WG1 summary -
Laser Wakefield Accelerators

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European Advanced Accelerator Conference

2 – 6 June 2013, Elba, Italy

WG1 - Electron beams from plasmas

After the success of the SLAC experimental program PWFA experiments are multiplying. The self-modulation instability (SMI) has emerged as a new topic of investigation both for the propagation of long charged particle bunches (e^-, e^+, p^+, …) in long plasmas ($\lambda_{pe}<<\sigma_z$) and for the resonant excitation of wakefields to large amplitudes. But while seemingly attractive because of the use of existing long bunches, this PWFA excitation method has a number of challenges.
For laser wakefield acceleration, Europe is home to a number of both mature and emerging programs in laser driven wakefield acceleration. A number of groups have generated electron beams on the GeV energy scale and significant work is being invested into both understanding and improving the reproducibility of existing experiments, as well as developing the next generation of facility that will increase repletion-rate/ energy /charge of laser wakefield acceleration.
Starting from the current status of both plasma and laser wakefield research, we will review current research programs, before assessing novel implementations. For plasma wakefield experiments, both single or multiple drive bunch experiments will be assessed, whilst in laser wakefield experiments we will discuss novel injection techniques as well as novel laser drivers and staging. We will discuss experimental plans, challenges and goals, plasma sources and diagnostics. We hope to generate a common understanding of the physics and issues at play.
We will interact with the simulation WG (WG6) to review progress in simulations of wakefield. We will attempt to determine the direction the field is taking and discuss the various ways the field could impact light sources (x-ray FEL), linear e^-/e^+ colliders and lepton/hadron colliders.

Co-Leader: Patric Muggli *(Max-Planck-Institut für Physik - München, Germany)*
Co-Leader: Zulfikar Najmudin *(Imperial College - London, UK)*

15:00 **Experiments on laser plasma acceleration driven in longitudinally-profiled plasmas** *15'* Speaker: Mr. Wolf Rittershofer (university of Oxford)
15:15 **Stable and tunable laser-wakefield acceleration and x-ray generation** *15'* Speaker: Prof. Stefan Karsch (LMU Munich)
15:30 **Advanced Reproduction of Space Radiation Studies by overdense laser plasma interaction** *15'*
Speaker: Mr. Oliver Karger (University of Hamburg, Institute for Experimental Physics)
16:15 **Laser wakefield acceleration experiments at the University of Michigan** *15'* Speaker: Prof. Karl Krushelnick (University of Michigan/Laboratoire d'Optique Appliquee)
16:30 **Status and plans of laser-plasma acceleration research in IAP RAS** *15'* Speaker: Dr. Kostyukov Igor (Institute of Applied Physics RAS, Nizhny Novgorod State University)
Tuesday
16:00 **Prospects for High-Repetition-Rate Multi-Pulse Laser Wakefield Accelerators** *15'* Speaker: Prof. Simon Hooker (University of Oxford)

16:18 **High efficiency fiber laser systems for wake-field particle accelerators** *15'* Speaker: Prof. Jens Limpert (FSU Jena)

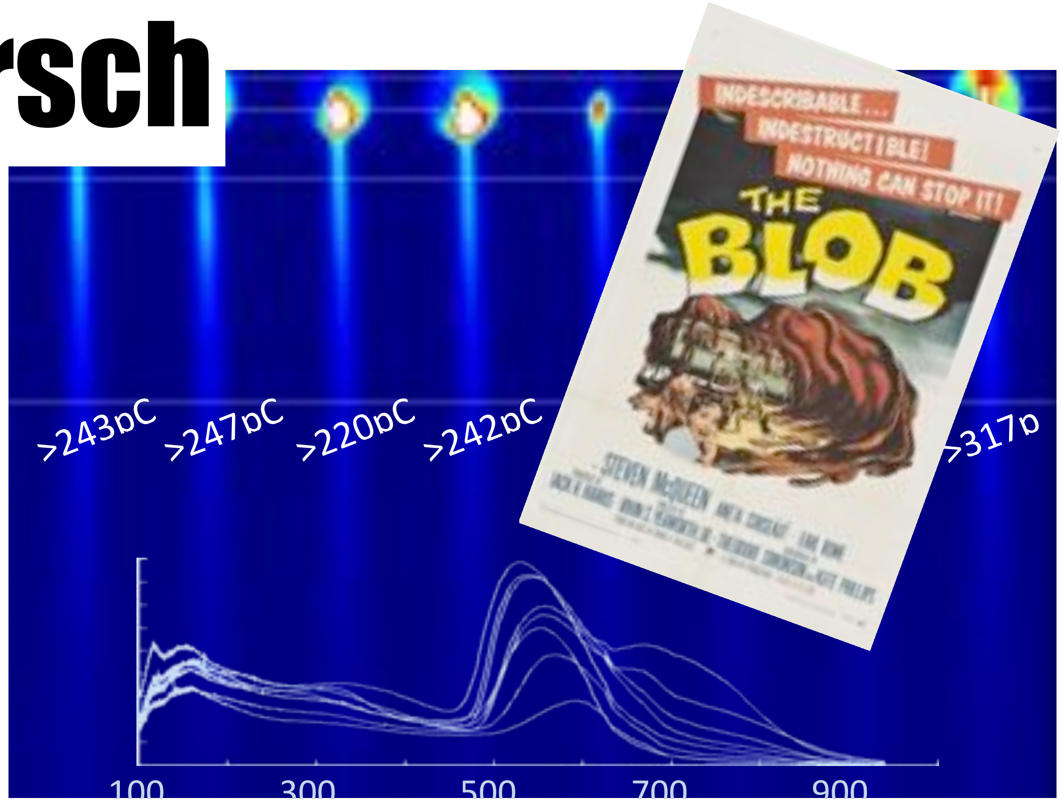
18:36 **Development of a kHz laser plasma accelerator for ultrafast electron diffraction** *15'* Speaker: Dr. Jerome Faure (LOA)

