8-GeV Complex Requirments for Future Kaon experiments at Fermilab

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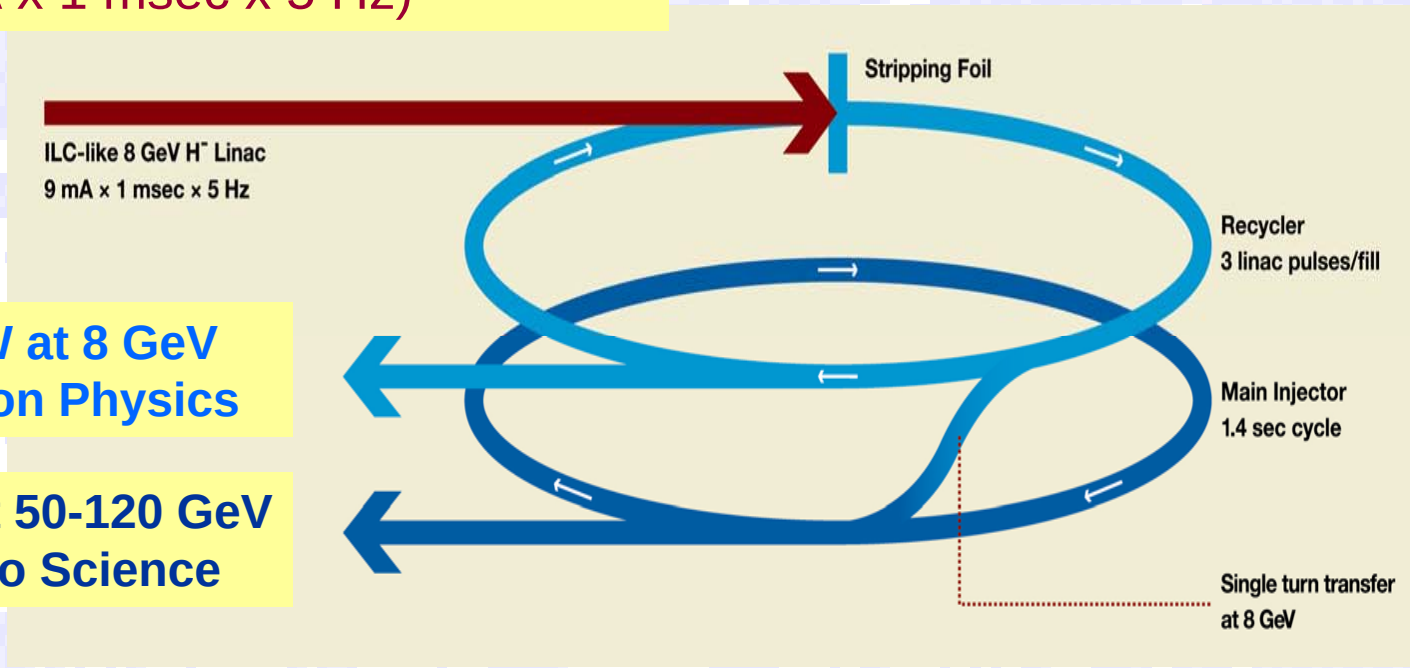
December 13th , 2007

Project X: What is it?

8 GeV H^- Linac with ILC Beam Parameters
(9 mA x 1 msec x 5 Hz)



100-200 kW at 8 GeV for Precision Physics

>2.0 MW at 50-120 GeV for Neutrino Science

Project X Linac:

ILC-like (0.6 – ~1.0 GeV)

ILC-identical (~1 – 8 GeV)

Vehicle for National & International Collaboration

Results of the First Project-X Physics Workshop, Nov, 2007.

- Conceptual kaon experiments that exploit the unique features of the Fermilab 8 GeV complex and eventually Project-X emerged and are gaining momentum.
- Conceptual kaon experiments driven by Main Injector protons stretched into the Tevatron are technically attractive but are not getting traction now due to the estimated Tevatron operating costs ($20M-$30M/year)
- The Physics community is turned-on by the potential of high sensitivity rare-decay experiments.
- Next Workshop January 25th/26th 2008 will refine the physics case, and a strategy for the complex will be developed.
- Discussion of Project-X R&D Scope to include Research Program.

Unique Features of the Fermilab 8 GeV Complex for Kaon Physics

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	50 (charged)
Tevatron-Stretcher (120 GeV)	90%	5550	5000	200 (charged)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	300 (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	50 (neutral)
ProjectX Stretcher (8GeV, 200kW)	90%	5550	5000	300 (neutral)

☆ **Moving toward full approval.**

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

Issues to Discuss Today

- 1) Brief review of experimental requirements.
-
- 2) How can the complex be reconfigured into stretcher rings that can provide a high duty factor for experiments? Can the Accumulator and Debuncher be used simultaneously to drive experiments with different RF beam structure requirements?

- 3) How can extraction work? What are the losses, beam power limitations?

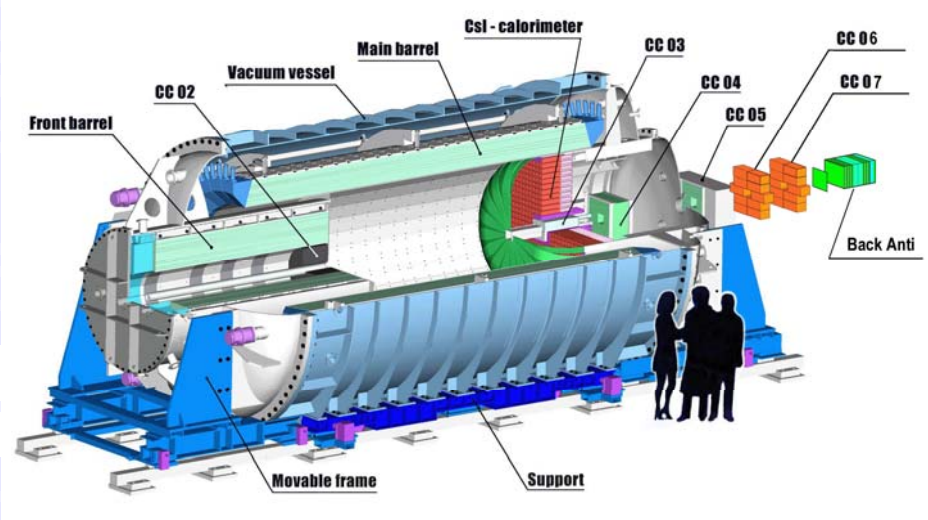
- 4) The neutral kaon experiment requires an RF train of pings (see attached description of how this was proposed for the AGS). How can the necessary RF structure be established? What are the limits to ping fidelity? Can a sigma of 100 picoseconds be realized?

