UoL Diagnostics Update for AWAKE run-2c

AWAKE collab meet

Debdeep Ghosal, J. Wolfenden, C. Swain, A. Guisao Betancur, C. Welsch

7th Nov., ‘24

What to expect?

Key points…

- Emittance
- Longitudinal bunch profile

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What to expect?

Key points…

- Emittance
  - OTR…
  - OSR…
  - BR…
- Longitudinal bunch profile

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What to expect?

Key points…

- Emittance
  - OTR…
  - OSR…
  - BR…
- Longitudinal bunch profile
- Discussion & Next steps

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Emittance measurement

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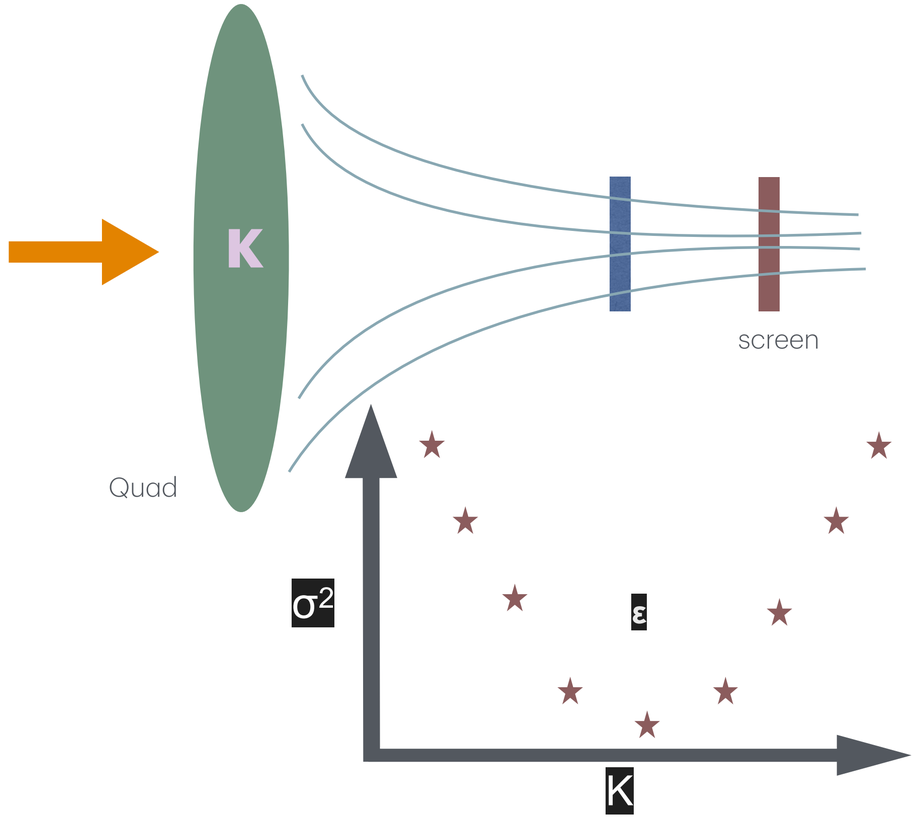
Emittance

Emittance measurement: Pepper-pot & Corresponding Optical Mapping

- Single shot (over multi-shot Quad scans)
- Phase space mapping



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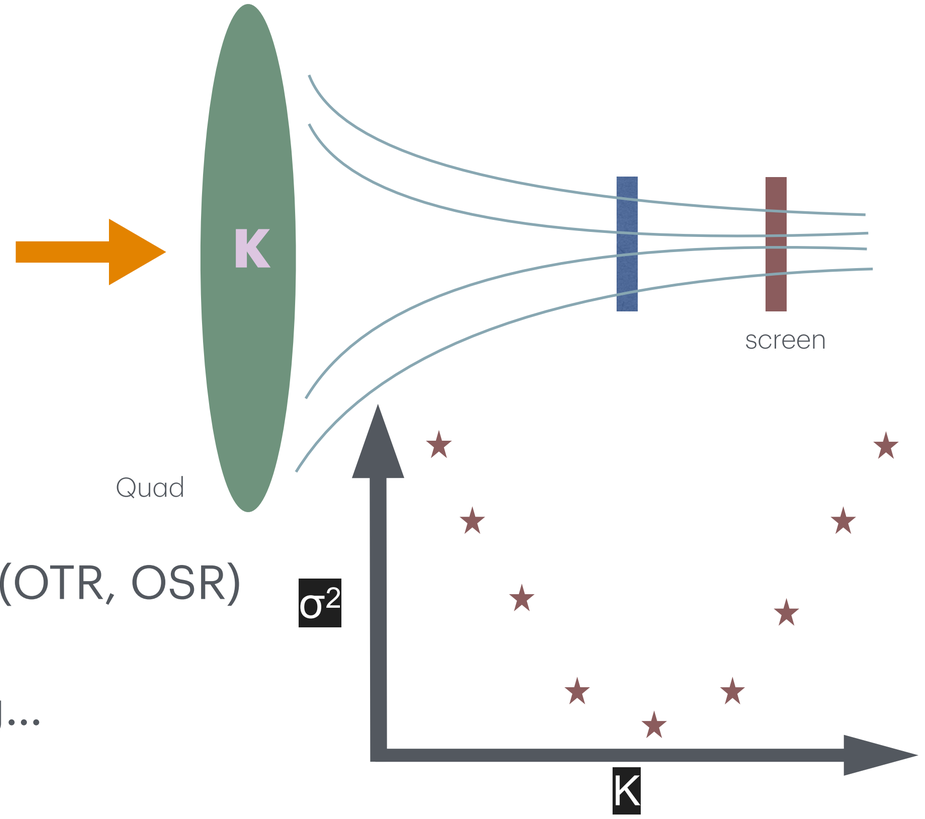

- Lower energy-limitation of Slit/pinhole scans & pepper-pot
  —> Possible solution: Optical version

- Non-/minimally invasive optical radiation sources can be used (OTR, OSR)

- Increase in Divergence resol. with energy, Real-time monitoring...

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Emittance measurement

OTR & OSR

- Possible solution: Optical version
  Non- **(OSR)** /minimally invasive **(OTR)** optical radiation sources

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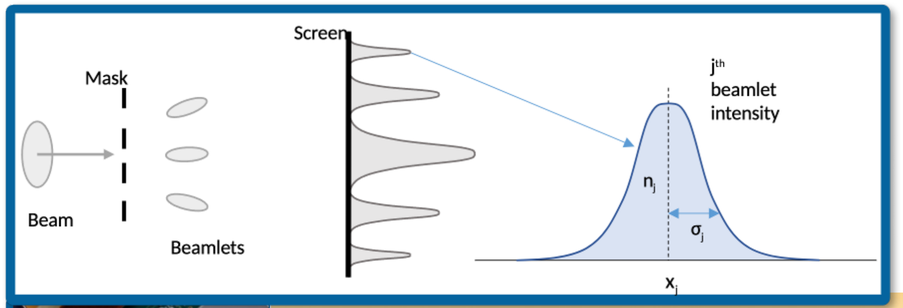

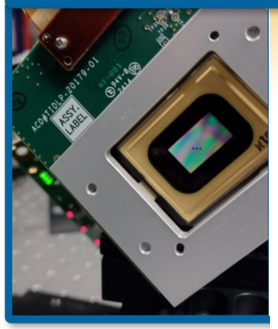

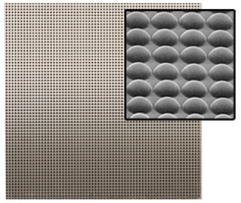

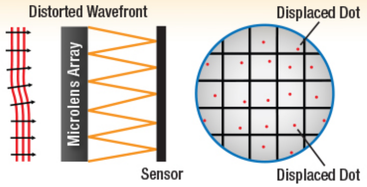

DMD **MLA**

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Emittance measurement

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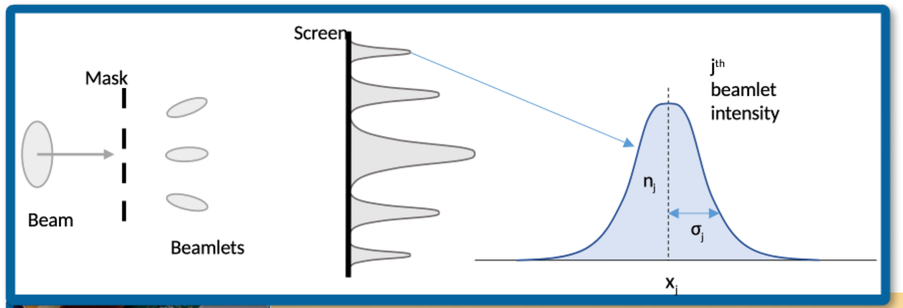

