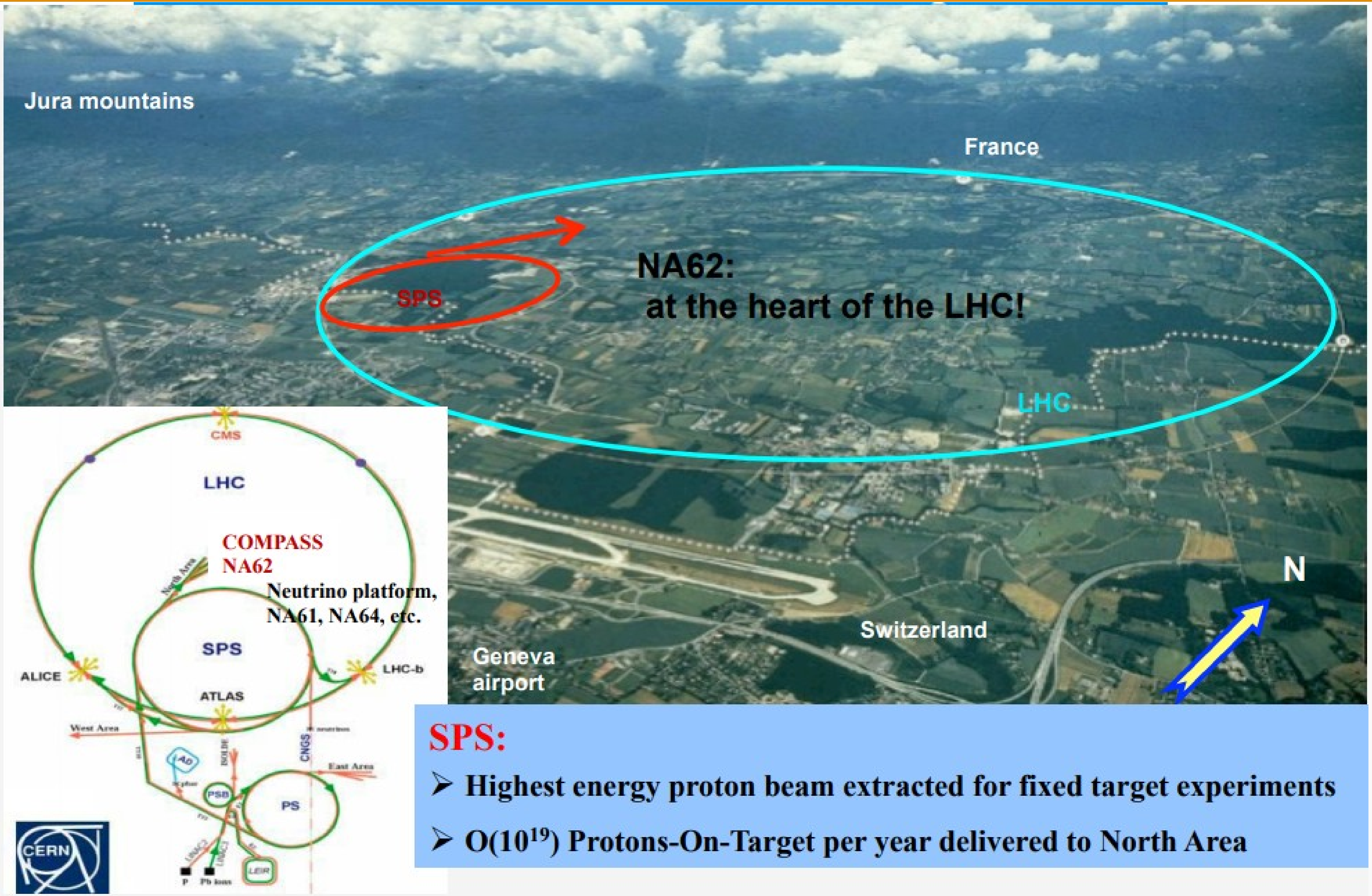
Analysis of the rare K^+ decay:

$K^+ \to e^+ \nu \mu^+ \mu^-$

Dosbol Baigarashev
JINR, Dubna

The CERN accelerator complex



SPS:

- Highest energy proton beam extracted for fixed target experiments
- $O(10^{19})$ Protons-On-Target per year delivered to North Area

The NA62 Experiment @ CERN

MAIN GOAL: Measurement of BR($K^+ \to \pi^+ \nu \bar{\nu}$) @ 10% accuracy

Broad physics program

- Rare K^+ decays
- LNV-LFV in K^+ decays
- Hidden sector particles

Future plans: Run 3 (2021-2023)

