Multi-GeV electron acceleration using the Texas Petawatt laser

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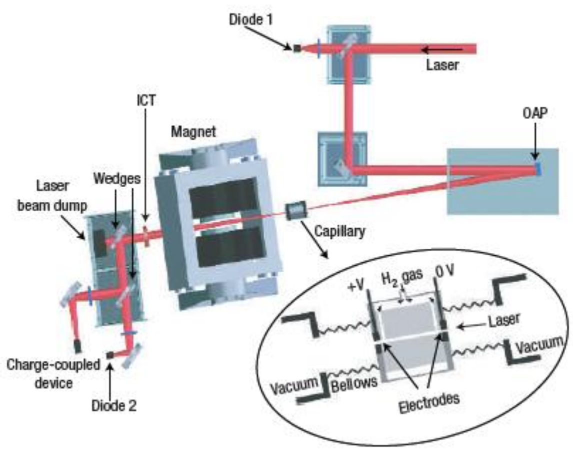
Outline

- Strategy for multi-GeV electron generation
- Summary of TPW LWFA simulations
- Layout of TPW LWFA experiment
- Experiment issues
  - electron self-injection at $n_e < 10^{18} cm^{-3}$(see Kalmykov's talk for detail)
  - low cost calorimetric characterization of multi-GeV electron (possible role of betatron x-rays)
  - FDH reconstruction(visualization) of bubble dynamics
- Experimental plan
- Conclusion

Generation of high energy and mono-energetic electron with LPA

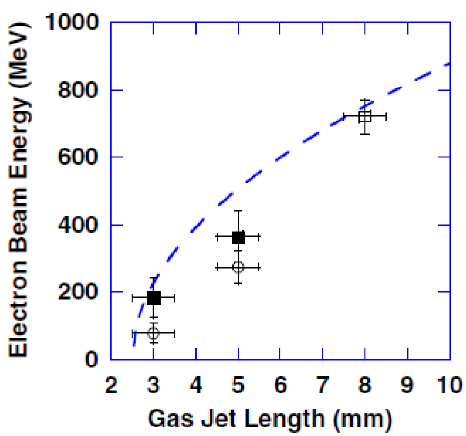
- **MANGLES** et. al., ***Nature* 431**, 535–538 (2004)
- **GEDDES** et. al., ***Nature* 431**, 538–541 (2004)
- **FAURE** et. al., ***Nature* 431,** 541–544 (2004)

Plasma "bubble" accelerator can generate~100MeV monoenergetic, highly collimated, nC charge electron beam with LPA using TW laser system

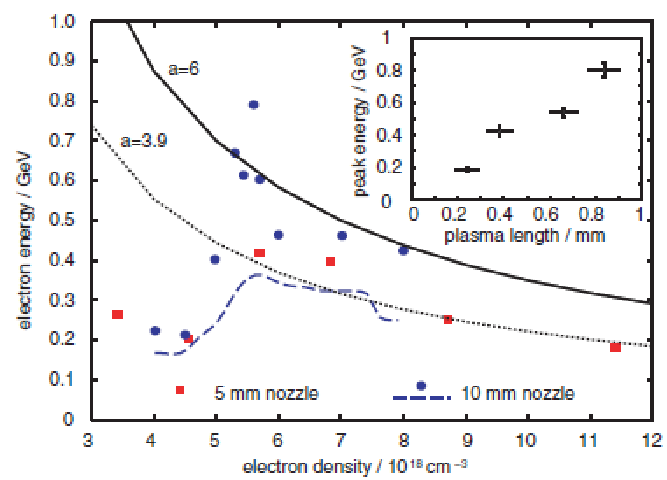


1GeV generation

W.P.Leemans et.al.,
Nature Phys. 2, 696 (2006)



D.H. Froula et.al.
PRL.103,215006 (2009)



S. Kneip et.al.,
PRL 103, 035002 (2009)

How to get Multi-GeV electron with laser-plasma accelerator ?

