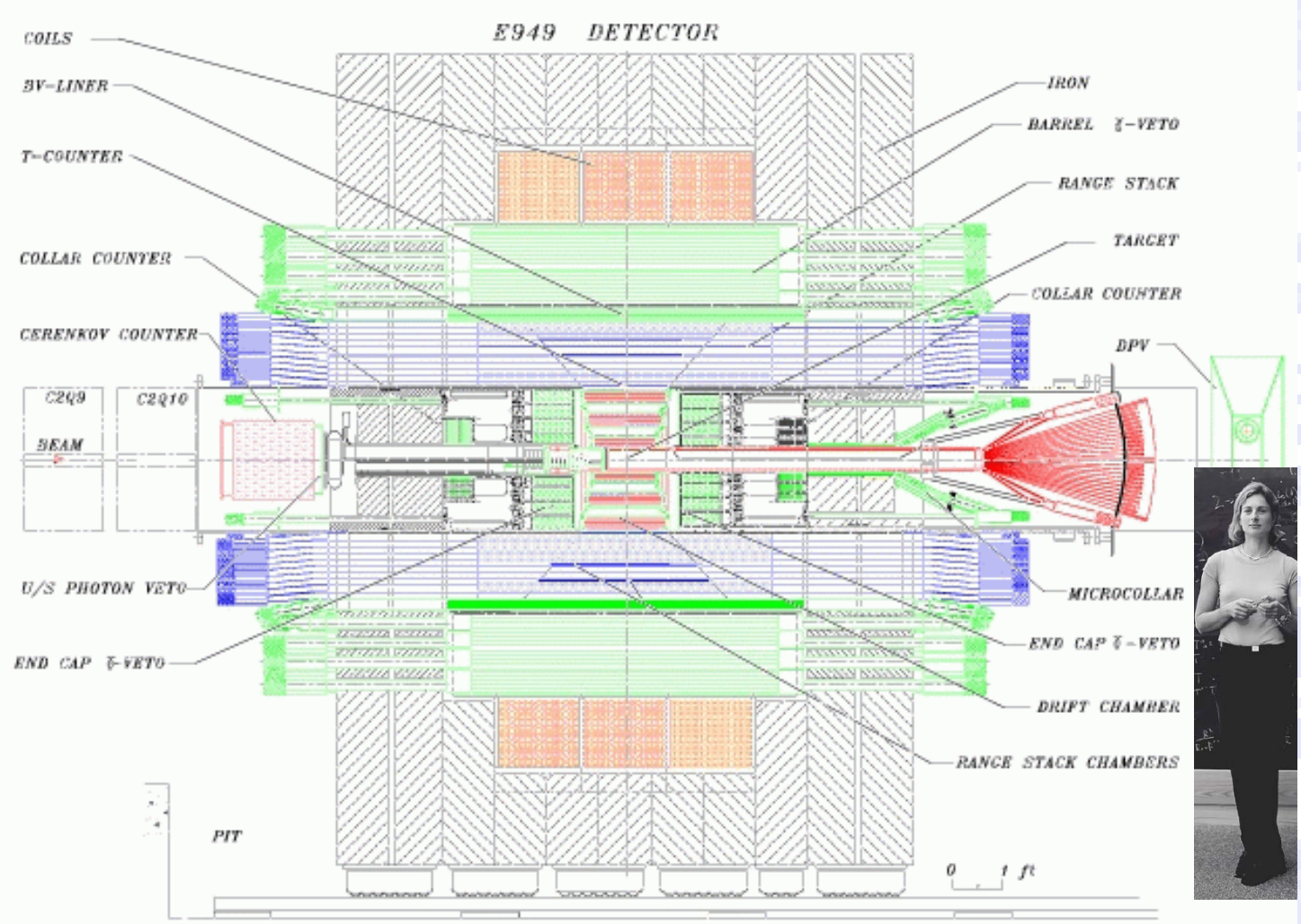
Sensitivity of stopped K^+ and K_L TOF (KOPIO) experiments driven with ICD2

