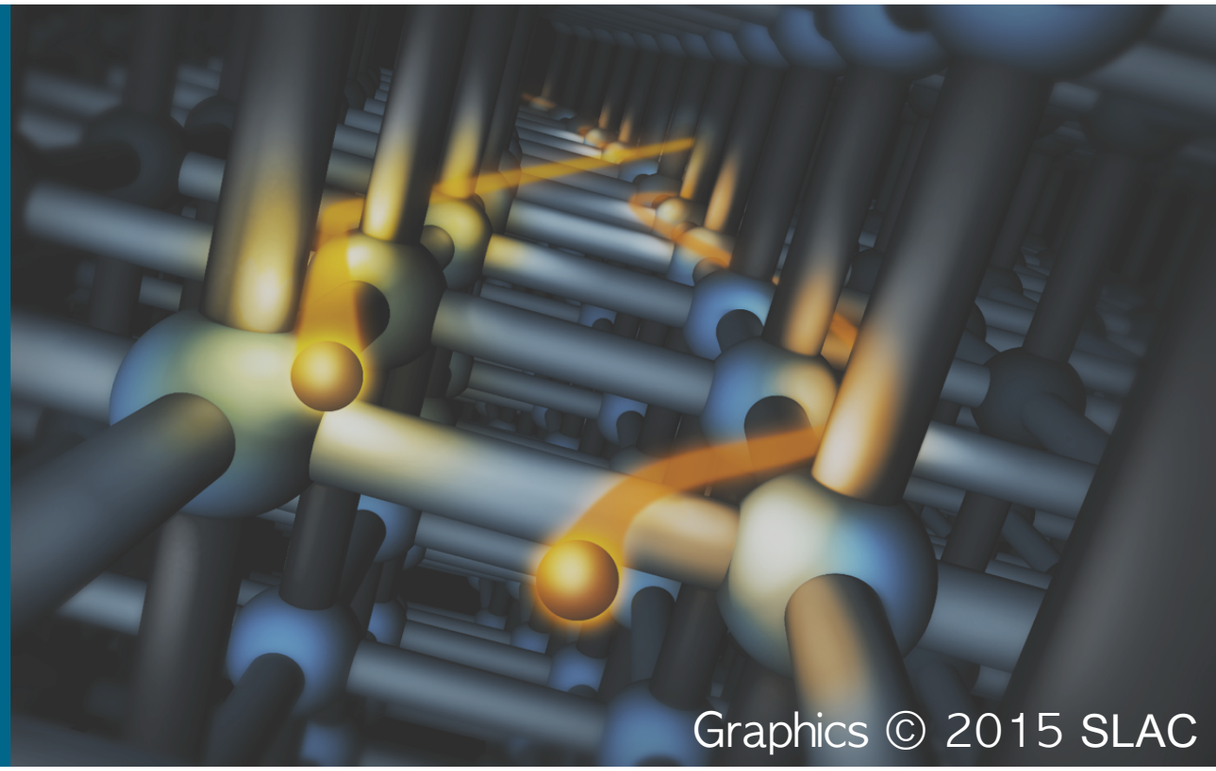
Crystal Experiments at SLAC FACET and ESTB



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Motivation (deflection)

- Bent crystals can deflect high energy beams with small bending radii (O(0.1m))
  - lots of proton data, little data for high-energy e^- or e^+
  - There is interest in crystal collimation for e^+ and e^-
    - Expected benefits in size and efficiency of collimation
    - Not enough data to actually design such a system
    - Possible application to ILC, LCLS-II
  - What channeling efficiency can one expect?
  - How does it scale with beam energy?
  - Can VR be used for beam collimation?

Motivation (radiation)

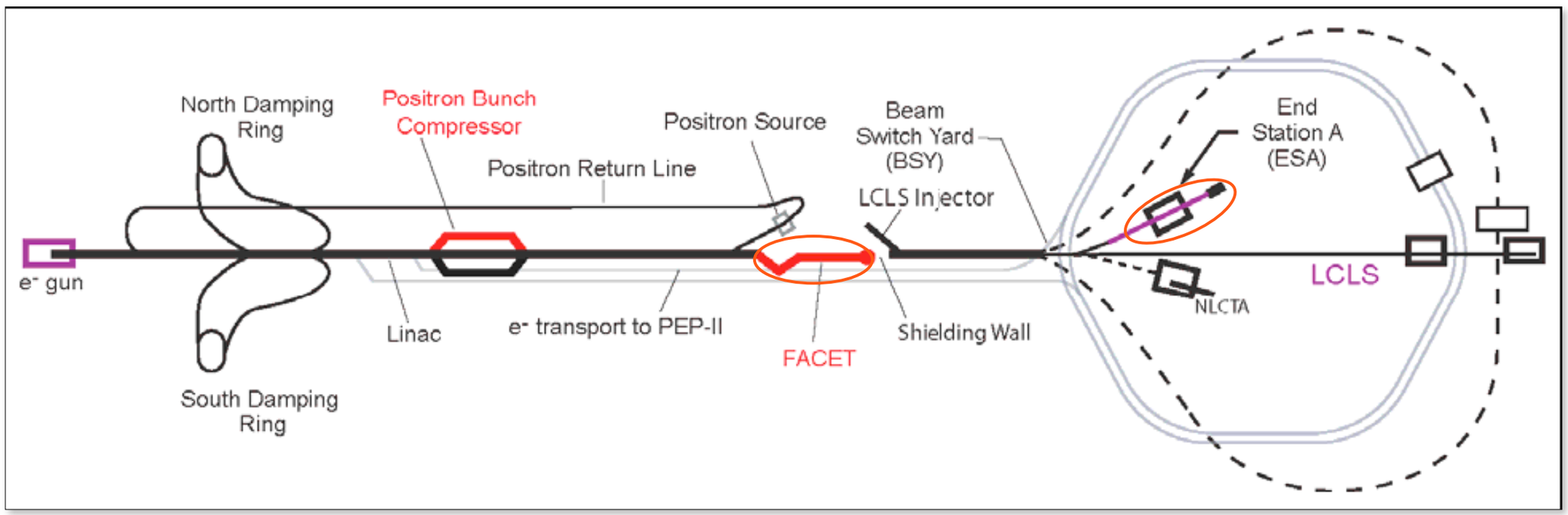
- There is interest in channeling radiation
  - Intense γ ray production, can we demonstrate narrow-band?
  - Use Crystal undulators with e^- ??
  - Can we make use of VR radiation?
- γ rays have applications in materials science and radiography techniques
  - penetrating γ rays can radiograph thick pieces.
  - crystal targets have been used with some success in γ sources for photo-nuclear reactions.
- Can crystal sources become competitive to Compton sources?

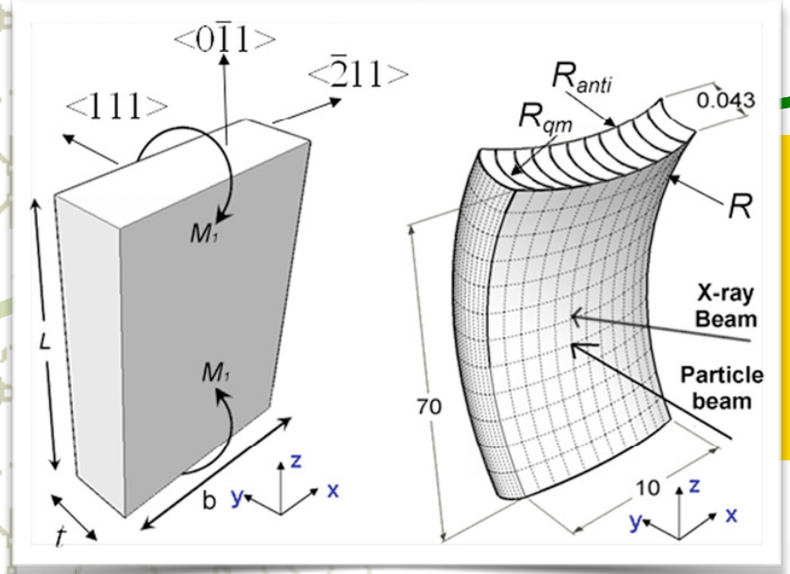
Crystal Experiments at SLAC

- T513 (Wienands et al., ESTB, complete)
  - Channeling and Volume-Reflection Studies of High-Energy Electrons in Crystals
  - SLAC—U Ferrara—U Aarhus—Cal Poly
- E212 (U. Uggerhøj et al., FACET)
  - Radiation from GeV electrons in diamond – with intensities approaching the amplified radiation regime
  - U Aarhus—U Ferrara—SLAC—Cal Poly—CERN—U New Mexico—U Frankfurt—U Mainz—U Amsterdam—U Johannesburg
- T523 (Wienands et al., ESTB)
  - γ-Ray Production Study with Electrons
  - SLAC—U Ferrara—U Aarhus—Cal Poly

FACET and the End Station A Test Beam (ESTB)

- ESTB: up to 15 GeV e^-, 5 Hz, ≤ 200 pC/pulse
  - "pulse stealing" from LCLS
- FACET: 20 GeV e^+ or e^-, 2 nC/pulse, 10 Hz, "20^3 μm^3"
- control of optics, momentum spread
  - both can provide relatively parallel beam (<10 μrad)
  - FACET has a e^- spectrometer downstream; ≈ 0.1% resolution





