Peak Current Performances from

Microscopic Tips

Paul Scherrer Institut

Low Emittance Gun Project

Goals :

- **Electron Beam Emittance < 5.10^{-8} m.rad**
- **Capable of driving an X-FEL Linac (Peak Current / Stability / …)**

	Goals
Minimum Peak Current (A)	5
Normalized Slice Emittance (m.rad)	5.10^{-8}
Pulse Duration, full width (ps)	40
Repetition rate (Hz)	10
Gun Energy (MeV)	4

http://leg.web.psi.ch/

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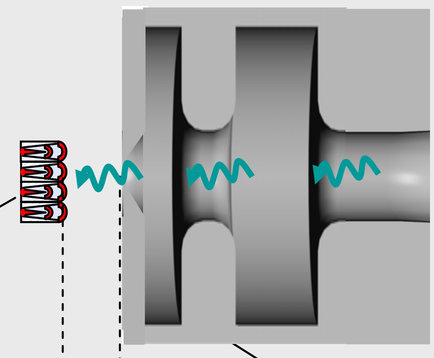
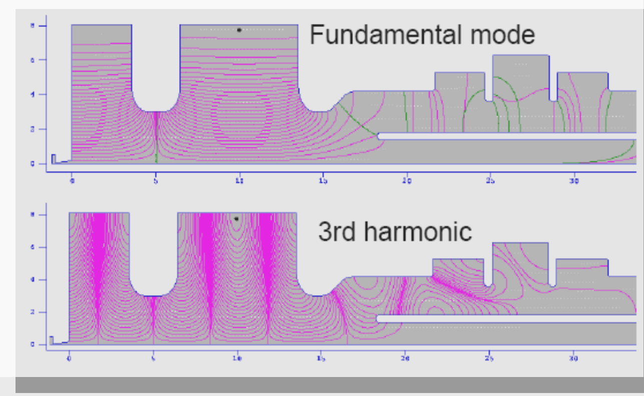
Low Emittance Gun Project





1. Electron Source

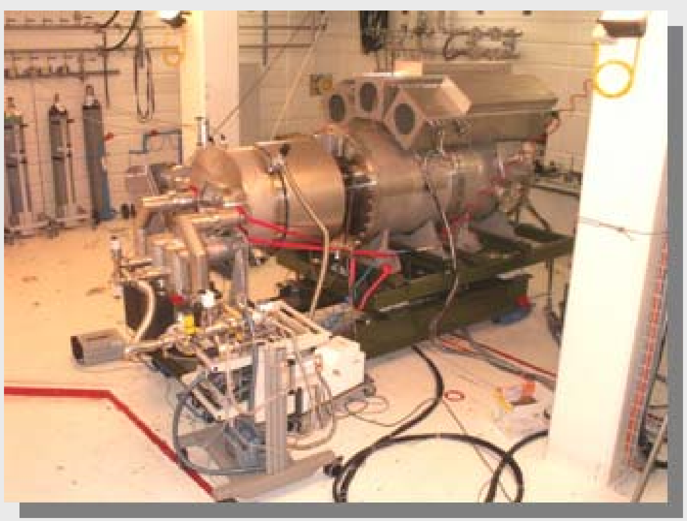
-Field Emitter Arrays
-Single Tip
-Laser Assisted

2. Diode Acceleration

- Gap : 4mm
- Pulser: 500 kV; 250ns
- High Gradient: 250 MV/m

3. RF Acceleration

- Two frequency Cavity Design
- 1.5 GHz + 4.5 GHz
- Flat Top wave



Thermal Emittance

Ultimate limit in Accelerators: Intrinsic emittance of the Electron Source

$$\varepsilon_{n,rms} = \frac{r}{2}\sqrt{\frac{2E_{kin}}{3mc^2}}$$

Size of the produced Electron Beam

Thermal Agitation
(r.m.s transverse momentum)
of emitted electrons

Field Emission: High Current Density (10^{12}A/m^2)

Energy Spread (4kT < 0.3eV)

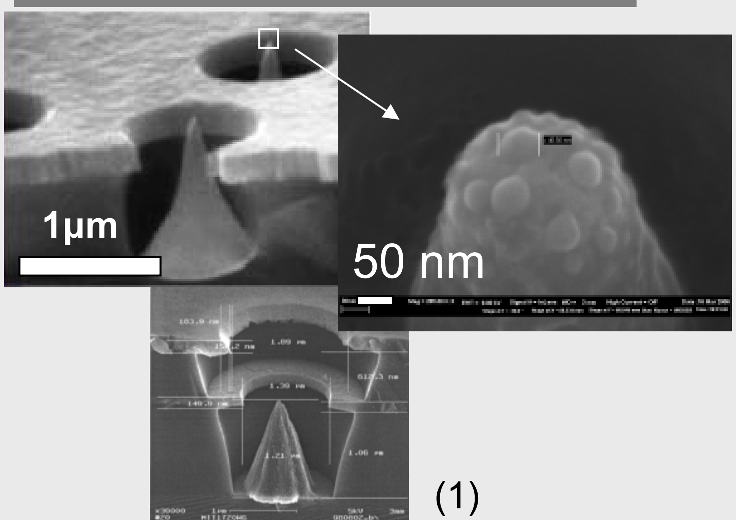
Uniform Beam over r
+ Maxwell Distribution

Electron Source - Field Emitter Arrays or Single Tip

Field Emission requires High Field: $F_{Surface} > 3$ GV / m

Field Enhancement with Tip Effect

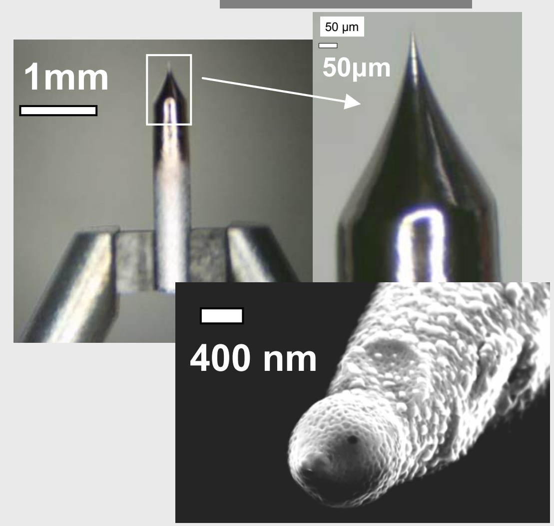
Field Emitter Arrays (FEAs)



(1)

Microelectronic Techniques

Single Tip



Etched Wire (ZrC; HfC; …)

