KOPIO Specifications for AGS Performance

AGS-RSVP Review

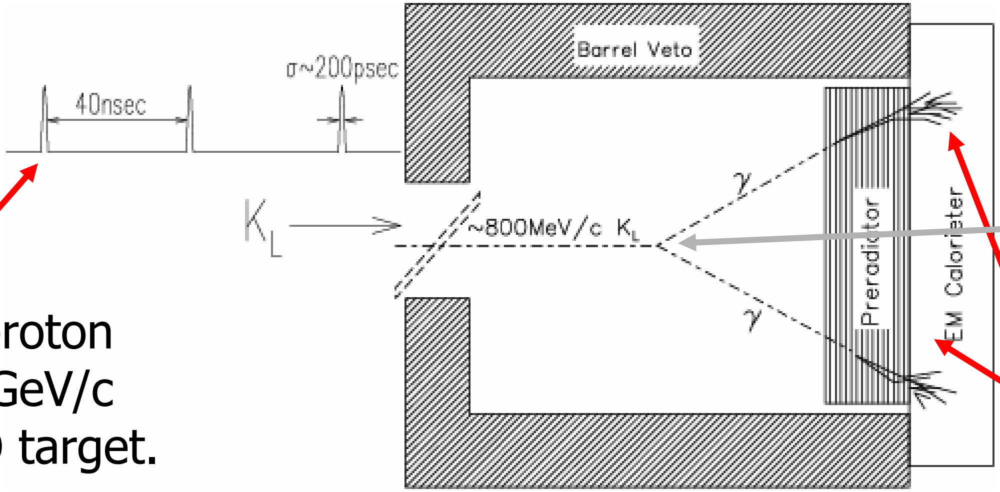
4-5 November 2004

Kopio

BROOKHAVEN NATIONAL LABORATORY

Physics Motivation: Microbunch Width

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.

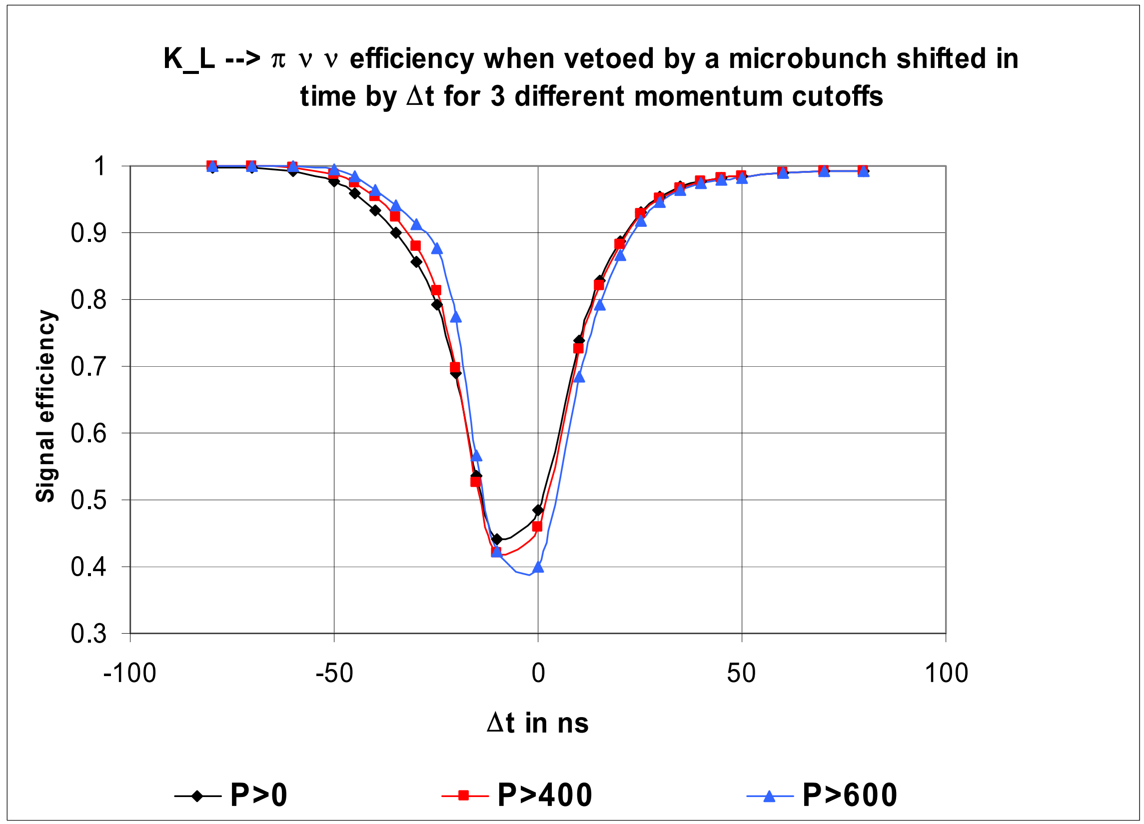
End at the decay time and decay point reconstructed from the two photons.

