Wakefield Acceleration using Two Electron Beams

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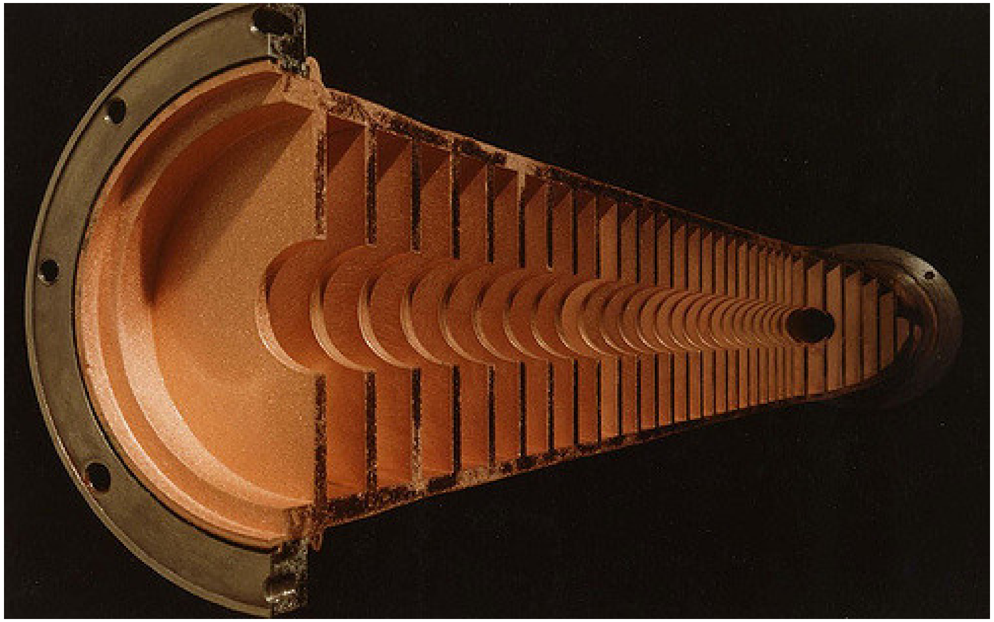
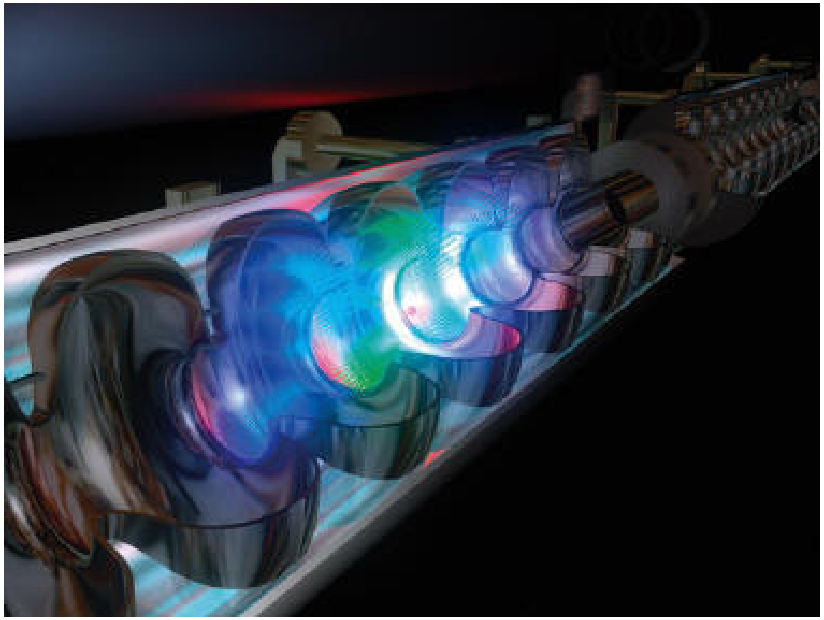
OUTLINE

- What and Why Wakefield Acceleration
- Argonne Flexible Linear Collider
- Two Beam Acceleration R&D @Argonne Wakefield Accelerator facility
- Bunch Shaper for Wakefield Acceleration @Argonne Wakefield Accelerator facility
- Summary

RF Driven Linear Accelerator Currently Used





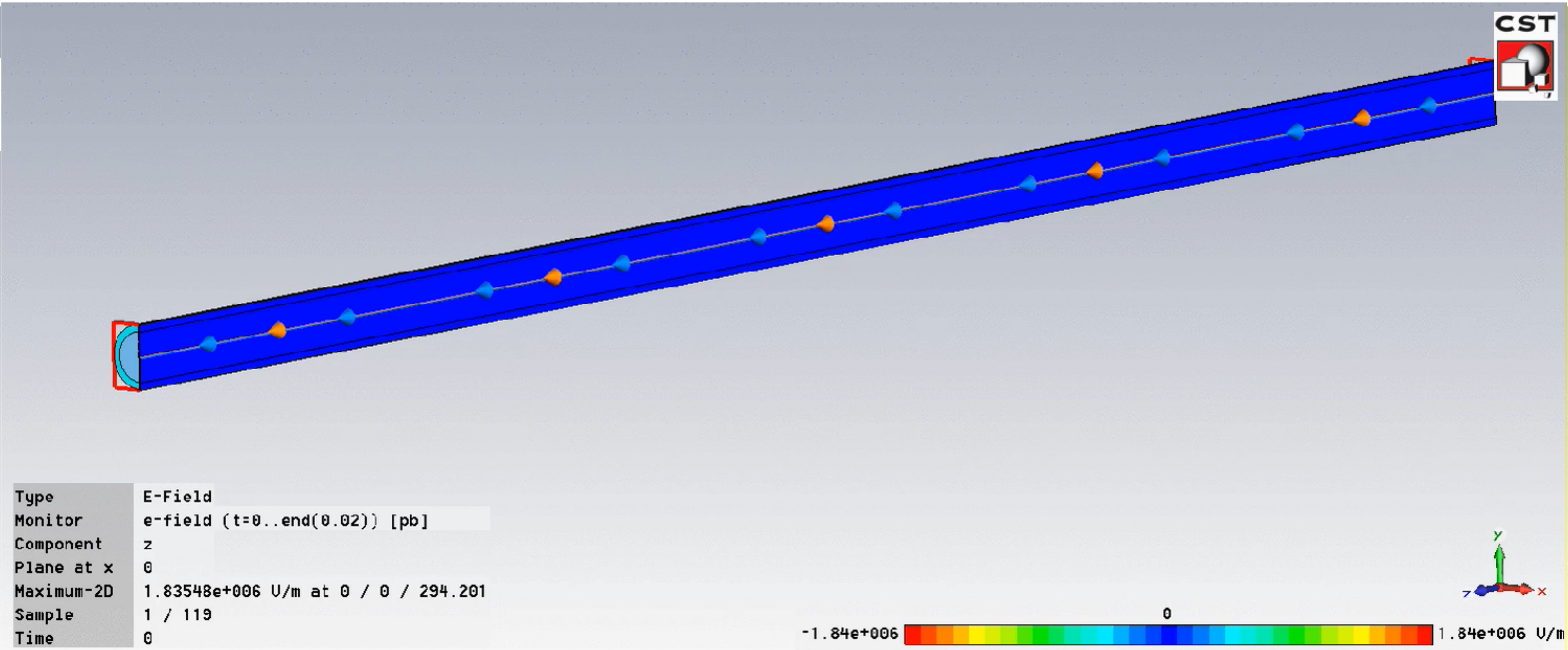
Resonant linear accelerators are usually single-pass machines. Charged particles traverse each section only once; therefore, the kinetic energy of the beam is limited by the length of the accelerator. Strong accelerating electric fields are desirable to achieve the maximum kinetic energy in the shortest length.

~100MV/m for NC (~10GHz)

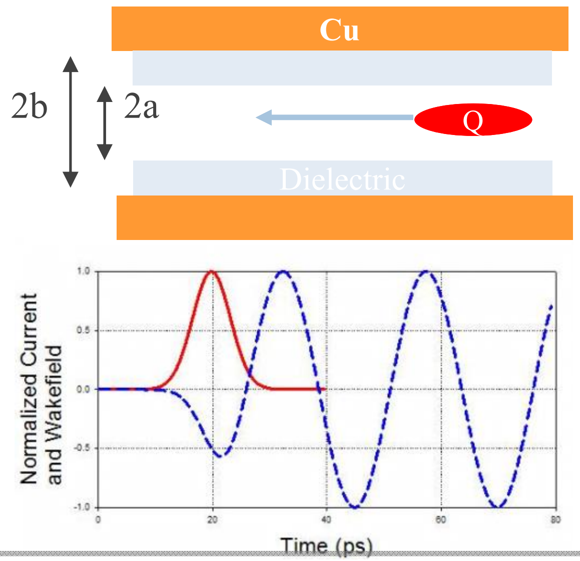
~30MV/m for SC (~1GHz)

OUTLINE

- What and Why Wakefield Acceleration

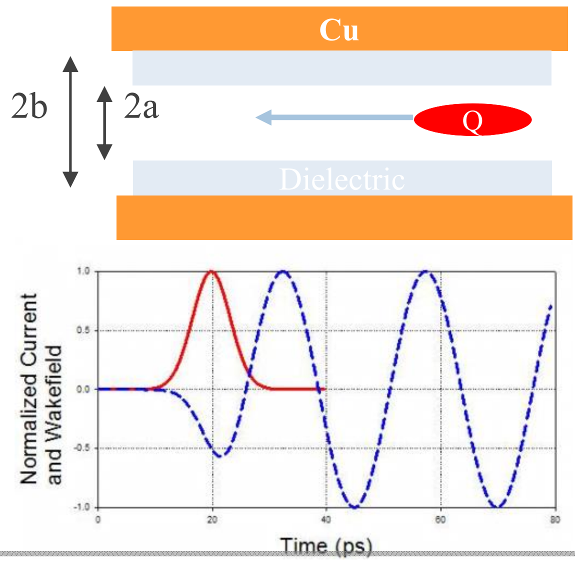


Wakefield Acceleration: High Gradient



Voltage: $$V(t) = -\int_{-\infty}^{t} I(\tau) W_z(t-\tau) d\tau$$

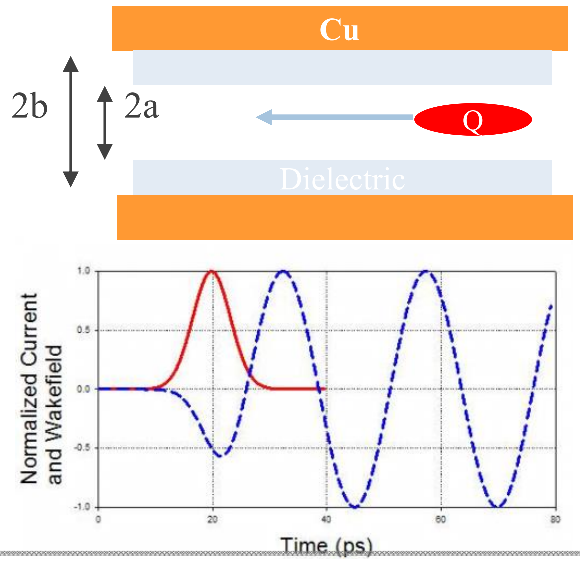
Wakefield Acceleration: High Gradient



Voltage: $V(t) = -\int_{-\infty}^{t} I(\tau) W_z(t-\tau) d\tau$

Wake function: structure related; favors high frequency;

