The Main Part of a Linear Accelerator for Proton Therapy.

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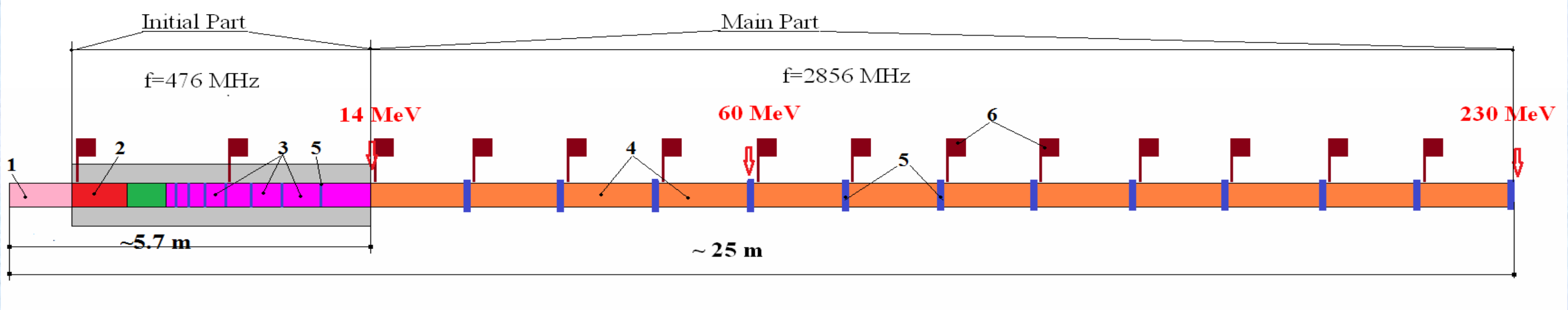
XIV ***Международный семинар по проблемам ускорителей заряженных частиц.***
Alushta, Crimea, Russ
20 -25 September 2022

Main features

1.Output proton energy, max, MeV - 230,
2. Total length, m ~25.5,
3. Pulsed operation, repetition rate, ~50 Hz,
4. Operating frequencies, MHz, 476/2856
5. Pulsed operation, repetition rate, ~50 Hz,
6. RF pulse length, ms, up to 16,
7. Beam pulse length, ms, up to 15,
8. Pulse beam current, mA up to 2.5,
9. Energy regulation, range, MeV 60-230,
10. Time for energy change, ms, <20
(max, to be considered on more details in this report)

Linac scheme.

A classical proton linac scheme with some non classical proposals and operating modes.



1 - proton source, 2 – RFQ, 3 – DTL, 4 – TW structure, 5 – focusing elements, 6 – RF sources.

