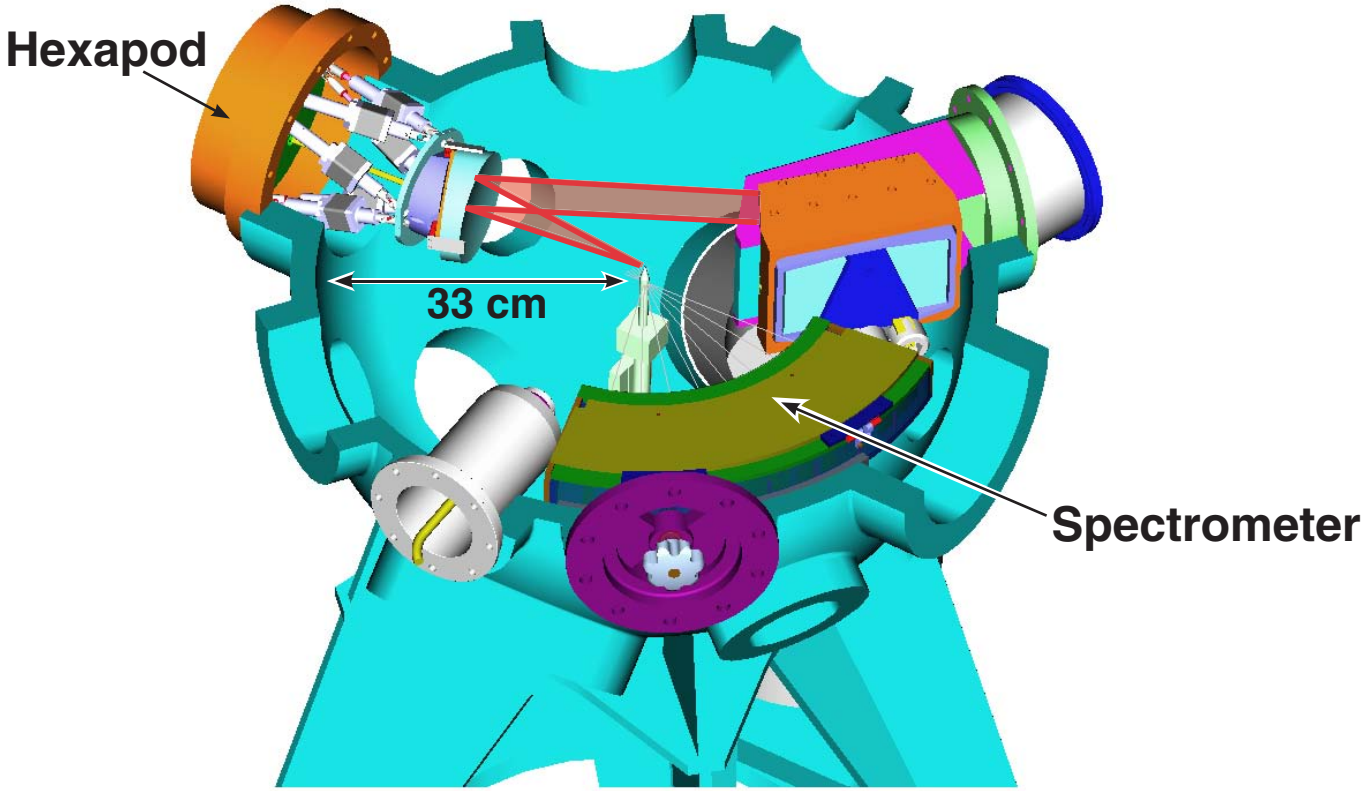
A Compact, Multi-Angle Electron Spectrometer for Ultra-Intense Laser–Plasma Interaction Experiments



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Summary

A compact spectrometer will simultaneously record spectra of electrons ejected from the laser focus at multiple angles

UR LLE

- The instrument will be deployed on the multiterawatt (MTW) laser at LLE (10J energy in a 1-ps pulse with up to 4×10^{19} W/cm^2).
- By measuring both the angular and spectral distributions, we can study ponderomotive acceleration and collimation of electrons.
- A system of replaceable magnets makes the device compact while providing an extended energy range (currently 0.3 to 5 MeV).
- Eight spectra spanning 70° are recorded on reusable imaging plates, which are scanned with an off-the-shelf reader.

