Поиск тяжелых нейтрино в распадах каонов

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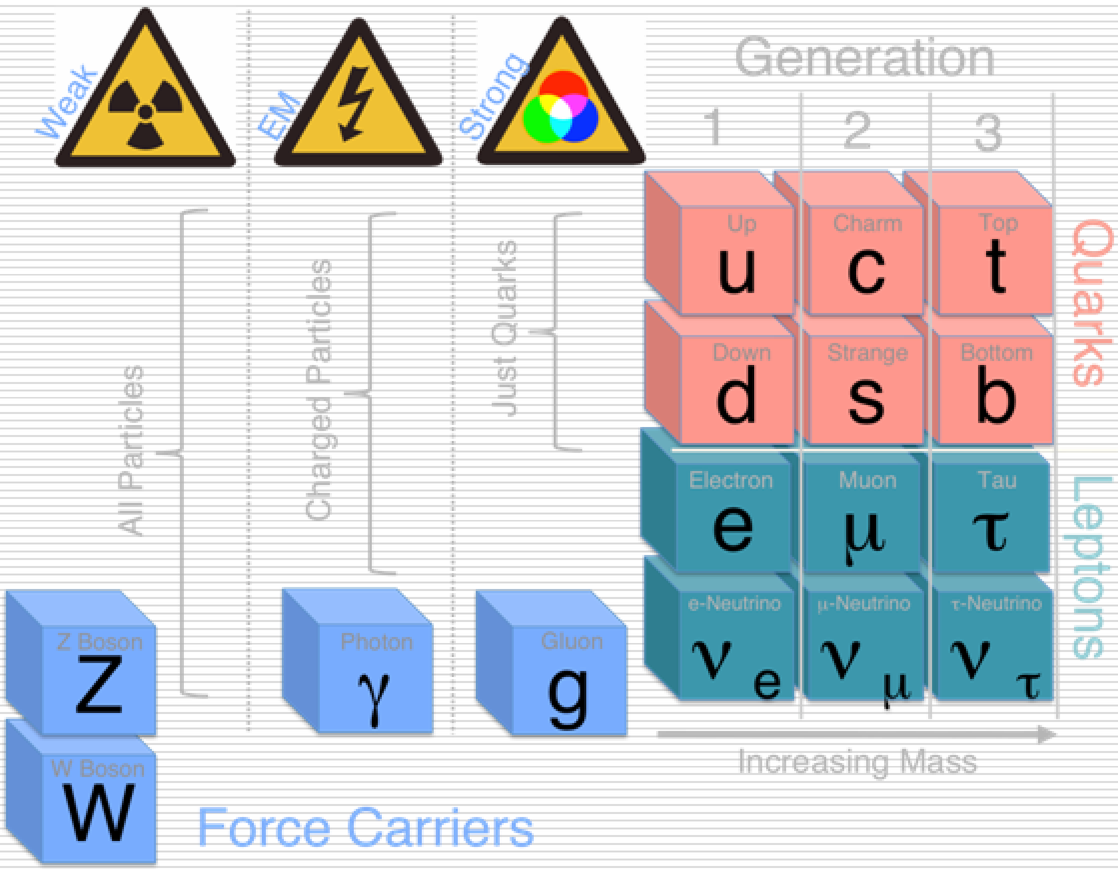
Outline

- Neutrino beyond the Standard Model
- Previous experiments
- Experiment BNL-E949
- Selection criteria
- Sensitivity for the $K^+ \to \mu^+ \nu_H$ decay
- Conclusion

Standard Model neutrino



Neutrino beyond the SM

Three types of neutrino ν_e ν_μ ν_τ

$L_e = +1$ $L_\mu = +1$ $L_\tau = +1$

$$\nu_l = \sum U_{li} \nu_i, \; l = e, \mu, \tau; \; i = 1, 2, 3$$

There is new physics beyond the Standard Model, but we don't know exactly what is it

Neutrino Oscillation

Dominance of matter over antimatter

Dark matter and dark energy

νMSM

arXiv:0804.4542v2 [hep-ph]
arXiv:0901.0011v2 [hep-ph]

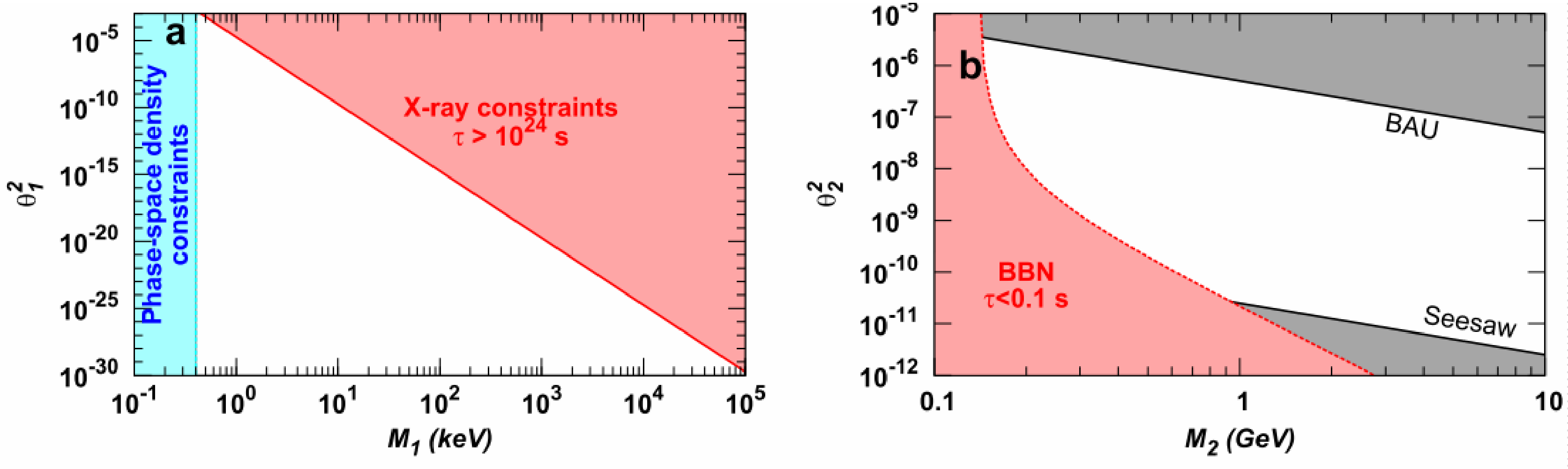
SM + 3 neutral right-handed heavy leptons

$M_{N_1} \in O(10)$ кэВ

Dark matter

$M_{N2,3} \in O(1)$ ГэВ

baryon asymmetry



θ_1 and θ_2 - mixing angels with SM particles

How to find heavy neutrino?