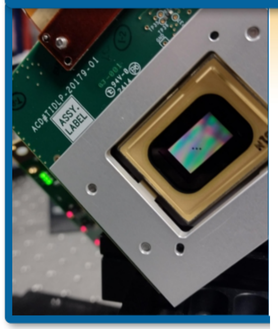

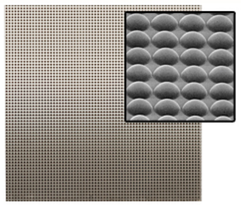

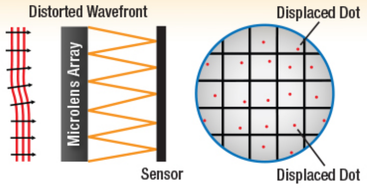

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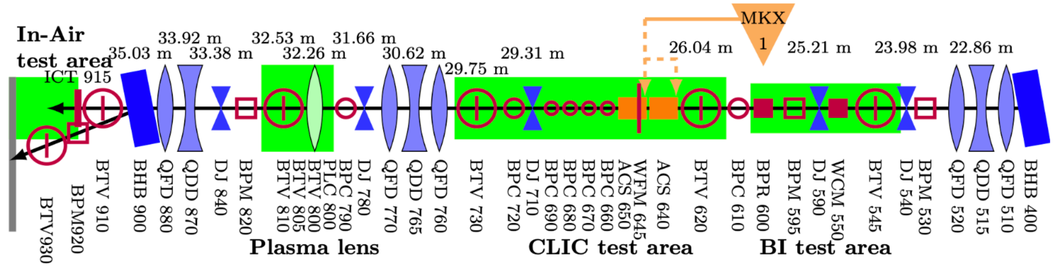

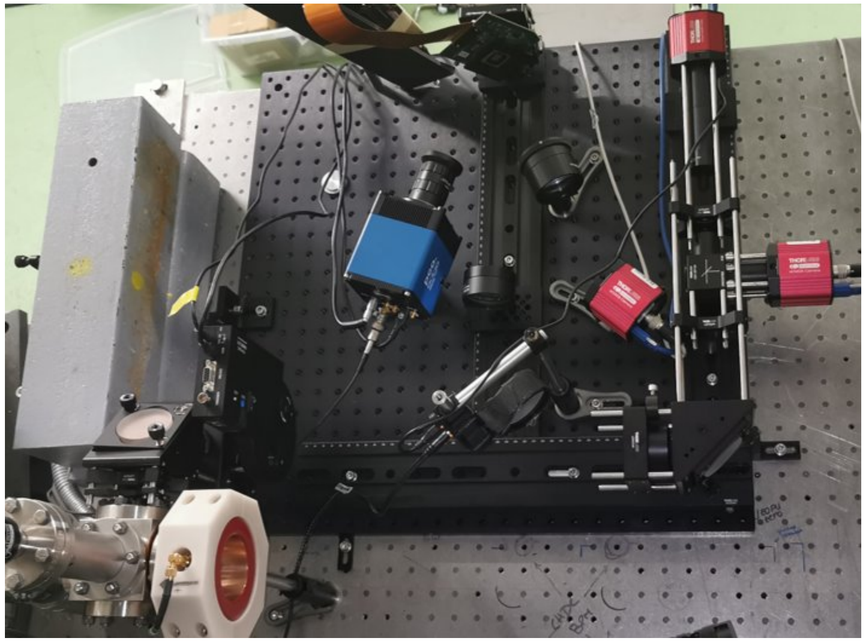

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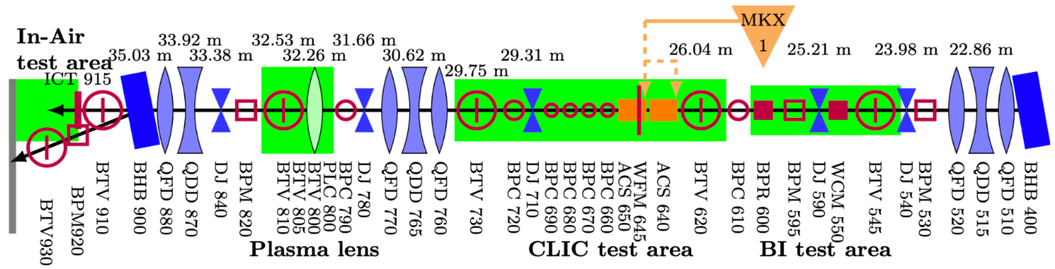
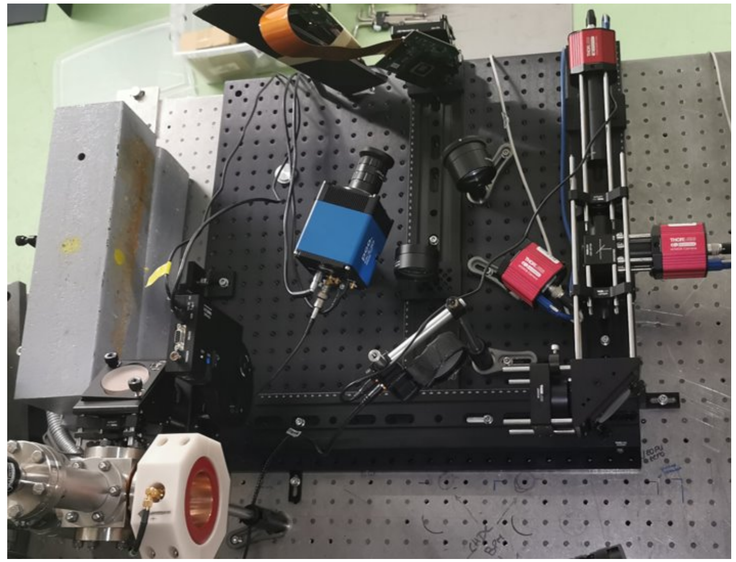


CLEAR beam parameters

Parameters	Values
E (MeV)	200 ± 1
Q (nC)	0.1-2
ε_x (mm.mrad)	15.6 ± 2.6
ε_y (mm.mrad)	4.2 ± 0.7



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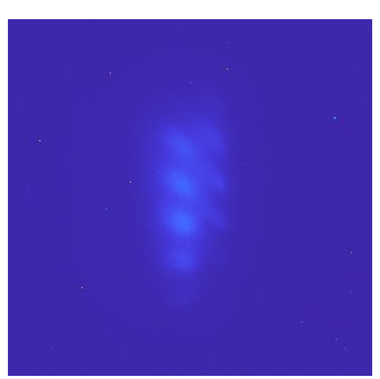
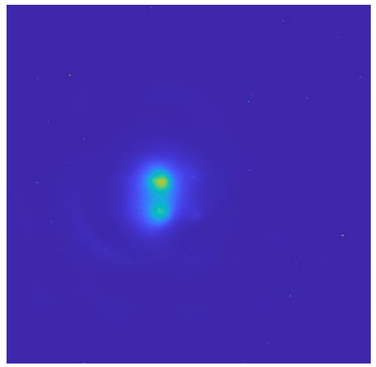
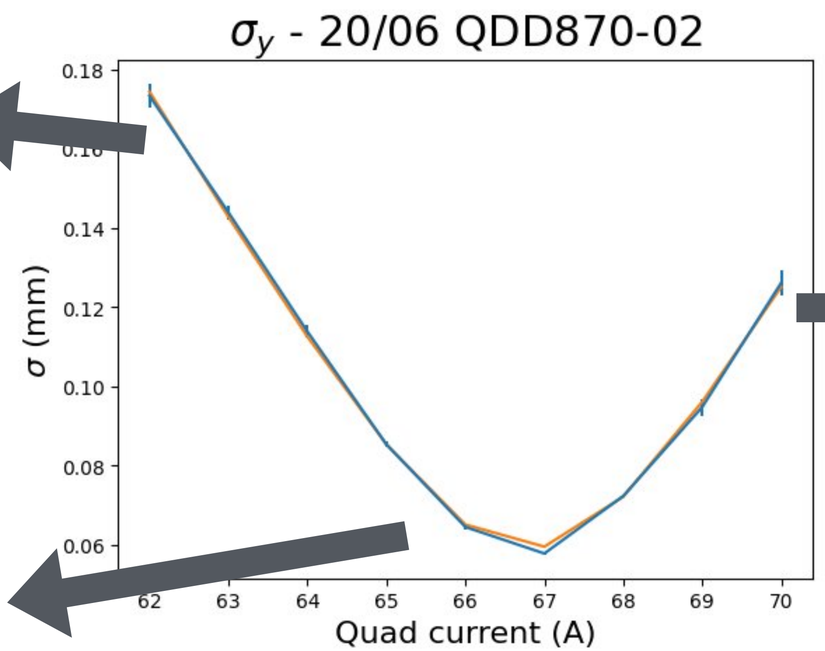
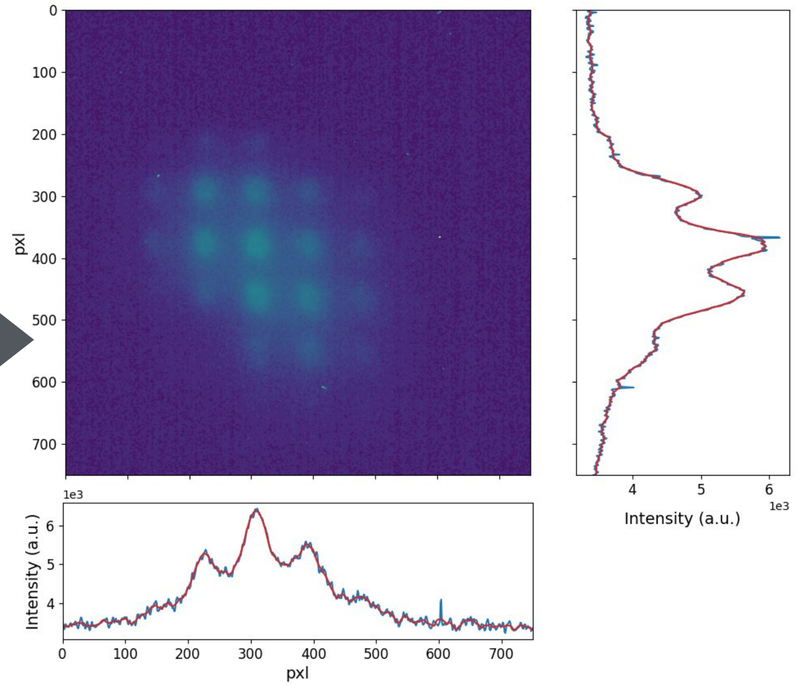
OTR Sim/Analysis

