中国科学技术大学
University of Science and Technology of China

Design of a soft X-ray imaging system and tomography analysis based on Bayesian principle

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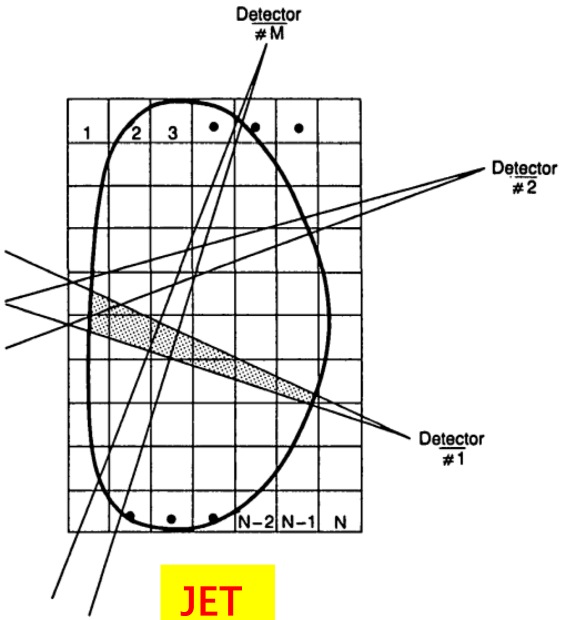
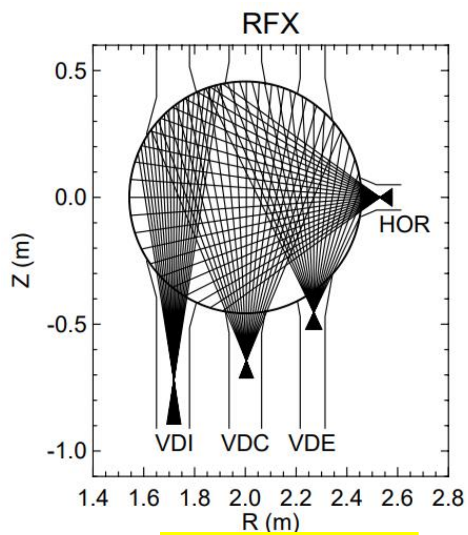
Outline

- Background
- Bayesian experimental design
- Bayesian tomography analysis
- Summary

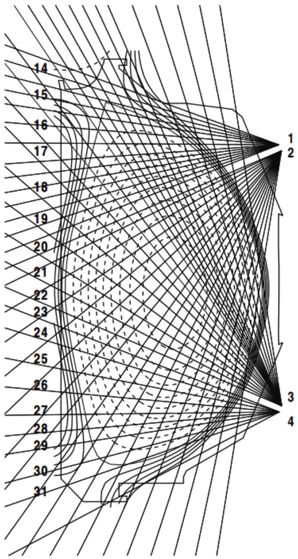
Soft X-ray tomography



JET



RFX-mod



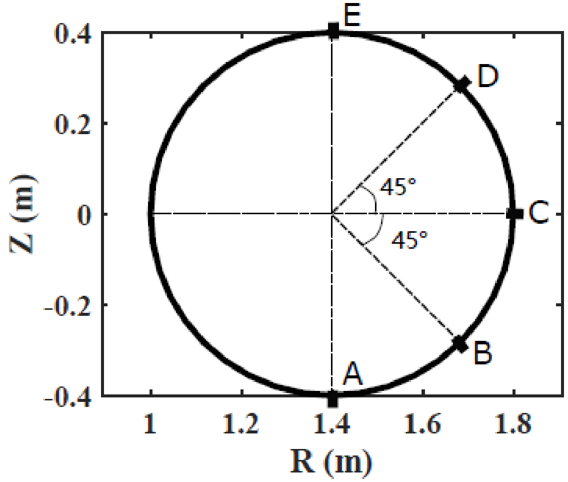
DIII-D

- SXR tomography is widely used in fusion device
- SXR tomography can get the 2d image quickly
- SXR tomography has non-invasive character

Keda Torus eXperiment (KTX)

