Scintillating Screens for laser-accelerated relativistic electron bunch diagnostics

A. Buck, A. Popp, K. Schmid, C. M. S. Sears, L. Veisz, S. Karsch, F. Krausz
Ludwigs-Maximilians-Universität, München
Max-Planck-Institut für Quantenoptik, Garching

K. Zeil, A. Jochmann, S. D. Kraft, J. Pawelke, R. Sauerbrey, T. Cowan, U. Schramm
Forschungszentrum Dresden-Rossendorf

B. Hidding, T. Kudyakov
Heinrich-Heine-Universität, Düsseldorf

www.attoworld.de

Outline

- Laser-driven electron acceleration
- Typical setup and electron detection
- Charge calibration at ELBE accelerator
  @ Forschungszentrum Dresden Rossendorf
- Summary

Relativistic electron acceleration

- „Conventional“ radio-frequency accelerators:

  Maximum accelerating fields limited due to breakdown
  - Maximum field: $E_{max} \approx$ 100MV/m
  - many km long accelerators needed
  - Expensive
  - Long pulse duration
  - Big timing jitter

SLAC

- Alternative: Laser-plasma-based Accelerators:

  Already ionized acceleration medium → no breakdown
  - Possible fields: E ≈ 100GV/m - 1TV/m
  - 10^3 - 10^4 times higher
  - Shorter acceleration distance
  - Intrinsically short (few fs) pulses
  - Intrinsically synchronized with laser pulse

Super-sonic Helium Gas Jet

Laser acceleration milestones

1979: First proposal

VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

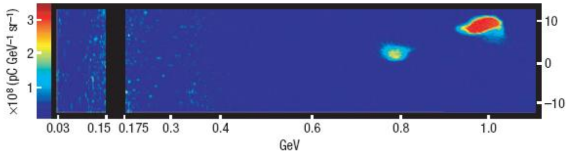
1995: First observation of relativistic electrons from laser plasmas

- Modena, A., *et al.*, Nature, **377**, 606 (1995).

2004: Realization of quasi-monoenergetic electron spectra

- Mangles, S. P. D. *et al.*, Nature, **431**, 535 (2004)
- Geddes, C. G. R. *et al.* Nature, **431**, 538 (2004)
- Faure, J. *et al.*, Nature, **431**, 541 (2004)