Bunch-by-Bunch Emittance









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OTR Analysis

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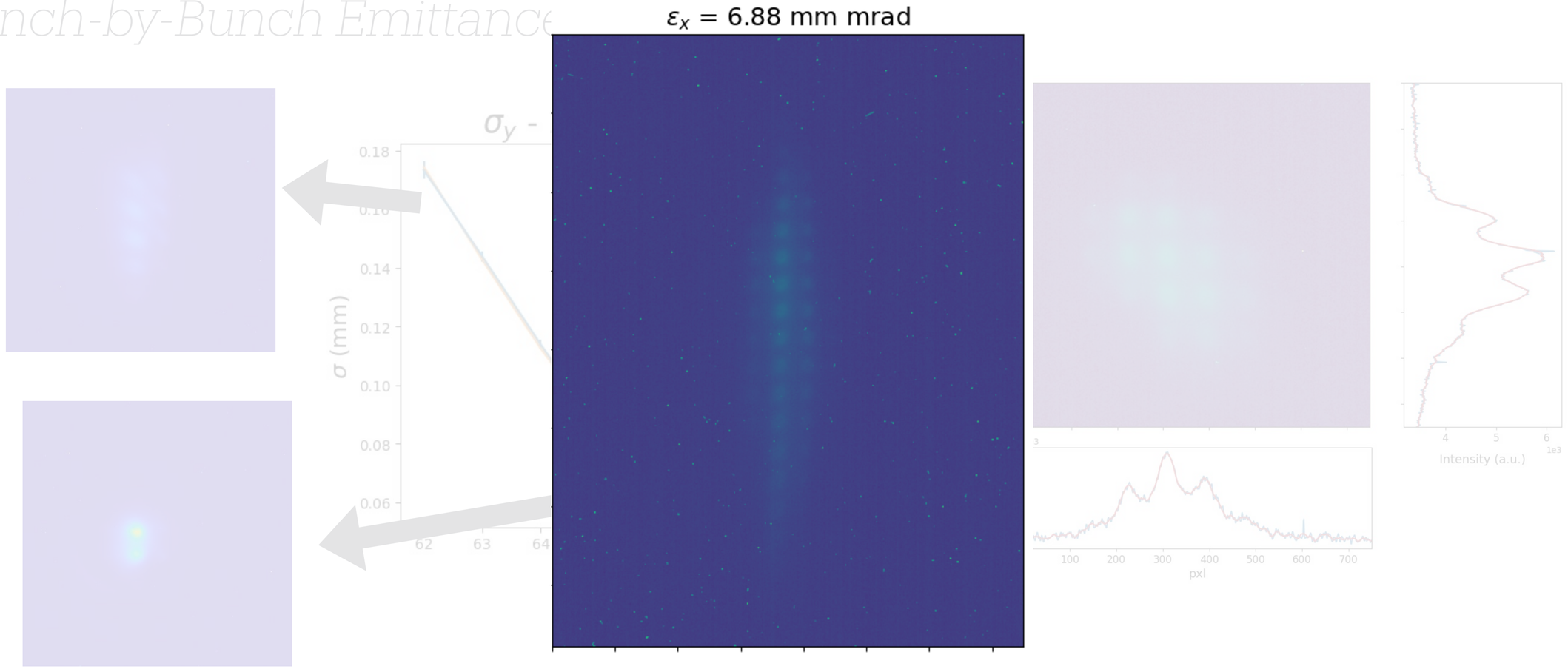

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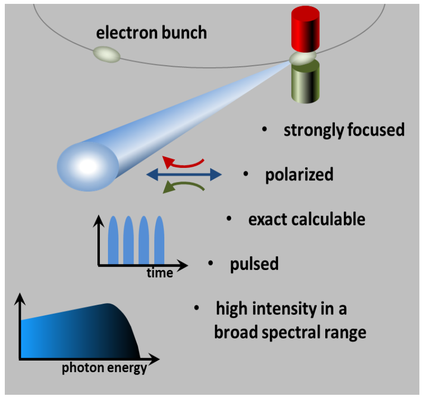
OSR for facilities like- CLEAR, AWAKE etc.

Potentials over OTR (Why SR/OSR can be the Game-Changer)



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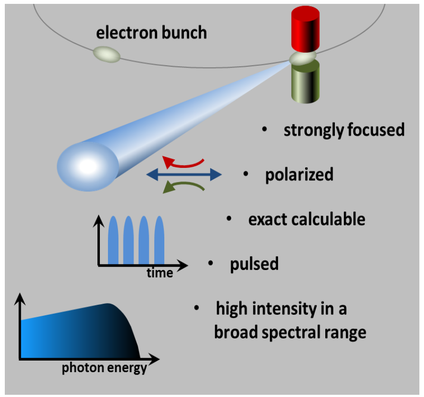
OSR for facilities like- CLEAR, AWAKE etc.

Potentials over OTR (Why SR/OSR can be the Game-Changer)

- *Key points like:*
  - **Non-invasiveness**
  - Wide spectral range (SR is broadband)
  - Polarization and Angular distribution



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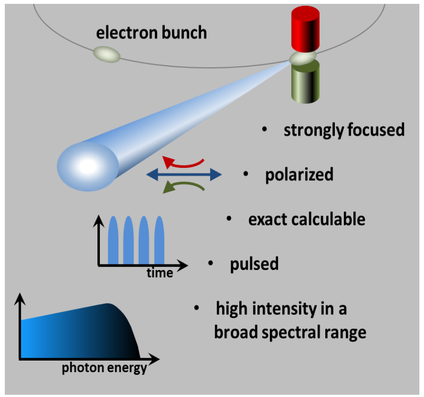

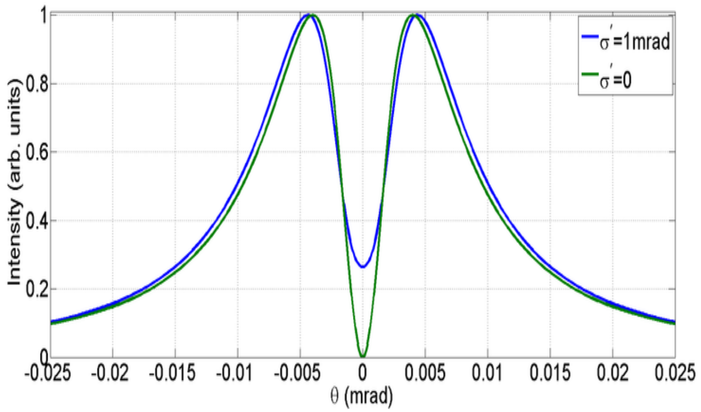

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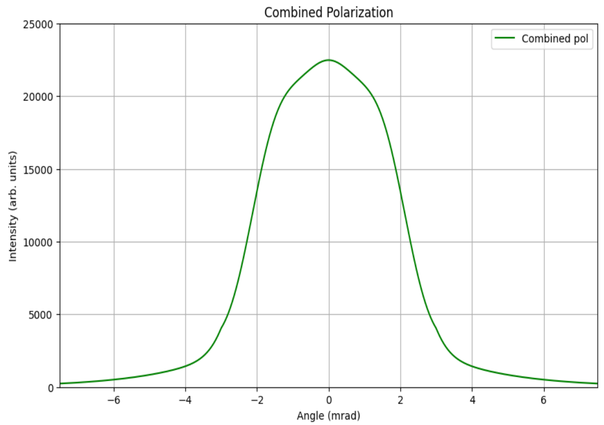