The required device specifications are determined from the expected experimental conditions

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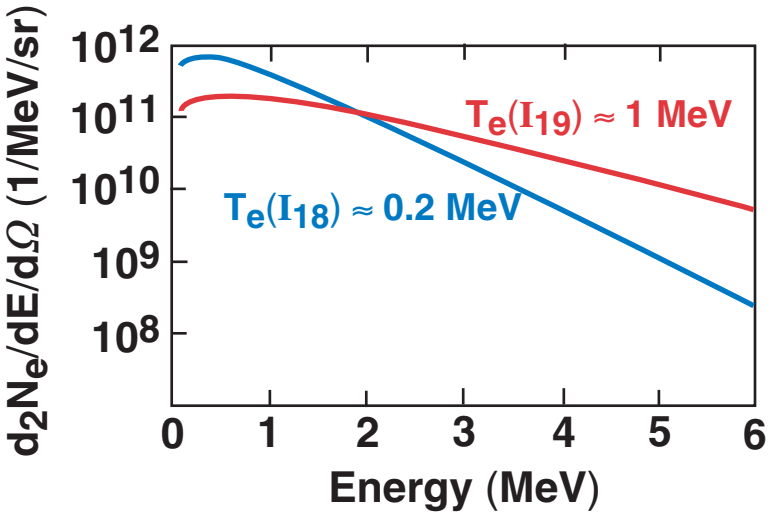
- Electron conversion efficiency ~30% of the focused laser energy



Energy range	0.3 to 5 MeV
Energy resolution	≤30%
Angular range	0° to 90°
Angular resolution	5° to 10°
Dynamic range	$>10^3$
Sensitivity	A few e^-/mm^2

$$\frac{dN}{dE} \propto \mathrm{Exp}\left[-E/T_e\right], \text{ where}$$

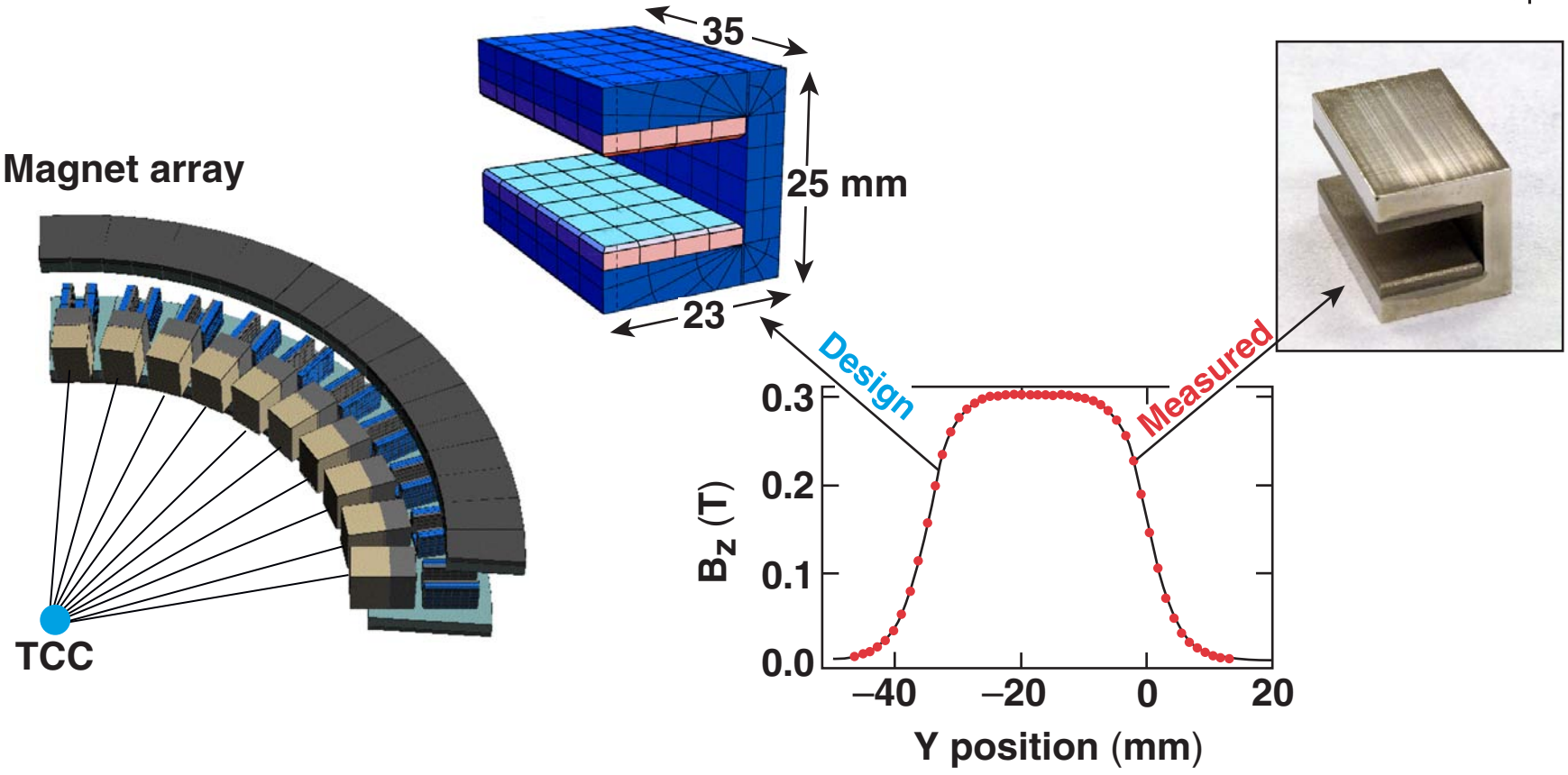
$$T_e \cong 0.511\left(\sqrt{1 + I_{18}/1.37} - 1\right) \text{ MeV}$$ [1]