Stable structure for plasma bubble propagation, matched a_0 and spot size **:**

$$k_p w_0 \approx k_p R_b \approx 2\sqrt{a_0} \qquad a_0 \approx 2\left(\frac{P}{P_c}\right)^{1/3}$$

Long pump depletion length

$$L_T \approx \frac{4}{3}\left(\frac{k_0}{k_p}\right)^3 \sqrt{a_0}\, k_0^{-1}$$

Long dephasing length:

$$L_{dp} \approx \frac{2}{3}\frac{k_0}{k_p}\frac{1}{\sqrt{a_0}} Z_R = \left(\frac{P}{TW}\right)^{\frac{1}{6}} \left(\frac{10^{18}cm^{-3}}{n_e}\right)^{4/3}$$

Energy gain**:**

$$\Delta E \approx \frac{2}{3} mc^2 \left(\frac{k_0}{k_p}\right)^2 a_0 = 1.7\left(\frac{P[TW]}{100}\right)^{1/3} \left(\frac{10^{18}}{n_p[cm^{-3}]}\right)^{2/3} \left(\frac{0.8}{\lambda_0[\mu m]}\right)^{4/3}$$

Self-guiding mechanism to cancel Vacuum diffraction effect:

$$\frac{P}{P_{cr}} > 1$$

W. Lu et.al., *Phys. Rev. Special Topics -Accelerators & Beams* 10, 061301 (2007)

- Low plasma density ($n_e < 10^{18} cm^{-3}$)
- High power laser ($P > 10^{15}$w)
- Large Rayleigh range (~cm)
- Pulse duration around 150fs

→ Texas Petawatt Laser!

Texas Petawatt Laser System is ideal for multi-GeV LPA

• Laser pulse energy	200J
• Laser pulse duration	150fs
• Laser peak power	1.33PW
• Focusing geometry	w_0=80μm
	$f^{\#}$/=40
	Z_R=1.9cm

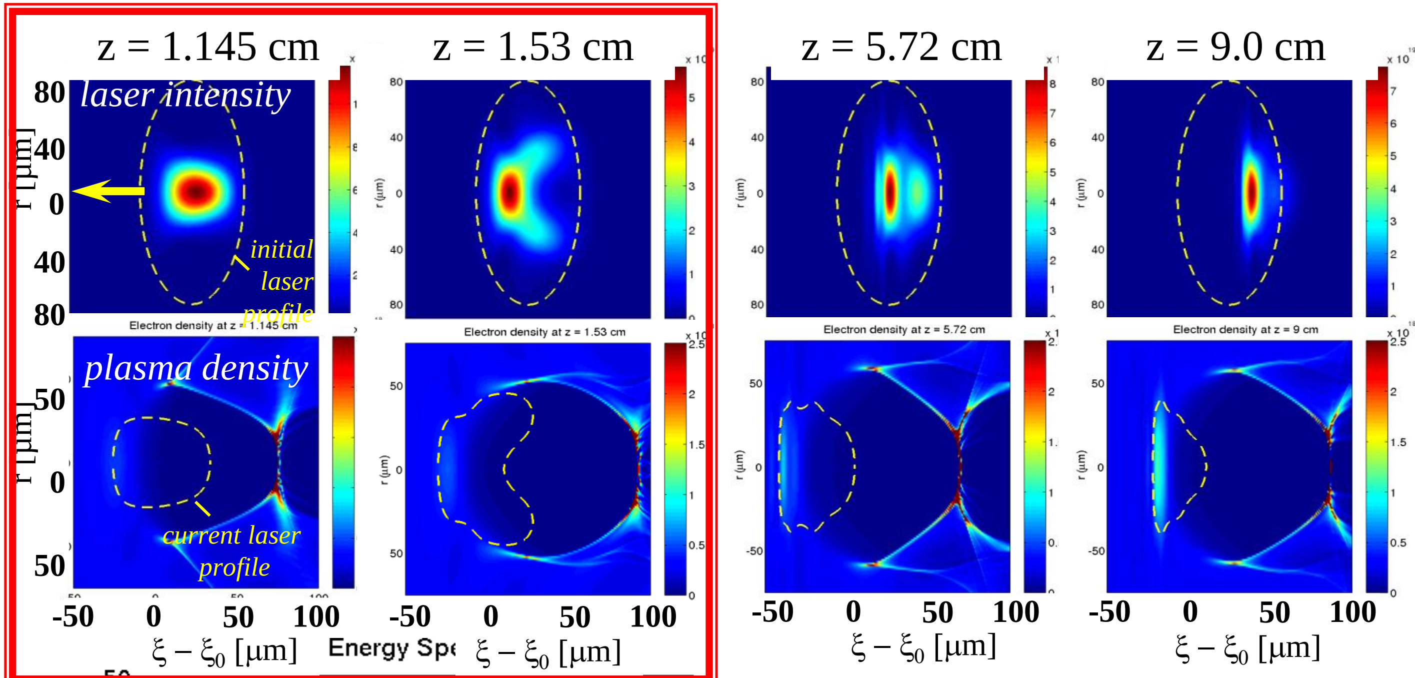
Two questions at n_e=1-3x10^{17}cm^{-3}:

•Will laser pulse self-guide over 10cm (multiple Z_R) at $2.7 < \omega_{pe}\tau_{laser} < 4.2$ and $8<P/P_{cr}<20$ w/o catastrophic filamentation?

•Can the electrons self-inject into plasma bubble and be accelerated monoenergetically?

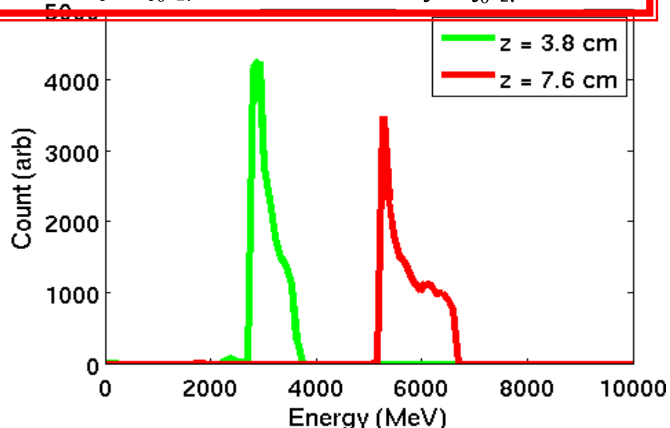
Summary of simulation results for Texas petawatt laser LPA

S. Kalmykov et. al., New J. Phys. 12, 045019 (2010)



Simulations show that at $n_e = 2.5 \cdot 10^{17}$ cm^{-3}

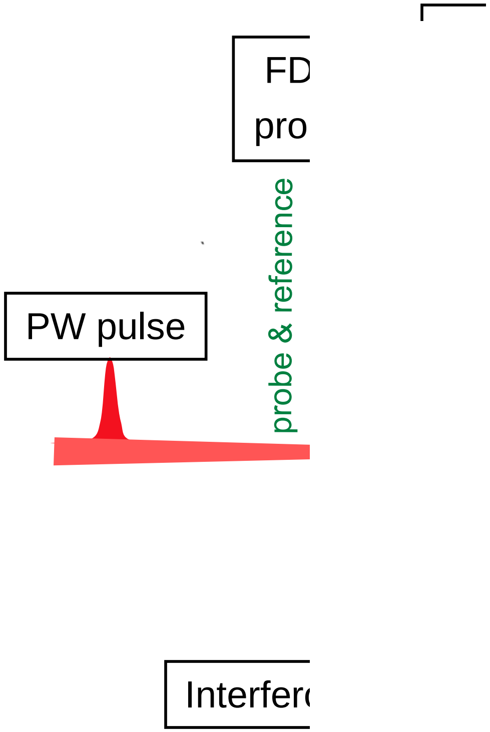
- laser self-guides over 10 cm
- bubble initially grows rapidly (signature of self-injection), then has stable propagation