- Complete $\pi^+ \nu\nu$ measurement
- Address new physics cases:
  - LFV/LNV measurements, rare decays
  - Dump mode → MeV-GeV mass hidden-sector
    - ⇨ Dark Photons, Heavy Neutral Leptons, Axions/Axion-Like-Particles, etc

2012-2014	2014	2015	2016	2017	2018	2019-2020
Installation	Pilot run	Commissioning	Final Commissioning Physics run (30 days)	Physics run (160 days)	Physics run (217 days)	LS2

2016: 40% of nominal intensity → 5×10^{11} K^+ decays

2017-18: 60% of nominal intensity → 8×10^{12} K^+ decays

1 $K^+ \to \pi^+ \nu\bar{\nu}$ event observed

Expected Background:

$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

SES: $(3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}$

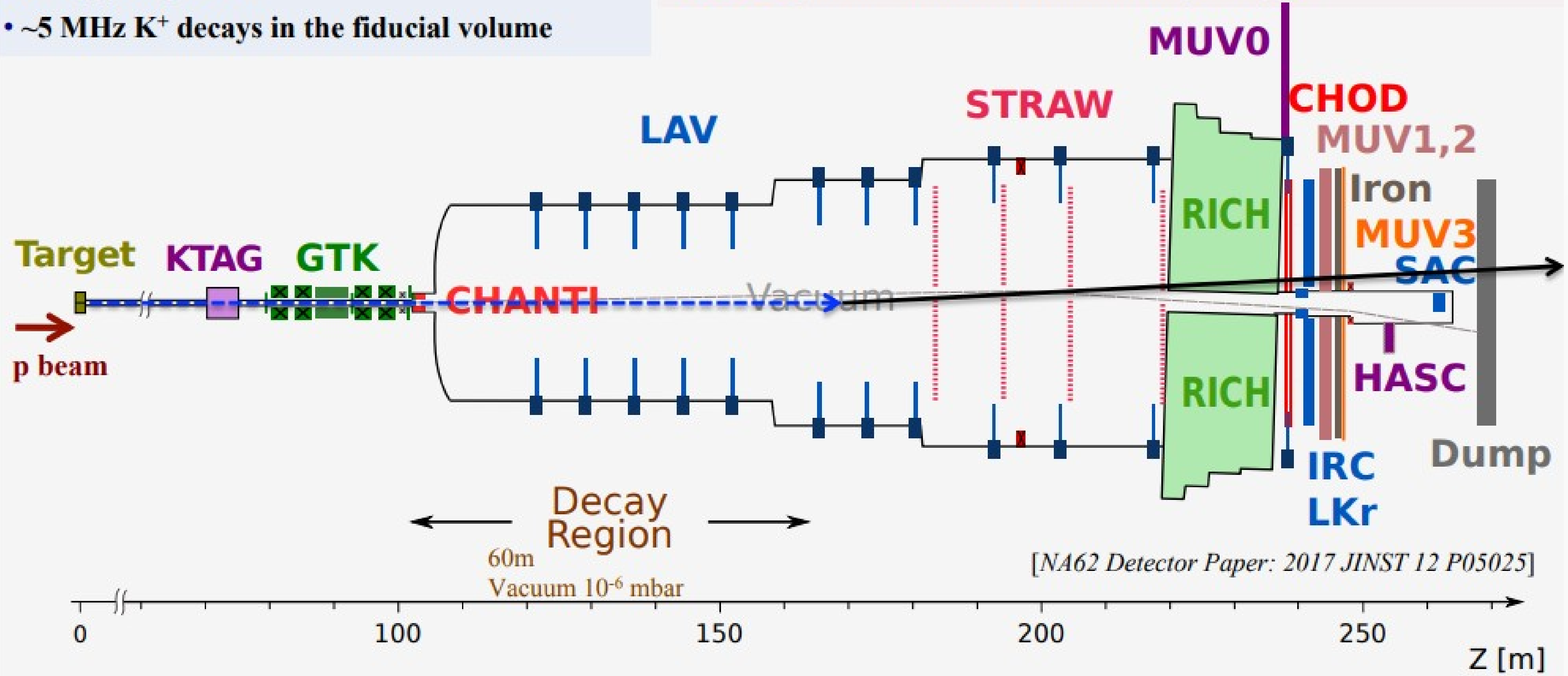
arXiv:1811.08508 (accepted by PLB)