Mesons decays

The search for additional peak

$$\Gamma(M^+ \to l^+ \nu_h) = \rho \times \Gamma(M^+ \to l^+ \nu_l) \times |U_{lh}|^2$$

Heavy neutrino decays

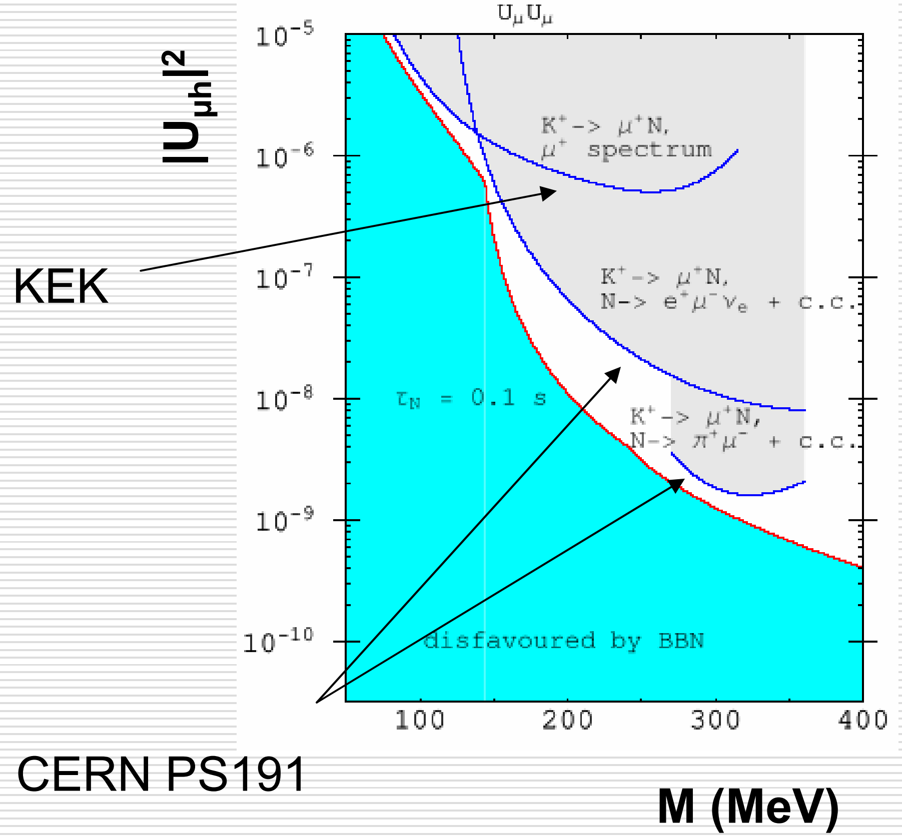
"Nothing" $\to$ leptons and hadrons

$$N \to e^+ e^- \nu_\alpha, N \to \mu^\pm e^\mp \nu_\alpha, N \to \mu^+ \mu^- \nu_\alpha$$

$$N \to \pi^0 \nu, \pi e, \pi \mu, Ke, K\mu ...$$

plot from
arXiv:0705.1729v1
[hep-ph]

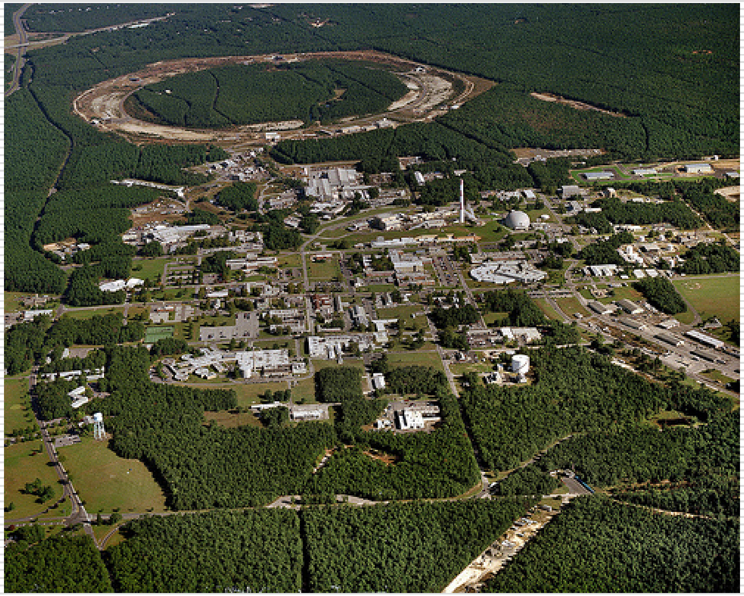
Current limits



It was suggested to use E949 data to study heavy neutrino mass region from 150 MeV to 270 MeV in decay channel

$$K^+ \to \mu^+ \nu_H$$

Experiment BNL E949



$$K^+ \to \pi^+ \nu \bar{\nu}$$

Phys. Rev. D 79, 092004 (2009)