Timing uncertainty due to microbunch width should not dominate the measurement of the kaon momentum; requires RMS width < 300ps

Physics Motivation: 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)



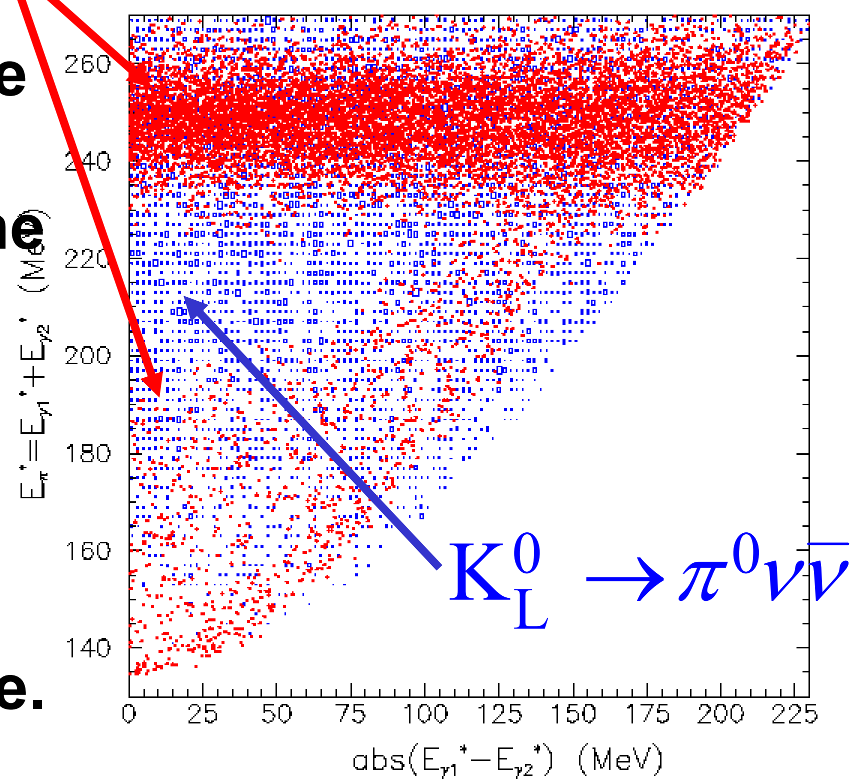
Signal efficiency drops when neighboring microbunch too close

Separating signal from background

$K_L^0 \to \pi^0\pi^0$

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

Microbunching is crucial to the measurement of the kaon momentum which allows us the 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

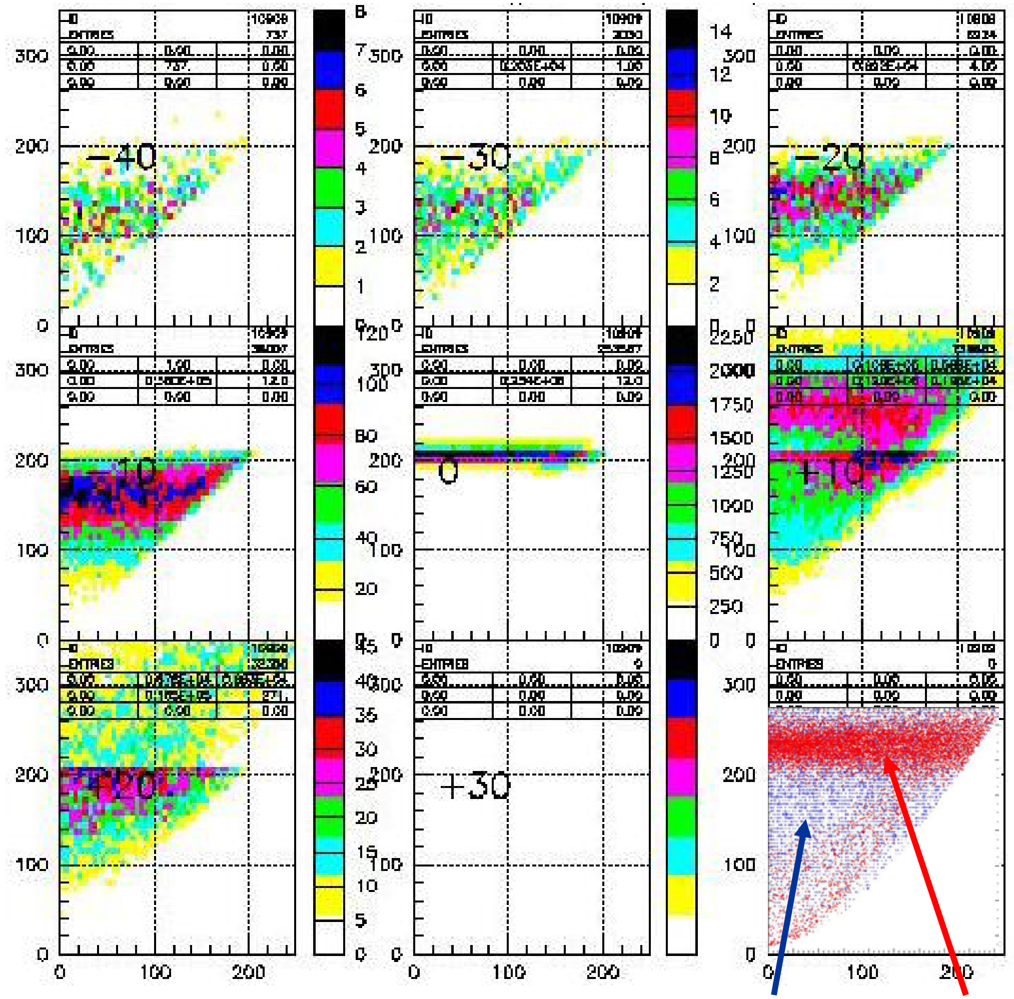
Effects of Interbunch Kaons

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*(π)



