Bent Crystal Pre-Collimation at RHIC and Proposed Slow-Extraction Uses at BNL

Ray Fliller III, BNL/USB

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ICFA
International Committee for Future Accelerat

Outline

Crystal Channeling

RHIC Crystal Collimation

Proposed Slow-Extraction uses in AGS

Proposed Crystal uses in Booster and BAF

Collaborators

RHIC

Angelika Drees

Dave Gassner

Lee Hammons

Gary McIntyre

Steve Peggs

Dejan Trbojevic

Valery Biryukov

Yuriy Chesnokov

Viktor Terekov

Booster/AGS

Kevin Brown

Angelika Drees

J. Woody Glenn

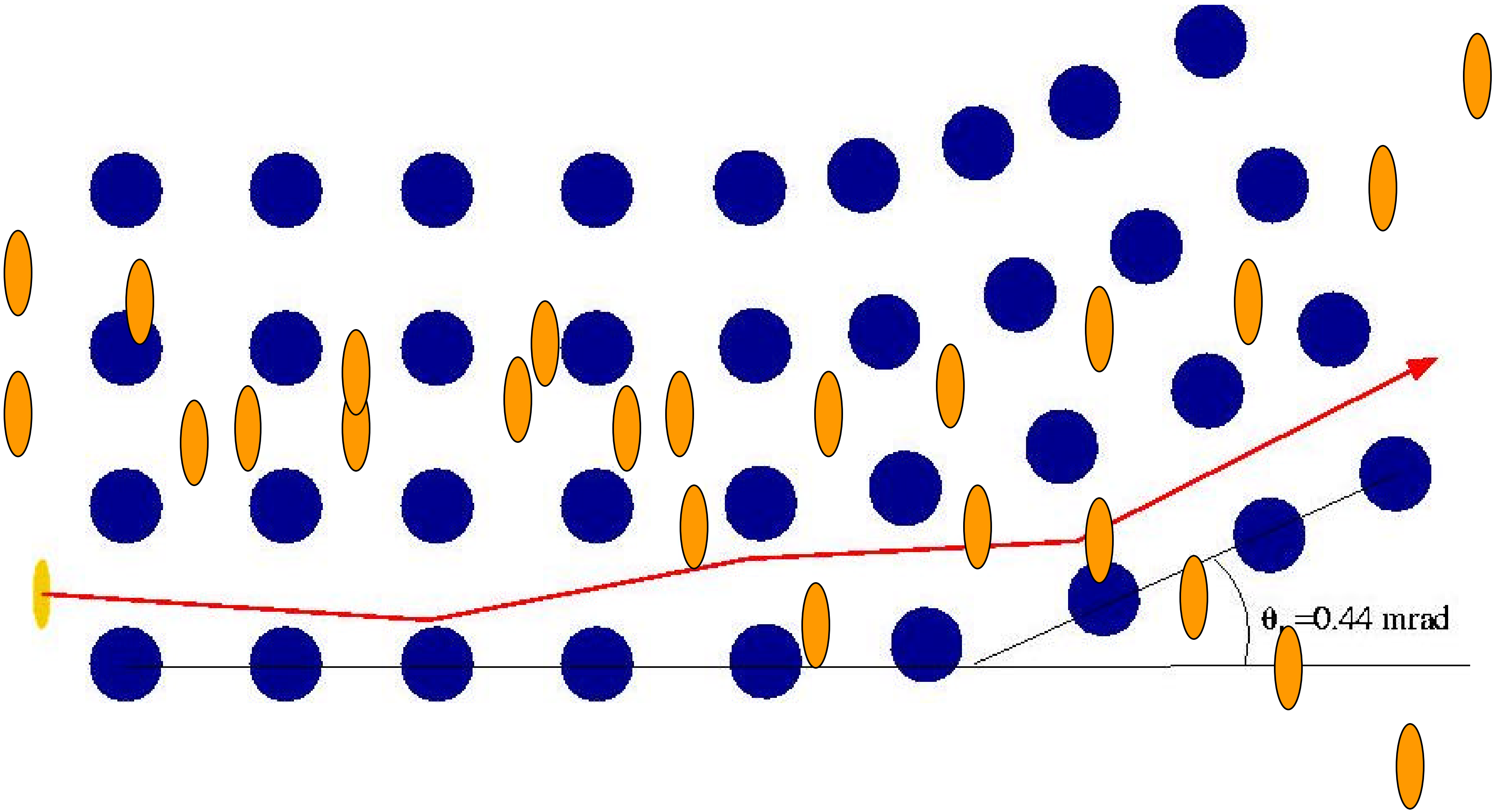
Steve Peggs

Nick Tsoupas

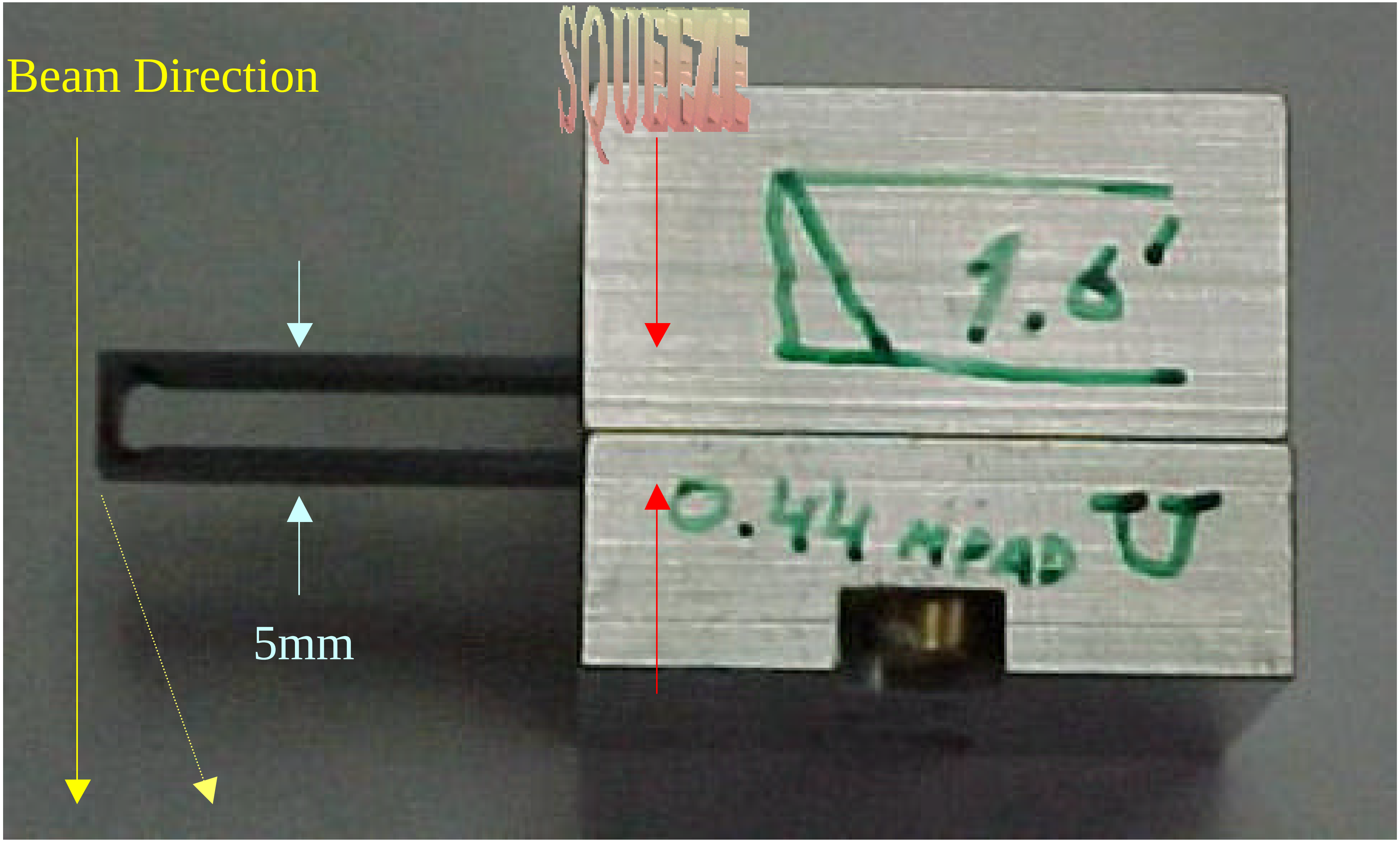
Valery Biryukov

Crystal Channeling

Crystal Channeling



Crystal



Crystal Courtesy of IHEP, Protvino

The Critical Angle (1)

If a particle enters a channel with a transverse kinetic energy greater than the maximum of the interplanar potential,

$$\frac{p_x^2}{2m} \geq U(x_c)$$

it will not be channeled.

