8-GeV Complex Requirements for Future Kaon experiments at Fermilab

R. Tschirhart

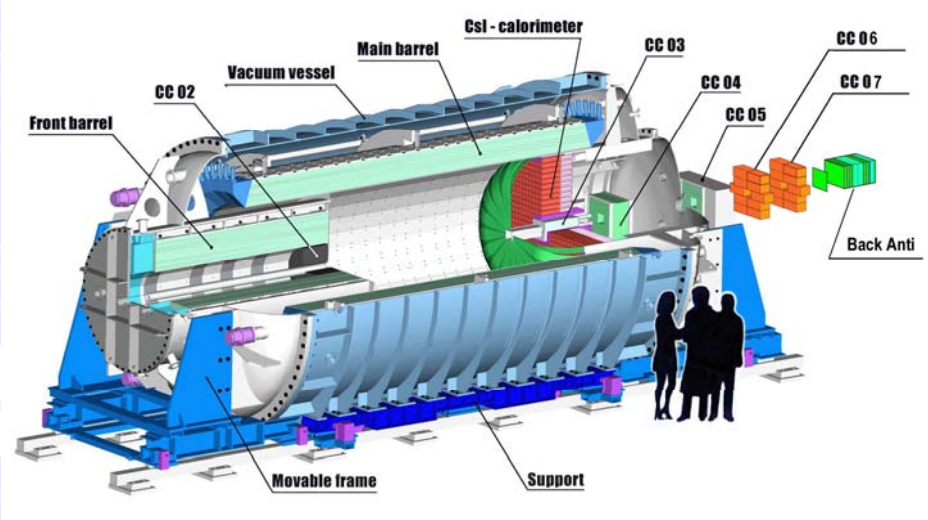
Friday May 2nd, 2008

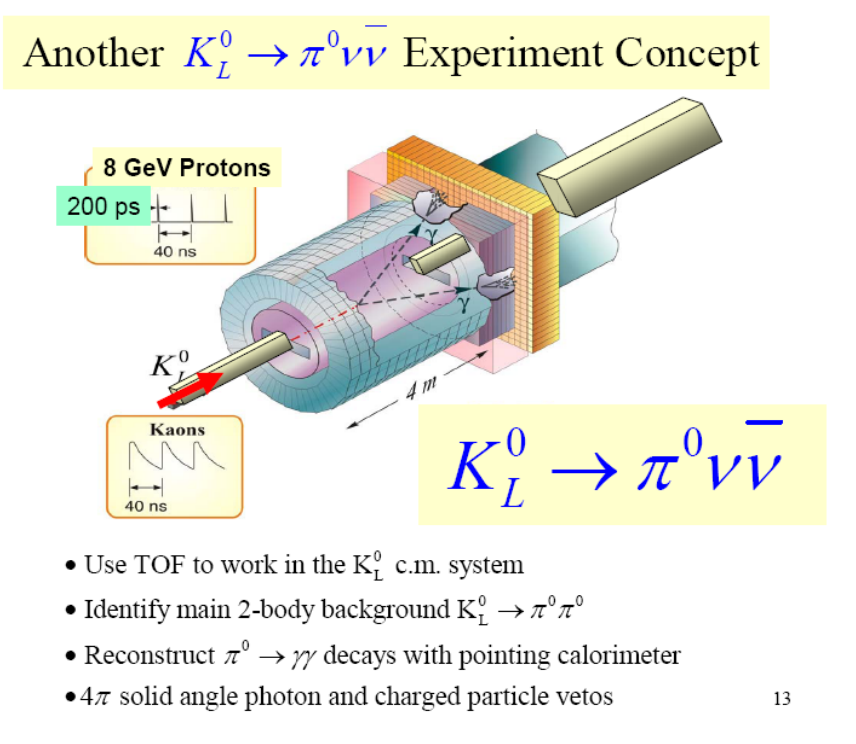
$K_L \rightarrow \pi^0 \nu\nu$ Experimental Challenge: "Nothing-in nothing out"

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

A hermetic "bottle" approach.

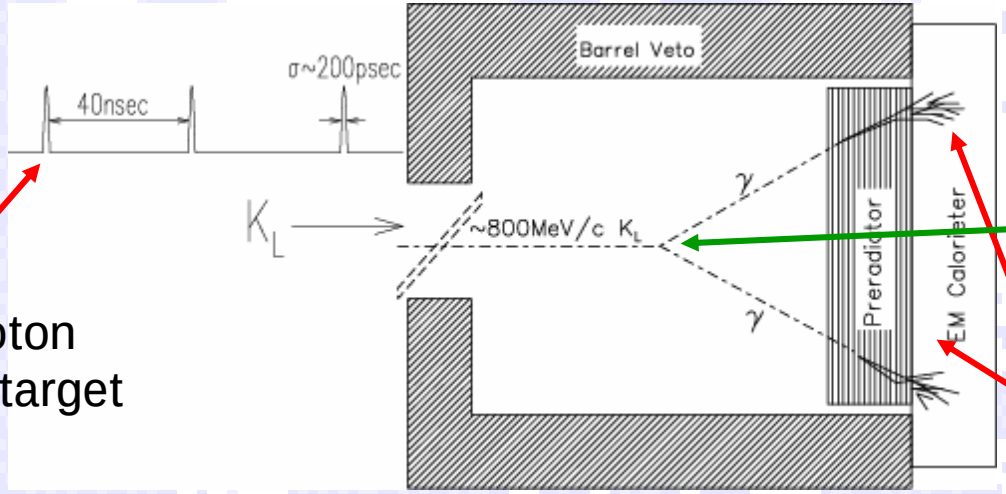
•The original KOPIO concept measures the kaon momentum and photon direction…Good! But costs detector acceptance and requires a large beam to compensate. Project-X Flux can get back to small kaon beam!





Physics Motivation: Microbunch Width

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

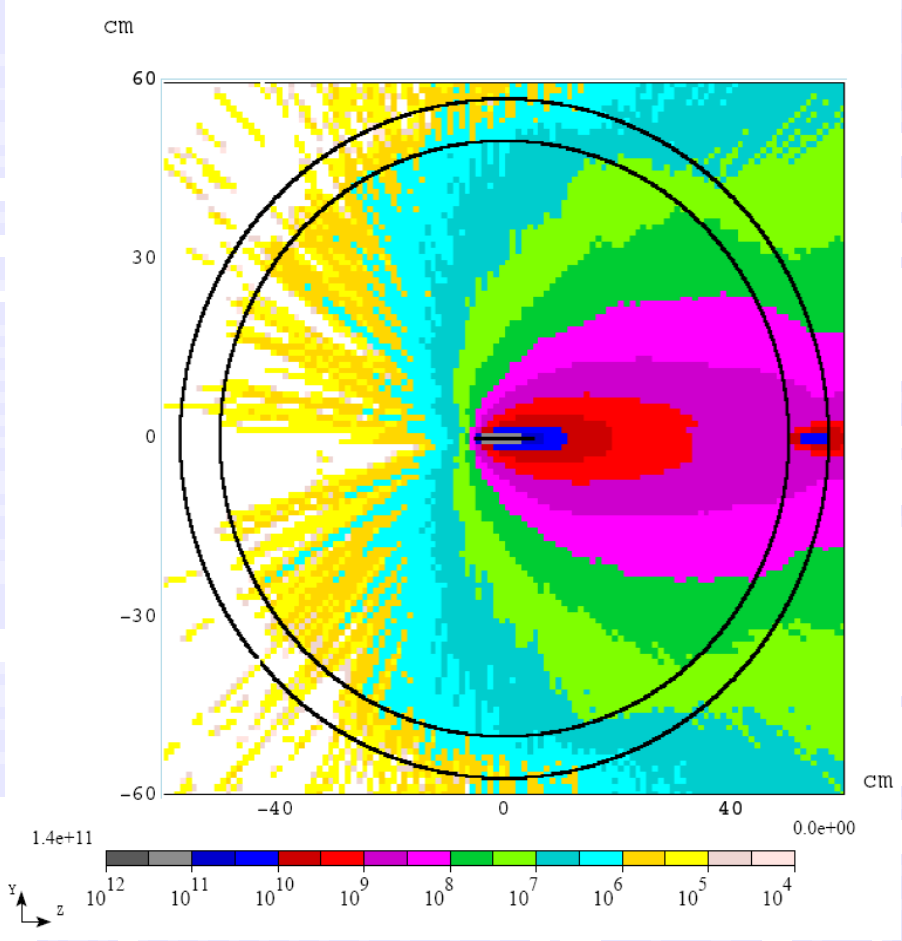


End at the decay time and decay point reconstructed from the two photons.

