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Prospects to measure neutrino oscillation pattern with UNK underground detector

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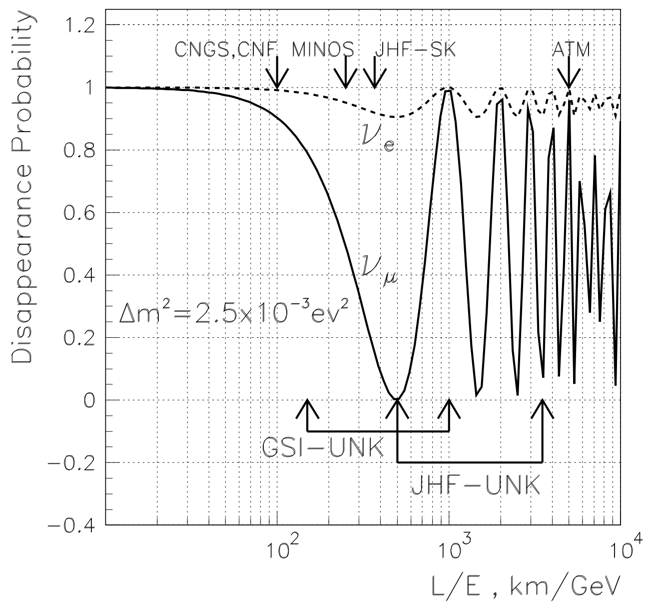
1 Physics motivation

Statement:

Observation of oscillation pattern is unique proof for existence of neutrino oscillations.



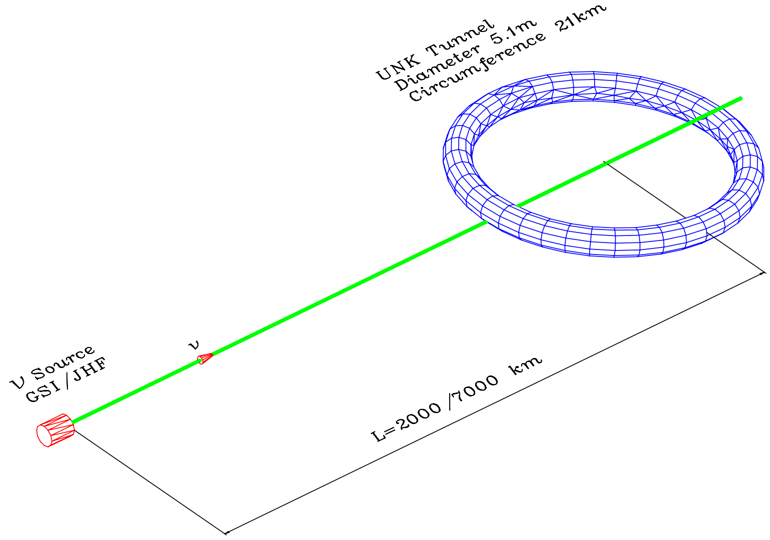
Parameter	JHF, Japan	GSI,Germany*	MI FNAL,USA
Baseline from the UNK, km	7000	2000	7600
Incline angle, degree	33	9	34
Proton momentum,GeV/c	50	50	120
Cycle time, sec	3	3	2
One turn time, μsec	5	4	10
Proton intensity/spill	$3.3 \cdot 10^{14}$	$1 \cdot 10^{14}$	$4 \cdot 10^{13}$
Protons/sec	$1 \cdot 10^{14}$	$3 \cdot 10^{13}$	$2 \cdot 10^{13}$
π^+ yield/p at 7 GeV/c	0.05	0.05	0.12
π^+ yield/sec at 7 GeV/c	$5 \cdot 10^{12}$	$1.7 \cdot 10^{12}$	$2.4 \cdot 10^{12}$
duty factor	$1.7 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$	$5 \cdot 10^{-6}$

Event rate $\sim (\pi$ yield/sec$)/\mathbf{L^2}$
rate/bkg $\sim$ rate/(duty factor)

GSI and JHF are in favor

2 Experimental lay-out

2.1 Concept of experiment



- **UNK tunnel - huge double sc. counter**
- **surrounding soil - neutrino target**
- **FE, $\sim$ 50 m underground - CM bkg suppression**
- **a few energy settings - oscillation pattern**

