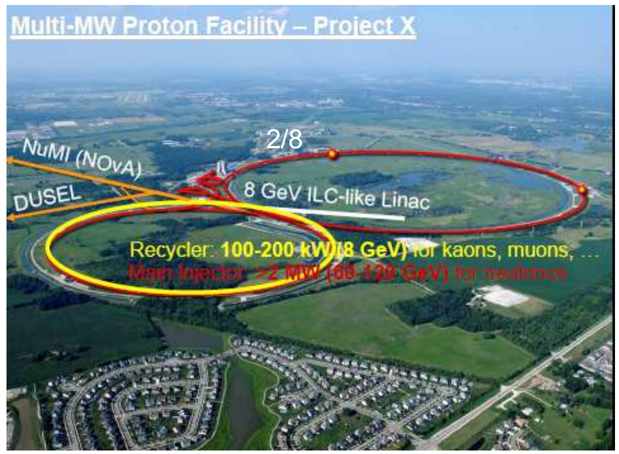
Initial Thoughts on Beam Requirements for Rare K Decay Experiments at Project X ICD-2



Douglas Bryman
University of British Columbia

K^+ Beam for $K^+ \to \pi^+ \nu \bar{\nu}$ Measurement

ICD-2 can produce 10x the flux of low energy K's than possible at the AGS.

Fermilab Proposal 996

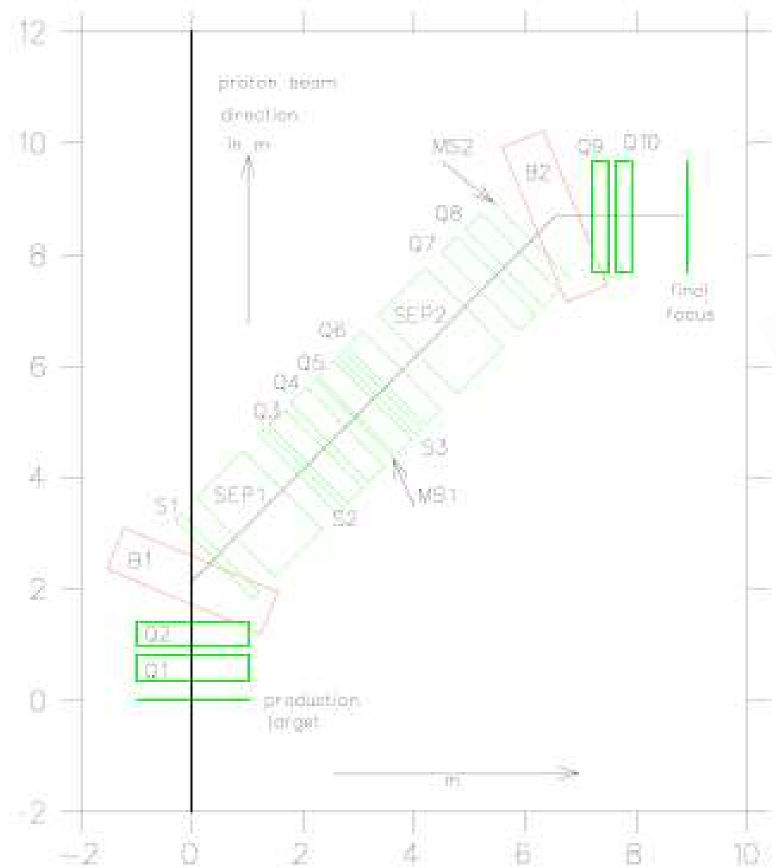
	Beam Energy T_p	Protons/second (avg) on [target (λ_I)]	$p(K^+)$ (MeV/c)	Stopping K^+/second	K^+/π^+ Ratio
BNL AGS (E949)	21 GeV	12×10^{12} on [0.7 λ_I Pt.]	700-730	0.7×10^6	1:24
Tevatron Stretcher Initiative [K.7]	150 GeV	3.6×10^{12} on [1.1 λ_I Pt.]	530-570	$(3\text{-}5) \times 10^6$	1:20
ICD-2 K^+ expt	2.6 GeV	$1/3 \times 6000 \times 10^{12}$ on [1.0 λ_I C]	530-570	43×10^6	1:120

Table 4: Compares the measured rate of stopping K^+ in the BNL-E949 experiment with full LAQGSM/MARS thick-target simulations for stopping rates in the Tevatron Stretcher Initiative and an identical beamline and stopping target with 1/3 of the ICD-2 beam power.