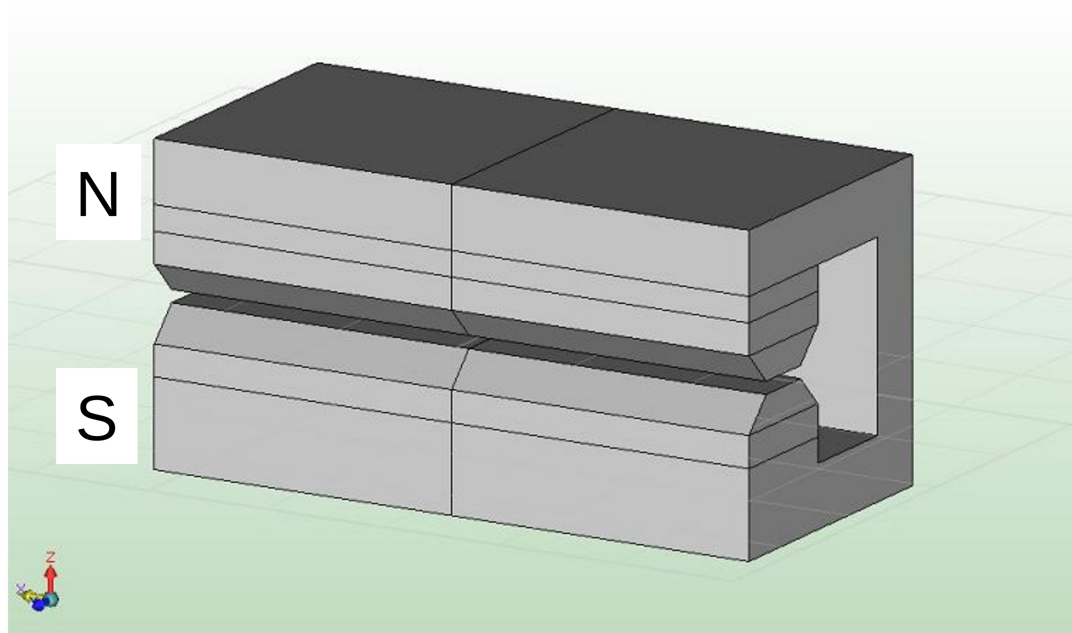


Simulations show self-injection and quasi-monoenergetic electron acceleration > 6 GeV

Single stage, self-injection, table top, multi-GeV LPA

TPW LWFA experimental layout





2nd generation, magnet spectrometer

- Laser plasma interaction diagnostics

  Transverse interferometer, Thomson scattering and frequency shift
  plasma density, Self-focusing, self-guiding, bubble size variation

- Electron beam diagnostics

  Lanex, OTR, ICT and calorimeter

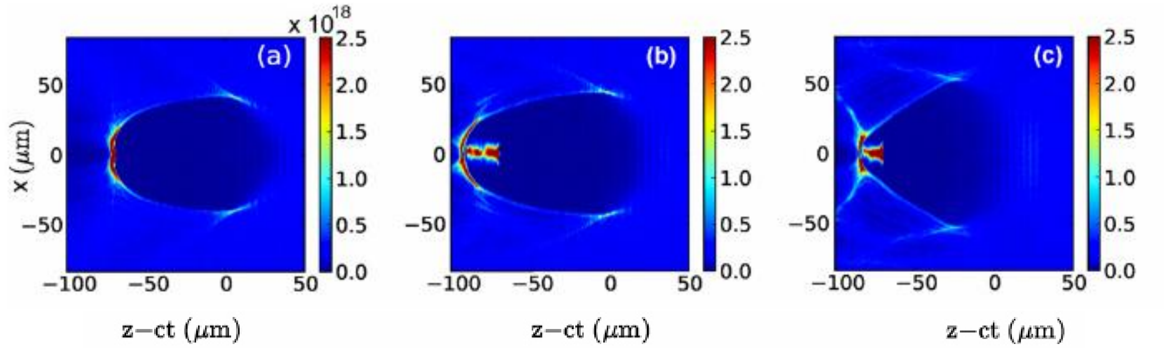
  electron beam divergence, electron energy

- Plasma bubble diagnostic

  Small angle FDH(“FDSC”)