Provide

1 Mt - level detector

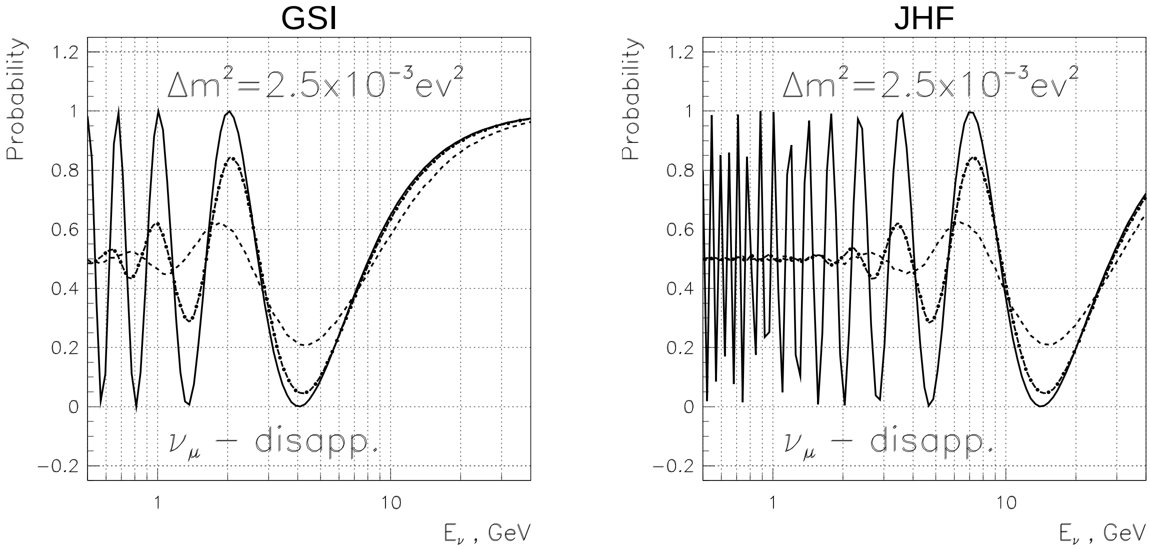
for ν_μ ($\bar{\nu}_\mu$) CC interactions

from accelerator source

measured/expected counts

$\Downarrow$

oscillation pattern



Ideal curve - solid line
smeared one for $\delta\mathbf{E}_\nu/\mathbf{E}_\nu = \mathbf{0.15}$ - dash-dotted line
smeared one for $\delta\mathbf{E}_\nu/\mathbf{E}_\nu = \mathbf{0.36}$ - dashed line

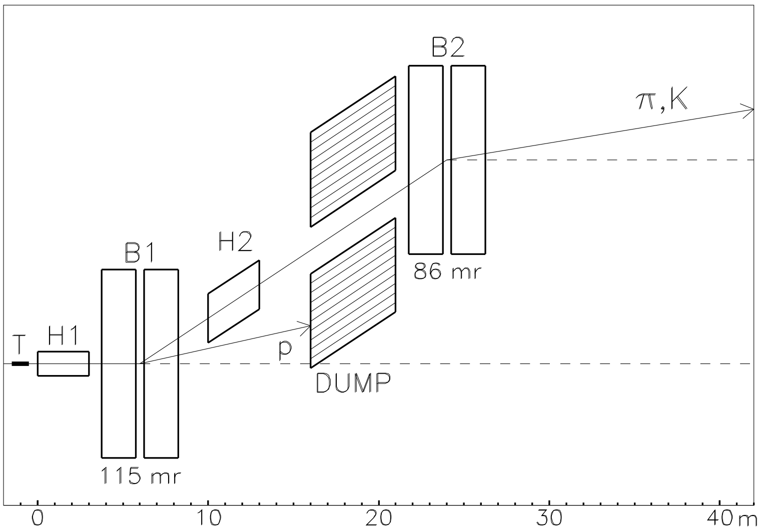
$\Downarrow$

NB beam with $\delta E_\nu/E_\nu \sim 0.15$

Thus UNK approach is improvement of atmospheric neutrino experiments. Here we know

- **exact distance between source and detector**
- **type of neutrino (ν_μ or $\bar{\nu}_\mu$)**
- **energy of neutrino**

