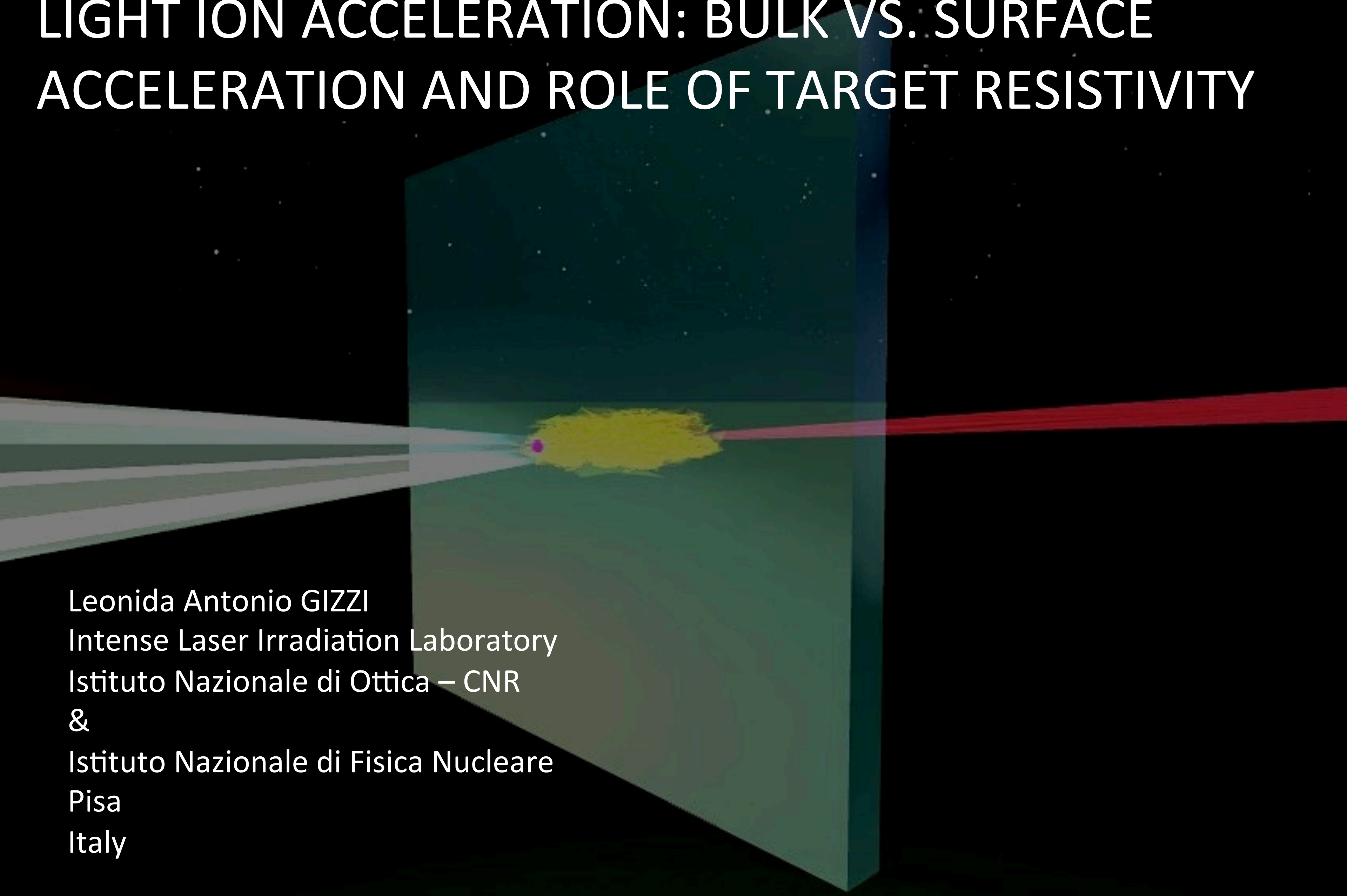
LIGHT ION ACCELERATION: BULK VS. SURFACE ACCELERATION AND ROLE OF TARGET RESISTIVITY



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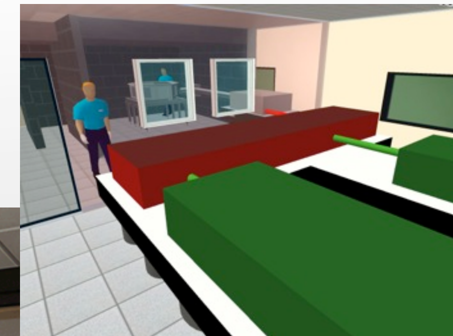

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MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA

Ministero della Salute

ELI-ITALY INO-CNR (Pisa)

EUPRAXIA H2020

Laserlab Europe

INFN Istituto Nazionale di Fisica Nucleare

L.A.Gizzi, EAAC2015

Lab's Main research topics

- Laser-wakefield acceleration (ELI/Euronnac/Eupraxia)
  - – Radiobiology with laser-driven electrons;
  - – Self-injection mechanisms (see D.Palla WG6 Thu. 18:20H);
  - – X-ray and γ-ray generation
- Plasma and laser diagnostics;
- Amplification with diode pumping (collaboration)
- Ultraintense laser-solid interactions
  - **Light ion acceleration**

Contents

- Motivation
- Experimental set up
- Overview of results
- Summary

Motivations

- Ongoing activity on basic physics of generation of high energy density using ultrashort laser pulses (ICF relevant);
  - Fast electron generation and transport, X-ray emission, laser absorption;
  - Laser-driven shock wave generation;
- National initiative on laser driven proton acceleration (**L3IA** - Line for Laser Light Ions Acceleration) submitted to INFN and based upon the ILIL laser upgrade currently in progress;

Objectives of L3IA

A laser-accelerated beamline for light ions:

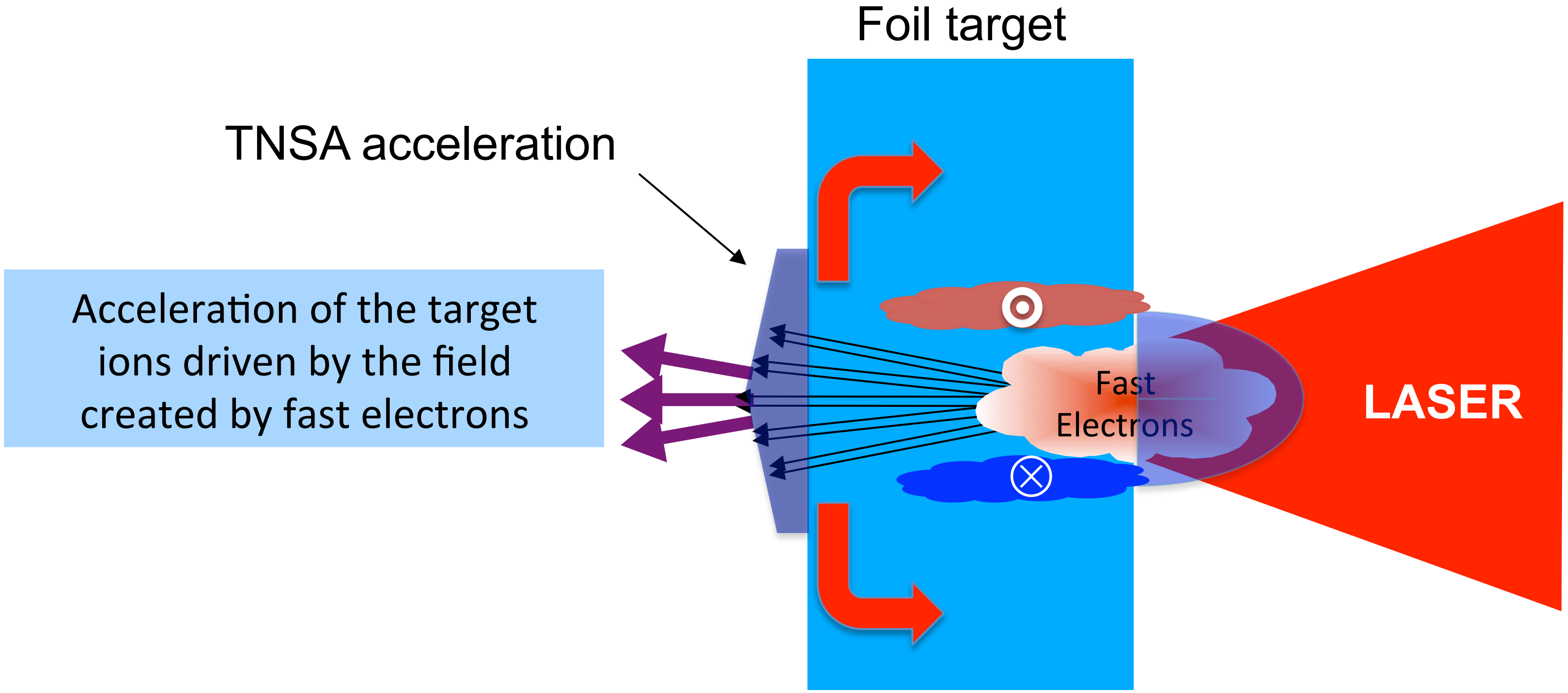
- Develop ion acceleration with ultraintense lasers;
- New target techniques for control of energy spectrum and beam collimation;
- Establish a proton beam line at 14 MeV for applications;
- Provide a dedicated test beamline for ELI (e.g. ELImed@LNS)
- A platform for radiobiology studies with laser accelerated ions
- …

L3IA: Groups

Milano: detectors development – dedicated TP, Beam manipulation and post acceleration;
Pisa: laser, laser-plasma acceleration, laser and plasma diagnostics and control
Bologna: Theory: particle in cell modelling, beam dynamics modeling
LNS (Catania): beam characterization, dosimetry, medical applications;
LNF(Frascati): detectors and post acceleration
Napoli: radio-biology and medical applications, analytical laser-plasma modelling
Florence: Ion beam based analysis

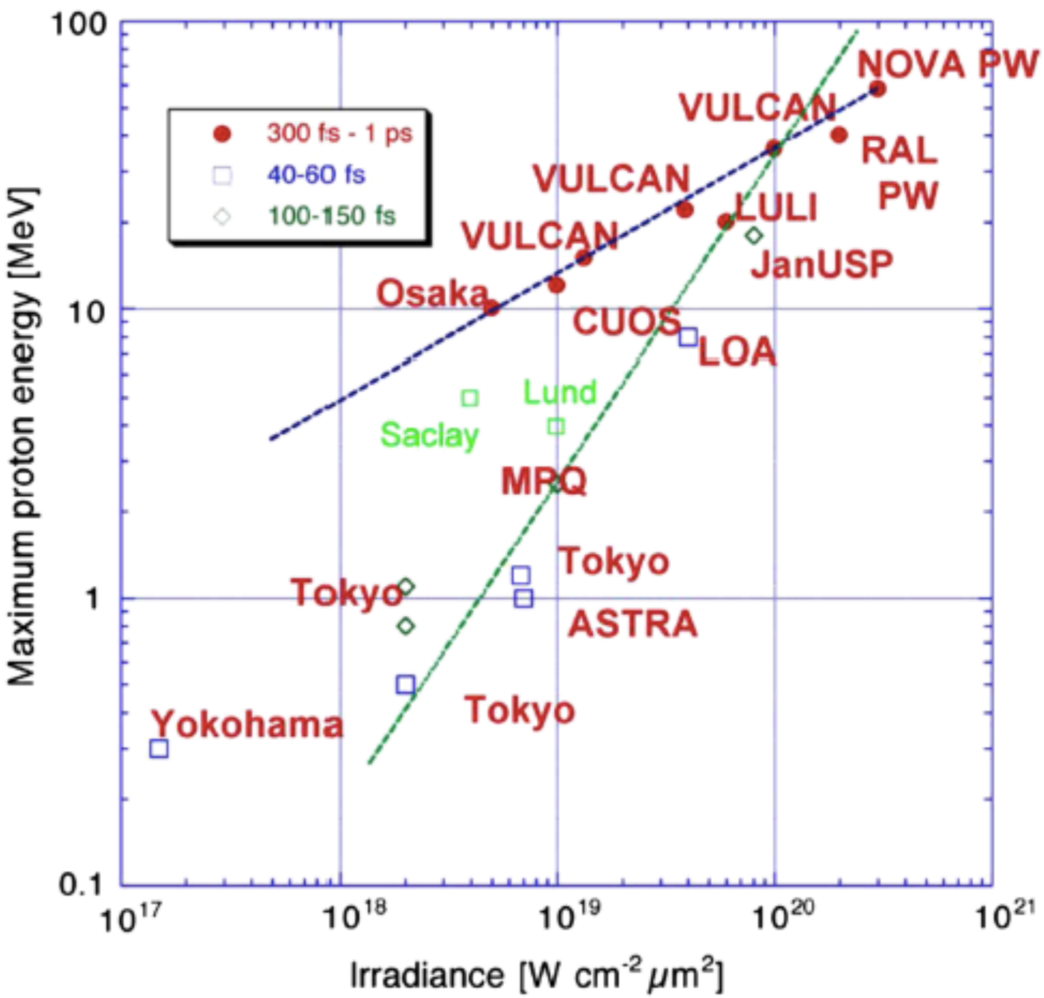
Laser solid interactions

Laser-foil interactions creates huge currents of relativistic eletrons propagating in the solid and giving rise to intense X-ray emittion and, ultimately, ion emission from the rear surface of the foil



