T-513: Channeling and Reflecting e^- at the ESTB

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Office of Science

Motivation

SLAC

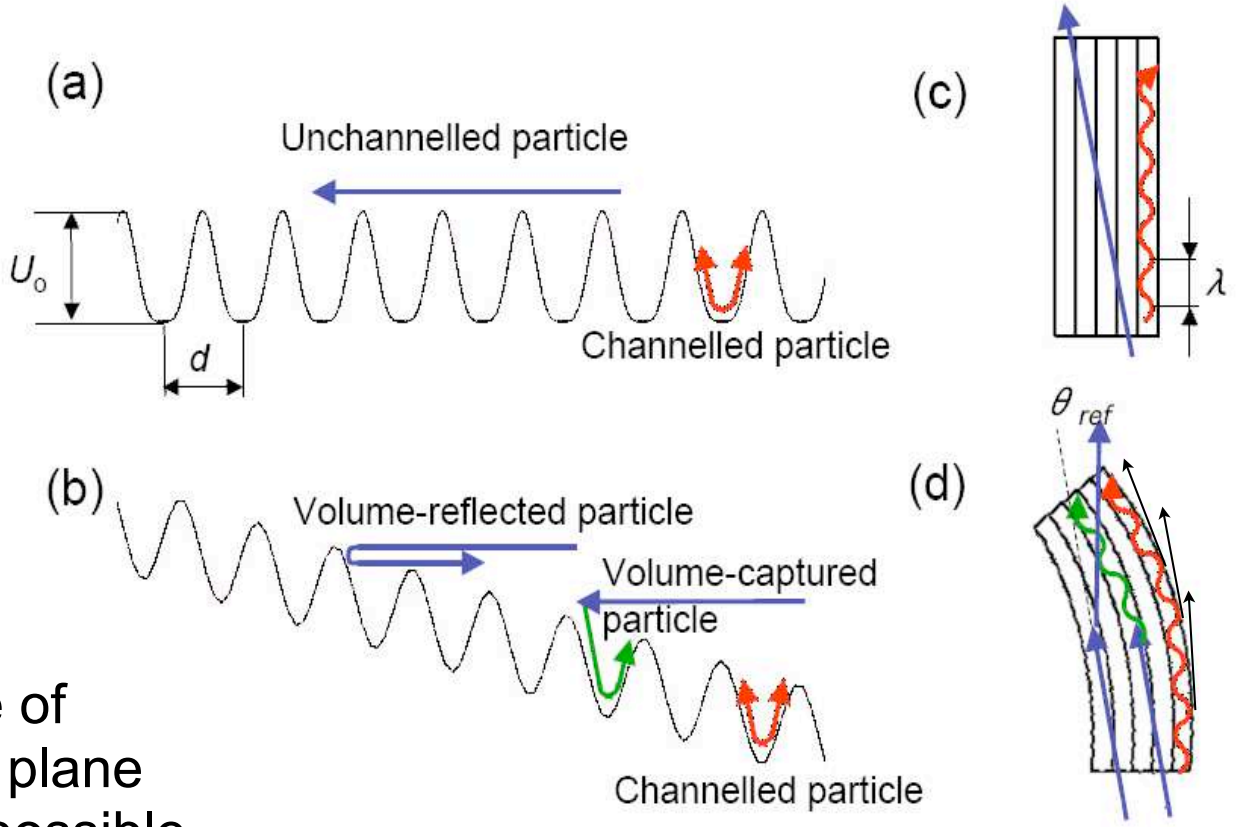
- Bent crystals can deflect high energy beams with small bending radii (O(0.1m))
  - lots of proton data, little data for high-energy e^-
- **There is interest in crystal collimation for e^+ and e^-**
  - Expected benefits in size and efficiency of collimation
  - Not enough data to actually design such a system
  - Possible application to ILC, LCLS-II
- **There is interest in in channeling radiation**
  - Intense γ ray production, possibly narrow-band
  - "Crystal undulators" with e^- ??
  - Volume-reflection (VR) radiation not well understood (?)
- How well does VR work with e^- anyway?

Particle-Crystal Interaction

W. Scandale (adapted)

Possible processes:

- multiple scattering
- channeling
- volume capture
- de-channeling
- volume reflection



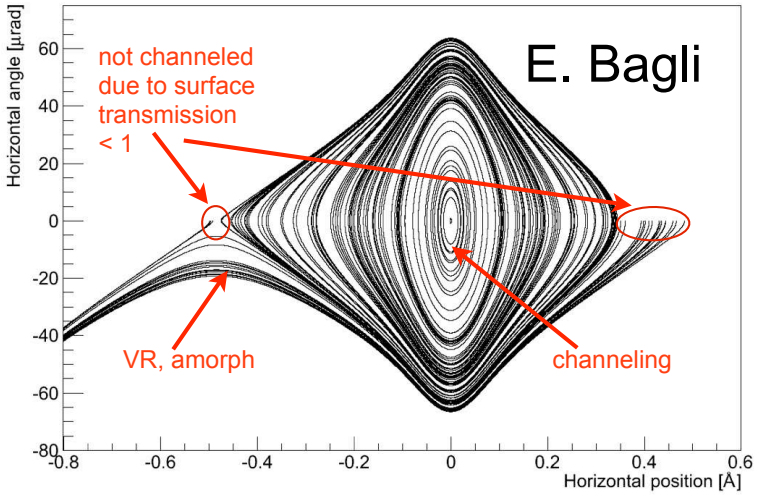
Critical angle: max. angle of incoming particle against plane where channeling is still possible

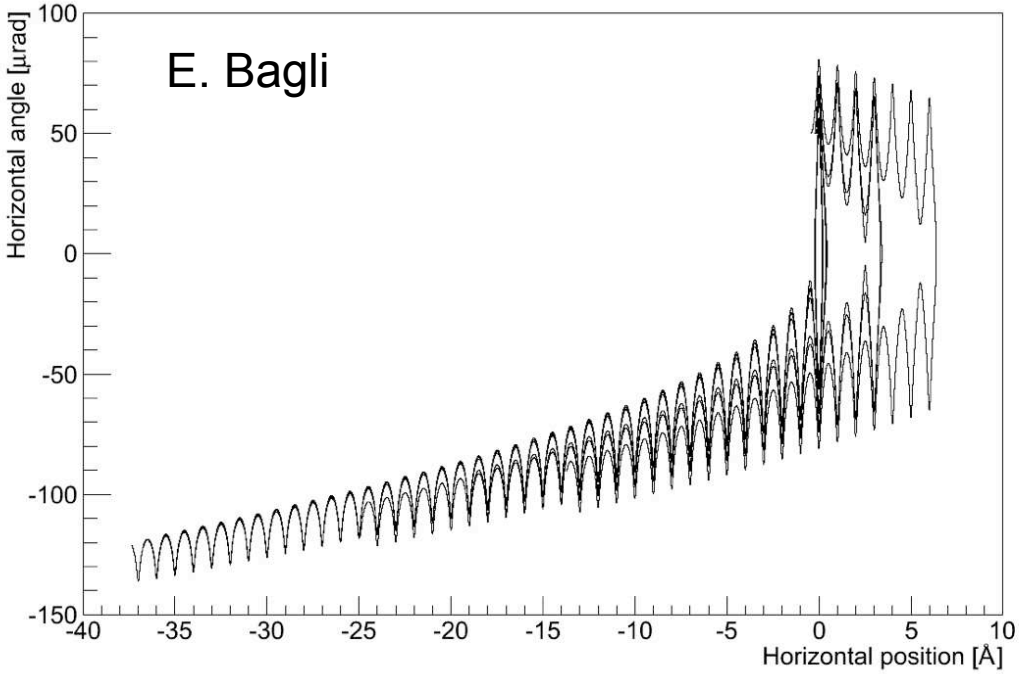
$$\theta_{crit} = \sqrt{2U_0/E}$$

Dechanneling rate ∝ # in channel => ∝ e^{-s/L_d}; L_d is called *dechanneling length*

Volume Reflection

- Deflects e^+ by ≈ 1.4…1.8*θ_{crit}, the critical channeling angle
  - independent of crystal length
  - scales with $1/\sqrt{E}$
  - bending angle = VR acceptance in beam divergence angle.
  - Will incur multiple scattering (channeling particles don't ?)
- e^- undergo VR as well
  - VR angle ≈ 0.8*θ_{crit}



