# Advanced Accelerator Research

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*High Energy Physics Advisory Panel*

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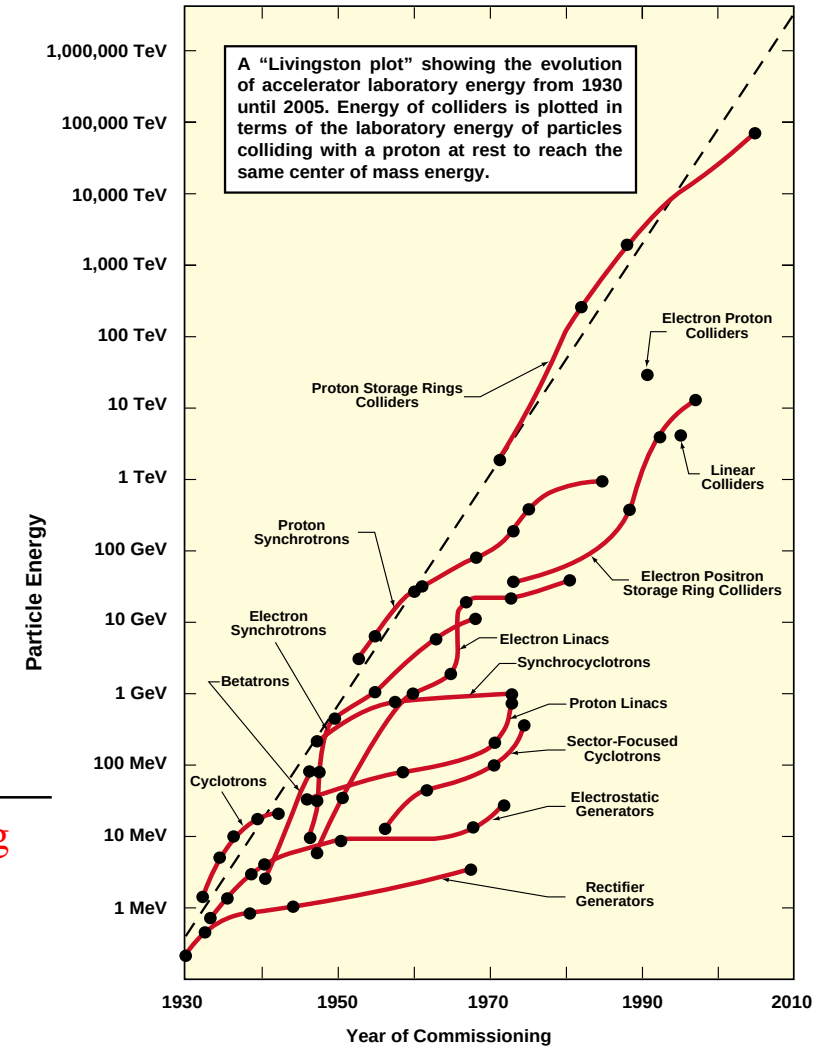
1. Introduction
2. Advanced Accelerator Research at SLAC
3. Two-Beam Linear Collider
   Concept, Research, and Future
4. Plasma Wakefield Experiments
   Wakefield Accel., $e^+$ & $e^-$ Dynamics, Center for Advanced Accelerator and Beam Physics

# High Energy Physics ⇔ Energy Frontier

## The Livingston curve is the context

Exponential growth of $E_{CM}$ through accelerator physics and technology innovation has lead to

- Many of the discoveries central to our understanding of particle physics
- Multi-TeV collisions




## Today's High Energy Physics Program

| Accelerator | Technology & Topology |
|---|---|
| Tevatron, HERA, LHC | SC Magnets, Storage Ring |
| CESR, LEP | SC RF, Storage Ring |
| PEP-II, KEK-B, DAPHNE | Digital Signal Processing, Storage Ring |
| TeV Linear Collider | SC RF or High Power RF, Linear Collider |

# Advanced Accelerator Research at SLAC

## Accelerator research and development has always been a major component of the SLAC program

- High power microwave sources, components and linear accelerators
- Storage rings –SPEAR was not the first storage ring, but it was the critical step in the evolution of the storage ring topology that is central to almost all of today's experiments
- Linear colliders – The SLC was the first and only operating linear collider. It was an essential first step towards high energy $e^+e^-$ collisions.

