Probing lepton flavor violation with NA64 experiment

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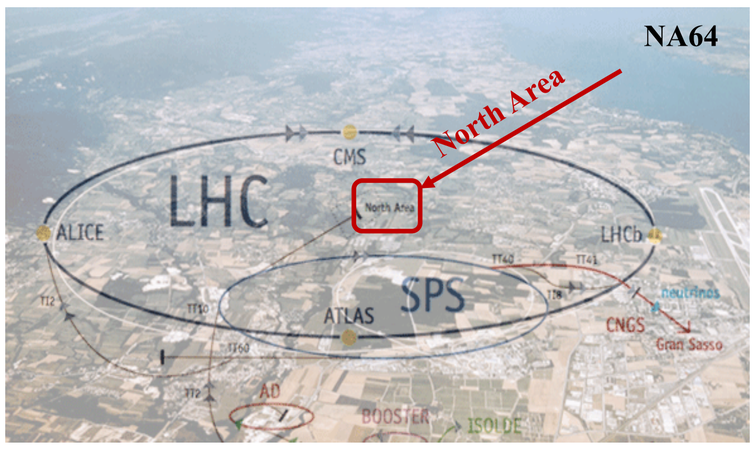
introduction



NA64e
100 GeV *e*-beam
arXiv:1312.3309

NA64*μ*
160 GeV μ-beam
CERN-SPSC2019-002/ SPSC-P-359

NA64h in future
~100 GeV h-beam
arXiv: 1503.01595; 1409.2288

The primary goal of the NA64 is searching for a vector mediator between dark and our matter. The NA64e, one of the subprograms, looks for a dark photon A'. In NA64μ is considered another type of vector mediators Z′ or Z_μ, which predominantly interact with the second and third generations of leptons.

Search for lepton conversion is another opportunity to explore new physics. Although the setup is optimized for other tasks, it is possible to investigate the charged lepton flavor violation (CLFV) process. Current experimental upper limits of branching ratio suitable for our study are given in the Table 1.

Process	Experiment	Branching ratio
$\mu \to e\gamma$	MEG (2016)	4.2×10^{-13} arXiv:1605.05081
$\mu \to e\bar{e}e$	SINDRUM (1988)	1.0×10^{-12} 10.1016/0550-3213(88)90462-2
$\mu N \to eN$	SINDRUM-II (2006)	6.1×10^{-13} Ti 10.1140/epjc/s2006-02582-x
$\tau \to e\gamma$ $(\mu\gamma)$	BaBar (2006)	$3.3\ (4.4) \times 10^{-8}$ arXiv:0908.2381
$\tau \to eee$ $(\mu\mu\mu)$	Belle(2010)	$2.7\ (2.1) \times 10^{-8}$ arXiv:1001.3221
$\tau \to \mu ee$ $(e\mu\mu)$	Belle(2010)	$1.8\ (2.7) \times 10^{-8}$ arXiv:1001.3221

Table 1. *Current experimental bounds with 90% C.L. of CLFV processes for muons and some taus.*

possibility of the CLFV study at NA64

$$\mathcal{L} = \frac{\text{couplings}}{\Lambda^{\text{n}}} \to \textit{mass scale of new physics}$$

Cross section of the $l \to l'$ conversion on a nucleus:

$$\boldsymbol{\sigma(l + (A,Z) \to l' + X) = \sum_{I,if,XY} \frac{Q^{A}_{I_{if},XY}}{\Lambda^{4}_{I_{if},XY}}},$$

where $l = \tau, \mu(e)$,
A, Z are mass and atomic numbers,
$I = S, V, T$ are scalar, vector or tensor operators,
$i, f = u, d, s, c, b, t$ are quark flavors,
X, Y are left and right chiralities
$Q^{A}_{I_{if},XY}$ is a double moment of quark parton distribution functions (PDFs)
$\Lambda^{4}_{I_{if},XY} \equiv \Lambda$ is a mass scale parameter

Limits on the LFV scales for Pb target:

S − operators: $\Lambda^{e\tau} \geq 0.04 - 0.19$ TeV, $\Lambda^{\mu\tau} \geq 0.56 - 2.45$ TeV,

V − operators: $\Lambda^{e\tau} \geq 0.05 - 0.35$ TeV, $\Lambda^{\mu\tau} \geq 0.78 - 4.46$ TeV,

T − operators: $\Lambda^{e\tau} \geq 0.09 - 0.63$ TeV, $\Lambda^{\mu\tau} \geq 1.45 - 8.01$ TeV.

S. Gninenko et al. Phys. Rev. D 98, 015007 (2018)

$\Lambda^{e\tau}_{\text{ZEUS}} \geq 0.41 - 1.86$ TeV (sum of all operators)

S. Chekanov et al. (ZEUS Collaboration), Phys. Rev. D 65, 092004 (2002)

sensitivity estimation

The estimation of NA64 sensitivity was preliminary simulated for the **Vector operator** (**red** markers on Fig.1 and Fig.2).