Main crystal features

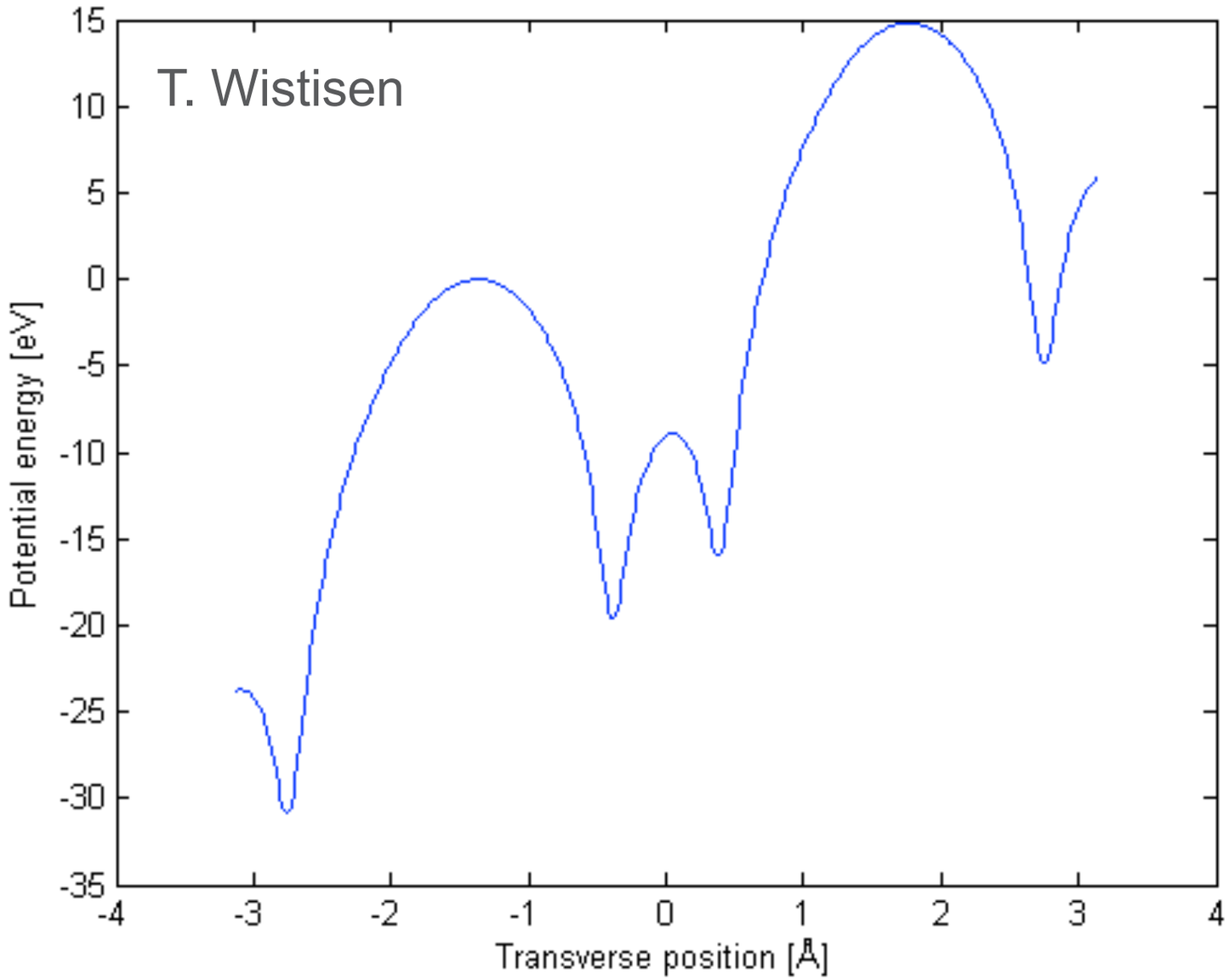
- **Crystal thickness 60±1 μm**
  Once the crystal will be back in Ferrara we will measure crystal thickness with accuracy of a few nm.

- **(111) bent planes (the best planes for channeling of negative particles).**

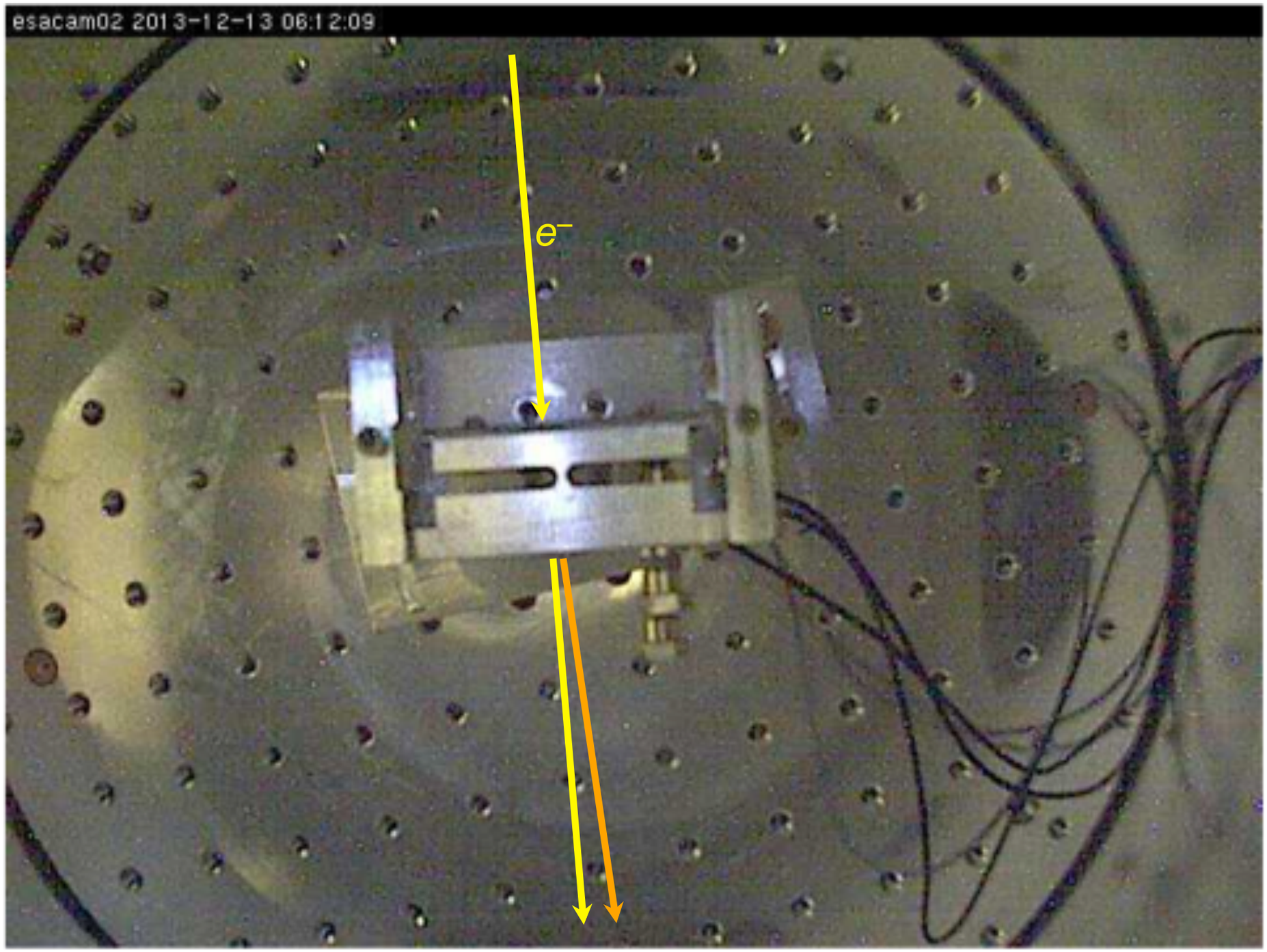
- **Bending angle 402±9 μrad (x-ray measured). If needed I can provide a value with lower uncertainty.**

Si (111) Potential for T513 Crystal (ρ = 0.15 m)

$$\theta_{crit} = \sqrt{2U_0/E} \approx 80\ \mu\text{r} \text{ @ } 6.3\ \text{GeV}$$