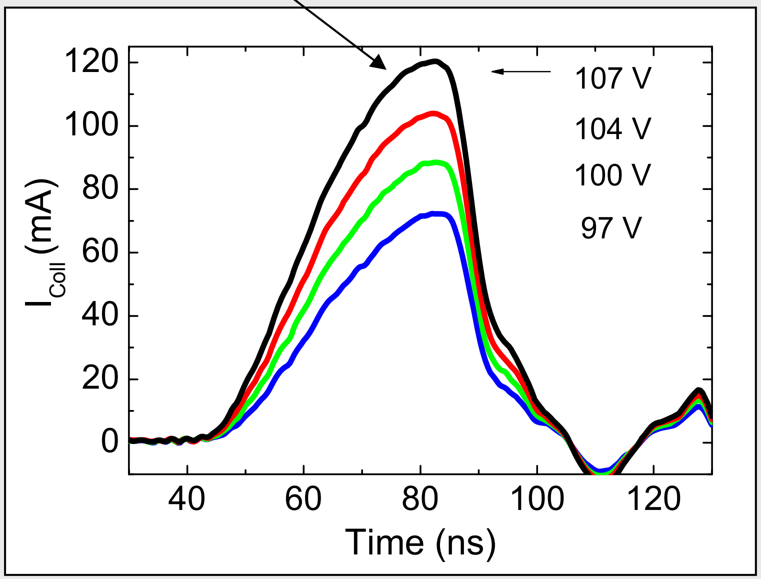
[1] *Courtesy of C. Spindt and A. Akinwande*

Field Emitter Array (FEA)

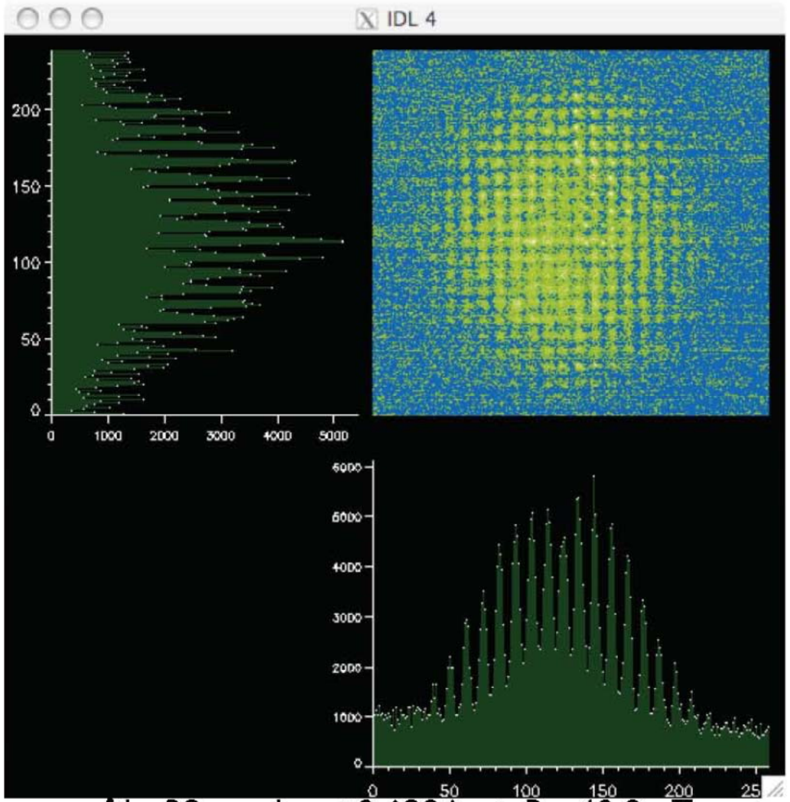
Tests on Commercial Field Emitter Arrays

120 mA (Pulses of 30ns at 10HZ)

(Commercial Device)

