Experimental investigation of micrometeoroid ablation using a dust accelerator – preliminary results

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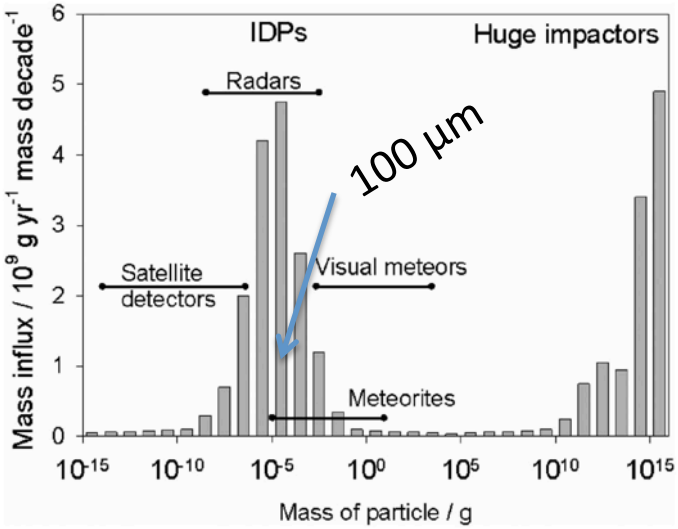
Motivation

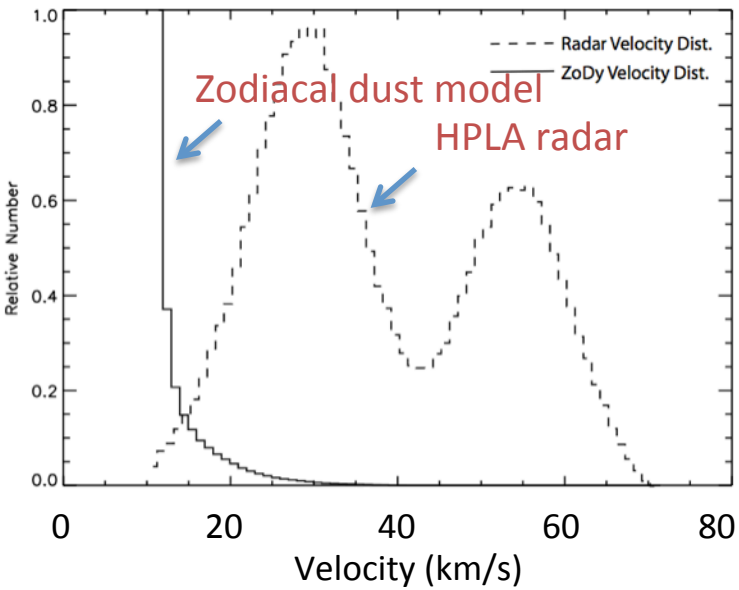
Meteors - incoming cosmic material

Mass distribution, detection techniques



Plane (2012)

Velocity distribution – biased?



Janches et al. (2014)

Unknowns:

- Total mass input (5-200 tons/day)
- Velocity distribution – what is the bias of radar measurements?
- Origin/composition (cometary/asteroidal)

Ablation model

$$\frac{dV}{dt} = -\Gamma V^2 \frac{3\rho_a}{4\rho_m R}$$

Momentum equation, **Γ = molecular drag coefficient**

$$\frac{1}{2}\pi R^2 V^3 \rho_a \Lambda = 4\pi R^2 \varepsilon\sigma (T^4 - T_{env}^4) + \frac{4}{3}\pi R^3 \rho_m C \frac{dT}{dt} + L\frac{dm}{dt}$$

Energy conservation (heating) equation
Λ – heat transfer coefficient

$$\frac{dm_i^A}{dt} = \gamma\, p_i S \sqrt{\frac{\mu_i}{2\pi k_B T}}$$

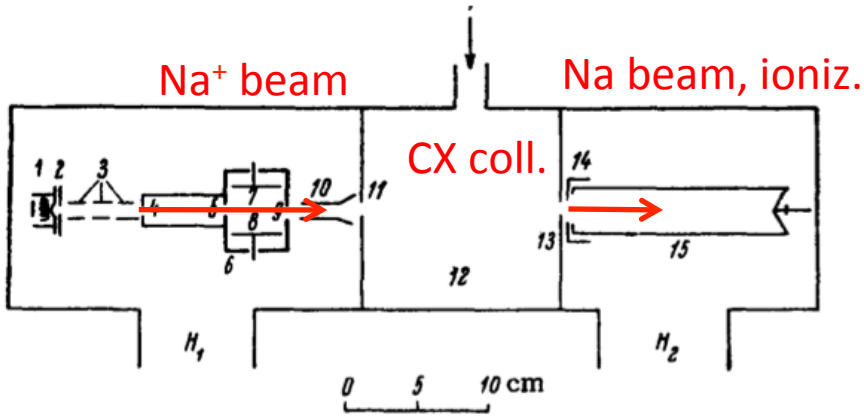
Mass loss rate, **γ** = uptake coefficient

(dm/dt) * β(v) = ionization rate

Ionization efficiency

Old ionization efficiency measurements

1- Ionization cross section measurements



Na, K on N2, O2, etc

Bydin & Bukhteev, 1960
Moutinho et al., 1971
Cuderman et al., 1972
Kleyn et al.,1978

2- Dust accelerator/ablation measurements

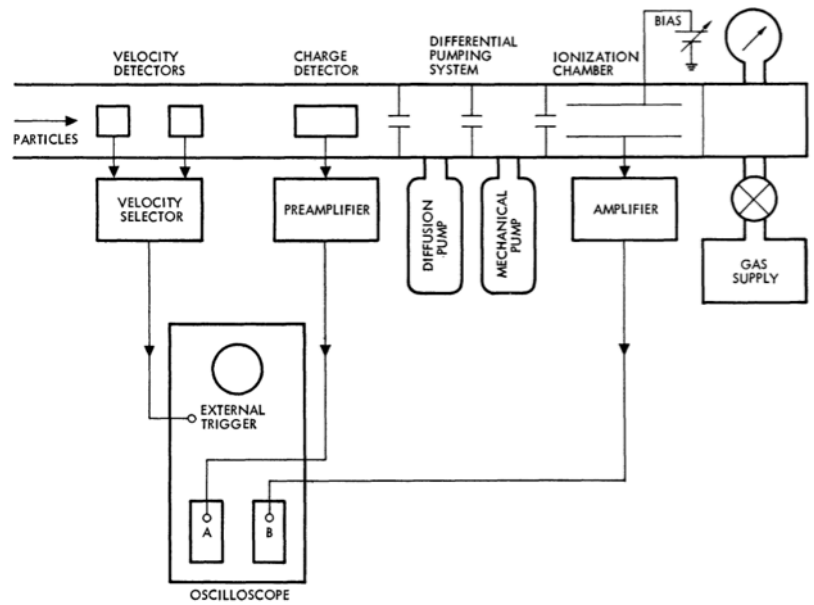


FIG. 1.—Block diagram of experimental configuration

Fe, Cu on N2, Ar, CO2, air, etc
(20 – 45 km/s)

Slattery and Friichtenicht, 1966
Friichtenicht et al., 1967
Friichtenicht and Becker, 1971