ICD-2 Research Program Task Force Report 2009

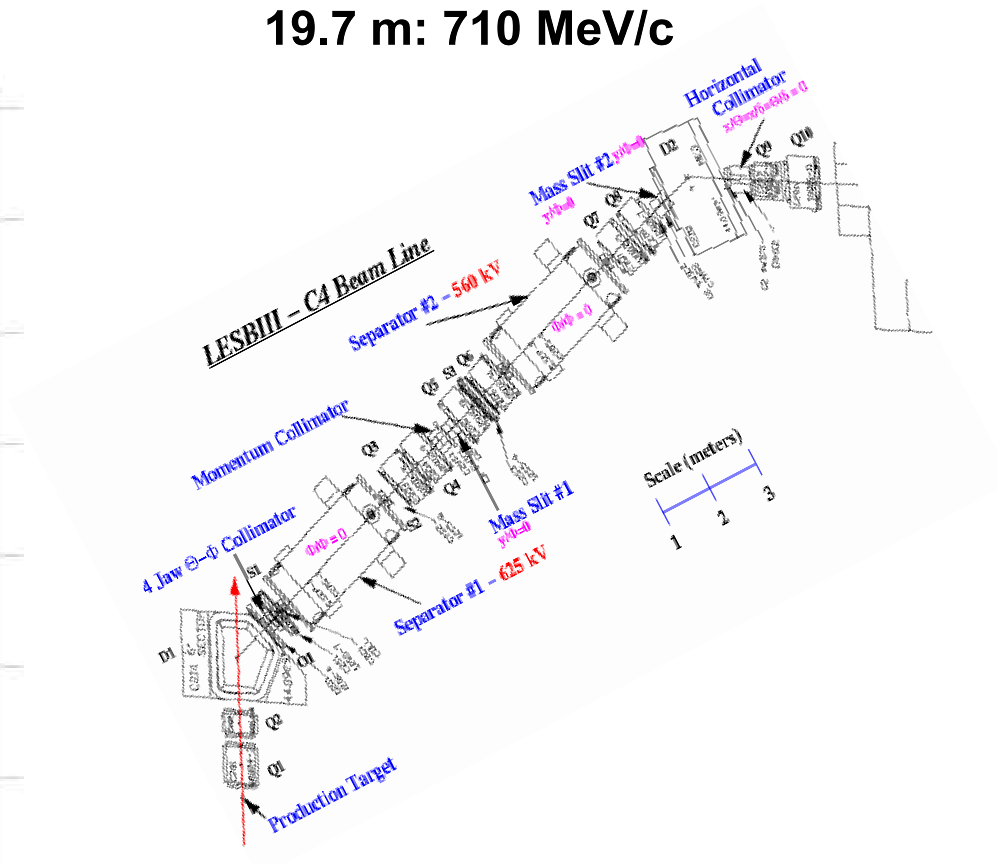
Secondary K+ Beam

P996 Beam line designed by Jaap Doornbos: 13.74m for 500-550 MeV/c



ExB separators: 1.2mx 0.12m @600kV

LESB3 (AGS E949) 19.7 m: 710 MeV/c



ExB separators: 2.2mx 0.13m @575kV

P996 Beam – J. Doornbos

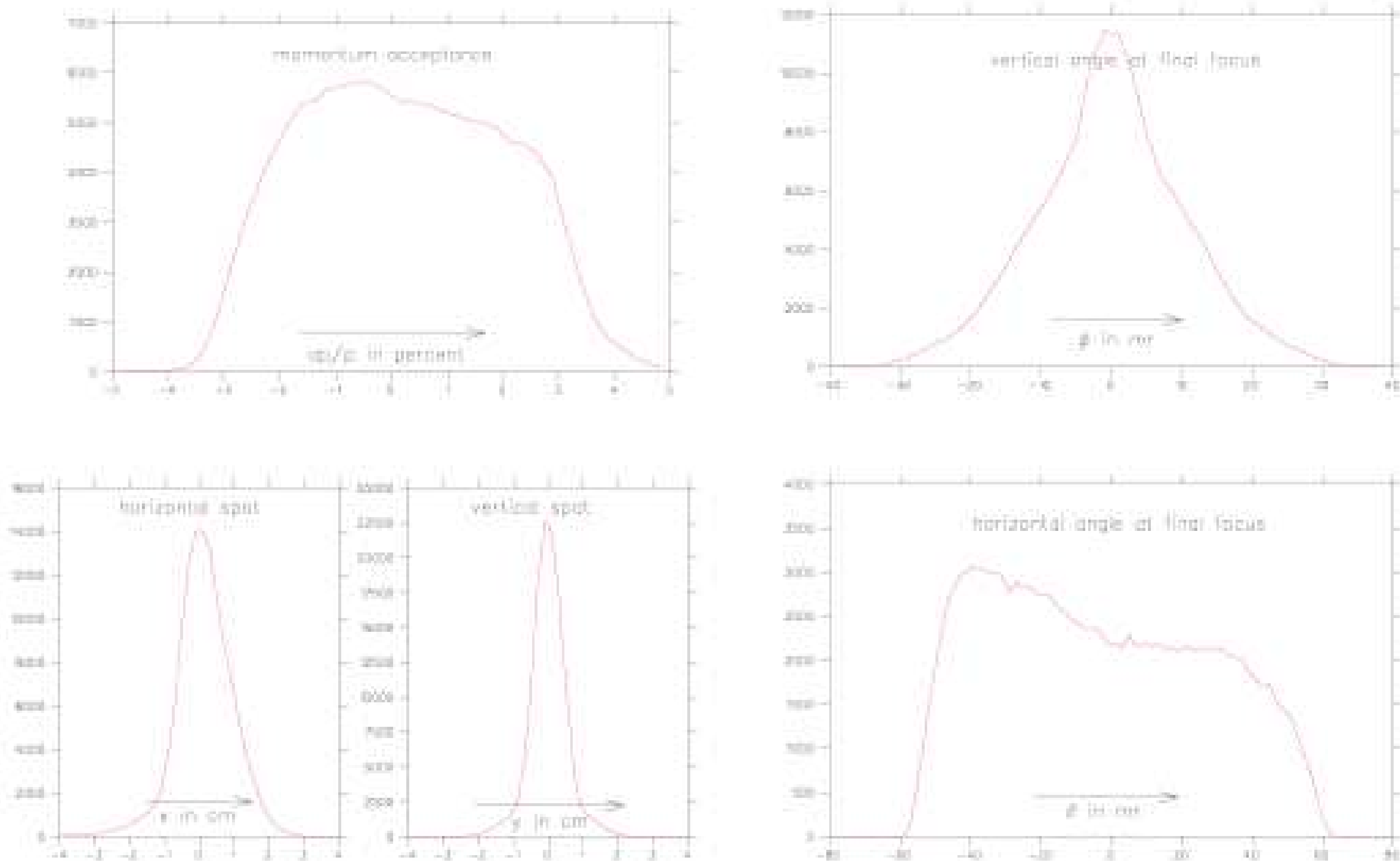


Figure 6.2: Left: The momentum acceptance (top) and the spot sizes at the focal plane (bottom). Right: The beam divergences at the focal plane