2006: GeV electrons



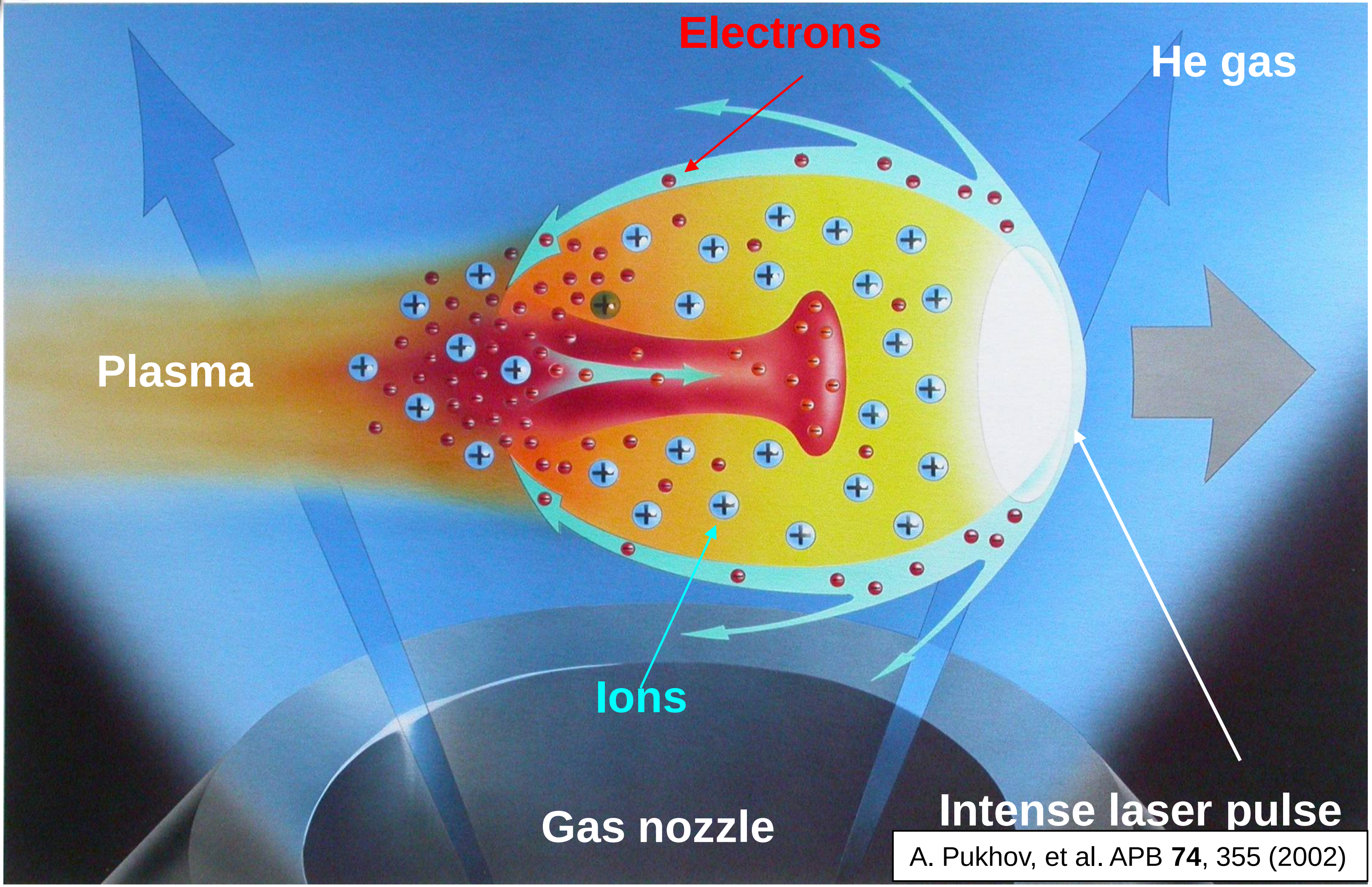
- Leemans, W. P. *et al.*, Nature Phys. **2**, 696699 (2006)

2011: Ultra-short bunch duration confirmed (< 5 fs RMS)

- Lundh, O. *et al.*, Nature Phys., published online (2011)
- Buck, A. *et al.*, Nature Phys., accepted (2011)

- Ultra-short multi-TW laser systems needed for acceleration
- Typical: Ti:Sa-systems, 30 fs, ~ 1 J

