Opportunities for the $K_L^0 \to \pi^0 \nu \tilde{\nu}$ decay search at U-70 synchrotron (IHEP, Protvino)

A. Ostankov for the *KLOD* collaboration

Joint Project :

IHEP, Protvino
JINR, Dubna
INR, Moscow, RAS

Proposal

– published as IHEP Preprint 2007-08
– reported at KAON-07
– some materials are available at *http://kaon.jinr.ru/*

STATE RESEARCH CENTER OF RUSSIA
INSTITUTE FOR HIGH ENERGY PHYSICS

Stable operation last few years

2 running periods per year 30÷40 days each

Normally (20÷30)×2 days available for physicist in a year

Extra beam time is technically possible. ($1M per Run)

70 GeV IHEP proton synchrotron

Constantly under development & improvement
Last years achievements:

Increasing intensity (10^{13} ppp – nominal condition)

- 2×10^{13} already achieved (stable @60GeV)
- 3×10^{13} unstable @present
- 5×10^{13} possible (H^+)

Spill duration

Stochastic Slow Extracted Proton Beam regime implemented in 2006

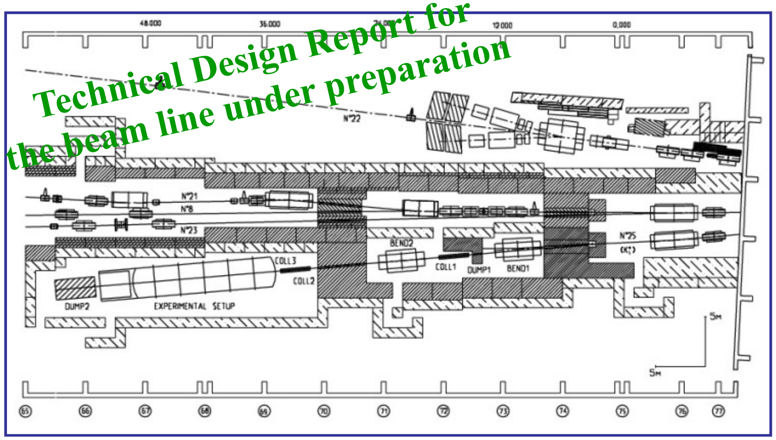
60 GeV protons, 8 sec period / 3 sec flat top

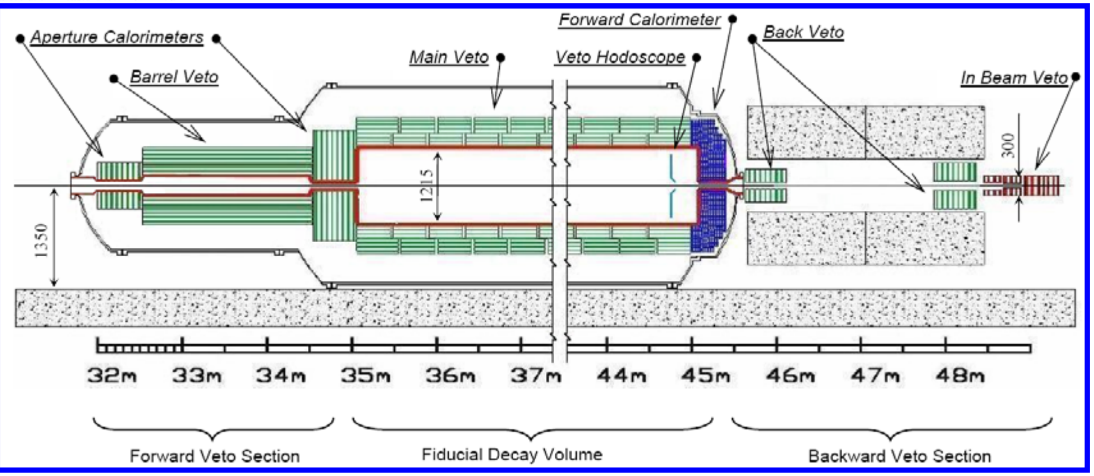
Note: Spill duration is limited by possible accelerating field plateau (heating)
(2 – 3 – 4)sec @ (70 – 60 – 50) GeV correspondingly

For our estimation we considered

10^{13} ppp @60GeV, 3 sec spill

KLOD Detector





-- **Measurement strategy similar to *KAMI, E391a, K0TO***
narrow beam approach, Kaon bottle

