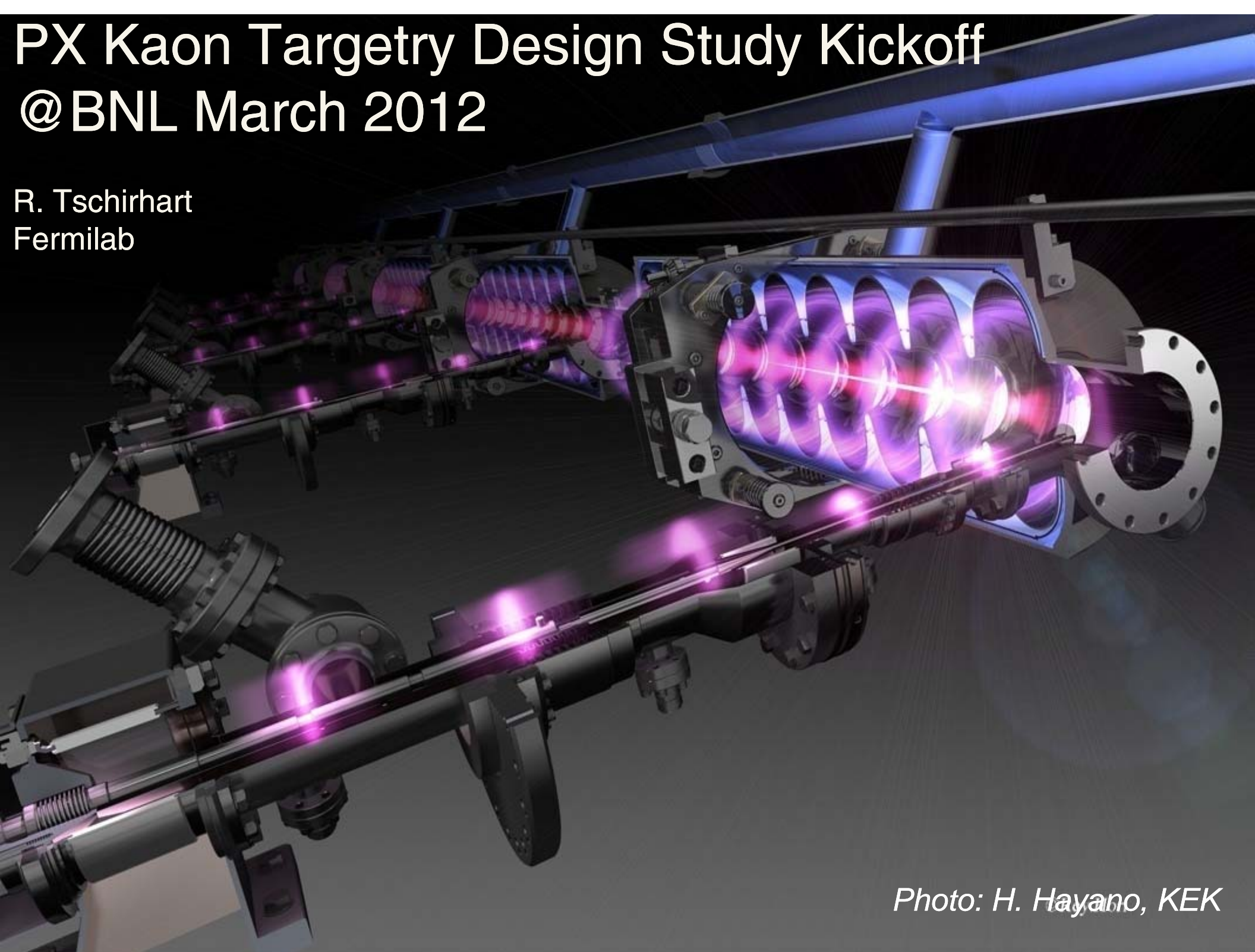


# PX Kaon Targetry Design Study Kickoff @BNL March 2012

R. Tschirhart  
Fermilab



*Photo: H. Hayano, KEK*

# The Project-X Research Program

- ***Neutrino oscillation experiments***
  - A high-power proton source with proton energies between 8 and 120 GeV would produce intense neutrino beams directed toward near detectors on the Fermilab site and massive detectors at distant underground laboratories.
- ***Kaon, muon, nuclei & neutron precision experiments***
  - These could include world leading experiments searching for muon-to-electron conversion, nuclear and neutron electron dipole moments (edms), precision measurement of neutron properties and world-leading precision measurements of ultra-rare kaon decays.
- ***Platform for evolution to a Neutrino Factory and Muon Collider***
  - Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.
- ***Nuclear Energy Applications***
  - Accelerator, spallation, target and transmutation technology demonstration which could investigate and develop accelerator technologies important to the design of future nuclear waste transmutation systems and future thorium fuel-cycle power systems.

Detailed Discussion: [Project X website](#)



# Project-X Accelerator Functional Requirements

## CW Linac

Particle Type	H <sup>-</sup>
Beam Kinetic Energy	3.0 GeV
Average Beam Current	1 mA
Linac pulse rate	CW
Beam Power	3000 kW
Beam Power to 3 GeV program	2870 kW

## RCS/Pulsed Linac

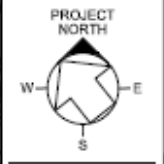
Particle Type	protons/H <sup>-</sup>
Beam Kinetic Energy	8.0 GeV
Pulse rate	10 Hz
Pulse Width	0.002/4.3 msec
Cycles to MI	6
Particles per cycle to Recycler	$2.6 \times 10^{13}$
Beam Power to 8 GeV program	190 kW

## Main Injector/Recycler

Beam Kinetic Energy (maximum)	120 GeV
Cycle time	1.3 sec
Particles per cycle	$1.6 \times 10^{14}$
Beam Power at 120 GeV	2200 kW