E*(γ1) – E*(γ2)

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

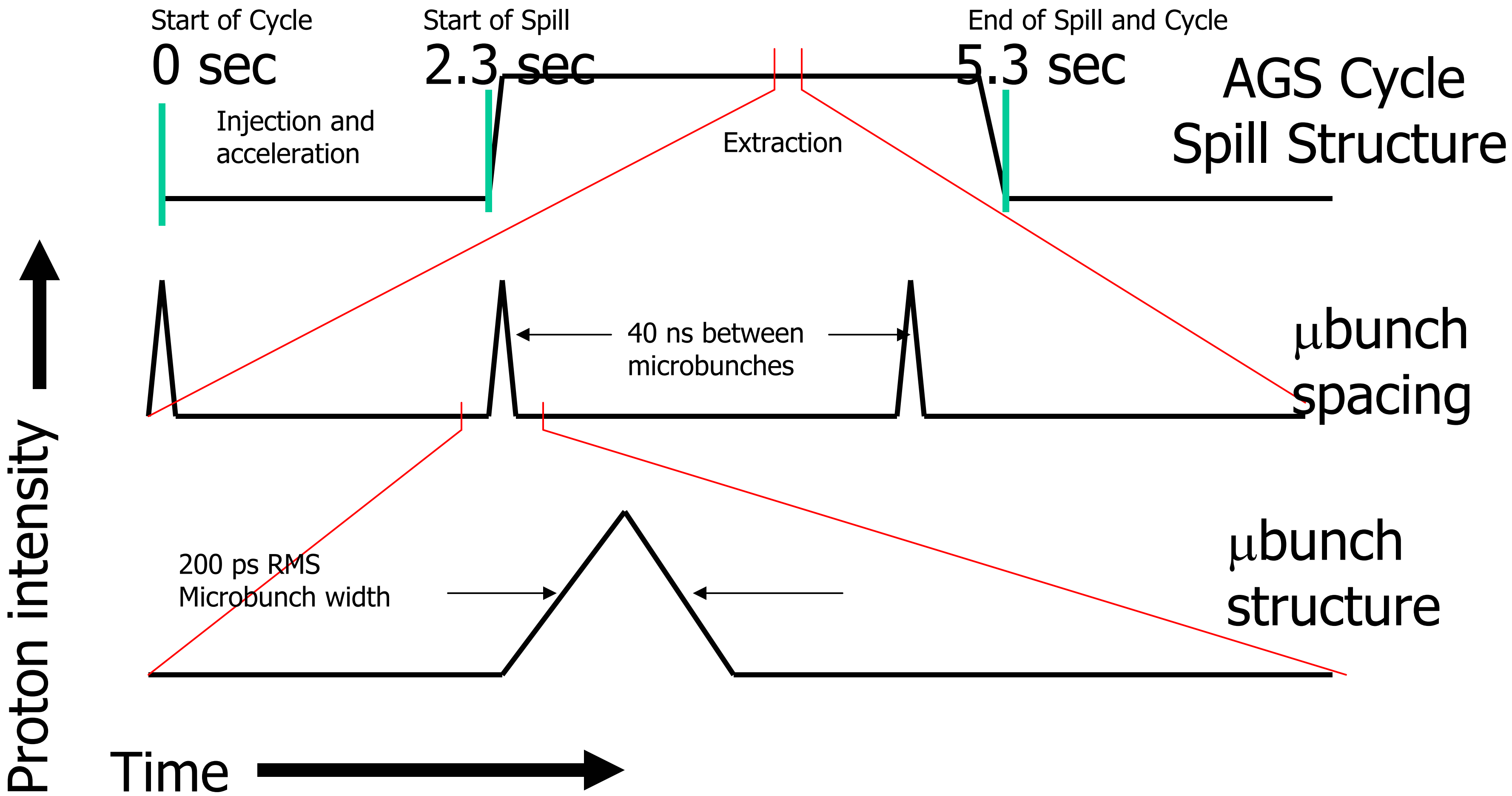
Physics Motivation: Intensity

- KOPIO studies the very rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$ which has a BR = $3\text{x}10^{-11}$.
- The goal is to collect ~100 events with a S/B > 2/1.
- This requires more than 1.5 $\text{x}10^{14}$ decays and for cleanliness we want ~0.5 decay/spill in the decay region.
- Optimization of duty factor and running time indicates 100Tp/spill.

