SUMMARY

AAC 2012 Working Group 1: Laser Plasma Accelerators

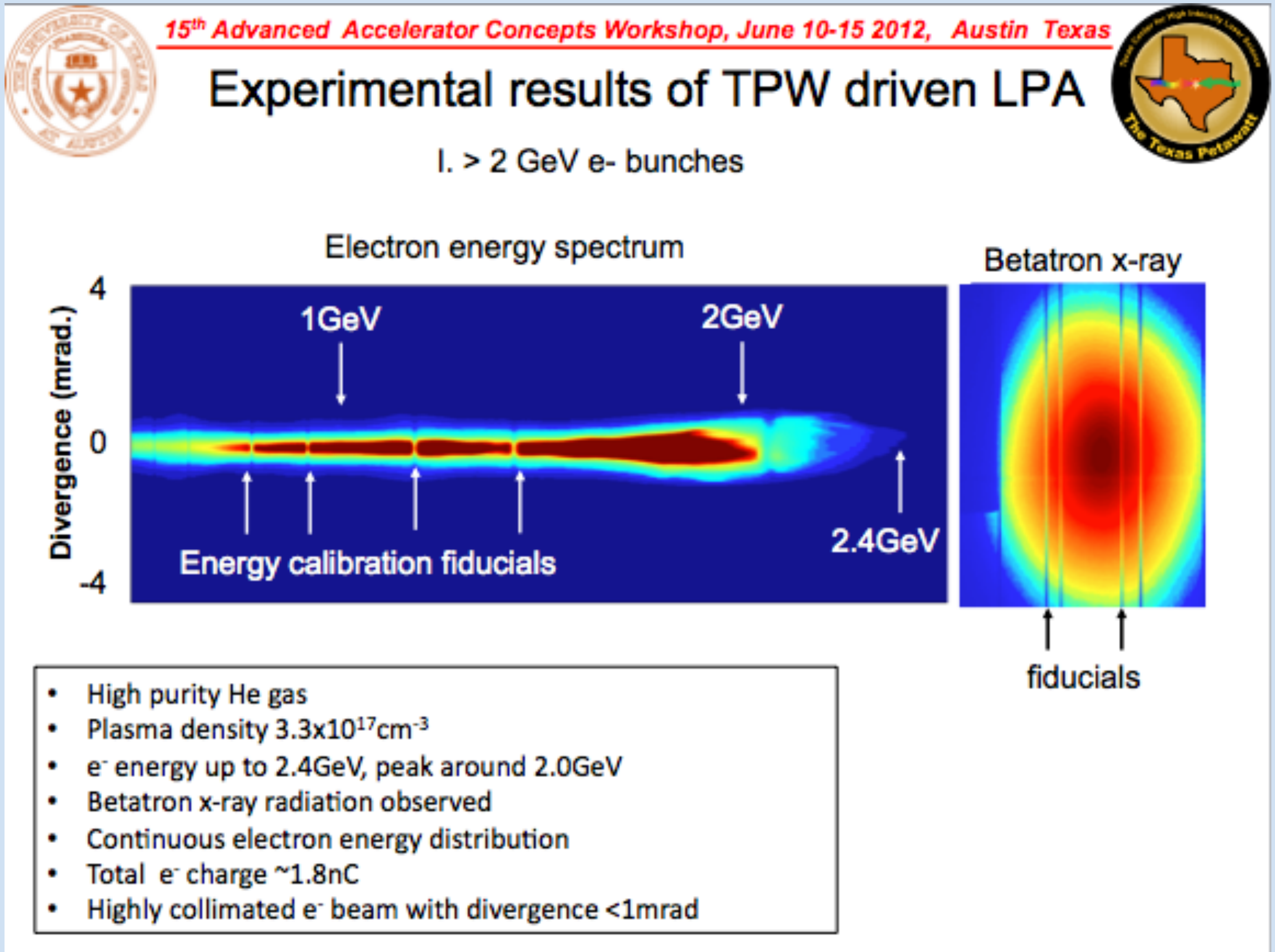
WG1 Leads:
Carl Schroeder (LBNL) and Mike Helle (NRL)

WG1 Sessions

	Monday	Tuesday	Wednesday	Thursday
AM		**Electron Acceleration:** Wang, Lopes, Walker, Mangles, Cros, Schumaker	**Plasma Structures:** Krishnan, Suk, Rittershofer, Schaper, Matlis	**Diagnostics (WGs 1&5)**: Kaluza, Geddes, Bourgeois, van Tilborg, Powers
PM-I		**Radiation generation (WGs 1&5):** Maier, Wenz, Sheng, Miura, Irman, Pai	**Laser Propagation:** Shiraishi, Pollock, Benedetti, Yoon, Kalmykov	**Laser Plasma Interactions:** Popp, Nam, Vieira, Kalmykov, Vranic
PM-II	**Laser facilities (WGs 1&8):** Krushelnick, Karsch, Osterhoff, Liu, Speka	**Injection & Staging:** Kaganovich, He, Chen, Liu, Sokollick	**Simulation of LPA (WGs 1&2):** Gordon, Cowan, Shadwick, Chen, Zhu, Cummings	
		POSTERS: (16)		

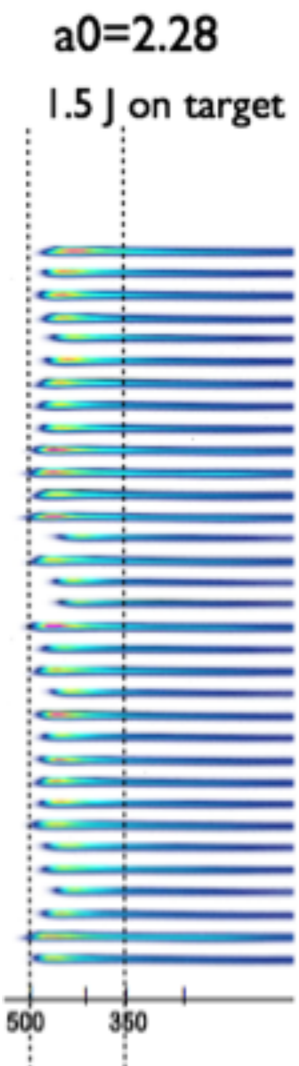
Electron acceleration

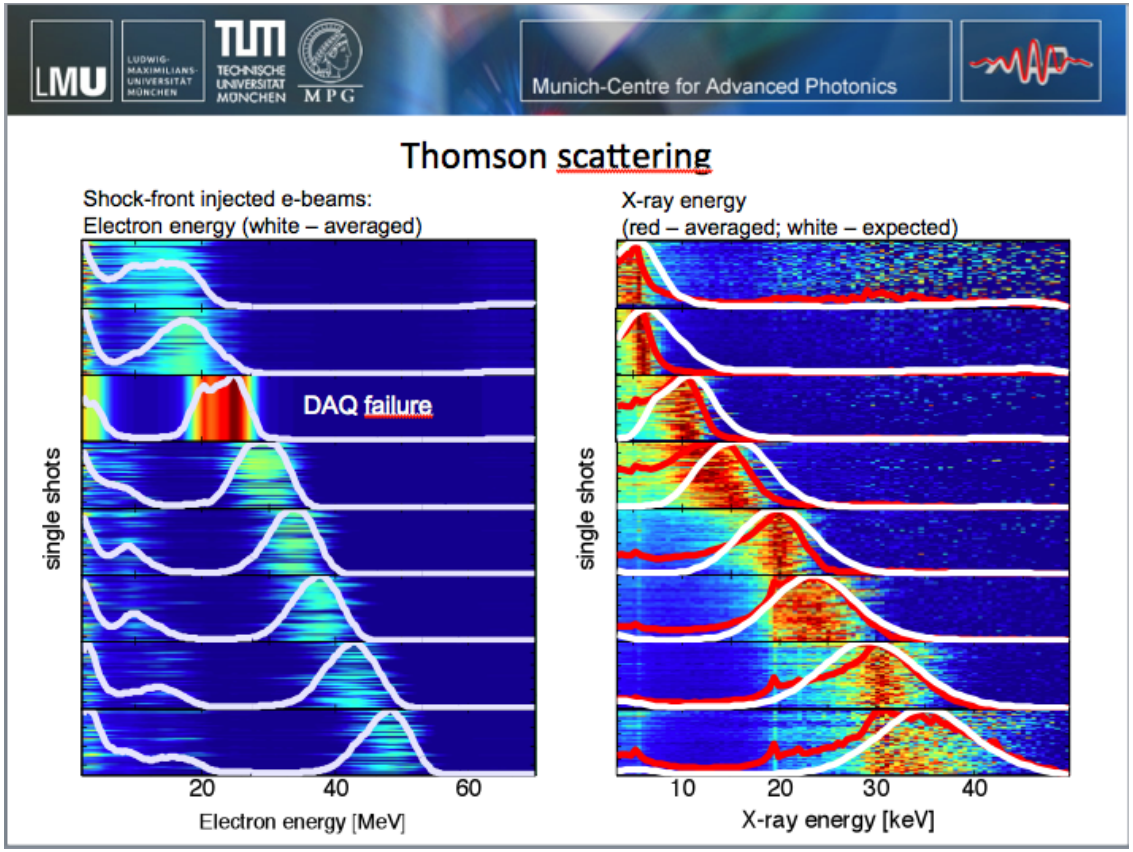
Xiaoming Wang (Texas) - Electron Acceleration to >2GeV by Petawatt Laser-driven Wakefield in 10^{17} cm^{-3} Plasma



- Texas Petawatt: 150 J focused into 7cm He gas cell
- Highly-collimated <1 mrad, high charge ~1.8nC
- Betatron x-ray radiation observed
- Observed quasi-monoenergetic beams: ~1.1GeV, ΔE~0.2GeV , 64 pC

S. Karsch (MPQ) - Electron acceleration and radiation generation at Munich



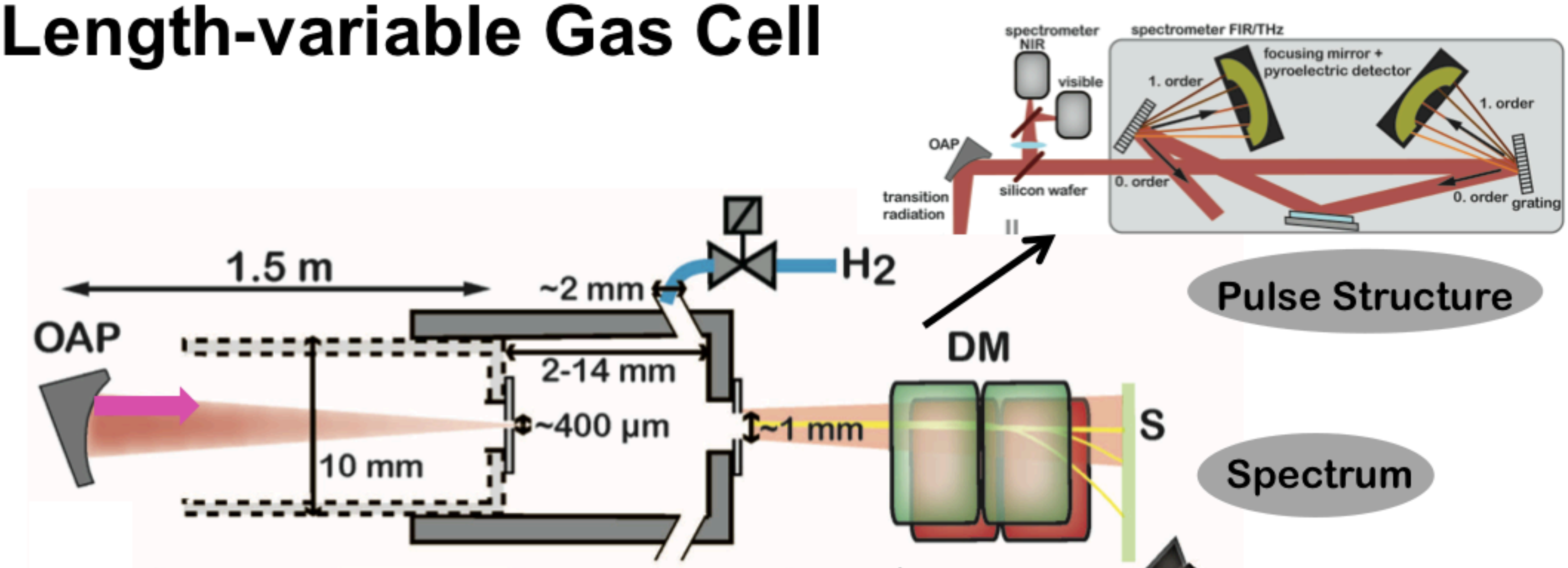


- Laser upgrade at MPQ: ATLAS60 - 1.5 J, 25 fs: 500 MeV , ~100 pC LPA beams
- Investigated energy gain versus gas cell length
- Undulator radiation generation ~6 nm
- Emittance measurement (norm. emitt. = 0.14 mm mrad) using quads to image
- CTR for temporal characterization: ~5 fs (FWHM) beams
- Triggered injection using density transitions (shocks)
- Betatron radiation measurements (tomography)
- Thomson scattering measurement

A. Popp (MPQ) - Acceleration Dynamics in Laser-Driven Wakefields

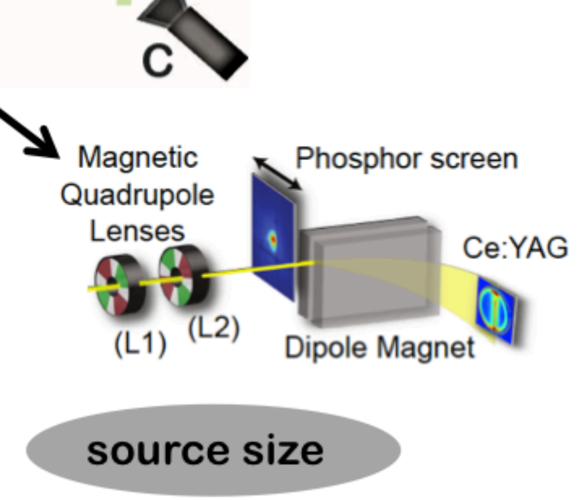
LMU Ludwig-Maximilians-Universität München | TUM Technische Universität München | MPG | Munich-Centre for Advanced Photonics

Length-variable Gas Cell



- energy evolution beyond dephasing length shown
- basic parameters could be retrieved
- acceleration limits could be determined
  target conditions (pressure, length) can be adapted to available laser parameters