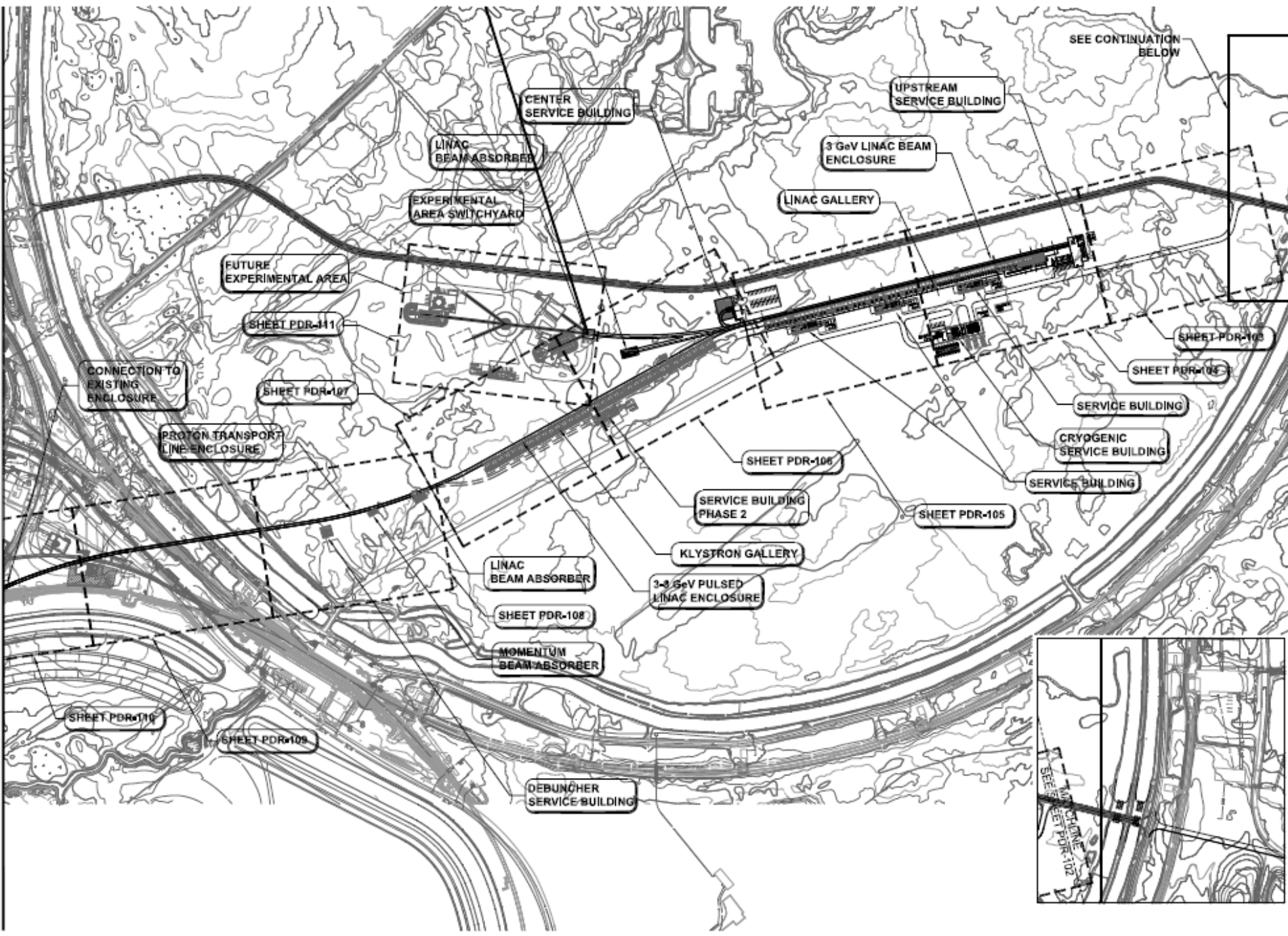
simultaneous





**PROJECT X**  
**CONVENTIONAL FACILITIES**  
PROJECT SITE & UTILITIES  
PROJECT OVERVIEW SITE PLAN

PDR  
**Fermilab**  
U.S. DEPARTMENT OF  
**ENERGY**  
DATE: **JUNE 2010**  
PROJECT NO.: **4-2-1**  
DRAWING NO.: **PDR-101**









# Footprint of charged and neutral detectors motivated by BNL-E949, KOPIO and JPARC



Project-X kaon physics white paper

# Project-X High-Intensity Campus

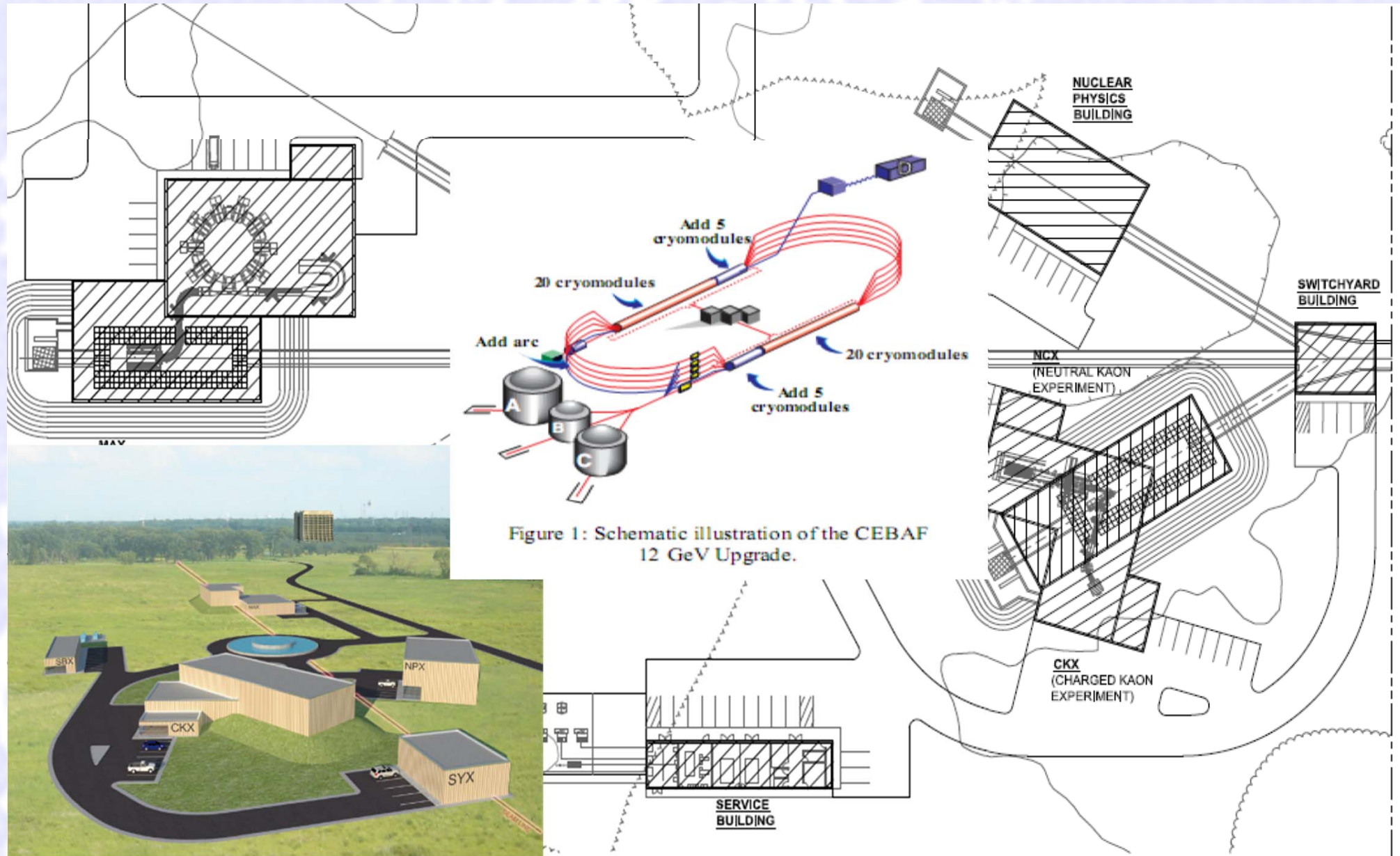
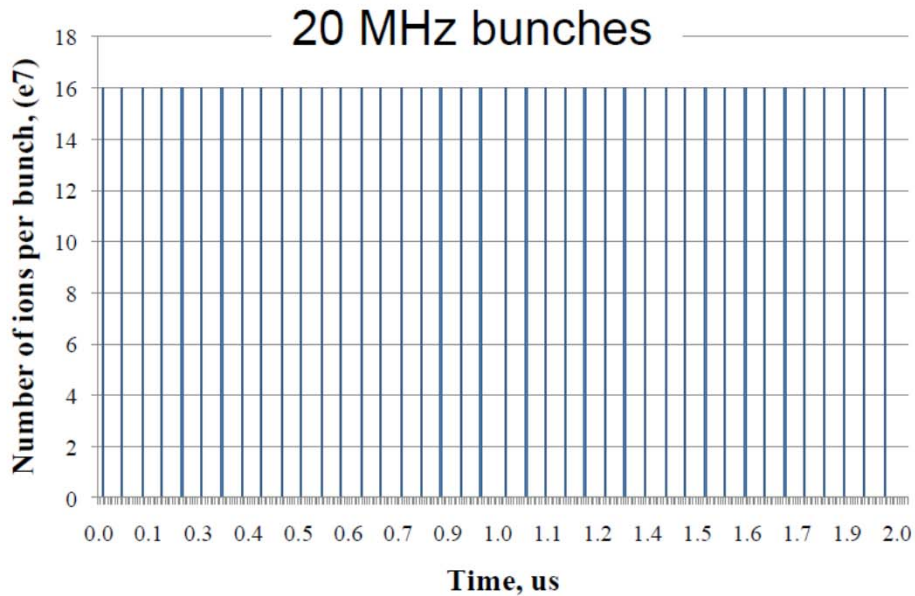
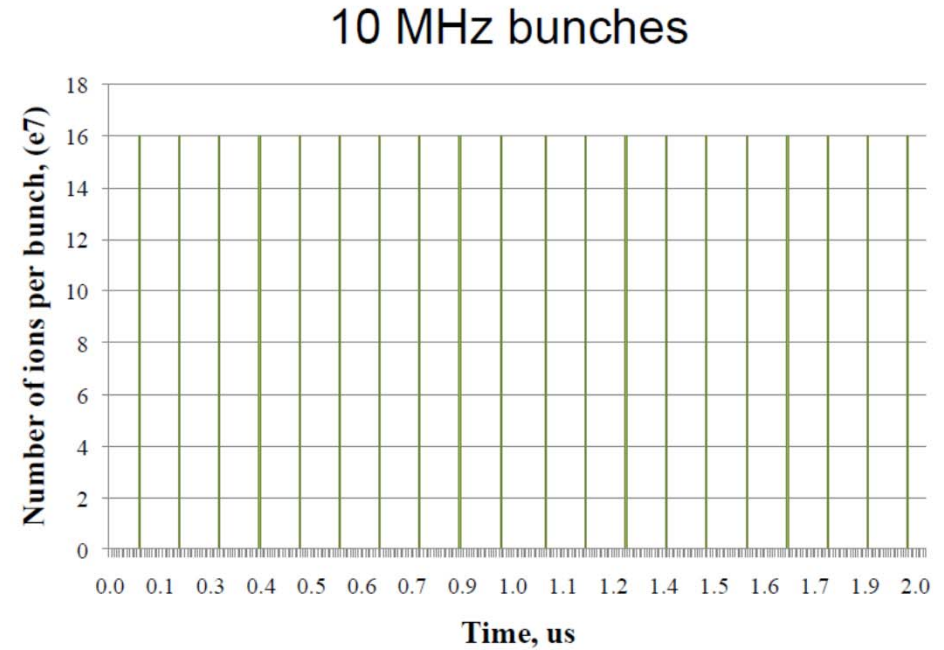
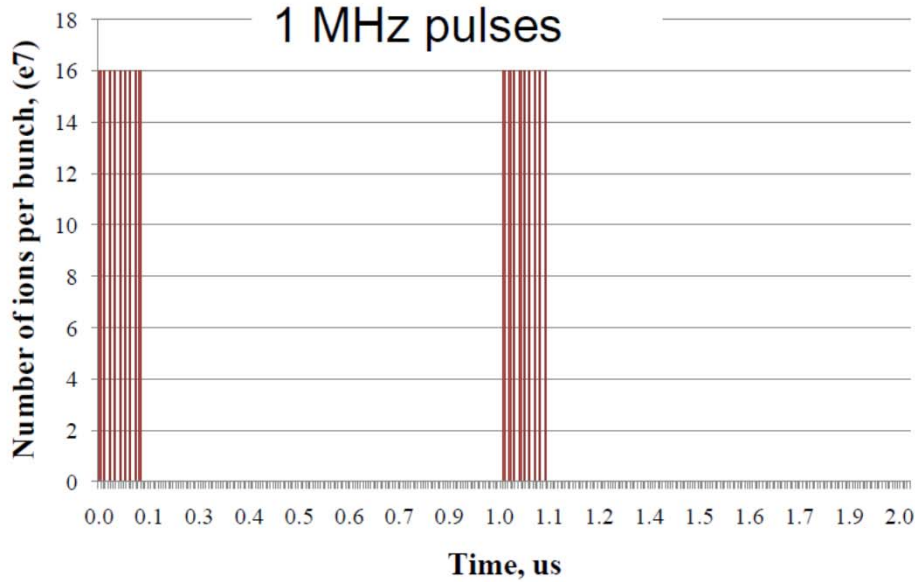


