Design Considerations of *table-top* FELs

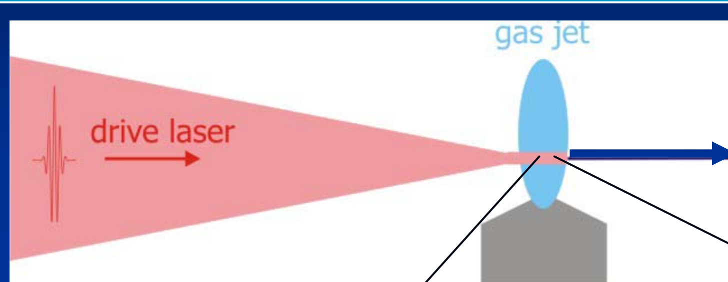
FLS 2006, May 15, 2006

LMU: F. Grüner, U. Schramm, S. Becker, R. Sousa, T. Eichner, **D. Habs**
MPQ: S. Karsch, M. Geissler, L. Veisz, J. Meyer-ter-Vehn, **F. Krausz**
UCLA: S. Reiche

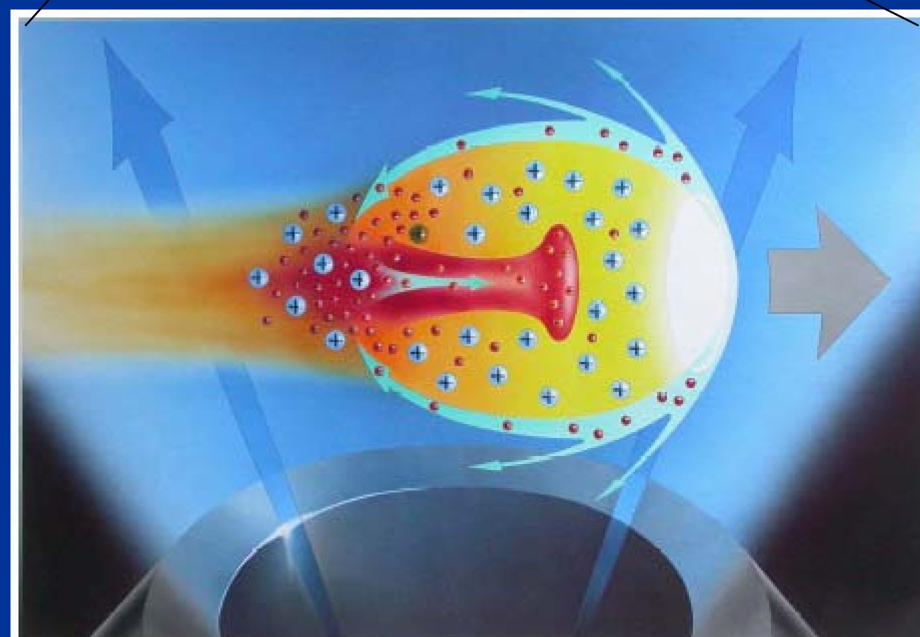
- laser-plasma accelerators
- principal possibility of *table-top* FELs
- possible VUV and X-ray scenarios
- experimental status

Laser-Plasma accelerators: “bubble acceleration”

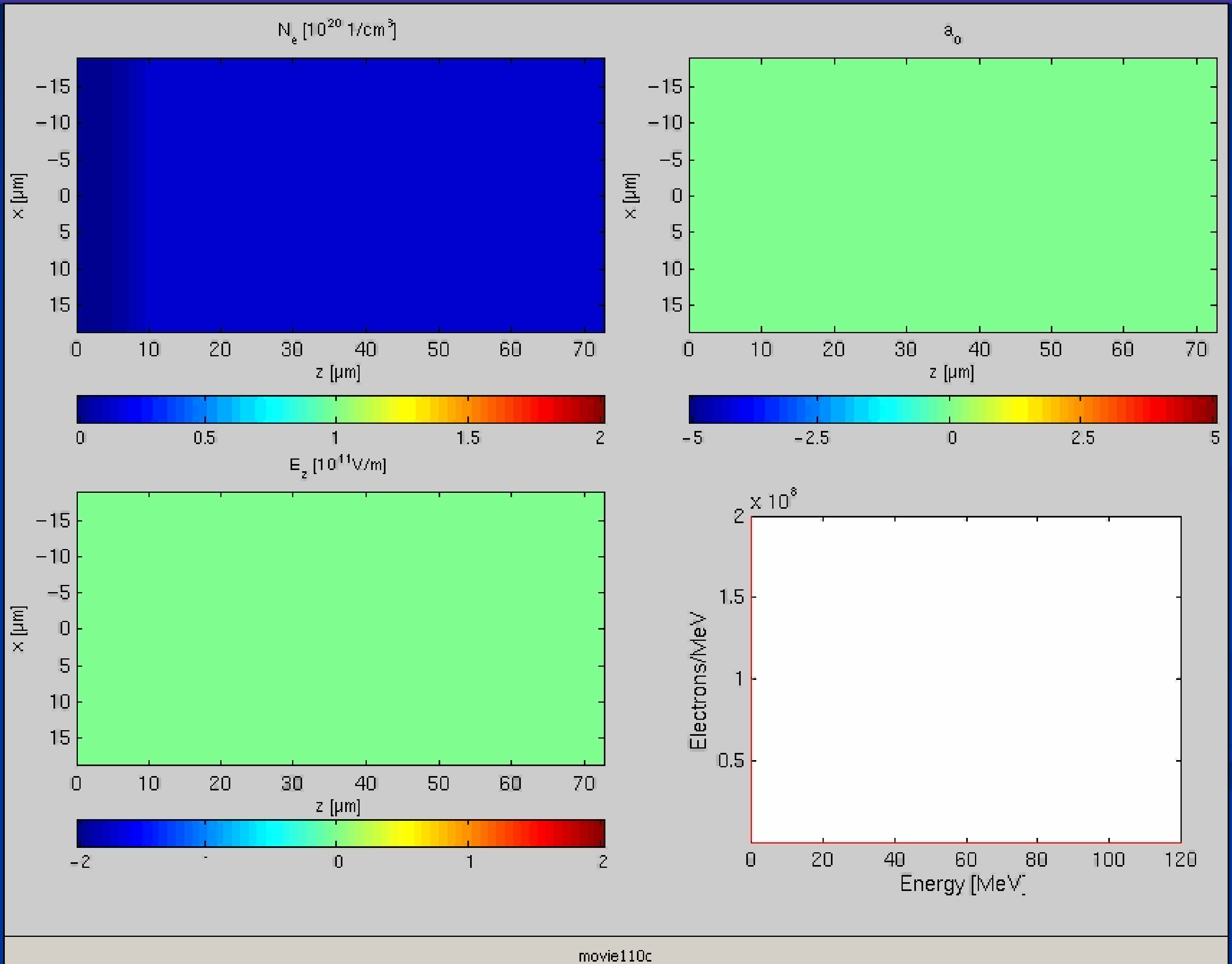
TW laser,
5-50 fs



electron bunch:
e.g. 170 MeV (LOA),
rumor: 1.2 GeV (Berkeley)