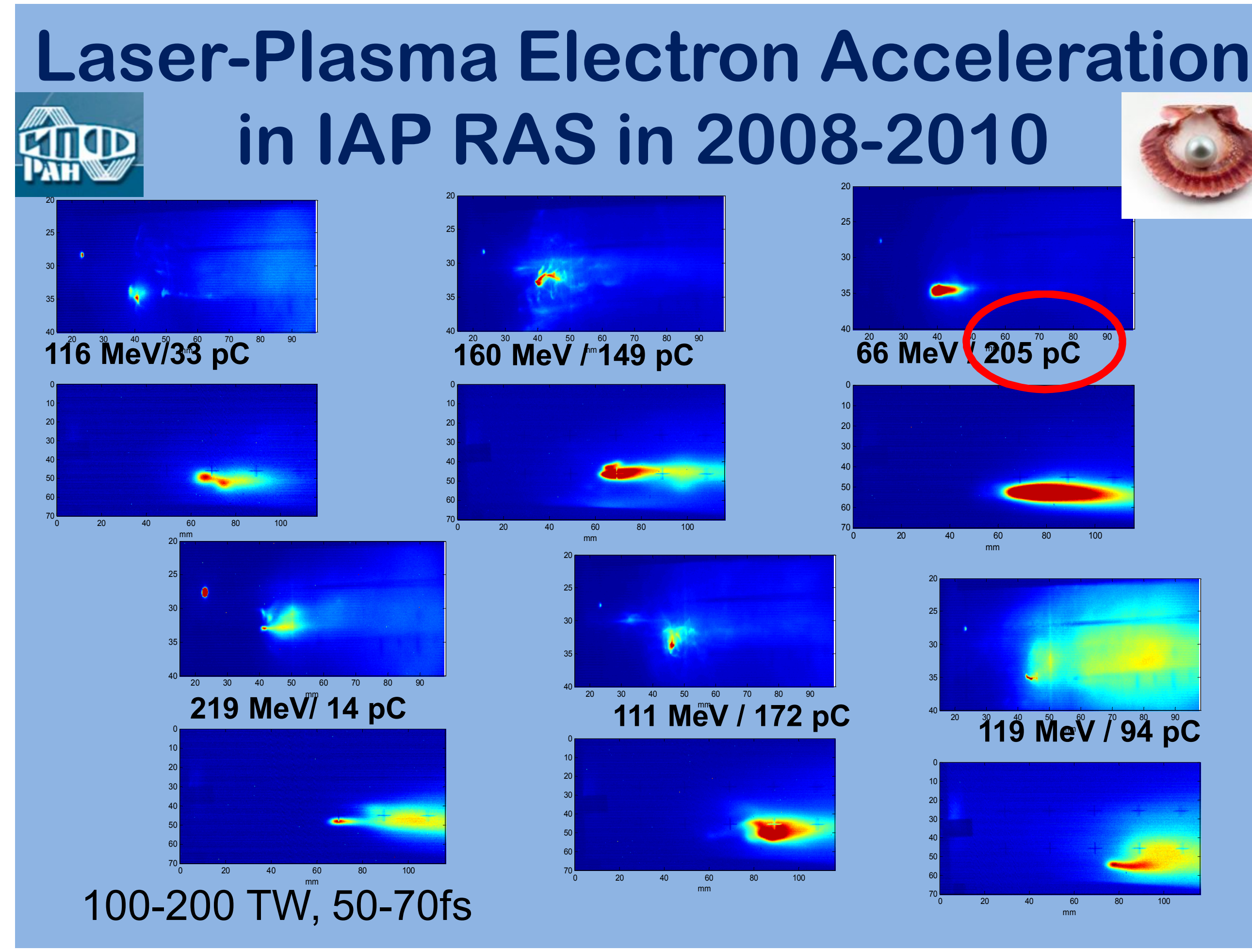
+ WG1+6 working group

self-injection results

High-charge 0.5 GeV beams from a 1.5J, 60 TW laser

Karsch



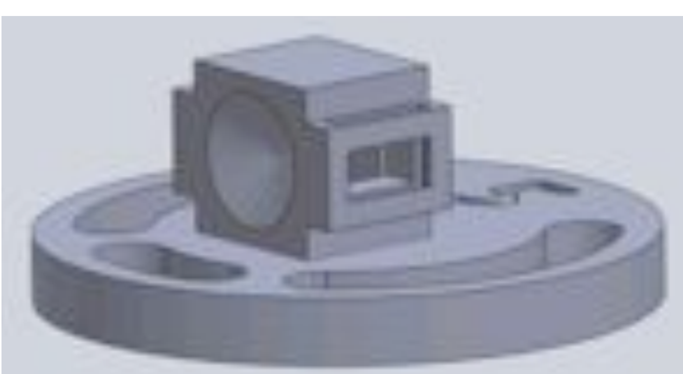


Experimental Setup: Plastic Gas Cells - 3D printer

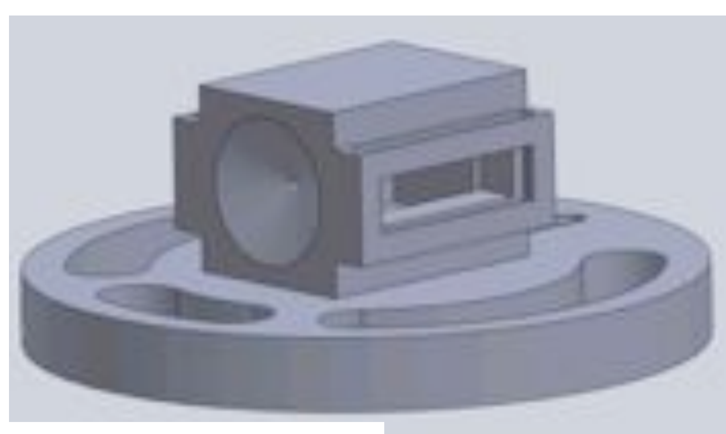
Plans to go to 5 PW - PEARL-X

Kostyukov

5mm

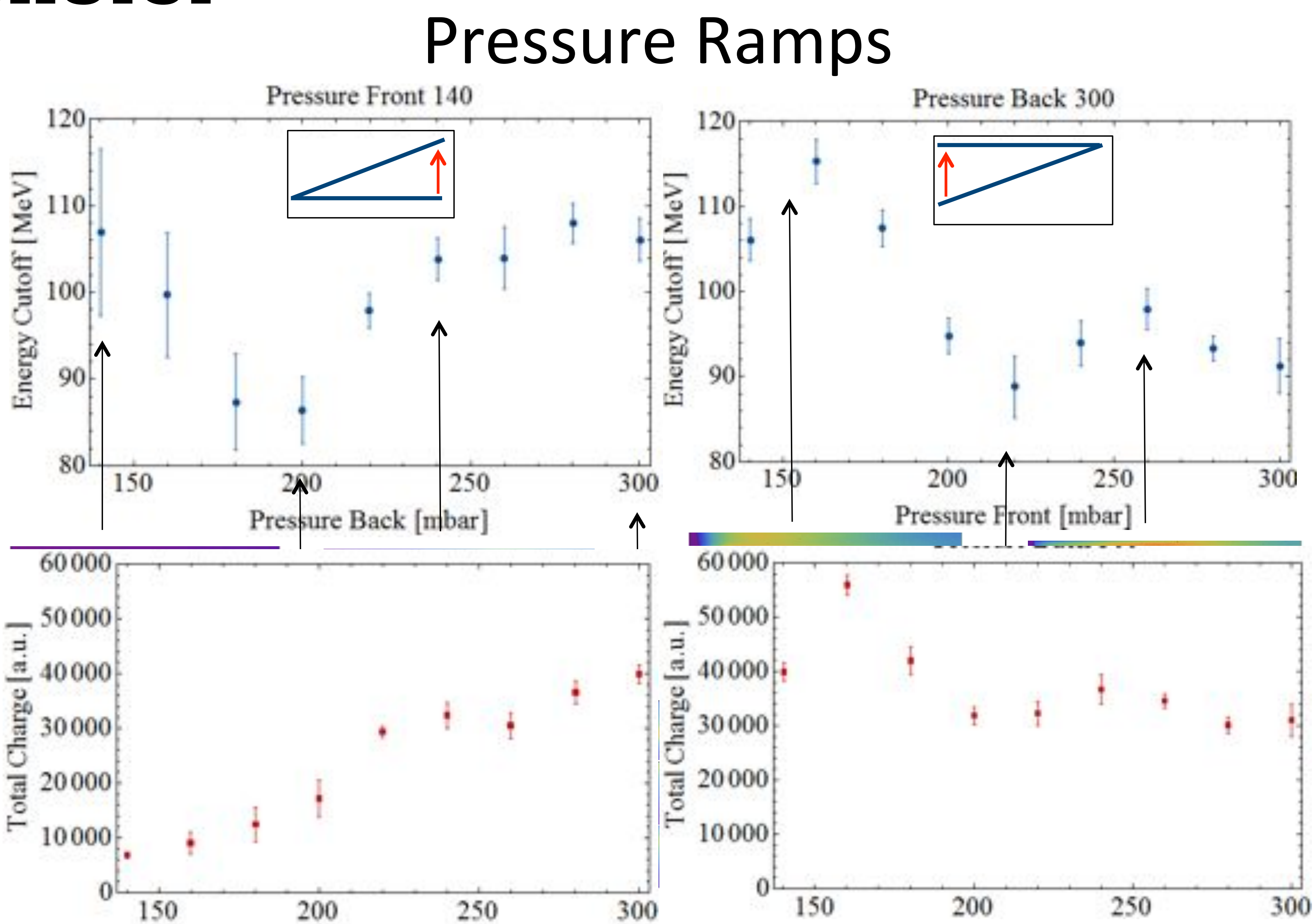


10mm



Krushelnick

Ritershofer



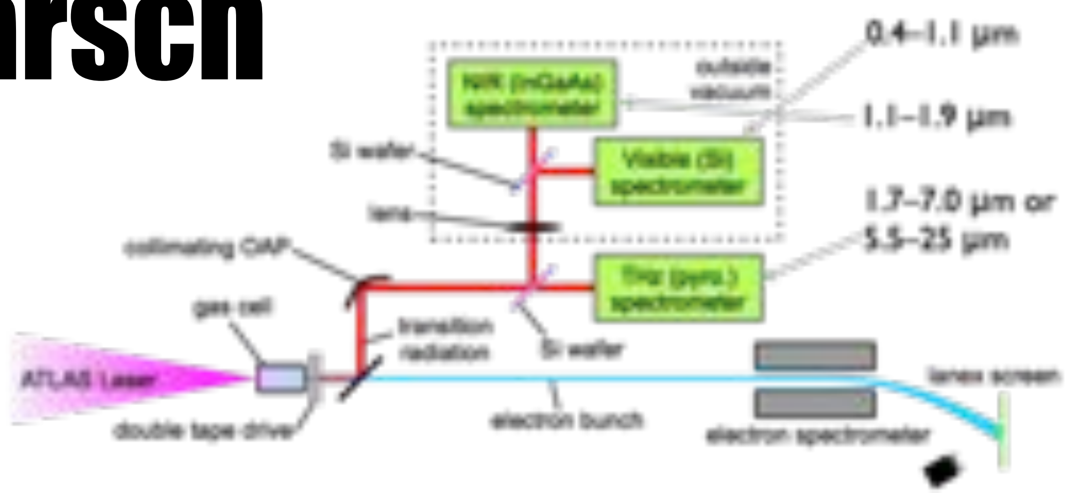
Also self-injection observed to:

- 1.3 GeV self-guiding, 2 GeV guided **Najmudin**

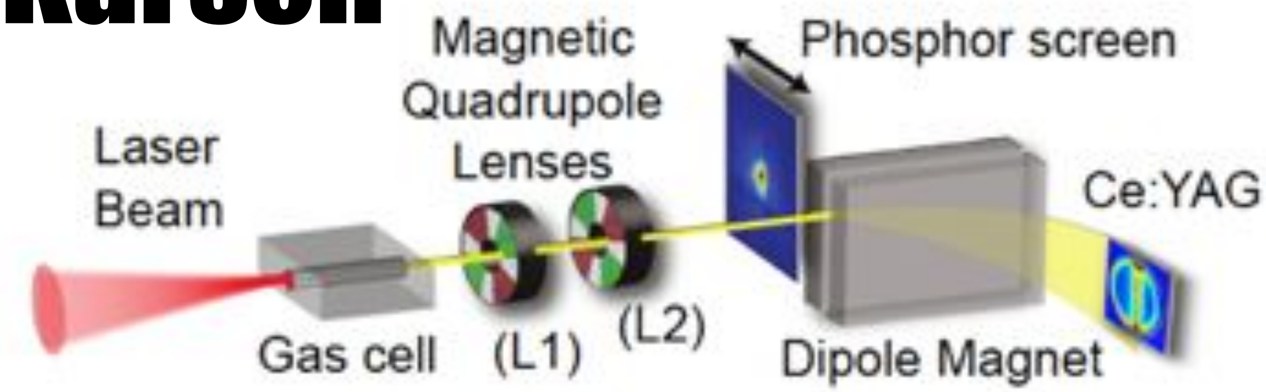
characterisation

Multi-spectrometer setup

Karsch

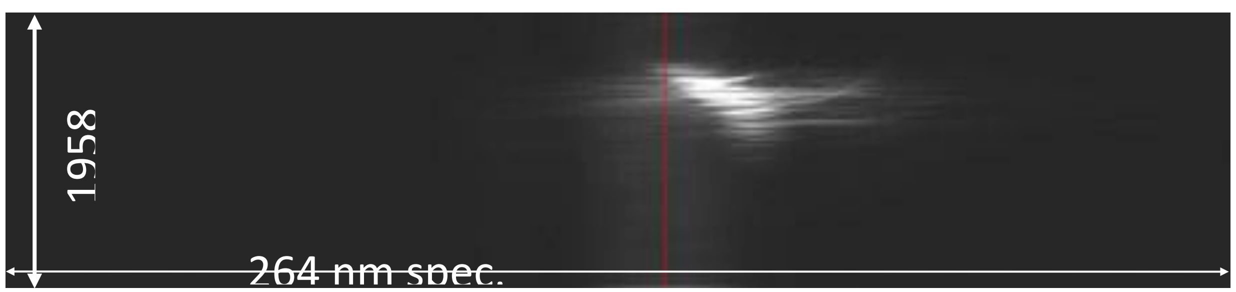


Karsch



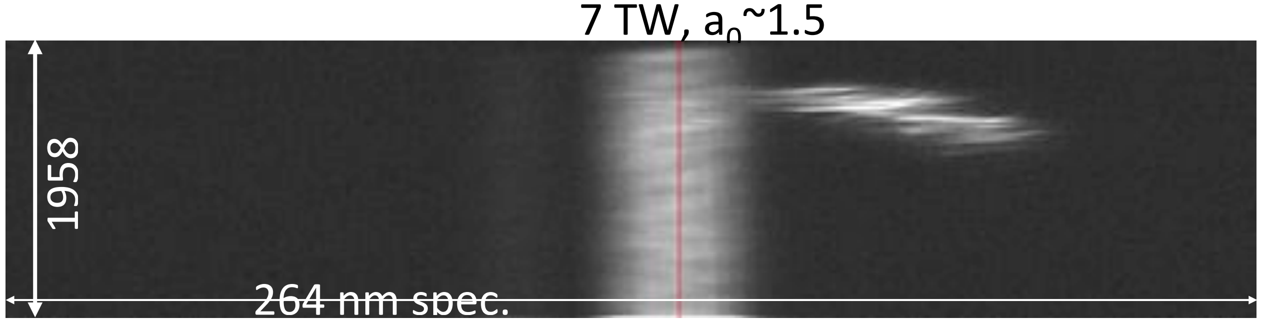
Normalized emittance:
0.14 π mm mrad

Raman side scattered light is emitted in “bursts” and is relativistically shifted



100 TW,

7 TW, a_0~1.5

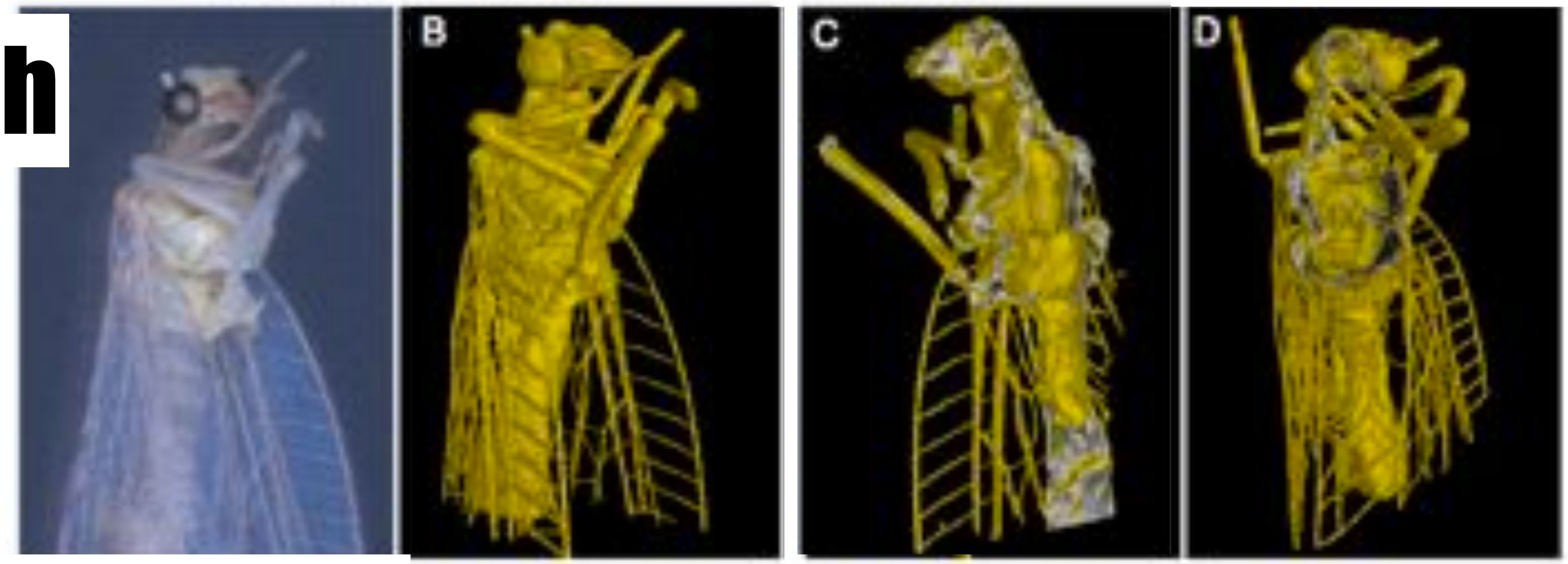


Krushelnick

betatron sources

3D rendering of the fly (with S. Schleede, F. Pfeiffer et al., TUM)

