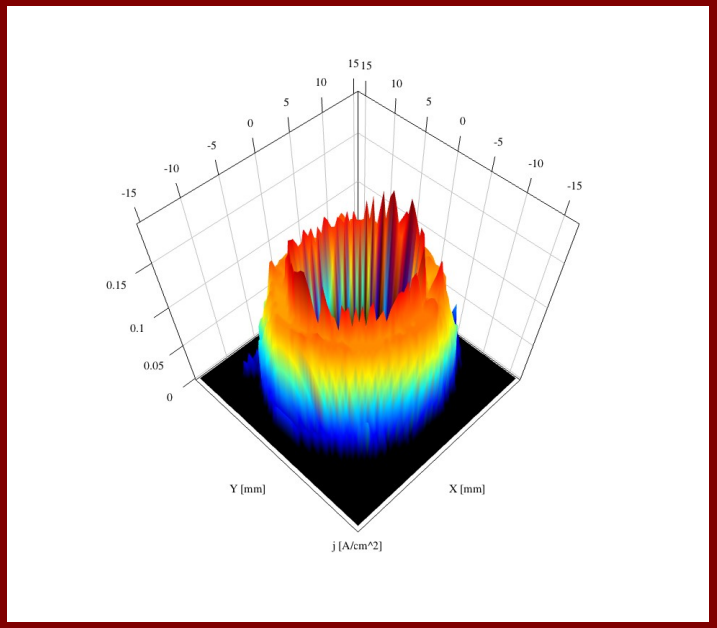
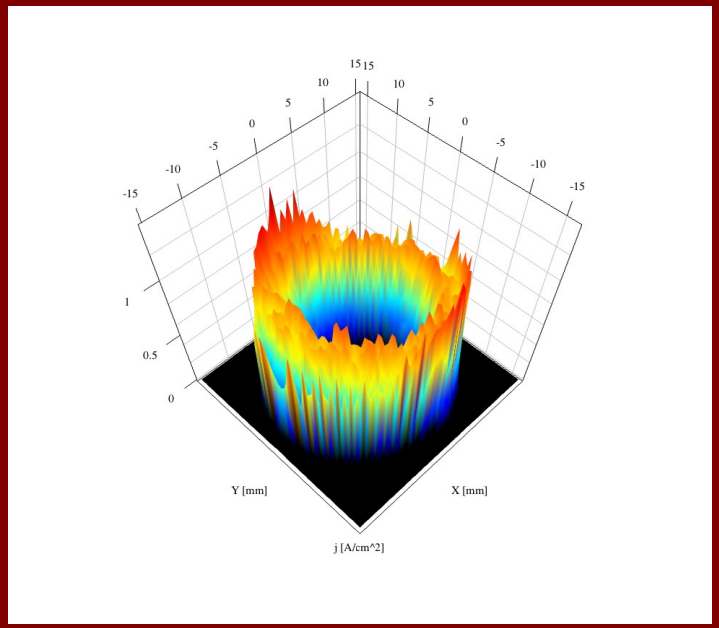
# Electron Hollow Gun Collimation Performance & Simulations

Vince Moens,
11.04.2013

**Topics:**

- What has been done?
  - Perveance Measurements
  - Profile Measurements
  - Electric Field Measurements
  - Polar Decomposition
  - WARP Commencement
  - Transmission
- To be done & Deadlines?
  - WARP @ CERN
  - Implementation

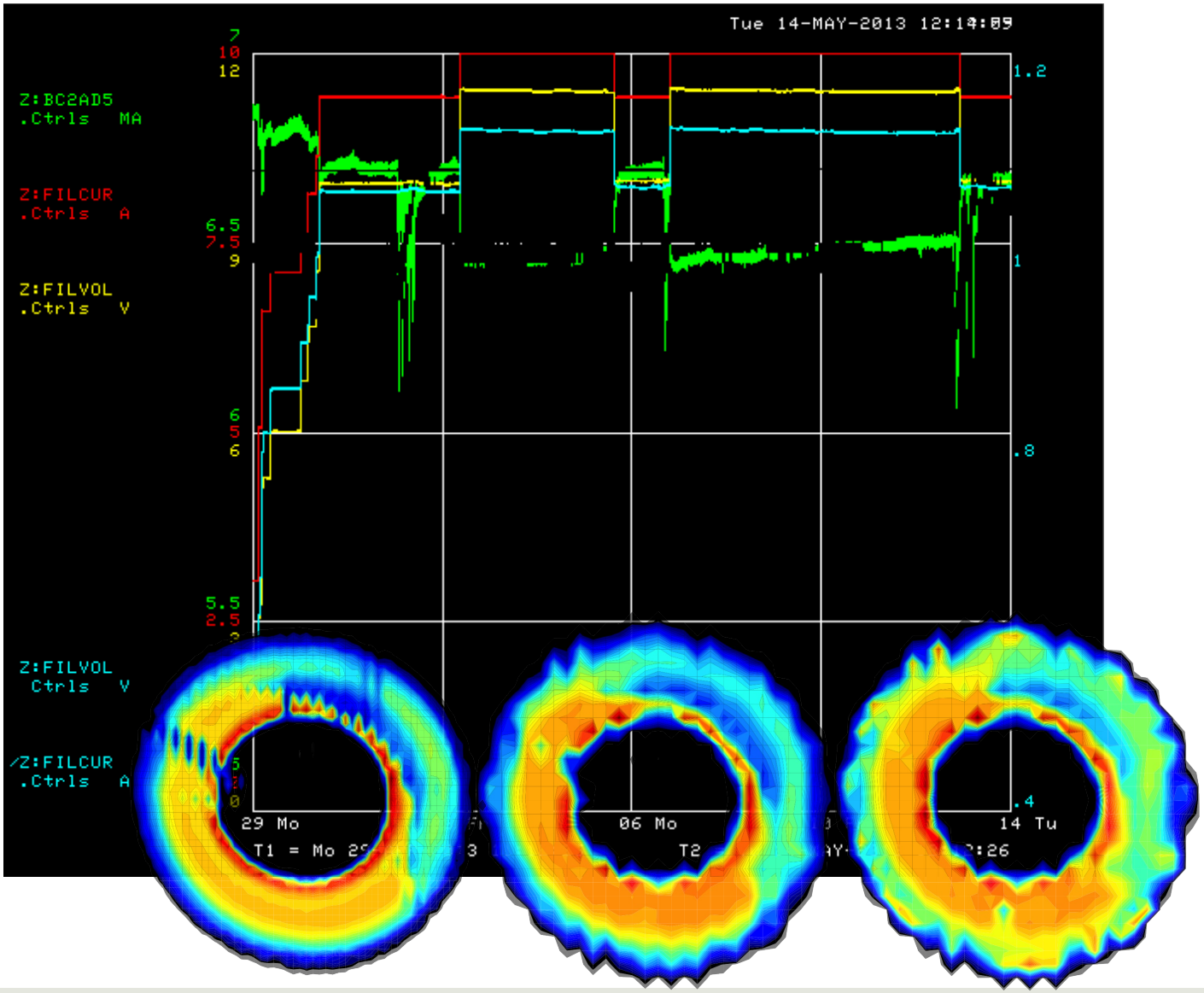



# What has been done?

- Perveance
- Profile Measurements
- Field measurements
- Polar Decomposition
- Transmission

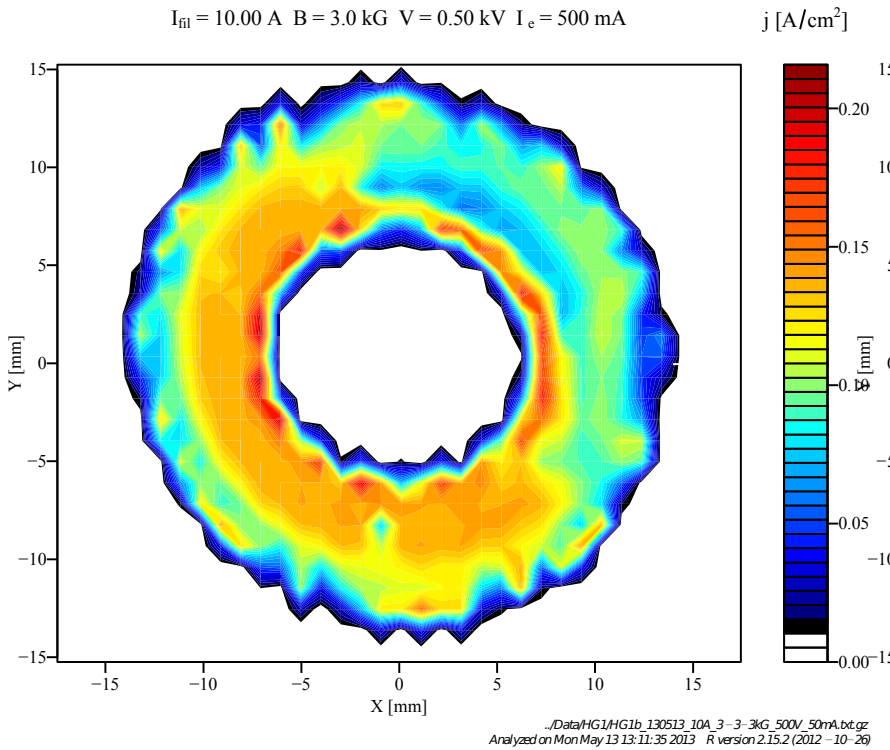
# Electron Gun Characterization
# - Conditioning -

