Lepton Number Violation in Taus at Belle II

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Outline

- Lepton Number Violation
- Taus
- The Belle II detector
- Analysis

Lepton number violation

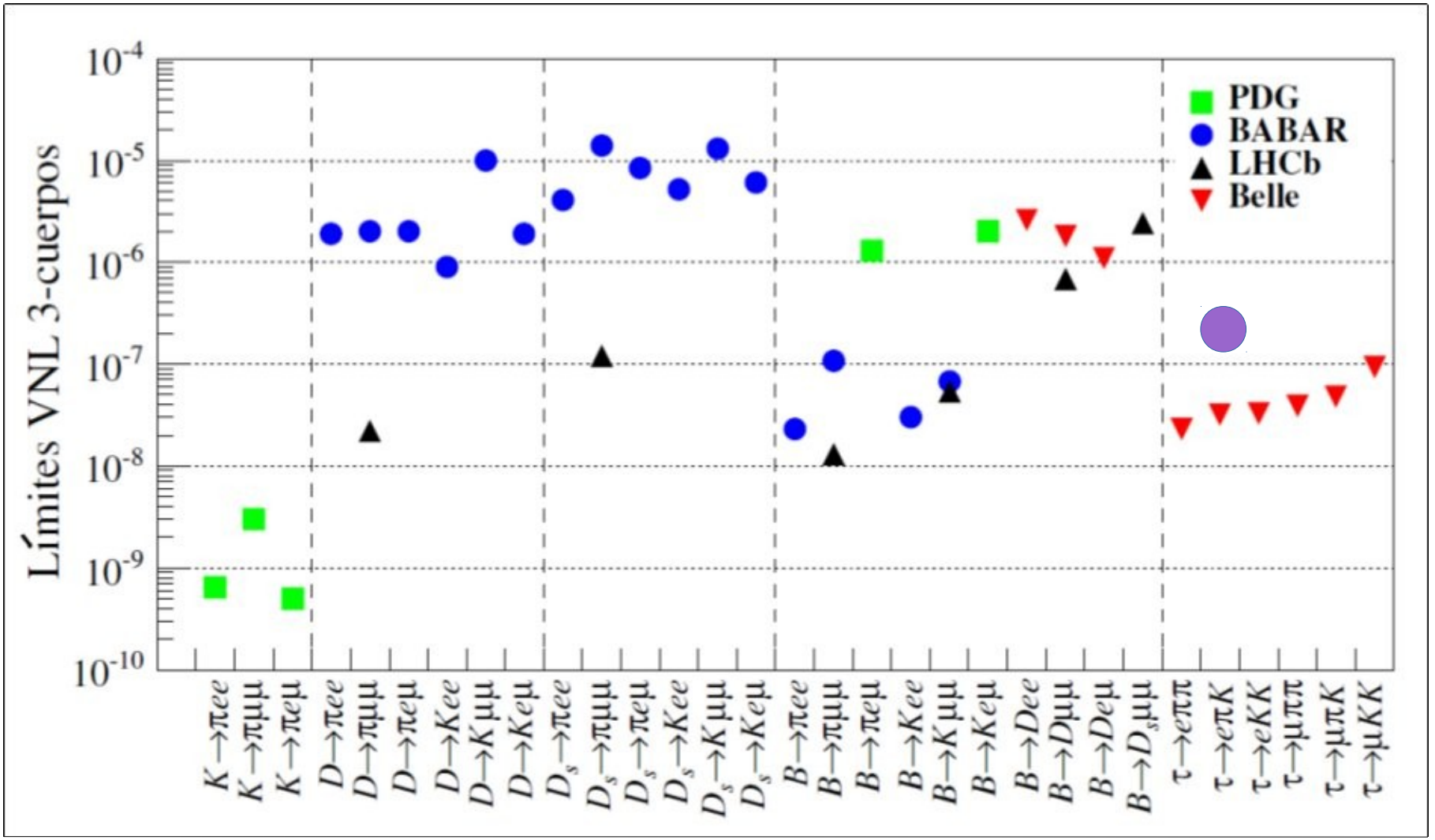
- Quite simple N(L)-N(anti-L) is a conserved quantity, accidental symmetry
- If you look for it 61,500 results in Google schollar 3450 in 2016
- After neutrino oscillations very active field

Many approaches to LNV

- https://arxiv.org/abs/1607.06328 331 models (Extended Standard Model)
- https://arxiv.org/pdf/1605.03625v2.pdf Light sterile neutrinos (SM)
- http://dx.doi.org/10.1016/j.physletb.2016.07.043

