MICROMETEOROID FOCUSSING IN X-RAY OPTICS - STATUS REPORT

Institute for Space Systems (IRS), Univ. Stuttgart - Anna Mocker, Yanwei Li, Ben Hofmann, Ralf Srama
Etamax GmbH - Kalle Bunte, Anatoli Miller

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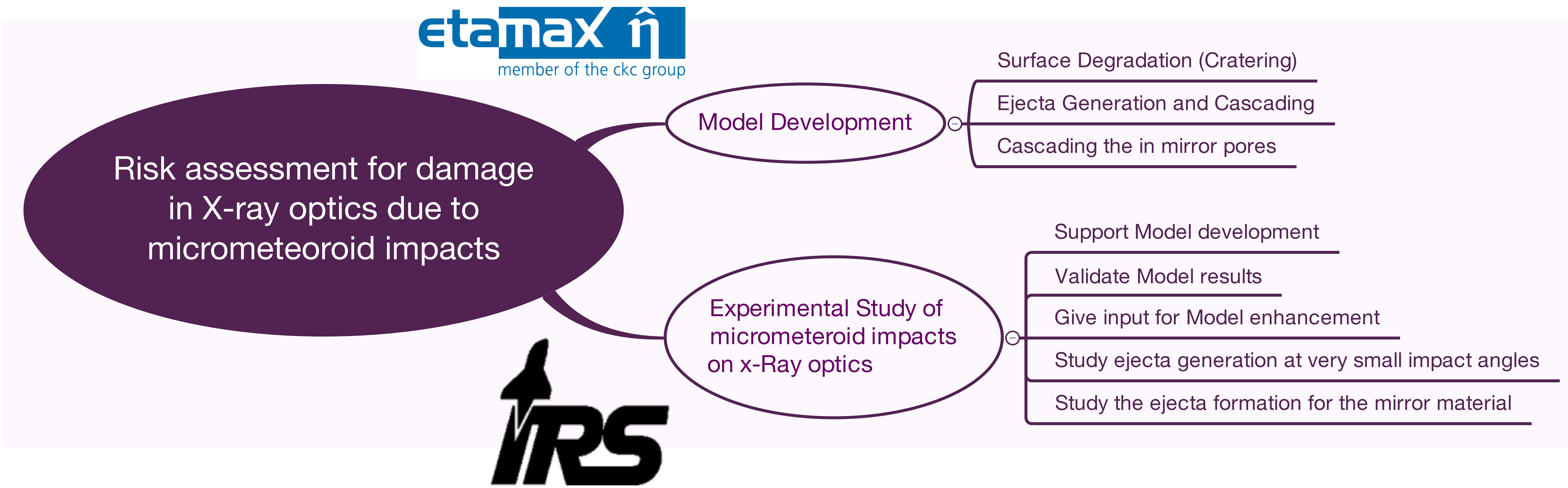
AGENDA

Overview
1) Objective and Scope of the Study
2) Background and Motivation
3) HVI impacts of µm-sized particl
4) Requirements for the experimental set up
5) Experimental set up
6) Test at the small accelerator with the DLD
7) Challenges and open questions

OBJECTIVE AND SCOPE OF THE STUDY

1 OBJECTIVE AND SCOPE OF THE STUDY



1 OBJECTIVE AND SCOPE OF THE STUDY

1. To investigate the scattering of representative dust particles and the ejecta generation upon HVI impacts on representative samples of the ATHENA mirror optics.

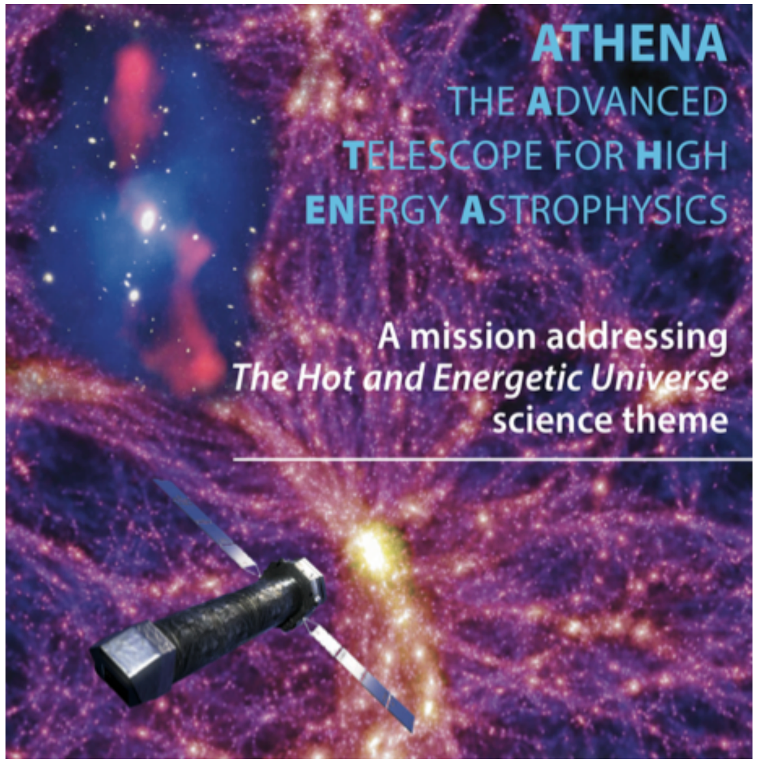
2. Analyzing the results and to derive a respective scattering model.

3. Derive a model for the scattering and the secondary particle generation for impacts of µm and sub-µm sized articles

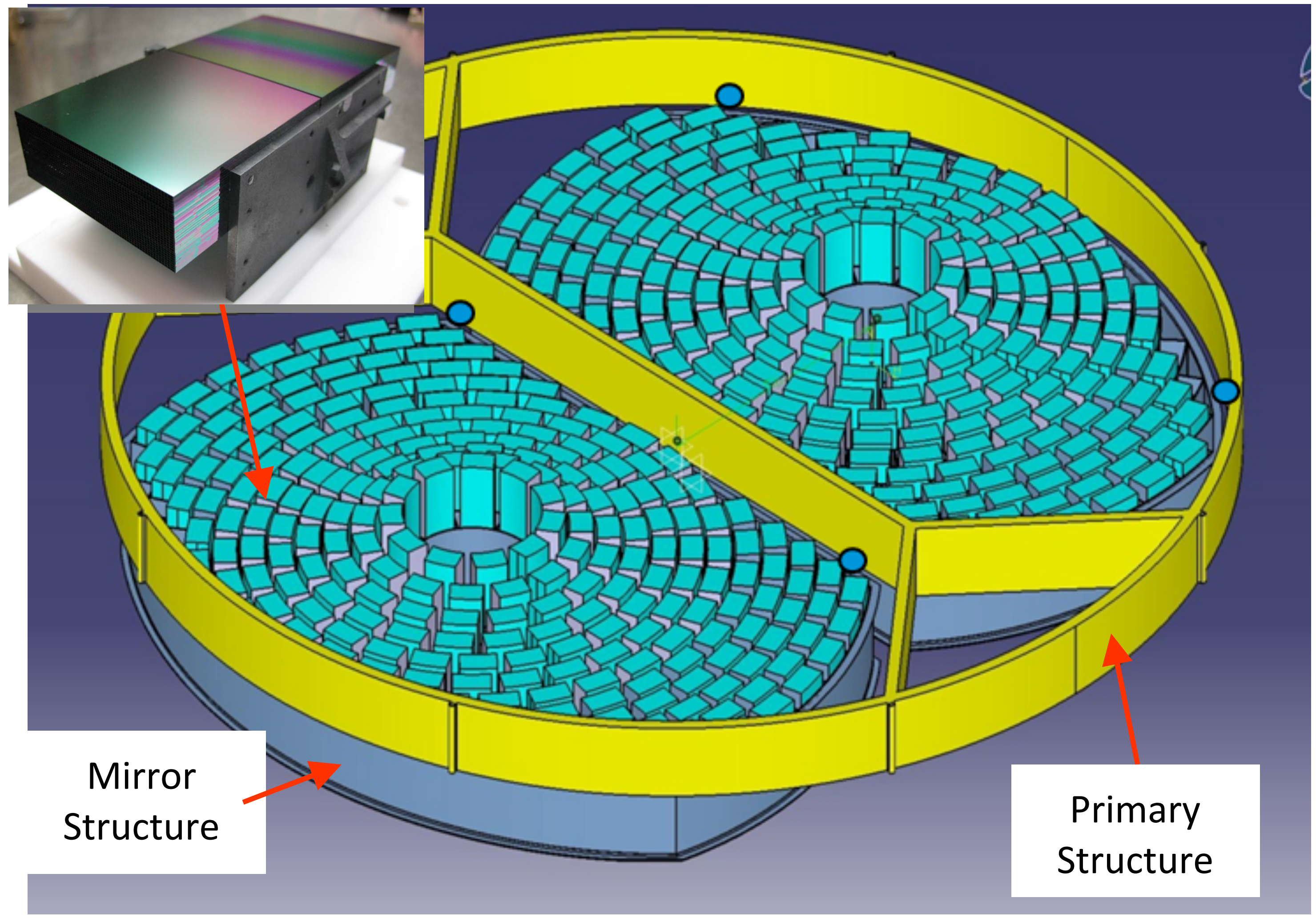
Experiment parameters, measured and derived values

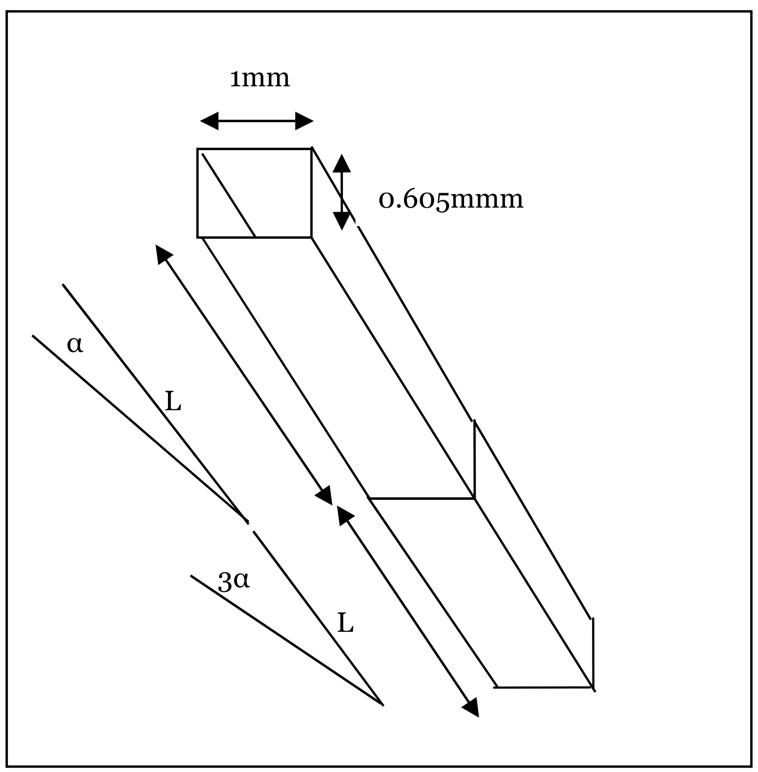
Model Input	Model Output
Impact velocity	Ejecta number
Impact angle	Ejecta velocity vector
Particle mass	Ejecta Mass
Particle density and material	*Crater size and shape*

BACKGROUND AND MOTIVATION



ATHENA is the next generation X-ray astronomy mission providing advanced x-ray imaging and spectroscopy





- ATHENA's x-ray optics are comprised of a large number of stacked individual Mirror Modules (MM).
- The mirror modules are composed by two connected stacks of silicon plates, consisting of a large number of individual pores. The two stacks approximate the parabola and hyperbola mirror segments as from the Wolter-I telescope design.
- A single pore consists of two sections with offset angles, allowing the light to be reflected at very small (grazing) angles. The path of light also defines a possible path for impacting µm-sized particles to reach and possibly damage the CCD.

2.1) BACKGROUND & MOTIVATION: ATHENA MISSION AND INSTRUMENT

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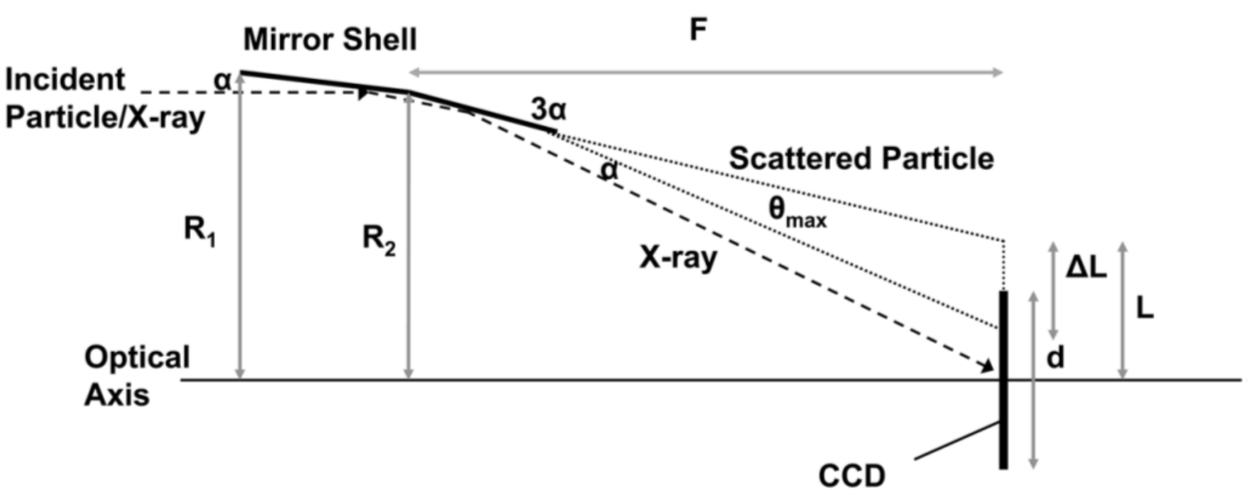


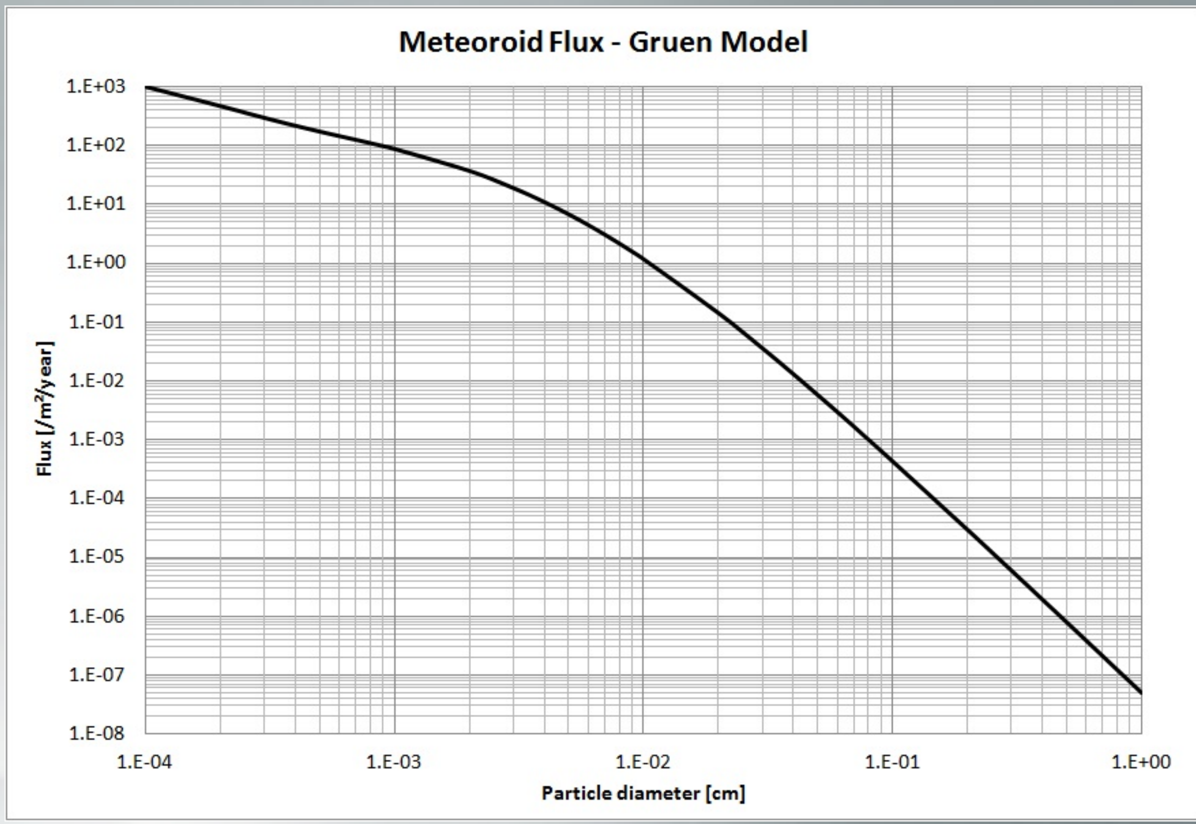
Issues:

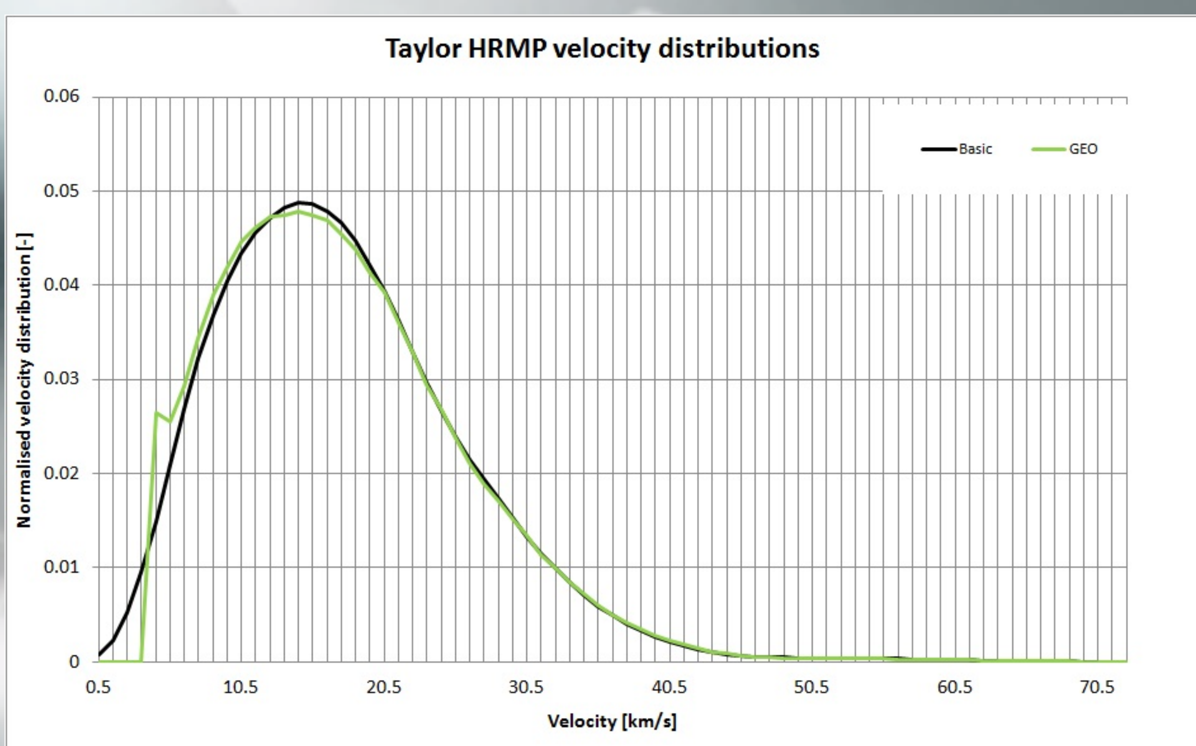
- Possible scattering of micrometeoroids impacting under very narrow incident angles through the mirror shells which then could reach and damage the CCD.
- Possible generation of secondary particles (ejecta) due to micrometeoroid impact in grazing angles onto the pore walls and even the formation of an exacta cascade. These ejecta could then again reach and damage the CCD.

