HEPAP Review of RSVP KOPIO

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Presentation Plan

- KOPIO – Introduction and overview of expected results
- Theoretical Perspectives on KOPIO (Gino Isidori, INFN)

KOPIO is Unique

- Excellent discovery potential for non-SM physics

  Two orders of magnitude window

  Many candidate theories

- The only experiment that directly measures the crucial SM CP violation parameter

- The only reviewed, approved, experiment sensitive enough to measure $K_L^0 \to \pi^0 \nu \bar{\nu}$; uses a robust innovative technique to suppress background

Roles of $K \to \pi\nu\bar{\nu}$ Measurements in Flavor Physics

New flavor physics in the s-d sector may be very different from that in the b sector:

* *If B - physics is consistent with the SM:*

*N*ew physics could be revealed $K \to \pi\nu\bar{\nu}$.

* *If deviations from the SM are indicated:*

$K \to \pi\nu\bar{\nu}$ would add crucial additional information; the complexity of the flavor sector beyond the SM is foreseen in many models.

Results from $K \to \pi\nu\bar{\nu}$ will be needed to interpret non-SM physics discoveries at BABAR, BELLE, CDF/D0, and the LHC.

Experiments Seeking $K_L^0 \to \pi^0 \nu\bar{\nu}$

SM: $B(K_L^0 \to \pi^0 \nu\bar{\nu}) = (3.0 \pm 0.6) x 10^{-11}$

Limit based on $K^+ \to \pi^+ \nu\bar{\nu}$ via isospin : $< 1.4 x 10^{-9}$ • [Grossman, Nir]

- KTEV (FNAL) result: $B(K_L^0 \to \pi^0 \nu\bar{\nu}) < 5.9 x 10^{-7}$ (90%CL)
- KEK E391a: $> 10^{-9}$??
- KOPIO (BNL): Single event Sensitivity $< 10^{-12}$

Discovery (5σ) for $B(\text{"}K_L^0 \to \pi^0 \nu\bar{\nu}\text{"}) > 4.5 x 10^{-11}$

or 300 "SM" events

LOI at JPARC

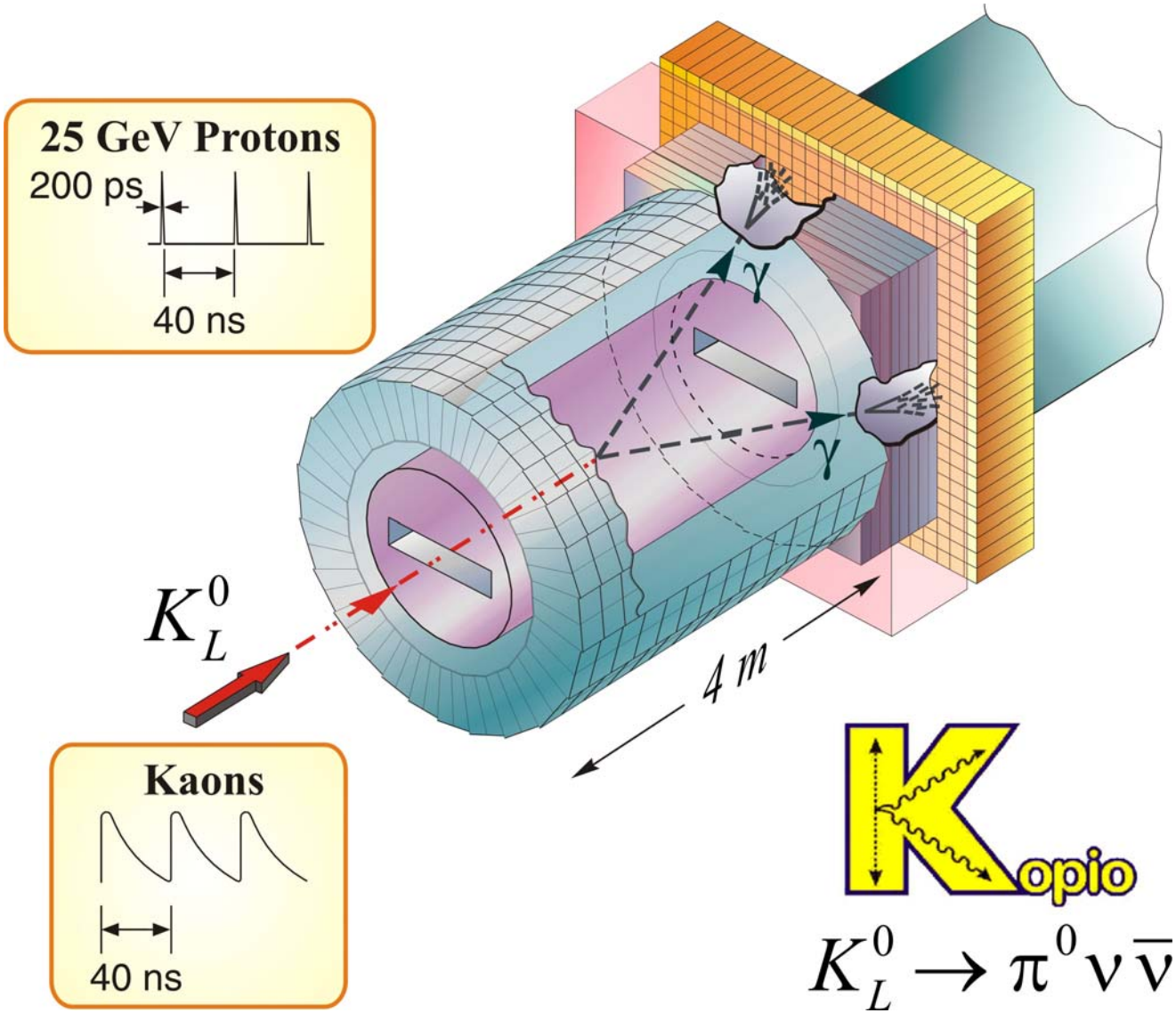
$K_L^0 \to \pi^0 \nu \bar{\nu}$ Measurement

Background suppression factor needed: 10^{10}

Primary Backgrounds

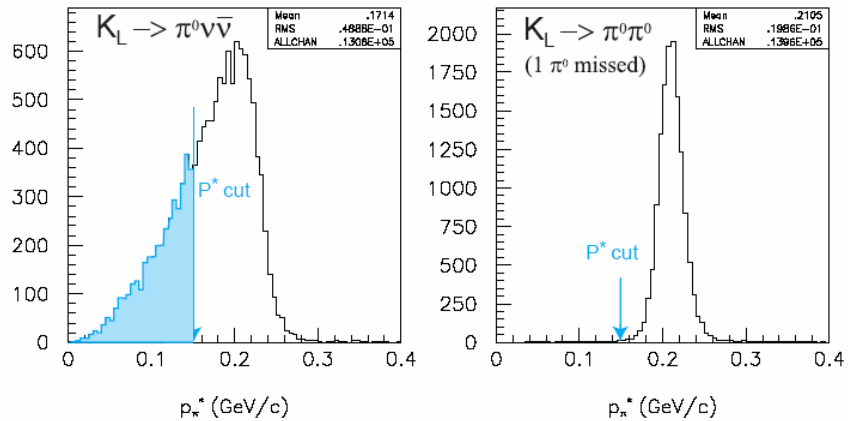
Mode	Branching Ratio
$K_L^0 \to \pi^0 \pi^0$	$0.93 \ x \ 10^{-3}$
$K_L^0 \to \pi^- e^+ \nu \gamma$	$0.36 \ x \ 10^{-2}$
$K_L^0 \to \pi^+ \pi^- \pi^0$	0.1255
$K_L^0 \to \pi^0 \pi^0 \pi^0$	0.2105
Others	

KOPIO Concepts



$$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$$

Kaon Center of Mass Measurements



Concepts

- Maximize micro-bunched beam from the AGS
- Measure everything! (Energy, Position, Angle, Time)
- Eliminate extra charged particles or ***photons***
  - * KOPIO: π^0 inefficiency < 10^{-8}
- Suppress backgrounds
  - * Predict backgrounds *from data*: dual cuts
  - * Use "Blind analysis" techniques
  - * Test predictions "outside-the-box"
- Weight candidate events with S/N likelihood function

Nominal AGS Beam Parameters

Proton Beam:

100 Tp/spill (Upgraded from present 70 Tp)

~5.5 s spill, 2.3 s interspill period

25 MHz micro-buching frequency

Bunch width 200ps

Interbunch extinction 10^{-3}

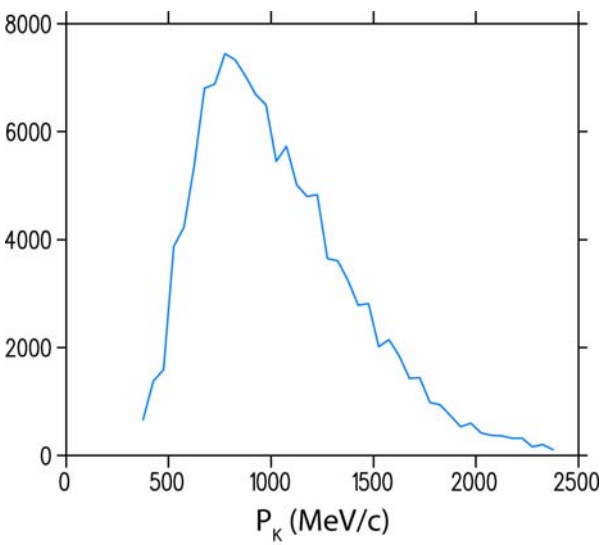
Kaon Beam:

42.5 degree take-off angle

Soft momentum spectrum [0.5,1.5 GeV]

3×10^{8} K_L / spill, 8 % decay

10 GHz neutrons



KOPIO Collaboration

6 countries 19 institutions 80 scientists 10 Grad students

Arizona State University J.R. Comfort, *J. Figgins*

Brookhaven National Laboratory D. Beavis, I-H. Chiang, A. Etkin, J.W. Glenn, A. Hanson, D. Jaffe, D. Lazarus, K. Li, L. Littenberg, G. Redlinger, C. Scarlett, M. Sivertz, R. Strand

University of Cinncinnati K. Kinoshita

IHEP, Protvino G.Britvich, V. Burtovoy, S.Chernichenko, L, Landsberg, A. Lednev, V. Obraztsov, R.Rogalev, V.Semenov, M. Shapkin, I.Shein, A.Soldatov, N.Tyurin, V.Vassil'chenko, D. Vavilov, A.Yanovich

INR, Moscow A. Ivashkin, *D.Ishuk*, M. Khabibullin, A. Khotjanzev, Y. Kudenko, A. Levchenko, O. Mineev, N. Yershov and *A.Vasiljev*.

INFN-University of Perugia G. Anzivino, P. Cenci, *E. Imbergamo*, A. Nappi, M. Valdata

KEK M. Kobayashi

Kyoto University of Education R. Takashima

Kyoto University *K. Misouchi, H. Morii*, T. Nomura, N. Sasao, *T. Sumida*

Virginia Polytechnic Institute & State University M. Blecher, *N. Graham*, A. Hatzikoutelis

University of New Mexico B. Bassalleck, N. Bruner, D.E. Fields, J. Lowe, T.L. Thomas

University of Montreal J.-P. Martin

Stony Brook University N. Cartiglia, *I. Christidi*, M. Marx, P. Rumerio, D. Schamberger

TRIUMF P. Amaudruz, M. Barnes, E. Blackmore, J. Doornbos, P. Gumplinger, R. Henderson, N. Khan, A. Mitra, T. Numao, R. Poutissou, F. Retiere, A. Sher, G. Wait