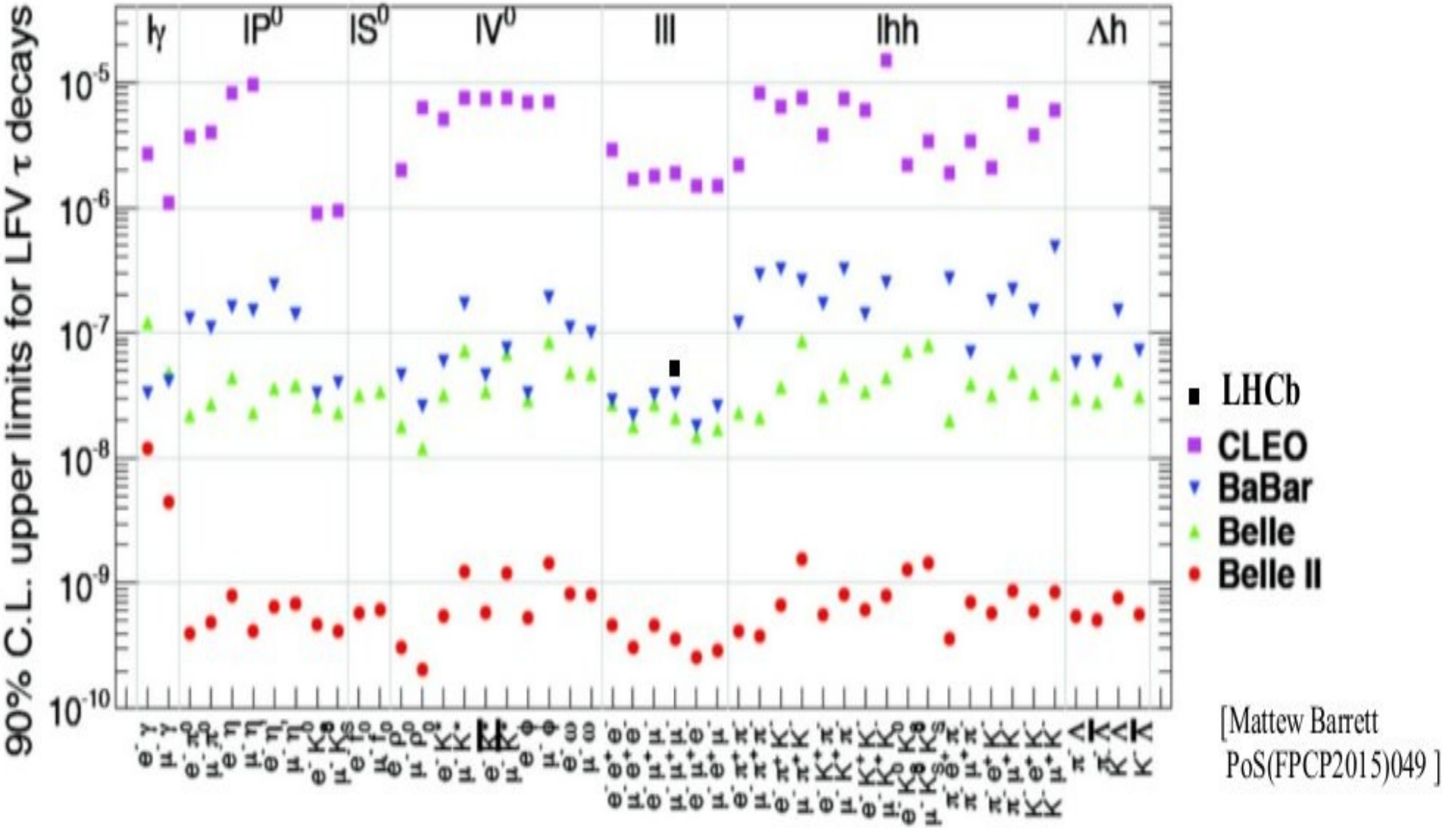
  Double beta decay (Majorana or Dirac SM)

LNV in accelerators (N=2)



The Searches are (barion) → barion + lepton + lepton
(lepton) → lepton + barion + barion

Tau- → p- mu+ mu-, tau- → p mu- mu- (August 2016)



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- Tau- → p- mu+ mu-, tau- → p mu- mu- (August 2016)

NP in τ

Belle II physics prospect – tau physics

$\tau \to \mu\gamma$

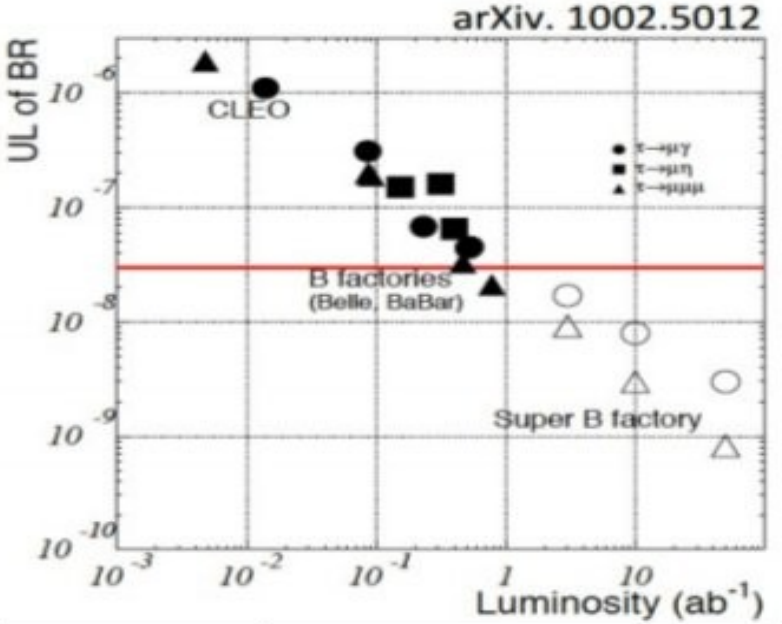
main background from $ee \to \mu\mu\gamma_{ISR}$

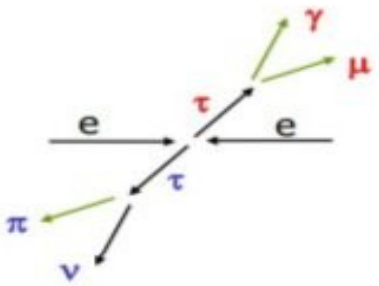
possible to reduce sensitivity by a factor ~7

