# RTML Emittance Measurement Station

Yuri Kubyshin (1), Robert Apsimon (2), Hector García (1,2)

(1) Technical University of Catalonia (UPC)
(2) CERN

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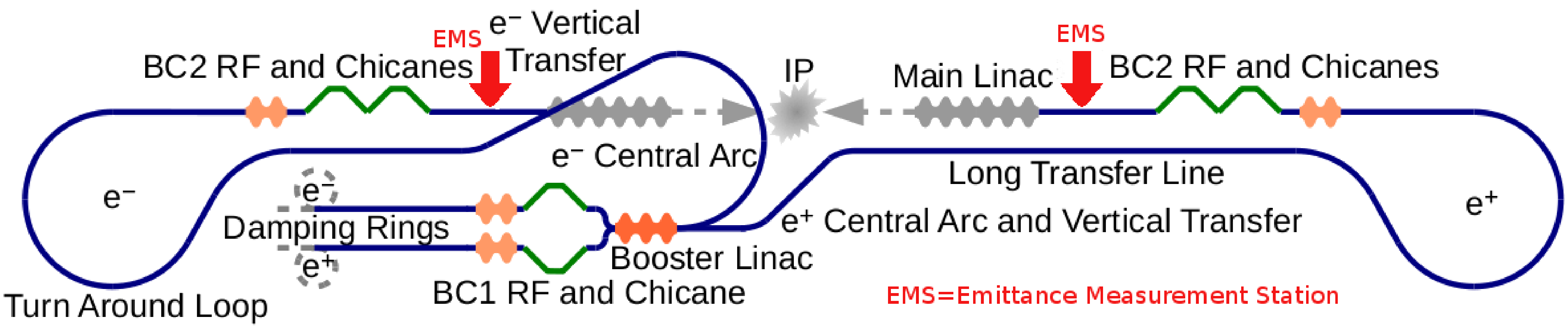
## Talk outline:

1. Emittance measurement section (EMS) at the RTML line
2. Emittance measurement scheme
3. Optics of the EMS and measurement simulations
4. Proposal of the laser wire (LW) monitor
5. Concluding remarks

- Yu. Kubyshin, H. Garcia, E. Marin, D. Schulte, F. Stulle, PAC-2011
- H. Garcia, Yu. Kubyshin, G. Blair, T. Aumeyr, D. Schulte, F. Stulle, IPAC-2011
- R. Apsimon, CLIC seminar 14/11/2012

# Proposed EMS location




**Main beam parameters at the EMS location and requirements:**

- **Beam energy** 9 GeV
- **Horizontal normalized emittance** $\varepsilon_{N,x} \leq 600$ nm·rad
- **Vertical normalized emittance** $\varepsilon_{N,y} \leq 10$ nm·rad
- **Bunch length** 0.15 ps
- **Bunch repetition frequency** 2 GHz

- **Precision of emittance measurements:** better than 10%

# Emittance measurement scheme

•To determine the emittances it is proposed to measure $e^-$ and $e^+$ beam profiles and sizes within a bunch train in an EMS with 4 FODO cells.

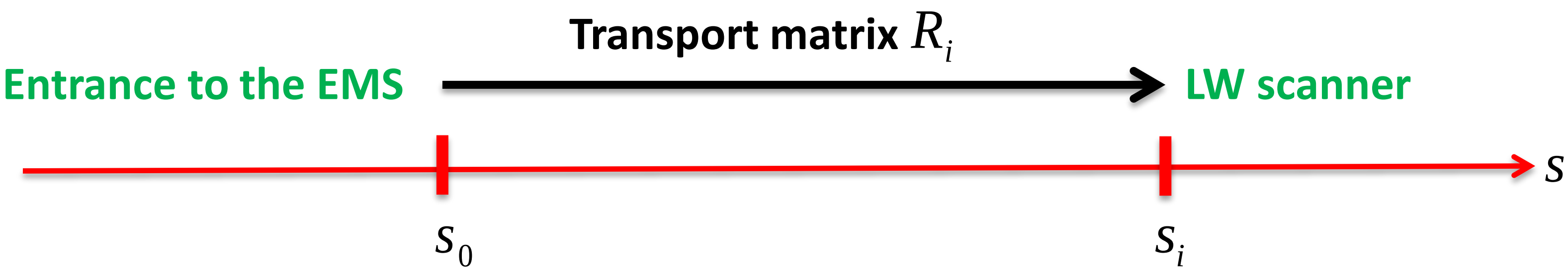
•2D emittance measurement scheme is proposed, i.e. the beam profiles are measured in the H- and V- planes only.