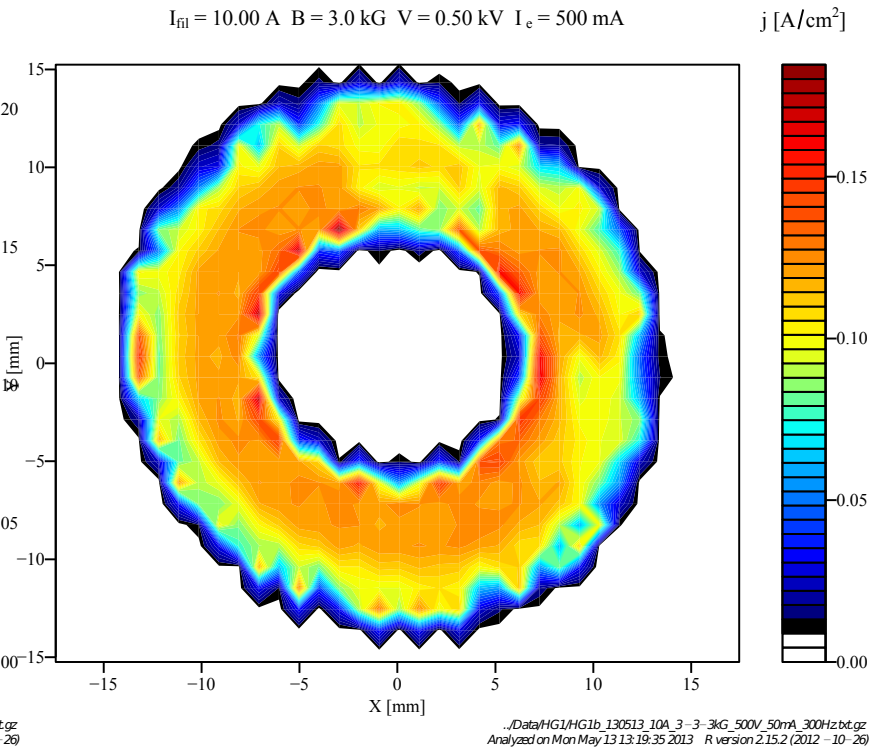


# Electron Gun Characterization
# - Dependence on Repetition Rate -

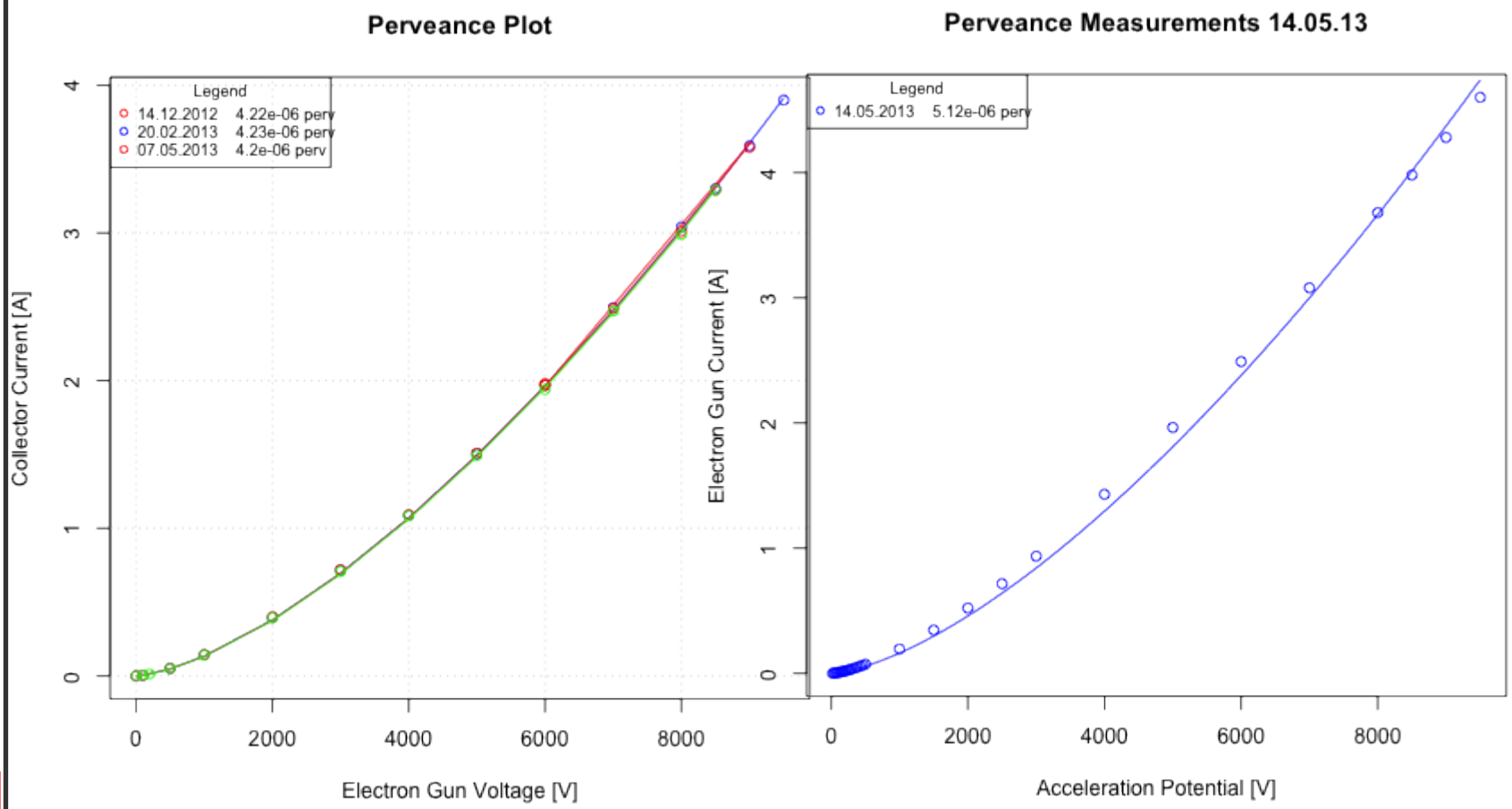
Left measurement taken at 1 kHz and right at 300 Hz