Crystal mounted in “Kraken” Chamber in ESA

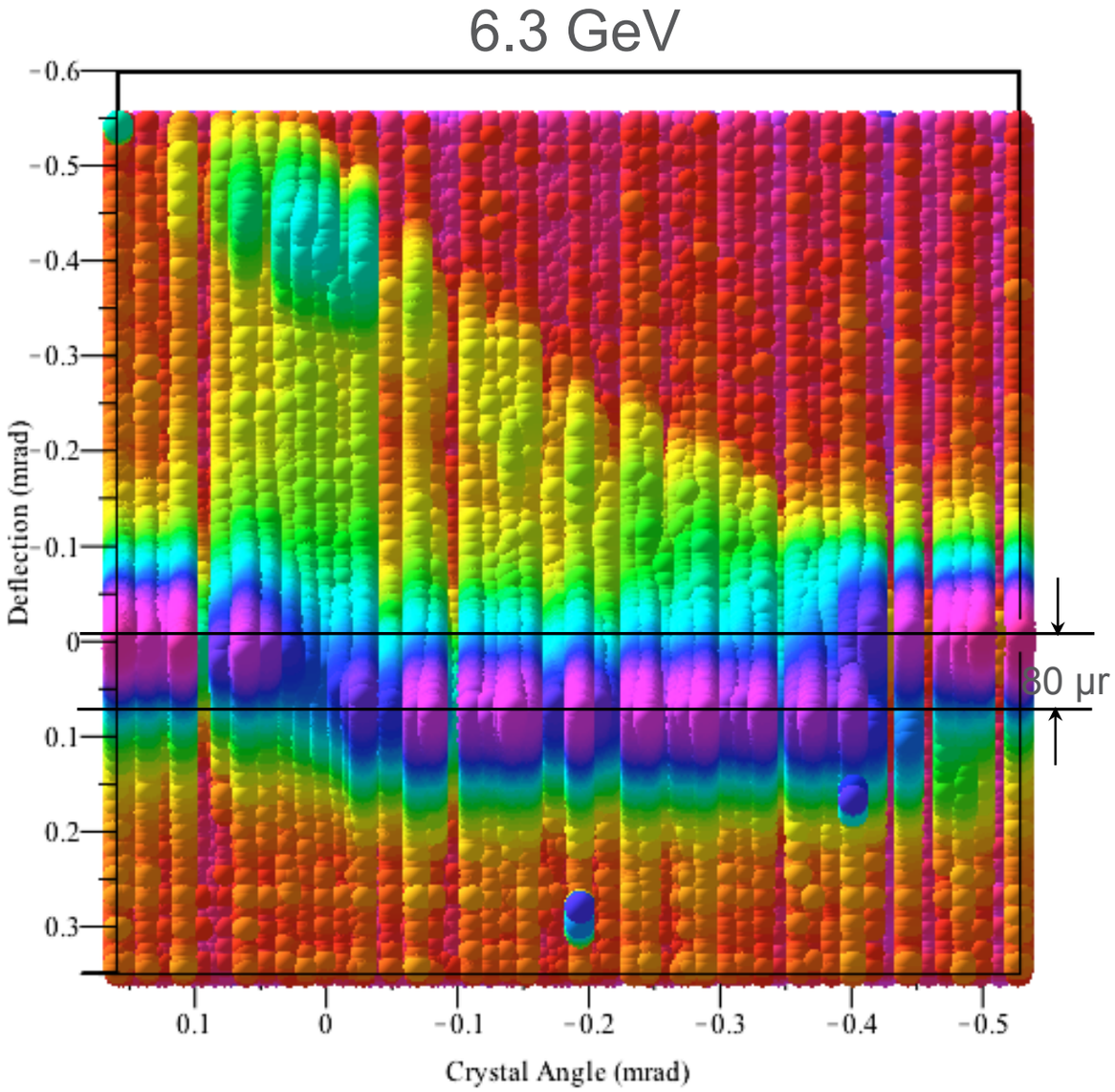


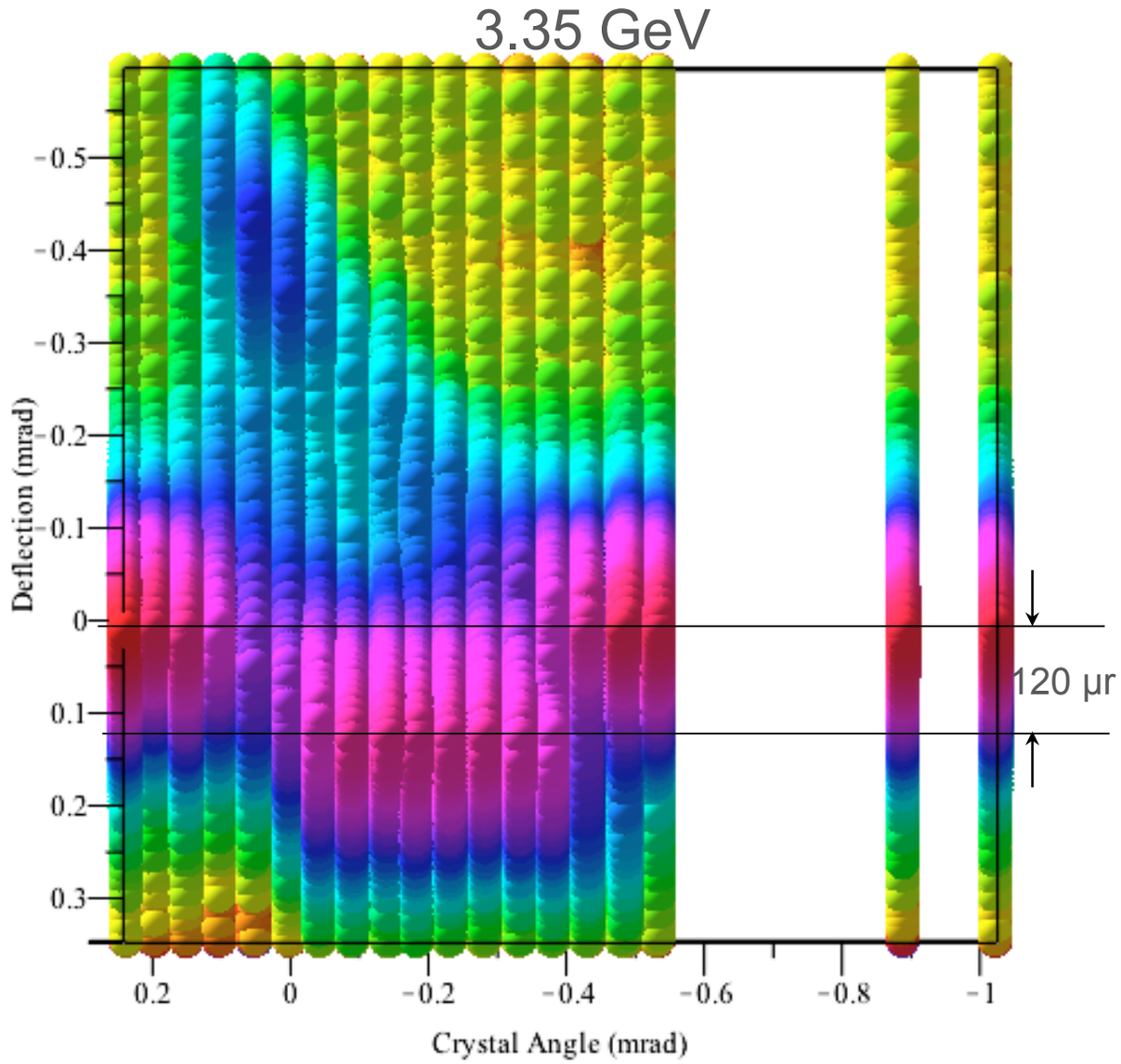
Crystal-Rotation @ 4.2 GeV

(Movie credit: T. Wistisen)

Triangle Plots

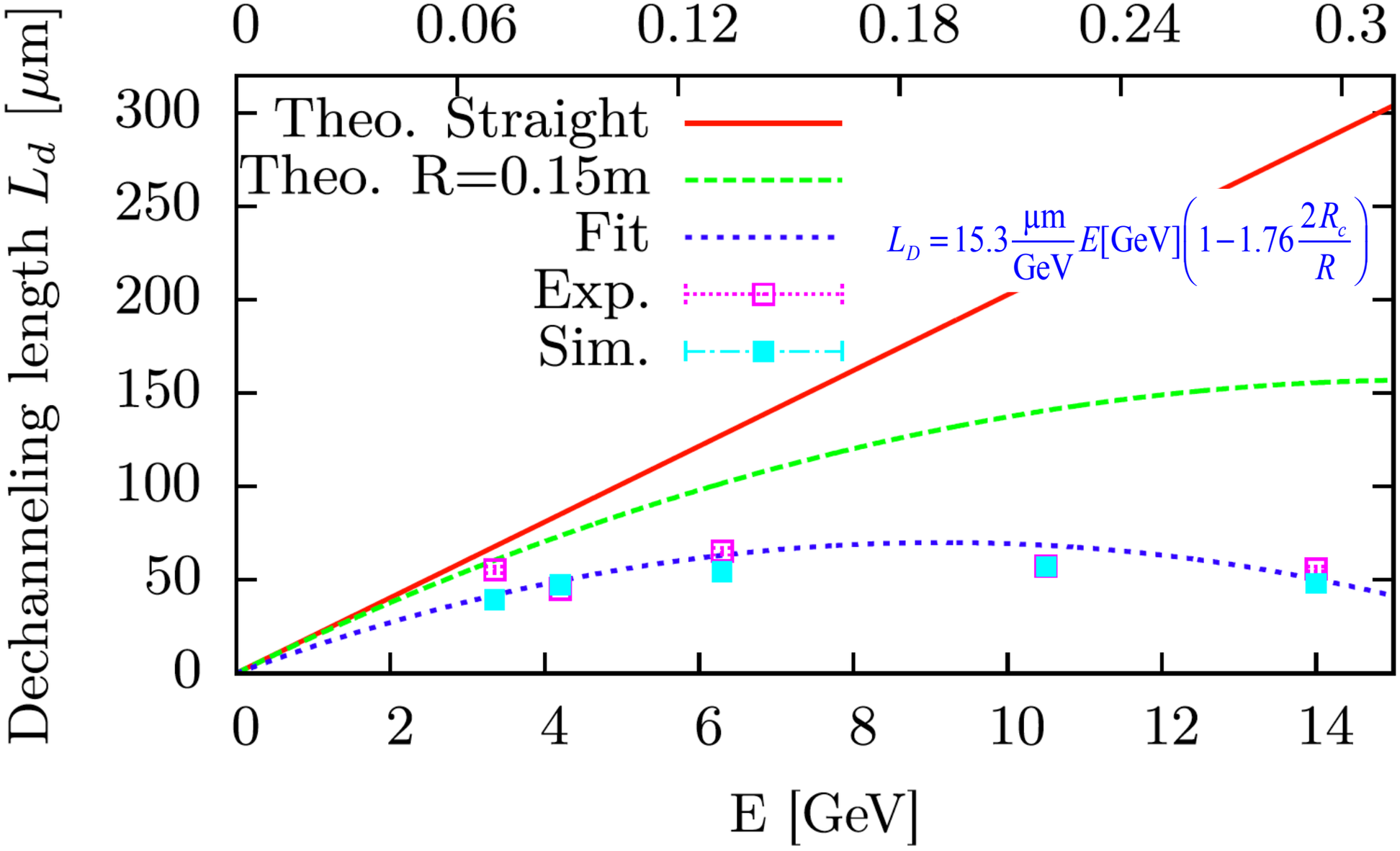
Colors rep. log(intensity).
Crystal angles from fit to laser spot (est'd uncertainty 2…5 μrad)





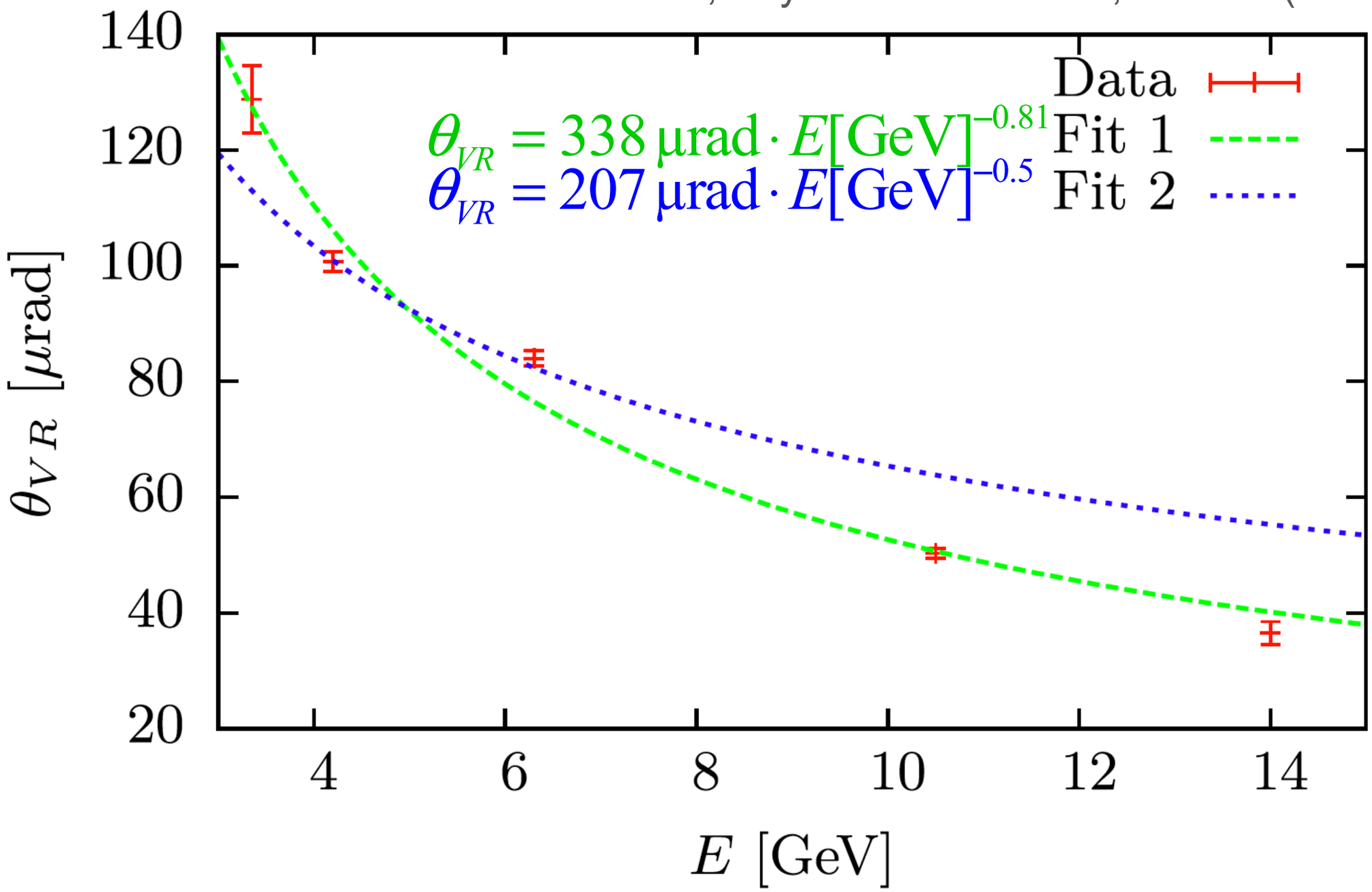
Dechanneling Length of e^-

T.N. Wistisen et al., Phys. Rev. ST-AB 19, 071001 (2016)



