Preliminary injector linac design

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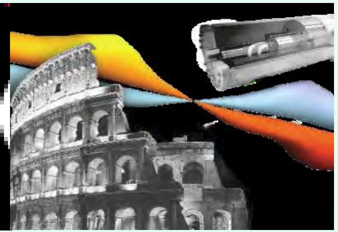


FCC Meeting
May 11-15 2016, Rome

1. Beam parameters and general linac layout (preliminary);
2. Beam dynamics in RF-gun;
3. Beam dynamics in regular section;
4. RF-gun electrodynamics simulations.
5. ED of regular section incl. 2000 and 3000 MHz comparison.
6. General results and discussion.
7. Technology and other possible MEPhI activities

1. Beam parameters and general linac layout (preliminary)

Base injection parameters:

- Intensity up to $4 \cdot 10^{13}$ e^-/s;
- $4 \cdot 10^{10}$ e^- / bunch, 10 ps bunches,
- 10 bunches per pulse, bunches are separated with distance 25 or 50 ns (very good, decreases beam loading influence),
- up to 100 Hz pulse repetition rate;

Record space charge domination!!! About 6 nC per bunch

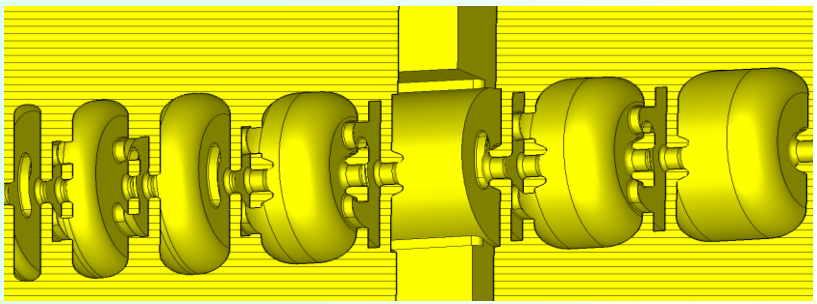
We preliminary discuss two operating frequencies: traditional 3000 MHz and novel 2000 MHz which gives brilliant matching with 400 MHz accelerating cavities proposed for booster. Both give 25 (50) ns bunches separation easily. It gives (for 10 ps laser pulse):

	3000 MHz	2000 MHz
RF period	~330 ps	500 ps
Bunch phase length	10 degree	6.7 degree
Physical bunch length (theoretically)	3 mm	5 mm
Current pulse duration (10 bunches per pulse)	25 or 50 ns ???	

1. Beam parameters and general linac layout (preliminary)

We study **two scenarios**: high, but not extreme bunch charge as 200-300 pC to define general structure layout and further to design a RF gun for extreme 6 nC (step-by step, starting with 1 nC).

We can use traditional biperiodical accelerating structure (BAS) in storage energy regime, on $\mu=\pi/2$ RF mode, having high shunt impedance and accelerating gradient. We will have no problem with RF power load and coupling here. But other types of accelerating structures should be studied and compared in future (travelling wave DLW with E and M coupling, diaphragms and washers, etc.)



When we accelerate very short bunch (~5 mm) in the storage energy mode, we need to realize some conditions for BAS:

-Low time of power feeding transient process leads to design of high group-velocity structure;

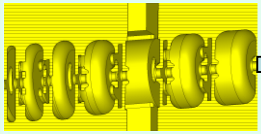
-We need V_g about 0.10-0.12c to fill 3m length structure during 200 ns;

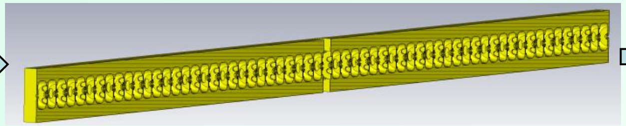
-If we have 200 ns transient process + 100 ns for reserve, we can decrease time of the SLED storage or klystron power;

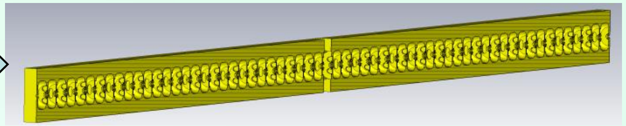
-Structure should operate in storage mode and RF coupler will be designed for critical coupling.

1. Beam parameters and general linac layout (preliminary)

RF-gun **10-20 regular sections for 2 GeV in total (3000 or 2000 MHz)**







3000 MHz **or** **2000 MHz** **?**

π/2 mode, st. wave
12 BAS periods
~60 cm of length
12 MeV output
350 kV/cm on axe
(for ~50 nC)

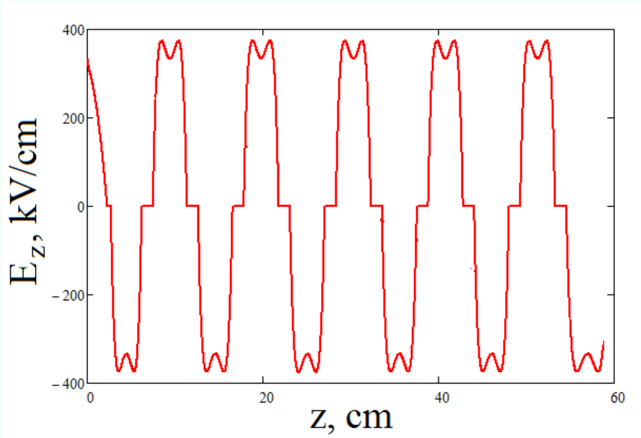
Not enough place
for first coupling cell !
side coupling should
be used

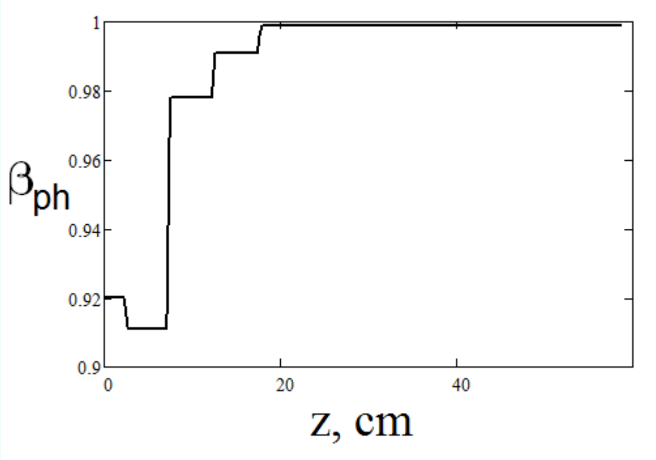
π/2 mode, st. wave
61 BAS periods
305 cm length
400/600/900 kV/cm
70/105/160 MeV
per section