SM expectation

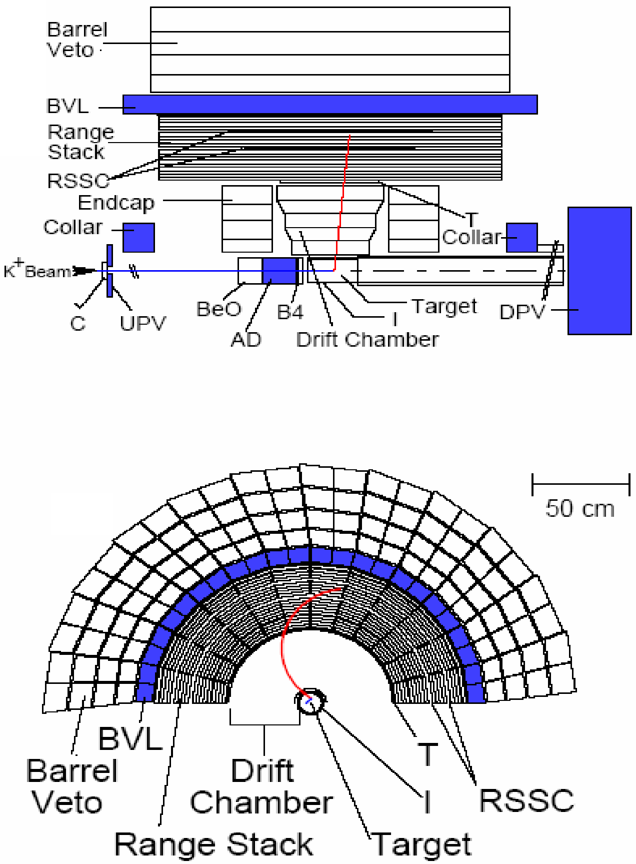
$$\mathcal{B}_{SM}(K^+ \to \pi^+ \nu \bar{\nu}) = (0.85 \pm 0.07) \times 10^{-10}$$

E949 + E787

4 + 3 (from E787) = 7

$$\mathcal{B}(K^+ \to \pi^+ \nu \nu) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

The Detector



- ~700 MeV/c kaon beam is slowed down by degraders.
- K^+ stops and decays in scintillating fiber target
- Measure π^+ momentum in drift chamber, energy and range in target and Range Stack (RS)
- π^+ stops and decays in RS – observe $\pi^+ \to \mu^+ \to e^+$ decay chain
- Set of photon veto detectors

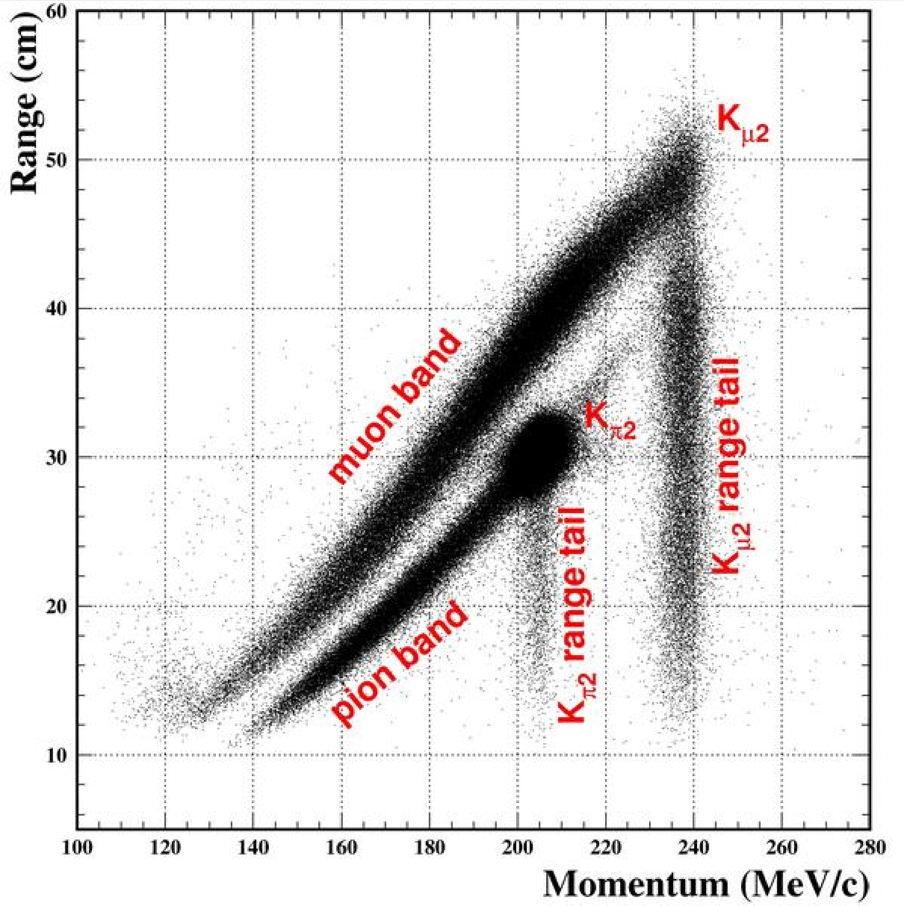
Heavy neutrino trigger

$K^+ \rightarrow \mu^+ \nu_H$ has the same experimental signature as $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

single charged particle + “nothing” → use standard E949 trigger

- Wait at least 2 ns for K^+ decay
- Stopping layer in RS between 6 and 18
- Photon veto: no showers in RS, Barrel,…
- π^+ identification: online check $\pi^+ \rightarrow \mu^+$ decay chain in the stopping counter

