RSVP Extinction Conference
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KOPIO Specifications for Extinction: Simulation and Measurement

Michael Sivertz

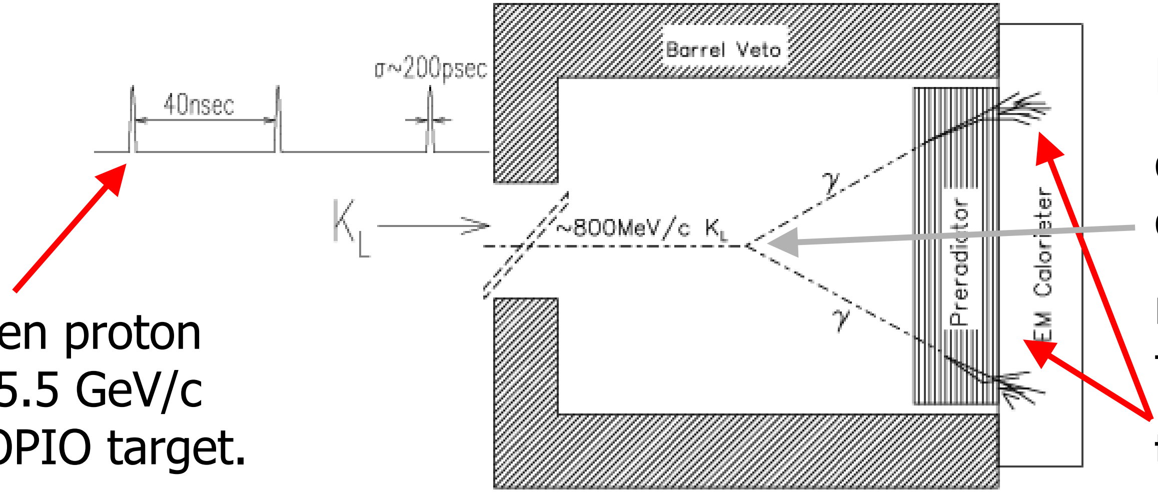
BROOKHAVEN NATIONAL LABORATORY

KOPIO Extinction

- Description of Experiment/Beam
  - Why microbunching matters
  - Why extinction matters
- Description of Simulation
- Description of Test Beam Results
- Where do we go from here?