$\tau \to \mu\mu\mu$

very clean mode

possible to reduce sensitivity by a factor of 50



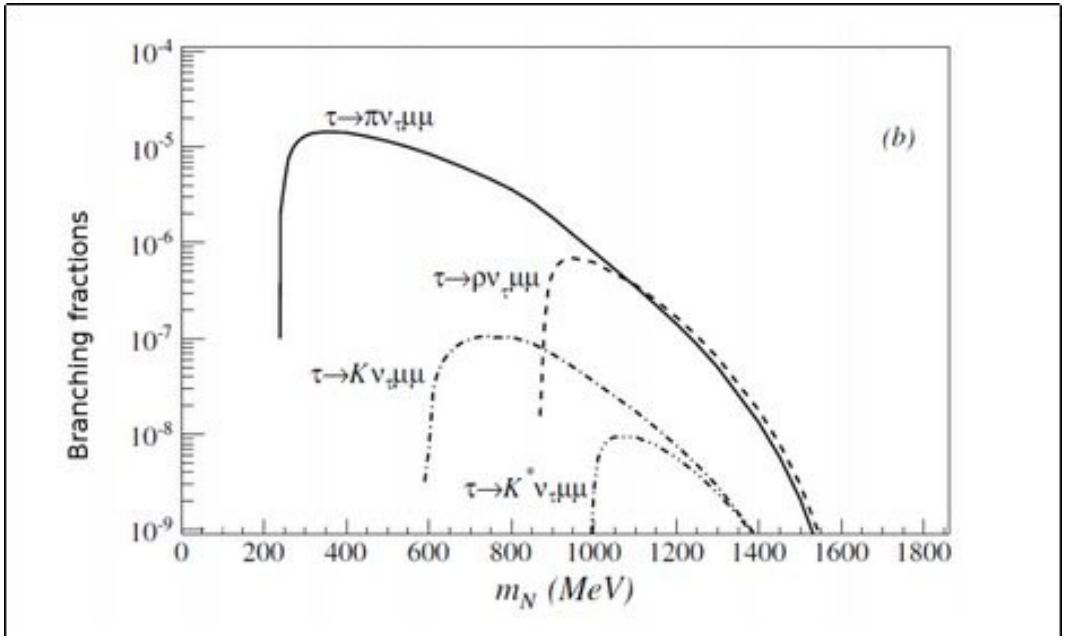


	$\mathcal{B}(\tau \to \mu\gamma)$	$\mathcal{B}(\tau \to \mu\mu\mu)$	
mSUGRA+seesaw	10^{-7}	10^{-9}	PRD 66(2002) 115013
SUSY+SO(10)	10^{-8}	10^{-10}	PRD 68(2003) 033012
SM+seesaw	10^{-9}	10^{-10}	PRD 66(2002) 034008
Non-Universal Z'	10^{-9}	10^{-8}	PLB 547(2002) 252
SUSY+Higgs	10^{-10}	10^{-7}	PLB 566(2003) 217

possible reach by Belle II (50 ab^{-1}) $<10^{-9}$ $< 10^{-10}$ → good to test NP models

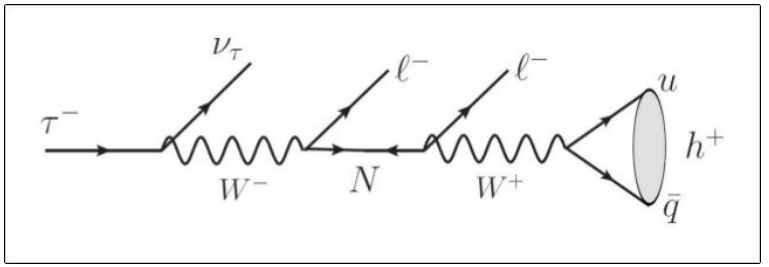
G. López Castro and N. Quintero (Phys. Rev. D 85 (2012) 076006)

Study of four-body $\tau^{\pm} \to \nu_\tau l^{\pm} l^{\pm} X^{\mp}$ decays where l = e or μ and X = n, K, ρ and K^* mesons. These decay processes violate the total lepton number ($\Delta L = 2$) and can be induced by the exchange of Majorana neutrinos. We consider an scenario where these decays are dominated by the exchange of only one heavy neutrino which produces an enhancement of the decay amplitude via the resonant mechanism.



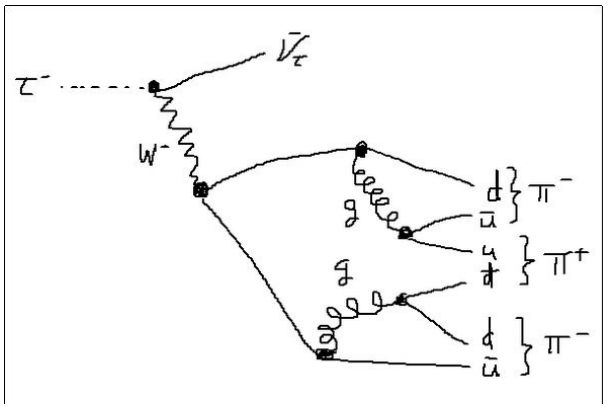
The Good

$$\tau- \to \pi^+\mu^-\mu^-\nu_\tau \text{ (BR} \lesssim 10^{-8}\%)$$



The bad

$$\tau- \to \pi^+\pi^-\pi^-\nu_\tau \text{ (BR } 9.31 \pm 0.06\%)$$



The ugly

$$\tau- \to \pi^-\mu^+\mu^-\nu_\tau \text{ (BR} \sim 10^{-6}\%)$$

SuperKEKB and Belle II x40 Higher luminosity!!

Belle II

New superconducting /permanent final focusing quads near the IP

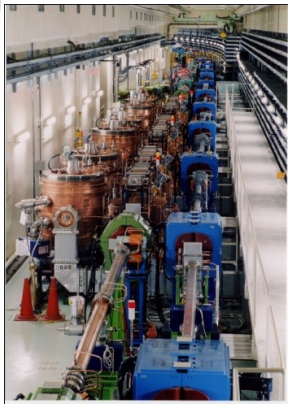
New IP

Colliding bunches

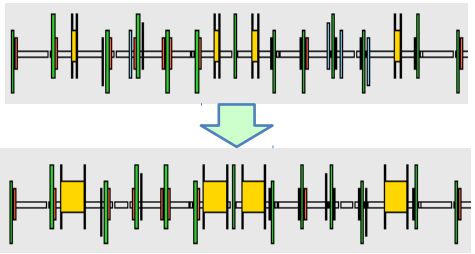
e+ 4GeV 3.6 A

e- 7GeV 2.6 A

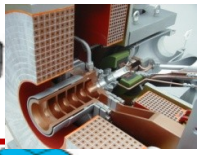
Target: L = 8×10^{35}/cm2/s



Replace short dipoles with longer ones (LER)



