The Fermilab Accelerator Science Program: Beam Sources & Instrumentation A0 Photoinjector Part 1

H. Edwards
Fermilab
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Outline

Part 1

- Introduction
  - connection to future HEP facilities &
  - new accelerator based tools for other disciplines
- History
- Recent Accomplishments and Present Activities
  - Present Experiments, Diagnostics, Technology

Part 2

- Schedule & Layouts
- Proposal for FY2009-2012
  - Future activities FY09-10
  - NML activities
- Organization and Personnel
  - Students & Collaboration
- Budget Request
- Conclusion

Introduction- History & Connection to Future Facilities

History

- Built to bring expertise to FNAL in the areas of :
  - High brightness Electron Injector physics
  - Laser technology
  - Superconducting RF cavity experience, operation and control
- Built as part of TESLA Collaboration
  - Has brought strong collaboration between DESY and Fermilab
  - Injector built as twin to TTF Injector 2
- Collaboration, Training, and Technology
  - Other institutions helped in the assembly and supply of students
  - Students training ground unencumbered by operations demands
  - Test bed for SRF, RF Controls, and Diagnostics

Introduction- Connection to Future Facilities & New Accelerator Tools

Technology

- The e beam injector needed for electron linac (linear collider) systems tests & for SRF module tests and training

Present (& past & future) Emphasis

- Low emittance beam sources
- 6D Beam emittance manipulations
  - The realization that brightness is a 6D concept, and that 6D emittance εx εy εz can be redistributed between the 3 beam phase space planes.
  - Leads to optimization of the partition of the 2D emittances for the particular accelerator requirement
  - Flat beam transformer (FBT)- εx to εy ratio ~100
  - Emittance exchange(EEX) εx<-> εz, or εz<-> εx

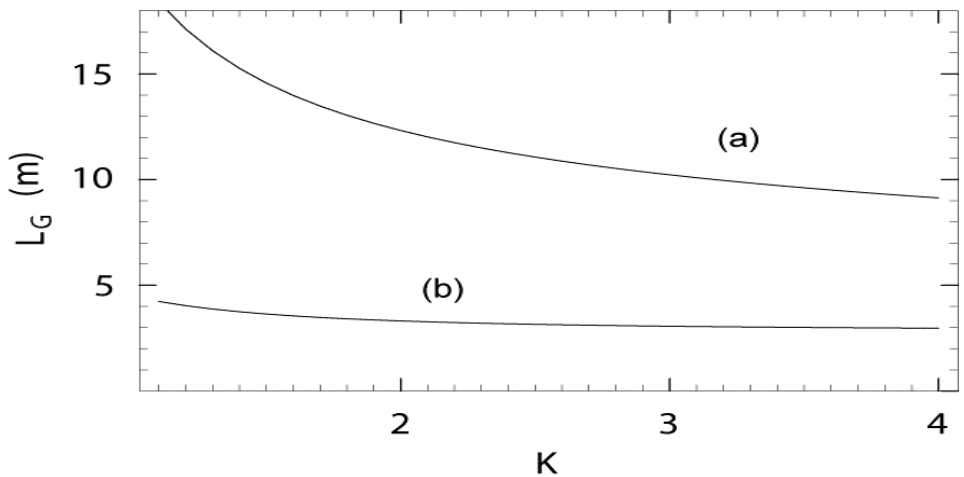
Connection to Future Facilities (see overview Kim PAC07)

- Linear collider εx, εy, εz ~ (8.0, 0.02, 3000) mm-mr
- FELs - beam energy spread much smaller than needed, optimize to reduce transverse emittance-> shorter undulators, lower energy linac

Education - Future Accelerators will need trained physicists

Connection to Future Facilities
Dreams are important

- Linear Collider
  - Could one make a linear collider beam from an RF photoinjector WITHOUT a damping ring?
    - Make a very low emittance and polarized beam from a RF gun.
    - Need excellent vacuum for GaAs cathode (SRF?)
    - Need to get the right emittances and emittance ratios
    - Start $\varepsilon x = \varepsilon y = \sim 1\mu m$, $\varepsilon z = \sim 8\mu m$
    - FBT ratio 400 (20,0.05,8) , then EEX(8,.05,20), close but…
- FEL Gain Length



a) $\varepsilon x = \varepsilon y = 1\ \mu m$, I=3,5kA (1.0, 0.1 ,0.1)
b) $\varepsilon x = \varepsilon y = 0.1\ \mu m$, 1kA (0.1, 0.1, 10)

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + K^2\right)$$

- **Higher gain**
- **The same gain with smaller K**
  - **Less magnets**
  - **Lower energy**

