FACET-II | Facility for Advanced Accelerator Experimental Tests

E326: Non-Intercepting Diagnostics for High Intensity Beams and Computer Control

October 26-29, 2020

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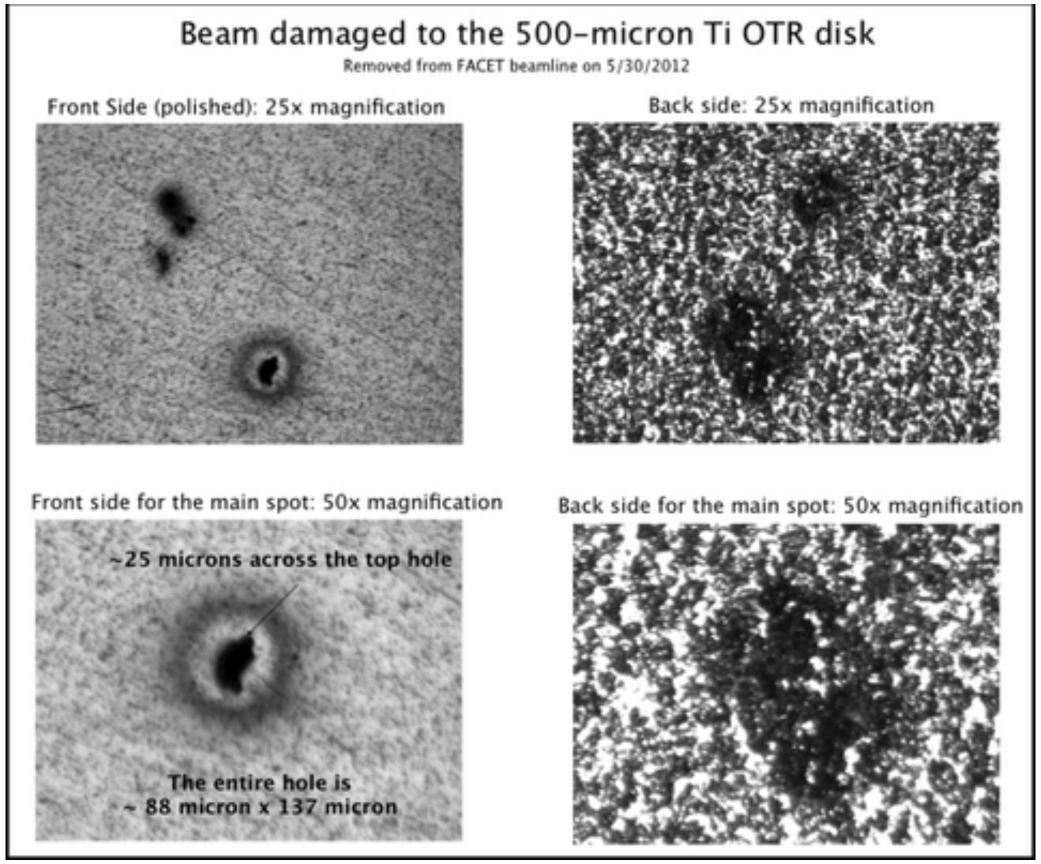
SLAC NATIONAL ACCELERATOR LABORATORY

E326 Motivation

- FACET produced $\mathcal{O}$(30 kA) beams
  - Punctured some foils, drilled through some diamond
- FACET-II expects to produce 100+ kA
- Future accelerators want to get to MA!

