# Modeling relativistic electron pulses using Neural Networks

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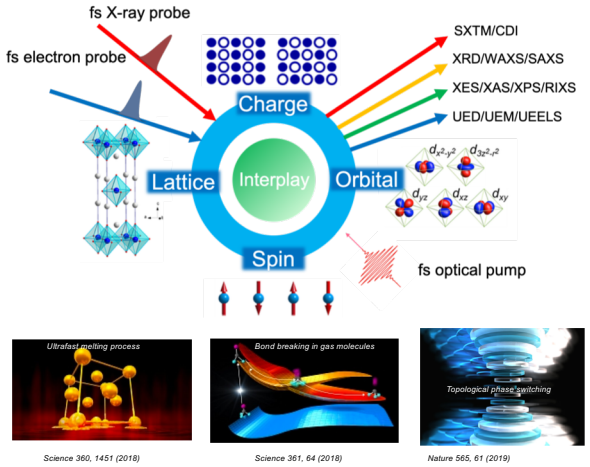
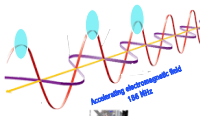
## Relativistic electrons as powerful probe to investigate fundamental processes in nature




Science 360, 1451 (2018) · Science 361, 64 (2018) · Nature 565, 61 (2019)

## HiRES: cutting-edge UED/UEM facility at LBNL

| | |
|---|---|
| Electron beam energy | 700-900 keV |
| Repetition rate | 1 Hz to 1 MHz |
| Temporal resolution | 100 fs to 1 ns |
| Electrons per pulse | $10^5$ to $10^8$ |
| Relative energy spread ΔE/E | $10^{-5}$ to $10^{-3}$ |

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Phys. Rev. ST Accel. Beams 15, 103501 (2012)
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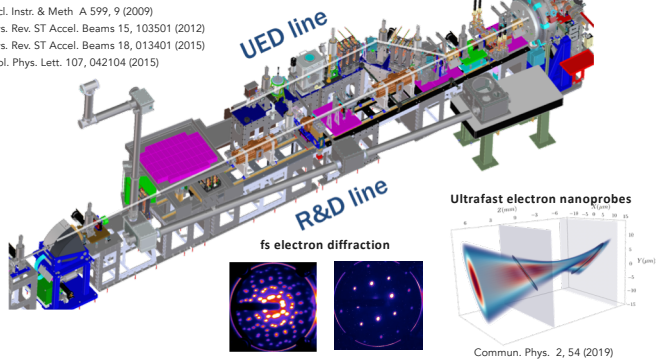


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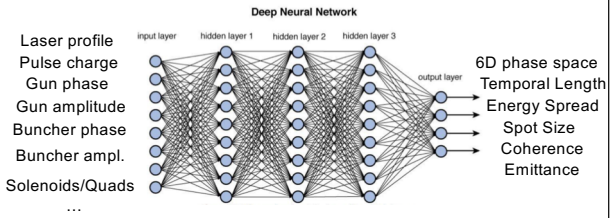
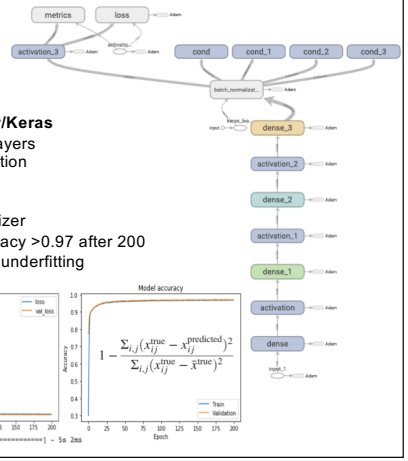
## Challenges and Motivation

- **HiRES beamline** is extremely complex which involves a large number of parameters, non-linear behavior and many interactive systems
- Different scientific/beam physics applications call for highly automated, rapid switching between different operational modes
- **Conventional numerical simulation methods** are computational expensive and too slow to be directly used during operation
- **Neural Networks (NN)** can be used to predict various electron pulse properties as well as the 6-dimensional phase space using nondestructive measurements as inputs




## NN architecture

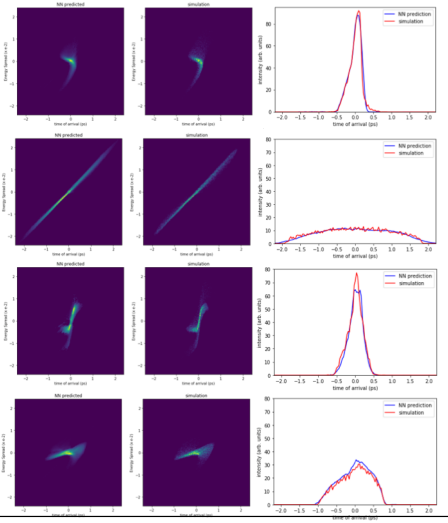
- Input: non-destructive beamline parameters
- Output: Longitudinal/transverse phase space images
- Trained on 3000 simulations dataset



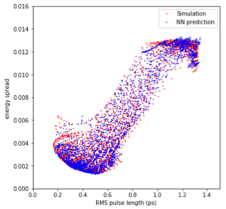

- **TensorFlow/Keras**
- FC hidden layers
- ReLU activation
- MSE Loss
- Batch Norm
- Adam optimizer
- Model accuracy >0.97 after 200 epochs, still underfitting

## Phase space prediction

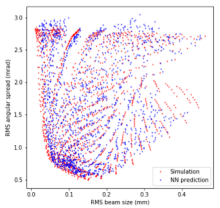
Phase space projections · Temporal profile




RMS pulse length VS energy spread




RMS spot size VS angular spread




## Conclusions & future works

- **NN prediction** agrees well with simulation results
- **Detailed phase space** features reproduced
- **Fast execution** (~1 ms) comparing with particle tracing software (hours)
- **Key beam parameters** (rms pulse length, rms spot size, energy spread, coherence legnth and emittance) can be extracted from 6D phase space distributions

- Further optimize training
- Train NN surrogate models using measured data set at the HiRES beamline.
- **Online virtue diagnostics** of key beam parameters. Similar Approach has been applied at LCLS at SLAC National Laboratory [1]
- **Genetic Algorithm(GA) + NN** to perform fast online beamline optimization/searching for switching between different operational modes

[1] Phys. Rev. Acc. Beams 21, 112802 (2018)

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