Microjetting sous choc laser

D. Loison, B. Jodar,

C. Roland, T. de Rességuier,

E. Brambrink

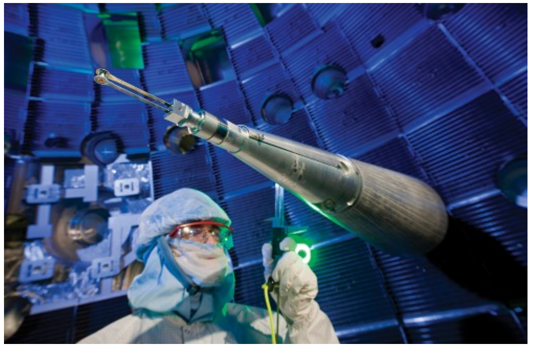
A. Sollier, E. Lescoute, G. Prudhomme, P. Mercier

L. Berthe

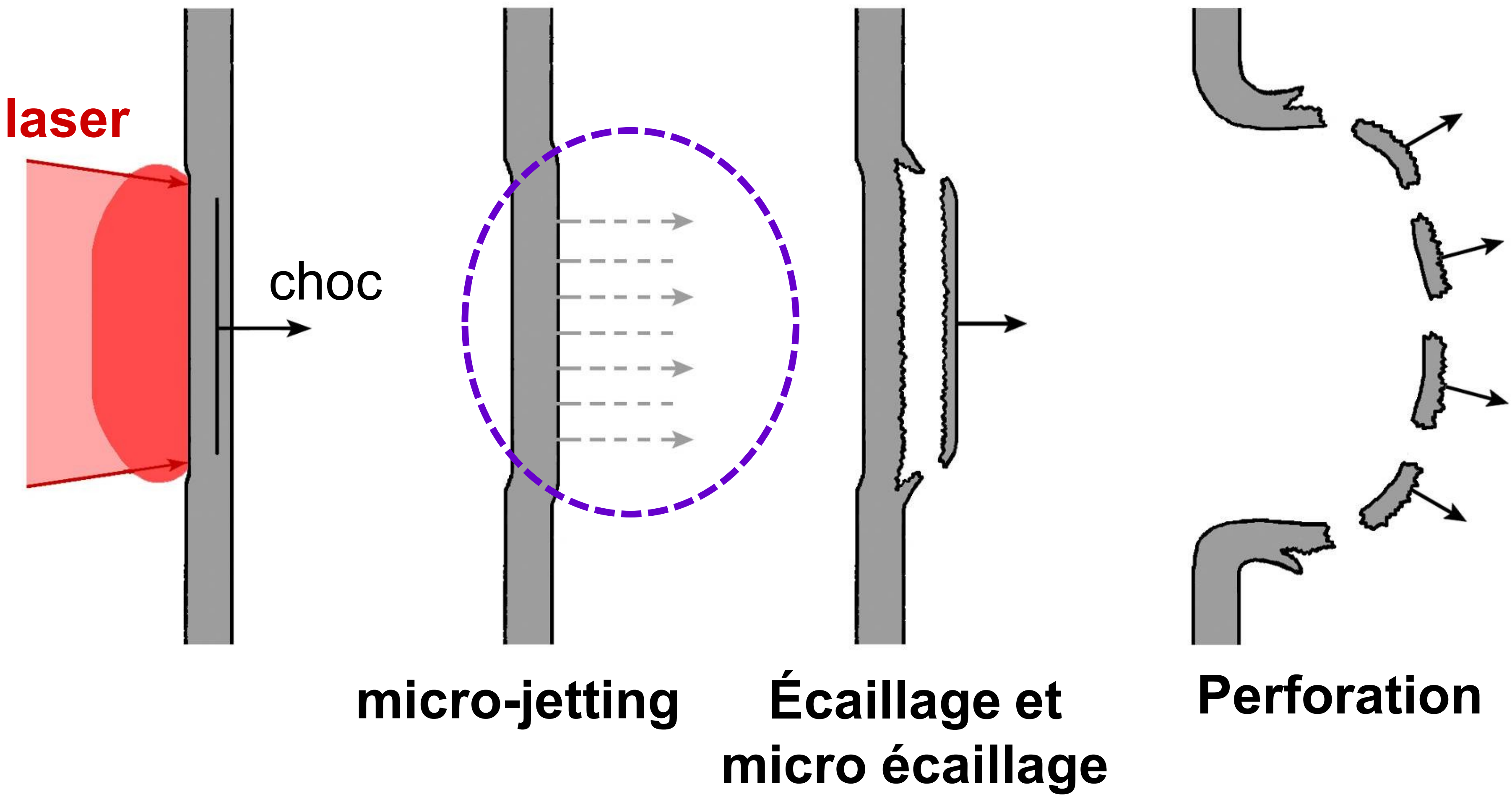
Expérience de choc laser

- sciences des matériaux à haute vitesse de déformation (~ 10^7 s^{-1})
  - Impact hypervéloce (B. Aubert)
  - Equation d'état et loi de comportement en conditions extrêmes (J.P Guin, B. Jodar)
  - Procédés de contrôle de systèmes industriels (R. Ecault)

- prédire la production de débris et leurs propriétés balistiques notamment pour le "terme source" du LMJ



Processus de fragmentation



➡ Diversité de tailles de fragments et de vitesse d'éjection

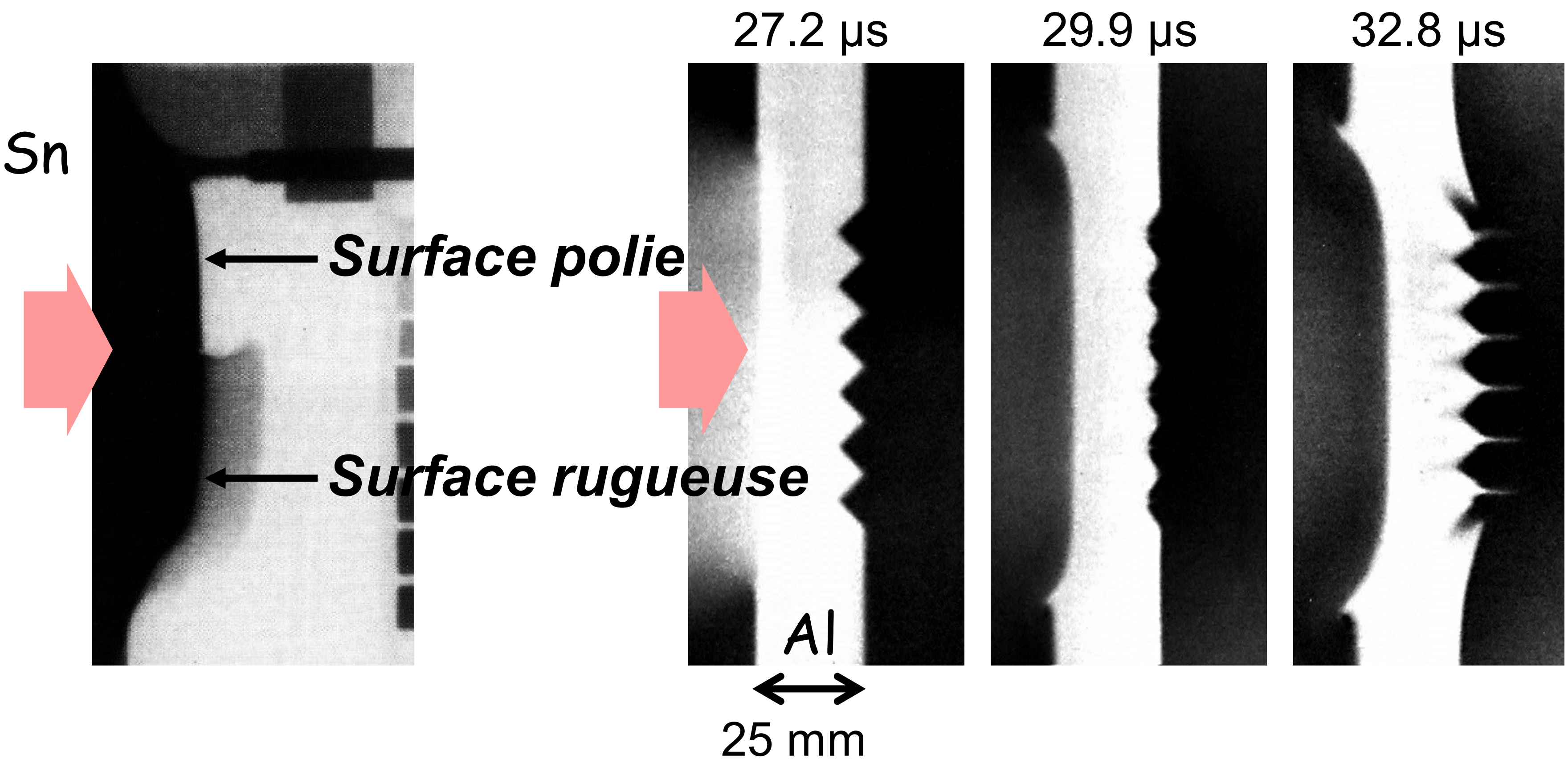
Premiers travaux sous explosif

Rugosité 'aléatoire'

Chapron, **CEA**, 1983

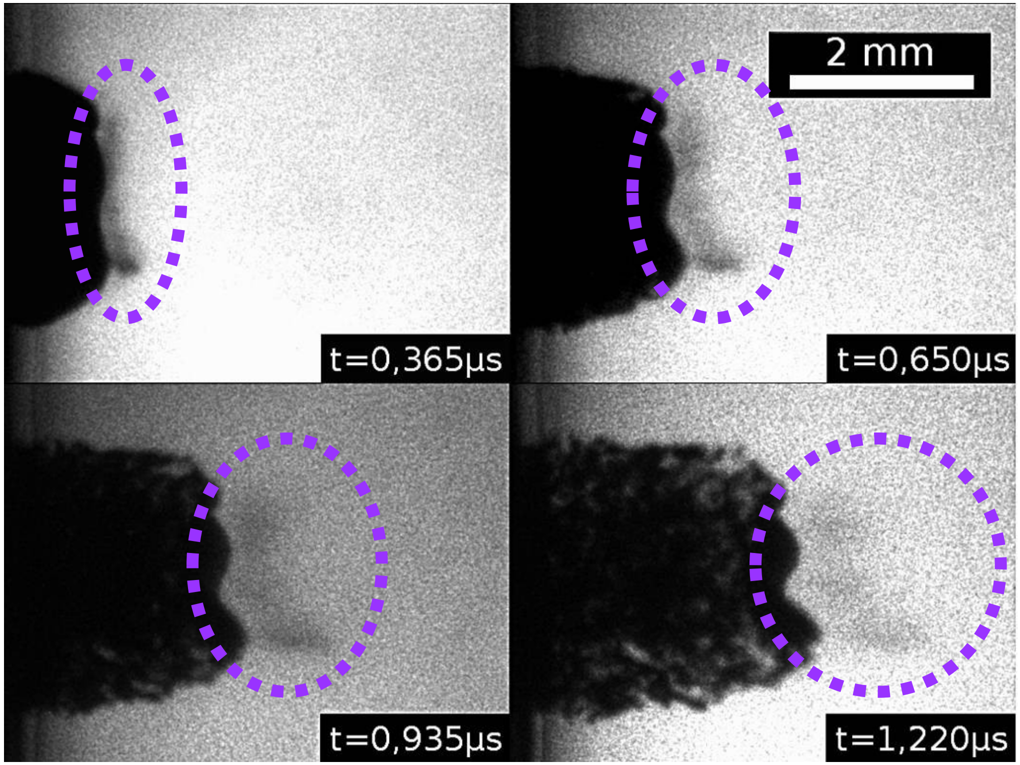
Défauts calibrés

PHERMEX facility, **LANL**, 1960s



Micro-jetting 'naturel' sous choc laser

Al, 200 µm, 58 GPa

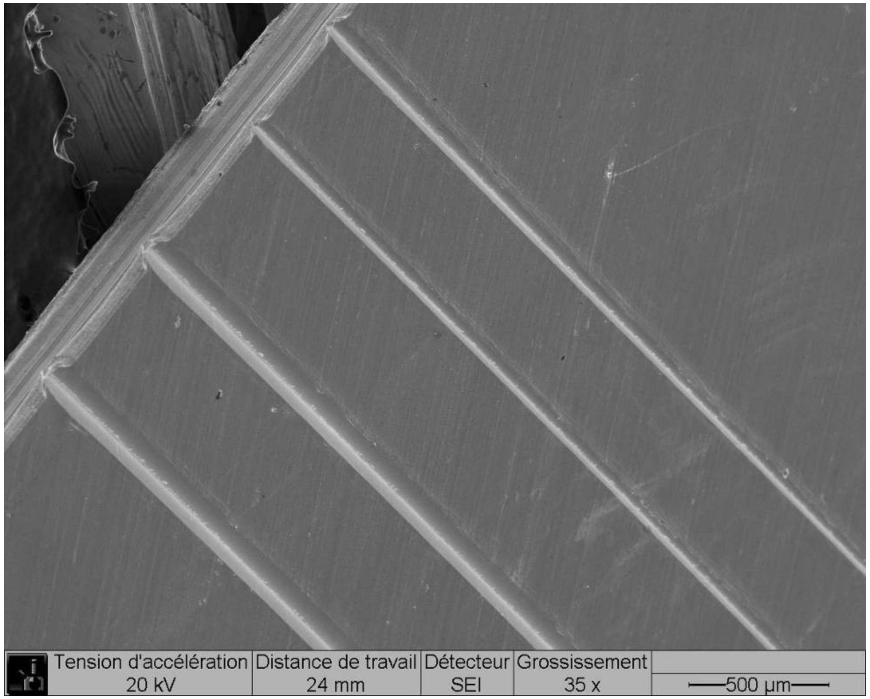


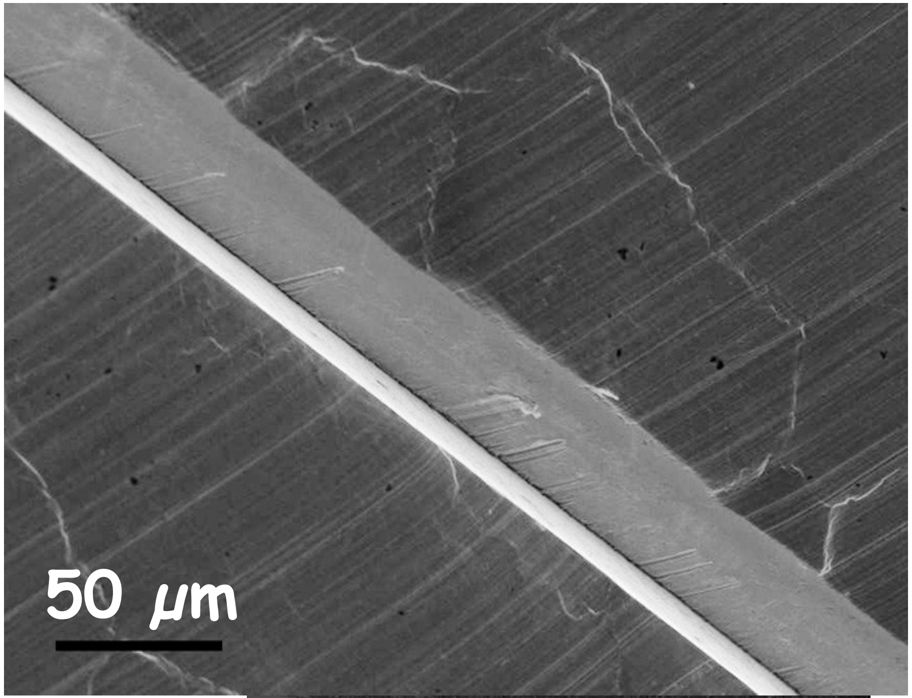
écaille ~ 1996 m/s
têtes de jets ≈ 3000 m/s