Both measurements at B=0.3T and V = 500 V

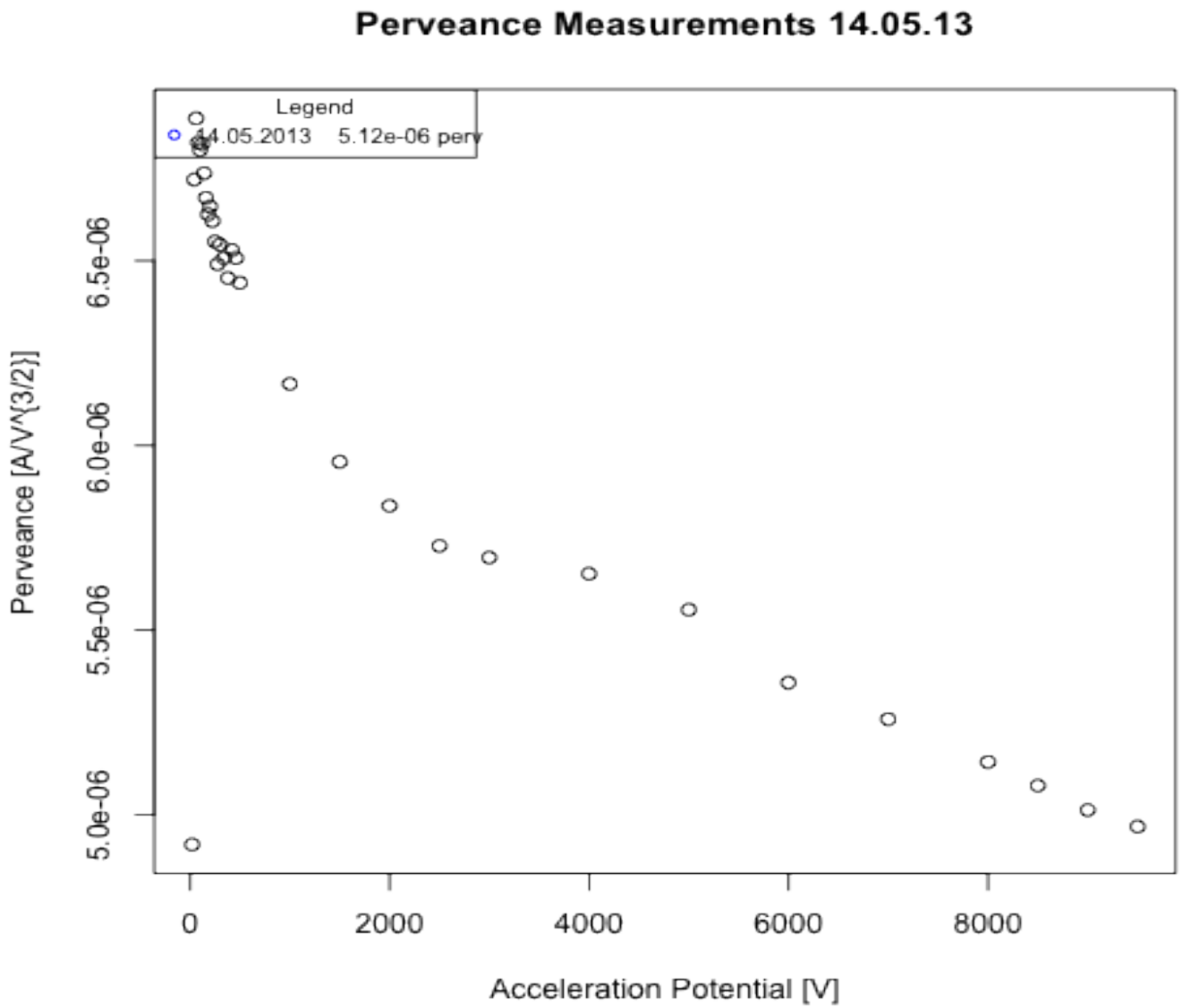


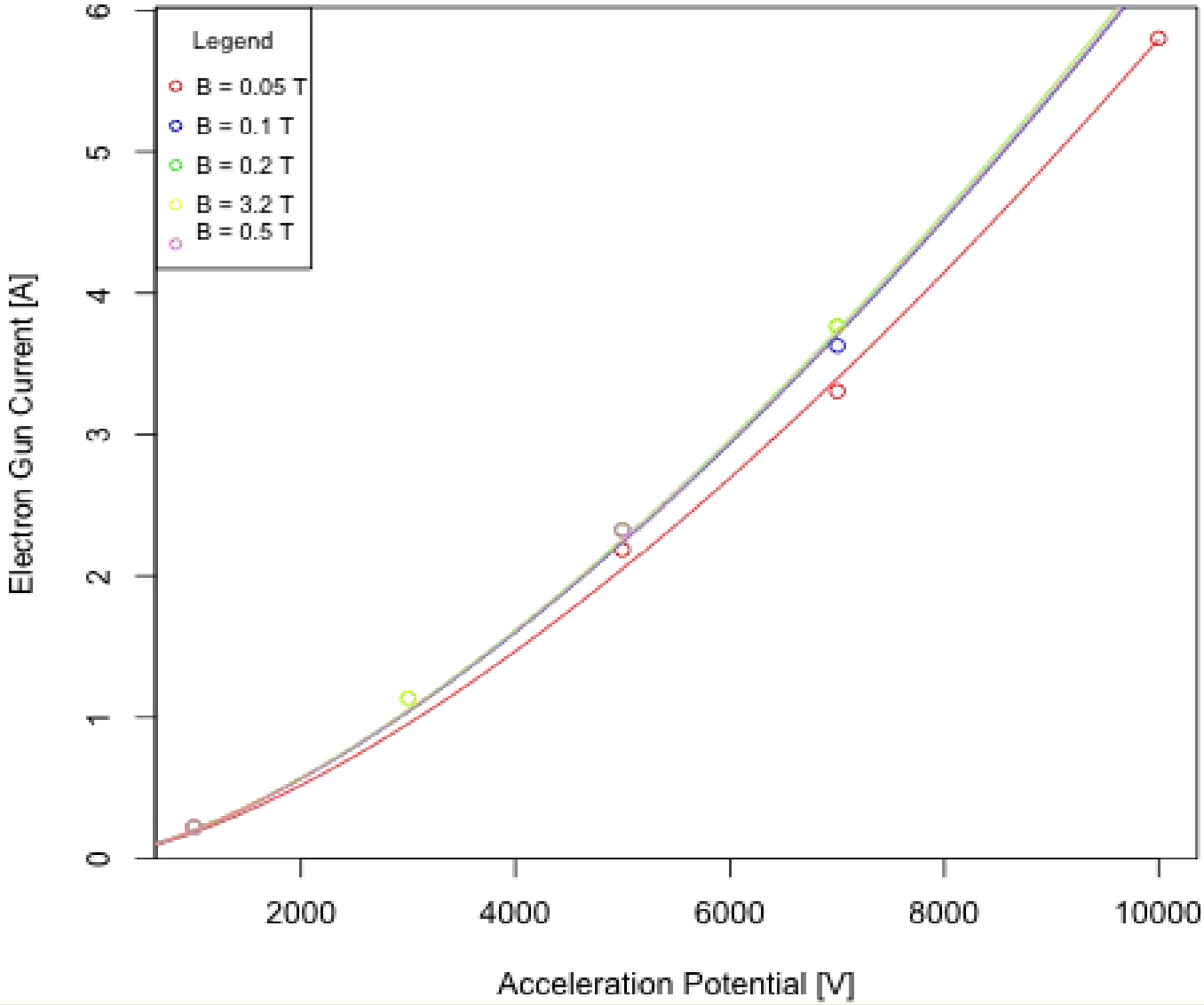
# Yield
# - Time Comparisons -



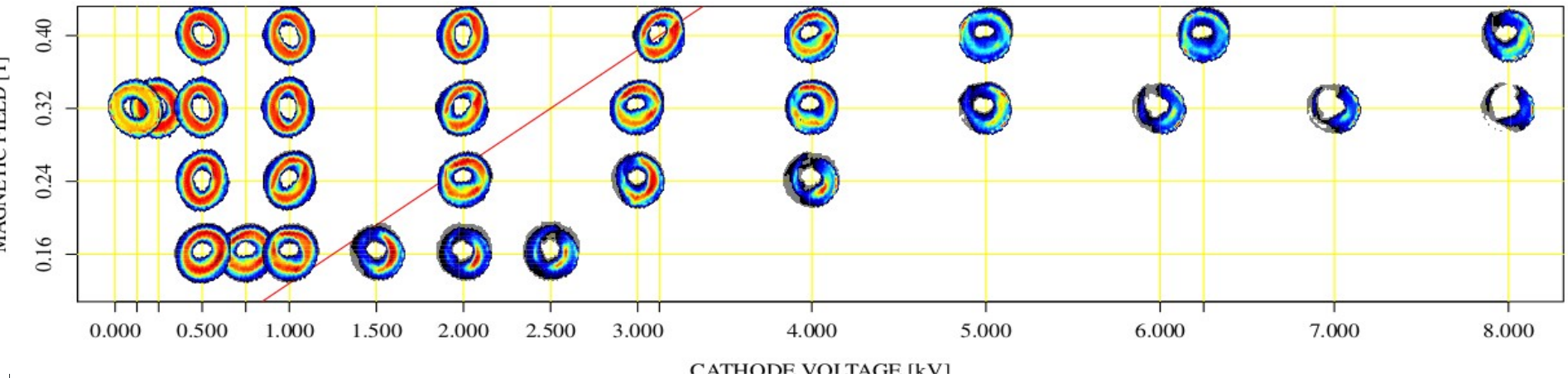
# Perveance

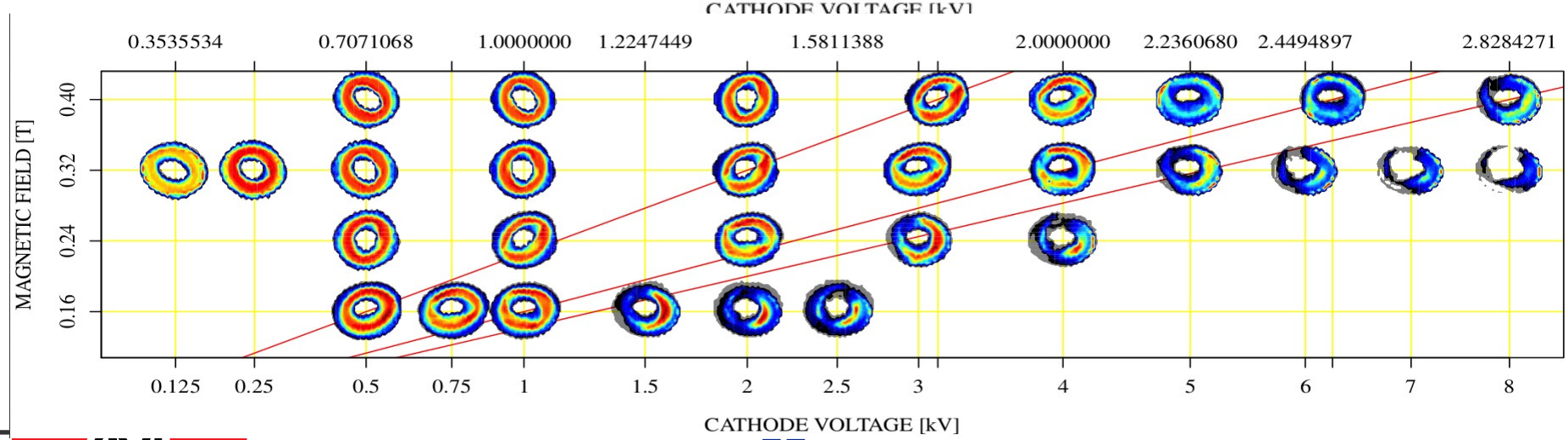

Perveance Measurements 14.05.13
Legend
14.05.2013 5.12e-06 perv
Perveance [A/V^{3/2}]
5.0e-06
5.5e-06
6.0e-06
6.5e-06
0
2000
4000
6000
8000
Acceleration Potential [V]

