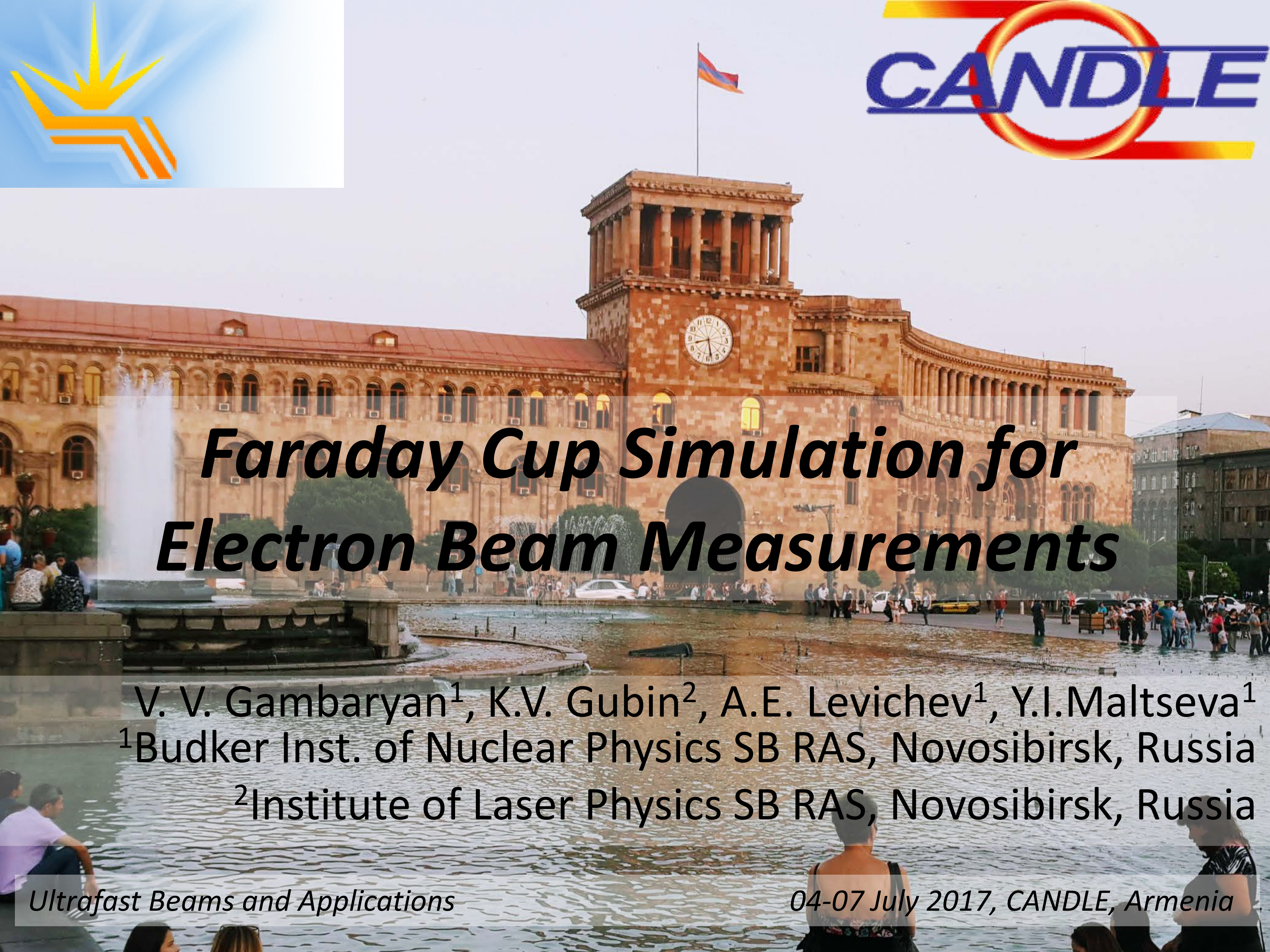


Faraday Cup Simulation for Electron Beam Measurements

V. V. Gambaryan[1], K.V. Gubin[2], A.E. Levichev[1], Y.I.Maltseva[1]
[1]Budker Inst. of Nuclear Physics SB RAS, Novosibirsk, Russia
[2]Institute of Laser Physics SB RAS, Novosibirsk, Russia

BINP

- Accelerators
- Detectors
- Plasma facilities
- Power and digital electronics
- Theoretical
- Cancer therapy

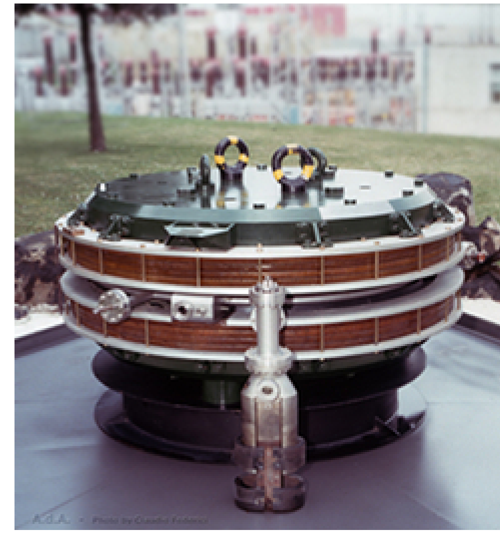
- Siberian Synchrotron Radiation Centre
- Workshop (0.25 km^2)

BINP Location

BINP. Accelerators

VEP1- 1963

BINP founded at 1958 by Gersh Itskovich Budker

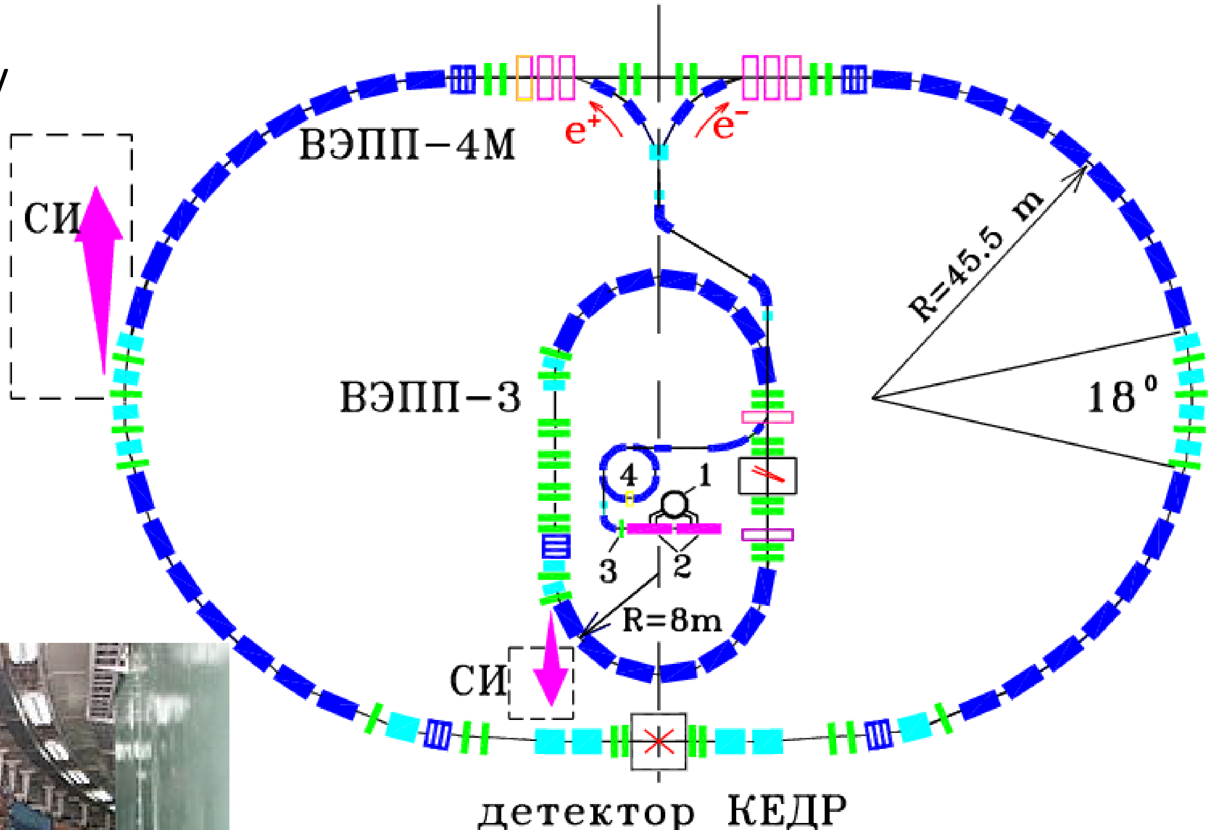


ADA – 1961
LNF in Frascati, Italy

Name	comiss. year	E, GeV	Brigtnes, 10^{30}, $cm^{-2}s^{-1}$	Circumfery , km
VEPP4M	1994	1,0	20	0,366
VEPP2000	2006	6	100	0,024
Super c-tau	?	2.5	100 000	0,780

BINP. Accelerators

10^{-7} beam energy measurements accuracy
J/psi and psi(2s) meson masses measured and included in 10-th best in the world



Инжектор:

1 – Гирокон (430 МГц)

2 – Линейный ускоритель (50 МэВ)

3 – электрон–позитронный конвертор

4 – синхротрон Б–4 (350 МэВ)

