Electrical field generated during interaction of high intensity laser with structured targets

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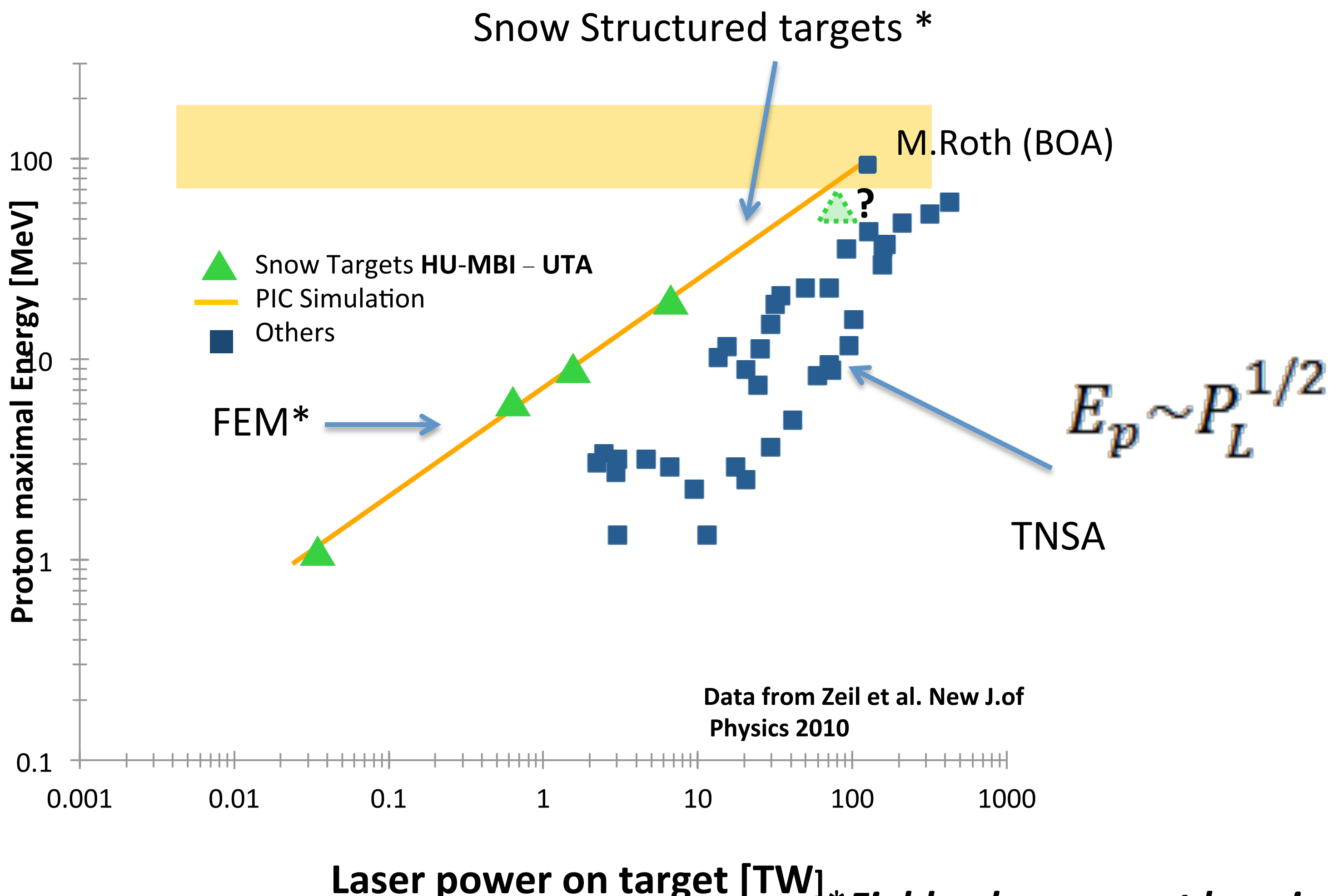
Proton energy vs. laser power



*Field enhancement by microwires
Zigler et al PRL 2011, 2013*

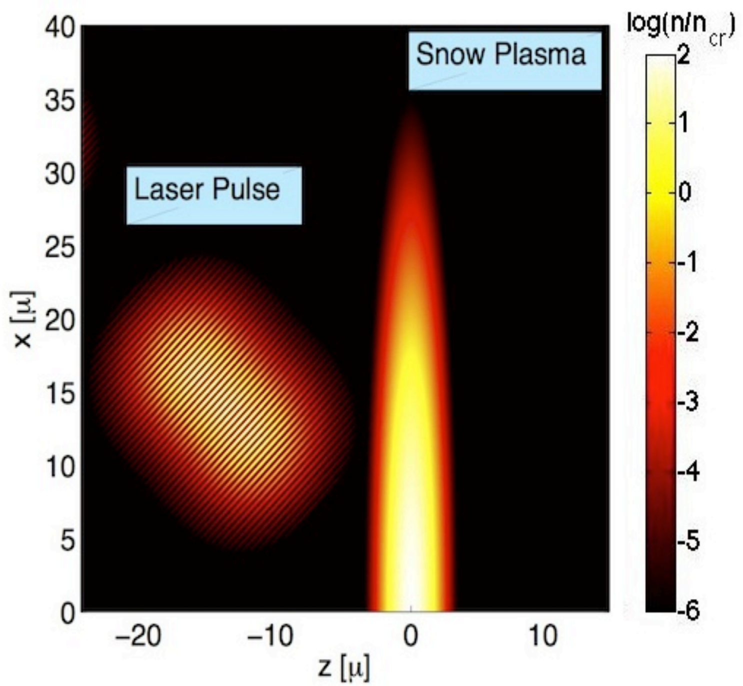
Enhanced proton acceleration from snow micro-wire targets

The higher proton energy can be attributed to several effects:

- The density gradient generated by the laser prepulse – verified by experiment

- Localized field enhancement near the tip of the snow needle ? - this talk

Laser – wire interaction by 2D PIC simulations TURBOWAVE*



Laser: 88 fs (32 + 24 + 32), 0.8 μm, 4-5 μm spot size, $2.5 \cdot 10^{17} - 2.5 \cdot 10^{19}$ W/cm^2

The core of $100 \cdot n_{cr}$, : ellipsoid ~ 0.1-0.2μm x 1-2μm .
The critical density contour: ellipsoid ~ 1-2μm x 10μm .

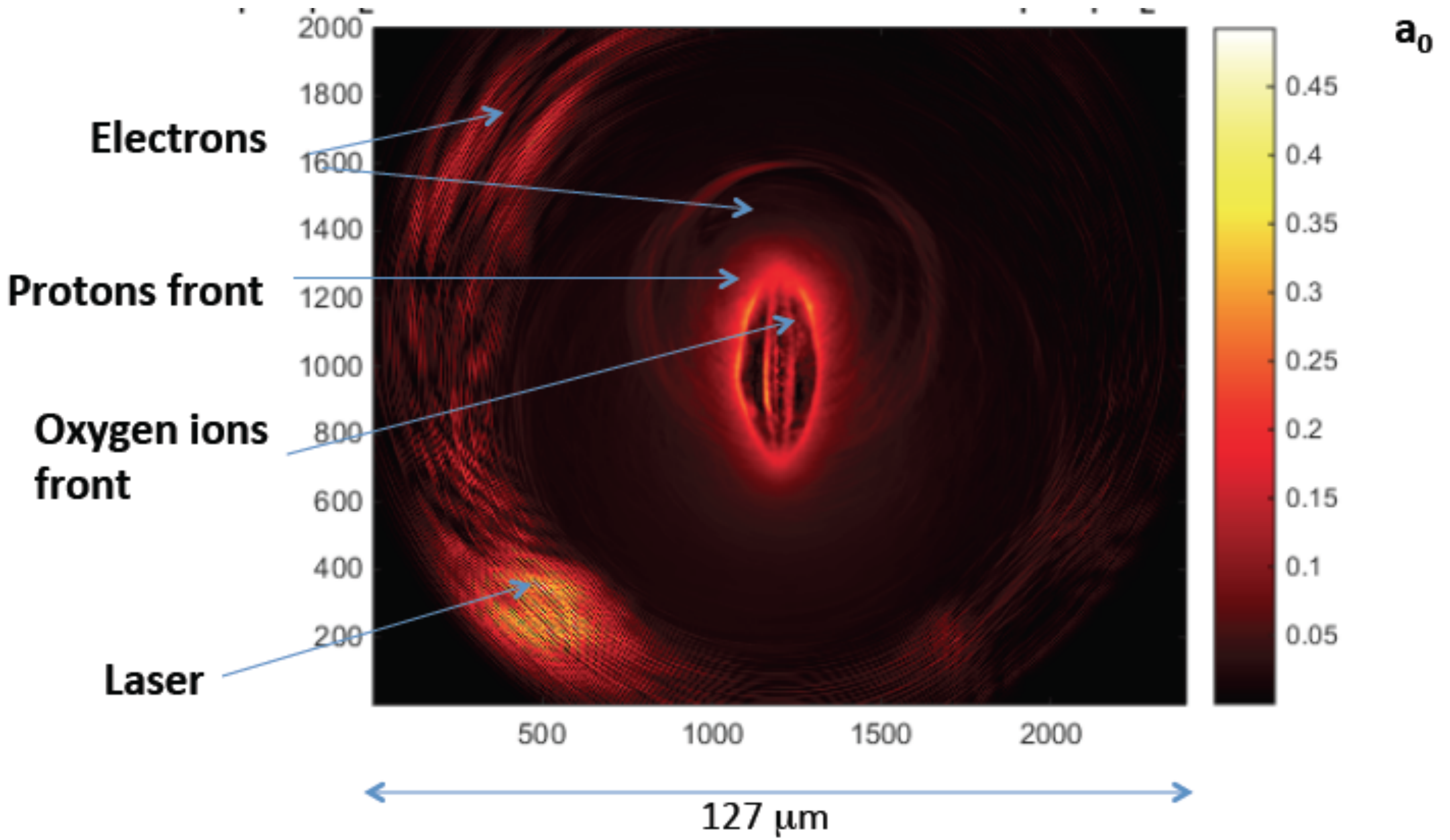
***TURBOWAVE, Gordon et al., IEEE Trans. Plasma Sci. 35, 1486 (2007).**

