BROOKHAVEN NATIONAL LABORATORY

Building 911C
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-4531
Fax 631 344-5954
hershcovitch@bnl.gov

Memo

DATE: *March 11, 2005*

TO: RHIC E-Coolers

FROM: *Ady Hershcovitch*

SUBJECT: **Minutes of the March 11, 2005 Meeting**

Present: Andrew Burrill, Rama Calaga, Yury Eidelman (ORNL & BINP Novosibirsk, Russia), Alexei Fedotov, Wolfram Fischer, Ady Hershcovitch, Dmitry Kayran, Jorg Kewisch, Vladimir Litvinenko, Thomas Roser, Gang Wang (SUNY Stony Brook), Jie Wei.

Topics discussed: Experiments at CELSIUS, SCRF Injector.

Experiments at CELSIUS: most of the meeting consisted of a detailed presentation by Alexei regarding experiments and their interpretations that were just performed at CELSIUS. This is a second series of experiments whose main purpose is accurate benchmarking of the cooling force and to study scaling laws as it applies to high-energy cooling. The experiments are designed to determine the following:

1. Measure longitudinal cooling force and determine which formulas are better for use in magnetized cooling.
2. Compare the model of Parkhomchuk versus the model of Derbenev, Skrinsky and Meshkov, which is for infinite magnetic field. And, benchmark codes.
3. Benchmark new models of IBS that are needed to accurately treat ion distributions as their thermal spread shrinks under cooling.
4. Generate conditions that are expected in high energy cooling.
5. Study numerous issues like magnetized cooling with small cooling logarithm, effect of solenoid errors, etc.

The following was achieved:

1. Longitudinal cooling force was measured accurately (within a few % far better than the factor 2 goal, or the previously done order of magnitude).
2. Can control V effective and not be sensitive to unknown parameters.
3. Time evolution of beam profiles; IBS model based on non-Gaussian distributions due to rapid cooling of beam core, while tails cool at much slower rate.
4. Measure cooling for various magnetization regimes. Existing models treat cases with either zero or infinite magnetic fields. Experiments with electron beam currents ranging from 50 to 250 mA, and magnetic fields of 0.03 T, 0.06 T and 0.12 T can cover and fill the gap of magnetization levels not treated by the models.

5. Experiment designed to determine maximum cooling force as a function of solenoid errors and V effective. Experiments are to be compared with both formulas and numerical simulation using VORPAL.

Tens of friction force curves in various regimes that have yet to be analyzed were obtained. Basically the results seem to support results obtained in December 2004. One difference is that in the conclusion of those experiments, the Parkhomchuk model had good agreement with experimental that was better than the model of Derbenev, Skrinsky and Meshkov. For both models single particle formulas were used. But after averaging over distribution functions, there was agreement between the models and both agreed with experiments. This increases confidence in predicting RHIC E-Cooling.

In summary

1. First set of basic experiments was concluded. Results should help answer various questions regarding high-energy magnetized cooling and increase our confidence in computer simulations.
2. Depending on analysis of results some experiments (like effect of solenoid error) may need to be repeated or improved at other coolers.
3. Other experiments like Z scaling, transverse cooling force, etc. will need to be performed at other cooler.

Below is Alexei's presentation.

SCRF Injector: the meeting was concluded with Andrew showing what the 703.75 MHz gun will look like as well as the ERL setup in 912. Andrew also reported that AES has an SBIR to fabricate the deposition chamber. He also reported that some initial experiments in 939 indicated that the multiplication factor of the diamond cathode seems to decrease at cryogenic temperatures. If this is the case the cathode surface will need to be heated. But, it is possible that a different crystalline structure will not be adversely affected at low temperatures.

Below are selected viewgraphs from Andrew's presentation.

Beam experiments towards high-energy cooling

- **In present low-energy coolers:**

 # 1 & 2: Accurate measurement of cooling force and code benchmarking.

 # 3: Benchmark new models of IBS required to treat accurately distribution shrinking under cooling.

 # 4 & 5: Create condition expected in High Energy Cooler and study some issues like magnetized cooling with small cooling logarithm, effect of solenoid errors, etc.

Experiment #1 and # 2: ACCURATE benchmarking of cooling force

- **Assuming ALL parameters are known:**

1. **First we want to be sure that we are using the most appropriate magnetized cooling force formulas.**

A. **Infinite magnetic field formulas.**

B. **Empiric formula (any field) – can show very different cooling dynamics**

C. **Direct simulation/testing of formulas and experimental benchmarking.**

Goal: to have description of cooling force with about factor of 2 accuracy (or better).

Experiment #3: Detailed IBS & Cooling

3. Dynamic beam profile evolution under Cooling and IBS

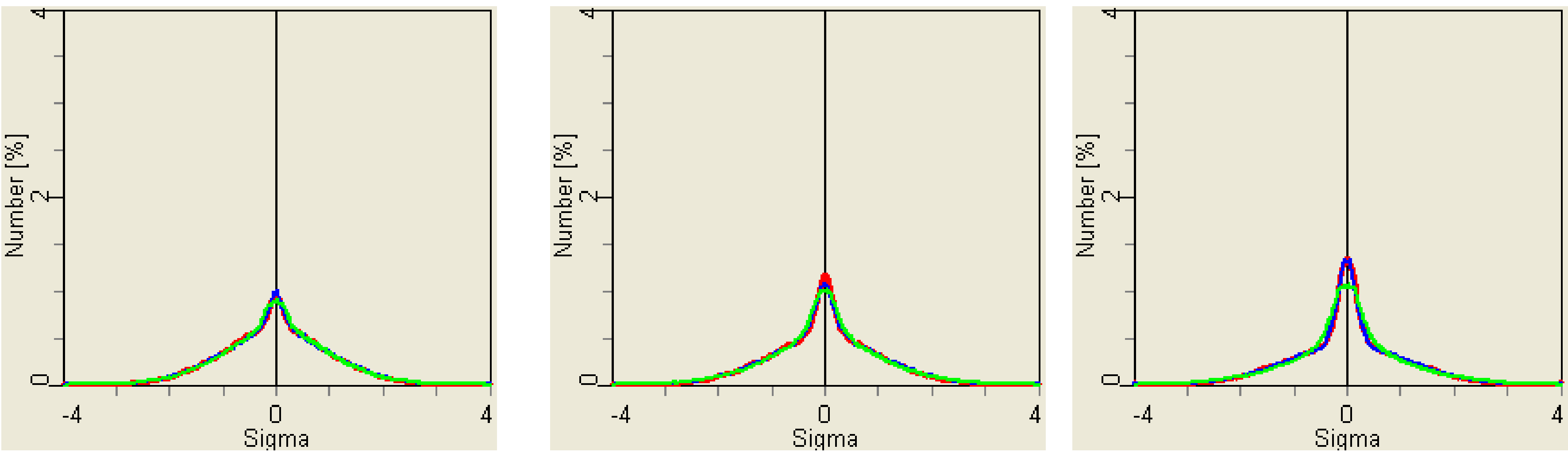
(Checks accurate treatment of IBS for distributions which are not Gaussian as a result of rapid cooling of beam core)

Need measurement of beam profiles before an equilibrium between IBS and Cooling is reached:

Cooling of bunched beam – to increase IBS

Intentionally decrease cooling speed

Beam profiles – at three different time steps based on “core-tail” model of IBS (different diffusion coefficients for particles in the core and tails of beam distribution)



simulations

BROOKHAVEN NATIONAL LABORATORY

Experiment #4: Transition from good to bad magnetization

Scaling magnetic field to test transition from good to bad magnetization:

Celsius:

1. using electron beam current and magnetic field set up 3 regimes: good, transition, bad magnetization.
2. Measure dependence on magnetic field in each regime
3. Compare with codes. Can our codes describe accurately cooling force even in transition regime?