## Advanced accelerator research at SLAC

- On the "R" side of R&D
- Research into "advanced" technologies and concepts that could provide the next innovations needed by particle physics

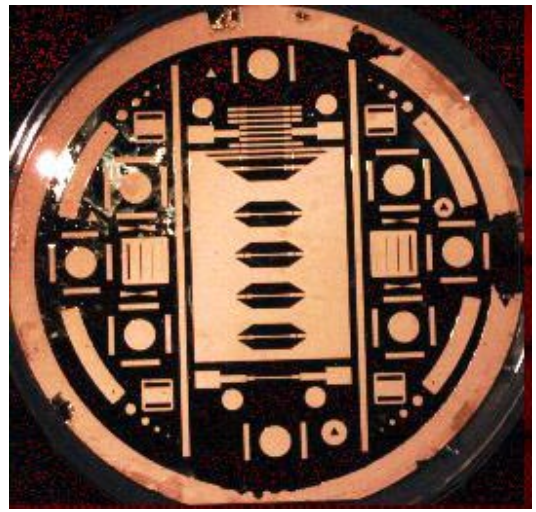
## "Advanced"

- In many cases one is applying or extending physics and technology that is its *own discipline* to acceleration – ex. plasma physics, digital signal processing
- This interdisciplinary attracts a broad range of scientists that extends well beyond classical accelerator physics

# Advanced Accelerator Research at SLAC

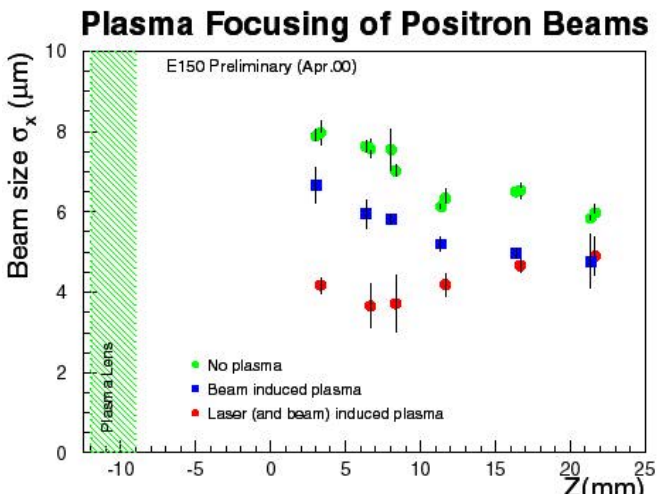
## Advanced accelerator R&D activities

- 3D electromagnetic calculations
- Final focus designs using a low energy beam as a lens
- High frequency RF
- High power RF pulse compression
- Laser driven structures
- *Plasma acceleration*
- Plasma focusing
- Pulsed heating as a gradient limit
- *Two-beam acceleration*

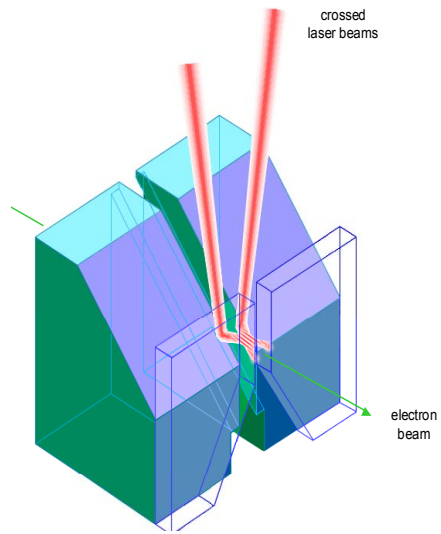


**Mm-wave sheet-beam klystron:** Prototype fabricated by LIGA (deep X-ray lithography). The center of this 3.5" dia wafer is a 92 GHz, 1 MW klystron circuit. The surrounding features are for quality control and non-contact measurements.

**First observation of focusing of $e^+$:** Measurement of plasma focusing of a 30 GeV positron beam. $1.5\times10^{10}$ $e^+$ per pulse.




**LEAP acceleration cell:** Two Gaussian beams of 850 nm laser light cross at 1.4° to form the acceleration field. Electrons are injected between the prisms into the crossed laser field.