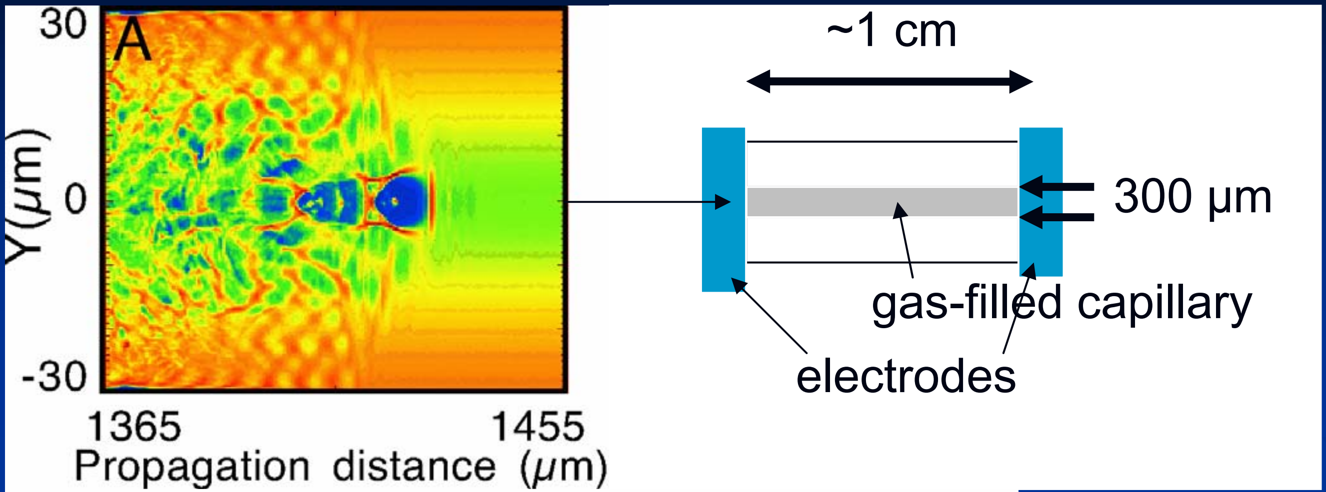


PIC code



N_e [10^20 1/cm^3]
a_0
x [µm]
z [µm]
E_z [10^11 V/m]
x 10^8
Electrons/MeV
Energy [MeV]
movie110c

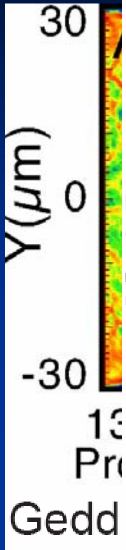
Discharge capillary

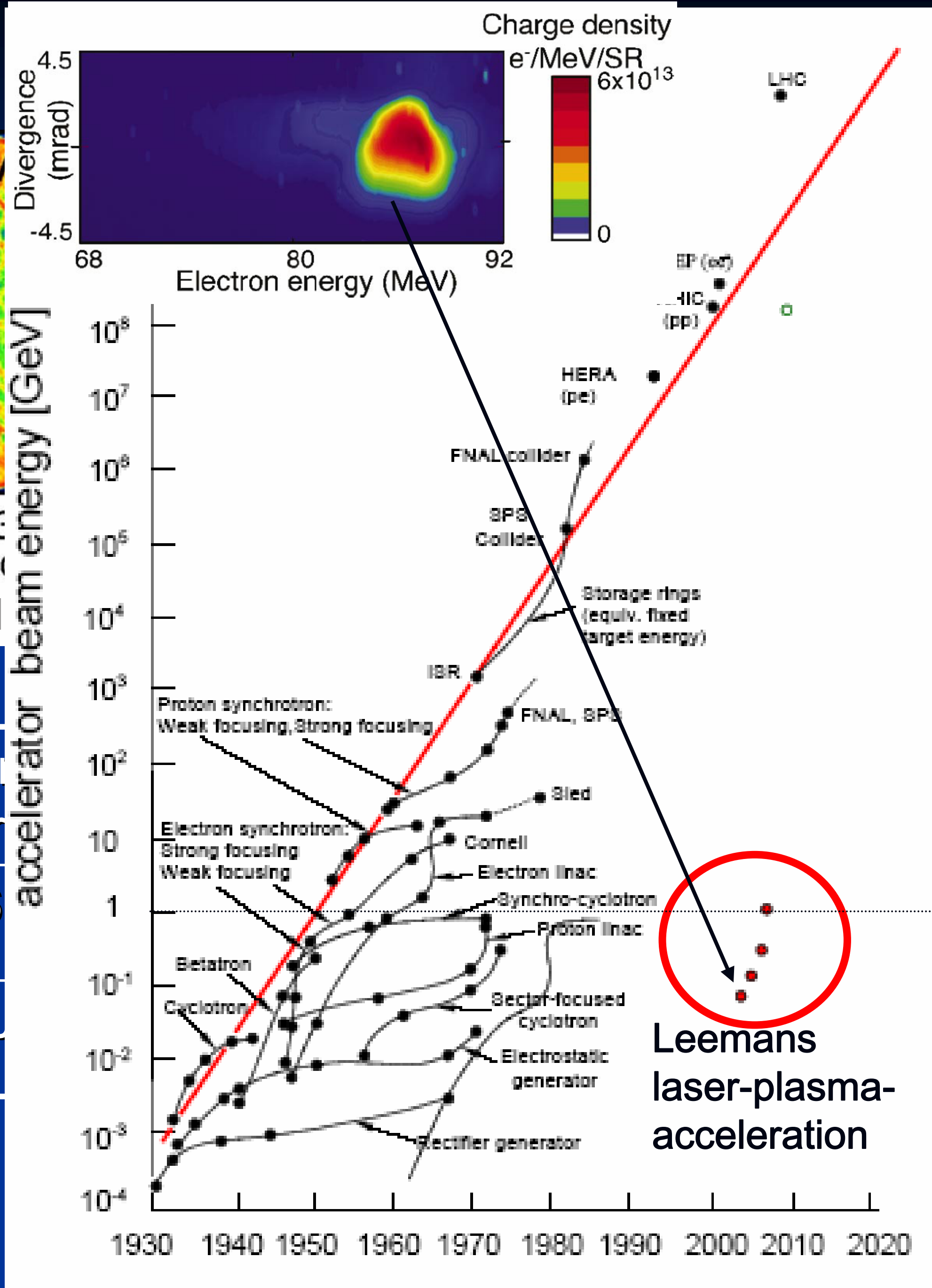


Geddes *et al.* Phys. Plasmas **12**, 056709 (2005)

year	laser pulse energy	Pulse length	electron energy	energy spread	divergence
2004	0.36 J	40 fs	86 MeV	2 %	3 mrad
2006*	1.3 J	33 fs	1.2 GeV	< 2%	?