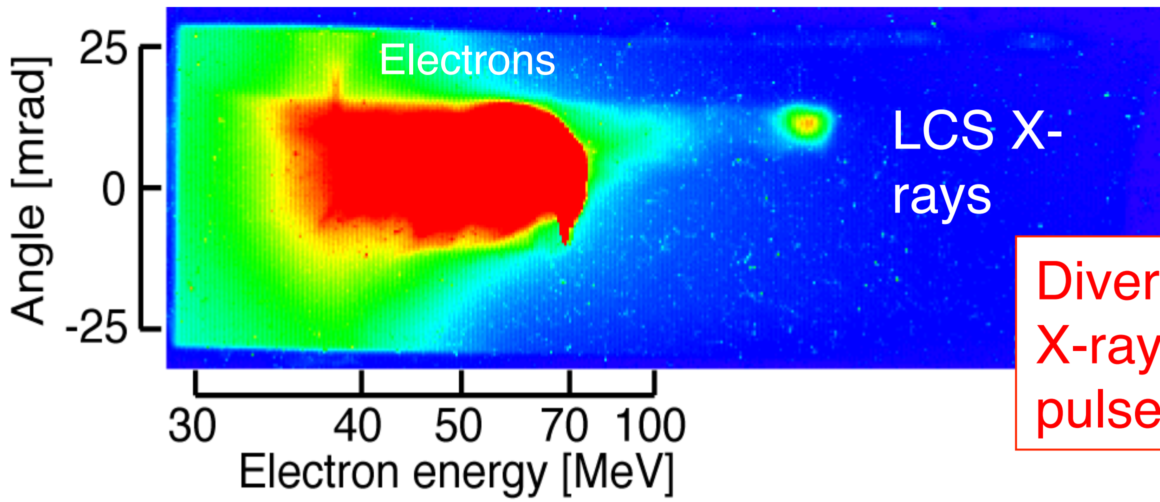
transition to beam-driven regime was shown



X-rays produced by laser Compton scattering (LCS) using laser-accelerated quasi-monoenergetic electron beam

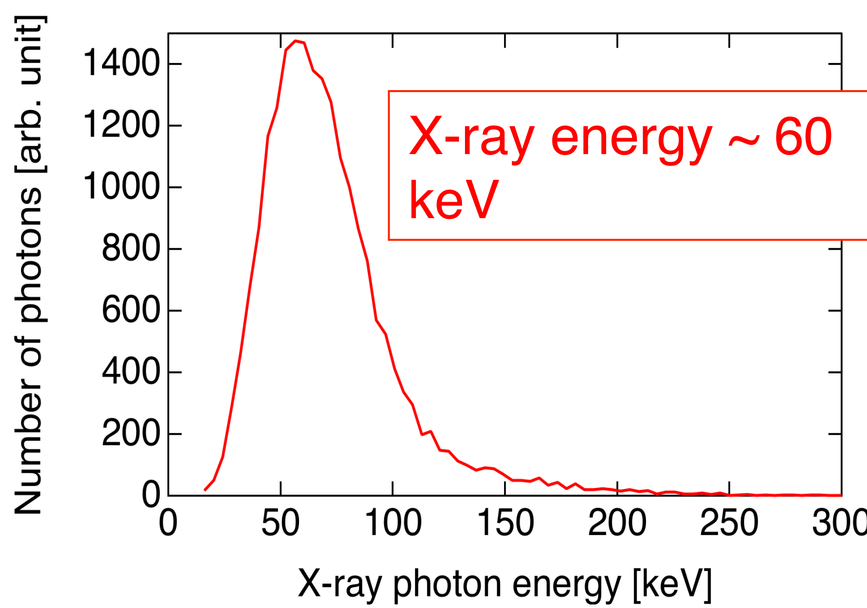
Simultaneous observation of LCS X-ray image and energy-resolved electron image of quasi-momoenergetic electron beam with single shot

(E. Miura, AIST Japan)



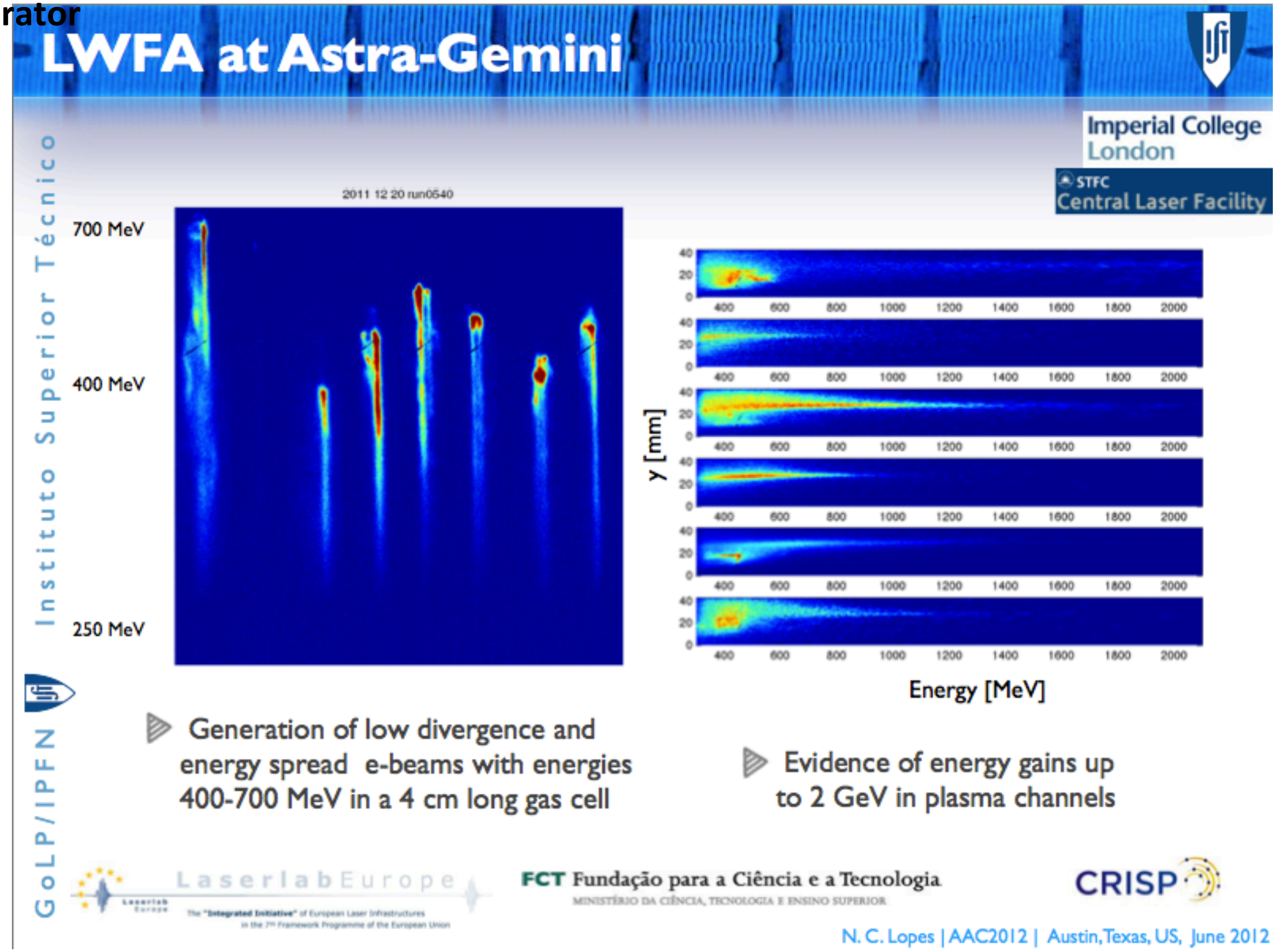
Divergence angle ~ 5 mrad
X-ray yield ~ 2×10^7 photons/pulse

X-ray spectrum within 5-mrad scattered angle
(Simulation result)



X-ray energy ~ 60 keV

N. Lopez (IST) – High energy beams produced by a laser wakefield accelerator



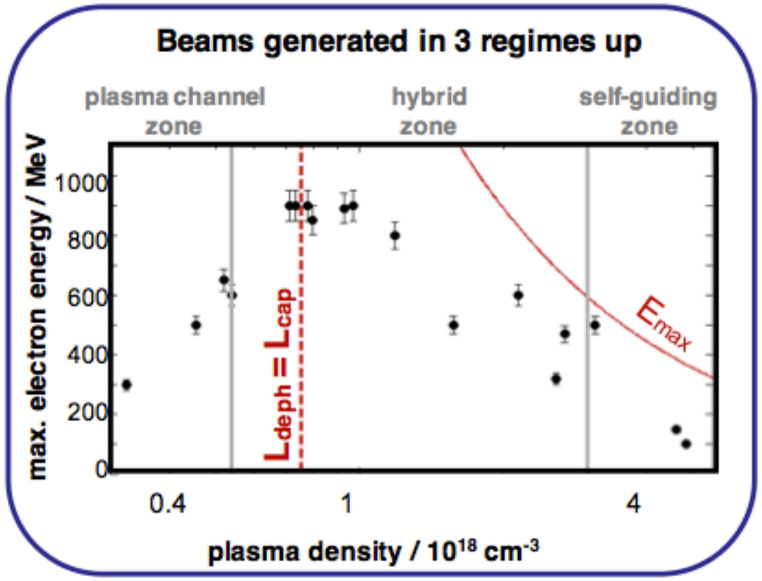
- LWFA experiments at Astra-Gemini Laser Facility
- Using pre-formed (discharge) plasma channels, up to 2 GeV beams observed

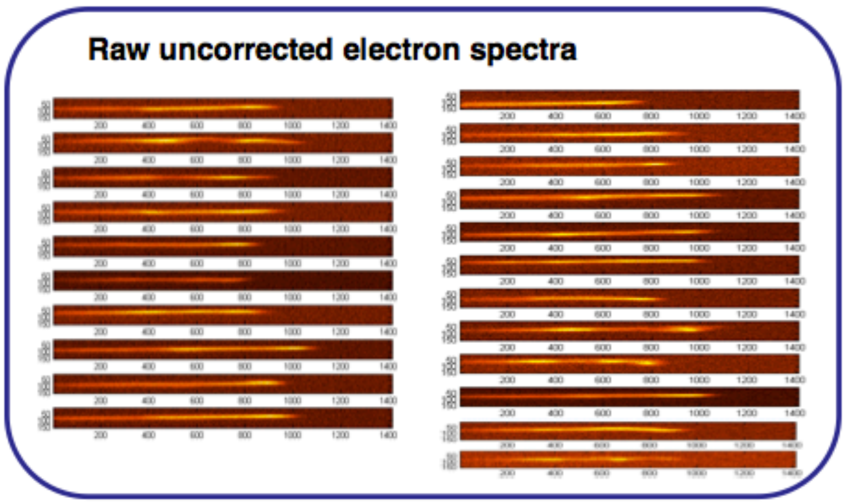
A. Walker (Oxford) - Electron Acceleration in Capillary Discharge Waveguide at Astra-Gemini

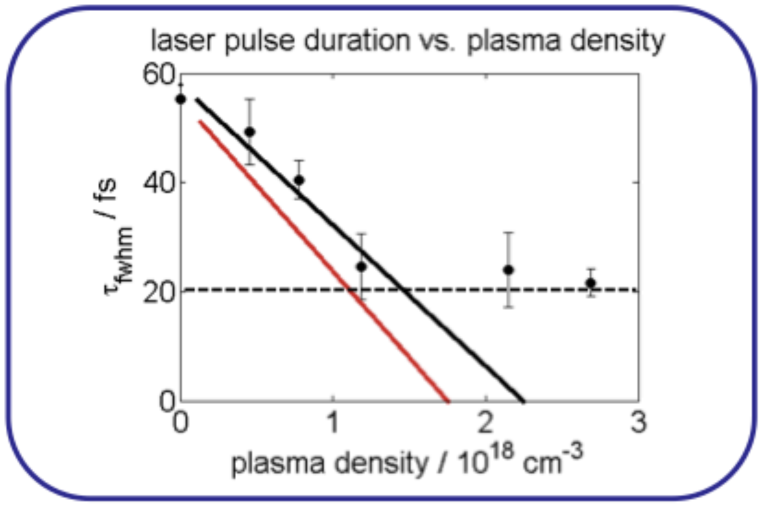
UNIVERSITY OF OXFORD

Electron acceleration in a plasma channel

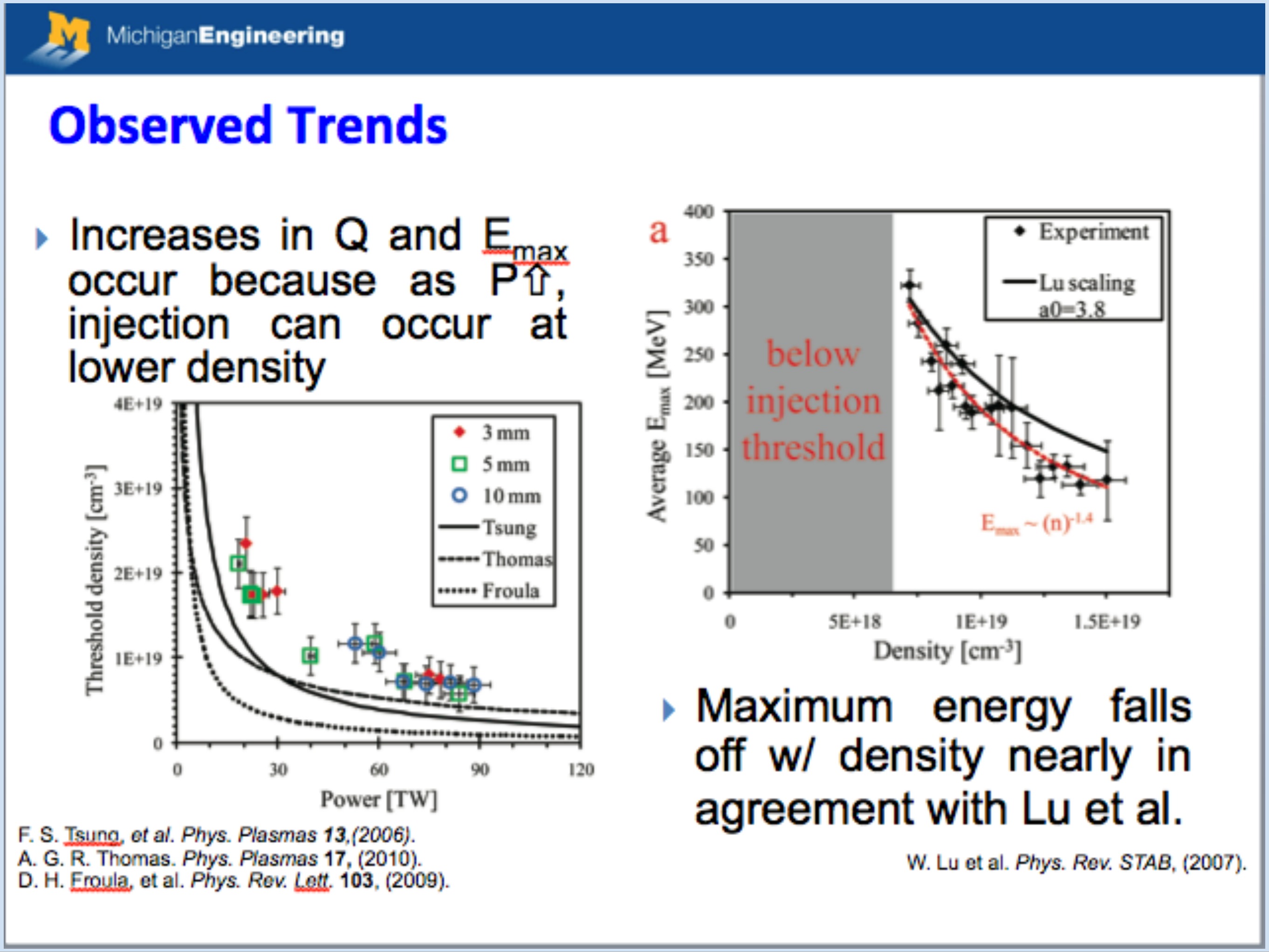
- Electron beams generated with energies up to 900 MeV using only 3.2 J pulses from Astra-Gemini laser
- Electron beams generated on 100% of 40 shots
- Low beam divergence 3.5 ± 1 mrad
- Electrons beams generated in 3 guiding regimes
- Simultaneous GRENOUILLE measurements show first observation of laser pulse compression in plasma channel