Slattery and Friichtenicht, 1967

Experimental setup

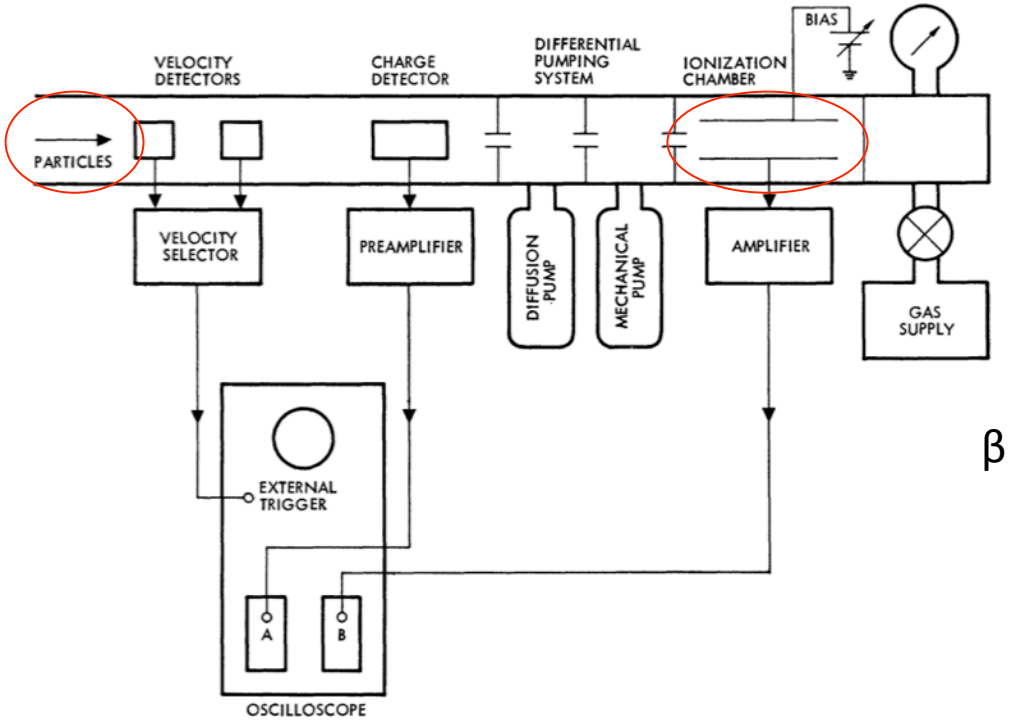
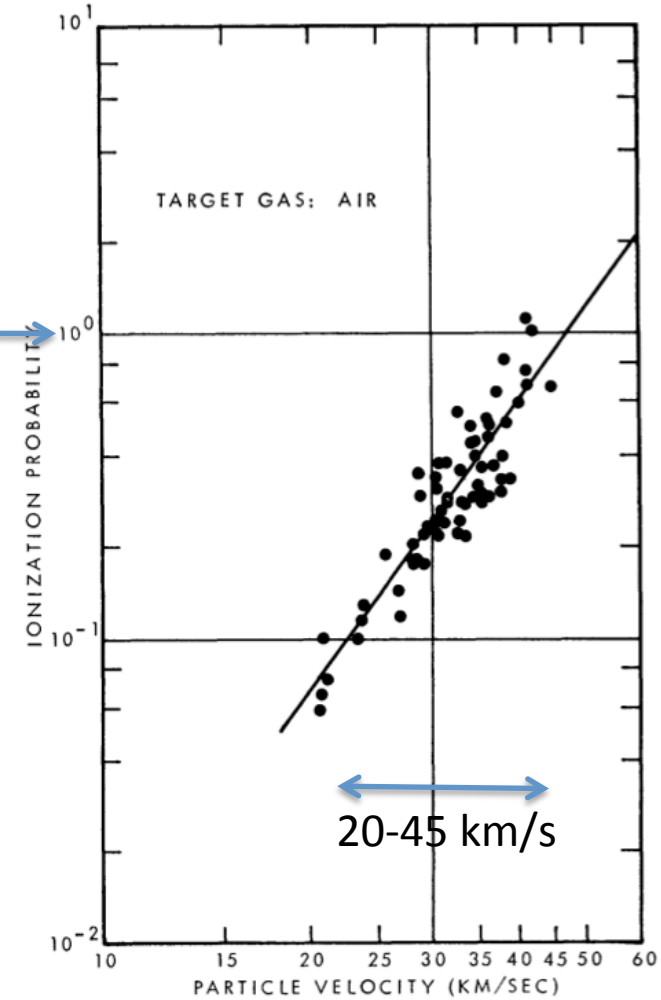


FIG. 1.—Block diagram of experimental configuration

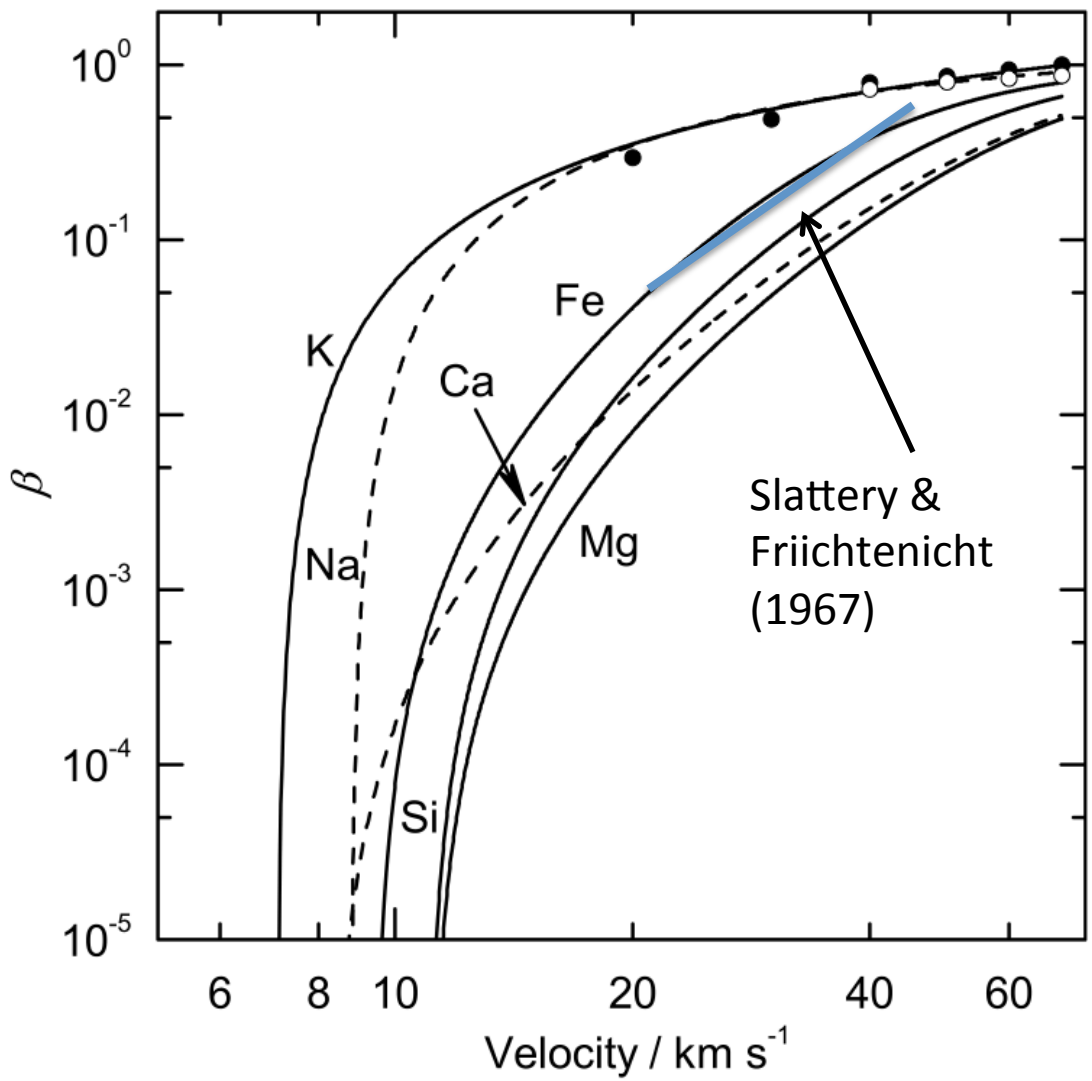
Experimental data



β =1

$\beta_{Fe} = 5.96 \times 10^{-6} \times v^{-3.12}$
(measured in ***air***)