**Beam envelope matrix:**

$$\sigma = \begin{pmatrix} \Sigma_{x,x} & 0 \\ 0 & \Sigma_{y,y} \end{pmatrix}$$

**Projected (=intrinsic) emittances:**

$$\varepsilon_x = \sqrt{\det(\Sigma_{x,x})}, \qquad \varepsilon_y = \sqrt{\det(\Sigma_{y,y})}$$




- For an EMS with ***N*** laser wire (LW) scanners located at points $s_i$

$$\sigma_i = R_i \sigma_0 R_i^T, \qquad (i = 1,2,\ldots,N)$$

$$(\sigma_i)_{11} = (R_i)_{11}^2 (\sigma_0)_{11} - 2(R_i)_{11}(R_i)_{12}(\sigma_0)_{12} + (R_i)_{12}^2 (\sigma_0)_{22}$$

$$(\sigma_i)_{33} = (R_i)_{33}^2 (\sigma_0)_{33} - 2(R_i)_{33}(R_i)_{34}(\sigma_0)_{34} + (R_i)_{34}^2 (\sigma_0)_{44}$$

**Measurement of** $(\sigma_i)_{ab}$ → **Computation of** $(\sigma_0)_{ab}$ → **Determination of** $\varepsilon_x, \ \varepsilon_y$

- For ***N*>3** the system is overdetermined.
- The measured data may lead to non-physical solutions $\varepsilon^2 < 0$

**I. Agapov et al. Phys.Rev. ST (2007)**

## 2D emittance measurement scheme vs. 4D emittance measurement scheme:

- **Advantages of the 2D scheme:**
  - Each monitor measures only x- or y-beam size, no beam scan along a rotated axis is needed
  - Far less non-physical solutions are generated

- **Drawbacks of the 2D scheme:**
  - The beam at the entrance must be uncoupled, so a skew correction section must be added (L ~ 120m)

# EMS optics and simulations

**LW scanner**

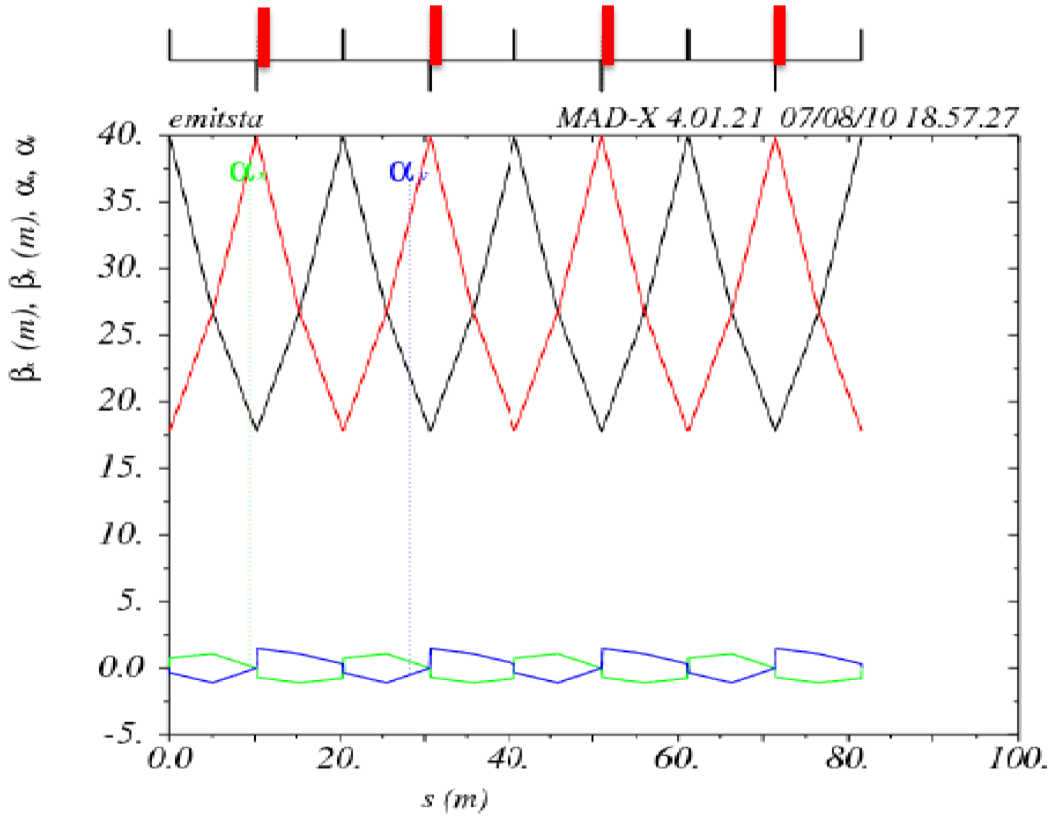
- **4 FODO cells**
- **Phase advance per cell**