BINP. Accelerators

10^{-7} beam energy measurements accuracy

3 – электрон–позитронный конвертор
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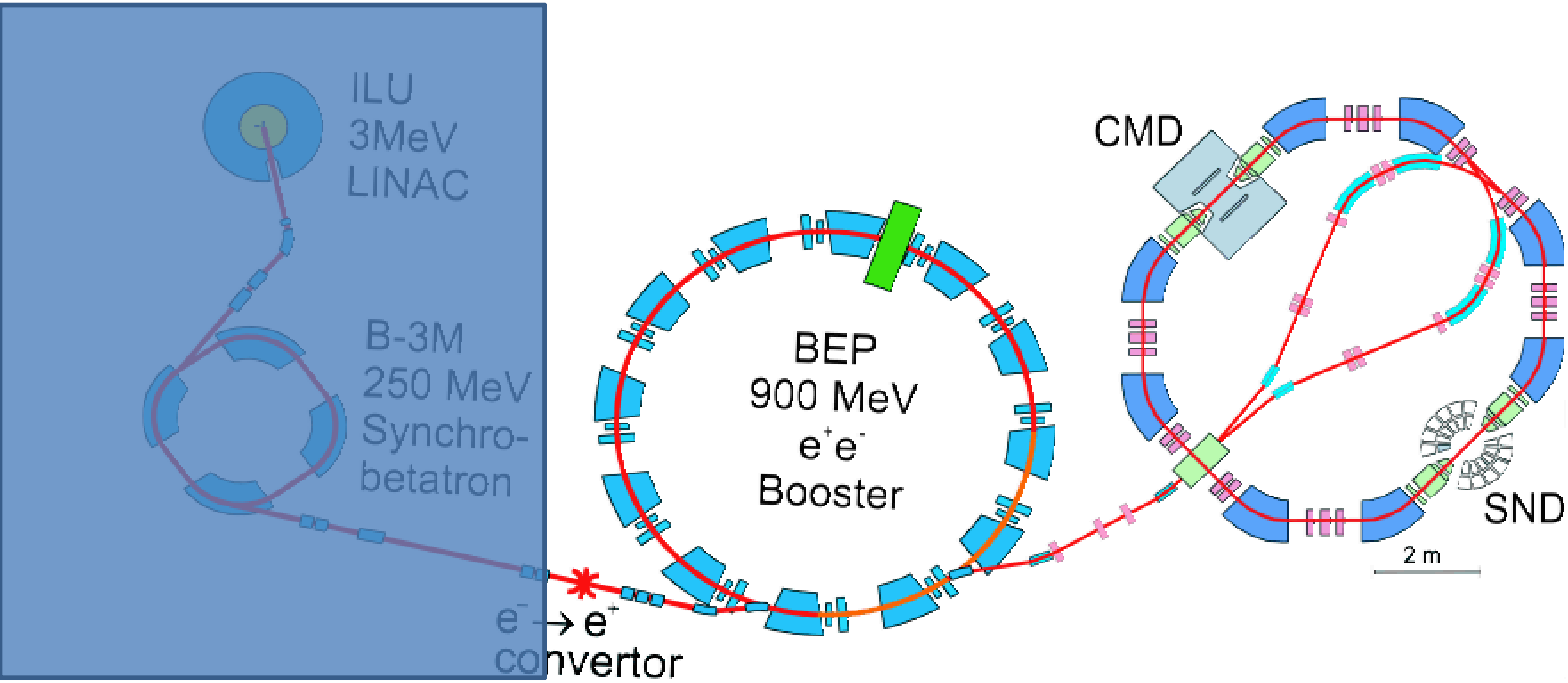
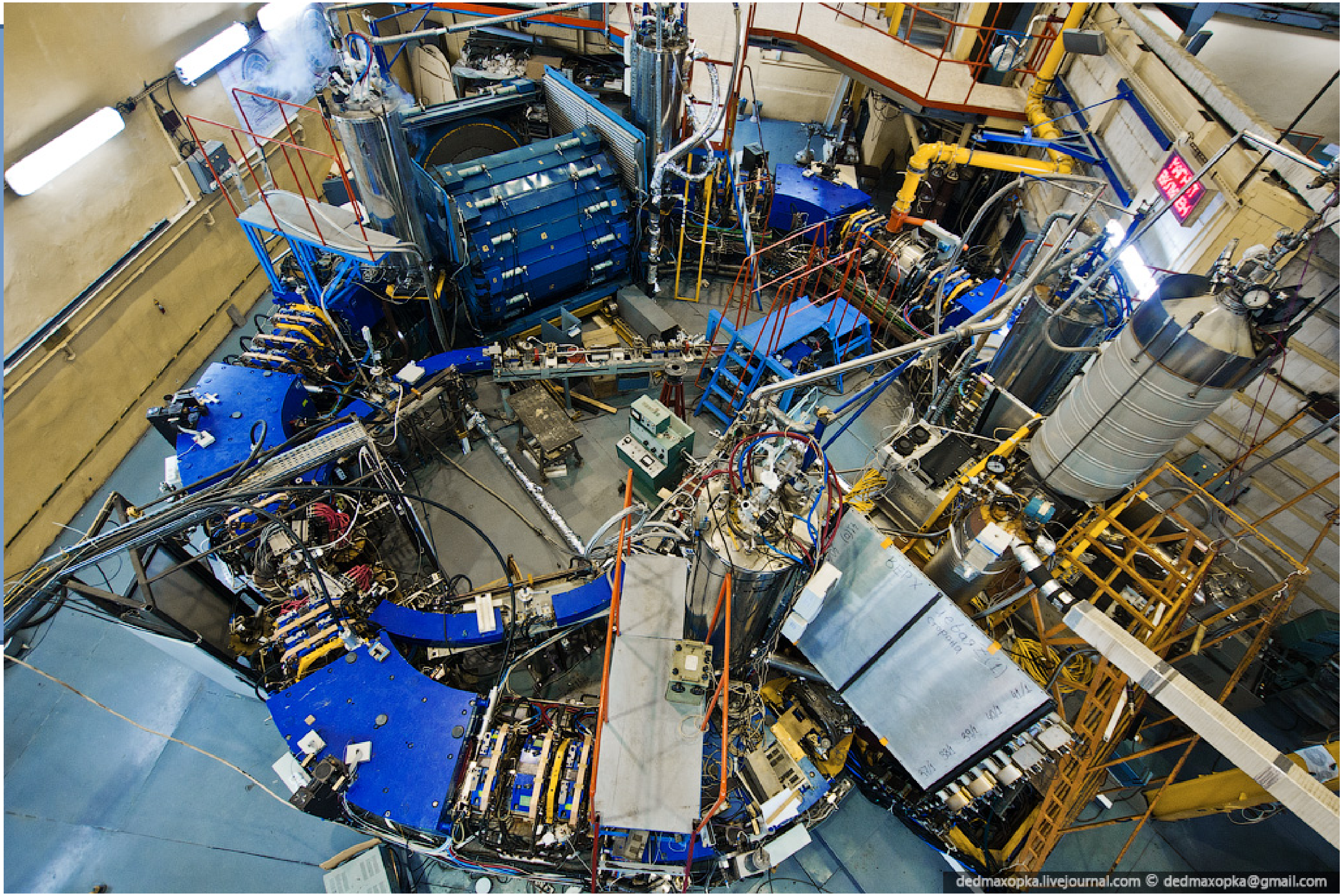
BINP. Accelerators