Functional purpose and particular features

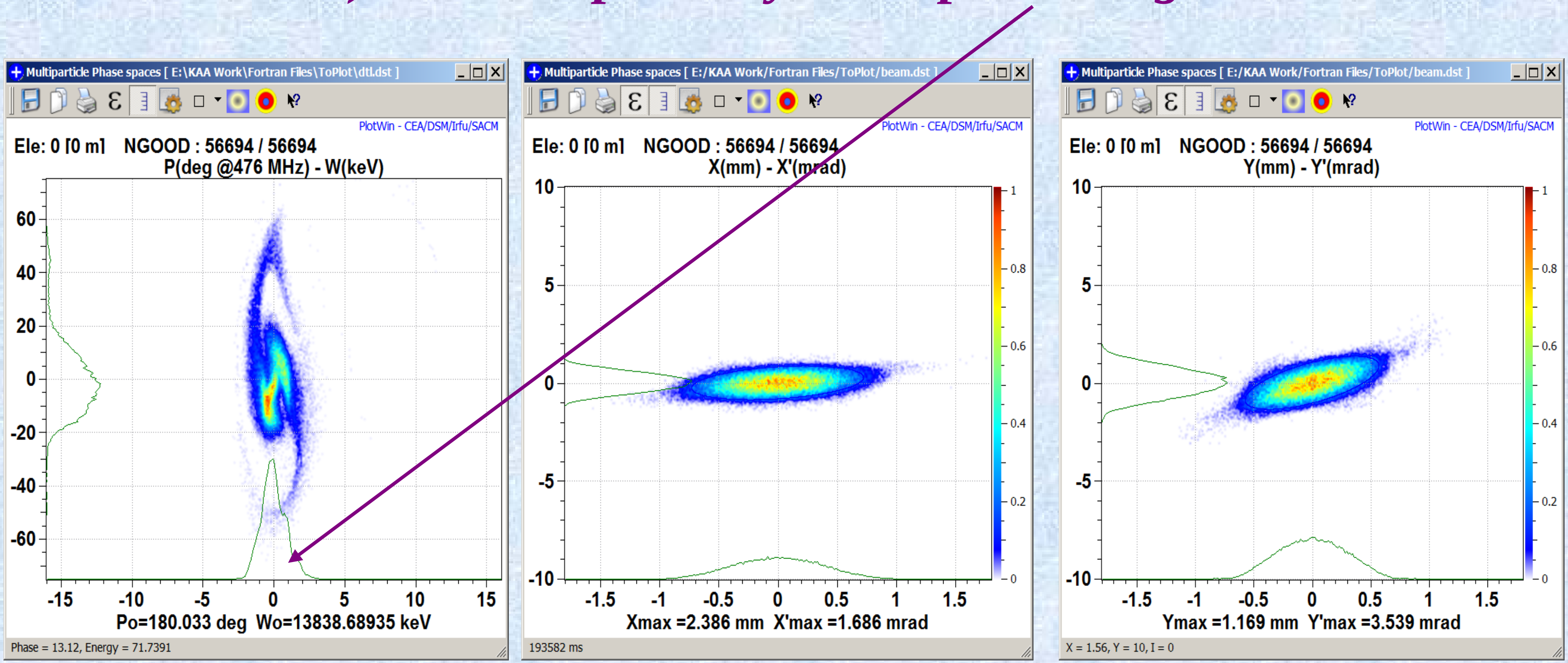
Proton source ***- 60 kV pulsed proton beam with peak current up to 3 mA and emittance 0.1 π mm mrad.*** *Formation is not possible. Beam collimation is possible.*

RFQ ***- pre-acceleration, bunches formation with small longitudinal emittance.***

Initial Part ***- acceleration, collimation (below 7 MeV) and conservation of longitudinal emittance.***

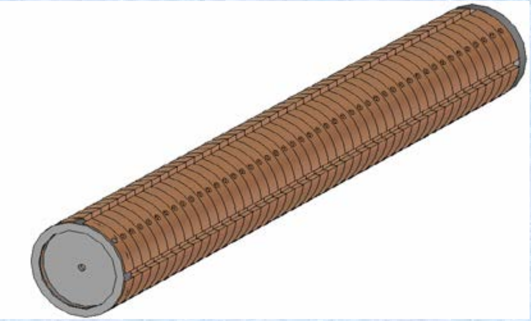
Main Part ***- main acceleration, energy regulation, traveling wave structure.***

Initial Part operates at frequency 476 MHz.
As the result of initial concept and deep optimization,
at output energy ~ 13.8 MeV we expect:
a) – pencil-like beam;
b) with exceptionally small phase length.



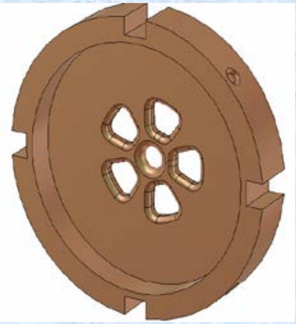
A frequency jump of 6 times is possible!