Wakefield Acceleration: High Gradient

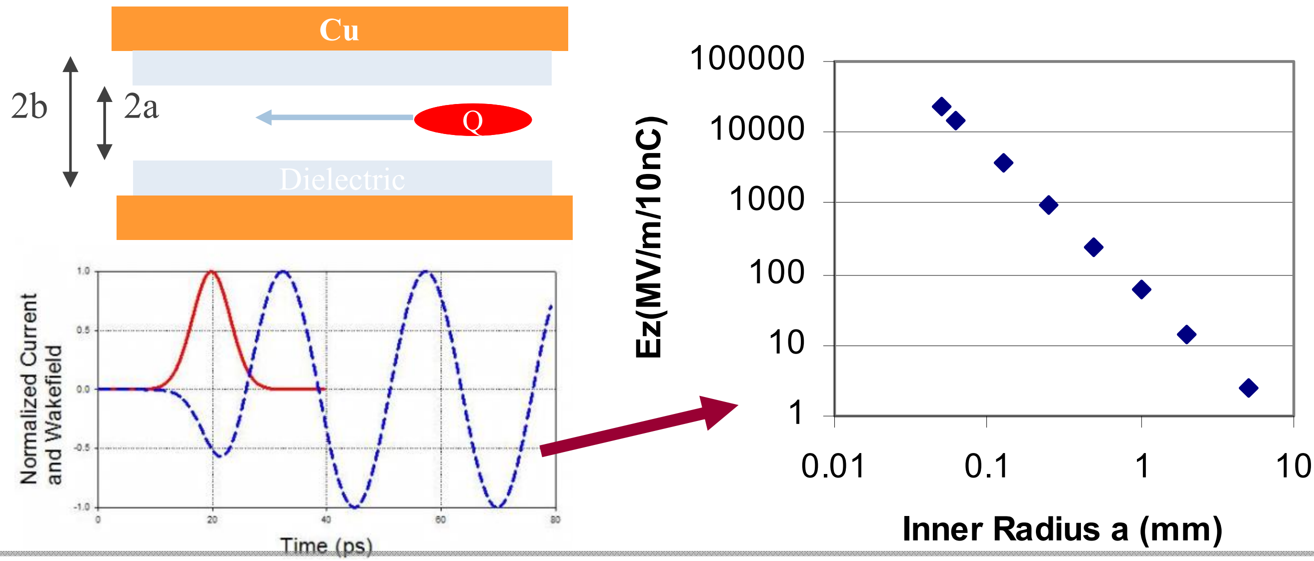


Voltage: $V(t) = -\int_{-\infty}^{t} I(\tau) W_z(t-\tau) d\tau$

Drive bunch current:
bunch length related;
favors shorter bunch;

Wake function:
structure related;
favors high
frequency;

Wakefield Acceleration: High Gradient

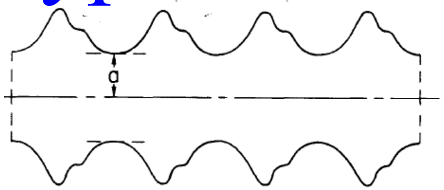


Voltage: $$V(t) = -\int_{-\infty}^{t} I(\tau) W_z(t-\tau) d\tau$$

Drive bunch current: bunch length related; favors shorter bunch;

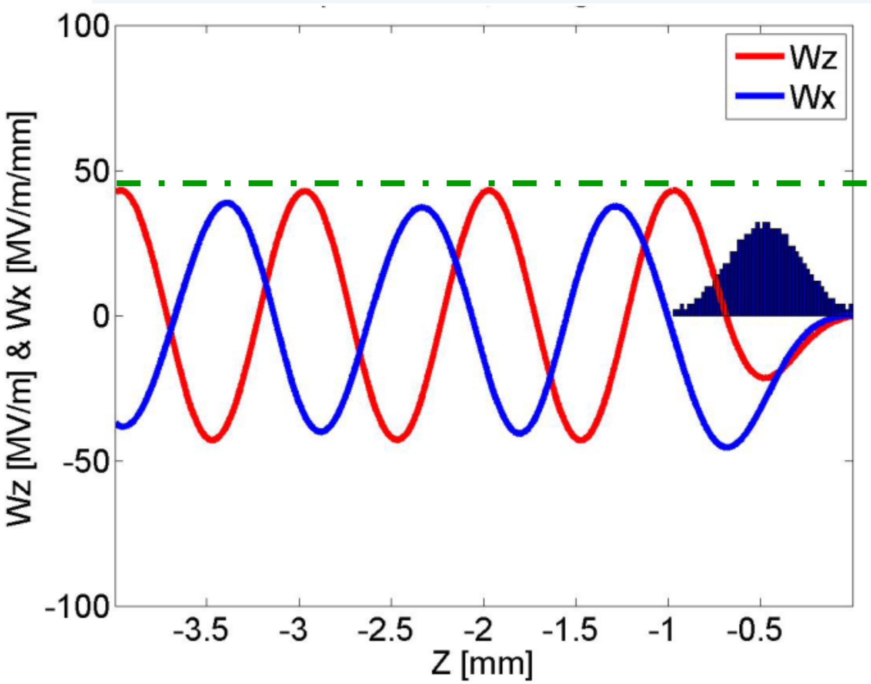
Wake function: structure related; favors high frequency;

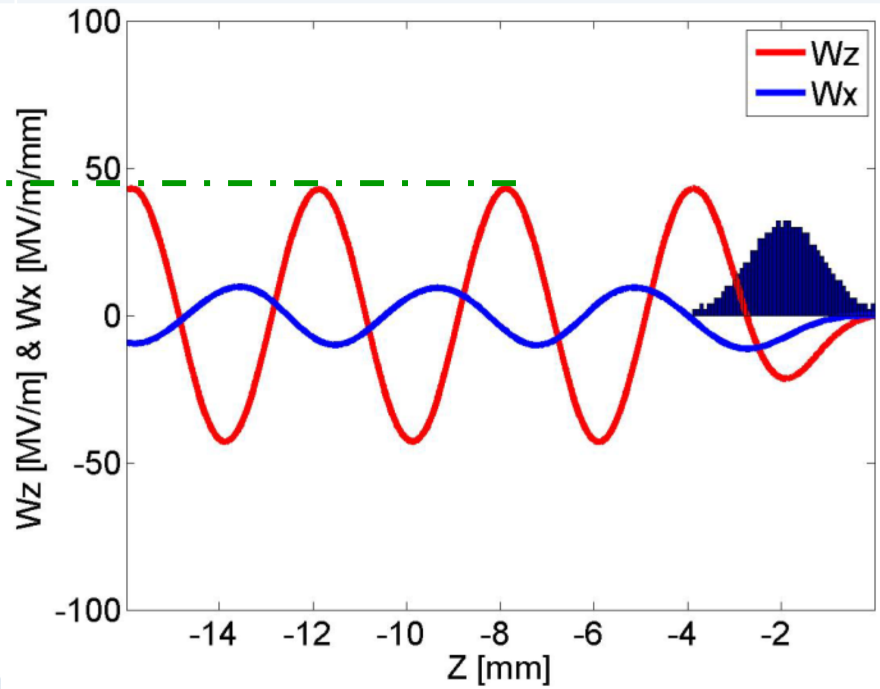
Two Types of Wakefield



$W_z \sim Q/a^{\wedge}2,\ W_{\perp} \sim Q/a^{\wedge}3$

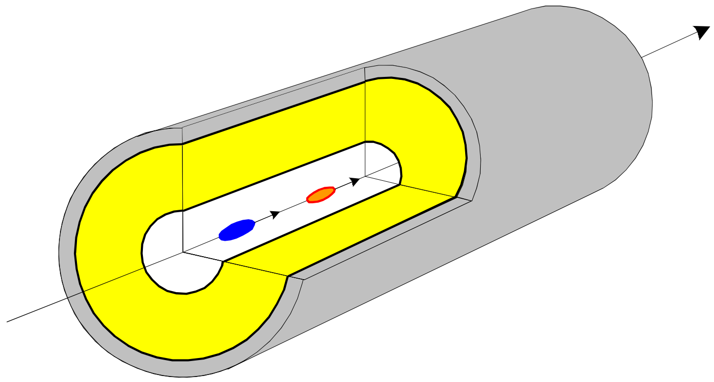
Case I	Case II
a=0.5mm	a=2mm
Q=1nC	Q=16nC
Freq.=300GHz	Freq.=75GHz
σz/λ=0.2	σz/λ=0.2

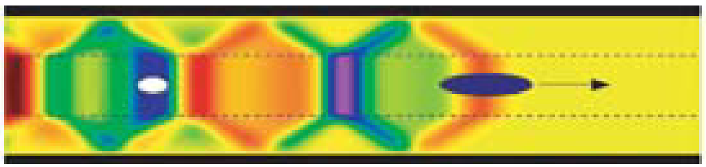




Two Main Formats of Wakefield Acceleration

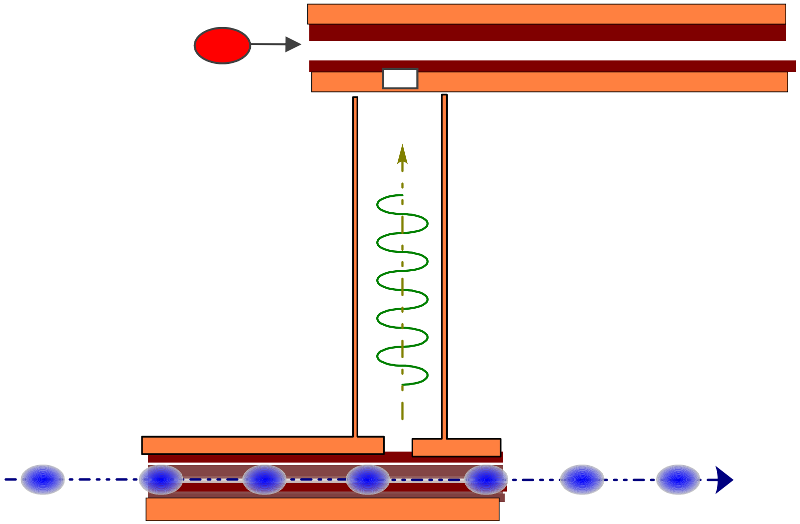
Collinear wakefield acceleration





- Single bunch acceleration
- low charge
- high repetition rate

Two Beam Acceleration



- bunch train acceleration
- high charge
- low repetition rate

Mission of Wakefield Accelerator Technologies

High Energy $e^- e^+$ Collider:

- High efficiency: ~10% (wall plug)
- High gradient: >200MV/m (effective)
- High luminosity (high beam power)