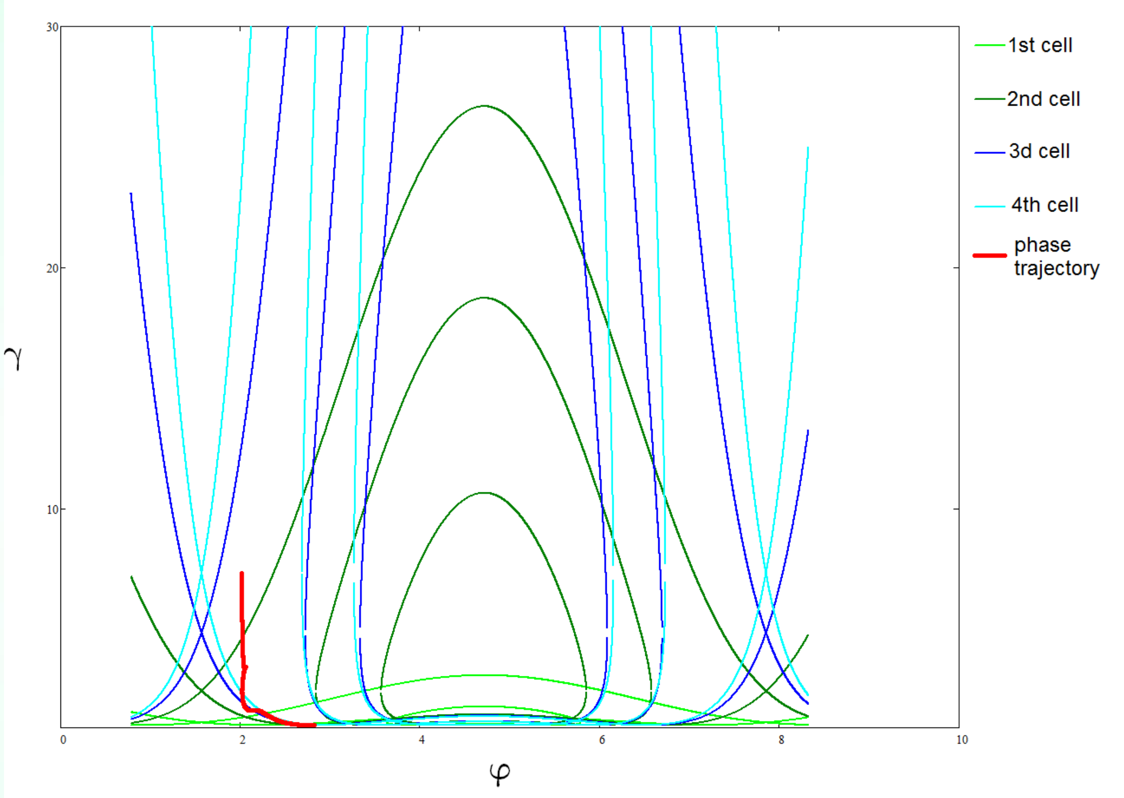
π/2 mode, st. wave
41 BAS periods
307.5 cm length
400/600/900 kV/cm
75/110/170 MeV
per section

High (12-14 %) coupling coefficient to achieve high group velocity and low time of transient process!!!

2. Beam dynamics in RF-gun (for hundreds of pC bunches)



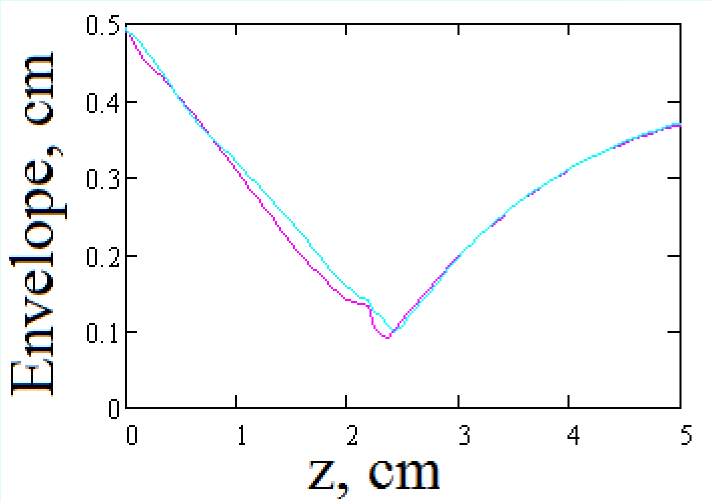


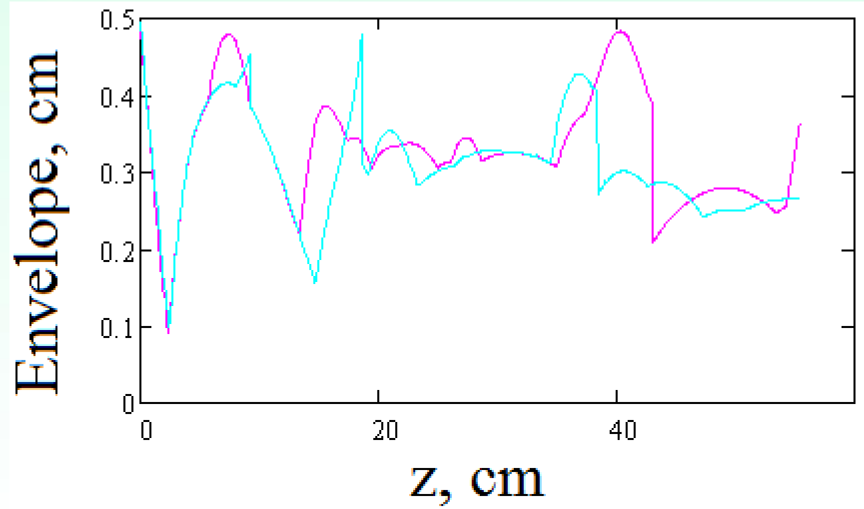


12 acc. cells, E_z=350 kV/cm, B_{sol}=0.03 T, side coupling for 1-2 cells

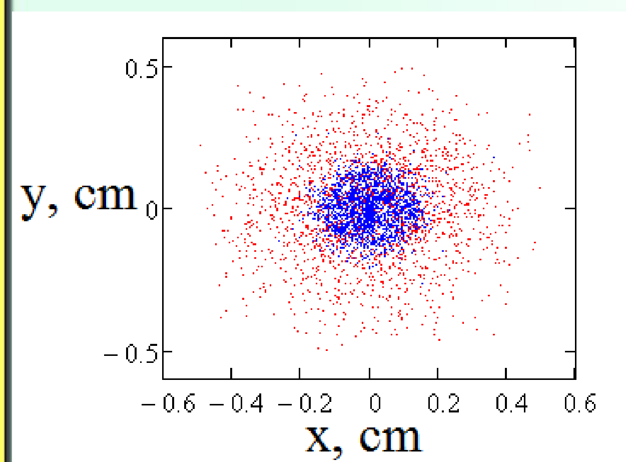
BEAMDULAC-BL code was used for beam dynamics study. It was developed in MEPhI for beam dynamics simulation in e-linacs taking into account Coulomb and beam loading selfconsistently

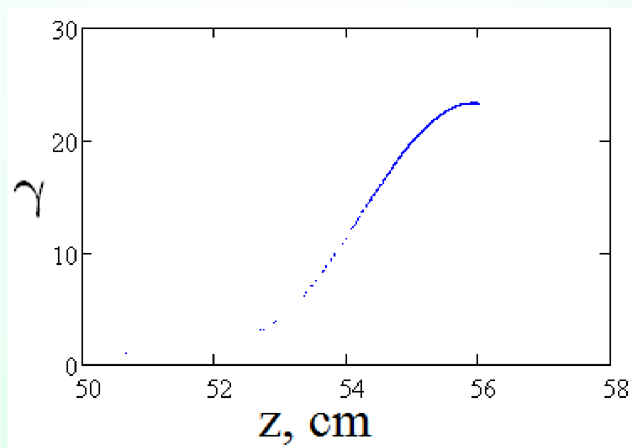
2. Beam dynamics in RF-gun (for hundreds of pC bunches)