NA62 detector

Primary beam: CERN SPS protons
- 400 GeV/c
- 3.3×10^{12} ppp

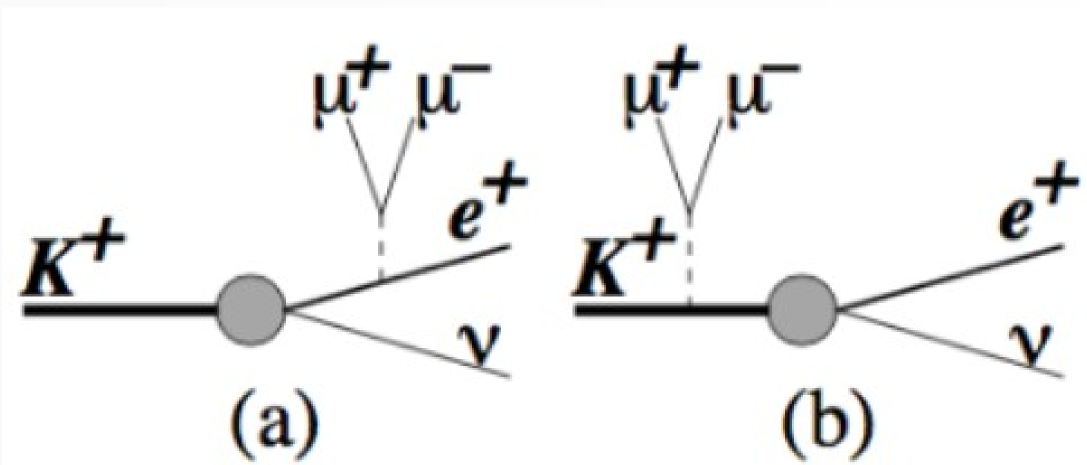
Secondary beam:
- unseparated positive beam π(70%)/K(6%)/p(23%)
- p_K = 75 GeV/c ($\Delta p/p \sim 1.1\%$)
- Nominal beam rate = 750 MHz@GTK
- K^+ rate ≈ 45 MHz
- ~5 MHz K^+ decays in the fiducial volume

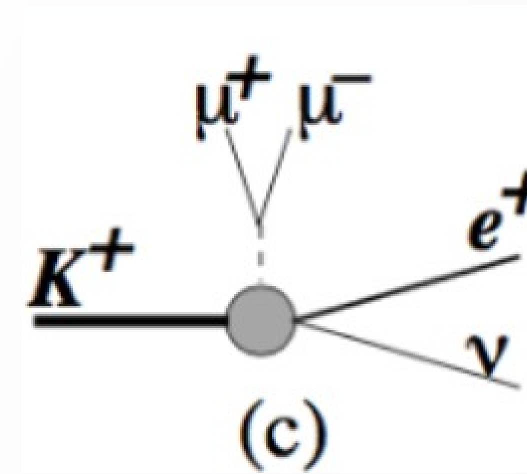
Main Detectors
- **Tracking:** Si-pixel beam tracker **(GTK)** + Straw spectrometer in vacuum **(STRAW)**
- **PID:** Cherenkov for K^+ beam **(KTAG)** and for decay products **(RICH)**
- **Hermetic veto: Photon-veto/calorimeters** + muon veto system
- **CHANTI:** inelastic interactions of beam and collimator/GTK3
- **CHOD:** plastic scintillators for fast charged trigger



[NA62 Detector Paper: 2017 JINST 12 P05025]

$K^+ \rightarrow e^+\nu_e\mu^+ \mu^-$





- (a),(b) – Inner Bremsstrahlung (IB - 0.03%)
- (c) – Structure Dependent (SD)
- J. Bijnes, G. Ecker and J. Gasser, Nucl. Phys. B 396, 81 (1993).
- ChPT prediction: $Br(K^+ \rightarrow e^+\nu_e\mu^+ \mu^-)=1.12 \times 10^{-8}$

- H. Ma *et al.*, Phys. Rev. D73, 037101 (2006).
- First observation, BNL E865: $Br(exp)=(1.72 \pm 0.37(stat.) \pm 0.17(syst.) \pm 0.19(model)) \times 10^{-8}$

$K^+ \to e^+\nu\mu^+\mu^-$

- Data: 2017A sample (8134-8282);

- Dimuon three track vertex - “2MU3TV” filter;
- Trigger: Mask6 (RICH-QX-MO2);
- MC: $Ke\nu\mu\mu$: v0.11.3

Didn’t work with normalization channels yet (to do...)

