ASSESMENT OF OPPORTUNITY FOR

A COLLINEAR DIELECTRIC WAKEFIELD ACCELERATOR FOR A SOFT X-RAY FEL FACILITY

Many hurdles to overcome as you will see…

Alexander Zholents, ANL

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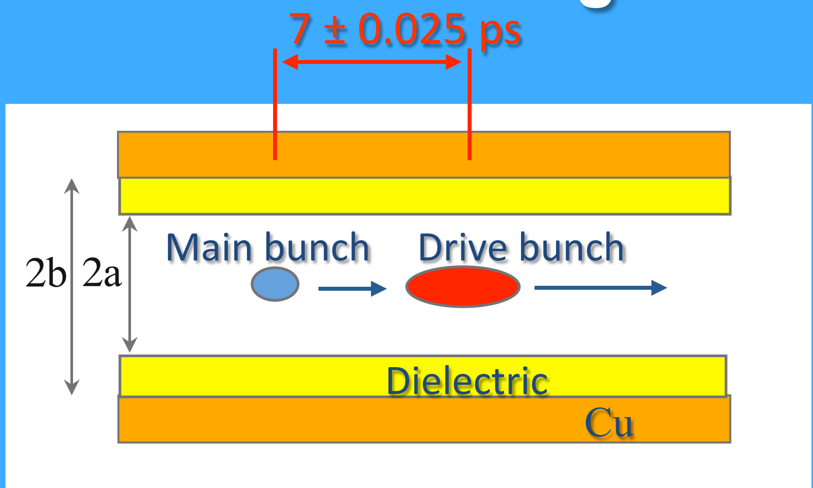
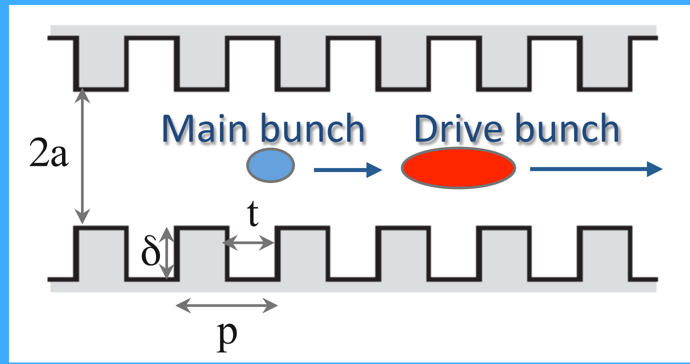
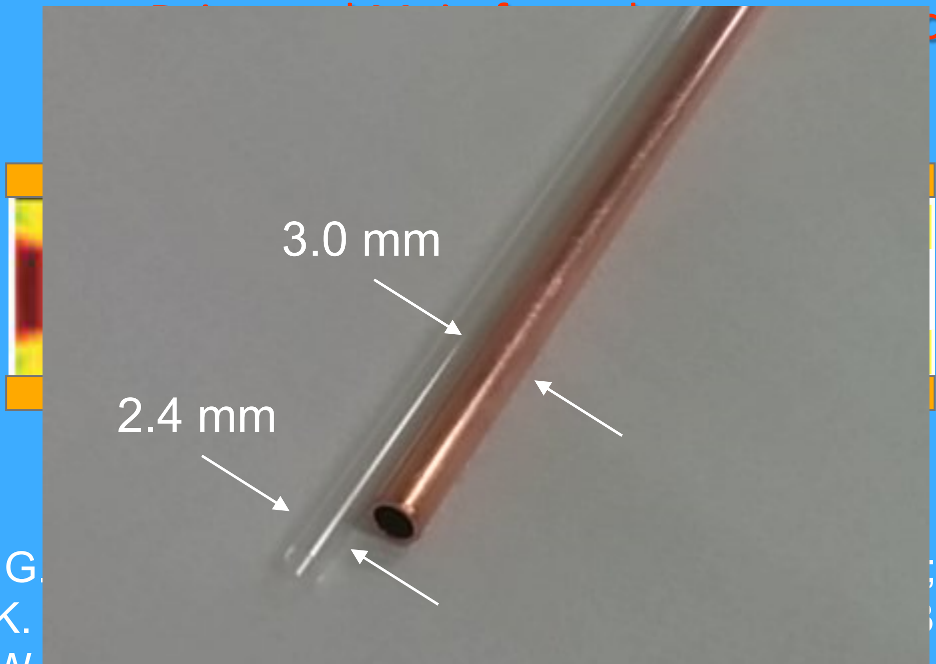
Collinear acceleration in a hollow dielectric channel or corrugated wall waveguide*