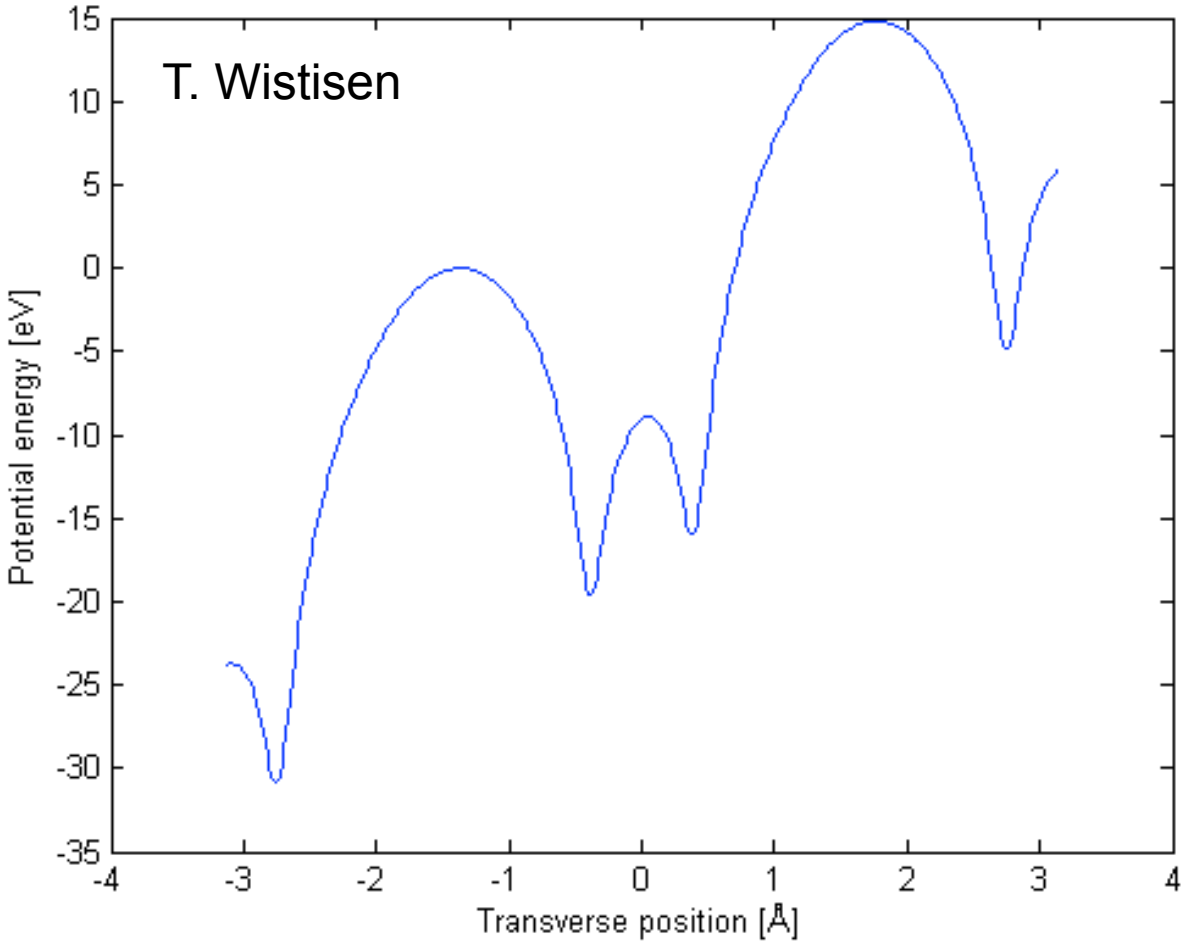


Main crystal features

- **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.**

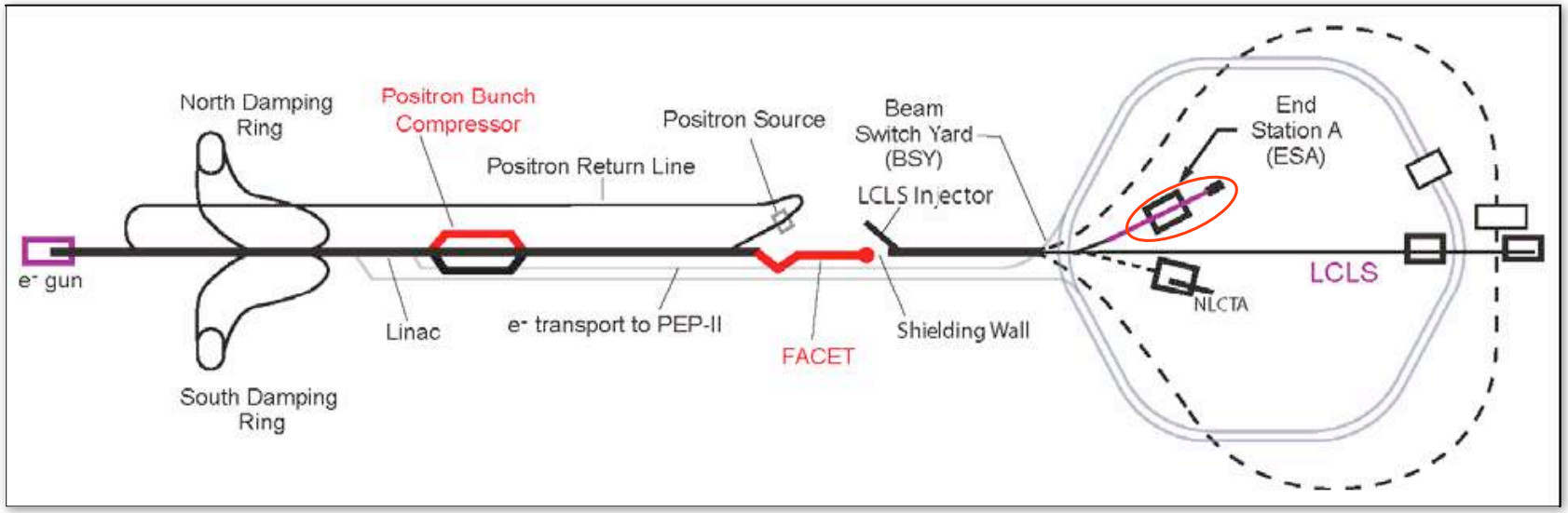
Si (111) Potential for T513 Crystal (ρ = 0.15 m)