Technologies extended beyond HEP --- High Rep. Rate FEL

- Ultrahigh repetition rate: >100KHz
- High efficiency collinear wakefield acceleration: >10%
- Low construction and operational cost

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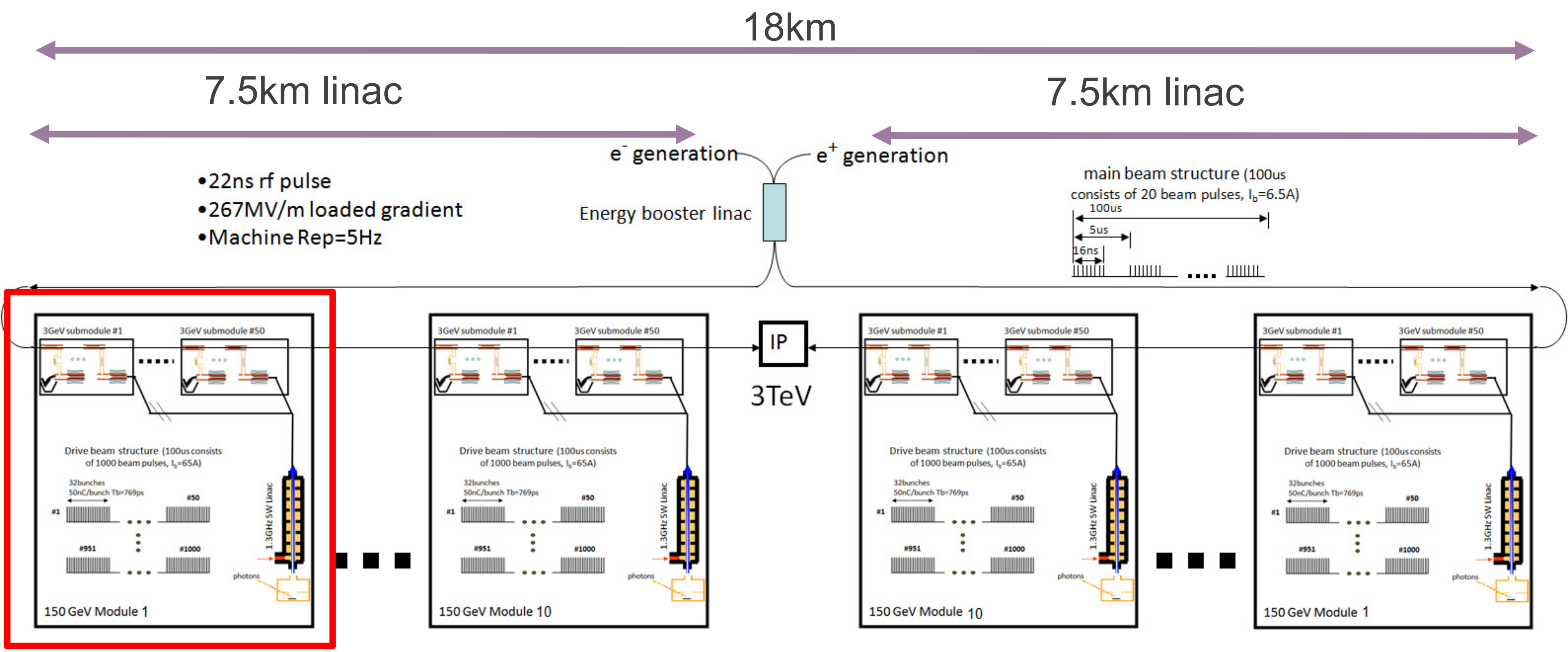
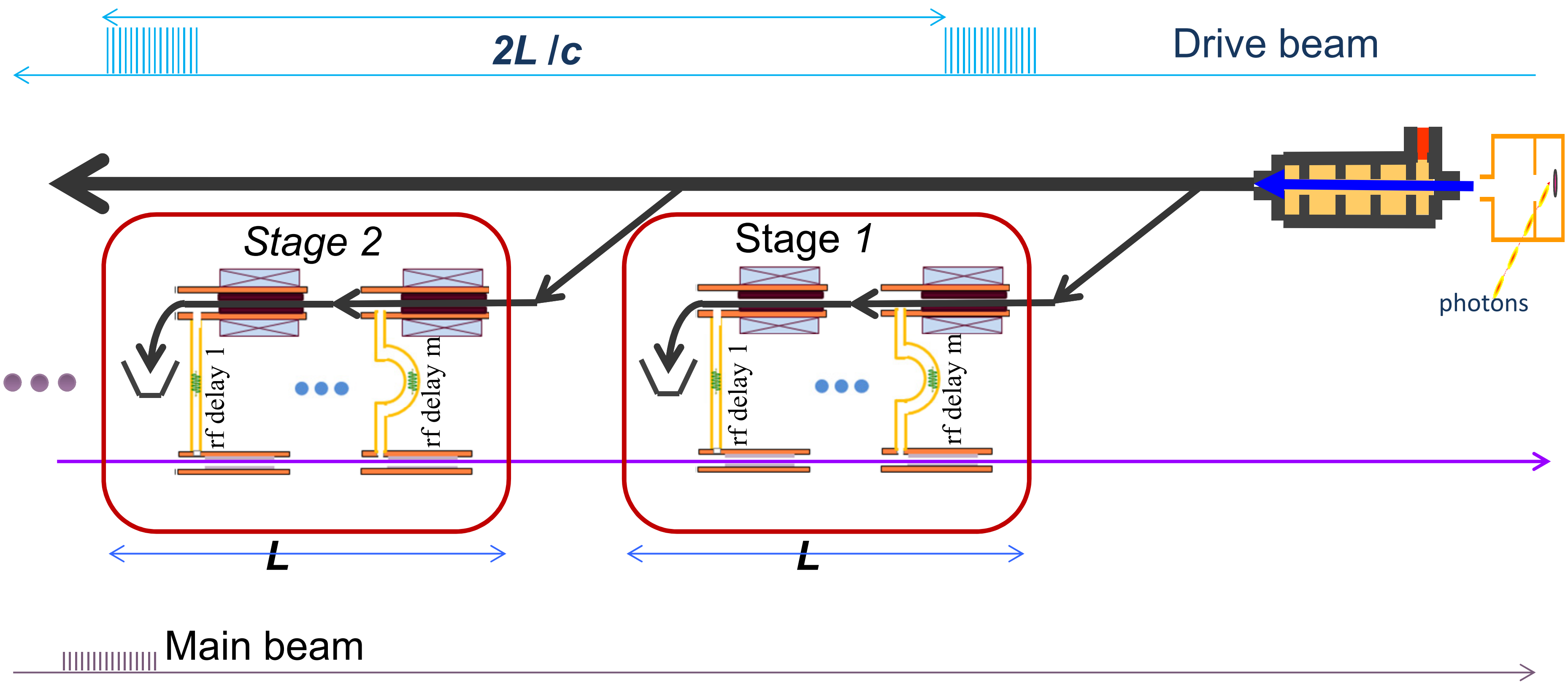
3TeV 30MW Beam Argonne Flexible Linear Collider

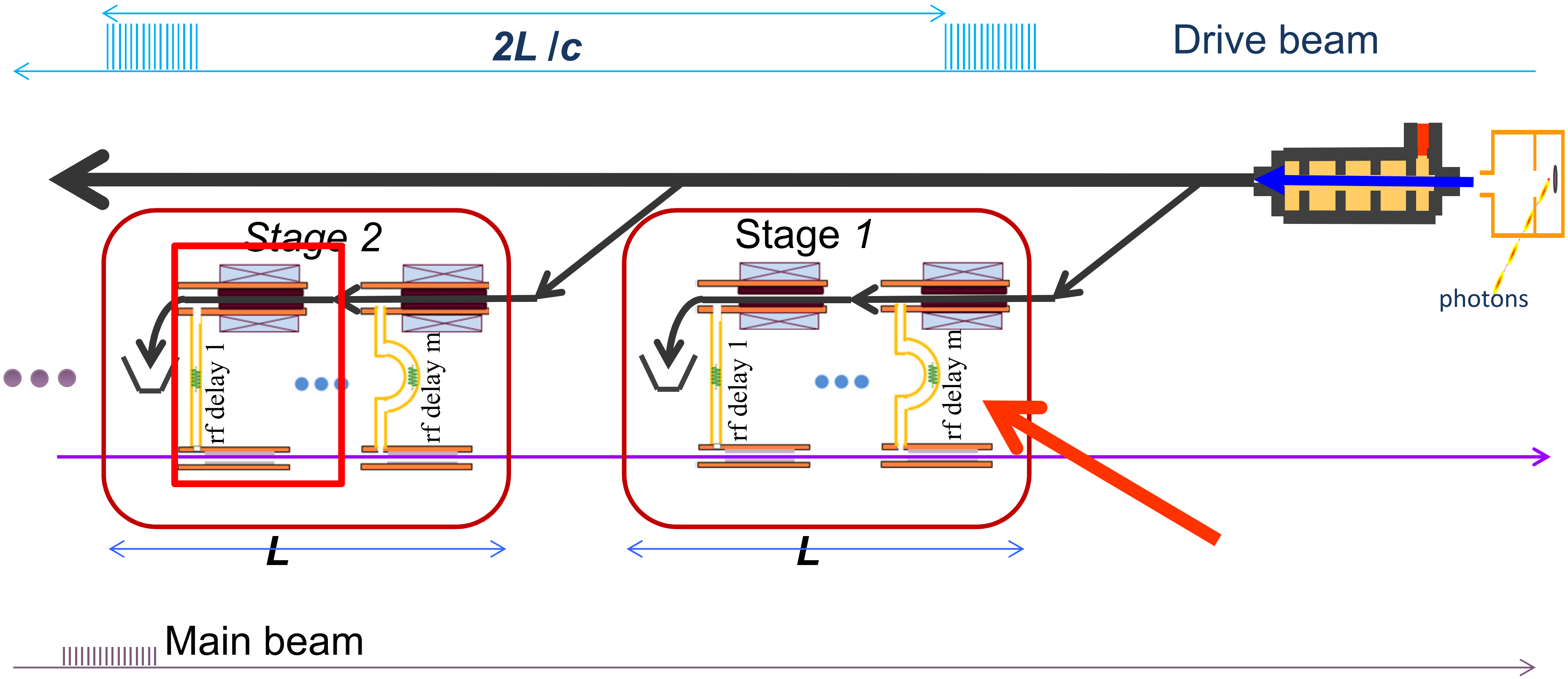


- **Based on scientifically mature and low cost Dielectric TBA technologies**
  - Short rf pulse (**20ns**) for high gradient ($e^+ e^-$ **200MeV/m of effective gradient**)
  - Modular design → easily staged
  - Wall plug efficiency (~10%)