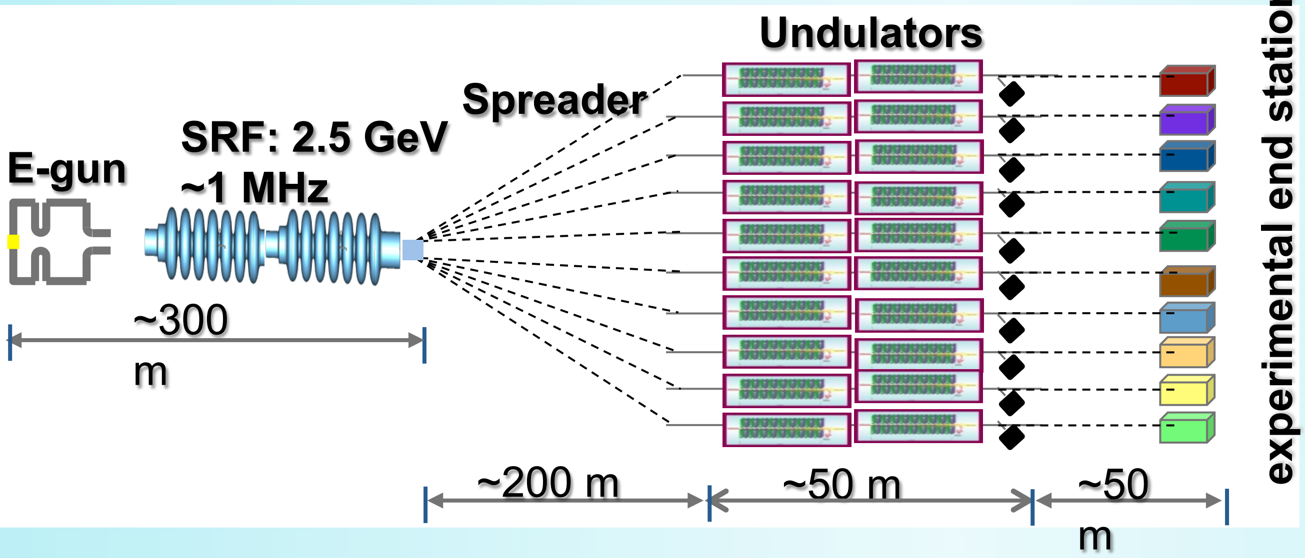
...ce bunch→ minimal timing jitter

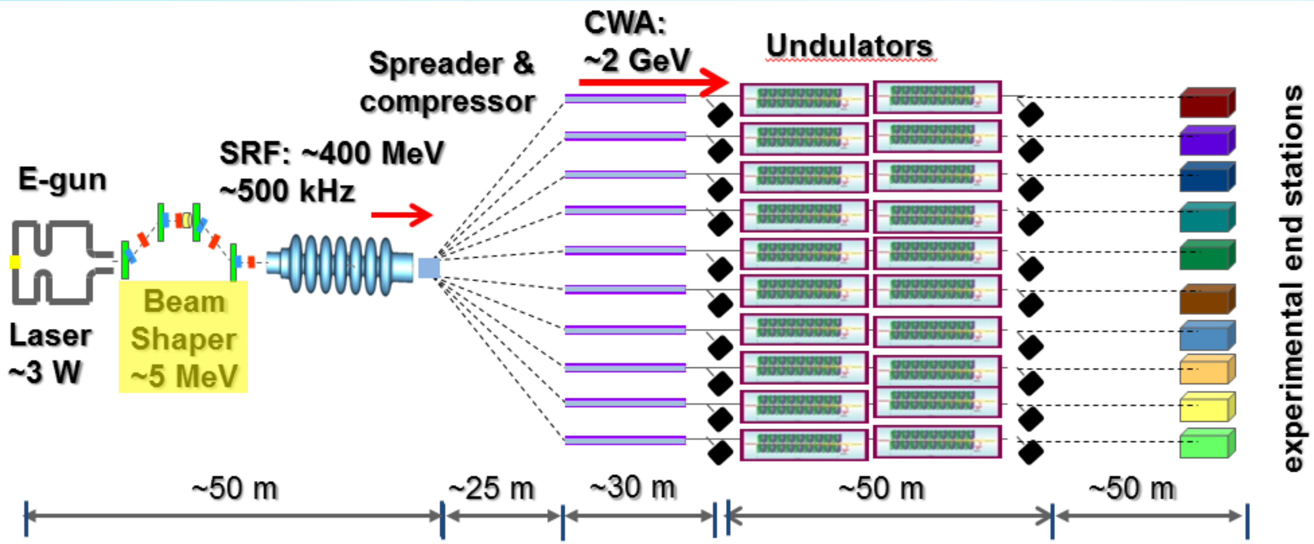


- Low cost device (likely)
- Potential for:
  - high field gradients
  - high wall plug power efficiency
  - high bunch repetition rate

*) G. ... ;
K. ... 662,1985;
W. Gai et al. Phys. Rev. Lett. 61, 2756, 1988.

A concept of a multi-user FEL facility





Based on:

High repetition rate SRF linac

⇓

Collinear Wakefield Accelerator (CWA)

- Low E spreader
- Up to 100 MV/m
- CWA imbedded in FODO lattice
- Tunable *E* ~ a few GeV
- Tunable I_{pk}> 1 kA
- Rep. rate ~50 kHz/FEL

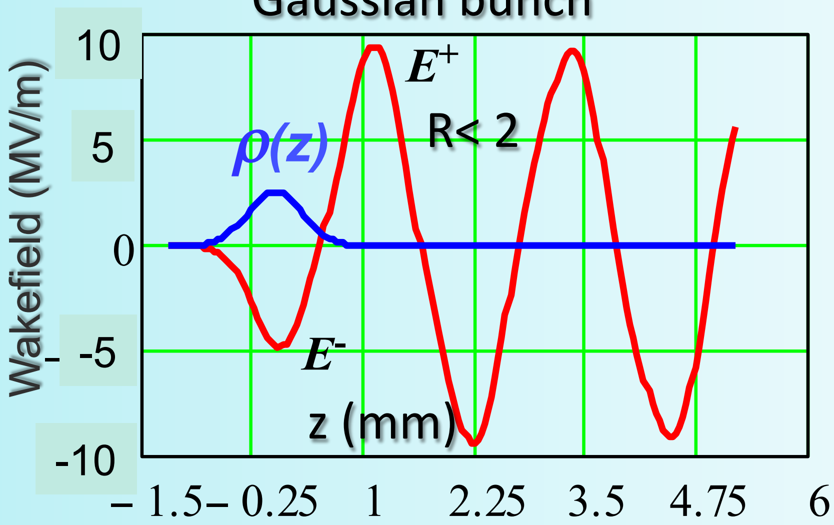
Compact **Inexpensive** **Flexible**

Beam by design: beam shaper and why we need it

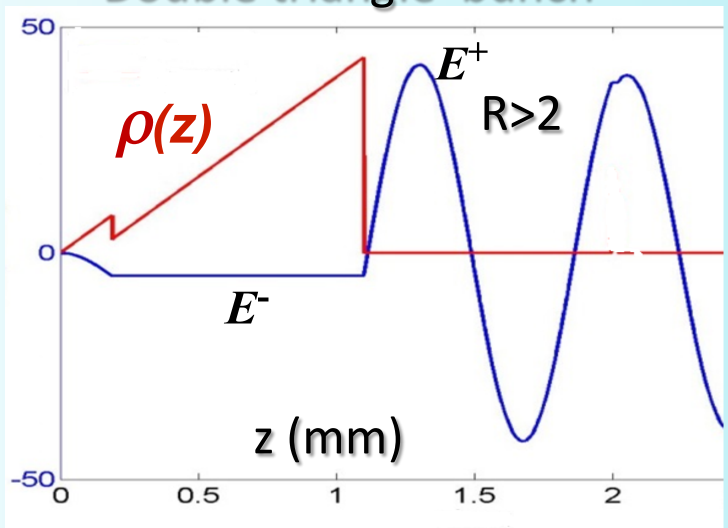
Road map to a high energy gain acceleration: transformer ratio[1]

$$R = \frac{E^+}{E^-} = \frac{\text{(Maximum field behind the drive bunch)}}{\text{(Maximum field inside the drive bunch)}}$$

Gaussian bunch



Double triangle bunch

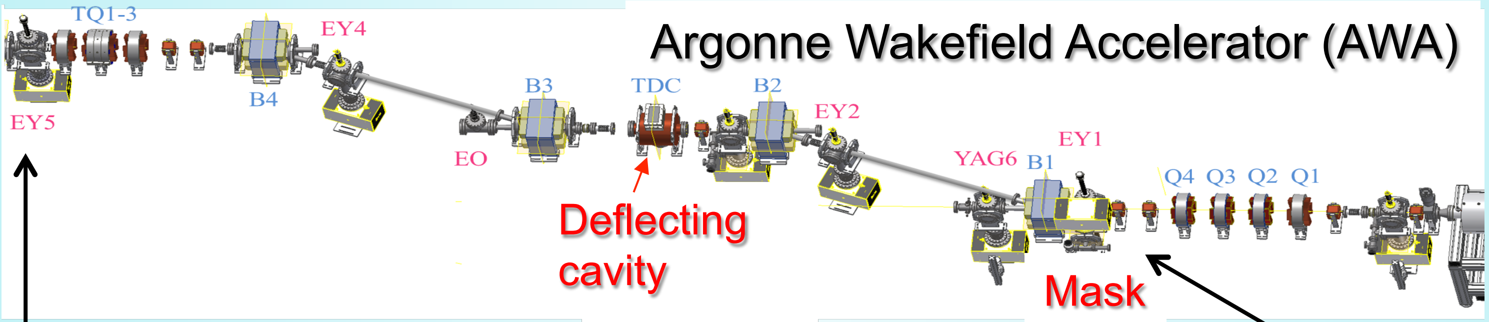


Other distributions also possible[2]

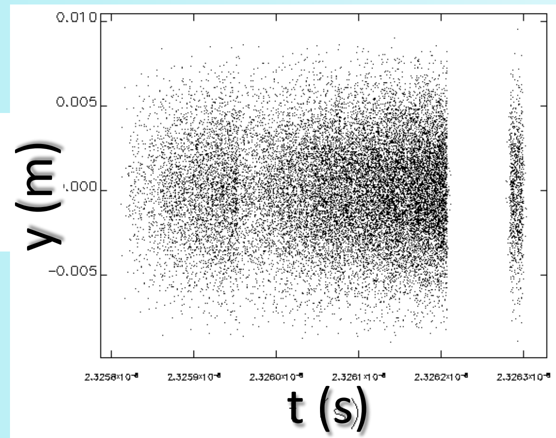
Goal is to extract maximum energy from drive bunch, up to 80%

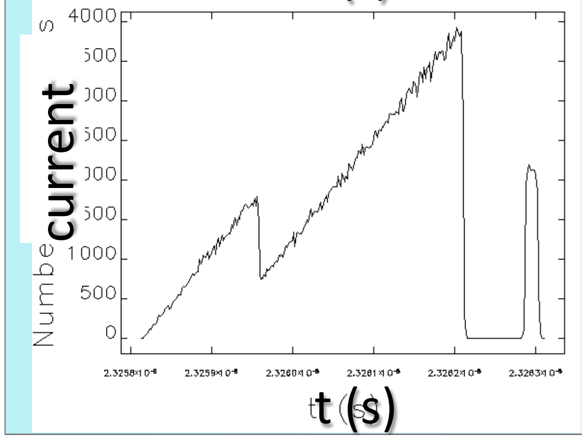
1) Bane et. al., *IEEE Trans. Nucl. Sci.* NS-32, 3524 (1985).
2) F. Lemery, P. Piot, *Phys. Rev. Spec. Topics – Acc. and Beams*, 18, 081301 (2015).