Keda Torus eXperiment

Windows for SXR



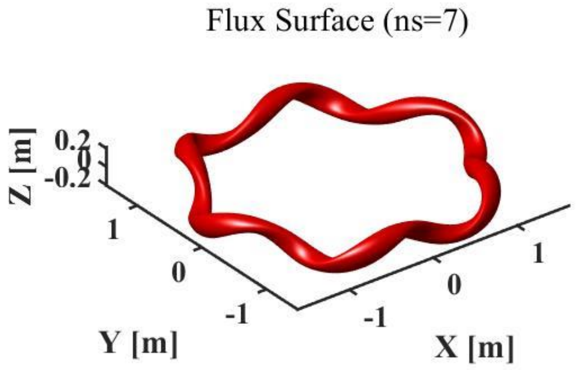
Reversed field pinch

parameters	KTX
Major radius R (m)	**1.40**
Minor radius a (m)	**0.40**
R/a	3.5
Thickness of conductive shell (mm)	1.5
Poloidal magnetic flux	3~5Wb
Loop voltage V_{loop}(V)	10~50
Plasma density ($10^{19}m^{-3}$)	**2**
Electronic temperature T_e (eV)	**300 (Phase I)**
Maximum toroidal field Bt (T)	**0.35 (Phase I)**

Purpose of SXR design

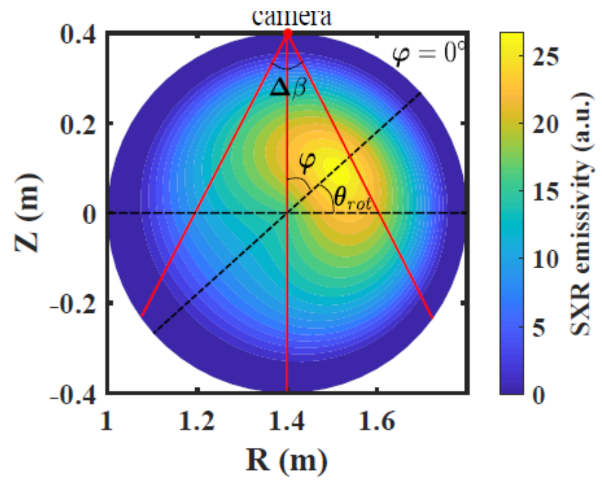
flux surface of QSH state

Quasi-single-helical states is an important way to improve the confinement of RFP and it will be studied on KTX in the future



Requirement

- Get enough information of changed QSH states
- Get the 2d image of QSH states
- Use less resources (camera location, sight line)



Meet requirements with as few resources as possible!

Outline

- ◆Background
- ◆Bayesian experimental design
- ◆Bayesian tomography analysis
- ◆Summary

Bayesian experimental design

$$p(X|Y,I) = \frac{p(Y|X,I) \cdot p(Y|I)}{p(X|I)}$$

Bayesian theory

$$P(\alpha|\eta) = \frac{1}{\alpha_{max} - \alpha_{min}}$$

$$P(D|\alpha,\eta) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{(D - f(\alpha))^2}{2\sigma^2})$$