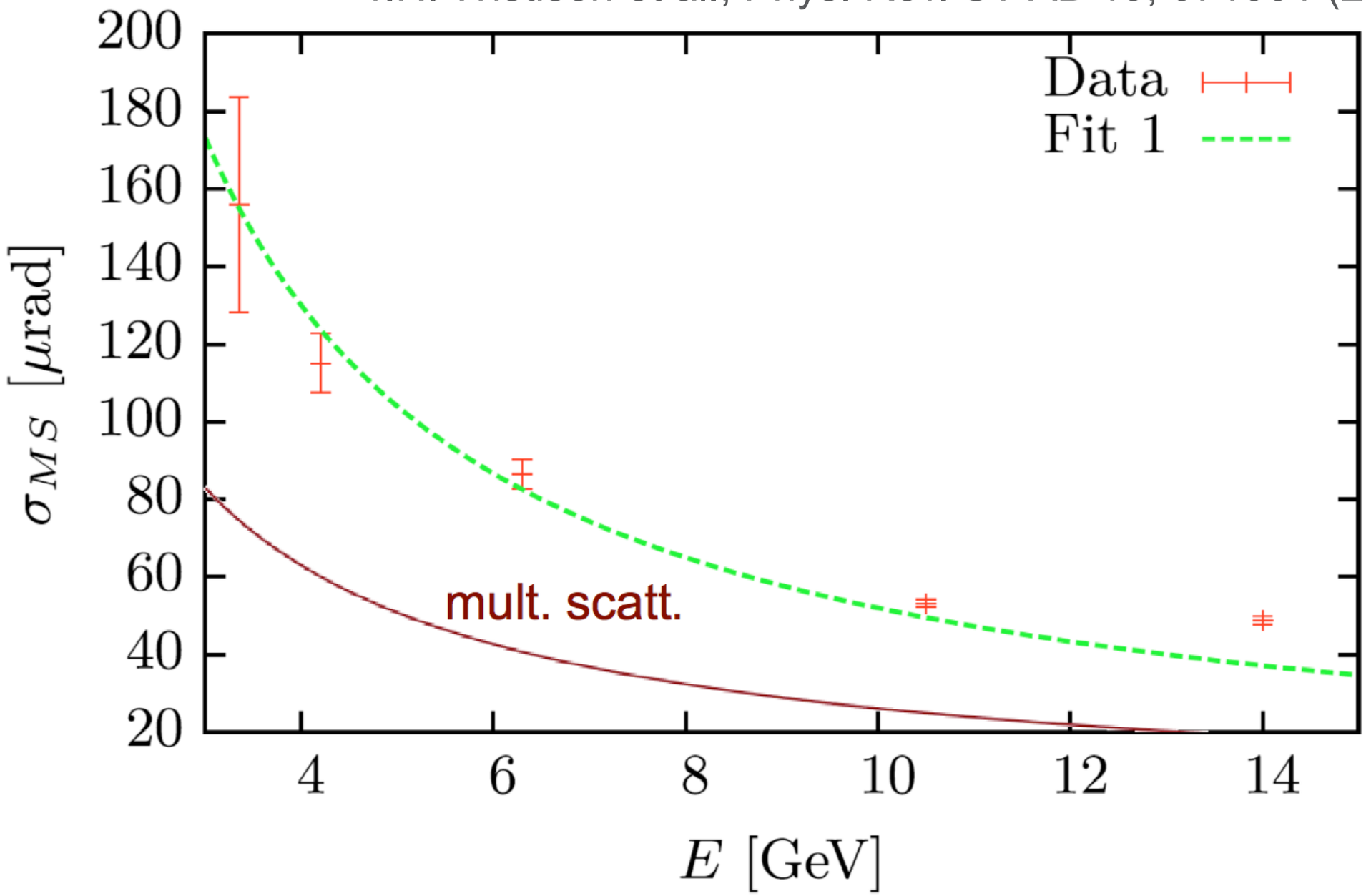
Volume Reflection Angle

T.N. Wistisen et al., Phys. Rev. ST-AB 19, 071001 (2016)



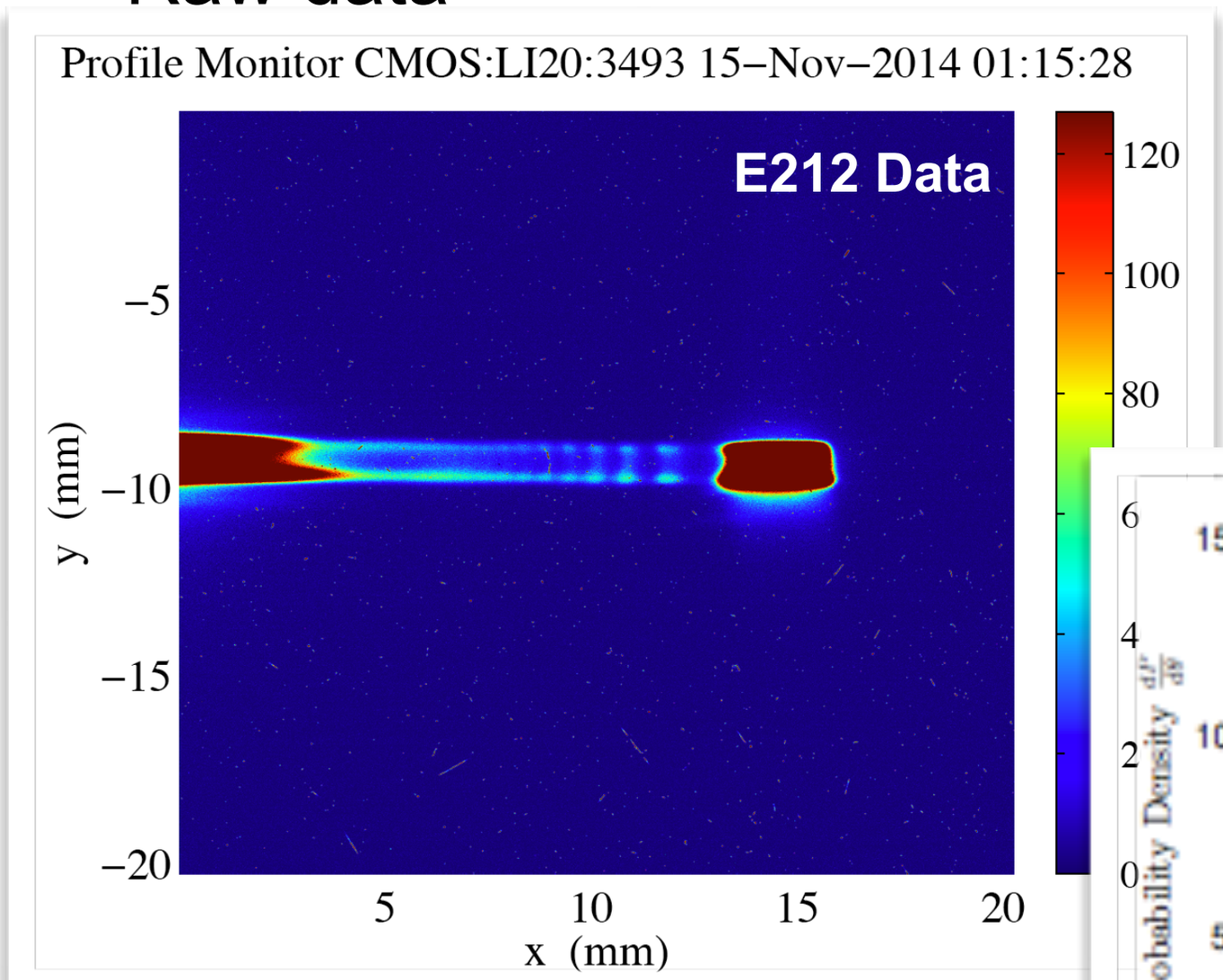
Scattering in “Free” Direction

T.N. Wistisen et al., Phys. Rev. ST-AB 19, 071001 (2016)



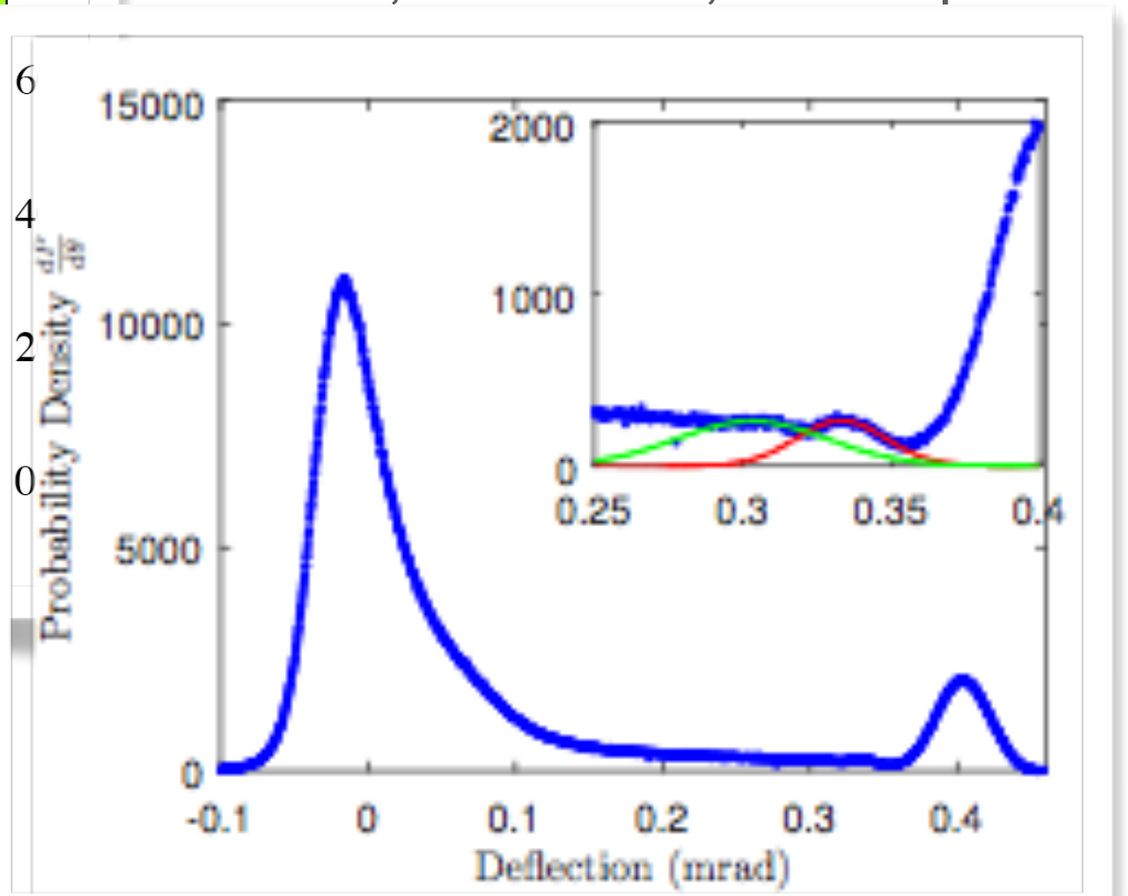
E212: First Channeling Data of 20 GeV e^+ in Bent Crystal