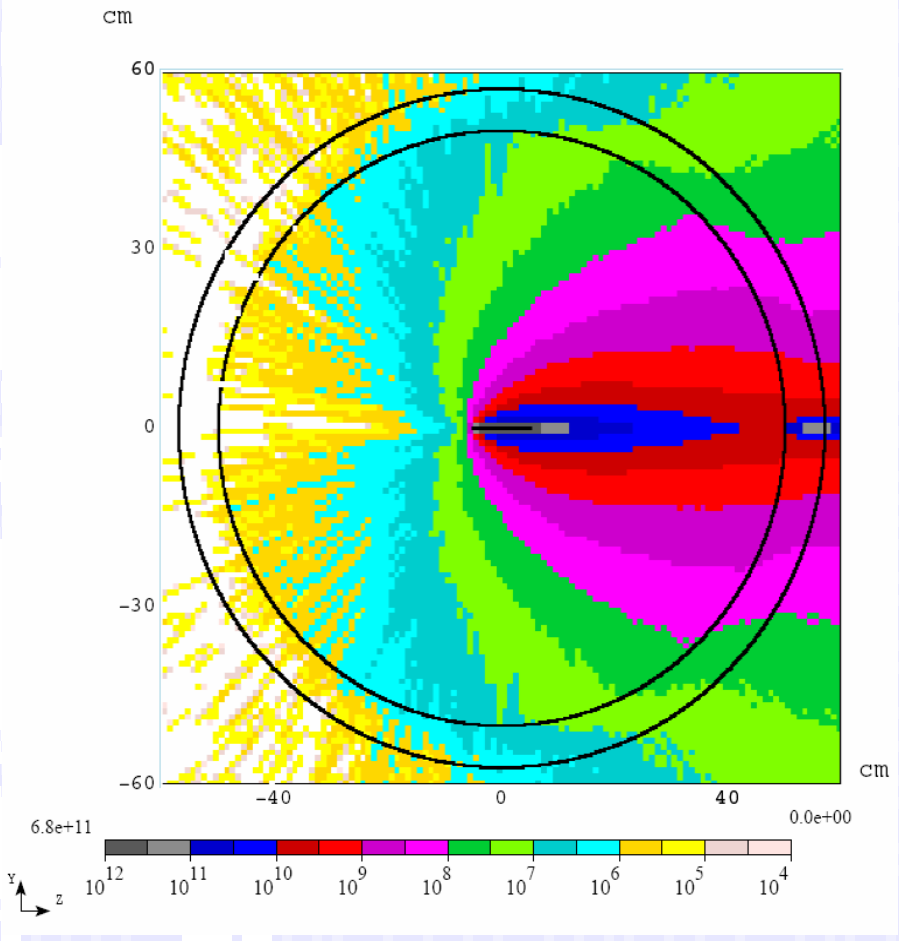
Start when proton beam hits the target

Timing uncertainty due to microbunch width should not dominate the measurement of the kaon momentum; requires RMS width < 200ps

Protons on 10 cm platinum target. Charged mesons flux (1/cm^2/10^{12} protons in target)



