Study of atomic beam interactions in fusion plasmas using the RENATE synthetic BES diagnostic

Gergő Pokol[1], Örs Asztalos[1], Borbála Szondy[1], Károly Tőkési[2]

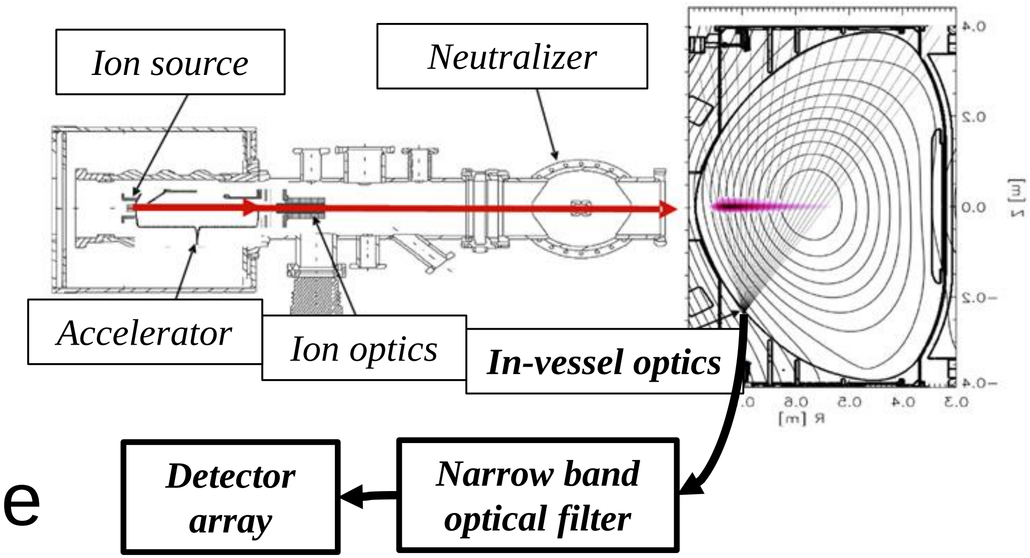
[1]Institute of Nuclear Techniques, Budapest University of Technology and Economics, Budapest, Hungary

[2]Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary

***1st IAEA Research Coordination Meeting on Data for Atomic Processes of Neutral Beams in Fusion Plasma*, 19-21 June 2017, IAEA Headquarters, Vienna**

BES diagnostics

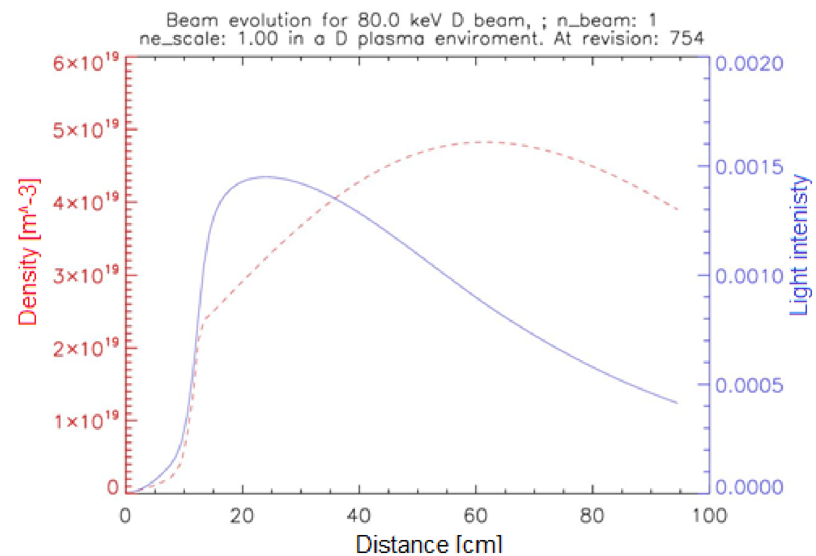
- **Active** plasma diagnostics procedure
- Use of H-like atoms such as D,Li,Na. (which posses **one valence electron**)
  - Heating beams (H, D)
  - Diagnostic beams (Li, Na)
- **Purpose:** density profile and fluctuation measurement



RENATE Simulation code

- Based on CR model:
  1. Quasi-static for H from Open ADAS (2010)
  2. Bundled-n for H from ALADDIN (2010) with corrections from E. Delabie, et al. PPCF 2010 → benchmarked with O. Marchuk's CRM (2011)
  3. l-resolved for Li from J. Schweinzer, et al. Atomic Data and Nuclear Data Tables 1999 → benchmarked with J. Schweinzer's simula (2007)
  4. l-resolved for Na from K. Igenbergs, et al. Atomic Data and Nuclear Data Tables 2008

→ Revise cross-section data?