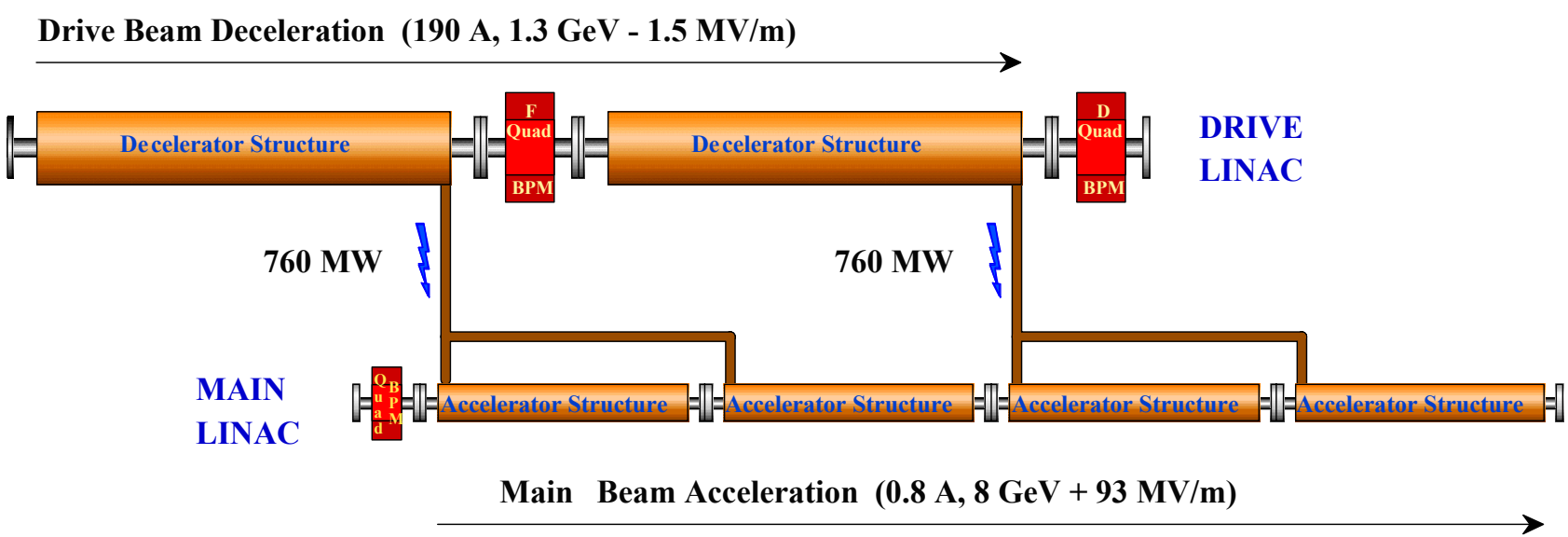


# Two-Beam Linear Collider

- Offers high-gradient acceleration which scales to multi-TeV energy and higher frequency.
- Basic idea is a transformer: Decelerate high-current, low-energy beam, accelerate low-current, high-energy beam.
  - Efficiently accelerate a low-energy, high-current beam.
  - Compress energy by multi-turn stacking in a ring.
  - Distribute beam pulses to high-gradient accelerator.
  - Decelerate Drive Beam and Accelerate Main Beam.
- Net effect: Map energy from a <u>long-pulse</u> accelerator to <u>different locations</u> along the high-gradient linac. Allows the use of low-frequency, conventional RF technology for Drive Beam acceleration.