Description of Experiment/Beam

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

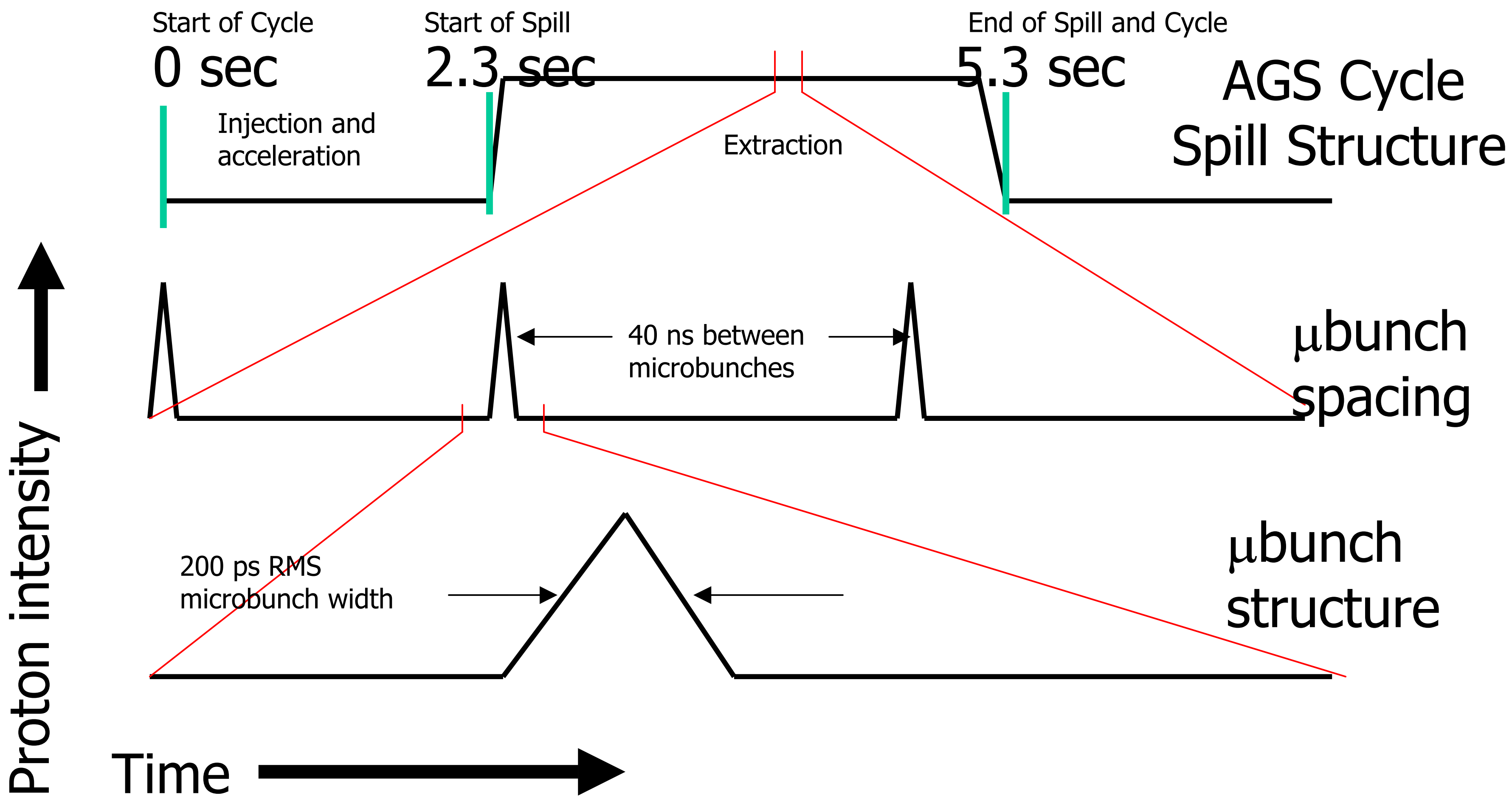


START when proton beam of 25.5 GeV/c hits the KOPIO target.

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

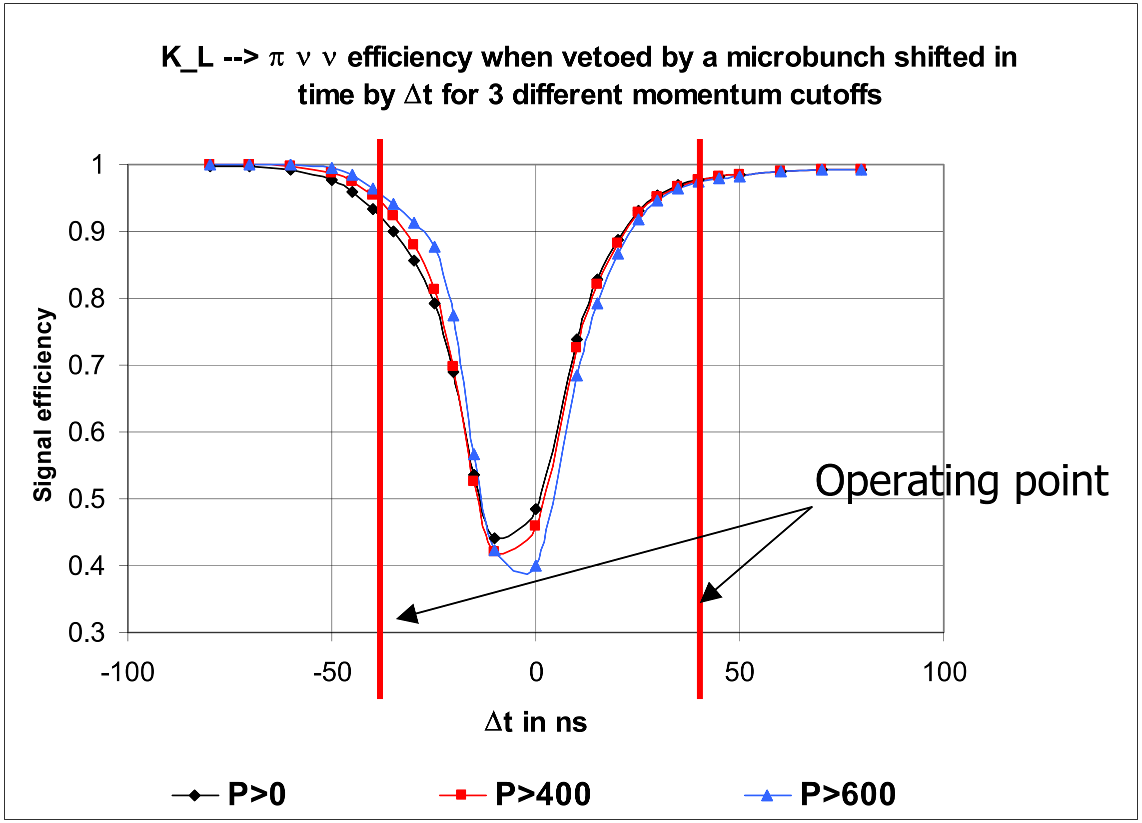
Description of Experiment/Beam: Time Structure of Beam



Description of Experiment/Beam: Microbunch Separation

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)



