Luminescence materials for high power targets

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Outline

1. Introduction:
   – Use of luminescent materials
   – Cases for accelerators and issues with high power beams

2. Focus on Beam on target imaging
   – ESS Imaging system
   – Material selected: Al_2O_3:Cr
   – Performance required: luminescence, lifetime decay, spectrum, radiation tolerance
   – Characterisation: photo-luminescence, proton luminescence, irradiation
3. Other materials
   – Yttrium based, lanthanides doped

Usage of Luminescent materials

Applications:

- Imaging of beam of particles
- Detection of particles
- Medical imaging
- Radiation detection
- Radiation dose
- …

Detection:

- X-ray, gamma-ray
- Neutrons
- Protons
- Electrons
- …

Materials:

- Organic materials
- Inorganic materials

M.J. Weber / Journal of Luminescence 100 (2002) 35–45

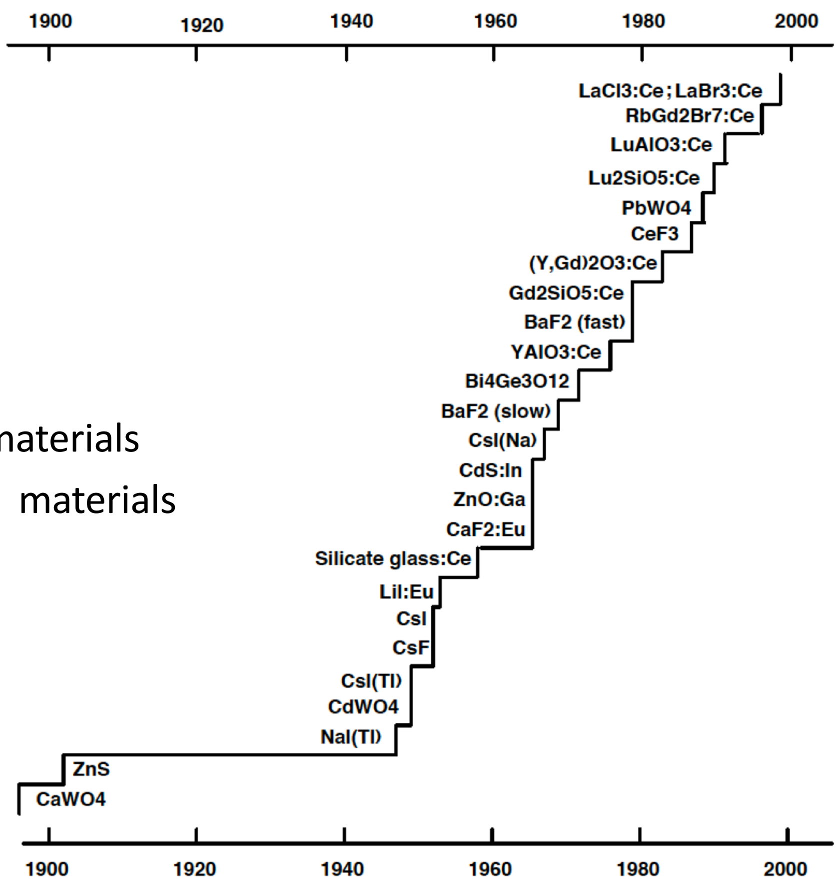


Fig. 1. History of the discovery of major inorganic scintillator materials.

Imaging high power beam

Objectives:

- [ ] Perform an image of the 2D particle beam distribution

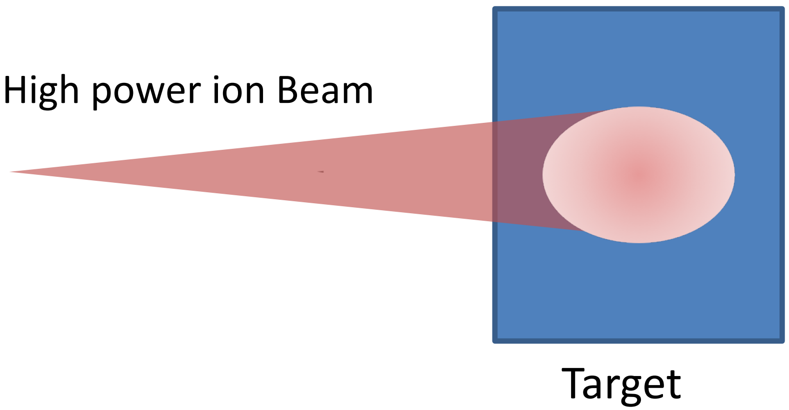
Issues:

- Heat-load: decay or extinction of the luminescence
- Heat-load: permanent damage of the material
- Radiation dose: mutation of the material / material defect that affect luminescence properties
- Radiation environment: additional signal from other particles

Examples:

- Heavy ion beams
  - e.g. GSI U beam, 5MeV/nucleon 10^{11} particles per bunch: 2kJ per pulse (1ms) / 5mm x 5mm
- Undulator radiation
  - e.g. Diamond, U27 undulator (MX beamline), 3kW /100µm x 10µm
- Proton beam on target
  - e.g. ESS, 2GeV 10^{15} particles per pulse: 320kJ per pulse (3ms) / 15mm x 5mm

Imaging high power beam: beam on target



Beam Properties:

- current density distribution
- size
- position

- ➢ Support tuning / operation
- ➢ Heat-load
- ➢ Damage
- ➢ Dose

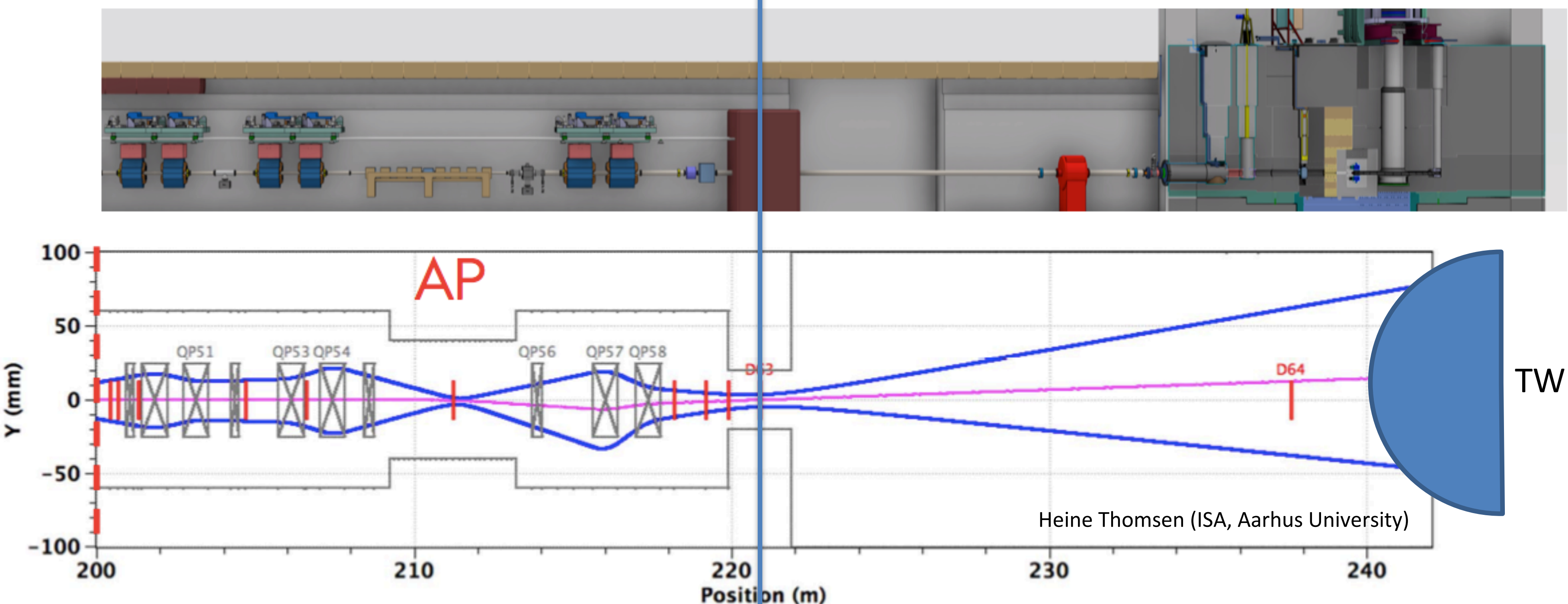
  Component lifetime

Requirement specification and performance:

- ✓ Luminescent material
- ✓ Imaging system

Beam on Target: Case of ESS

Accelerator region | Target region

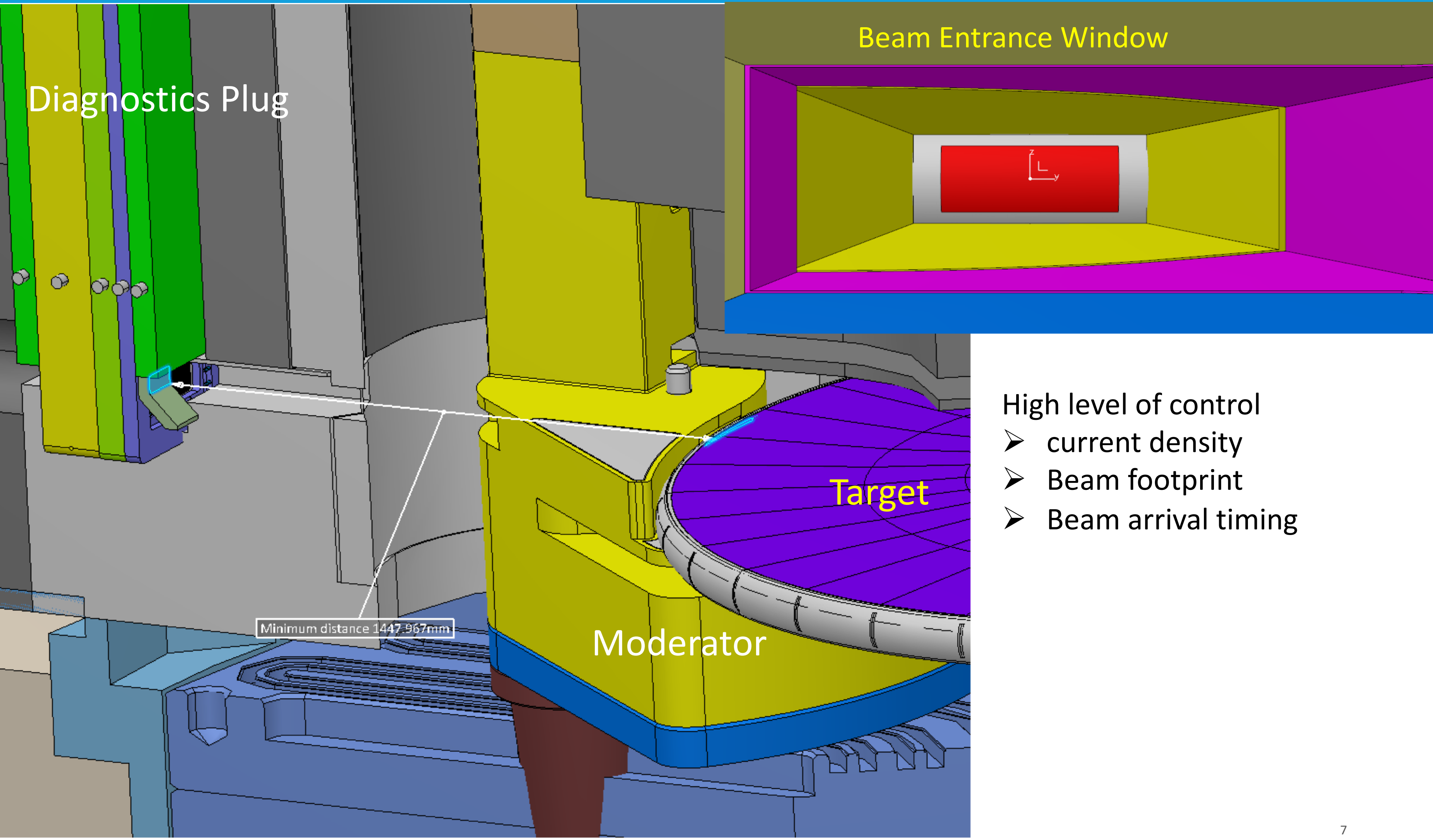


Current: 62.5mA
Energy: 1-2 GeV
Area = π 3x3 mm²
Peak power: 440 MW/cm²

Area = π 0.5x0.5 mm²
Peak Power: 16 GW/cm²

Area = 160x60 mm²
Peak Power: 1.3 MW/cm²

Beam on Target: Case of ESS

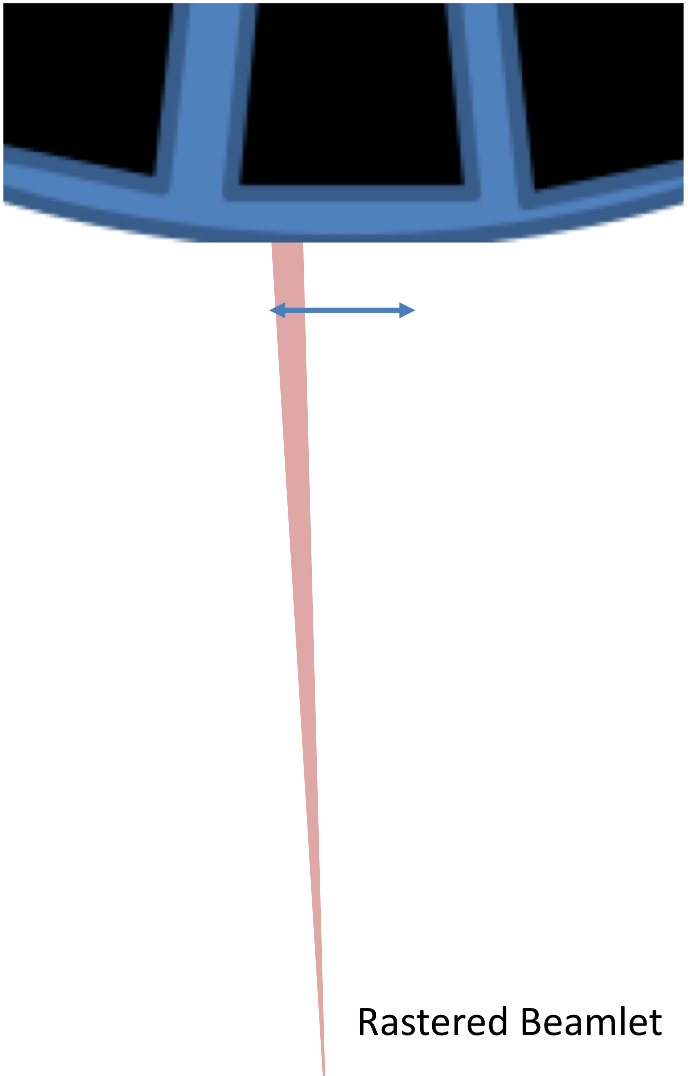


High level of control
- current density
- Beam footprint
- Beam arrival timing

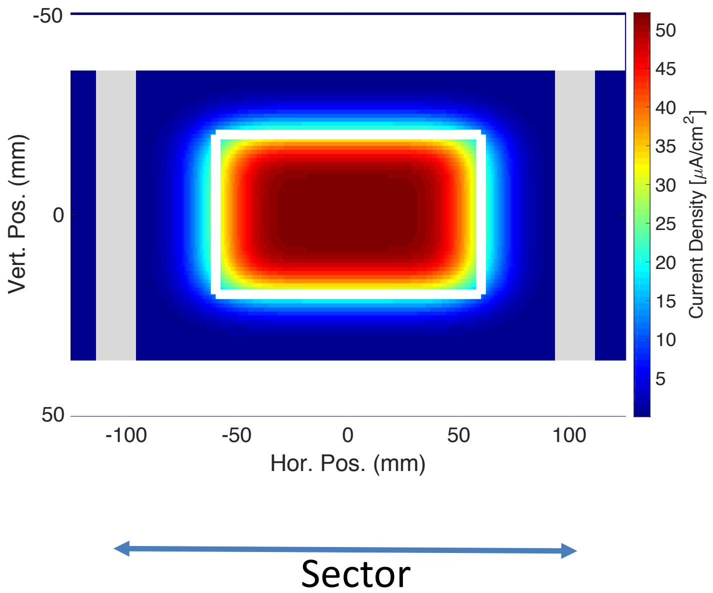
Beam on Target: Case of ESS

Beam parameters:
Power: 5MW
Peak Current: 62.5mA
Avg Current: 2.5mA
Pulse: 2.86 ms

Spinning Target wheel top view

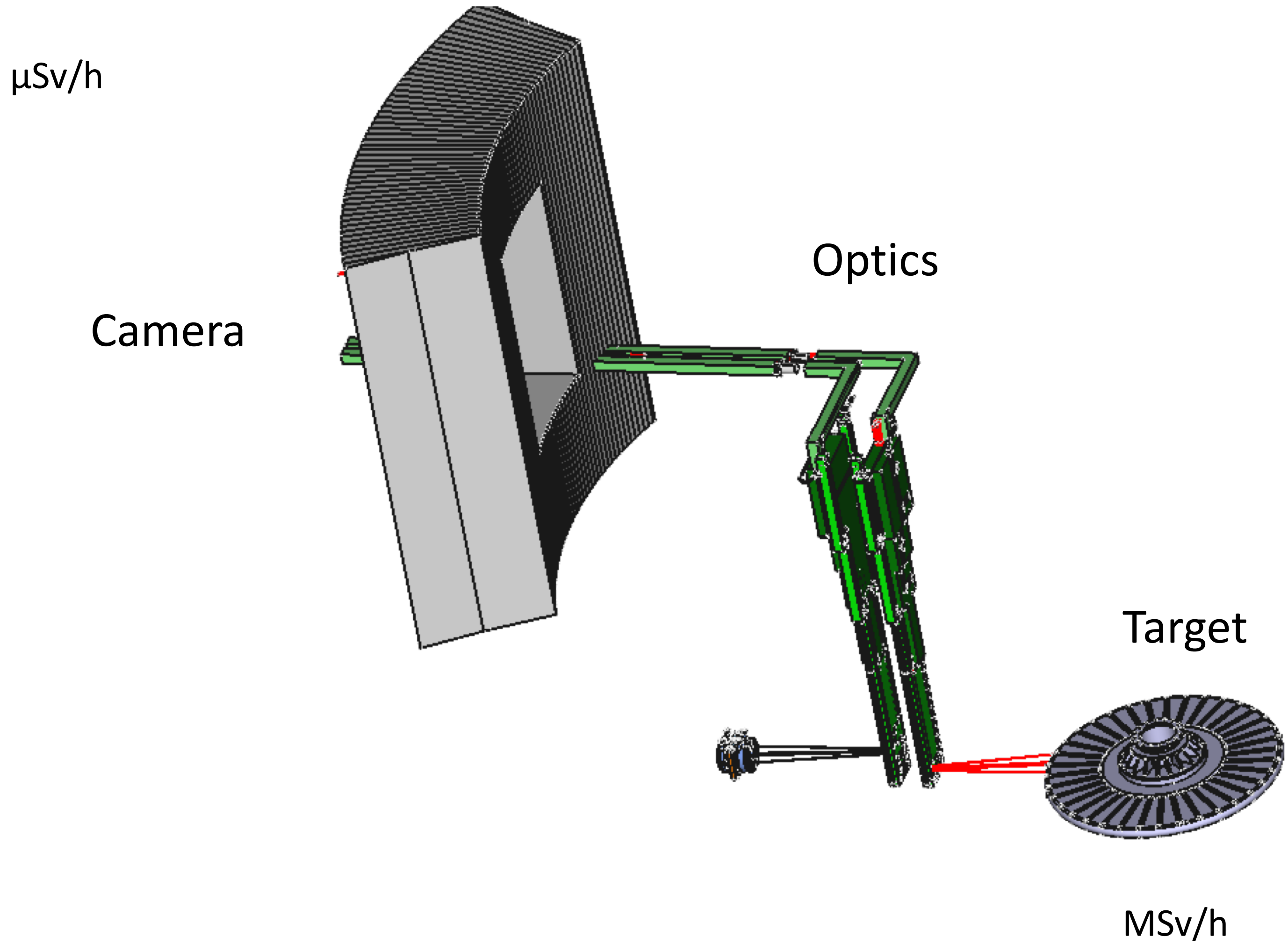


Beam Entrance Window Front view



- Spatial requirement
- Timing requirement

Imaging System



Luminescent material

Selected Material: Al_2O_3:Cr

- Same material used at SNS: proven to work in this environment
- Material lifetime long enough for ESS (based on SNS experience)
- Sprayable materials on large surfaces
- No other material demonstrated and validated for the first ESS target

But:

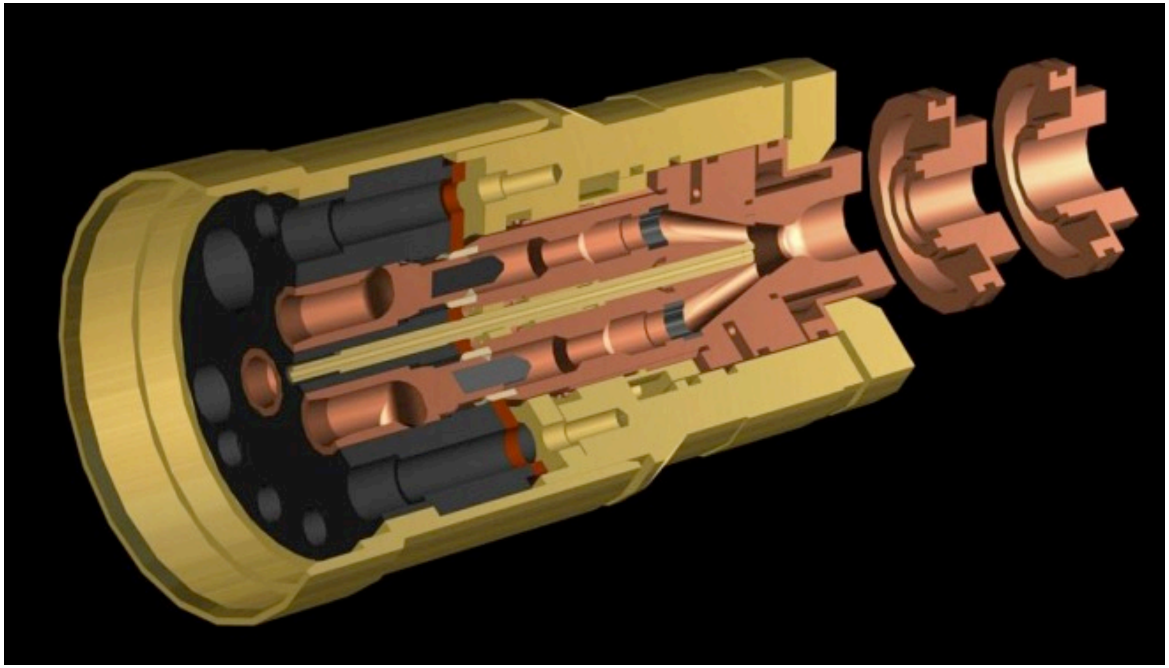
- Target temperature may an issue
- Luminescence time decay similar to spinning speed
- No studies to support the choice

Luminescent Coating Requirements

1. **The photon yield:** predict signal signal intensity and signal to noise ratio and related image quality
2. **The emission spectrum:** the photons wavelength (or energy) is of prime importance.
   - It should be in an efficient range for the readout image systems
   - It should be on a different from the proton beam induced fluorescence of the (residual) gas environment.
3. **The luminescence lifetime:** should be less or much less than 1µs in order to perform a still image of the rastered beam on the moving target
4. **Radiation tolerance**: the luminescence properties should remain sufficient to permit minimal imaging performance along the life of the coated component
5. **The temperature dependence**: the luminescence yield should be understood. The SNS coating has a strong dependence on temperature, and at 473K its luminescent yield is dramatically reduced
6. **Luminescence from secondary particle:** neutron, gamma, and other hadron particles may distort the beam density profile
7. **Mechanical properties:** compatibility with the coating process and strength of the coating
8. **Vacuum compatibility:** outgassing rate of the material should be acceptable for the vacuum system

Unique Plasma Spraying Facility

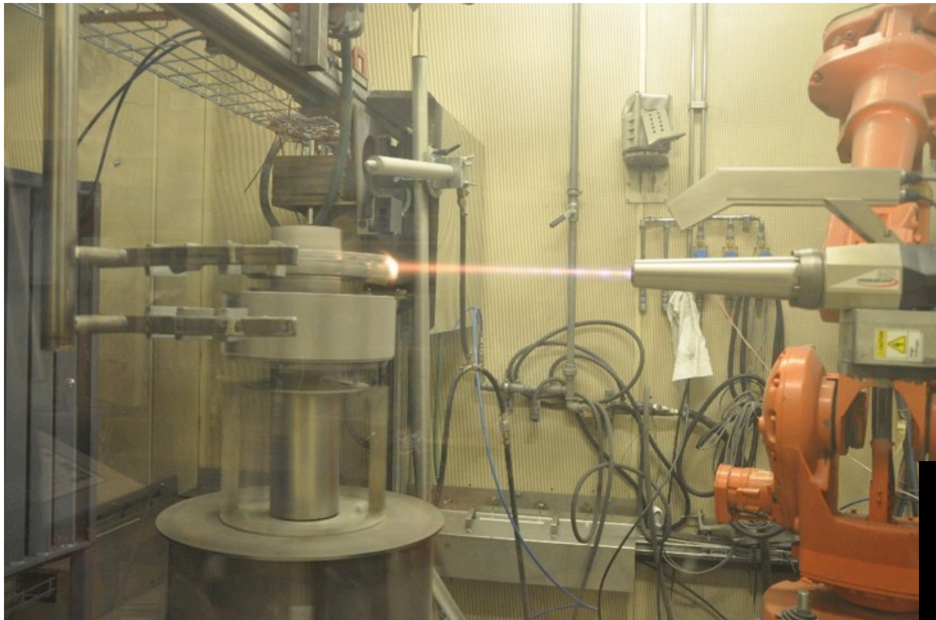
- University West possesses state-of-the-art axial-feed thermal spray gun

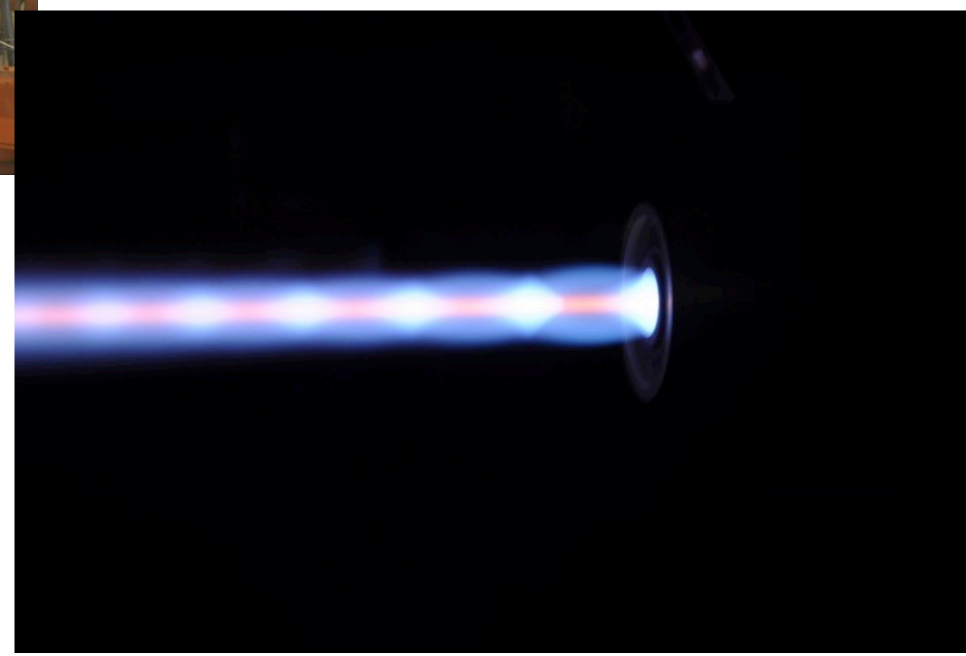


- Such axial-feed plasma spray equipment available only in two groups in Europe and none other in Sweden.
- University West has unique knowledge in powder and suspension plasma spraying….as well as their combination!

Courtesy Shrikant Joshi, HV

Unique HVAF Spraying Facility





- University West's HVAF facility also among the first in Europe
- Still one of only few such facilities in the region

Courtesy Shrikant Joshi, HV

Plasma spray trials with Brodmann powder

Parameters Mettech Axial III

RUN	Sample	Feed rate (ml/m)	Nozzle (in)	TGF (lpm)	Ar (%)	N2 (%)	H2 (%)	Carrier, slpm	Curr. , (A)	SOD, mm	surf.speed	step	Cooling	Power	Enthalpy	t before	t after
1	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	230	150	103	5	Stefan L	112	17	0,495	0,555
2	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	8	230	150	103	5	Stefan L	112	17	0,495	0,512
3	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	8	230	150	103	5	Stefan L	112	17	0,495	0,545
4	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	180	150	103	5	Stefan L	99	17	0,495	0,556
5	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	180	150	103	5	Stefan L	99	17	0,495	0,556
6	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	150	150	103	5	Stefan L	86	16	0,495	0,56
7	50*50 al 0,5	(15%) 35 g/min	1/2	150	50%	30%	20%	30	180	150	103	5	Stefan L	75	11,5	0,49	0,55
8	see comment	(15%) 35 g/min	1/2	150	0%	80%	20%	30	230	150	103	5	Stefan L	112	17	0,495	0,555
9	see comment	(15%) 35 g/min	1/2	150	0%	80%	20%	30	230	150	150	5	Stefan L	112	17	0,495	0,515
10	50*50 al 0,5	(15%) 35 g/min	1/2	180	0%	80%	20%	4	230	150	103	5	Stefan L	128	19	0,49	0,545
11	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	230	150	103	5	Stefan L	112	17	0,495	0,545
12	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	30	150	150	103	5	Stefan L	112	17	0,495	0,545
13	50*50 al 0,5	(15%) 35 g/min	1/2	150	0%	80%	20%	8	230	150	103	5	Stefan L	112	17	0,495	0,545

Notes:

1	Carrier gas feed 30 l/min is still within the normal range of the Mettech axial III, I did not use the possibillity of even higher flows in the Uniquecoat feeder.
2	In run 9 the passing speed was increased to 150 m/min from 103 m/min in order to be able to hit the target value of 20 µm thickness without changing the feedrate
3	Low DE (build rate) in run 7, had to double the number of strokes to get same thickness
4	Some of the bending, not all, (when it occurs) would probably come from the comressive stress from only grit blasting one side…