# Yield
# - SAM Simulations -



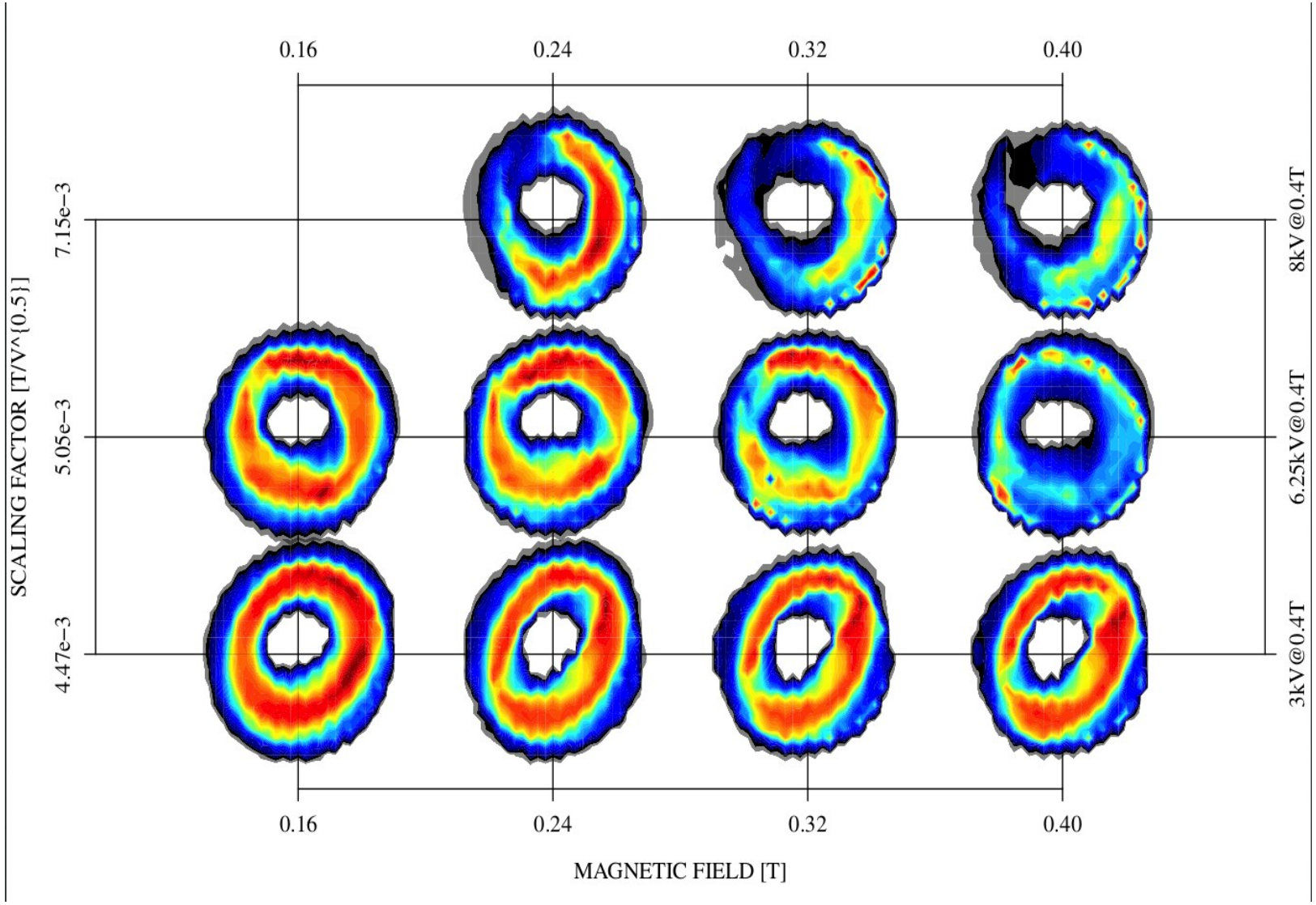
# Profiles
# - Measured Profiles -



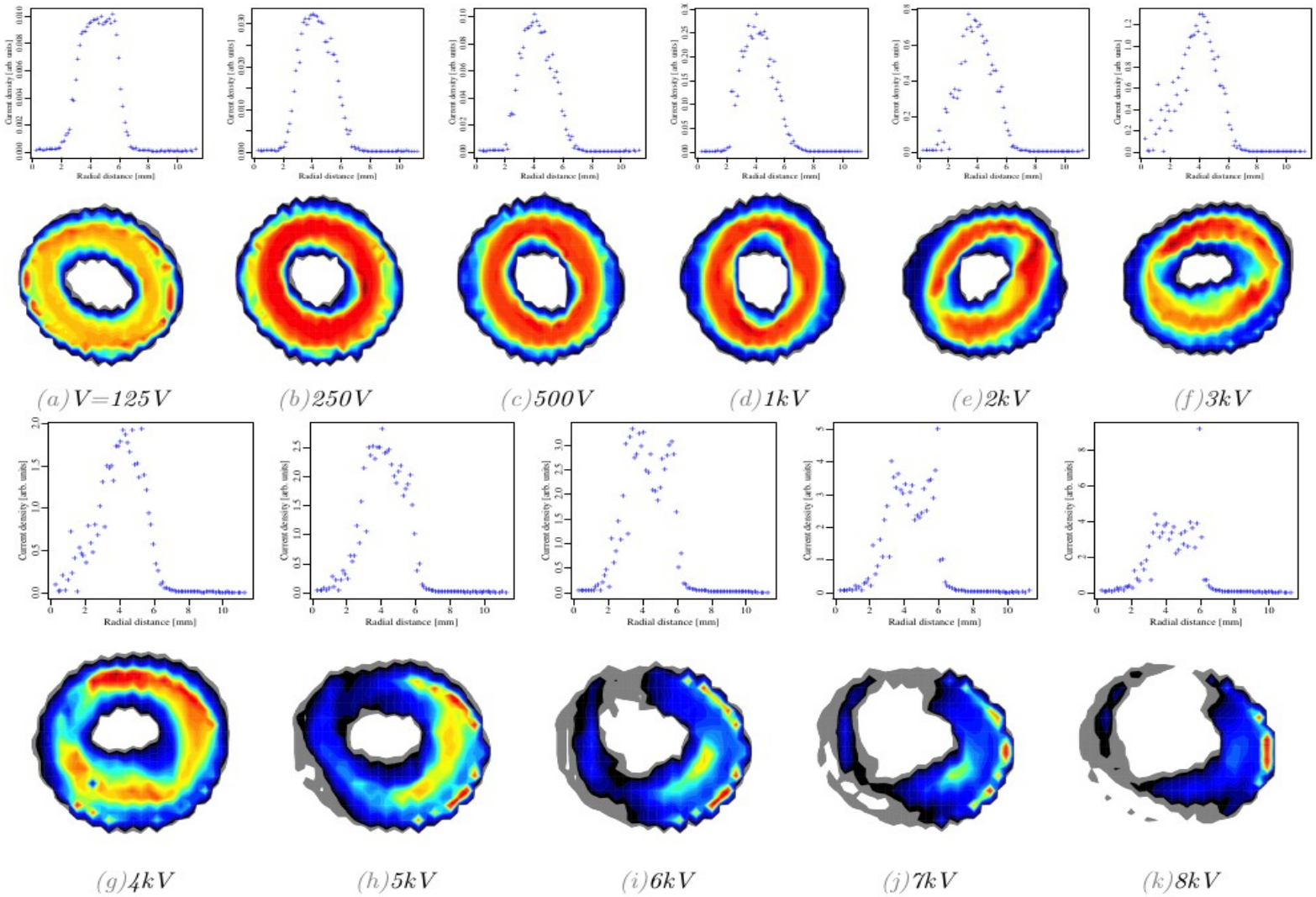




ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

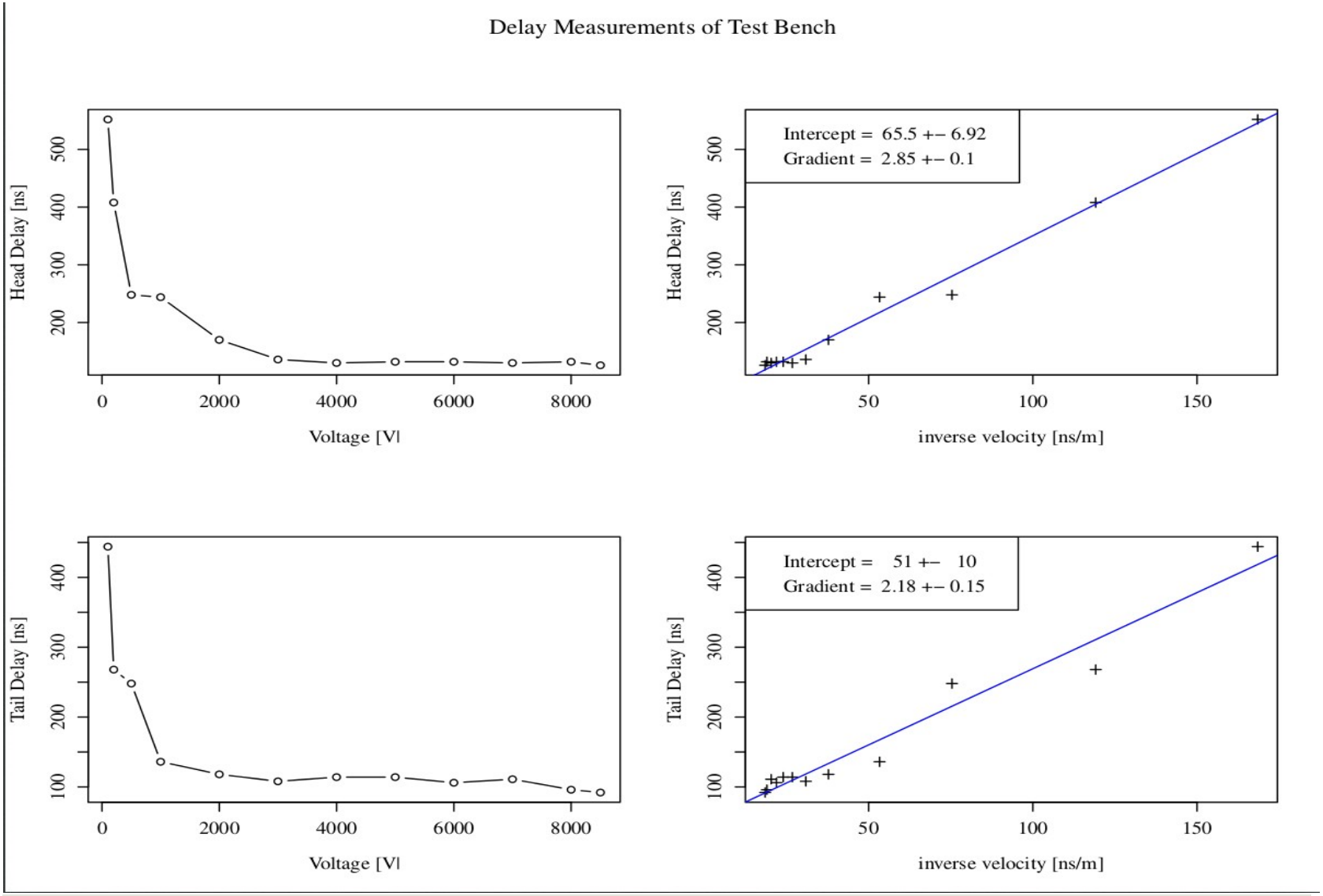
# Profiles
# - Scaling-



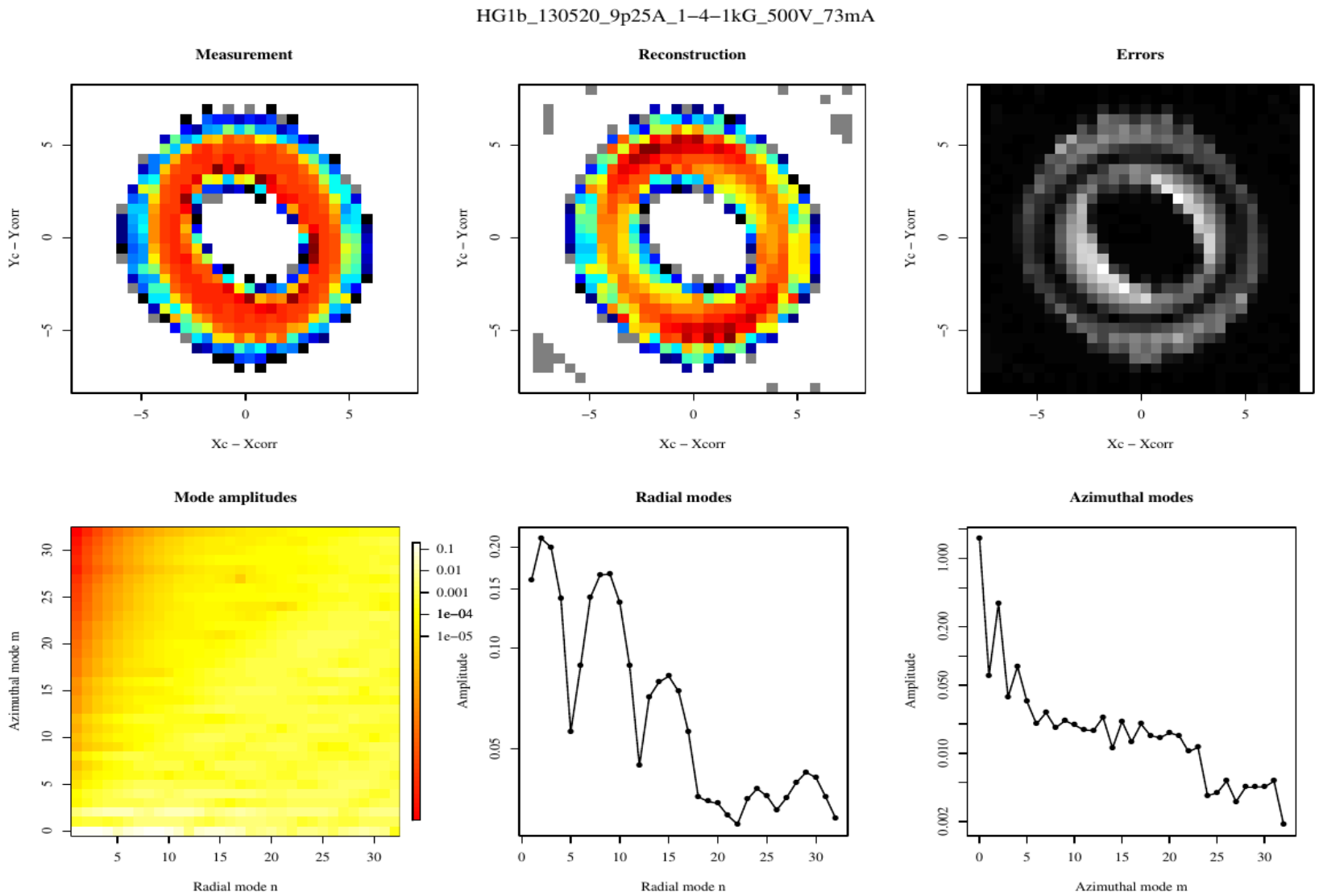
# Electron Gun Characterization
# - Change with Voltage -