Figure 1: Schematic illustration of the CEBAF 12 GeV Upgrade.





# Beam after splitter



Courtesy of Nagaitsev



# Chopping and splitting for 3-GeV experiments

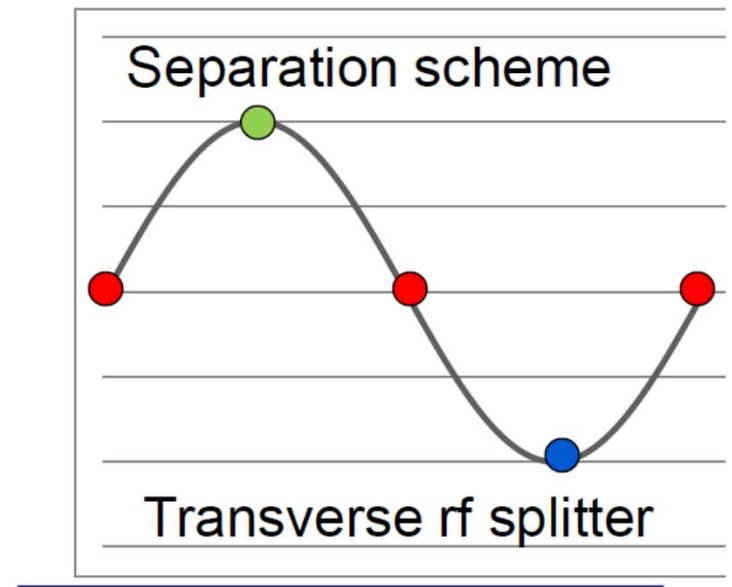
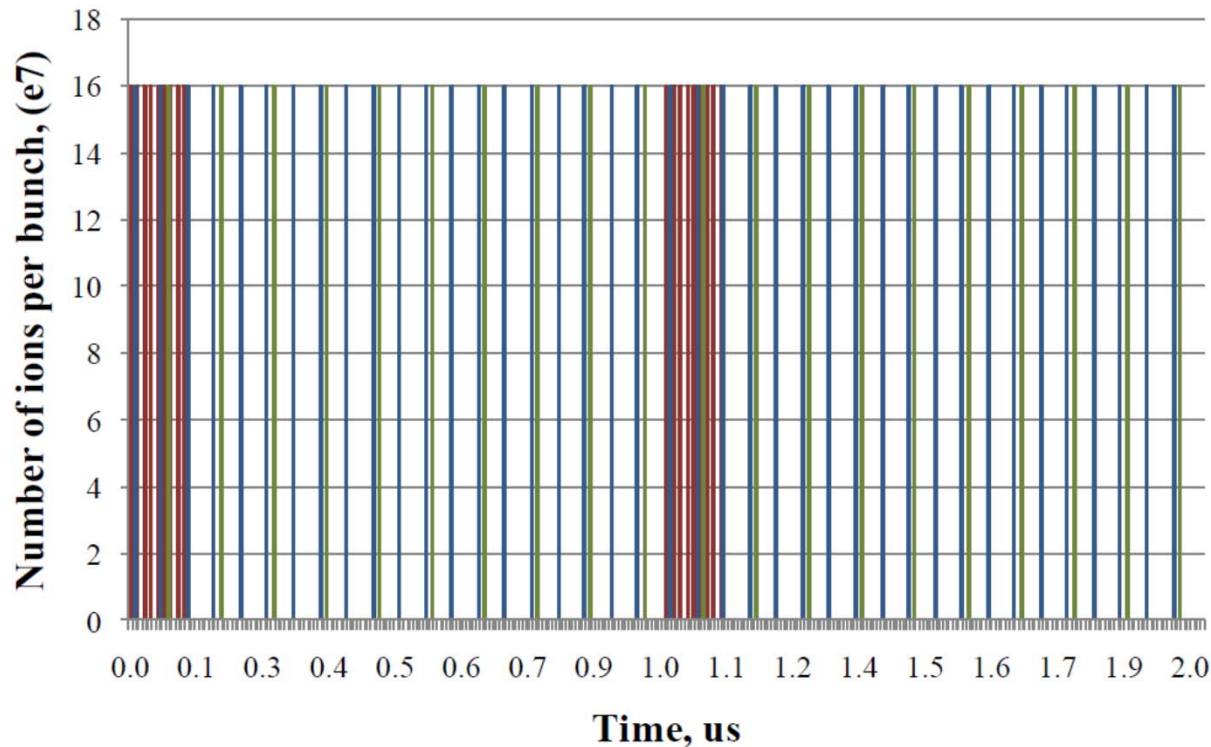


1  $\mu$ sec period at 3 GeV

Muon pulses (16e7)	81.25 MHz, 100 nsec at 1 MHz	700 kW
Kaon pulses (16e7)	20.3 MHz	1540 kW
Nuclear pulses (16e7)	10.15 MHz	770 kW