2.2 Concept of neutrino beam



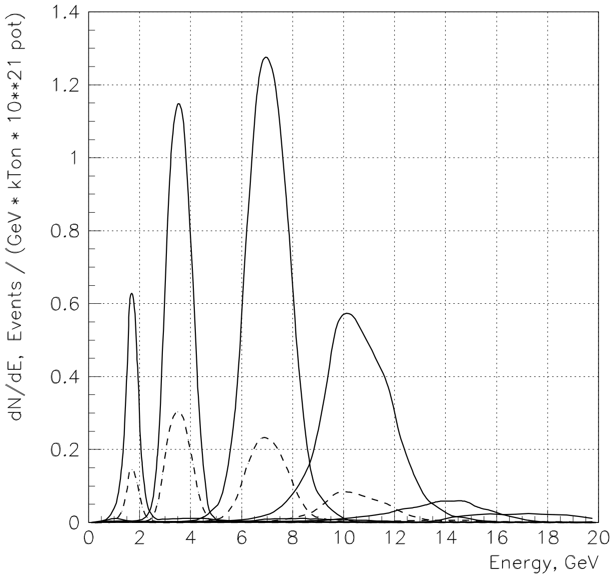
- **2 λ graphite target**
- **H1,H2 - 3 m parabolic horns (200 kA)**
- **B1,B2 - 2 m dipoles with 400 mm gap**
- **400 m decay region (40 m target area)**
- **ϕ2 m decay pipe**

Energy setting is tuned by

- **scaling dipole currents**
- **adjustment of target location**

Calculations are based on optimization of the NuMI Project system in IHEP

Beam energy range, GeV	1.0–2.3	2.3–5.0	5.0–9.0	6.0–15.	8.0–19.
Target $Z_{upstream}$, m	–0.34	–0.34	–1.94	–2.64	–3.34
Mean energy, GeV	1.7	3.5	7.0	10.5	14.0
Energy spread HWHH, %	∼16	∼16	∼14	∼14	∼13
ν_μ events/kTon/10^{21}pot	0.45	1.5	2.8	2.1	0.33
Fraction of $\tilde{\nu_\mu}$ events, %	0.8	0.4	0.3	≤0.3	≤0.3
$\tilde{\nu_\mu}$ events/kTon/10^{21}pot	0.11	0.38	0.49	0.27	0.033
Fraction of ν_μ events, %	≤16	≤6	≤10	≤17	≤30



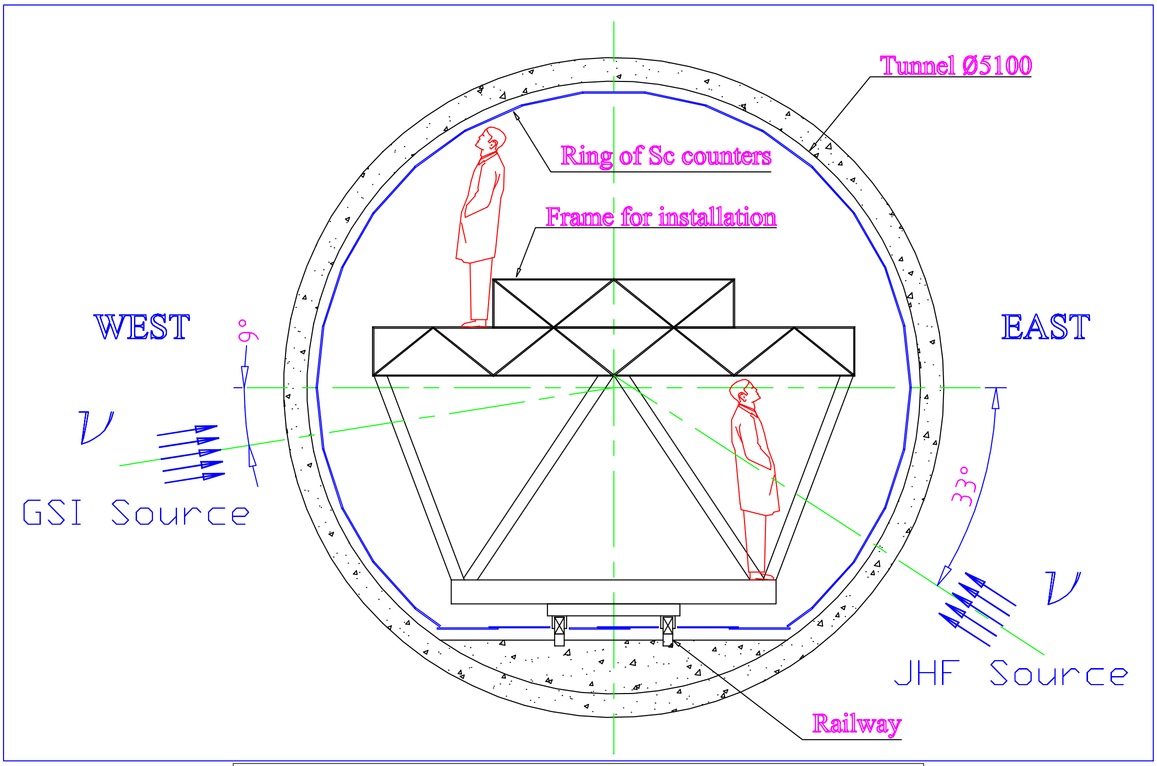
1.7, 3.5, 7.0, 10.5 and 14.0 GeV energy settings
ν_μ CC events -solid lines
$\bar{\nu}_\mu$ CC events - dashed lines