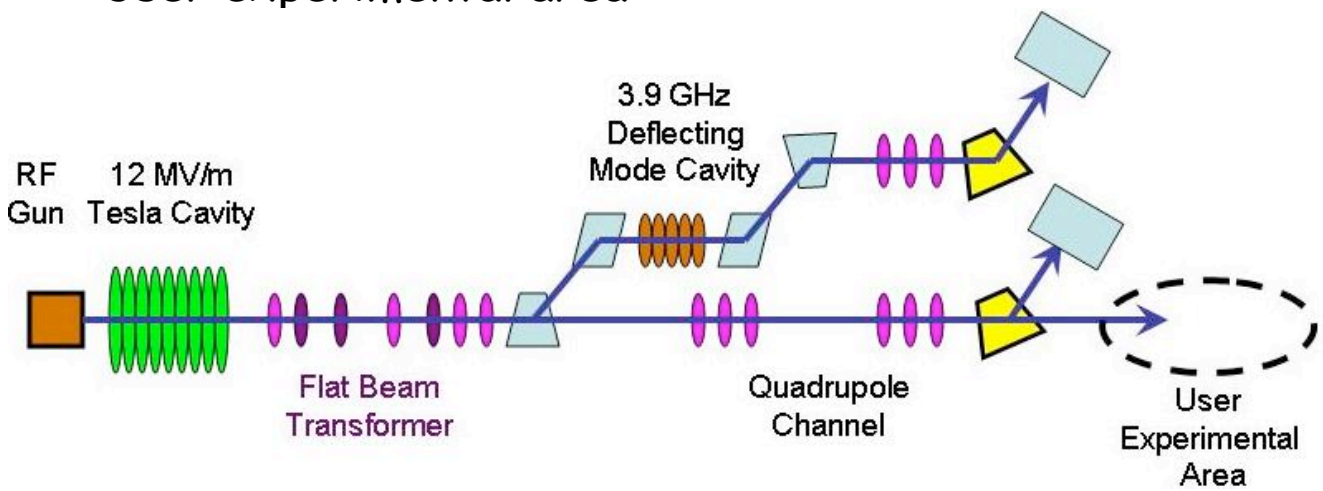
From KJ Kim, Z Huang

Connection to Future Facilities &New Accelerator Tools-Dreams are important

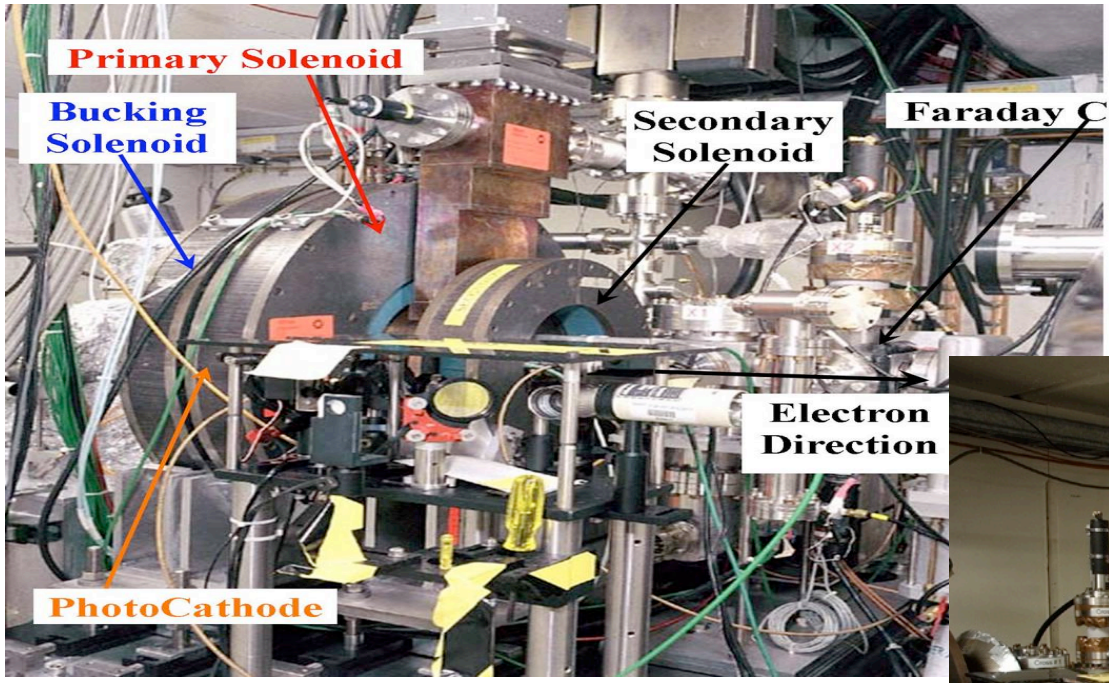
- The concepts introduced for emittance manipulations are imaginative and conceptually beautiful (magic). “They are linear dynamics. Of course they work”??
- However their experimental realization, understanding the limitations is far from simple, especially at low energy. (space charge, CSR!)
- The illustrated potential applications appear very challenging, and may not be realistic, however first steps are a necessary beginning.
- Electrons and electron-photon accelerator science is a very fertile field.
- To advance strategic goals for science, accelerator research should not be limited by the perception of the presumed end use discipline

