Mushroom

Multi-**U**se **S**pectrometer for **H**igh **R**ate **O**bservation **O**f **M**aterials

A cold neutron spectrometer with a difference

Rob Bewley
FRMII
31/1/18

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ISIS Facility

Diamond
Light source

TS1
32 years

TS2
10 years

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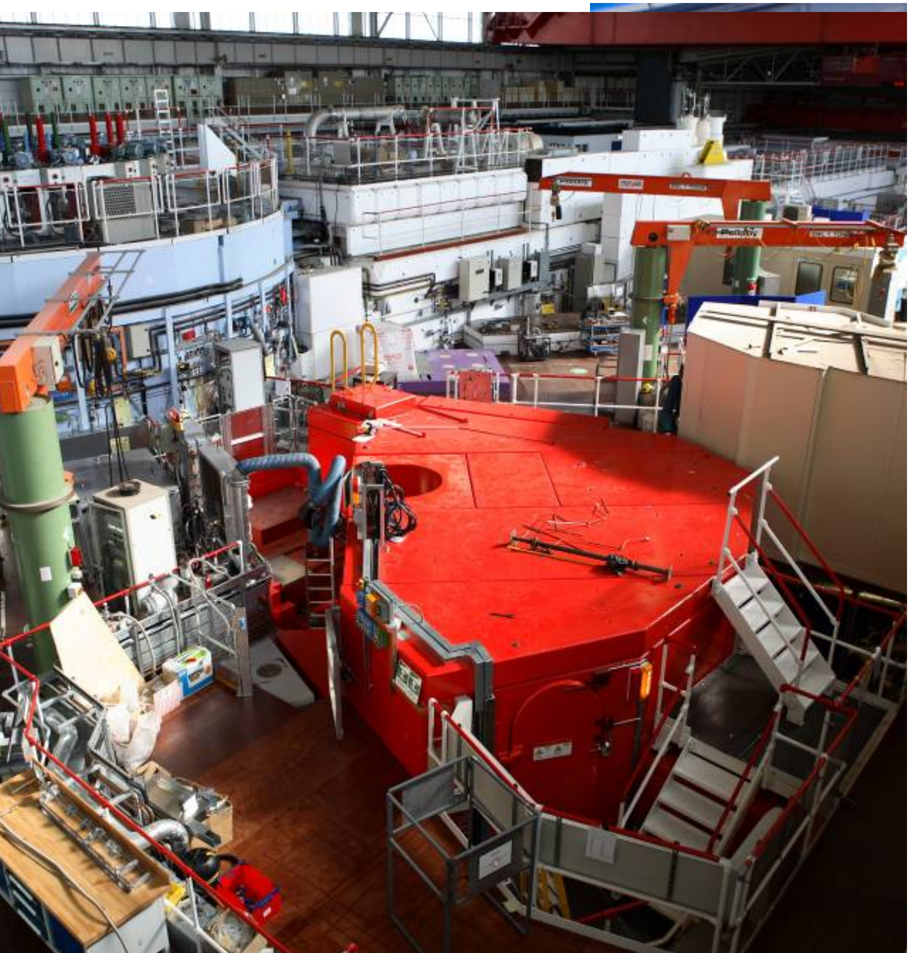
- Have built two direct geometry spectrometers at ISIS
- Would like to build one more in-direct spectrometer - MUSHROOM

MERLIN (TS1)
Hot-thermal neutrons



LET (TS2)
Cold-thermal neutrons

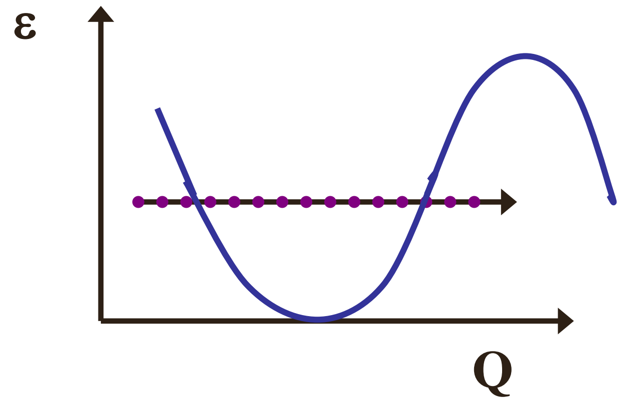
The talk

1. The TOF direct geometry technique
2. Problems with the TOF technique and 3D systems
3. A potential solution - The MUSHROOM spectrometer
4. Properties of the MUSHROOM spectrometer

Comparison of triple-axis and time-of-flight technique

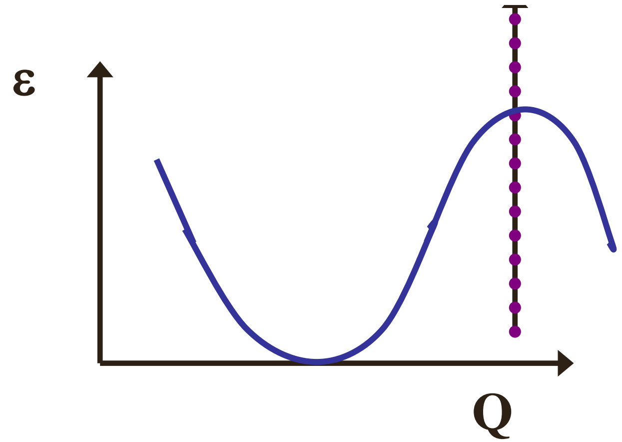
Triple axis spectrometer

- Supreme workhorse spectrometer for measuring S(**Q**,ε) in single crystals
- Every reactor has a suite optimised for different energy ranges and resolution



Why successful?

- Go anywhere in (**Q**,ε)
- Constant-ε or constant-**Q** according to requirement
- Focus on a single point at chosen (**Q**,ε)
  - Focussing monochromator, analysers
  - Tune resolution (collimation)



$\Rightarrow$ if one knows where want to study: ultimate

Comparison of triple-axis and time-of-flight technique

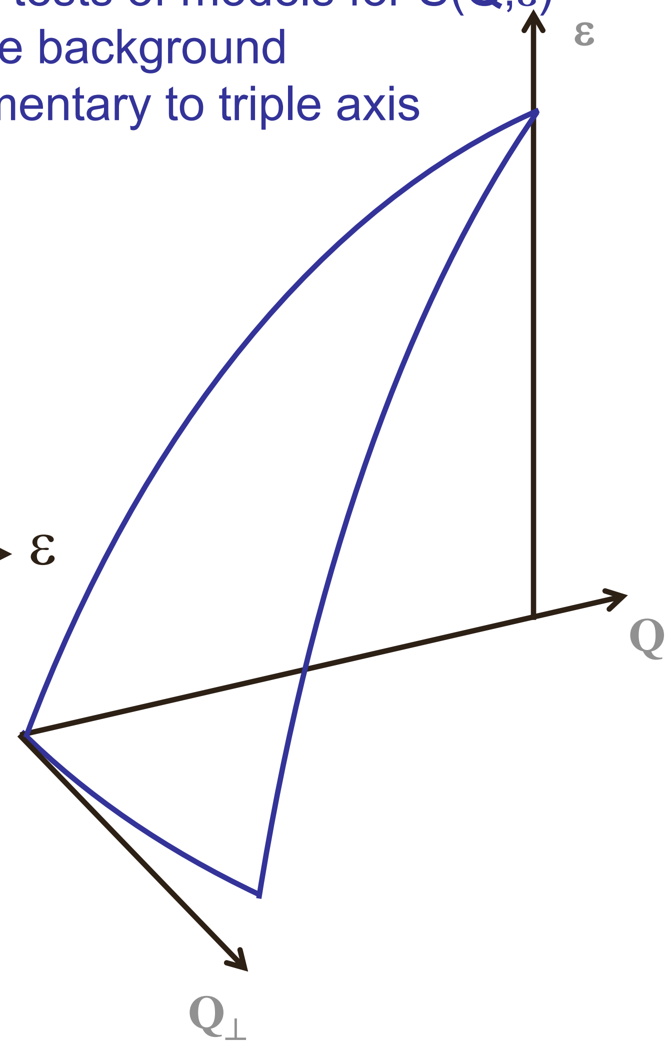
Time-of-flight chopper instruments

- Equivalent workhorse spectrometer

Why successful?

- Comprehensive measurement of S(**Q**,ε)
  - Intrinsically **parallel**
  - Large solid angle and bandwidth
  - Full tests of models for S(**Q**,ε)
- Negligible background
- Complementary to triple axis

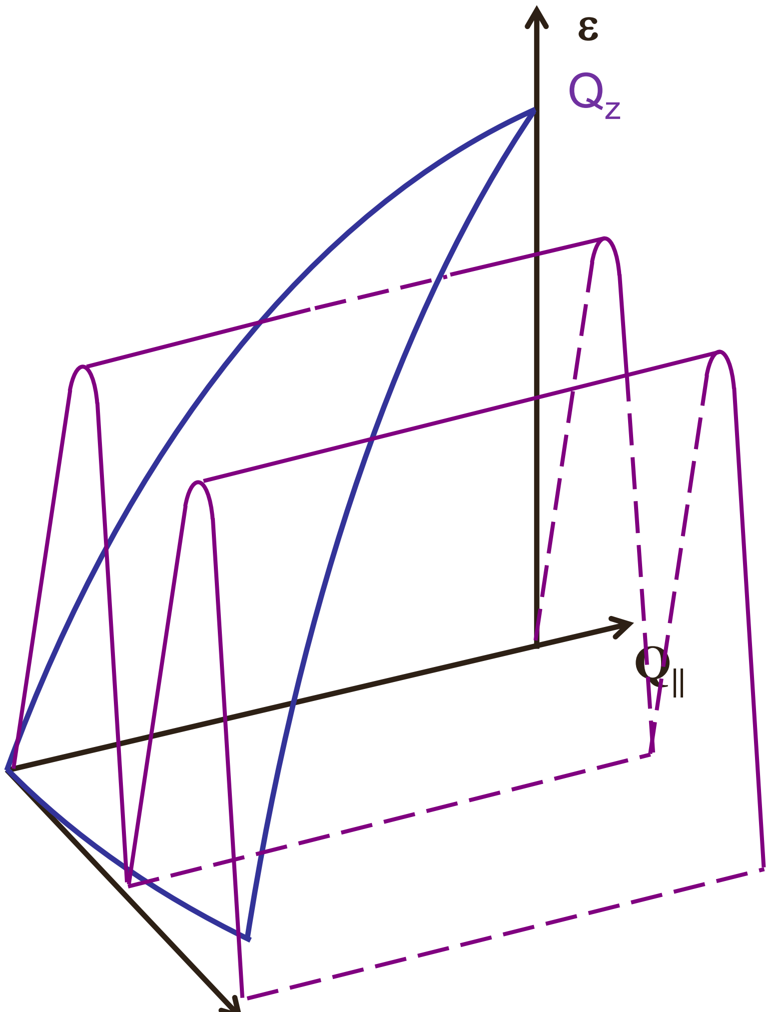
Time of flight → ε



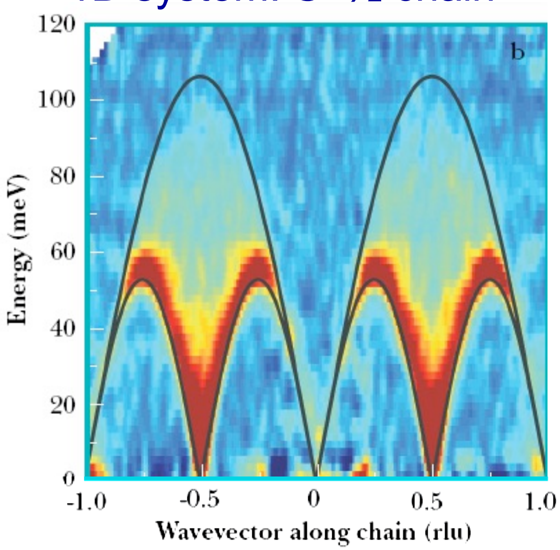
•Highly successful in 1D and 2D systems
S=1/2 chain, square lattice, high-Tc, ...

Position sensitive detector array:

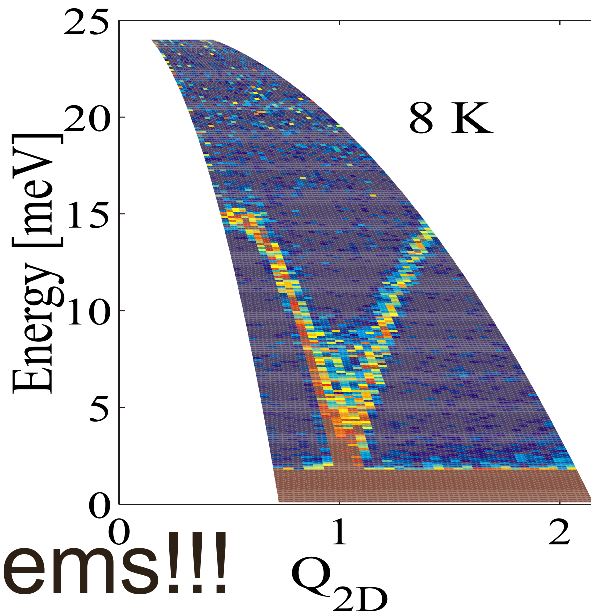
Three degrees of freedom
(two scattering angles, time-of-flight)



1D system: S=½ chain

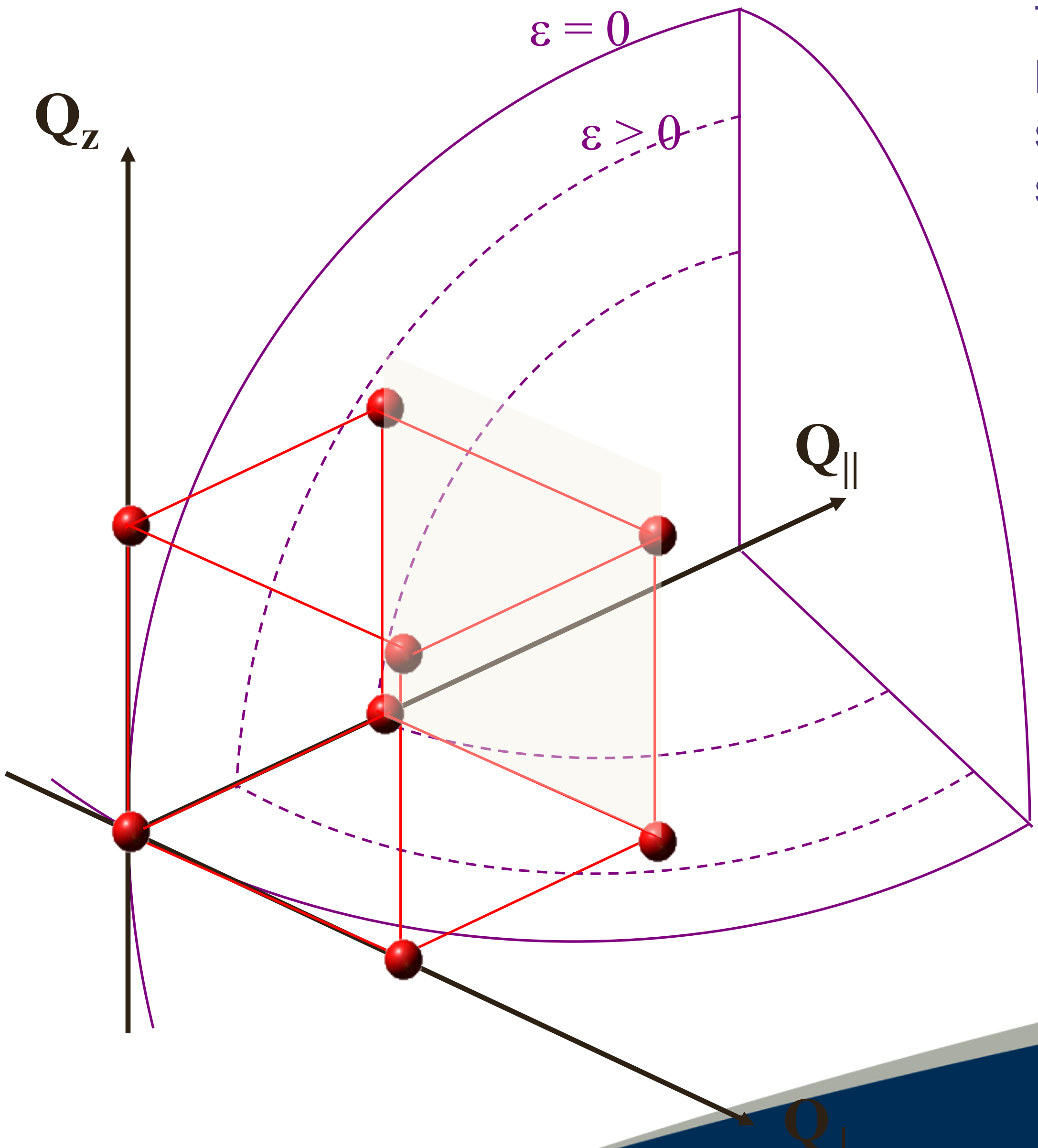


2D system: S=½ square lattice



Rubbish for 3D systems!!!