* to be presented at *Anomalous Absorpt. Conf., June 6, 2006)*





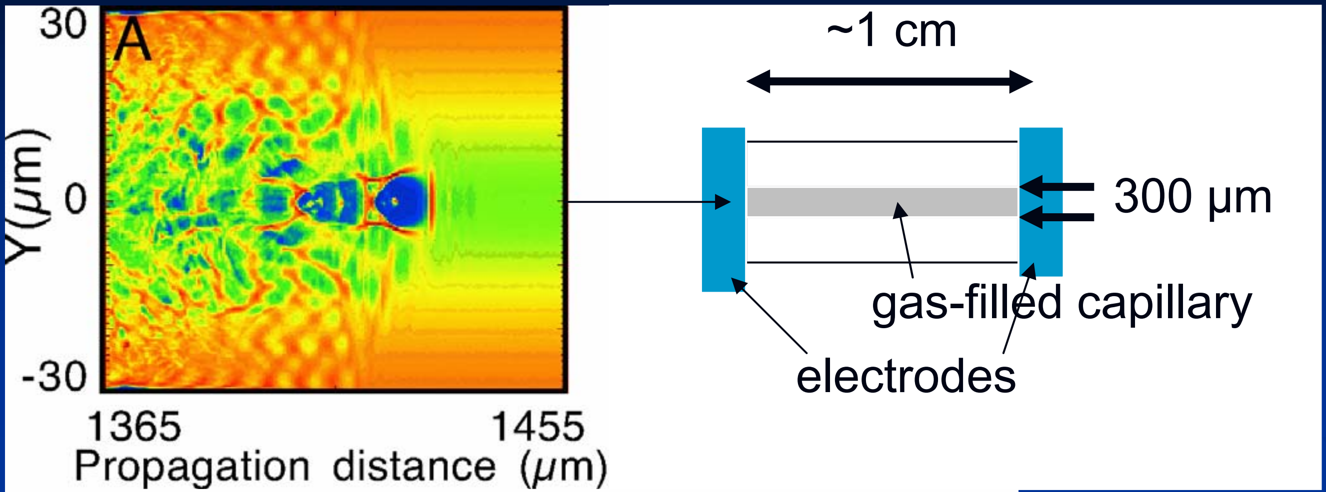
300 μm

apillary

year	laser energy	divergence
2004	0.36	3 mrad
2006*	1.3 J	?

* to be presented at

Discharge capillary



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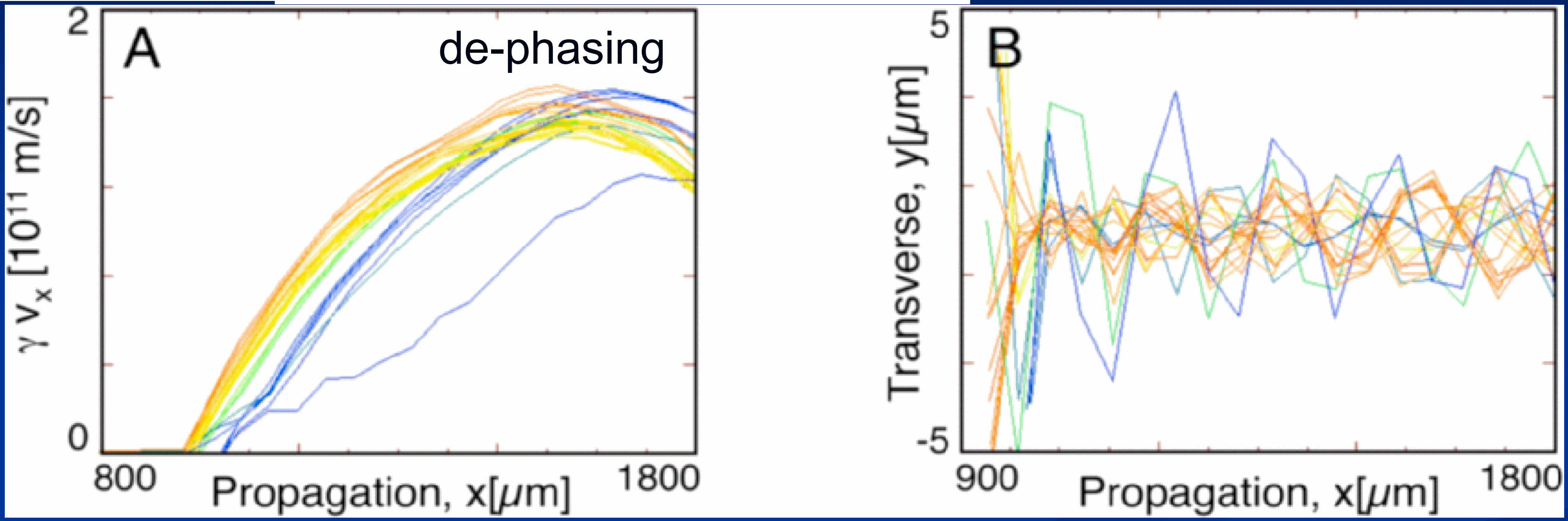
MPQ: in few weeks 1-2 J, 37 fs, future: 5 J, 5 fs (=1 PW), 1 kHz