K. Krushelnick (Michigan) - Laser wakefield acceleration up to 200 TW: physics and applications



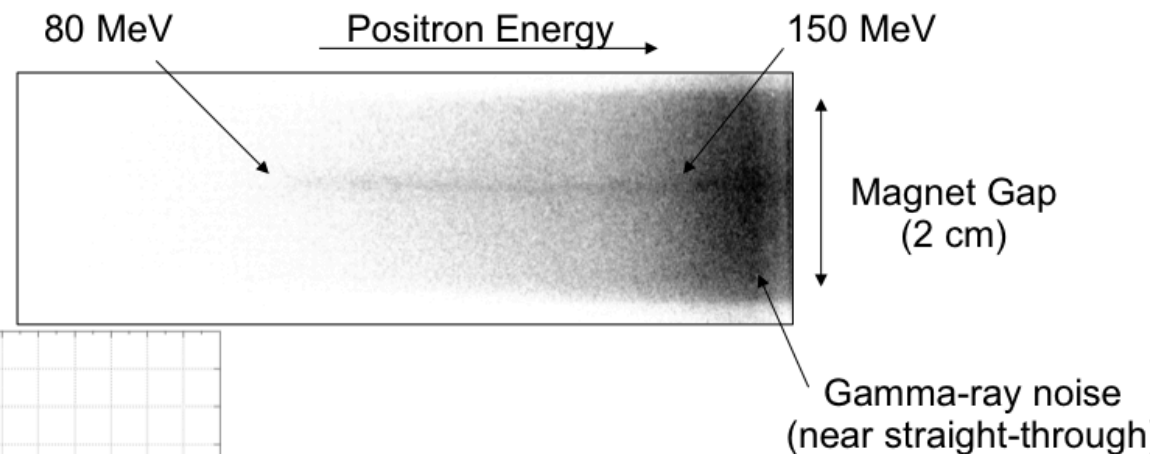
- Laser-plasma electron acceleration with Hercules Laser System
- Betatron x-ray radiation measurements and phase-contrast tomography
- Probing magnetic fields (generated in laser-solid interaction) with fs LPA-produced e-beam

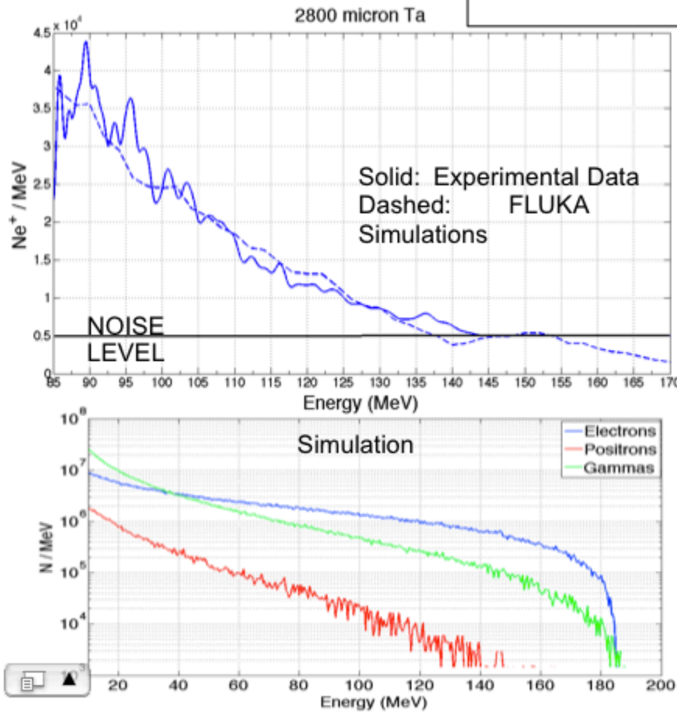
W. Schumaker (Michigan) - Electron Acceleration and Radiation Generation up to 200TW

MichiganEngineering

Positron Spectra from 2.8mm Ta Converter

Image Plate integrated over 10 shots





- High-energy (>100 MeV) positron beams with narrow divergence observed
  - Broad energy, up to 10^6 /J efficiency per 100MeV electron, 1/γ divergence, ultrashort bunch
  - Yield scales linearly with converter Z and thickness
  - Complementary gamma spectrum measured up to ~80 MeV

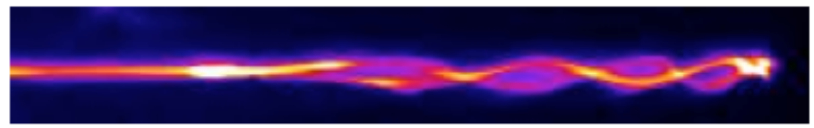
S. Mangles (IC) -High energy electrons and hard x-rays from a laser wakefield accelerator

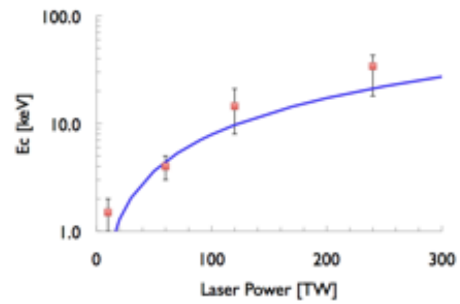
Imperial College London

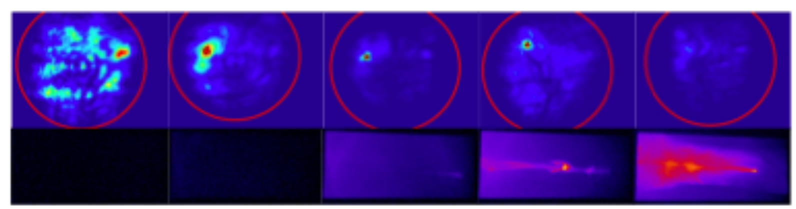
J.A.I.

Summary

- 3D momentum space reconstruction using two screen spectrometer reveals betatron motion probably injection during bubble expansion
- Scaling of betatron radiation with laser power to $E_c \sim 35$ keV
- Self-guiding, pump depletion and pulse compression measured over 15 mm propagation

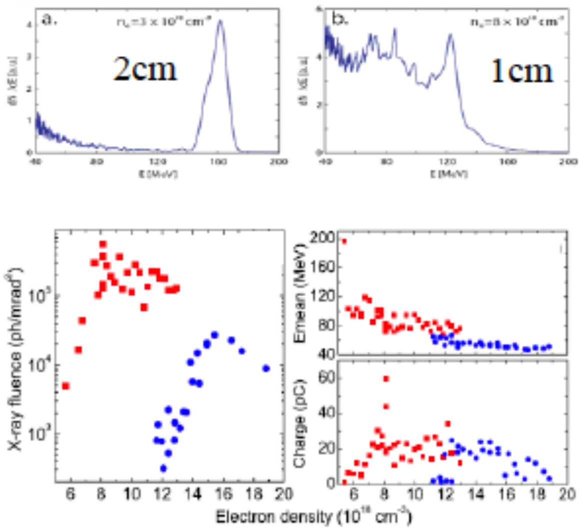


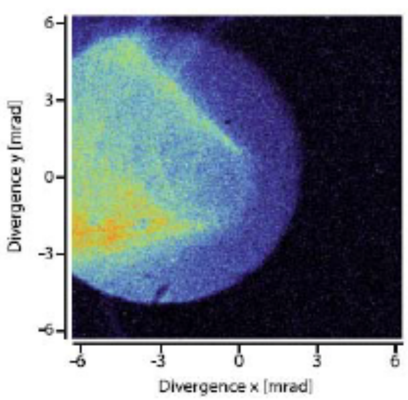




B. Cros (LPCP-CNRS) - Electron beams and X-ray radiation generated by laser wakefield in capillary tubes

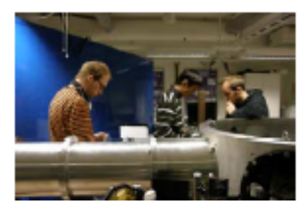
Characterization of electron acceleration in long plasmas





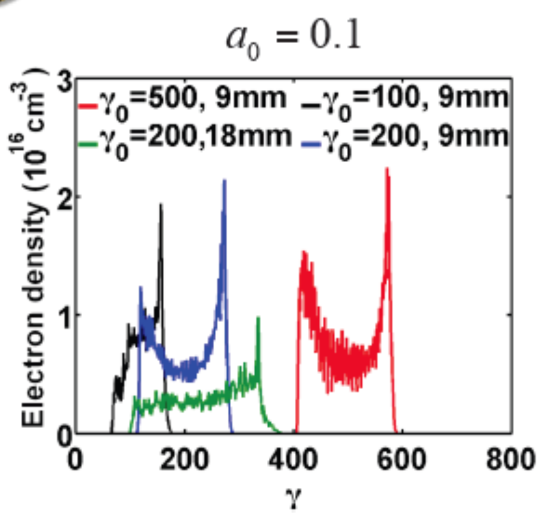
- Electrons with energies in the 200 MeV range are produced with 16TW laser power in 1-2 cm long plasmas inside capillary tubes
- Self-focusing and laser guiding increase the local intensity:
  - Electron injection observed for a_0~0.6 for ne ≥ $3x10^{18}cm^{-3}$
  - Multiple injection along the propagation for higher density
- X-rays in the 1-10keV range produced with 10^4 -10^5 photons/mrad^2 per pulse
- X-ray beam footprint used to determine the emission source position and extension, useful to extract local information on the electron acceleration process

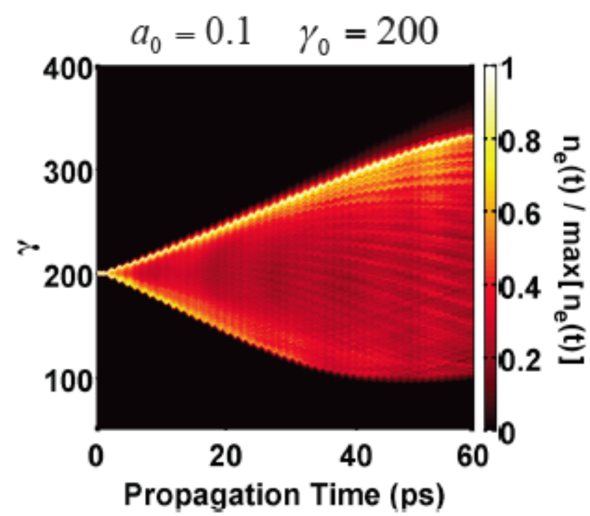
B. Cros, AAC Workshop, Austin, 12th June 2012



S. Y. Yoon (Maryland) - Quasi-Phase Matched Direct Laser Acceleration In a Corrugated Plasma Waveguide

Spectra of the accelerated electrons





- FWHM(ΔE)/E: 5%, 4%, and 2.8% for γ_0 = 100, 200, and 500 respectively
- Energy spread decreases as the initial V_e is closer to $c = V_p$ of accelerating spatial harmonic
- FWHM(ΔE)/E for γ_0=200 :
  after 9mm acceleration: 4%
  after 18mm acceleration: 1.5%,
- Energy spread decreases during acceleration

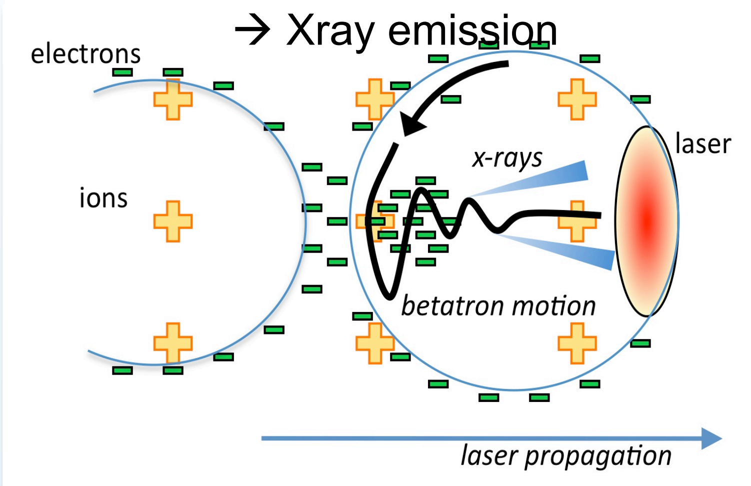
- Normalized energy spectrum at each time step
- Mono-energetic peak appears near the maximum energy
- The electrons that gain energy have narrow energy spread over 1.8 cm

- Quasi-Phase Matched Direct Laser Acceleration of electrons is an alternative LWFA
- 2D PIC simulations of DLA in a corrugated plasma channel – narrow energy spread

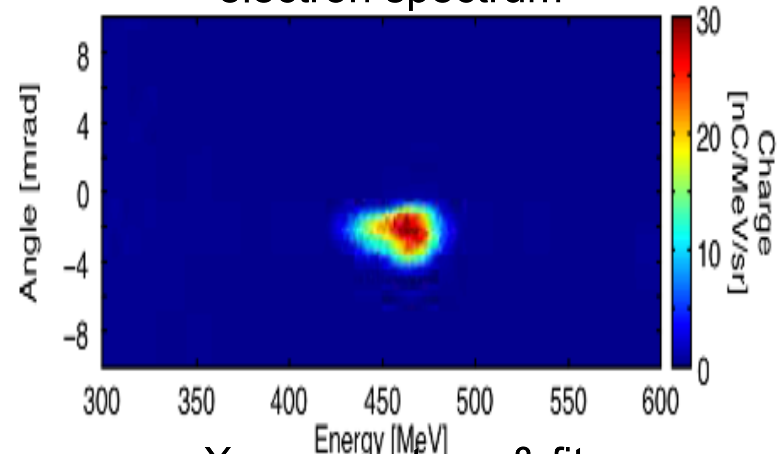
C. Geddes (LBNL) - Low emittance electron bunches from a laser plasma accelerator, measured using single shot X-ray spectroscopy

Low-emittance bunches measured using single-shot X-ray spectroscopy

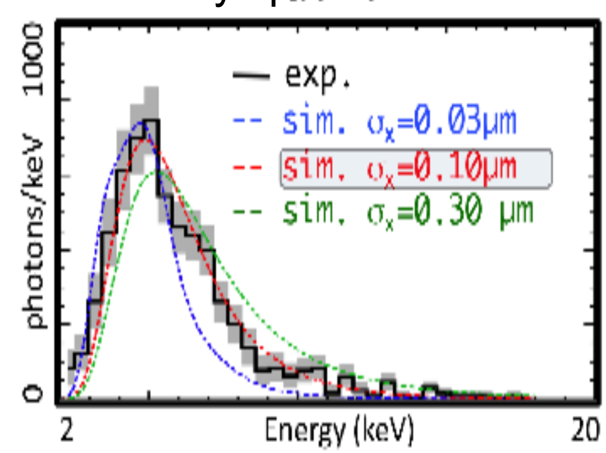
Betatron oscillations in wake → Xray emission



electron spectrum



X-ray spectrum & fits



- Single shot X-ray spectra with statistics sufficient for fit
  - matches $r_\beta \sim 0.1$ μm std
  - consistent with matched beam
- Estimate normalized emittance:

$$\epsilon_x \approx \gamma \sigma_x \sigma_\theta \approx 0.1 \text{ mm-mrad}$$

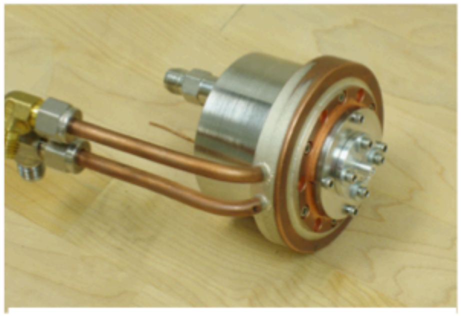
- Competitive w/state of art RF accel.