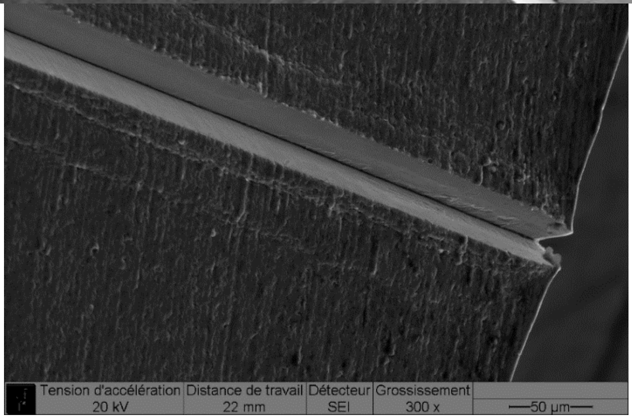
~~VISAR~~

Thèse Emilien Lescoute - 2010

Rainures triangulaires



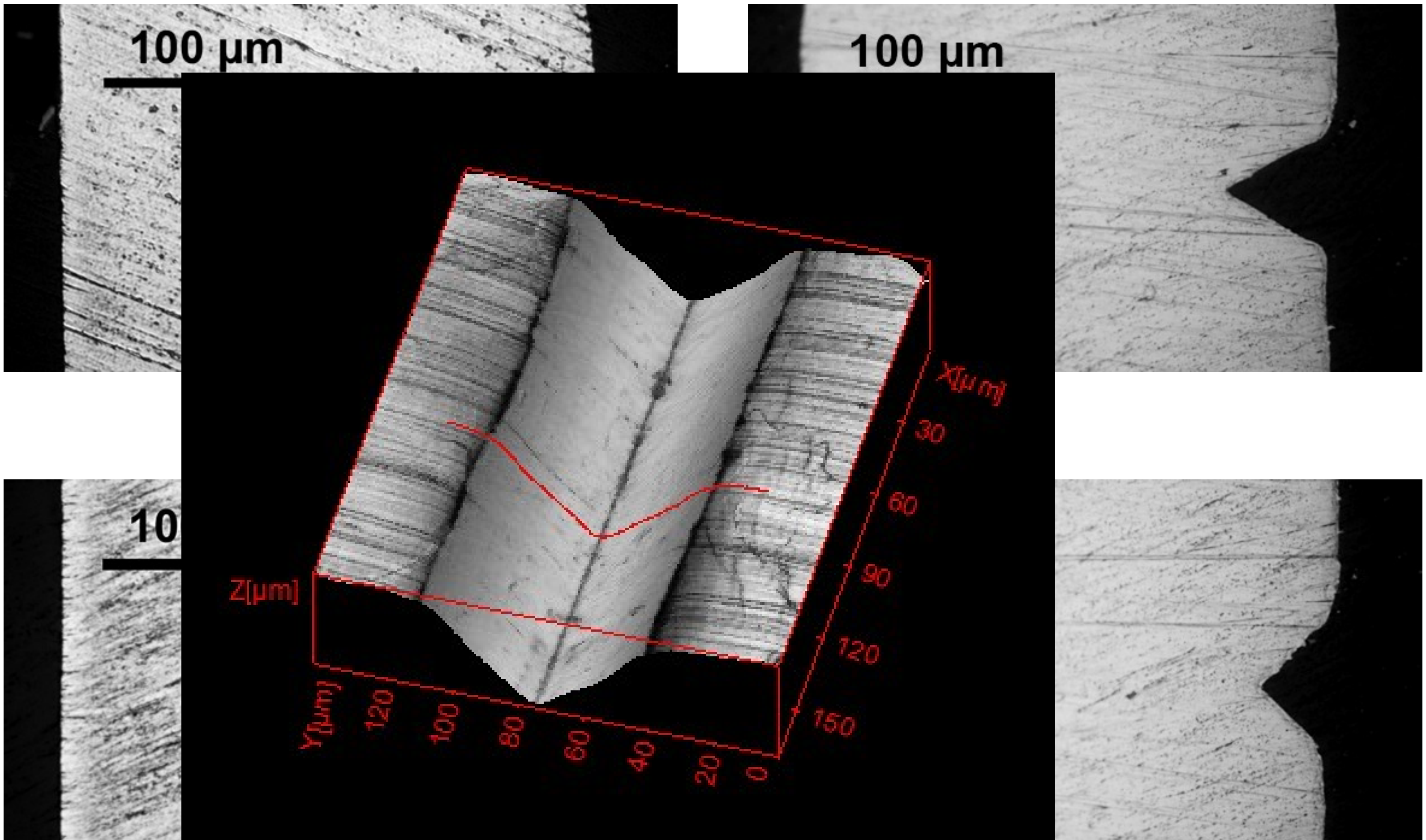




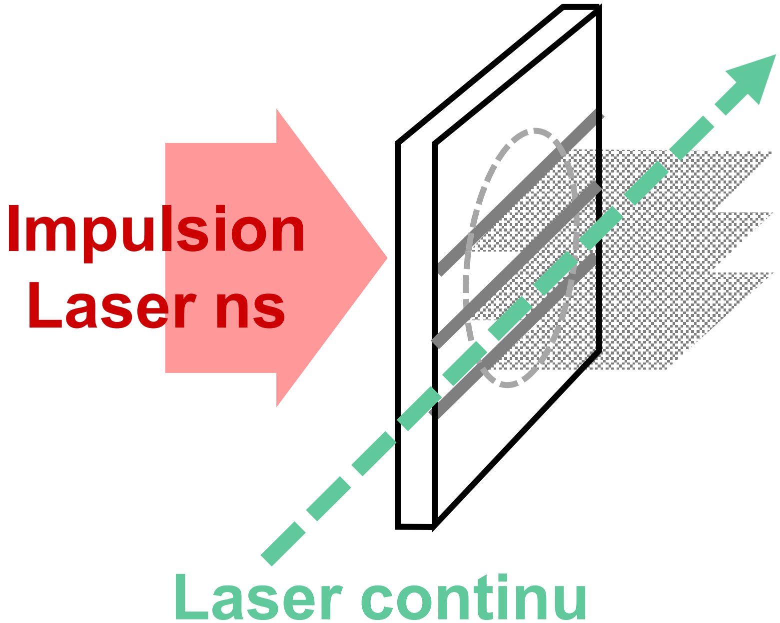
- ✓ Al, Sn, Au, Cu, Pb ~300 µm
- ✓ demi-angles 20°, 30°, 45°
- ✓ profondeurs ~50 µm

Rainures triangulaires

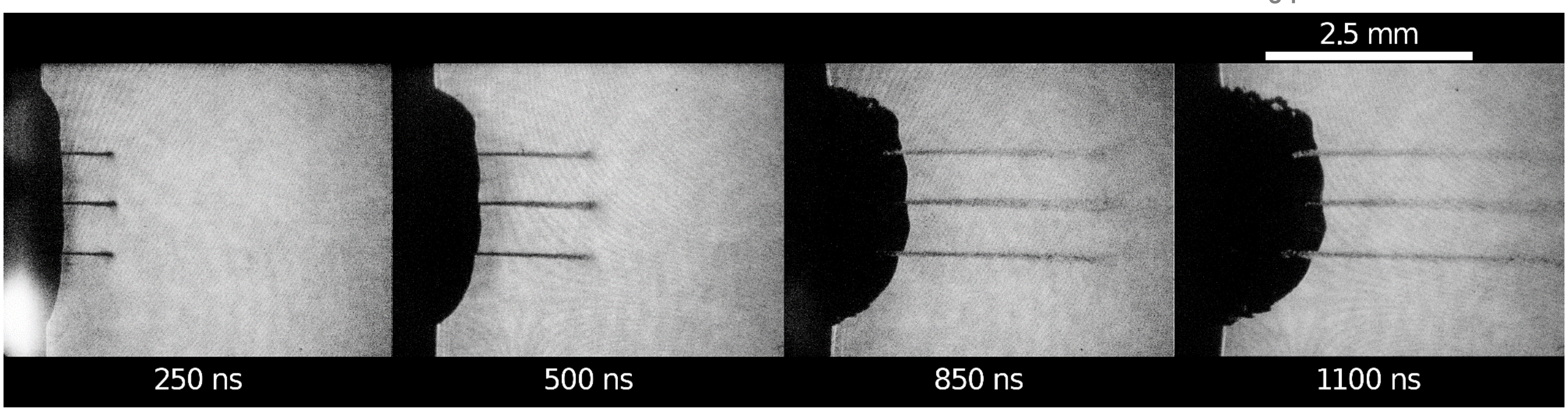
- ✓ Al, 20° et 30°
- ✓ Sn, 30° et 45°



Visualisation transverse



Cu 250 µm
Demi angle 20°
I = 3.48 TW/cm²
P_{SB} = 33.4 GPa
V_{FS} = 1.28 km/s
V_{JT} = 4.3 km/s

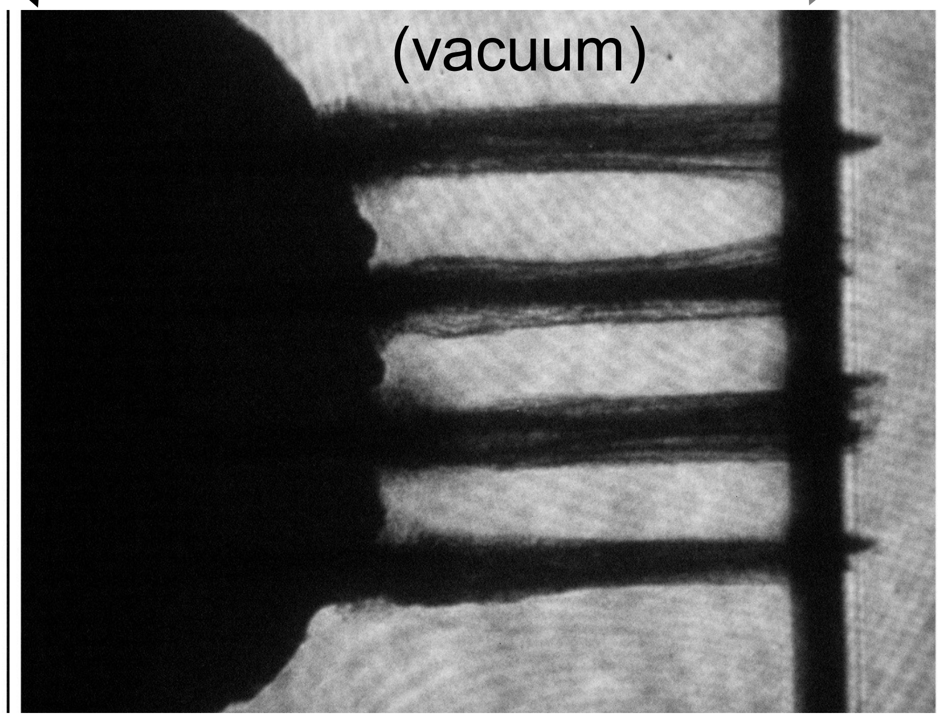


Visualisation transverse

Sn 300 µm, demi-angle 30°

(Cu 20 µm)

73 GPa

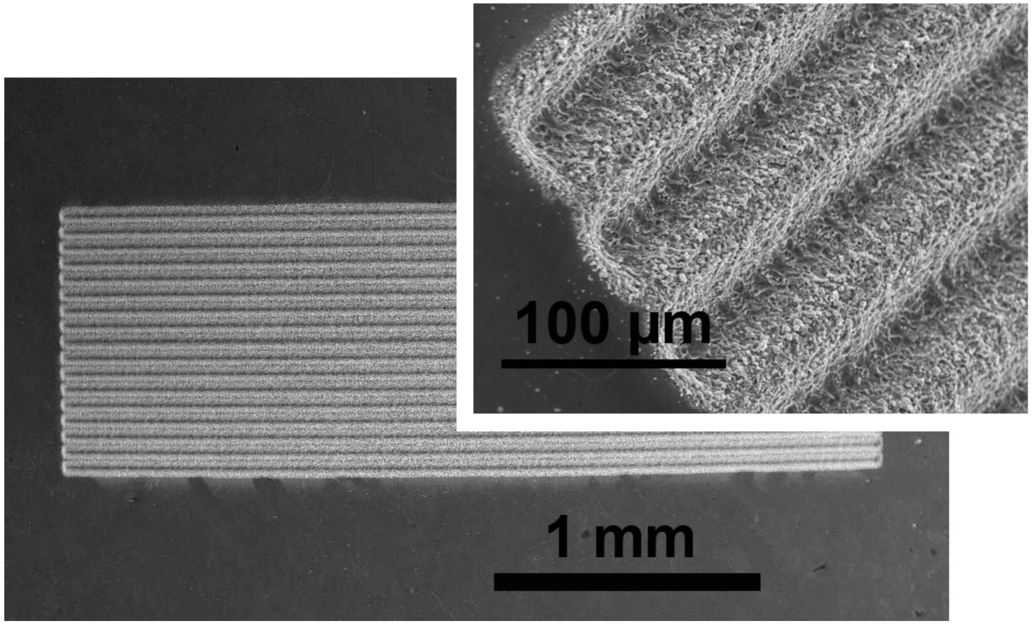


► 1,39 km/s

► 3,84 km/s

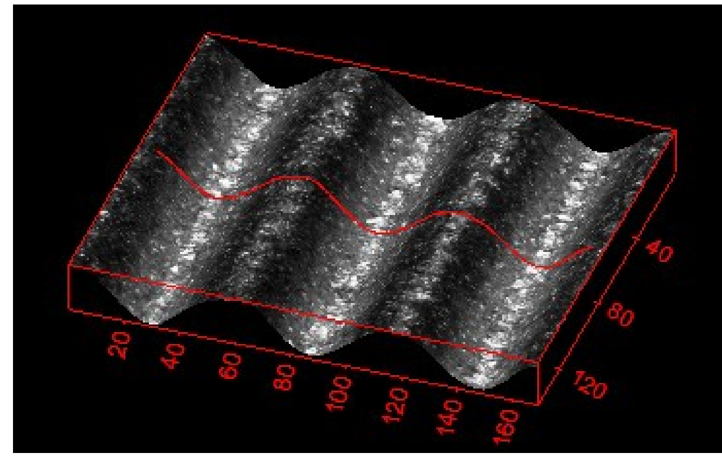
t_0 + 8600 ns

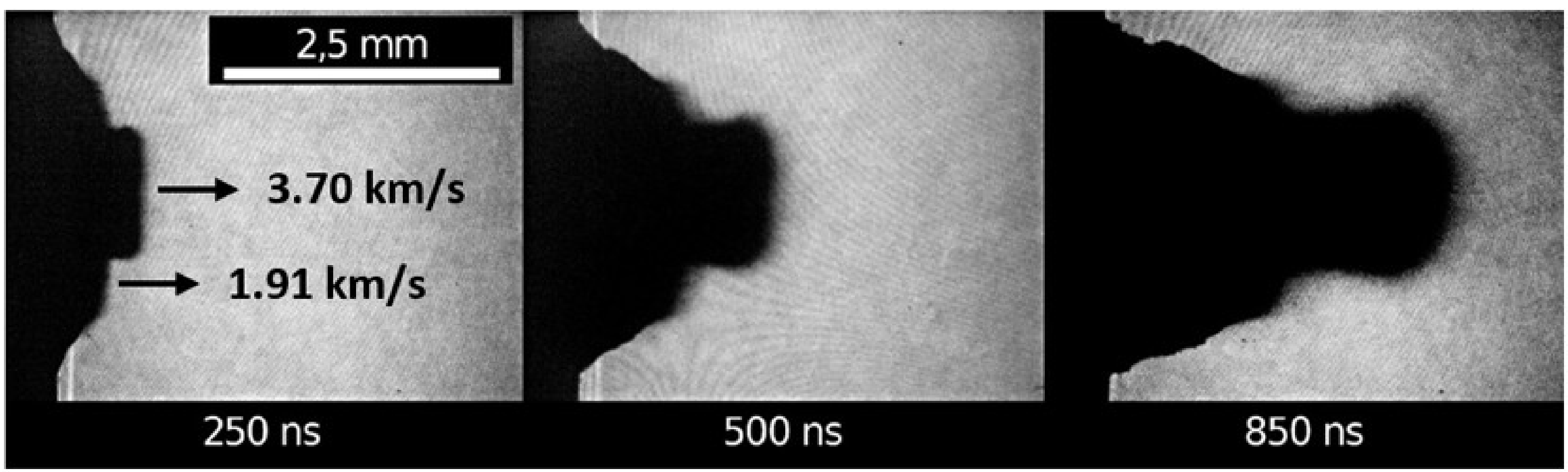
Rainures périodiques (1)



