A synthetic diagnostic for coherent electromagnetic scattering

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Acknowledgements

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Outline

- ETG turbulence simulations vs high-k turbulence measurements
- Structure of a synthetic diagnostic for coherent electromagnetic scattering
- Example of application on a case study, shot 124901

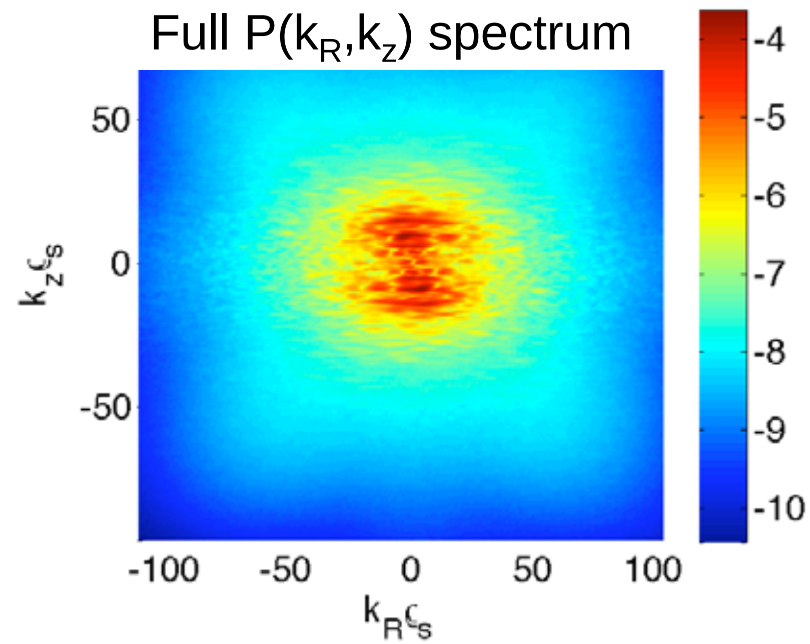
Simulations of ETG turbulence

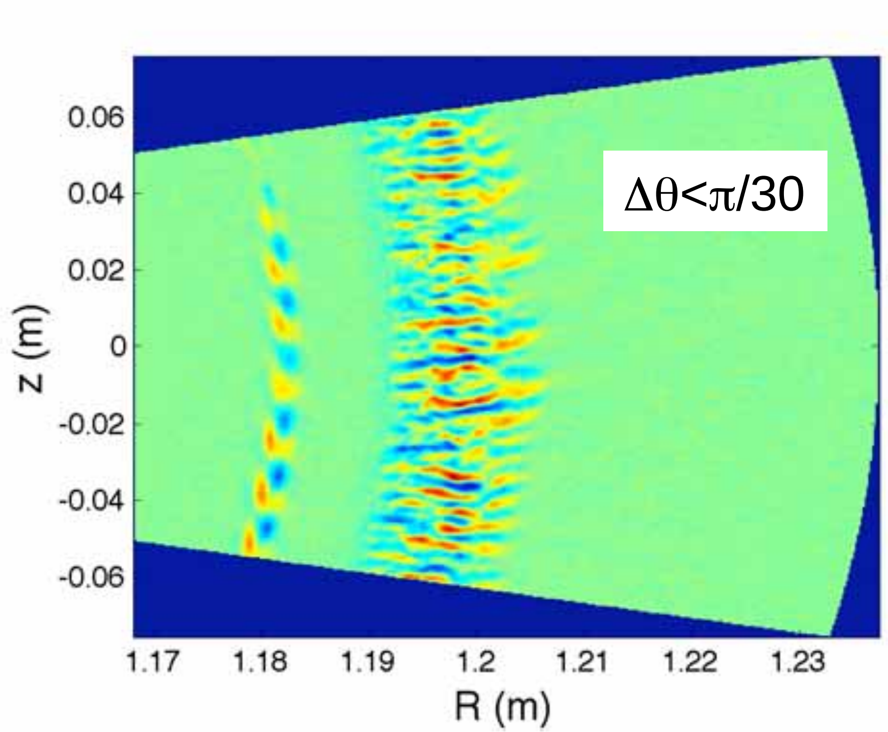
Full poloidal cross-section

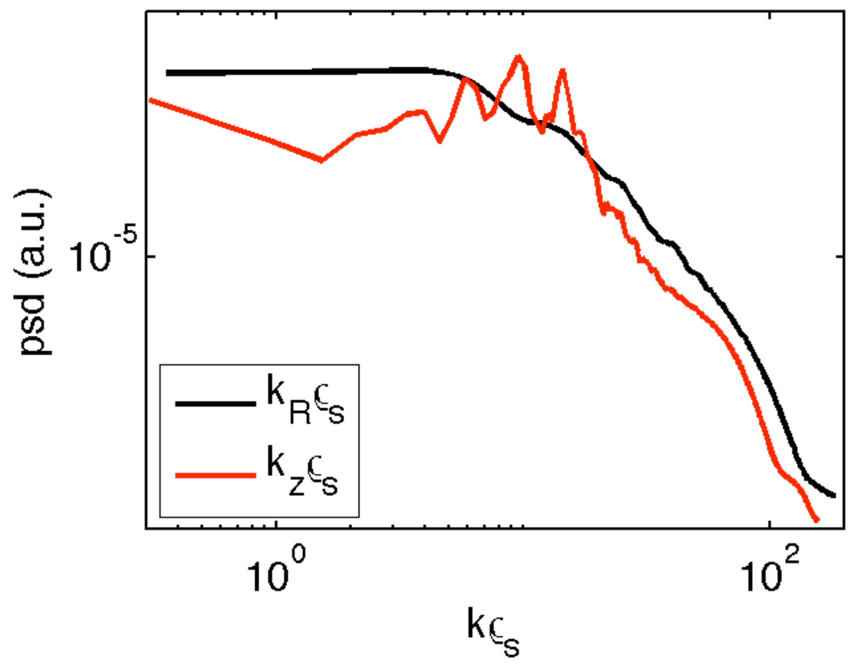
64 planes, toroidally separated

$\delta t = 0.1 L_T/v_{th} \sim 10^{-2}\ \mu s$

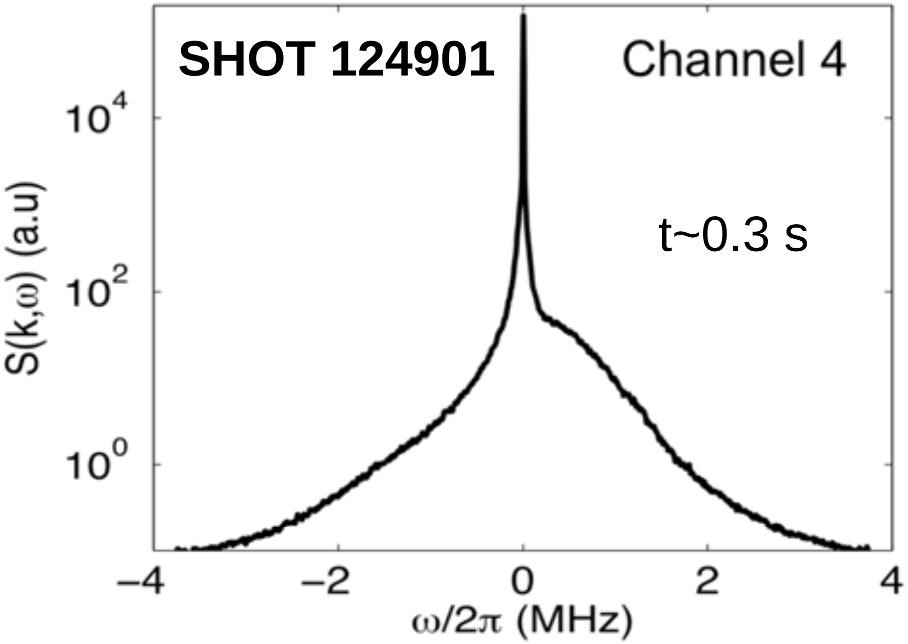
@ L_T =10cm, v_{th}=10^8cm/s







Measurements of high-k turbulence

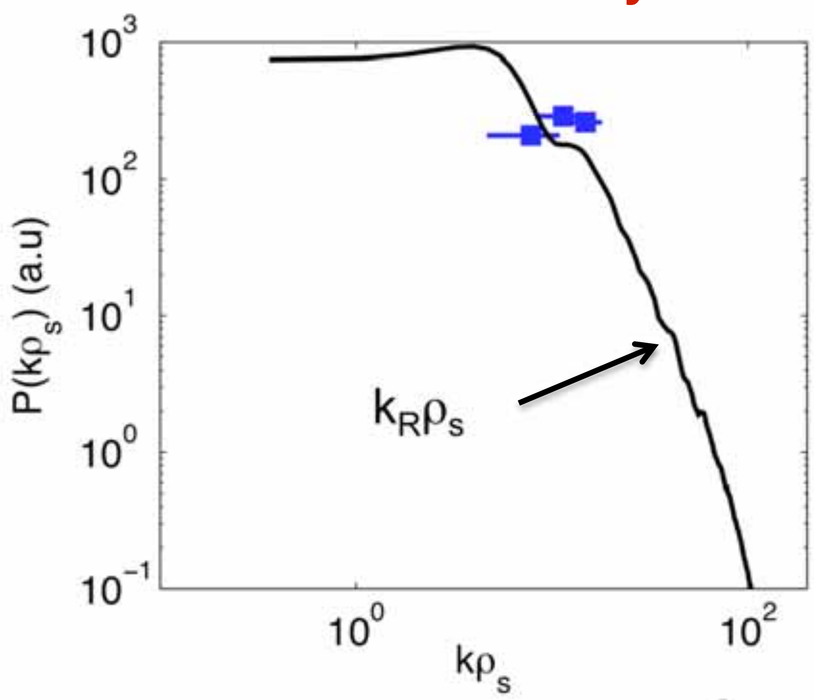