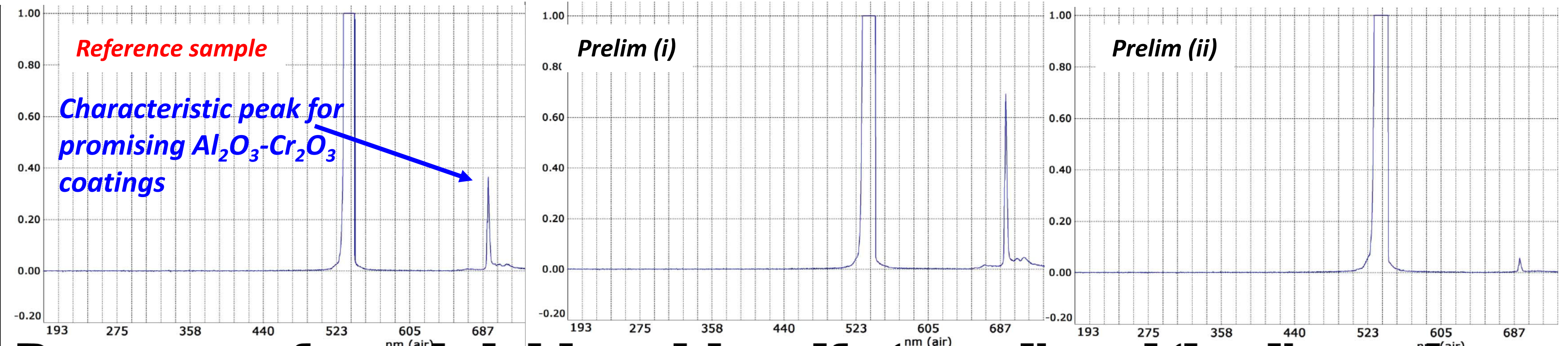
Varied parameters over a wide plasma power, enthalpy window

Courtesy Shrikant Joshi, HV

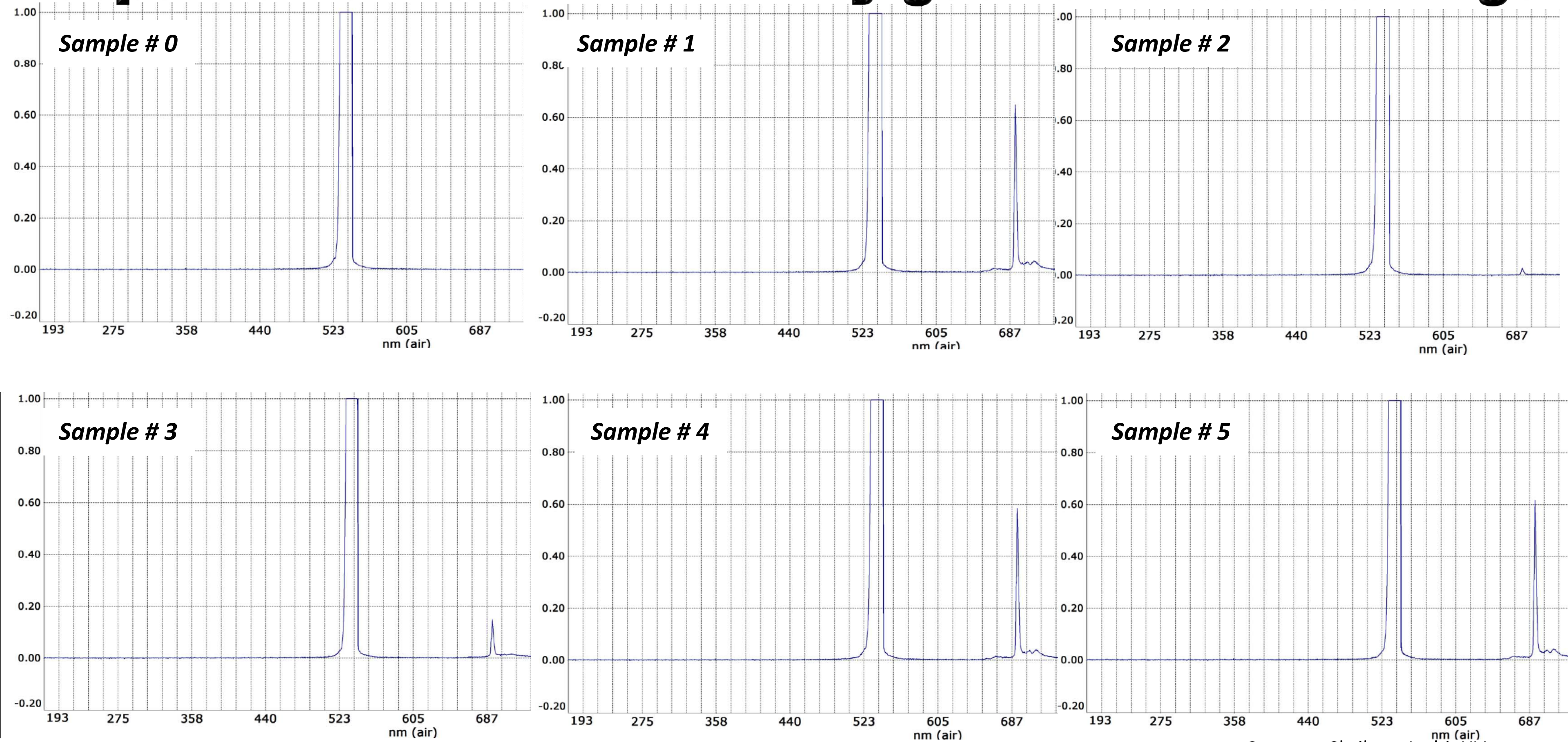
Preliminary evaluation of luminescence

Lab kit provided by ESS; measures photo-excitation response; characteristic 'R lines' around 693-695 mm

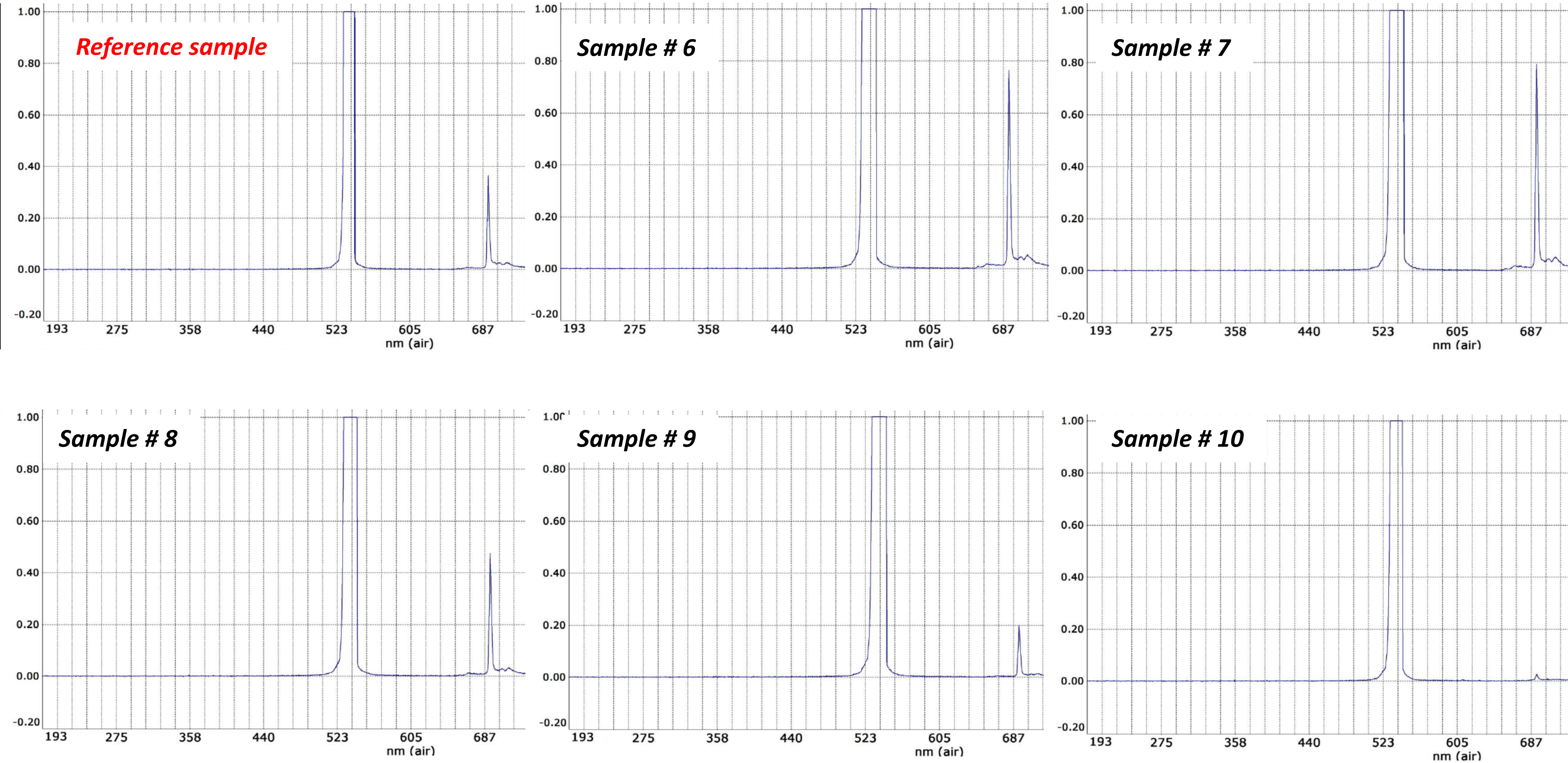
Courtesy Shrikant Joshi, HV



Response from lab kit to identify 'good' and 'bad' coatings



Courtesy Shrikant Joshi, HV



Initial promise evident over a wide parametric window !!!

