Linear Collider based on Short Pulse Two-Beam Accelerator Technology

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Outline

- Concept of Argonne Flexible Linear Collider
- 250GeV Higgs Factory
- AWA---Test bed for short pulse high gradient technologies
- Other

Argonne Flexible Linear Collider (based on AWA short pulse, high power, high gradient technologies)

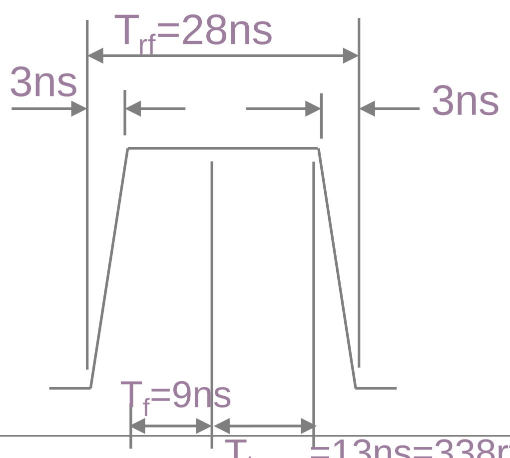
Core of Concept:

1. Short rf pulse: tens of nanosecond
2. Modular TBA scheme: energy scalable easily
3. Flexible drive beam structure

1. Short rf pulse w/ a high efficiency

- TBA scheme in the main linac → fast rf rise time.
- Broad band TW accelerator → fast rf rise time.
- Large (~10%c) Vg → less filling time.
- high frequency and optimal beam loading → higher rf-to-beam efficiency.

e.g. rf-to-beam efficiency of a 26GHz Short Pulse Accelerator:



Competitive rf-beam efficiency for the short pulse TBA

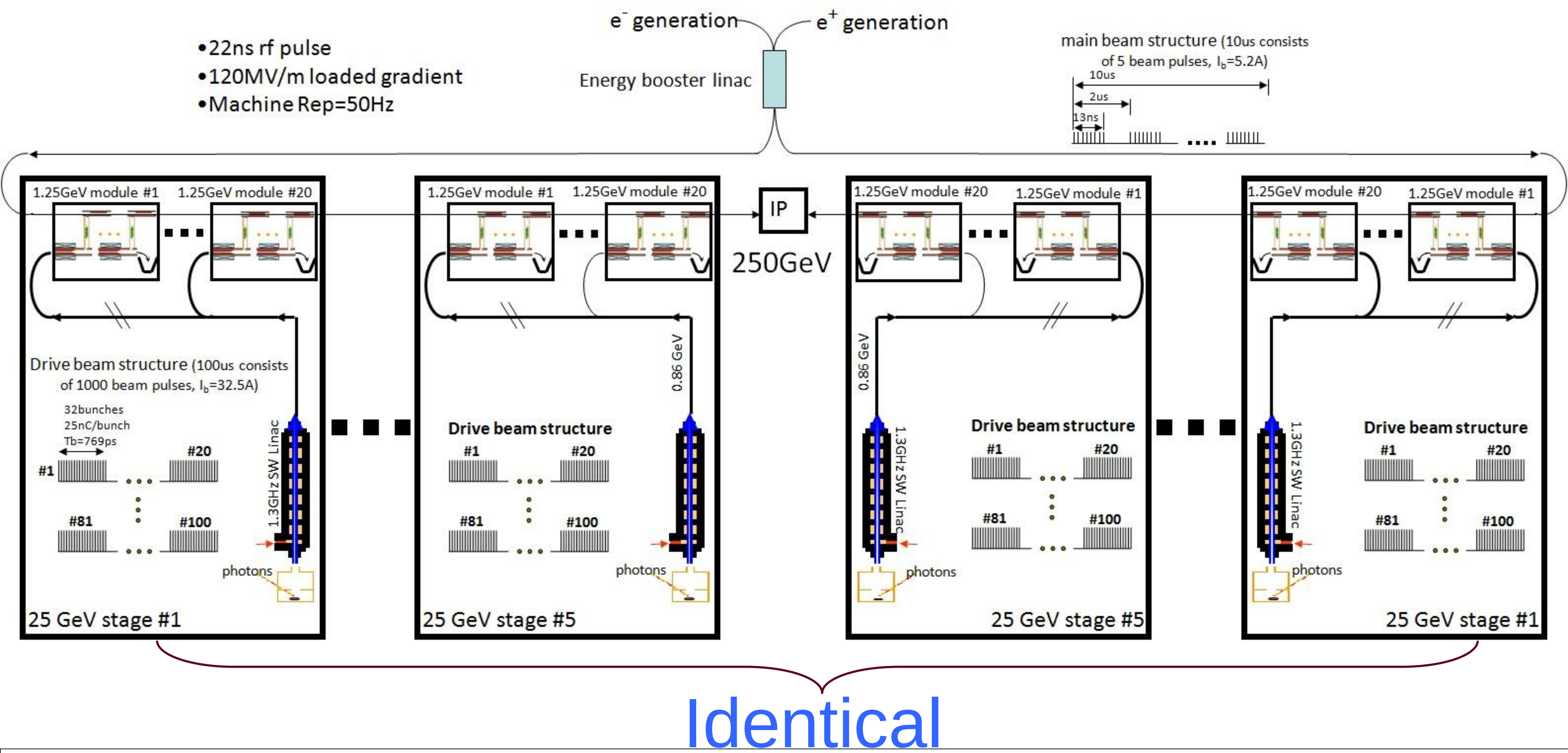
5.2A 120MeV/m 0.3m 13ns

$$\eta_{bRF} = \frac{I_{beam} E_{load} L_s}{P_{rf}} \times \frac{T_{beam}}{T_{rf}} = 30.8\%$$