Measuring Excitations - 3D



These days with large banks of PSDs and new software 'HORACE' 3D systems are possible

Three degrees of freedom

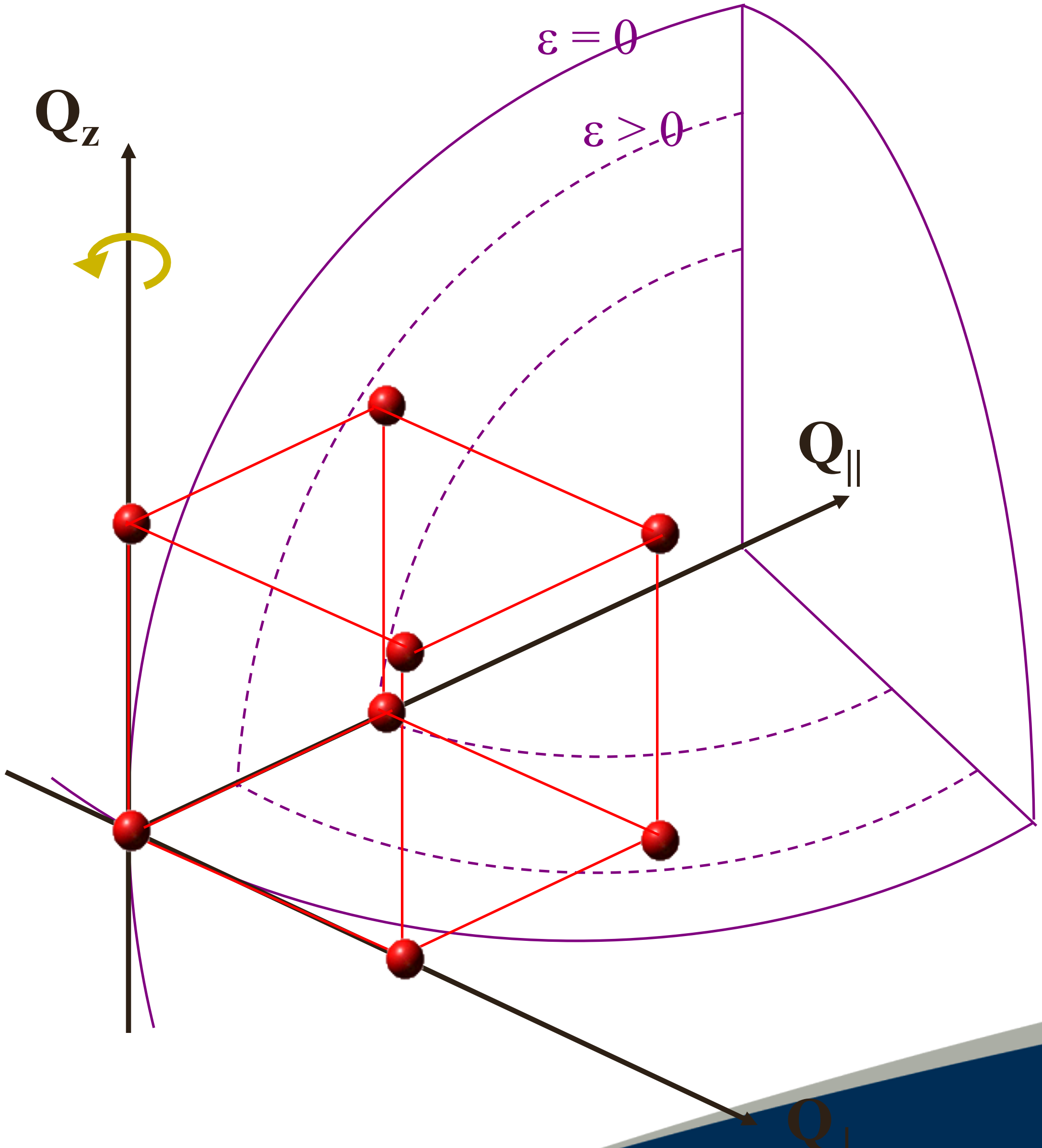
Four independent coordinates: $(Q_{||}, Q_{\perp}, Q_z, \varepsilon)$

Need fourth degree of freedom:

E_i or crystal rotation

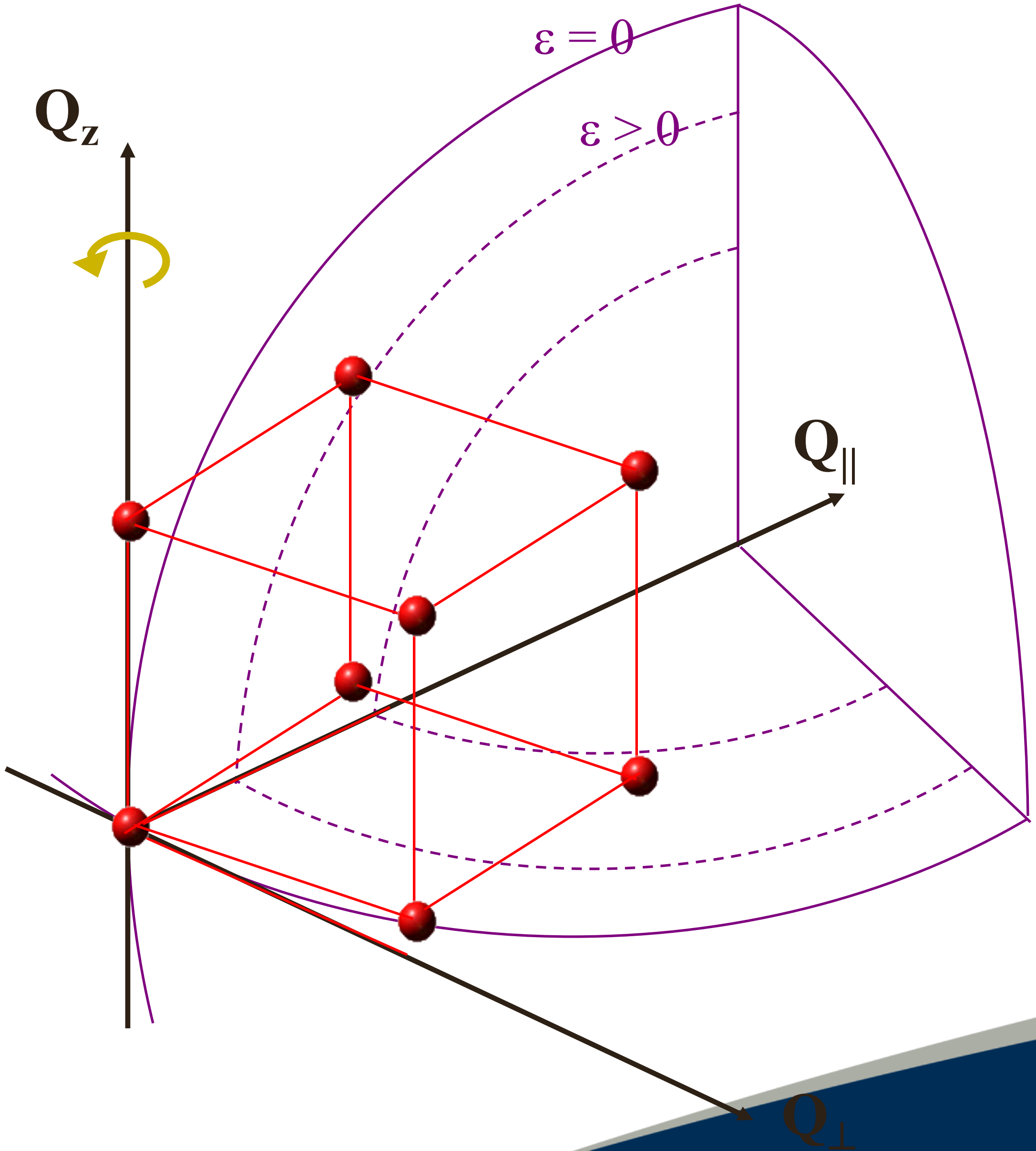
Measuring Excitations

Scan crystal angle



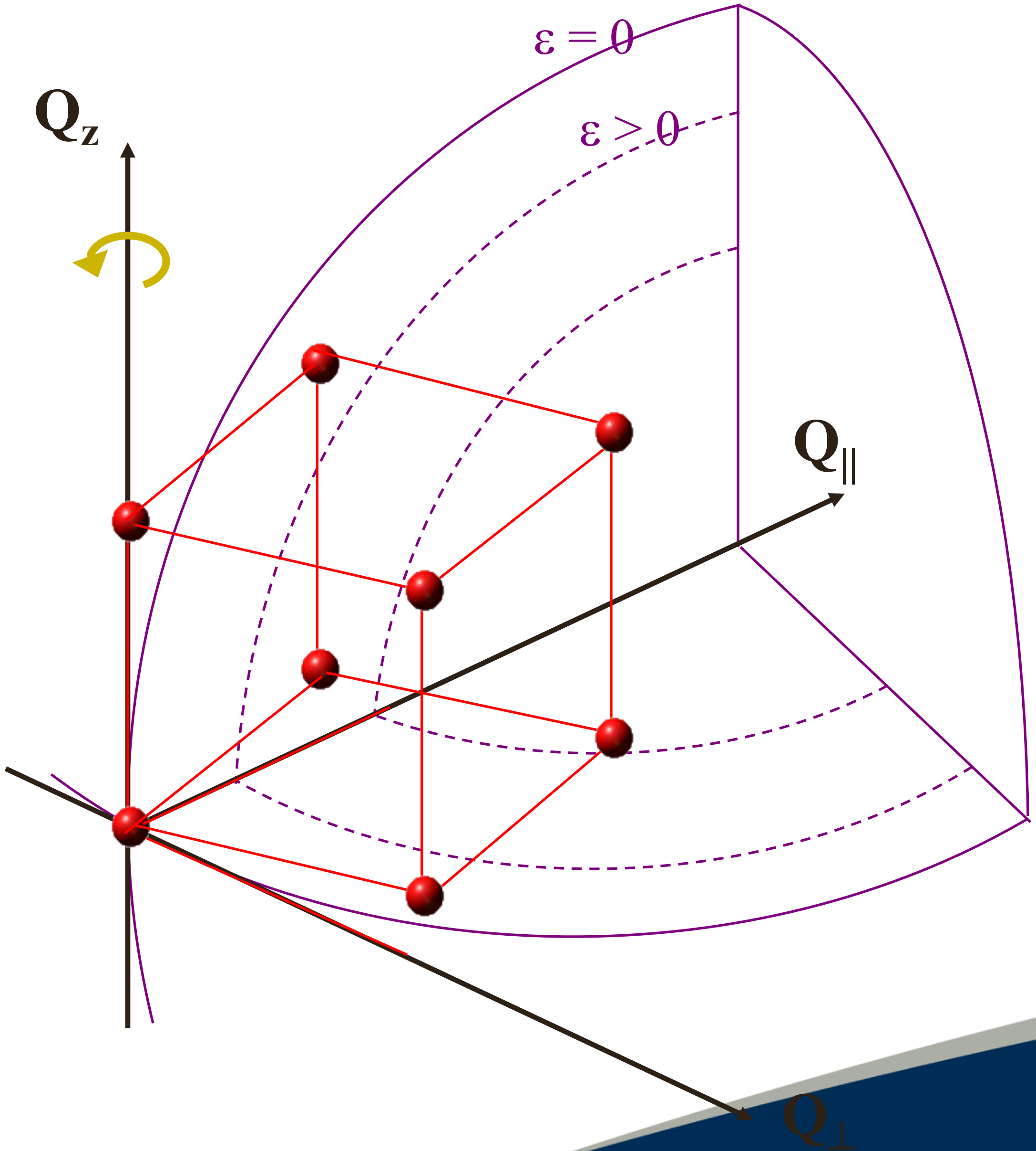
Measuring Excitations

Scan crystal angle

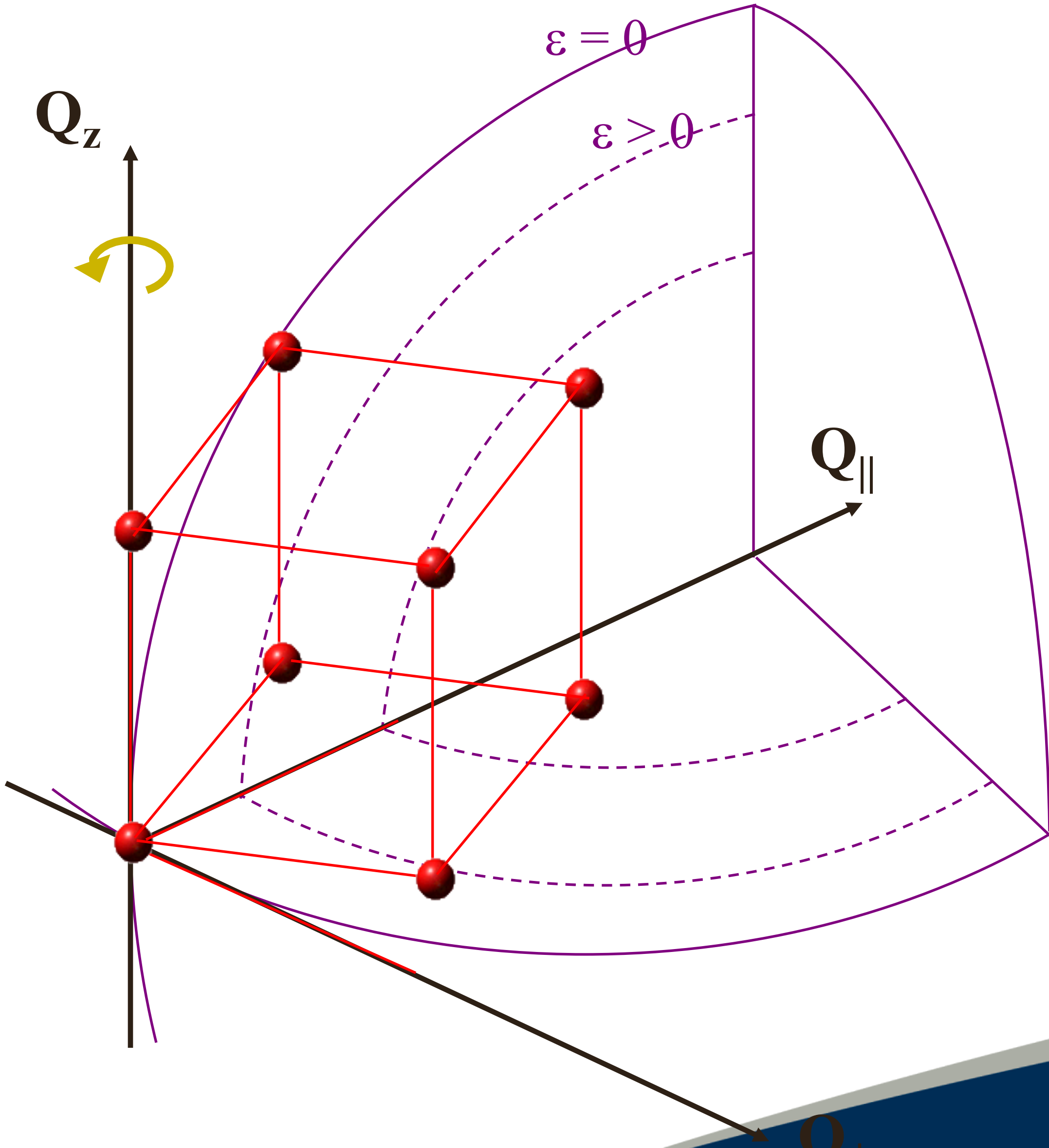


Measuring Excitations

Scan crystal angle



Measuring Excitations



Scan crystal angle

Need 100-200 scans

- Can make short runs (15 mins typically on LET)
- Finish with large data file now ~100GB !

