Ion Beam Probe System for Potential Measurement in the Low Aspect-Ratio Torus Experiment Device

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Outline

1. Background and Objectives

2. Overall System Configuration

3. Ion Source, Ion Gun

4. Estimation of the Secondary Ion Beam Current

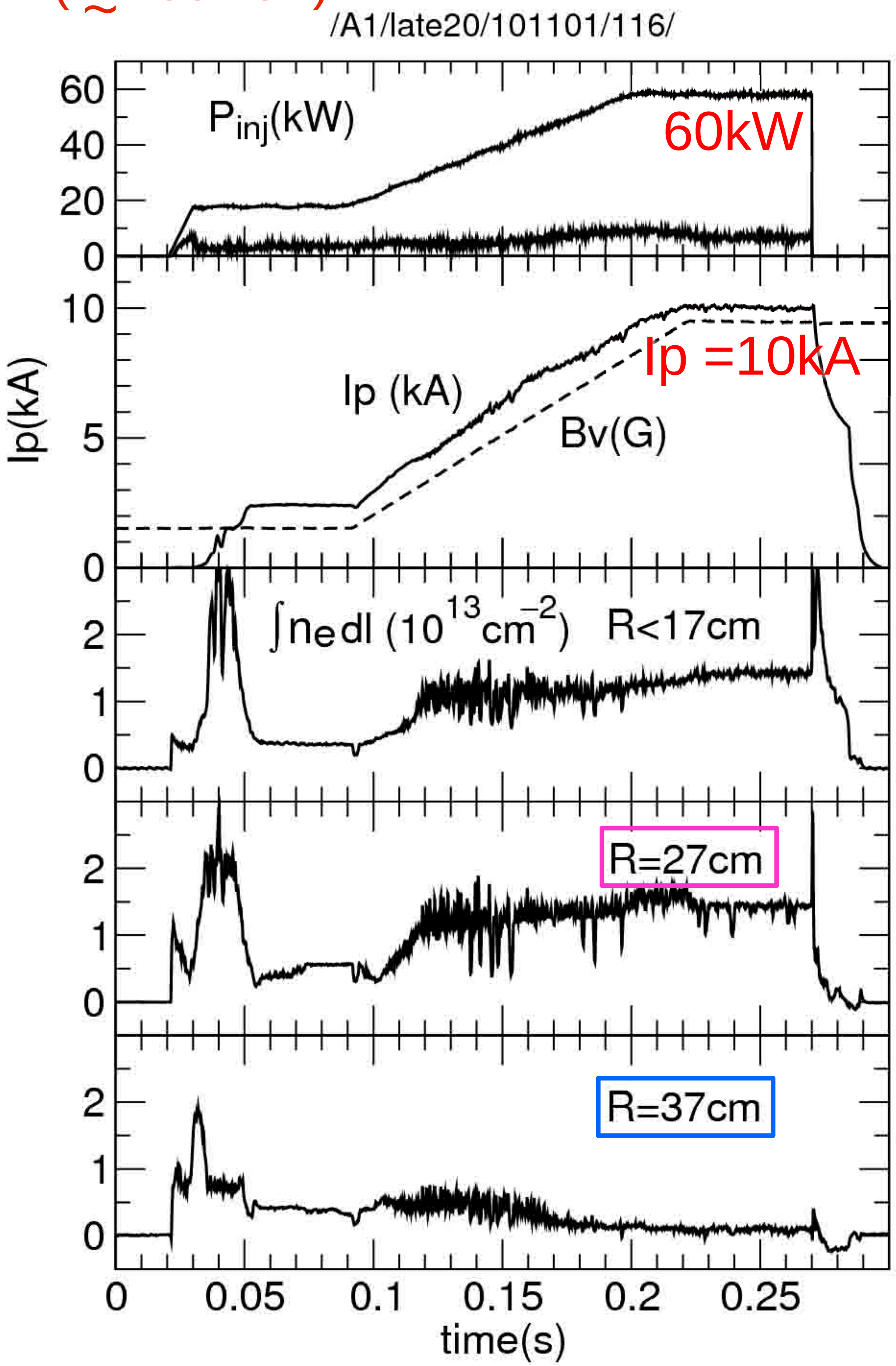
5. Beam Control
   - Injection Beam Line
   - Collection Beam Line
   - Calculation Code for Ion Beam Orbit

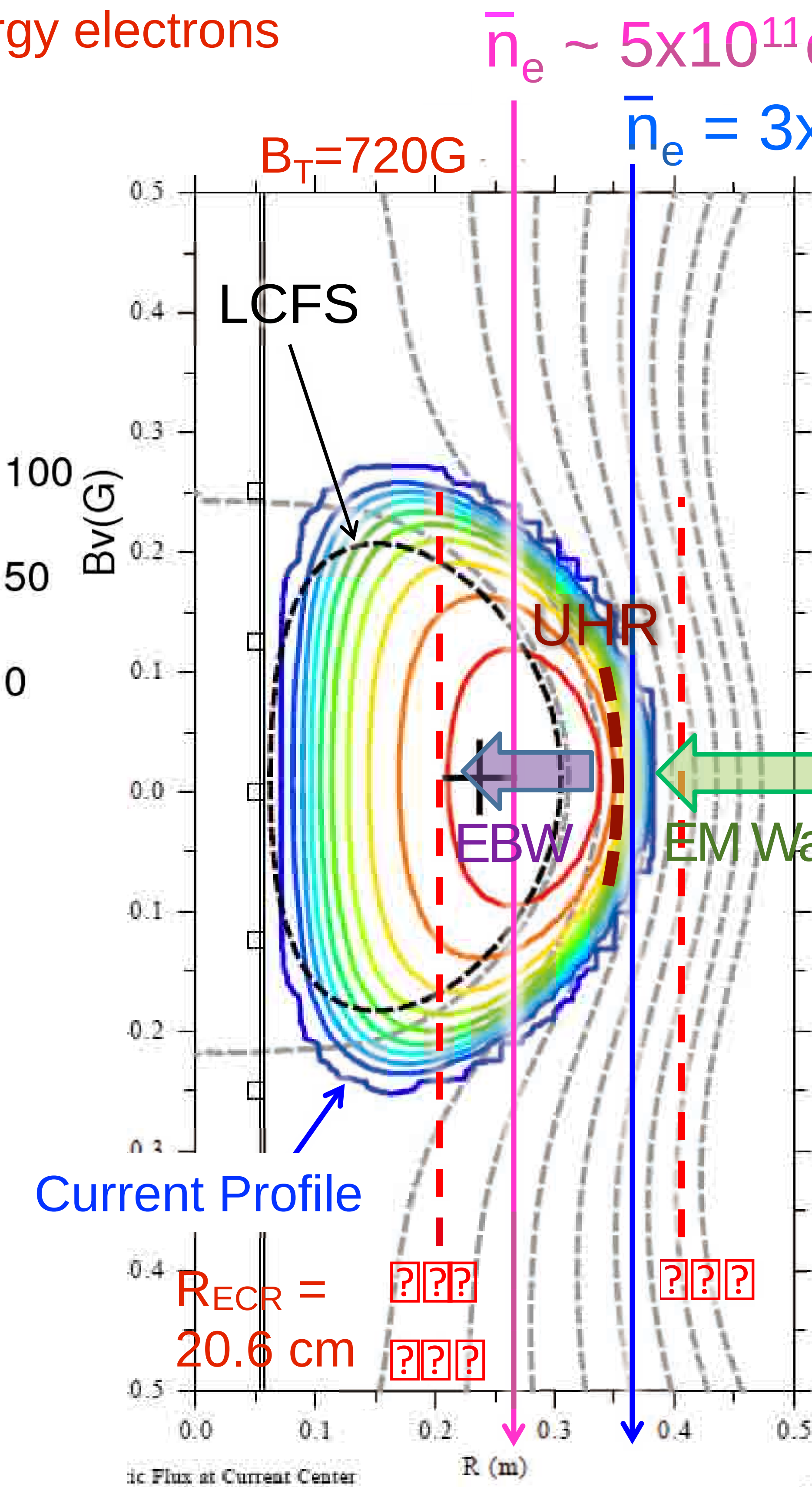
6. Design of Energy Analyzer

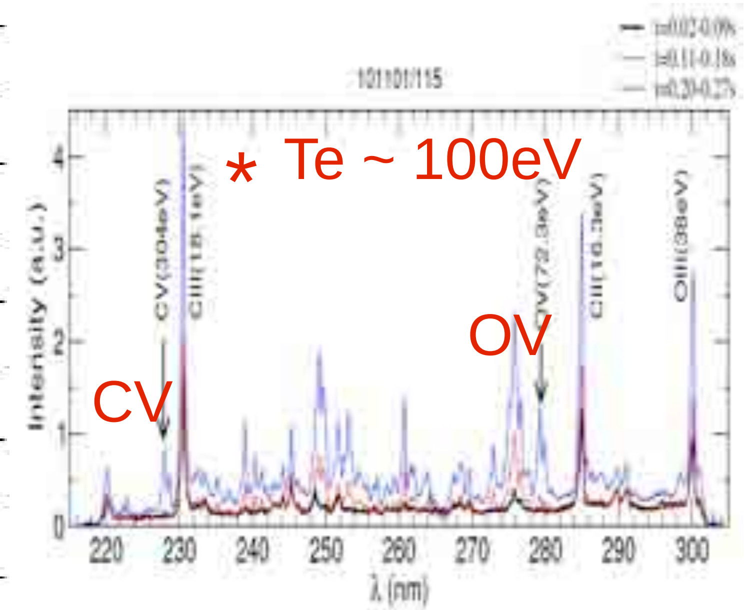
Microwave Spherical Tokamak

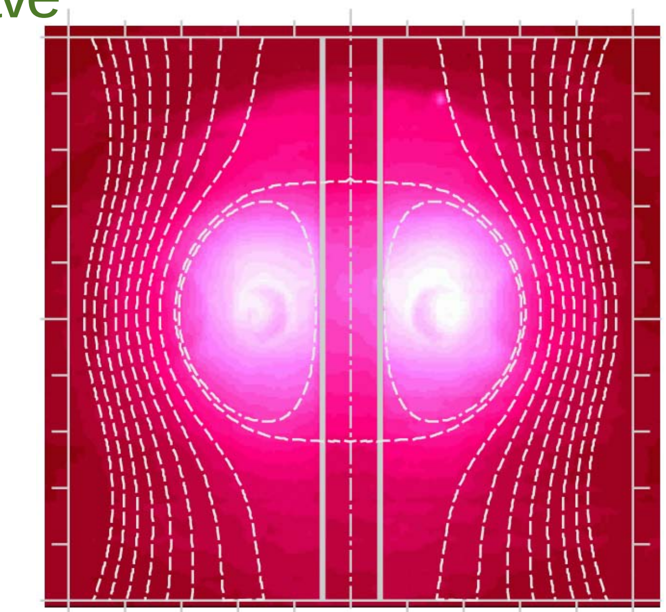
* Overdense ($n_e > 10\ n_c$) plasma is maintained by EBW heating and current drive

* Plasma current is carried by high energy electrons ($\lesssim$ 100 keV)

