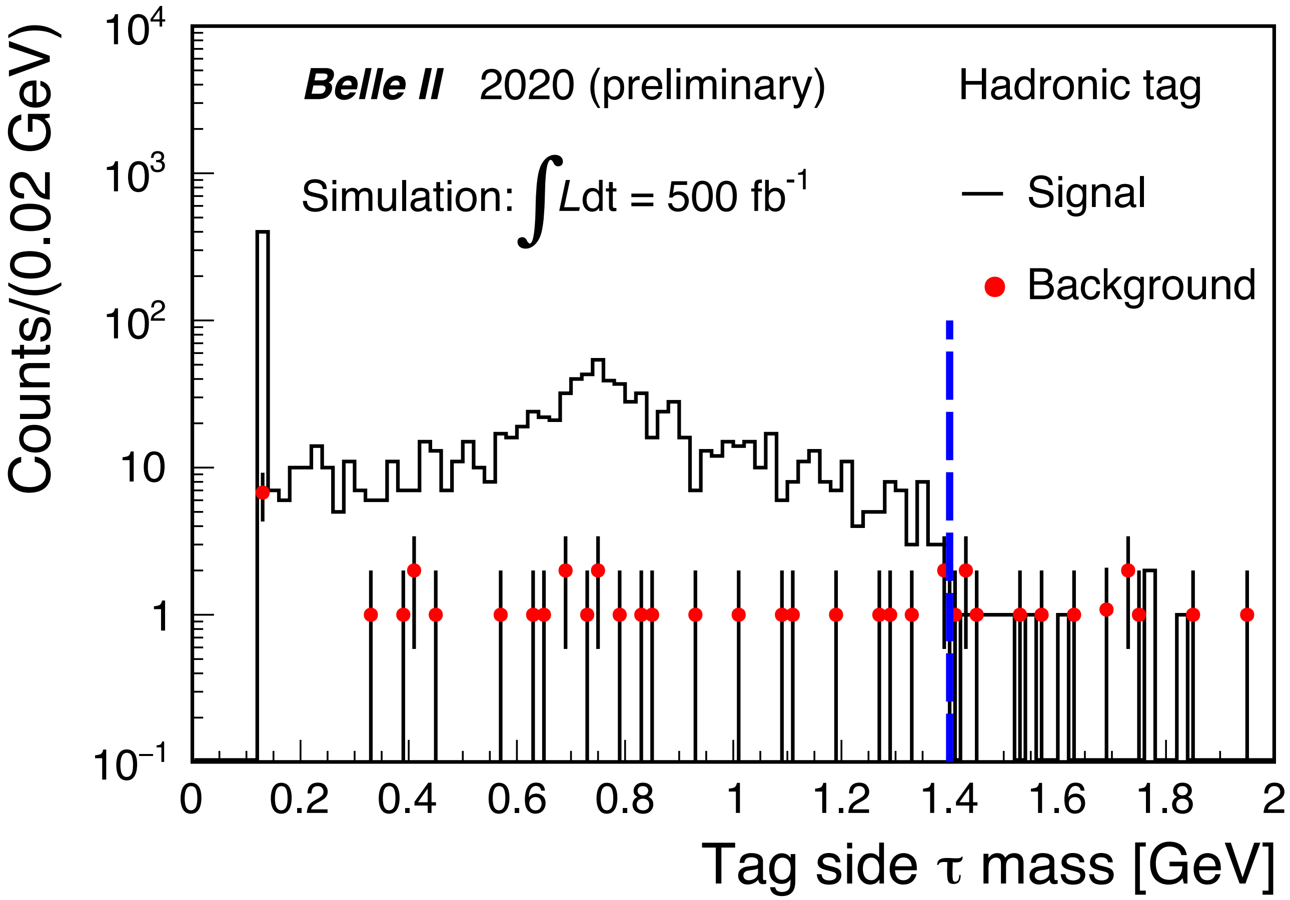