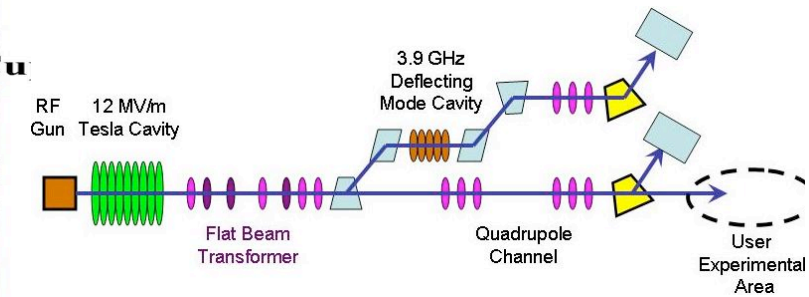
A0 Photoinjector Layout

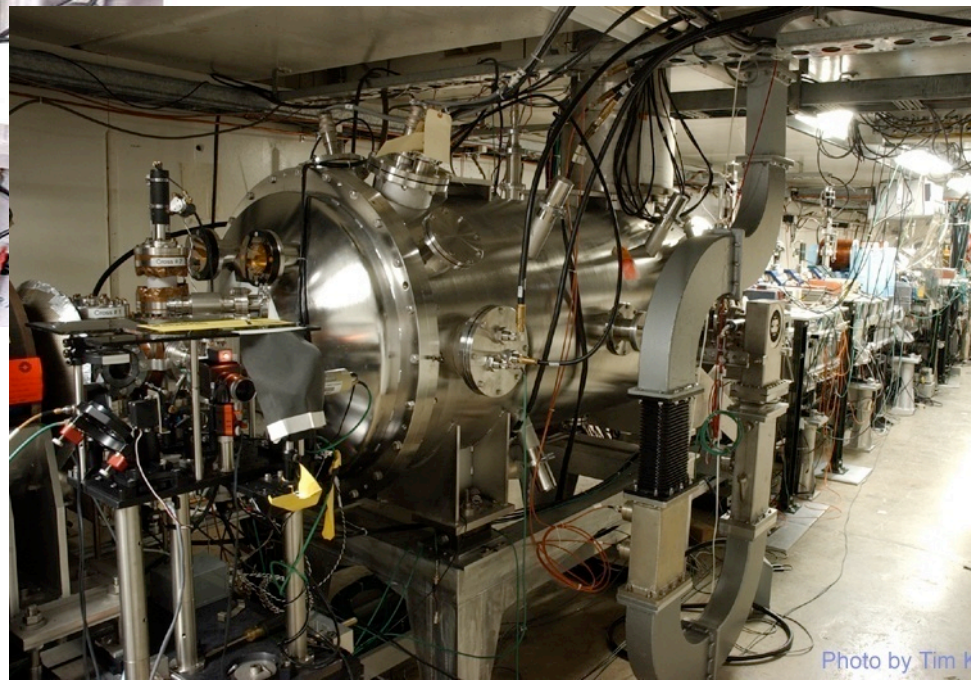
- 1.3 GHz 1.5 cell NC RF gun with Cs_2Te photocathode
  - 35 MV/m maximum cathode gradient
- 9-cell TESLA-type SC accelerating cavity
  - 12 MV/m accelerating gradient
- Round to Flat beam transformer
- Transverse to Longitudinal Emittance Exchange Beamline
  - Dipoles recycled from Bunch Compressor
- Quadrupole transport channel
- User experimental area



A0 Photoinjector Layout





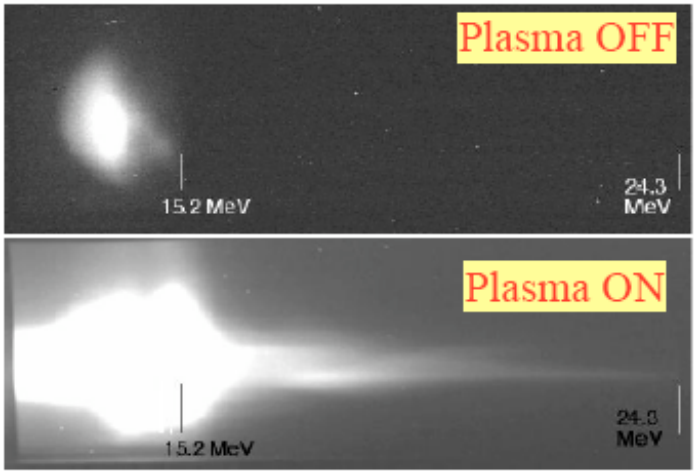


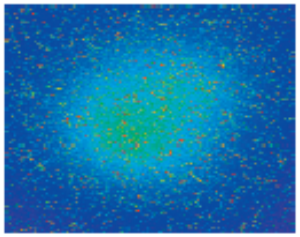
Past Accomplishments overview

- Significant accomplishments include:
  - Plasma wakefield experiments with high charge beams
  - Measurement of beam transverse wakefields with electro-optical sampling
  - Characterization of bunch compression with two macroparticles
  - Round-to-flat beam transformation attaining an emittance ratio of 100:1
  - Emittance exchange experiments (ongoing)
  - 9 graduate student PhD's (past and current students); Yin-e Sun won 1st place for Beam Dynamics Thesis at PAC05; Mike Fitch won the URA thesis award in 2001