Only 3 channels with good sensitivity for this shot

Direct comparison

with $\sum_{k_z} P(k_R,k_z)$

WARNING! arbitrary scale



- Not enough experimental points
- in a small range of **k**
- spectra are not in physical units
- contribution from ALL k_z is taken here

Comparison is not conclusive for this shot

Different domain for simulations and expt

Experiments

$$I(t) = A(t)\cos[\alpha(t)]$$ In-phase

$$Q(t) = A(t)\sin[\alpha(t)]$$ Quadrature

$$I(t) + iQ(t) = A(t)e^{i\alpha(t)} \propto \tilde{n}(\vec{k}^{\,j}, t)$$

$$\vec{k}^{\,j} \equiv (k_R^j, k_\phi^j, k_z^j)$$ j=1,…,5

1 FT^ω operation

$$P^{EXP}(k_R^j, k_\phi^j, k_z^j, \omega)$$

Simulations

$$\tilde{n}^{SIM}(\rho, \theta, \phi, t)$$

$$\tilde{n}^{SIM}(R, z, \phi, t)$$

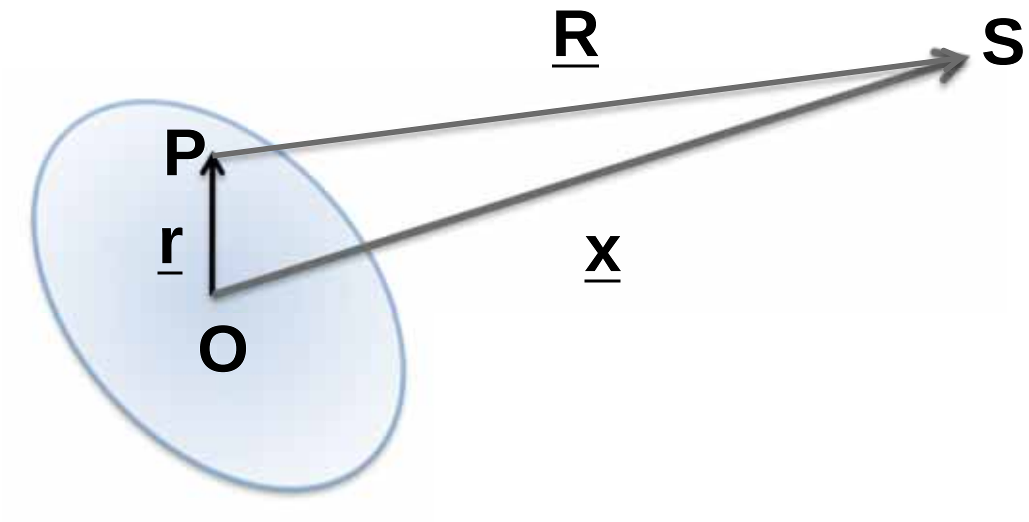
?