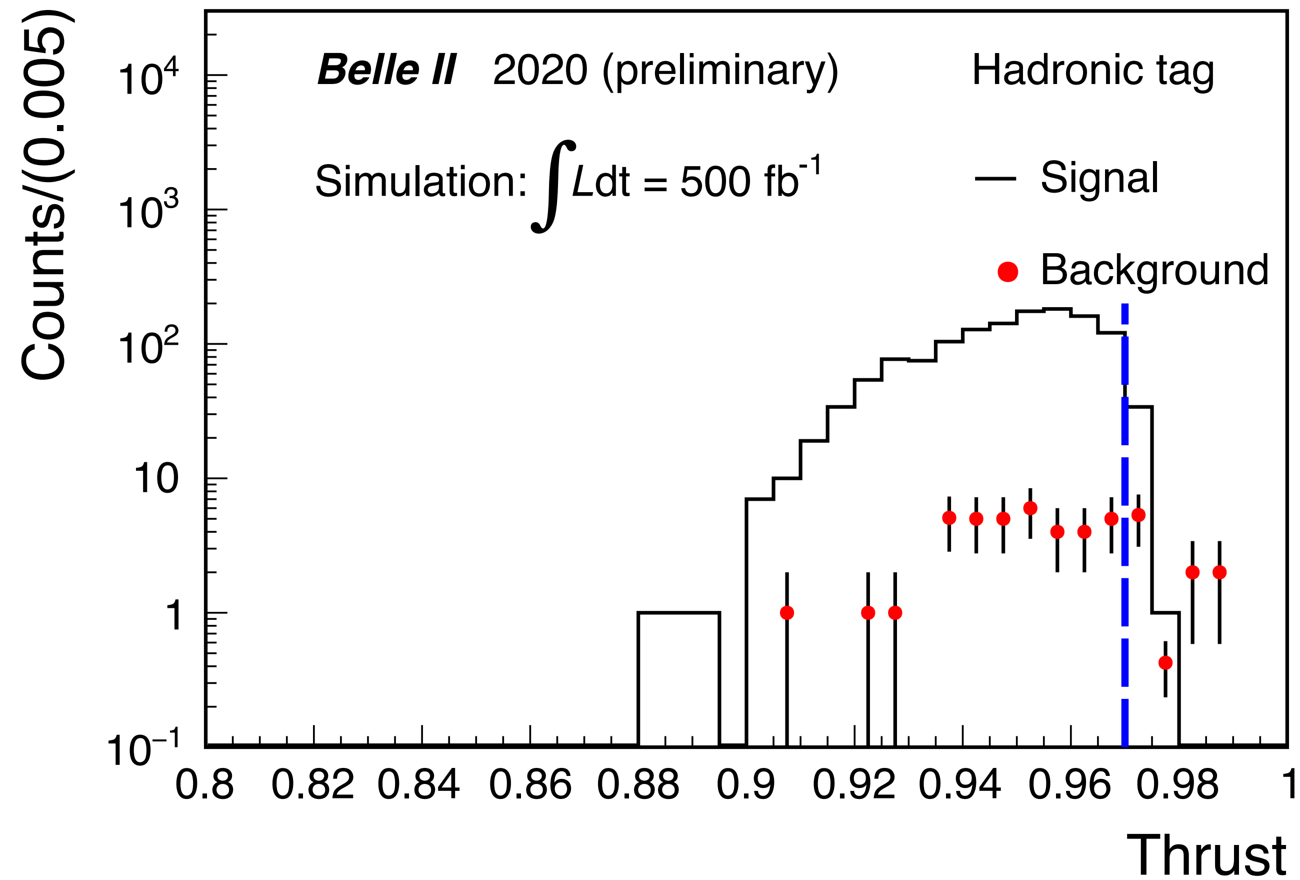




