# Parametric Analysis of KOPIO-like experiment

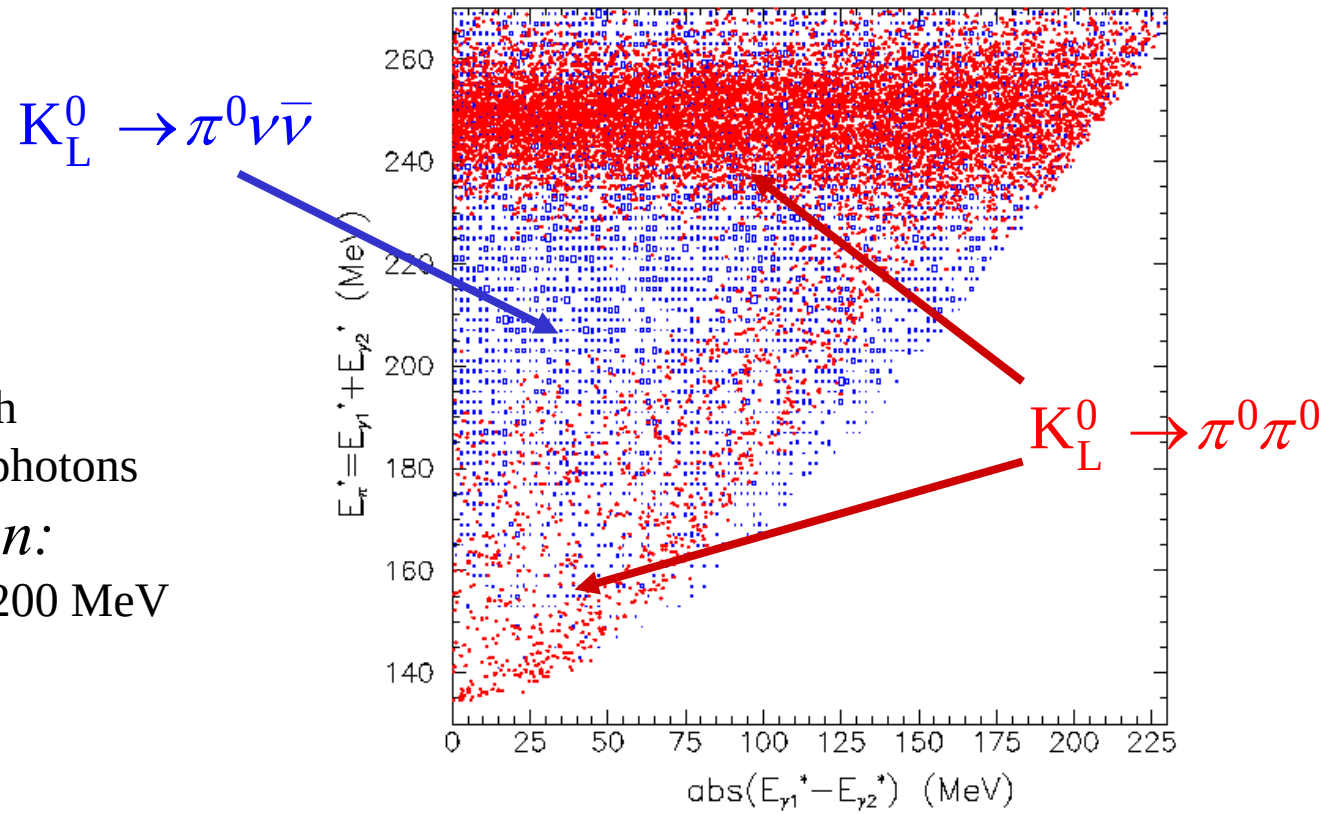
- (short) review of KOPIO
- Variation of key parameters
- Conclusions