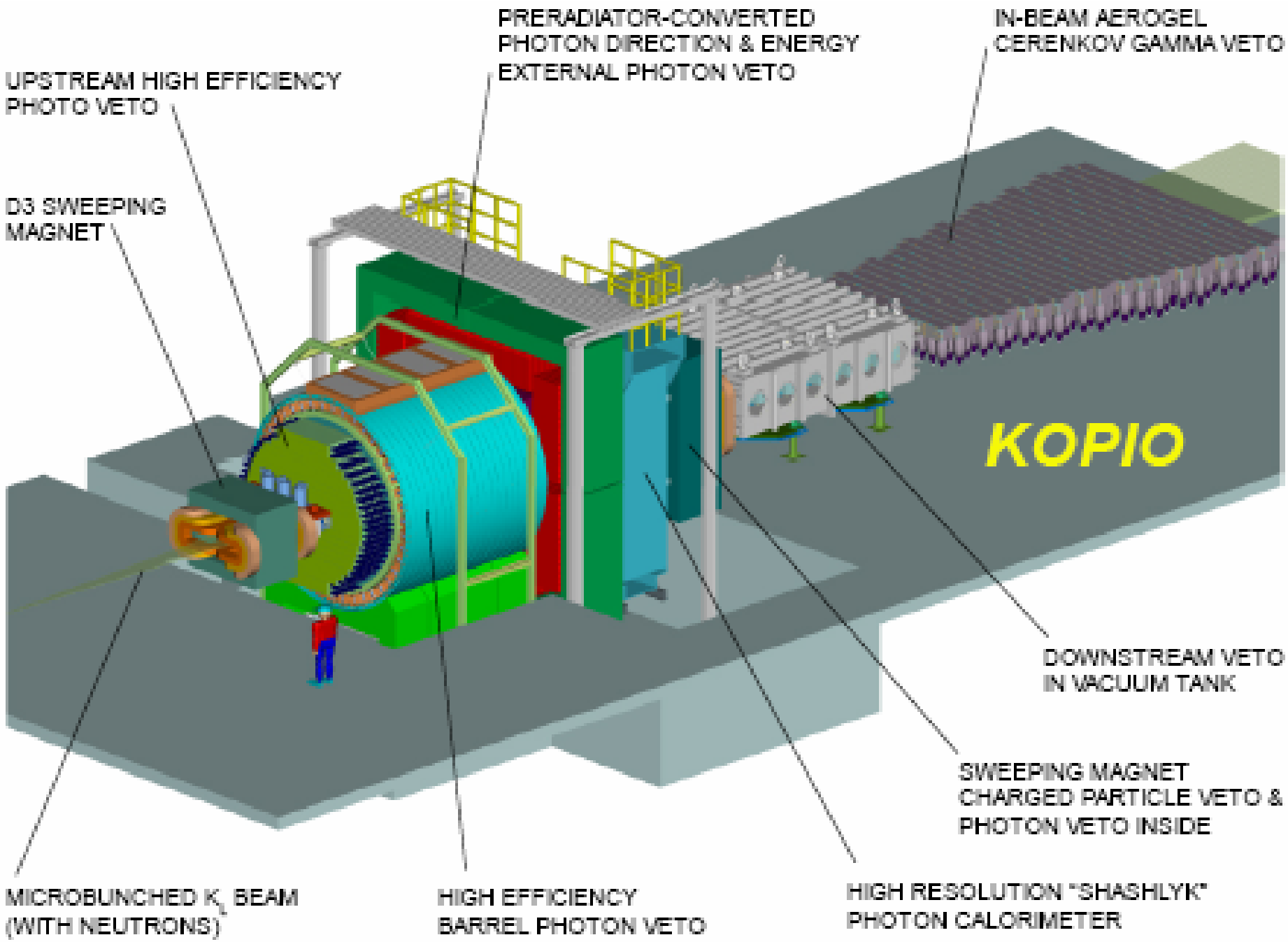
University of British Columbia D. Bryman, M. Hasinoff, *J. Ives*

Tsinghua University S. Chen

University of Virginia E. Frlez, D. Pocanic

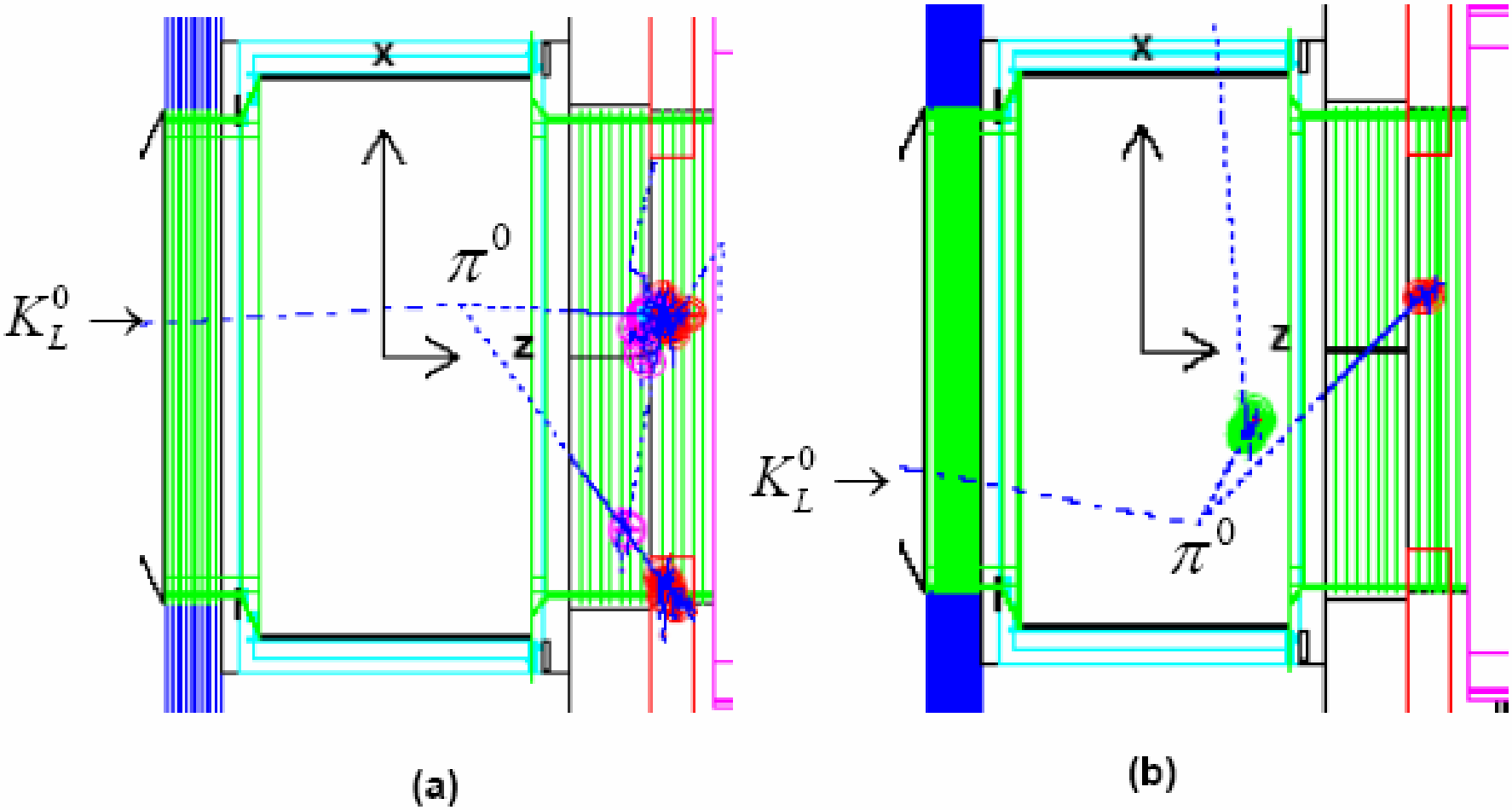
University of Zurich P. Robmann, P. Trüol, A. van der Schaaf, *S. Scheu*

Yale University G. Atoyan, S.K. Dhawan, V. Issakov, H. Kaspar, A. Poblaguev, M.E. Zeller


PRERADIATOR-CONVERTED
PHOTON DIRECTION & ENERGY
EXTERNAL PHOTON VETO
IN-BEAM AEROGEL
CERENKOV GAMMA VETO
UPSTREAM HIGH EFFICIENCY
PHOTO VETO
D3 SWEEPING
MAGNET
KOPIO
DOWNSTREAM VETO
IN VACUUM TANK
SWEEPING MAGNET
CHARGED PARTICLE VETO &
PHOTON VETO INSIDE
MICROBUNCHED K_L BEAM
(WITH NEUTRONS)
HIGH EFFICIENCY
BARREL PHOTON VETO
HIGH RESOLUTION "SHASHLYK"
PHOTON CALORIMETER

Primary detection mode:
2 photons covert in preradiator

Secondary mode:
1 photon in preradiator, 1 in BV



Reconstruct first $\gamma \rightarrow e^+e^-$ in "Preradiator"

Point to K decay vertex in vacuum.

KOPIO Signal and Background Estimates

The key features of the KOPIO approach have been established by ***measurements*** supported by simulations

- Micro-bunching and neutral beam design
- Photon pointing, energy resolution
- Vetoing – charged particles and photons

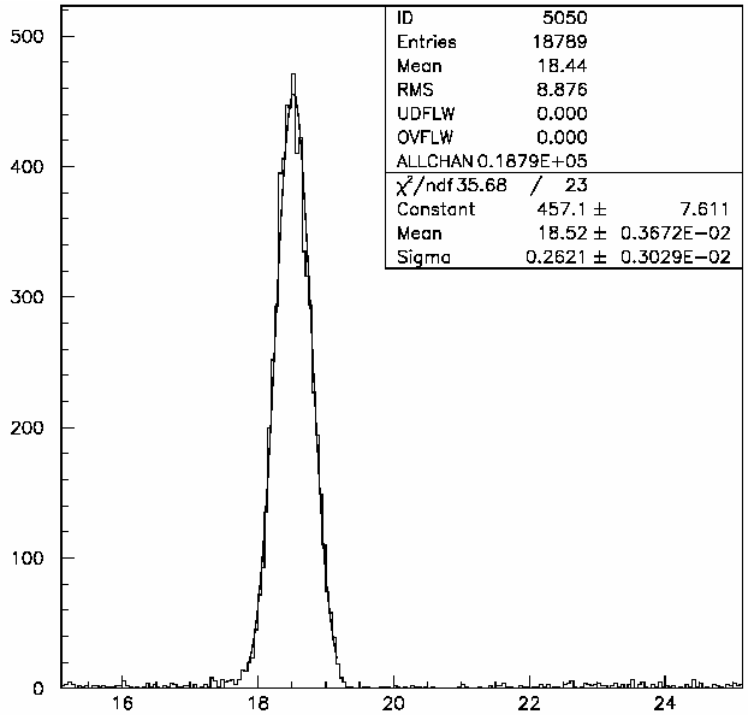
	Expected Performance
μ Bunch Width (Extinction)	200 ps (10^{-3})
θ_γ Resolution (250 MeV)	25 mr
E_γ Resolution	$2.7\% / \sqrt{E_\gamma(GeV)}$
t_γ Resolution	$90ps / \sqrt{E_\gamma(GeV)}$
Photon Veto Inefficiency	E949 or better
Charged Particle Inefficiency	$10^{-5}(\pi^+), 10^{-4}(\pi^-)$

AGS Microbunching Beam test

Microbunch width

Studied the RF extraction mechanism proposed for KOPIO & measured a microbunch rms width of 244 ps -- KOPIO requires <300 ps rms