This gives a maximum angle between the crystal planes and the incoming particles

$$\theta_c = \sqrt{\frac{2U(x_c)}{pv}} \propto \sqrt{\frac{1}{B\rho}}$$

This is known as the Critical Angle

For RHIC storage energies and Si Crystal, θ_c is 11 μrad.

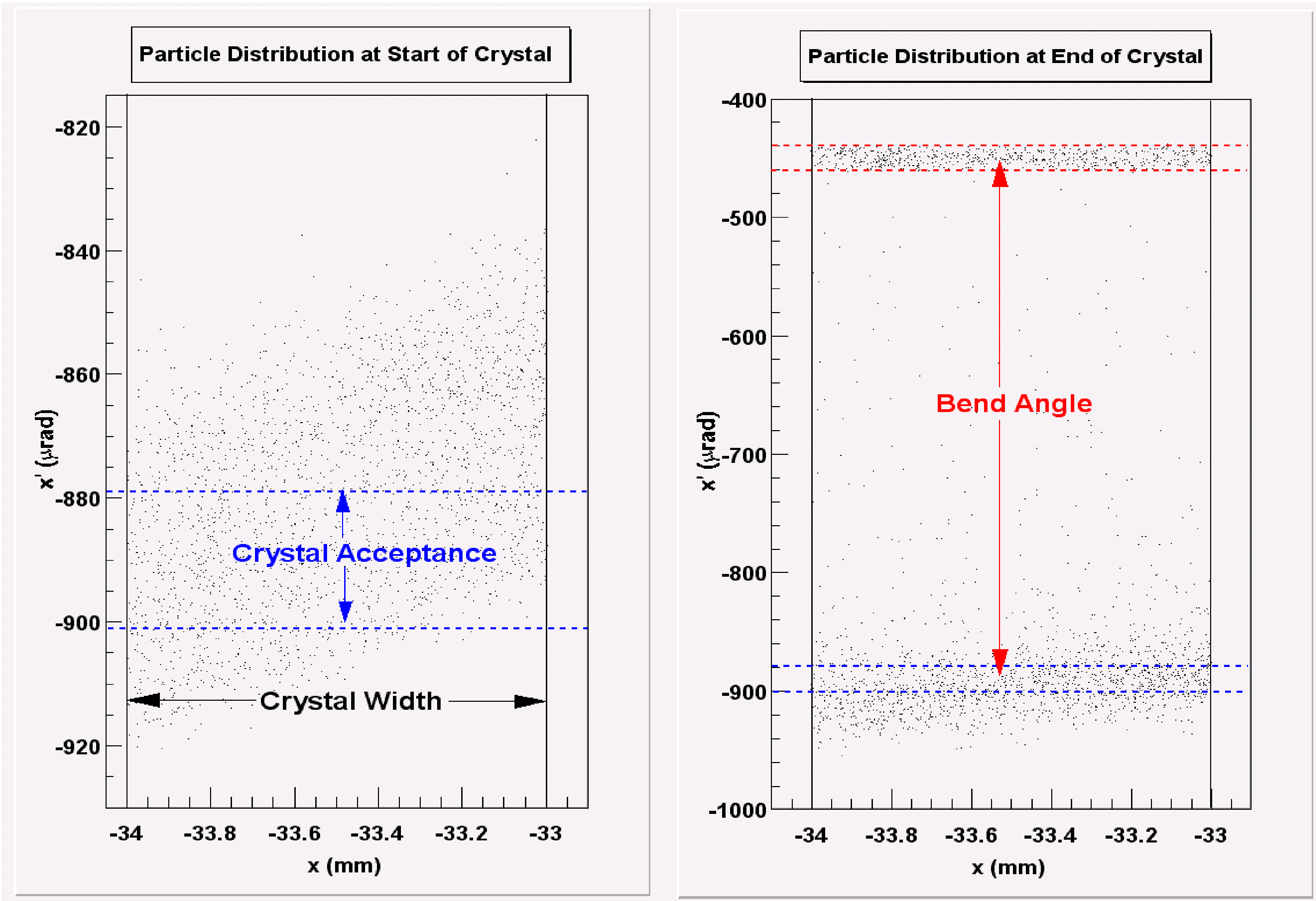
The Critical Angle (2)

The Critical Angle is one of the most important parameters to consider when designing a crystal. It determines

1) the angular acceptance since particles with larger angles will not be channeled.
2) The angular divergence of the beam exiting the crystal.

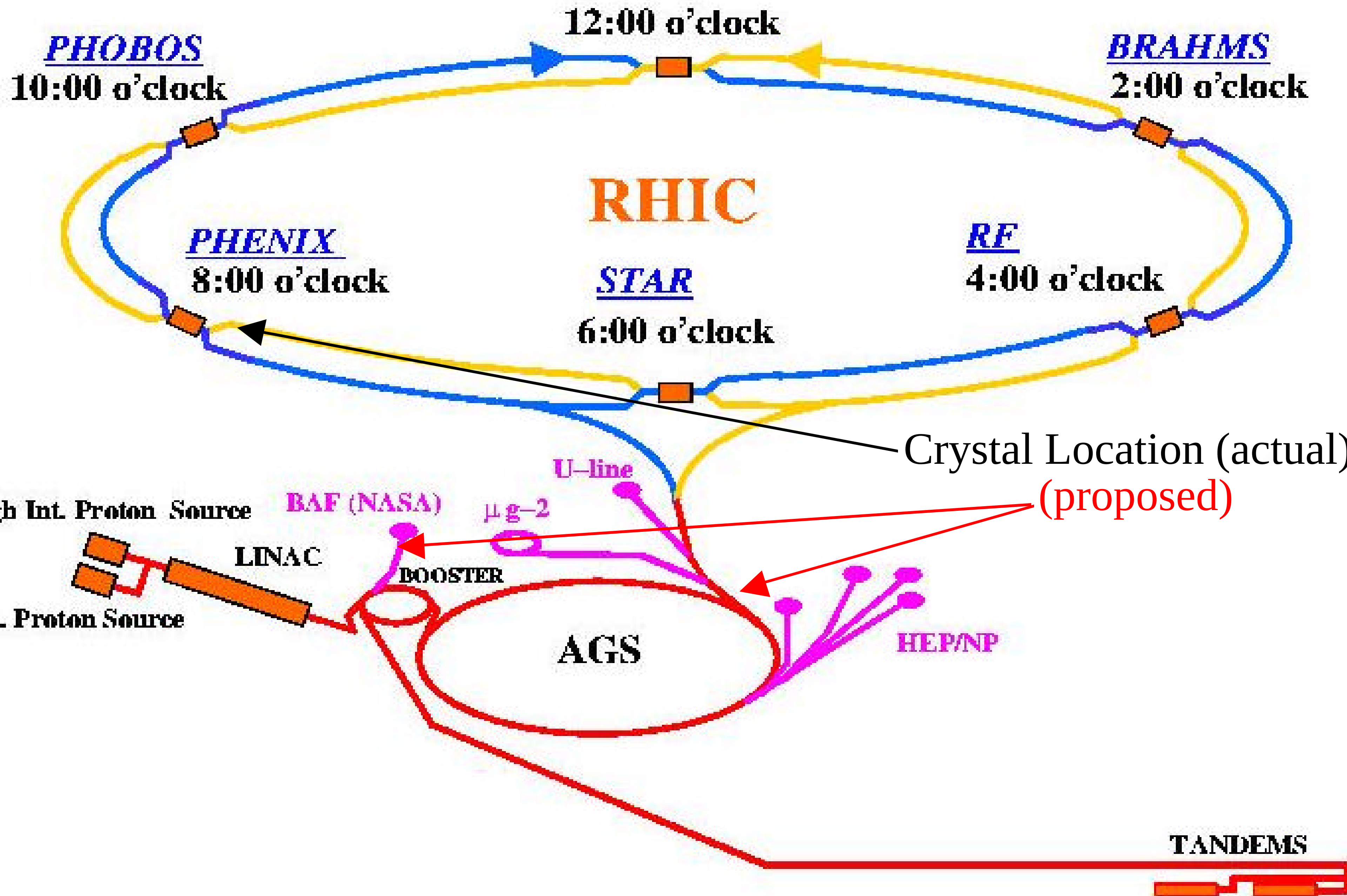
By using different crystal lattices and/or atomic elements, it is possible to adjust the critical angle for a particular application. In practice, since crystal quality is paramount, Silicon is most often chosen.