- To have $\Delta T_e/T_e \leq 10\%$ uncertainty as measured from the data we need energy resolution $\Delta E/E \leq 30\%$.

E14188

[1] G. Malka and J. L. Miquel, Phys. Rev. Lett. 77, 75 (1996).

A simple, 3-kGauss magnetic dipole optimized for compactness is used as the dispersive element



- Two Sm_2Co_7 magnets on a low-carbon steel yoke plated with nickel.
- The dipole gap (10 mm) can tolerate large entrance apertures (up to 4-mm diameter) and misalignment of up to 2°.

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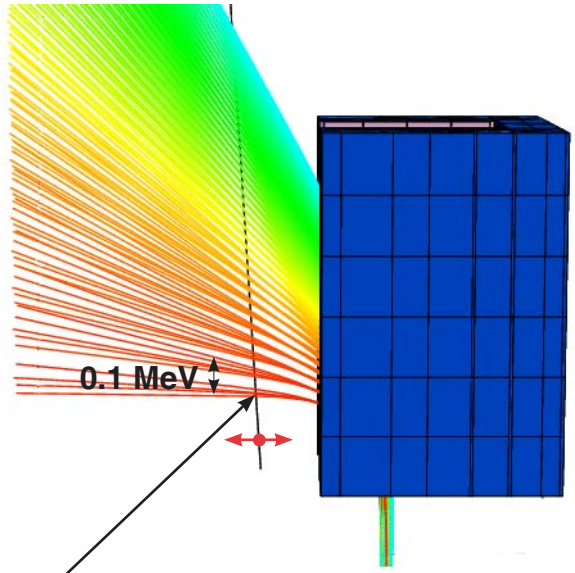
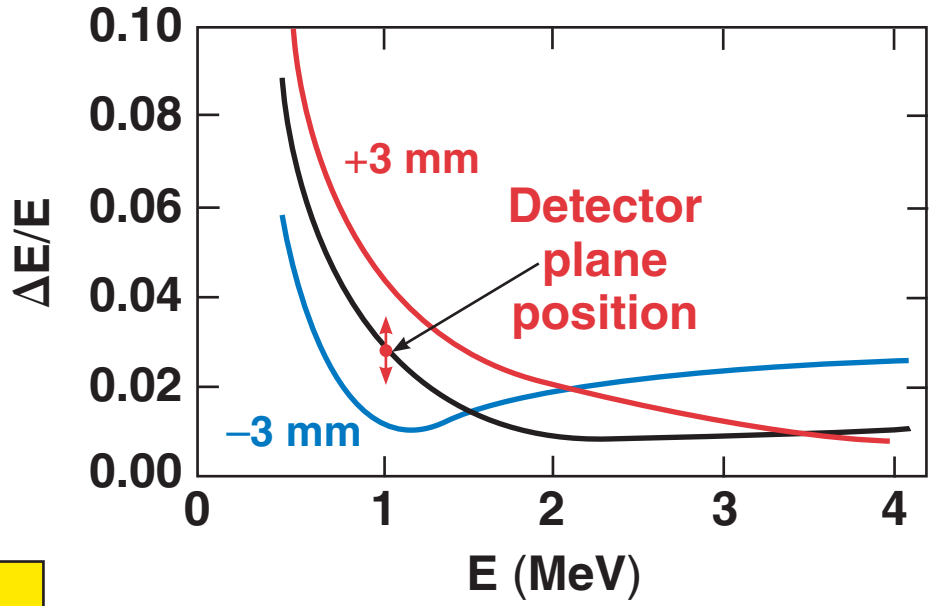
The intersection of the focal surface with the detector plane determines energy resolution