KOPIO Beams requirements

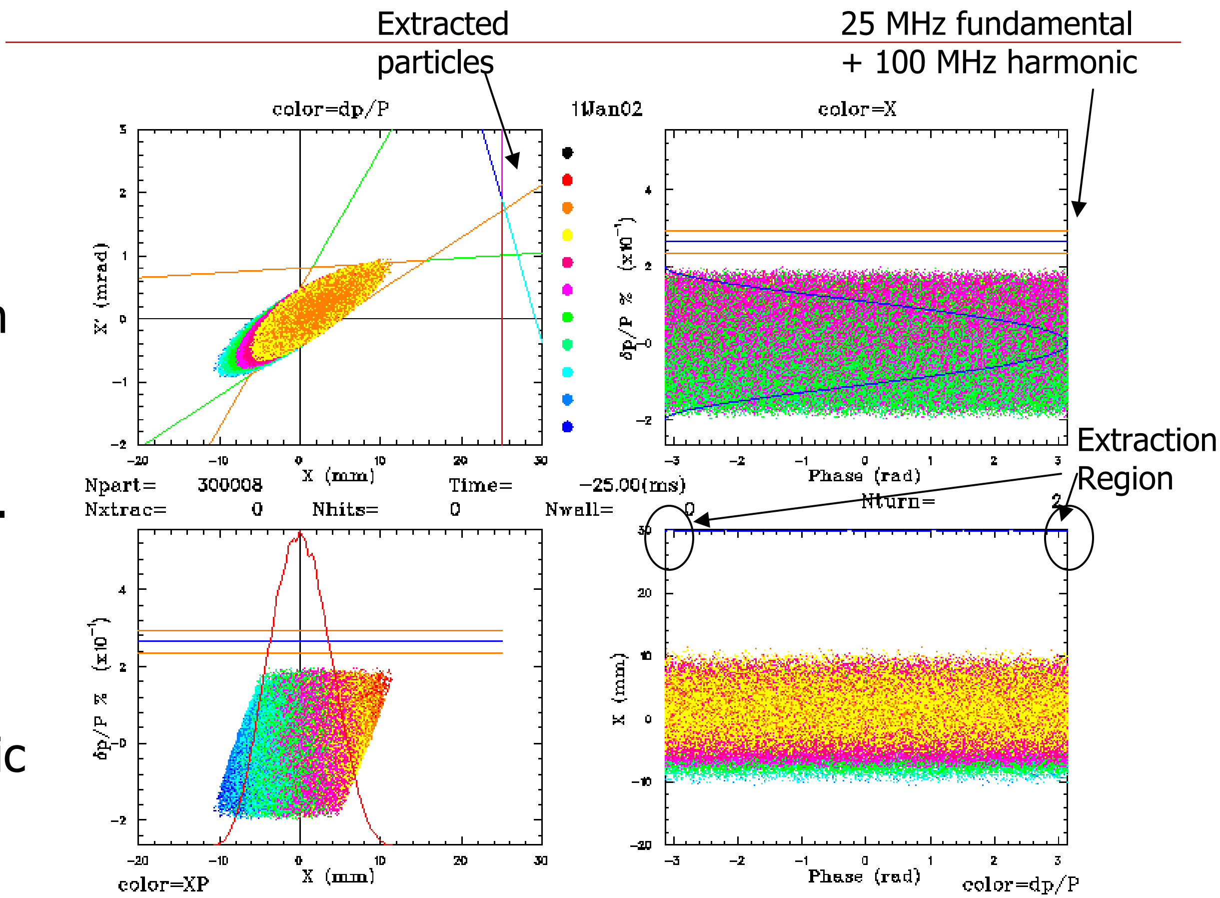
- Primary Proton Beam Momentum 25.5 GeV/c
- Spill length with 100TP of ~3 seconds.
- Number of K_L decays per microbunch: 3.57
  - Yields ~0.5 K_L decay in $10 < Z < 14$ meters
  - Both are a flat optimum
- Variation of intensity between microbunches only impacts total run time (duty factor)
- Microbunch rms < 300psec (goal 200psec)
- Number of protons outside microbunches $< 10^{-3}$ inside microbunches ($\pm$ 2 nsec)

Time Structure of Beam



Microbunching the AGS Beam

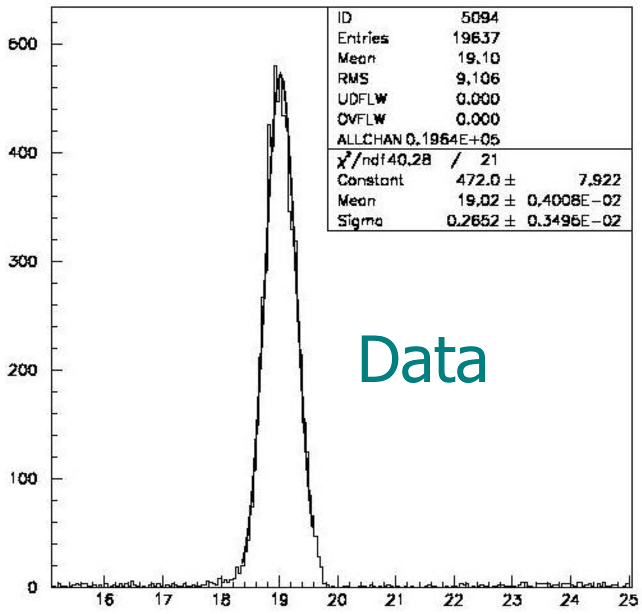
- Simulation of the extraction process for 25+100 MHz RF cavities.
- Impose a high frequency longitudinal oscillation on the beam.
- Slowly bring the beam into resonance ($8^2/_3$) with RF.
- Beam is forced through the narrow phase region between the RF buckets.
- Adding the 100MHz harmonic cavity sharpens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