Track selection

Track in acceptance with: Straw, RICH, LKr, MUV3

Straw Track:
- χ^2_{STRAW} <= 20;
- 5 GeV <= P_{STRAW}track <= 65 GeV;
- $|Time_{RICH}$ - $Time_{NEWCHOD}|$ < 4 ns

GTK Track:
- NCedarCandidate > 0
- N_{CEDAR}sectors >= 4
- $|Time_{GTK}$ - $Time_{CEDAR}|$ < 1.5 ns

Electron Particle ID: *EoPtotalForFilter > 0.85* and
RICH ID as e and
0.9 < EoP < 1.1
DDeadCell > 20 mm

RICH linear discriminant for positive particles:
- d(e) < 0.9
- d(μ) < 0.9
- d(π) < 0.9

where:
- d(e) = 1- L(e) + L(μ) + L(π),
- d(μ) = 1- L(μ) + L(e) + L(π),
- d(π) = 1- L(π) + L(μ) + L(e),

where: **L** is RICH Likelihood

Muon Particle ID: Not an e
Requare association with MUV3(in time 4 ns)
RICH ID as μ
No association with LKr or
ELKr < 1.5 GeV or EoP < 0.2

Pion Particle ID: Not an e
Not a μ
RICH ID as π

Vertex selection

Vertex:

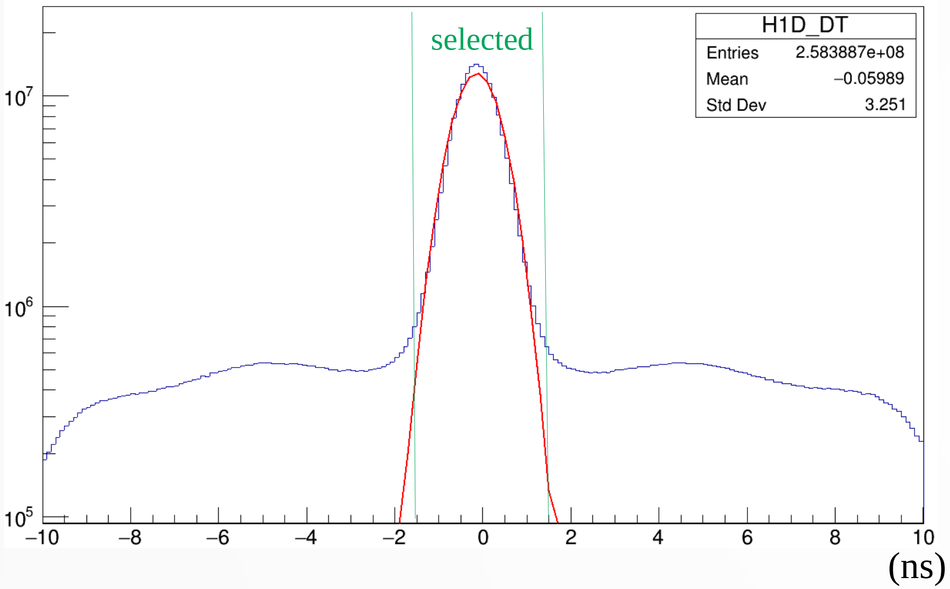
- Three-track vertex >= 1;
- Particle ID: $N_{\mu} = 2$ and $N_e = 1$;
- $q_{3tr\_vtx} = +1$;
- $\chi^2_{3tr\_vtx} \le 40$ (filter cut);
- $106\ m \le Z_{vtx} \le 180\ m$;
- $P_{vtx} < 80$ GeV ;
- VertexTime: average of 3 tracks NewCHOD times;
- |VertexTime - GTKtime| < 2 ns ;
- Distance beetween GTK track and vertex in the vertex plane < 15 mm

