ALBA
BEAM DIAGNOSTICS

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Beam Diagnostics

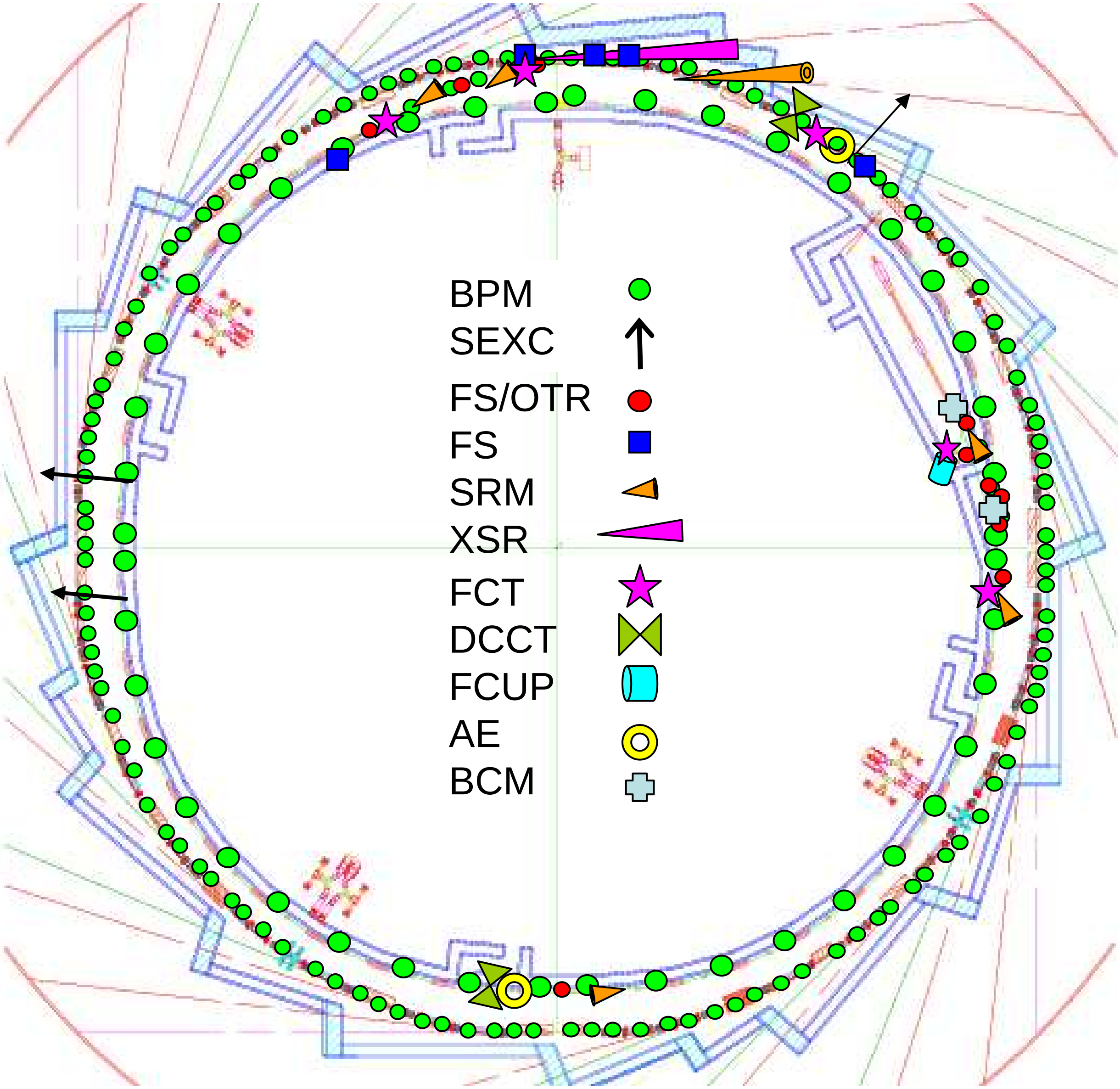
- **Beam Characterization** is done by:
  - direct measurements of beam parameters
    - **Beam position:** horizontal and vertical position inside the chamber
    - **Beam size:** transverse and longitudinal beam bunch distribution
    - **Beam current:** circulating intensity and bunch by bunch charge
  - and global (or indirect) measurements of beam parameters
    - **emittance, energy, tunes, chroms…**
- How do we measure these parameters?
  - Using the particle beam interactions with its surrounding.

1. Introduction
2. Measuring beam position
3. Measuring beam size
4. Measuring beam charge/current

Beam parameter	SNS	RHIC	ALBA
Species	protons	Au ions	Electrons
Bunch rms length	35m	1.25 – 0.3 m	15mm
Bunch Hor. rms	10mm	2mm	60 – 200 um
Bunch Ver. rms	10mm	2mm	5 – 30 um
Bunch charge	2e14 |e|	7.9e10 |e|	5.6e9 |e|
Bunch spacing (min)	…	107 ns	2 ns
# of bunches (max)	1	112	400
Circumference	248 m	3.8 km	268 m
Energy	1.9 GeV	10 - 105 GeV	3 GeV
Chamber semi-axes	10 – 10 cm	6 - 6 cm	36 – 14 mm

Different beams ➔ different techniques

ALBA Beam Diagnostics

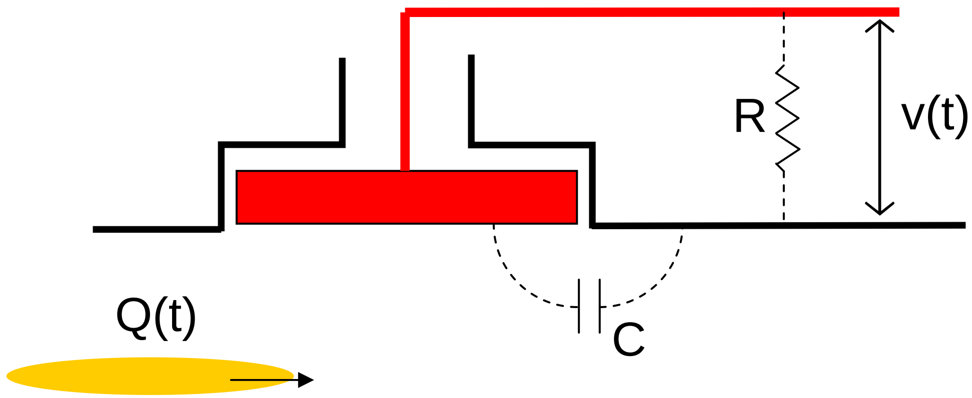


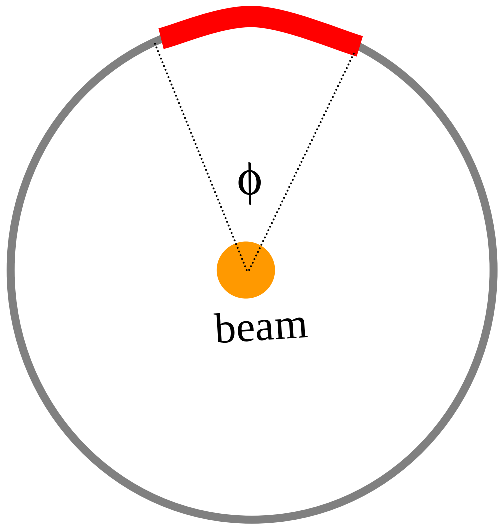
ALBA Beam Diagnostics

	Instrument Name	*Acronym*	*LTB*	*Booster*	*BTS*	*SR*
Position	Beam Position Monitor	**BPM**	4	44	4	120+3
	Stripline BPM	**Stripline**	0	2	0	1
Charge	Faraday Cup	**FCUP**	1	0	0	0
	Fast Current Transformer	**FCT**	3	1	2	1
	Beam Charge Monitor	**BCM**	2	0	0	0
	DC Current Transformer	**DCCT**	0	1	0	1
	Annular Electrode	**AE**	0	1	0	1
Size	Fluorescent Screen	**FS**	0	1	0	4
	Fluorescent Screen / OTR	**FS/OTR**	4	4	3	2
	Synch. Rad. Monitor	**SRM**	1	3	2	2*
Others…	Scrapers	**SCR**	2	0	0	2
	Fast FeedBack Kickers	**FFK**	0	0	0	2

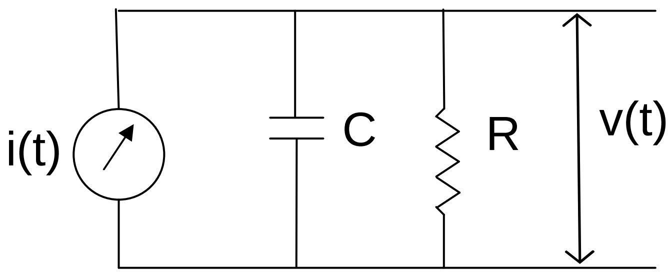
2* → **XSR**, **VSR**

Signal Treatment





RC Equivalent Circuit:



Current source ←→ beam image charge captured by the electrode:

$$i(t) = (\phi/2\pi)\, dQ(t) / dt$$

Transfer function:
(freq. domain)

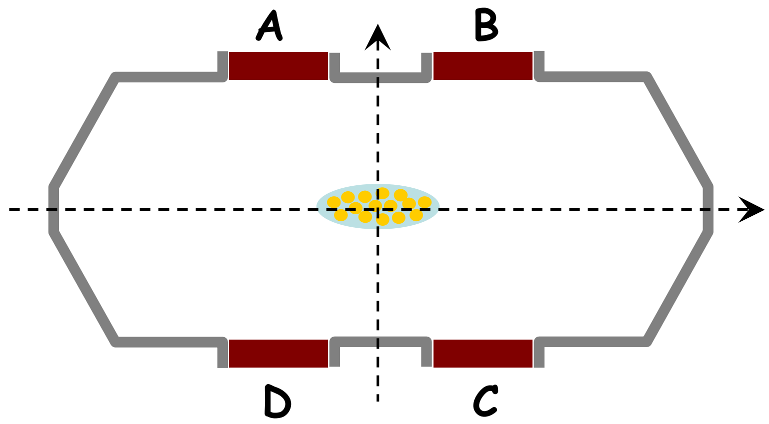
$$Z = \frac{R}{1 + i\omega RC}$$

BPMs at ALBA SR

Four buttons are located at the vacuum chamber

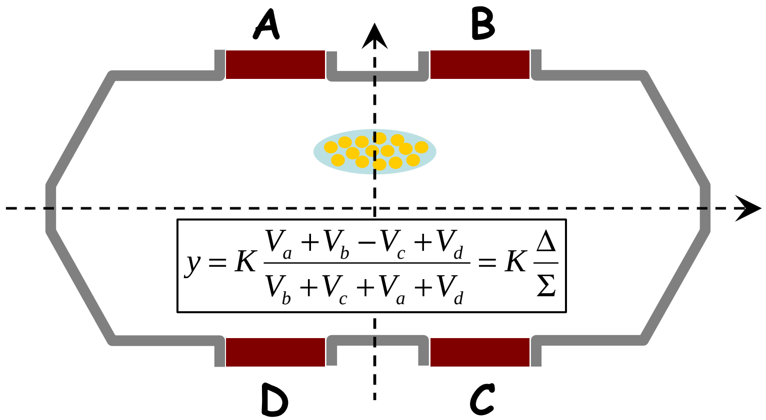
- If the beam is centered (x, y) = (0,0) signal at all buttons is the same:

Va = Vb = Vc = Vd



- If the beam is displaced y > 0:

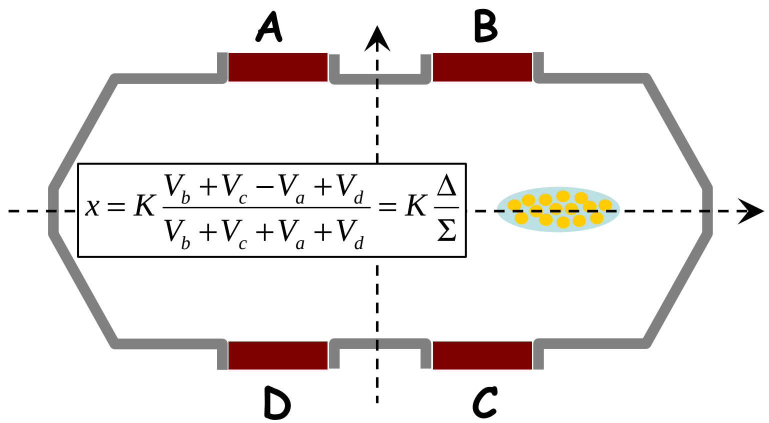
(Va and **Vb) > (Vc** and **Vd)**



$$y = K\frac{V_a + V_b - V_c + V_d}{V_b + V_c + V_a + V_d} = K\frac{\Delta}{\Sigma}$$

- If the beam is displaced x > 0:

(Vb and **Vc) > (Va** and **Vd)**



$$x = K\frac{V_b + V_c - V_a + V_d}{V_b + V_c + V_a + V_d} = K\frac{\Delta}{\Sigma}$$

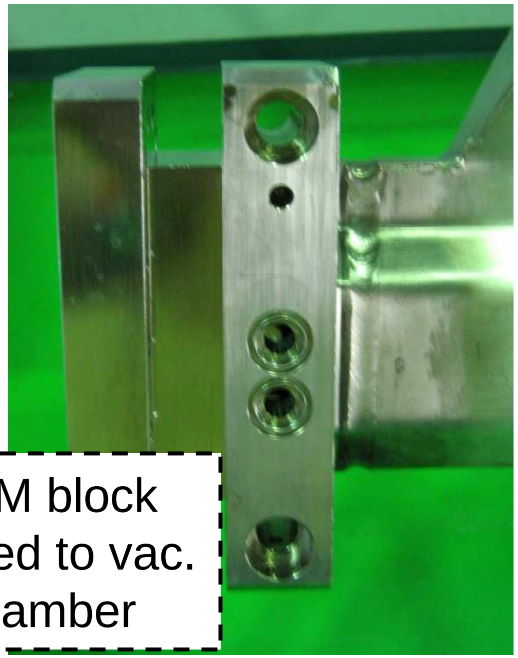
BPMs at ALBA SR

Sub-micron resolution is achieved!
We constantly read the signal from the 4 buttons and compute its position.
We usually do so at three different rates:

- -> Turn By Turn (1.1MHz every 896ns)
- -> Fast Acquisition Rate (10 kHz - every 1ms)
- -> Slow Acquisition Rate (10 Hz – every 0.1s)

Libera Electronics

BPM buttons before assembly at BPM Block

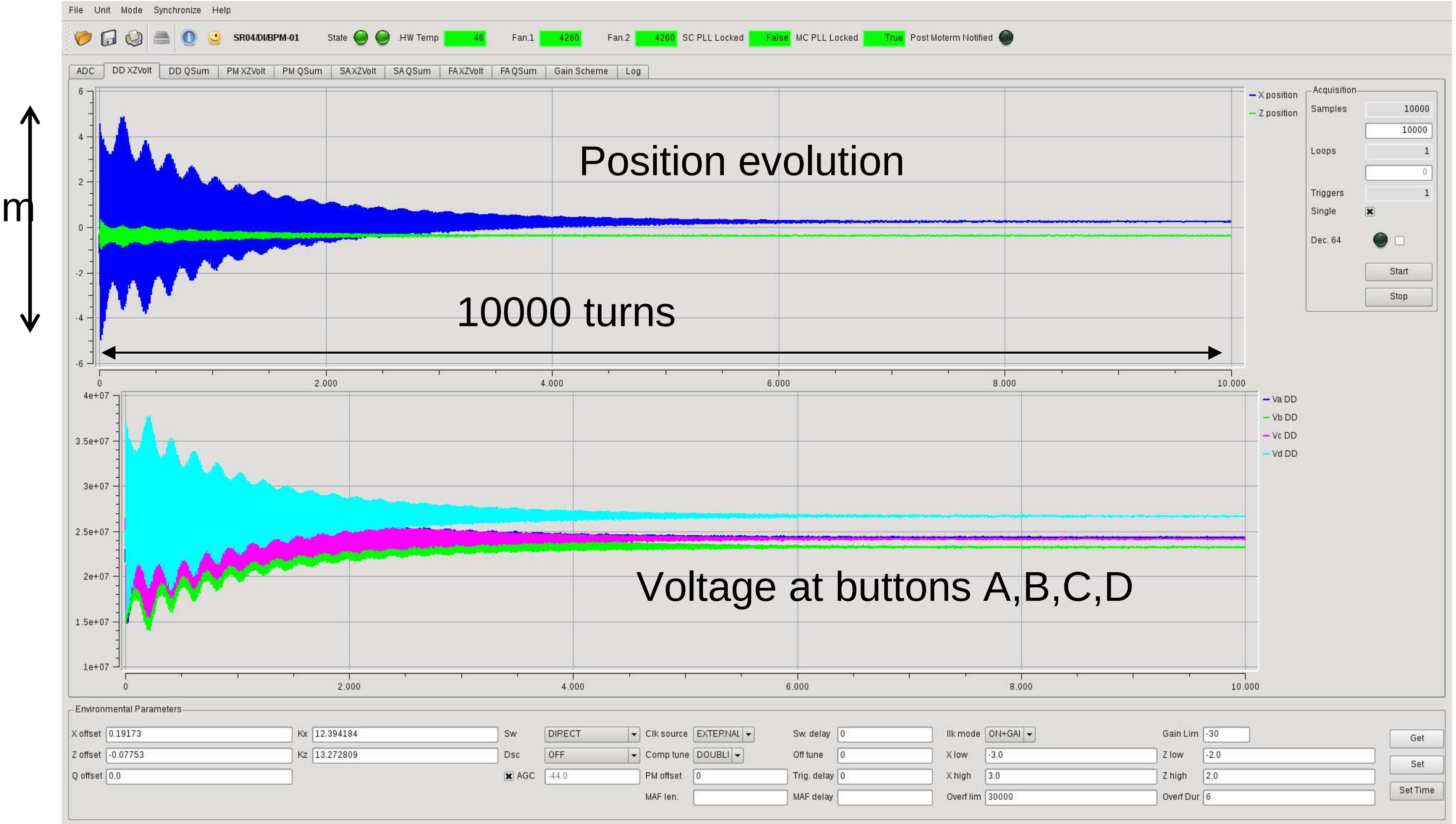


BPM block welded to vac. chamber

BPM at SR

BPMs: Turn by Turn Meas.