Pion Contamination: K/pi~3

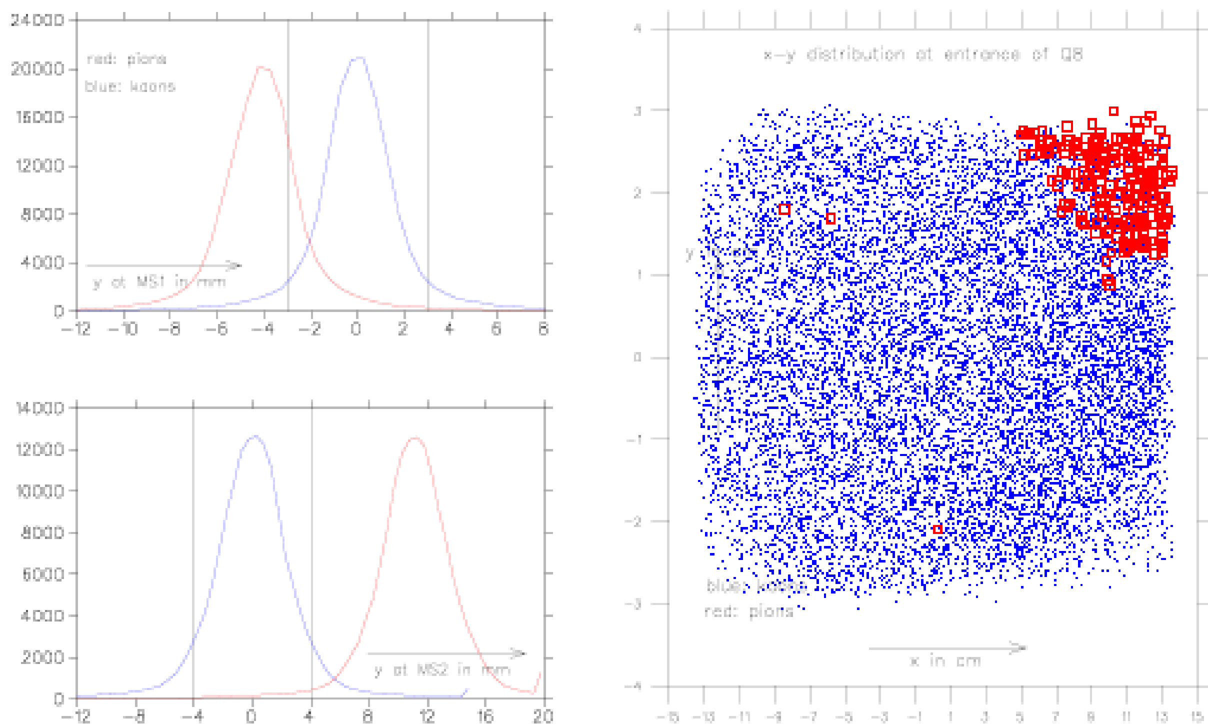
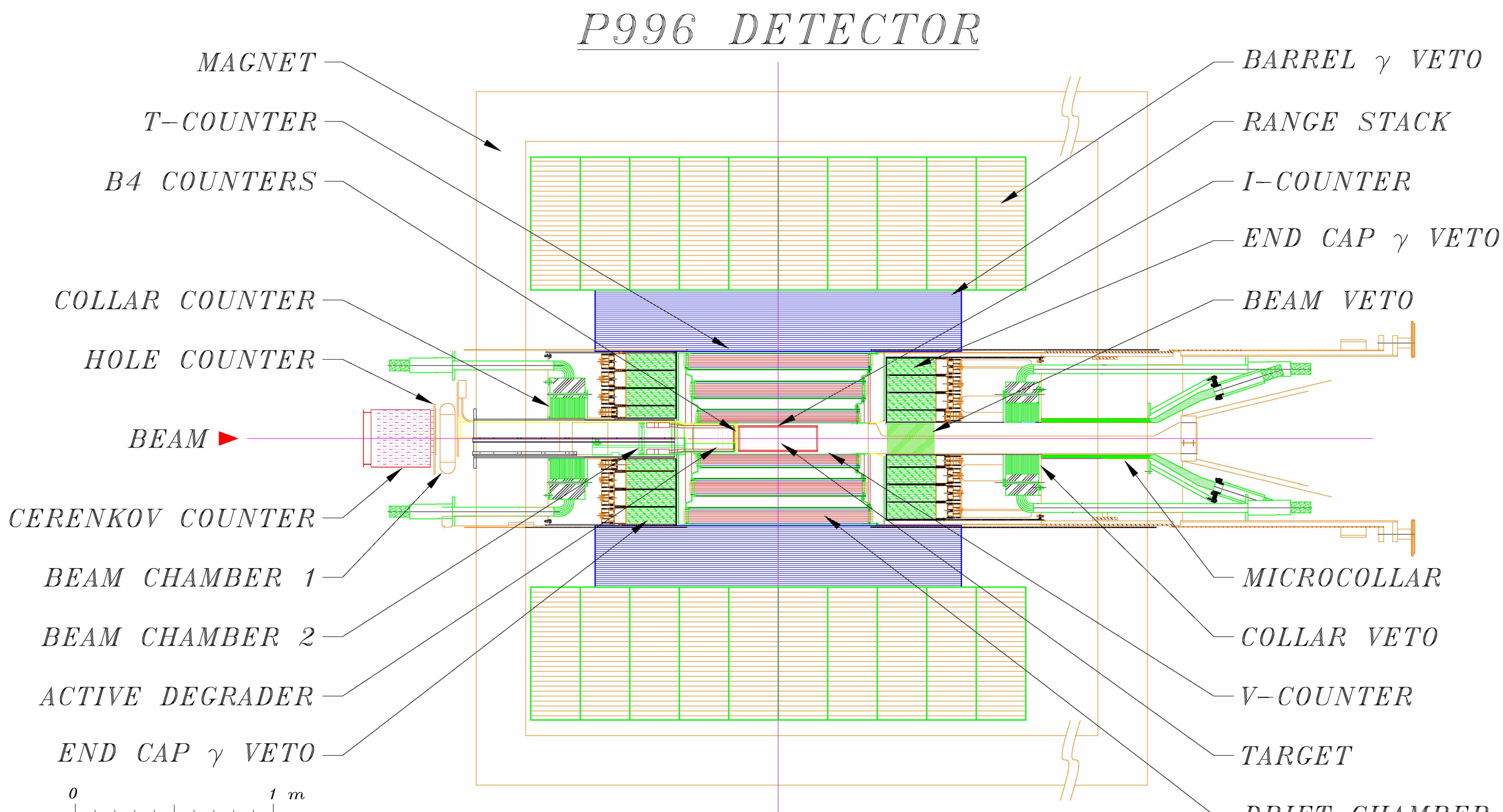


Figure 6.3: Left: Vertical kaon and pion spots at the mass slits. Right: Kaon and pion scatter plot at the entrance of Q8 for those particles transmitted through the mass slits when MS1 is 6 mm wide and MS2 has 8 mm aperture.



Magnetic Field: B=1.25 T

Possible Beam Improvements for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at Project X ICD-2