The electric field in units of a_0

(x $1.37 \cdot 10^{11}$ V/cm) $I_L = 2.5 \cdot 10^{19}$ W/cm^2

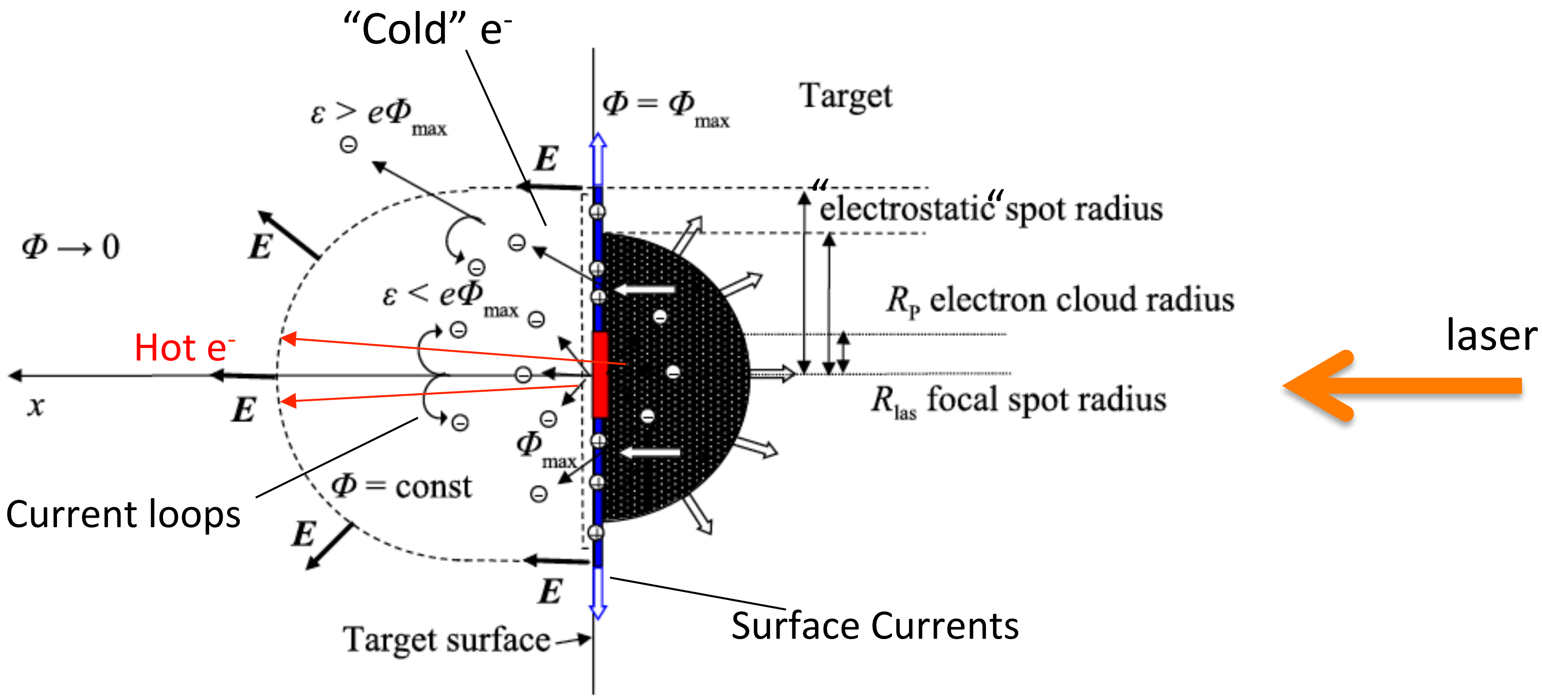
after 200fsec

$$a_0 = \frac{eE}{mc\omega}$$



This is for a single wire but what about a large foil target?

Target charge and the electric field in the case of short-pulse interaction with a solid *target**



$$\epsilon_0 \Delta\phi_{th} = -e\left(n_i - n_e \exp(e\phi_{th}/T_h)\right)$$

ϕ_{th} decrease with cloud dilatation and temperature (Collisions +recombination)

For our laser parameters x10^{18}W/cm^2 , the estimate of hot electrons : kT_h ~ 300 - 500KeV

Thus* : $e\,\phi_{th}$ > 6 – 10 MeV will be able to escape

* A. Poye´ et al PHYSICAL REVIEW E 91, 043106 (2015)

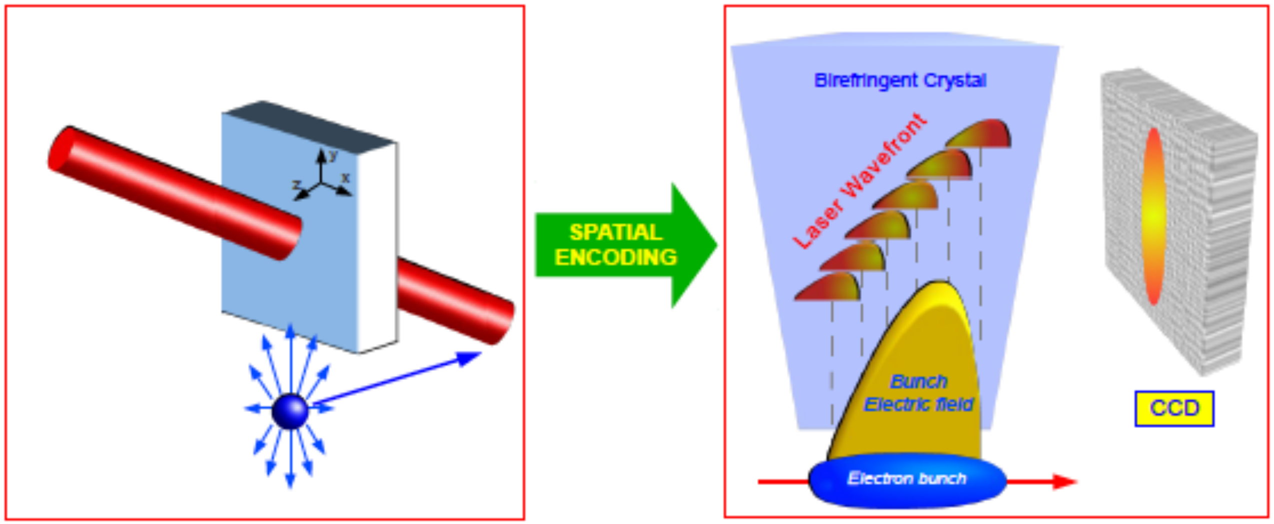
Can we measure the temporal profile of an electrical charge generated during the interaction of a high intensity laser pulse ? ***YES , WE CAN!***

- Possible approach – use of Electro Optical Sampling

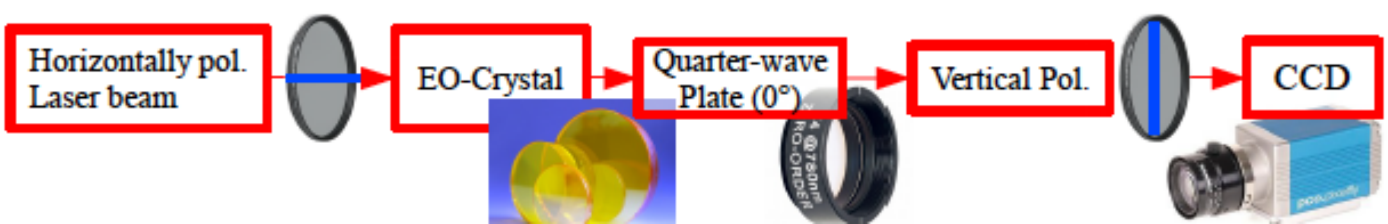
EOS Requirements:

1. 30 fs synchronization between the main (interacting) beam and the probe beam
2. Spatial overlap better than 10 microns

