Emittance measurements using single slit technique

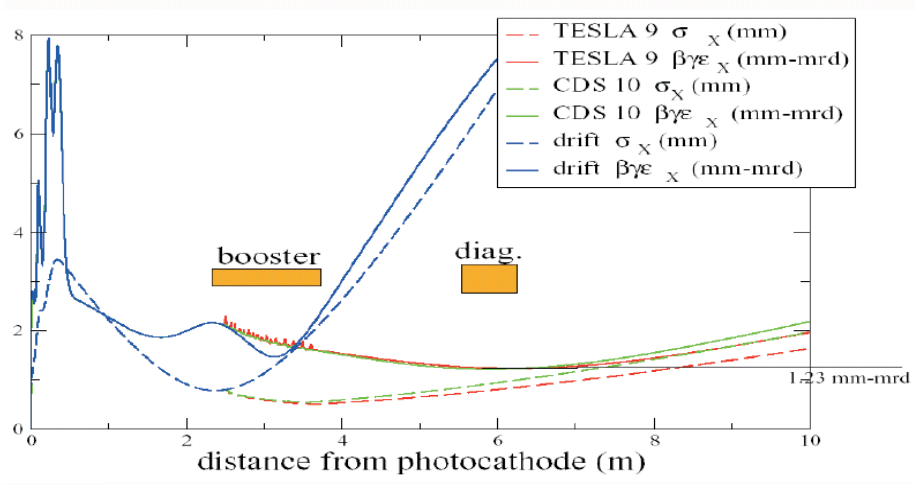
Lazar Staykov

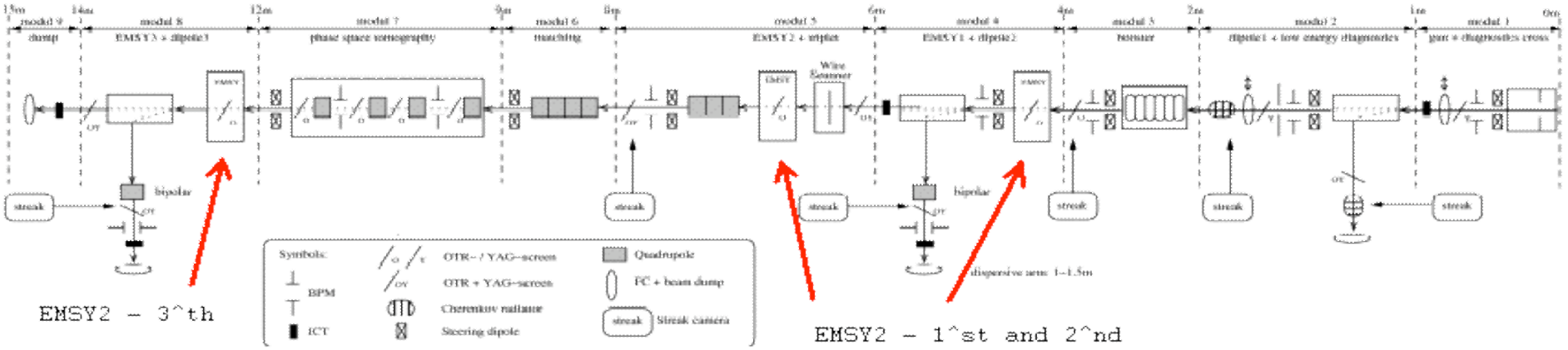
ICFA High Brightness Workshop

Erice – 2005.07.19

PITZ – layout and expected beam

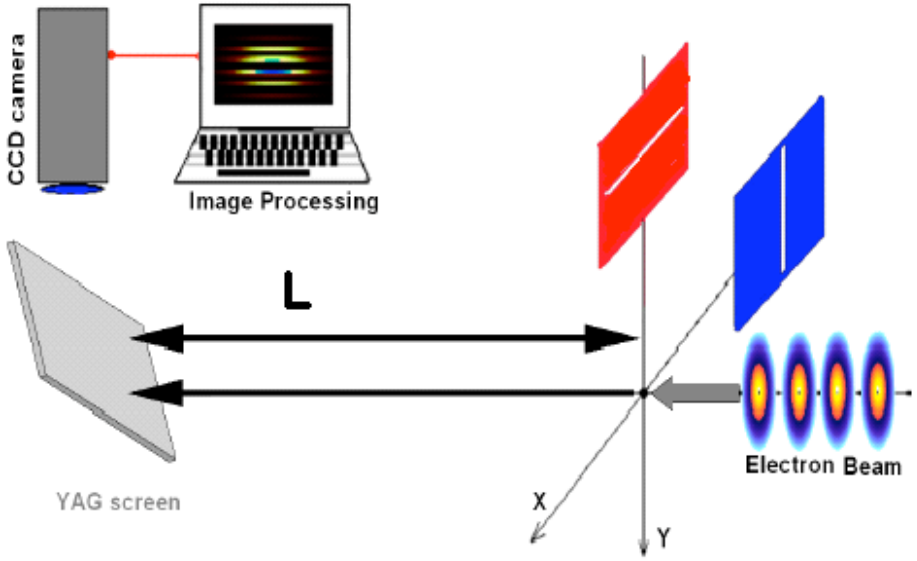
- 1.3 GHz gun cavity
- Focusing solenoids
- Installed booster cavity will increase the energy of the beam to 30 MeV
- The emittance is expected to improve to less than 1 π.mm.mrad