BINP. Accelerators



BINP. Accelerators

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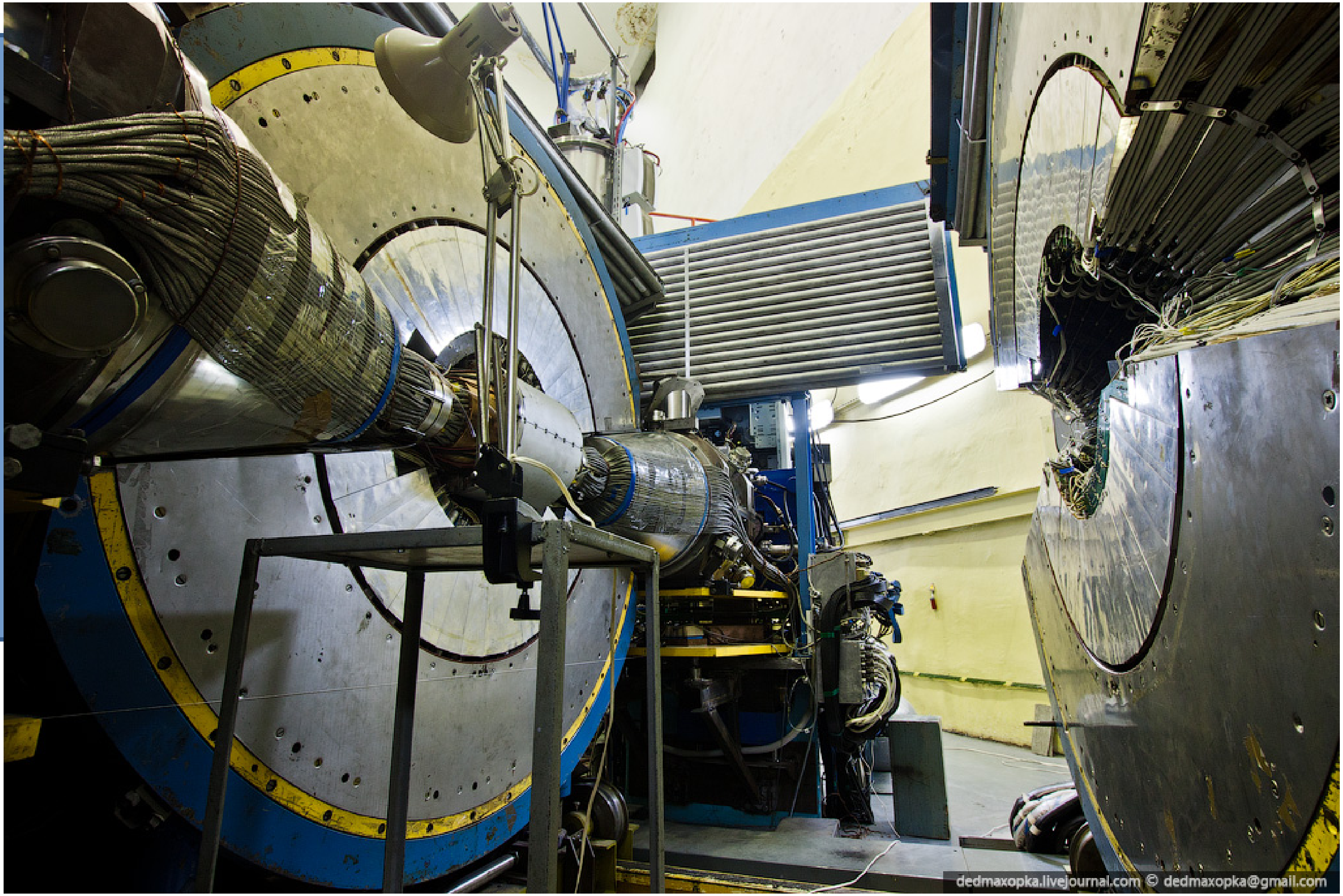
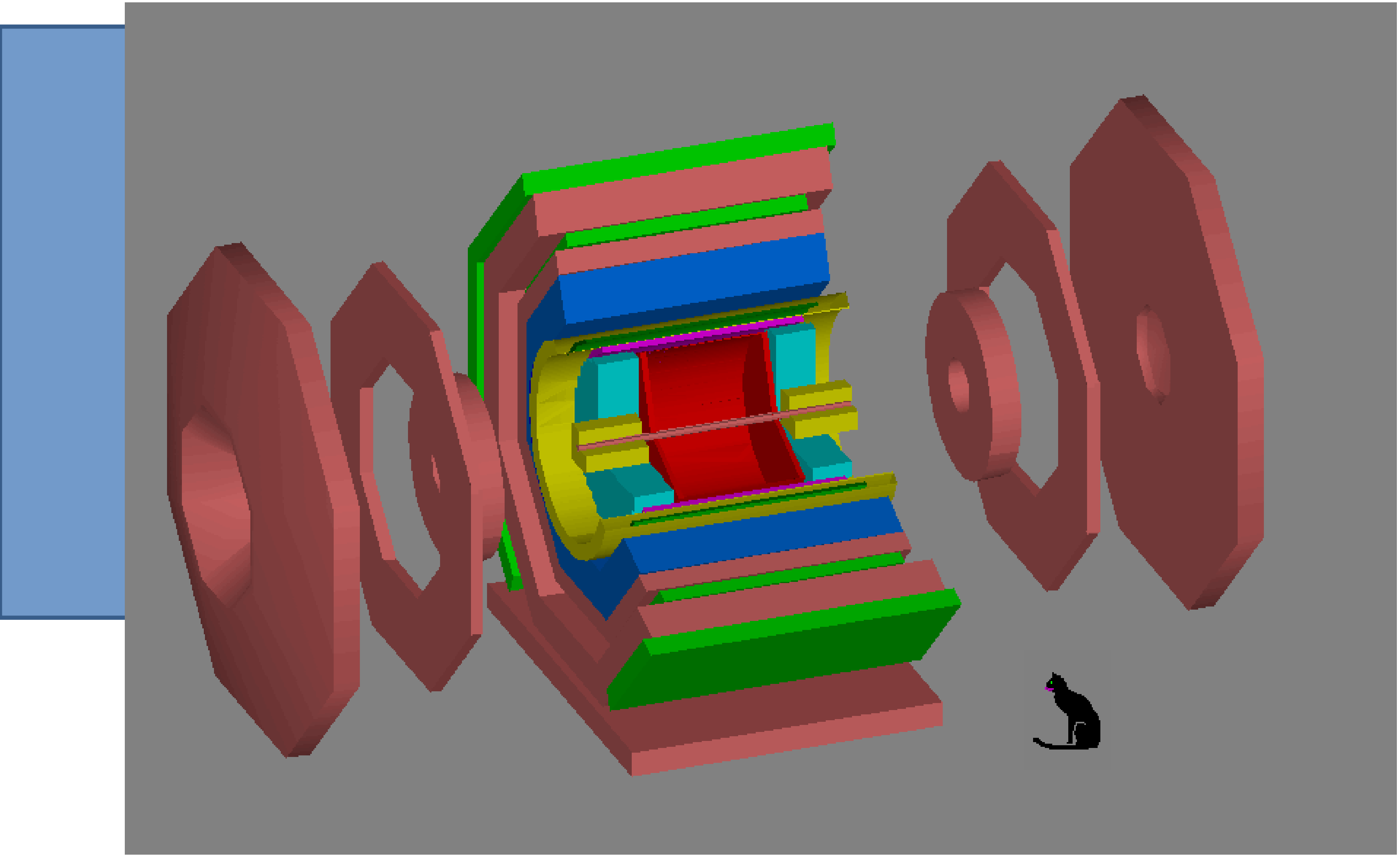
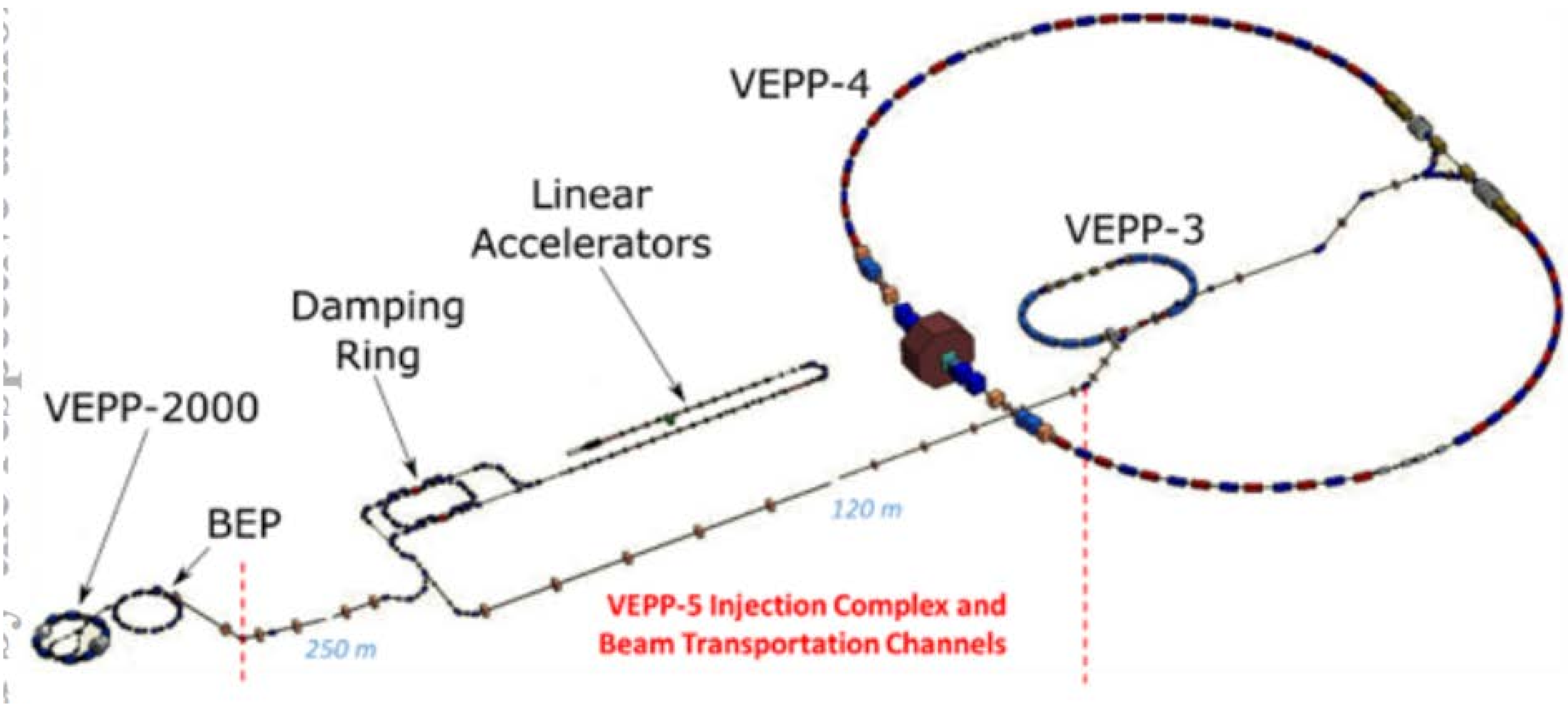


BINP. Accelerators



Injection complex



D.Berkaev, VEPP-5 INJECTION COMPLEX: TWO COLLIDERS OPERATION EXPERIENCE
http://accelconf.web.cern.ch/AccelConf/ipac2017/papers/wepik026.pdf

Injection complex

D.Be

http://accelconf.web.cern.ch/AccelConf/ipac2017/papers/wepik020.pdf

Injection complex

D.I
htt

D.B
http://accelconf.web.cern.ch/AccelConf/ipac2017/papers/wepik026.pdf

Outline

- Motivation
- Calculation FC capacity using simple theoretical model
- Calculation FC capacity with EM solver
- Calculation FC capacity with PIC solver
- FC radio frequency analyze
- Conclusion

Motivation

Laser-driven Compton light source in ILP SB RAS in collaboration with BINP SB RAS

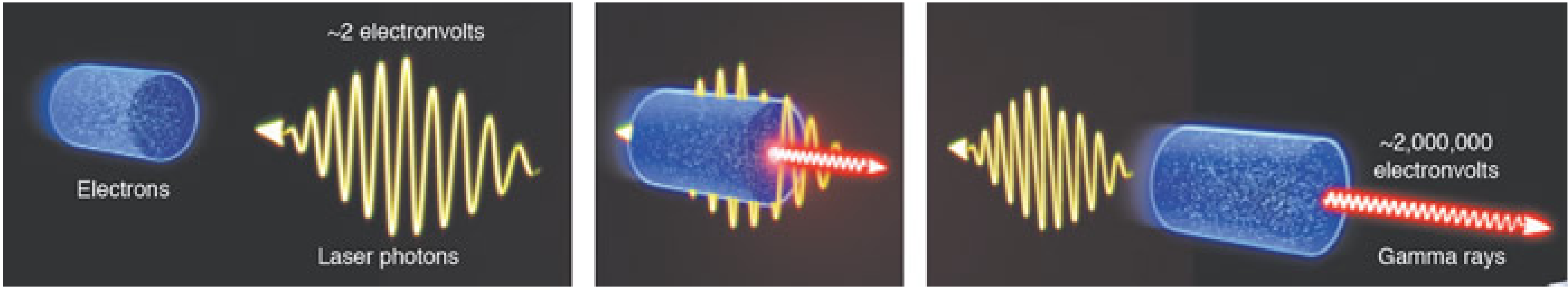
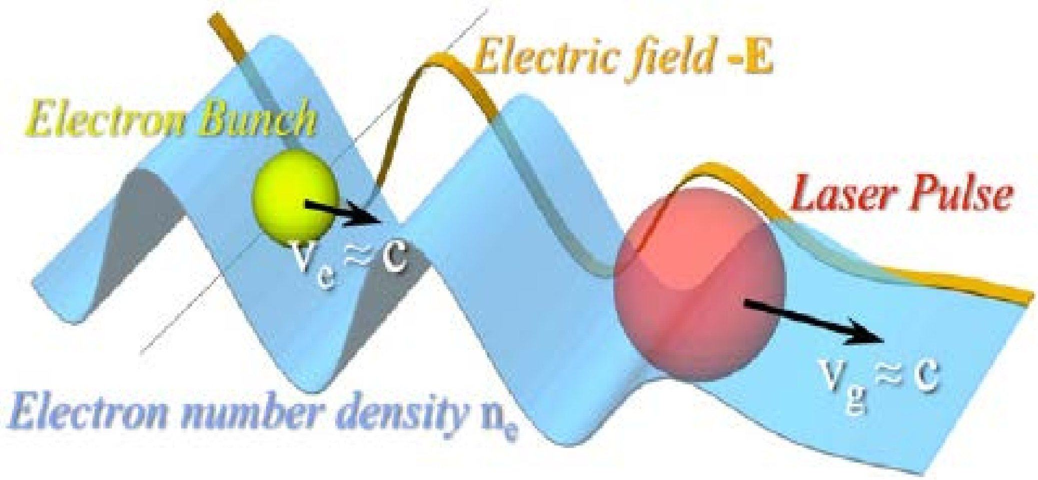