$$L_{vp} = \ln\left(\frac{\rho_{\max} + \rho_{\min} + r_L}{\rho_{\min} + r_L}\right) \xrightarrow{\rho_{\min} << r_L} L_{vp} = \ln\left(\frac{\rho_{\max}}{r_L} + 1\right) = \frac{\rho_{\max}}{r_L}$$

for $\rho_{max} < r_L$

$$\mathbf{F} = -\frac{1}{\pi}\omega_{pe}^2 \frac{(Ze)^2}{4\pi\varepsilon_0} \frac{1}{\left(V_{ion}^2\right)} \left(V\tau eB / m\Delta_{et}\right)$$

$$\mathbf{F} -> \frac{B}{V_{ion}\Delta_{et}}$$

1. one gets only 1/V instead of 1/V^2 dependence
2. in addition $1/\Delta_{et}$ dependence outside logarithm

CELSIUS (experiment #4 estimates)

Magnetic field of cooling solenoid, beam energy: $B := 0.05$ Tesla $E_e := 26\cdot 10^3$

$$\rho_L := \frac{mc2}{q\cdot c\cdot B}\cdot\frac{V_{et}}{c}$$

$$\rho_L = 1.617\times 10^{-5}$$

Cooling log ration:

$$ne := \frac{Ie}{q\cdot bet\cdot \gamma\cdot c\cdot\left(\pi\cdot a_e^{\;2}\right)}$$

$$ne = 2.051\times 10^{14}$$

$$\frac{\rho_{max}}{\rho_L} = 0.63$$

Coulomb log:

$$\Lambda_p := \ln\left(\frac{\rho_{max} + \rho_L}{\rho_L}\right)$$

$$\Lambda_p = 0.489$$

CELSIUS (experiment #4 estimates)

1. Bad magnetization. I=1A.
Do measurements at 3 values of B=0.03, B=0.06, B=0.12
(or any other values with B=0.12 and less).

2. Transition: I=0.5A, B=0.05, B=0.1, B=0.15

3. Good magnetization: I=0.1A, B=0.5, B=0.1, B=0.15

Experiment #5: Solenoid errors/V_effective

1. Movement of force maximum with respect to introduced errors (controlled by correctors) in solenoid – V_effective and benchmarking with simulations

Both with formulas and direct numerical simulation (Vorpal)

Will allow to remove some questions/uncertainties about empiric formulas.

CELSIUS – experiments December'04-March'05

ALL proposed experiments were tried during December'04 and March'05 beam time.

Participants:

December'04 – B. Galnander, T. Lofnes, V. Ziemann (TSL)
A. Fedotov, V. Litvinenko (BNL)
A. Sidorin, A. Smirnov (JINR)

March'05 - B. Galnander, T. Lofnes, V. Ziemann (TSL)
A. Fedotov (BNL)

December'04 measurements established

1. Accurate phase-shift measurements were established.
2. We can measure (measured for Ie=250mA and three angles) linear part and maximum of friction force with extremely good accuracy.
3. We can control V_effective and thus maximum of the friction force, making it bigger than:
   - longitudinal temperature of electron beam
   - effective angular spread given by magnetic field imperfections

We are therefore may be not sensitive to unknown parameters

Accuracy of Phase Shift method:
important since it allows to find location of the force maximum

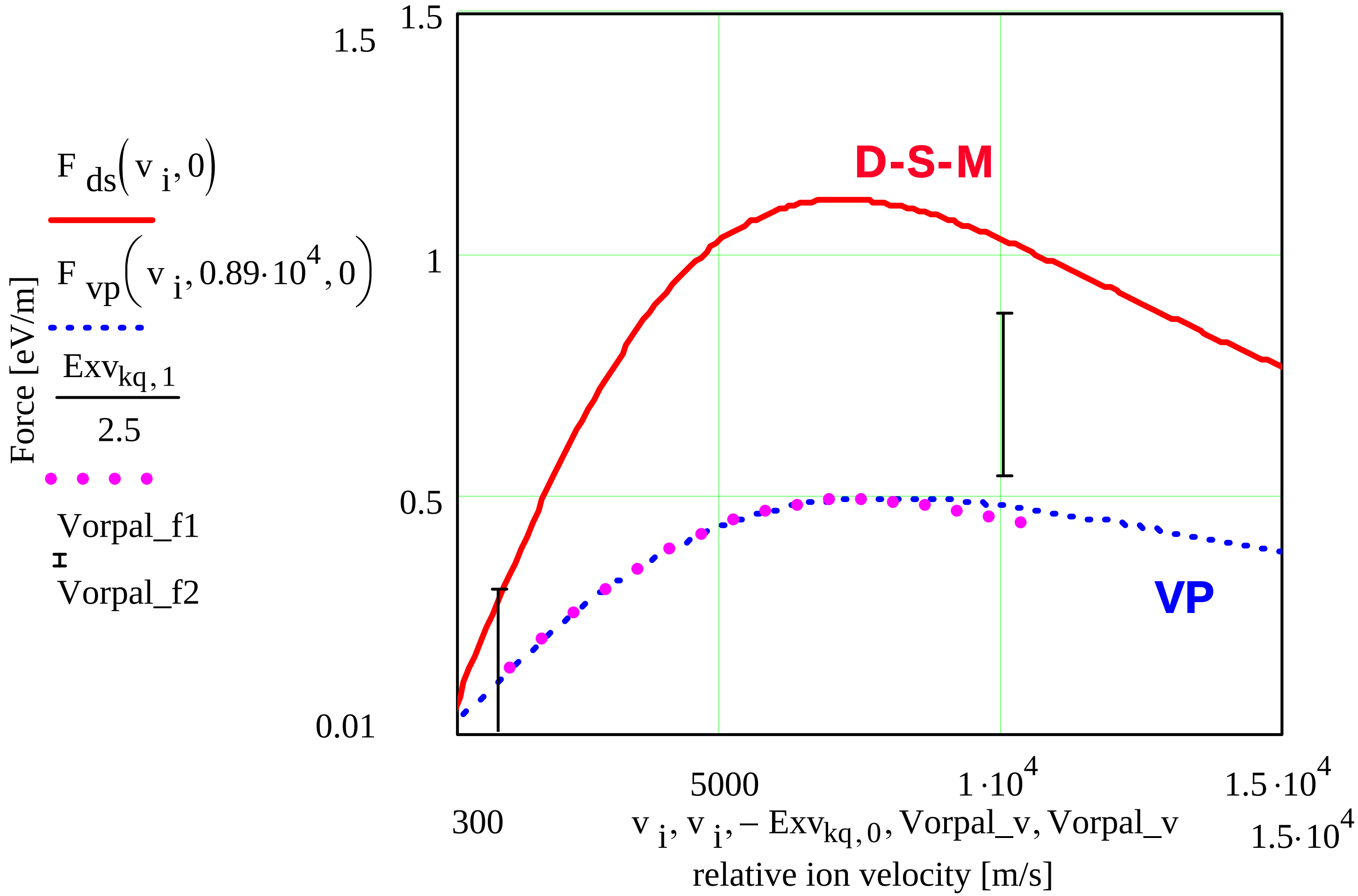
1. One needs to introduce small velocity difference between electrons and ions – typically, voltage step is used to change energy of electrons.
2. One needs accurate measurement of the phase difference between the bunch and rf signal.

In our experiment at CELSIUS this measurement was improved by:

1. Changing rf frequency – allows very fine steps in velocity difference.
2. Instead of network analyzer without phase lock loop the phase was measured by phase discriminator.

As a result, very accurate experimental data was obtained !

Comparison of experiments, VORPAL runs and single-particle formulas VP and D-S-M (Feb.18,2005)



Measurements and single-particle formulas

1. Measurements:

a) Measured dp/p suggests that there is significant longitudinal spread of ion velocities.