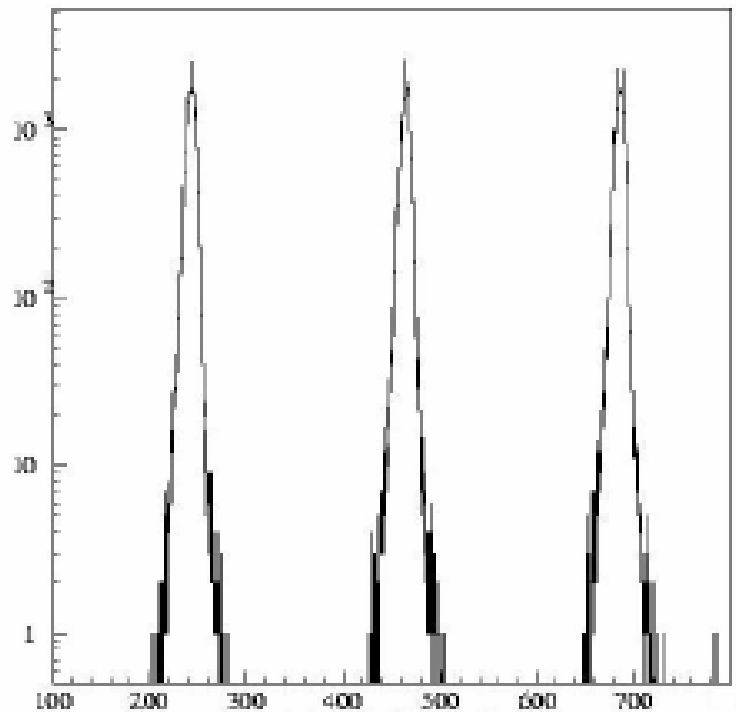
93 MHz



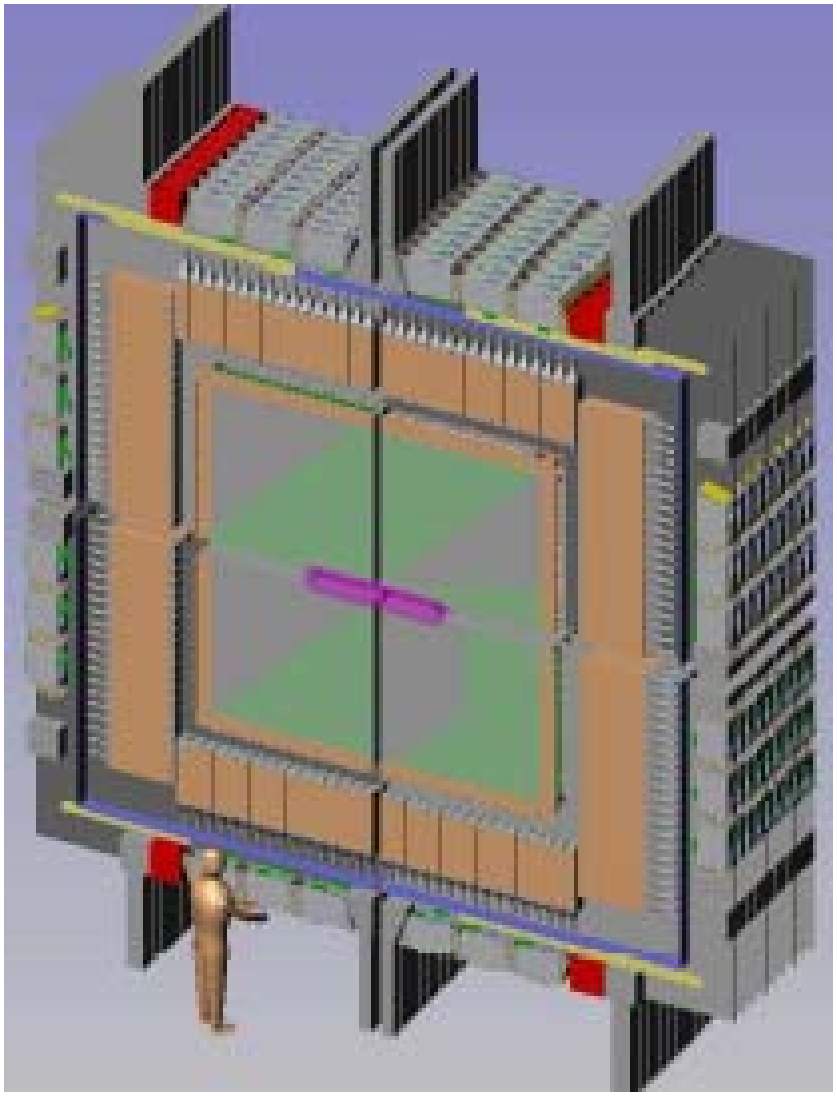
Interbunch extinction

Measured the inter-bunch extinction ratio (flux between bunches/within bunch). KOPIO requires ~ 10^{-3}.

4.5 MHz



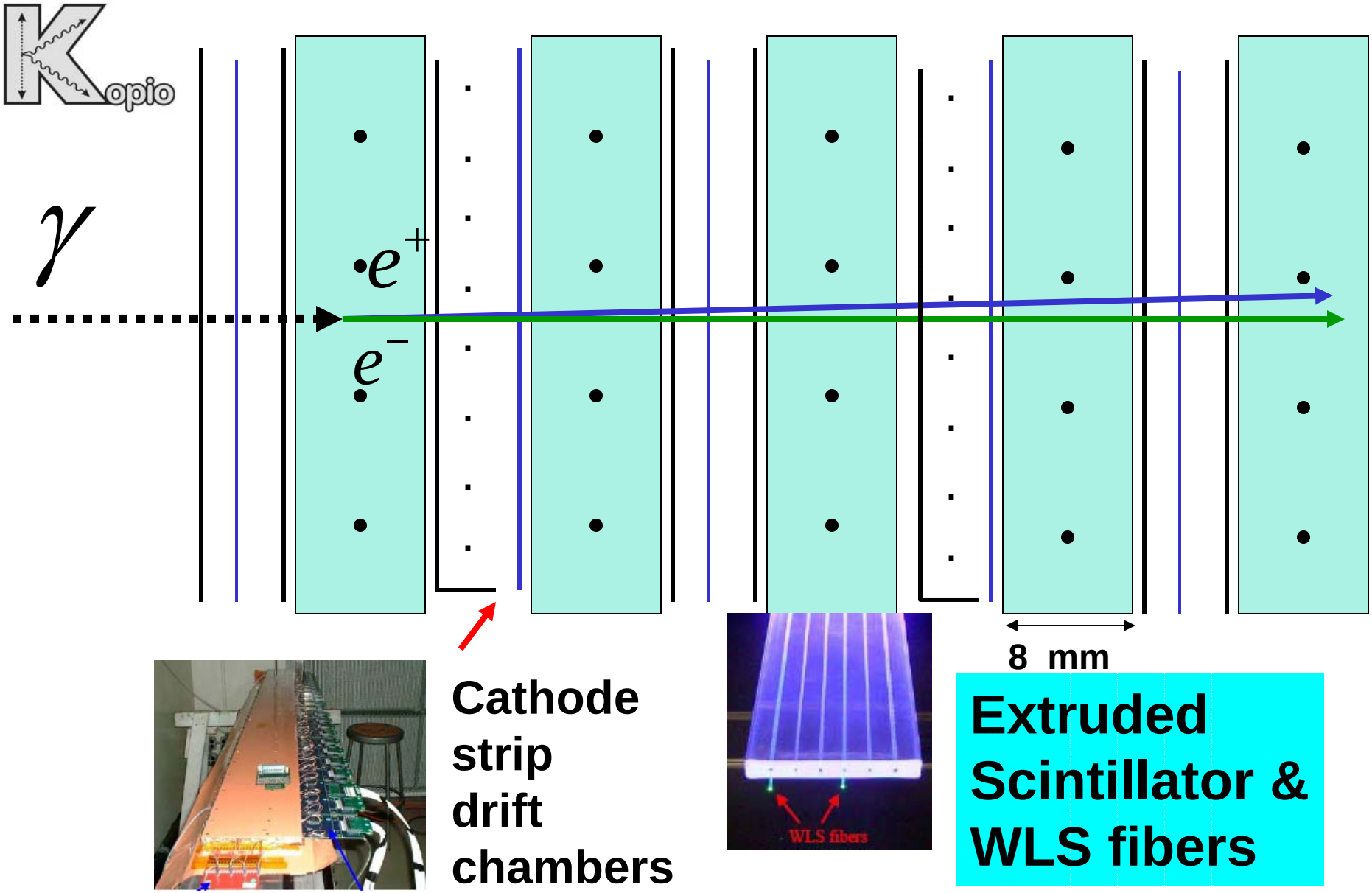
Preradiator



4m

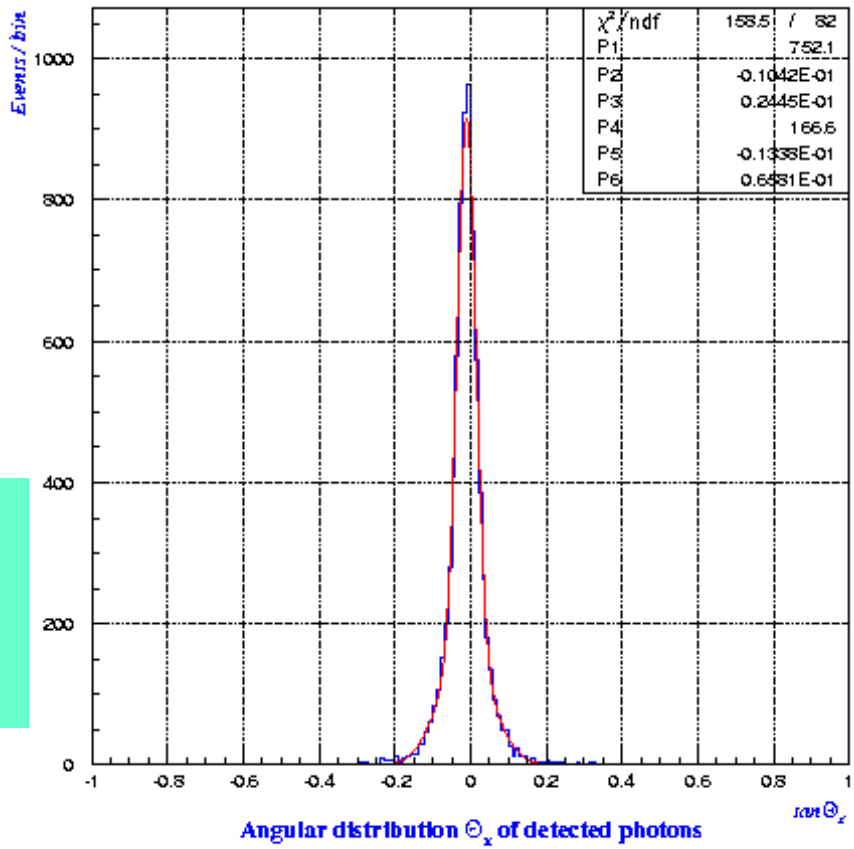
64 Layers (4% X_0/layer, 2.7 X_0)
256 Chambers
288 Scintillator Plates (1200 $m^{2)}$
150,000 Channels Readout

Preradiator Angle Measurement of $\gamma \to e^+e^-$



KOPIO Prototype Measurements – BNL LEGS Tagged Photon Beams

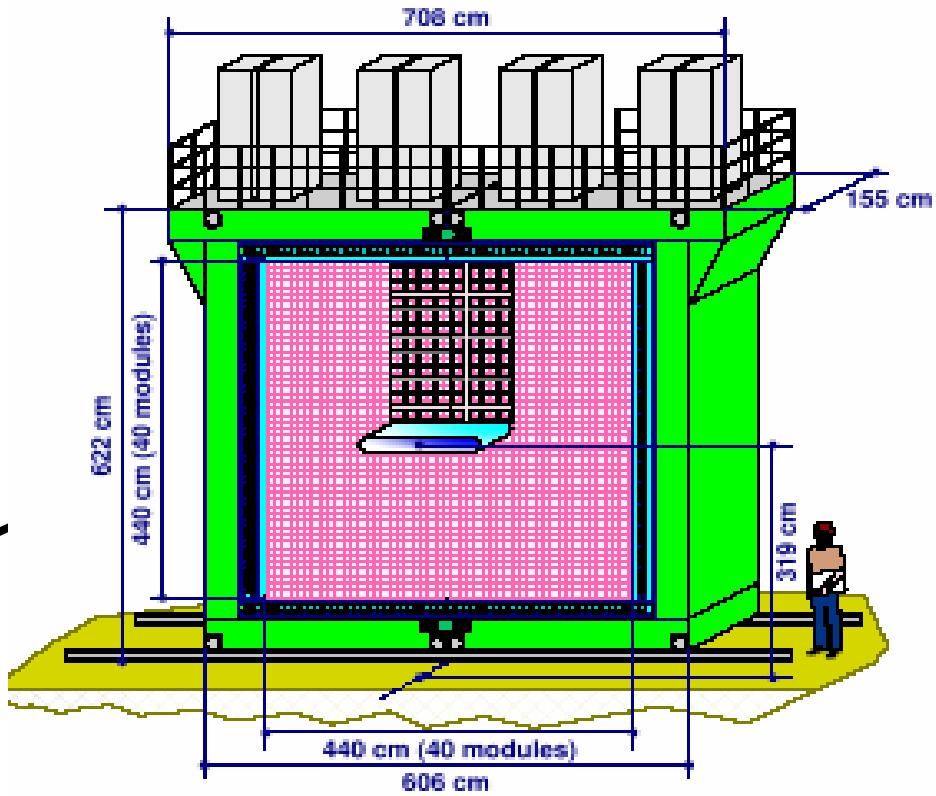
Preradiator Angular resolution:
25 mr at 250 MeV/c

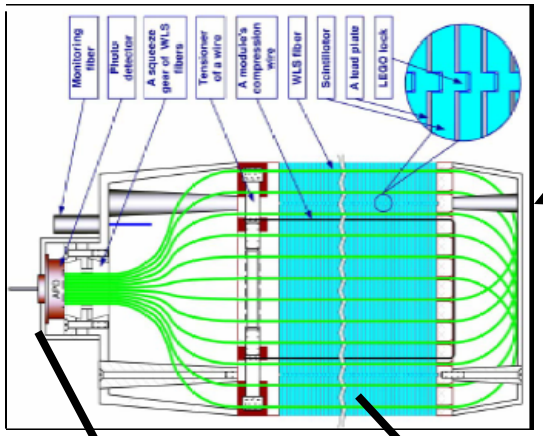


Simulations agree with measurements.