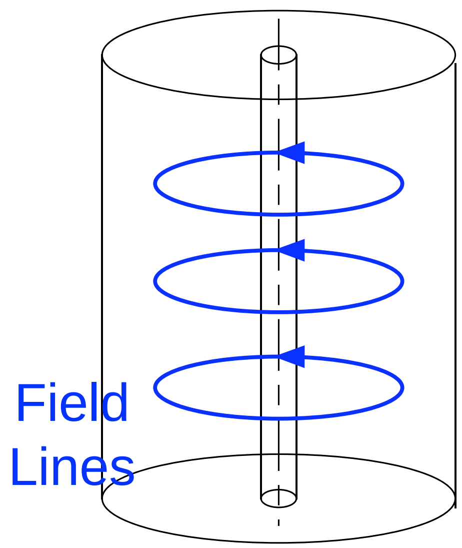


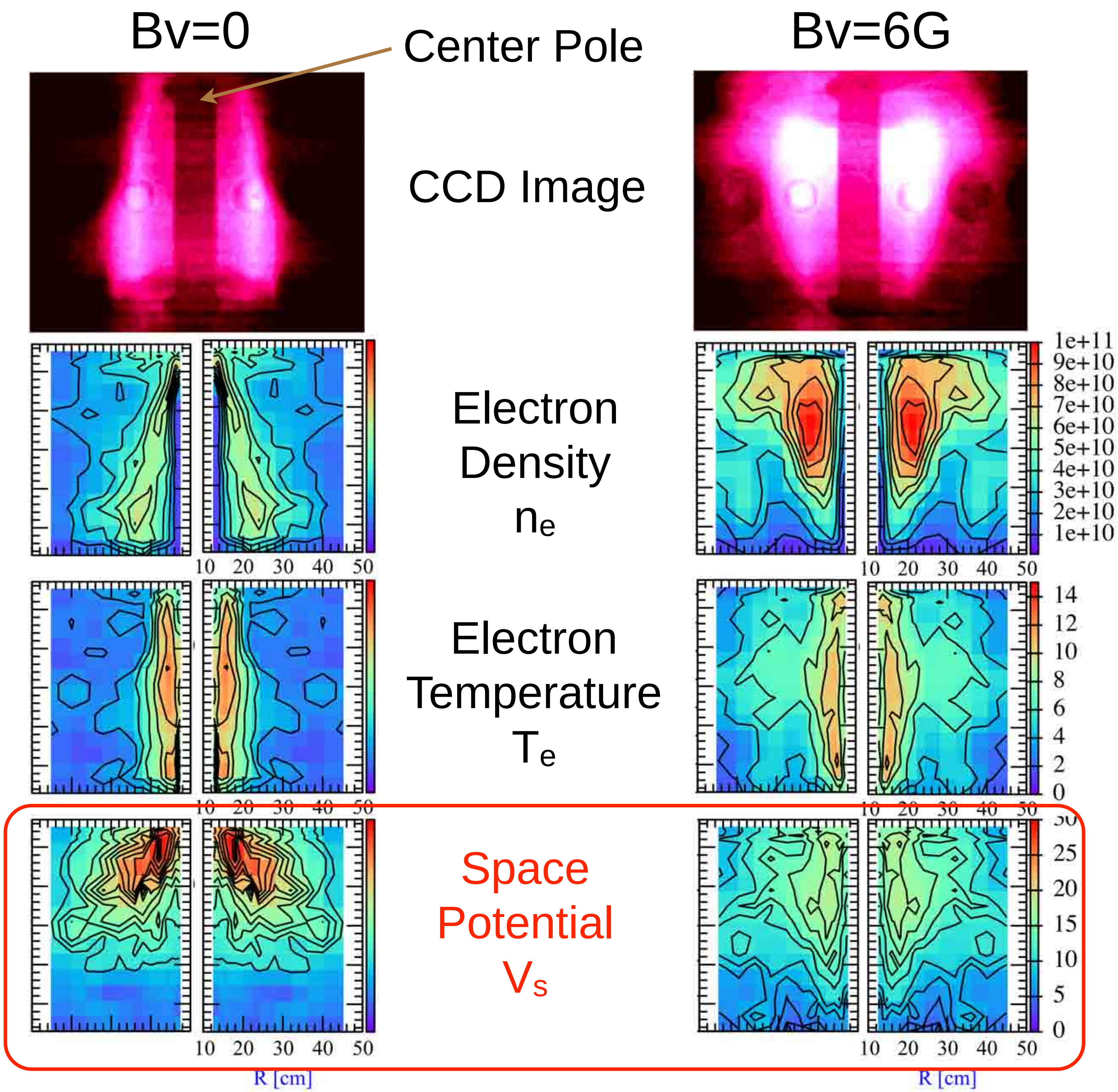


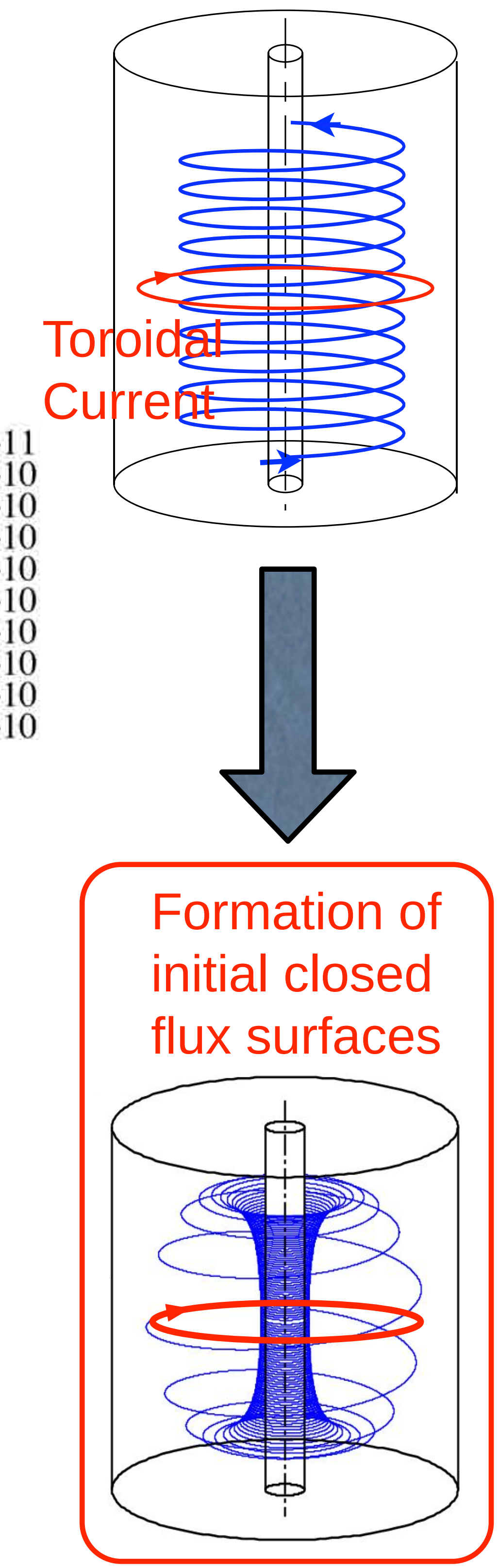



Visible Light Image

Change of Potential Profile due to Bv







When the vertical field is applied, the space potential distribution changes to support the toroidal equilibrium.

Nishi, et al., Plasma Phys. Contrl. Fusion 52 (2010) 065011, and 52 (2010) 125004.

Motivation and Objectives

Microwave Spherical Tokamak

There is no measurement of potential distribution so far!

How the electric field has effects on

✓ Formation of initial closed flux surfaces

✓ Equilibrium and confinement

in the ST plasma produced and maintained by EBW/ECW heating and current drive ?

* Measurement of electrostatic potential distribution
* Electron temperature measurement (10 < Te < 100 eV)
* Plasma current profile measurement with aid of magnetic measurement
* Measurement of density fluctuation
* Measurement of potential and magnetic field fluctuation

Overall System Configuration

Target Plasma Parameters

B_t = 480G, 720G
@R=25cm

R_{ECR} = 13.7cm, 20.6cm
for 2.45GHz

B_v = 15 ~ 100G
$I_p \lesssim$ 10kA

Core

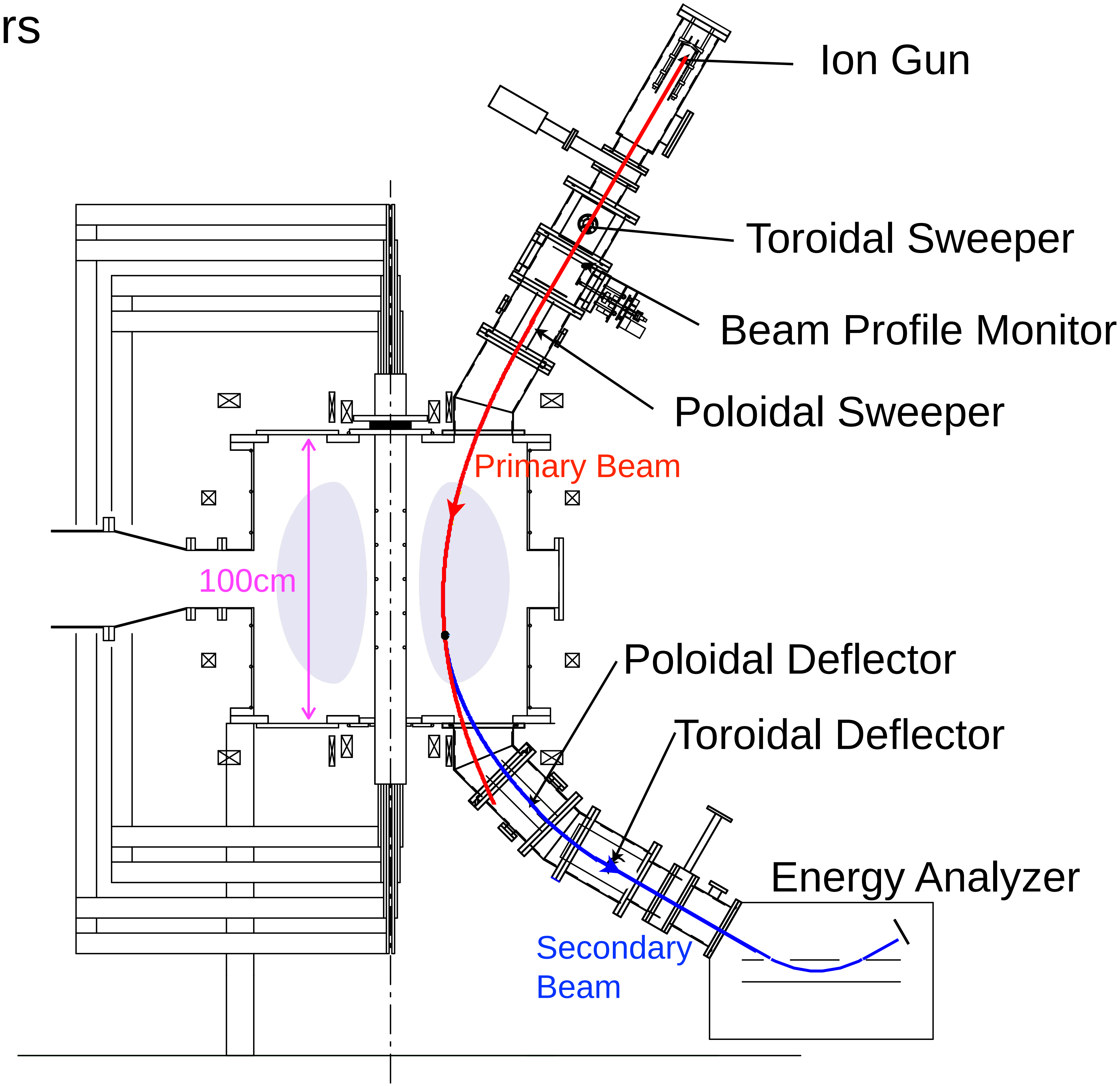
$10^{11} \sim 10^{12}$ cm^{-3}

~100 eV

Peripheral

$10^{9} \sim 10^{10}$ cm^{-3}

10～50 eV



Ion Source & Ion Gun

6mm

Ion Source Li^+, Na^+, K^+, Rb^+, Ce^+

Thermionic ion source ... low energy spread (< 1eV)

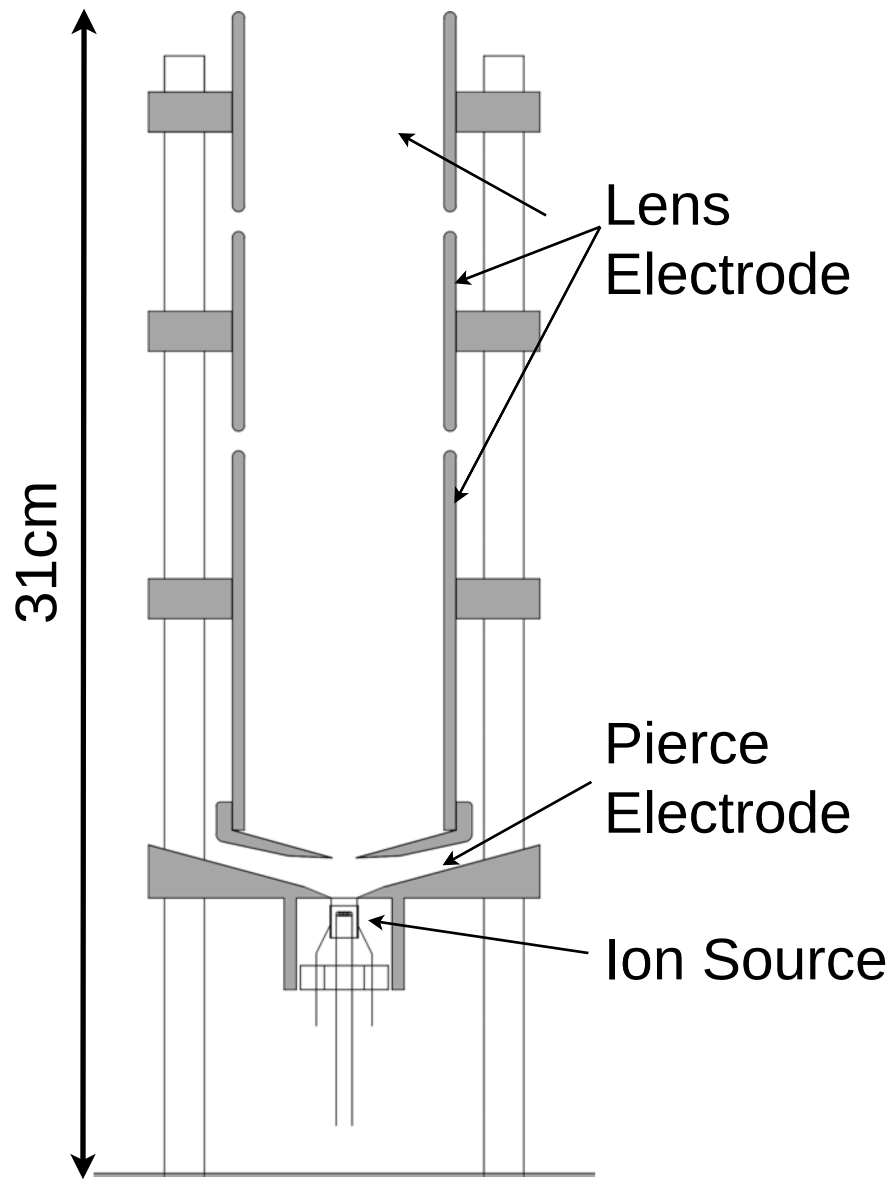
Na zeolite base
Exchange Na ions with alkali metal (Li, K, Rb, Ce) ions in hot water solution
Recrystalization at ~1000°C in vacuum