Damping time after injection into SR



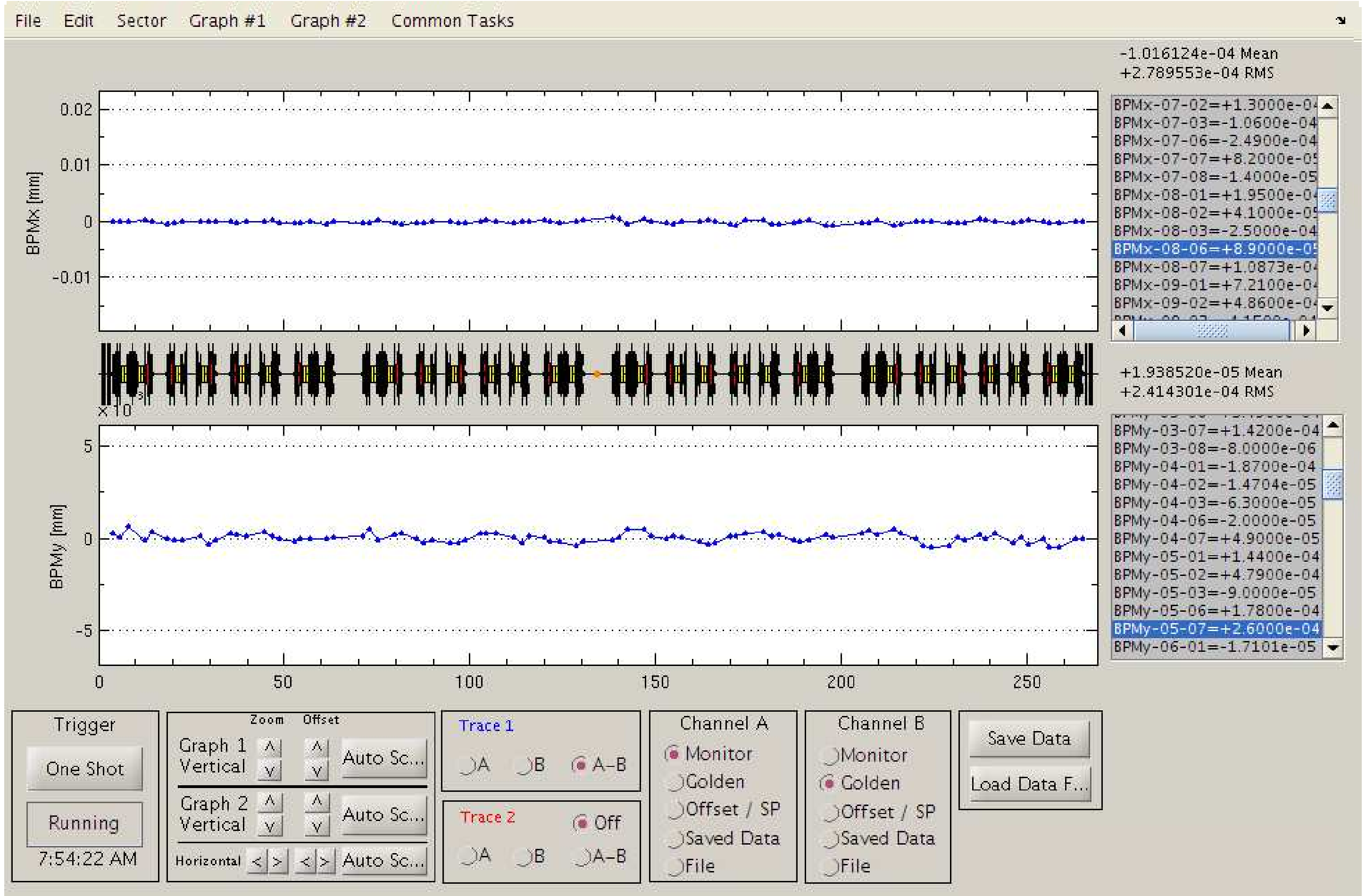
BPMs: Orbit Control

HOR

+/-20um

VER

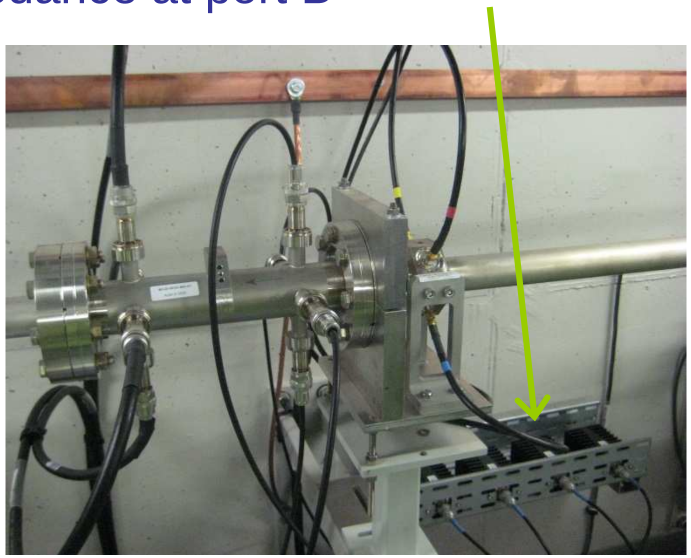
+/-5um



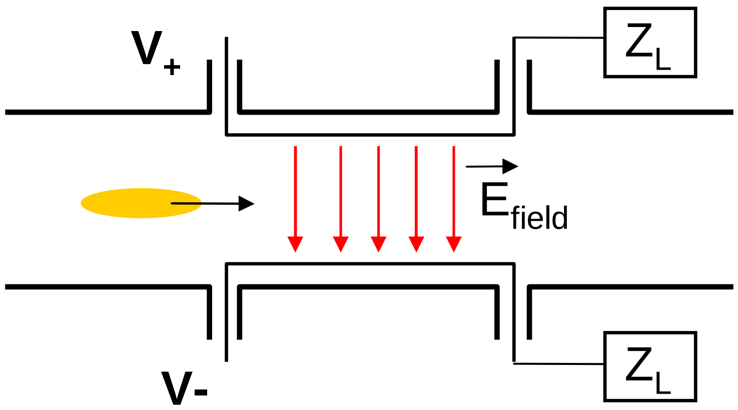
Stripline Beam Position Monitors (BPM)

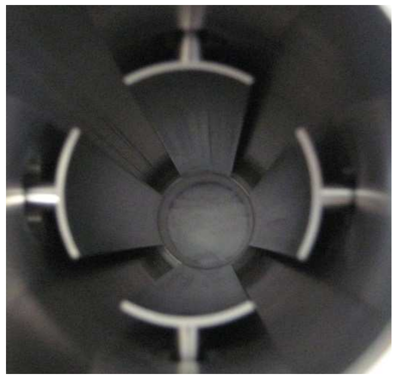
- TEM stripline (length >> button) → more sensitivity than a button BPM
- Used for both ***beam excitation*** and *__position measurements*__,

A. <u>Beam excitation:</u> Load Matched to line impedance at port B
→ $Z_L = 50\Omega$



Voltage of different polarities at each electrode





Inside view

<u>Reflection coefficient:</u> $$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$Z_L=50\Omega$ → $\rho=0$ → Power is absorbed

B. Position Measurements: Short-circuit at downstream port (B) → $Z_L = 0\Omega$

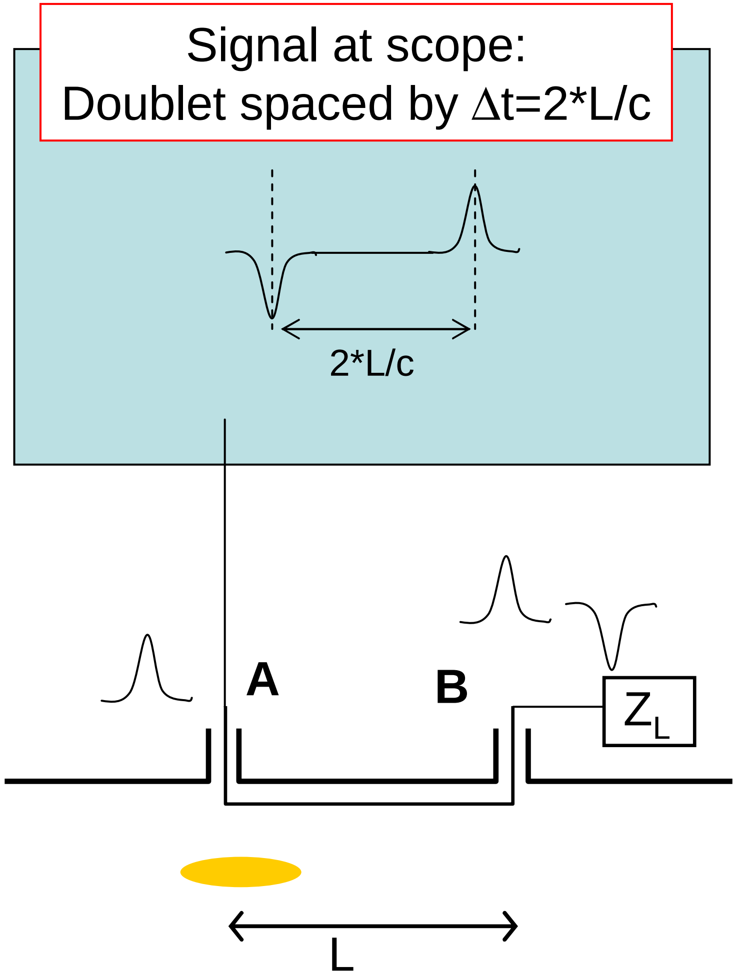
At t=0, signal goes through the port-A towards scope

At t=L/c, bunch arrives at port B, and the signal travels towards the load

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Since $Z_L=0\Omega$ → ρ=-1 → **Signal reflected**!!

At t=2L/c, reflected signal from port-B arrives at port-A and goes towards scope



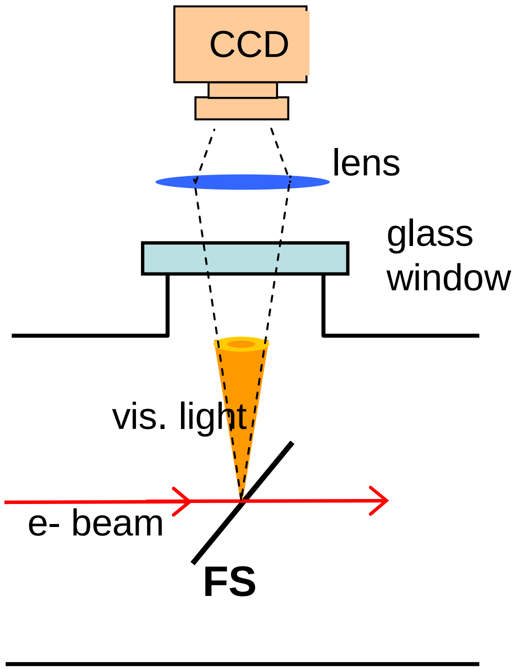
Measuring beam size

- Fluorescent Screens
- Optical Transition Radiation
- Synchrotron Radiation Monitors:
- The Pinhole Camera
- Long. Meas: Streak Camera

Fluorescent Screen (FS)

- Electron beam hits a fluorescent screen (placed at center chamber)
- The emitted light is directed towards a CCD camera

- **Destructive method**: beam is fatally affected after the collision
- Widely used during commissioning periods



SR-FS

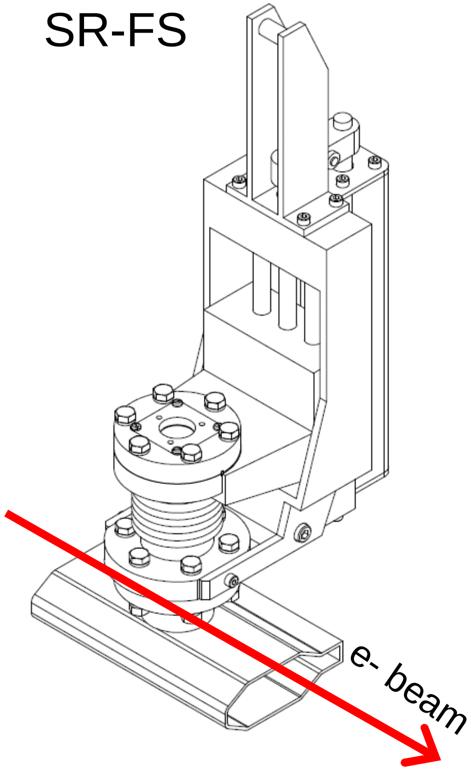
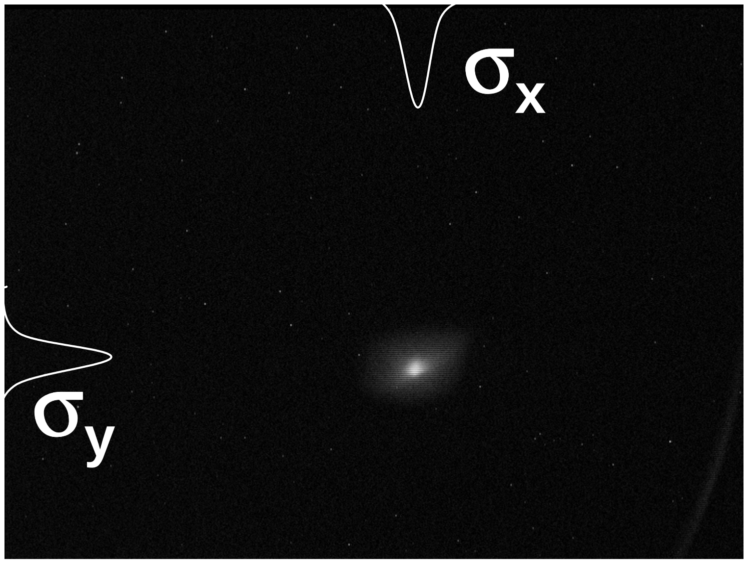


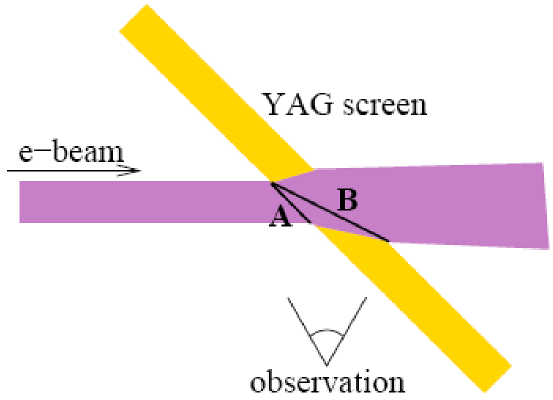
Image analysis to infer beam size and position:



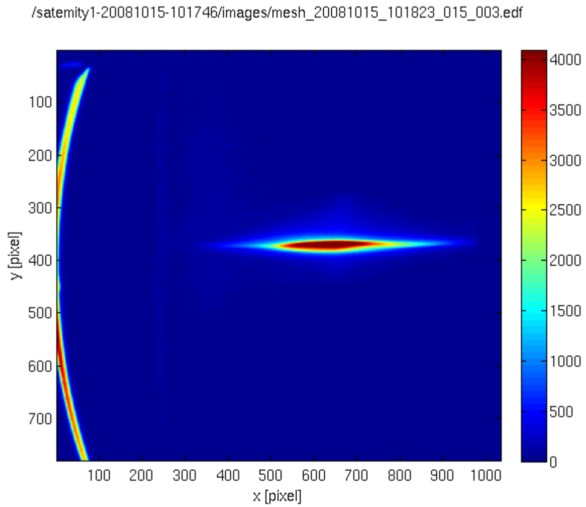
Fluorescent Screen (FS)

Advantages: Lots of light

Disadvantage: Beam size enlargement for beam sizes ~ FS thickness
FS saturation for large beam densities
Such large amount of light can saturate:
- the CCD camera (easily detected)
- the fluorescence emission (no longer linear)



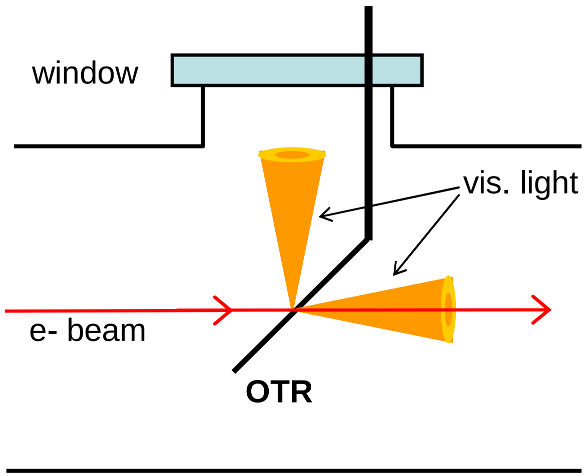
The distance A appears from the observation point as B due to multiple scattering



Example at Linac: image fully saturated (pixels 4095!)