Kl4: Keνμμ

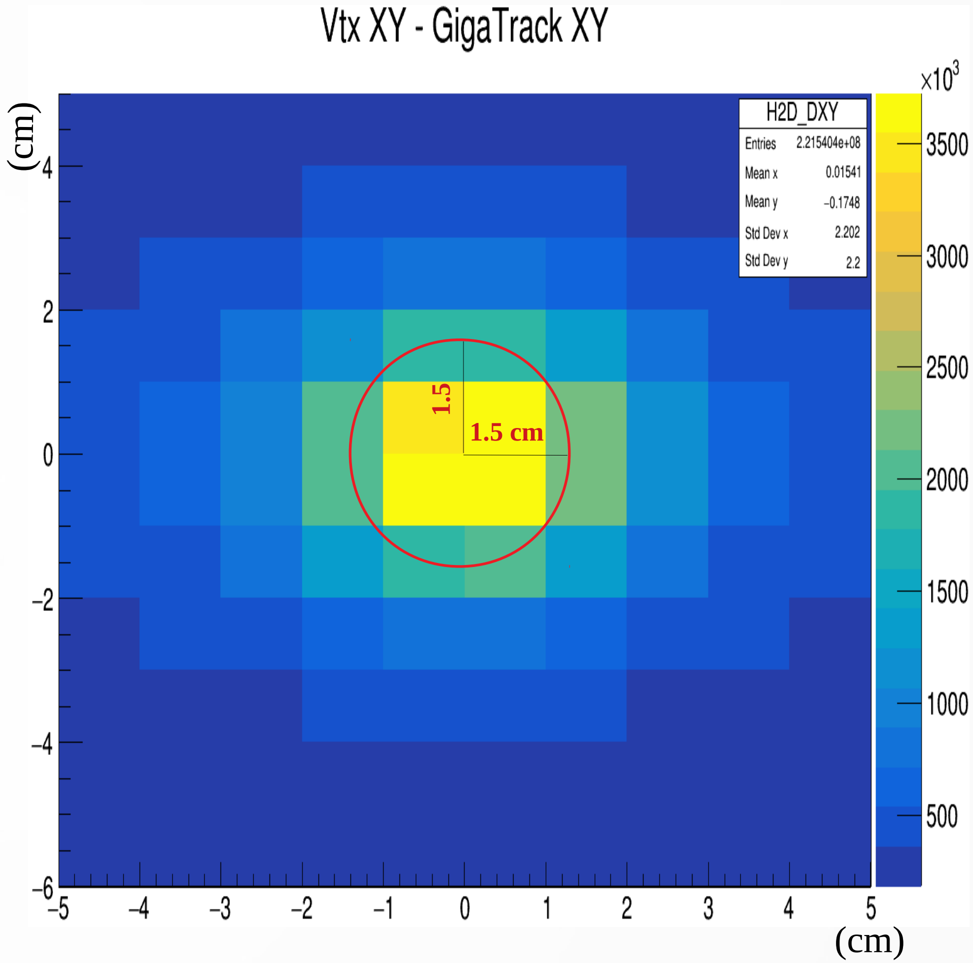
$(P_K - P_e - P_{\mu} - P_{\mu}) = P_{\nu}$, $|P_{\nu}| > 5$ GeV (to reduce the background)