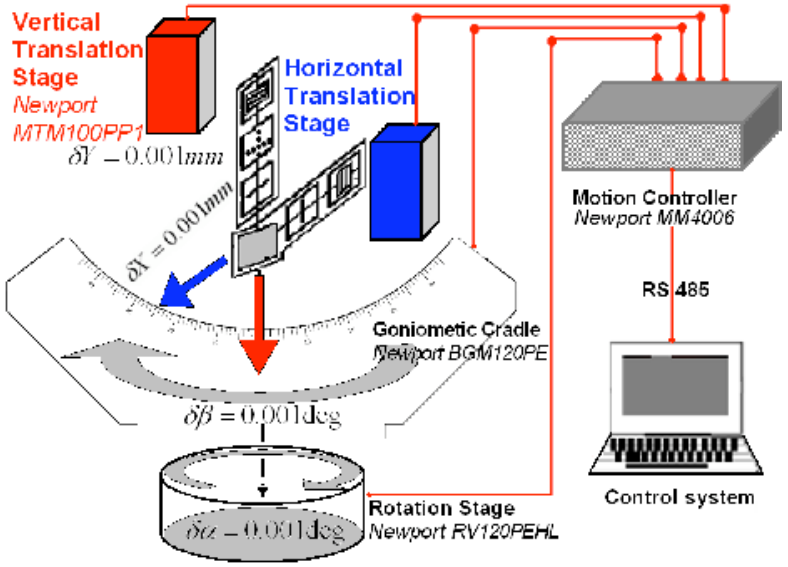




Slit base technique

- Slit technique is used
- The image of the slit is observed with CCD on a distance ***L*** downstream





$$\langle x' \rangle = \frac{\langle p_x \rangle}{\langle p_z \rangle} = \sqrt{\frac{\sigma_b}{L^2}}$$

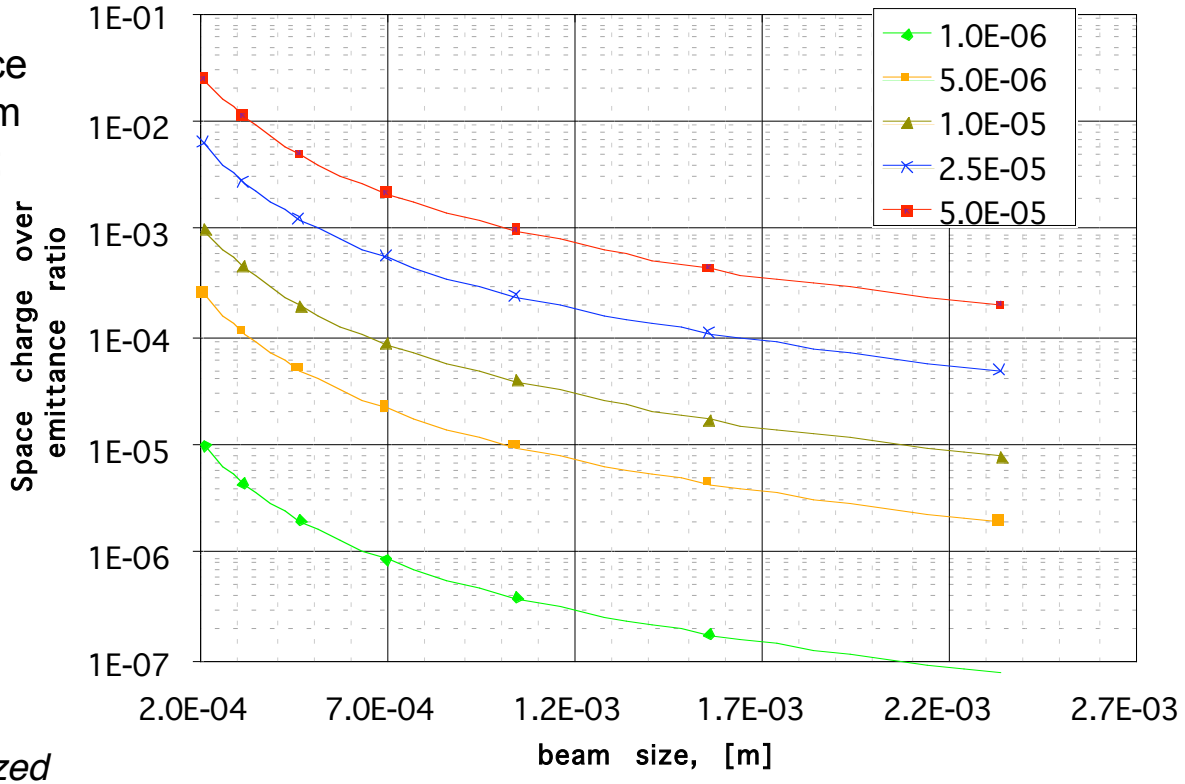
$$\varepsilon_n = \beta\gamma \cdot \sqrt{\langle x \rangle^2 \cdot \langle x' \rangle^2 - \langle x \cdot x' \rangle^2}$$

Space charge

- The space charge over emittance ratio estimated for different beam sizes and different slit openings;