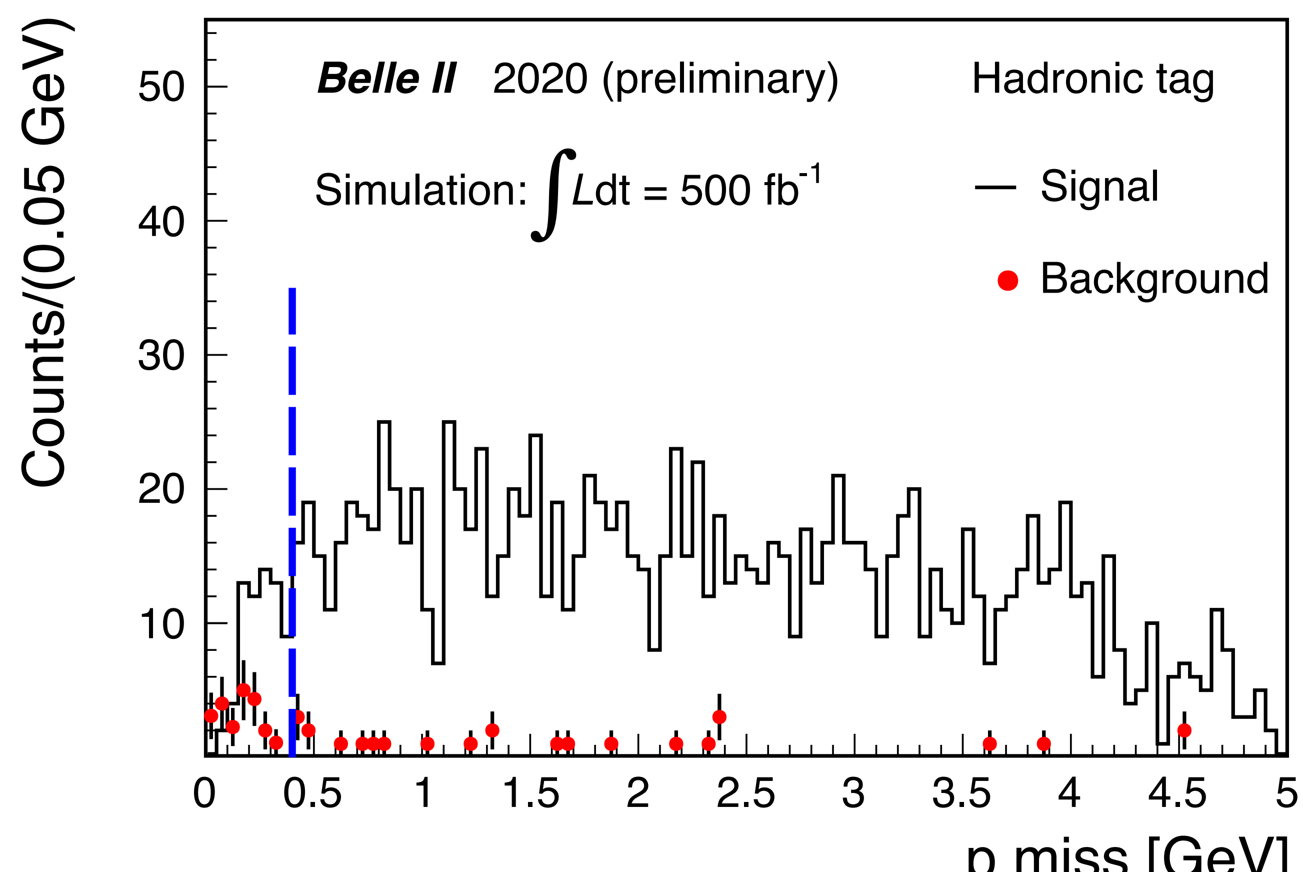
Hadronic tag

μID probability cuts:

p<0.7 GeV: μID>0.7

0.7<Pμ<1 GeV: μID>0.5

p>1 GeV: μID>0.9



Preliminary MC results

\\	# expected bkg	Sig Efficiency (%)	Punzi fom value
leptonic tag	1	11.58	0.063
hadronic tag	0	10.82	0.129
Total	**1**	**22.4**	**0.123**

No data-MC discrepancies are taken into account but…

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Belle estimation of the same fom	**0.13**	**7.6**	**0.064**

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No systematics are taken into account yet → **BF limit** estimation will come **after a complete systematic study**