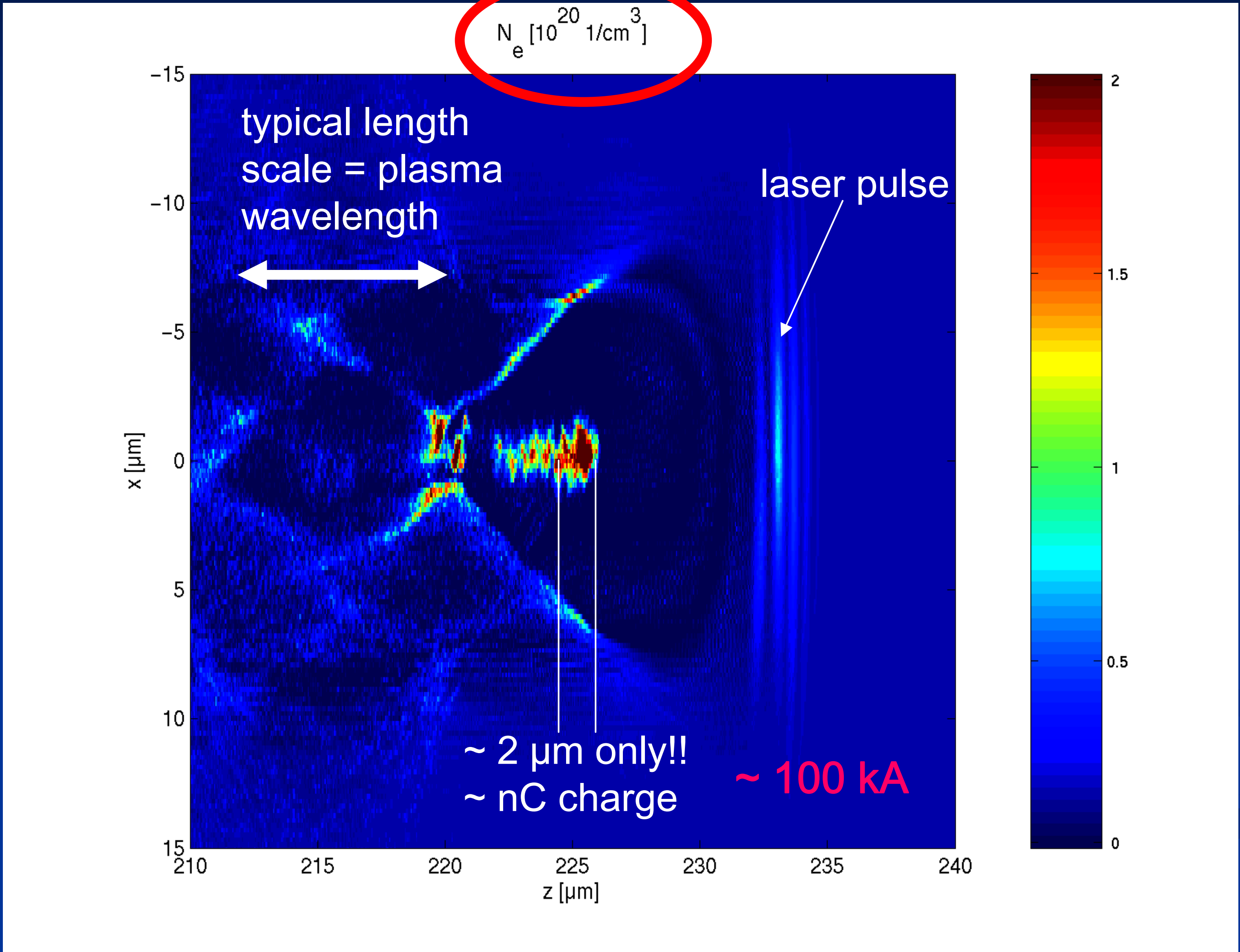
Improvement by capillaries

Geddes *et al.* Phys. Plasmas **12**, 056709 (2005)



- discharge introduces parabolic electron density
- laser guiding beyond Rayleigh length → higher energies
- de-phasing: reducing energy spread
- ion-channel: reducing electron beam diameter and divergence

Important feature: ultra-high current



Principal possibility for *table-top* FELs

simplest estimate: ideal 1d Pierce parameter (no energy spread, emittance, diffraction, time-dependence)

$$L_{gain,\mathrm{ideal}} = \frac{\lambda_u}{4\pi\sqrt{3}\rho}$$

current : few 100kA (classical: 5 kA)

und. period : few mm (class. few cm)

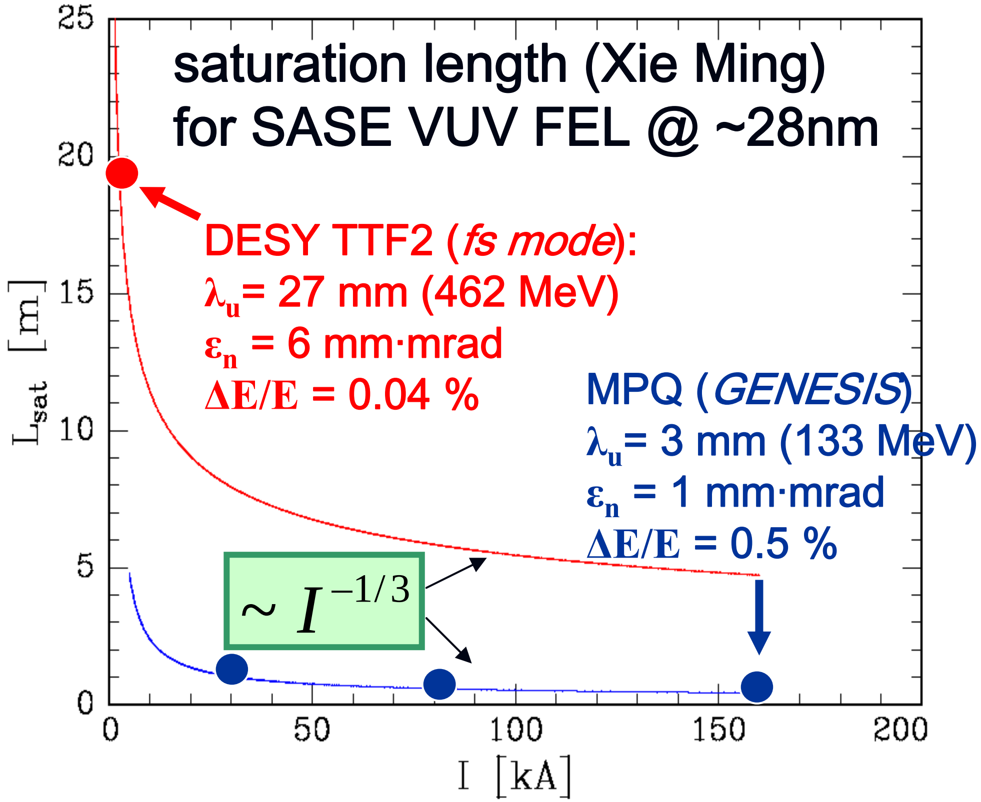
$$\rho = \frac{1}{2\gamma}\left[\left(\frac{I}{I_A}\right)\cdot\left(\frac{\lambda_u A_u}{2\pi\sigma_x}\right)^2\right]^{1/3}$$

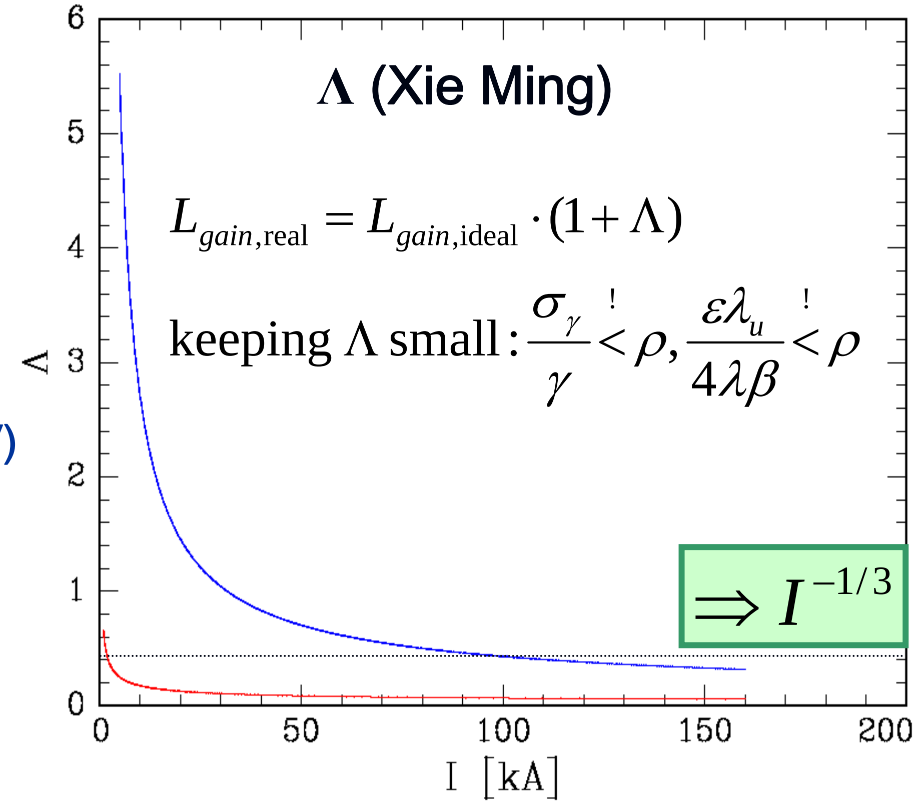
beam diameter (optimal!)