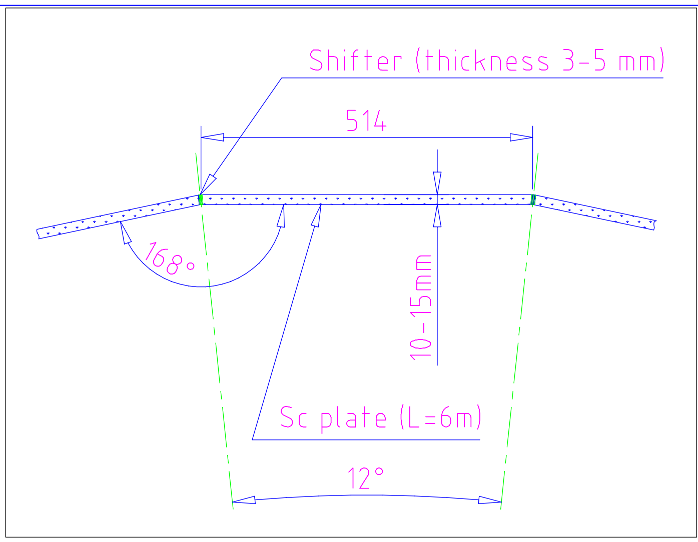
Baseline is 7000 km

WBB

E_ν, GeV	3.5	7.0
ν_μCC/kTon/10^{21}pot	4.5	9.0

2.3 Concept of detector





- **extruded polystyrene sc. plates (production in IHEP)**
- **PMMA Kumarin-30 doped WL shifters**
- **light collection from both ends by PMTs**
- **10 ph. el. at least**
- **TDC and ADC digitization of each PMT signal**

Main features of the UNK underground detector

Item	Value
sc. plate dimensions	$10 \times 500 \times 6000$ mm^3
time resolution	1 ns
coordinate resolution	25 cm
inefficiency	$4 \cdot 10^{-5}$
number of plates in section	32
total number of sections	3500
total number of plates	112000
total weight of scintillator	3400 t
total volume of UNK tunnel	400000 m^3

- **Each cylinder section (ϕ5.1 m, length 6 m) is independent unit with own trigger for read-out.**
- **Trigger is defined as coincidence at least two non-adjacent sc. plates within source spill time**
- **Source - detector unit synchronization by the GPS**

3 Physics performance

was studied by MC simulation of ν_μ and $\bar{\nu}_\mu$ events using the SCAT BC event generator.

