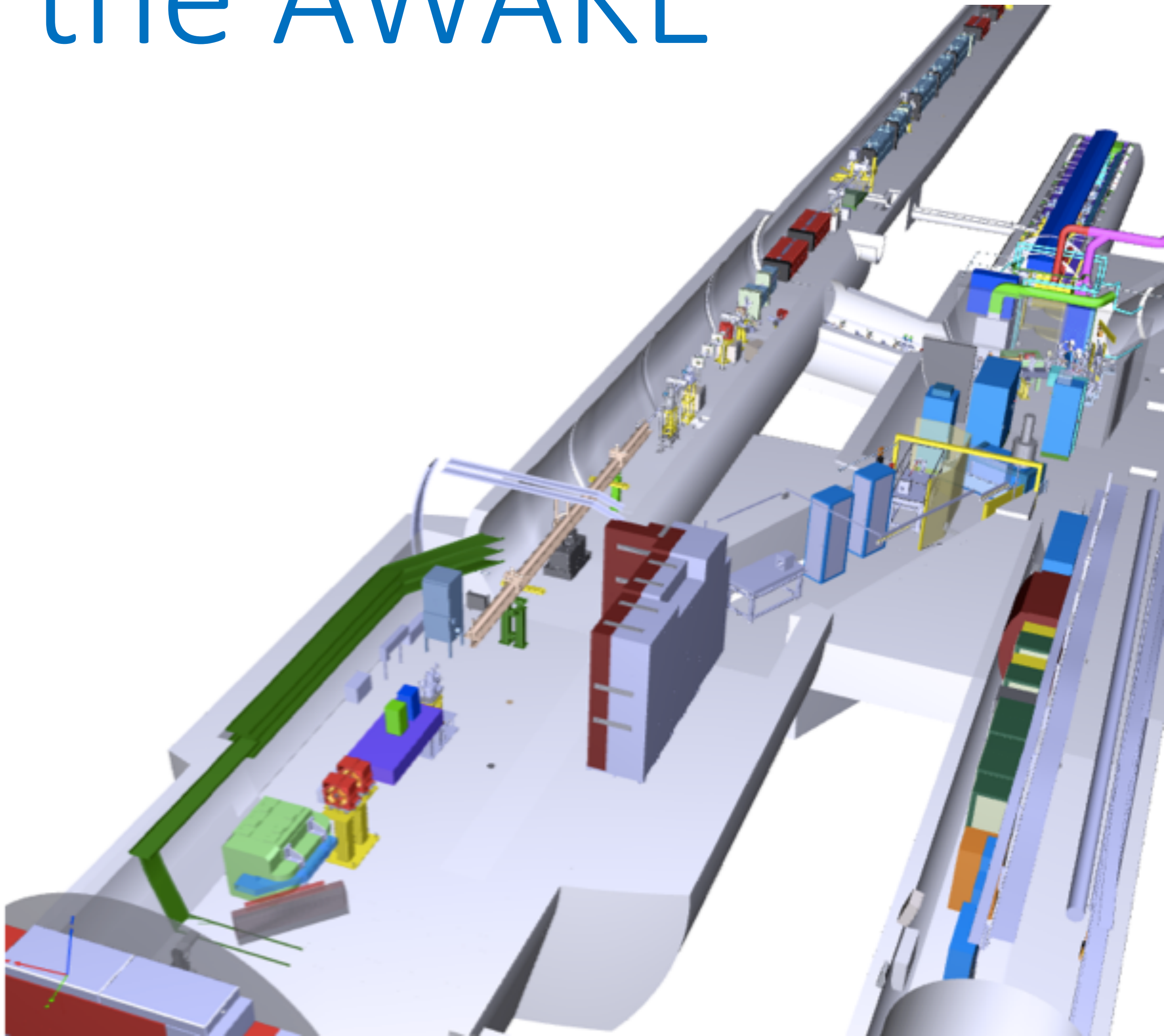
Pre-Modulation of the AWAKE Proton Bunch