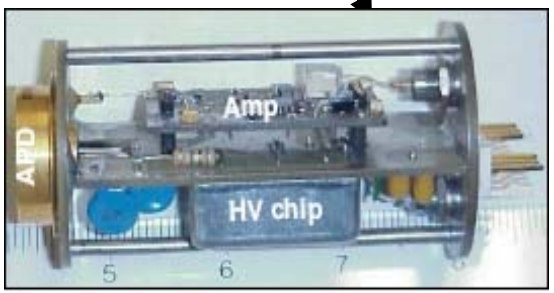
Shashlyk Calorimeter

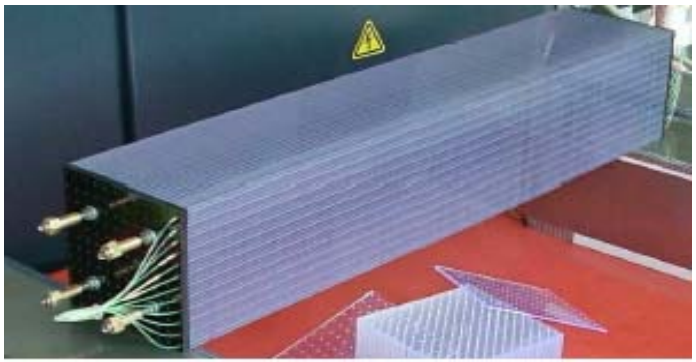
Shashlyk modules prototyped and tested in beams.
Mechanical design in progress



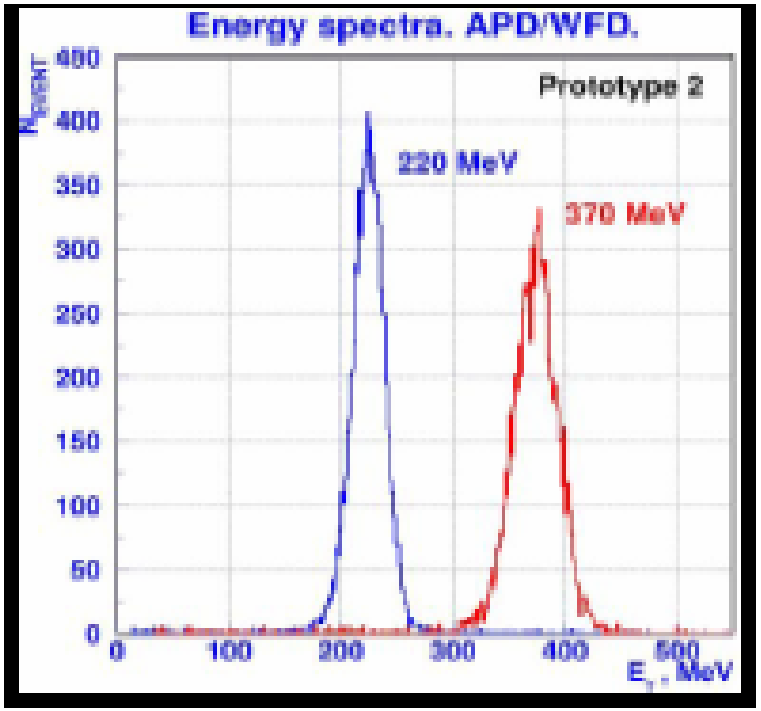


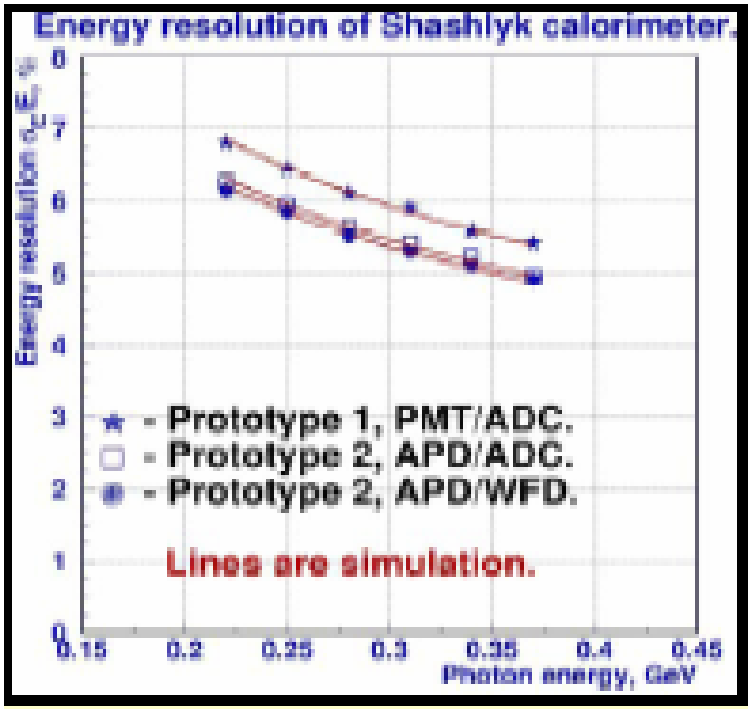
APD





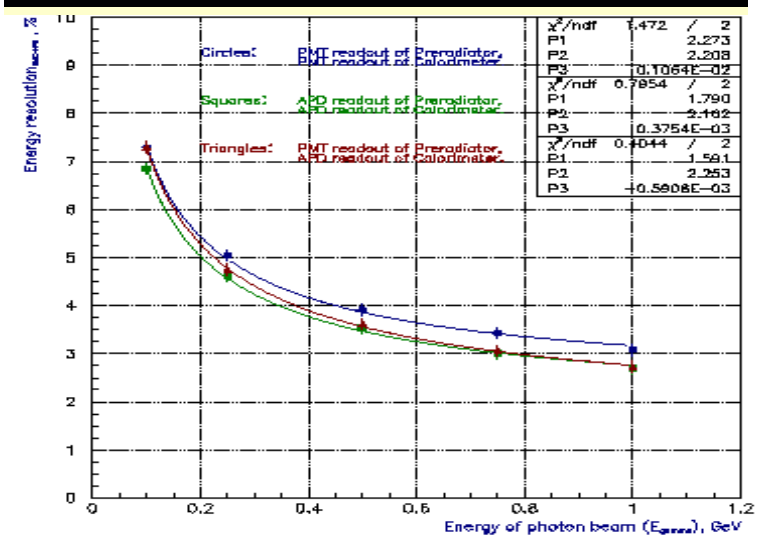
Shashlyk Beam Measurements





Simulation: Combined Energy Resolution

$$\sigma = \frac{2.7\%}{\sqrt{E(GeV)}}$$



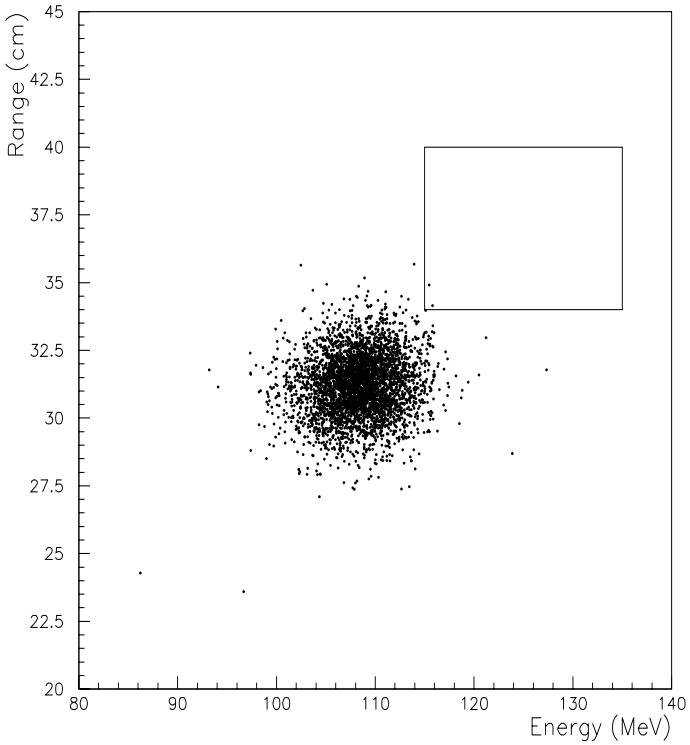
Photon Veto Background Suppression

$E949$ $\mathbf{K}^+ \rightarrow \pi^+\pi^0$ Background Suppression

Dual cuts: γ Veto and Kinematics (P,R,E...)