R.A.Snavely et al., Phys. Rev. Lett. **85**, 2945 (2000)
M Borghesi, et al., Phys. Rev. Lett. **92** (5), 055003 (2004)
L. Romagnani *et al.*, Phys. Rev. Lett. **95** 195001 (2005).
S. Betti *et al.*, Plasma Phys. Contr. Fusion **47**, 521-529 (2005).
J. Fuchs et al. Nature Physics **2**, 48 (2006).
X.H.Yuan et al., New Journal of Physics **12** 063018 (2010)

Proton Acceleration - TNSA



Macchi, Passoni, Borghesi, RMP, **8**5,751 (2013)

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Laser driven ion acceleration

- High gradient acceleration: MeVμm−1, compared with ~MeV m−1 provided by radio frequency (RF) based accelerators;
- Ultra-short duration at the source of the ion bunch of the order of picoseconds;
- Very small effective source size: ≈10 μm;
- highly laminarity and very low emittance;
- Broad energy spectrum, low collimation
- High charge: 10^8-10^9 particles

Macchi, Passoni, Borghesi, RMP, **8**5,751 (2013)

Current effort

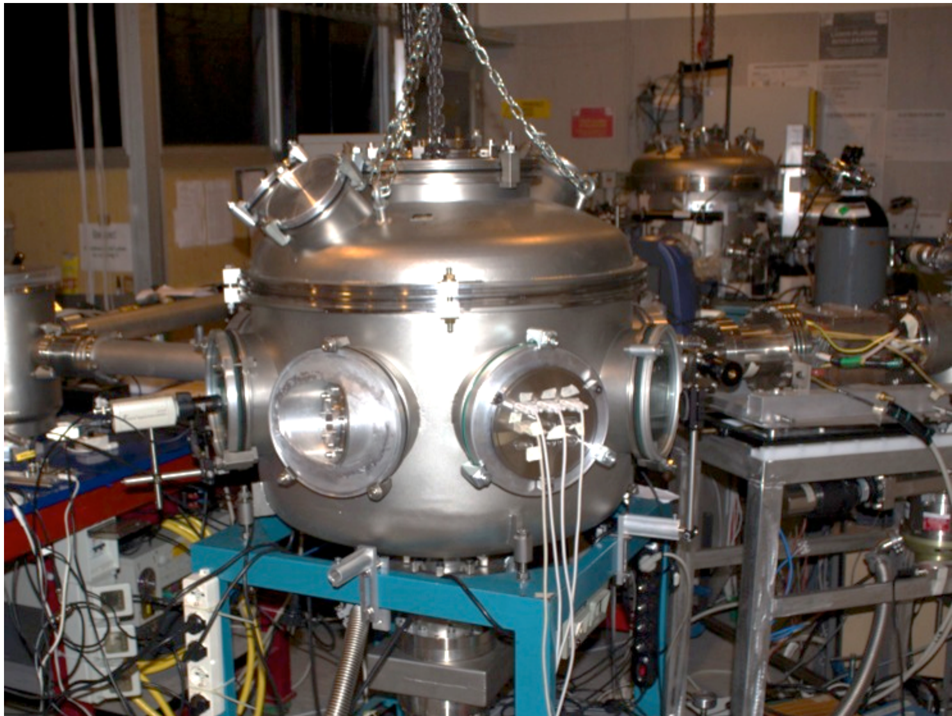
- New acceleration mechanisms at ultrahigh intensity
  - Radiation pressure acceleration
  - Collisionless shock acceleration
- Target engineering: surface, geometry, conductivity
- Post acceleration: selection, collimation, injection
- Dosimetry and radiobiology: fast (ps) ion source

Our recent activity
(PlasmaMED 2013-14)

- Dedicated experimental chamber for ion acceleration commissioned end 2014 (**Pisa**, **ILIL** laser);
- Ion acceleration runs started Jan. 2014 with existing laser parameters (10 TW);
- Collaboration Pisa, Milano, Catania, Bologna (and Napoli);

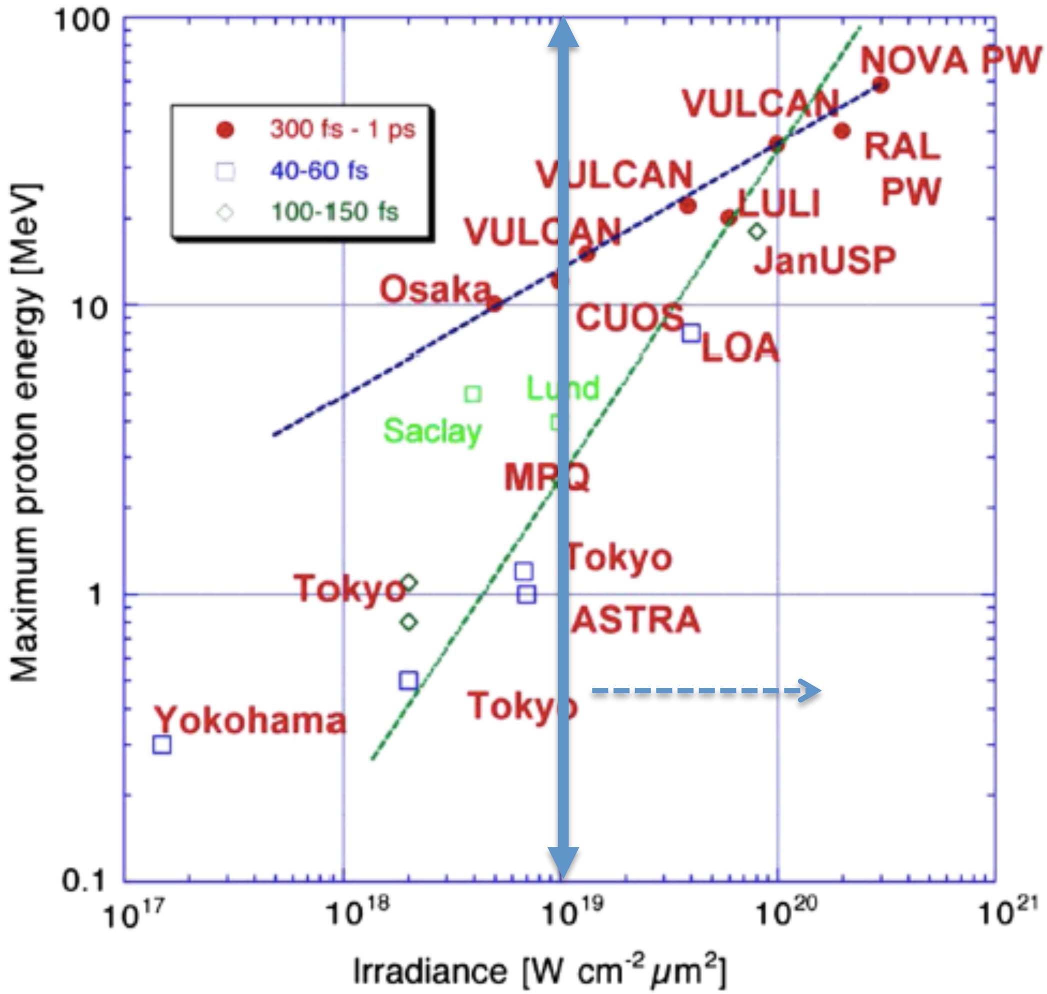
A new experimental chamber "Pavone" is operational for laser-solid interaction, dedicated to:

1. TNSA acceleration of light ions;
2. Fast electron transport;
3. Shock generation in nanoengineered target;
4. X-ray generation and applications



ILIL@ INO-CNR(Pisa)
Waist= 8.5 μm
FWHM=5μm
Tau=40 fs
E_on_target=400mJ
Intensity on target> 1E19 W/cm2
Target thickness=1-15 micron
Target Material=Al, Mylar, Cu, CH2, CD2
Angle of incidence=15°
Contrast: >1E9
10 TW on target 100 TW Upgrade in progress
Quanta-Ray

Light ion acceleration



Macchi, Passoni, Borghesi, RMP, **8**5,751 (2013)

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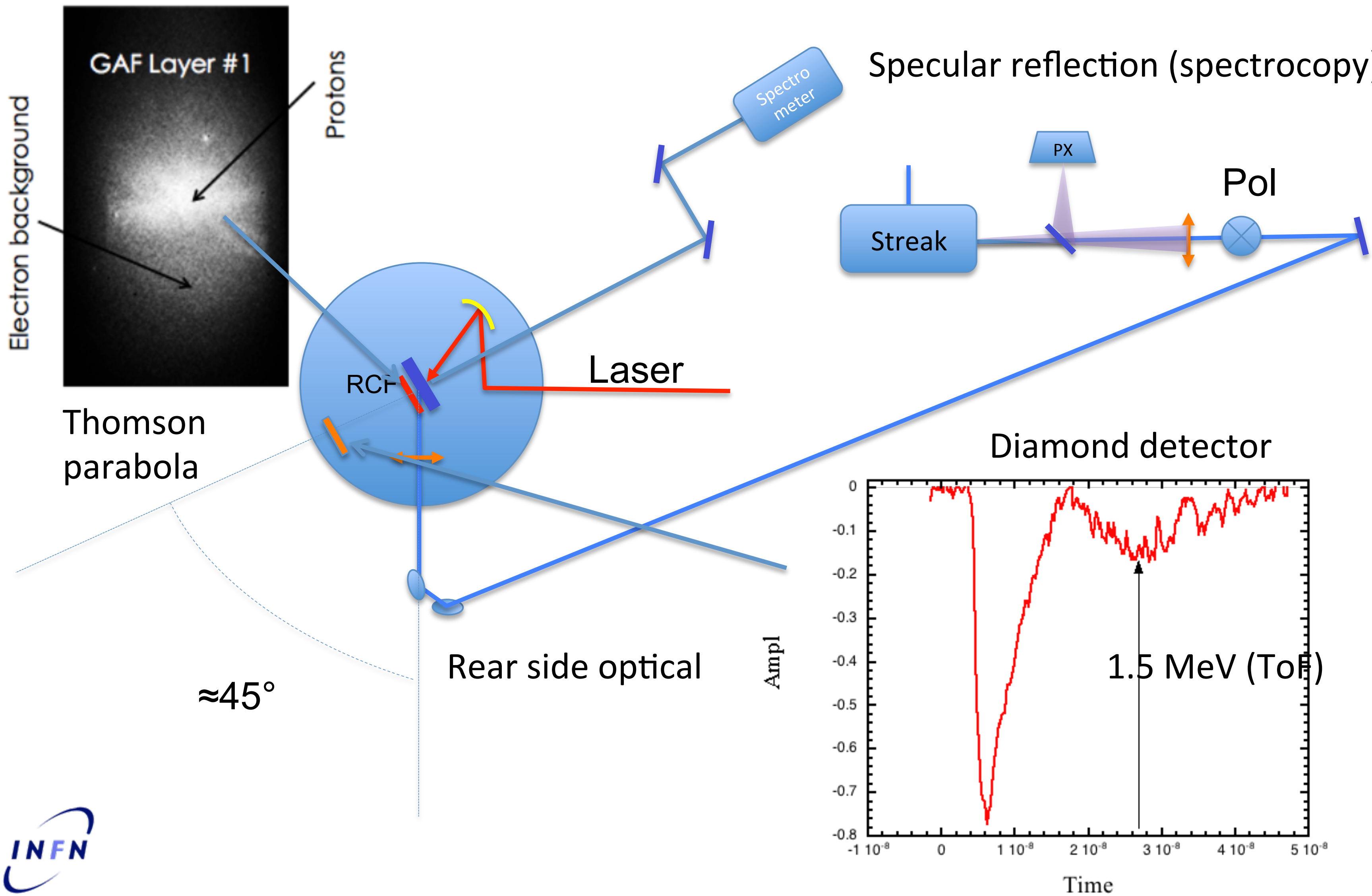
Experimental set - up