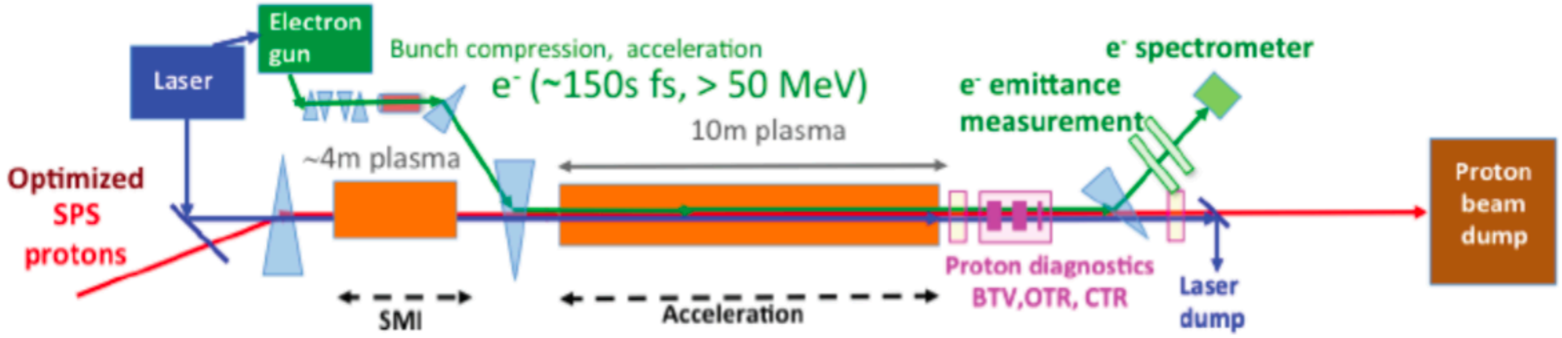


Spencer Gessner

27 August, 2018

Plasma Pre-Modulation

AWAKE Run 2 Baseline achieves plasma pre-modulation with a 4-m long plasma cell.



Advantages:

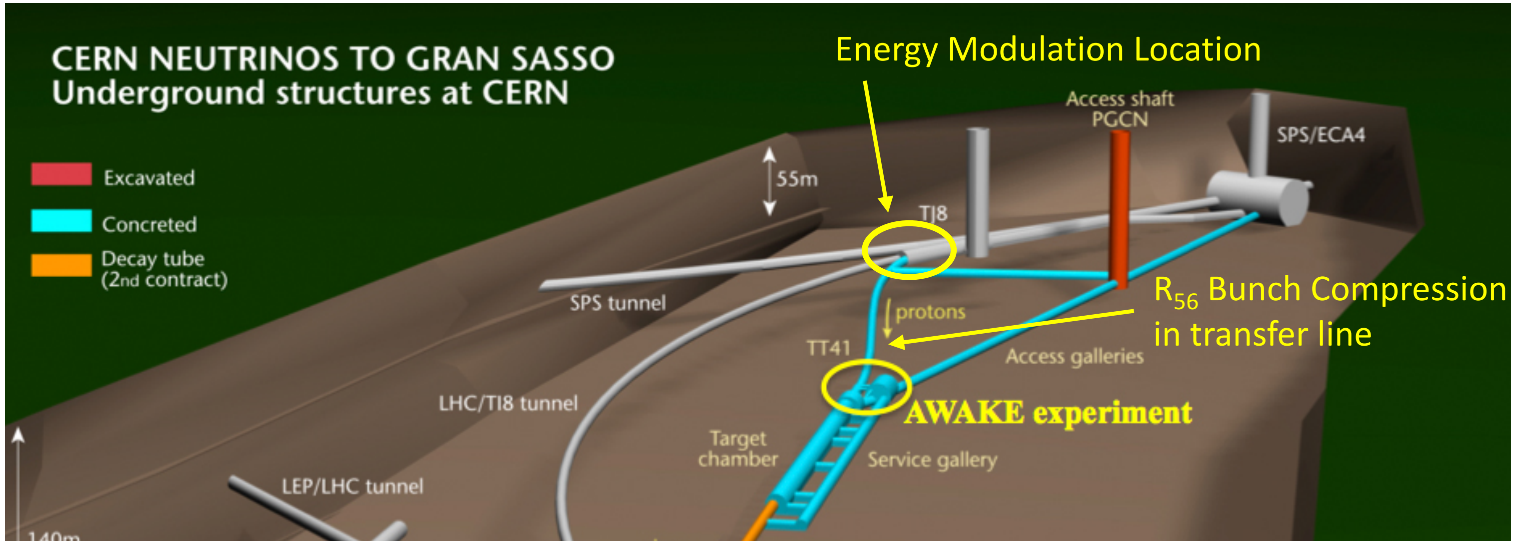
- All plasma solution
- Variable density and frequency of modulation

