Slow extraction septa requirements for Rare Symmetry Violating Processes (RSVP) experiments at BNL

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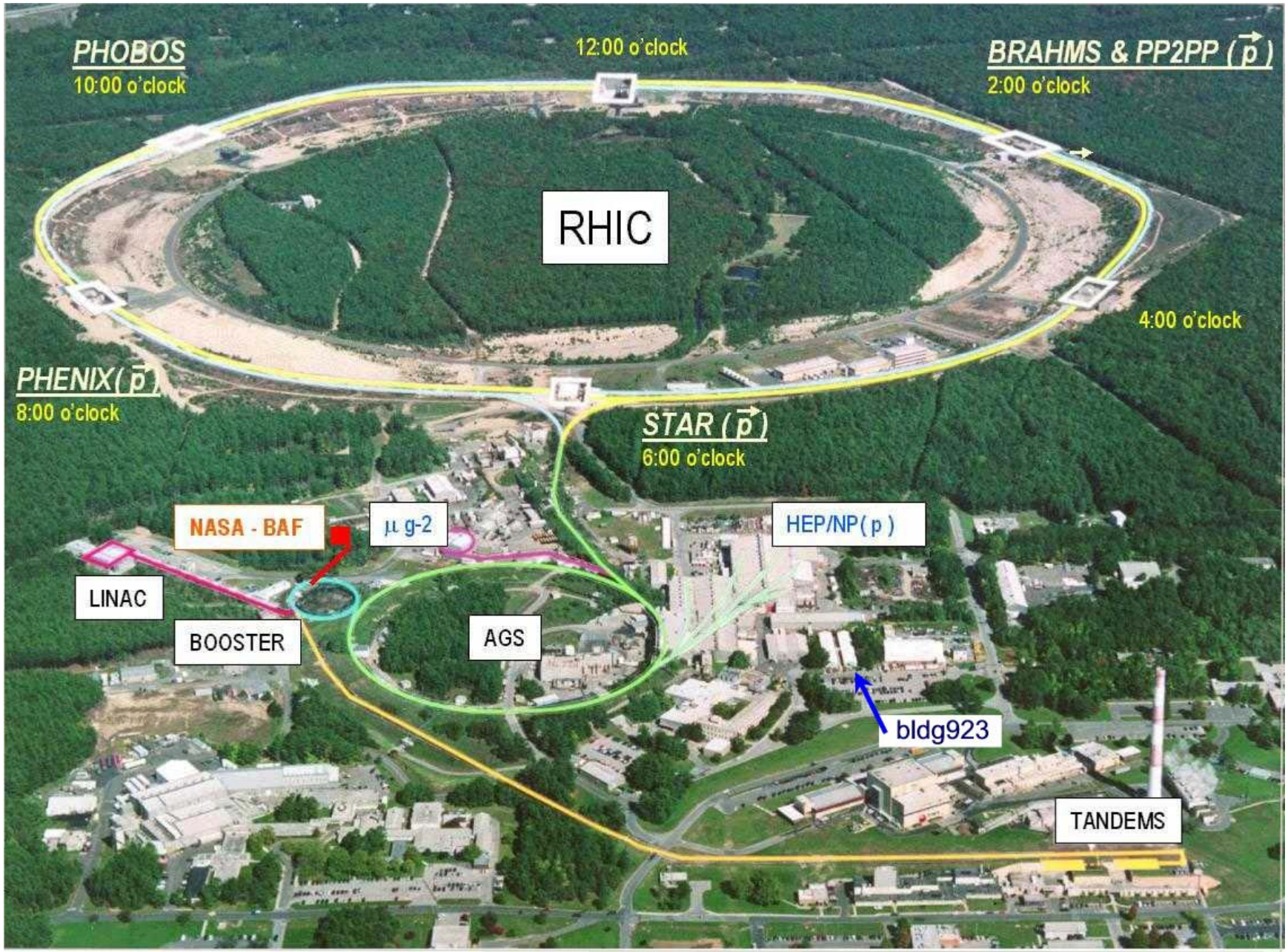

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RSVP Physics

KOPIO- Measurement of $K_L \rightarrow \pi^0 \nu\bar{\nu}$

- Uniquely determines $\mathbf{J_{CP}}$, the fundamental parameter of SM CP-violation, with ~2% precision
- Single event sensitivity $<1 \times 10^{-12}$ (SM predicts 3×10^{-11})
- 10^5 improvement over previous experiments

MECO – Search for $\mu^- N \rightarrow e^- N$

- Not allowed in SM, allowed in SUSY models at 10^{-15} level
- Single event sensitivity $<2 \times 10^{-17}$ (present limit 6×10^{-13})

RSVP Participants

Scientific Collaborations –

US Collaborators –

- Arizona State University
- Boston University
- Brookhaven National Laboratory
- University of California, Irvine
- University of California, Berkeley
- University of Cincinnati
- University of Houston
- University of Massachusetts, Amherst
- Stony Brook University
- University of New Mexico
- New York University
- University of Pennsylvania
- Syracuse University
- Thomas Jefferson National Accel Facility
- University of Virginia
- Virginia Polytechnic Institute and State University
- College of William and Mary
- Yale University

International Collaborators –

- Canada
- Italy
- Japan
- Russia
- Switzerland

Sponsoring agency –

National Science Foundation, Division of Mathematical and Physical Sciences, MREFC Program.

Host Laboratory –

Brookhaven National Laboratory, Operated by Brookhaven Science Associates for the Department of Energy, Office of Science, Division of Nuclear Physics

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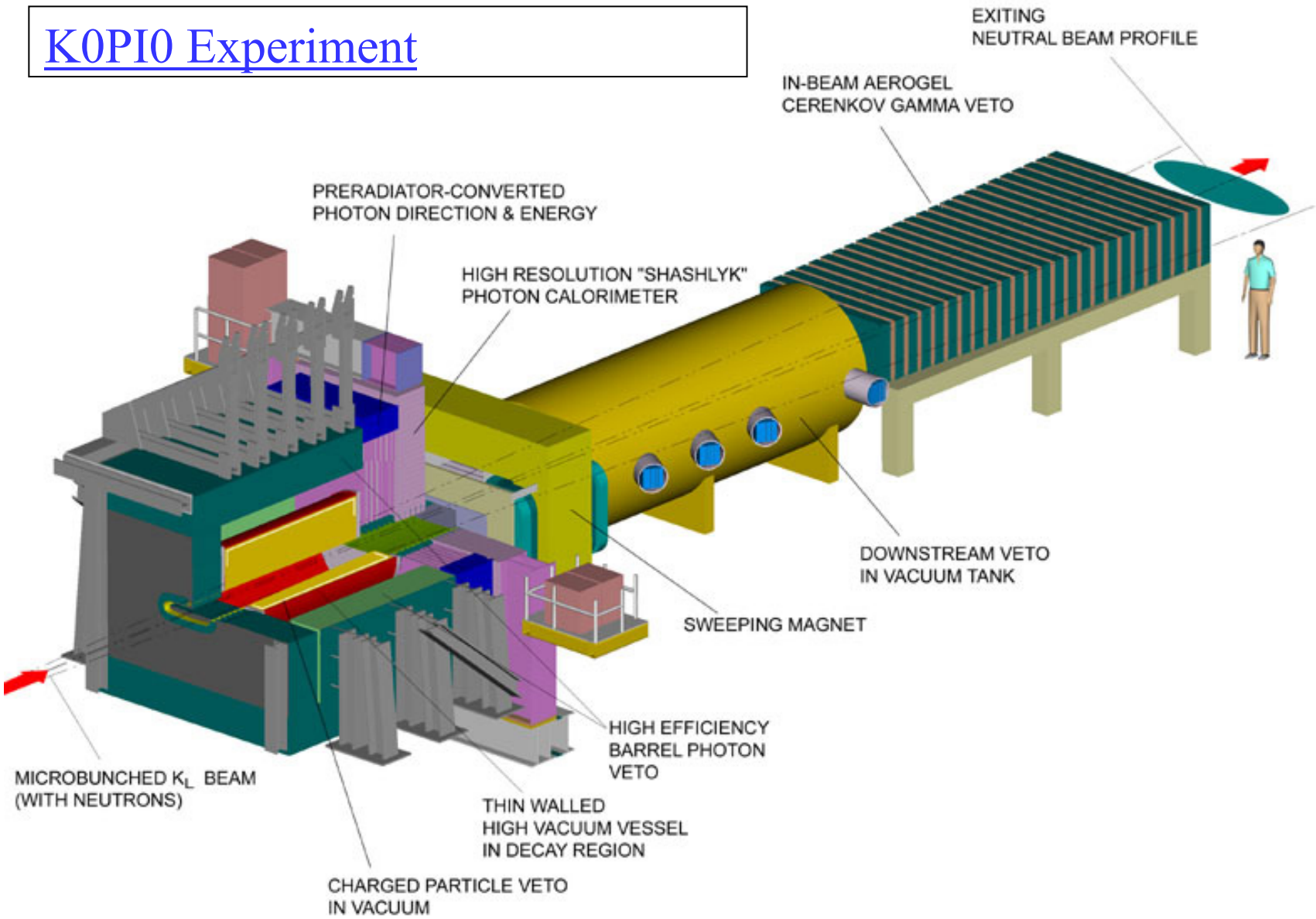
K0PI0 Experiment