Drive bunch shaping using emittance exchange EEX*

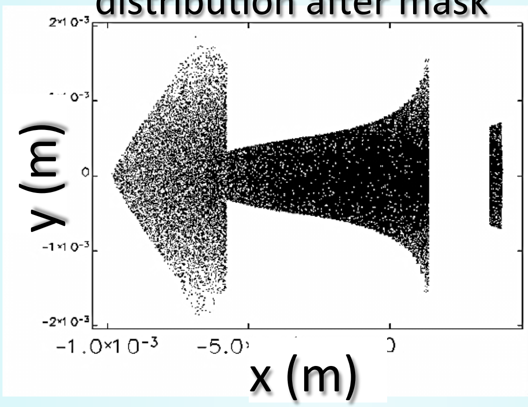


After EEX

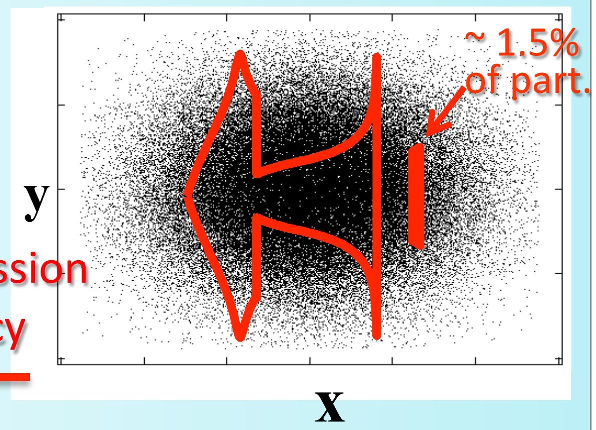




Transverse particle distribution after mask



30 % transmission efficiency

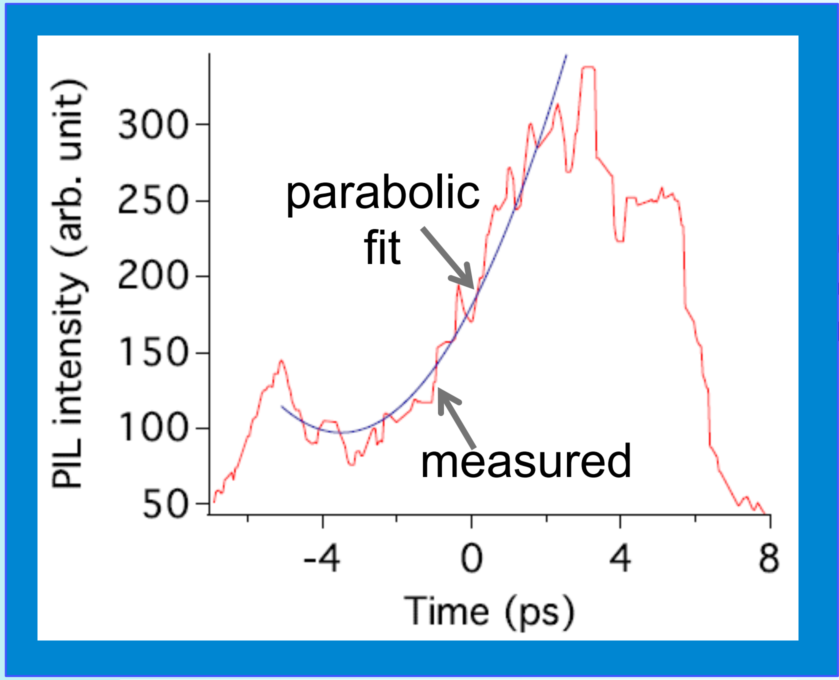


- ~25 kW is deposited on mask at low energy 5 MeV, i.e. below threshold energy for isotope production

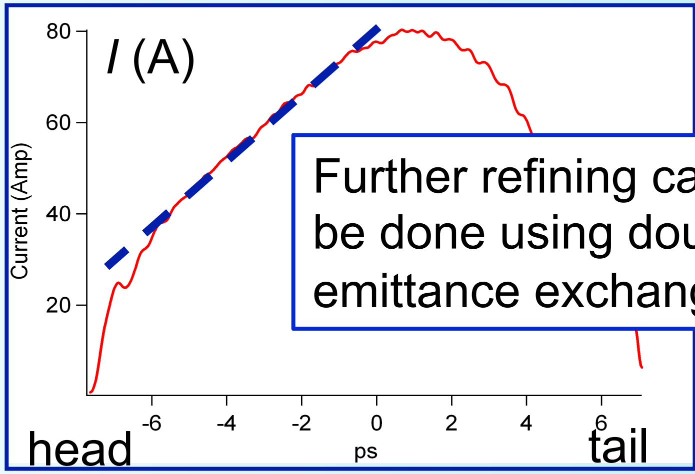
Talk by J. Power, this workshop

*) M. Cornacchia, P. Emma, *Phys. Rev. ST - Acc. Beams*, 5, 084001 (2002)

Drive bunch shaping using photocathode laser [1]



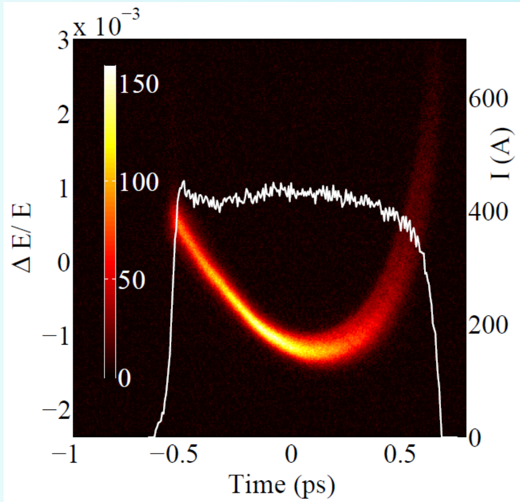
Laser pulse intensity



Further refining can be done using double emittance exchange [2]

At the end of the injector at 100 MeV

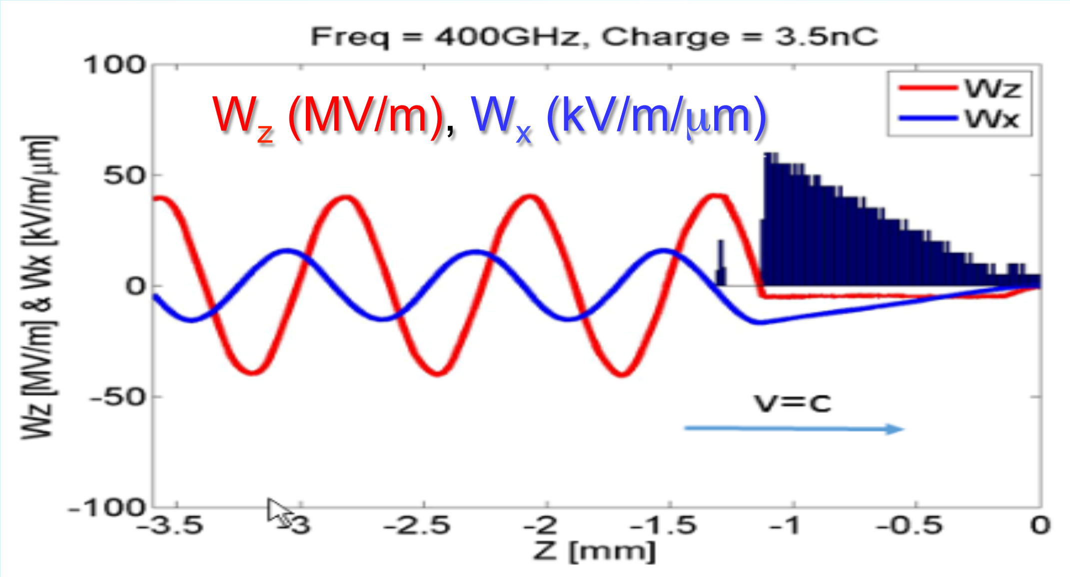
… was proposed to remove significant quadratic energy chirp at the end of the FERMI FEL linac