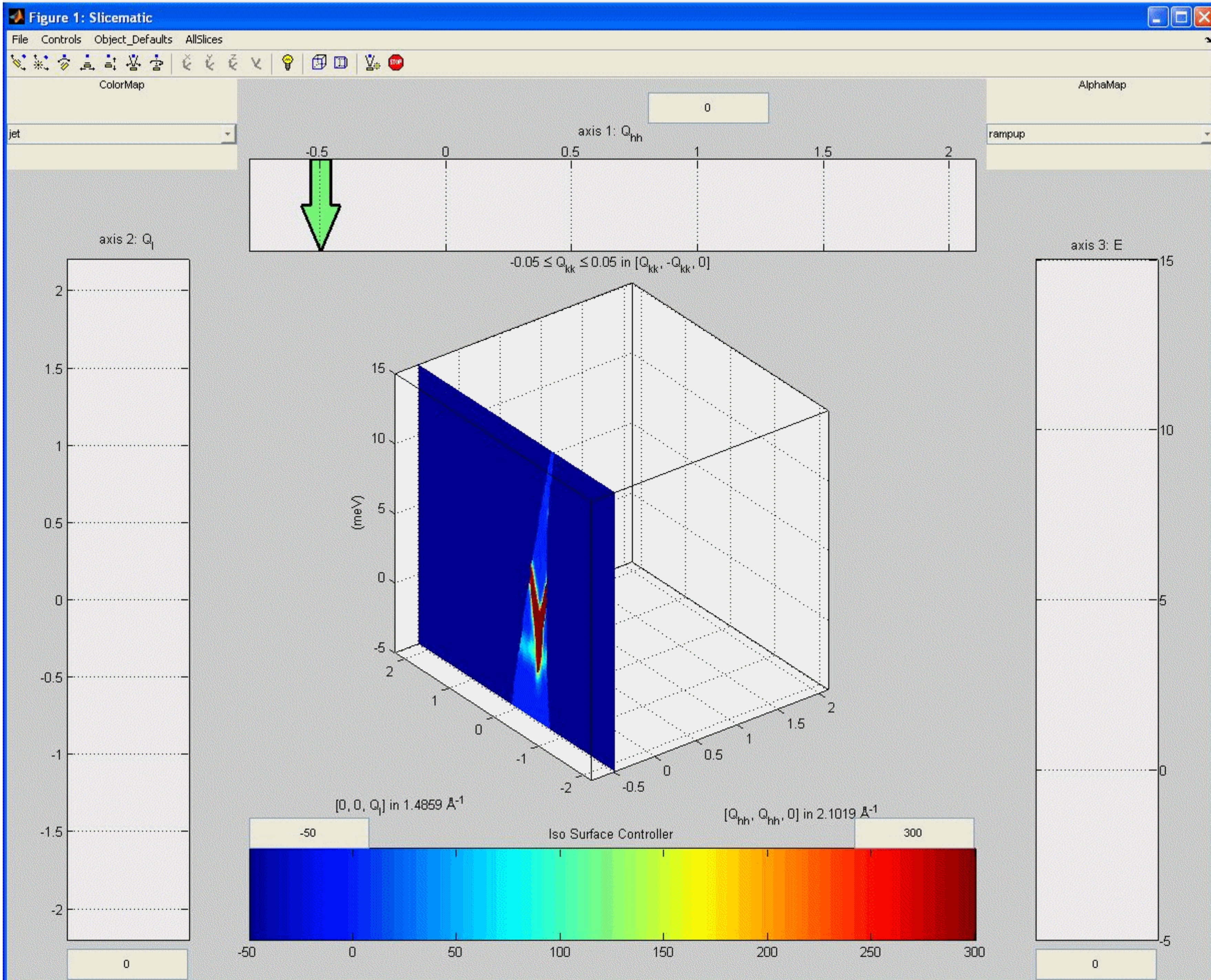
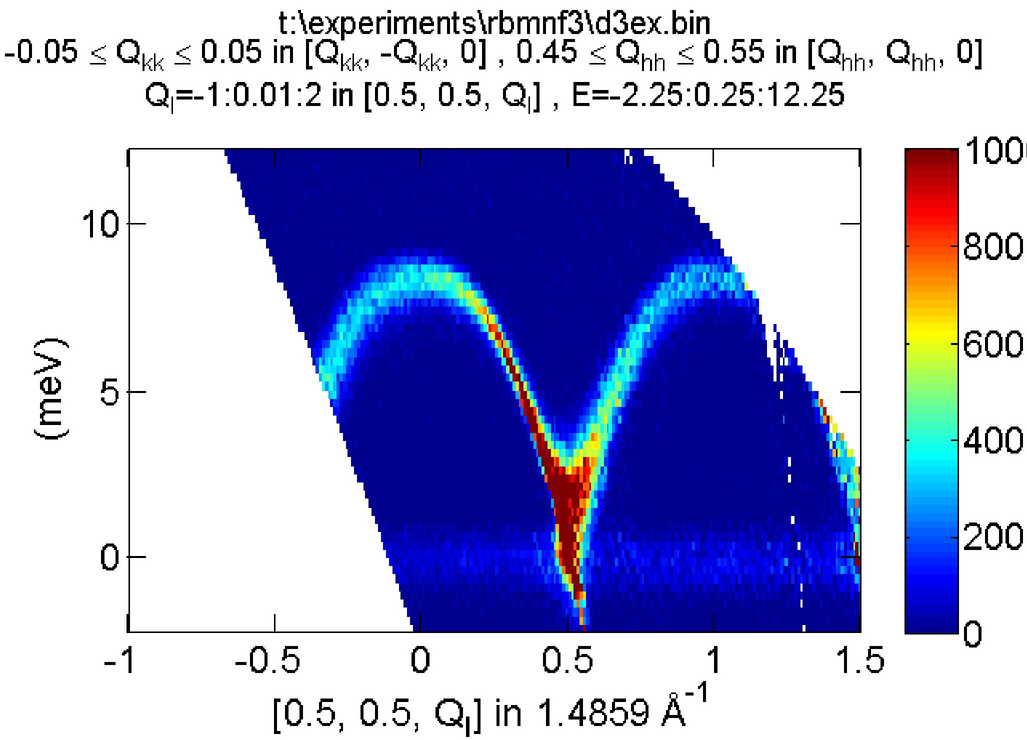


Figure 1: Slicematic
File Controls Object_Defaults AllSlices
ColorMap
jet
AlphaMap
rampup
axis 1: Q_{hh}
axis 2: Q_l
axis 3: E
$-0.05 \le Q_{kk} \le 0.05$ in $[Q_{kk}, -Q_{kk}, 0]$
(meV)
$[0, 0, Q_l]$ in 1.4859 $Å^{-1}$
$[Q_{hh}, Q_{hh}, 0]$ in 2.1019 $Å^{-1}$
Iso Surface Controller
-50
300

3D Heisenberg antiferromagnet – $RbMnF_3$



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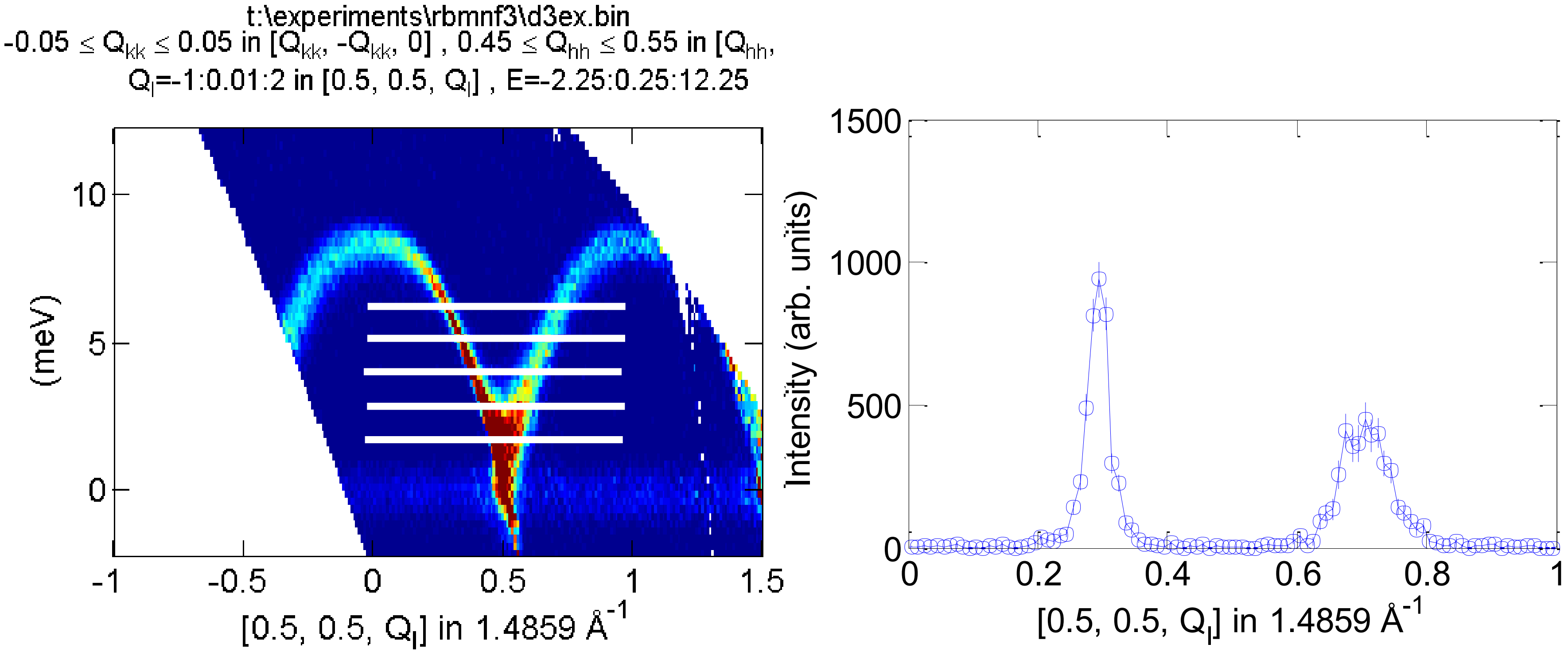
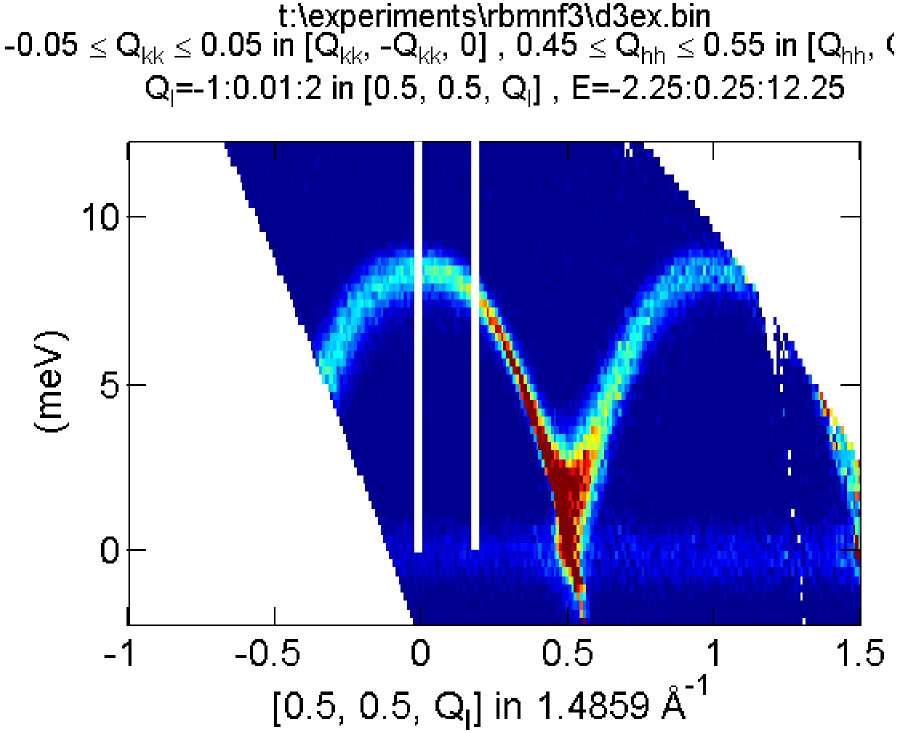
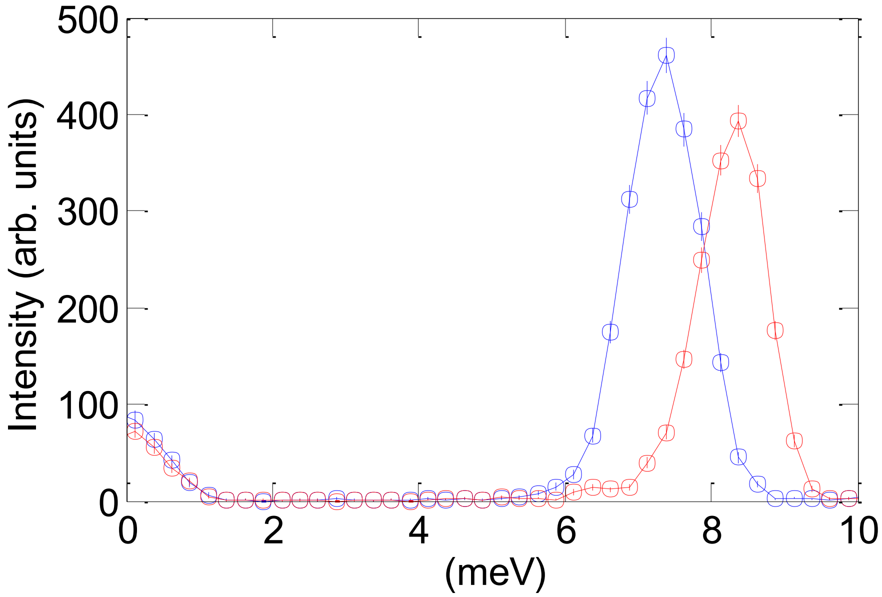
3D Heisenberg antiferromagnet – $RbMnF_3$



Constant energy cuts

3D Heisenberg antiferromagnet – $RbMnF_3$

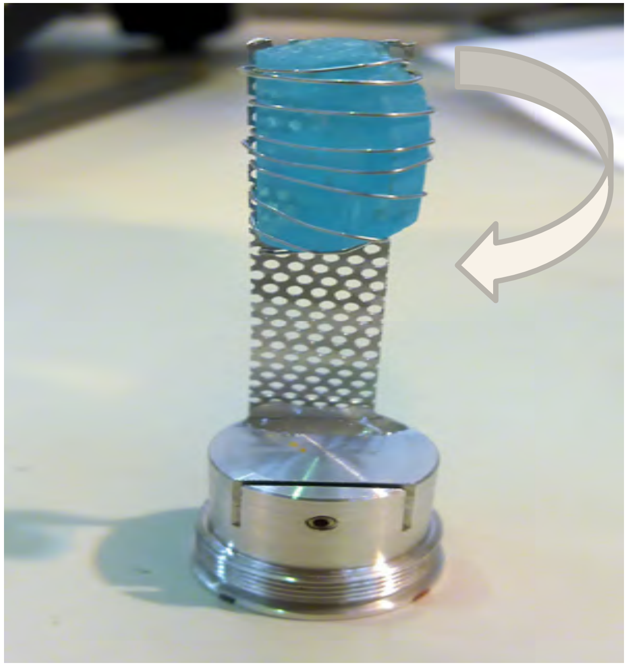




Constant Q cuts

The Problem – long measurements

- Most experiments on LET/MERLIN want to do HORACE scans (measure the full 4D Qx, Qy, Qz , E data set). Very time consuming taking around 1-2 days for one scan.
- Samples getting smaller as systems become more complex/more complex sample environments
- Want parametric HORACE scans as function of pressure/field and temperature
- We need much higher flux/count rates to be able to do these measurements in a reasonable time or to measure smaller samples



Rotate-measure-rotate-measure
To build up 4D S(**Q**,w)

- He3 costs have made these instruments too expensive

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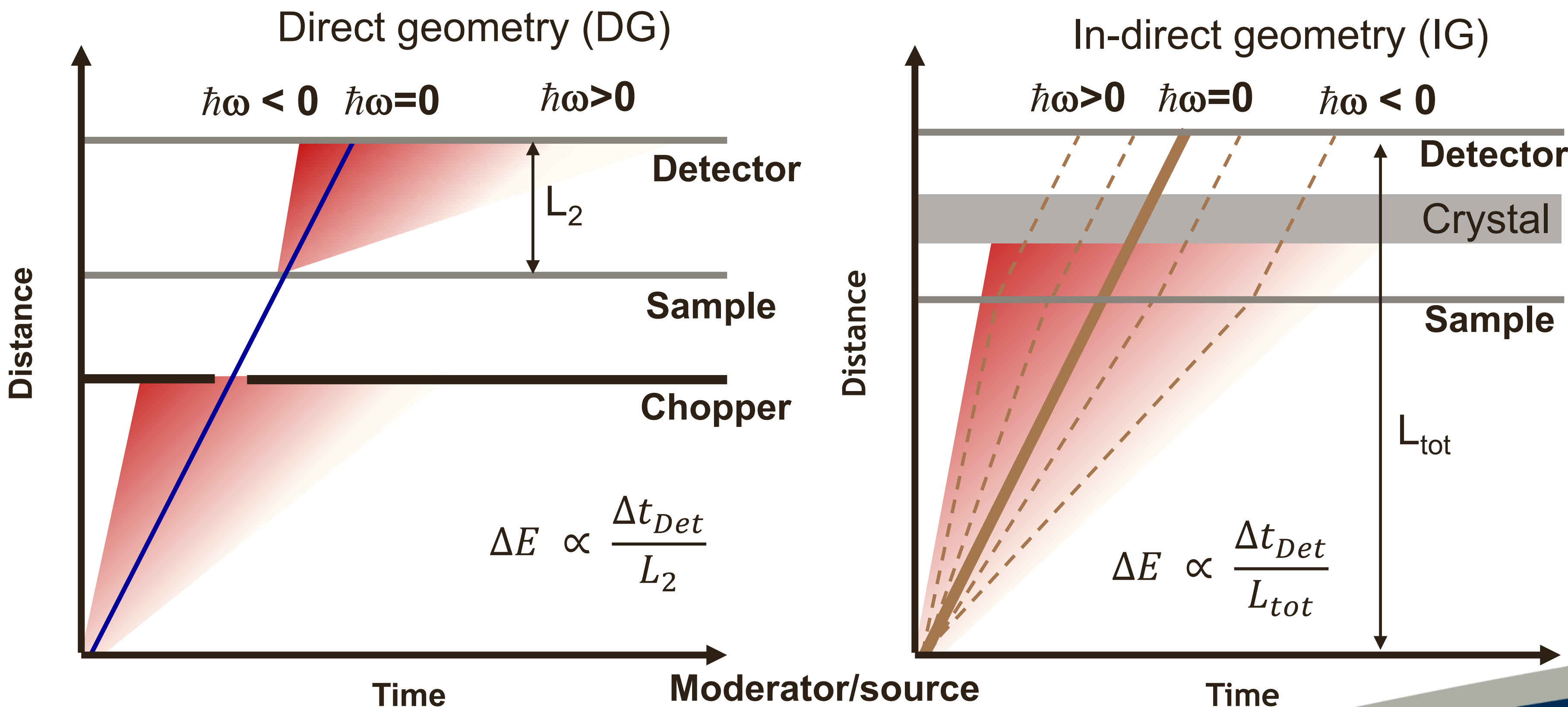
Solution – an In-Direct Geometry (crystal) spectrometer