Some cuts illustration

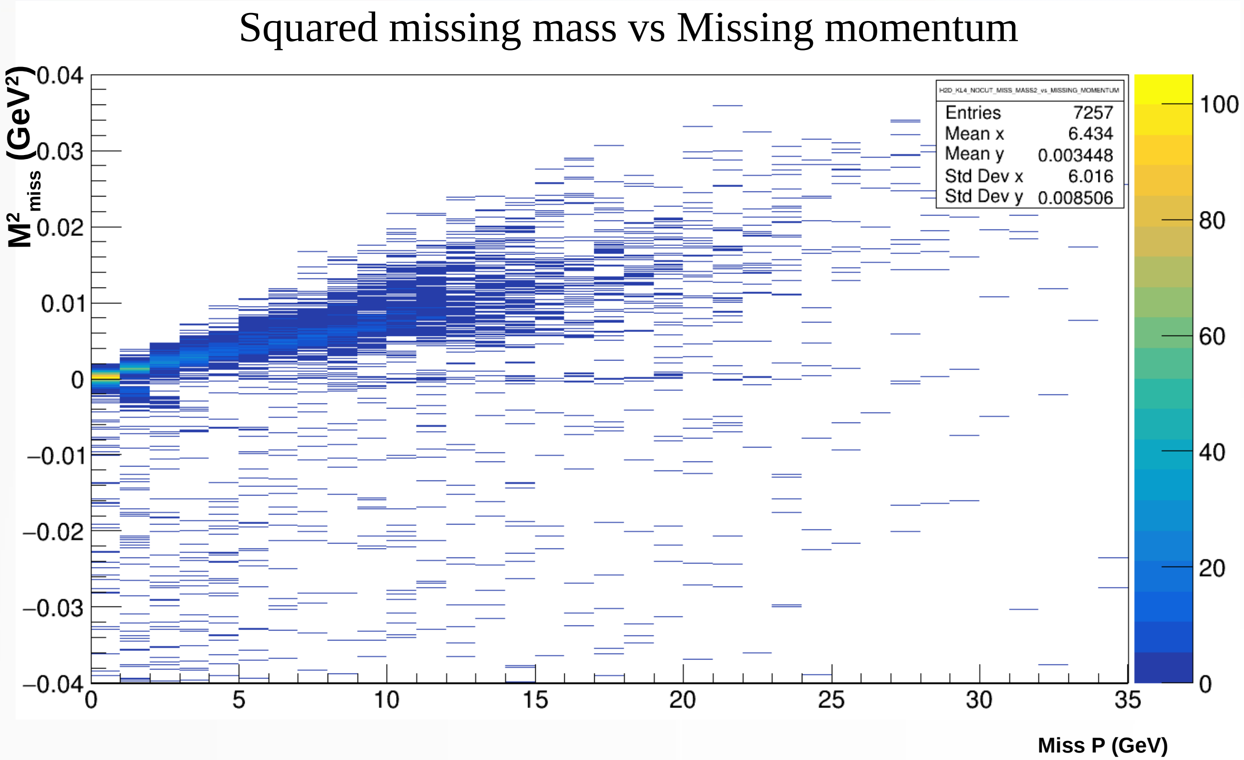
$|Time_{GTK} - Time_{CEDAR}| < 1.5$ ns

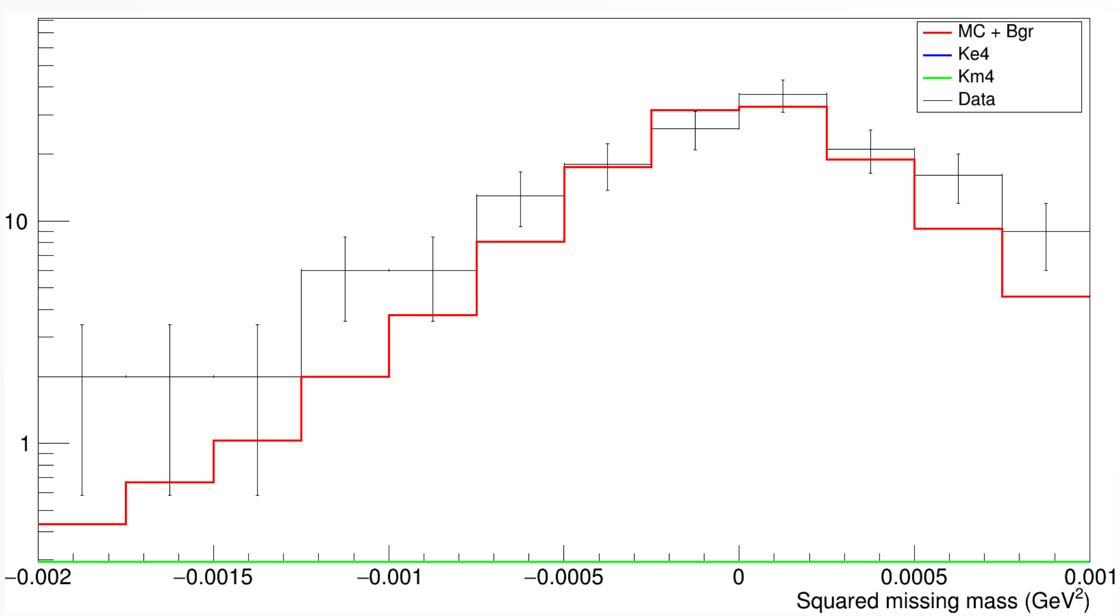


Distance beetween GTK track and vertex in the vertex plane < 15 mm

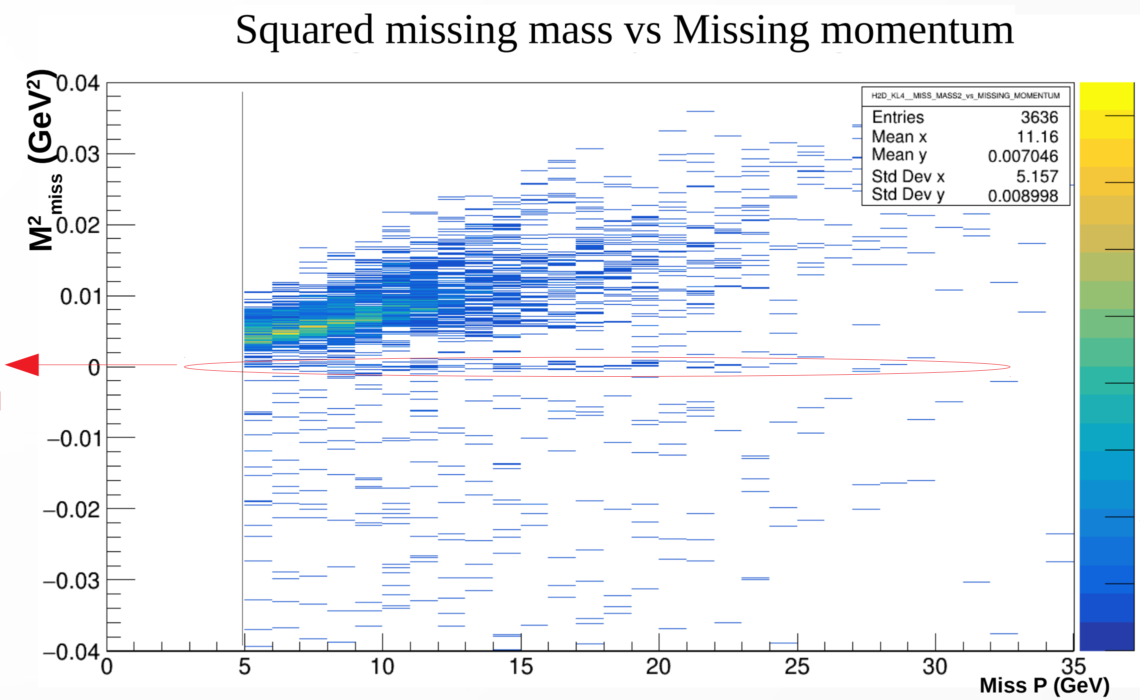


