SCINTILLATION AND OTR SCREEN CHARACTERIZATION WITH A 440 GEV/C PROTON BEAM IN AIR AT THE CERN HIRADMAT FACILITY

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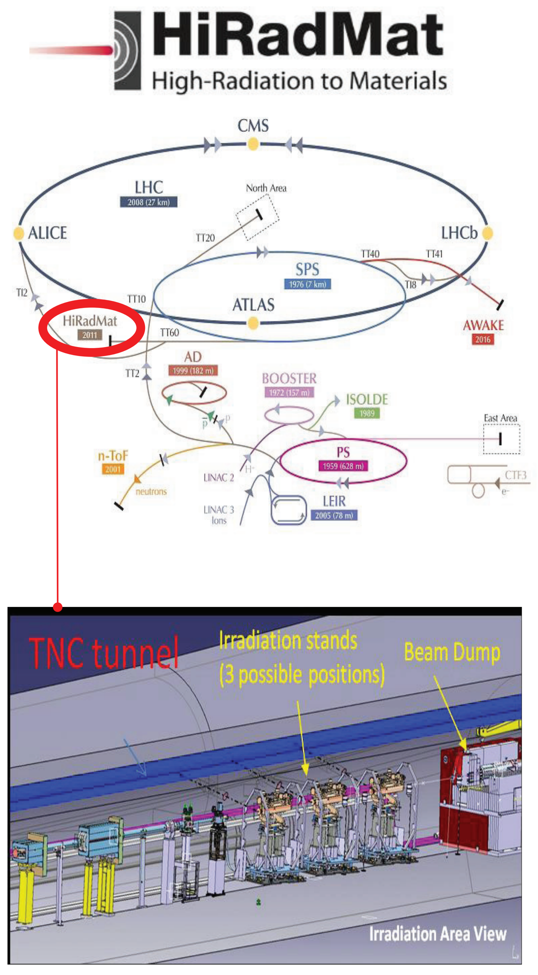
Abstract