Ion source and RFQ operate at 4.2 mA

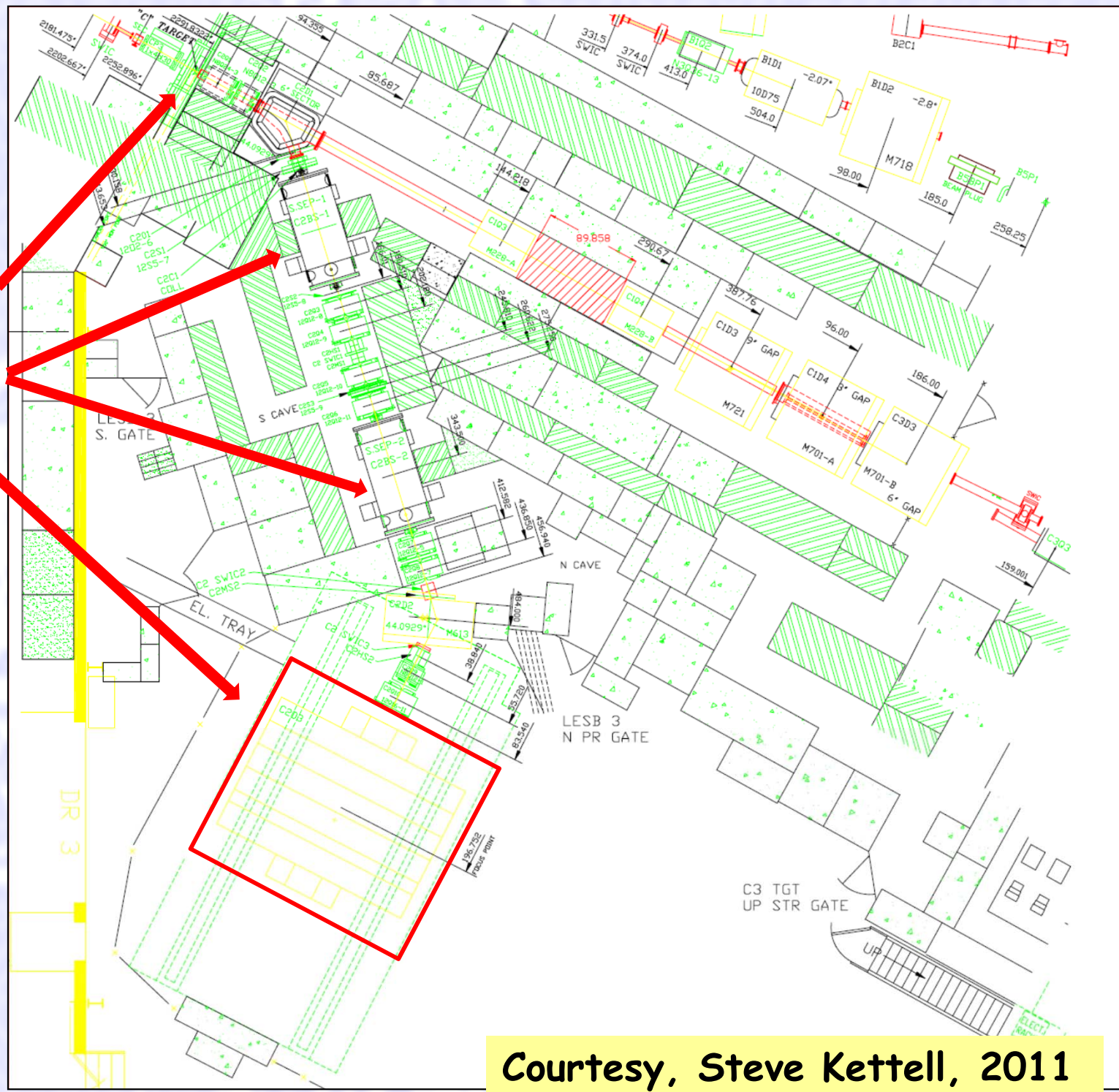
75% of bunches are chopped at 2.5 MeV after RFQ



Courtesy of Nagaitsev

# Siting of the E949 experiment at the BNL AGS operated at 50 kW

Target  
ExB separators  
Detector



Courtesy, Steve Kettell, 2011





AGS Extraction

KOPIO Experiment

B-Target

Collimation and Sweeping

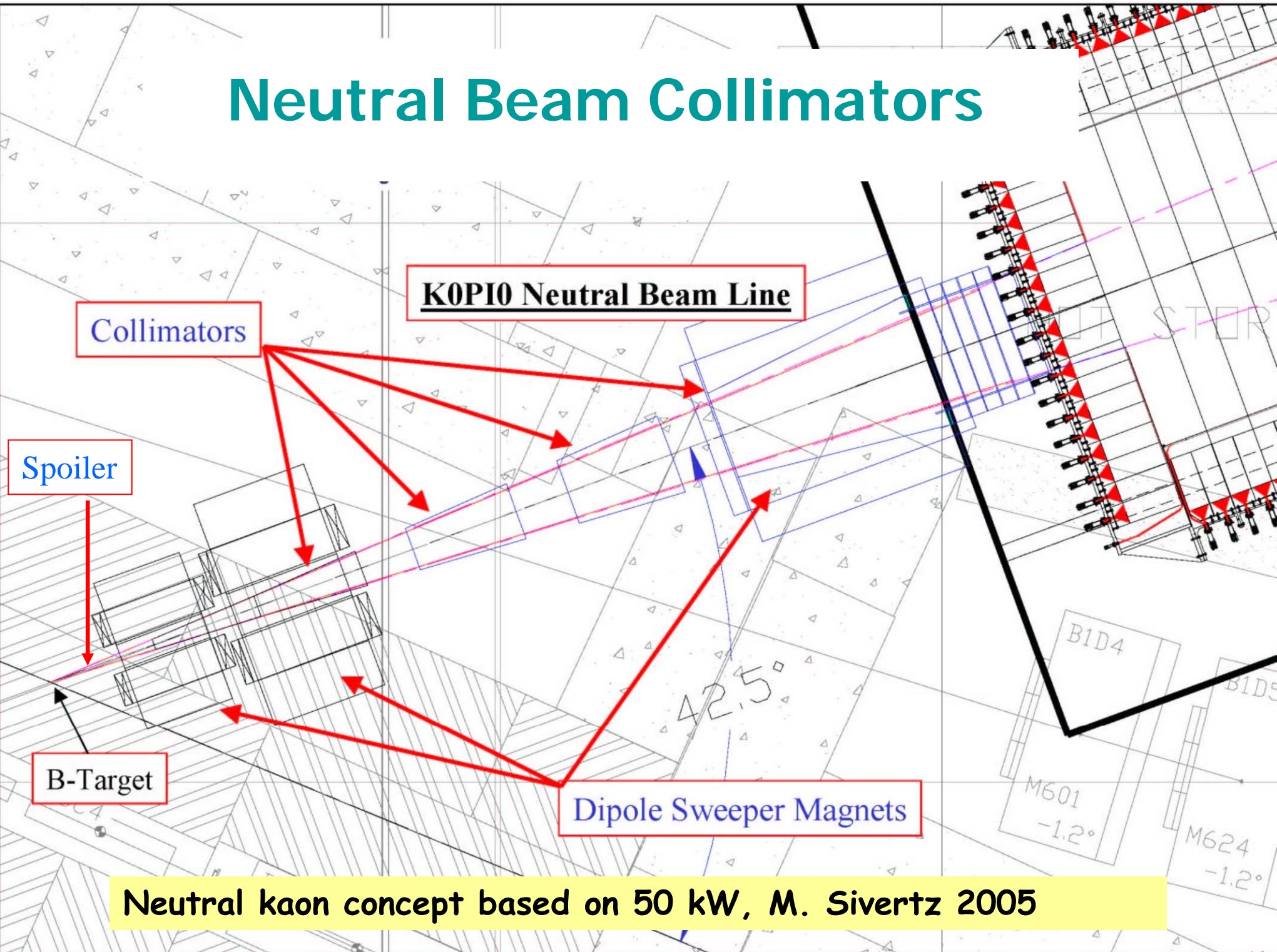
Neutral kaon concept based on 50 kW, M. Sivertz 2005







# Neutral Beam Collimators



Neutral kaon concept based on 50 kW, M. Sivertz 2005

# Status of Project X Targetry & Beam-line Studies

- Neutrinos: Synergy with LBNE effort.
- Muons: Studies underway on 1 MW carbon targets, Mu2e & (g-2) development, engaging Muons Inc.
- Kaons: Initiating now, ORKA development.
- Spallation targets for particle physics. Initiating a study of ISOL and UCN yields and pre-conceptual designs starting March 2012.



# Goals for Discussion Today

- Plan to identify and electronically capture the engineering drawings and knowledge base for the realized BNL E949 charged kaon target and separated kaon beamline.
- Plan to identify and electronically capture the engineering drawings and knowledge base for the proposed but not realized KOPIO neutral kaon target and beamline systems.
- Plan to estimate energy deposit profile and yields for 3 GeV proton beam on the targets listed in Appendix 1. (Mokhov group)
- Plan to develop a mechanical and power management concepts for the target materials and geometries considered in Appendix 1. Separate design concepts for charged and neutral targets.

High power targetry expertise (McDonald, Kirk, Pendzick, Pearson, Pile) will provide some course correction and feedback to Anatoli and the Project X team.

# Appendix A

## MARS effort for the following target simulations:

- What we want:
- 99% interaction fraction of 1000 kW on a 1mmx1mmx1mm source for perfect optics.

Back to reality....What is possible, What we will we study??

- 10 cm of carbon, 5mm x 5mm, shooting center with 1mm beam sigma.
- 20 cm of carbon, 5mm x 5mm, shooting center with 1 mm beam sigma.
- 10 cm of Ga, 10 cm (waterfall) wide 5 mm thick, shoot through center, 1 mm sigma.
- 10 cm of Hg, 10 cm (waterfall) wide 5 mm thick, shoot through center, 1 mm sigma.
- 10 cm of Ni, 10 cm wide (spinning disk) 5mm thick, shoot center, 1 mm sigma.
- .....