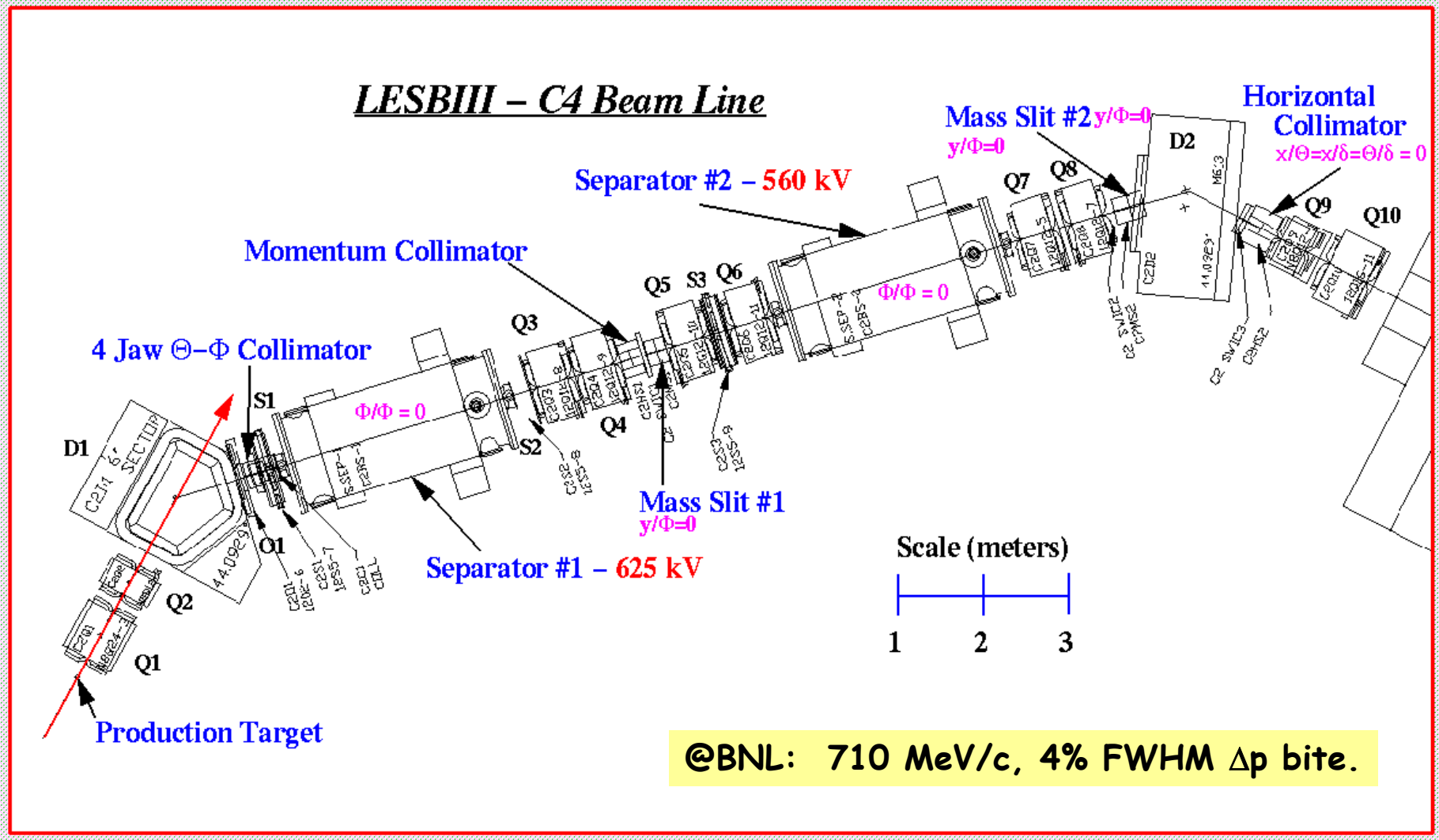
R.Tschirhart, August 28th , 2009

BNL E787/E949: Stopping K+ Experiment that established the $K^+ \to \pi\nu\nu$ decay process



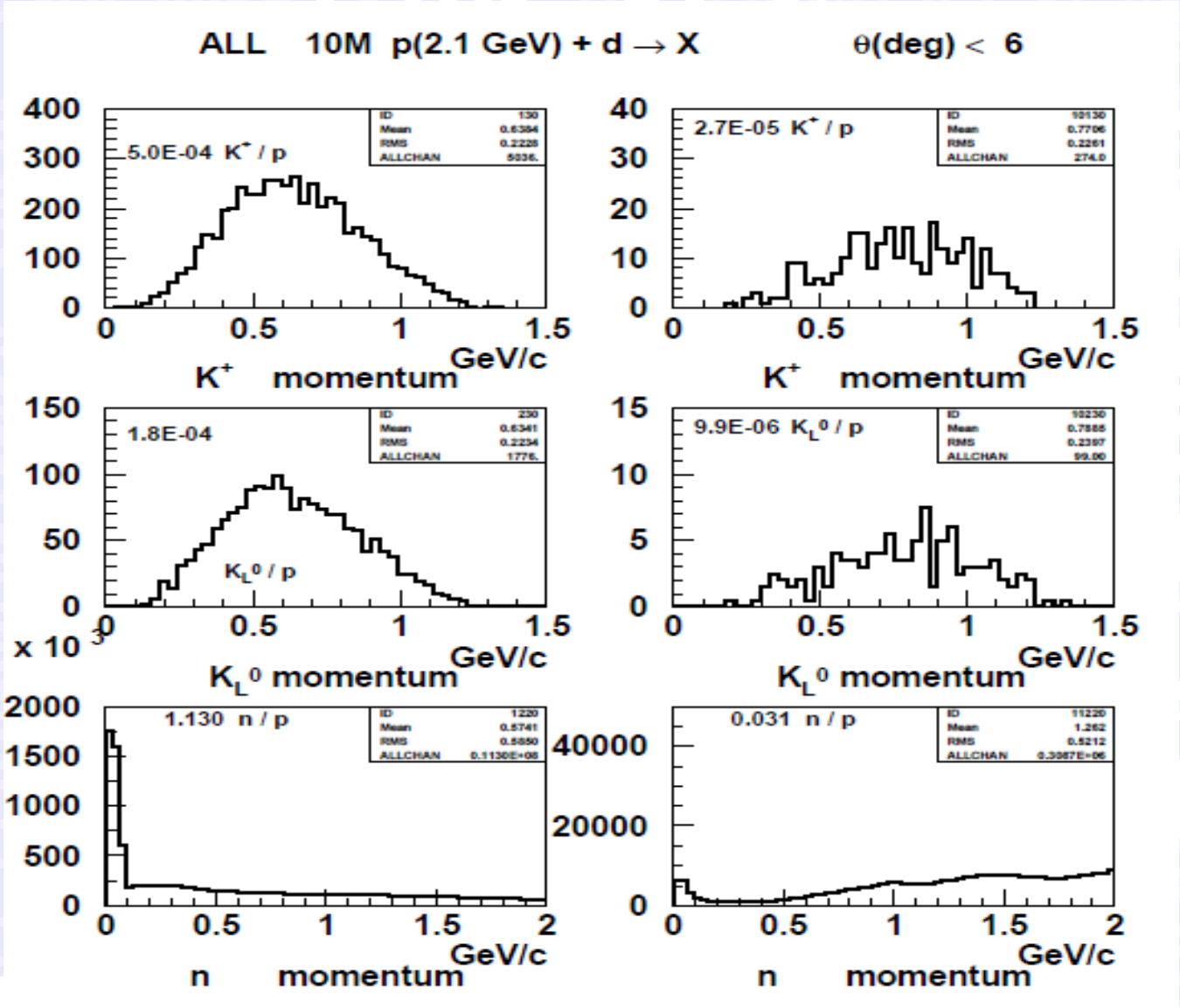
Elevation view of the E949 detector.