-- **Sensitivity is compatible to *J-Parc(2)***
in consideration of *U-70* intensity reserve (2×10^{13} ppp),
but note beam time available

-- **Worse Signal/Background ratio**
due to beam size

	KOPIO	*KAMI*	*E391A*	*J-Parc (1)*	*J-Parc (2)*	*KLOD*
Proton energy	24 GeV	120 GeV	12 GeV	30 GeV	30 GeV	60 GeV
#Protons/spill	10^{14}	3×10^{13}	2.5×10^{12}	2×10^{14}	3×10^{14}	10^{13}
Duration cycle/ (spill)	5.3/(3) s	3/(1) s	4/(2) s	3.3/(0.7) s	3.3/(0.7) s	8/(3) s
K_L^0 **extraxtion angle**	$40^\circ \div 45^\circ$	15 mrad	4°	16°	5°	35 mrad
K_L^0 **momentum** average/(in peak)	920/(750) MeV/c	20/(12) GeV/c	2.6/(1.8) GeV/c	2.1/(1.3) GeV/c	5.2/(−) GeV/c	10/(6.5) GeV/c
Beam profile	5.2mrad×96mrad	–	4 mrad, ∅	–	–	4 mrad, ∅
Spatial beam angle	500 μstr	0.41 μstr	12.6 μstr	9 μstr	2 μstr	12.6 μstr
K_L^0 **/spill** (@setup)	2.6×10^{8}	6.2×10^{7}	3.3×10^{5}	8.1×10^{6}	4.4×10^{7}	5.4×10^{7}
Effective decay region	3 m	65 m	2 m	2 m	11 m	10 m
Decay probability in fiducial volume	≈16 (8) % (×1 decay/spill)	15 %	2.7 %	3.6 %	6 %	4.8 %
Beam time	3×10^{7}s	2×10^{7}s	6 months	3×10^{7}s	3×10^{7}s	10 days
Sensitivity	6×10^{-13}	–	$\sim10^{-9}$	8×10^{-12}	3×10^{-13}	2.6×10^{-11}
# **signal events** (@SM)	96	88		3.5	133	1
Signal/Background	2	4.6		1.4	4.8	3

The data were taken from the original Proposals without recalculations and tracking the values changes

The current work on the project *KLOD* includes in particular the R&D for the most crucial detectors:

-- In-Beam Veto

-- Main Barrel Veto

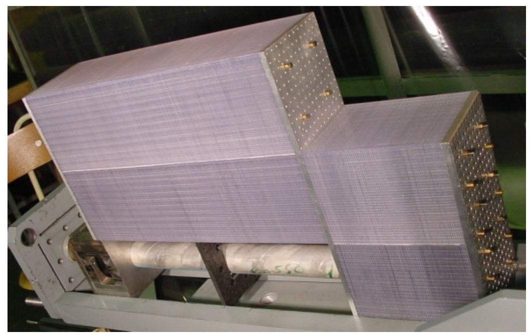
-- … …

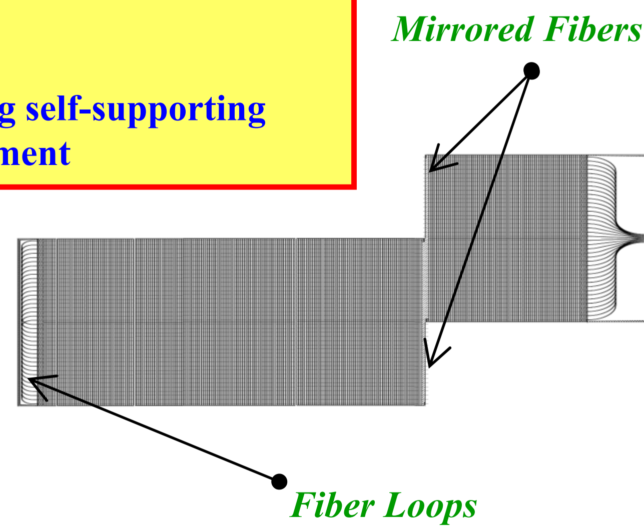
Main Veto Prototypes

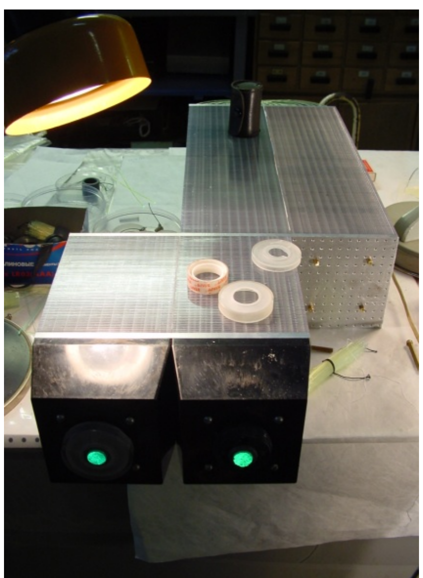
-- Main Veto dominates in overall cost estimation
-- Best γ-detection efficiency up to the smallest energy is needed

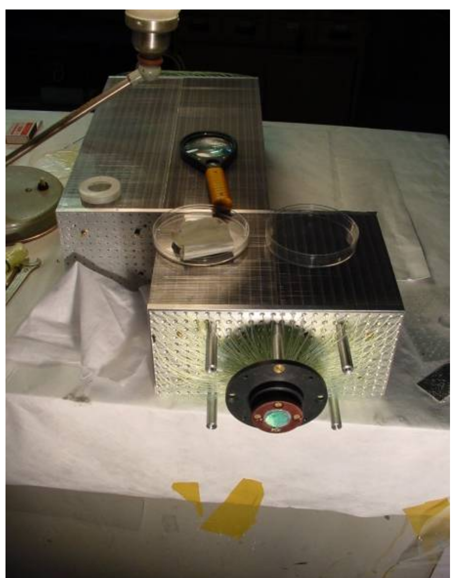
- To our opinion the fine Shashlyk-structure (0.3mm Pb + 1.5mm molding Scint.) is the best choice to keep detection threshold low
- Stair-like shape – to avoid any possible gaps

Prototyping goal -- to demonstrate the capability of manufacturing self-supporting modules of such type + mass scale production technology development









By beam test we confirmed:

- ≈ 30000 photons per 1 GeV γ-shower
- ≈ 5 ph.e⁻ per single Scint. plate for *m.i.p.*
- ≈ 15 ph.e⁻ per 1 MeV of “visible” energy
- $\sigma_E/E \approx 3\%/\text{sqrt}(E)$

In-Beam Veto-Calorimeter – real challenge

Problems:

1. γ-detection from background decays in aperture of high int. beam

   2% of $K_L^0 \to \pi^0\pi^0$ have 2 γ's (π^0) at In BeamVeto

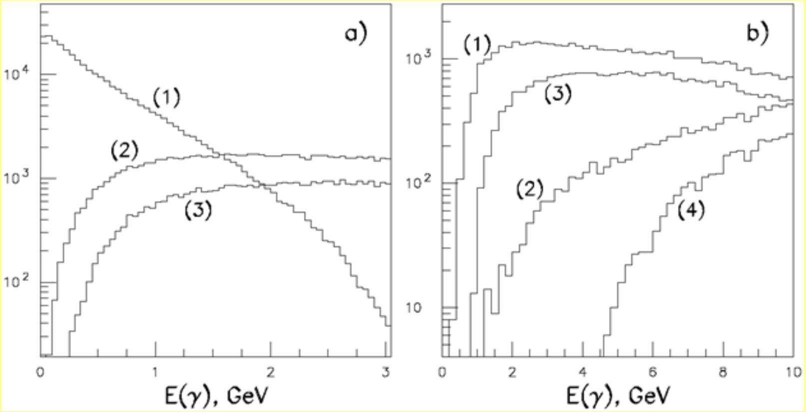
   such topology should be suppressed, 10^{-6} !!!

   hard spectrum (fortunately)

2. avoid "over-veto" (acceptance lost) from the beam particles misidentified as a γ's

   ~300 MHz neutron flux – major problem

γ-spectra from $K_L^0 \to \pi^0\pi^0$ at condition
"2 γ's hit Forward Calorimeter"



(1) – @ Main Veto
(2) – @Hole in FCal
(3) – @ InBeamVetoCal.

