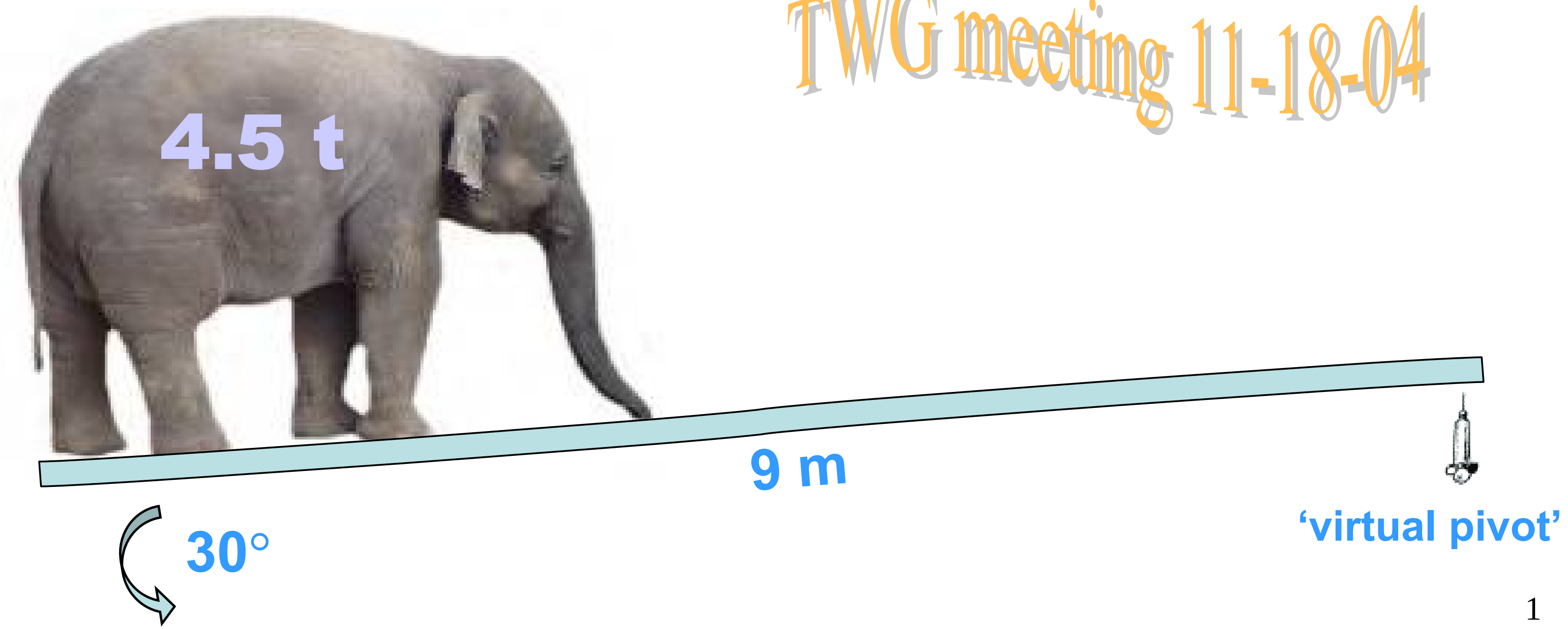
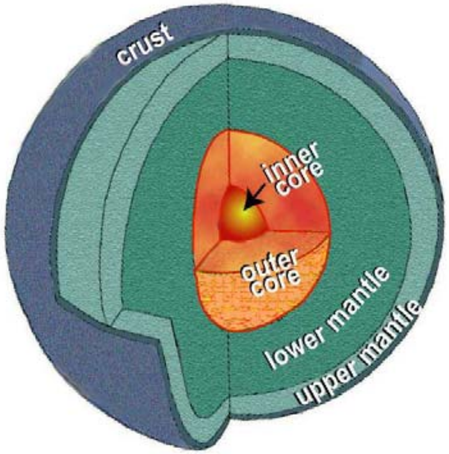
Design of the HERIX spectrometer (IXS-CDT, Sector 30)

Harald Sinn, Bran Brajuskovic, Deming Shu

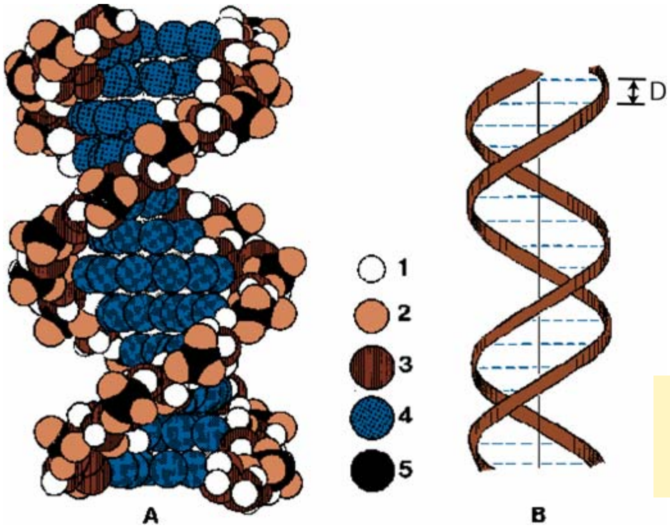
TWG meeting 11-18-04



What is IXS good for?

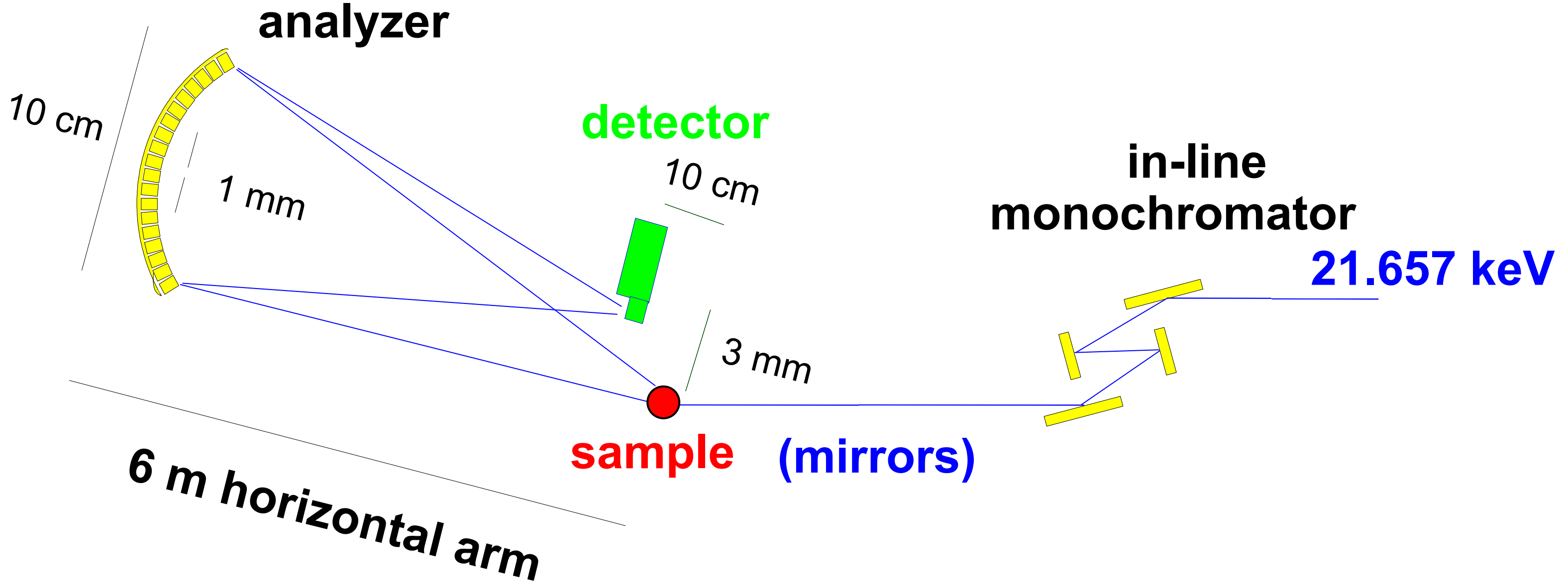


Dynamics under extreme conditions



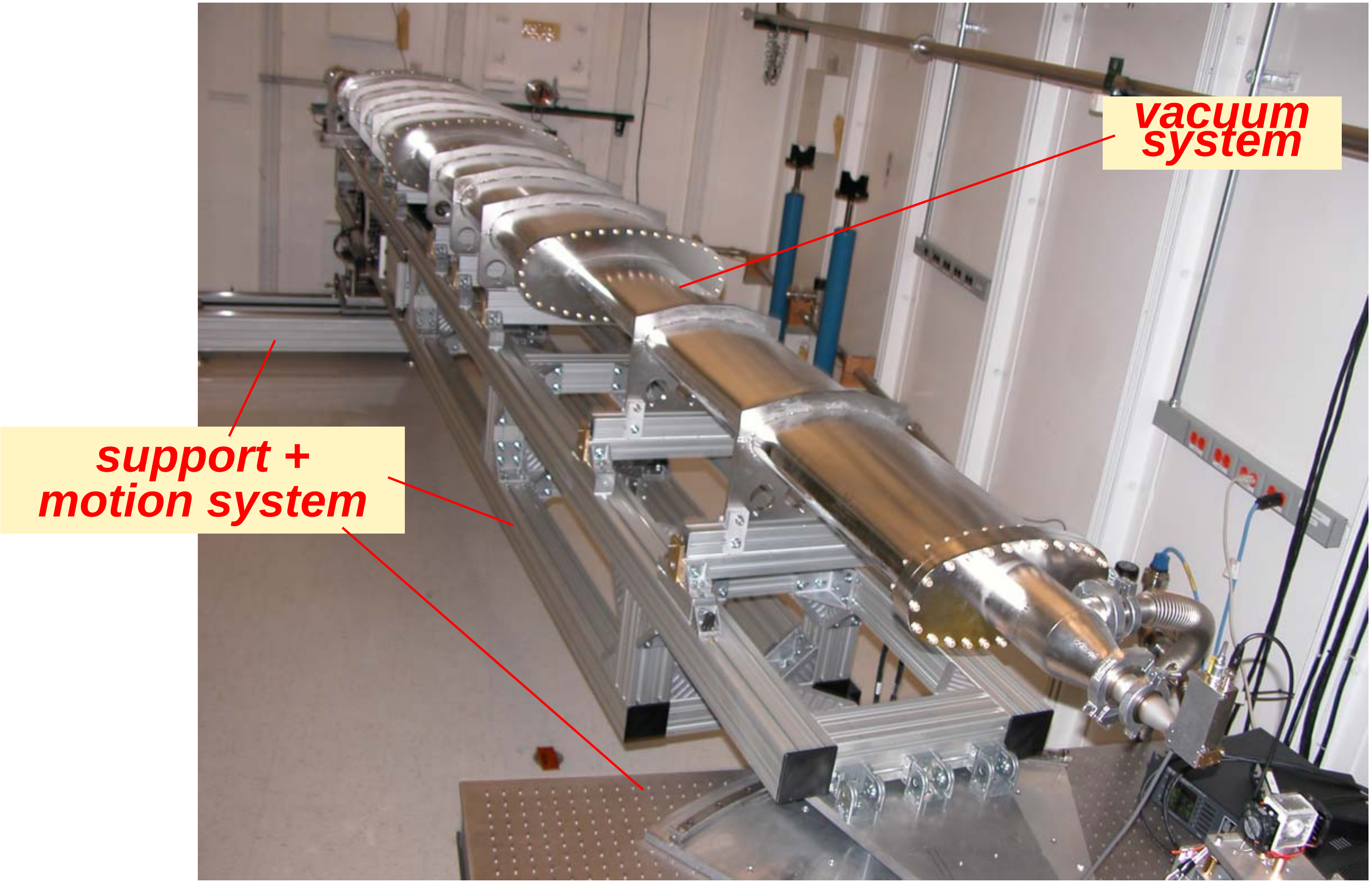
+ in complex systems

IXS Spectrometer at 3-ID-C



3 ID-C today: ***Energy resolution: 1.8 -2.2 meV***
4 analyzers
max. 2θ = 17° = 3 Å^{-1}

Inelastic spectrometer at 3-ID-C



Design goals for new instrument ‘HERIX’