8 GeV/c

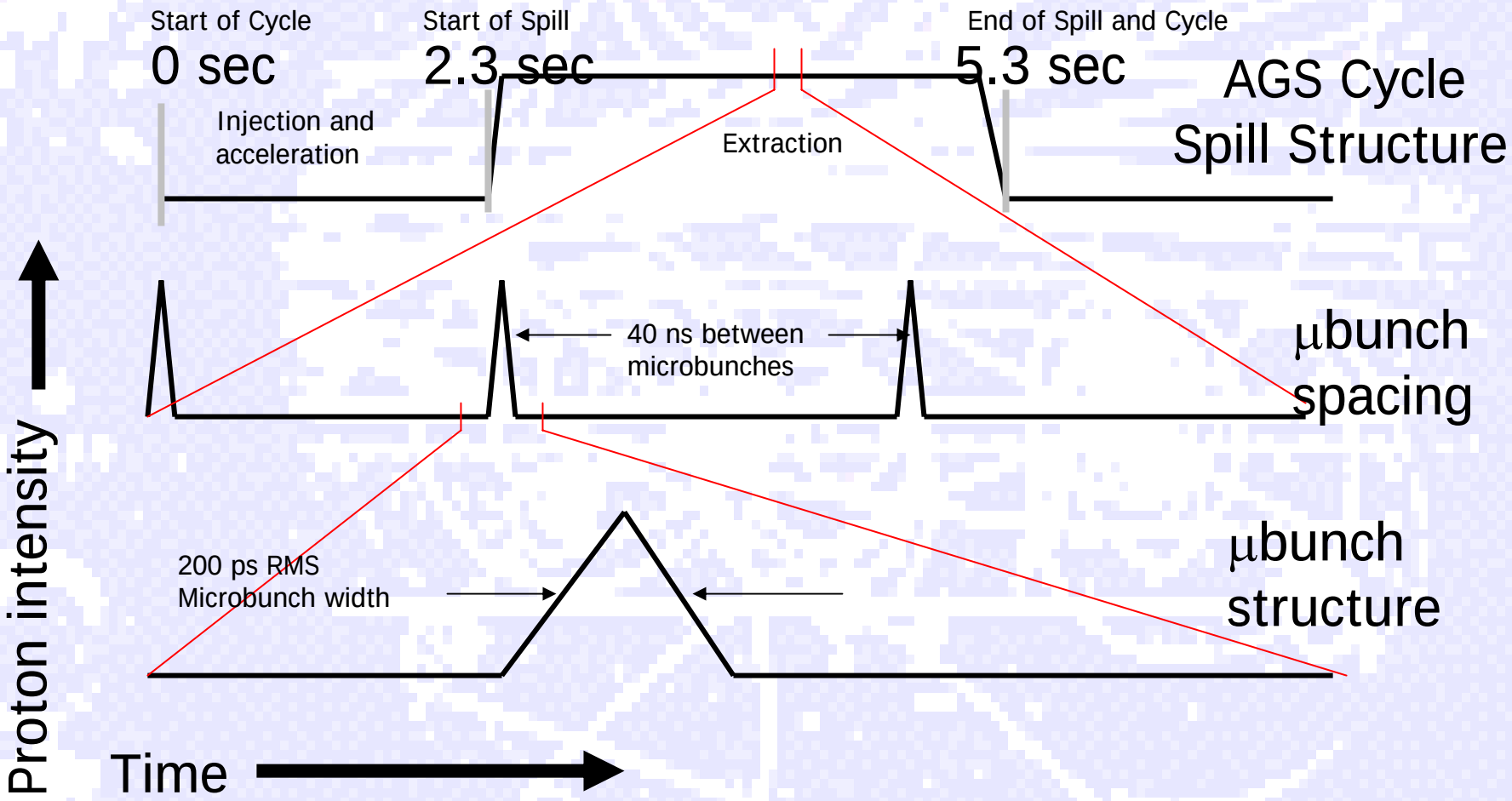


24 GeV/c

kinetic energy of mesons > 294 MeV

Sergei Striganov

Structure AGS of Beam

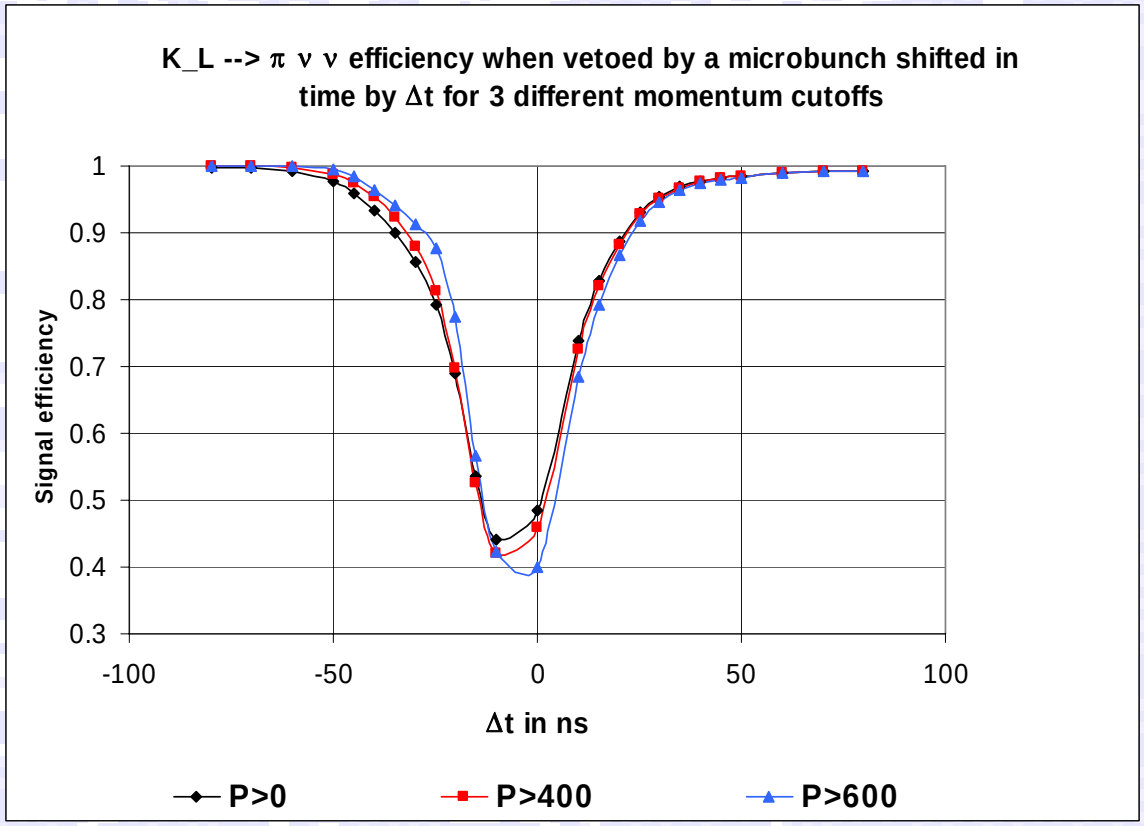


Physics Motivation: Microbunch Separation

AGS KOPIO Requirement slides from Phil Pyle, BNL.

Microbunch separation determined by the length of time required to clear out kaons from the previous microbunch.

Difference in time-of-flight between high momentum and low momentum kaons is ~30 nsec
=> 40nsec (25MHz)

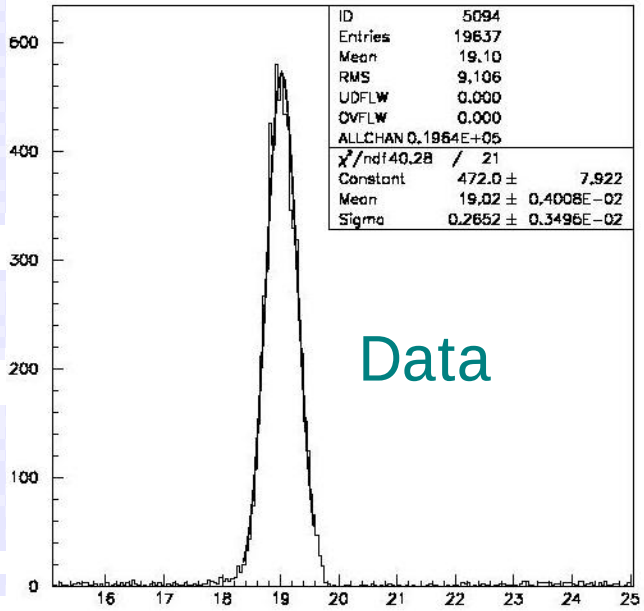


Signal efficiency drops when neighboring microbunch too close

AGS Test Beam Results: Microbunch Width

Data

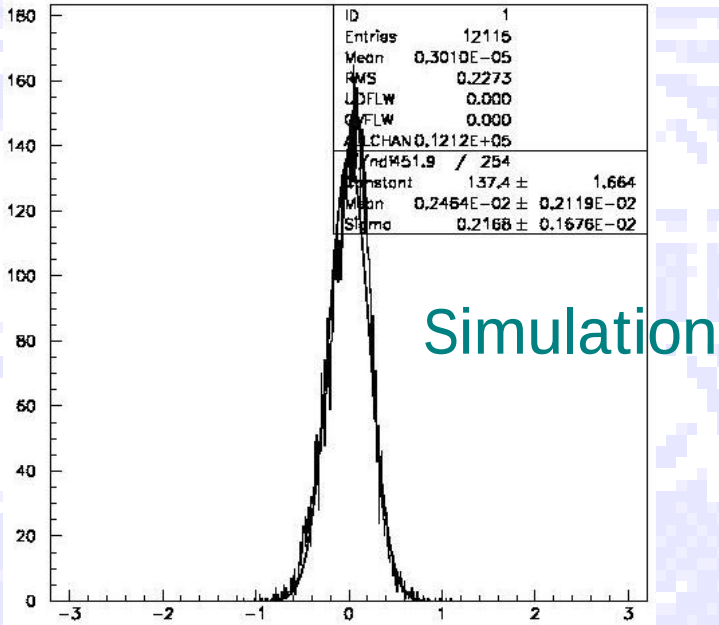
93 MHz cavity at 22 kV gave σ = 240 ps.