Zoom-in for each 150GeV AFLC Module



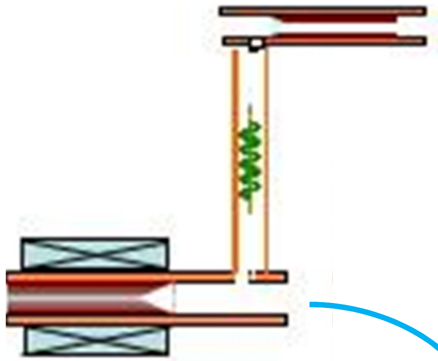
Zoom-in for each 150GeV AFLC Module



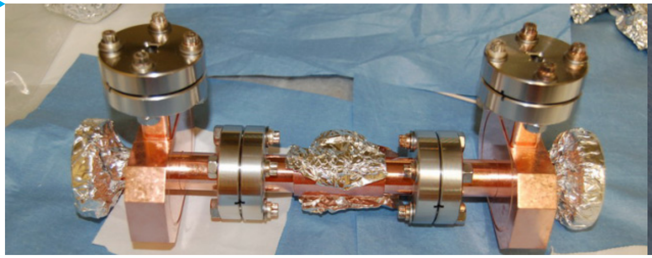
Simplified Staging by manipulating RF instead of high energy drive beam

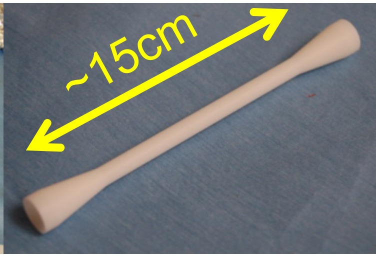
Zoom-in to AFLC Structure Level

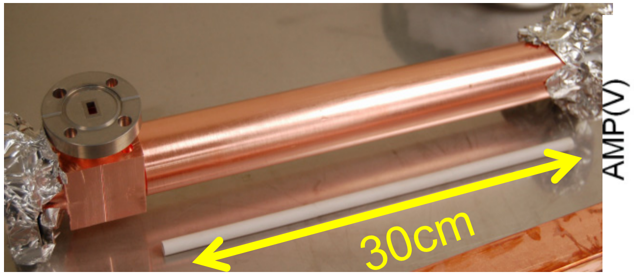
Short pulse accelerator

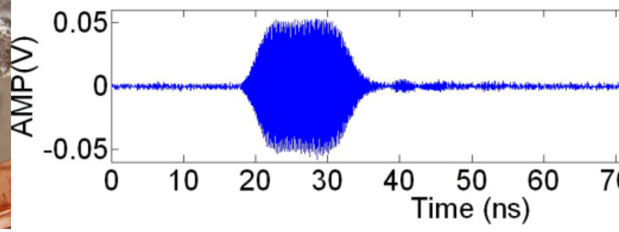


Power Extractor



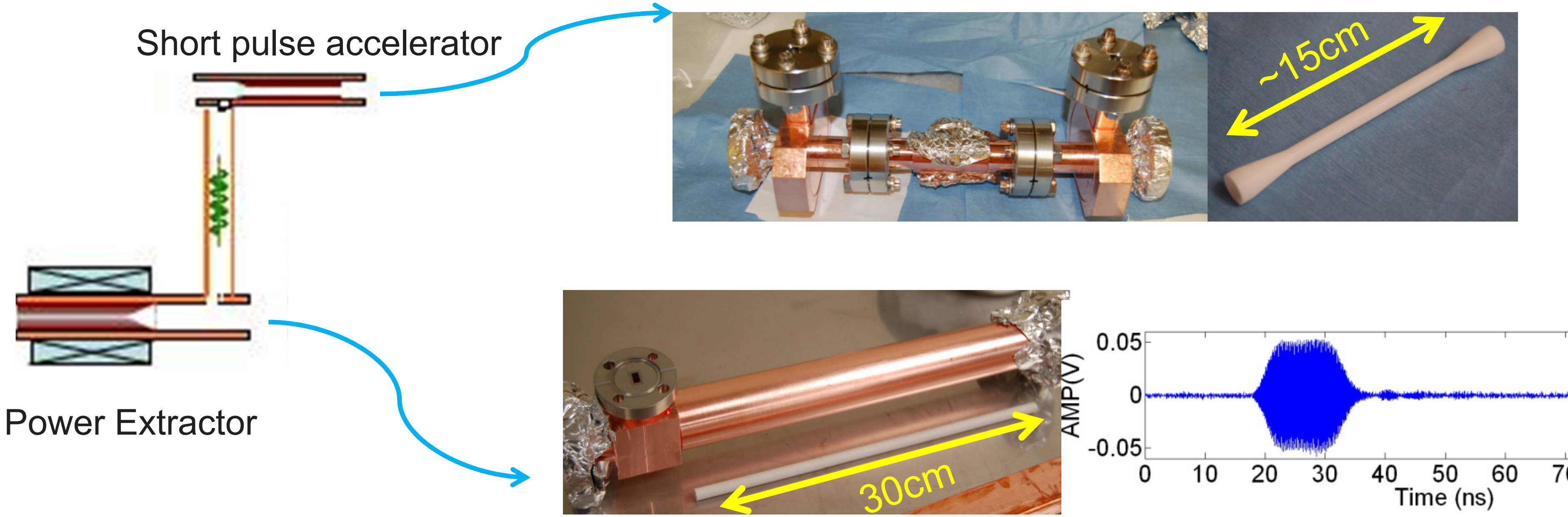






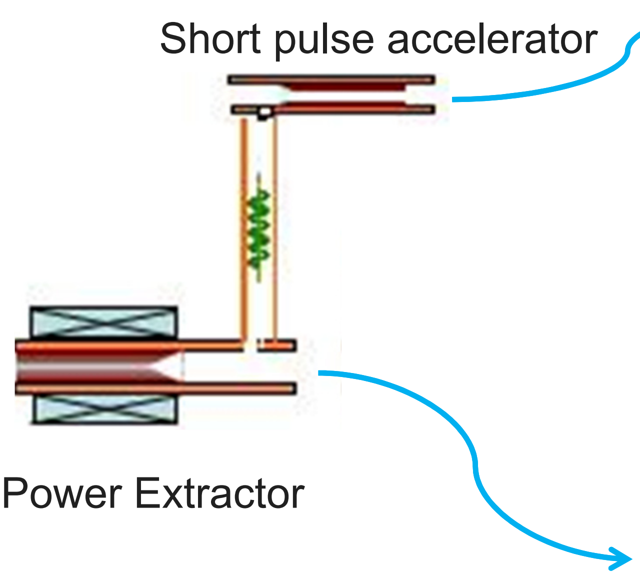
Gradient needs ~300MV/m

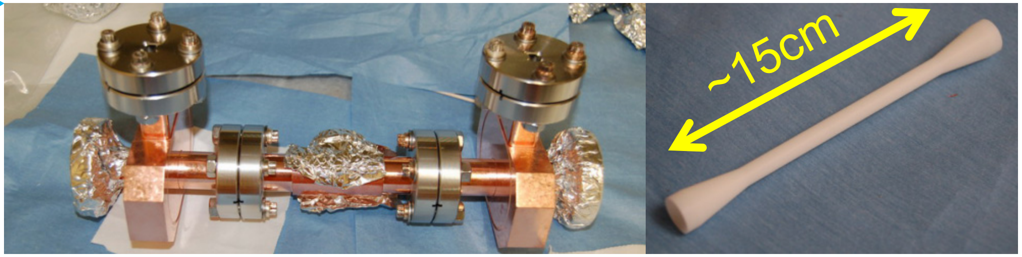
Zoom-in to AFLC Structure Level

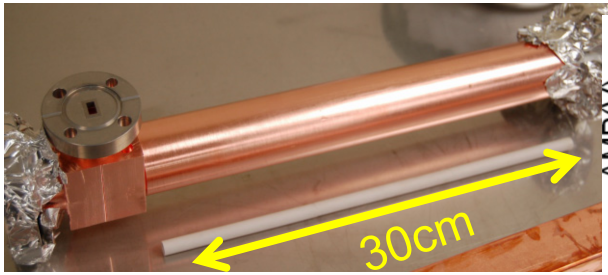


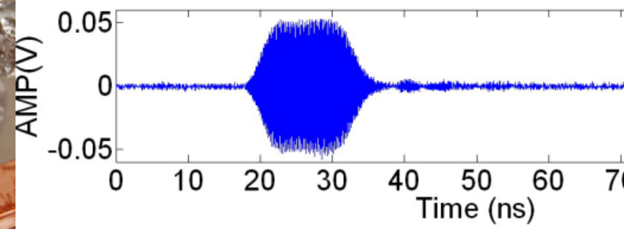
Gradient needs ~300MV/m ➡ Shorten the rf pulse length ~20ns

Zoom-in to AFLC Structure Level







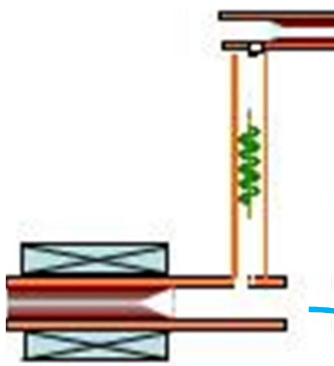


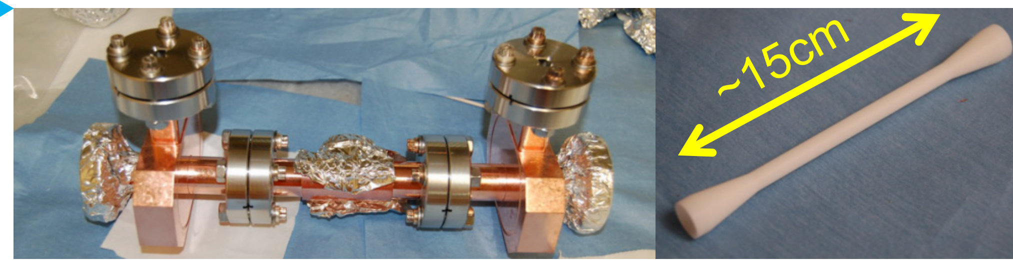
Gradient needs ~300MV/m → Shorten the rf pulse length ~20ns

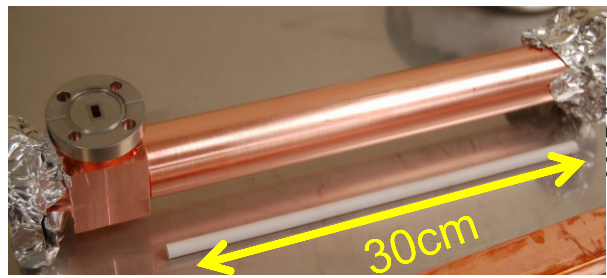
High group velocity accelerator (10%c) to reduce rf filling time

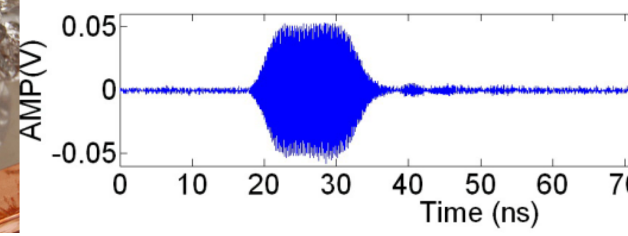
high frequency (26GHz) to high shunt impedance