$$L_{gain,\mathrm{real}}^{XieMing} = L_{gain,\mathrm{ideal}}\cdot(1+\Lambda)$$

$$L_{sat} \approx 15\cdot L_{gain}$$

Constraints for *table-top* FELs



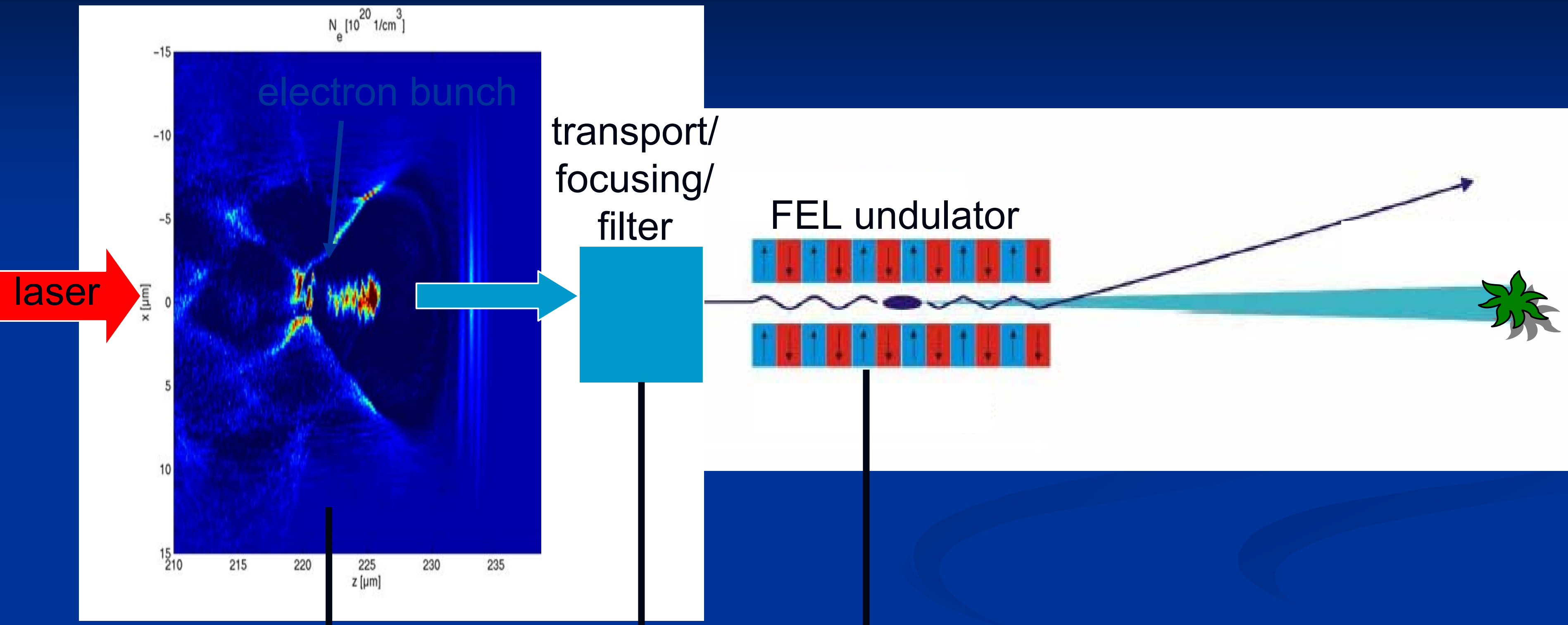


• not only table-top size, but sufficient output power:

$$P_{sat} \sim \left(\frac{1}{1+\Lambda}\right)^2 \cdot (I \cdot \lambda_u)^{4/3}$$

reduction in λ_u gives a reduction in γ, but <u>needs ultra-high current</u> for keeping ρ and also saturation power large enough

