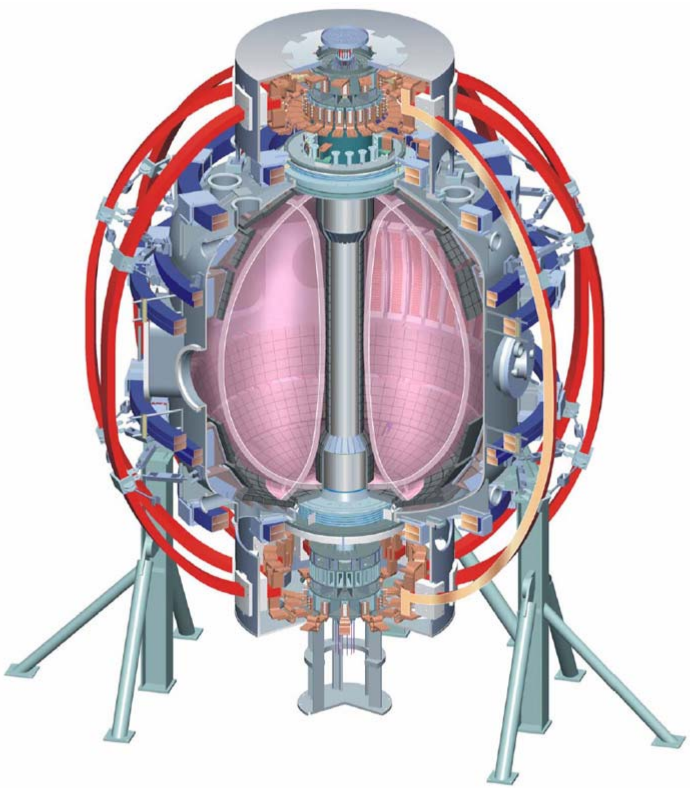
In-situ calibration of the high-k scattering system on NSTX



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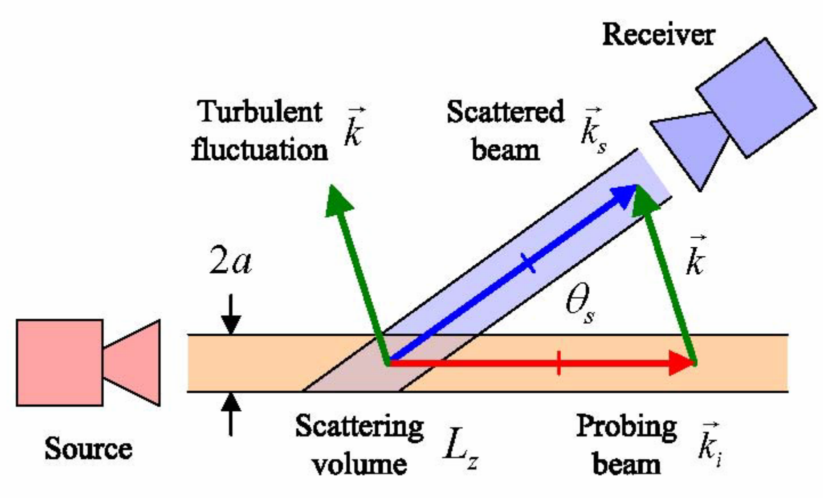
I. Study of Scattering Length Dependence Upon Various Magnetic Field Configurations

1. **Spatial resolution**
2. **Uniform magnetic field**
3. **Toroidal magnetic curvature**
4. **Magnetic shear**

1. Spatial Resolution of Scattering Experiment

- The scattering volume is the beam overlap region for isotropic turbulence.

$$L_z = 2a / \sin \theta_s$$



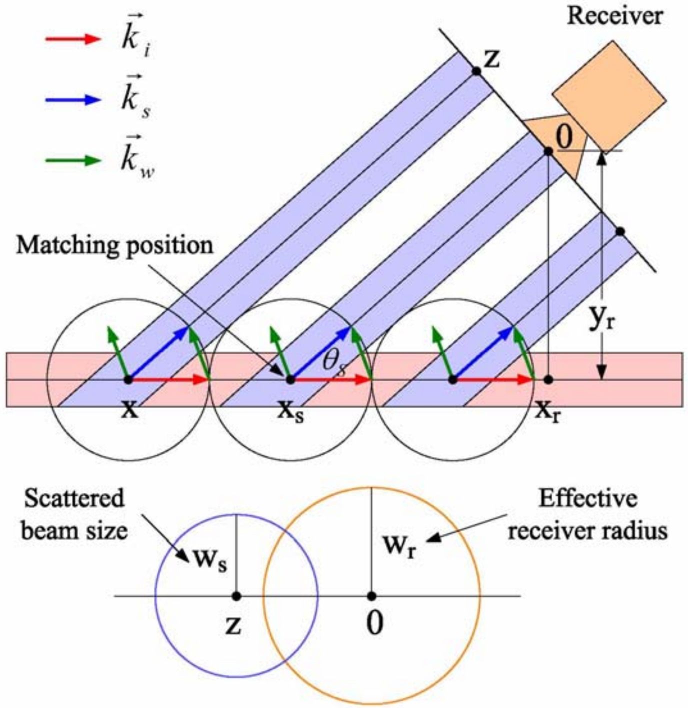
- An anisotropy of plasma micro turbulence with the fluctuation wave nearly perpendicular to the local magnetic field can improve the spatial resolution.