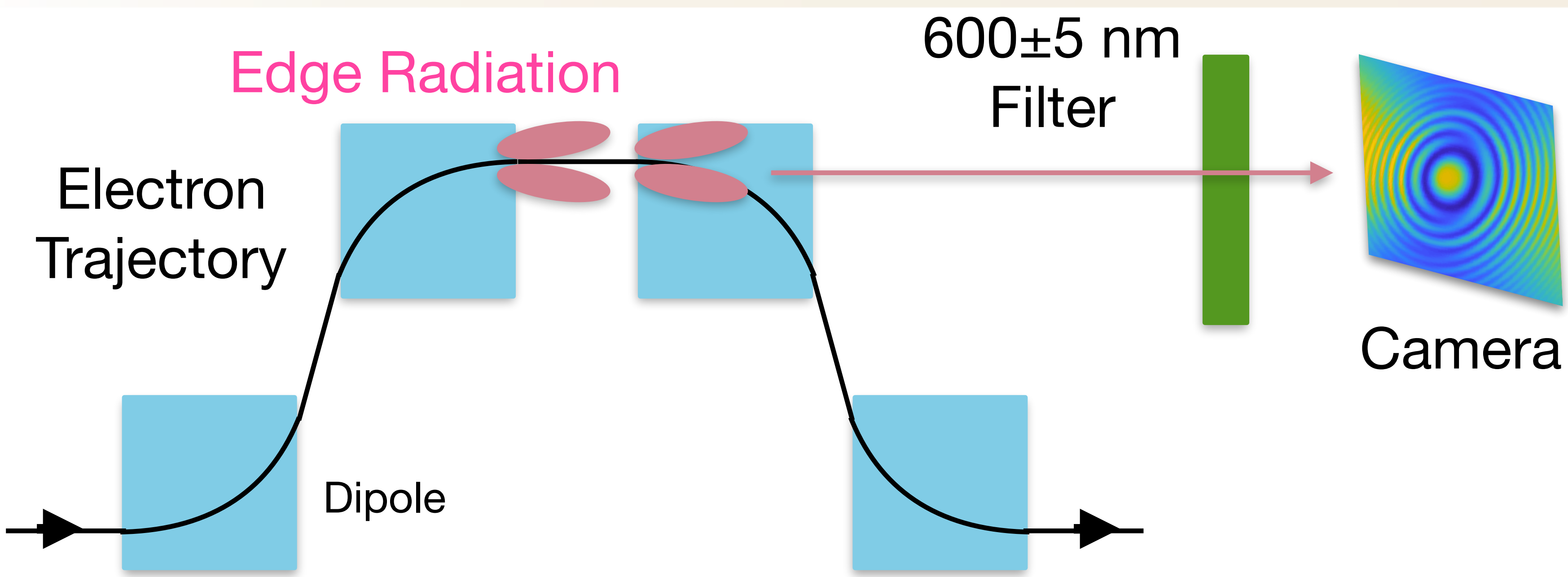
These accelerators pose diagnostic challenges:

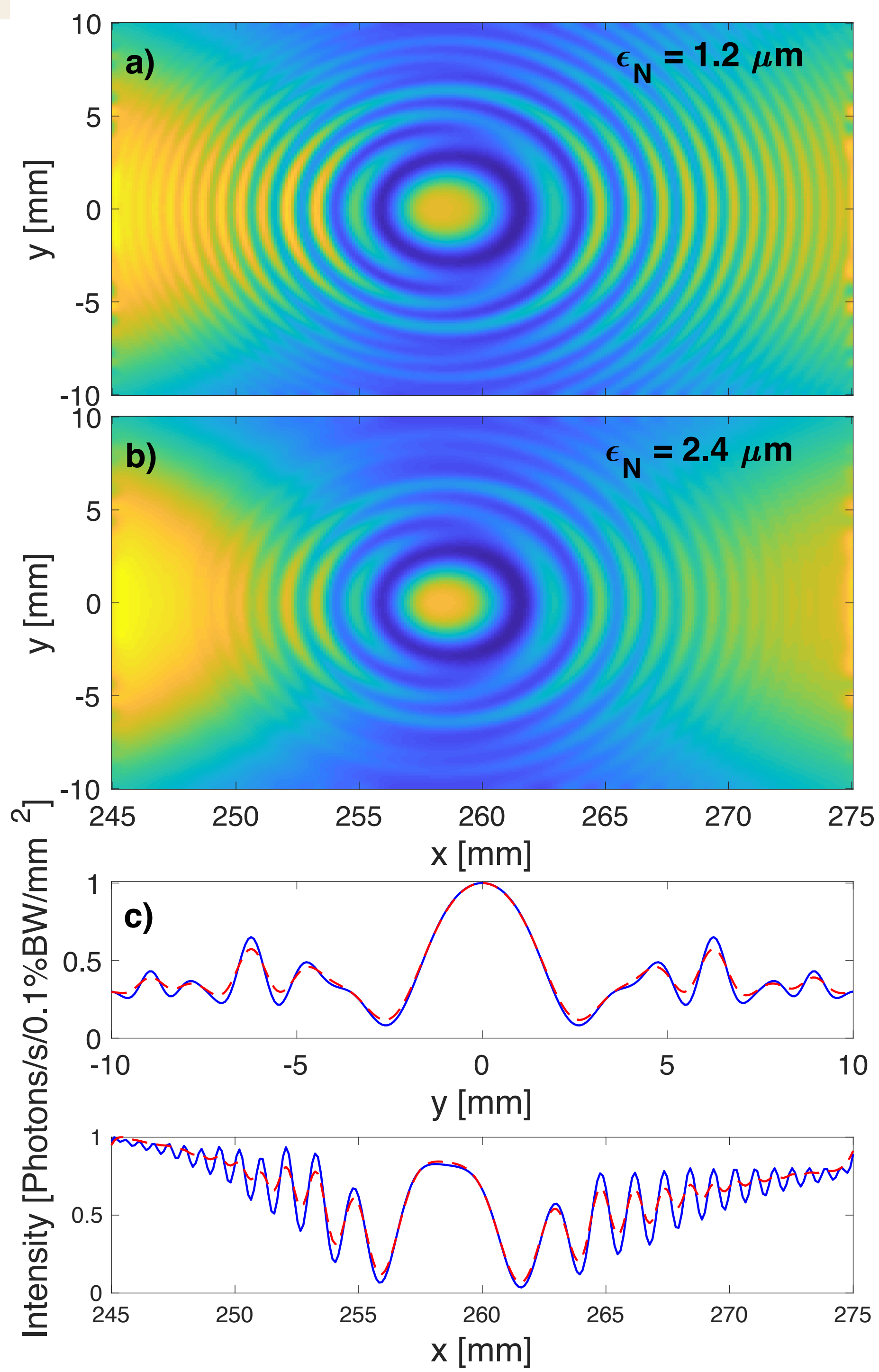
- Materials in, or near the beam, are a non-starter
- Extremely short beams (FACET-II) need to be handled carefully to preserve quality



The future is both high quality and high intensity - diagnostics are needed

Edge Radiation Based Diagnostic





- Great for measuring high-current beams: non-intercepting
- Ideal for computer control: single shot
- Edge Radiation generated at dipole magnet edges
- Interference between edges used to measure divergence and energy spread
  - Phase differences due to beam size minimal
- To be fast, diagnostic requires advanced image analysis

Continuous quantification of high-current beams, ideal for machine learning

Convolutional Neural Network for real time diagnostic

- Integral to generate image not tractable and numerical integration is “slow”, $\mathcal{O}$(mins)
- Convolutional Neural Networks excel at image analysis
- Examines entire image instead of lineouts - no data is lost for speed
- Trained on simulation data that is generated offline - no sacrifice of fidelity or accuracy for speed

$$I(\vec{x}) = \left| \int \vec{E}(\vec{x} - \vec{x}', p)\rho(\vec{x}', \sigma)\mathrm{d}\vec{x}' \right|^2$$