2.2) BACKGROUND & MOTIVATION: MICROMETEOROID DAMAGE IN A PREDECESSOR MISSION (XMM-NEWTON)

Constituents of dust@ 1AU

	Interstellar Dust (ISD)	Interplanetary dust (IDP)	Space debris
Origin	Outside the SS	Asteroids, comets, moons and planets	Artificial
Composition	chondrites, silicates (i.e. pyroxene and olivine), metals (e.g. Fe/Ni), salts, ices, carbonates and phosphates		Metals, alloys etc.
relvant @ L2?	x	x	-





2.3) BACKGROUND & MOTIVATION: DUST @ 1AU

Particle flux:

- Flux is defined as number of intercepted objects per unit time and area: $$f = \frac{N}{A \cdot T}$$
- The dust environment at 1 AU is best described by the Grün model. It shows the significance to study especially the µ- and sub-µ-sized particles with the most probable encounter speed.

Particle velocities:

- The Taylor HRMP velocity distribution of interplanetary dust particles at 1AU distance is obtained with radio measurements of meteors impacting Earth's atmosphere.
- The maximum speed centers at roughly 15.5 kms^{-1}, The distribution is rather broad such that speeds between 6.5 kms^{-1} and 25 kms^{-1} dominate. For L2 orbits, the "basic" distribution is applicable.
- For the ATHENA trajectory the Earth shielding can be ignored as well as the gravitational focusing.

HVI IMPACTS OF µm-SIZED PARTICLES

3.1) HVI IMPACTS OF µm-SIZED PARTICLES: WHAT HAPPENS UPON IMPACT?

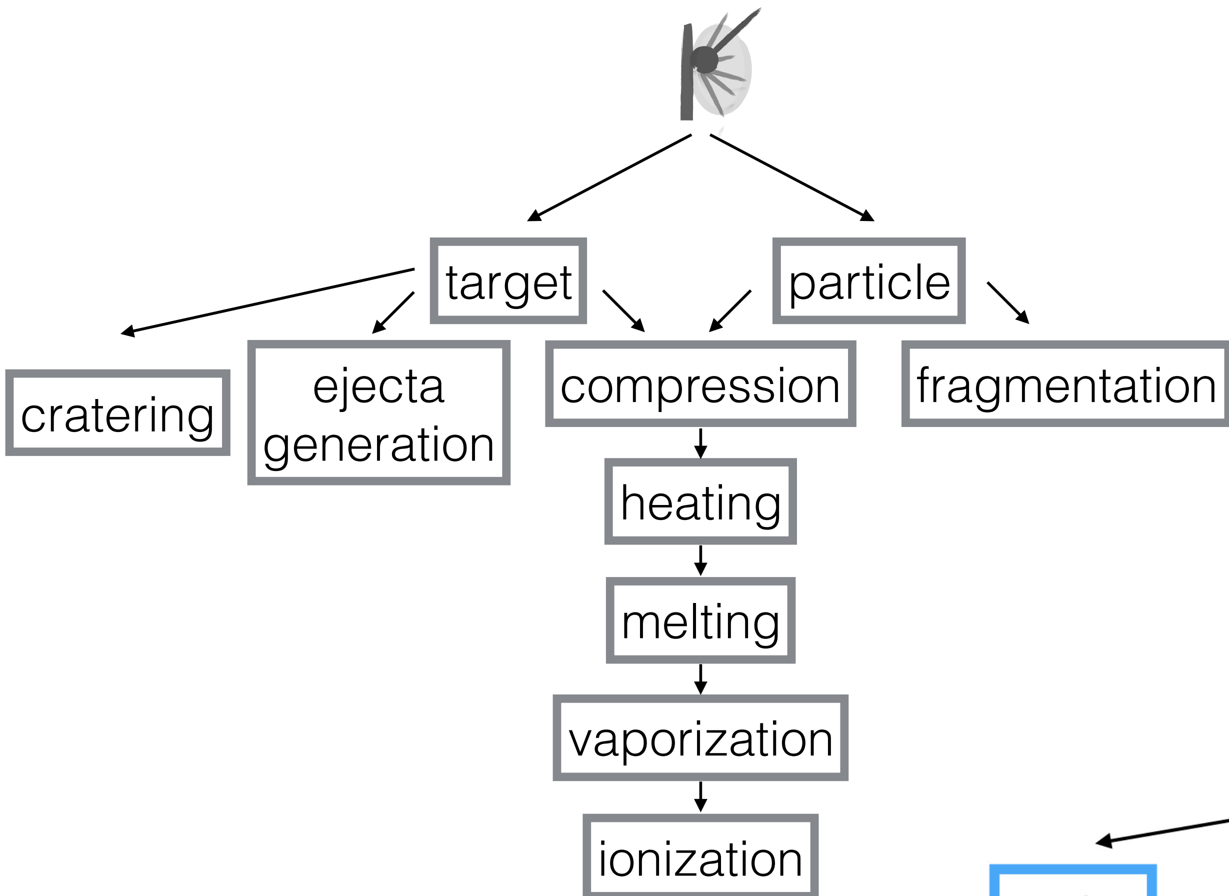
HVI:

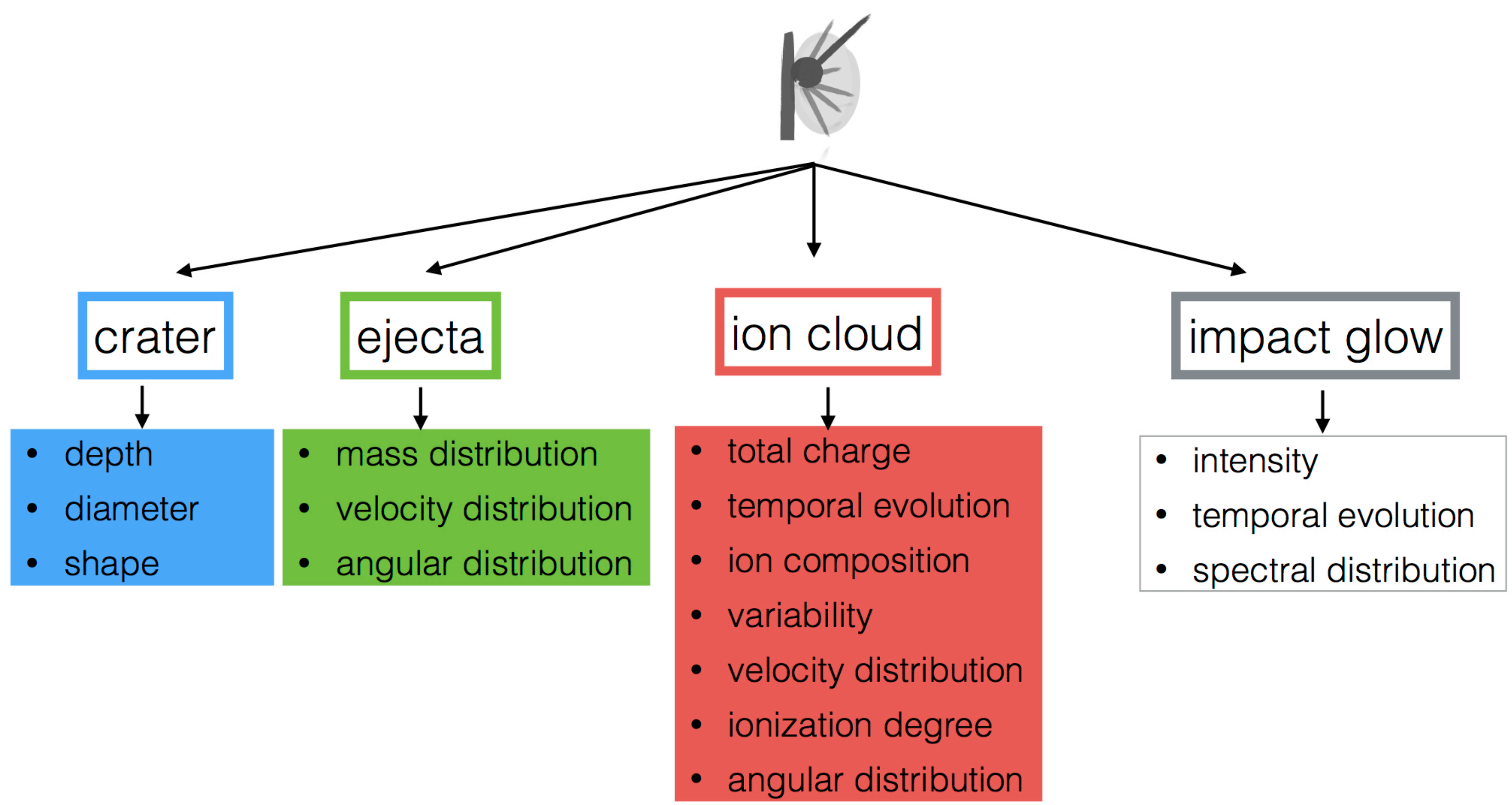
- Impacts at velocities exceeding the speed of sound within the materials in question.
- The impact speed is so high, that the strength of materials upon impact is very small compared to inertial stresses, leading the material to behave like fluids under the impact.

1. A fast particle impacting a solid surface causes mechanical stress in the particle and the target body, generating compression and even shock waves depending on the impact velocity.
2. Subsequently the particle and the affected target area are compressed to high pressures and temperatures.
3. For strong shocks ($v_{imp} > 10$ kms^{-1}), the specific internal energy gained by the system due to the strong shock depends only on the impact speed v and the ratio of particle (ρ_p) and target material (ρ_t) densities:

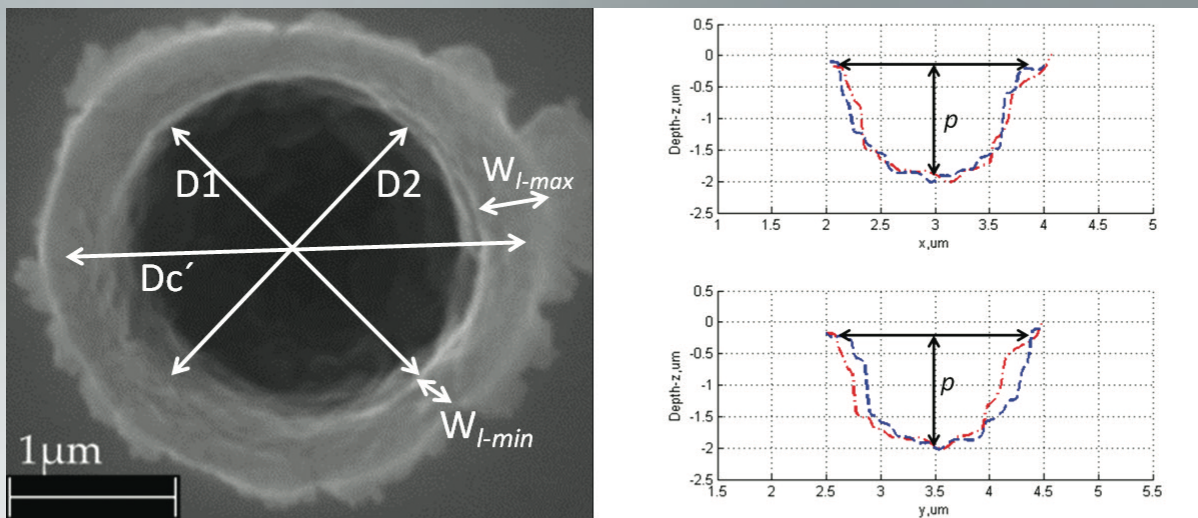
$$\Delta\epsilon \approx 1\,/\,2\left(\sqrt{\rho_p\,/\,\rho_t} + 1\right)^{-2} \cdot v^2$$

3.1) HVI IMPACTS OF µm-SIZED PARTICLES: PARTITION OF ENERGY AND OBSERVABLE PHENOMENA

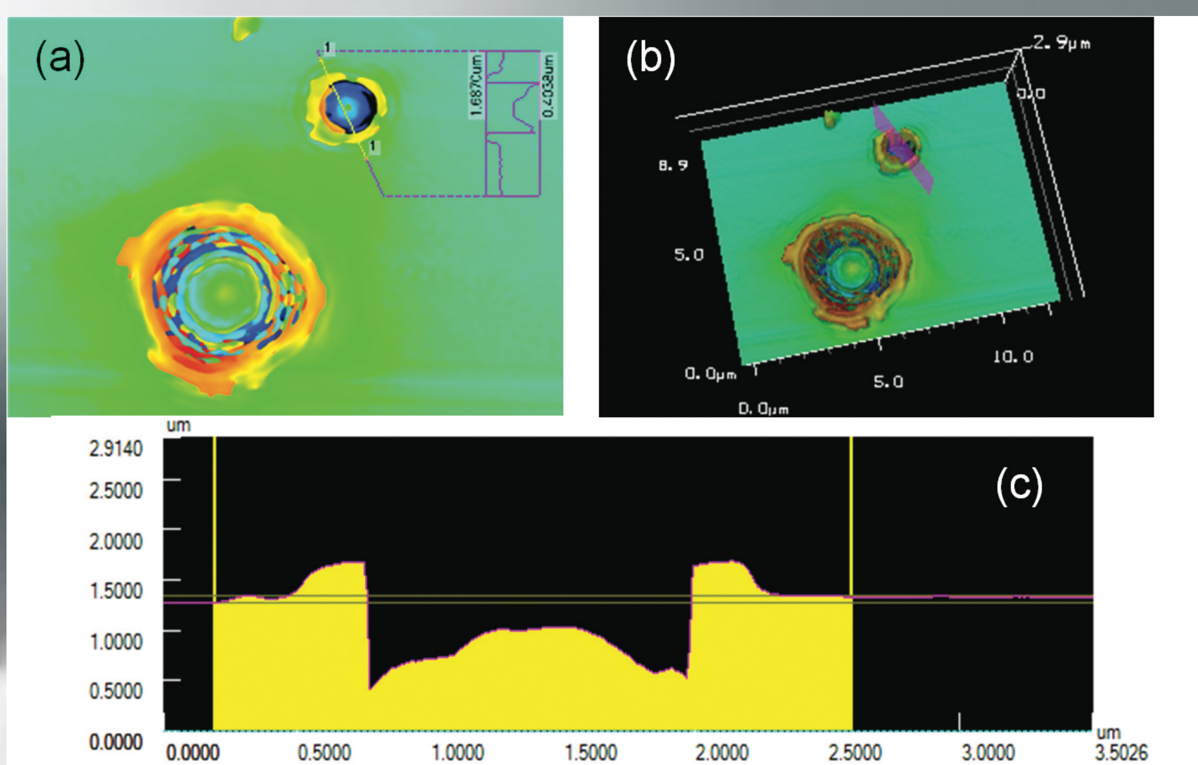




3.1) HVI IMPACTS OF µm-SIZED PARTICLES:
Cratering and degradation of the surface



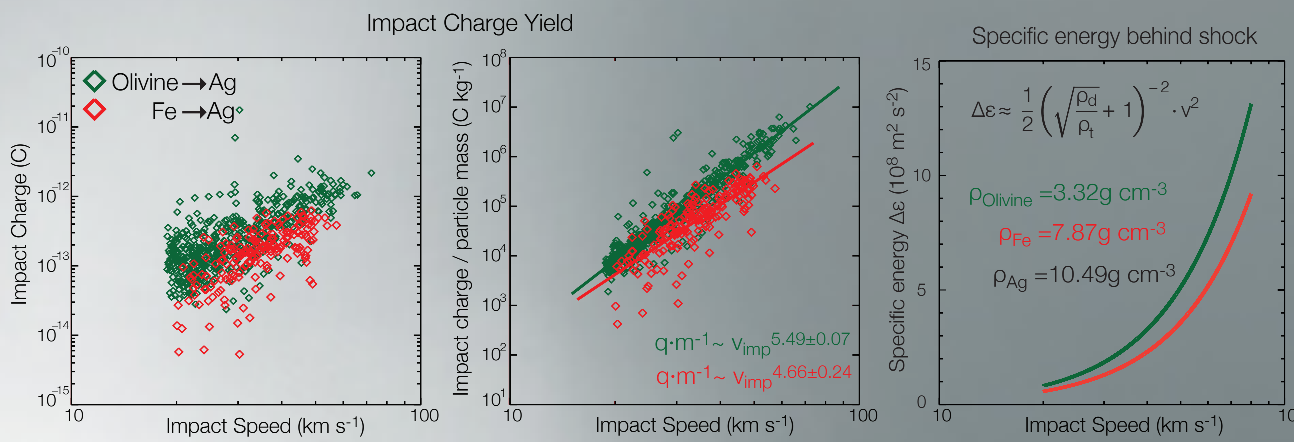
Characterization of a crater created by the impact of an iron particle onto an aluminum target at 5 km s^{-1} with a SEM image.



3D laser microscope images of micron sized craters

- The damage depends heavily on the particle and target material, the projectile shape, the impact speed and the impact angle and orientation.
- Cratering is characterized by the depth and shape of the craters in dependence on the impact parameters.
- The properties of the craters can be evaluated with Electron Microscopy, EDX analyses, optical microscope or 3D laser microscope.

3.1) HVI IMPACTS OF µm-SIZED PARTICLES: ION GENERATION AND IMPACT GLOW



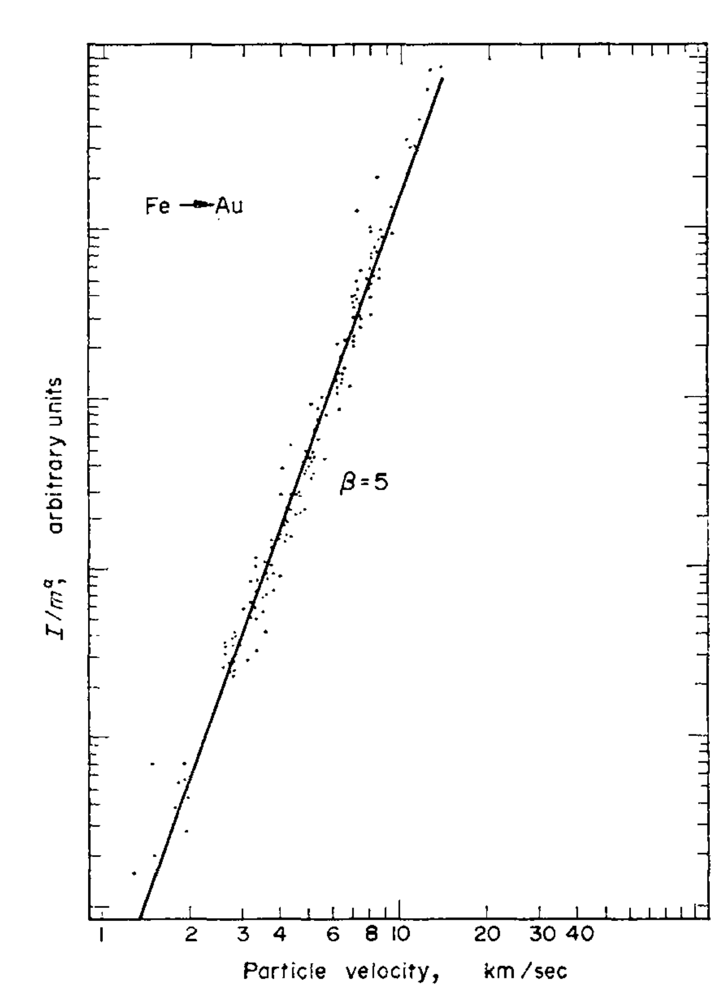


FIG. 6(a). INTENSITY OF THE FIRST PEAK NORMALIZED TO THE PARTICLE MASS AS A FUNCTION OF THE PARTICLE VELOCITY.