„Bubble“ acceleration



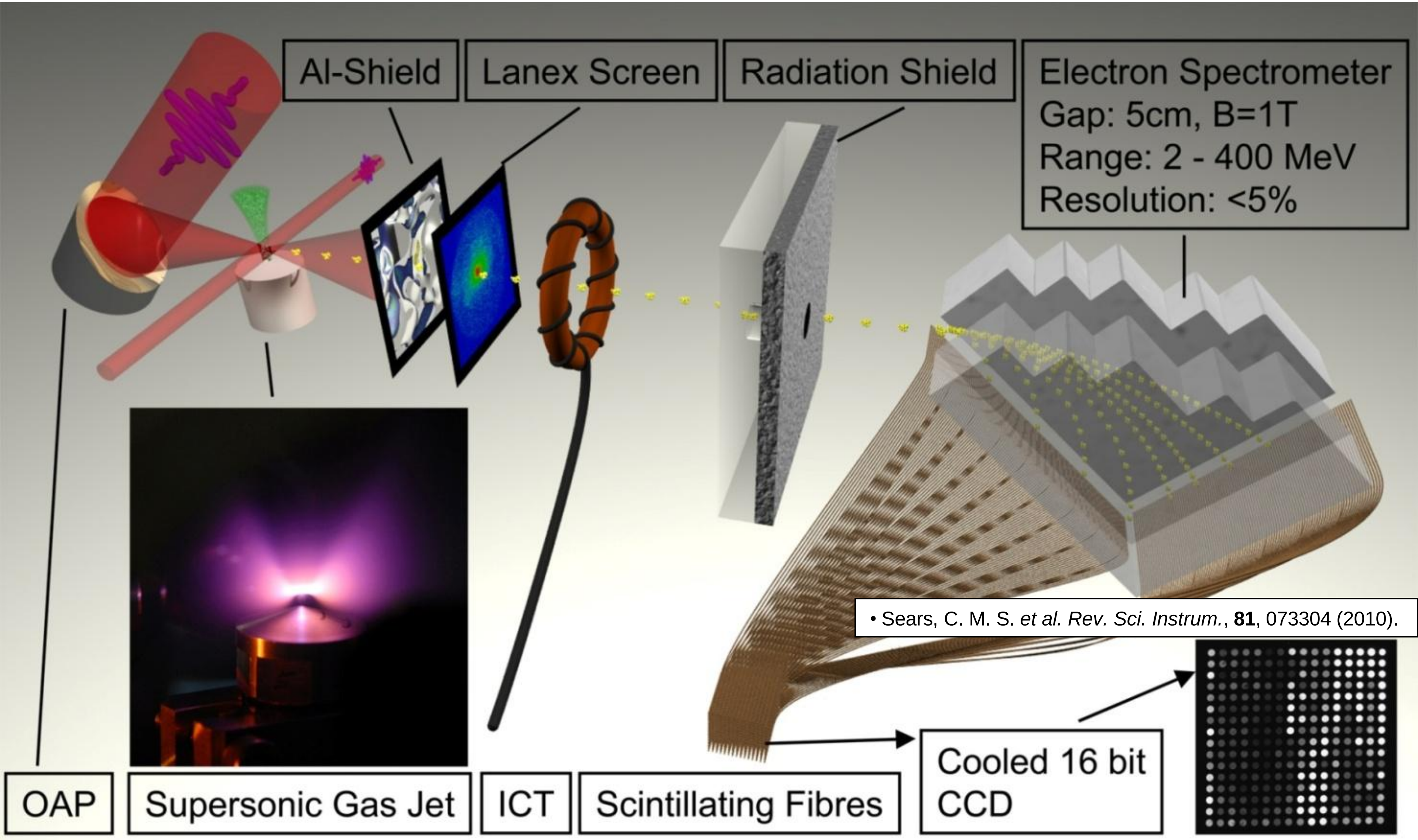
Electron characterization

- Laser-electron acceleration is evolving, but still large shot-to-shot fluctuation are present
  → **Single-shot** characterization techniques necessary

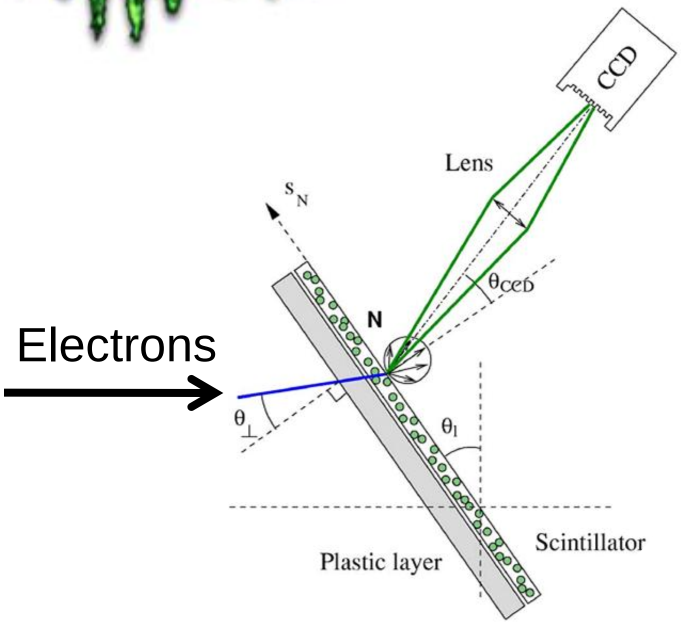
- Interesting parameters
  – Electron energy spectrum
  – Charge in electron bunch
  – Divergence and pointing