Plateau et al, PRL accepted

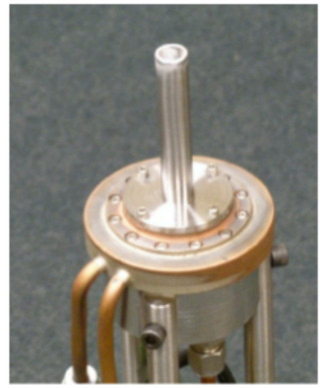
Plasma sources and structures

M. Krishnan (AASC) - Tailored supersonic gas jet targets for wakefield acceleration

Fast Valve Works With Many Nozzle Geometries

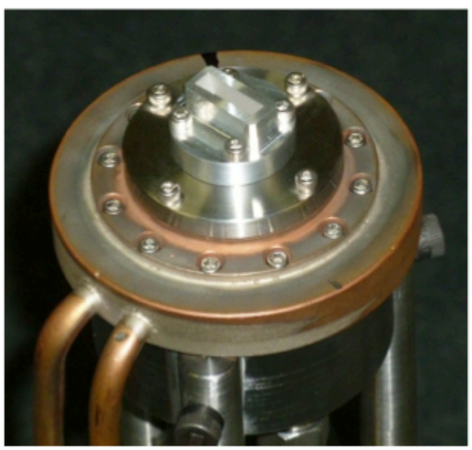


Valve with simple conical nozzle



Valve with “snout” nozzle

Valve with “hollow” nozzle



Tailored slit nozzle

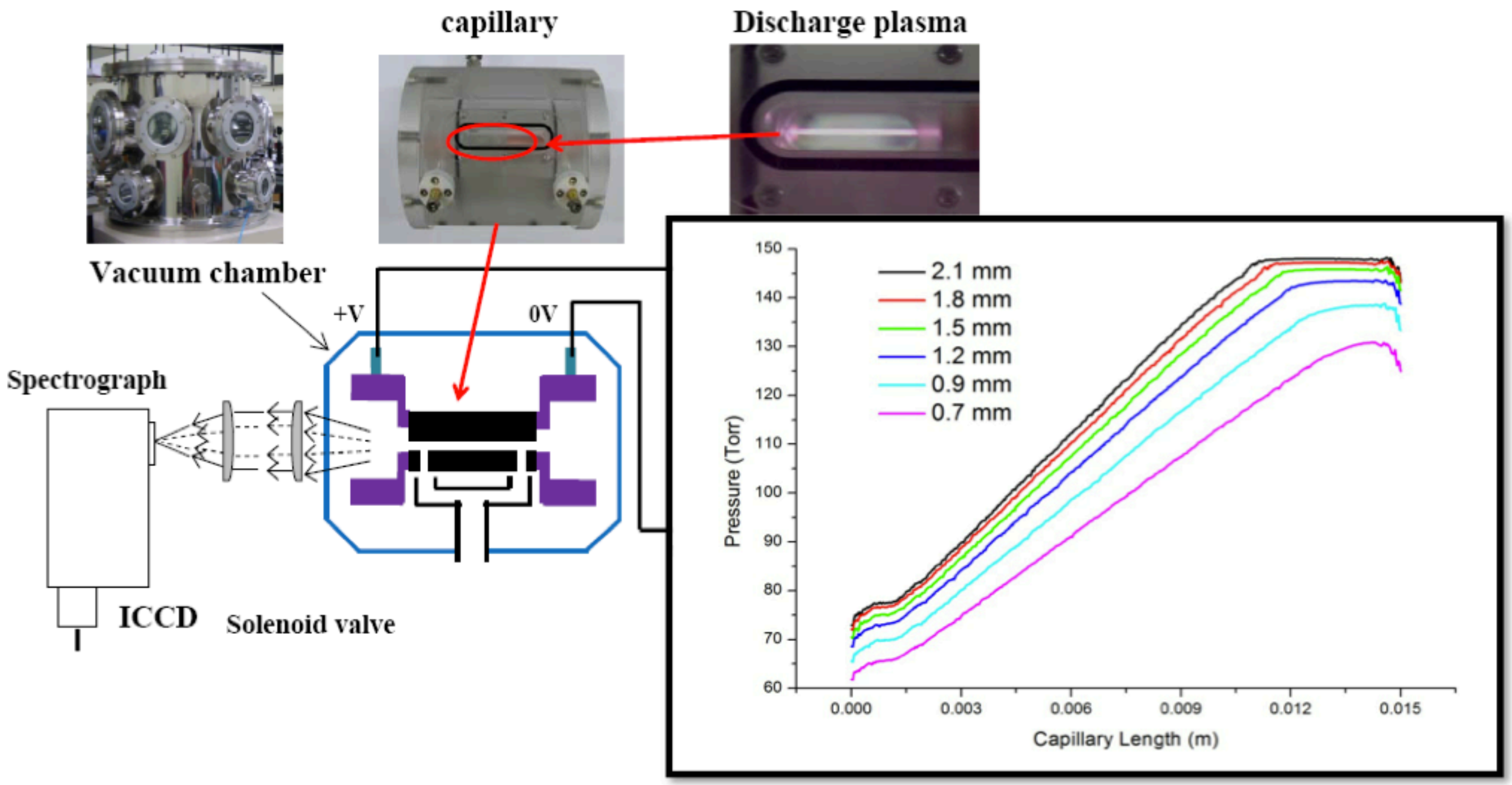
- Pulsed supersonic gas jets for applications:
  - Laser Plasma Accelerator (LPA), Capillary discharge injection, Laboratory astrophysics research
- Valve opens in <100μs and closes in <500μs at 1000 psia
  - Cooled for high rep-rate operation (10Hz)
  - Fast closing allows rep-rate w/o loading vacuum system
  - An energy recovery circuit reduces average power input
- Valve is easily adapted to a variety of nozzle geometries:
  - Simple conical (Mach 6) nozzles
  - Linear nozzle arrays (to give tailored density profile)
  - A slit nozzle (to give tailored density profile)

• Gas jet designs allow for high rep-rate, density tapering, and unique density profiles

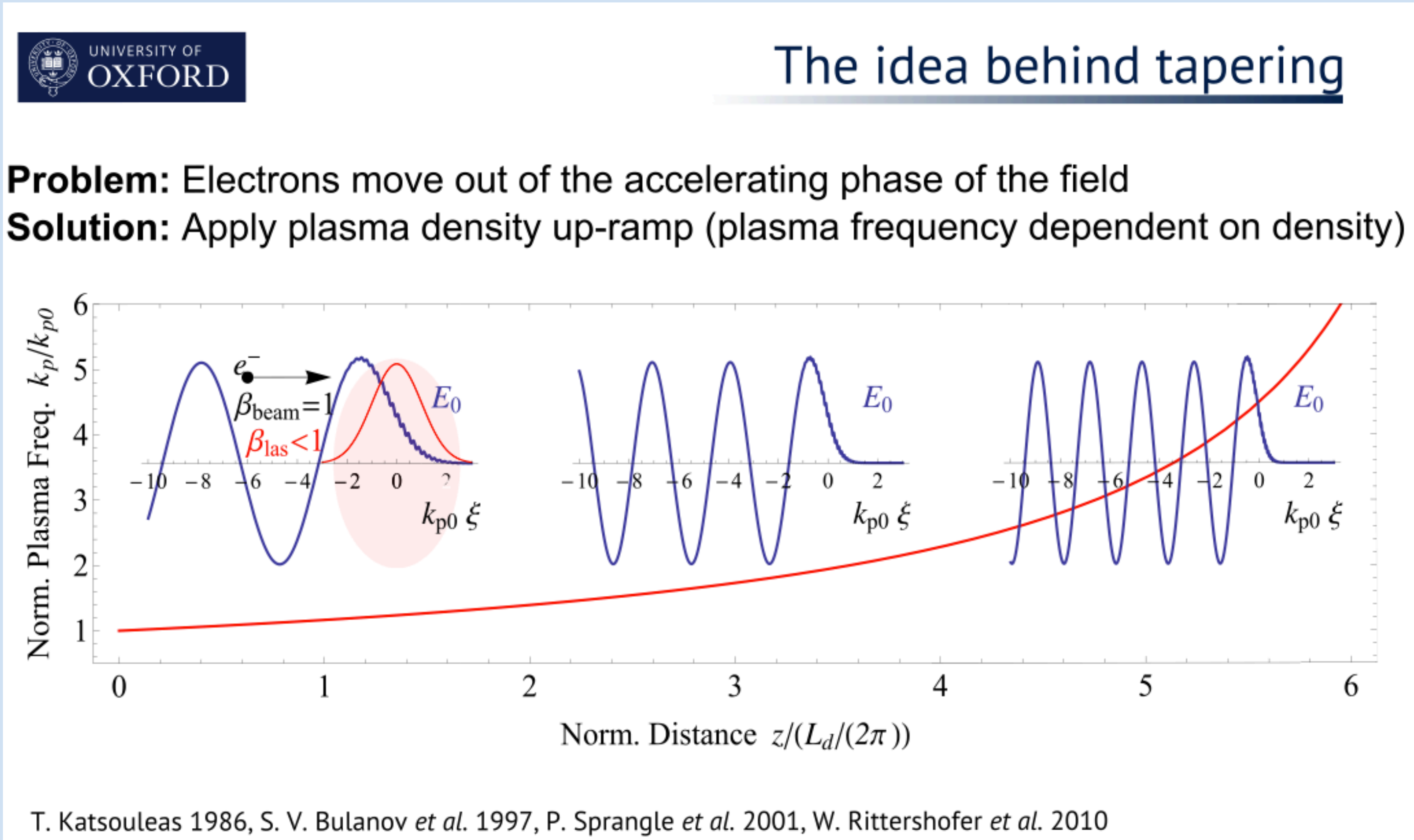
H. Suk (GIST) - Tapered-capillary plasma source development for laser wakefield acceleration

Capillary Development at APRI

- Density tapering in a discharge capillary



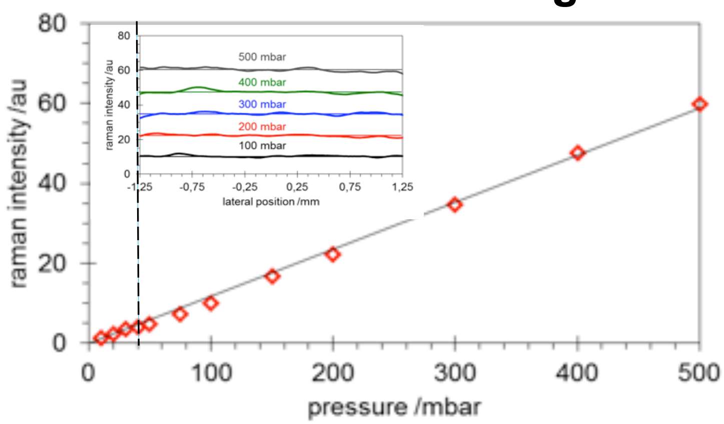
W. Rittershofer (Oxford) - Optical Spectra Analysis for Staged Laser-Plasma Accelerators

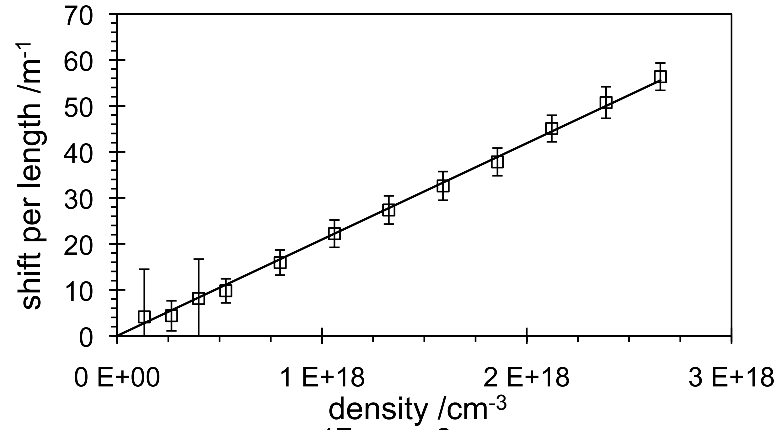


- Calculated density and plasma radius variation for phase locking witness bunch
- Performed gas dynamics simulations for tapered capillary design

High Sensitivity Gas Density Profilometry.