UR LLE

- The electron source (TCC) is in the plane of the detector, to minimize background.





The beam width at the detector defines an energy-resolution element.

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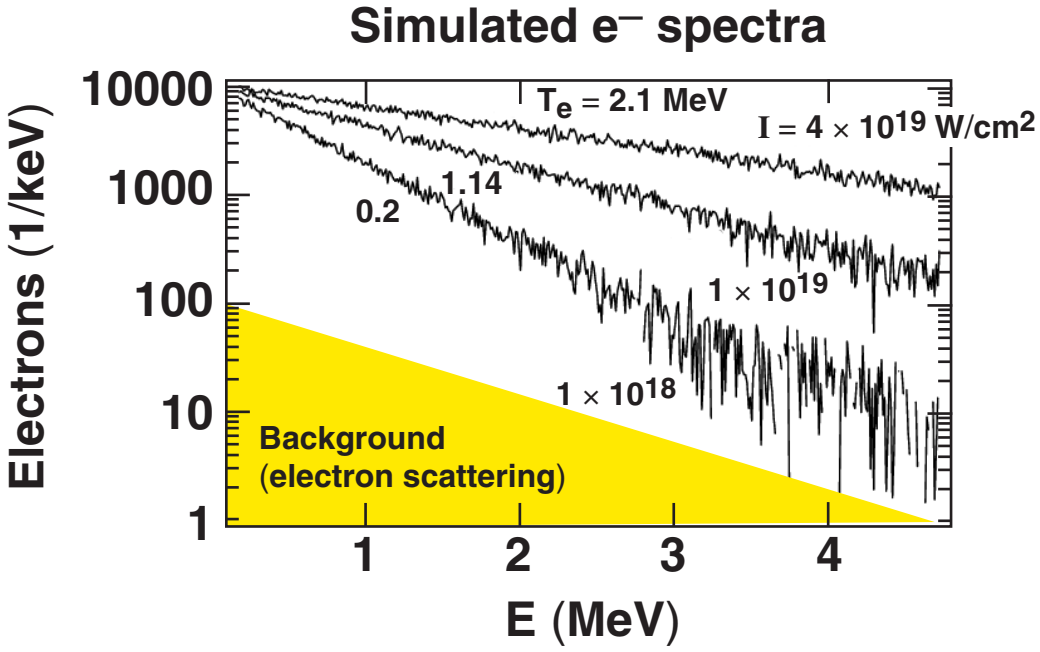
The needed accuracy in determining the hot-electron temperature T_e is guaranteed by the energy resolution



I, W/cm^2 (T_e, MeV)	Pixel size (μm)	$\Delta T_e/T_e$ (%)	$\Delta T_e/T_e$ (%*)
10^{18} (0.2)	50	1.32	1.15
	200	2.77	2.46
4×10^{19} (2.11)	50	0.86	0.60
	200	1.93	1.52