FT^κ, FT^ω

Selection over k

$$P^{SIM}(k_R^j, k_\phi^j, k_\theta^j, \omega)$$

Measured power is proportional to density fluctuations

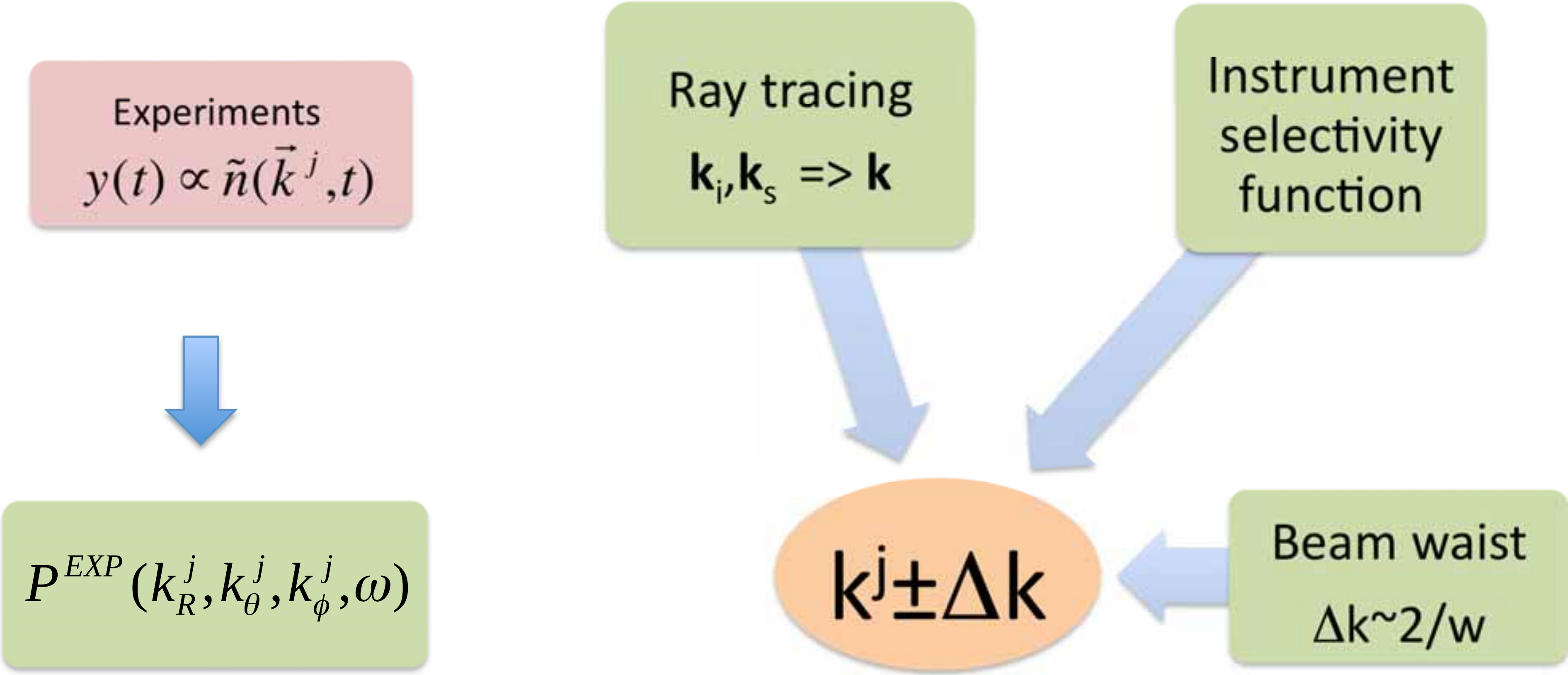


$$\vec{E}_s(\vec{x},t) = \left[\frac{r_e}{R}\hat{s}\times(\hat{s}\times\vec{E}_i)\right]$$

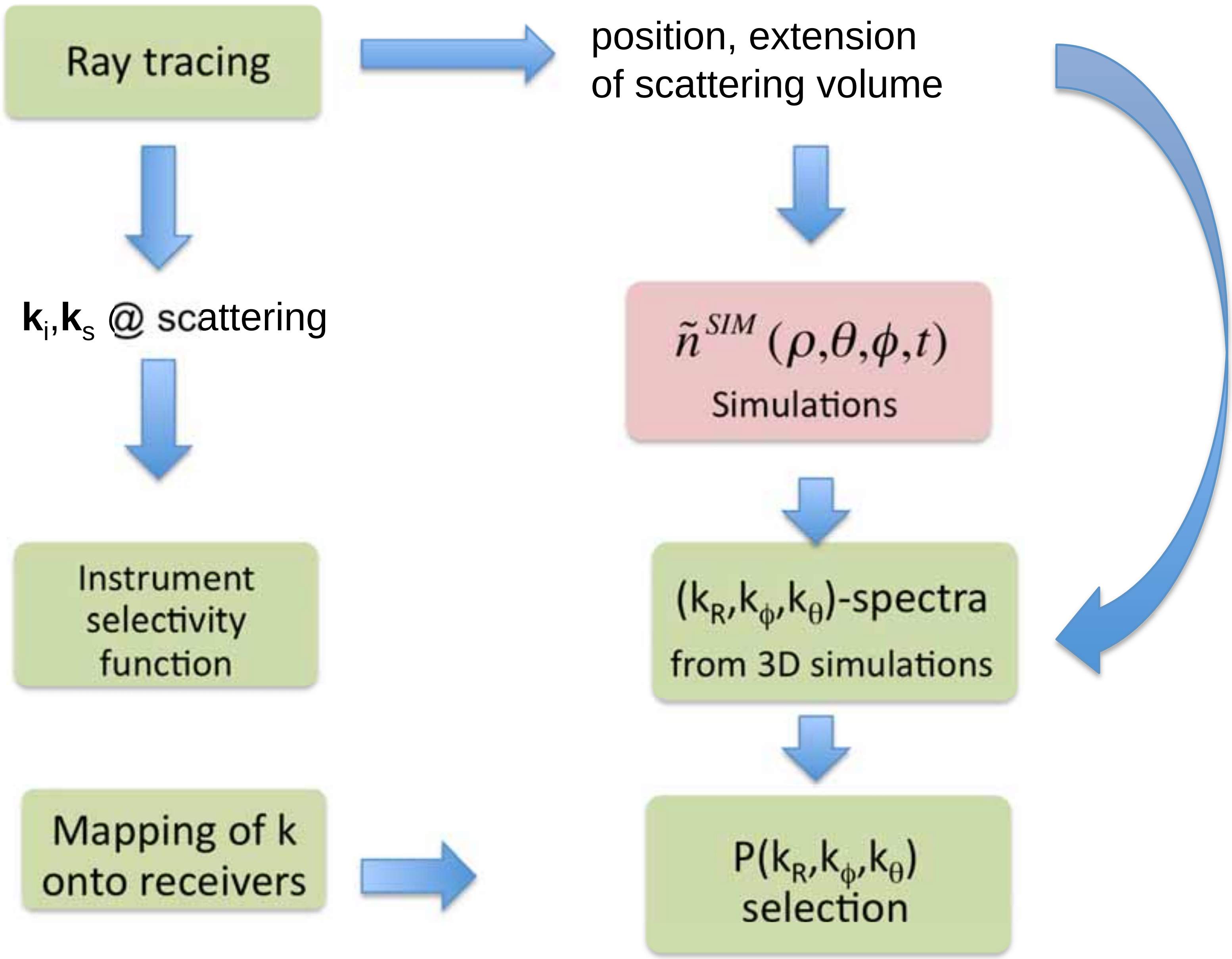
$$t' = t - \frac{R}{c} \approx t - \frac{x - \hat{s}\cdot\vec{r}'}{c}$$

$$\vec{E}_s(\nu_s) = \frac{r_e}{x}e^{ik_s\cdot x}\,(\hat{s}\hat{s}-\mathbf{1})\cdot\int_{T'}dt'\int_V d^3r'\,\vec{E}_i(\vec{r},t)e^{i(\omega t'-\vec{k}\cdot\vec{r})}\tilde{n}(\vec{r}',t')$$

Ray tracing is the core of coherent scattering experiments



The synthetic diagnostic should reproduce the experimental conditions



Ray tracing

Source code provided by D.R.Smith => modified to include:

- a 2D background density profile $n_0(R,z,t_0)$
- contribution of simulated density fluctuations
- *Adaptive incremental step*

$\Rightarrow$ Run for parallel rays (work in progress to include Gaussian shape)