Rate equations for beam-plasma collisional radiative model

Collisional terms Electron collisions

$$\frac{dn_i(x)}{dx} = n_e(x)\Bigg[-n_i(x)\Bigg(\sum_{j=i+1}^{m}\frac{R_{i\to j}^{e-ex}(T_e(x))}{v_B}+\sum_{j=0}^{i-1}\frac{R_{i\to j}^{e-dex}(T_e(x))}{v_B}+\frac{R_{i\to +}^{e-ion}(T_e(x))}{v_B}\Bigg)+\Bigg(\sum_{j=0}^{i-1}n_j(x)\frac{R_{j\to i}^{e-ex}(T_e(x))}{v_B}+\sum_{j=i+1}^{m}n_j(x)\frac{R_{j\to i}^{e-dex}(T_e(x))}{v_B}\Bigg)\Bigg]+$$

$$+\sum_I n_I(x)\Bigg[-n_i(x)\Bigg(\sum_{j=i+1}^{m}\frac{R_{i\to j}^{I-ex}(T_I(x))}{v_B}+\sum_{j=0}^{i-1}\frac{R_{i\to j}^{I-dex}(T_I(x))}{v_B}+\frac{R_{i\to +}^{I-ion}(T_I(x))}{v_B}+\frac{R_{i\to +}^{I-CX}(T_I(x))}{v_B}\Bigg)+\Bigg(\sum_{j=0}^{i-1}n_j(x)\frac{R_{j\to i}^{I-ex}(T_I(x))}{v_B}+\sum_{j=i+1}^{m}n_j(x)\frac{R_{j\to i}^{I-dex}(T_I(x))}{v_B}\Bigg)\Bigg]-$$

$$-n_i(x)\sum_{j=0}^{i-1}\frac{A_{i\to j}}{v_B}+\sum_{j=i+1}^{m}n_j(x)\frac{A_{j\to i}}{v_B}$$

$$(i = 0, 1, \ldots, m)$$

Loss terms

Source terms

Spontaneous emission

Ion collisions

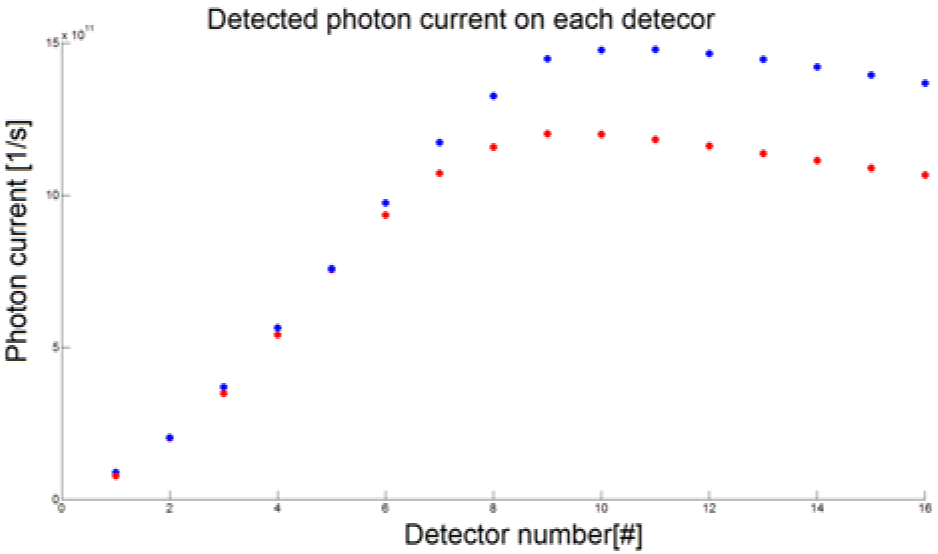
$$R_{particle}^{reaction} = \iiint \sigma_{reaction}(|\mathbf{v}-\mathbf{v}_{beam}|)|\mathbf{v}-\mathbf{v}_{beam}|f_{particle}(\mathbf{v})d^3\mathrm{v}$$

→ **Effect of non-thermal particle populations?**

Treatment of unmonitored atomic levels

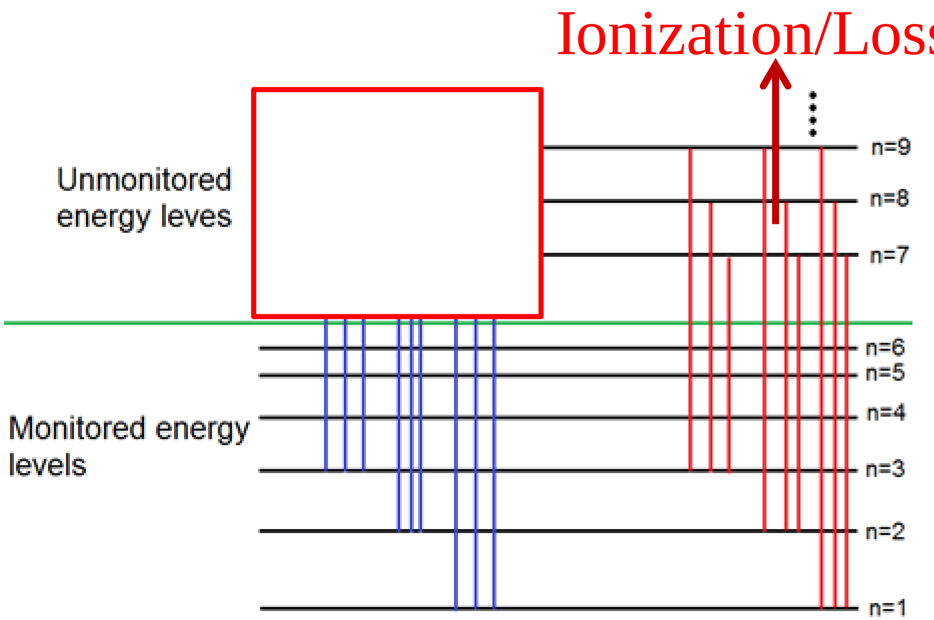
Comparison of rate equation solvers:

- old method by RENATE
- method by B. Geiger, PhD Thesis, 2012



Difference:

- Accountability for electron loss from monitored levels to unmonitored levels



→ Optimize number of monitored levels – E field limit?