Eichhorn 1975

- The charge generated during an impact is a function of both particle mass and speed, describable by a power law:

$$Q=k \cdot m^{\alpha} \cdot v^{\beta},$$

with $\alpha \approx 2/3$ for $v_{imp} < 10 kms^{-1}$ and $\alpha \approx 1$ for $v_{imp} \gg 10 kms^{-1}$.

- The relation between the light intensity I and the energy E of the flash in visible light with the particle mass m, and the impact velocity v can be described as

$$I=c_1 \cdot m^{\alpha 1} \cdot v^{\beta 1} \text{ and}$$

$$E=c_2 \cdot m^{\alpha 2} \cdot v^{\beta 2}.$$

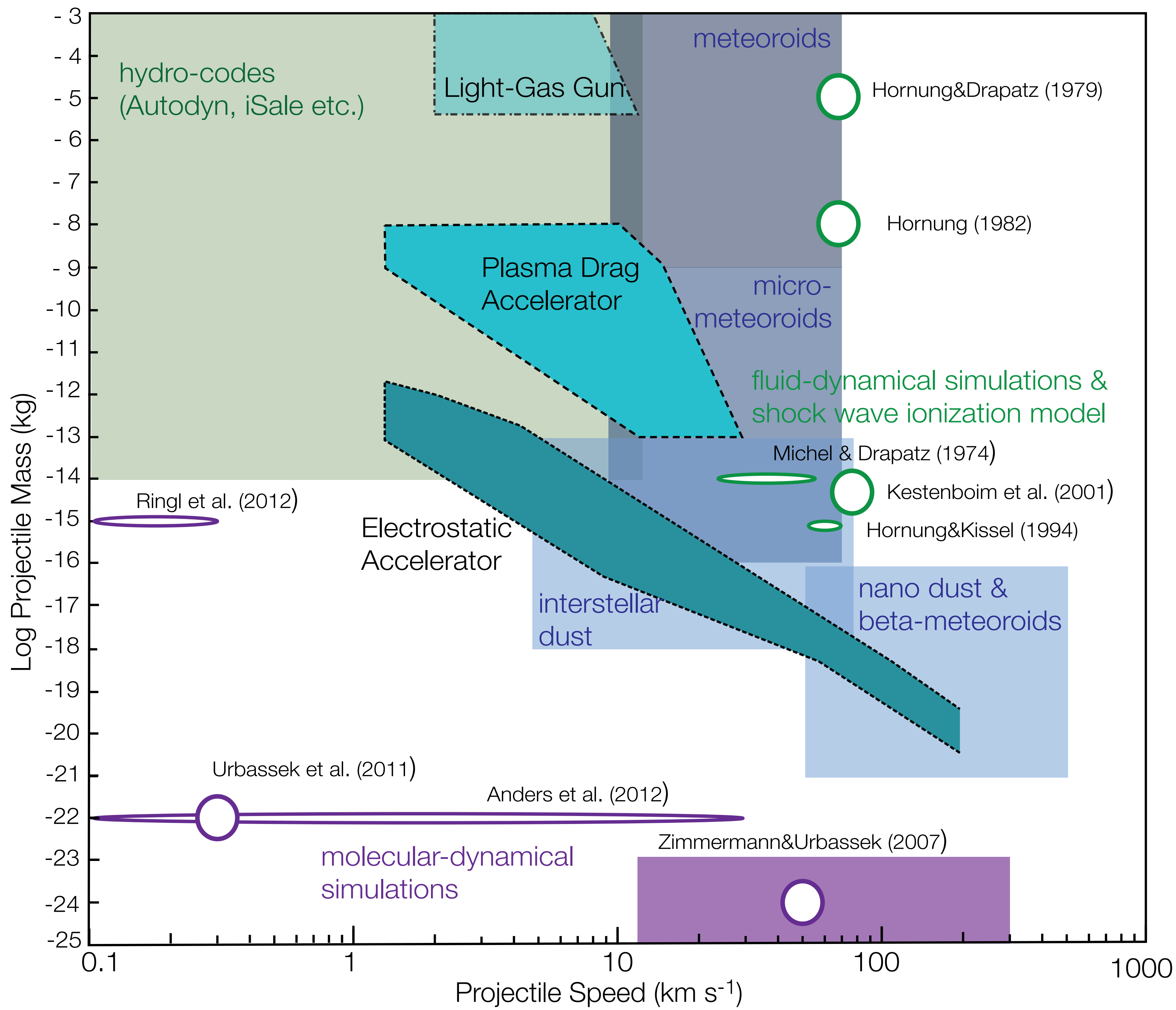
3.1) HVI IMPACTS OF µm-SIZED PARTICLES: Ejecta generation

	Existing studies			
	D > 10µm[1)]	D > 10µm[2)]	XMM study [3)]	this study
Accleration method	LGG and plasma drag	electrostatic	Electrostatic	electrostatic
Particle material	Glass	FeNi	Fe	Fe + silicate
Particle sizes	> 10µm	0.2µm - 2µm	0.2µm - 1.2µm	40nm - 3µm
Impact speeds	x00ms^{-1} - 3kms^{-1}	1-10 kms^{-1}	1-10 kms^{-1}	0.4 - 50 kms^{-1}
Target	Ices	Au	Gold coated x-Ray mirror	Silicon pore mirror
Detection method	thin foil for direction and size distribution, piezo for velocity	PMT	SEM, EDX, impact charge, live CCD	DLD + impact charge
Impact angle	90°	90°	1°,1.5°,2°,4°	1°-4°
				Simultaneous measurement of mass and velocity

1) Koschny and Grün, 2001.
2) Eichhorn, 1975
3) Meidinger et. al, 2003

EXPERIMENTAL REQUIREMENTS AND TEST PLAN DESIGN

3.1) TEST REQUIREMENTS – PARTICLE PROPERTIES



etamax
member of the ckc group
IRS

3.1) TEST REQUIREMENTS – PARTICLE PROPERTIES

1. Definition of test requirements: Particle Properties

- Materials: Iron and othroPyroxene
- Impact angles: 1°, 2°, 3° and 4°
- Size and velocity ranges

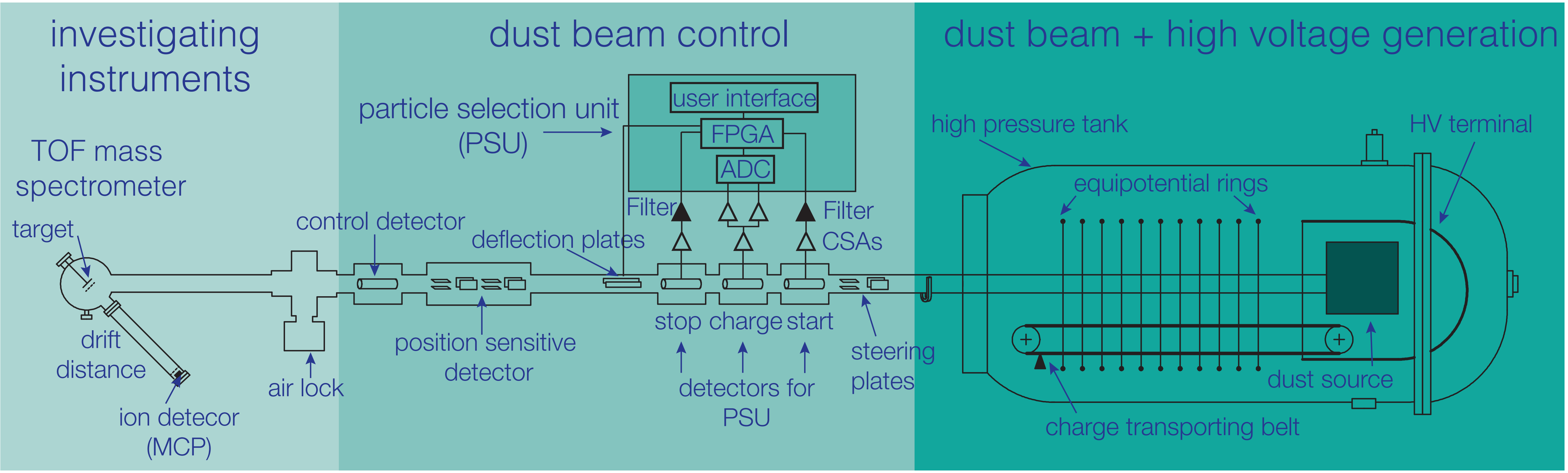
Size @3MV	3MV accelerator Impact speed	Small accelerator Impact speed
0.5 - 5µm	1 - 3 km s^{-1}	0.2 - 0.5 km s^{-1}
0.4 - 1.5µm	5 - 6 km s^{-1}	0.5 - 1 km s^{-1}
0.3 - 1.2µm	7 - 9 km s^{-1}	1.5 - 2 km s^{-1}
0.2 - 0.75µm	11 -15 km s^{-1}	2.5 - 3 km s^{-1}
below 0.3µm	above 15 km s^{-1}	3.5 - 4.5 km s^{-1}

3.1) TEST REQUIREMENTS - MEASURED AND DERIVED VALUES

Data source	Raw data / measured values		Derived values
Accelerator / PSU	Impacting dust particle: Mass, size, charge and speed	➜	impact time @ mirror: trigger for detector
Mirror set up	exact impact time due to the emerging of the impact charge	➜	Impact location, incident and exit angle
Detector	Impact times and locations	➜	Ejecta number, exit angle and speed
	Impact ionization signal	➜	+calibration: Ejecta mass