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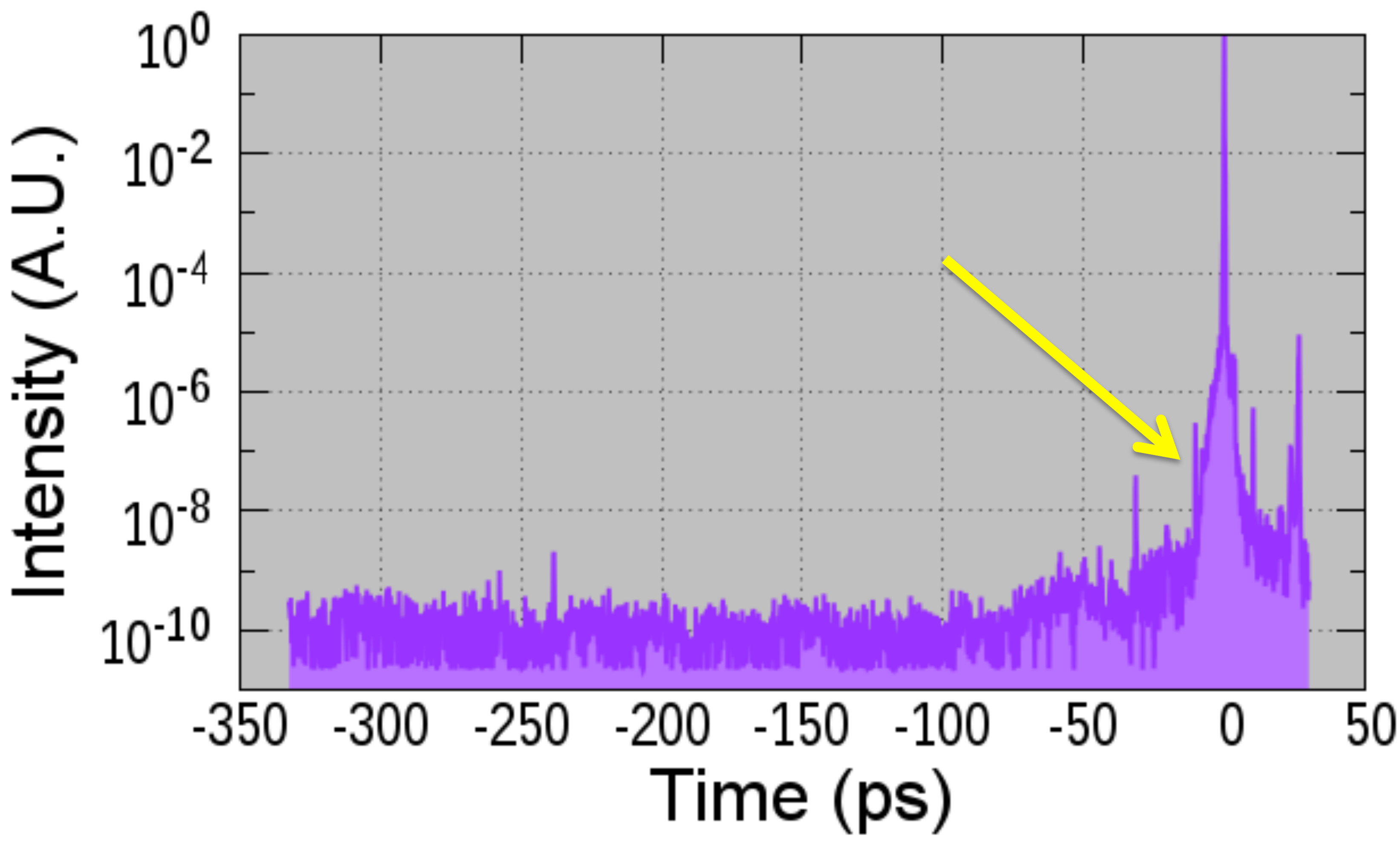
ILIL Laser: contrast



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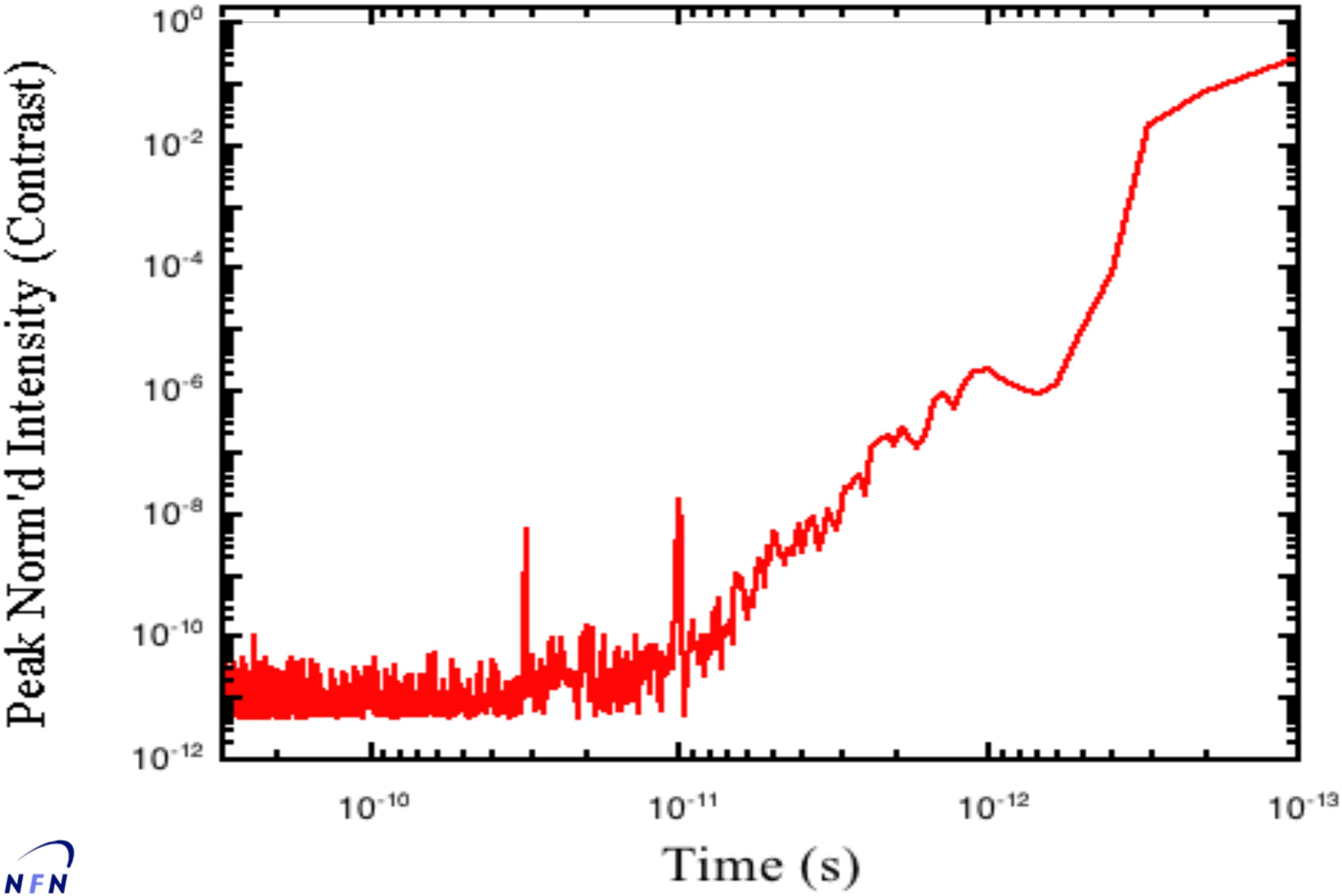
ILIL Laser contrast: ps tscale



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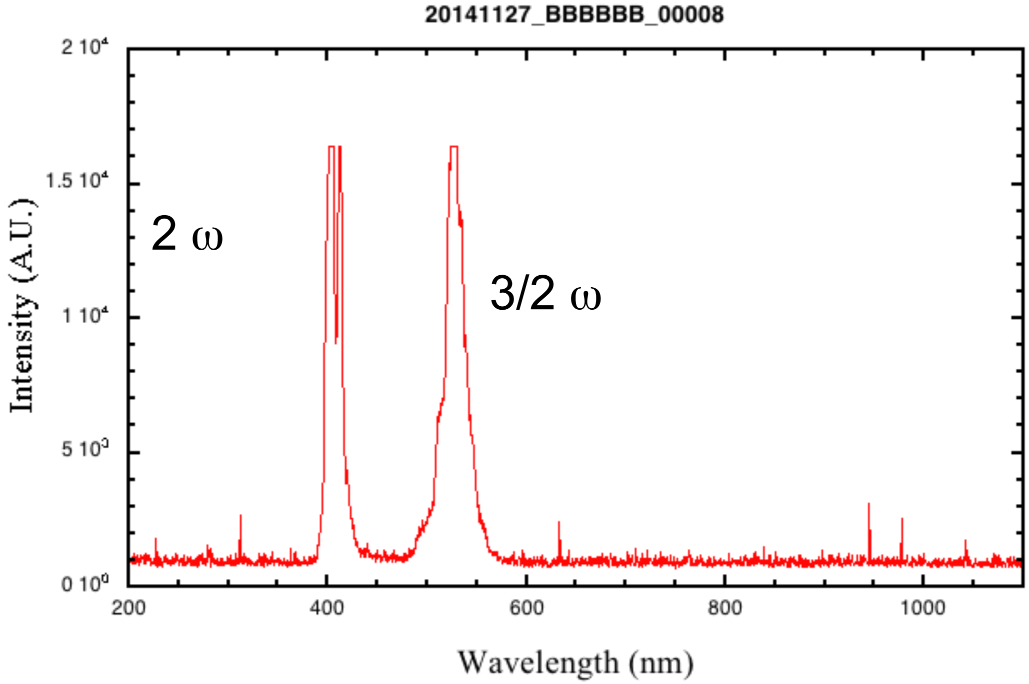
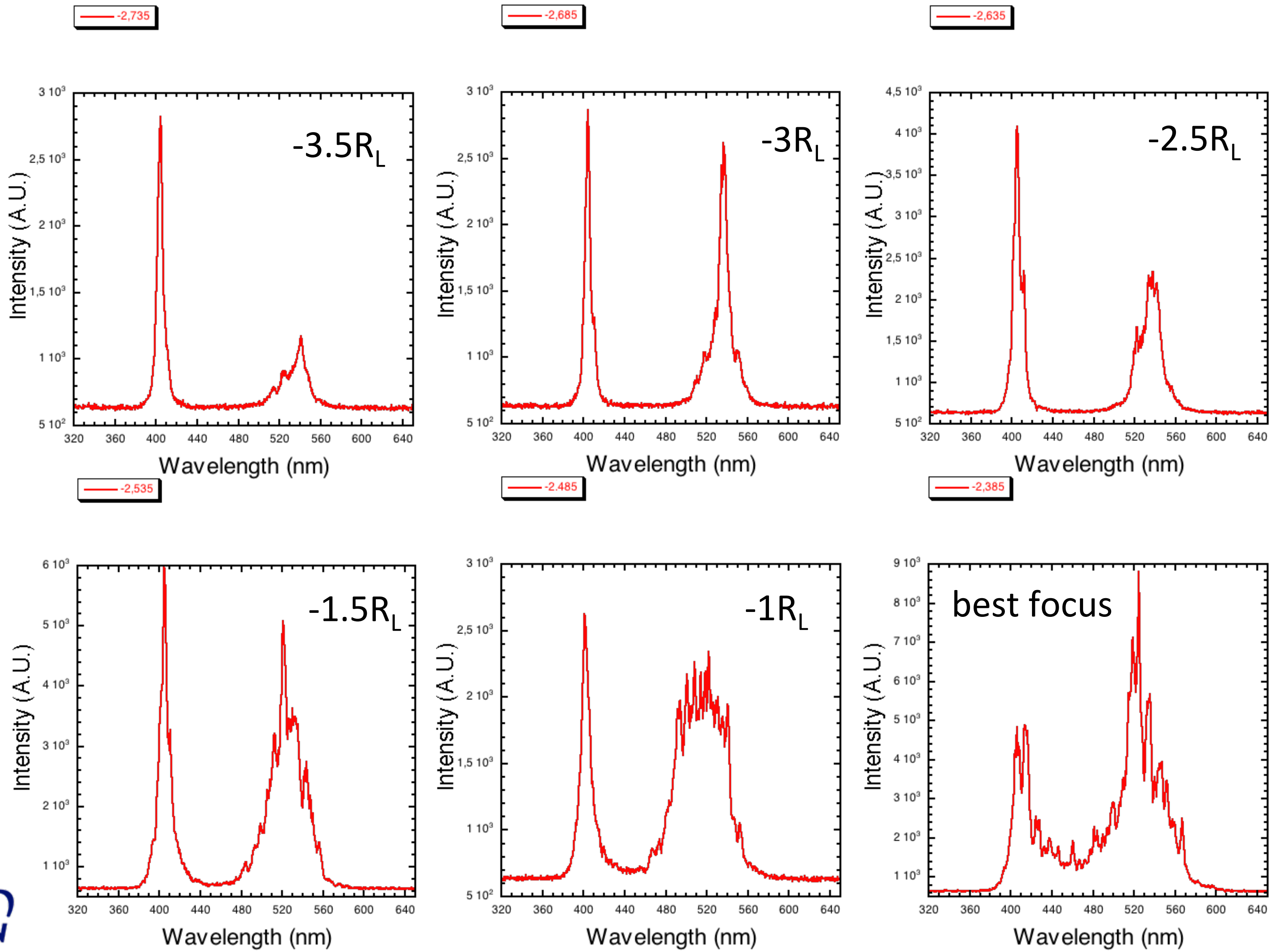
Monitor of plasma gradient



$2\ \omega_L$ emission => interaction at the critical density layer[&]
$3/2\ \omega_L$ - two-plasmon decay from underdense plasma