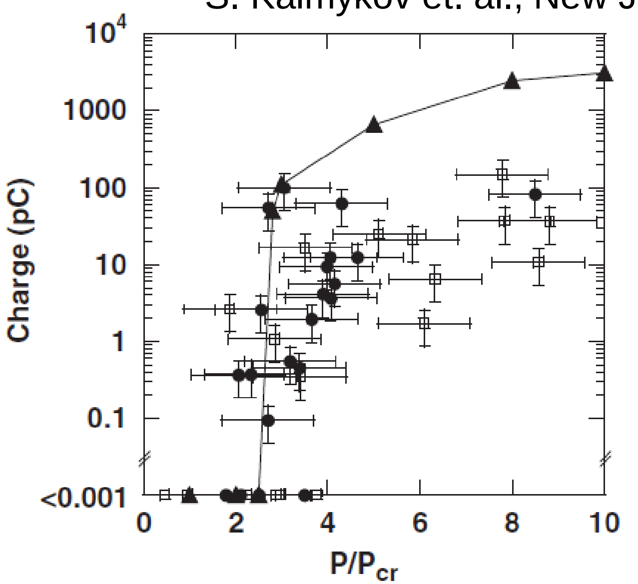
Experimental issues of the PW LWFA

- Electron self-injection at low density (2.5x10^{17}cm^{-3})



Simulations do show that electron self-injection is positive

S. Kalmykov et. al., New J. Phys. 12, 045019 (2010)



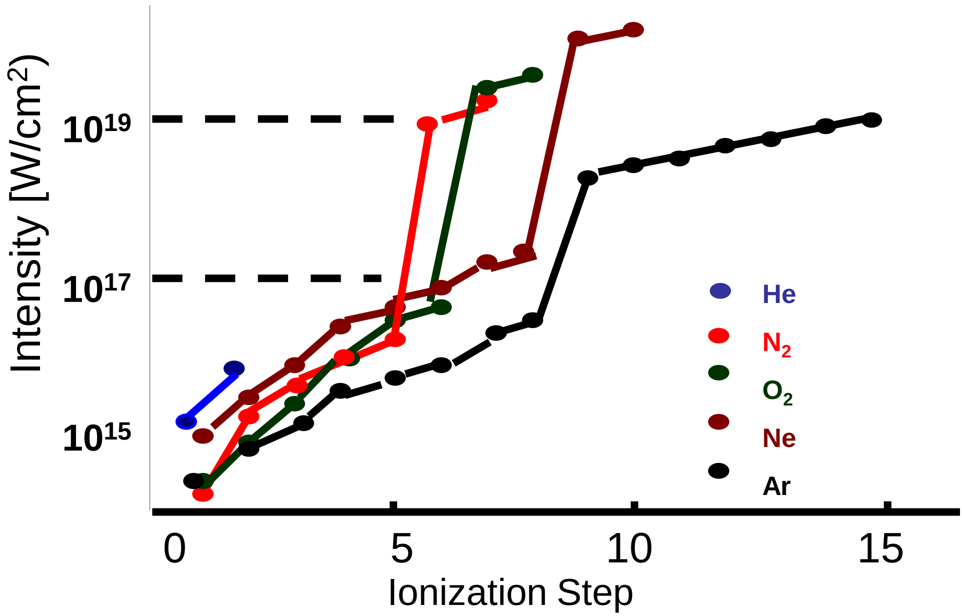
Some recent experiments suggest that self-injection threshold is higher than prediction