Example of CNN Identifying written numbers

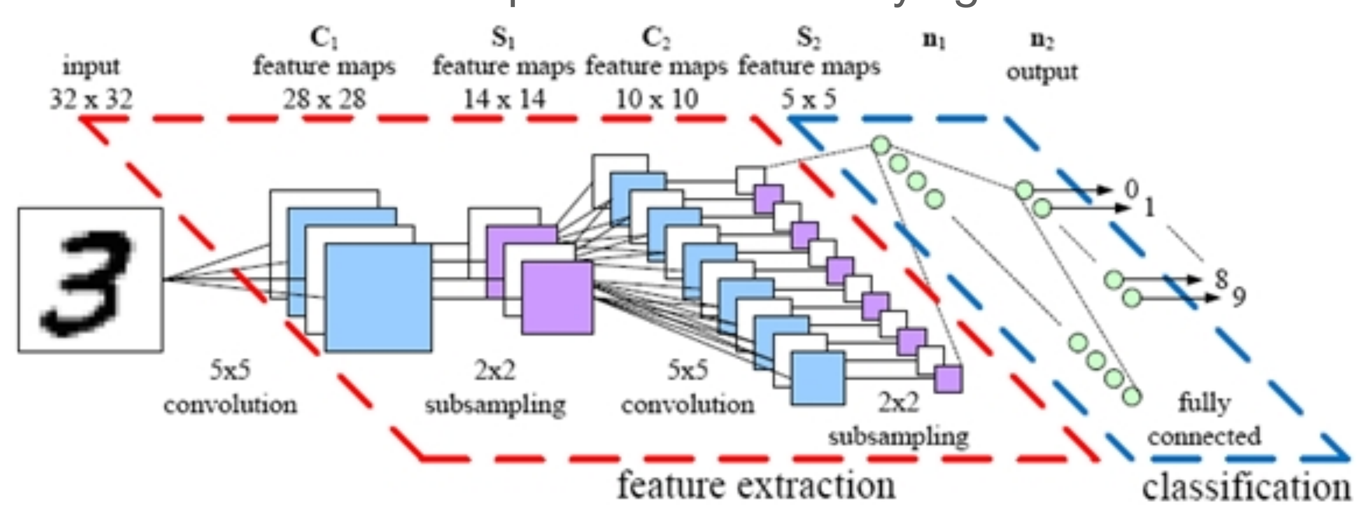


Image from PARsE
http://parse.ele.tue.nl/education/cluster2

- Understanding beam dynamics
  - Good SRW simulations
    - Good Image analysis
      - Good control

Quickly determine beam distribution from interference pattern using machine learning