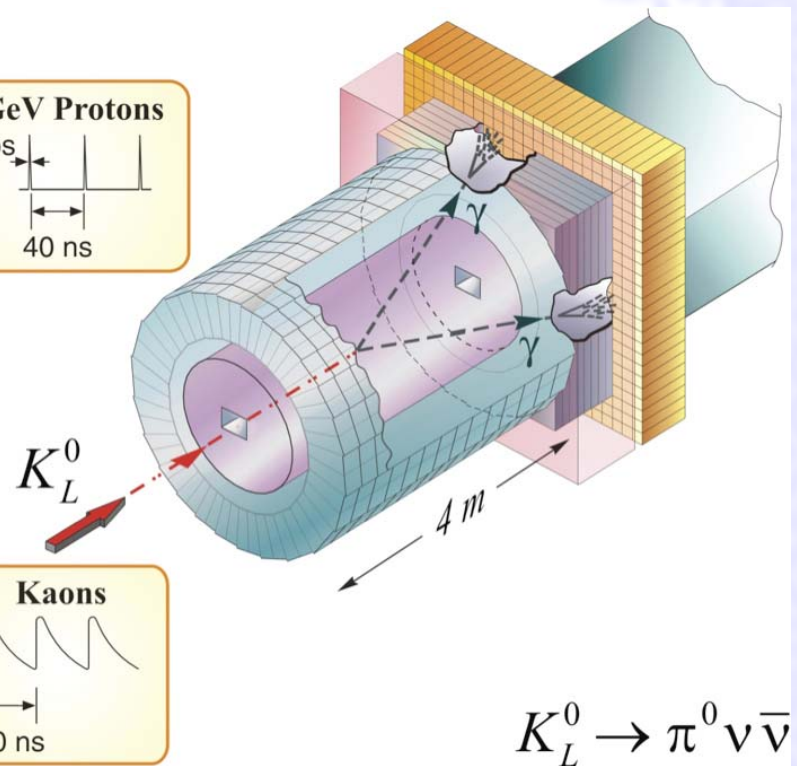
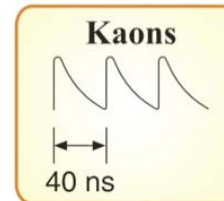
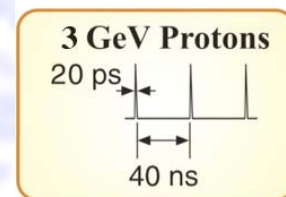
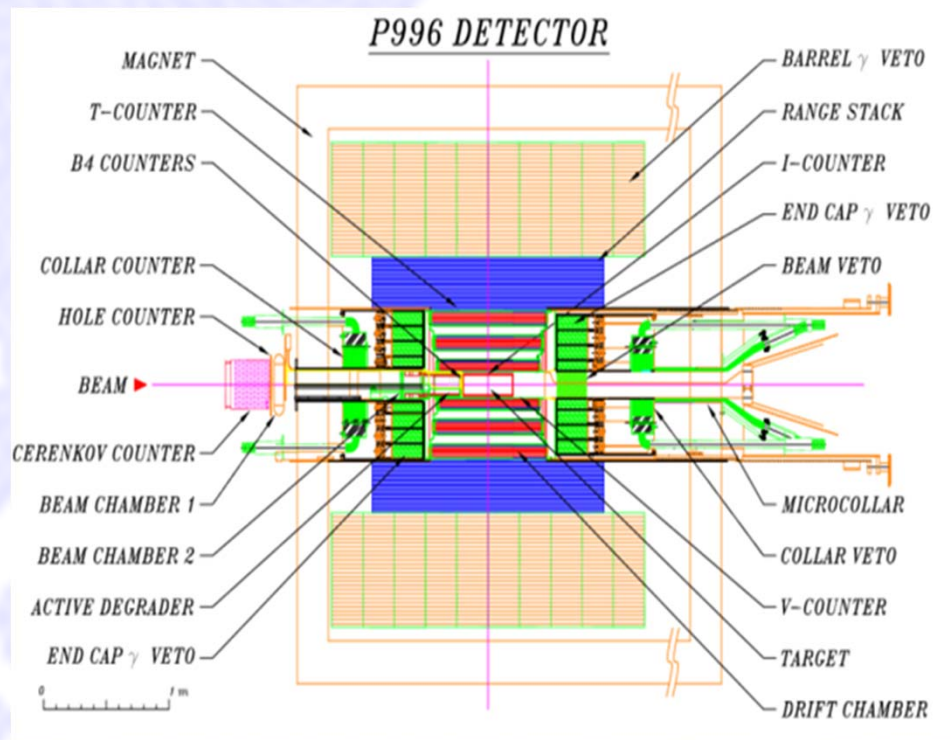


# Spare Slides

# Project X Day-1 program goals: Definitive Measurement of $K \rightarrow \pi \nu \bar{\nu}$

In the Project-X era the Fermilab ORKA experiment would precisely measure the rate and form-factor of  $K^+ \rightarrow \pi \nu \bar{\nu}$ .

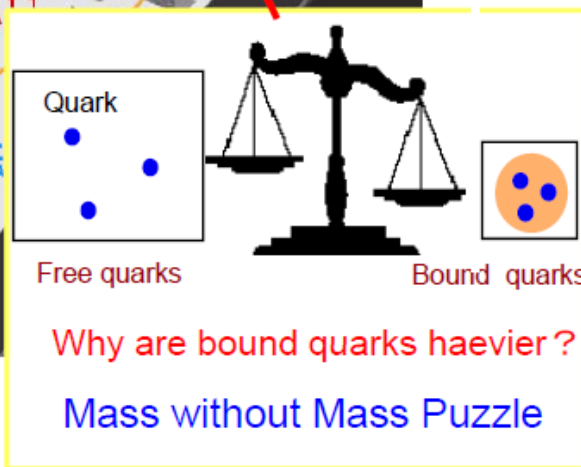
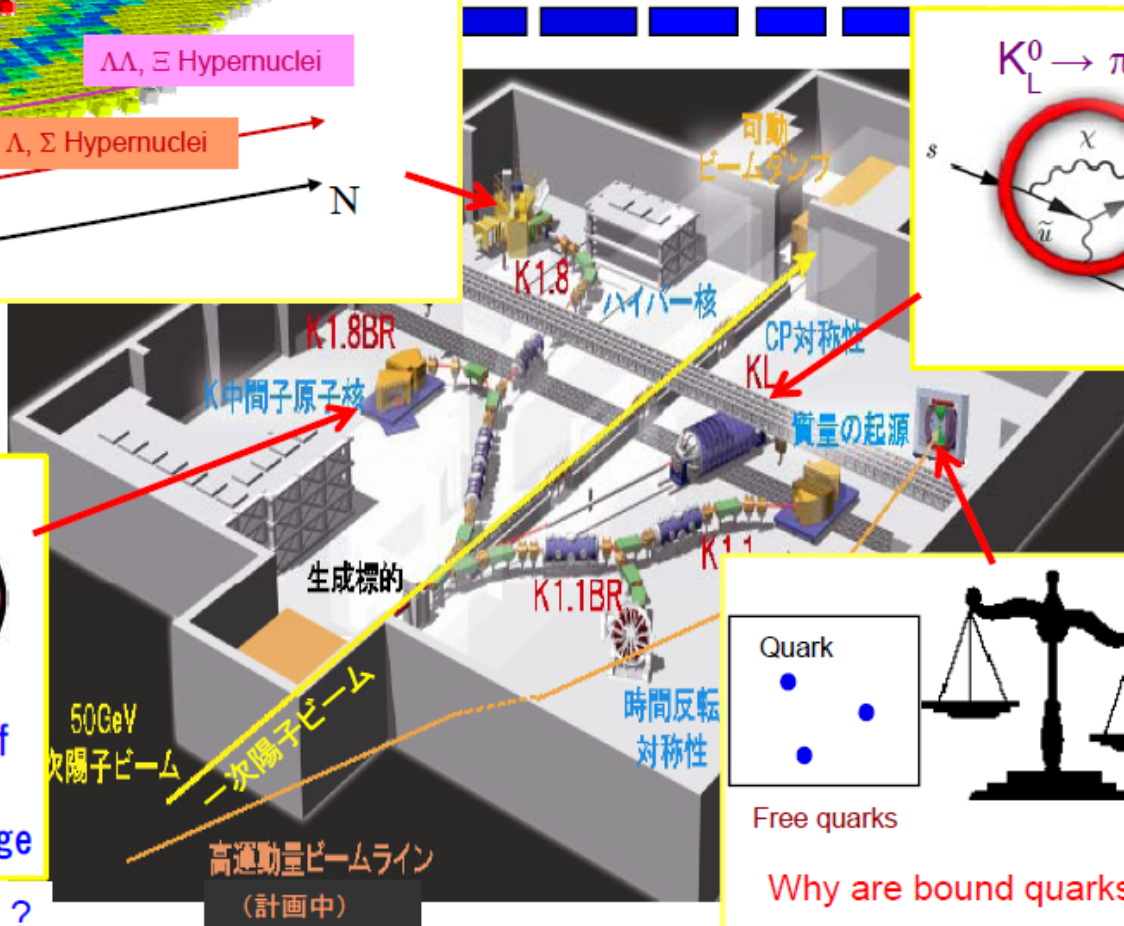
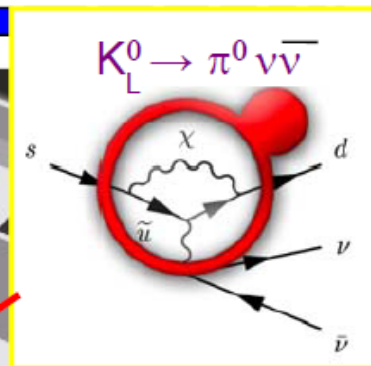
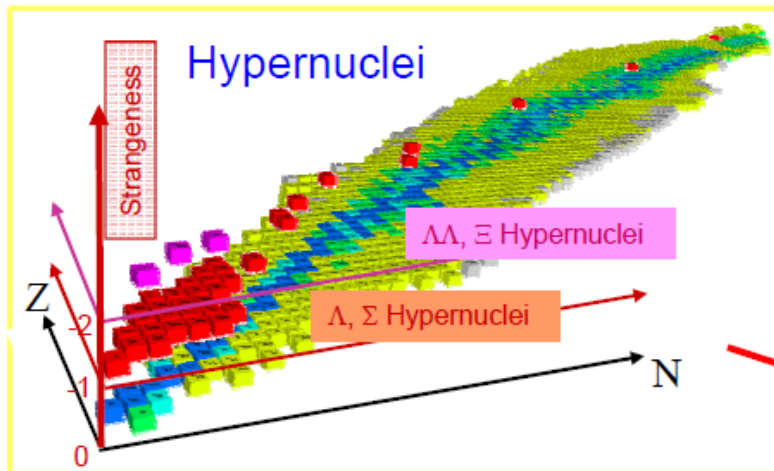
The Project-X era presents an opportunity to measure the holy grail of kaon physics with precision:  $K_L \rightarrow \pi \nu \bar{\nu}$ .