β(v) poorly constrained by experimental data



$$\beta_0 = \frac{c(v - v_0)^2 v^{0.8}}{1 + c(v - v_0)^2 v^{0.8}}$$

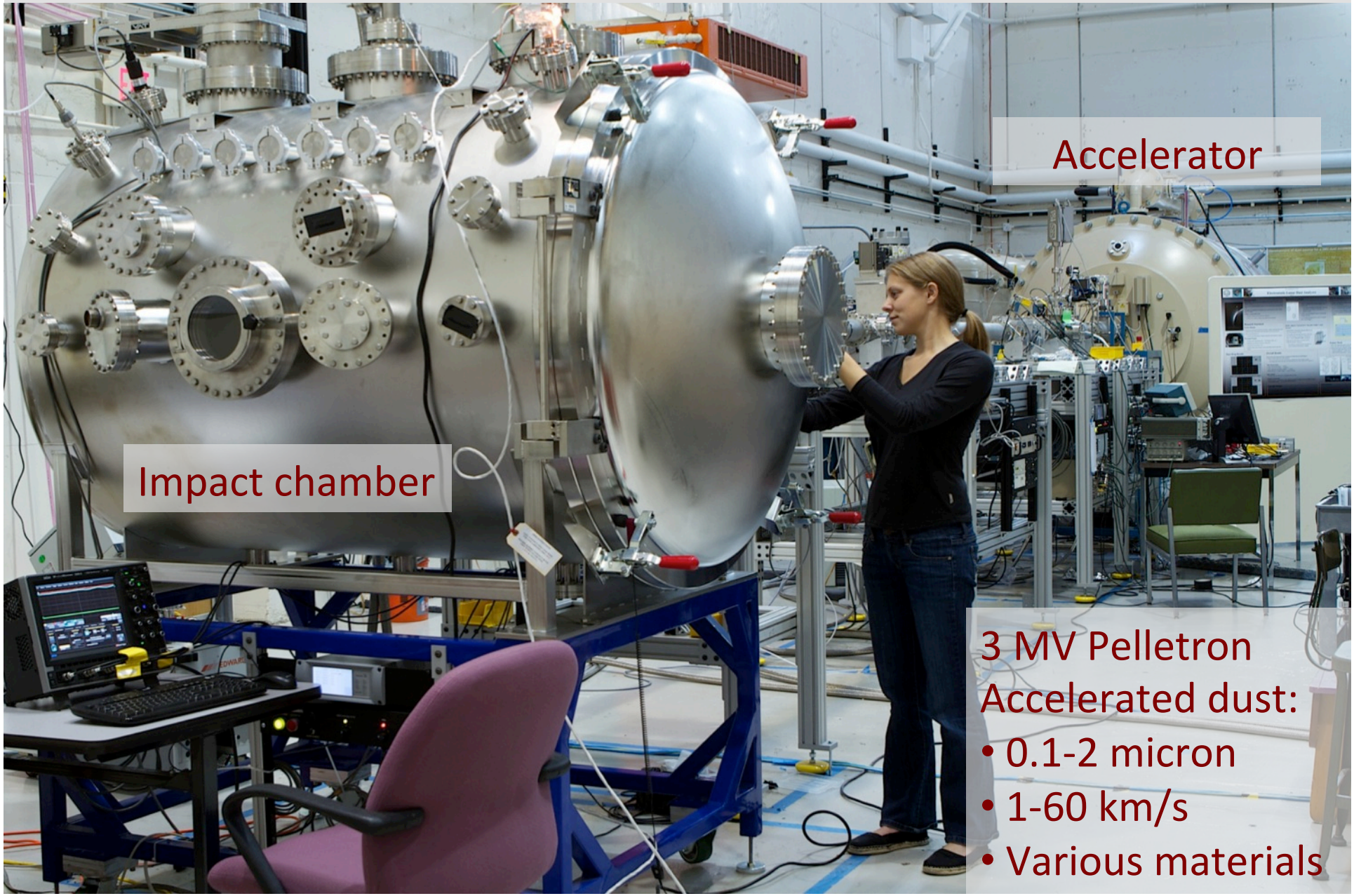
Jones (1997)

Minimum ionization speed:

$$v_0^2 = \frac{2(m + M)}{mM}\varphi_{IE}$$

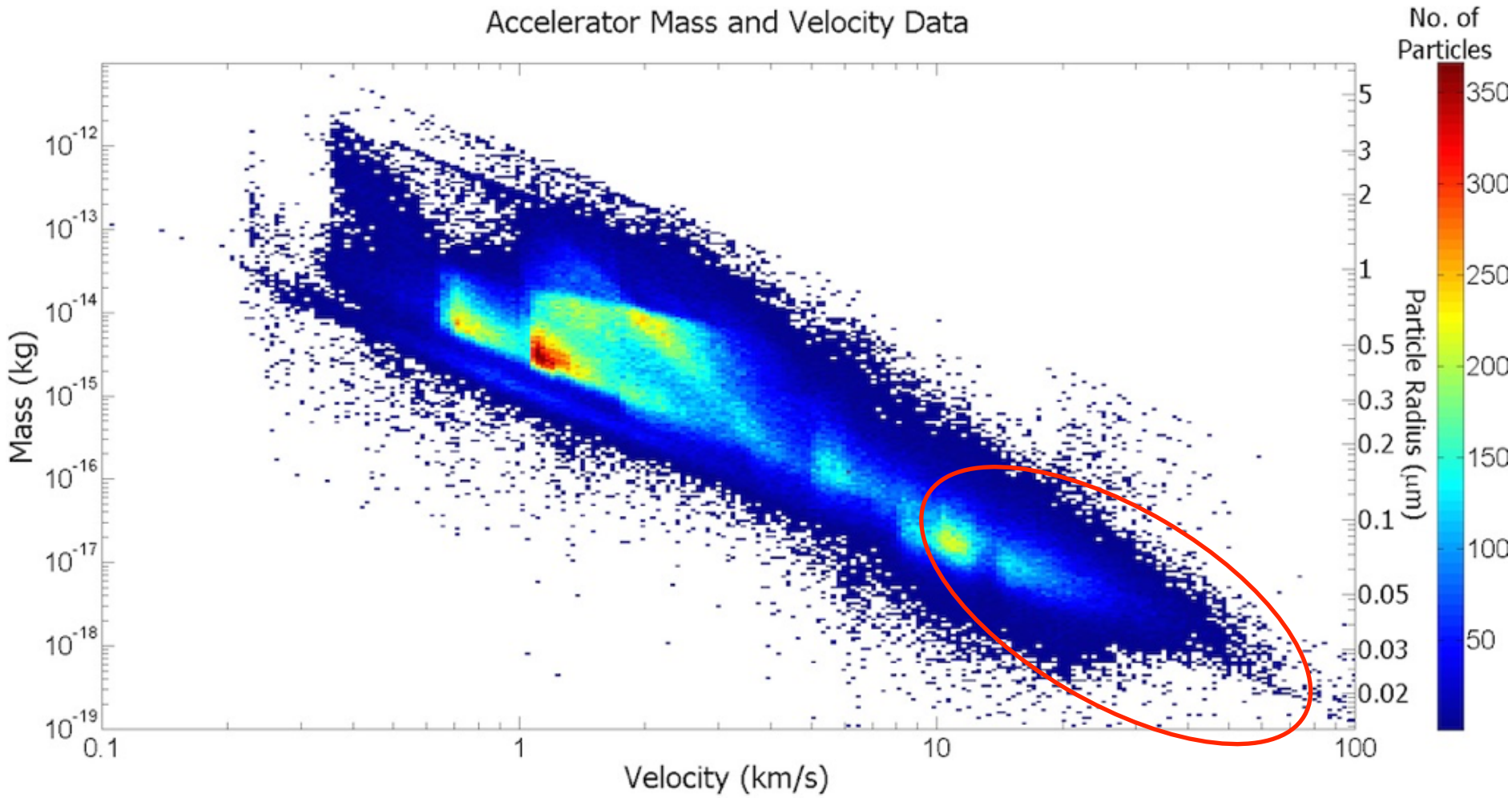
From Vondrak et al.(2008)