Add / modify RF systems for higher beam current



Positron source

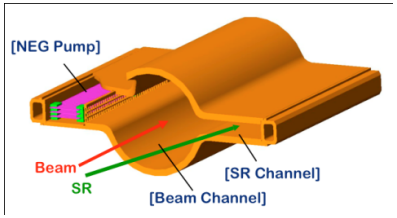
New positron target / capture section

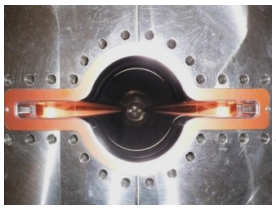
Damping ring

Low emittance positrons to inject

Low emittance gun

TiN-coated beam pipe with antechambers





$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

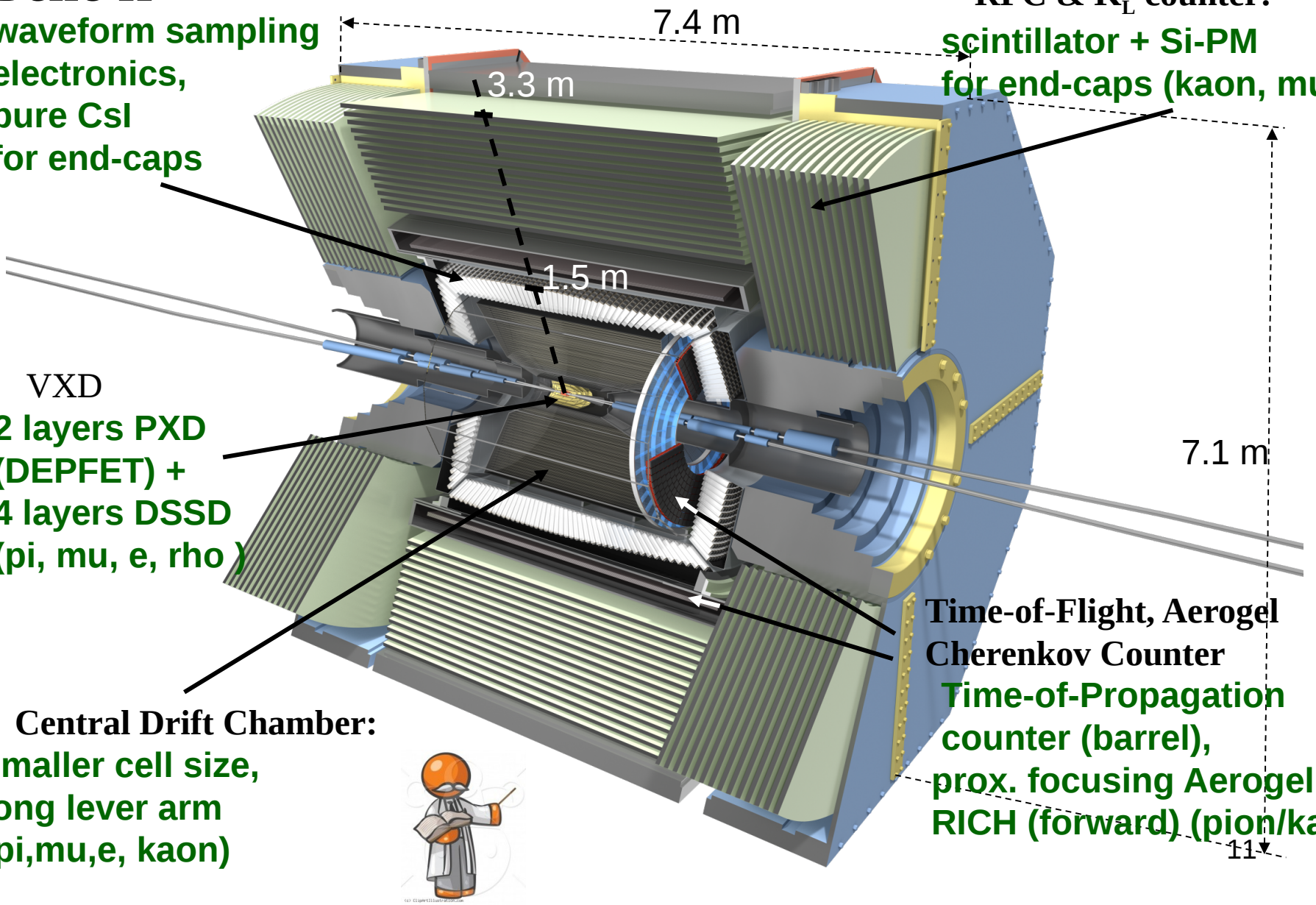
Low emittance electrons to inject

Belle II detector upgrade

Belle II

waveform sampling electronics, pure CsI for end-caps

RPC & K_L counter:
scintillator + Si-PM for end-caps (kaon, muons)



VXD
2 layers PXD (DEPFET) + 4 layers DSSD (pi, mu, e, rho)

Time-of-Flight, Aerogel Cherenkov Counter
Time-of-Propagation counter (barrel), prox. focusing Aerogel RICH (forward) (pion/kaon)

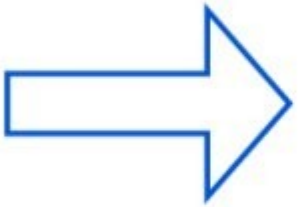
Central Drift Chamber:
smaller cell size, long lever arm (pi,mu,e, kaon)

40 billion of tau expected in the full run

Respuesta total del detector: hits, clusters, sincronización.