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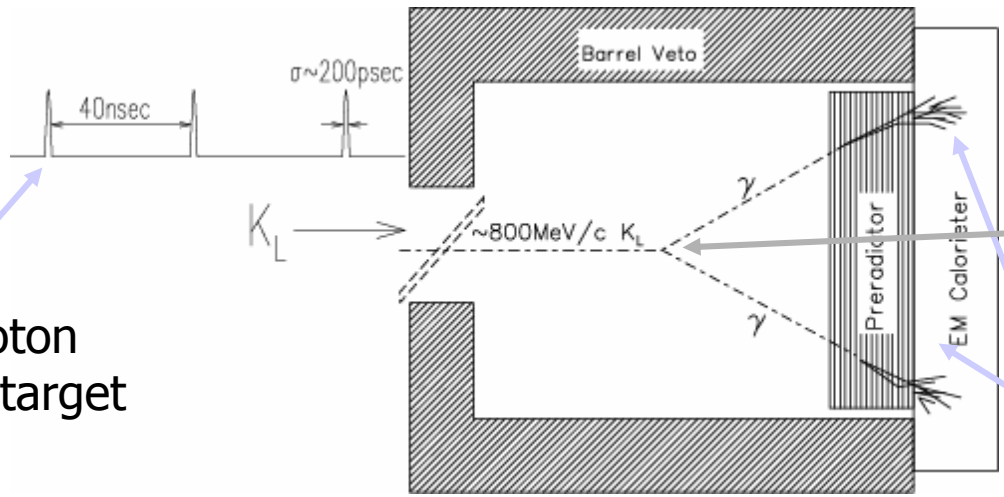
Physics Motivation: Microbunch Width

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



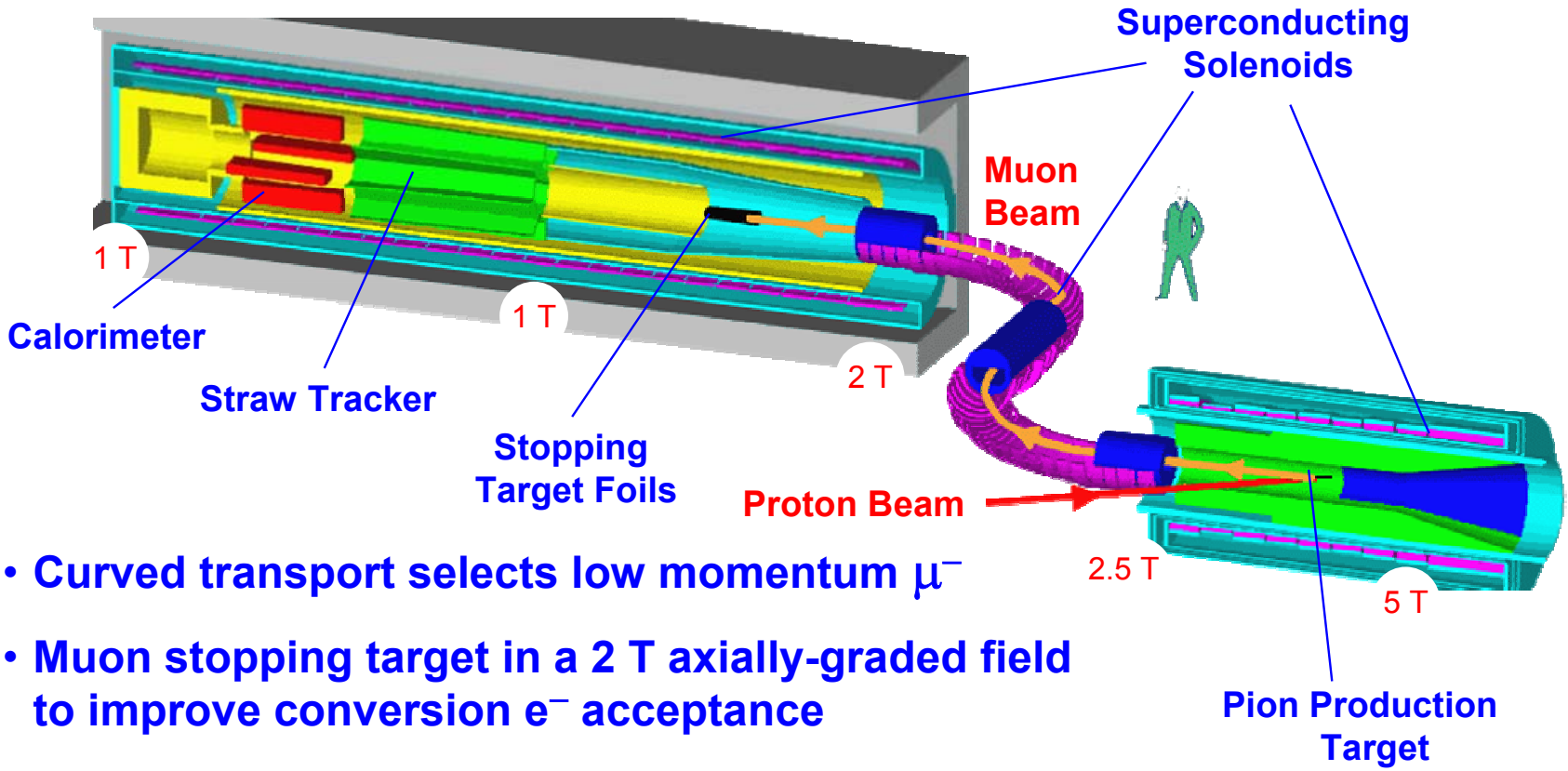
Start when proton beam hits the target

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

Features of MECO

- **1000–fold increase in μ beam intensity over existing facilities**
  - High Z target for improved pion production
  - Axially-graded 5 T solenoidal field to maximize pion capture



- **Curved transport selects low momentum μ^-**
- **Muon stopping target in a 2 T axially-graded field to improve conversion e^- acceptance**
- **High rate capability e^- detectors in a constant 1 T field**

Muon to Electron Conversion

Low energy muons are stopped in thin Al foils, forming muonic atoms

Three possible fates for the muon

- **Nuclear capture** $\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$
- **Three body decay in orbit** $\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$
- **Coherent Lepton Flavor Violating decay** $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$

Signal is a single mono-energetic electron originating the stopping target

$$E_e = m_\mu - E_{recoil} - E_{binding} \approx 105\ MeV$$

Achieving the desired sensitivity will require ~10^{18} stopped muons and extremely tight control of possible background sources

RSVP Basic Requirements

	Normal SEB	KOPIO	MECO
P (GeV/c)	25.5	25.5	7.5
Rep. Time (sec)	5.3	5.3	1
Spill Length (sec)	3	3	0.5
Intensity	$> 70 \times 10^{12}$ p/pulse	100×10^{12} p/pulse	40×10^{12} p/pulse, 2 bunches
Bunch lengths & spacing	DC	200 psec 40 nsec	~30 nsec 1.35 usec
$\Delta p/p$ (%)	0.7 - 0.9	< 0.5	~ 1.0
Integrated Intensity* (# protons)	6.3×10^{20} (post-Booster)	9×10^{20}	4×10^{20}
Extinction	NA	10^{-3}	10^{-9}

* Normal SEB value Includes non-SEB proton operations.