- Parameter range:
  – Charge: 0.1 – 100 pC
  – Energy: few MeV to 1 GeV

Typical electron acceleration setup



Scintillating screens



Item	Material	Density (g/cm^3)	Thickness (cm)
Laser shielding			
Aluminium shielding	Aluminium	2.7	0.0100
Kodak Lanex Fine screen			
Protective coating	Cellulose acetate1	1.32	0.0010
Plastic substrate	Poly(ethylene terephtalate)	1.38	0.0178
Scintillator	Gd_2O_2S+urethane binder	4.25	0.0084
Protective coating	Cellulose acetate	1.32	0.0005

• Glinec, Y. *et al. Rev. Sci. Instrum.*, **77**, 103301 (2006).

Plastic screens with a layer of powdered inorganic scintillator („Lanex“ screens)

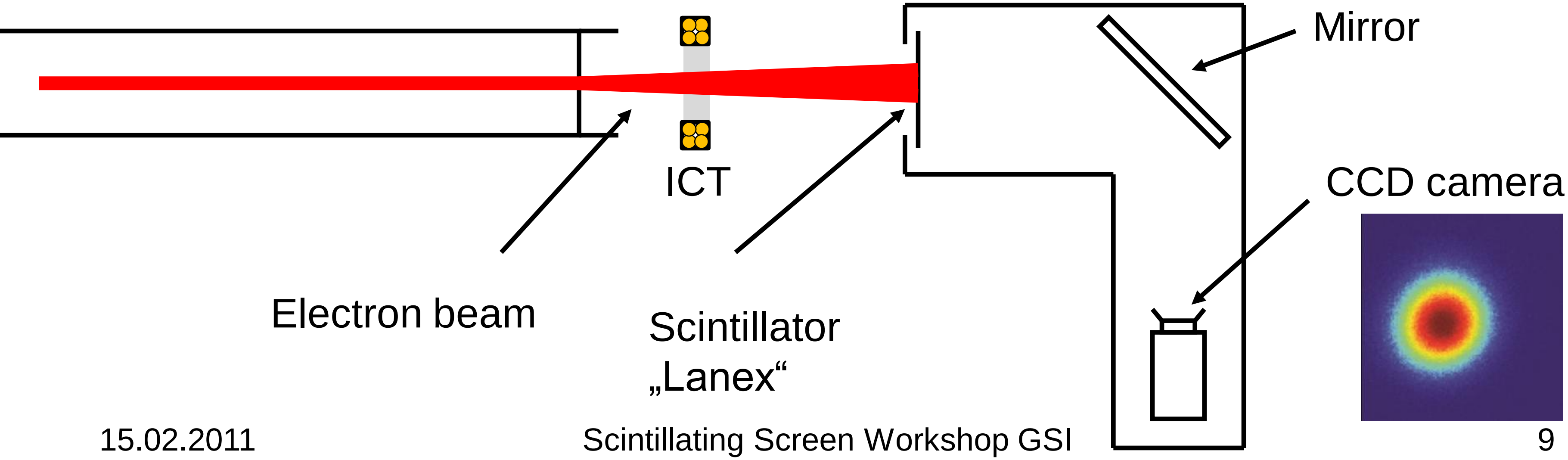
- Kodak
  - Lanex Regular
  - Lanex Fine
  - Biomax MS
  - Biomax TranScreen HE
  - Biomax TranScreen LE
- Cawo
  - OG 16
- Konica
  - KR
  - KF