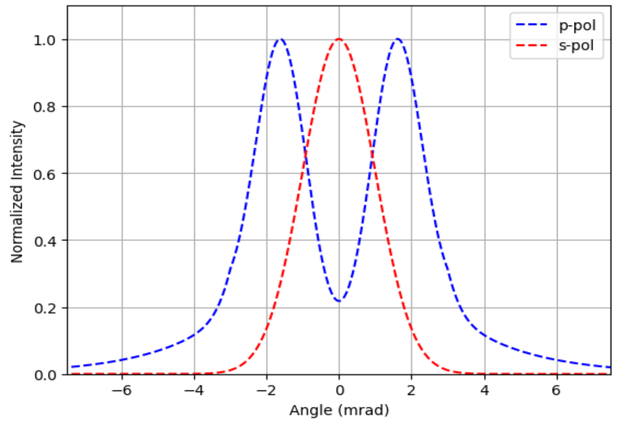

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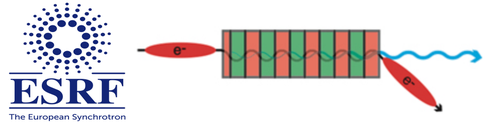
OSR Simulation



Synchrotron Radiation Workshop (SRW) & Zemax

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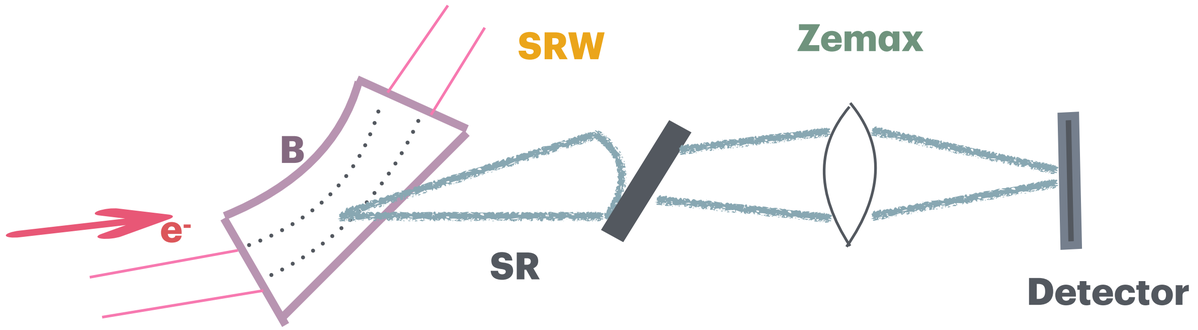
OSR Simulation

SRW & Zemax

https://github.com/ochubar/SRW

- **SRW** is a comprehensive software toolkit developed *(by O. Chubar & P. Elleaume, @ESRF)* for simulating the emission, propagation, and interaction of SR with materials.
  Fast computation of SR emitted by relativistic electrons in mag. field of arb. configuration
- SR **wavefront propagation**
- Simulation of experiments involving SR
- Python-based API
- Accurate **Field computation**



- **Zemax** is used to simulate the optical path for OSR collection and imaging
- Helpful with **ray tracing**, **PoP** and **spot size analysis**

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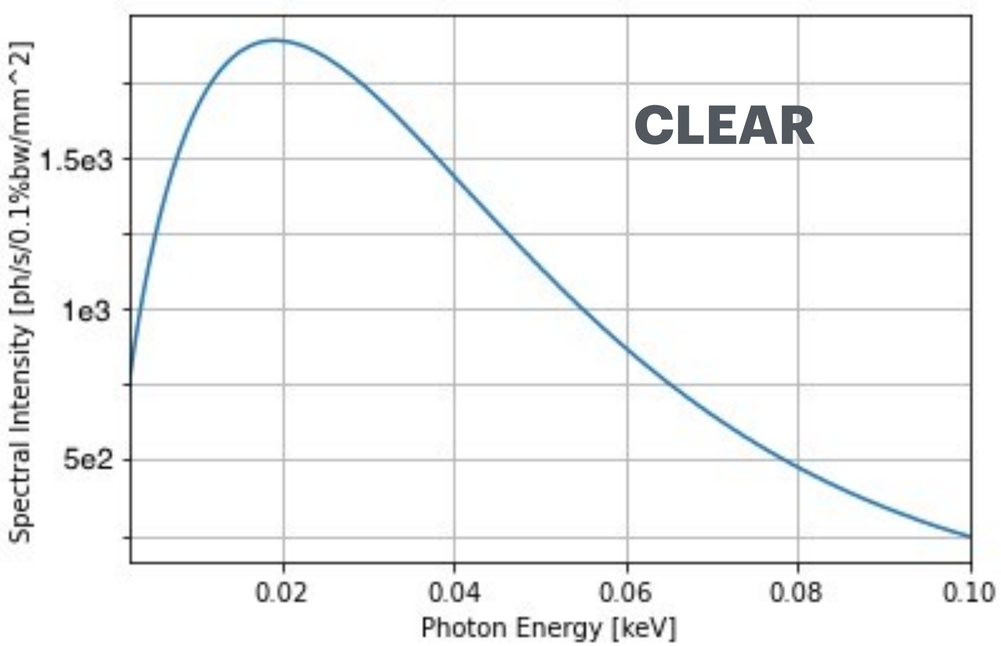
OSR Simulation

SR Spectral Intensity plot (Bandwidth feasibility): CLEAR Vs AWAKE



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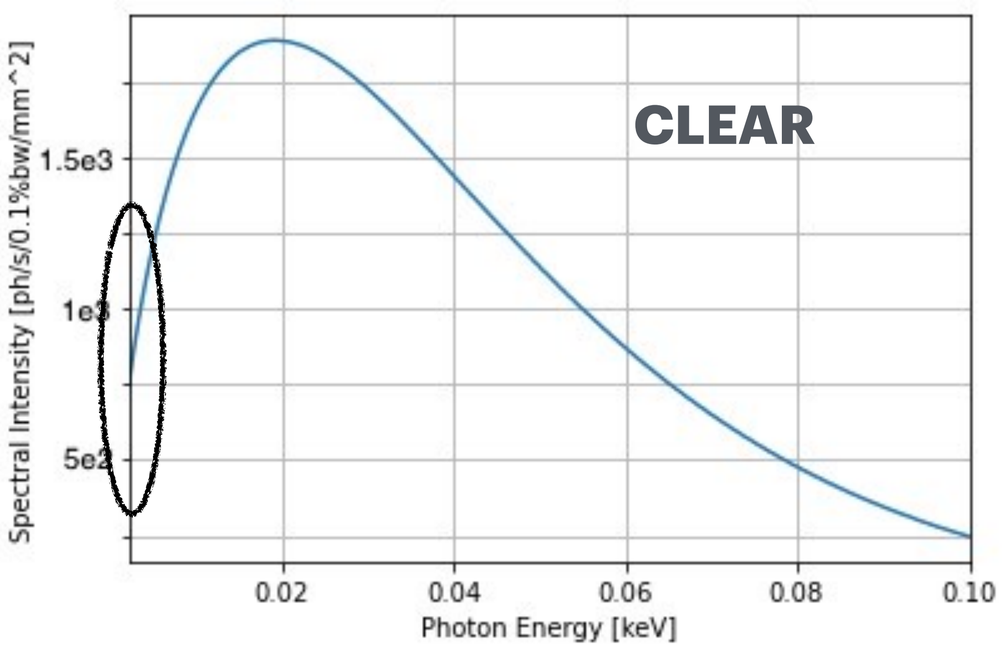