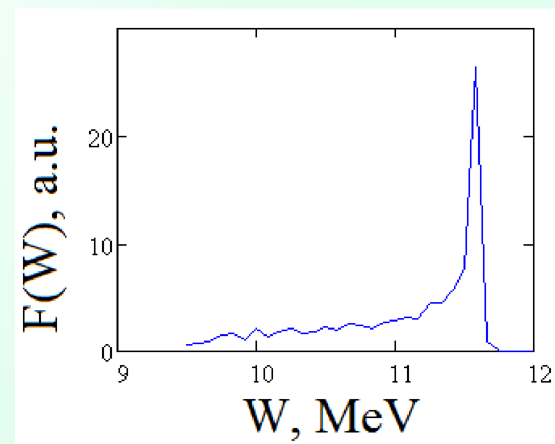




I=1 A, focusing field *B*=0.03 T, E_t =10 cm·mrad, r_0=5 mm





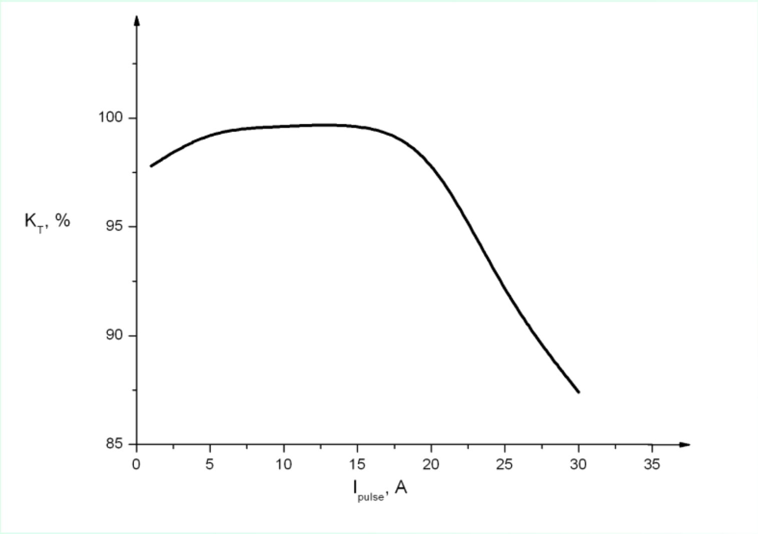


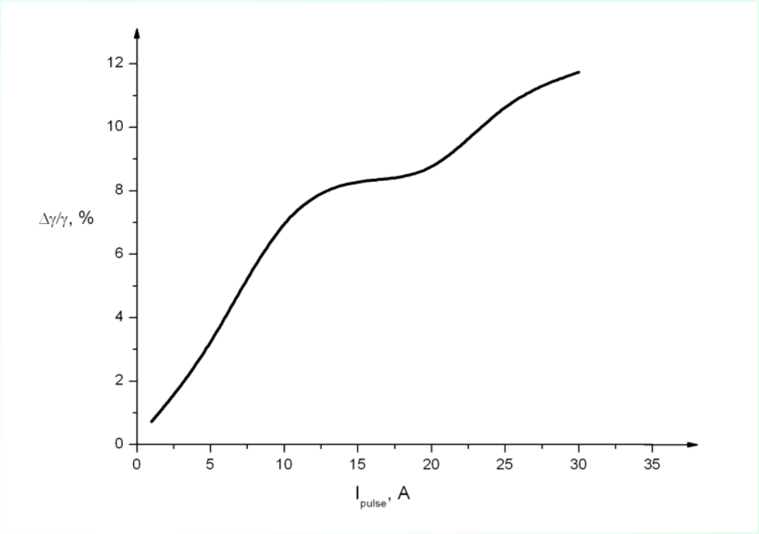
Bunch length ~19 mm
(is 10 ps to long ???)

Energy spectrum ~0.7 %

2. Beam dynamics in RF-gun (for hundreds of pC bunches)

Coulomb field and beam loading





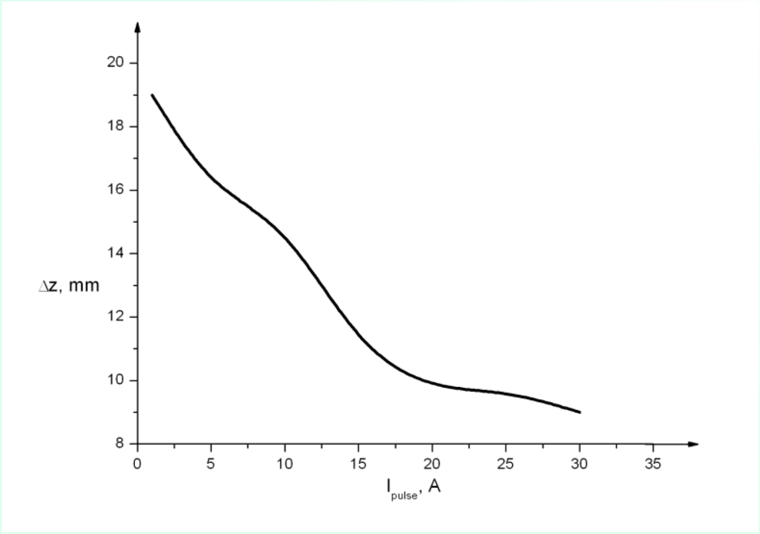
B=30 mT for I<20 A

50 mT for 20

70 mT for 25

100 for 30

no tr. loses

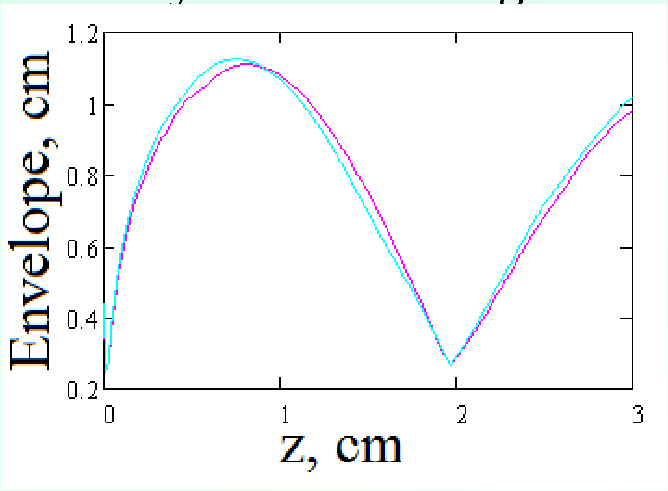


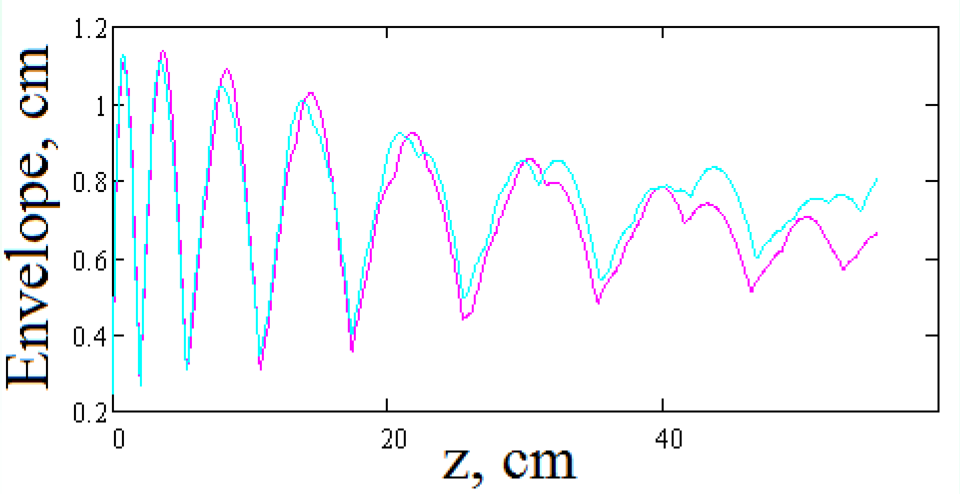
RF-gun will further optimized to minimize δγ

Beam loading influence is not sufficient for 10-30 A of pulse current and separated bunches : after bunch E_z is less than 0.3 % lower than for unloaded structure. For example, if E_z will differs 0.5 %, we will have 11.91 MeV comparatively 11.97 MeV.