@ InBeamVetoCal.
+ "2 γ's hit InBeamVetoCal"
(1) – E(γ); (2) – E(γ1)+E(γ2)
+ "2 γ's are from one π0"
(3) – E(γ); (4) – E(γ1)+E(γ2)

Solutions:

1. to use Cherenkov light

Quartz fibers are only sensitive to *em* shower component

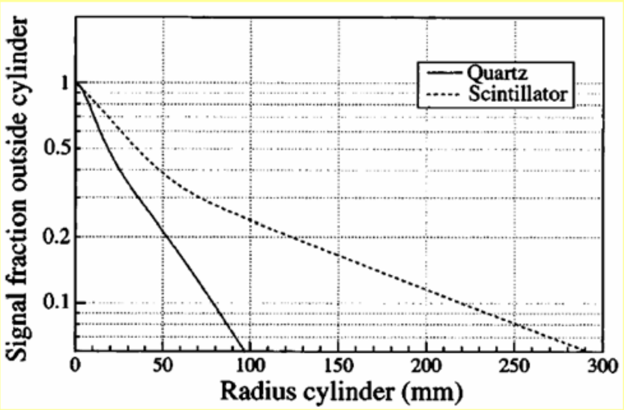
CMS HF: e/h ~ 5, NIM A399 (1997) 202

2. Dual Readout (Scint.+Ch.)

It's proven by DREAM collaboration that Scint. and Ch. signals have different behaviors for *em* and *had.* showers, NIM A536 (2005) 29

3. + enough amount of X_0's
   + small amount of λ's
   + very fast
   + segmentations
   + no dead time readout (FADC)

Transverse profiles of 80 GeV π showers
N.Akchurin, R.Wigmans Rev.Sci.Instrum., Vol.74, 2003



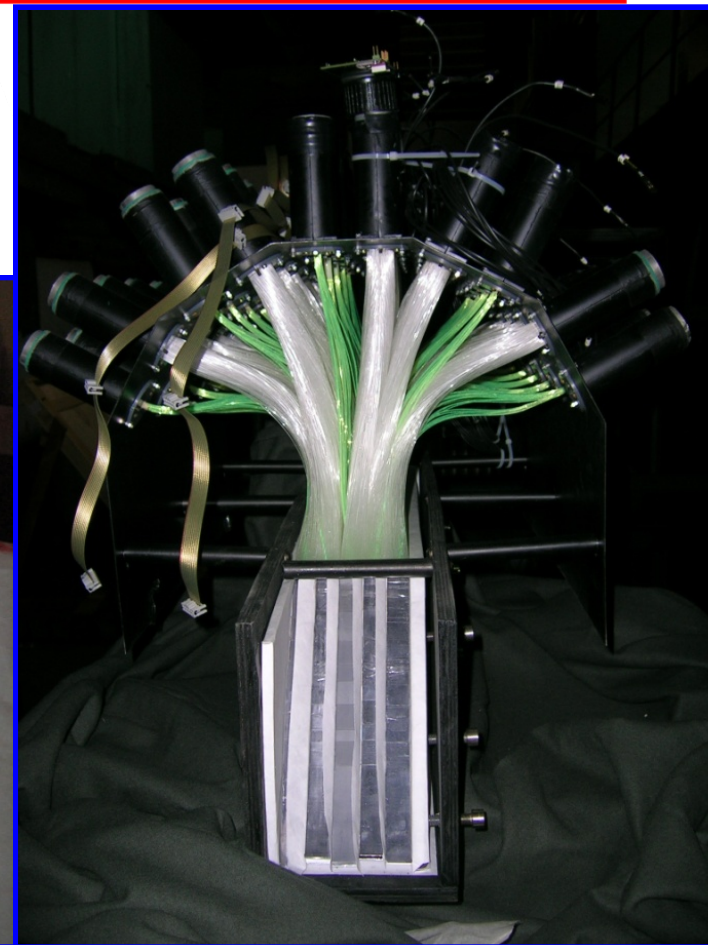
No such difference for γ-showers !

+ very different behavior for γ & hadron showers in longitudinal direction

In-Beam Veto-Calorimeter Prototype

Structure along the beam: (0.3mm Pb + 1mm Acril + 1.5 mm Scint.) × 100 layers
Segmentation: -- across the beam (Y, in one direction only): 17mm (17 fibers) × 5 cells
-- along the beam, (Z): 20 layers × 5 cells
Elementary cell: 200mm (X) × 17mm (Y) × 60mm (Z)
Full prototype: (200 mm × 85 mm × 100 layers)
➔ $\approx (1R_M \times 2R_M \times 7.5X_0)$

The purpose is to look at Ch/Sc signals ratio & its behavior in transverse and longitudinal directions