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

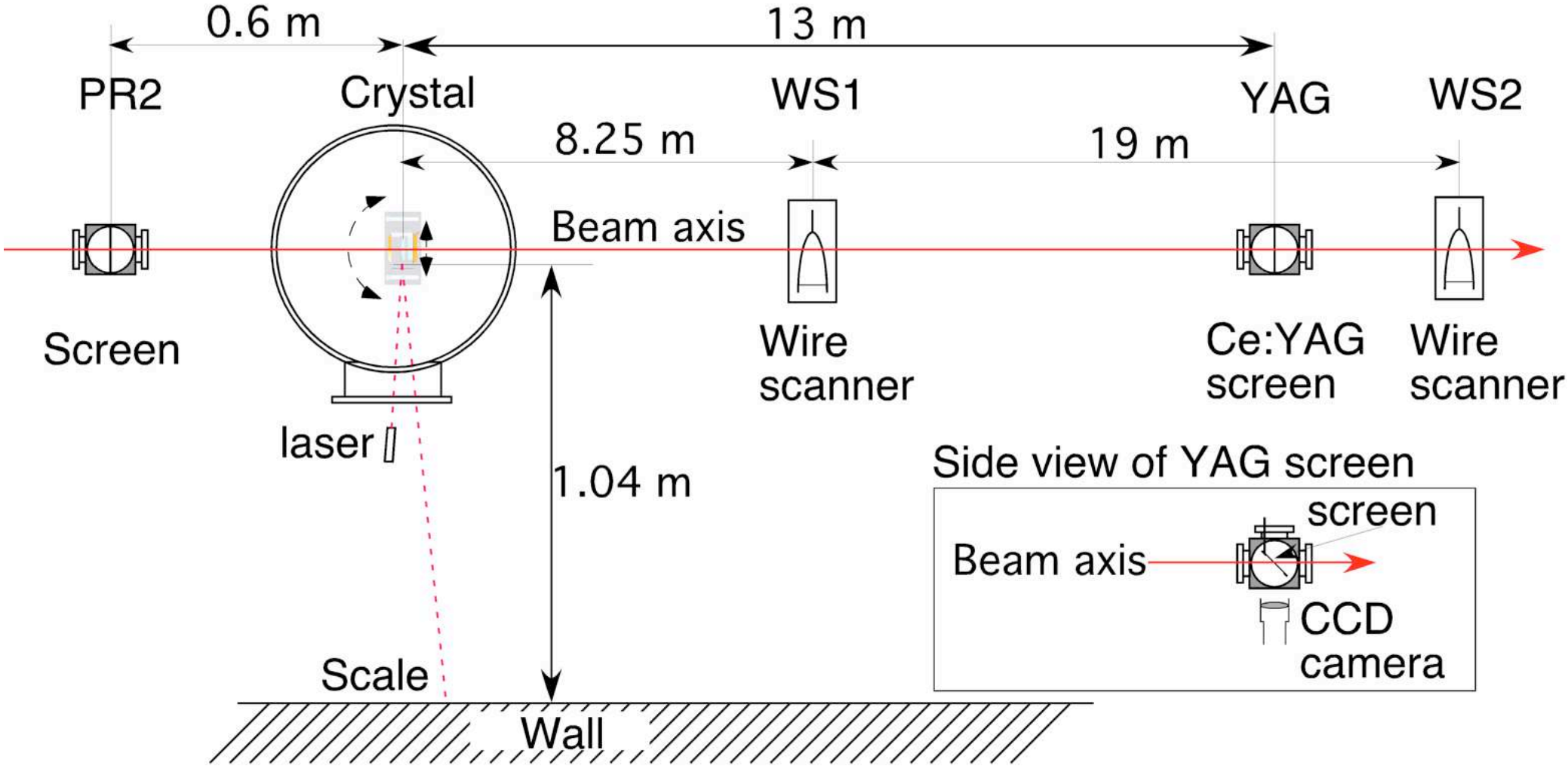


End Station A Test Beam (ESTB)

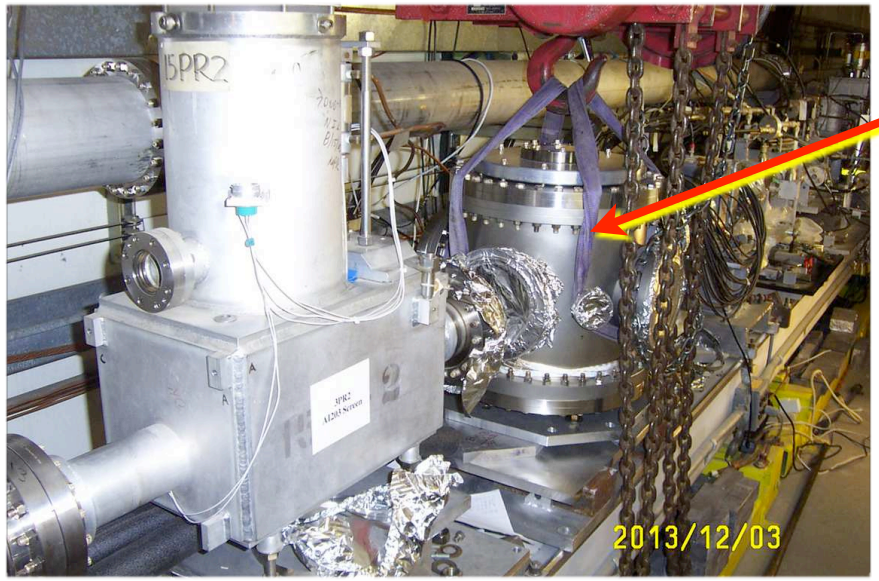
- up to 10 (15) GeV e^-, 5 Hz, ≤ 200 pC/pulse
  - "pulse stealing" from LCLS
- control of optics, momentum spread
  - ability to provide relatively parallel beam (<10 μrad)



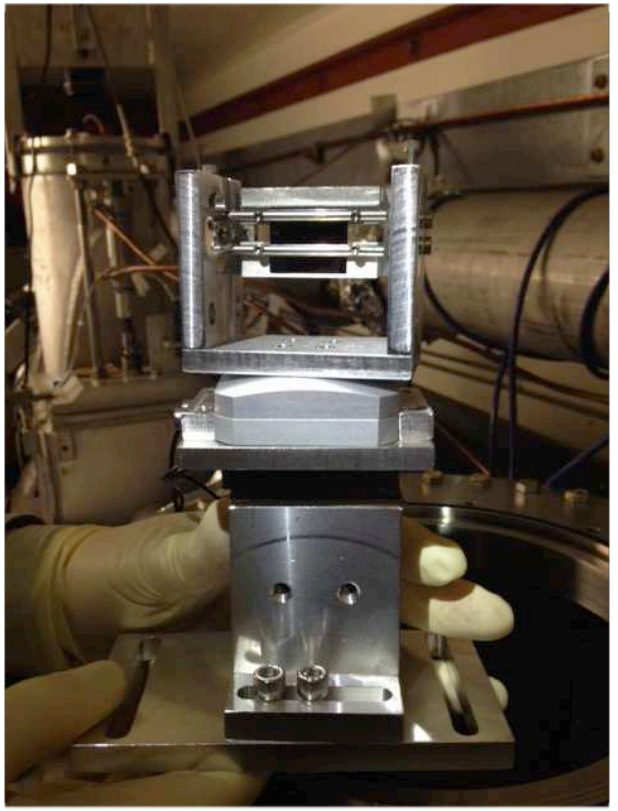
T513 Experiment Layout



T-513 being installed (by ESTB Group)

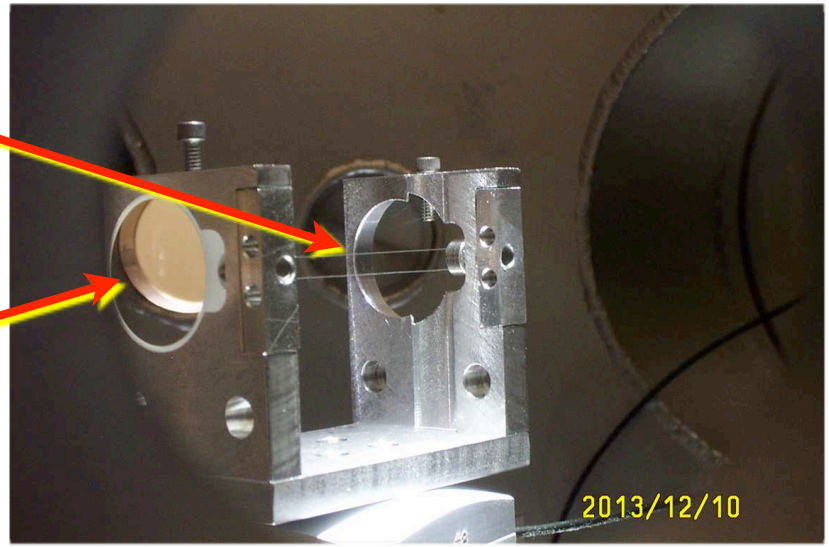


Chamber
("Kraken")