With 10 x beam power to burn…

- Reduce momentum to ≤500 MeV/c

  However… need upstream photon veto

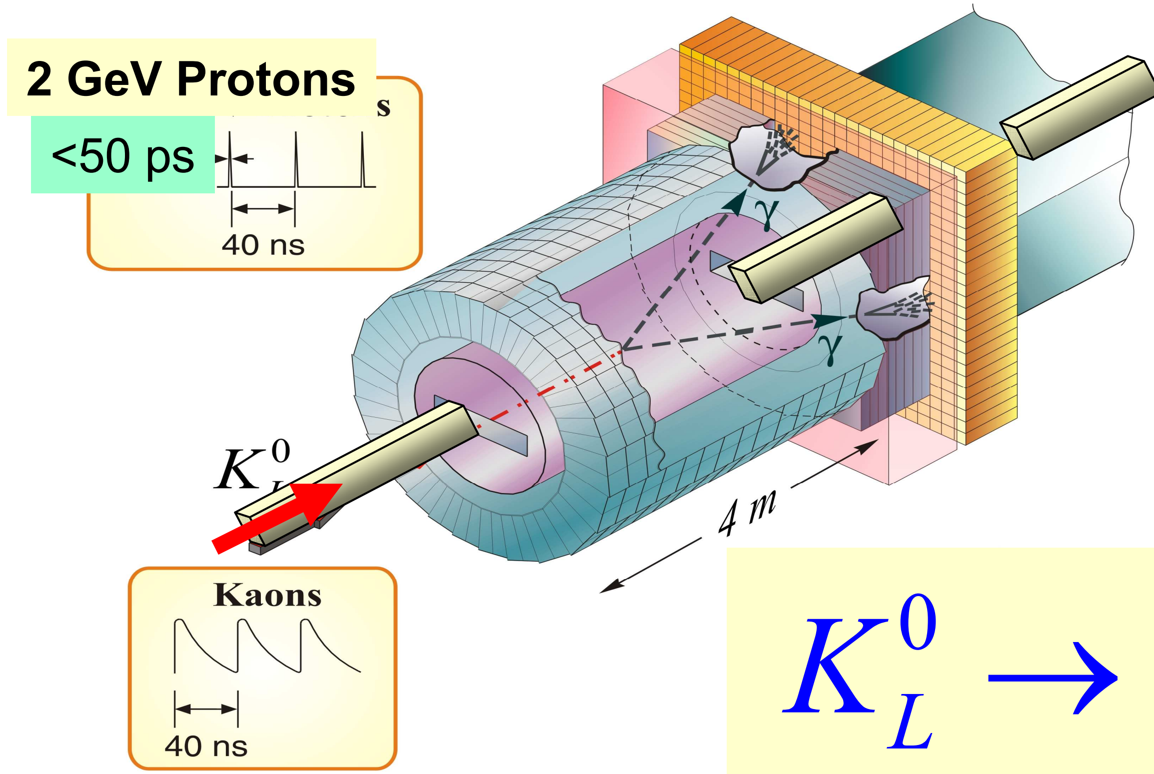
- Reduce beam size and divergence

  Possible improvement in total momentum resolution with smaller target

- *Increase* length of separators to improve pi rejection; or develop improved separators

Project X ICD-2: $K_L^0 \to \pi^0 \nu \bar{\nu}$ Experiment Concept

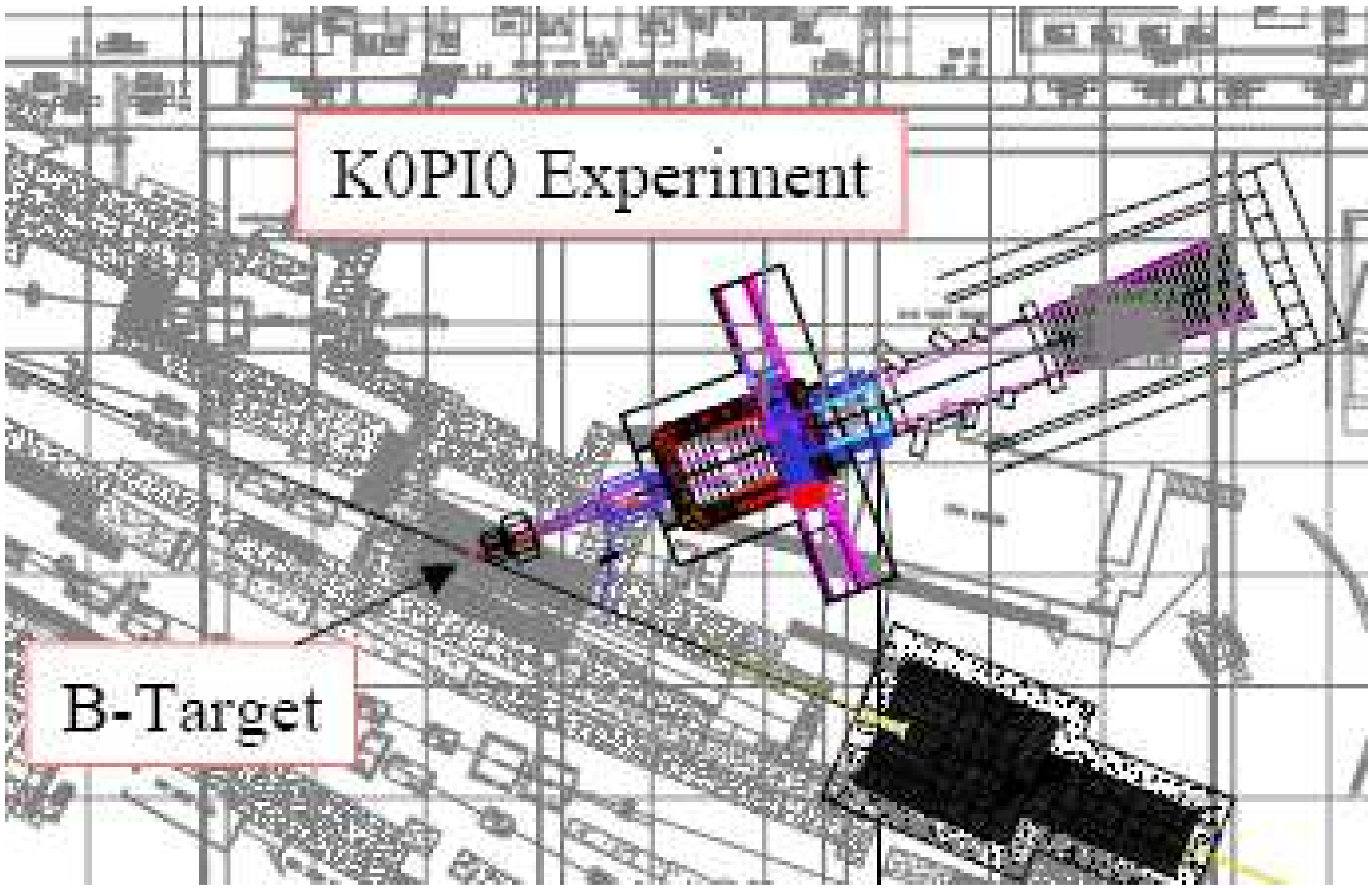
a la KOPIO



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

- Use TOF to work in the K_L^0 c.m. system
- Identify main 2-body background $K_L^0 \to \pi^0 \pi^0$
- Reconstruct $\pi^0 \to \gamma\gamma$ decays with pointing calorimeter
- 4π solid angle photon and charged particle vetos