$$\mu = 180^\circ / N$$

- **Restriction on the EMS length:**

$$L_{EMS} \geq \frac{\sigma_{\min}^2 \gamma}{\varepsilon_{N,y}} \frac{\sin\mu}{1+\sin\mu/2}$$

$$\approx 0.9 \left(\frac{\sigma_{\min}}{1\mu m}\right)^2 \text{ m}$$

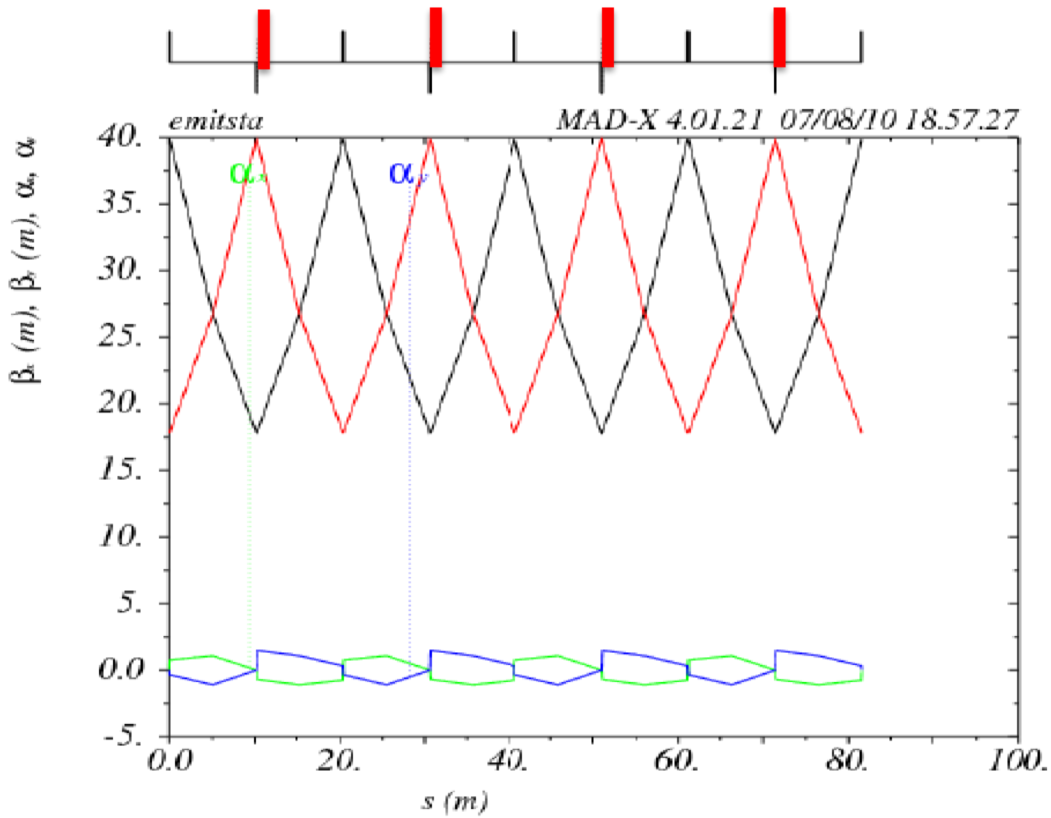



$$L_{EMS} \geq \frac{16\sin\mu/2}{k_Q l_q} = 81.6\left(\frac{0.075\,\text{m}^{-1}}{k_Q l_Q}\right)\text{m}$$