BNL AGS Charged K+ Beamline: Channel a low energy *separated* charged beam to the stopping target:

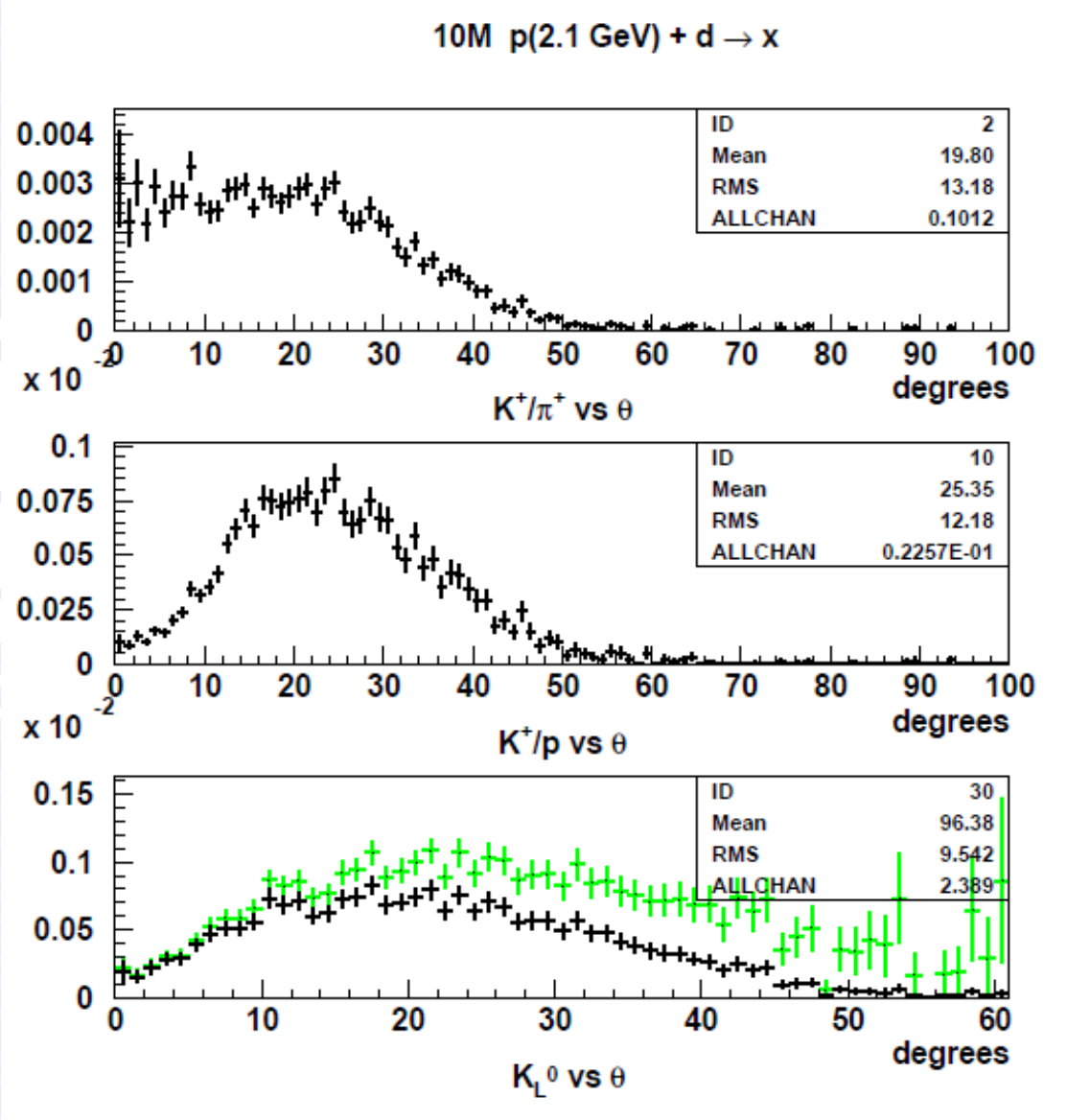


@BNL: 710 MeV/c, 4% FWHM Δp bite.

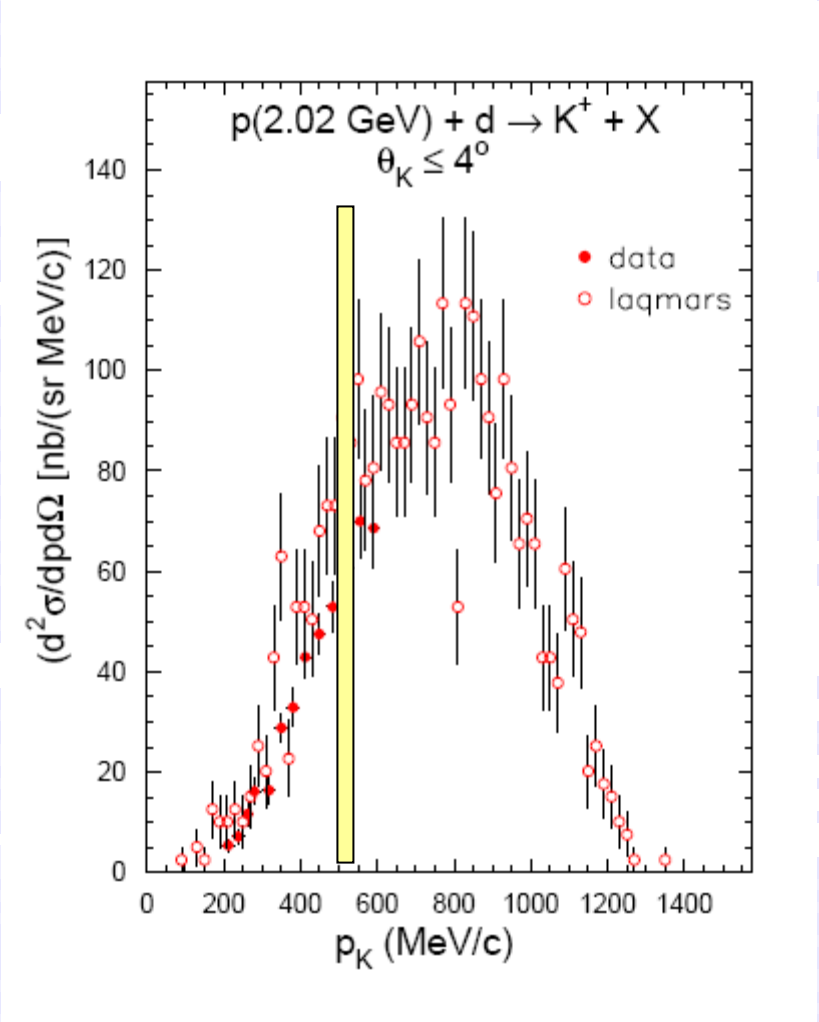
Estimated Charged and Neutral Kaon Yields