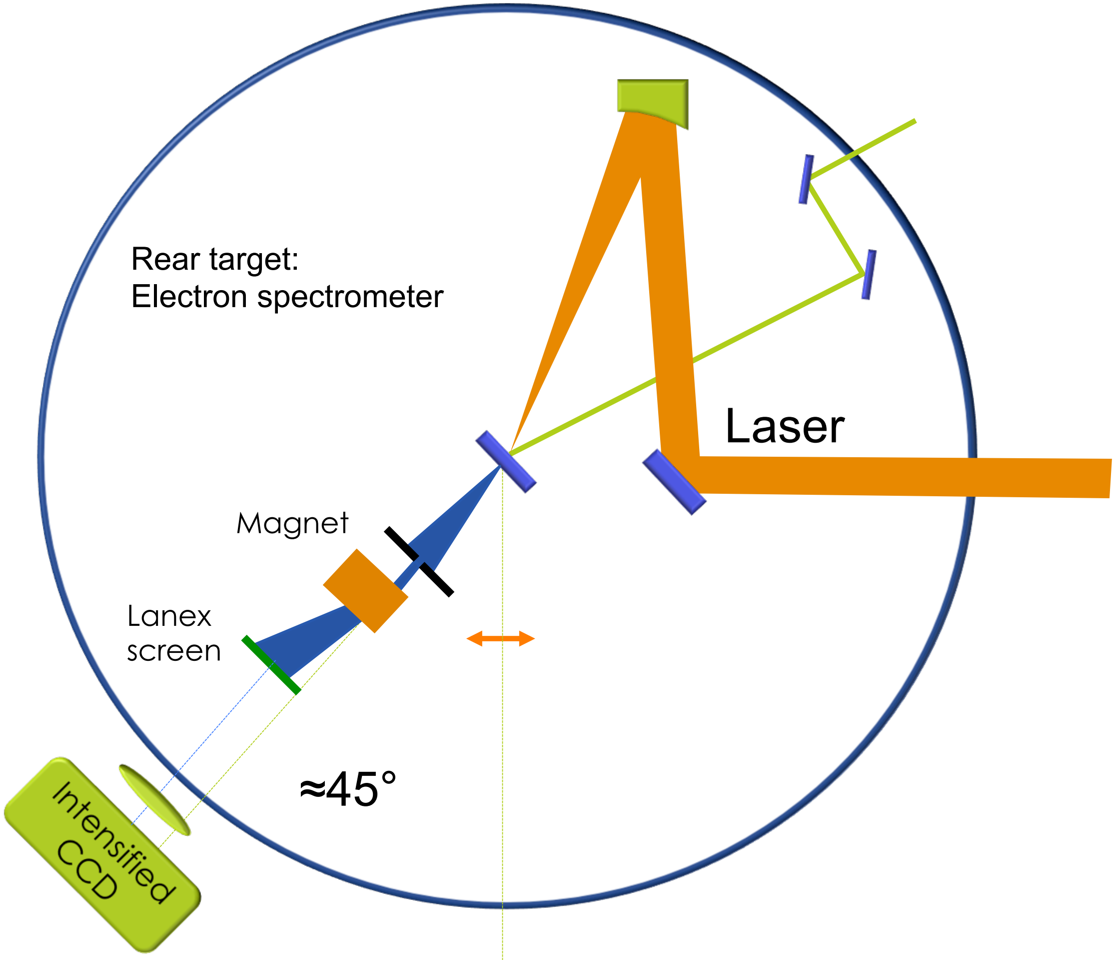
[&]L.A.Gizzi et al., Phys. Rev. Lett. **76** , 2278 (1996)

Scattered spectrum vs. focus



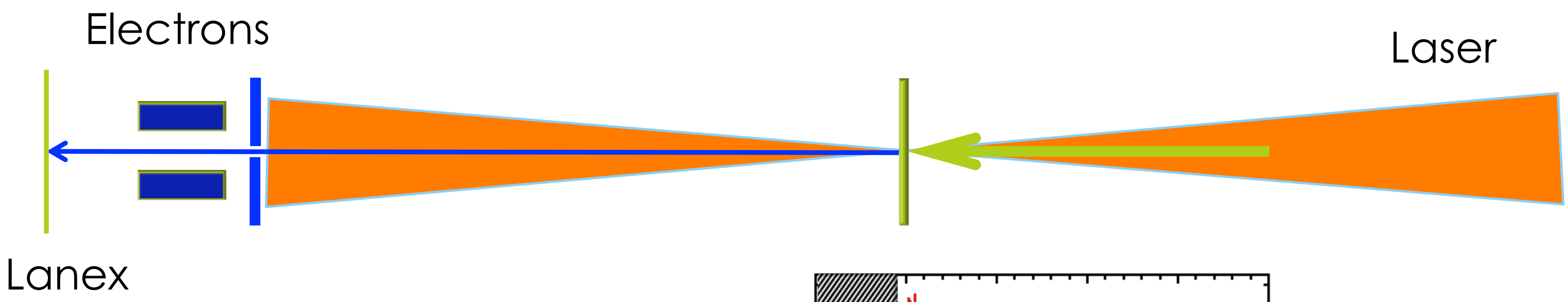
Electron spectrometer

Aim: measure energy of forward accelerated (escaping) fast electrons

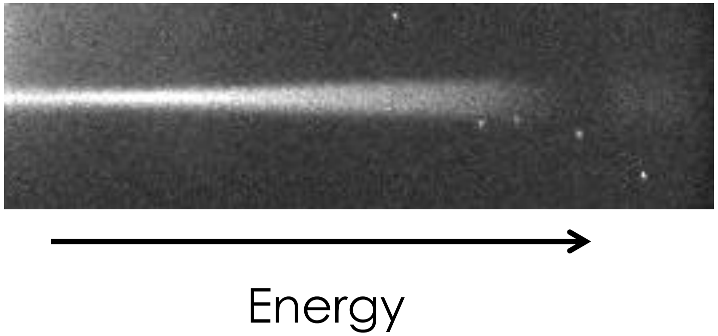


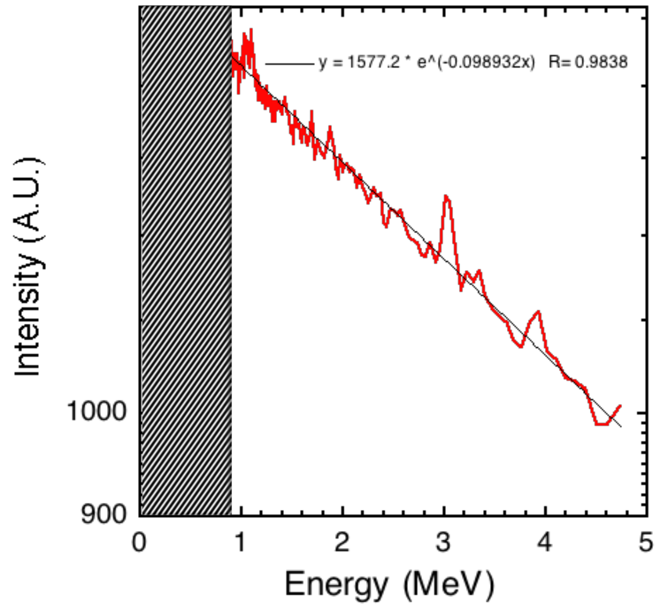
Fast electrons at best focus

- Fast electrons are measured **only** at optimum focal position within two Raileigh lengths



Raw electron spectrum

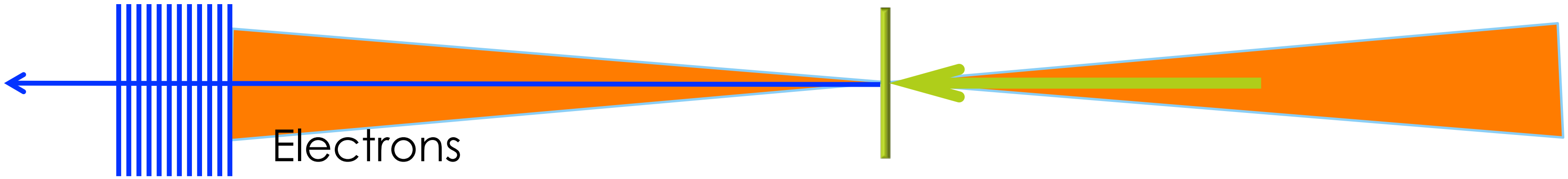


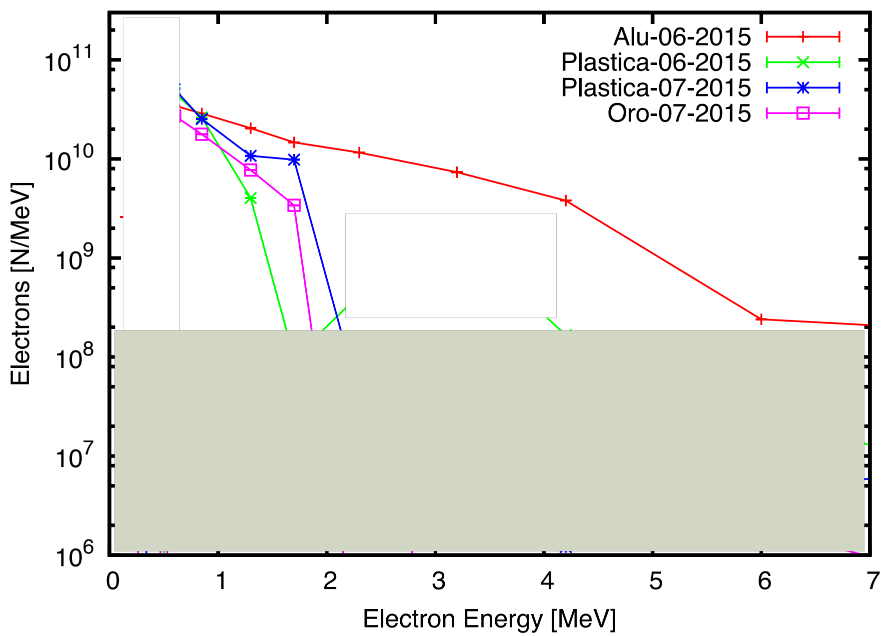


kT≈10 MeV

Fast electrons at best focus

- Independent measurement using RCF film stack (Sheeba)*



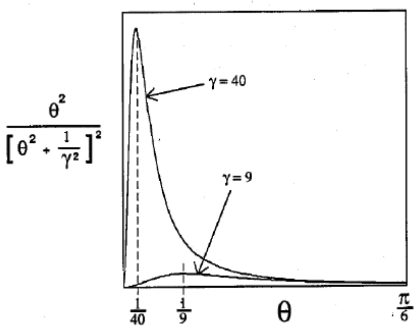


M. Galimberti, A. Giulietti, D. Giulietti, L.A. Gizzi, SHEEBA: a spatial high energy electron beam analyzer Rev. Sci. Instrum. 76, 053303 (2005)

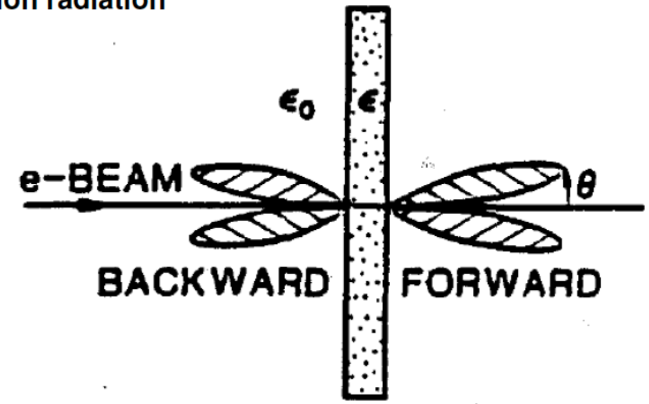
Rear side optical imaging

- Imaging rear side of the target at 45° and 30° from target axis
- Expected maximum of OTR signal for >MeV fast electrons