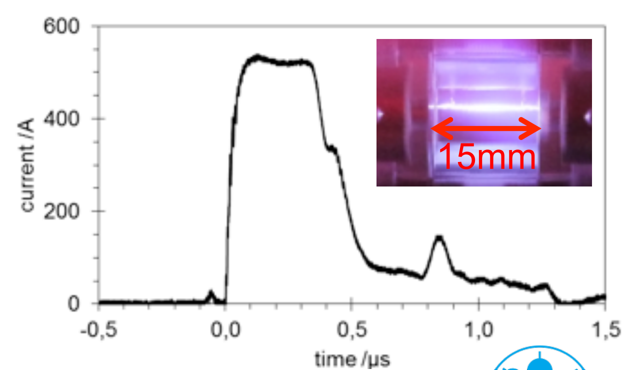
Raman Scattering and **longitudinal Interferometry**





In combination allow for absolute density profiles in 10^{17} cm^{-3} density range

> Transverse density profiles:
  - Matched PFN grants steep gradients, dV/dt and dI/dt < 20ns
  - Tuning of energy deposition via active discharge termination



Universität Hamburg
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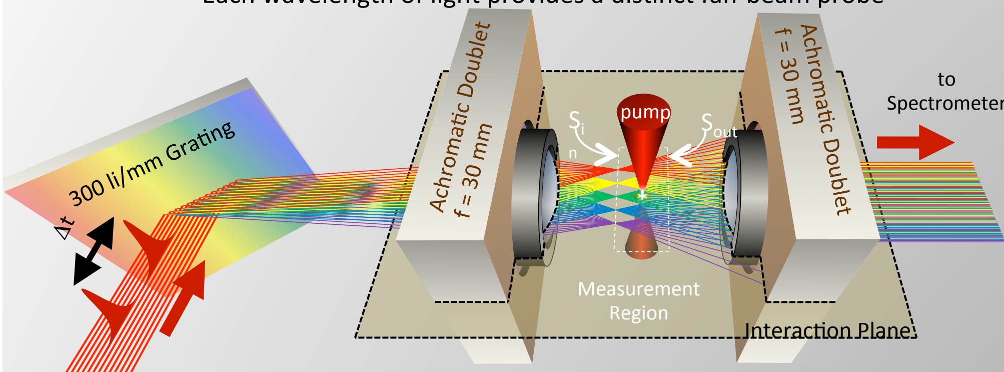
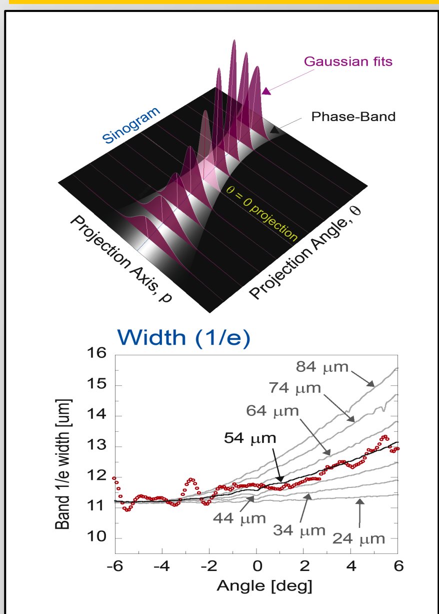
Spectrally Multiplexed Tomography Summary

N.H. Matlis, A. Axley, W.P. Leemans: Submitted to Nature Communications

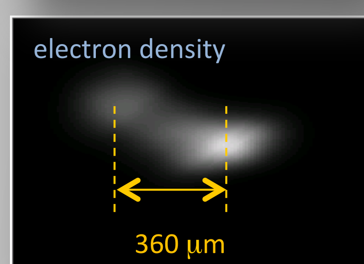
- Each wavelength of light provides a distinct fan-beam probe



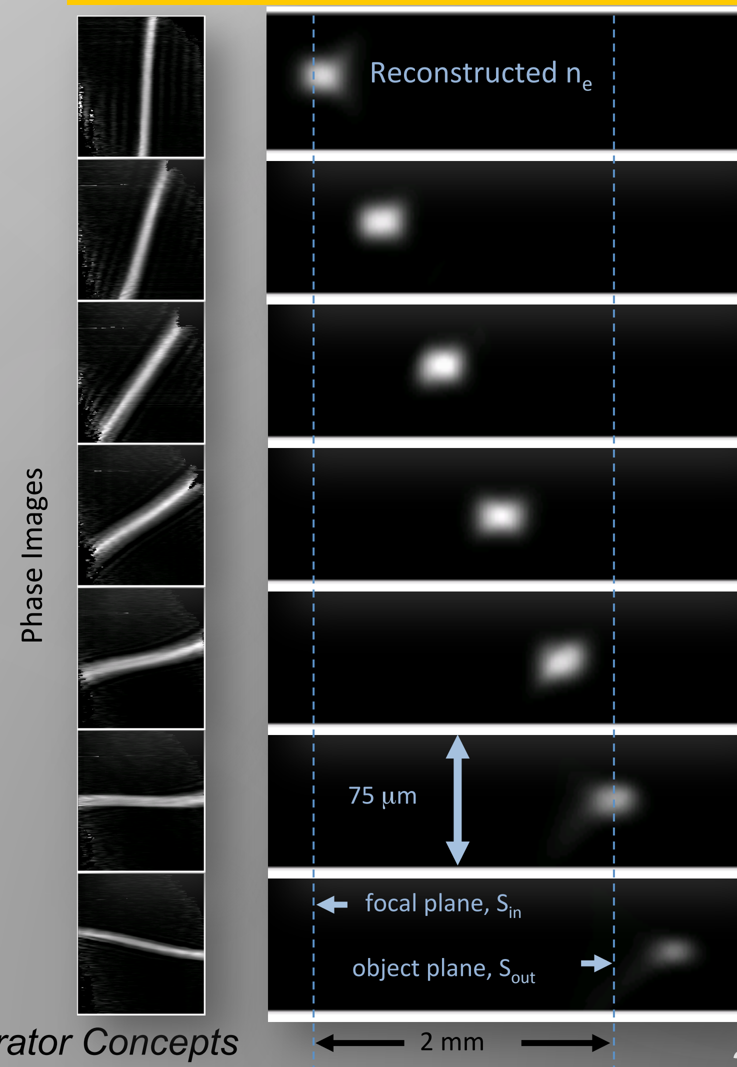
SMT Resolves plasma profile ellipticity



SMT Resolves double plasma structure



SMT resolves longitudinal position



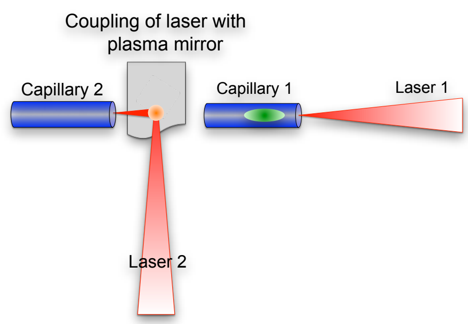
Laser propagation

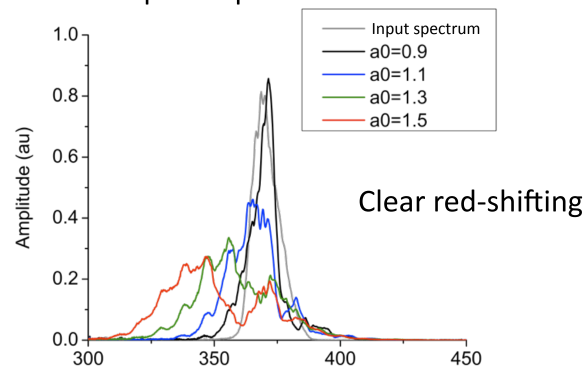
S. Shiraishi (LBNL, Chicago) - Optical Spectra Analysis for Staged Laser-Plasma Accelerators

BERKELEY LAB

Optical spectra analysis for staged LPA

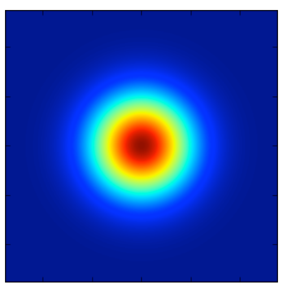
- Understand energy depletion in the 2nd capillary of the staging experiment
- Compare experimental data and simulation on optical spectra



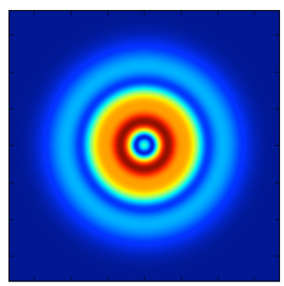


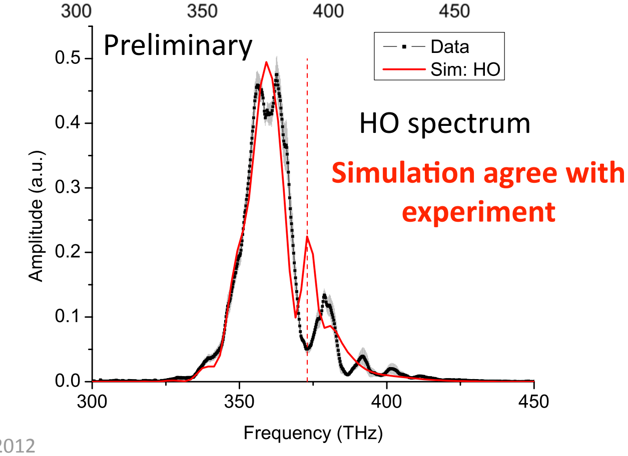
Input transverse laser profiles to *INF&RNO*

Gaussian Mode



HO Mode

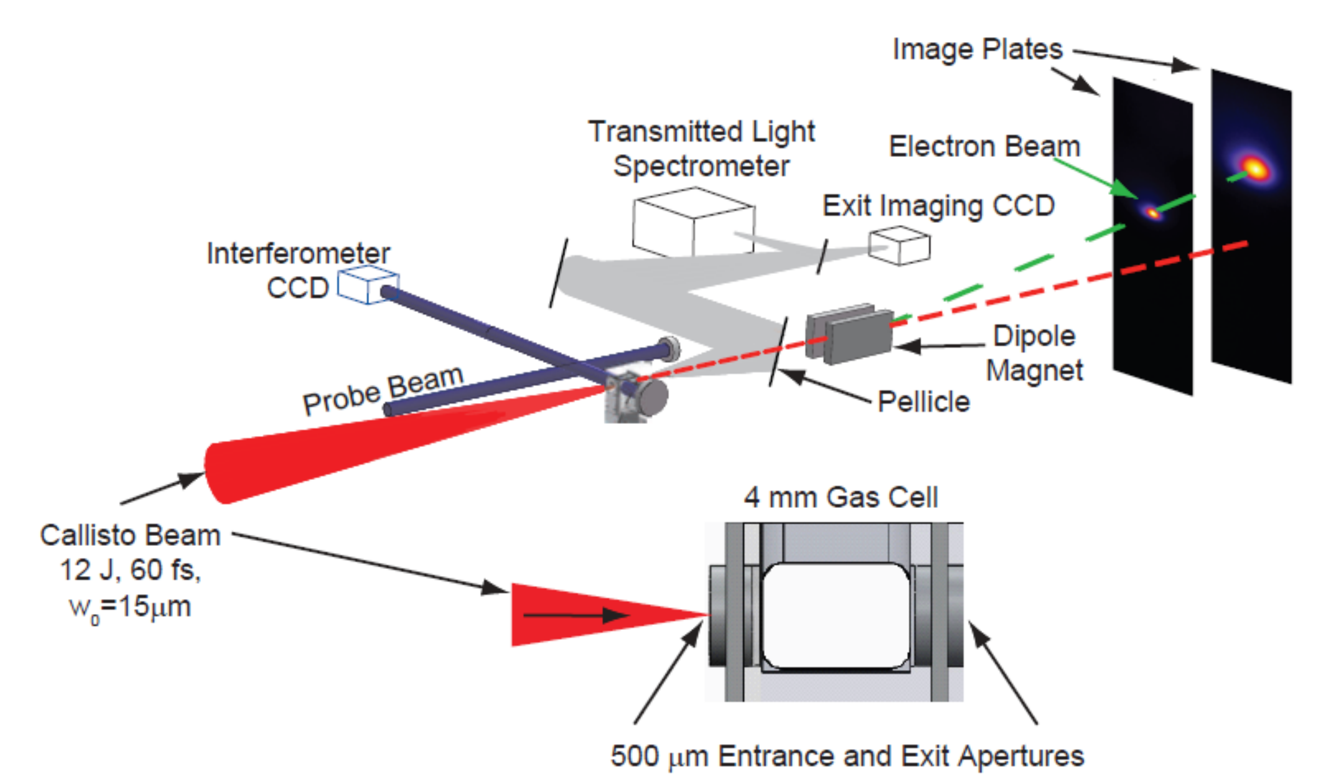




- Optical spectra as a non-destructive diagnostic of (staged) laser-plasma accelerators
- Red-shifting determine laser energy depletion and wake amplitude
- Measurements compared with modeling (including realistic laser mode content)

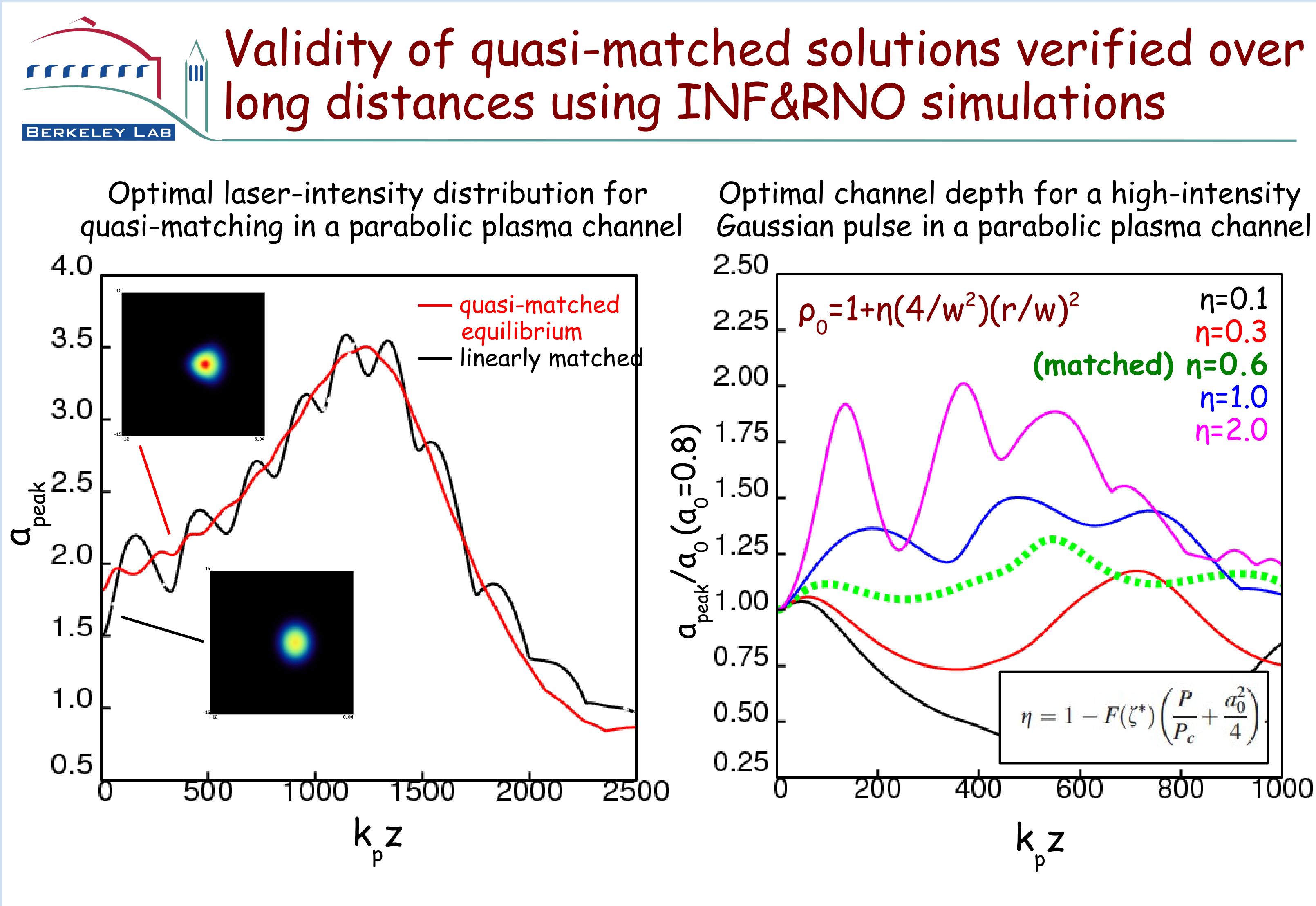
B. Pollock (LLNL) - Self-Guided Laser Wakefield Acceleration in High-Z Gases in the Blowout Regime

The effects of increasing the dopant concentration are examined in a 4 mm gas cell



- Self-guiding experiments are performed with the 200 TW, 60 fs Callisto laser at LLNL
- Self-guiding demonstrated in 100% N2, enabling more charge from ionization injection
- Self-guiding with up to 5% Ar with He was demonstrated (x3 increase in charge)