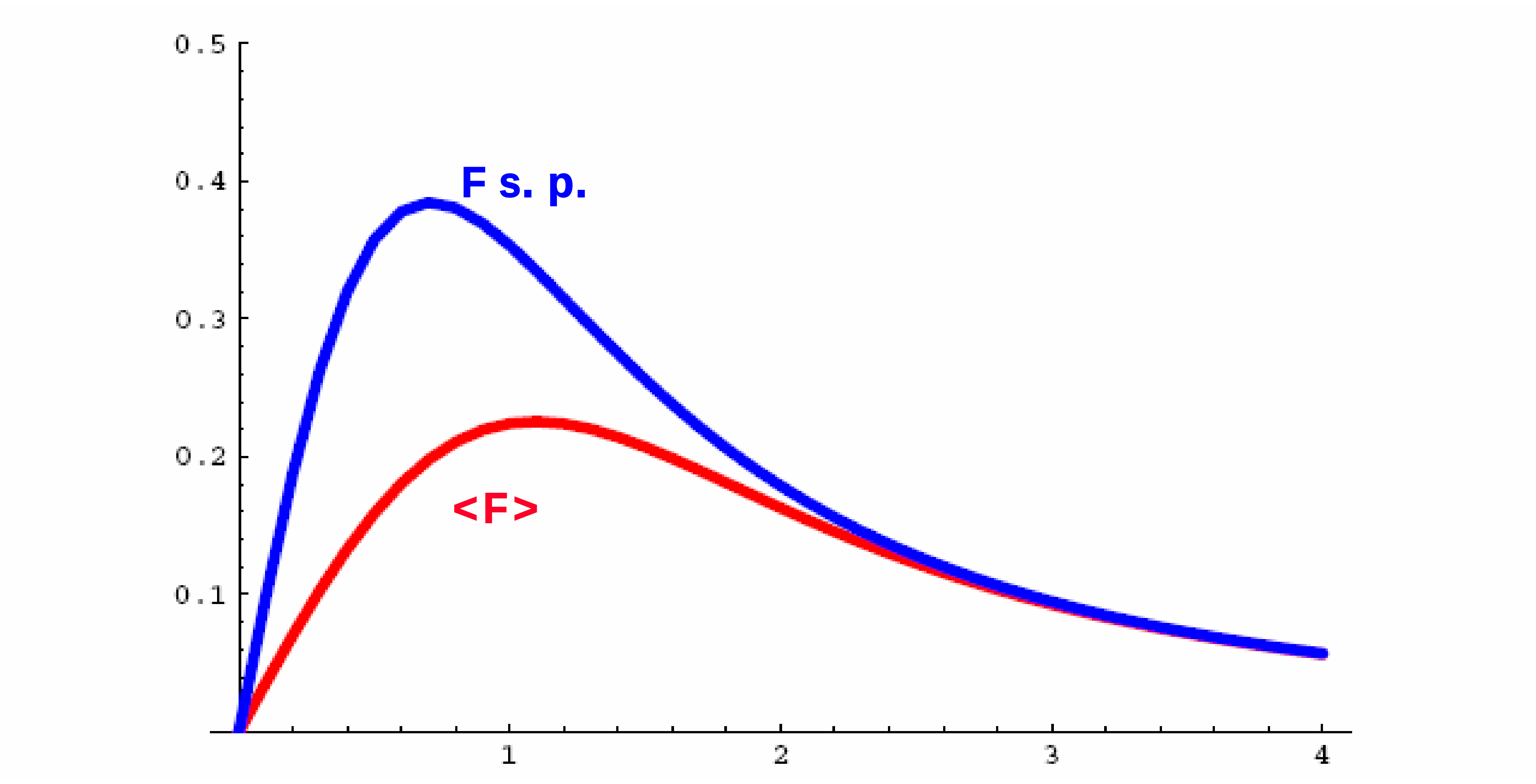
b) Big uncertainty in measured transverse spread for such low current.

2. Simulations:

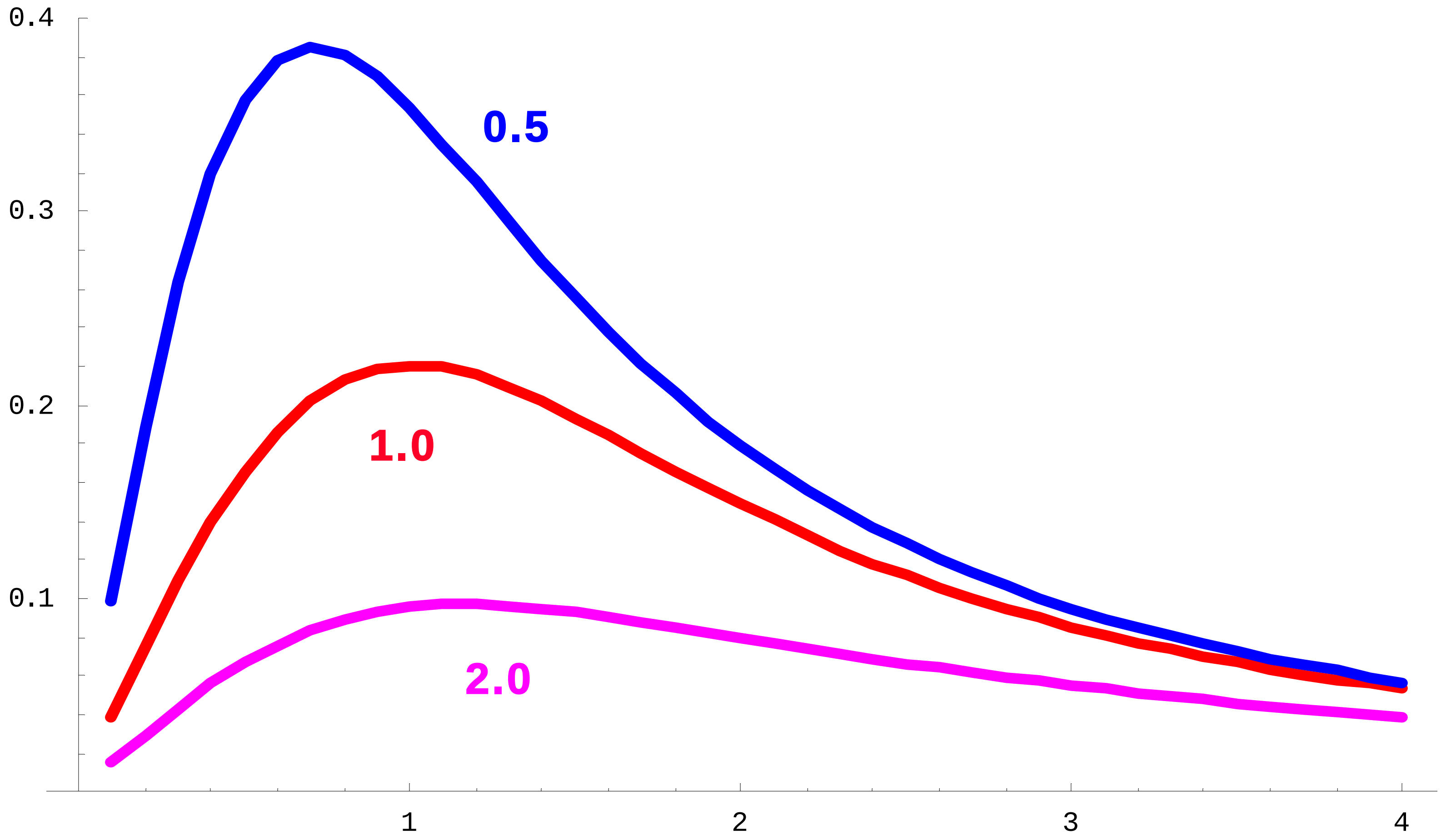
BetaCool simulations for CELSIUS gave expected rms spreads which turned out to be significant.

As a result, single ion friction force should be averaged over ion distribution function.