Calibration of scintillating screens

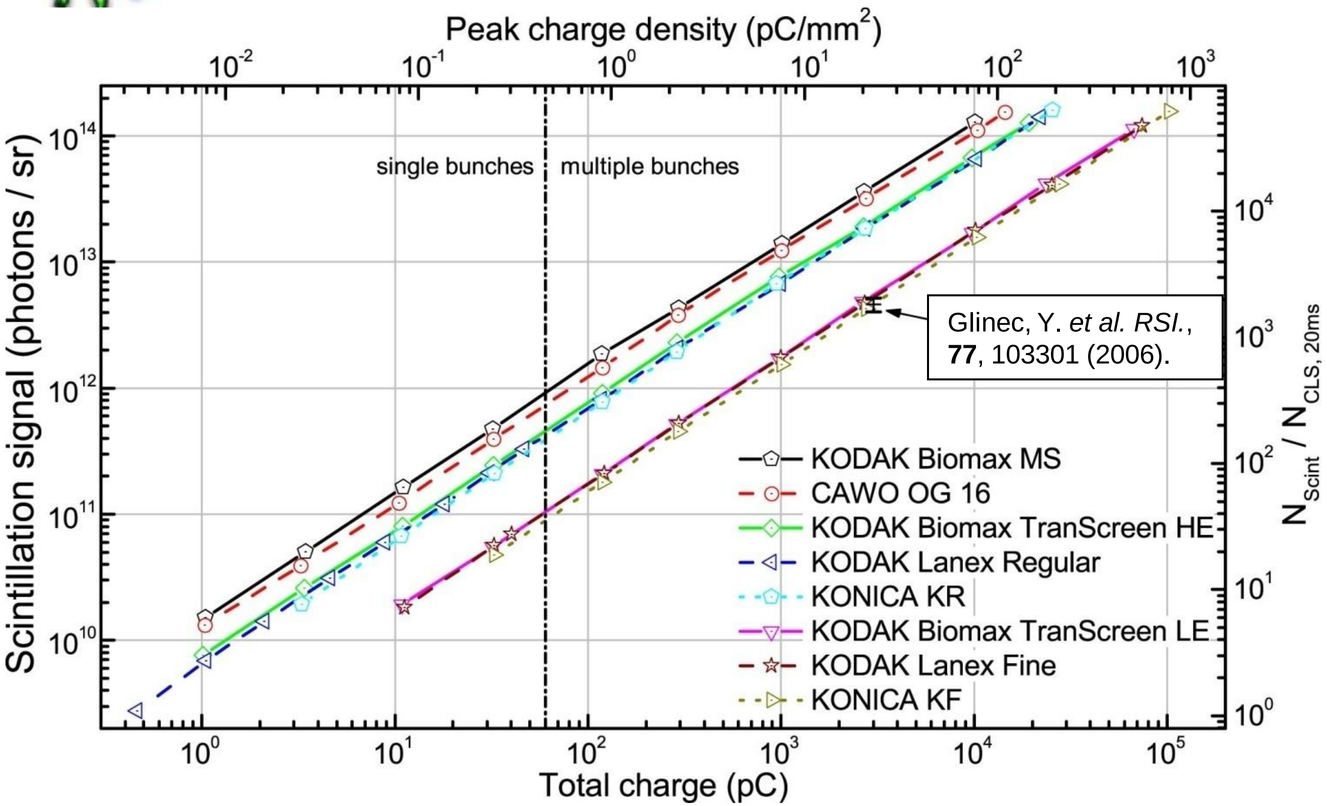
Measurements at ELBE linear accelerator in Dresden:

- Electron energy: 40 MeV
- Maximum charge per bunch: 50 pC
- Pulse duration: 2 ps
- Pulse spacing: 154 ns

Charge and number of bunches are variable.