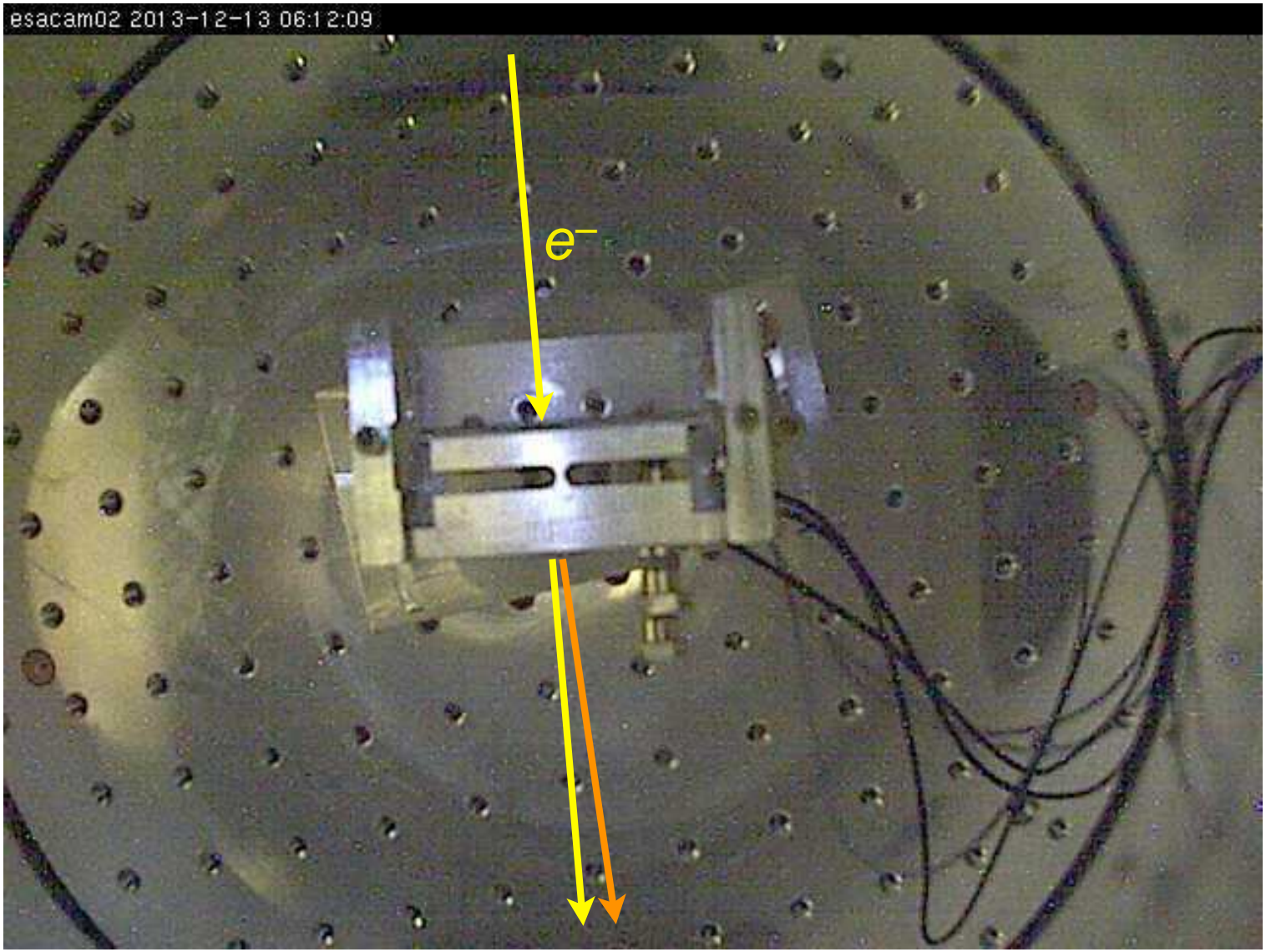


Beam finder wire installed for 1st beam

Mirror for angle readout

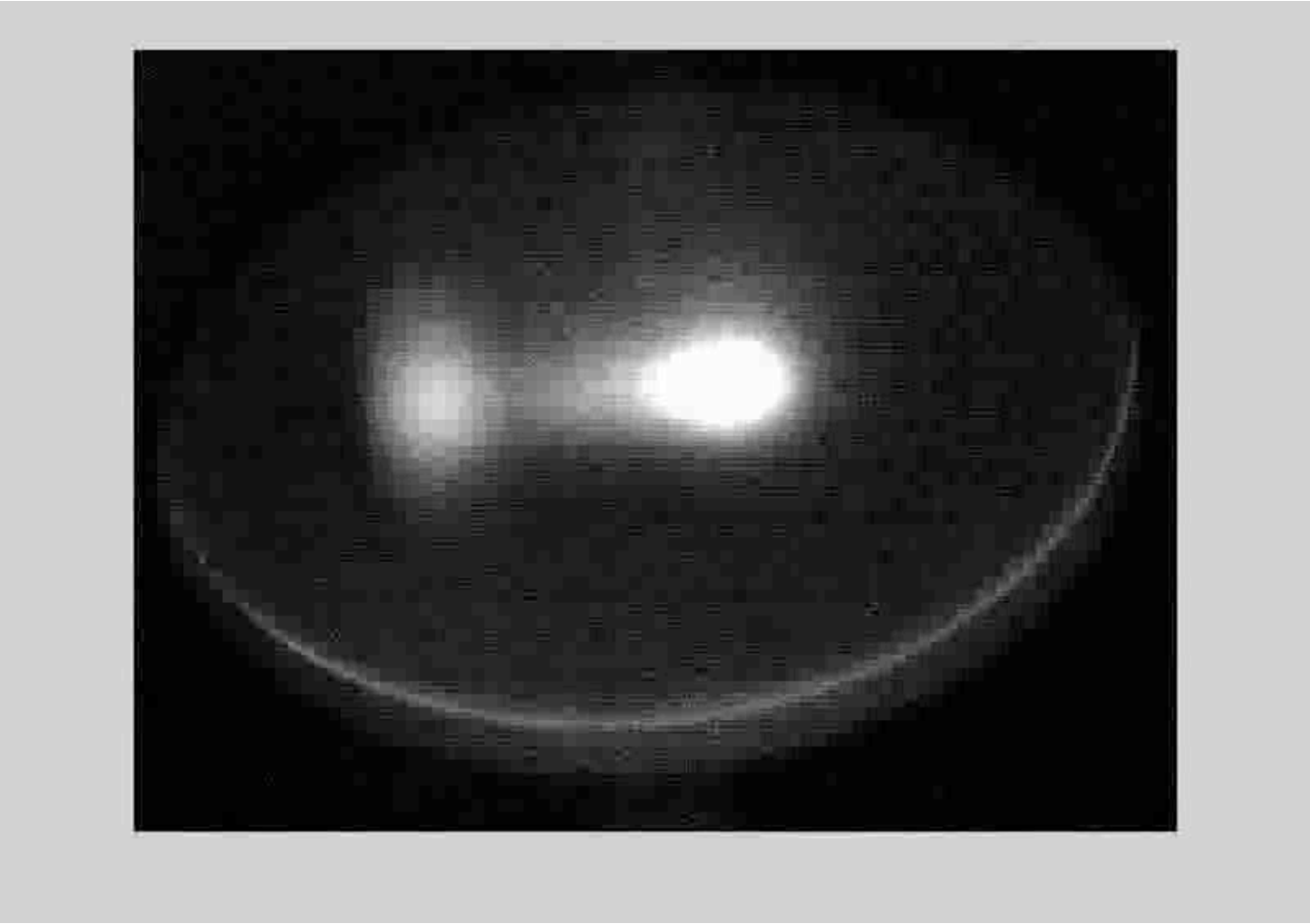


Crystal mounted in “Kraken” Chamber in ESA



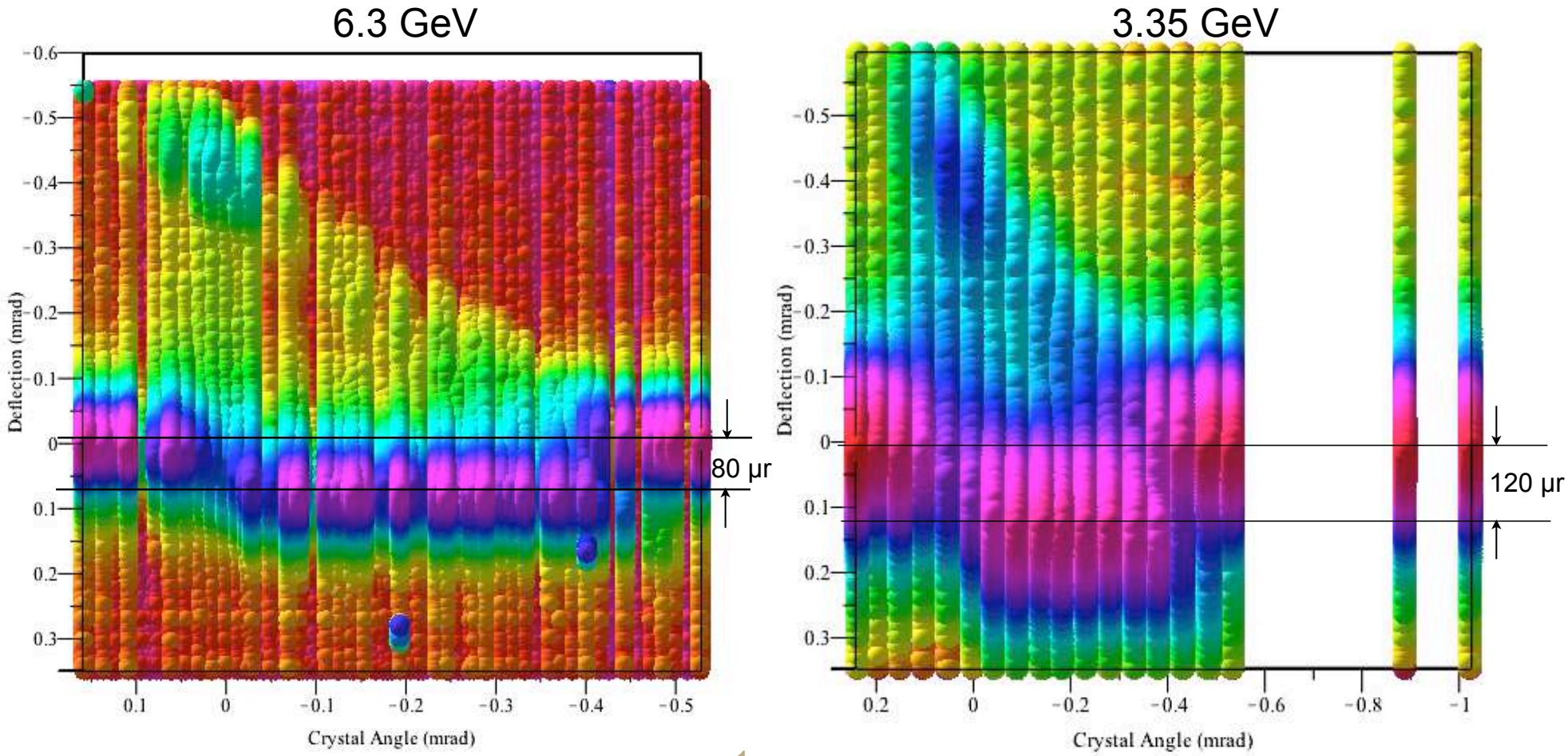
Crystal-Rotation @ 4.2 GeV

(Movie credit: T. Wistisen)