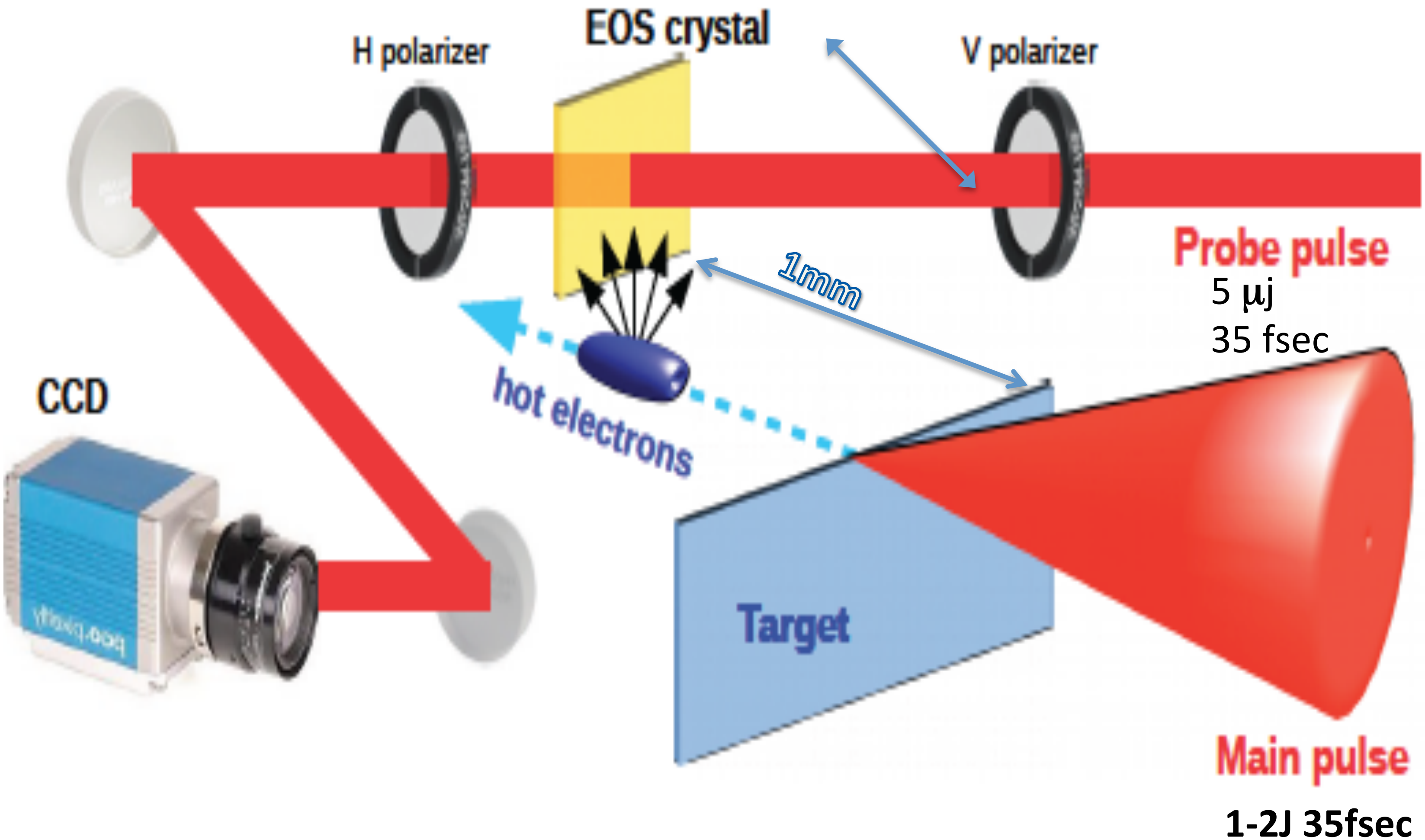
EOS Spatial Encoding Setup



- **Laser crosses the crystal with an incident angle of 30°** → one side of the laser pulse arrives earlier on the EO crystal than the other by a time difference Δt.
- Coulomb field inducing birefringence is encoded in the spatial profile of laser pulse
- Benefits: **simple**, **no high energy laser needed**.
- **Crossed Polarizer Setup**
  - *Measured intensity is equal to* $I_{det} = I_{laser} \sin^2 \Gamma \propto E_{THz}^2$

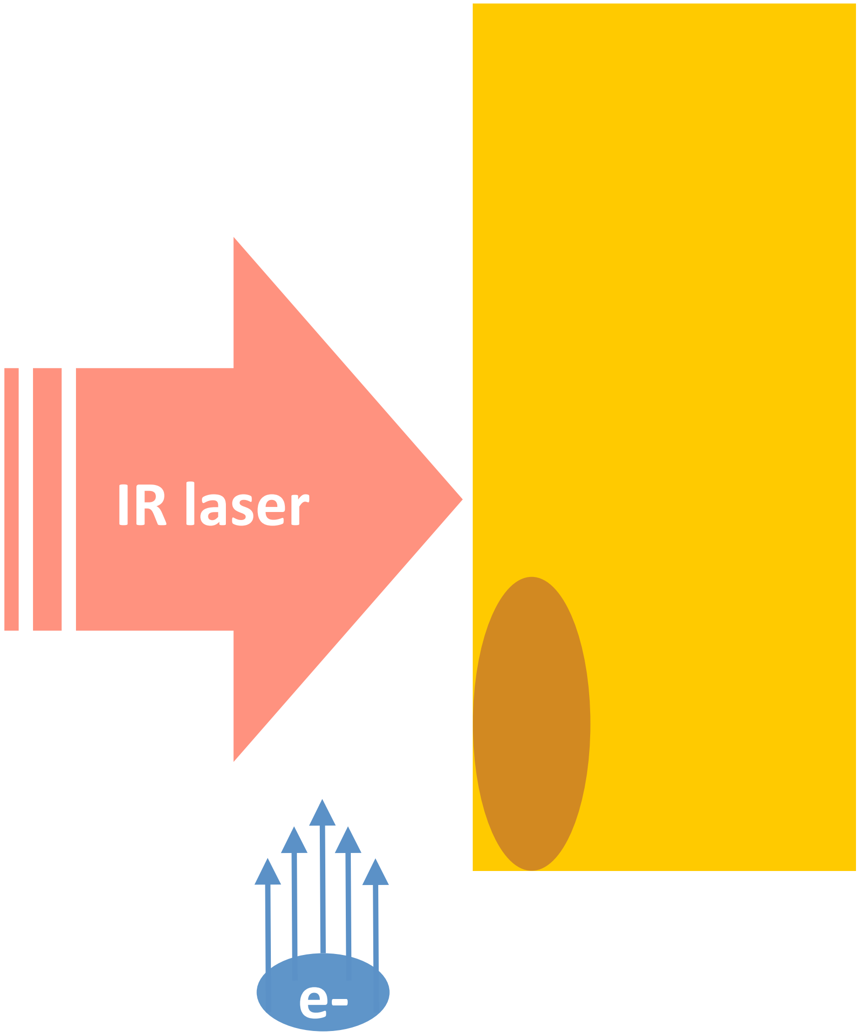


SINGLE-SHOT ONLINE MONITOR FOR THE HOT ELECTRON CLOUD

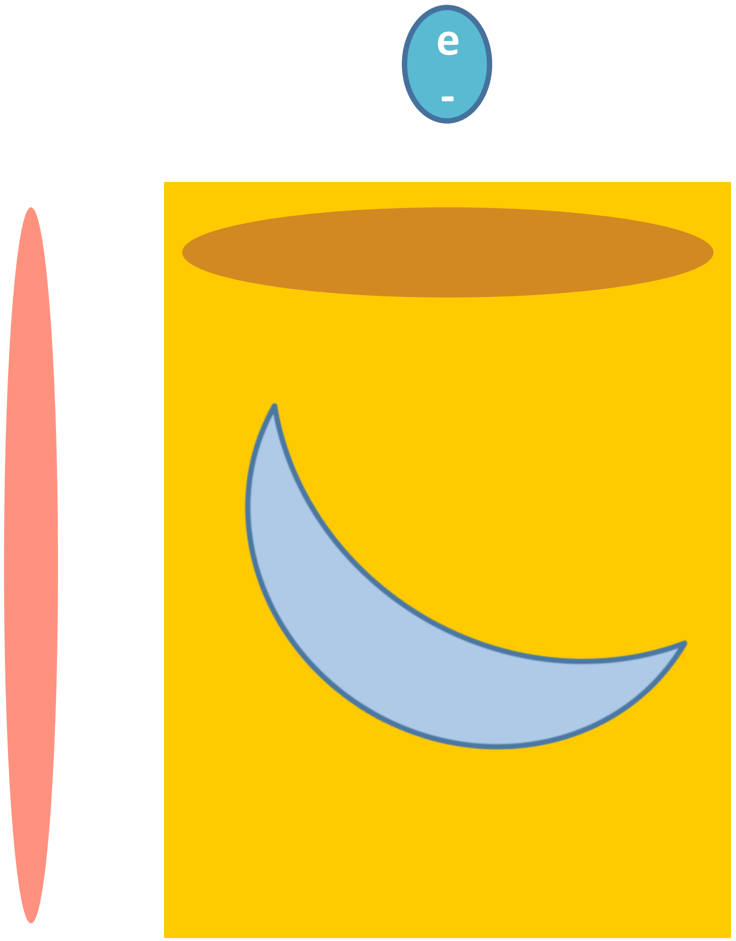


Schematics for measuring quantity and temporal evolution of the escaping electrons

Interpretation of electro-optic signals (longitudinal view)

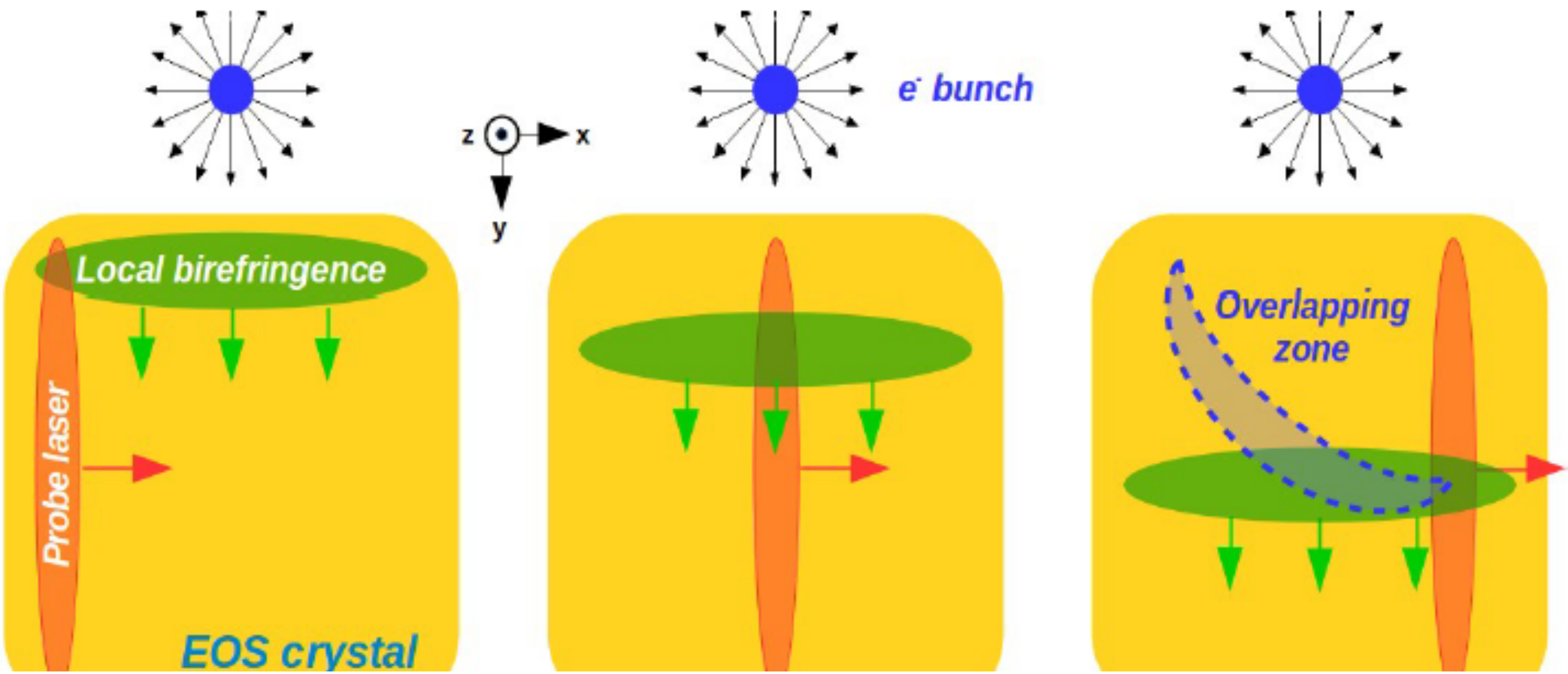


Interpretation of electro-optic signals (transverse view)