Ray tracing is run twice

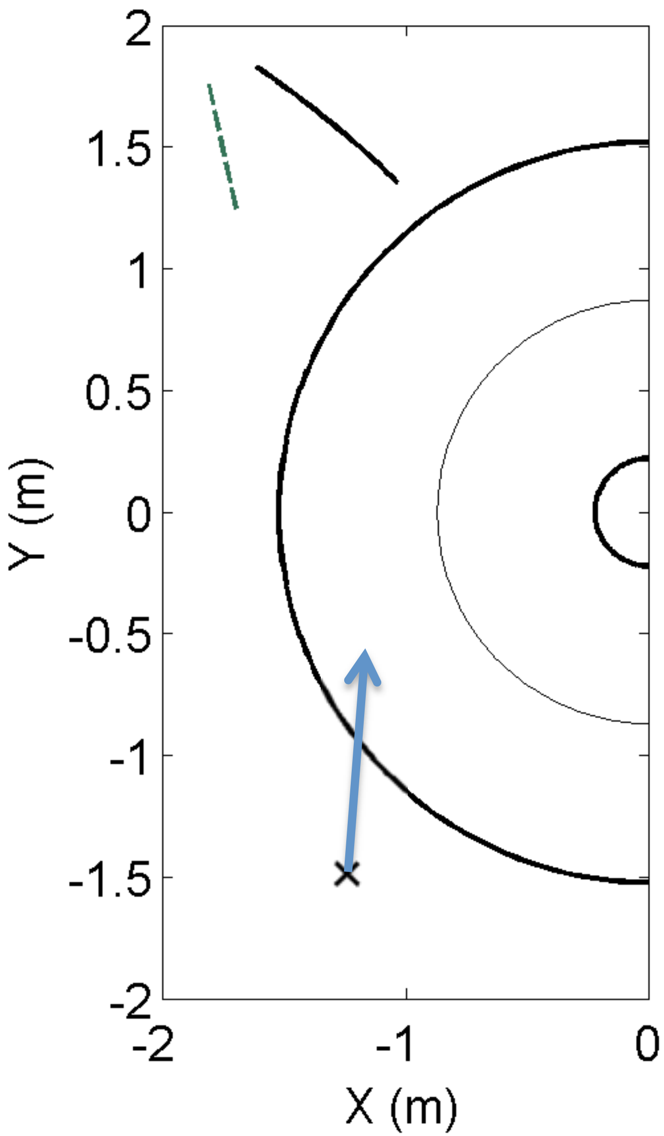
$\Rightarrow$ Only on background density and 1 ray to find region of scattering

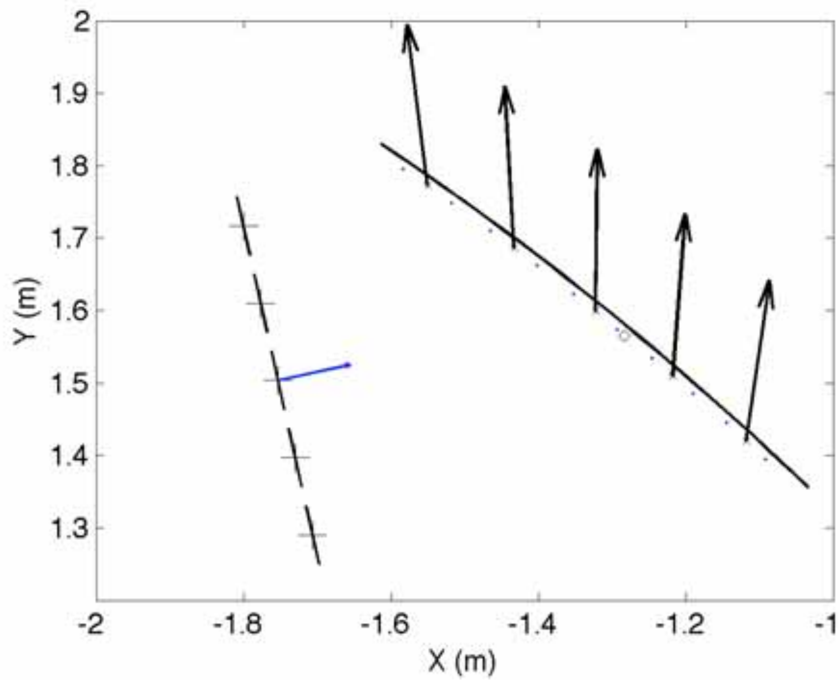
- Extension of useful region for simulations

$\Rightarrow$ On full beam and fluctuation profile to estimate the spread in **k**