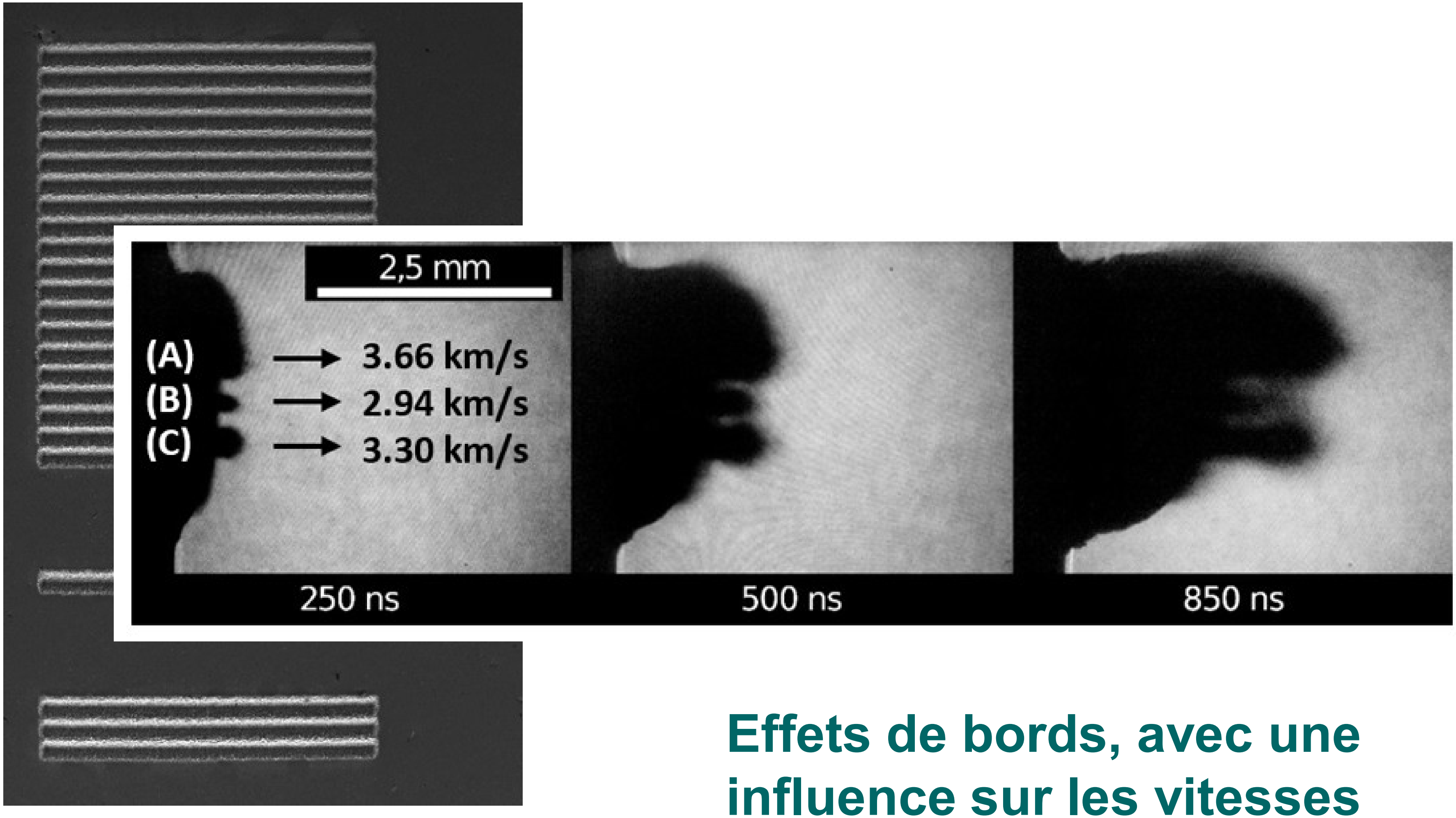
$2h = 18\ \mu m,\ \lambda = 58\ \mu m$

$(kh = 2\pi h/\lambda = 1)$



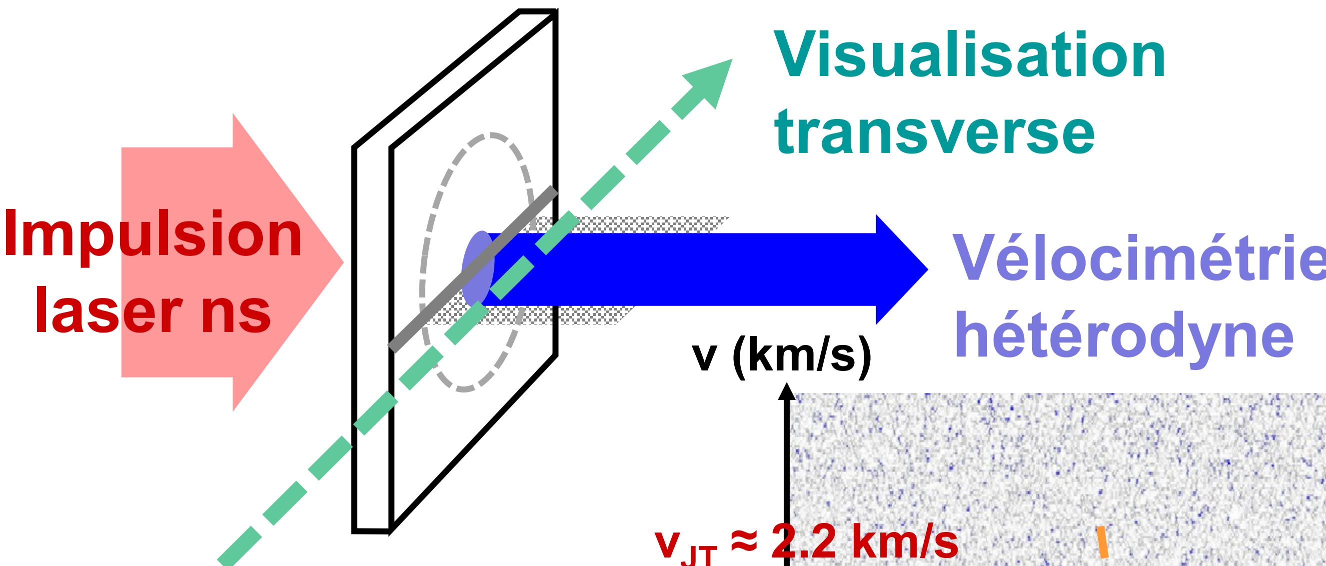


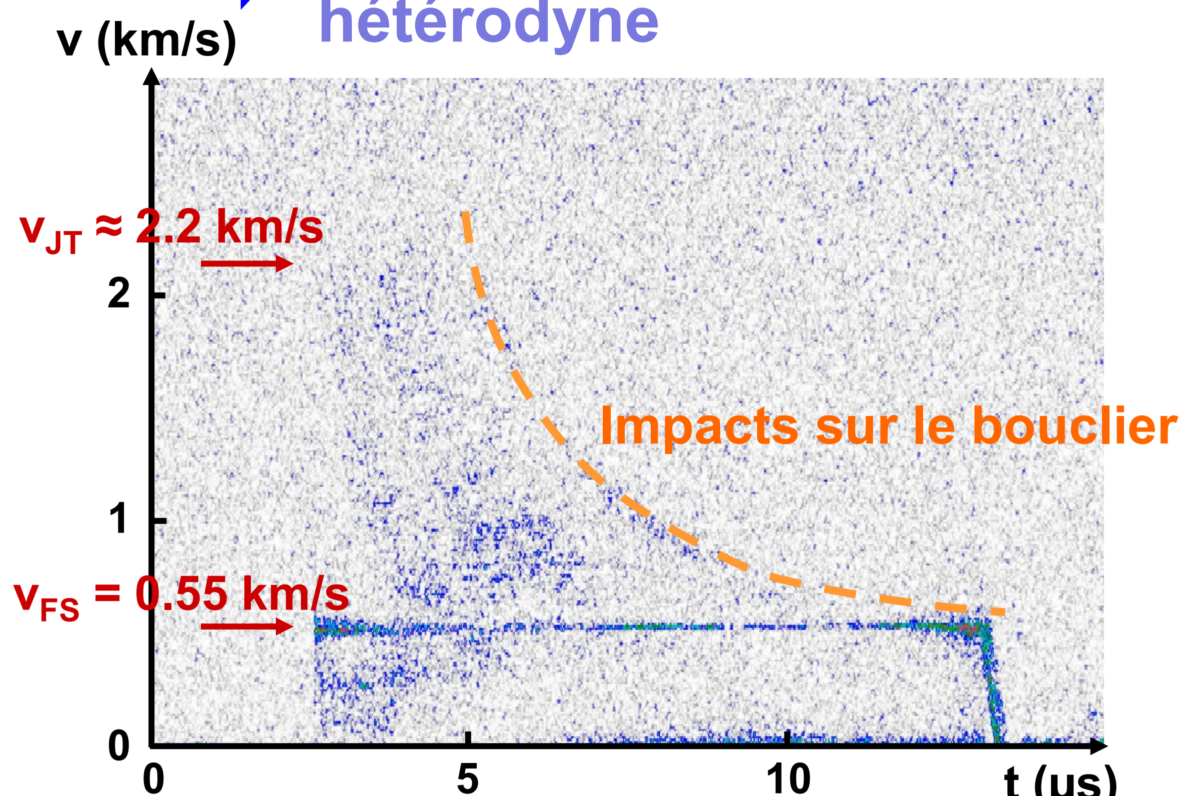
Rainures périodiques (2)



Effets de bords, avec une influence sur les vitesses
(pas encore bien compris…)

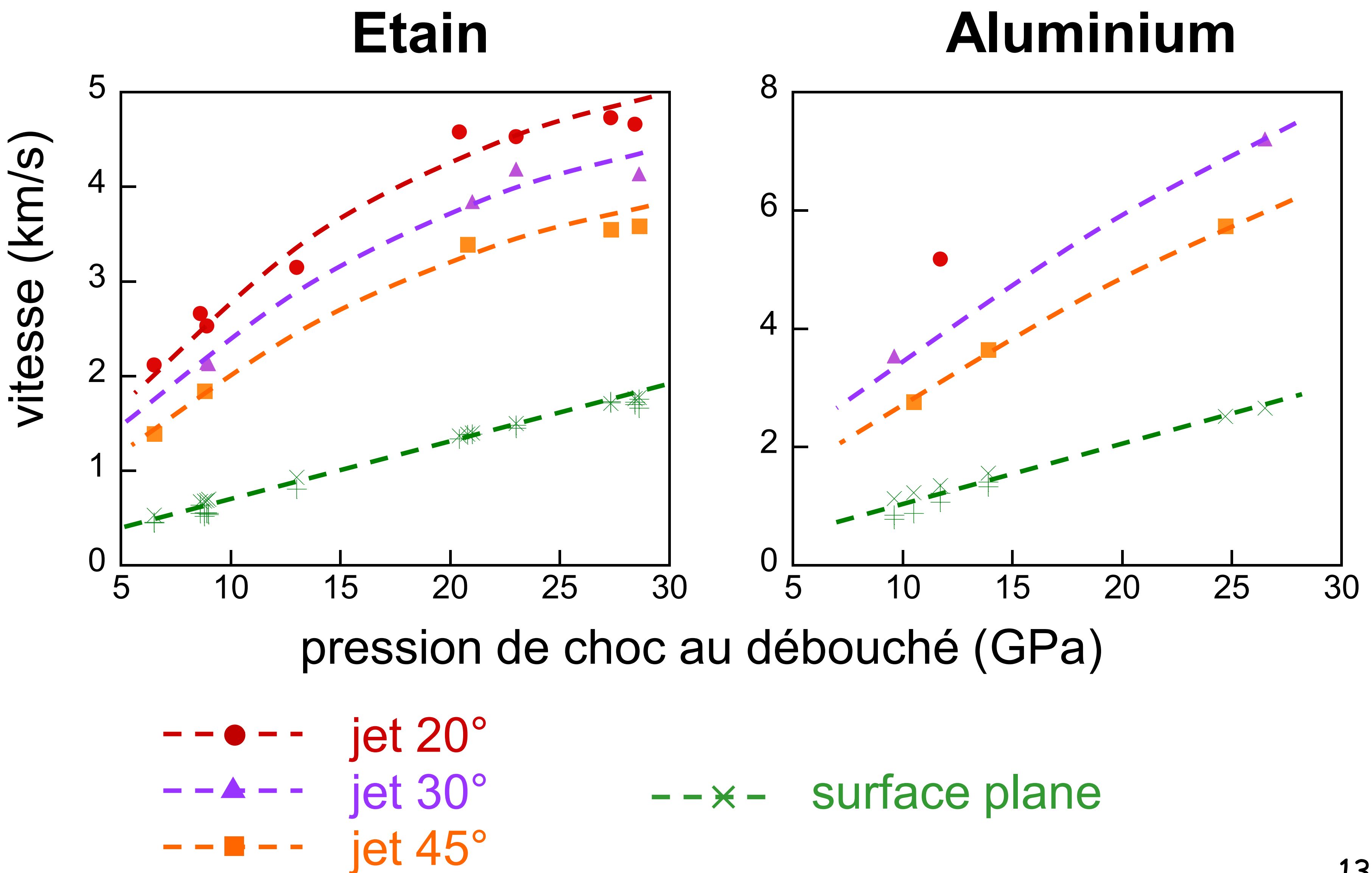
Mesures de vitesse par VH





Sn 260 µm
Demi angle 30°
$I = 0.46$ TW/cm²
$P_{SB} = 9$ GPa
$V_{FS} = 0.55$ km/s
$V_{JT} = 2.15$ km/s