Need another mechanism to image the beam without saturation:
→ **Optical Transition Radiation (OTR)**

Optical Transition Radiation (OTR)



- Transition Radiation is emitted when a charged particle crosses the interface of two media with different permittivities ε
- Intensity proportional to beam intensity and $\ln(\gamma)$
- Intensity cone with angle $\sim\gamma^{-1}$

- Light is emitted towards a CCD camera
- **Destructive method** as well

Advantage: No saturation (as opposed to the FS)
Instantaneous effect (no decay time)

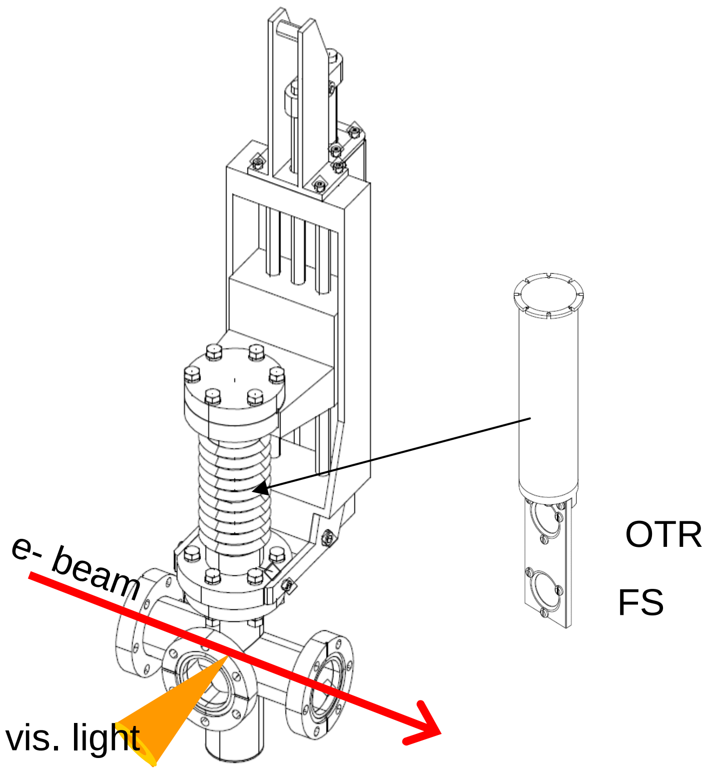
Disadvantage: Little vis. light is produced for low beam currents

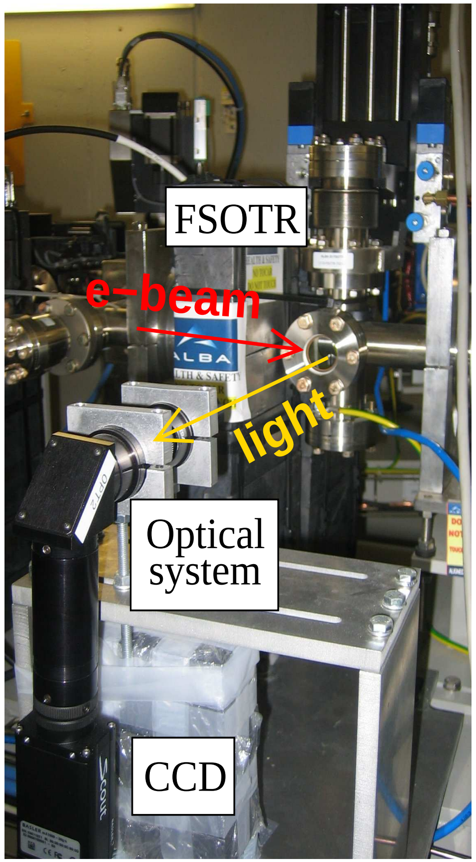
→ ALBA solution: Use of FS/OTR

Two screens (FS and OTR) are held in the same support:

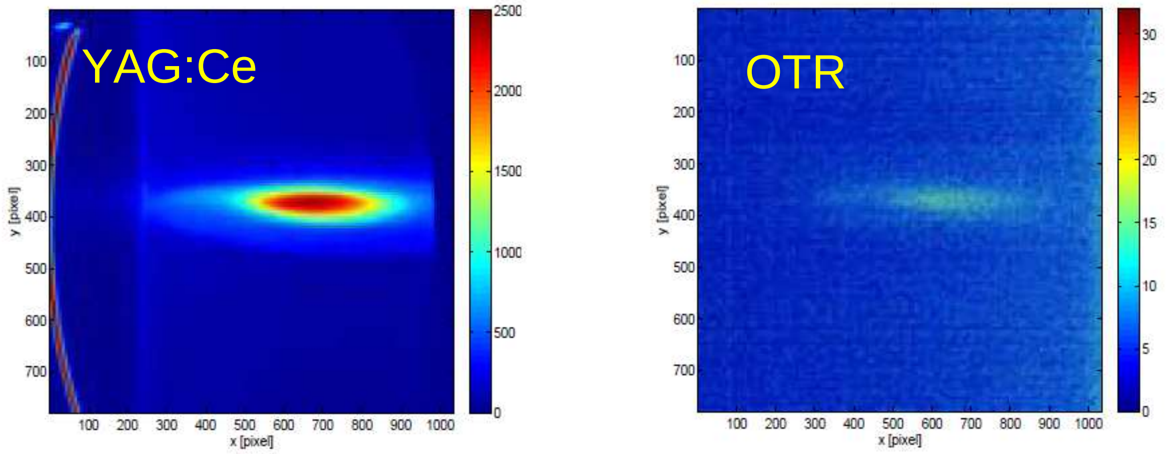
- FS usage for low beam intensities
- OTR usage for high intensity beams

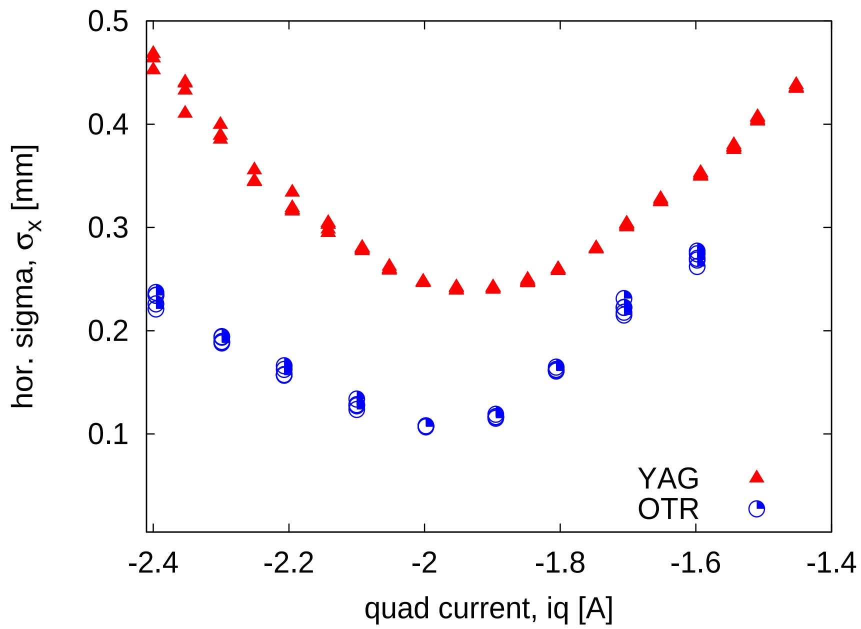
FS: YAG:Ce
OTR: Al-foil of 100nm





Comparison FS vs OTR





Comparison:

Using the YAG screen the beam sizes can be twice as large

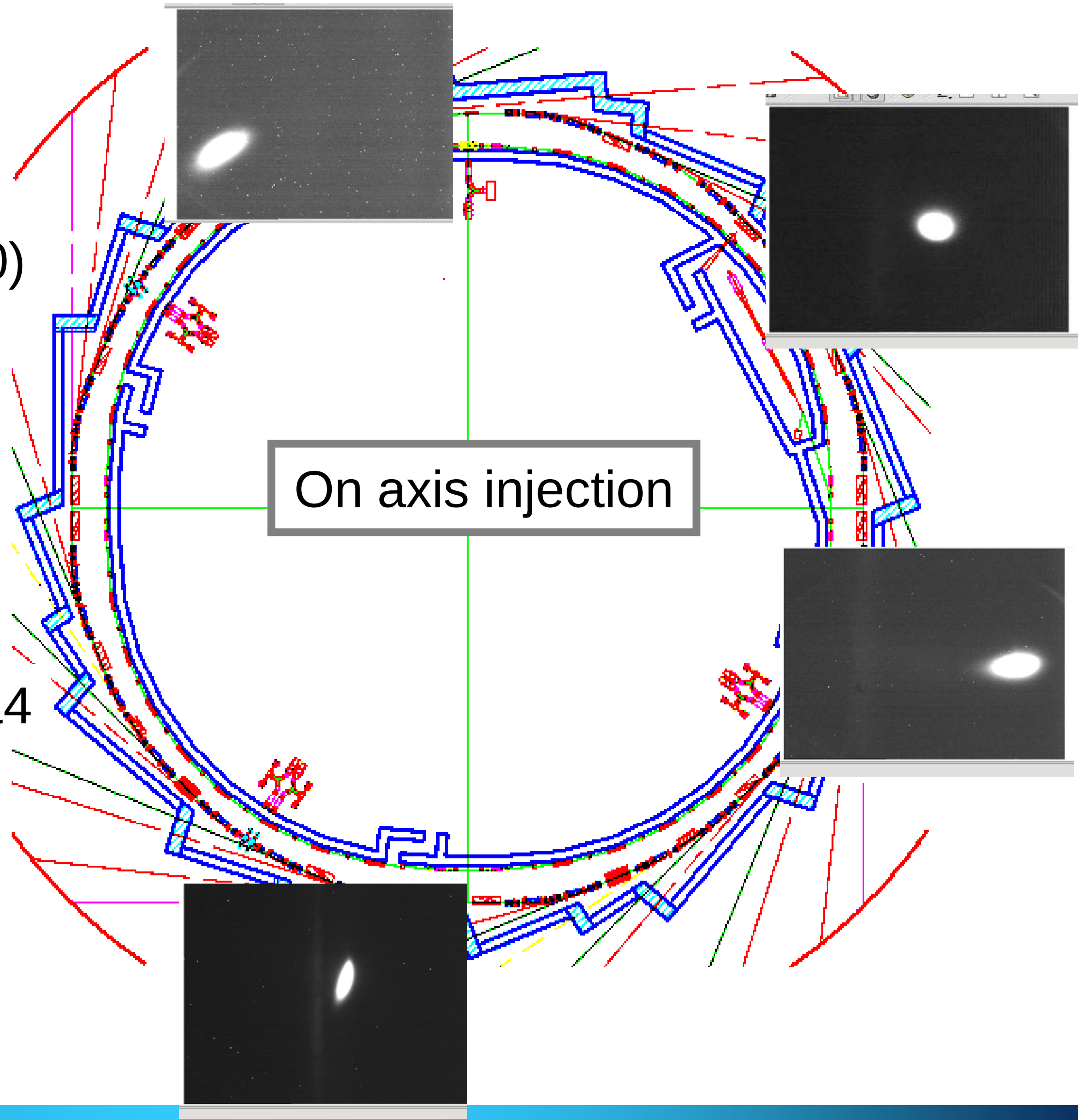
→Need OTR screen to perform precise beam size measurements

→Use YAG screen more often for routine operation

Screens at SR

Essential element to perform the 1st turn at SR Commissioning

- Recabling Quads (14h00)
  - ✓ Sectors 1&2
  - ✓ Quadrant 1
  - ✓ Quadrant 2
  - ✓ Quadrants 3&4



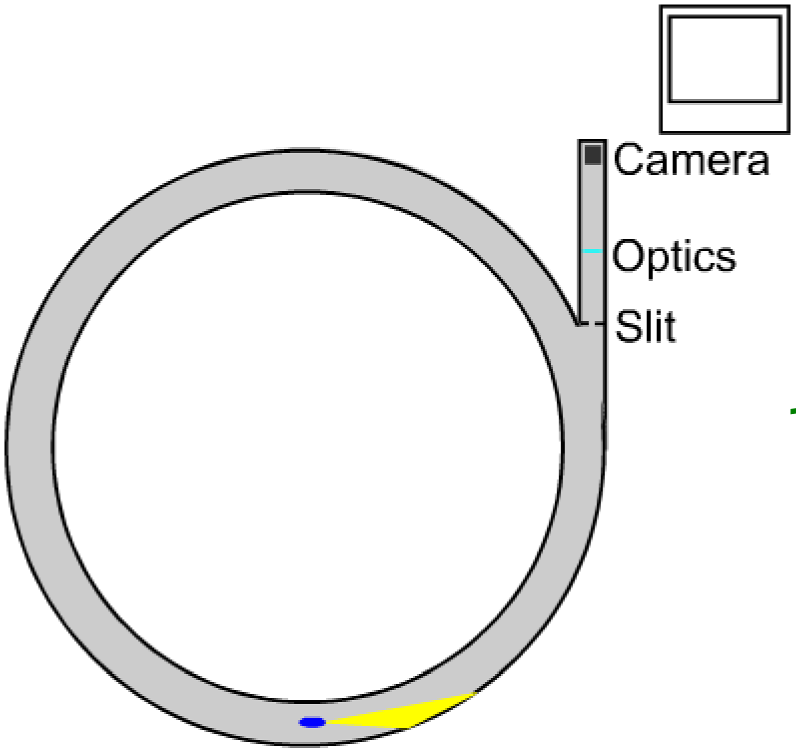
19h35: 1st turn !