α: interest parameters –plasma edge

η: design parameters – sightline

D: experimental data

$$p(\alpha|D,\eta) = \frac{p(D|\alpha,\eta) \cdot p(\alpha|\eta)}{p(D|\eta)}$$

The probability for interest parameters

Bayesian experimental design

information theory

$$EU(\eta) = \int dD\, p(D|\eta)U(D|\eta)$$

The information gain of η

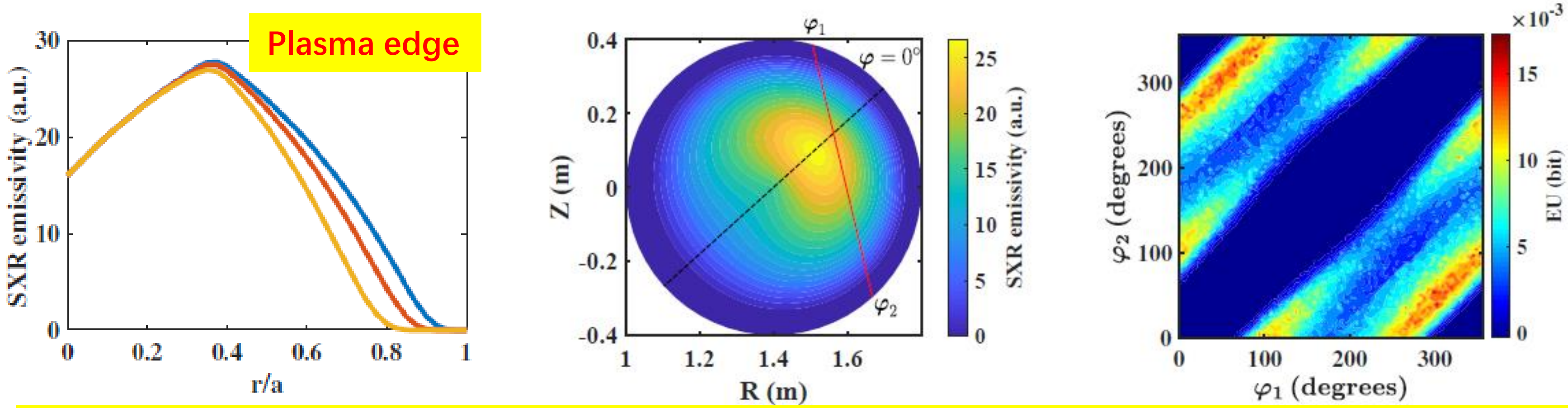
Bayesian theory

$$EU(\eta) = \iint dD d\alpha P(D|\alpha,\eta)P(\alpha)\log[\frac{P(D|\alpha,\eta)}{P(D|\eta)}]$$