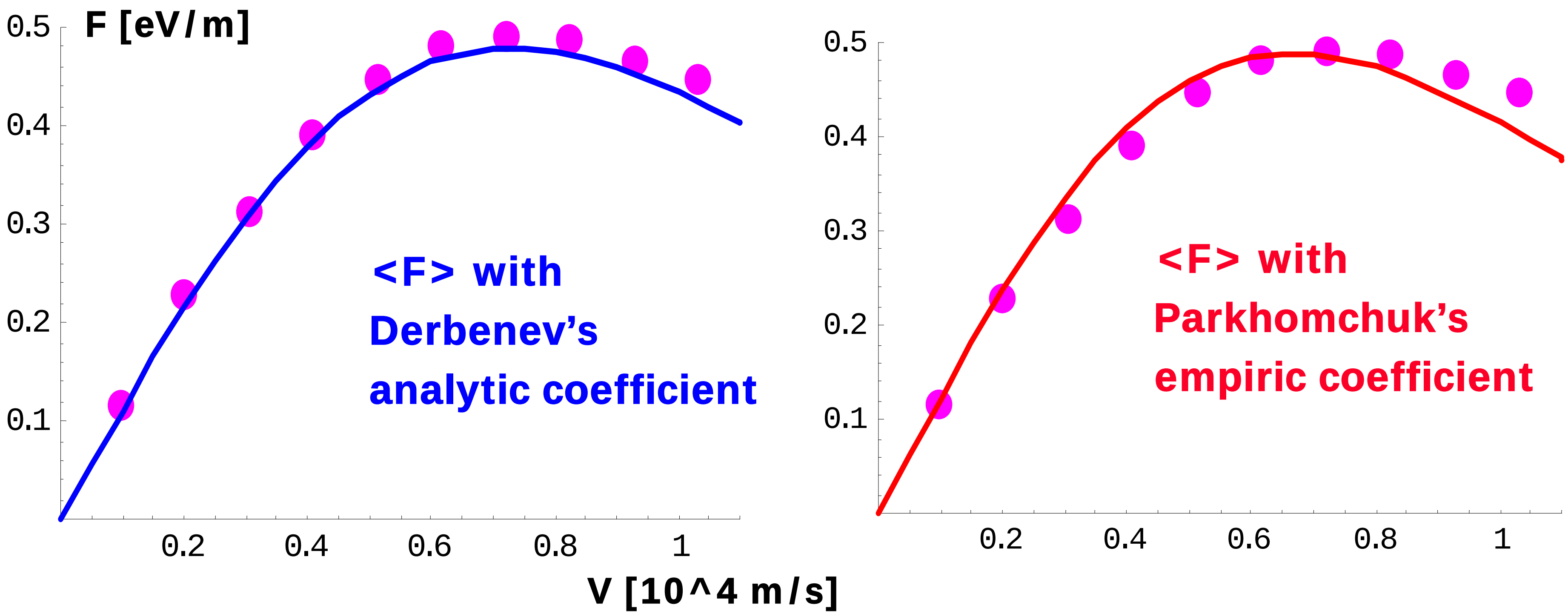
VP-type S.P. (Single Particle) vs <VP-type> with the same v_eff=1.0 (sigmaVT=sigmaVL=0.5)



<VP> sigmaVL=0.5, v_eff=0.6, sigmaVT=0.5, 1.0, 2.0



Single-particles formulas averaged over distribution (with sigmaVL, sigmaVT taking based on BetaCool prediction)



$V\_err = 0.3 * 10^4$ m/s

$\theta\_rms = 3 * 10^{-5}$ rad

$V\_err = 0.14 * 10^4$ m/s

$\theta\_rms = 1.4 * 10^{-5}$ rad

Results of averaging

- Previously (Feb.18, first slide) we saw that VP single-particle which has 1/pi coefficient was a good fit to experimental data which gave V_effective=0.9*10^4 m/s.

- Force averaged over distribution also gives agreement with measured data but now suggests smaller V_err=0.13-0.3*10^4 m/s, depending on which numerical coefficient (1/pi of Parhkomchuk or 1/Sqrt[2*pi] of Derbenev) is used (note that numerical coefficient in single-particle formula is then not underestimated). Exact numbers for v_err are subject to the uncertainty of sigmaVT.

Note that available data for measured errors suggests that reasonable estimate for V_err is 0.2-1*10^4 m/s.

March 2005

1. B=0.1T, current dependence:

1.1) measured cooling force for several electron currents:

Ie=500mA, 250mA, 100mA, 20 mA

1.2) measured for several values of tilt in both horizontal and vertical direction – both negative and positive directions.

1.3) for different values of V_effective.

1.4) always recorded longitudinal and transverse sigmas to perform accurate convolution over distributions. Measured values are close to those predicted by BetaCool simulations.

2. Measured for various values of B with various currents:

2.1) B=0.03T , Ie=500mA, 300mA, 100mA, 50 mA

2.2) B=0.04T – various currents

2.3) B=0.05T

2.4) B=0.06T

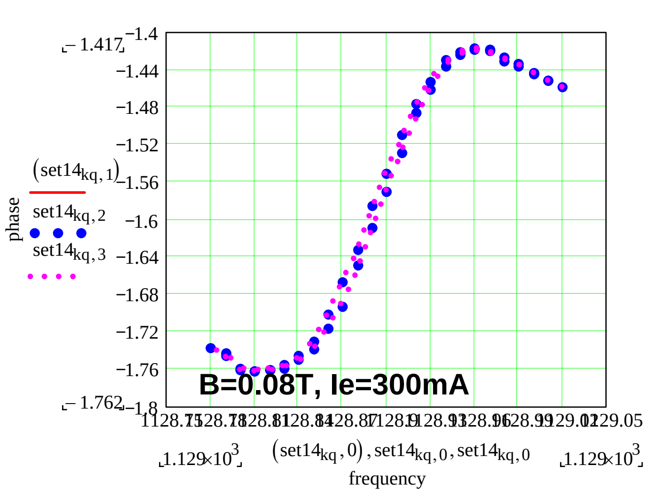
2.5) B=0.08T

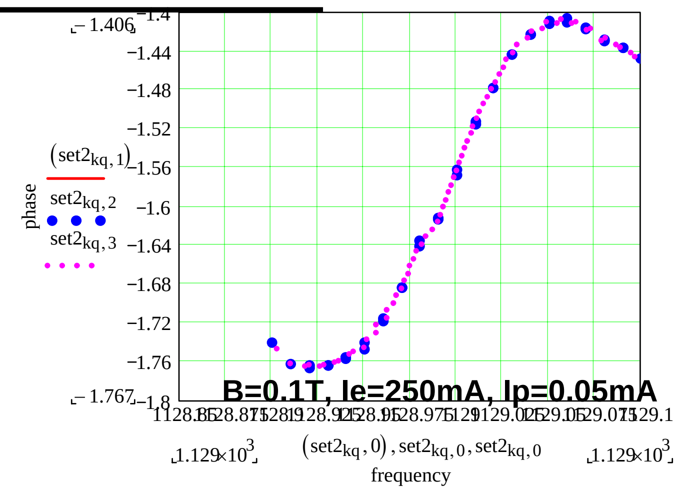
2.6) B=0.1T

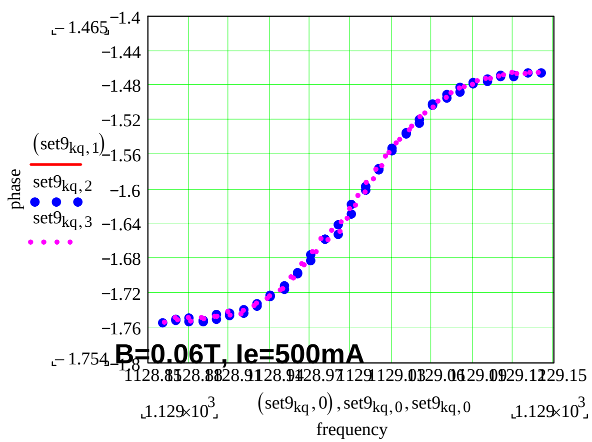
2.7) B=0.12T

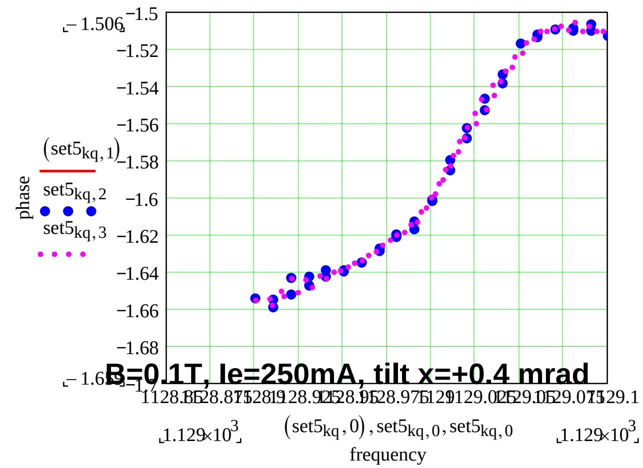
3. Measured transient cooling (ibs+cooling) both for longitudinal and transverse profiles