**From KOPIO CDR April 2005**
**Work by David Jaffe**

**Steve Kettell**
**BNL**

# Kinematic suppression of backgrounds

$$E^*_{\pi^0} \ vs. \left| E^*_{\gamma 1} - E^*_{\gamma 2} \right|$$



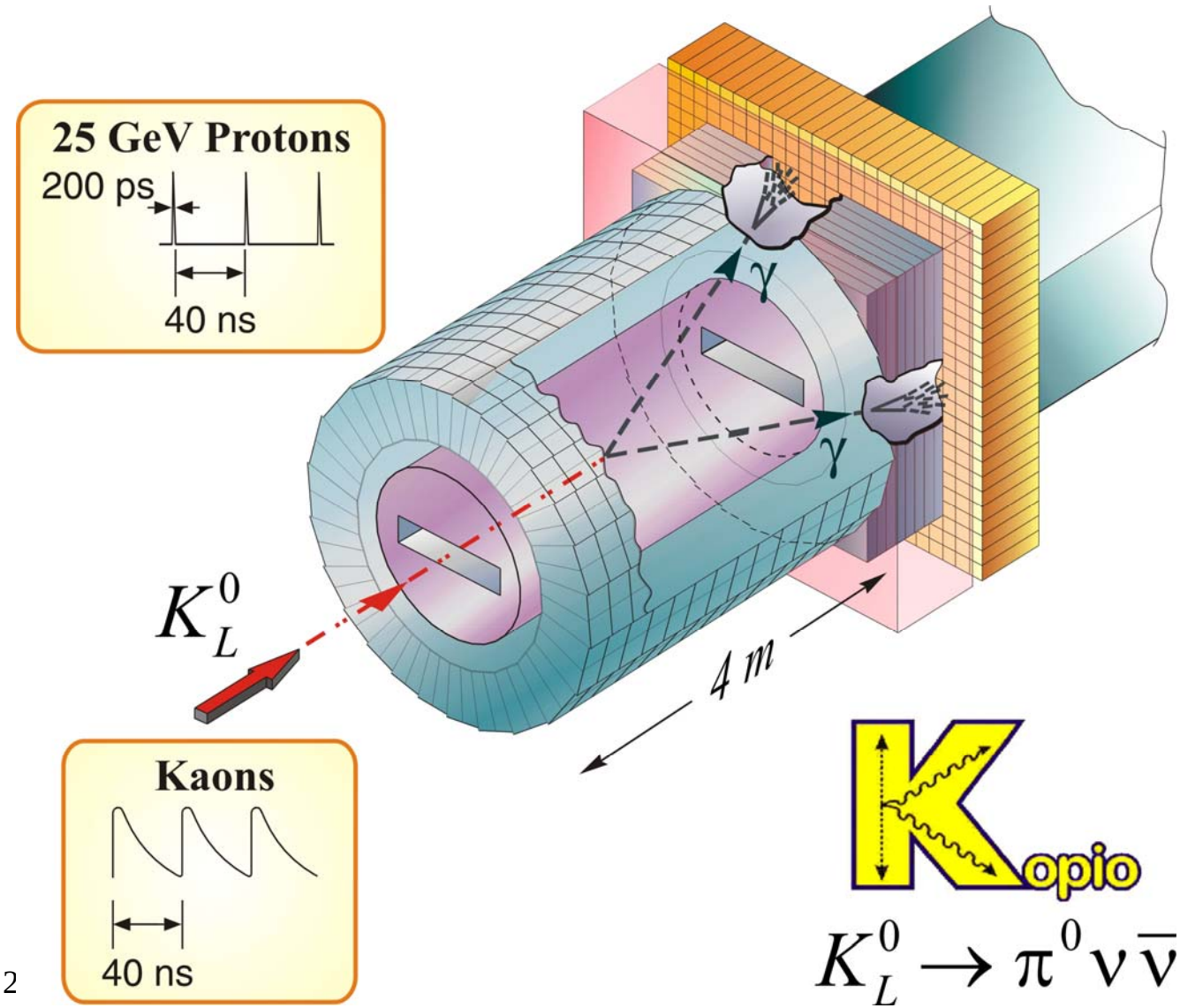

*Kinematic reconstruction*

Eliminate events with missing low energy photons

*Photon detection:*

Inefficiency $10^{-4}$ at 200 MeV

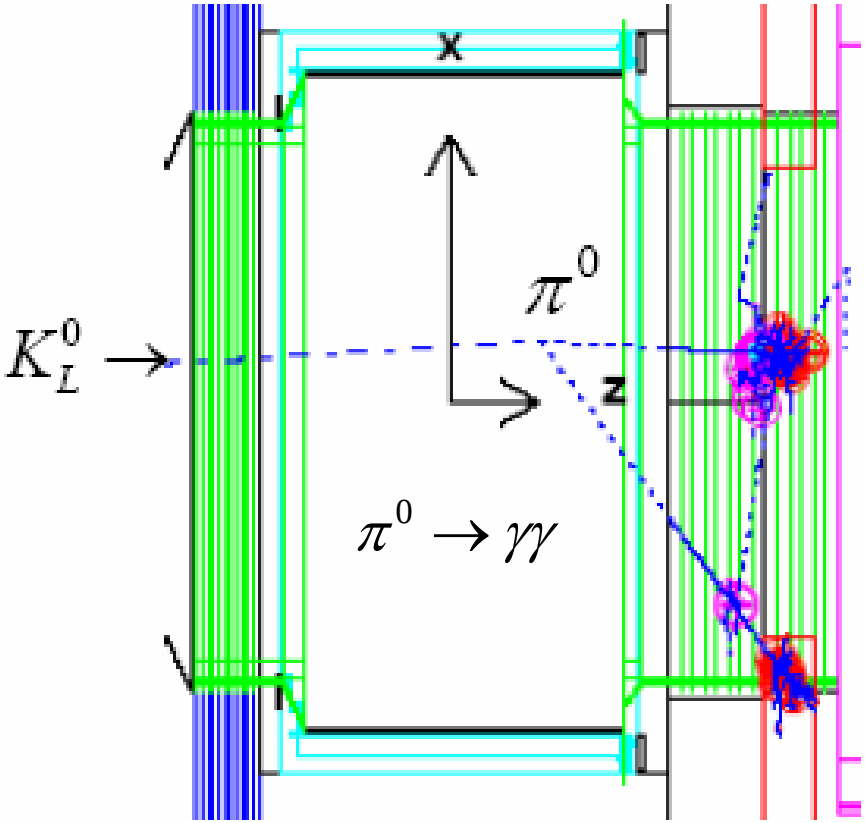
# KOPIO Concepts

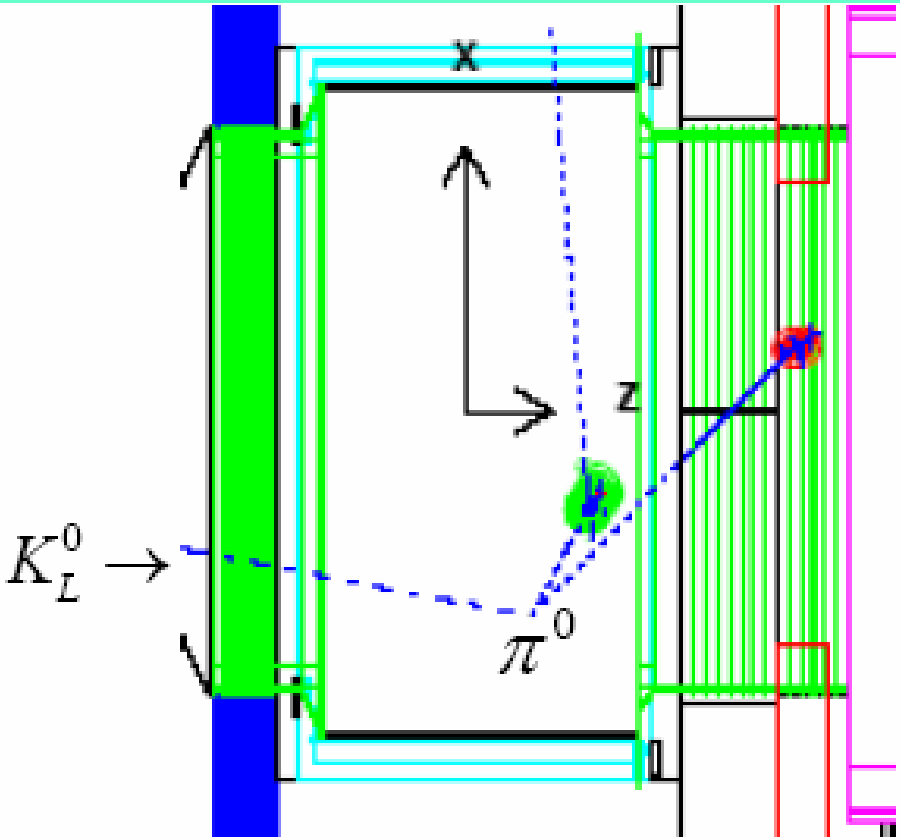



$$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$$

***Primary*** detection mode: (2γPR)
2 photons covert in preradiator

Secondary mode:
1 photon in preradiator, 1 in BV



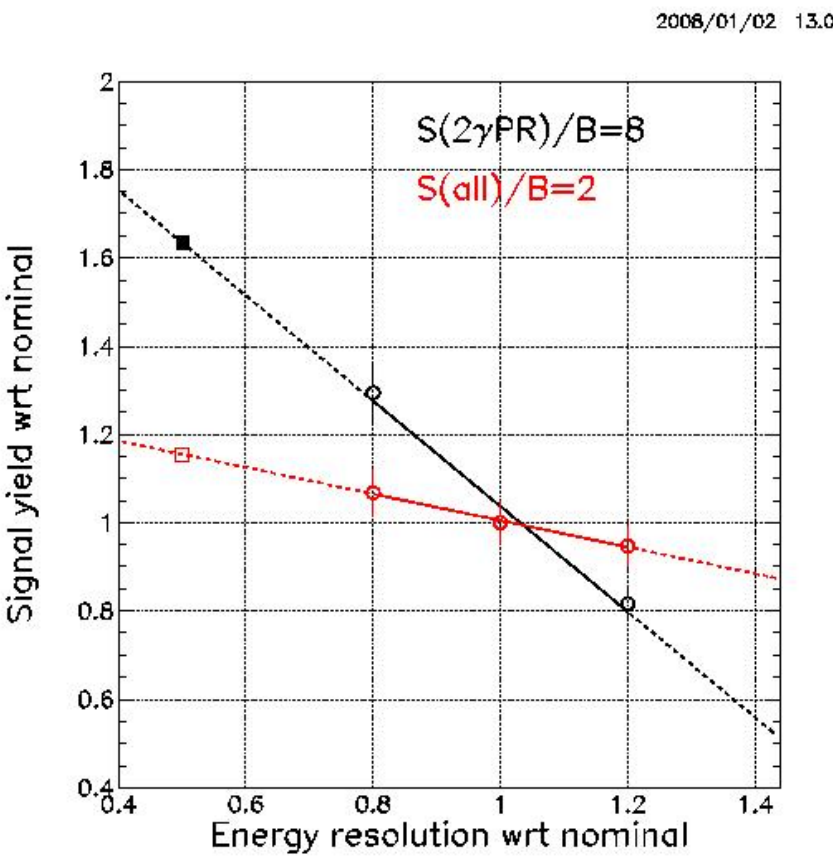

Reconstruct first $\gamma \rightarrow e^+e^-$ in "Preradiator"