D. H. Froula, PRL **103**, 215006 (2009)

Electrons injection with ionization trapping mechanism

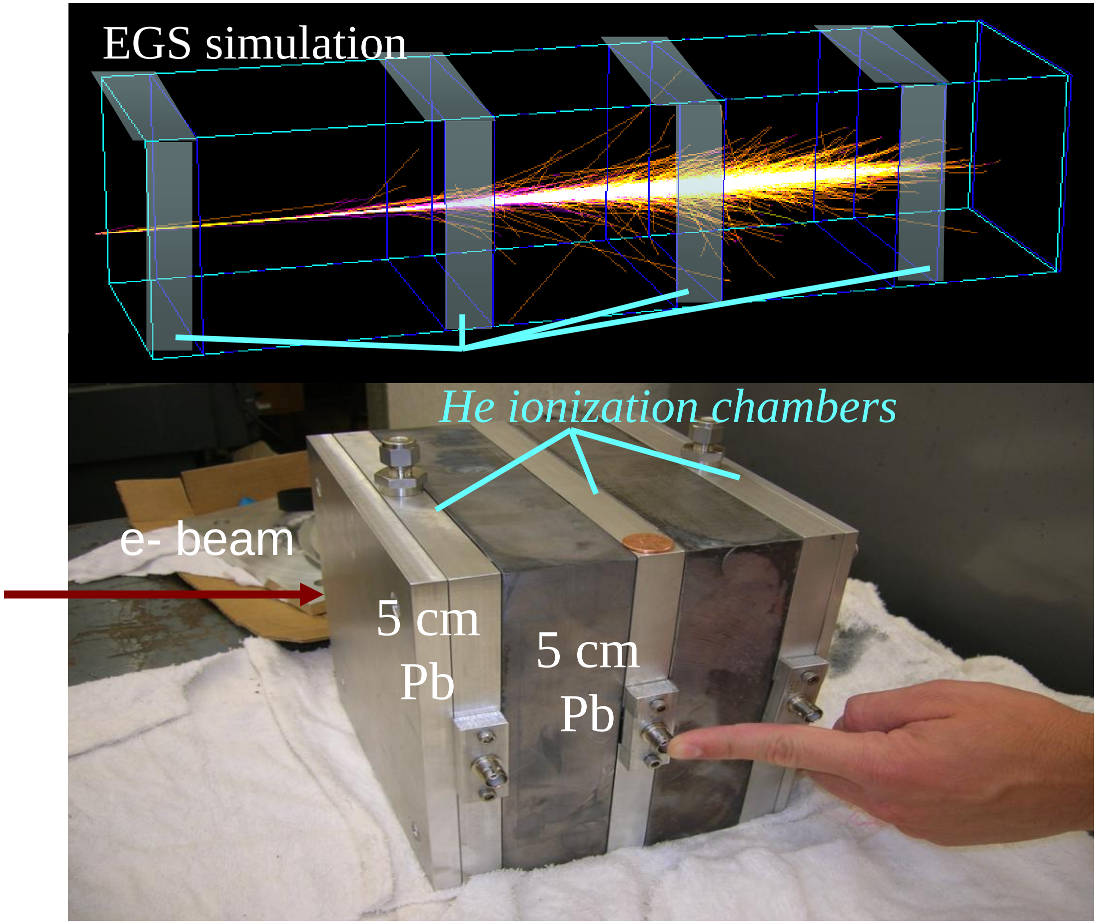
A. Pak et.al, PRL **104**, 025003 (2010)

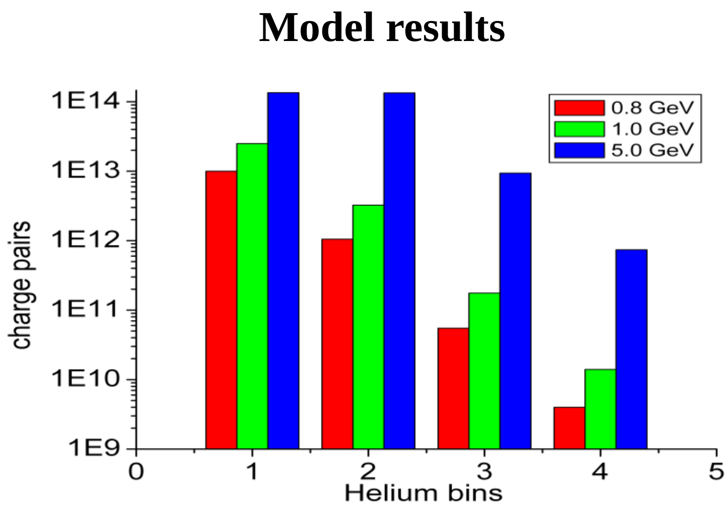
Ionization levels using barrier suppression ionization



- Intensity for ionizing He^+, H^{2+}, N^+ to N^{5+} is below 10^{17}Wcm^{-2}, electron can be ionized by the front edge of PW laser pulse
- N^{6+} is around 10^{19}Wcm^{-2}, can be ionized at the peak PW laser pulse
- Simulations are underway and new gas cell is being designed