10 m long Neutral Beam for KOPIO at ~43 degrees



KOPIO: Neutral Beam (neutrons) Collimated to Suppress Halo

Vertical Collimation Scheme

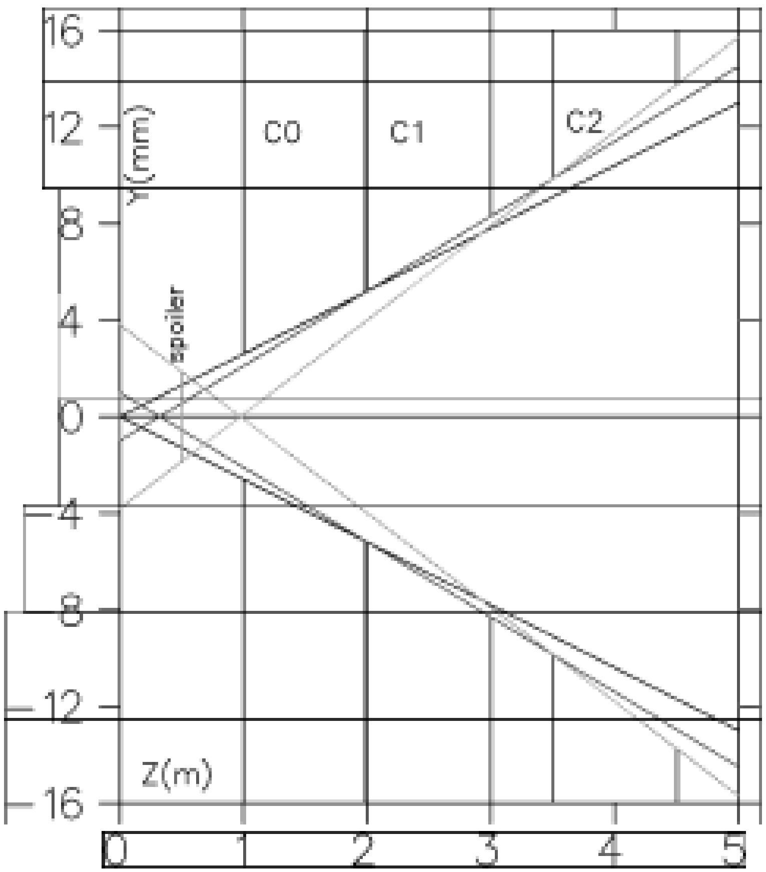


Figure 2: Construction of the vertical apertures of collimators C0 to C2

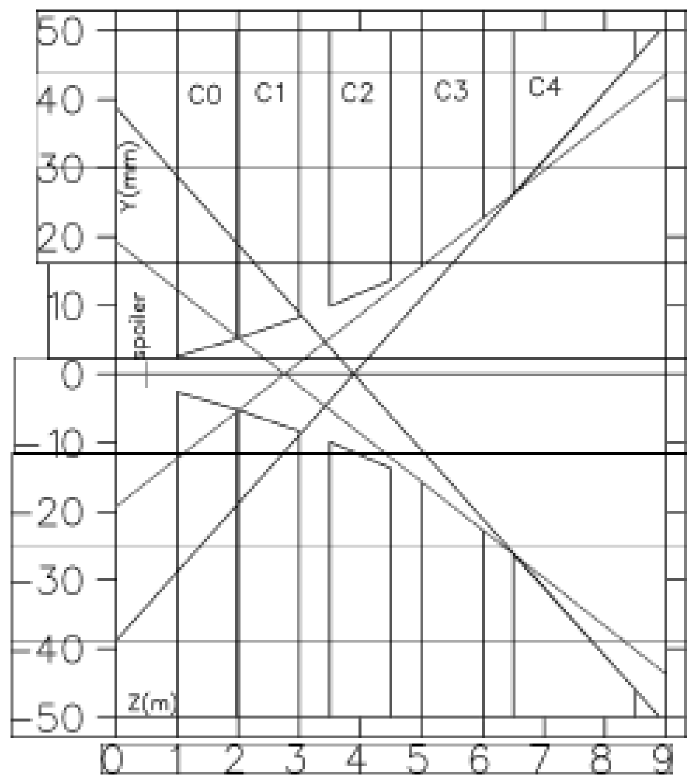


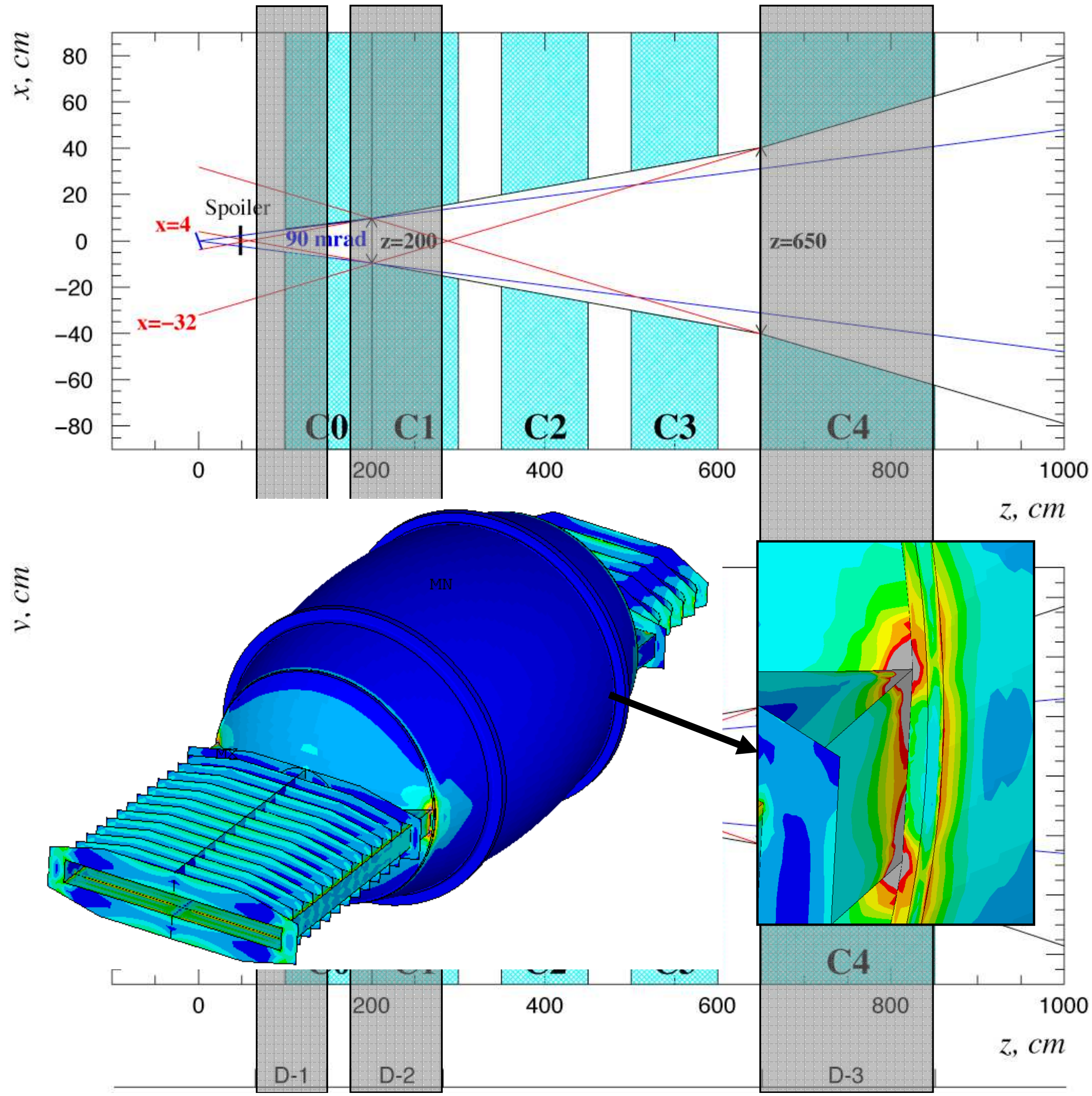
Figure 1: Construction of the vertical apertures of collimators C3 and C4