CATCH Code

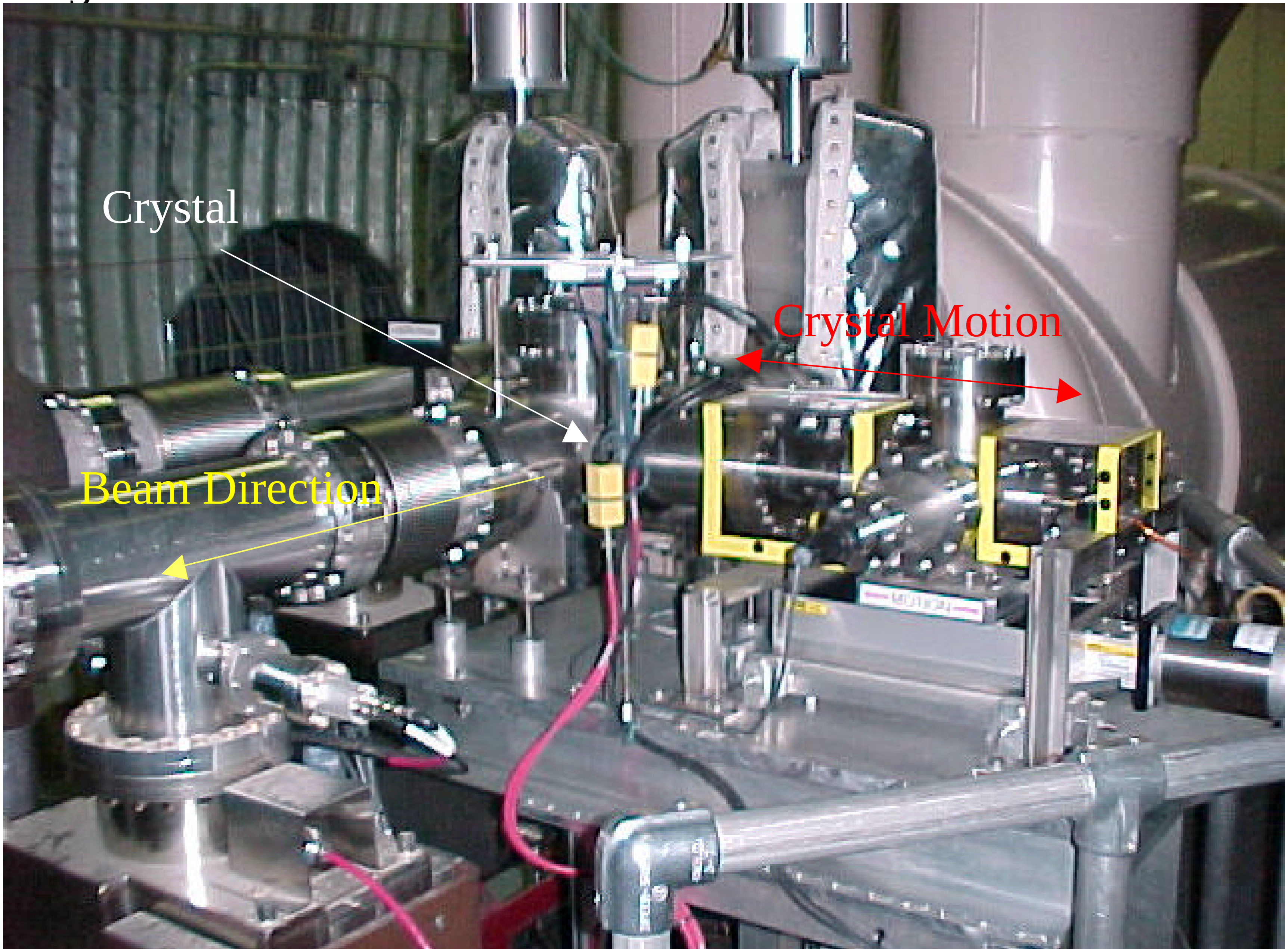


CATCH : written by Valery Biryukov

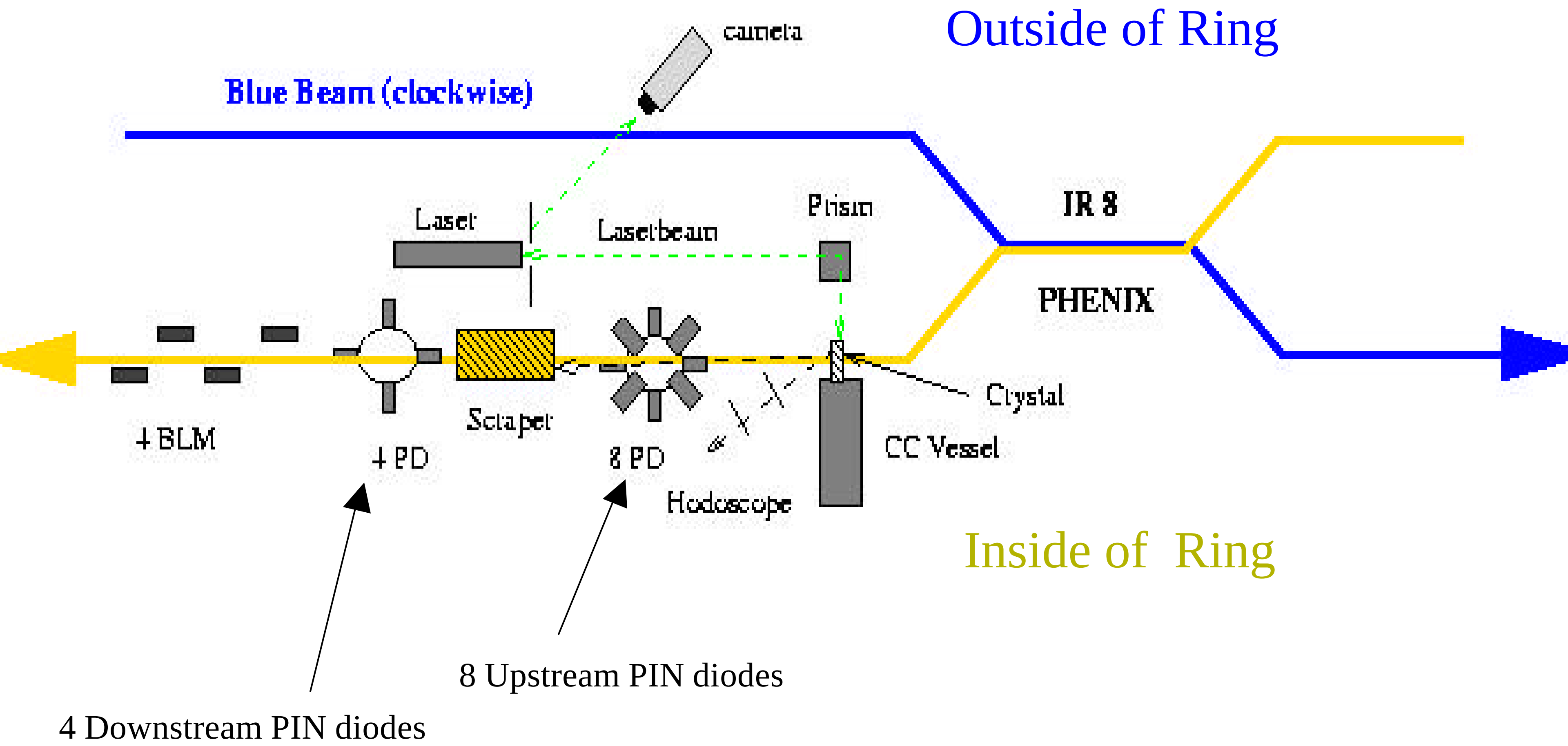
Accelerator Complex



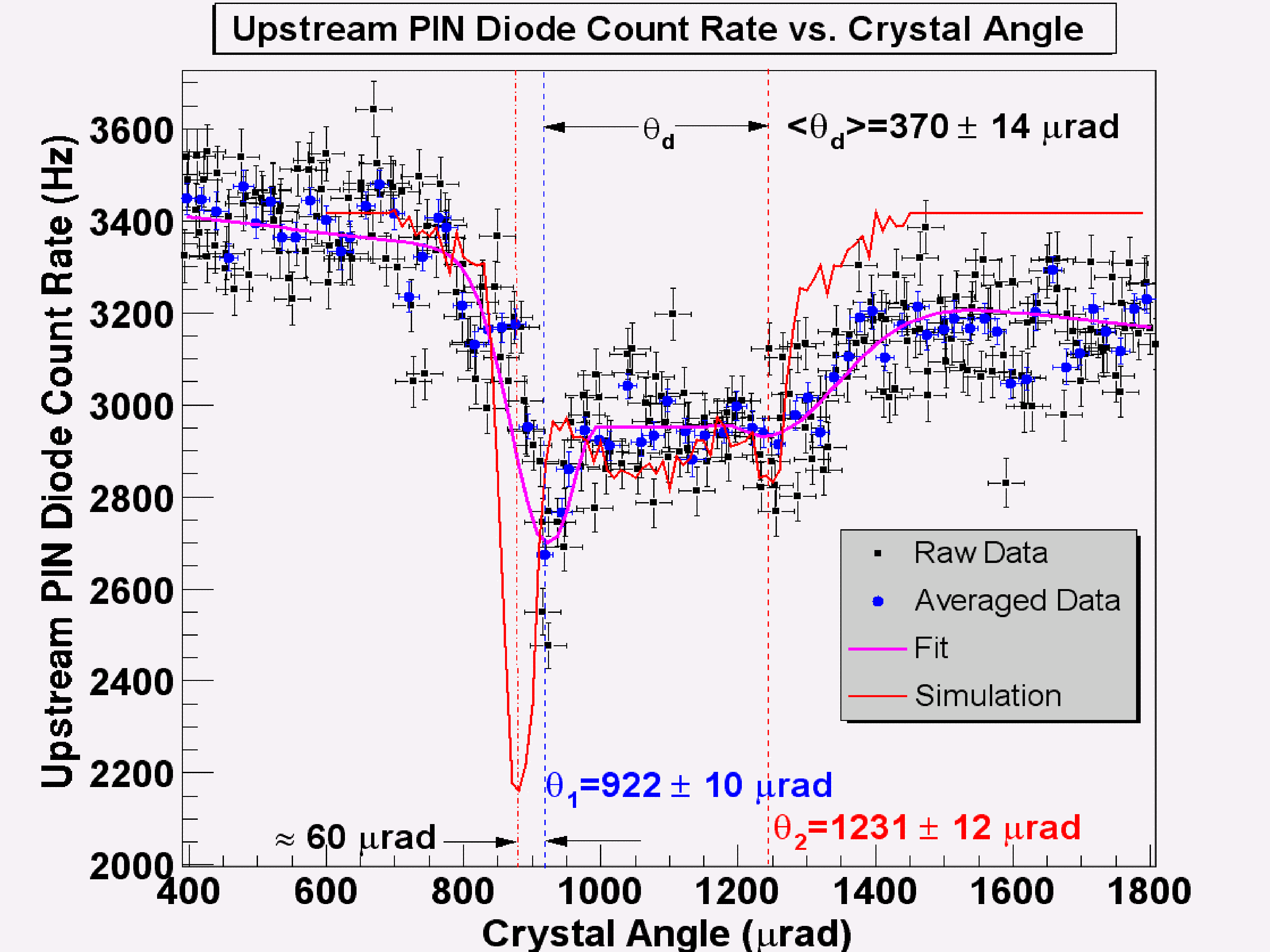
Crystal Vessel



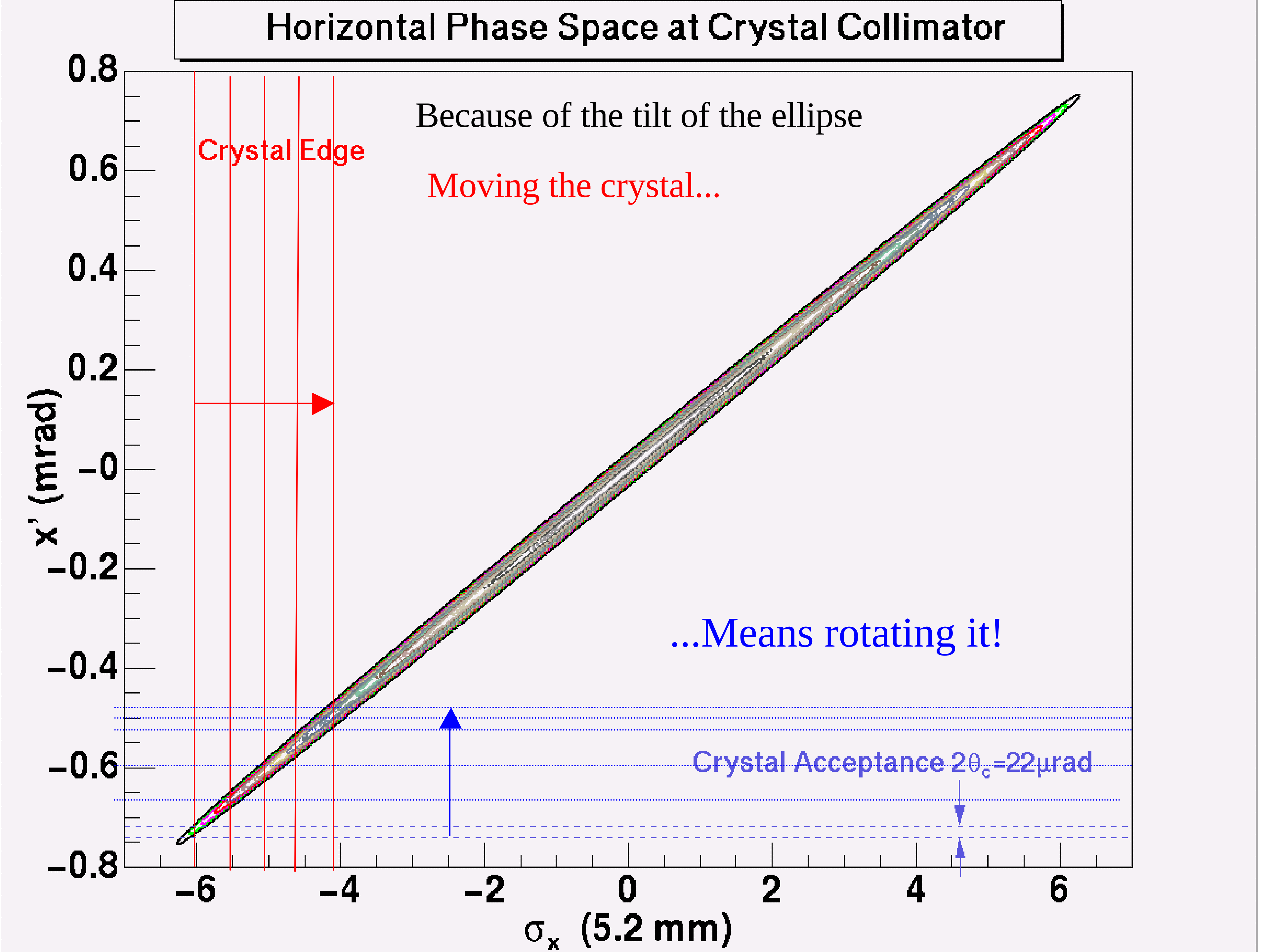
RHIC Collimator Setup



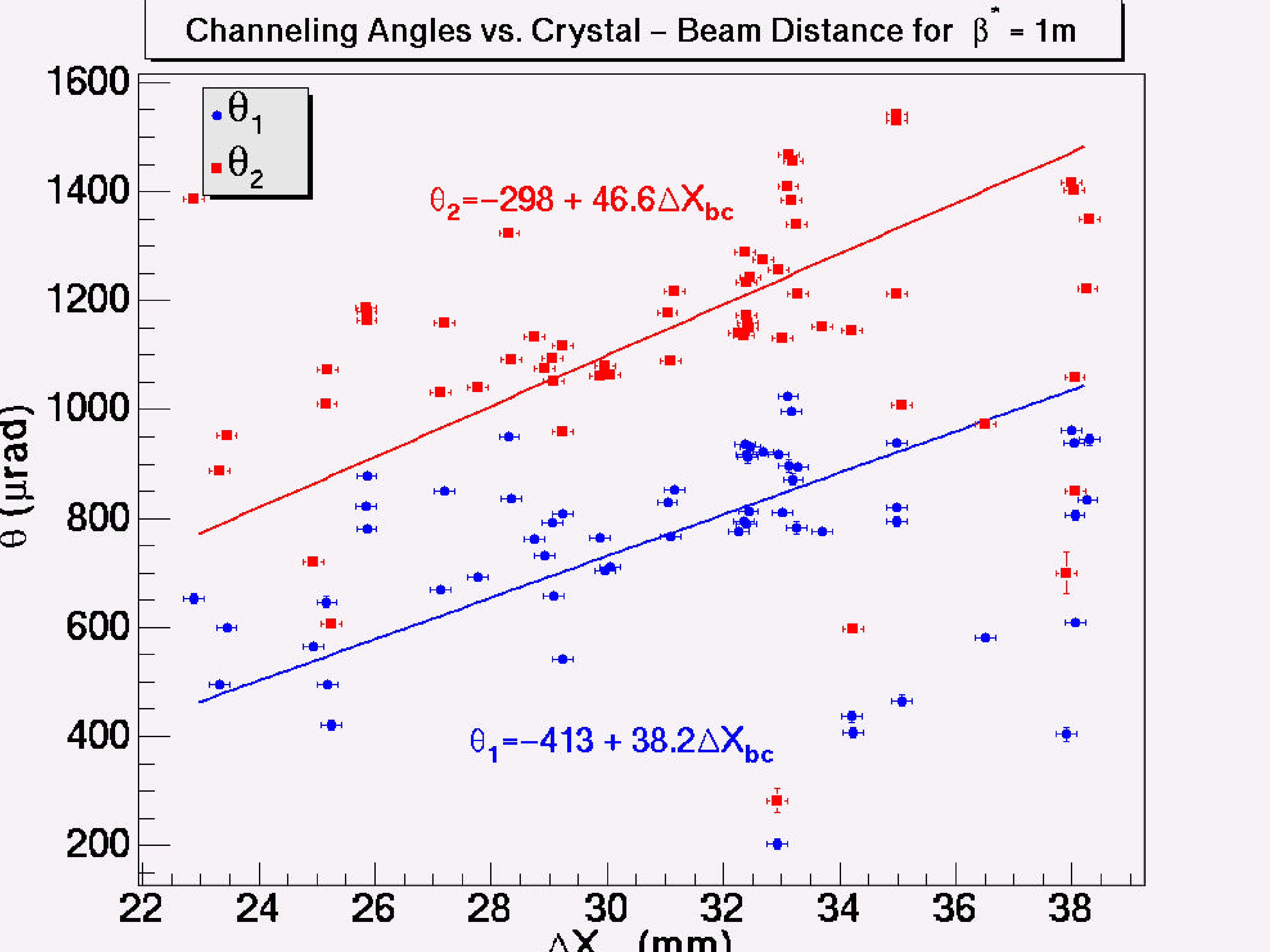
Data fill focus on upstream PIN diodes



Upstream PIN Diode Count Rate vs. Crystal Angle
Upstream PIN Diode Count Rate (Hz)
Crystal Angle (μrad)