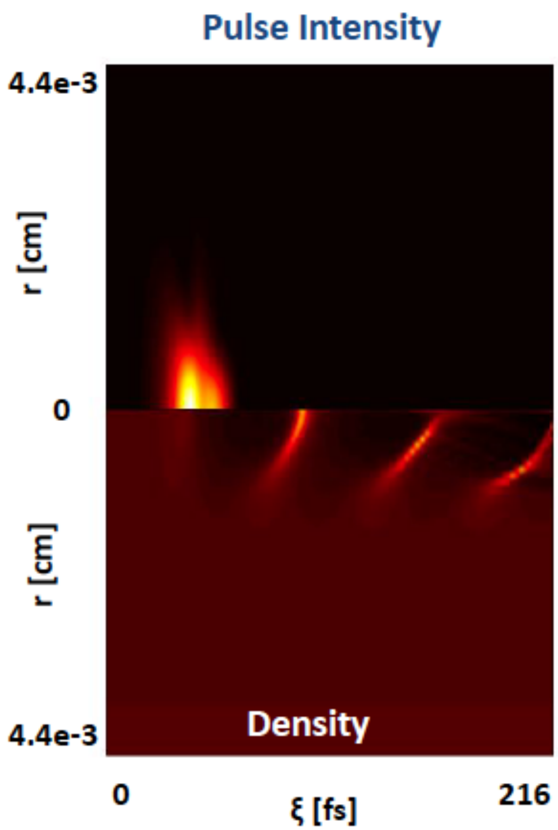
C. Benedetti (LBNL) - Quasi-matched propagation of ultra-short, intense laser pulses in plasma channels

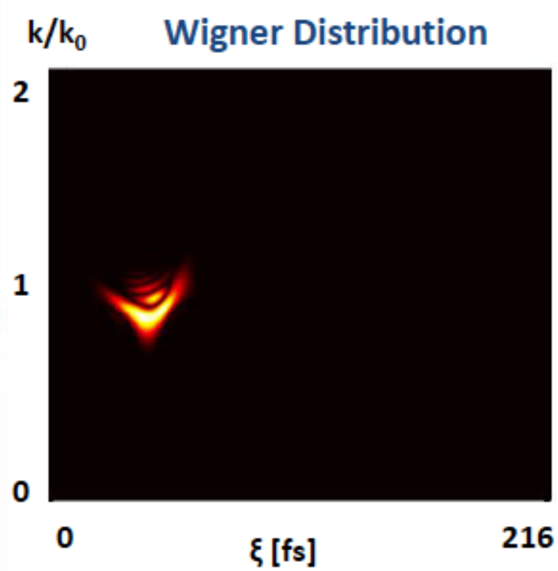


- Condition for matched laser propagation (valid for a_0~1) calculated
- Determined channel depth or pulse profile for matched propagation

W. Zhu (Maryland) -Studies of Spectral Modification and Extensions of the Paraxial Equation in Laser Wakefield Simulations

Intensity, Density and Spectral Evolution for UMD Parameters (FWE)





Movie

Part of the laser pulse slides to the back of the simulation domain.

As the pulse length extends the bubble becomes longer, until the associated ponderomotive force can no longer support the extension. The bubble is then shortened.

The Wigner plot shows that the red shifted spectral elements leave the simulation domain

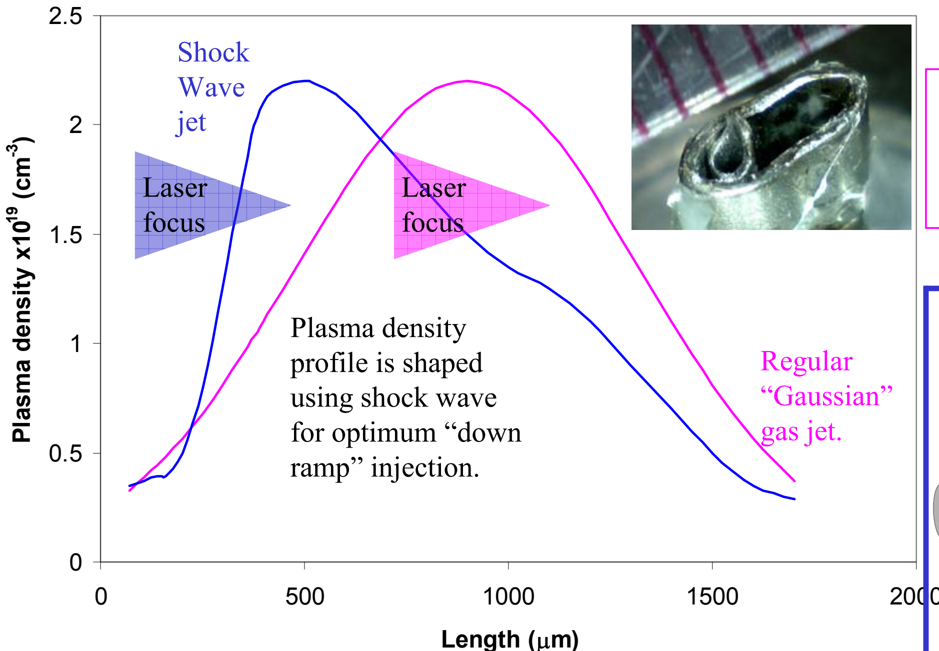
- Spectral broadening, energy depletion, and action conservation of nonlinear LPA examined
- Full wave equation in WAKE (similar results to Modified Paraxial Equation)

Injection and Staging

D. Kaganovich (NRL) - Laser Wakefield Electrons Injection and Acceleration in Gaseous Foils

NRL Plasma Physics Division

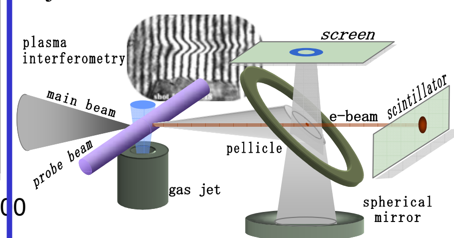
Shock Enhanced Self-Injection with "Down-Ramp" and Bubble Diagnostics.



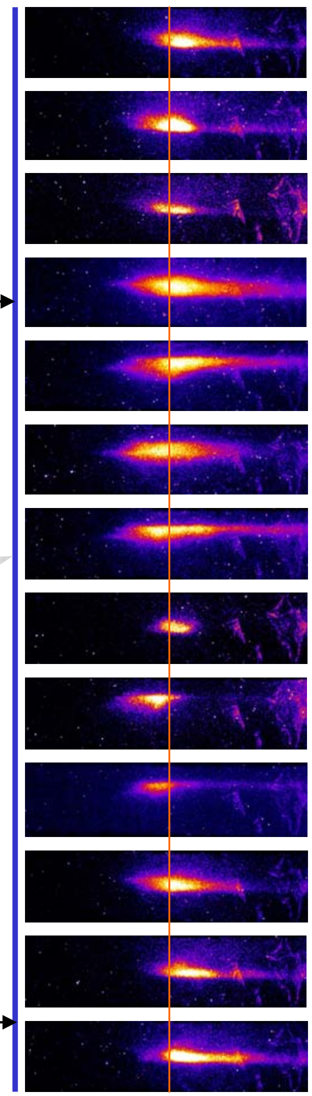
1 MeV Regular Gaussian gas jet.

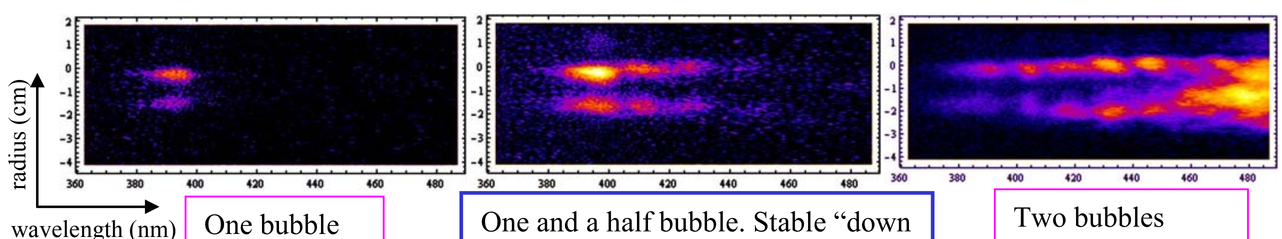
40 MeV stable injector using shaped plasma density profile.

Electro-Optical Shock (bubble) diagnostics of the "Down Ramp" injection:



40 MeV





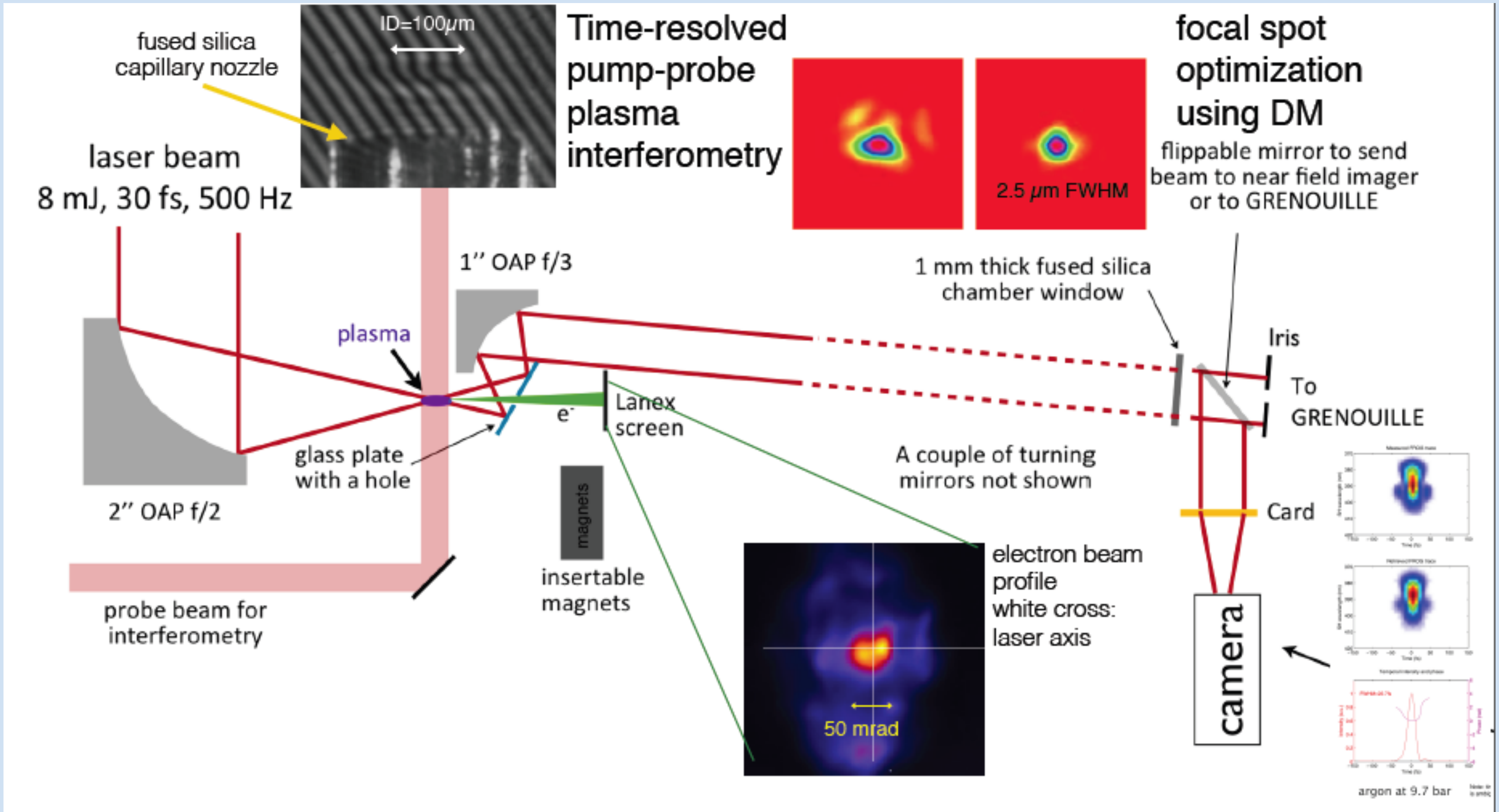
One bubble no electrons

One and a half bubble. Stable "down ramp" injection for both Gaussian and shock wave modified gas jets.

Two bubbles unstable electrons

Phys. Rev. Lett. 101, 045004 (2008), Phys. Rev. Lett. 105, 105001 (2010), Appl. Phys. Lett. 97, 191501 (2010), Physics of Plasmas 18, 120701 (2011)

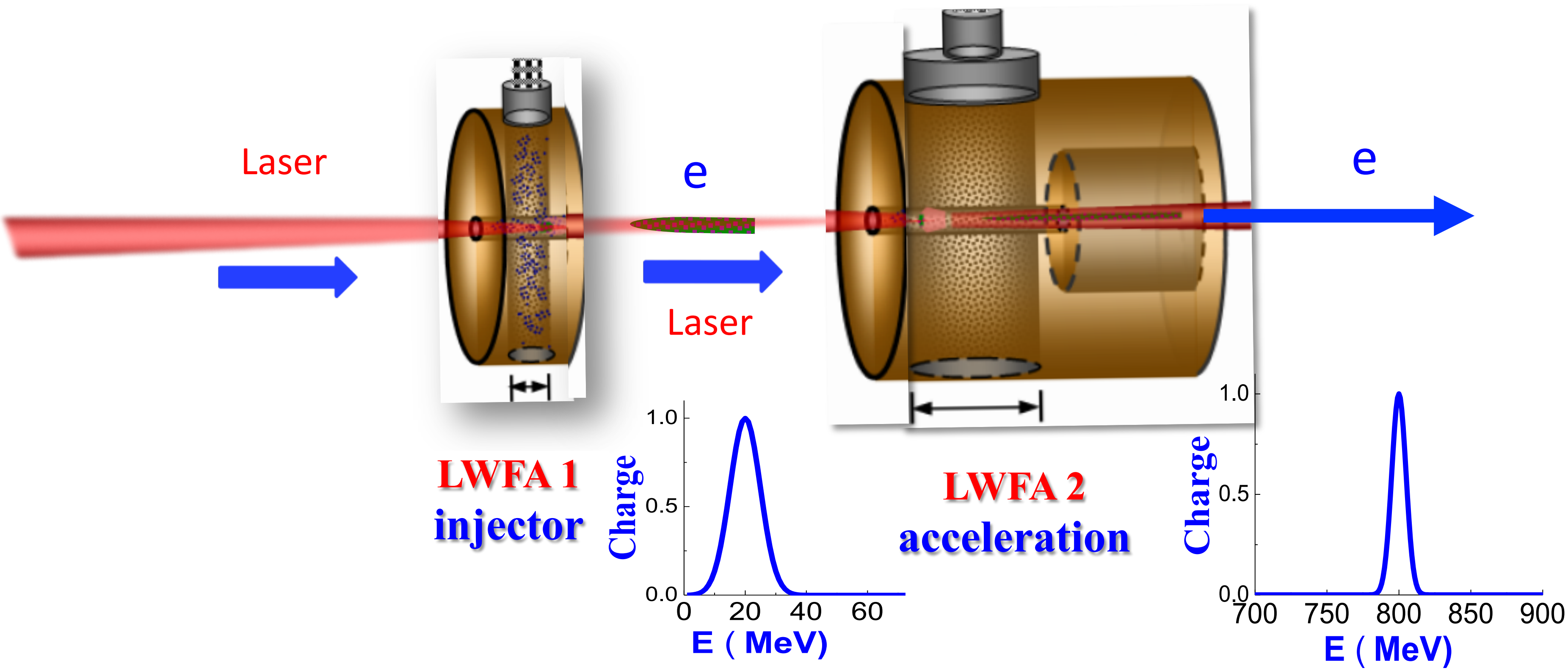
Zhaohan He (Michigan) - High-repetition Rate Wakefield Electron Source Driven by Few-millijoule Ultrashort Laser Pulses