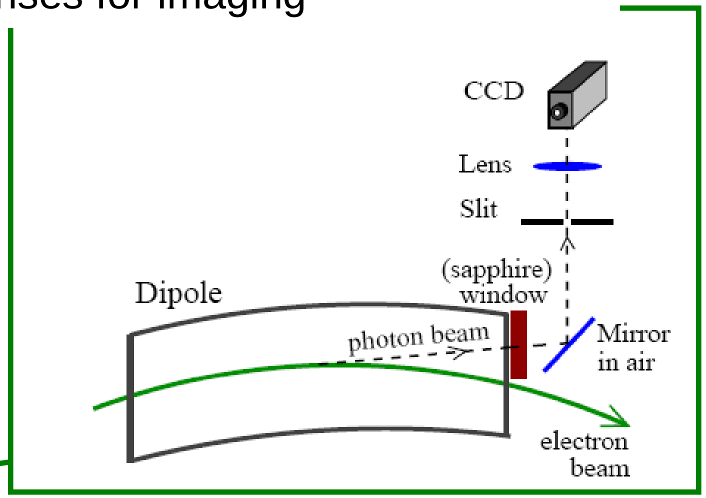
Synchrotron Radiation Monitors (SRM)

How:

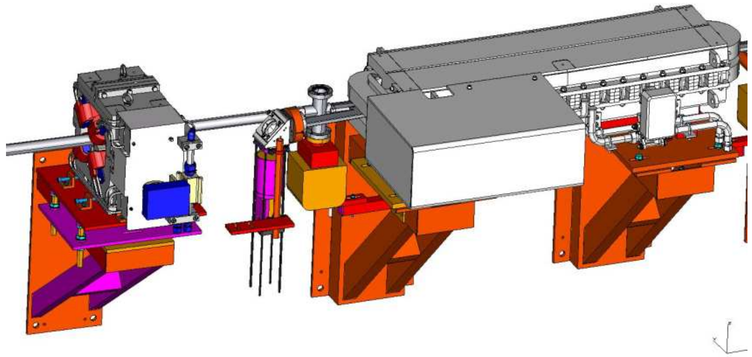
• Use of the synchrotron radiation produced when the e- beam traverses a bending magnet to image the e-beam **transverse** profile

• Need slit (image source not well determined) and lenses for imaging



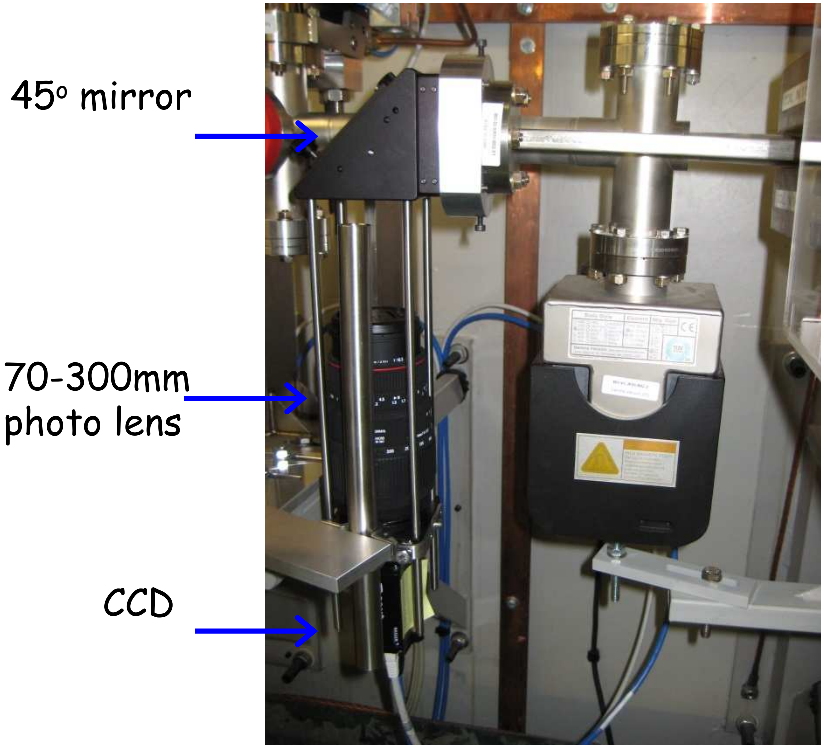


SRM - Booster



Booster SRM

Lateral view:



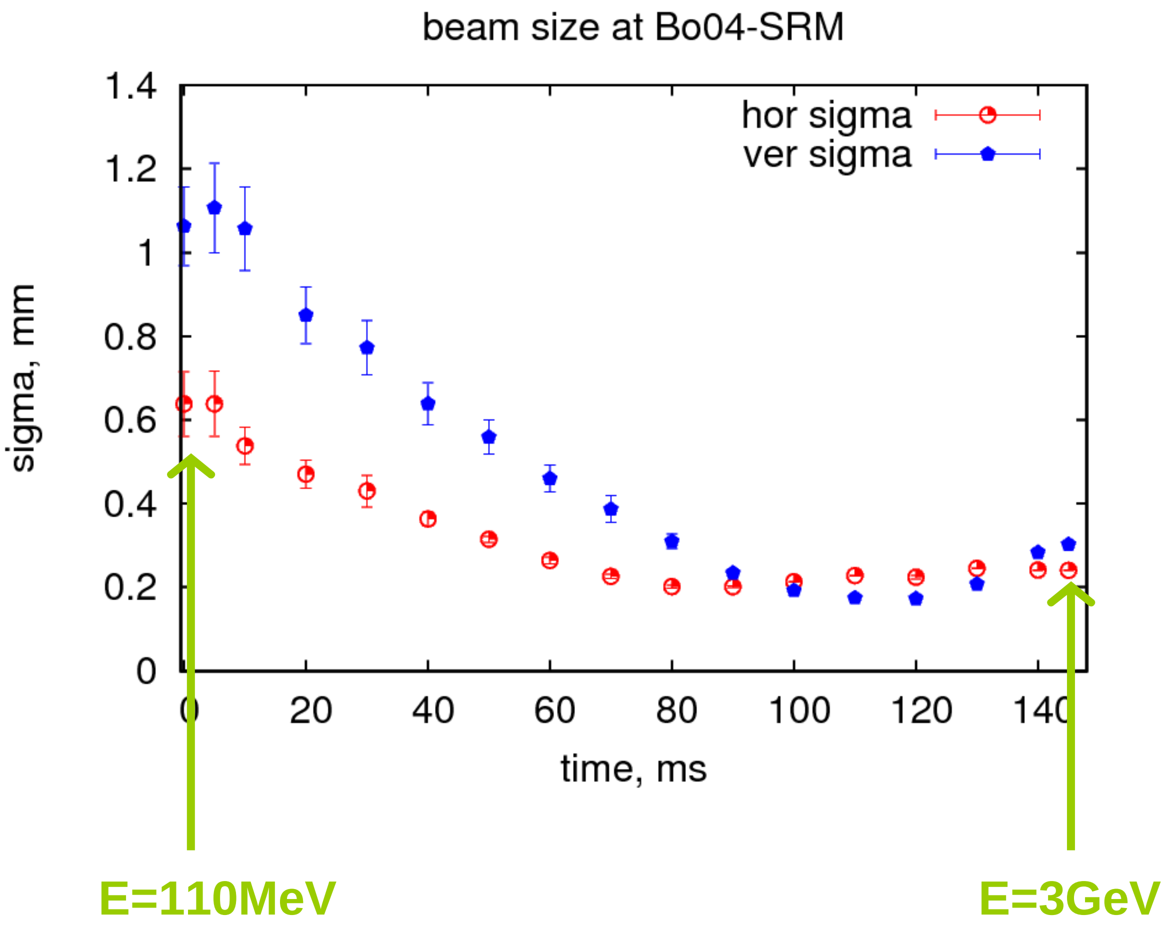
Advantages:

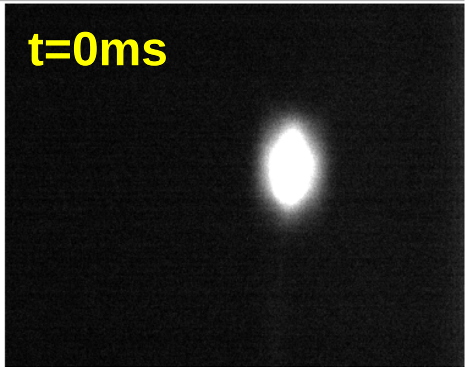
- Non-destructive method (e- beam continues its path)

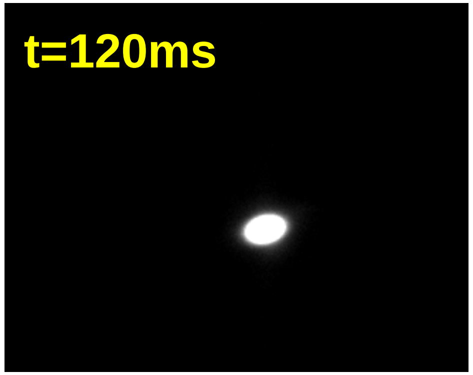
Disadvantages:

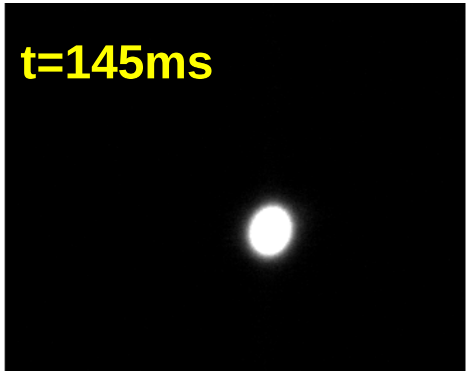
- Due to angular nature of synchrotron radiation, image is **diffraction limited**
- In the Storage Ring, we require a “beamline” for the setup – see **Pinhole System**

Beam size during Booster Ramp







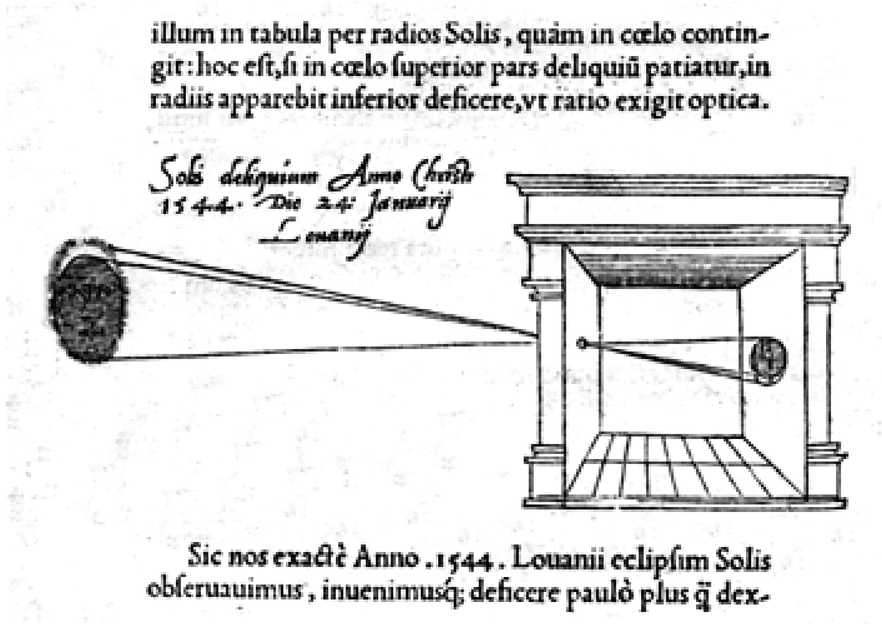


The Pinhole Camera

Pinhole, or camera obscura, a “camera without lens”.

Light going through a small hole, image keeps source properties

Used since XVI century to image solar eclipses

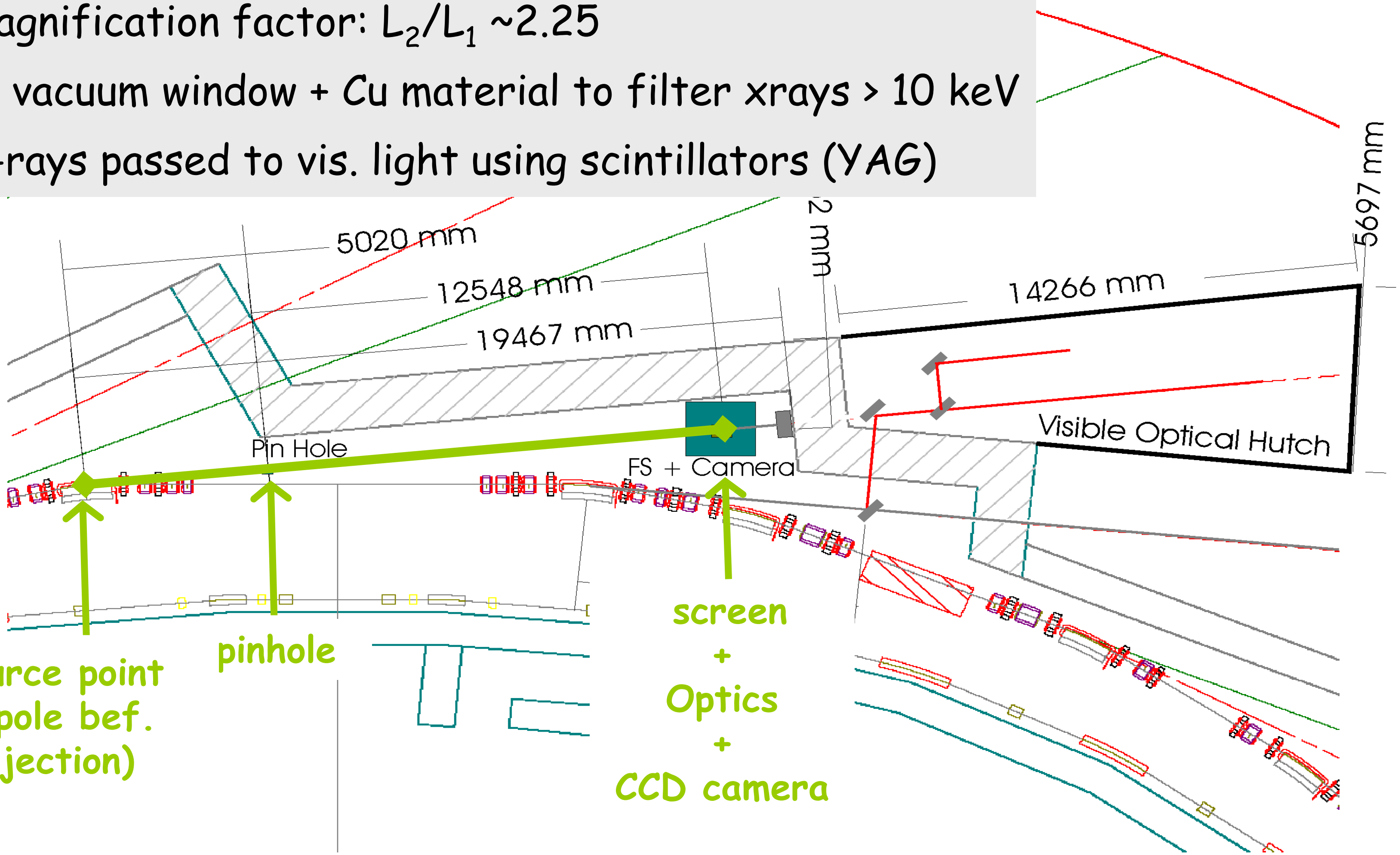

illum in tabula per radios Solis, quàm in cœlo contin-
git: hoc est, si in cœlo superior pars deliquiũ patiatur, in
radiis apparebit inferior deficere, vt ratio exigit optica.