Ion Gun

Gun Voltage $V_G \leq 20kV$

Pierce electrode
3 Cylindrical lens electrode

The same type used for HIBP system of CHS

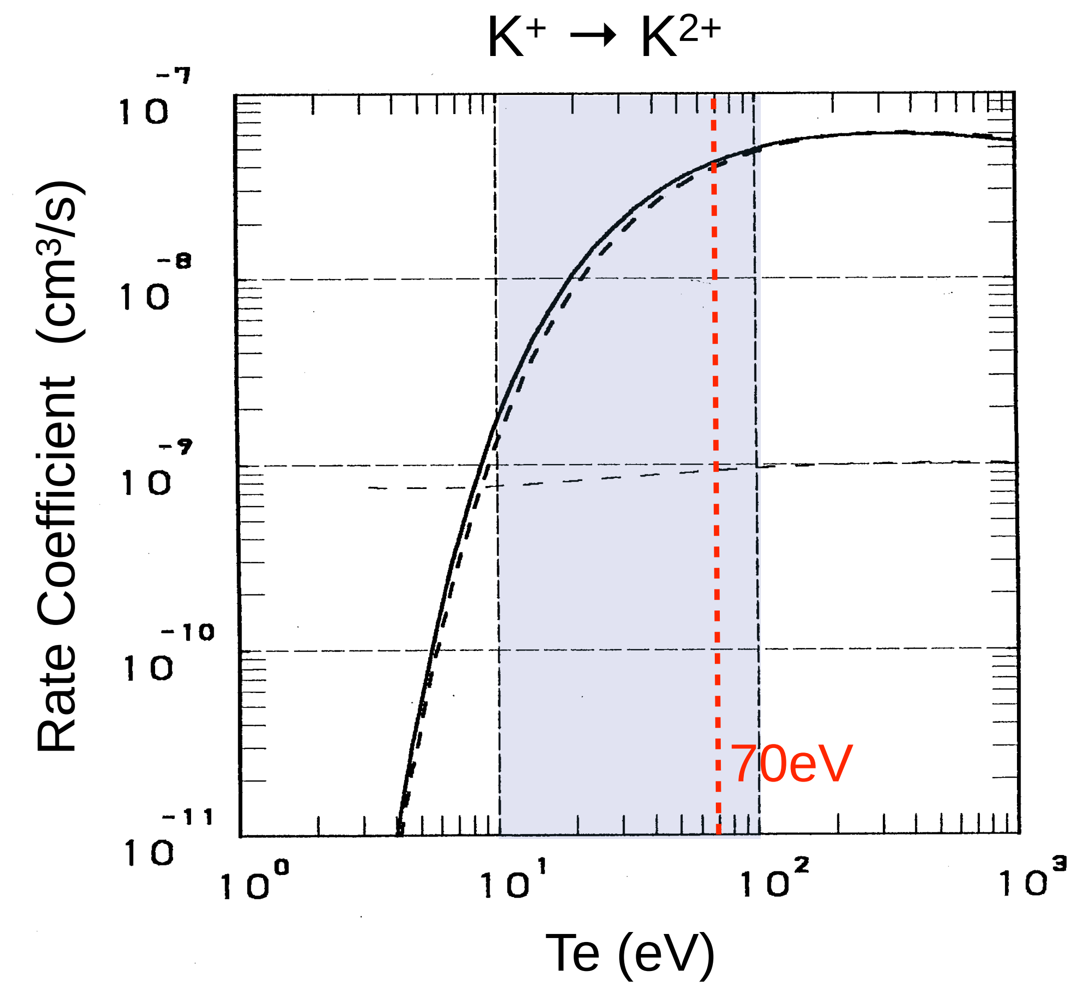


Estimation of Secondary Beam Current

Primary Beam Current $I_p = n_b e v_b A$

Secondary Beam Current $I_s = Z_i e n_b n_e \langle \sigma v \rangle_i A l$

Ratio $\frac{I_s}{I_p} = Z_i n_e l \frac{\langle \sigma v \rangle_i}{v_b}$

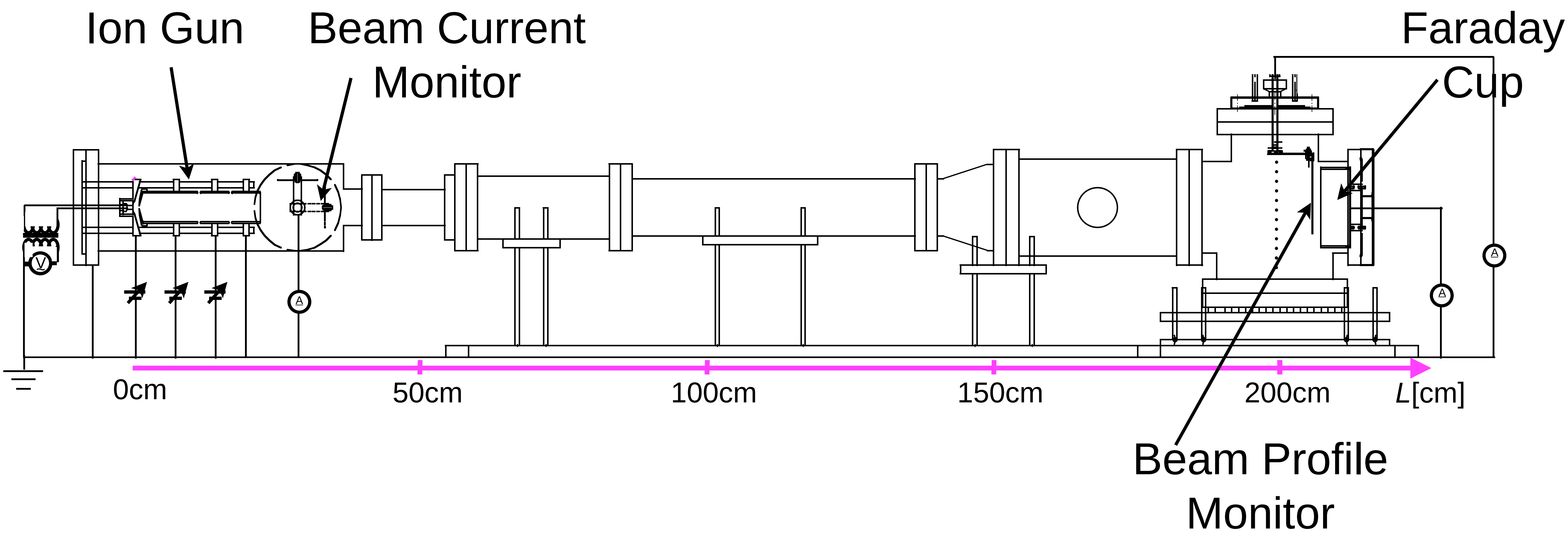


ions	mass number	$A^+ \rightarrow A^{2+}$ Ionization Energy	$\langle \sigma v \rangle_i$@Te=70eV	Secondary Beam Current
Li^+	7	75.6 eV	0.1×10^{-8} cm^3/s	1.4 nA
Na^+	23	47.3 eV	0.9×10^{-8} cm^3/s	22 nA
K^+	39	31.6 eV	4×10^{-8} cm^3/s	130 nA
Rb^+	85	27.3 eV	~8×10^{-8} cm^3/s	380 nA
Cs^+	133	23.2 eV	~10×10^{-8} cm^3/s	590 nA

Zi = 2
Length of Sample Volume
l = 1cm

Primary Beam Energy
20 keV, Current 100μA
$n_e = 5 \times 10^{11}$ cm^{-3}
T_e = 70 eV

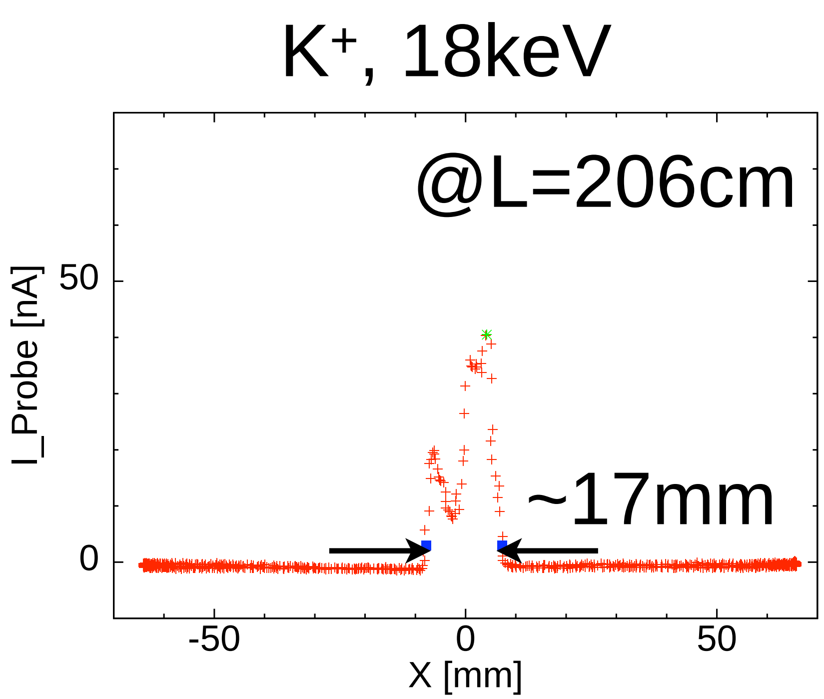
Test of Ion Gun at Test Bench



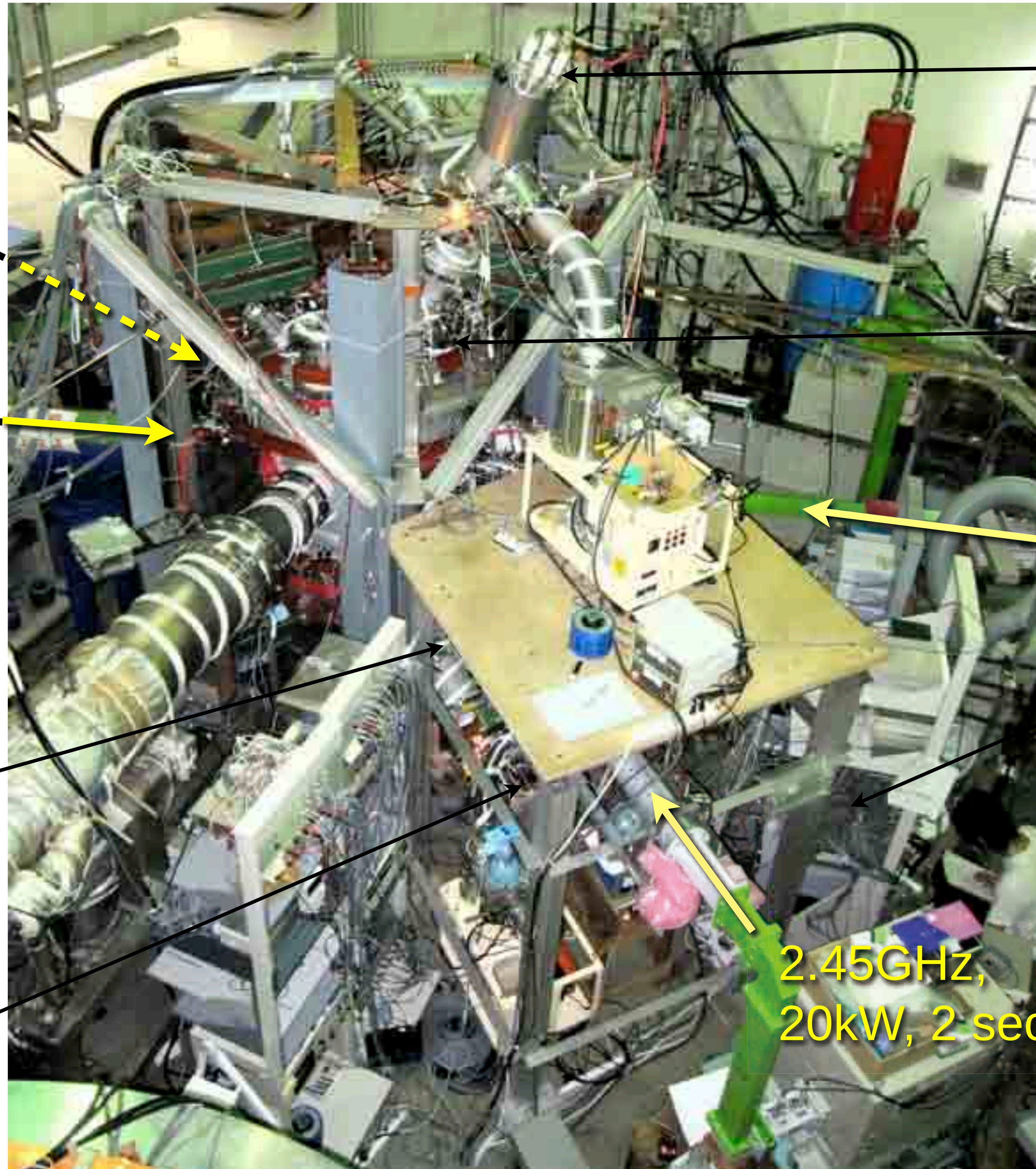
∗ K^+ ion current more than 100 μA is obtained sometimes.

∗ K^+ ion current of ~ 40 μA is routinely extracted.