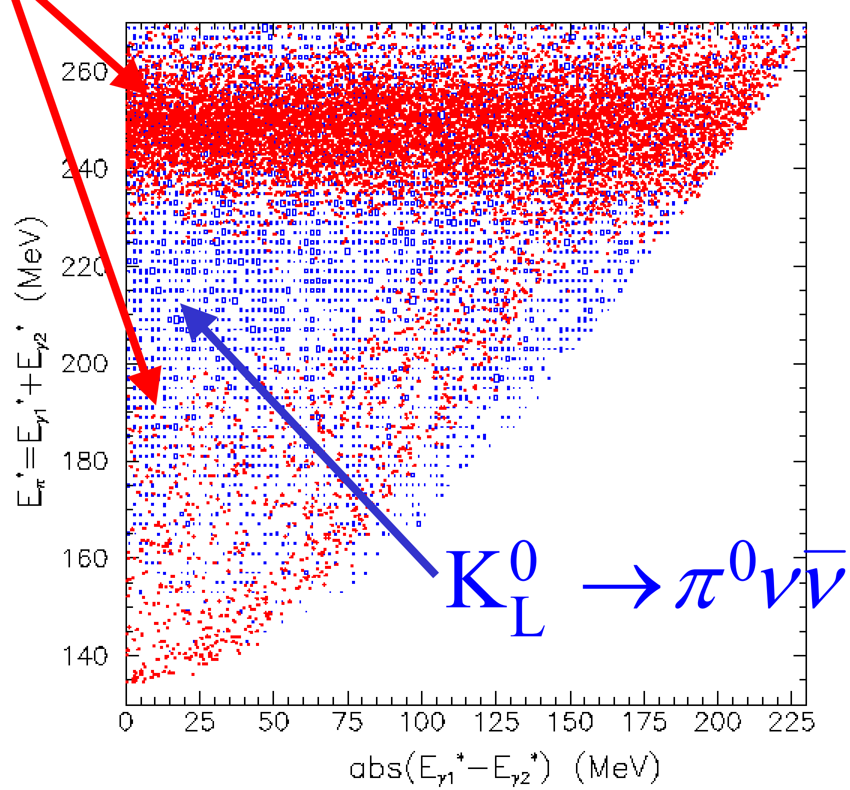
Signal efficiency drops when neighboring microbunch is too close

Description of Experiment/Beam: 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 us kinematical 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.



Description of Experiment/Beam: Interbunch Extinction

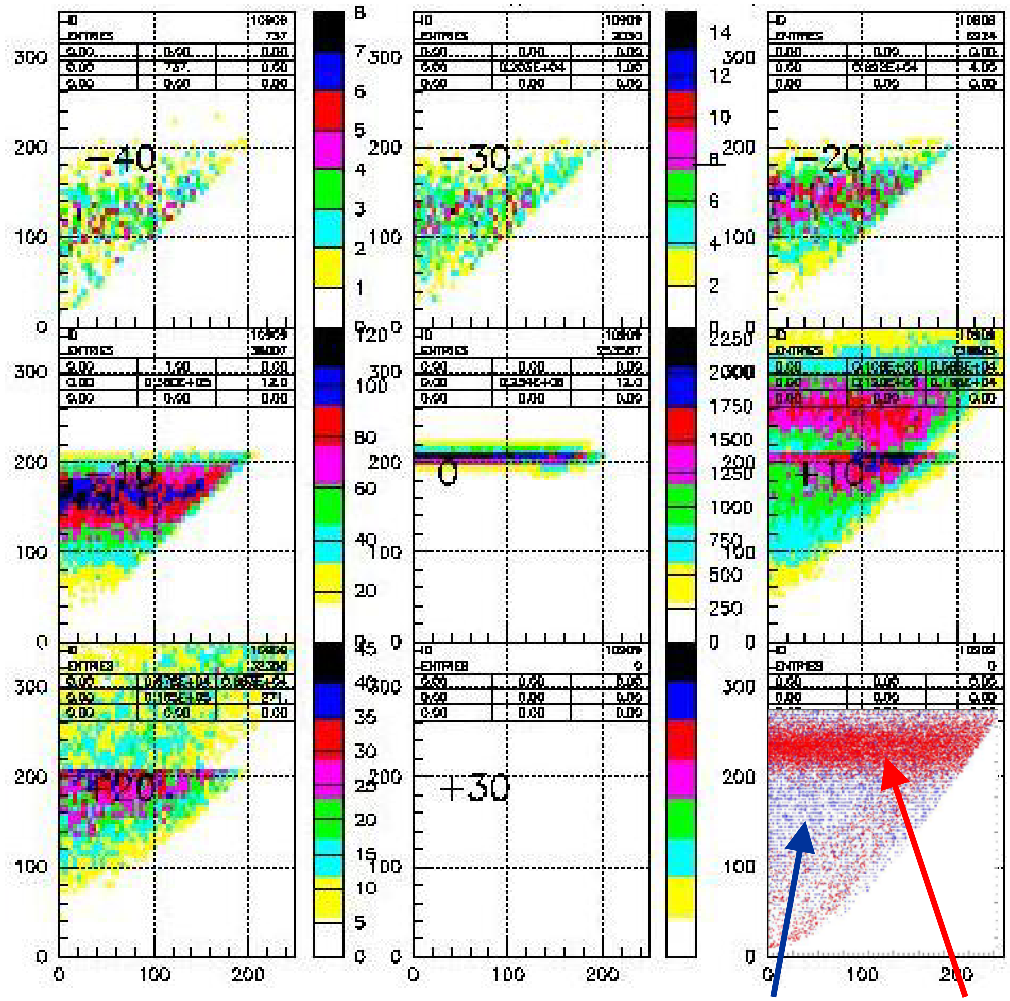
Effects of Interbunch Kaons

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.