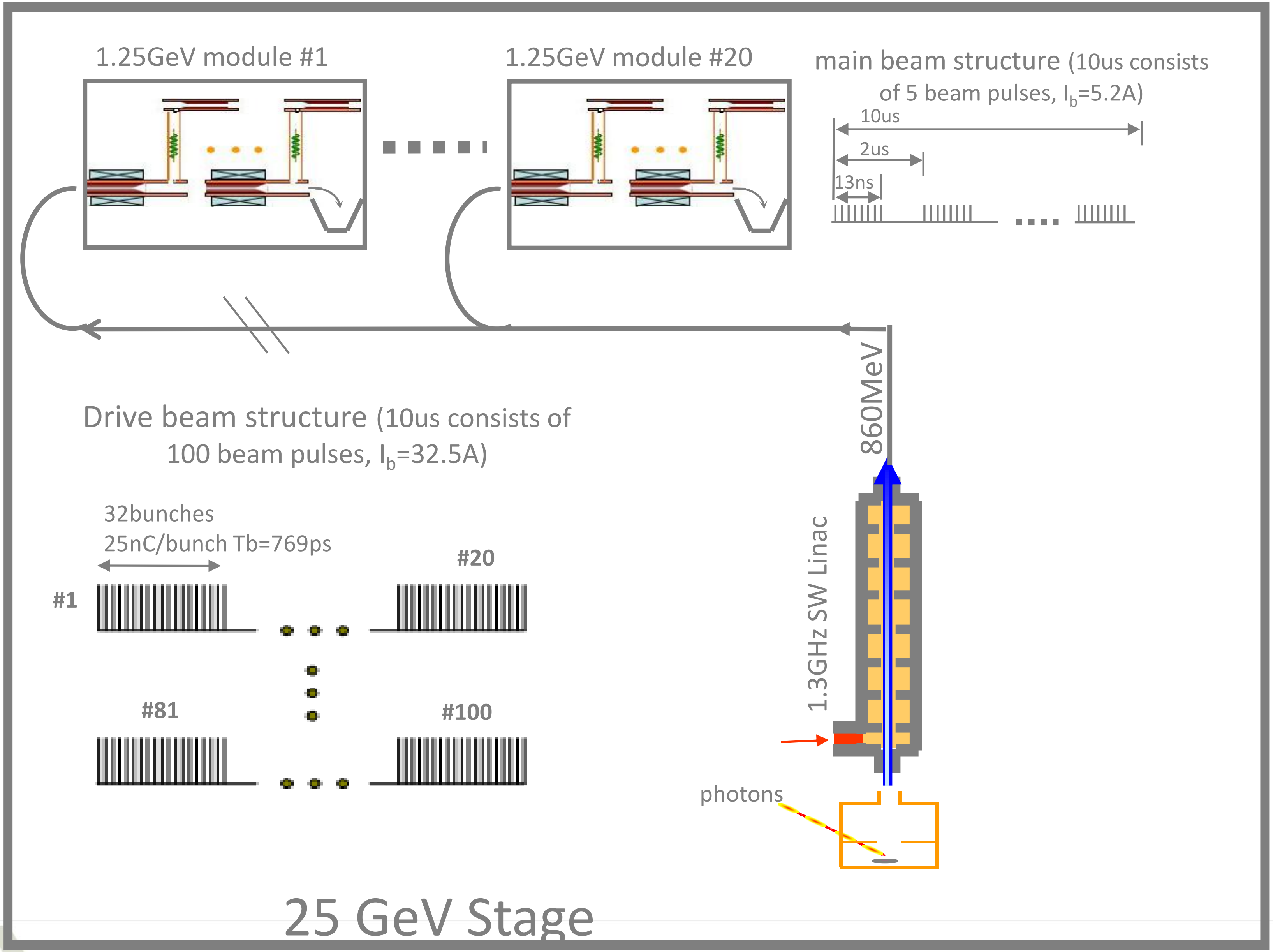
316MW 25ns

2. Modular TBA scheme

Layout of the ANL 26GHz 250GeV Flexible Linear Collider



3. Flexible drive beam structure



Design of the 250GeV K-band (26GHz) Dielectric Accelerator Based Linear Collider

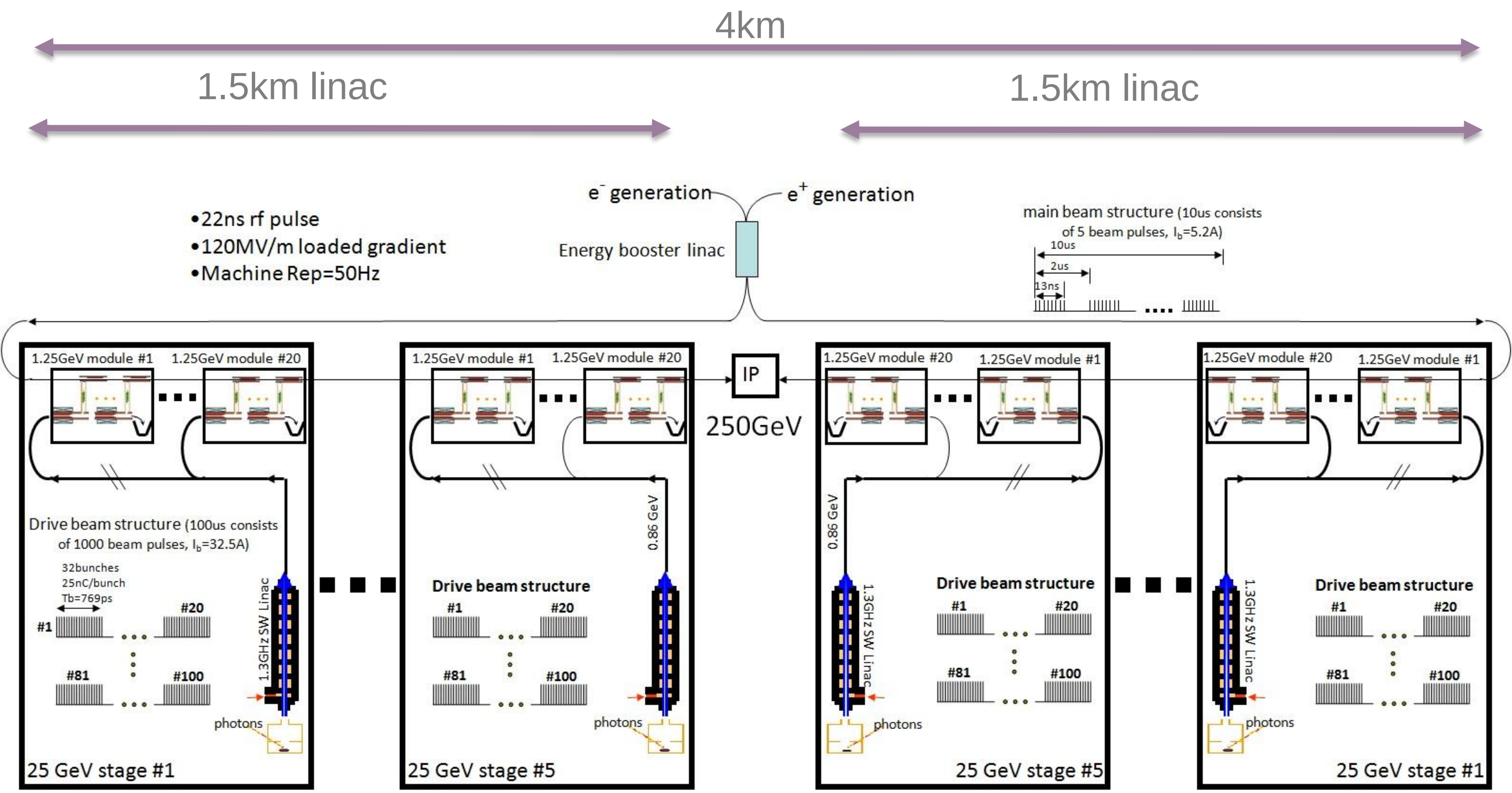
Features:

1. Dielectric based TBA scheme

2. ~20ns rf pulse, ~120MV/m loaded gradient

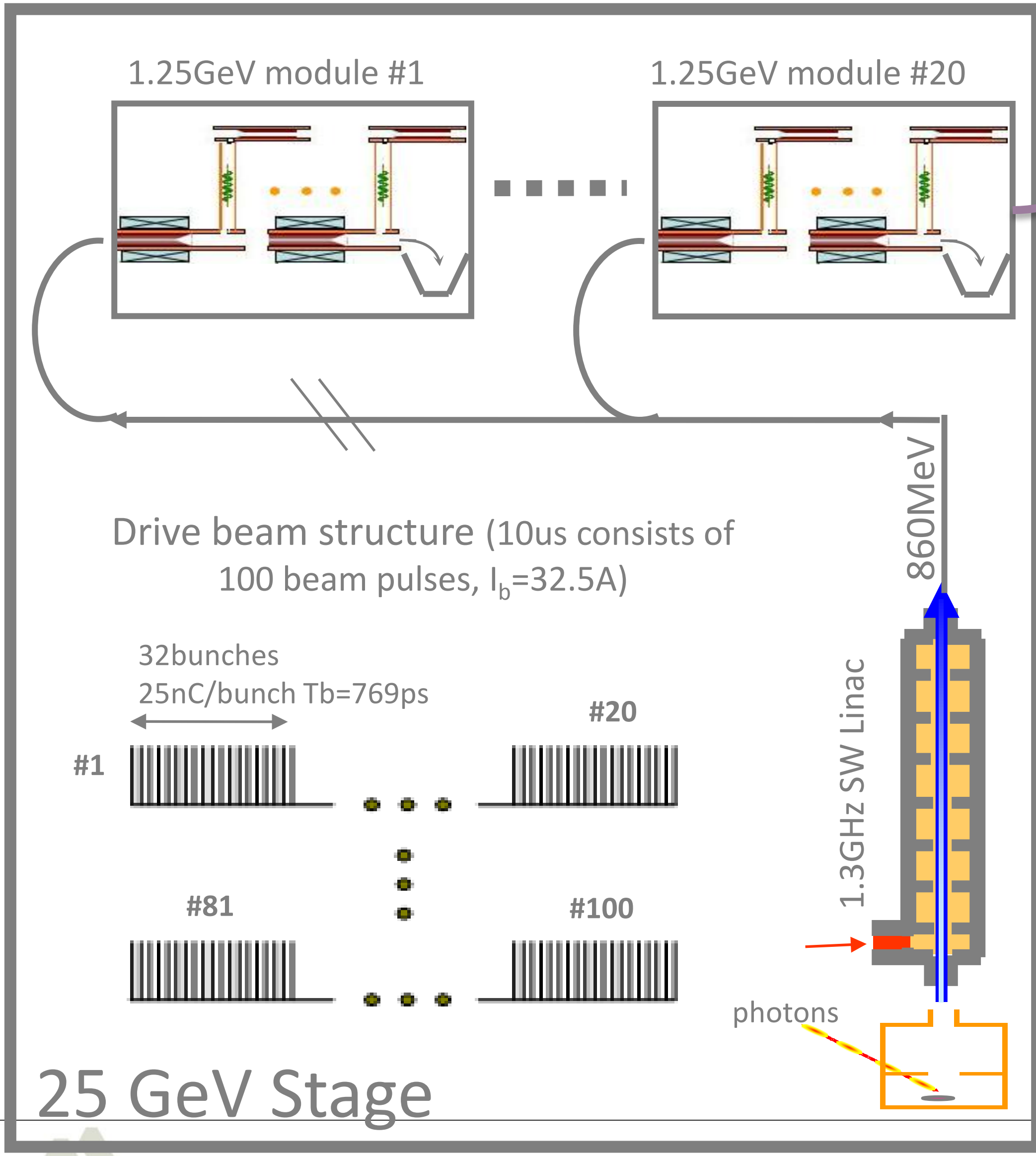
3. ~4.2MW beam power, ~4.7% wall plug efficiency, <100MW grid power