Further tests in progress

Courtesy Shrikant Joshi, HV

Oslo Cyclotron
Low energy proton beam

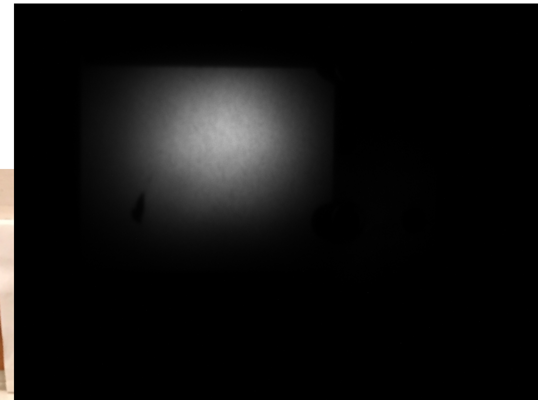
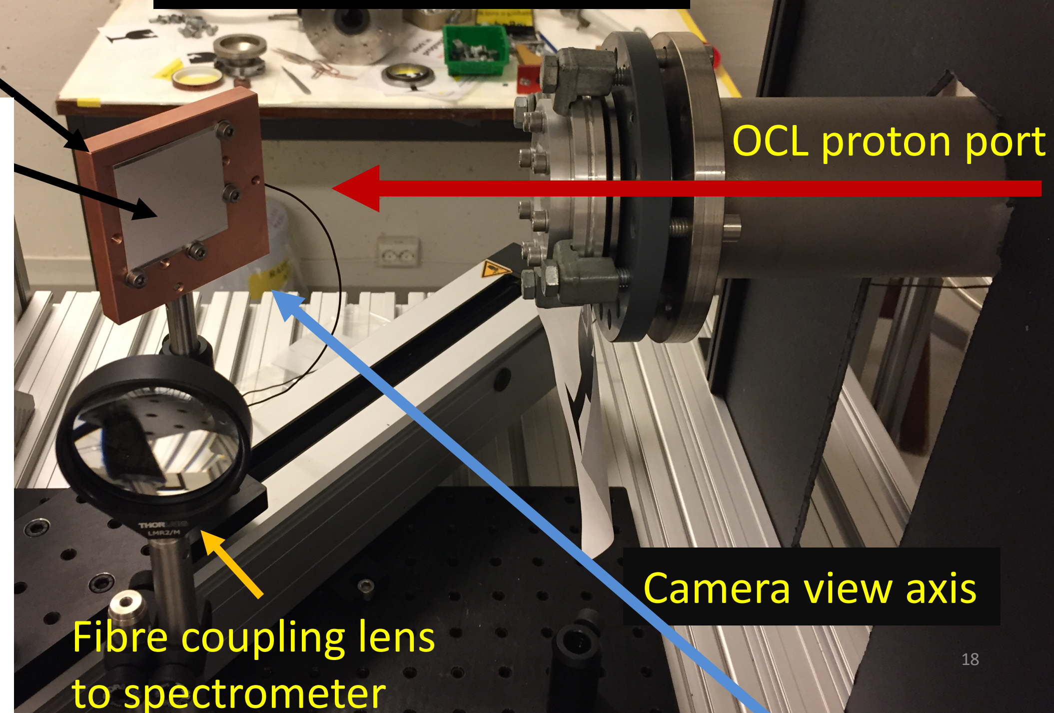
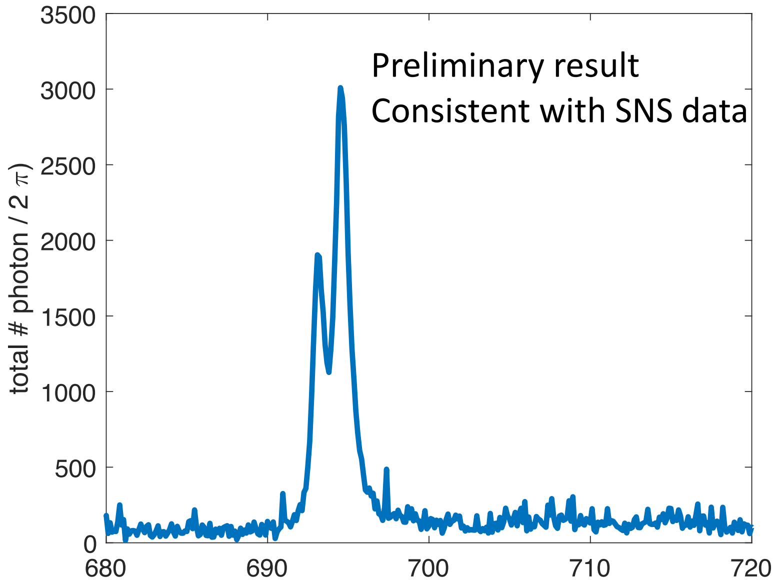


Image of the beam

New OCL FC (ESS – Oslo) 19/04/2017

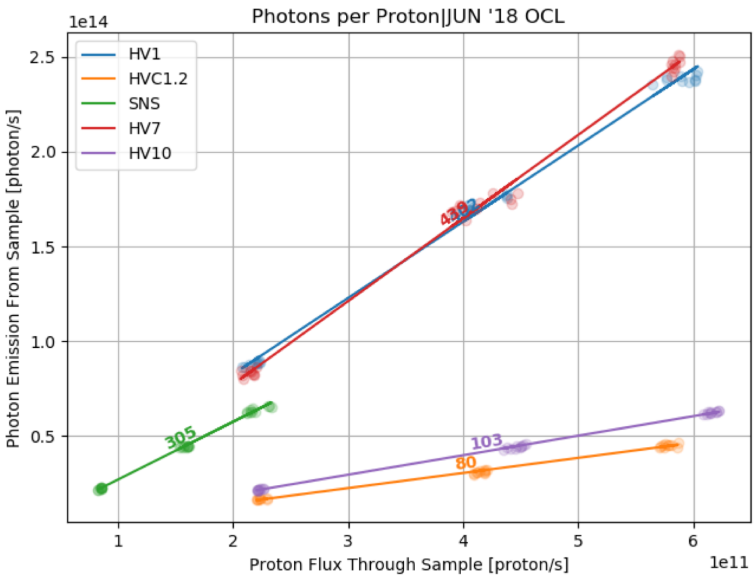
HV coated sample

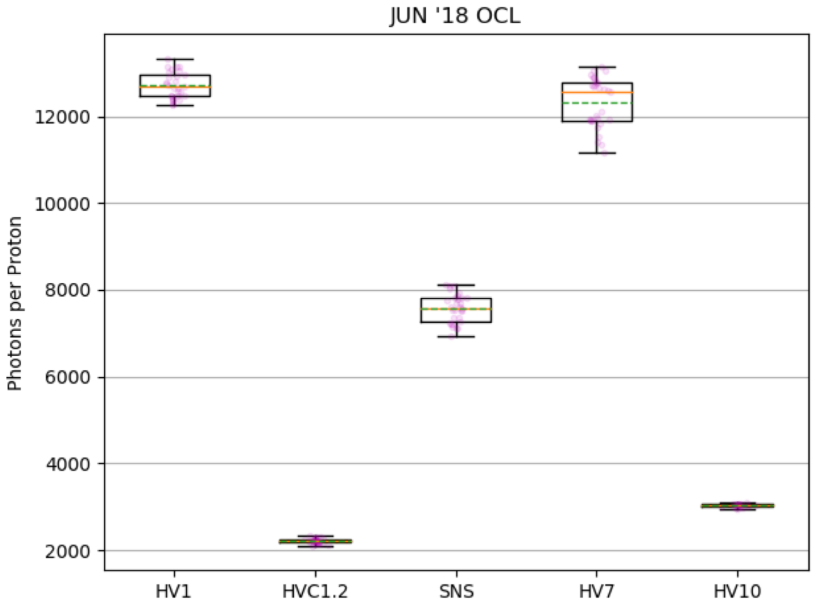




Al_2O_3:Cr Plasma sprayed

Photon yield and spectrum

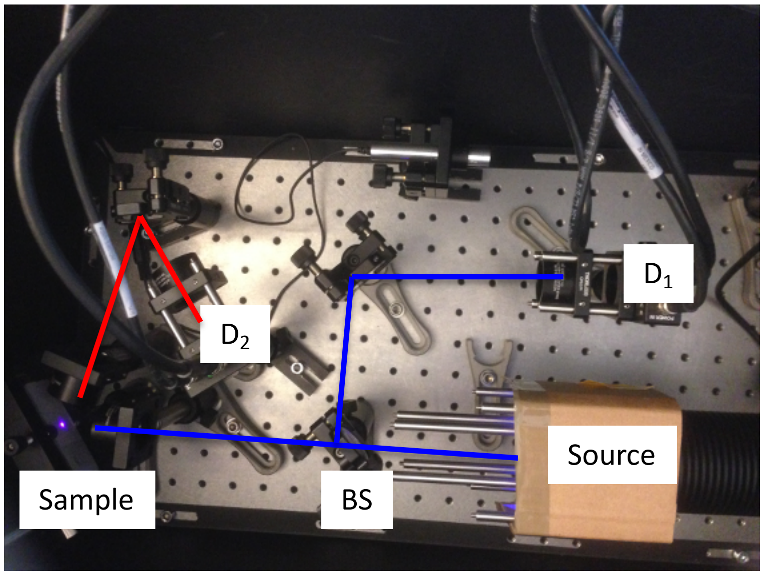


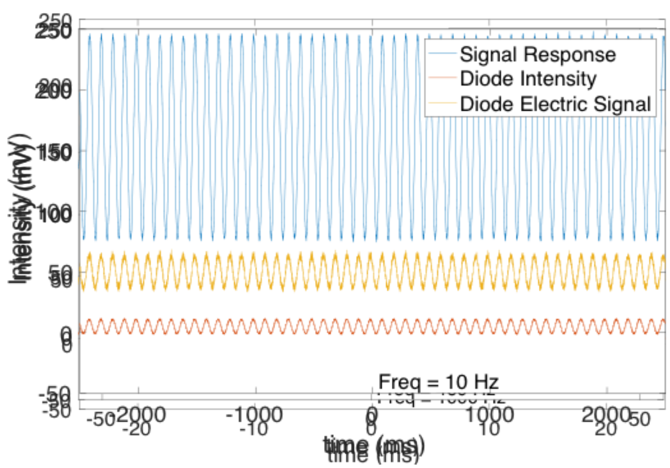


luminescence lifetime

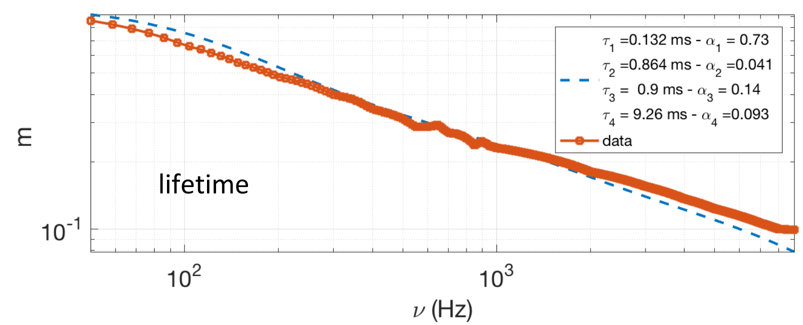
EUROPEAN SPALLATION SOURCE

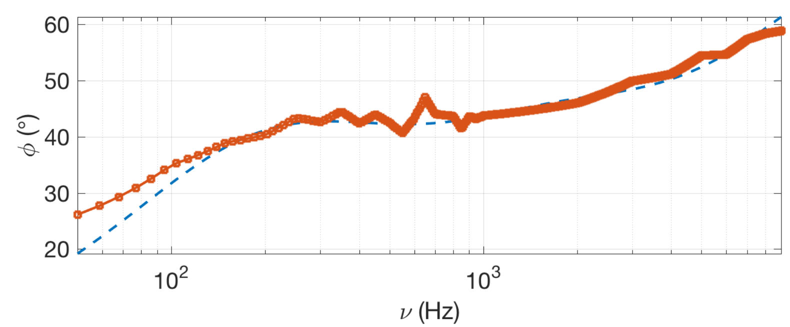
Bench test setup at ESS





ms scale lifetime!