2. Beam dynamics in RF-gun

Beam dynamics in RF-gun for extreme 6 nC bunches (first results are for 1 nC)

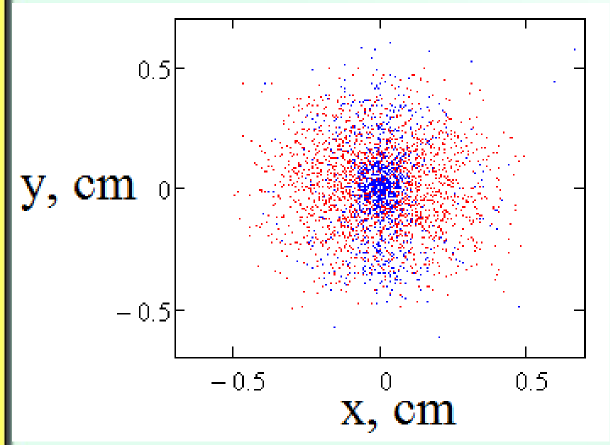


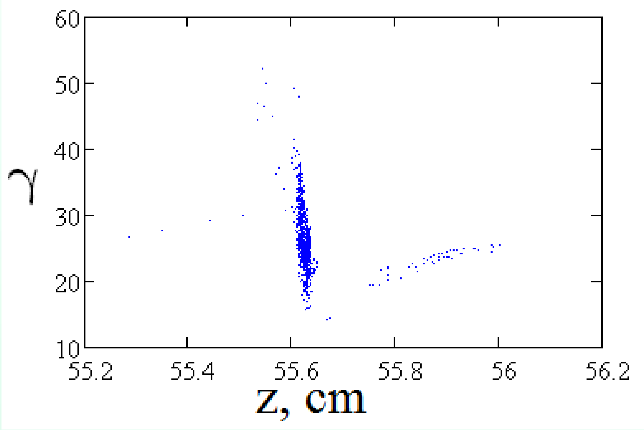


E_z=400 kV/cm (was 350),

B_{sol}=0.40 T (was 0.10) Aperture was enlarged to 15 mm (was 8 mm)

K_t is only 75-80 %





After optimization energy spectrum was improved to ±(1.5-2.0) %

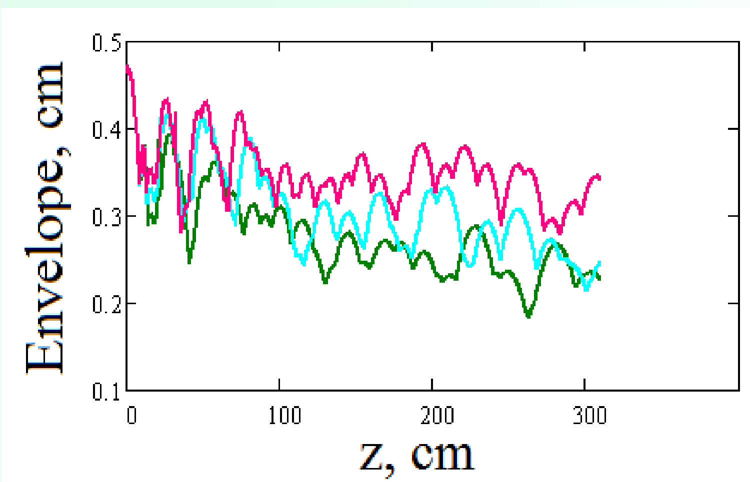
Further for 6 nC it will much more interesting !!!

Injection energy is ~12 MeV, length of regular section ~3 m.

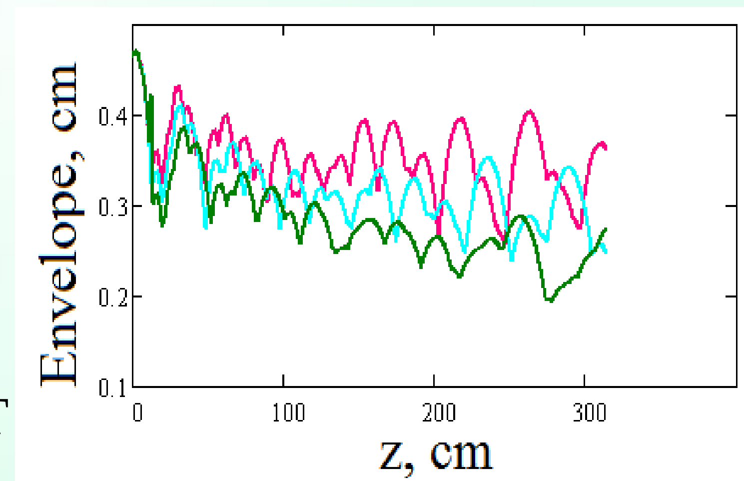
E_z, kV/cm	3000 MHz		2000 MHz	
	K_T, %	ΔW_{sec}, MeV	K_T, %	ΔW_{sec}, MeV
400	98.4	69.9	98.2	74.2
600	98.4	104.9	98.2	111.4
900	98.4	157.5	98.3	166.9

Low field scenario
Real scenario
Optimistic scenario

Pulse current 30 A, injection distribution is taken after RF-gun,
ΔW_{sec} is energy gain per section, K_T is current transmission for first regular section