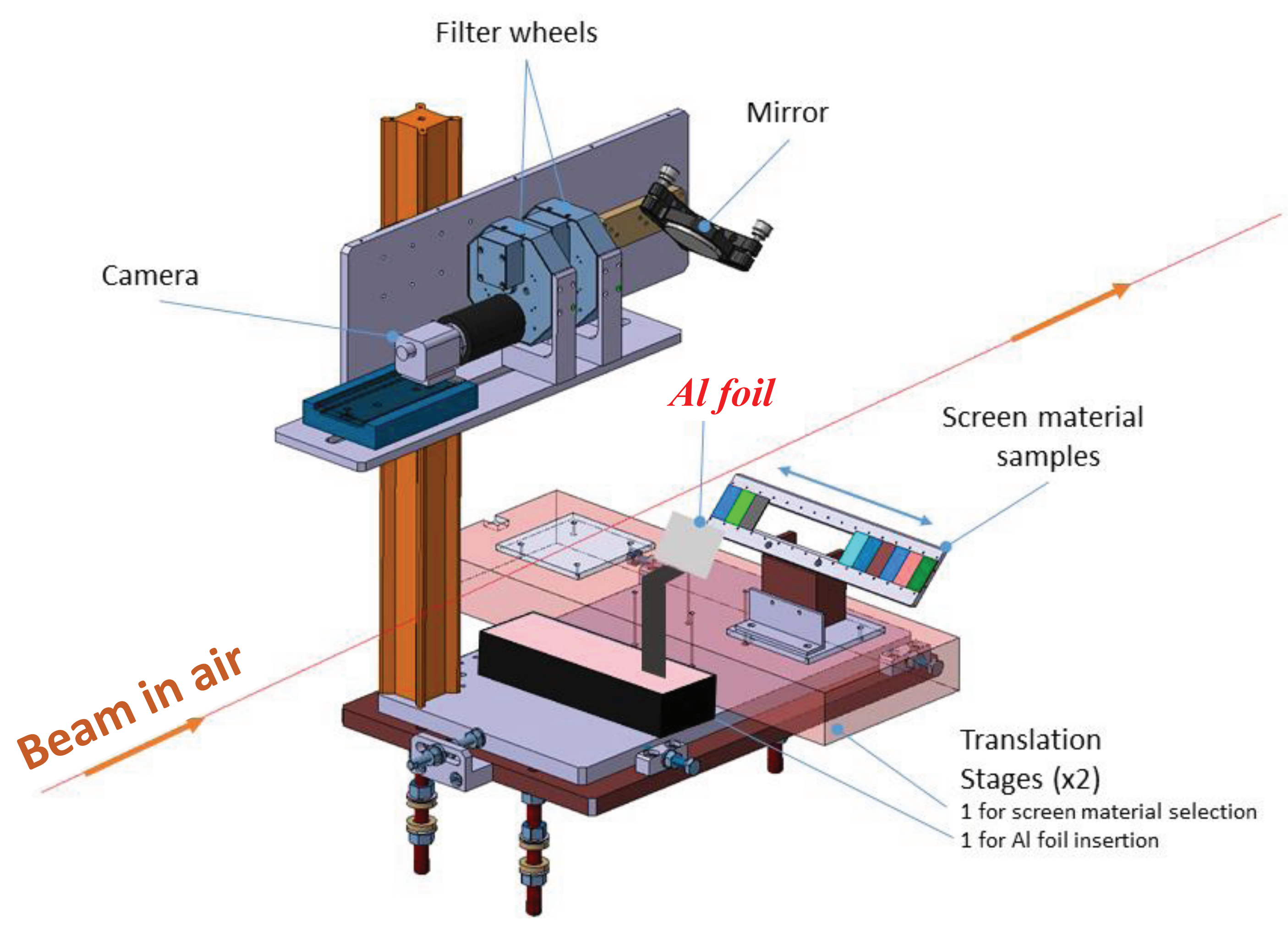
Beam observation systems, based on charged particles passing through a light emitting screen, are widely used and often crucial for the operation of particle accelerators as well as experimental beamlines. The AWAKE experiment, currently under construction at CERN, requires a detailed understanding of screen sensitivity and the associated accuracy of the beam size measurement. We present the measurement of relative light yield and screen resolution of seven different materials (Chromox, YAG, Alumina, Titanium, Aluminium, Aluminium and Silver coated Silicon). The Chromox and YAG samples were additionally measured with different thicknesses. The measurements were performed at the CERN's HiRadMat test facility with 440 GeV/c protons, a beam similar to the one foreseen for AWAKE. The experiment was performed in an air environment.

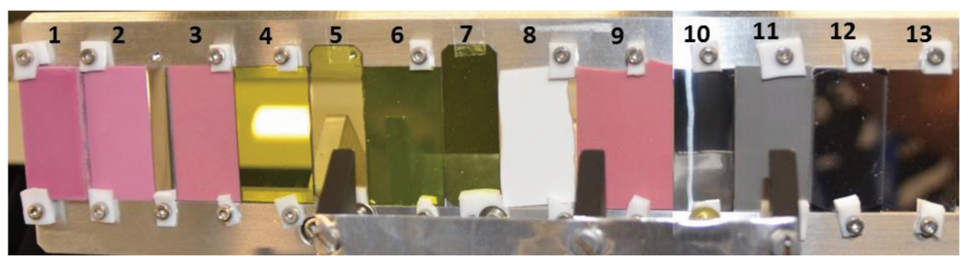
Experimental Setup



HiRadMat (High-Radiation to Materials) is a users facility at CERN, designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested.