Visible spectrum of interested bandwidth

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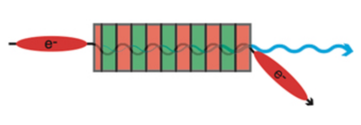
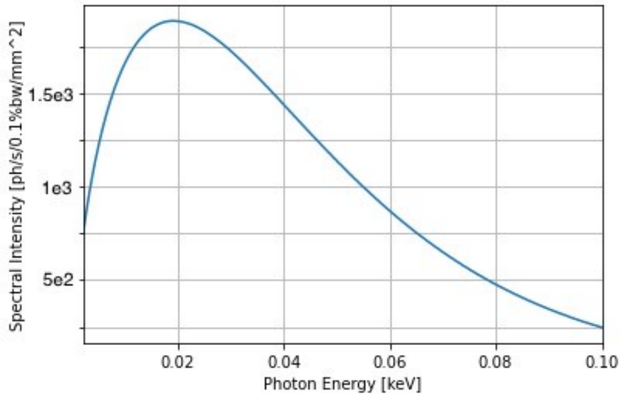
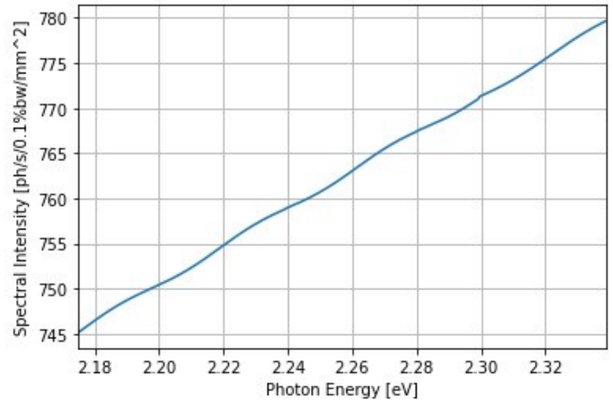
OSR Simulation



SR Spectral Intensity plot (Bandwidth feasibility): CLEAR Vs AWAKE



CLEAR



Visible spectrum of
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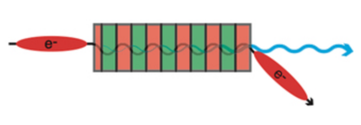
OSR Simulation



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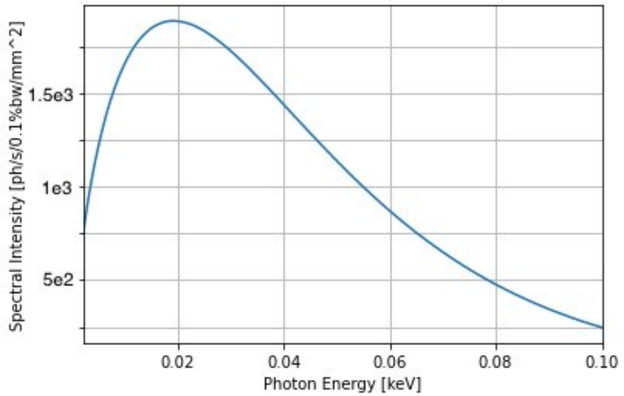
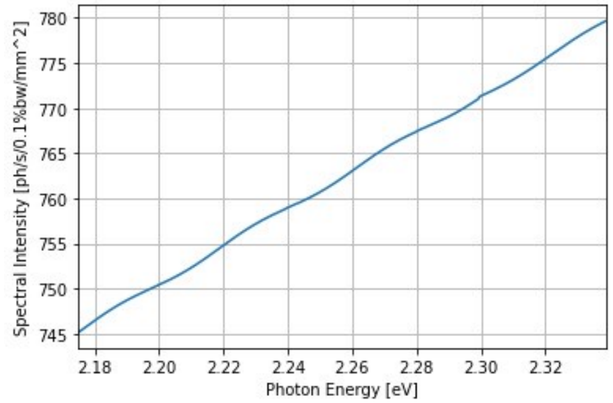
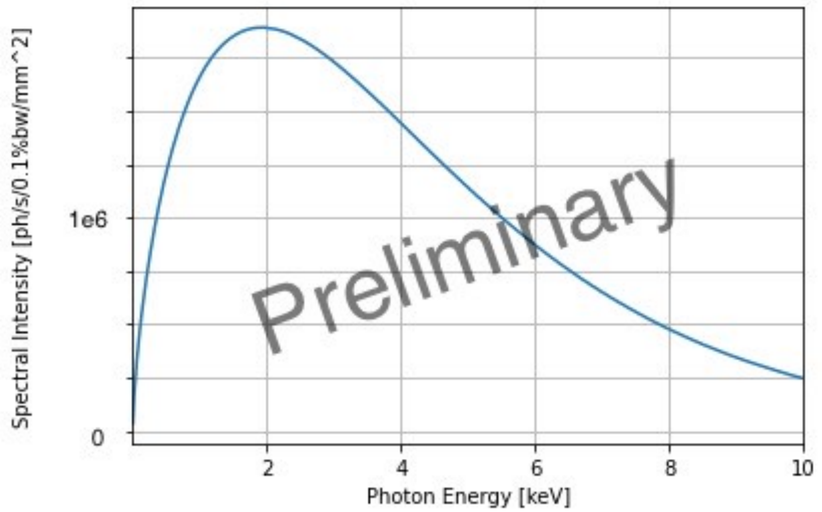


CLEAR



Visible spectrum for beam profile and position diagnostics

AWAKE



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OSR Simulation

SR Intensity CLEAR Vs AWAKE & Extraction options

CLEAR

AWAKE

Extraction	Pros	Cons
On-Axis	less dispersion expected, Easier alignment	extract radiation with mirror with a hole/ half surface (halo effect)
Off-Axis	Not much trouble from proton beam	modification in the dipole, extra dispersion, OSR intensity...

Current and Next goal:

Benchmarking sim and to be tested at CLEAR —> follow the sim studies for the case of AWAKE (location of OSR extraction and how well emittance can be measured)

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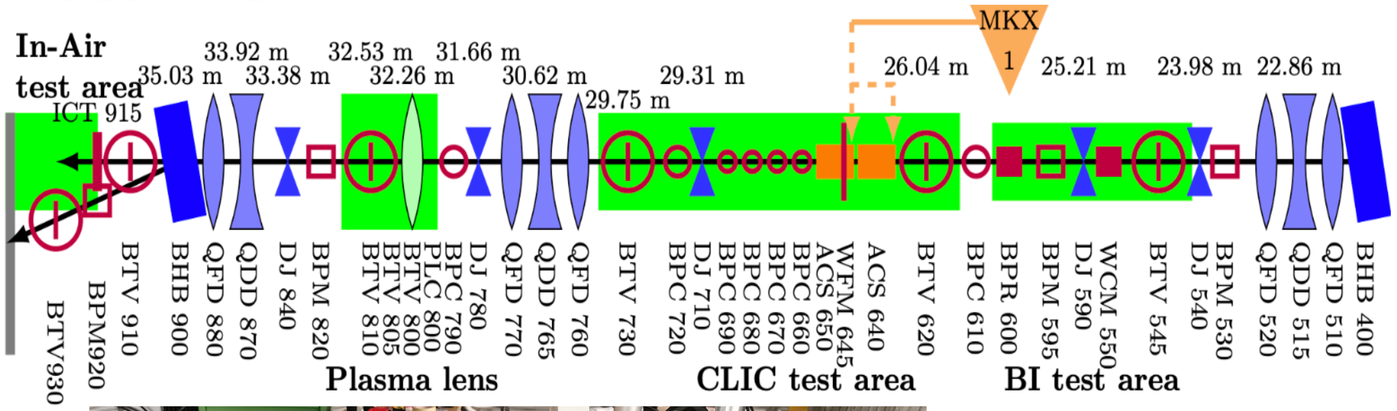
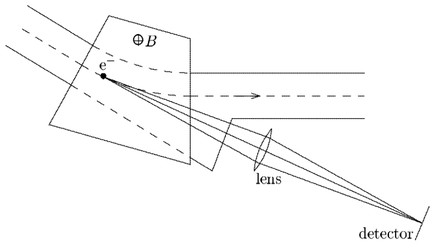
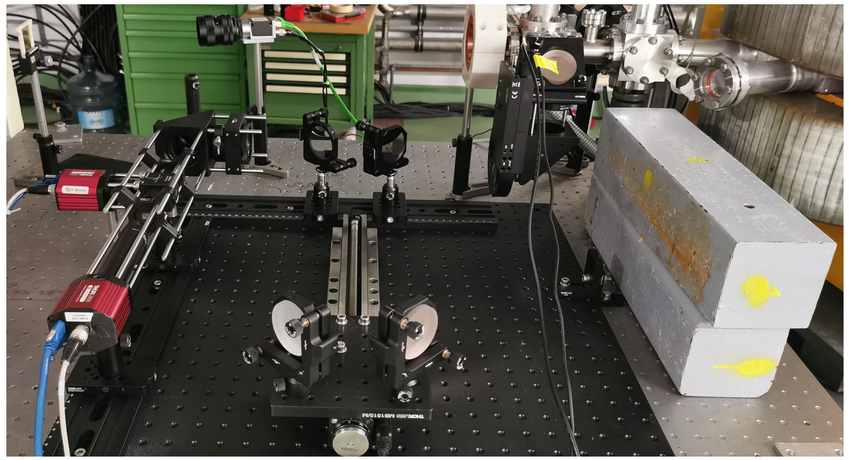
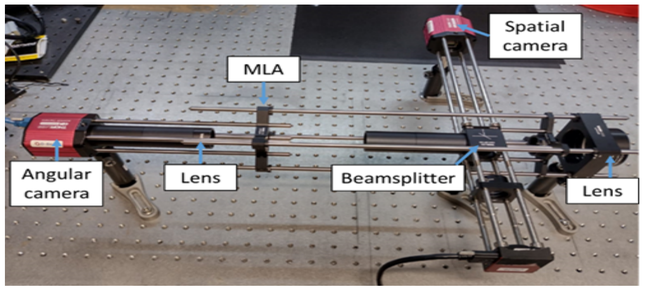
Emittance measurement Plan