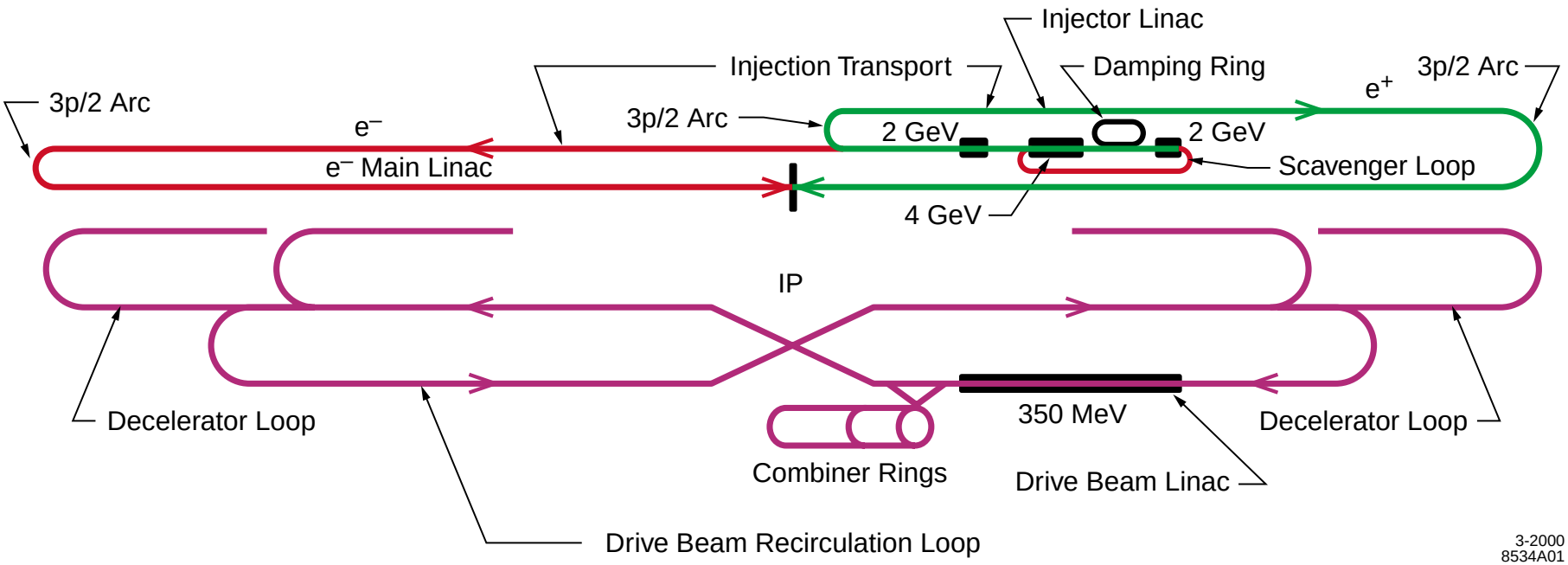
# The Two-Beam Transformer Concept

## Two-Beam Module Layout




Two Beam Acceleration (TBA)