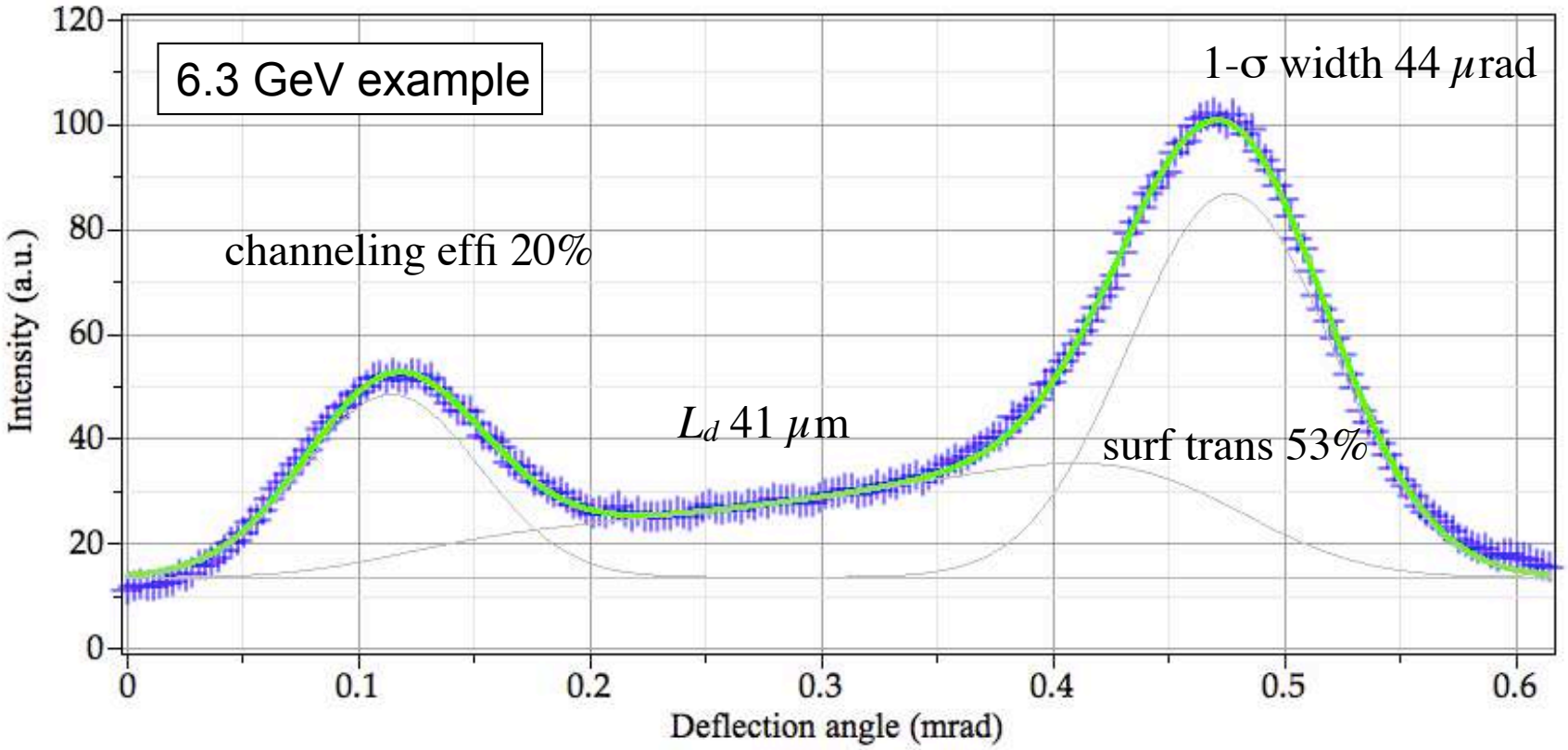
Triangle Plots

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



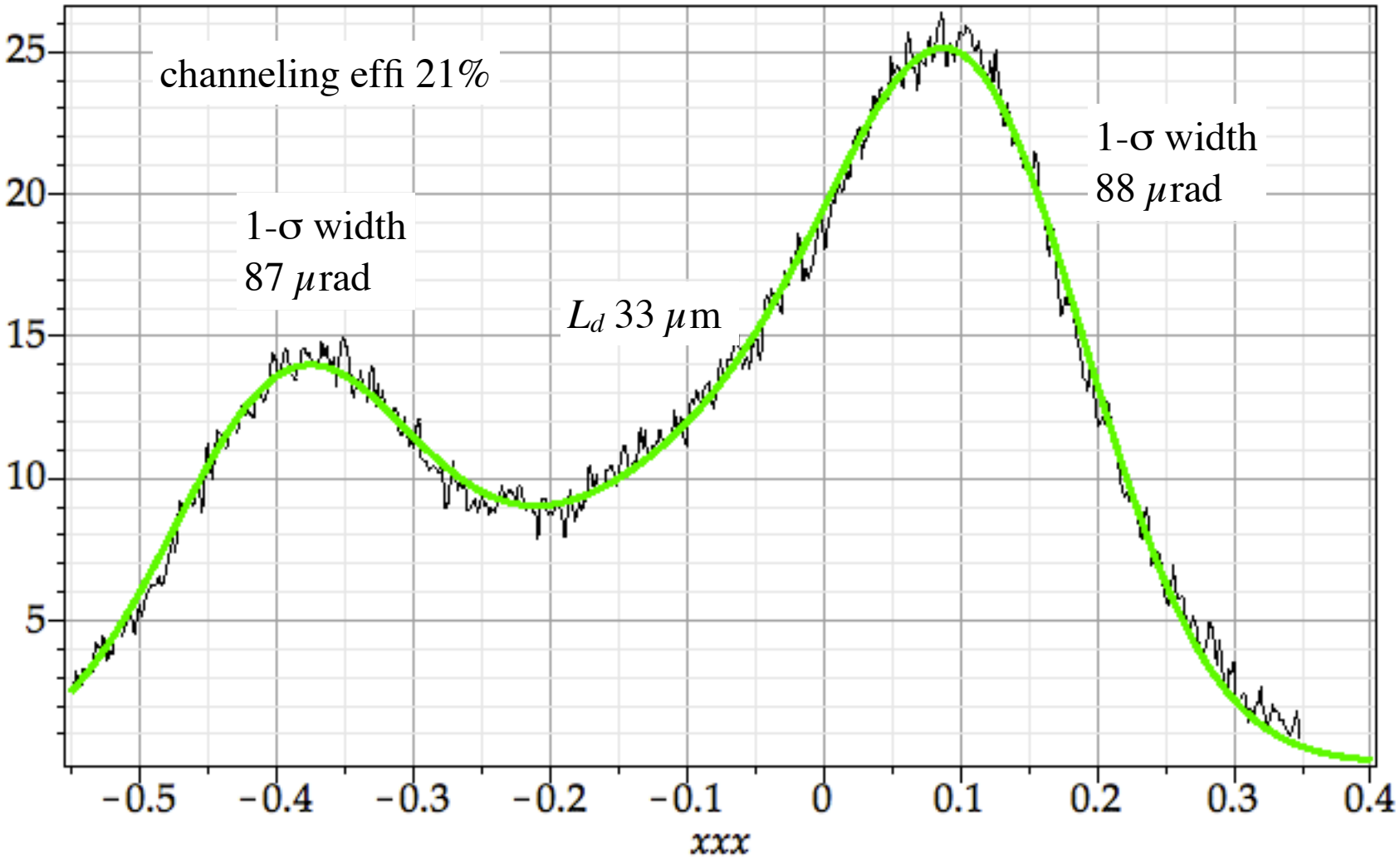
Fit to Intensity Distribution

- unfold 2 peaks + exponential dechanneling tail

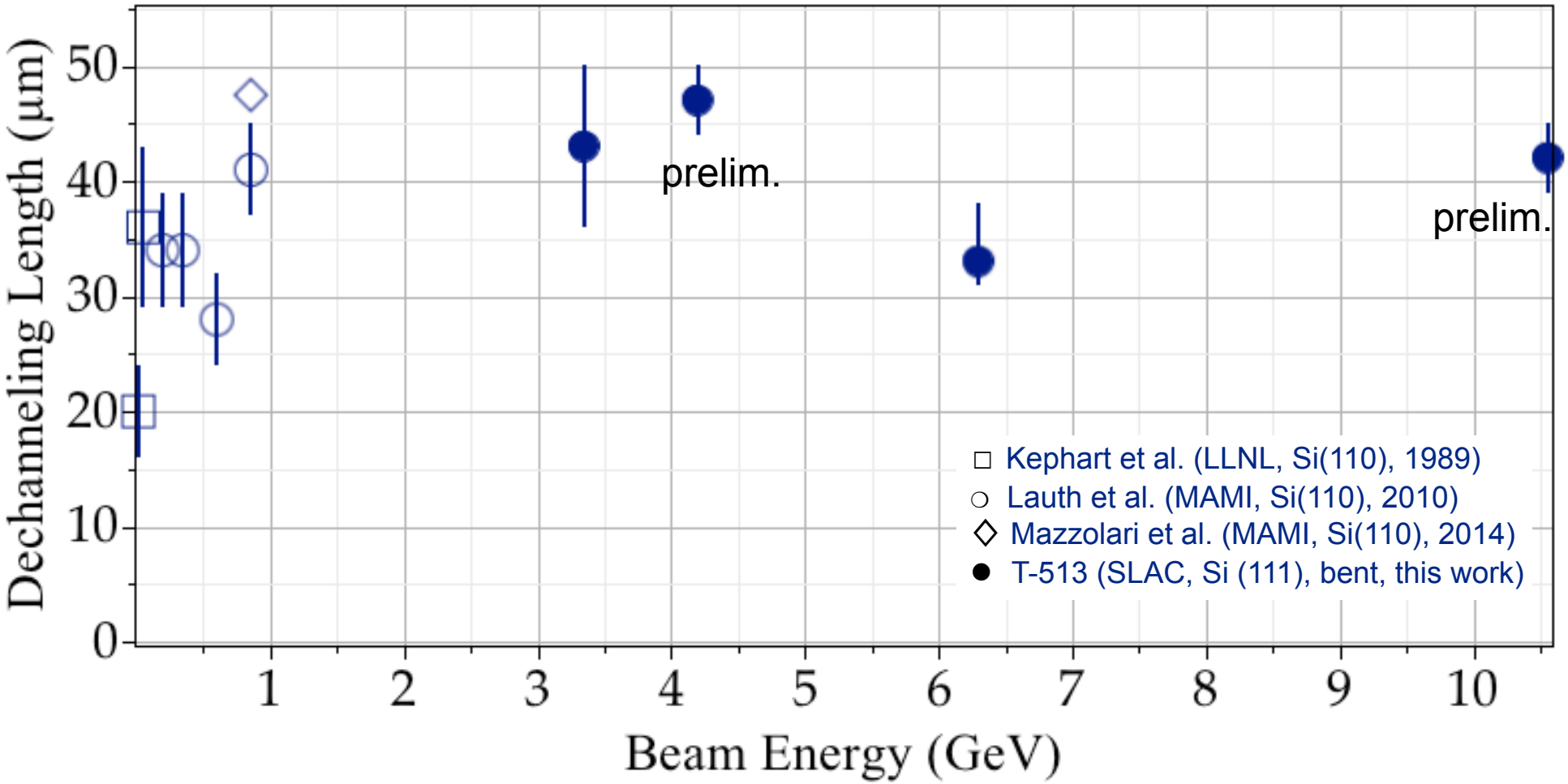


Channeling efficiency := (channeling peak)/(all)
Surface transmission := (channeling + tail)/(all)
Dechanneling Length := xi/(defl. angle) * (crystal length)

3.35 GeV Fit Example



e^- Dechanneling Length Data Summary