- IG spectrometers are much more efficient than DG



Same resolution and solid angle

count rate $\frac{IG}{DG} \approx \frac{L_{tot}}{L_2}$

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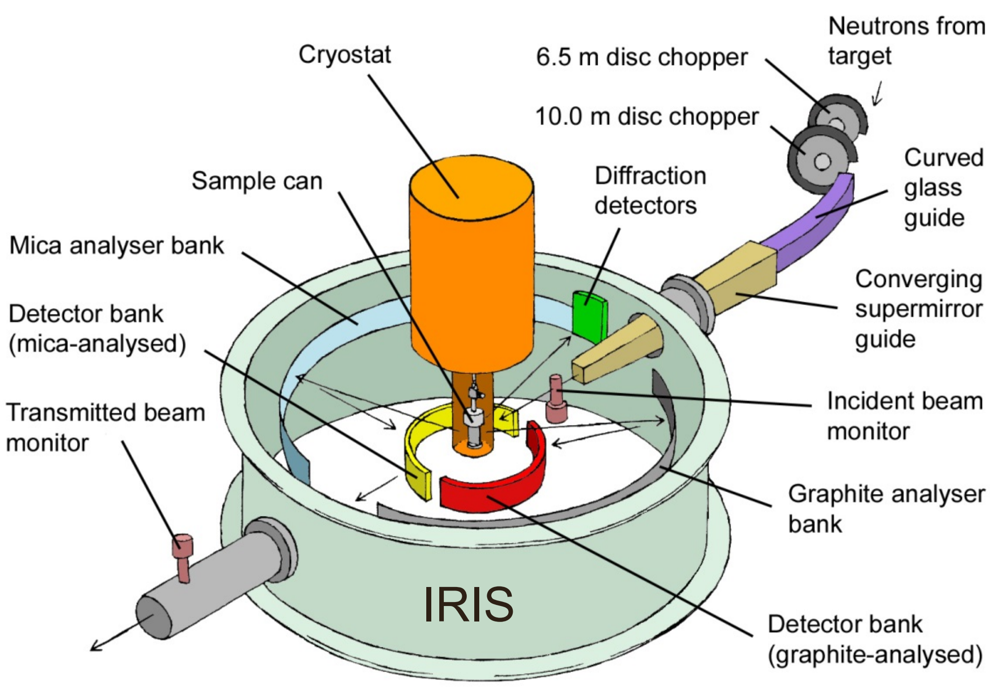
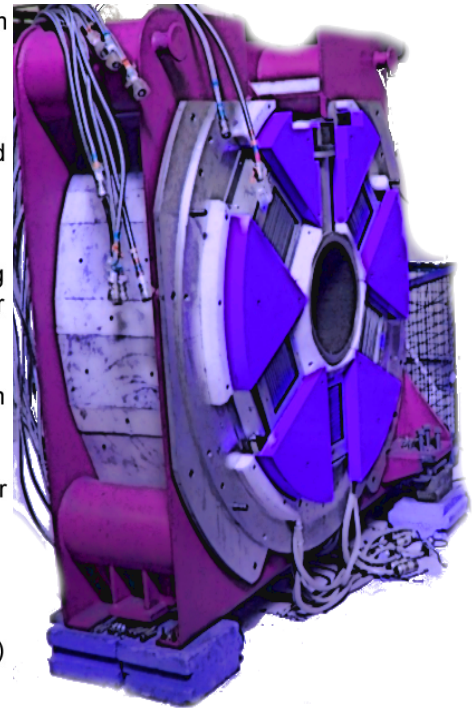
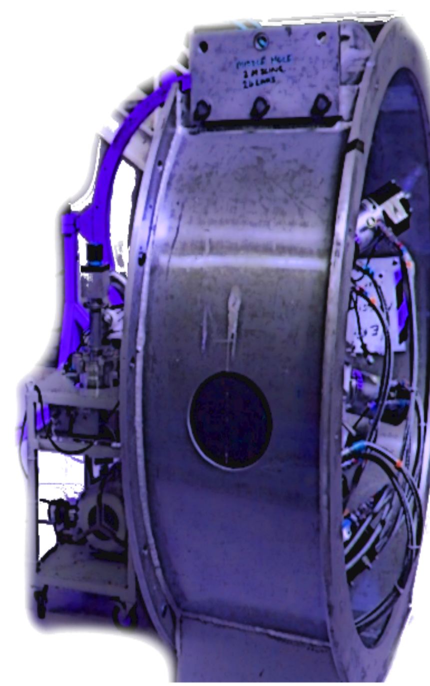
Problem- No TOF IG machines for 4D mapping

Backscattering spectrometers
In plane, quasi elastic instruments



Molecular spectroscopy – for hydrogenous materials, almost no Q info

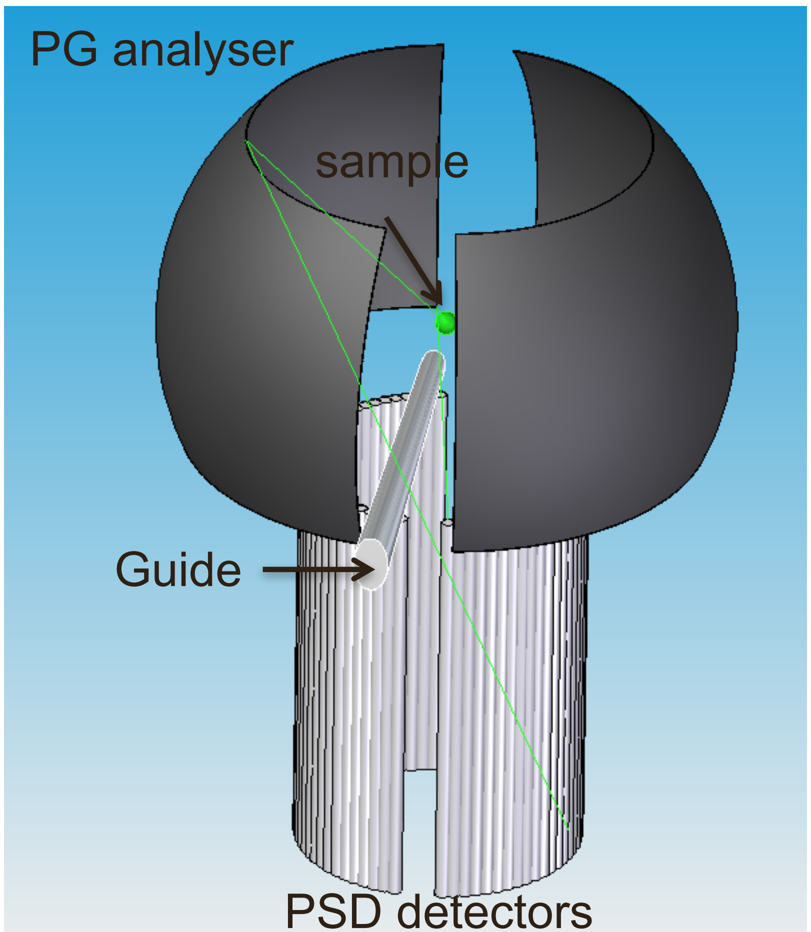




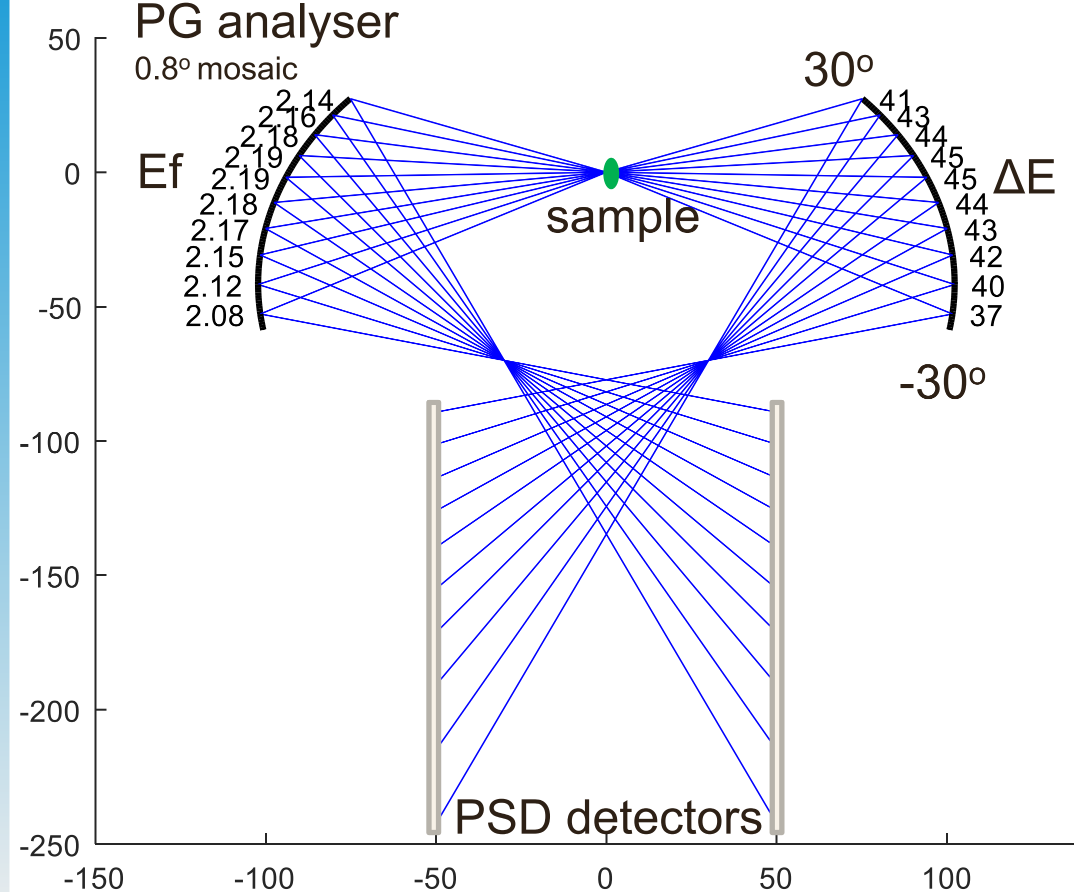
Solution – The MUSHROOM

- There is no reason why you cannot have a large position sensitive coverage using a crystal analyser and position sensitive detectors

The MUSHROOM

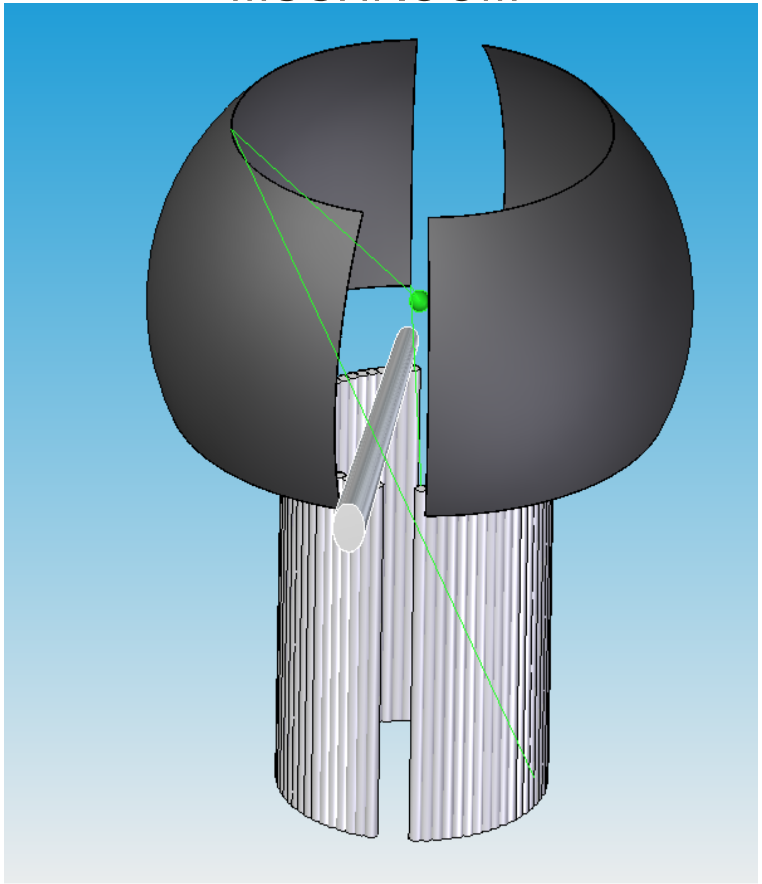


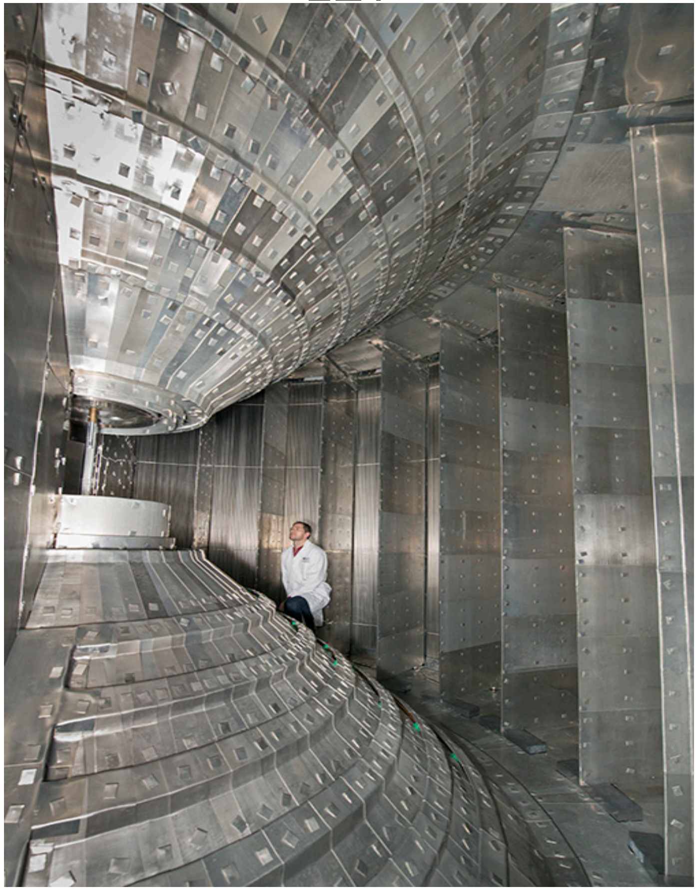
6 Steradians PSD coverage
45 ueV resolution at elastic



Performance - Count rate

MUSHROOM VERSUS LET

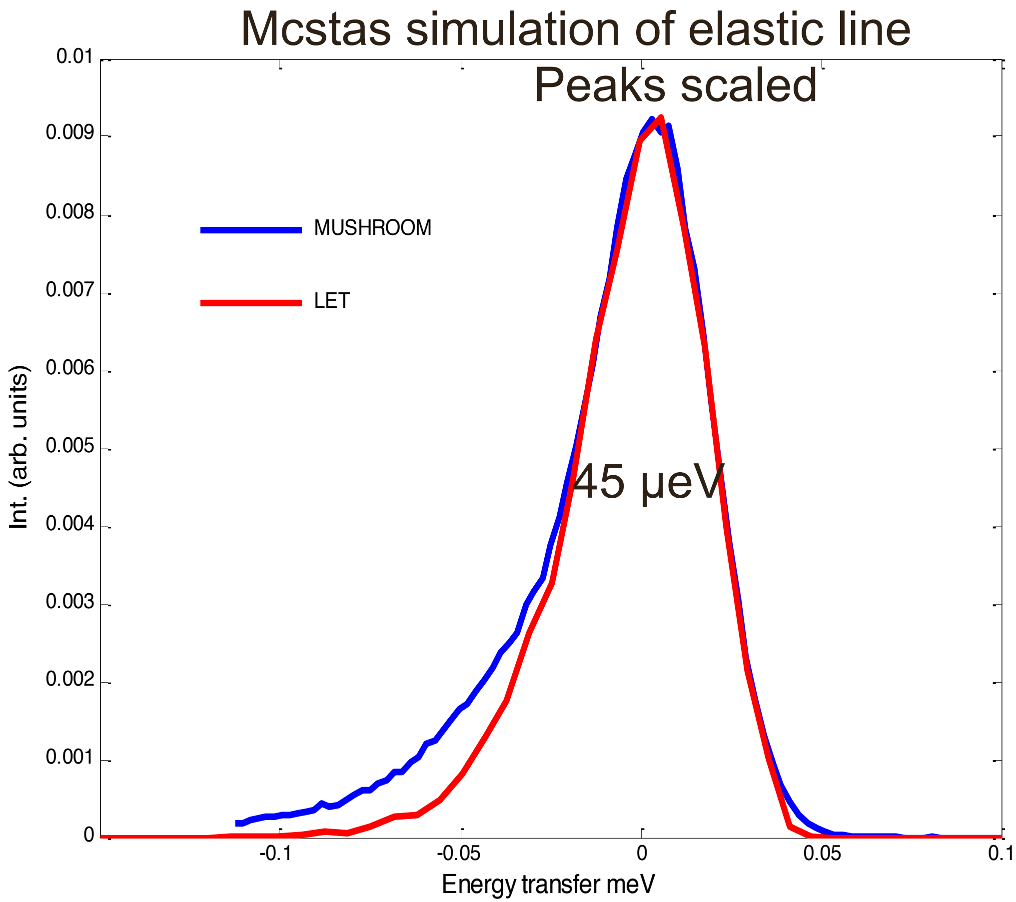




- Used Mcstas simulations to compare
- Put Mushroom on end of LET guide
- Ei=2.2 mev for LET, Ef=2.2 meV for Mushroom
- Both simulated for 45 μeV elastic resolution
- Both scatter 1cm^3 vanadium to same solid angle