Microbunch time, in ns

Simulation

93 MHz cavity at 22 kV gave σ = 217 ps.

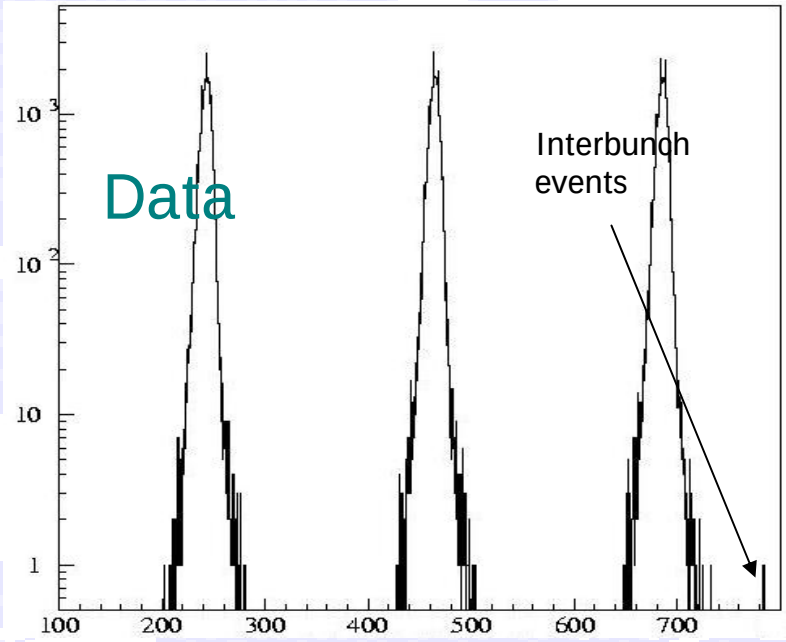


Microbunch time, in ns

AGS Test Beam Results: Interbunch Extinction

Data

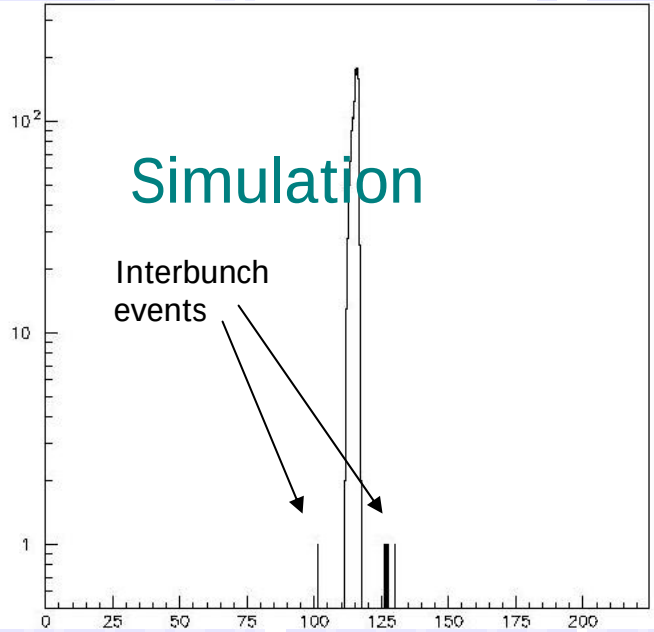
4.5 MHz cavity at 130 kV gave $\varepsilon = 8$ (+/- 6) x 10^{-6}



Microbunch time, in ns

Simulation

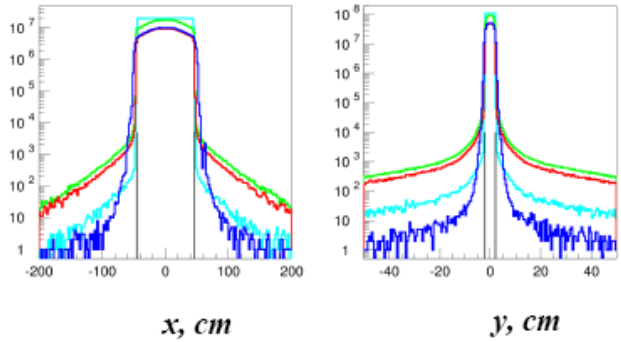
4.5 MHz cavity at 130 kV gave $\varepsilon = 1.7$ (+/- 0.9) x 10^{-3}.



Microbunch time, in ns

KOPIO geometry vs "simple" geometry

Neutron profiles at z=1000 cm. (p_n > 0.75 GeV/c)



Simple geometry, no spoiler, pointlike target

Simple geometry, no spoiler

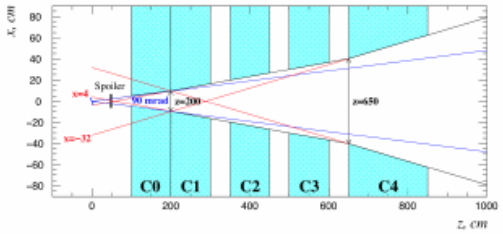
Simple geometry

KOPIO geometry

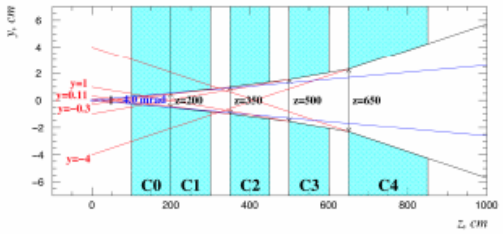
Halo / Beam ratio ~ 10^{-5}

At 8 GeV a neutral channel is a neutron beam will a small kaon component. The neutral kaon Experiment requires Time-Of-Flight measurement of netural kaons event by event, which means low-energy kaons (300-1200 MeV) -> Large angles!

KOPIO Collimators



X – projection
2-stage geometry



Y – projection
3-stage geometry

D1 D2 D3

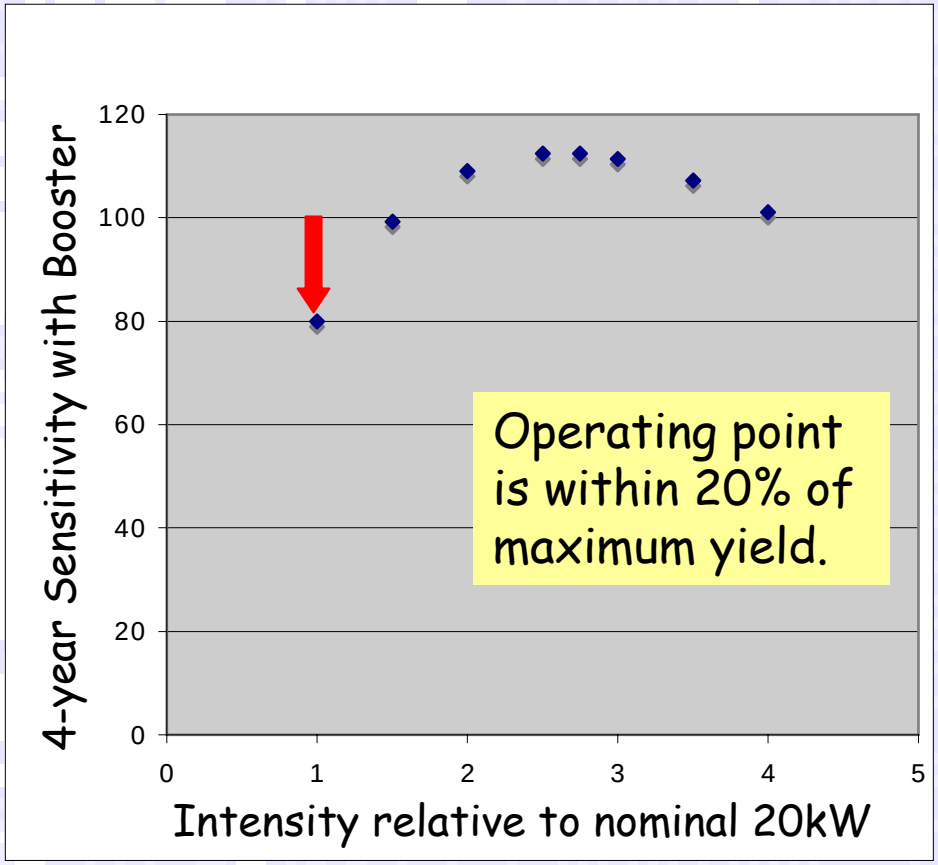
Magnetic Field

Spoiler:
130x6x70 mm^3 lead block

A. Poblaguev
Yale University

Intensity Dependence of the KOPIO Design

- The KOPIO design is instantaneous rate-limited, primarily due to the large aperture of the neutral beam.
- The sensitivity could be increased by improved detector resolutions.
- **But** the KOPIO design is already not a cheap experiment, large area of detectors, many constraints.
- Could the potentially huge intensity increases of Project-X qualitatively change the picture?