10's of measured friction force curves in various regimes – to be analyzed

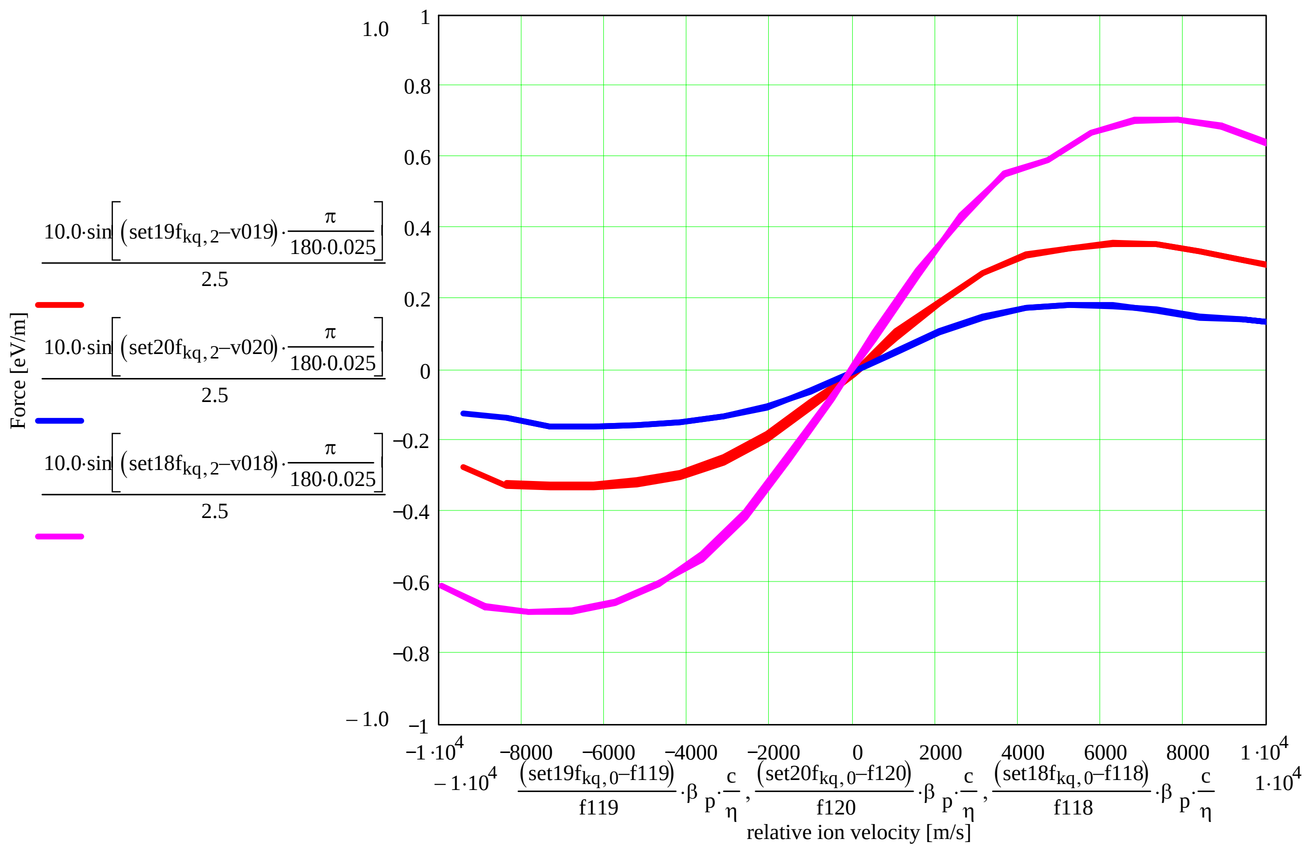








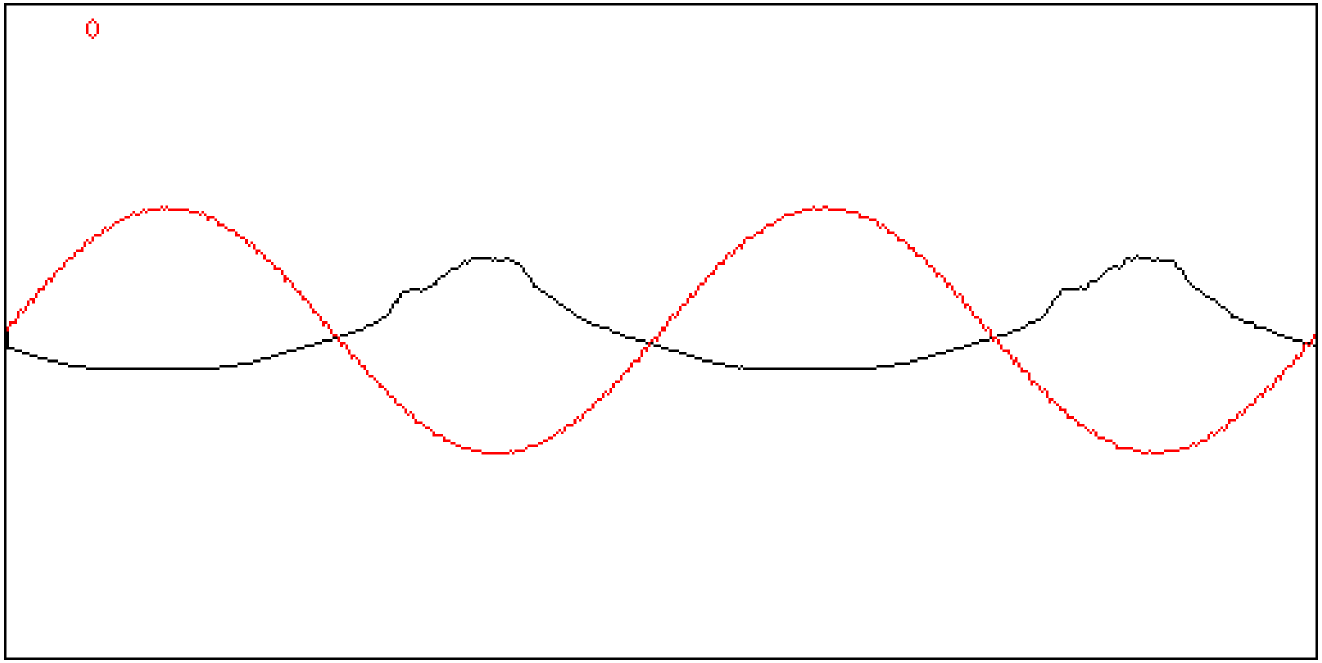
Example of measured friction force for B=0.12T for three different currents of electron beam.