Vitesses jets et surface libre



Simulation 1 : Eléments Finis

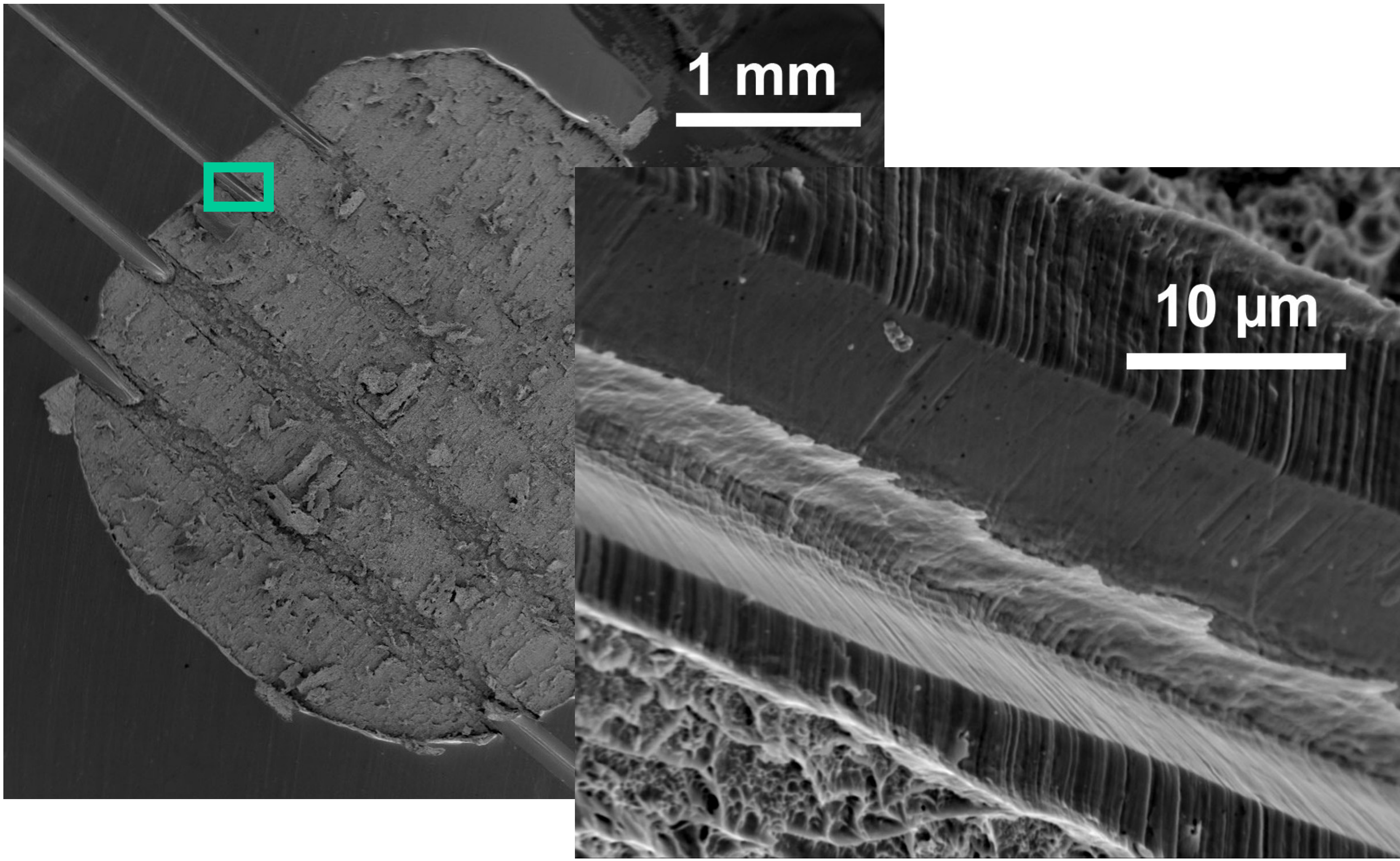
Au 300 µm
Demi angle 45°

- ✓ Physique des chocs oblique
- ✓ Formation du jet
- ✓ écaillage
- ✓ vitesses

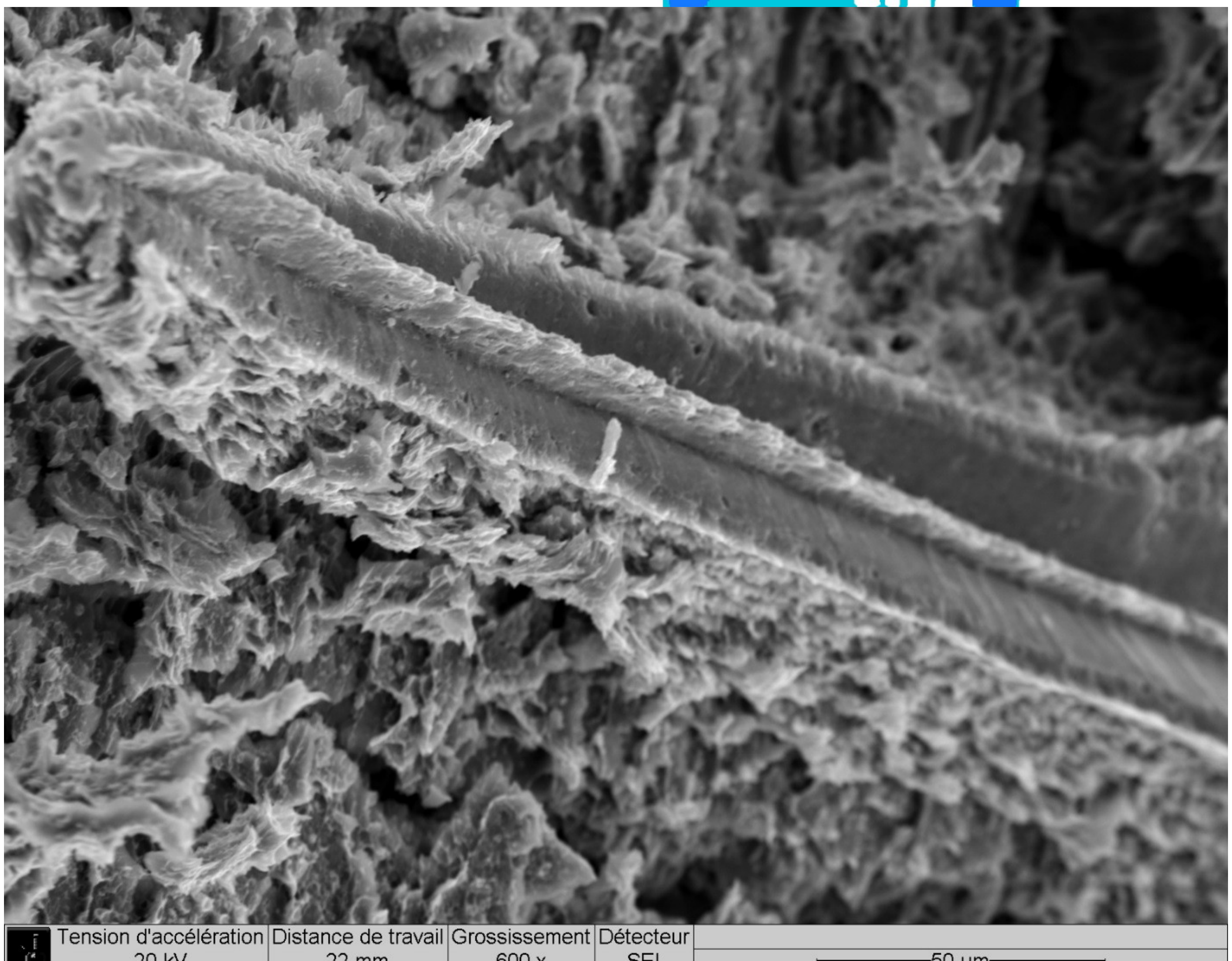
  en accord ~~ avec les mesures

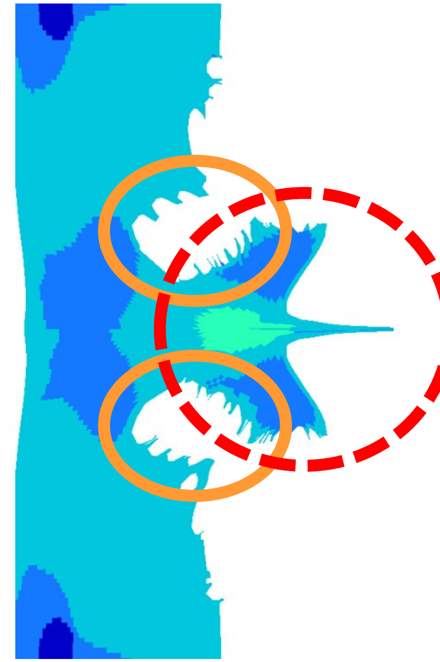
- x pas d'outil pour
  la fragmentation des jets