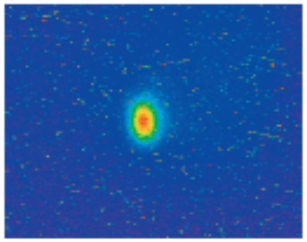
Past Accomplishments

- Plasma wakefield acceleration & focusing
- UCLA Rosenzweig, Barov, Thompson
- Achieved maximum accelerating gradient of ~130 MeV/m
- Observed time-dependent focusing in a plasma lens operating in under-dense regime Barov

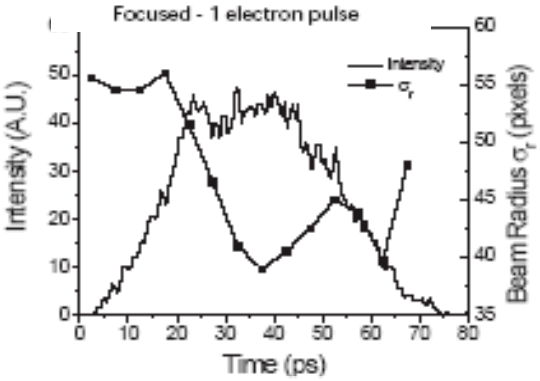




Unfocused - 5 electron pulses



Focused - 1 electron pulse



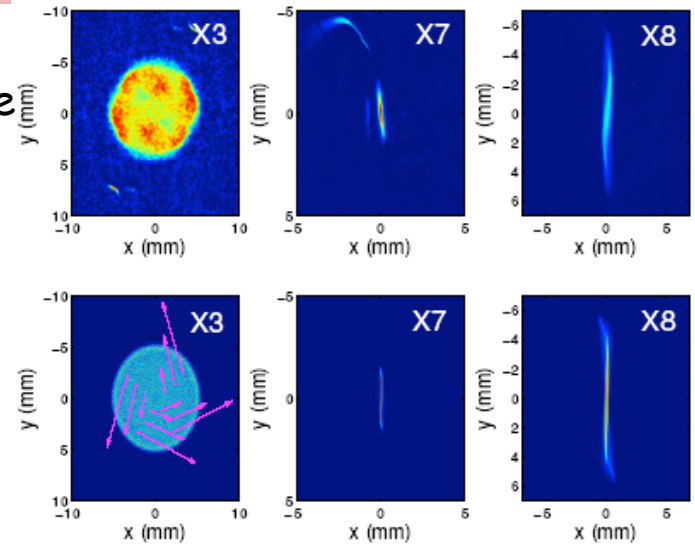
Matt Thompson (UCLA)

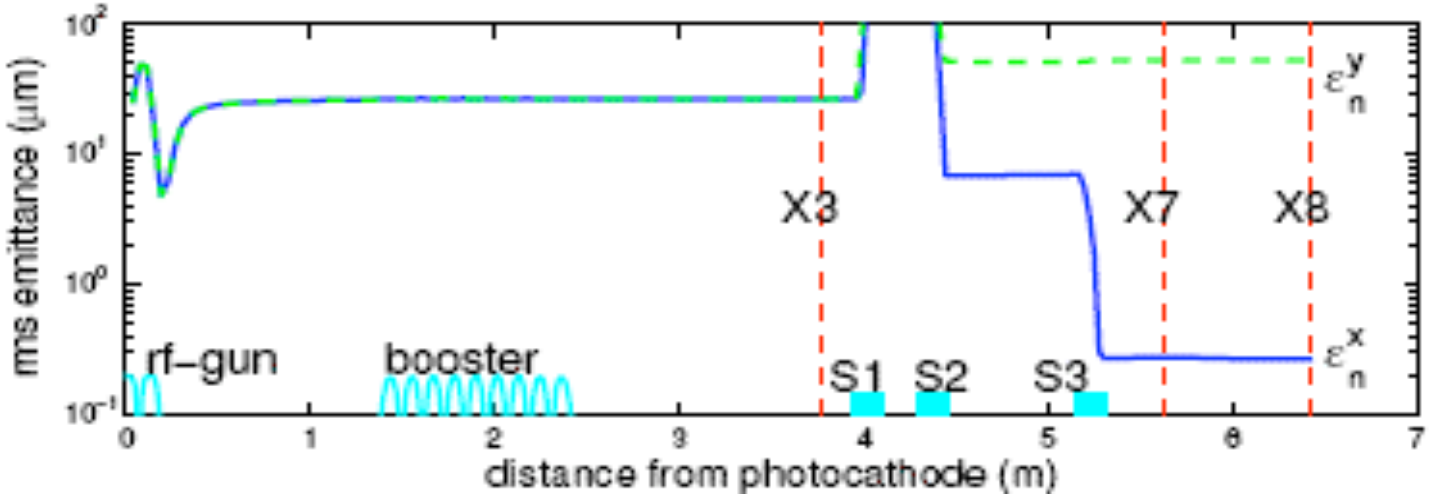
Past Accomplishments

- Flat beam transformation
- K J Kim, Yin-E Sun (Univ Chicago)
- Demonstrated the transformation of a round magnetized beam into a flat beam
- Achieved a transverse emittance ratio of 100 εx=0.4, εy= 40
- εx< thermal
- Experiment is resolution-limited