kV/cm
400
600
900
I_0=30 A
B=100 mT

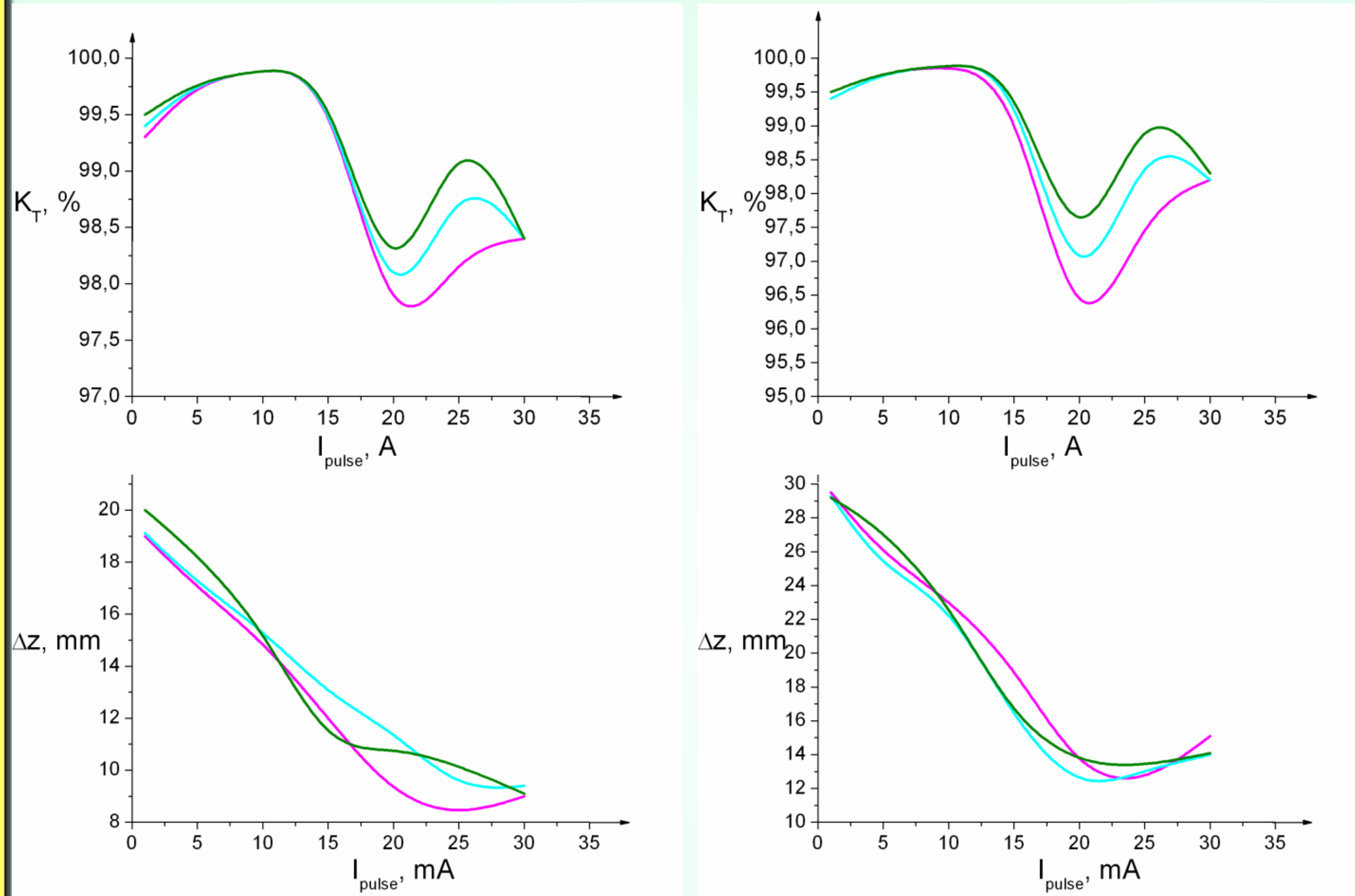


3000 MHz

2000 MHz

3. Beam dynamics in regular section

Coulomb field and beam loading



Current transmission and bunch length v. pulse current (3000 MHz left, 2000 MHz right)

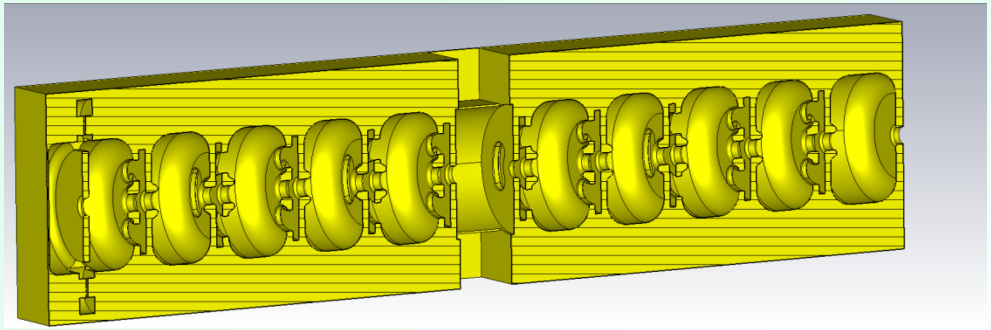
400 kV/cm
600
900

Beam loading influence is not sufficient for 30 A and 10 ps of pulse current : after bunch E_z is less than 0.25 % lower than before bunch. If E_z will differs 0.5 %, we will have (Table)

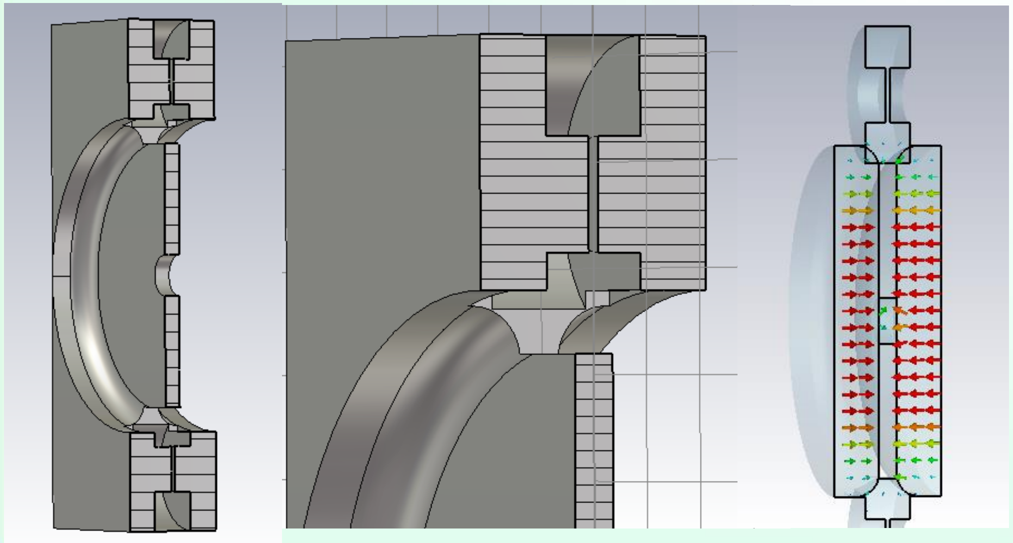
E_z, kV/cm	3000 MHz		2000 MHz	
	100 % of E_z	99.5 % of E_z	100 % of E_z	99.5 % of E_z
400	82.4 *	82.04	85.7	85.35
600	116.4	115.9	122.9	122.4
900	169.0	168.2	178.4	177.6

* Energy (MeV) after RF-gun and first regular section

4. RF-gun electrodynamics simulations



We haven't enough place for first coupling cell and side coupling for 1st and 2nd accelerating cavities was simulated



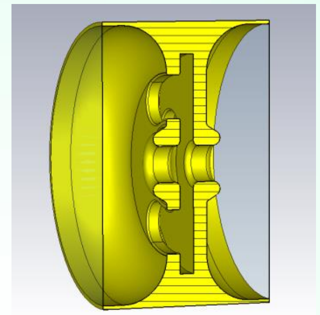
Section parameters:

$\pi/2$ mode
standing wave
f=3000 MHz
12 BAS periods (one side-coupled), 59 cm of length
12 MeV output
E_z= 350 kV/cm
Storaged energy mode
Coupling with RF source - critical
Q-factor 6600 (first cell) and 15500 (regular cell)
R_{sh}=80 MOhm/m (regular cells)
Coupling coefficient (regular cells) 11.5 % and 4 % (1-2 cells, should be increased further)
Time of transient process ~120 ns
Necessary RF power P_{rf}=26 MW