Detection of electro- optic signals

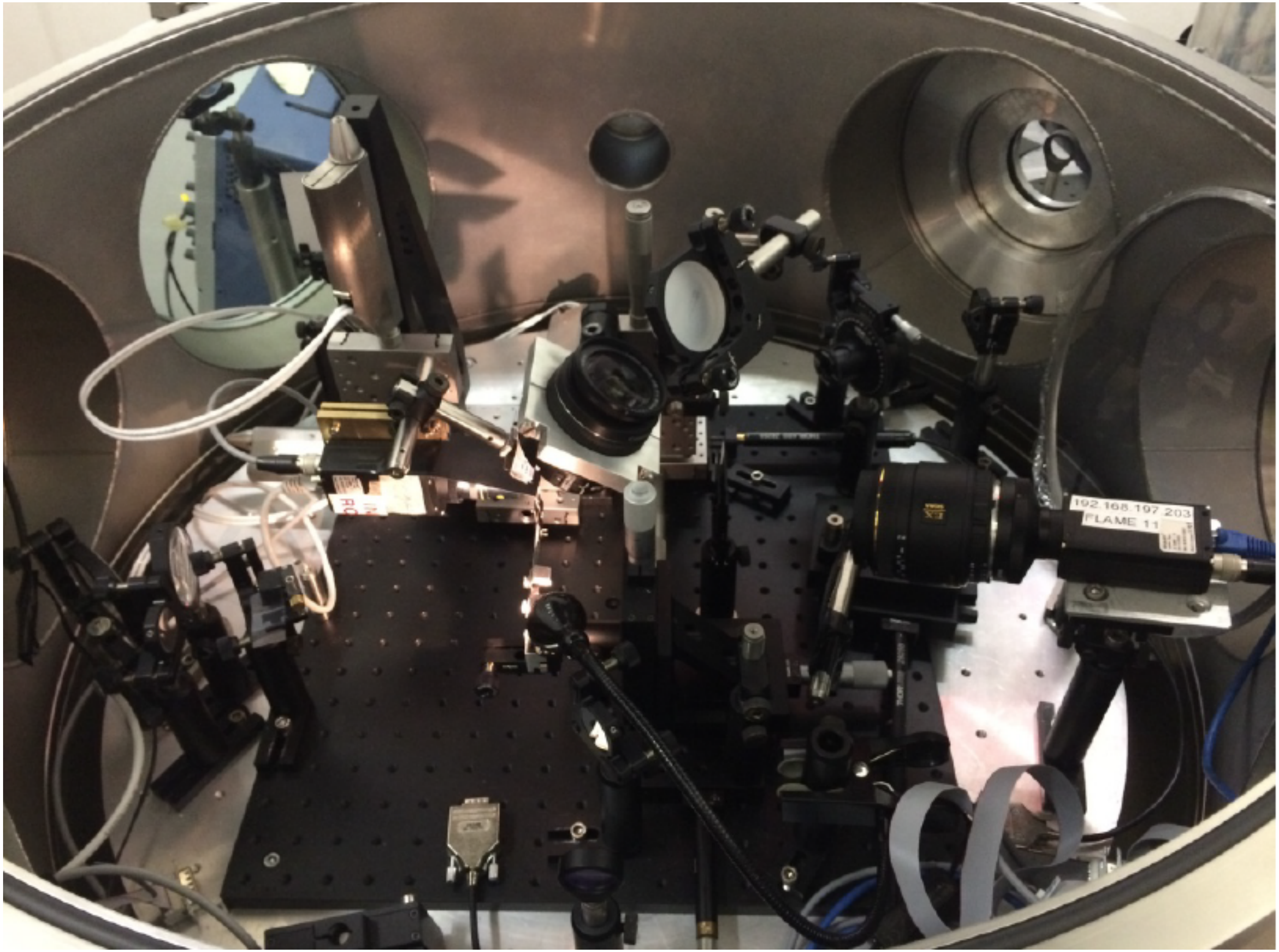
- Picosecond time-window → particle selection by changing the probe delay
  - *Detection only of emitted fast electrons (no protons/ions, gammas, late electrons)*
- Encoding process results in curved signals



FLAME LASER
SPARC_LAB, INFN Frascati

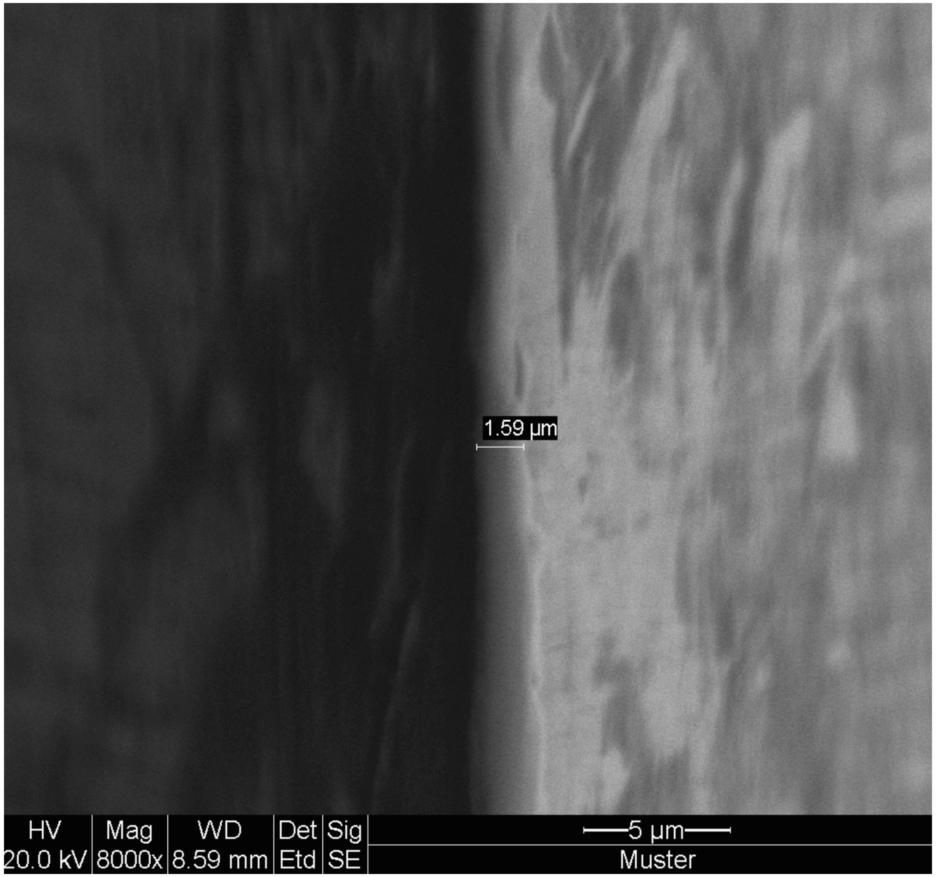
Laser energy		2-4 Joules
Duration		35-40 fsec
Spot size	~	30 microns

Targets :	Al foil	-	11 microns
	St. St Blade	-	(edge ~ 1micron)
	Needle	-	tip < 10 microns