Assuming 90% Duty Factor, 5000 hours.

Improved Rate Performance of a "Pencil Beam" TOF Experiment.

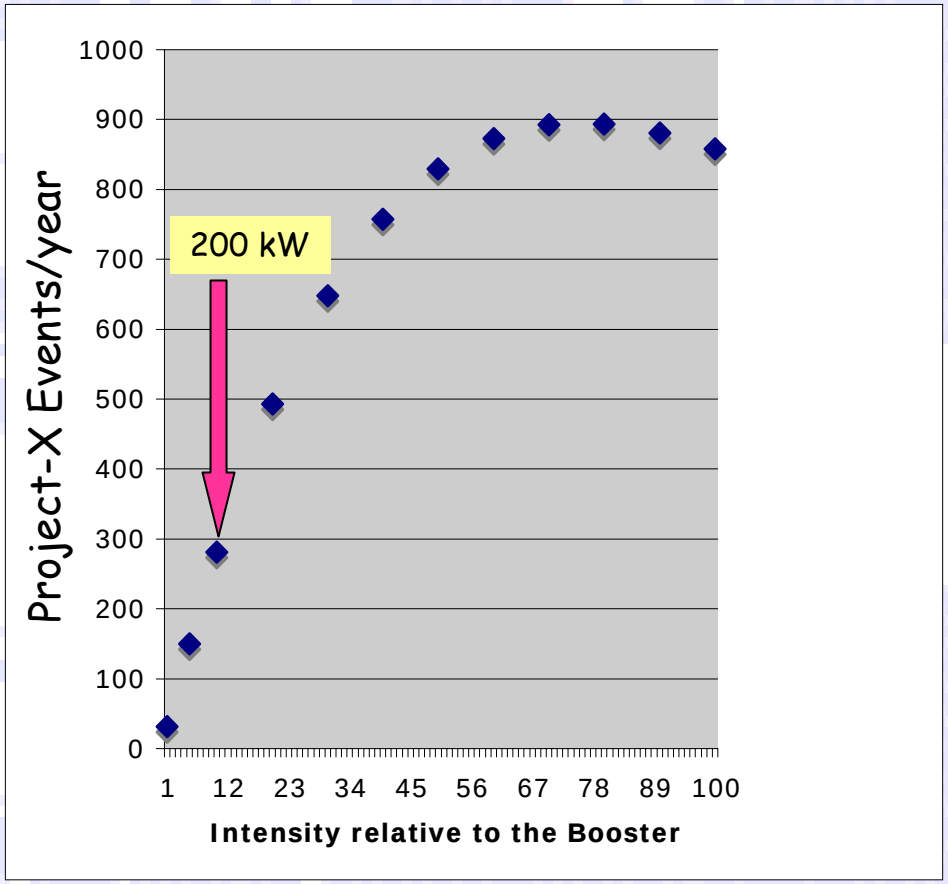
- Booster Power (20 kW):

30 equivalent events per year

- Project-X (200 kW):

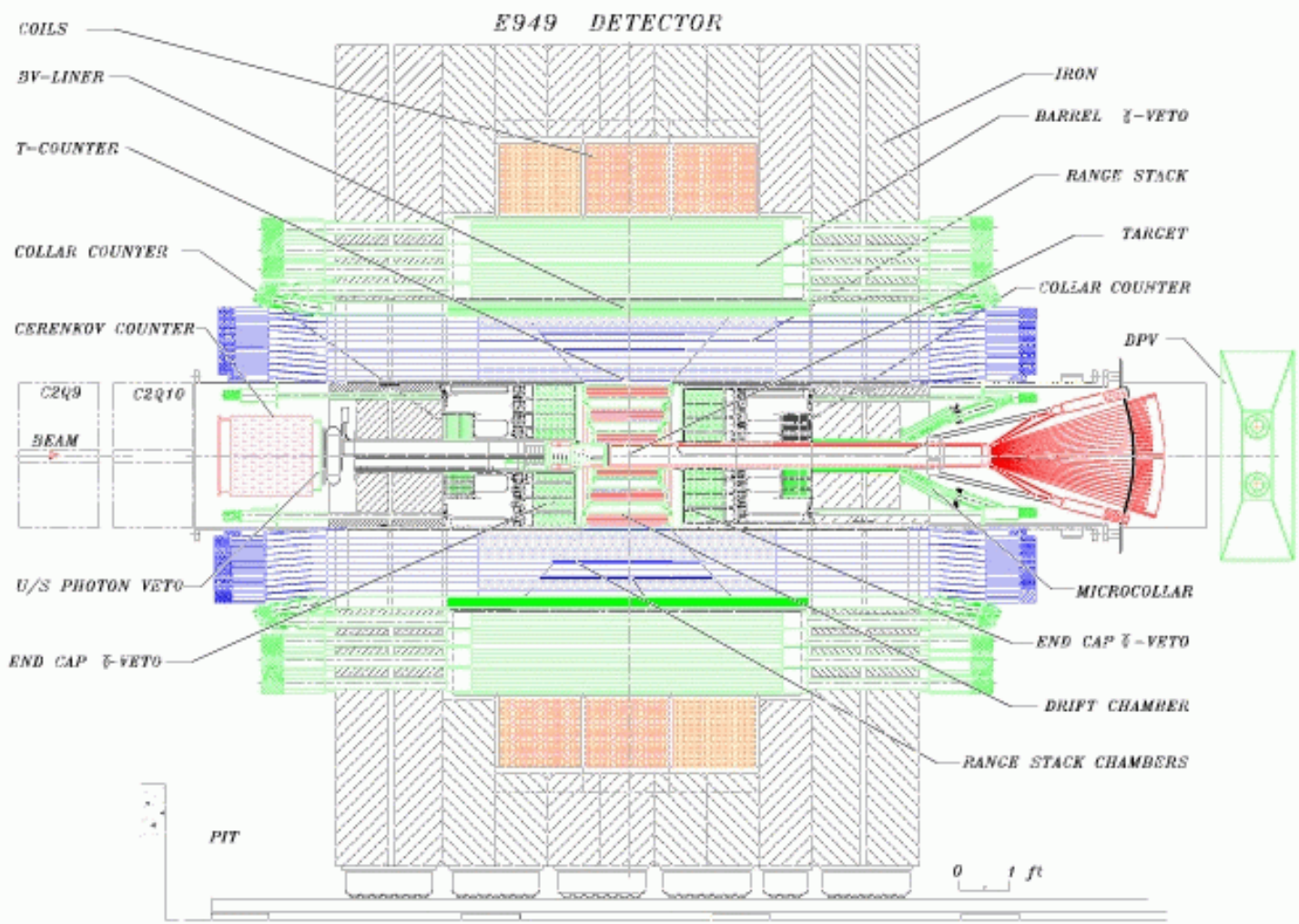
300 equivalent events per year

- 200 kW operating point has robust rate performance which can be scaled to much higher beam power.
- Experiment designed with a pencil beam has substantially lower technical risk and likely lower cost.