Performance - Count rate

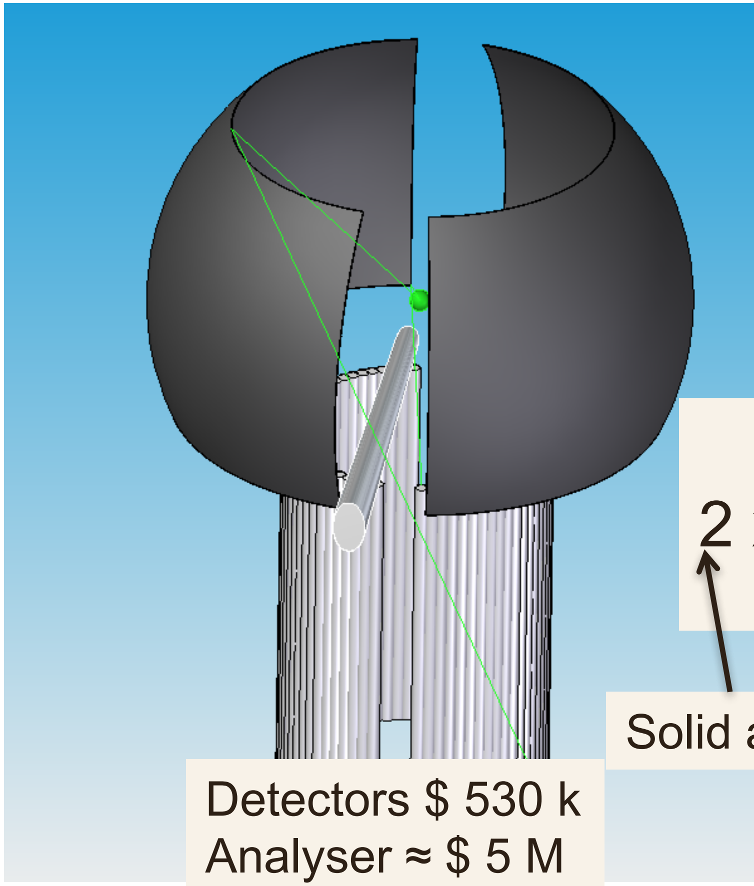
MUSHROOM has12 x count rate of LET for same resolution and solid angle

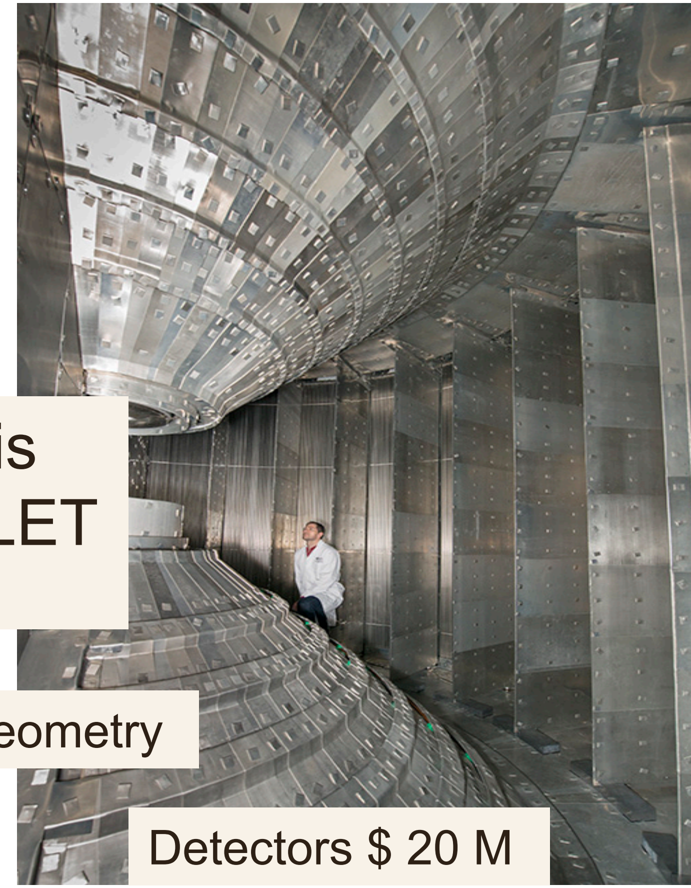


…….but this can easily be doubled……..

Performance - Count rate + cost

- Mushroom has **2π** steradians solid angle compared to **π** steradians for LET





Count Rate is
2 x 12 = 24 x LET

Solid angle x Inverse geometry

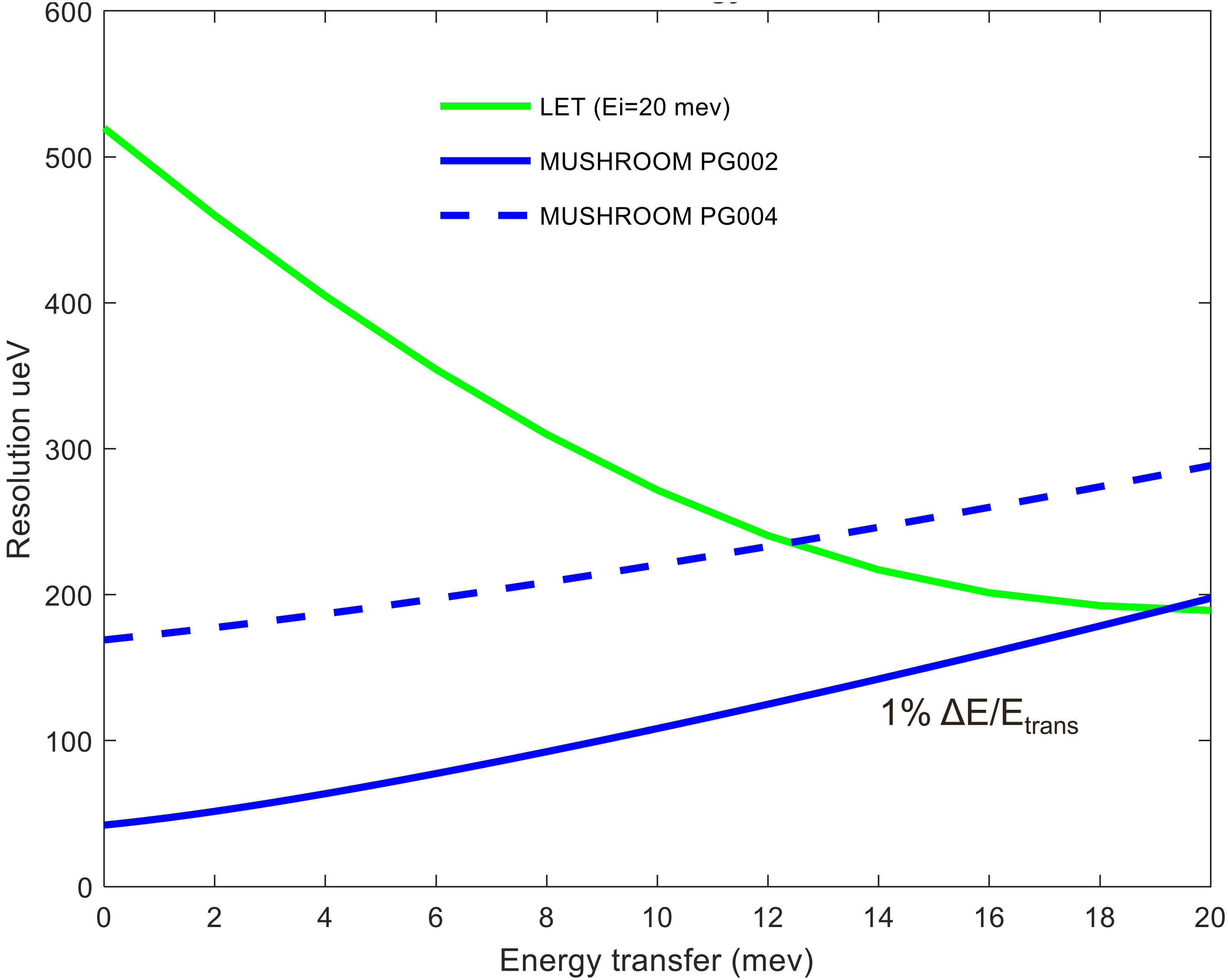
Detectors $ 530 k
Analyser ≈ $ 5 M

Detectors $ 20 M

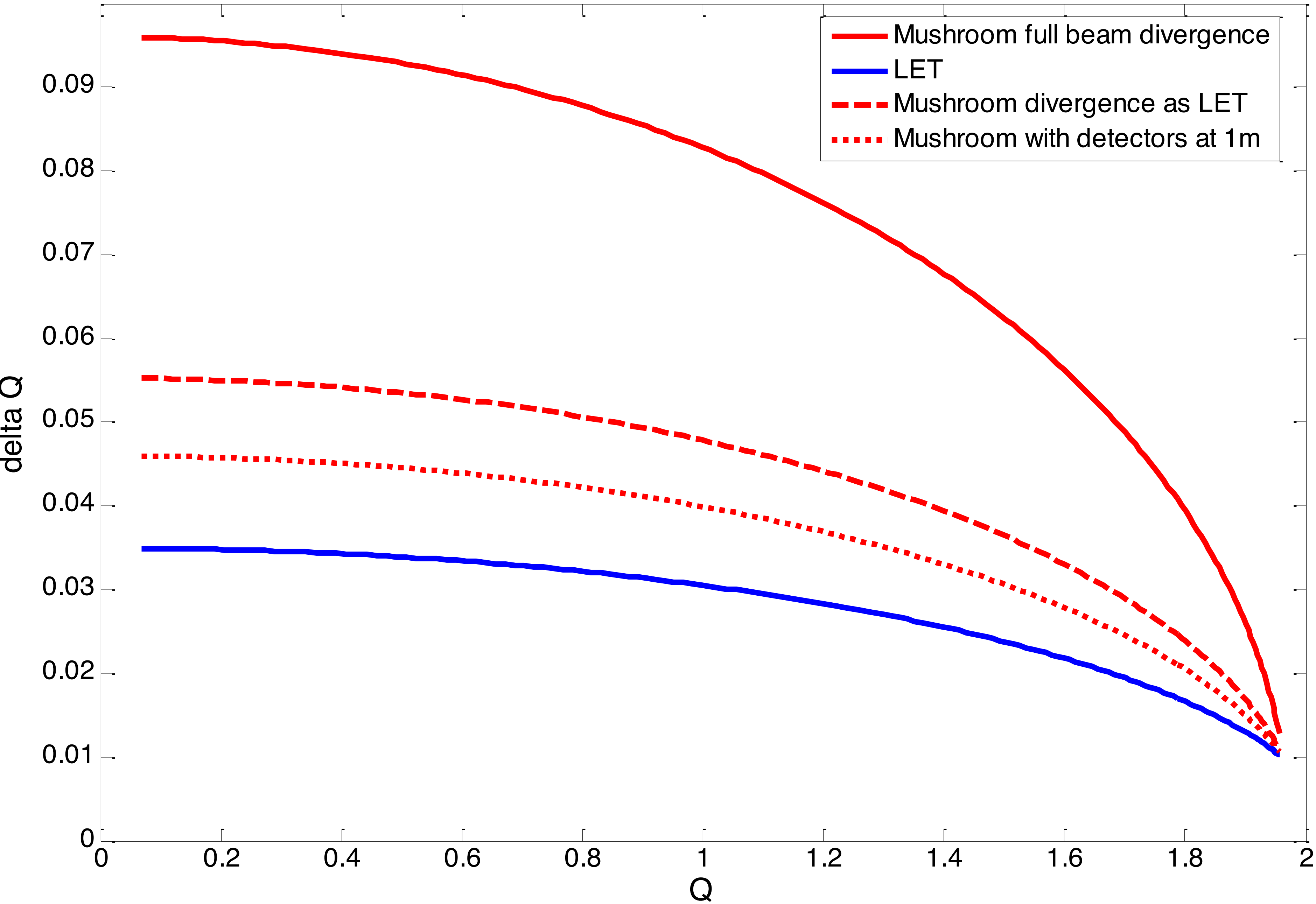
- ΔE/E depends on TOTAL flightpath
- 8mm 6 atm He3 tubes
- 1.5 m long @ 0.5m radius
- 80 % efficient at Ef=2.2 meV

- ΔE/E depends on secondary flightpath
- 25 mm 10 atm He3 tubes
- 4m long @ 3.5m radius
- Efficiency dependent on Ef