Figure source: Rendering by Kwei-Yu Chu (https://lasers.llnl.gov/science/photon-science/mega-ray)

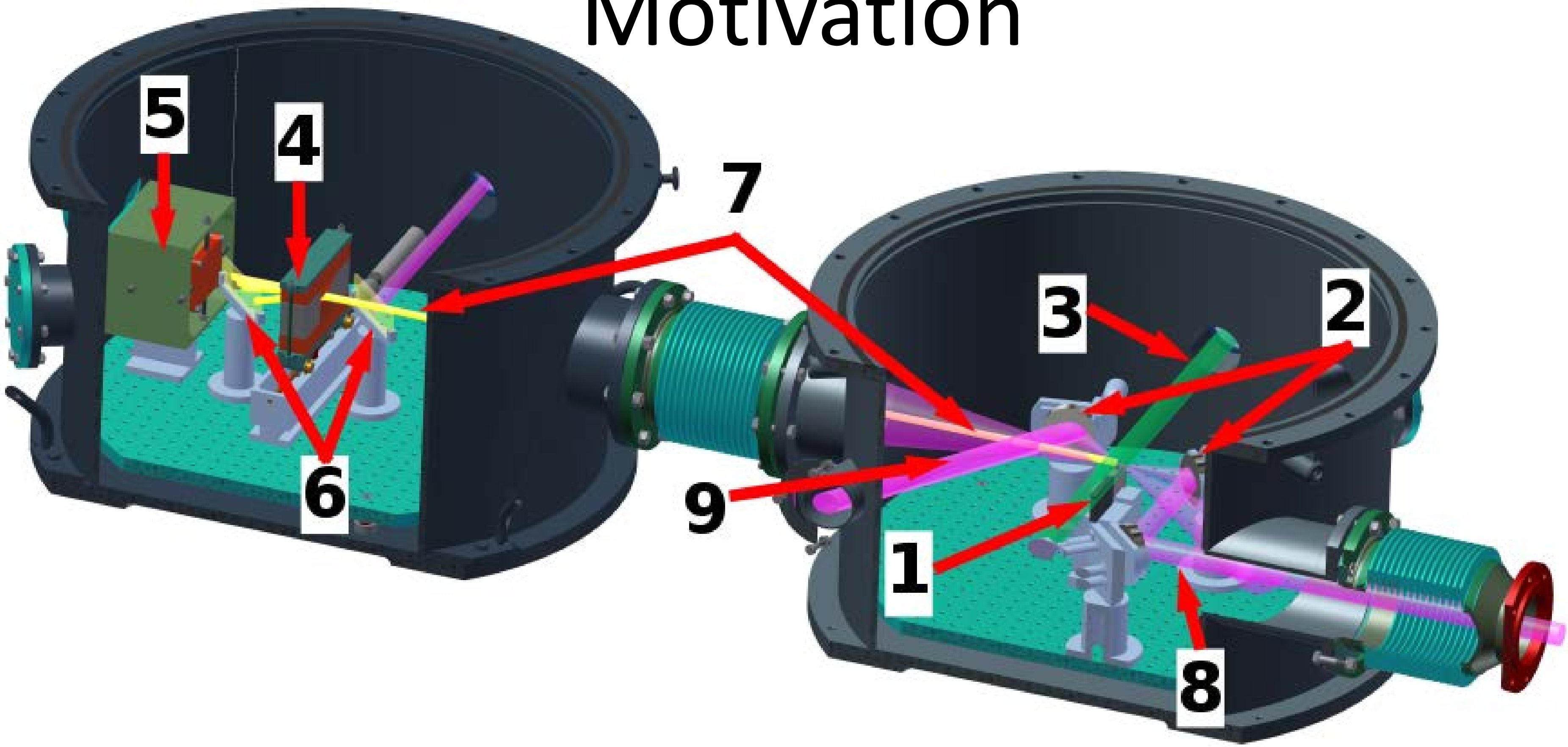
Motivation



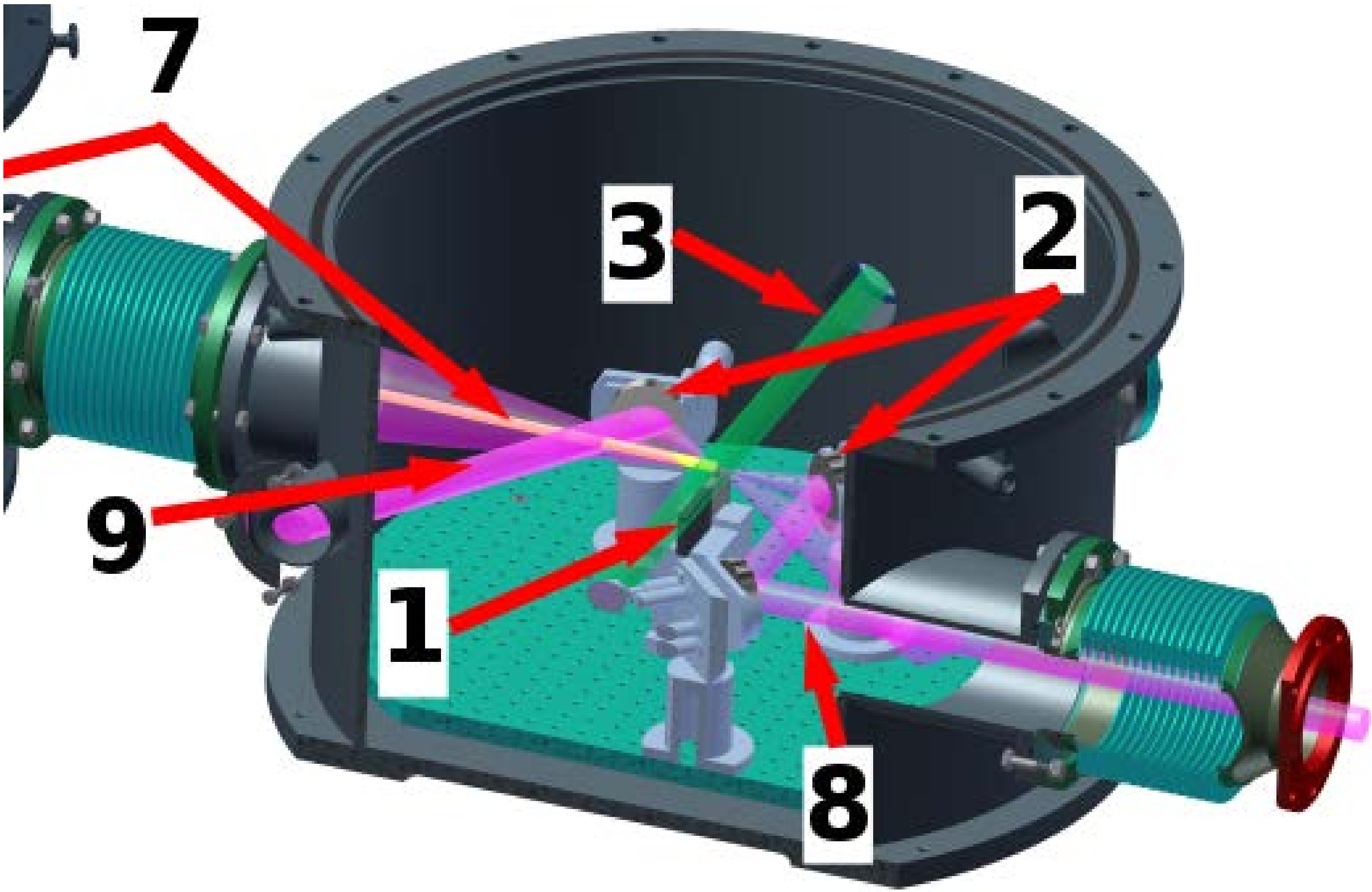
Name	Value
Laser focus size	~10 µm
Laser pulse duration	~10÷100 fs
Laser intensity	> 10^{19} W/cm^2
He-gas jet density	10^{18}÷10^{19} cm^{-3}
Plasma density	10^{18}÷10^{20} cm^{-3}
Beam energy	50-100 MeV
Beam charge	1-10 pC
Beam divergence	~1-10 mrad

Figure source: Albert, F., et al. "Laser wakefield accelerator based light sources: potential applications and requirements." *Plasma Physics and Controlled Fusion* 56.8 (2014): 084015. DOI: 10.1088/0741-3335/56/8/084015

Motivation



Two experimental chambers (without the compressor chamber):
1 – supersonic gas jet, 2 – focusing mirrors, 3 – laser beam for diagnosing the jet density, 4 – electron spectrometer magnet, 5 – Faraday cup, 6 – phosphor screens, 7 – electron beam, 8 – driving laser beam, 9 –scattered laser beam.