# Schematic Layout of a Two-Beam Linear Collider

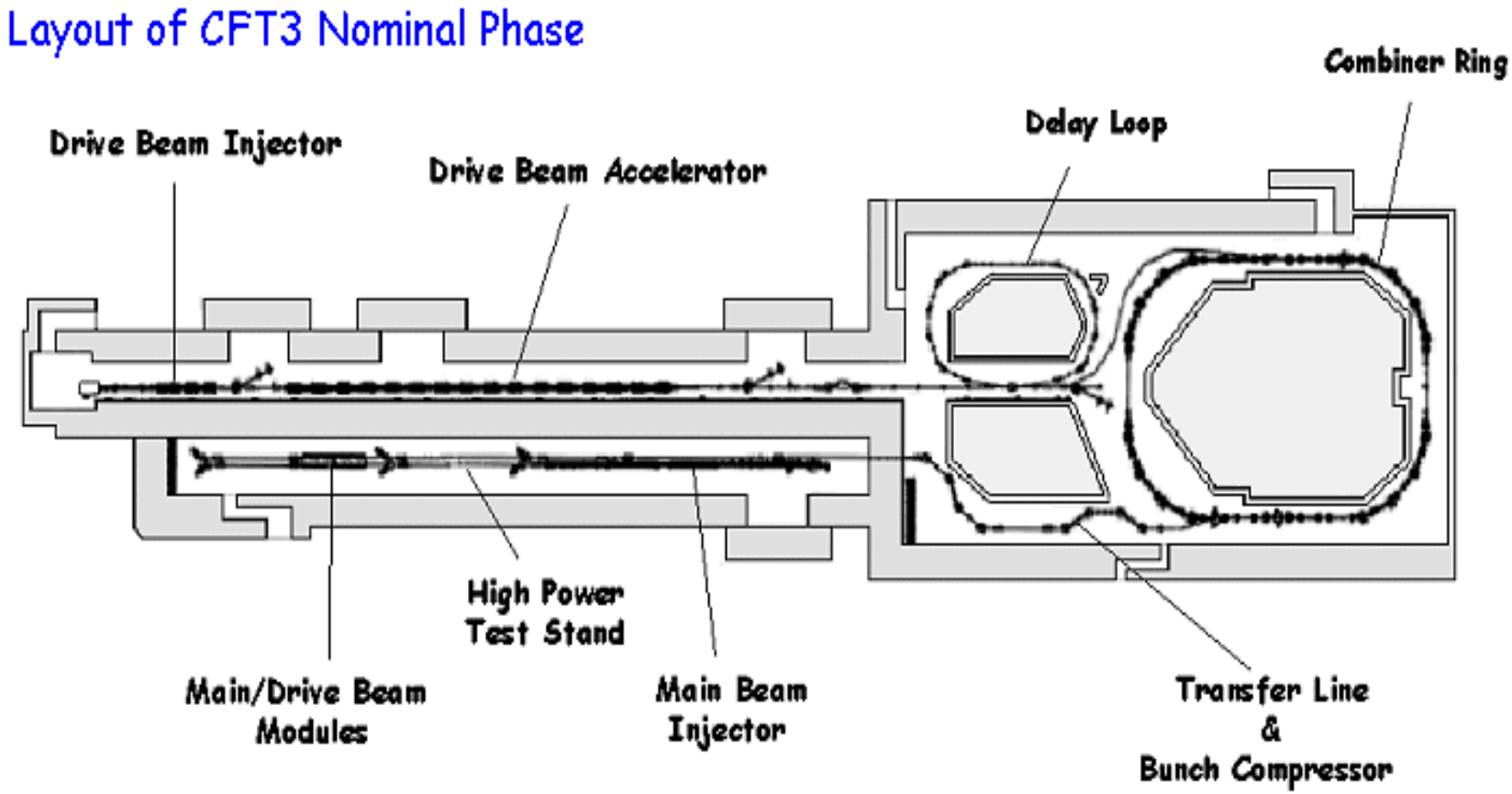



- **The total pulse length of the Drive Beam Accelerator is set equal to the twice the total length of the high gradient linac.**
- **The first half of the drive beam pulse is used for positrons while the second half is used for the electrons.**
- **The configuration above uses recirculation to use fewer drive beam RF sources but with longer length.**

# Issues and Studies

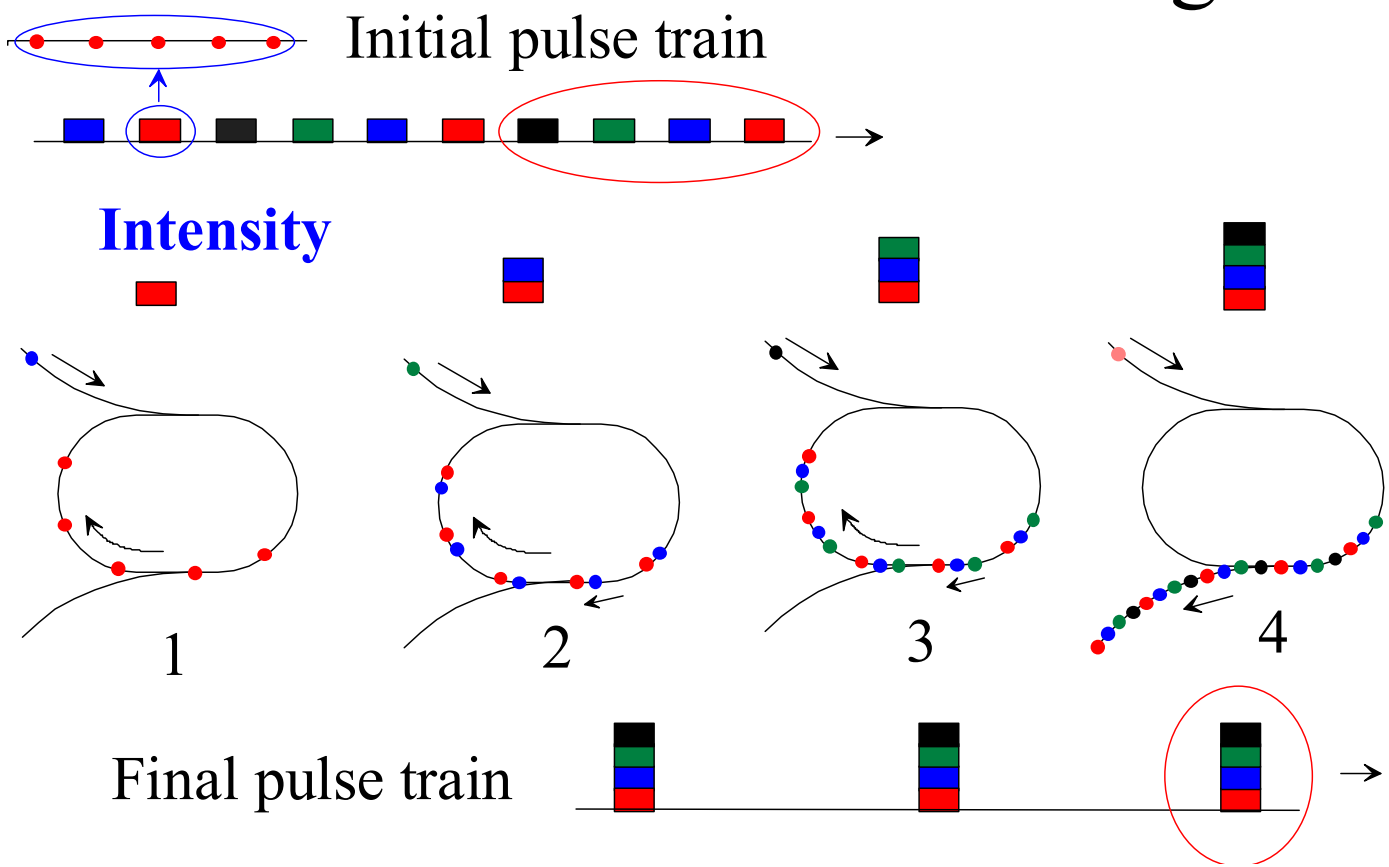
- Gradient and choice of RF frequency (SLAC/NLC).
- Efficient Drive-Beam Acceleration (CTF3).
- Drive-beam combiner/energy compression (CTF3).
- Deceleration and RF power production (CTF2, CTF3).
- Compatibility as an upgrade to conventional approach (SLAC)
- Energy Reach (SLAC)
  - To upgrade energy, <u>increase length of linac and drive-beam transport.</u>
  - <u>Drive Beam complex is the same</u>, except for longer pulse length.
- Some of these issues can be addressed in a test facility.
- CERN is planning a test facility, CTF3, which will convert the present LEP injector to a two-beam test facility.