α: interest parameters –plasma edge

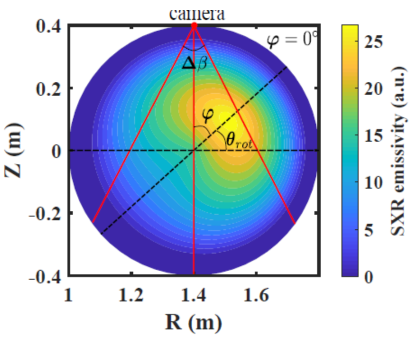
η: design parameters – sightline

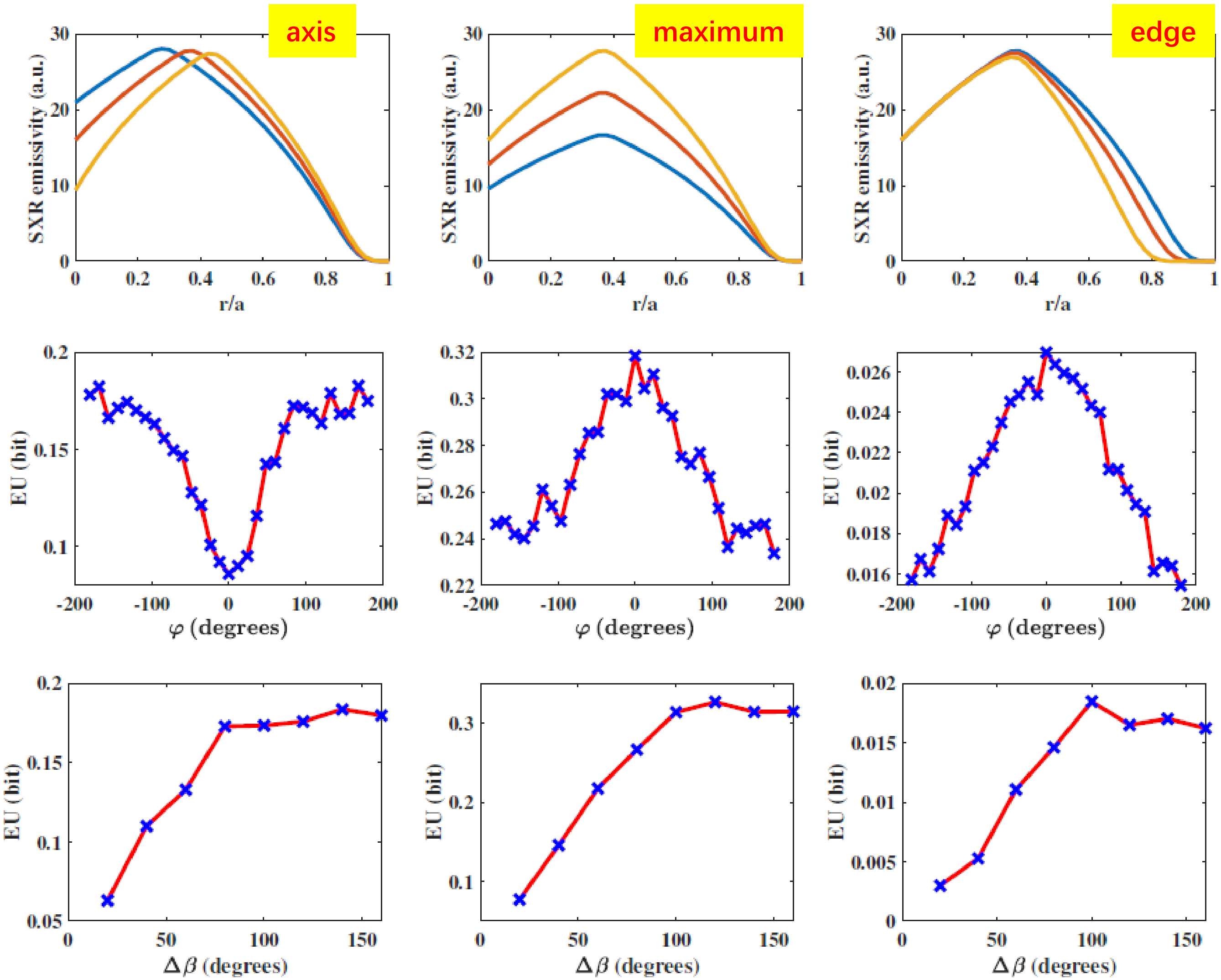
D: experimental data – SXR emissivity



The BED approach allows us to quantitatively evaluate the performance of the design, and to estimate the design robustness