Accelerating Structure in the Main Part

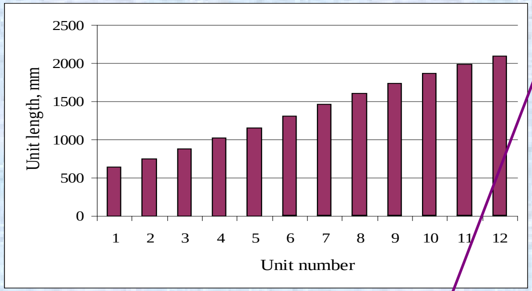


TW structure

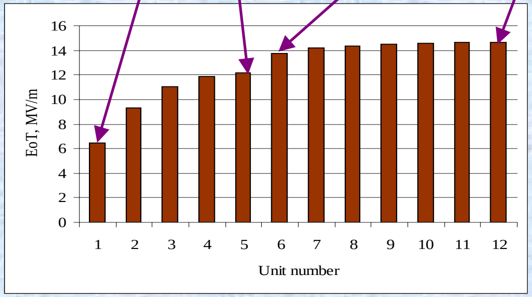
1. – Frequency 2856 MHz;
2. - Traveling Wave (TW) structure;
3. – Constant gradient EoT mode;
4. - Magnetic coupling –negative dispersion;
5. - 12 accelerating unitss;
6. – Usage of backward, n= -1, and direct, n = 0, field harmonics;
7. - Short filling time;
8. – High average accelerating rate of 13.2 MV/m;
9. – Rather conservative surface field;



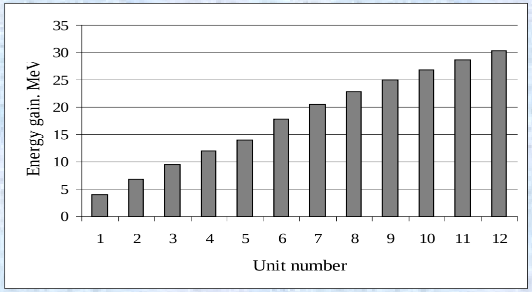
Cell



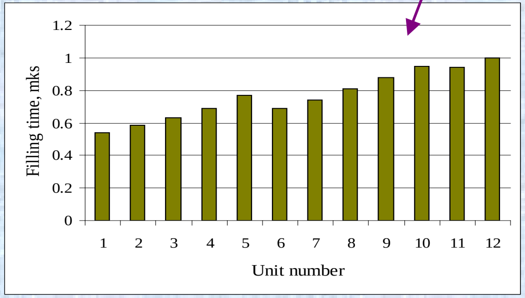
Unit length, mm,



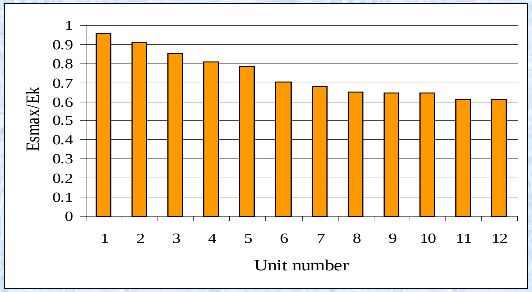
EoT, MV/m,



Energy gain, MeV.



Filling time, mks,



Esmax/Ek ratio

RF sources for Main Part

We need in total 144 MW of pulse RF power (average240 kW) .

Klystrons:

D.A. KOMAROV, E.P. YAKUSHKIN, YU.N. PARAMONOV, S.V. SURKOV

JSC "RPE "Toriy", Moscow, Russia

DEVELOPMENT OF A HIGHT-POWER S-BAND AMPLIFIER KLYSTRON KIU-278

A high-power pulsed amplifier klystron of the S-wavelength range KIU-278 was developed and manufactured at JSC "RPE "Toriy". The klystron operates in the frequency range 2846-2866 MHz with a maximum output pulse power of 8 MW and a gain of 50 dB at a cathode voltage of not more than 58 kV.