OTR basics



Transition radiation

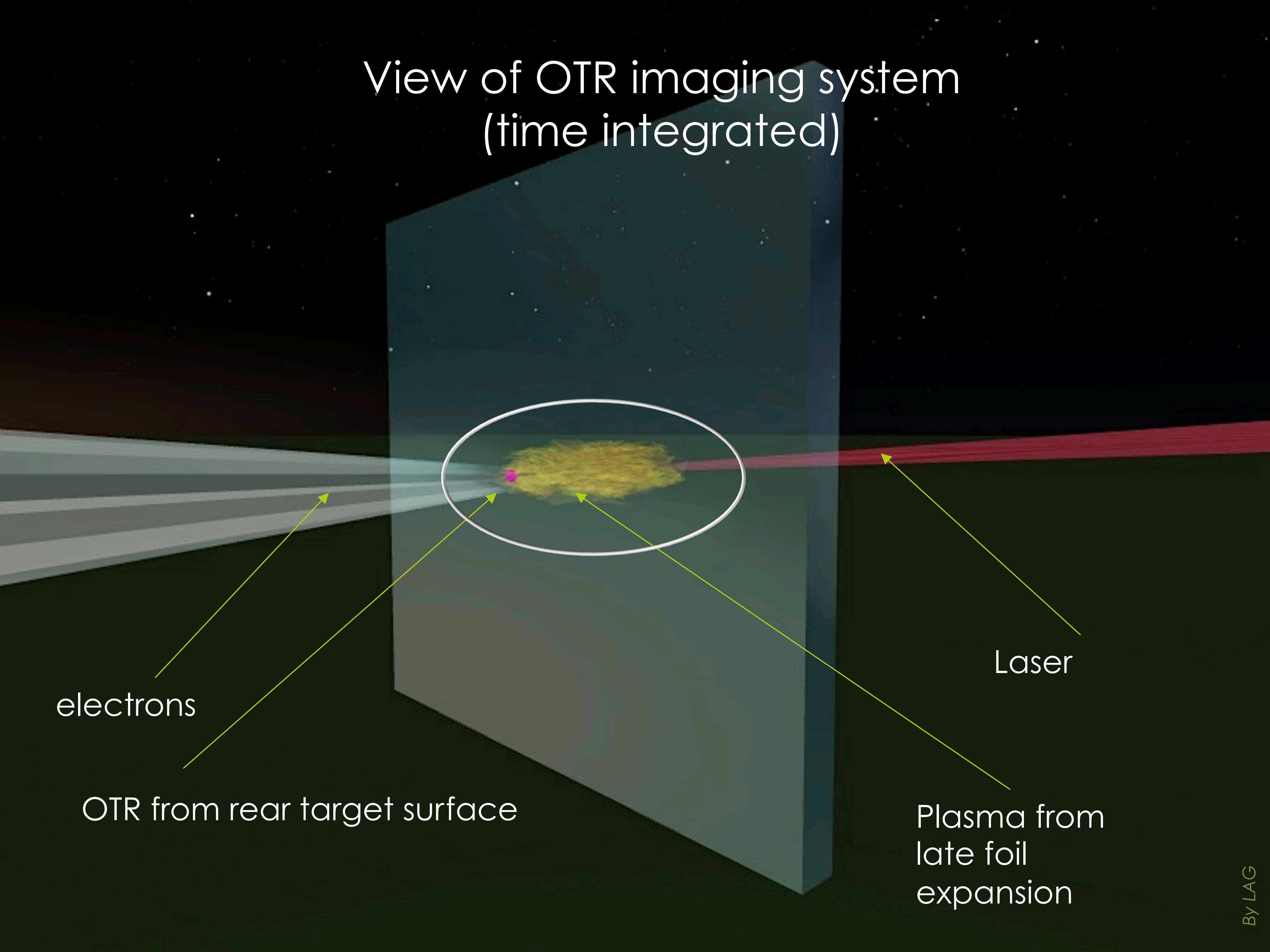


Transition radiation single electron:
Depends on w through ε → flat spectrum in the visible range

$$\left.\frac{\mathrm{d}^2 W}{\mathrm{d}\omega \mathrm{d}\Omega}\right|_{\parallel} = \frac{e^2}{\pi^2 c} \frac{\beta^2 \sin^2\theta \cos^2\theta}{(1-\beta^2\cos^2\theta)^2}$$

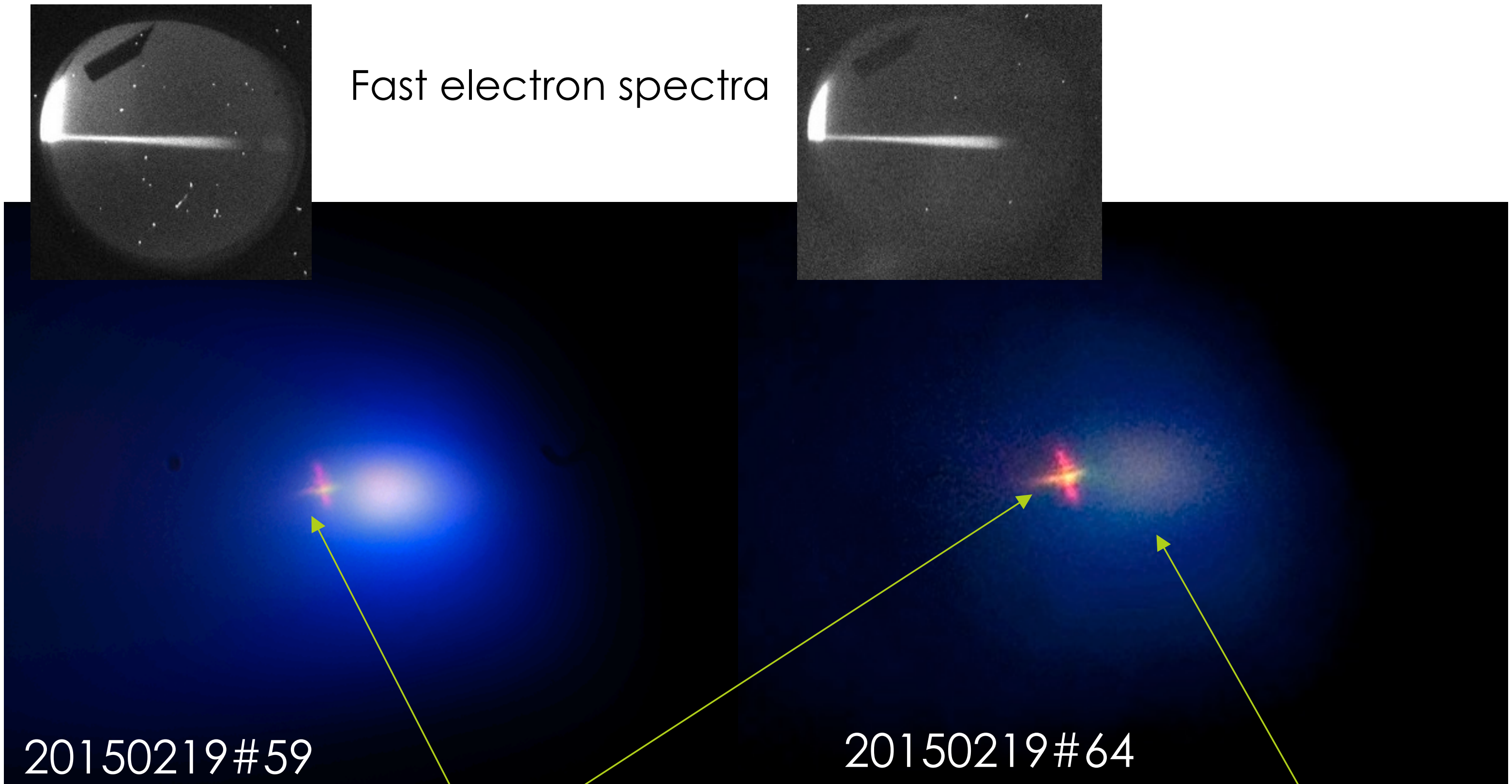
$$\times \left| \frac{(\varepsilon_r - 1)[1 - \beta^2 - \beta(\varepsilon_r - \sin^2\theta)^{1/2}]}{[\varepsilon_r \cos\theta + (\varepsilon_r - \sin^2\theta)^{1/2}][1 - \beta(\varepsilon_r - \sin^2\theta)^{1/2}]} \right|^2$$

Bellei et al, 2012 Plasma Phys. Control. Fusion 54 035011


View of OTR imaging system
(time integrated)
electrons
OTR from rear target surface
Laser
Plasma from
late foil
expansion
By LAG

45° rear side imaging (OTR) 10 μm Al

Image taken with fast electron beam on



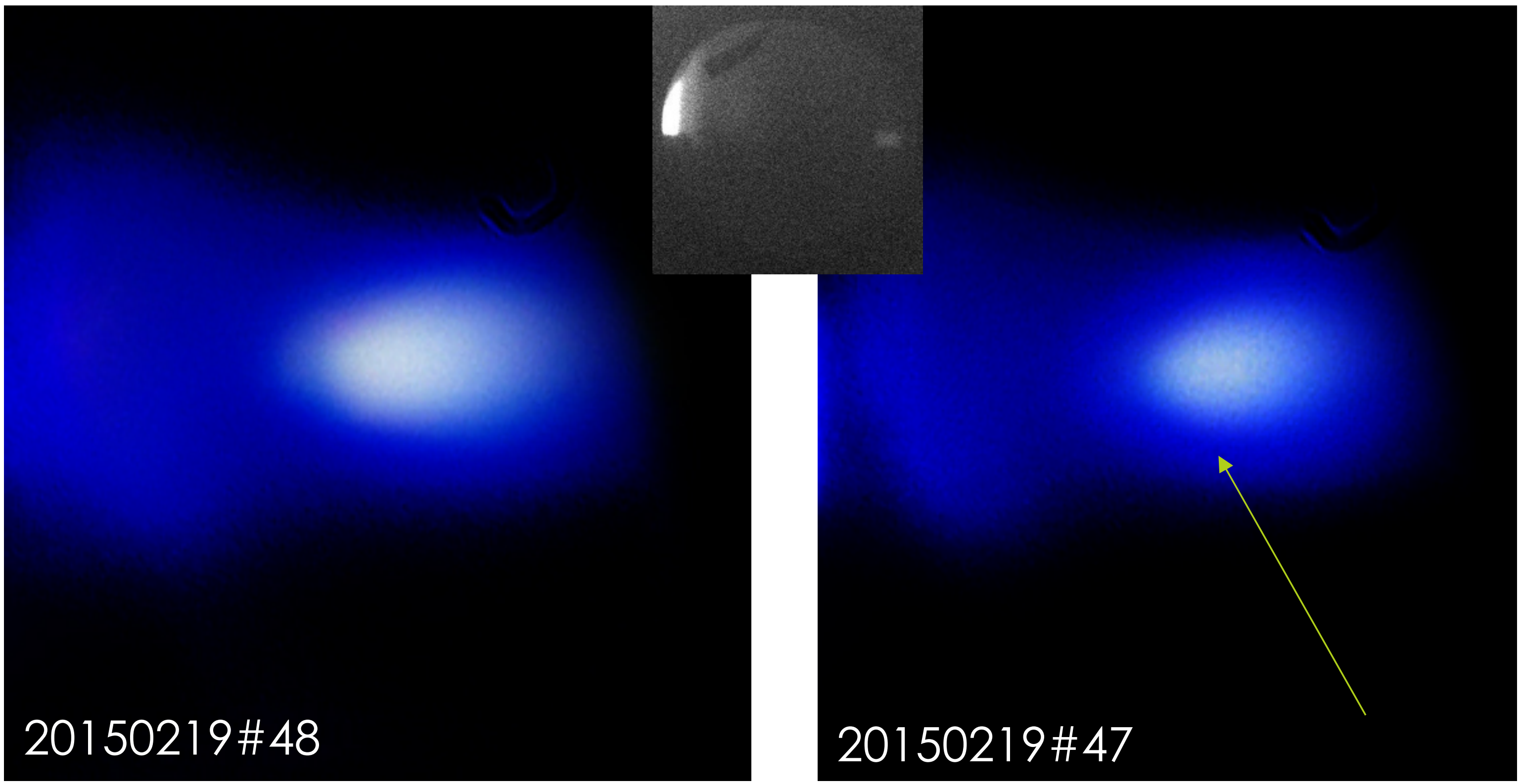
OTR from rear target surface

Plasma from late plasma expansion

45° rear side imaging - 10 µm Al

Image taken with fast electron beam **off (no signal from electron spectrometer)**

Target was displaced by 100µm from best focus position



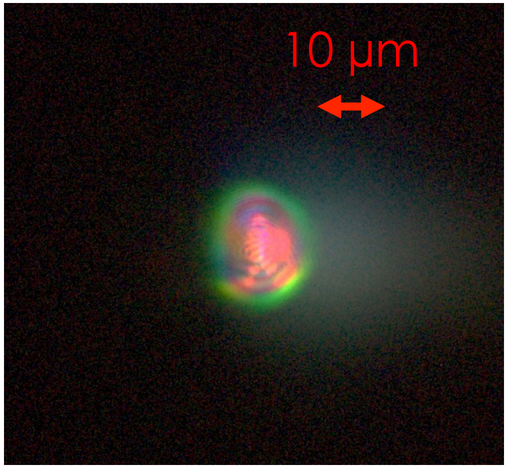
No OTR visible!