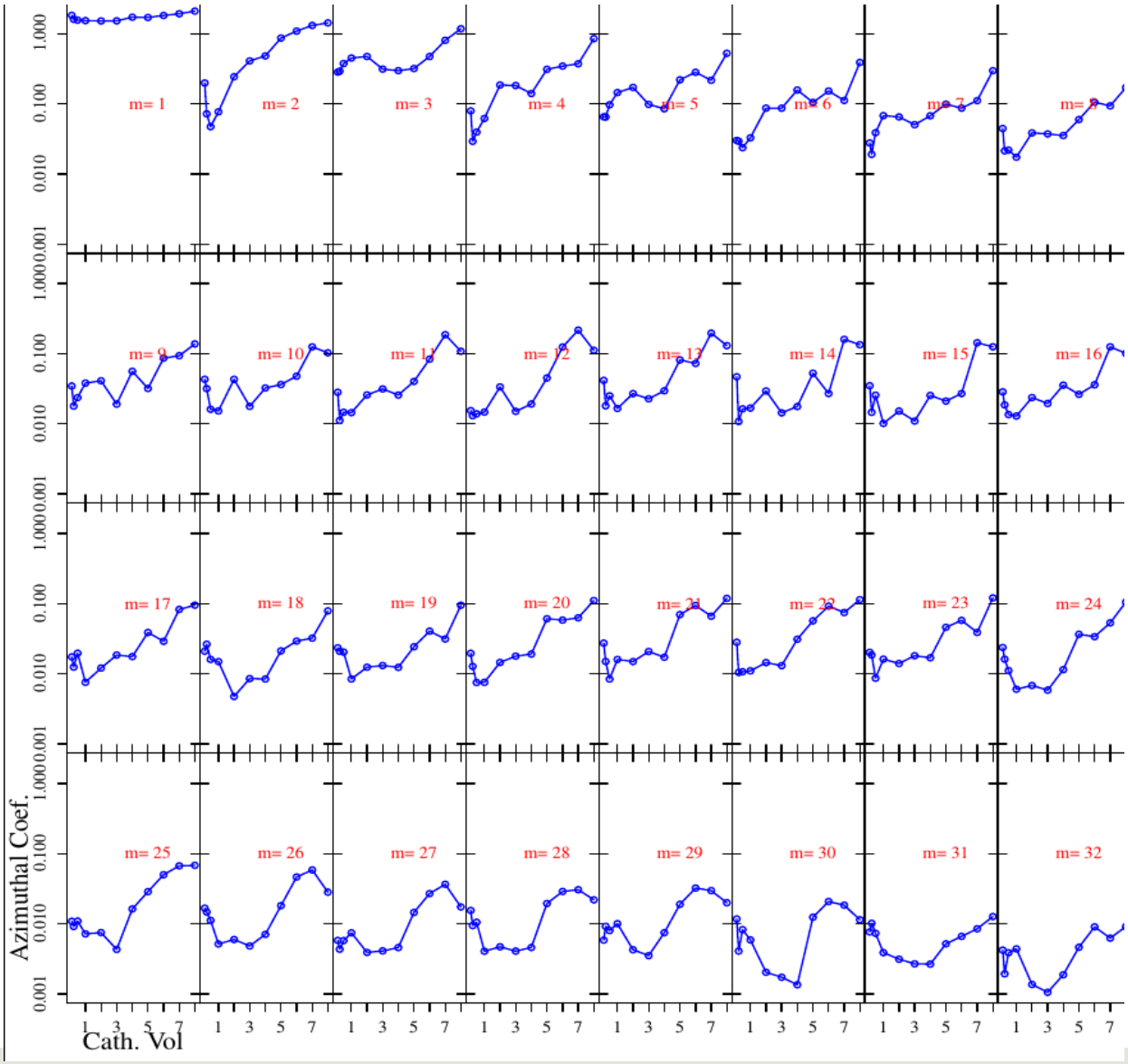
# Delay Measurement



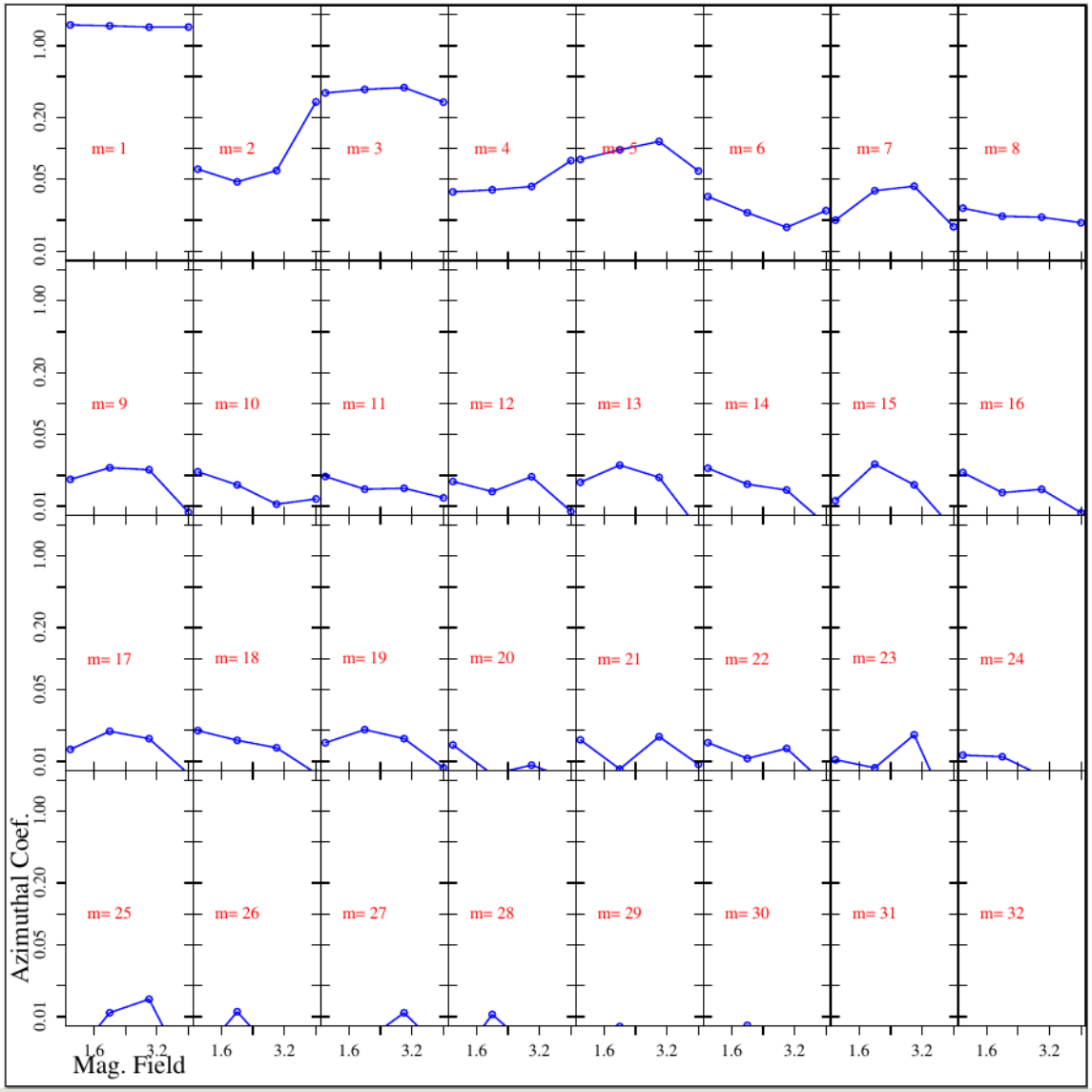
# Polar Decomposition
# 1-4-1 500V



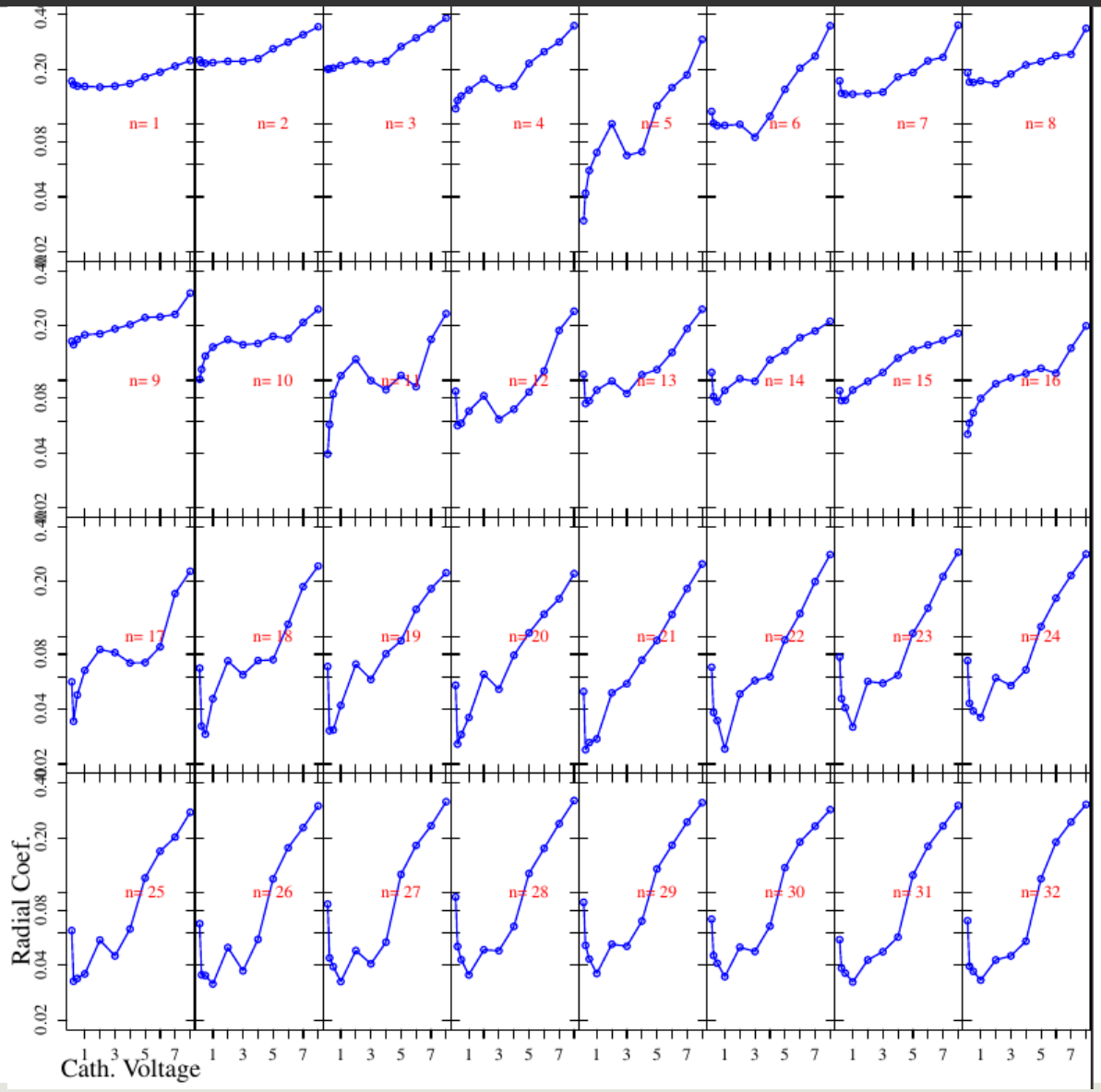
# Electron Gun Characterization
# - Azimuthal Components - B32 -



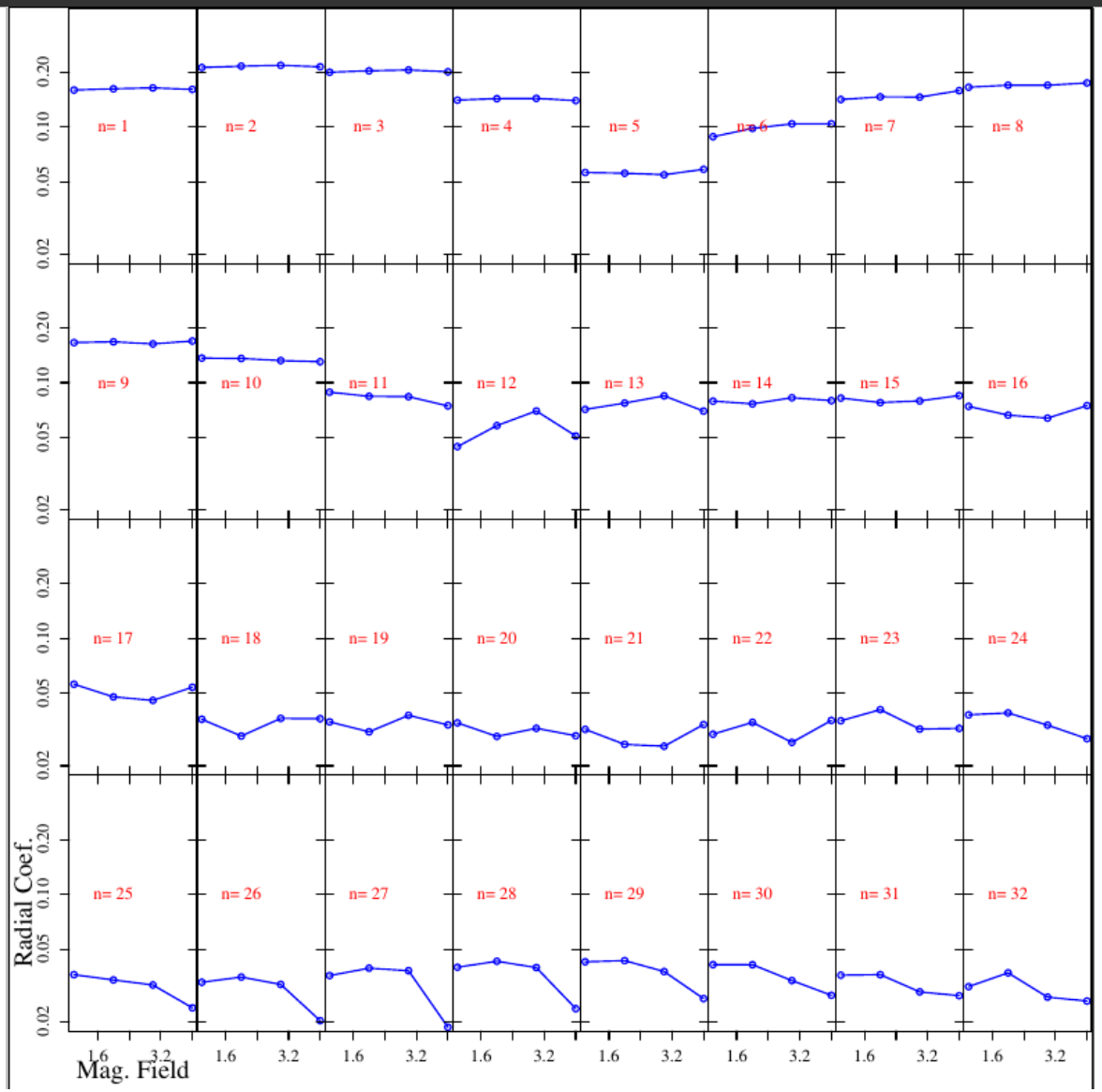
# Electron Gun Characterization
# - Azimuthal Components - V500 -