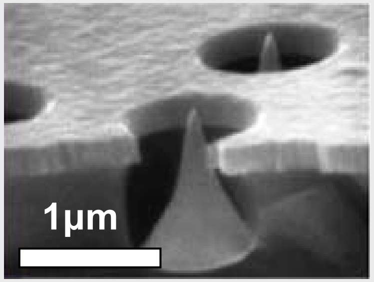


40kV, Q=56pC



ΔL=39mm, I_{sol}=+0.698A → B_z=40.8mT

50000 Tips
Ø = 1 mm



Projected Emittance Single Gated FEA:
ε_n~ 2.10^{-6} m.rad at 40 keV

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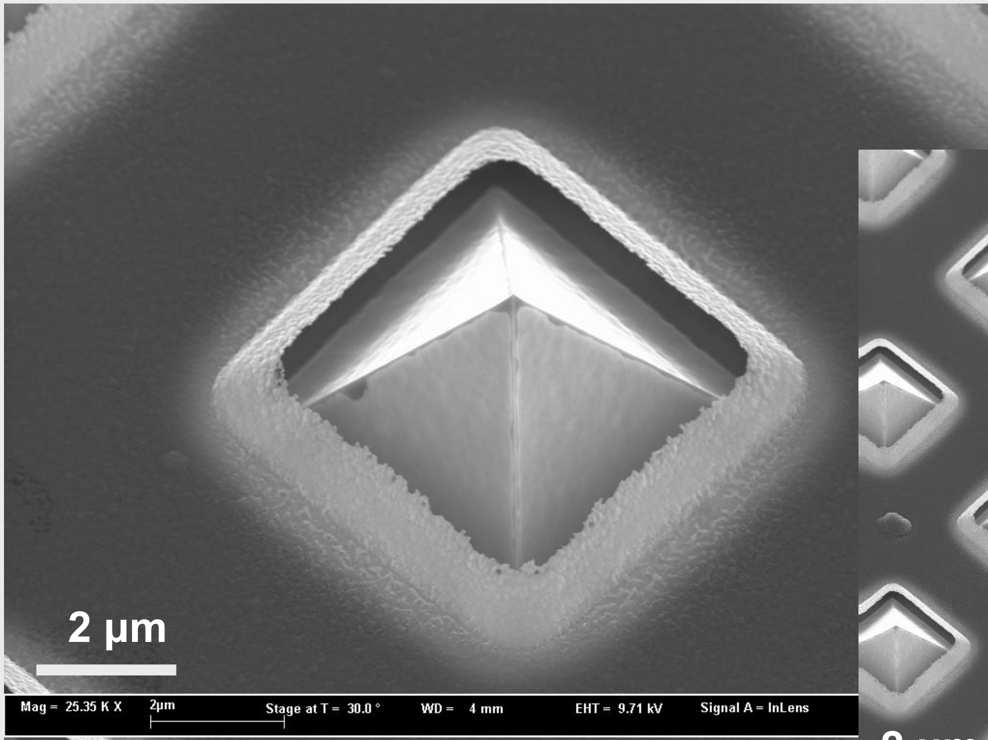
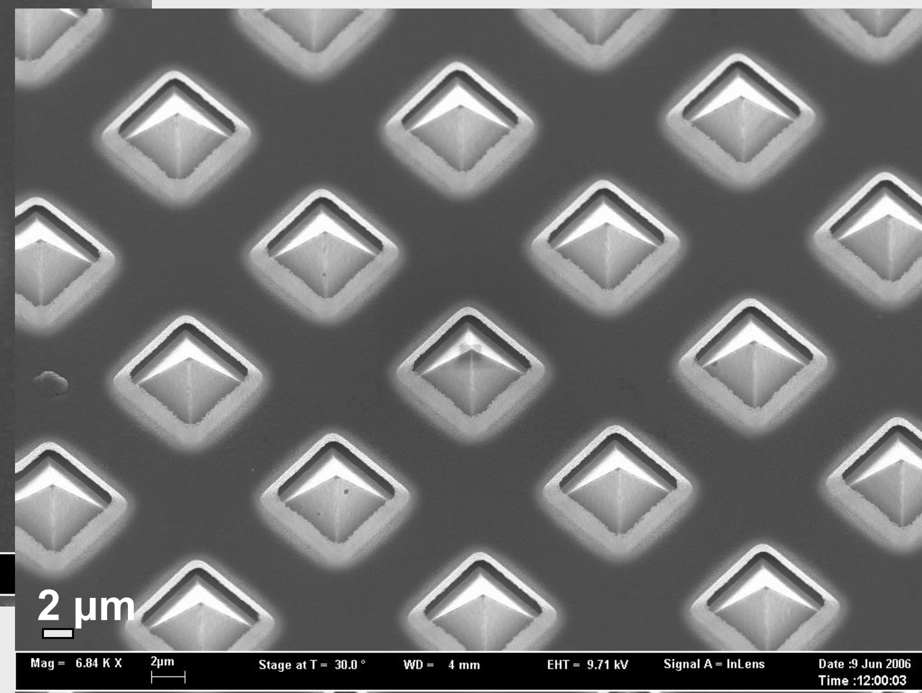
Field Emitter Arrays Fabrication at PSI



Pyramid Shape



- Mo Tips (Field Enhancement Factor: <β> ~ 90)
- Metallic wafer

Single Tip

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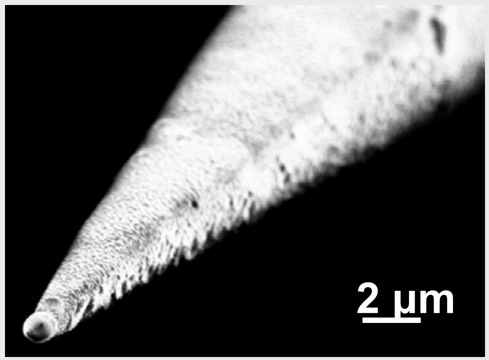
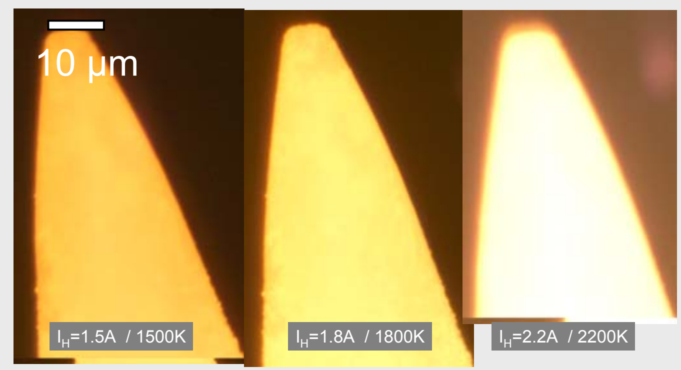
Single Tip Electron Source