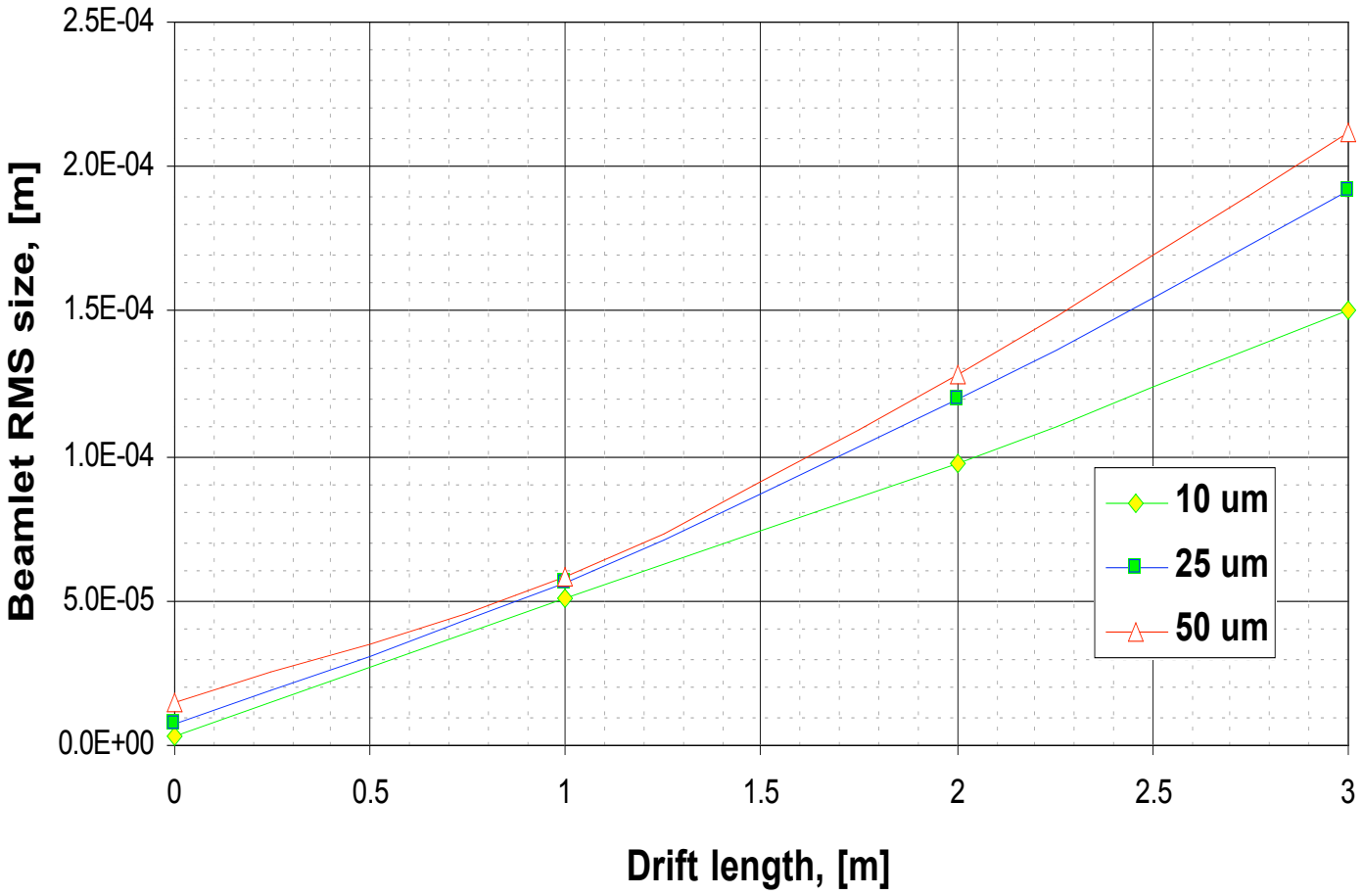
$$R_{beamlet} = \sqrt{\frac{2}{3\pi}} \cdot \frac{I}{\gamma \cdot I_0} \cdot \left(\frac{d}{\varepsilon_n} \right)^2$$

where:
d – slit opening; I – peak beam current;
I_0 – characteristic current; ε_n – normalized emittance; γ – Lorenz factor; π – 3.14;



See Anderson et al. *"Space charge effects in high brightness electron beams - Phys. Rev 2002"*