Start-to-End Simulations

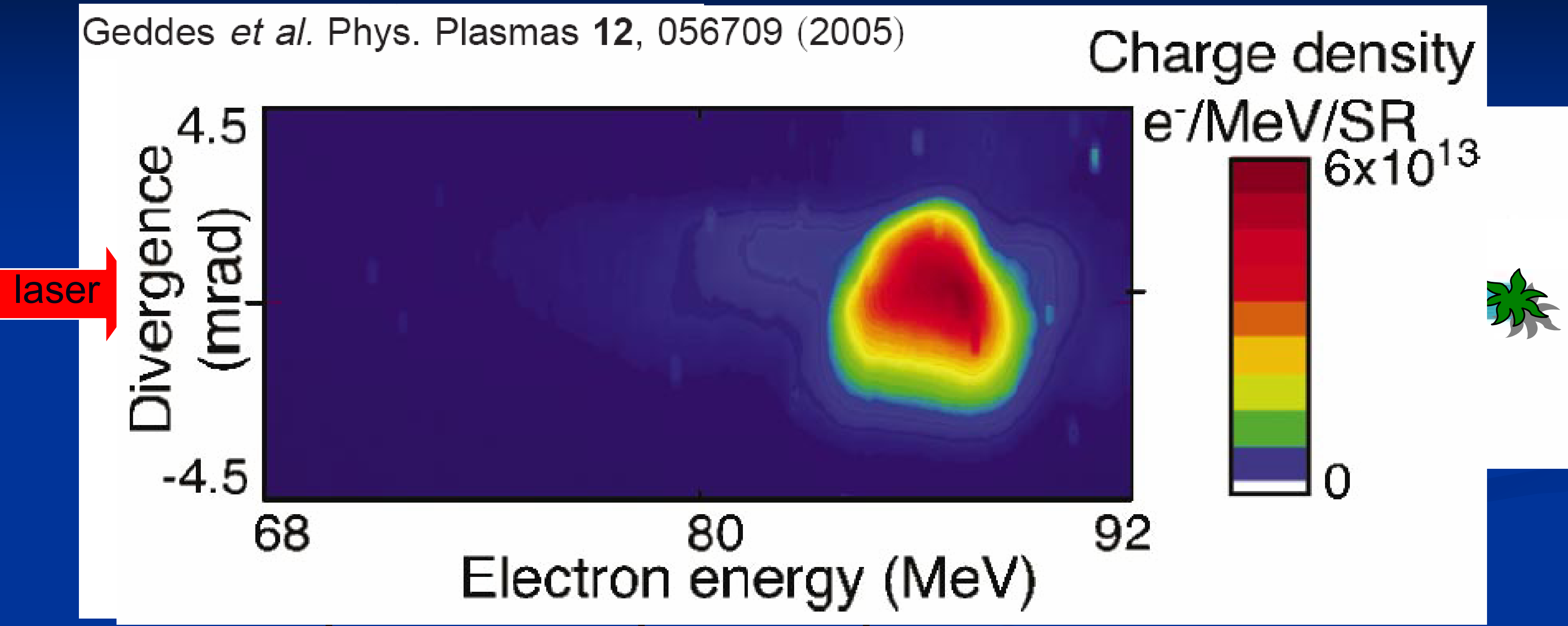


own 3d PIC code

GPT, Geant

CSRTrack, Spur; GENESIS 1.3

Start-to-End Simulations



own 3d PIC code

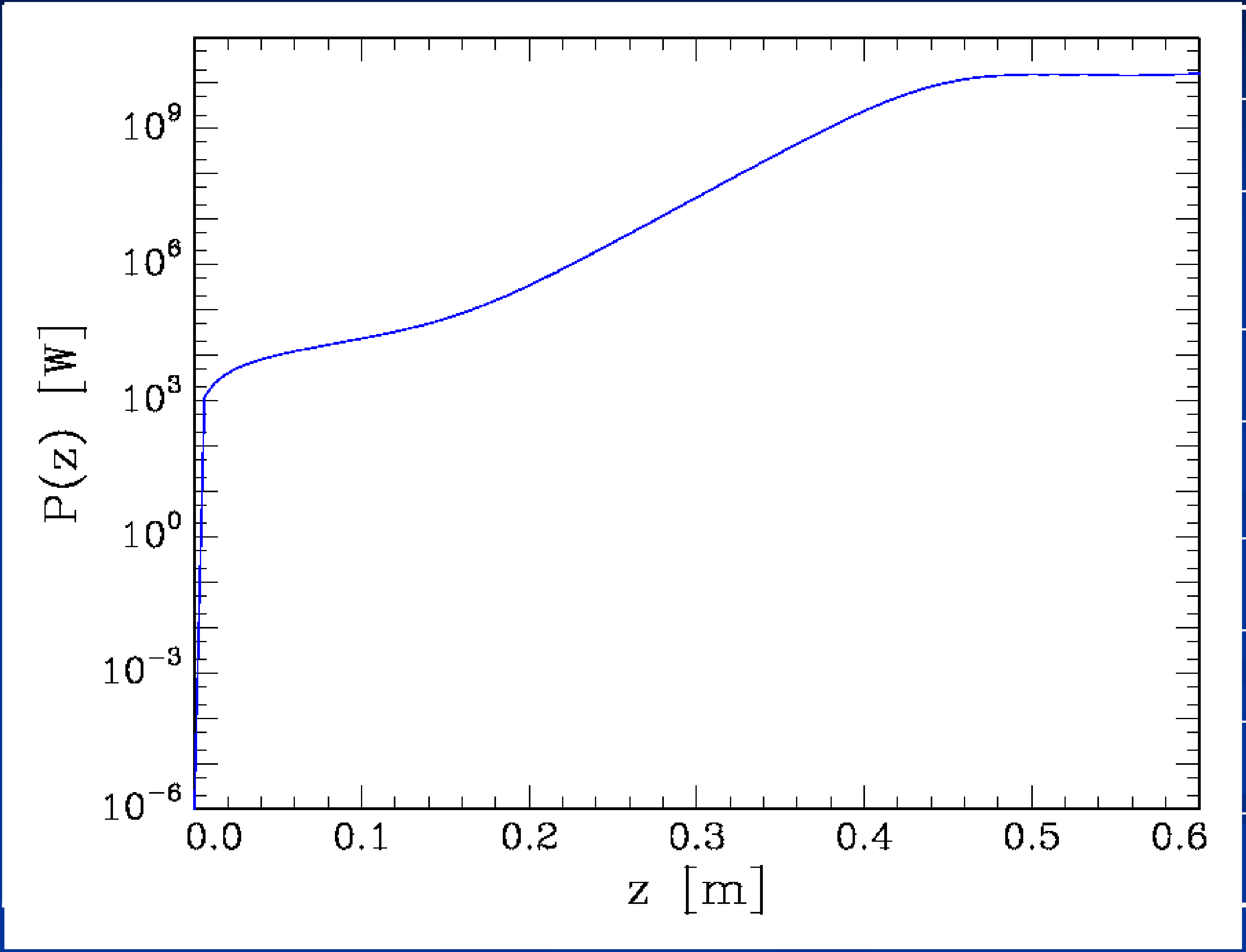
GPT, Geant

CSRTrack, Spur; GENESIS 1.3

A possible first VUV case

Parameter	DESY (TTF2, fs-mode)	MPQ
Current	1.3 kA	160 kA
Norm. Emitt. (rms)	6 mm·mrad	1 mm·mrad
Energy	461.5 MeV	130 MeV
Energy spread	0.04 %	0.5 %
Wavelength	30 nm	25 nm
Pierce par.	0.0016	0.0117
Sat. Power	0.66 GW	5 GW
Sat. Length	19 m	45 cm