late foil expansion

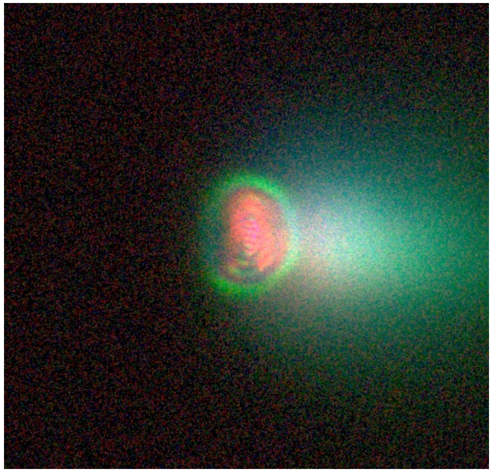
30° rear side imaging

Rear side optical emission

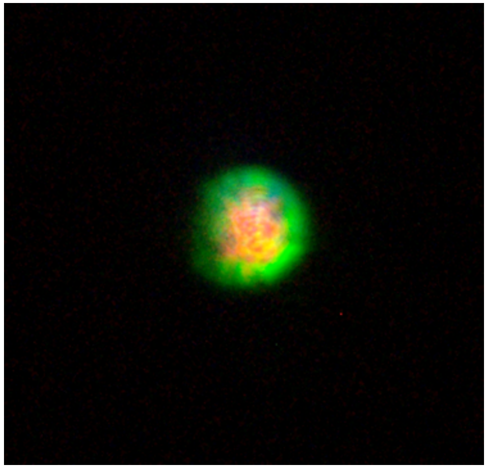
Aluminium 3 μm



Copper 8 μm



Plastic 0.9 μm



Preliminary conclusions on OTR

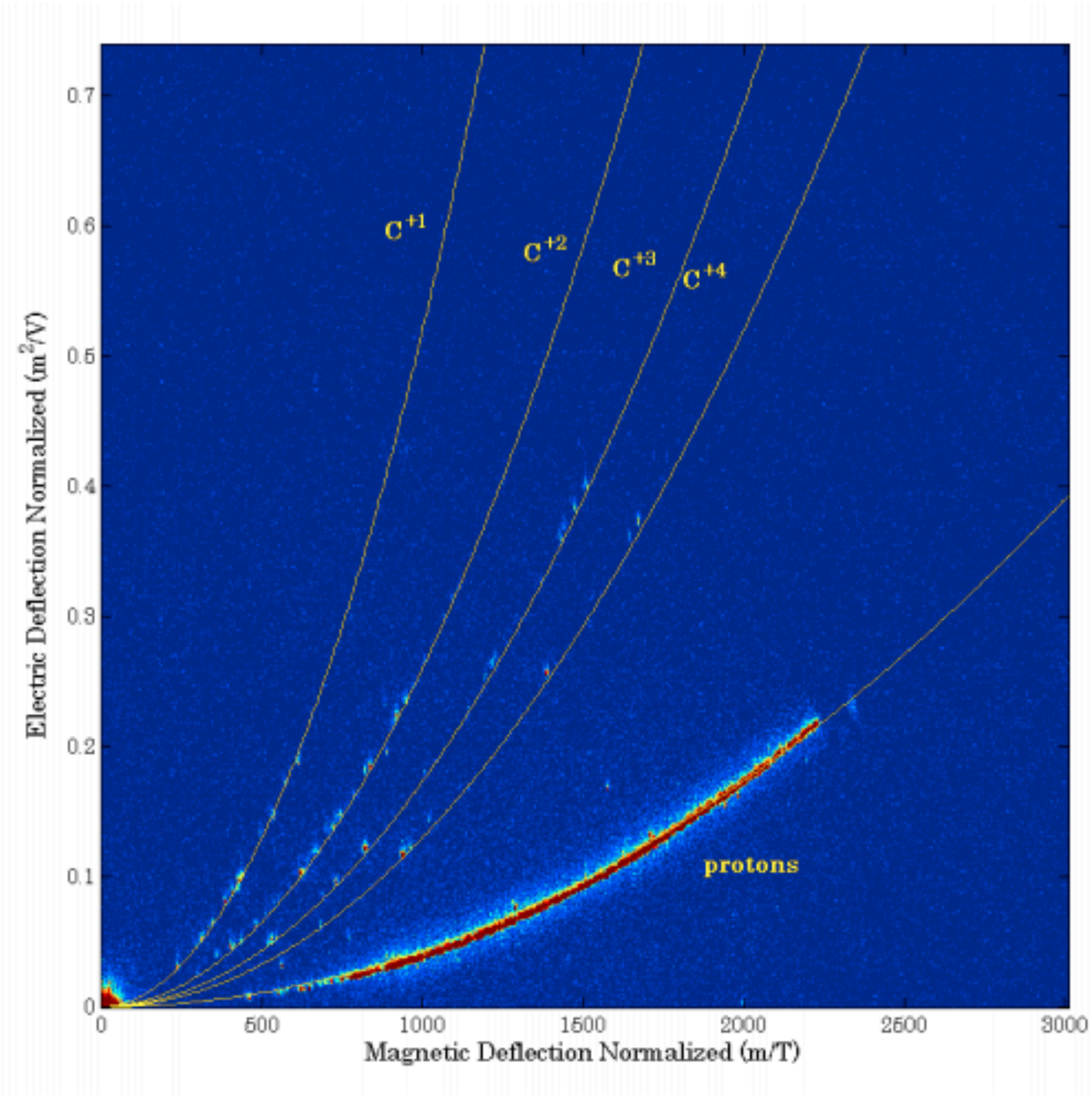
- Well localized optical emission
- **Correlation** with fast electron emission
- Polarization analysis consistent with OTR
- Shape of emission reproducible from shot to shot
- Similar emission found for Al, Cu and mylar

Thomson Parabola results

(Detailed analysis still in progress)

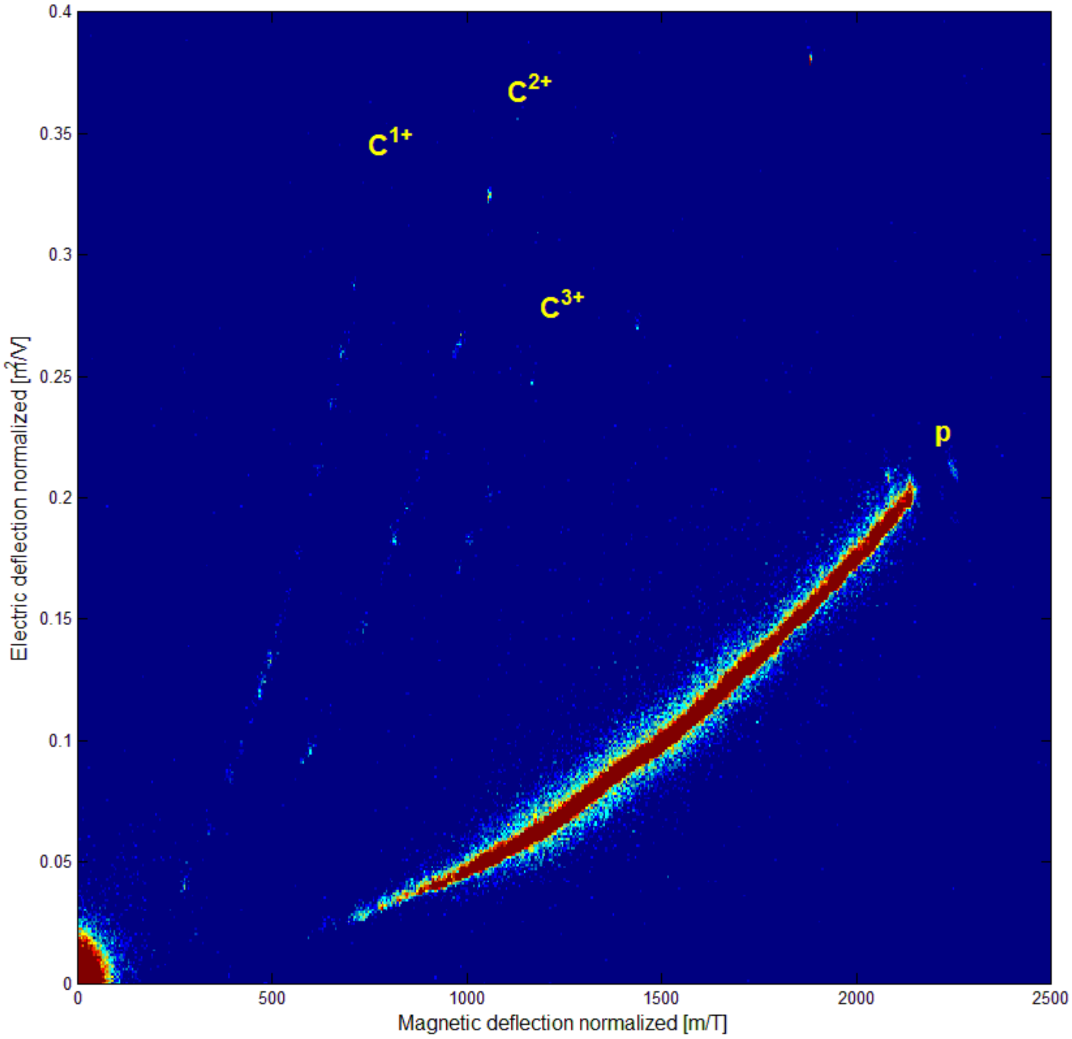
Thomson parabola: raw data

Al 10(μm)



p	1,55 MeV
C1+	1.05 MeV
C2+	1.09 MeV
C3+	1.17 MeV

Thomson parabola: raw data 3



p	1,017 MeV
C1+	450,1 keV
C2+	407,7 keV
C3+	316,8 keV

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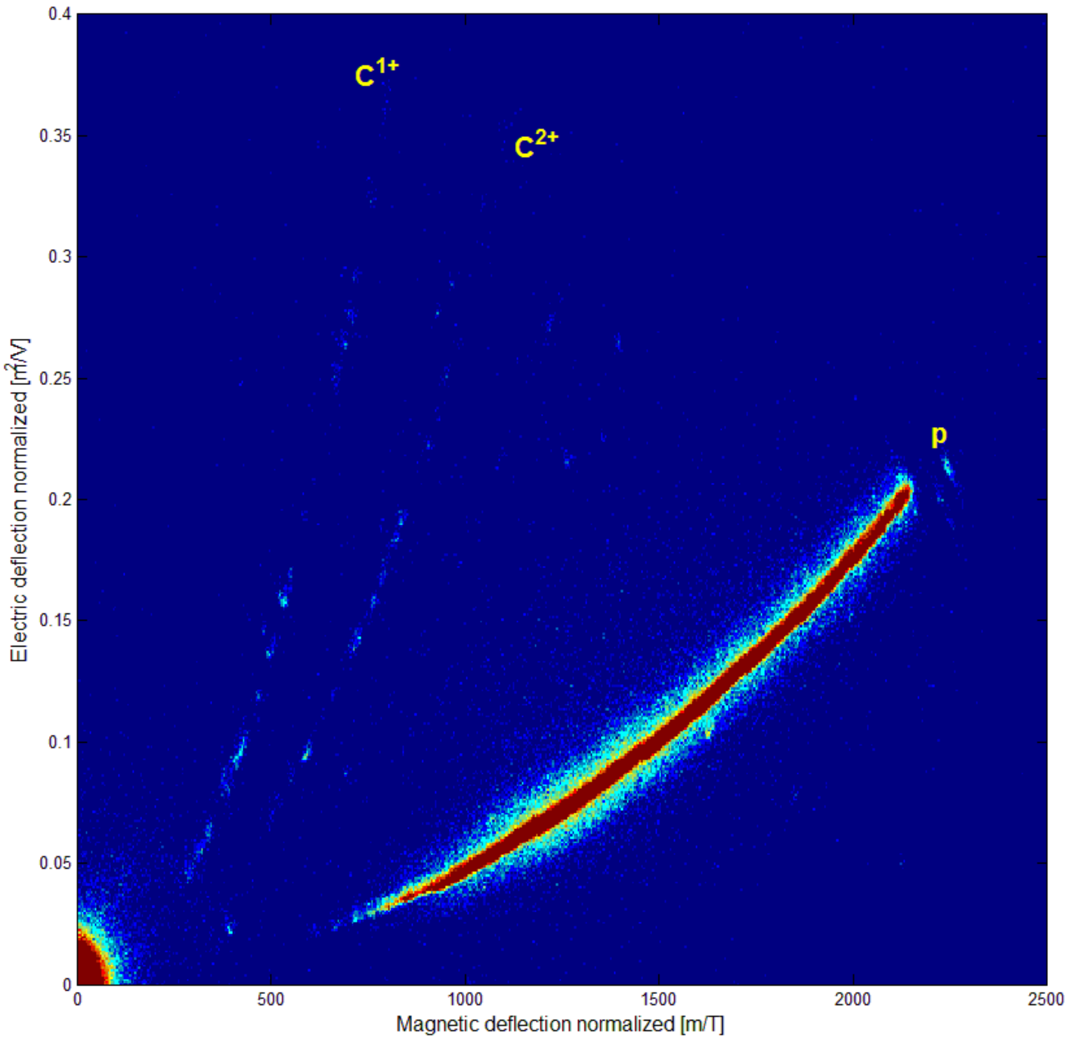
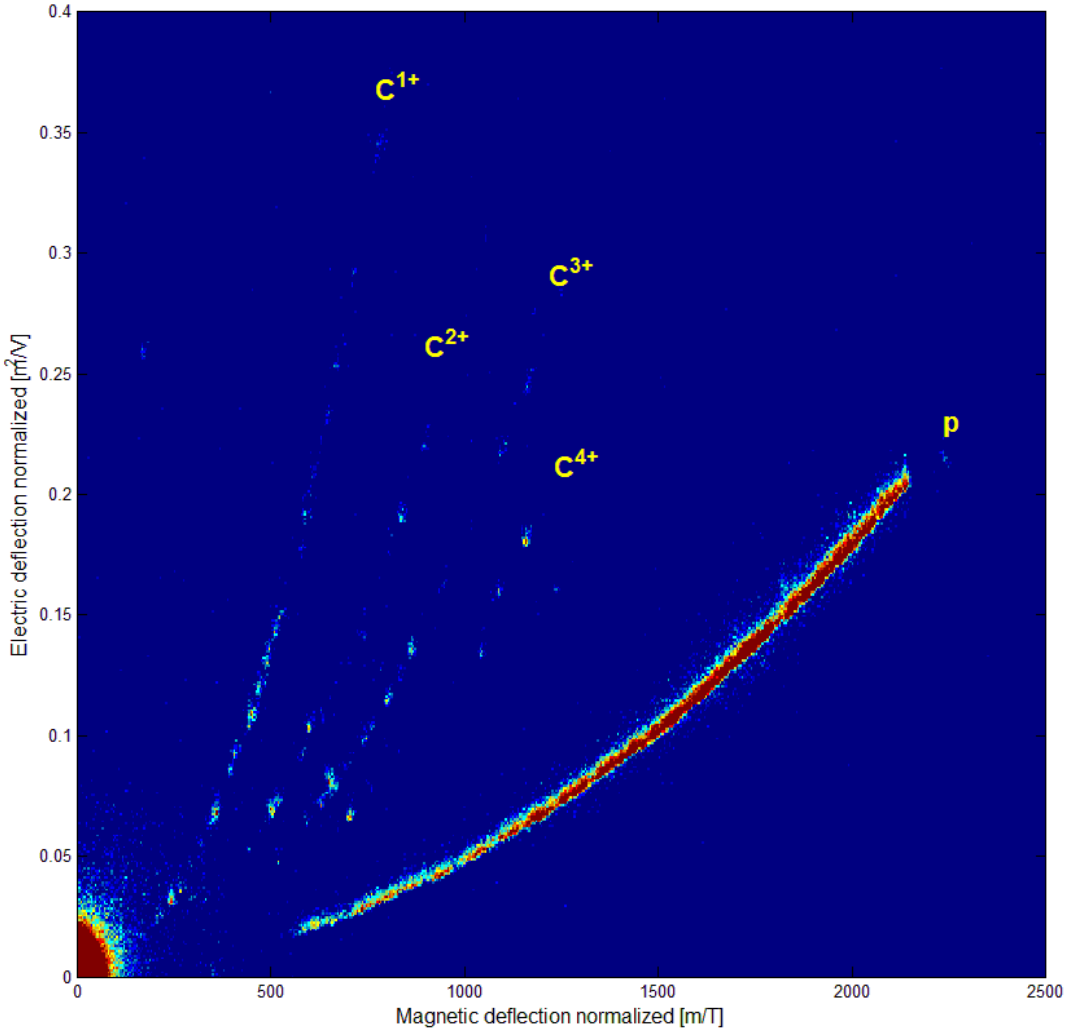
Thomson parabola: raw data 4