Récupération de cibles



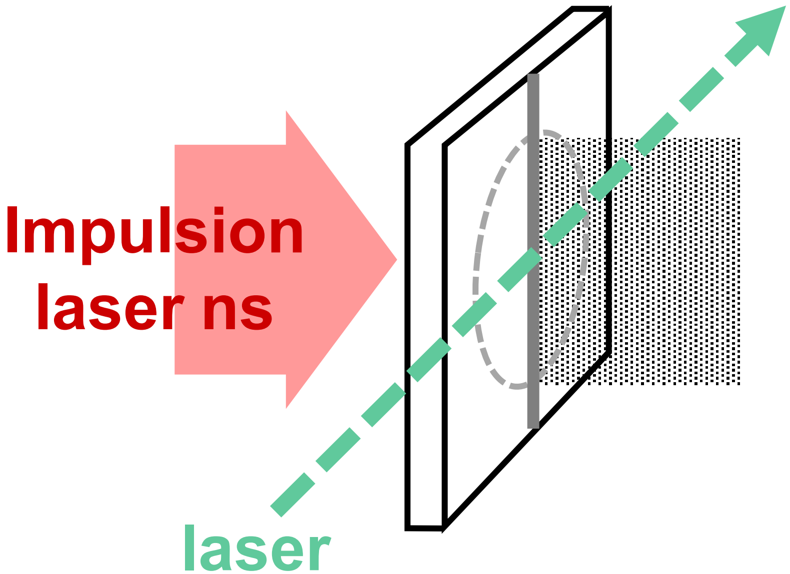
Simulation EF vs. observations



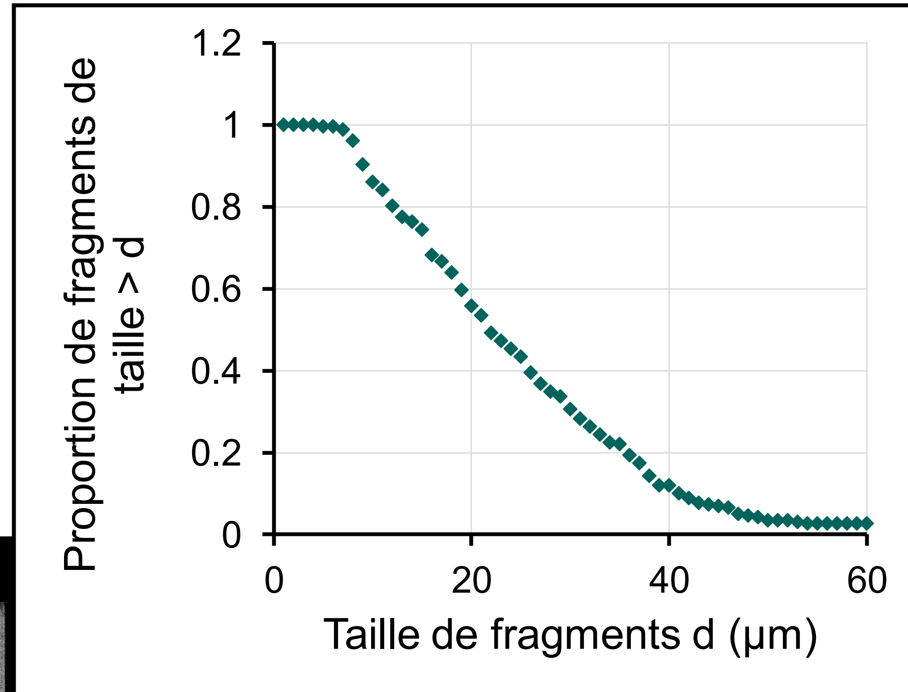


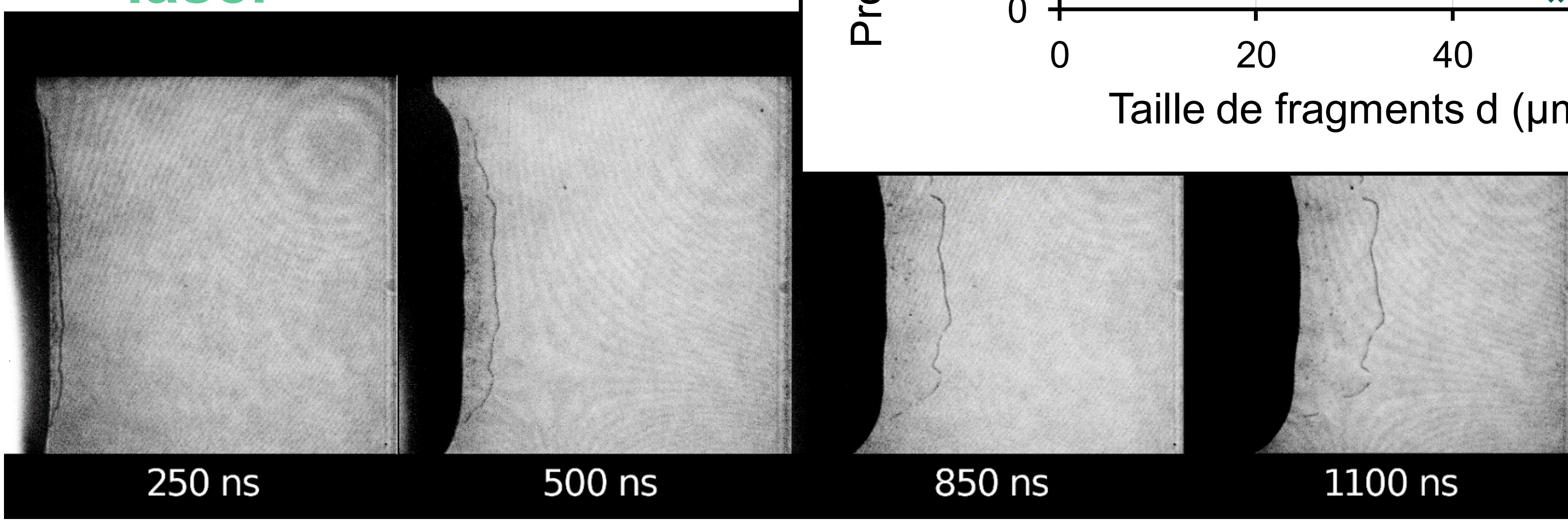
- ✓ qualitativement OK

Fragmentation des jets



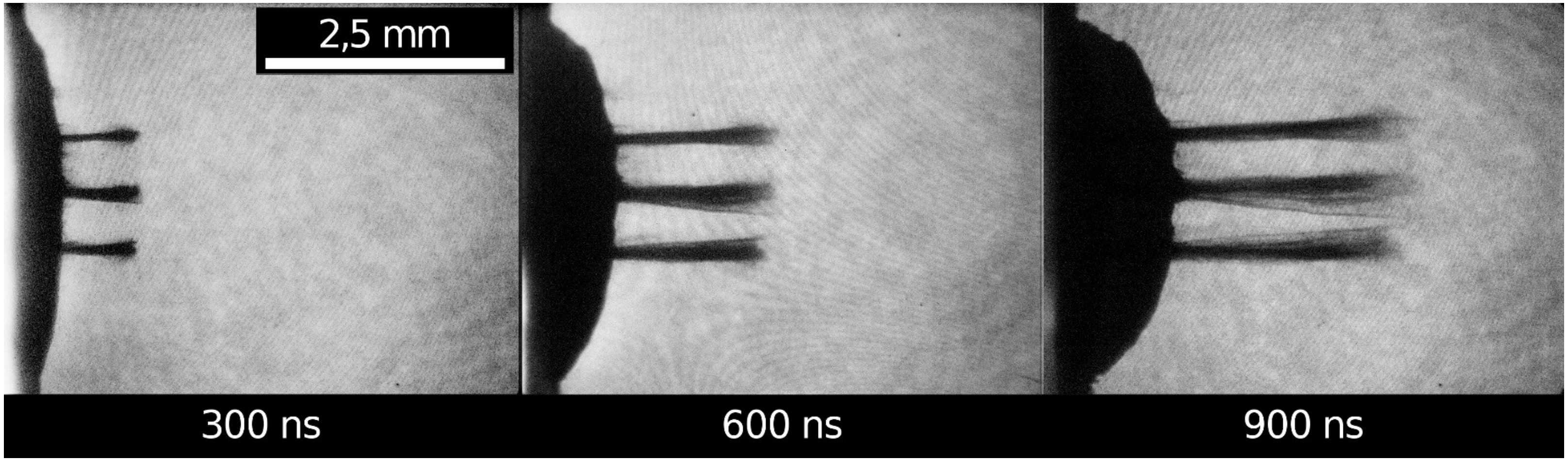
Visualisation transverse



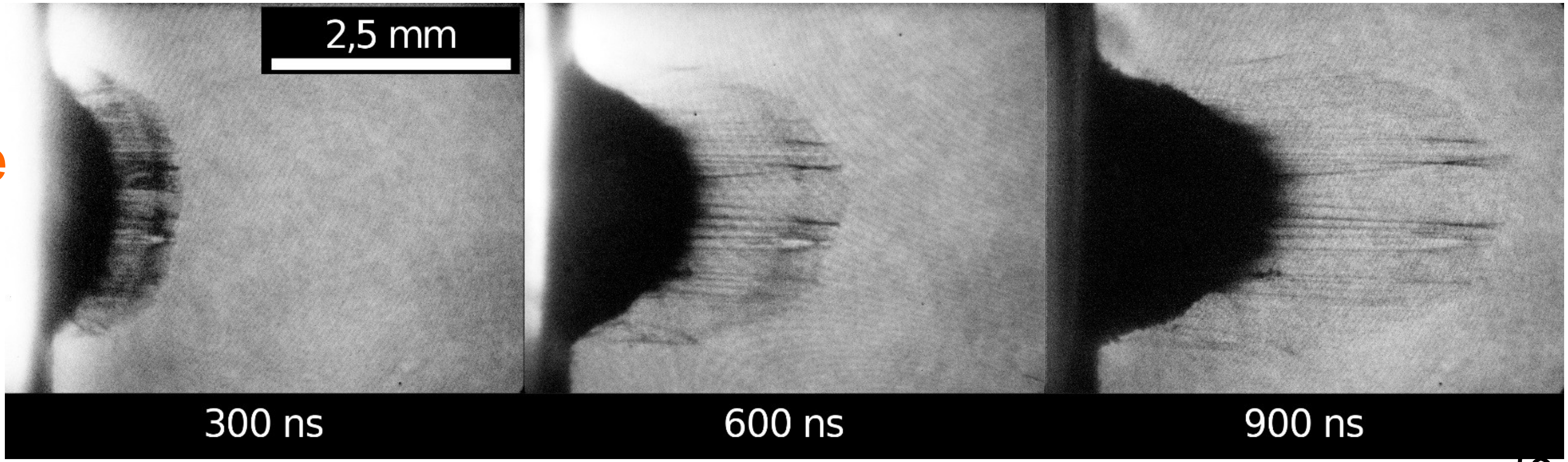


Fragmentation des jets : Sn

3 de 'profil'

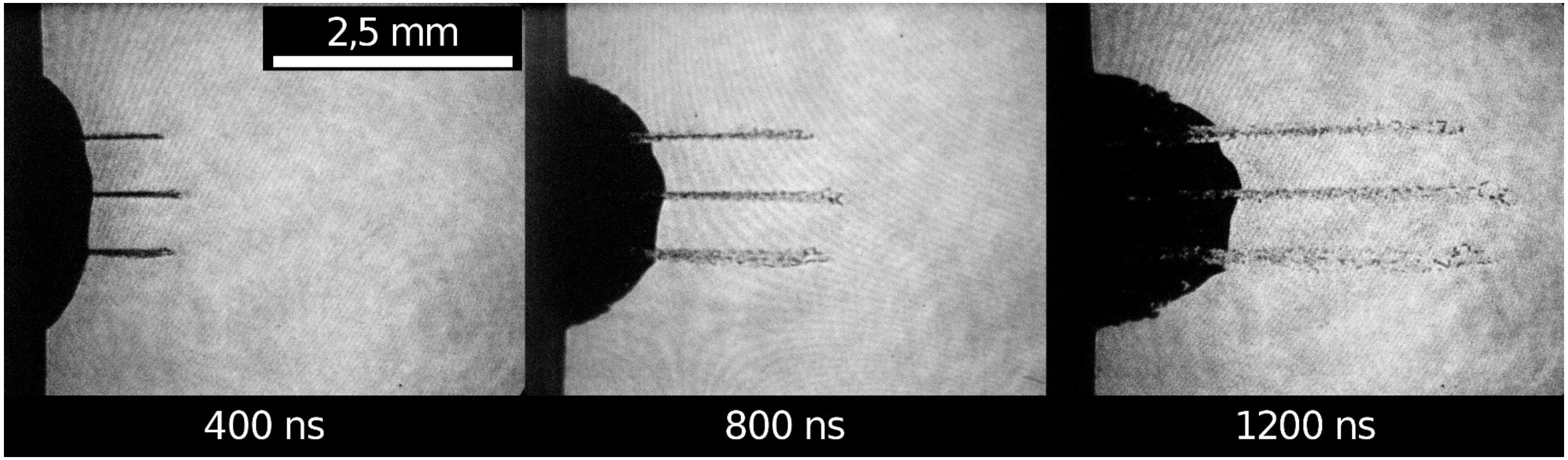


1 in-plane

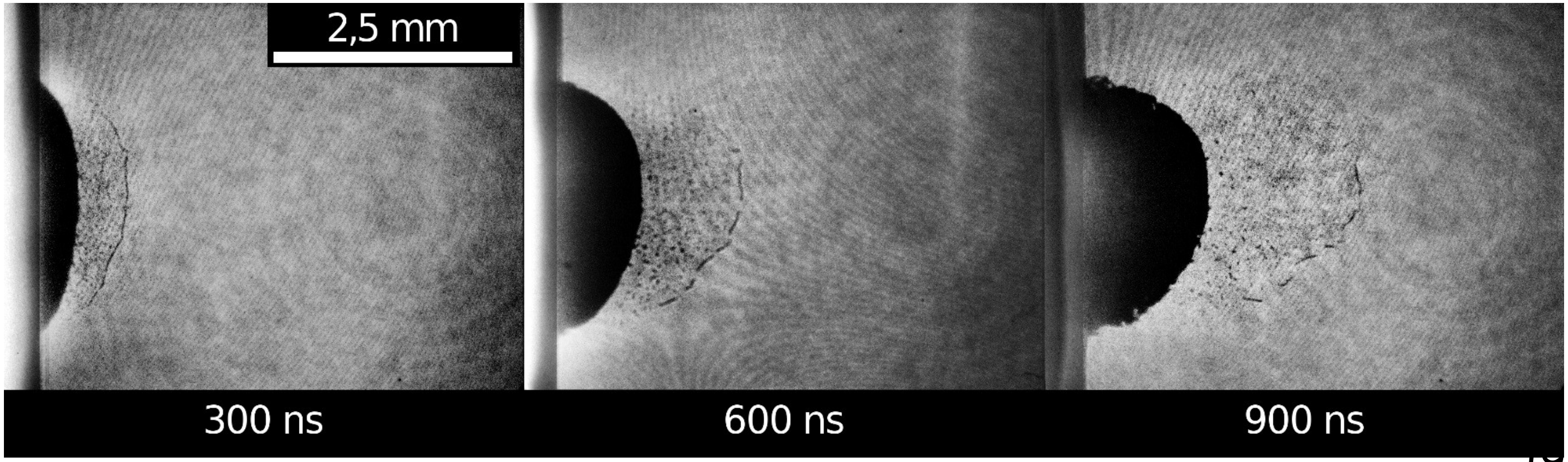


Fragmentation des jets : Cu

3 de 'profil'