Zoom-in to AFLC Structure Level









Gradient needs ~300MV/m → Shorten the rf pulse length ~20ns

High group velocity accelerator (10%c) to reduce rf filling time

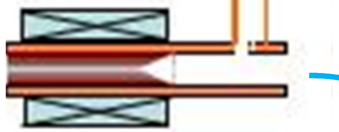
high frequency (26GHz) to high shunt impedance

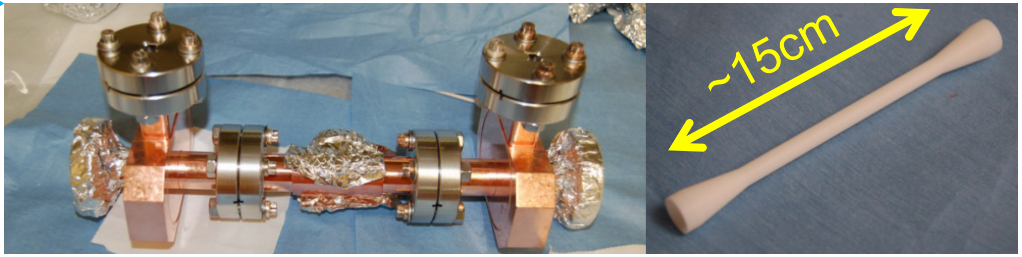
GW level rf power → TBA

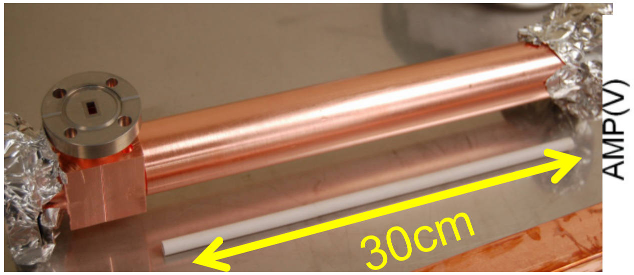
Zoom-in to AFLC Structure Level

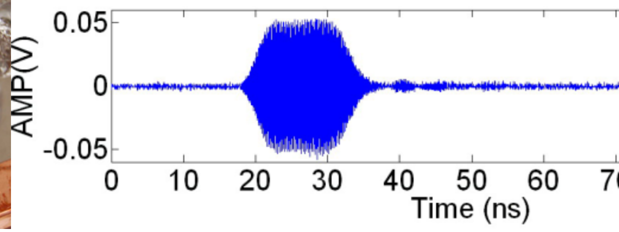
Short pulse accelerator

Power Extractor









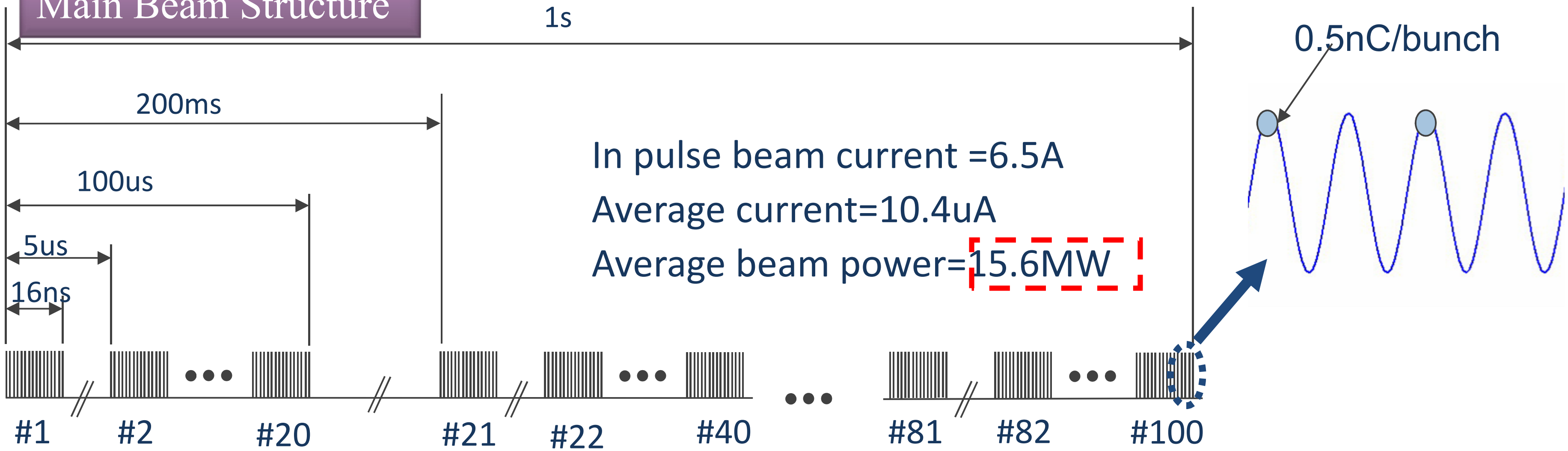
Gradient needs ~300MV/m → Shorten the rf pulse length ~20ns

High group velocity accelerator (10%c) to reduce rf filling time → GW level rf power → TBA

high frequency (26GHz) to high shunt impedance → Dielectric accelerator for low cost

AFLC Beam Power for high luminosity:

Main Beam Structure



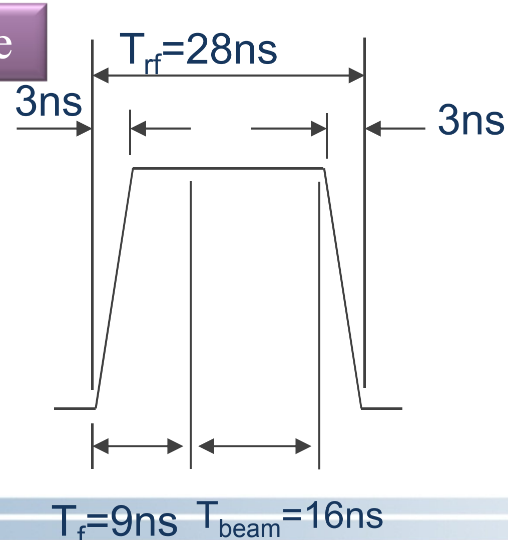
In pulse beam current =6.5A

Average current=10.4uA

Average beam power=15.6MW

AFLC RF-to-beam efficiency:

RF Structure



Competitive rf-beam efficiency for the short pulse TBA

$$\eta_{bRF} = \frac{I_{beam} E_{load} L_s}{P_{rf}} \times \frac{T_{beam}}{T_{rf}} = 26\%$$

I_{beam} = 6.5A, E_{load} = 267MV/m, L_s = 0.3m, T_{beam} = 16ns, P_{rf} = 1.264GW, T_{rf} = 25ns

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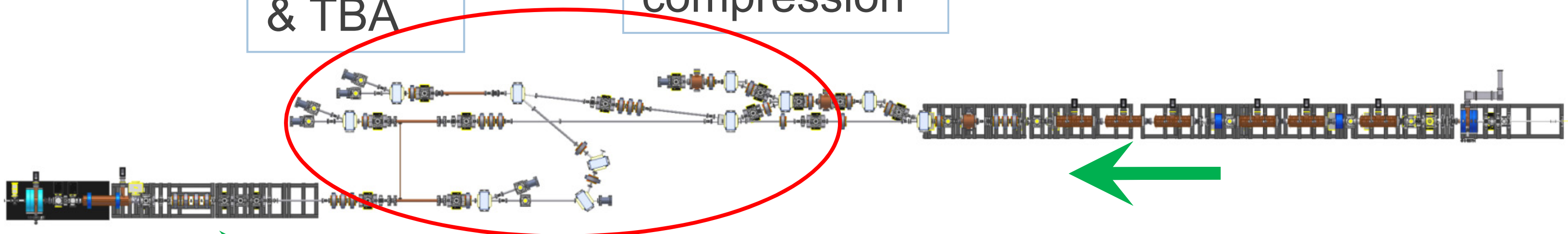
A Pathway to AFLC using the AWA facility

AWA facility

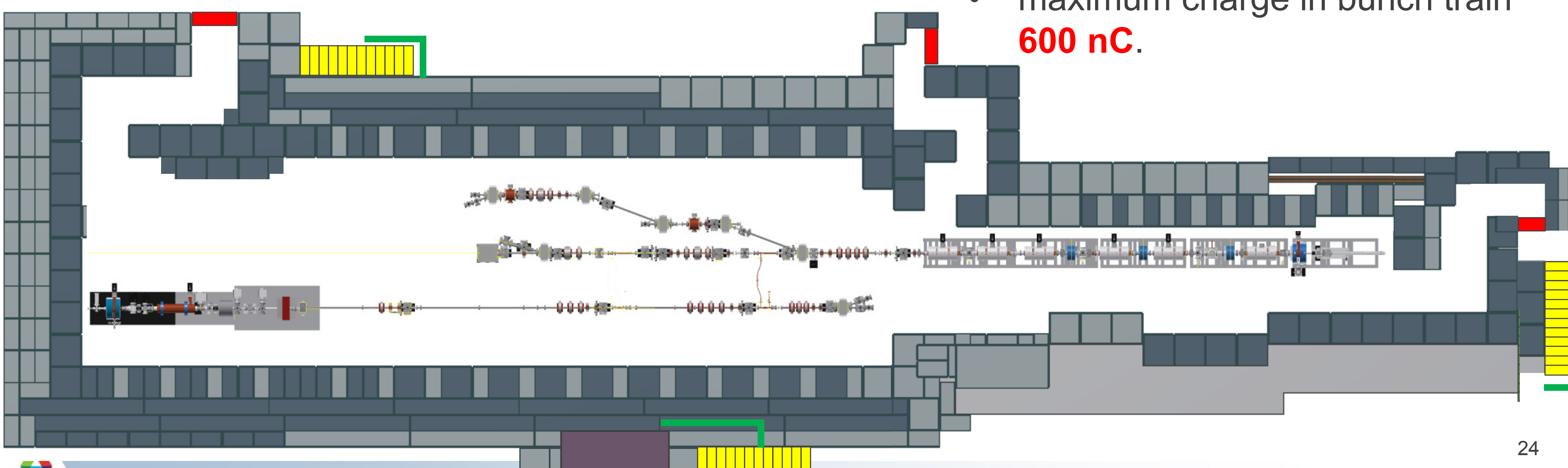


70 MeV drive beam

- bunch trains of up to 32 bunches
- Maximum charge in single bunch **100 nC**
- maximum charge in bunch train **600 nC**.