SXR sightline design



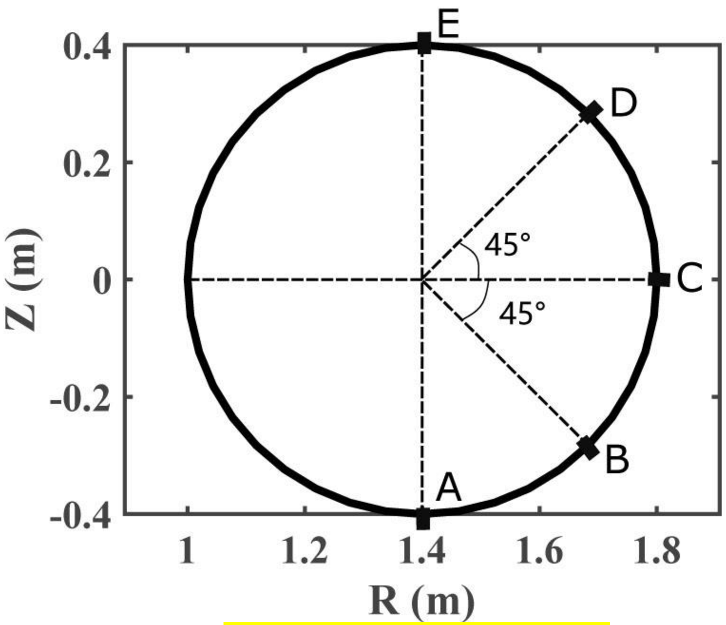


Camera location

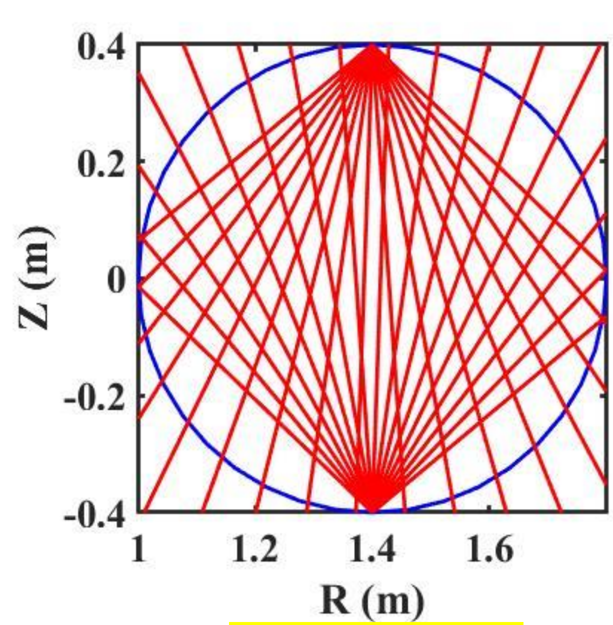
Camera opening angle

SXR sightline design

Camera location: $\varphi = 0^{\circ}, \varphi = 180^{\circ}$
Camera opening angle: $\Delta\beta = 100^{\circ}$



Windows for SXR



Sight design

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Tomography Reconstruction

$$p(\alpha|D,\eta) = \frac{p(D|\alpha,\eta) \cdot p(\alpha|\eta)}{p(D|\eta)}$$

$$p(g|f,\theta) = \frac{p(f|g) \times p(g|\theta)}{p(f|\theta)}$$

g: interest parameters – emissivity distribution

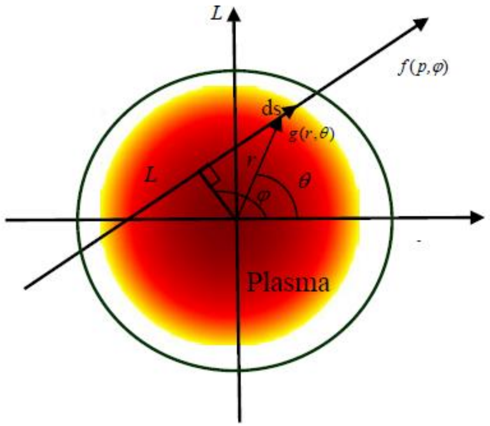
θ: design parameters – reconstruction method

f: experimental data – brightness

Get g from f

Cormark-Bessel method

$$f(p,\varphi) = \int_{L(p,\varphi)} g(r,\theta)dl$$



Tomography Reconstruction

$$g(r,\theta) = \sum_{m=0}^{\infty}\sum_{l=0}^{\infty}[a_m^{(c)l}\cos(m\theta) + a_m^{(s)l}\sin(m\theta)]g_m^l(r)$$

Expend in Fourier series

$$f(p,\varphi) = \sum_{m=0}^{\infty}\sum_{l=0}^{\infty}[a_m^{(c)l} f_m^{(c)l}(p,\varphi) + a_m^{(s)l} f_m^{(s)l}(p,\varphi)]$$

$$f_m^{(c,s)l}(p,\varphi) = \int_L (\cos(m\theta), \sin(m\theta))g_m^l(r)ds$$

$$g_m^l(r) = J_m(\lambda_m^{l+1}r)$$

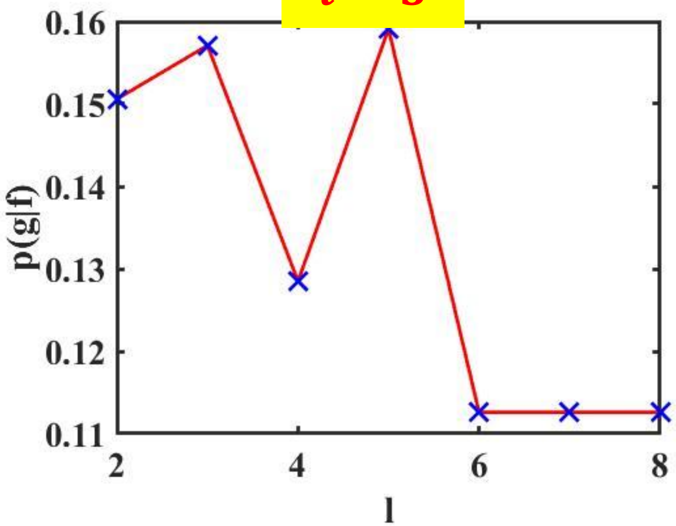
λ_m^l is the lth zero of mth Bessel function