with OSR









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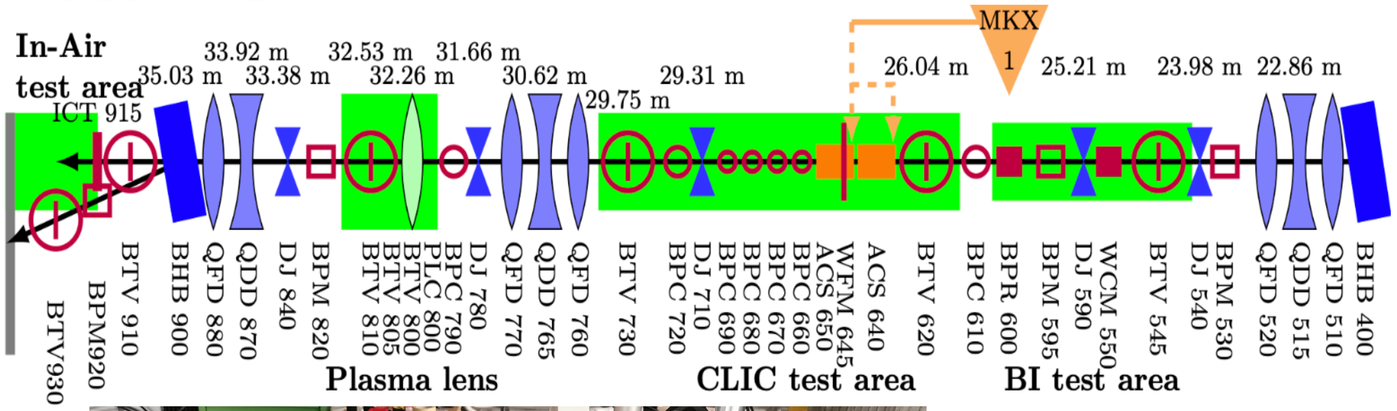
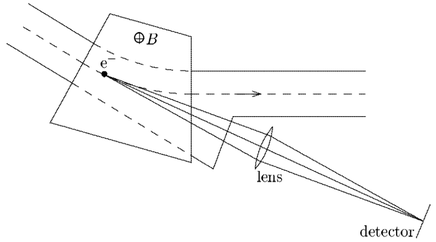
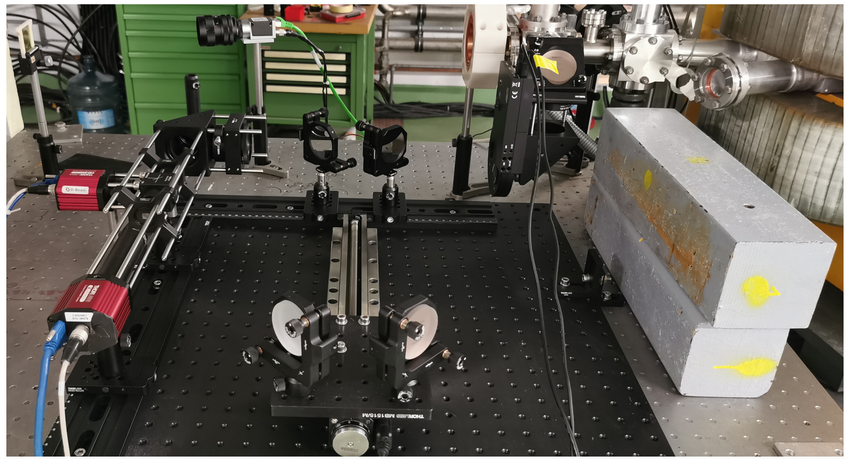
Emittance measurement Plan

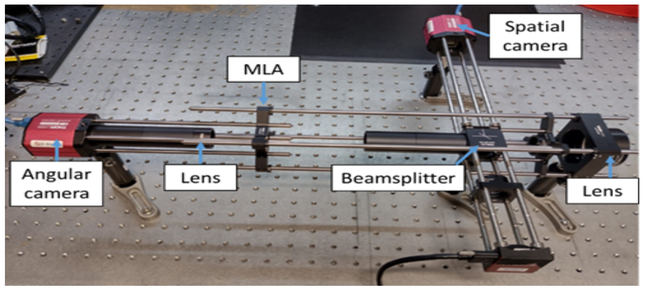
with OSR

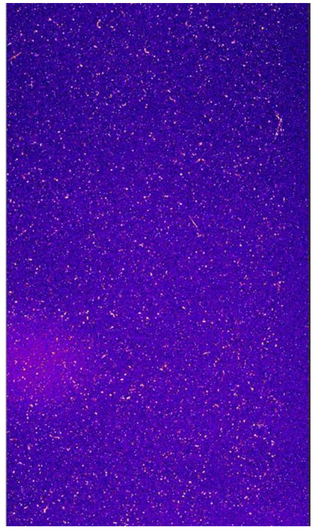






Summer Beam time, 2024





Optimised OSR system (MLA)
Beam time @CLEAR 1st week of Dec.

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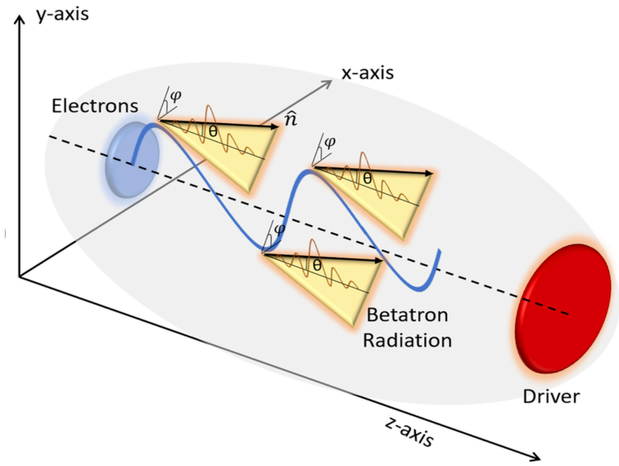
Betatron Radiation

Relevance…



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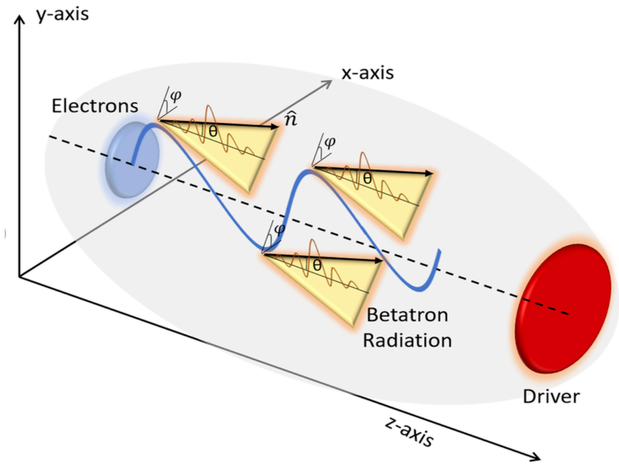
Betatron Radiation

Relevance…

- A form of SR emitted by relativistic charged particles due to their transverse oscillation in a plasma wakefield case.
- BR —> a promising non-invasive means to reconstruct beam parameters (energy, emittance, and divergence)

Diagnostic Regimes…	BR
Diagnostic Wavelength:	X-ray/gamma-ray (sub-micron)
Diagnostics:	Beam emittance, divergence, and beam size (suited for high-energy beams)
Limitations/Advantages:	Less sensitive to beamline obstructions due to X-ray penetrability; BR's higher energy spectrum allows diagnostics of small emittances and beamspot sizes