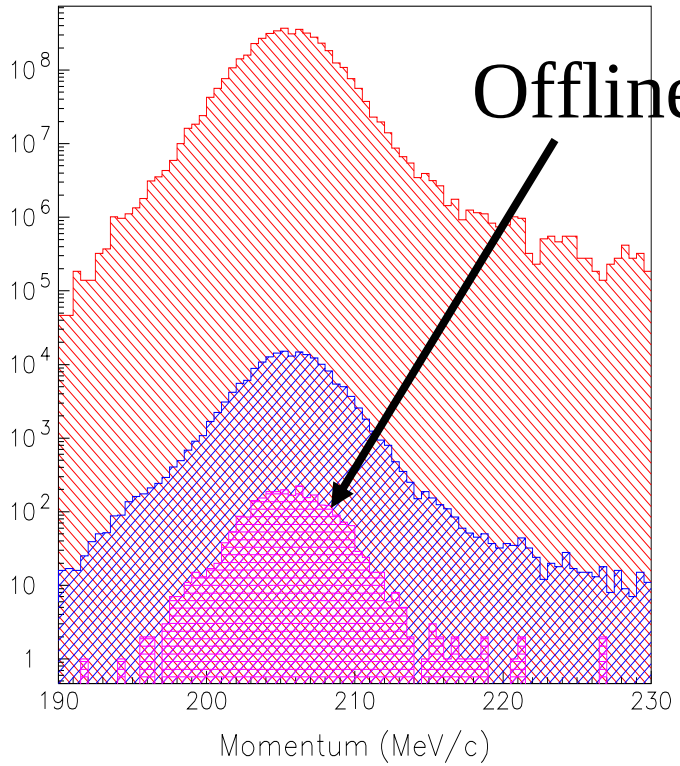
γ Veto Reversed

Range vs. Energy



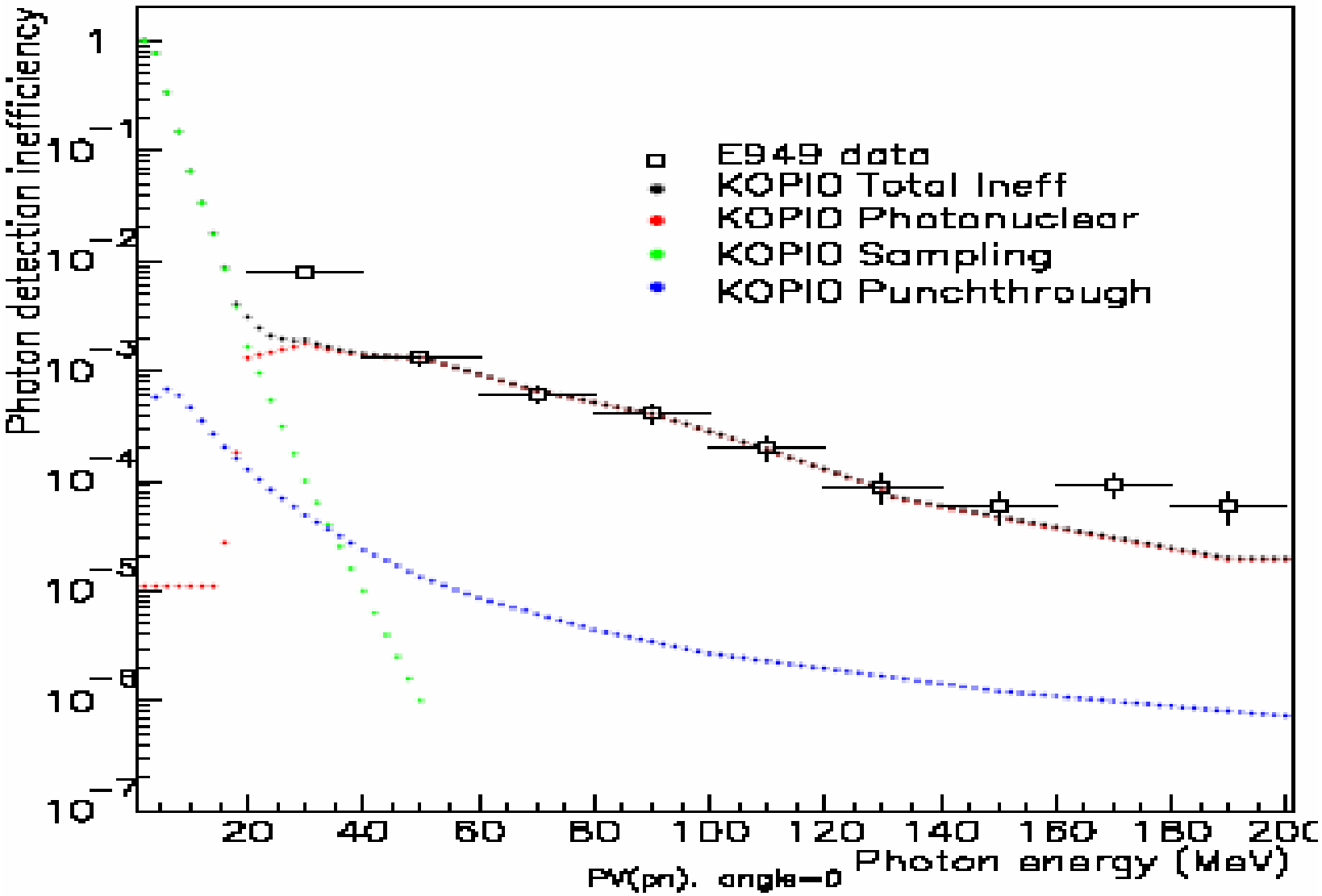
γ Veto Applied

Momentum



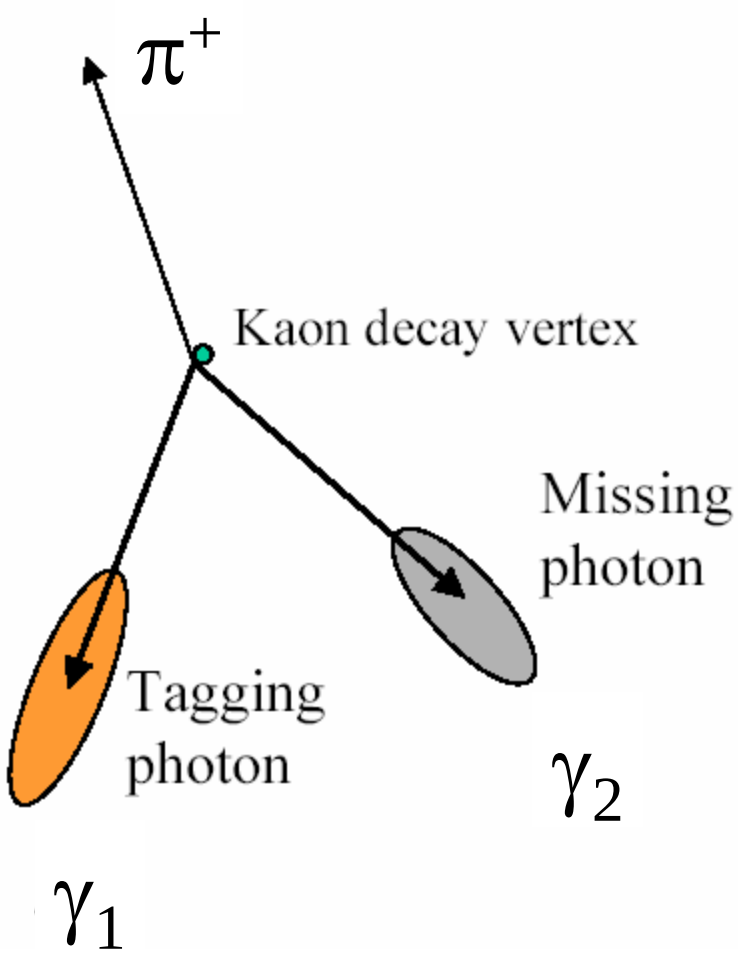
Check for correlations

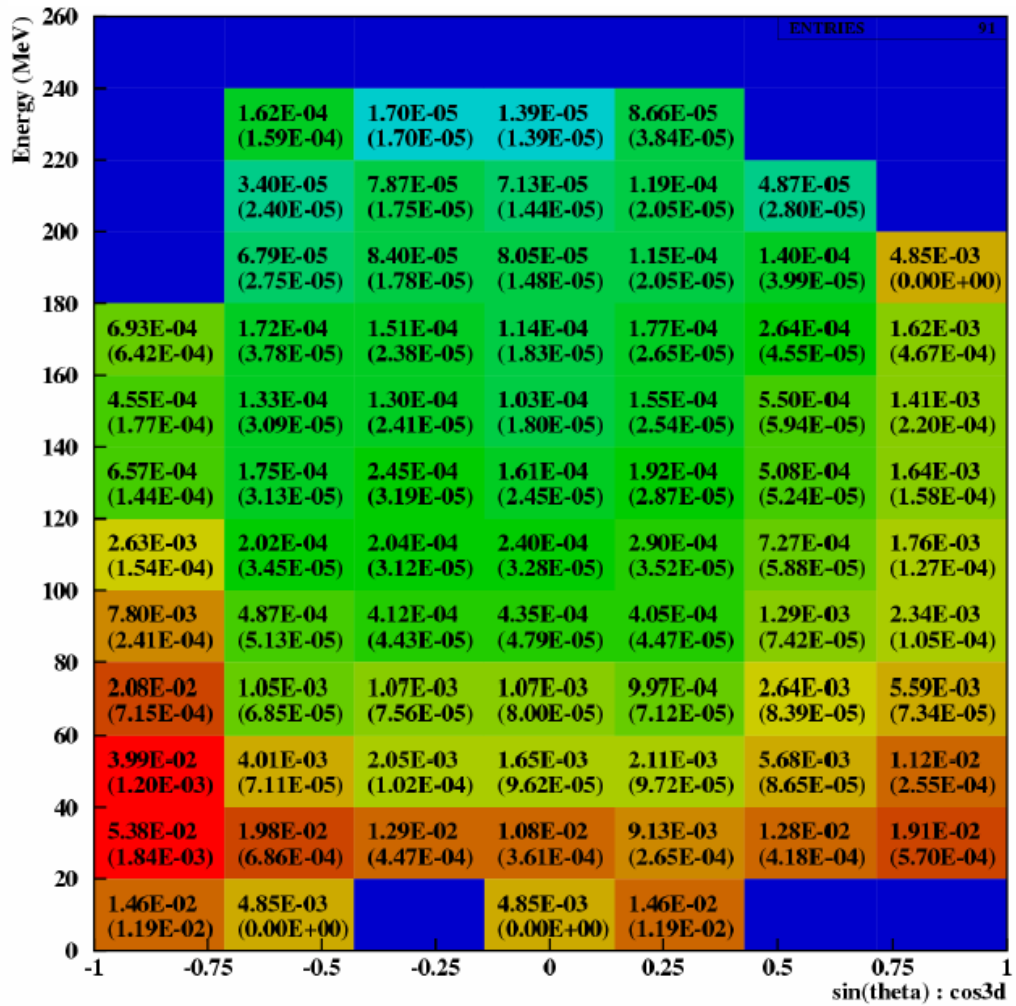
KOPIO PV Estimates and Simulations based on improved E949 Measurements supplemented by FLUKA calculations



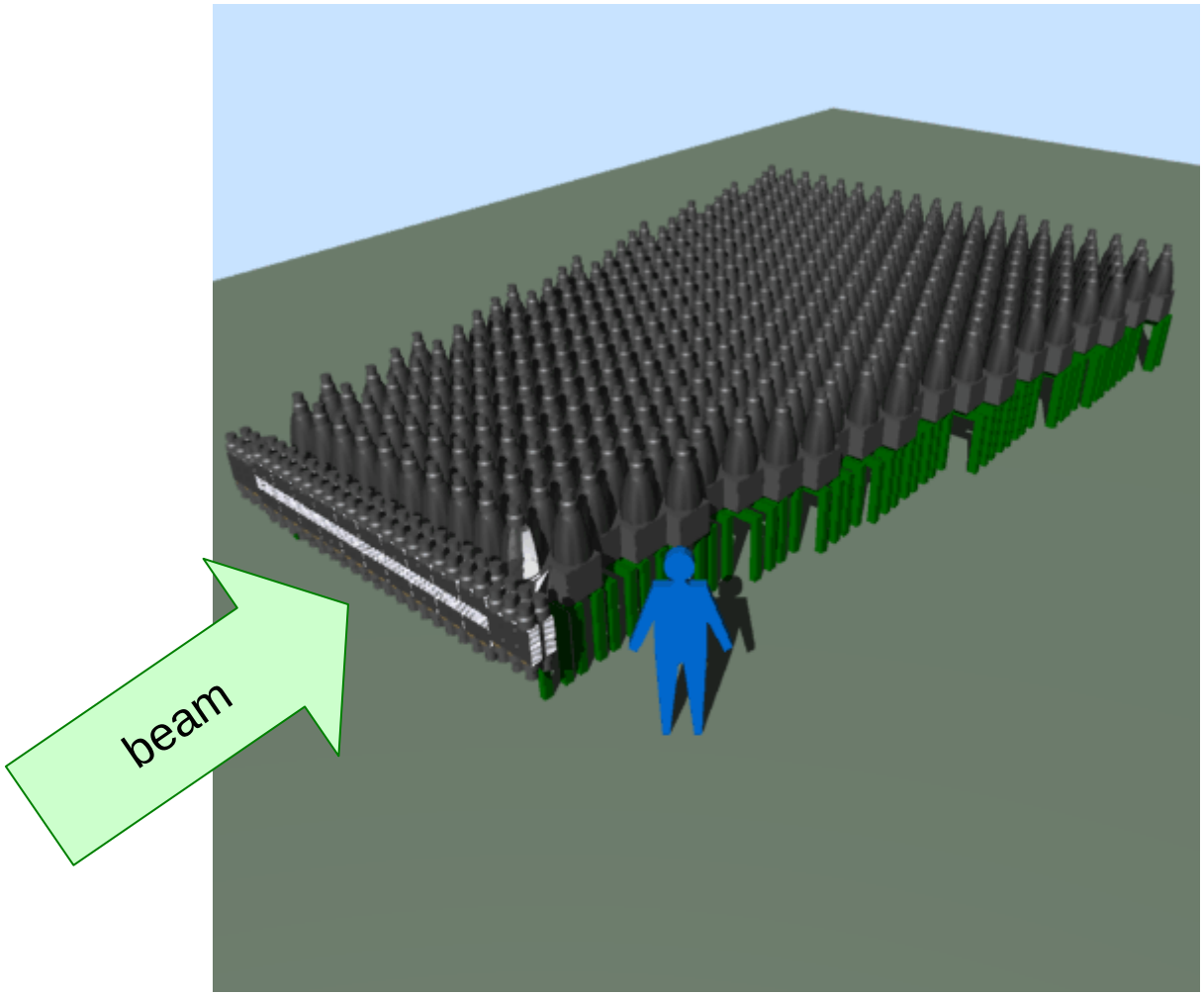
E949 Single Photon Inefficiency Measurement