- Stable collimated electron beams with 100 keV energies were observed using mJ laser
- mechanism is based on injection in the plasma wake at the density down-ramp
- Application: ultrafast electron diffraction (beam has short temporal duration)

Cascaded laser wakefield accelerators provide a promising route to obtain controllable multi-GeV monoenergetic e-beams

Cascaded Laser Wakefield Accelerator



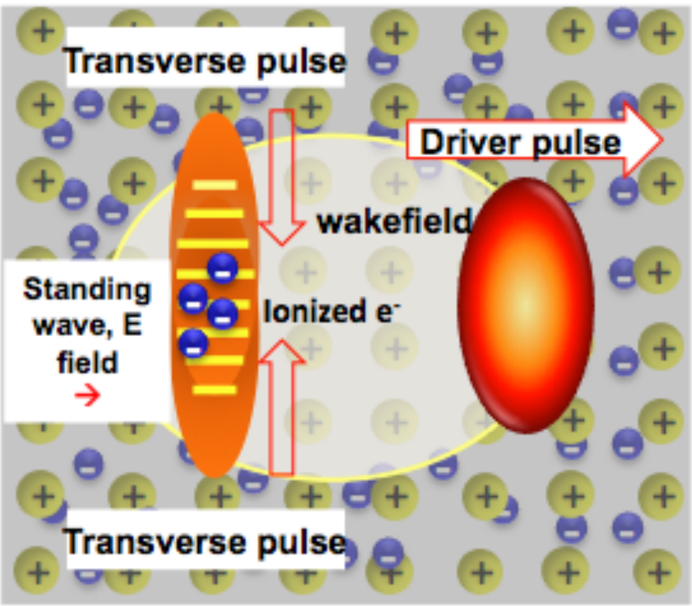
Electron injection and acceleration are successfully separated, controlled, and optimized in different LWFA stages to ensure the efficient coupling between them.

J. S. Liu et al, Phys. Rev. Lett. 107, 035001 (2011)

Min Chen (LBNL) - Electron injection and emittance control by transverse colliding pulses in a Laser-Plasma Wakefield Accelerator

Transverse colliding pulse & ionization injection

To get low transverse emittance injection, 2 conditions:
1. Electrons have low initial transverse momentum at injection position
2. Injection position should be as close to the bubble center as possible



1. **Longitudinal injection position control (delay)**
   Energy control
2. **Longitudinal injection width (width of T-pulse)**
   Energy spread and Charge control
3. **Transverse injection position control (overlapping position);**
   Betatron intensity factor control for radiation
4. **Transverse injection beam size control (length of T-pulse);**
   Charge control, transverse injected beam size control
5. **Tansverse beat wave intensity and velocity control**
   Final beam transverse emittance control

Reduce initial transverse momentum by transverse pulse polarization, intensity and frequency control.

Simulation shows final transverse momentum spread can be as low as $0.08m_ec$.

Magnetic Assisted Self-Injection for LWFA and PWFA (J. Vieira)

Theoretical model

Evolution of $\mathcal{H} = H - v_\phi P_z$ for a trapped particle[1]

$$1 + \Delta\psi^{\mathrm{pl}} = \frac{\gamma}{\gamma_\phi^2} - \int \frac{d\mathcal{H}}{d\xi} d\xi - \Delta\psi^{\mathrm{ext}}$$

Plasma wakefields ($\psi = \phi - A_z$)

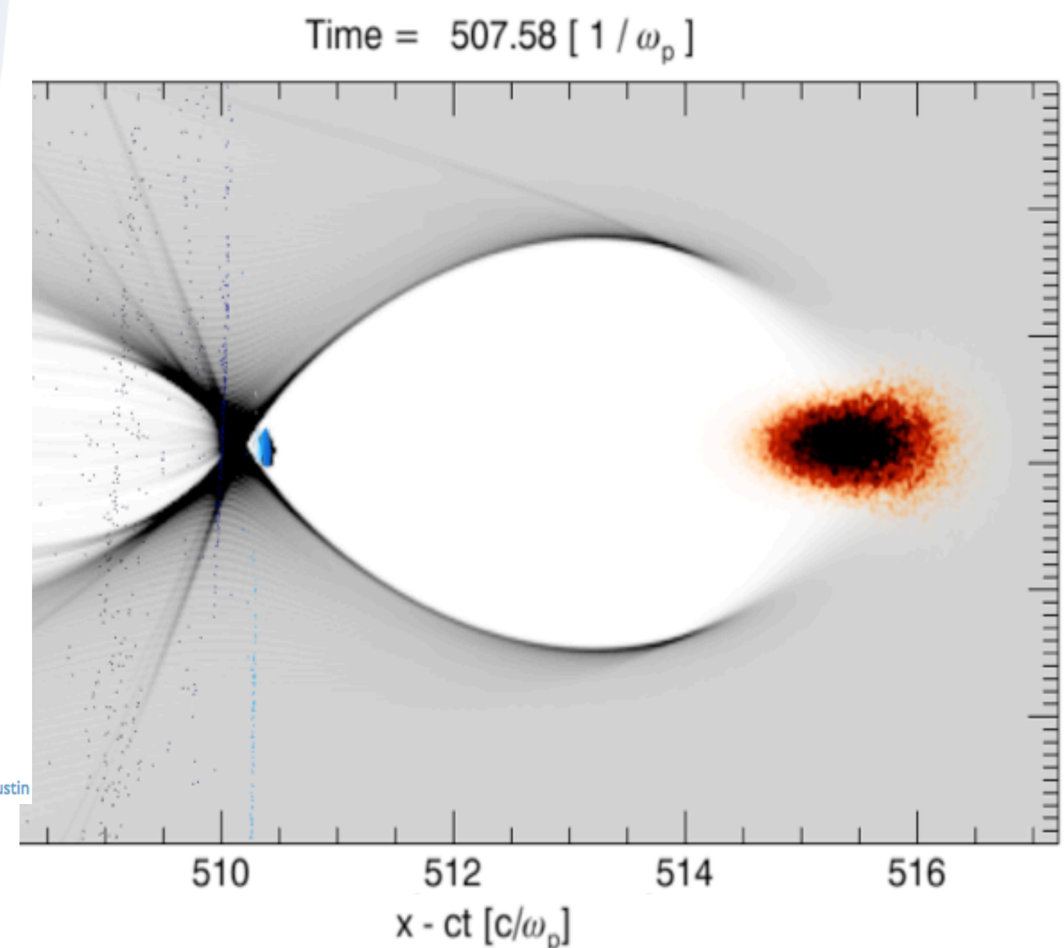
γ/γ_ϕ :: e⁻/wake relativistic factor

Wakefield expansion[2] ($\xi = z - t$)

External fields

Relaxed trapping conditions in presence of external fields[3]

J.Vieira | AAC 2012 - 14th June 2012 | Texas, Austin

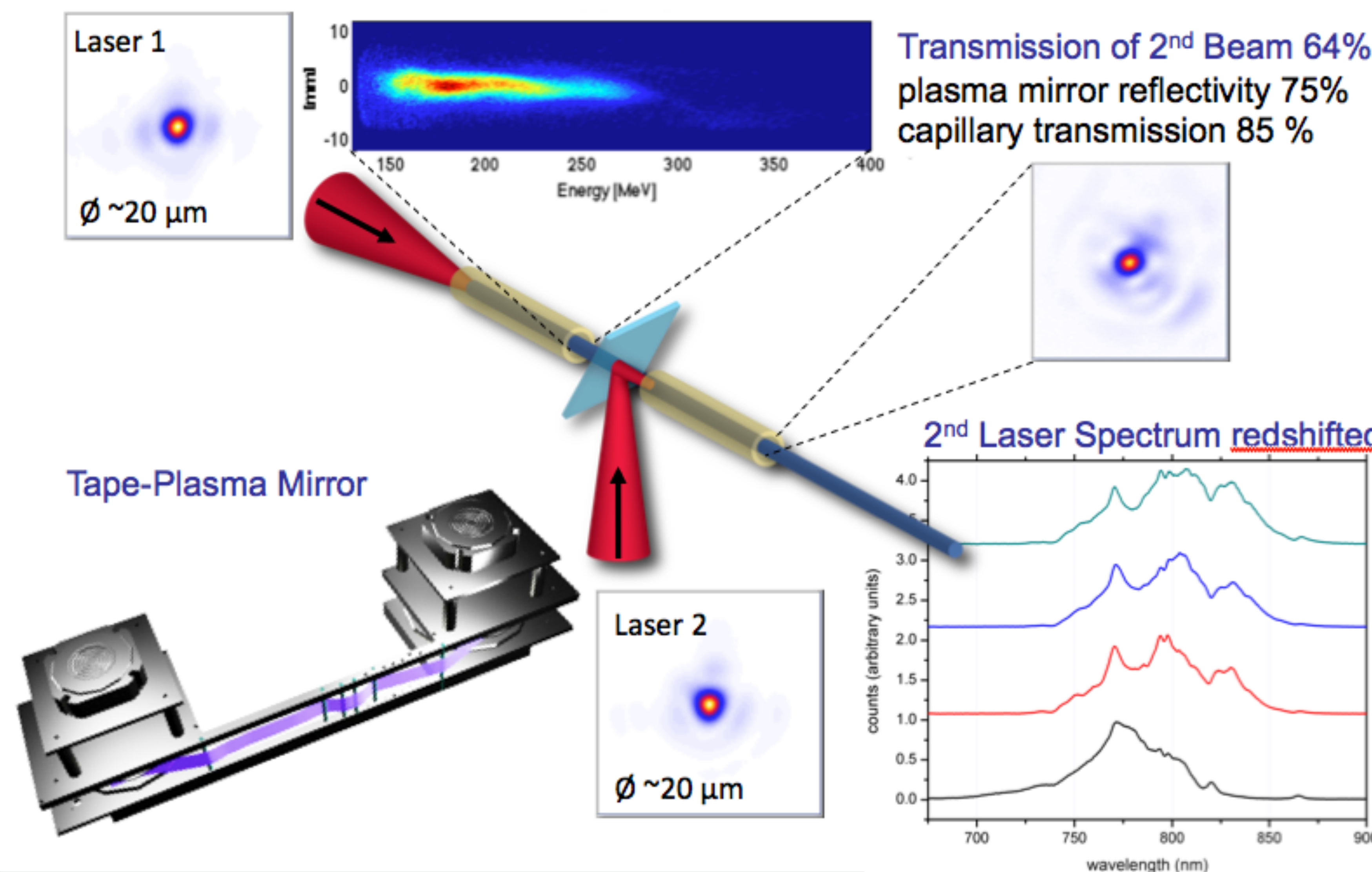


SLAC e⁻ beam
\# = 3x10[10] e⁻s
$\sigma_\perp$ = 50.4 μm
σ_z = 84 μm
$n_0 = 10^{15}$ cm^{-3}

Magnetic field 5 T

Charge ~13 pC

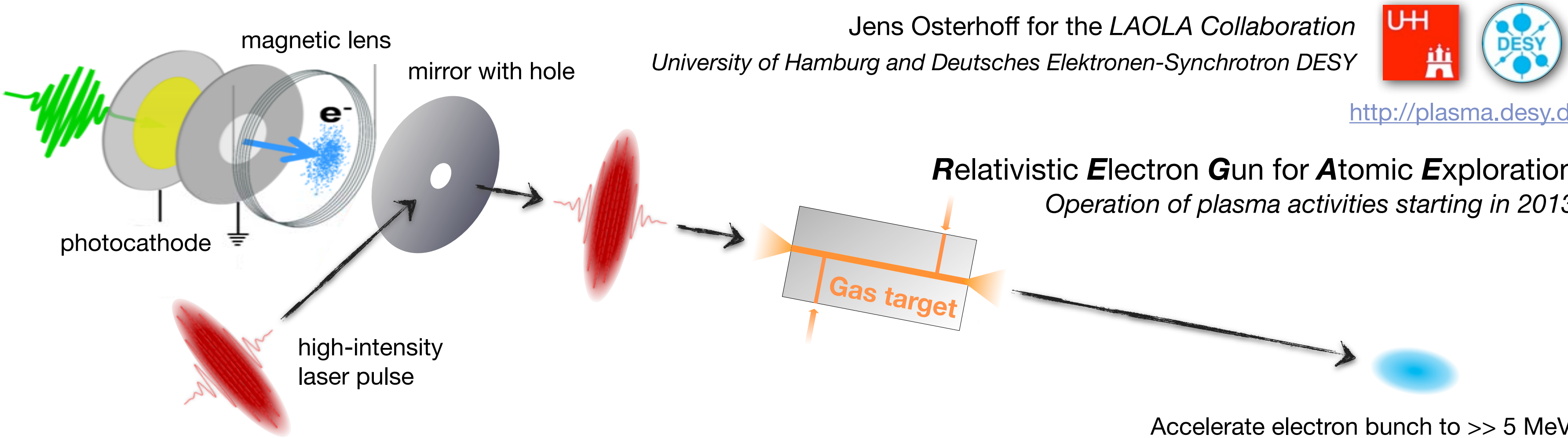
Summary



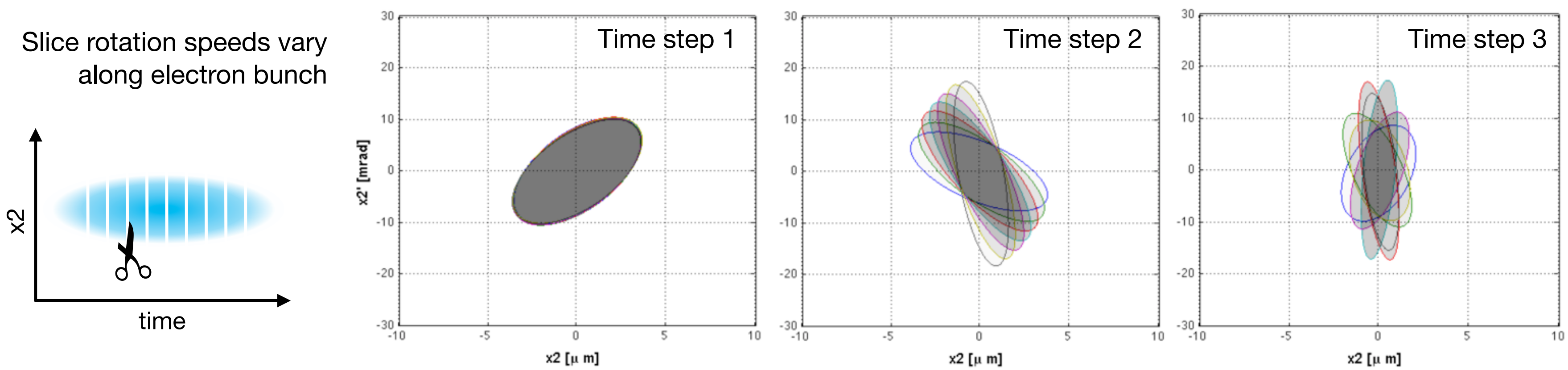
Laser 1
Ø ~20 µm
[mm]
10
0
-10
150
200
250
300
350
400
Energy [MeV]
Transmission of 2nd Beam 64%
plasma mirror reflectivity 75%
capillary transmission 85 %
Tape-Plasma Mirror
Laser 2
Ø ~20 µm
2nd Laser Spectrum redshifted
counts (arbitrary units)
4.0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
700
750
800
850
900
wavelength (nm)