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Betatron Radiation

BR diagnostics & simulation

- Possibly best-suited candidates for the X-ray detectors depending on **energy & time resolution**, **sensitivity**, **durability**, **efficiency** etc. -

- → *as a next step, extend that test to AWAKE case*

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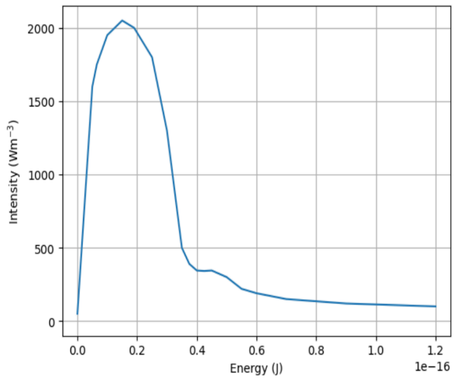
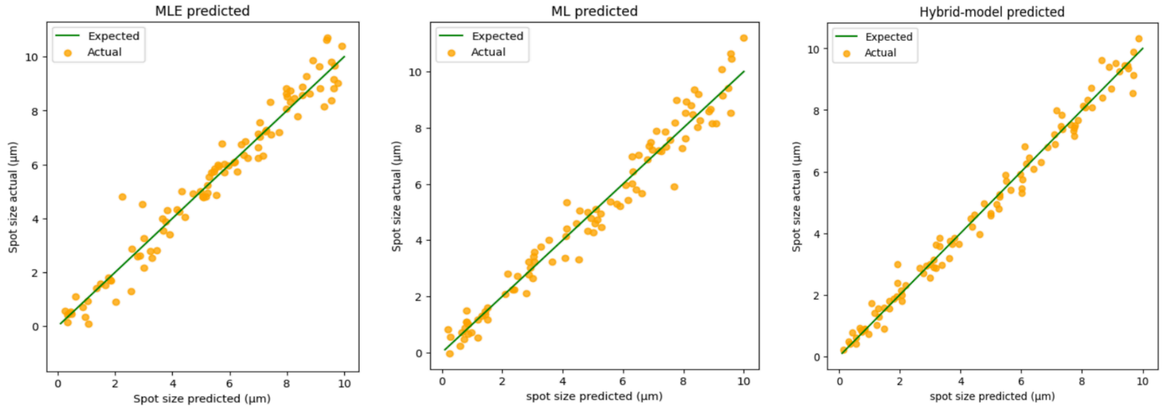
Betatron Radiation

BR diagnostics & simulation

- Possibly best-suited candidates for the X-ray detectors depending on **energy & time resolution**, **sensitivity**, **durability**, **efficiency** etc. -

- **PIC** (PywarpX) modelling tested with Wakefield-like params —> BR spectra —> extract info on spot sizes with 3 diff. approaches





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Background & Radiation Dose

Things to be considered for AWAKE…

- co-propagating proton bunch and the secondary particles generated by interactions between the proton beam and materials, e.g. plasma or any obstacles. **This background can interfere with X-ray diagnostics since protons and secondary particles might hit the detector**.
  - *Magnetic Separation of Protons and X-rays (?)*
  - *Filtering and Shielding*
  - *Diff. Extraction options*

Radiation dose:
value ~ 10^{-16} Gy for a single event.
Now total radiation dose received per unit time - depends on the proton beam intensity
Considering the proton beam intensity for AWAKE, the overall dose rate: ~ 10^{-5} Gy per sec,
and let's say over a 1 hour of period ~ **10^{-2} Gy**.

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Longitudinal Bunch Profile

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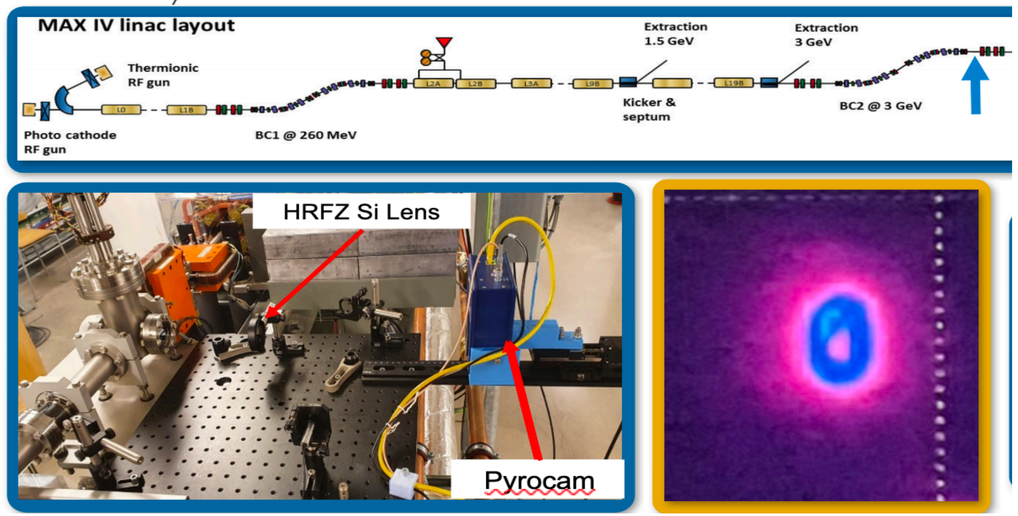
Longitudinal Bunch Profile

Longitudinal beam prop. —> pivotal for efficiency of novel accelerators

$$\frac{d\,I^{i}_{bunch}}{dr} \approx N_e^2 \int_{\Delta\omega} \frac{d^2 I^{i}_{e}}{d\,\omega\,dr} \left| F_z(\rho(z),\omega) \right|^2 d\,\omega$$



MAX-IV short pulse facility

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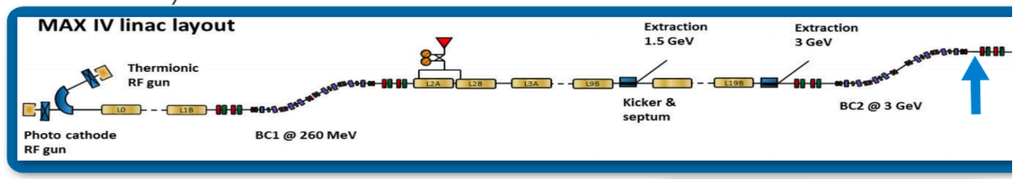
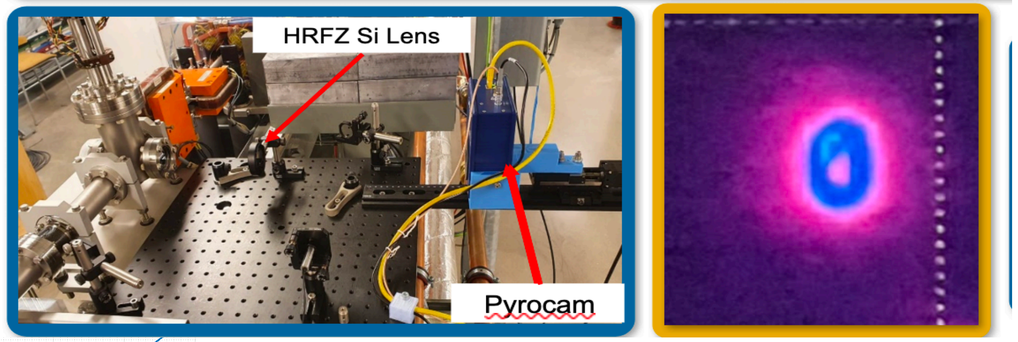
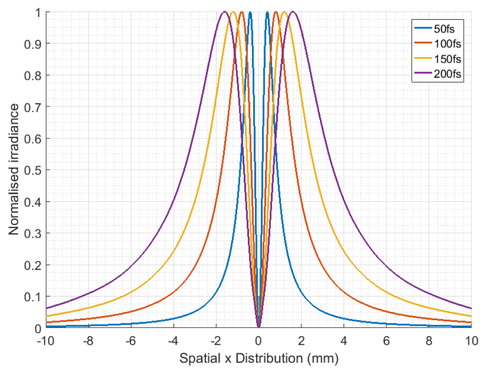
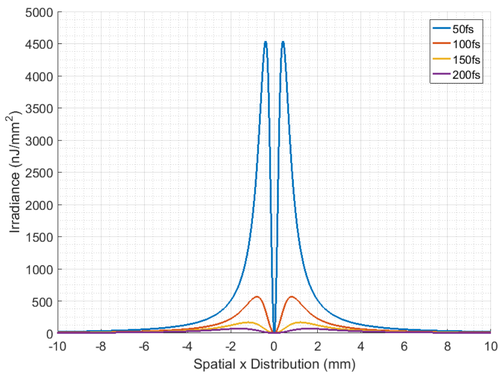
Bunch form factor