HiRadMat beam specs	
Beam Energy	440 GeV
Pulse Energy	up to 3.4 MJ
Bunch intensity	3E9 to 1.7E11 p
Number of bunches	1 to 288
Maximum pulse intensity	4.9E13 p
Bunch length	11.24 cm
Bunch spacing	25, 50, 75 or 150 ns
Pulse length	7.2 µs
Minimum cycle length	18 s
Beam size at target	variable around 1 mm²





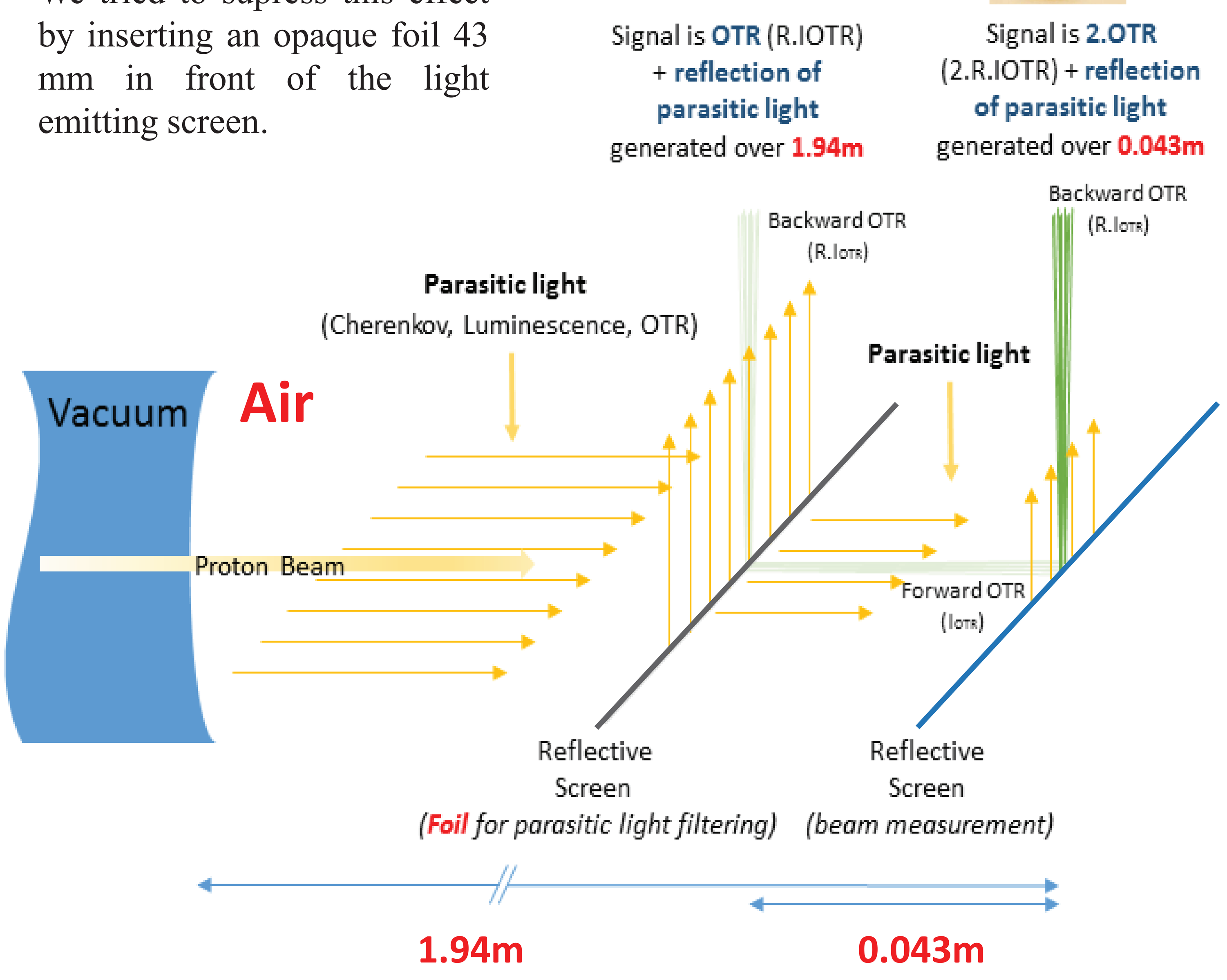
Screen materials installed for testing with a 440GeV/c p beam in air.