→ Treat bound levels not taken into account in CR modell?

RENATE development

Diagnostics design and prediction tool

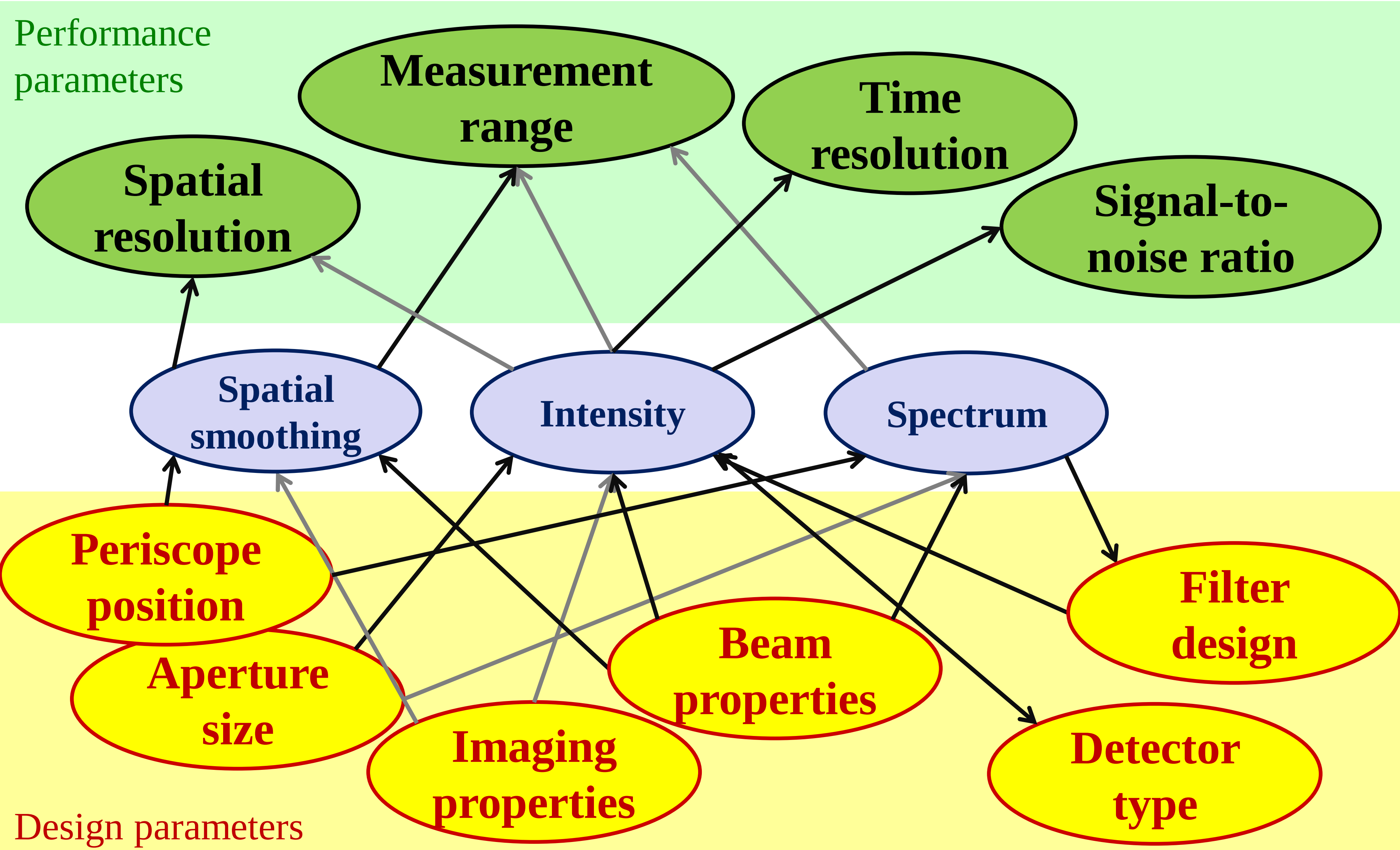
- Modelling for **COMPASS**, **TEXTOR**, **KSTAR**, **JET**
- Modelling of **W7-X** observation geometry
- Modelling and predicting **JT-60SA** observation geometries (LiBES and DBES)
- Modelling of **EAST** observation geometries (LiBES and DBES)
- Modelling of **ITER** BES fluctuation system
- Modelling of **MAST** observation geometries