Background sources



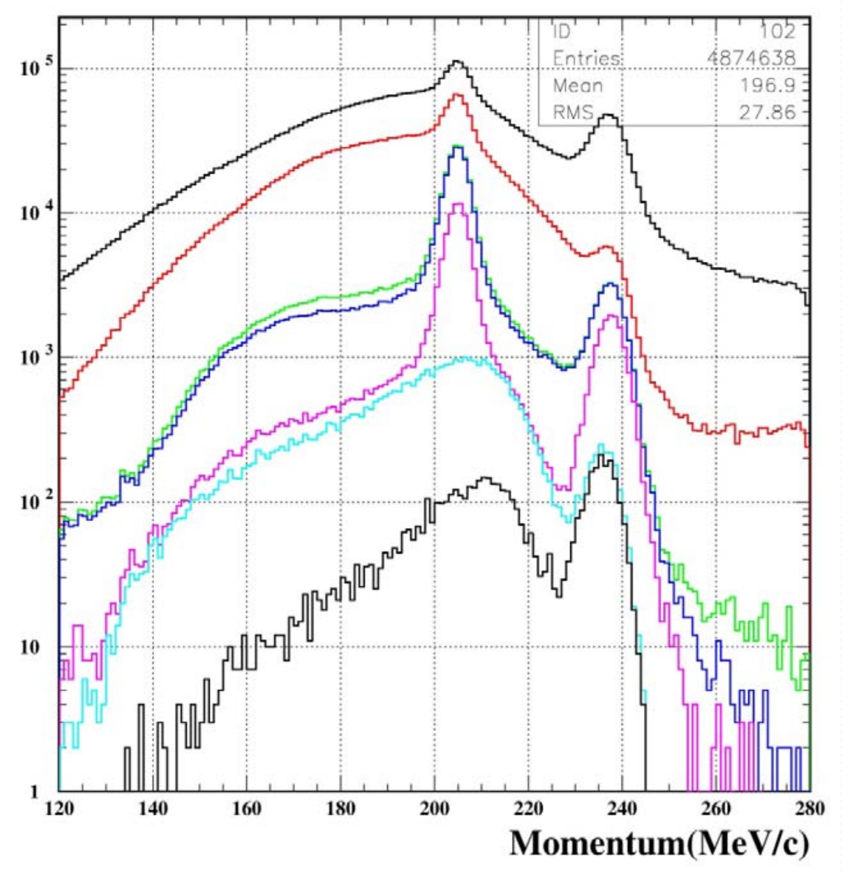
- Muon band: generally $K_{\mu2\gamma}$, $K_{\mu3}$ decays
- Pion band: $K_{\pi2\gamma}$, $K_{\pi2}$ in which pion scattered in the target or RS and beam pion

MC simulation of background sources

Process	Trigger+cuts rej	BR	Total rejection
$K_{\mu\nu\gamma}$	$\sim 10^4$	6.2×10^{-3}	$\sim 10^7$
$K_{\mu 3}$	$\sim 10^7$	3.35×10^{-2}	$\sim 10^9$
Only $\pi\nu\nu(1+2)$ trigger			
$K_{\pi 2\gamma}$	$\sim 5 \times 10^4$	2.75×10^{-4}	$\sim 2 \times 10^9$

$K_{\pi 2\gamma}$ can be ignored due to 3 gamma in the final state and the strong range-momentum rejection of pions (~500). So the $K_{\mu 2\gamma}$ is the dominant background source for decay into heavy neutrino.

Background suppression



after trigger

after kinematics

after beam

after DELCO2

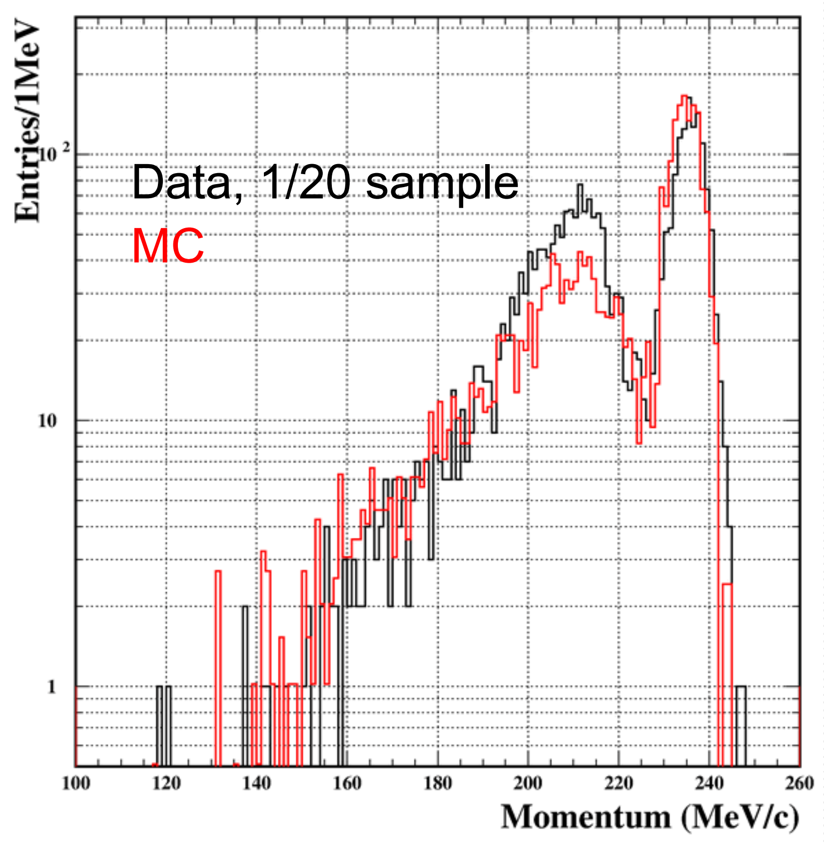
after target

after inv RNGMOM

after PV, 90% Acc.