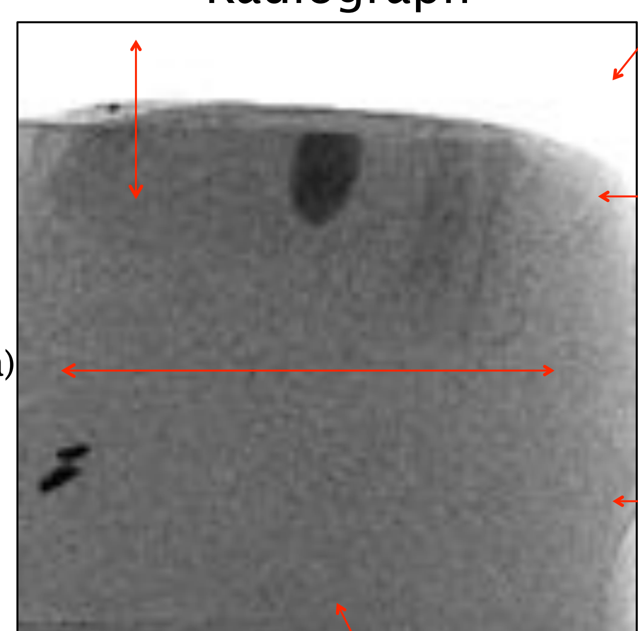
Karsch



J. Wenz et al., submitted to Nat. Photonics

Artery Sample in Paraffin Wax

Radiograph



Straight-through (20000+ counts, saturated)

Arterial Plaque (dark spot)

Artery (dark area)

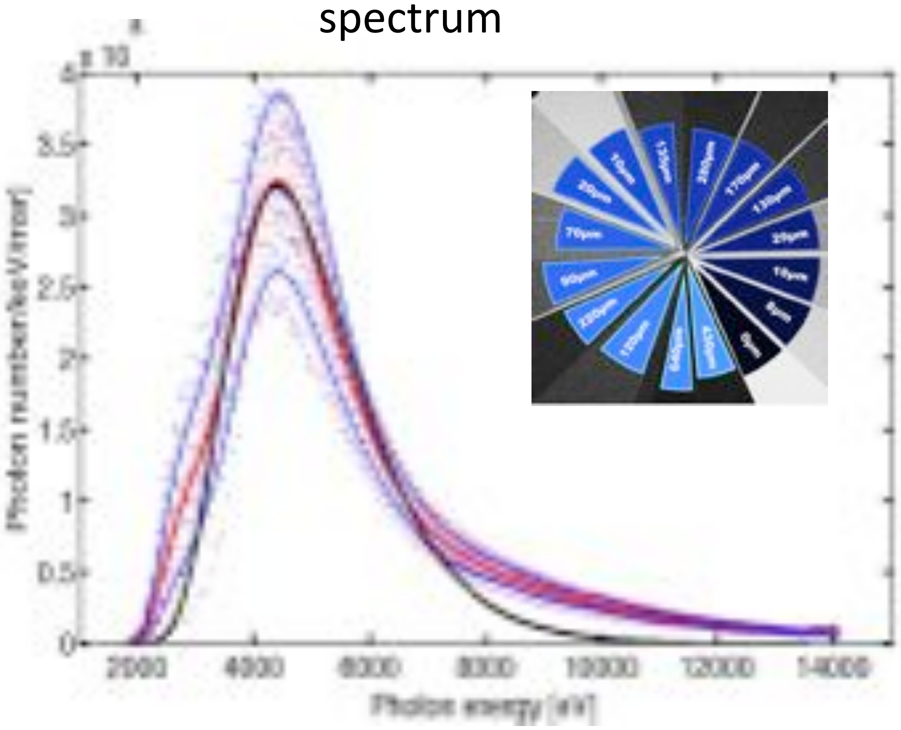
Metal Shaving on Surface (dark spot)

Sample Signal (~4000 counts)

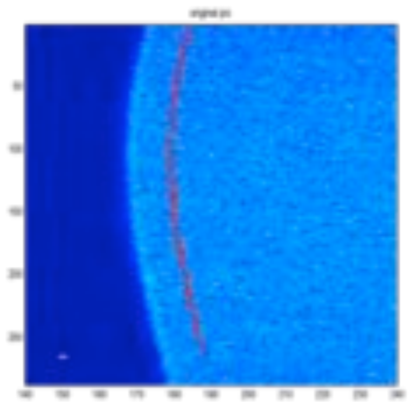
Phase-contrast imaging shown by: Kneip and Formaux

Krushelnick

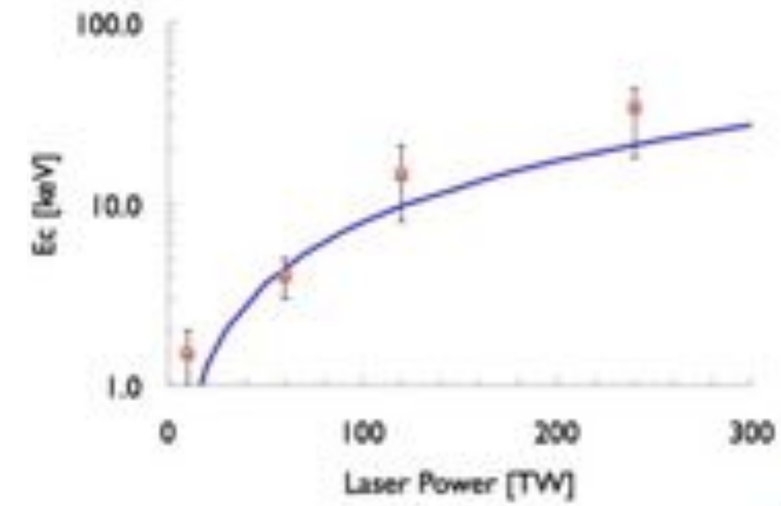
spectrum



source size



Position on X-Ray CCD (m)

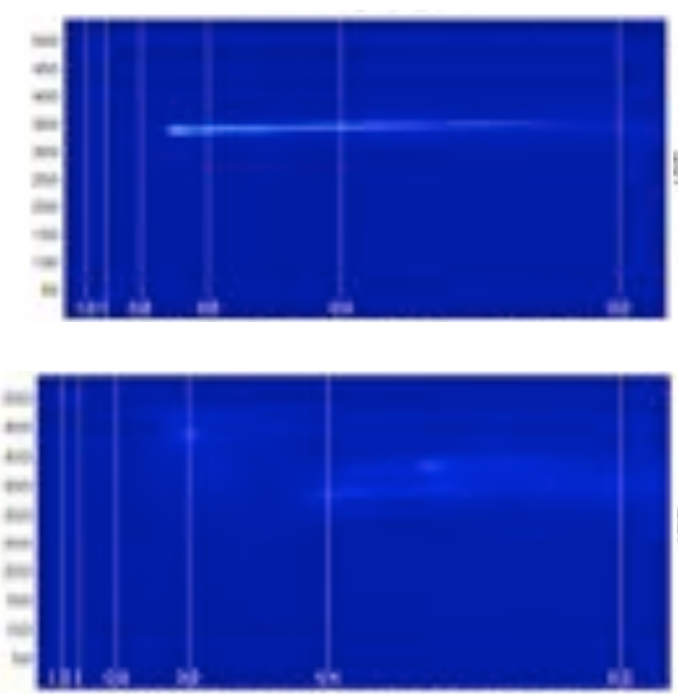


Karsch

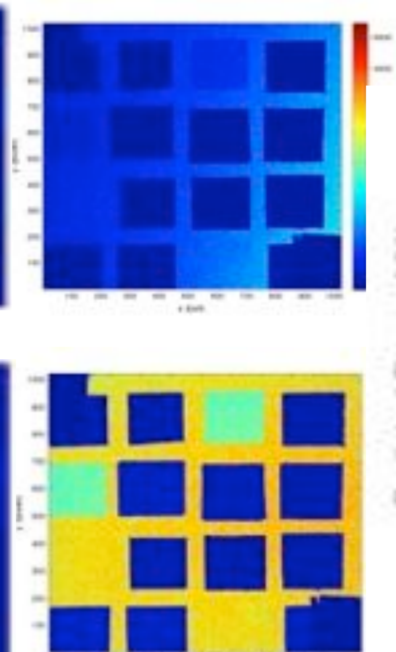
assuming a 5-fs pulse duration, this infers a peak brilliance of 10^{22} ph/($s^2mm^2mrad^2$ 0.1% bandwidth)