EXPERIMENTAL SETUP

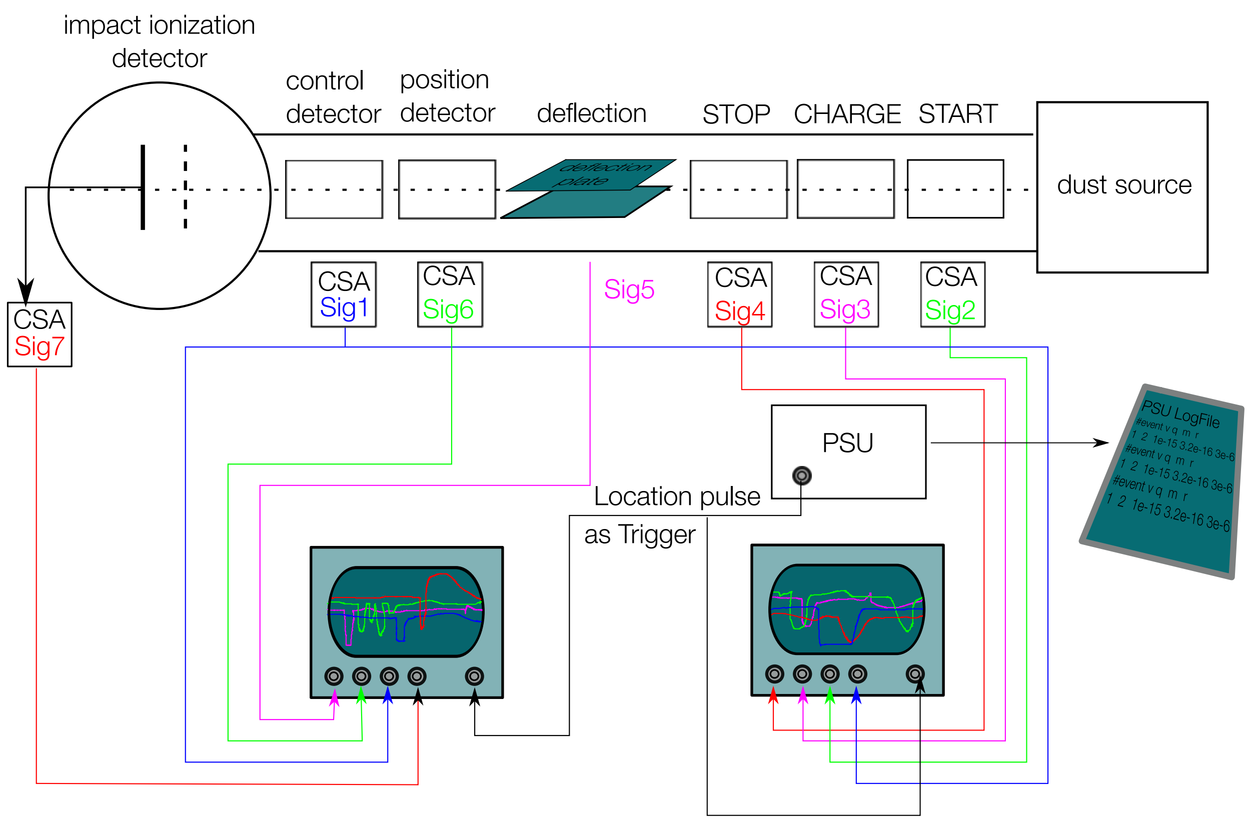
5) EXPERIMENTAL SET UP – ELECTROSTATIC DUST ACCELERATORS

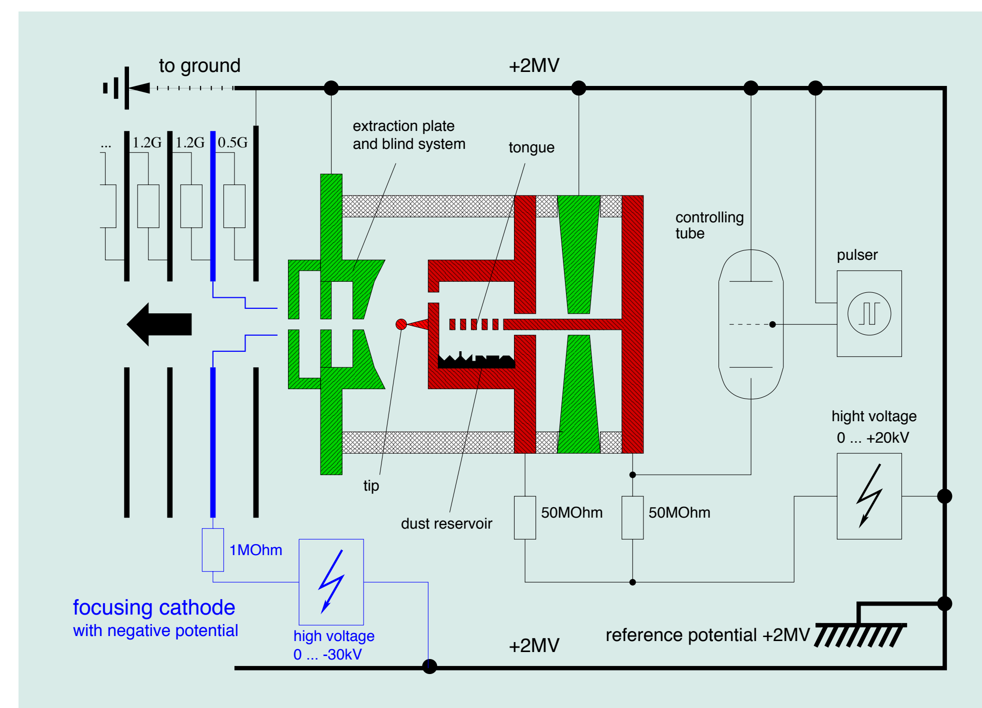


$$q \cdot U_{acc} = {}^{1}/_{2} \cdot m \cdot v^{2}$$

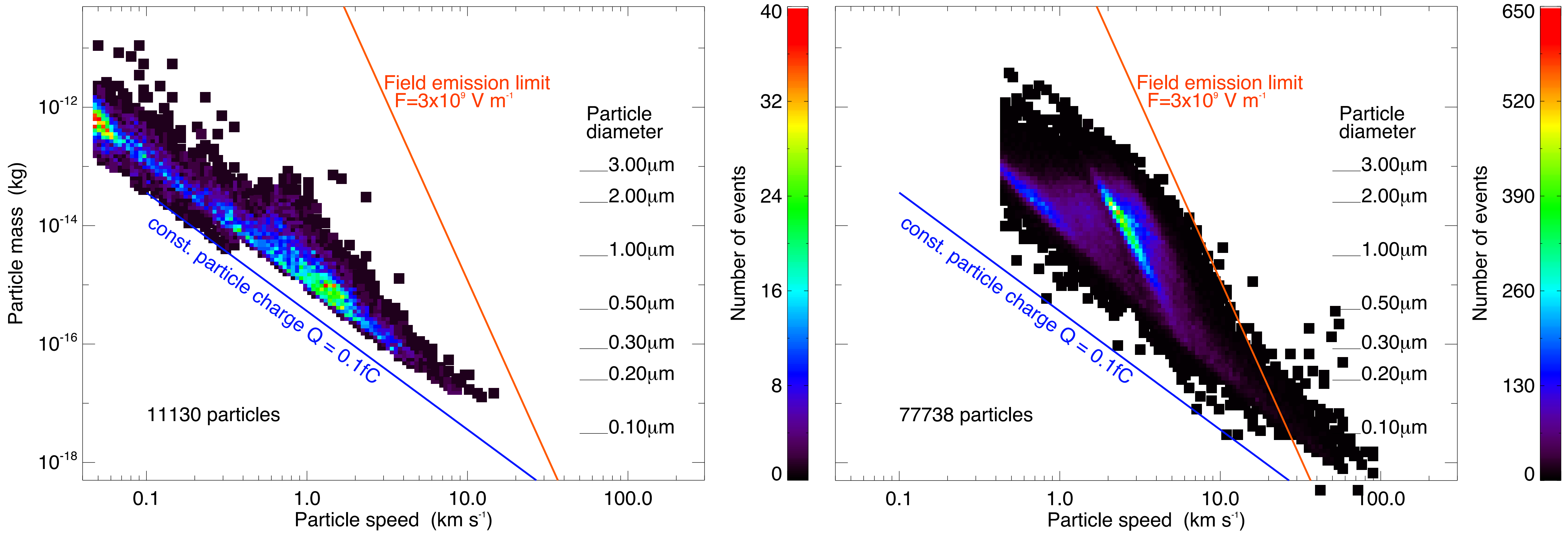
$$U_{acc} = 2MV$$

SMALL 20KV TEST ACCELERATOR @ IRS

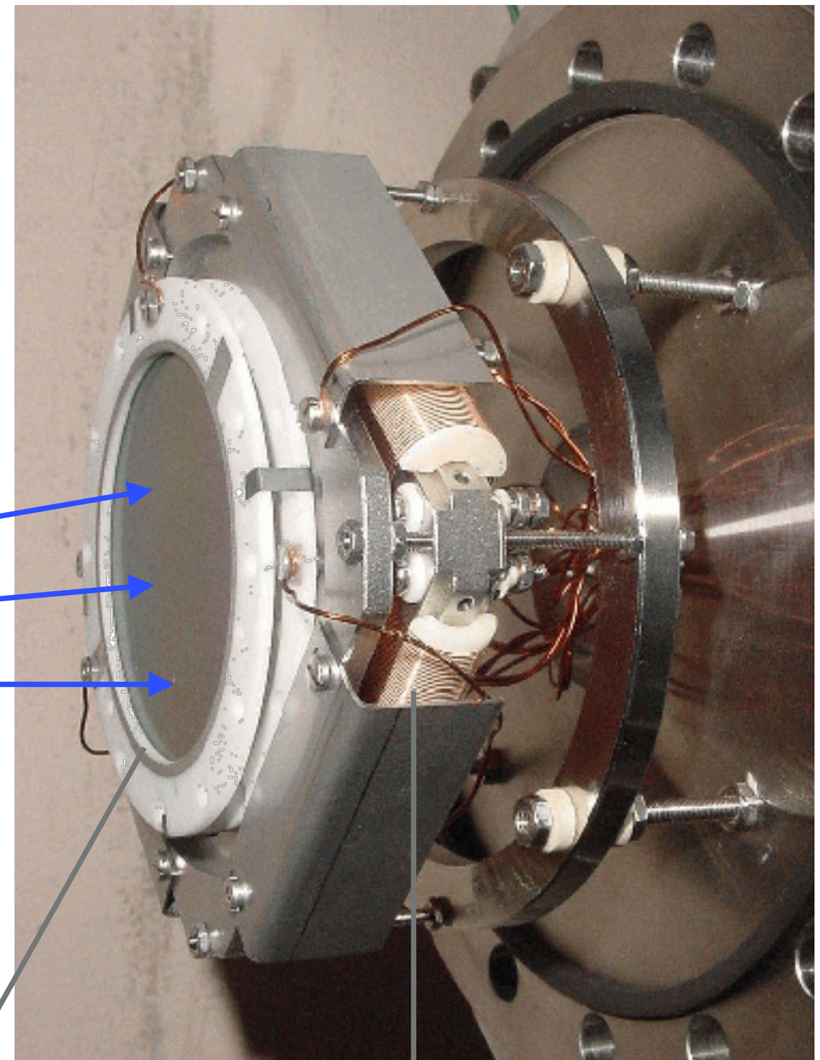




COMPARISON OF THE MASS-VELOCITY DISTRIBUTION



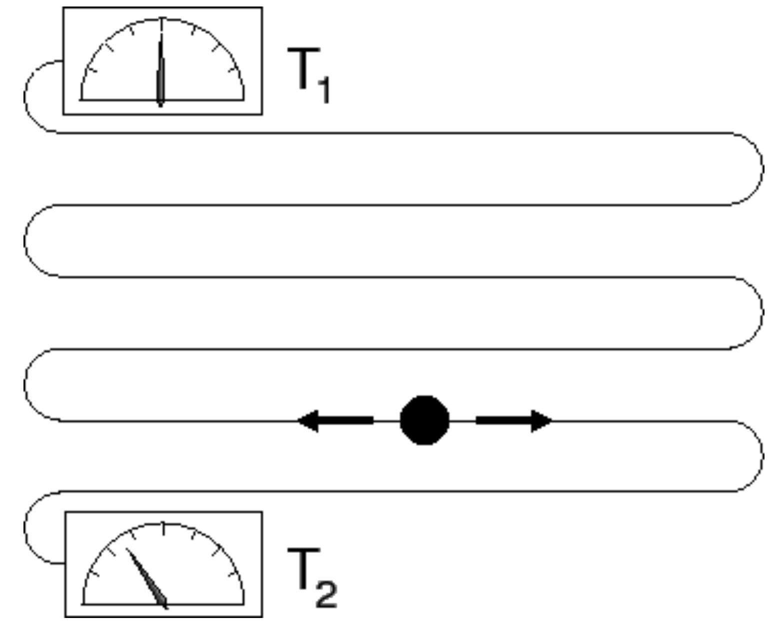
5) EXPERIMENTAL SET UP – DELAY LINE DETECTOR

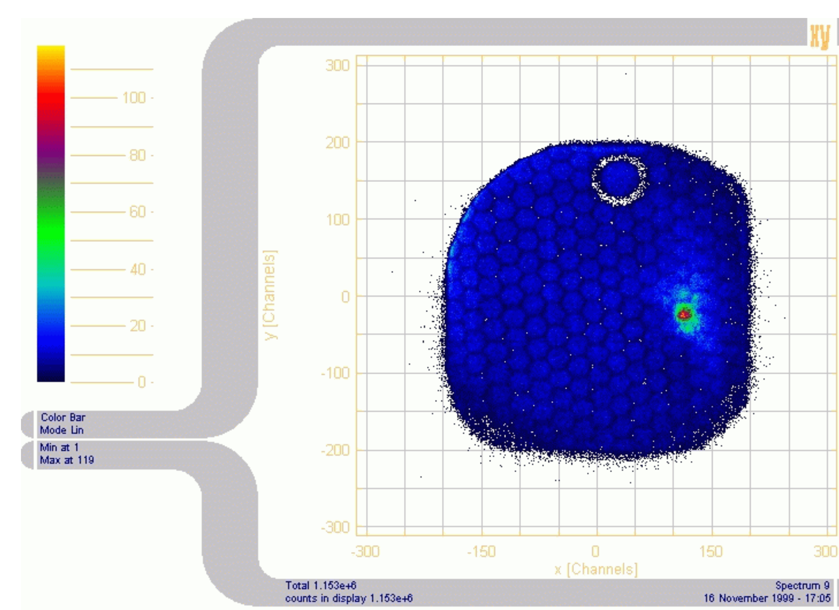


Ejecta

MCP stage

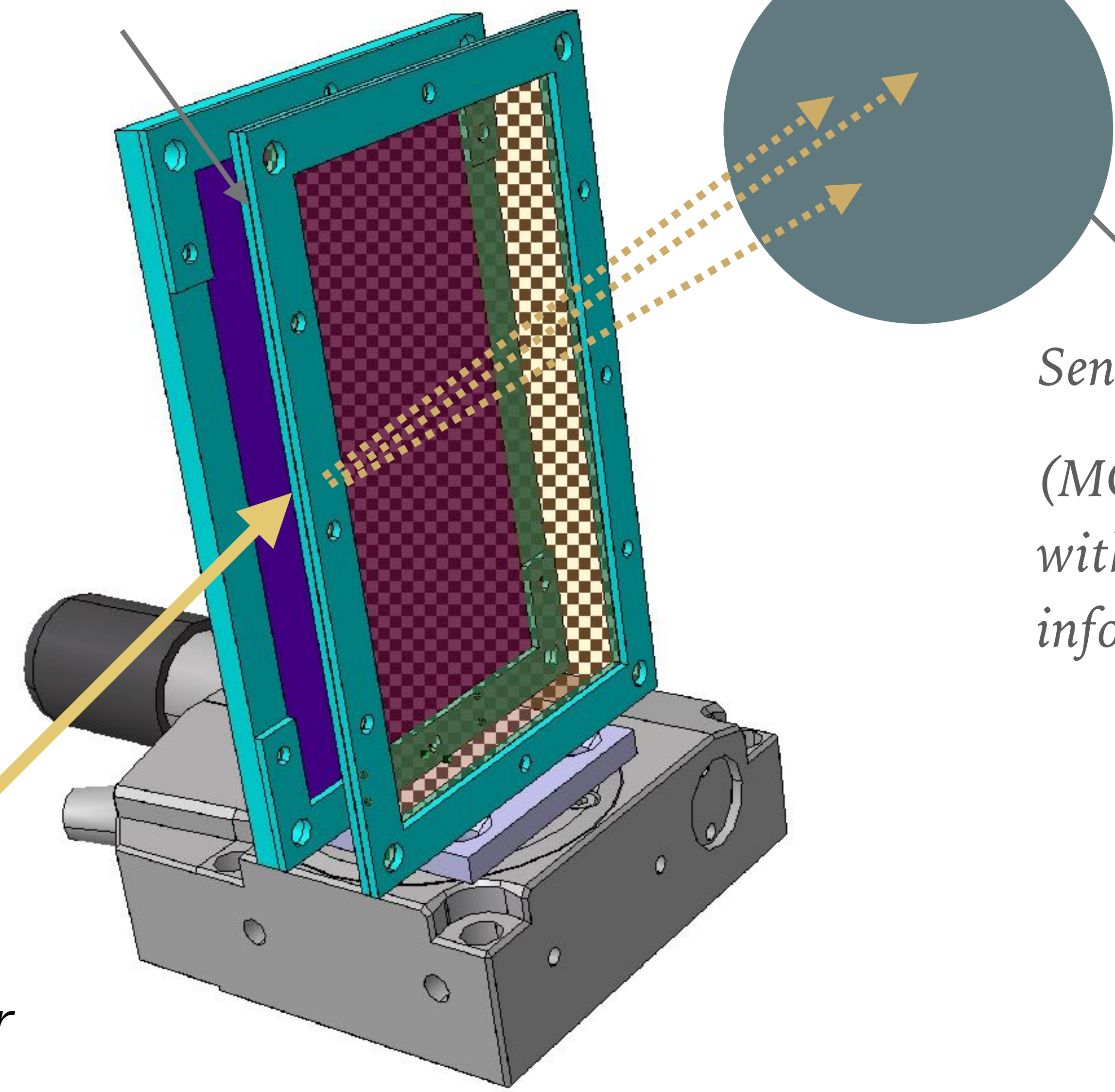
Delay line stage





5) EXPERIMENTAL SET UP – MIRROR SET UP

Single mirror plate with grid electrode



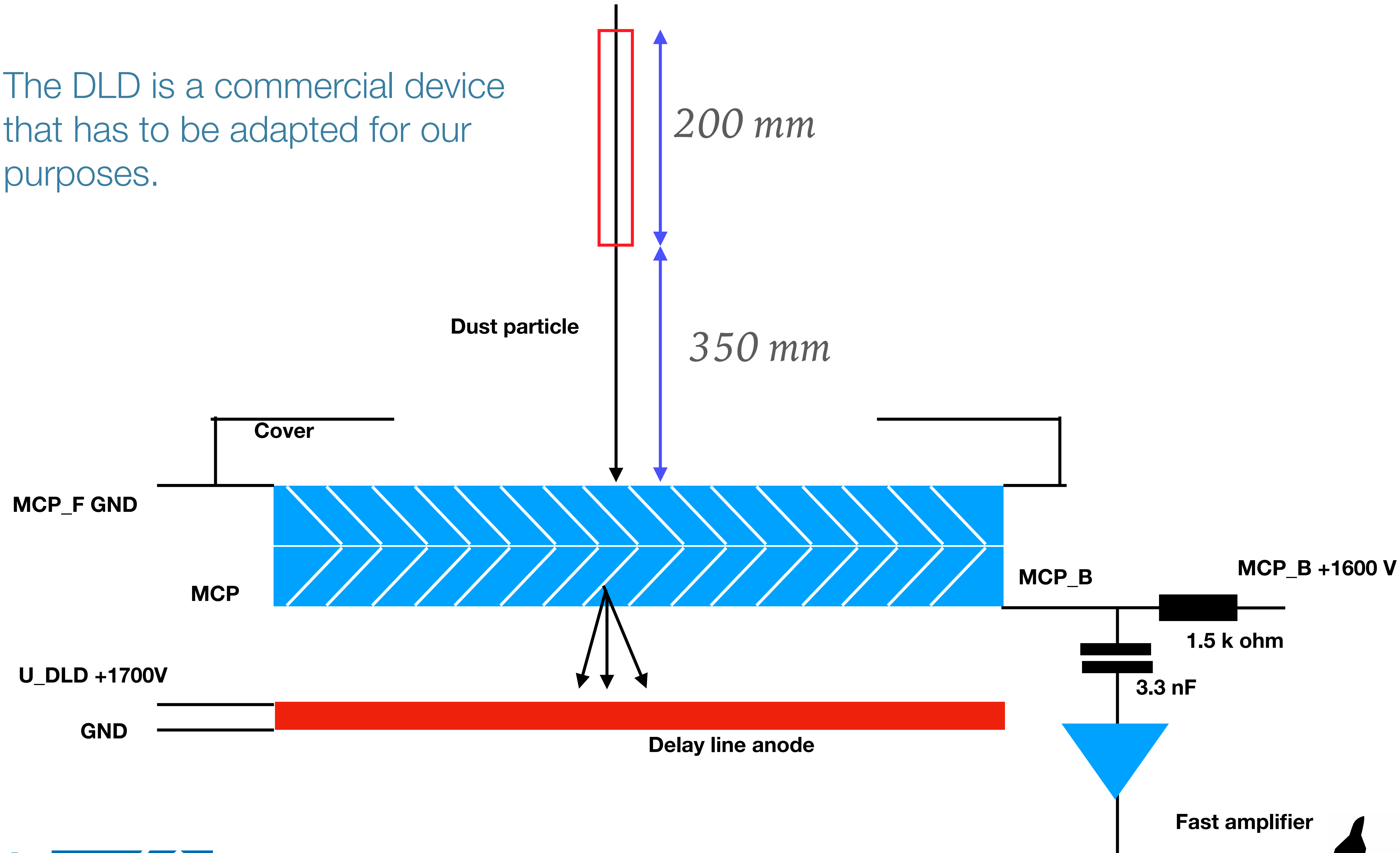
5) EXPERIMENTAL SET UP - ALTERNATIVE DETECTOR CONCEPTS

Detector Types	Test and design plan	Status	Further planning
MPPC (impact flash)	Functional test	After some back and forth, all detectors arrived	Functional tests with a 5ns laser ablation set up
µPMT (impact flash)	mass / velocity calibration	Functional tests for the MPPC and the µPMT at the small test accelerator have shown no signals so far	
	determination of uncertainties and difficulties		Functional test at the big accelerator
MiniChanneltron (impact ions)	design of complete detector	Test with miniChanneltron(s) are in preparation	Comprehensive tests at the 2MV acc