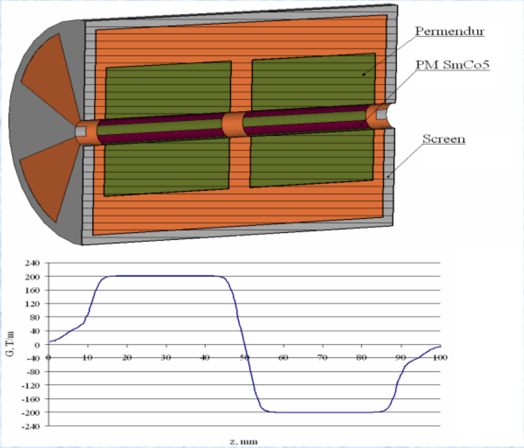
Very promising,
nice development!
For us it is much more suitable!
Our wishes – up to 12 MW!

Рисунок 2.
Фотография клистрона КИУ-278.

Focusing Elements and Lattice

FDO lattice with PMQ lenses with SmCo5 magnets.
Due to a small aperture of r < 4 mm,
the high focusing gradient can be achieved up to 260 T/m (simulations).

PMQ ,
G<215 T/m



For details see A. Durkin et. al., LaPLAZ 2021, Moscow, v.2, p. 311

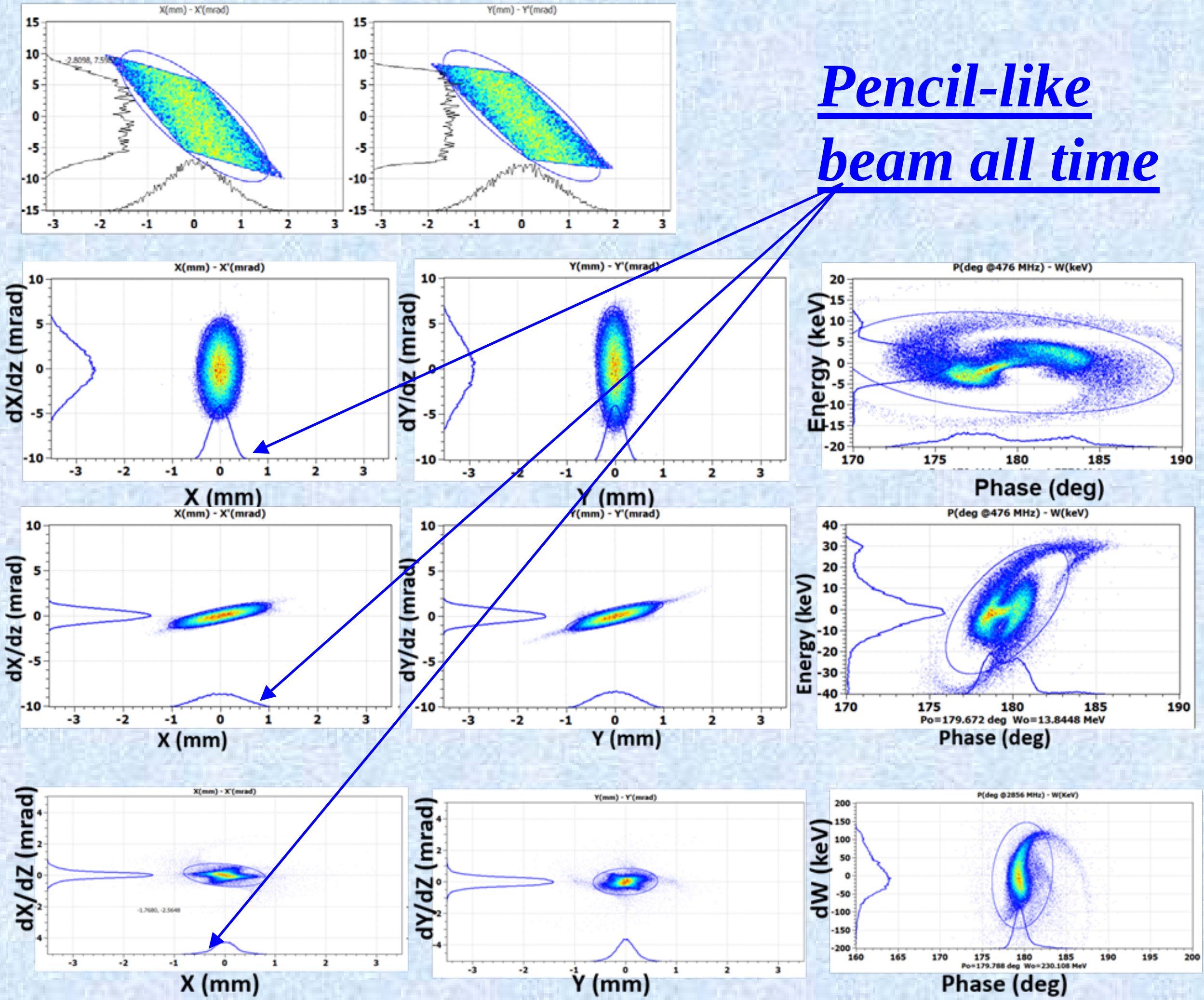
Reserve is sufficient. Not so easy, but possible.