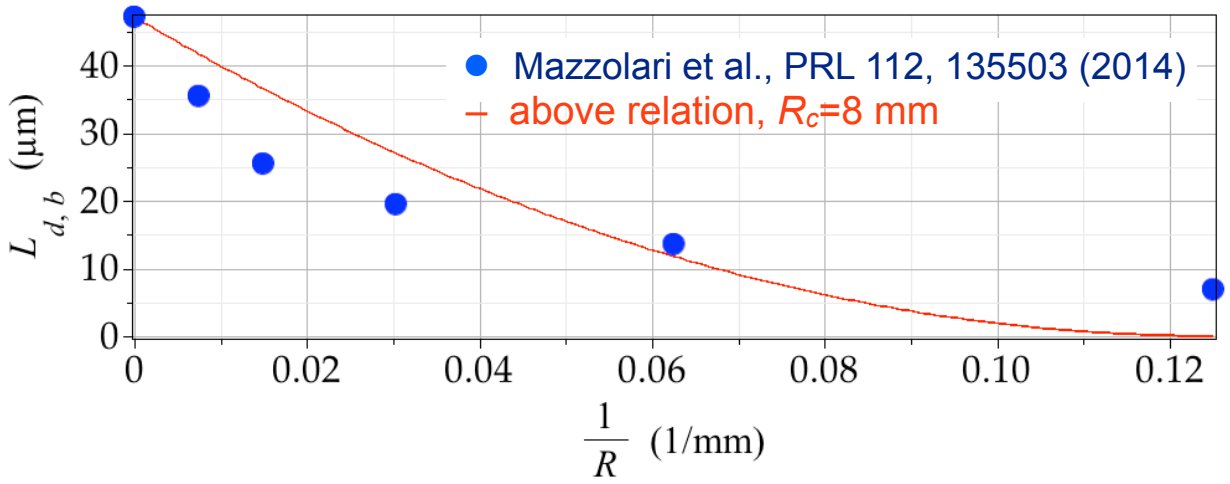


Comparison of Straight and Bent-Crystal Data

- for e^+, p: use scaling law based on the Tsyganov-radius

$$L_{d,b} = L_{d,s}\left(1 - \frac{R_c}{R_b}\right)^2$$

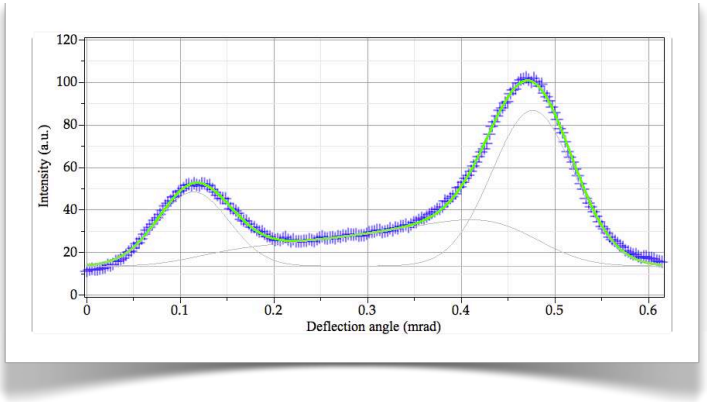
  - 10% @ 3.35 GeV, 20% @ 6.3 GeV: not overly significant
- for e^-: ???
  - 855 MeV data from MAMI (Mazzolari et al.) does not follow this law



  - At present, no theoretical basis for this correction for e^- (??)