p	1,096 MeV
C1+	407,6 keV
C2+	573,4 keV

Thomson parabola: raw data 5

CH2(4μm) +
Al(0.1μm)
#68

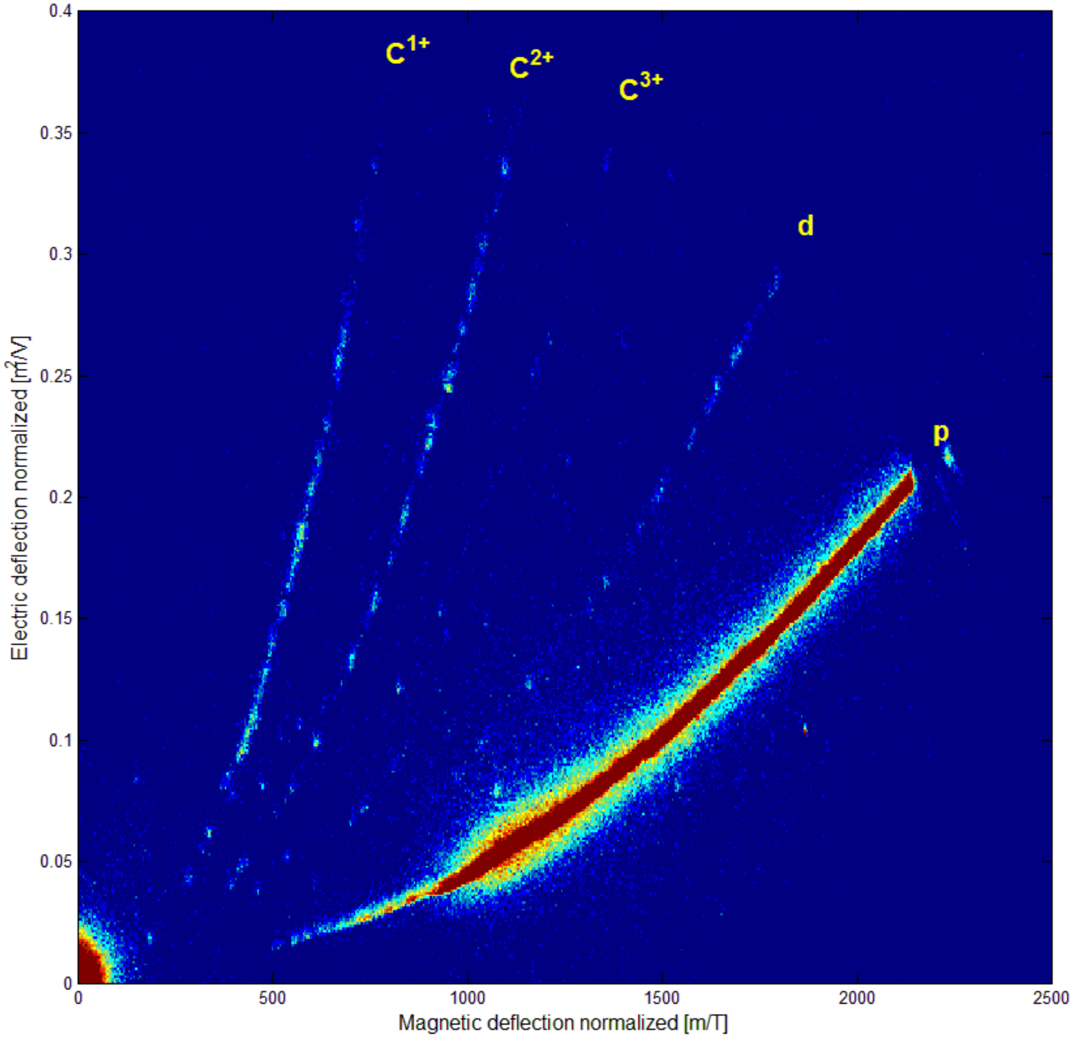


p	1,306 MeV
C1+	557,8 keV
C2+	834,7 keV
C3+	1,098 MeV

L.A.Gizzi, EAAC2015

Thomson parabola: raw data 2

CD2 (4µm) +
Al(0.1µm)
#84



p	1,612 MeV
d	155,3 keV
C1+	1,145 MeV
C2+	933,2 keV
C3+	1,499 MeV
C4+	1,115 MeV

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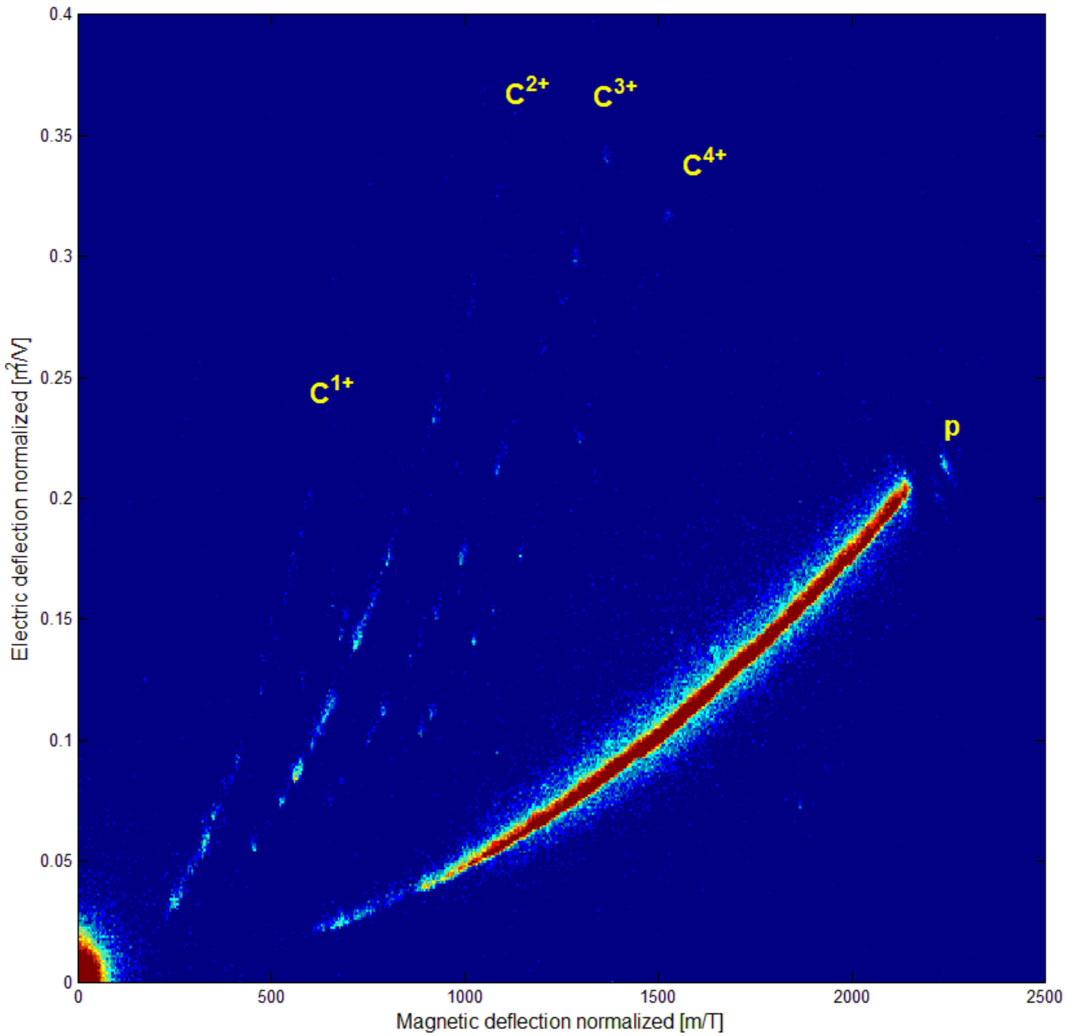
Thomson parabola: raw data 6

CH2(4μm) + Al(0.1μm) #60



p	1,096 MeV
C1+	652,8 keV
C2+	652,8 keV
C3+	719,6 keV
C4+	694,5 keV

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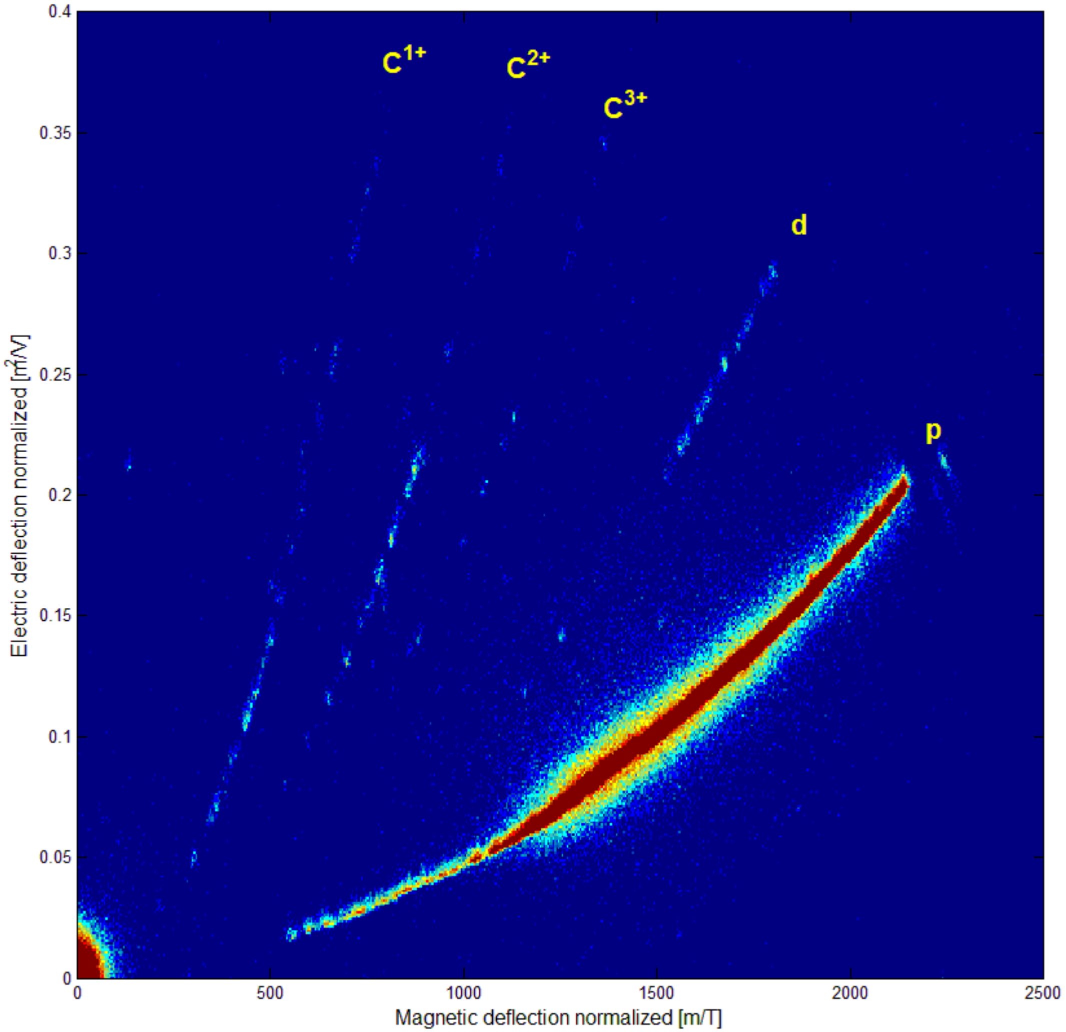
Thomson parabola: raw data 7