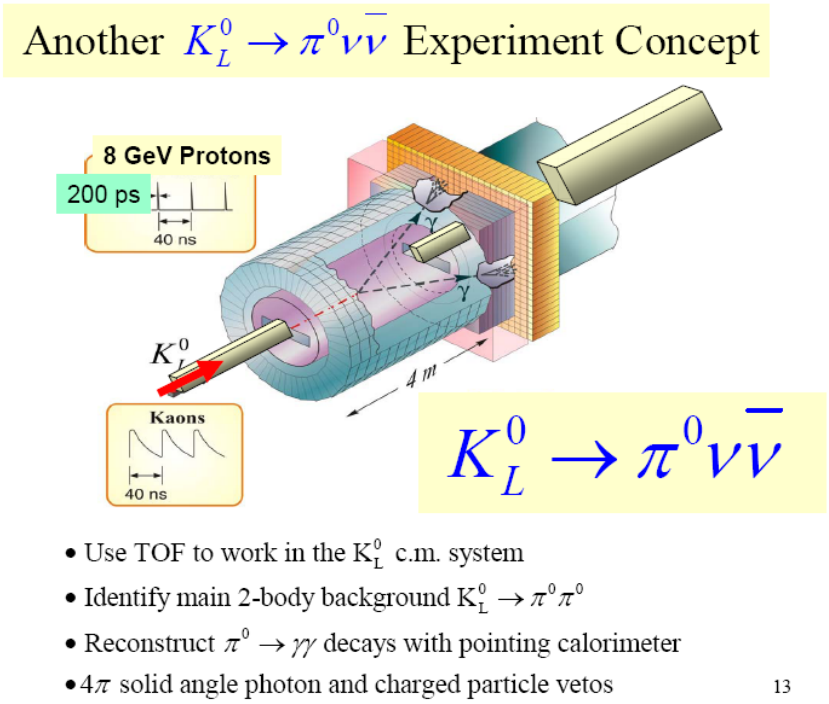
$K_L \rightarrow \pi^0 \nu\nu$ Experimental Challenge: "Nothing-in nothing out"

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

A hermetic "bottle" approach.

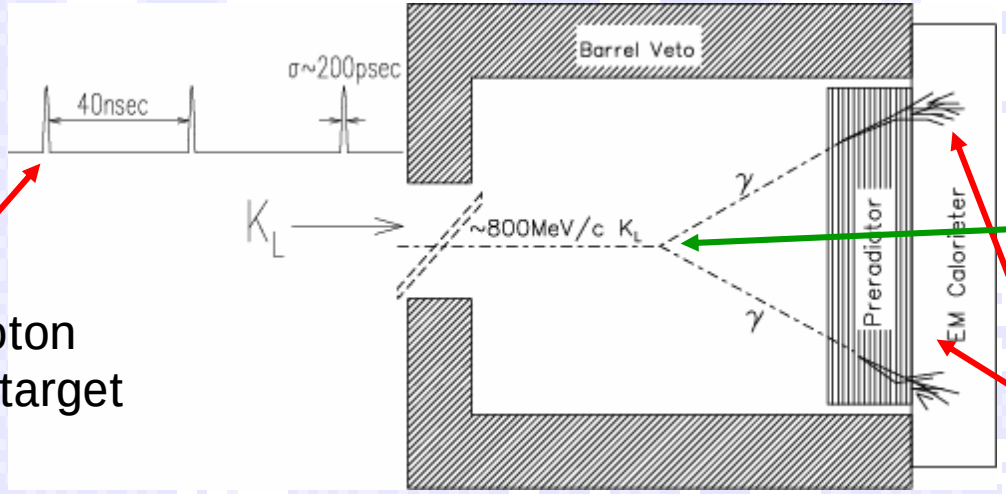
- The original KOPIO concept measures the kaon momentum and photon direction…Good! But costs detector acceptance and requires a large beam to compensate. Project-X Flux can get back to small kaon beam!





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.



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 < 300ps

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

Background suppression factor needed: 10^{10}

Primary Backgrounds

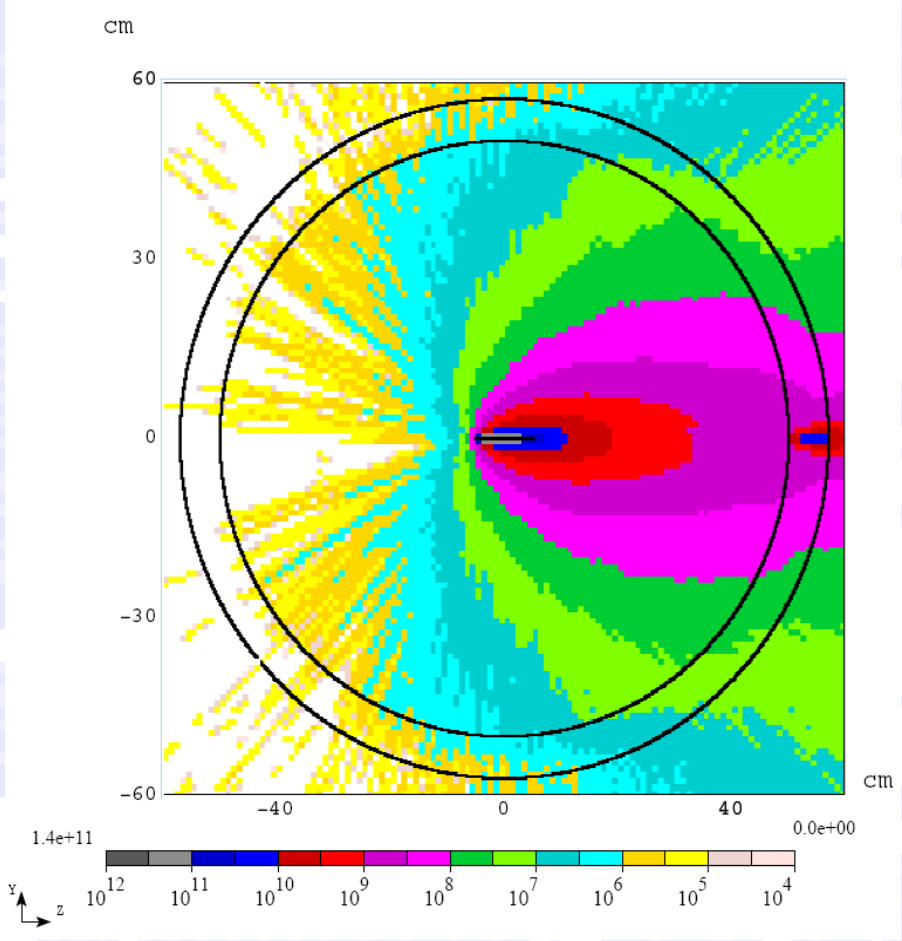
Mode	Branching Ratio
$K_L^0 \to \pi^0 \pi^0$	$0.93 \ x \ 10^{-3}$
$K_L^0 \to \pi^- e^+ \nu \gamma$	$0.36 \ x \ 10^{-2}$
$K_L^0 \to \pi^+ \pi^- \pi^0$	0.1255
$K_L^0 \to \pi^0 \pi^0 \pi^0$	0.2105