AGS Equipment for RSVP

For KOPIO

- 25 MHz RF Cavity and Power amplifier. To be designed and built at TRIUMF. Based on RHIC 28 MHz RF Cavity design.
- 100 MHz RF cavity

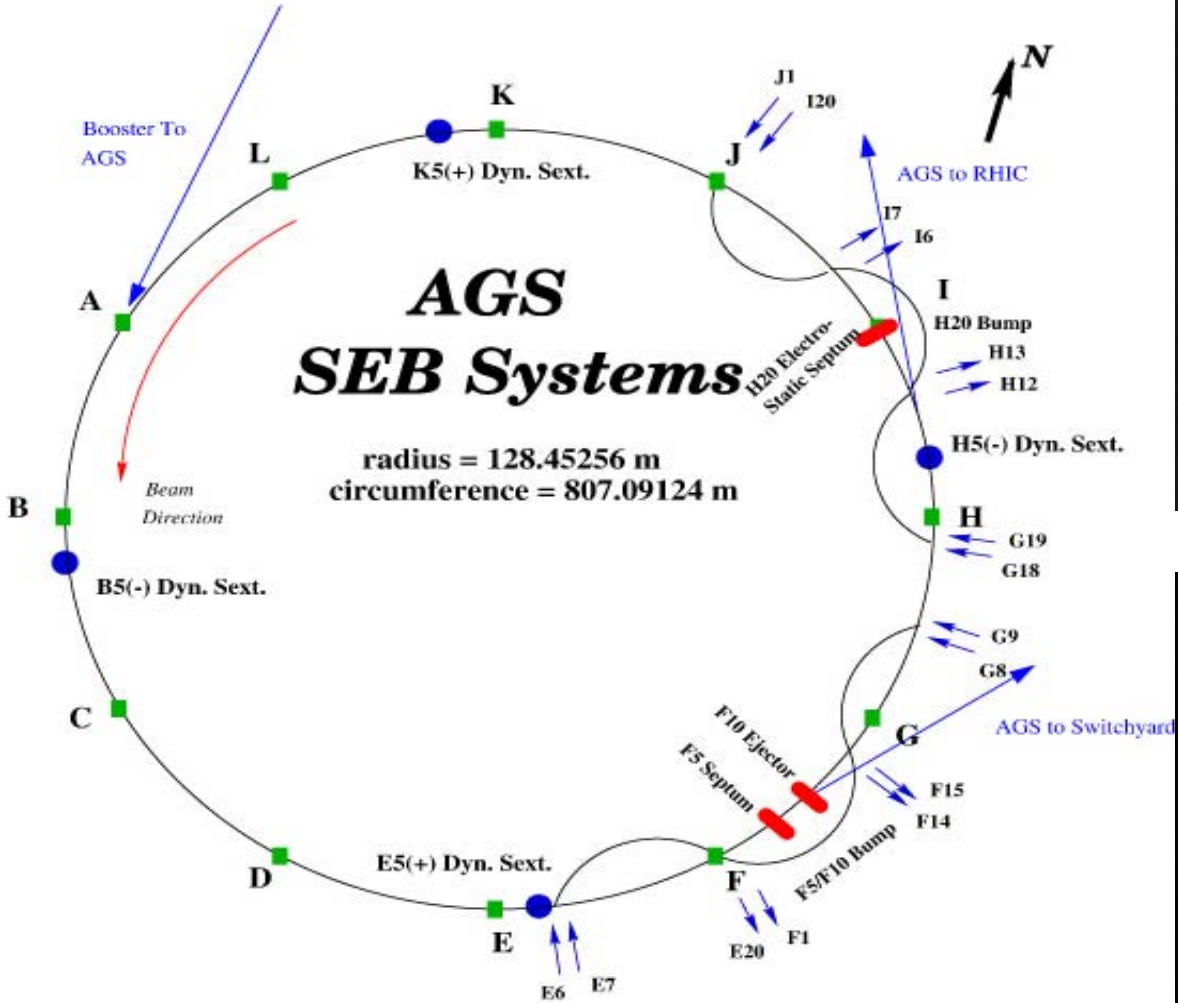
For MECO

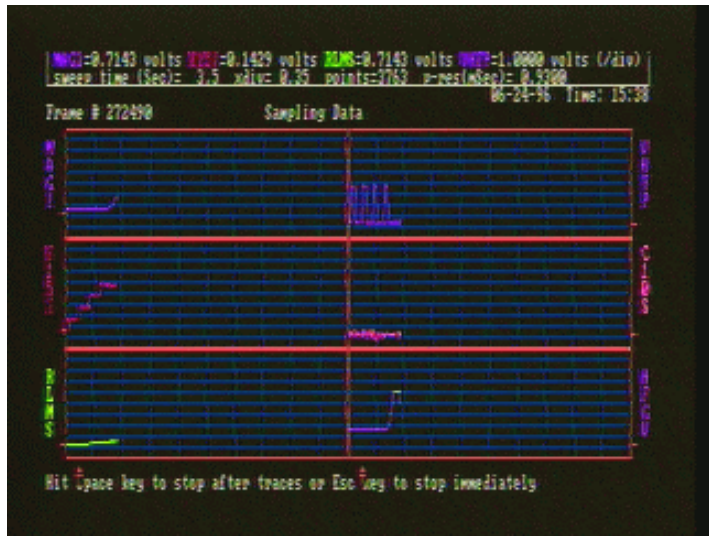
- Upgrade AC Dipole for CW operation.
- Install HV pulsers for strip-line kickers, in an existing 5' straight section (many available).

RSVP Common Issues:

RC Networks, Extraction Septa, AGS Impedance.