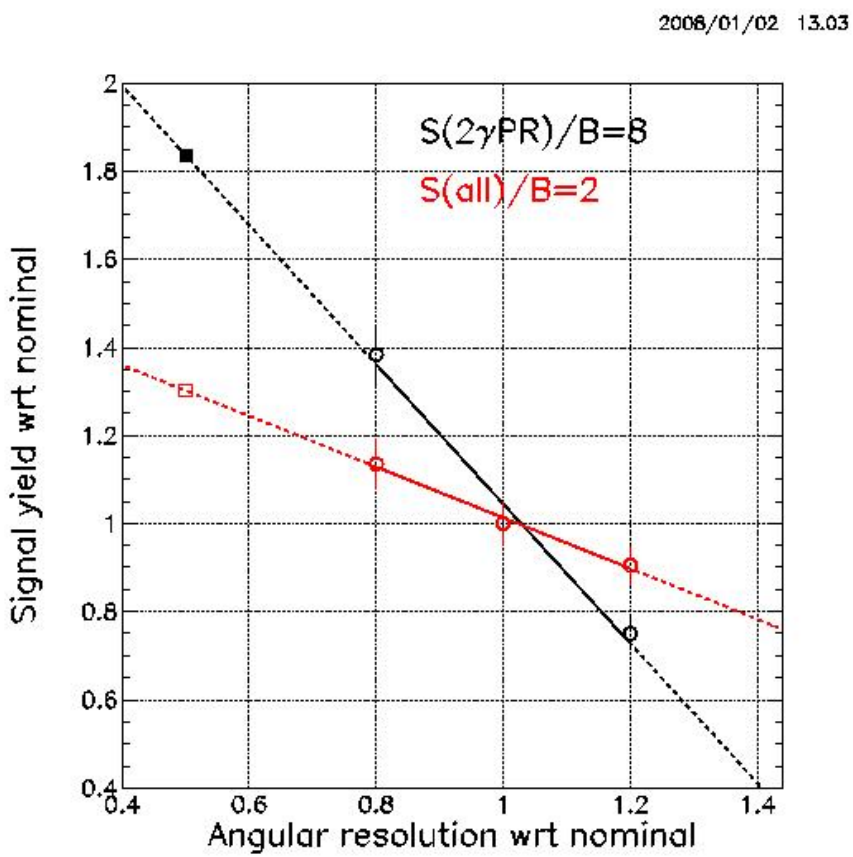
Point to K decay vertex in vacuum.

| | **Baseline KOPIO performance** |
|---|---|
| $\mu$ Bunch Width (Extinction) | 200 ps $(10^{-3})$ |
| $\theta_\gamma$ Resolution (250 MeV) | 25 mr |
| $E_\gamma$ Resolution | $2.7\% / \sqrt{E_\gamma (GeV)}$ |
| $t_\gamma$ Resolution | $90ps / \sqrt{E_\gamma (GeV)}$ |
| Photon Veto Inefficiency | E949 or better |
| Charged Particle Inefficiency | $10^{-5}(\pi^+), 10^{-4}(\pi^-)$ |

# *Importance of Energy and angular resolution*

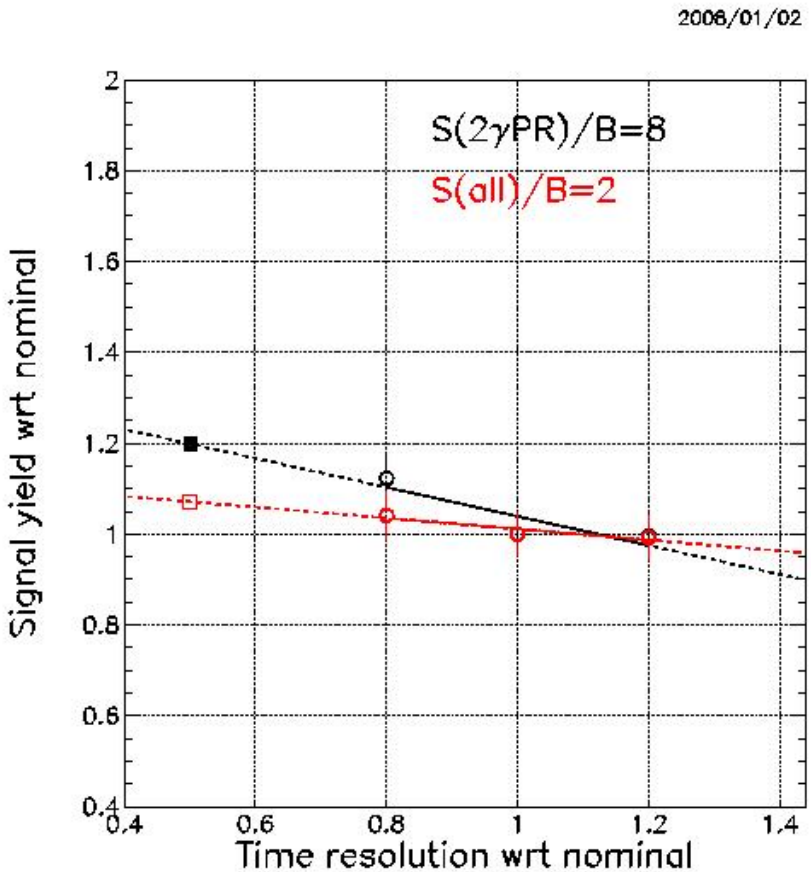
**Sensitivity to energy and angular resolution is high**