Beam Purity Studies



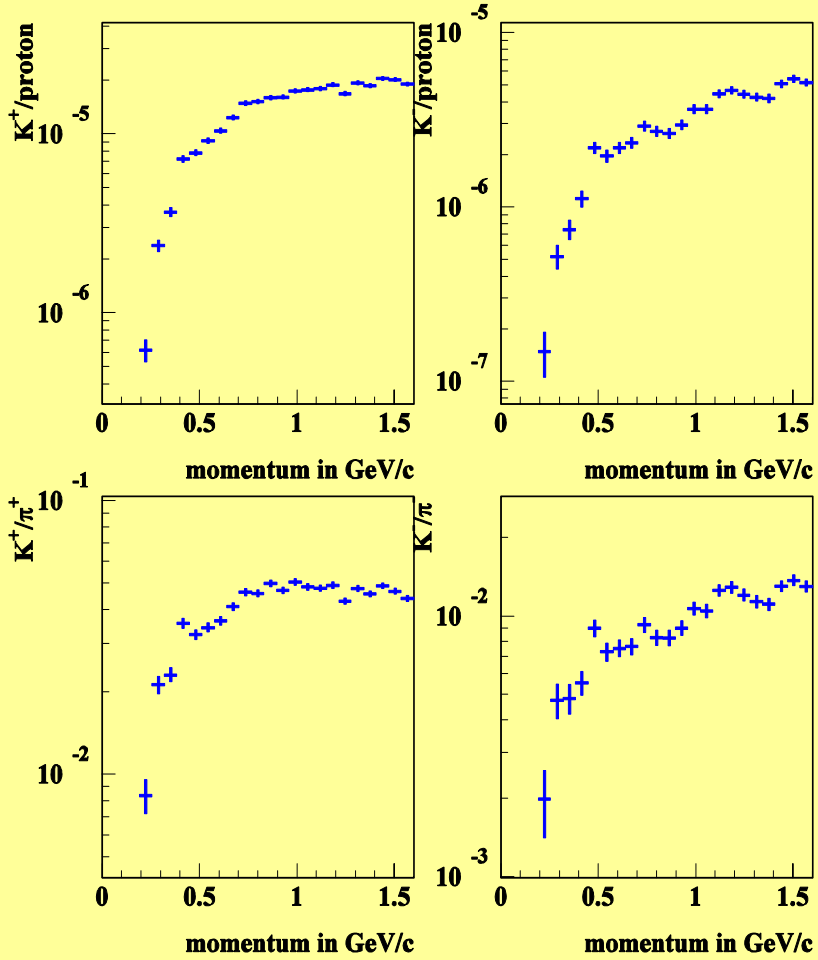
K^+ momenta spectrum



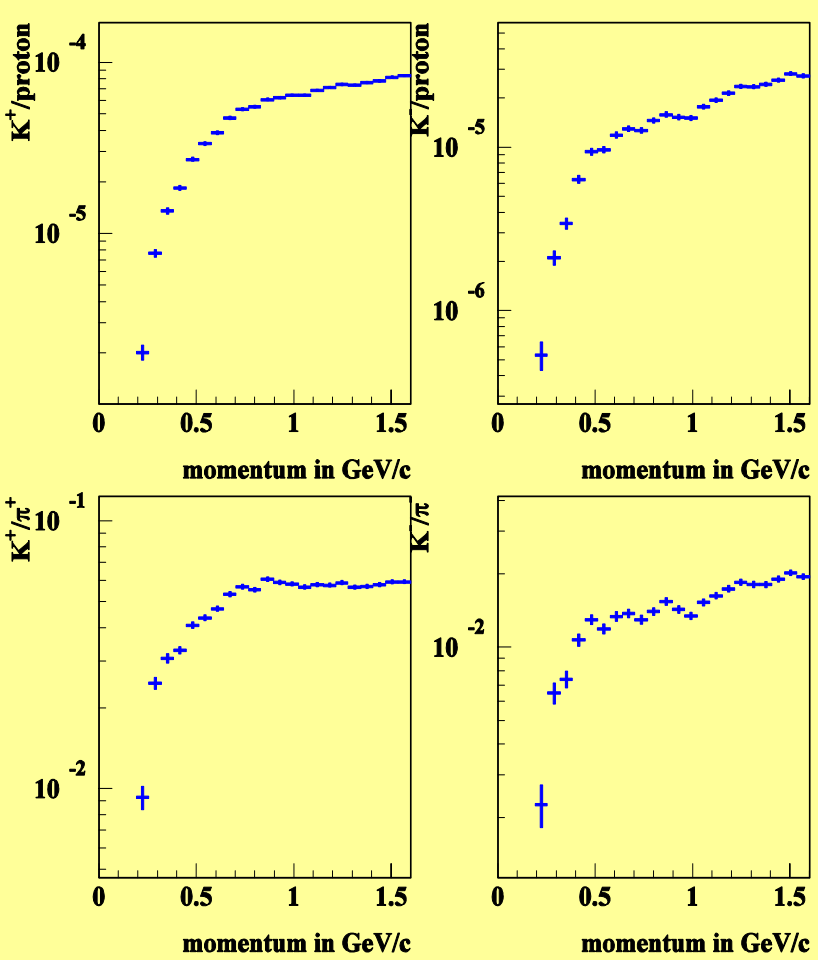
- Los Alamos + MARS simulation suite (LAQMARS) is the state of the art tool set to simulate the challenging region between 1-4 GeV/c proton beam momentum.
- Validated against the high quality data sets from COSY.
- Data shown: Buscher et al (2004) ANKE experiment at COSY, absolutely normalized.

4% of yield in 500-550 MeV/c: Prefered momentum slice for stopped experiment.

24 and 120 GeV/c charged meson yield. LAQGSM predictions (S. Striganov)