Overview of AGS Slow Extraction





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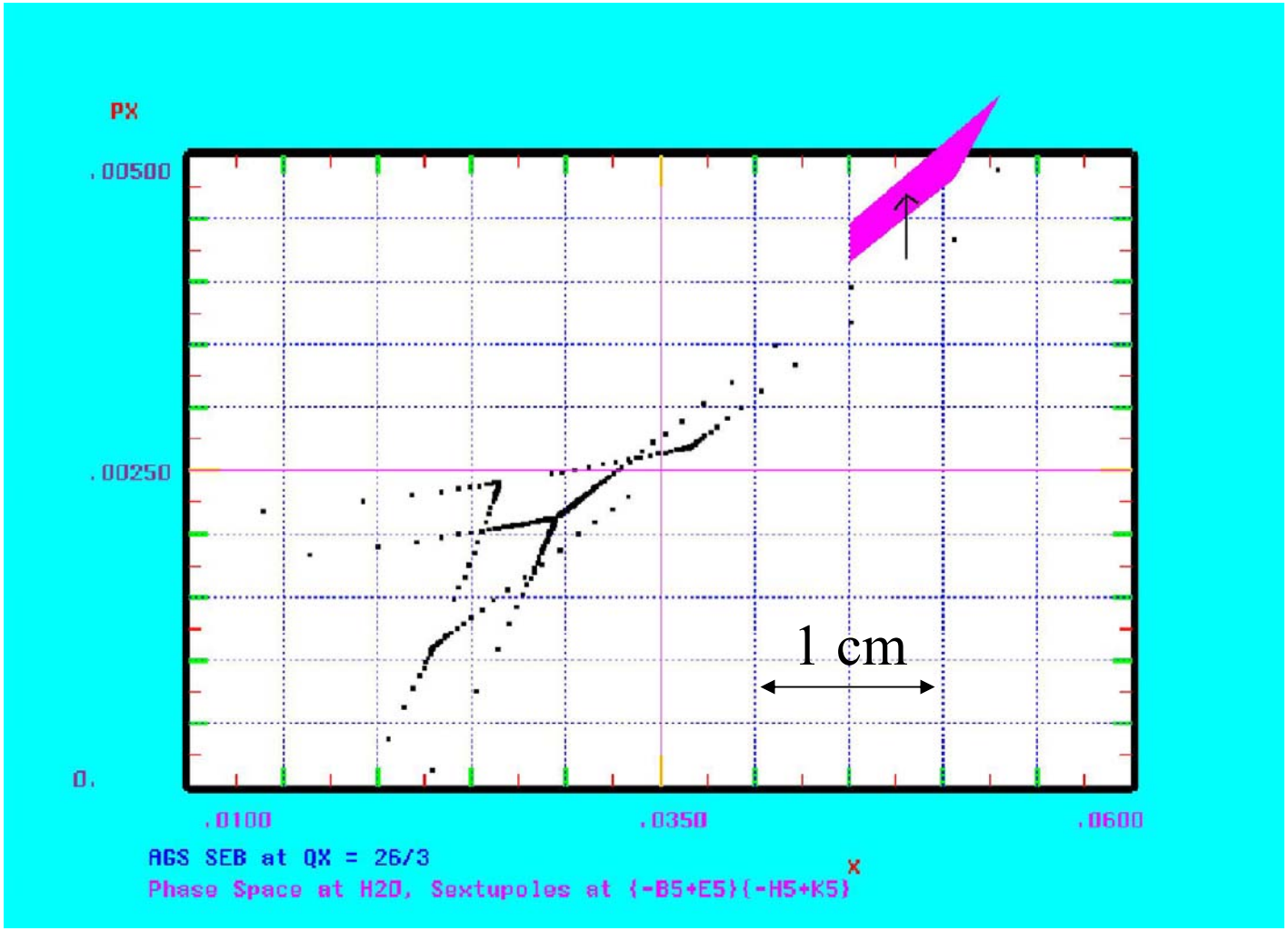
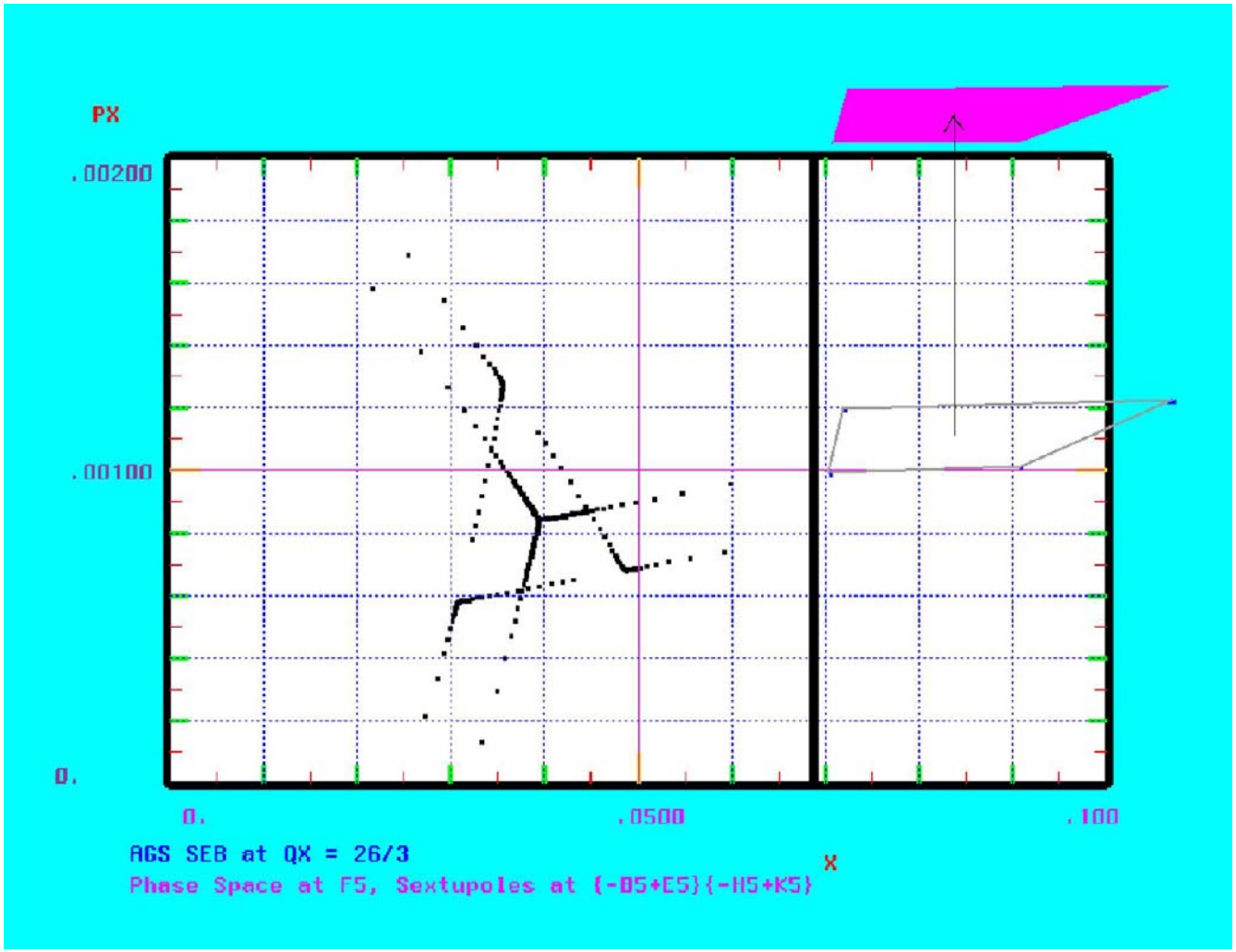
Slow Extraction: ES Phase Space



Slow Extraction: Thin MS Phase Space



Present SEB Devices Parameters

	Elect. Septum [H20]	Thin Septum [F5]	Thick Septum [F10]
β_x [m]	12.0 – 19.9	22.1	19.9 – 12.0
β_y [m]	19.9 – 12.0	10.5	12.0 – 19.9
Vert. Gap [mm]	20.0	17.8 (25.4)	19.1
Horiz. Gap [mm]	10.0	44.45	38.1
Length [m]	2.30	0.667	0.81+1.22 = 2.03
N turns		1	4
Septum w [mm]	0.051 / 3.175 space WRe 1.58 wide foil	0.76	13.5 / 15.85
Deflect. [mrad]	0.43	1.1	18.5
Field B/E	80 kV/cm	1.5 kG	9.5 kG

Measured extracted beam emittance with High Intensity Protons

	$\varepsilon_H^{99\%,N}$ (π mm-mrad)	$\varepsilon_V^{99\%,N}$ (π mm-mrad)
Pre-Booster (1980) 200 MeV injection	49	60
Post-Booster (1997) 1.94 GeV injection	99	85

Normal SEB AGS Parameters

Parameter	Value	Units
Peak Intensity	74.0	10^{12} protons/pulse
Extraction Efficiency	97-98	%
Spill Lengths	1.8 – 5.8	Seconds
Working Point	8.667 / 8.78	Horiz./Vert. Tune
Normalized Chromaticity	-2.5 / 0.05	Horiz./Vert. Chrom.
Extraction Momentum	25.5	GeV/c

Acceptance Parameters: KOPIO

$A_{H,V} = \dfrac{r^2}{\beta_{\max}}$, where r is the half aperture. $\quad A^N_{H,V} = A_{H,V}(\beta\gamma)$

Parameter	H20 septum	F5 septum	F10 septum
β_H [m]	12.0 – 19.9	22.1	19.9 – 12.0
β_V [m]	19.9 – 12.0	10.5	12.0 – 19.9
Horz. Gap [mm]	10.0	44.45	38.1
Vert. Gap [mm]	20.0	25.4	19.1
$\beta\gamma$	27	27	27
A_H [π-mm-mrad]	1.25	22.35	18.24
A_V [π-mm-mrad]	5.03	15.4	4.58
A_H^N [π-mm-mrad]	(34)*	603	492
A_V^N [π-mm-mrad]	136	415	124

* Beam size depends on step size, acceptance not a significant parameter.