# Conversion of LPI to Two-Beam Test at CERN




- **SLAC will contribute electron gun and injector design.**

# Energy Compression by interleaving bunches in a combiner ring




- The injection region uses matched RF deflectors to interleave four bunches at the quarter points of the cycle

# E-157 PWFA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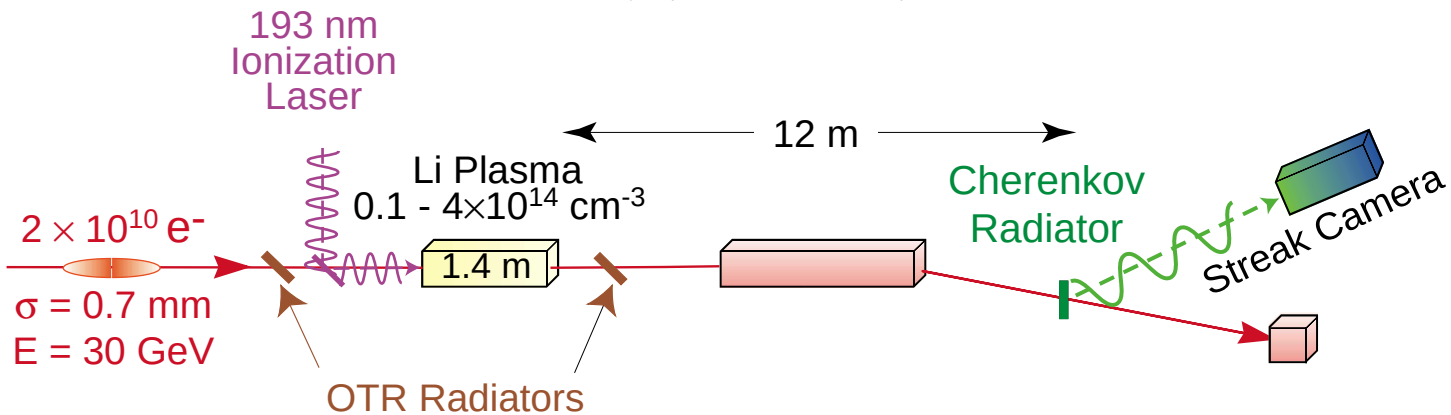
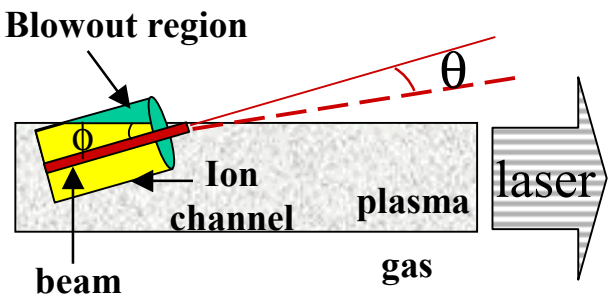