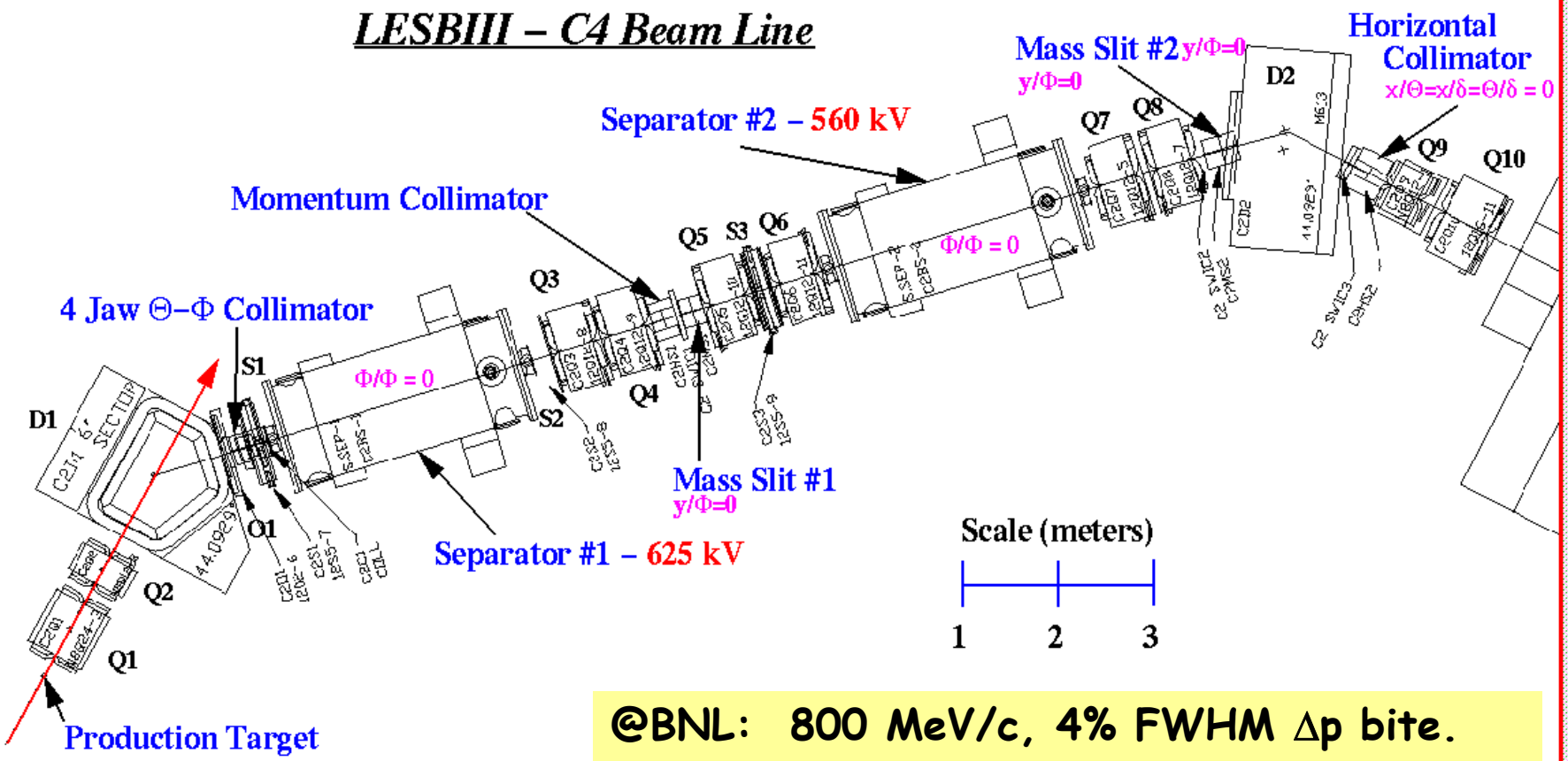
Assuming 90% Duty Factor, 5000 hours.

Next Generation Stopping K^+ $K^+ \to \pi\nu\bar{\nu}$ Experiment based on previous BNL experiment E787/E949.



Elevation view of the E949 detector.

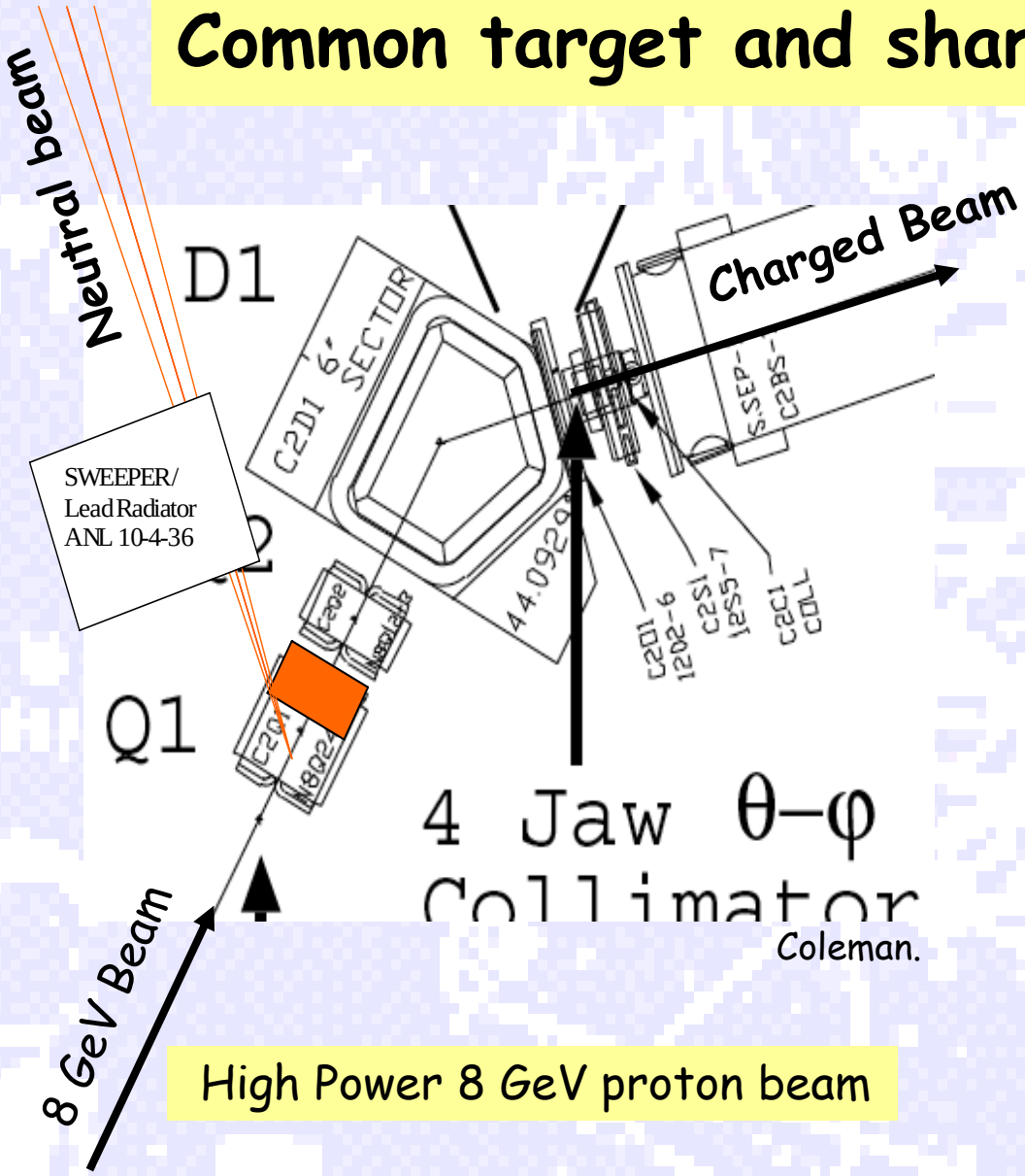
BNL Charged K+ Beamline: Channel a low energy *separated* charged beam to a stopping target: Measure kaon decays at Rest!