Test Beam Results: Microbunch Width

2002 test beam result

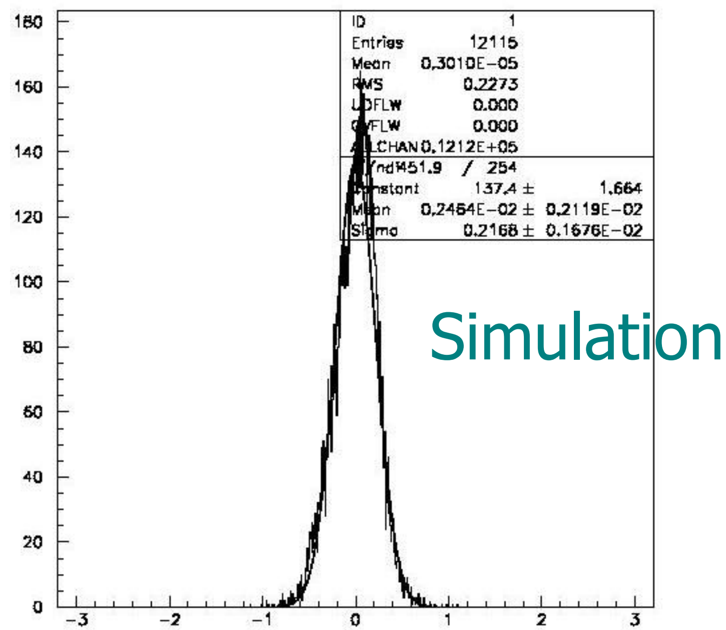
93 MHz cavity at 22 kV gave σ = 240 ps.



Microbunch time, in ns

Simulation

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

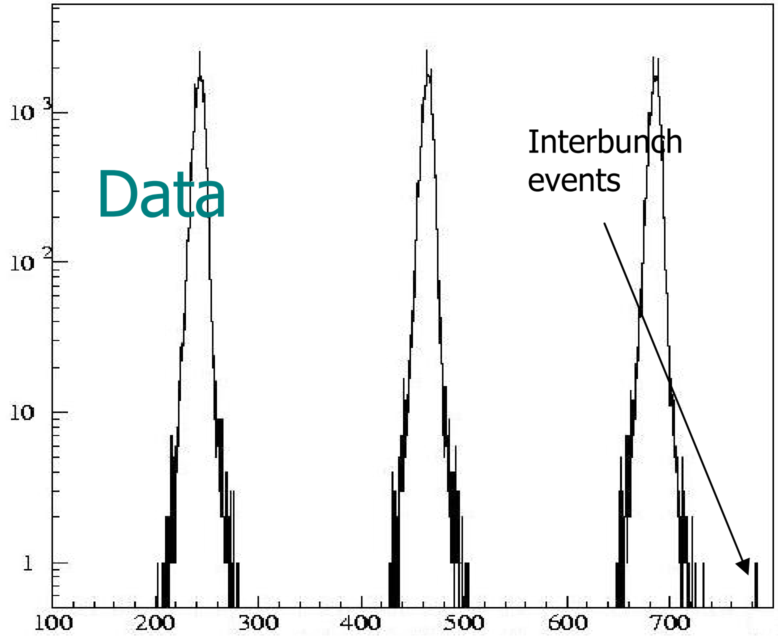


Microbunch time, in ns

Test Beam Results: Interbunch Extinction

2004 Test Beam Result

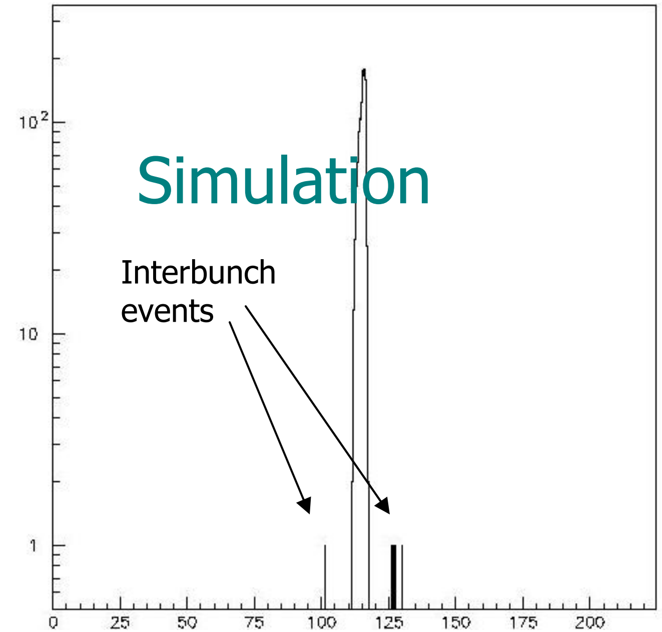
4.5 MHz cavity at 130 kV
gave $\varepsilon = 8$ (+/- 6) x 10^{-6}



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

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.

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.

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.

Beam Development Schedule

FY	AGS Beam Development	Shifts	KOPIO Beam Use	Shifts
2006	Improve injection	15		
2007	25 MHz extraction, 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* higher intensity running and microbunching.
- Beam program integrates achieving requisite AGS performance, testing of new neutral beam, and testing of detector components.