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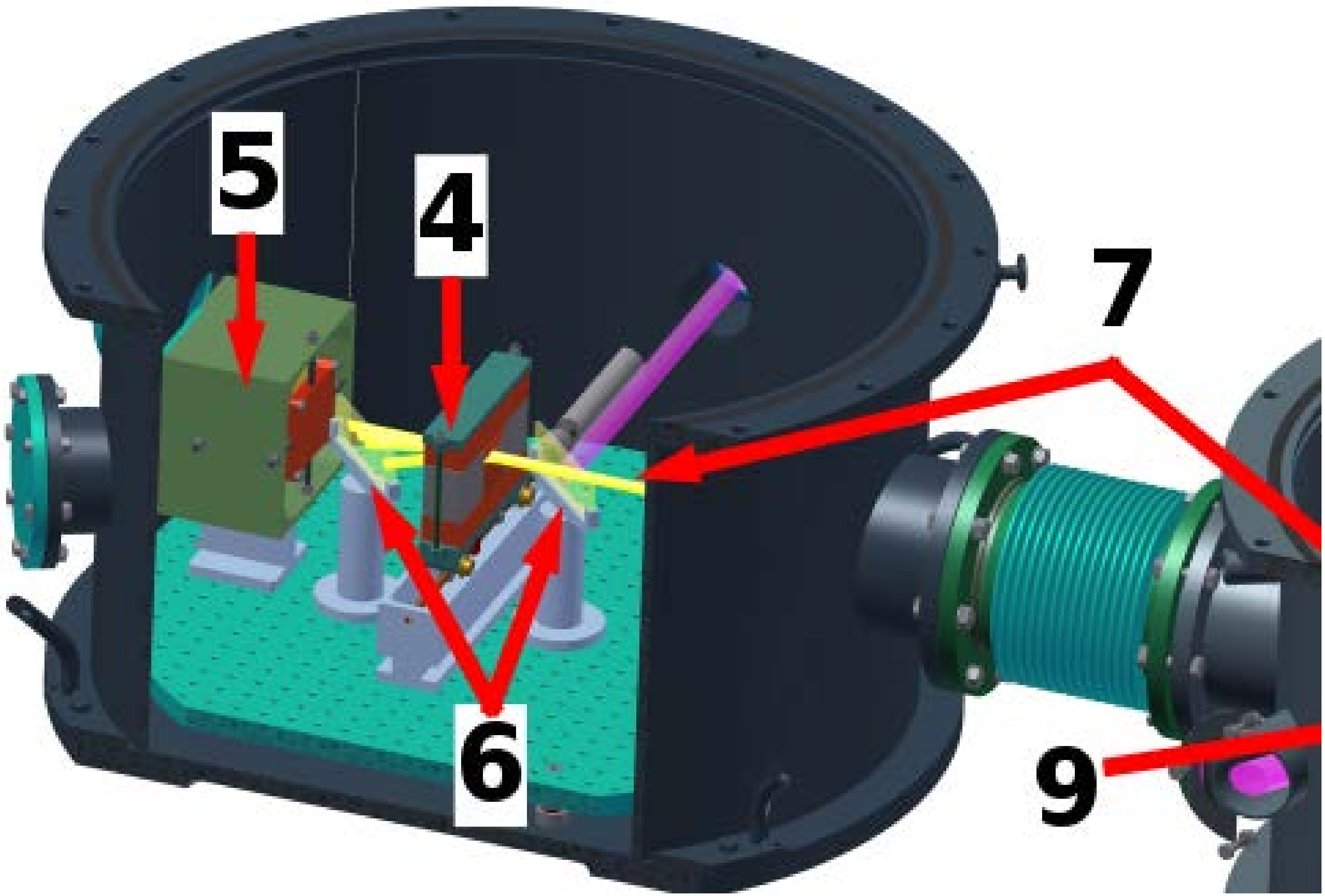

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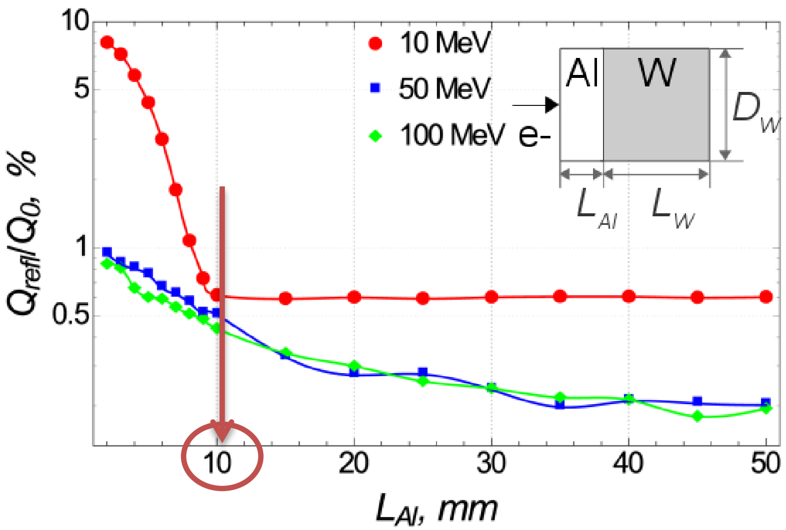
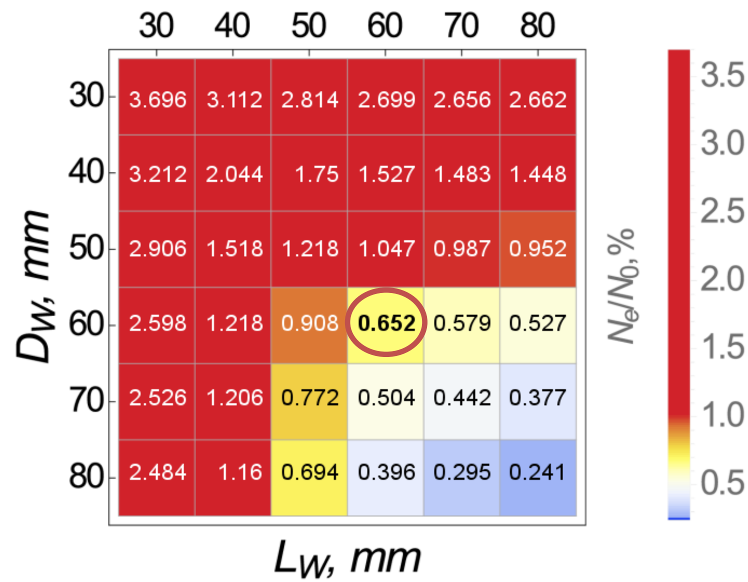
Faraday cup purpose and requirements

- FC materials have to be nonactivated, nonmagnetic, vacuum usable.
- FC has to provide full stopping of primary beam as well as secondary charged particles. It means the total charge losses should be less than 1%.
- Compact size (boundary dimensions 20-25 cm). Device must be placed inside limited volume of experimental vacuum chamber.
- Small capacity, not more than 10-30 pF (several tens pF including output circuit). It is caused by small bunch charge and by requirement to register the signal with sufficiently high precision.

Electron beam stopping simulation



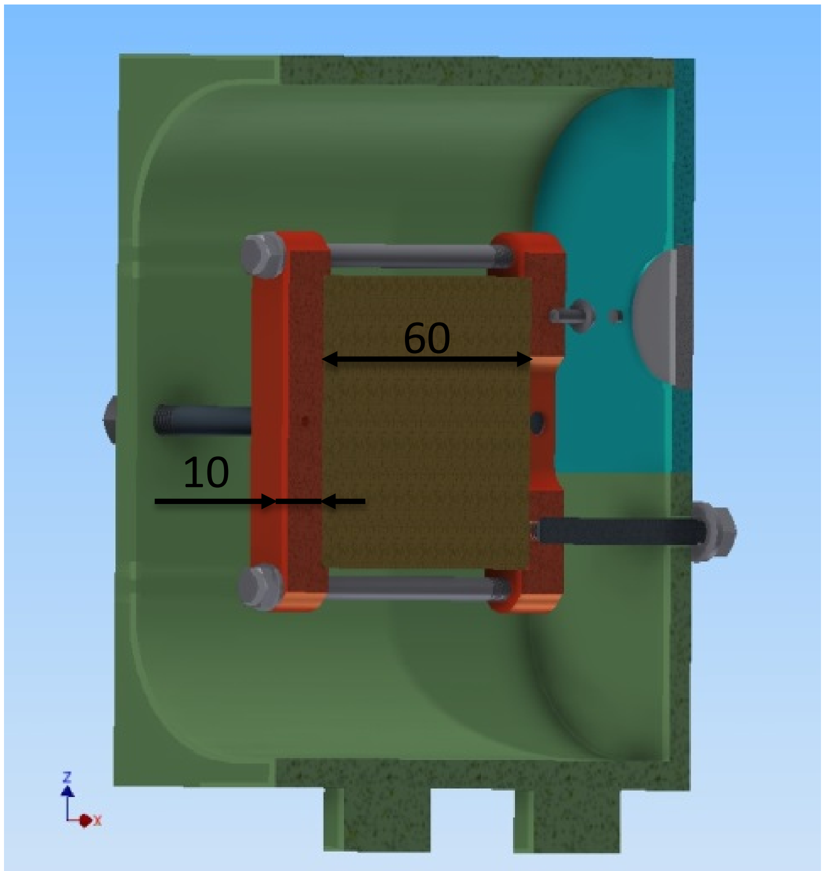
Dependence of charge reflection on thickness of Al layer for 10, 50, 100 MeV electron beam.



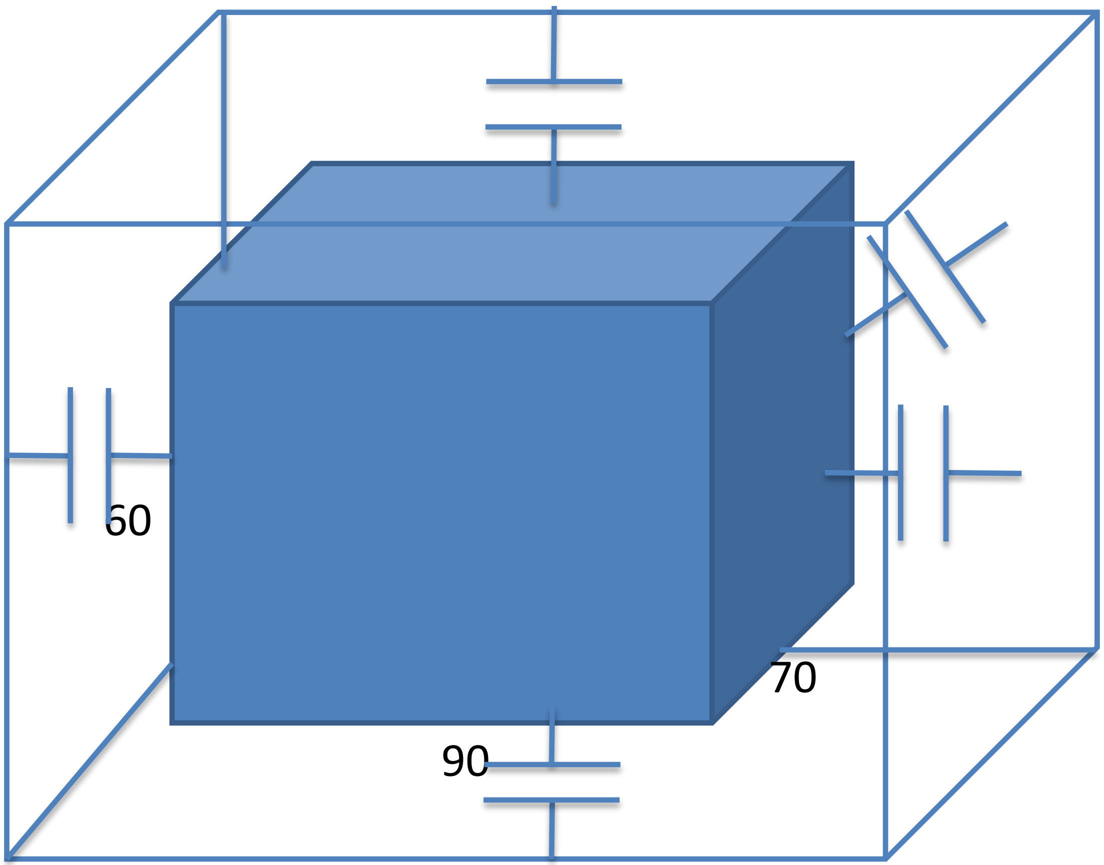
Number of penetrated particles for different W cylinder sizes, %. Primary beam energy is 100 MeV.