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

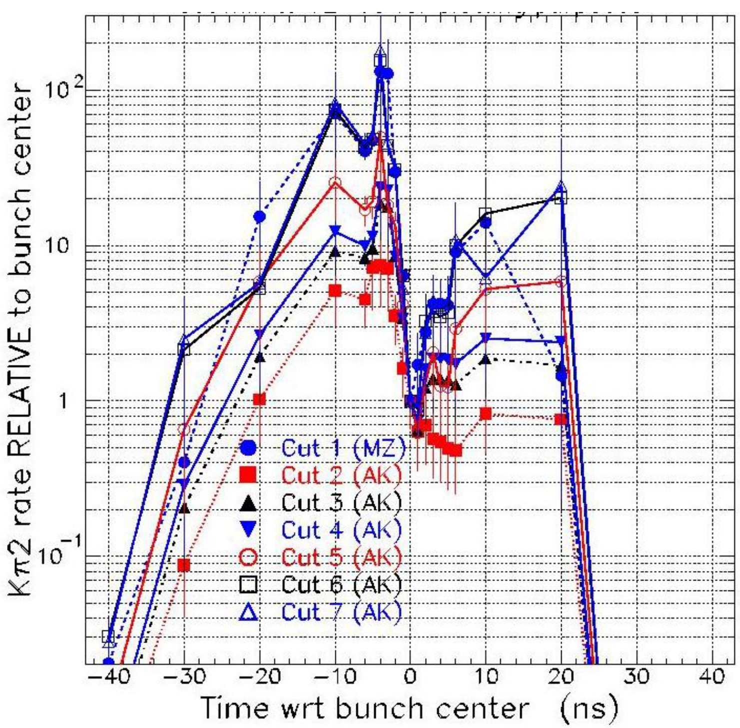
$P^*(\pi)$

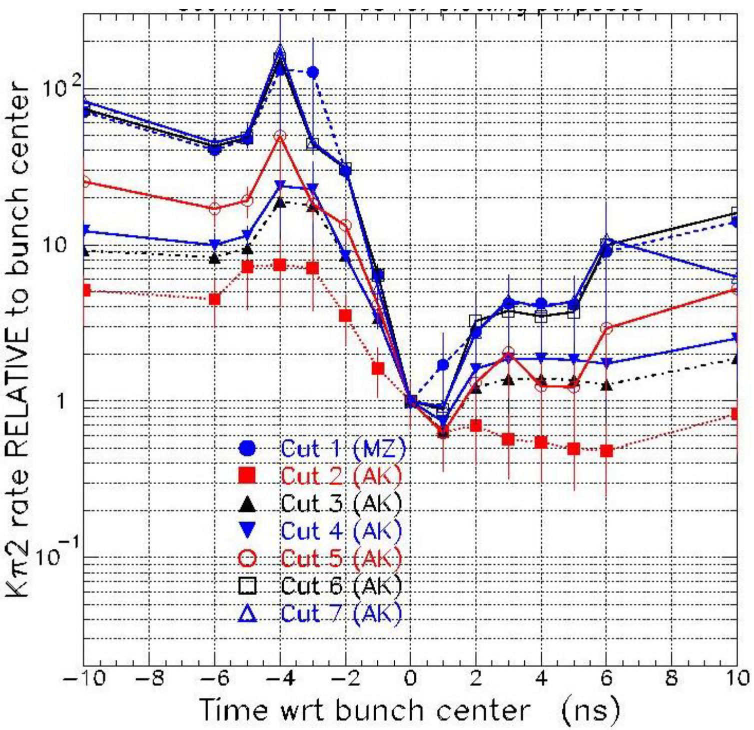


$E^*(\gamma 1) - E^*(\gamma 2)$

Signal and $\pi^0\, \pi^0$

Description of Experiment/Beam: Interbunch Extinction





These figures show, in coarse and fine time binning, the loss of kinematical rejection power for background events as a function of the time for a proton hitting the target relative to the nominal microbunch center (from TN052).

Description of Experiment/Beam: KOPIO Beams requirements

- Primary Proton Beam Momentum 25.5 GeV/c
- Spill length with 100TP of ~3 seconds.
- Number of K_L decays per microbunch: 3.57
  - Yields ~0.5 K_L decay in $10 < Z < 14$ meters
  - Both are a flat optimum
- Variation of intensity between microbunches only impacts total run time (duty factor)
- Microbunch rms < 300psec (goal 200psec)
- Number of protons outside microbunches $< 10^{-3}$ inside microbunches ($\pm$ 1 nsec)

Description of Beam Simulation: SLEX-Long1D

- SLEX-Long1D is a simulation of a slow extraction system employing chromatic 1/3 integer betatron resonance driven by sextapole magnets.
- 2+2 dimensions, Longitudinal s and s′, Transverse, x and x′. (y,y′ not considered)
- Longitudinal and Transverse motion is not explicitly coupled. Only chromatic dependencies of tune, ν, and lattice functions couple the two, x and s.