KOPIO Challenge #1: Beamline

- Complex, costly series of collimators

- 3 large sweeping magnets

- Plenty of aperture for particles created upstream to reach fiducial region
- “Difficult” vacuum vessel



L. Littenberg

Simulation of Neutron Collimation

Nominal beam

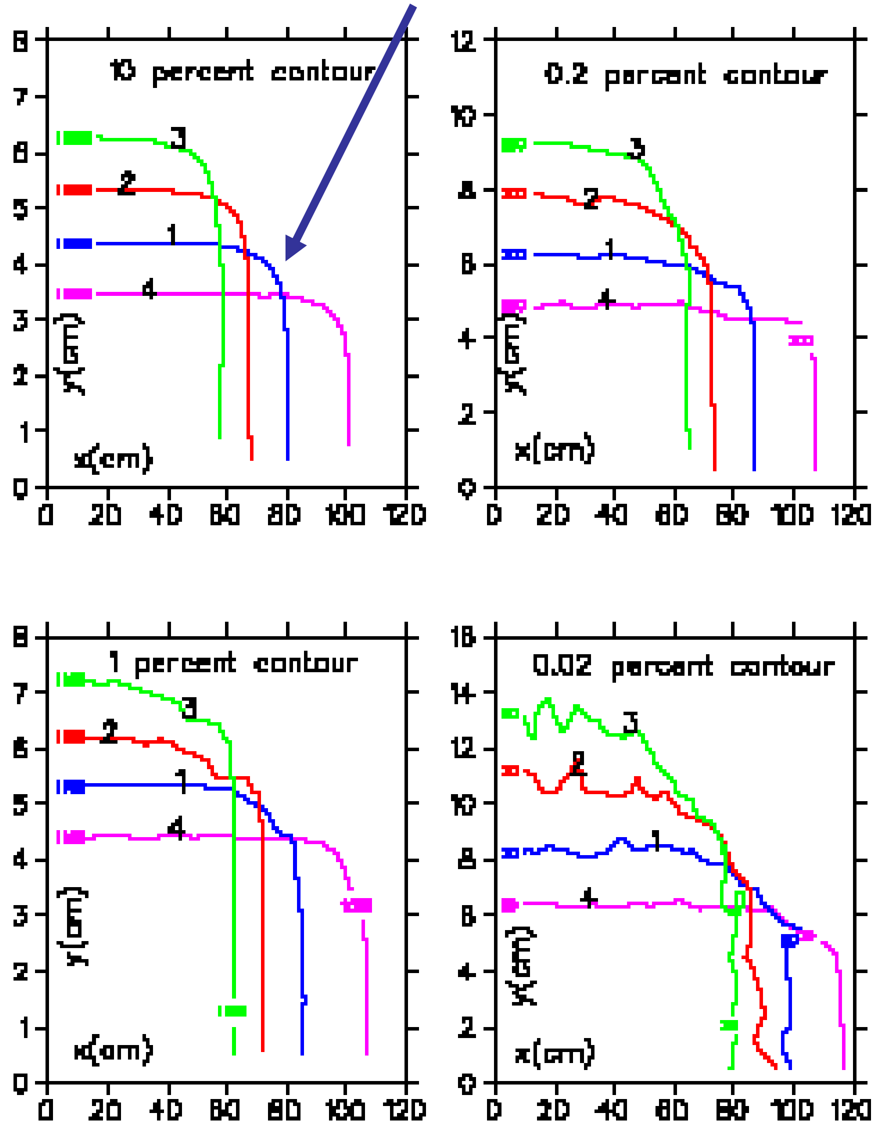
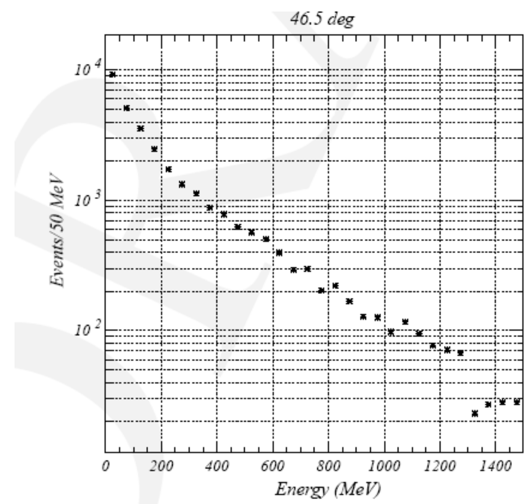
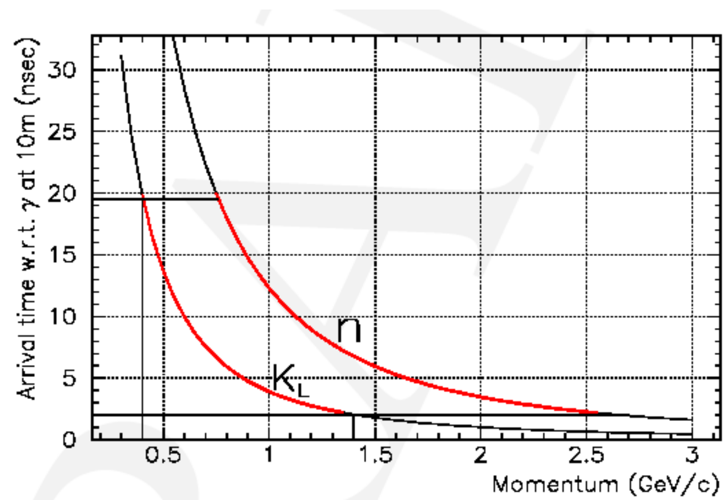


Figure 20: Contour plots at 14 m

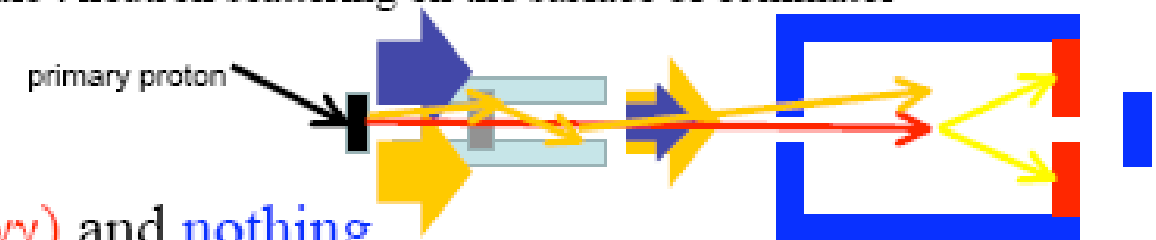
Neutron Energy Spectrum





Concept of Experiment

- K_L beam (proton → target)
  - neutral beam line
    - » Long beam line → Kill particles with shorter lifetime
    - » Charged particle sweeping magnet.
    - » Pb photon absorber → reduce beam photons
    - » Collimator → shaping KL →Pencil Beam (source of beam halo)
  - Core : K_L, photon, neutron
  - Halo : neutron scattering on the surface of collimator



- Detector
  - $\pi^0\ (\rightarrow\gamma\gamma)$ and nothing
    - Photon calorimeter and hermetic vetos.
    - Pencil Beam Method. (small beam hole and KL rec.)