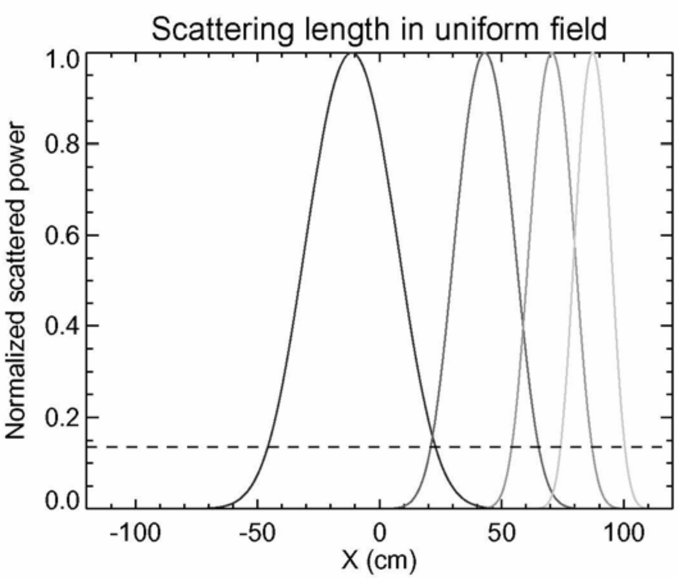
$$\vec{k} \cdot \vec{B} \approx 0 \;\Rightarrow\; k_\perp >> k_{||}$$

- A non-uniform magnetic field (curvature and shear) detunes portions of the overlap region to the detector. This imposes an instrumental selectivity function which constricts the scattering length (Mazzucato, Plasma Phys. Control. Fusion, 2006).

2. Scattering Length in Uniform Magnetic Field

- If magnetic field is uniform, the direction of the turbulent wave vector is the same in all space.
- The scattering length is determined by the effective receiver area if the receiver is oriented along the direction that satisfies the Bragg condition .





λ (cm) = 0.107000 w_r (cm) = 3.0000
a (cm) = 3.00000 x_r (cm) = 149.46
R (cm) = 115.000 y_r (cm) = 22.611
step (cm) = 0.500000
dr (cm) = 0.300000

θs (deg)	k (cm-1)	Xs (cm)	w (cm)
8.00000	8.19239	-11.4288	3.52169
12.0000	12.2761	43.0815	3.24415
16.0000	16.3449	70.6045	3.14124
20.0000	20.3937	87.3356	3.09247