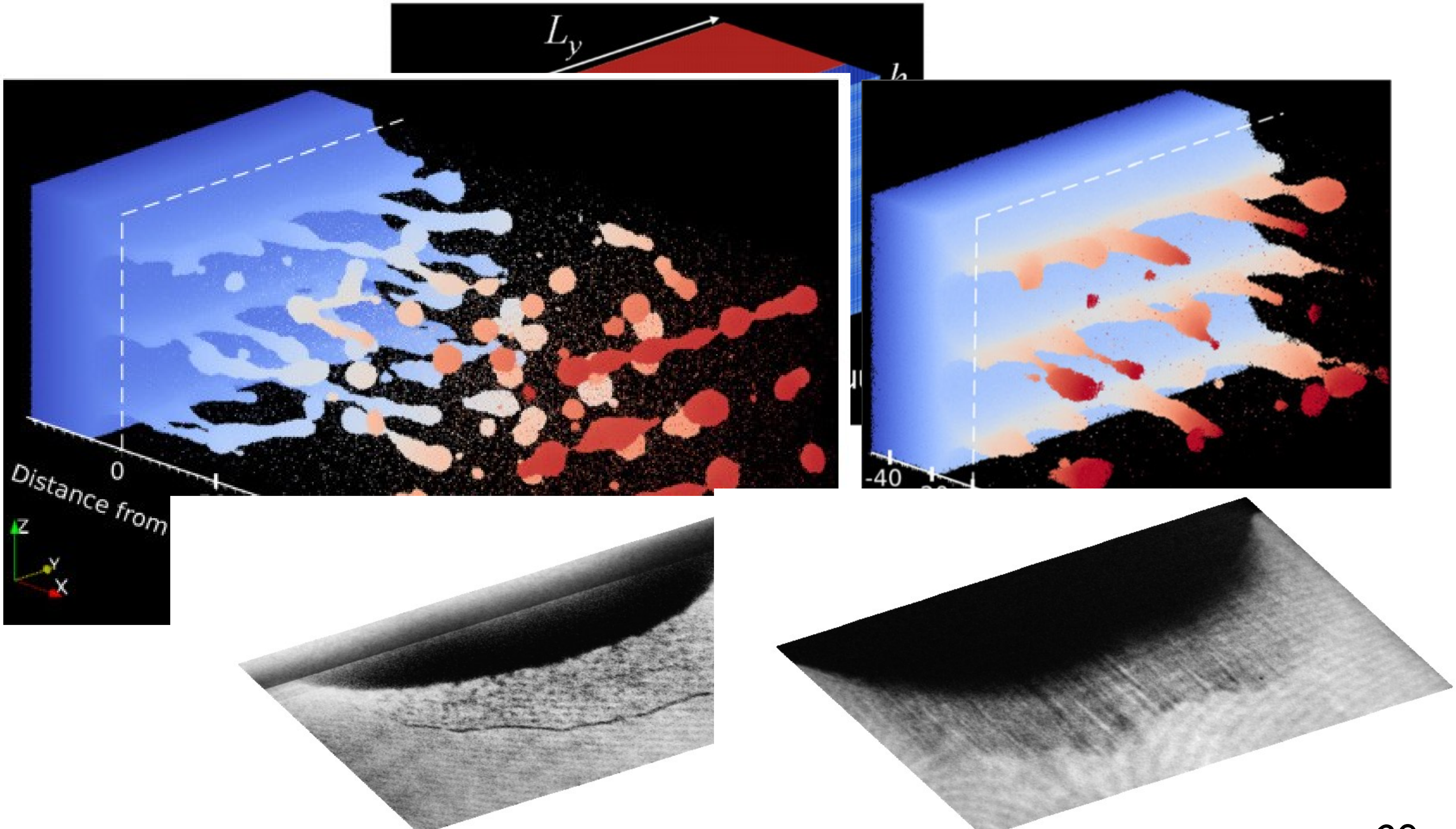
1 in-plane



Simulation 2 : Dynamique moléculaire

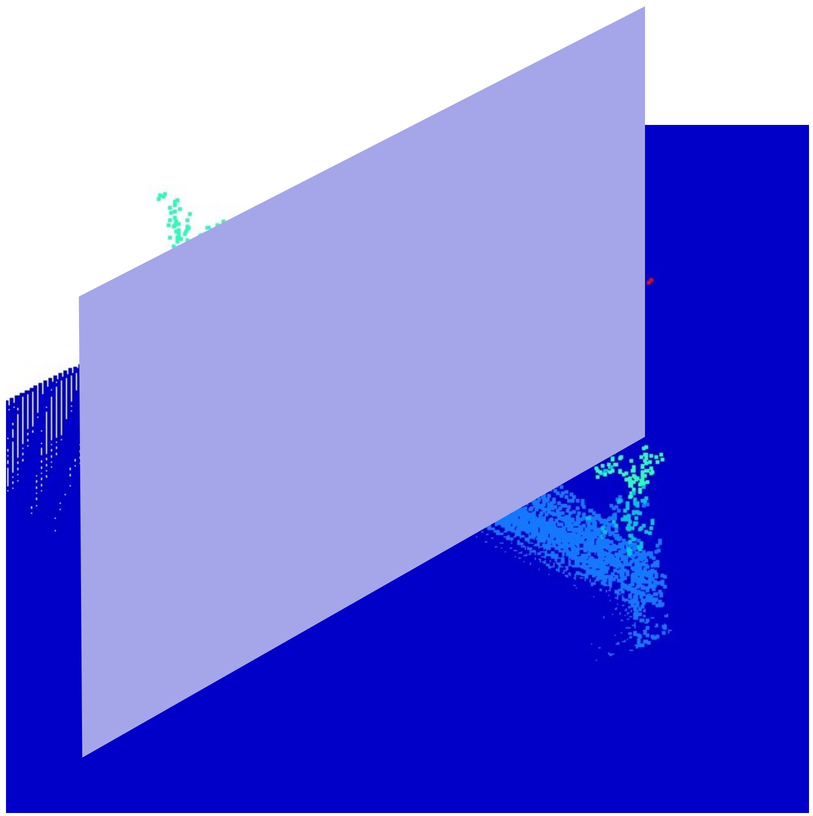
O. Durand et L. Soulard, CEA

☺ **mais ~ nm, ps**



Simulation (3) : SPH

Smooth Particles Hydrodynamics

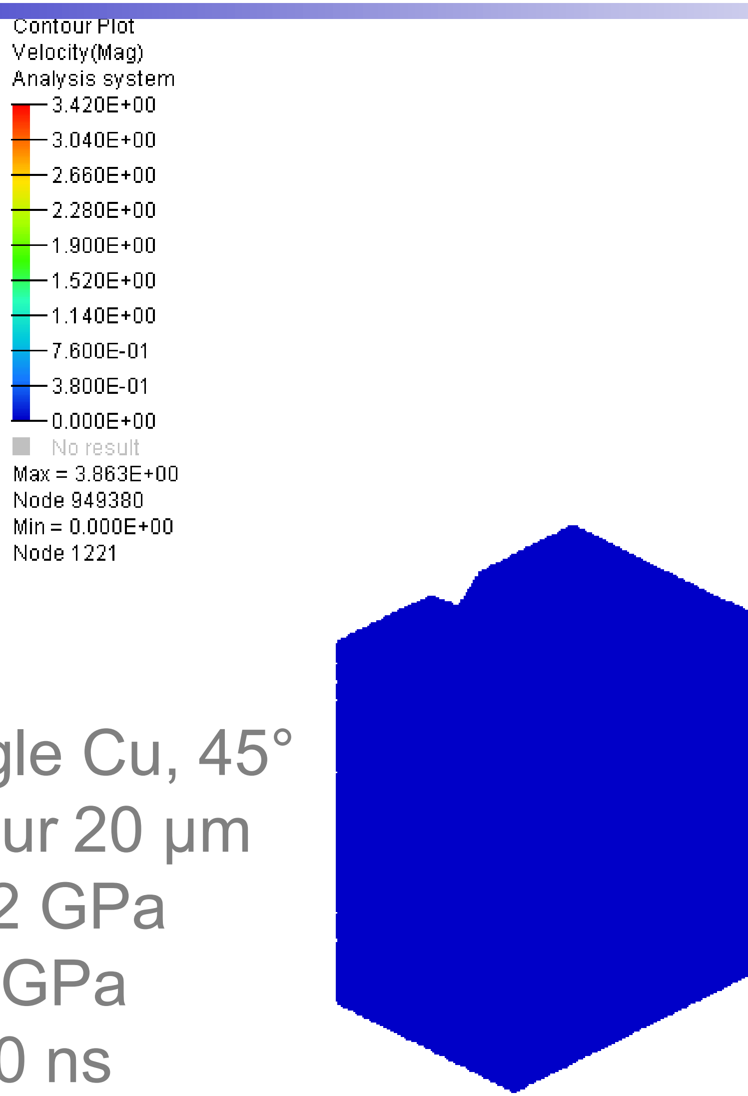


≈ idem FE

+ « fragmentation » …

mais ~linéïque
et sans physique

Simulation 3 : SPH



Model info: sph_moyen

Distance entre élément 2 µm
Bruit aléatoire < 0.2 µm

"agrégats"
~ 5 µm
~ 1 to 3 km/s

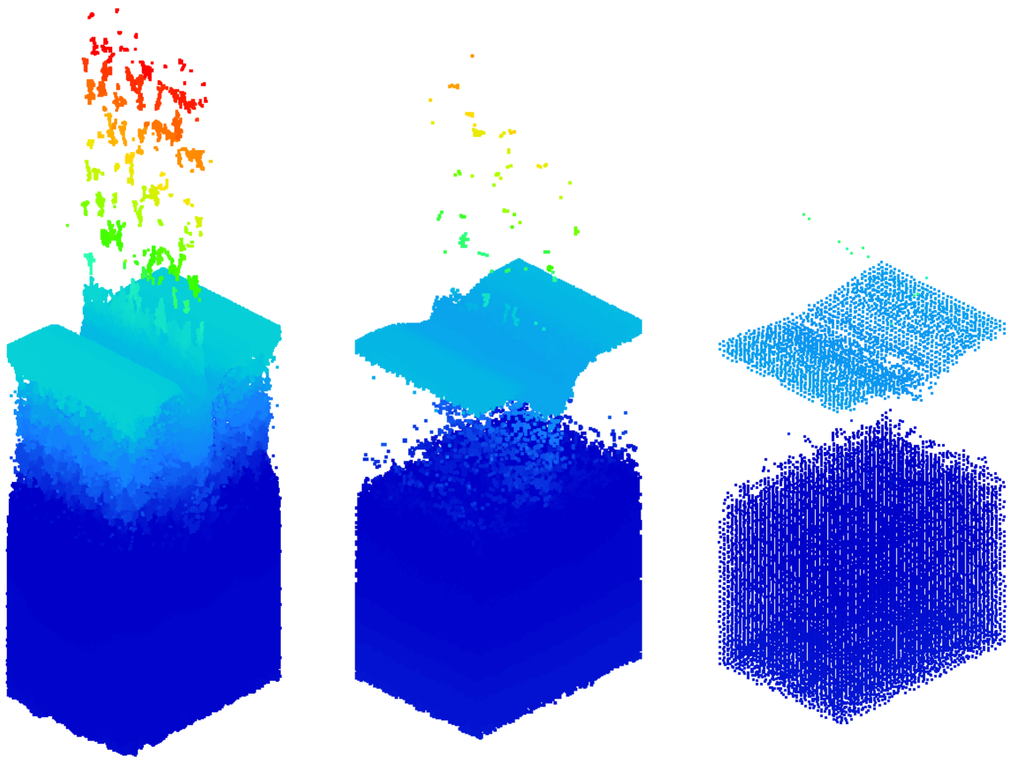
Demi angle Cu, 45°
Profondeur 20 µm
σ_{HEL} = 0.2 GPa
P_{SB} = 40 GPa
durée 200 ns

toujours pas de physique,
mais étude paramétrique
(thèse Caroline Roland)

Fragmentation "numérique"

Distance particules

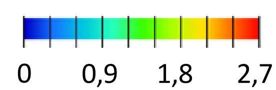
δ



	δ ↗	h ↗	r ↗
Nombre de fragments	↘	↘	↗
Tailles de fragments	↘	↗	↘
Erosion	**Entre 10 et 24 %**		

Rainure et jet moins bien discrétisés

Vitesse (km/s)

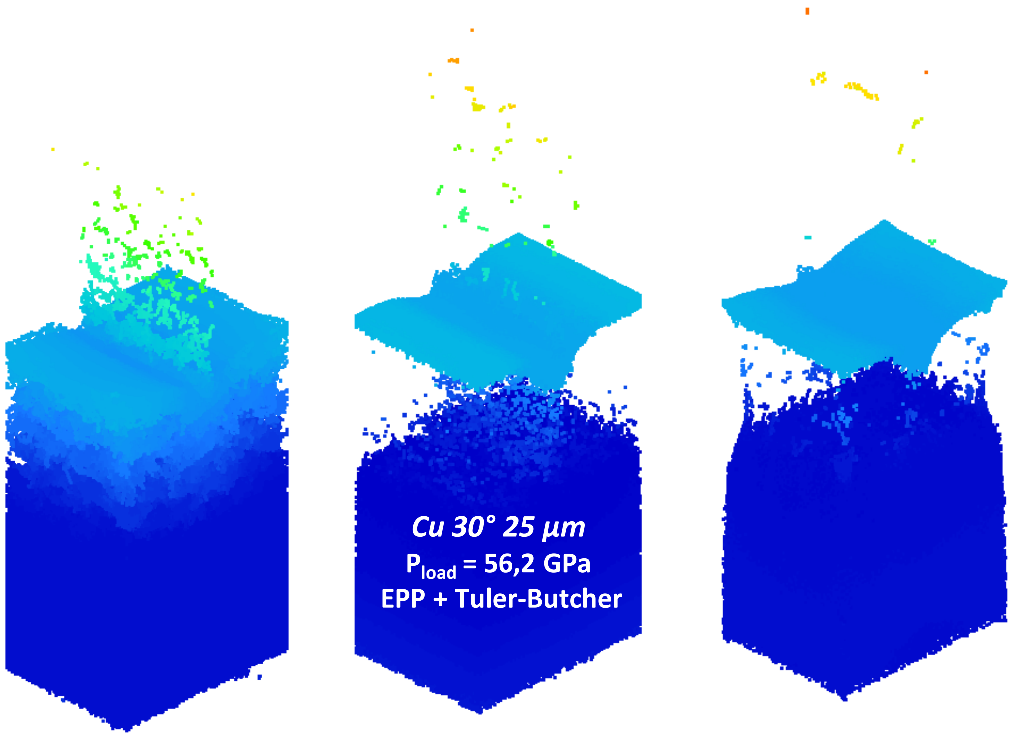


δ- = 1 µm h = 1,117 µm	δ = 2,5 µm h = 2,77 µm r = 10 % δ	δ+ = 5 µm h = 5,47 µm

Fragmentation "numérique"

Smoothing Length

h

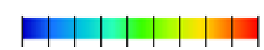


h- = **2** µm	δ = 2,5 µm **h = 2,77 µm** r = 10 % δ	h+ = **3,5** µm

	δ ↗	h ↗	r ↗
Nombre de fragments	↘	↘	↗
Tailles de fragments	↘	↗	↘
Erosion	Entre 10 et 24 %		

Matériau moins laxe

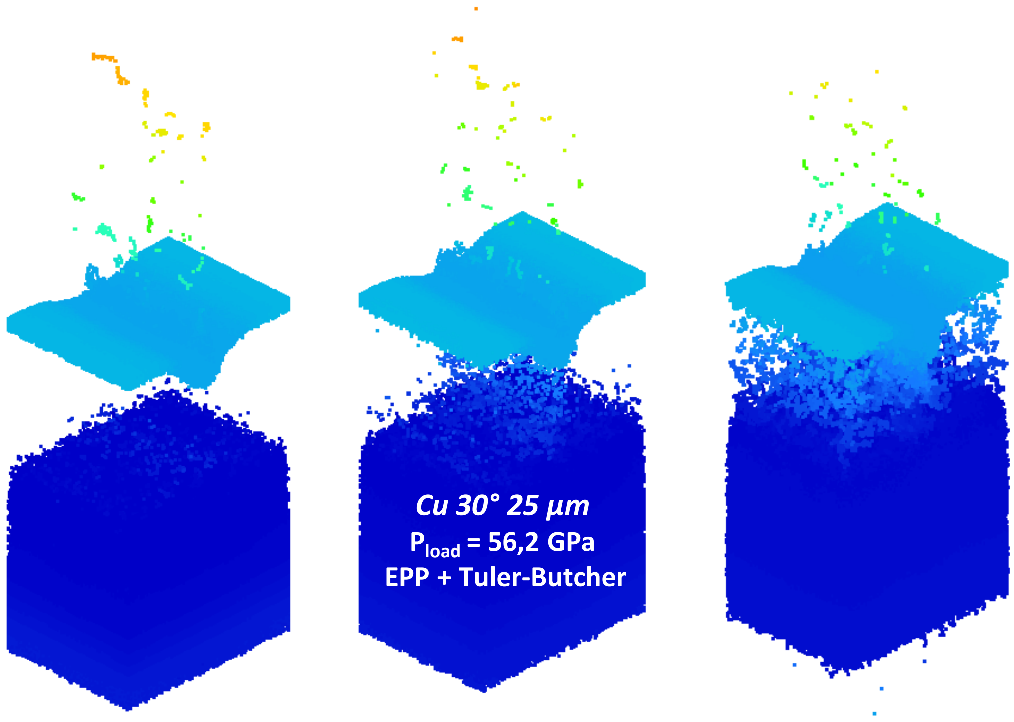
Vitesse (km/s)



Fragmentation "numérique"

Random noise

r



r- = 5 % δ

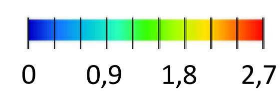
δ = 2,5 µm
h = 2,77 µm
r = 10 % δ

r+ = 20 % δ

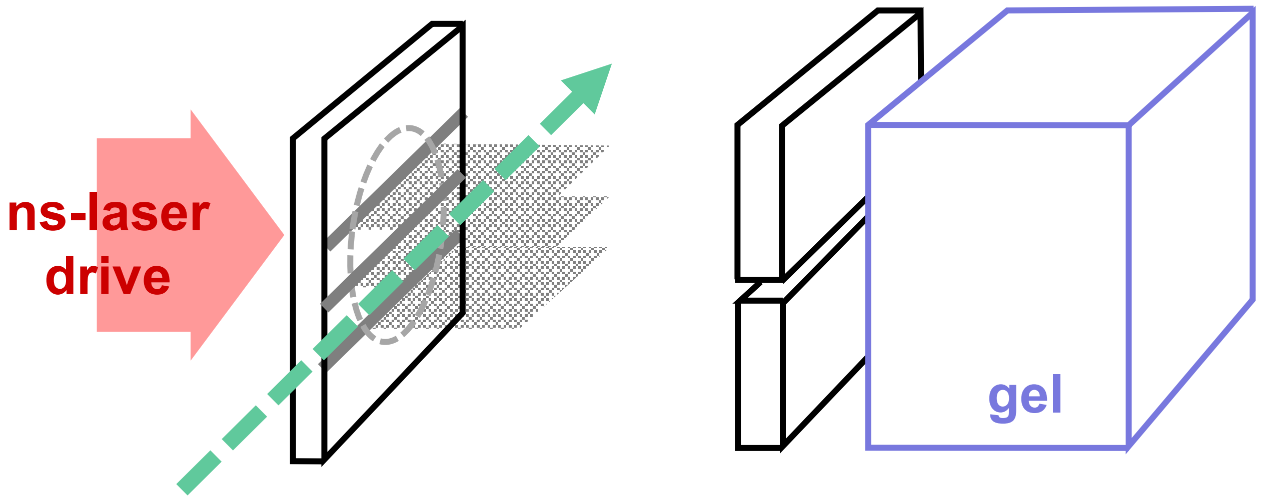
	δ ↗	h ↗	r ↗
Nombre de fragments	↘	↘	↗
Tailles de fragments	↘	↗	↘
Erosion	Entre 10 et 24 %		

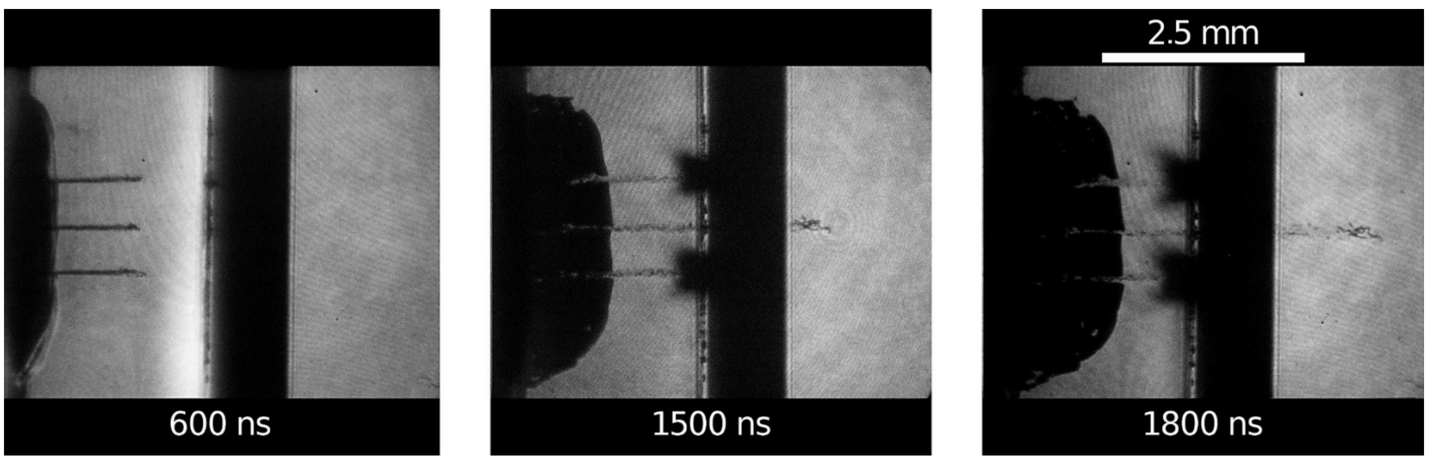
Fragments moins linéiques

Vitesse (km/s)