- Raw data



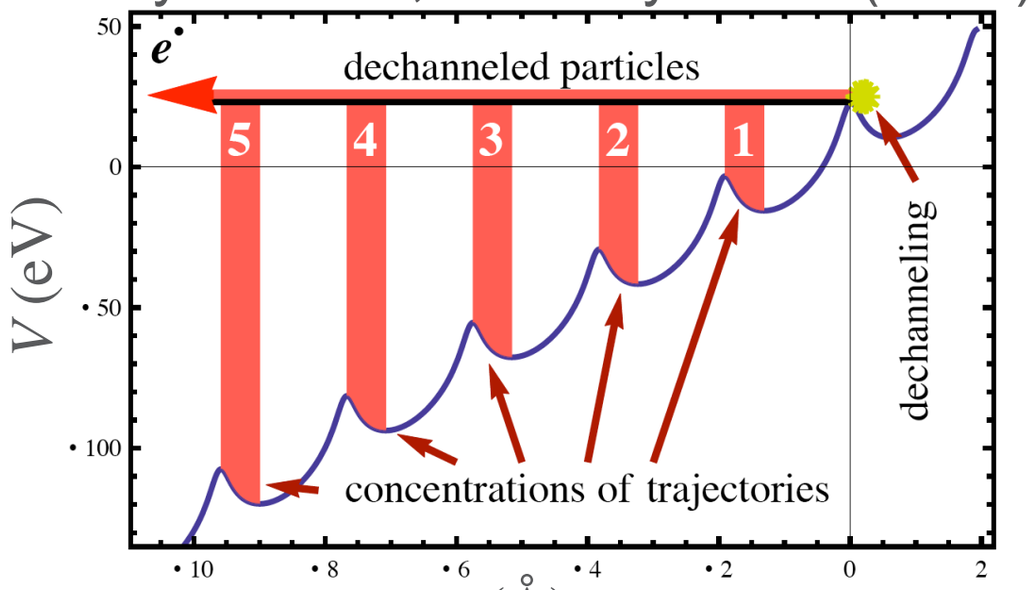
20.35 GeV e^+
10^{10} e^+/pulse

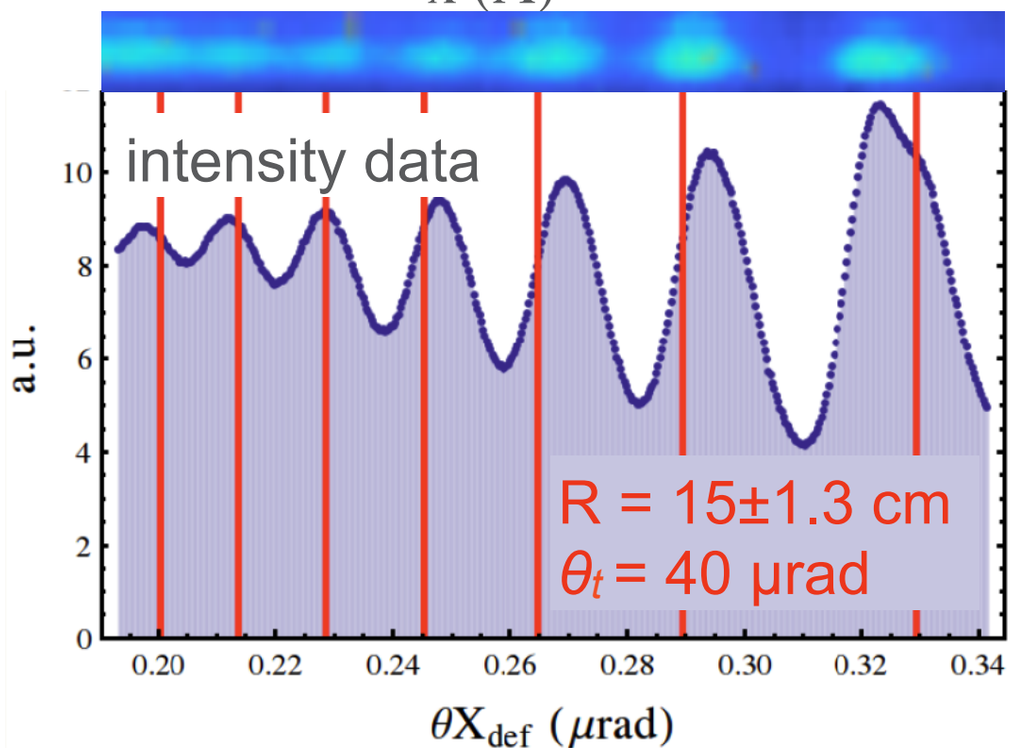
e^- data, 20.35 GeV, 10^{10} e^-/pulse



Analysis of the "Quasi-Channeling Oscillations"

A. Sytov et al., Eur. Phys. J. C (2016) 76: 77

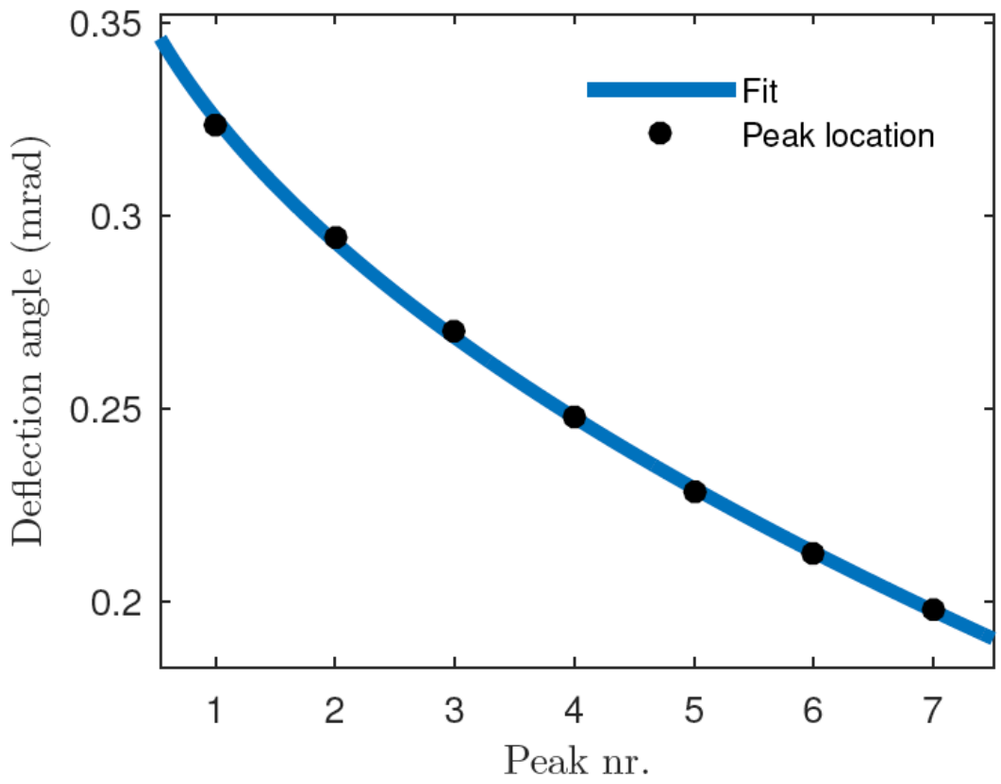




R. Mikkelsen et al., in prep.

$$\theta_{def} = (\theta_b + \theta_t) - \sqrt{\frac{2d_0(n-1)}{R} + \frac{2d_s}{R}}$$

$\theta_b = 402 \pm 9\ \mu\text{rad}$, $R = 0.15$ m,
$d_s = 3.14$Å (known), $d_0 = 4\ d_s$

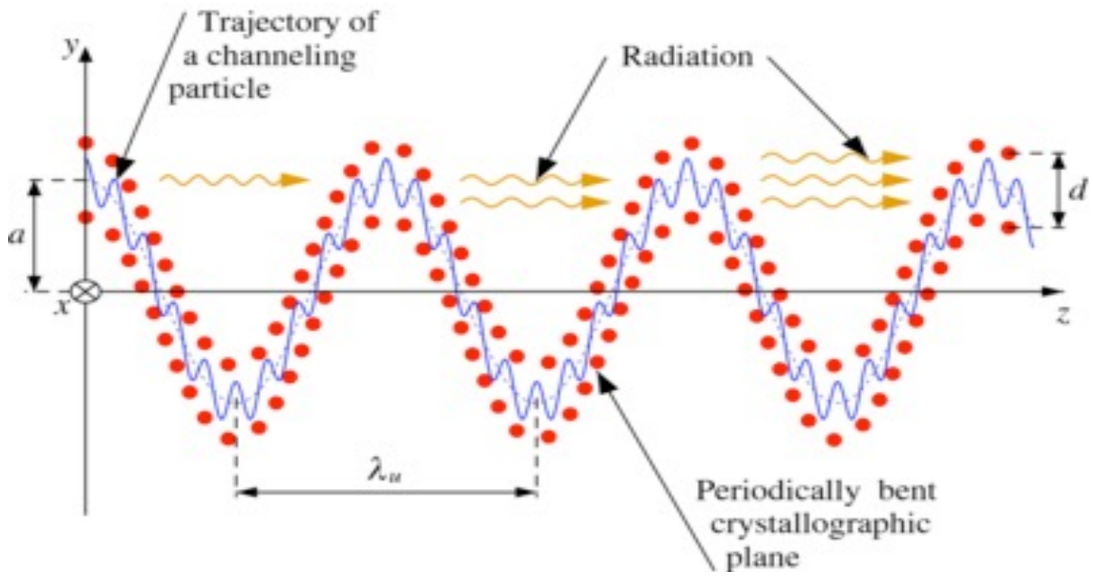


Summary of Deflection Results

- Channeling efficiency ≈ 18…24 %, VR up to 95%
- Dechanneling length ≈ 40…60 μm
  - independent of the beam energy
- Surface transmission 57% (6.3 GeV)…65% (3.35 GeV)
  - calc: 57% @ 6.3 GeV
- Scattering is enhanced in the vertical plane for channeled particles
  - by roughly a factor 2 (X0 –> X0/4)
- Quasi-Channeling oscillations observed with e^+ (and hints with e^-).