DST
ARICH
CDC
ECL
Tracks
PXD
SVD
TOP

"reconstrucción"



Trazas, PID, Fotones

mDST	
Track	Fit result
PID	Top
	ARICH
ECL	Shower
	Gamma
	π^0
	eID
dE/dx	CDC
	VXD
KLM	MuID
	KLID
Vertex	Ks
	Lambda

"fino"

Candidatos y topología del evento

μDST
Particle(Lists)
MCParticle
Vertex
Topology*
Tag*

TSDT para Taus

Simulation

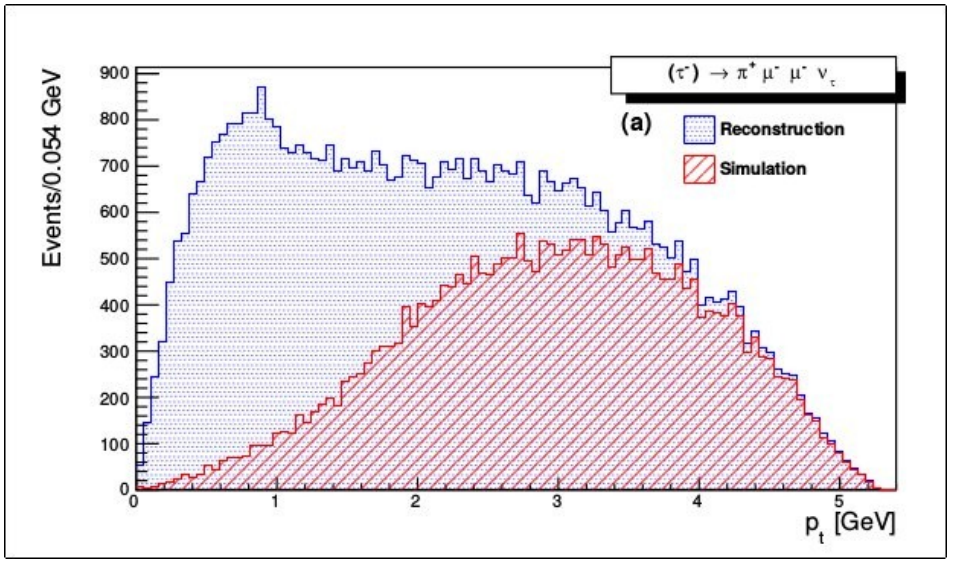
- KKMC generates ee → μμ(γ) and ee → τ τ (γ), the KKMC4.19.
- Experimental setup includes next to leading order (NLO) corrections to initial state radiation (ISR) and final state radiation (FSR),
- Final state masses are taken into account also for higher order QED corrections but the electron masses are neglected apart from kinematics effects.
- τ decays within KKMC are handled by the TAUOLA package and radiative correction to τ decays are included using the PHOTOS package.

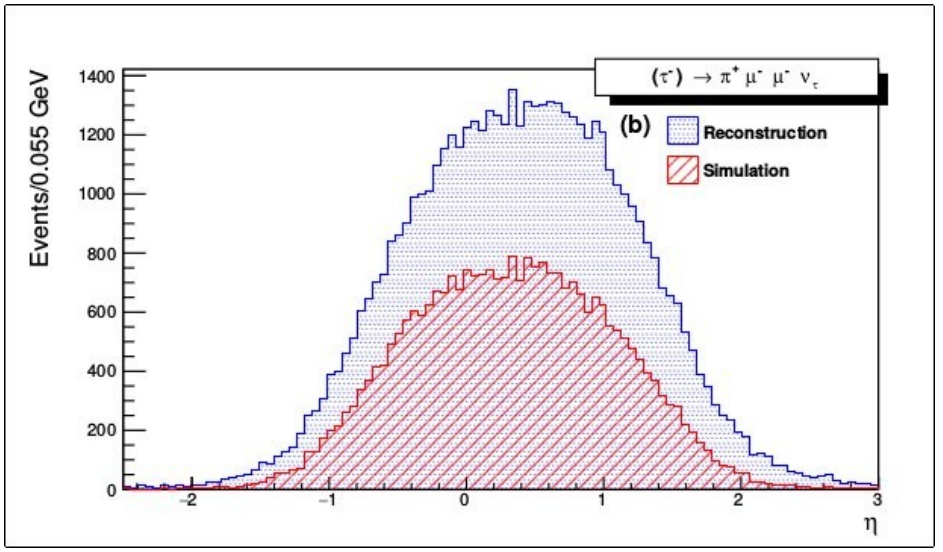
The variables

- Four momentum;
- Invariant mass of the particles;
- Vertex position;
- Number of associated Hits, PXD, SVD, CDC;
- Number of charged ECL Clusters;
- Track size;
- Pion and Muon ID probability