- **Extraordinarily high fields developed in beam plasma interactions**
- **Many questions related to the applicability of plasmas to high energy accelerators and colliders**
- **E-157: First experiment to study Plasma Wakefield Acceleration (PWFA) of electrons over meter scale distances**
- **Physics for positron beam drivers qualitatively different (suck-in vs. blow-out) ⇨E-162**

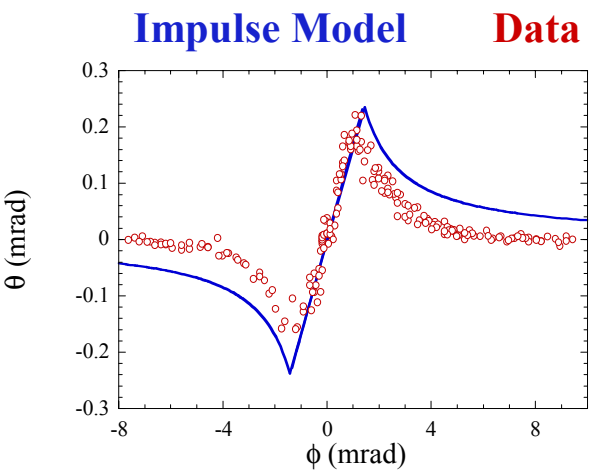
# E-157 PWFA

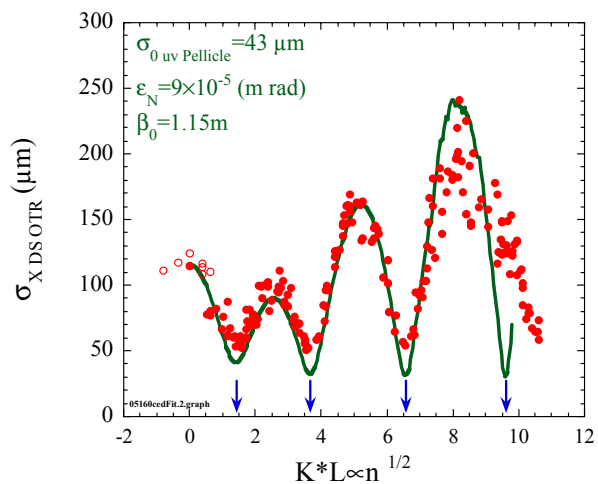
## Three Highlights!

### 1. Electron Beam Refraction at the Gas–Plasma Boundary

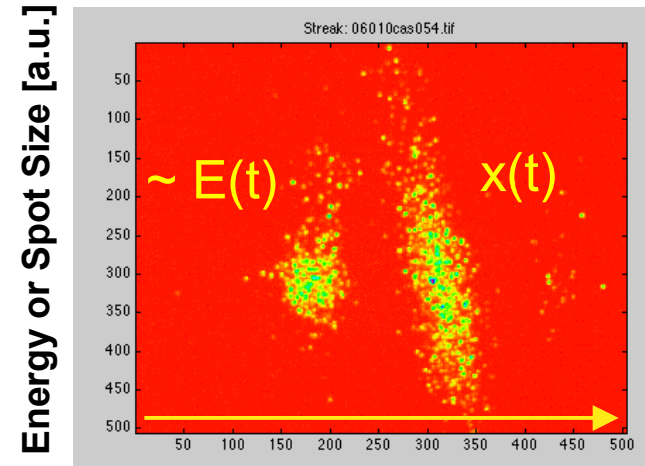


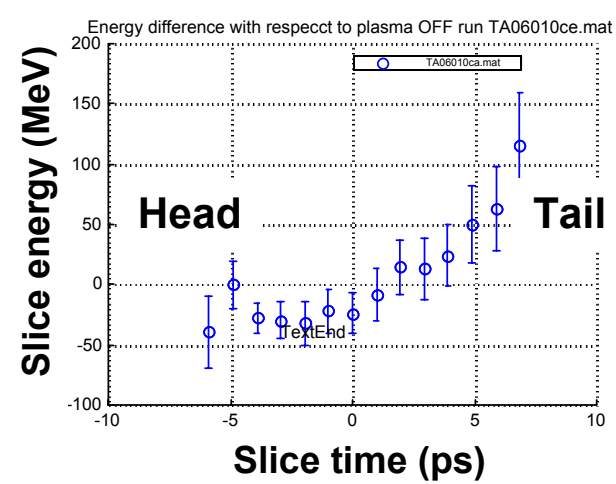

### 2. Transverse Wakefields and Mismatched Beam ⇨ Betatron Oscillations




### 3. Longitudinal Wakefields ⇨ Core De-acceleration and Tail Acceleration



# Experimental Program

- ***Run 1: A First Look at Positron Propagation in Long Homogeneous and Hollow Plasmas.***
  - **Use working E-157 apparatus**
  - **Positrons in homogeneous and hollow plasmas**
  - **Transverse dynamics (time integrated & time resolved) in the "suck-in" regime**