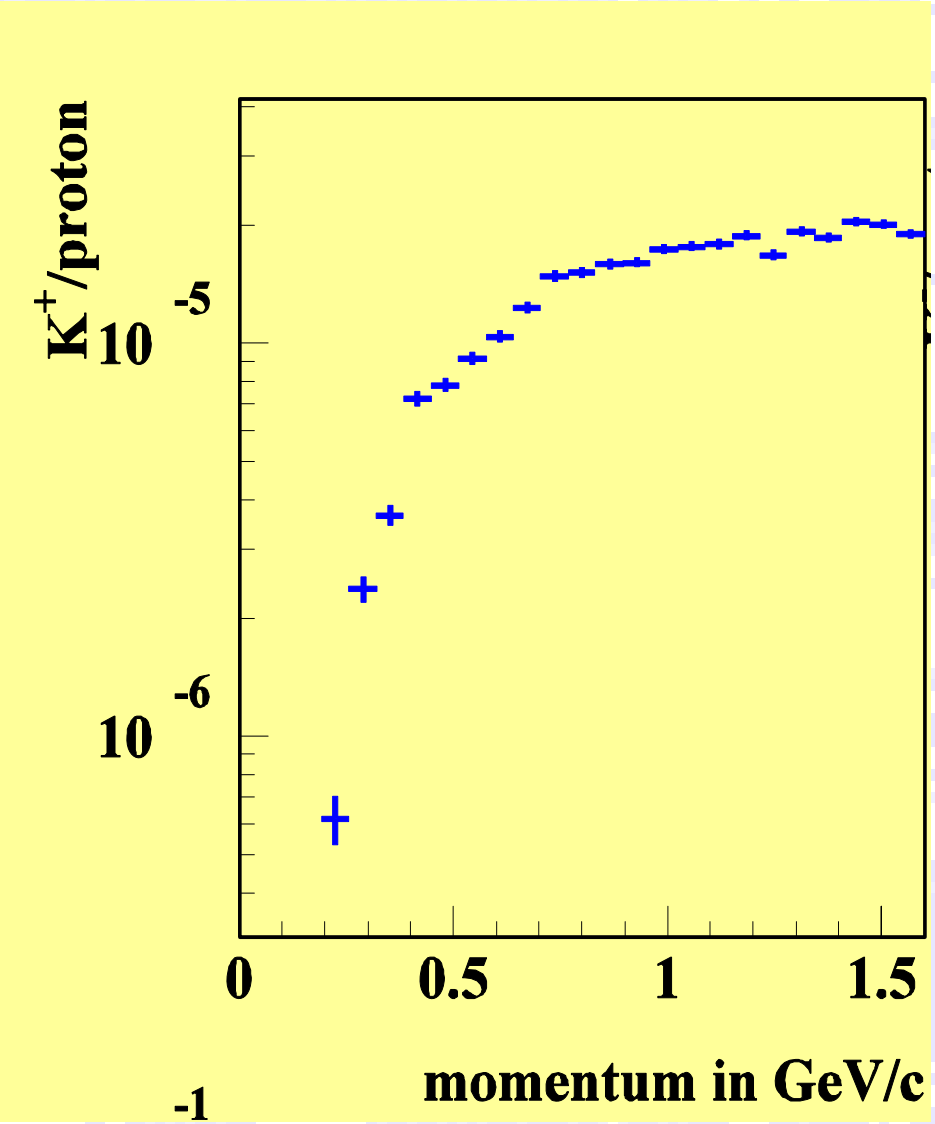


24 GeV/c proton on 10 cm platinum target (< 100 mrad)



120 GeV/c proton on 10 cm platinum target (< 100 mrad)

LAQGSM Simulation of AGS Kaon Yield (S. Striganov)

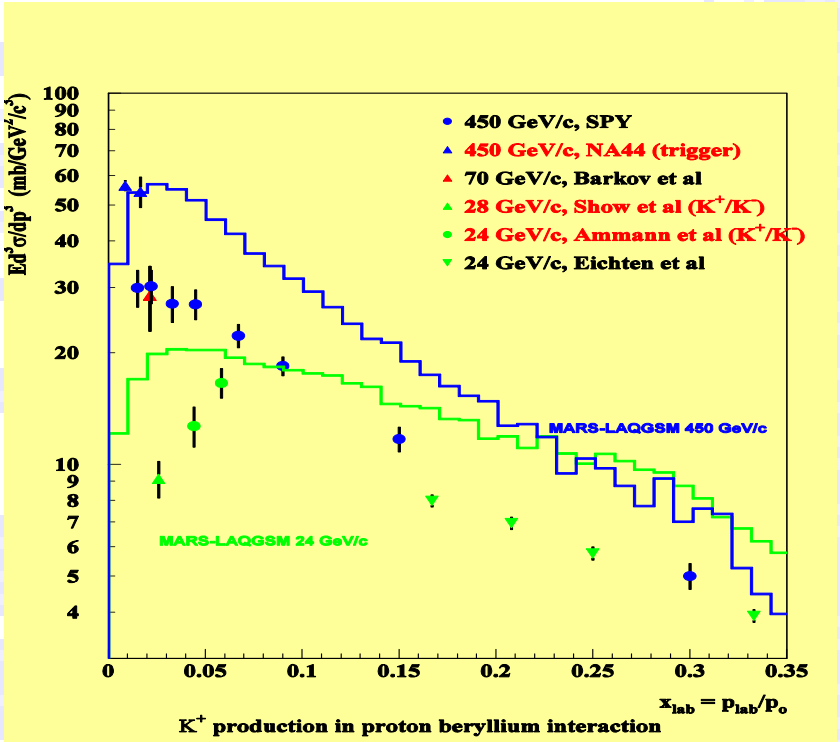


AGS 24 GeV protons on 10cm of Pt.

K^+/proton yield, Y_{K+} (θ<100 mR):

500-550 MeV/c: 8×10^{-6}

700-750 MeV/c: 13×10^{-6}



Stopped K^+ experiment (based on BNL-E949) is driven by 500-550 MeV/c K^+ into θ<100mR

- ICD2: 2.6×10^{-5} (K^+/p (θ<100mR)) x 4% ($\Delta P_K/P_K$) = 1×10^{-6} K^+/p
- BNL AGS (Striganov LAQGSM estimate) = 8×10^{-6} K^+/p
- Tevatron Stretcher estimate (Striganov)* = 30×10^{-6} K^+/p

BNL AGS yield is only x8 greater than ICD2. Naively expect no better than x12 with beam power scaling!

AGS maximum flux goal was 1×10^{14} p/5-sec vs ICD2 design of 6×10^{15} p/sec: Proton flux ratio of x300. ICD2 design K^+ flux is x38 of the Max AGS goal.

ICD2 K^+ design flux is x50 the stopping K^+ experiment initiative with the Tevatron Stretcher (1×10^{14} p/25-sec).

* Scaling from the measured 710 MeV/c K+ yield at the AGS.