- Enable standard energy resolution of < 1 meV

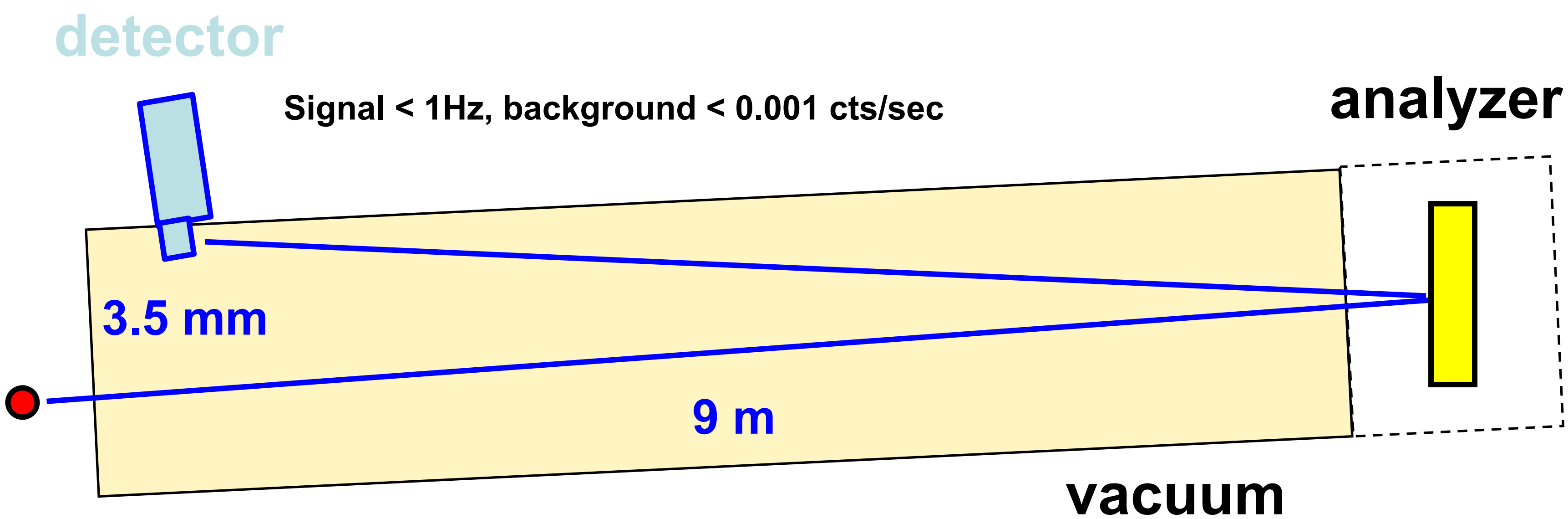
  (→ 9 m long arm versus 6 m at 3 ID-C)
- Maximum number of analyzers with upgrade capabilities (large vacuum)
- Larger 2θ angle (30° versus 15°)
- Large flexibility for various sample environments

  (→ no real pivot at center of rotation)
- Micro-focusing capabilities (30 x 5 micron)

Scientific perspectives

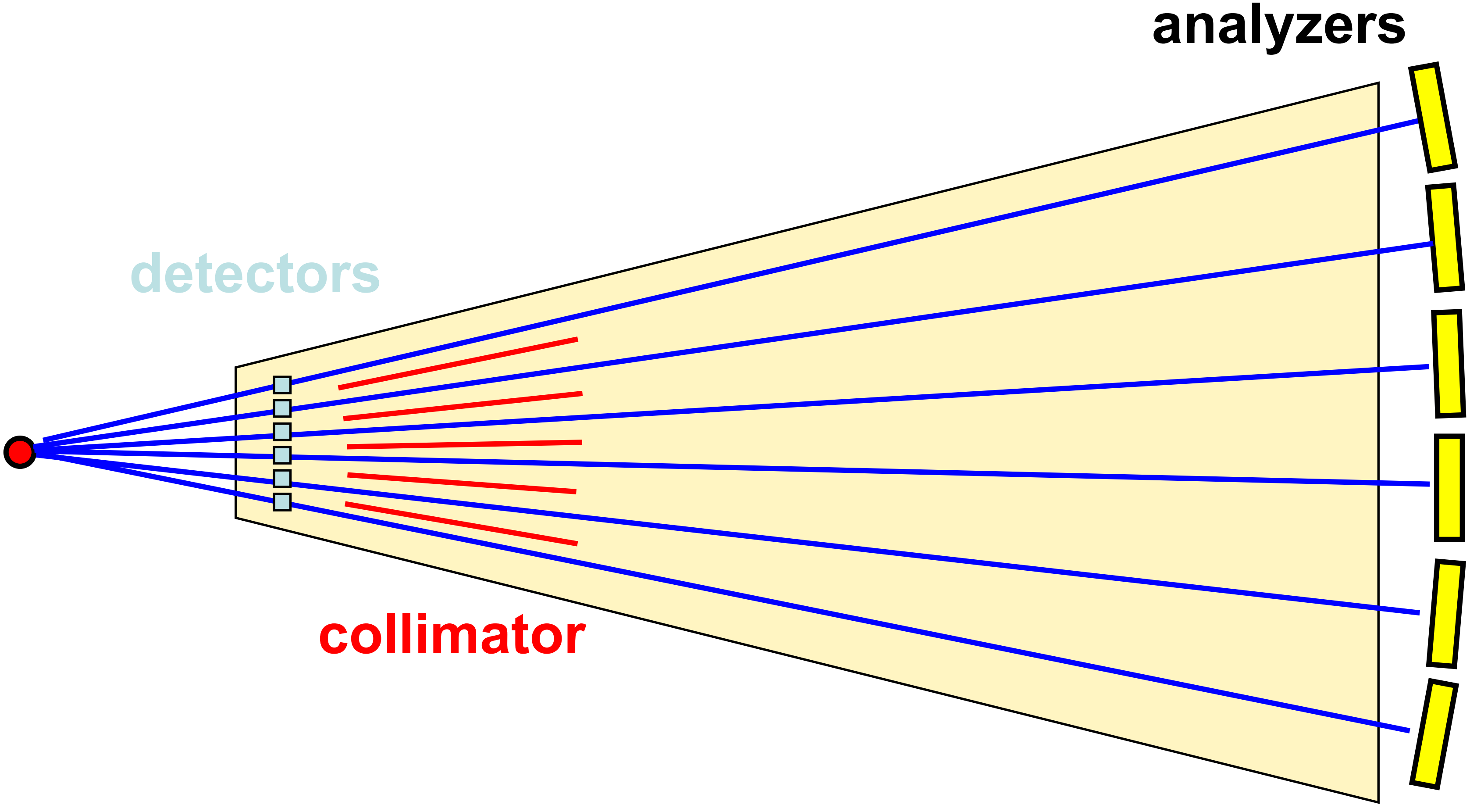
- New experiments in the area of biophysics and nanophysics that require better energy resolution and a small focus
- High pressure experiments

Design of the Analyzer setup

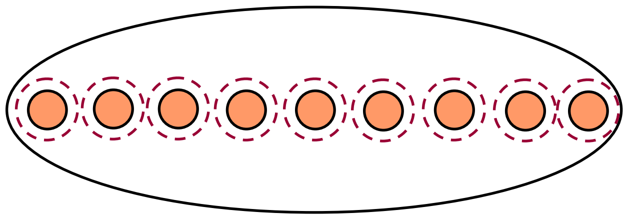


$$I_{Compton} \propto {}^{1}\!\!\diagup_{R^2{}_{window}} \qquad I_{6m} \approx 2 \times I_{9m}$$