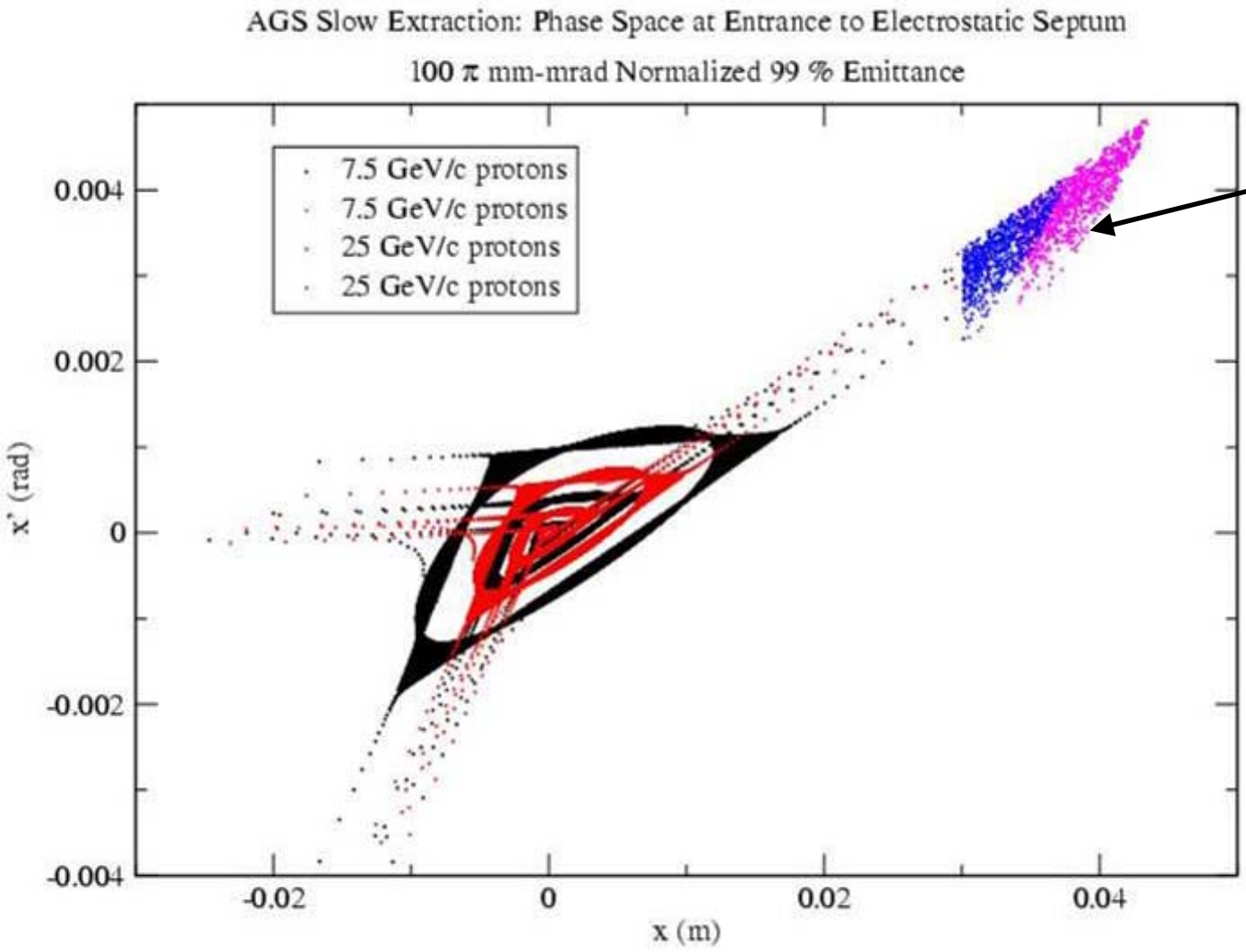
Acceptance Parameters: MECO

$A_{H,V} = \dfrac{r^2}{\beta_{\max}}$, where r is the half aperture. $\quad A^N_{H,V} = A_{H,V}(\beta\gamma)$

Parameter	H20 septum	F5 septum	F10 septum
β_H [m]	12.0 – 19.9	22.1	19.9 – 12.0
β_V [m]	19.9 – 12.0	10.5	12.0 – 19.9
Horz. Gap [mm]	10.0	44.45	38.1
Vert. Gap [mm]	20.0	17.1	19.1
$\beta\gamma$	8.6	8.6	8.6
A_H [π-mm-mrad]	1.25	22.35	18.24
A_V [π-mm-mrad]	5.03	6.96	4.58
A_H^N [π-mm-mrad]	(11)*	192	157
A_V^N [π-mm-mrad]	43	59.9	39

* Beam size depends on step size, acceptance not a significant parameter.

Electrostatic Septum aperture



To achieve same extraction efficiency with lower energy beam, requires larger step size and thus larger extracted beam.