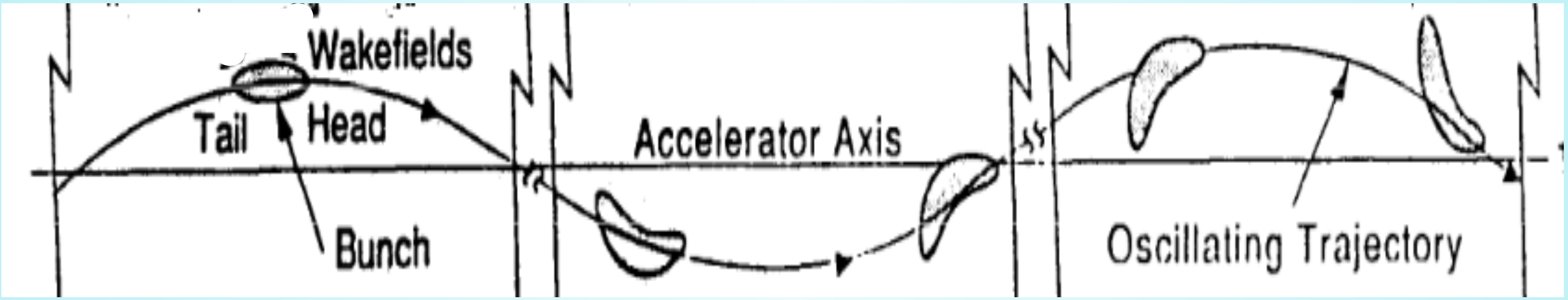
1) Cornacchia, Di Mitri, Penco, Zholents, *Phys. Rev. ST-AB*, 9, 120701(2006).
   See also, F. Lemery, P. Piot, Phys. Rev. Spec. Topics – Acc. and Beams, 18, 081301 (2015)
2) Zholents and Zolotorev, ANL/APS/LS-327, (2011)

Drive Bunch Beam Breakup Instability

Examples of longitudinal and transverse wakefield functions



Cumulative collective instability arises from continuous exposure of tail electrons to transverse wake field*

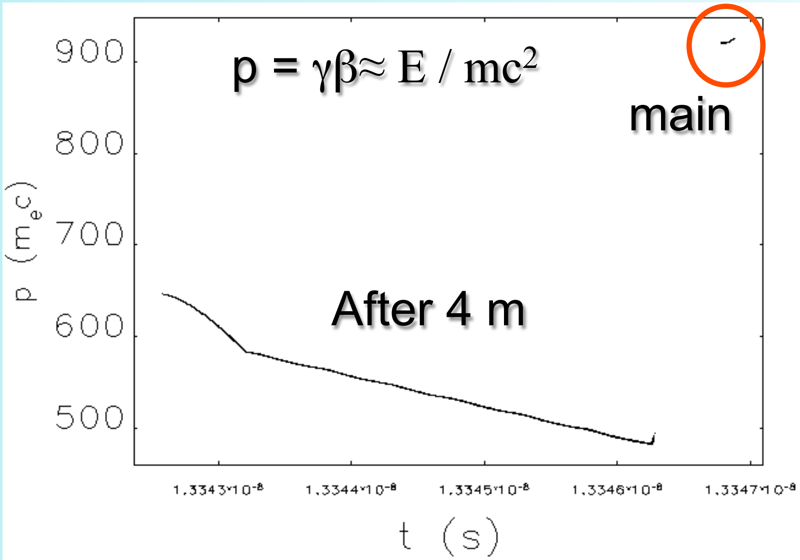


*) A.Chao, "Physics of collective beam instabilities in high energy accelerators", New York: Wiley.

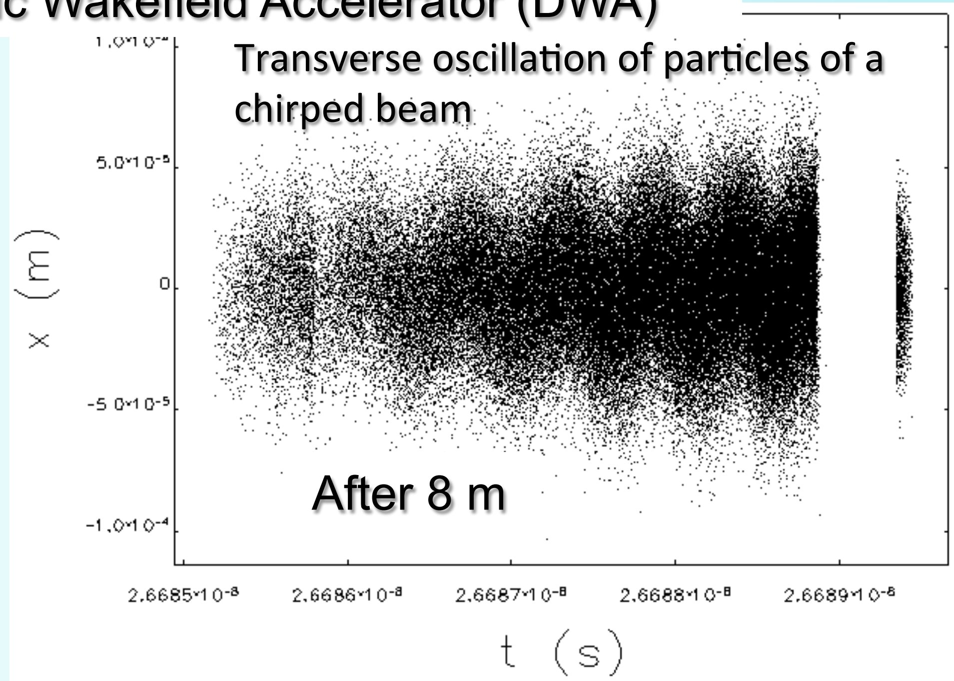
Balakin-Novokhatsky-Smirnov (BNS) damping of BBU

- Use FODO
- Produce "chirp" in the betatron tune along the electron bunch using the energy "chirp", and
- Force tail to oscillate faster than head, thus averaging the impact of transverse wake fields.

Illustration for Dielectric Wakefield Accelerator (DWA)



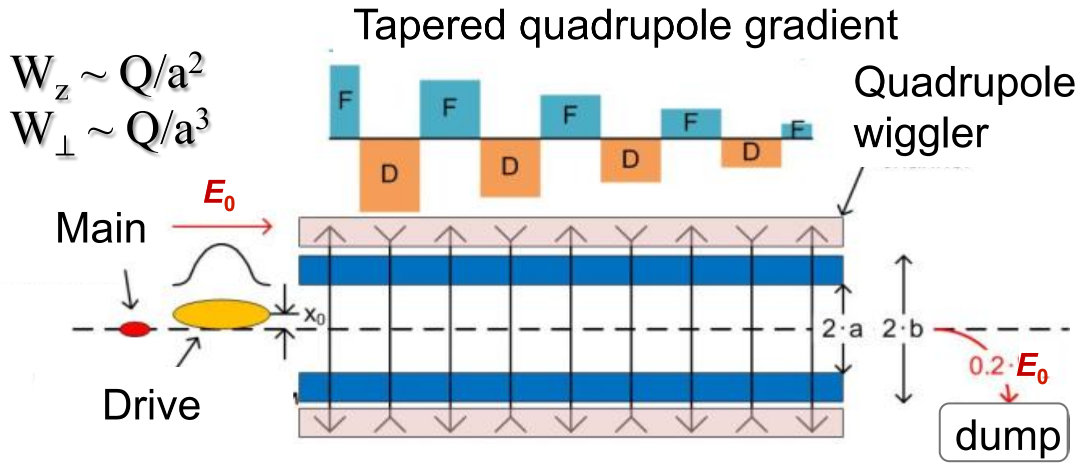
Initial energy chirp ~15 % (peak-to-peak)