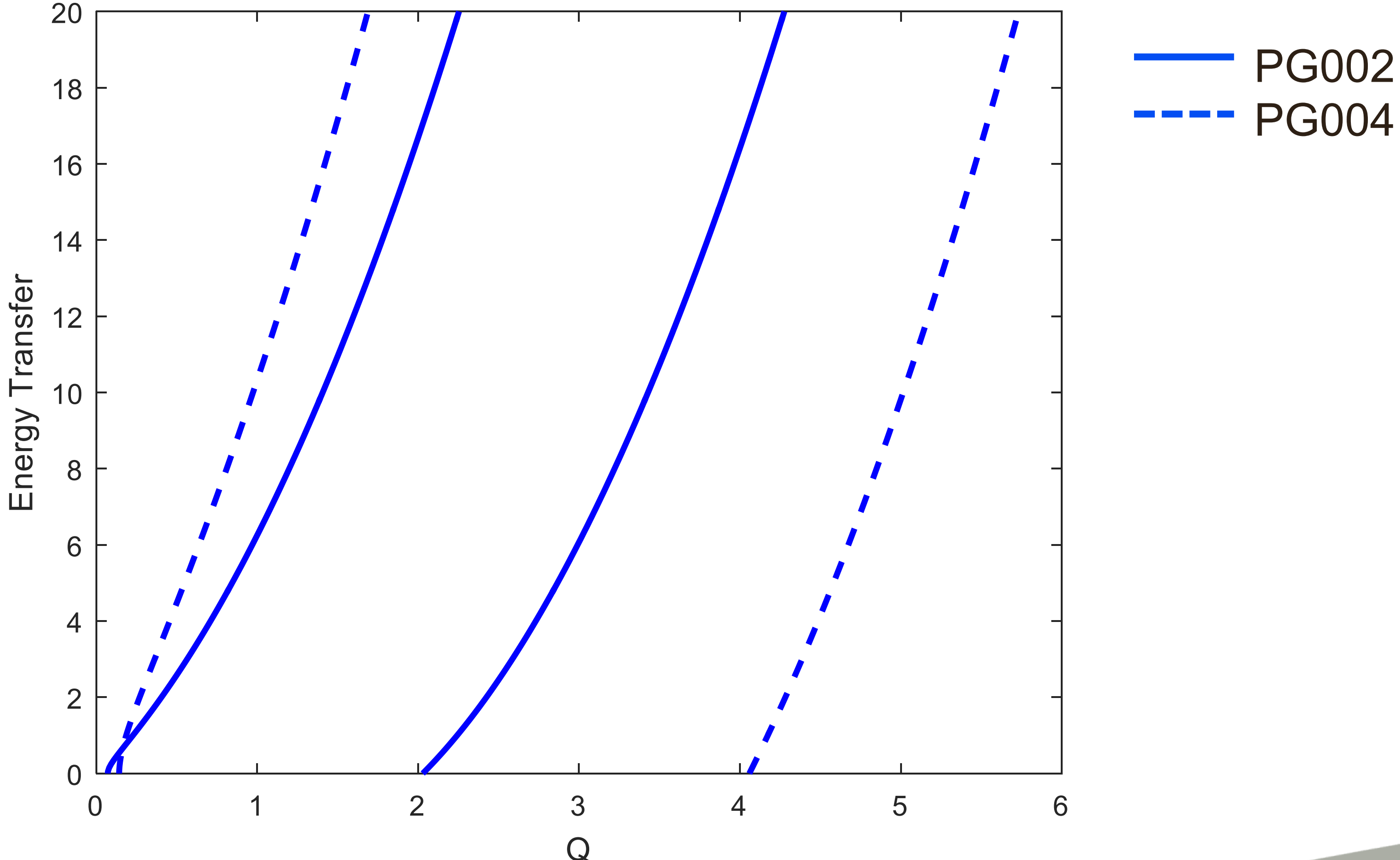
Performance - Energy resolution



Performance - Q resolution

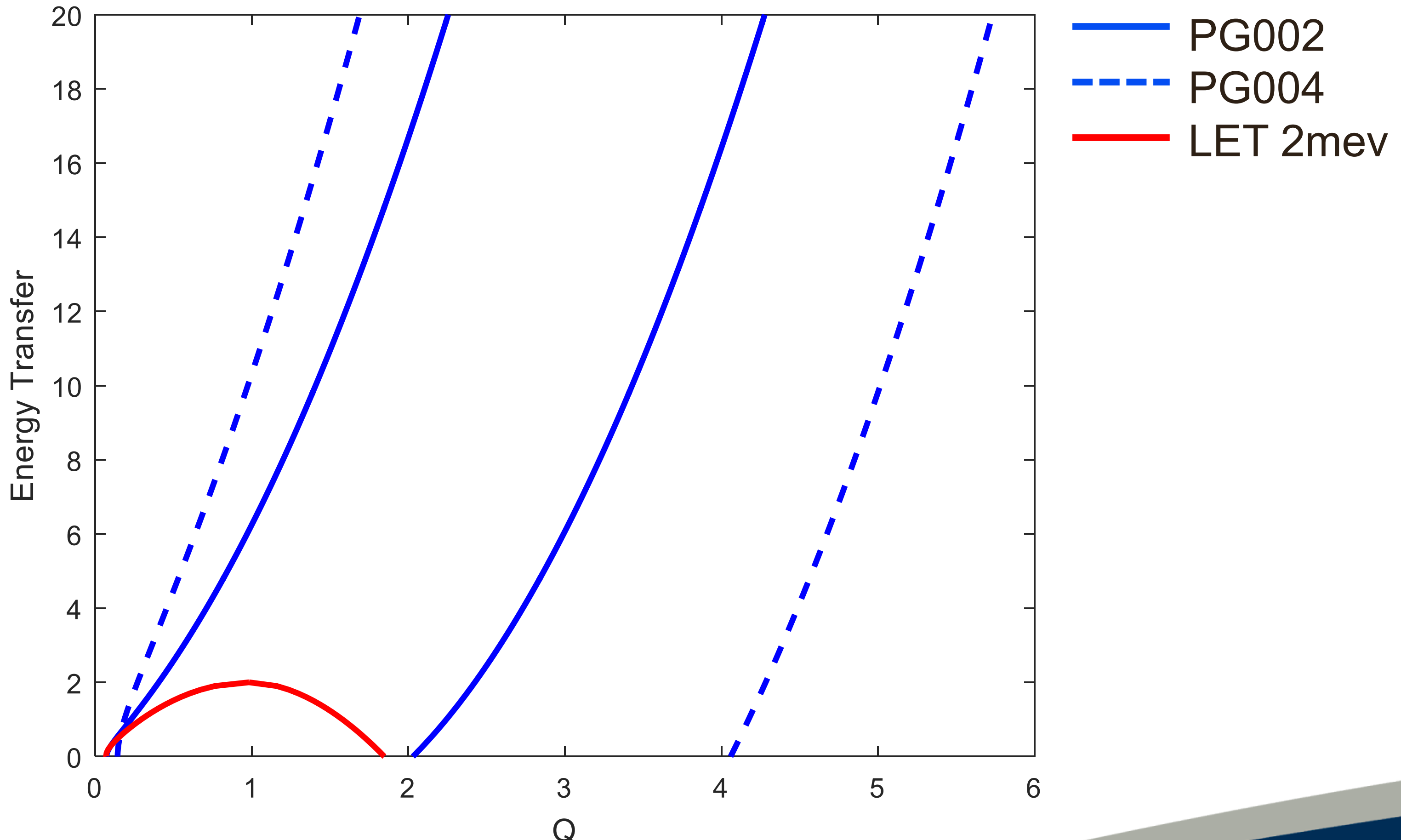


Performance - Q range



MUSHROOM needs PG004 as well as PG002
to get enough Q range

Performance - Q range



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to get enough Q range

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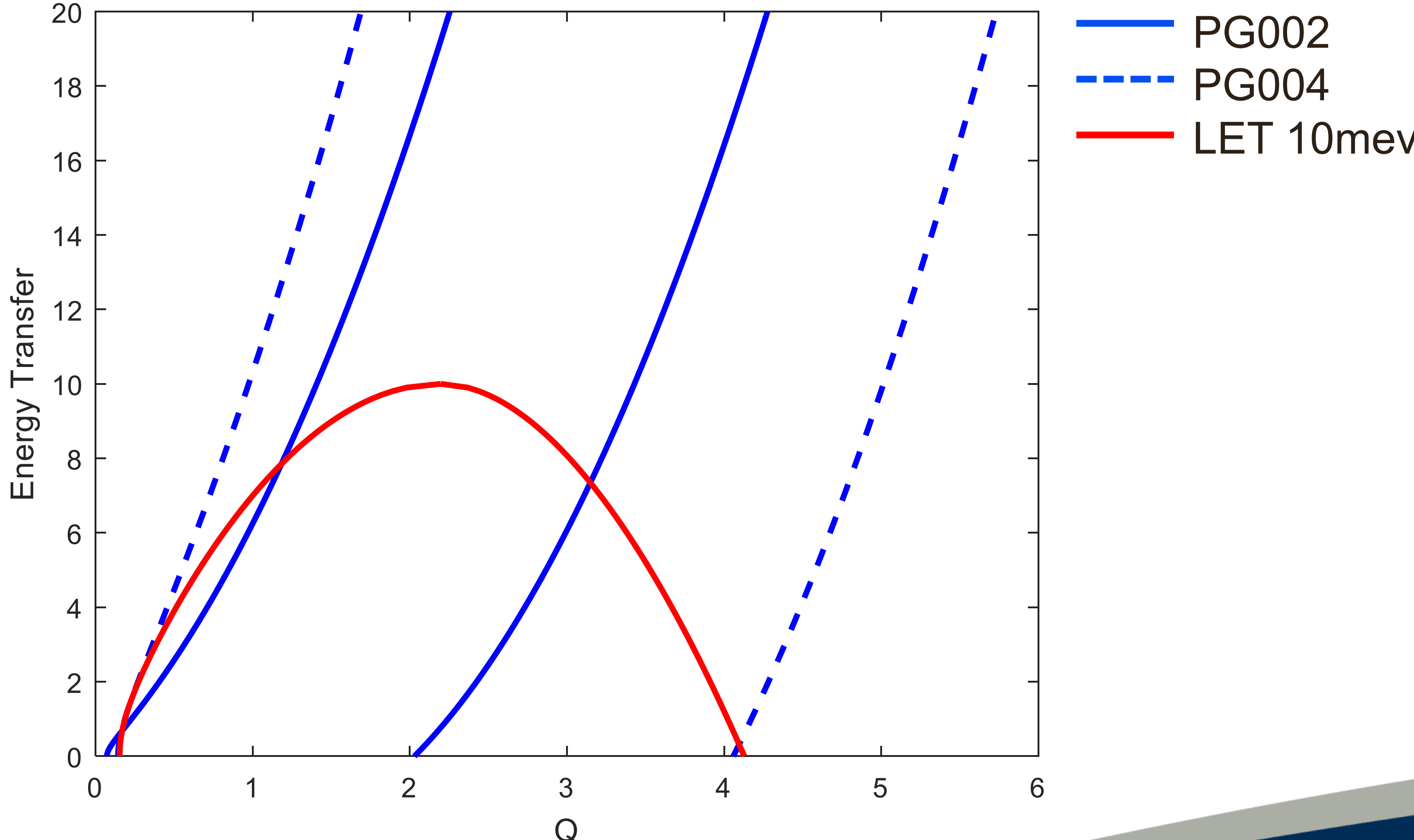
Performance - Q range



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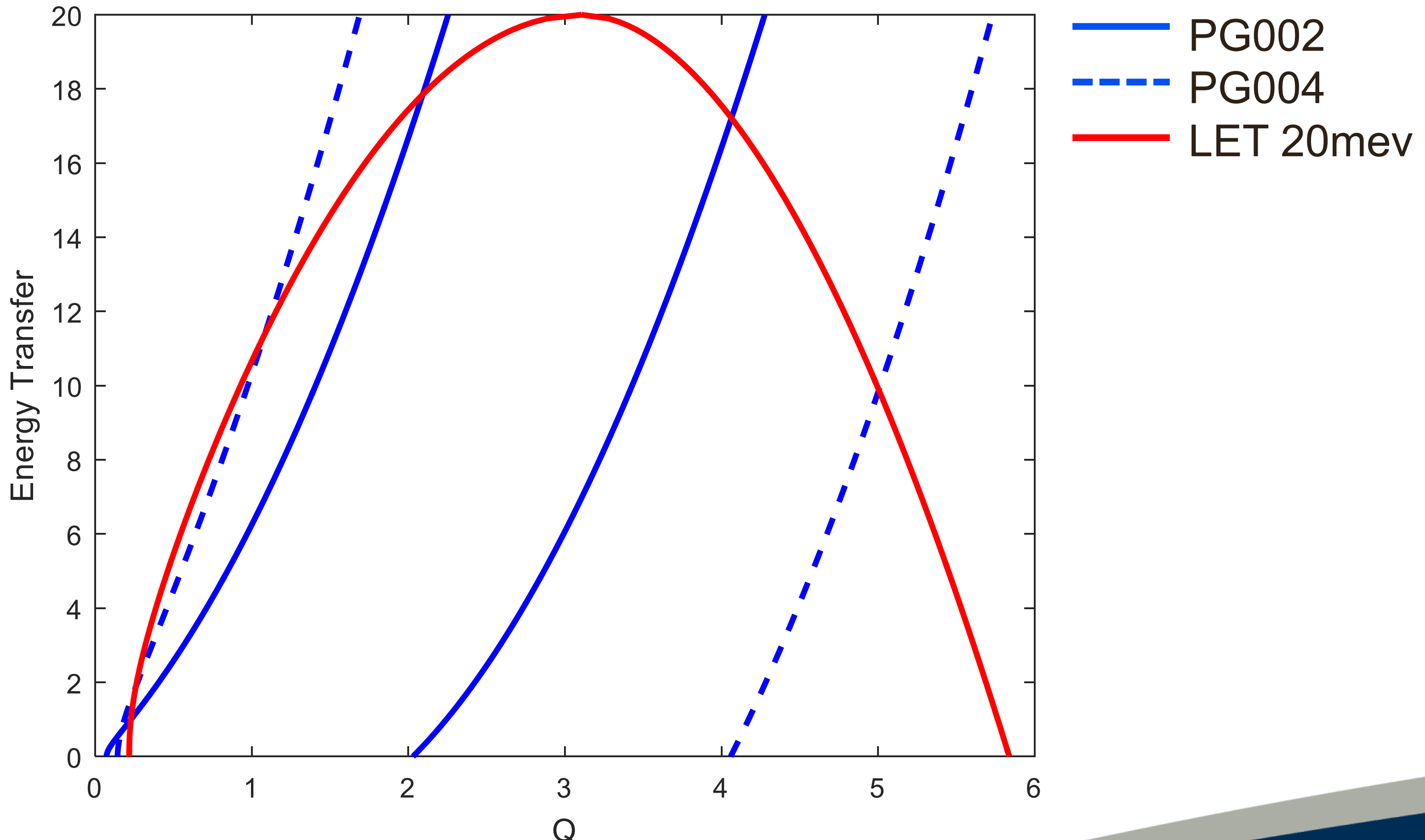
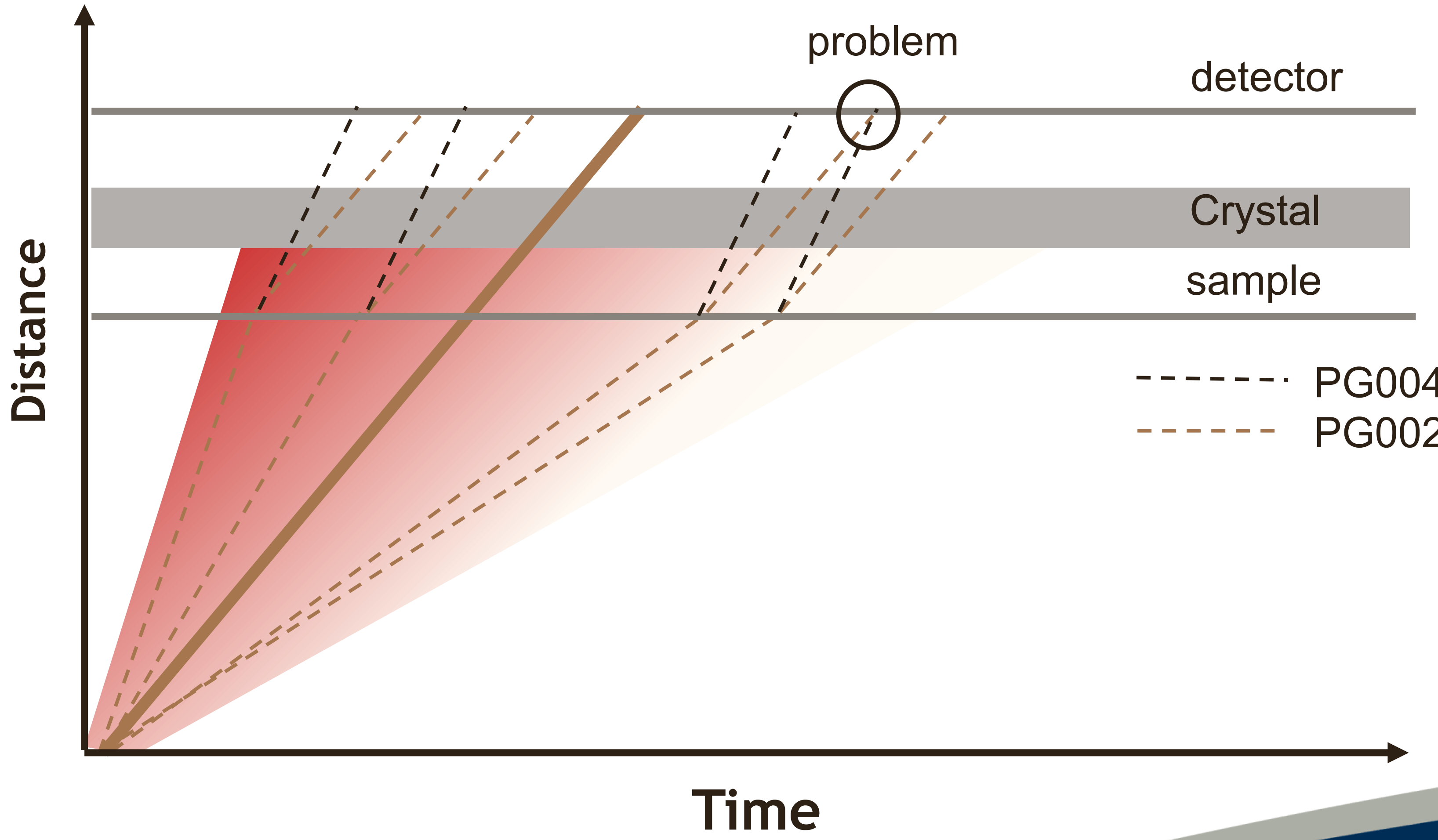
Performance - Q range



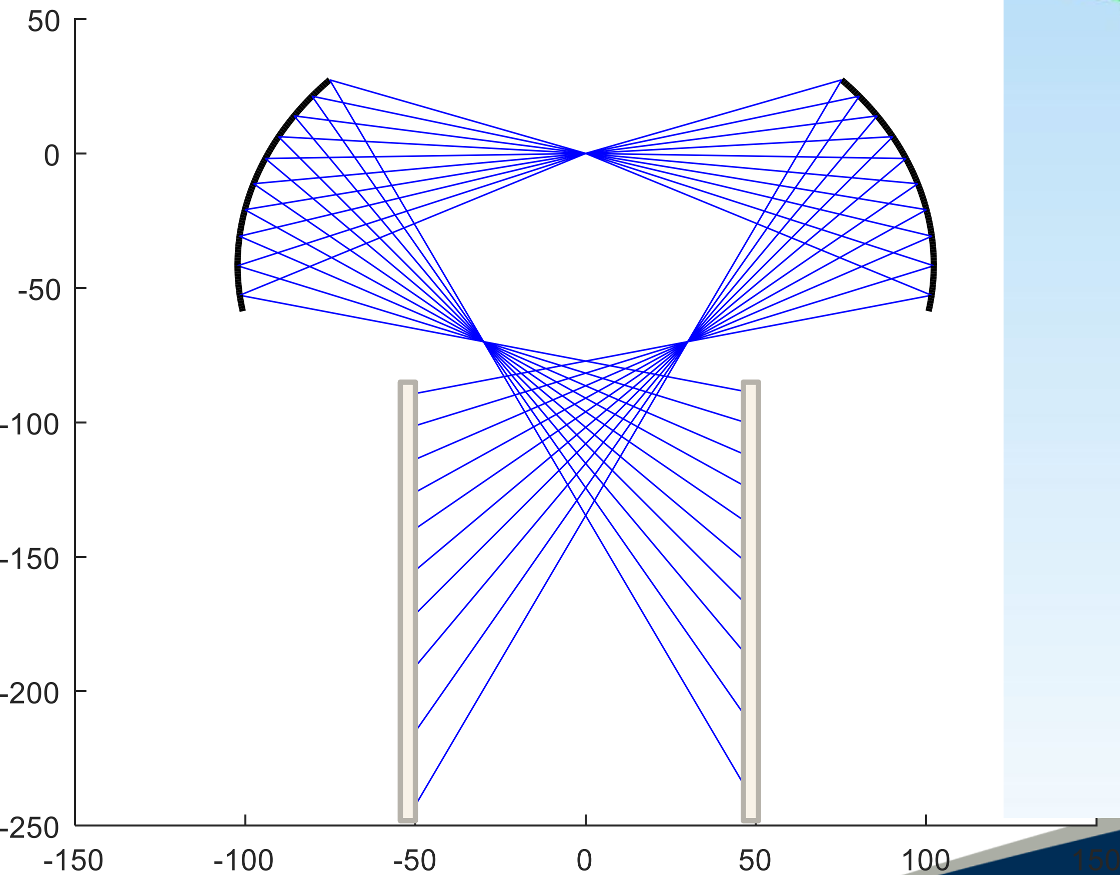
MUSHROOM needs PG004 as well as PG002
to get enough Q range

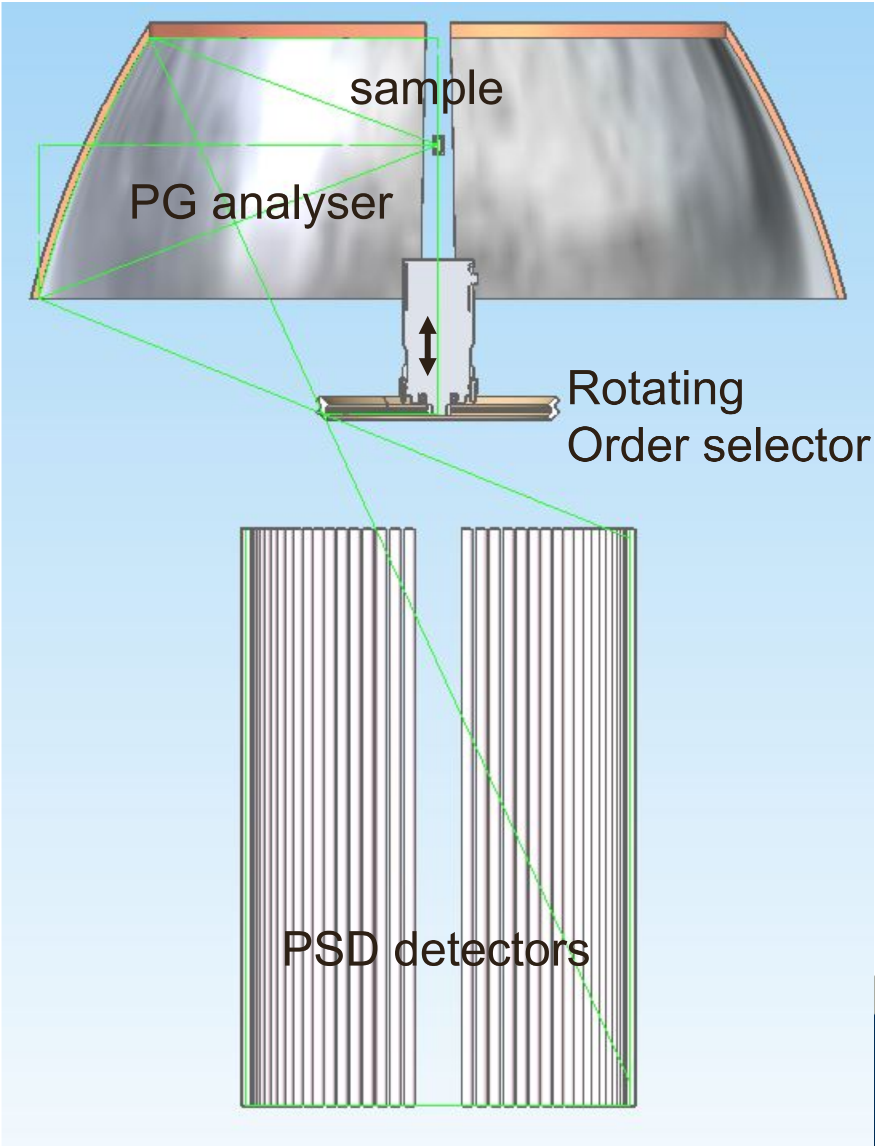
How do we cleanly select PG004 or PG002 ?