@BNL: 800 MeV/c, 4% FWHM Δp bite.

@FNAL: Lower momentum, higher eff??

8 GeV Facility Vision: Common target and shared infrastructure.



Coleman.

High Power 8 GeV proton beam

- The large targeting angle required for the low energy neutral beam allows consideration of a simultaneous charged forward beam!
- First look at the layout is encouraging.
- **Big payoff** in beam and infrastructure economy.

Perseverance Pays Off: Hours and Duty Factor matter most!

Per year

Facility	Duty Factor	Clock hours	Beam hours	Projected # of K → $\pi\nu\bar{\nu}$
☆ CERN-SPS (450 GeV)	30%	1420	405	40 (charged)
Booster Stretcher (8GeV, 16kW)	➡ 90%	5550	5000	40 (charged)
Tevatron-Stretcher (120 GeV)	➡ 90%	5550	5000	200 (charged)
ProjectX Stretcher (8GeV, 200kW)	➡ 90%	5550	5000	250 (charged)
☆ JPARC-I (30 GeV)	21%	2780	580	~1 (neutral)
BNL AGS (24 GeV)	50%	1200	600	20 (neutral)
JPARC-II (30 GeV)	21%	2780	580	30 (neutral)
Booster Stretcher (8GeV, 16kW)	➡ 90%	5550	5000	30 (neutral)
ProjectX Stretcher (8GeV, 200kW)	➡ 90%	5550	5000	300 (neutral)

☆ **Moving toward full approval.**

J-PARC - Neutrino:Kaon = 50%:50%

Rate Study of Charged Experiment.

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	BNL	FNAL	FNAL	FNAL
	"E949"	Booster X0	Proj X1	Proj X2
K/s (inst.)	1	0.3	1.8	11.2
hr/yr	2500	5000	5000	5000
p/yr(E20)	0.9	2.9	28.9	289.3
Kstop/yr.	1	3	23	157
Detect. "Accept."	1	2.50	2.50	2.50
Accidental 'losses'	0.20	0.04	0.06	0.24

Summary of Requirements

- >5000 hours of operation/year.
- >50% Duty factor. **Duty factor x Operation hours > 2500 hours.**
- Experiments can be optimized for 20kW-1000kW of beam power, more is better! Good strategic argument for basing a neutral beam program on small solid-angle beams.
- 40 MHz RF structure with tight pinging (<200psec RMS) and modest extinction ($<10^{-3}$) required for neutral experiment, acceptable for charged experiment.
- Common target for neutral and charged experiment plausible at cartoon level of study….Many non-trivial issues: Neutral beams with very low halo, Charged beam separators operating in high radiation environment….etc.

Spare Slides

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

Challenge to Experimenters

- $B(K_L \rightarrow \pi^0 \nu\bar{\nu}) \sim 3\times10^{-11}$;
  need huge flux of kaons -> high rates
- Weak Kinematic signature (2 particles missing)
- Backgrounds with π^0 up to 10^{10} times larger
- Veto inefficiency on extra particles must be $\leq 10^{-4}$
- Neutrons dominate the beam
  - ✓make π^0 off residual gas – require high vacuum
  - ✓halo must be very small
  - ✓hermeticity requires photon veto in the beam
- Need convincing measurement of background

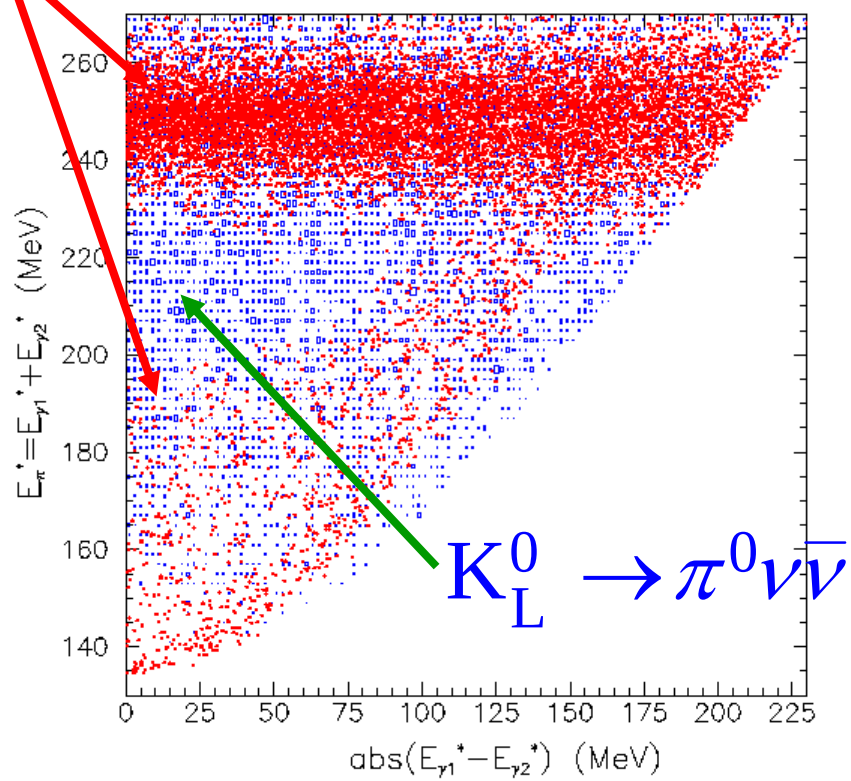
Separating signal from background

$$K_L^0 \rightarrow \pi^0 \pi^0$$

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

Microbunching is crucial to the measurement of the kaon momentum which allows kinematic suppression of backgrounds by transforming to the kaon rest frame.

Make cuts on the pion energy and the difference in photon energies in the kaon rest frame.