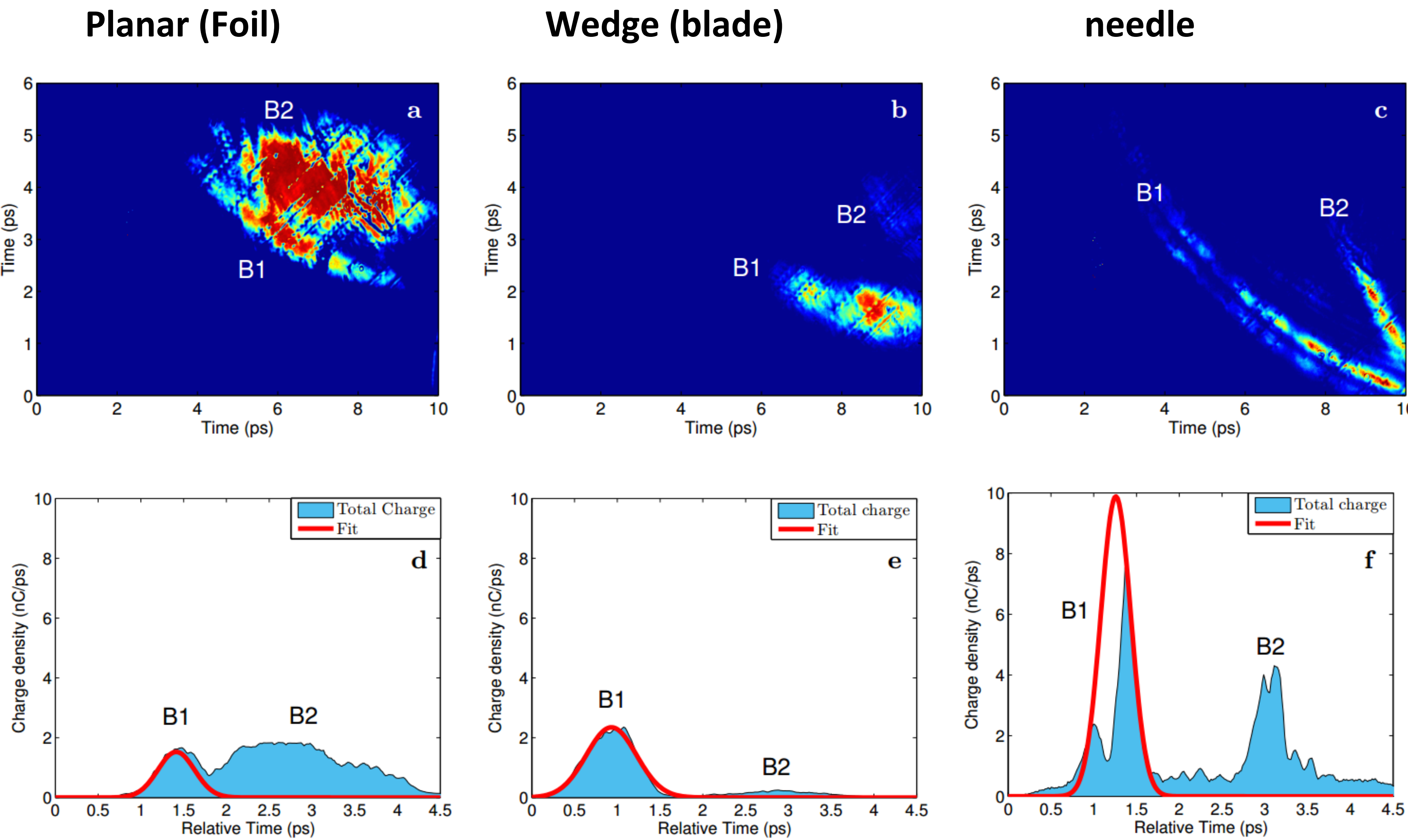


4 - XYZ (motor), 6 CCD cameras, EOS, Electron spectrometer, CR39

Blade target



Influence of the target shape on the escaping electrons



ND filter added for recording images b and c
The main laser parameters are the same in all cases.

(R.Pompili et al Scie. Rep 2016)

Influence of the target shape on the escaping electrons

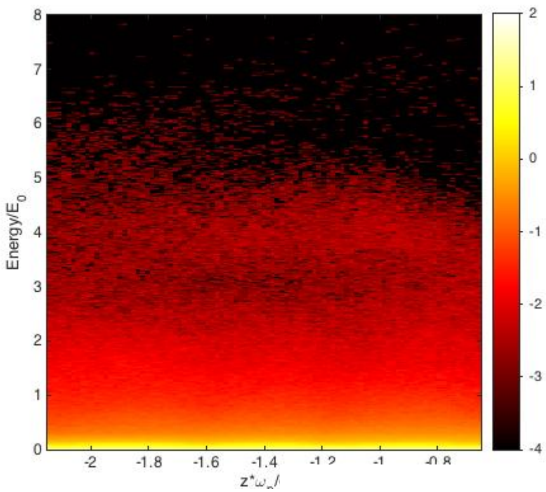
Target shape	I_L (W cm^{-2})	Q_e (nC)	ϵ_e (MeV)
Planar	2×10^{18}	1.2^{*}	7 ± 1
		3^{**}	1.0 ± 0.1
Wedged	2×10^{18}	2.0^{*}	7 ± 1
		0.3^{**}	0.8 ± 0.1
Tip	2×10^{18}	7^{*}	12 ± 2

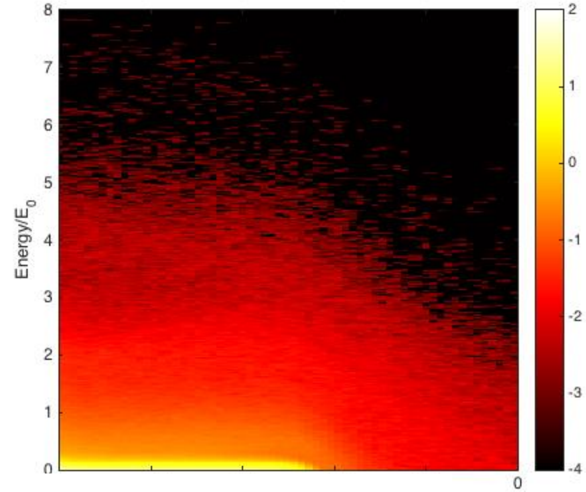
Q_e charge in the first (*) "bunch" only, (**) the second "bunch"

These are the electrons that escaped the potential barrier.

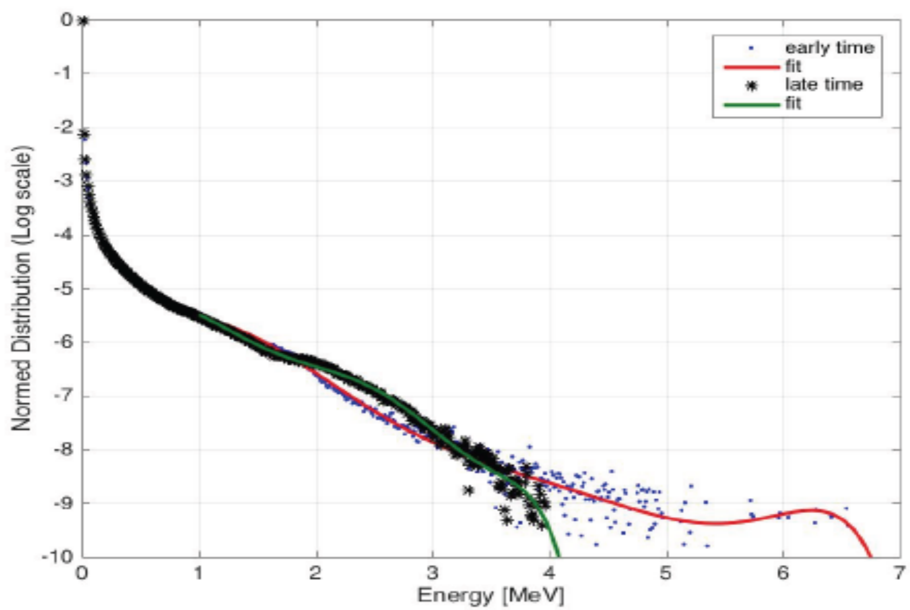
PIC Simulation: Energy distribution ($a_0 \sim 0.3$)

50fsec

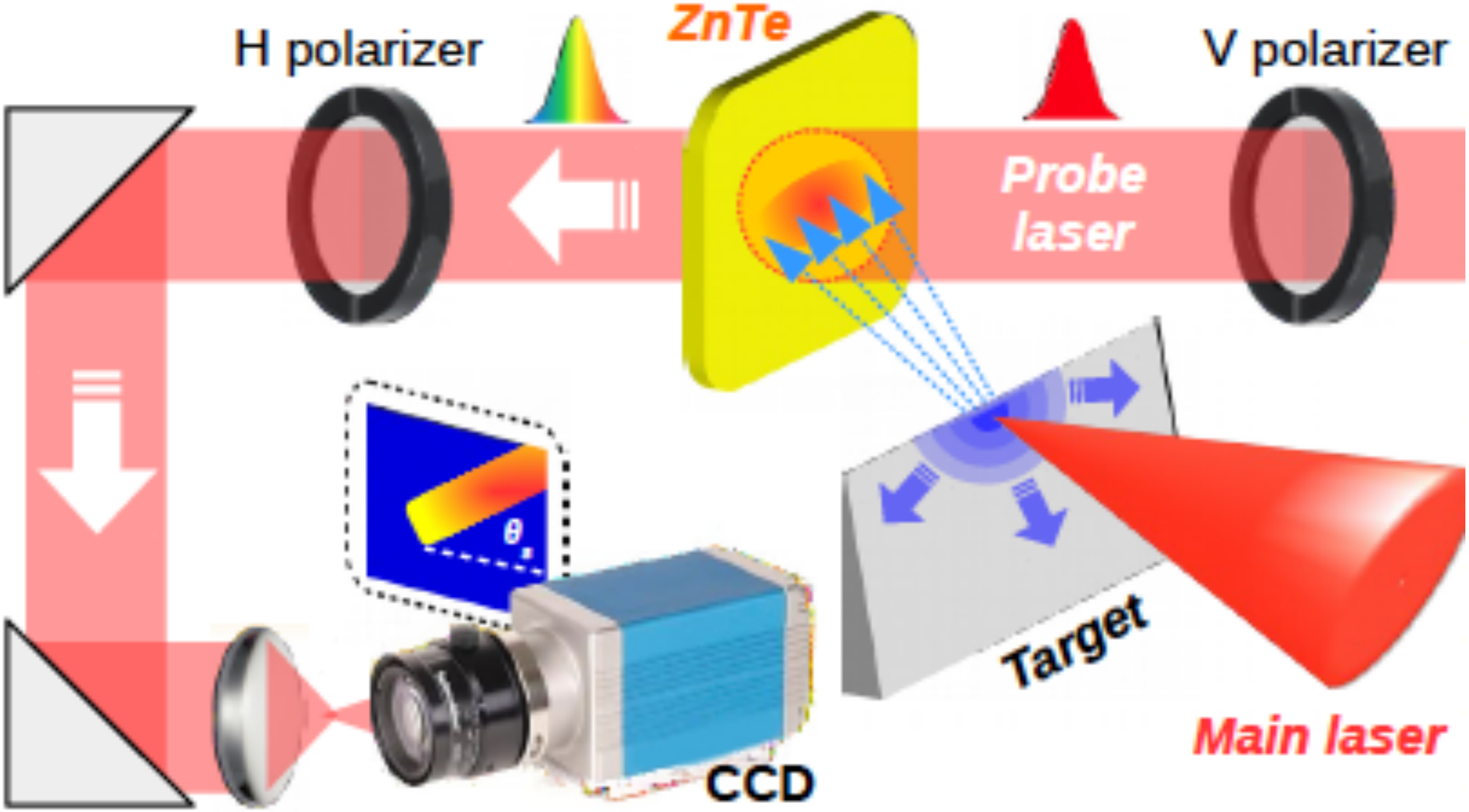




300fsec



Can we use this diagnostic to measure the produced electrical fields?