Are the data consistent?

- Sanity check: Can we account for all intensity:
  - e.g. @ 6.3 GeV, channeling: Surface transmission 57% and dechanneling length 33 μm (≈1/2 crystal)
    - => 16% of 57% (≈ 9%) should be in the channeling peak
      - we see 23%



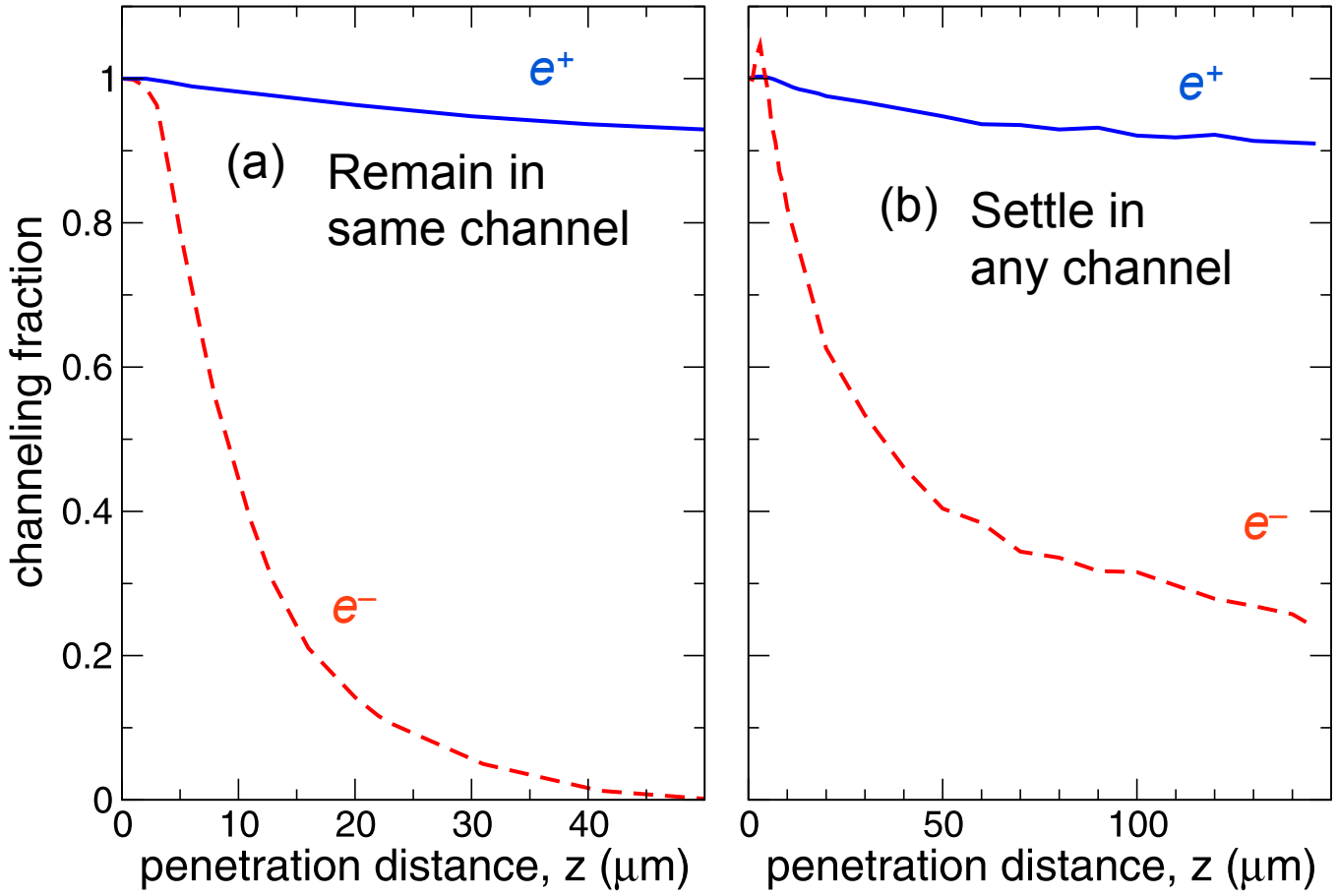
- How to resolve this discrepancy?
  - Parameter sensitivity? Unlikely at the factor-2 level
  - De-channeling model wrong?
    - Rechanneling ?(see e.g. model of Sushko et al.)

Dechanneling estimates (Sushko et al., 2013)

G.B. Sushko et al., J. Comp. Phys. 252, 404-418 (2013)

855 MeV beam, (110) Si, straight. Case (b) can be fitted with two exponentials, dechanneling lengths would be 16.8 μm and 223 μm.

What do our data suggest?



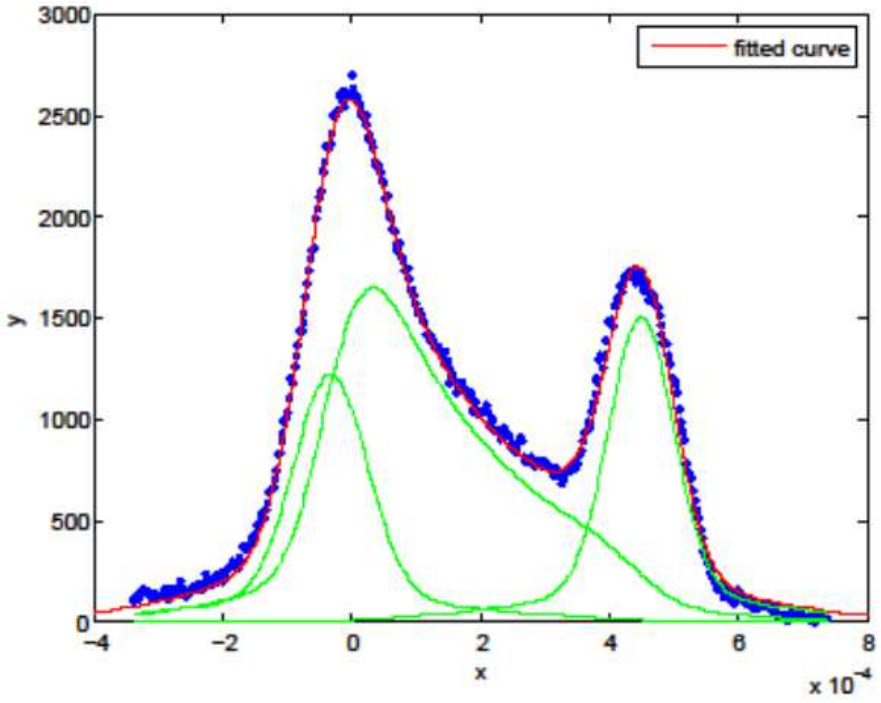
Unfolding Two-Dechanneling-Lengths (Wistisen)

$$P(\theta) = Ae^{-\frac{\theta}{\theta_{D1}}} + (1-A)e^{-\frac{\theta}{\theta_{D2}}}$$