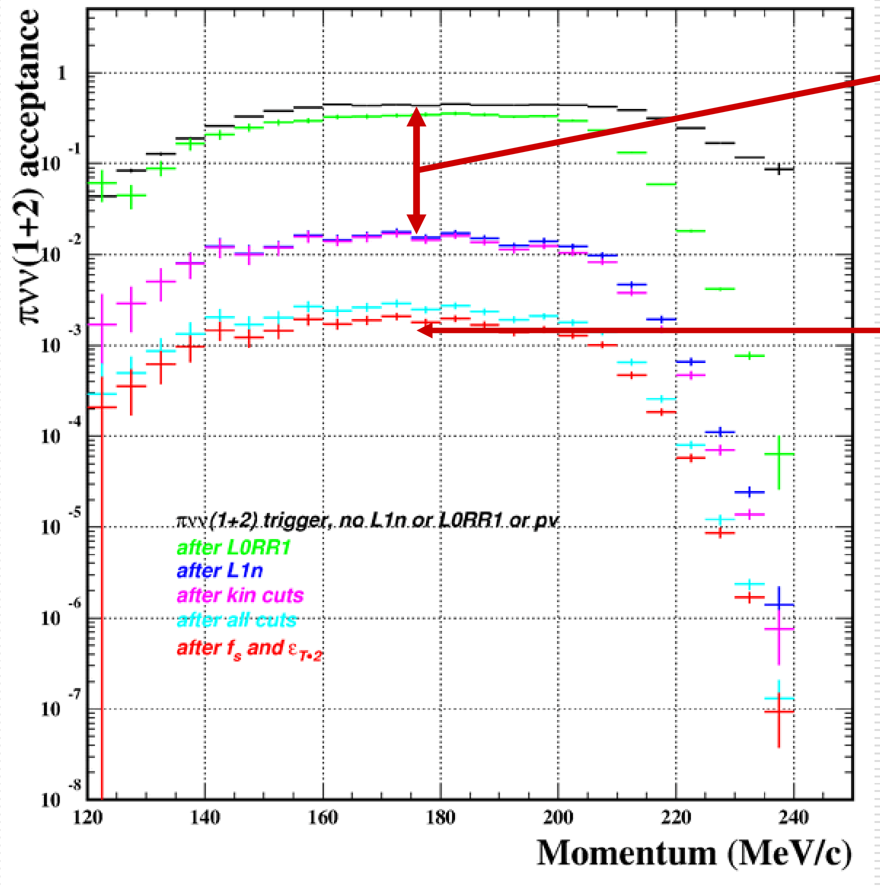
1/20 of data

Comparison between data and MC



Km2+Km2g+Km3 events were simulated.
PV60 is applied to experimental data.
Spectra are normalized by number of Km2 events.

Total acceptance



Acceptance loss due to online pion identification

Heavy neutrino acceptance $1.5x10^{-3}$

For 155<p_mu<205 MeV

BR(Km2) calculation

$$BR(K_{\mu 2}) = \frac{N_{K_{\mu 2}}}{\varepsilon_{T\bullet 2} \times f_s \times (KBlive)_{1/20} \times A^{UMC}_{K_{\mu 2},trig} \times A^{UMC}_{K_{\mu 2},kin} \times A_{L1n} \times A_{\overline{19}_{ct}} \times A_{L0rr1} \times A_{offline\_cuts}}$$

$N_{K_{\mu 2}}$	7916 ± 97
$(KB_{live})_{1/20}$	9.1×10^{10}
$\epsilon_{T\bullet 2}$	0.9505 ± 0.0012
f_s	0.7558 ± 0.0075
$A^{UMC}_{K_{\mu 2},pnn1}$	0.4551 ± 0.0016
$A_{\overline{19_{ct}},onlinepv}$	0.1074 ± 0.0021
$A_{L0RR1,L1n}$	$(1.49 \pm 0.40) \times 10^{-4}$
$A_{UTCQUAL}$	0.9503 ± 0.0007
$A^{UMC}_{K_{\mu 2},kin}$	0.7948 ± 0.0010
A_{PRRF}	0.1486 ± 0.0106
A_{beamtg}	0.4195 ± 0.0003
$A_{OPSVETO}$	0.9742 ± 0.0006
A_{tgkin}	0.9799 ± 0.0003
A_{PV90}	0.6977 ± 0.0011
$\mathcal{B}(K_{\mu 2})$	0.5302 ± 0.1478

These cuts have low acceptances for Km2 events

$$BR(K_{\mu 2}) = 0.5302 \pm 0.1478$$

$$BR^{PDG}(K_{\mu 2}) = 0.6355 \pm 0.0011$$

BR(Km2g) calculation

$$BR(K_{\mu\nu\gamma}) = \frac{N_{K_{\mu\nu\gamma}}}{\varepsilon_{T\bullet 2} \times f_s \times (KBlive)_{1/20} \times A^{UMC}_{K_{\mu\nu\gamma},trig} \times A^{UMC}_{K_{\mu\nu\gamma},kin} \times A_{L1n} \times A_{L0rr1} \times A_{offline\_cuts}}$$

	$\pi\nu\nu(1)$ trigger	$\pi\nu\nu(2)$ trigger
$A^{UMC}_{trigger}$	0.2676 ± 0.0006	0.0544 ± 0.0003
$A_{RefinedRange}$	0.5189 ± 0.0251	0.9852 ± 0.0066
A_{L1n}	0.0392 ± 0.0016	0.0413 ± 0.0021
$A_{beam\&target}$	0.4195 ± 0.0003	0.4195 ± 0.0003
A_{tgkin}	0.9799 ± 0.0012	0.9799 ± 0.0012
A_{kin}	0.9115 ± 0.0010	0.9012 ± 0.0015
$A_{UTCQUAL}$	0.9503 ± 0.0007	0.9503 ± 0.0007
$A_{OPSVETO}$	0.9742 ± 0.0006	0.9742 ± 0.0006
A_{RNGMOM}	0.9739 ± 0.0012	0.9739 ± 0.0012
A_{PRRF}	0.9520 ± 0.0007	0.9520 ± 0.0007
A_{box}	0.3332 ± 0.0009	0.8509 ± 0.0016
A_{PV}	0.0077 ± 0.0003	0.0049 ± 0.0004
A_{f_s}	0.7558 ± 0.0075	0.7558 ± 0.0075
$A_{\epsilon_{T\bullet 2}}$	0.9505 ± 0.0012	0.9505 ± 0.0012
$(KB_{live})1/20$	9.1×10^{10}	9.1×10^{10}
$N_{K_{\mu\nu\gamma}}$	710 ± 27	414 ± 21
$\mathcal{B}(K_{\mu\nu\gamma})$	$(2.4 \pm 0.2) \times 10^{-3}$	$(2.2 \pm 0.2) \times 10^{-3}$

$$BR^{pnn1}(Km2g) = (2.4 \pm 0.2) \times 10^{-3}$$

$$BR^{pnn2}(Km2g) = (2.2 \pm 0.2) \times 10^{-3}$$

For 155<p_mu<205 MeV

PDG BR(Km2g)