Top view: multiple analyzers

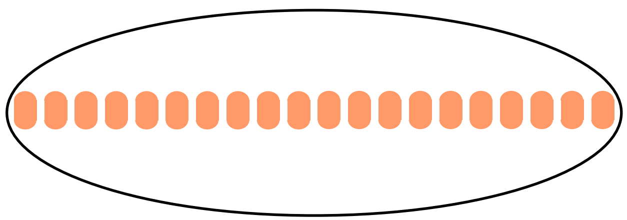


Multi Analyzer Setup + Upgrade possibilities



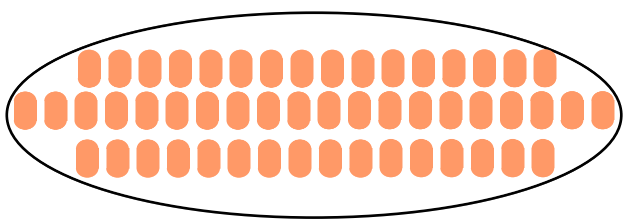
9 analyzers

Extension of current design



20 analyzers

Integration of analyzers design

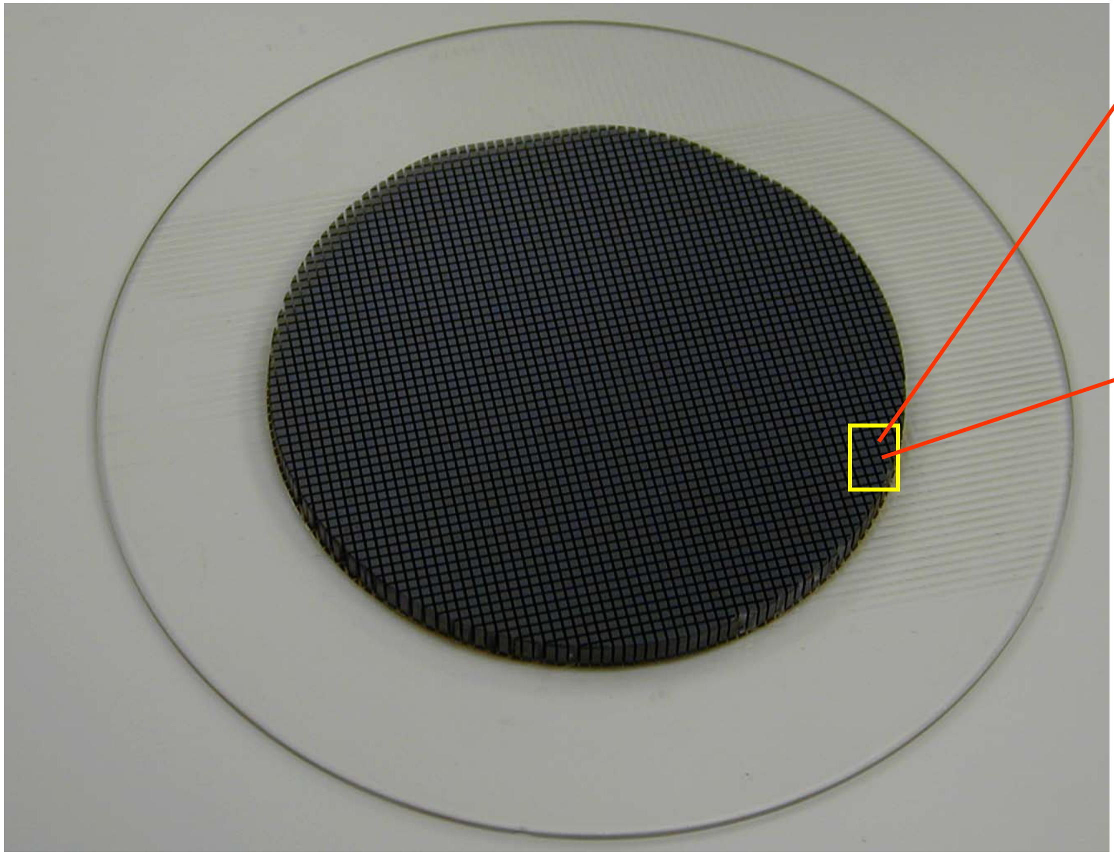


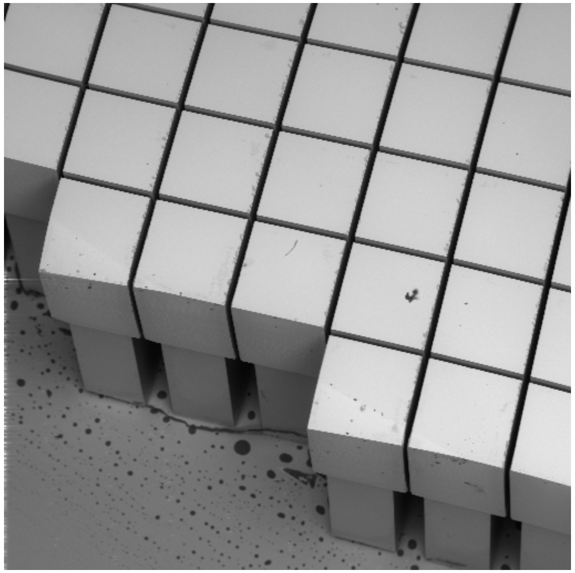
52 analyzers

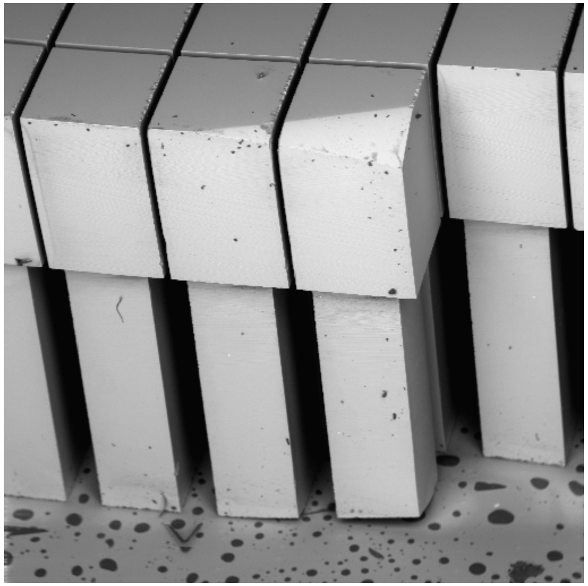
Integration of detector design

Analyzer disk

Diced and dynamically bent
Si (18 6 0) wafer (all in-house)

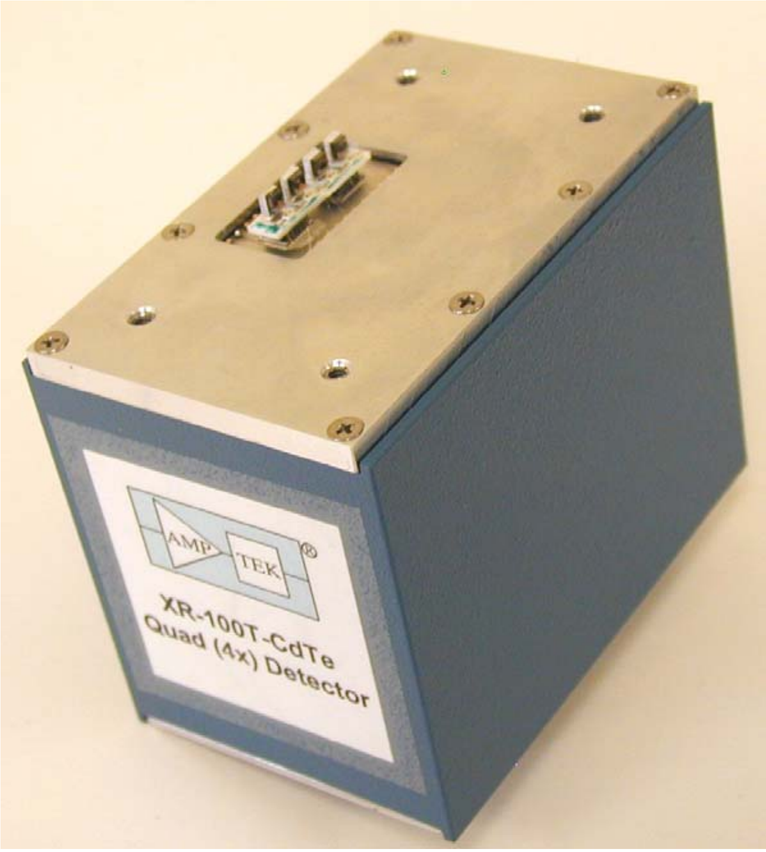






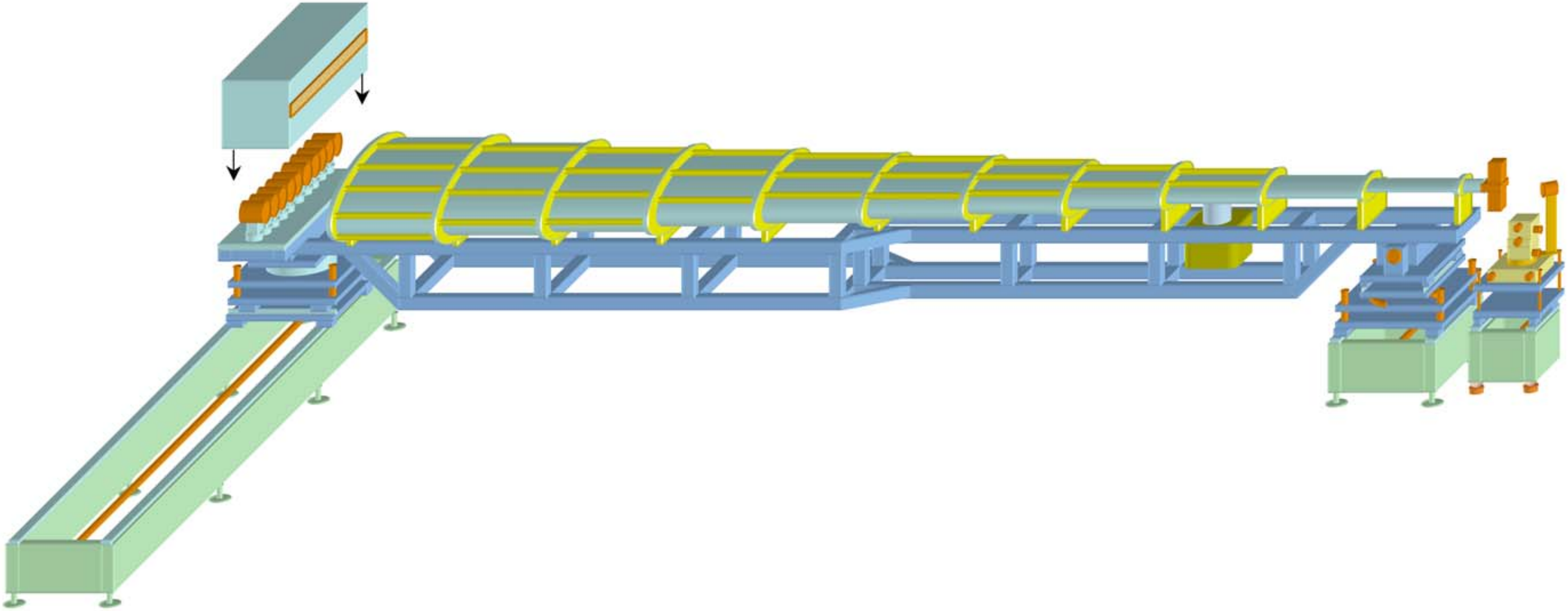
Detectors

1 x 4 + 1 x 5 element detector

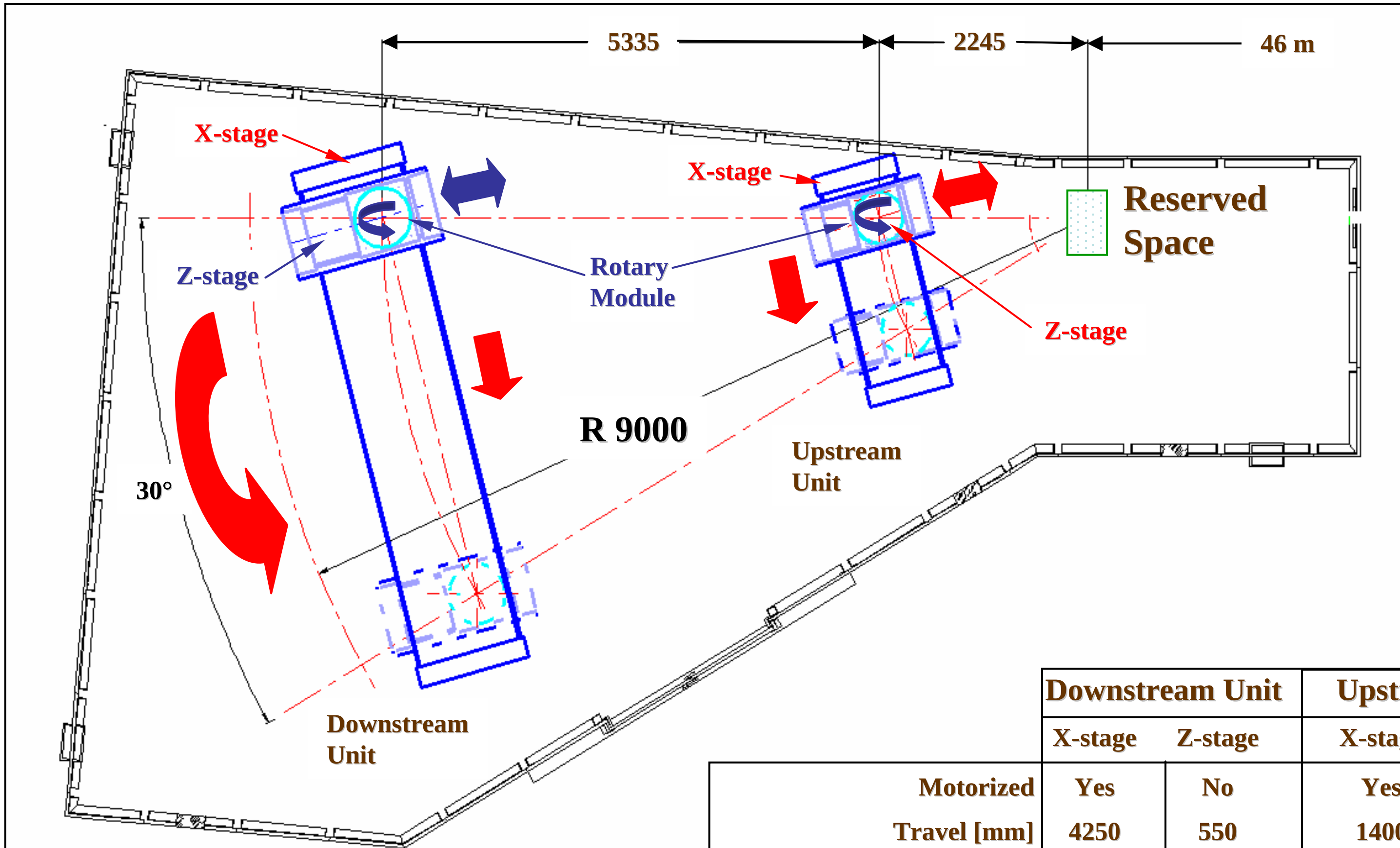


AMPTEK CdZnTe
(modified from 1 element standard detector)
dark current: 3 cts/hour
Efficiency: 1.0 (up to 60 keV)
Max. count rate: 10 kHz

Conceptual Layout HERIX (2003)