Hajime Nanjo (*Kyoto*)

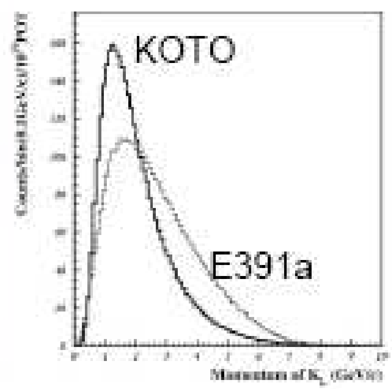
(1)High intensity beam

- Flux x RunTime x Acceptance = 3000 x E391

→ 2.8 SM events (3 order higher sensitivity than E391a)

Expected S/N~1

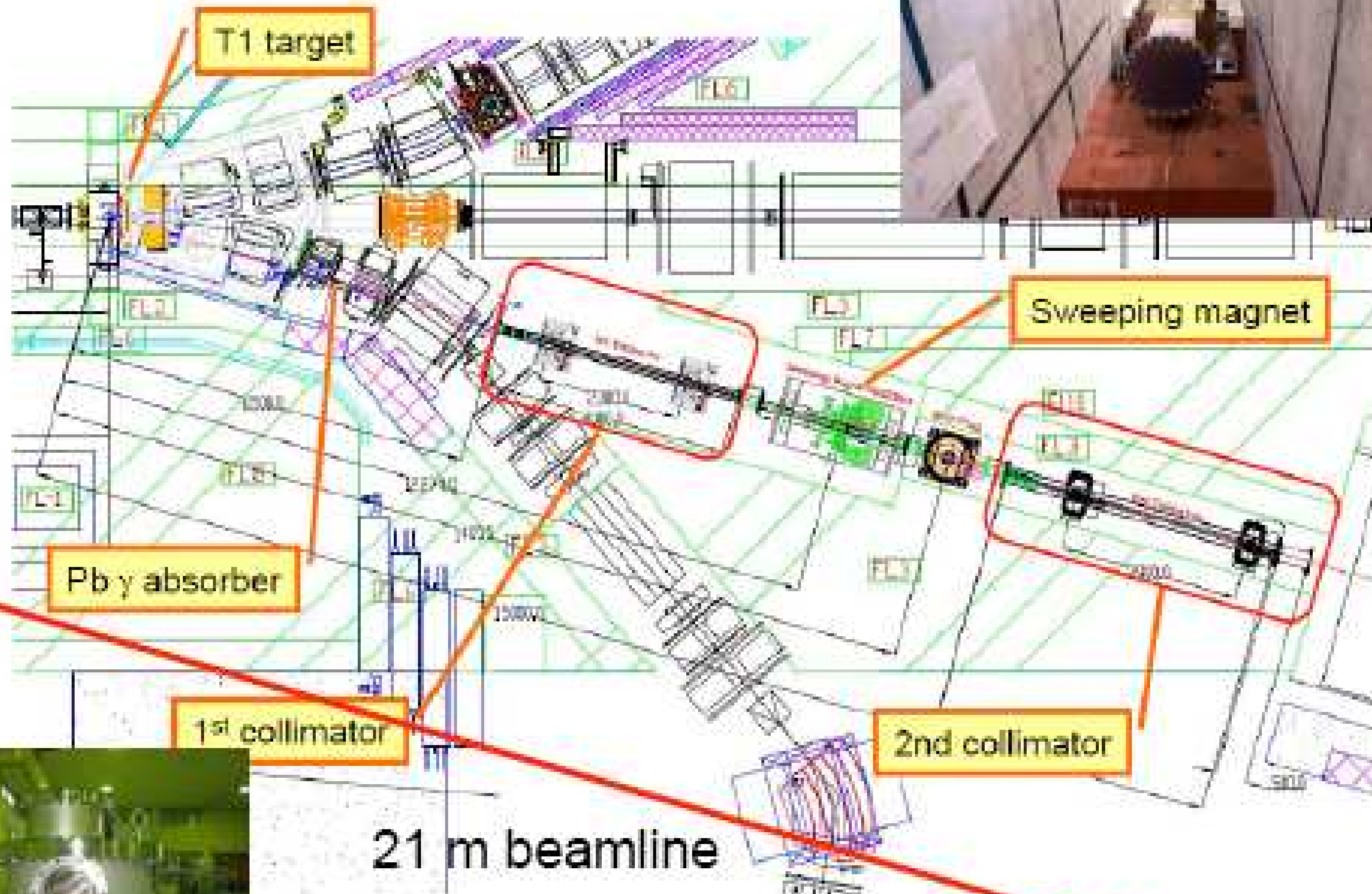
	KOTO	E391a (Run2)	
Proton energy	30 GeV	12 GeV	
Proton intensity	2e14	2.5e12	
Spill/cycle	0.7/3.3sec	2/4sec	
Extraction Angle	16 deg	4 deg	
Solid Angle	9μStr	12.6μStr	
KL yield/spill	7.8e6	3.3e5	x30 /sec
Run Time	3 Snowmass years =12 months.	1 month	x10
Decay Prob.	4%	2%	x 2
Acceptance	3.6%* *without Back splash loss	0.67%	x5



Kaon09

Hajime Nanjo (*Kyoto*) KAON09

(2)New Beamline

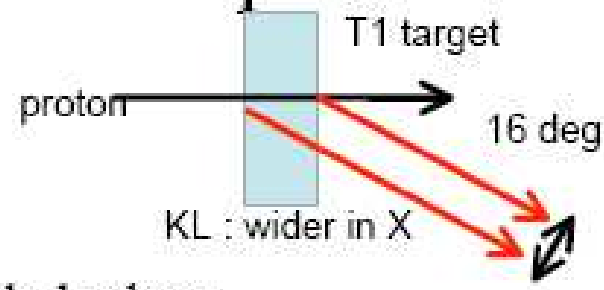


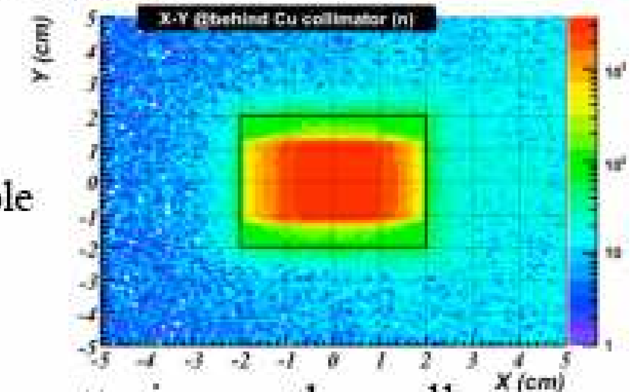
Finish the construction in this September including Shields