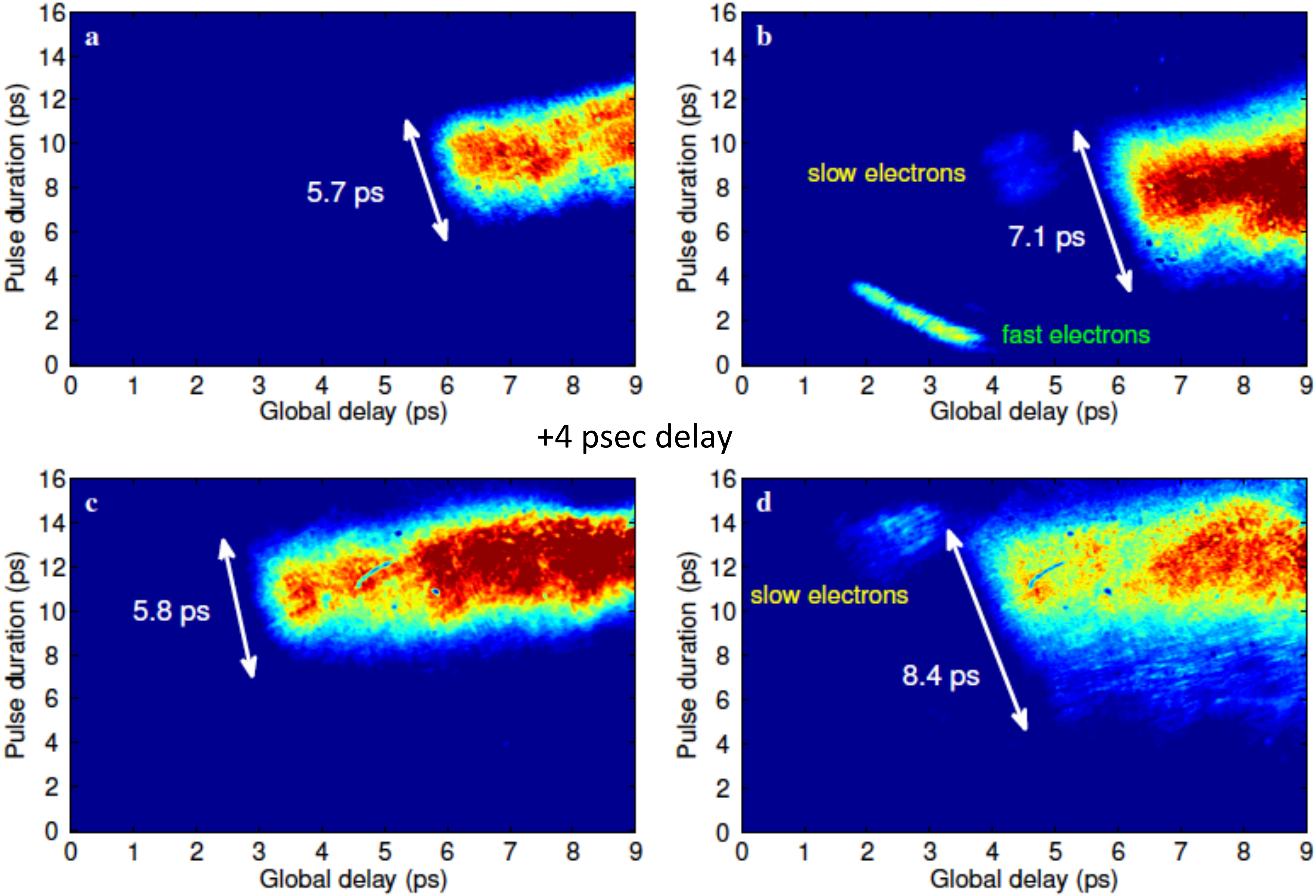
Measurements of electrical fields

Measured electrical fields I~ $10^{18}W/cm^2$

50% laser energy

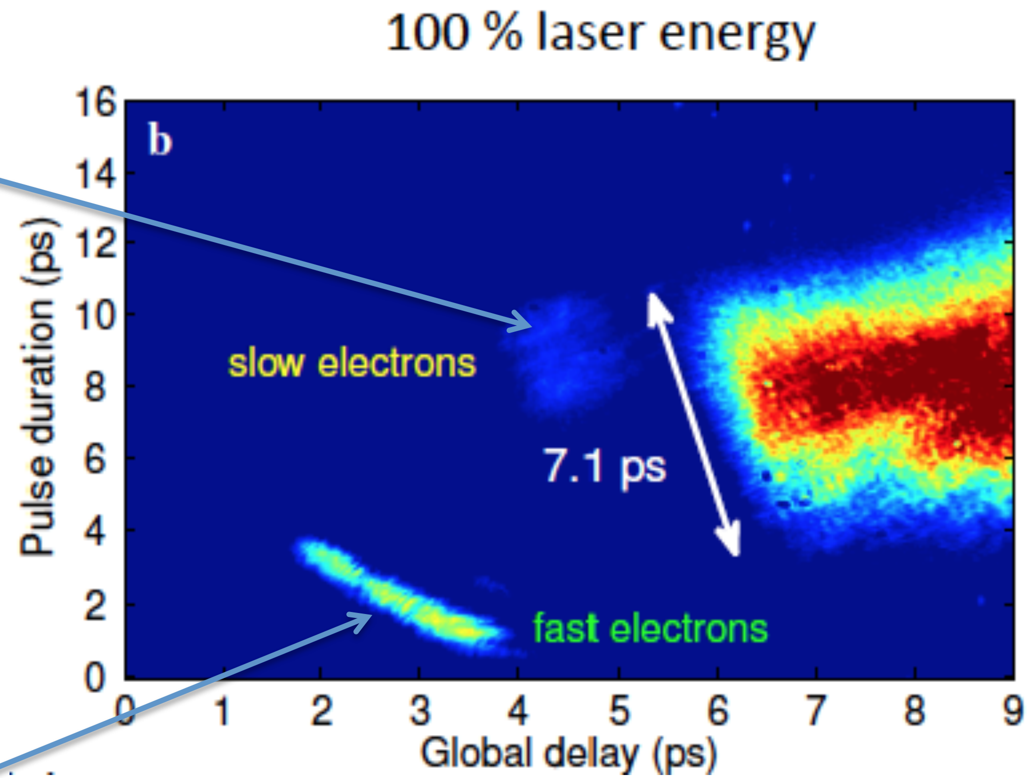
100 % laser energy

+4 psec delay



Low energy component of escaped Electrons

Charge	~ 0.3 nC
Average energy	~ 0.6MeV
Duration	~ above 2 ps



High-energy electrons

Charge	~ 2nC
Average energy	~ 7 MeV (TOF)
Duration	~400 fs (fwhm).

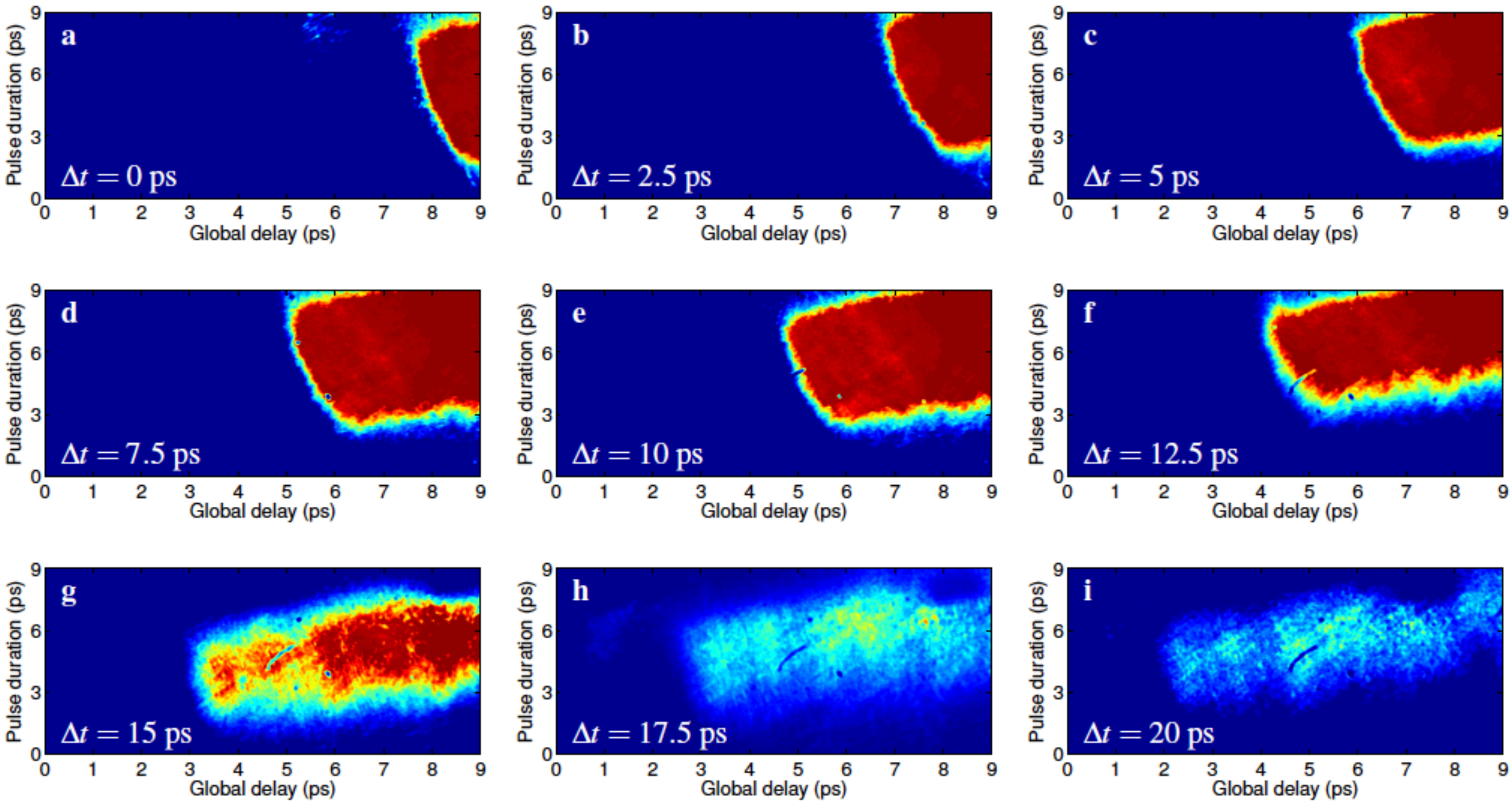
~ 0.8 % of total charge

$\mathbf{Q_e}$ ~ 2 nC - the positive surface charge $\mathbf{Q_i}$ induced on the target surface

A surface charge density $\sigma_T = Q_e/\pi r^2_L$ thus **Electric field E_T ~ 0. 6 TV/m**.