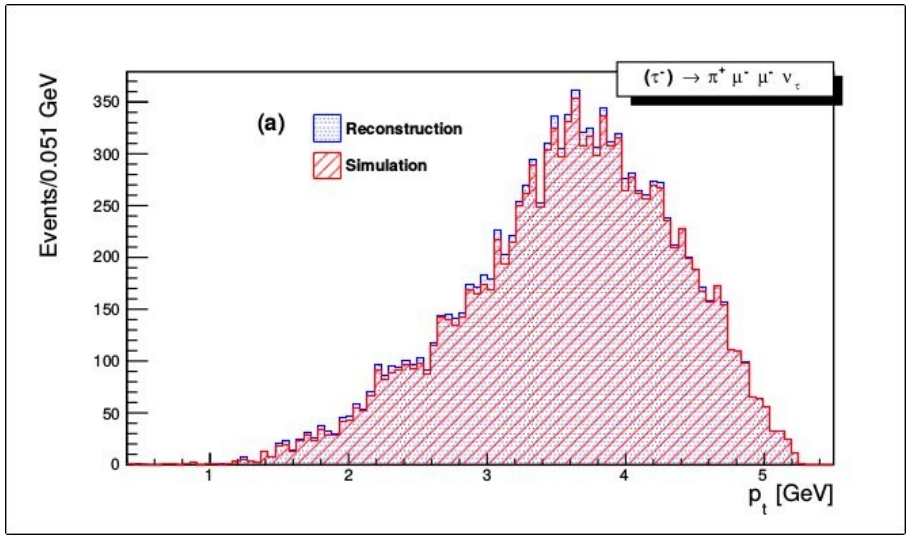
Reconstruction

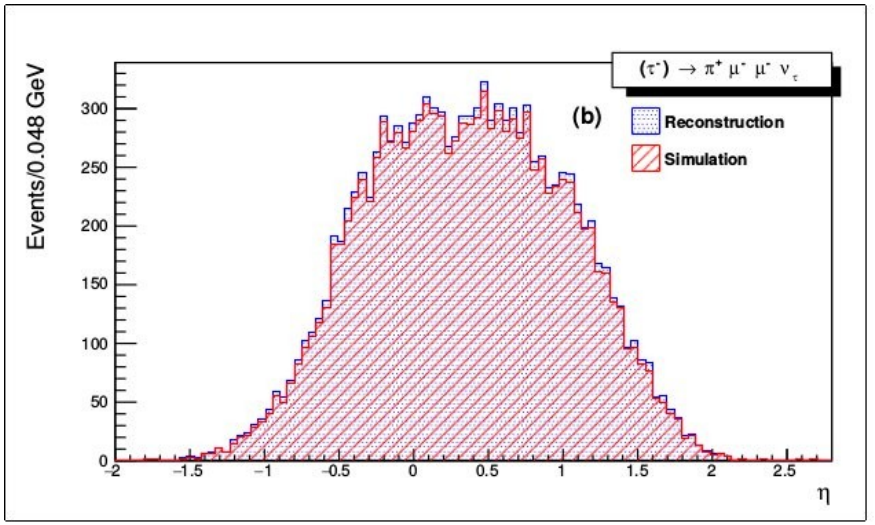
50 K events , 80 K recontructed, no PID





After optimization of the cuts

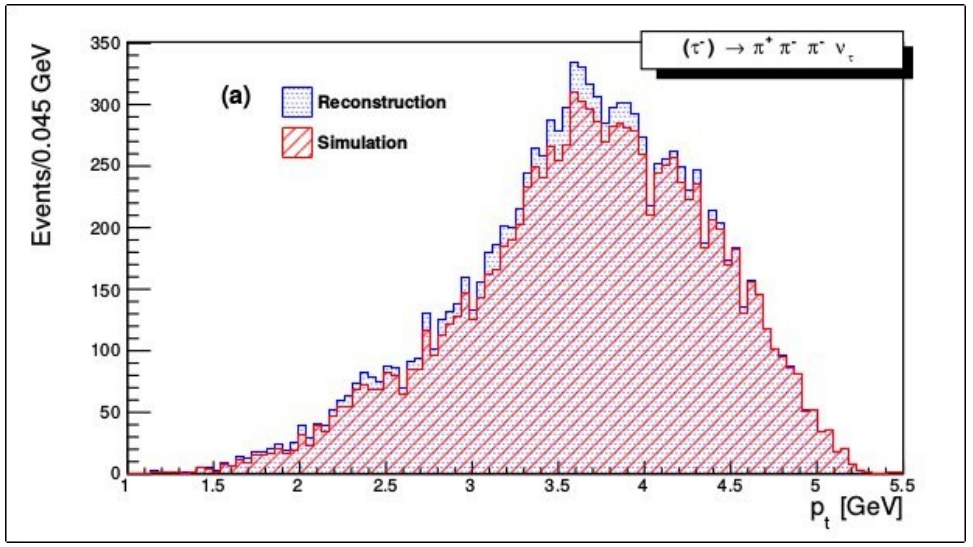


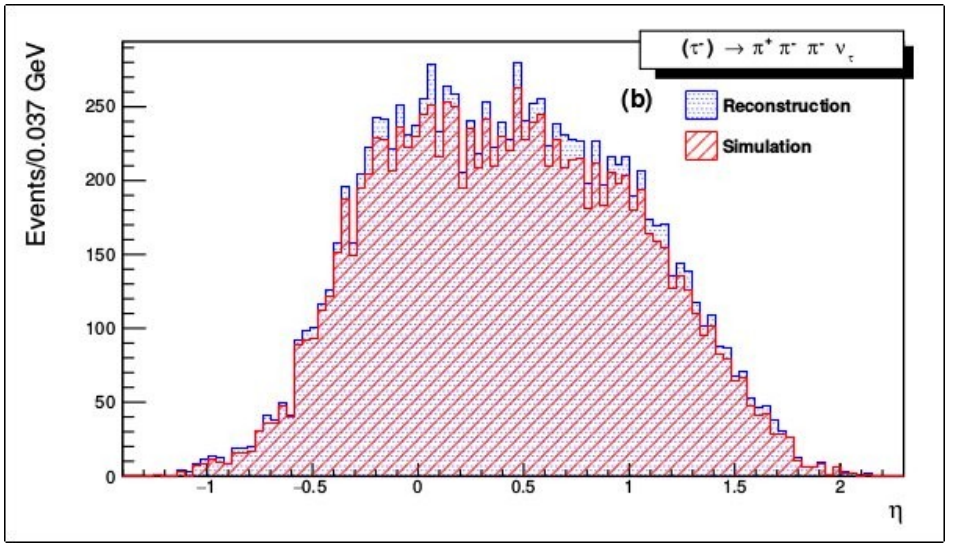


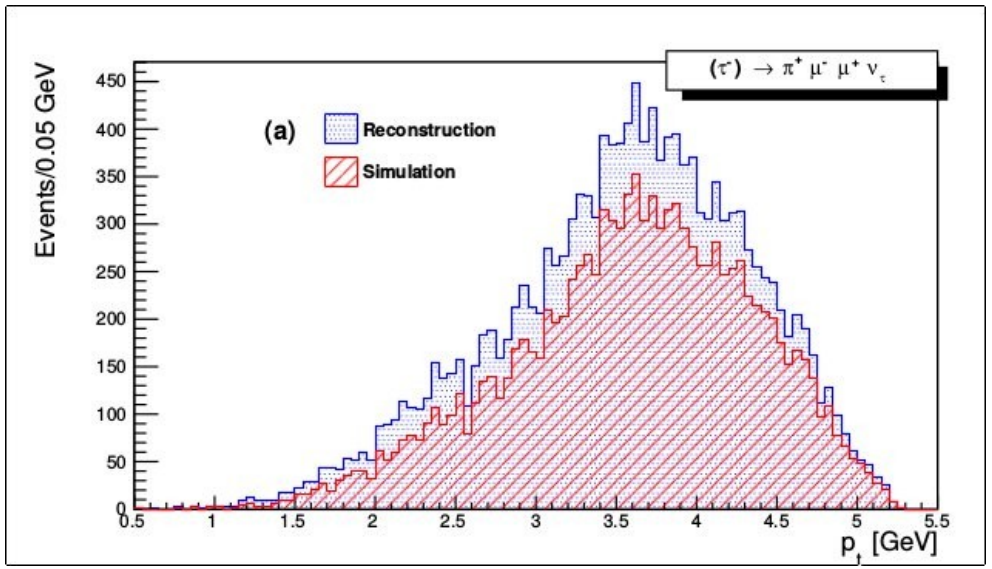
The Final cuts

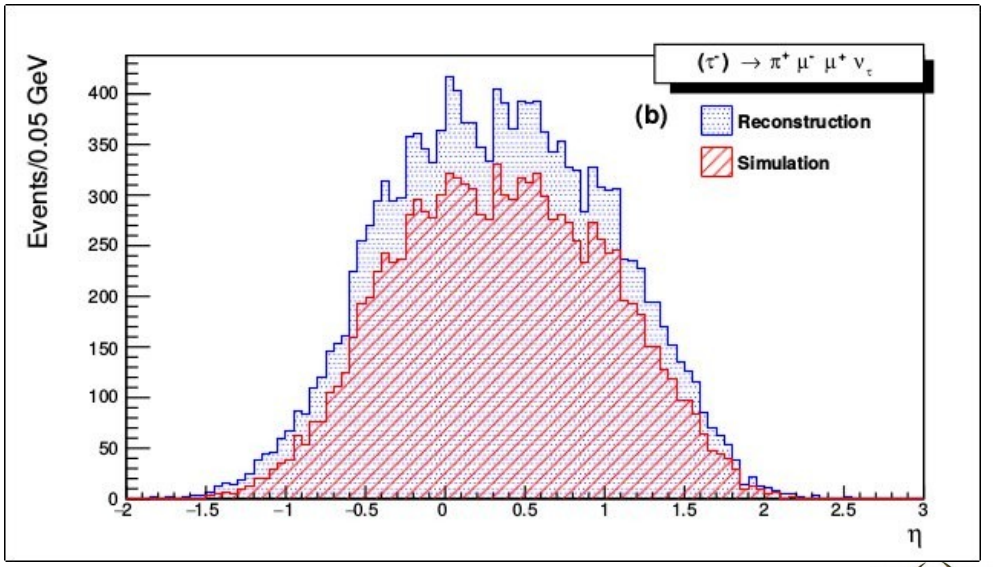
- $1{,}0 < M_\tau < 1{,}9$ GeV
- PID $\mu > 20\,\%$ $\pi > 80\,\%$
- $M_{bc} \leq 4$