Top view: Station C

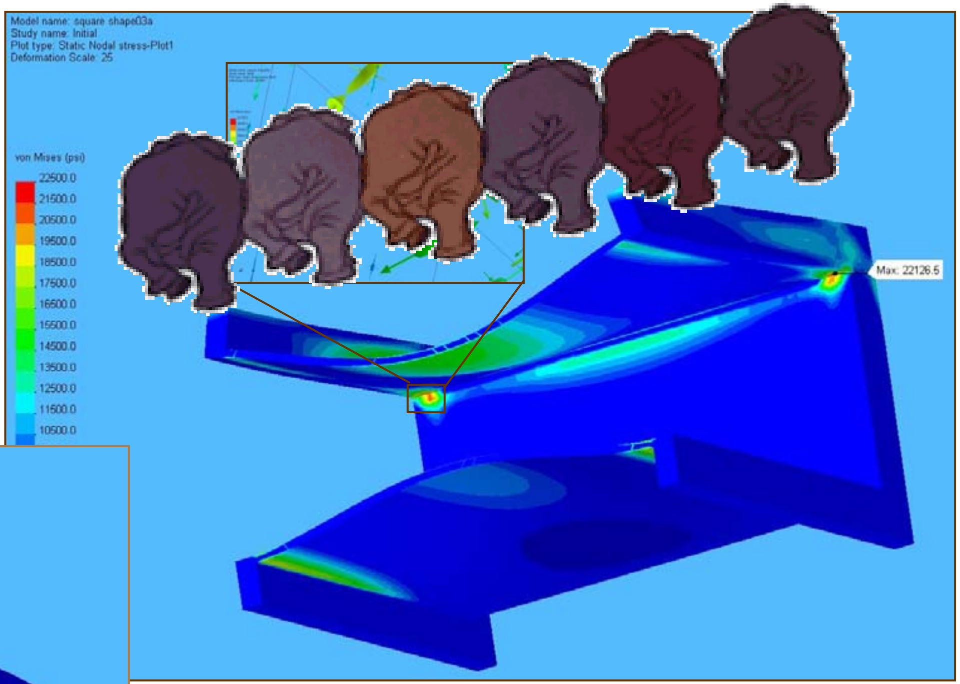


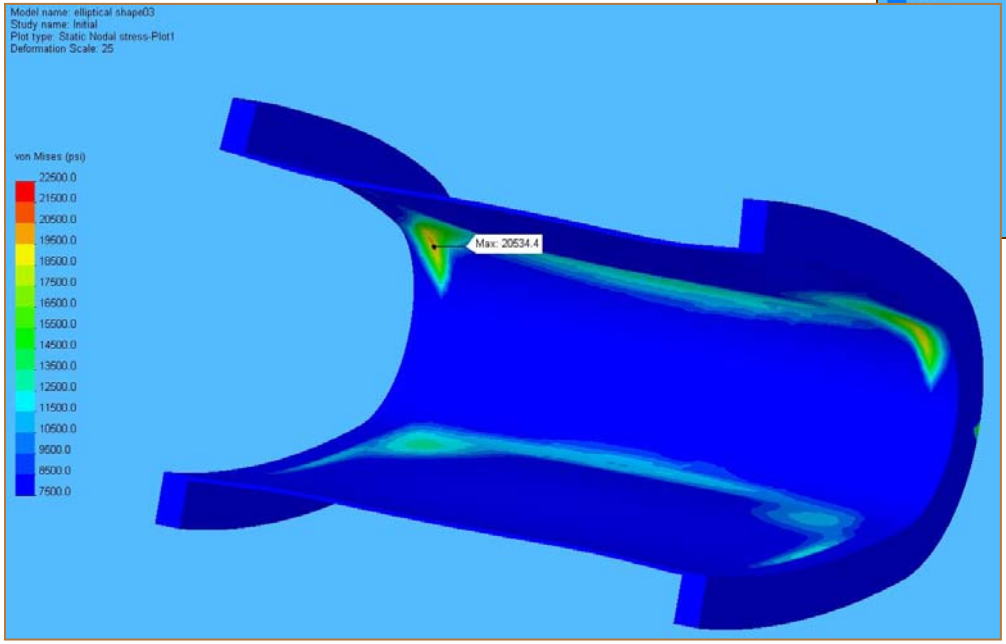
	Downstream Unit		Upstream Unit	
	X-stage	Z-stage	X-stage	Z-stage
Motorized	Yes	No	Yes	Yes
Travel [mm]	4250	550	1400	250
Position repeatability [mm]	±0.05	N/A	±0.005	±0.005
Encoder resolution [mm]	0.010	0.010	0.001	0.001

Vacuum chamber

Initial shape optimization

Due to the limited available space only rectangular and elliptical cross-section could be used.





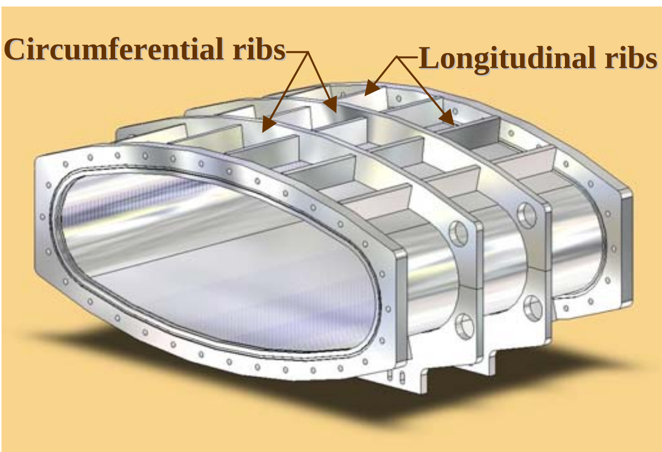
In order to satisfy s_{max} < 21.5 KSI, the rectangular chamber should have wall thickness > 5/8” with weight of over 775 kg.

The elliptical chamber with ¼” thick walls satisfies s_{max} < 21.5 KSI and weights app. 370 kg less!

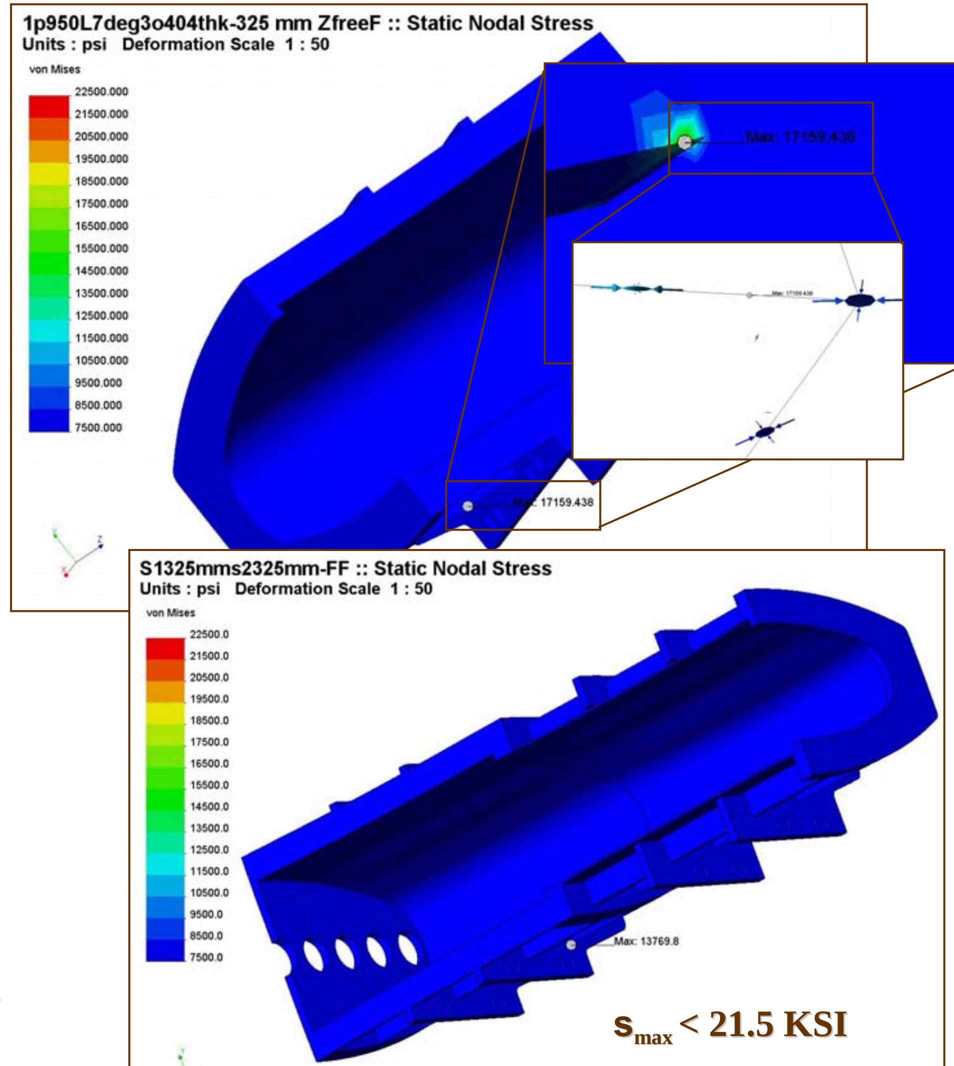
Vacuum chamber

Final shape optimization

To improve structural characteristics of the chamber segments and provide means to connect them to the supporting arm, longitudinal and circumferential ribs were added.

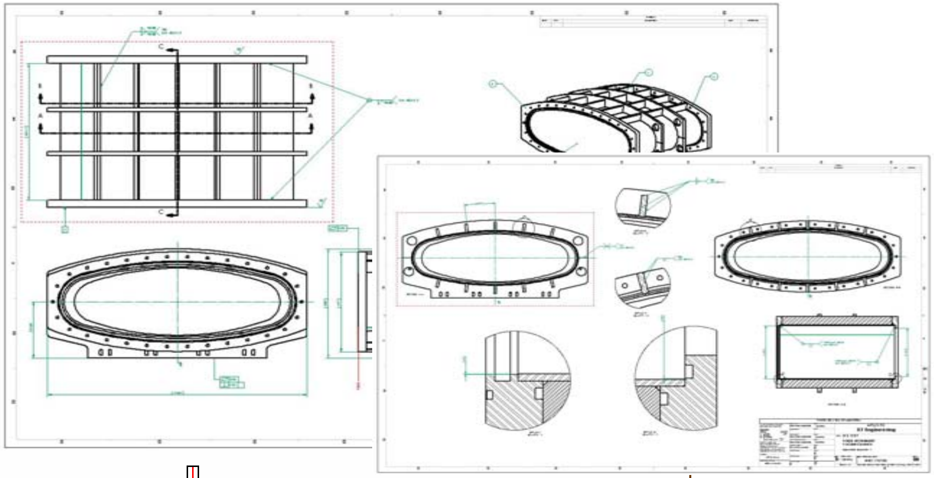


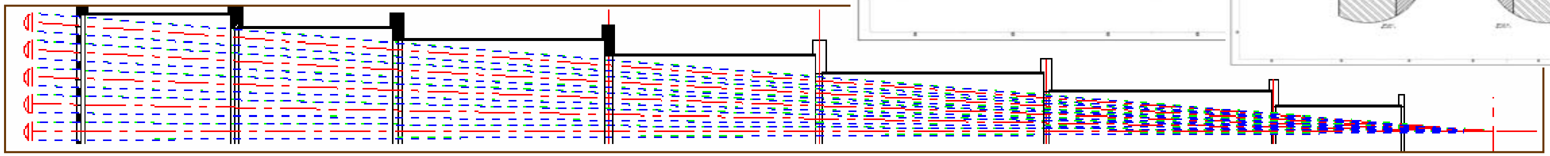
The number, thickness and angular distribution of the longitudinal ribs as well as the thickness and the position of the circumferential ribs were optimized in order to achieve minimum values of stress and deformation of chamber walls.