A. Picardi et. al., PRAB, 23, 020102 (2020)

Front – end simulations

Beam portraits in phase space

Pencil-like beam all time



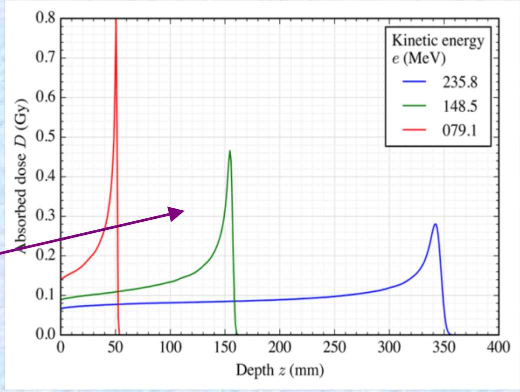
RFQ input

RFQ output

DTL output

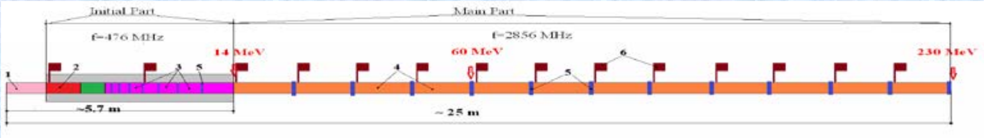
TW output

3D spot scanning

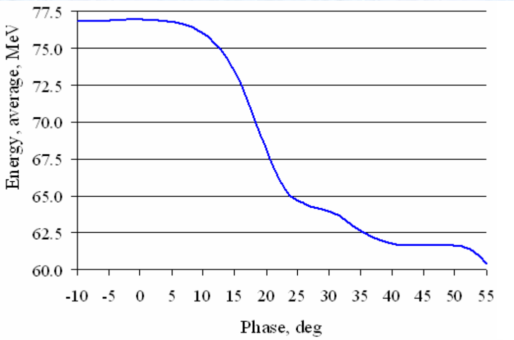


1. *Deflection in transverse x-y position with a relatively slow (~50 Hz) magnetic system.*
2. *Control longitudinal of Bragg peak position with control of output energy of protons.*
3. *Two approaches are possible -*
   - from one RF pulse to another RF pulse;
   -within one RF pulse.