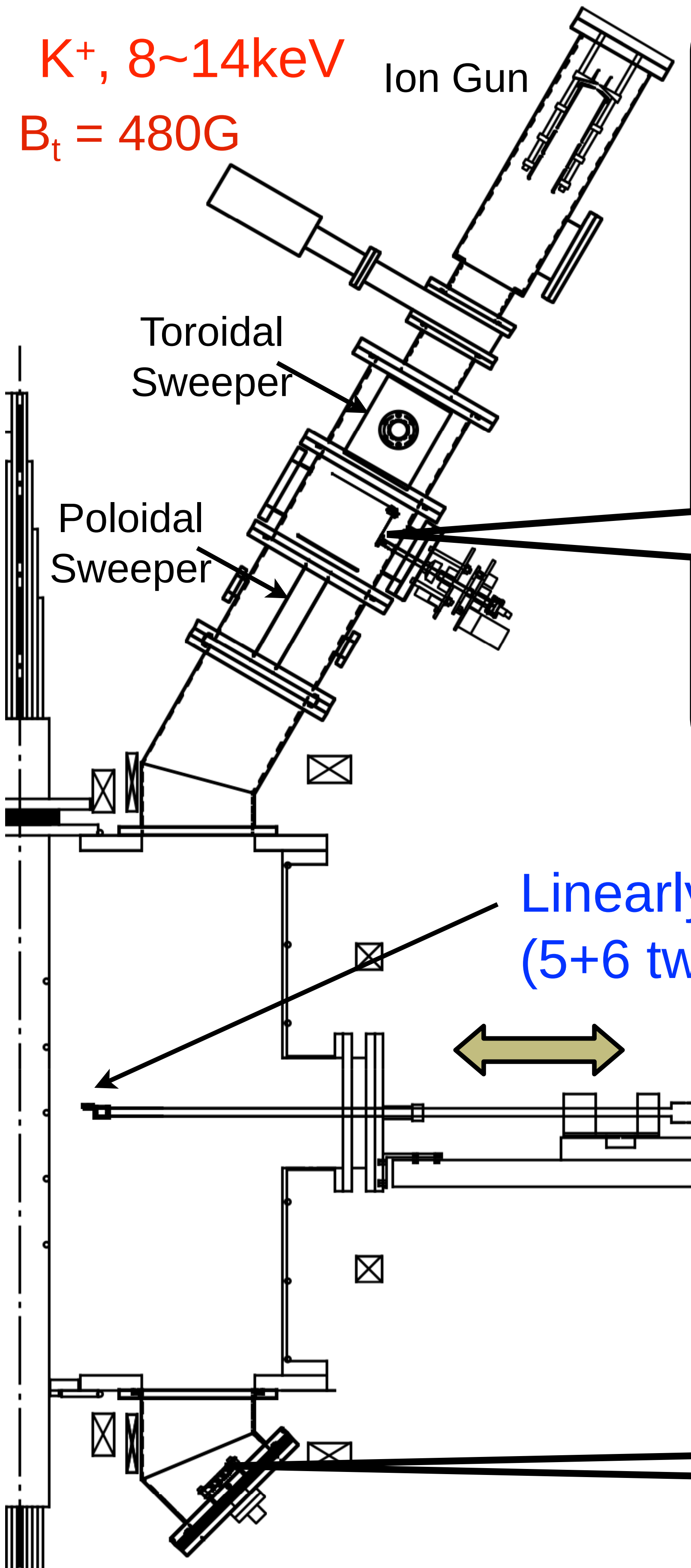
∗ Beam diameter is less than 2 cm at 206 cm away from the ion source (corresponding to z ~ 10 cm in LATE)



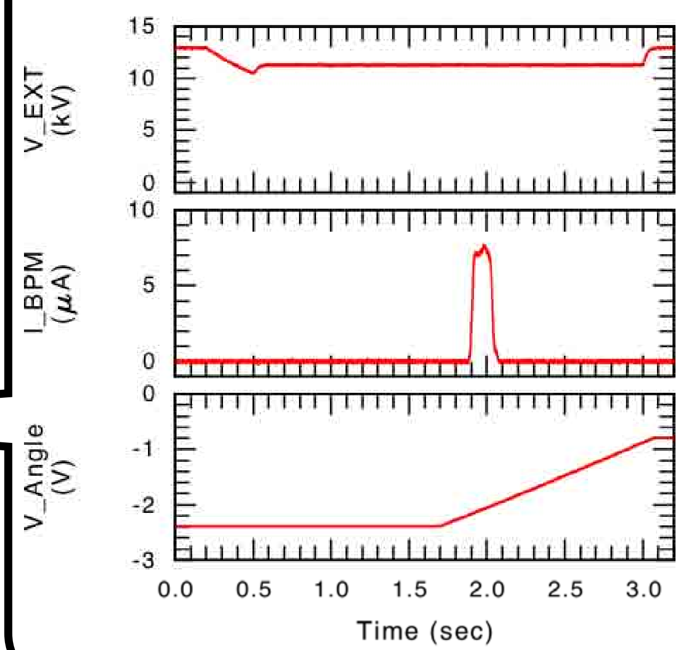
Installation of IBP Beam Line to LATE

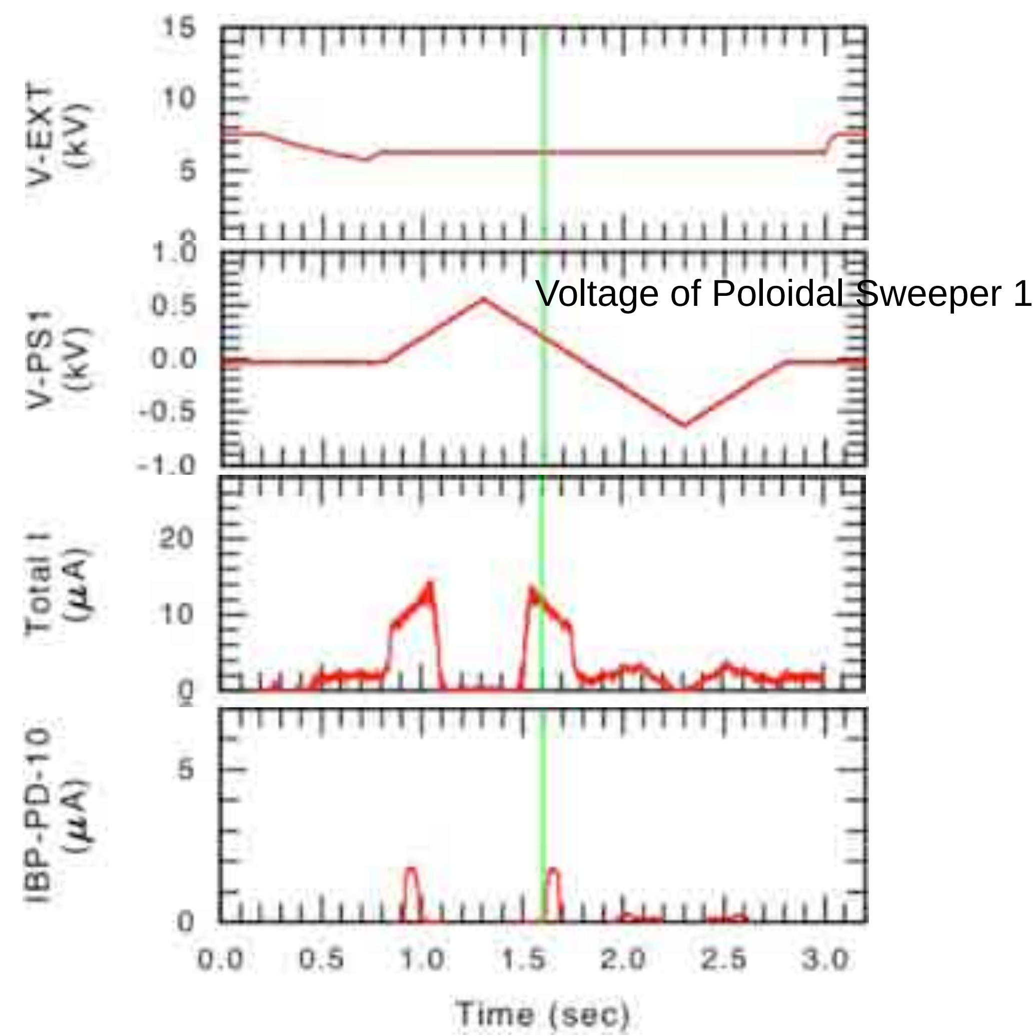


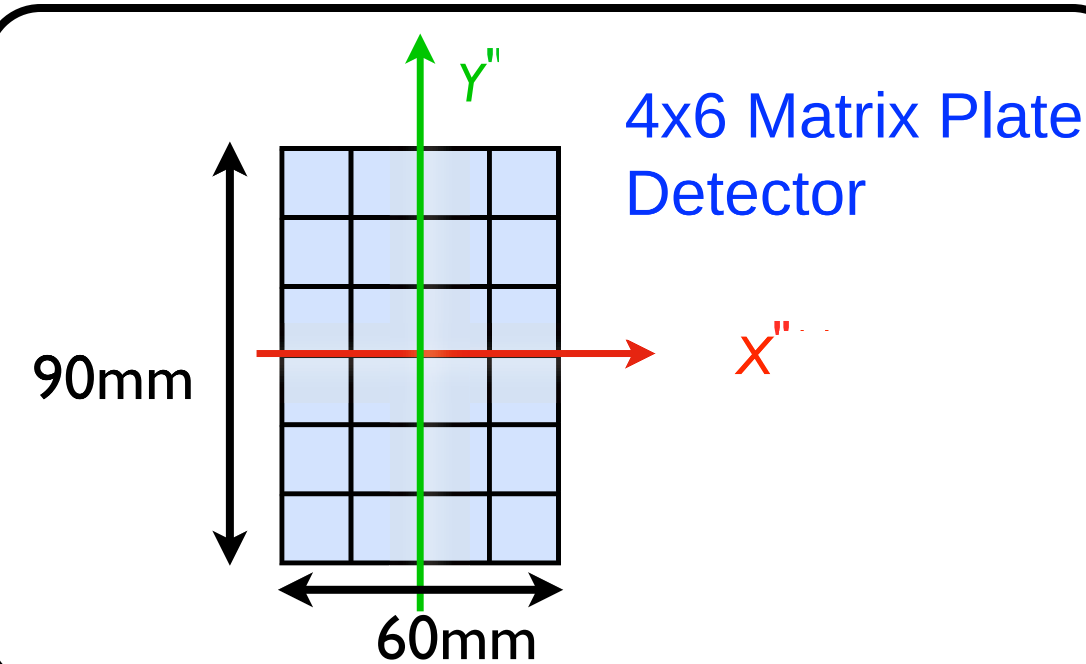
Test of Beam Injection (1)



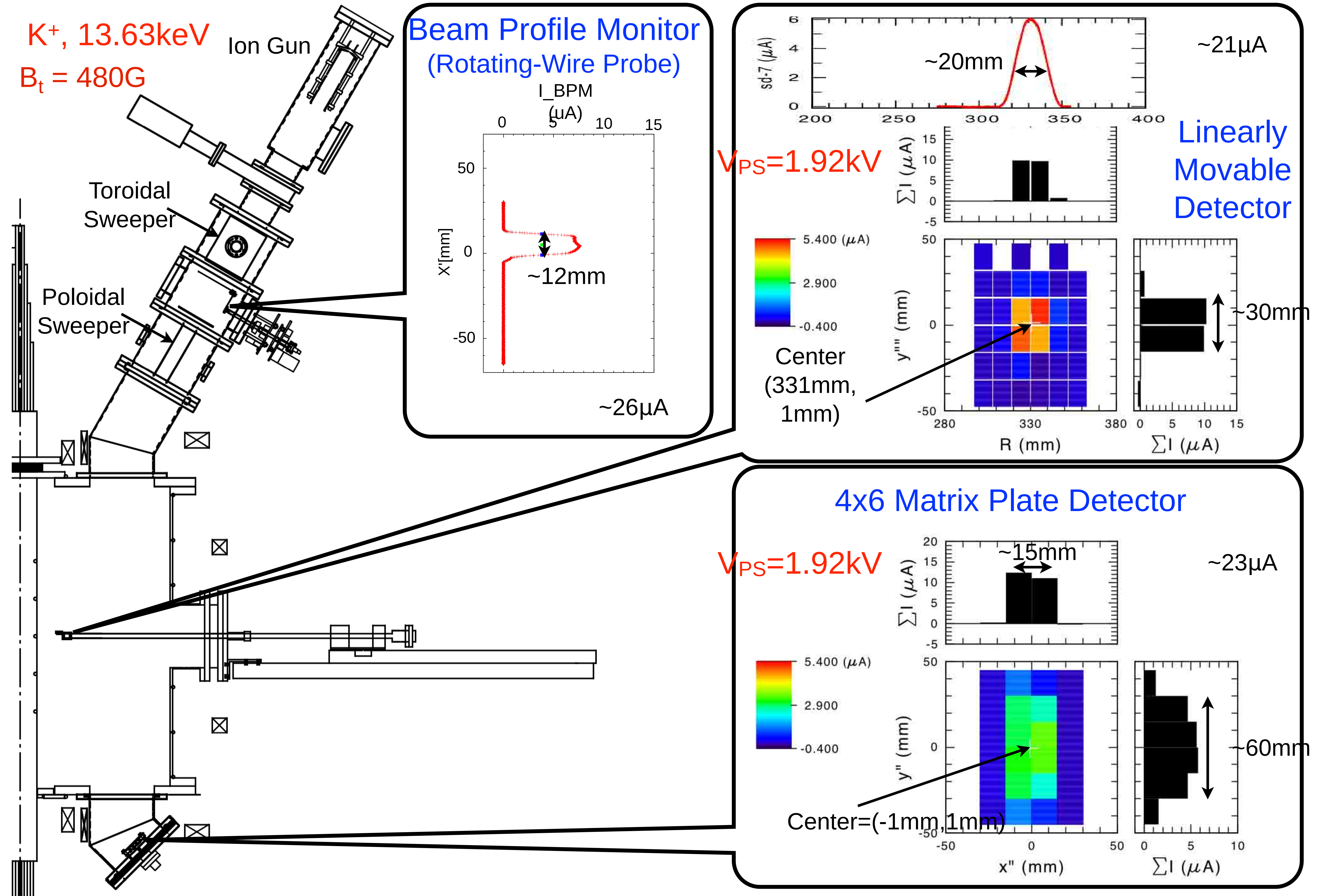
Beam Profile Monitor
(Rotating-Wire Probe)