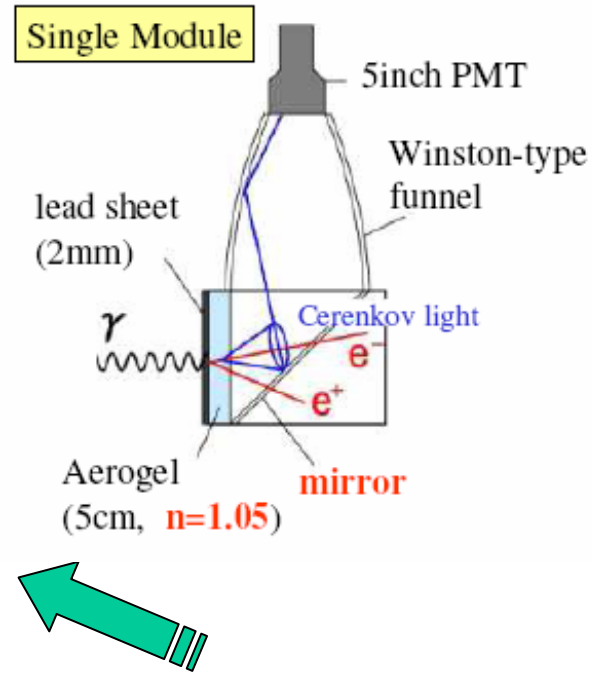
Kπ2 Decay





Catcher





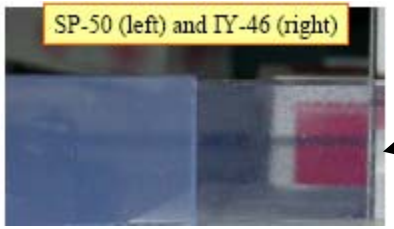
Aerogel Counter

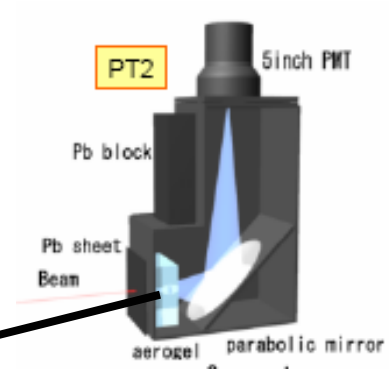
420 modules of Pb-Aerogel counter

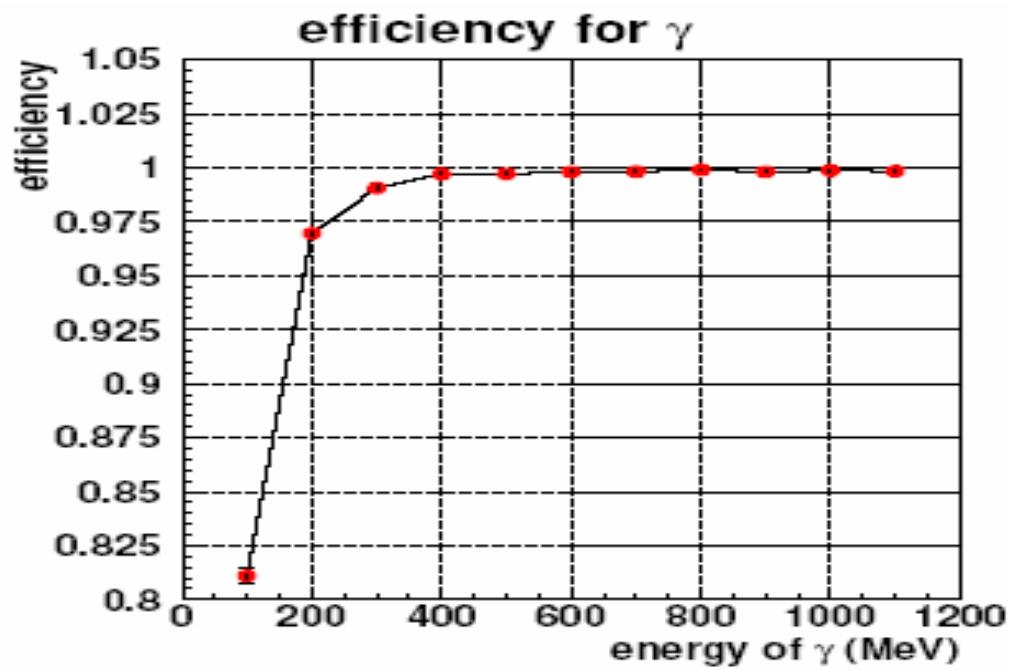
Catcher R&D

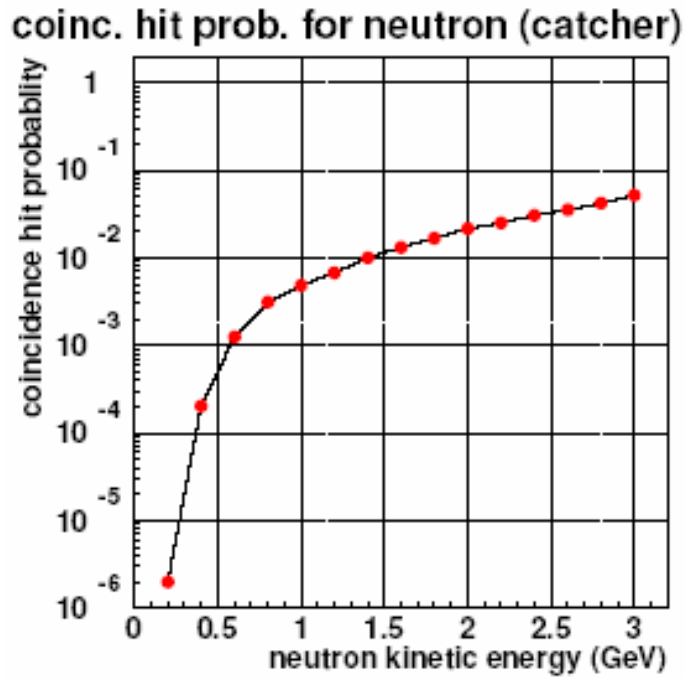
Modules prototyped and tested in beams.

New Aerogel tiles







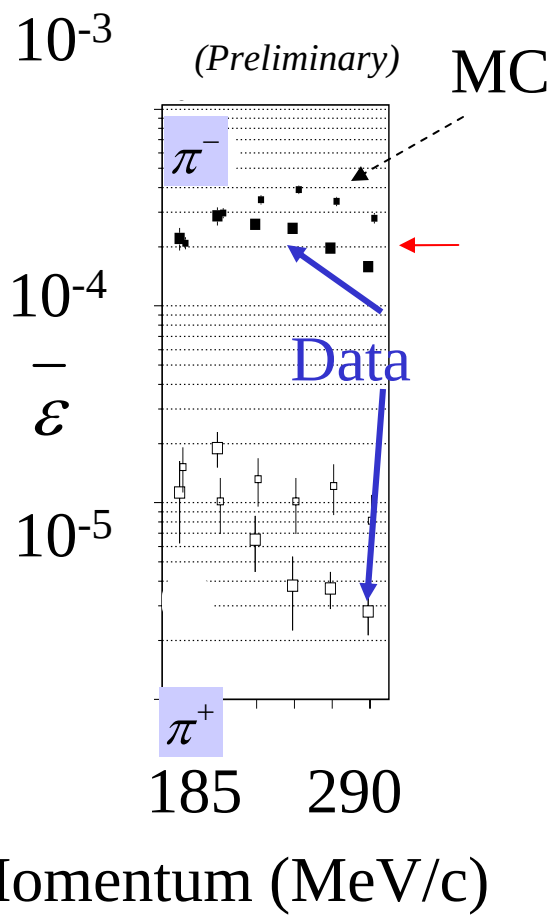


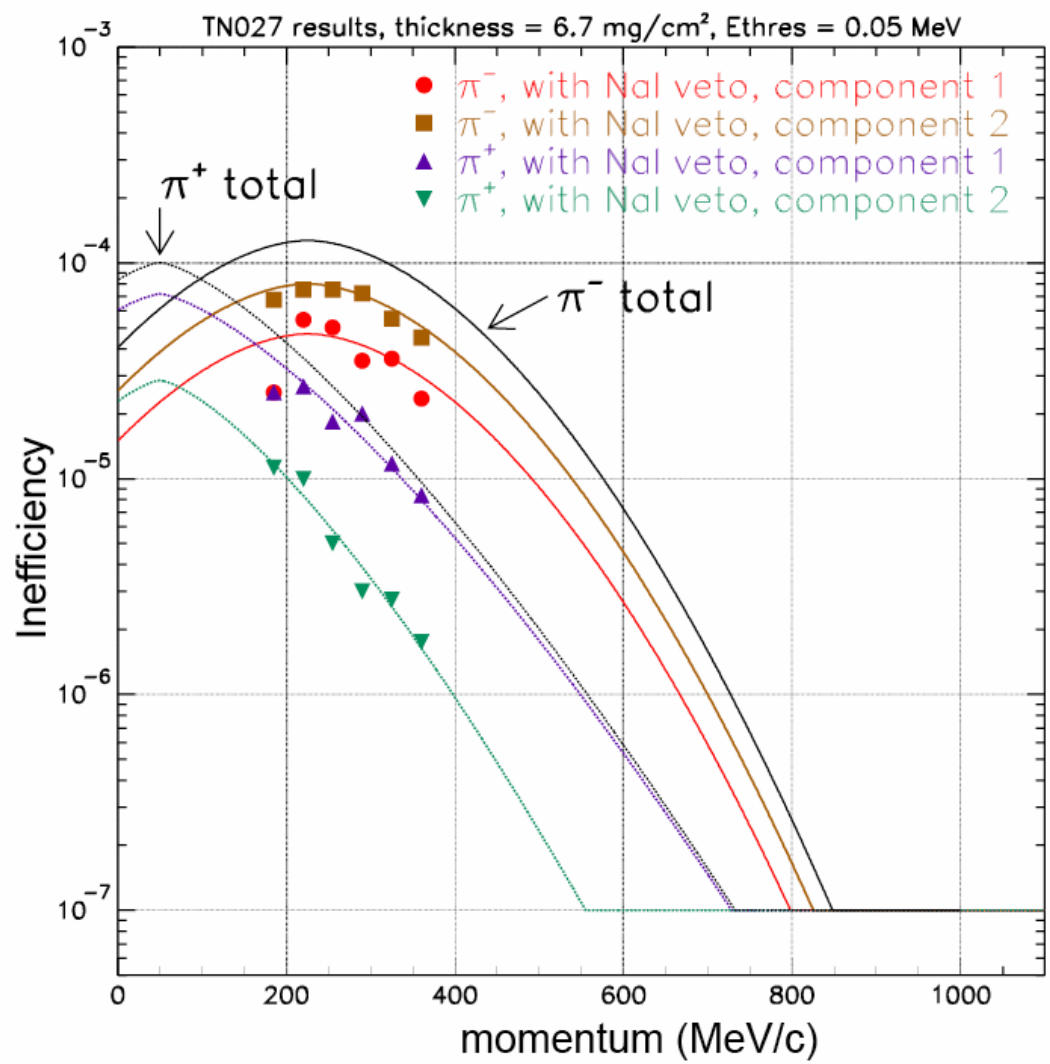
Charged Particle Vetoing

Example Background: $\mathbf{K}_L^0 \rightarrow \pi^- e^+ \nu \gamma$

Plastic Scintilla

PSI Measurement

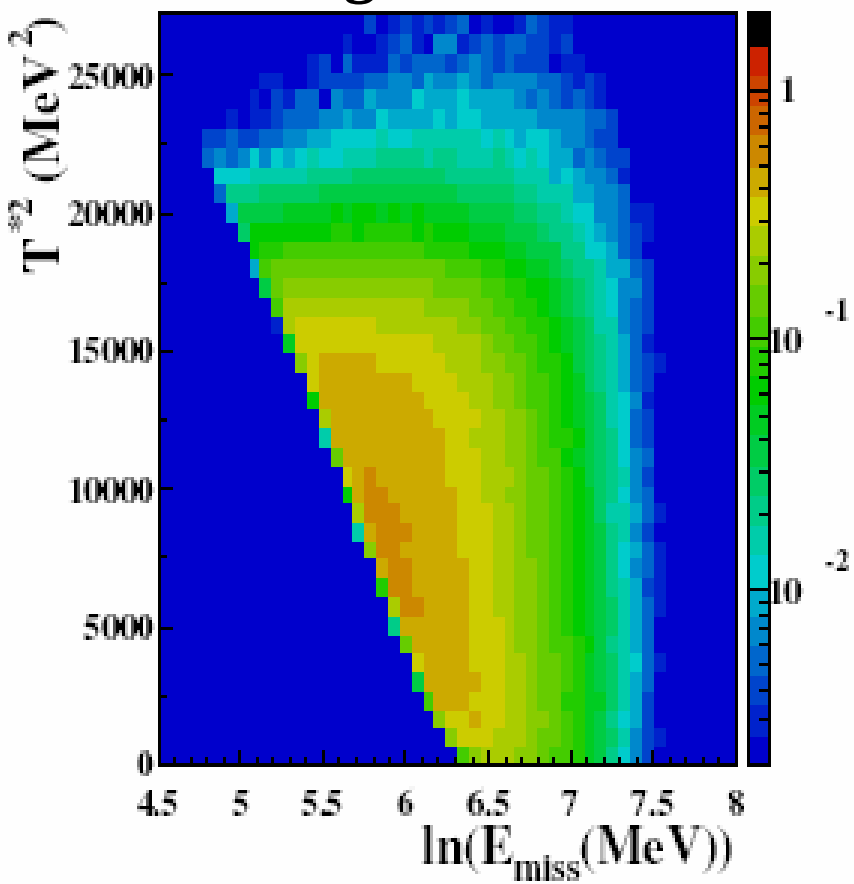




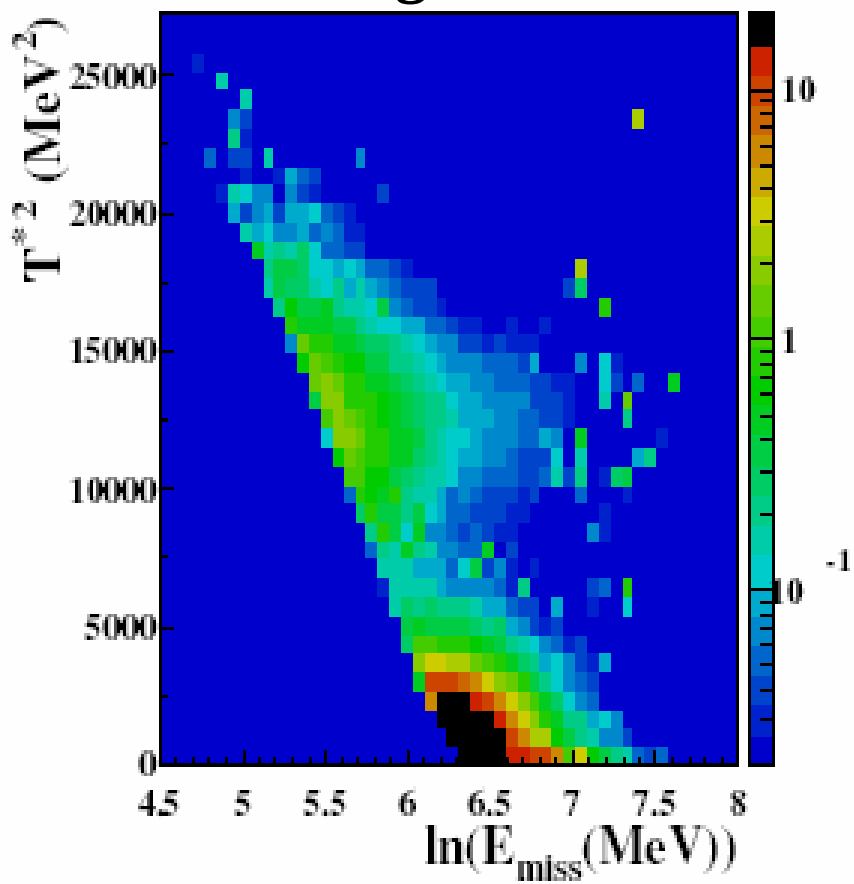
Kinematic Separation of Signal and Backgrounds