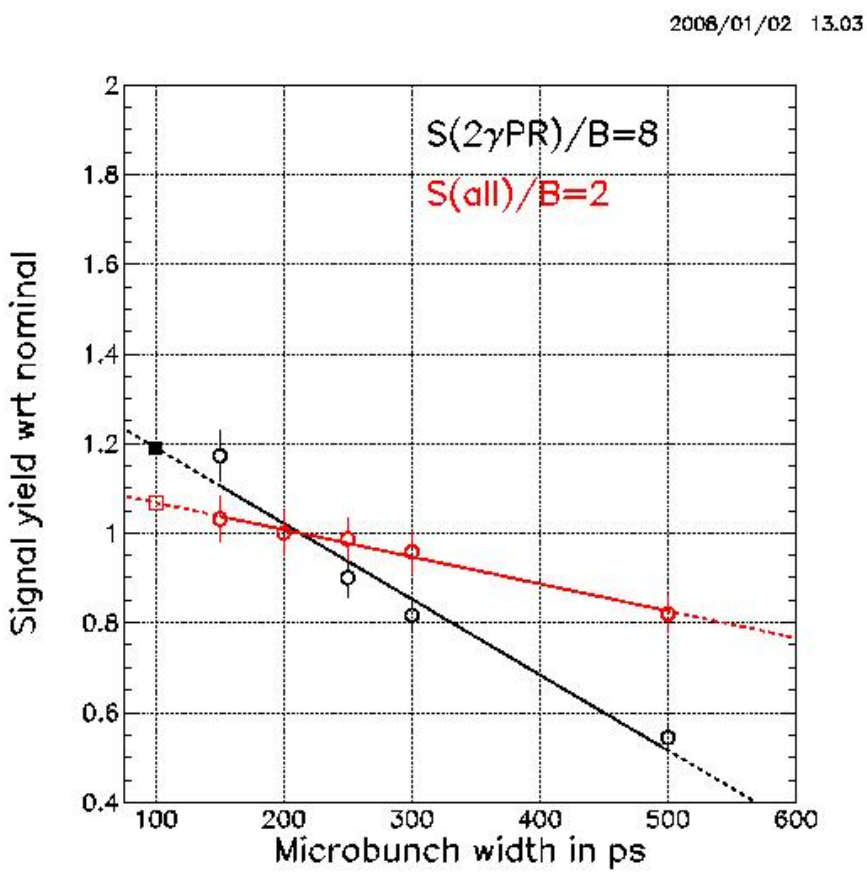


# *Timing resolution and Microbunch width*

**Sensitivity to time resolution and microbunch width is less**



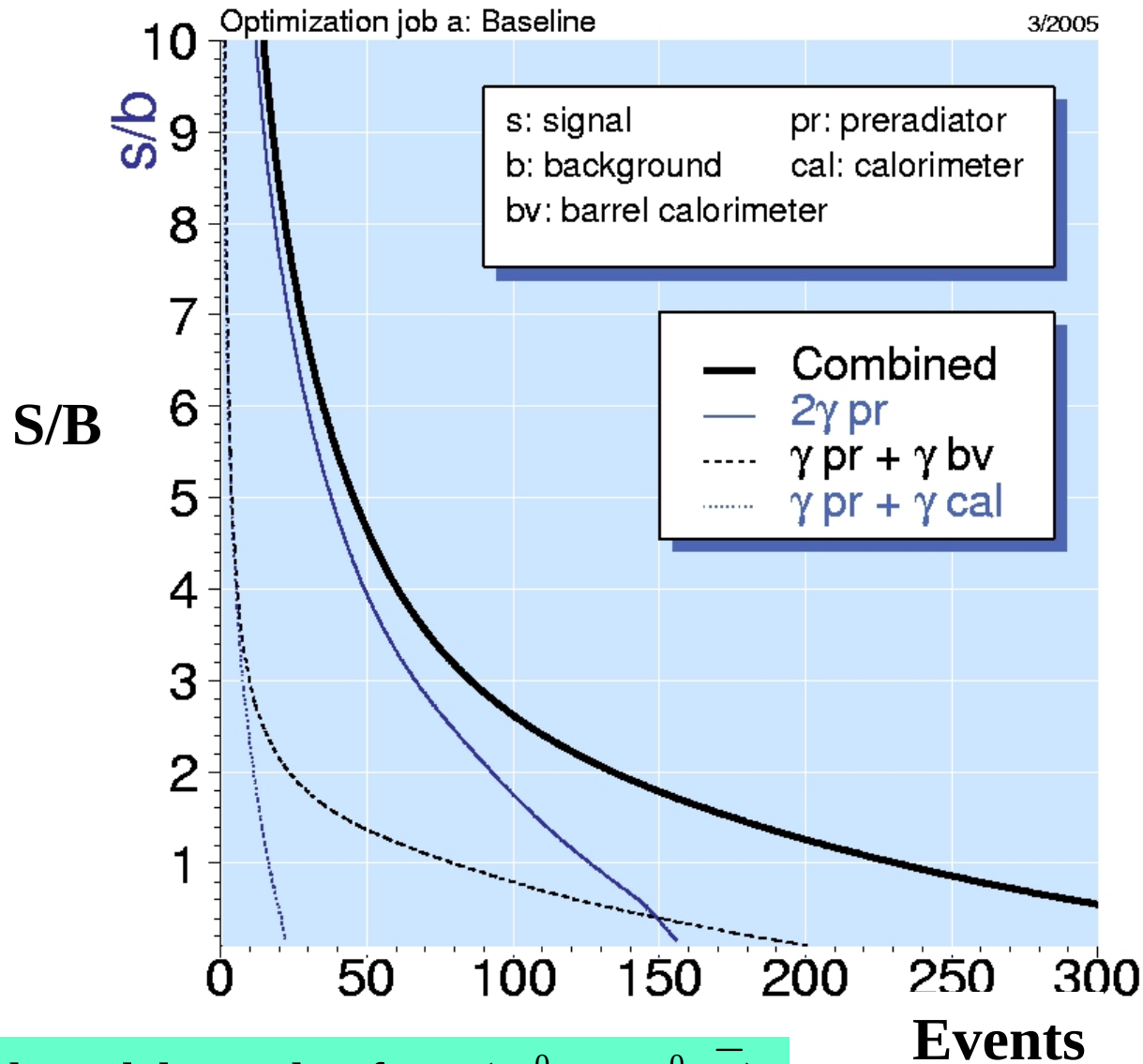



# *Summary*

**If the resolutions can be improved by x2, the yield of clean events can increase by x4 and less clean events by x2**

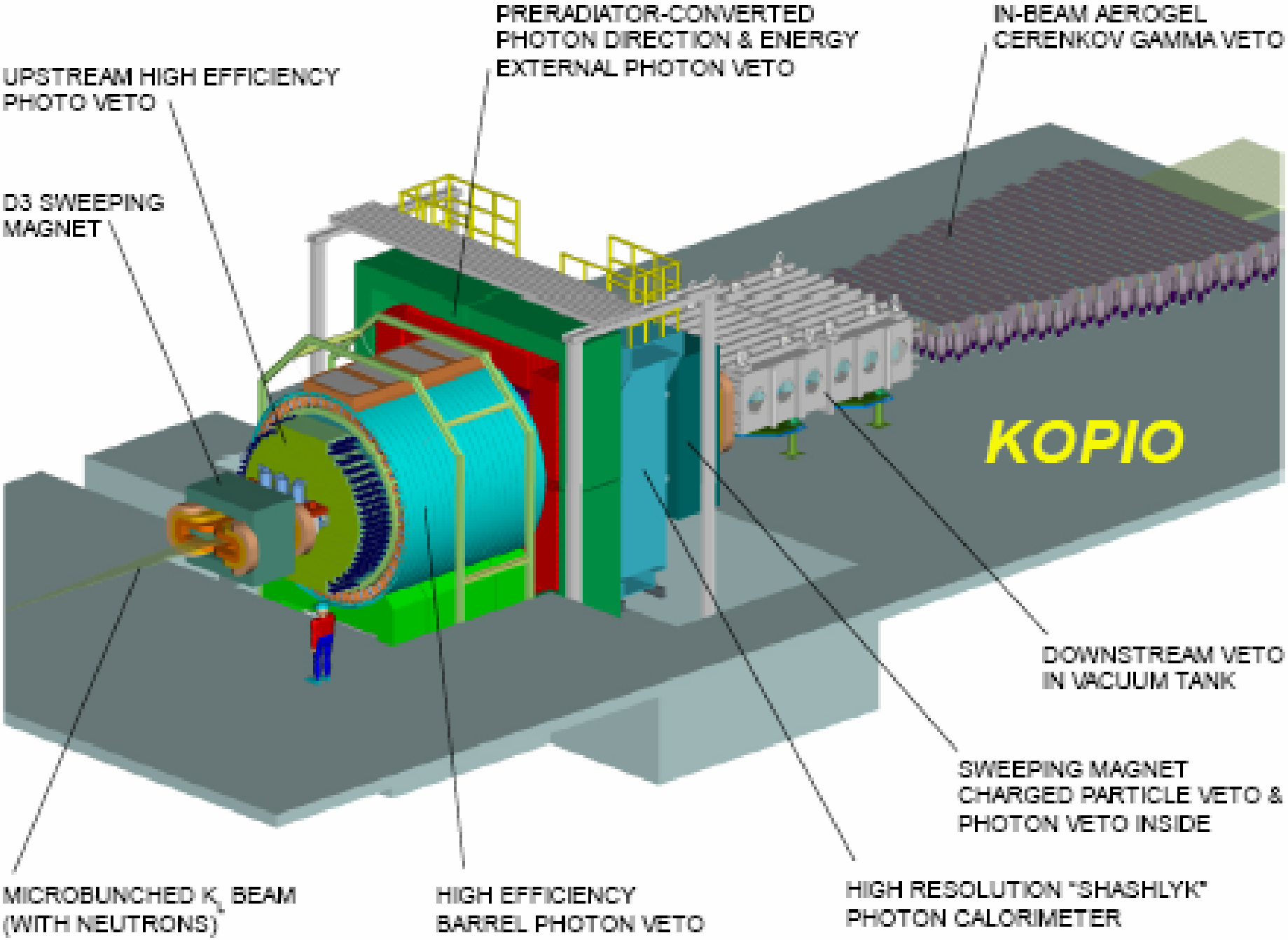
| | 80% | | 50% | |
|---|---|---|---|---|
| | S/B=8 | S/B=2 | S/B=8 | S/B=2 |
| $\sigma_{Energy}$ | 1.28 | 1.07 | 1.63 | 1.16 |
| $\sigma_{angle}$ | 1.36 | 1.13 | 1.84 | 1.30 |
| $\sigma_{time}$ | 1.10 | 1.04 | 1.20 | 1.07 |
| $\sigma_{microbunch}$ | 1.02 | 1.01 | 1.19 | 1.07 |
| Total | 1.96 | 1.25 | **4.28** | **1.72** |