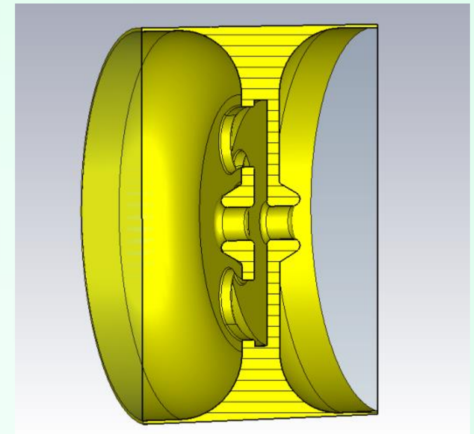
5. Electrodynamics of regular section

π/2 mode
Standing wave
Storaged energy mode
Coupling with RF source - critical

3000 MHz

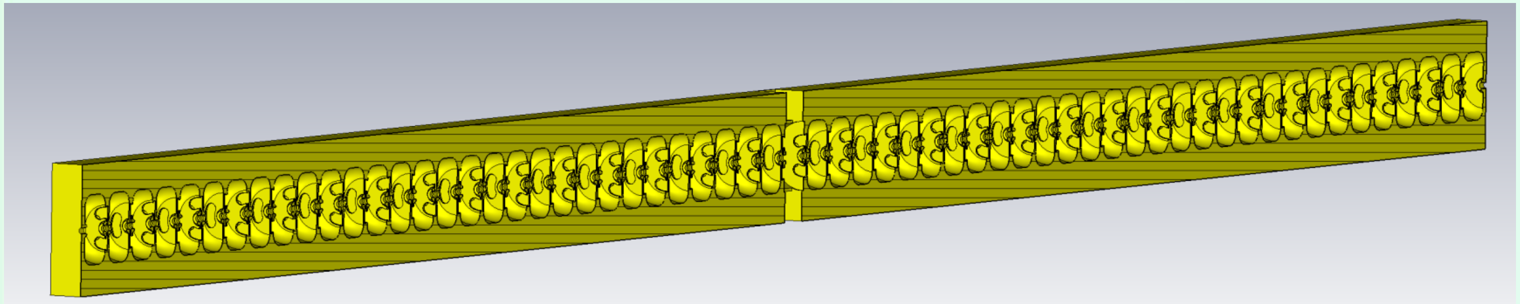


2000 MHz

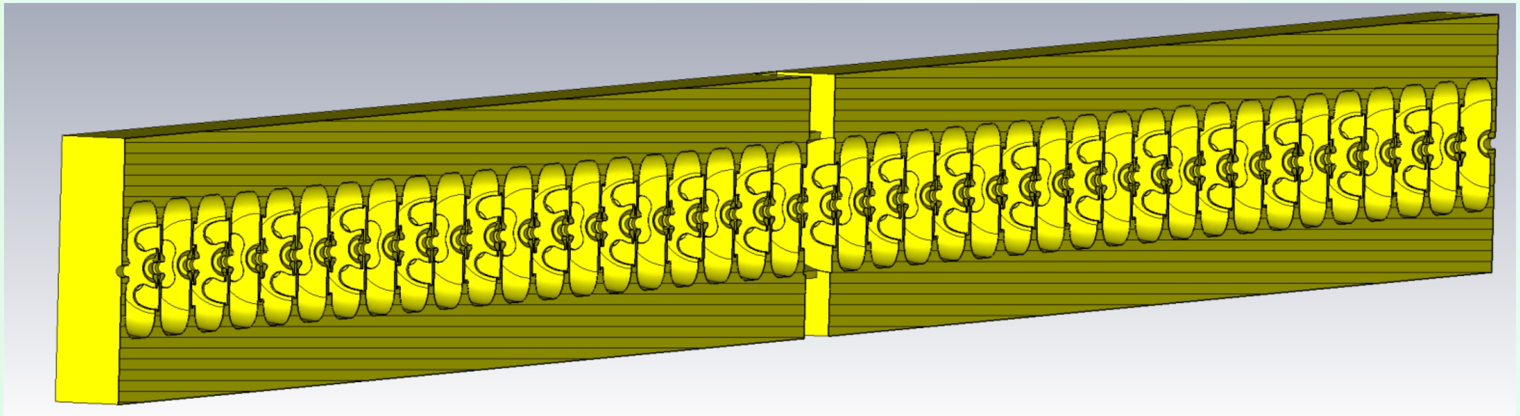


Acc. cell diameter, mm	76	116
Length of acc. cell, mm	38	63
Length of coupling cell, mm	4	4
Q-factor	15500	13700
R_{sh}, MOhm/m	79.5	49.7
Coupling coefficient, %	11.5	11.0
Group velocity	0.102c	0.11c
Time of transient process, ns	200	185

5. Electrodynamics of regular section



3000 MHz:
61 acc. cells,
305 cm



2000 MHz:
41 acc. cells,
307.5 cm

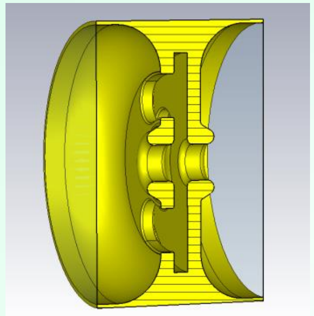
Necessary RF power, MW

***E*$_z$, kV/cm**	**3000 MHz**	**2000 MHz**
400	61	99
600	138	223
900	311	501

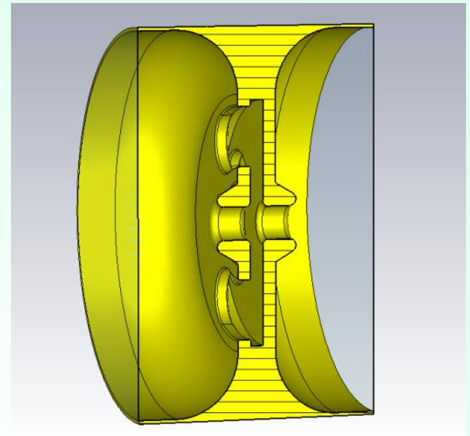
For traditional SLED amplification coefficient eq. 4 it gives 15/35/75 of necessary klystron power for 3000 MHz or 25/56/125 for 2000 MHz (is amp. Factor =6 available ???)

6. General results and discussion

3000 MHz



vs.



