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

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E326 Motivation

- FACET produced $\theta (30 \text{ kA})$ 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”, $O$(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

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

Quickly determine beam distribution from interference pattern using machine learning

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


Example of CNN Identifying written numbers

Image from PARsE
http://parse.ele.tue.nl/education/cluster2
**Machine Learning Ecosystem at FACET-II**

### Machine Control and Understanding

<table>
<thead>
<tr>
<th>Diagnostics</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Need information to make decisions)</td>
<td>(How to make decisions)</td>
</tr>
<tr>
<td>Edge Radiation Emittance Diagnostics (E326)</td>
<td>Virtual TCAV Predictive Diagnostics (E327)</td>
</tr>
<tr>
<td>Non-destructive, single shot continuous monitoring of emittance of high-current beams</td>
<td>Adaptive Feedback (E325)</td>
</tr>
<tr>
<td></td>
<td>Learned Control (Reinforcement Learning, New proposal)</td>
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</tbody>
</table>

- **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**
• 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
Prioritizing tunnel hardware to meet FACET-II schedule

### Experimental Timeline - Prioritized tunnel hardware

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<tbody>
<tr>
<td>Dogleg</td>
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<td>3</td>
<td></td>
<td></td>
<td></td>
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<td>4</td>
<td></td>
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<tr>
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<td></td>
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<td>BC11 @ 90%</td>
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<td>2</td>
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<tr>
<td>BC14</td>
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<td>2</td>
</tr>
<tr>
<td>BC20</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>0</td>
<td>BC20 @ 90%</td>
</tr>
</tbody>
</table>

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

Prioritizing tunnel hardware to meet FACET-II schedule

<table>
<thead>
<tr>
<th></th>
<th>Readiness [%]</th>
<th>Beam Chambers</th>
<th>Optics</th>
<th>ML</th>
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<tbody>
<tr>
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<td>90</td>
<td>5</td>
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<tr>
<td>BC11</td>
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<td>70</td>
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<tr>
<td>BC14</td>
<td>100</td>
<td>60</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>BC20</td>
<td>0</td>
<td>50</td>
<td>5</td>
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</tbody>
</table>

Safety Review: Done
Beam Requirements: Single bunch preferred
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