Experimental issues of PW LWFA

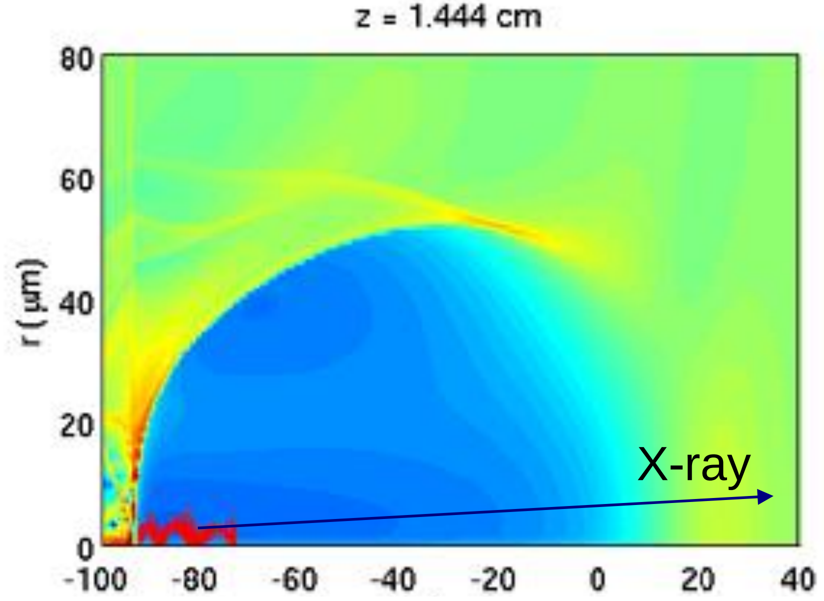




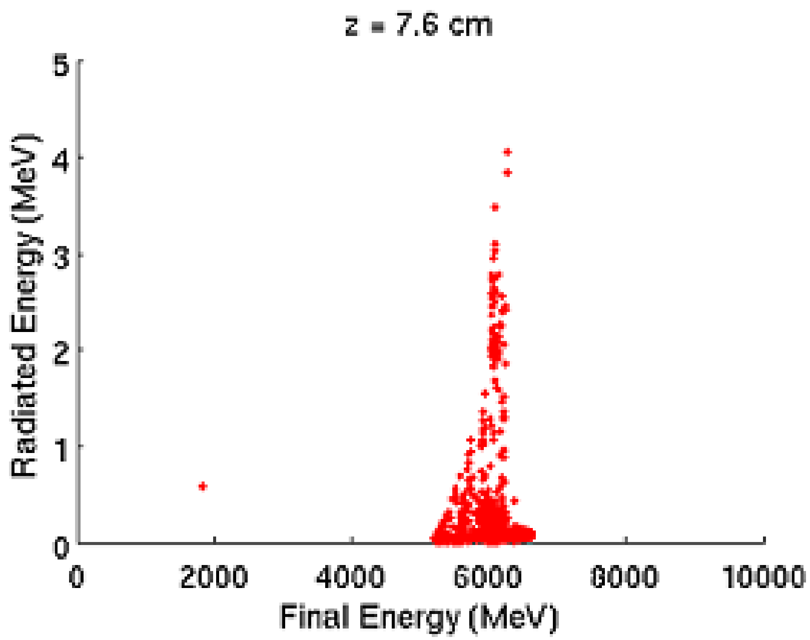
CALORIMETER: 1st version, inexpensive GeV e^- energy measurement

Will betatron radiation from accelerated electron affect calorimeter measurement?