Back-up slides follow:

Current design: RF

Specification of 25 MHz cavity is well understood.
Equipment - TRIUMF

- **25 MHz cavity including prototype, HOM dampers, coupling loop, ceramic window.**
- **RF Amplifier (including tetrode) and its power supplies (plate, screen, and bias).**
- **Impedance reduction circuitry to be integrated with cavity and amplifier.**
- **Mechanical trolley for servicing of amplifier.**
- **30 kW dummy load for amplifier tests.**
- **Ferrite tuner including its power supplies and local control circuitry**
- **Minimal set of cavity local controls for voltage regulation and tuning**

Current design: RF

Equipment - BNL

- **RF Driver - to be shipped to TRIUMF**
- **Fast feedback, integration into main controls, low-level RF for beam control and synchronization.**
- **Cabling and services.**

Equipment - Both

- ***Vacuum pump*. Issue: for testing purposes only a turbomolecular pump is needed; but an ion pump is required for AGS operations. Vacuum level at BNL AGS is 10^{-7} torr, but for RF testing at TRIUMF, specification is less stringent.**
- ***Water cooling*. TRIUMF to provide basic plumbing for c.w. power test.**

RF specifications: 25 MHz cavity

Cavity centre frequency: 24.8694 MHz (67th harmonic of revolution frequency).

Gap voltage: Design to 300 kV,

Expected operating voltage 150 kV.

Mechanical Design: BNL to specify flange-to-flange dimension and lateral space available in AGS tunnel.

Insertion length: 101 in (2.56 m)

Vertical space: down/up 24 in (61 cm)/48 in (122 cm)

Horizontal space: in/out 36 in (91 cm)/48 in (122 cm)

RF Mechanical specifications

Coupling loop: solid copper and water cooled.

HOM dampers: copy the BNL 28 MHz designs (high pass filter type) which were fabricated for RHIC by *Continental Electronics*, but adapted to 25 MHz.

Active impedance reduction by fast feedback (BNL): reduce gap impedance from 1 MΩ to 10 kΩ.

Cooling Water: separate cooling water supplies for cavity and power amplifier. Inner and outer conductors of the cavity are water cooled. Water cooling of the cavity is a closed loop system with heat exchanger. Water temperature should be maintained within ±5°F; pressure to be controlled also.

Dummy load: This equipment is comprised of a quarter wave transformer (at 25 MHz) from 1 kΩ to 10 Ω and a water-cooled resistive load.

RF Power amplifier

Amplifier is to be directly mounted on the cavity. Any length of transmission line between the amplifier and the cavity should be avoided.

The amplifier is coupled to the cavity by an inductive loop.

The amplifier will operate with quiescent plate dissipation of 60 kW (12 kV, 5A).

The cavity power requirement is around 50 kW.

Hence total input power to the amplifier is 110 kW.

RF Power amplifier

A sliding trolley on rails is to be designed to install and service the amplifier on top of the cavity This is a major mechanical engineering job, and must be consistent with space limitations.

A mechanical system will connect an external low impedance load to the anode circuit of the amplifier when the amplifier is non operational. The impedance transformed to the cavity should be of the same value as with fast feedback, i.e. 10 kΩ.

Passive impedance reduction at fundamental: 40 dB. The power rating of this low impedance anode circuit is to be based on a circulating beam current of up to 1.2 Amp at 25 MHz.

RF Tetrode

Tetrode: Eimac 4CW150,000-V57B For ease of installation and connection, make sure to purchase model with same water jacket dimensions as those of existing RHIC cavity.

Power supplies: 480 volt *Universal Voltronics*, 3 phase, 300 Amp/phase was mentioned.

RF Tuning

The accelerating gap dimension is a free parameter for bringing the cavity design frequency down from 28 to 25 MHz.

Fixed tuning: part of the mechanical design and used to compensate for manufacture and assembly tolerances; range to be determined by TRIUMF.

Ferrite tuner: ±10 kHz with resolution of 1%, slew rate up to 1 Hz/millisecond. Ferrite tuner consists of a stripline partially filled with microwave ferrite and coupled to the cavity.

RF Ceramic Window

An RF window employing a disk ceramic is preferred by BNL. Although a tubular ceramic may be superior with regards to RF characteristics, a disk ceramic window was chosen for mechanical considerations and few failures due to multipacting.

The 18″ diameter uncoated ceramic disk window is fabricated without any brazing.

The window is air cooled.

RF System Action Items

R&D Program at TRIUMF

- Build a model 25 MHz cavity of wood + copper

At BNL

- Drawings of BNL standard vacuum flange and seal.
- Engineering note on HOM dampers.
- Alex Zaltsman overseeing RF work in contact with Amiya Mitra at TRIUMF.
- More simulation work required (added processing farm at C-A) to explore need for 100 MHz cavity.