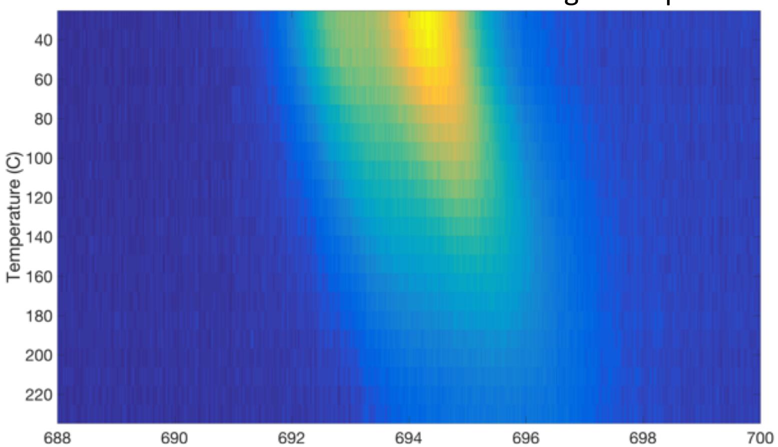




Temperature dependency

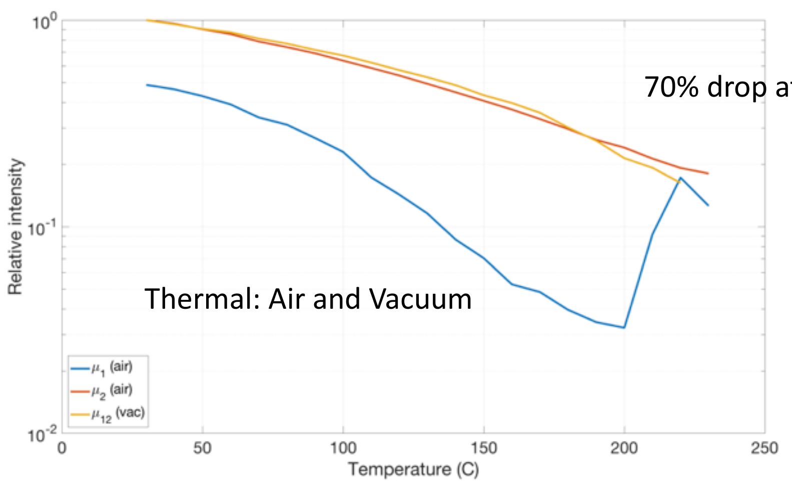
In-vacuum and in-air setup (ESS Vacuum Group):
Controlled sample heater + Spectrometer

- ➢ Measure Outgassing
- ➢ Measure Photon Yield at nominal Target temperature



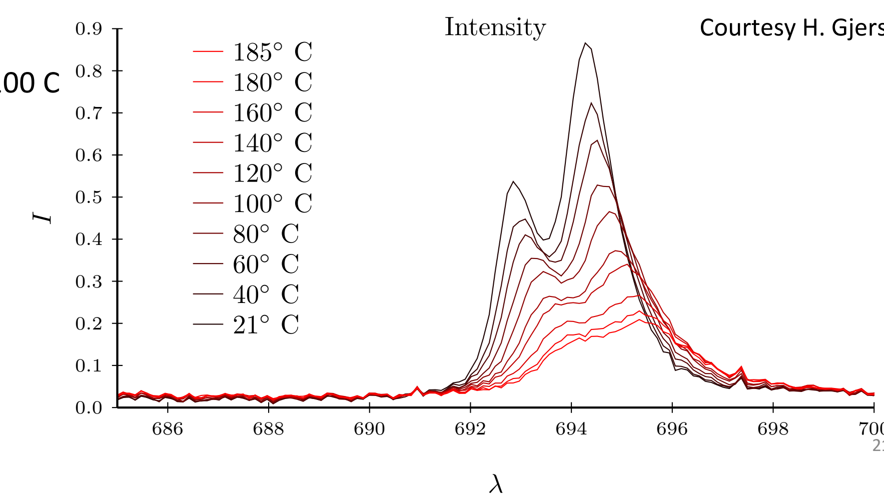
Found same properties of the photo- proton- emission spectra vs. temperature:

- Large drop photon yield at Target operating temperature: 200 degrees C



Proton excitation (OCL)

Courtesy H. Gjersdal



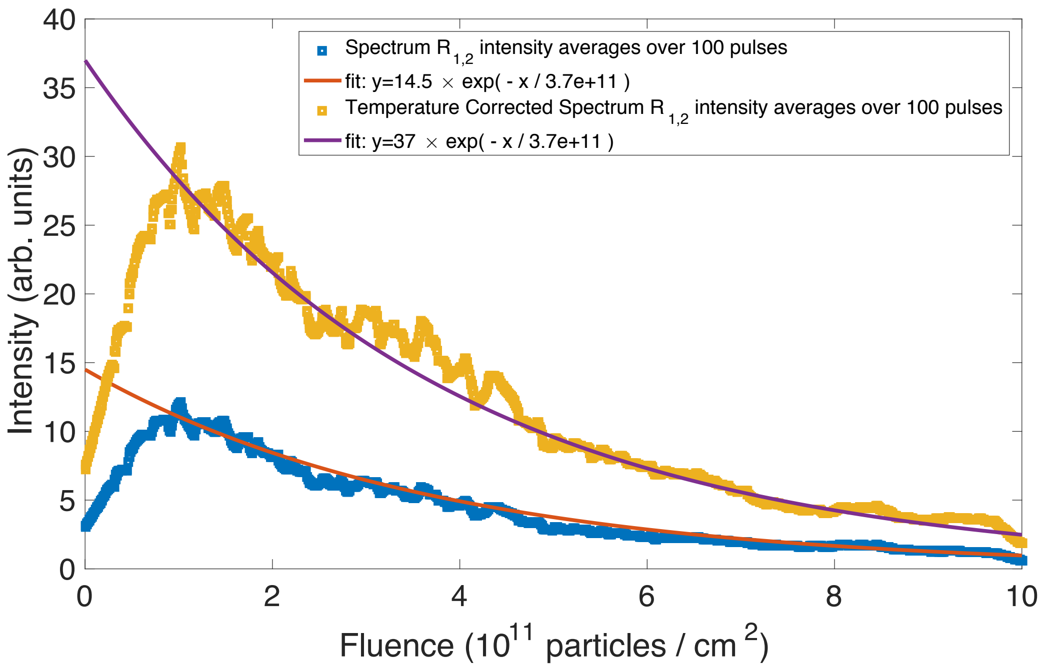
Initial Irradiation studies with low energy Heavy Ions

U irradiation at GSI

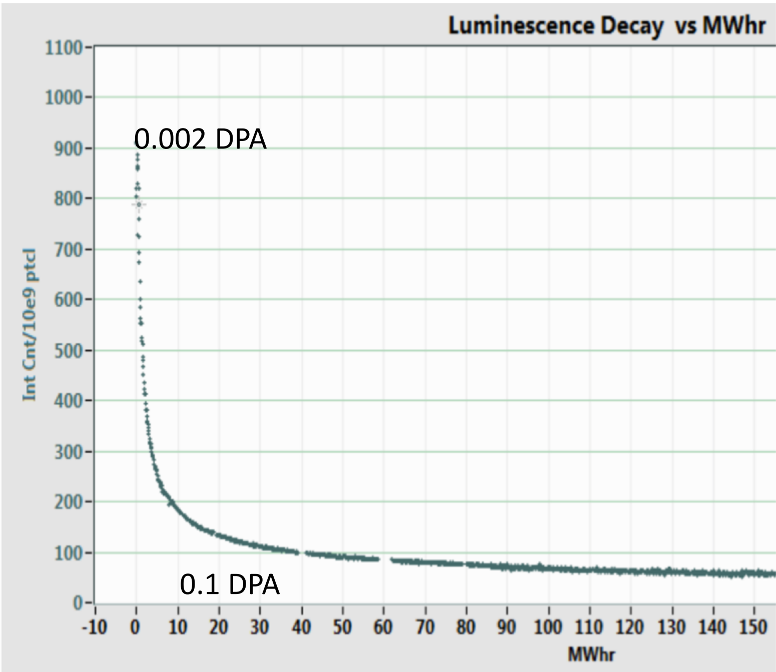
From Fluka: 10^{12} U -> 1.8 10^{-3} DPA

DPA is linear in this regime: is DPA the right scaling parameter?

SNS coupon sample

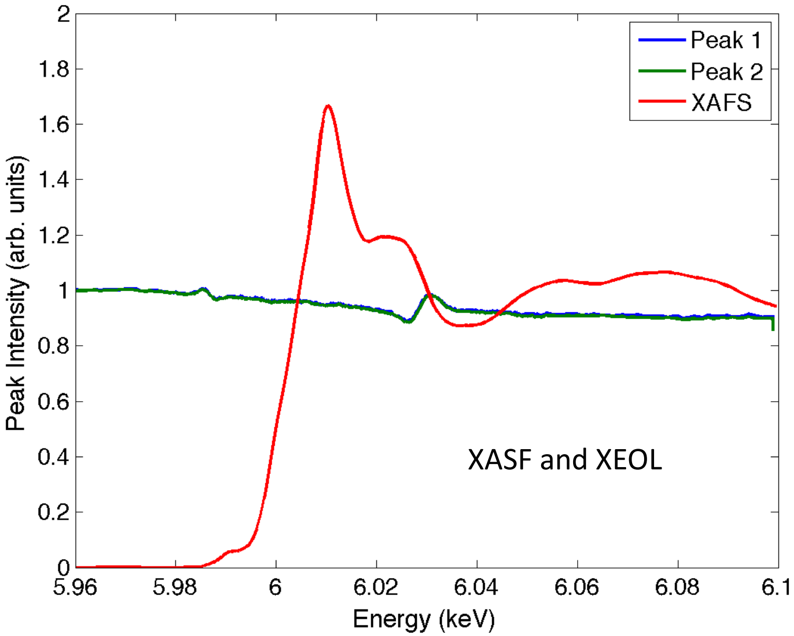


SNS TIS intensity



Investigation and PIE of SNS samples

XASF performed at MAX II



Expected Cr^{3+}

Structure: octahedral

ISIS user labs:

X-ray fluorescence spectroscopy:

Al_2O_3	95.208	%
P_2O_5	0.563	%
Cr_2O_3	3.791	%

"P" might influence the structure formed upon spraying

- Further investigation needed:
- Knowledge to produce precursor powder!