15 MeV witness beam

- single bunches
- bunch charge 0.05 to 60 nC



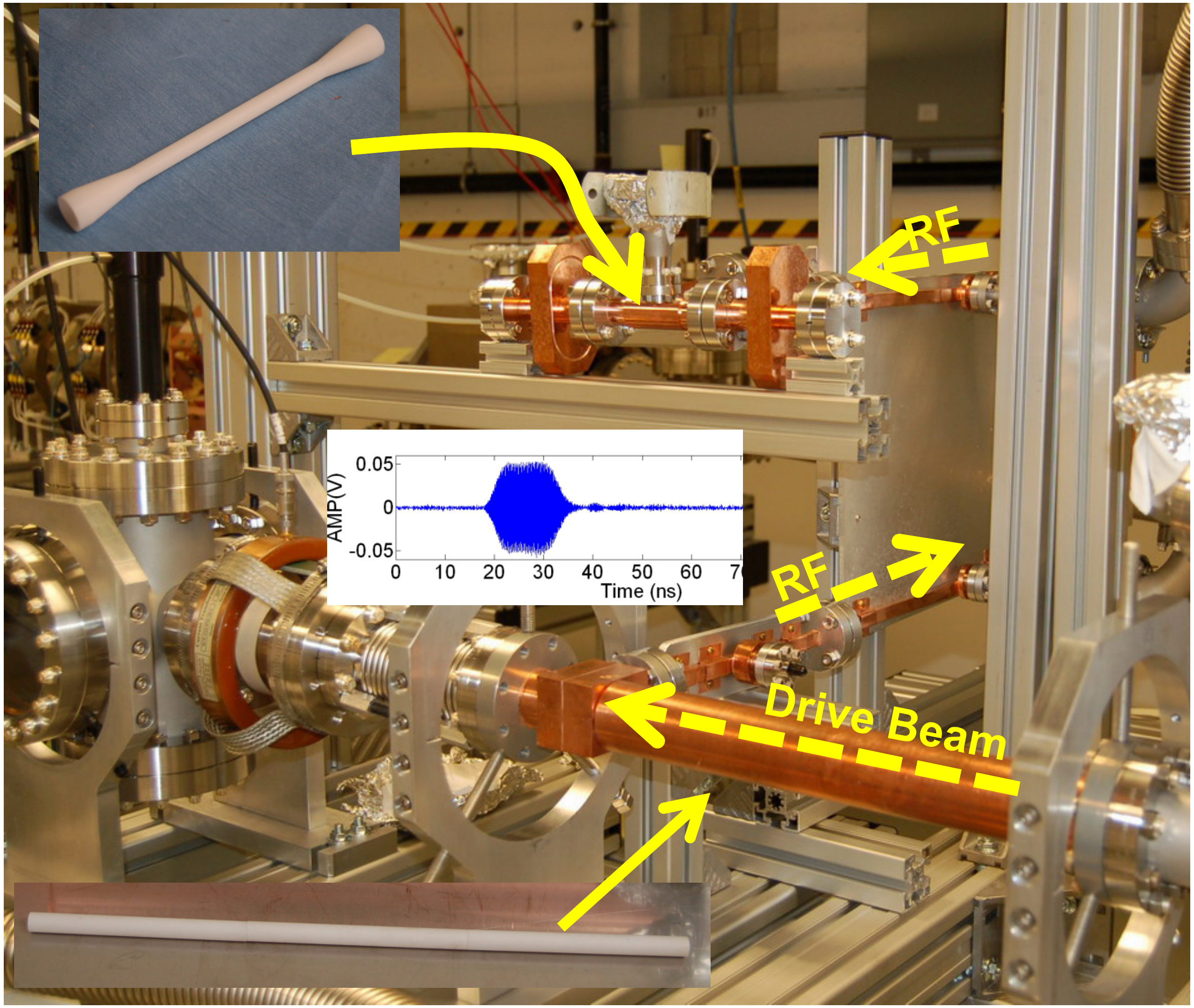
AWA Transformed

Where we stand now

REPORT ON RECENT EXPERIMENTAL RESULTS @ AWA

- ✓ 26GHz Dielectric TBA High Power RF Test
- ✓ 11.7GHz Metallic TBA Acceleration
- ✓ Staging Demonstration

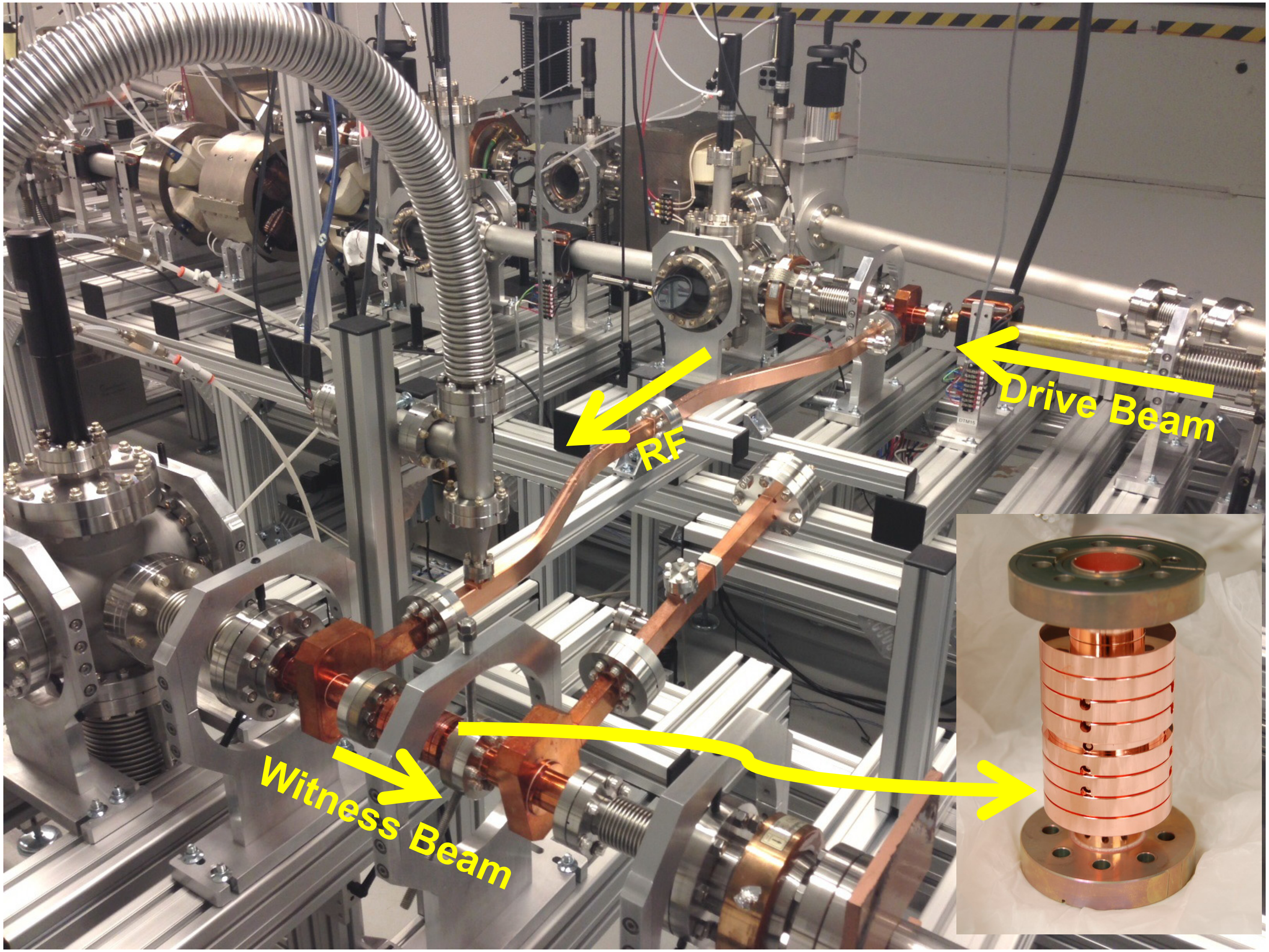
High power test of 26GHz dielectric TBA during AWA Commissioning



- <u>37MW</u> max RF power measured out of Power Extractor.
- Equivalent to <u>54MV/m</u> gradient in DLA structure.
- No breakdowns were observed.
- RF pulse is <u>5ns~15ns</u> depending on the #s of bunches in a train.

Aim for ~300MW power &~150MeV/m in 2016

11.7GHz Metallic TBA Acceleration

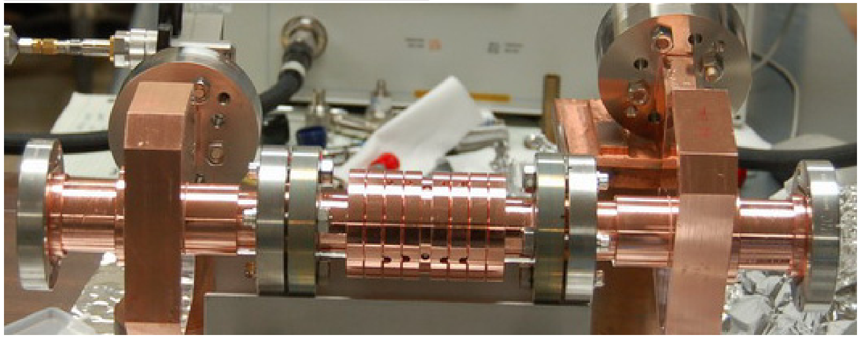


Structures used in the TBA/Staging PoP Experiment

Power Extractor

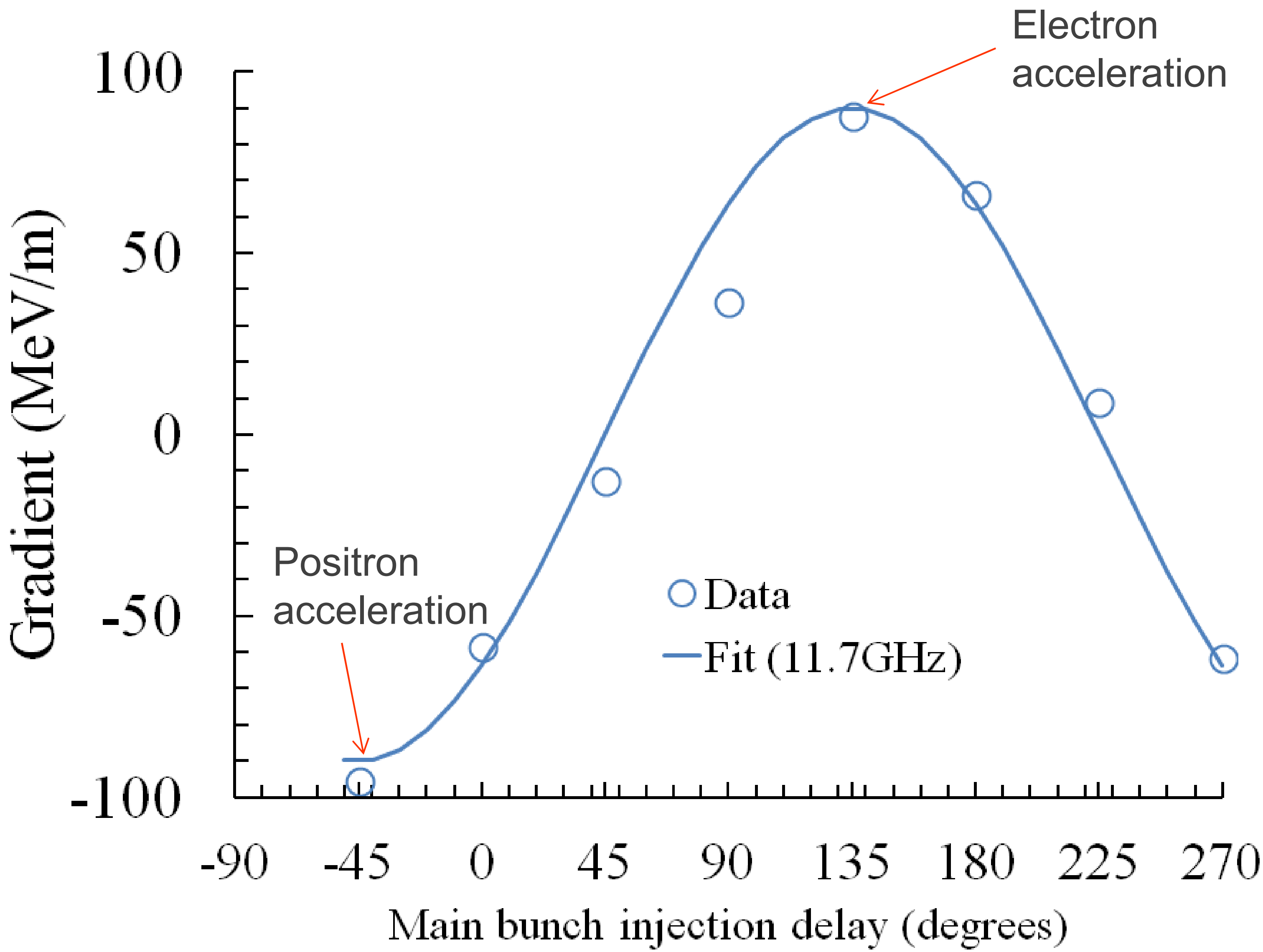
	Value
Freq.	11.7GHz
Mode	2pi/3
Aperture	17.6mm
Length	30cm
Passing Charge	8 x 20nC
Power	55MW