Krushelnick

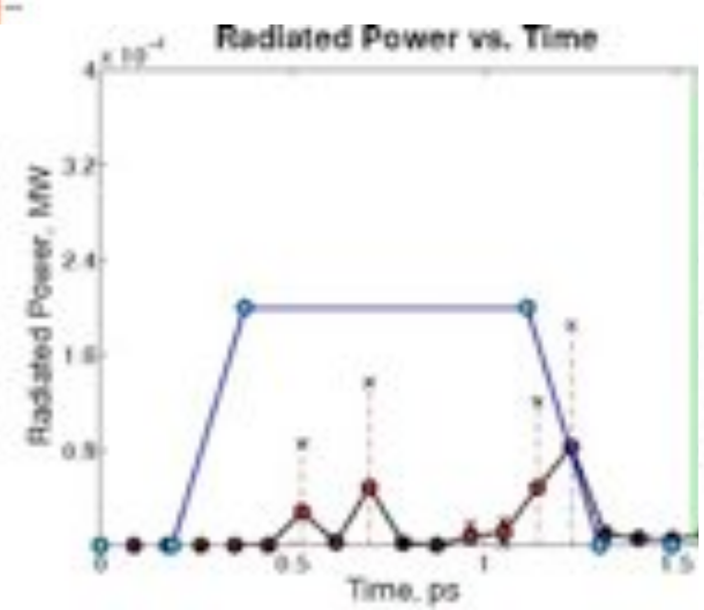
Electron Energy



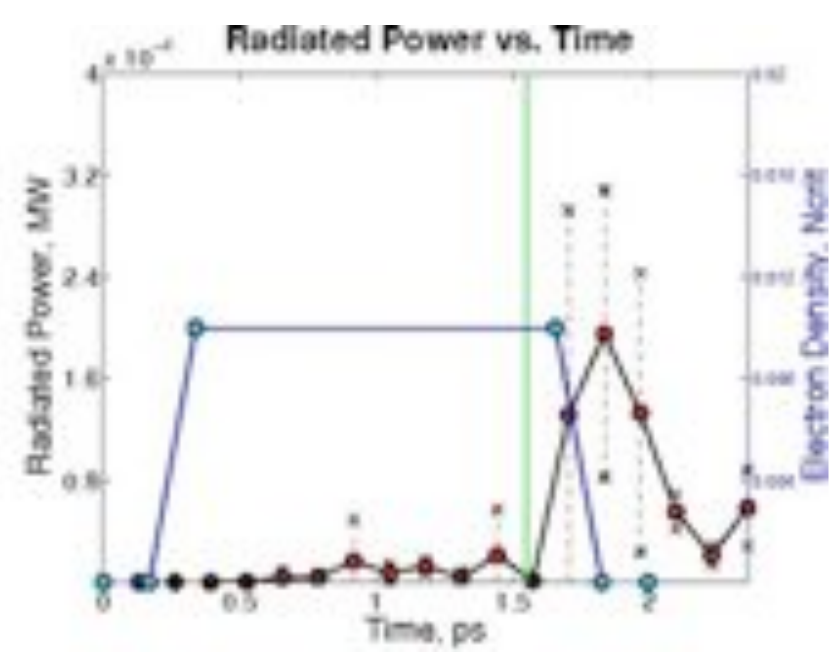
X-ray filter pack image



Propagation Distance = 0.75 L_d



Propagation Distance = 1.50 L_d



injection

Injection schemes talked about (mostly in WG6):

- External bunch injection (**Andreev**, **Rossi**)
- Bubble size variation (**Buck, Pausch, Kolmykov**)
- Colliding pulse (**Lehe**)
- Double pulse ionisation (**Bourgeois**)

Supporting data from:

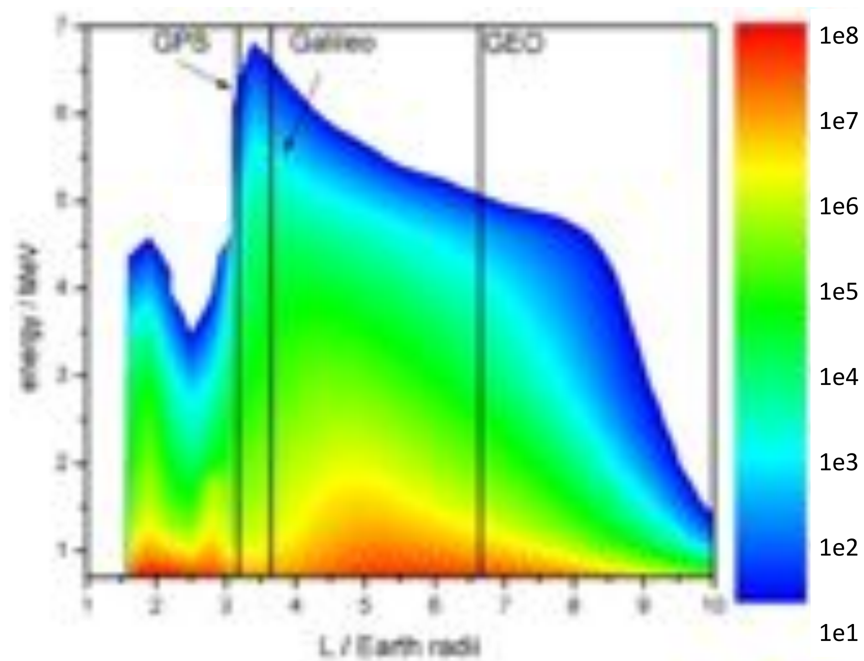
- **Malka** / **Najmudin** - plenary talks & **Karsch** (shock-front injection)