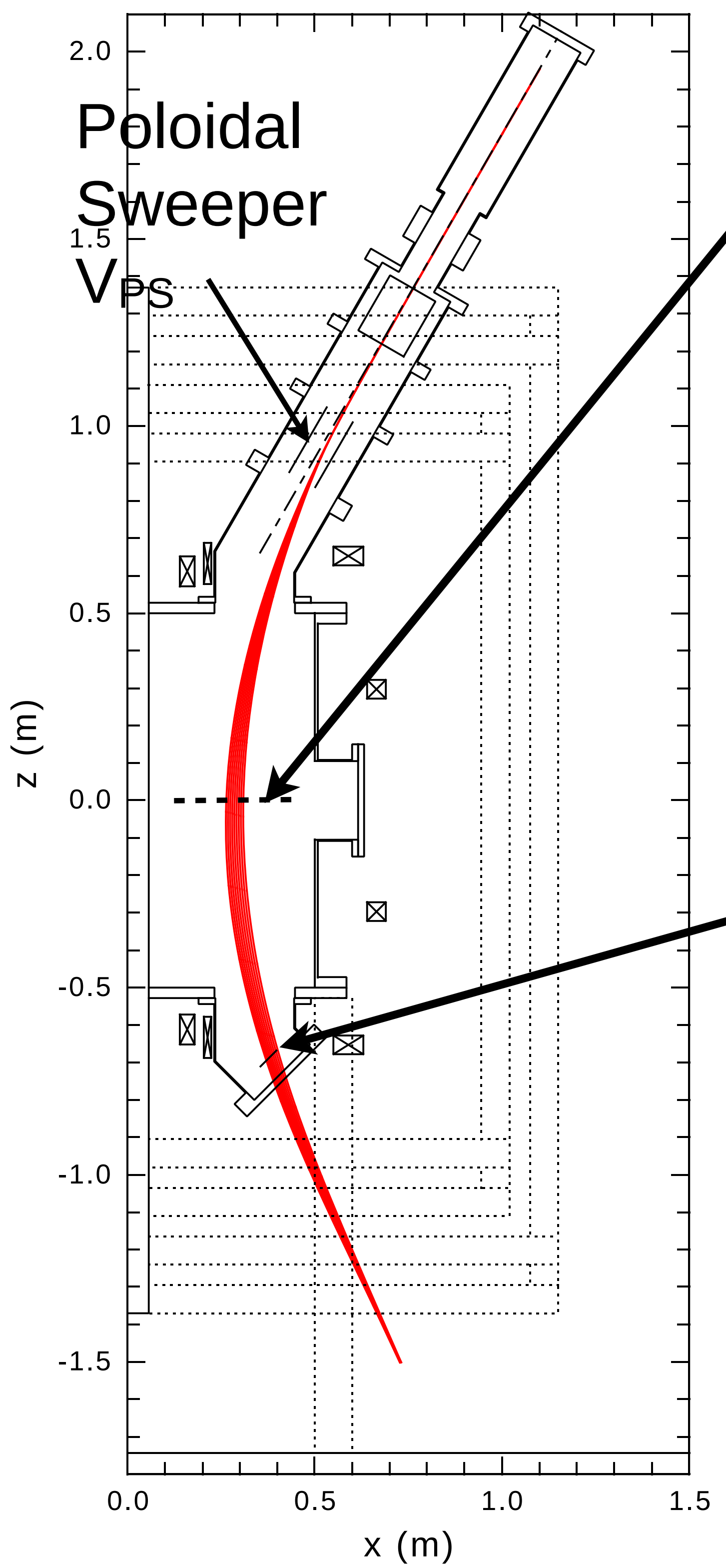
Test of Beam Injection (1)



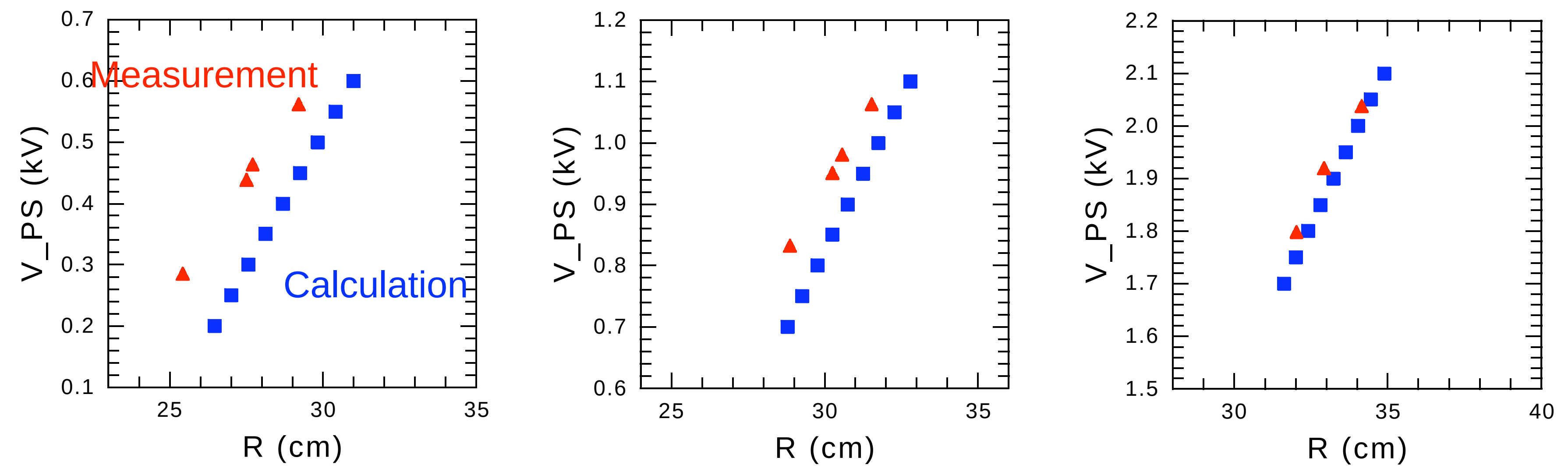
Comparison of Measured Position and Calculated One (1)

K^+ $B_t = 480G$

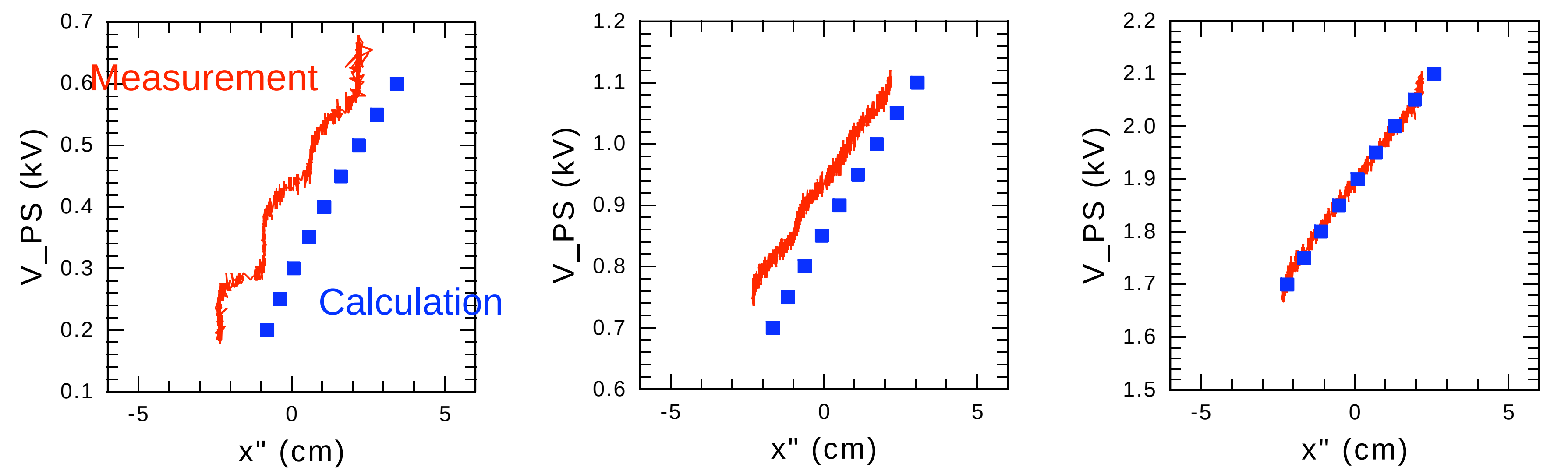
8.08keV 9.91keV 13.63keV



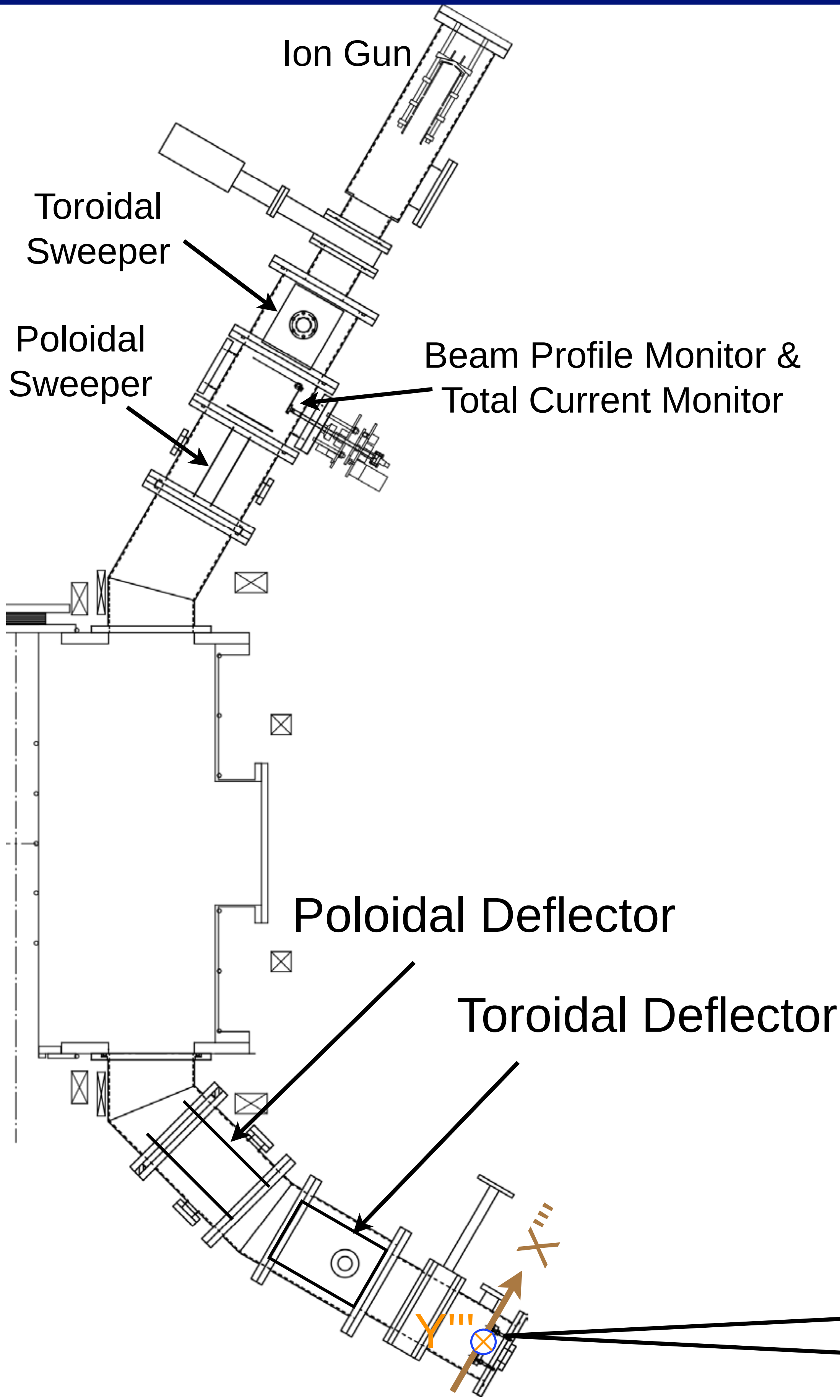
z=1.5cm (Movable Detector)