Stopped K^+ Optimization Considerations

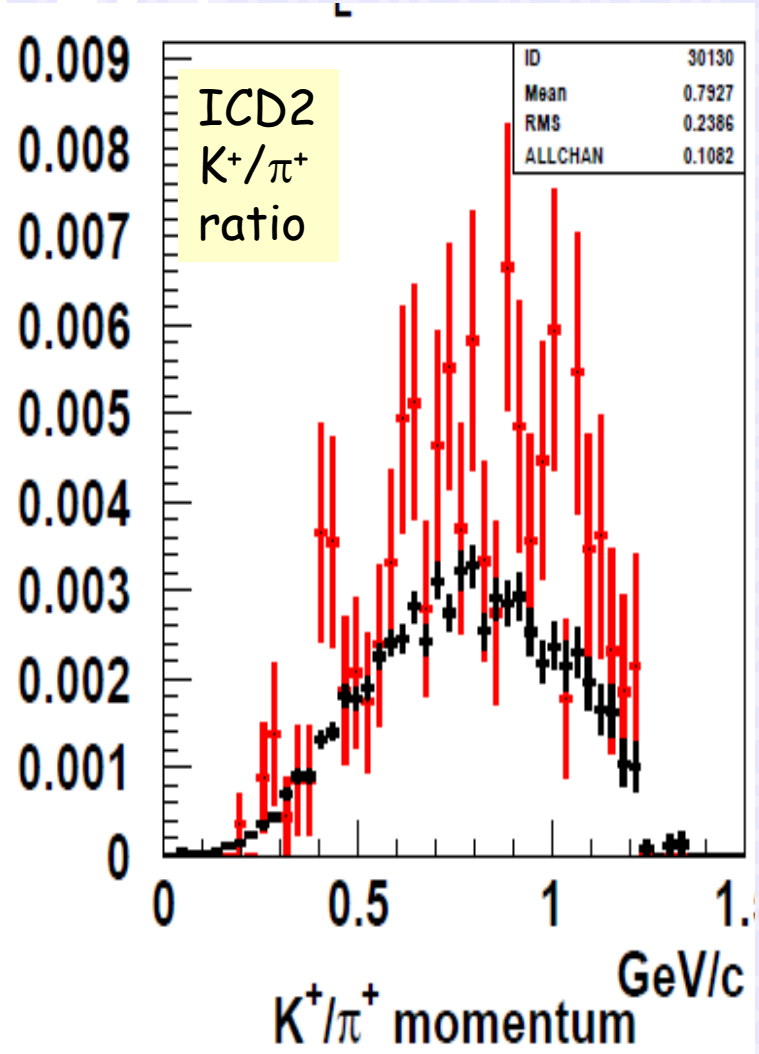
- ICD2 K^+ Yield is great, but K^+/π^+ ratios incident on the separator are less than the AGS or Stretcher. About 0.004 vs 0.04 for the AGS(710 MeV/c) or the Stretcher.

- The better K^+/Watt ratio (ICD2 50% better than AGS) and a smaller kaon beamline acceptance ($d\Omega$, Δp) can help deal (e.g. smaller quads) with the lower K^+/π^+ ratio.

Assume this costs a factor of 1/2 in K^+/p

- Targeting near 20 degrees removes the proton contamination in the channel and pulls the beamline magnets away from the remnant forward beam. The yield at 20 degrees is 2/3 of 0 degrees.

This costs a factor of x2/3 in K^+/p



$K^+ \rightarrow \pi\nu\nu$ Sensitivity

Adding these safety factors reduces the maximum reach of ICD2 (6×10^{15} p/sec) to x17 the reach of the Tevatron Stretcher running at (1×10^{14} p/25-sec).

The goal of the Tevatron Stretcher concept is 1000 events in 5 years.

For ICD2, a 300kW target station (15% ICD2) can reach 1000 events in two years of running.....after ICD2 is built and commissioned.

Can imagine a staged program where the same detector is driven with:

Phase-I:	2 years of 70kW Tevatron Stretcher beam:	400 events.
Phase-II:	2 years of 300kW of ICD2 beam:	1000 events.

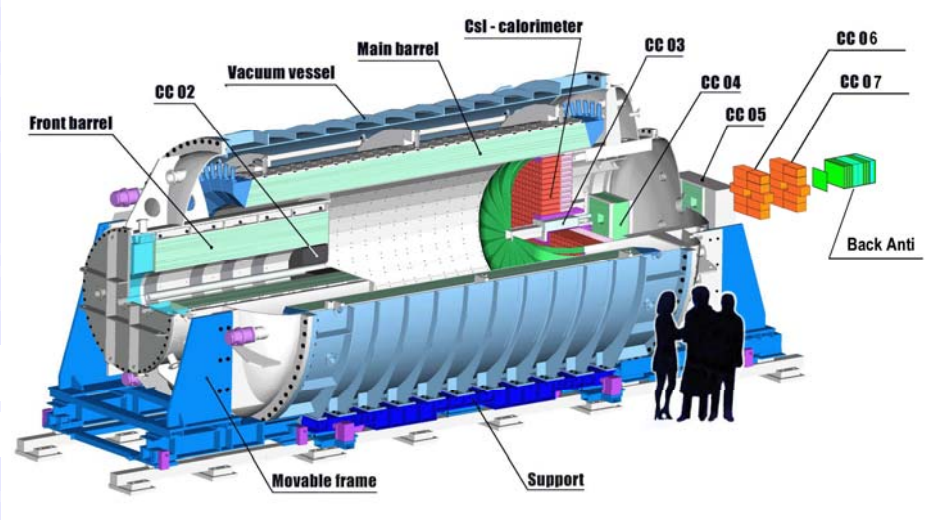
		1400 events.

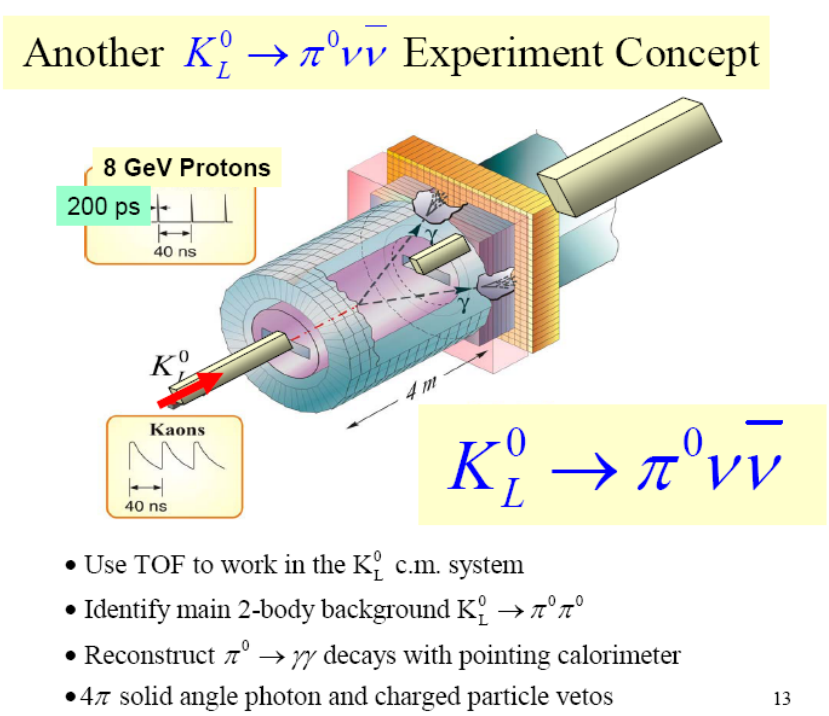
$K_L \to \pi^0 \nu\nu$ Experimental Challenge: "Nothing-in nothing out"

•JPARC approach emphasizes high acceptance for the two decay photons while vetoing everything else:

A hermetic "bottle" approach.