Particles of different energies have different oscillation periods in the FODO lattice

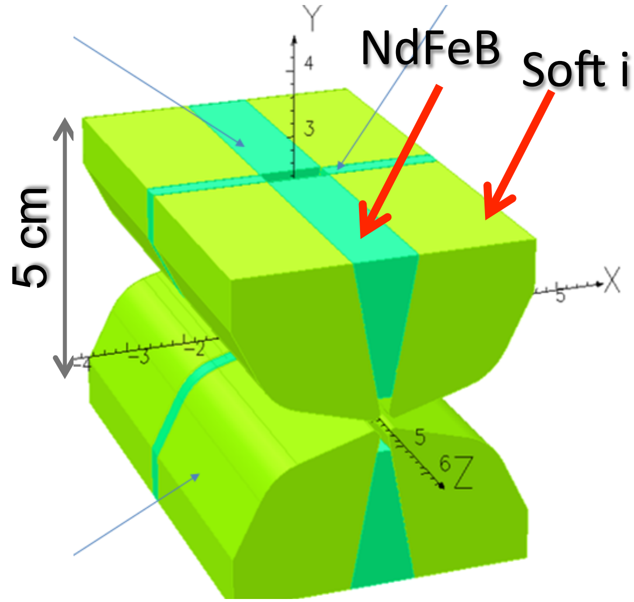
Maximum energy gain is defined by quadrupole strength