Récupération des éjectas

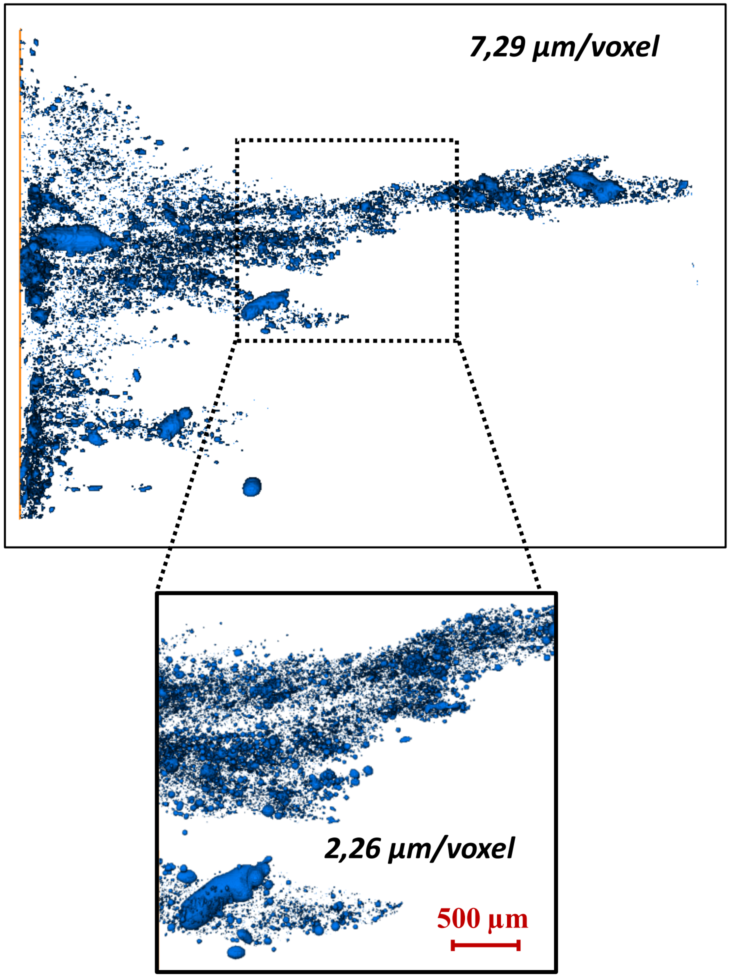


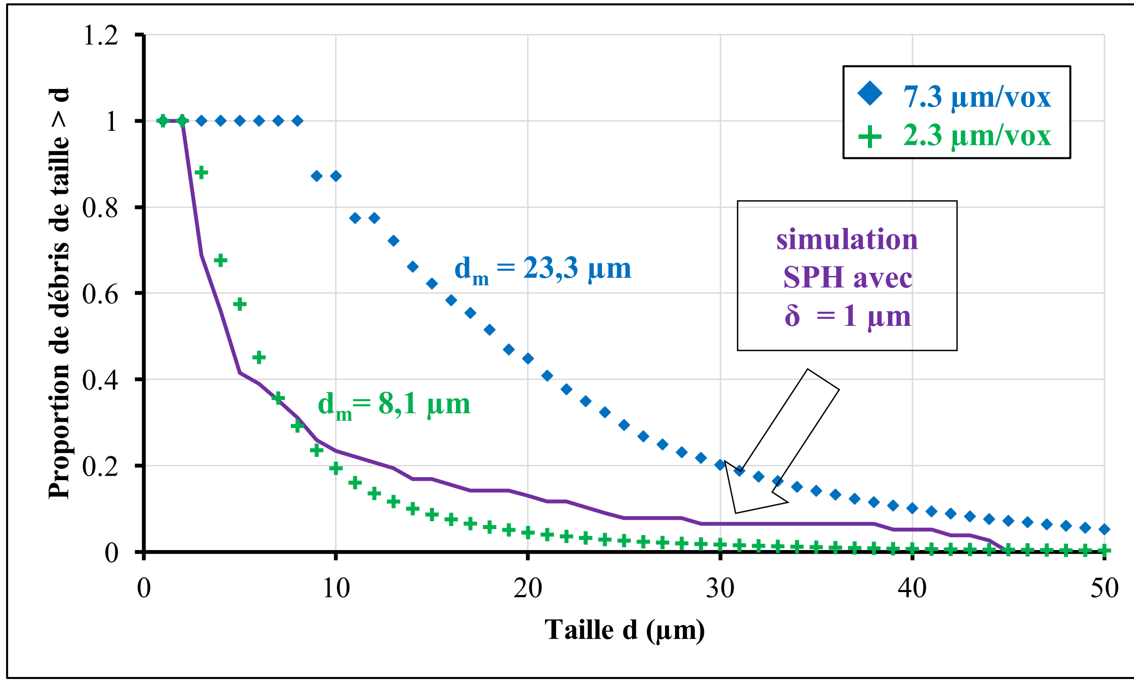


Cu 250 µm, demi angle 30°, I = 2.0 TW/cm²

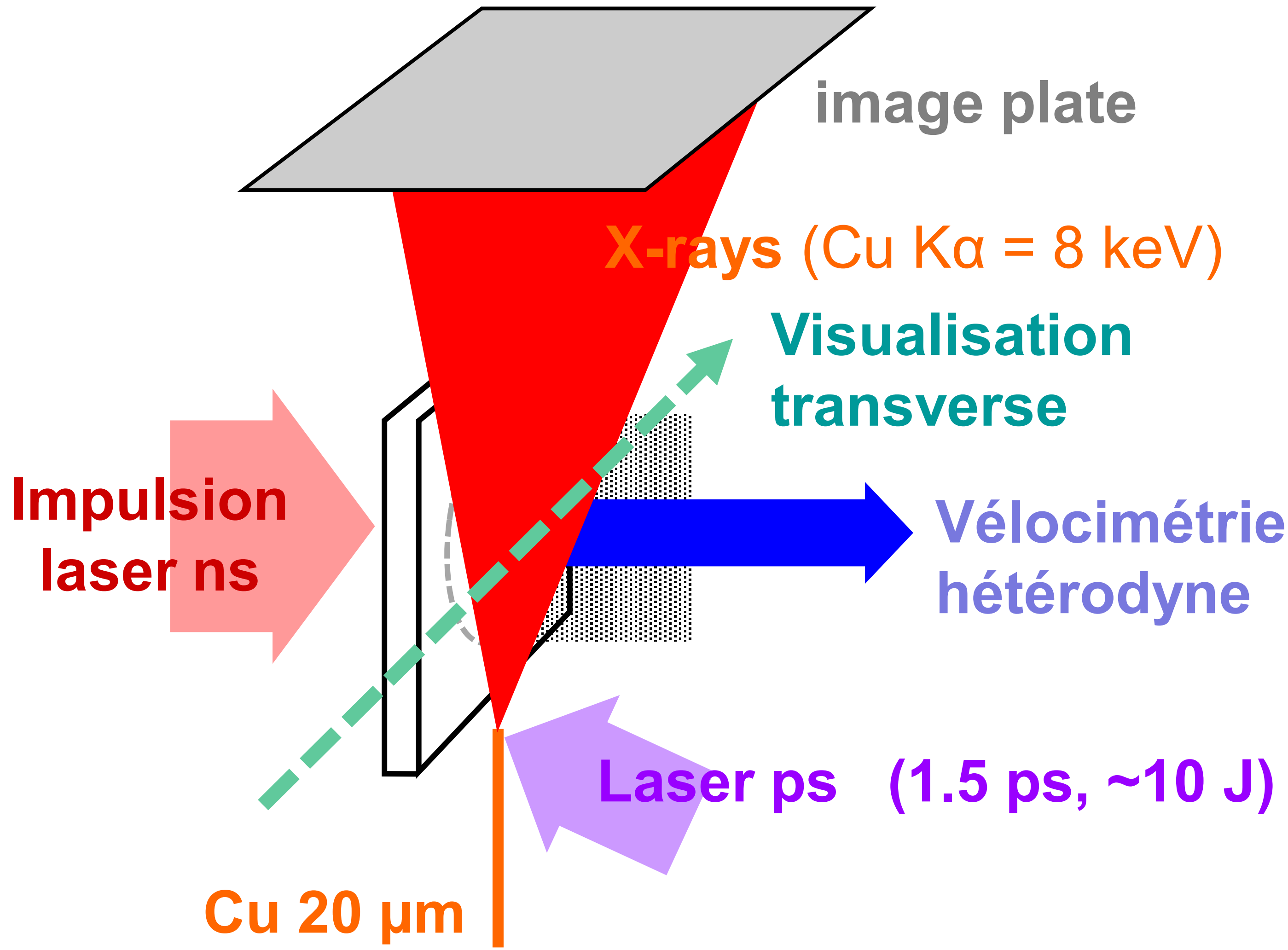
Tailles des éjectas

Etain 30° 78,6 GPa

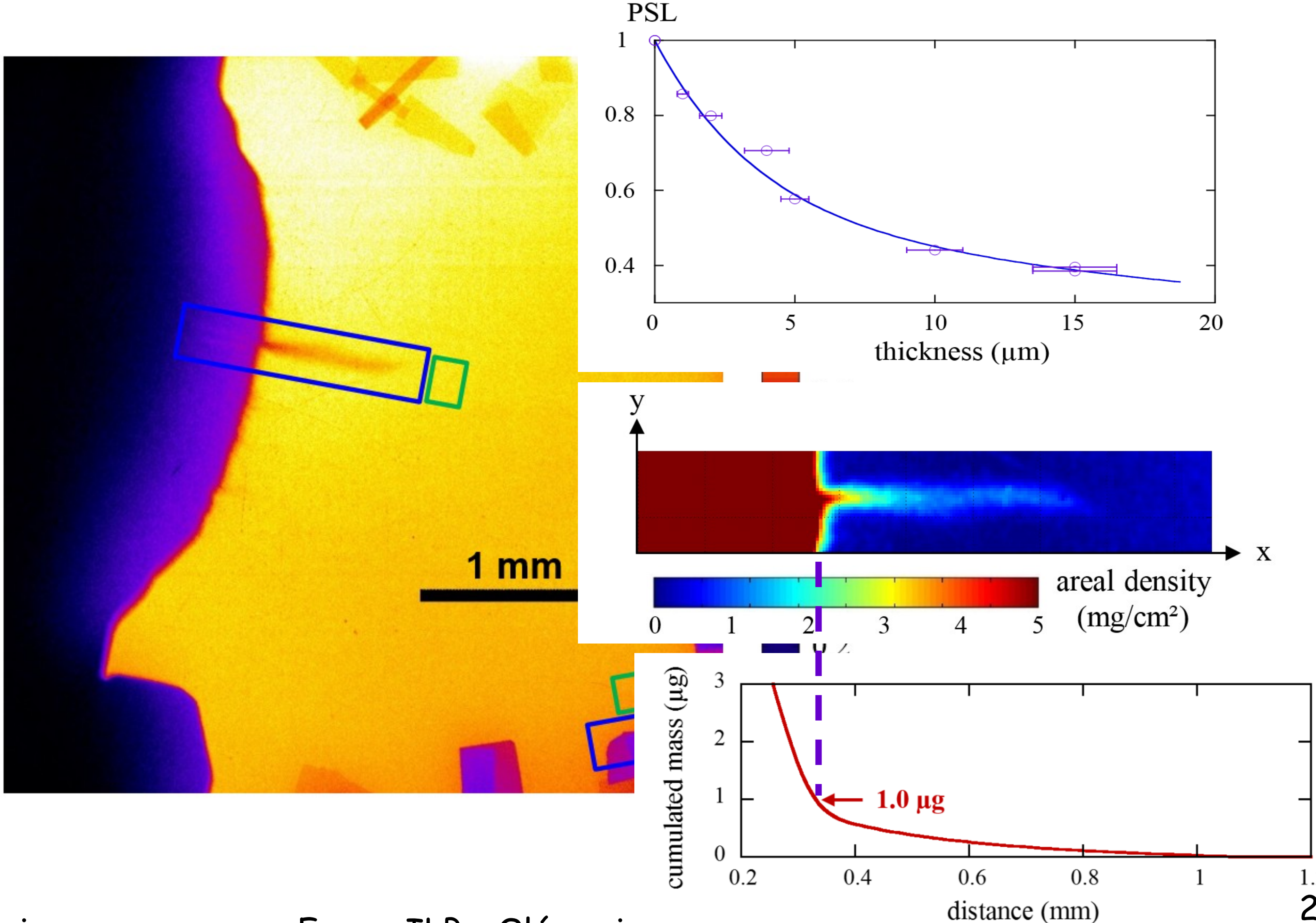




Radiographie ultra rapide



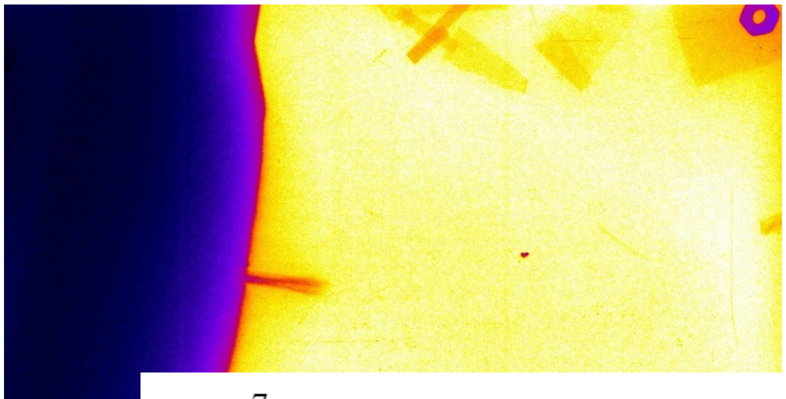
Sn, rainure triangulaire

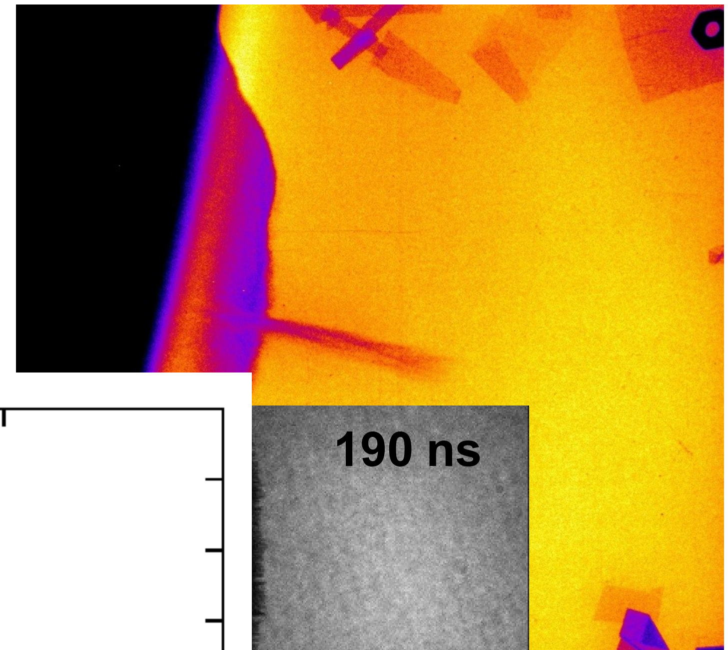


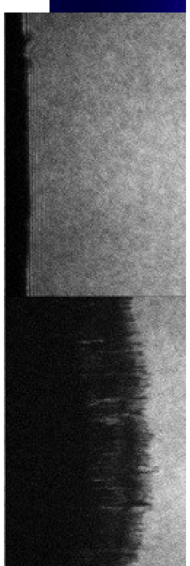
Sn, " séquence "