Simulations was done by Yulia Maltseva using GEANT4 code.

FC geometry



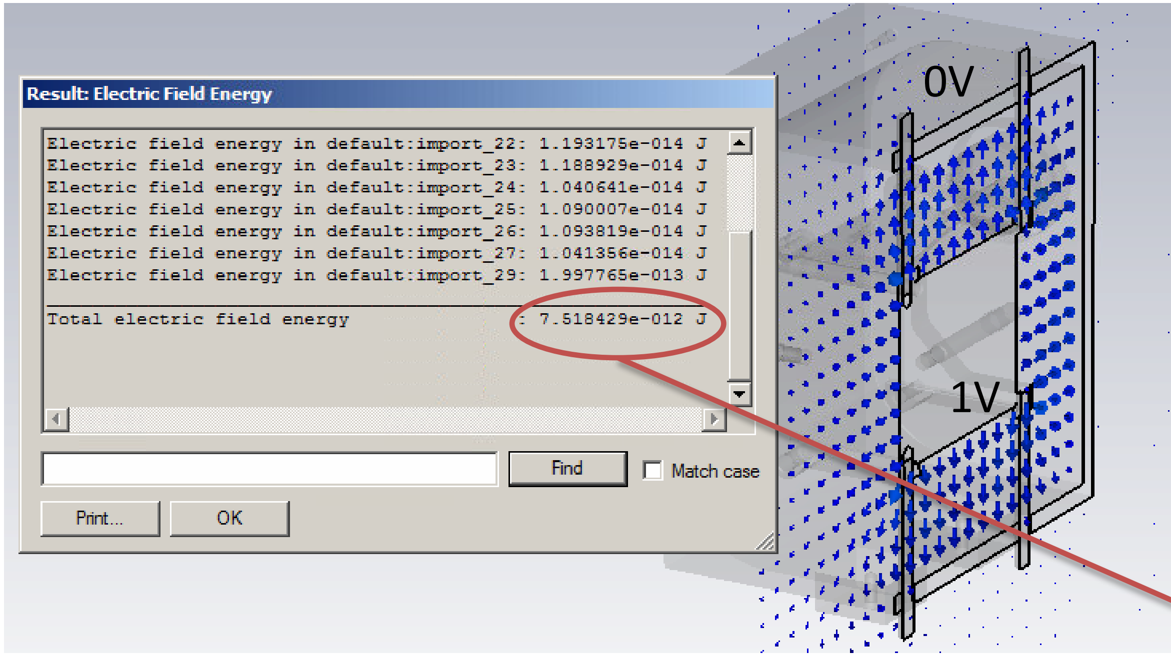
Simple FC capacity model



№	a, mm	b, mm	d, mm	S, m^2	C, F
1	60	70	30	0,0042	1,24E-12
2	60	70	30	0,0042	1,24E-12
3	70	90	30	0,0063	1,86E-12
4	70	90	30	0,0063	1,86E-12
5	60	90	30	0,0054	1,59E-12
					7,79E-12

FC Capacity >7.79 pF

Calculation FC capacity with EM solver



$$W_E = \int_{V_{all}} \frac{1}{2} \vec{E}\vec{D} dV$$

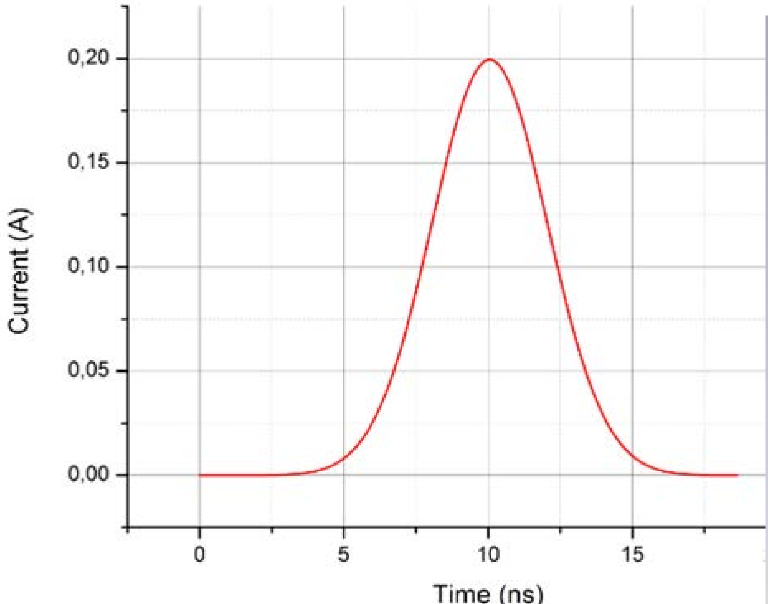
$$W_E = \frac{CU^2}{2},$$

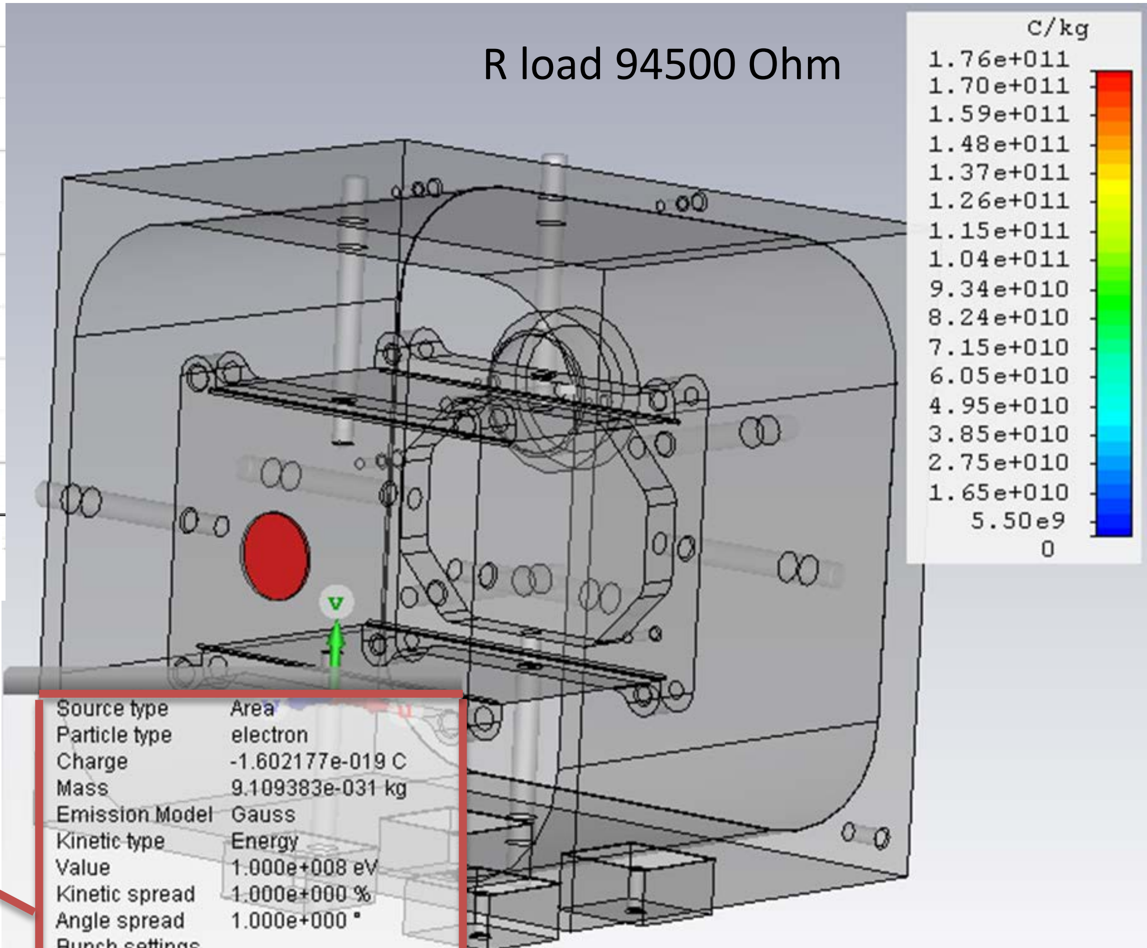
$$C = \frac{2W_E}{U^2}.$$

$$C = 2 \cdot 7.52 \cdot 10^{-12} = 15.04\, pF$$

Gap, mm	Capacity, pF	Outer dimensions, mm
10	~53	110x100x80
30	~15	150x120x140
50	~ 6	190x160x180

Calculation FC capacity with PIC solver





Source type	Area
Particle type	electron
Charge	-1.602177e-019 C
Mass	9.109383e-031 kg
Emission Model	Gauss
Kinetic type	Energy
Value	1.000e+008 eV
Kinetic spread	1.000e+000 %
Angle spread	1.000e+000 °
Bunch settings	
Charge (abs)	1.000e-009 C
Sigma	2.000e+000 ns
Cutoff	1.000e+001 ns
Offset	1.000e+001 ns