# Outside the US: The JPARC Play Book

## Hadron Hall Experimental Programs



Courtesy Nagamiya-san

# An Incomplete Menu of World Class Research Targets Enabled by Project-X

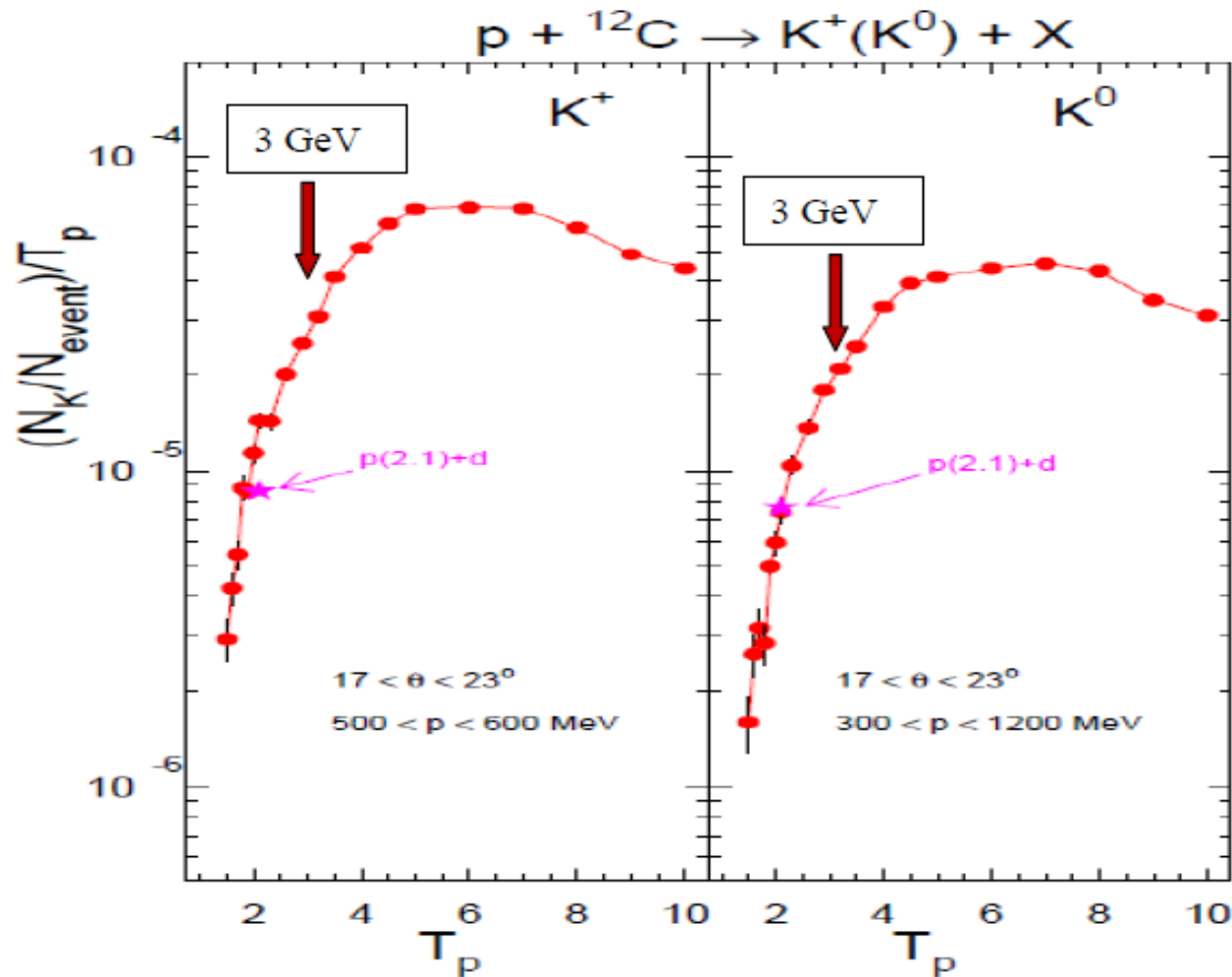
## Kaon Physics:

Possible Day-1 Experiments

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ : >1000 events, Precision rate and form factor.
- $K_L \rightarrow \pi^0 \nu \bar{\nu}$ : 1000 events, enabled by high flux & precision TOF.
- $K^+ \rightarrow \pi^0 \mu^+ \nu$ : Measurement of T-violating muon polarization.
- $K^+ \rightarrow (\pi, \mu)^+ \nu_\chi$ : Search for anomalous heavy neutrinos.
- $K^0 \rightarrow \pi^0 e^+ e^-$ : <10% measurement of CP violating amplitude.
- $K^0 \rightarrow \pi^0 \mu^+ \mu^-$ : <10% measurement of CP violating amplitude.
- $K^0 \rightarrow X$ : Precision study of a pure  $K^0$  interferometer:  
Reaching out to the Plank scale ( $\Delta m_K / m_K \sim 1/m_P$ )
- $K^0, K^+ \rightarrow L F V$ : Next generation Lepton Flavor Violation experiments  
...and more