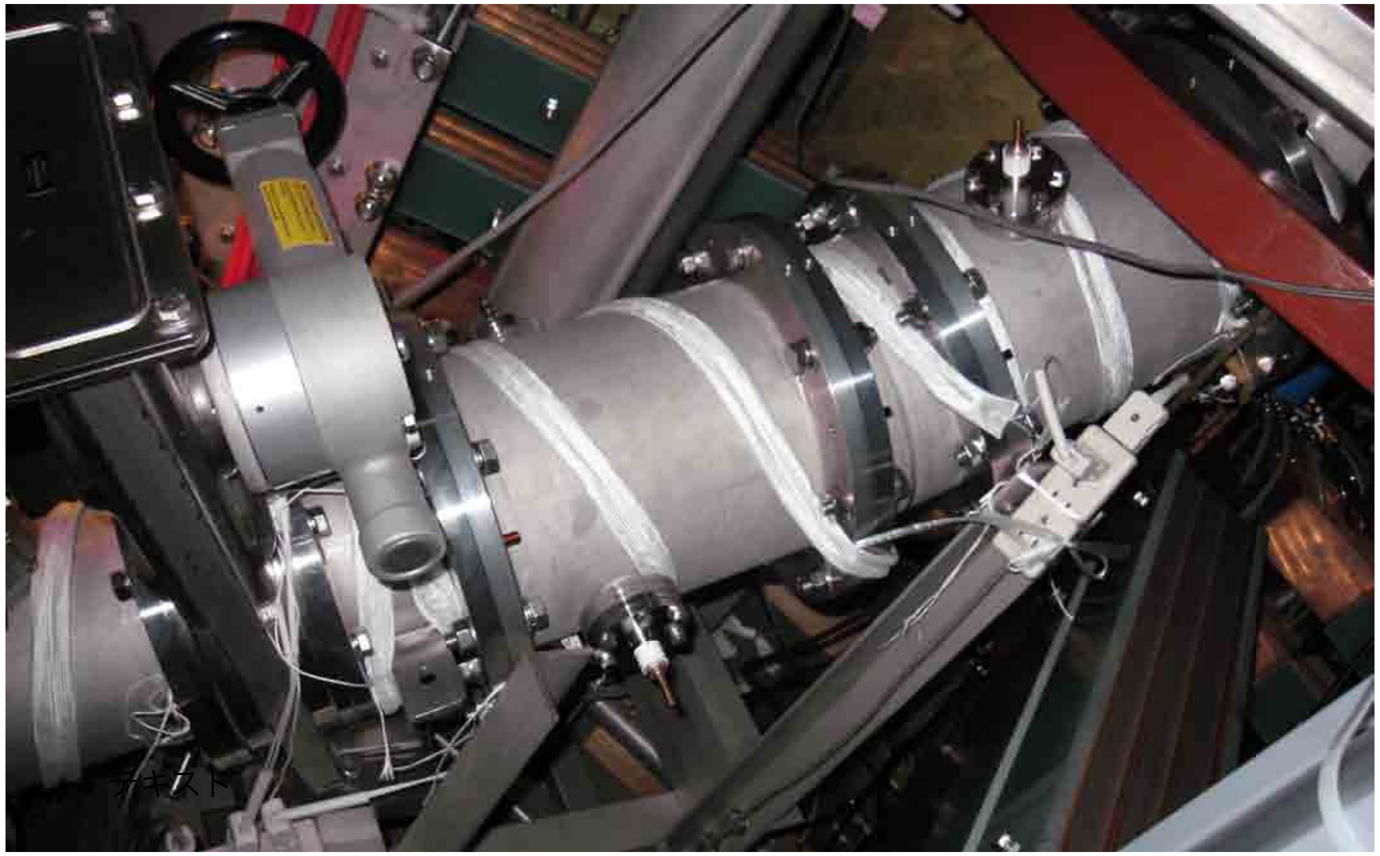


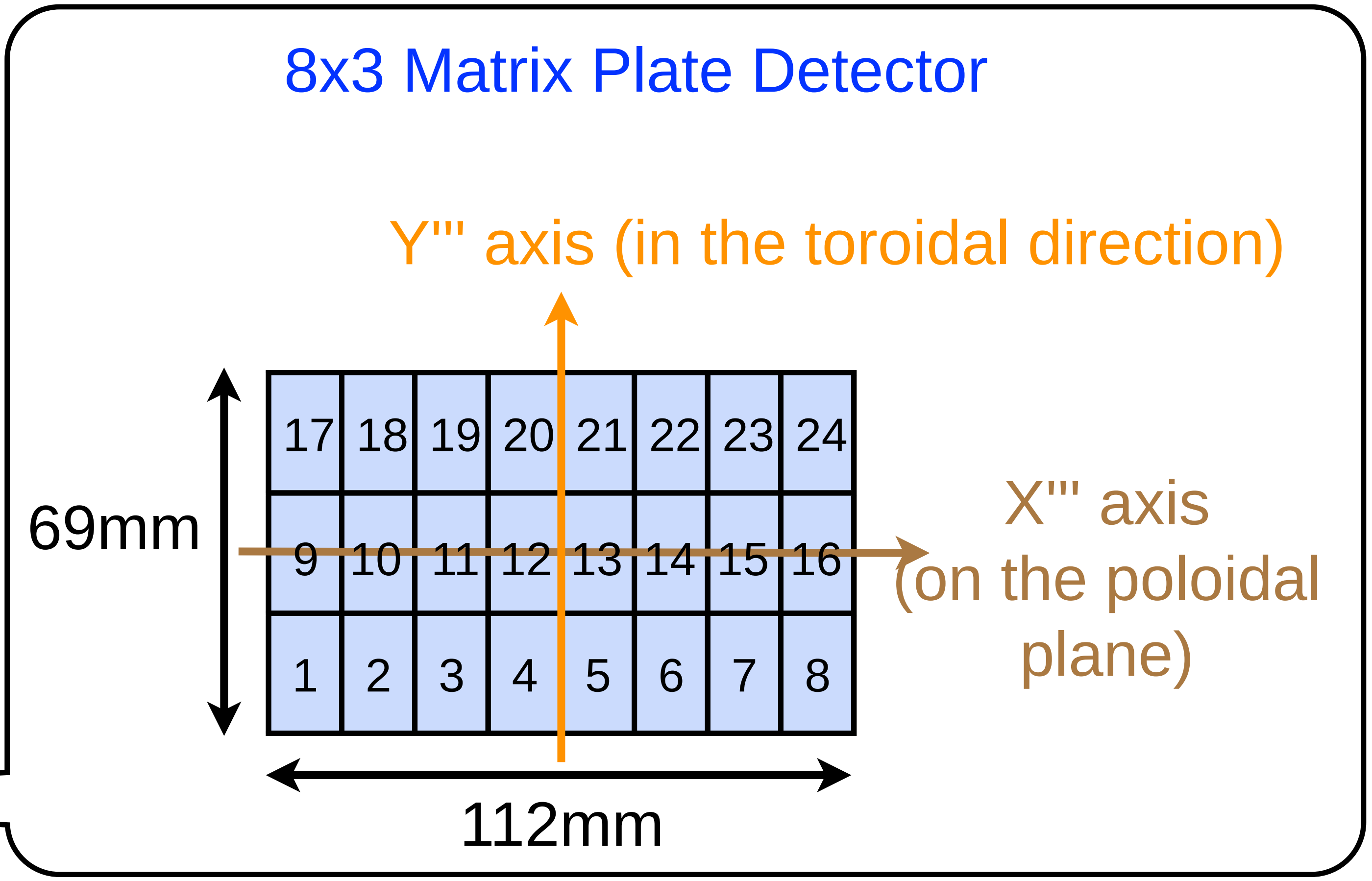
Bottom Port (4x6 Matrix Plate Detector)



Test of Beam Injection (2)



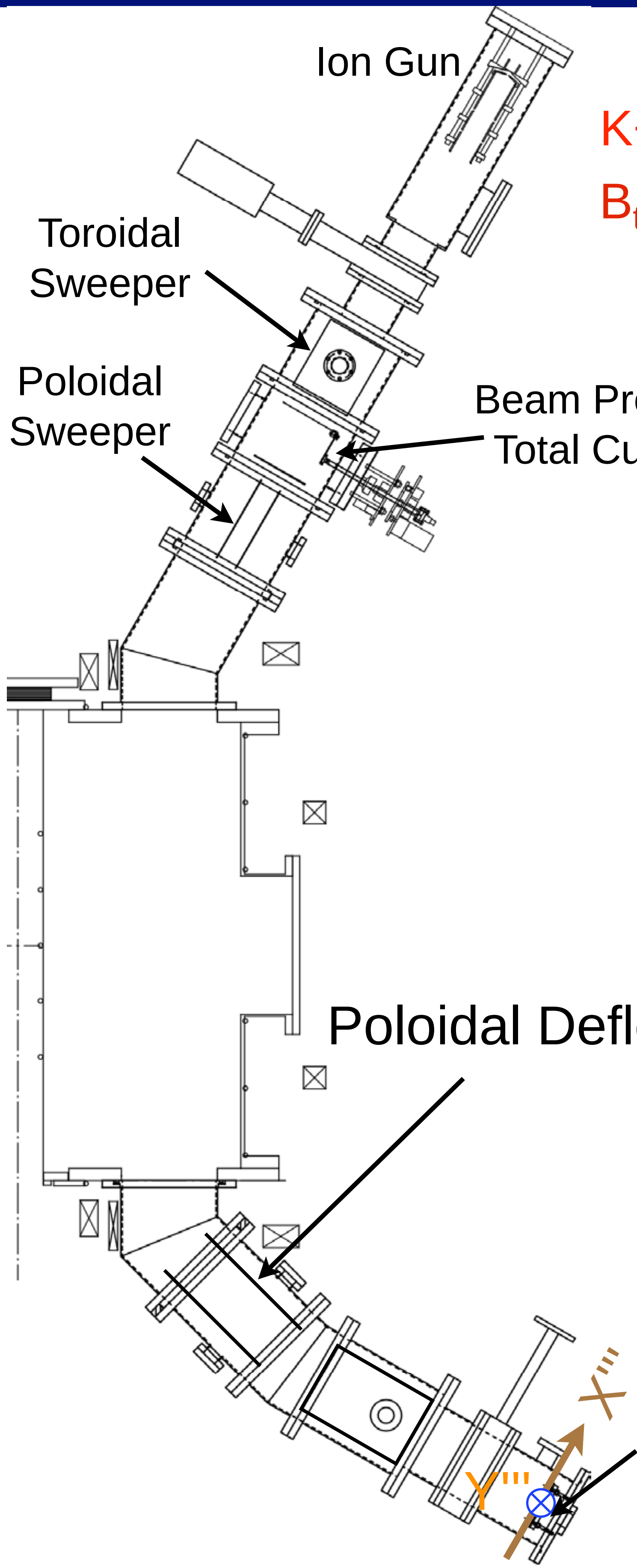




Test of Beam Injection (2)