XRD (**Olso**):

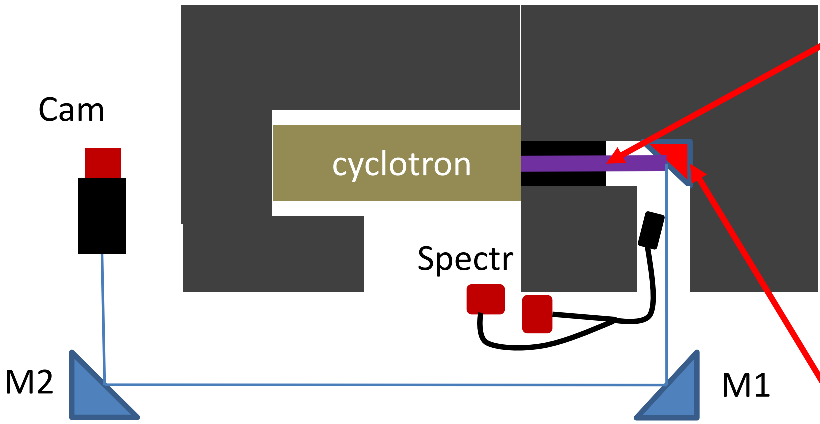
	Phase 1: Corundum	Phase 2: η-Al_2O_3	Phase 3: Iron	Phase 4: Aluminium
Screen (fresh)	39.8%	60.1%	0.06%	-
Screen (Irr)	42.0%	56.8%	0.31%	0.89%

Al_2O_3 -> 2Al + 3/2 O_2

DTU irradiation setup

EUROPEAN SPALLATION SOURCE

Proton beam (7MeV, 30μA)



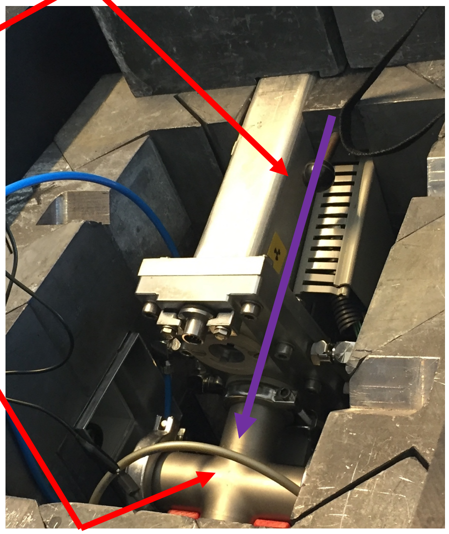
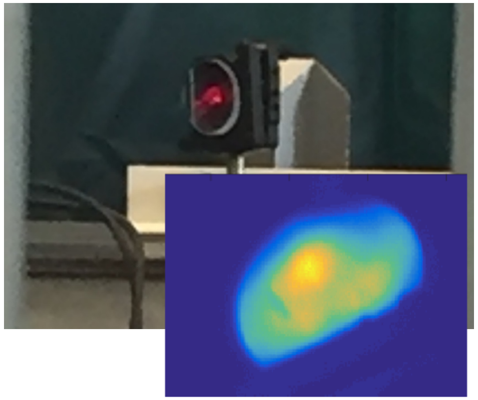
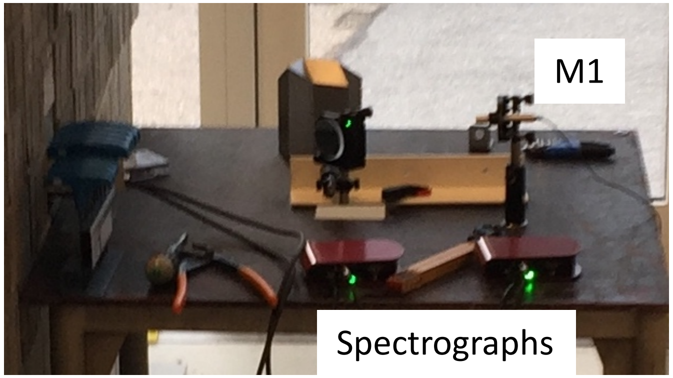


Image of the beam



Cooled sample holder
Sample: Al2O3:Cr



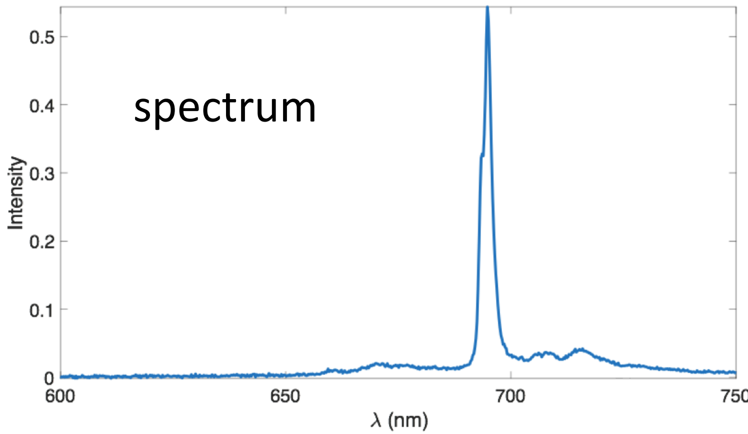
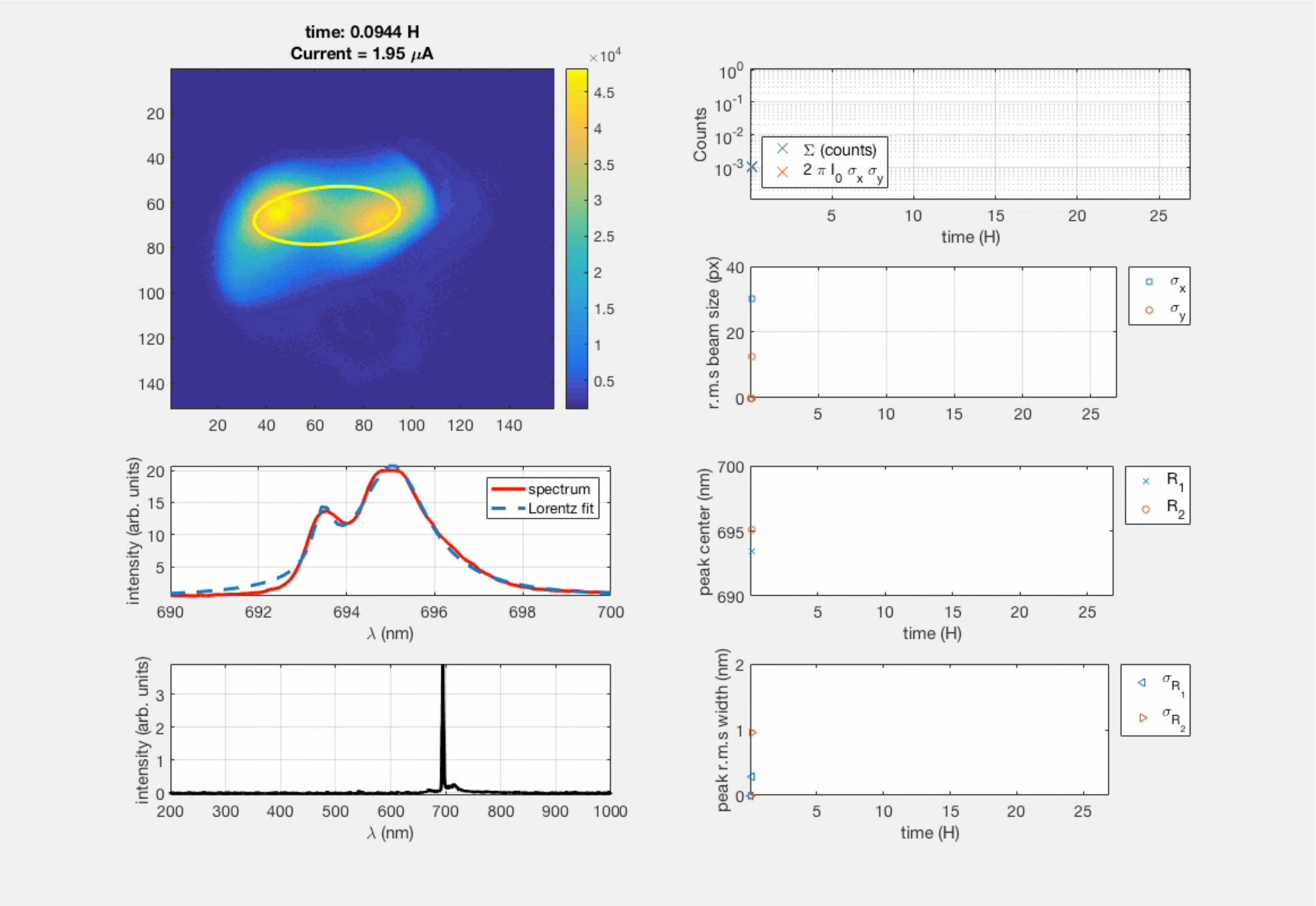
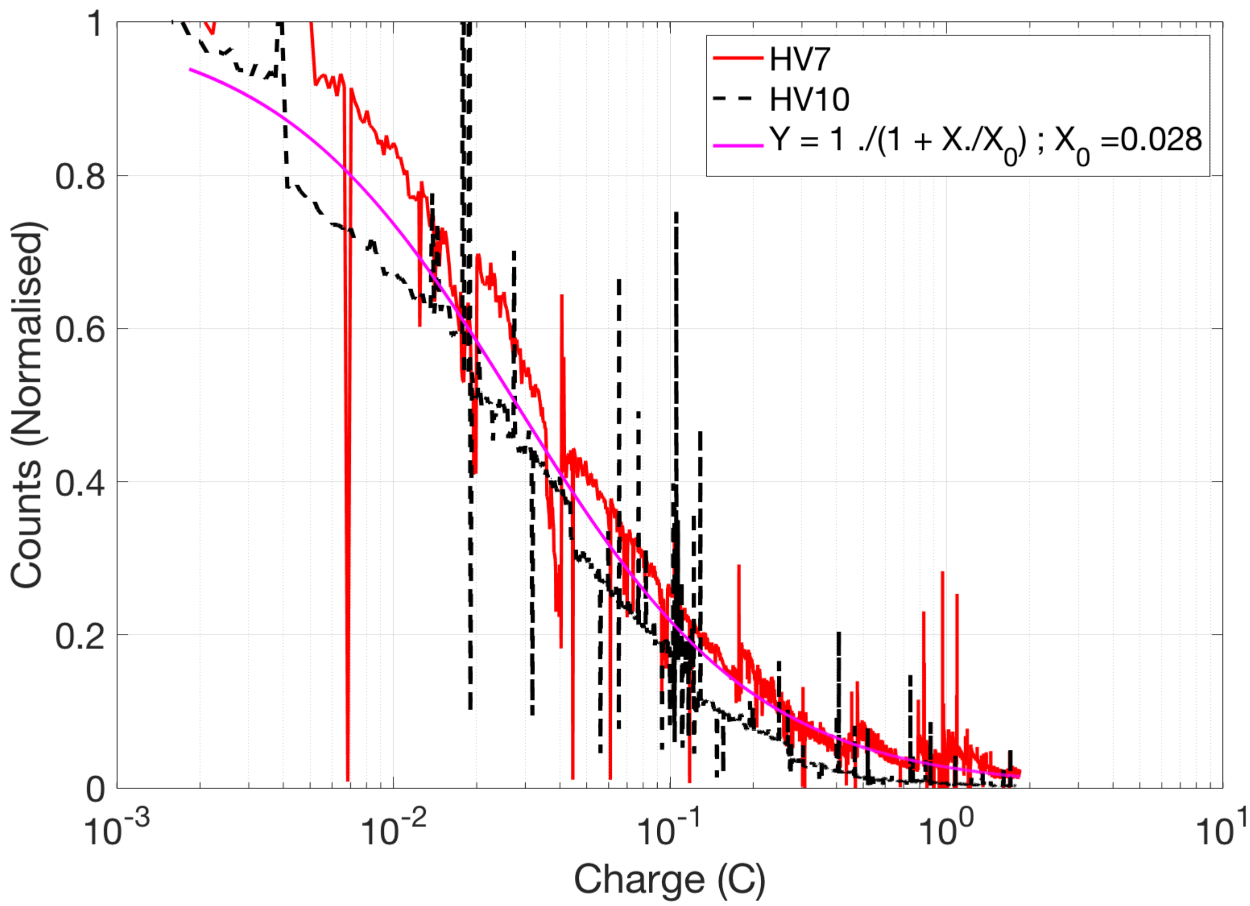