Disadvantages:

- Complicates ionization/seeding
- Low density plasma in between cells
- Not much available space

Alternative Approach

Modulate beam energy in the 100-200 GHz regime using a meter-scale linac powered by a gyrotron. Longitudinal modulation is achieved using R_{56} of transfer line.



Advantages:

- Bunch is already modulated when it reaches plasma cell
- No seeding required, can use Rb source, discharge source, or helicon source

Disadvantages:

- Can only operate at a single frequency/density
- Need a way to sync gytotron with electron injection
- Need space to install gyrotron and meter-scale linace in TT40 or TT41

History of this Concept at AWAKE

Alexey has previously studied this concept at AWAKE:

- Presentation 1
- Presentation 2

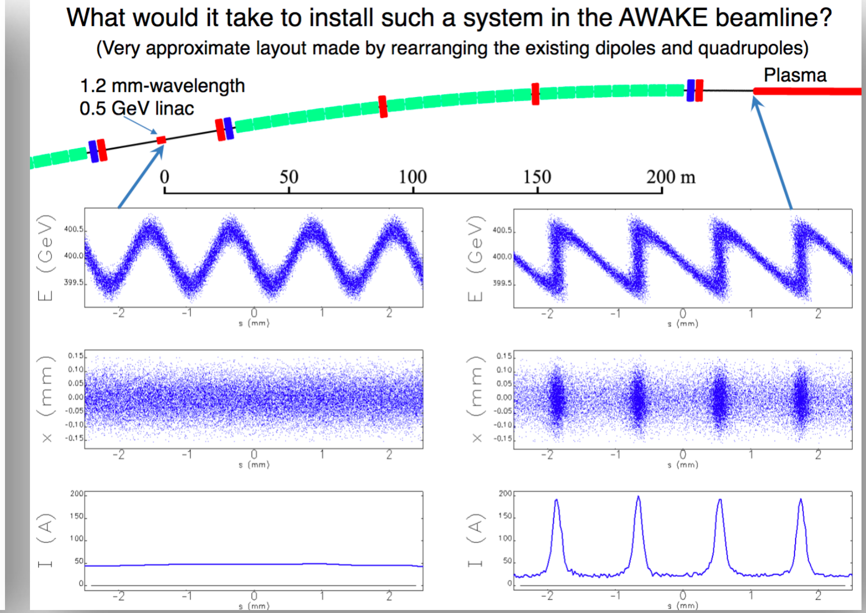
He identified a major disadvantage: requires 500 MeV electron beam to drive wake in modulating linac.

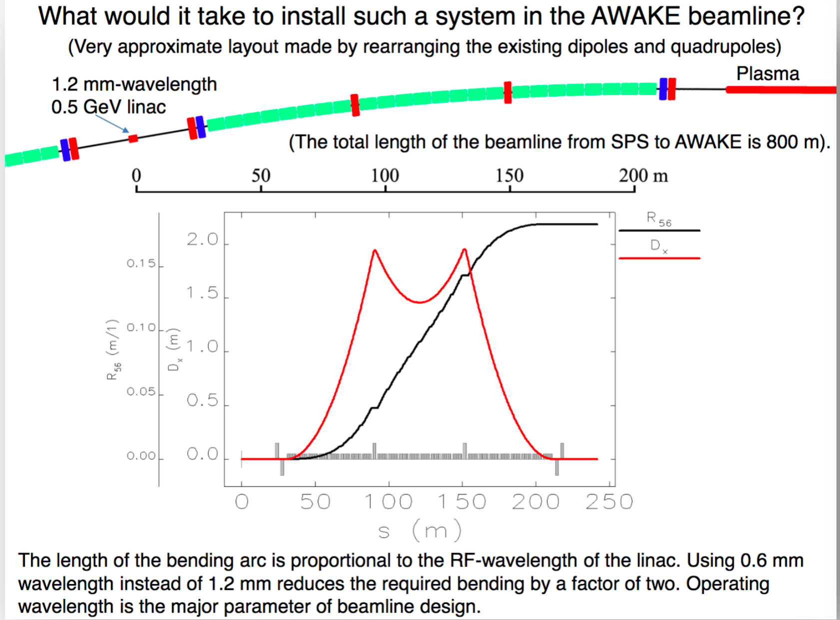
Proton beam micro-bunching using mm-wavelength accelerators