Others

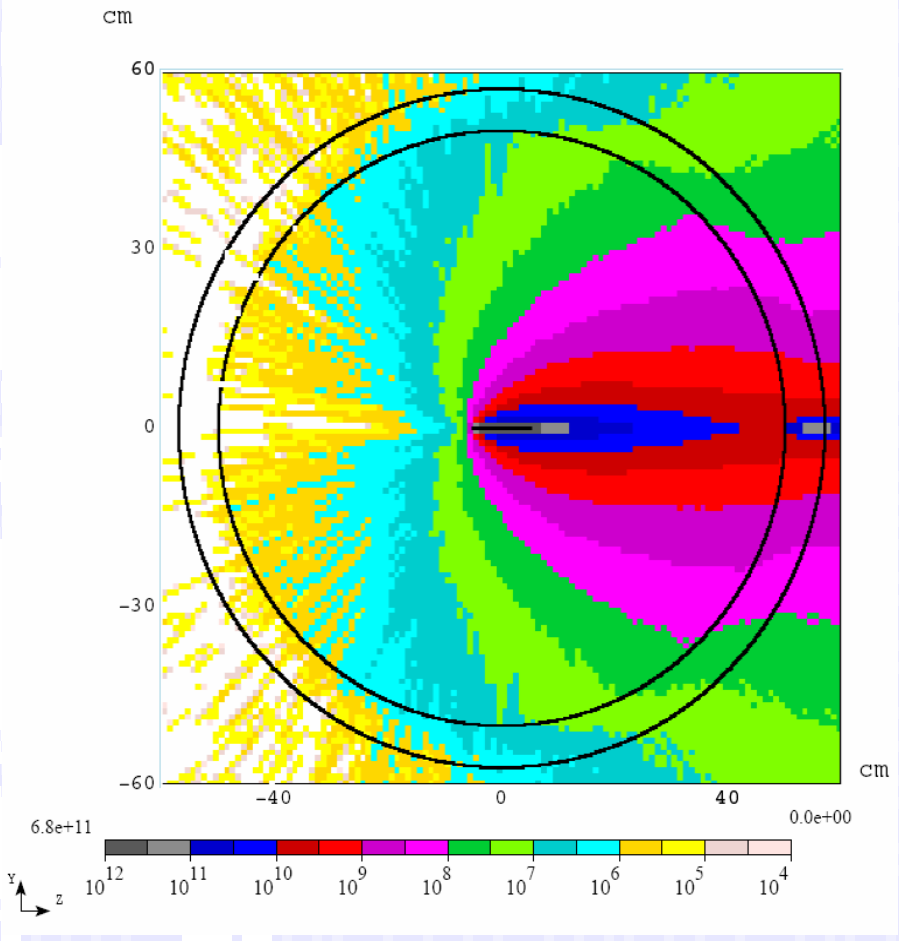
Challenge to Experimenters

- $B(K_L \rightarrow \pi^0 \nu\bar{\nu}) \sim 3\times10^{-11}$;
  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