After $|P_\nu| > 5$ GeV cut

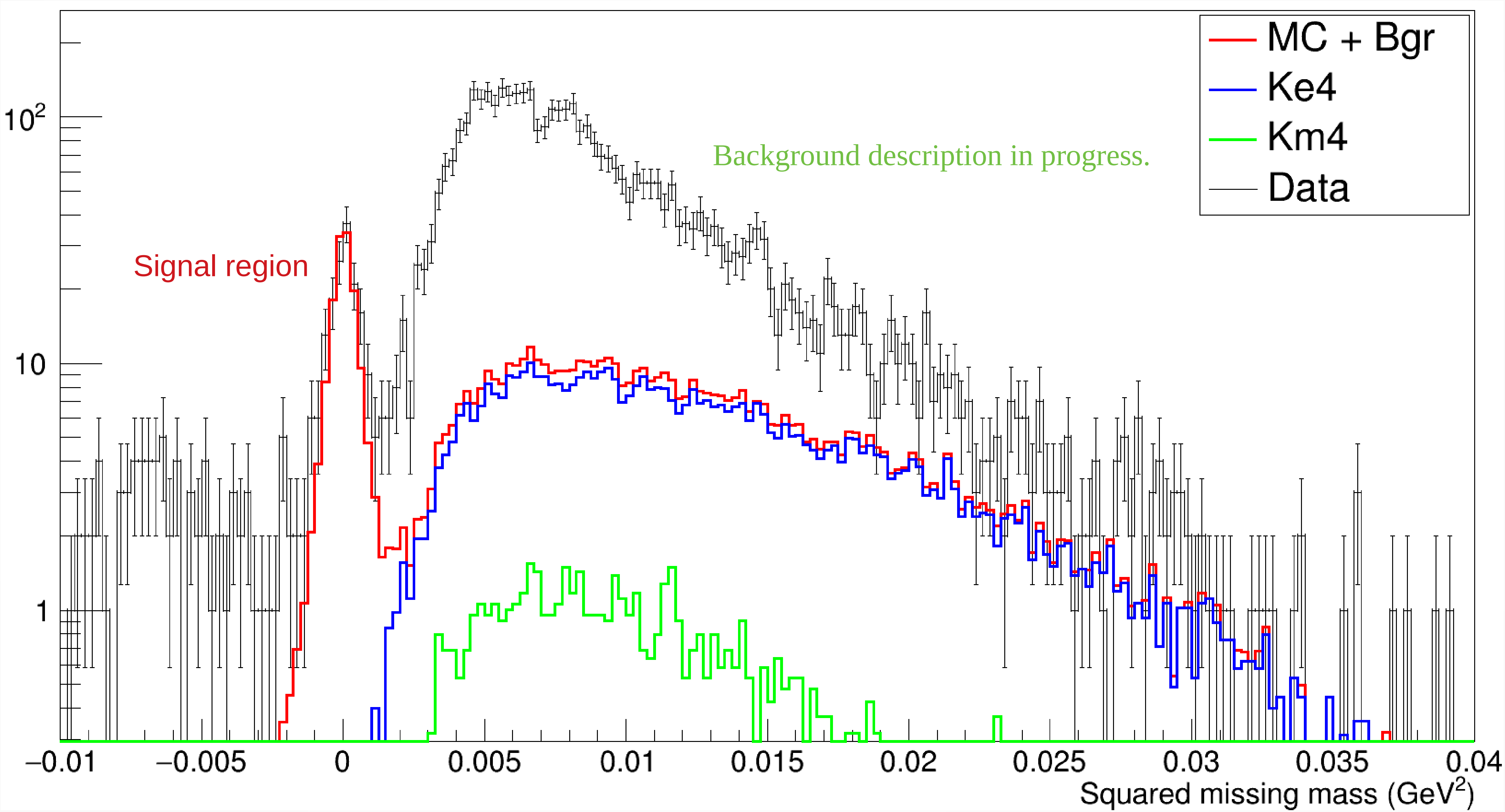




Signal region



Selected $K_{e\nu\mu\mu}$



Conclusions

- Signal selection is developed;
- Signal is visible in **Data2017A;**
- Background description in process

To do ...