The dust accelerator facility at the Univ. of Colorado

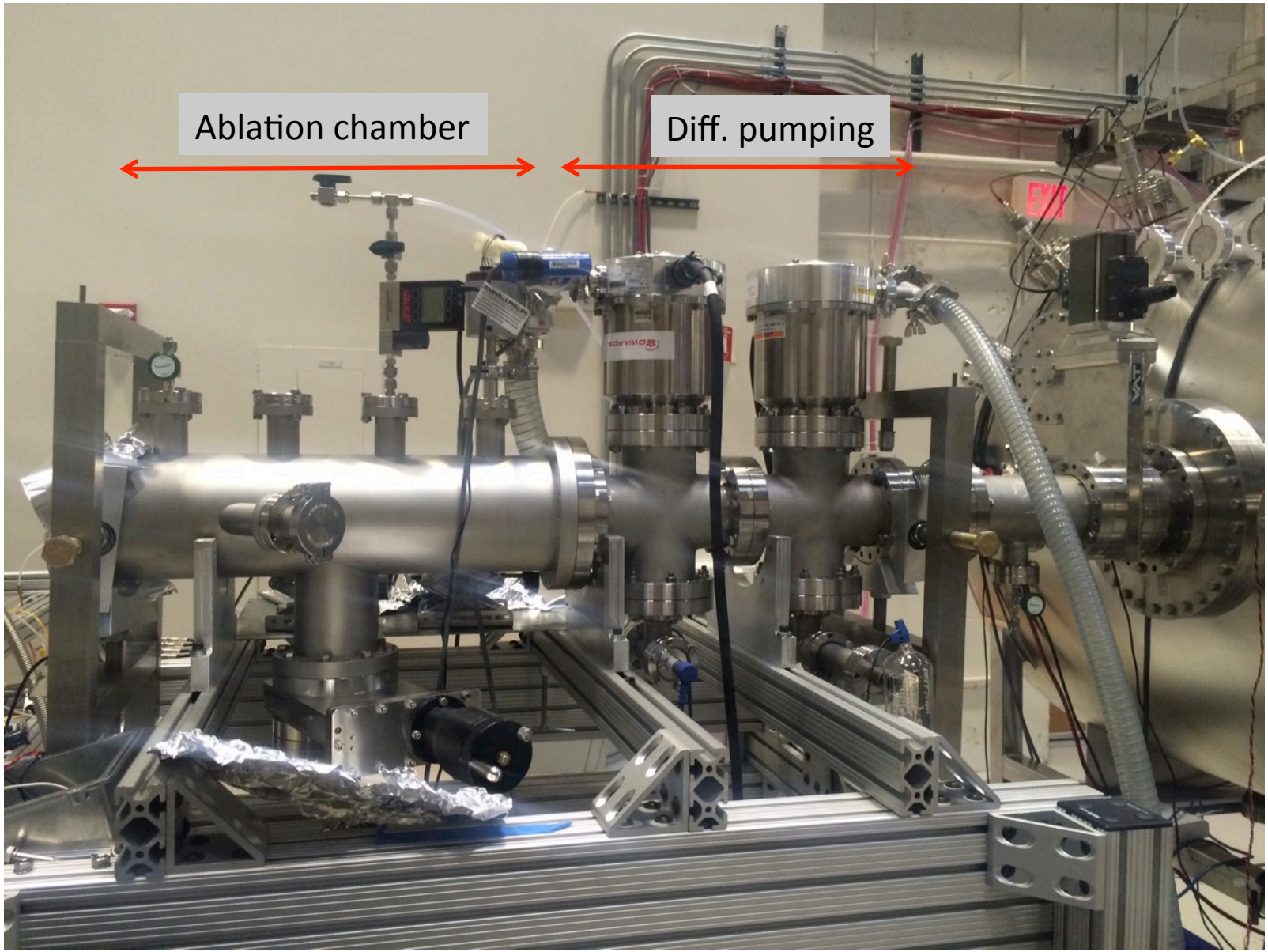


3 MV Pelletron
Accelerated dust:
- 0.1-2 micron
- 1-60 km/s
- Various materials

Particle mass vs. velocity distribution



The ablation facility



What's inside

Segmented and biased charge collectors

Accelerator beam line

Differential pumping system

Ablation chamber (50 cm long)

Shielding grid and segmented collectors

10^{-7} Torr

10^{-5} Torr

10^{-3} Torr

0.02 – 0.5 Torr

Incoming dust

Electric signals

Impact detector

Pick-up detector

Skimmers

Gas inlet

Vacuum pump (125 l/s)

Vacuum pump (300 l/s)