Monolithic Undulator

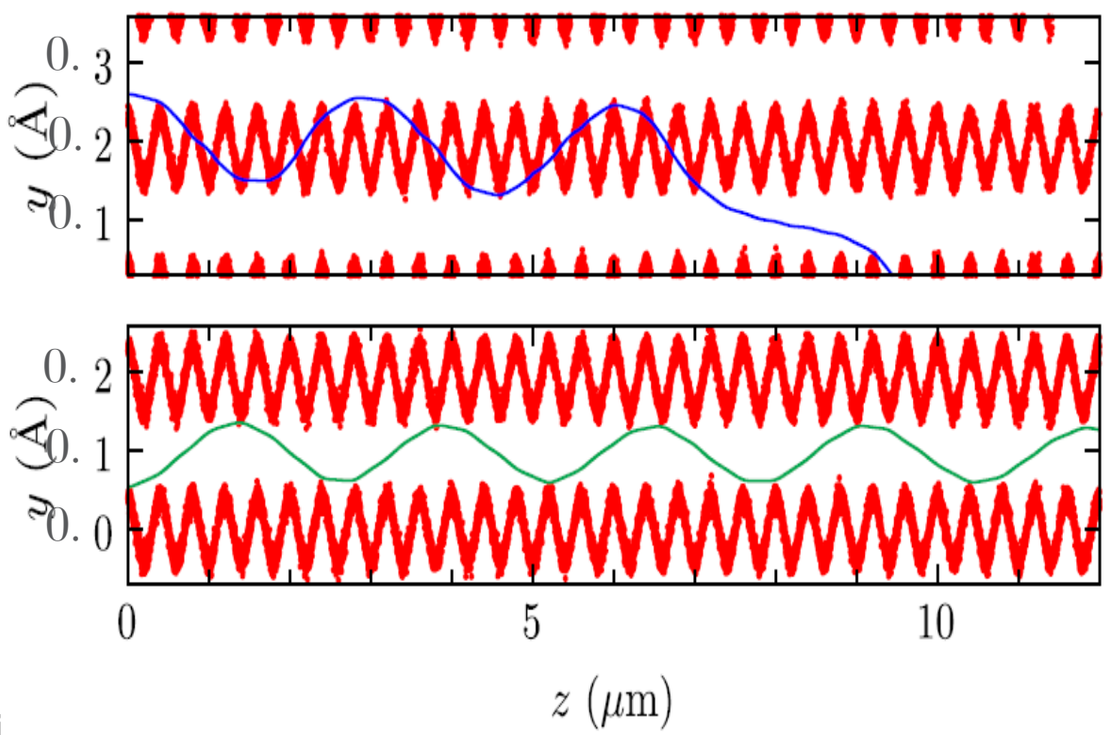
Large amplitude, long period (LALP, Solov’yov *et al.*):



Small amplitude, short period (SASP, Kostyuk 2014):

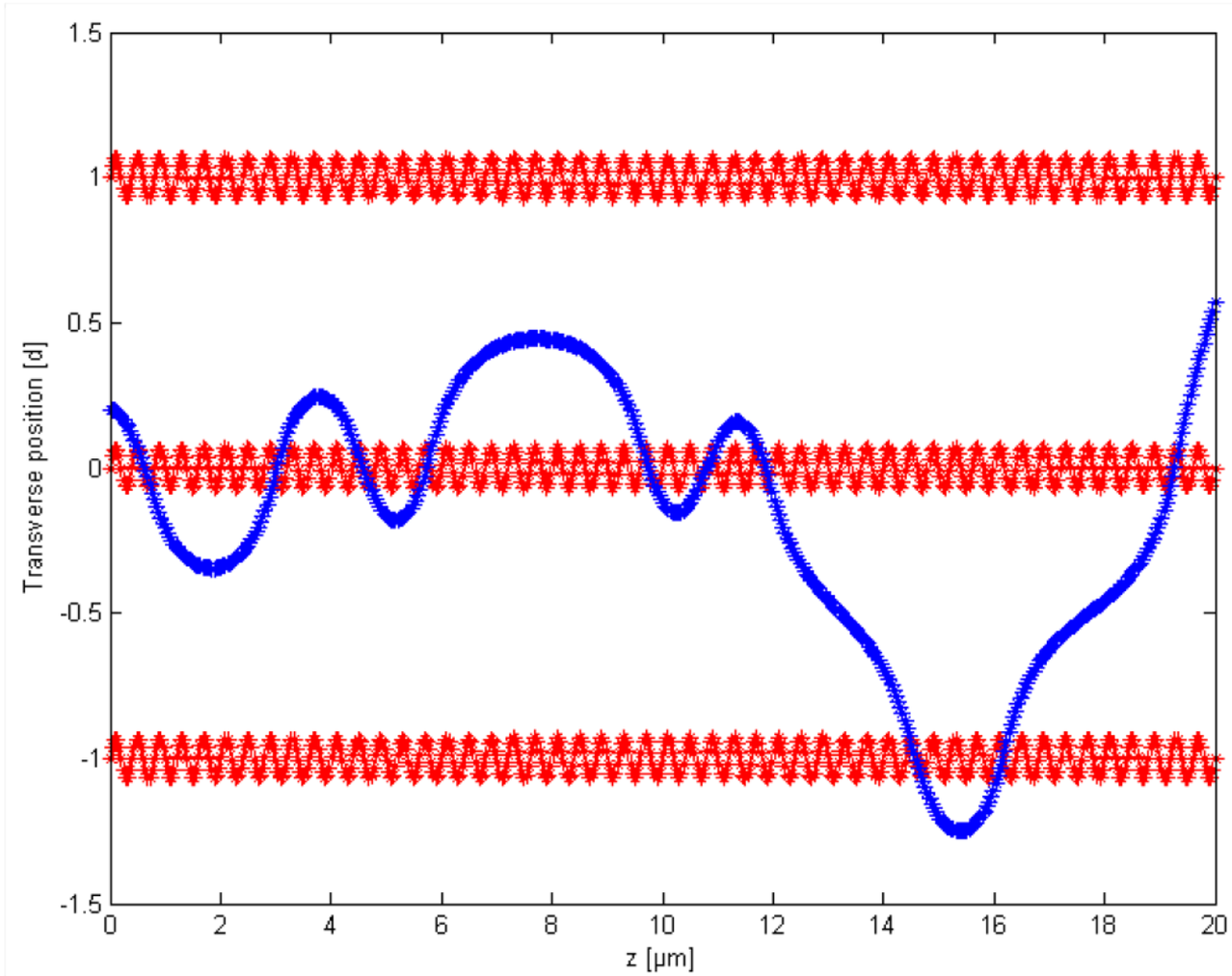
- “Slow” betatron oscillations, fast undulations
- 37 μm long, 120 periods, (110)
- 0.7 GeV @ 6.2 GeV e^-
- 4 GeV@ 16.1 GeV e^-
- K ≈ 0.07