Experimental issues of PW LWFA



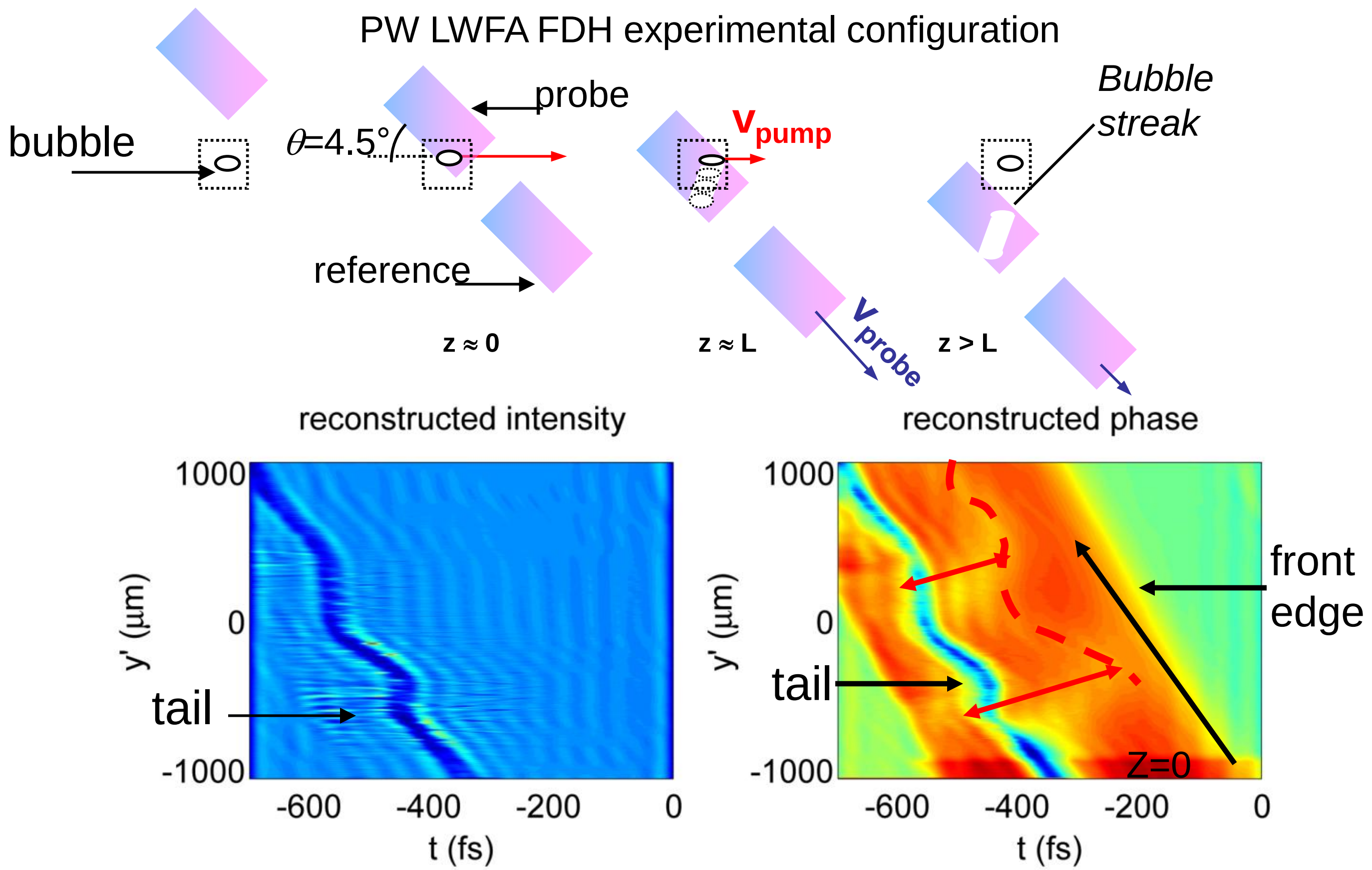
- Betatron radiation from the accelerated electron wiggling will enter the calorimeter



Simulation results shows that:

- electron oscillation amplitude is very small (a few μm)
- GeV electrons only radiate several MeV energy during the wiggling
- Betatron X-ray contributes <<1% to the calorimeter signal

Simulation results for reconstruction of plasma bubble with small angle FDH



- Both phase and amplitude reconstruction for plasma bubble is possible with FDH at small angle between main beam and FDH probe beam
- Bubble front and back edges and length variation can be resolved

Time line for the TPW LWFA experiment

- Summer 2010: complete setup of interaction and diagnostic chambers
- Fall 2010: full alignment with low power shots
- Early 2011: full PW shots with calorimeter and all supporting diagnostics
- Second generation: implement multi-GeV magnetic spectrometer

Conclusion

- Simulations show TPW laser is ideal for multi-GeV electron generation
- Ionization trapping mechanism can be used for electron injection
- Betatron radiation effect is considered for calorimeter and found to have effect<<1%
- Small angle FDH probe beam can be reconstructed well in both “AM” and “FM”