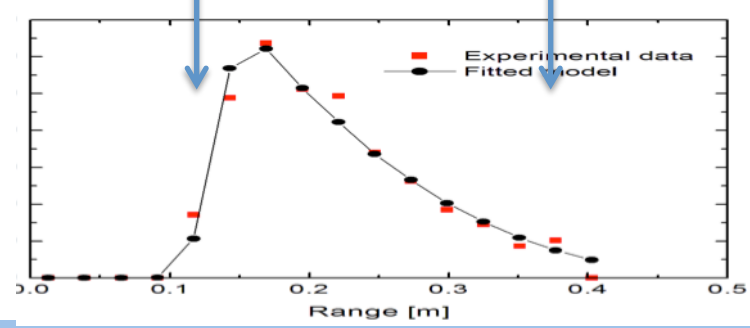
Vacuum pump

Pressure gauge

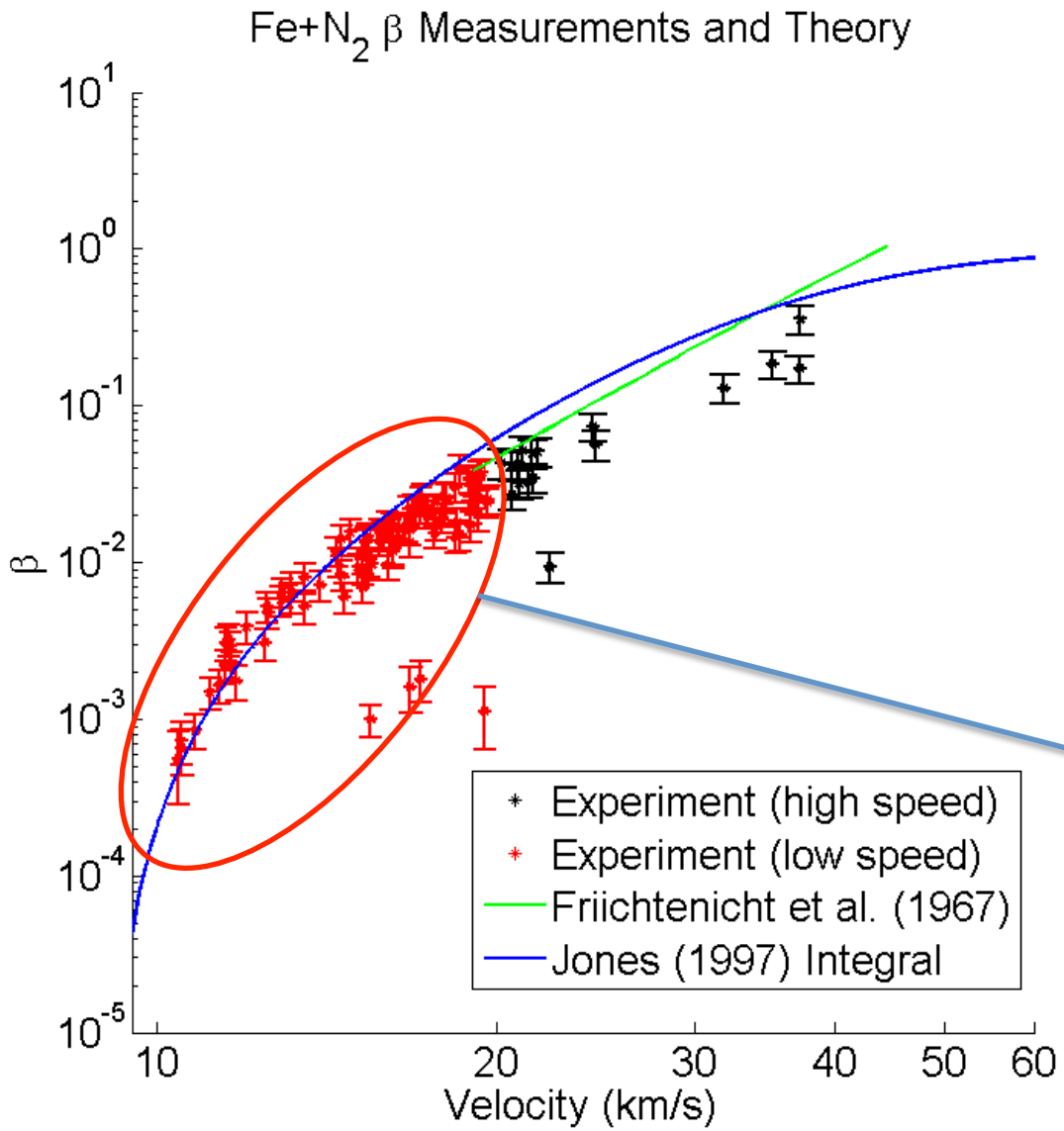
Accurate velocity measurement

Calibrated charge (mass) measurement

$$\frac{1}{2}mv^2 = QU_p,$$

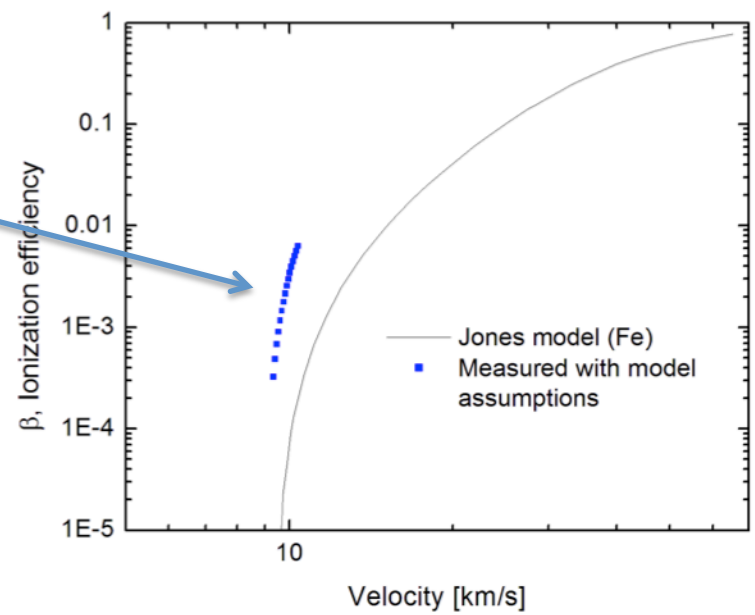


Ionization efficiency, Fe + N_2

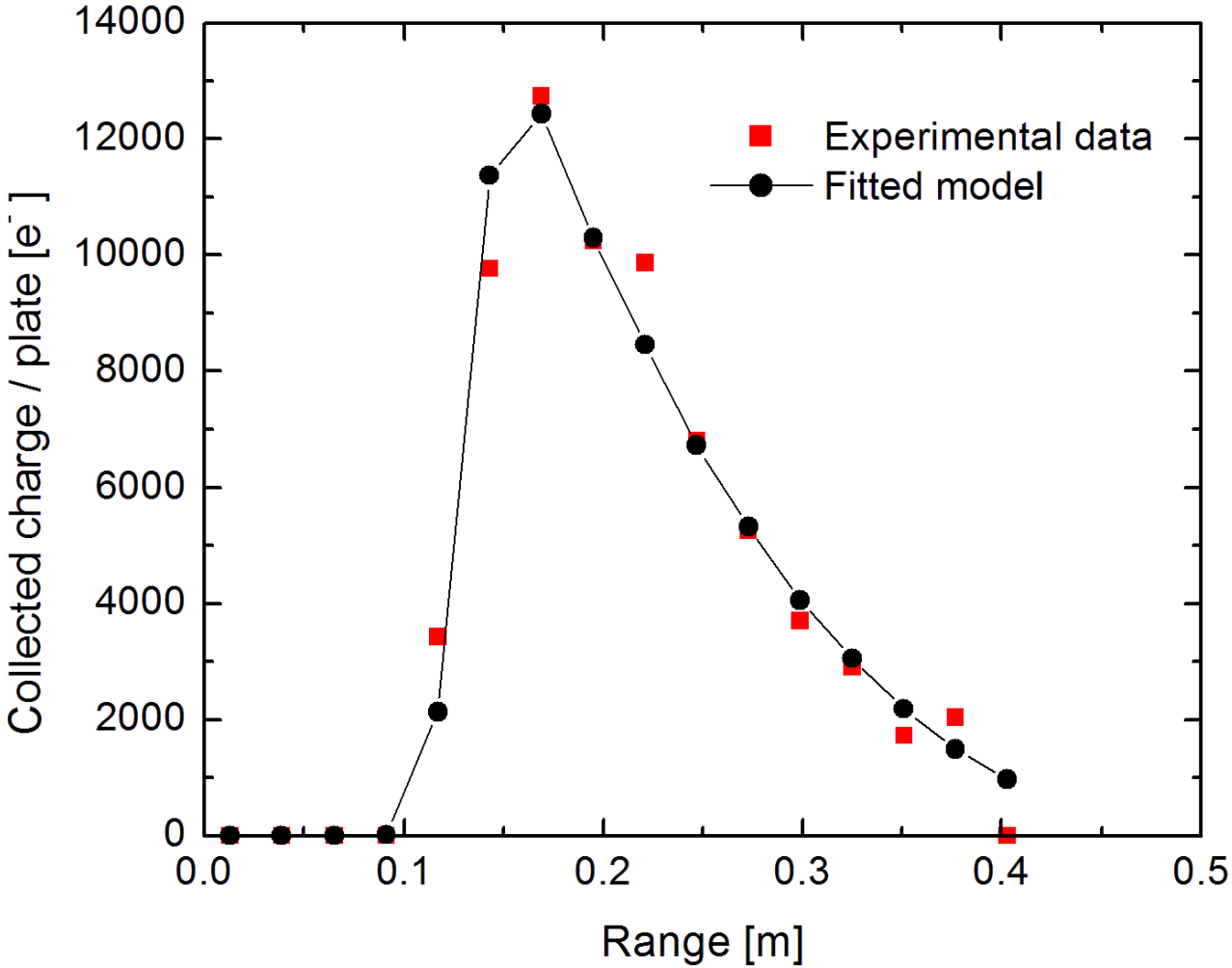


Complete ablation: β =