- Effect on the value and direction of $\mathbf{k}_i$ and $\mathbf{k}_s$

Experimental layout

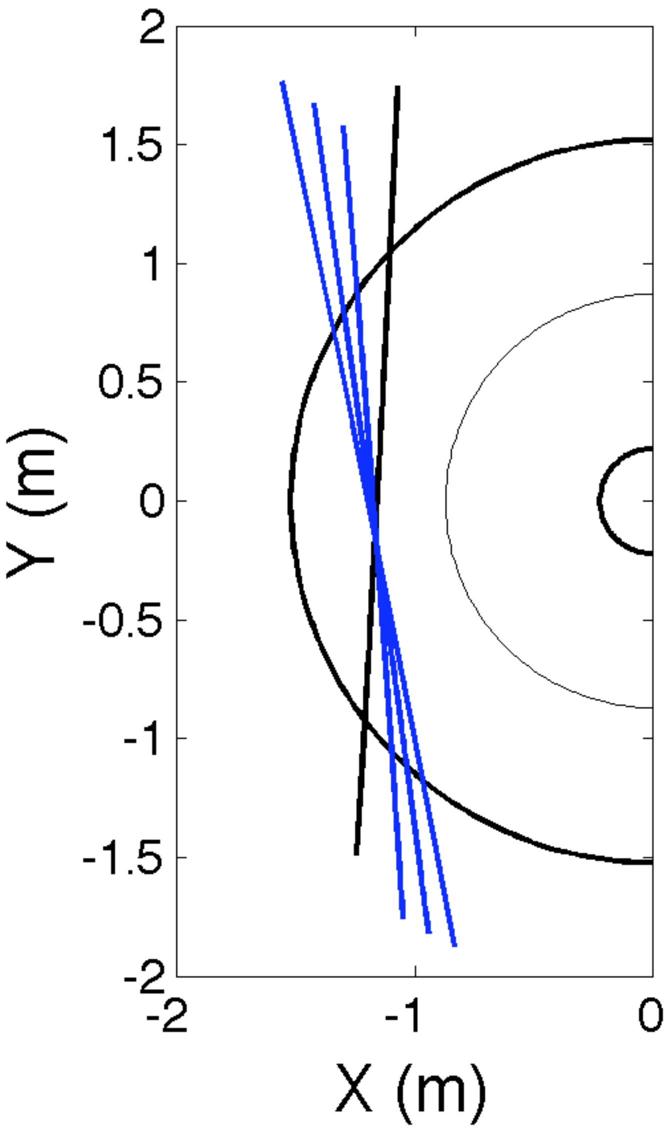




Input parameters for ray tracing

- Launching geometry
- Receiving geometry
- Size of receiving windows

Scattering region determined by intersection between probe and received beam



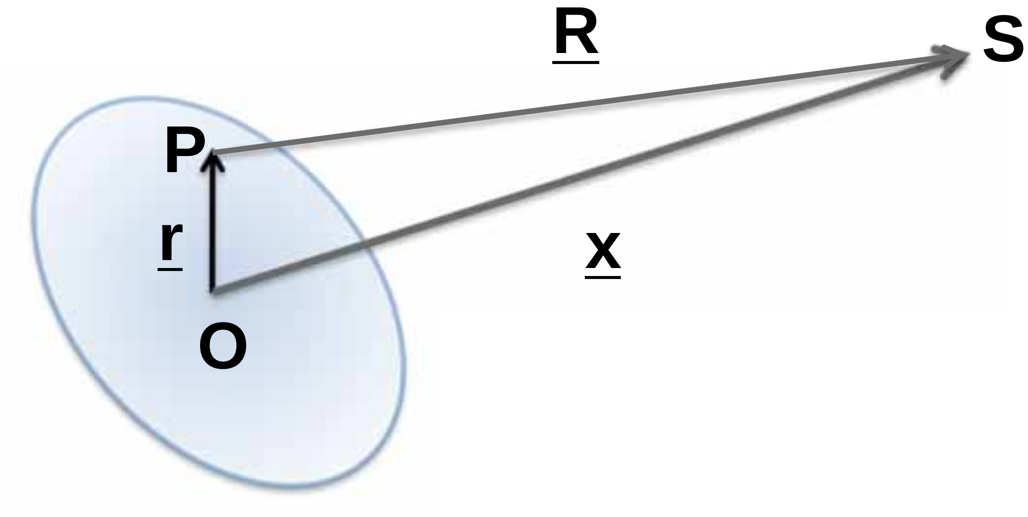
Radial position of closest approach between probe and received beam (central rays)

R (m)	**Δz (m)**
1.168	0.018
1.172	0.025
1.174	0.032

Minimum distance comparable to beam waist

Closer approach found when 2D density profile is taken into account