# Electron Gun Characterization
# - Radial Components B32 -

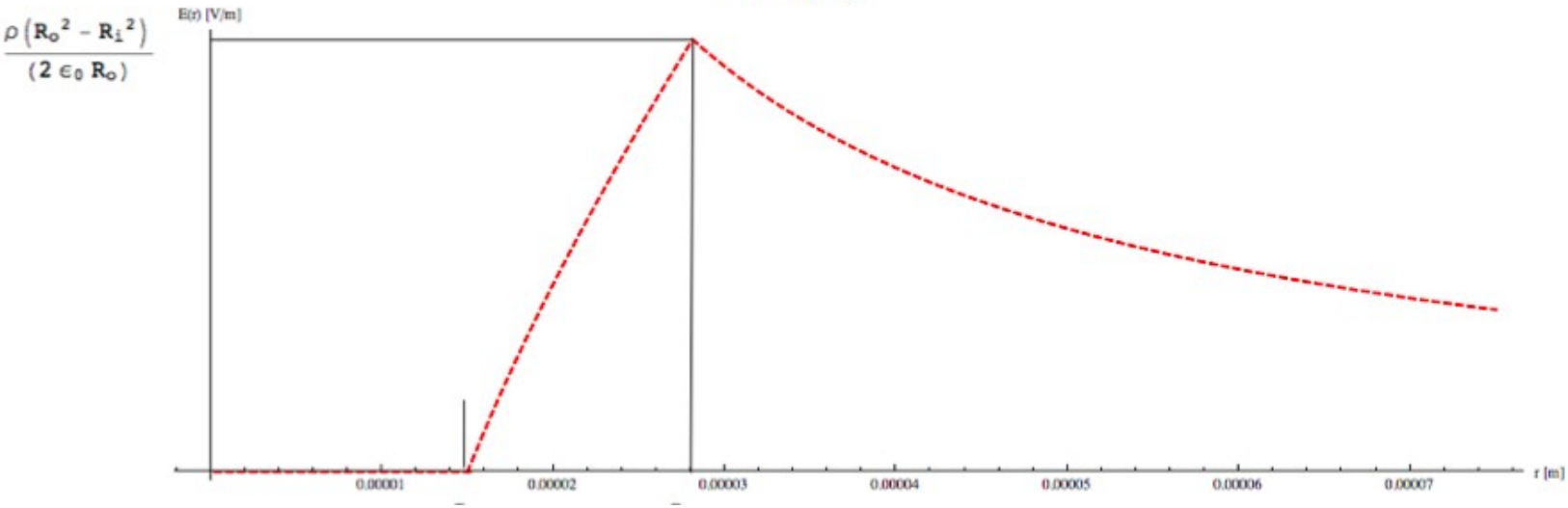


# Electron Gun Characterization
# - Radial Components V500 -



# Electron Gun Characterization
# - Electric Field & Potential -

Field.png



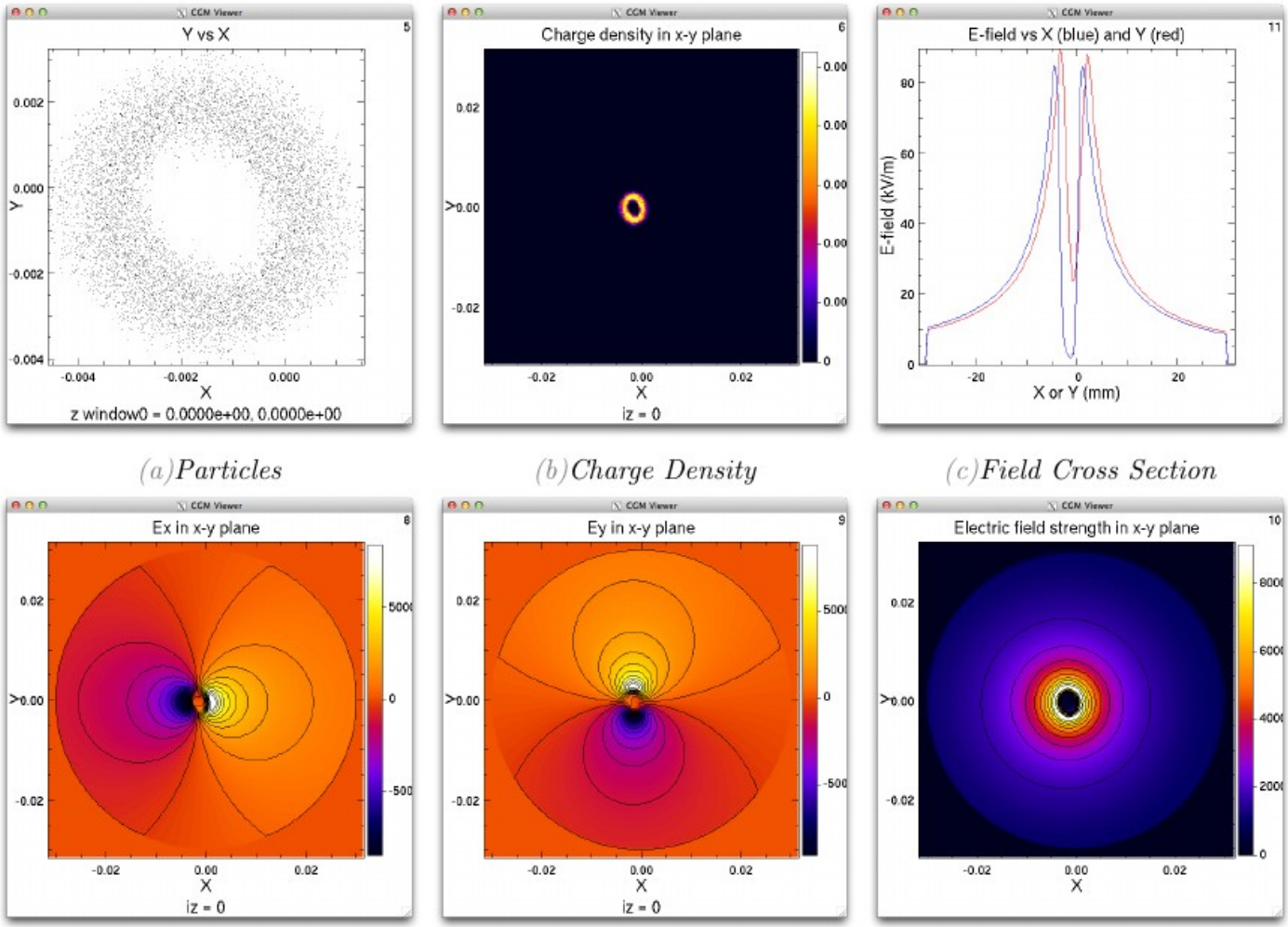

$$\oiint_{\partial\Omega} E \cdot \mathrm{d}S = \frac{Q_{\mathrm{encl},\Omega}}{\varepsilon_0}$$

$R \leq R_o$ $\qquad E = 0$

$R_i \geq R \leq R_o$ $\qquad E = \frac{\rho(R^2 - R_i^2)}{2\varepsilon_0 R}$

$R_o \geq R$ $\qquad E = \frac{\rho(R_o^2 - R_i^2)}{2\varepsilon_0 R}$

# Electron Gun Characterization
# - Electric Field & Potential -




(a)Particles (b)Charge Density (c)Field Cross Section

(d)Field in $x$ (e)Field in $y$ (f)Field in $x$-$y$

*Fig. 14: The particle distribution, electric potential and electric field of the beam at 0.3T and 4kV.*

# Electron Gun Characterization
# - Emittance Growth -

$$p_r = qEt$$

$$\vartheta = \frac{\gamma m_0 q E_r L}{E_0^2 - m_0^2}$$

$$\varepsilon = \gamma x_n^2 + \alpha x_n x_n' + \beta x_n'^2$$

$$\Delta\varepsilon = \beta\vartheta^2 = \beta\left(\frac{E_0 q E_r L}{(E_0^2 - m_0^2)}\right)^2$$

$$\varepsilon_{RMS} = \frac{\sigma_x^2}{\beta} \qquad \varepsilon_N = \varepsilon_{RMS} \times \gamma\beta_c$$

$$\sigma_x = \sqrt{\varepsilon_{RMS}\beta} = \sqrt{\frac{\varepsilon_N \beta}{\gamma\beta_c}} = 4.69 \times 10^{-4}\ m$$

# Electron Gun Characterization
# - Emittance Growth-

OLD – PROBLEM – NEW TOO BIG

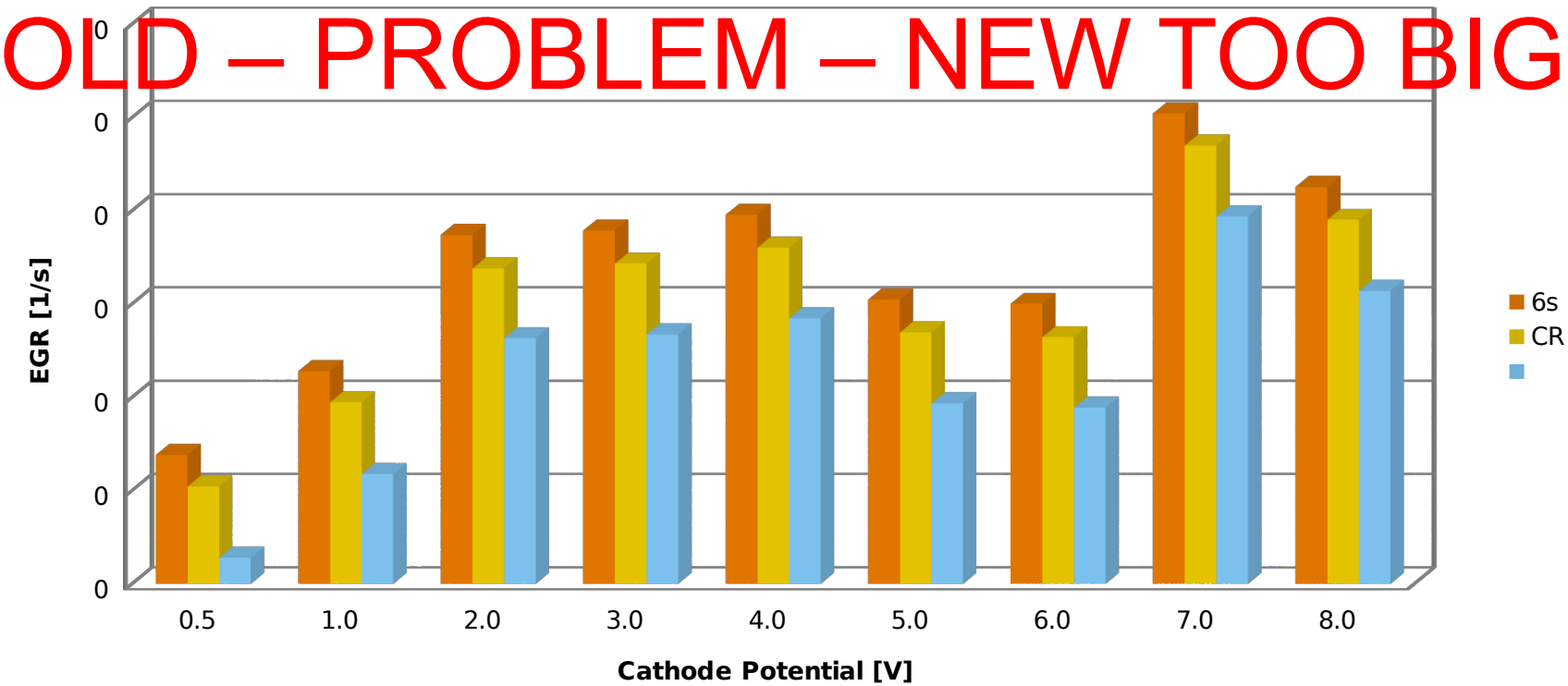
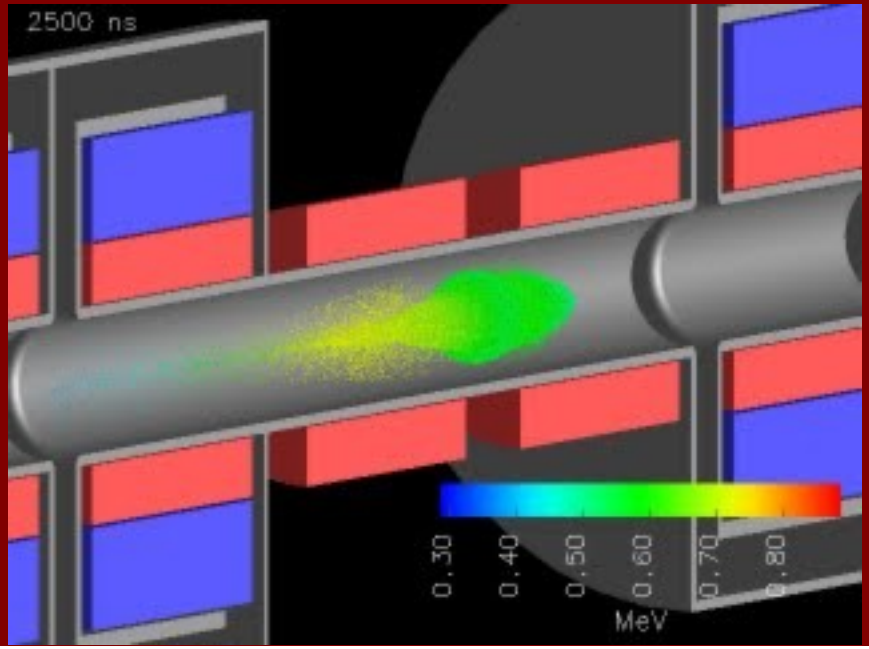