$$\frac{\text{Charge collected } (e^-)}{\text{\# of Fe atoms in dust}}$$



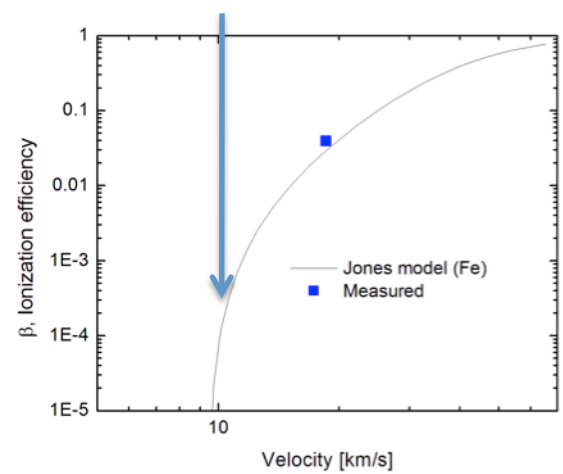
Recorded data sample



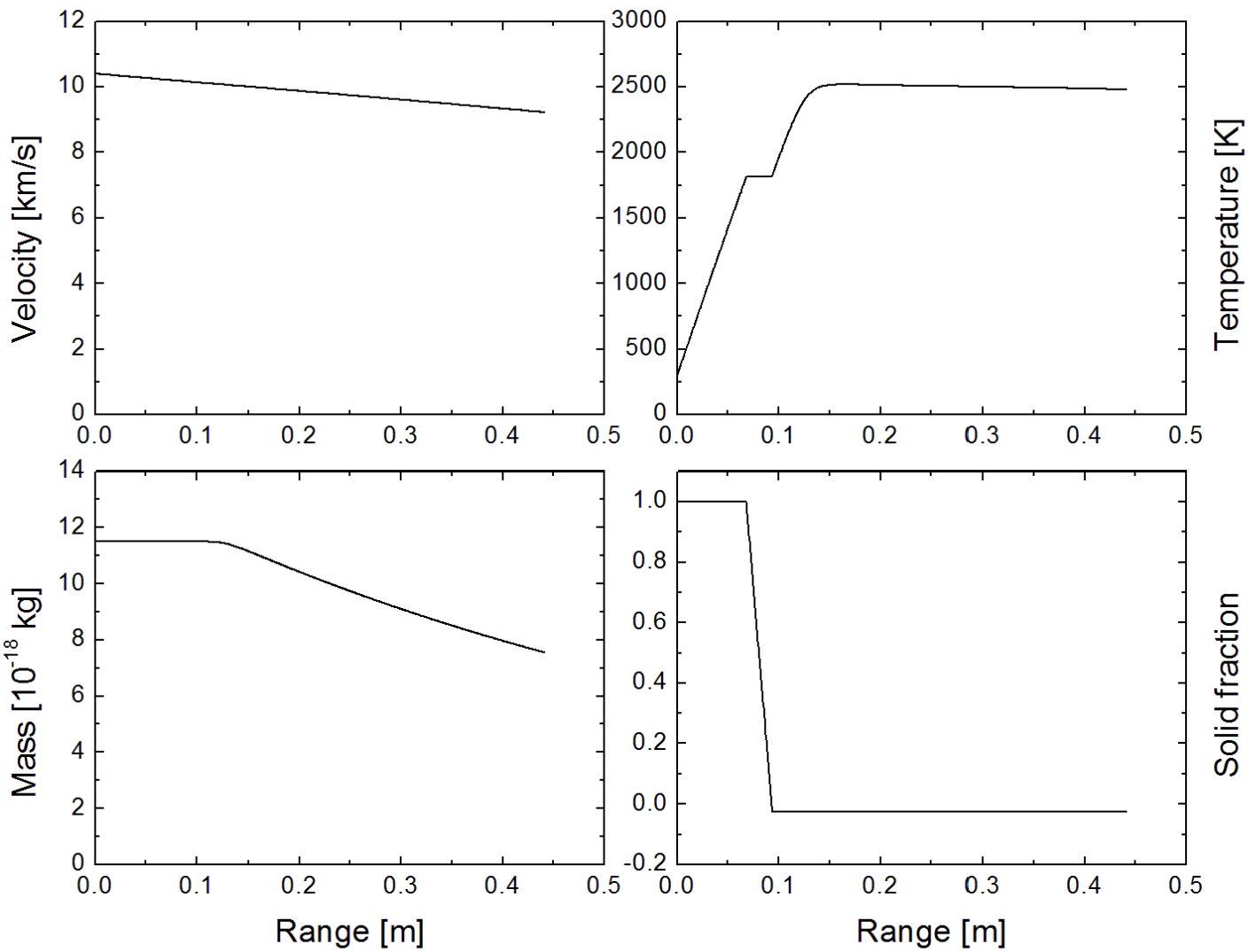
10.4 km/s
~70 nm in radius

Fit parameters:
Γ = 0.75
Λ = 0.55

β is strongly varying with velocity



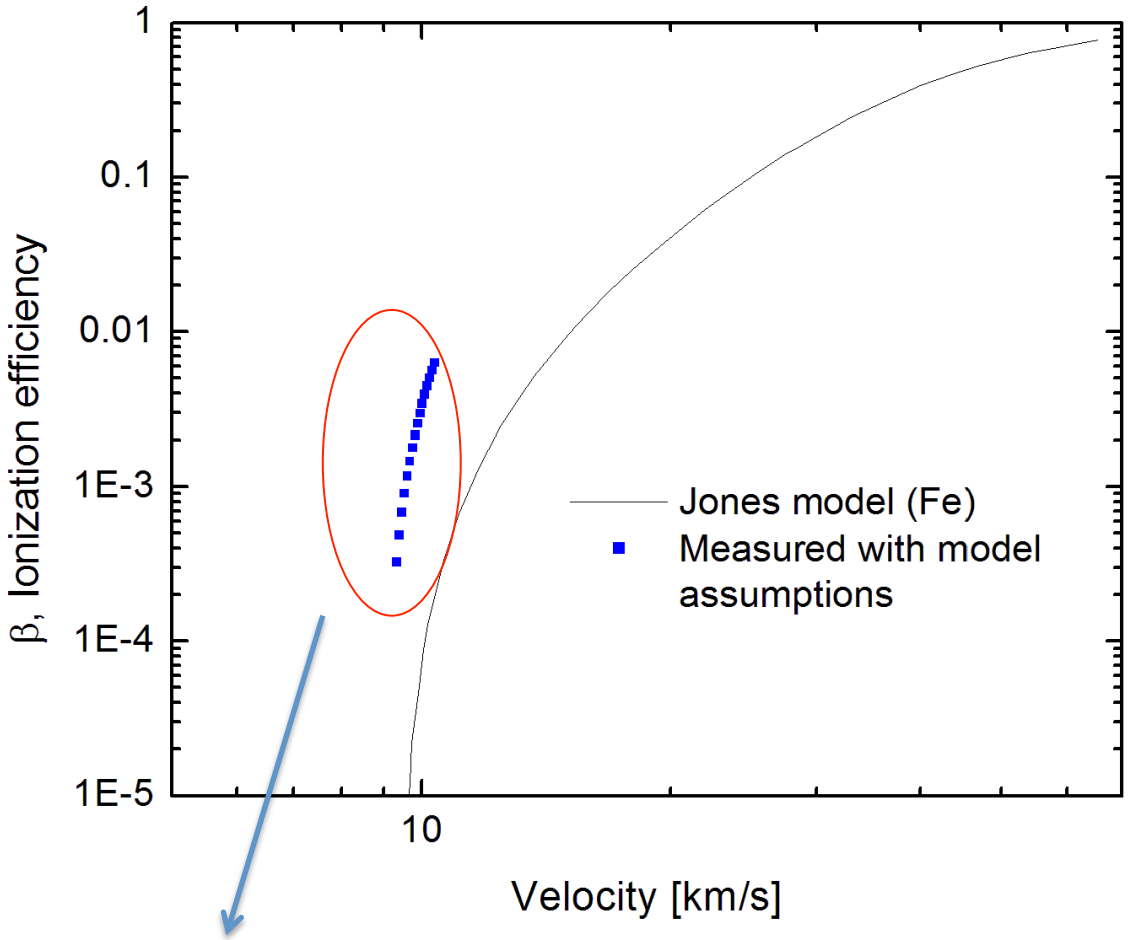
Sample solution