Measured power is proportional to density fluctuations



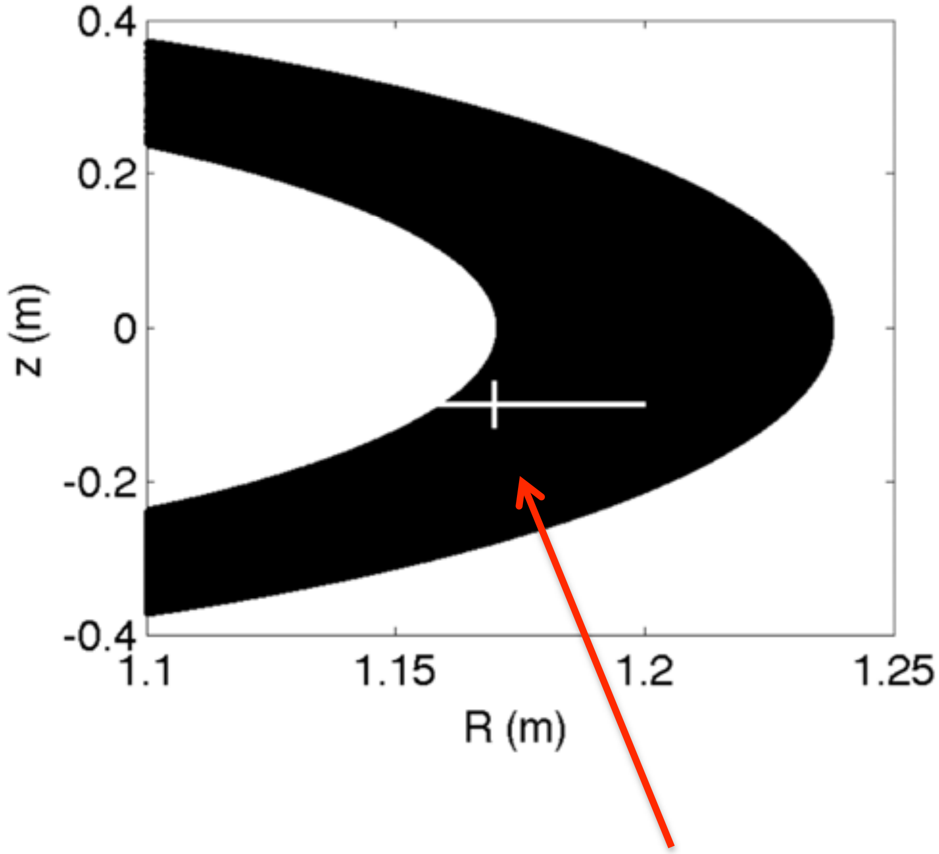
$$\vec{E}_s(\vec{x},t) = \left[\frac{r_e}{R}\hat{s}\times(\hat{s}\times\vec{E}_i)\right]$$

$$t' = t - \frac{R}{c} \approx t - \frac{x - \hat{s}\cdot\vec{r}'}{c}$$

$$\vec{E}_s(\nu_s) = \frac{r_e}{x} e^{ik_s\cdot x}\,(\hat{s}\hat{s} - \mathbf{1})\cdot \int_{T'} dt' \int_V d^3r'\,\vec{E}_i(\vec{r},t) e^{i(\omega t' - \vec{k}\cdot\vec{r})}\tilde{n}(\vec{r}',t')$$

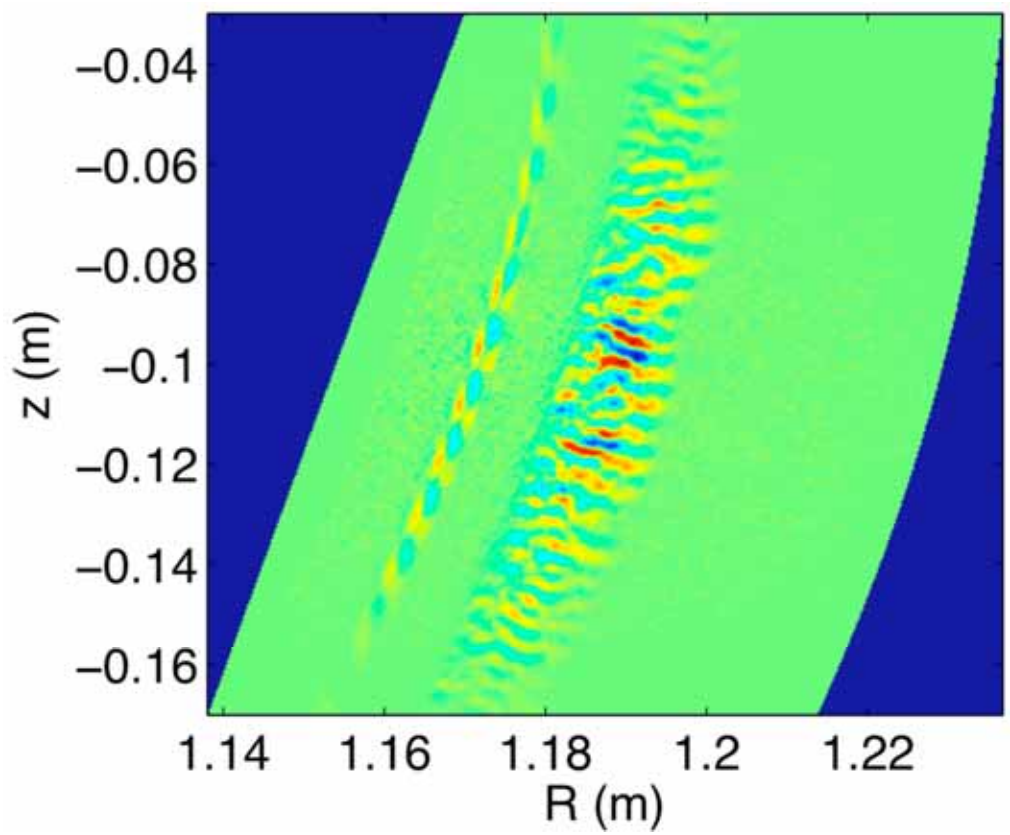
$$\vec{E}_i(\vec{r},t) = E_i \hat{e}_i e^{-(x^2+y^2)/a^2} e^{i(k_{iz}z - \omega_i t)}$$