PDG value for p<231.5: $BR^{PDG} = (6.2 \pm 0.8) \times 10^{-3}$

Use MC simulation of the Km2g decay to measure ratio $\frac{N_{155<p<205}}{N_{p<231.5}}$

$$\frac{N_{155<p<205}}{N_{p<231.5}} = 0.2351 \pm 0.0054$$

PDG value for 155<p<205: $BR^{PDG} = (1.4 \pm 0.2) \times 10^{-3}$

Sensitivity

$$S.E.S = \frac{1}{KBlive \times A_{tot}} =$$

$$= \frac{1}{1.7044 \times 10^{12} \times 1.53 \times 10^{-3}} =$$

$$= 3.8 \times 10^{-10}$$

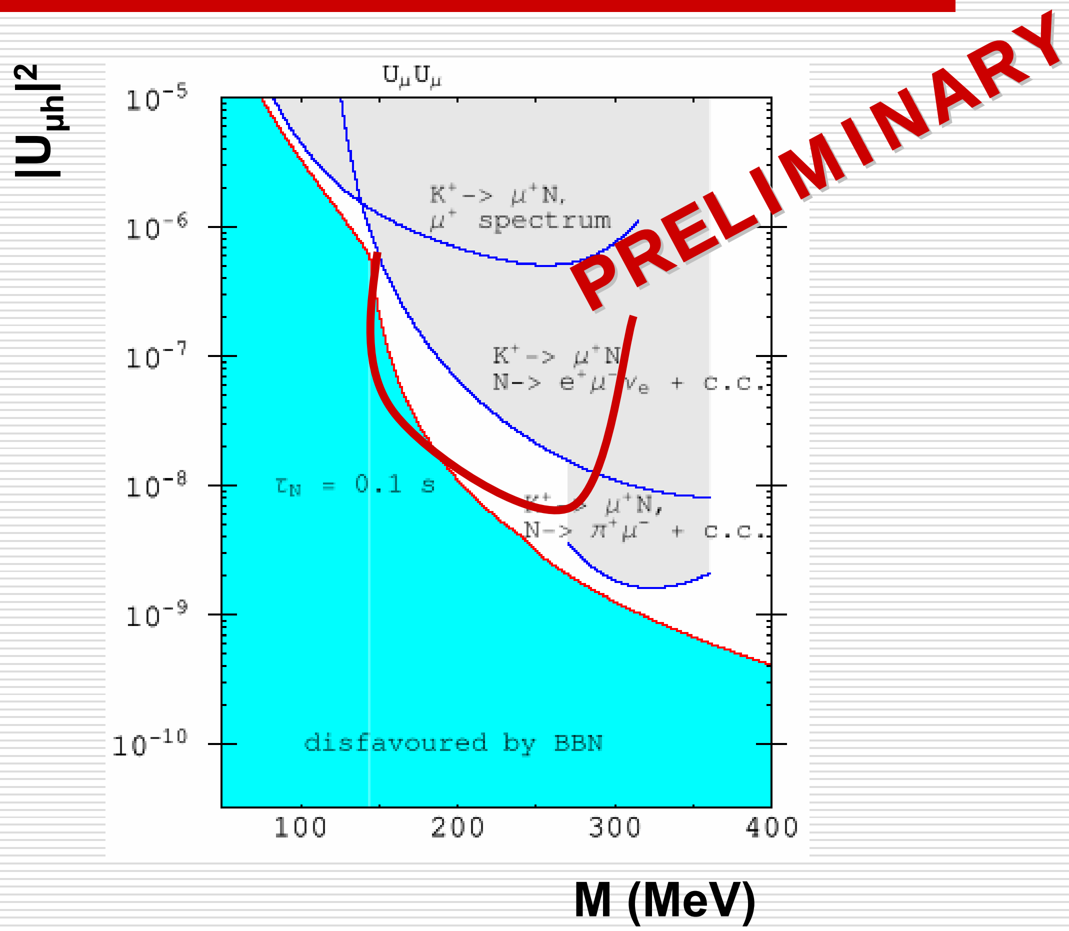
For muon momentum from155 to 205 MeV

$$\Gamma(K^+ \to \mu^+ \nu_h) = \rho \times \Gamma(K^+ \to \mu^+ \nu_\mu) |U_{\mu h}|^2$$

$$1 < \rho < 4$$

- heavy neutrino mass 200 MeV
- extrapolate 1/20 data sample to get total events number
- estimate sensitivity
- extrapolate estimation to other mass values using muon momentum spectrum shape

Sensitivity



Conclusions

- According to νMSM there is a possibility of existence of heavy neutrino with mass above pion mass
- It was suggested to use E949 data to search for $K^+ \to \mu^+ \nu_H$ decay
- SES equals 3.8×10^{-10}
- Final result ~ end of 2011

Thank you!

