Scintillation Screen Investigations for High Energy Ion Beams at GSI

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Abstract

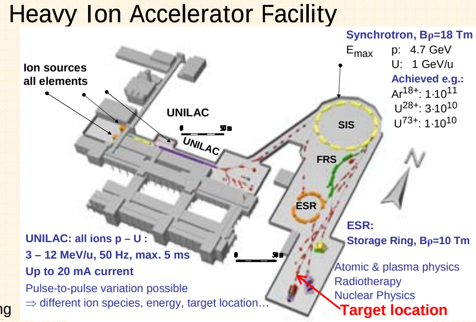
Various scintillation screens were irradiated with high energy ion beams as extracted from the GSI synchrotron SIS18. Their imaging properties were studied with the goal to achieve a precise transverse profile determination. Scintillation images were characterized with respect to the light yield and statistical moments. To study the scintillation properties over a wide range of intensities a 269 MeV/u Uranium ion beam with 10^4 to 10^9 particles per pulse was applied as well as a 296 MeV/u Carbon beam. Sensitive scintillators, namely CsI:Tl, YAG:Ce, P43 and Ce-doped glass were investigated for lower beam currents. Ceramics like Al_2O_3, Al_2O_3:Cr, ZrO_2:Y and ZrO_2:Mg as well as Herasil-glass were studied. For the various screens remarkable differences have been observed, e.g. the recorded profile width varies by about ±30 %.

GSI Heavy Ion Accelerator Facility

The existing facility:
- LINAC build in the 70th
- SIS in the 90th
- further upgrades in preparation for FAIR
- Serve as injector for FAIR for high current operation

Detailed investigations:
- C at 296 MeV/u
- Ar at 292 MeV/u
- U at 269 MeV/u

Beam energy after passing vacuum window and current measurement devices



Standard Screen Realization

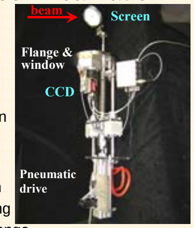
Advantage:
- Cheap device
- Direct 2-dim image
- Suited for all beams
- Single pulse operation

Requirement:
- Undistorted image
- Prevent for saturation
- Prevent light scattering
- Very large dynamic range

⇒ **detailed target investigations required**

Foreseen at FAIR at ≈ 40 locations

Dedicated workshop: www-bd.gsi.de/ssabd/index.html



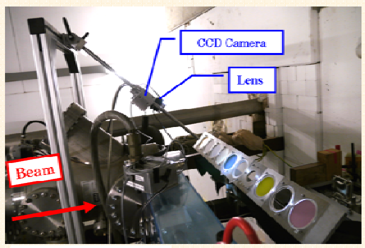
Investigated Materials

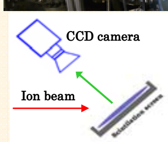
Type	Material	Supplier
Single Crystal	YAG:Ce CsI:Tl	Saint Gobain Crystals
Powder on Al	P43 (Gd_2O_2S:Tb) (layer of 50 μm)	Proxitronic
Ceramics	Al_2O_3 Al_2O_3:Cr (Chromox) ZrO_2:Y(Z700 20 A) ZrO_2:Mg (Z507)	BCE Special Ceramics
Quartzglass	Pure (Herasil 102) Ce doped (M382)	Heraeus Quartzglass

CCD: AVT Marlin F033C, images at different Uranium currents

Experimental Setup

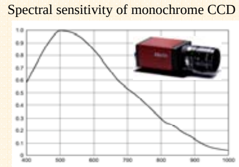
A stepping motor driven target ladder 1.20 m length for 10 screens of up to ∅80 mm
⇒ Observation without longer interrupts to ensure the same beam properties for all materials.





Camera: AVT Marlin F033B, VGA variable gain, FireWire interface
Lens: Pentax B2514ER, remote controlled iris for dynamic range
DAQ: RT-LabVIEW
GUI: C++, individual image storage

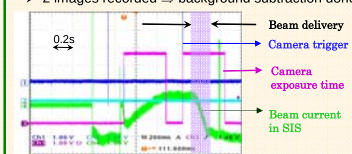
Spectral sensitivity of monochrome CCD

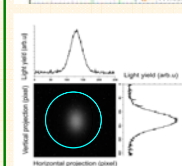


Planar arrangement → depth of focus
Investigation in air → cheaper realization
Normalization to beam current → Ionization chamber
→ Secondary Electron Emi. Monitor

Timing, Raw Data and Evaluation

Timing of experiment:
- Beam delivery typically 0.4 s
- 2 images recorded ⇒ background subtraction done





Single image:
- Fixed region-of-interest
- Projection on axis
- Background subtraction on projection
- Integration → light yield
- Gaussian fit
- Statistical moments variance σ & kurtosis κ

$$\kappa = -3 + \frac{1}{\sum p_i} \cdot \sum p_i \cdot \left(\frac{x_i - \mu}{\sigma}\right)^4$$