$Si_{1-x}Ge_x$-graded composition



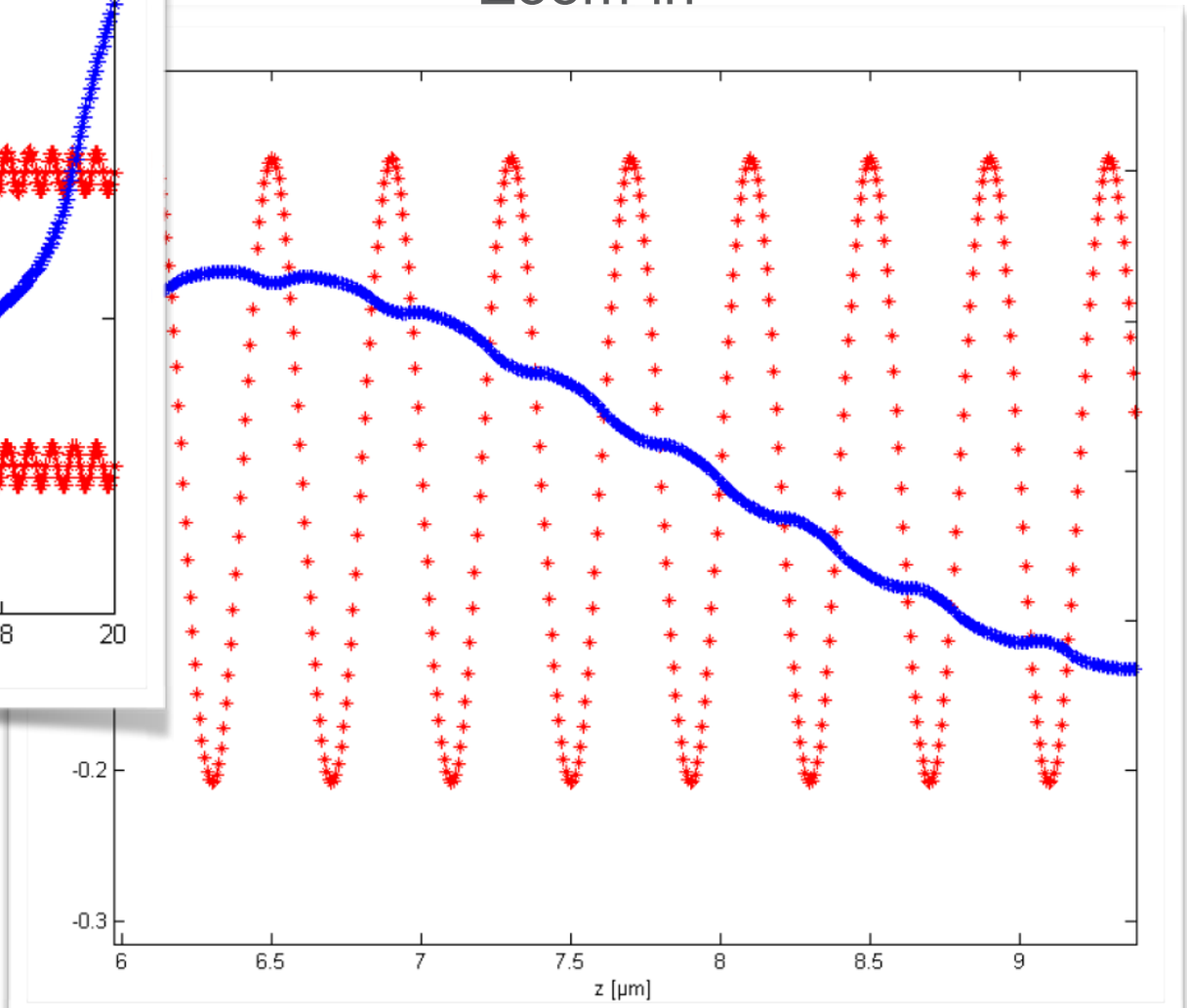
Trajectories of e^-

Overview



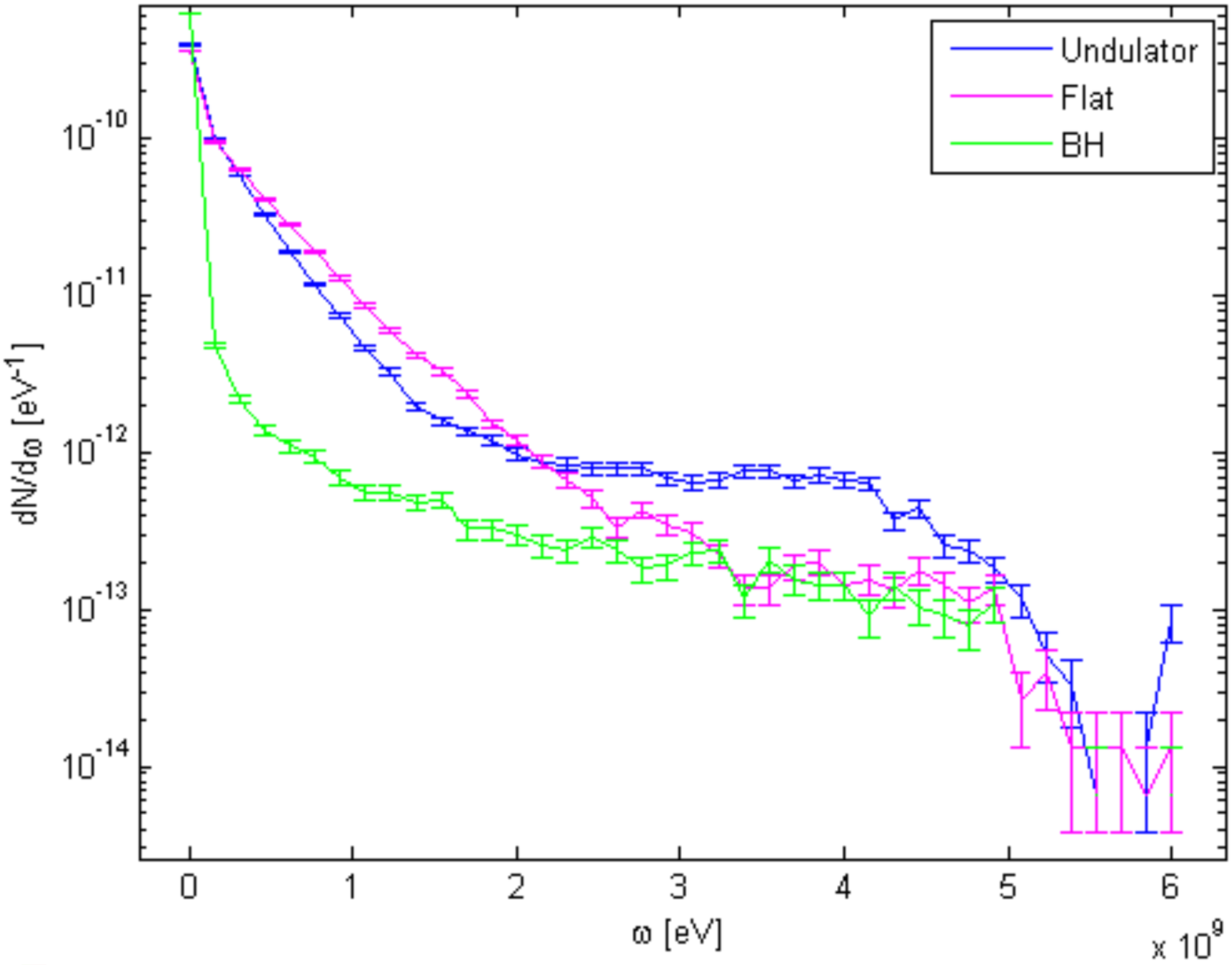
High-frequency wiggles can produce undulator radiation (logitudinally coherent)

Zoom-in



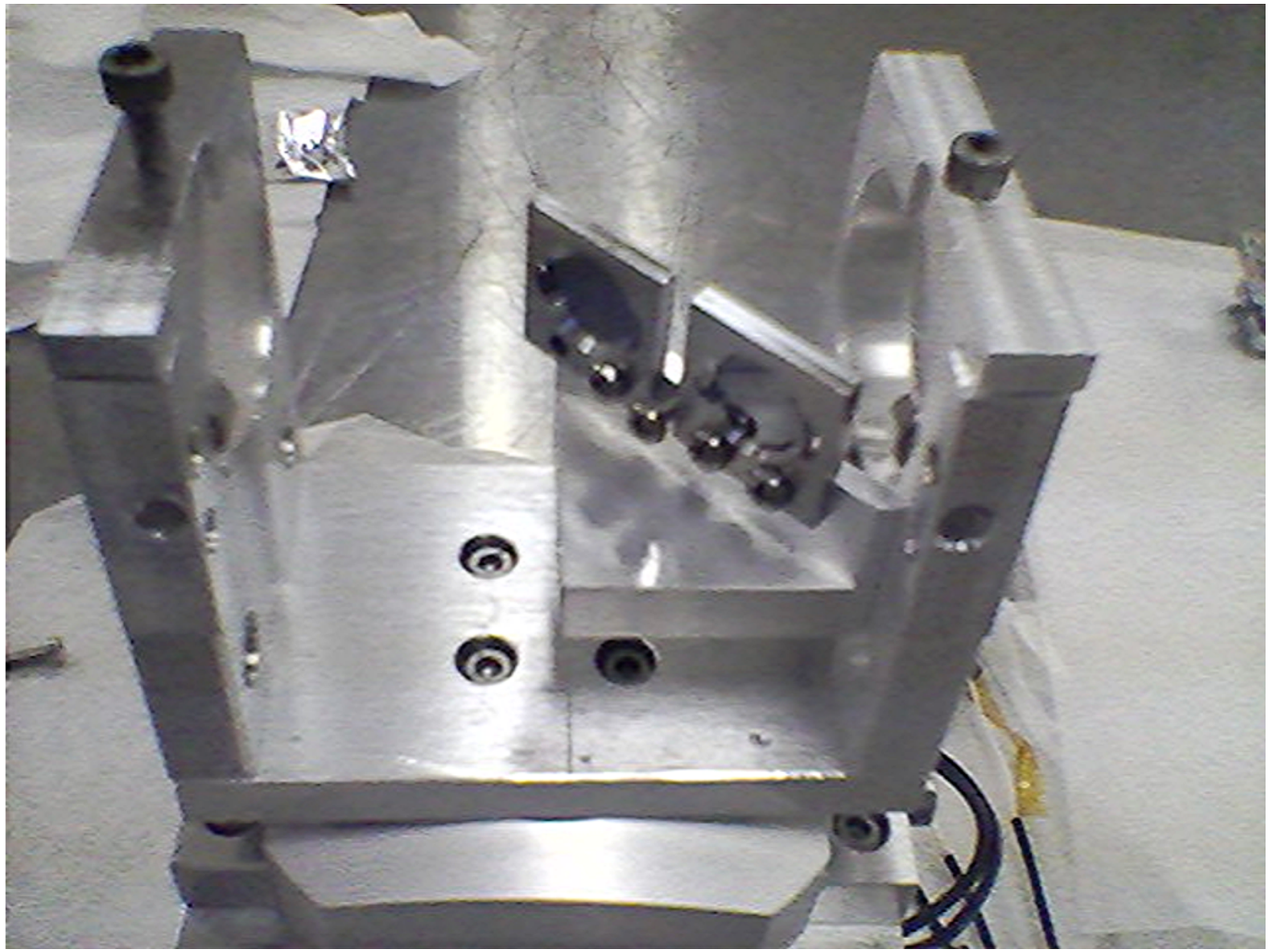
Expected spectra, 16 GeV

Note: Spectral feature mostly from over-the-barrier motion as $R_{wigg} < R_c$



Aarhus Monolithic Undulator

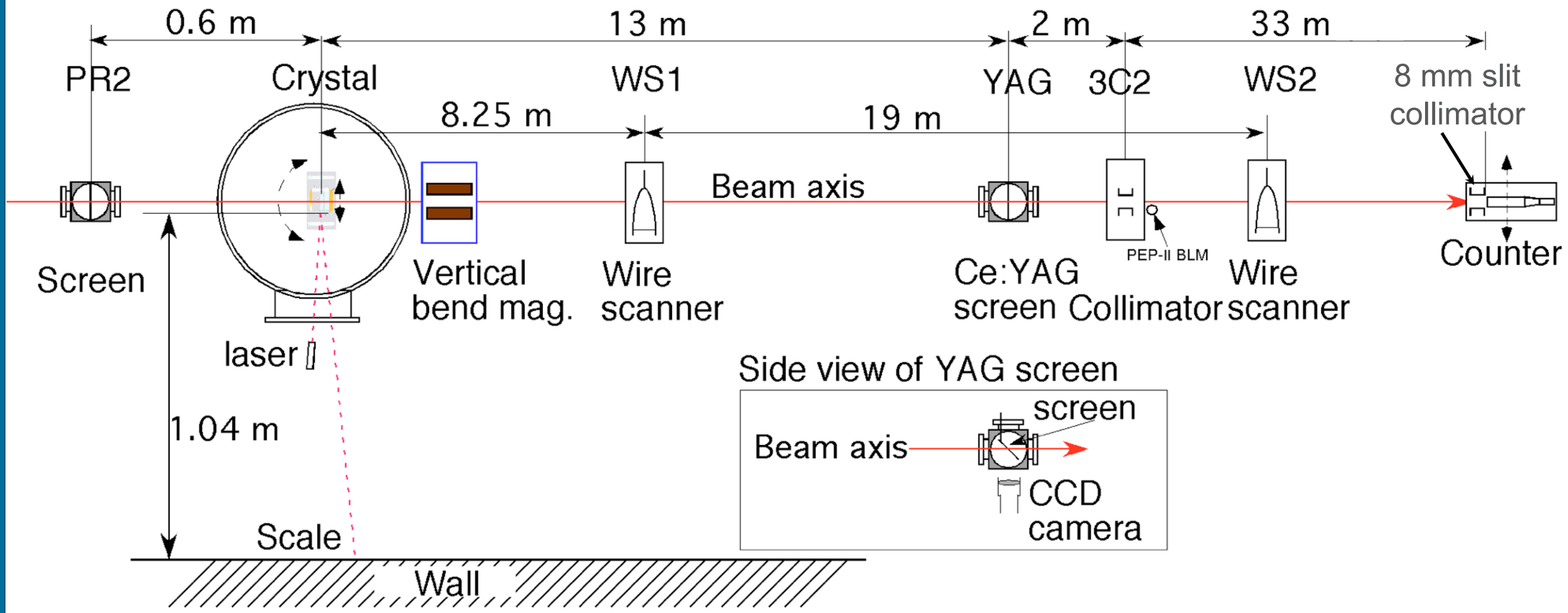
- 37 μm thick; 120 periods.