# Optimized S/B vs. Signal (SM Events)

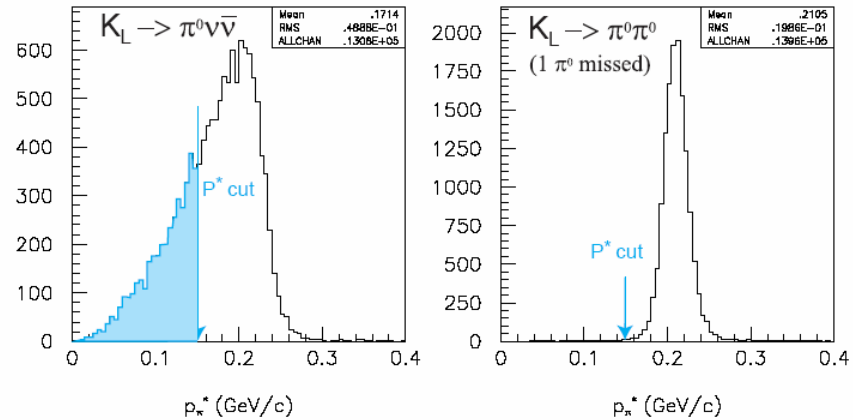



Standard Model Results for $B(K_L^0 \to \pi^0 \nu \bar{\nu})$

# Backup


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

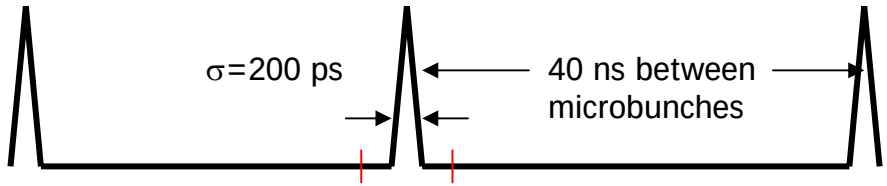
# Kaon Center of Mass Measurements




## Concepts

- Maximize micro-bunched beam from the AGS
- Measure everything! (Energy, Position, Angle, Time)
- Eliminate extra charged particles or ***photons***
  - * KOPIO: $\pi^0$ 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:

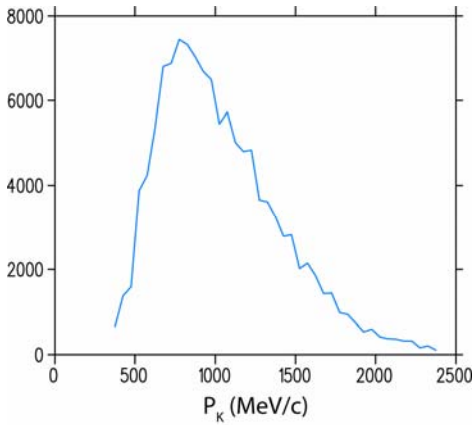
100 Tp/spill (Upgraded from present 70 Tp)

~5.5 s spill, 2.3 s interspill period

25 MHz micro-buching frequency

Bunch width 200ps

Interbunch extinction $10^{-3}$



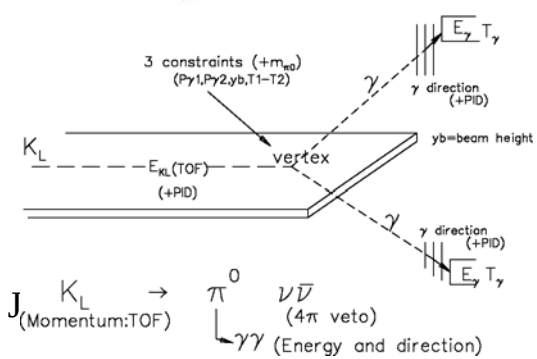

Kaon Beam:

42.5 degree take-off angle

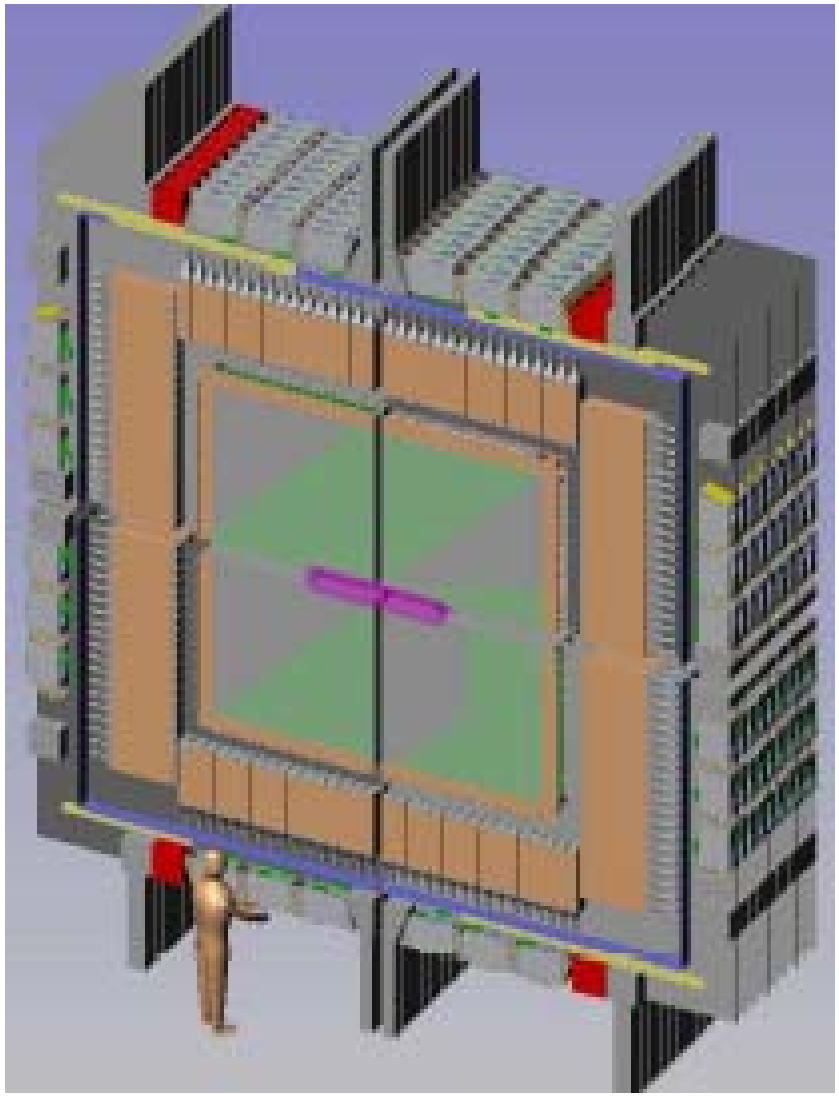
Soft momentum spectrum [0.5,1.5 GeV]