Pion Kinetic Energy Squared (T_{π}^{*2}) vs. Ln (Missing Energy)

Signal



Backgrounds



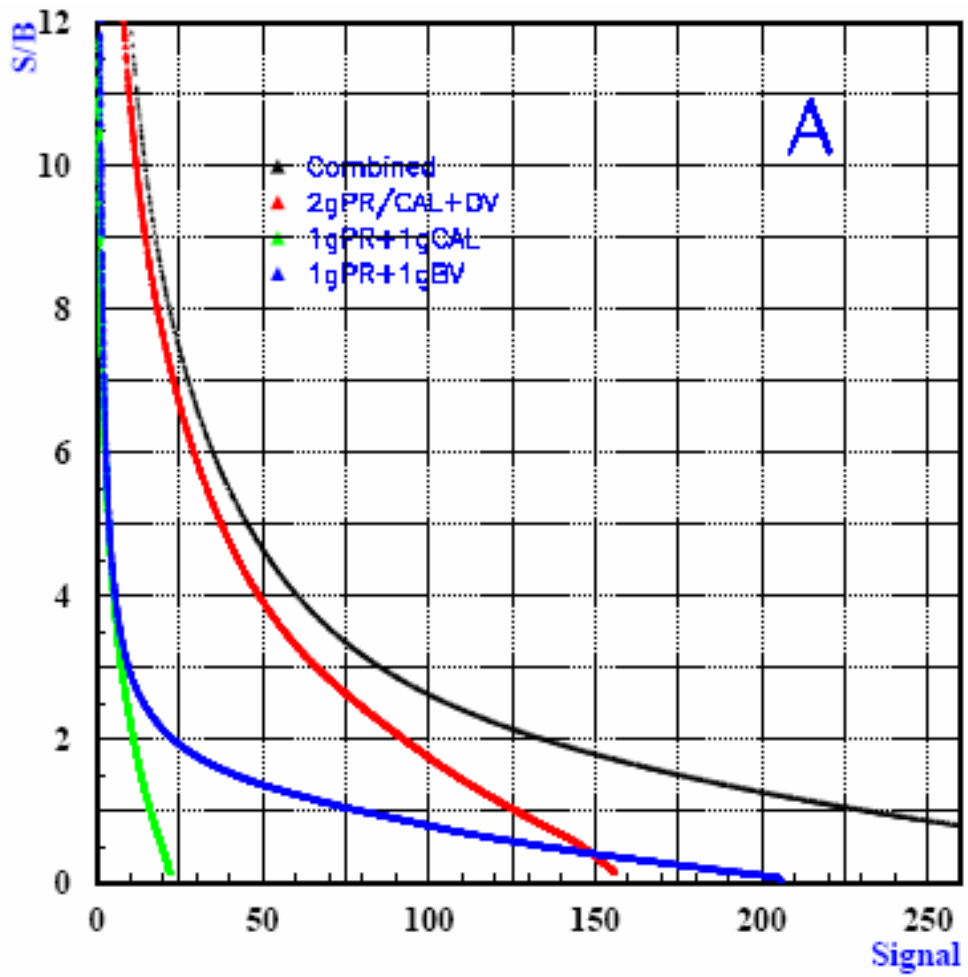
Normalization Factors and Uncertainties

- Losses
  - Rate dependent trigger effects
  - Signal “self-vetoing”
  - Accidental vetoing
  - Multiple decays/microbunch
- Additional Uncertainties
  - Flux
- Possible Gains
  - Improved photon efficiency

Optimized S/B vs. Signal (Events)

Results for SM $B(K_L^0 \to \pi^0 \nu\bar{\nu})$

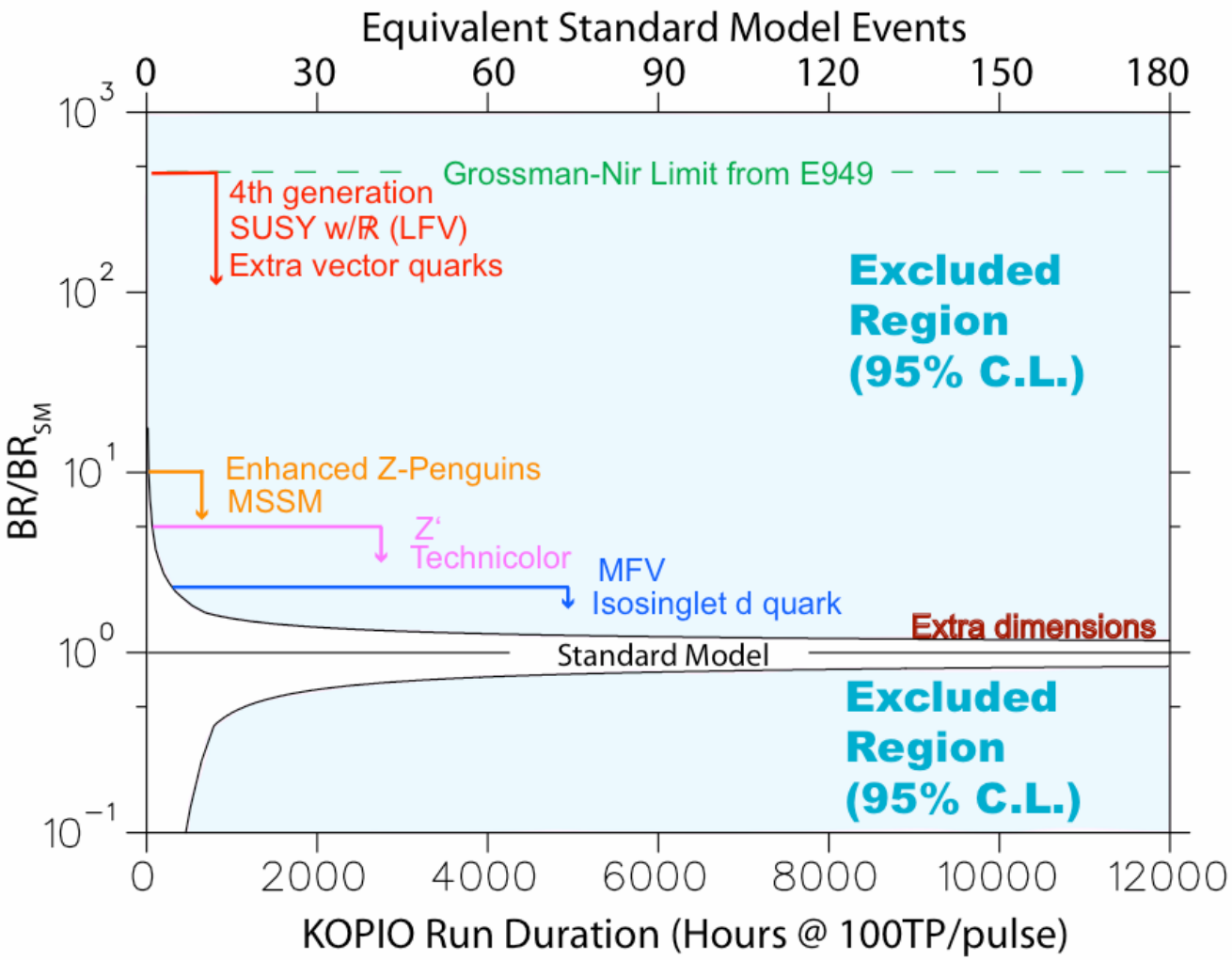
S/B



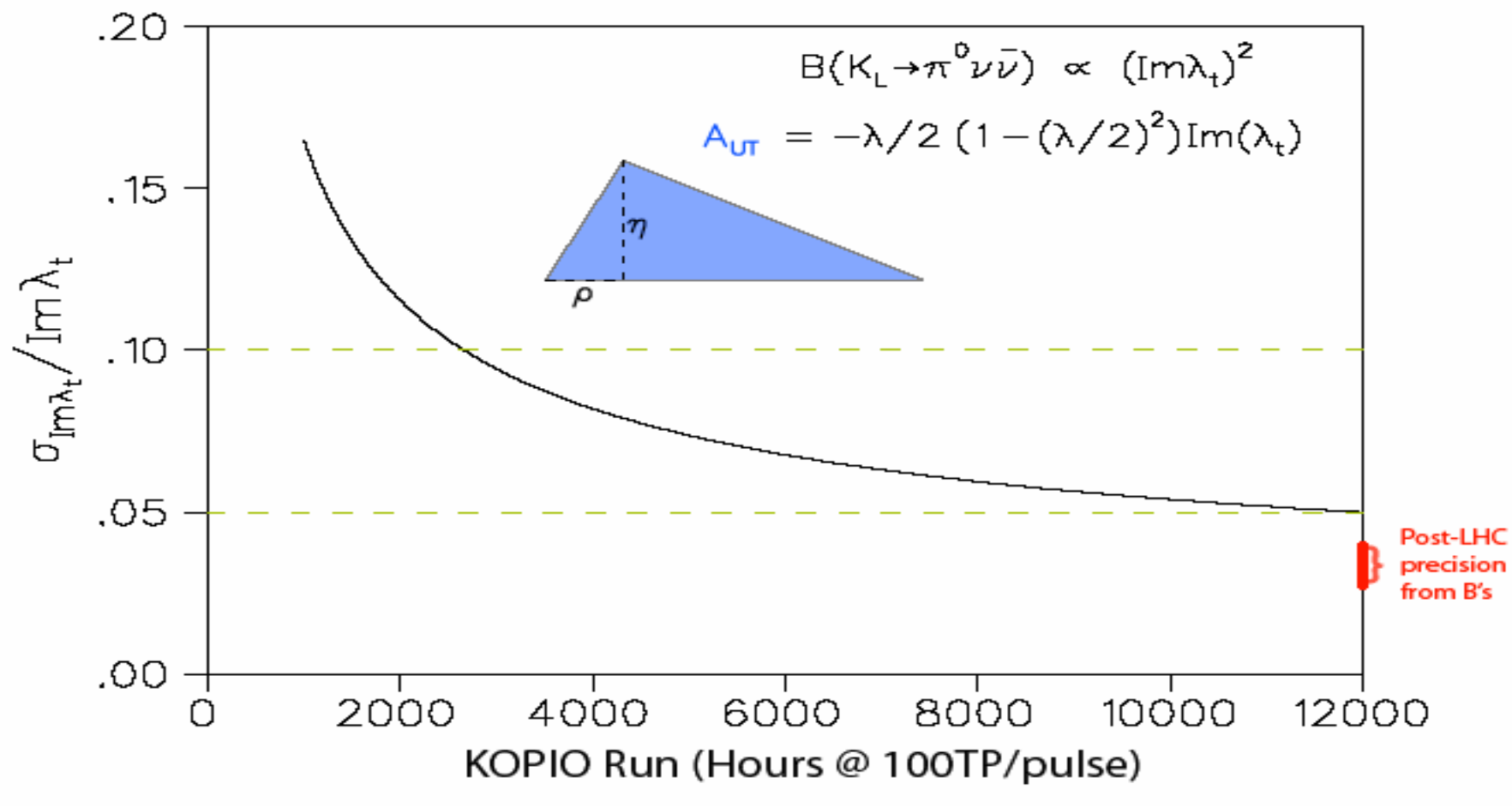
Standard Model Results for $B(K_L^0 \to \pi^0 \nu\bar{\nu})$

Events

Constraining New Physics



KOPIO: SM Precision



Branching Ratio Measurement Precision Estimates

- Precision at $B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) = 3.0x10^{-11}$

Using probability likelihood method employing all observed events (approximately 300):