How do we cleanly select PG004 or PG002 ?

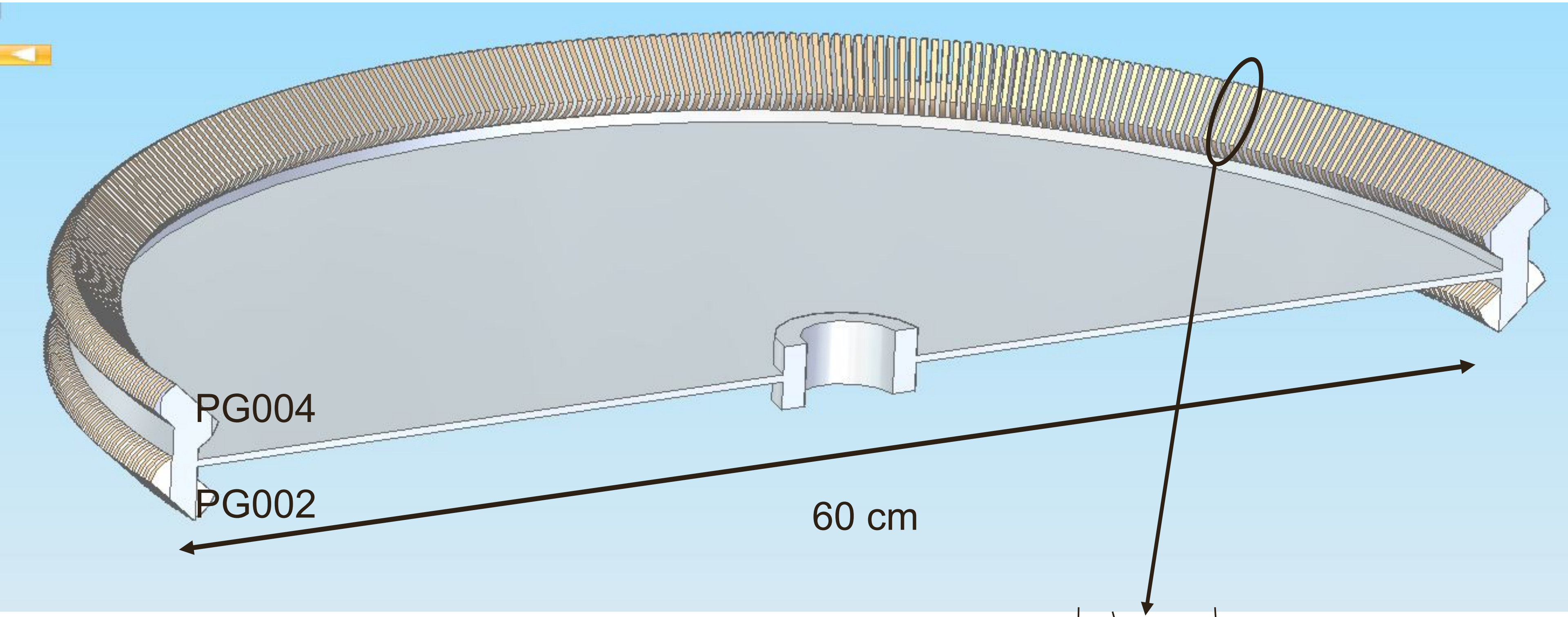
Focussing the neutrons through a point allows one to build a realistic ‘order selector’



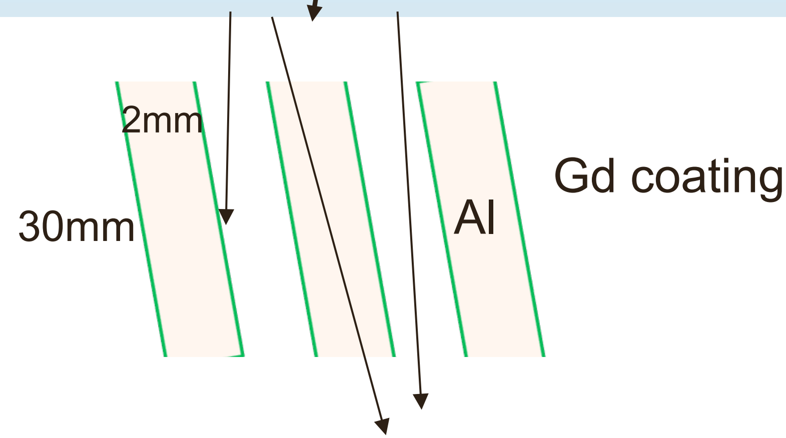


The 'order selector'

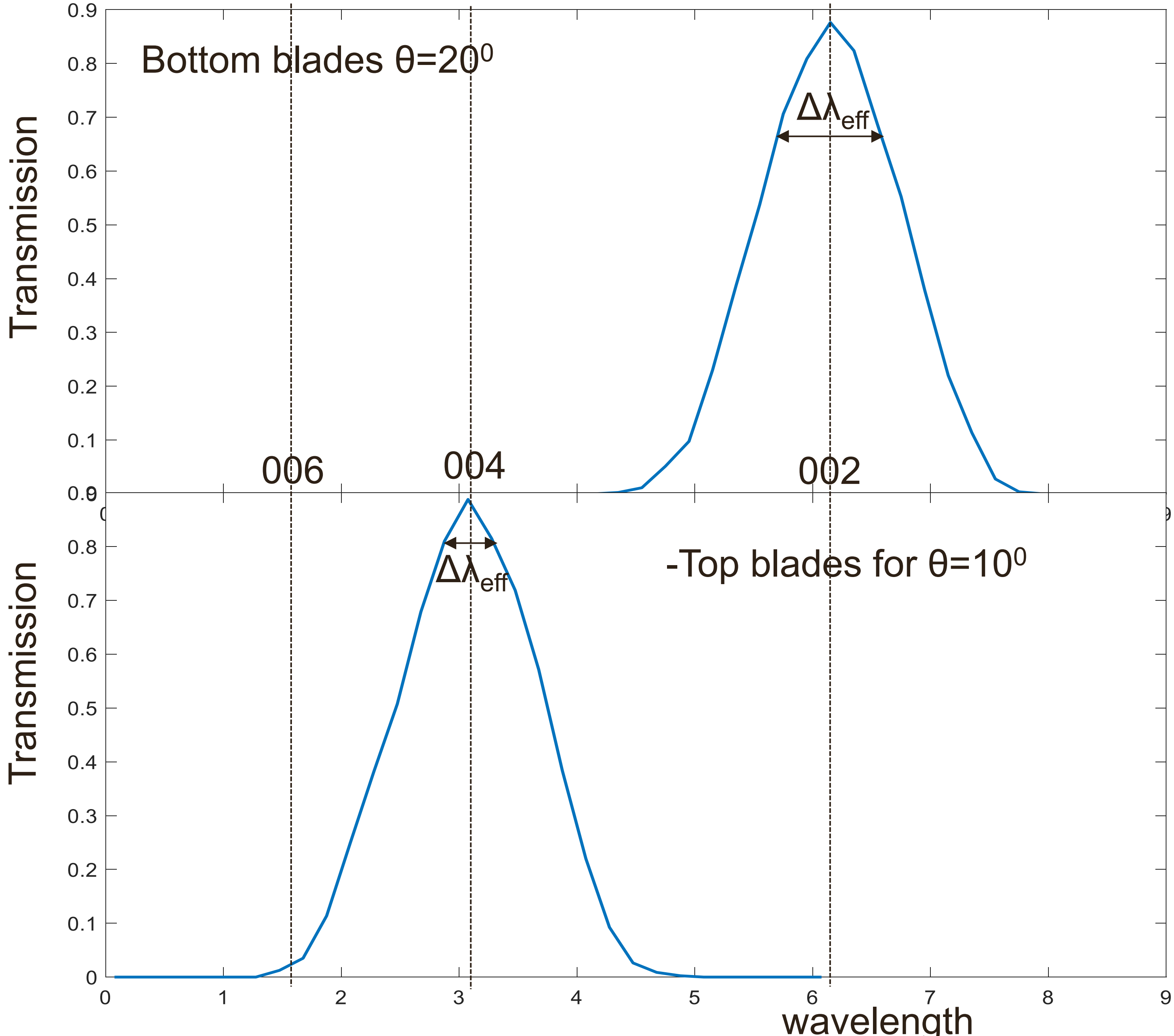
- A velocity selector with Aluminium blades coated in Gadolinium (electroplating)



- Rotates @ 120 Hz
- Blades set at two different angles (θ)
  - -Top blades for PG004 $\theta=10^0$
  - -Bottom blades PG002 $\theta=20^0$
- Initial FEA analysis shows its OK
- Hoping to 3D print in Aluminium



Performance - order selector



Performance - background

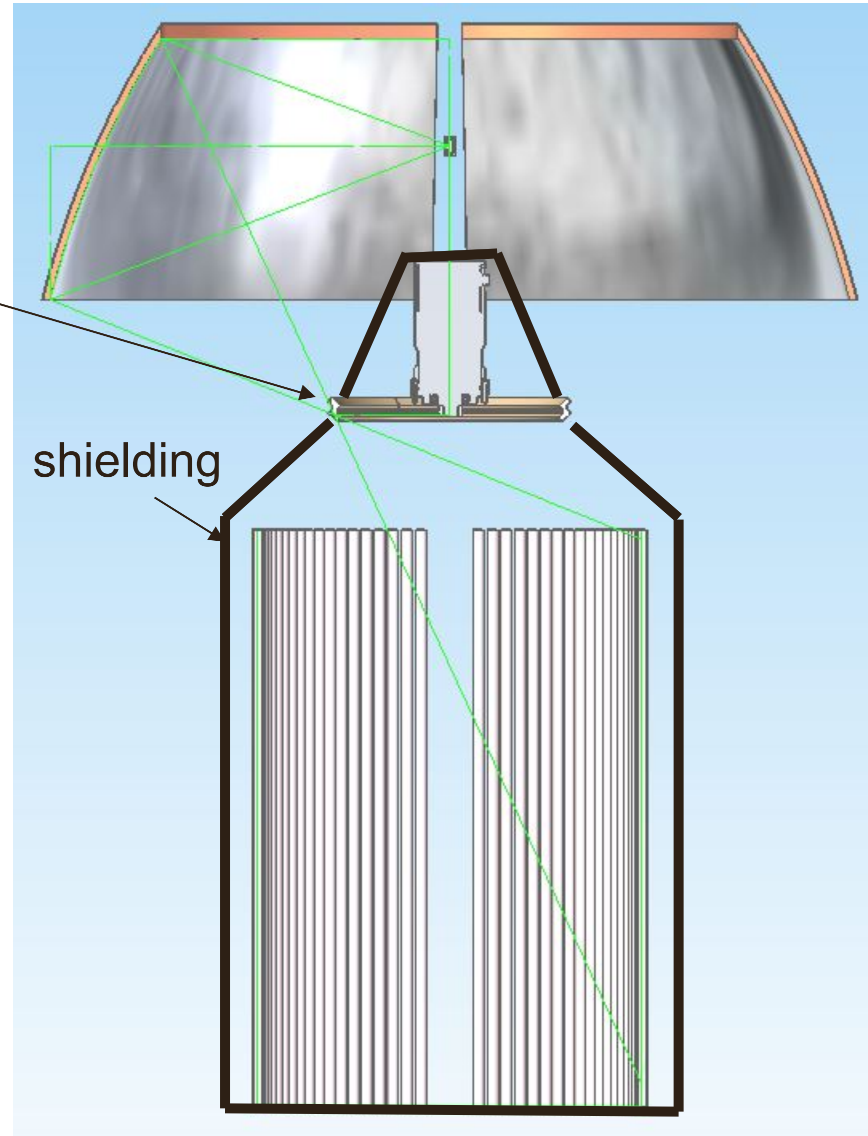
- **Diffuse thermal scattering (particularly from PG crystals)**

- Detectors view analysers through a narrow 3cm slit. Should substantially reduce Diffuse thermal contribution to background

- Detectors in a well shielded box well away from sample, whitebeam and analysers

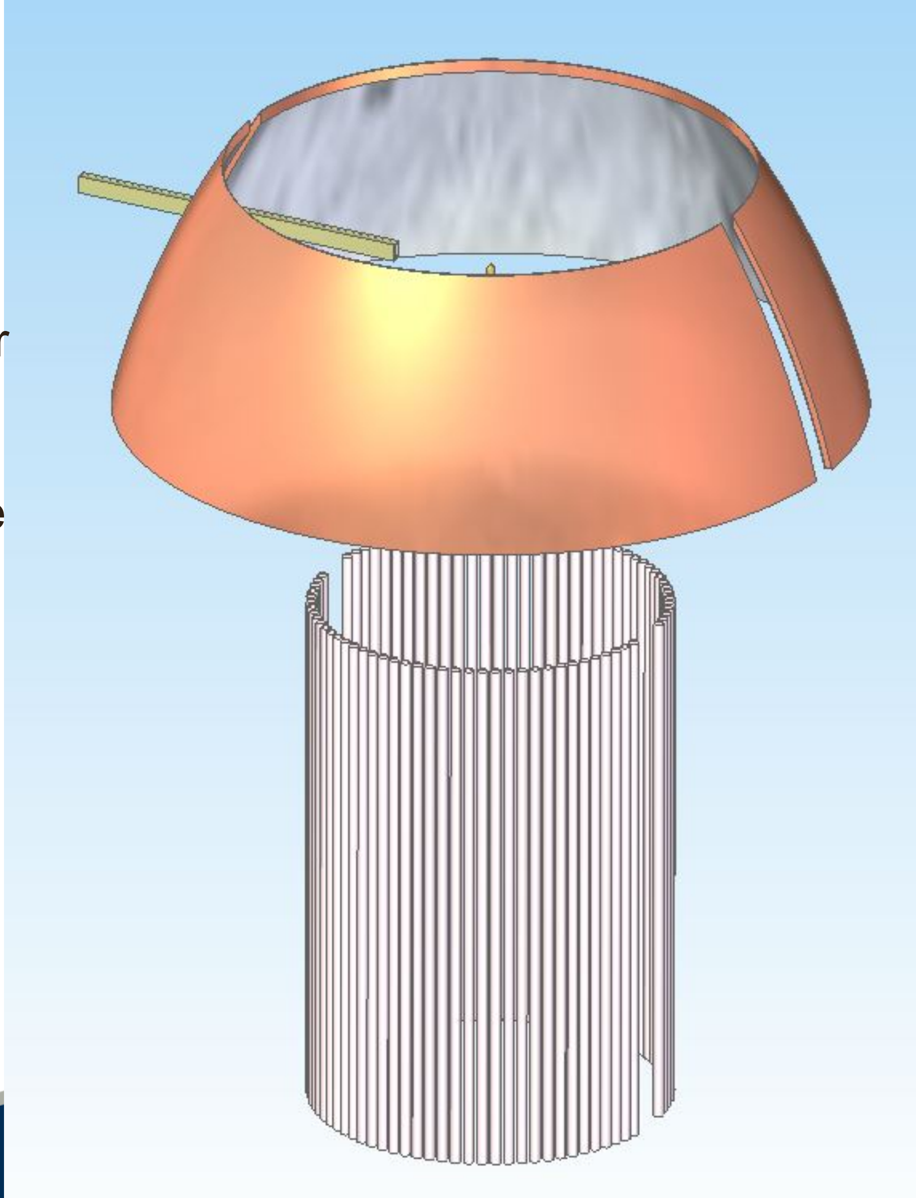
- Order selector stops contamination from different orders plus will reduce possible spurions from bragg scattering from sample

- Will never be as quiet as Direct geometry



Summary

Presented a new style of cold in–direct geometry spectrometer capable of rapid 4D S(Q,w) mapping of crystals or for studying small samples



Advantages

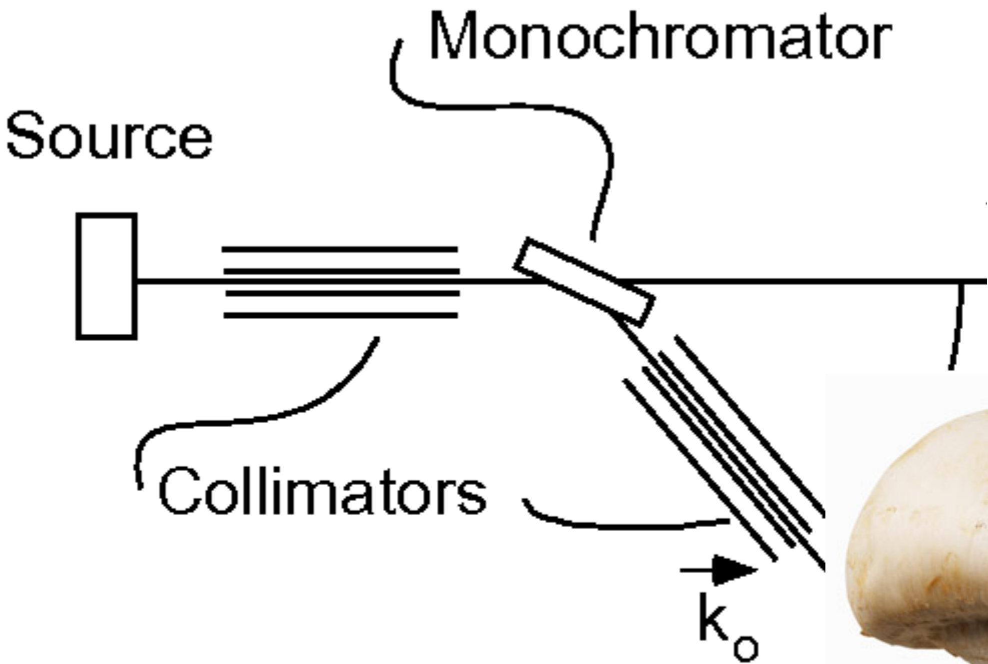
- High count rates >20 x direct geometry instruments like LET
- Easy to cleanly select PG002 or PG004 for 1% or 3% $\Delta E/E_{trans}$ and different Q ranges
- Massive 2π steradians of position sensitive detector coverage
- MUCH cheaper and smaller than a direct geometry machine.