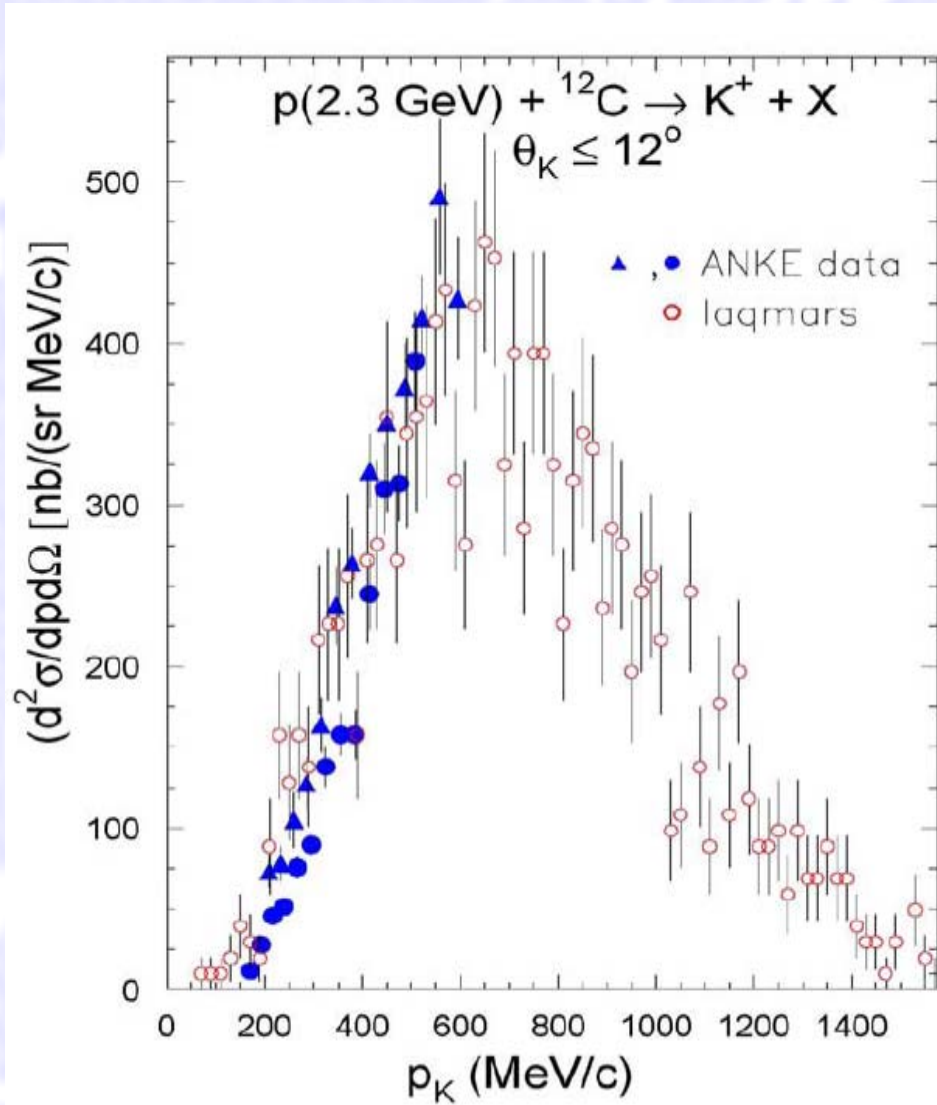


# Project-X Kaon Yields at Constant Beam Power



**Figure 2:** The estimated (LAQGSM/MARS15) kaon yield at constant beam power (yield/ $T_p$ ) for experimentally optimal angular and energy regions as a function of  $T_p$  (GeV).

# Validating Simulation Tools...



- Los Alamos + MARS simulation suite (LAQGSM + MARS15) is now a state of the art tool set to simulate the challenging region between 1-4 GeV/c proton beam momentum.

[Gudima, Mokhov, Striganov]

- Validated against the high quality data sets from COSY.

- Data shown: Buscher et al (2004) ANKE experiment at COSY, absolutely normalized.



# BOE Guess for Kaon Research Program (circa January 2011)

	<b>FY2010 costs (TPC metric)</b>	<b>Basis of Estimate</b>
Civil and conventional facilities including secondary proton beam enclosure:	\$25M	Conceptual facility layout (Figures 1-4) from the Project-X kaon research program white paper and assuming \$1500/ft <sup>2</sup> fully burdened facility square-foot costs from NOvA (CD-2) & Mu2e (CD-1).
Beam-line from the Project-X switch-yard and kaon target (1500 kW) systems, infrastructure and dump:	\$45M	Short secondary proton beam-line (150 ft) conceptual design exists, base cost estimate of \$2M with 60% contingency. Pre-conceptual design for target systems and dump is based on JPARC. Target systems cost is based on beam power scaling (x2.2) of the NOvA-ANU 700 kW target systems (CD-2 reviewed) base cost estimate with 100% contingency added.
Charged kaon experiment:	\$60M	BNL-E949 experience used to develop the conceptual design (60% mean contingency).
Neutral kaon experiment:	\$80M	KOPIO(RSVP), NSF cost review (CD-2 equivalent) estimate with 40% contingency. Modifications and upgrades to the BNL AGS accelerator systems are removed.
<b>Total:</b>	<b>\$210M</b>	

# Guess of total effort and effort categories need to develop a 1500kW Target System CDR appropriate for DOE CD-1

Sum of effort from CD0-CD1, assume a 3 year duration of effort:

- 1.00 FTE Accelerator Physicist Experimental
- 1.00 FTE Accelerator Physicist Theory
- 1.00 FTE Applications Development & Systems Analyst FN.X.IT.IT.AD
- 0.25 FTE Chemist
- 0.50 FTE Computational Physics Developer
- 0.25 FTE Computer Customer Support
- 0.25 FTE Computing Services Specialist
- 0.50 FTE Control System Engineer
- 2.00 FTE Design
- 1.00 FTE Electrical Design Engineer
- 1.00 FTE Electrical Designer
- 0.50 FTE Electrical Drafter
- 1.00 FTE Electrical Engineer
- 0.50 FTE Electronics Design Engineer
- 1.00 FTE Engineering Physicist
- 0.15 FTE General Administrative
- 0.50 FTE Magnet Design Engineer
- 0.50 FTE Magnet Designer
- 0.50 FTE Magnet Scientist
- 1.00 FTE Mechanical Design Engineer
- 1.00 FTE Mechanical Designer
- 1.00 FTE Mechanical Drafter
- 1.00 FTE Mechanical Engineer
- 0.50 FTE Particle Physicist Experimental
- 1.00 FTE Radiation Protection
- 0.15 FTE RF Design Engineer
- 0.15 FTE RF Scientist
- 2.00 FTE Un-costed Scientists
- 0.15 FTE Web Applications Developer

Total of 21.5 FTEs for 3 years, about 7 FTEs/year.

Sanity check is a recollection of the SNS target CDR effort (~6 FTE sustained for 2-3 years, not counting simulation and software) made by Tom McManamy (Senior ME, worked on SNS since 1996), private communication.



# K<sup>+</sup> Beamline: Focus a low energy separated charged beam on a stopping target. Measure kaon decays at rest!



ELSEVIER

Nuclear Instruments and Methods in Physics Research A 444 (2000) 546–556

NUCLEAR  
INSTRUMENTS  
& METHODS  
IN PHYSICS  
RESEARCH  
Section A

[www.elsevier.nl/locate/nima](http://www.elsevier.nl/locate/nima)

## Optics design and performance of LESB3, a two-stage separated 800-MeV/c kaon beamline

J. Doornbos<sup>a,\*</sup>, P. Pile<sup>b</sup>, F. Meot<sup>c</sup>, M. Aoki<sup>a,1</sup>, E.W. Blackmore<sup>a</sup>, I-H. Chang<sup>b</sup>,  
C.J. Kost<sup>a</sup>, K.K. Li<sup>b</sup>, J.A. Macdonald<sup>a</sup>, T. Nakano<sup>a,2</sup>

<sup>a</sup>TRIUMF, Vancouver, B.C., V6T 2A3, Canada

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Received 29 September 1999; accepted 22 October 1999

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### Abstract

The optics design and the measured performance are described for LESB3, the 800-MeV/c kaon beamline at the Brookhaven AGS used by E787 to search for rare K<sup>+</sup> decays. The beamline provides a flux of  $\sim 5 \times 10^5 \text{K}^+ / 10^{12}$  protons on target, with a K/ $\pi$  ratio of  $> 3$ . © 2000 Elsevier Science B.V. All rights reserved.

*Keywords:* Brookhaven AGS; Secondary beam; Kaon beam; Separated beam; Wien filter; Beam optics

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# Neutral Beam Collimators

GEANT-based MC optimize the design of the KOPIO collimator.

Each stage of collimation points to a different vertex.