TABLE VI. Initial emittances (wire scan, synch-light, average), emittance growth rates (EGR) $\gamma$, and diffusion slopes $D'$.

| | Emittance [$\mu$m] | | | | | | EGR [1/s] | | Diffusion [$\mu$m/s] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Plane | $\epsilon_{ws}$ | $\delta\epsilon_{ws}$ | $\epsilon_{sl}$ | $\delta\epsilon_{ws}$ | $\epsilon$ | $\delta\epsilon$ | $\gamma$ | $\delta\gamma$ | $D'$ | $\delta D'$ |
| B1 H | 1.92 | $1.3 \times 10^{-2}$ | 2.15 | $9.6 \times 10^{-3}$ | 2.03 | 0.07 | $5.23 \times 10^{-5}$ | $1.50 \times 10^{-5}$ | $2.49 \times 10^{-8}$ | $7.4 \times 10^{-9}$ |
| B1 V | 1.36 | $2.0 \times 10^{-3}$ | 1.29 | $4.7 \times 10^{-3}$ | 1.33 | 0.02 | $1.70 \times 10^{-5}$ | $1.00 \times 10^{-5}$ | $5.27 \times 10^{-9}$ | $3.2 \times 10^{-9}$ |
| B2 H | 1.69 | $6.6 \times 10^{-3}$ | 2.43 | $1.3 \times 10^{-2}$ | 2.06 | 0.21 | $5.37 \times 10^{-5}$ | $1.90 \times 10^{-5}$ | $2.60 \times 10^{-8}$ | $9.6 \times 10^{-9}$ |
| B2 V | 1.73 | $4.6 \times 10^{-2}$ | 1.98 | $1.2 \times 10^{-2}$ | 1.85 | 0.09 | $1.10 \times 10^{-5}$ | $1.70 \times 10^{-5}$ | $4.79 \times 10^{-9}$ | $7.2 \times 10^{-9}$ |




# Electron Beam Evolution

- WARP Simulations
- Non-Linear Maps

s

# WARP
# - Installation Parallel -

- WARP is running on TEV (single mode)
- Parallel mode to come
- Cross-Checking required

Installation of WARP on the TEV cluster

Vince Moens
vince.moens@epfl.ch
*Ecole Polytechnique Fédérale de Lausanne (EPFL)*

May 14, 2013

## 1 Introduction

*For the purpose of this document, TEV refers tot he Wilson Cluster.*

The tarball that accompanies these instructions can be found at: `https://cdcvs.fnal.gov/redmine/documents/619`.

Installing WARP on TEV brings a few complications. These include compatibility issues with the python installed on TEV, compiler issues and super user rights. Instead of finding a solution in which one could bind the python package WARP, which has to be installed locally, into the native python of TEV by creating links and changing a lot of PATHS, we decided to just install a clean version of python in the local directory and use that distribution.

These instructions are for the installation of a non-parallel version of WARP. A parallel version of WARP will be installed later and a new set of isntructions will be drafted.

Unless someone sent you this document, you should have found these instructions in a directory named `INSTRUCTIONS` in a tarball named `WARP_Install`.

## 2 Installation procedure

Place that tar file in your home directory on TEV. You can use scp to place it there.

```
scp -r WARP_Install.tar.gz username@tev.fnal.gov:/home/username/
```

Open up a terminal and go to your home directory. Once there expand your tarball using:

```
cd
tar -xvf WARP_Install.tar.gz
```

You will now find a directory labeled `WARP_Install` in your home directory. Create a directory where you would want to install Python and WARP. For the purpose of this tutorial we will use the directory `Python` in your home directory.

```
cd
mkdir Python
```

Next we want to make sure that every compilation of a python script from this point is done using the same compilers and your new python installation. There is two methods to do this. The first is the recommended one and automatically loads the new path upon opening a window. In order to do this check for a file named `.bash_profile` in your home directory.

```
cd
ls -lisa
```

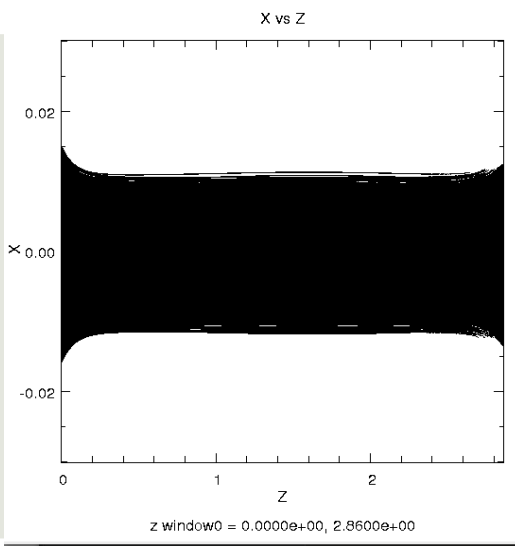
If it does not exist, create it by typing:

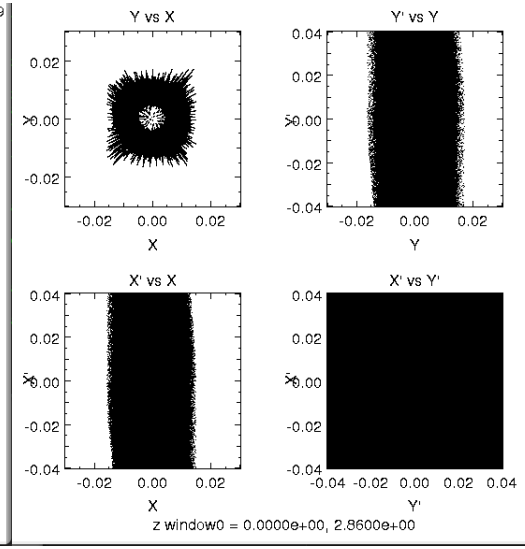
# WARP
# - First True Simulations -

```
Atomic number of ion =  5.4858e-04
Charge state of ion  = -1.0000e+00
Initial X, Y emittances =  0.0000e+00,   0.0000e+00 m-rad
Initial X,Y envelope radii  =  1.7500e-02,   1.7500e-02 m
Initial X,Y envelope angles =  0.0000e+00,   0.0000e+00 rad
Input beam current =  5.0000e-02 amps
Current density =  5.1969e+01 amps/m**2
Charge density =  3.9215e-06 Coul/m**3
Number density = -2.4476e+13
Plasma frequency     =  2.7910e+08 1/s
  times dt          =  8.3088e-03
  times quad period =  0.0000e+00
Plasma period        =  2.2512e-08 s
X-, Y-Thermal Velocities     =  0.0000e+00,   0.0000e+00 m/s
  times dt                   =  0.0000e+00,   0.0000e+00 m
  times dt/dx, dt/dy (X, Y) =  0.0000e+00,   0.0000e+00
X-, Y-Debye Wavelengths  =  0.0000e+00,   0.0000e+00 m
  over dx, dy (X and Y) =  0.0000e+00,   0.0000e+00
Longitudinal thermal velocity (rms) =  0.0000e+00 m/s
  times dt                   =  0.0000e+00 m
  times dt/dz                =  0.0000e+00
Longitudinal Debye wavelength =  0.0000e+00 m
  over dz                    =  0.0000e+00
```

```
Beam velocity =  1.3252e+07 m/s
  over c     =  4.4205e-02
Kinetic energy =  5.0000e+02 eV
Weight of simulation particles =  1.1399e+03
Number of simulation particles =      815
Number of real particles =  9.2905e+05
Total mass =  8.4630e-25 kg
Total charge = -1.4885e-13 Coul
Generalized perveance =  6.7719e-02
Characteristic current = -1.7045e+04 amps
Budker parameter =  6.6359e-05
Timestep size dt =  2.9770e-11 s
Tune length =  0.0000e+00
Undep. X-, Y-Betatron frequencies  =  6.2832e+36,   6.2832e+36 1/s
Undep. X-, Y-Betatron periods      =  0.0000e+00,   0.0000e+00 s
Undep. X-, Y-Betatron wavelengths  =  0.0000e+00,   0.0000e+00 m
Dep.   X-, Y-Betatron frequencies  =  6.2832e+36,   6.2832e+36 1/s
Dep.   X-, Y-Betatron periods      =  0.0000e+00,   0.0000e+00 s
Dep.   X-, Y-Betatron wavelengths  =  0.0000e+00,   0.0000e+00 m
X-, Y-Tune Depressions (sigma/sigma0) =  0.0000e+00,   0.0000e+00
Space charge wave velocity =  3.2501e+06 m/s
Effective wall radius =  4.2426e-02 m
Geometric factor =  1.7711e+00
X-, Y-Emittance over Space charge forces =  0.0000e+00,   0.0000e+00
```

- Simulations at Larmor frequency
  - 8000 timesteps
- First try: Simple Solenoid
- File Size:
- 3.9 GB
- 256x256x256
- Duration → Ages



# WARP
# - Issues dealt with -

- Speed up simulation.
  - Max: approx: 8 days
  - Currently: approx: 8 hours
- Local testing for 500 steps on 6-core computer => 10-15 min
- No plotting
  - Error in Plot-Freq setup
- Profile Injection makes sense
- Field Grid > # Processes!
- File Names must start with Letters
-