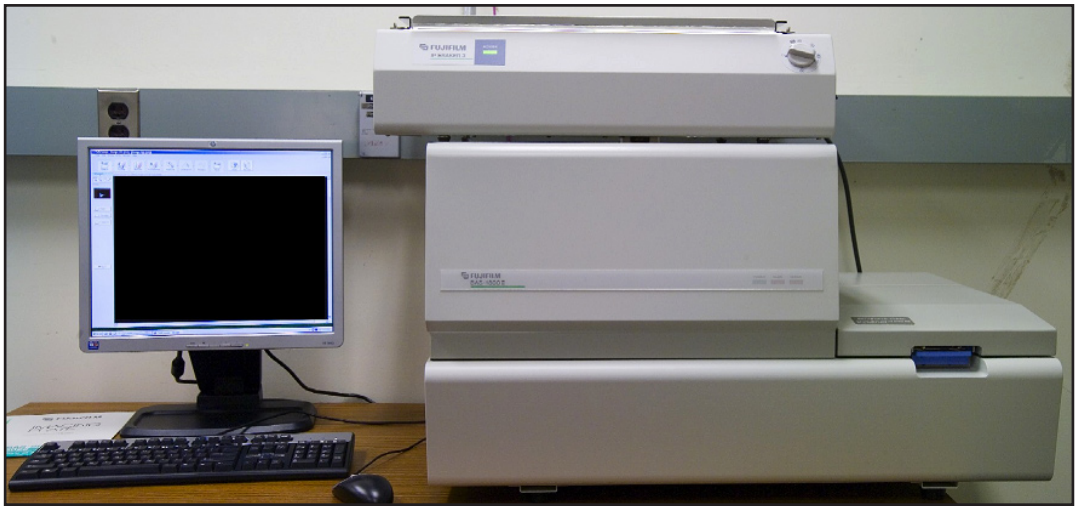
- Error analysis of the least-square fit to a realistic spectrum is performed and accounts for the energy-resolution curve.
- The relative error in the hot-electron temperature $\Delta T_e/T_e$ (from the fit) is below 3% for this system.

*From the regression report of the linear fit.

The spectra are recorded on reusable imaging plates (IP's) scanned with a dedicated, off-the-shelf reader

UR LLE

BAS-1800II scan beam size: 50–200 μm



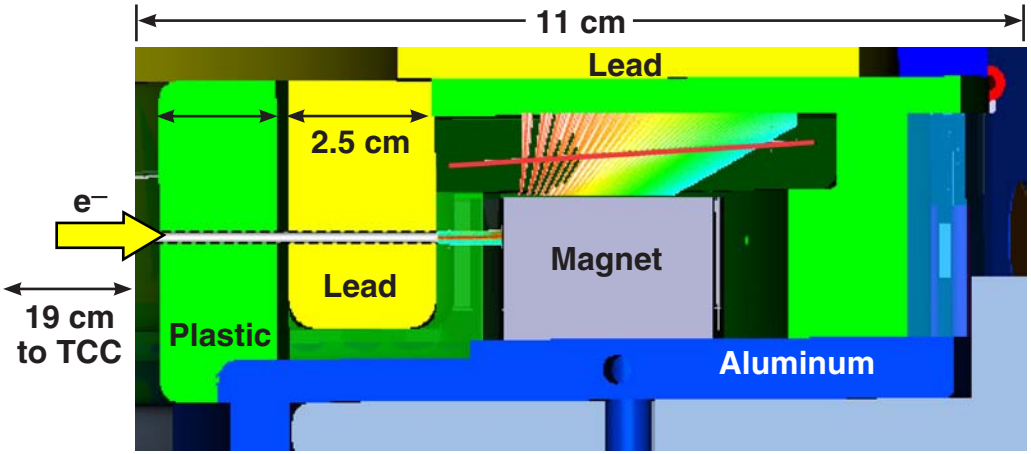
Imaging plate reading station

- **Dynamic range of 10^4–10^5.**
- **Detection threshold for ^{32}P (1.7 MeV): $6e^-/mm^2/h$**
- **The luminescence emission is proportional to the dose in the entire range.**
- **Sensitivity[1]: ~0.007 PSL/e^-**

E14164

[1] K. A. Tanaka *et al.*, Rev. Sci. Instrum. 76, 013507 (2005).