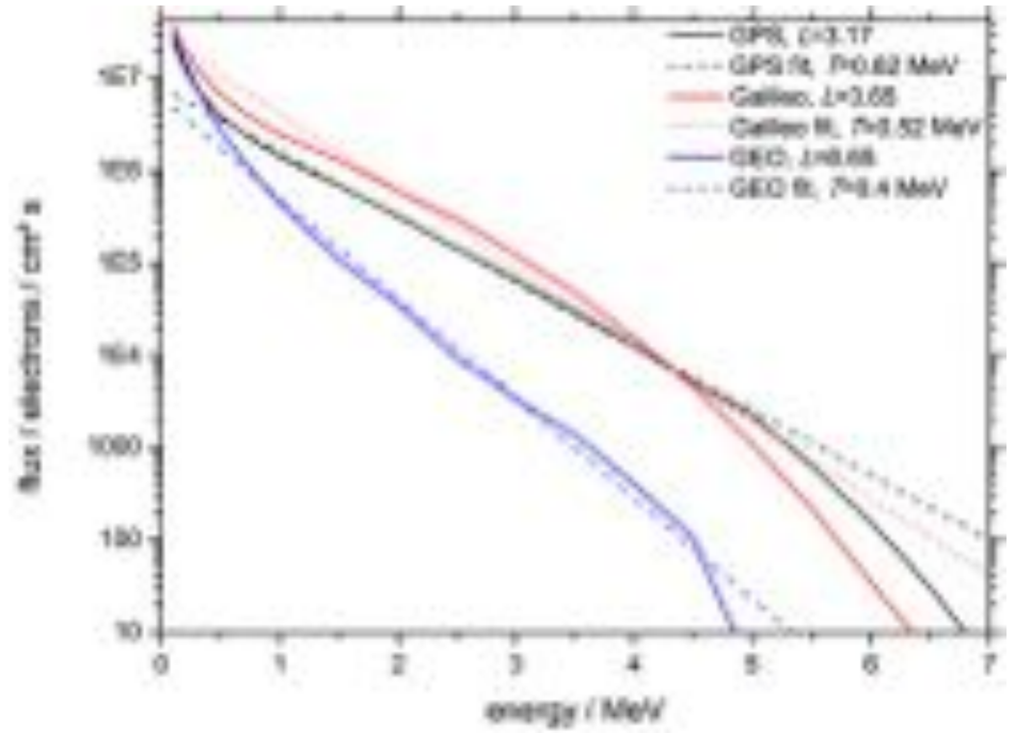
applications

Space radiation testing

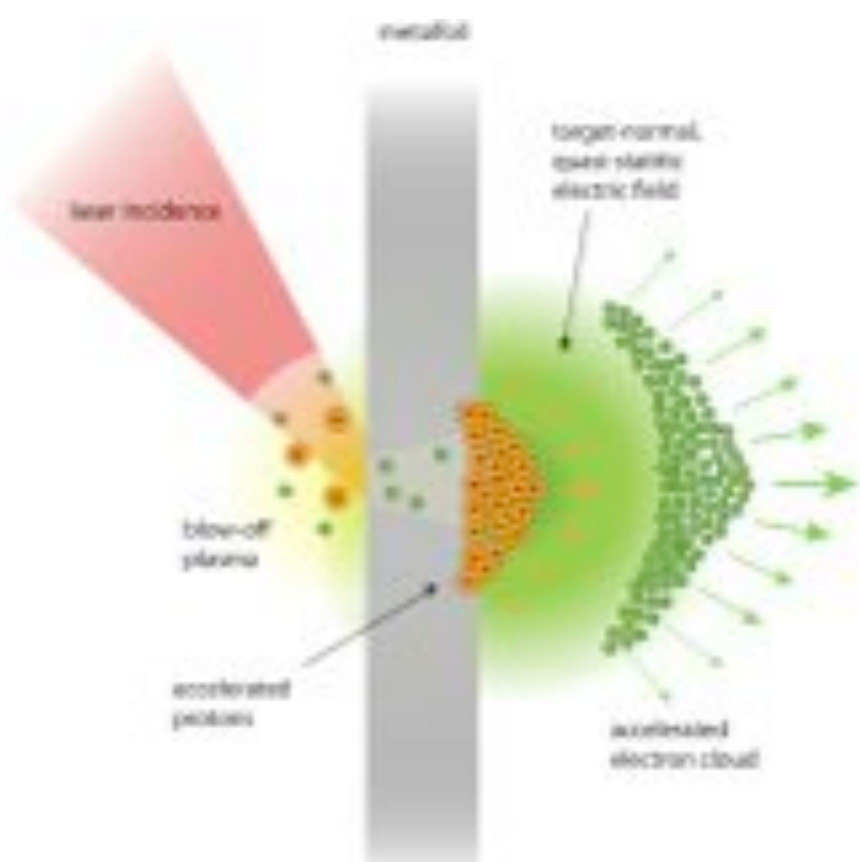
Karger

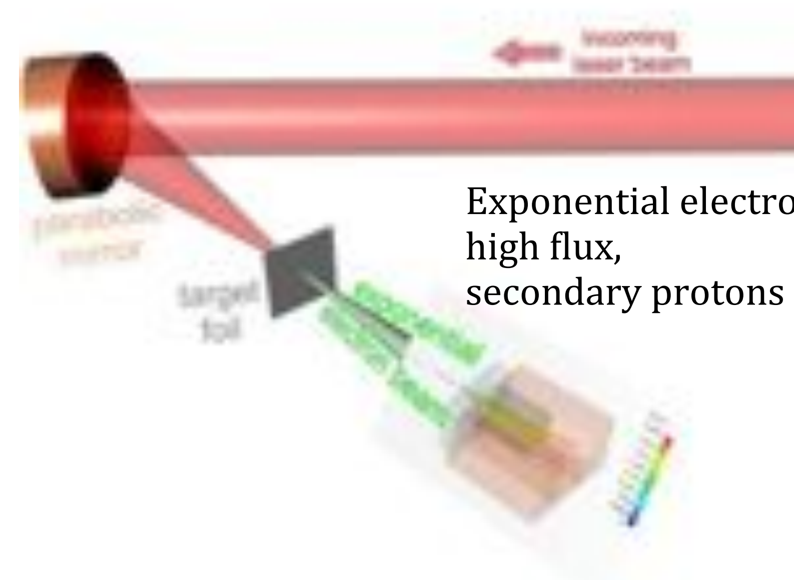
Van Allen belt electron flux
(NASA's $AE8_{min}$-model)





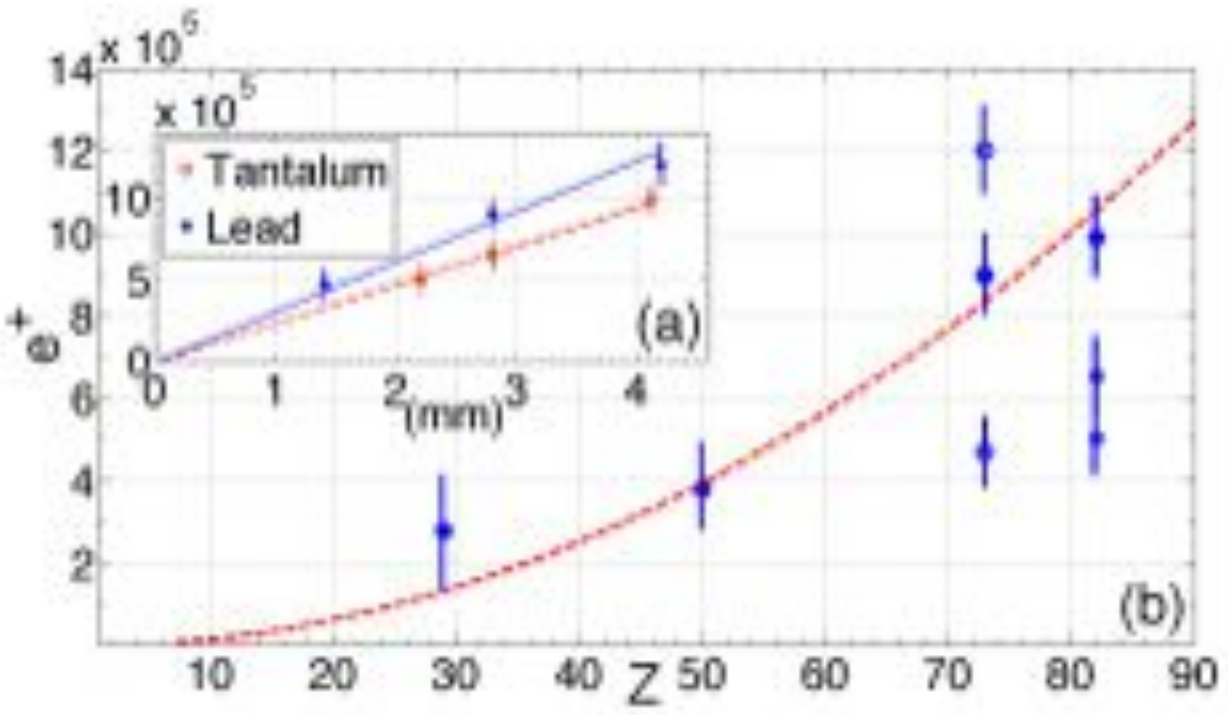
Königstein, Karger et al., J. Plasma Physics (2012), vol. 78, part 4, pp. 383-391





Exponential electron spectra,
high flux,
secondary protons and ions

Observed Positron Yield/Dependence

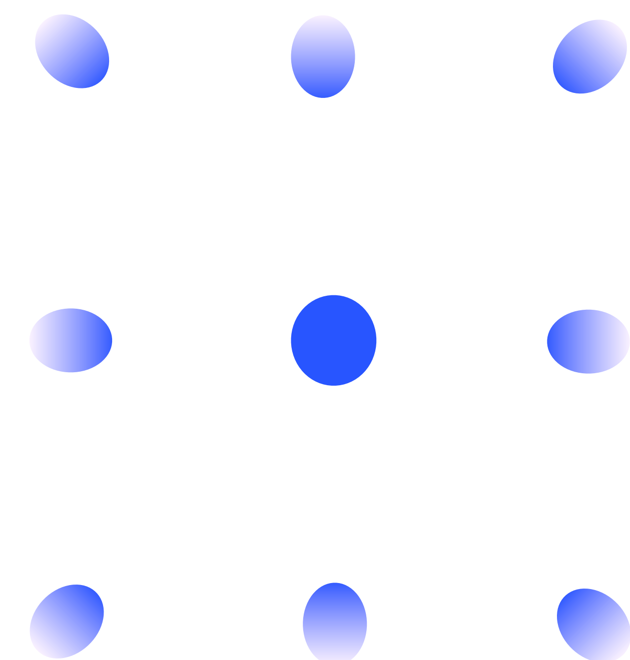


Krushelnick

Bragg scattering with electrons

- Yield scales quadraticly with target Z, linear with thickness
  - Evidence of direct Trident process ($e^- + Z \rightarrow 2e^- + e^+ + Z$)
- Positron/laser efficiency is nearly 10^6/J at 100 MeV
  - Comparable yield to kJ-class laser experiments [1]
  - Short pulse nature and low divergence preserved