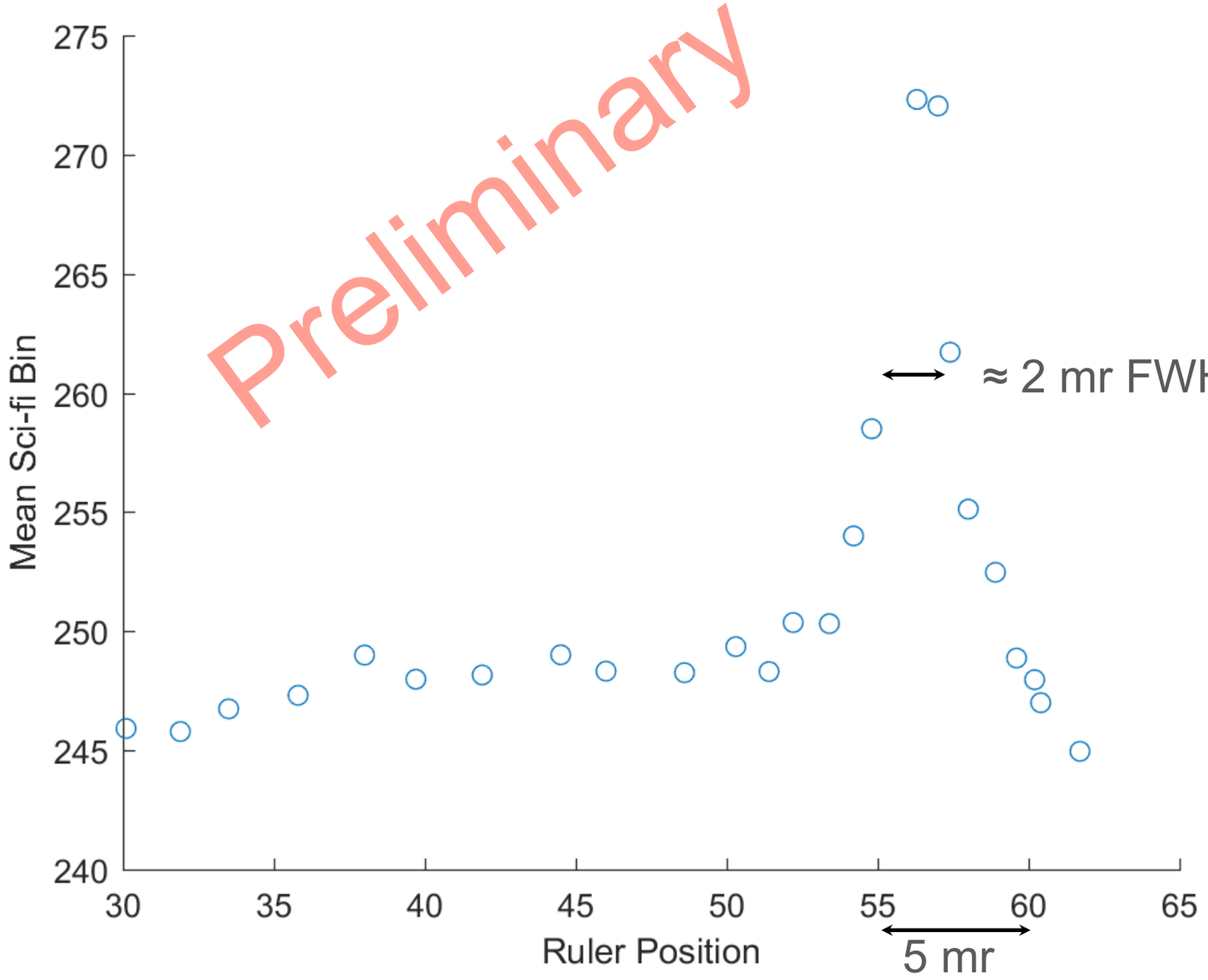
T513/T523 Experiment Layout (ESTB)

Top View, not to scale

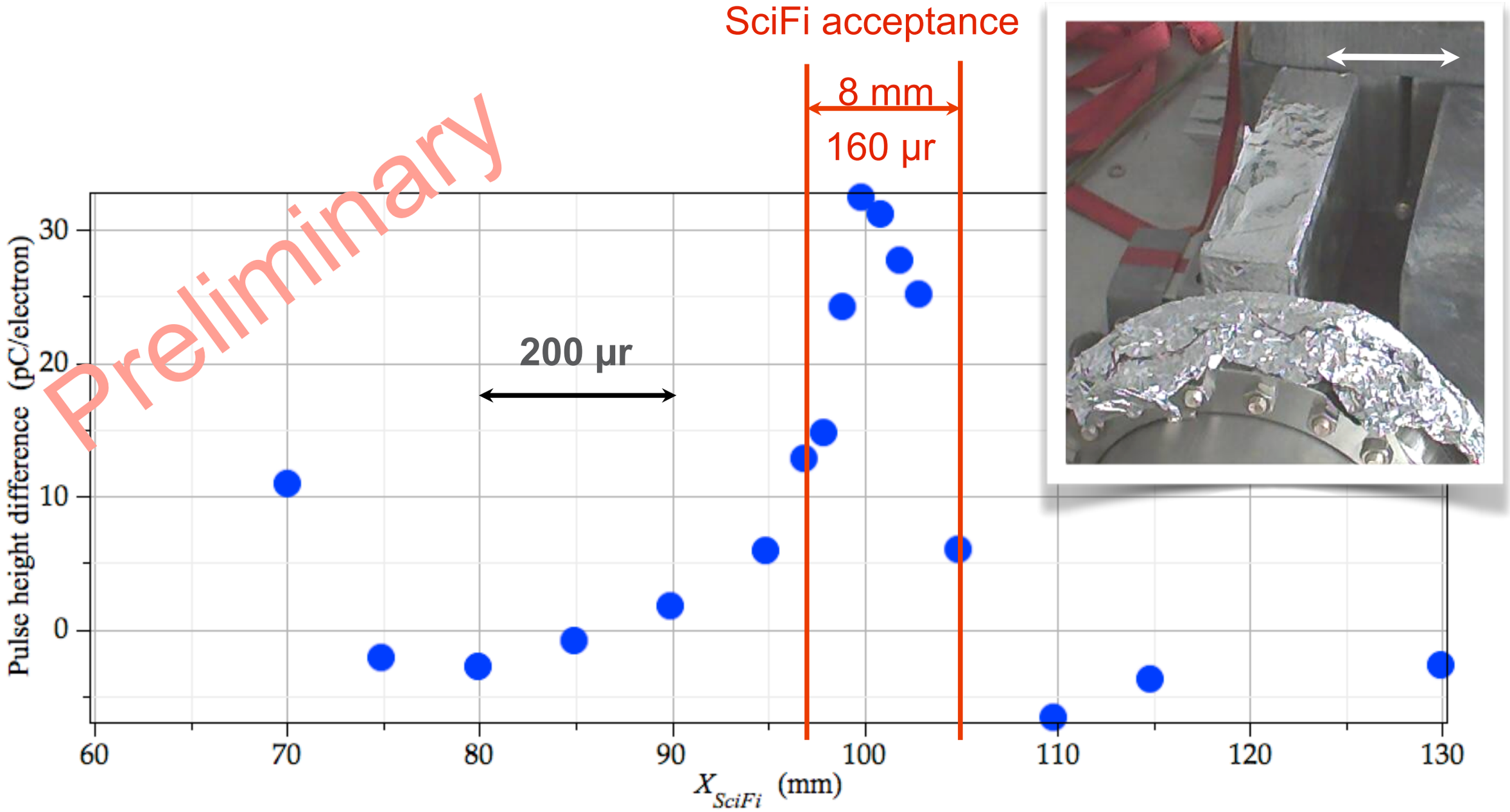
U. Wienands et al., Phys. Rev. Lett. 114, 074801 (2015)



Crystal Alignment with Full Beam



Angular Distribution Aligned – Amorph



E212/T523 Summary

- Gamma rays detected from the crystals
  - In 2015 we saw evidence for channeling and VR gamma rays from the Ferrara bent Crystal (60 μm, 400 μrad, 0.15 m)
  - Gamma rays from 37-μm Aarhus Undulator seen this summer
- Clearest signals in intensity distributions
  - VR radiation from Ferrara crystal
  - Channeling radiation from Aarhus undulator
  - Signal/background ratio 1:1 -> 1:4
- Energy spectra have been difficult to acquire.

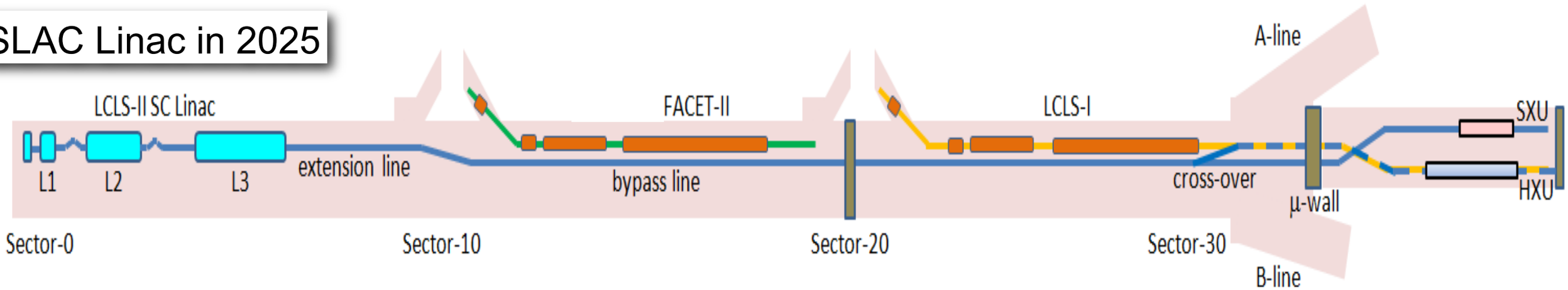
Beyond T523 and E212

- Continuing focus on radiation experiments
- Possibly explore lower beam energies
  - ESTB will go off-line soon for LCLS-II installation.
  - FACET is off-line now for the same reason.
  - ESTB to be reconnected to the linac mid-2017;
    - resume operation July...Oct. 2017; until June 2018
    - then down a year for LCLS-II install., back up July 2019.
    - same beam parameters as now.
- Potential competition by DASEL proposal for a Dark Matter experiment.

Planning for FACET-II as a Community Resource

- FACET stopped running in April 2016 to begin LCLS-II construction
- Over the next few years FACET-II will add new capabilities:
  - LCLS style photoinjector with state of the art electron beam (low emittance, small divergence)
  - Flexibility e.g. low-charge mode or 'two color' operation for two-bunch PWFA
  - Nominal $\mathbf{e^-}$ parameters: 10GeV, 2nC, 15kA, 30Hz (**2019**) → Beam quality
  - Nominal $\mathbf{e^+}$ parameters: 10GeV, 1nC, 6kA, 5Hz (**2021**) → Positron Acceleration
  - External injection → Staging studies, ultra-bright sources
- Continue to plan experimental program with **Science Workshops**

SLAC Linac in 2025



FACET-II has been designed to address many of the R&D challenges of the Beam Driven Roadmap

Thank you!