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



8 GeV/c



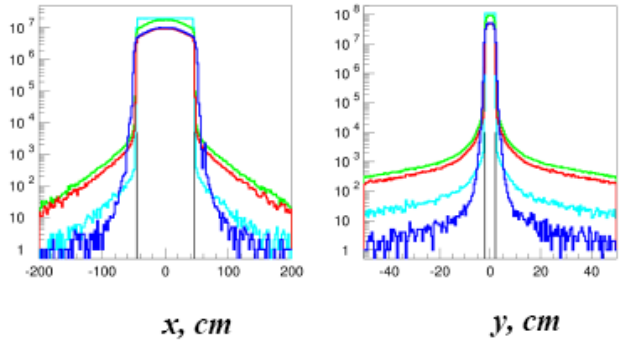
24 GeV/c

kinetic energy of mesons > 294 MeV

Sergei Striganov

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

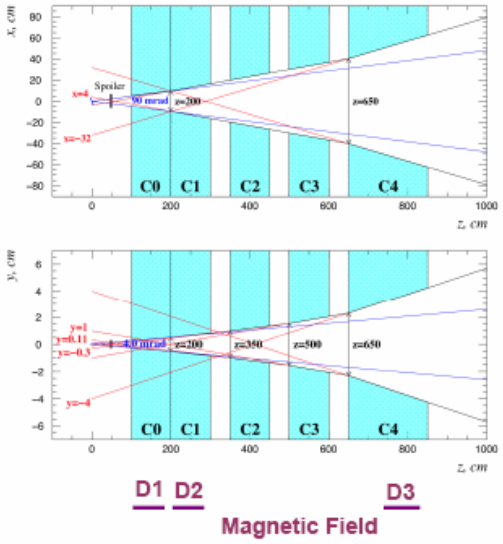
Simple geometry

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



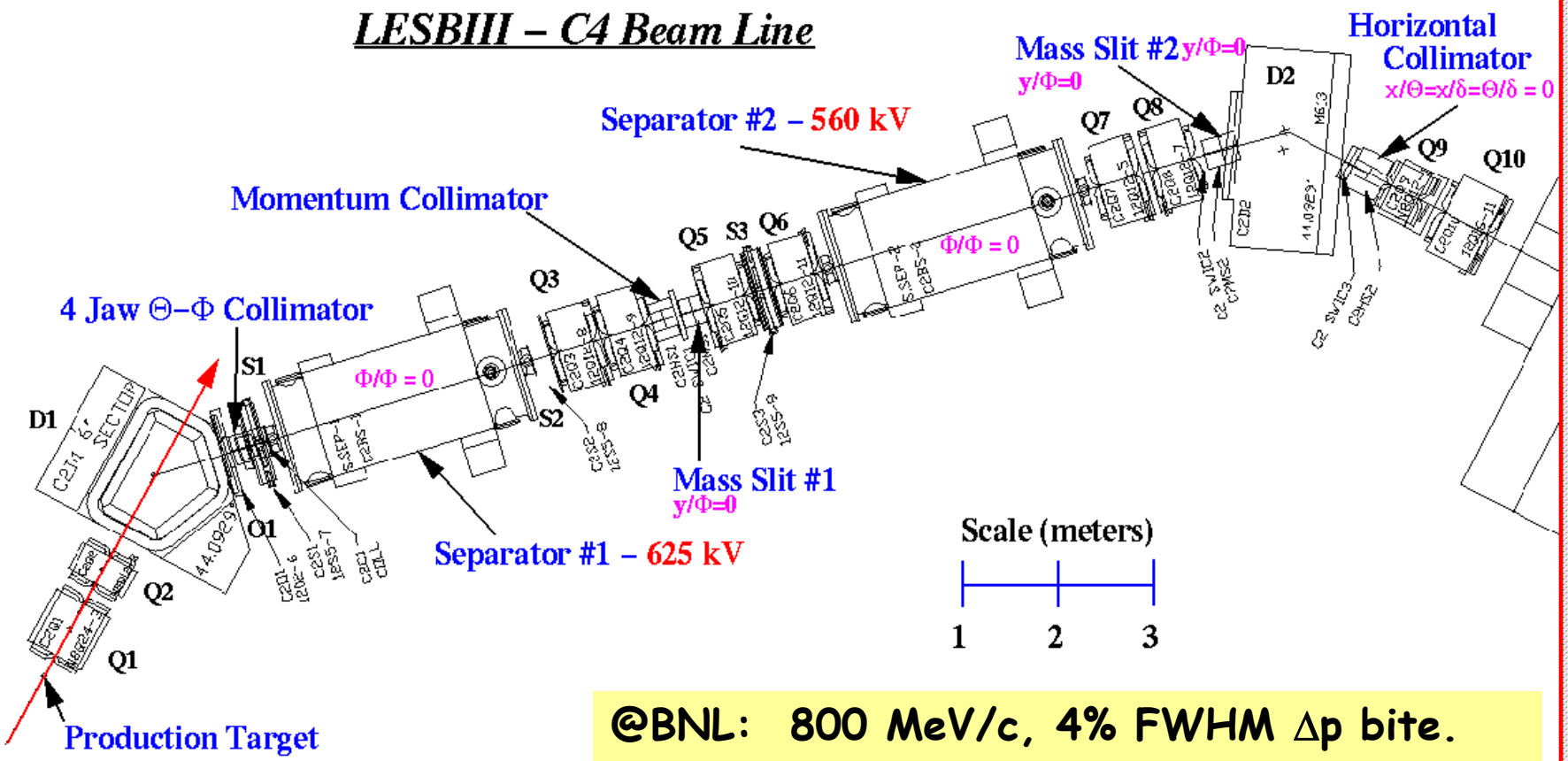
X – projection
2-stage geometry

Y – projection
3-stage geometry

Spoiler:
130x6x70 mm^3 lead block

A. Poblaguev
Yale University

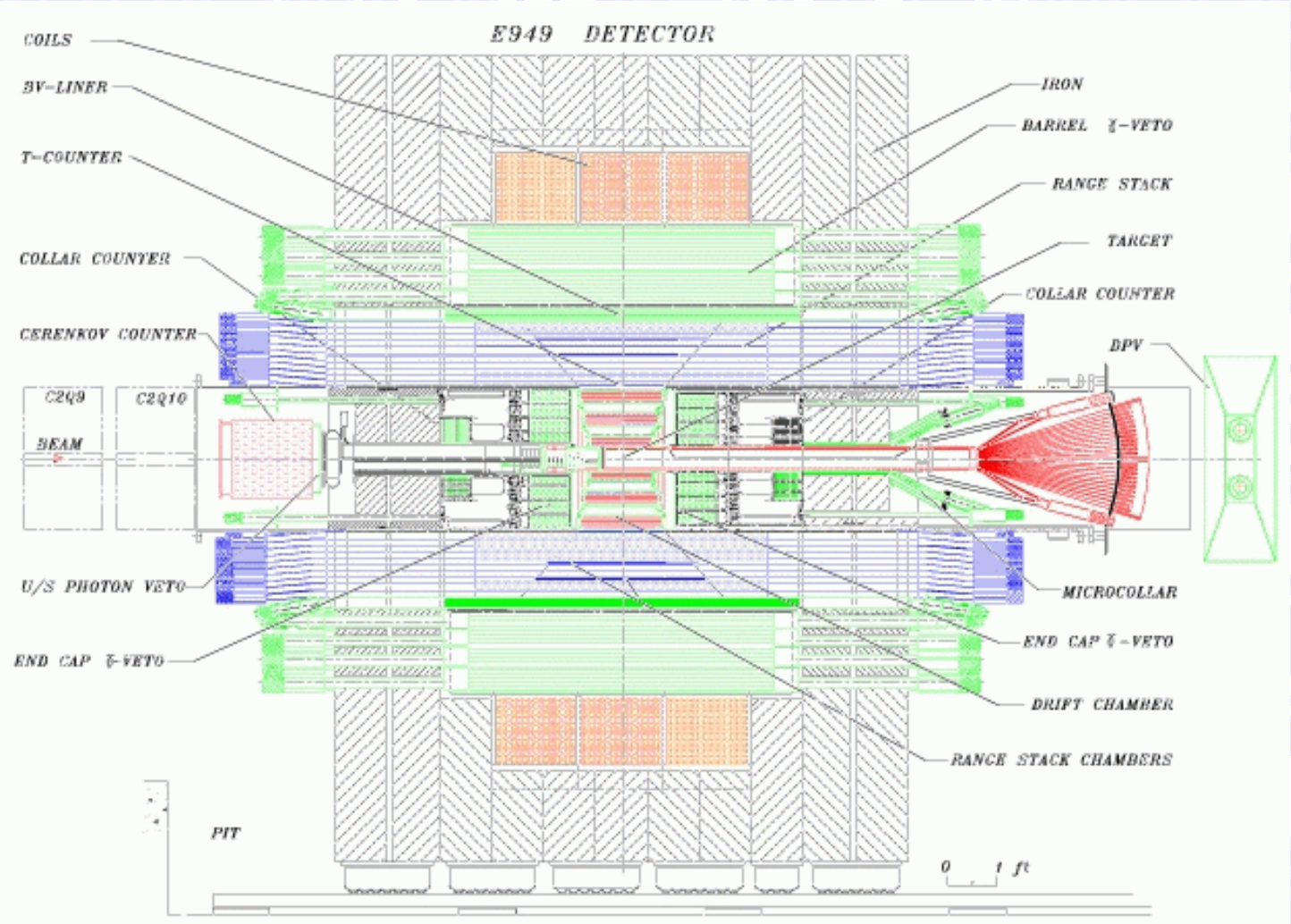
BNL Charged K+ Beamline: Channel a low energy *separated* charged beam to a stopping target: Measure kaon decays at Rest!