Sic nos exactè Anno .1544. Louanii eclipsim Solis
obseruauimus, inuenimusq; deficere paulò plus q̃ dex-

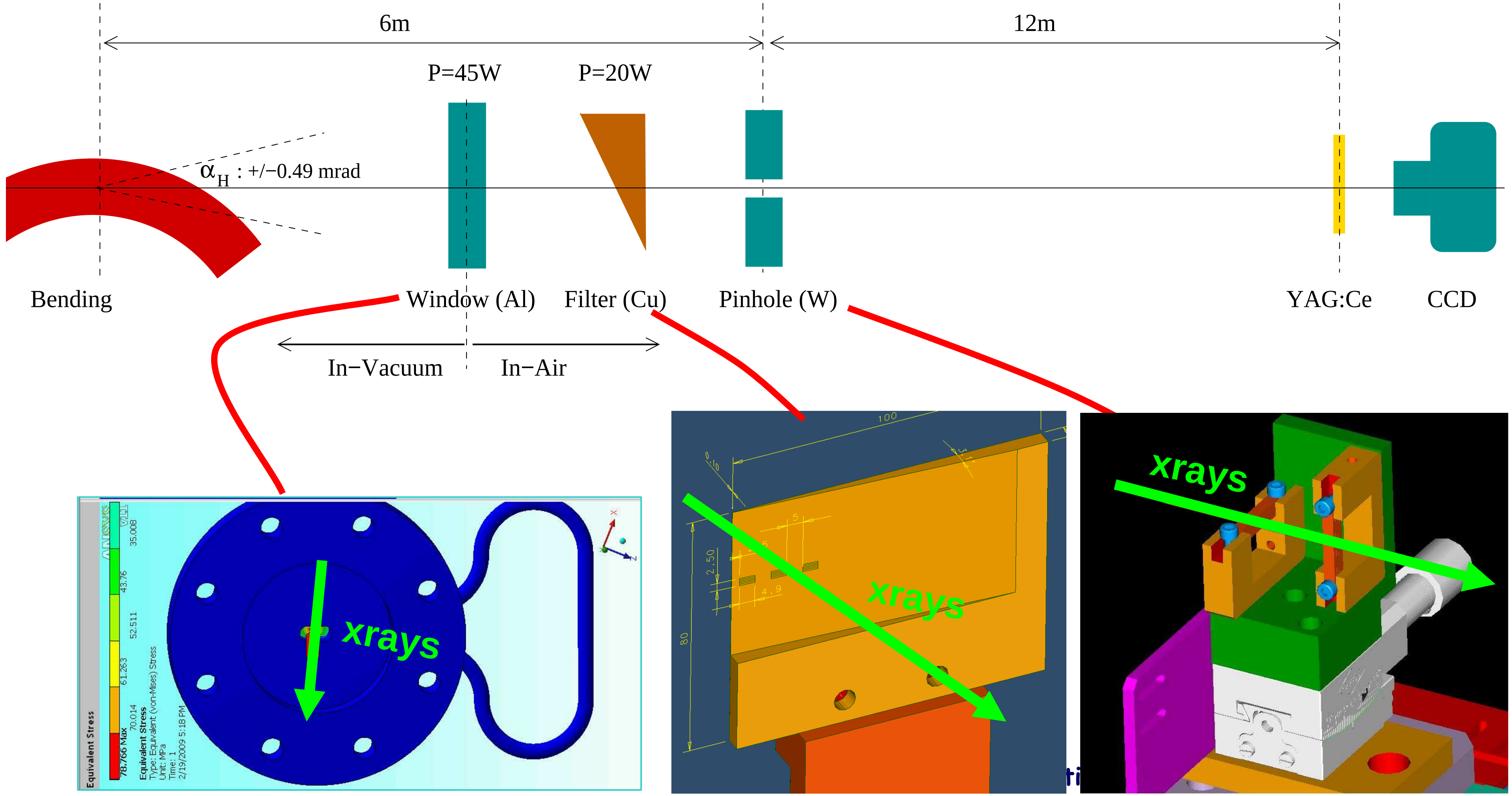
The same principle is widely used in e- machines!!!
(NSLS, ESRF, SPEAR, APS, BESSY-II, ALS, SLS, Elettra, PEP-II, Soleil, Diamond…)

ALBA XSRM (Pinhole) Layout

- Pinhole material: Tungsten (to withstand radiation)
- Magnification factor: L_2/L_1 ~2.25
- Al vacuum window + Cu material to filter xrays > 10 keV
- X-rays passed to vis. light using scintillators (YAG)



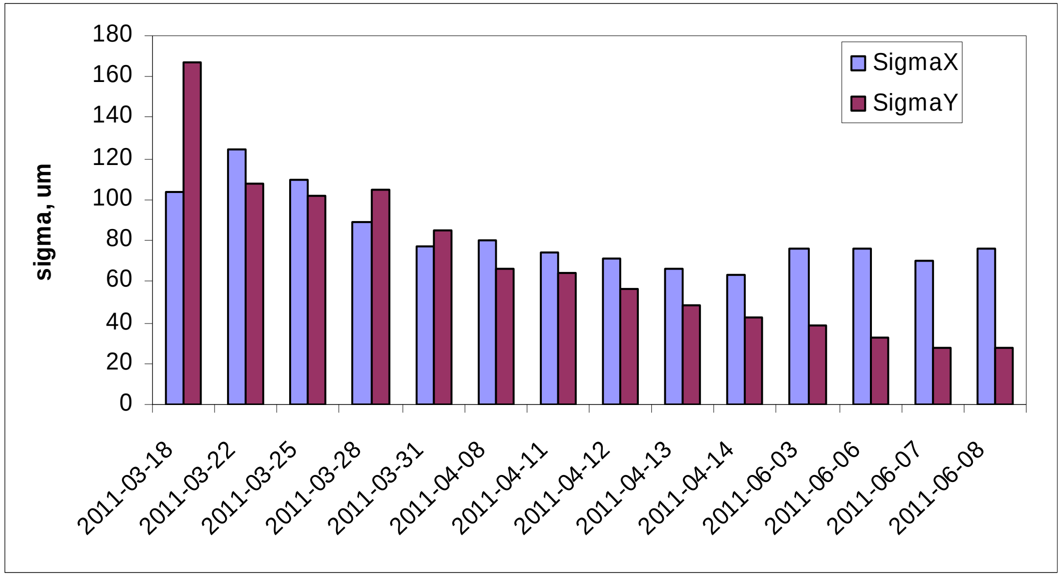
X-Ray Pinhole Camera



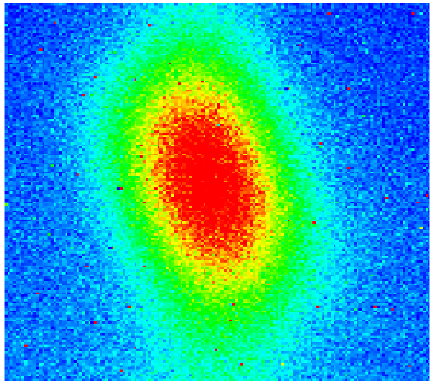
X-Ray Pinhole Camera

Beam size evolution during Commissioning March – June 2011:

Day-1:
(105, 160)um

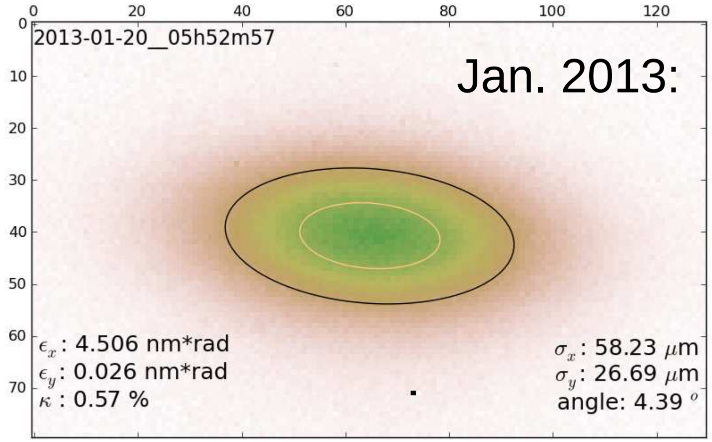


Last Day:
(64, 29)um

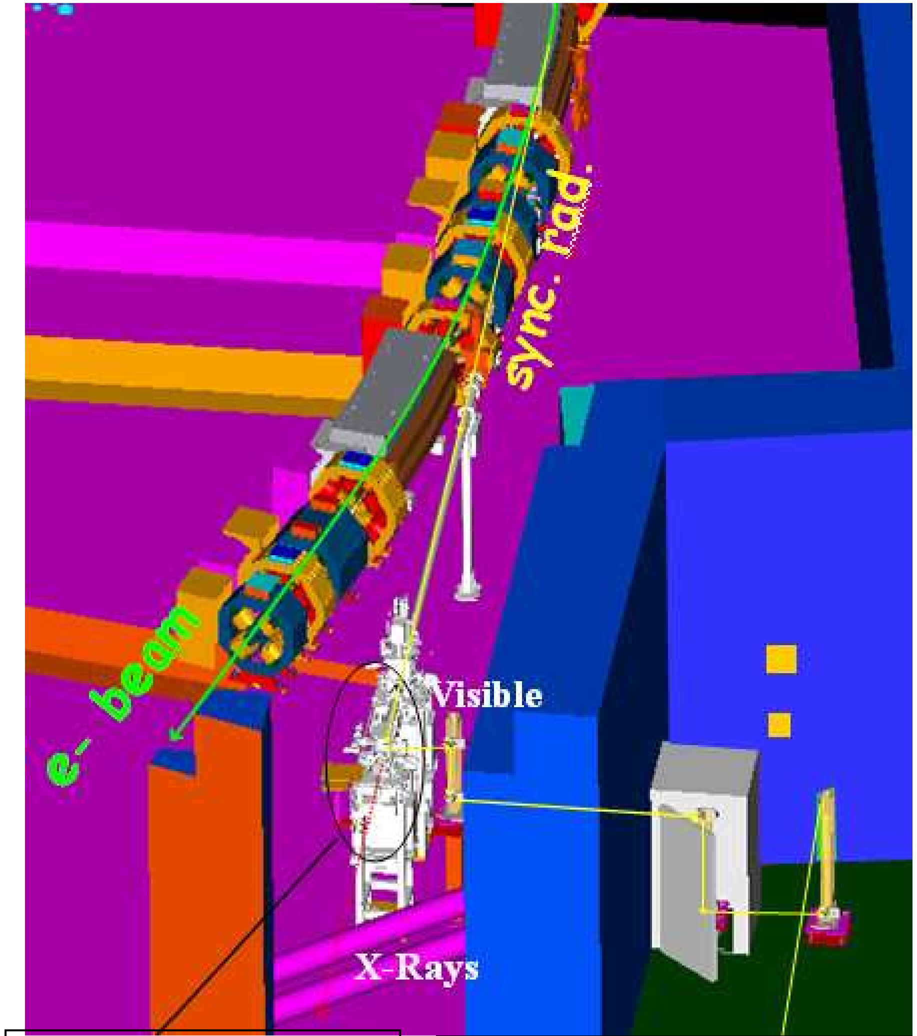


March 2011:

σ_x=121um
σ_y=218um

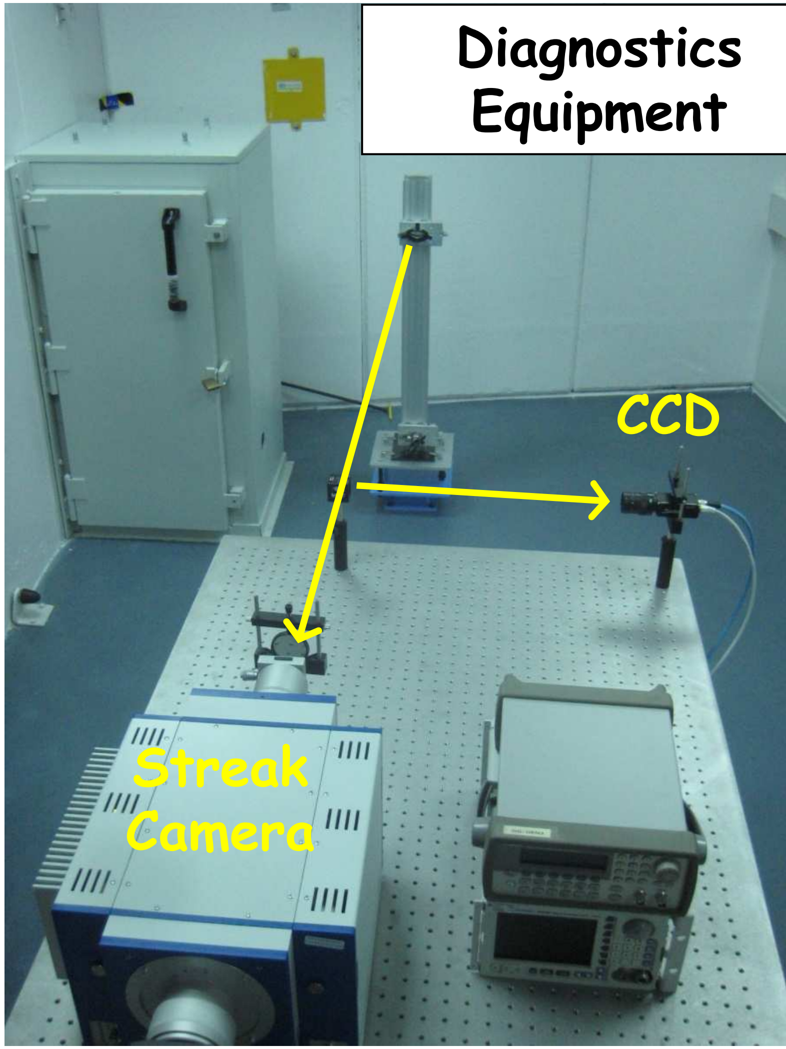


Diagnostics BeamLine

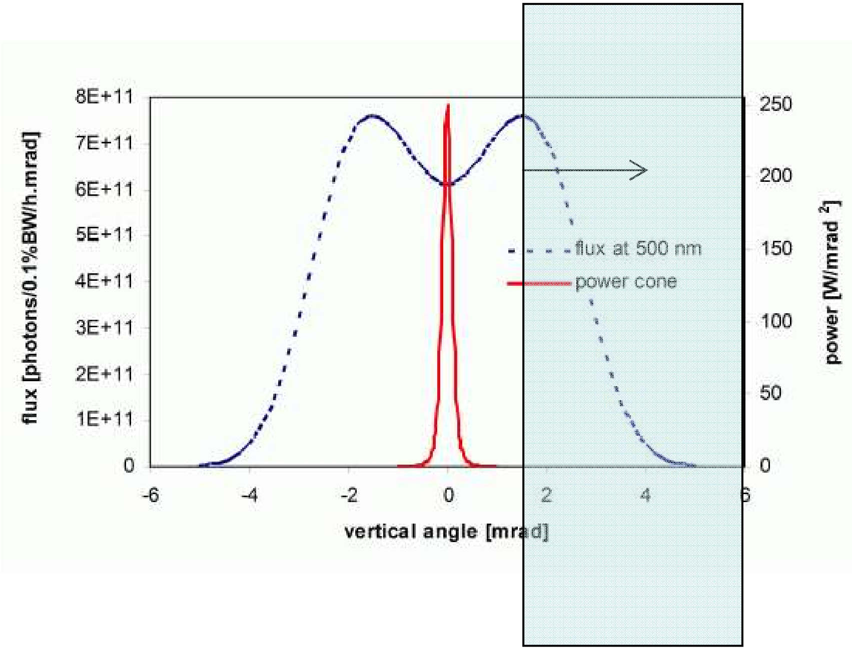


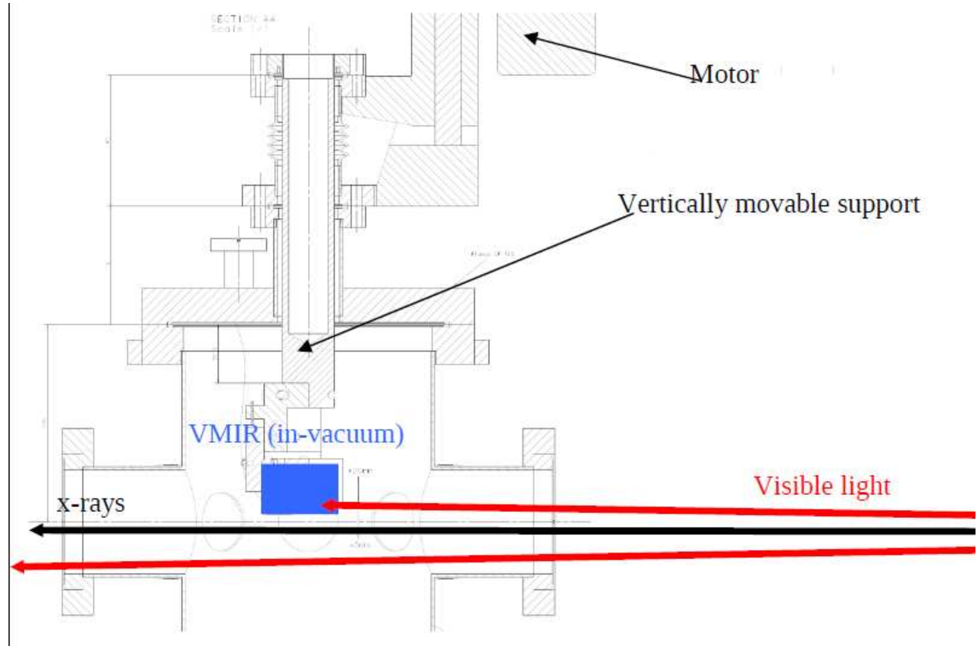
In-Vacuum Mirror

DIAGNOSTICS BeamLine



Wavelength Selection at In-Vacuum Mirror

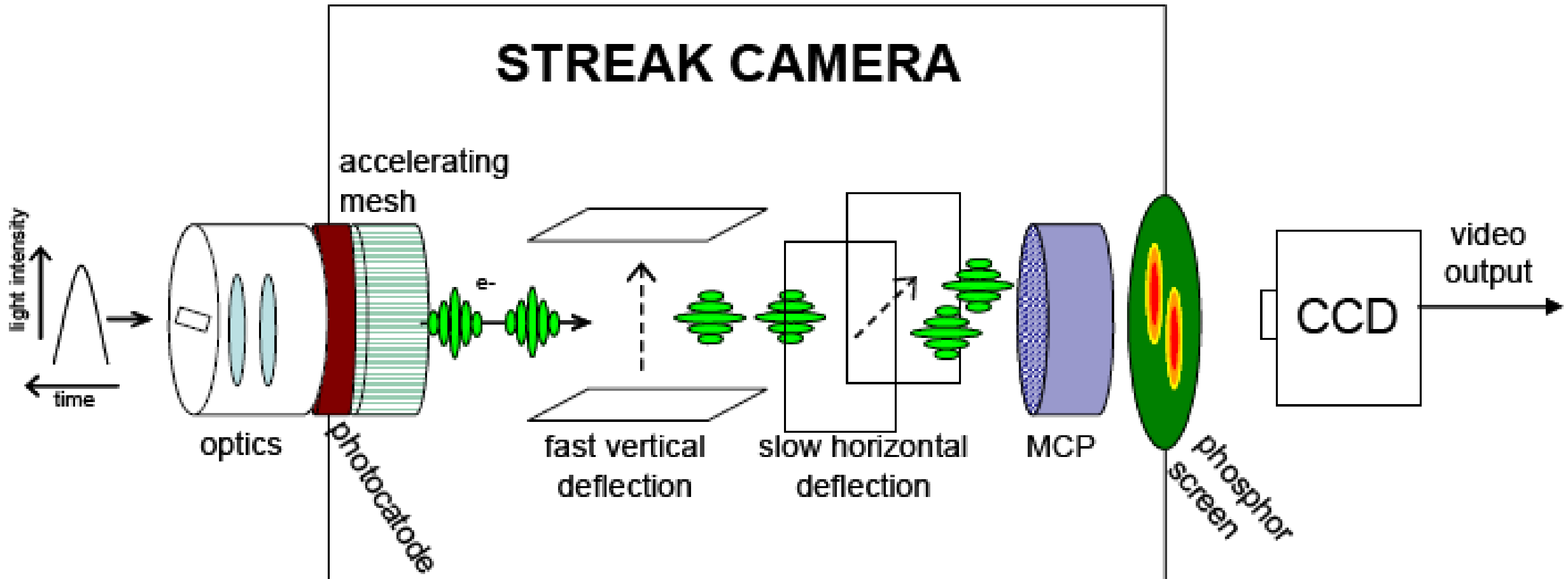




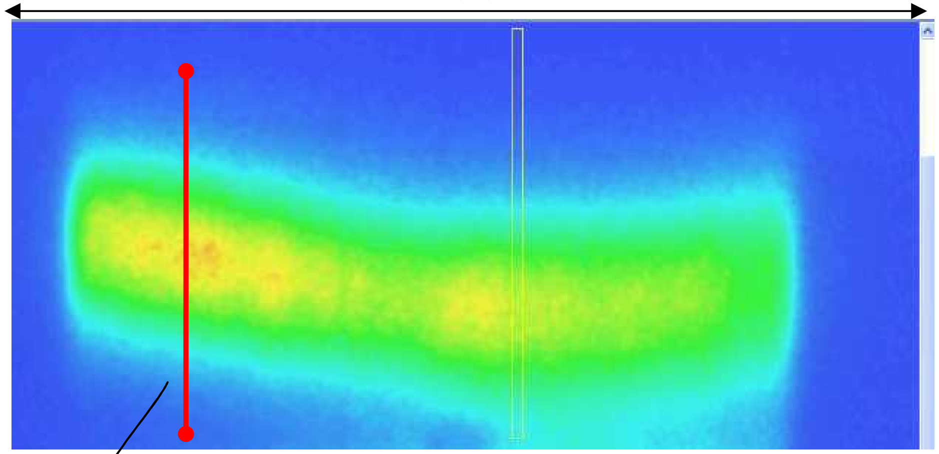
Bunch Length - Streak Camera

<u>Working Principle:</u>

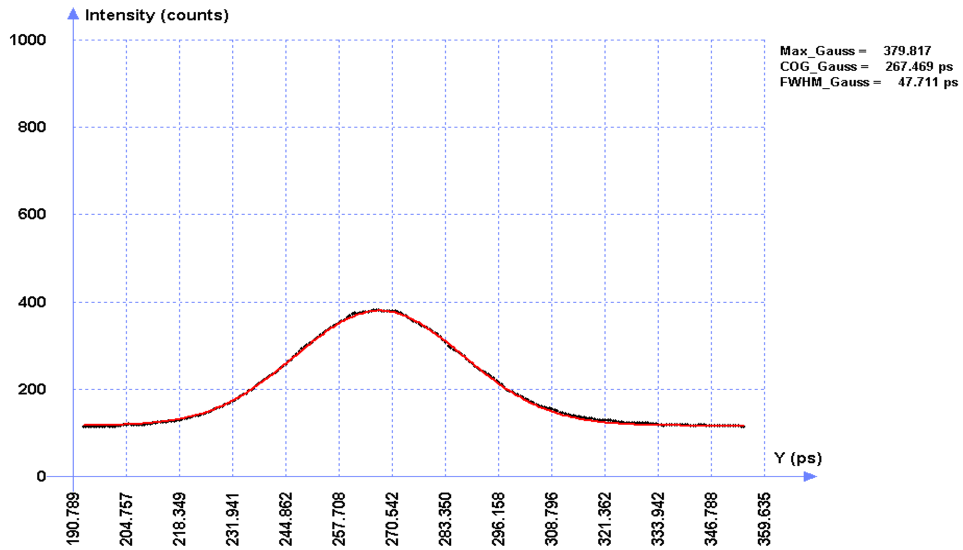
- use visible radiation coming from a SR (same long. structure as e-beam)
- the streak camera:
    1. converts photons into e- at photocathode
    2. deflects the e- with fast electric sweeps and separates them spatially
    3. converts the e- into photons, and takes an image



Example



The starting shape (becoming like a banana)
Means the rf phase is not the same for all bunches and
We are starting to have a beam instability



In any case, the vertical projection provides the bunch length:

FWHM~47ps

Measuring beam charge/current

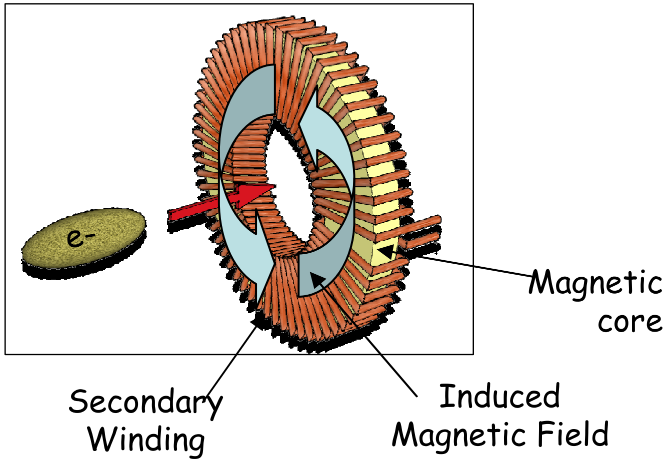
- Fast Current Transformer
- DC Current Transformer
- Faraday Cup

Fast Current Transformer (FCT)

Ferromagnetic core surrounded by a winding embedded in the vacuum chamber.

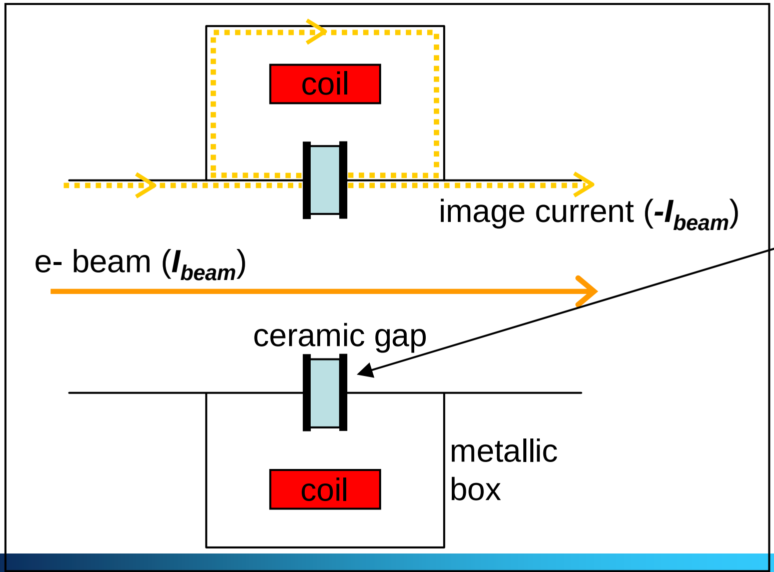
The e-beam acts as 1ary coil and induces a magnetic field in the core.

The induced signal is captured by the winding (2ary coil), and then read by a scope



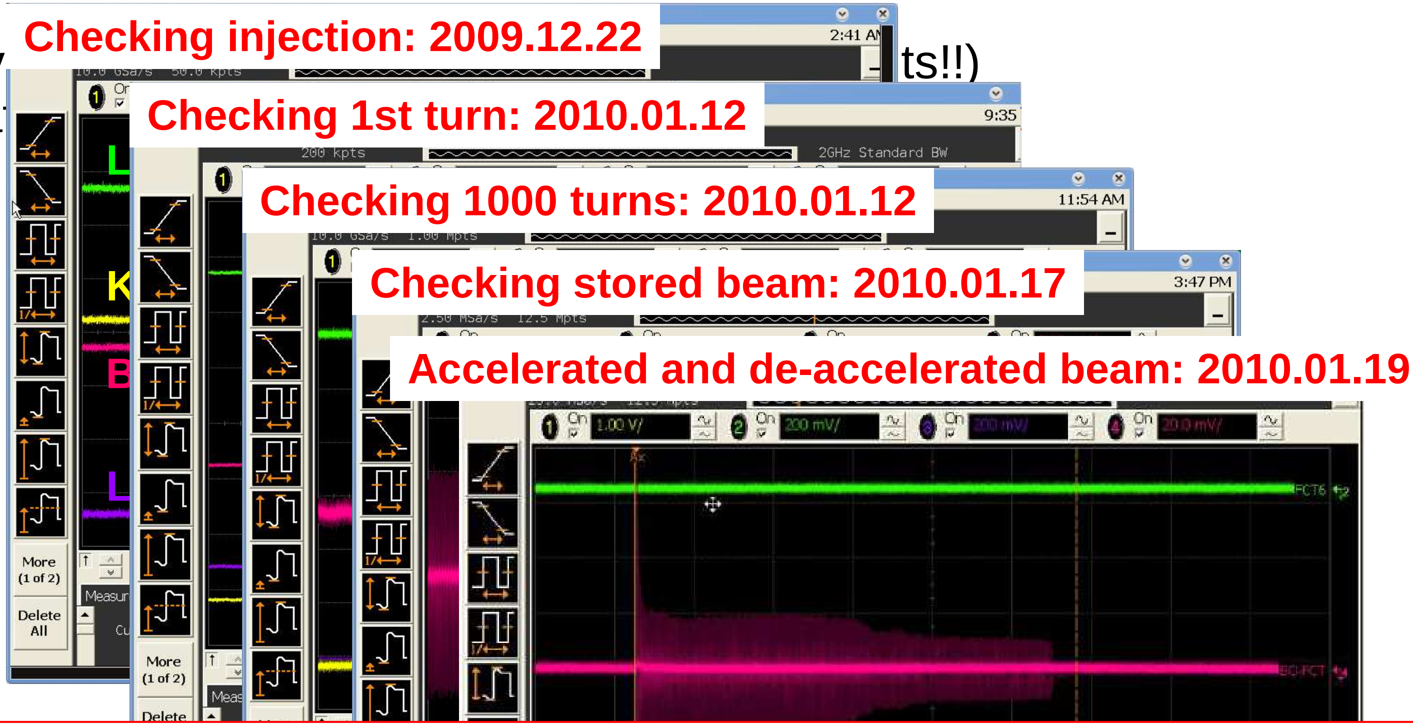
The relation between the 1ary (e-beam} and 2ary currents is *N* is the number of turns around the coil

$$I_{beam} = N\, I_{coil}$$



→ Need to cut the electrical conductivity using ceramic break to allow image currents be catched by coil

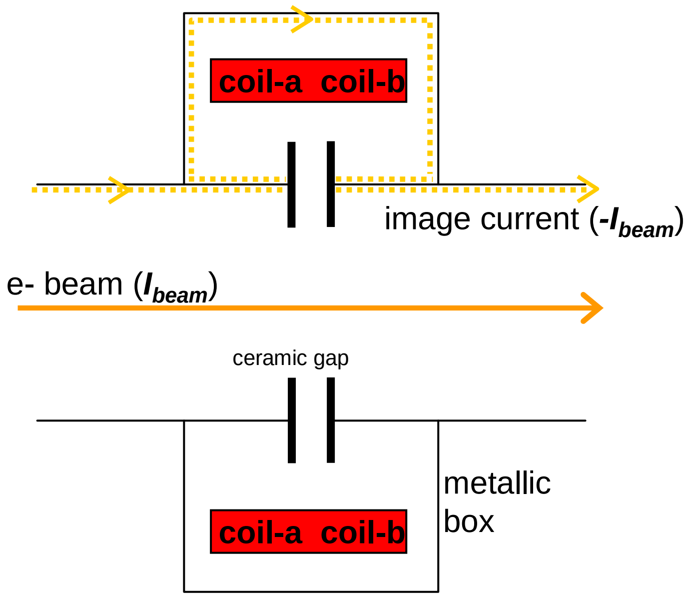
- Extensiv ts!!)
- Only 1 a

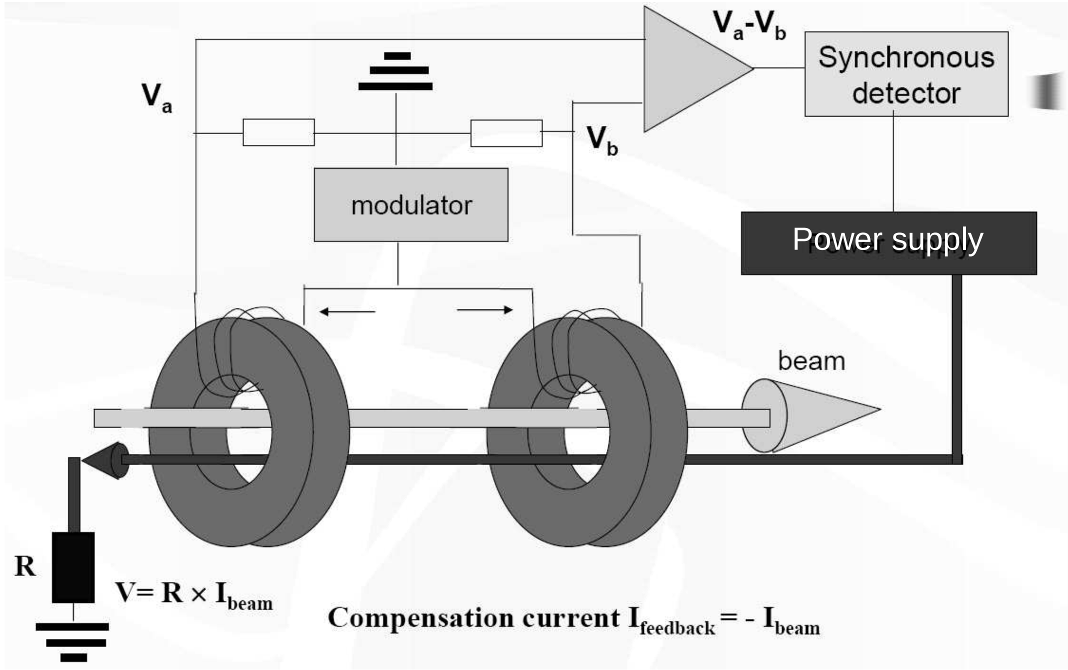


But this is a qualitative measure of the beam current.
Recall that signal is distorted depending on the freqency, and DC currents are not detected!