measure

simulate





Recent Accomplishments- Beam EEX

Emittance Exchange

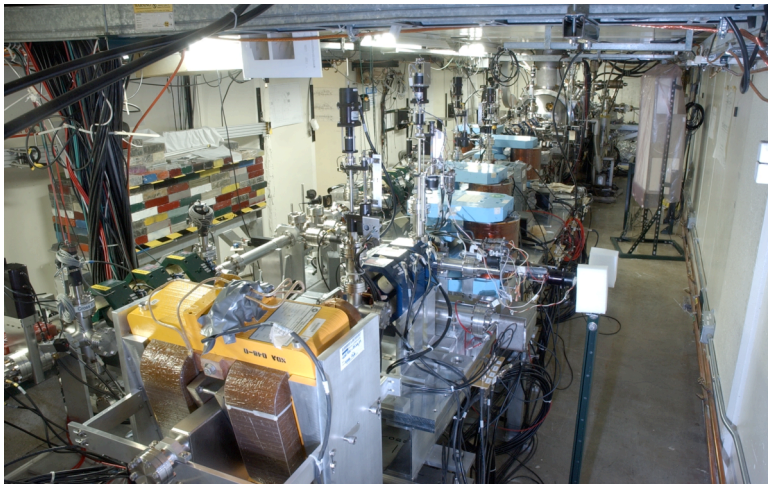
Tim Koeth thesis,Rutgers

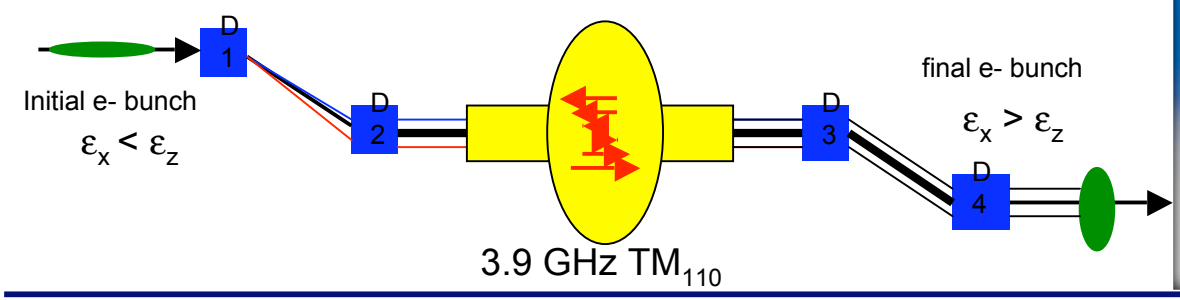
$$M_{dog} L_2 M_{cav} L_2 M_{dog} = \begin{pmatrix} 0 & 0 & -\frac{1}{\alpha} - \frac{L_2}{D} & -L_2\alpha \\ 0 & 0 & \frac{-1}{D} & -\alpha \\ -\alpha & -\alpha L_2 & 0 & 0 \\ \frac{-1}{D} & \frac{-1}{\alpha} - \frac{L_2}{D} & 0 & 0 \end{pmatrix}$$

α=dipole bend
L1=space B1 to B2
L2=space B2 to cav
Vcav= deflecting V
D= disp of dogleg

$$M_{cav} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & T & 0 \\ 0 & 0 & 1 & 0 \\ T & 0 & 0 & 1 \end{pmatrix}$$