@BNL: 800 MeV/c, 4% FWHM Δp bite.

@FNAL: Lower momentum, higher eff??

BNL E787/E949: Stopping K+ Experiment that observed three $K^+ \to \pi\nu\nu$ events.



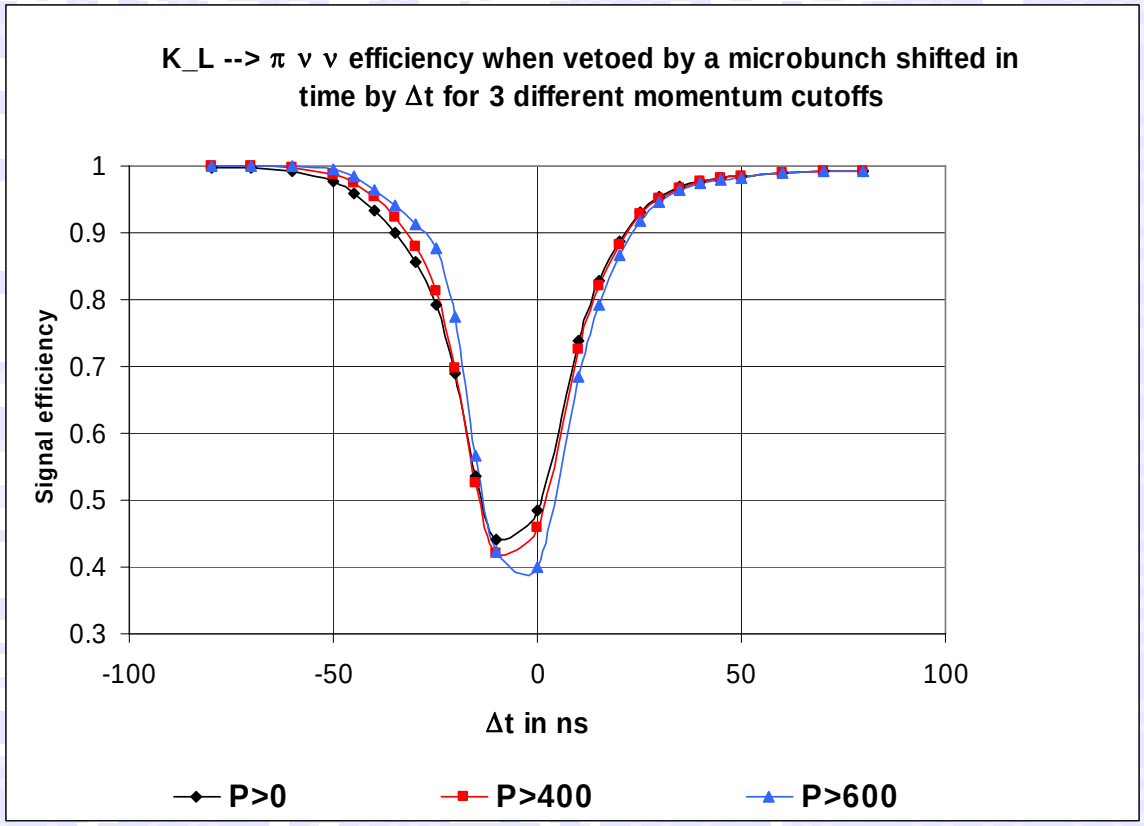
Elevation view of the E949 detector.