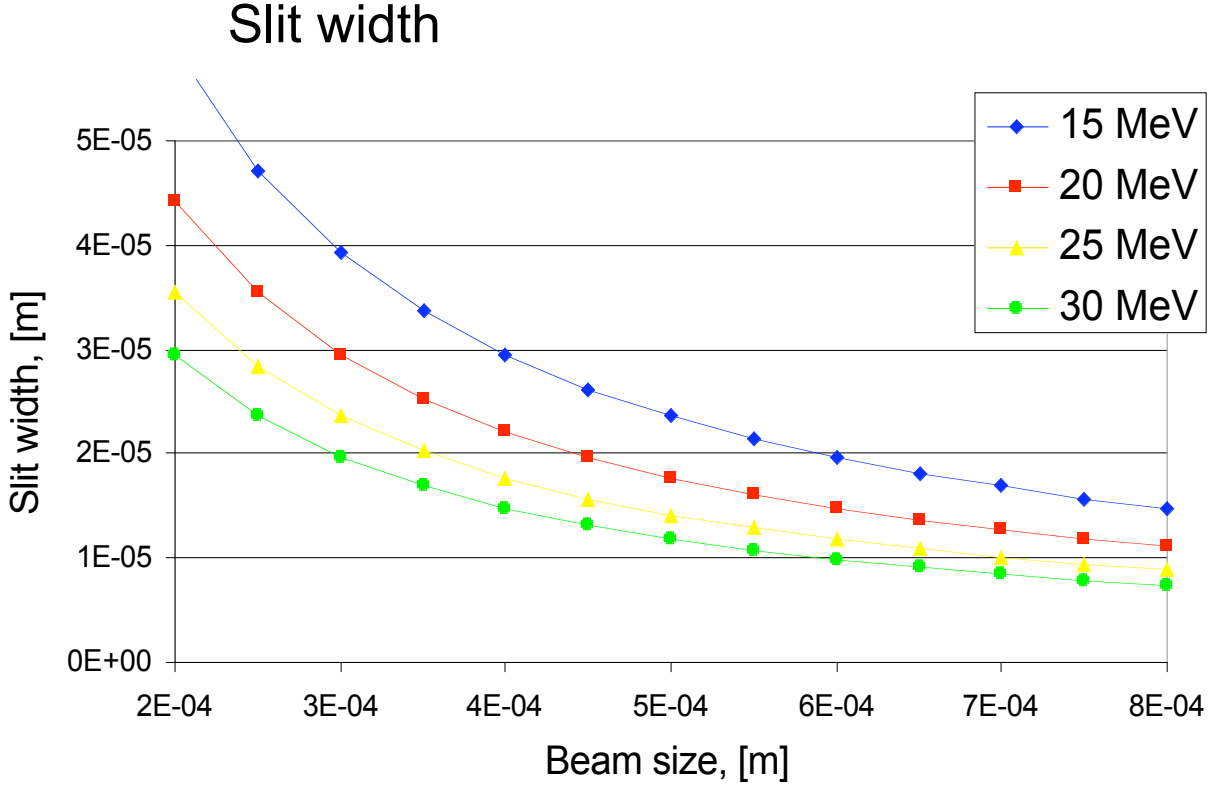
Slit width – space charge



Resolution

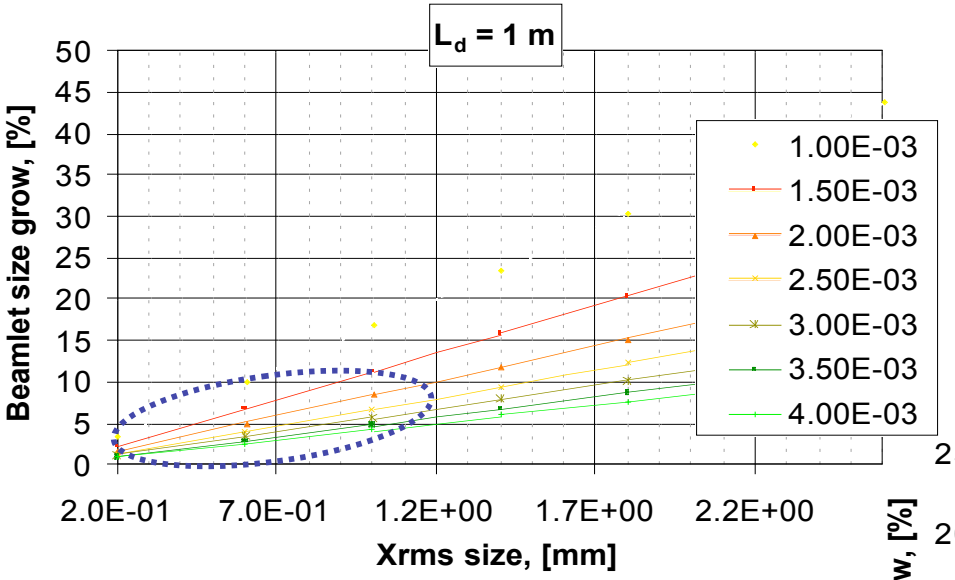
$$d \le \sqrt{\frac{2}{3\pi}} \cdot \frac{L\varepsilon_n}{\gamma \cdot \sigma_0 \cdot 10}$$

here:
L _ drift distance;
σ_0 *_ RMS size of the beam;*



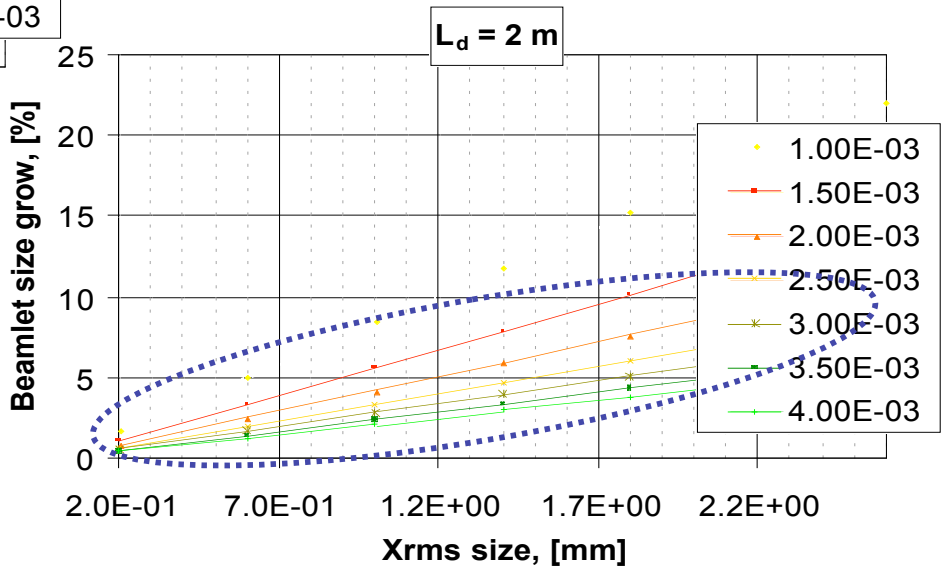
Slit opening as a function of the beam size at 30 MeV, the emittance is fixed at 1 π.mm.mrad

Resolution



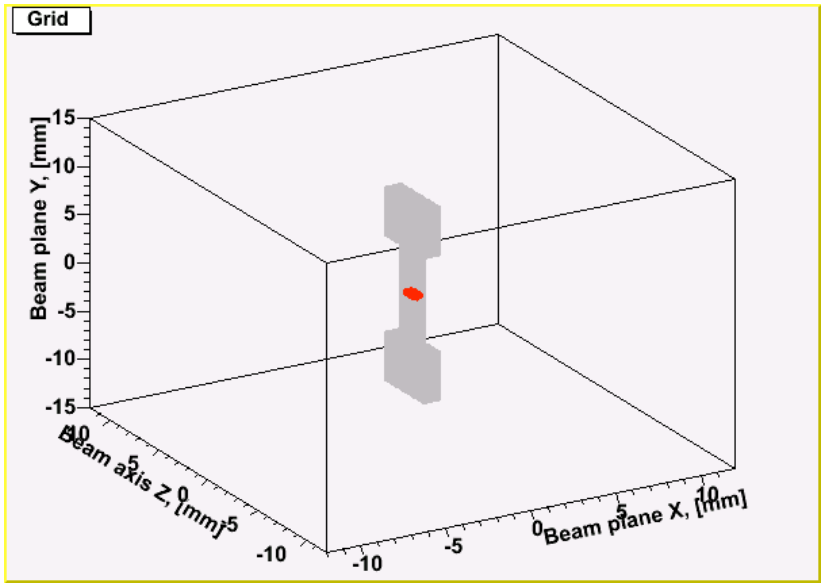
$$\chi_b = 100\% \cdot \left(\frac{\sigma_b + \sigma_{b_0}}{\sigma_b} - 1 \right)$$