Screen Nr.	Material	Thickness [mm]	Supplier
1	Chromox (Al_2O_3:CrO_2)	3	CeraQUest
2	Chromox (Al_2O_3:CrO_2)	1	CeraQuest
3	Chromox (Al_2O_3:CrO_2)	0.5	CERN stock
4	YAG (YAG:Ce)	0.5	Crytur
5	YAG (YAG:Ce)	0.1	Crytur
6	YAG Al back-coated (YAG:Ce + Al)	0.5	Crytur
7	YAG back-coated (YAG:Ce + Al)	0.1	Crytur
8	Alumina (99% purity)	1	GoodFellow
9	Chromox-old type (Al_2O_3:CrO_2)	1	CERN stock
10	Aluminium	1.	CERN stock
11	Titanium	0.1	GoodFellow
12	Aluminium coated Silicon	0.25	MicroFabSolutions
13	Silver coated Silicon	0.3	Sil'Tronix

Theoretical Aspects

Cherenkov and luminescence processes are considered as parasitic light that add, by reflection on the screen, to the scintillating or OTR light generated by the screen itself.

We tried to supress this effect by inserting an opaque foil 43 mm in front of the light emitting screen.



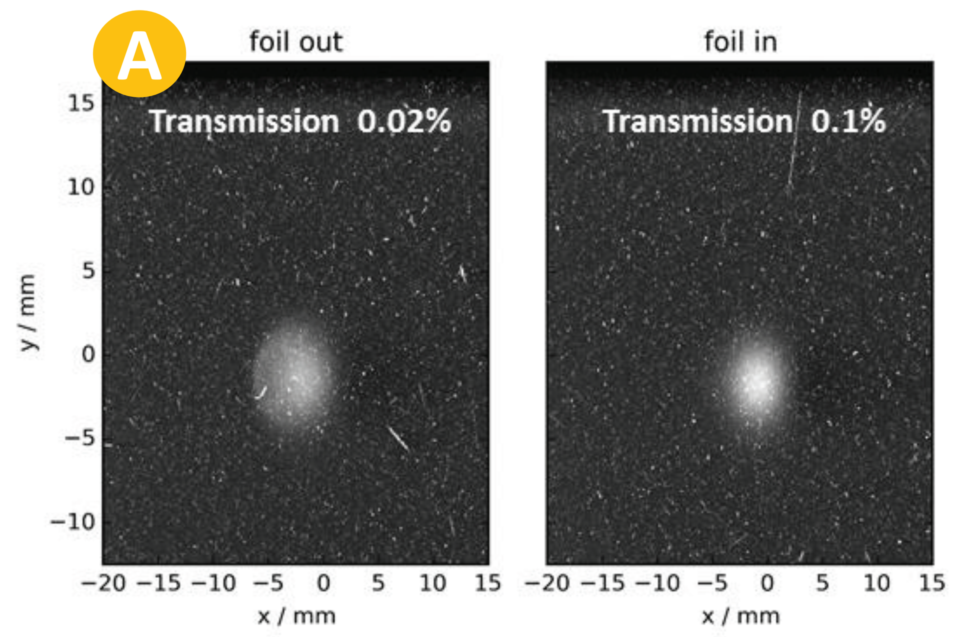
Layout of the different light emission processes included in the screen measurements. The foil inserted before the beam screen blocks the parasitic light generated upstream in the air but itself generates forward OTR that reached the measurement screen.

	Without Foil	With Foil
Path length of protons ***in air***	1.94 [m]	0.043 [m]
Number of photons	**N**	**N_f**
N_{OTR} (protons on screen)	2.98E-2	2.98E-2
NCherenkof (protons in air)	**4.266**	**1.132**
N_{Lu} (protons in air)	6.60E-2	1.23E-04
Total	$N_{OTR}+N_{Ch}+N_{Lu}$	$2xN_{OTR}+Nf_{Ch}+Nf_{Lu}$
Ntotal	4.36E+00	1.19E+00
N/Nf	3.66E+00	