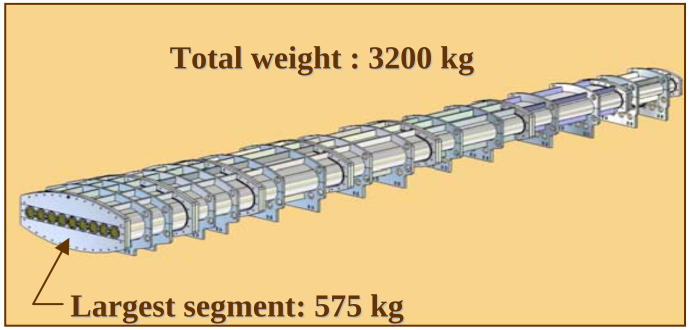
1. **Design suitable for HV (~10^{-5} Torr) will provide scattering free environment,**

2. **No element of vacuum chamber should obstruct optical path between the analyzer and detector arrays (wide X-section at the analyzer end),**





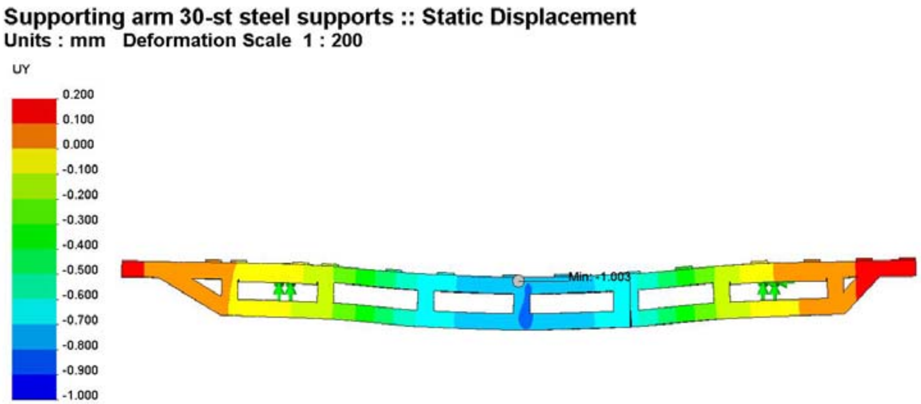
3. **Viable for installation and integration into the beam line (segmental design, weight of each segment bellow 1 ton).**

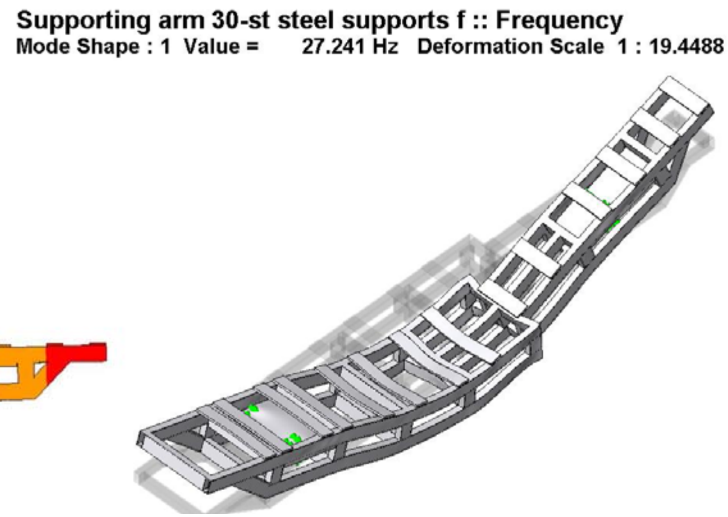


4. **Meets Pressure Vessel Safety Code (maximum stresses < 21.5 KSI)**

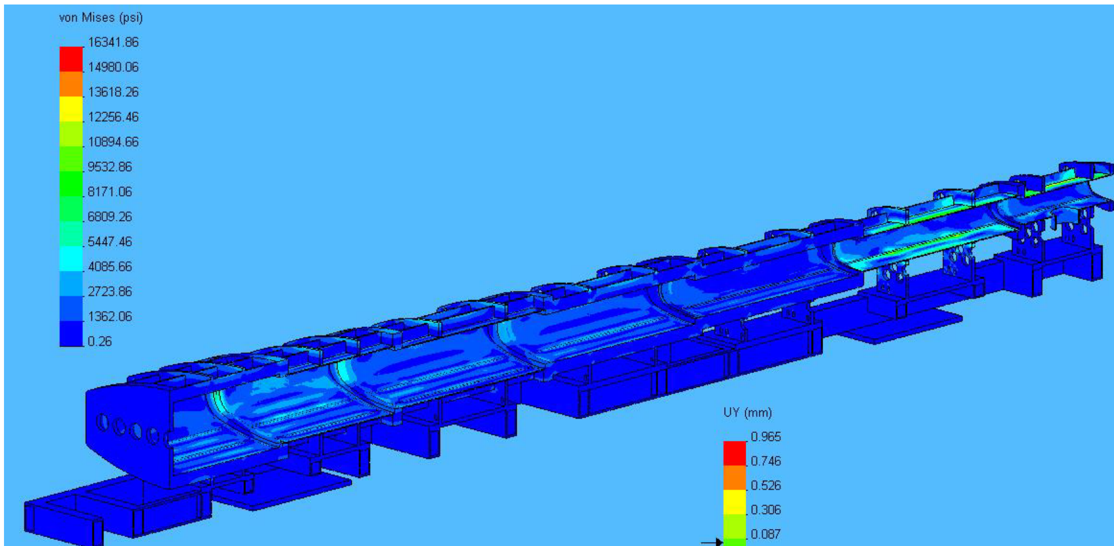
Support Arm

- **Made of extruded aluminum profiles,**
- **Preliminary analysis shows that 80x180 mm BOSH heavy profiles can provide satisfactory structural properties,**
- **Further optimization needed.**

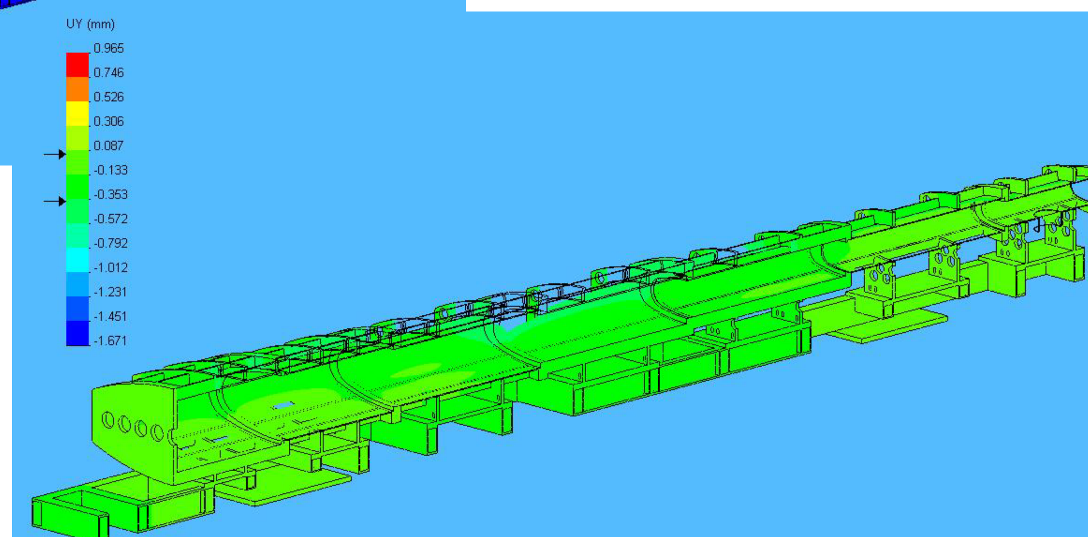




‘Assembly’ or ‘Connecting’ Arm

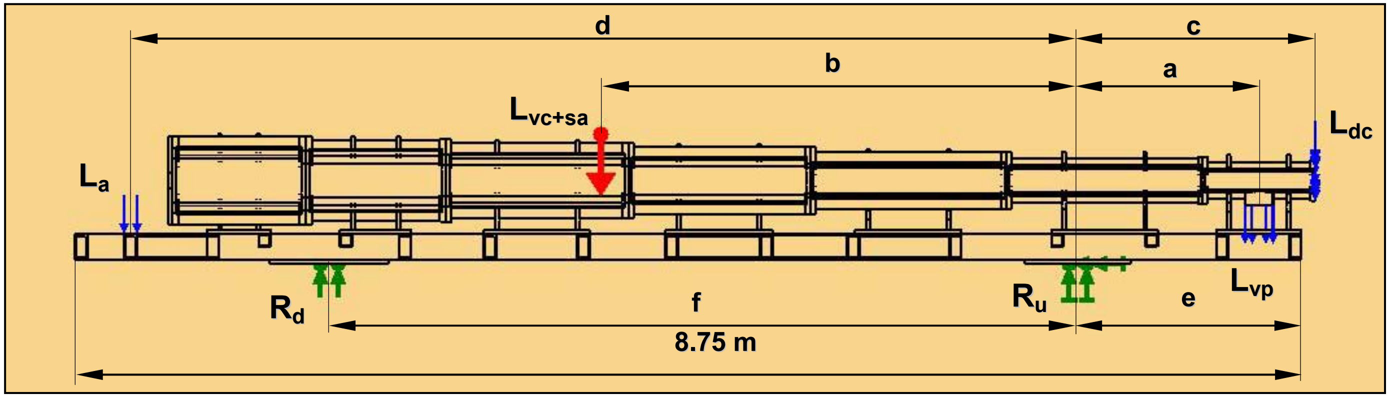


- **Made of extruded aluminum profiles,**
- **FEM analysis shows that 90x180 mm BOSH heavy profiles can provide satisfactory structural properties,**



Weight distribution

Sizing of the Supports



L_a – weight of the analyzer assembly, 250 kg — a = 1.29 m

L_{vc+sa} – weight of the vacuum chamber and connecting arm, 4200 kg — b = 3.4 m

L_{vp} – weight of the vacuum pump, 25 kg — c = 1.79 m

L_{dc} – weight of the detector chamber, 40 kg — d = 6.76 m

R_u – reaction force, upstream support — e = 1.69 m

R_d – reaction force, downstream support — f = 5.34 m

$$\Sigma F = 0: \quad R_d + R_u - L_{vc+sa} - L_a - L_{vp} - L_{dc} = 0$$

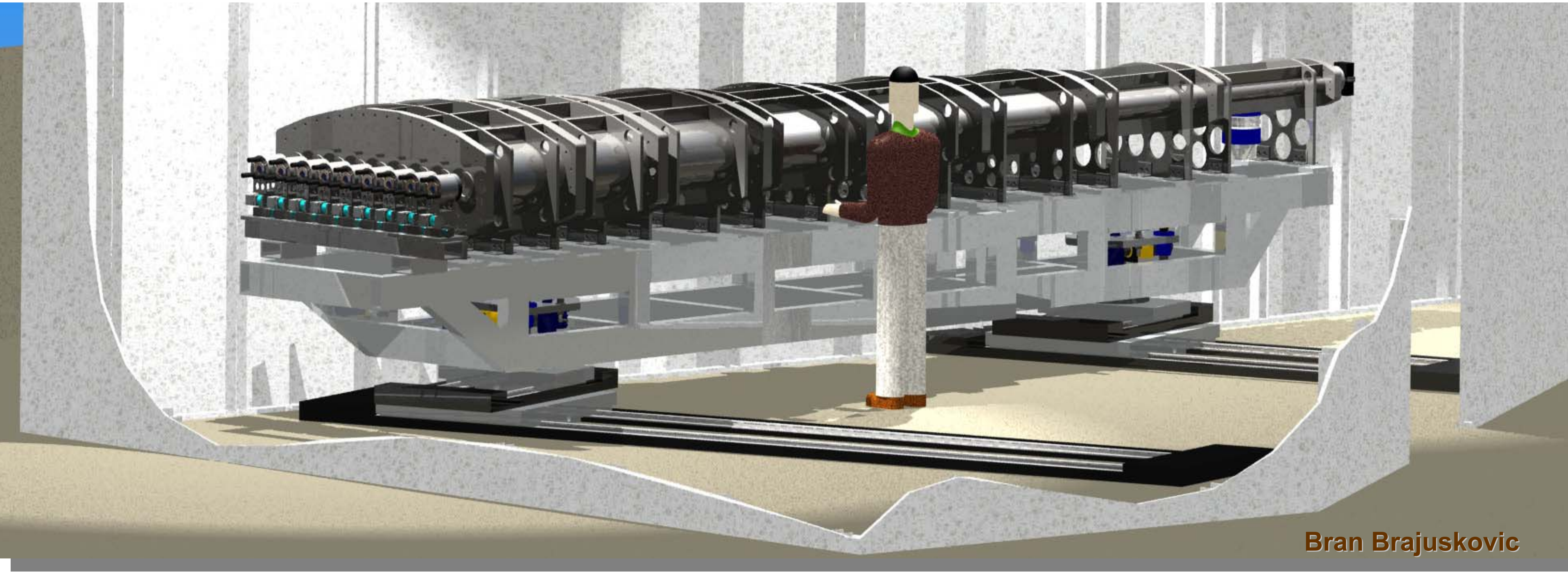
$$\Sigma M = 0: \quad R_d \times f - L_{vc+sa} \times b - L_a \times d + L_{vp} \times a + L_{dc} \times c = 0$$