Wakefield accelerator

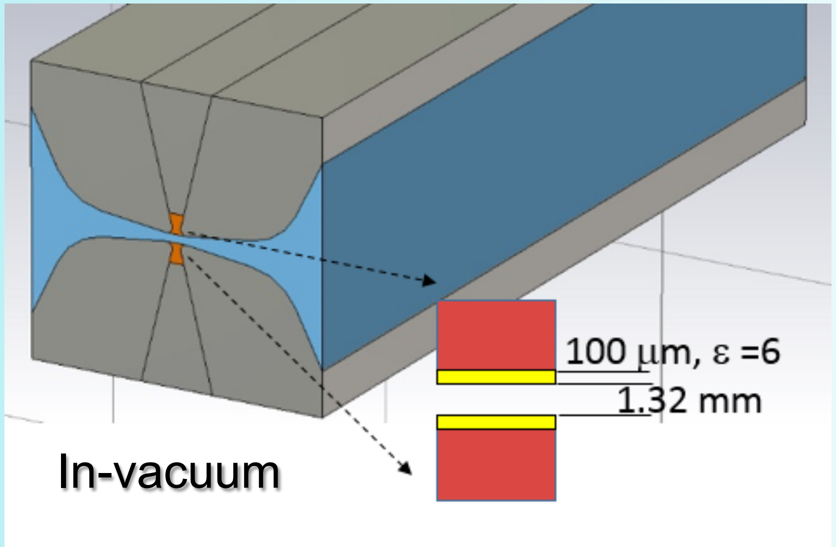


Dielectric channel imbedded into *quadrupole wiggler*

Two quadrupoles back-to-back



N. Strelnikov, I. Vasserman

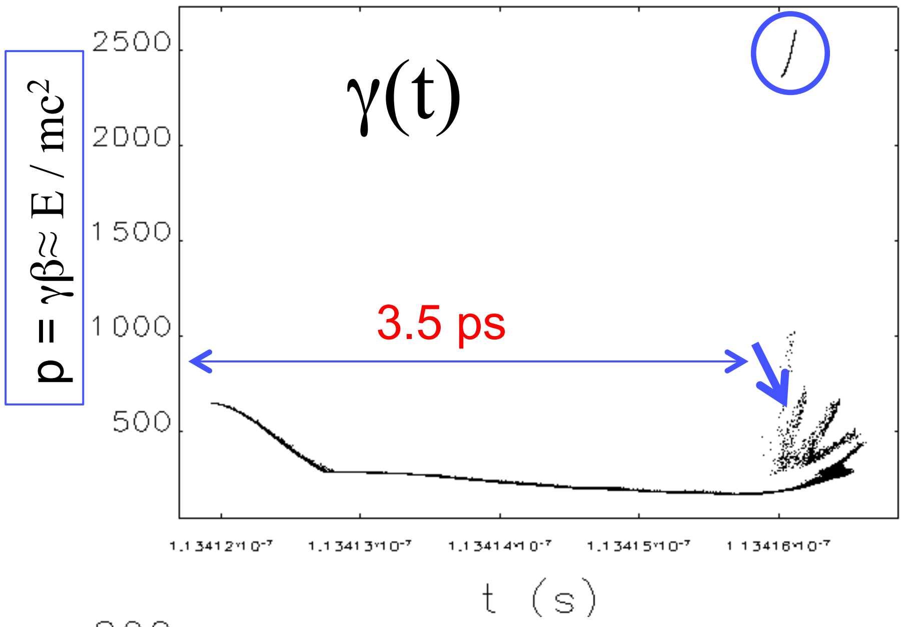


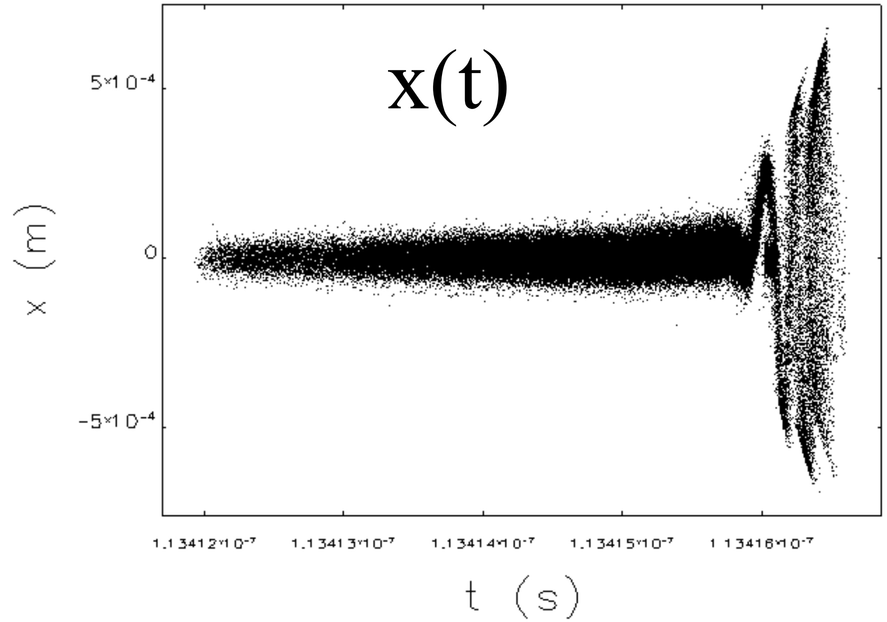
High gradient permanent magnet quad

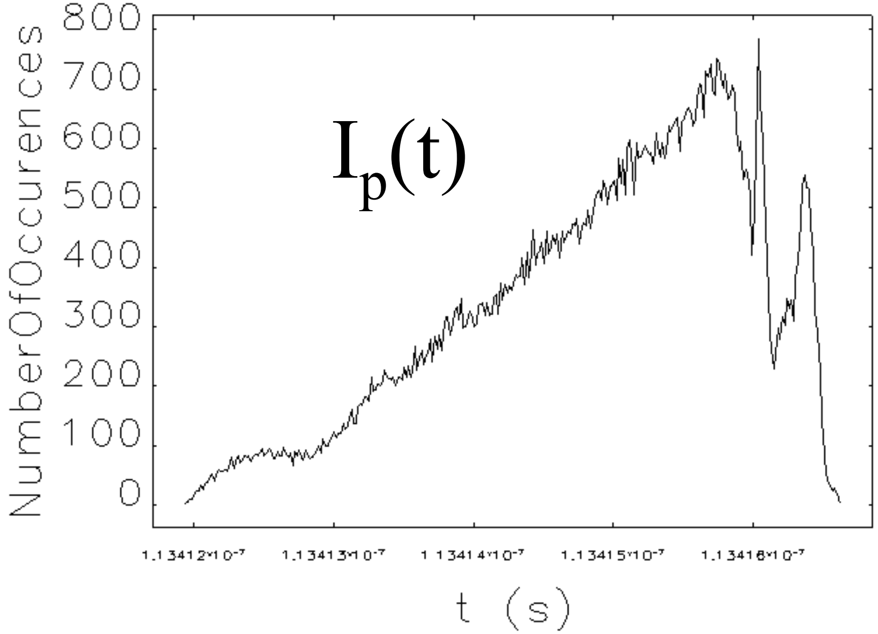
- Bore radius = 1.5 mm.
- Peak gradient = 0.96 T/mm.
- Gradient integral / length = 0.9 T/mm.
- Weight = 300 g.
- Magnetic force between top and bottom parts = 30.5 kg.

*) C. Li, W. Gai, C. Jing, J. G. Power, C. X. Tang, A. Zholents, PRST-AB, 17, 091302 (2014)

Illustration using 3.5 nC drive and 50 pC main bunch





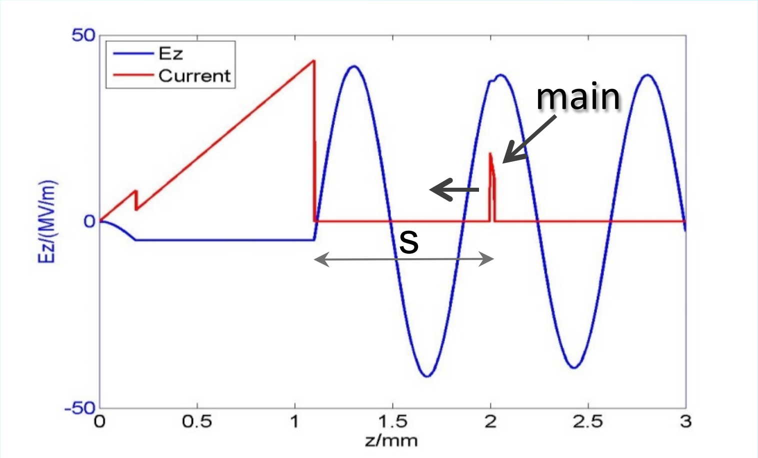


34 m

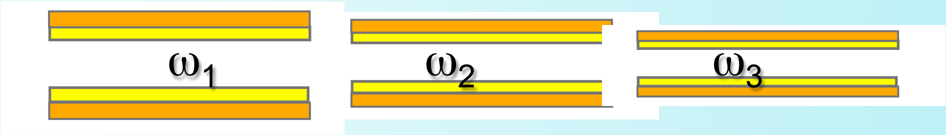
- the drive beam tail decelerates more,
- develops more lagging, and
  sees the wake's accelerating field

Problem mitigation

- Move main bunch to second maximum (can be difficult if done using the mask)



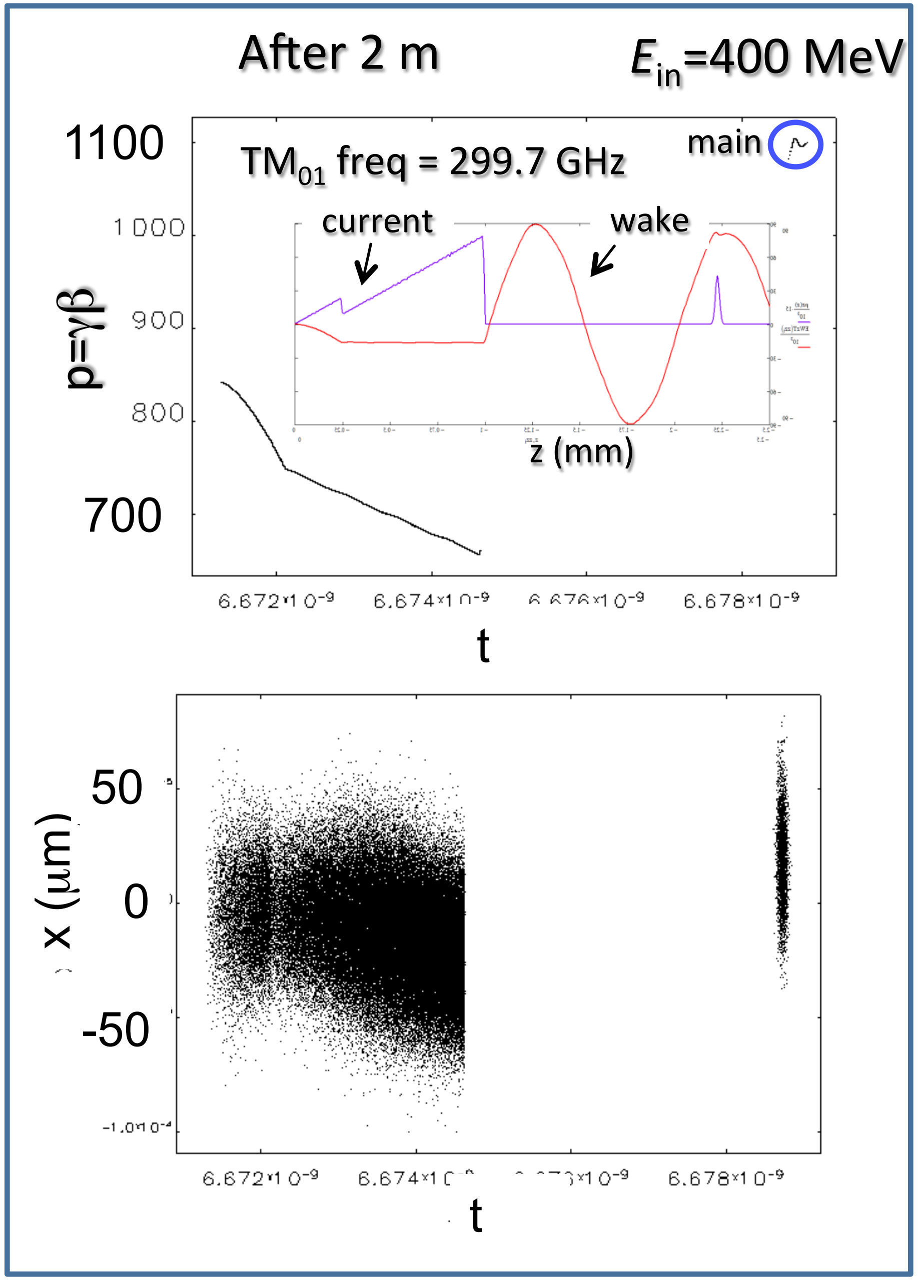
- Make adaptive frequency channel and always keep main bunch at or near to the maximum (easy)