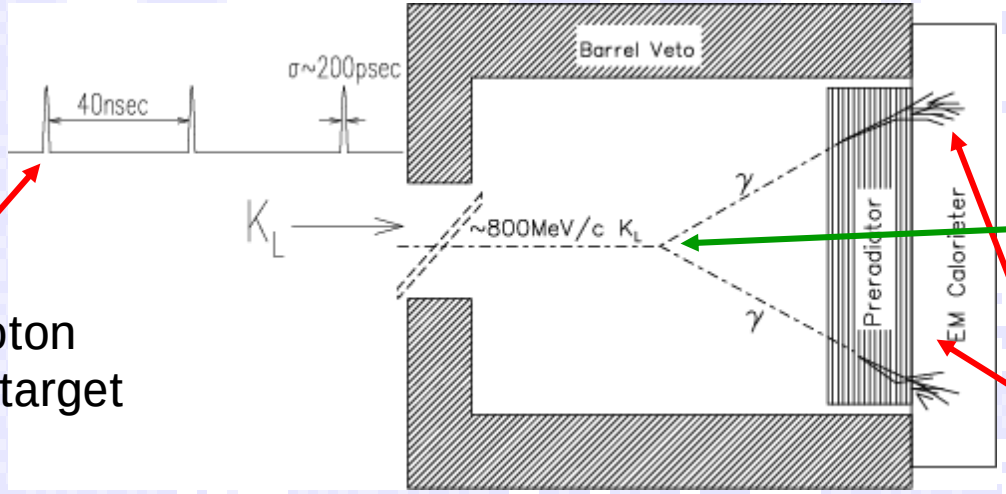
•The original KOPIO concept measures the kaon momentum and photon direction…Good! But costs detector acceptance and requires a large beam to compensate. Project-X Flux can get back to small kaon beam!





KOPIO inspired: Micro-bunch the beam, TOF determines K_L momentum.

Fully reconstruct the neutral Kaon in $K_L \rightarrow \pi^0 \nu \bar{\nu}$ measuring the Kaon momentum by time-of-flight.



Start when proton beam hits the target

End at the decay time and decay point reconstructed from the two photons.

Timing uncertainty due to microbunch width should not dominate the measurement of the kaon momentum; requires RMS width < 200ps. CW linac pulse timing of less than 50ps is intrinsic.

What is the momentum spectrum of KOPIO (AGS, 45°, 24 GeV, 10 cm Pt) vs 2.1 GeV on D?