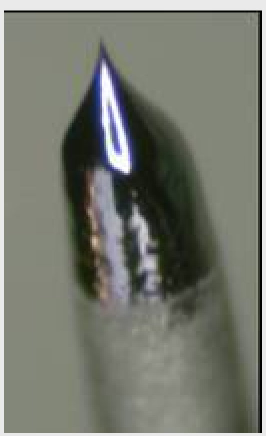
ZrC robust, Φ_{ZrC} ~ 3.5 eV

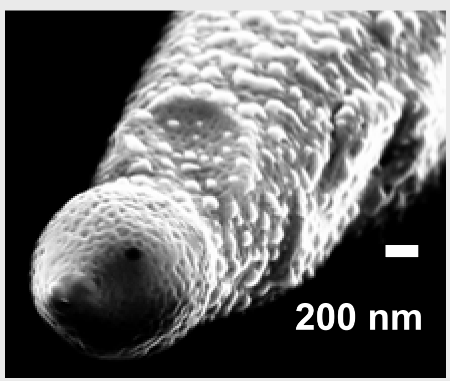
Possibility of Faceting the Tip

r_{apex} ~ 1 to 5 µm



1 mm

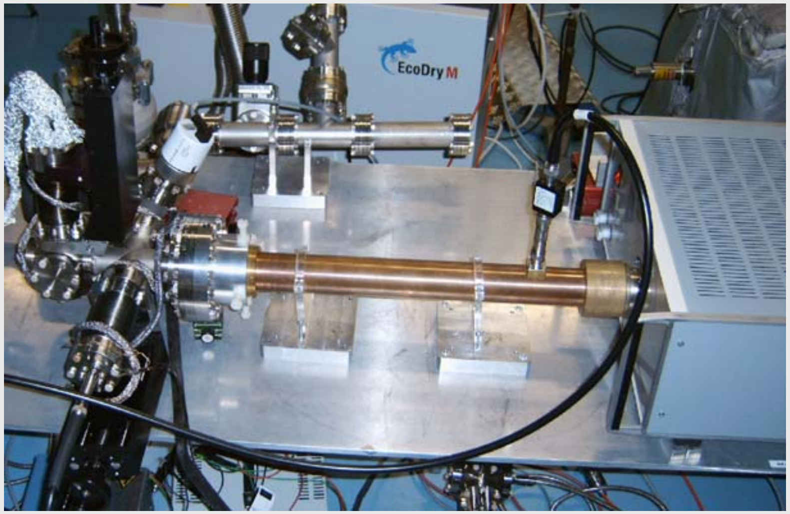


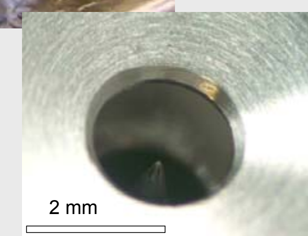


Required Operating Voltage

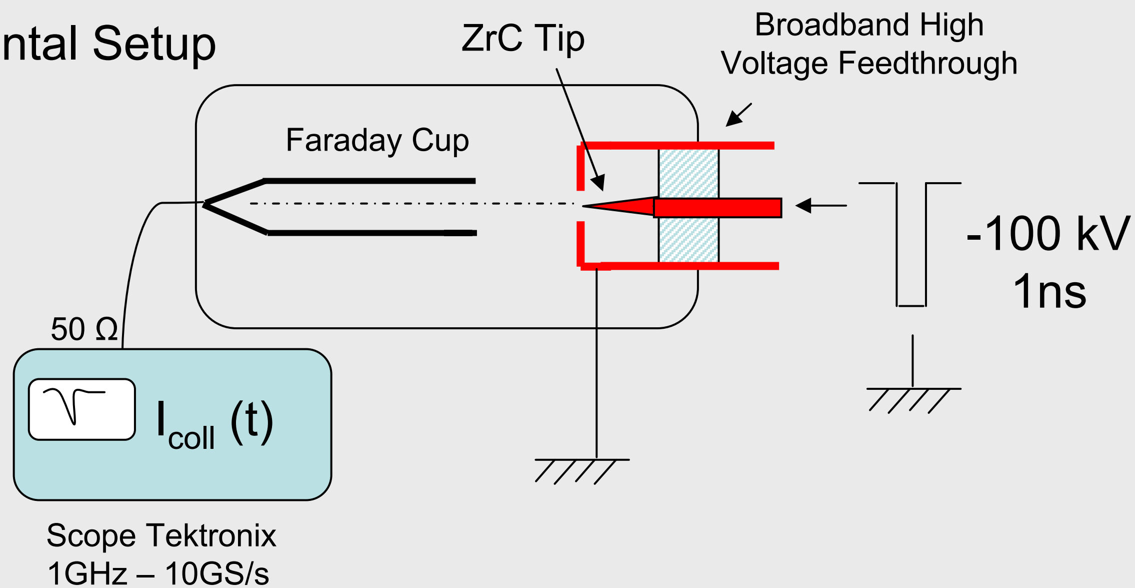
V_{Tip} > 10 kV

Single Tip ZrC performances