Study of plasma turbulence

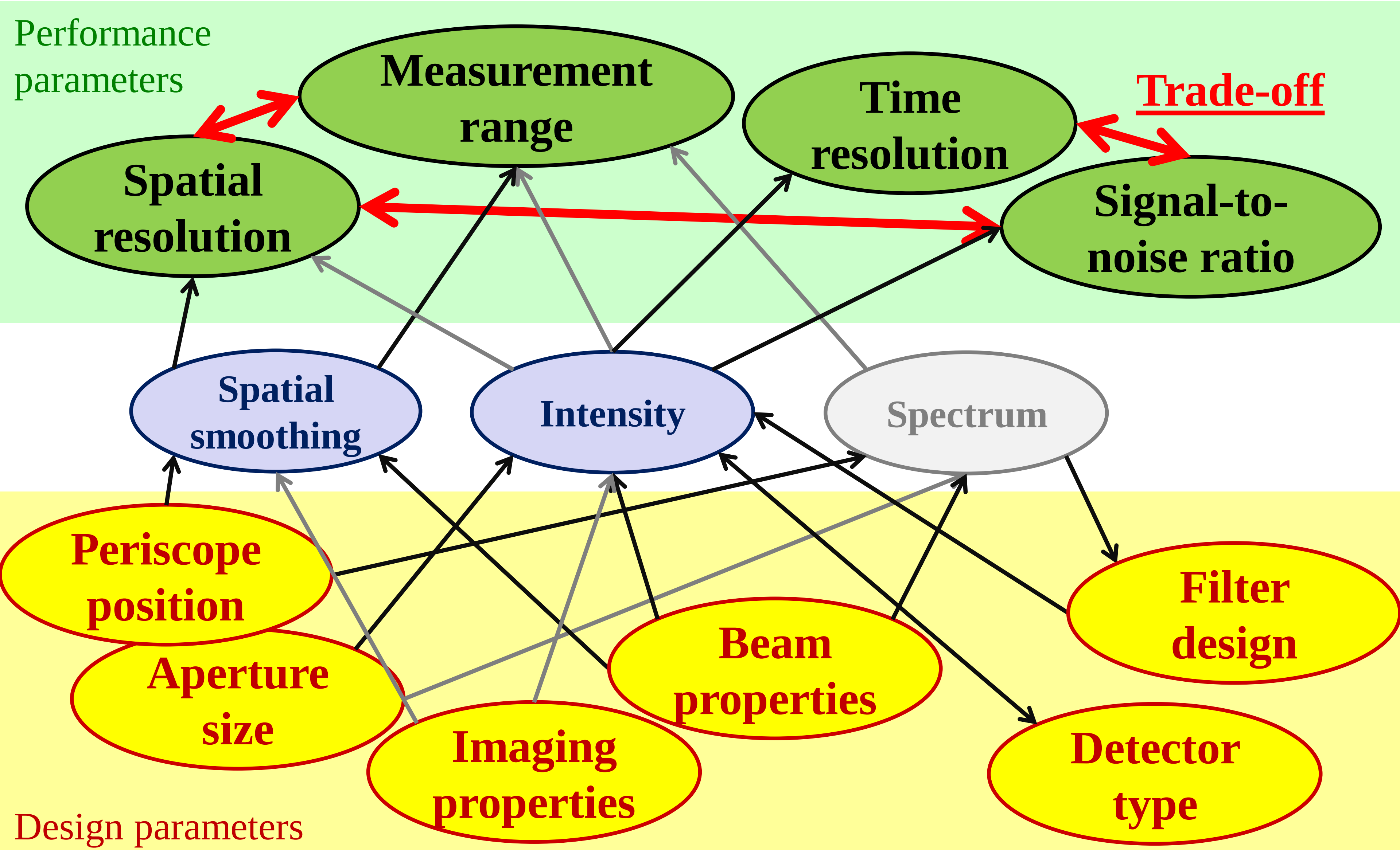
- **Synthetic diagnostics**
  - SOL and edge plasma turbulence
  - Plasma core turbulence
- **Fluctuation response** calculation and perturbation reconstruction
- Integration into **EU – IM, IMAS** in progress - RENATE Open Diagnostics

→ Extend range of validity to ~ MeV energy heating beams?