Physics Motivation: Interbunch Extinction

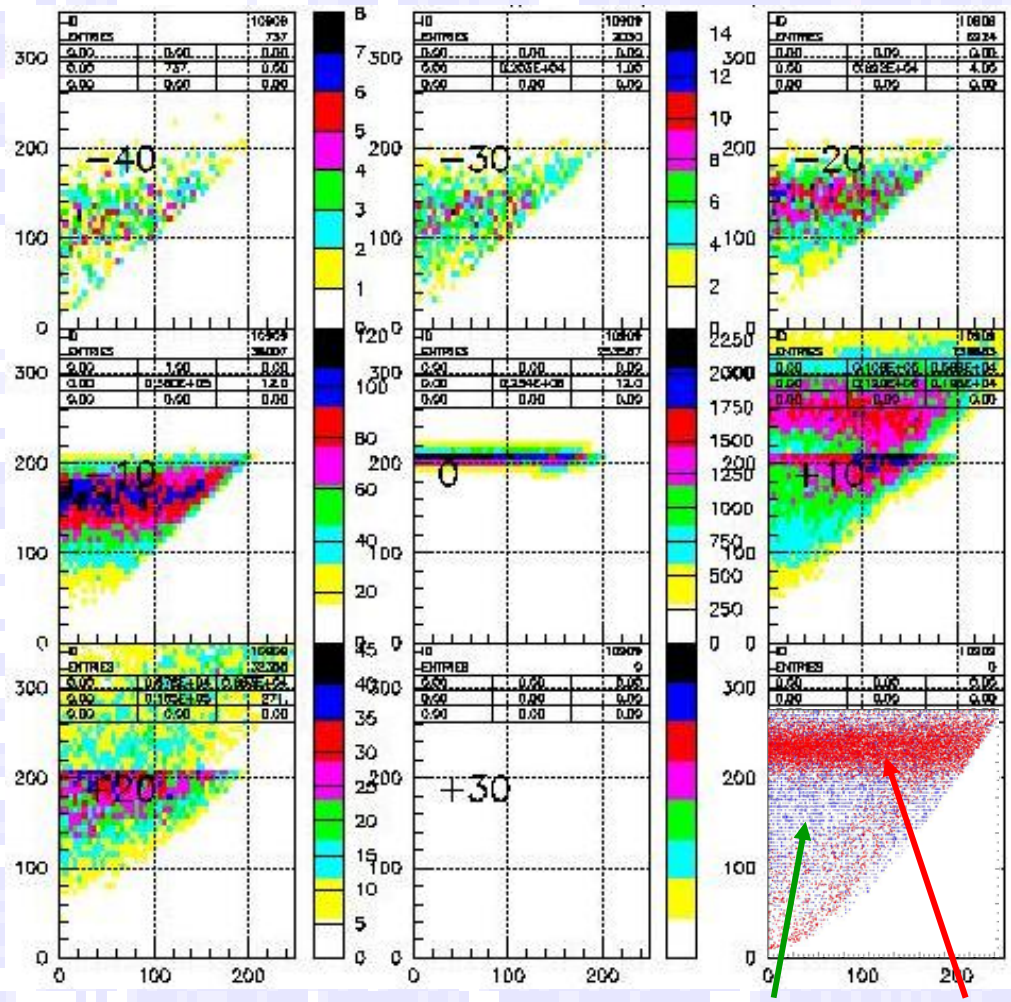
Effects of Interbunch Kaons

$K_L \rightarrow \pi^0 \pi^0$ events, shifted in time

Kinematic cuts are used to reduce background due to $K_L \rightarrow \pi^0 \pi^0$

When K_L does not come from the microbunch, incorrect kinematic fit does not allow for good rejection. Panels show effect of K_L production at varying interbunch times.

10^{-3} Extinction Adequate



AGS: New Hardware Required: Kickers

Provide high-efficiency high-intensity Injection/Extraction:

- Add magnets to create A10 kicker system.
- Upgrade the F3 kicker for Booster extraction.
- Upgrade the A5 kicker system for AGS injection.

AGS: New Hardware Required: RF

Provide KOPIO microbunching:

- Add a 25 MHz 150 kV RF cavity to AGS Ring to provide the 40 ns microbunch spacing and preliminary microbunch width structure.
- Add a 100 MHz 150 kV harmonic RF cavity "afterburner" for very narrow microbunch width.

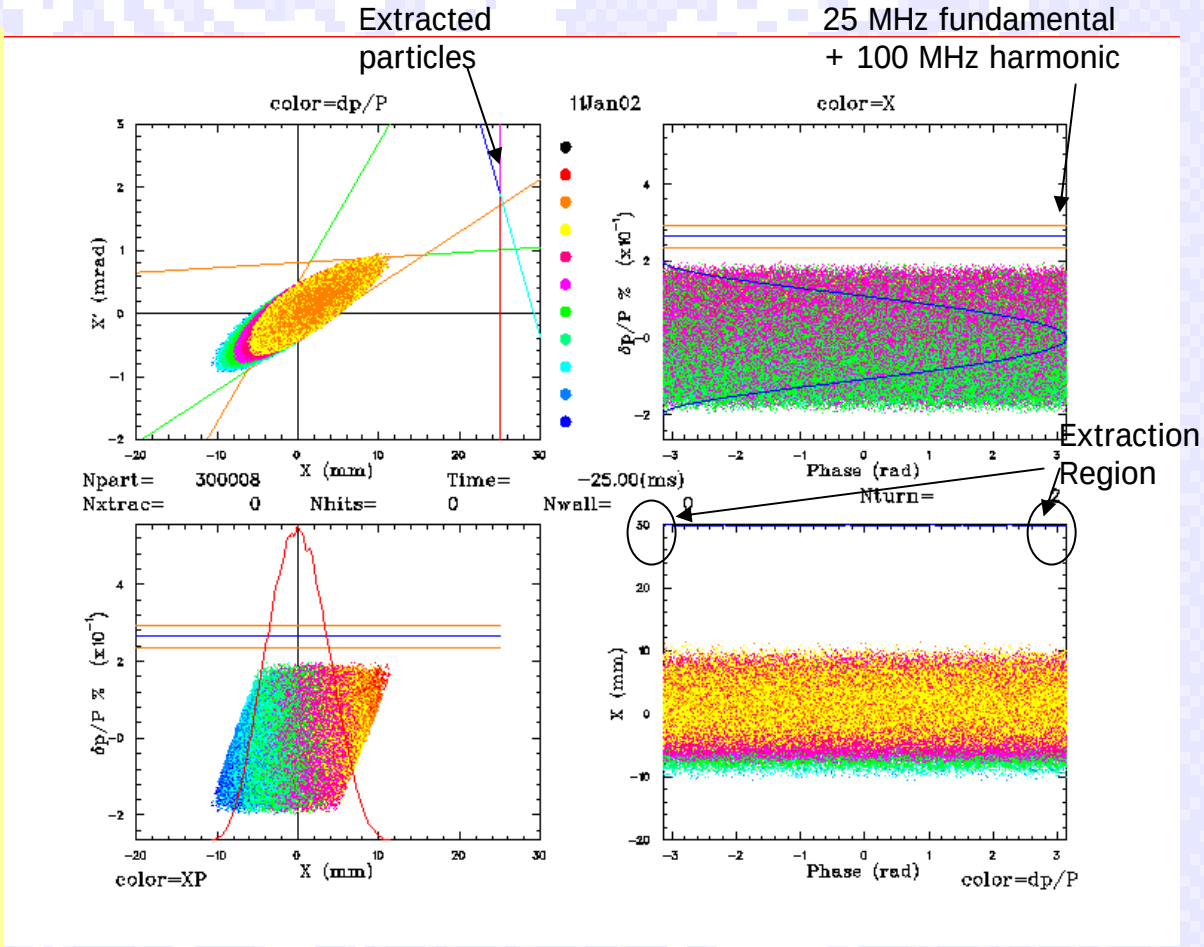
AGS: Specification from physics: Kicker

Current kickers do not provide enough kick to get the beam into equilibrium orbit. We inject at 1.94 GeV with ~2 mrad kick.

New kicker system required to inject beam from Booster into AGS without emittance blow-up. It allows for higher transfer energy at injection, 2 GeV, with lower losses.

Need new Pulse Forming Network (PFN) for faster switching to keep one bunch from interfering with its neighbors.

Must keep from activating the machine and damaging equipment in the AGS and Booster.

Microbunching the AGS Beam

- Simulation of the extraction process for 25+100 MHz RF cavities.
- Impose a high frequency longitudinal oscillation on the beam.
- Slowly bring the beam into resonance ($8^2/_3$) with RF.
- Beam is forced through the narrow phase region between the RF buckets.
- Adding the 100MHz harmonic cavity sharpens up the phase region in resonance.