$\rightarrow$ R_d = 2985 kg

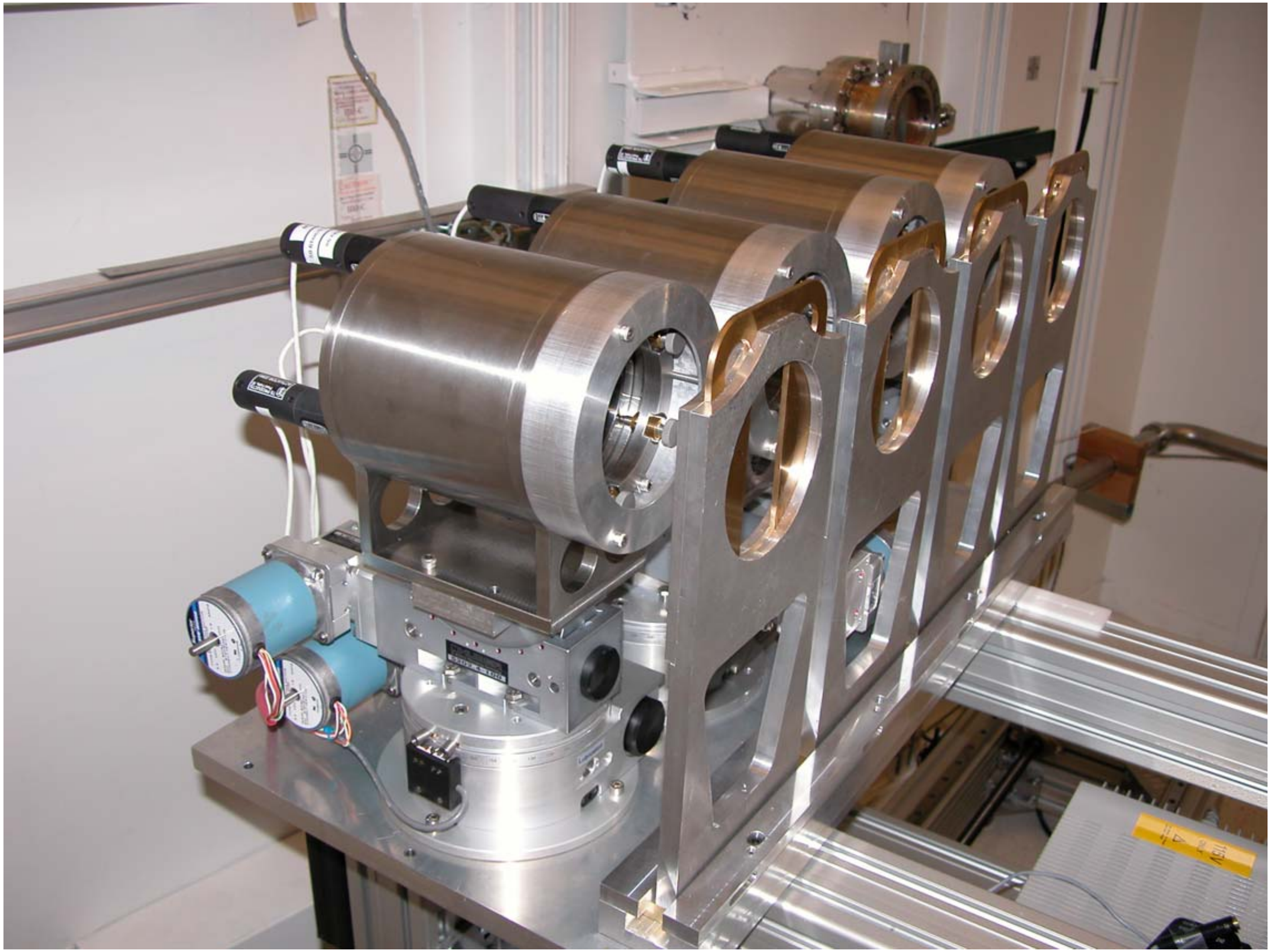
R_u = 1540 kg

Timeline

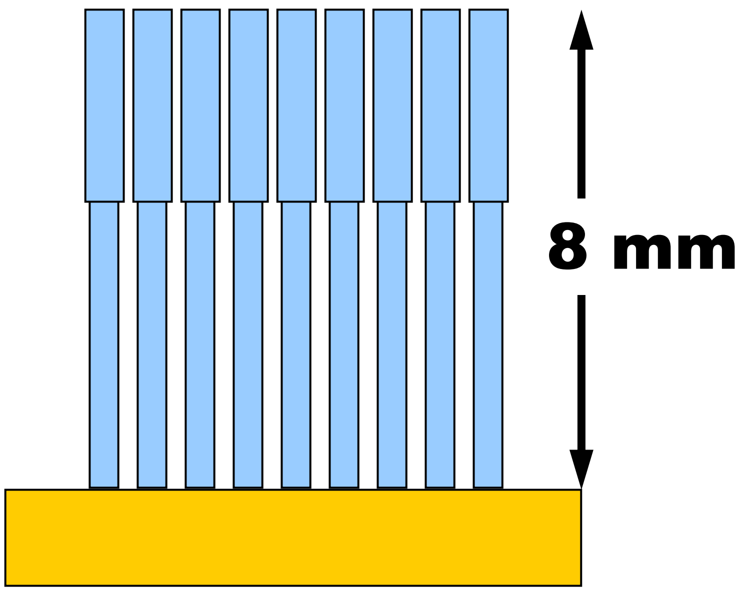
Nov. 2004: ***Requests for bid***
Mar. 2005: ***Motion system***
May 2005: ***Vacuum vessel***
Later 2005: ***First test experiments + Analyzer tests***