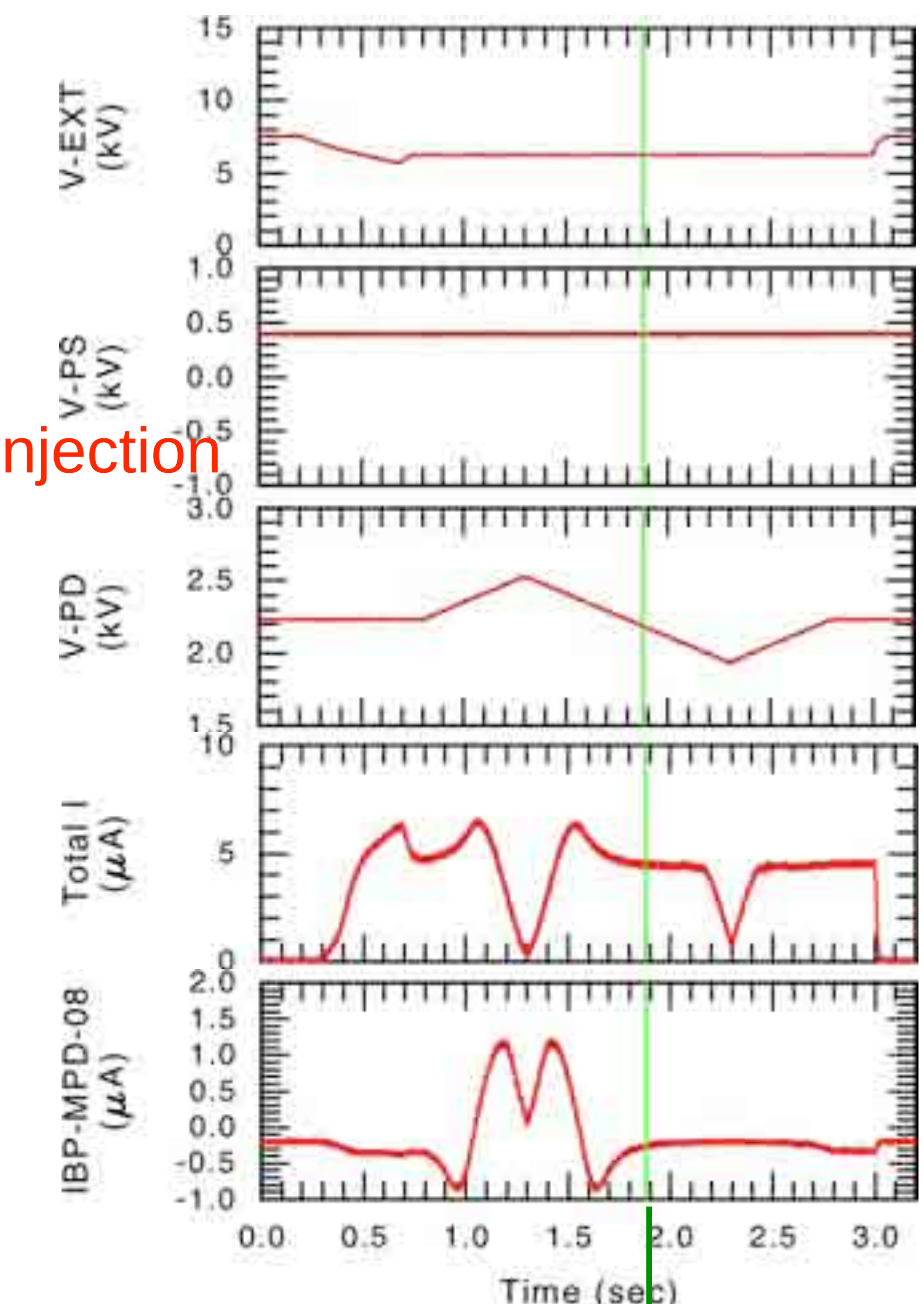
K+, 7.69 keV

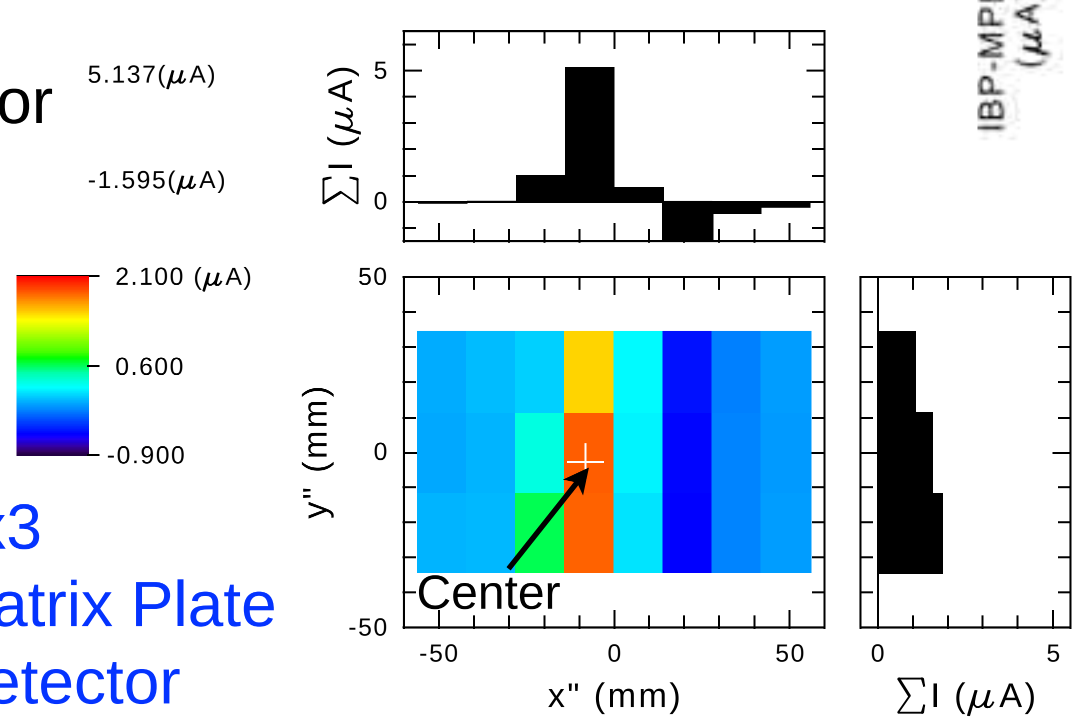
B_t = 480G



V_{PS}=0.4 kV
constant during beam injection

V_{PD}=1.8~2.6 kV



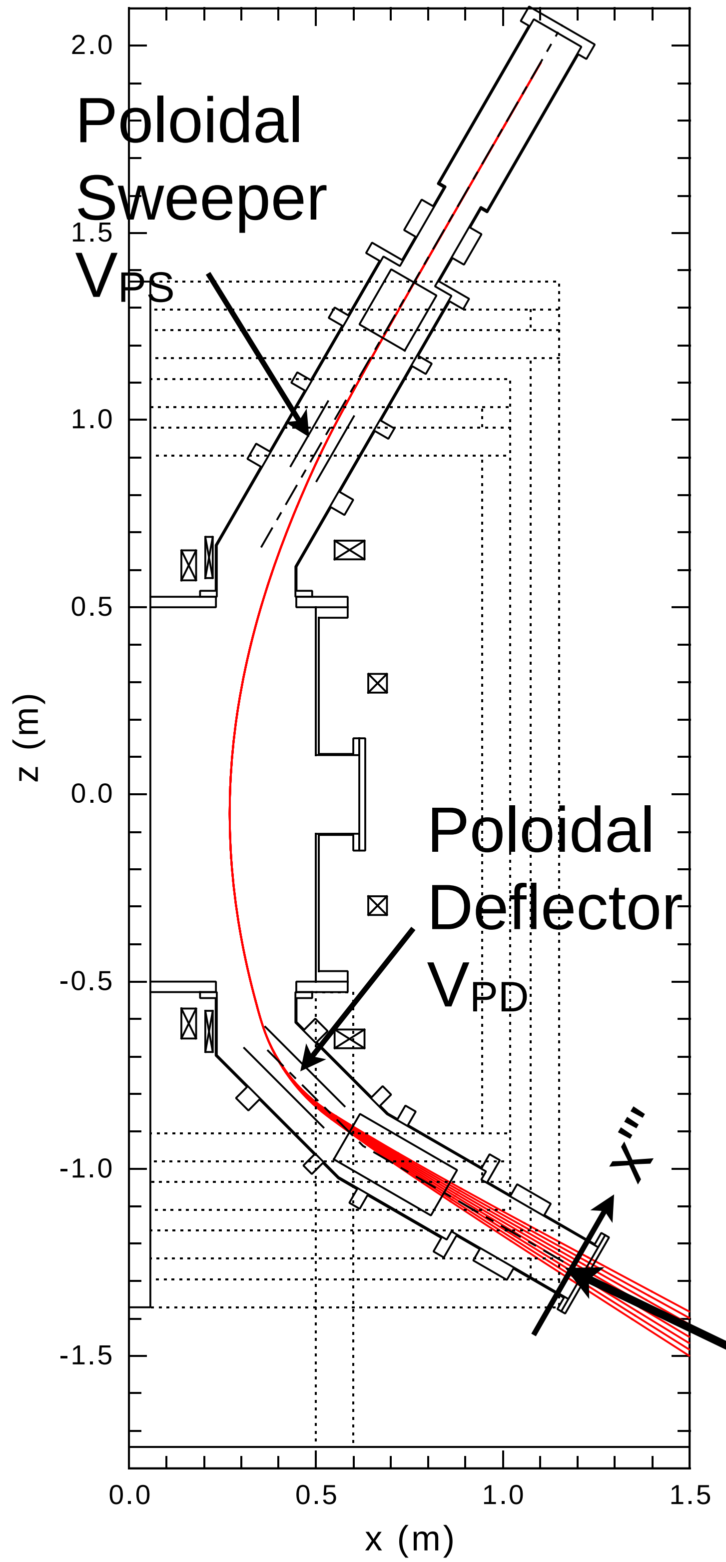


t=1.88sec

V_{PD}=2.18 kV

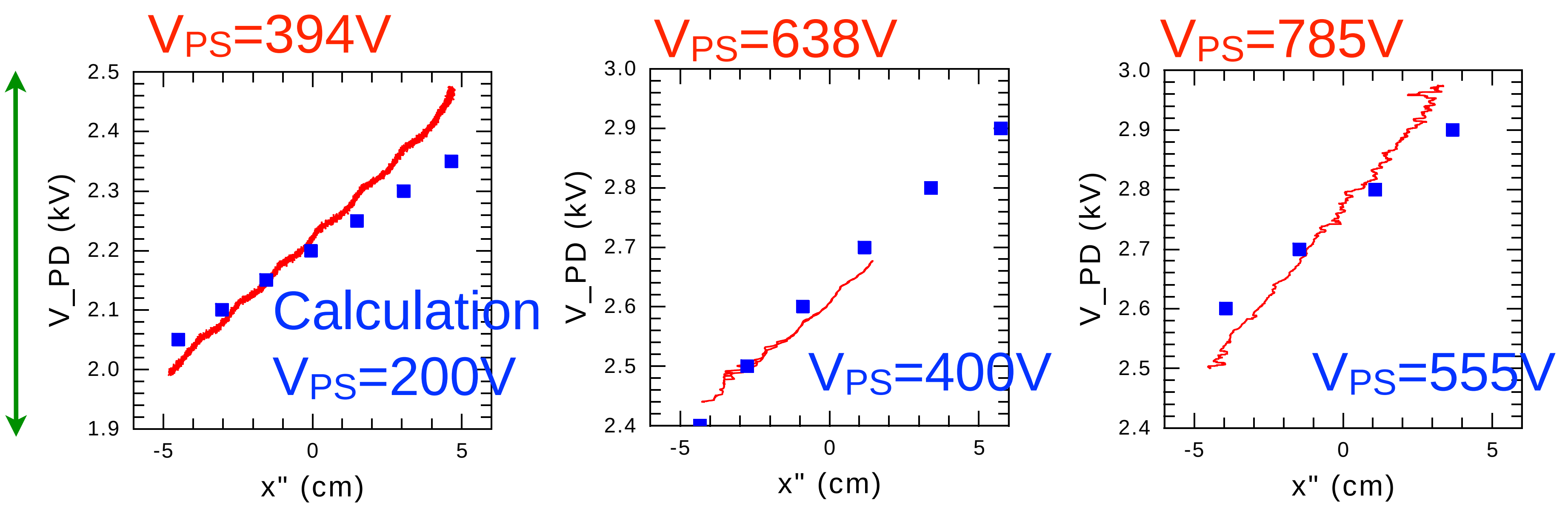
Comparison of Measured Position and Calculated One (2)

K^+ B_t = 480G



* V_{PD} is the same range for both measurement and calculation

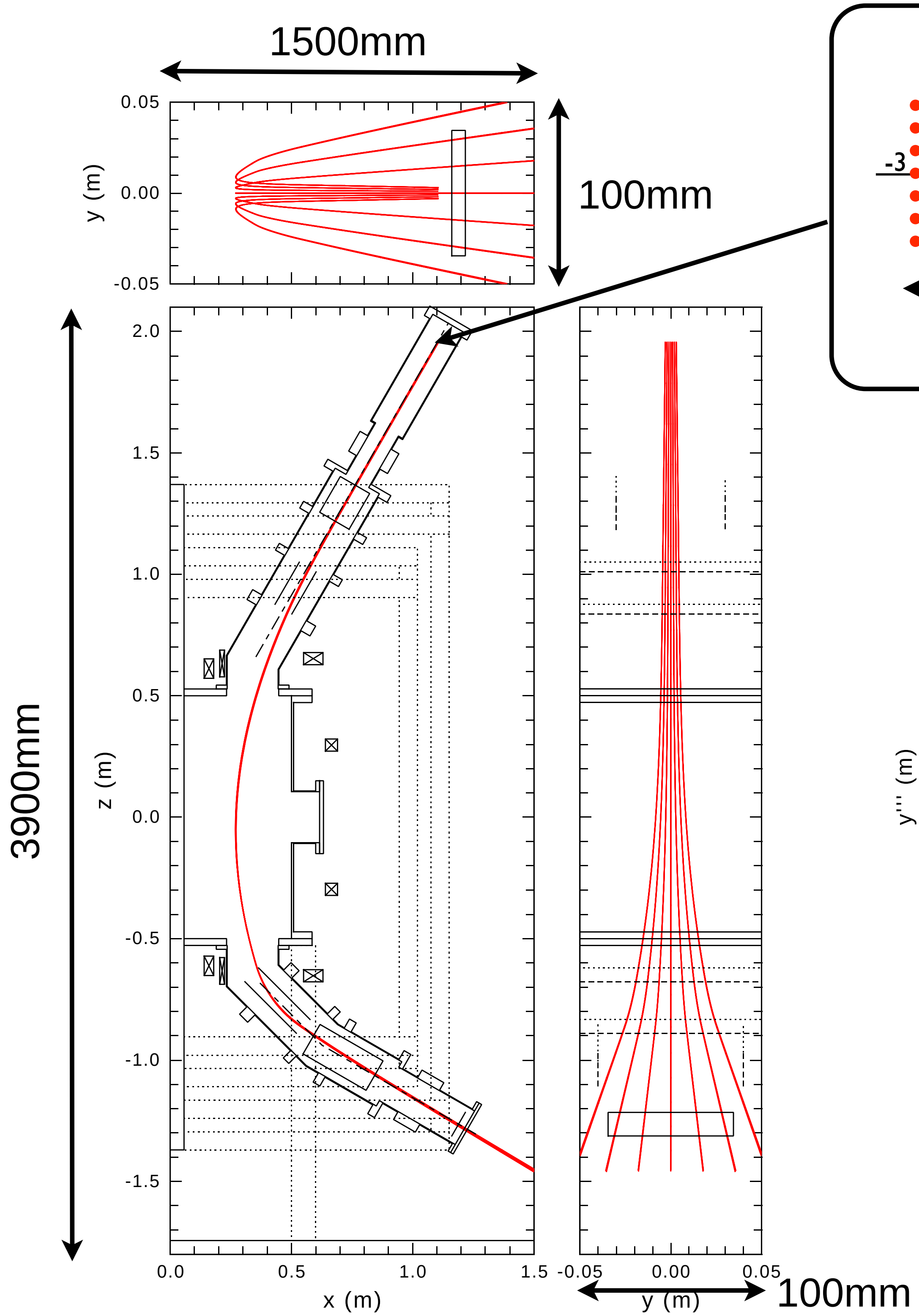
7.69keV 8.64keV 8.64keV



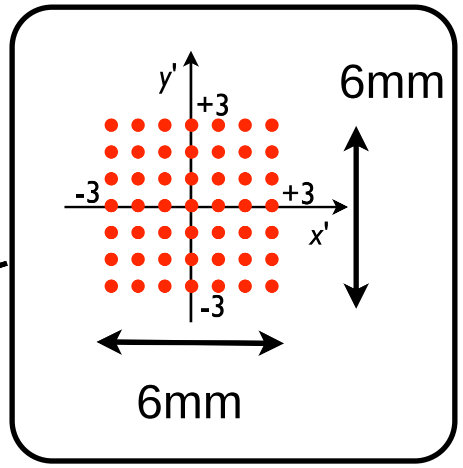
8x3 Matrix Plate Detector

Beam Spreading in the Toroidal Direction

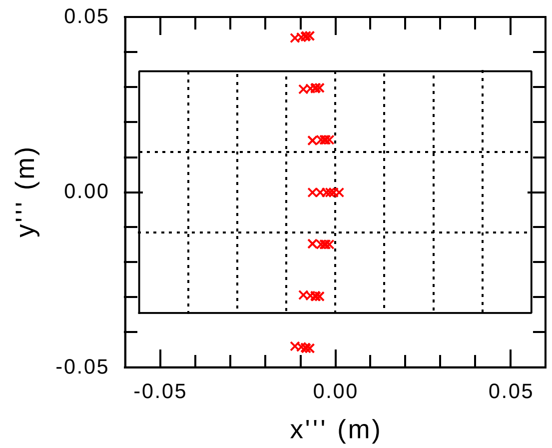
V_{GUN}=7.69kV, V_{PS}=200V, V_{PD}=2200V



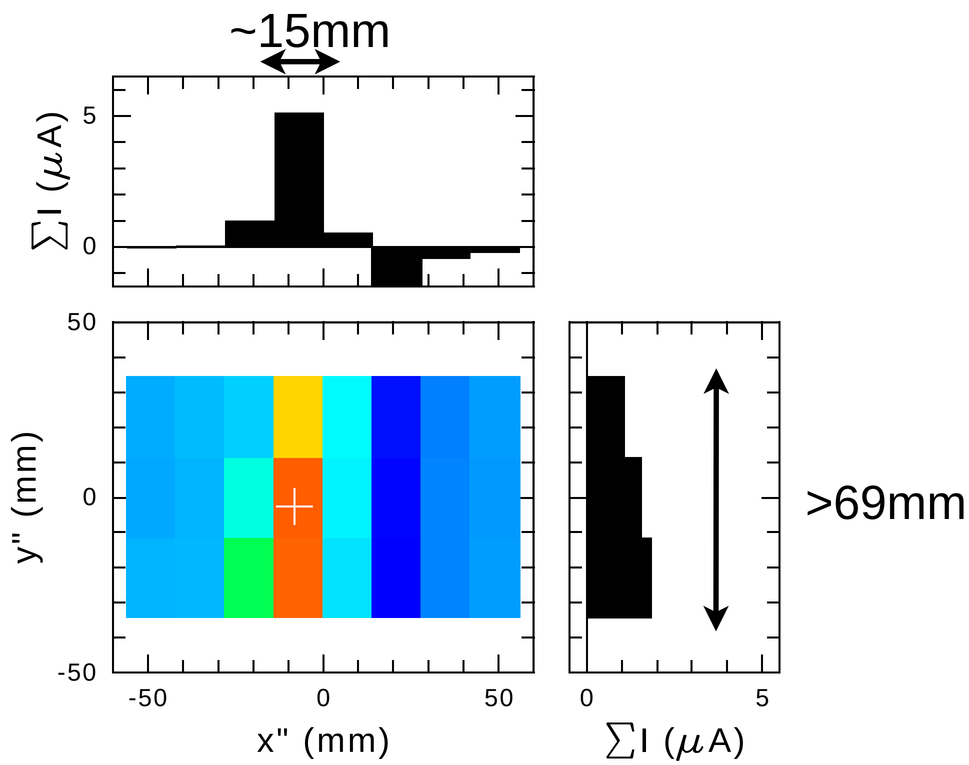
Starting Points



Toroidal focussing is required so that the beam is directed to the major axis.