Dis-advantages

- Likely to have worse background/spurions
- Q resolution is slightly worse

Thanks for your attention

MUSHROOM on a reactor

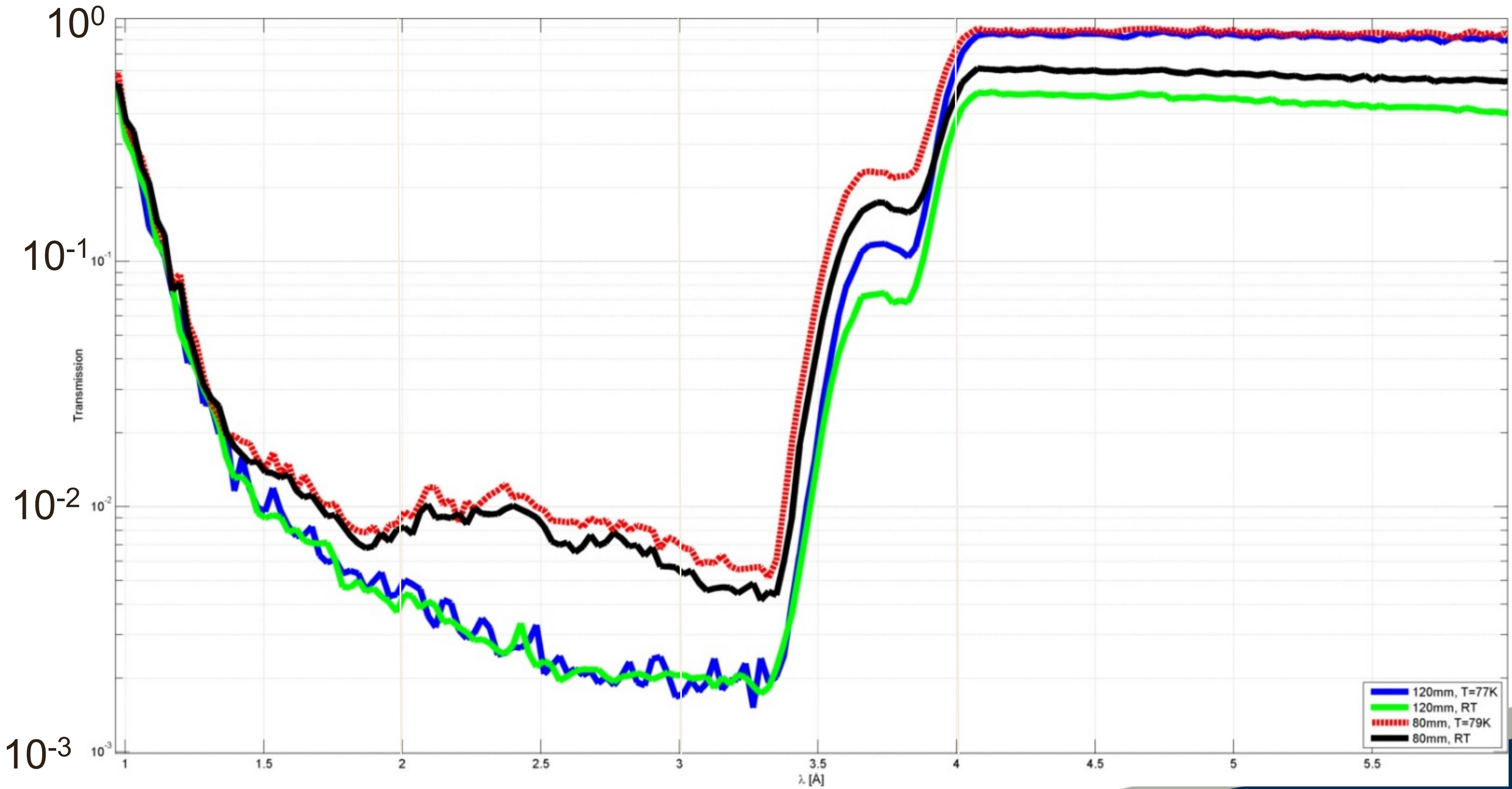


Could work;

- Would scan Ei and sample rotation

- Would effectively be a super flatcone

Be transmission

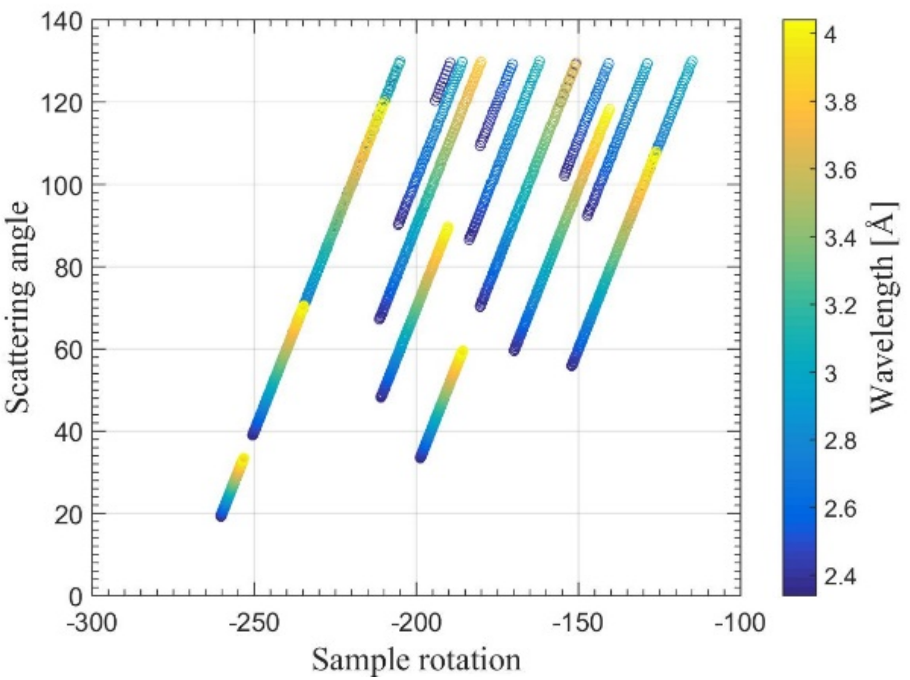


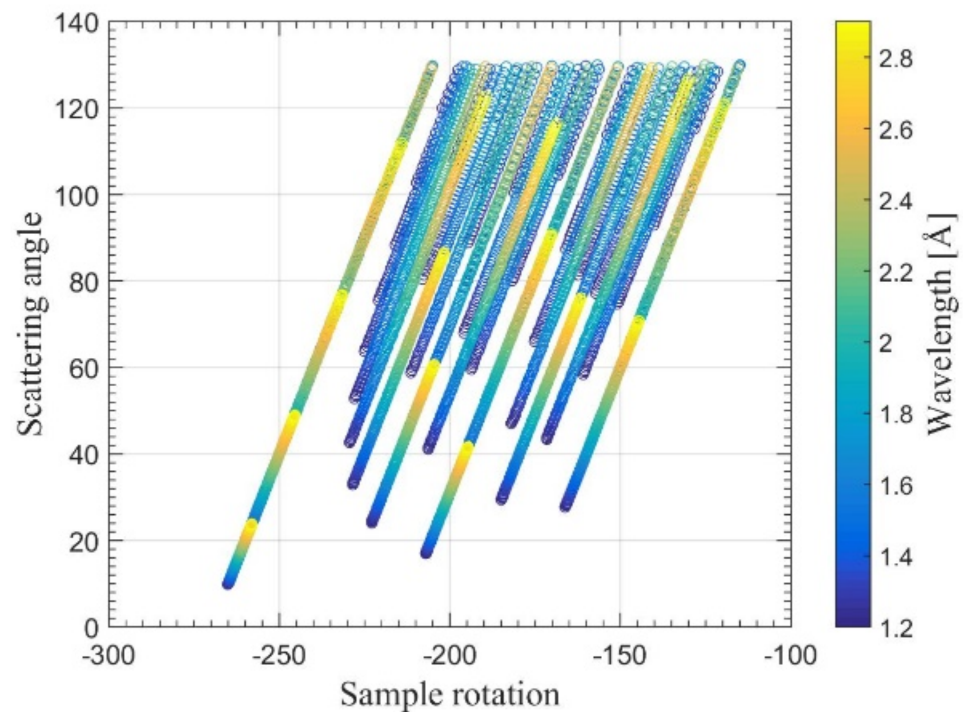
1Å 2Å 3Å 4Å 5ÅÅ

Bifrost Bragg peaks

EUROPEAN
SPALLATION
SOURCE

**Bragg peak distribution for a standard cubic sample with lattice paramet
for high and low wavelengths**





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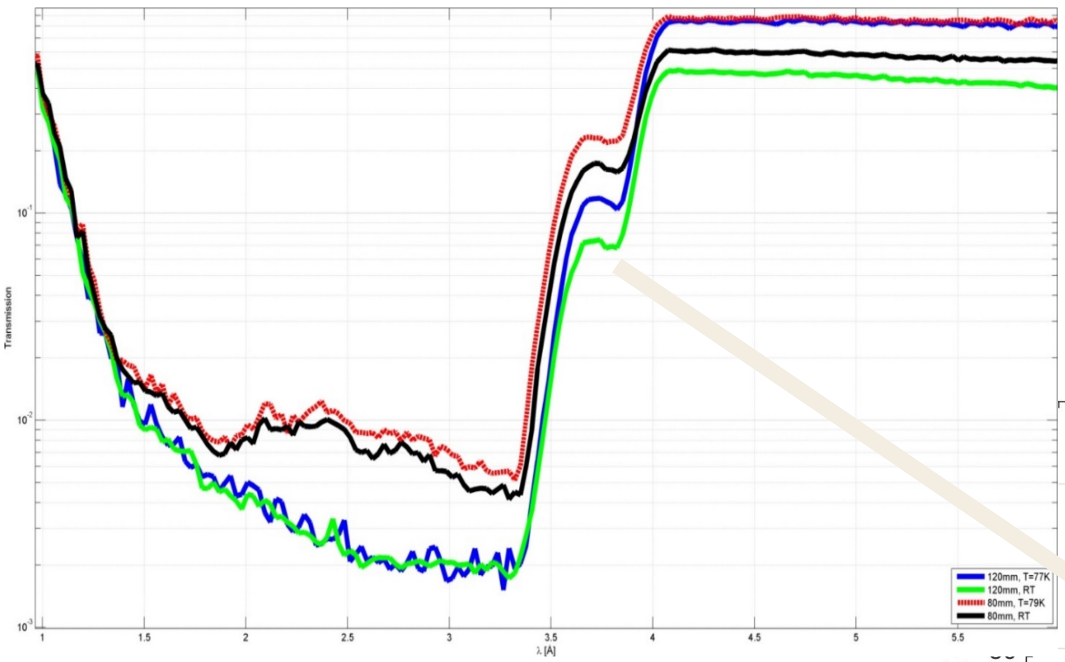
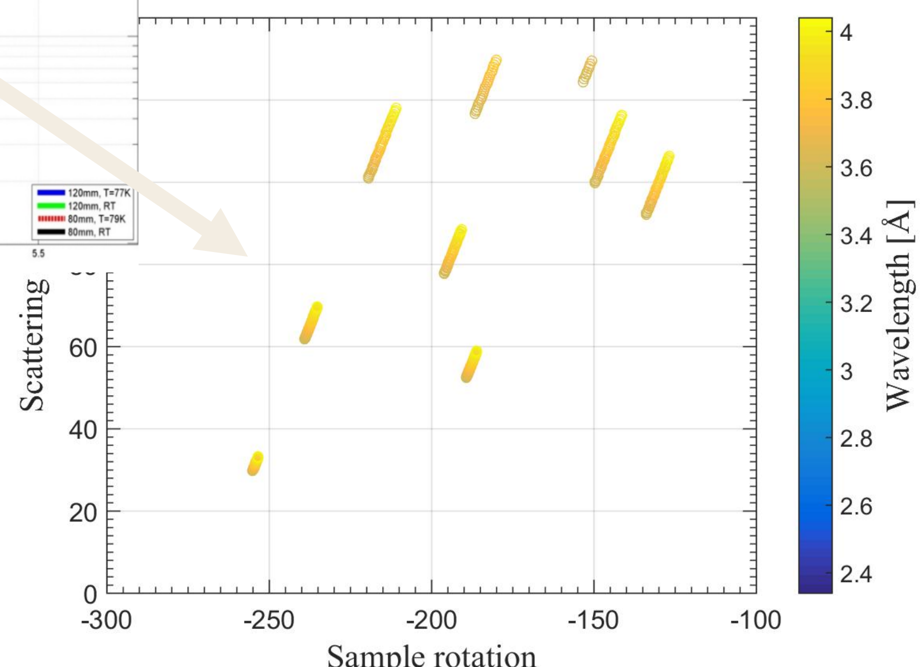
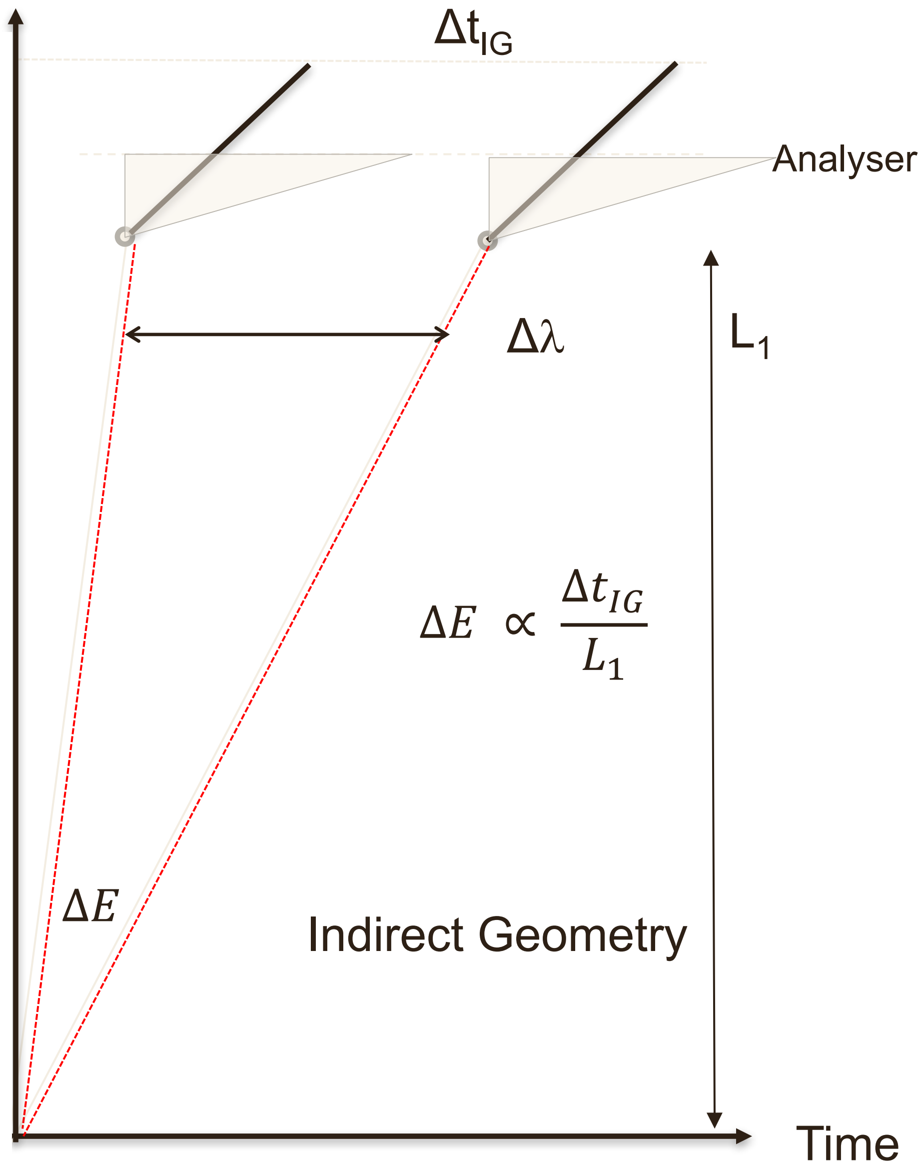
Shoulder Bragg peaks






Δt_{IG}
Analyser
$\Delta\lambda$
L_1
$\Delta E \propto \frac{\Delta t_{IG}}{L_1}$
ΔE
Indirect Geometry
Time

Indirect Geometry is much more efficient

$$\frac{\Delta\lambda^{in}}{\Delta\lambda^{d}} = \frac{L_{tot}^{d}}{L_{f}^{d}} \approx 8 \text{ for LET or 11 for CNCS}$$