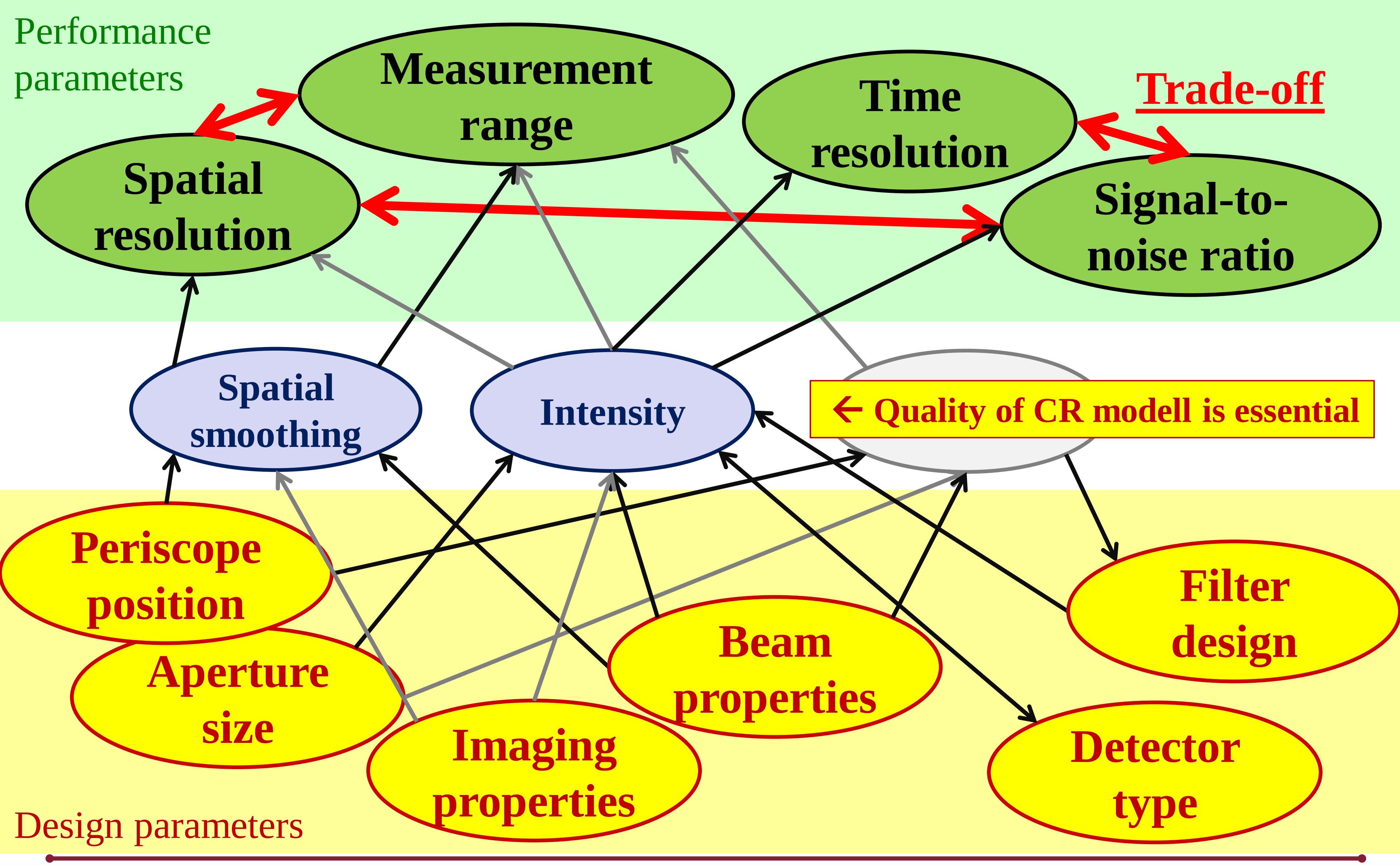
Parameters of a fluctuation BES system



Trade-offs in performance parameters



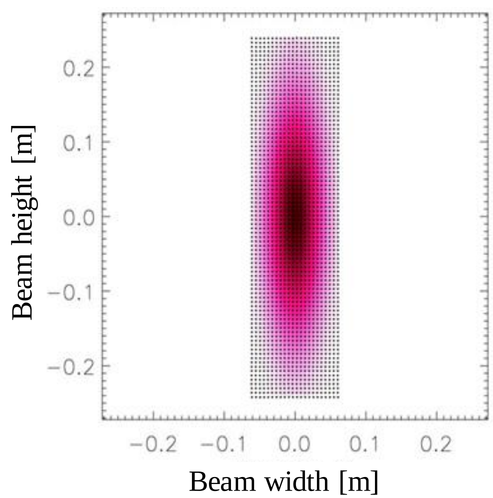
Trade-offs in performance parameters

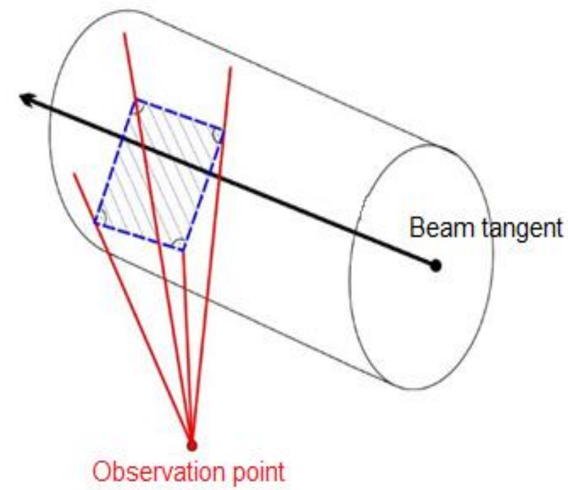


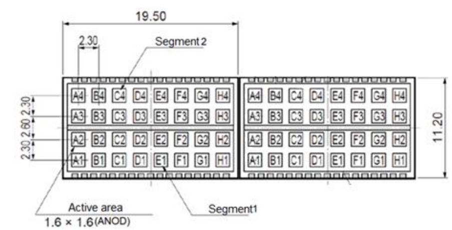
3D modelling by RENATE

- Various **3D beam geometries represented by an array of 1D beamlets**:
  - Elliptical
  - Rectangular
- Pinhole optics creates **observation profiles** for arbitrary detector set-ups
- Observation cones integrate emission resulting in **synthetic BES signals**
- RENATE models any **observation geometry**
- Alternative observation modelling by **optical transfer matrices provided by optical design software**