Machine Learning Ecosystem at FACET-II

SLAC

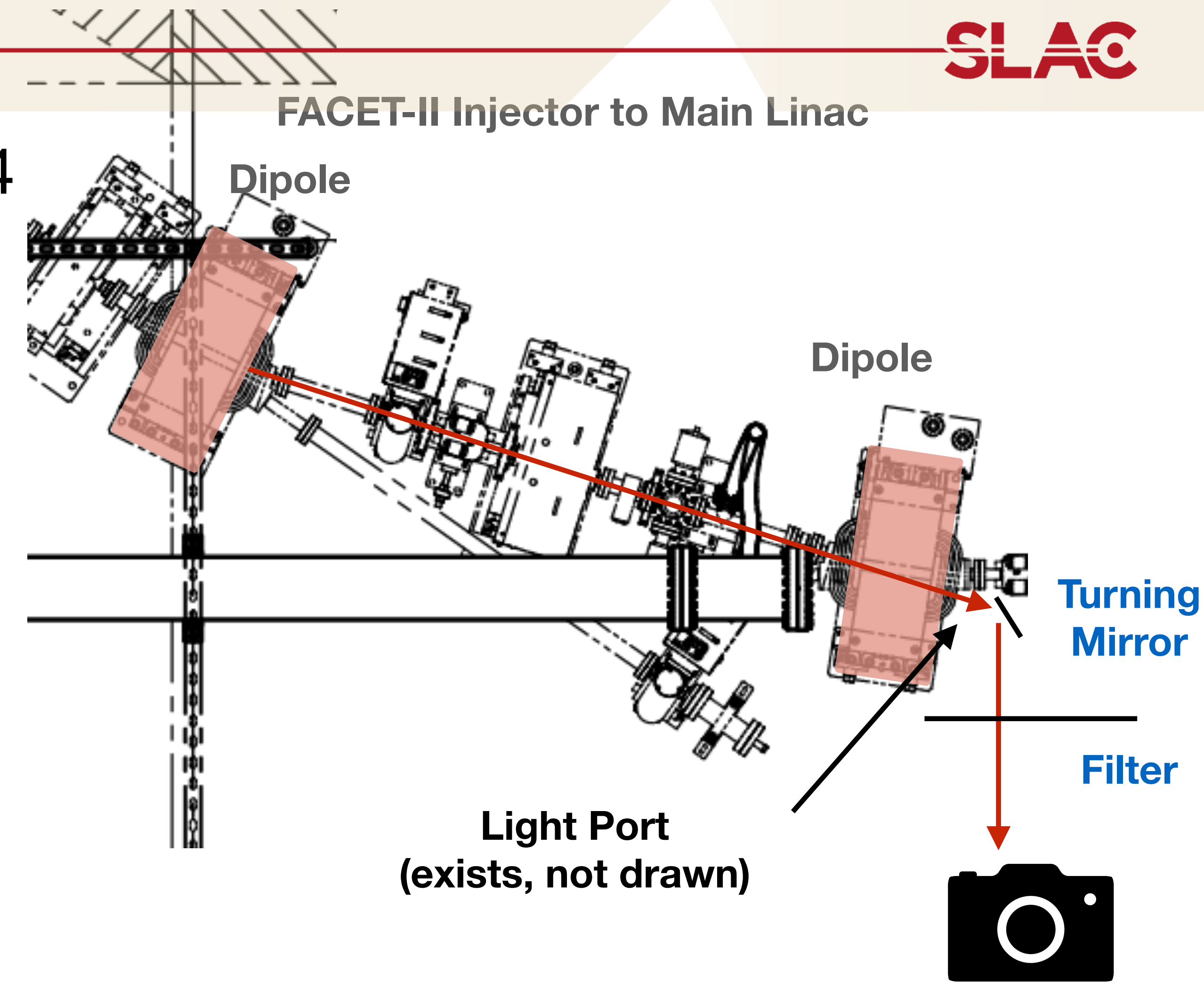
Machine Control and Understanding

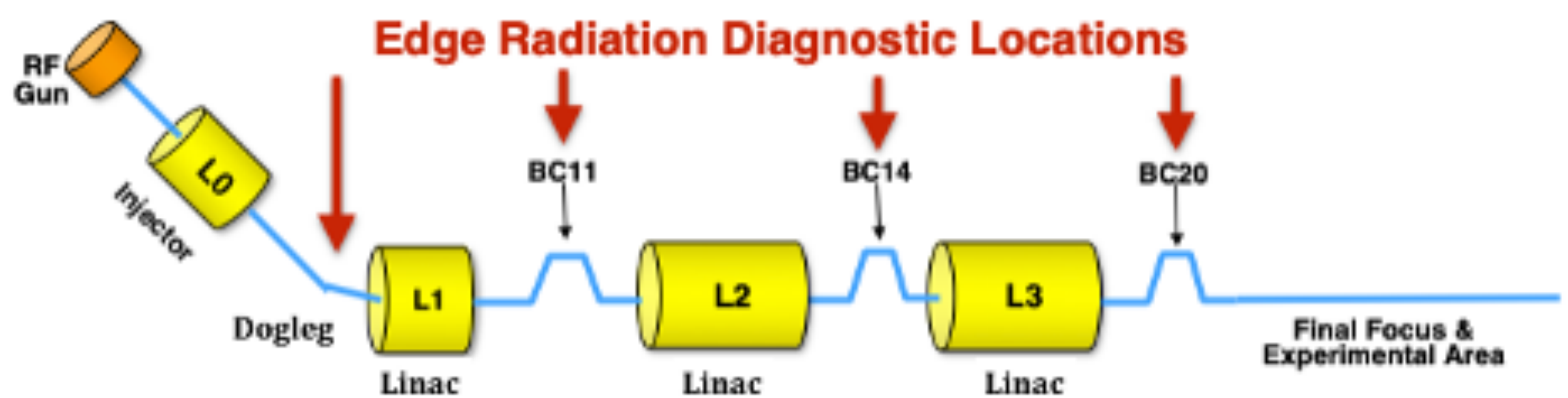
Diagnostics (Need information to make decisions)		Control (How to make decisions)	
Edge Radiation Emittance Diagnostics (E326)	Virtual TCAV Predictive Diagnostics (E327)	Adaptive Feedback (E325)	Learned Control (Reinforcement Learning, New proposal)
Non-destructive, single shot continuous monitoring of emittance of high-current beams	Longitudinal phase space diagnostics, always on, and for extremely short bunches	Stable, high-quality beams through control of unmodeled accelerator behavior	Fast, high-quality control of extreme beams by exploiting learned FACET-II responses

Synergistic experiments, individual success enhances all research

Experimental Layout

- 14 ports spread across Dogleg, BC11, BC14 and BC20
  - Ports already exist in Dogleg and BC14
- Off the shelf camera objectives and filters, standard FACET gigE cameras, laser optomechanics
- “Divide and conquer” the accelerator





Challenges increase down linac, program works from dogleg down to BC20

Experimental Timeline - Prioritized tunnel hardware

	Oct 2020	Nov 2020	Dec 2020	Jan 2021	Feb 2021	Mar 2021	Apr 2021	May 2021
Dogleg		2 ★	3 ★					4 ★
BC11	0 ★	BC11 @ 90%		1 ★	2 ★	3 ★		
BC14							2 ★	
BC20				0 ★	BC20 @ 90%			1 ★

0) Design beam chambers

1) Install Beam chambers
- Success: Beam chambers installed

2) Install optics
- Success: Light/interference on cameras