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

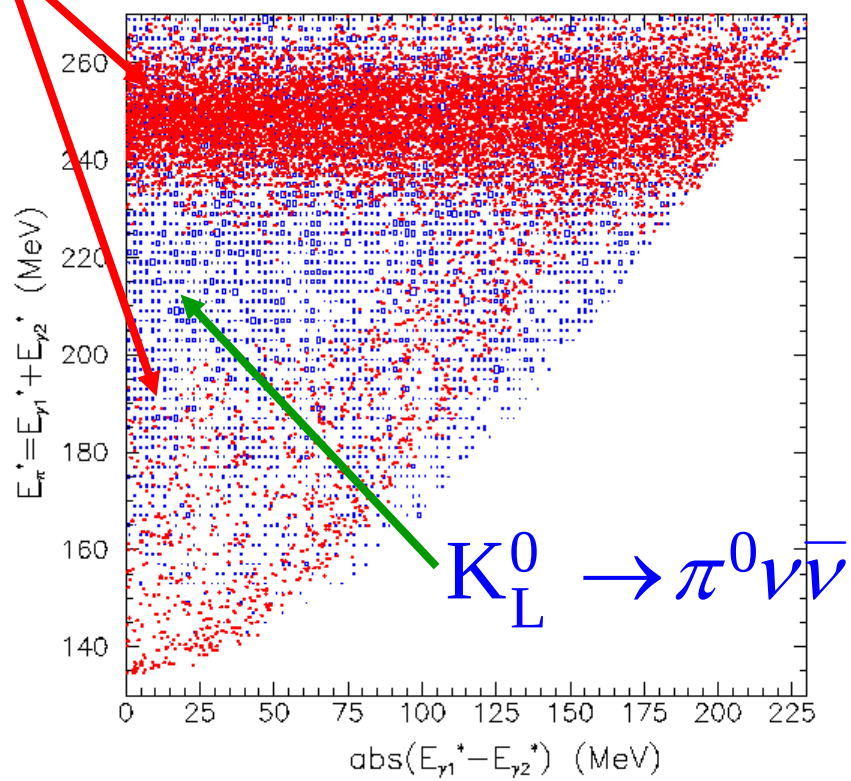
Separating signal from background

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

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

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

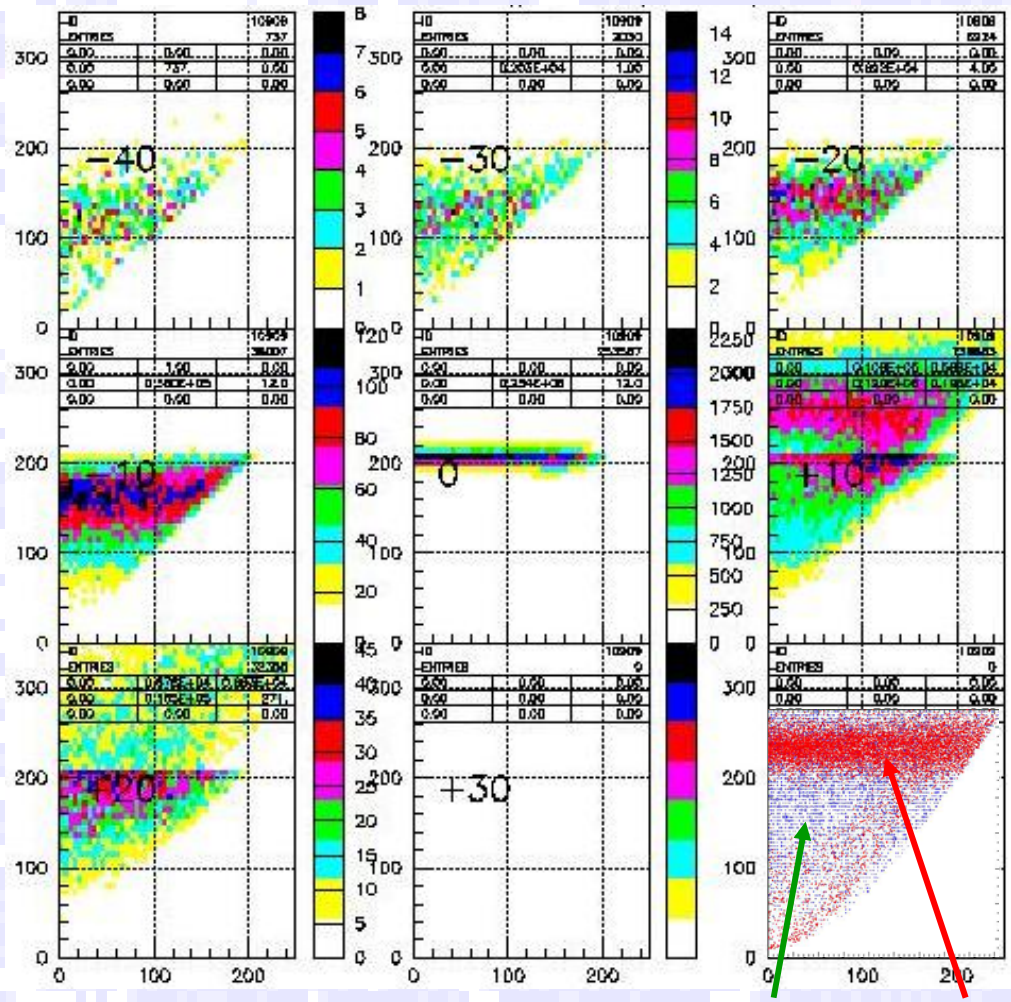
Effects of Interbunch Kaons

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



8-GeV Beam Requirements for Kaon Experiments

- **High Duty Factor.**

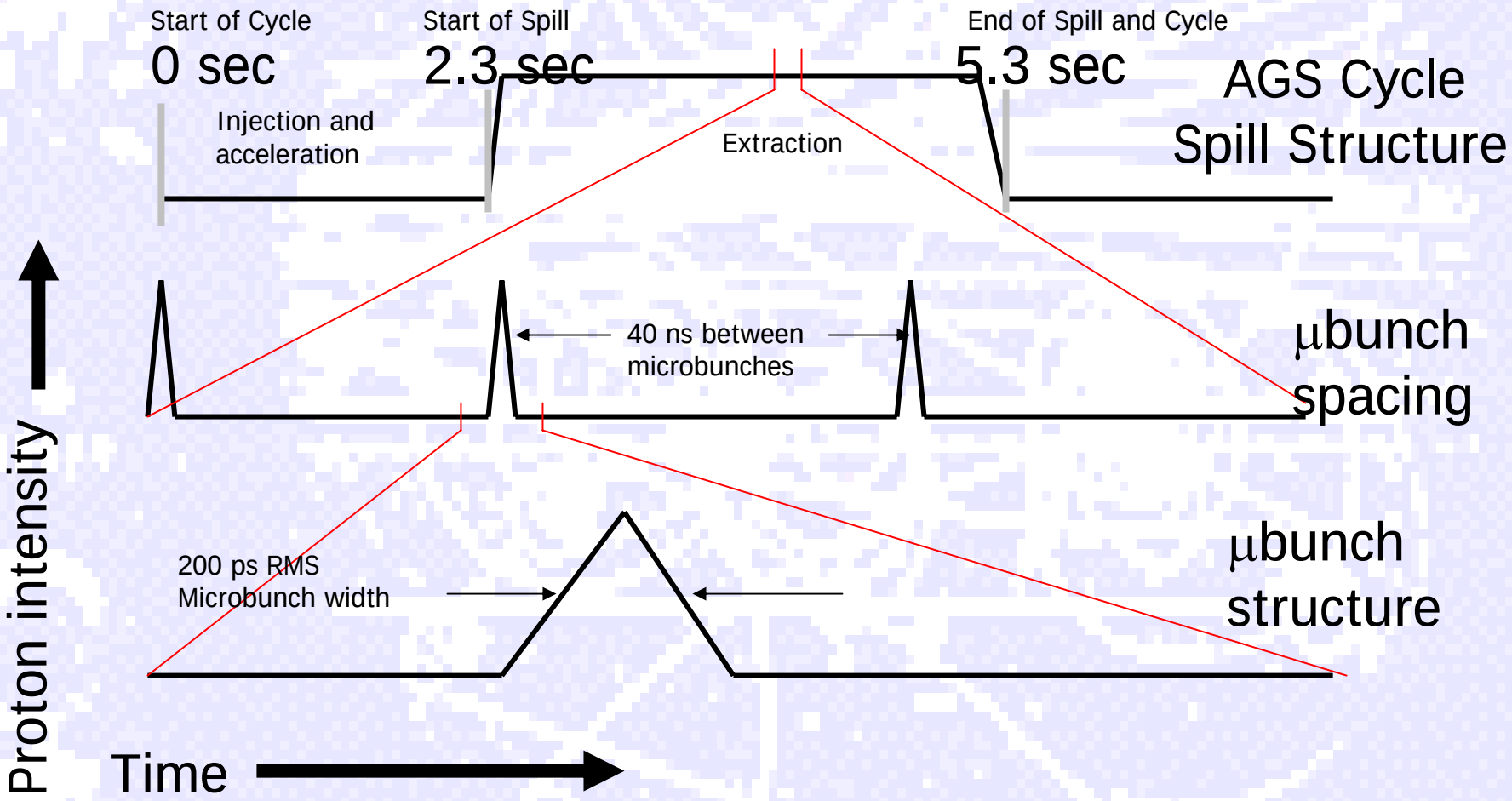
- **High Power 8-GeV Target Station. Stage-I 20 kW, Stage-II 200 kW.**