Parameters of method

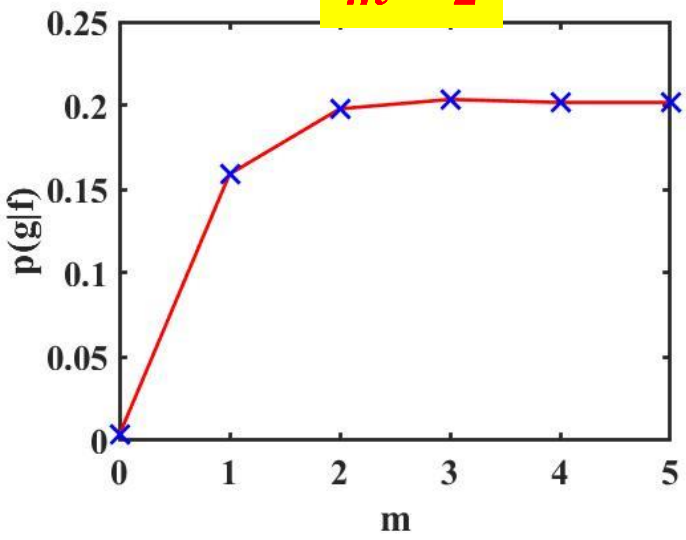
$$f_m^{(c,s)l}(p,\varphi) = \int_L (\cos(m\theta), \sin(m\theta)) g_m^l(r) ds$$