Conclusion and future prospects

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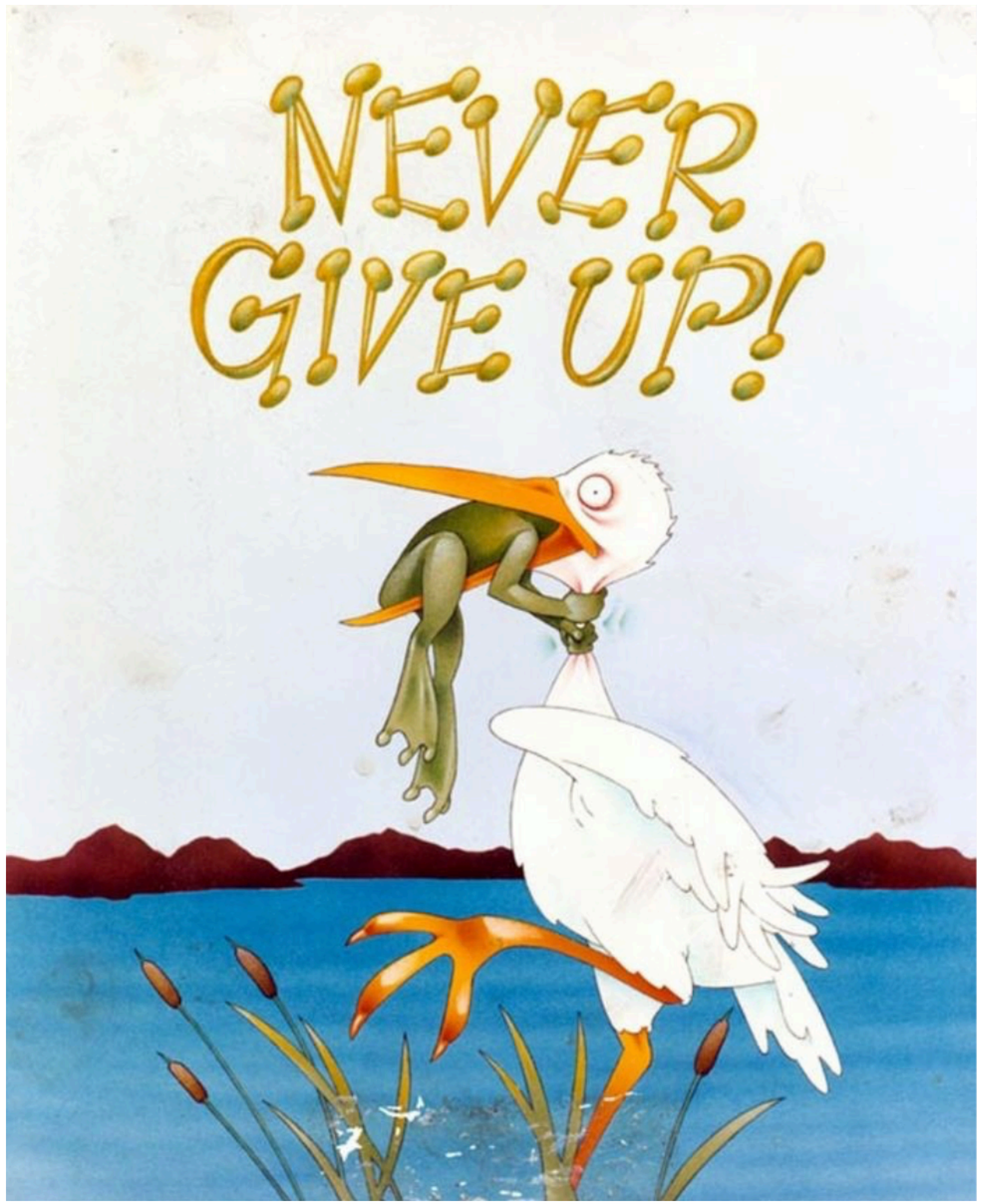
NEXT STEP

- Use a larger MC sample → get a more stable optimisation procedure and reduce uncertainties on expected background events;
- Insertion of data-MC discrepancies;
- Look at the data outside and inside the signal region.

Emergency slides!!