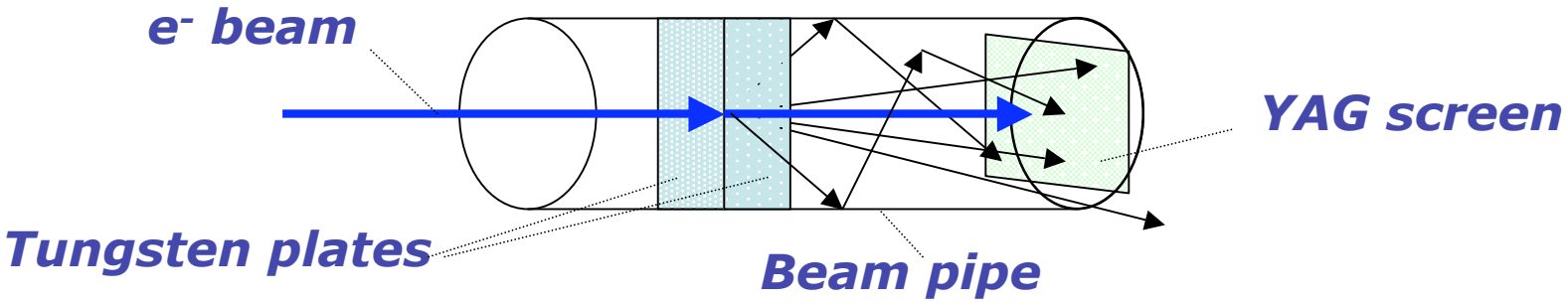
here: χ_b – relative beam size grow at the screen; σ_{b0} – RMS size of the slit;



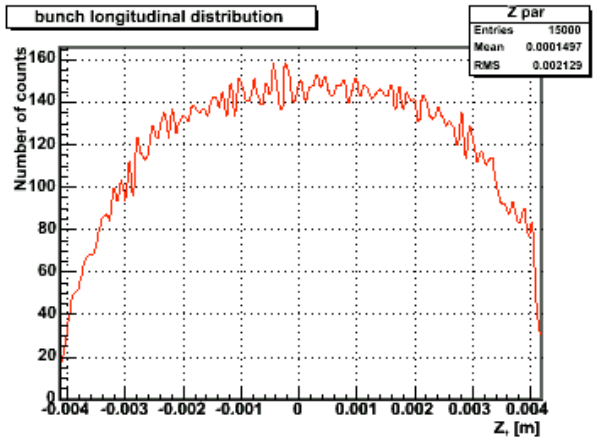
GEANT4 simulations - input

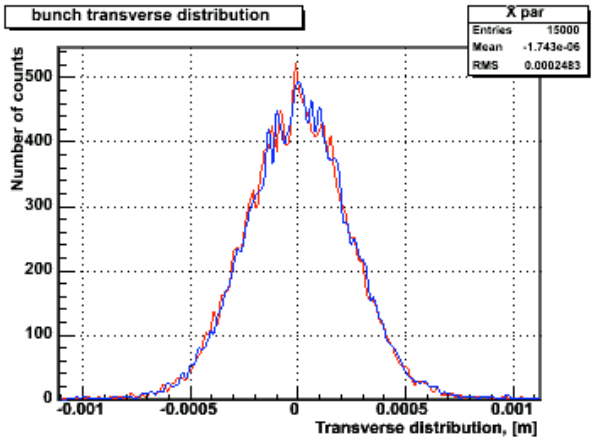
- Simplified model is used to estimate
  - The signal to noise ratio
  - The energy deposited in the tungsten
- The plate thicknes, the distance to the screen and the slit opening were used as variables