2000 GHz

•Well known

•**Many klystrons are available**
(SLAC, Thales, Toshiba, …)

•**Higher R_{sh} and lower necessary RF power**

• **No simple matching with 400 MHz frequency in booster**

•Difficulties in design of RF-gun first cell

•**Brilliant matching with 400 MHz frequency in booster**

•No problem in design of RF-gun first cell

•Higher (~5 %) rate of the energy gain

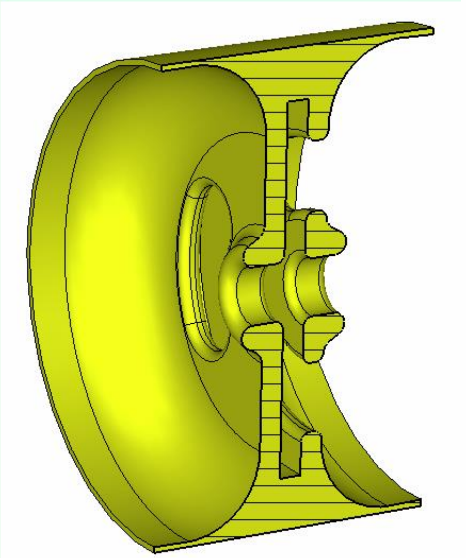
•Conceptually new (but 1.3 and 1.8 GHz bands are widely used)

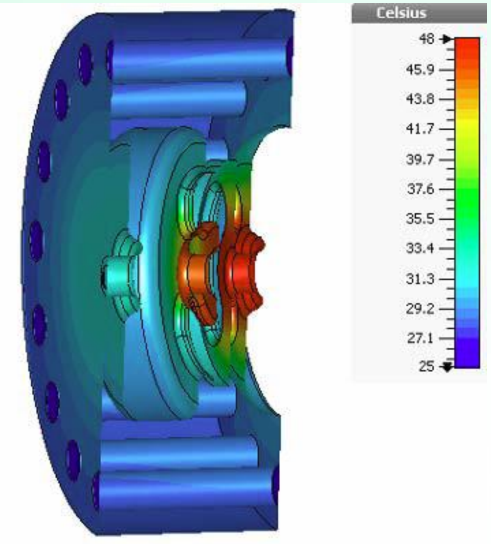
•**No RF power sources**

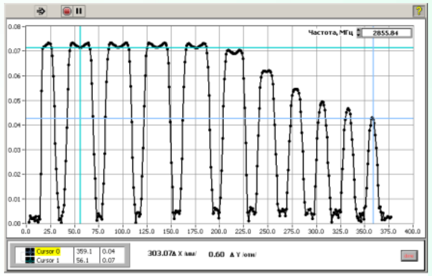
•**Lower R_{sh} → twice higher necessary RF power**

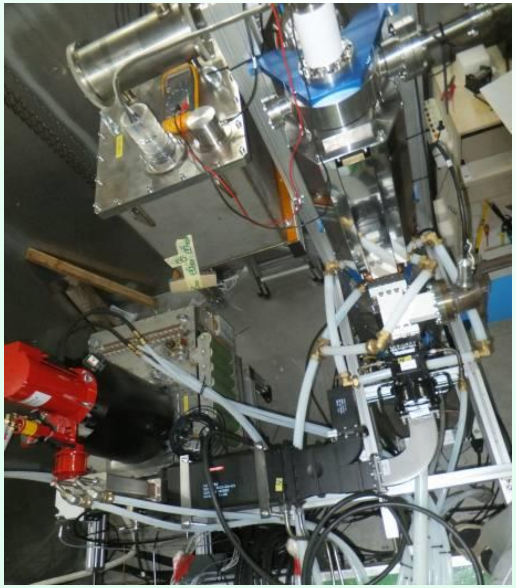
7. Technology and other possible MEPhI activities

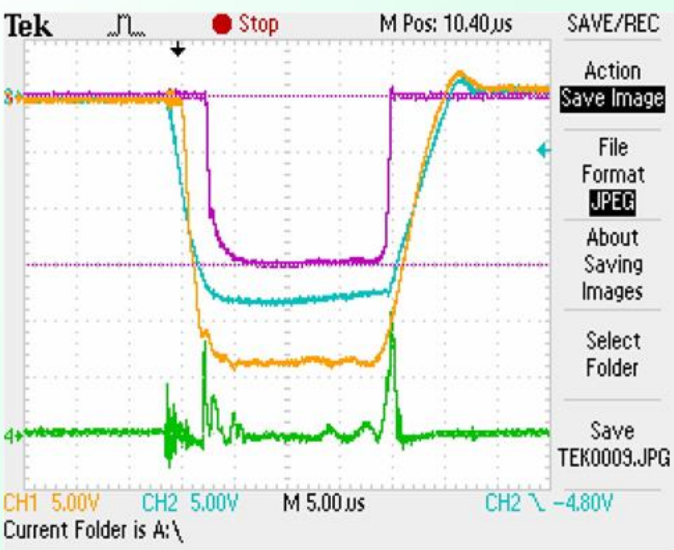
MEPhI + Korad Co., LLC project of 10 MeV/20 kW industrial linac











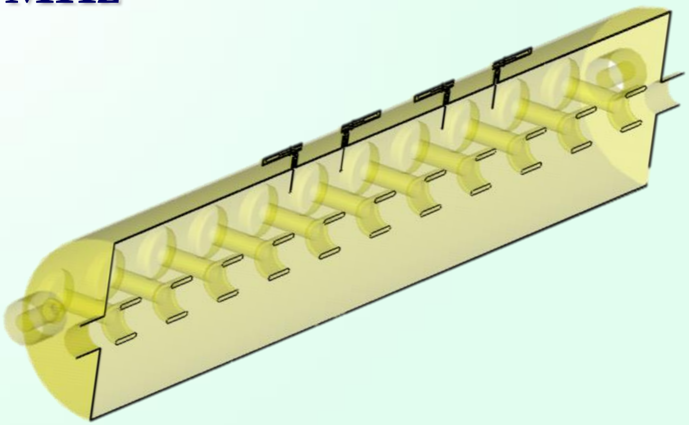
Commissioned in Sep. 2015

HL-LHC: DEVELOPMENT OF THE SUPERCONDUCTING 800 MHZ HARMONIC CAVITY

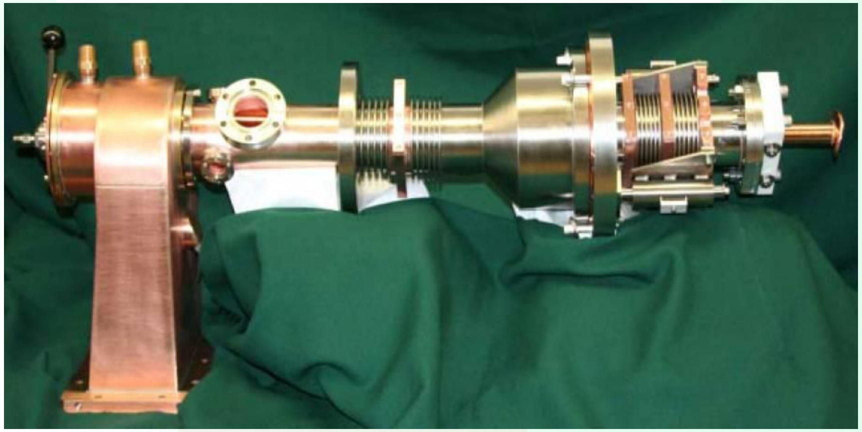
Different higher order modes damping techniques were proposed and compared

HIGHER ORDER MODES DAMPING IN SPS TW ACCELEARING CAVITY AT 200 MHz

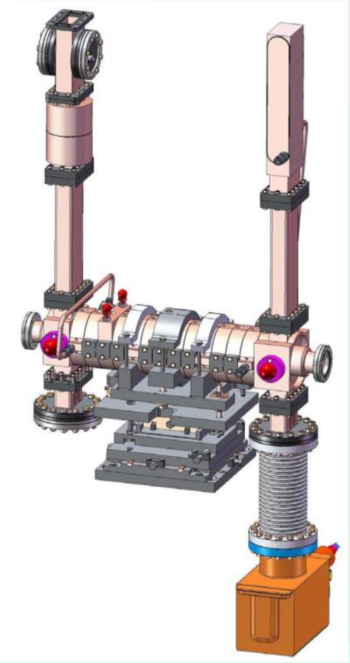
Several longitudinal HOM's near 630 MHz could limit the maximum beam intensity in SPS accelerator.
MEPhI RF-Lab is also contributing in the development of the improved HOM damping system



DESIGN OF HIGH POWER INPUT COUPLER FOR CORNELL ERL INJECTOR CAVITIES



Adjustable power coupler for superconducting injector cavities of Cornell ERL project has been designed. Feeds 75 kW CW @1.3GHz.
Several couplers produced at Beverly Microwave (CPI) and tested.