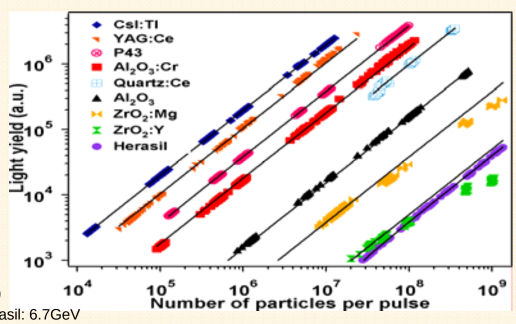
Result: Light Yield for Uranium Impact

4 orders of magnitude different light yield:
- Most sensitive: CsI:Tl, YAG:Ce, P43, Al_2O_3:Cr
- **Very linear behavior for CsI:Tl, YAG:Ce, P43, Al_2O_3:Cr, Al_2O_3**
- Insensitive: Herasil, ZrO_2:Y
- Non-linear behavior for ZrO_2:Y and ZrO_2:Mg

Evaluation done by image integration ⇒ within CCD spectral range

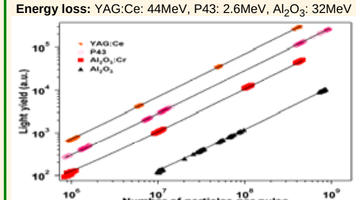
Boundary for the range of number of particles:
- Lower current boarder given by camera threshold level
- Upper current boarder given by camera saturation

Beam: Uranium 269 MeV/u, 10^4 to 10^9 ppp, 300 ms spill
(269 MeV/u after traversing windows & detectors, 300 MeV/u accelerated)
Energy loss per ion: YAG:Ce: 10GeV, P43: 0.7GeV, Al_2O_3: 7.9GeV, Herasil: 6.7GeV



Light Yield for Carbon Impact

Beam: C^{6+} 296 MeV/u, 10^6 to 10^9 ppp, 400 ms spill
Energy loss: YAG:Ce: 44MeV, P43: 2.6MeV, Al_2O_3: 32MeV



Result: YAG:Ce most sensitive
Same relative behavior between materials
Linearity of light yield of 3 orders of mag.

Result: Image width for Uranium Impact

Quite different distributions measured:
- Significant overestimation for CsI:Tl and YAG:Ce
- **Same profile reading for P43, Al_2O_3:Cr and Al_2O_3**
- Underestimation for Herasil, ZrO_2:Mg and possibly Quartz:Ce
- Wrong reading for ZrO_2:Y
- Same tendency for other methods of width determination

Conclusion:
- **P43, Al_2O_3:Cr (Chromox) and Al_2O_3 are good candidates**
- More investigations required for CsI:Tl and YAG:Ce e.g. concerning neutron background or absorption + re-emission
- Herasil not useful (confirmed by previous investigations)
- **BUT:** not all materials reproduce a Gaussian shape!

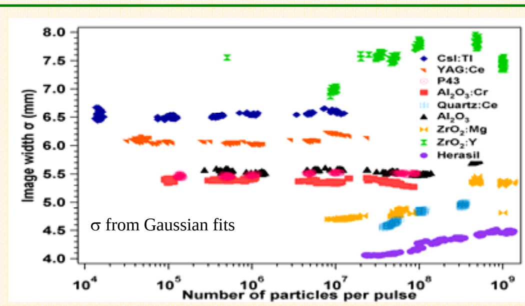
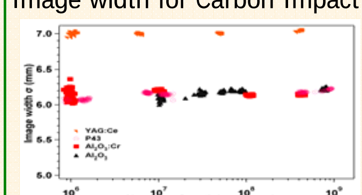


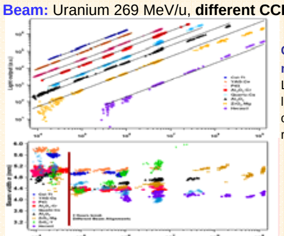
Image width for Carbon Impact



Result: YAG:Ce overestimate beam width
Same profile reading for P43, Al_2O_3:Cr and Al_2O_3 on entire range

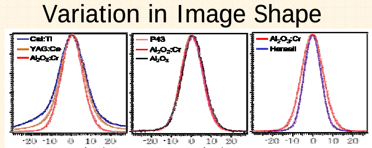
2nd meas. for Uranium Impact

Beam: Uranium 269 MeV/u, **different CCD setting**



Comparable results!
Light yield linear over large range

Variation in Image Shape



Features:
- CsI:Tl and YAG:Ce produces shoulders
- P43, Al_2O_3:Cr, Al_2O_3 have same distribution
- Herasil produces too small images
- Typical behavior, but Physical reason not understood

Relative Light Yield

Y_{rel}: yield relative to YAG:Ce

Result: Same 'high score' for U and C
Yield per ion: $Y_U/Y_C \approx 120$

Scintillator	Uranium Y_{rel} (%)	Carbon Y_{rel} (%)
CsI:Tl	180	
YAG:Ce	100	100
P43	34	38
Al_2O_3:Cr	15	15
Al_2O_3	1.4	1.7
Quartz:Ce	8.3	
ZrO_2:Mg	0.35	
ZrO_2:Y	0.048	
Herasil	0.035	

Planned: Meas. with different ions

Summary and Outlook

- Light yield of various materials investigated
- Different values of the profile width for various materials, even for 'well known' scintillators
- The described behavior is reproducible
- Ongoing data analysis with statistical moments to distinguish saturation ↔ self-absorption
- More beam-based test with different ions and energies foreseen for characterization
- Quantitative understand of behavior in preparation
- Spectroscopic investigation foreseen
- Determination of absolute light yield foreseen
- Test of radiation hardness required