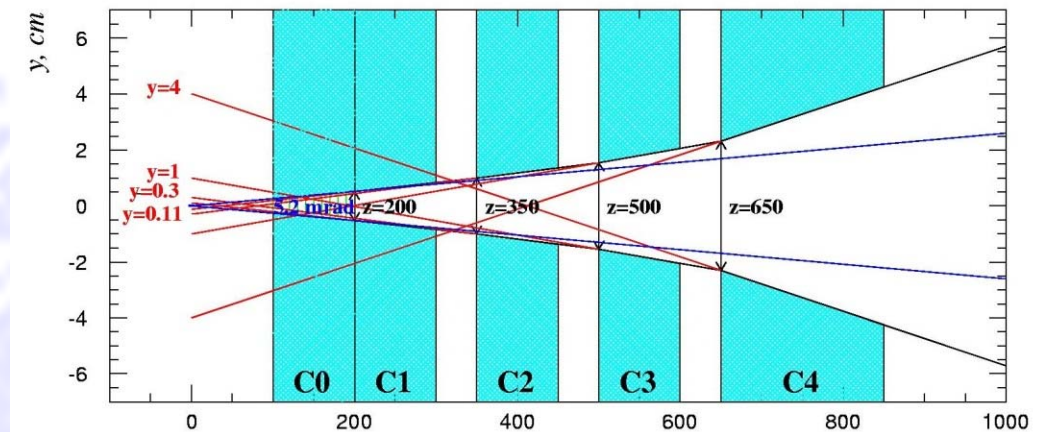
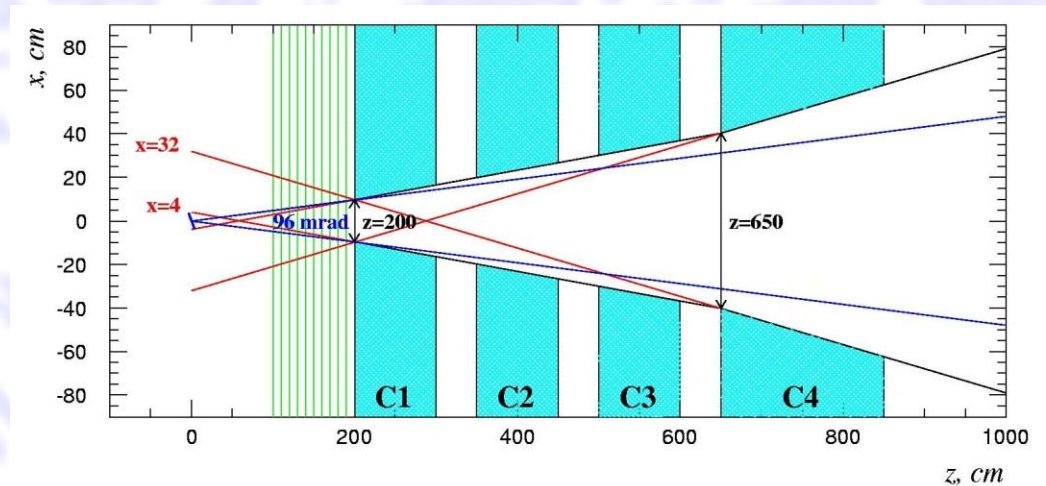
This reduces contributions to the halo due to neutrons with multiple "bounces" in the collimators. choice of material and geometry.

**Pb** collimators and **Stainless Steel** beam pipe.

**W** liners of thickness from 1mm to 10mm.

Collimators interleaved with **borated concrete** to reduce neutrons.

Horizontal

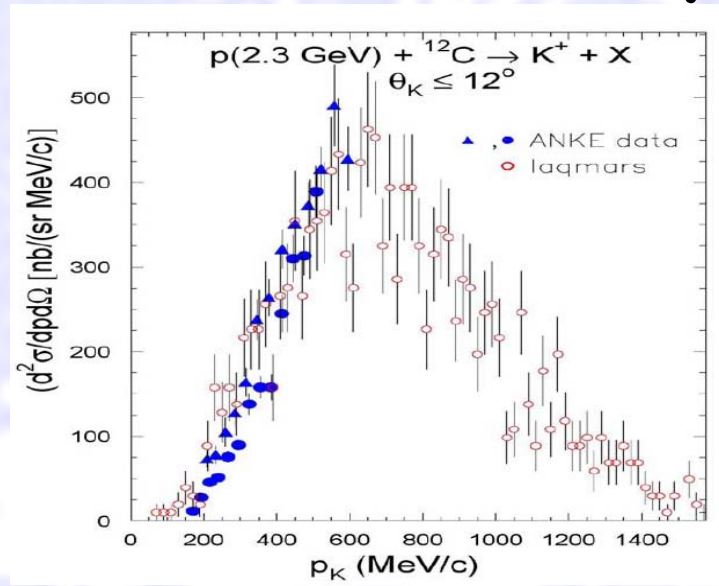


Vertical

M. Sivertz 2005



# BNL E949 and Project-X kaon momentum spectra and sensitivity comparisons

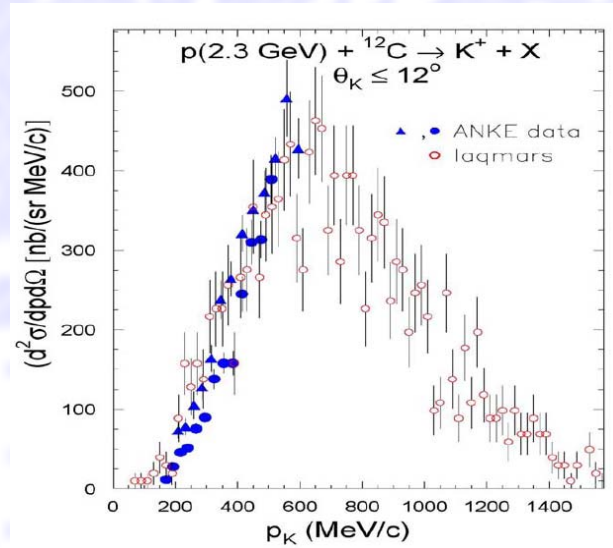


x140 average rate of stopping kaons with respect to BNL E949, x11 the average stopping rate of ORKA.

	Beam Energy $T_p$	Protons/second (avg) on [target ( $\lambda_I$ )]	$p(K^+)$ (MeV/c)	Stopping $K^+$ /second	$K^+/\pi^+$ Production Ratio
BNL AGS (E949)	21 GeV	$12 \times 10^{12}$ on $[0.7 \lambda_I \text{ Pt.}]$	700-730	$0.7 \times 10^6 \text{ K}^+/\text{sec}$	1:24
Project-X/ $K^+$ expt	3.0 GeV	$1/2 \times 6000 \times 10^{12}$ on $[1.0 \lambda_I \text{ C}]$	450-570	$98 \times 10^6 \text{ K}^+/\text{sec}$	1:80

**Table 1:** Compares the measured rate of stopping  $K^+$  in the BNL-E949 experiment with full LAQGSM/MARS thick-target simulations for Project-X charged kaon yield with  $1/2$  of the 1 ma 3.0 GeV proton beam.

# KOPIO-AGS and Project-X kaon momentum spectra and sensitivity comparison



x8 flux into KOPIO  
 solid angle, nominal  
 5 year run is an  
 aggregate x20 over  
 KOPIO...permits a  
 smaller beam!

	Beam Energy	Target ( $\lambda_T$ )	$p(\text{K}^+)$ (MeV/c)	$\text{K}_L$ /second (into 500 $\mu\text{sr}$ )	$\text{K}_L/n$ Ratio ( $E_n > 10 \text{ MeV}$ )
BNL AGS	24 GeV	1.1 Platinum	300-1200	$60 \times 10^6 \text{ K}_L/\text{sec}$	$\sim 1:1000$
Project X	3.0 GeV	1.0 Carbon	300-1200	$450 \times 10^6 \text{ K}_L/\text{sec}$	$\sim 1:2700$

**Table 2:** Comparison the Project-X  $\text{K}_L$  production yield from a thick target fully simulated with LAQGSM/MAR15 into the KOPIO beam solid angle and momentum acceptance. The BNL AGS kaon and neutron yields are from RSVP reviews in 2004 (Bryman) and Jaffe (2005).



# $K \rightarrow \pi \nu \bar{\nu} \dots$ Past, Present, Future

Facility (Experiment)	Proton Power	Kaon Decay/stop rate	Kaon Properties	$K \rightarrow \pi \nu \bar{\nu}$ Sensitivity
BNL AGS (E787/E949):	50kW	$1 \times 10^6$ K <sup>+</sup> /sec	Pure stopped K <sup>+</sup> source	7 events (charged)
CERN (NA62):	20kW	$10 \times 10^6$ K <sup>+</sup> /sec	Un-separated 1- GHz K <sup>+</sup> /π <sup>+</sup> /p <sup>+</sup> beam	80 events (charged)
Fermilab: (ORKA):	75kW	$9 \times 10^6$ K <sup>+</sup> /sec	Pure stopped K <sup>+</sup> source	1000 events (charged)
Project-X K <sup>+</sup> → π ν $\bar{\nu}$	1500 kW	$100 \times 10^6$ K <sup>+</sup> /sec	Pure stopped K <sup>+</sup> source	>1000 events (charged)
JPARC (KOTO):	<300 kW	< $0.5 \times 10^6$ K <sub>L</sub> /sec	Pencil beam	1 event (neutral)
Project-X K <sub>L</sub> → π ν $\bar{\nu}$	1500kW	$50 \times 10^6$ K <sub>L</sub> /sec	Pencil beam & Precision TOF	1000 events (neutral)