Background noise is kept low by combining adequate shielding with "low visibility" IP orientation

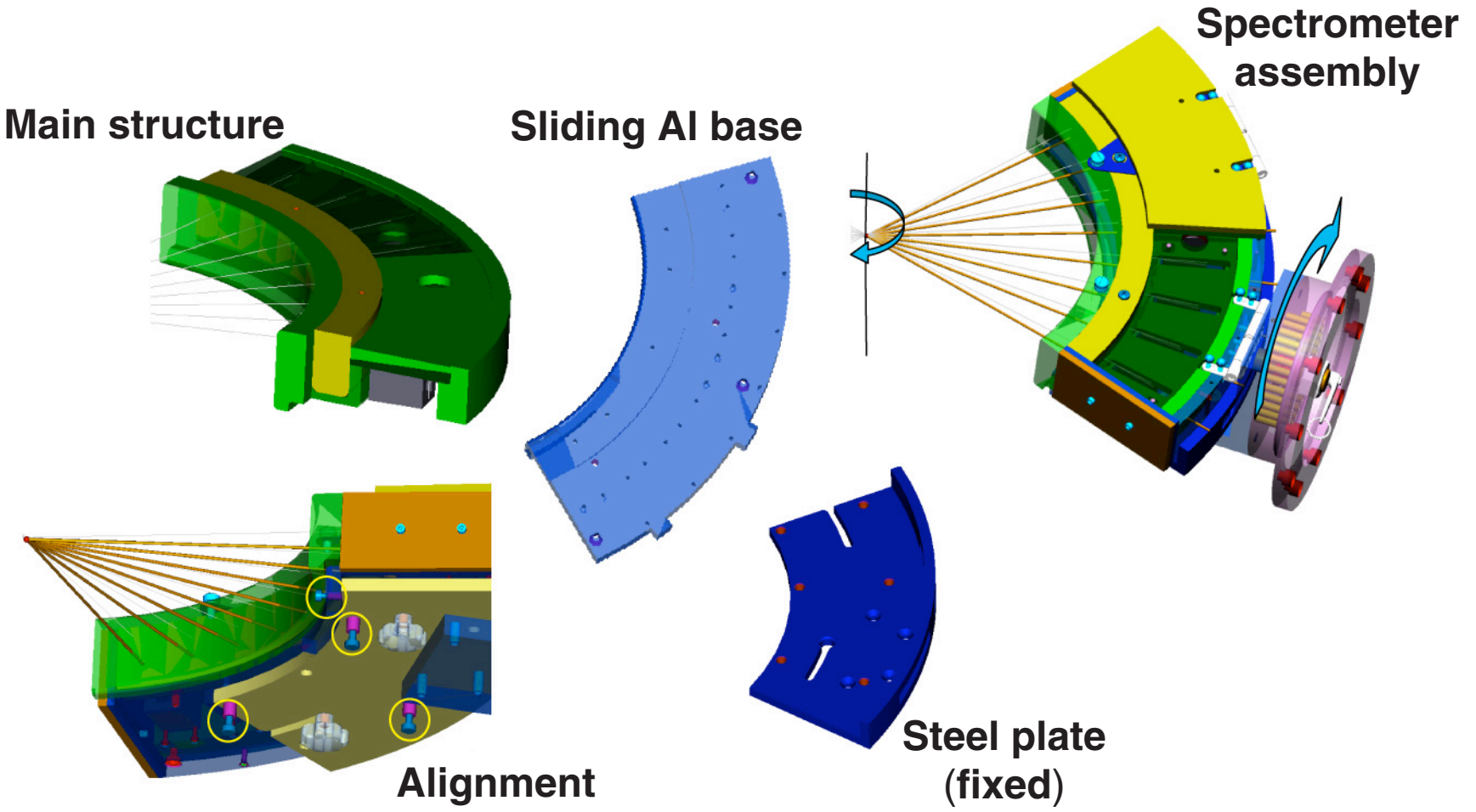


- Sources
  - Bremsstrahlung
  - Electron backscattering
  - Compton scattering
  - Pair production

- The mean free path of 1-MeV gamma rays is 2.4 cm in lead.
- The shielding geometry was validated using simulations with the GEANT4 Monte Carlo code.[1]
- Because of the IP's orientation, gammas deposit in the detector only 0.6 keV for every 100-MeV energy deposited by electrons.[2]

[1] S. Agostinelli *et al.*, Nucl. Instrum. Methods Phys. Res. A 506, 250 (2003).
[2] Input spectrum from P. A. Norreys *et al.*, Phys. Plasmas 6, 2150 (1999).

The array of spectrometers can scan arbitrary sets of angles by rotating about TCC



Summary/Conclusions

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