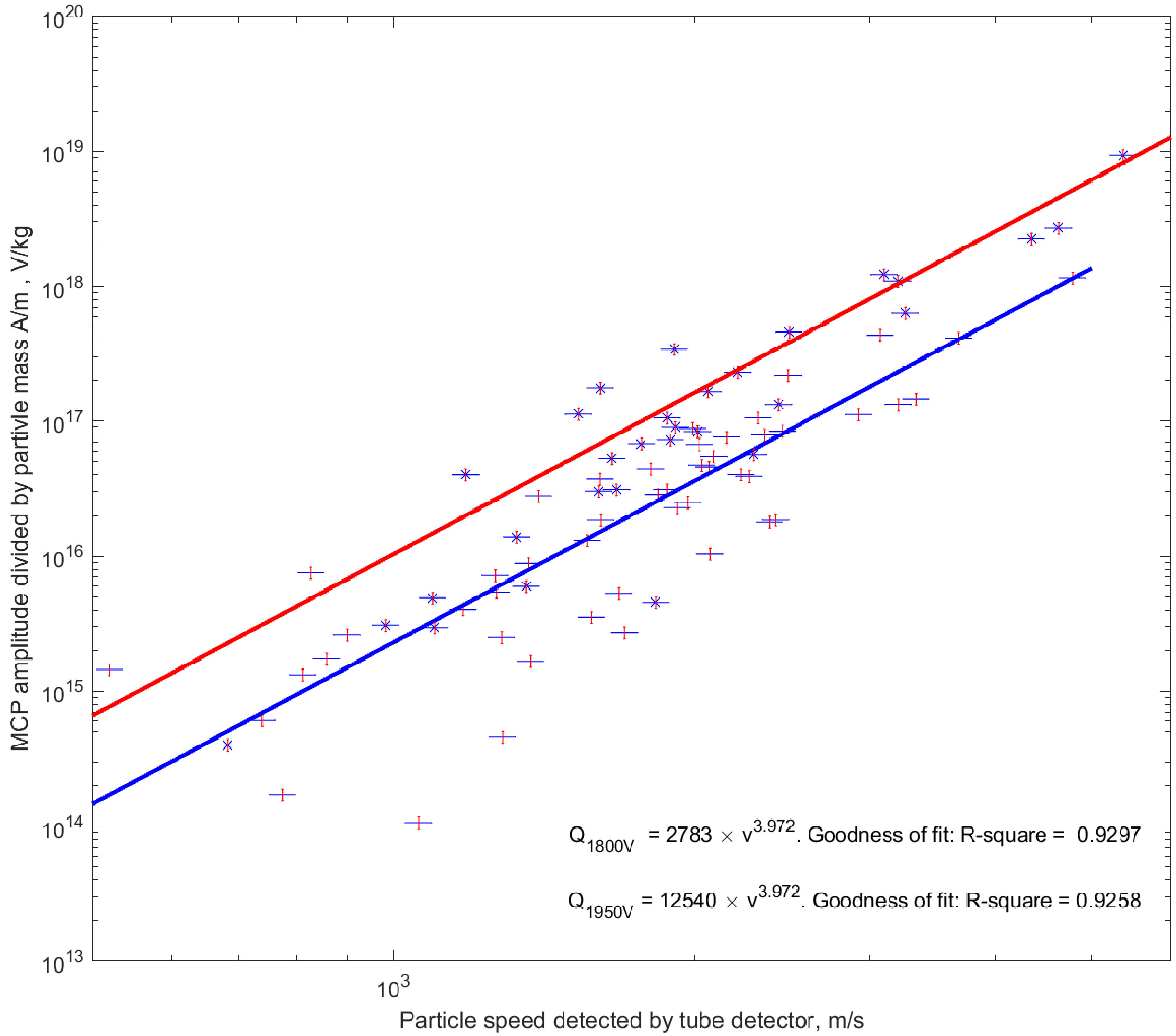
TESTS AT THE SMALL ACCELERATOR

6) TESTS AT THE SMALL ACCELERATOR – MASS – VELOCITY CALIBRATION

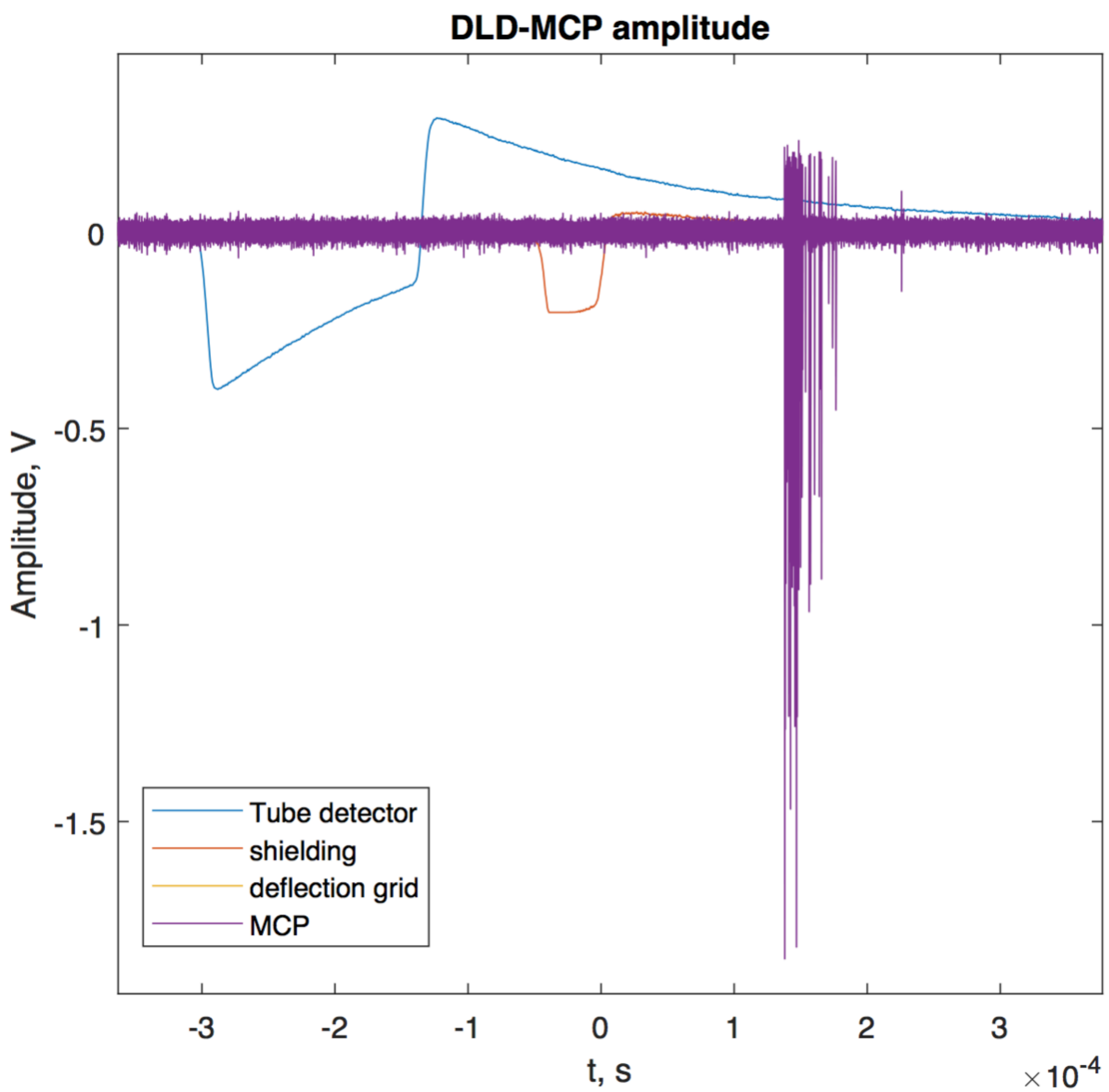
The DLD is a commercial device that has to be adapted for our purposes.



6) TESTS AT THE SMALL ACCELERATOR - MASS - VELOCITY CALIBRATION

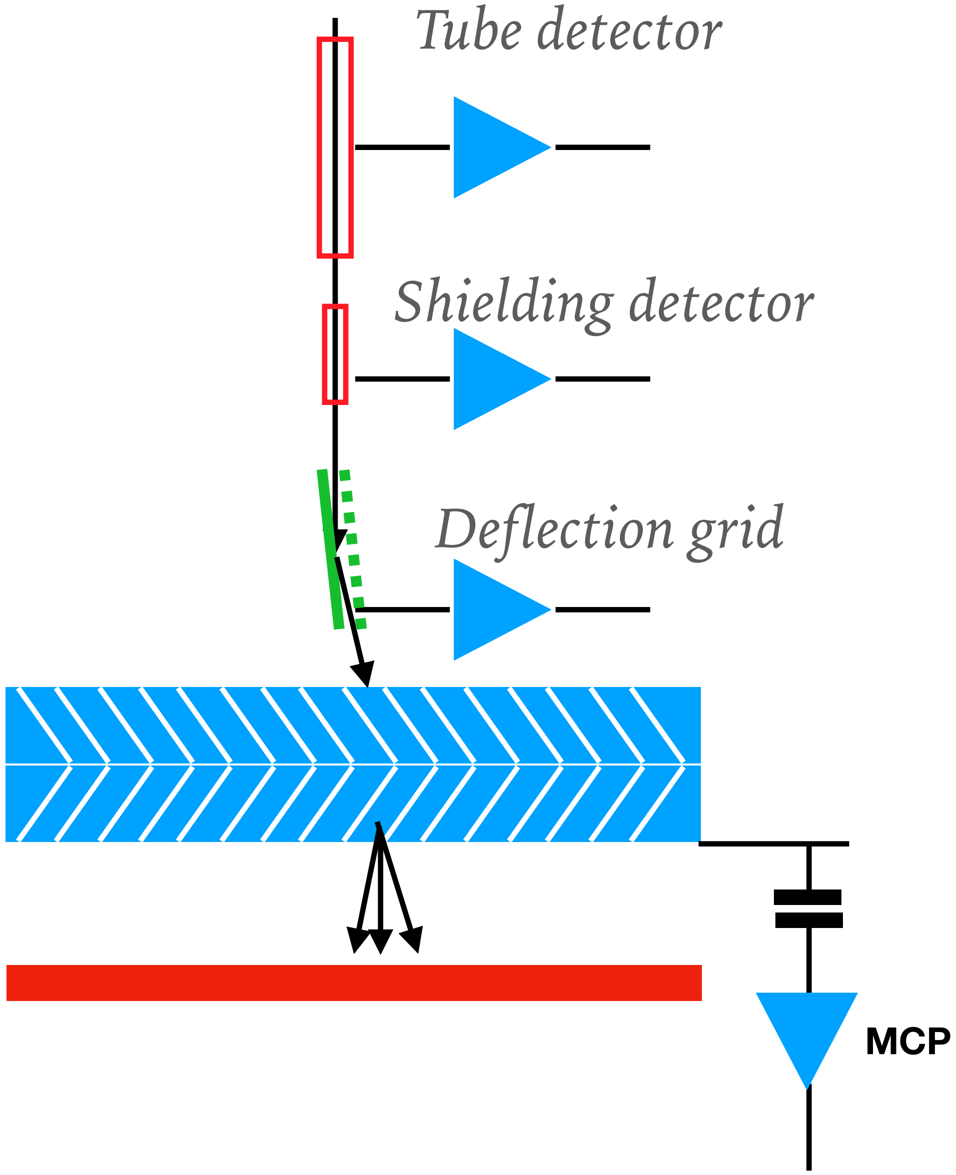


6) TESTS AT THE SMALL ACCELERATOR – EJECTA MEASUREMENTS

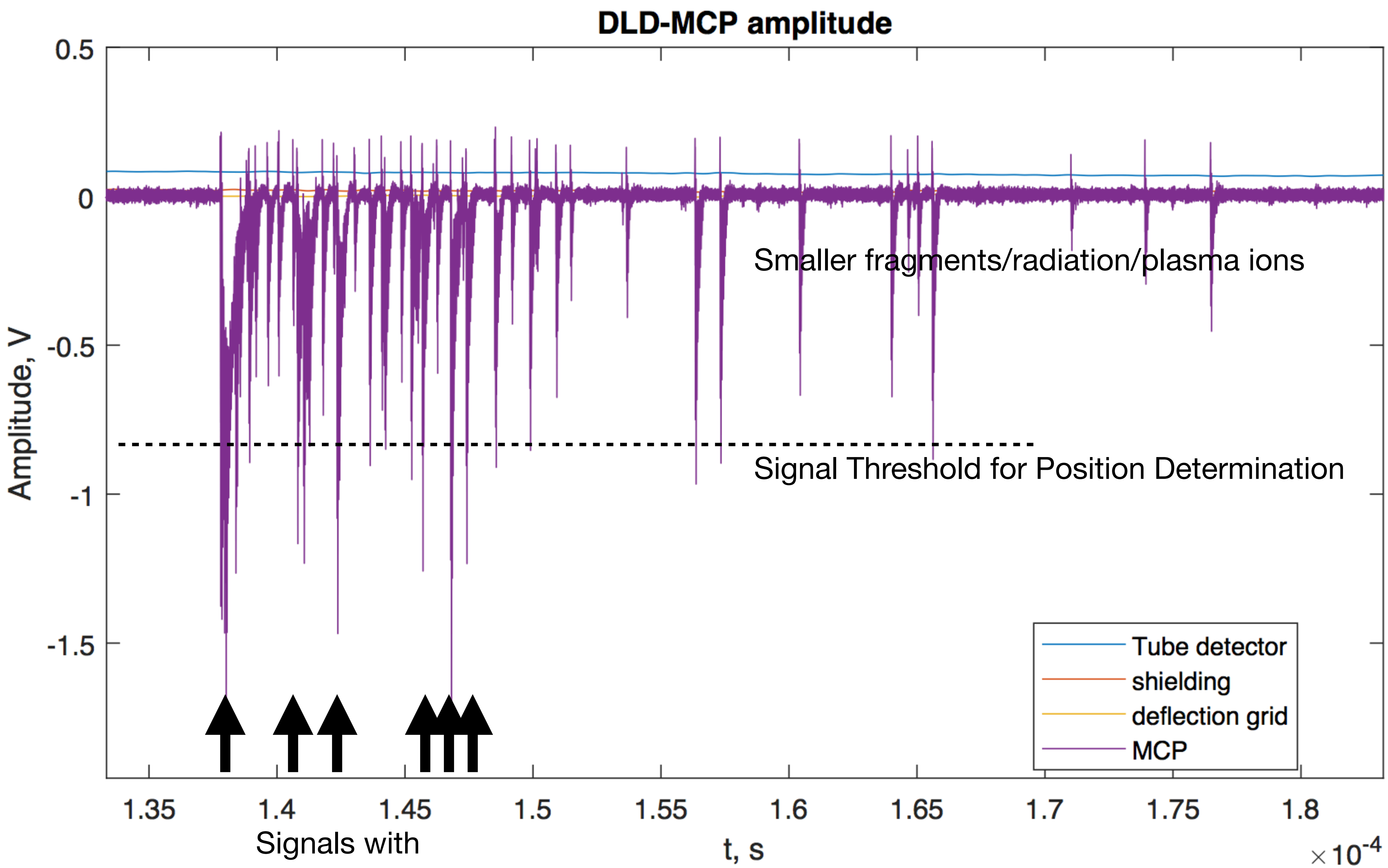


Typical ejecta signals

Only for pluses with amplitude above 0.8 mV, the position information can be calculated.