3) Tune beam optics to check dynamic range
- Success: cross check fringe contrast against traditional diagnostics

4) Start building and implementing ML model

Readiness [%]	Beam Chambers	Optics	ML
Dogleg	100	90	5
BC11	50	70	5
BC14	100	60	5
BC20	0	50	5

Safety Review: Done
Beam Requirements: Single bunch preferred

Prioritizing tunnel hardware to meet FACET-II schedule

Diagnostics and Observables, Future Evolution and Desired Upgrades

Diagnostics and observables:

- Current emittance diagnostics are sufficient

Future Evolution:

- Control! Both simple and novel
- Potential use in the dump at FACET-II
- Add to design of CSR chicane
- AWA has shown interest
- LCLS has shown interest too
- FACET-III could use this technique downstream of the plasma

Desired Upgrades:

- Laser heater to study coherence effects
  - Coherence effects change what you measure, not if you can measure
- Dipole pairs everywhere!

Thanks!

Questions?

1 slide: what is desired facility upgrades

Backup slides:

1 slide: collaboration

1 slide: publications, students

1 slide: experimental timeline:

experimental design (90%) : date

installation plan: date

ready for Experimental safety review: date

ready for installation: date

Ready for commissioning: beam requirements

first science: beam requirements

2 phases of the program: prerequisites, date, etc.

1 slide: diagnostics and observables

Science Goals - Slide #1

1 slide: what are the science goals: indicate for each target time (ex. 6 mo, 1 year, 3 years), the definition of success for each goal