CD2(4μm) + Al(0.1μm) #80



p	1,351 MeV
d	156,7 keV
C1+	407,6 keV
C2+	334,0 keV
C3+	416,6 keV

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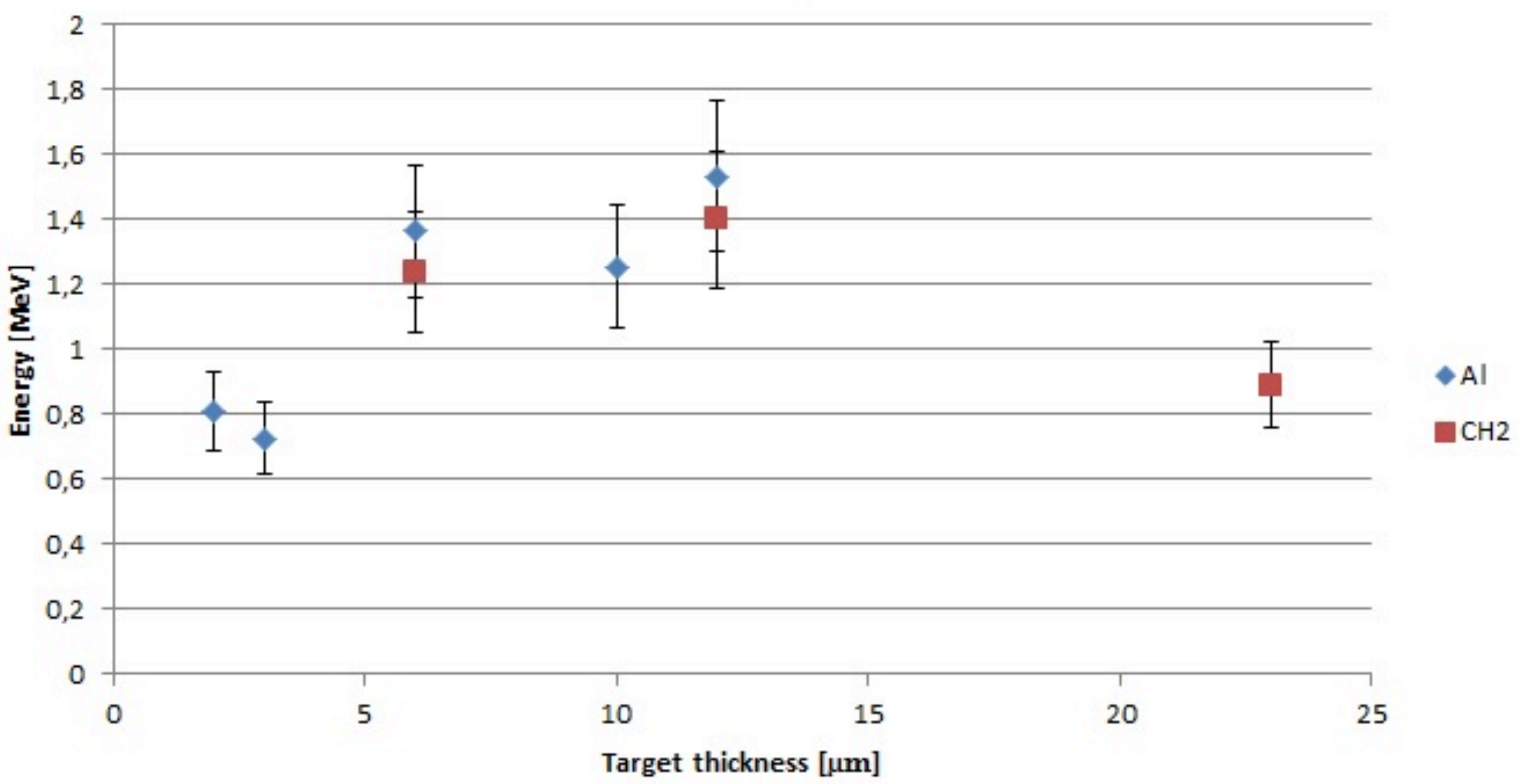
Energy vs. target thickness



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Summary

– TNSA process reproducible and controllable;
– Multiple diagnostics tested (TP, Diamond, RCF …)
– Standard targets fully explored
– Surface vs. volume acceleration
– Scaling with laser intensity confirmed
– Target engineering still to be explored

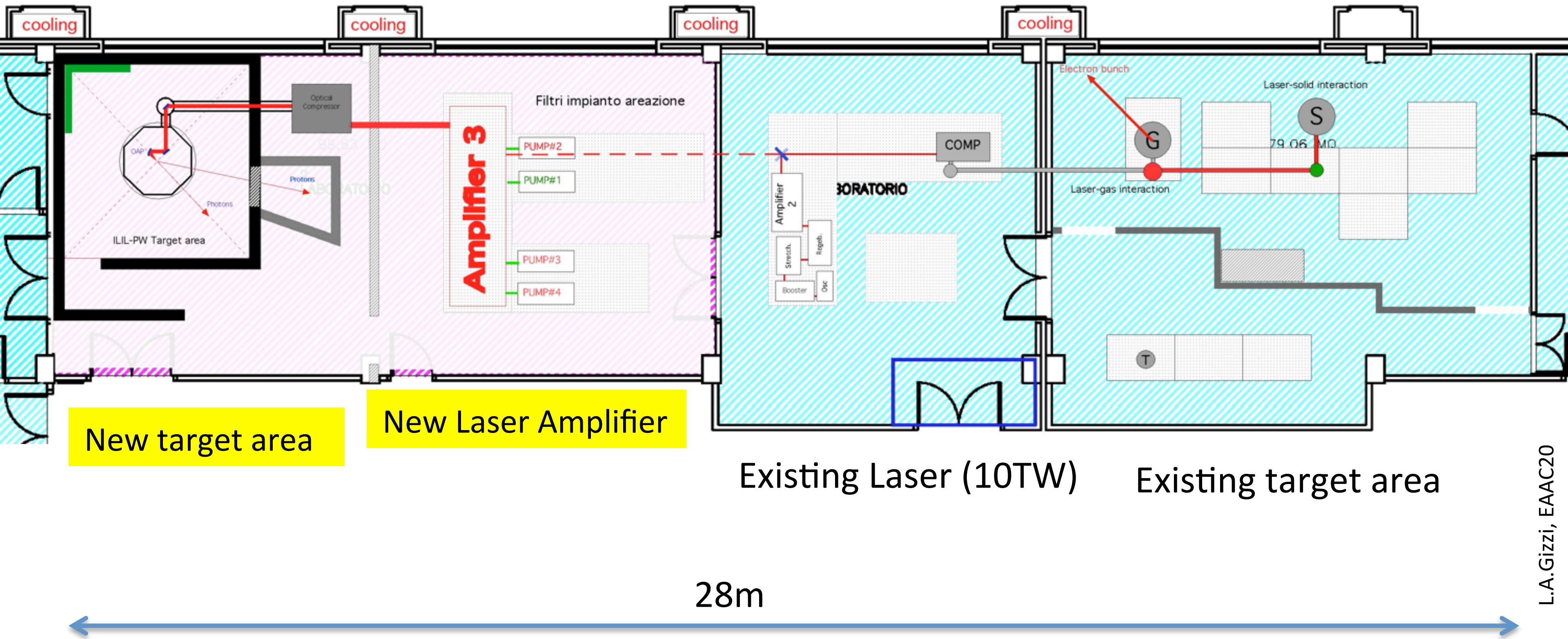
ILIL Laser upgrade

ILIL(Pisa) - MAIN LASER BEAM PARAM.	Current (dec.2015)	1° phase (6-2016)	Final
Wavelength (nm)	800	800	800
Pump Energy (J)	1.8	6(12)	24
Pulse duration(fs)	40	30	25
Energy before compression (J)	0.6	2(4)	7
Energy after compression (J)	0.4	1.5(3)	5
Rep rate (Hz)	10	1	1
Max Intensity on target	2E19	7.5E19(1.2E20)	4E20
Contrast (ns)	>1E9	>1E9	>1E10
Expected proton beam energy (MeV)	2	6(8)	12

- Upgrade will be developed in phases:
- 1° phase (mid 2016) will deliver a minimum of 1.5 J on target, >4x current energy.
- Ion energy scaling sets max ion energy around 5 MeV
- Final goal is 12 MeV, to be achieved with 5 J of energy on target.

INO-CNR (PI): Infrastructure development

ILIL LASER UPGRADE TO 200 TW AND NEW, SHIELDED TARGET AREA



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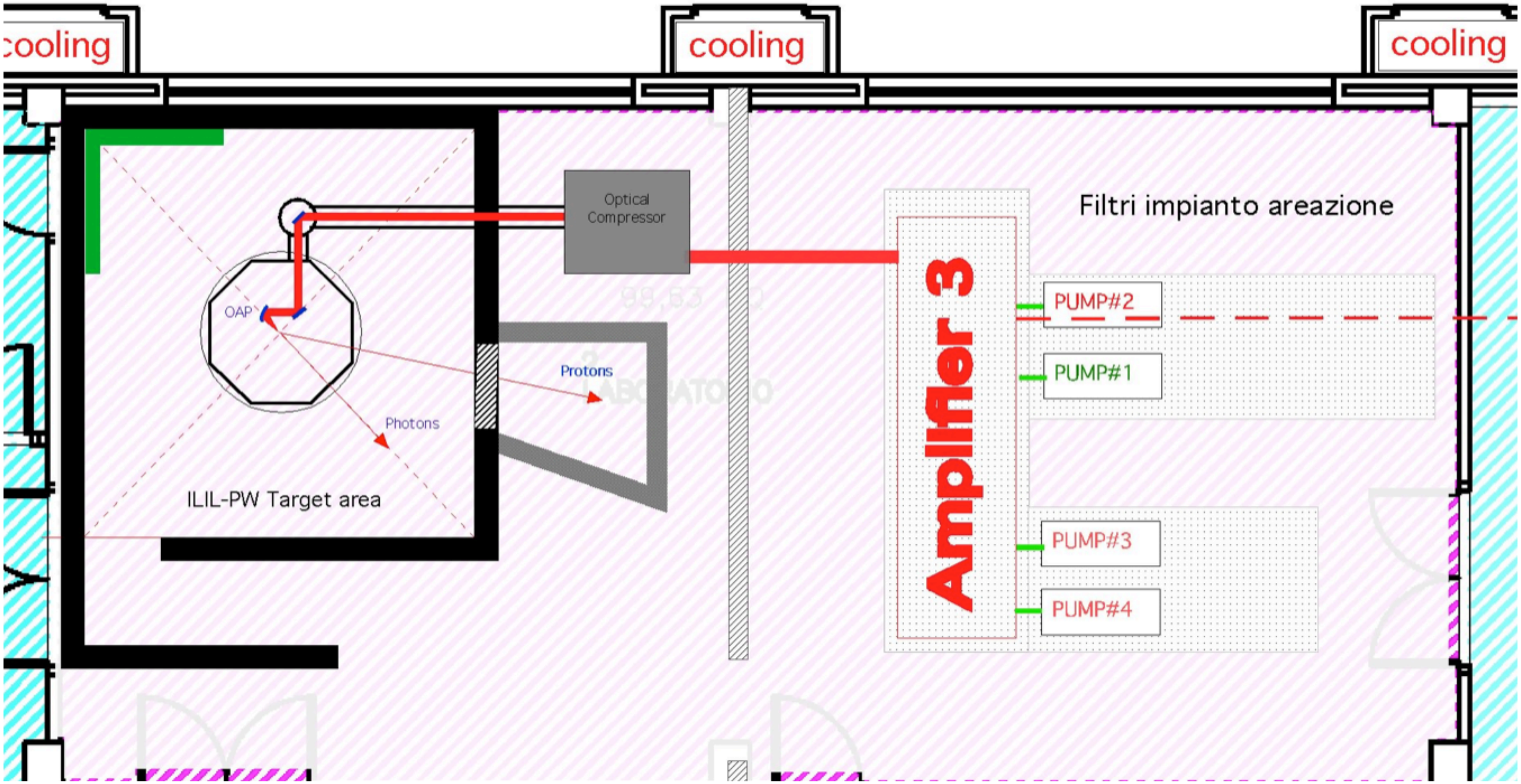
ILIL-PW – Layout



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Thank you!