In-Beam Veto-Calorimeter Monte-Carlo

Energy resolution for γ's:

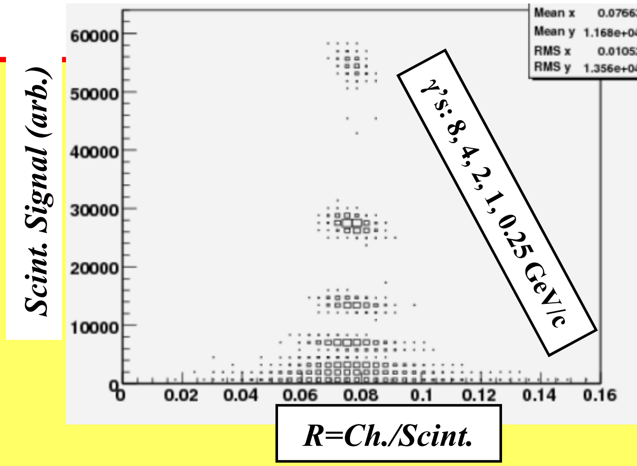
$\sigma_E/E \sim 5.5\%/\sqrt{E}$ *by Scint.*

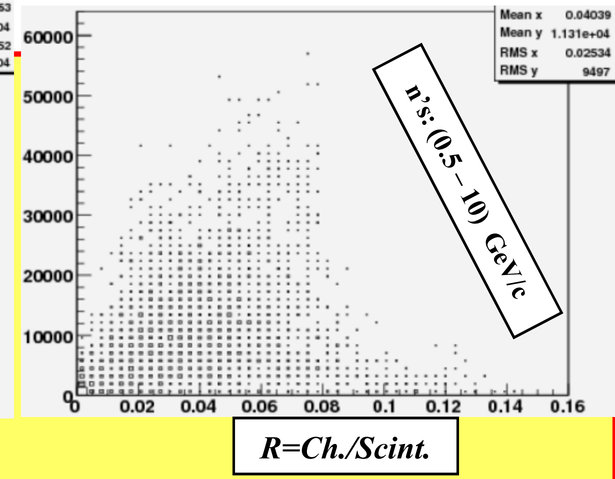
$\sigma_E/E \sim 7.6\%/\sqrt{E}$ *by Cher.*

For γ's (at full energy range studied):

$R_0 = Ch/Scint \approx 0.075$

$\sigma_R/R_0 \approx 8\%/\sqrt{E}$





The simplest algorithm for γ-shower recognition, registered $R=(R_0 \pm 3\sigma_R(E_{Scint}))$, suppress *n*-component by factor of ~100 ➔ (300 ➔3) MHz *n*-flux ➔ ~2% acceptance lost (10 nsec)

E_γ, GeV	0.25	0.5	1	2	4	8
Nonefficiency	1.3×10^{-2}	3.5×10^{-3}	10^{-3}	6×10^{-4}	5×10^{-4}	5×10^{-4}
Nonefficiency in presens of neutron (beam spectrum)	3.5×10^{-2}	1.1×10^{-2}	3.5×10^{-3}	10^{-3}	6×10^{-4}	5×10^{-4}

Preliminary beam test (Spring 2009)

Prototype partially equipped by PMT's (20 channels out of 50) => only μ-Runs are relevant

Uniformity: +/− 5% in both directions across the beam

Light yield: 10 ph.e from Cherenkov light per single cell @45º for *m.i.p.*
=> 0.5 ph.e per fiber layer. Scint./Cher. = 10

Response vs. angle of incidence: for Cher. -- max. at @45º, proper angular behavior
no dependence for Scint. Light

Data will be used for fine Monte-Carlo tuning.

In absence on n-beam only indirect proofs of working capabilities of device are possible

To conclude

The current status of the KLOD project is as follows: there are three working groups from three scientific centers of Russian Federation (JINR, IHEP, INR) belonging to different Ministries with independent financings. The Scientific Committees of IHEP, JINR and INR have clearly recognized the scientific importance of this experiment.

The financial situation is that, at present, 3 Institutes will not be able to provide needed money resources in the framework of existing budgets. It means that somehow we'll have to obtain an independent dedicated financing or/and to involve more participants.

However, there are enough resources for the R&D phase and the common will is to do it. In parallel, at IHEP a detailed calculations related to the beam are in progress, as well as the Technical Proposal preparation for the beam-line.