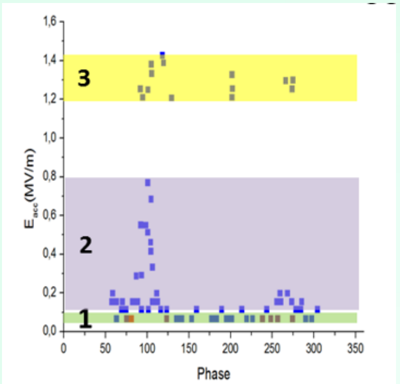


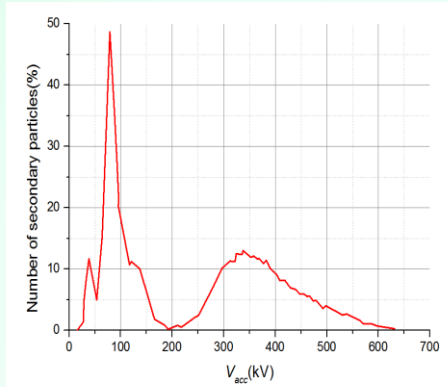
BEAM DEFLECTOR SYSTEMS for PITZ (X-FEL) developed (cooperation with Nuclear Research Institute of RAS and Introscan LLC as industrial partner.
Now under commissioning at DESY.

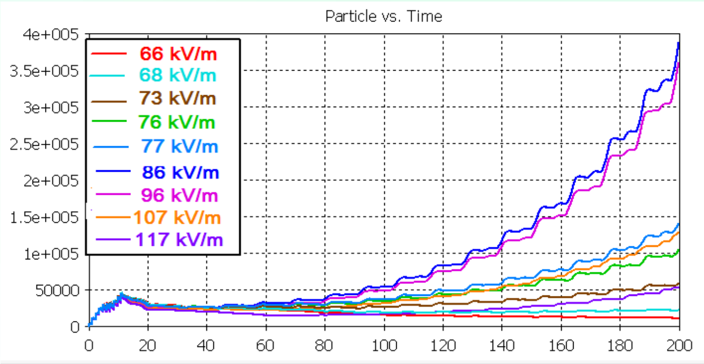
7. Technology and other possible MEPhI activities

MULTIPACTOR DISCHARGE SIMULATIONS

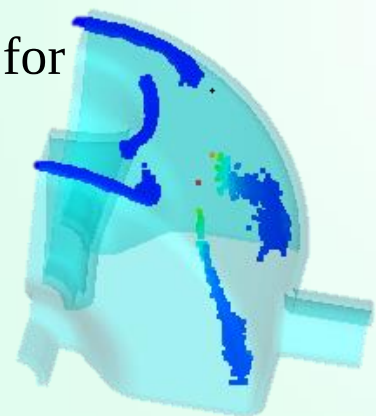
Codes: **MultP-STL** (by MEPhI) and **CST PS** (By CST AG),

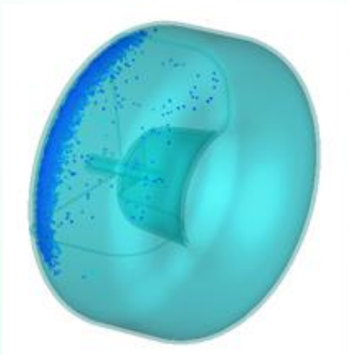






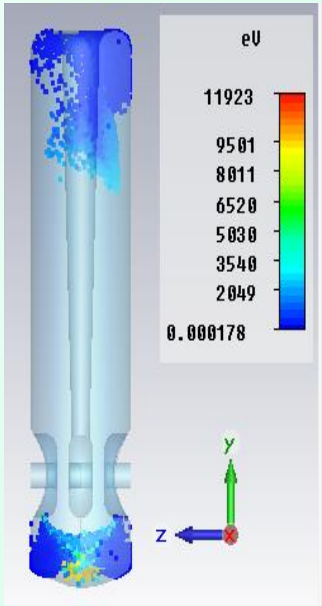
Spoke cavity for TRIUMF





NICA buncher cavity

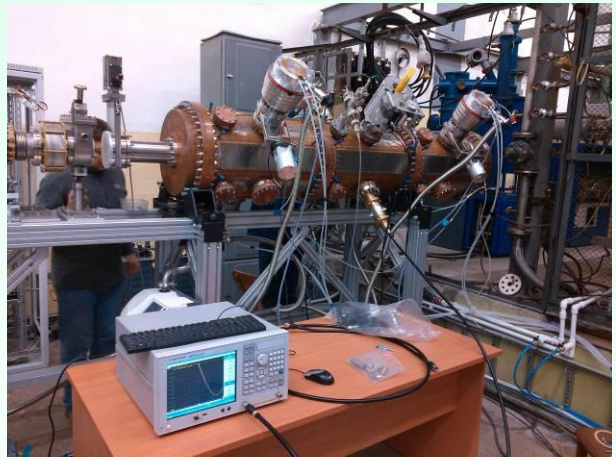
TRIUMF QWR

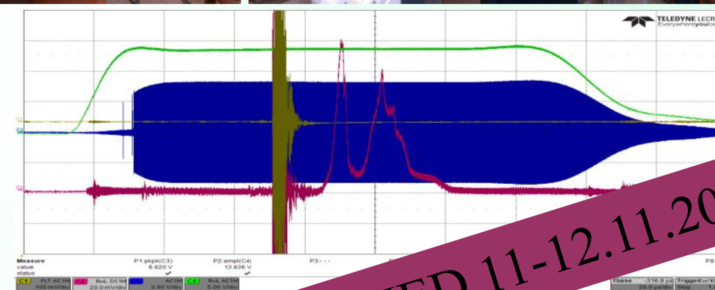


[ ] Multipacting simulation in accelerating RF structures, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 599 (1), pp. 100-105

New RFQ injector for NICA (JINR) collider

JINR+MEPhI+ITEP project for Nuclotron-NICA injection complex modernization





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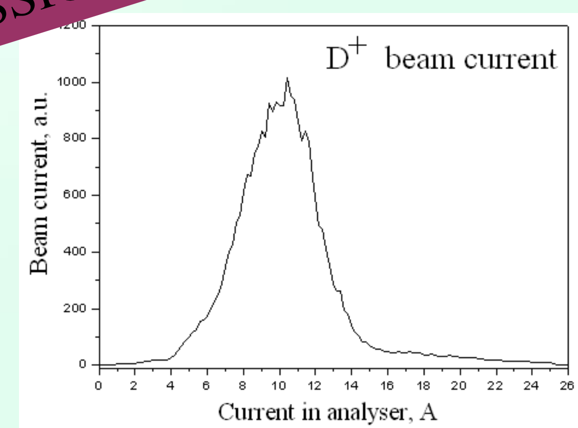

Thank you!