- $K3\pi$ to be mis-identified by LKr;
- Normalization channels

Spares

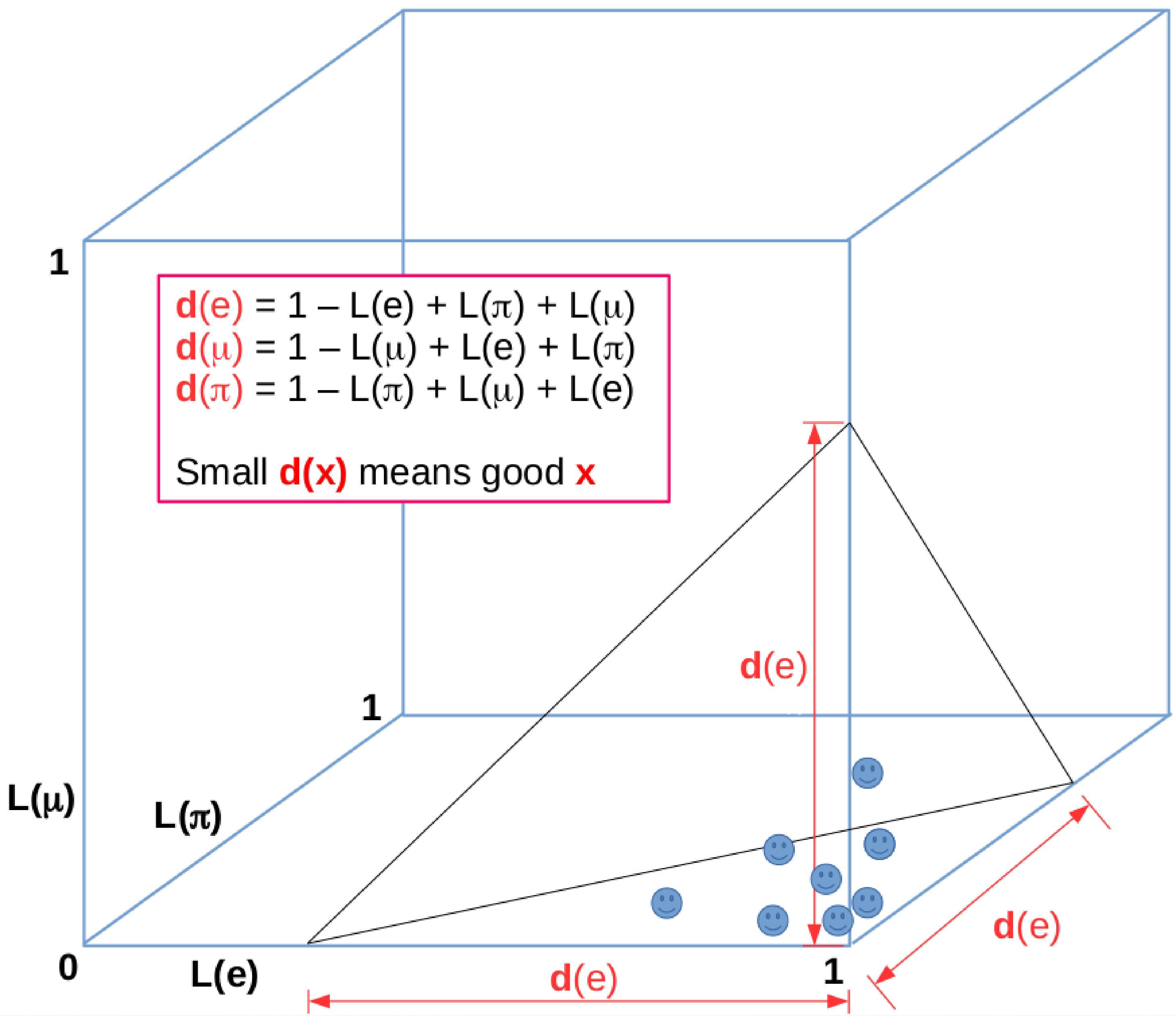
Positron ID

RICH linear discriminant d

L is RICH Likelihood

$d(e) = 1 - L(e) + L(\pi) + L(\mu)$
$d(\mu) = 1 - L(\mu) + L(e) + L(\pi)$
$d(\pi) = 1 - L(\pi) + L(\mu) + L(e)$

Small **d(x)** means good **x**



Unlike the L-ratio criteria, **d** also suppress the low-likelihood area, that is also uncertain for RICH.

One could invent some “radius” of ellipse, but 3D points here are not distributred elliptically.

So linear discriminant is just the simplest one.

Cuts on **d**(e), **d**(μ), **d**(π) may be different in various analyses.

Soft cut : **d** < 0.9 just exclude other corners