Selection criteria :

1 **Only two hits in different sc. plates.**

2 **Time difference between hits is greater than 10 ns.**

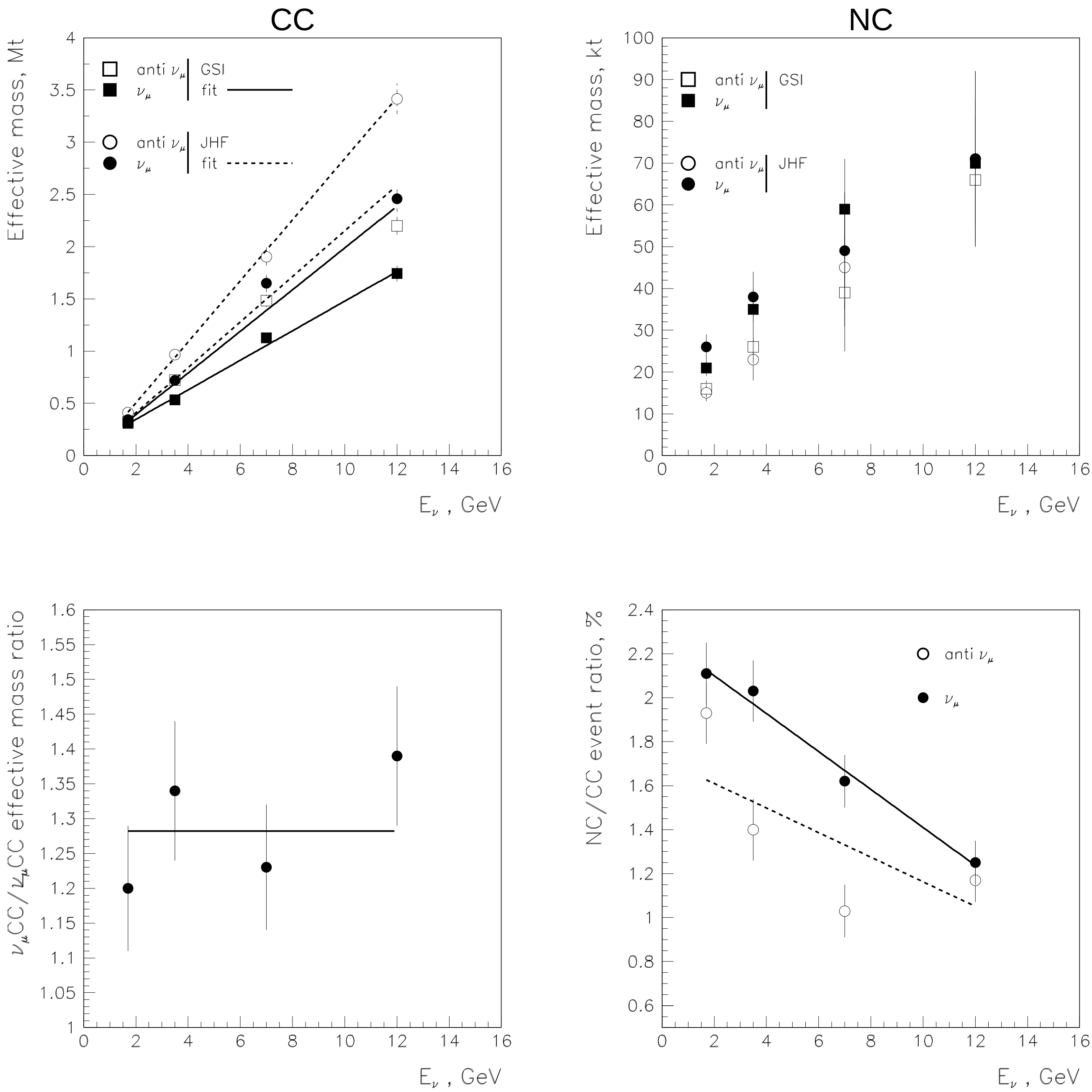
3 **Time difference is pointed to the neutrino beam direction.**

4 **Angle between neutrino and "track" directions is less than 30^0 in each plane, and "track" direction is below horizon.**

5 **$0.7 < \beta = v/c < 1$.**

	ν_μ				$\bar{\nu}_\mu$			
	CC		NC		CC		NC	
Enu,GeV	GSI	JHF	GSI	JHF	GSI	JHF	GSI	JHF
1.7	560	160	12	4	150	50	3	0.7
3.5	3400	1100	70	18	1100	360	15	3.3
7.0	12000	4200	200	40	2800	1000	30	9
14.0	2800	1000	34	9	380	130	4	1.1