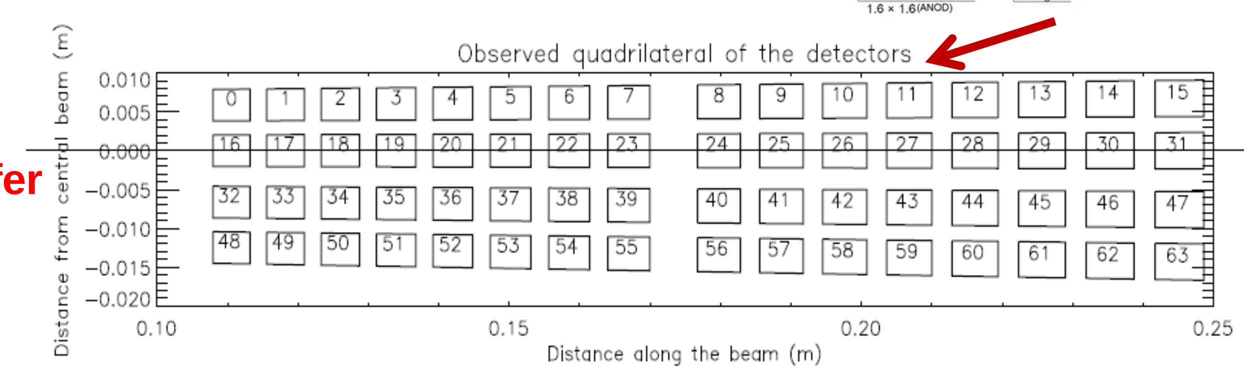
Elliptical beam





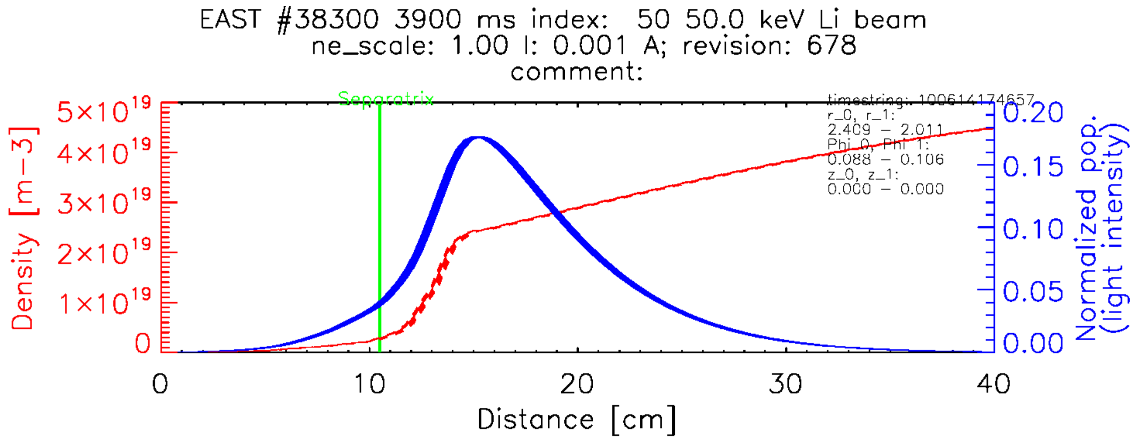


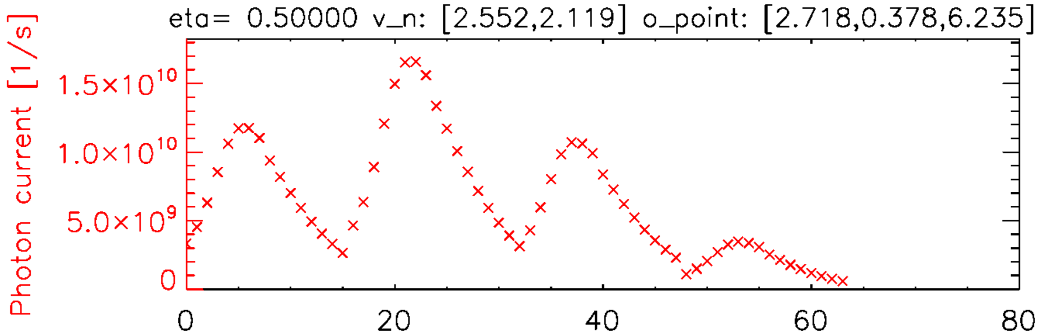
Detector Array Projection



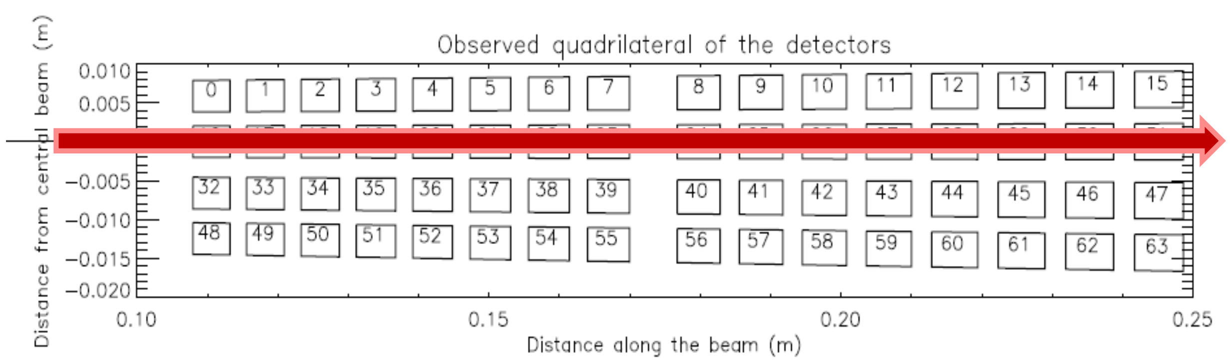
Intensity modelling by RENATE

- **3D beam** and **3D pinhole observation** modelled
- Delivers **estimated photon current** on each detector
- Determines **SNR** for given detector type and sampling time.