7.5 GeV/c beam is 1.5 times larger.

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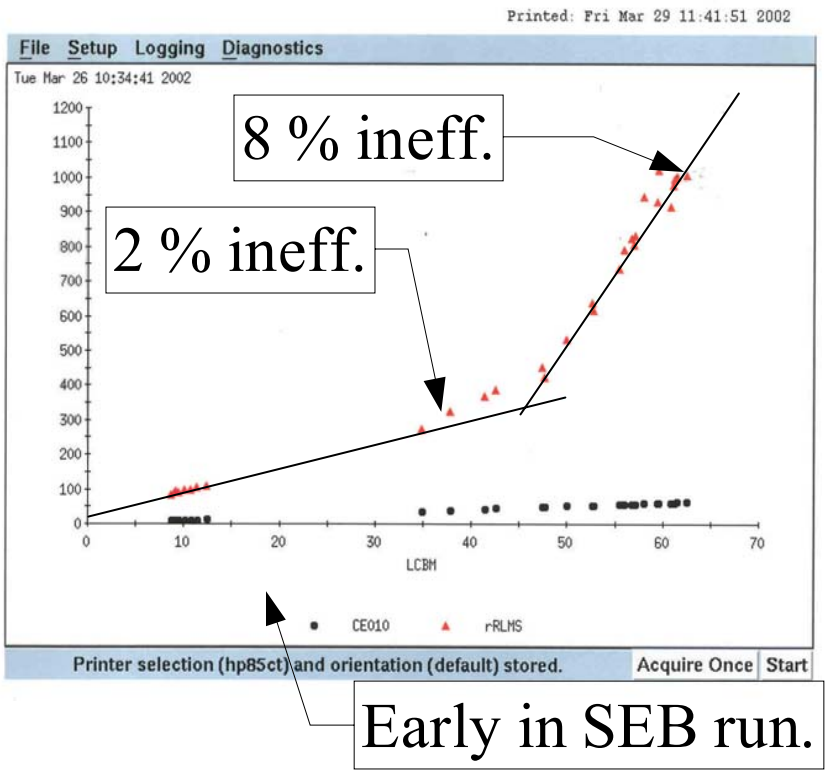
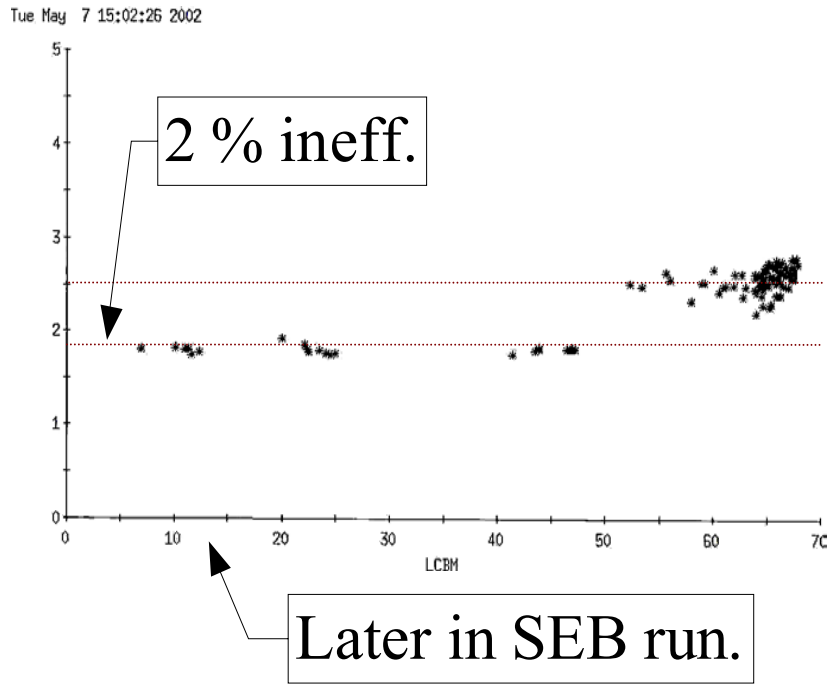
High Intensity Slow Extraction

70 TP Slow extracted beam observations. Vertical Chromaticity is kept positive after transition.





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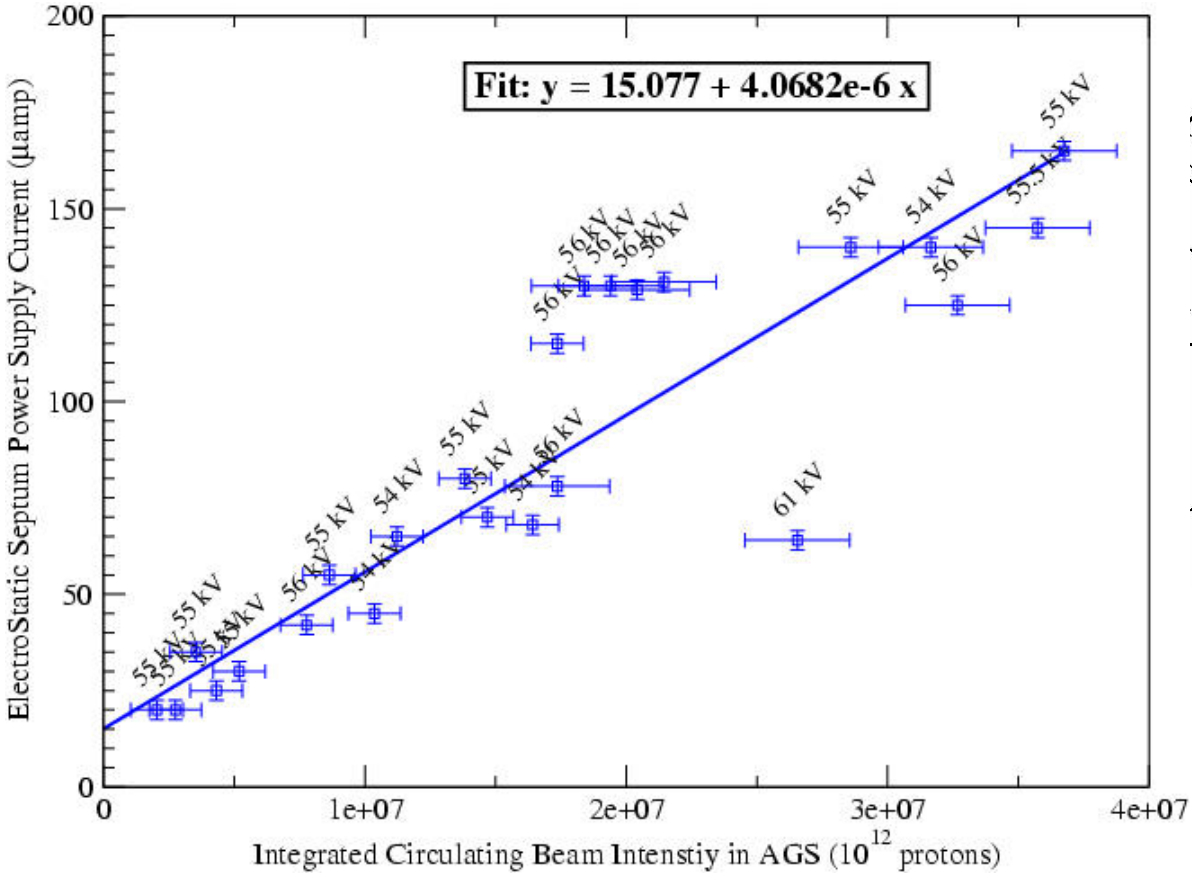
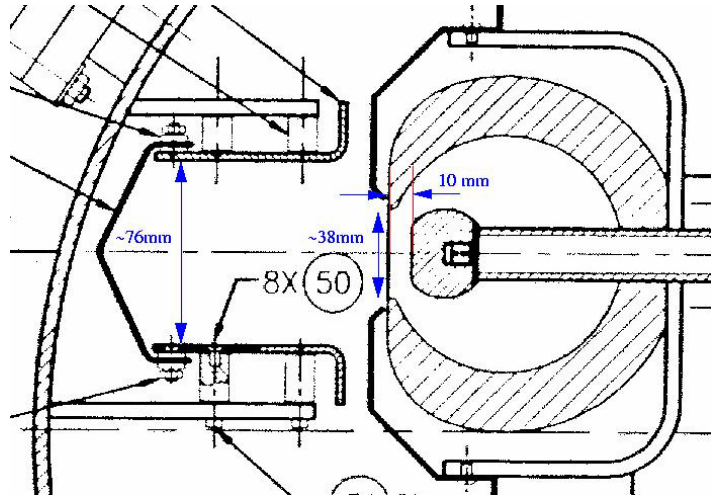
AGS High Intensity Extraction





Cross section of existing electrostatic septum.