- The PID of π's is less significant than μ's, and the beam constrained mass was the most important variable to reconstruct as well as possible the generated events

	Events
$\tau^- \rightarrow \pi^+ \mu^- \mu^- \nu_\tau$	11812
$\tau^- \rightarrow \pi^- \mu^- \mu^+ \nu_\tau$	2,825
$\tau^- \rightarrow \pi^+ \pi^- \pi^- \nu_\tau$	537


(a)
Reconstruction
Simulation
$(\tau^-) \to \pi^+ \pi^- \pi^- \nu_\tau$
Events/0.045 GeV
p_t [GeV]

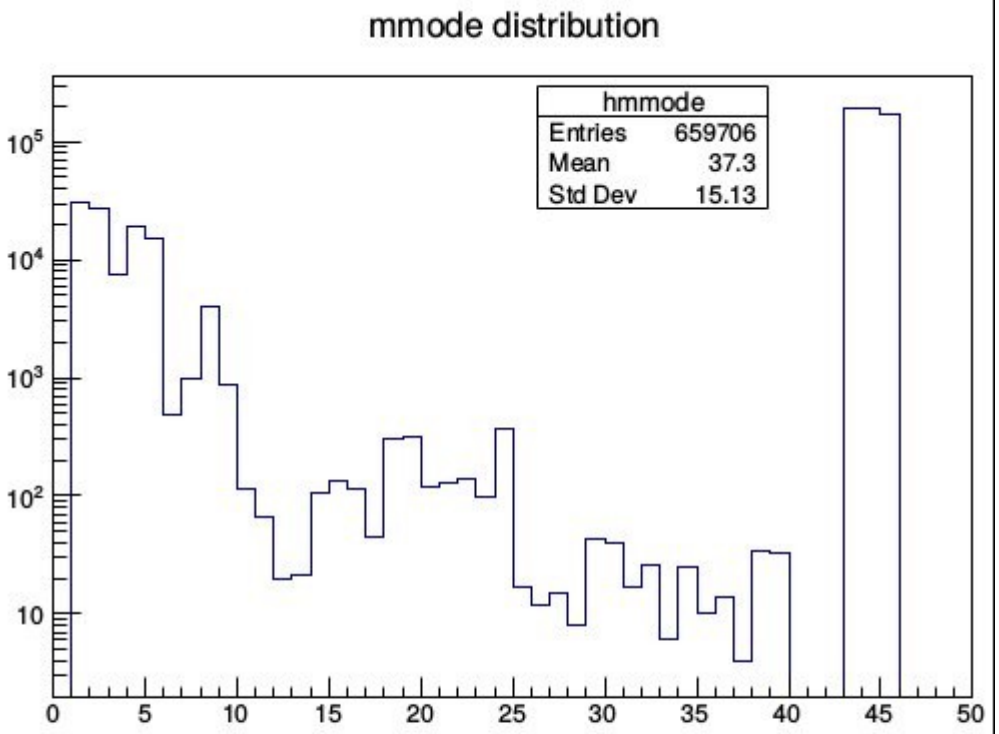

(b)
Reconstruction
Simulation
$(\tau^-) \to \pi^+ \pi^- \pi^- \nu_\tau$
Events/0.037 GeV
η