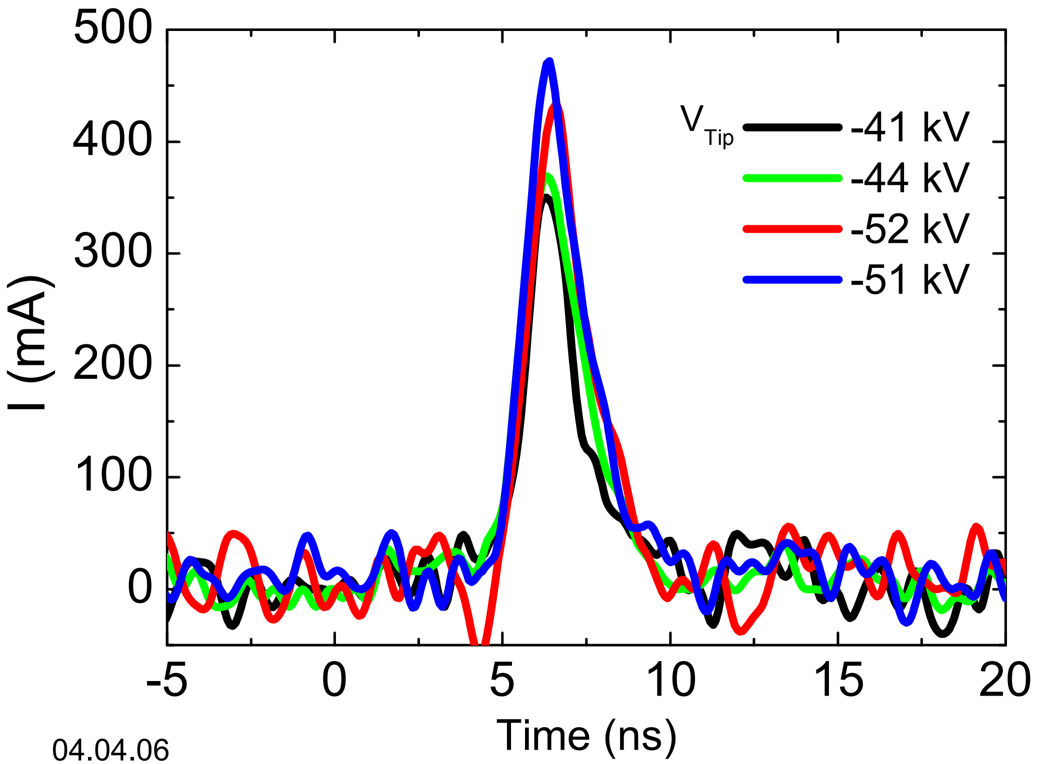




Experimental Setup

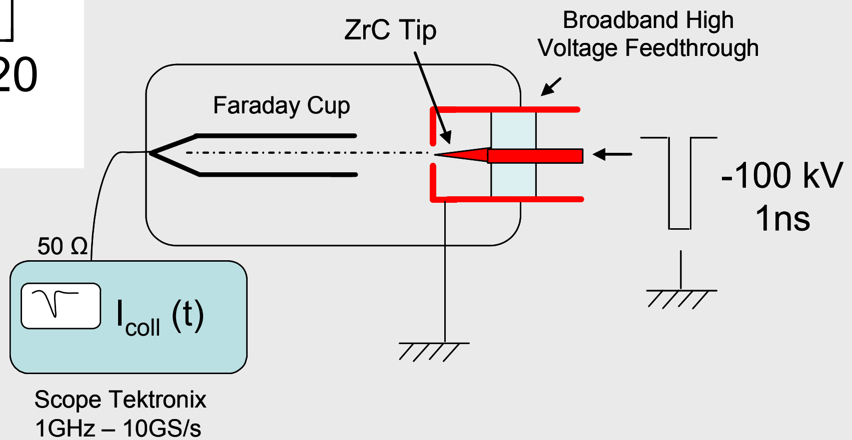


High Current Pulses from a ZrC Tip

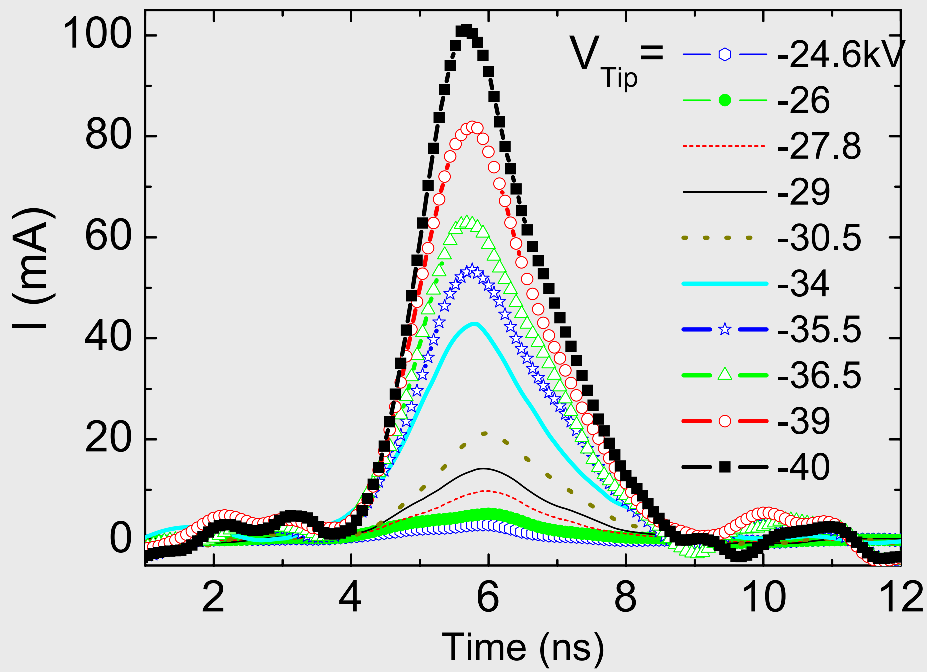


ZrC Tip
10^{-9} Torr

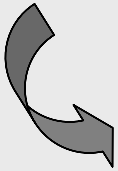
Peak Current
as high as **470 mA**



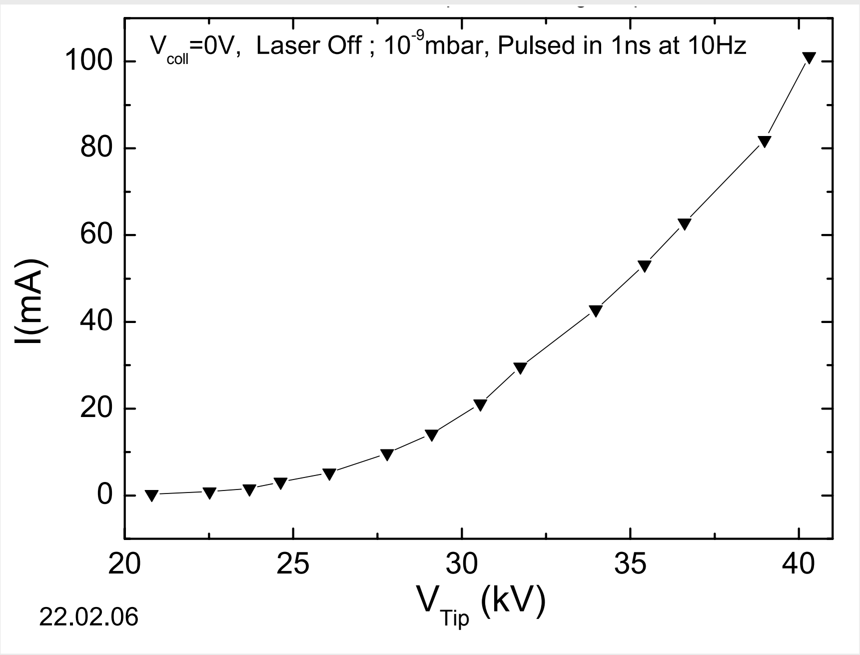
Field Emitted Current – Voltage Characteristic