$\pm 9\%$

- (Statistical) Precision on $\mathrm{Im}\,\lambda_t$: $\pm 5\%$

KOPIO Operations Plan

- 2010 Test Run – partial detector
- 2011 Engineering Run

  "Discovery phase": Sensitivity goal:~10^{-10}
- 2012-16 Data Acquisition

$K_L^0 \to \pi^0 \nu \bar{\nu}$

Summary and Outlook

- Extraordinary discovery potential for non-SM physics:

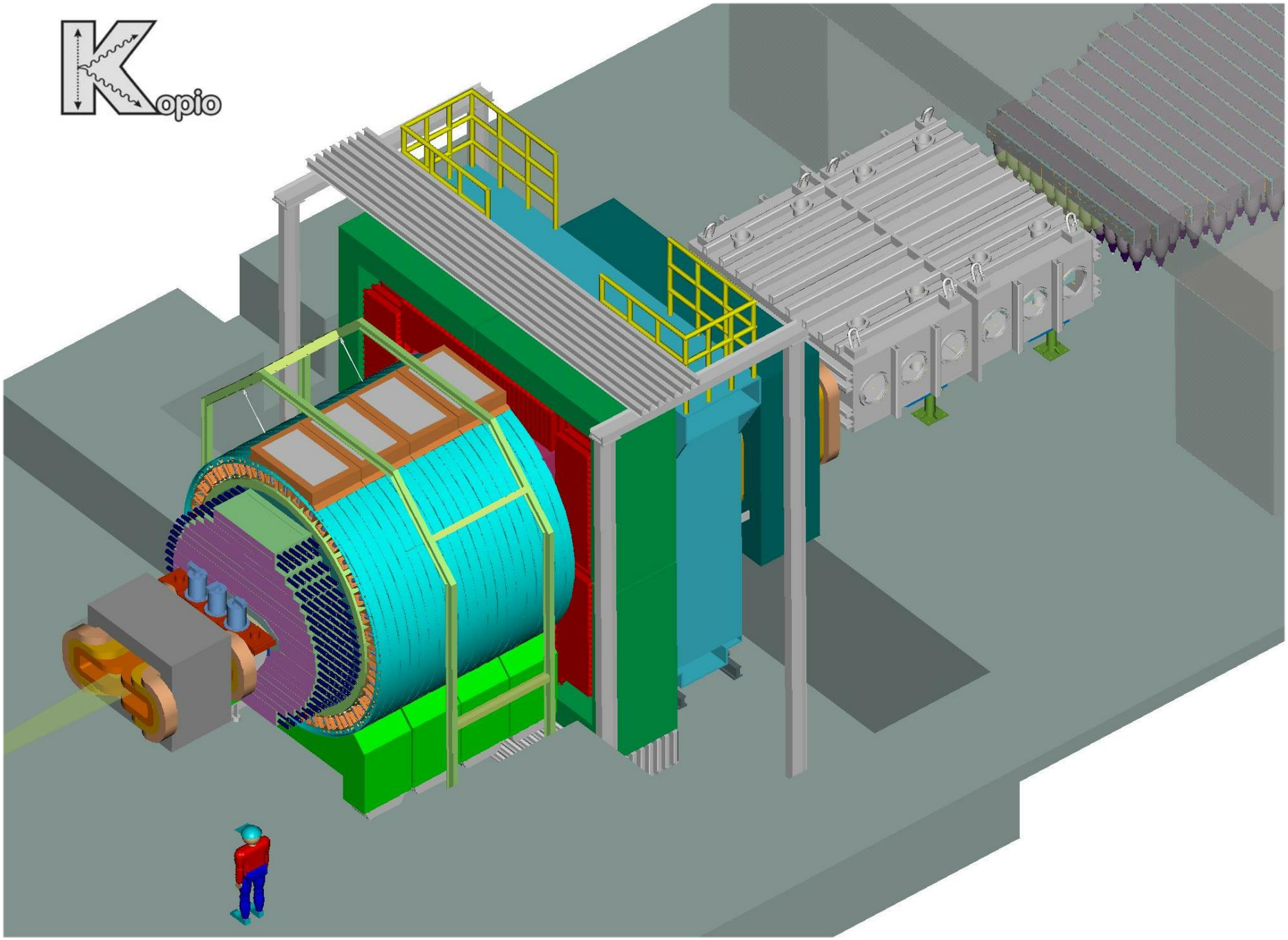
  Unique connection with underlying parameters

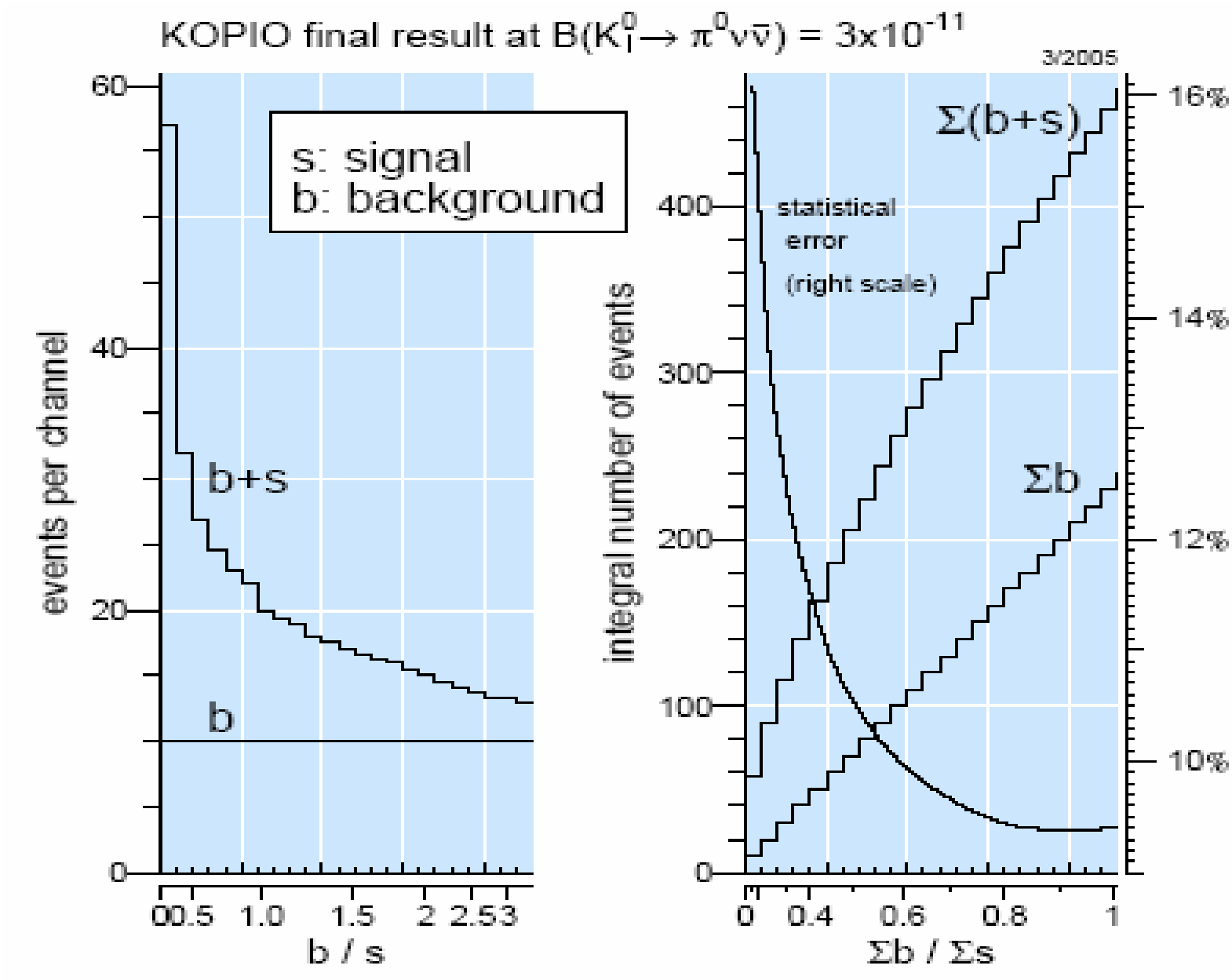
  5σ discovery if Br < $0.6\mathrm{Br}_{SM}$ or >$1.7\ \mathrm{Br}_{SM}$

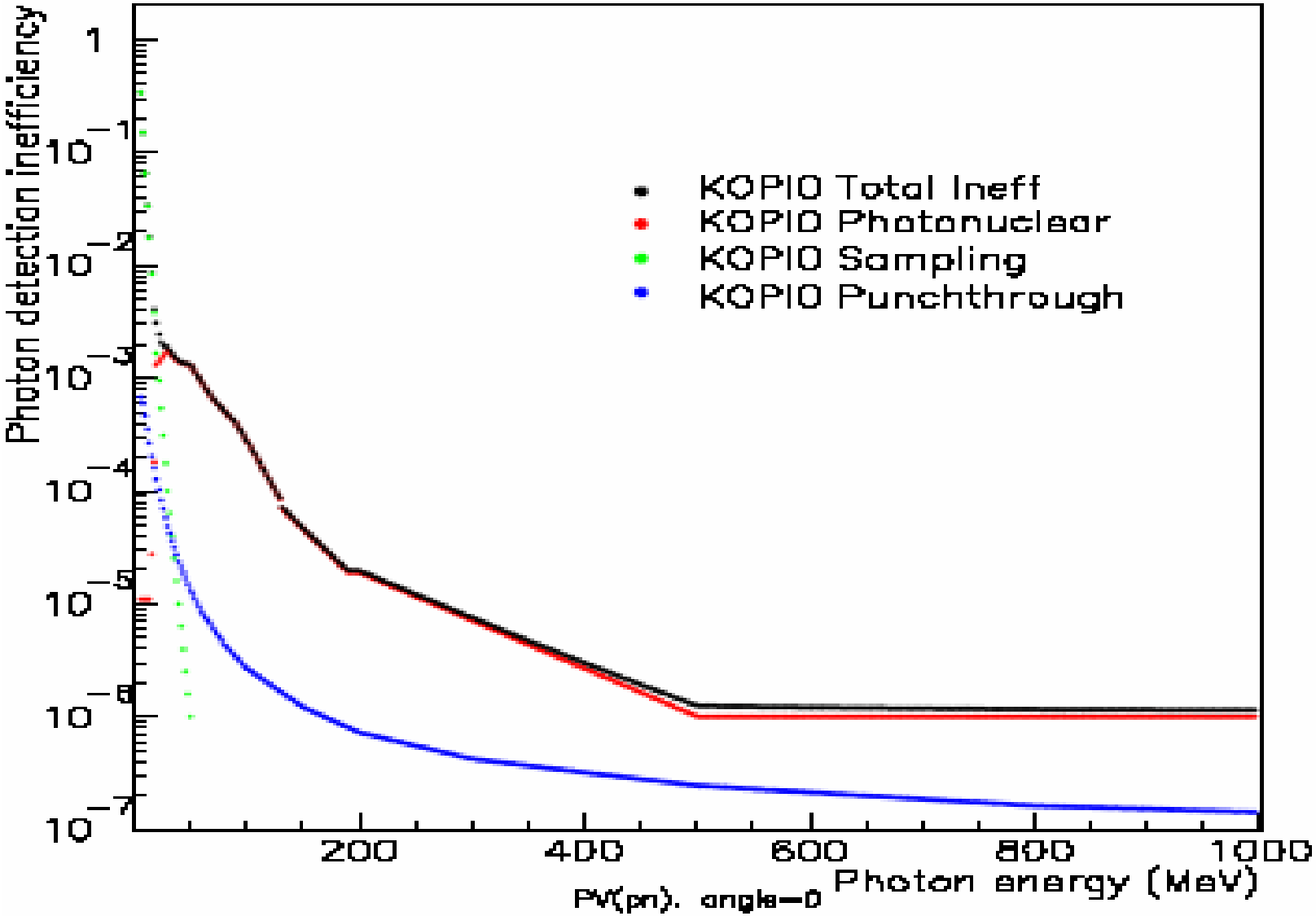
- In the absence of new physics, precision on Im λ_t: <5%

Rule out non-SM effects outside $(1 \pm 0.17) \times \mathrm{Br}_{SM}$

Extras?


Kopio


KOPIO final result at B($K_l^0 \to \pi^0 \nu\bar{\nu}$) = 3×10^{-11}
3/2005
s: signal
b: background
b+s
b
events per channel
b / s
Σ(b+s)
Σb
statistical
error
(right scale)
integral number of events
Σb / Σs
16%
14%
12%
10%


Photon detection inefficiency
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
KOPIO Total Ineff
KOPIO Photonuclear
KOPIO Sampling
KOPIO Punchthrough
200
400
600
800
1000
Photon energy (MeV)
PV(pn), angle=0