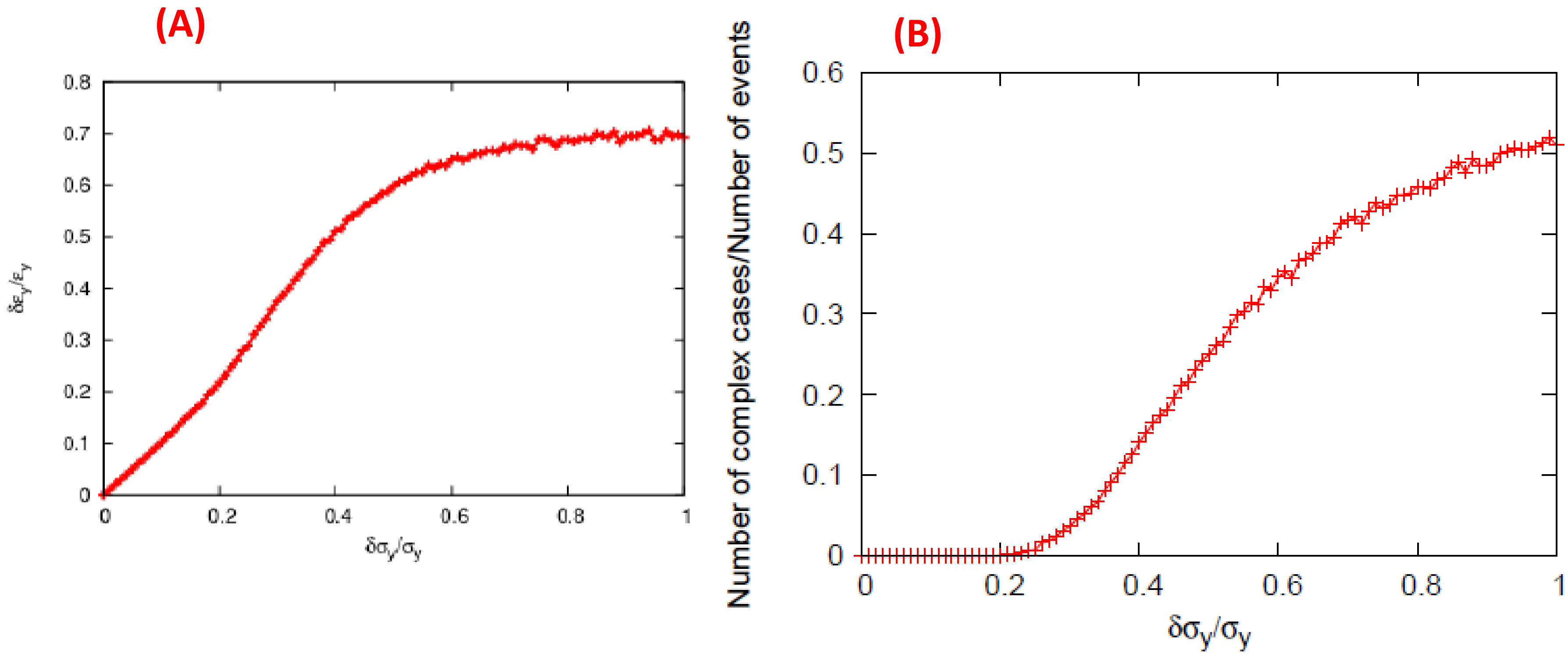
# EMS optics and simulations

## EMS lattice design parameters

| | |
|---|---|
| $L_{FODO}/2$ | 10 m |
| $L_{EMS}$ | 81.6 m |
| $l_Q$ | 0.20 m |
| $k_Q$ | $0.38\,\mathrm{m}^{-2}$ |
| $\beta_{max}$ | 39.8 m |
| $\beta_{min}$ | 17.8 m |