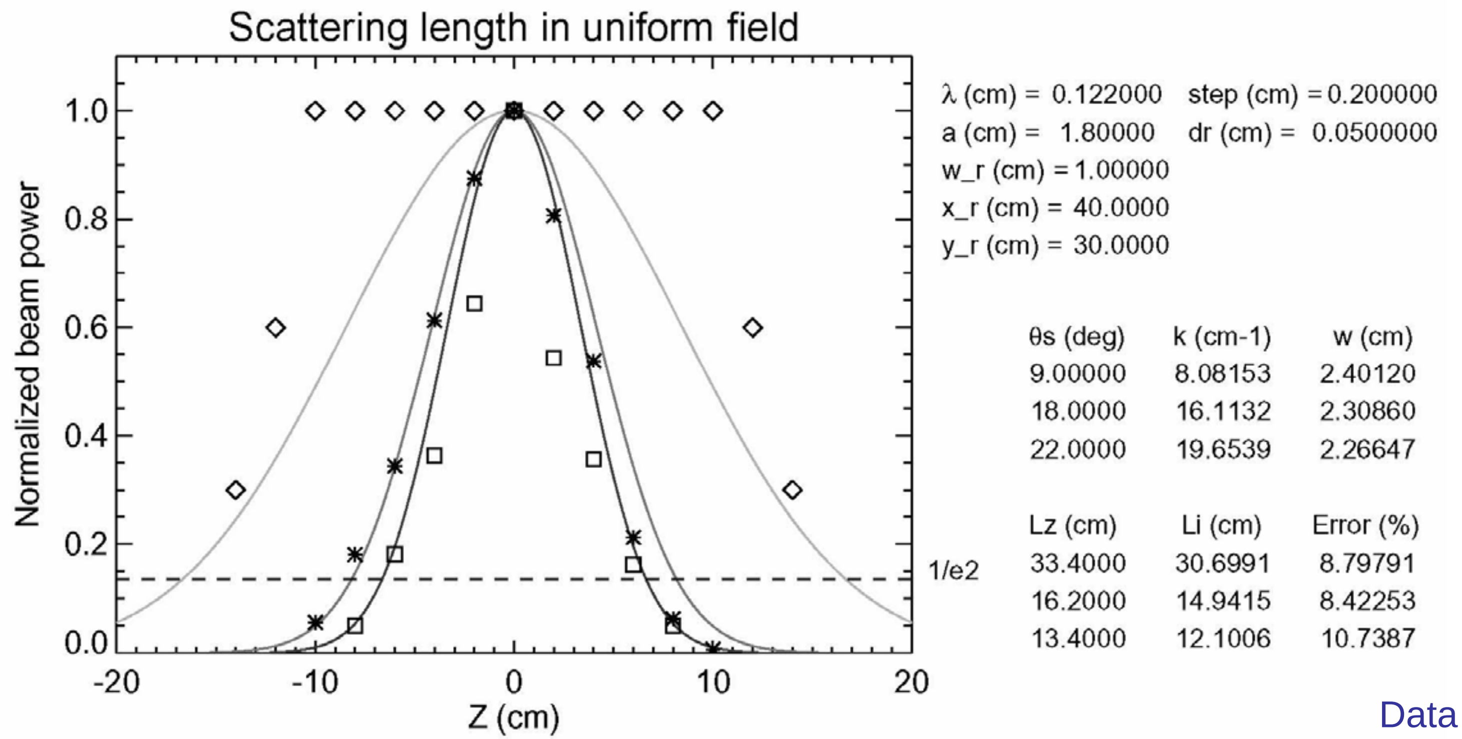
1/e2

Li (cm)	Lz (cm)	Error (%)
43.1118	68.5000	58.8893
28.8584	44.5000	54.2012
21.7677	33.0000	51.6006
17.5428	26.5000	51.0589

This is not satisfactory !

Comparison with Experiment

NSTX



Data of H. Park, RSI, **53** (1982) p1535

- Simulation result is comparable with high-k (16 and 20 cm^{-1}) data, but not the low-k (4 and 8 cm^{-1}) data.

3. Scattering Length Dependence on Magnetic Curvature

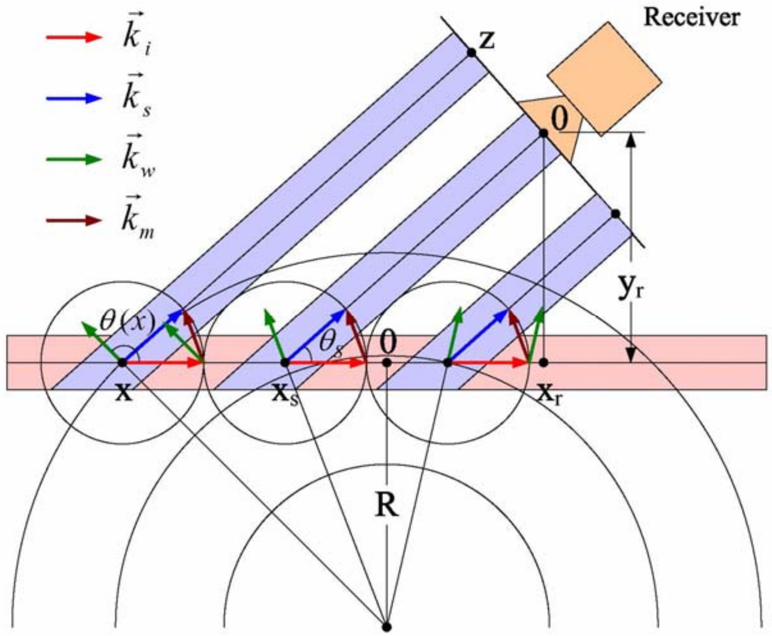
NSTX

- Toroidal magnetic curvature makes an anisotropic fluctuation as

$$\vec{k}_w \cdot \vec{B} \approx 0$$

- If the receiver orientation satisfies the Bragg condition, fluctuation waves from other locations cannot satisfy Bragg condition.
- The scattered beam power arising from a coherent fluctuation is well known:

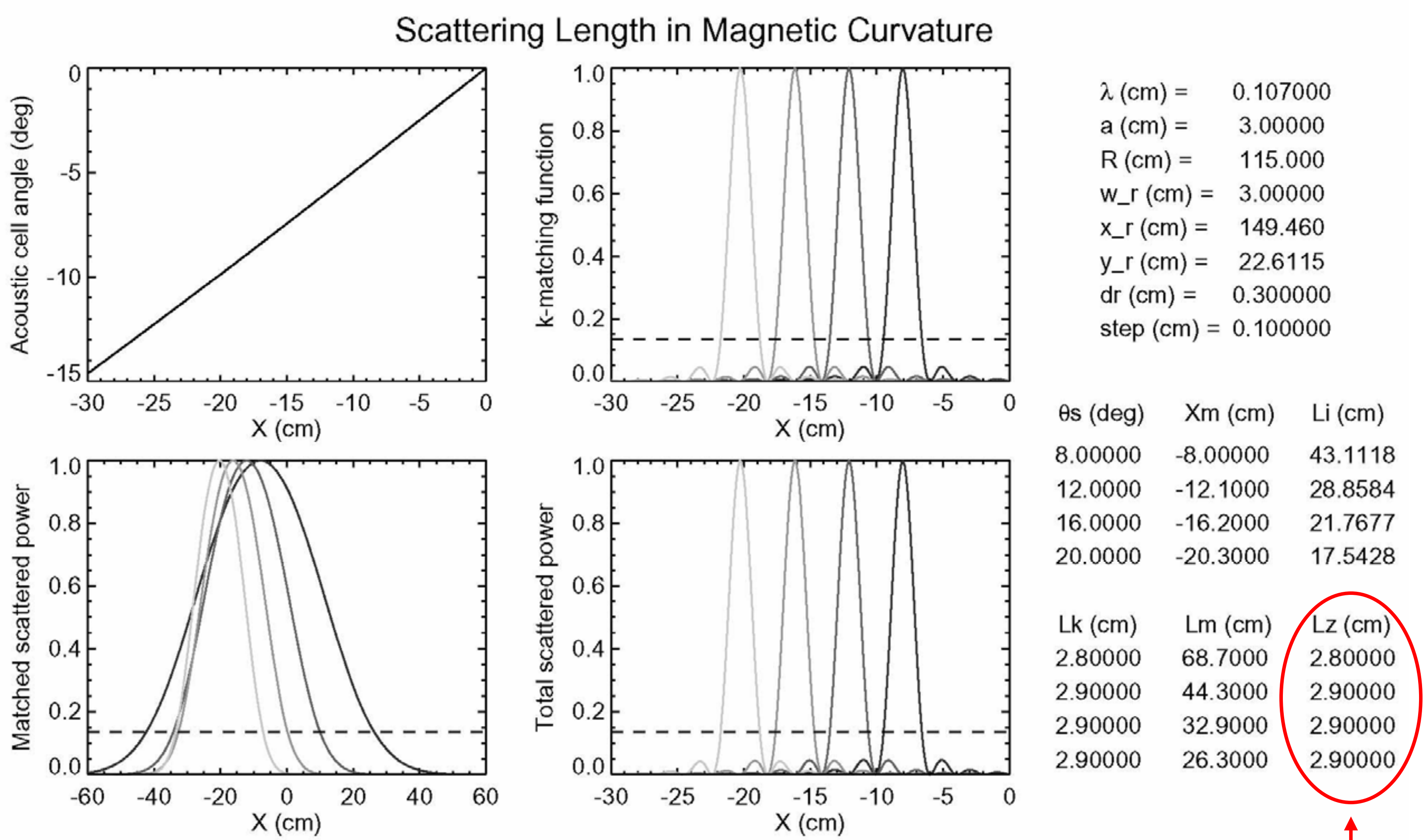
$$P_s = \frac{1}{4} P_0 \tilde{n}_e^2 r_0^2 \lambda_i^2 L_z^2 f(\vec{k}_w, \vec{k}_m)$$



where the k-matching function which determines the scattering length, is defined as

$$f(\vec{k}_w, \vec{k}_m) = \exp\left[-\frac{a^2 (\vec{k}_w - \vec{k}_m)_\perp^2}{2} \right] \mathrm{sinc}^2 \left[\frac{(\vec{k}_w - \vec{k}_m)_\parallel L_z}{2} \right]$$