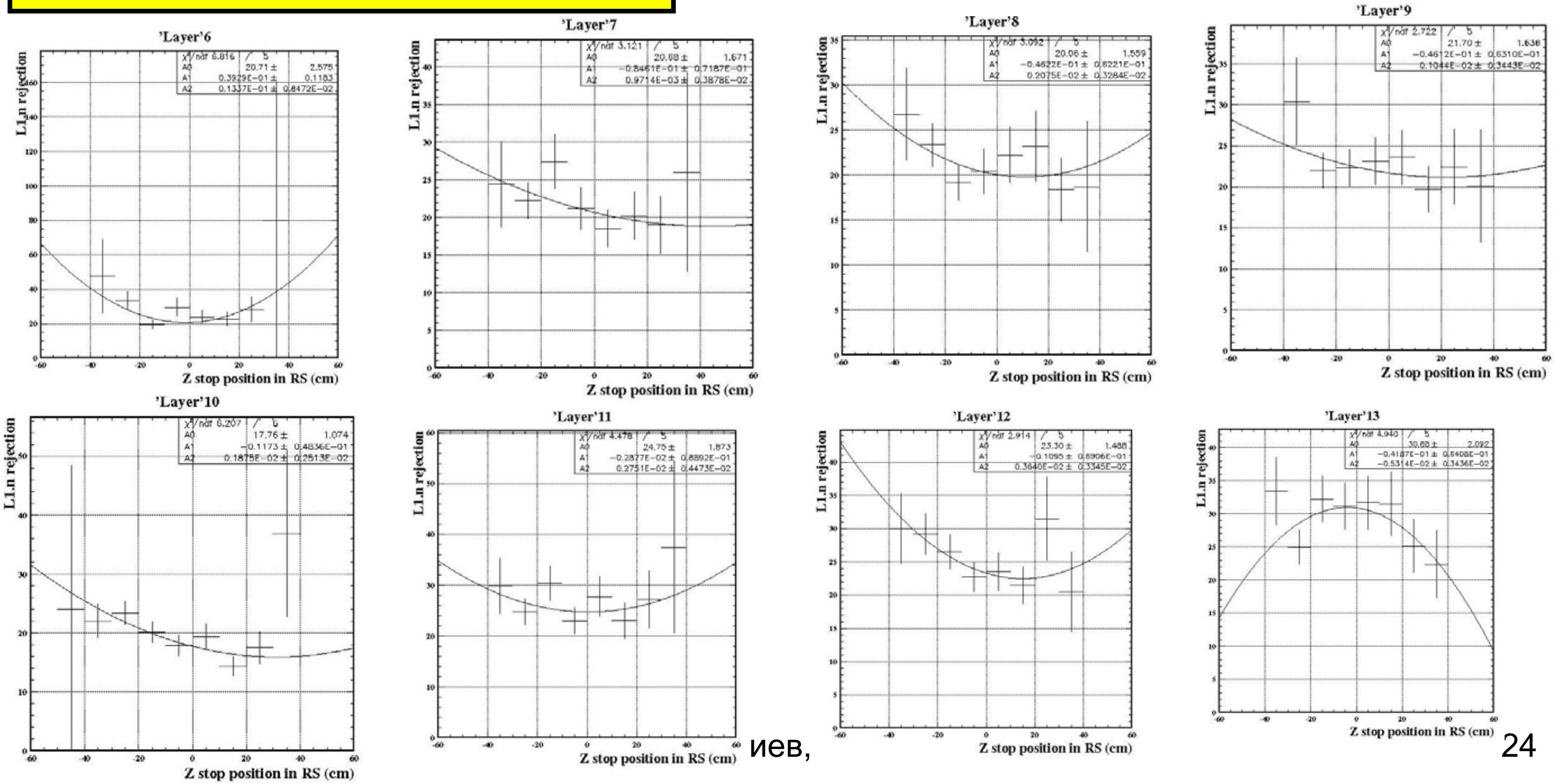
BACKUP

L1.n rejection for layers 6 – 18

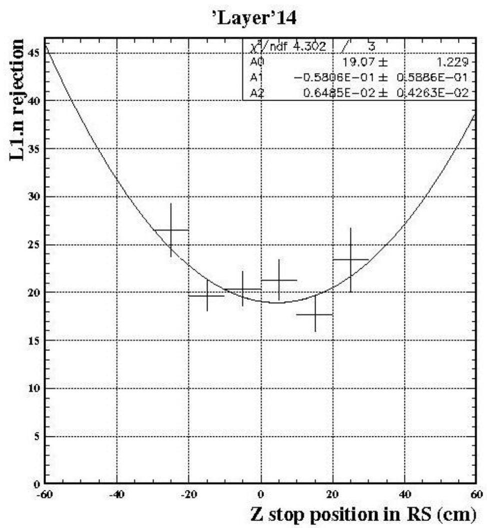
For each layer we tried to fit L1.n rejection factor by function

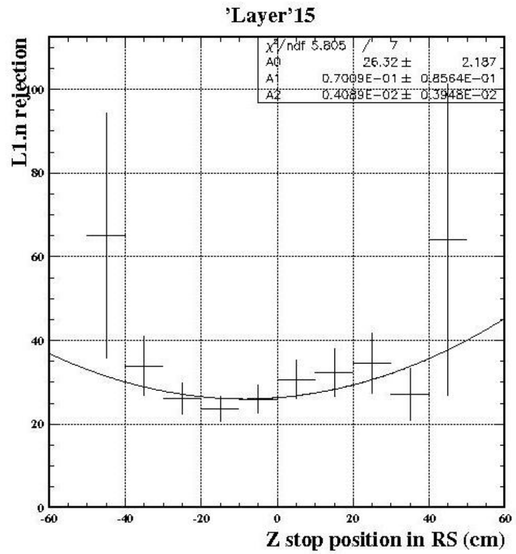
$$F = A0 + A1 \times zf + A2 \times zf^2$$