Alexei Fedotov

BROOKHAVEN NATIONAL LABORATORY

Example of bunch length cooling (movie)



Summary

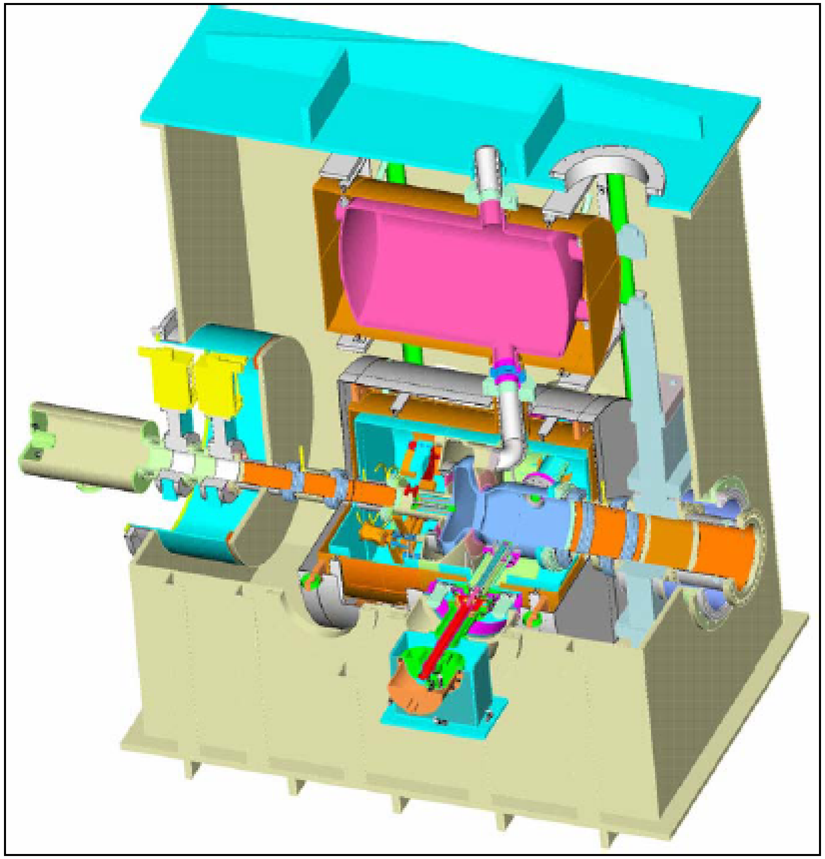
1. We now completed the first set of basic experiments which should help to answer several questions regarding future high-energy magnetized cooling and have confidence in our computer simulations.

2. Depending on the analysis of the experimental data, some of the experiments (like effect of solenoid errors) may be repeated/improved at other coolers.

3. Other important experiments, like Z dependence, transverse cooling force, etc. will continue at other coolers.

Andrew's Presentation

Overview of the SCRF Injector for the ERL



Andrew Burrill

photo courtesy of AES

BROOKHAVEN NATIONAL LABORATORY

Parameters

- ½ cell SCRF photoinjector with a flat cathode and 24 cm beampipe
- 500 mA average current
- Retractable cathode and RF choke joint
- Cathode prep chamber
- Expected Delivery mid 2007

Photocathode inserted in Cavity

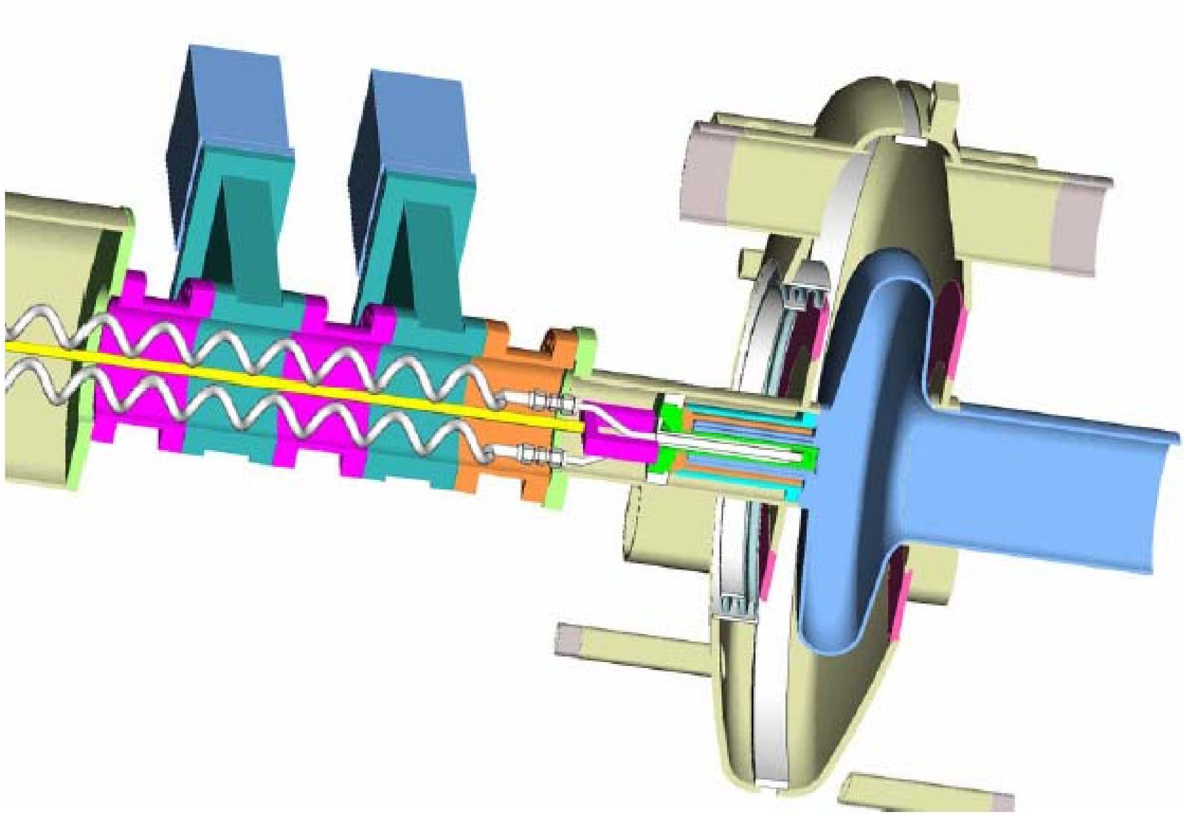
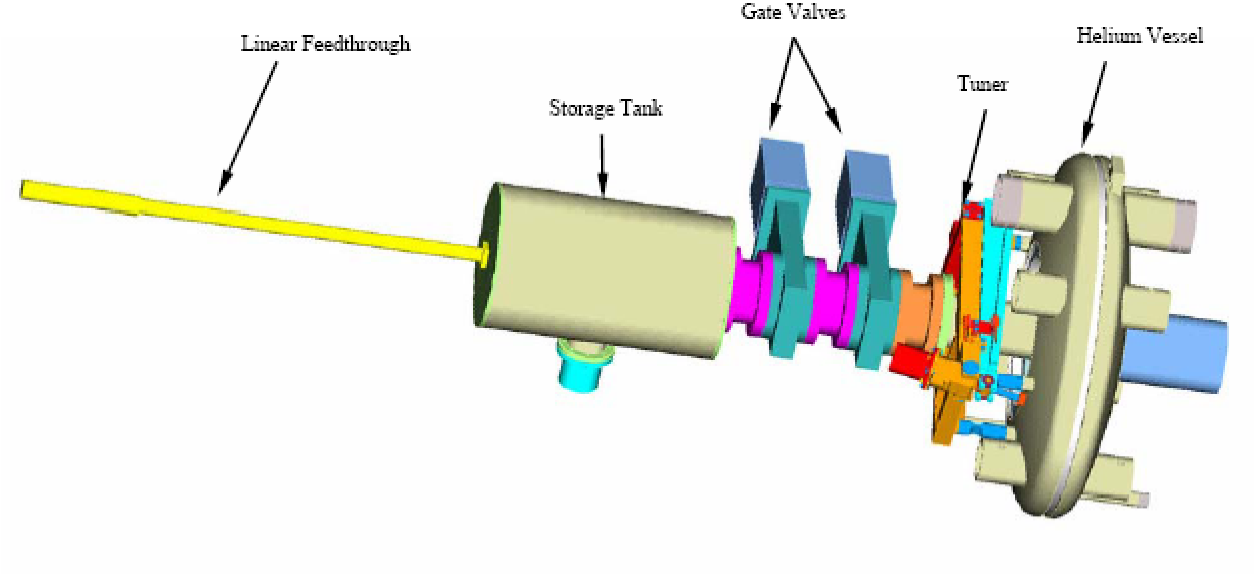