For the ***e* – beam**
- accumulated around 10^{12} EOT
- expected sensitivity of $\Lambda^{e\to\tau(\mu)} \leq 0.13$ TeV
- ~ 100 events of conversion

For the ***μ* – beam**
- for the run 2022 with 2×10^{10} MOT
- expected sensitivity of $\Lambda^{\mu\to\tau(e)} \leq 0.095$ TeV
- less than 1 events of conversion

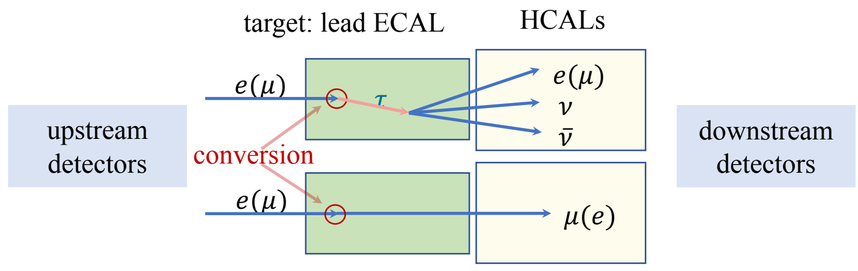
conclusion

Search for charged lepton conversion is one of the opportunity to explore new physics. The study of lepton conversion was started on the NA64 experiment. The probability of observing the process in the experiment on the current statistics was studied. The expected sensitivity of the experiment to the Λ parameter is estimated for both beams. It is necessary to change the strategy for analysing the μ → τ (e) transition.

plans

- estimate sensitivity and branching ratio for the NA64 for all operators
- data analysis
- define analysing strategy for the muon-to-other-lepton conversion

lepton conversion search method



Event selection criteria for *e*-beam:
- ECAL < 50 GeV
- HCAL0 < 1 GeV
- HCAL1, HCAL2 < MIP, VETO < 1 MIP
- ECAL Shower Profile $\chi^2 < \chi^2_{cut}$ (χ^2_{cut} from 4 to 8)

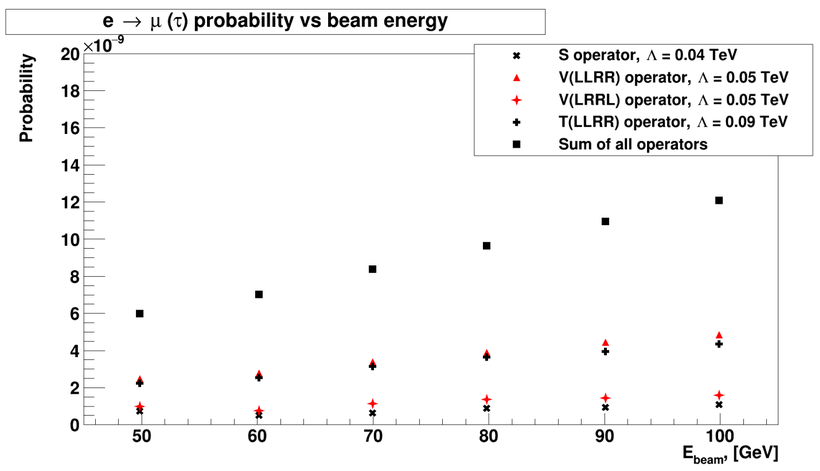
The criteria for selecting events for the μ-beam have not yet been determined, but:
- ECAL < 80 GeV

Signature for *lτ* conversion: SM tau's decay production ($\tau \to e(\mu)\nu\bar{\nu}$) and missing energy

Signature for *eμ* conversion: single muon production and missing energy

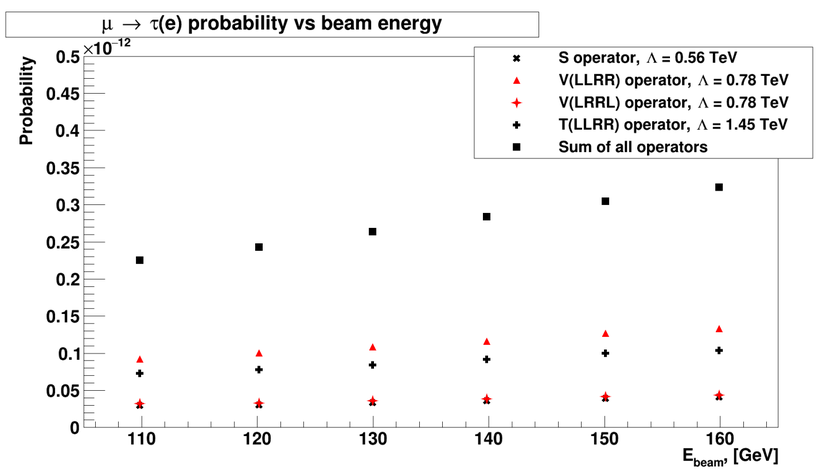
probability of lepton conversion

The probability of the process at a step of 1 mm in a lead target depending on the beam energy is shown in Fig.1 and in Fig.2 for electron and muon beam respectively. It was calculated for the minimum value of Λ for each operator and the sum of all operators.



$\Lambda^{e\tau}_{S} = 0.04$ TeV,
$\Lambda^{e\tau}_{V} = 0.05$ TeV,
$\Lambda^{e\tau}_{\text{T}} = 0.09$ TeV

Fig.1. *The probability of $e \to \mu(\tau)$ conversion as a function of electron energy for scalar, vector (red points), tensor operators and their sum.*



$\Lambda^{\mu\tau}_{S} = 0.56$ TeV,
$\Lambda^{\mu\tau}_{V} = 0.78$ TeV,
$\Lambda^{\mu\tau}_{\text{T}} = 1.45$ TeV

Fig.2. *The probability of $\mu \to e(\tau)$ conversion as a function of electron energy for scalar, vector (red points), tensor operators and their sum.*