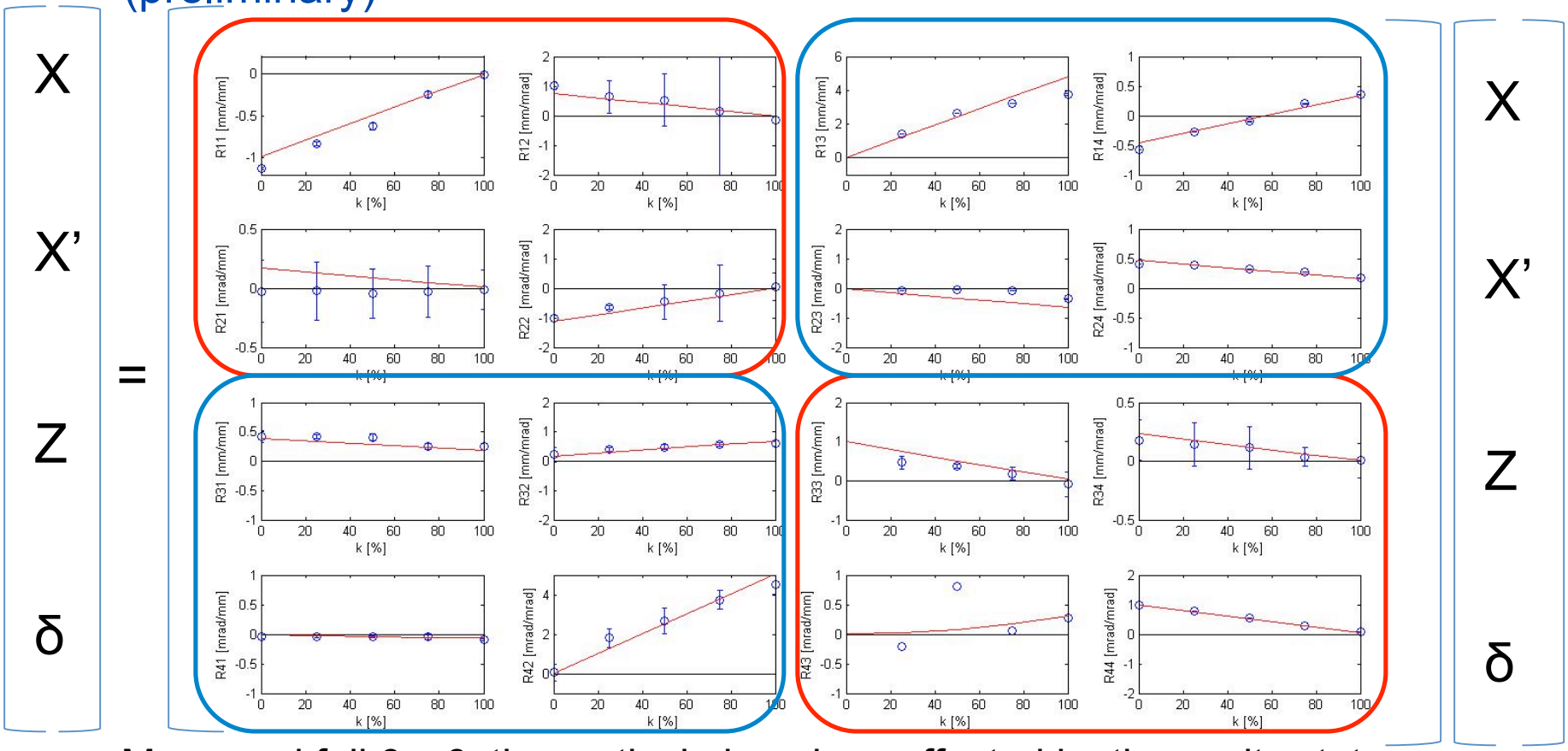
for exchange $T = -1/D = \frac{-1}{\alpha L_1} = \frac{\omega}{c} \frac{eV_{cav}}{E_{beam}}$





Recent Accomplishments- Beam EEX

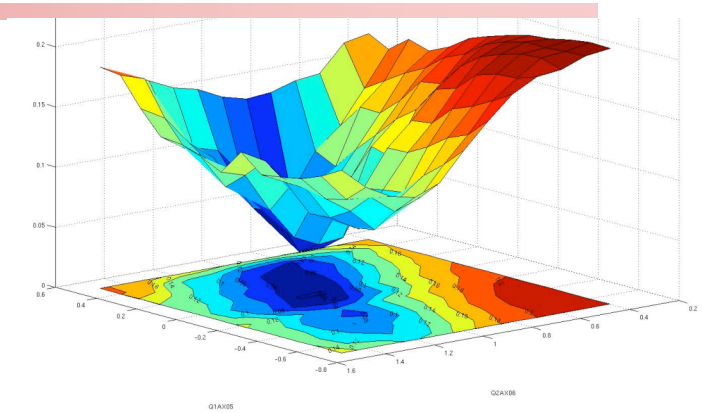
- Emittance Exchange Transport Matrix as function of cavity strength (preliminary)



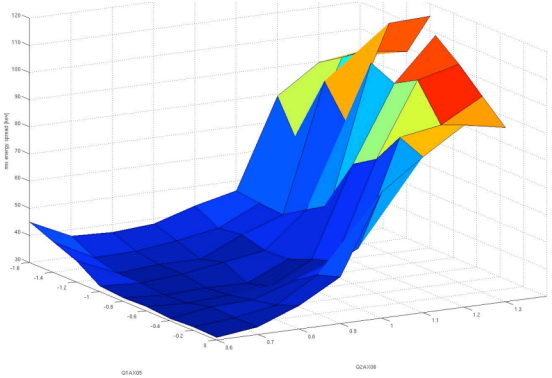
Measured full 6 x 6; the vertical plane is unaffected by the cavity status…

Recent Accomplishments- Beam EEX

- Emittance Exchange - Emittance measurements On Going
- Initial emittances εx=9 εz=33 (mm mr)
- Present Focus on εz out
  - Measure bunch length and energy spread
  - Scan 2 quad settings before exchange
  - Find minimum dE*dz product
- Measurement difficult
  - Bunch length minimum ~ 0.4ps (0.12mm)
  - Beyond streak camera resolution
  - Pyro detector uncalibrated
  - Interferometer slow
  - Space charge & CSR may effect dE especially at these bunch lengths
- Preliminary result εx=9 -> εz=13
- But εz-> εx, εy-> εy may not be trivial either