The region of scattering is the necessary input for the computation of spectra



Scattering volume

Density fluctuations filtered by a Gaussian function



Mapping of k_w onto receivers

$$\cos\theta_s = \frac{\vec{k}_i \cdot \vec{k}_s}{\left\|\vec{k}_i \cdot \vec{k}_s\right\|}$$

$$k_w = 2k_i \sin(\theta_s/2)$$

$$\vec{k}_s = \vec{k}_i + \vec{k}_w$$

Find θ_s

- $\mathbf{i}=\mathbf{k}_i/k_i$
- $\mathbf{s}=\mathbf{k}_s/k_s$

find $|k_w|$

- θ_s
- k_i

Find k_R, k_ϕ, k_θ

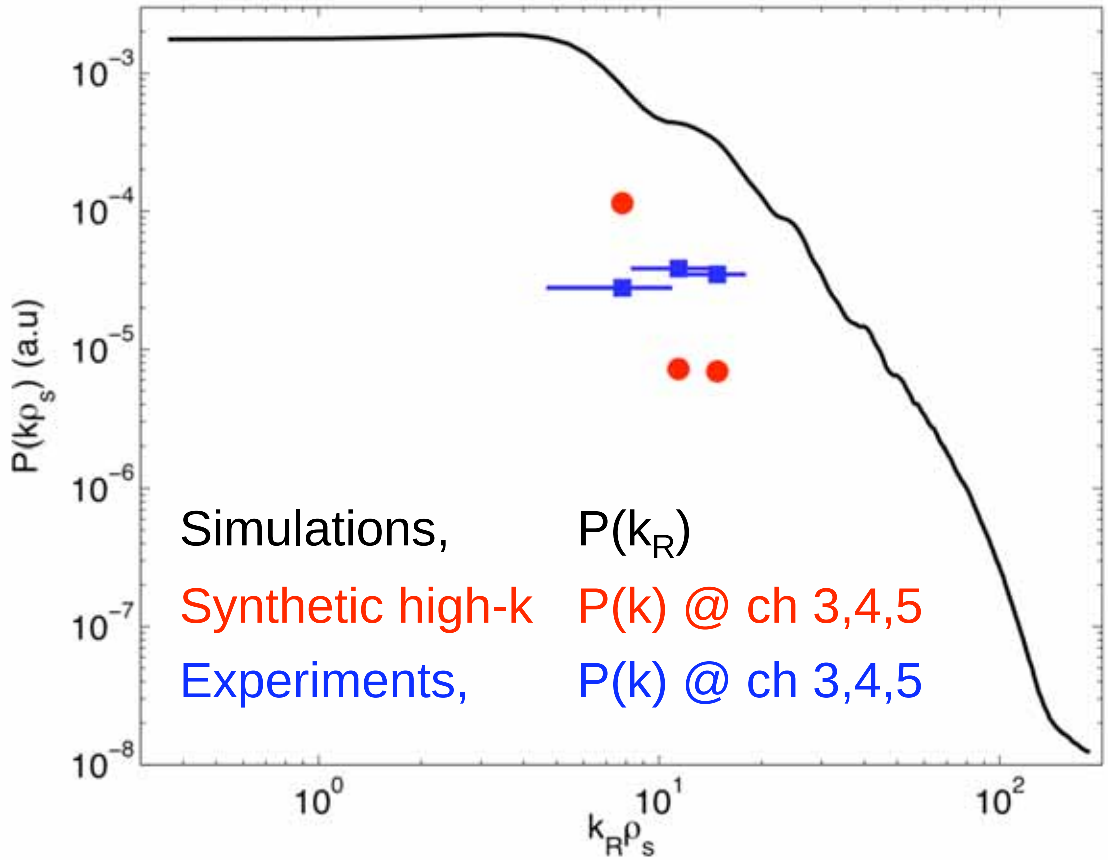
k_w

Finite beam extension, window size → $\Delta\theta_s$ → Range of k_w

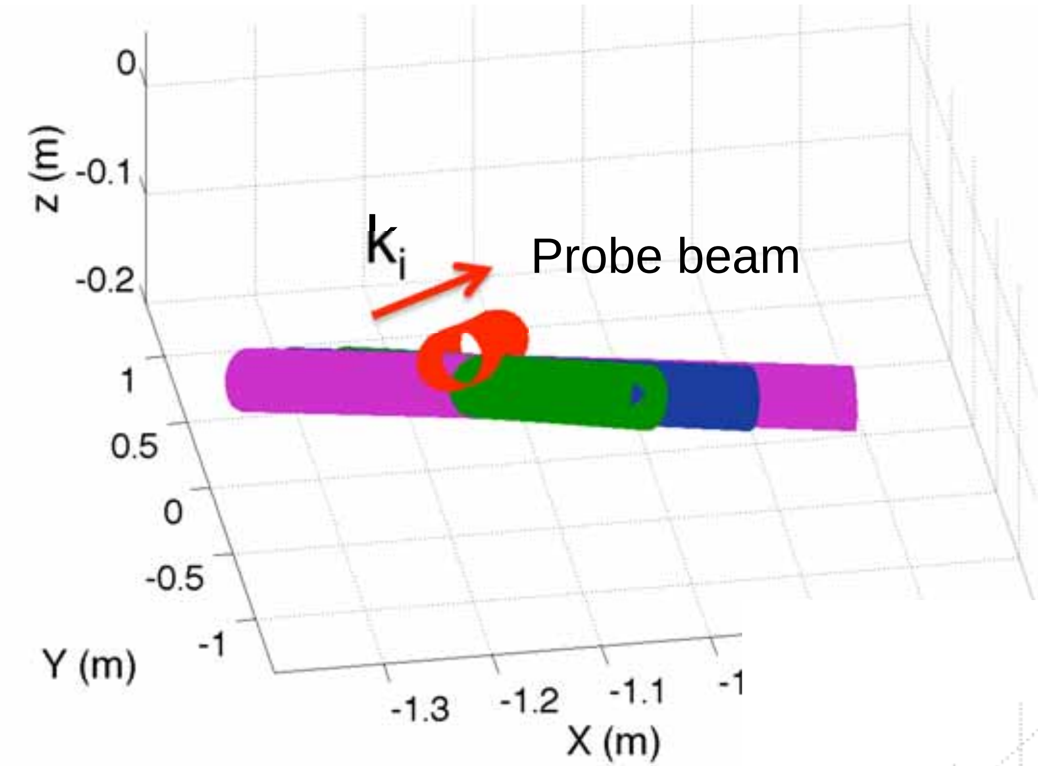
The comparison is far from obvious

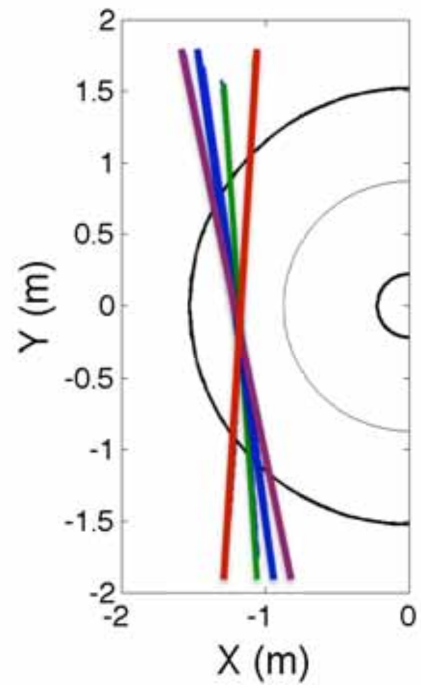
	k_R (cm^{-1})	k_ϕ(cm^{-1})	k_z(cm^{-1})	$\lvert k \rvert$(cm^{-1})
ch3	7.66	-0.73	0.71	7.80
ch4	11.17	-0.94	1.04	11.40
ch5	14.54	-0.93	1.37	14.83

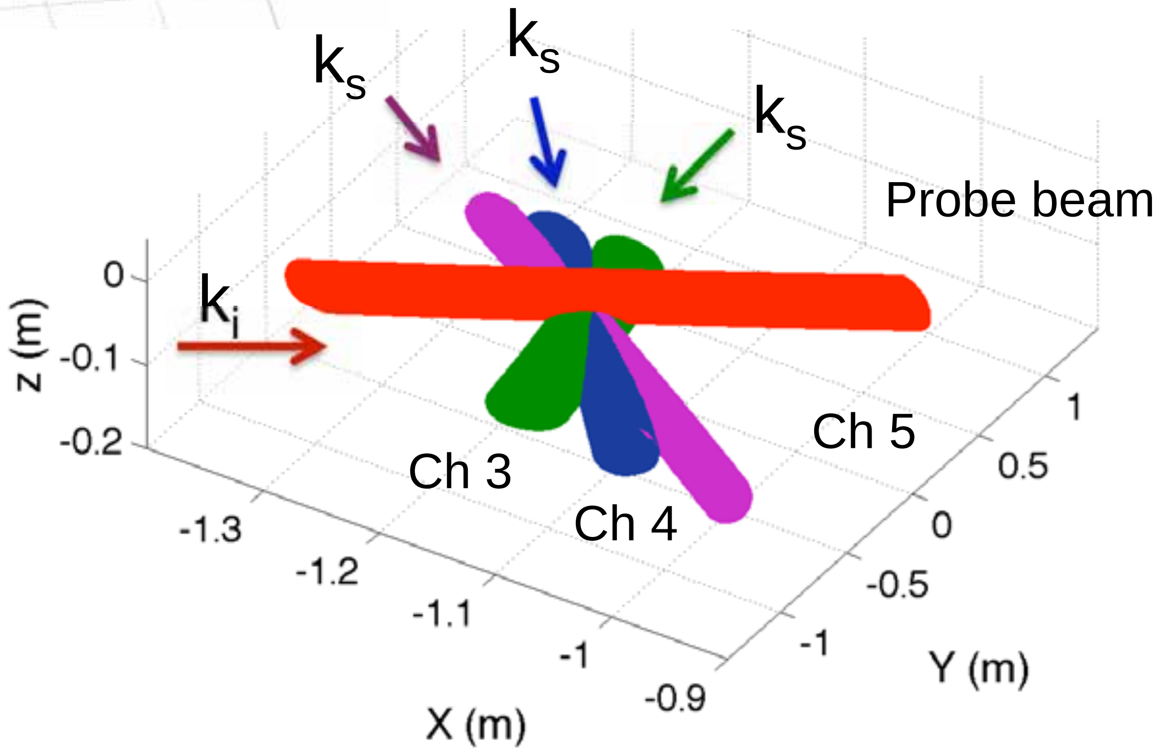
How finite beam size and fluctuations affect the results?