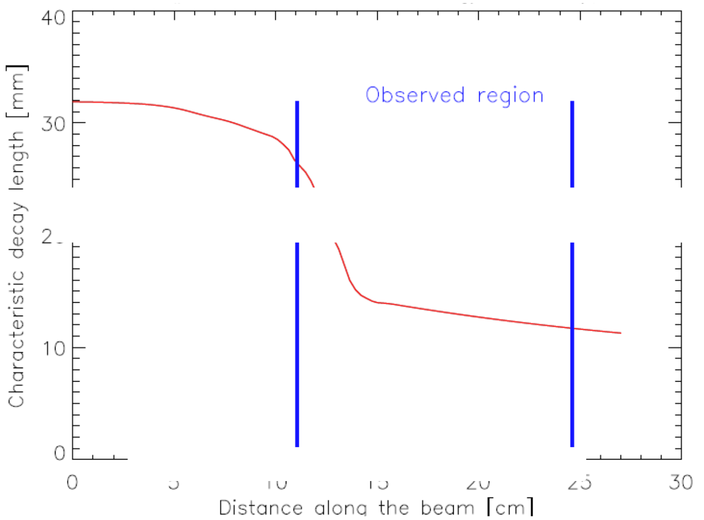


Beam direction

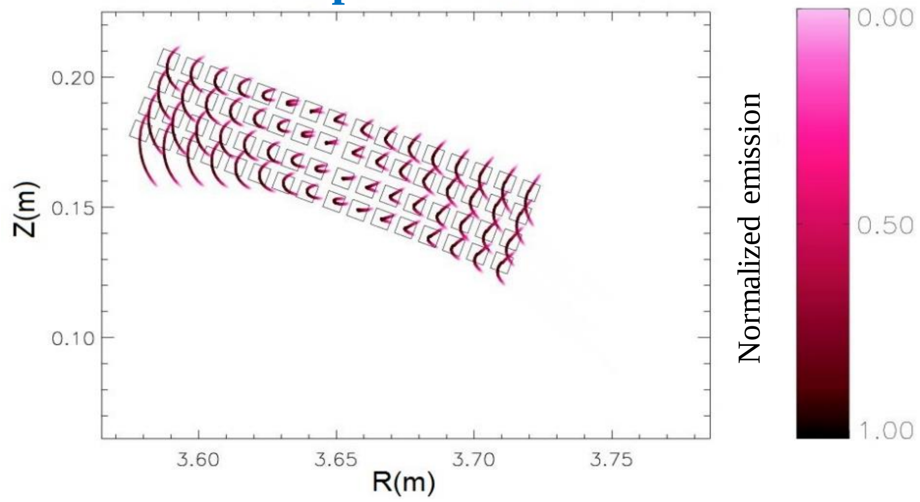


Spatial resolution modelling by RENATE

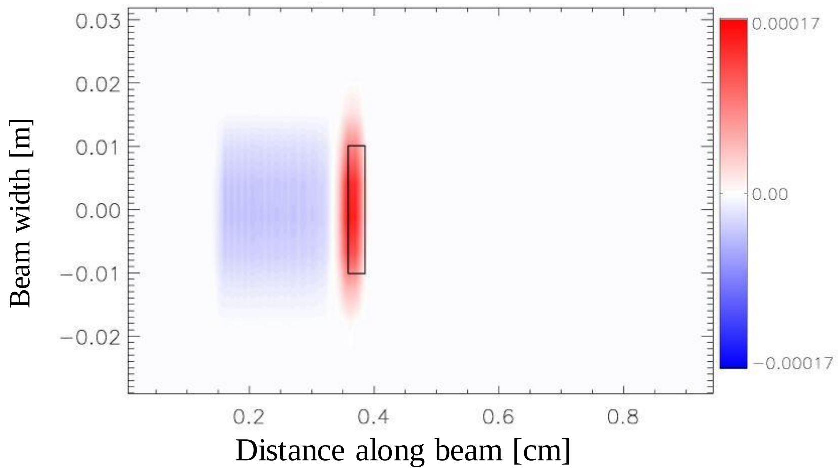
Finite lifetime of atomic levels



Point Spread Function

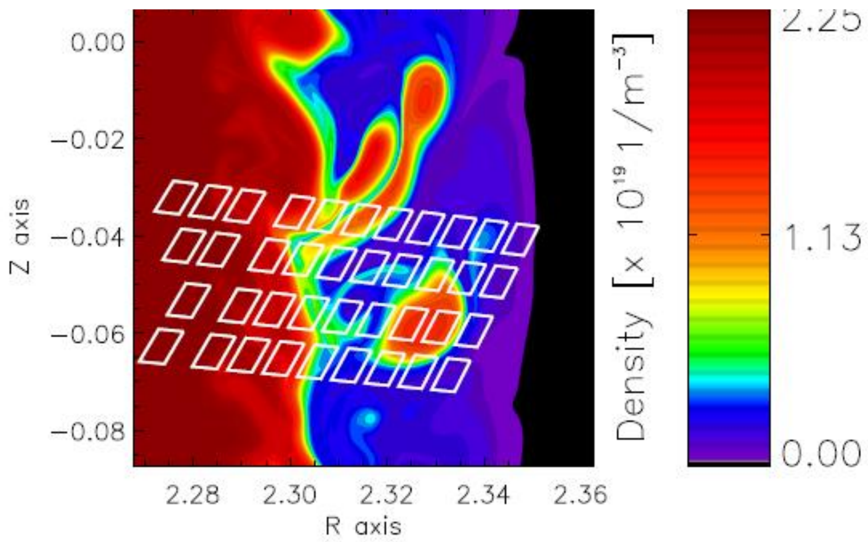


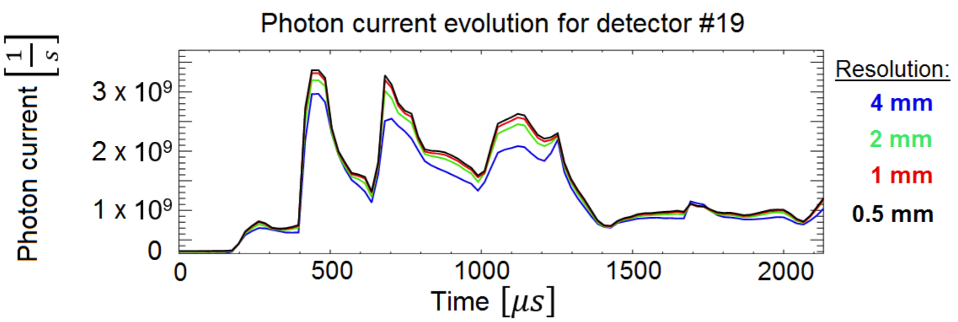
Fluctuation response calculation

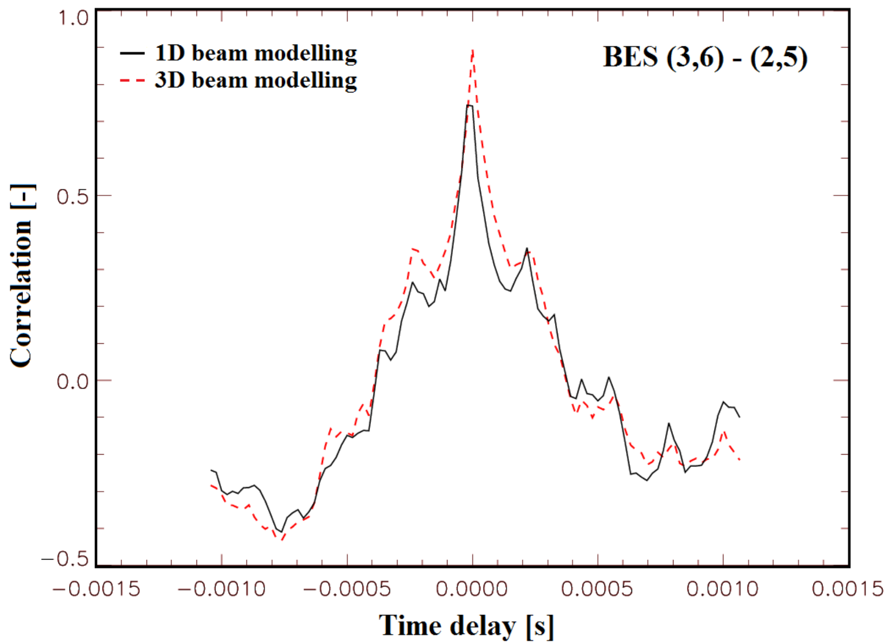


- **Components of spatial resolution:**
  - **Detector projection**
  - **Finite lifetime of levels**
  - **Point Spread Function: LOS and field line misalignment**
- **Fluctuation response** calculation to be used for the reconstruction of density perturbation from light fluctuations

Synthetic diagnostic for HESEL







- <u>**Synthetic diagnostics set-up**</u>:
  - **2D** density and temperature **profiles extended along field lines**
  - **3D RENATE modelling**
- <u>**Results**</u>:
  - **Simulated signals** for each detector segment
  - **Processing like measured signals**
- Works for any modelled plasma region

→ Effect of collisions with neutrals?

Planned activities

1. Participate in **Code Comparison Workshop on Neutral Beam Penetration and Beam-based Photoemissions**

2. Learn about **most recent available cross-sections**

3. Extend **range of validity to high energy** heating beams

4. Explore the effect of **number of levels taken into account**. (Explore upto the theoretical **maximum energy bound level** in given electric field.)

5. Explore the best way to treat **bound levels not taken into account** in the CR modell – **non-existent / ionized** / ?

6. Investigate the effect of **non-thermal particle populations**

7. Investigate the effect of **collision with neutrals**

8. Further effects that might have significance?

Required atomic physics expertise is expected to be delivered by Károly Tőkési (ATOMKI, Debrecen), and any interested collaborators.

→ ***Further activities proposed by Károly in next presentation***