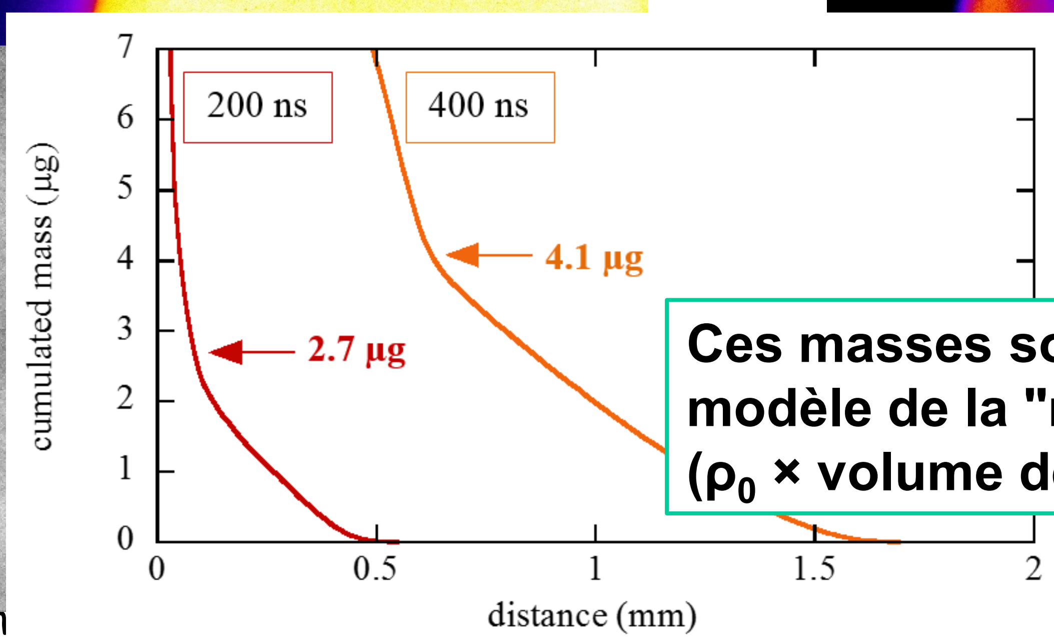
Demi angle 20°
Délai 200 ns

Délai 400 ns



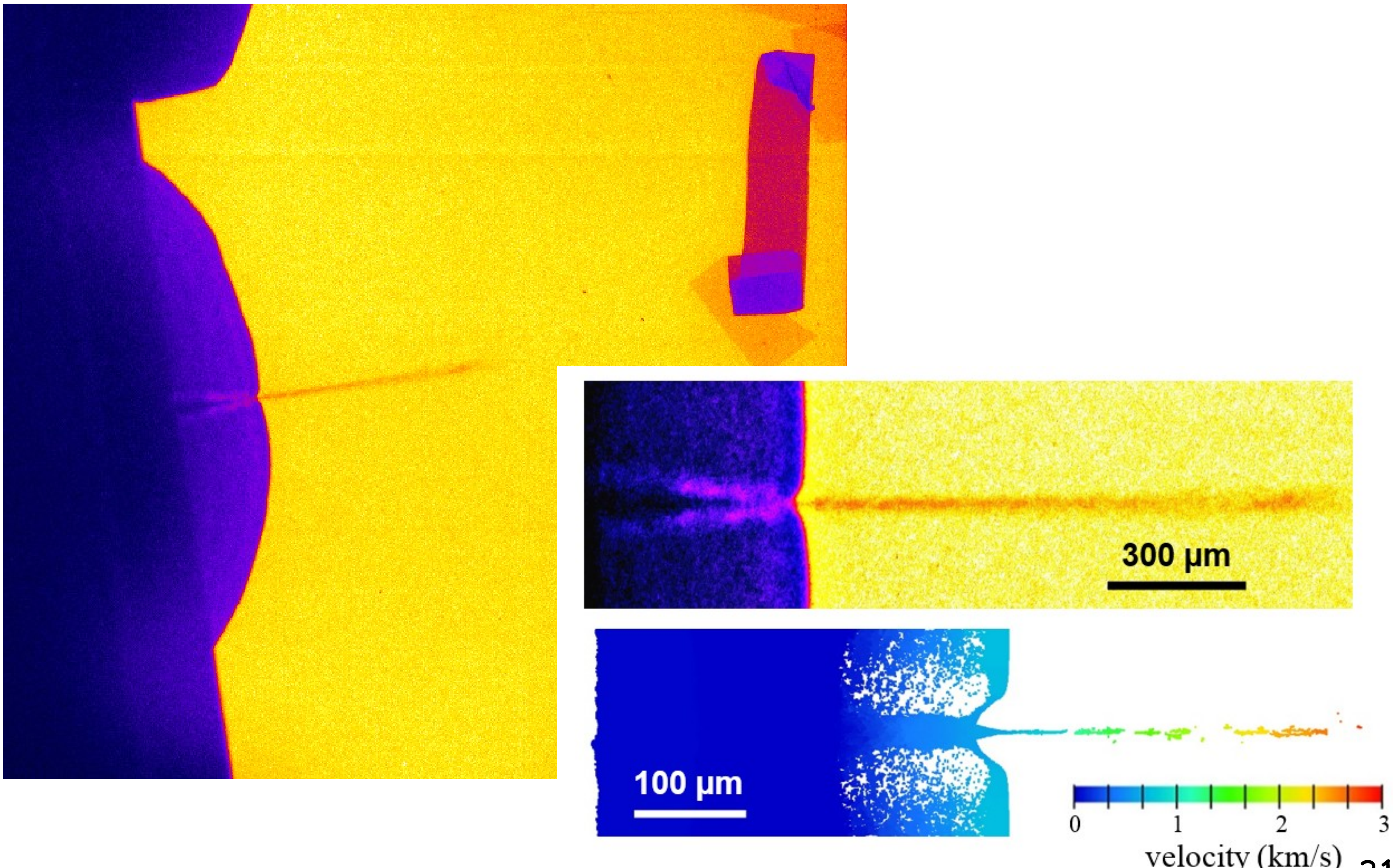




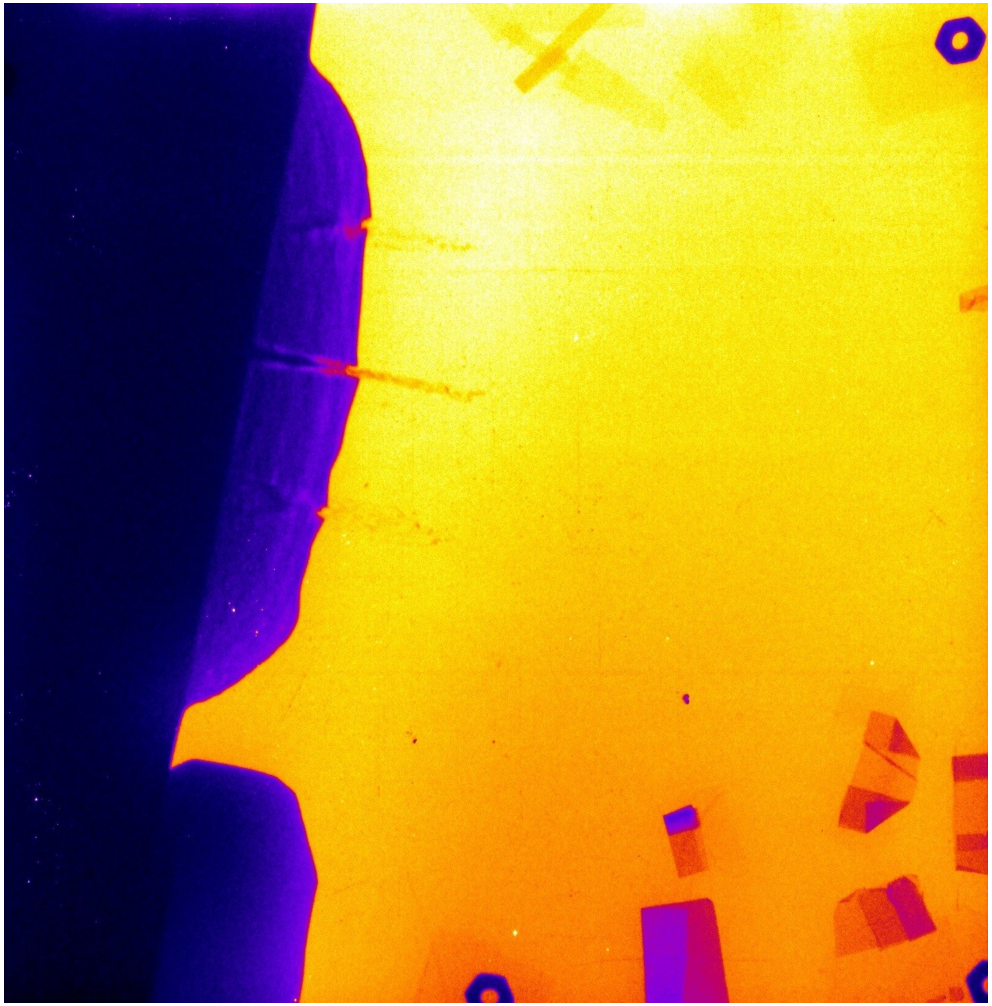


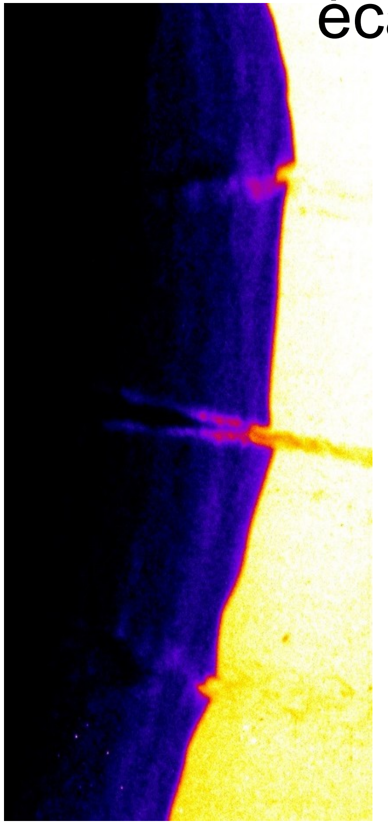
Ces masses sont en accord avec le modèle de la "masse manquante" (ρ_0 × volume de la rainure) [Asay]

Cu, rainure triangulaire



Cu, 3 rainures

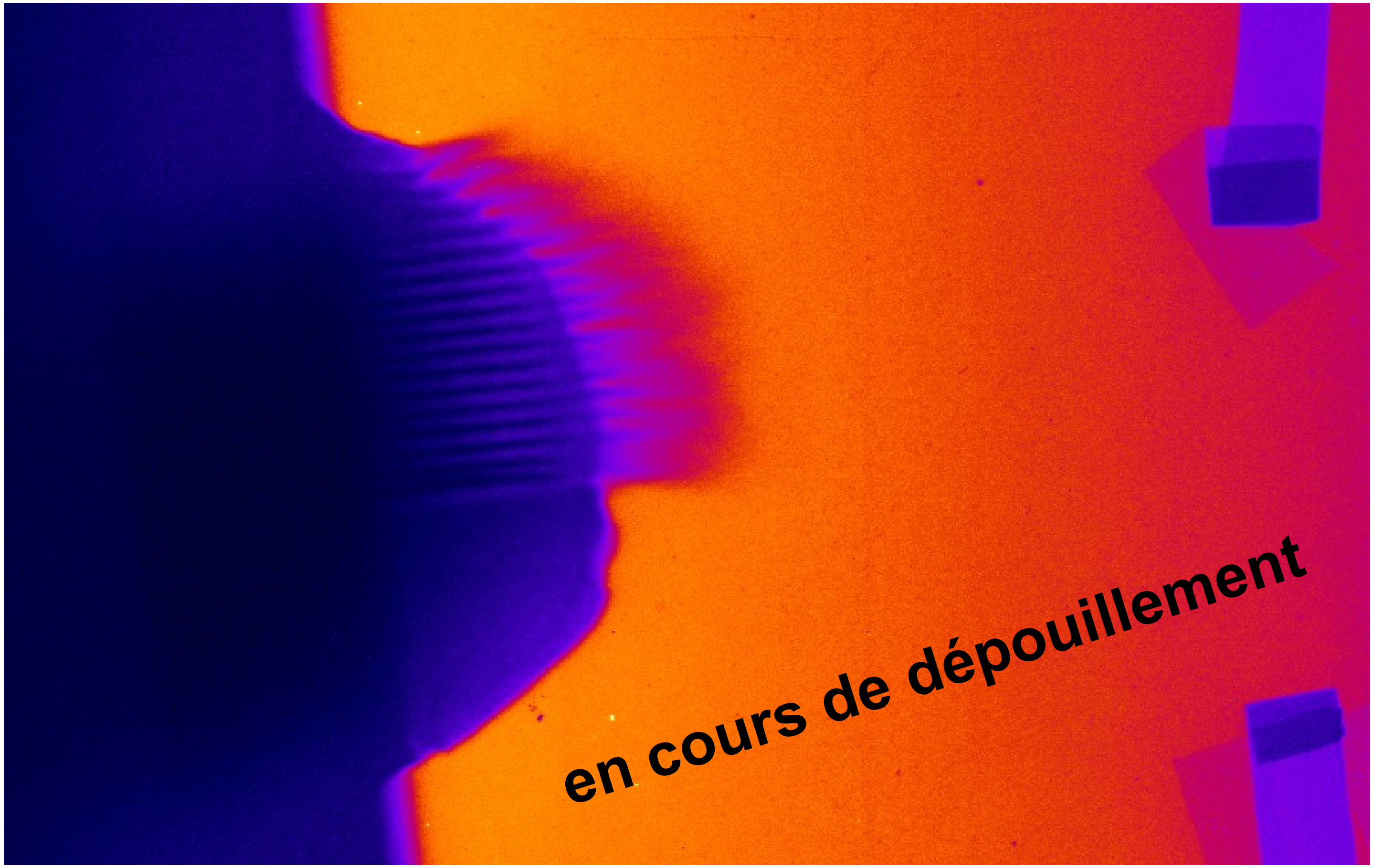




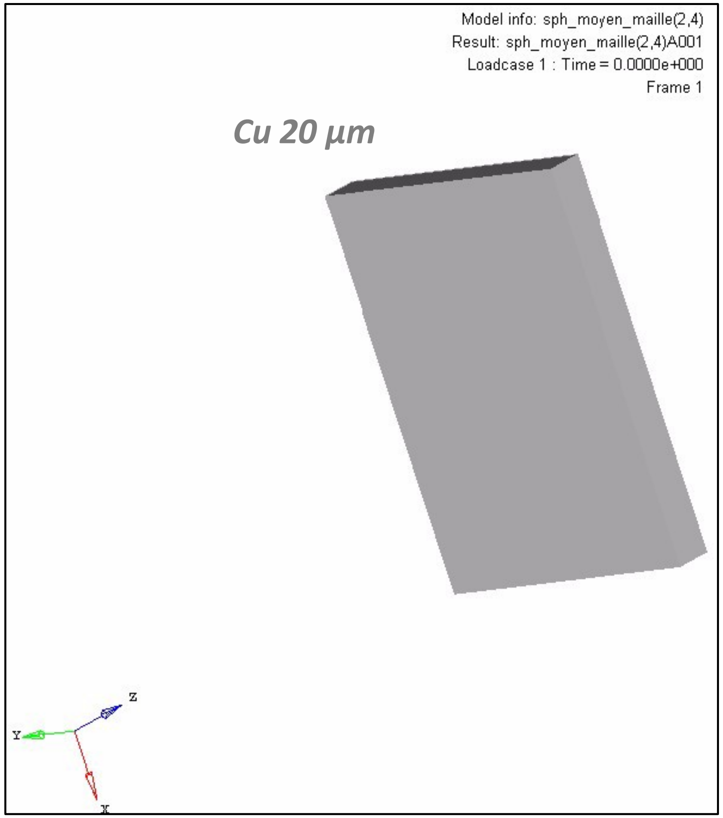
écaillage

45° half-angle
400 ns delay
~ 3 mm-spot

Sn, rainures périodiques sinusoïdales



Diamètre tache focale 1.7 mm
Délai 400 ns



Merci de votre attention