- ***Run 2: High Resolution Energy Gain Measurements of Positrons***
  - **Move to new location in FFTB to build true imaging spectrometer**
  - **Positrons in homogeneous and hollow plasmas**
  - **Detailed structure of longitudinal wakes (acceleration)**

- ***Run 3: High Resolution Energy Gain Measurements of Electrons***
  - **Electrons in homogeneous and hollow plasmas**
  - **Matched beam propagation in a long plasma**
  - **Higher resolution acceleration measurements**

# UCLA, USC, Stanford Pre-proposal to NSF for a Physics Frontiers Center

## Principal Investigators

R. Byer, Stanford Applied Physics
C. Joshi, UCLA Electrical Engineering
T. Katsouleas, USC Electrical Engineering
W. Mori, UCLA Physics & Electrical Engineering
J. Rosenzweig, UCLA Physics
R. Siemann, SLAC & Stanford Applied Physics

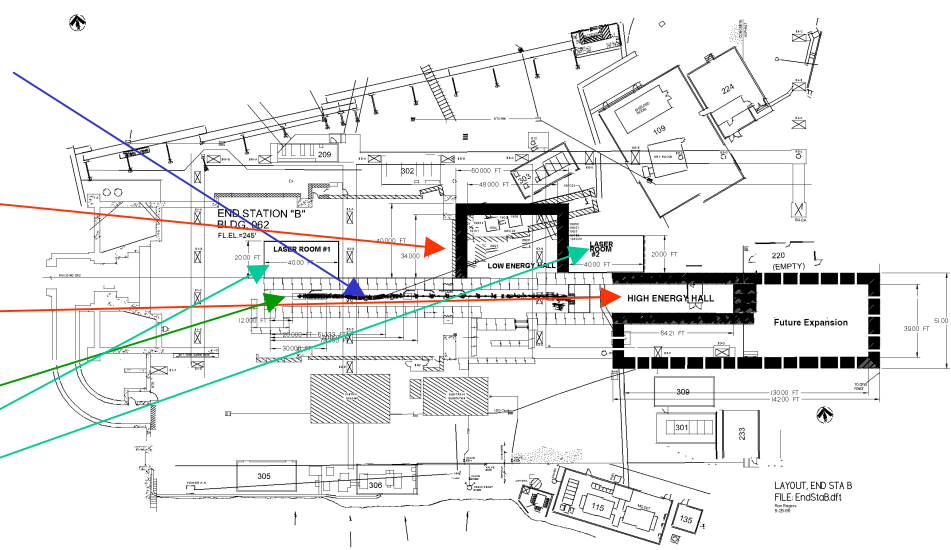
## The Center

- PI's with diverse experience in plasmas, lasers, particle sources, RF, computer simulation & classical accelerator physics. Committed to making the Center a major part of their research activities.
- SLAC would host the Center and make unique facilities including the FFTB and NLCTA available. This leverages the investment in the Center.

# Center for Advanced Accelerator and Beam Physics

## The Center's Program

- Begin with plasma acceleration experiments at the FFTB & high brightness electron source physics.
- In parallel, add experimental halls and lasers to the NLCTA complex. The resultant ORION facility would be designed for rapid turn-around of experiments through shared diagnostics, layout, etc.
- ORION would support a wide-ranging program in plasma, laser driven, RF acceleration.
- Computer modeling is an integral part of the Center

## ORION

- Based on the NLCTA (NLC Test Accelerator) - 300 MeV, 11.4 GHz linac with a ~ 200 nsec long beam with X-band bunches
- Low Energy Hall for experiments with ~50 MeV beam available most of the time
- High Energy Hall for experiments with ~300 MeV beam that would have to be scheduled together with NLC RF development
- New injector - A single bunch, RF gun
- Two laser rooms for RF gun laser and experimental laser