Description of Simulation (contin)

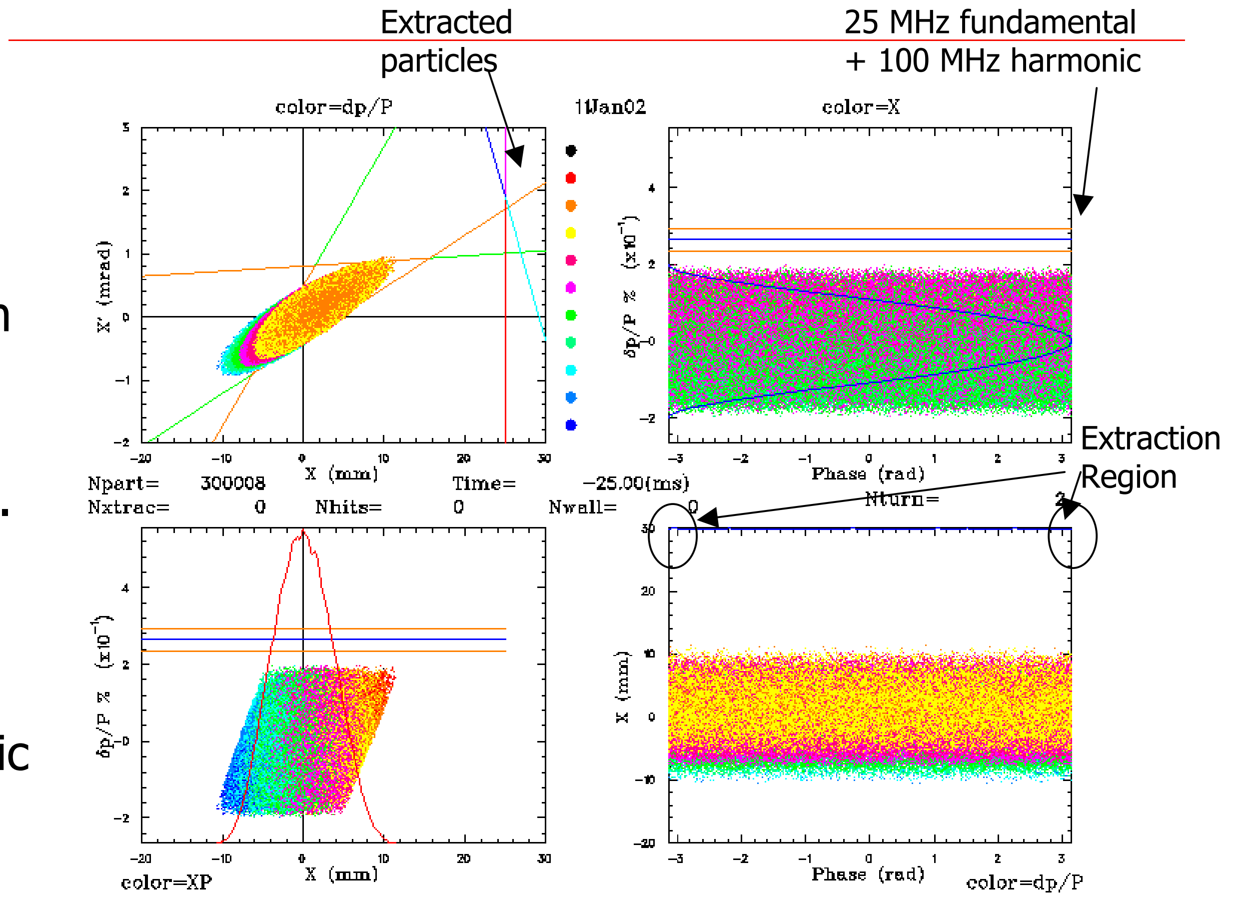
Hamiltonian-based integrator (does not make use of beam elements).

Deviations from the “ideal” synchronous equilibrium orbit are tracked; variables are momentum Δp, RF phase $\Delta\phi$, tune shift $\Delta\nu$, coordinates Δx, Δs, $\Delta x'$, $\Delta s'$.

Each integration represents “once around the ring”. Integration is “symplectic” or preserving of area in phase space.