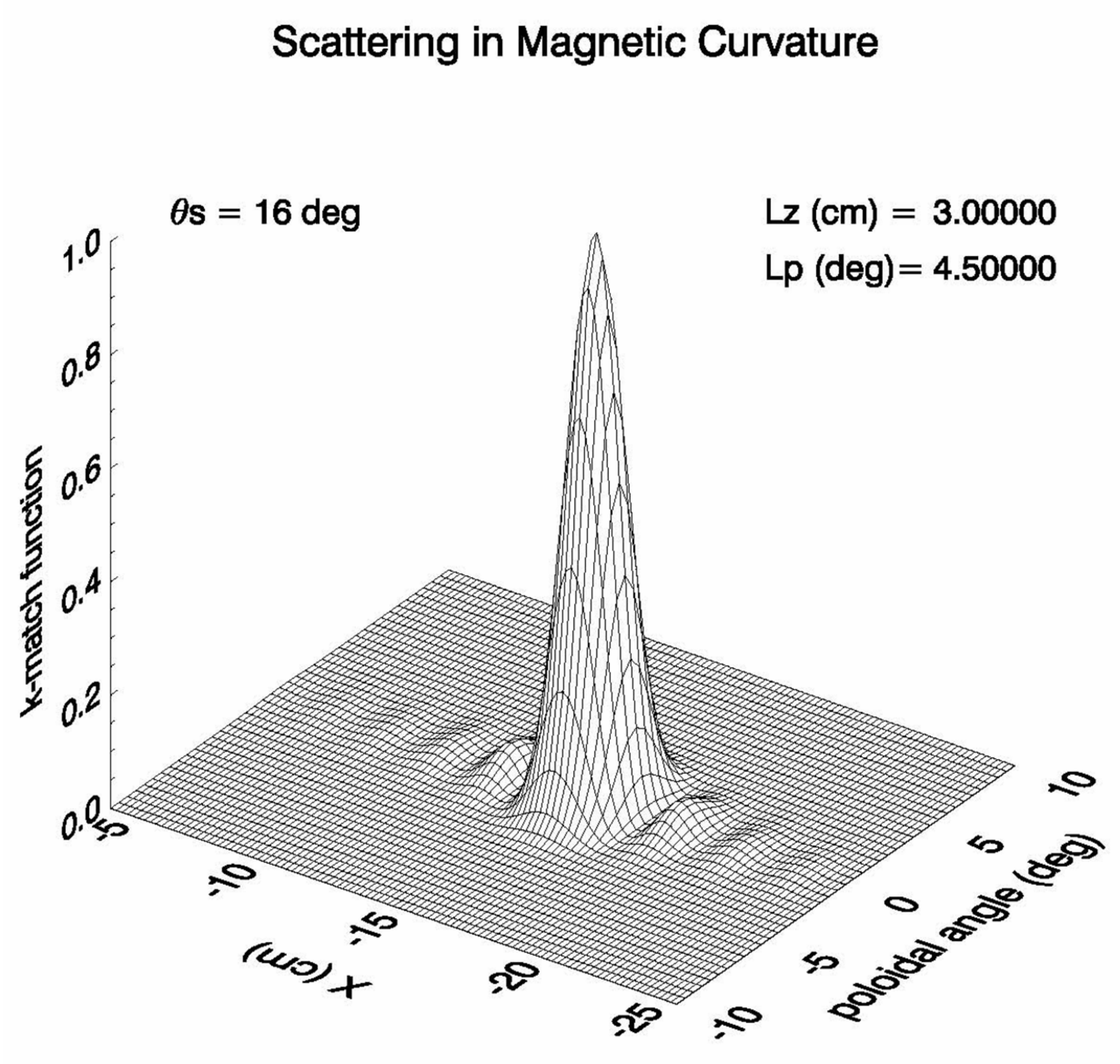
Simulation Result



Reduced !

- Scattering length is mainly affected by the k-matching function.
- Toroidal magnetic field provides most tight matching condition.

Simulation Result (cont.)



When the fluctuation wave vector *k* has a poloidal component, 1/e2 width has ~4.5 degrees wrt poloidal angle for 16-deg scattering angle.

4. Scattering Length Dependence on Magnetic Shear [1]

- New orthogonal coordinates (u, v, t) with the t-axis parallel to k_0 and u-axis parallel to the equatorial plane.
- The scattered wave vector can be represented in these coordinates.

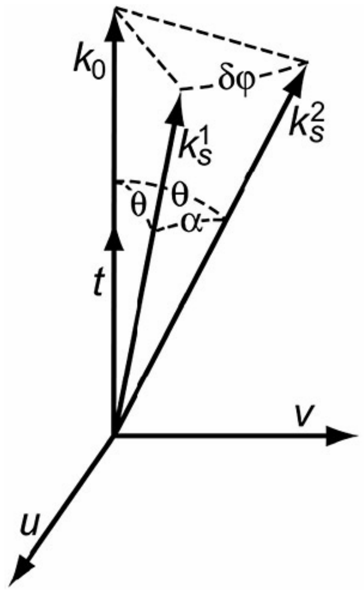
$$k_{su} = k_0 \sin\theta \cos\varphi, \quad k_{sv} = k_0 \sin\theta \sin\varphi, \quad k_{st} = k_0 \cos\theta$$

- Two scattered waves from two points of the probe beam with identical scattering angles but different wave vectors are:

$$\frac{k_s^1 \cdot k_s^2}{k_0 \cdot k_0} \equiv \cos\alpha = 1 - 2\sin^2(\delta\varphi/2)\sin^2\theta$$