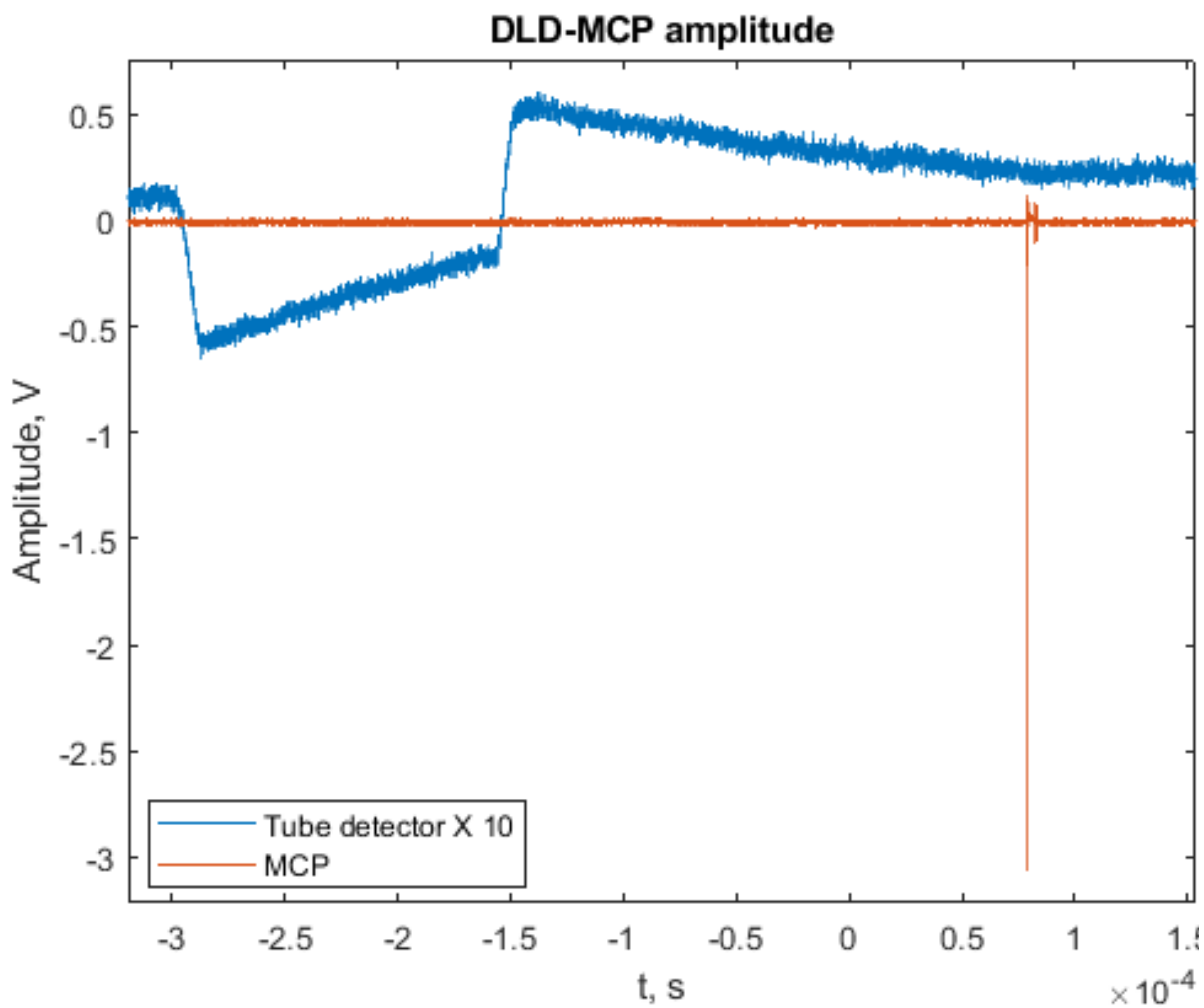


6) TESTS AT THE SMALL ACCELERATOR - EJECTA MEASUREMENTS

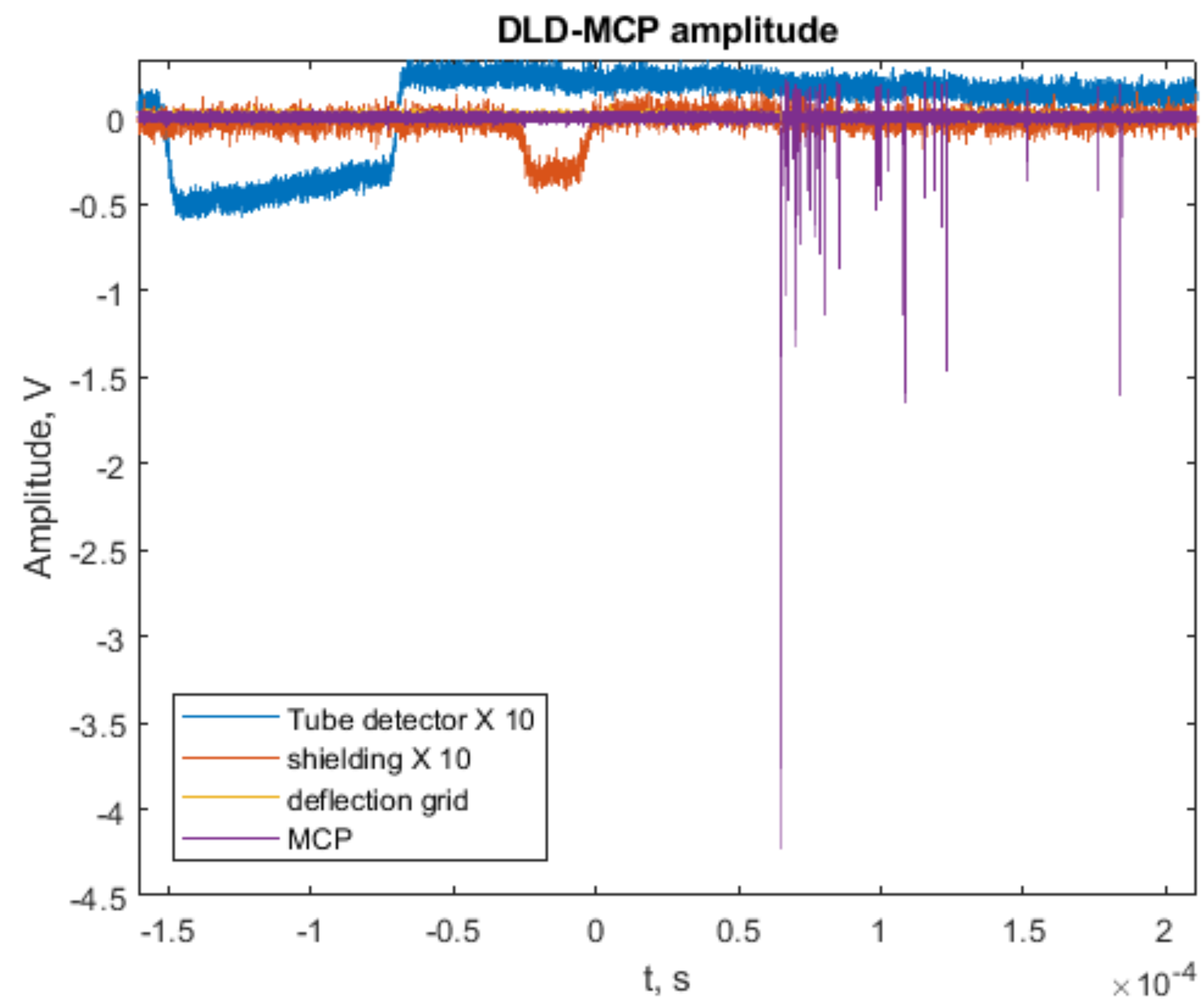


Signals with
time, amplitude and
position information

COMPARISON OF DIRECT IMPACT AND EJECTA IMPACT

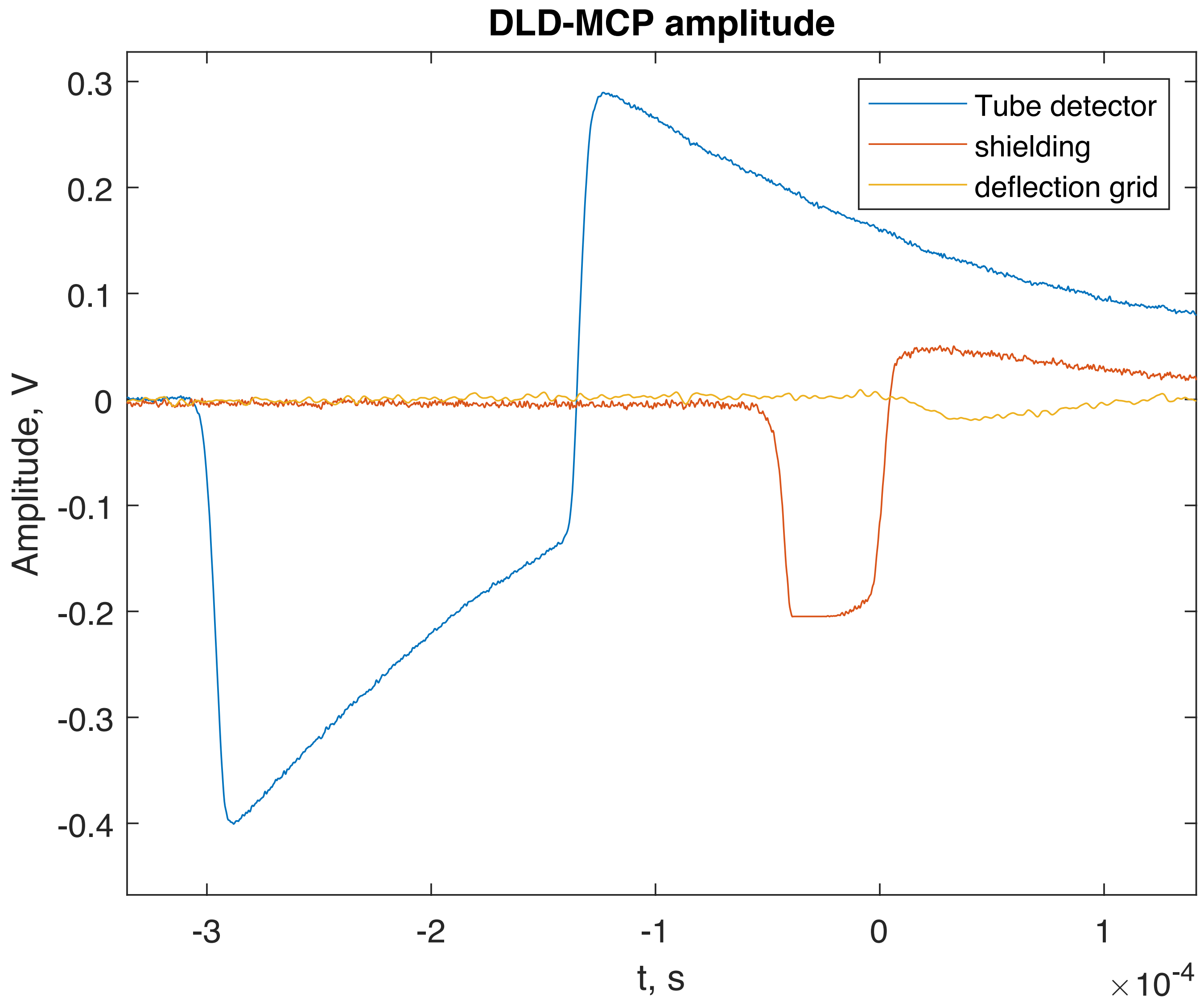


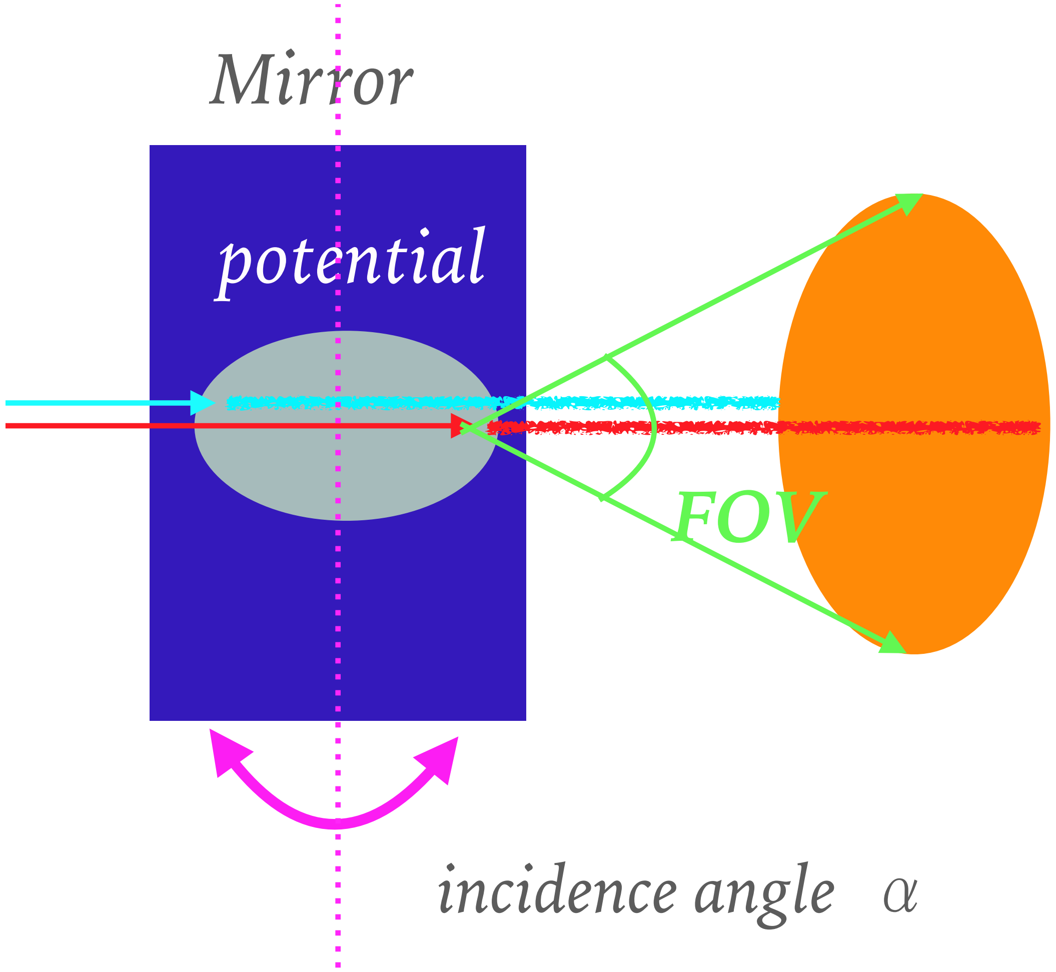
Direct impact



Ejecta impact

6) TESTS AT THE SMALL ACCELERATOR – EJECTA MEASUREMENTS

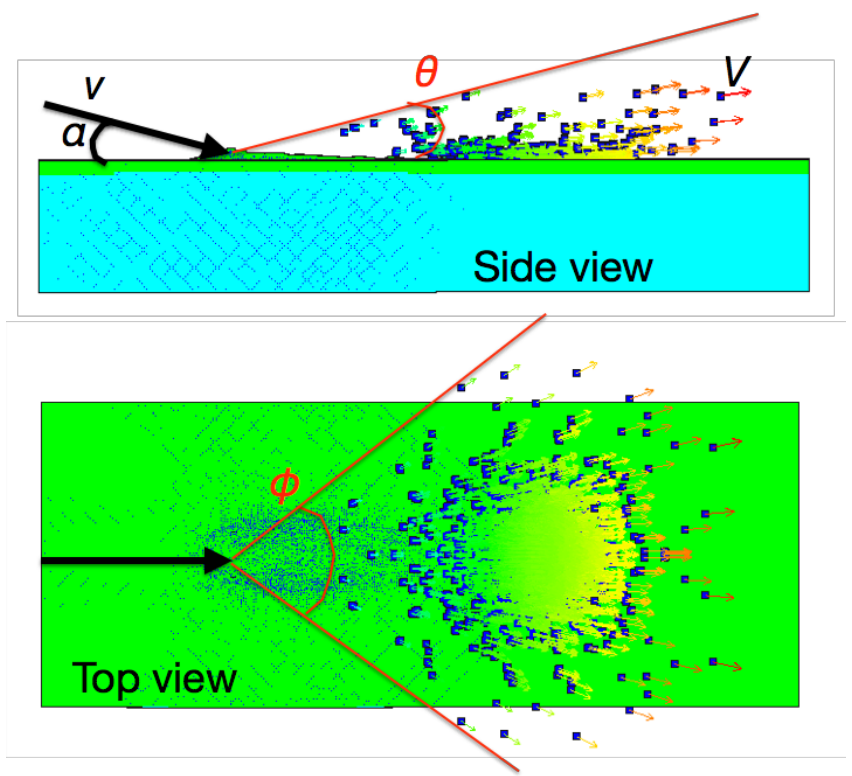


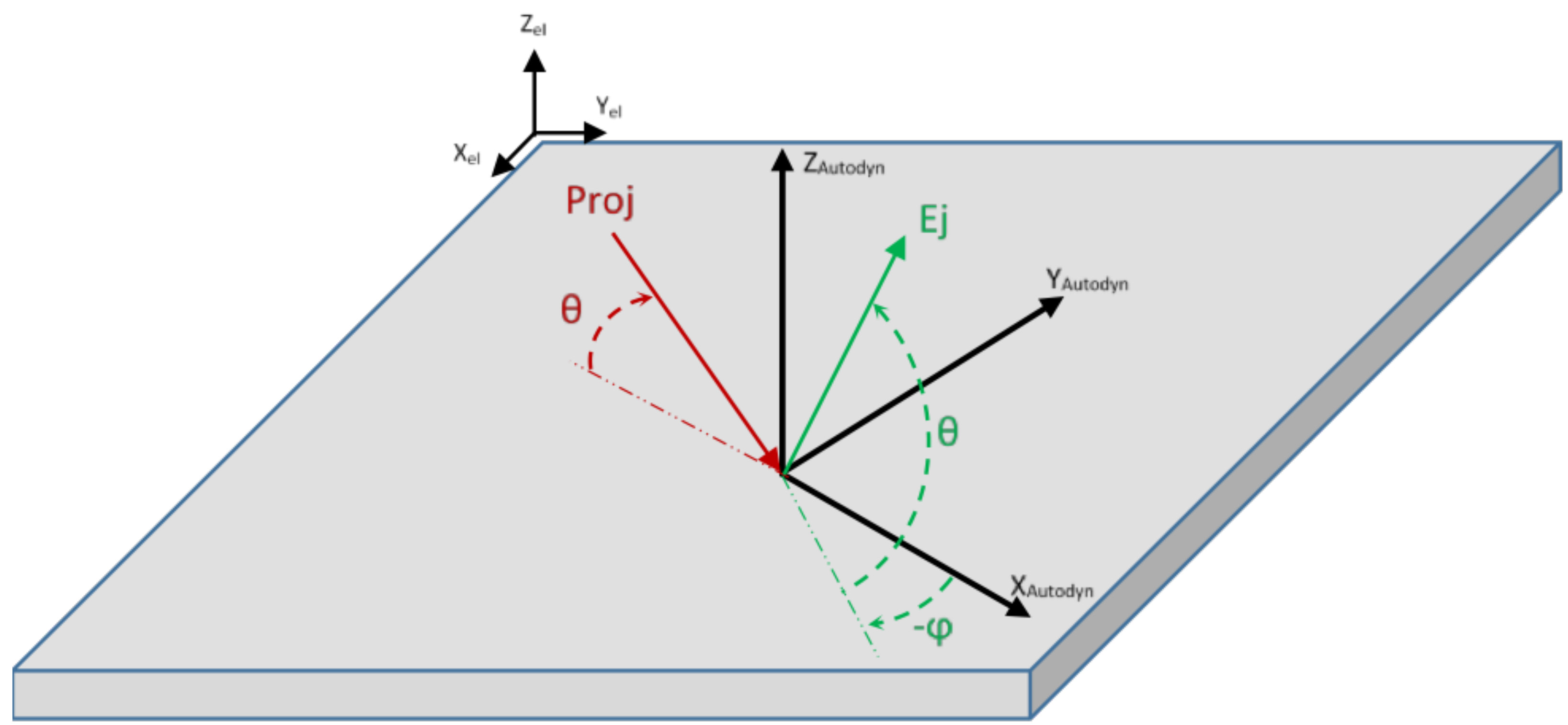


Determination of the impact time with impact charge: For the low impact velocities at the small acc, the impact charge is to small to be measured at the deflection grid.

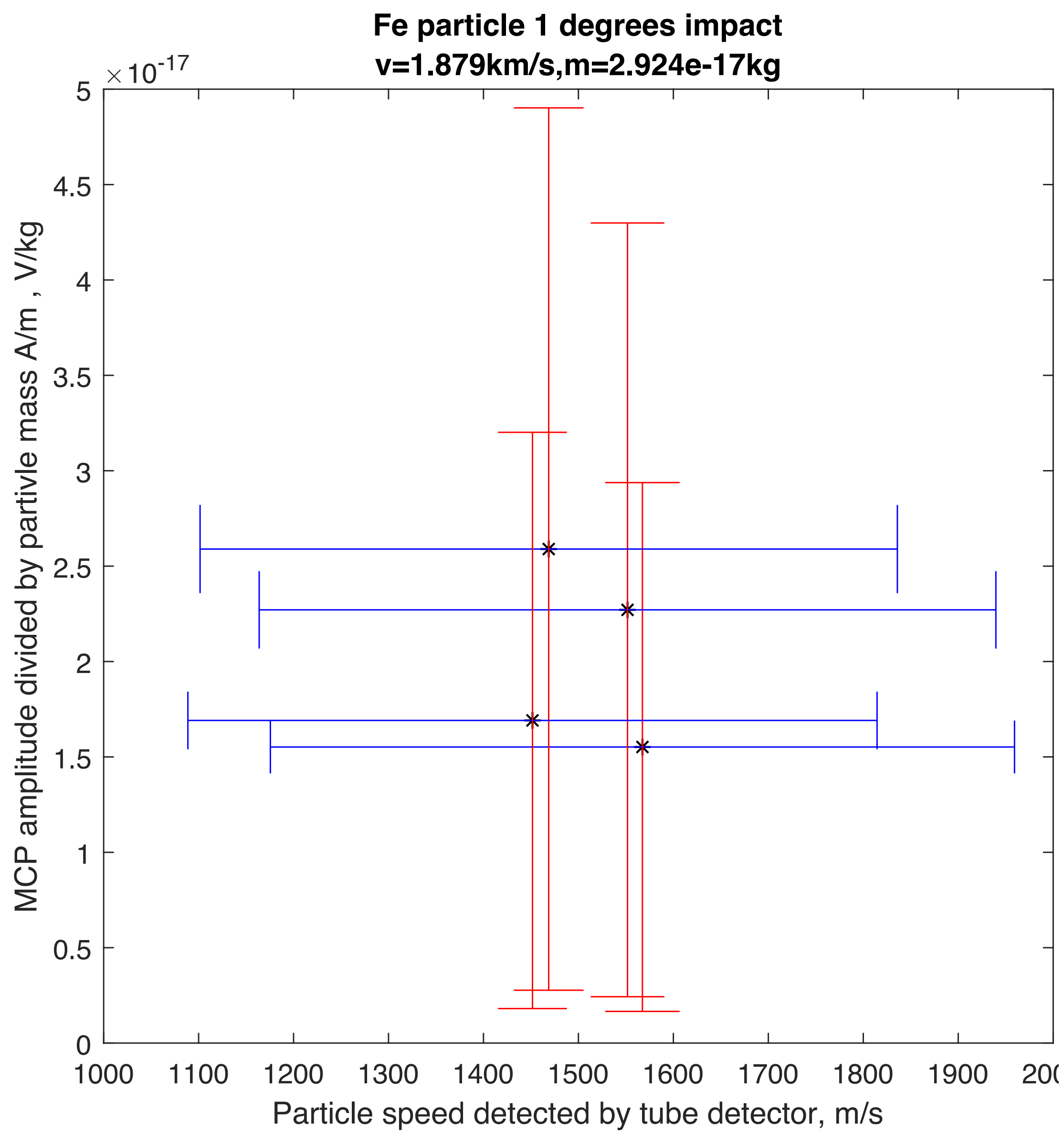
6) TESTS AT THE SMALL ACCELERATOR – EJECTA MEASUREMENTS

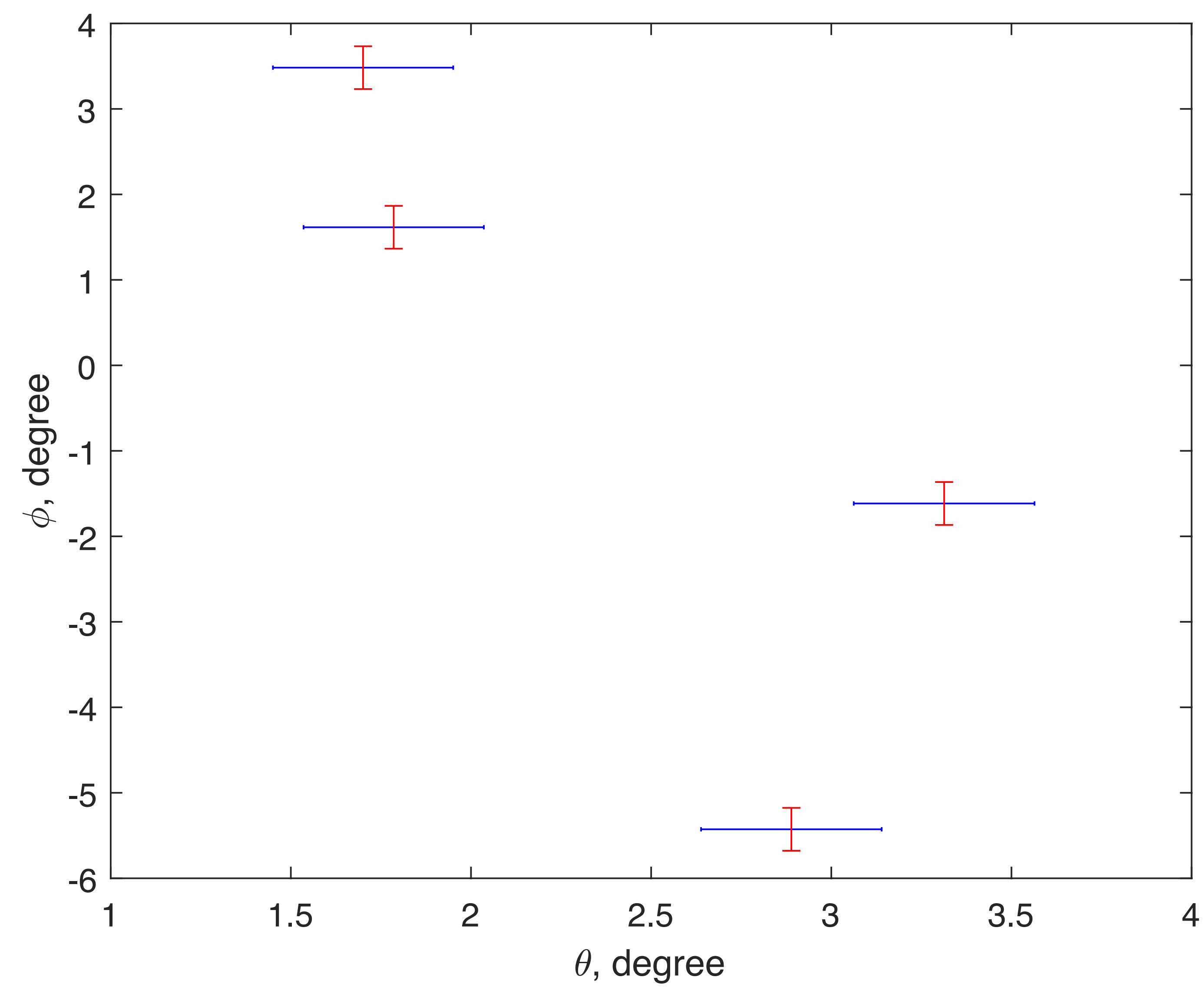
1. The mirror is mounted on a rotation work platform, the incident angle (1º, 2º ,3º, 4º) is adjusted with a angular resolution of 0.02 degrees.
2. The position of mirror is adjusted by a laser beamline.