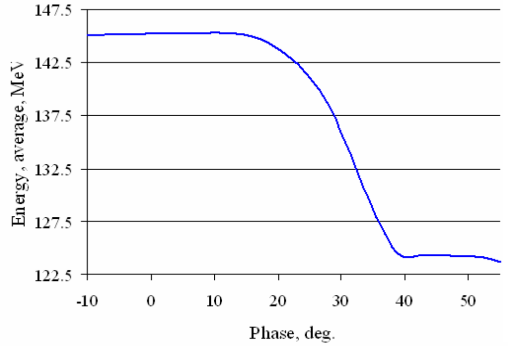
Energy regulation from one RF pulse to another.



The simplest option is RF phase change in one unit (subsequent ones are disabled).
The time for energy change is ~ 1/RR.
Thus way requires special hardware –short RF pulses with RR~1000 Hz .

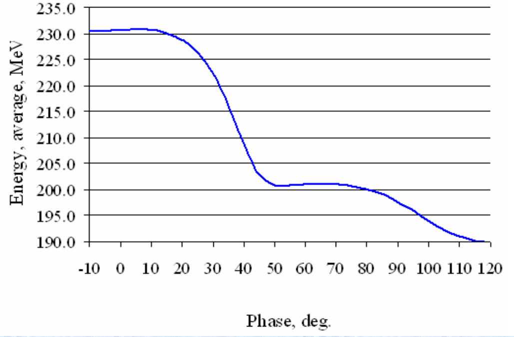


Units 7-12 off



Units 11-12 off

All time the beam envelope along the Main Part is within 1.0 mm.

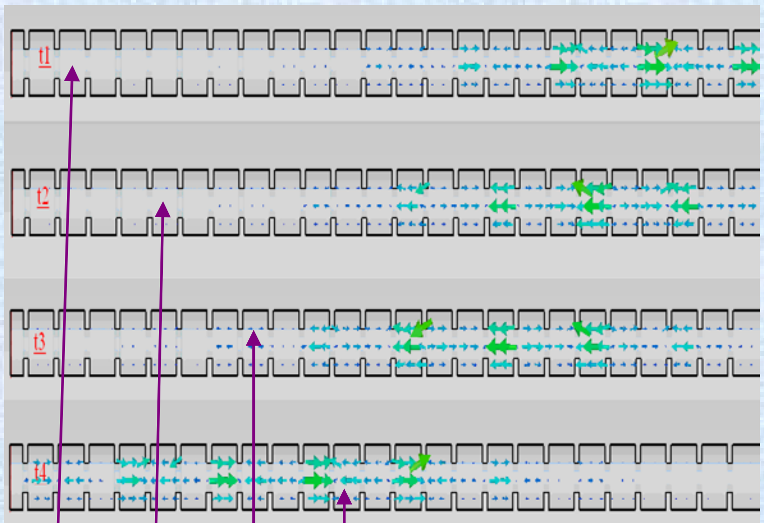


Last unit is much more flexible.

Energy regulation within one RF pulse.

Procedure is under development!

Differing from SW cavities, TW structures are non inertial element. ***Just for illustration! – CST example.***



t1 < t2 < t3 <t4

We can not put into CST long TW structure with variable cells dimensions along structure.
Other approach – Coupled Cells Model – is much more flexible.

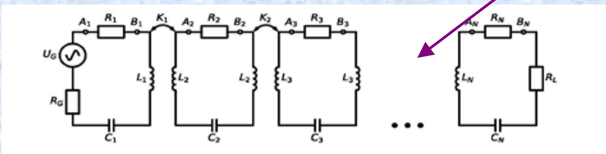
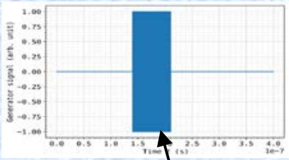
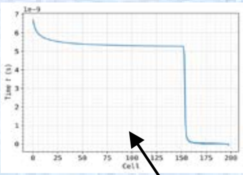


Рис. 2. Эквивалентная схема ускоряющей структуры. R_L — согласованная нагрузка (нет отражения).