Spread in k due to finite beam size





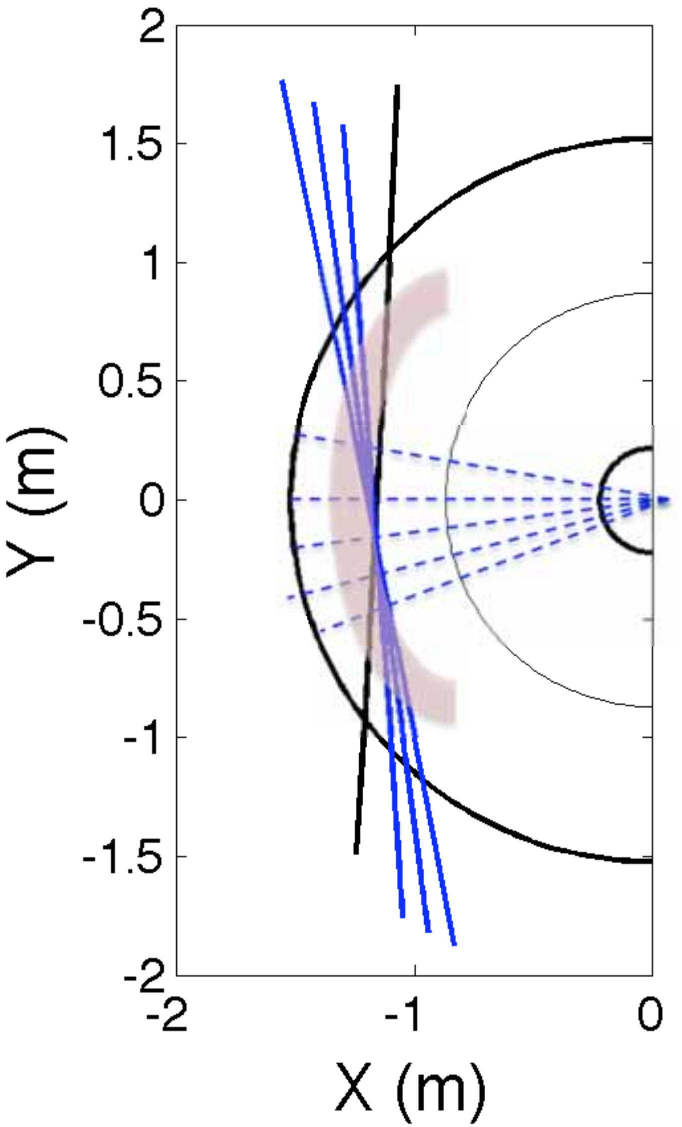


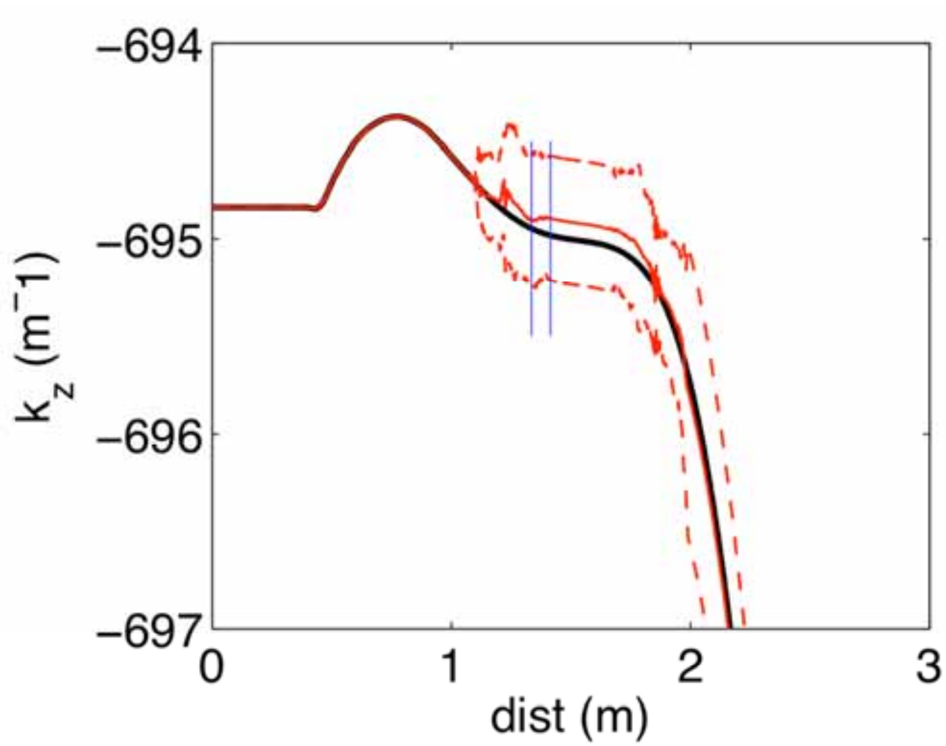
Δk_R ~2-4 cm^{-1}

$\Delta k^{i,s}_z$ ~1%

→ Δk_R ~20%

Effect of anisotropic density fluctuations

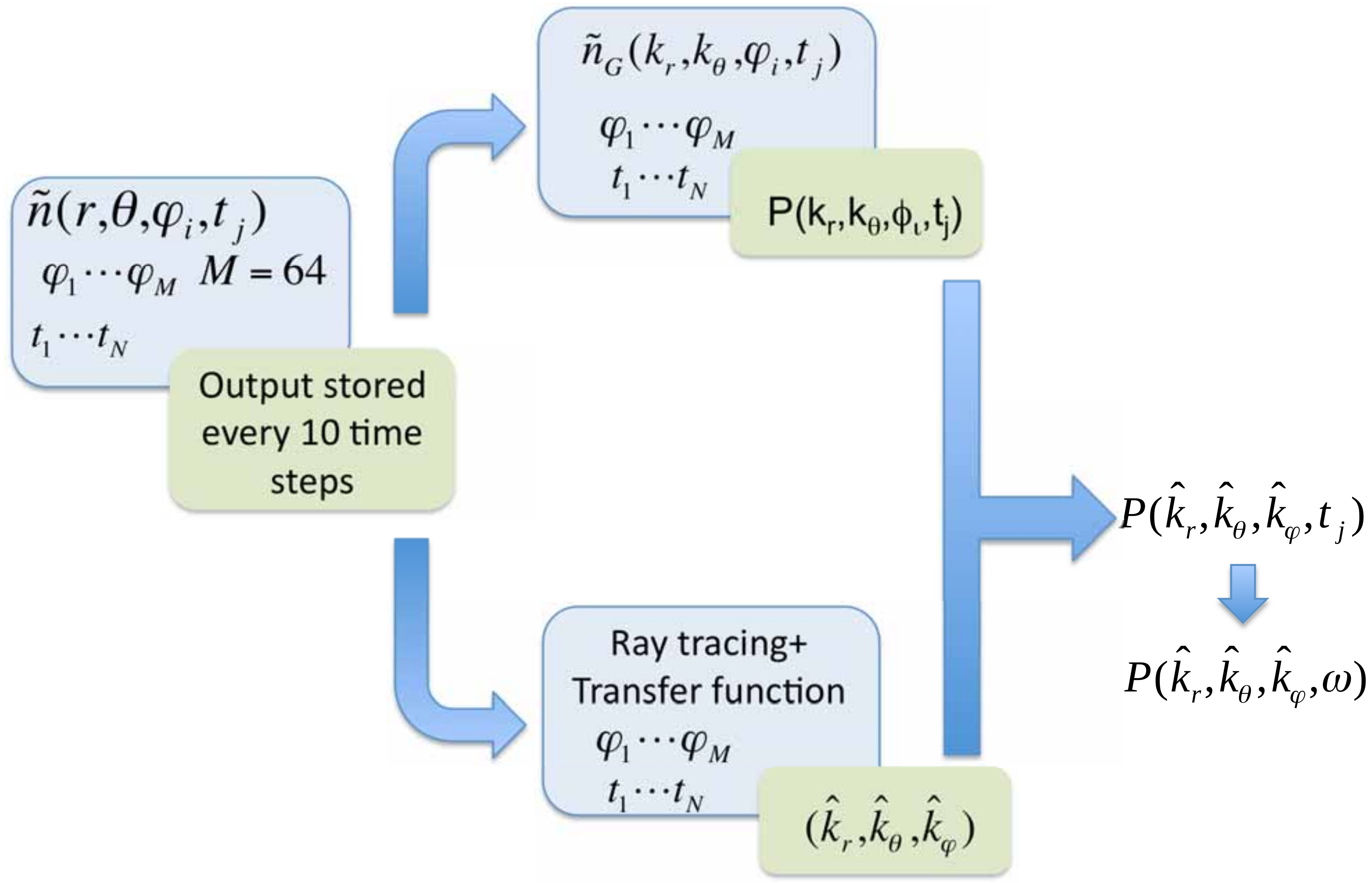




Δk_R ~2 cm^{-1}
$\Delta k^{i,s}_z$ ~1%

Convergence studies on step are ongoing

Implementation into simulations



Summary and future work

- We have built a synthetic diagnostic that simulates coherent electromagnetic scattering
    - Under the hypothesis of geometrical optics
    - As close as possible to the experimental conditions

  $\Rightarrow$ beam size and effect of anisotropic fluctuations on k_i,k_s

- Future implementations include
    - Gaussian beam, solve complex eikonal for E_i amplitude
    - Beam attenuation, beam focalization and spread, instrumental noise