Faure



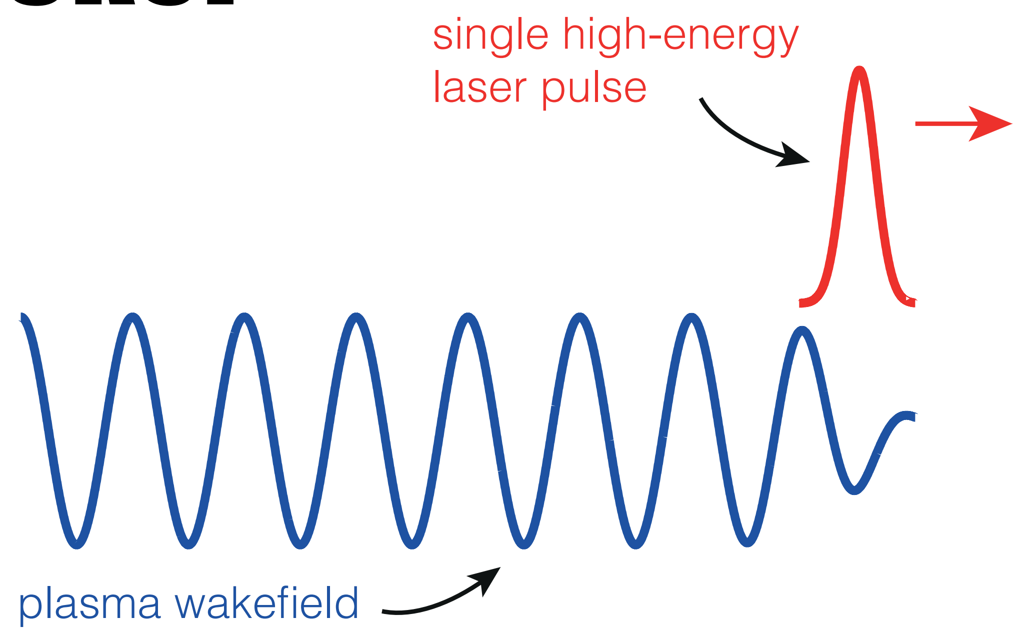
Also talked about:

- Injection into an undulator **Karsch**
- Thomson back scattering **Karsch**
- Hard x-ray production **Karsch**

high rep-rate

Hooker

- Almost all LWFA experiments today use a single driving pulse
  - Pulse energy ~ few joules
  - Pulse duration ~ 50 fs
  - Rep. rate typically < 10 Hz
  - Wall-plug efficiency <0.1%



- But many potential applications require:
  - Rep. rate ⩾ 1 kHz

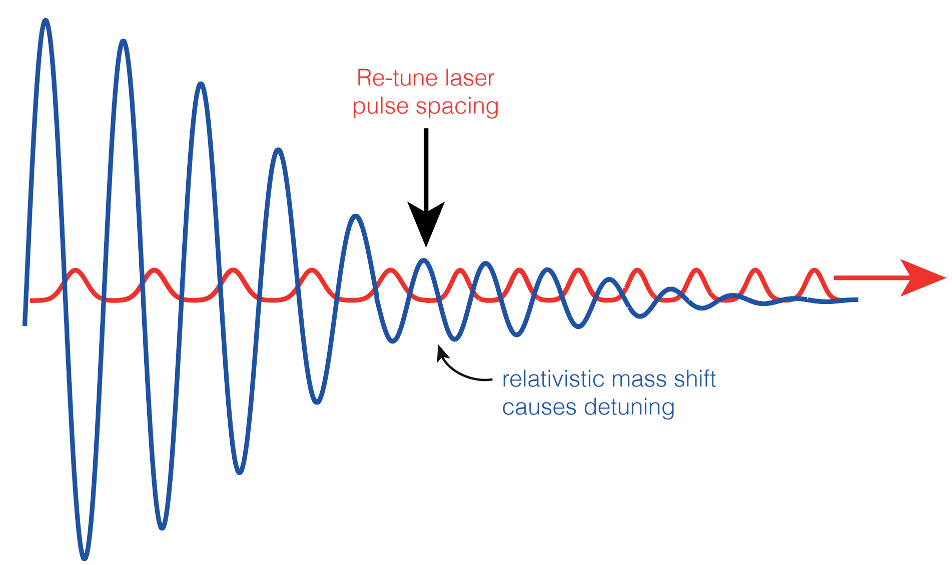
    ARPES

    XAS & XPS

    Tomography etc.
  - Wall-plug efficiency ≫1%

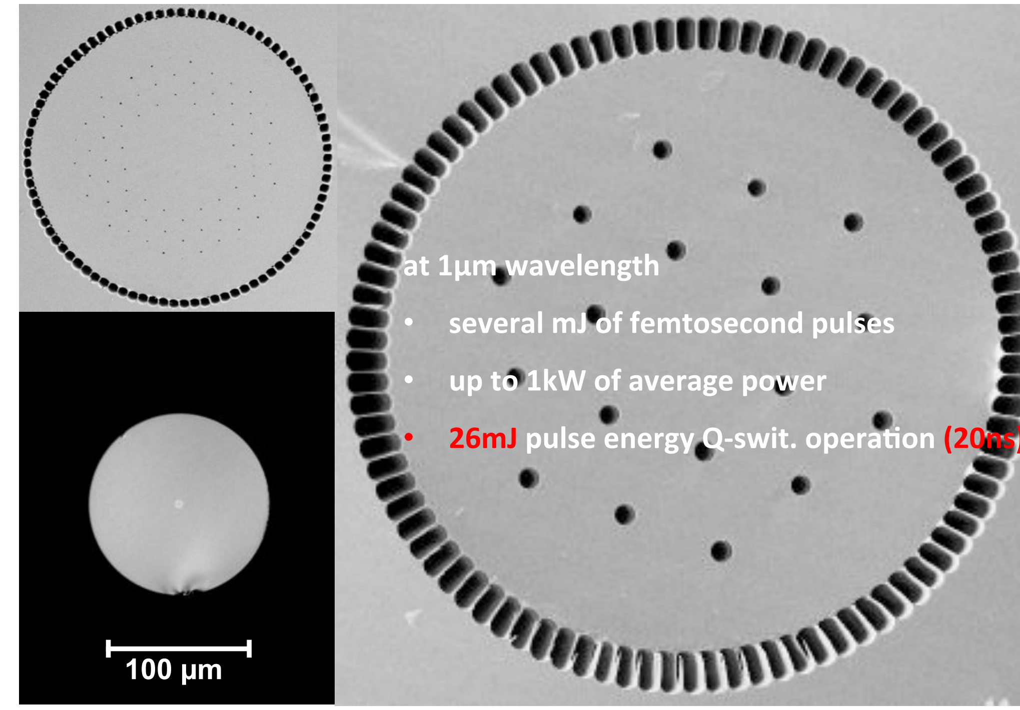
    Vital for particle colliders

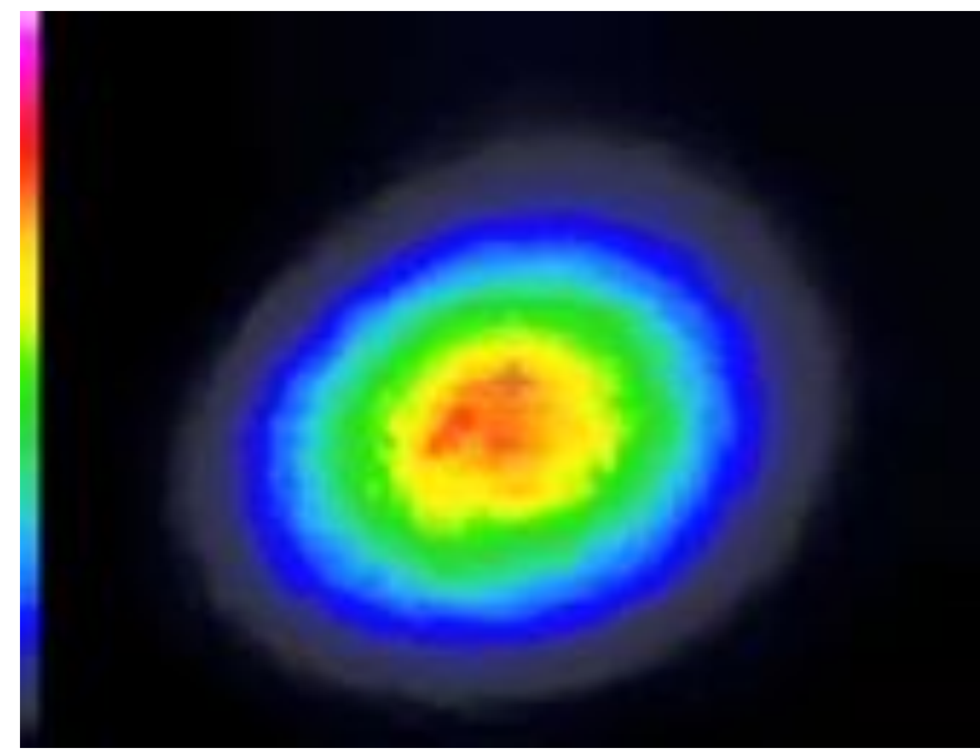
- Can overcome effect of detuning by using sub-trains
  - 40 pulses - re-tune - 30 pulses - re-tune - 20 pulses
  - Gives E_{acc} = 13.6 GV/m
  - ΔW = 3.6 GeV in L_d = 265 mm
  - Close to 90× single-pulse value