Dataset

MC signal sample: 10000 events

Signal channel: $e^+e^- \to \tau\, [\to 1prong]\ \tau\, [\to 3\mu]$

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

MC background samples:

- Continuum: $u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$
- τ pairs

→ **500 fb^{-1}**

- **Low multiplicity:**
  - $e^+e^- \to e^+e^-\mu^+\mu^-$
  - $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$
  - $e^+e^- \to \mu^+\mu^- (\gamma)$

→ **Weighted to 500 fb^{-1}**

- **Low multiplicity weights:**
  - $e^+e^- \to e^+e^-\mu^+\mu^-$ 100M evts & Int Lumi: 5.29 fb^{-1} → Weight: **94.5**
  - $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$ 2M evts & Int Lumi: 5.88 ab^{-1} → Weight: **0.085**
  - $e^+e^- \to \mu^+\mu^- (\gamma)$ 55M evts & Int Lumi: 47.91 fb^{-1} → Weight: **10.4**

Belle II

Comparison with Belle results

Deeper investigation of the variables used by Belle/BaBar:
It seems that there are no more powerful variables available

Reproduced Belle results to check the efficiency discrepancy

Applying Belle cuts I got **~8% efficiency**, the main reasons are:

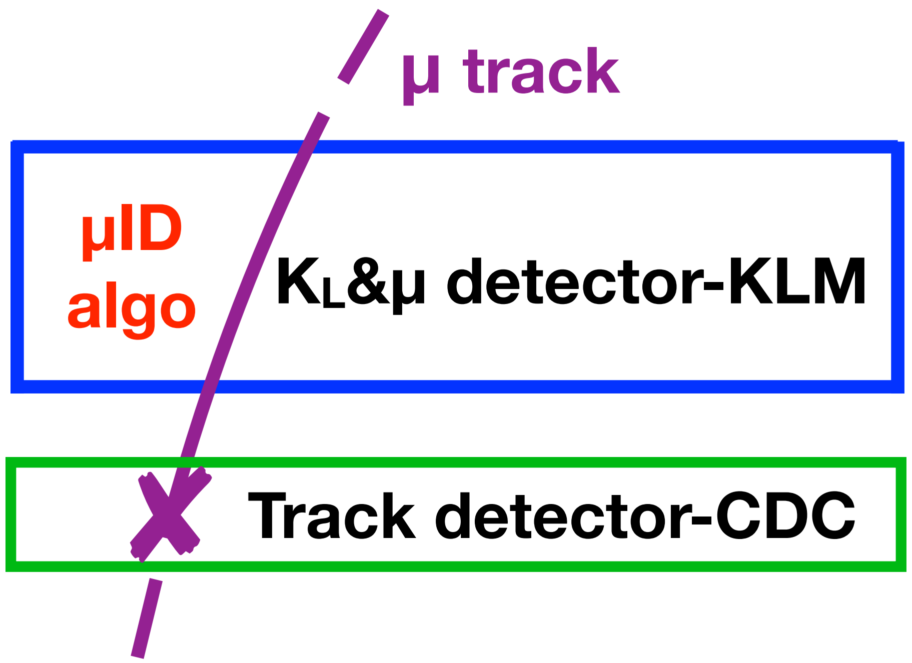
- **μID and p_μ>0.6;**
- **track on the tag side not identified as μ.**