ANL K-Band 250GeV Higgs Factory

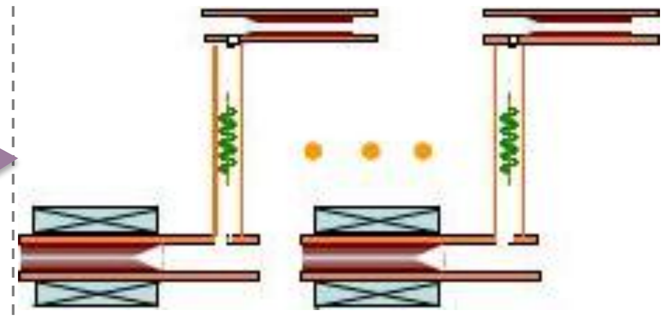


Let’s survey the Argonne campus

Some technical details:

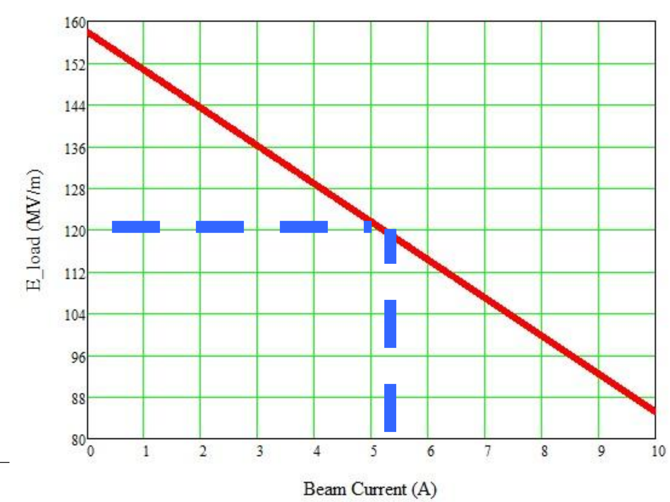


1.25GeV module (15m)
(35 DWPE & 35 DLA→ fill factor=70%)

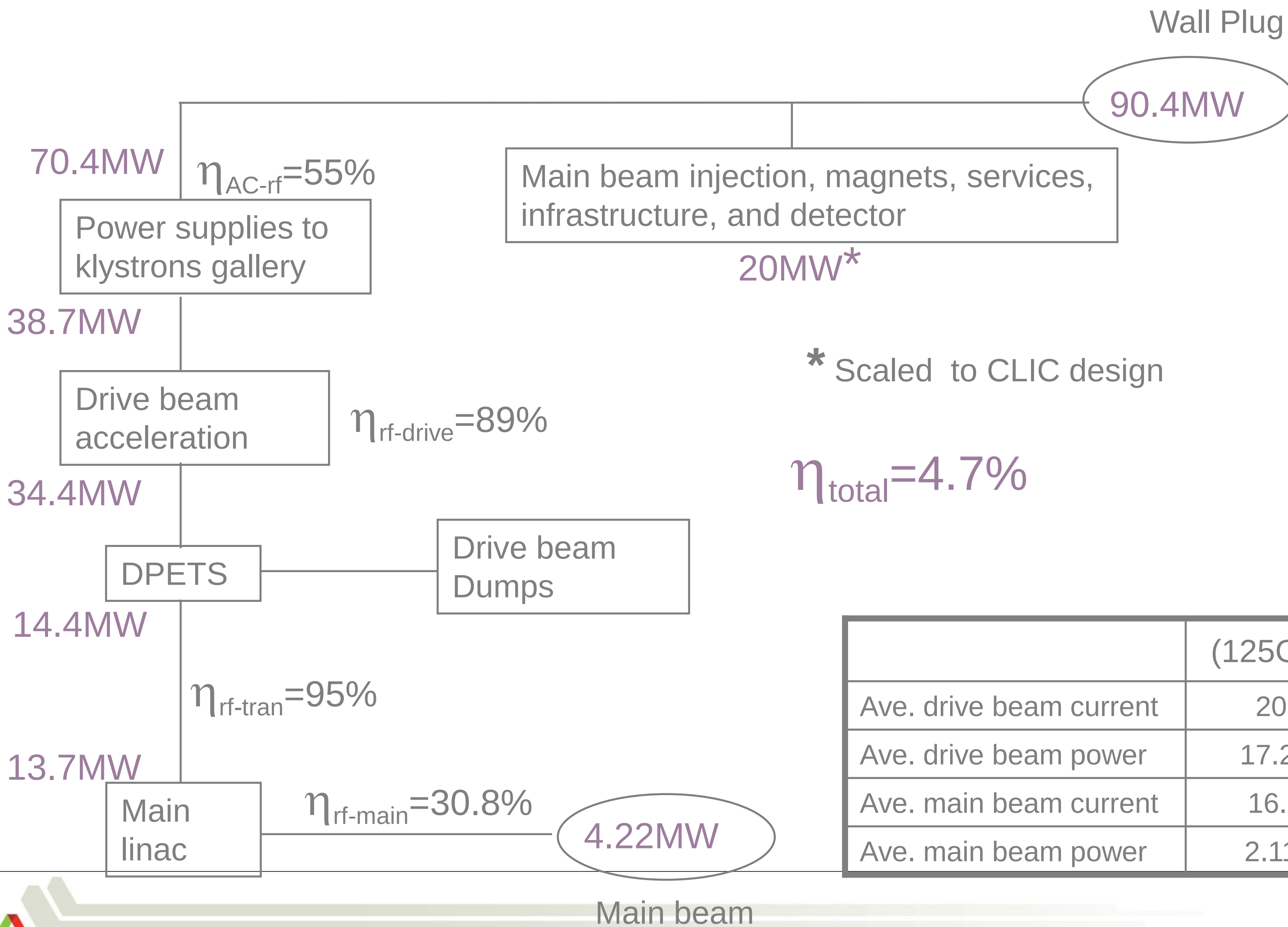


333MW output/Dielectric PETS;
5% rf transportation loss;
E_{load} =120MV/m (I_b=5.2A);