θd
<θd>=370 ± 14 μrad
θ1=922 ± 10 μrad
θ2=1231 ± 12 μrad
≈ 60 μrad
Raw Data
Averaged Data
Fit
Simulation
2000
2200
2400
2600
2800
3000
3200
3400
3600
400
600
800
1000
1200
1400
1600
1800



Horizontal Phase Space at Crystal Collimator
Because of the tilt of the ellipse
Crystal Edge
Moving the crystal...
...Means rotating it!
Crystal Acceptance 2θc=22μrad
x' (mrad)
σx (5.2 mm)
0.8
0.6
0.4
0.2
−0
−0.2
−0.4
−0.6
−0.8
−6
−4
−2
0
2
4
6


Channeling Angles vs. Crystal – Beam Distance for β* = 1m
θ1
θ2
θ2=−298 + 46.6ΔXbc
θ1=−413 + 38.2ΔXbc
θ (μrad)
1600
1400
1200
1000
800
600
400
200
22
24
26
28
30
32
34
36
38

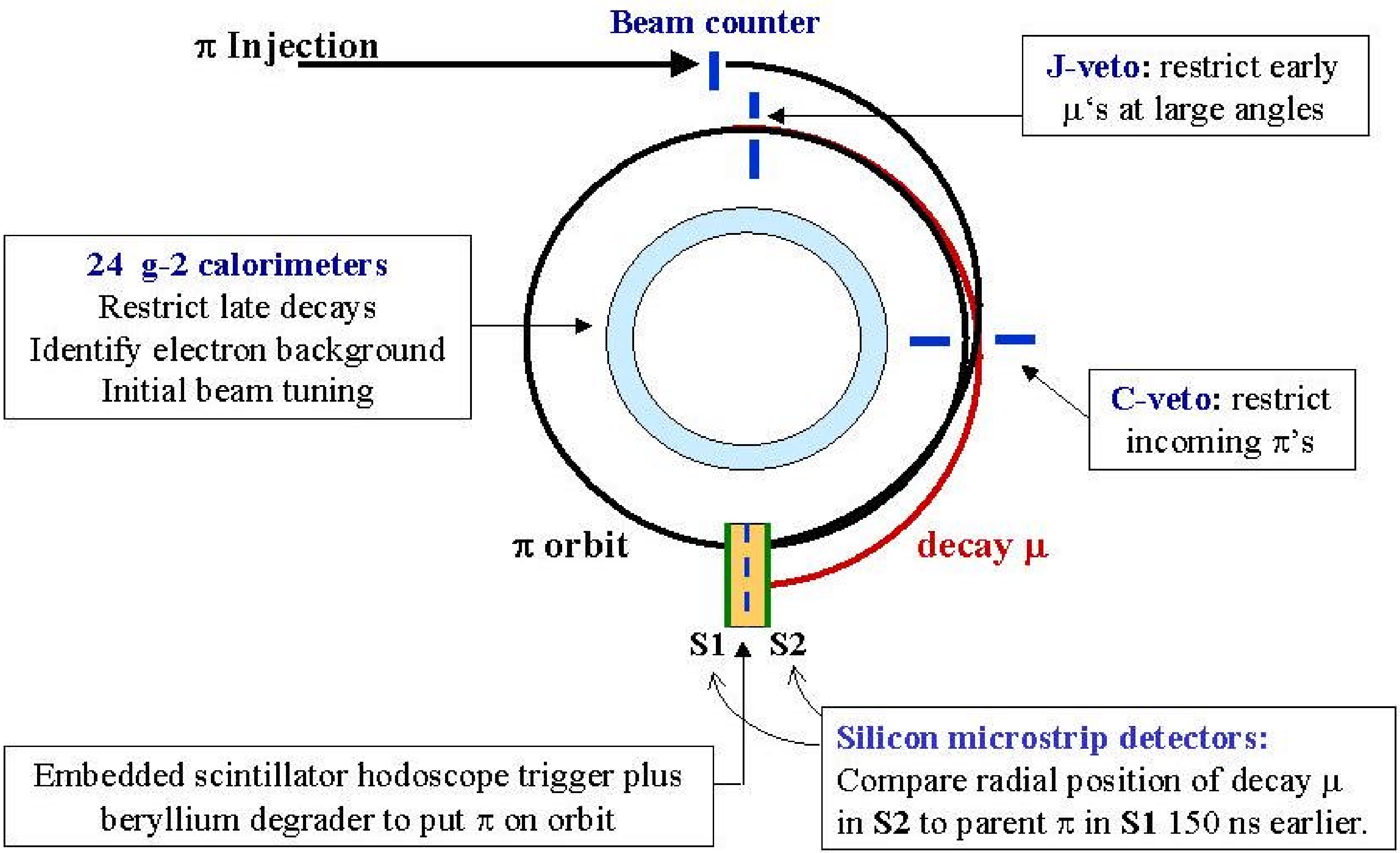
Proposals for Crystal Uses in the AGS and Booster

E952: NuMass

8 keV/c^2 Direct Muon Neutrino Mass Limit

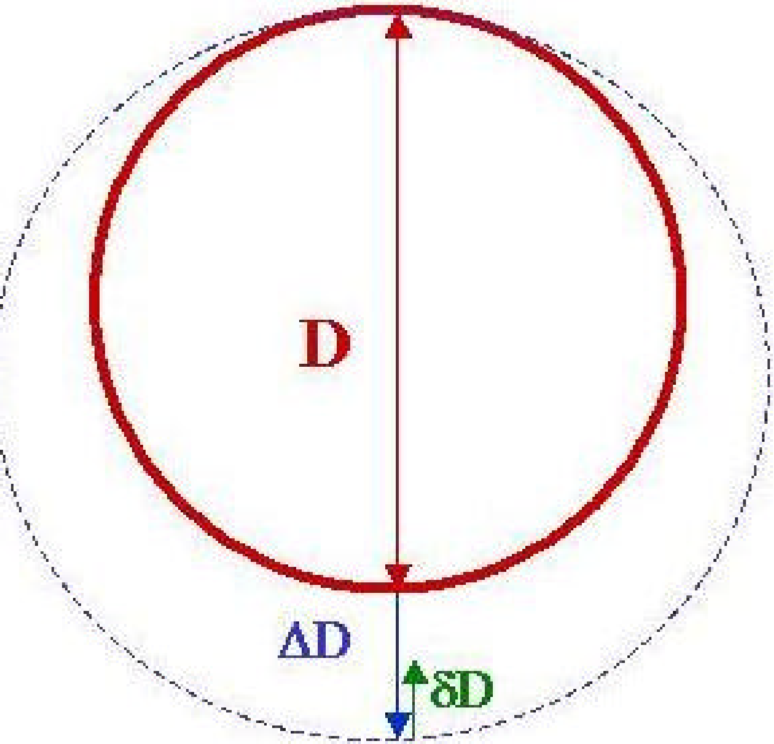
The 14 m diameter g-2 Storage Ring becomes a one-turn Spectrometer observing $\pi \rightarrow \mu\nu$ decay in flight