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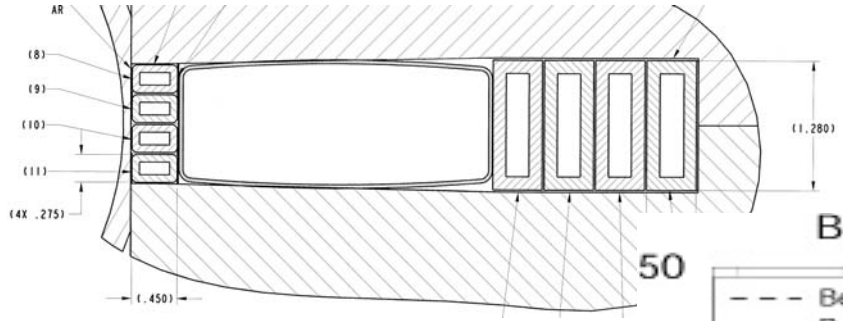
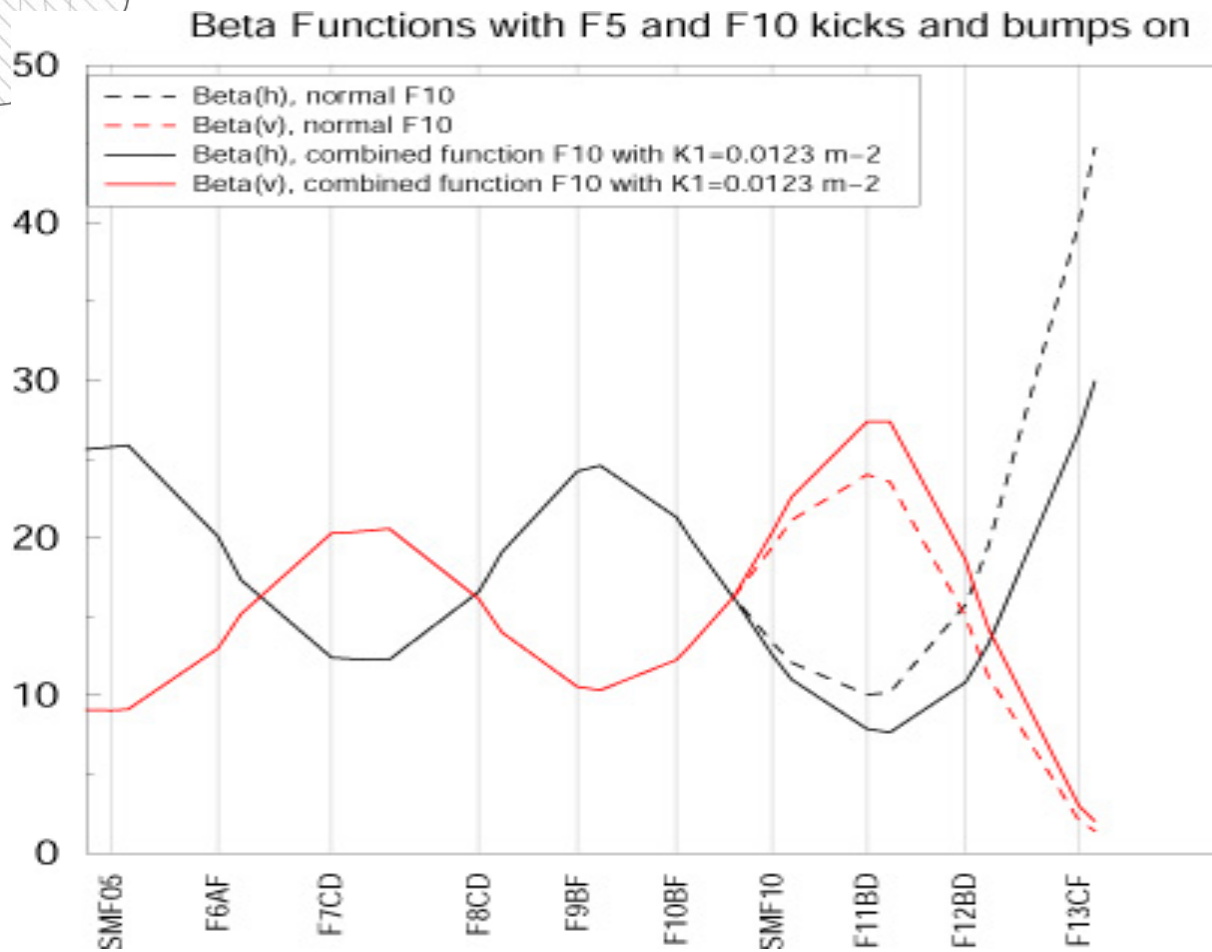
Extraction Channel Acceptance





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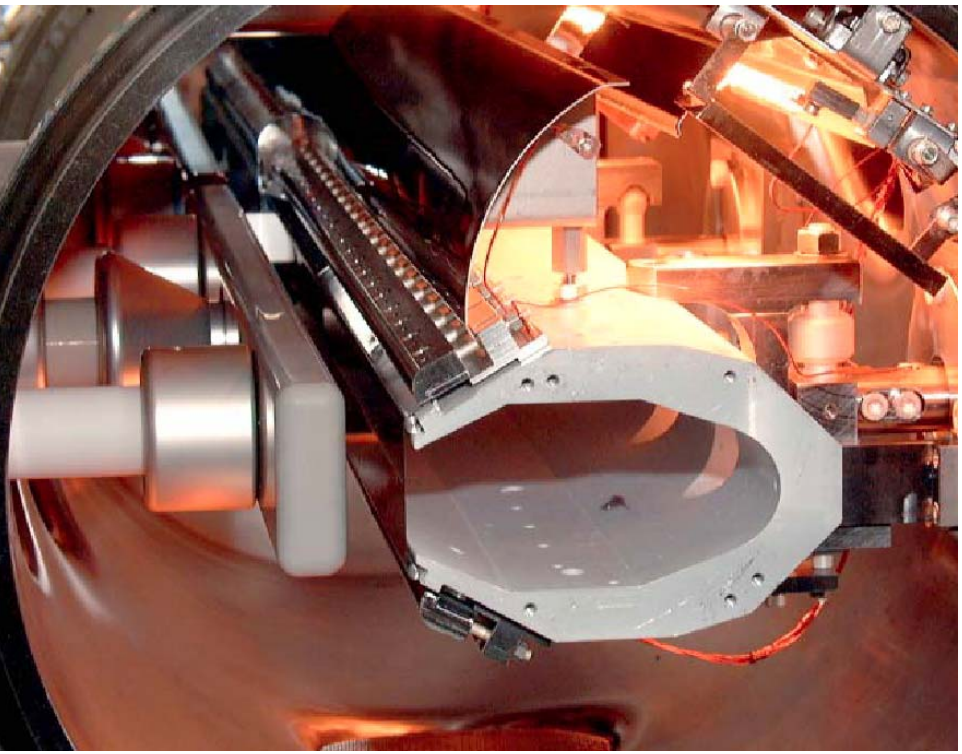
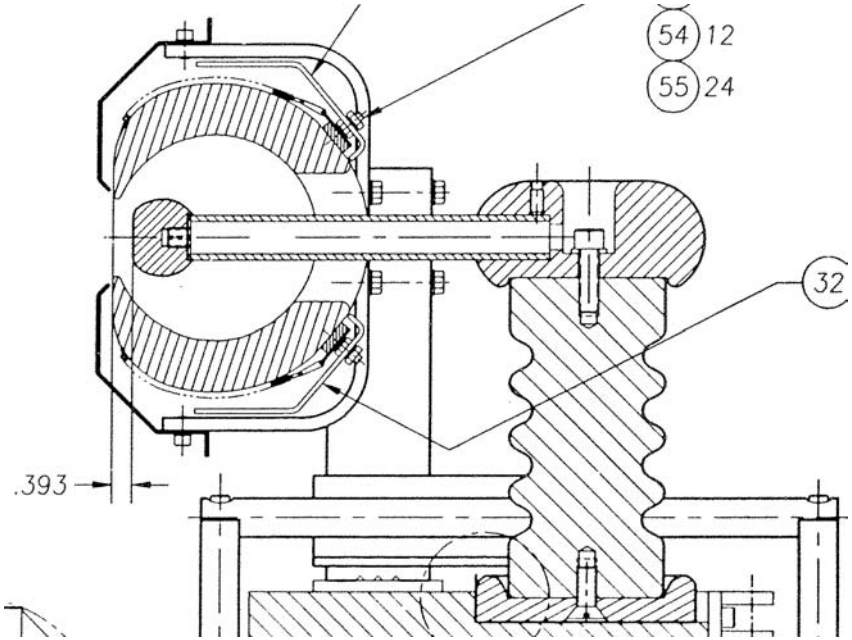
AGS Extraction Modifications