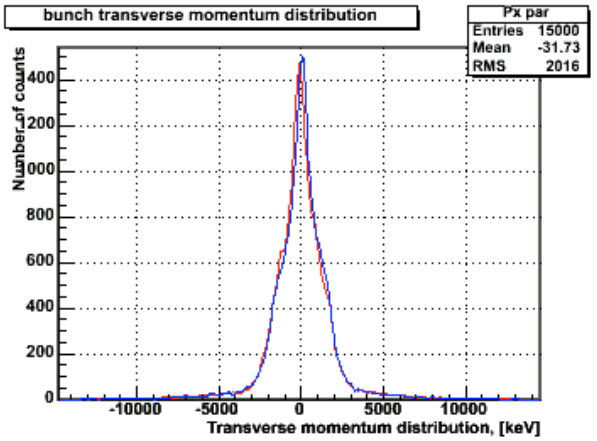


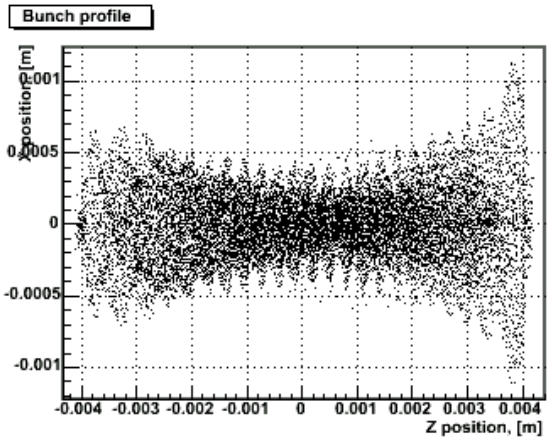


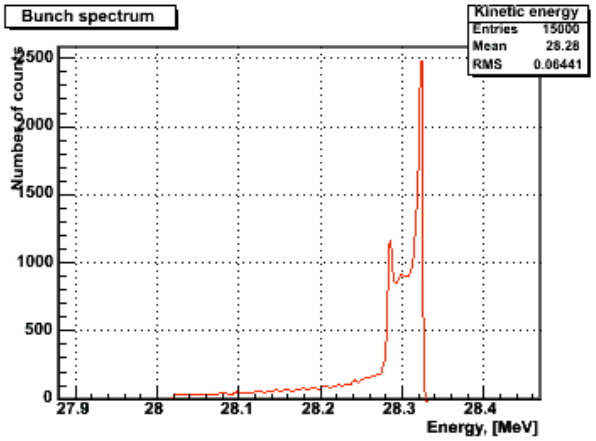
Reference beam

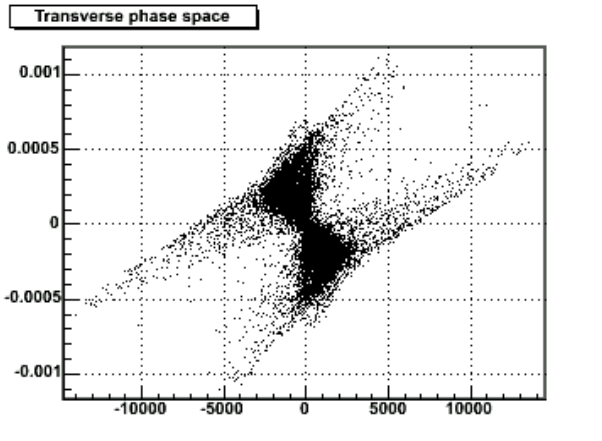




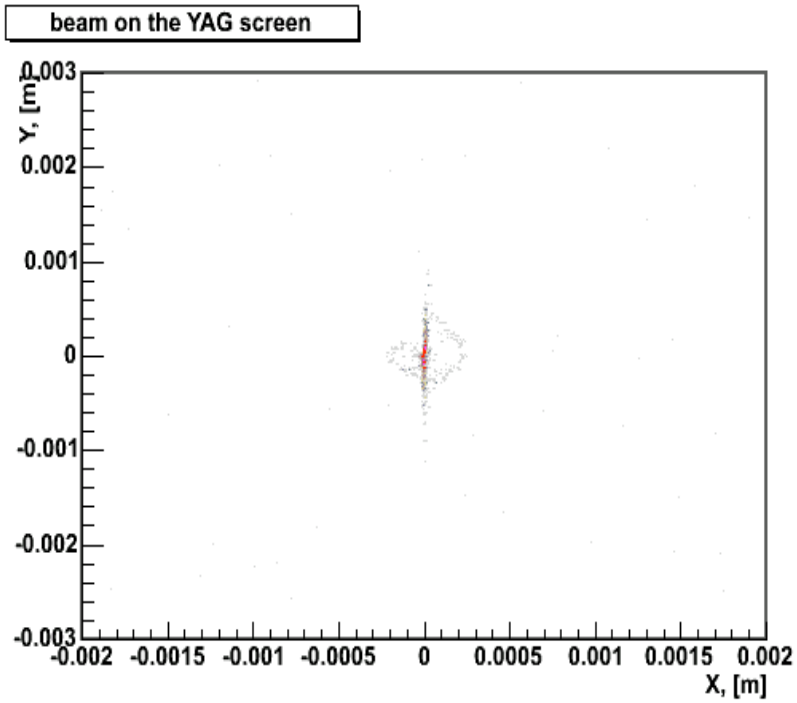


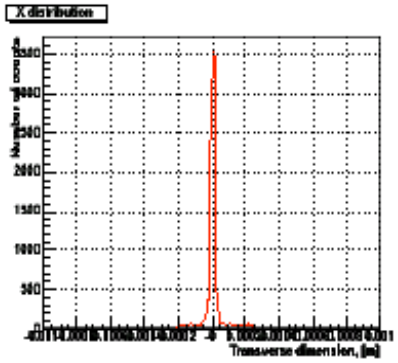


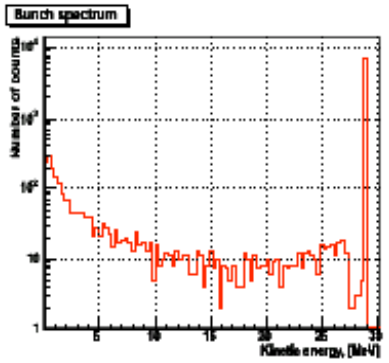


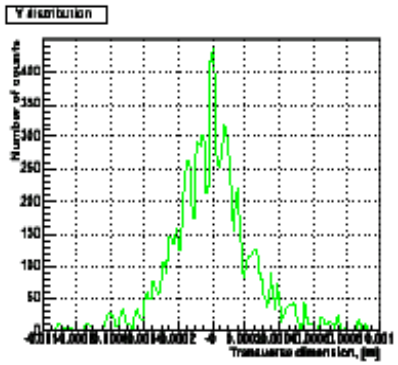


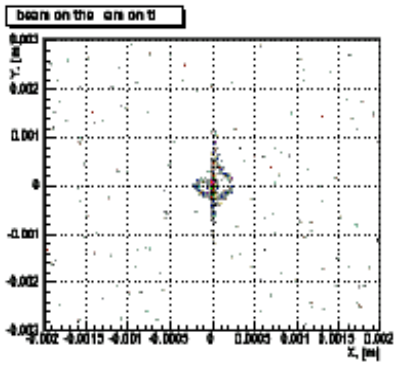
Results – GEANT4



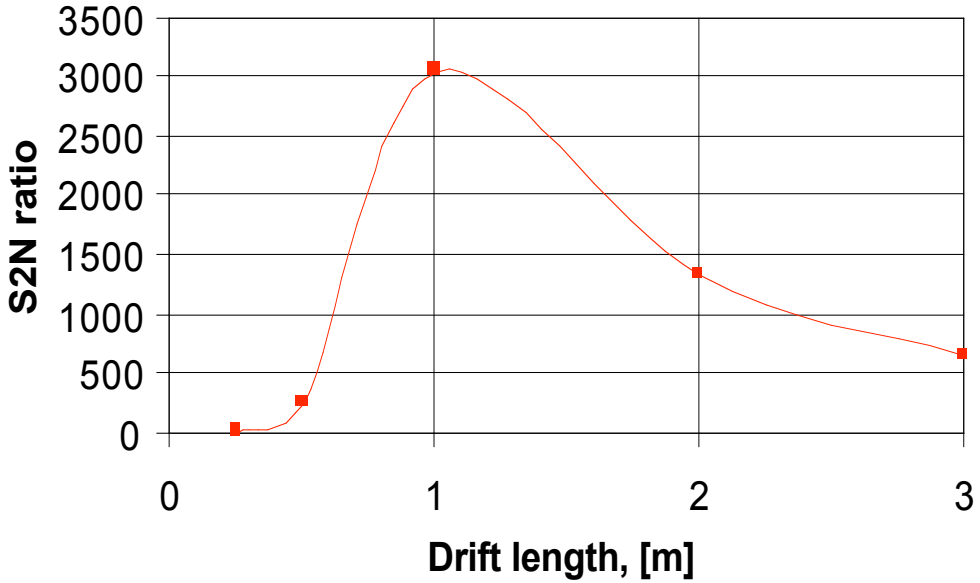


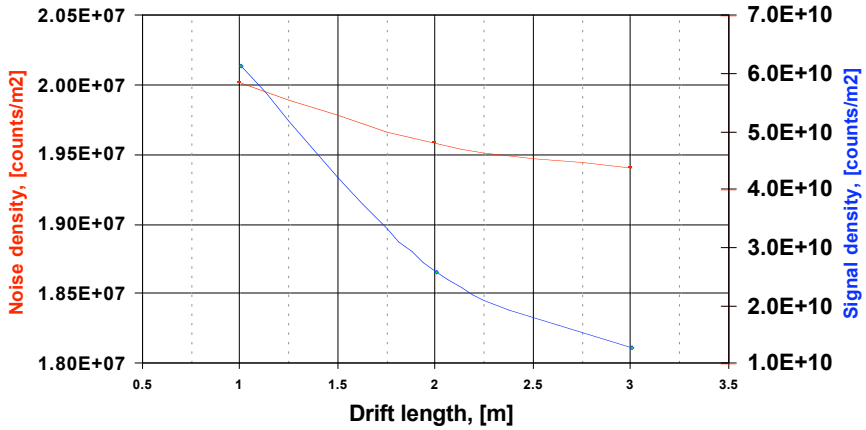






Results - signal to noise ratio





$$S2N = \frac{C_s}{C_n} \cdot \frac{A_n}{A_s}$$

Here:
- C_s – counts signal
- C_n – counts noise
- A_s – area of the signal
- A_n – area of the noise

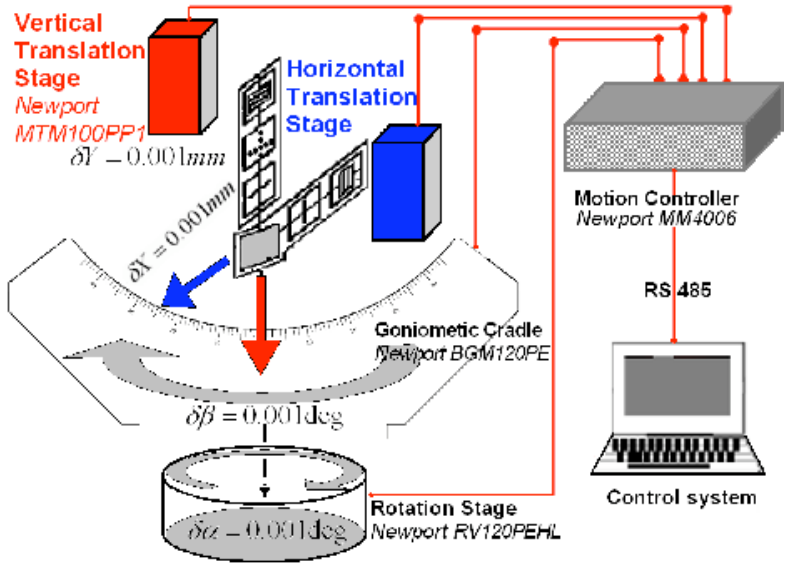
Summary - EMSY

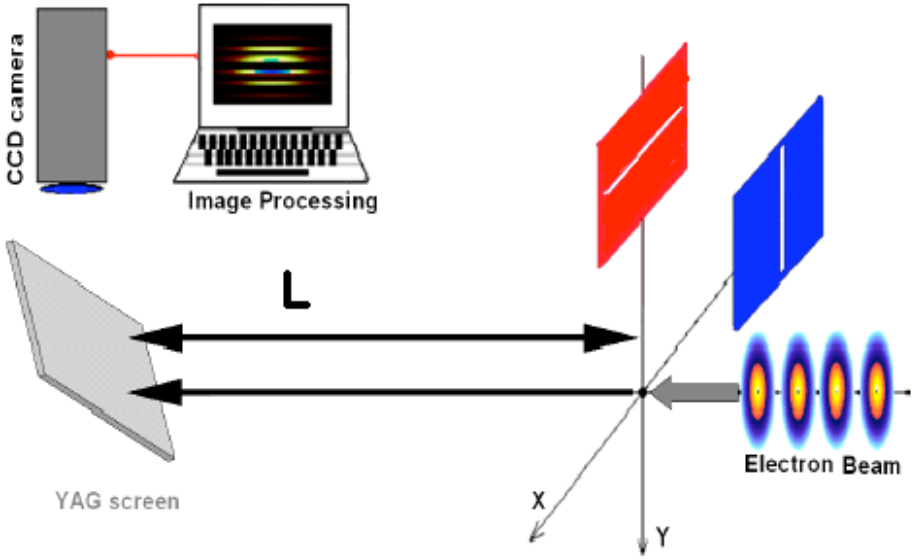
- Optimal slit opening is estimated to be 10 μm
- The optimal drift length and mask thickness is > 1.5 m.
- The production of the EMSY2 stations has started at High Energy Physics – Hi – Tech Group (INRNE HEPHIT GROUP) immediately after the funds receival
- EMSY stations are under construction. All EMSY's mechanical components were done until 4^{-th} of April
- Full assembling of EMSY including all NEWPORT stages and software has started from 4^{-th} of October at PITZ Zeuthen

Emittance measurement

Slit based technique

- Slit based technique, direct measurement of the area/volume – sheared area
- The image of the slit is observed with CCD on a distance ***L*** downstream





$$\langle x' \rangle = \frac{\langle p_x \rangle}{\langle p_z \rangle} = \sqrt{\frac{\sigma_b}{L^2}}$$

Assume it is zero – sheared emittance

$$\varepsilon_n = \beta\gamma \cdot \sqrt{\langle x \rangle^2 \cdot \langle x' \rangle^2 - \langle x \cdot x' \rangle^2}$$