Drive beam (860MeV) becomes 97MeV, main beam gain 1.25GeV



Power and efficiency flow chart (rough estimation)

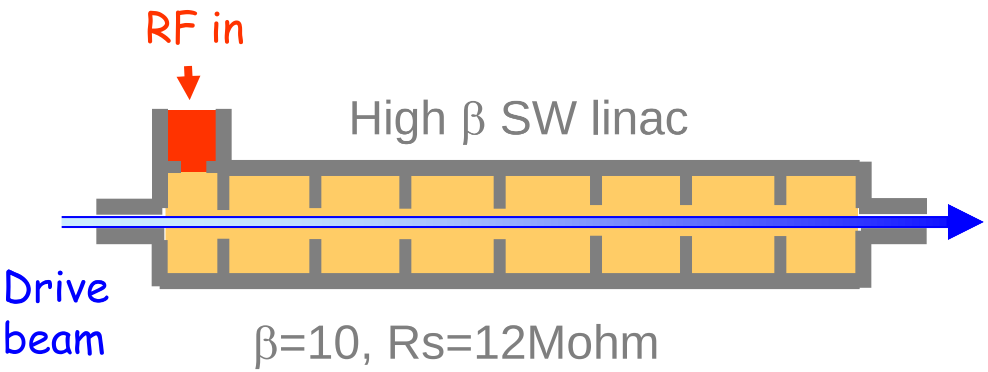


* Scaled to CLIC design

$\eta_{total}=4.7\%$

	(125GeV,e^-)
Ave. drive beam current	20 mA
Ave. drive beam power	17.2 MW
Ave. main beam current	16.9 uA
Ave. main beam power	2.11MW

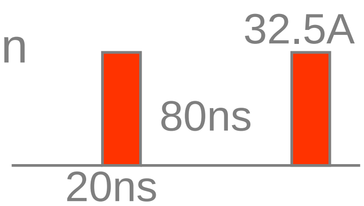
Drive beam accelerator



To enhance RF power delivered to the beam

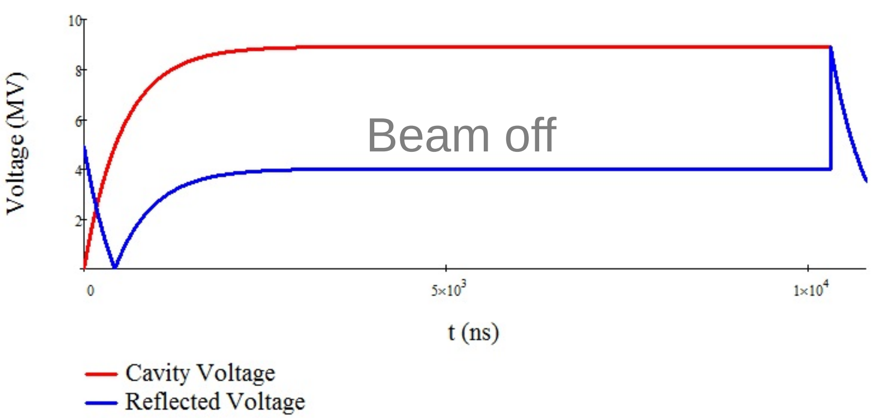
- Low reflection (P_R min)
- Low wall loss (P_d min)
- High beam loading (P_b/P_F max)

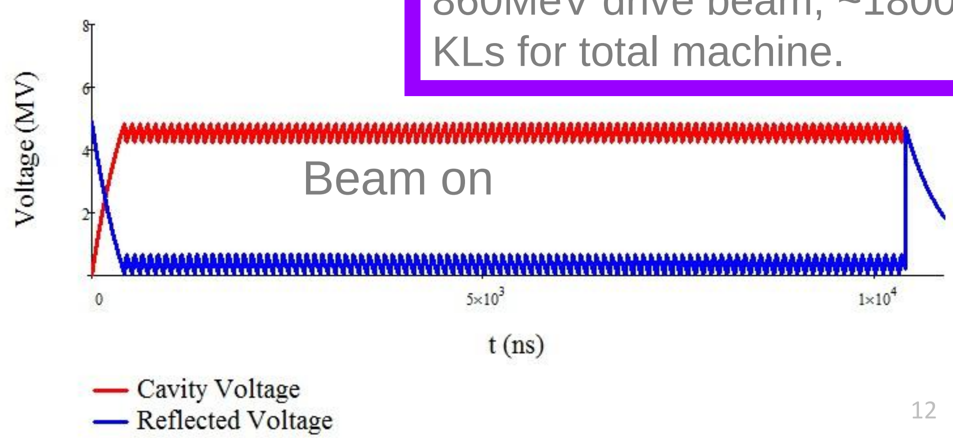
drive bunch train



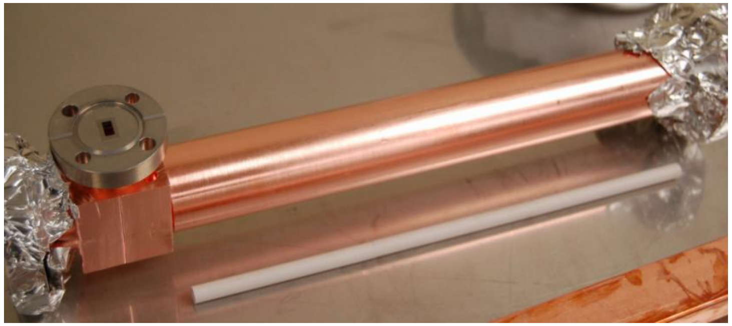
$$\frac{P_B}{P_F} = 89\%$$

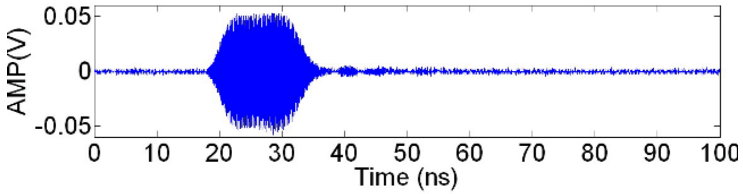
Ave. energy gain = 4.8MeV/structure , powered by a 20MW 10us Klystron. ~180 KLs are needed to 860MeV drive beam, ~1800 KLs for total machine.