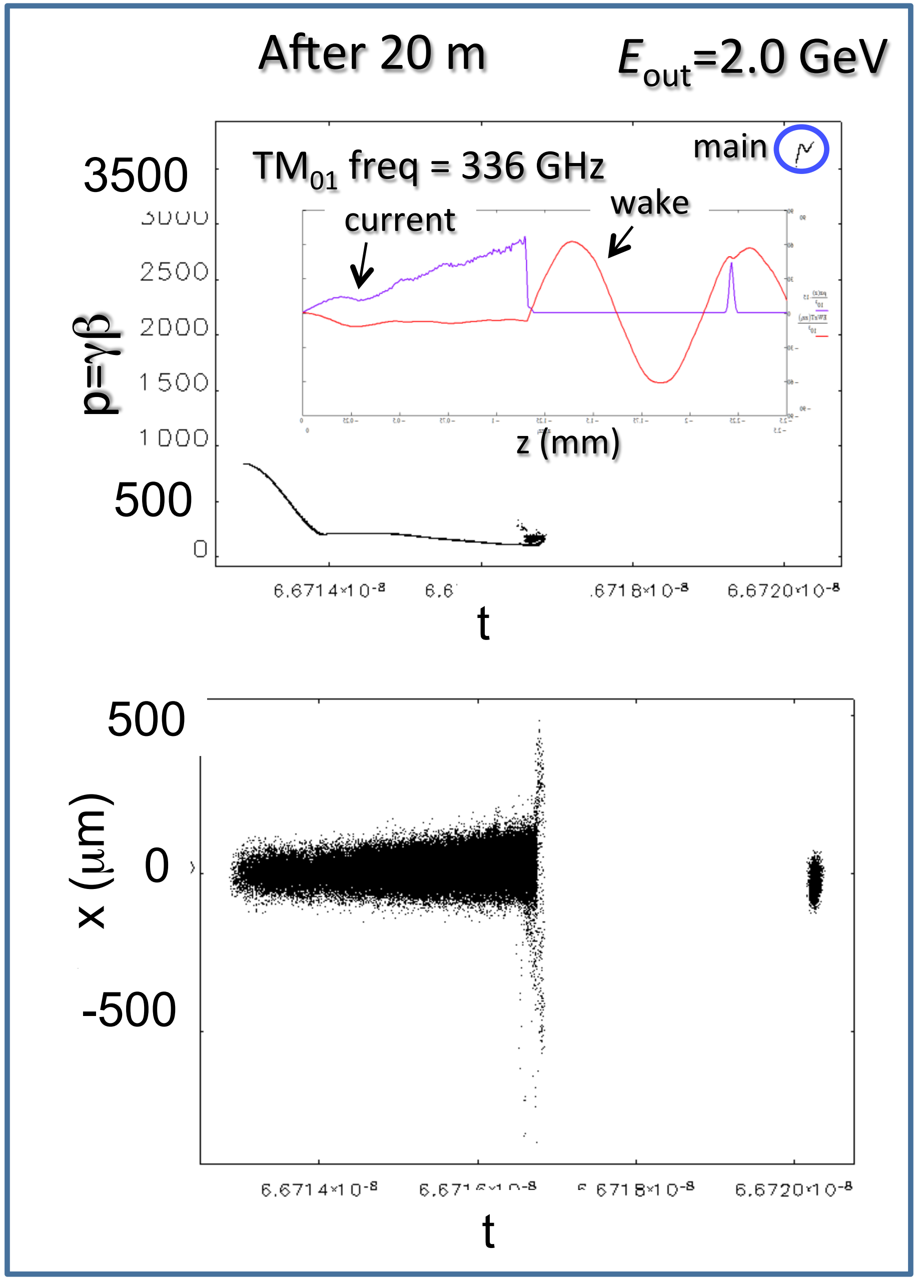


$\omega_1 < \omega_2 < \omega_3$

- Use drive bunch with higher energy (affects facility cost and energy efficiency)

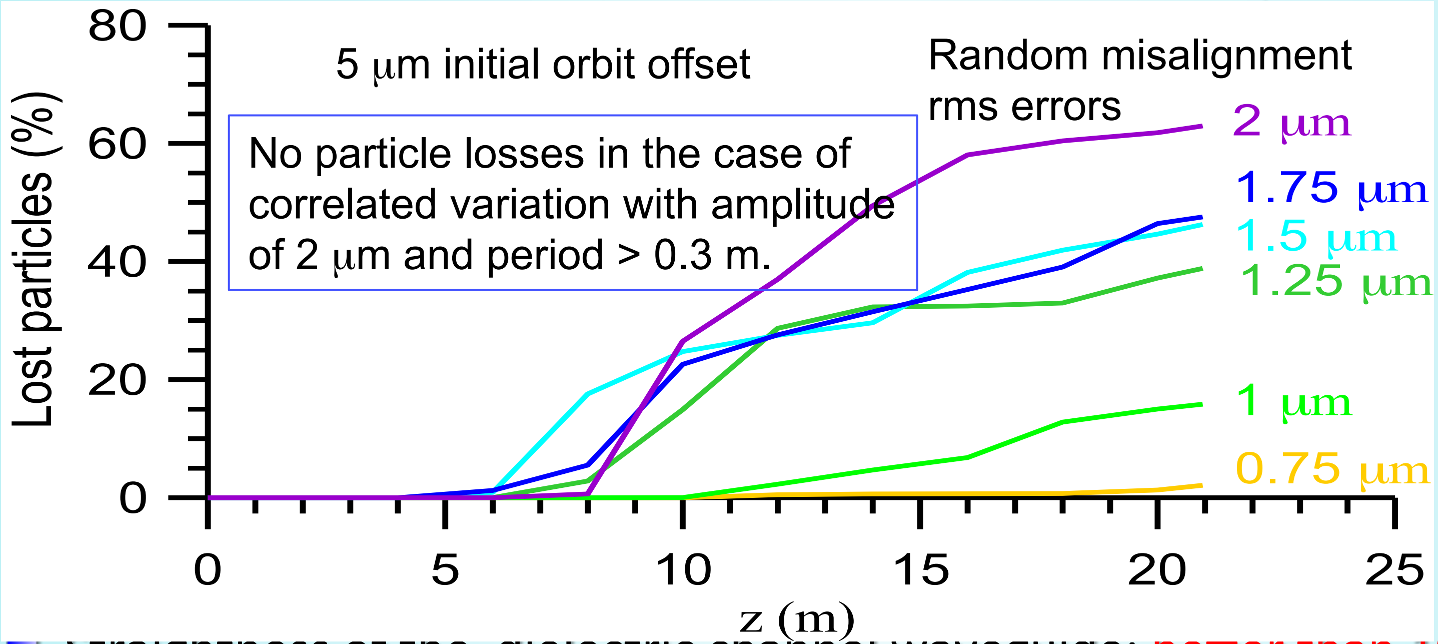
Result of tracking for 8nC drive and 250 pC main bunch



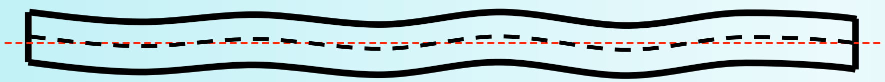


Tolerances

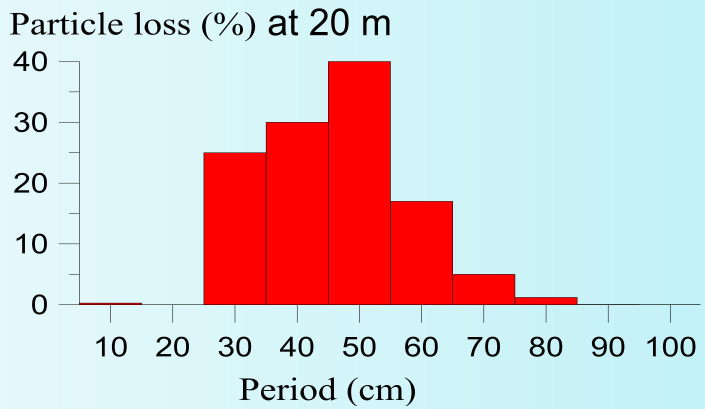
- Misalignment of FODO quadrupoles (or trajectory) < 1 μm