Description of Beam Simulation: Microbunching the AGS Beam

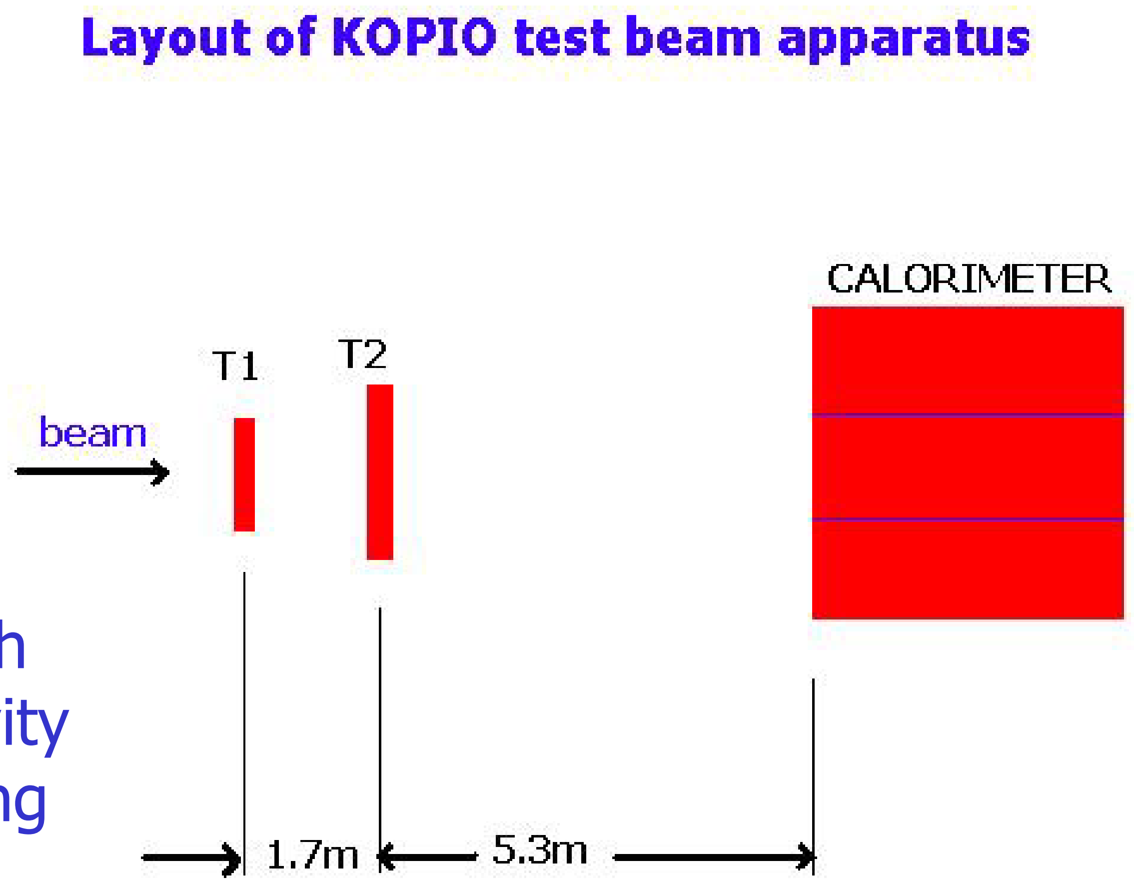
- Simulation of the extraction process for 25+100 MHz RF cavities.
- Impose a high frequency longitudinal oscillation on the beam.
- Slowly bring the beam into resonance ($8^2/_3$) with RF.
- Beam is forced through the narrow phase region between the RF buckets.
- Adding the 100MHz harmonic cavity sharpens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