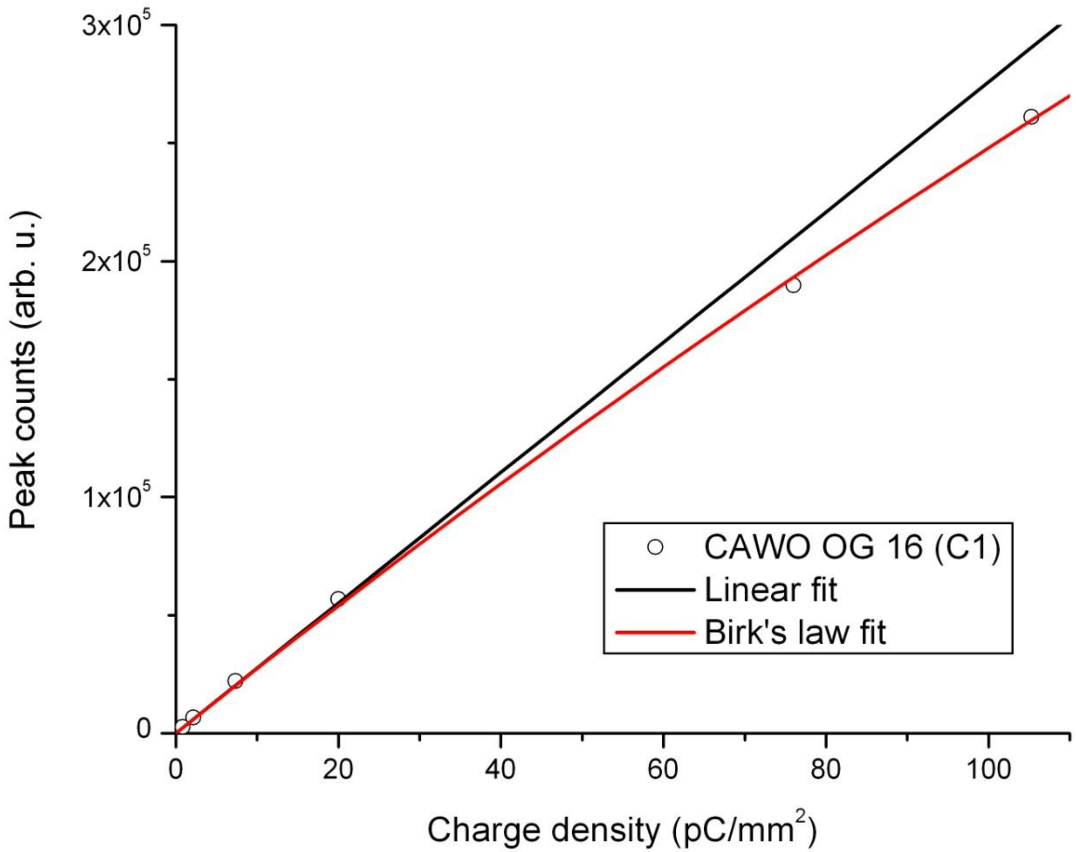
Calibration of scintillating screens



- Buck, A. *et al. Rev. Sci. Instrum.*, **81**, 033301 (2010).

- Linearity over more than four orders of magnitude measured
- Absolute calibration for each screen determined

Saturation?