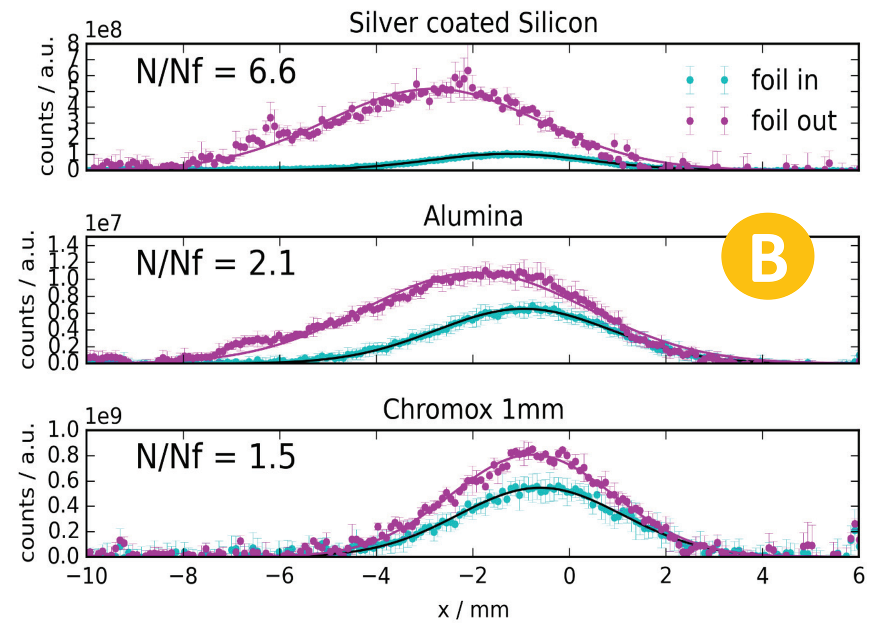
→ ***In air, the main light contributor is from Cherenkov emission, even limiting the path to 43mm.***

Results

Analysis process: After subtracting the background, the pixels are integrated over the vertical axis, resulting in an integrated horizontal profile. We normalized the image with respect to the beam intensity and choice of filter. The data shown in figure C below represent the mean (marker) and standard variation (error bar) of each pixel column. Finally, a Gaussian fit is performed, which gives the relative yield and measured beam sigma, shown both in figure D.

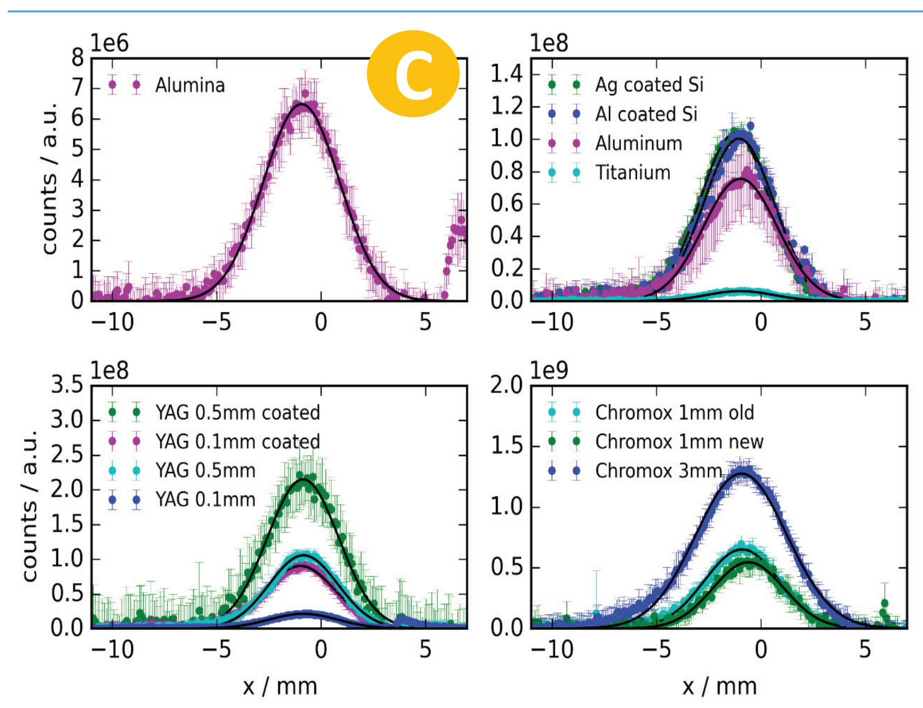


Example of raw images of the proton beam in air on a Silver coated Si OTR screen without (left) and with (right) blocking foil in place.