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Bunch settings	
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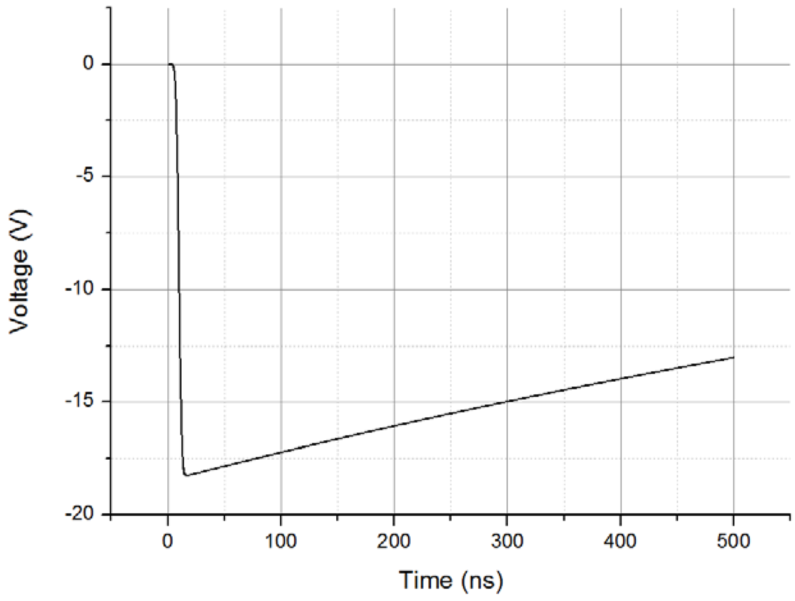
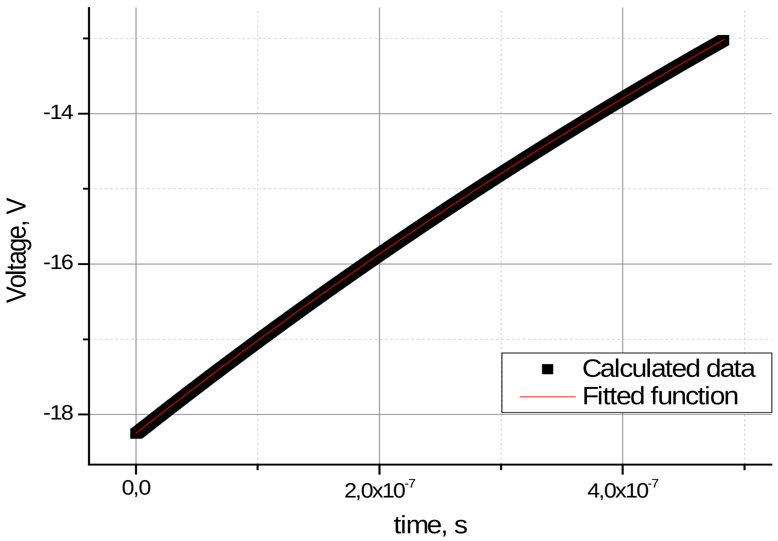
Sigma	2.000e+000 ns
Cutoff	1.000e+001 ns
Offset	1.000e+001 ns

Particle count: ~$9 \cdot 10^5$

Calculation FC capacity with PIC solver



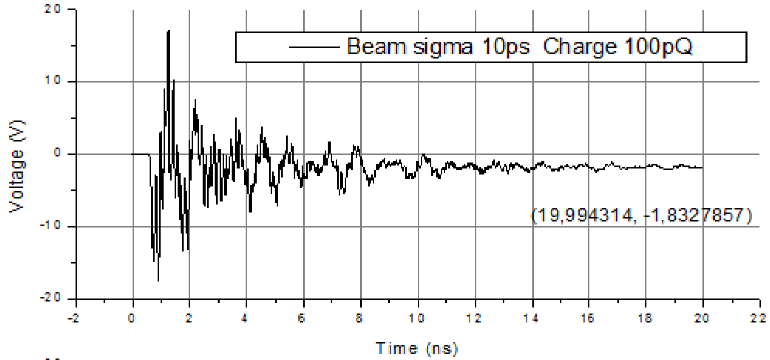


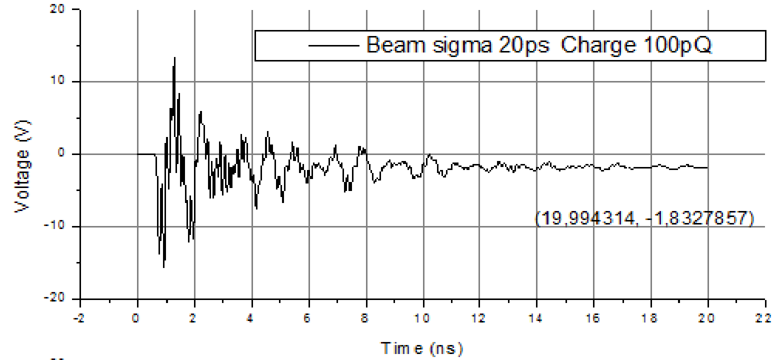
$$U = U_0 \cdot e^{-\frac{t}{RC}}$$

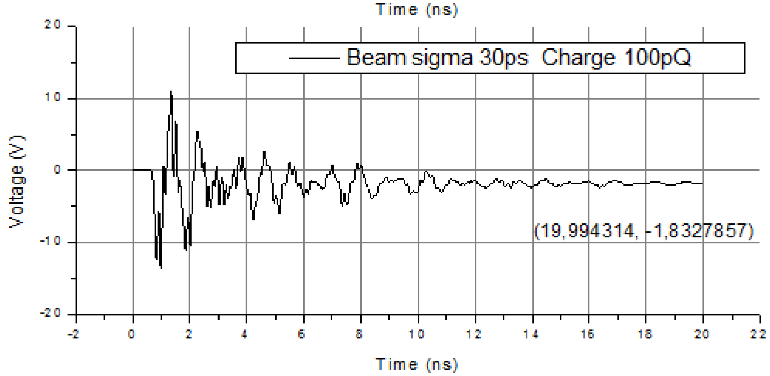
$$U = -18.25 \cdot e^{-\frac{t}{94500 \cdot 1.51 \cdot 10^{-11}}}$$

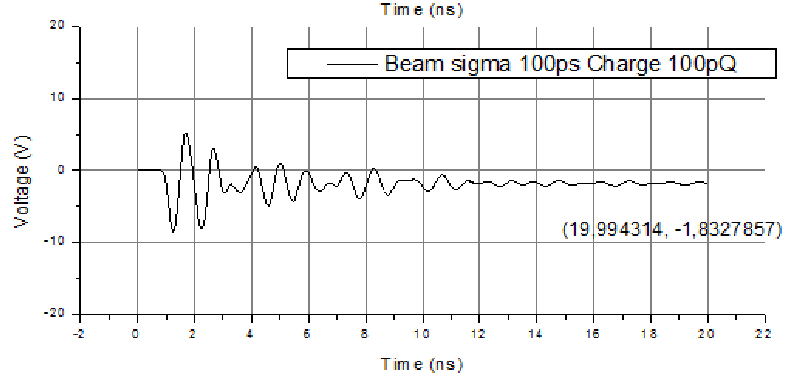
$C = 15.1pF$ (EM simulation give 15.01 pF, simple theoretical 7.8 pF)