Accelerator

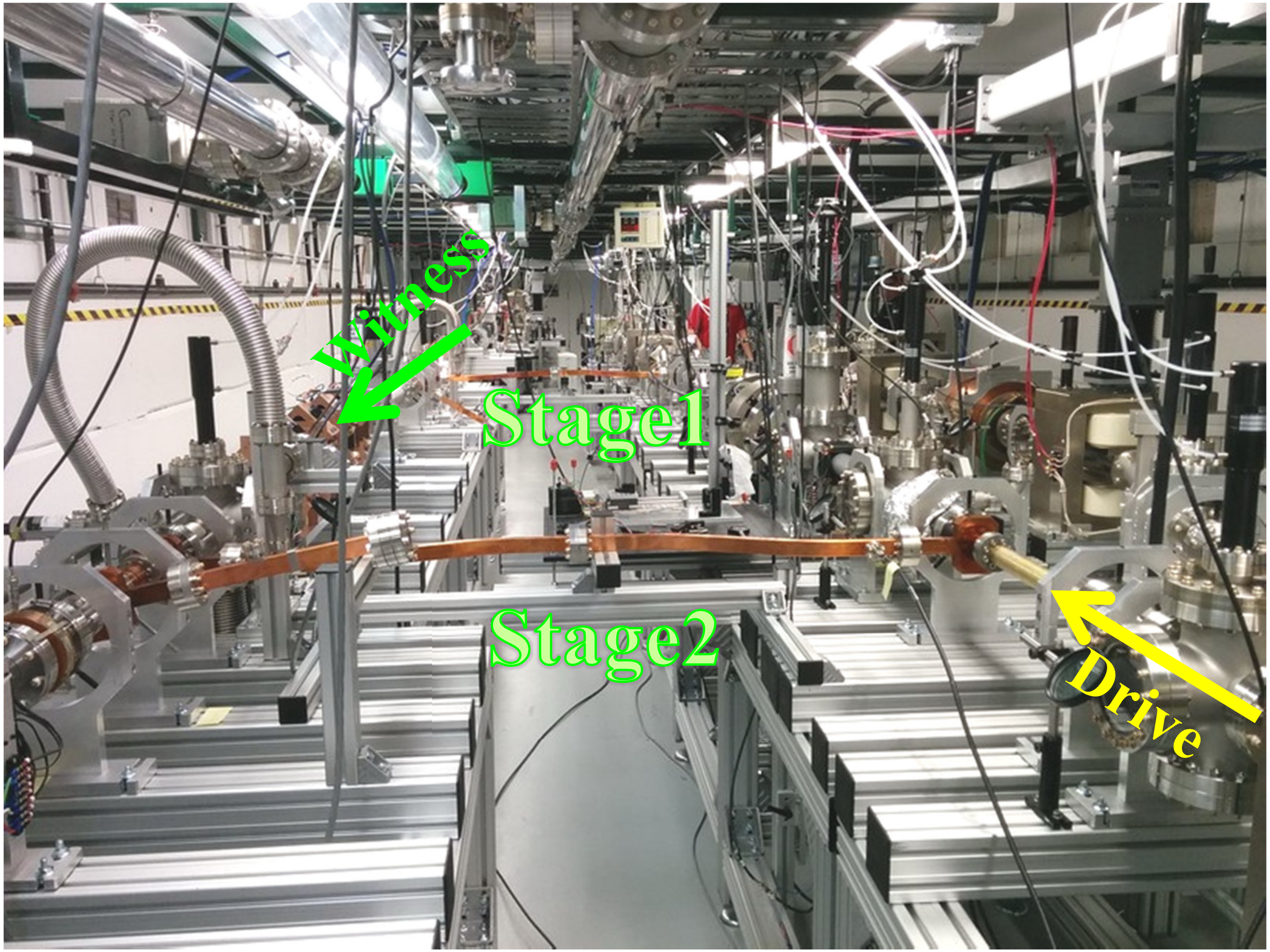


	Value
Freq.	11.7GHz
Mode	2pi/3
Aperture	6mm
Length	3cm
Input power	50MW
Gradient	100MV/m

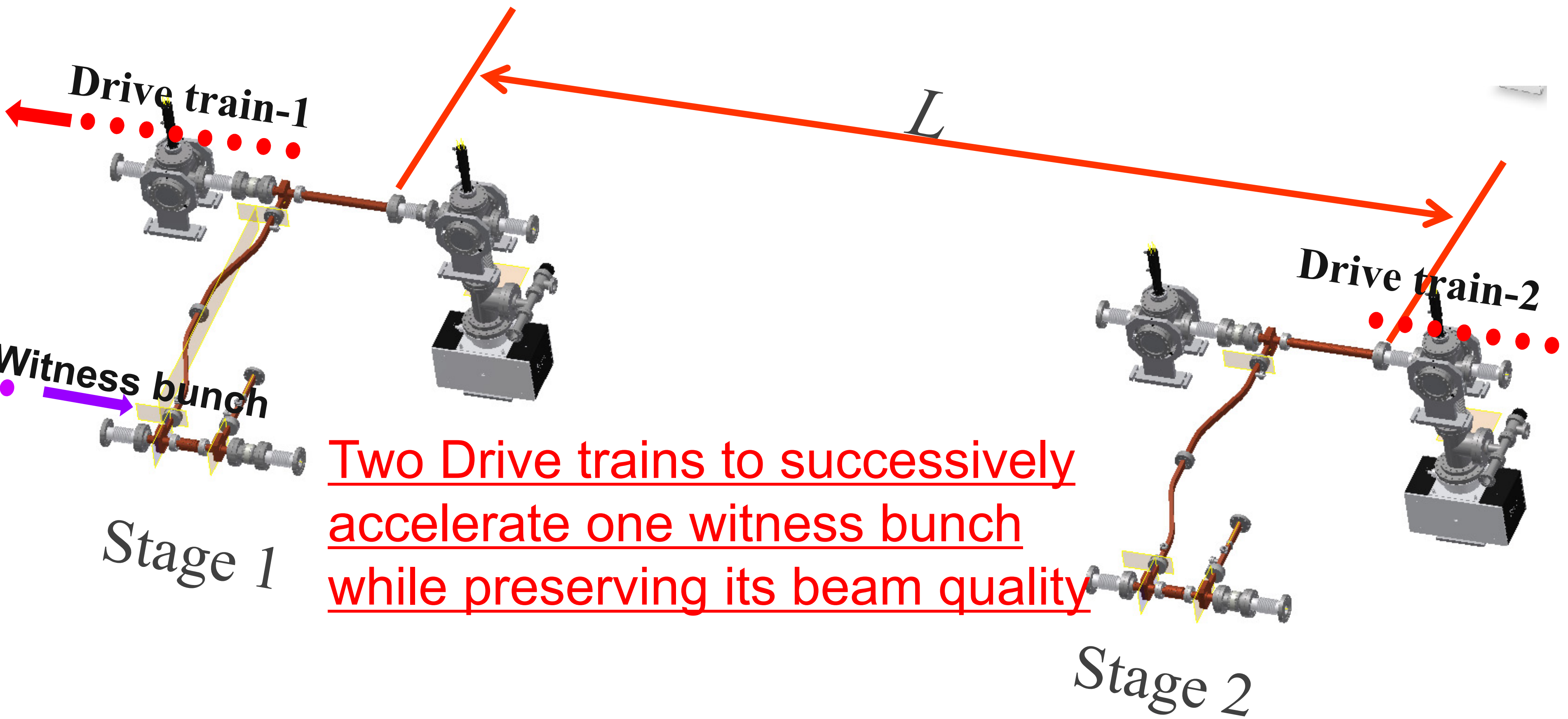
~100MeV/m Acceleration Achieved (aim for 200MV/m)