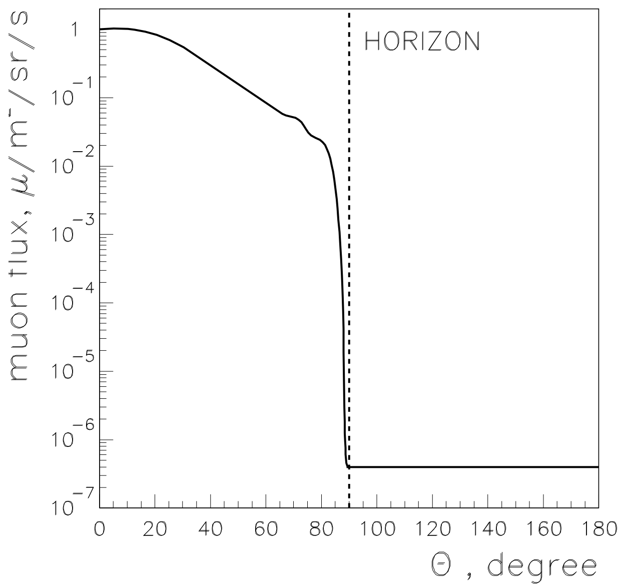
Number of events in case of no oscillation for 10^7 sec running time for each energy setting.


CC
Effective mass, Mt
anti ν_μ GSI
ν_μ fit
anti ν_μ JHF
ν_μ fit
E_ν , GeV
NC
Effective mass, kt
anti ν_μ GSI
ν_μ
anti ν_μ JHF
ν_μ
E_ν , GeV
ν_μCC/ν_μCC effective mass ratio
E_ν , GeV
NC/CC event ratio, %
anti ν_μ
ν_μ
E_ν , GeV

Background

Main background is due to cosmic muons.

N	Background source	Value,T=10^7 s
$\mu b1$	**muons which coincide in direction with accepted solid angle of muons from the source**	**0.8** ($\theta > 90^0$)
$\mu b2$	**muons which interact in the soil and produce through-going particles within the accepted solid angle**	**40 (from MACRO)**
$\mu b3$	**muons which are in opposite direction than the accepted solid angle but with wrong TOF identification**	**0.2** (6σ **of TOF)**



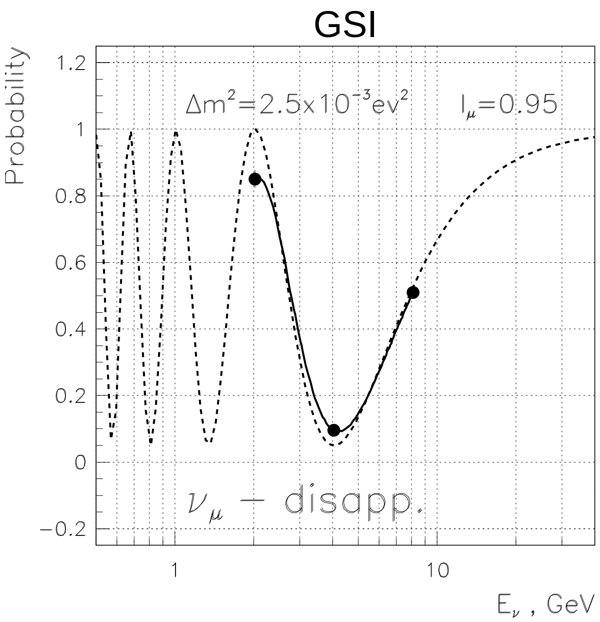
Muon flux as a function of zenith angle θ for the UNK underground detector (50 m depth in average).