Note: Current Mass limit: 190 keV



http://www.hep.mnu.edu/numass

Conceptual Details



Forward-going decay muons orbit a larger diameter by ΔD

CM

$$\nu_\mu \longleftarrow \quad \pi \quad \longrightarrow \mu$$

$$q = 29.7\ \mathrm{MeV/c}$$

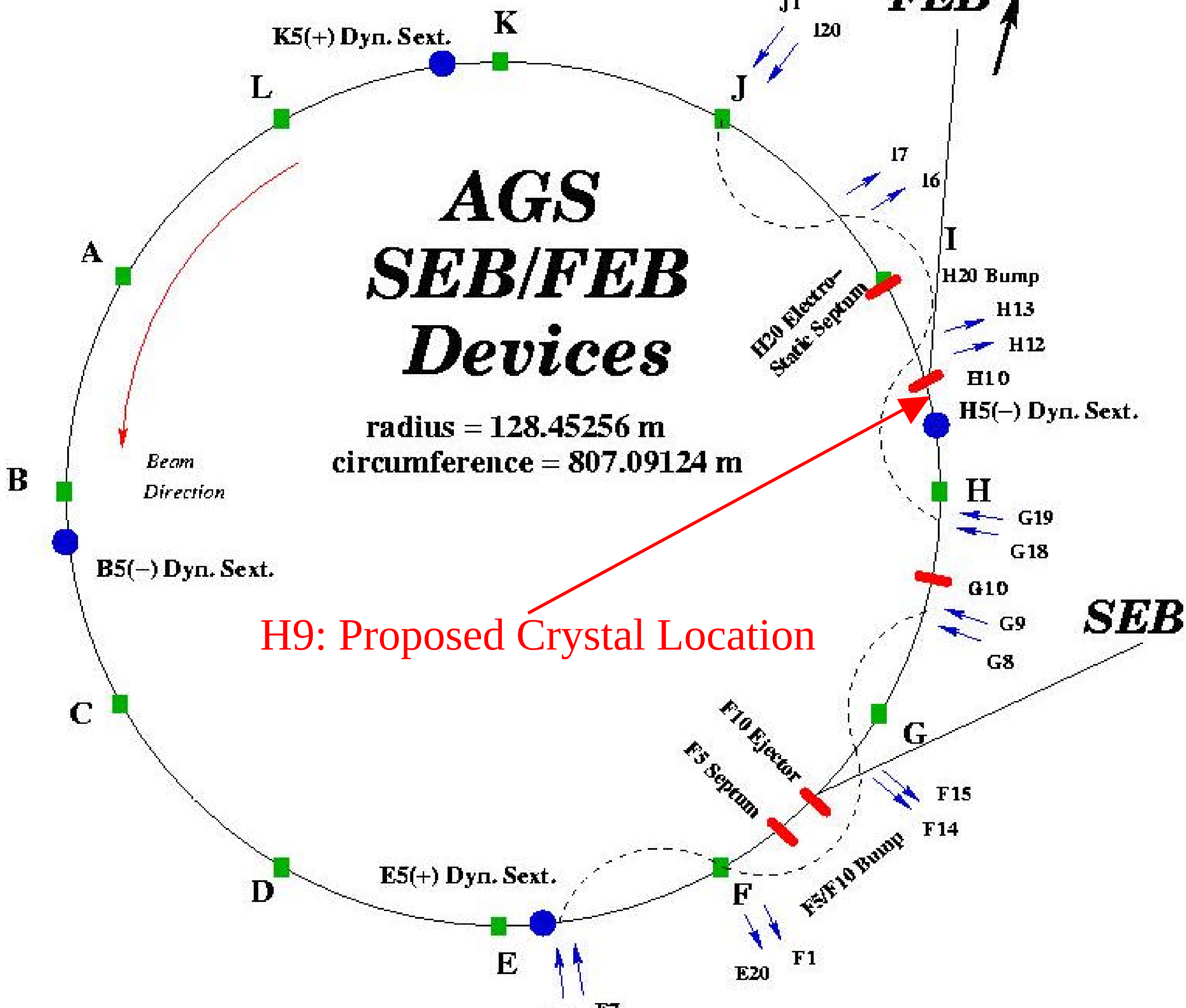
$$\frac{\Delta D}{D} = \frac{p_\mu - p_\pi}{p_\pi} = \frac{0.7\ \mathrm{MeV/c}}{3\ \mathrm{GeV/c}} = \frac{3.26\ \mathrm{mm}}{14\ \ \mathrm{m}}$$

Non-zero neutrino mass shrinks ΔD by

$$\frac{\delta D}{D} = \frac{-m_\nu^2}{2\,q\,m_\pi}$$

Corresponding to 0.04 mm for current limit

http://www.hep.mnu.edu/numass


AGS
SEB/FEB
Devices
radius = 128.45256 m
circumference = 807.09124 m
H9: Proposed Crystal Location
Beam
Direction
K5(+) Dyn. Sext.
K
L
J
I20
I7
I6
A
I
H20 Bump
H20 Electro-
Static Septum
H13
H12
H10
H5(–) Dyn. Sext.
B
H
G19
G18
B5(–) Dyn. Sext.
G10
G9
G8
SEB
C
G
F10 Ejector
F5 Septum
F15
F14
F5/F10 Bump
D
E5(+) Dyn. Sext.
F
F1
E20
E

AGS Requirements for NuMass Experiment

Protons per second (1 TP/s) on Pion production target for a flux of 1 pion in the g-2 ring, every two turns

The AGS is capable of handling 70 TP beams.

It may be possible to run parasitic to other experiments such as the Rare K Decay Experiment (E949).

E949 requires 25 GeV proton beam.
E949 is located down SEB beamline.
NuMass is located down FEB beamline.

Poses a problem!