(a)
Reconstruction
Simulation
$(\tau^-) \to \pi^+ \mu^- \mu^+ \nu_\tau$
Events/0.05 GeV
p_t [GeV]


(b)
Reconstruction
Simulation
$(\tau^-) \to \pi^+ \mu^- \mu^+ \nu_\tau$
Events/0.05 GeV
η

The basis decay modes

1	$e^-\nu\nu$	15	$K^0\pi^-\overline{K^0}\nu$	29	$K^-\pi^+\pi^-\pi^0\nu$
2	$\mu^-\nu\nu$	16	$K^-K^0\pi^0\nu$	30	$K^-\pi^0\pi^0\pi^0\nu$
3	$\pi^-\nu$	17	$K^-\pi^0\pi^0\nu$	31	$K^0\pi^-\pi^+\pi^-\nu$
4	$\rho^-\nu$	18	$K^-\pi^-\pi^+\nu$	32	$\pi^-\overline{K^0}\pi^0\pi^0\nu$
5	$a_1^-\nu$	19	$\pi^-\overline{K^0}\pi^0\nu$	33	$\pi^-K^+K^-\pi^0\nu$
6	$K^-\nu$	20	$\eta\pi^-\pi^0\nu$	34	$\pi^-K^0\overline{K^0}\pi^0\nu$
7	$K^{*-}\nu$	21	$\pi^-\pi^0\gamma\nu$	35	$\pi^-\omega\pi^+\pi^-\nu$
8	$\pi^-\pi^-\pi^+\pi^0\nu$	22	$K^-K^0\nu$	36	$\pi^-\omega\pi^0\pi^0\nu$
9	$\pi^-\pi^0\pi^0\pi^0\nu$	23	$\pi^-4\pi^0\nu$	37	$e^-e^-e^+\nu\nu$
10	$2\pi^-\pi^+2\pi^0\nu$	24	$\pi^-\omega\pi^0\nu$	38	$f_1\pi^-\nu$
11	$3\pi^-2\pi^+\nu$	25	$\pi^-\pi^+\pi^-\eta\nu$	39	$K^-\omega\nu$
12	$3\pi^-2\pi^+\pi^0\nu$	26	$\pi^-\pi^0\pi^0\eta\nu$	40	$K^-K^0\pi^+\pi^-\nu$
13	$2\pi^-\pi^+3\pi^0\nu$	27	$K^-\eta\nu$	41	$K^-K^0\pi^0\pi^0\nu$
14	$K^-\pi^-K^+\nu$	28	$K^{*-}\eta\nu$	42	$\pi^-K^+\overline{K^0}\pi^-\nu$



43 $\tau^- \to \pi^+\mu^-\mu^-\nu_\tau$

44 $\tau^- \to \pi^-\mu^-\mu^+\nu_\tau$

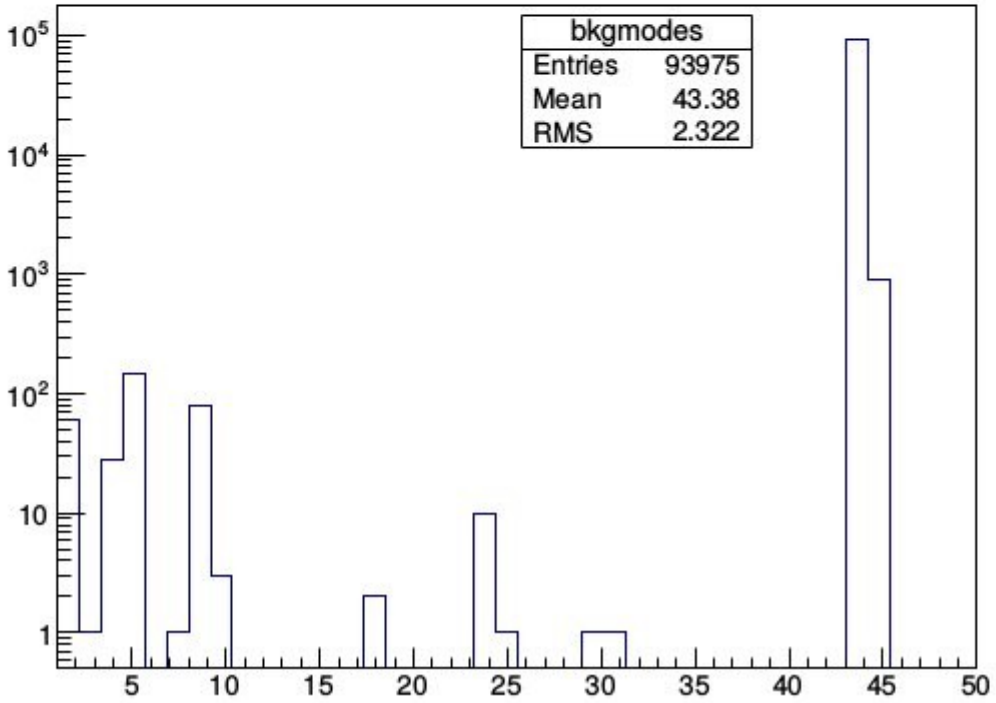
200 000 evento (1-42)

400 000 events 43+44 (unweighted)

mdst $\to$ tdst

$\tau^- \to \pi^+ \mu^- \mu^- \nu_\tau$

1. Looking for four tracks (tag + pi + 2mu) with total charge 0.
2. Tag: -thrust and one track and signal +thrust and 3 charged tracks should be in diferent sides.
3. Tag should be leptons
4. Signal pi 2mu: mu mass cuts



Conclusions

- We implemented the signal and some background in the belle 2 framework, very easy to extend to other modes.
- The background is the main issue in searching for these rare decays. Need to develop new ideas to improve the id.
- The possibilities to find new physics are really promising.
- A lot of work to do open to suggestions.