Bunch length Pyro Det scan



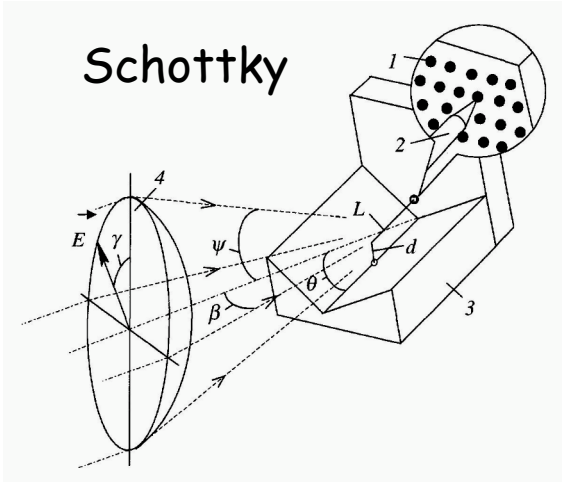
Energy spread scan

Recent Accomplishments -Diagnostics

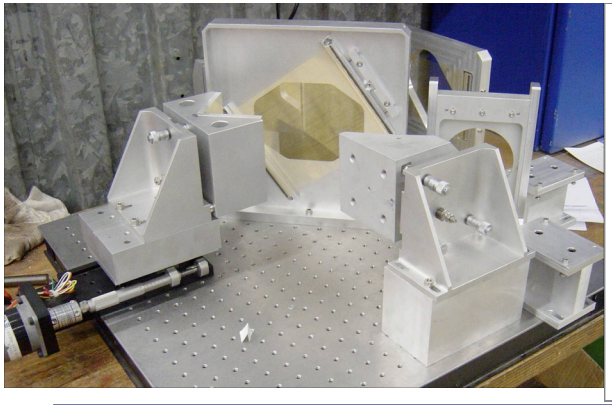
G Kazakevich, A Lumpkin, J Ruan, V Scarpine, R Thurmam-Keup, M Wendt

- Diagnostics key to making the measurements, especially bunch length, many follow from developments at DESY
- Diagnostics under use and development
  - Streak camera-improved resolution 2.6ps FWHM
  - Pyro Detector - max bunch compression
  - Martin-Puplett interferometer- bunch length
  - Electro-optical modulator, time of flight monitor
  - Optical transition radiation interferometry (OTRI)
  - Schottky Detector- CSR

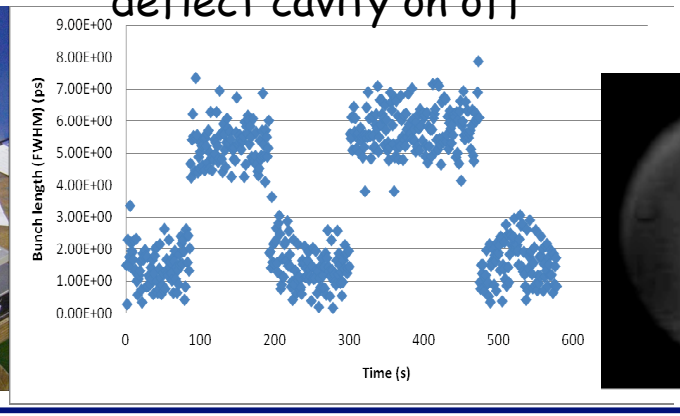
Schottky



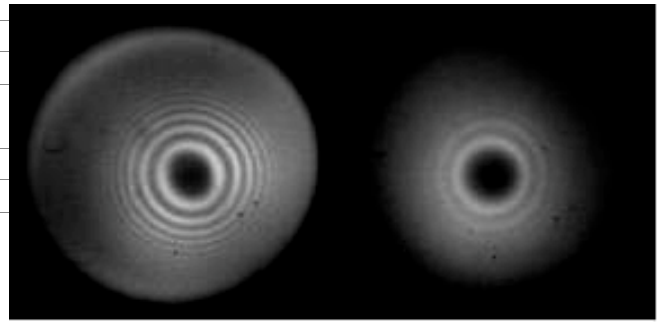
interferometer



Streak camera Bunch length deflect cavity on off



OTRI



Recent Accomplishments- Technology

J Branlard, G Cancelo, B Chase,
U Mavric, A Paytyan (students)