Hajime Nanjo (*Kyoto*)

KOTO New Beamline Concept

- 16 deg extraction
  - X-Y asymmetric target image
- Square detector beam hole
  - Fit beam shape to the detector hole shape
    - rectangular beam hole to increase KL flux
- Pencil Beam → ~9μ str
  - beam size v.s. background
    - higher inefficiency for beam hole veto detector.
- Halo neutrons suppression
  - Collimator design→ Suppress scattering on the wall
- Control neutron hit rate for detectors near beam .
  - → Accidental Loss → Collimator design

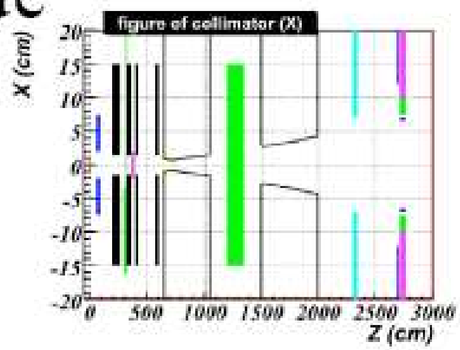




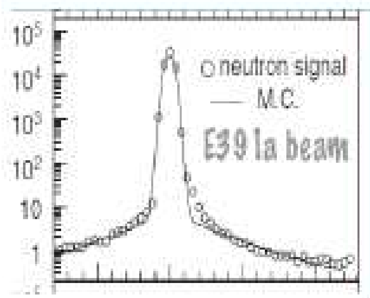
Hajime Nanjo (*Kyoto*)

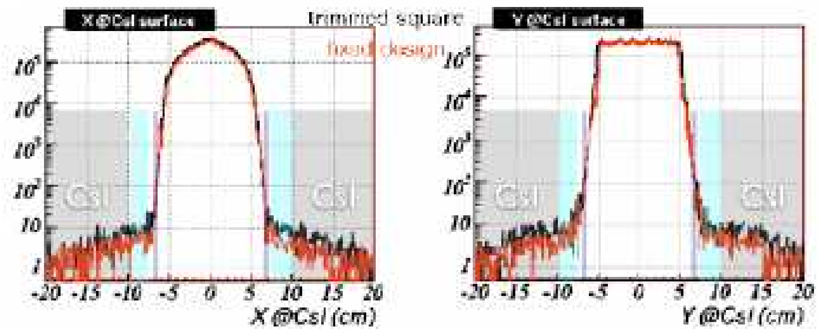
Design Value

	KOTO	E391a	
Halo neutron/spill (P>0.78GeV/c)	$1.1x10^4$	$1.1x10^5$	
KL/spill	$7.8x10^6$	$3.3x10^5$	
Halo neutron/KL	$1.4x10^{-3}$	$3.3x10^{-1}$	1/240



– halo-n/KL : 1/240 of E391a





Hajime Nanjo (*Kyoto*)

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

Project X ICD-2: Time structure ideal for TOF-based experiment.

	Beam Energy	Target (λ_I)	$p(K^+)$ (MeV/c)	K_L Yield (into 500 μsr)	K_L/n Ratio (E_n>10 MeV)
BNL AGS	24 GeV	1.1 Platinum	300-1200	30×10^{-7} K_L/p	~1:1000
ICD-2	2.6 GeV	1.0 Carbon	300-1200	1×10^{-7} K_L/p	~1:4000

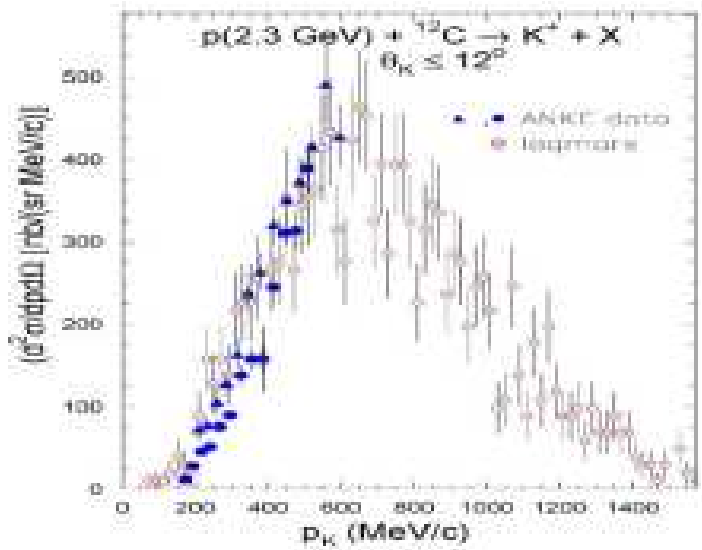
ICD-2 Task Force Report

- High intensity allows small beam dimensions (like KOTO):
  "Difficult" vacuum vessel disappears
- Geometric acceptance maximized; symmetry restored
- 2-D beam kinematic constraint increases S/B
- Upstream backgrounds, backgrounds in the fiducial volume reduced
- Same micro-bunch event spoilage reduced
- Random vetoes reduced due to high duty factor
- Beam veto may be unnecessary

(See 2008 Project X workshop talks by L. Littenberg, S. Kettell)

Kaon Spectra

50 ps pulses ICD2



KOPIO 200 ps pulses

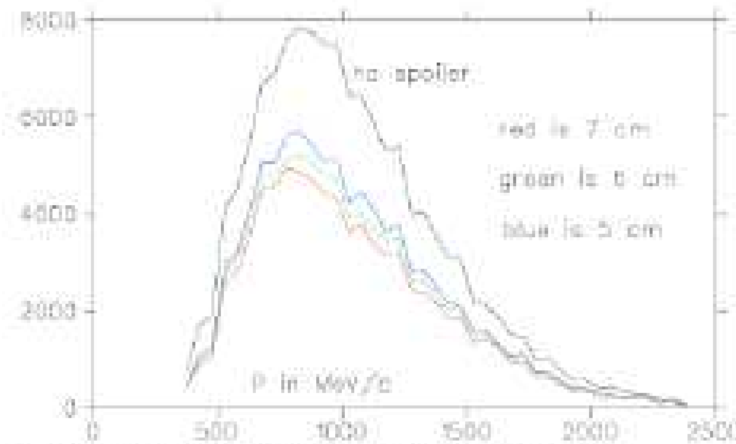


Fig. 5.8: K_L^0 momentum distribution at the entrance to the decay tank.

At production

At experiment

With 10-50 ps pulses, TOF measurements could be more effective if detector technology can keep up.

Possible Beam Improvements for $K_L^0 \to \pi^0 \nu \bar{\nu}$ at Project X ICD-2

With K flux 10x AGS:

- Use the pencil beam approach but make it shorter than KOTO’s beam: likely feasible
- Use TOF measurements and pointing calorimeter to pummel backgrounds
- ~200 events/yr “plausible” if acceptance of O(10)x KOPIO can be achieved