10.4 km/s = v

~70 nm = r

Slow particle



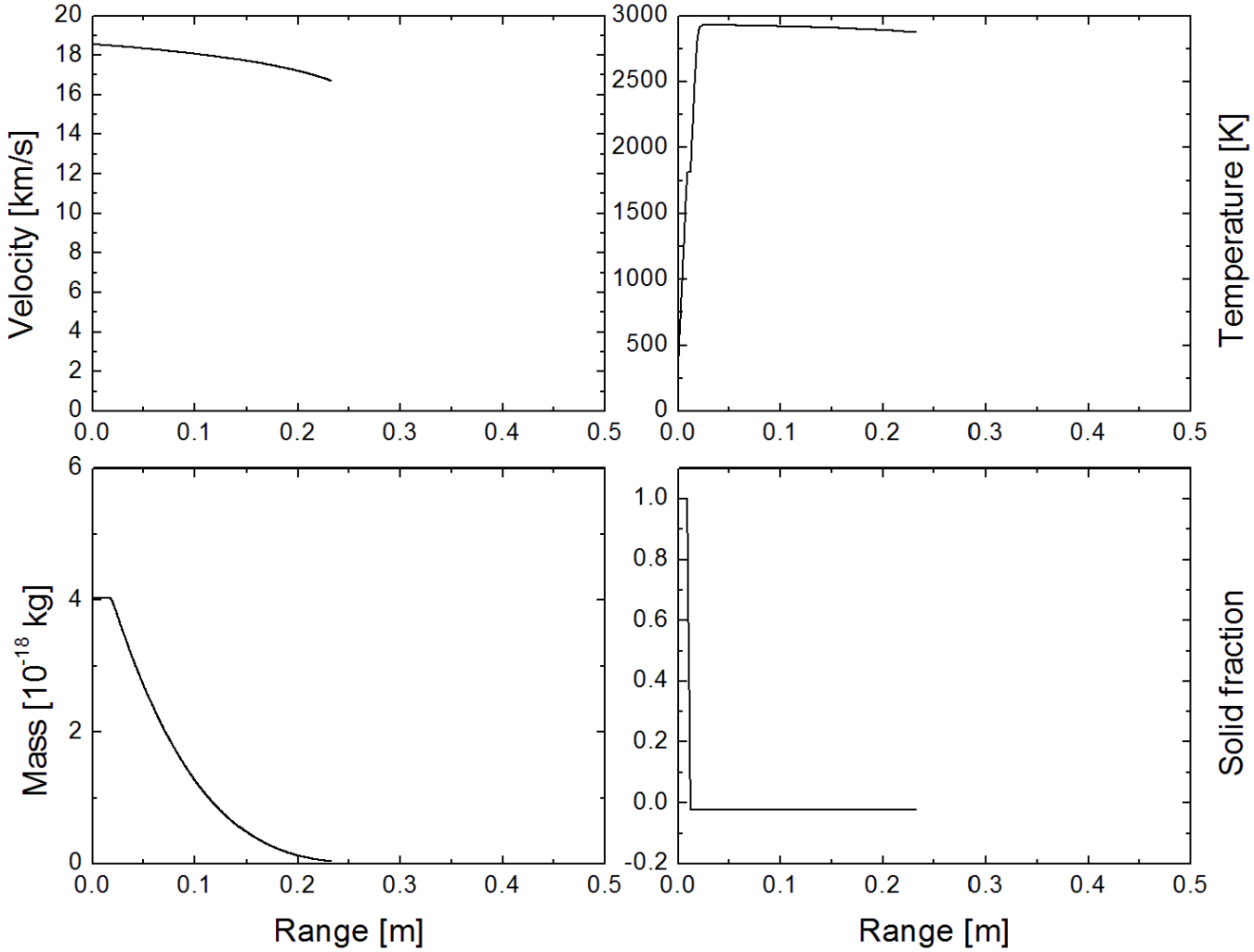
β will depend on parameters in the ablation mode and the assumed shape of β(v)

Need to consider change of velocity during the ablation process

The calculation of mass loss over each collection plate is dependent on the ablation model and parameters used (uncertainty)