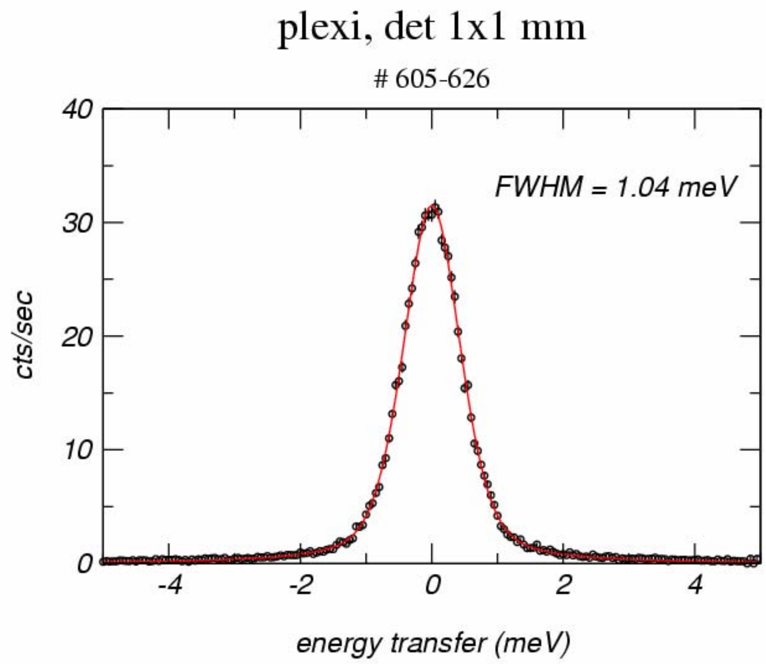


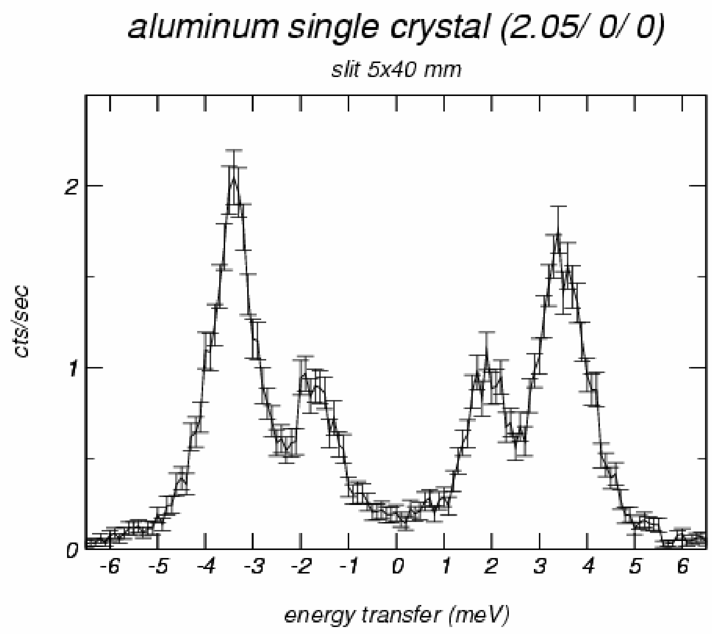
Analyzers



1 meV resolution



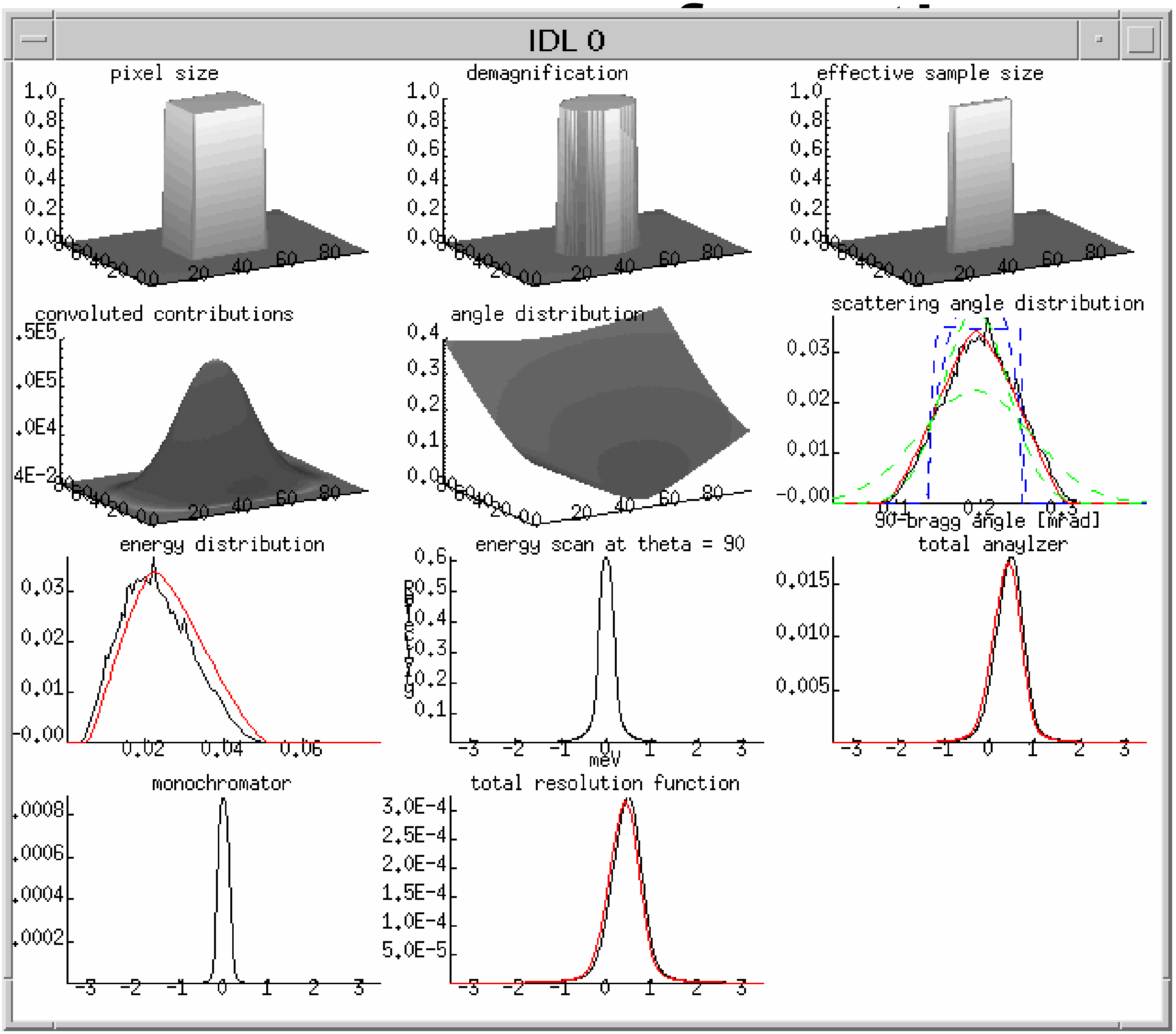




Silicon backreflections

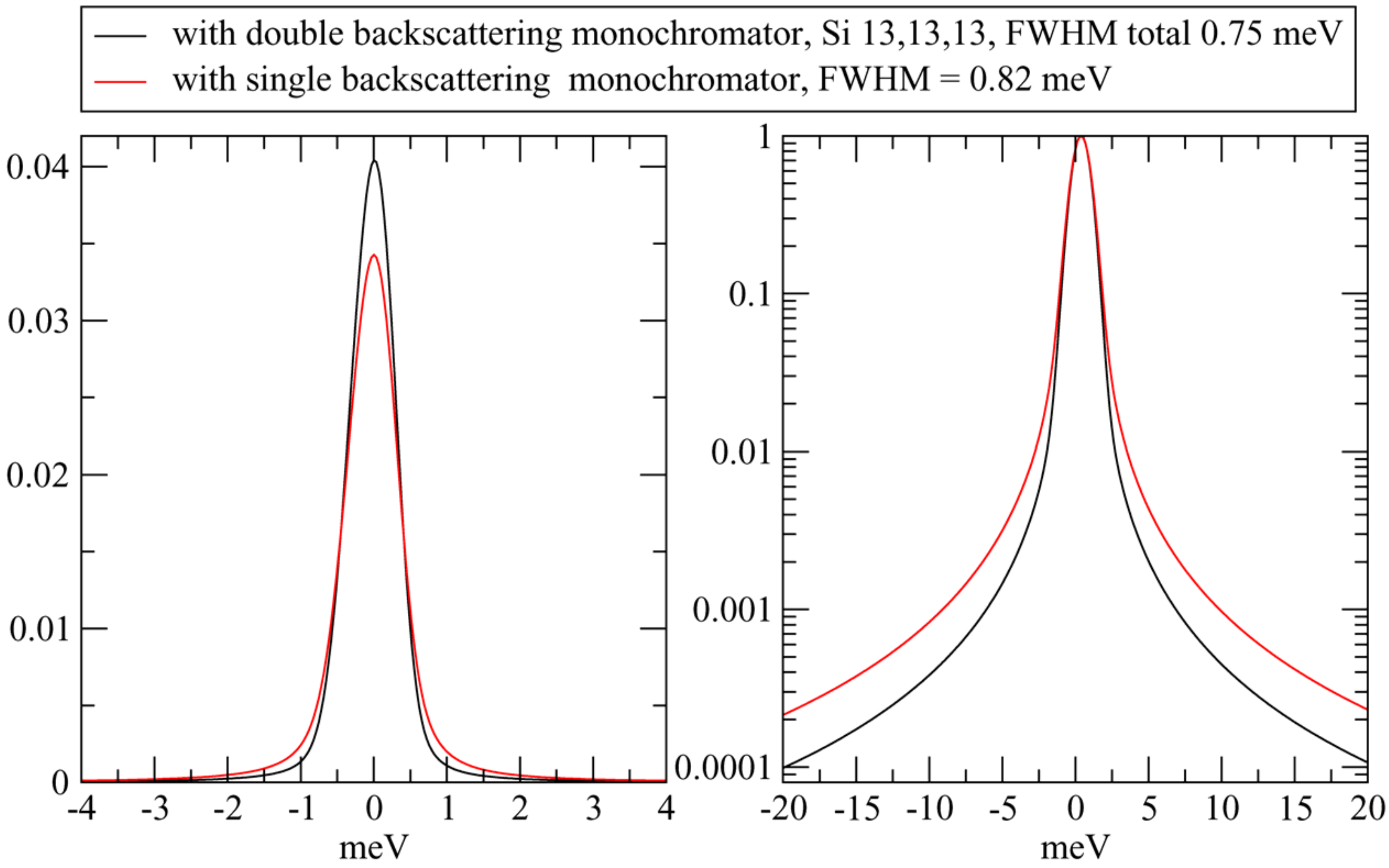
Refl.	7,7,7	12,4,0	18,6, 0	11,11, 11	13,13,13	15,15,15
E (keV)	13.8	14.4	21.6	21.8	25.7	29.6
τ_{ext} (μm)	40-250	30-190	200-1250	280-1800	600-3800	1400-8800
τ_{abs} (μm)	300	380	1220	1240	1990	2990
δE (meV)	5.1	6.2	1.2	0.85	0.37	0.15
reflectivity	81%	87%	78%	70%	61%	46%
tot. res.	> 10 meV		2 meV		< 1meV	0.4 meV

Calculation of the resolution

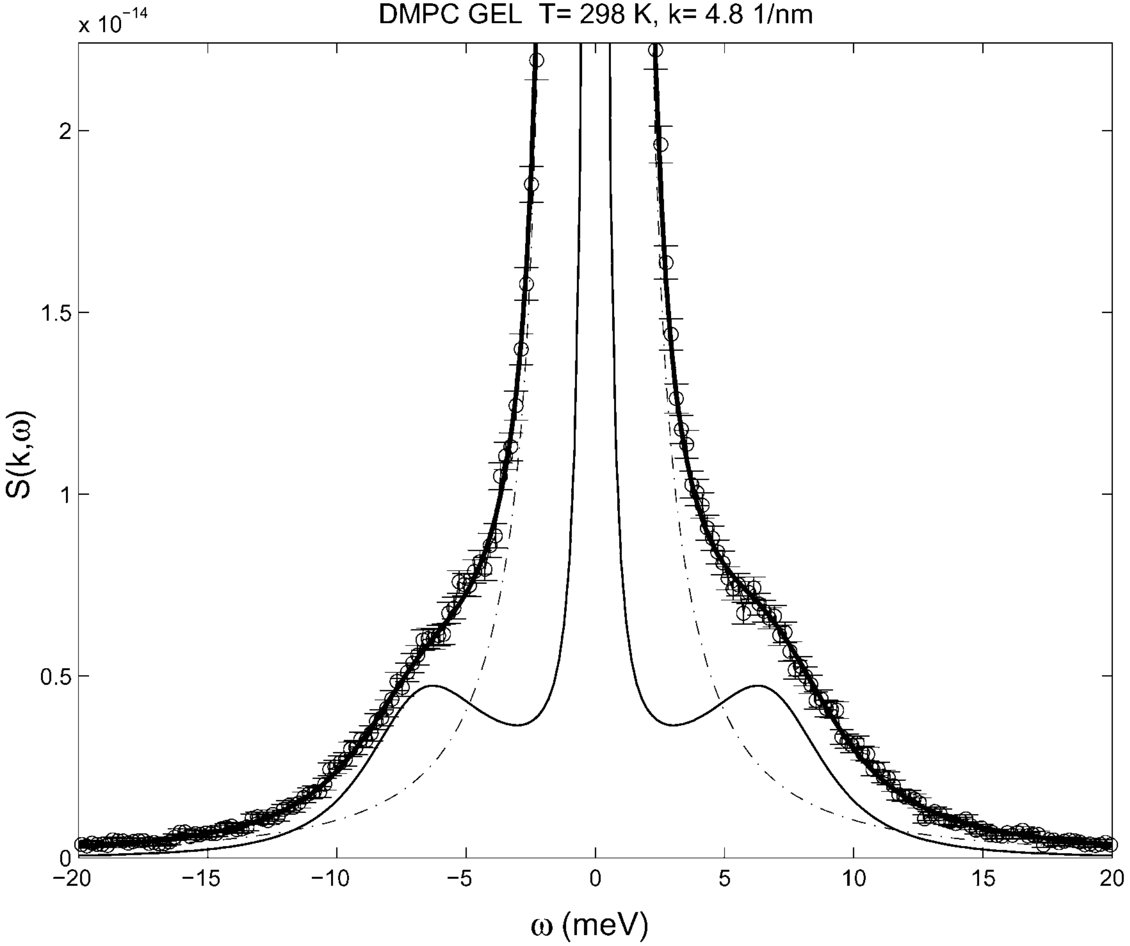



```
IDL> .run ixsres
% Compiled module: $MAIN$.
Radius              :      8909.09 mm
Espilon average     :     0.194444 mrad
dEspilon pixel      :     0.111111 mrad
dEspilon demag hor. :     0.113379 mrad
dEspilon sample hor.:    0.0888889 mrad
dEspilon sample ver.:    0.0222222 mrad
max. dEspilon       :     0.113379 mrad
dEspilon arrays     :     0.340136 mrad
    -0.016285919
Reflection      :       13       13       13
Temperature     :      300 K
Energy          :       25.7015 keV
Lambda          :      0.482404 A
H_hkl           :       26.0495 A-1
Structure factor:       2.82843
Form factor f(H):       1.23370
DWF: M          :      0.452863
exp(-M/lambda^2):      0.142843
fp              :     0.0381148
fpp             :     0.0317975
F_0             :(       112.305,      0.254380)
F_H             :(       1.02768,     0.0256937)
Chi_0           :( -1.46334e-06, -3.31457e-09)
Chi_H           :( -1.33907e-08, -3.34790e-10)
Reflectivity    :       61.4079 %
FWHM crystal    :      0.371811 meV
FWHM ana exact  :      0.688538 meV
FWHM ana approx :      0.729850 meV
FWHM mono approx       :      0.302957 meV
FWHM total exact:      0.743621 meV
FWHM total approx:      0.784933 meV
IDL>
```

Resolution function HERIX



IXS Experiment: Lipid Bilayers



Energy resolution:

1.9 meV FWHM

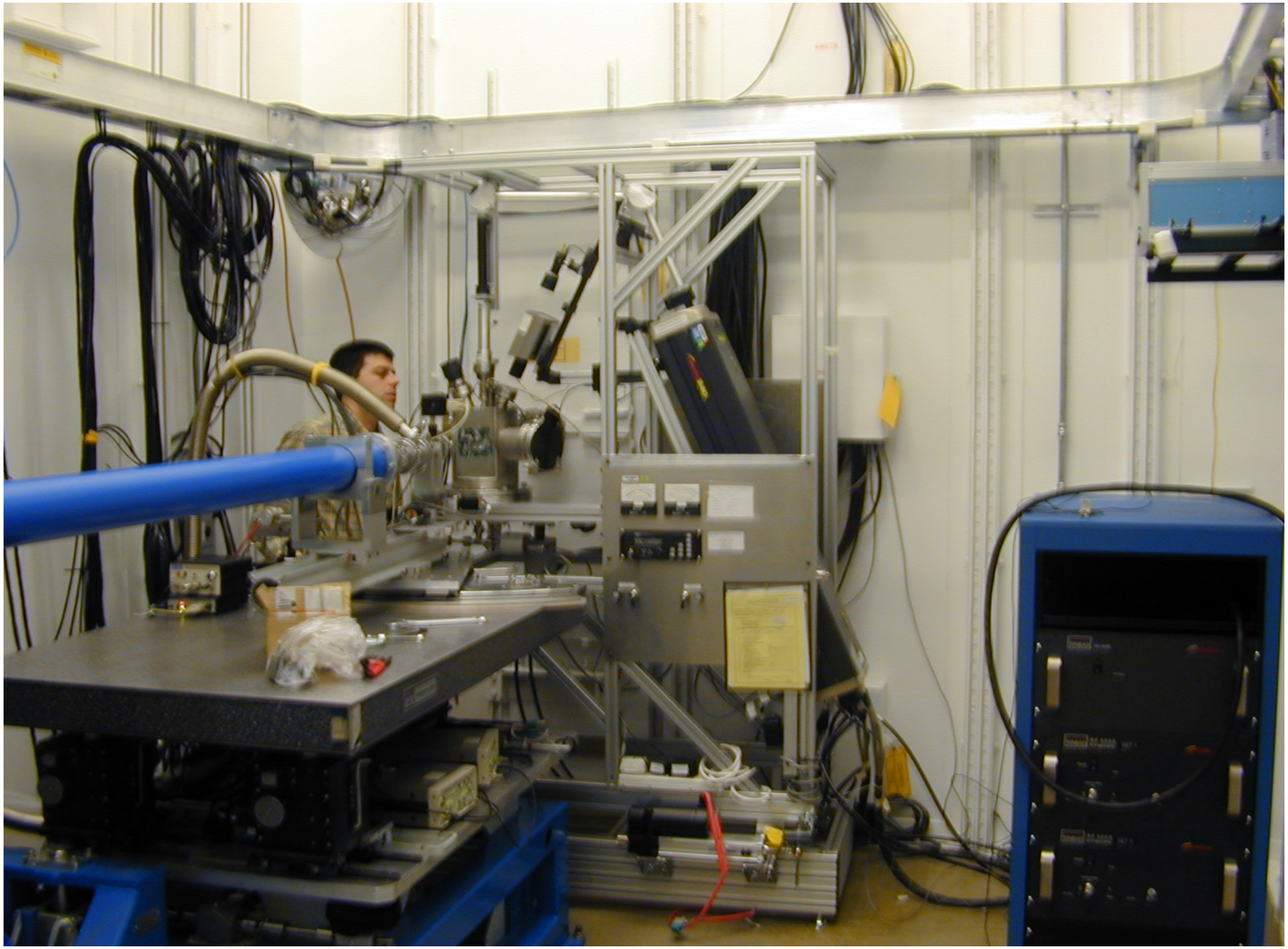
T. M. Weiss, P. J. Chen, H. Sinn, E. E. Alp, S. H. Chen, H. W. Huang: Collective chain dynamics in lipid bilayers by inelastic X-ray scattering, Biophysical Journal , 84, 3767, (2003)

Length of arm

Si 13/13/13 backreflection, DBM, 25.7 keV,
beam separation at detector 3.5 mm, 100 mm analyzer

Sample-Analyzer	6 m	7 m	8 m	9 m	10 m	20 m	9 m	9 m
Sample-Detector (mm)	180	180	180	180	180	180	180	90
Pixel size (mm)	1	1	1	1	1	1	0.7	0.7
Overall resolution (meV)	1.73	1.21	0.91	0.74	0.66	0.47	0.66	0.58

Levitation unit



Single crystals: reciprocal space

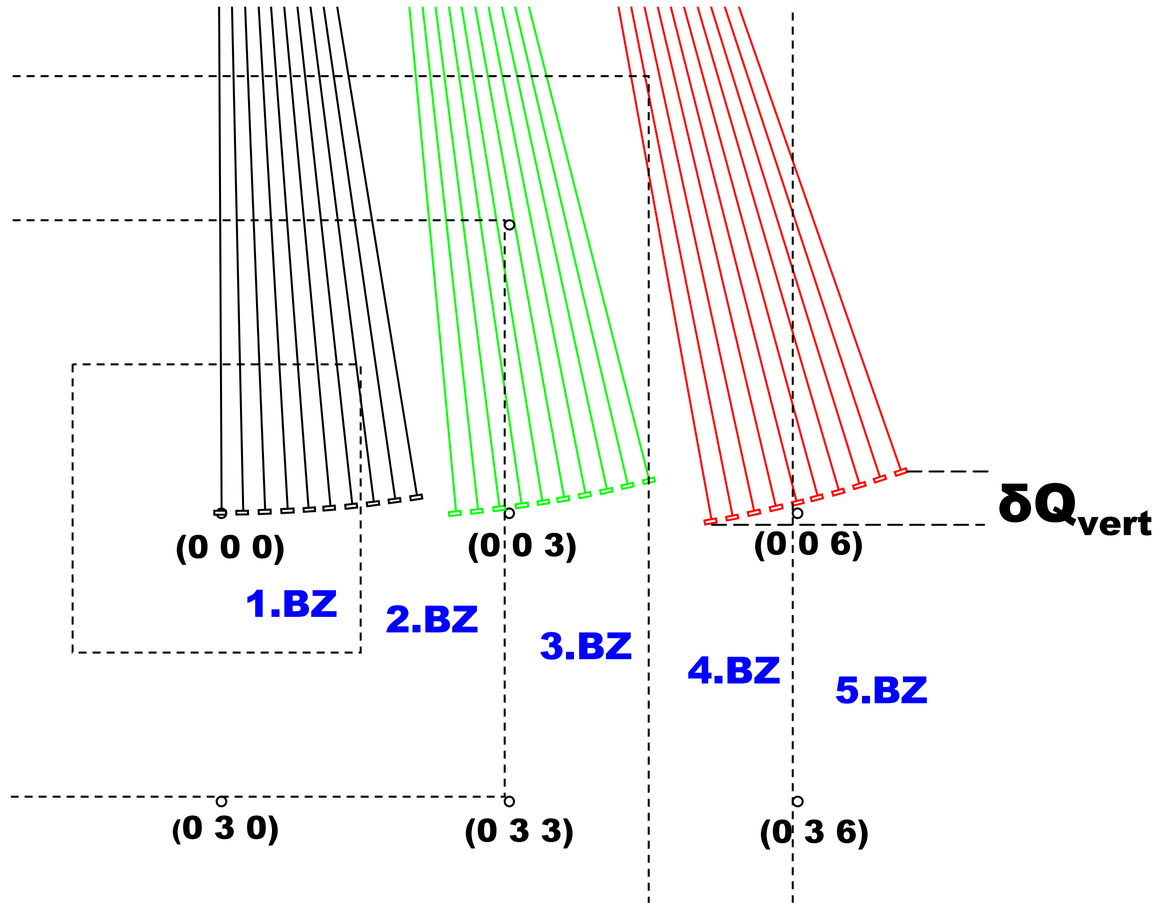
1 analyzer:

δQ = 0.13 Å^{-1}

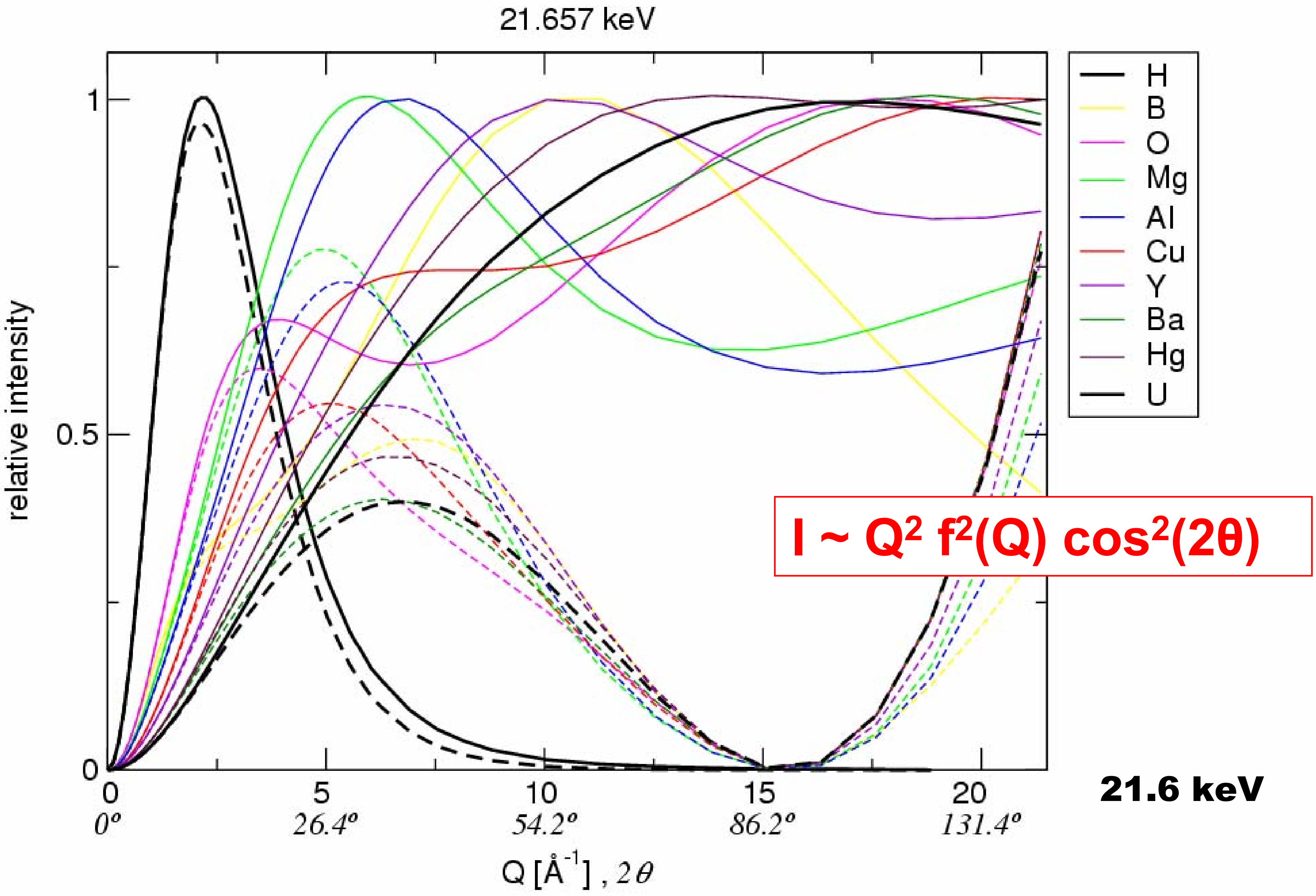
10 analyzers:

δQ_{vert} = 0.16 Å^{-1}

... 0.9 Å^{-1}



Vertical versus horizontal scattering plane



21.6 keV