A possible first VUV case

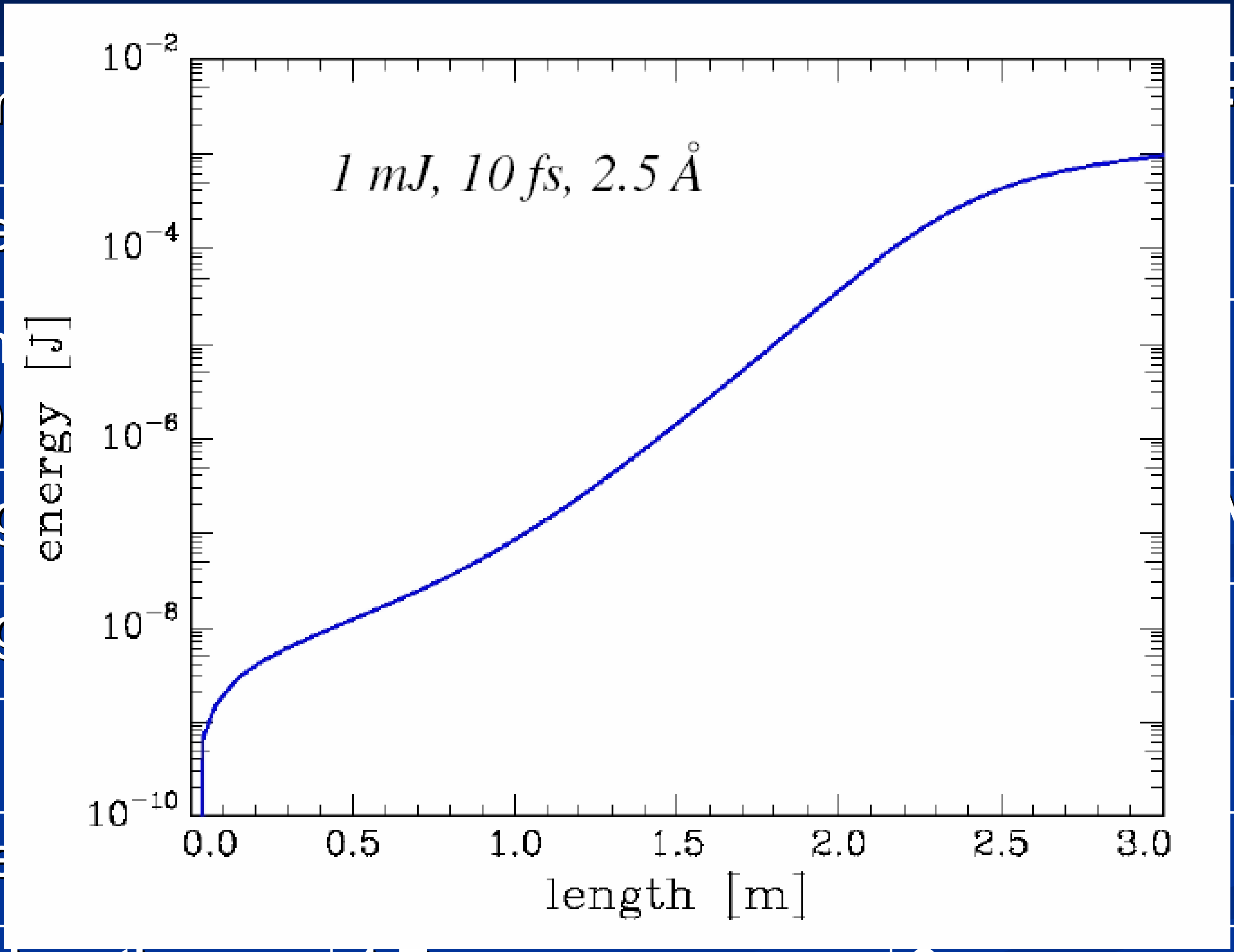


International competition and a possible first table-top XFEL case

Parameter	**Leemans** (FEL2005 conf.) 100 TW, 33 fs	MPQ (TT-XFEL) 1 PW, 5 fs
Current	25 kA	160 kA
Norm. Emitt. (rms)	1 mm·mrad	1 mm·mrad
Energy	1 GeV	0.9 – 1.2 GeV
Energy spread	1 %	0.1 %
Und. Period	10 mm	1.5 – 3 mm
Wavelength	2 nm	0.25 nm
Und. length	**4.7 m**	**3 m**

International competition and a possible first table-top XFEL case

Para		FEL)
Curre		
Norm (rms)		
Energ		V
Energ		
Und.		
Wave		
Und. length	4.7 m	3 m

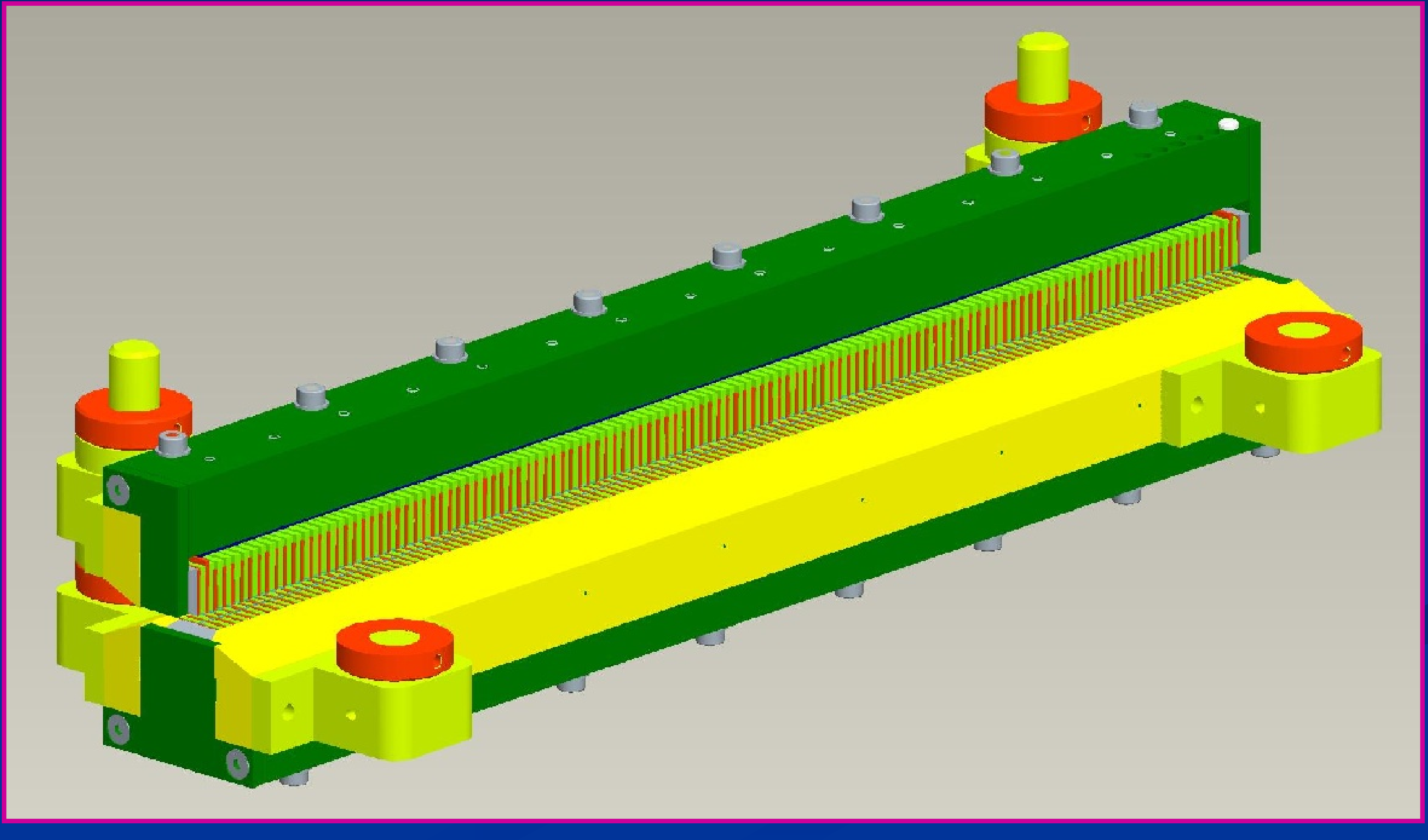


Experimental Status

- hybrid undulator
- mini-quads
- laser systems
  - 100mJ – 1 J; 10 – 50 fs; ~10 TW scale
  - LWS10 and ATLAS-upgrade
- time table:
  - in few weeks: first electrons with ATLAS
  - end of 2006: beam time at LOA
  - 2007-2008: proof-of-principle of SASE
  - 2008-2009: reaching 1 GeV, TT-XFEL