LLRF control

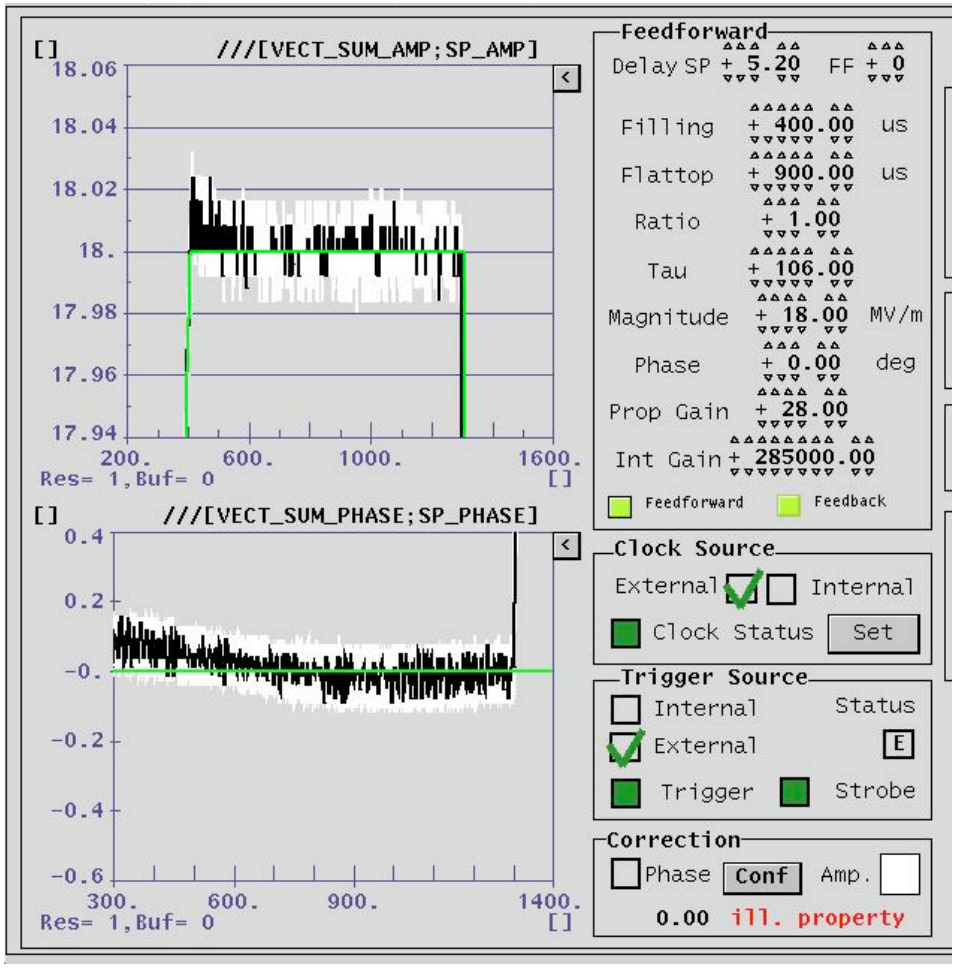
- Example of development work that is aided by the availability of the photoinjector to test systems with Rf and beam

- Shown is 3.9GHz acc system
  - RMS Amplitude ~2.5e-4
  - RMS Phase ~0.05 deg

System developed in collaboration with DESY, but is FNAL realization.

- Rf control will be basic to all new linac developments (e or p)

- Also 3.9 GHz SRF deflecting cavity excellent for bunch length measurement



Part 2 M. Church

Part 2

- Schedule & Layouts
- Proposal for FY2009-2012
  - Future activities FY09-10
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Backup

A0 Photoinjector Parameters

- Basic Features
  - Normal conducting 1 1/2 cell gun, CsTe cathode, 1.3GHz
  - Superconducting TESLA cavity, 1.3GHz
  - Beamline - 2 branches
  - Flat beam transformer
  - Magnetic chicane compressor (in past)
  - Double Dogleg
  - Nitrogen cooled 3.9 GHz Deflecting mode cavity
  - 2 Spectrometers
- Parameters
  - Laser energy 16 μJ/pulse @ 263nm
  - <5nC/bunch (have had >12 nC in the past)
  - Typically 10 bunches/RF pulse. 1 Hz rep rate
  - 4 MeV gun output energy, 16 MeV total energy,
  - $\Delta p/p \approx 0.1\%$@ 16MeV, Bunch length ≈ 1.2 mm (0.25nC)
  - $\gamma\varepsilon_z \approx 30$ mm-mrad (RMS @ 0.25 nC)
  - $\gamma\varepsilon_x, \gamma\varepsilon_y \approx 8$ mm-mrad (RMS @ 0.25nC) – Typically has been 4 in past

Summary

- The present and near term program explores emittance manipulations, low emittance generation from short laser pulses, generation of mini bunches, and their connection with effects such as space charge and CSR
- Diagnostic development is a critical part of the program as sophisticated diagnostics are needed to understand beam properties, especially longitudinal
- In FY2011 when the Tevatron turns off the injector will move to NML where it will be used both as an injector for SRF modules and accelerator science
- At present both funding and direct personnel support are under critical mass and it is important that more expertise and funding be found
- Collaboration outreach is necessary in order to enlarge the expertise base and to bring in more students. Presently we have good collaboration with ANL and NIU. We will be pursuing enlarging this group (e.g Univ Maryland, Univ Wisc, …)