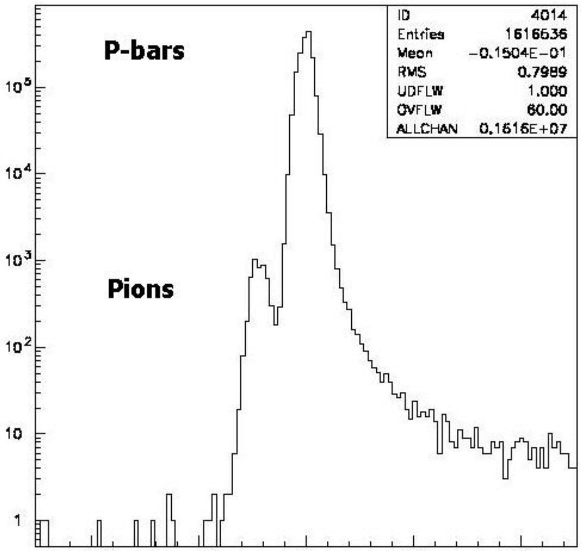
KOPIO Test Beam Set-Up

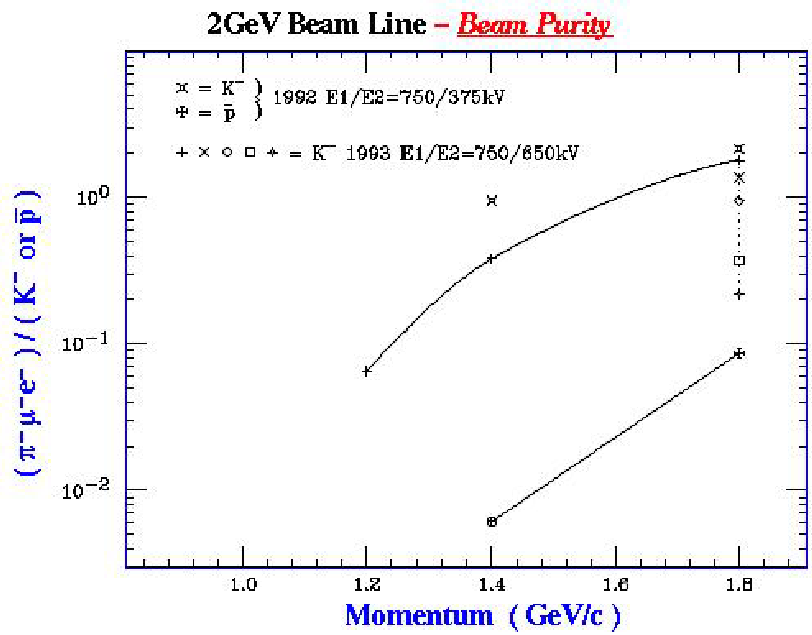
1.4 GeV/c
$\bar{p}$ beam

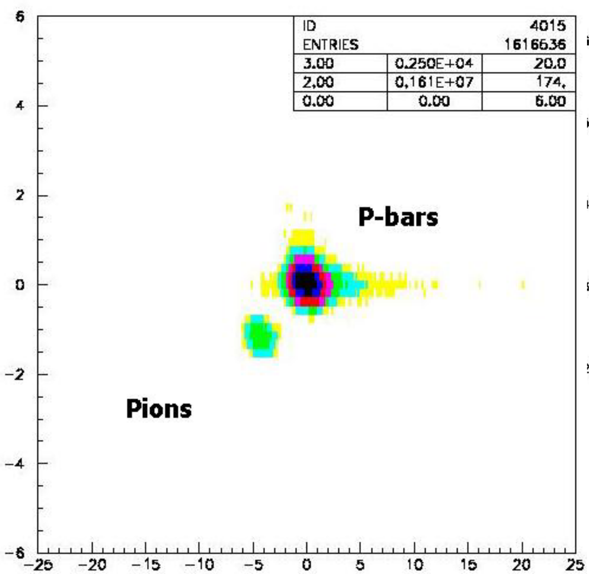
Running with
4.5 MHz cavity
for μbunching

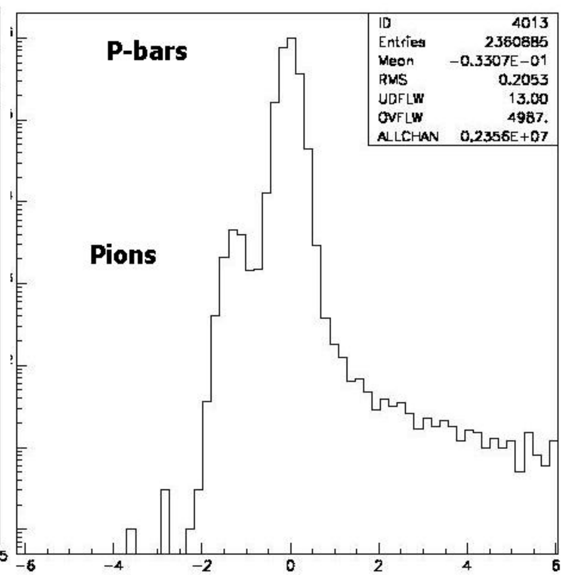


D-6 Beam Purity







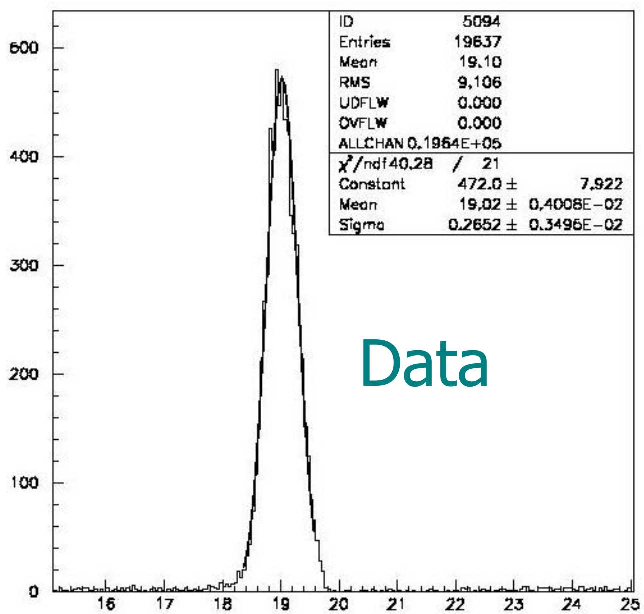


TOF(TCAL-T2)

TOF(T2-T1)

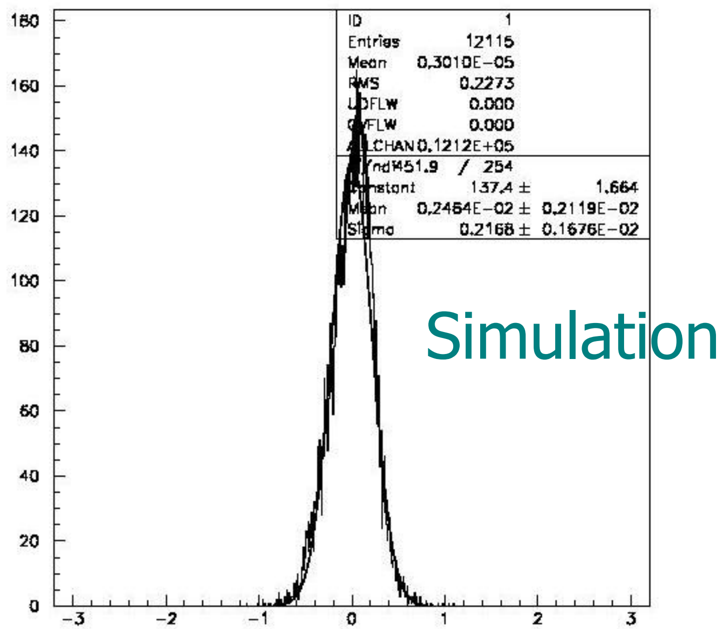
Test Beam Results: Microbunch Width

2002 test beam result
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.