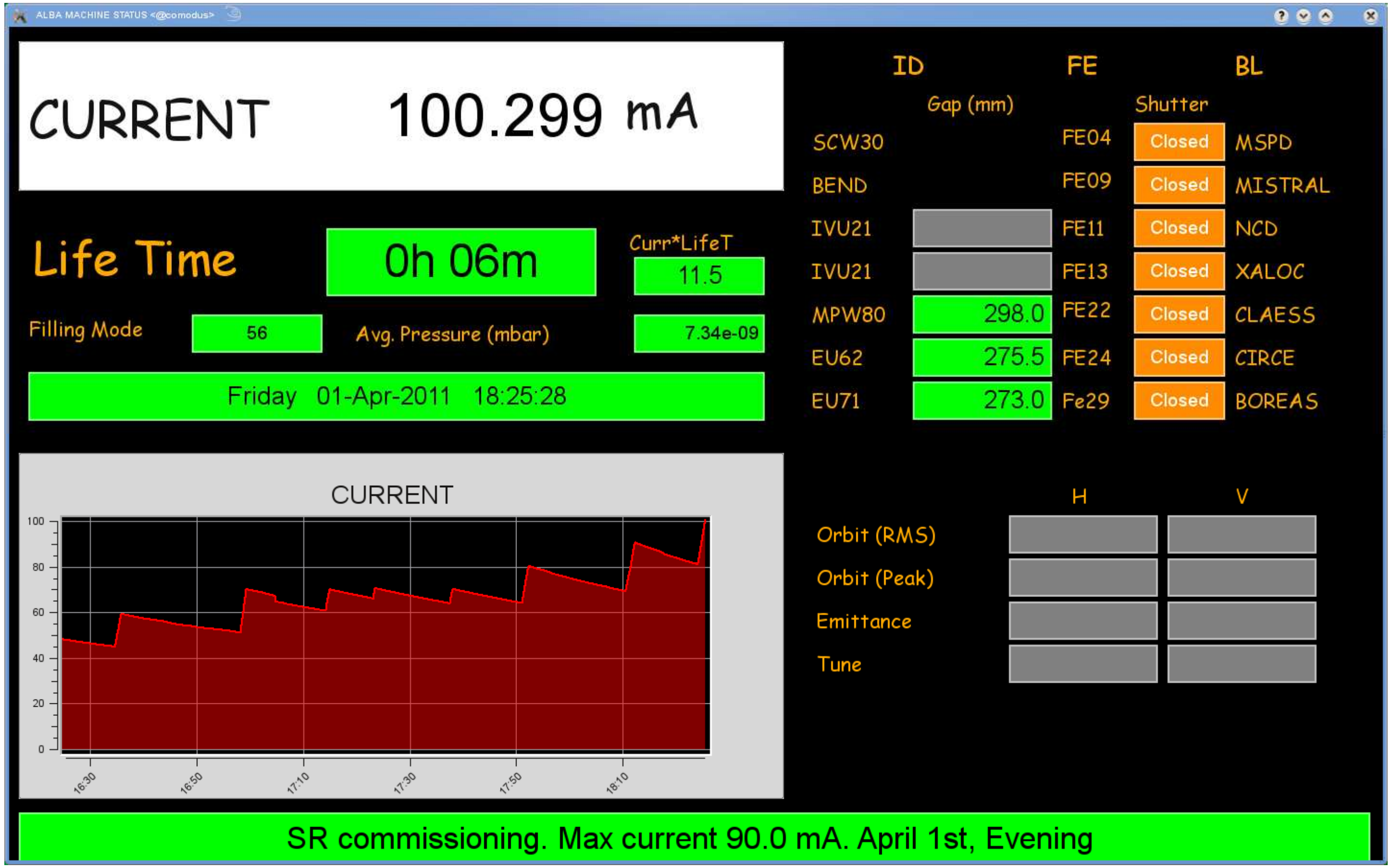
For quantitative analysis, need the ***DC Current Transformer → DCCT***

DC Current Transformer (DCCT)



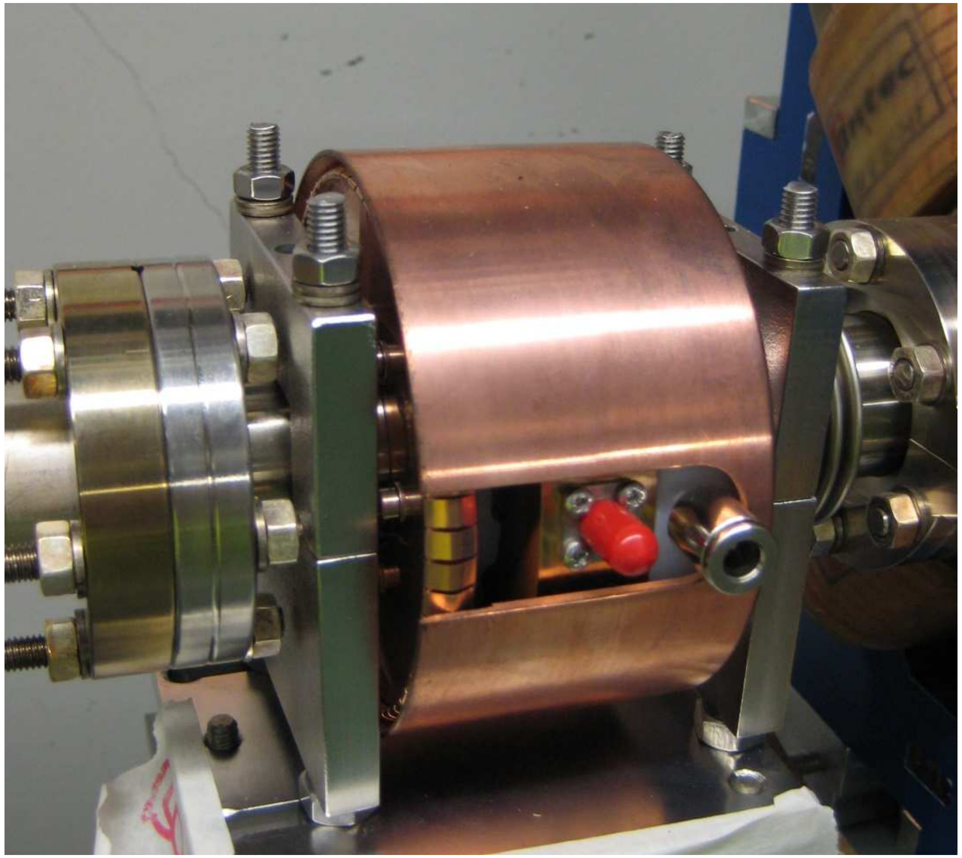


- As the FCT, but the DCCT includes (at least) two coils to get the **compensating magnetic** flux (“zero” flux).
- Coils are made of a ferromagnetic material (hysteresis B-H)


ALBA MACHINE STATUS <@comodus>
CURRENT 100.299 mA
Life Time
0h 06m
Curr*LifeT
11.5
Filling Mode
56
Avg. Pressure (mbar)
7.34e-09
Friday 01-Apr-2011 18:25:28
CURRENT
100
80
60
40
20
0
16:30
16:50
17:10
17:30
17:50
18:10
ID
FE
BL
Gap (mm)
Shutter
SCW30 FE04 Closed MSPD
BEND FE09 Closed MISTRAL
IVU21 FE11 Closed NCD
IVU21 FE13 Closed XALOC
MPW80 298.0 FE22 Closed CLAESS
EU62 275.5 FE24 Closed CIRCE
EU71 273.0 Fe29 Closed BOREAS
H
V
Orbit (RMS)
Orbit (Peak)
Emittance
Tune
SR commissioning. Max current 90.0 mA. April 1st, Evening

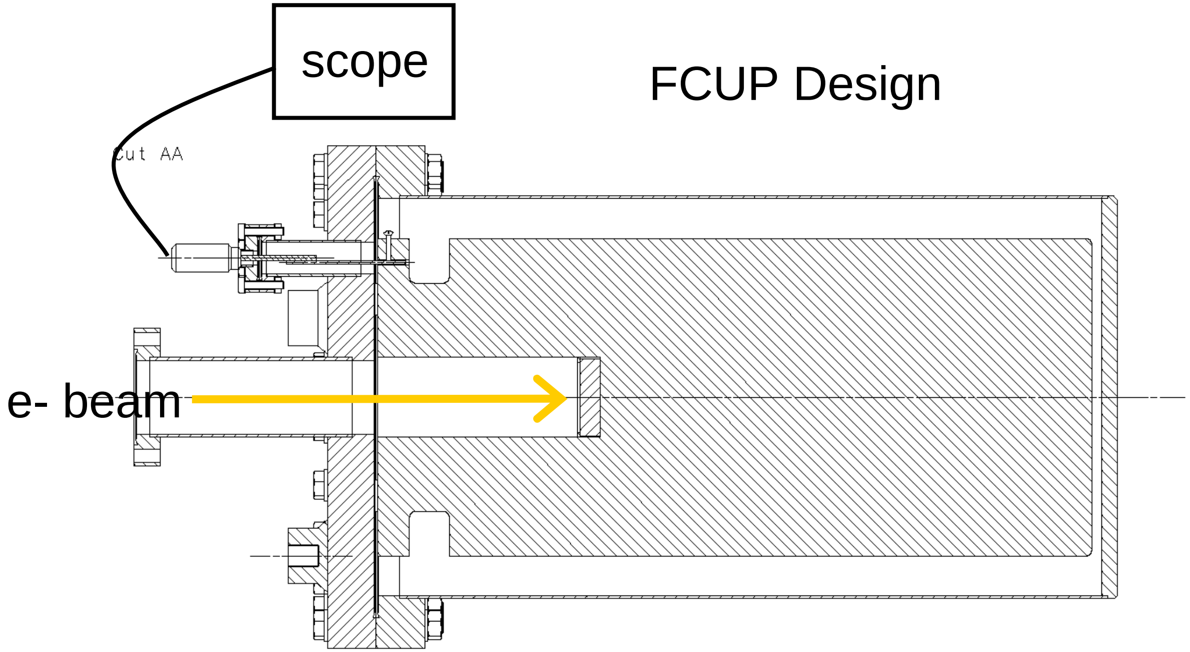
SR - DCCT

BO - FCT



Faraday Cup (FCUP)

- The e- beam hits a metallic block-electrode (Faraday Cup), which collects all beam's charge.
- This charge flows them to the scope, or multimeter.
- Totally destructive method (at ALBA only one in the Linac Diagnostics Beamline).



Beam Loss Monitors

- Quantify and locate particles lost by the beam
- Particles lost detected using ***BLM*** from Bergoz

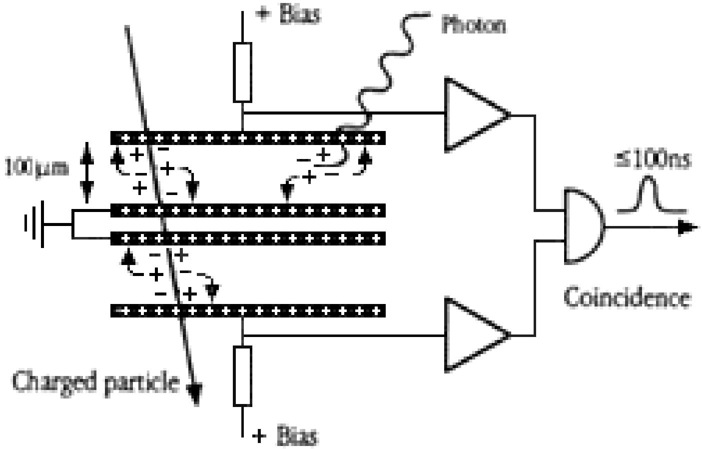
Operating Principle:

•Two pin-diodes mounted face to face produce electrical charge when a MIP* crosses a diode.

•The electronic board includes an **AND** gate that counts coincidence rates "Coincidence" implies photons will not be counted

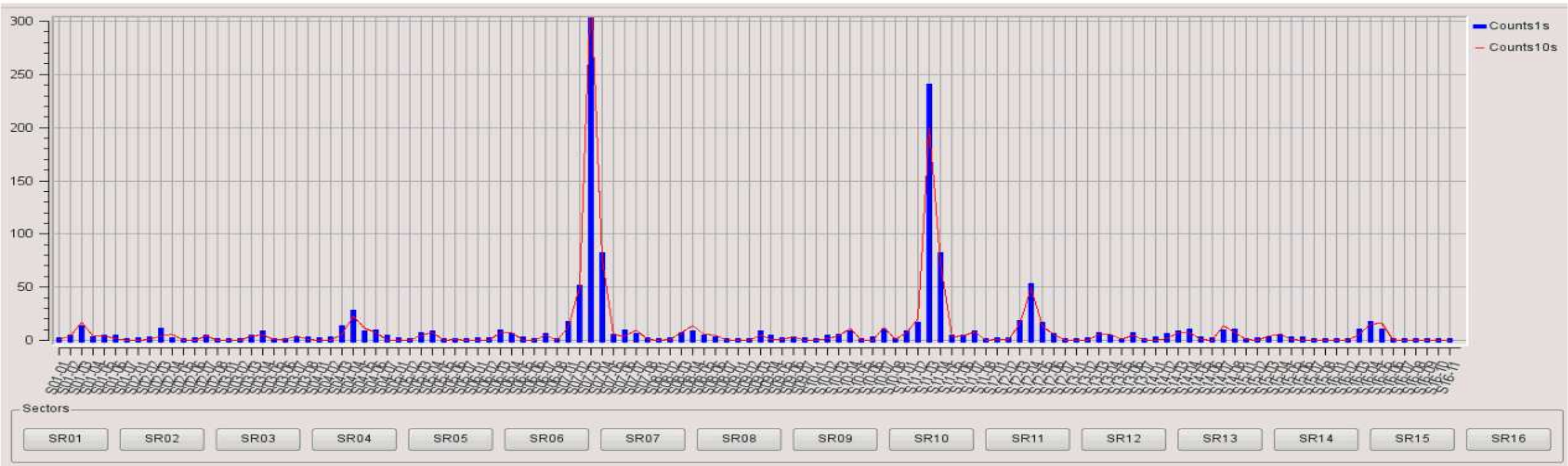
*MIP = Minimum Ionizing Particle.

Operating principle



Beam Loss Monitors

- 7/8 BLM/cell → 120 BLMs
- Located at same location as the BPMs
- We can follow the places where the e-beam is lost:



Example 2011.12.14:

Finding an explanation for a Low Lifetime (2h only!)

Critical locations S07-03 (Xaloc) and S11-03 (MPW)

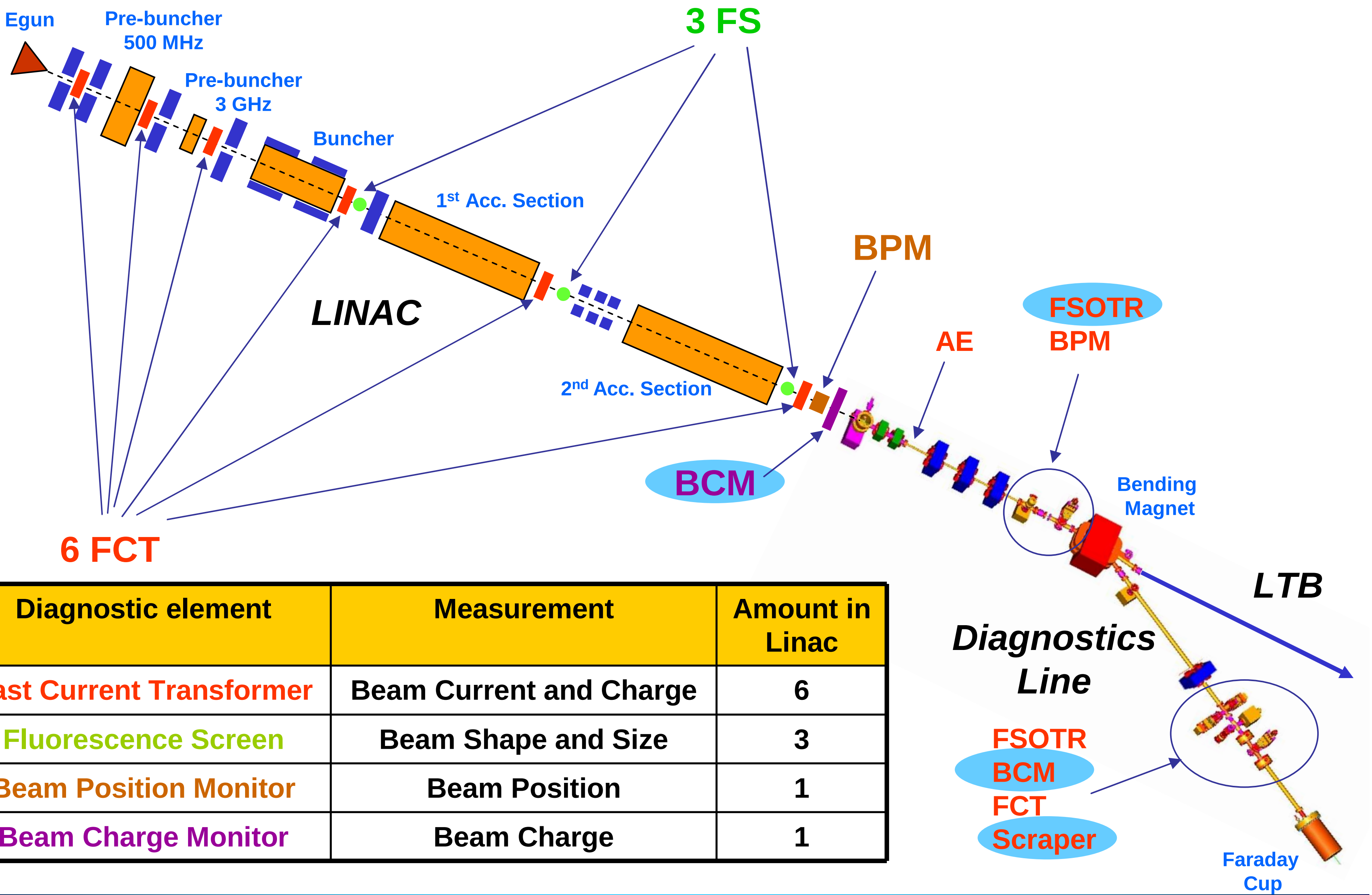
Realize that correction tables for MPW were not ok