  Can the same target station drive both the charged and neutral experiments?.....Why Not??

- **RF Train:**

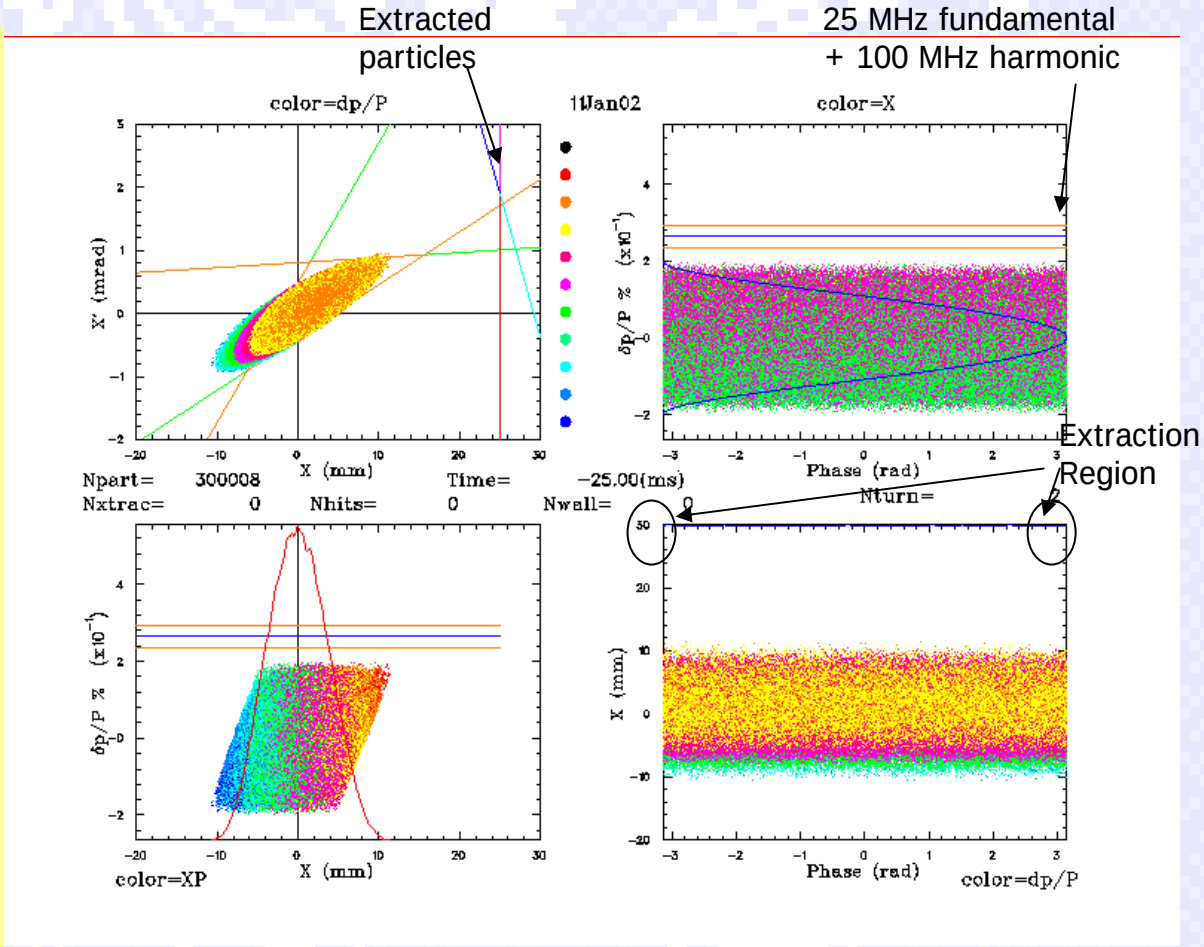
✓ 38 nsec pulse spacing
✓ 10^{-3} extinction outside of +/- 2 nsec from ping core.
✓ 100 psec ping sigma (goal).