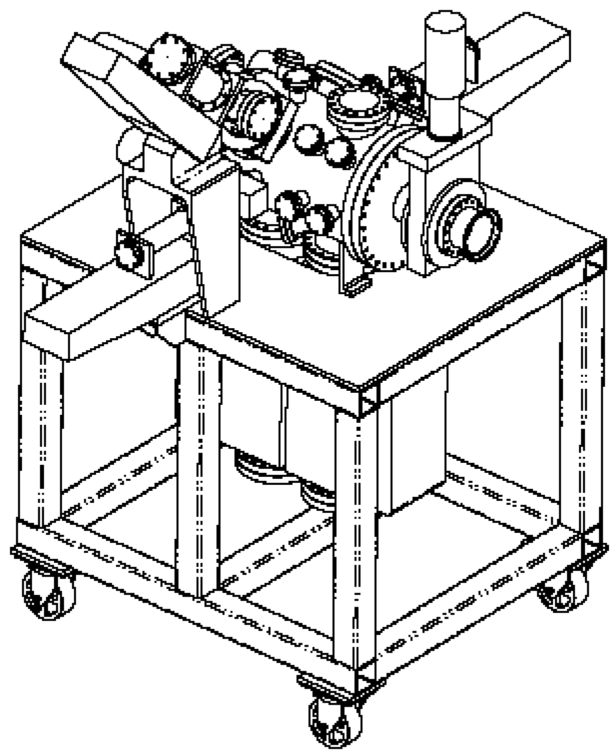
photo courtesy of AES



Andrew Burrill

photo courtesy of AES

Cathode Preparation Chamber



BROOKHAVEN NATIONAL LABORATORY

Andrew Burrill

photo courtesy of AES

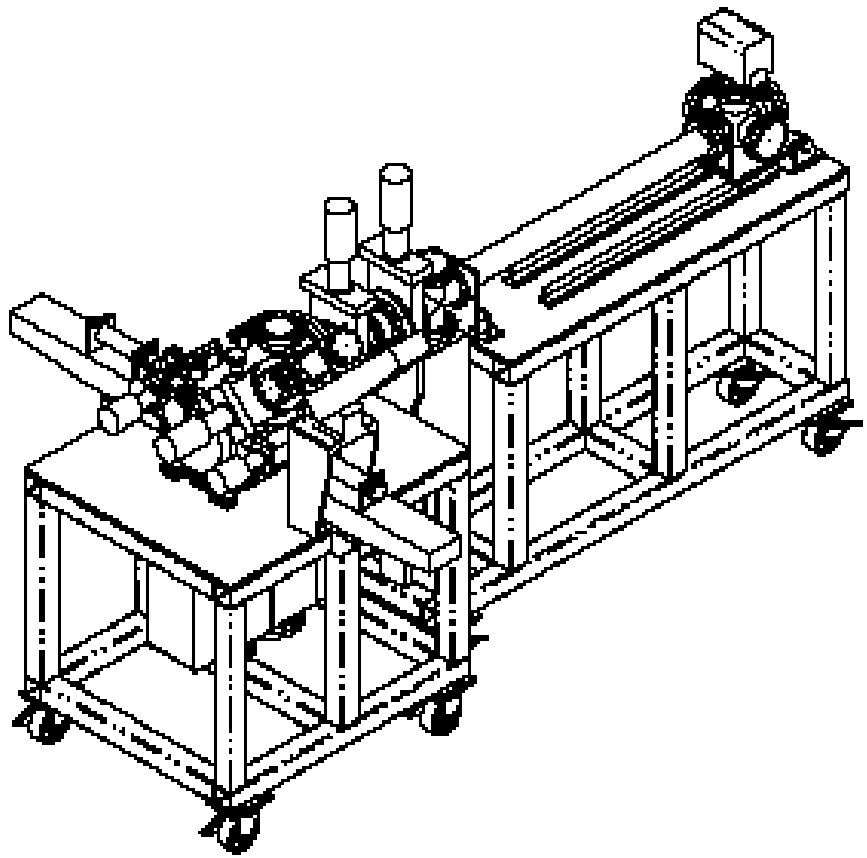


photo courtesy of AES

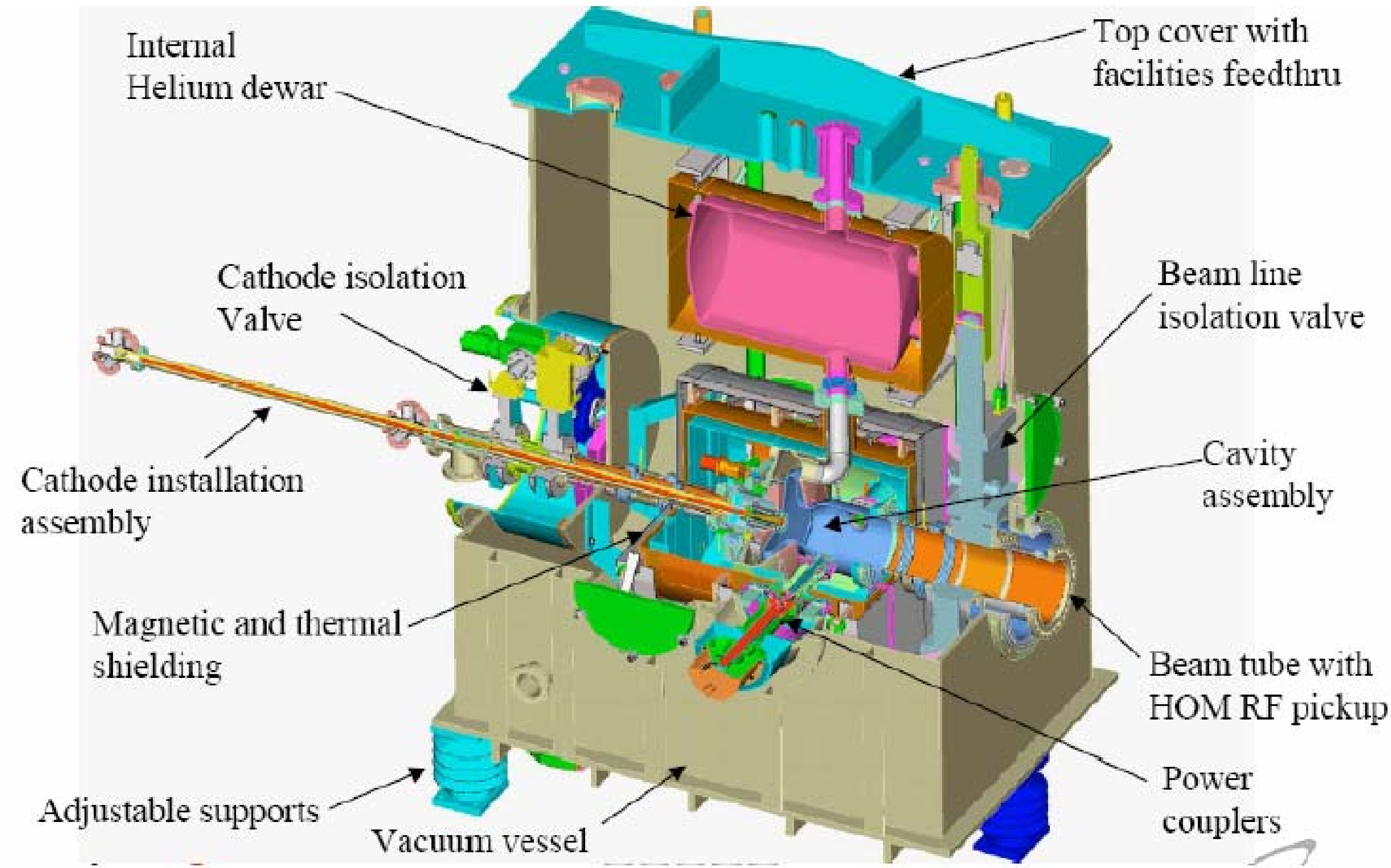
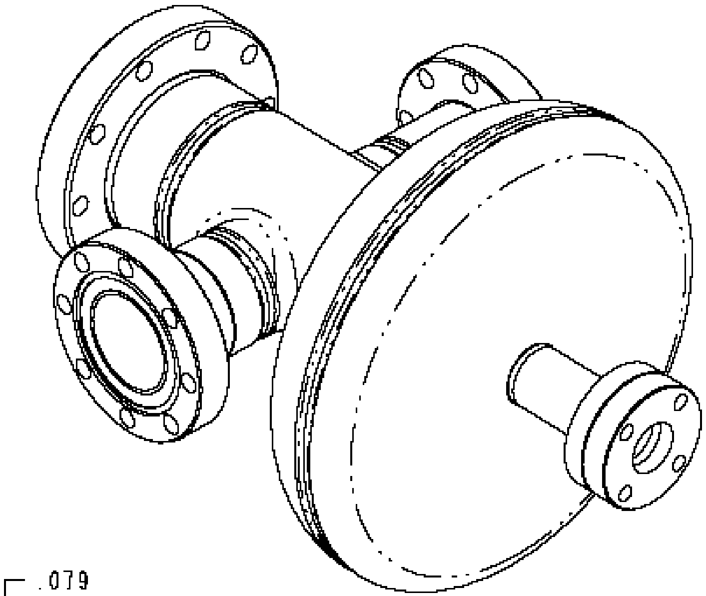
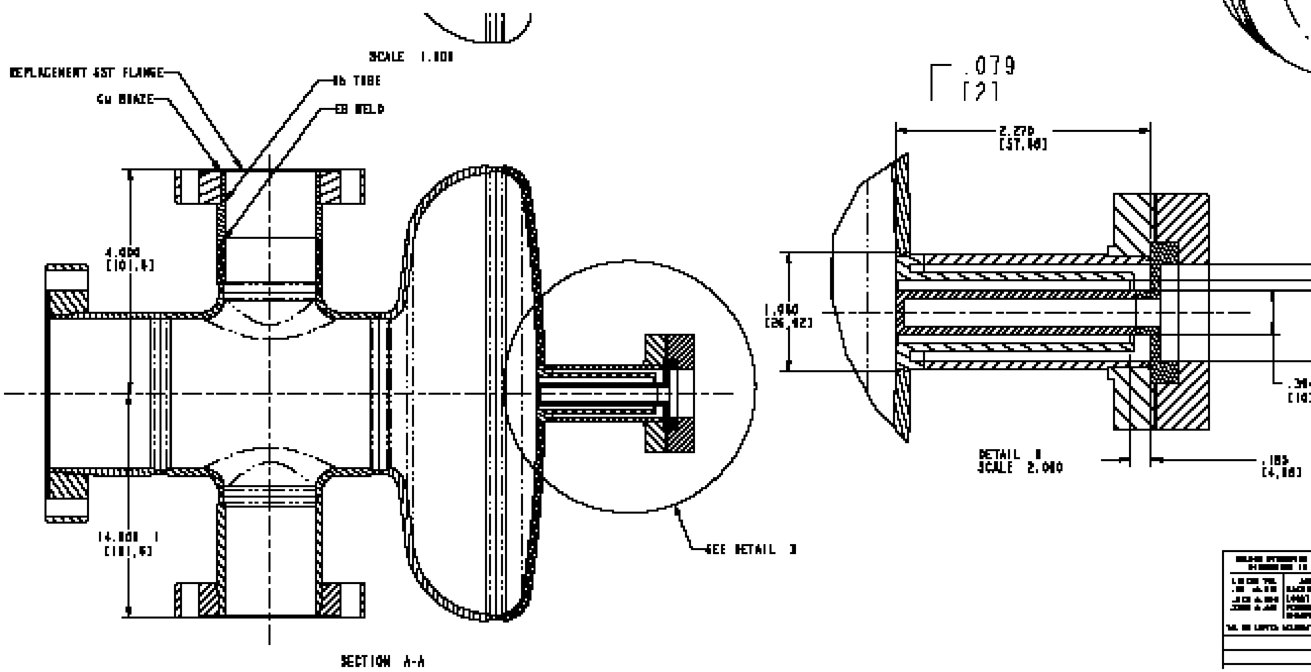