SUMMARY

	Instrument Name	*Acronym*	*LTB*	*Booster*	*BTS*	*SR*
Position	Beam Position Monitor	**BPM**	4	44	4	120+3
	Stripline BPM	**Stripline**	0	2	0	1
Charge	Faraday Cup	**FCUP**	1	0	0	0
	Fast Current Transformer	**FCT**	3	1	2	1
	Beam Charge Monitor	**BCM**	2	0	0	0
	DC Current Transformer	**DCCT**	0	1	0	1
	Annular Electrode	**AE**	0	1	0	1
Size	Fluorescent Screen	**FS**	0	1	0	4
	Fluorescent Screen / OTR	**FS/OTR**	4	4	3	2
	Synch. Rad. Monitor	**SRM**	1	3	2	2*
Others...	Scrapers	**SCR**	2	0	0	2
	Fast FeedBack Kickers	**FFK**	0	0	0	2

2* → **XSR**, **VSR**

Linac Diagnostic elements

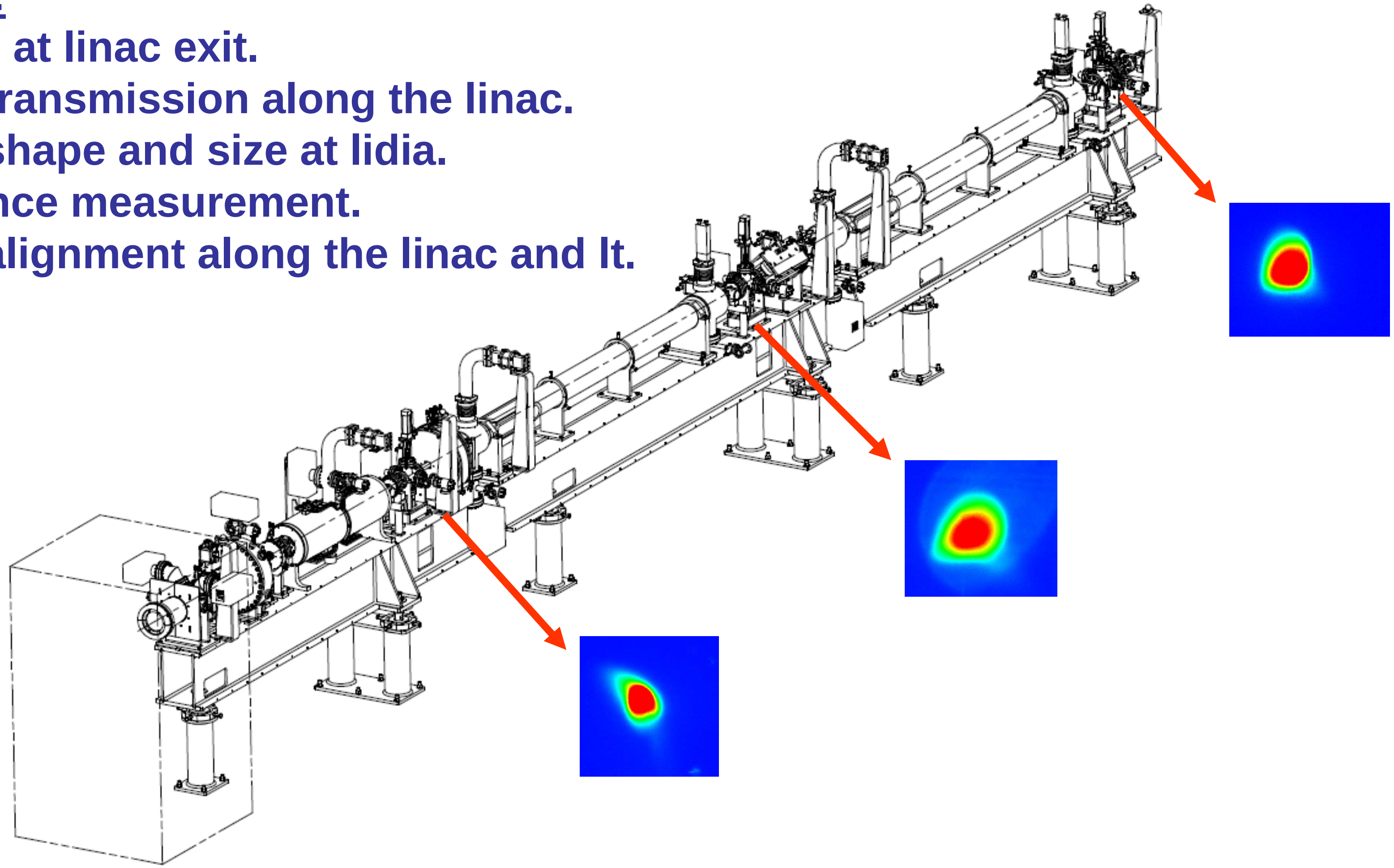


Diagnostic element	Measurement	Amount in Linac
Fast Current Transformer	Beam Current and Charge	6
Fluorescence Screen	Beam Shape and Size	3
Beam Position Monitor	Beam Position	1
Beam Charge Monitor	Beam Charge	1

Beam Optimization

Checks:

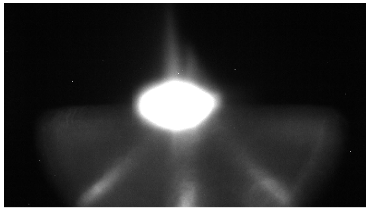
-Charge at linac exit.
-Beam transmission along the linac.
-Beam shape and size at lidia.
-Emittance measurement.
-Beam alignment along the linac and lt.



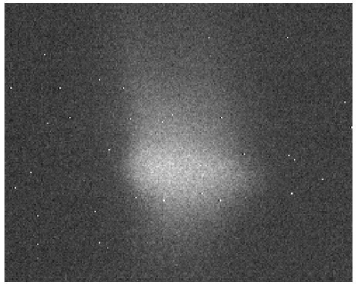
Beam Optimization

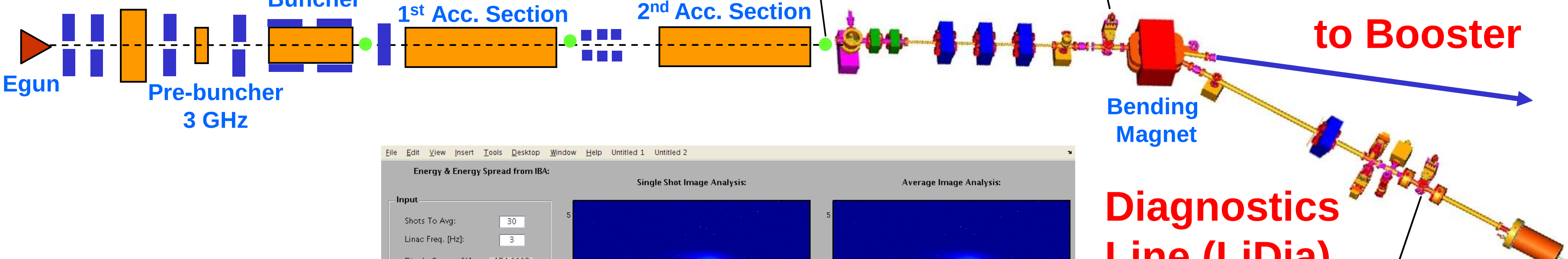
- **Round beam at Linac exit**

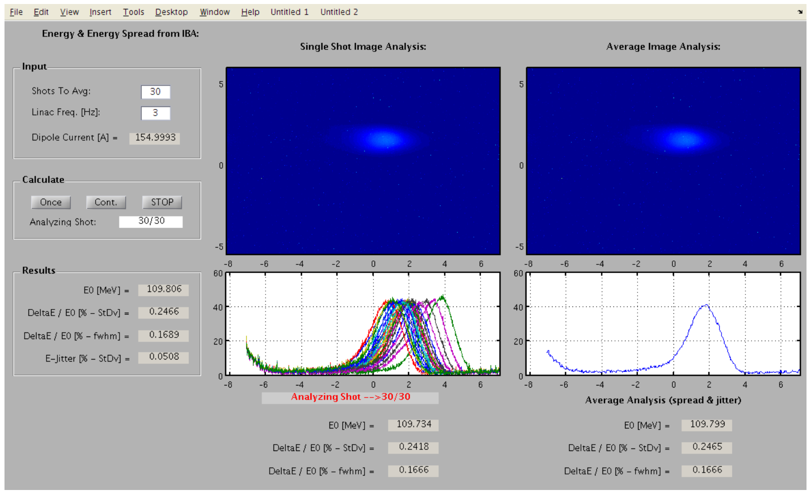
LI-FS-03



LT-FSOTR-01







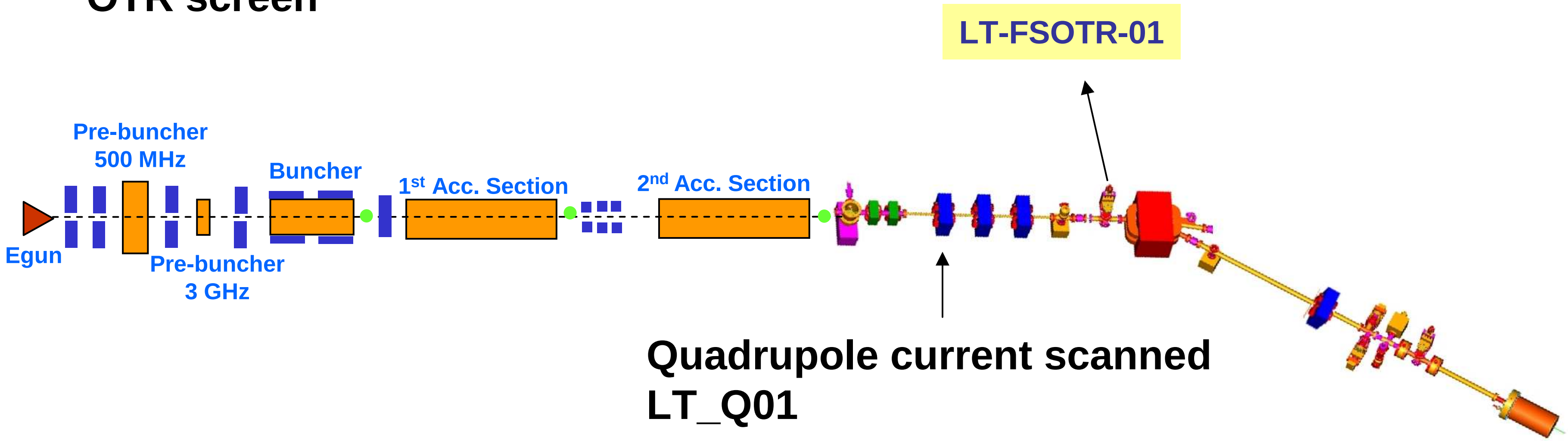
LiDia-FSOTR-01

Fast energy and energy spread measurement

Emittance

Quadrupole scan method

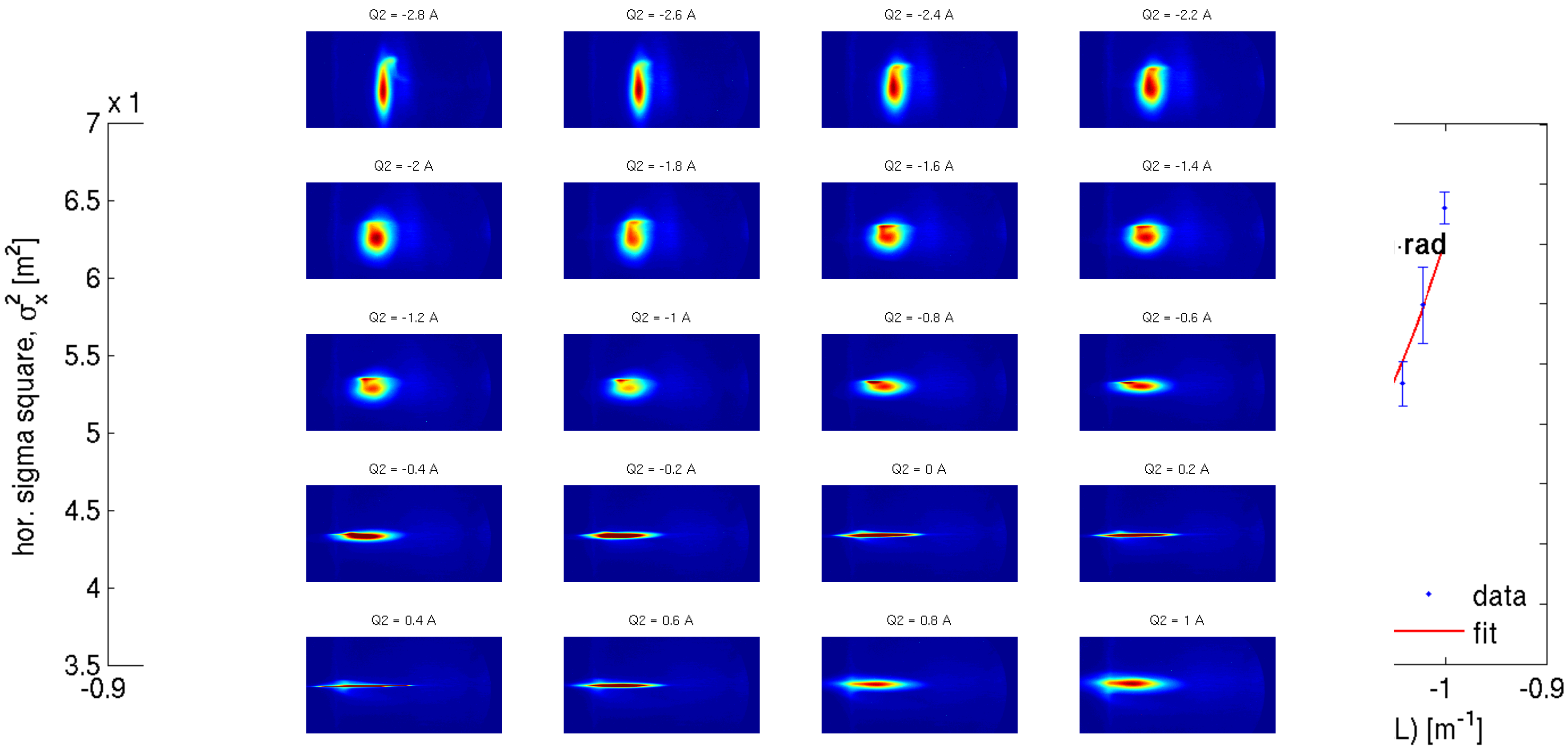
1) Beam size as a function of the quadrupole field strength recorded with OTR screen



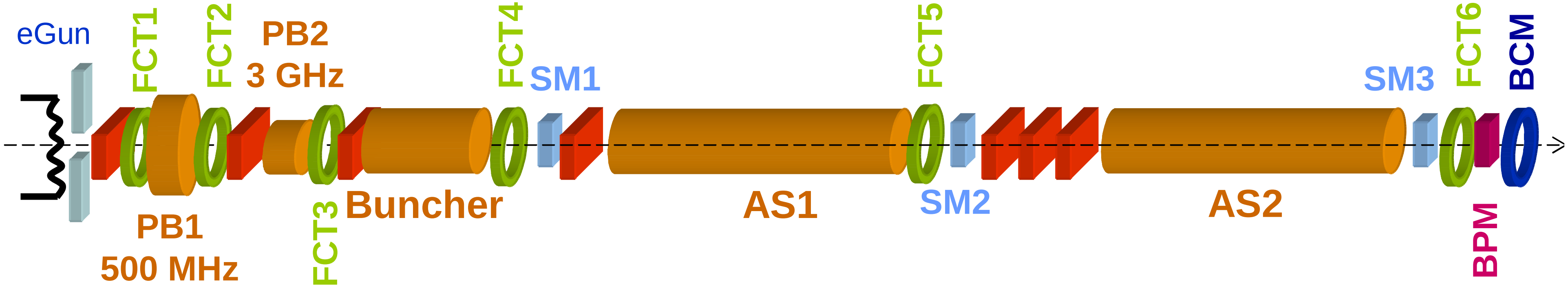
2) Parabola is fitted to extract the emittance from the fit parameters.

Emittance

- **Emittance measurements: MBM, 112 ns, 4 nC, 105 MeV, 1 Hz**



Beam transmission



MBM, measured transmission, 70 MeV

Beam mode	Buncher exit	AS1 exit
500 MHz & 3 GHz	96%	66%
3 GHz	83	58
500 MHz	80	47
No cavities	64	37

THANK YOU