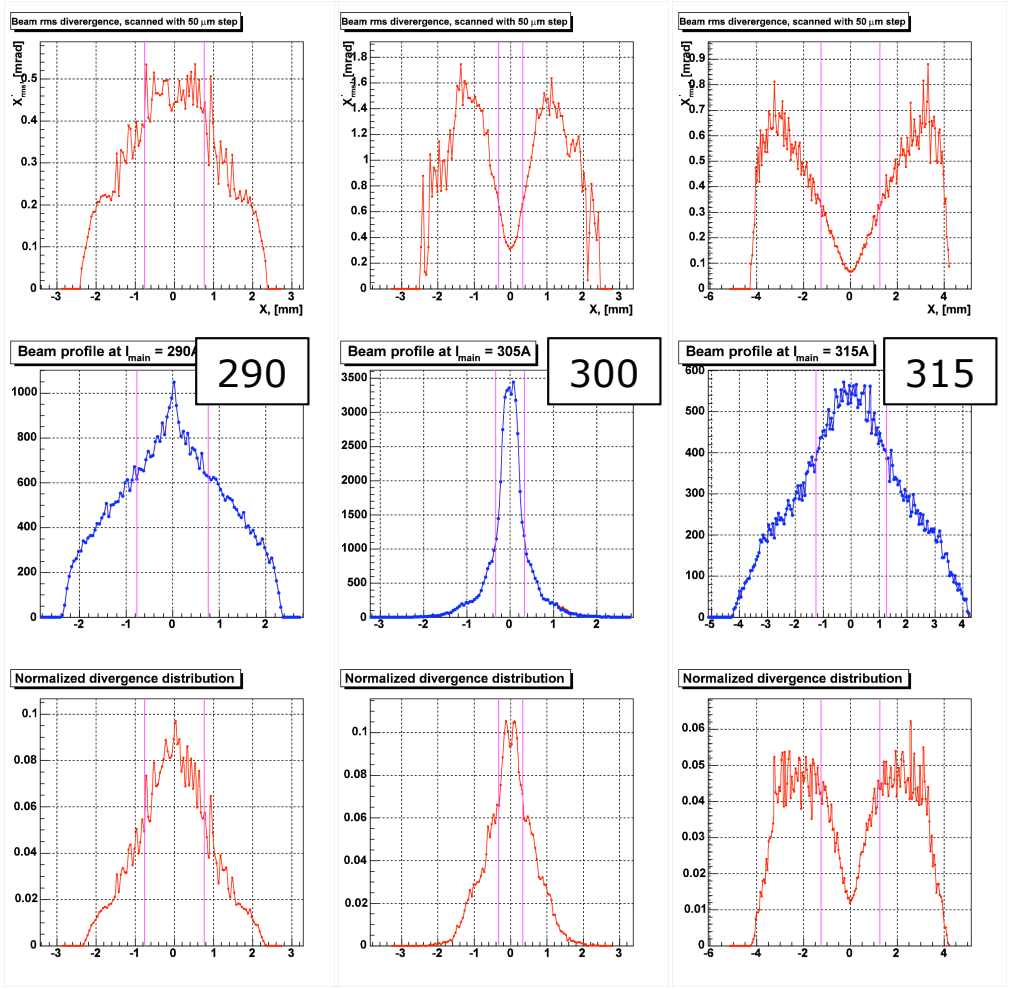
Emittance measurement
Sources of error

- $\beta\gamma$ – uncertainty of the momentum measurement is estimated to be ~50 keV
- beam size - statistical error and systematics:
    - ! calibration factor of the optics
    - ! screen/camera saturation
    - ! finite CCD resolution (!!!)
- beamlet size – all the same as for the beam size plus the uncertainty in the drift distance

Emittance measurement

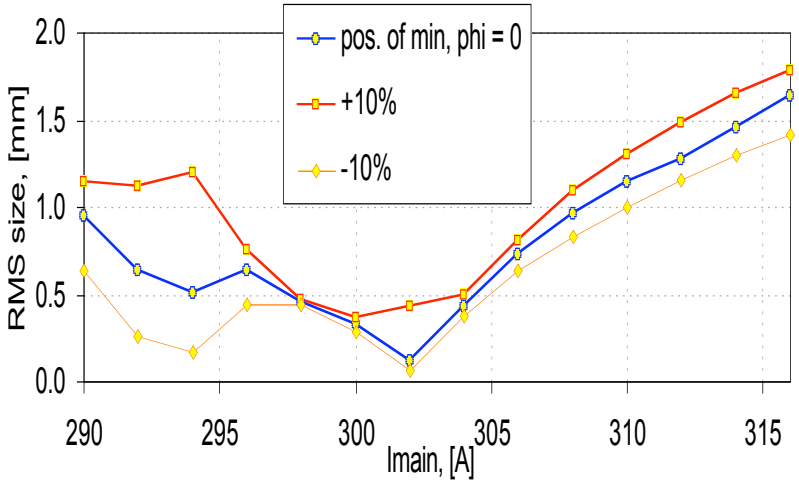
slit positioning

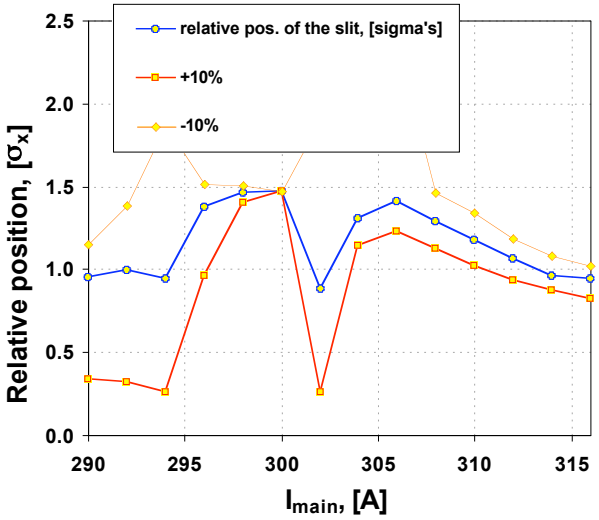
- direct measurement of the area occupied by the phase space
- which position of the slit is best describing the equivalent ellipse?



Emittance measurement

slit positioning





- beam dynamics with ASTRA
- results used to simulate the measurements
- direct measurement of the area occupied by the phase space
- which position of the slit is best describing the equivalent ellipse?
- 1 μm precision in the scan

(10 μm slit width)