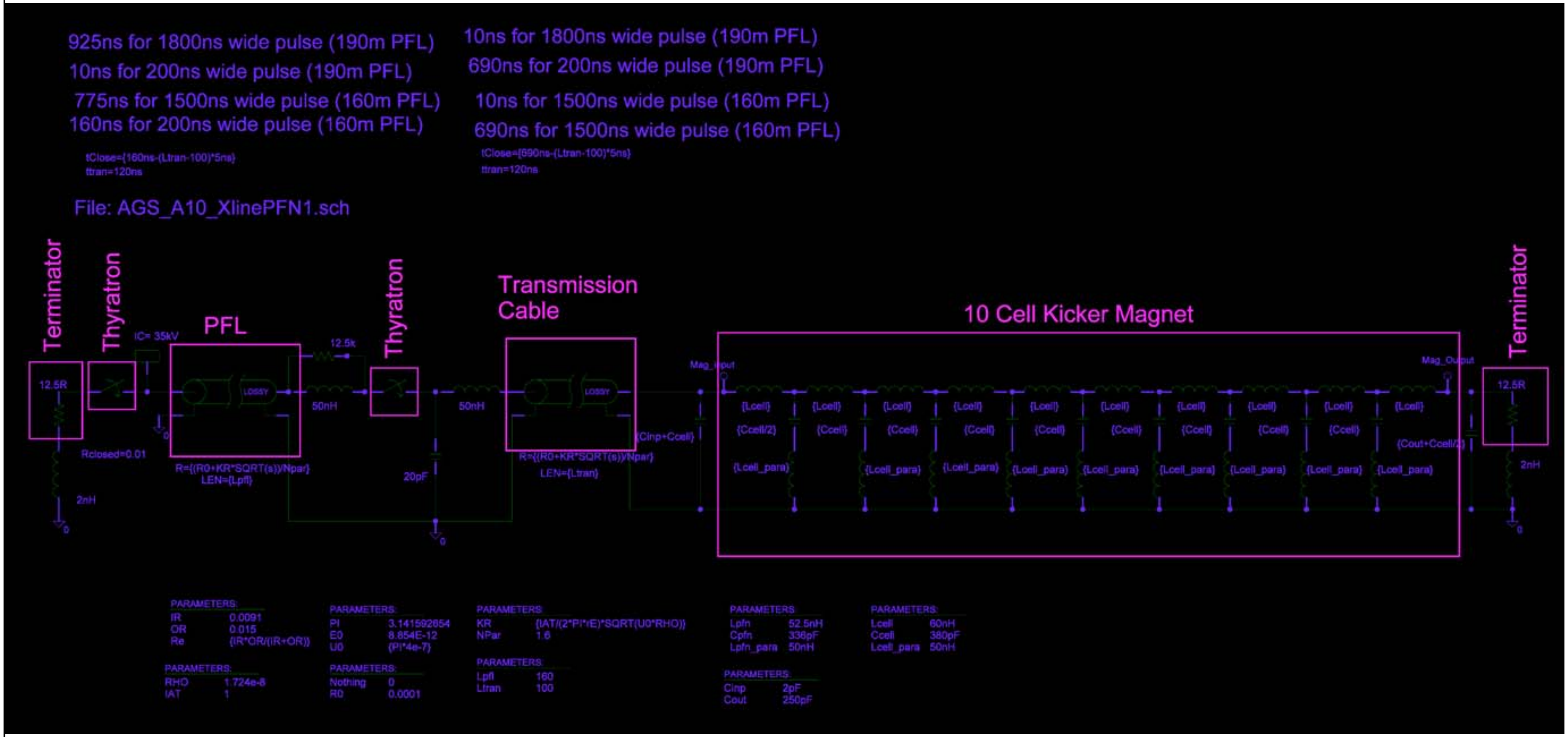
Current Design: A10 Kicker

Design of kicker system is still in the early stages.

- Upgrade the F3 booster extraction kicker
- Add 2 new design kicker elements at the A10 straight section.
- Possibly replace/upgrade the existing 3 kicker magnets at A5.

Simplified Schematic of AGS A10 Kicker System

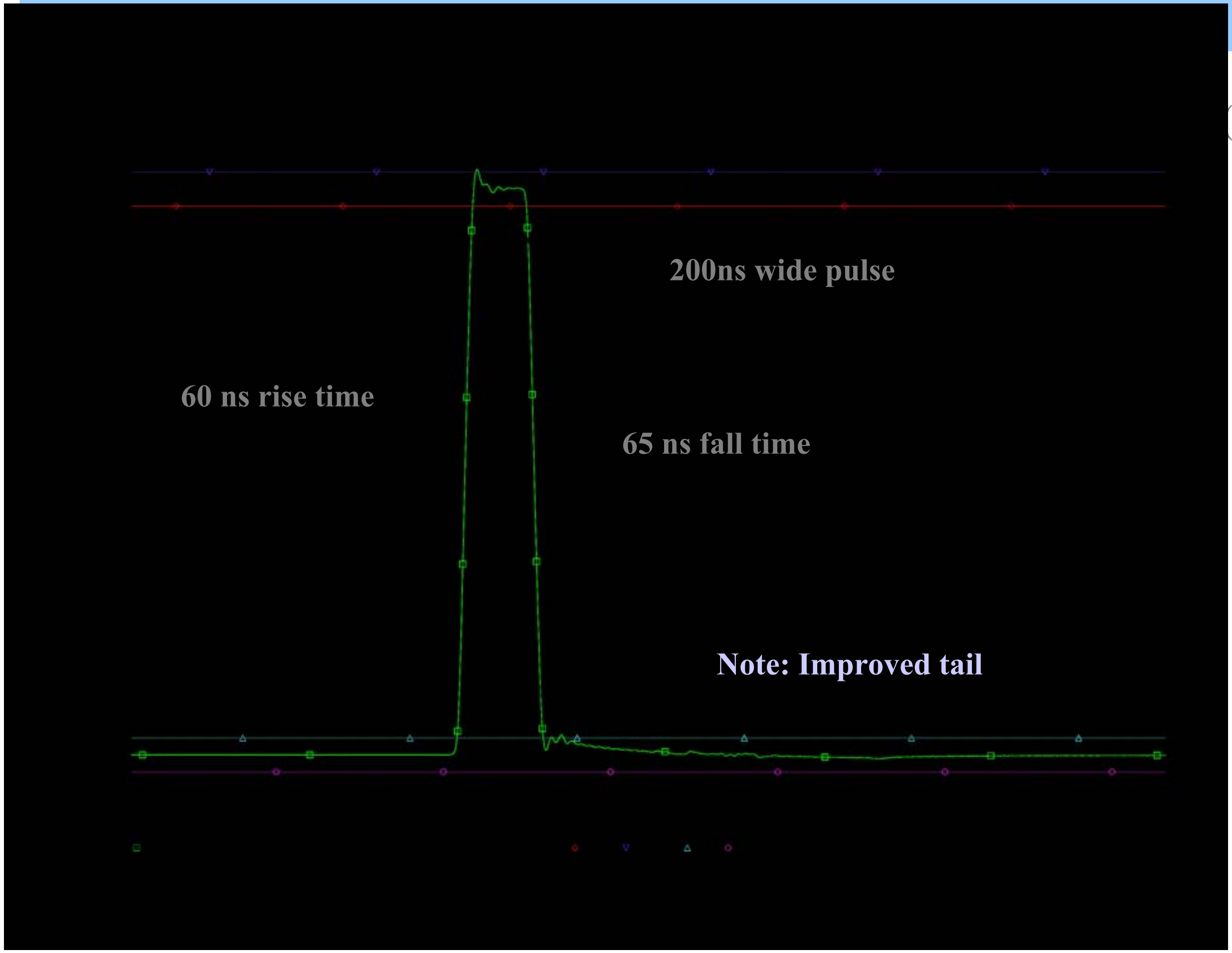
(from Michael Barnes)