# WARP
# - Big Simulation -

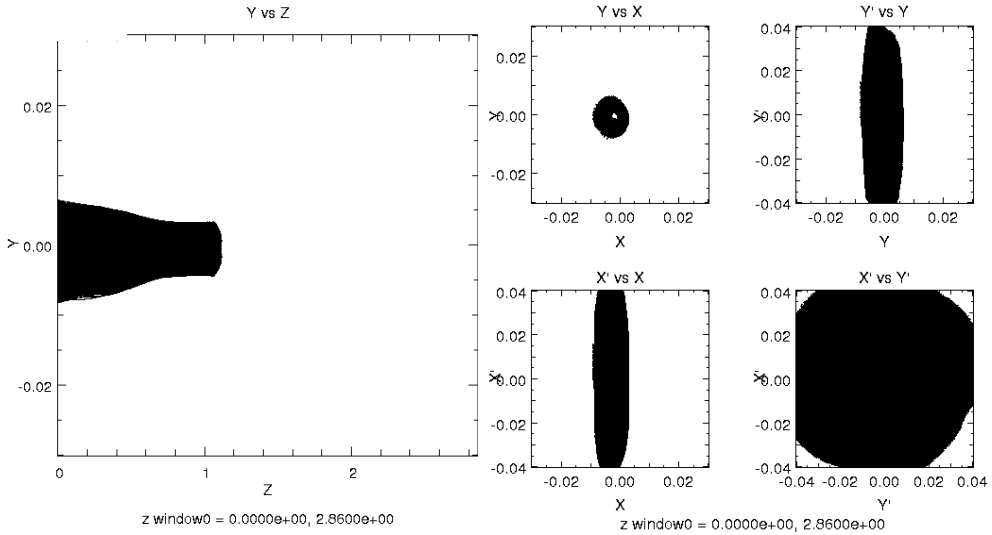
```
Atomic number of ion =  5.4858e-04
Charge state of ion  = -1.0000e+00
Initial X, Y emittances =  0.0000e+00,   0.0000e+00 m-rad
Initial X,Y envelope radii  =  1.7500e-02,   1.7500e-02 m
Initial X,Y envelope angles =  0.0000e+00,   0.0000e+00 rad
Input beam current =  7.3000e-02 amps
Current density =  7.5875e+01 amps/m**2
Charge density =  5.7254e-06 Coul/m**3
Number density = -3.5735e+13
Plasma frequency     =  3.3724e+08 1/s
  times dt           =  9.4121e-03
  times quad period =  0.0000e+00
Plasma period        =  1.8631e-08 s
X-, Y-Thermal Velocities     =  0.0000e+00,   0.0000e+00 m/s
  times dt                   =  0.0000e+00,   0.0000e+00 m
  times dt/dx, dt/dy (X, Y) =  0.0000e+00,  0.0000e+00
X-, Y-Debye Wavelengths  =  0.0000e+00,   0.0000e+00 m
  over dx, dy (X and Y) =  0.0000e+00,   0.0000e+00
Longitudinal thermal velocity (rms) =  0.0000e+00 m/s
  times dt                  =  0.0000e+00 m
  times dt/dz               =  0.0000e+00
Longitudinal Debye wavelength =  0.0000e+00 m
  over dz                   =  0.0000e+00
```

```
Beam velocity =  1.3252e+07 m/s
  over c      =  4.4205e-02
Kinetic energy =  5.0000e+02 eV
Weight of simulation particles =  1.5659e+03
Number of simulation particles =     8121
Number of real particles =  1.2716e+07
Total mass =  1.1584e-23 kg
Total charge = -2.0374e-12 Coul
Generalized perveance =  9.8870e-02
Characteristic current = -1.7045e+04 amps
Budker parameter =  9.6884e-05
Timestep size dt =  2.7909e-11 s
Tune length =  0.0000e+00
```

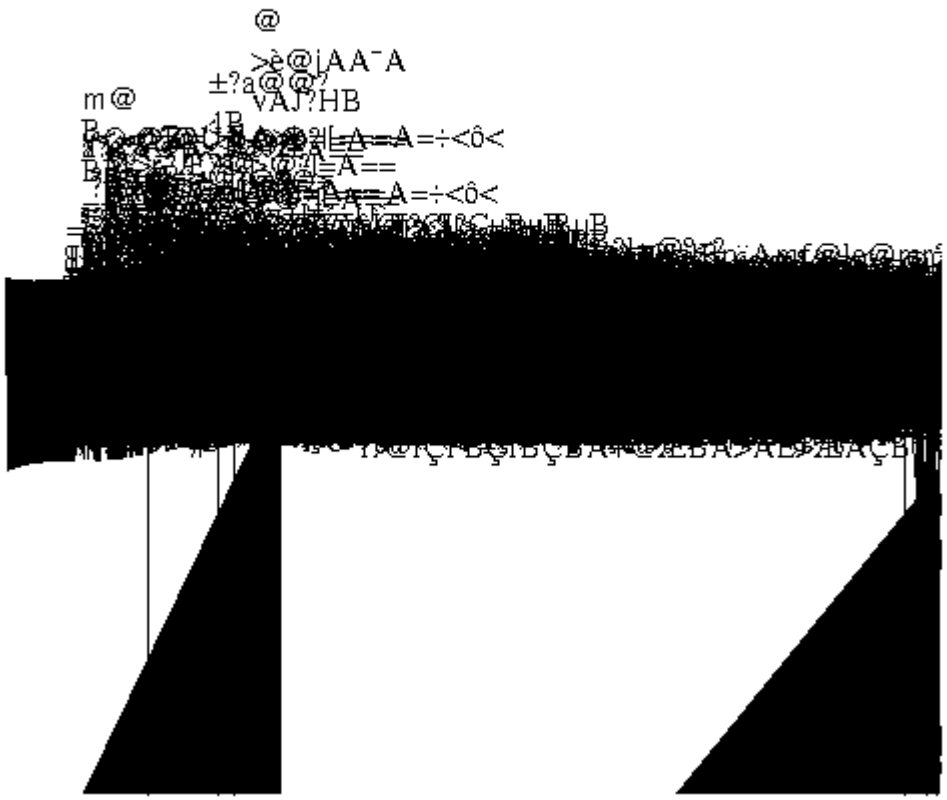
```
Particle distribution = none
Number of grid points in x =      32
Number of grid points in y =      32
Number of grid points in z =      32
Grid spacing in x =  1.8750e-03 m
Grid spacing in y =  1.8750e-03 m
Grid spacing in z =  8.9375e-02 m
Grid extends in x from -3.0000e-02 to  3.0000e-02 m
Grid extends in y from -3.0000e-02 to  3.0000e-02 m
Grid extends in z from  0.0000e+00 to  2.8600e+00 m
Geometry is 3-D
```

```
Undep. X-, Y-Betatron frequencies  =  6.2832e+36,   6.2832e+36 1/s
Undep. X-, Y-Betatron periods      =  0.0000e+00,  0.0000e+00 s
Undep. X-, Y-Betatron wavelengths  =  0.0000e+00,   0.0000e+00 m
Dep.   X-, Y-Betatron frequencies  =  6.2832e+36,   6.2832e+36 1/s
Dep.   X-, Y-Betatron periods      =  0.0000e+00,   0.0000e+00 s
Dep.   X-, Y-Betatron wavelengths  =  0.0000e+00,   0.0000e+00 m
X-, Y-Tune Depressions (sigma/sigma0) =  0.0000e+00,  0.0000e+00
Space charge wave velocity =  3.9271e+06 m/s
Effective wall radius =  4.2426e-02 m
Geometric factor =  1.7711e+00
X-, Y-Emittance over Space charge forces =  0.0000e+00,  0.0000e+00
```

- Simulations at Larmor frequency
  - 8000 timesteps
- First try: Tbench setup
- File Size: 38 Gb
- 32x32x32
- Duration → Ages



# WARP
# - Problem -



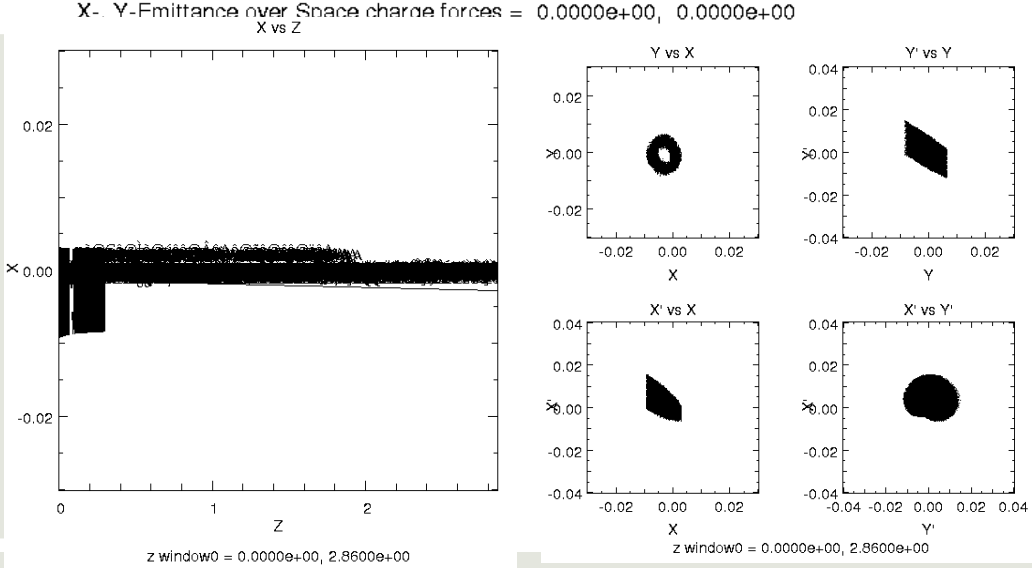
# WARP
# - Big Simulation -

```
Atomic number of ion =  5.4858e-04
Charge state of ion  = -1.0000e+00
Initial X, Y emittances =  0.0000e+00,  0.0000e+00 m-rad
Initial X,Y envelope radii  =  1.7500e-02,  1.7500e-02 m
Initial X,Y envelope angles =  0.0000e+00,  0.0000e+00 rad
Input beam current =  7.3000e-02 amps
Current density =  7.5875e+01 amps/m**2
Charge density =  5.7254e-06 Coul/m**3
Number density = -3.5735e+13
Plasma frequency     =  3.3724e+08 1/s
  times dt           =  9.4121e-03
  times quad period =  0.0000e+00
Plasma period        =  1.8631e-08 s
X-, Y-Thermal Velocities     =  0.0000e+00,  0.0000e+00 m/s
  times dt                   =  0.0000e+00,  0.0000e+00 m
  times dt/dx, dt/dy (X, Y) =  0.0000e+00,  0.0000e+00
X-, Y-Debye Wavelengths  =  0.0000e+00,  0.0000e+00 m
  over dx, dy (X and Y) =  0.0000e+00,  0.0000e+00
Longitudinal thermal velocity (rms) =  0.0000e+00 m/s
  times dt                   =  0.0000e+00 m
  times dt/dz                =  0.0000e+00
Longitudinal Debye wavelength =  0.0000e+00 m
  over dz                    =  0.0000e+00
```

```
Beam velocity =  1.3252e+07 m/s
  over c      =  4.4205e-02
Kinetic energy =  5.0000e+02 eV
Weight of simulation particles =  1.5659e+03
Number of simulation particles =      812
Number of real particles =  1.2715e+06
Total mass =  1.1582e-24 kg
Total charge = -2.0371e-13 Coul
Generalized perveance =  9.8870e-02
Characteristic current = -1.7045e+04 amps
Budker parameter =  9.6884e-05
Timestep size dt =  2.7909e-11 s
Tune length =  0.0000e+00
Undep. X-, Y-Betatron frequencies  =  6.2832e+36,  6.2832e+36 1/s
Undep. X-, Y-Betatron periods      =  0.0000e+00,  0.0000e+00 s
Undep. X-, Y-Betatron wavelengths  =  0.0000e+00,  0.0000e+00 m
Dep.  X-, Y-Betatron frequencies  =  6.2832e+36,  6.2832e+36 1/s
Dep.  X-, Y-Betatron periods      =  0.0000e+00,  0.0000e+00 s
Dep.  X-, Y-Betatron wavelengths  =  0.0000e+00,  0.0000e+00 m
X-, Y-Tune Depressions (sigma/sigma0) =  0.0000e+00,  0.0000e+00
Space charge wave velocity =  3.9271e+06 m/s
Effective wall radius =  4.2426e-02 m
Geometric factor =  1.7711e+00
X-, Y-Emittance over Space charge forces =  0.0000e+00,  0.0000e+00
```

```
Particle distribution = none
Number of grid points in x =      32
Number of grid points in y =      32
Number of grid points in z =      32
Grid spacing in x =  1.8750e-03 m
Grid spacing in y =  1.8750e-03 m
Grid spacing in z =  8.9375e-02 m
Grid extends in x from -3.0000e-02 to  3.0000e-02 m
Grid extends in y from -3.0000e-02 to  3.0000e-02 m
Grid extends in z from  0.0000e+00 to  2.8600e+00 m
Geometry is 3-D
```

- Simulations at Larmor frequency
  - 8000 timesteps
- First try: Tbench setup
- File Size: 2.5 Gb GB
- 32x32x32
- Duration → Ages



# Tasks in WARP

- Direct Injection → Coding is prepared ~ 3 days
- Profile Injection → Perveance ~ 2 days
- Handle Windows → Reduce File Size → speed?
- Histplot & Dump in parallel?
- Thermal Velocity
- Bends → Setup prepared
- Extracting Data from Simulation

# Questions?