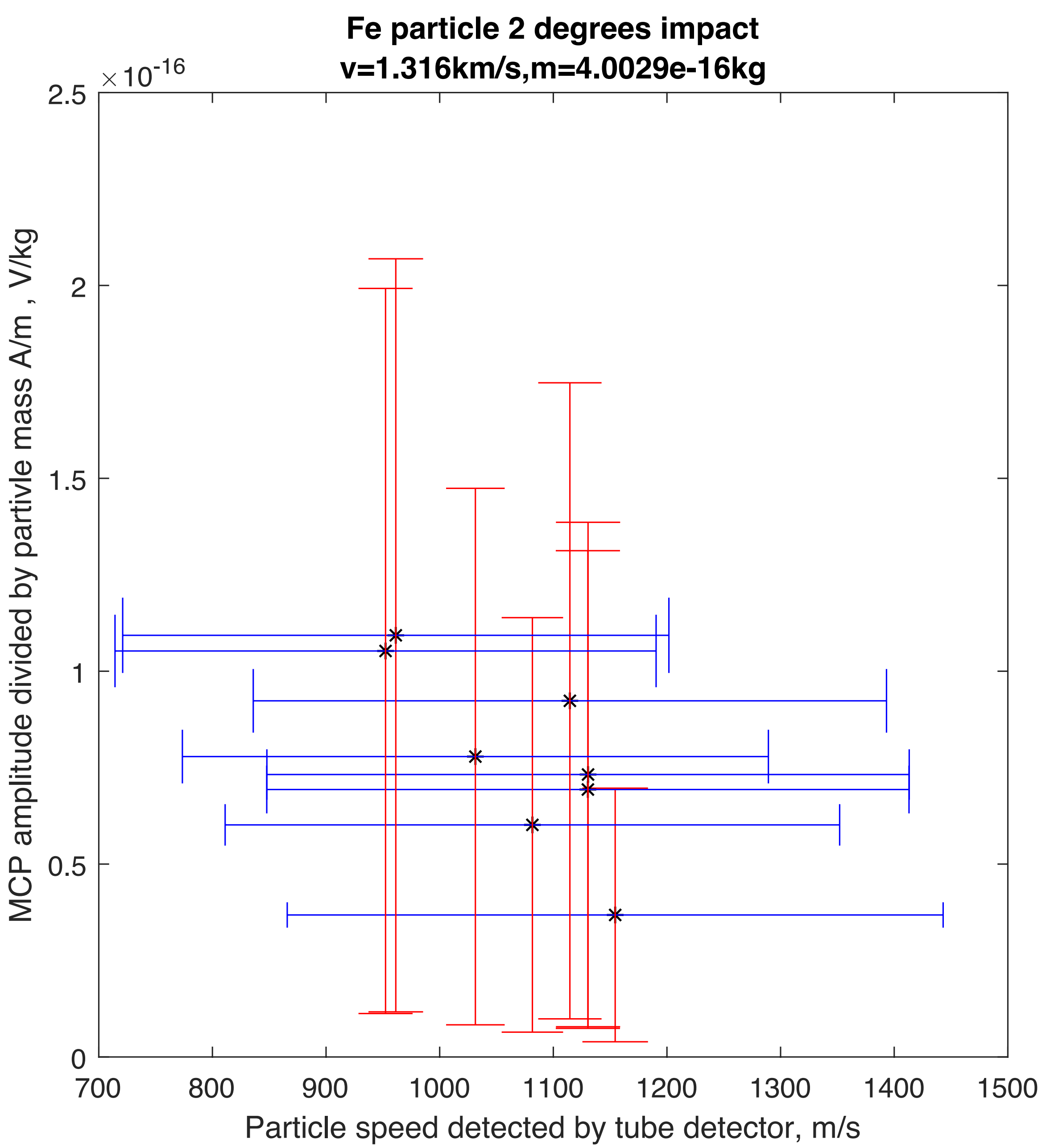


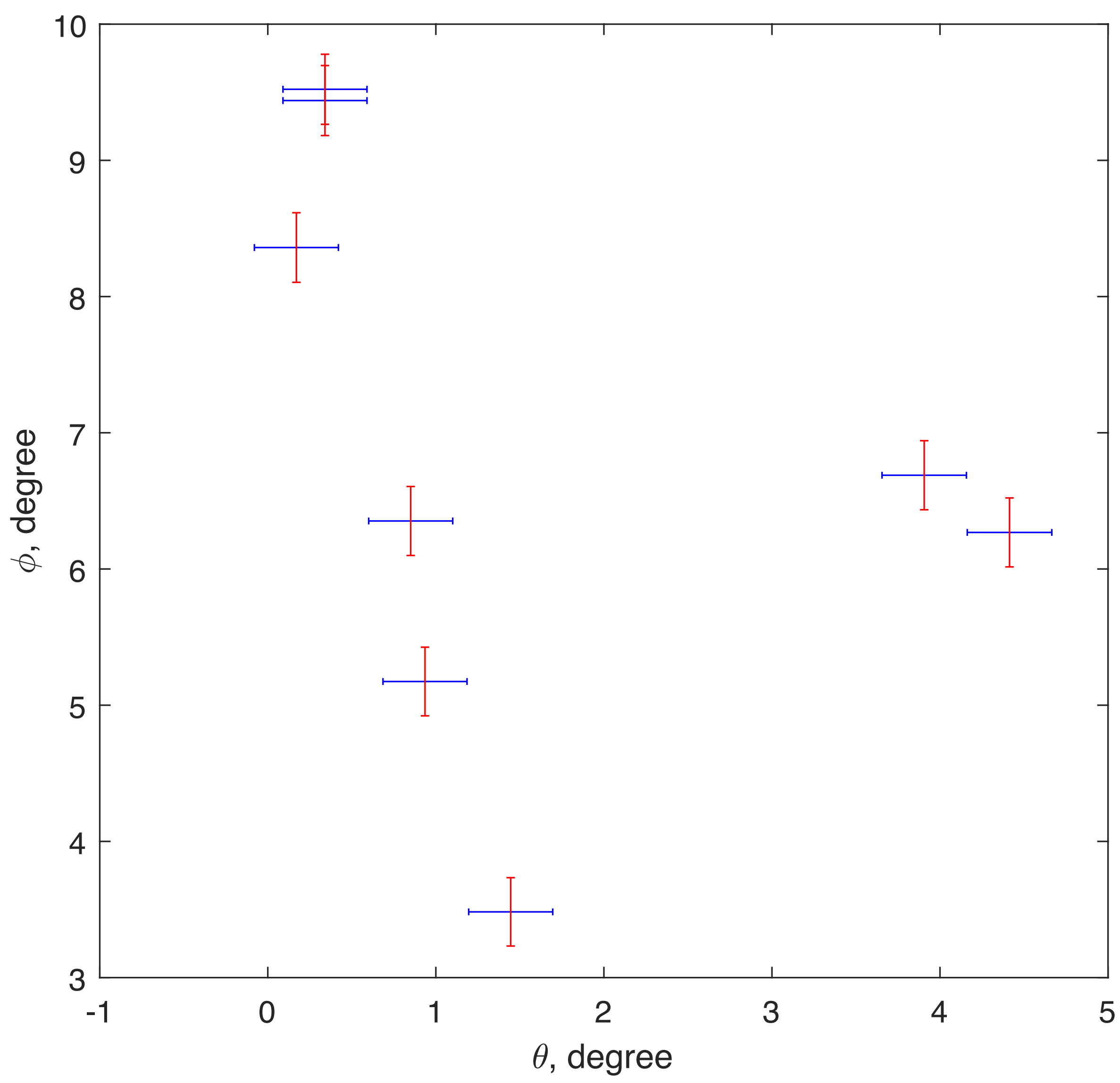
INCIDENT ANGLE = 1 DEGREE





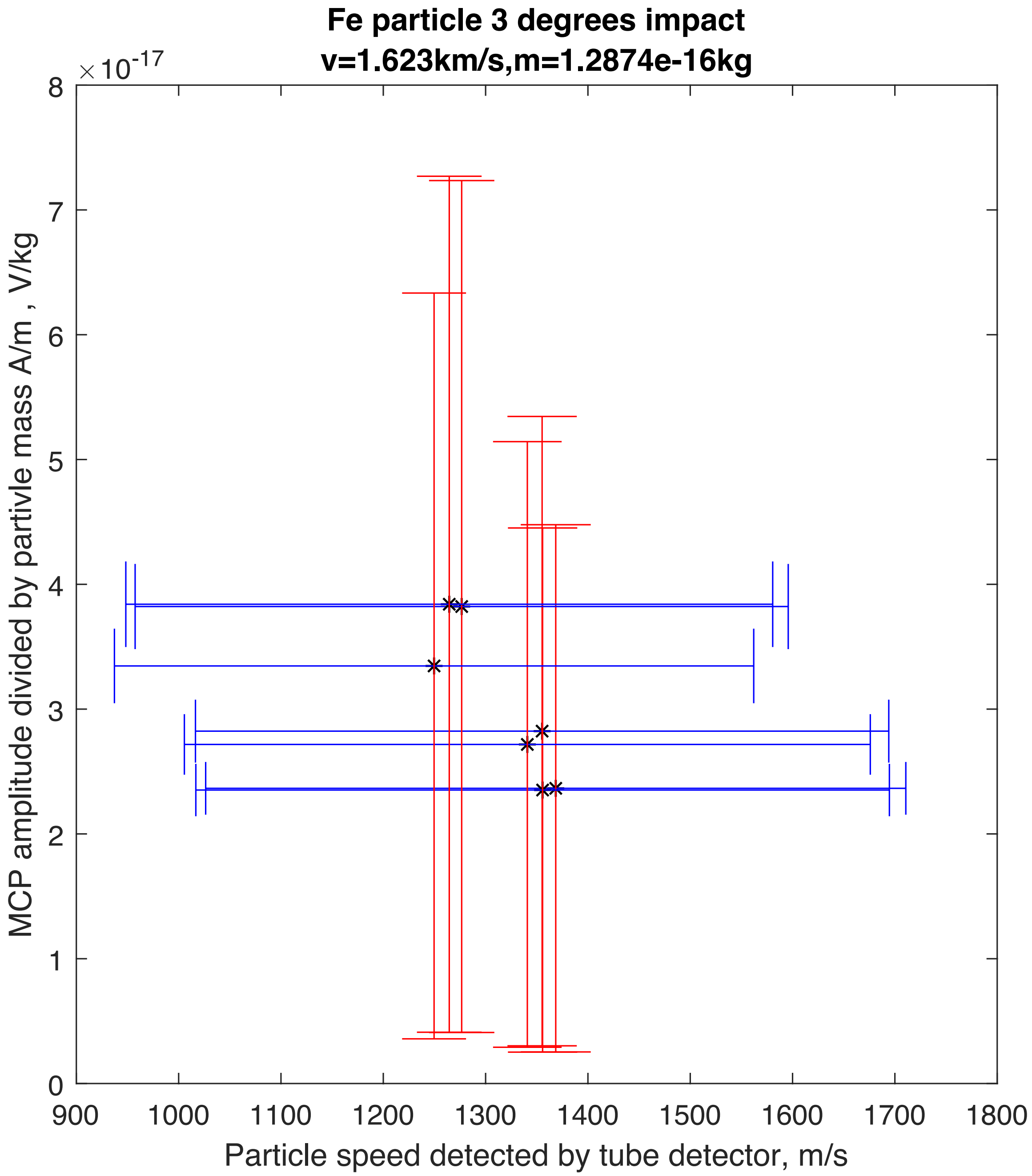
INCIDENT ANGLE =2 DEGREES

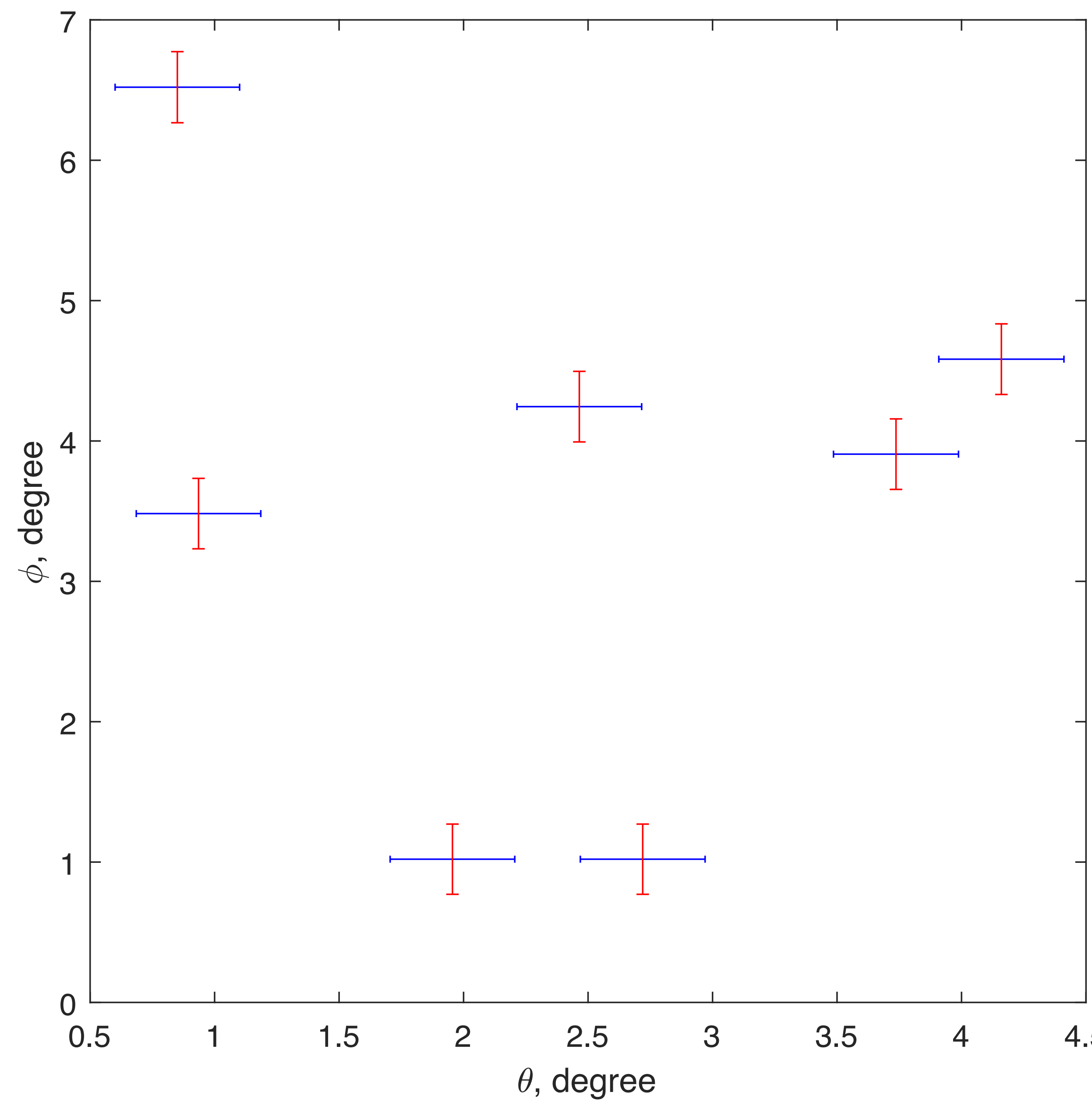




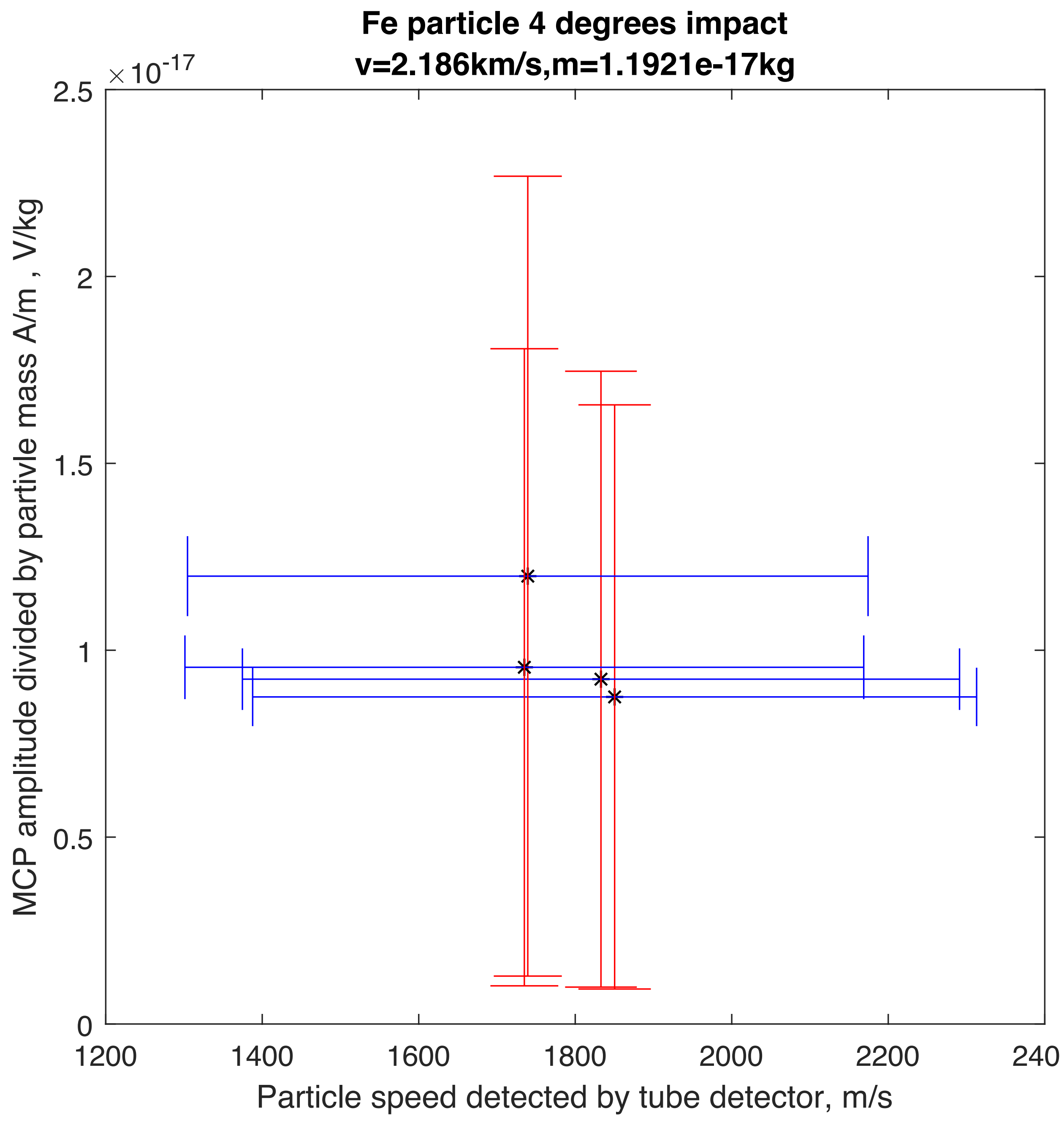
6) TESTS AT THE SMALL ACCELERATOR – EJECTA MEASUREMENTS

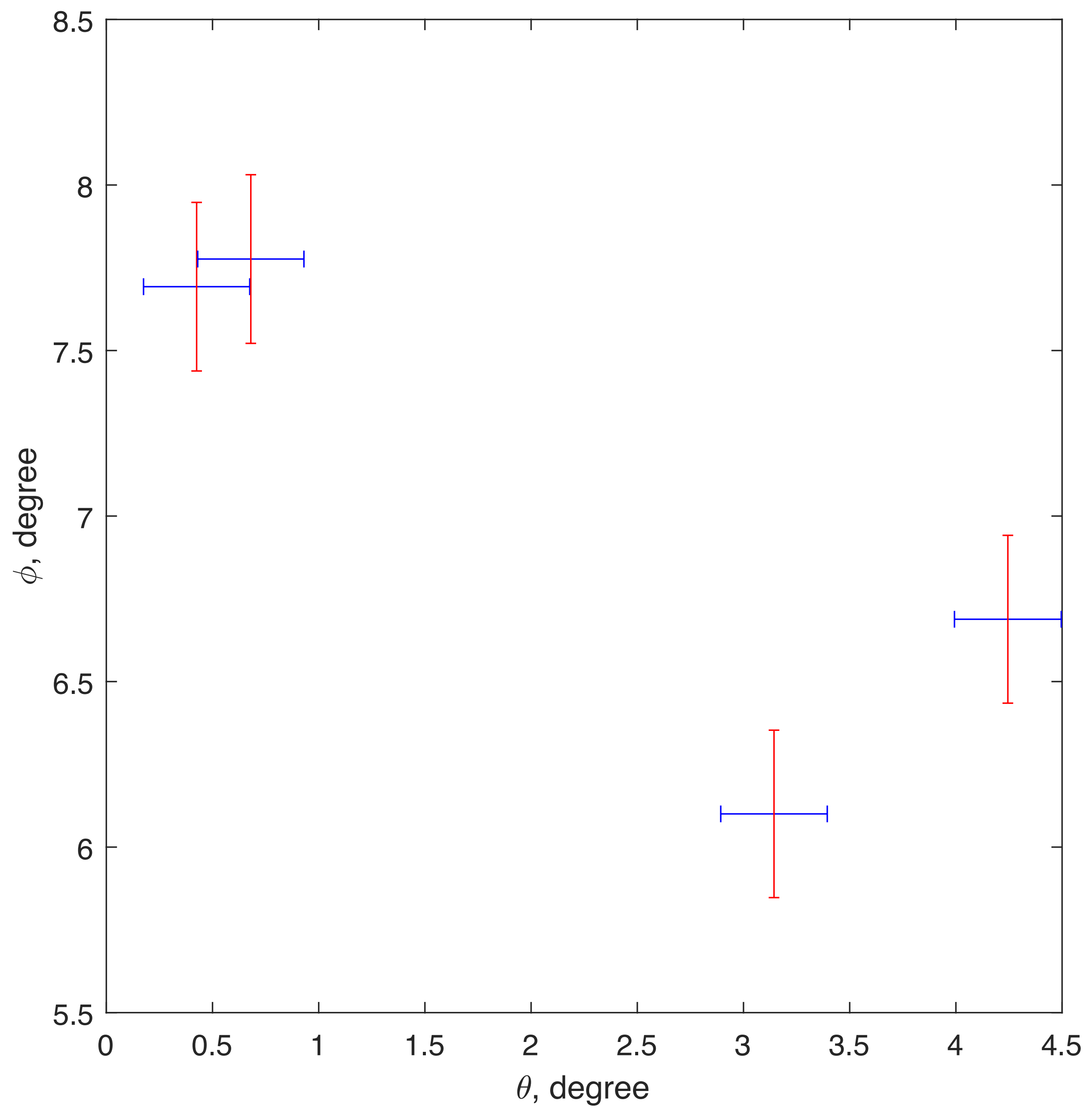
INCIDENT ANGLE =3 DEGREES





INCIDENT ANGLE = 4 DEGREES



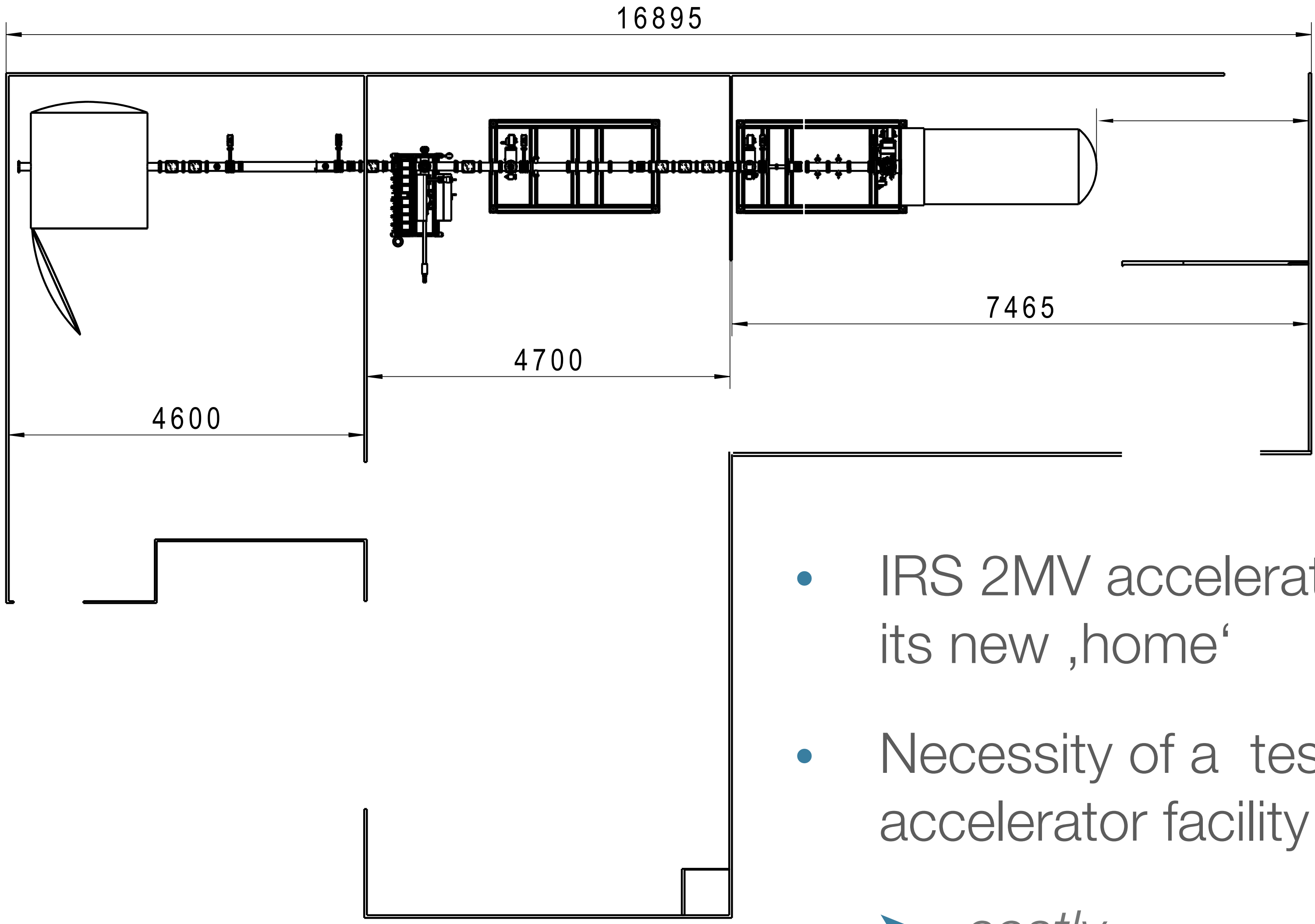


OPEN QUESTIONS AND CHALLENGES

7) OPEN QUESTIONS AND CHALLENGES

1. The peaks with low amplitude (<0.8V) provide no position information, the threshold is set by the manufacturer, for high impact charges the amplifier is saturated. A detailed analysis of the sensitivity boundaries will be performed.
2. The nature first peak of the ejecta is not yet understood:
    - The position recorded by DLD detector is in the „Shadow“ of the mirror sample.
    - The mass of such ‘fragment’ is about 5-10 times larger than the projectile
3. The amplitude - mass calibration can only be obtained for quite low impact velocities.
4. The rates at the test accelerator provides are to small for comprehensive test series.

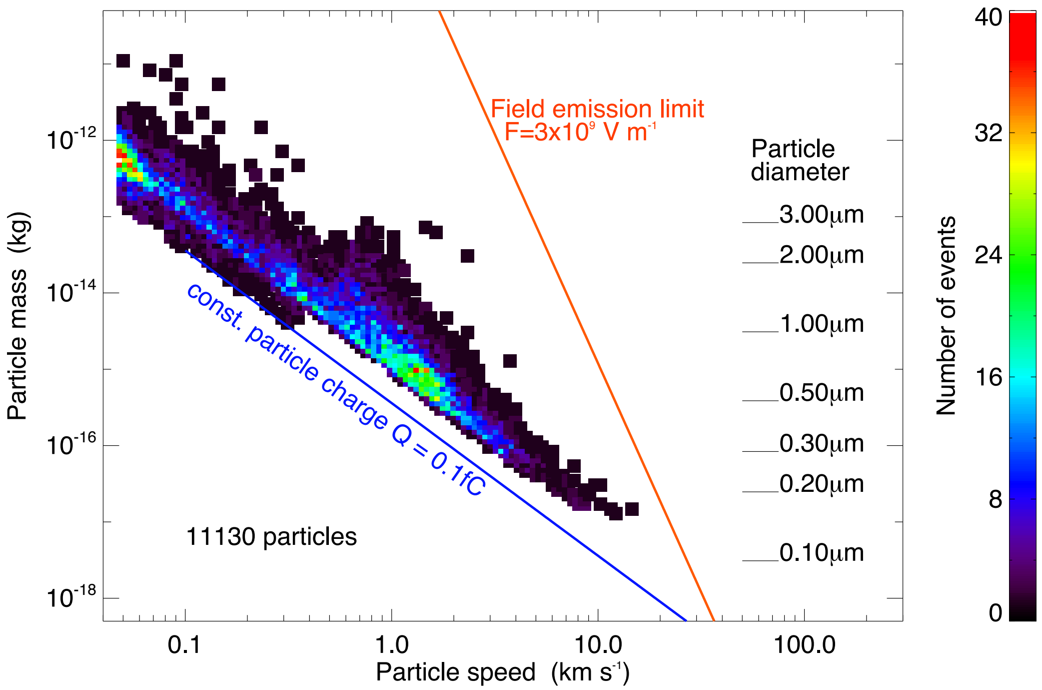