A better μID algorithm is a key role in the analysis final results

Belle μID efficiency $\simeq 85\,\%$
BaBar μID efficiency $\simeq 77\,\%$

Belle II efficiency $\simeq \mathbf{93}\,\%$

μ identification

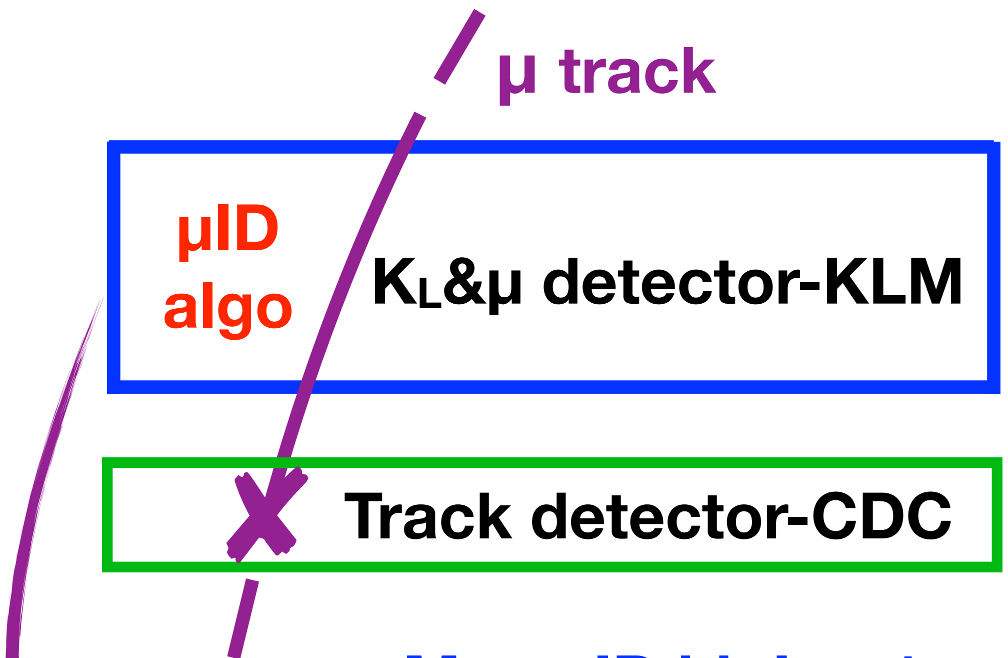


Muon identification process

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.

μ identification



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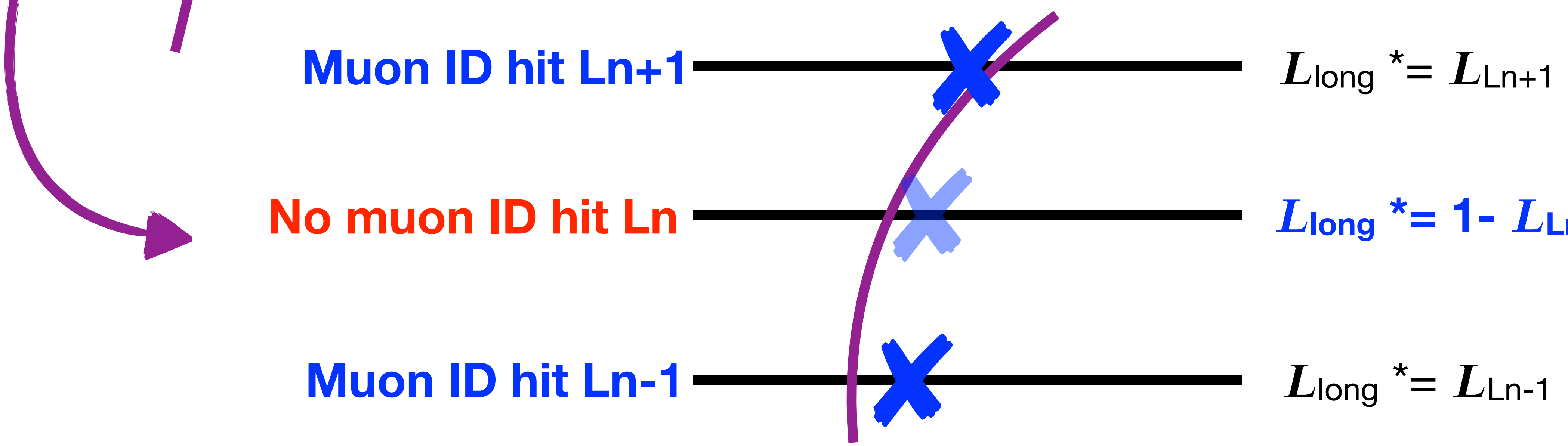

$\mathcal{L}_{Ln}$= probability of having a hit in the Ln layer, for a particle hypothesis (MC pre-calculation)

$\mathcal{L}_{long}= \prod_{n=1}^{n_{OuterExt}} \mathcal{L}_{Ln}$ is the longitudinal probability of a track to be the hypothesised particle.

In order to correctly treat inefficient layers, if there are no hits in the layer → take into account efficiencies and store: 1- $\mathcal{L}_{Ln}$ * Eff_{Ln}