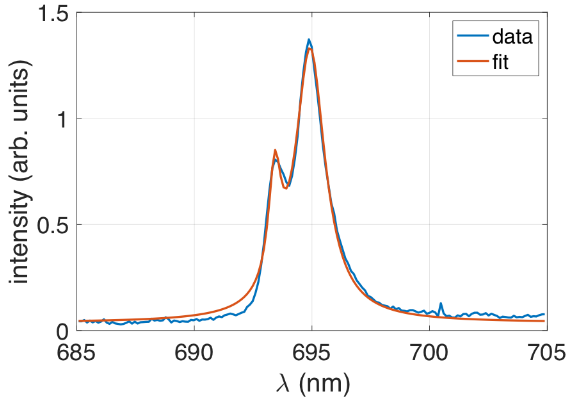
Image and Spectrum during irradiation



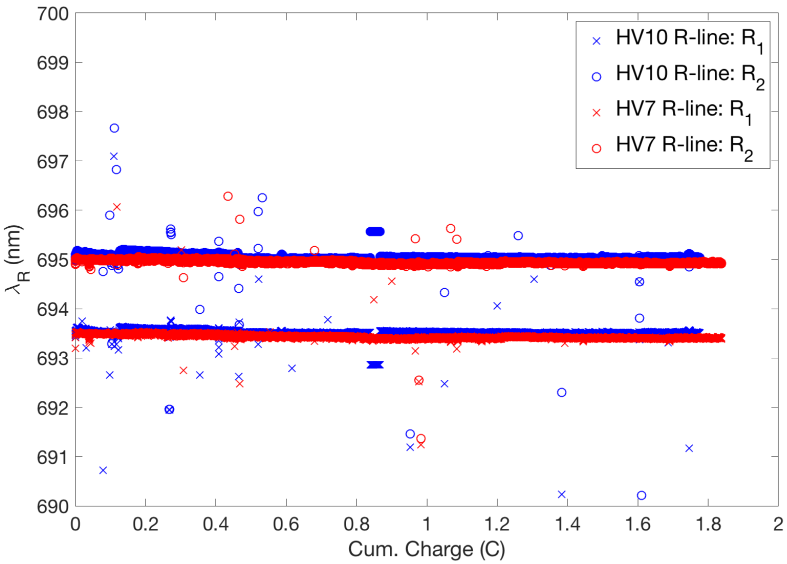


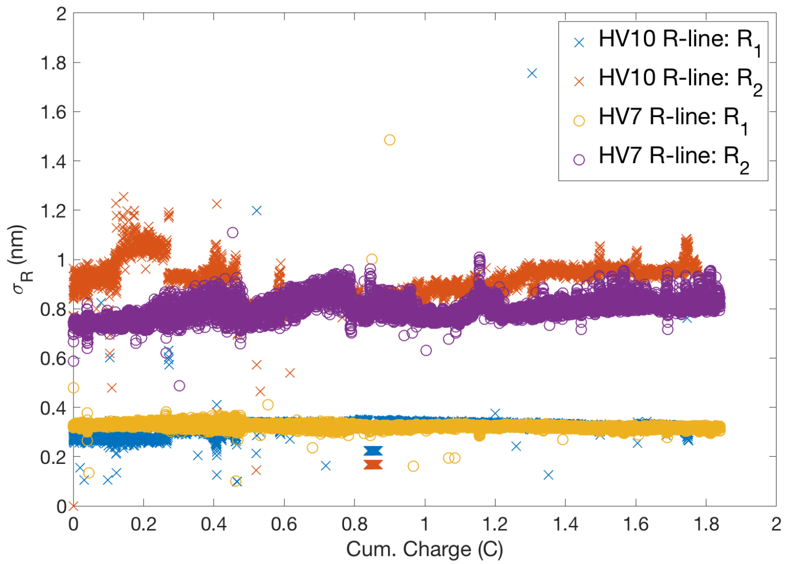
Counts (Normalised)
Charge (C)
HV7
HV10
Y = 1 ./(1 + X./X0) ; X0 =0.028
1
0.8
0.6
0.4
0.2
0
10-3
10-2
10-1
100
101

DPA= 0.09



Fit with 2-Lorentz





Next Possible Luminescent Materials for High Power Beams

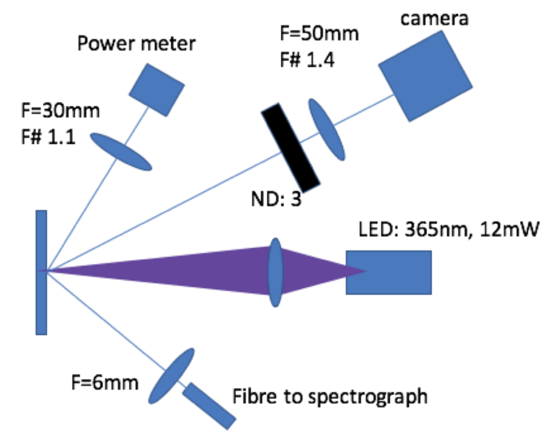
- Yttrium base luminescent materials:
  - High luminescent yield (literature)
  - Used at high temperature (literature: Y_2WO_6)
  - Potential for reduction and developing of extra spectral lines (O lines), used for imaging when main lines have decayed

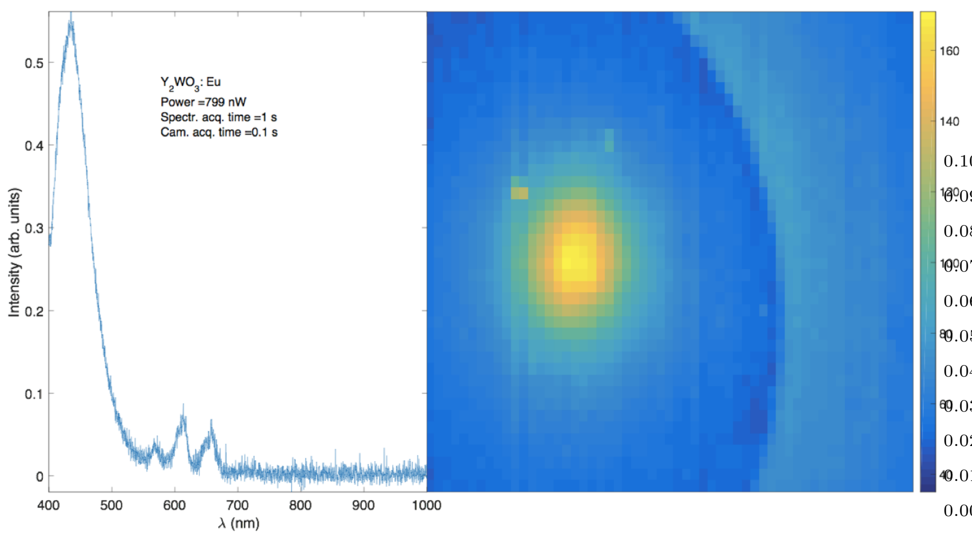
- Y_2WO_6 doped with lanthanides:
  - Prepared at ESS, luminescence characterised (Yield)
  - Next steps are to spray and irradiate the material

Initial results with doped Y_2WO_6:

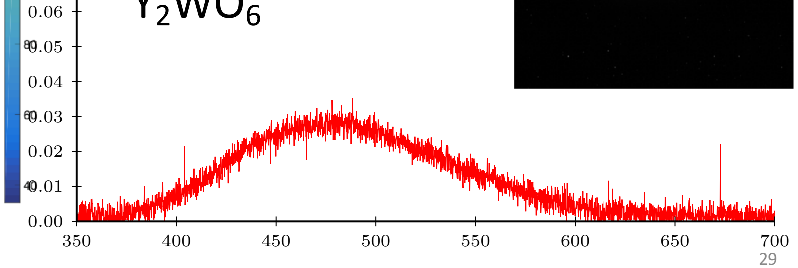
- Photo-luminescence
- XDR
- Proton luminescence

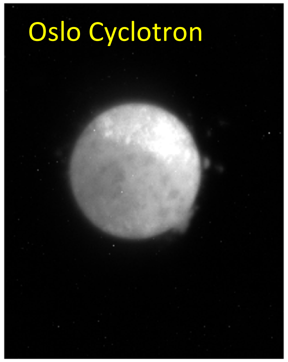
Y2WO6 :	Er	Eu	Nd	La	Pr	Sm
Power (nW)	982	799	692	898	913	981
Yield	1,8%	1,4%	1,2%	1,6%	1,6%	1,8%





Y_2WO_6





Concluding Remarks

Progress understanding the only qualified material for high power beam on spallation target:

- The material for the first target has been selected, it is Al_2O_3:Cr, powder from Broadman, and the production method will be combustion coating
- Plasma coated sample have been studied, they reproduce the performance of the SNS combustion coated sample;
  - yield is comparable
  - Decay time is similar, and for a moving target and rastered beam it can be an issue
  - Irradiation with protons shows similar degradation, but the post irradiation examination remain to be done
- Many more material could be use, offering better performance, however, they need to be studied and qualified in the target environment

Many thanks to all the collaborators in this project,

H. Gjersdal, E. Adli, *et al* from U. of Olso

S. Joshi *et al*, U. West

T. Shea, M. Hartl *et al* from ESS

M. Jensen from DTU

Thank you for your attention