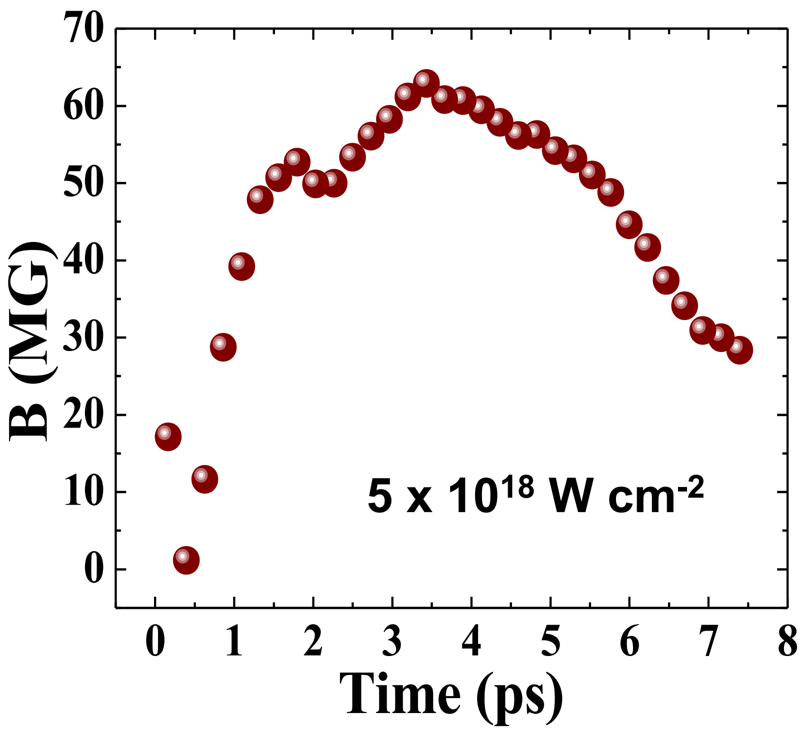
Escape only few electrons with energies ~ 5 MeV as confirmed by PIC

Timeline of the radiation pulse evolution

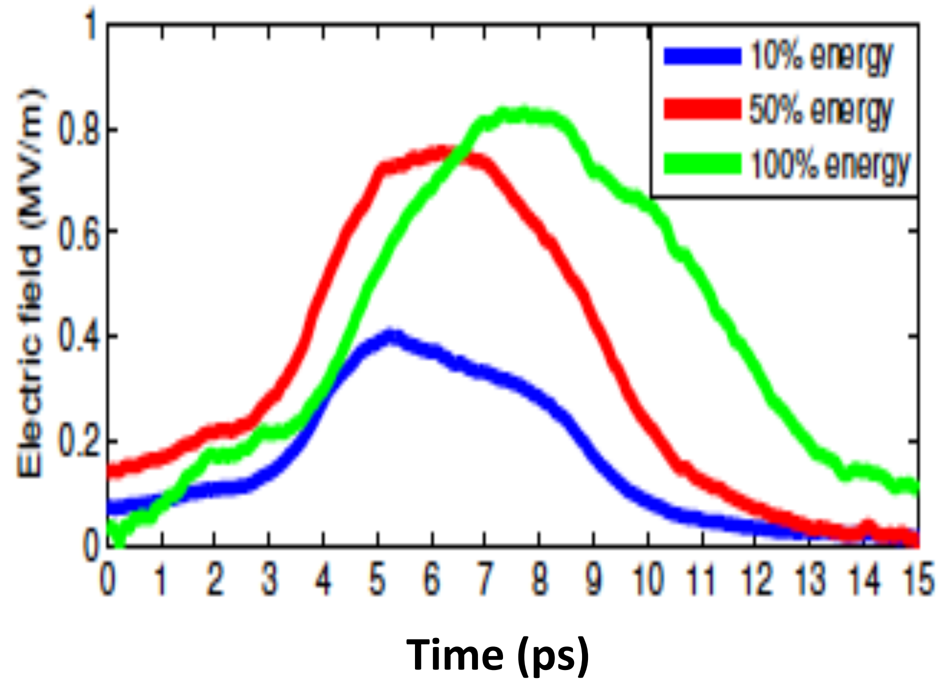


Measured Magnetic Field (TIFR)*

Aluminium film coated glass



EOS Measured Electrical Field



I ~ 5 10^{18}W/cm^2

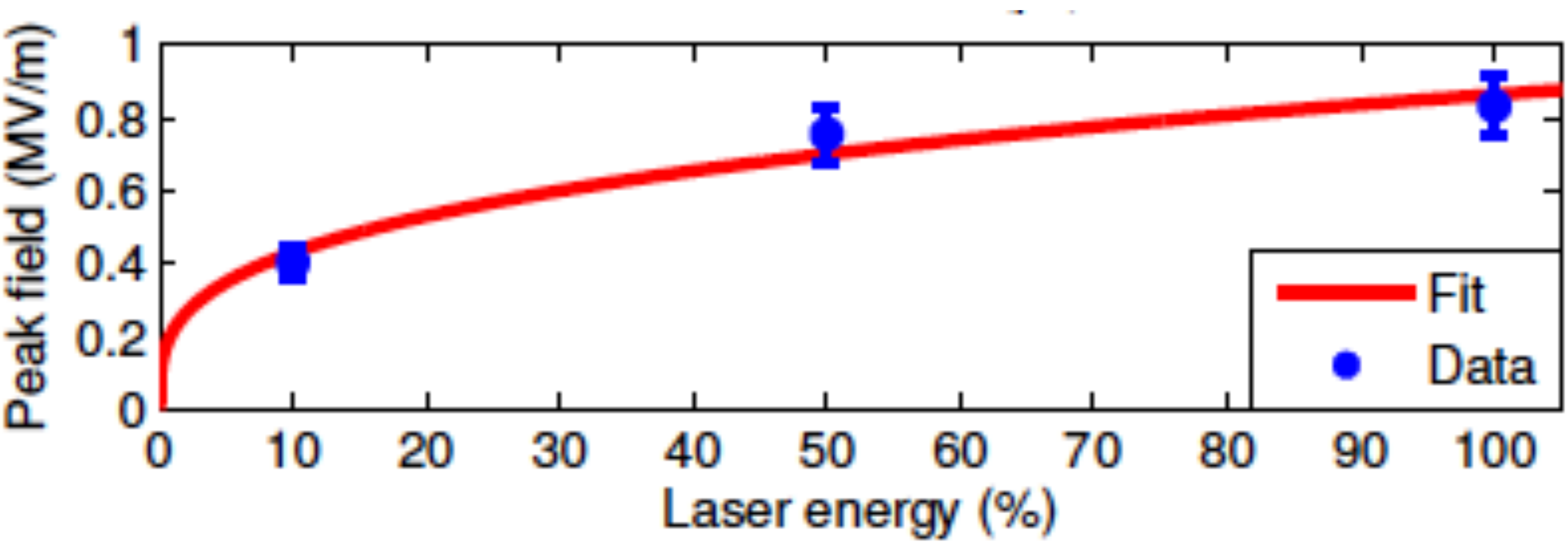
I ~ 0.2-2 10^{18}W/cm^2

*** Courtesy of Ravi Kumar TIFR, India**

Maximal measured signal – 0.8 MV/m corresponding to ~ **0.6TV/m** at the source

Scaling of E_T peak amplitudes with laser energy.

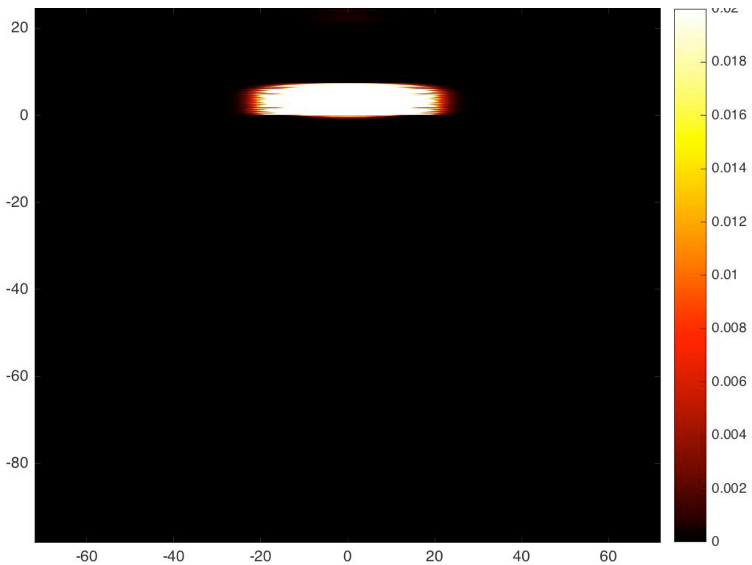
I~ x 10^{18}W/cm^2



Wedge (blade) Target

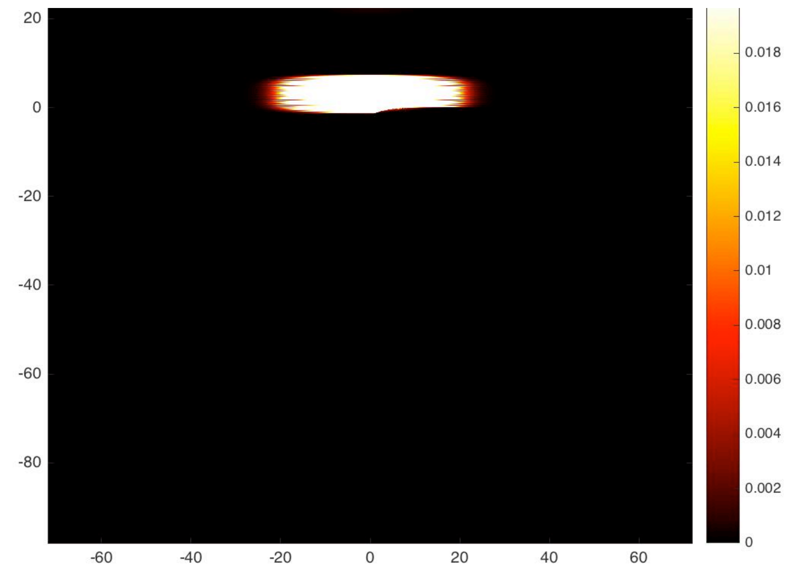
The fit is calculated according
to the power law $\mathbf{y} = \mathbf{a}\ \mathbf{x}^{\mathbf{b}}$, with $\mathbf{b}$ = 0.30