Alexey Petrenko,
AWAKE Collaboration Meeting, 10.03.2016, Lisbon

CERN AWAKE

This presentation is a follow-up on the earlier talk from the last Collaboration Meeting at CERN





Self-modulated vs prebunched beam as a driver for plasma wakefields

Transverse self-modulation:

Advantages

1. Plasma and beam parameters can be varied without restrictions.
2. The footprint of initial proof-of-principle experiment is small – minimum of infrastructure requirements.

Disadvantages

1. Large fraction of the proton beam is lost.
2. Wakefield phase is difficult to control since it is a result of intensity-dependent beam-plasma interaction => external injection is difficult.
3. Short laser or electron seed pulse is needed.

Longitudinal micro-bunching:

Advantages

1. Less protons are lost due to defocusing plasma wakefields.
2. All proton microbunches can be put into the focusing and decelerating phase of the wakefield => 2-3 times more efficient use of proton beam energy can be achieved.
3. Wakefield phase is clearly defined by the sequence of microbunches.
4. Easier to do with better quality proton beam (lower energy spread and emittance).

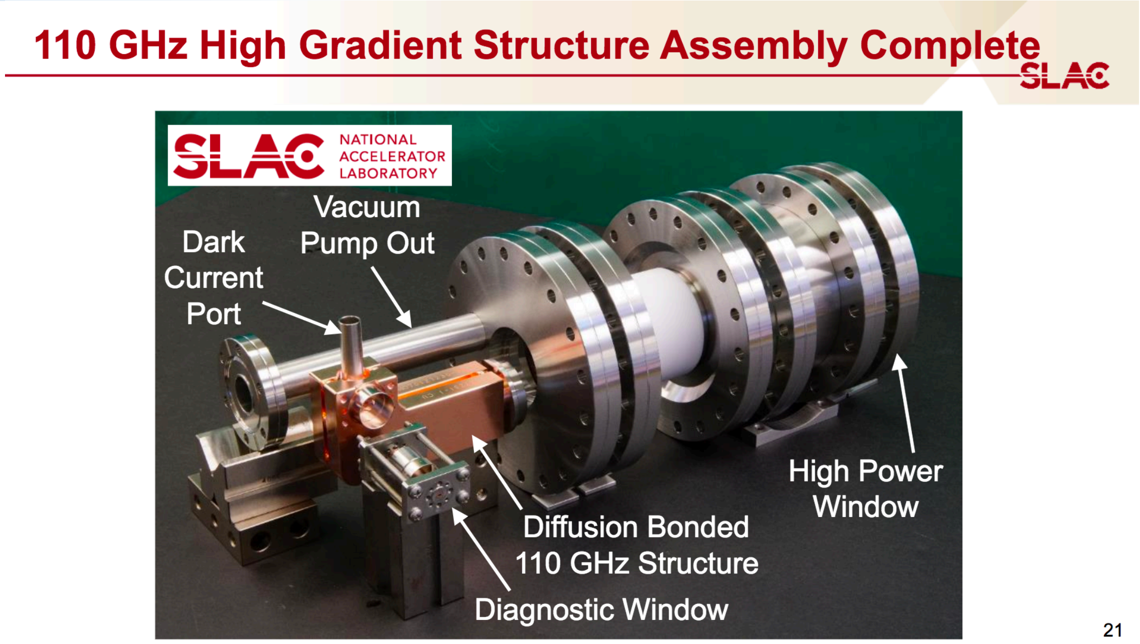
Disadvantages

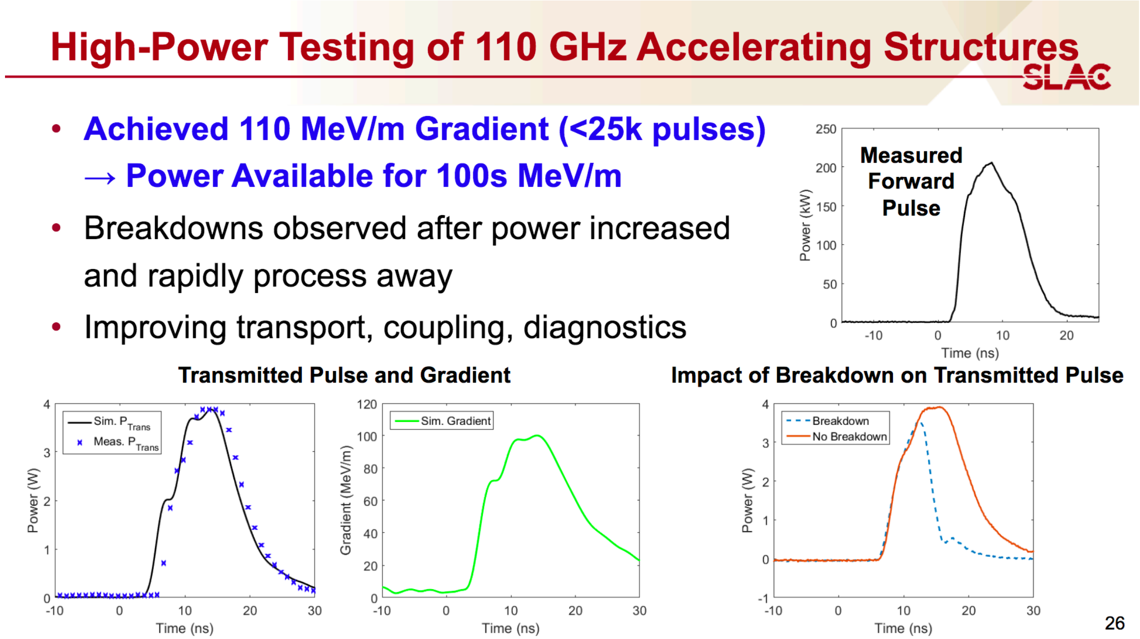
1. More investment into the infrastructure.
2. Plasma density is defined by the linac frequency.
3. Not fully tested technology of mm-wavelength accelerators is suggested (there's no mm-wavelength 0.5 GeV linac yet).
4. ~0.5 GeV ~1 nC electron beam source is needed as a driver for the modulating linac (however such source is also needed in the case of external injection).
5. Still some fraction of the proton beam is lost due to the defocusing plasma wakefields.

What's New: MW-class, stable Gyrotrons

During AAC 2018 in Colorado, Emilio Nanni of SLAC presented on advanced in mm-scale accelerator technology.

He highlighted recent results from their tests with a 110 GHz gyrotron. They achieve 110 MeV/m gradient with power available for more.