Fowler – Nordheim Dependence



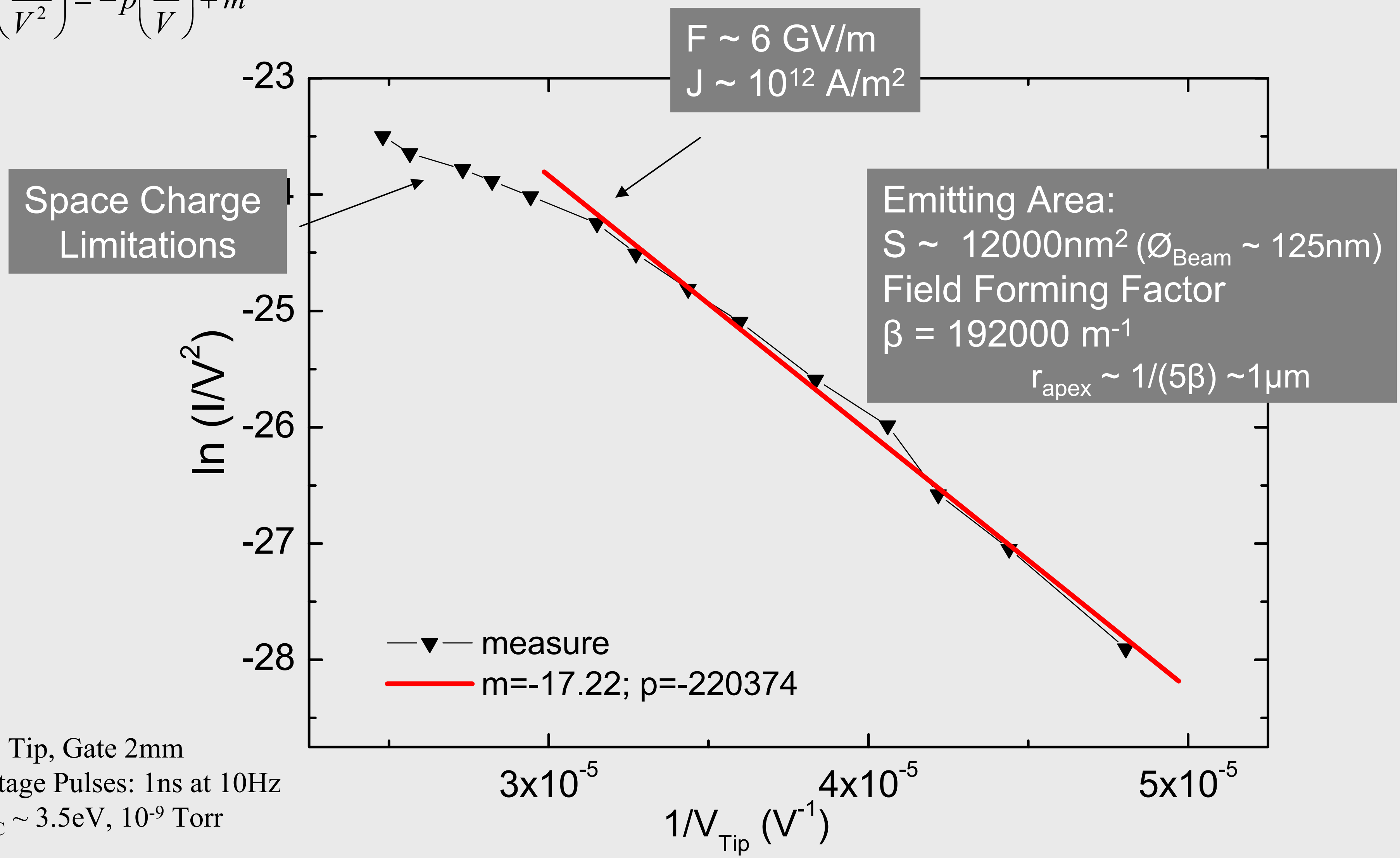
Field Emission Regime



ZrC Tip, Gate ø~2mm
Voltage Pulses: 1ns at 10Hz
Φ_{ZrC} ~ 3.5eV, 10^{-9} Torr

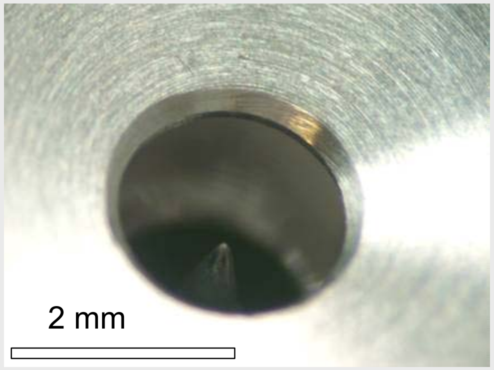
Fowler – Nordheim Analysis

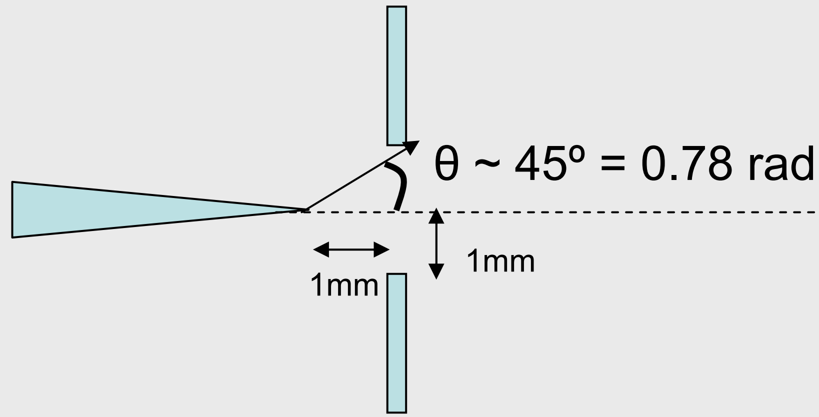
$$\ln\left(\frac{I}{V^2}\right) = -p\left(\frac{1}{V}\right) + m$$