Structure AGS of Beam



Microbunching the AGS Beam

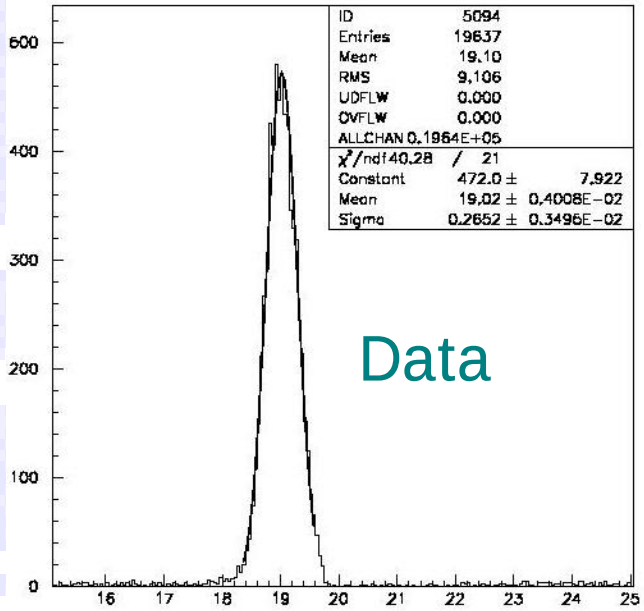
- Simulation of the extraction process for 25+100 MHz RF cavities.
- Impose a high frequency longitudinal oscillation on the beam.
- Slowly bring the beam into resonance ($8^2/_3$) with RF.
- Beam is forced through the narrow phase region between the RF buckets.
- Adding the 100MHz harmonic cavity sharpens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



Test Beam Results: Microbunch Width

Data

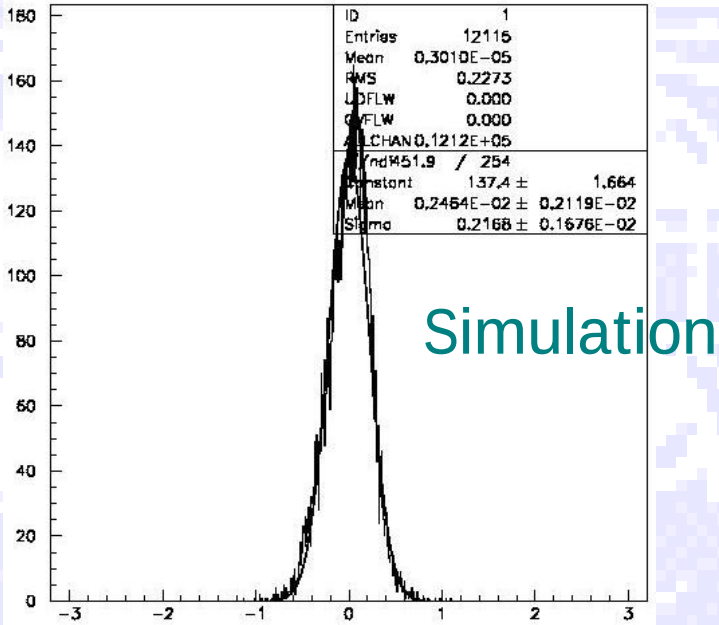
93 MHz cavity at 22 kV gave σ = 240 ps.



Microbunch time, in ns

Simulation

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

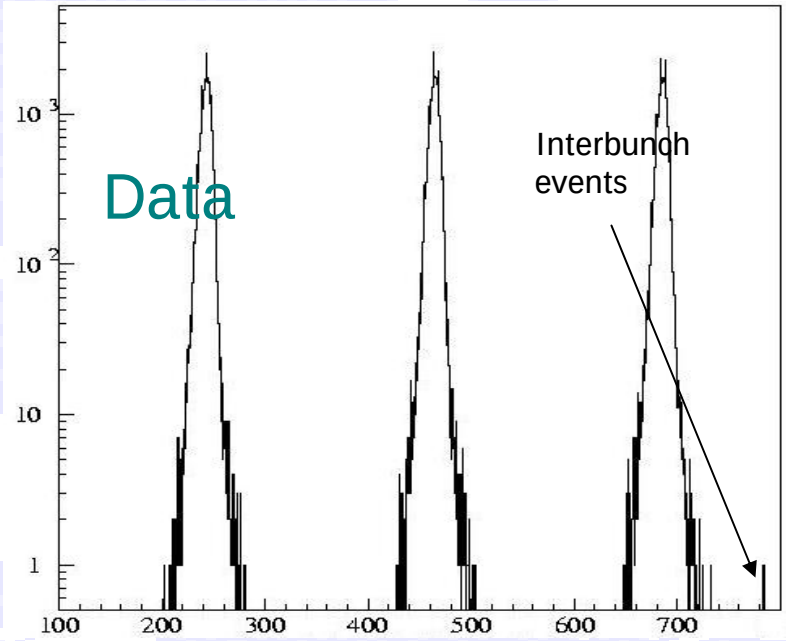


Microbunch time, in ns

AGS Test Beam Results: Interbunch Extinction

Data

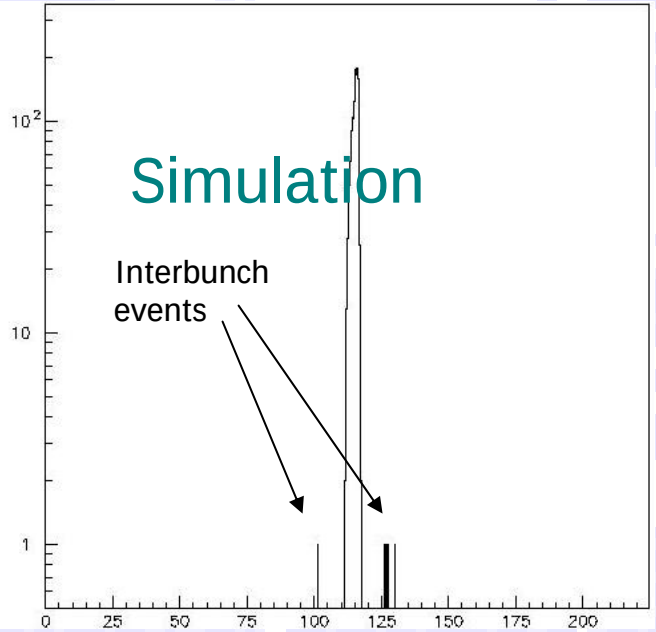
4.5 MHz cavity at 130 kV gave $\varepsilon = 8$ (+/- 6) x 10^{-6}



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

What you can do for the Project-X Kaon Physics Program...

- Develop the conceptual design for the high duty factor, high power, and unique RF systems required for the physics. Such a facility would be the leading world class platform for next generation rare decay experiments.

- Participate in the next workshop ! (January 25th & 26th 2008)

Spare Slides

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.