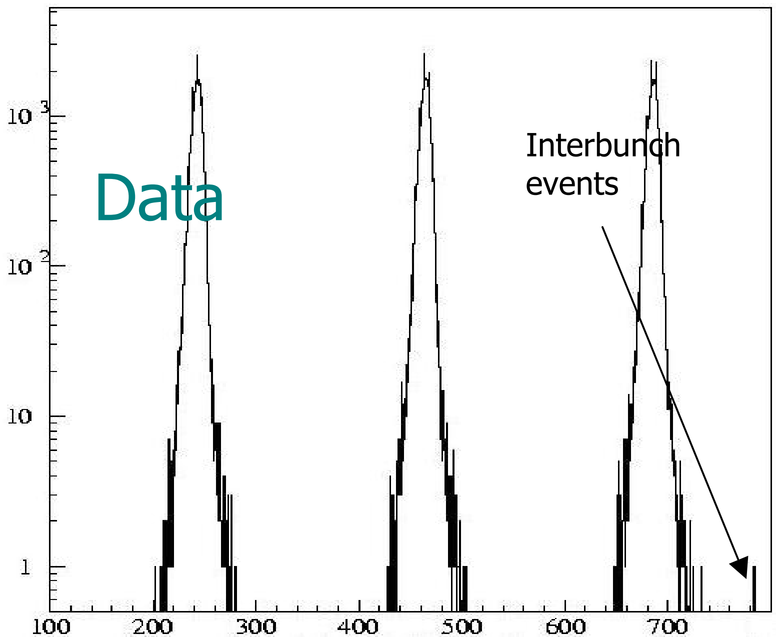


Microbunch time, in ns

Test Beam Results: Interbunch Extinction

2004 Test Beam Result

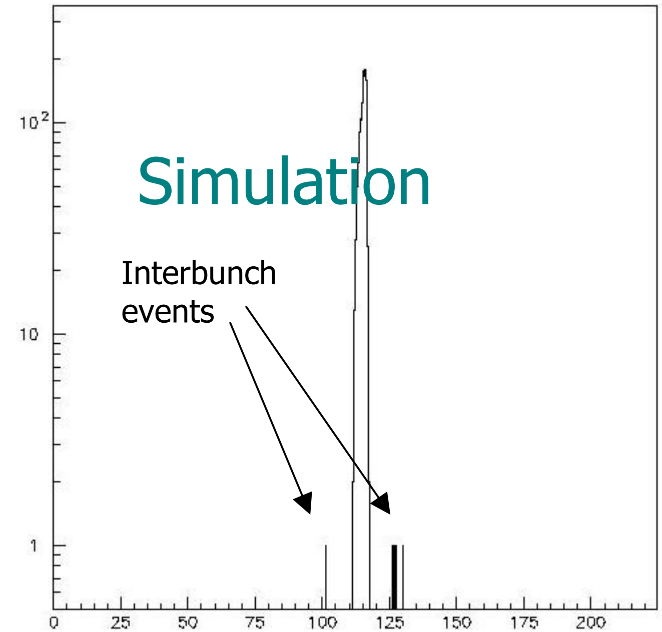
4.5 MHz cavity at 130 kV gave $\varepsilon = 8\ (+/-\ 6) \times 10^{-6}$



Microbunch time, in ns

Simulation

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



Microbunch time, in ns

Where do we go from here?

- Add a 25 MHz 150 kV RF cavity to AGS Ring to provide the 40 ns microbunch spacing and preliminary microbunch width structure.
- Construction of 25 MHz cavity complete ~18 months after funding starts (Spring 2007)
- Installation during 2007 summer shutdown.
- Commissioning in spring 2008.
- Add a 100 MHz 150 kV harmonic RF cavity "afterburner" for very narrow microbunch width.
- Construction starts, if necessary, after 2008 test beam measurements of 25 MHz width and extinction.
- Effect of high intensity still an open question!

Beam Development Schedule

FY	AGS Beam Development	Shifts	KOPIO Beam Use	Shifts
2006	Improve injection	15		
2007	Intensity study, BtA transfer	15		
2008	Extraction study, Intensity study, Commission 25 MHz	25	Neutral Beam development, Intensity study of microbunching And detector development.	100
2009	High intensity microbunching,	20	Commission 100 MHz cavity, Extinction study, Prototype detector study, Neutral Beam Development	70
2010			High intensity engineering run	100

Summary

- Demonstrated *Proof of Principle* for both microbunch width and interbunch extinction, with both experimental data and simulations
- Next phase requires the new hardware (RF cavities and kickers) and a planned program of commissioning with beam, focusing on achieving *simultaneous* high intensity running and microbunching with good extinction.
- Simulation development still has much work to be done before fully understood.