Dielectric Wakefield Power Extractor:

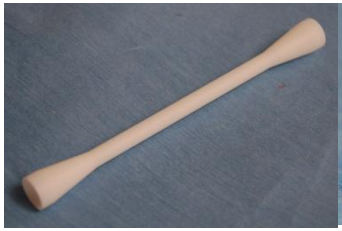




Parameters of 26GHz Dielectric Based Wakefield Power Extractor

Geometric and accelerating parameters	value
ID / OD of dielectric tube	7 mm /9.068 mm
Dielectric constant	6.64
Length of dielectric tubes	300 mm
Vg	0.254c
R/Q	9788 Ω/m
Rf pulse rise time	2.9 ns
$BW_{\_3dB}$ of the requested coupler	120MHz
Steady power (25nC/bunch,σ_z=1mm)	333 MW
RF pulse duration (32 bunches)	22ns (flat top)
Peak Gradient	84MV/m
Max Energy loss of the beam in the steady state	21.8MeV

Dielectric Accelerator:

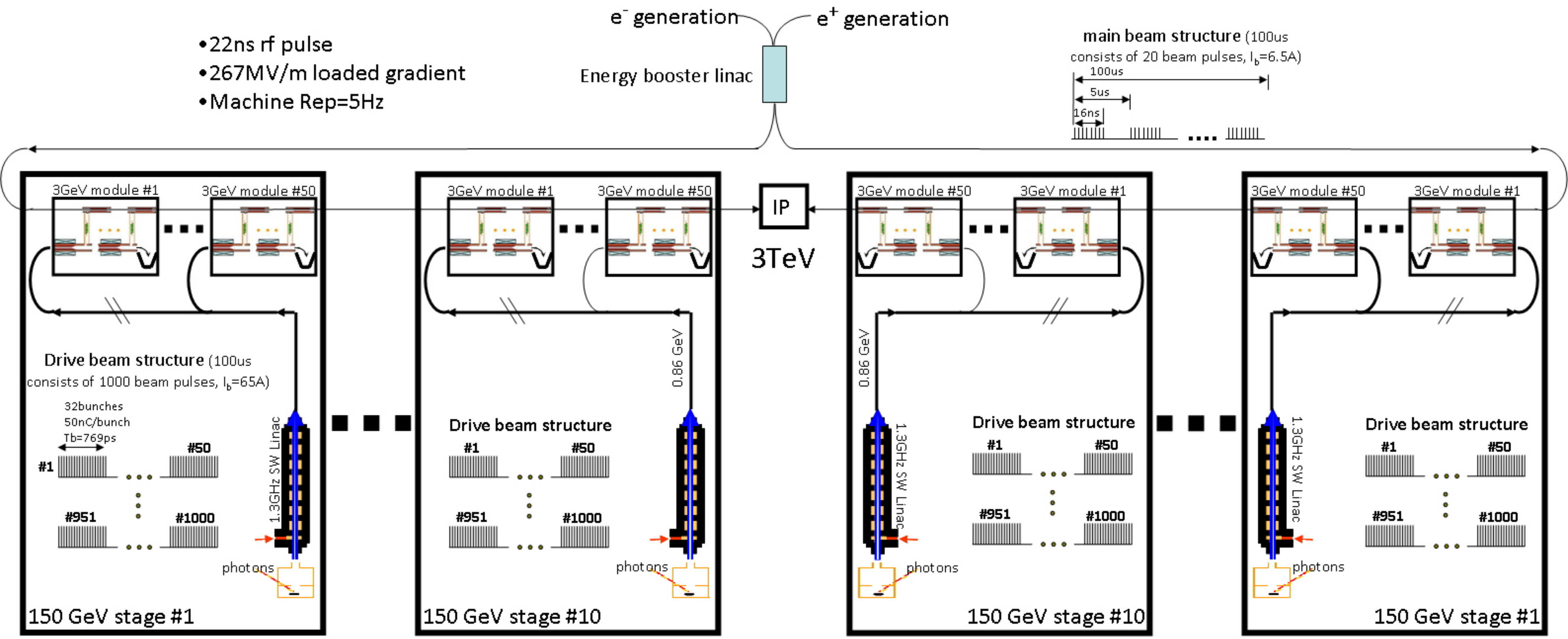


Parameters of 26GHz Dielectric Based Accelerator

Geometric and accelerating parameters	value
ID / OD of dielectric tube	3 mm /5.025 mm
Dielectric constant	9.7
Length of dielectric tubes	300 mm
Vg	11.13%c
T_{fill}	9ns
R/Q	21.98 kΩ/m
Q (loss tan=10^-4)	2295
Shunt impedance	50.44 MΩ/m
BW $_{\_3dB}$ of the requested coupler	120 MHz
E_{acc} for 316MW input	158 MV/m
E_{load} for 316MW input	120 MV/m

Using the same dielectric short pulse concept, energy of LC can be expandable from Multiple hundreds GeV to Multi-TeV.