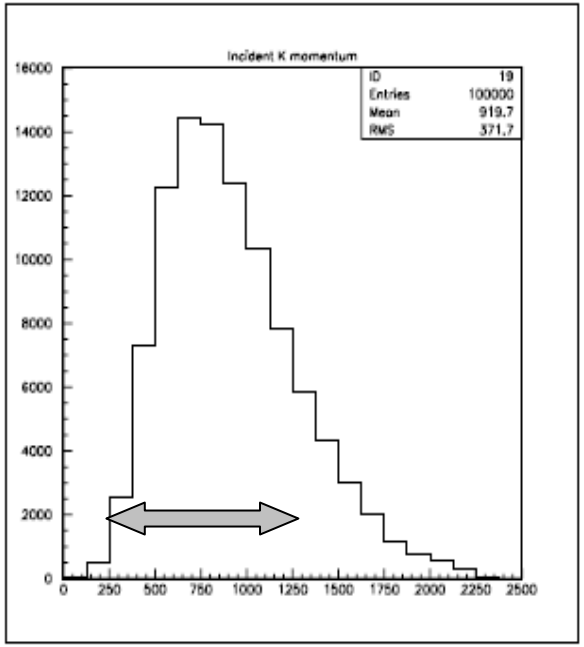
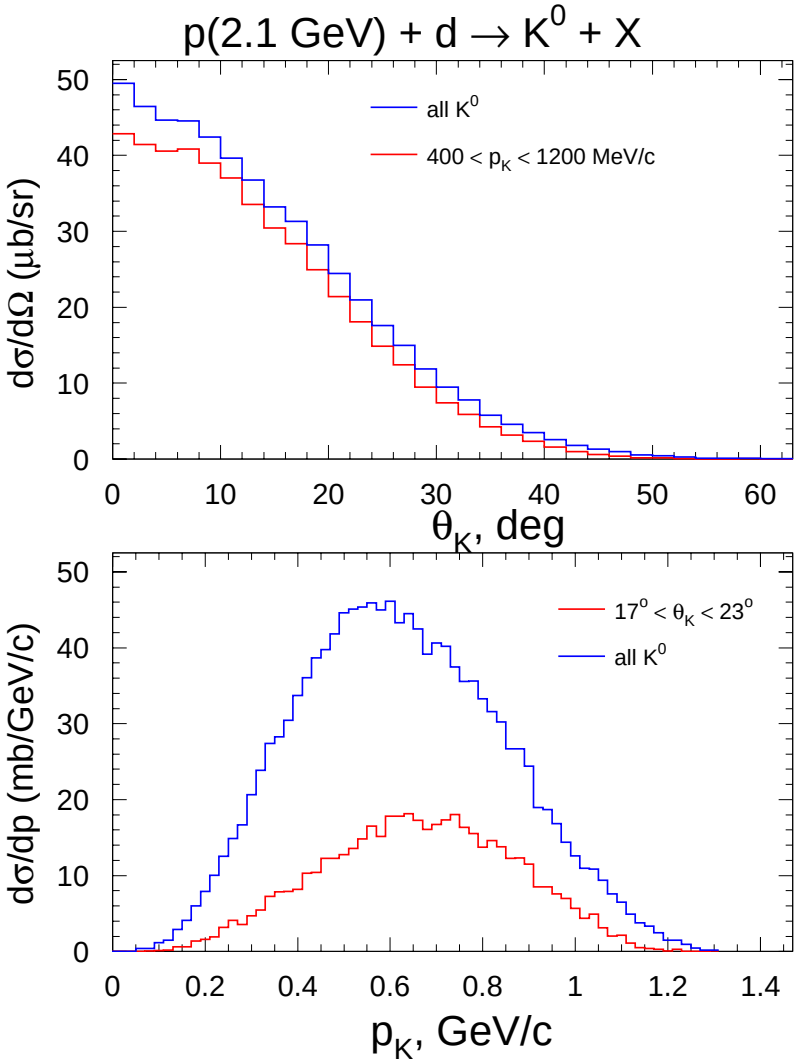
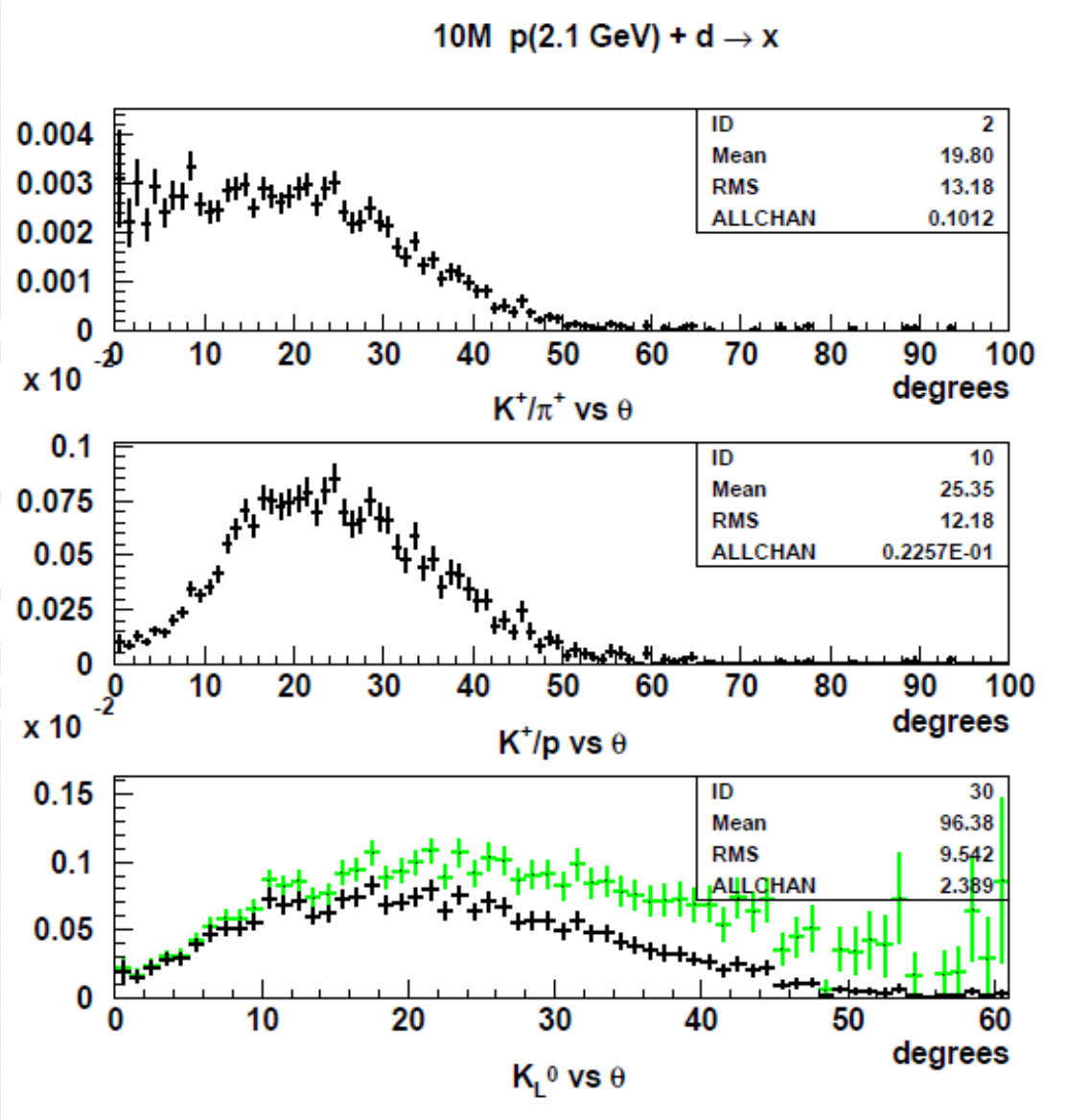


Figure 13: K_L^0 spectrum incident on KOPIO decay volume.

From KOPIO Proposal. Shaded arrow is ICD2 spectra, which has higher acceptance in KOPIO design.



Beam Purity Studies



K_L TOF experiment (based on KOPIO) is driven by 400-1200 MeV/c K_L into a 500 msr $d\Omega$ (100mR x 5 mR) solid angle

KOPIO is based on 1×10^{14} 24 GeV protons every 5-sec for 5500 hours yielding a 100 event statistical sensitivity.

		K_L/p	$n_{(>10MeV)}/K_L$
• BNL AGS(KOPIO proposal, before γ-spoiler)	=	430×10^{-8}	2000
• ICD2 (500 msr @ θ=0 degrees)	=	16×10^{-8}	5000
• ICD2 (500 msr @ θ=20 degrees)	=	11×10^{-8}	1000
• JPARC Phase-II (2msr @ 5 deg, 30 GeV)	=	15×10^{-8}	32

K_L/p yield @ AGS is x39 the ICD2 K_L/p yield. IC2D proton flux is x300 higher. Nominal 5-year ICD2 run is x4.5 KOPIO run. IC2D @ max-power is x35 times KOPIO sensitivity. x10 gets to 1000 nominal events, x3.5 reduces target station power to 600 kW…naïve.

K_L TOF Experiment Optimization Considerations

- Would likely re-optimize for a smaller beam size as per Littenberg analysis. There are big gains here that make the experiment more robust vs rate and easier to build.

- The excellent beam time resolution & lower K_L momenta will improve the TOF analysis and will increase acceptance and background rejection.

- Special running below the kaon production threshold will measure beam related backgrounds (e.g. neutron induced π^0)

- Think target studies are well motivated to increase K_L yield and decrease neutron background.