- Suppose the receiver is tuned for the 1st scattered wave. The 2nd scattered wave will be collected with a relative efficiency:

$$F = \exp[-(2k\sin(\delta\varphi)/(2/a))^2]$$

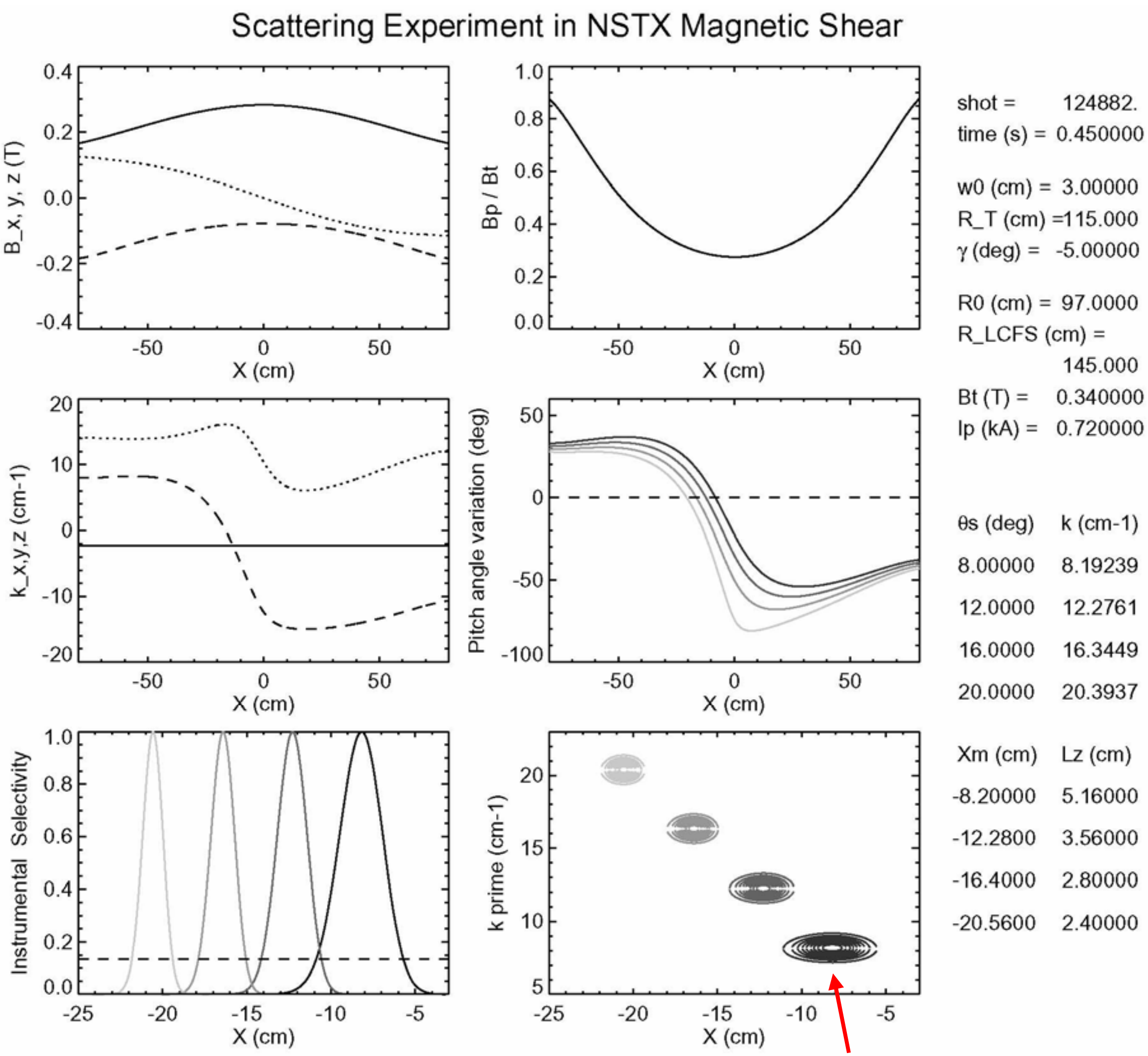


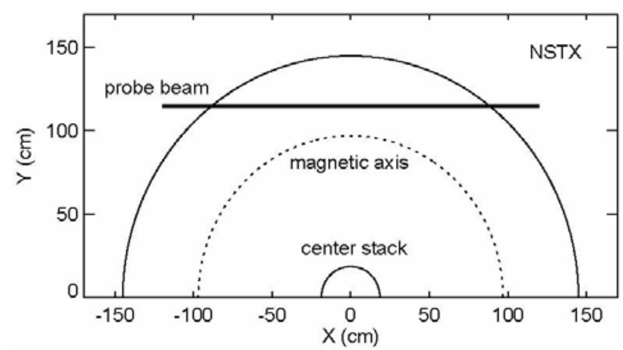
- The polar angle ϕ can be obtained from $\vec{k}_w \cdot \vec{B} \approx 0$, which gives ($B_\perp^2 = B_u^2 + B_v^2$)

$$\cos\varphi = \frac{B_u B_t (1-\cos\theta) \pm [B_u^2 B_t^2 (1-\cos\theta)^2 - B_\perp^2 (B_t^2 (1-\cos\theta)^2 - B_v^2 \sin^2\theta)]^{1/2}}{B_\perp^2 \sin\theta}$$

[1] E. Mazzucato, Plasma Phys. Control. Fusion **48** (2006) p1749

Simulation Result





- Magnetic shear reduces the scattering length, but larger than that of magnetic curvature for low-k wave.
- K prime of last graph shows that the instrumental selectivity is not only a function of pitch angle variation but also a function of wave number amplitude.