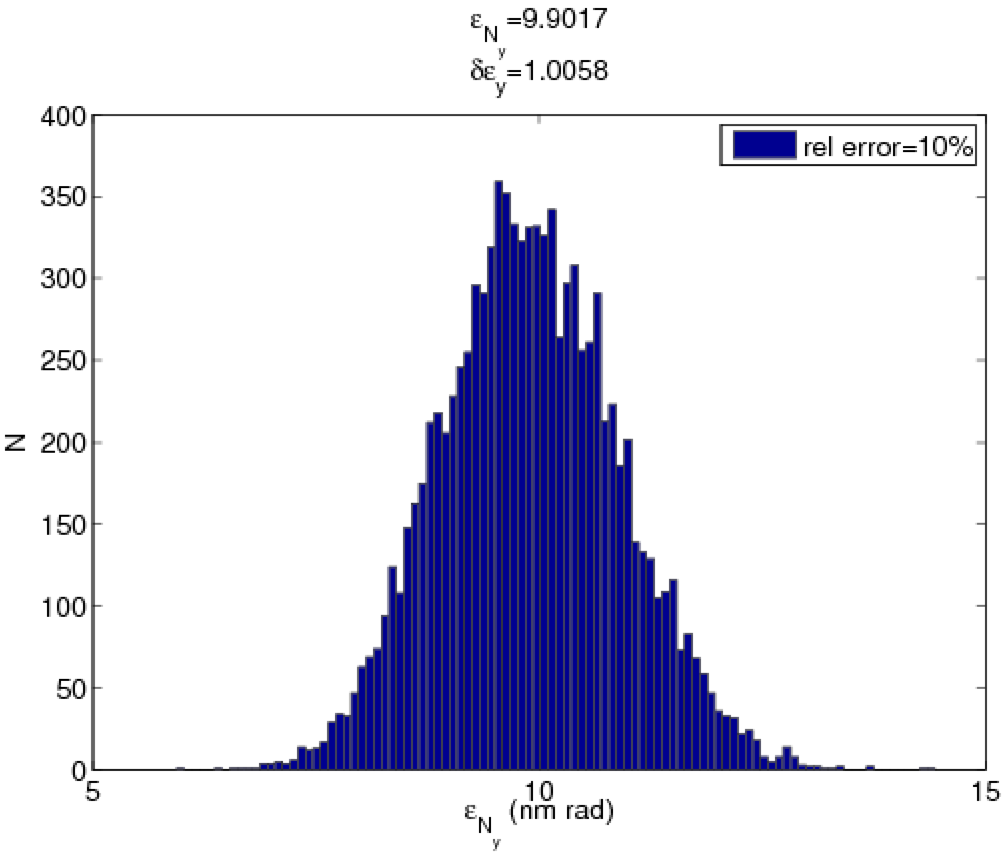
# EMS optics and simulations




**(A) Relative error of $\varepsilon_y$ measurement vs. relative beam size measurement error**

**(B) Fraction of simulations giving a non-physical beam matrix vs. relative beam size measurement error**

# EMS optics and simulations




**Distribution of reconstructed vertical emittance for 10% random relative beam size errors**

# New EMS simulation

Recent simulations attempt to describe beam size errors more realistically:

- Previous simulation assumes Gaussian distribution of beam size measurements
- This allows for negative beam sizes: Not physical
- Negative beams size not sufficient to produce imaginary emittance, so not rejected by simulation

Simulate laserwire system to obtain more accurate beam size distribution

- LW can get imaginary beam size due to deconvolution algorithm, but not –ve
- This will produce complex emittance measurement
- Simple simulation of LW system, but good enough for the modified simulation
- Fit Gaussian to intensity profile and deconvolute to obtain beam size measurement
- Reject measurement if $R^2$<50%; equivalent to retaking measurement if fit is poor in real system

Assumptions for new simulation:

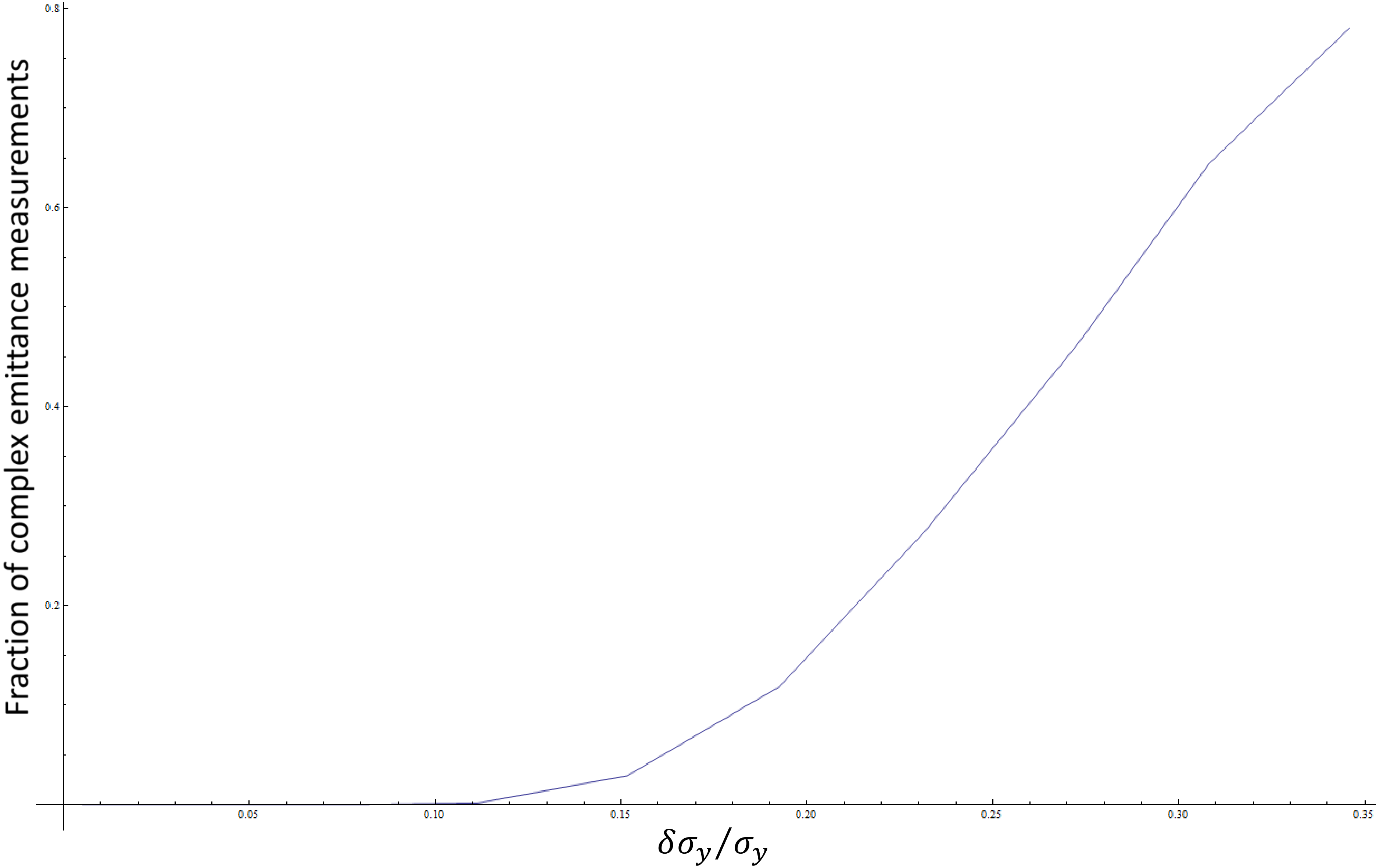
- Beam position changes for each LW intensity measurement point due to jitter
- Jitter Gaussian distribution
- Gaussian laser intensity profile
- Gaussian electron (or positron) intensity profile

Results:

For beam size errors >~30-40%, >80% of emittance measurements are complex

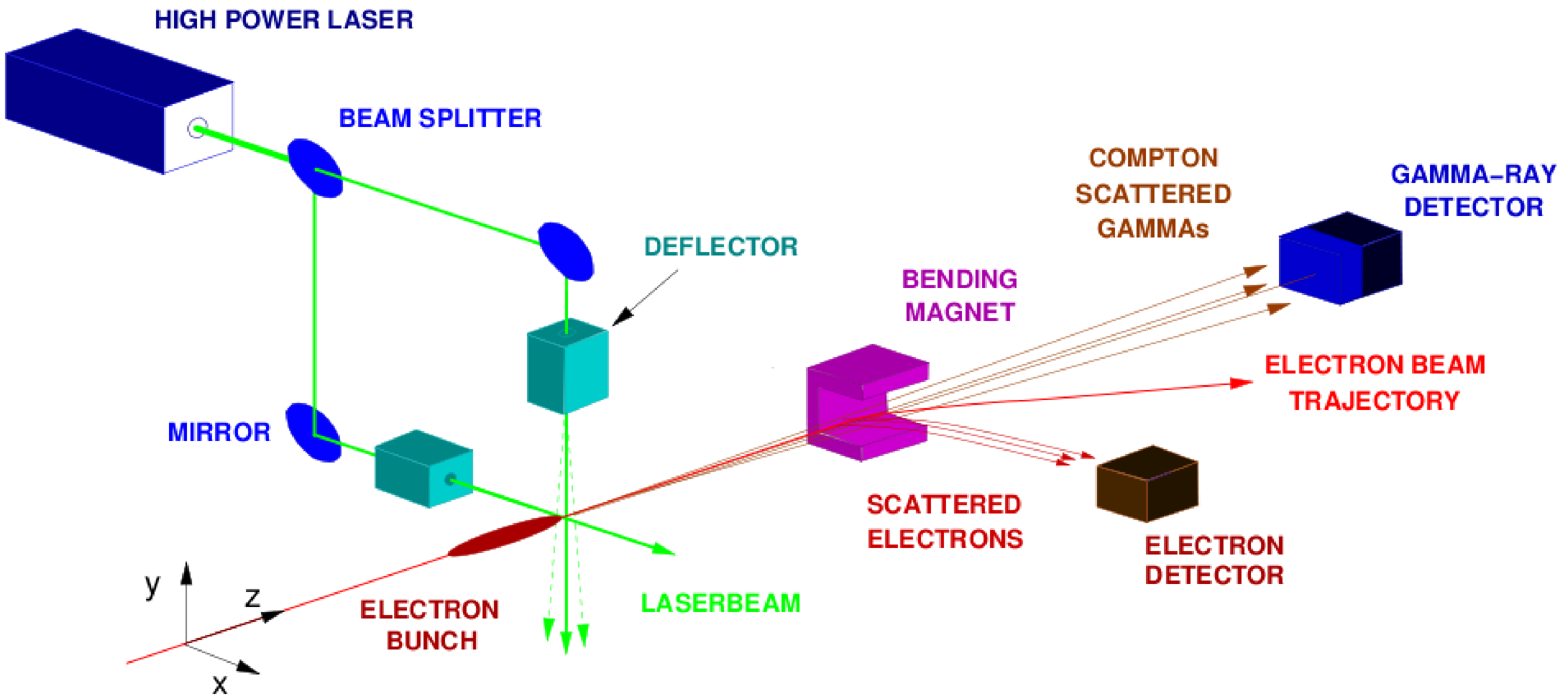
- Error on beam size measurement becomes meaningless
- For beam size errors <~30%, error on $\varepsilon_{x,y}$ agrees with previous study
- However number of unphysical results do not agree

# New EMS simulation



# LW beam profile monitor proposal

## General layout (ATF2, PETRA III)




**The LW method is based on the inverse Compton scattering of laser photons on electrons or positrons of the beam.**

# LW beam profile monitor proposal

**Main features:**

**Nd:YASG laser, λ=532 nm**
**Laser spot size 3 – 5 µm**
**Average laser power < 1 W**

| **Parameter** | **Mode locked** | **Q-switched** |
|---|---|---|
| Quality factor $M^2$ | 1 | 1.5 |
| Laser pulse duration | 0.15 ps | 5 ns |
| Pulse repetition freq. | 2 GHz | 50 Hz |
| Compton photons per laser pulse | 3200 | 250 |

$(\eta_{\text{det}} = 0.05)$

- **Bending dipole magnet with** $\int B ds = 0.75\,\mathrm{T \cdot m}$
- **Beam-gas bremsstrahlung photons** $N_{\gamma,B} = 0.18/1.8$ **per laser pulse (for** $D = 200\,\mathrm{m},\; P = 10\,\mathrm{nTorr}$**)**

**I. Agapov et al. Phys.Rev. ST (2007)**
**M. Price et al., EPAC-2006**

# LW beam profile monitor proposal

$$\sigma_{scan}^2 = \sigma_e^2 + \sigma_{jit}^2$$

$$\left(\frac{\delta\sigma_e}{\sigma_e}\right)^2 = \left(\frac{\delta\sigma_{scan}}{\sigma_{scan}}\right)^2 + \left(\frac{\delta\sigma_{jit}}{\sigma_{jit}}\right)^2$$

**The electron beam sizes extracted from the beam profile scan are**

$$\frac{\delta\sigma_{e,x}}{\sigma_{e,x}} < 0.003, \qquad \frac{\delta\sigma_{e,x}}{\sigma_{e,x}} < 0.06$$

$$\frac{\delta\varepsilon}{\varepsilon} < 0.1$$

# Concluding remarks

- Emittance measurements with the required precision using the LW method seem to be feasible.
- More detailed error study is necessary.
- Estimates of contributions of other effects (e.g. of the synchrotron radiation background) have to be added.
- Calculations for the EMS at other locations are missing.