- **Did not account for tails of X and T resolutions**
- **Direct measurements of the background in the UNK tunnel are needed**

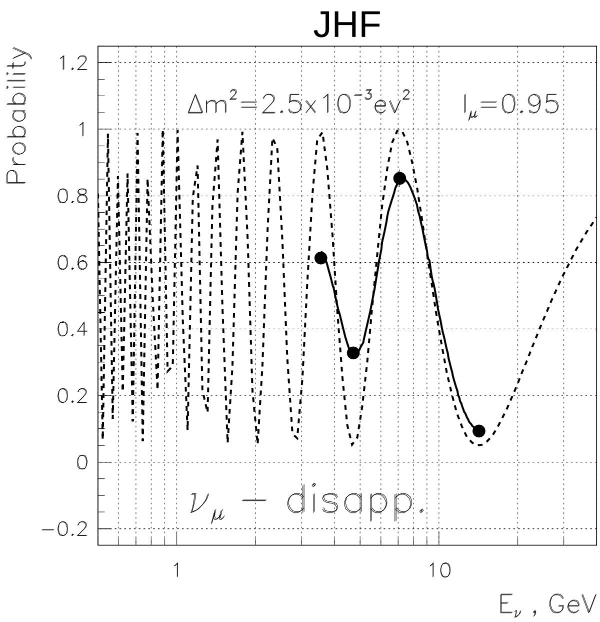
Expected sensitivity

ν source	E_ν,GeV	ν_μ			$\bar{\nu}_\mu$		
		N_{ev}	**pot**,$\cdot 10^{21}$	**T**,$\cdot 10^7 s$	N_{ev}	**pot**,$\cdot 10^{21}$	**T**,$\cdot 10^7 s$
JHF	**3.54**	**1000**	**0.90**	**0.90**	**400**	**1.12**	**1.12**
	4.72	**1000**	**0.47**	**0.47**	**1000**	**1.61**	**1.61**
	7.08	**1000**	**0.23**	**0.23**	**1000**	**1.04**	**1.04**
	14.2	**400**	**0.40**	**0.40**	**-**	**-**	**-**
		Total	**2.00**	**2.00**	**Total**	**3.77**	**3.77**
GSI	**2.02**	**1000**	**0.35**	**1.04**	**400**	**0.56**	**1.67**
	4.04	**1000**	**0.07**	**0.22**	**1000**	**0.24**	**0.72**
	8.09	**1000**	**0.02**	**0.07**	**1000**	**0.12**	**0.36**
		Total	**0.44**	**1.33**	**Total**	**0.92**	**2.75**

$P(\nu_\mu \rightarrow\ disapp.) = N_{osc}/N_{exp} = 1 - I_\mu \cdot sin^2(1.27 \cdot \Delta m^2 \cdot L/E)$
$\Delta m^2 = 2.5 \cdot 10^{-3}\ ev^2$,
$I_\mu = 0.95$



$\sigma_{\Delta m^2} = \mathbf{2 \cdot 10^{-5}\ ev^2}$
$\sigma_{I_\mu} = \mathbf{0.003}$



$\sigma_{\Delta m^2} = \mathbf{2 \cdot 10^{-5}\ ev^2}$
$\sigma_{I_\mu} = \mathbf{0.002}$

ν source	$\mathbf{\Delta m^2}$ **in** $\mathbf{10^{-3}\ ev^2}$
GSI	$\mathbf{1.5 < \Delta m^2 < 6}$
JHF	$\mathbf{0.5 < \Delta m^2 < 4}$

4 Conclusion

The performance of the VLBL neutrino oscillation experiment (baseline of 2000-7000 km) with the UNK 1Mt-level underground detector will provide:

- **Observation of the oscillation curve patterns for the ν_μ and $\bar{\nu}_\mu$ disappearance is possible in the**

  $$\mathbf{0.5 \cdot 10^{-3} < \Delta m^2 < 6 \cdot 10^{-3}\ ev^2}$$

  range using the NB neutrino beam. Both the JHF and the GSI high intensity proton accelerators can be used as neutrino sources.

- **Measurement of of $\mathbf{\Delta m^2}$ and $\mathbf{I}_\mu$ with sensitivity**

  $$\sigma_{\mathbf{\Delta m^2}} = \mathbf{2 \cdot 10^{-5}\ ev^2\ and}$$
  $$\sigma_{\mathbf{I}_\mu} = \mathbf{0.002}$$

  can be carried out both for ν_μ and $\bar{\nu}_\mu$ cases within a reasonable time schedule .

- **Search for the CPT violation in neutrino sector can be done with sensitivity**

  $$\mathbf{at\ the\ 10^{-4}\ ev^2\ level}$$

  for the $\mathbf{\Delta m^2}$ difference comparing the ν_μ and $\bar{\nu}_\mu$ disappearance $\mathbf{\Delta m^2}$ values.