7) ACCESSIBILITY OF A 2 MV DUST ACCELERATOR

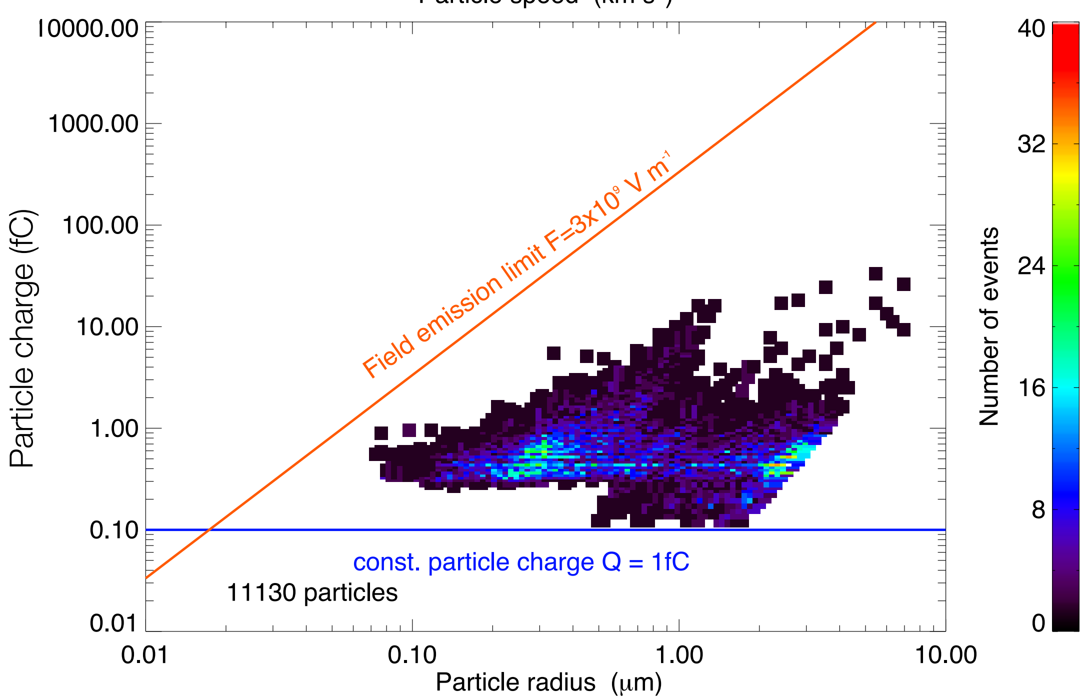


- IRS 2MV accelerator: currently in storage awaiting its new ‚home'
- Necessity of a test campaign at the dust accelerator facility at CU @ Boulder, Co - USA
  - *costly*
  - *bares risks due to transport of the set up and short campaign duration.*

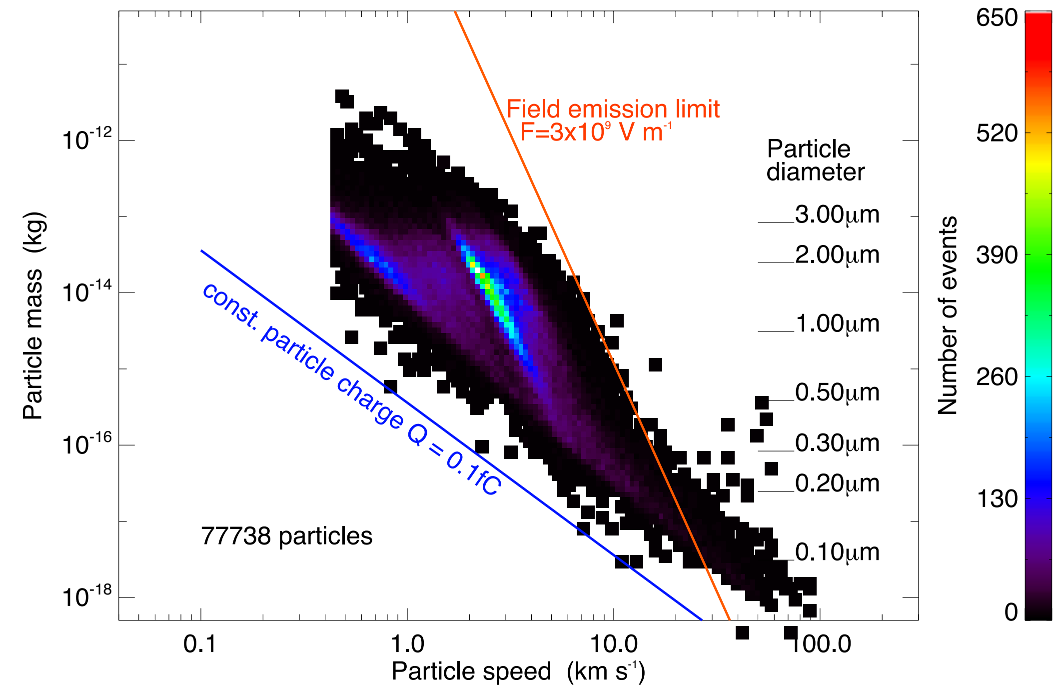
7)) TESTS AT THE SMALL ACCELERATOR – CHALLENGES AND PROBLEMS

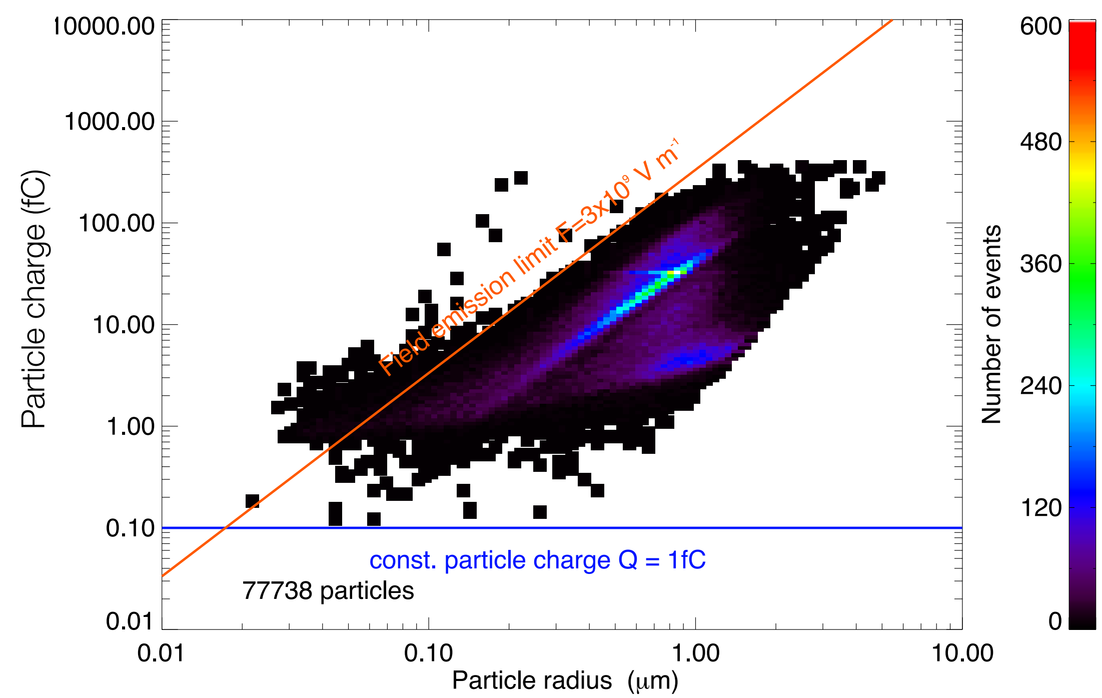
DUST SAMPLE AT THE 20KV ACCELERATOR





2MV ACCELERATOR





SUMMARY

- Proof of concept: The DLD set up is capable of measuring simultaneously the mass, velocity and direction of individual ejecta. The data set not big enough to draw valid conclusions from it.
- The accuracy of the angular measurement is about 1° with the current set up. It can be improved for faster primary impacts by measuring the impact time due to the impact charge
- We were able to obtain a first, rough mass - amplitude calibration for impacts with iron particles.
- This calibration will now be complemented by a calibration with pyroxene particles and enhanced for faster impacts and larger particles at the 2MV dust accelerator

THANK YOU FOR YOUR ATTENTION