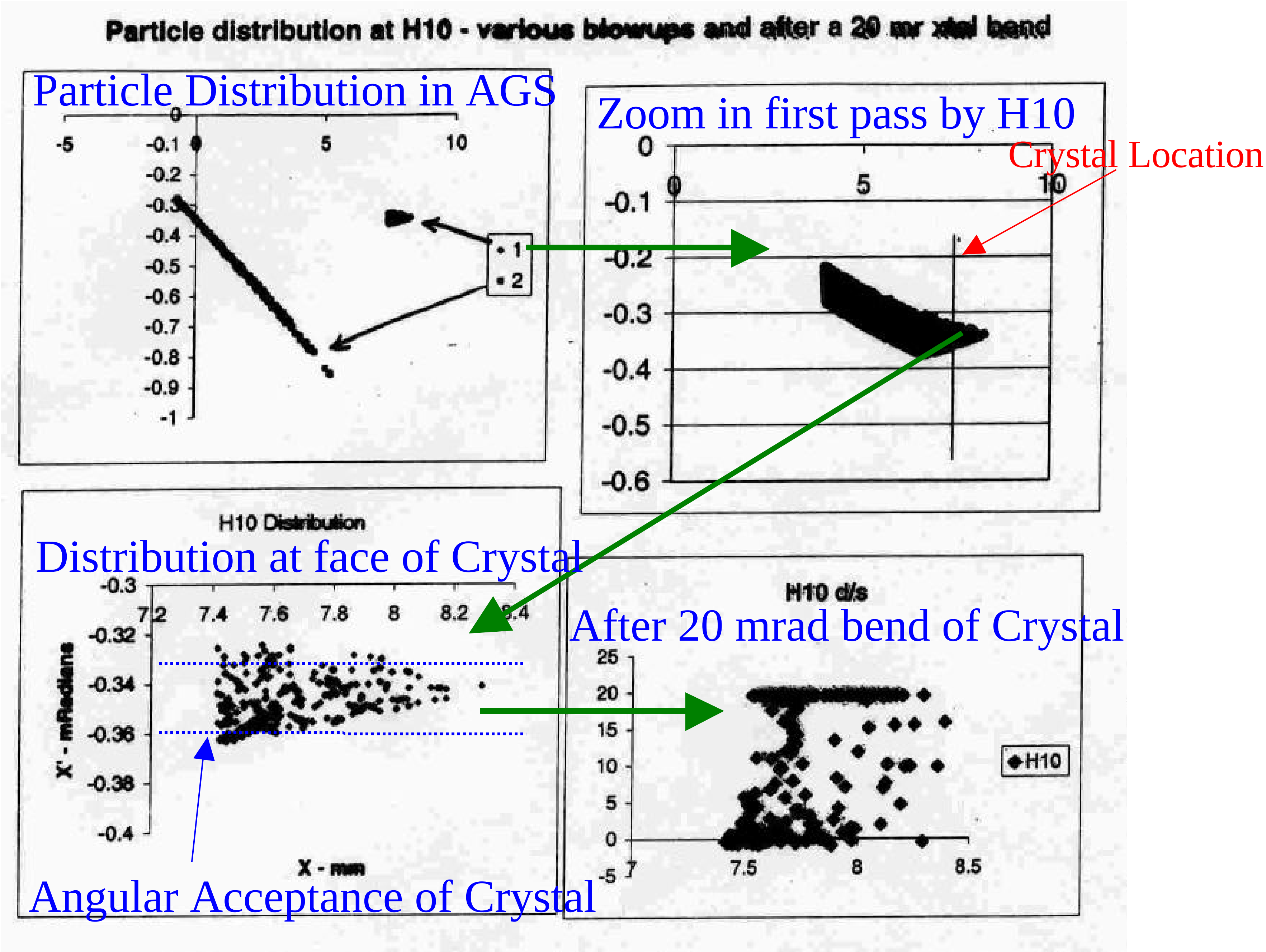
How to Run NuMass Parasitically to E949

AGS needs an additional thin septum to kick some of the beam across the fast extraction septum
The AGS fast extraction septum cannot run at 25GeV over the length of a spill because of heat buildup in the magnet. A "helper magnet" is needed.

This takes up space. AGS is crowded and real estate is at a premium, just like Manhattan!
A bent crystal can provide an answer.

Solves the need for a thin septum.
A bend can be chosen to assist the fast extraction septum.
Provides a flux of 1 TP per AGS cycle.
Added benefit of reducing background to E949.

Horizontal Phase Space at H10 Fast Extraction Septum with Crystal



Crystal Parameters in AGS

Critical Angle: θ_c=35μrad at 25 GeV

Bend Angle: θ_b<20 mrad. The H10 kick is 20 mrad. The goal is to run H10 at a lower field and boost the angle with the crystal.

The larger bend will require a few cm long crystal, longer than the RHIC crystal.
A longer crystal implies lower channeling efficiency do to increased probability of interactions with elections, lattice ions, and impurities.
Furthur simulation is necessary to find the correct balance of crystal length and bend to H10 kick.

Booster Applications Facility

The Booster Applications Facility being constructed at BNL, in collaboration with NASA, is a new experimental facility using heavy-ion beams from the AGS Booster accelerator for radiation effect studies for the Space Program.

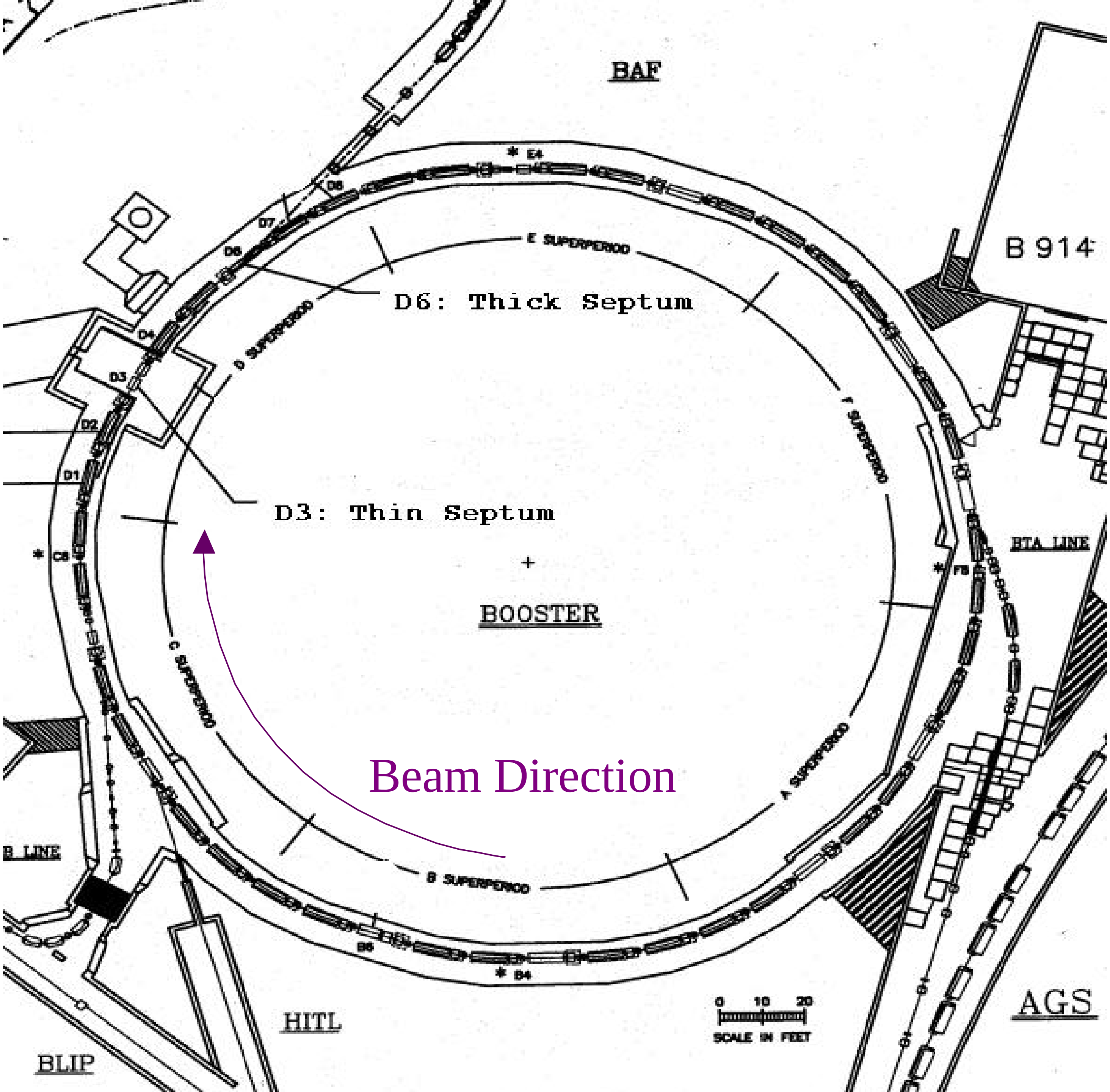
Of particular concern are the radiation effects to astronauts from the heavy ion components of the galactic cosmic ray spectrum.
The expected dose rates are as high as 30 to 50 rad/year. There is great uncertainty regarding the risks associated with such high dose rates. The relative biological effectiveness (RBE) or the risk weighting of energetic heavy ions are not known, and there are even serious doubts about the validity of such concepts.
Such factors can be very different for different organs and for different biological effects such as mutagenesis, carcinogenesis and cell necrosis. Many studies are required to reach adequate estimates of radiation-associated risks to humans in space.

BAF Beam Requirements

The most stringent requirements for BAF is single cell irradiation, leaving neighboring cells unharmed.