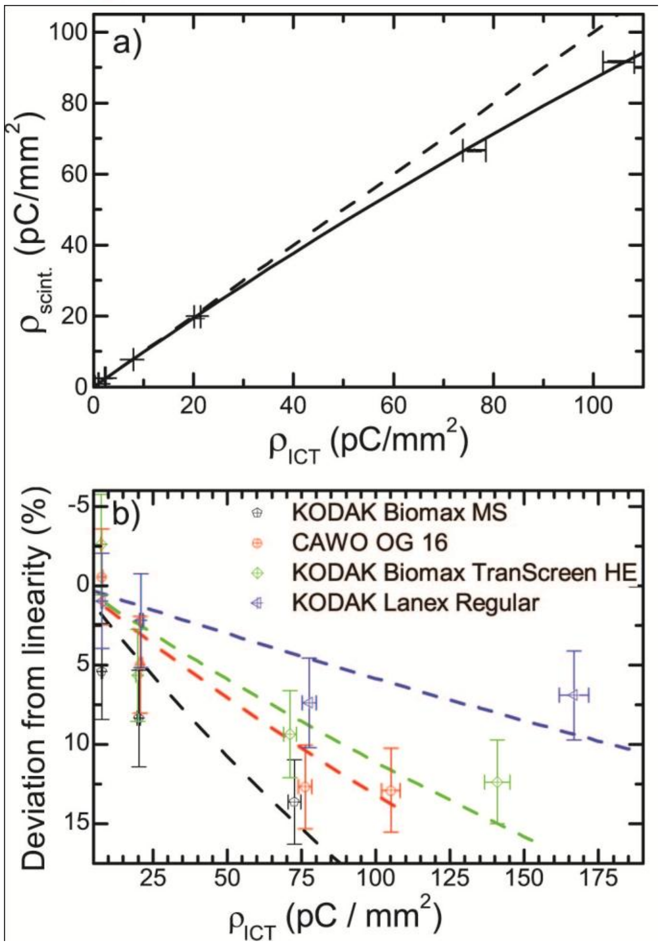
Birk‘s saturation law for scintillators:

$$Emission(\rho) = A \cdot \frac{\rho}{1 + B \cdot \rho}$$

ρ:	Charge density
A,B:	Fit parameter

• Buck, A. *et al. Rev. Sci. Instrum.*, **81**, 033301 (2010).

Saturation!

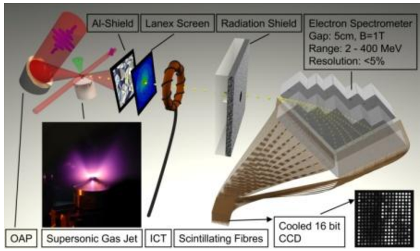


Screen	Absolute calibration (10^9 photons/sr/pC)	$N_{scint}/N_{CLS,20\ ms}/Q$ (pC^{-1})	ρ_{sat} (see Sec. III C) (pC/mm^2)
KODAK Biomax MS	14.8 ± 1.3	5.79 ± 0.26	21.8 ± 5.0
CAWO OG 16	12.4 ± 1.1	4.86 ± 0.21	32.9 ± 6.6
KODAK Biomax Transcreen HE	7.85 ± 0.67	3.02 ± 0.13	47 ± 10
KODAK Lanex Regular	6.95 ± 0.60	2.72 ± 0.12	66 ± 33
KONICA KR	6.58 ± 0.56	2.58 ± 0.11	>100
KODAK Biomax Transcreen LE	1.79 ± 0.15	0.700 ± 0.031	>100
KODAK Lanex Fine	1.75 ± 0.15	0.686 ± 0.030	>100
KONICA KF	1.54 ± 0.13	0.602 ± 0.027	>100

- Small deviation from the linear behaviour measured Starting around 20 pC/mm^2
- Nonlinearity can be corrected
- Screens are linear in the regime currently available

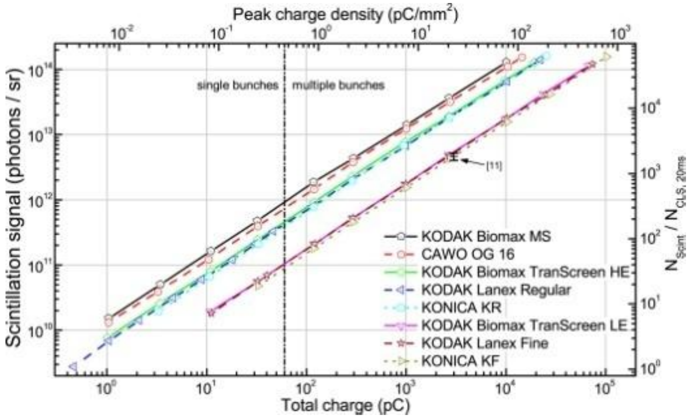
• Buck, A. *et al. Rev. Sci. Instrum.*, **81**, 033301 (2010).