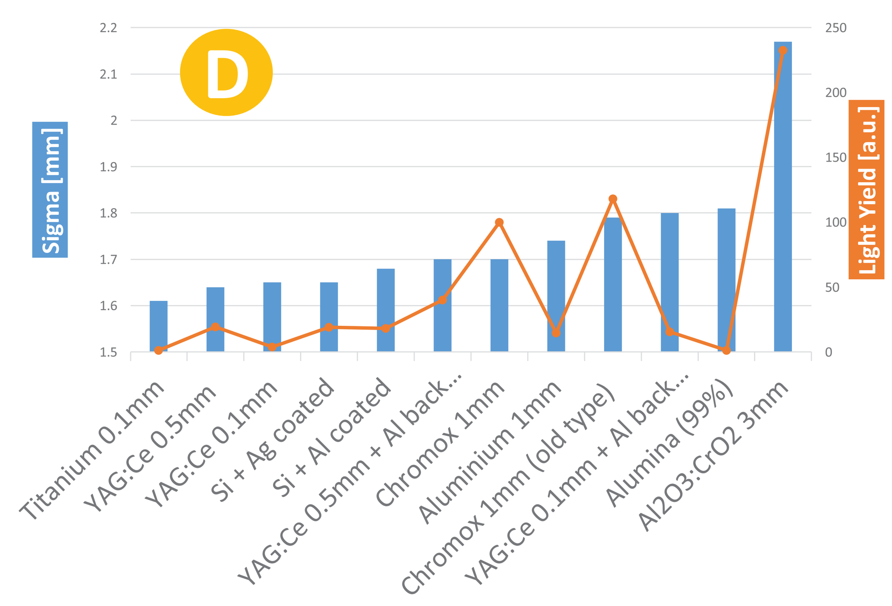


Results of the beam profile measurement showing the response of the silver coated silicon, Alumina and Chromox screens with and without blocking foil.

Figures A and B show that the main differences between blocking foil in and out are the lower light yield and reduced sigma of the Gaussian fit. Additionally the centre of the Gaussian shifts for the silver coated silicon and alumina screens. We explain this difference in yield and sigma by the contribution of the parasitic light, which is considerably reduced with the blocking foil in. The shift of the centre of the Gaussian is not yet understood, but we suspect this to be due to a change in the reflectivity and/or the diffusivity of the material combined with errors in the alignment of the optical line.



Results of beam profile measurements showing the response of all screens listed in table 1 with a foil blocking the parasitic light installed 43mm upstream.



Light yield and sigma measured on each screen with a foil positioned 43mm upstream to block part of the parasitic light.
Yield values are referenced to a 1mm thick Chromox screen as it is commonly used in many of the CERN beam observation systems.

As shown in figure C and D, the 3 mm thick Chromox screen gives both the highest yield and the largest beam size due to its thickness. Due to their high reflectivity the OTR screens (except for titanium) have a yield only a few times lower than scintillating material, which for comparison is 3 orders of magnitude difference in vacuum. The best resolution was obtained by the Titanium screen, probably due to its diffusive aspect and low reflectivity. Titanium additionally has the lowest light yield.

Conclusions

The light emission from a proton beam of 440 Gev/c in air was measured for three scintillators (Alumina, Chromox and YAG) of different thicknesses and four OTR emitting screens (Ag coated Si, Al coated Si, Ti and Al). A light blocking foil was inserted to reduce the contribution of parasitic light created upstream of the target material. Nevertheless, the majority of the photons observed due to Cherenkov light generated as the relativistic proton beam passes through the air in front of the screen. The conclusion is therefore that no precise OTR vs scintillator light yield and subsequent resolution studies can be performed with this data. Future studies under vacuum are thus foreseen to better asses these questions.

However, these set of measurements represent an extremely useful reference for setting up a beam imaging system in air.