$$p(g|f,\theta) = \frac{p(f|g) \times p(g|\theta)}{p(f|\theta)}$$

$l = 5$



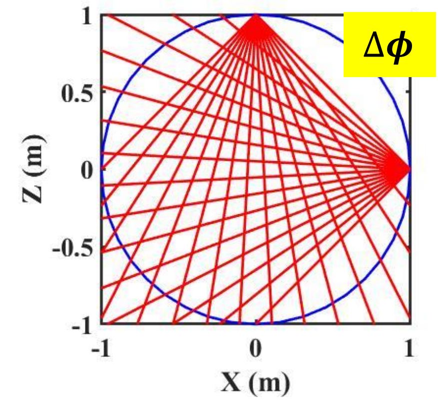
$m = 2$

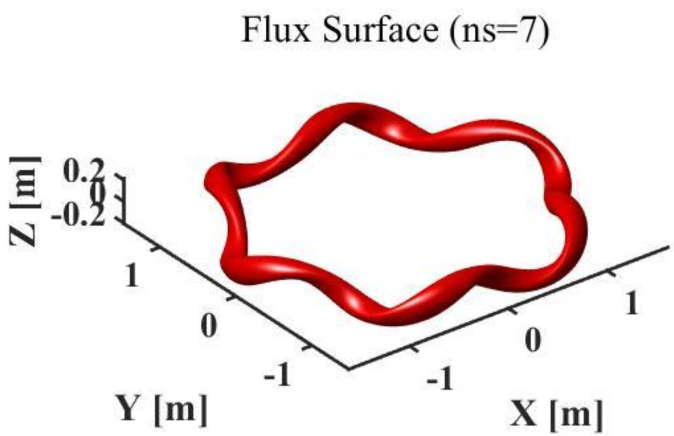


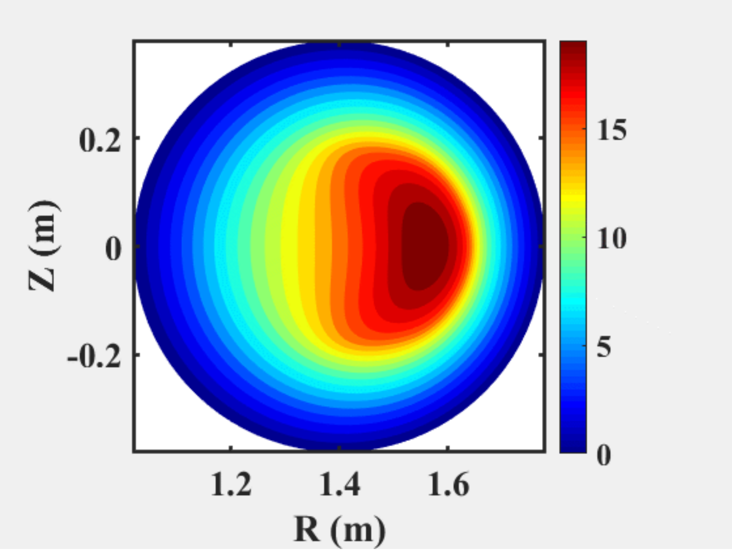
Tomography analysis

The reconstruction of QSH states need at least 2 SXR cameras

$\Delta\phi$ is the angle between 2 camera

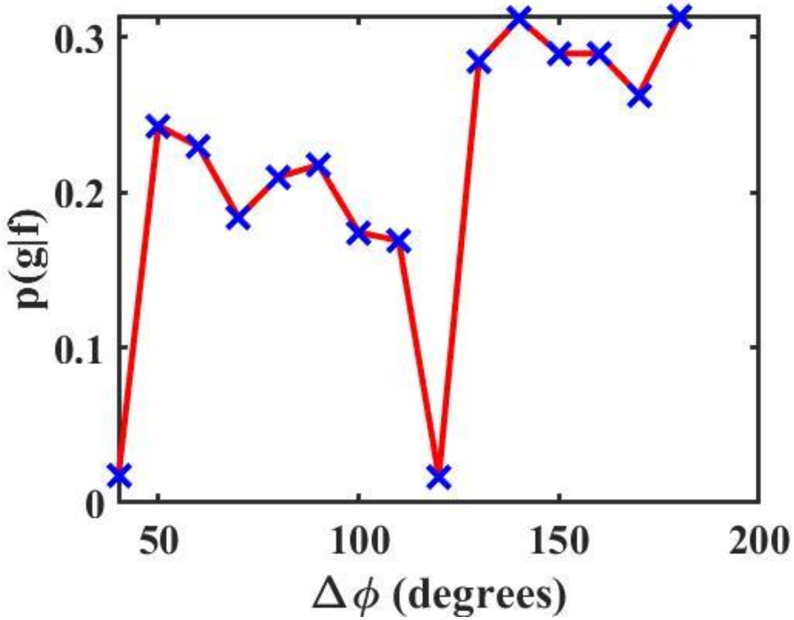




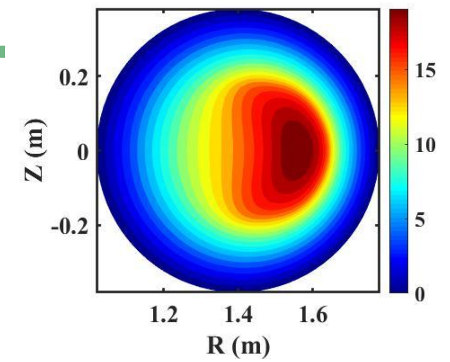


Tomography analysis

- It can be divided into two parts with $\Delta\phi = 130^0$
- Part 1 has a peak at $\Delta\phi = 60^0$
- Part 2 has a peak at $\Delta\phi = 180^0$