$3x10^8$ $K_L$ / spill, 8 % decay

10 GHz neutrons



# Preradiator

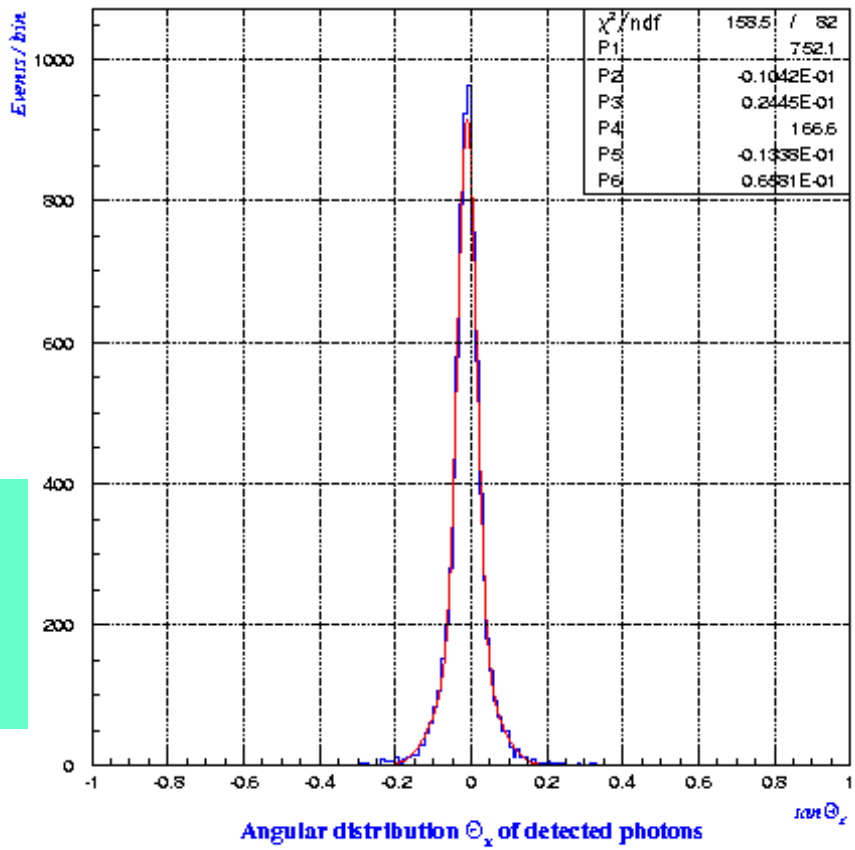


4m

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

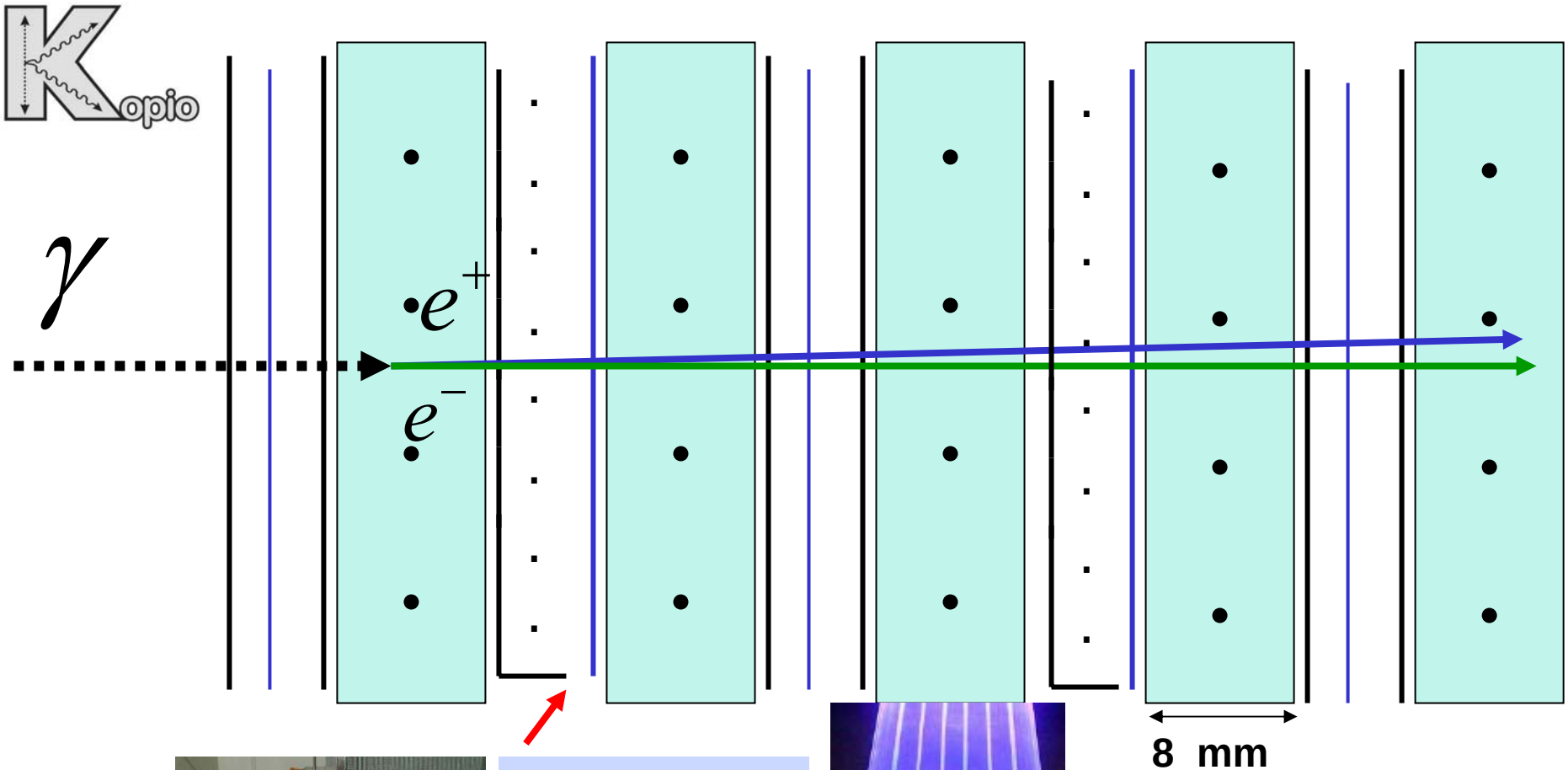
# KOPIO Prototype Measurements – BNL LEGS Tagged Photon Beams

Preradiator Angular resolution:
25 mr at 250 MeV/c

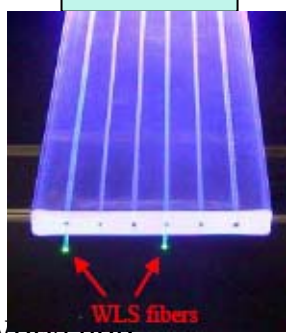



Simulations agree with measurements.