ZrC Tip, Gate 2mm
Voltage Pulses: 1ns at 10Hz
Φ_{ZrC} ~ 3.5eV, 10^{-9} Torr

Rough estimation of the Emittance from a ZrC Tip





Measure 1

$S \sim 12000 nm^2$

$\varnothing_{Beam} \sim 125nm$

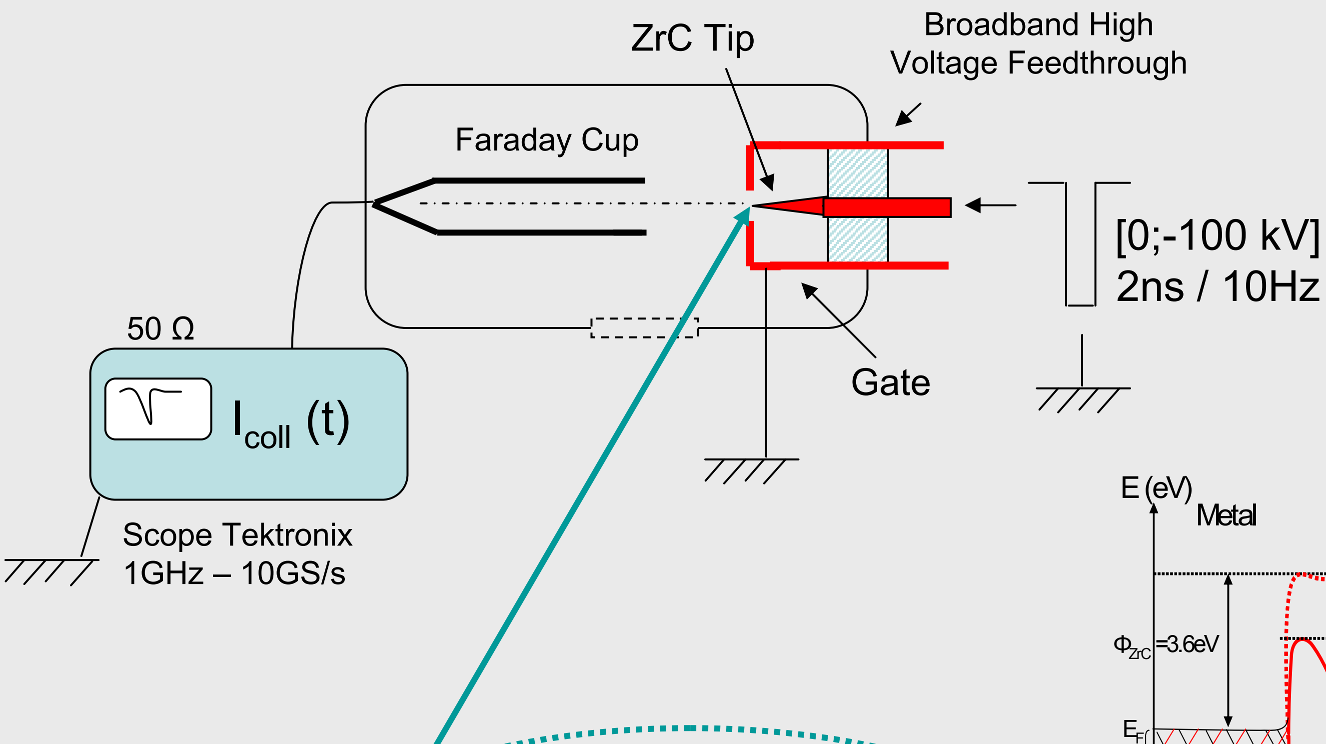
$\beta = 192000\ m^{-1}$

$r_{apex} \sim 1/(5\beta) \sim 1\mu m$

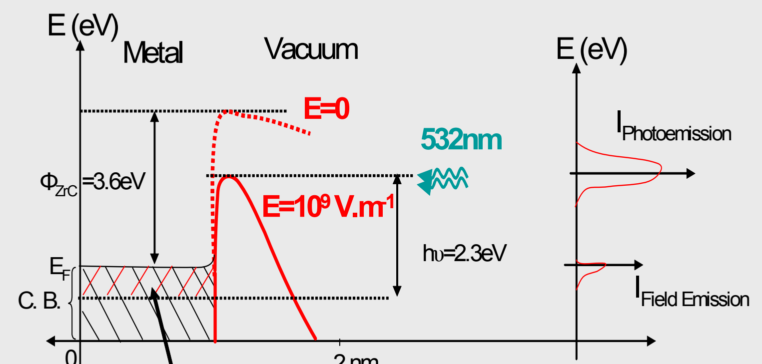
$\varepsilon_n \sim r_{beam}.\theta \sim 62$ nm*0.78 rad ~ **5.10^{-8} m.rad**

$$B_{Max} = \frac{I_{Max}}{(2\pi)^2 \varepsilon_n^2} \sim 10^{12}\ A.m^{-2}.rad^{-2}$$

Laser Assisted Field Emission (*)



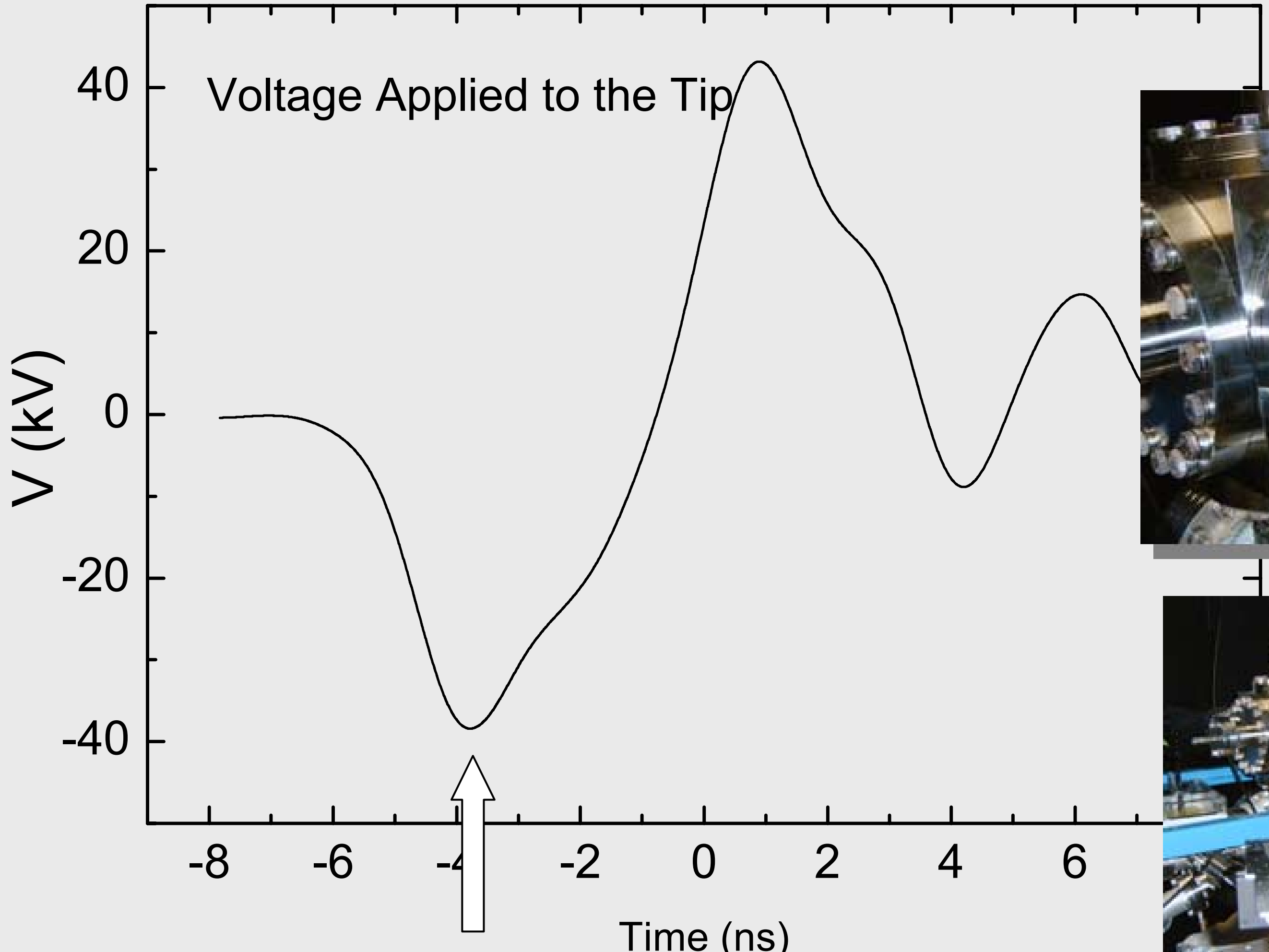
Picoseconds Laser Pulses
< 40µJ; 30ps Full Width;
10 Hz; 532nm