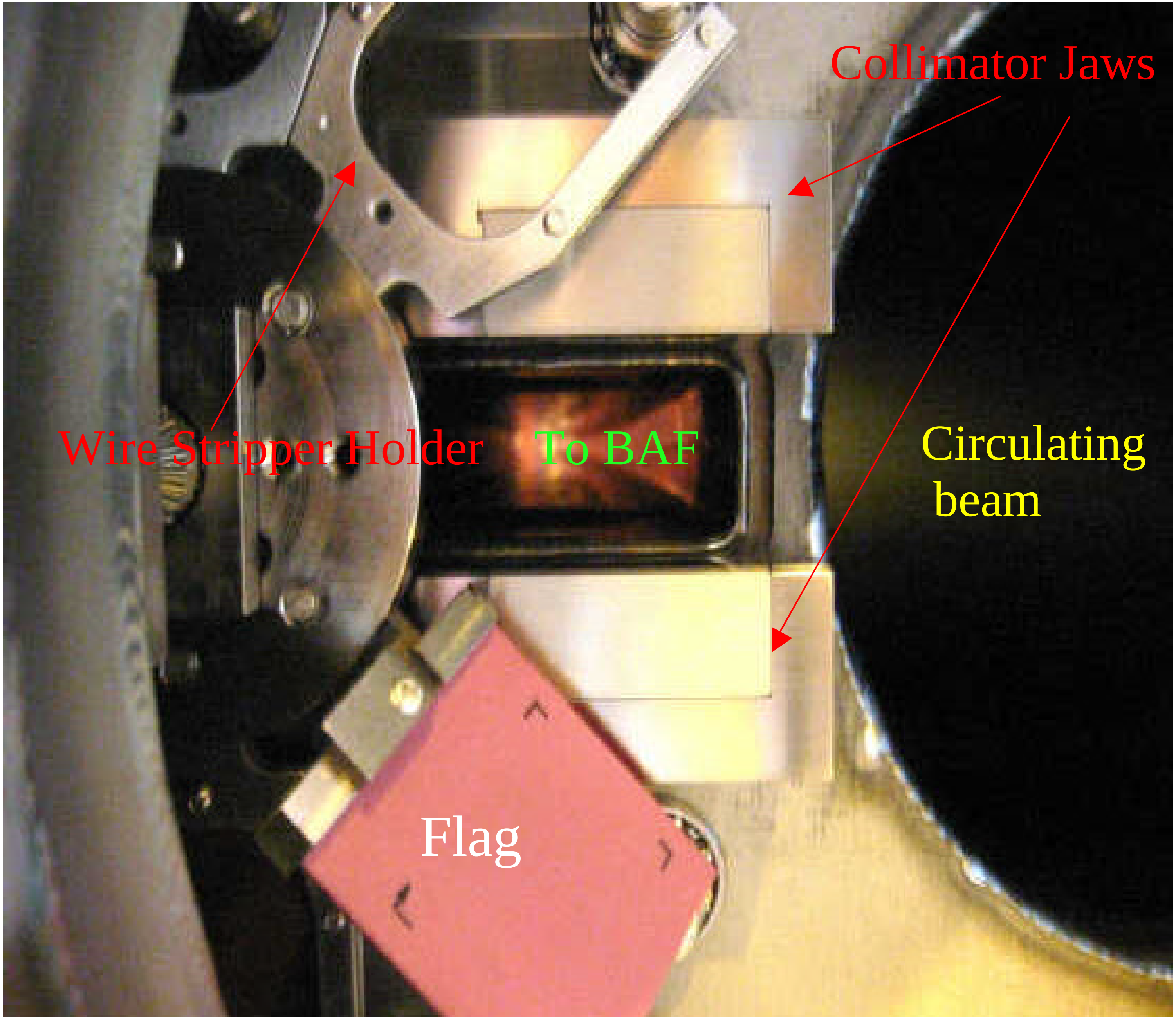
The minimal requirements for such an experiment are to aim the beam at a 10μm x 10μm spot on the petri dish with an extremely low flux as to irradiate a cell with a single ion.

Even smaller beam sizes are more desirable to allow individual organelles of cells to be irradiated as desired.



BAF
B 914
D6: Thick Septum
D3: Thin Septum
E SUPERPERIOD
D SUPERPERIOD
F SUPERPERIOD
C SUPERPERIOD
B SUPERPERIOD
A SUPERPERIOD
BOOSTER
BTA LINE
Beam Direction
B LINE
HITL
BLIP
AGS
0 10 20
SCALE IN FEET

D6 Thick Septum



Proposed Crystal uses for BAF

"1. "Replace" D3 thin septum with a crystal bent 3 mrad.

   Crystal has to power supply.

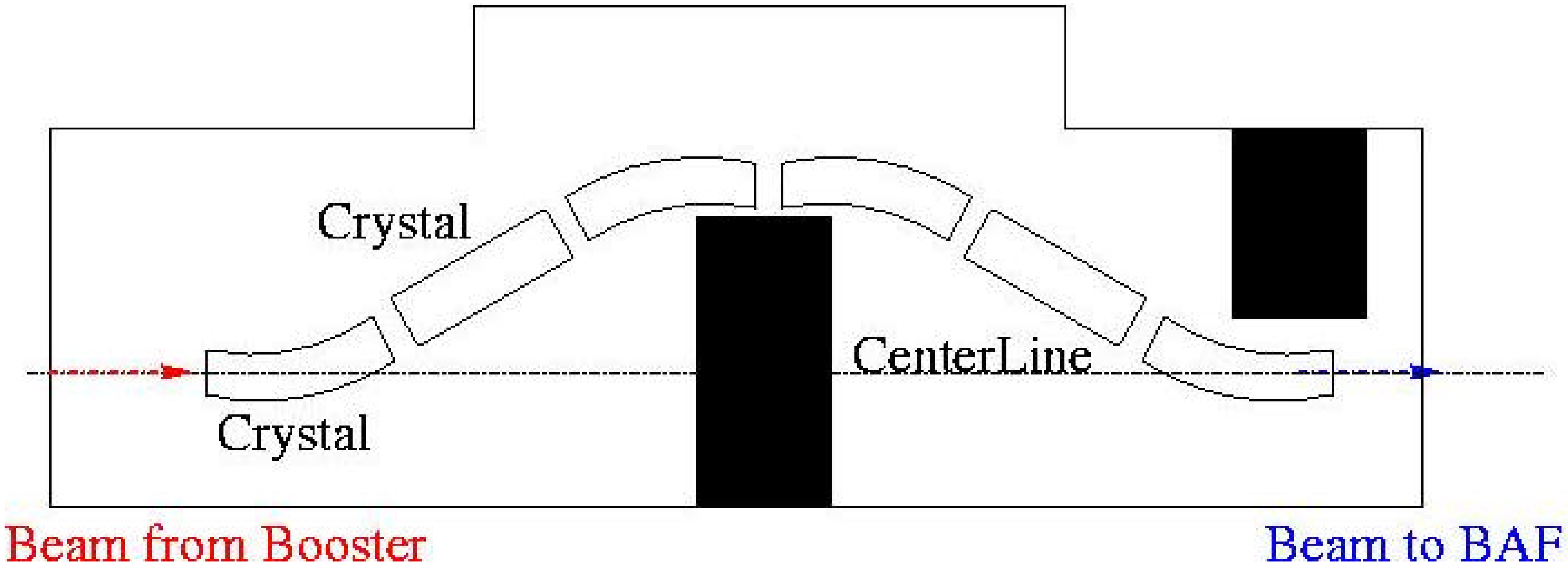
2. A BAF chicane.

   Use a combination of 2 bent crystals in opposite planes to better define the beam and permanent magnets to return beam to desired orbit.

   Provides a well defined position for the source of the BAF beam.

   Reduces the size and angular spread of the beam in both dimensions below the $10x10\mu m^2$ specification!

BAF Line Chicane Proposal



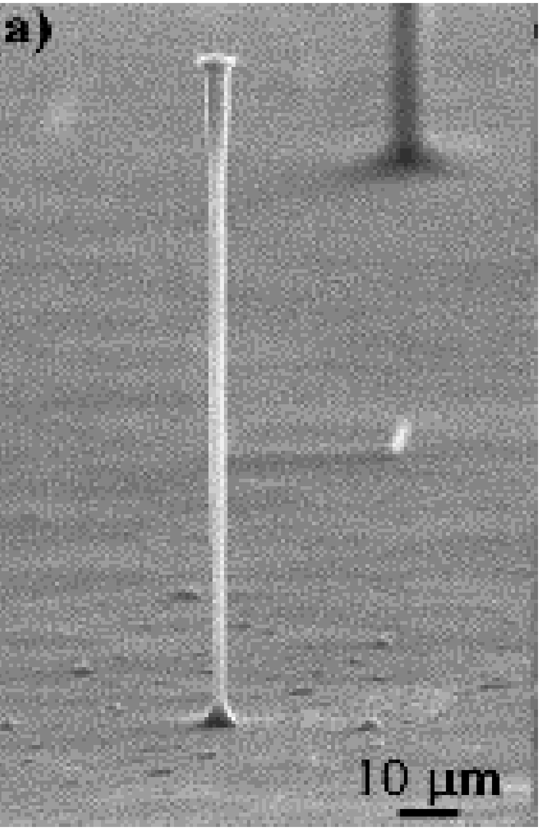
Second Crystal bent in opposite plane. Collimators reduce background to BAF. Other elements in the chicane return the beam to its original orbit.

Relevant Crystal Parameters

Critical Angle: θ_c =77μ rad at Bρ =17 Tm

=280μ rad at Bρ =2.2 Tm (p inj. Energy)

=1.61mrad at Bρ =0.9 Tm (Au^{32+} inj. Energy)



Using microcrystals it is possible to have extremely small beams. The added bonus is an automatic reduction in the flux!

Silicon MicroCrystal photo courtesy of

Summary

Crystal Channeling for pre-collimation has been successfully demonstrated at RHIC.

Crystal Extraction in the AGS seems like a viable option for the NuMass experiment.

A crystal in the BAF line looks like a promising way to produce very small beams.

Analysis continues ....