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



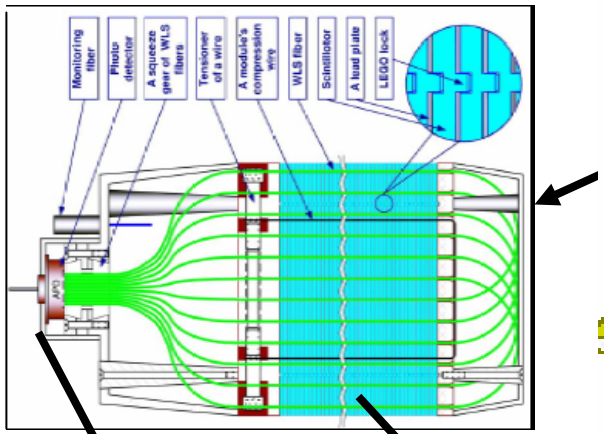
**Cathode strip drift chambers**

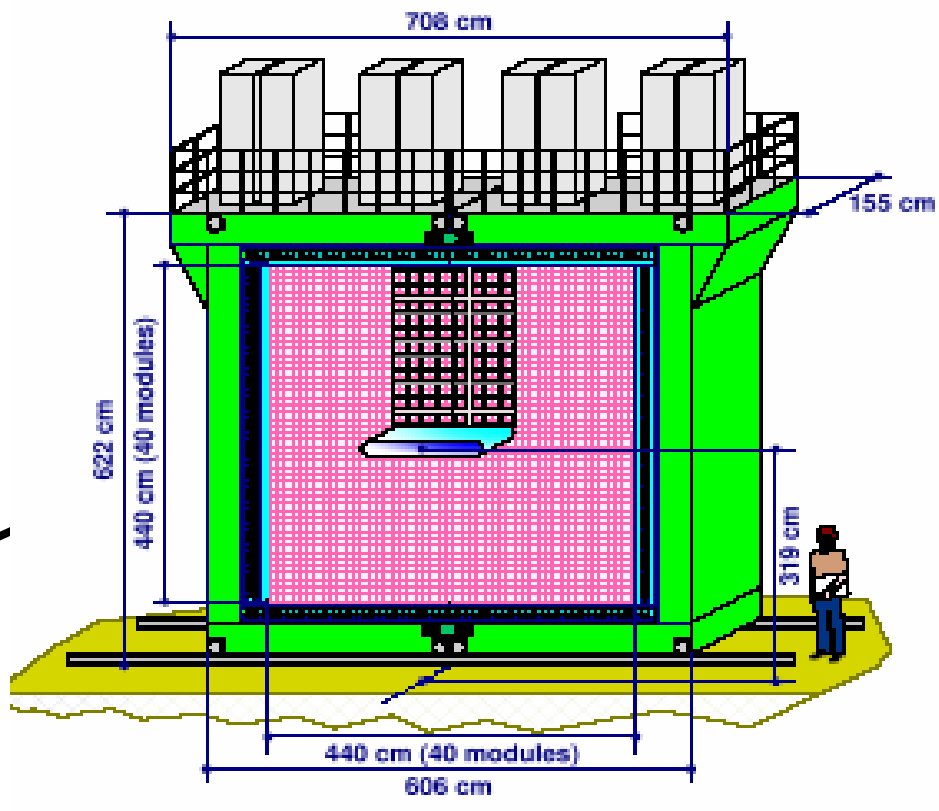



**Extruded Scintillator & WLS fibers**

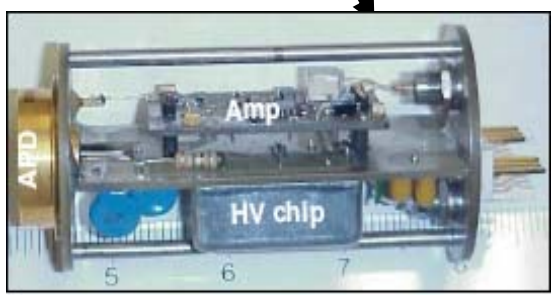
# Shashlyk Calorimeter

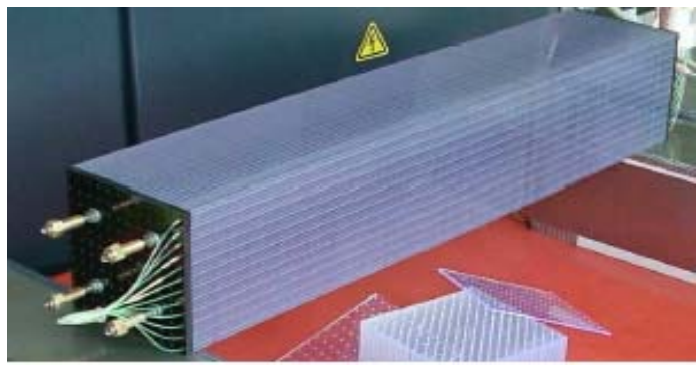
**Shashlyk modules prototyped and tested in beams.**
**Mechanical design in progress**



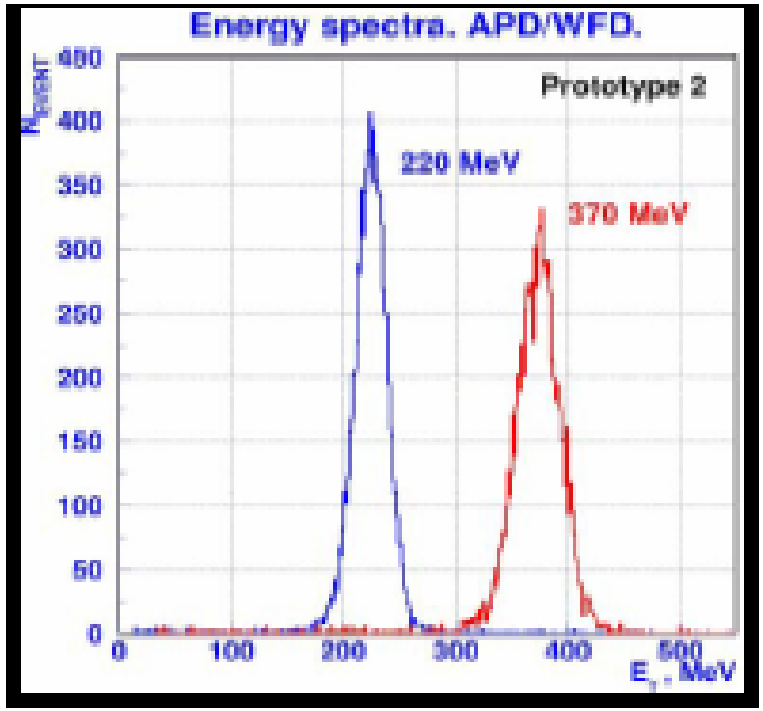



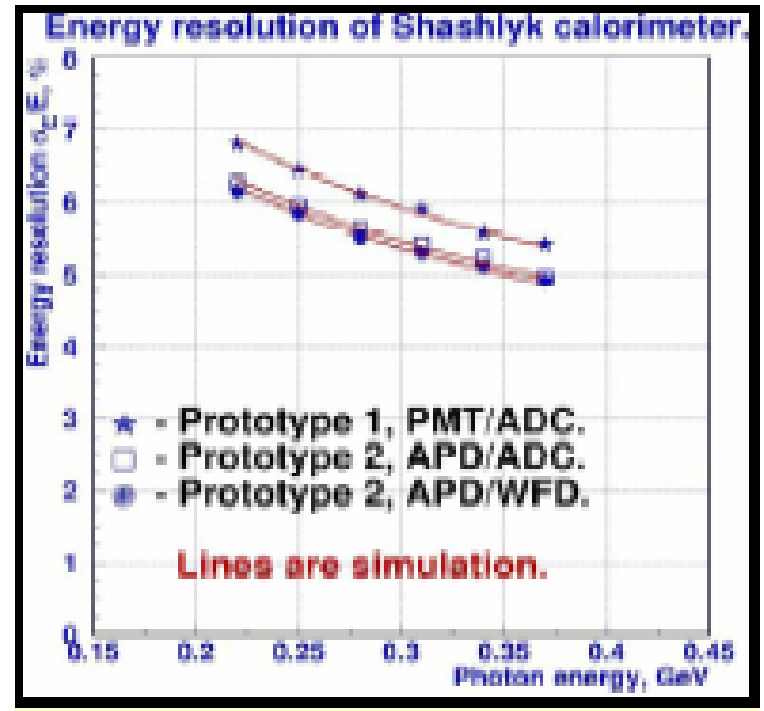

APD



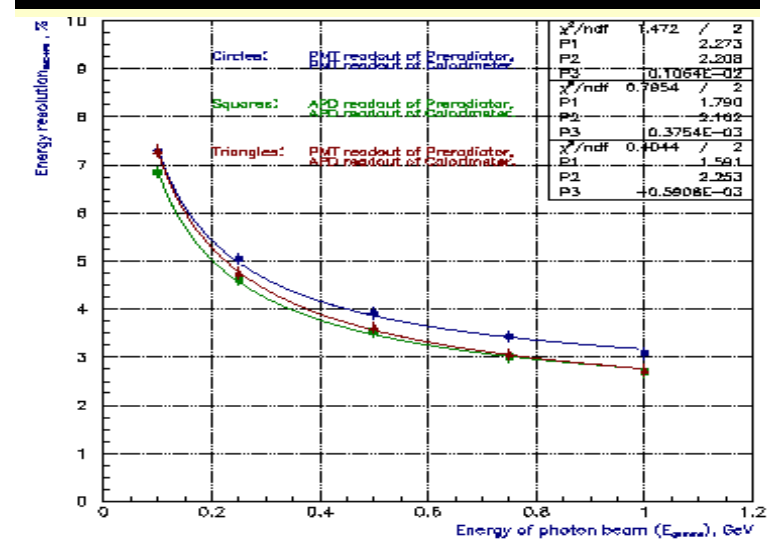
# Shashlyk Beam Measurements



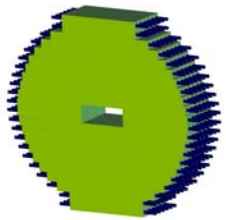

*Simulation*: Combined Energy Resolution

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

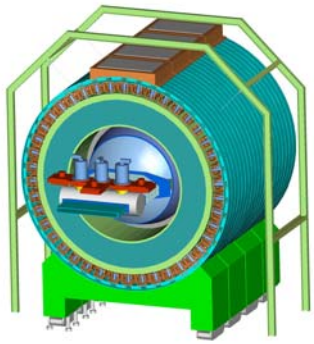


# Every detector is a photon veto!

US Wall



Barrel veto



Fine-sampling lead/scintillator-based shower counters of shashlyk & bar geometry. All thick enough so punch-through not an issue. All with sufficient efficiency