Figure 4. SRF Gun Preliminary Design.

CsK_2Sb research

- Finalizing optimization of recipe
- Studying QE as a function of Temp
- Studying Diamond amplification vs Temp
- Working on bonding of diamond to niobium and encapsulation techniques

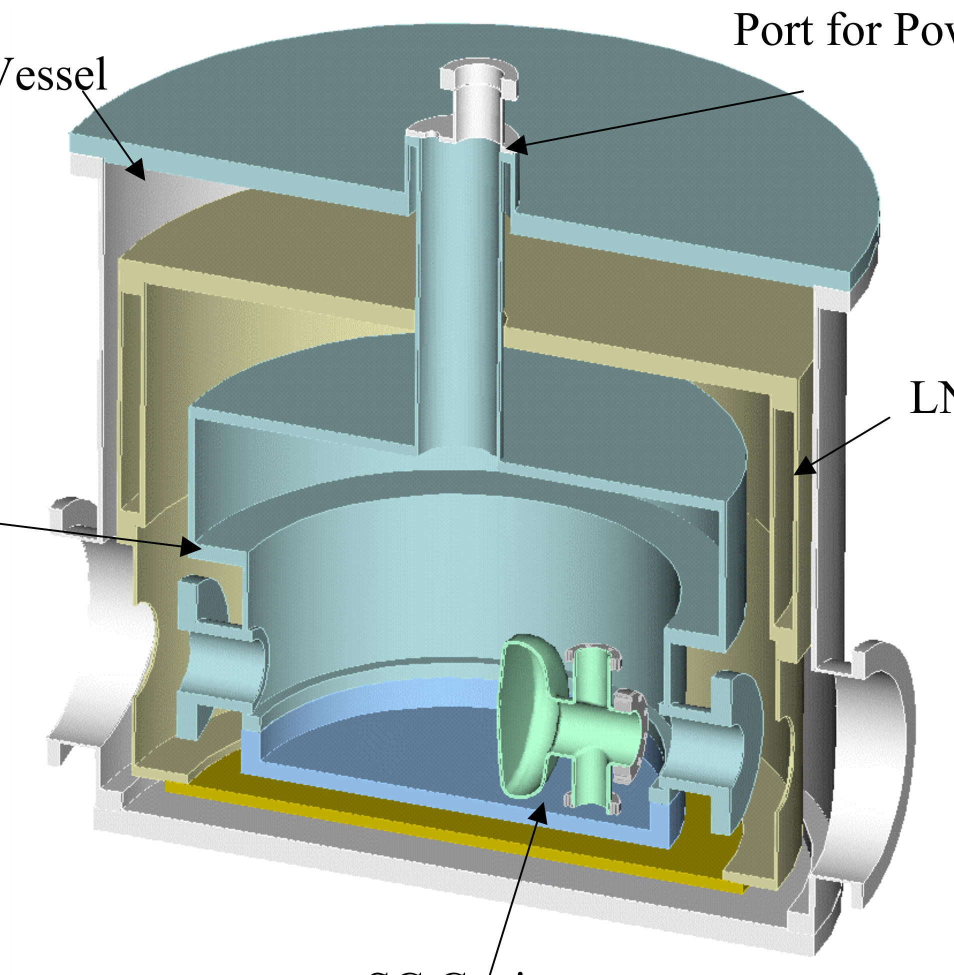




Andrew Burrill

BROOKHAVEN
NATIONAL LABORATORY

1.3 GHz SCRF injector



Andrew Burrill

BROOKHAVEN
NATIONAL LABORATORY