Calculation

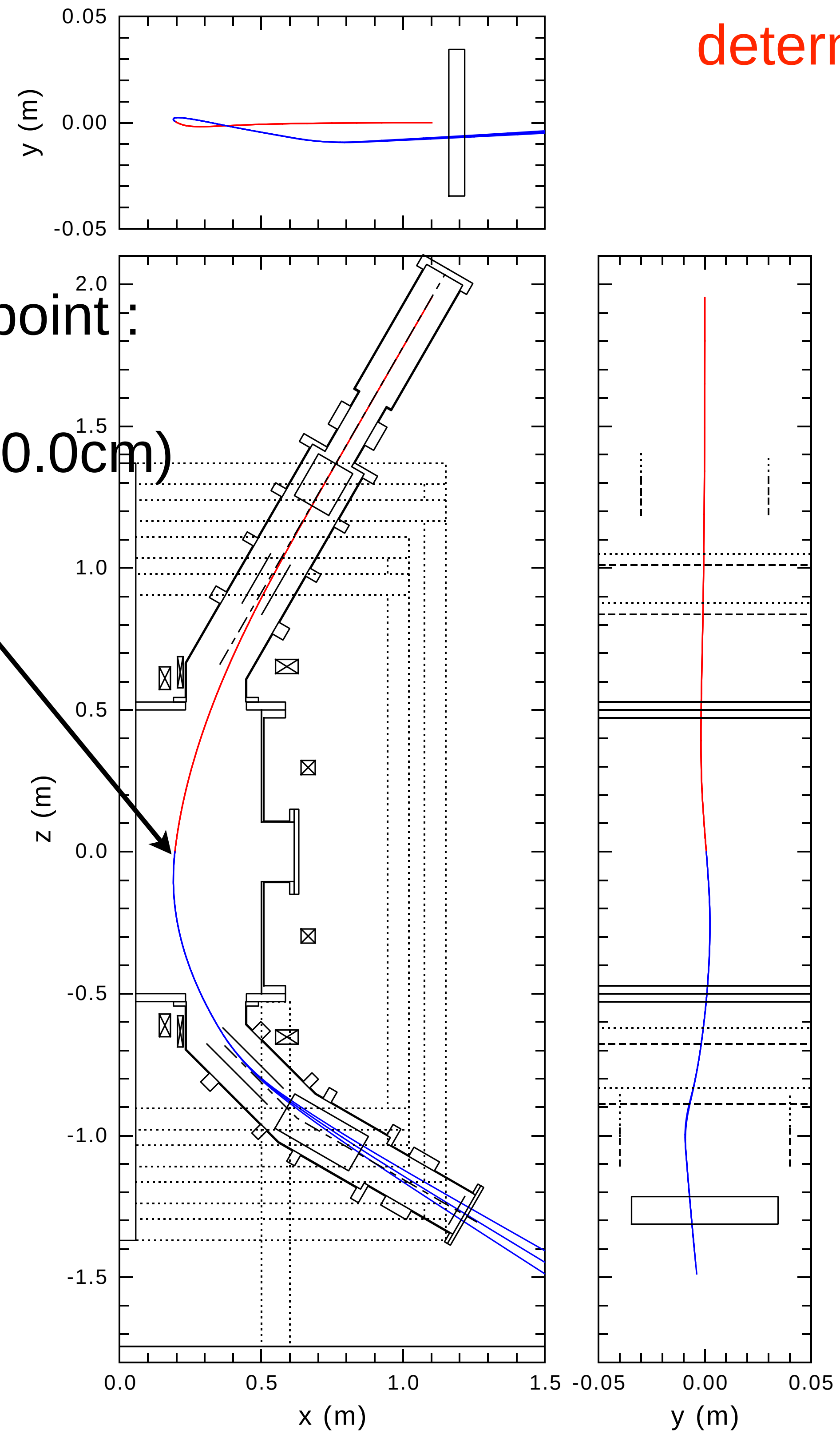


Measurement

Calculation of Secondary Beam Orbit

A set of 5 voltage values (V_G, V_{PS}, V_{TS}, V_{PD}, V_{TD}) determines an ionization point (R_{ion}, z_{ion}).

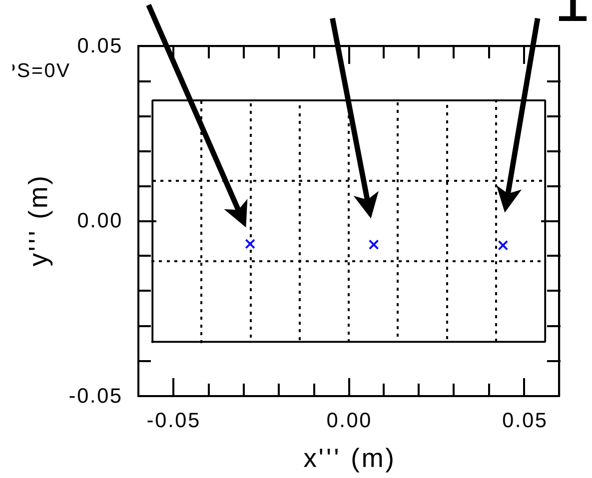
ionization point : (R_{ion},z_{ion}) =(19.2cm, 0.0cm)



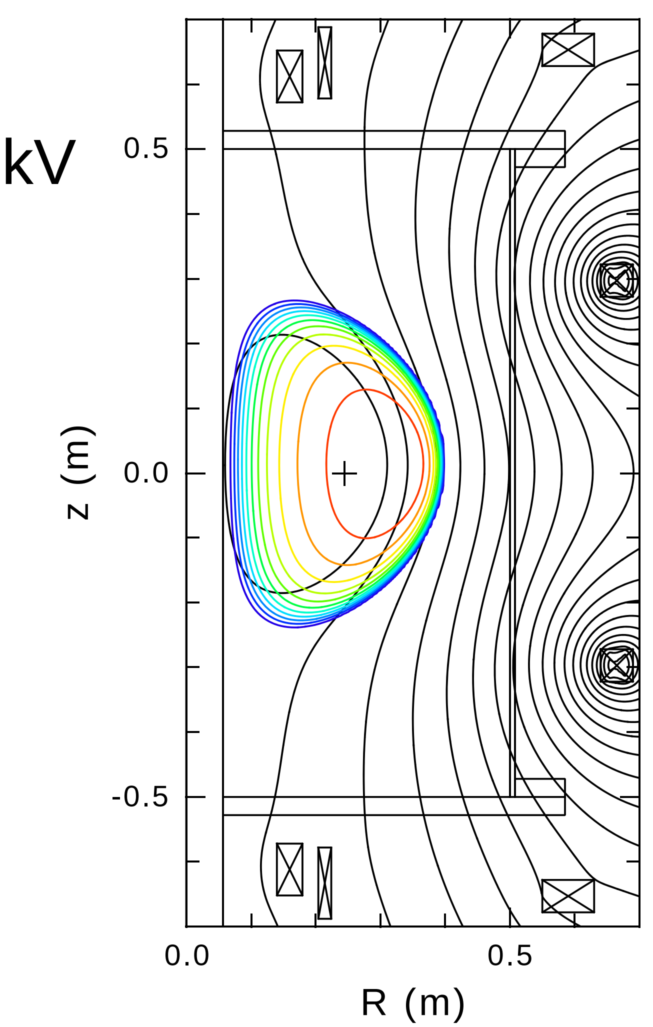
Rb+, Wk=14keV (V_G=14kV)

V_{PS}=0kV, V_{TS}=0kV,
V_{TD}=0.1kV

V_{PD} = 0.8kV 0.9kV 1.0kV



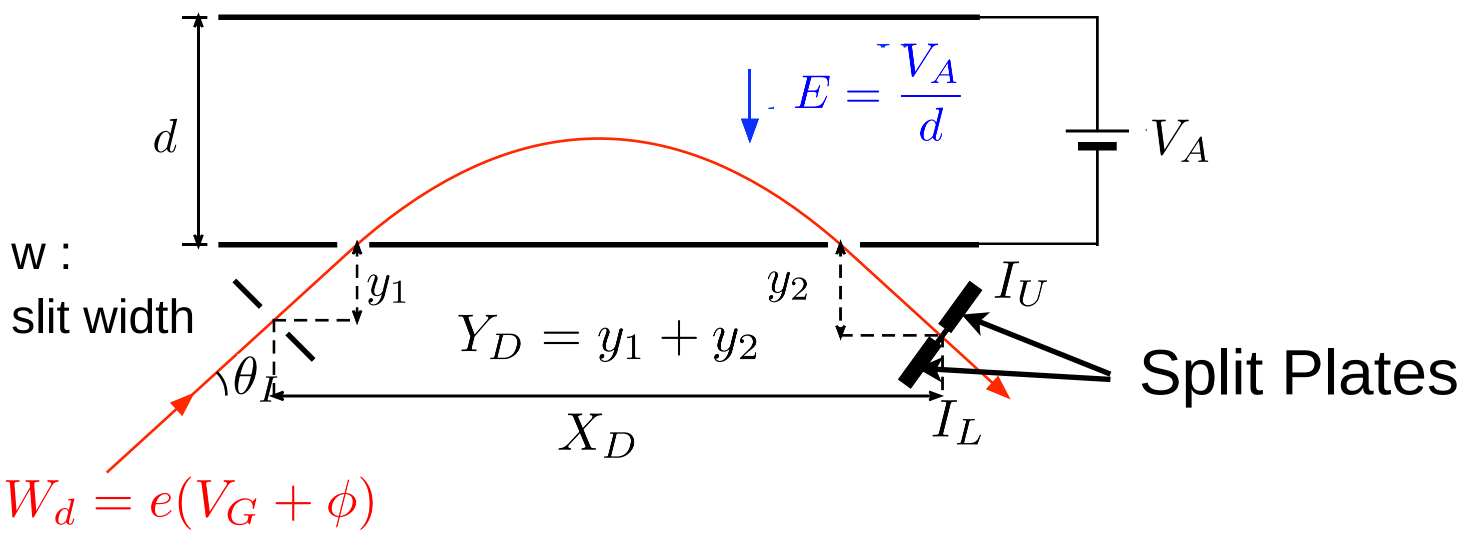
Bt=720G, Ip=10kA



Design of Energy Analyzer

Green-Proca Type Parallel Plate Energy Analyzer

T.S.Green and G.A.Proca, Rev. Sci. Instrum. 41 (1970) 1409.



$\theta_I = 30^\circ$ (Second order focussing)

$$\frac{W_d}{e} = V_G + \phi$$
$$= V_G + \frac{2w}{\sqrt{3}d} V_A \frac{I_U - I_L}{I_U + I_L}$$

$$\phi = \frac{2w}{\sqrt{3}d} V_A \frac{I_U - I_L}{I_U + I_L}$$

Design Parameters

$$\frac{V_G}{V_A} = \frac{4}{3\sqrt{3}} \frac{X_D}{d} = 5 \quad \text{(Gain Parameter)}$$

$$Y_D = \frac{d}{4} \frac{V_G}{V_A} \qquad X_D = 3\sqrt{3} Y_D$$

w : slit width

Design of Energy Analyzer

Parameter Comparison

w slit width (mm)	d (mm)	Y_D (mm)	X_D (mm)	Dynamic Range (V) @V_G=20kV	Minimum Detectable Potential Difference * (V)
2	50	62.5	324.8	±185	1.85
2	75	93.8	487.1	±123	1.23
2	100	125	649.5	±92	0.92

* when $\frac{\Delta I_{noise}}{I_{total}} = 10^{-2}$

The same parameters used for HIBP in CHS

Design of Energy Analyzer

For Achievement of Minimum Detectable Potential Difference

$\Delta\phi_m < 1$ V

Current-Voltage Converter (Conventional Type)

Gain : 4 x 10^6 V/A

Electrical Noise Level : ~1nA

If $I_{total} > 100$ nA, then $\Delta I_{noise}/I_{total} < 10^{-2}$

Potential Difference due to the variation of incident angle θ_I

$$\phi(\Delta\theta_I) = -\frac{40}{\sqrt{3}} V_A (\Delta\theta_I)^3$$

$\Delta\theta_I < 1.3°$ for $\Delta\phi_m < 1$ V

Summary

1. We are developing the ion beam probe system for the LATE device to investigate the electric field effect on formation, confinement and transport of the spherical tokamak produced and maintained by EBW/ ECW heating and current drive solely.
2. For the plasma parameters on LATE, electron temperature may be estimated as well as potential, magnetic field and their fluctuation measurement.
3. The ion gun, the injection beam line and the collection beam line were installed to LATE and tested. They meet a minimal demand level for the measurement but several developments are still required.
   Ion source ... increase current up to 100 μA
   Ion gun ... focussing in the toroidal direction
   Calculation ... improvement of accuracy
4. Initial design of energy analyzer is surveyed for achievement of minimum detectable potential difference less than 1 V.