Prospects for Plasma-Based Particle Acceleration at DESY

Jens Osterhoff for the *LAOLA Collaboration*
University of Hamburg and Deutsches Elektronen-Synchrotron DESY
http://plasma.desy.de/



- Bunch ***emittance evolution***, ***compression*** studies will be possible for the first time
- Results will be relevant for ***staging*** of plasma acceleration modules, HEP & photon science applications



Prospects for Plasma-Based Particle Acceleration at DESY

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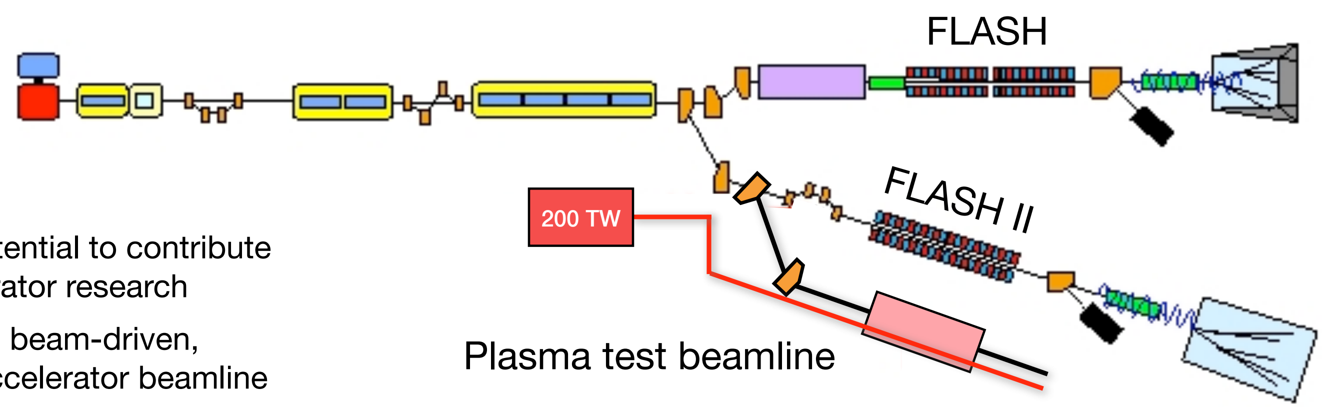
http://plasma.desy.de/

LAOLA

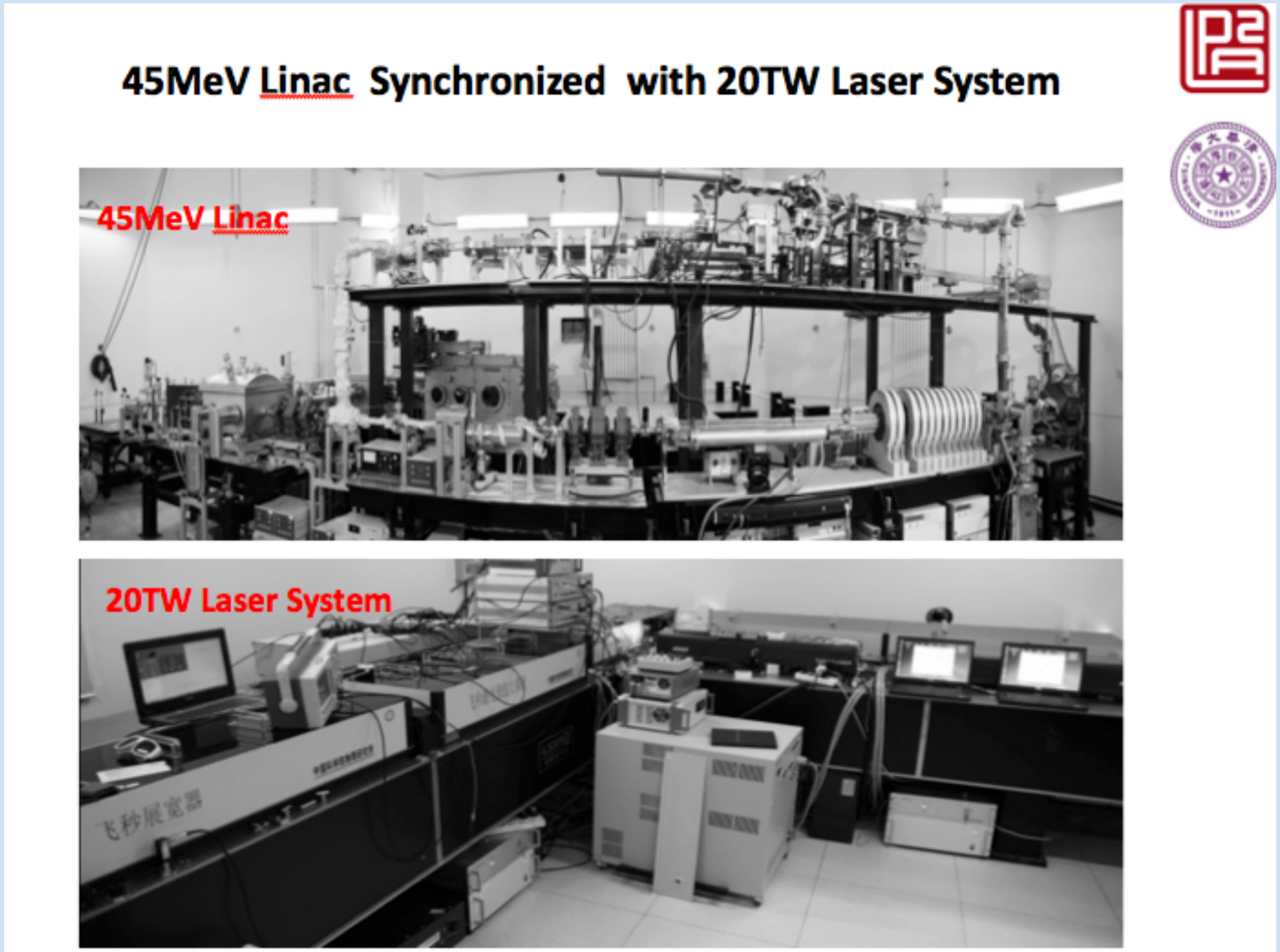
- *DESY*, Germany's leading accelerator center, is engaging in plasma-accelerator research, *LAOLA Collaboration* formed
- Emphasis on *combining conventional accelerator technology with plasma-acceleration* techniques for improved control over the injection/acceleration process



- *FLASH* has tremendous potential to contribute to progress in novel accelerator research
  - by providing a combined beam-driven, laser-driven wakefield-accelerator beamline
  - through its bunch shaping capabilities (e.g. triangular beams, bunch trains)
  - by offering FEL-quality, 1.2 GeV-beams for external injection

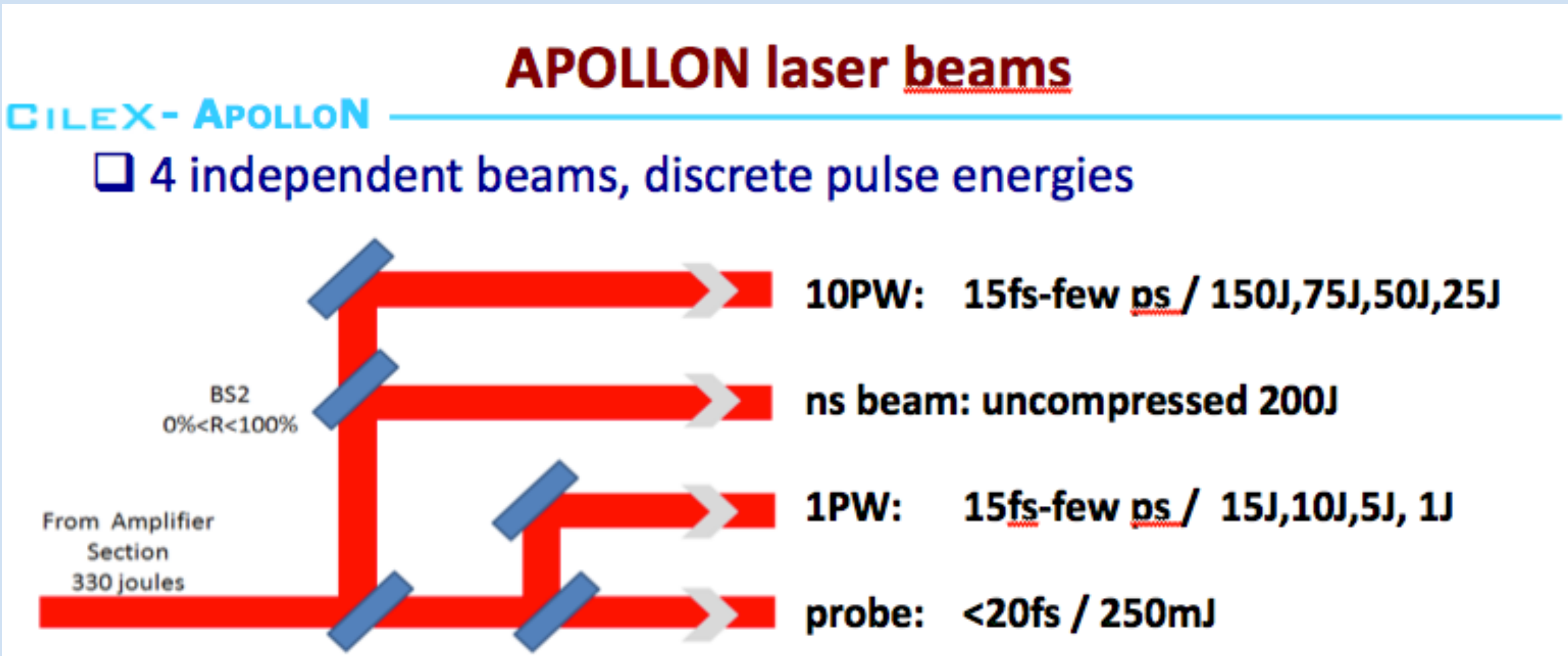
Operation of FLASH plasma activities starting in 2014/2015.

Wei Lu (Tsinghua) - Recent Progress of Laser Plasma Physics and Advanced Accelerator Research at L^{2}PA of Tsinghua University



- Laboratory of Laser Plasma Physics and Advanced Accelerator Technology – new research group for laser plasma physics and advanced accelerator technology
- 45 MeV linac synchronized with 20TW laser system
- Plans for Thomson scattering source; use ultra-short e-beam as wakefield probe

Arnd Specka - CILEX - Interdisciplinary Center for Extreme Light



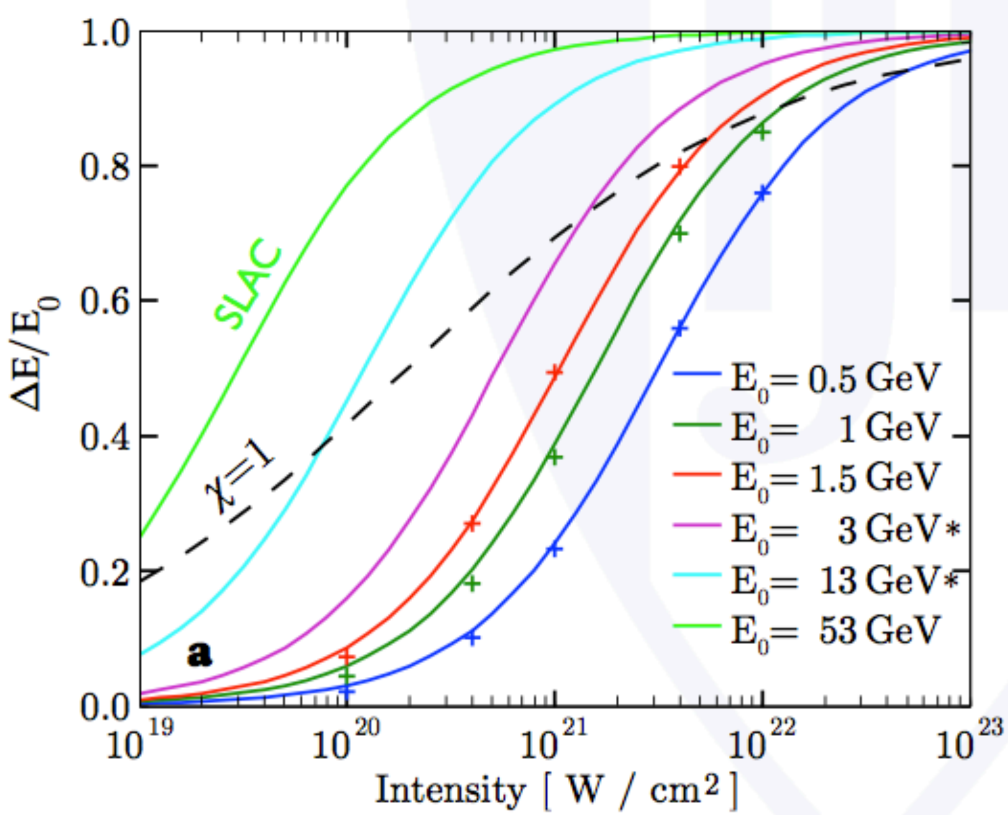
- New laser facility, 1st phase: ~2015; full operation ~2017
- 2 distinct experimental halls:
  (1) long focus: f = 10-20 m, a=1-10; gaseous targets
  (2) short focus: f=1-5 m, a=10-100, high contrast; solid targets
- Science program focused on laser particle acceleration and radiation generation

M. Vranic (IST) - All-optical radiation reaction configuration at 10^{21} W/cm^2

~40% energy loss for 1 GeV beam at 10^{21} W/cm^2

Radiation reaction can be tested with state-of-the-art lasers in this configuration

3D full-scale parameter scan



*S. F. Martins et al., Nat. Phys. 6, 311 - 316 (2010)

Conclusions/trends

- Advances in laser-plasma accelerator beam characterization and diagnostics
- Triggered injection concepts (for stability and quality); new concepts proposed
- Improved understanding of detailed beam dynamics in the LPA
- Applications are becoming reality (Radiation sources: Thomson scattering, ultra-short undulator radiation, betatron emission, etc)
- New laser facilities coming online
- Optimization of laser-plasma interaction at new and existing PW facilities -> more energy records are expected

Thanks to all the WG1 presenters and participants!