Predicted Field in A10 kicker.

Lossy PFL (160m) & Transmission Cable (75m). 200ns wide pulse. Cout=250pF.

(from Michael Barnes)



75m long Transmission cable:

- **shortens rise & fall times c.f. 100m.**
- **Slightly reduces tail field c.f. 100m.**

A10 Kicker Parameters

A10 kicker parameters	Specifications
Pulse repetition rate	7.5 Hz
Field uniformity in aperture (combined electric & magnetic field)	±3%
Pulse to pulse reproducibility of field	±1%
Maximum flat top duration	1800 ns
Aperture width	127 mm wide
Aperture height	81 mm high
Confirm rise and fall times	100 ns
Rise time definition	3% to 97%
Fall time definition	97% to 3%
Flat top ripple	±3%
Ripple between pulses	±3% of maximum

More A10 Kicker Parameters

A10 kicker parameters	Specifications
A10 kick strength for 2 GeV protons	1.5 mrad
Charge time for PFL:	10′s of ms
Available insertion length at A10:	94″ between gate valves
Vacuum:	10^{-7} to 10^{-9} Torr
Bake-able vacuum tank temp:	200 deg C
Length of cables from Pulse Forming Line (PFL) to A10 kicker:	200ft or less to minimize tail of field pulse
BNL-TRIUMF interface:	TTL and fiber optics to thyratron trigger
A5 distance between gate valves:	43″
A5 kicker length for 3 magnets:	36″

Even More A10 Kicker Params

A10 kicker parameters

Saturable ferrite's required on input to kicker magnet.

Length of cables from A10 kicker to terminator

Mount terminator on vacuum tank or use short cables to terminators located in tunnel.

Radiation levels in cables at input and output of kicker appears not to be a problem due to low radiation damage to cables in the AGS tunnel, providing we use polyethylene dielectrics with cable specified for 150kV DC.

TRIUMF contributions to Kicker

HV portion including:

- Transmission line kicker magnet
- HV Power Supply
- Thyratrons and switch assembly,
- optically isolated thyratron grid drive circuits (e.g. MA2709A from E2V),

PFL cables, HV transmission cables,

Terminating resistors, Vacuum tank

Fast anti-parallel ("clipper") diodes (e.g. EUPEC) with grading capacitors.

BNL contributions to Kicker

- Controls and timing.
- New A10 building
- New cable runs to A10 as short as possible to minimize tail on field pulse.

A10 Kicker Action Items

- Confirm A10 kick strength (1.5 mrad) for 2 GeV protons.
- Confirm that commercial capacitor charging power supply is to be used for charging PFL
- Confirm absence of beam pipe through kicker aperture.
- Thyratron choice to be determined by TRIUMF
  - (e.g. 2 gap CX1168C)
- Obtain drawings of existing AGS thyratron switch tanks in air
- Beam impedance issues needs better understanding.
- "Pspice" simulation work needs to be completed.

Space – Testing/Installation

There are plans for limited testing of RF cavities and kickers to be completed at TRIUMF before shipping to BNL, but we need more planning for *in situ* testing at BNL. It must be worked into the overall AGS schedule.

Safety

"Safety" is a concern in terms of the likelihood of failure of a component in a way that would impact the AGS schedule. The design has been studied to minimize such impacts.

Ease of maintenance and ALARA have been important design criteria.

Resources

- Injection kicker development at TRIUMF with BNL C-A support
  - Ready to call on CFI funding
- RF design is well suited to TRIUMF and BNL capabilities.

Issues

- Fast Feedback for RF power supply.
- Active Impedance reduction for RF.
- Better understanding of Beam Kick provided by A10 design.
- 100 MHz necessity.
- Scheduling.

Summary

The AGS Mods subsystem is in an advanced state of development.

There are few fundamental uncertainties remaining.

Both TRIUMF and BNL have strong groups ready to do the work.