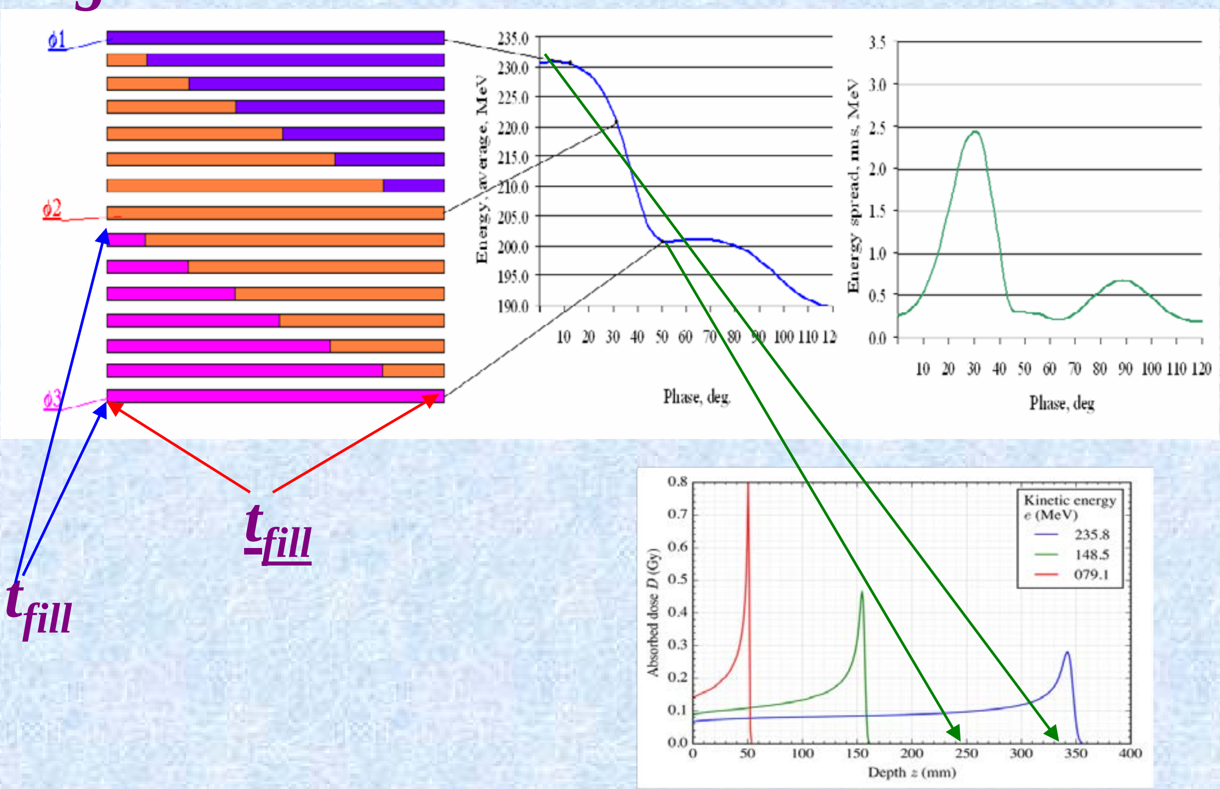


Input RF



Time difference

The time of particle flight t_{proton} is of ~ 0.007 mks.
The filling time t_{fill} – wave front propagation – is of ~1 mks.
Inside t_{fill} there are 476 bunches separated at ~2 2e-9 sec.
At this time the wave front will propagate at ~ 0.5 TW cell.
Suppose we can change RF phase inside RF pulse with time step t_{fill}.
Such modified pulse will be accepted by TW structure.
That case each bunch will see slightly different field distribution along structure.