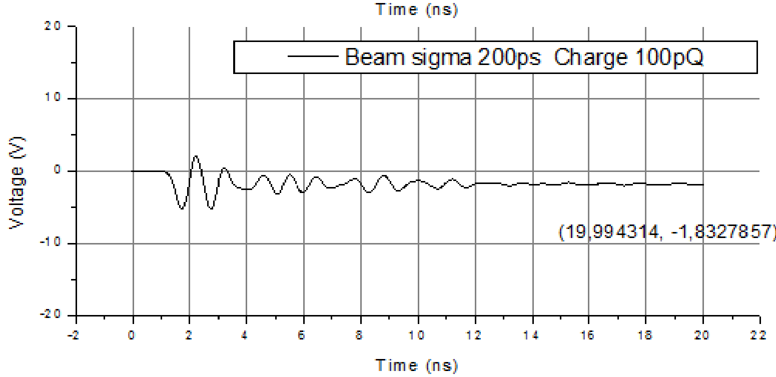
FC radio frequency analyze











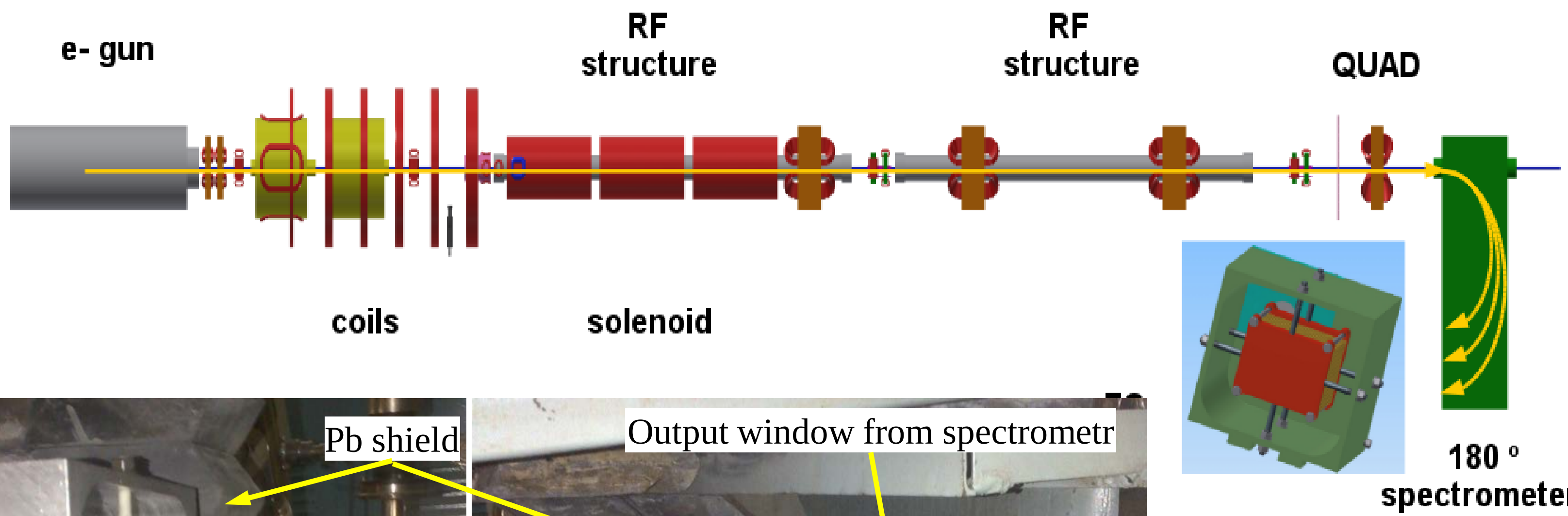
$$\tau_L = \frac{2Q_L}{\omega_0}[1]$$

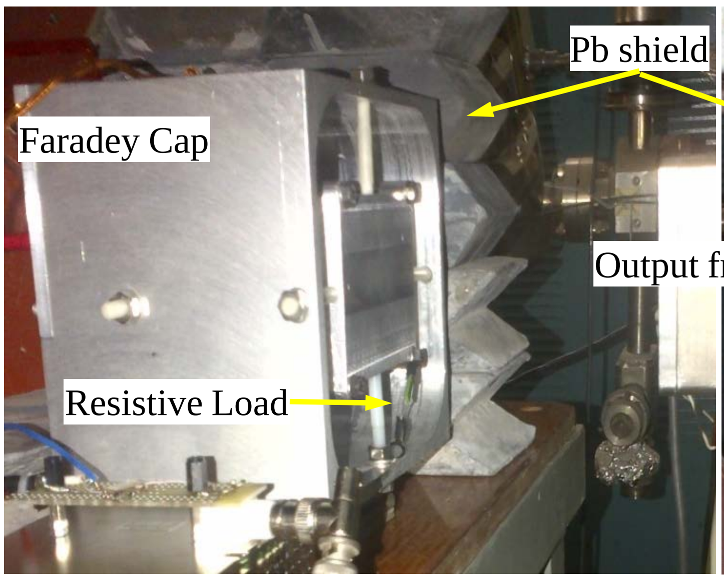
$$\tau_L = 20ns, \omega_0 = 1GHz$$

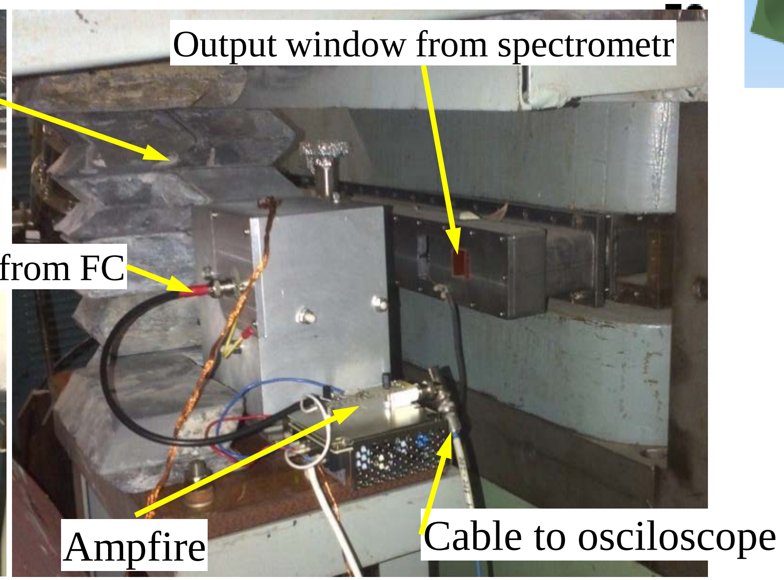
$$Q = 10$$

[1] T. Wangler. Principles of RF Linear Accelerators. John Wiley & Sons, NY, 1998, p. 152

Experimental results





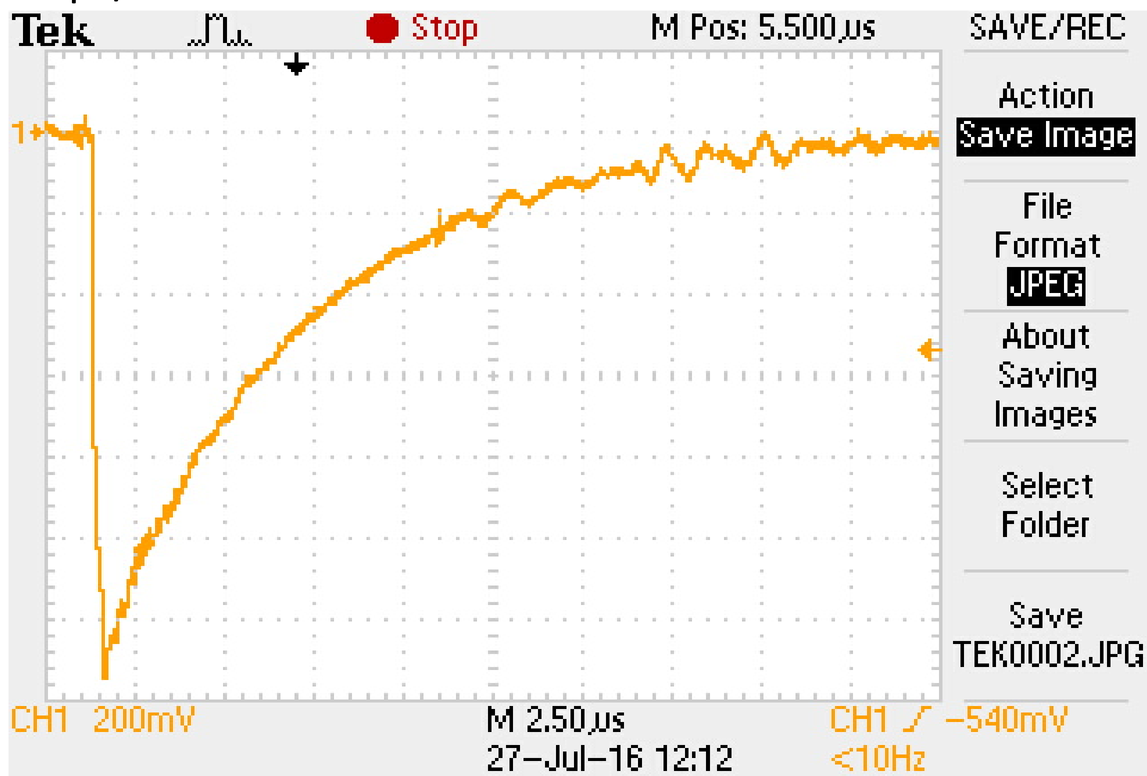


Experimental results

BNC connector ~5pF

30 cm
100pF/m

Total capacity should be equal to 15 pF+30 pF+5 pF=50 pF.



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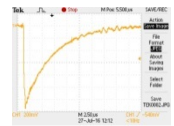

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30 cm
100pF/m

$$U(t) = U_0 \exp\left(-\, t/_{RC}\right)\left(1 - \exp\left(-\, t/_{\tau}\right)\right)$$

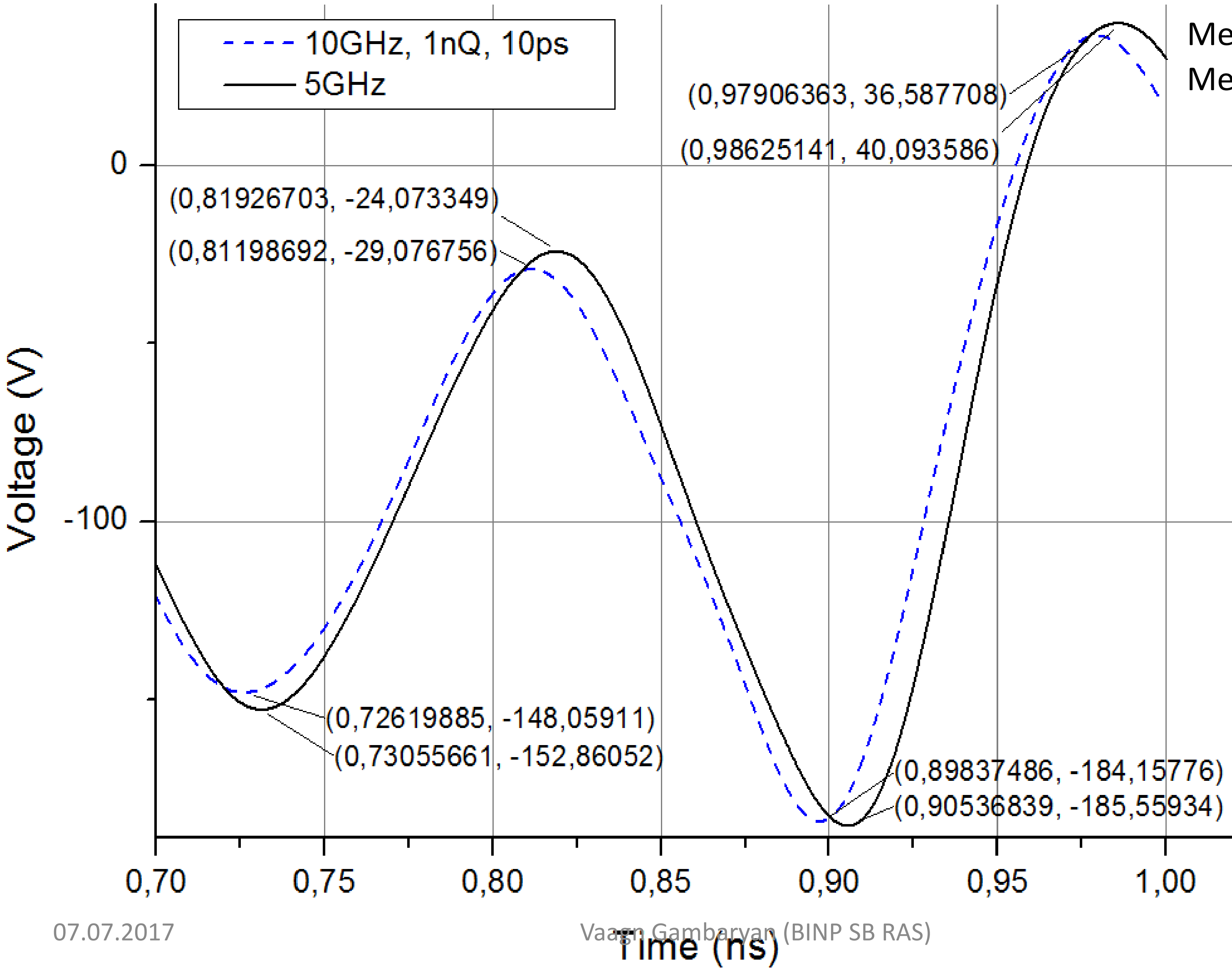
U_0 = 1.37 V
RC = 5.62 μs
τ = 0.127 μs
<u>C = 52.8 pF</u> (from fitting experimental data)
q= U_0C
Absorbed beam charge equals to 72.3 pC ($4.52 \cdot 10^8$ particles).

Conclusion

- Faraday cap optimal design obtained
  - beam stopping ability
  - capacity value
- Capacity simulations complited
- FC Q-factor estimated
- Calculation in good agreement with experimental data
- pC-rate beam charge measurement ability approved

Thank you.
Do You have any questions?

Accuracy checking



Mesh cells:24,944,524

Mesh cells:8,923,824