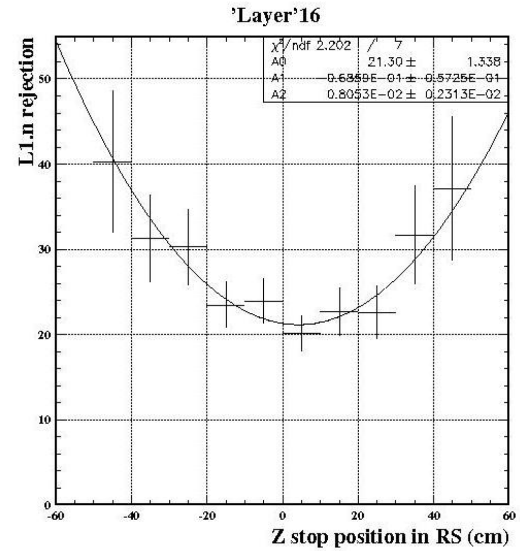
,where *zf* is Z stop position of muons in RS

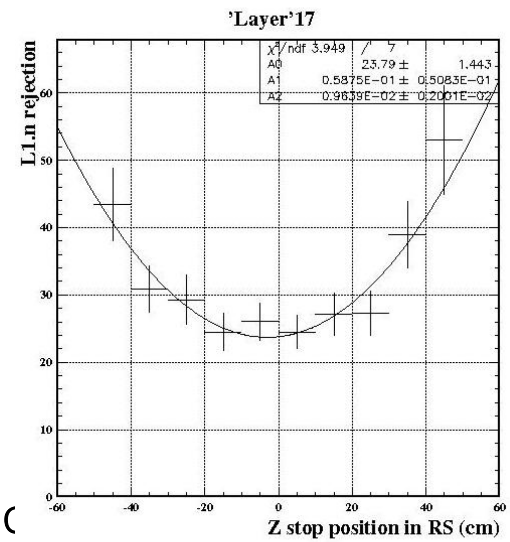


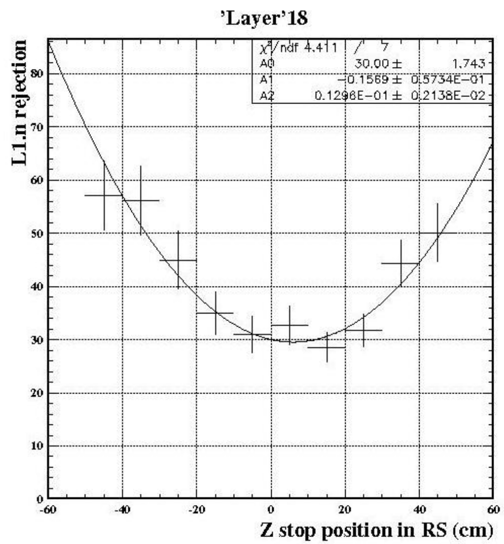
L1.n rejection for layers 6 – 18





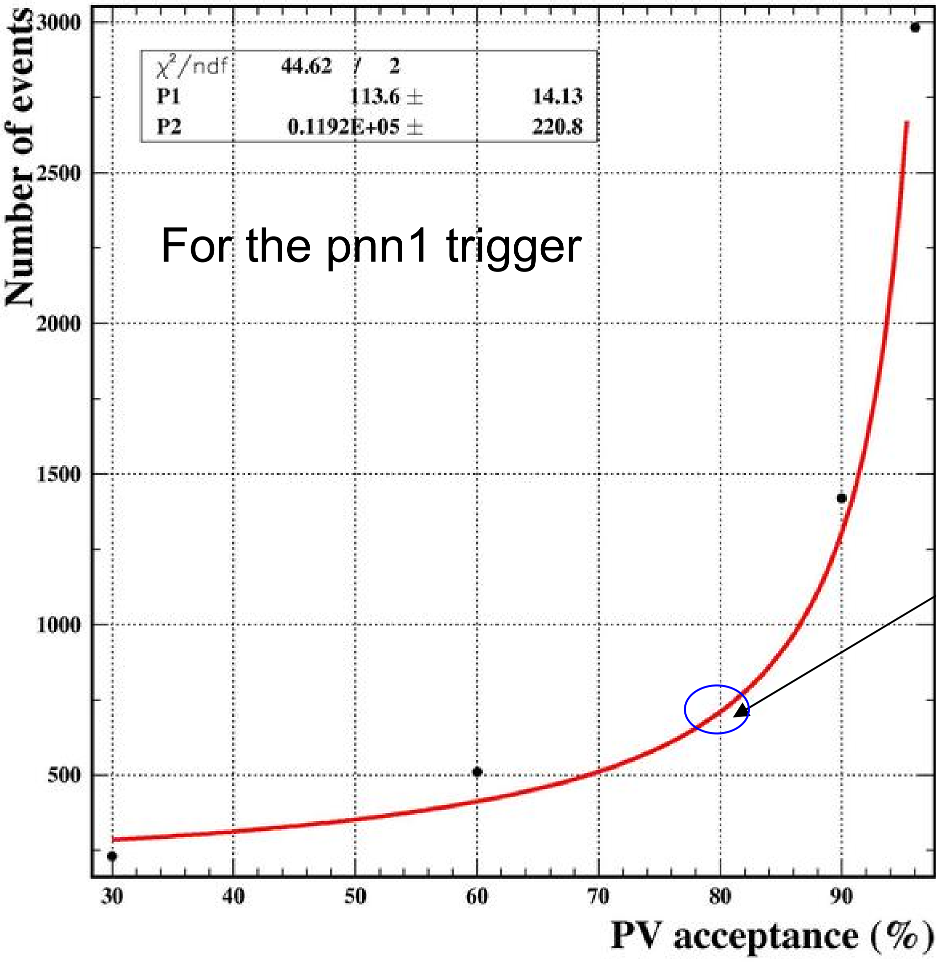






All plots for PISCAT trigger

Number of Km2g events



Fit by function

$$f = P1 + \frac{P2}{100 - x}$$

$$N_{K_{\mu\nu\gamma}}^{pnn1} = 710 \pm 27$$

Use the same method:

$$N_{K_{\mu\nu\gamma}}^{pnn2} = 414 \pm 21$$