Vertical width ~ wave number resolution ~ $2/w_0$

II. Preparation of Laboratory Experiment for Scattering Length Measurement

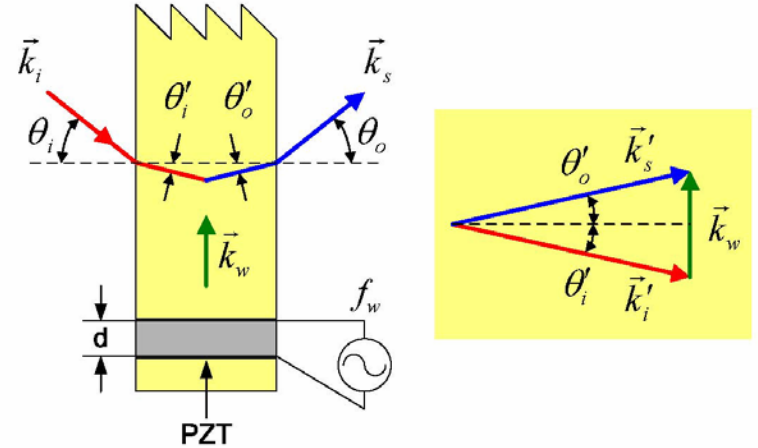
1. Characteristics of acoustic cell
2. Beam splitter grid angles

1. Characteristics of Acoustic Cell

- Acoustic cell launches the acoustic wave of the appropriate frequency.
- The wave frequency is related to the scattering angle as

$$f_w = \frac{k_w C_s}{2\pi} = \frac{k_i C_s}{\pi} \sin\frac{\theta_s}{2}$$

where $\begin{cases} k_i = \dfrac{2\pi \times 282\,\mathrm{GHz}}{3\times 10^{10}\,\mathrm{cm/s}} = 59.1\ \mathrm{cm}^{-1} \\ c_s = 2.16\times 10^5\ \mathrm{cm/s} \end{cases}$



- The resonant frequencies of 6-mm thick PZT are 330, 530, 1000, and 1710 kHz.
- The frequency of the largest resonant amplitude is 530 kHz.

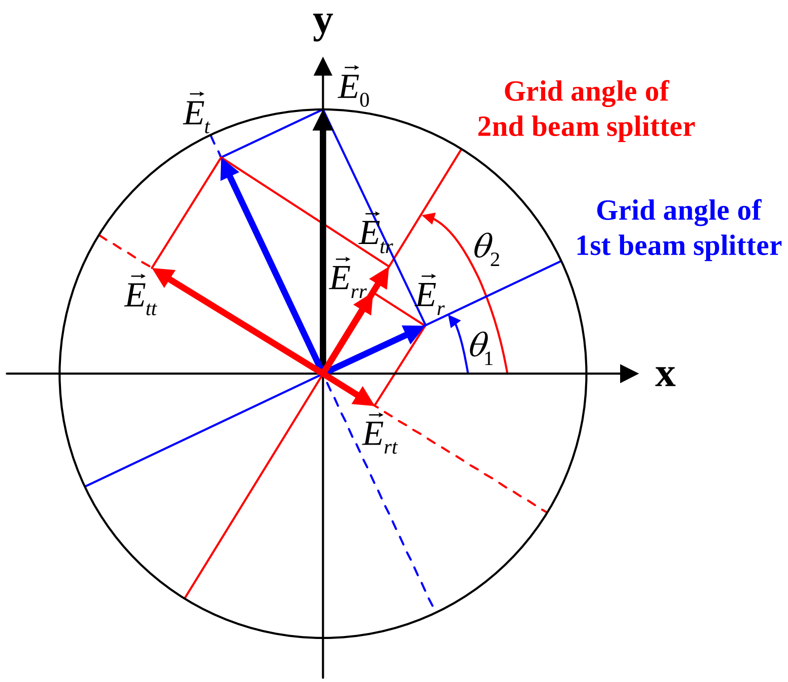
f_{res} (kHz)	Θ_s (deg)
330	9.5
530	15
1000	29
1710	51

(For d = 6 mm)

2. Consideration of Two Beam Splitter Angles

- Two beam splitter angles should be carefully selected because:

1. The electric field from the millimeter wave source is vertically polarized and
2. The mixer detects a vertically polarized electric field.



$$E_{probe,\,y} = E_0 \cos(\theta_2 - \theta_1)\cos\theta_1 \cos\theta_2$$

$$E_{ref,\,y} = E_0 \cos(\theta_2 - \theta_1)\sin\theta_1 \sin\theta_2$$

$$P_{probe} = P_0 \cos^2(\theta_2 - \theta_1)\cos^2\theta_1 \cos^2\theta_2$$

$$P_{ref} = P_0 \cos^2(\theta_2 - \theta_1)\sin^2\theta_1 \sin^2\theta_2$$

$$P_{total} = P_0 \cos^2(\theta_2 - \theta_1)(\cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2)^2$$