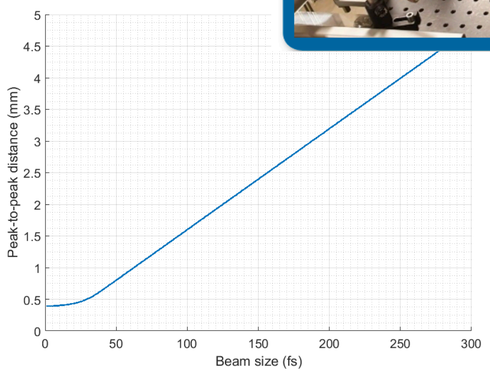




MAX-IV short pulse facility







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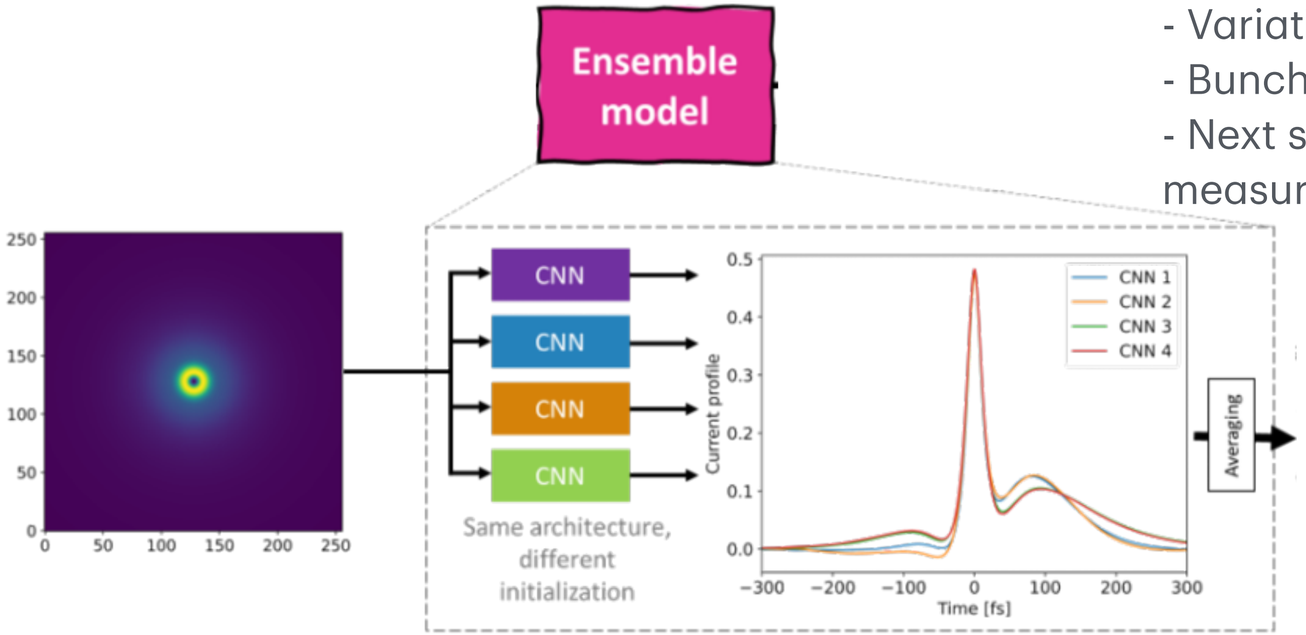
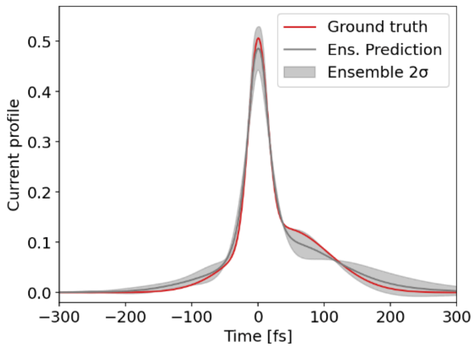
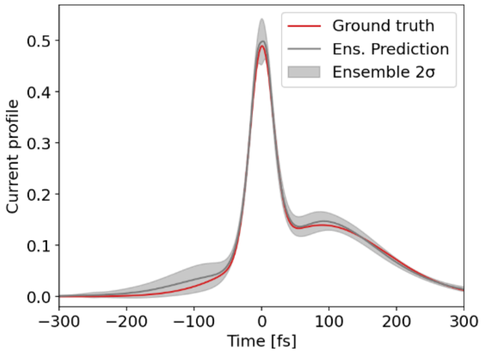
Longitudinal Bunch Profile

ML Analysis (to interrogate the full image)

- ML analysis of 10k simulated CTR images, in order to estimate longitudinal profile
- Variation of toy double Gaussian profile being tested
- Bunch profile prediction with ensemble of 4 CNNs
- Next step: sim. of bunch profiles with Elegant/PIC, new measurement (next year @MAX-IV)







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To Wrap up!

Conclusions and Next Steps…

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To Wrap up!

Conclusions and Next Steps…

- **OTR:-**
  - accuracy and uncertainty in resolution with variation in illuminated lenslet numbers (quantifying how many lenslet one needs) and how that varies with beam properties
  - Emittance values soon to be obtained (and compare to the quad scan results)

Emittance

- **OSR:-**
  - similar studies for the lenslet
  - Extraction-point identification and quantification (individual pros and cons of on-axis & off-axis)

- **BR:-** handling the high level of bkg and understand the physics process how that would affect the BR

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To Wrap up!

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Emittance

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- **BR:-** handling the high level of bkg and understand the physics process how that would affect the BR

- **CTR:-** integrating simulated bunch profiles
  - Similar things planned for **CSR**
  - Beamtime next year @MAX-IV to test these ideas

Long. Profile

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Thank you!

AWAKE collab meet

CERN

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Back up!

Emittance measurement: Quad Scanning method & its limitations

! **Multiple measurements** (beam stability issue), **Invasiveness**, **Energy spread** (plasma accelerator ~>1%)

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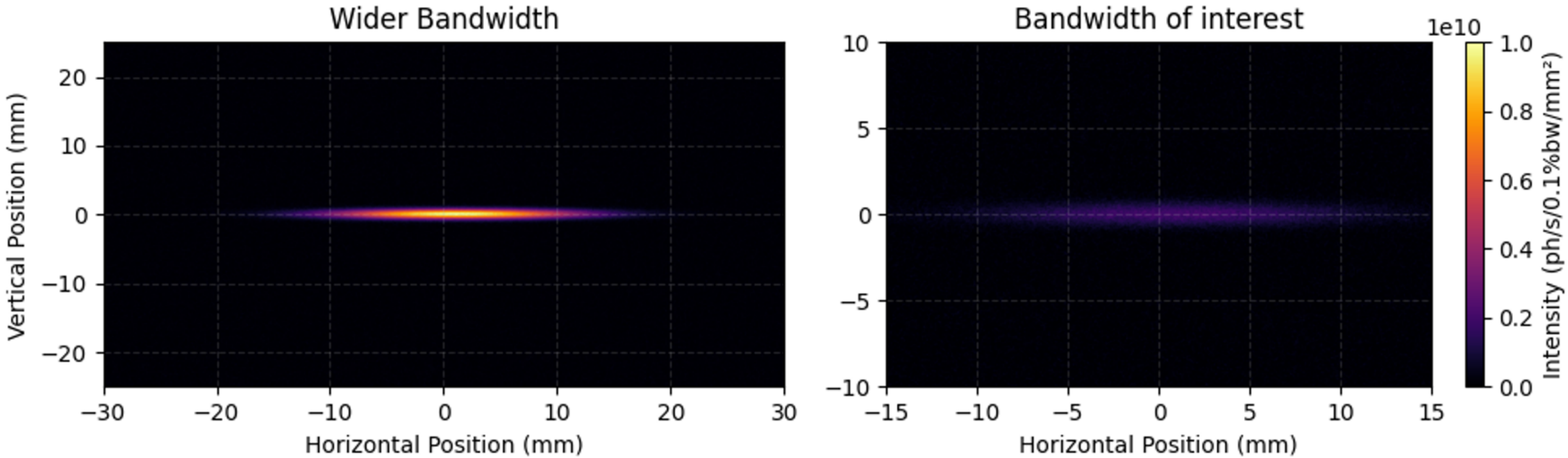
OSR Simulation

2D intensity profile (Wider Vs 540-560nm bandwidth)



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