Staging Demonstration



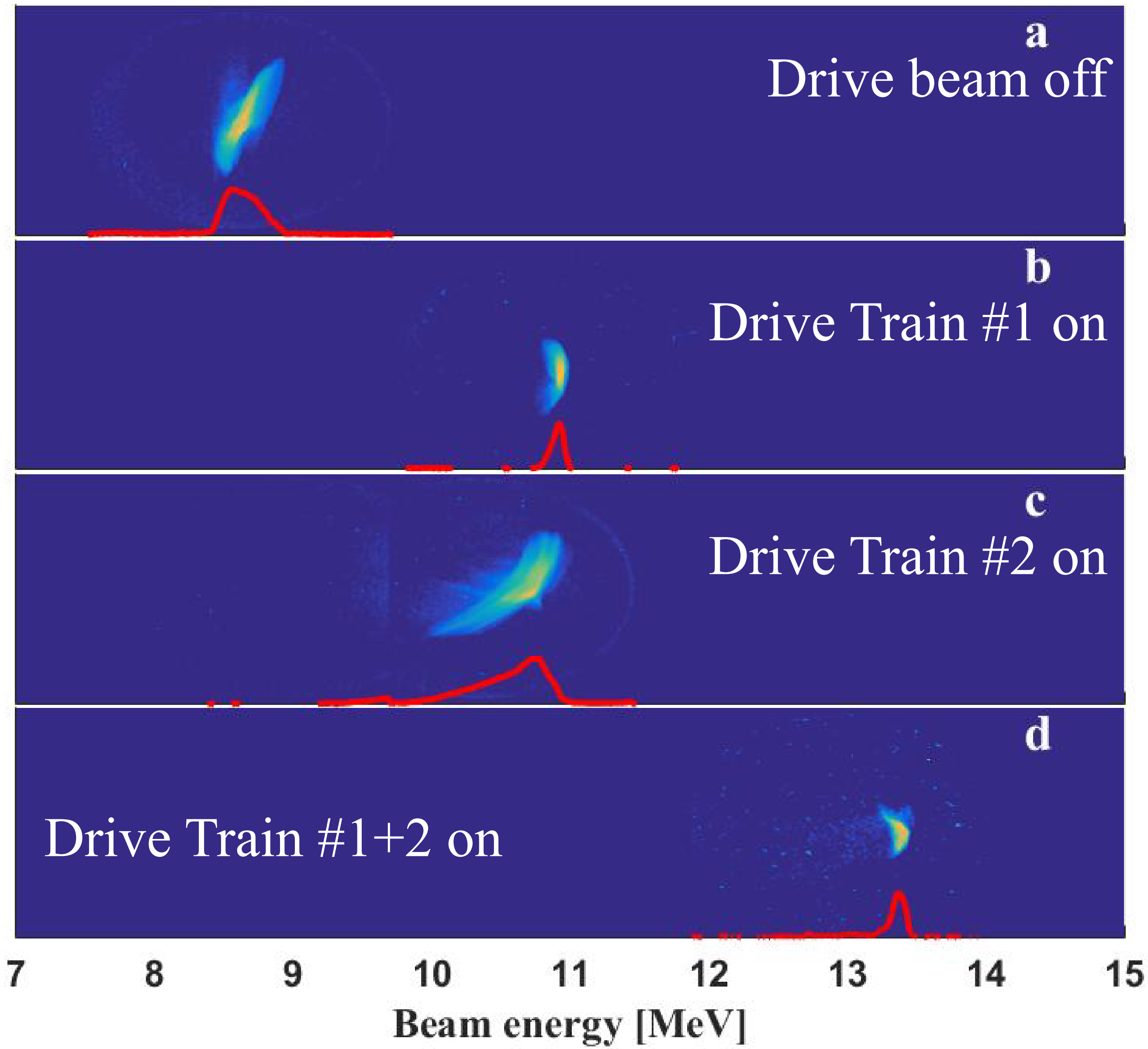
Timing Required for Staging PoP Experiment



Two Drive trains to successively accelerate one witness bunch while preserving its beam quality

$$L = N\lambda, \ (N \geq 6, \ \lambda = 23\,cm)$$

Staging Experiment at AWA



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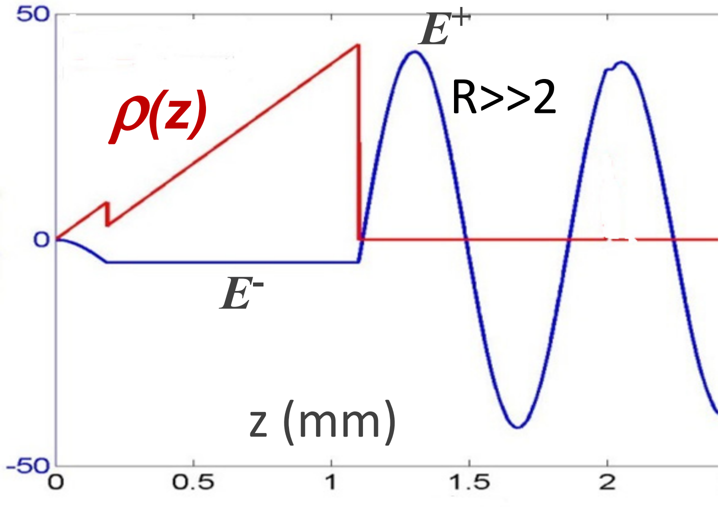
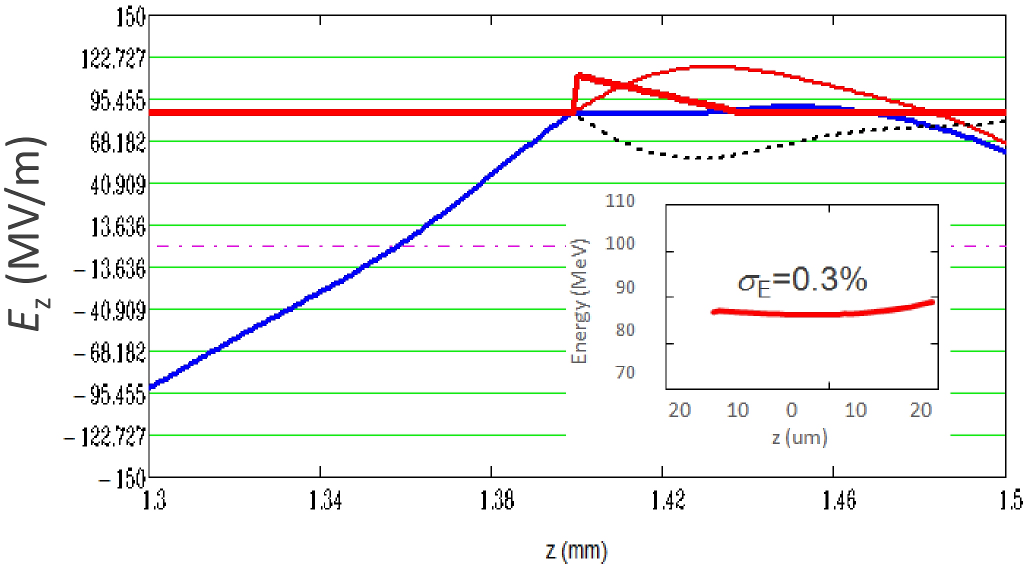
EEX for Longitudinal Bunch Shaping

- ❑ Drive Bunch Shaping (for collinear wakefield):
  - •Increase Transformer Ratio (double triangle peak current distribution)
  - •Metigate Beam Breakup instability (parabolic current distribution)
- ❑ Main Bunch Shaping (for collinear and TBA)
  - •Reduce Energy Spread (trapezoidal current distribution)

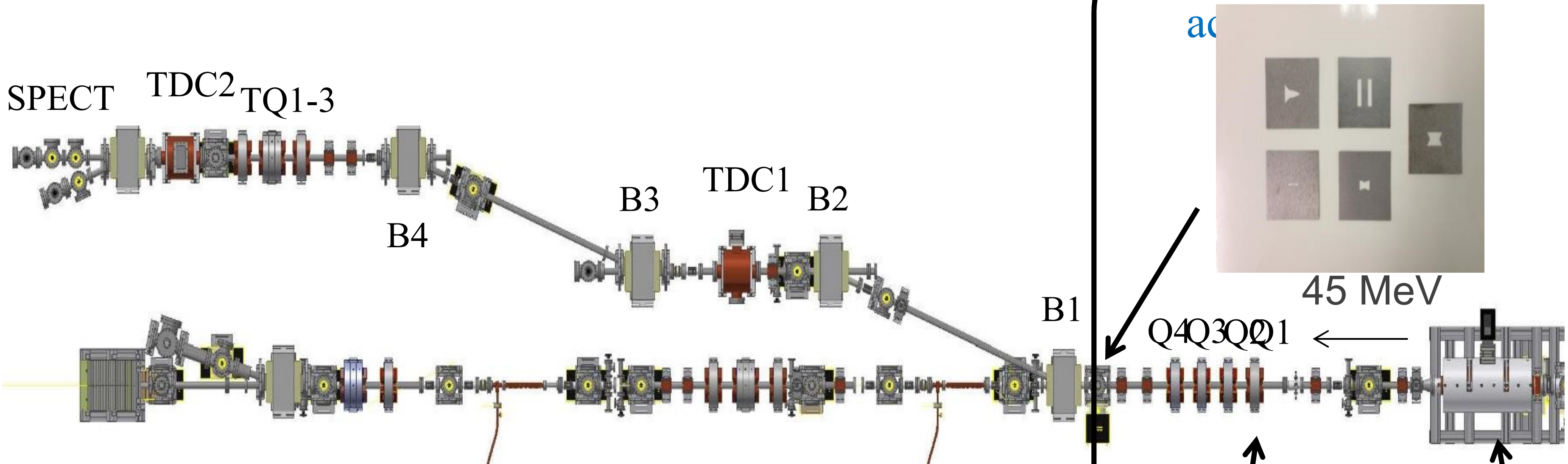
Double triangle drive bunch (other distributions also possible)



Reverse triangular main bunch



Bunch Shaping with EEX Demonstrated

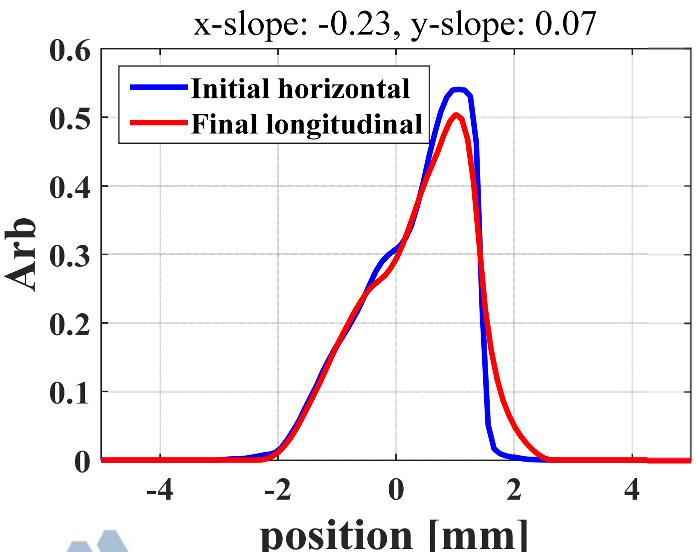


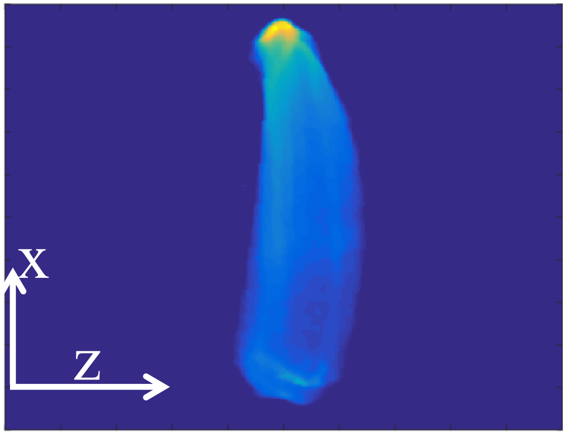
Five masks on
ac

x-x' & y-y' beam size & slope

Linac chirp

tunable parameters





SUMMARY

- Two Beam Acceleration is a feasible approach to the high gradient acceleration (moving from scientific feasibility to engineering feasibility)

- Critical Technology Elements for Two Beam Acceleration are under intensive studies AWA.
  - Gradient (100MV/m achieved, moving to 200MV/m)
  - RF power (moving to GW)
  - High quality staging demonstrated (moving to 100MeV net acceleration in stages)
  - Bunch manipulations using Emittance Exchanger (arbitrary bunch shaping)