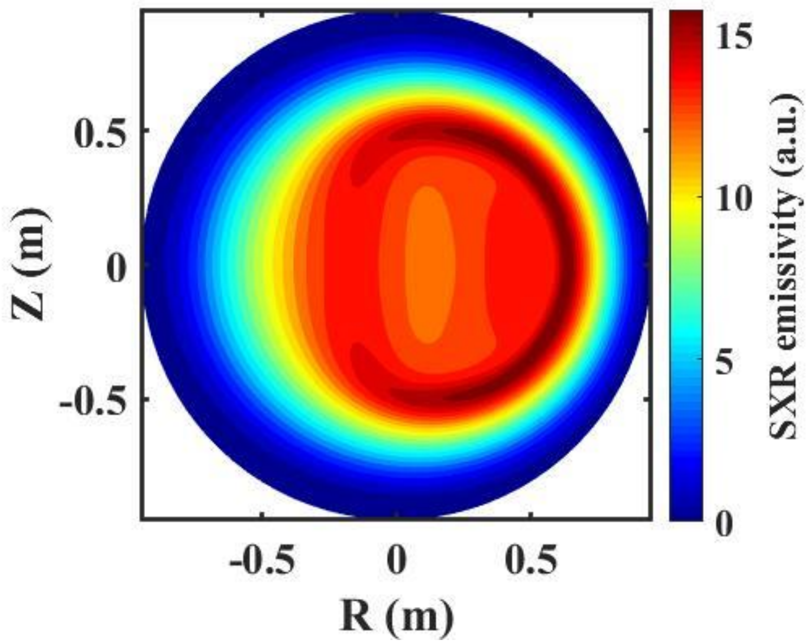


2D image of SXR

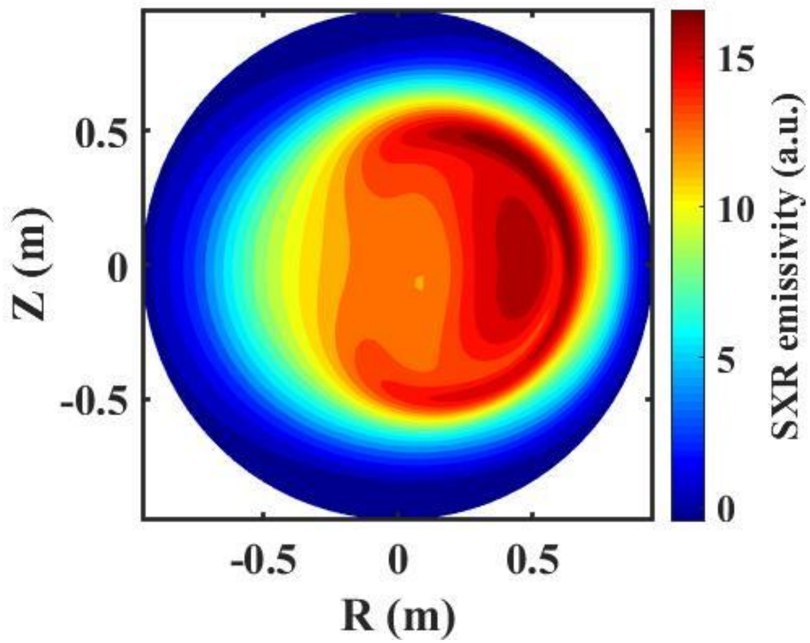


We choose $\Delta\phi = 180^0$

$\Delta\phi = 60^0$



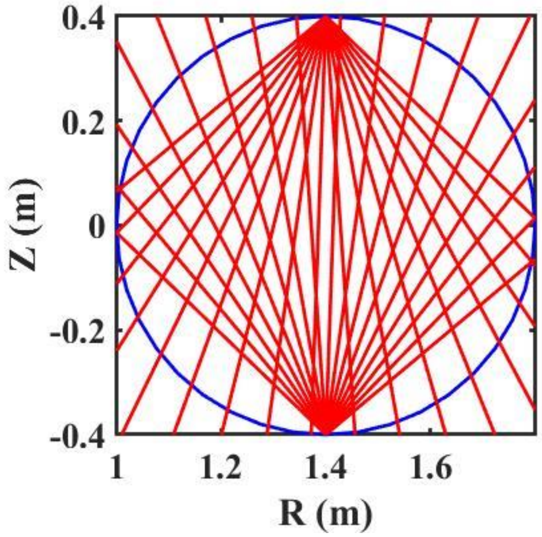
$\Delta\phi = 180^0$



Summary

- The experimental design is accomplished with two windows and open angle 100°
- The BED approach allows us to quantitatively evaluate the performance of the design, and to estimate the design robustness.
- The Bayesian theory can be used to analyse the tomography reconstruction and we use it to modify the reconstruction method and do two camera design.

Design result



Thank you!