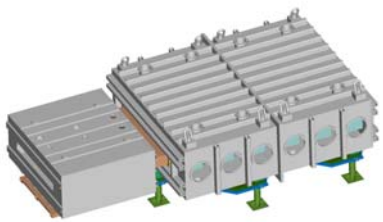
Preradiator

Prerad outer veto

Calorimeter

γ vetoes in D4 sweeping magnet

γ vetoes in DS vacuum pipe



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

# $K_L$ modes simulated for background Studies

| Name | Final state | Branching fraction | $\mathcal{B}/\mathcal{B}(K_L^0 \to \pi^0\nu\overline{\nu})$ |
|---|---|---|---|
| Kpnn | $\pi^0\nu\bar{\nu}$ | $0.3000 \times 10^{-10}$ | 1.000 |
| Kp2 | $\pi^0\pi^0$ | $0.9320 \times 10^{-3}$ | $0.31 \times 10^{8}$ |
| Kcp2 | $\pi^+\pi^-$ | $0.2090 \times 10^{-2}$ | $0.70 \times 10^{8}$ |
| Kgg | $\gamma\gamma$ | $0.5900 \times 10^{-3}$ | $0.20 \times 10^{8}$ |
| Kp3 | $\pi^0\pi^0\pi^0$ | 0.2105 | $0.70 \times 10^{10}$ |
| Kcp3 | $\pi^+\pi^-\pi^0$ | 0.1259 | $0.42 \times 10^{10}$ |
| Ke3 | $\pi^\pm e^\mp\nu$ | 0.3881 | $0.13 \times 10^{11}$ |
| Km3 | $\pi^\pm\mu^\mp\nu$ | 0.2719 | $0.91 \times 10^{10}$ |
| Ke3g | $\pi^\pm e^\mp\nu\gamma$ | $0.3530 \times 10^{-2}$ | $0.12 \times 10^{9}$ |
| Km3g | $\pi^\pm\mu^\mp\nu\gamma$ | $0.5700 \times 10^{-3}$ | $0.19 \times 10^{8}$ |
| Kpgg | $\pi^0\gamma\gamma$ | $0.1410 \times 10^{-5}$ | $0.47 \times 10^{5}$ |
| Ke4 | $\pi^0\pi^\pm e^\mp\nu$ | $0.5180 \times 10^{-4}$ | $0.17 \times 10^{7}$ |
| Km4 | $\pi^0\pi^\pm\mu^\mp\nu$ | $0.1400 \times 10^{-4}$ | $0.47 \times 10^{6}$ |
| Ke2g | $e^+e^-\gamma$ | $0.1000 \times 10^{-4}$ | $0.33 \times 10^{6}$ |
| Km2g | $\mu^+\mu^-\gamma$ | $0.3590 \times 10^{-6}$ | $0.12 \times 10^{5}$ |

Largest back-grounds

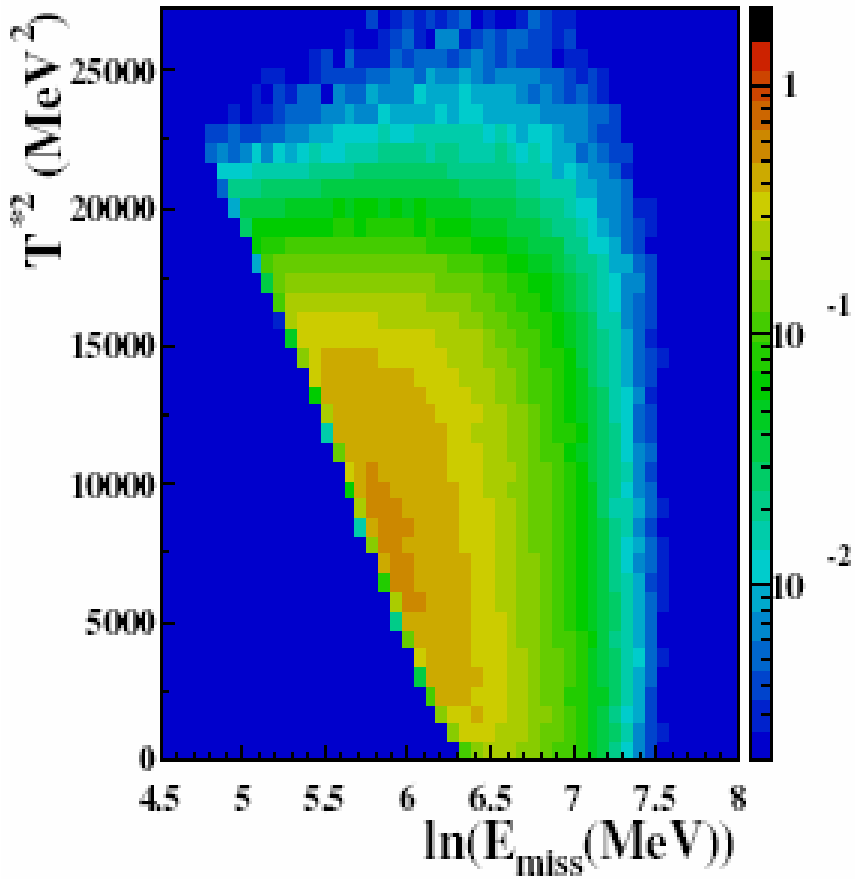
# Other Backgrounds

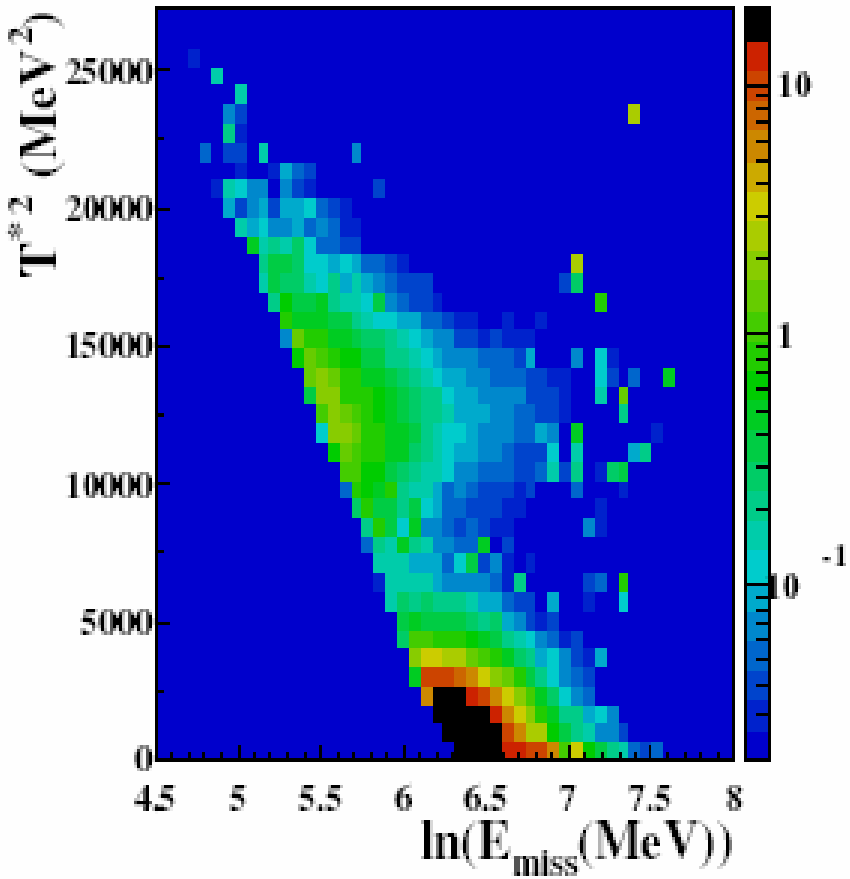
- $K^+$ contamination of beam: <0.001 of signal rate
- $K_L \rightarrow K^+e^-\nu$, $K^-e^+\nu$: ~ 0.001 of signal rate
- $nN \rightarrow \pi^0 N$: negligible production from residual gas in decay volume if pressure<$10^{-6}$ Torr. Requirements on reconstructed $Z_V(K_L)$ suppress rate from US wall to <0.01 of signal rate
- Anti-n: far smaller than neutron background
- Hyperons: <$10^{-5}$ of signal rate
- Fake photons < 0.05 of signal rate assuming ~$10^{-3} \times 10^{-3}$ suppression from (vetoing) × ($\gamma$/n discrimination)
- Two $K_L$ giving single candidate: negligible due to vetos
- $(K_L \rightarrow \pi^{\pm}X) \times (\pi^{\pm} \rightarrow \pi^0 e^{\pm}\nu)$: ~0.01 of signal rate
- $K_S \rightarrow \pi^0\pi^0$: ~$4 \times 10^{-4}$ of $K_L \rightarrow \pi^0\pi^0$ background rate

# Kinematic Separation of Signal and Backgrounds

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

**Signal**




**Backgrounds**