Limpert

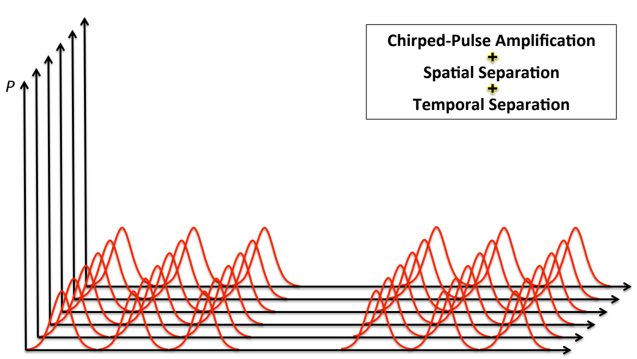
BELLA:
$28M project
for 10GeV accelerato

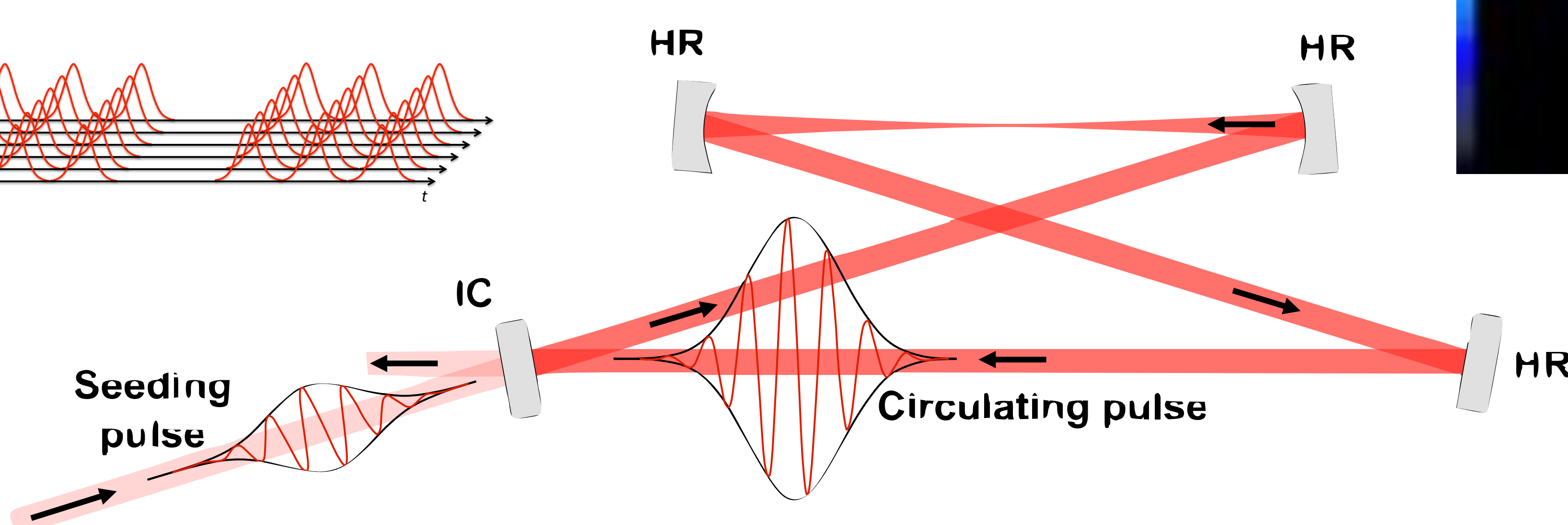




Laser system: Titanium-doped sapphire, commercial system by Thales

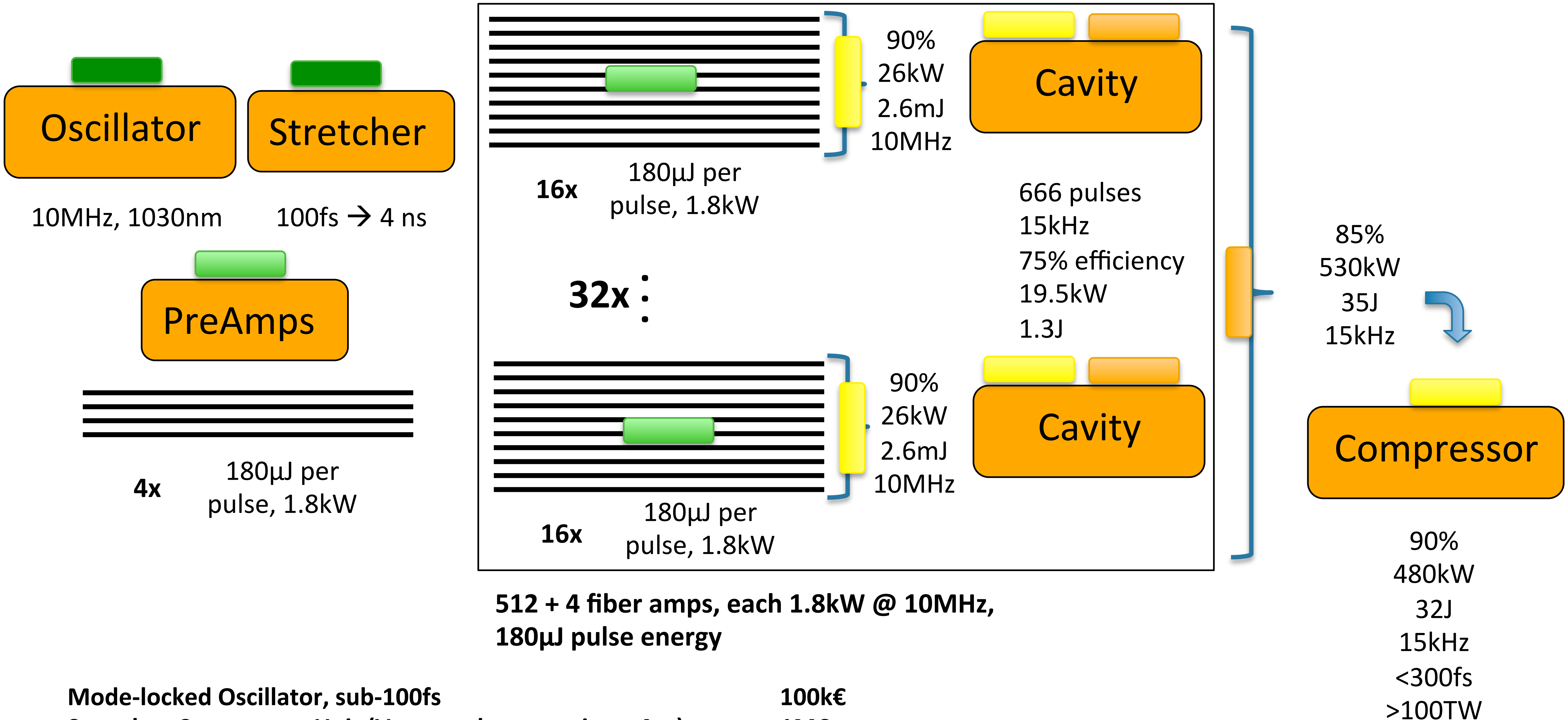
- Pulse energy: 42 J, pulse length: 40 fs: Petawatt peak power
- Repetition rate: **1 Hz**
- Efficiency: 40W out for 130kW in: **0.03%**





Concept - Stack and Dump

Budget Estimation



Mode-locked Oscillator, sub-100fs	**100k€**
Stretcher-Compressor Unit (Vacuum, large gratings, 4ns)	**1M€**
Pump Diodes (516x 2.5kW, 10€/W)	**516 x 25k€ = 12.9M€**
Fiber Amps (sealed modules, incl. optics and fiber, MFD>35µm)	**516 x 5k€ = 2.58M€**
Enhancement cavities with locking	**32 x 50k€ = 1.6M€**
Dumper system (light chopper)	**500k€**
Combining Setup	**1M€**
Sum:	**19.68M€**

>10.000x higher P_{avg}
>500x higher efficiency
than BELLA