Total Electrical field   I $=10^{18}$W/cm^2

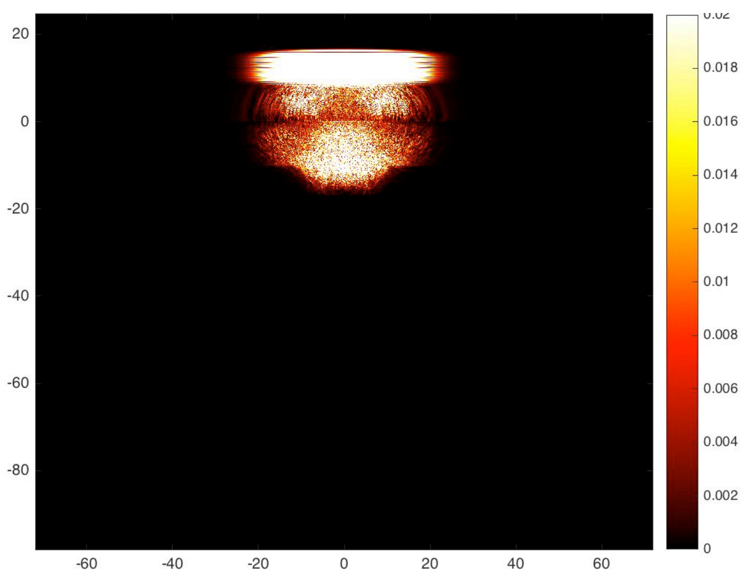


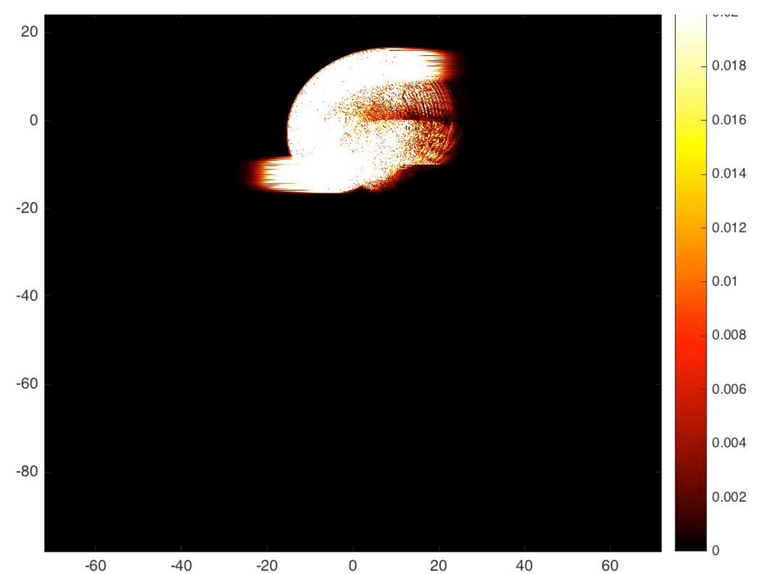
foil

T= 16 fsec



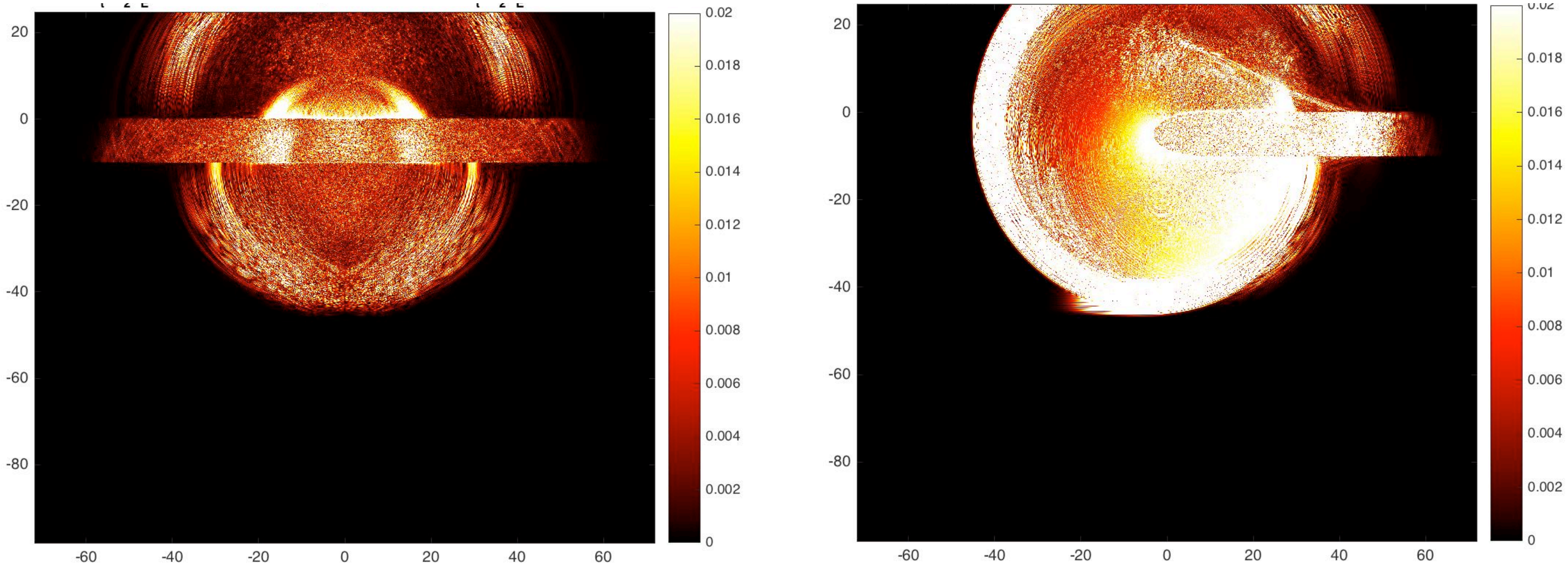
wedge



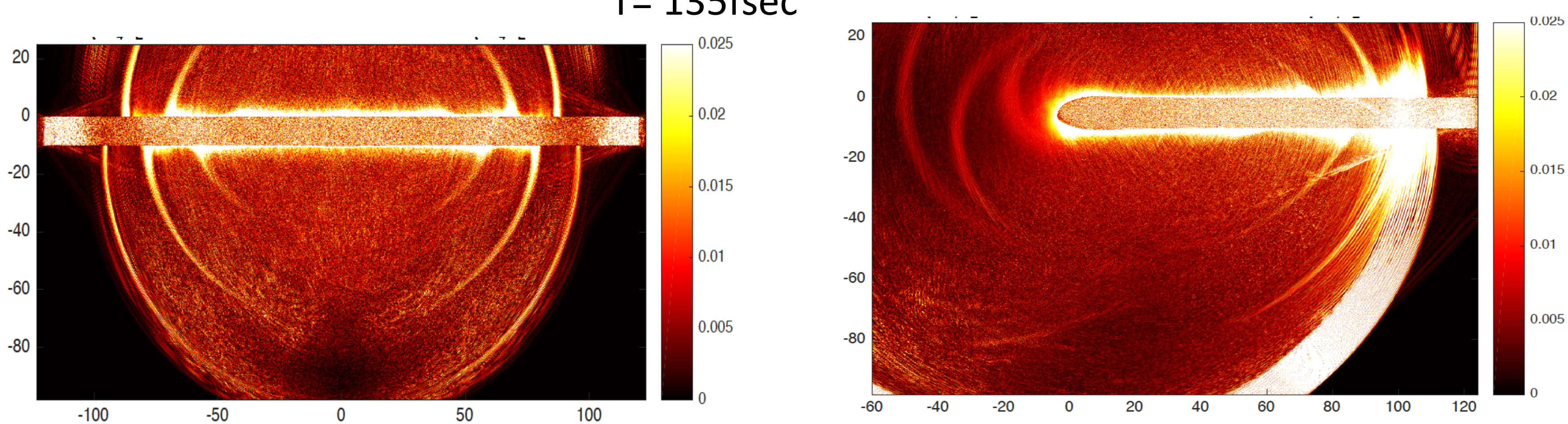


T= 86 fsec

Total Electrical field , I =10^{18}W/cm^2



T= 135fsec



T= 350 fsec

Summary

- **We measured the quantity, duration and temporal evolution of electrons that left the target at the beginning of interaction with high intensity laser**

- **Target structure effecting the quantity and energy of escaping electrons - pointing out to - field enhancement**

- **For the same laser intensity we measured 7nC of escaped electrons from a needle tip of in comparison 1.2 nC from thin foil**

- **Evolution of electrical fields resulted from interaction of intense ultra short laser pulse measured with sub-picosecond resolution**

Thank you


CHILI 2017
Conference on High Intensity Laser
and attosecond science in Israel
Tel-Aviv, December 11th-13th, 2017