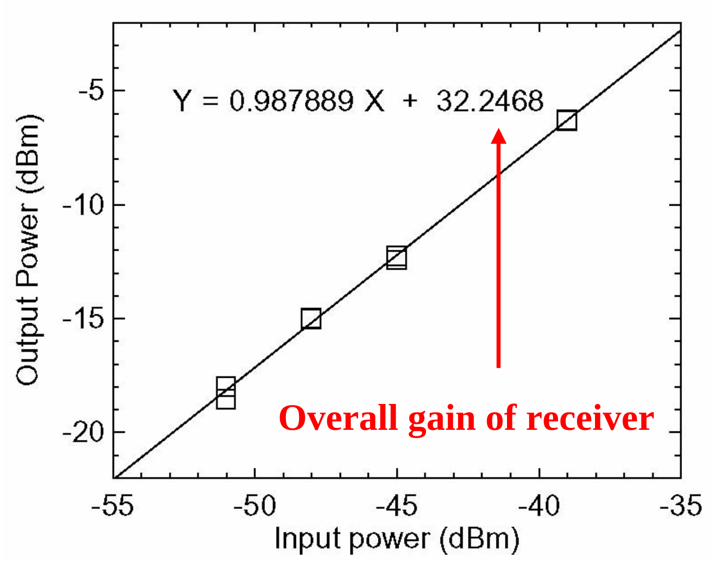
- The detected beam power is greatest when the two beam splitters have the same grid angles.

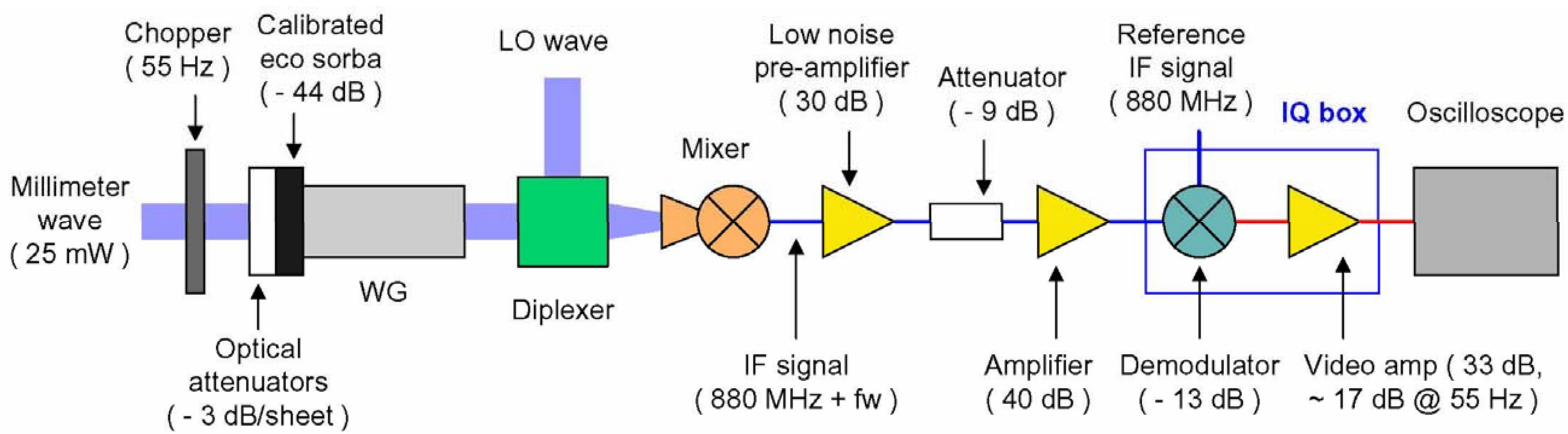
Because beam splitter is tilted by 45 degree, the effective angle should be considered:

$$\theta_{eff} = \tan^{-1}(\sqrt{2}\tan\theta)$$

Power Calibration of NSTX High-k Receiver

- We used 25-mW and 55-Hz chopping signal as an input power for Ch. 3.
- Input power was changed by adding 3-dB optical attenuators.
- Output power is RMS value on 50-Ω load.
- The gain from the IF amp to the video amp of the IQ box is ~ 65 dB.
- 33-dB loss is expected in the waveguide, diplexer, mixer, and cables.





Further Work

- Additional study of non-uniform magnetic field effect on the scattering length for the isotropic fluctuation and $\vec{k}_w \cdot \vec{B} \neq 0$
- Laboratory experiment of scattering length measurement in as many magnetic configurations as possible.
- More accurate power calibration of high-k system using another solid state millimeter wave source