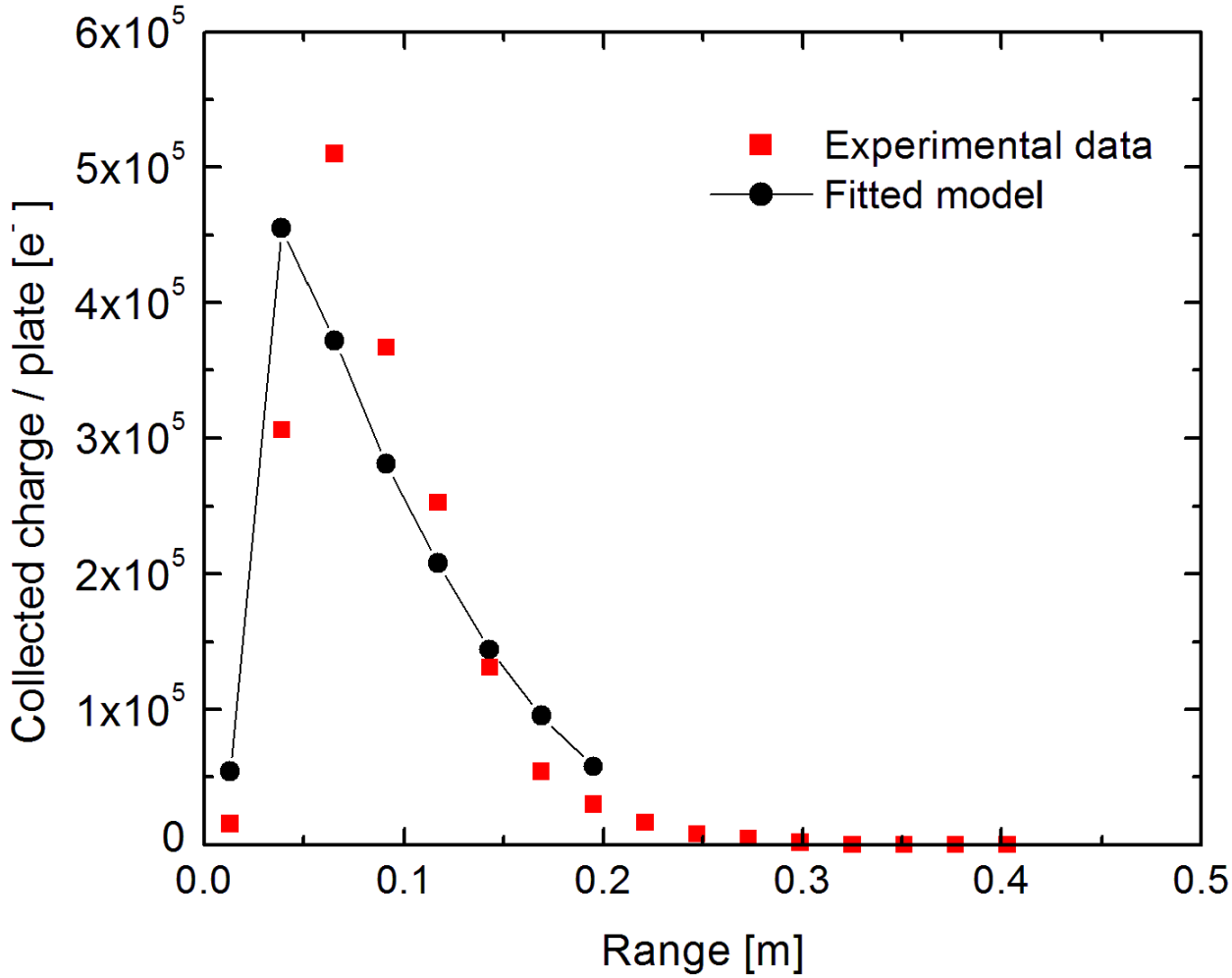
Need to analyze a large assemble of particles for reliable find the fitting parameters

Fast particle



18.6 km/s
~50 nm in radius

Fast particle

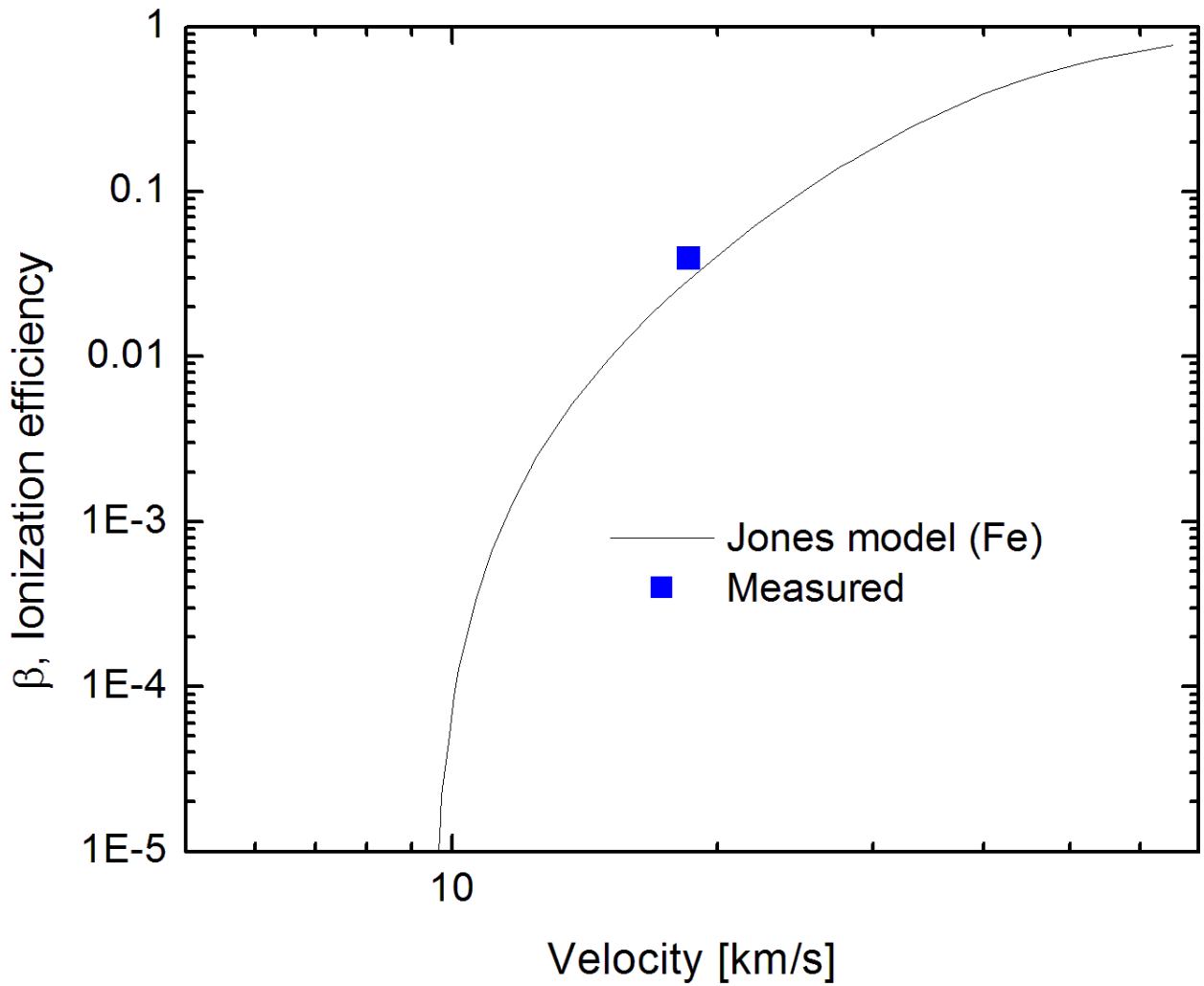


18.6 km/s
~50 nm in radius

Γ = 0.5 (insensitive)
Λ = 0.9

Better fit not achieved for realistic Γ and Λ values

Fast particle



Summary/Conclusions

- There is a need for better β (v) data and in particular at lower velocities
- New ablation facility operating at CU (open to collaboration)
- Good quality preliminary measurements already obtained for > ~ 20 km/s
- More careful analysis is needed at low velocities

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