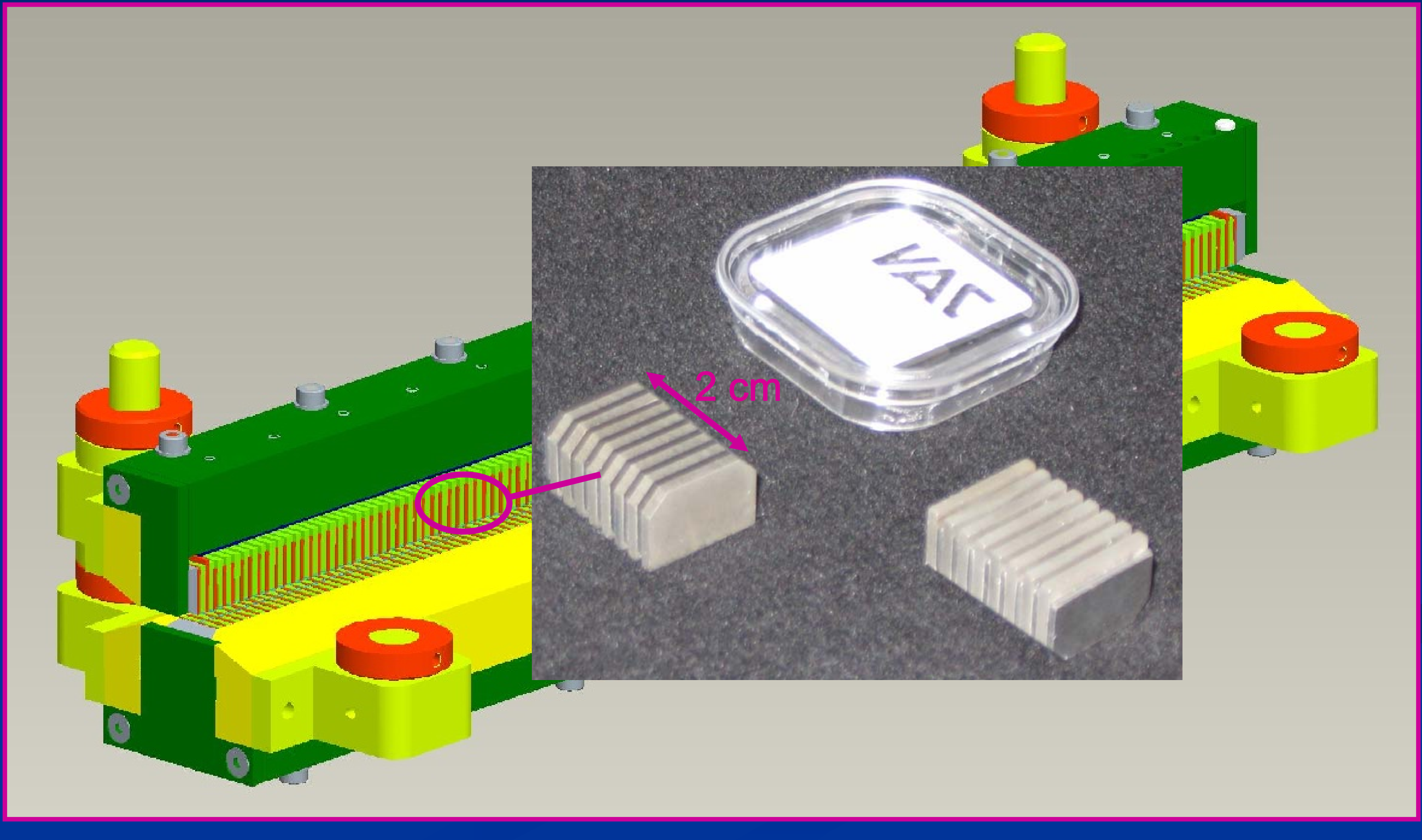
Experimental Status

- hybrid undulator



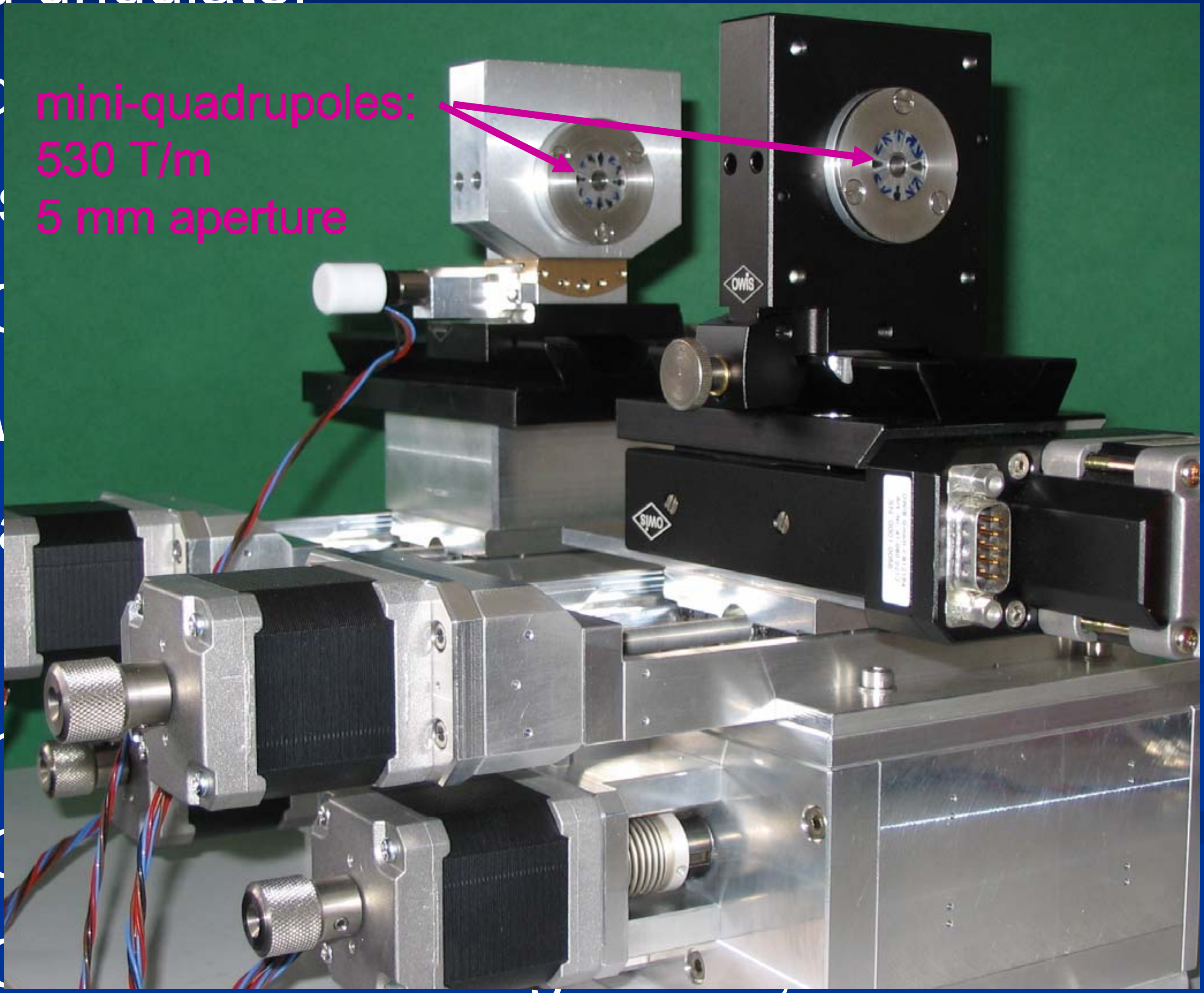
Experimental Status

- hybrid undulator



Experimental Status

- hybrid undulator
- mini-q
- laser s
  - 10
  - LV
- time ta
  - in
  - er
  - 20
  - 20



Conclusion

- **laser-plasma accelerators** demonstrated generation of 100 MeV – 1 GeV electrons with energy spread in the range of few % and below, charges 0.1-1nC, normalized emittances ~ 1 π mm·mrad
- main feature: **high currents**, up to few 100 kA
- thus, short-period undulators are feasible for SASE
- hence, table-top FELs are possible
- to do list:
  - further development of laser and capillaries
  - build next-generation undulator: period 3 mm
  - from SASE signatures to saturation; VUV→ X-rays