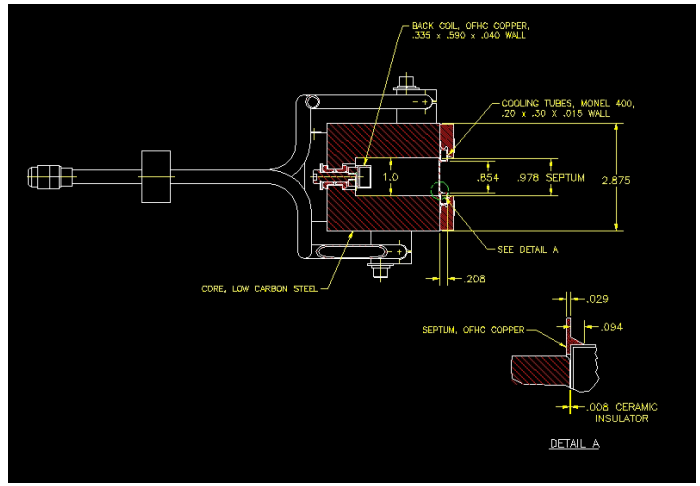


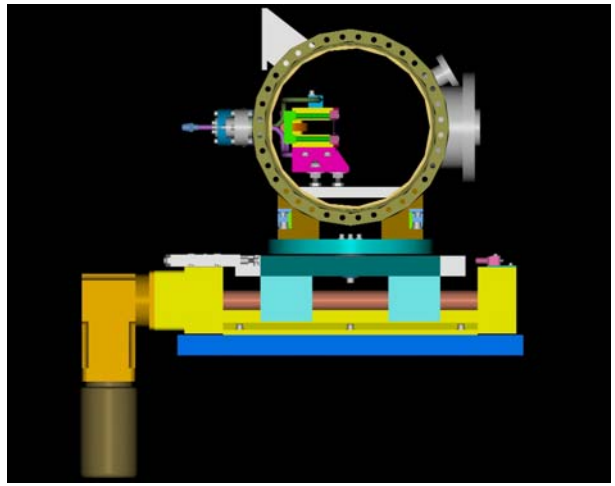
CERN Electrostatic septum

BNL Electrostatic septum

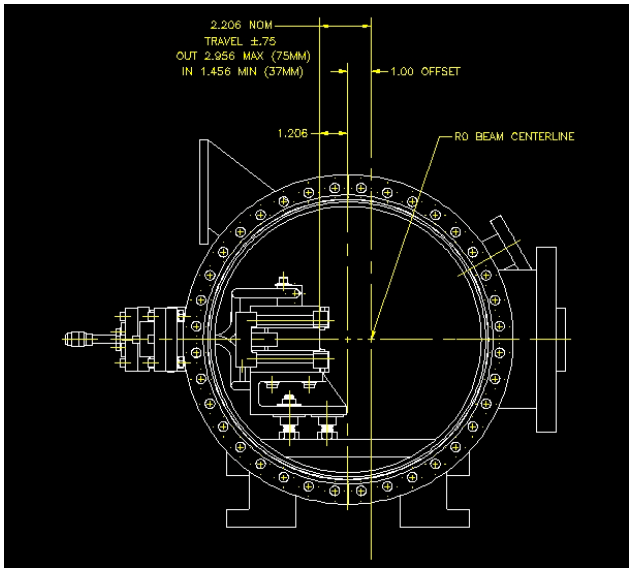
SEB Devices

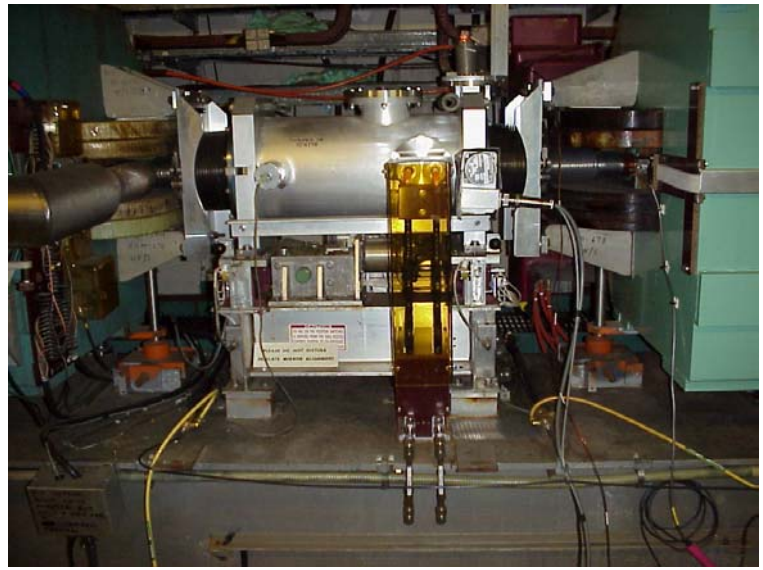

54 12
55 24
32
.393

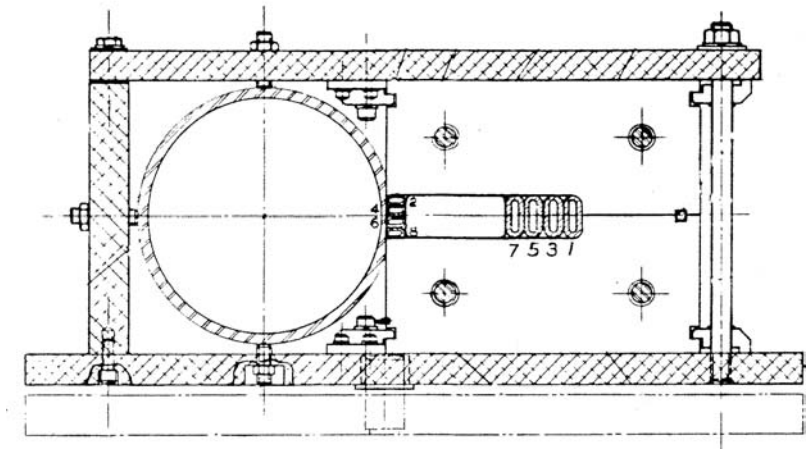

BACK COIL, OFHC COPPER, .335 x .590 x .040 WALL
COOLING TUBES, MONEL 400, .20 x .30 X .015 WALL
1.0
.854
.978 SEPTUM
2.875
SEE DETAIL A
CORE, LOW CARBON STEEL
.208
.029
.094
SEPTUM, OFHC COPPER
.008 CERAMIC INSULATOR
DETAIL A



SEB Devices


2.206 NOM
TRAVEL ±.75
OUT 2.956 MAX (75MM)
IN 1.456 MIN (37MM)
1.00 OFFSET
1.206
RO BEAM CENTERLINE

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RSVP Experience

KOPIO

- Beam tests demonstrate micro-bunch extraction works as predicted.
- Intra-bunch extinction requirements met in beam studies but not with 25 MHz system.
- 250 psec bunches achieved with 93 MHz cavity, low voltage

MECO

- Beam tests demonstrate mini-bunch extraction can be done.
- Intra-bunch extinction requirements not yet met in beam studies (although 10^{-7} achieved in initial beam studies).
- Spill structure was a significant problem in beam tests.

RSVP Summary

1. Slow Extraction for MECO and KOPIO is simply normal slow extraction with additional longitudinal manipulations.
2. Common issues are spill structure, and extraction efficiency, and normal extraction equipment maintenance.
3. For MECO the main issues are acceptance (lower energy, larger beam size), extinction, and spill structure.
4. For KOPIO the main issues are bunch lengths (<250 psec) extraction efficiency.
5. RSVP will not impact RHIC operations.