Summary

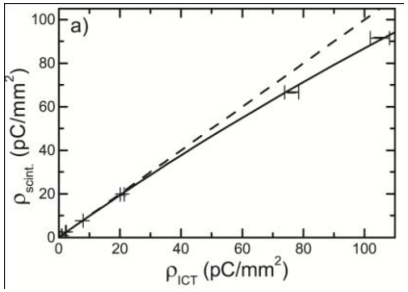


- Inorganic scintillating screens are commonly used in laser-driven electron acceleration experiments

- The screens have been absolutely calibrated at a linear accelerator (ELBE, Dresden-Rossendorf)



- Linear behaviour over several orders of magnitude confirmed



- Nonlinear effects found for high charges

Energy dependence of scintillators

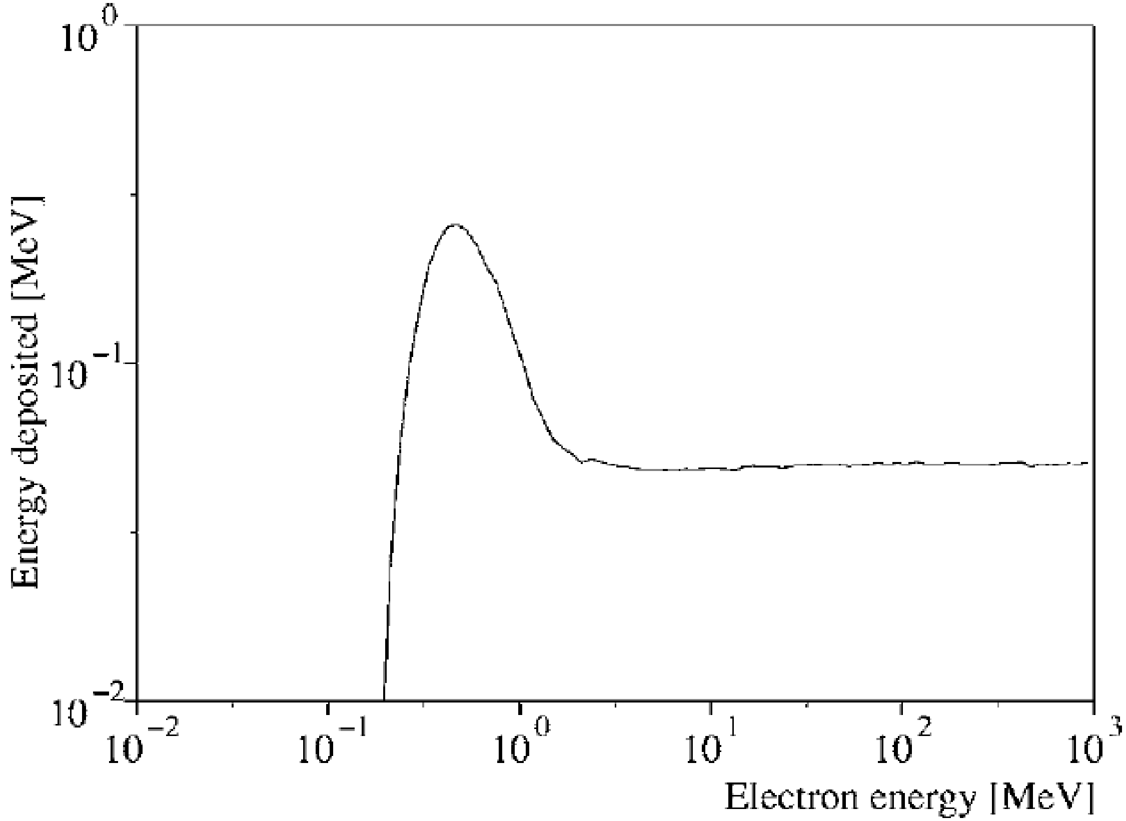


FIG. 1. Energy deposited in the scintillator layer of Lanex Kodak Fine screen for different electron energies.

Y. Glinec, et al. RSI **77**, 103301 (2006)

Resolution of the different screens