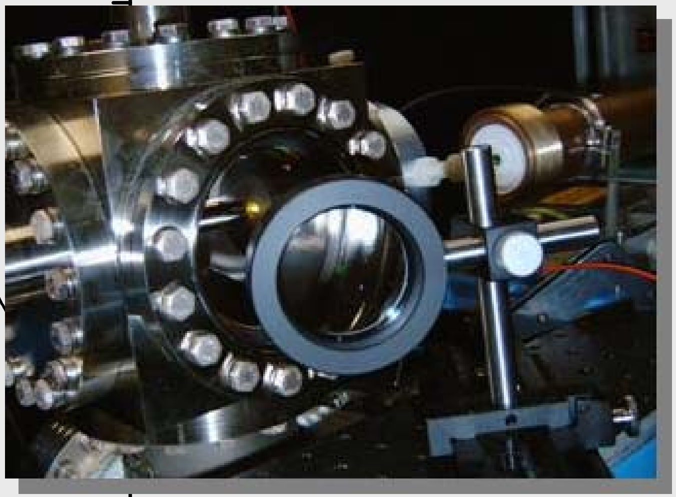


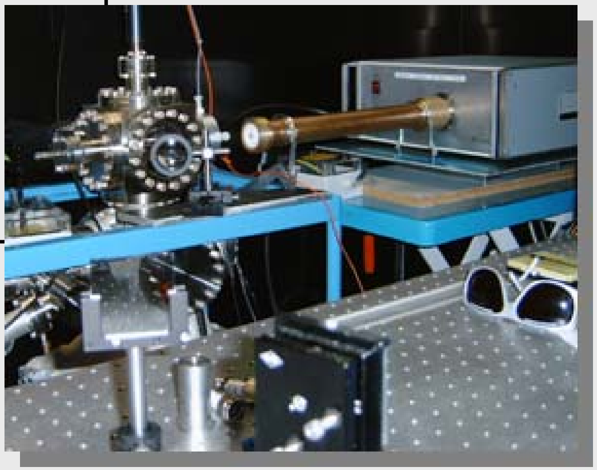
Energy range from where electrons can be directly photo-emitted !

* Ref: C. H. Garcia *et al.*, Nucl. Instr. and Meth. A **483,** 273-276 (2002).

Electric Pulses + Laser Pulses



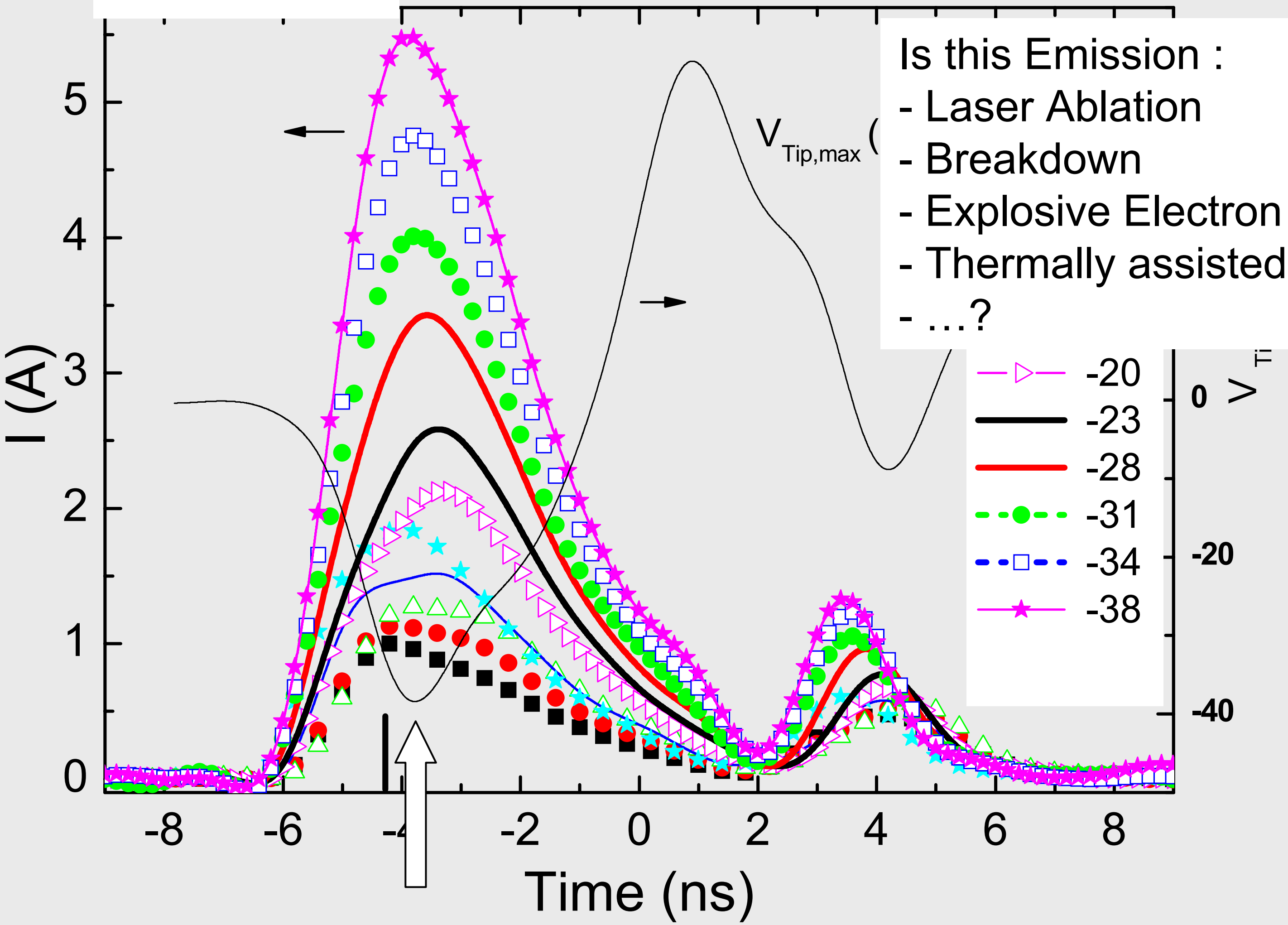




Laser Pulse: 532nm; 20µJ; 30ps; 10Hz;
P_{Laser}=0.7 MW; < 7.10^{9} W/cm2

Electric Pulses + Laser Pulses

above 5 A !



Is this Emission :
- Laser Ablation
- Breakdown
- Explosive Electron Emission
- Thermally assisted field emission
- …?

Laser Pulse: 532nm; 20µJ; 30ps; 10Hz;
P_{Laser}=0.7 MW; < 7.10^9 W/cm2

Perspectives …

FEA

- First tests of FEAs from PSI by Dec. 2006
- Laser Assisted FEAs

Single Tip

- Emittance Measurements
- Further tests of Laser Assisted Field Emission
- Implementation in 500kV Pulser