- Straightness of the dielectric channel waveguide: better than 10 μm

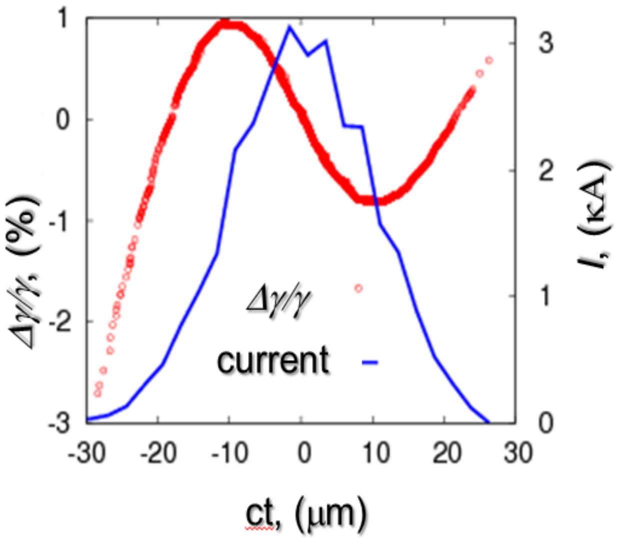


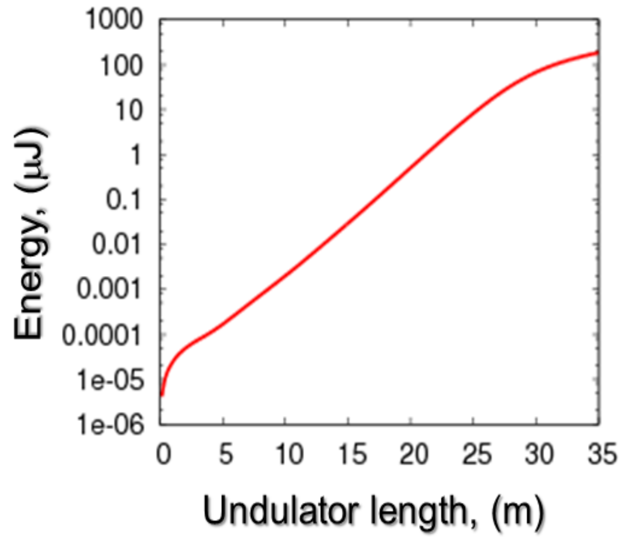
Maximum amplitude is 10 μm and the period is varied

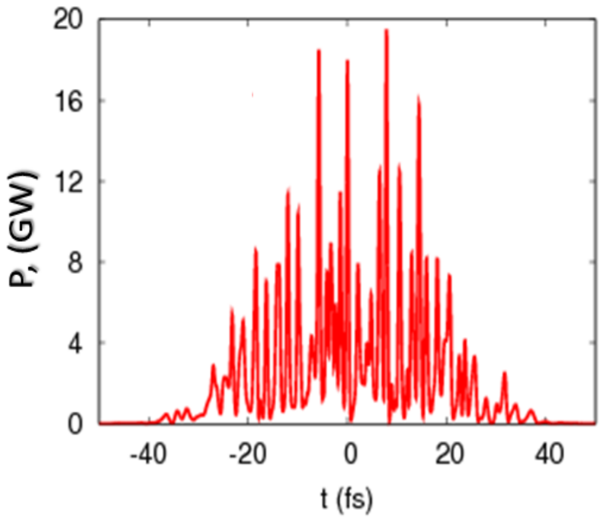


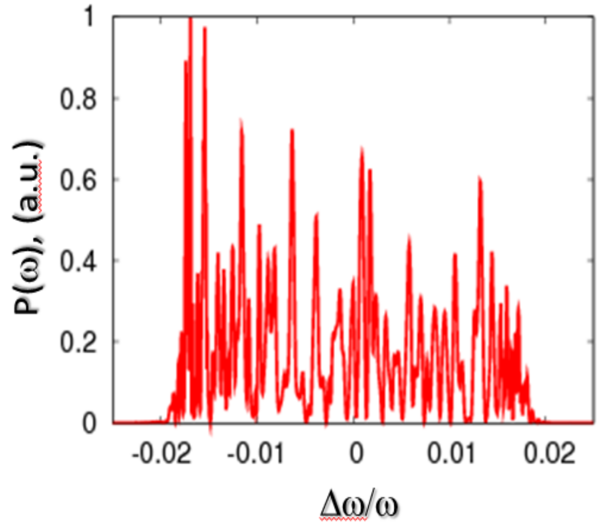
FEL simulations (illustration)

Undulator period, cm	1.8
Undulator parameter, K	1.0
Energy, GeV	1.88
Charge, pC	250
Current, kA	3
Emitt, μm	1
RMS energy spread, %	0.3
Pierce parameter,	0.01
X-ray wave-length, nm	1
Peak power, GW	5
Bandwidth, %	3.8

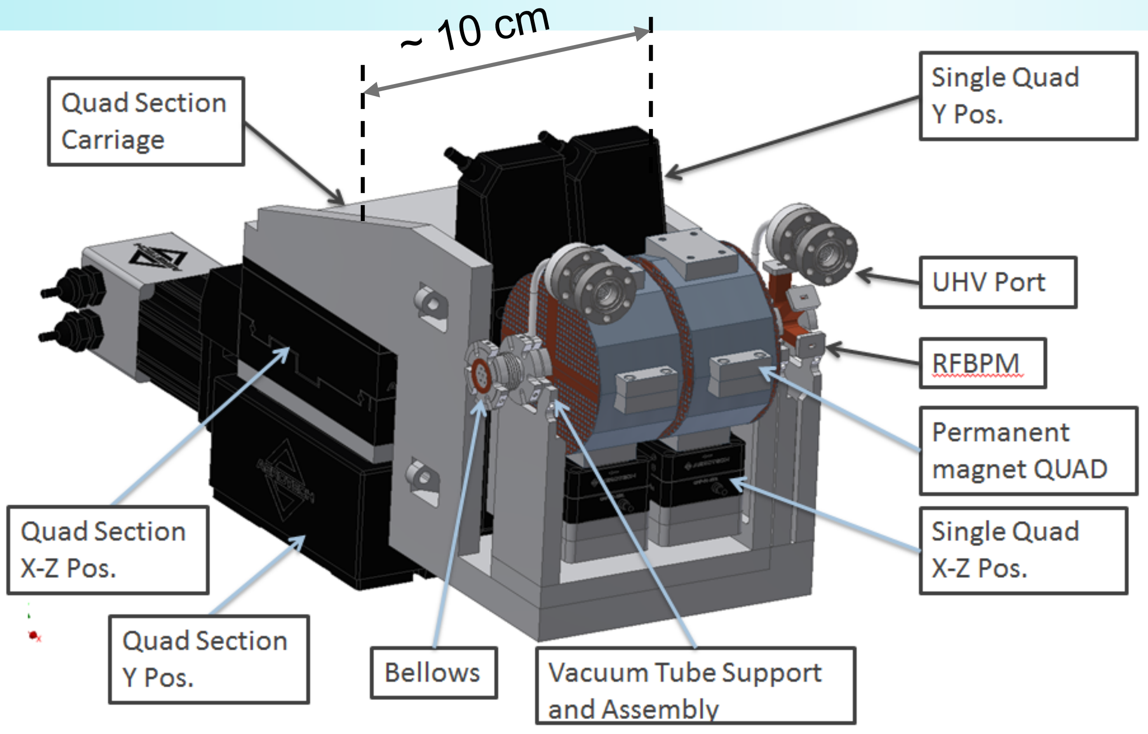








The initial goal is to build a 1 m long accelerator unit and test it in LEUTL tunnel using APS injector linac



A concept of a dual quad module*

APS 450 MeV injector linac

LEUTL tunnel is ~ 40 m long and is ready to accept the beam

*) courtesy of S. Doran

Summary

- High repetition-rate, soft X-ray FEL user facility
  - 10 CWAs linacs driven by a single 400 MeV SRF linac
  - 10 FEL lines @ 50 kHz bunch repetition rate
  - Compact, inexpensive, and flexible
- Progress
  - Drive bunch shaping (triangular + quadratic component)
  - Control of beam breakup instability
    - Quadrupole wiggler, adaptive frequency channel
  - Small "main bunch" energy spread
- Future development
  - improving transmission efficiency through the mask – critical
  - space charge effects
  - beam-based trajectory correction - potential showstopper
  - modular design: quadrupole wiggler, vacuum chamber, cooling - critical
  - break sections: BPMs, rf couplers, correctors, etc.

Thank you for your attention