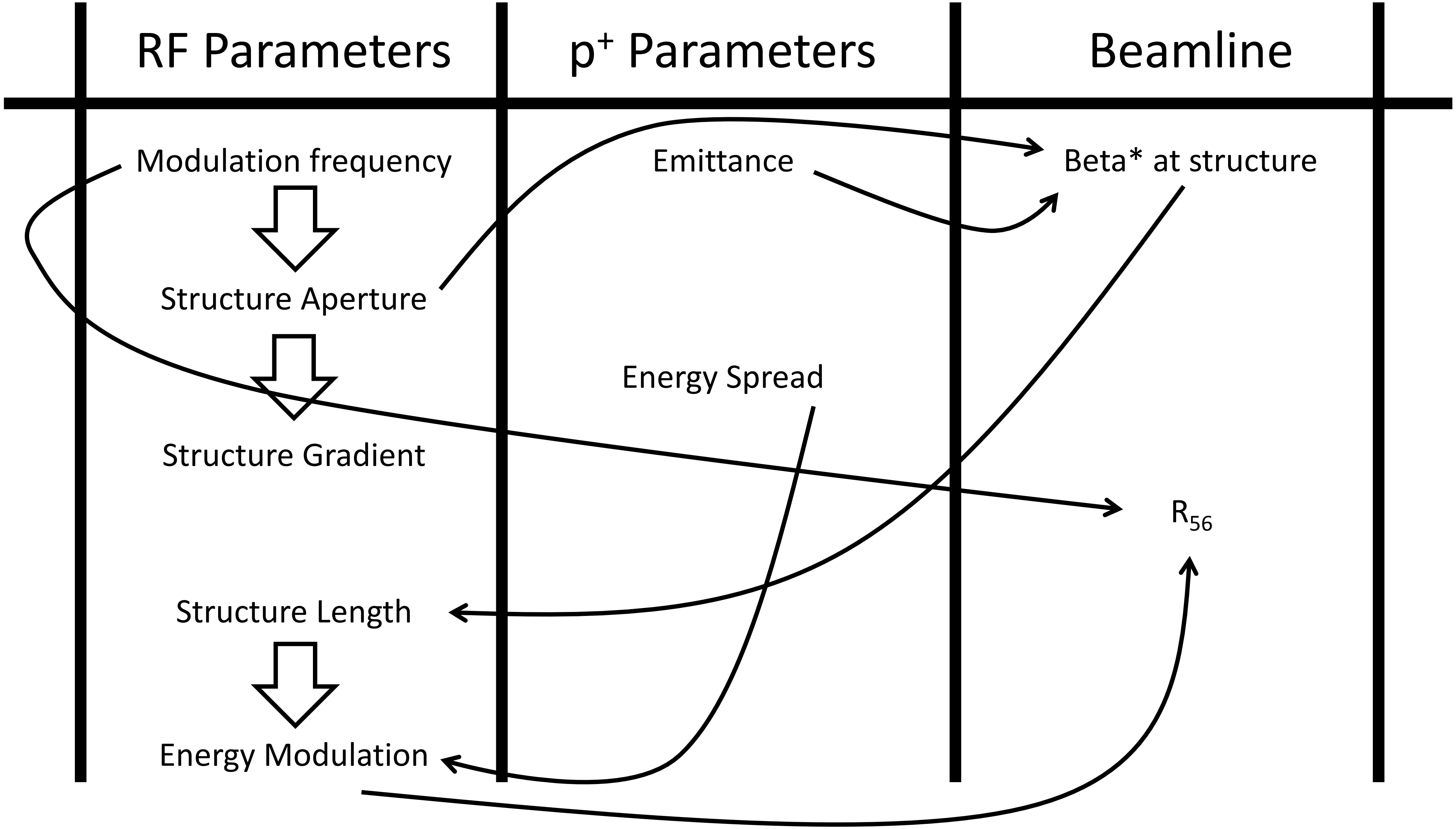




Considerations

RF Parameters	p^+ Parameters	Beamline
Modulation frequency	Emittance	Beta* at structure
Structure Aperture	Energy Spread	
Structure Gradient		R_{56}
Structure Length		
Energy Modulation		

Considerations



Working Point for a New Study

Gyrotron Parameters:

- Frequency = 170 GHz
- Wavelength = 1.76 mm
- Power = 1 MW
- Pulse length = 1 ms

Linac Parameters:

- Gradient = 100 MeV/m
- Length = 1.2 m
- Aperture 600 um

Proton Beam Parameters:

- Charge = 3E11
- Emittance = 1.5 mm mrad
- Energy 400 GeV
- Energy spread = 0.03 %

Beamline Parameters:

- Beta* at Linac = 96 m
- R_{56} = 2.93 m

Other Considerations

Timing:

- The gyrotron RF is not linked to laser or SPS.
- With 1 ms pulse length, should be enough time to feed-forward a fast trigger.

Location:

- The linac needs to be installed as far upstream as possible.
- Is it possible to install in TT40? Or only in TT41?
- Does the gyrotron need to be installed near the linac? Does this require civil engineering?

Opportunities for Collaboration

Gyrotron:

- Commercially available from Thales.
- Designed by EPFL.
  - Do they have spares? Would they make an in-kind contribution?

Linac:

- Designed by E. Nanni from SLAC.
  - Possible in-kind contribution?

Next Steps

MADX studies to examine compatible beam optics with minimal changes to the beamline.