Layout of the ANL 26GHz 3TeV Flexible Linear Collider



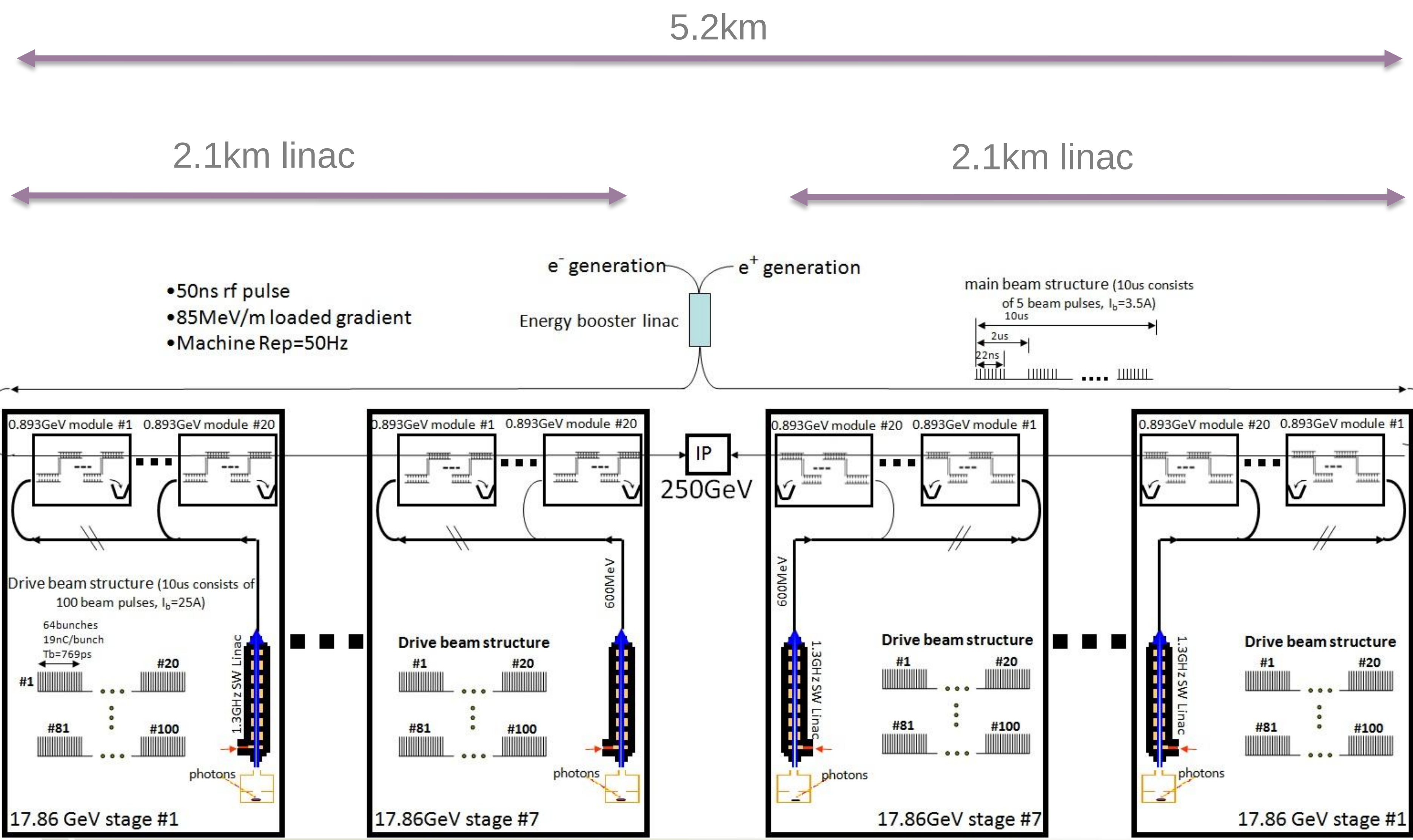
Short rf pulse LC concept works well with dielectric accelerators, however, with sacrificing some parameters, it works with metallic structures as well.

250GeV X-band Metallic Structure Based Linear Collider

Features:

1. Using matured X-band RF technologies
2. ~50ns rf pulse, ~85MV/m loaded gradient, eliminating concerns of rf breakdown
3. ~4.2MW beam power, ~3.4% wall plug efficiency, ~125MW grid power

ANL X-band Metallic Accelerator Based 250GeV LC



AWA Facility---Test Bed for short pulse TBA technology: 75 MeV Drive Beam+ 15MeV witness beam

Basic parameters for the drive beam:

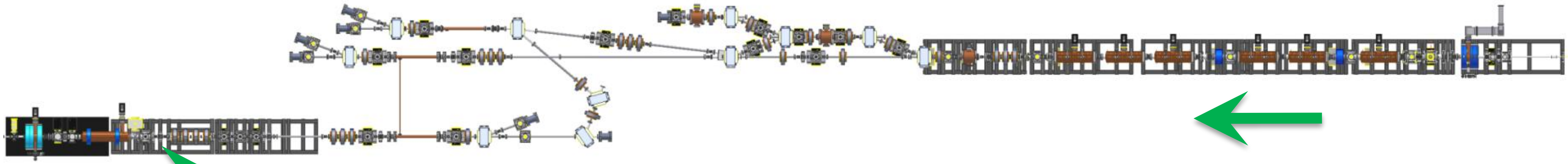
- 1.3GHz Photogun w/ CsTe cathode
- 75 MeV, 1 – 100 nC (reached 150 nC)
- 1~2.5 mm bunch length (a bunch compressor is planned)
- Normalized emittance < 200 mm mrad (at 100 nC)
- Bunch train operation: 32 X 30nC or 10 X 100nC
- Beam power: 3GW or 10GW

Experiments forecast in 5 years:

- High power rf generation: 0.1~1GW, ~20ns duration, frequency covers cm to mm wave.
- Two beam acceleration: >200MeV/m energy gain (short rf pulse, ~20ns).
- Collinear wakefield acceleration: >300MeV/m energy gain.
- Bunch shaping to improve efficiency for collinear wakefield acceleration

AWA Facility---Test Bed for short pulse TBA technology:

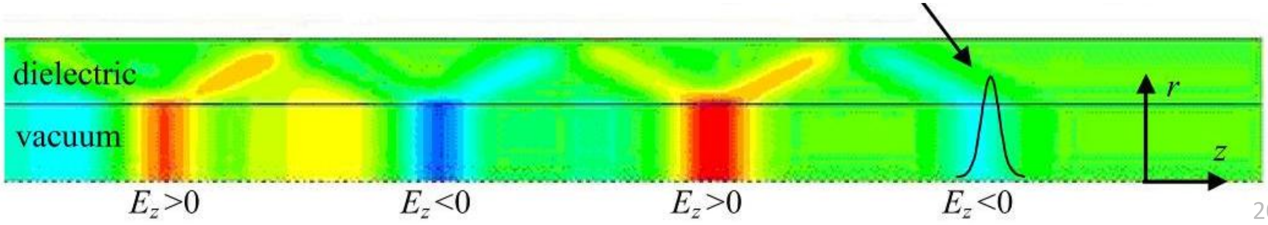
experimental area (TBA, Collinear, and bunch shaping**)**



75 MeV drive beam

15 MeV witness beam

Collinear Dielectric Wakefield Accelerator to drive the future X-ray FEL

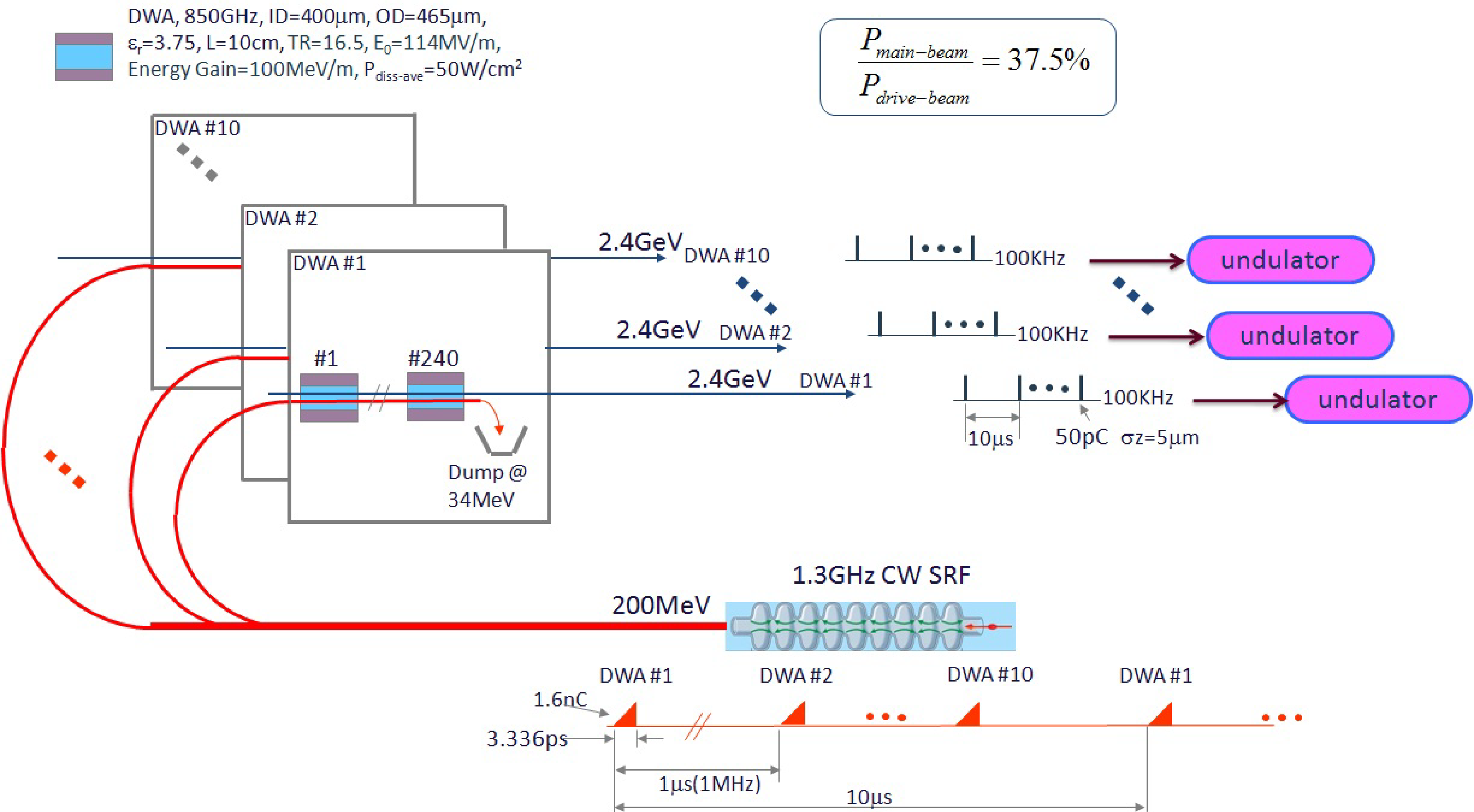


Motivation

- Light source is an intrinsic requirement for current and future scientific research. Particularly, ultrashort x-ray pulses are a powerful tool for addressing grand challenges in science.
  - e.g. LCLS came online in April 2010, but had received 314 proposals from 1,094 scientists in 25 countries to compete for a few opportunities.
- One particular obstacle limiting construction of FEL light source facilities is the cost, particularly, linacs to provide high energy, high brightness beam.
  - wanted: gradient >100MV/m, peak current >1KA, rep~1MHz, E~ a few GeV, etc.
- In the past few years, the field of high gradient acceleration, aimed at the future high energy linear collider, achieved many impressive results.
  - e.g. GV/m level in THz and 100MV/m in MW have been demonstrated in DWA structures.
- Share the same key technologies to the dielectric collinear wakefield collider scheme, including transformer ratio enhancement, DWA structure development, staging, etc.

A Schematic of a FEL facility based on a 2.4 GeV DWA

- Reduce construction and operational costs of a high bunch rep. rate FEL facility:
  - accelerating gradient > 100 MV/m, -- peak current > 1KA,
  - bunch rep. rate of the order of 1MHz, -- electron beam energy of a few GeV



Summary

Multi-hundred GeV linear collider, the next HEP machine, can be built with short pulse, high power, high gradient technologies currently being developed at AWA. Other facilities, like Fermi ASTA, is also an idea test bed for advanced accelerator concepts, like dielectric wakefield acceleration.