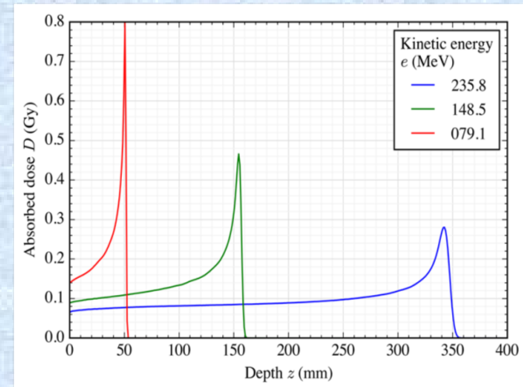
The maximal rate ~ 30 MeV/15 mks.

Equivalent bandwidth ~ 1 kHz.

Particles delivery

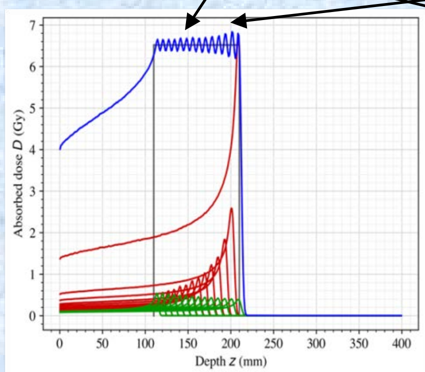
1. ***The low current concept and ideas, introduced in linac development, work for pulsed beam current up to 2.5-3 mA.***
2. ***With RF pulse length up to 16 mks linac can deliver up to ~2*10^{11} protons per RF pulse, inside ~7100 bunches with up to ~3*10^{7} per bunch.***
3. ***With possibility of fast RF phase control inside RF pulse this number of bunches can be distributed inside energy range up to 30 MeV by manipulations only with one accelerating unit.***

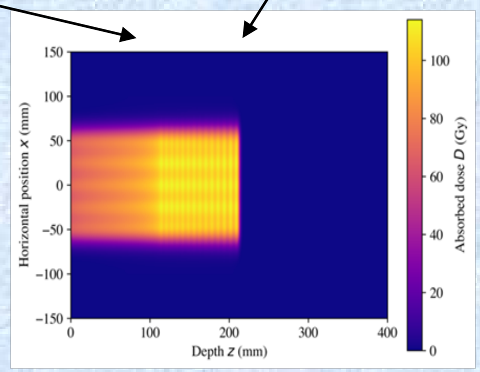
Radiation effect.

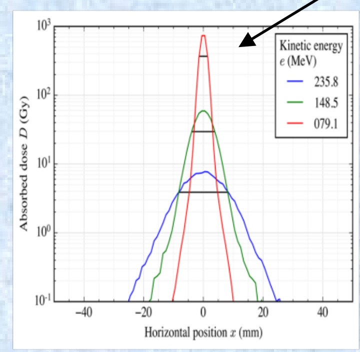


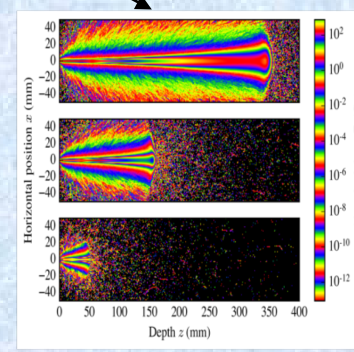
Mode

Therapy *FLASH* *Ultra FLASH*









~3Gr/sec *~100 Gr/sec* *~3000 Gr/sec*

SUMMARY

1. *The functional capabilities of the proposed linac are defined by the Main Part of this accelerator.*
2. *Application in the Main Part for accelerating units non inertial TW structures opens very attractive possibility for fast broad bandregulation of output energy by a change of input RF pulse phase inside RF pulse.*
3. *Linac general capabilities ensure its use in both practical and research medicine.*
4. *Conservative, long-term proven system parameters are selected for reliable stable operation.*
5. *In terms of a complete set of functional, economic and operational parameters, the proposed linac surpasses both cyclic facilities and advanced foreign competitors.*

Thank You for attention!