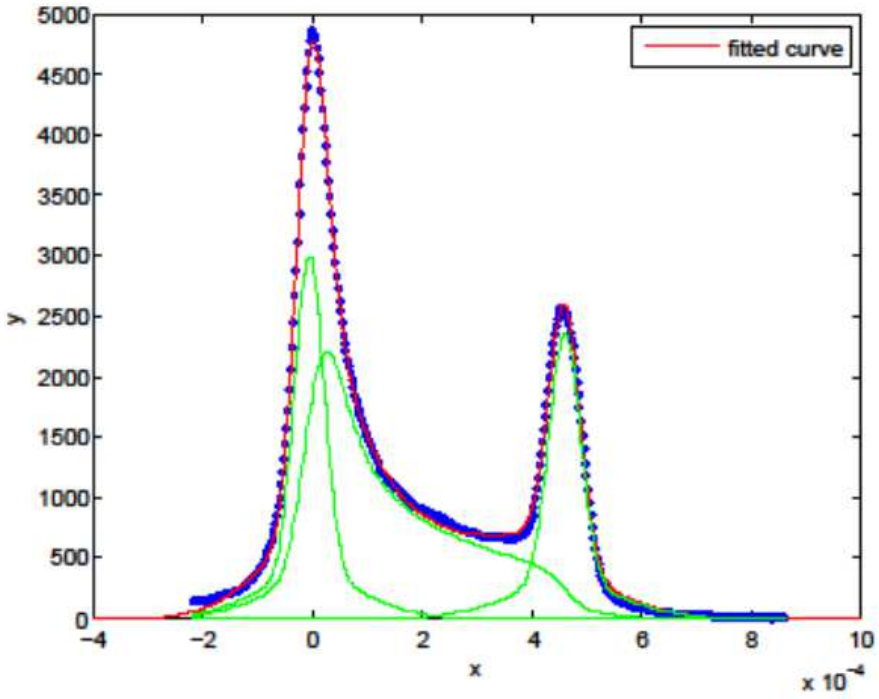
- L_{D1}=30 μm, L_{D2}="long" for 4.2 GeV data
- L_{D1}=6.9 μm, L_{D2}=75 μm for 10.5 GeV data…???

Very preliminary! Final conclusion not yet clear

4.2 GeV

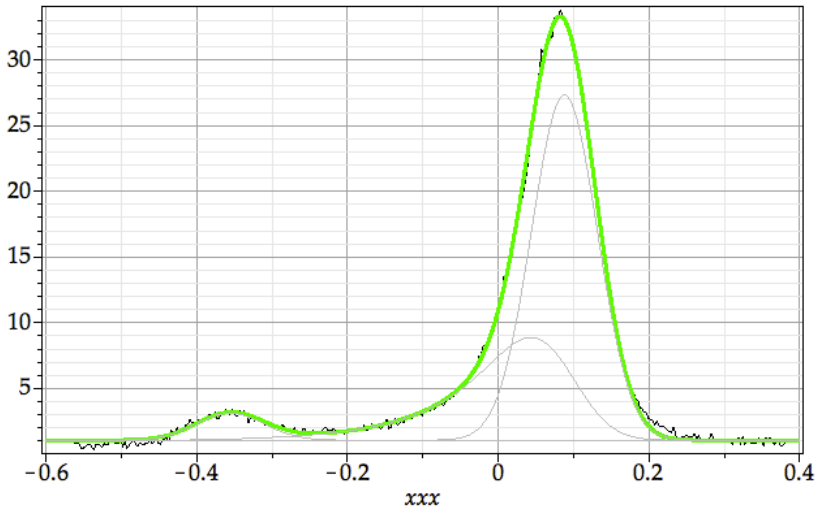


10.5 GeV

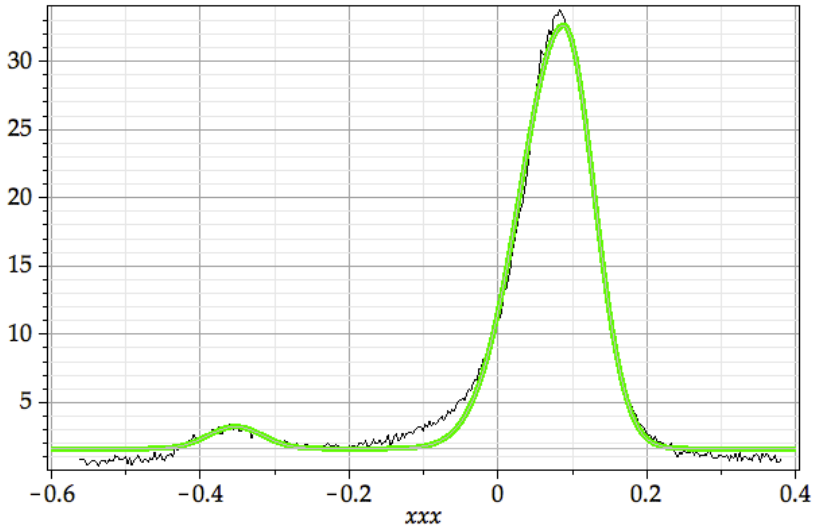


VR Efficiency (6.3 GeV)

- Fit with “universal function”
  - VR efficiency (main/all) is 63%.



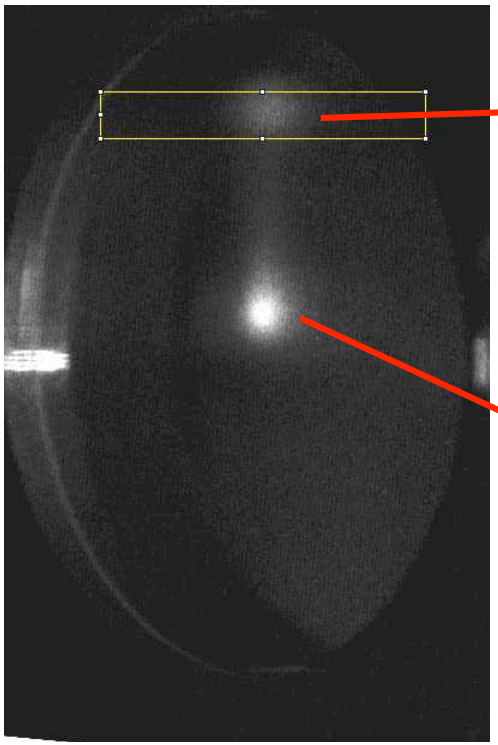
- Fit with asymmetric Gaussians
  - VR efficiency (main/both) is 96%.

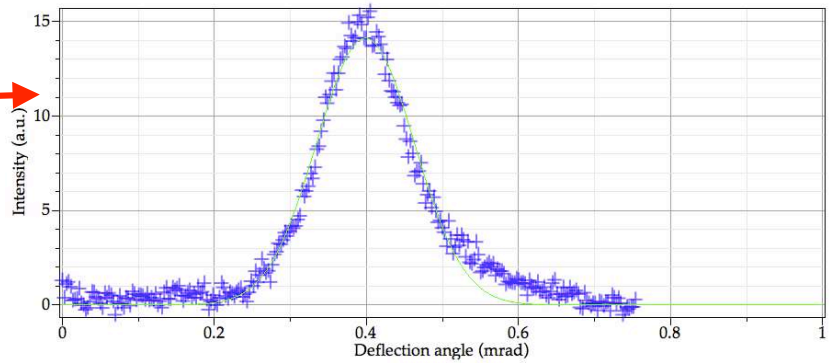


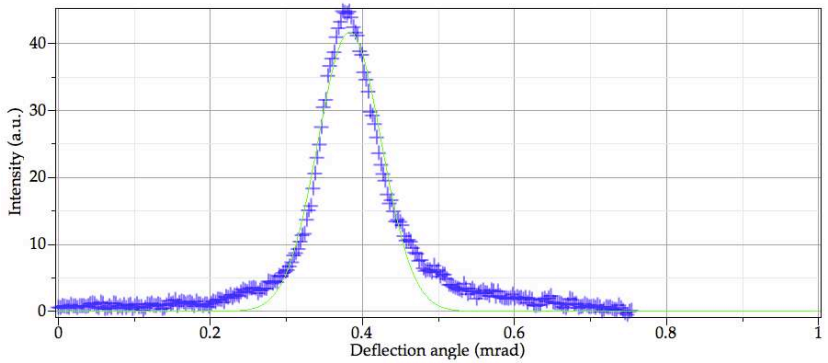
- ≈ 90% with deflection >0

Scattering of Channeled Beam

- Divergence widened by almost 1.5 in channeling (6.3 GeV)



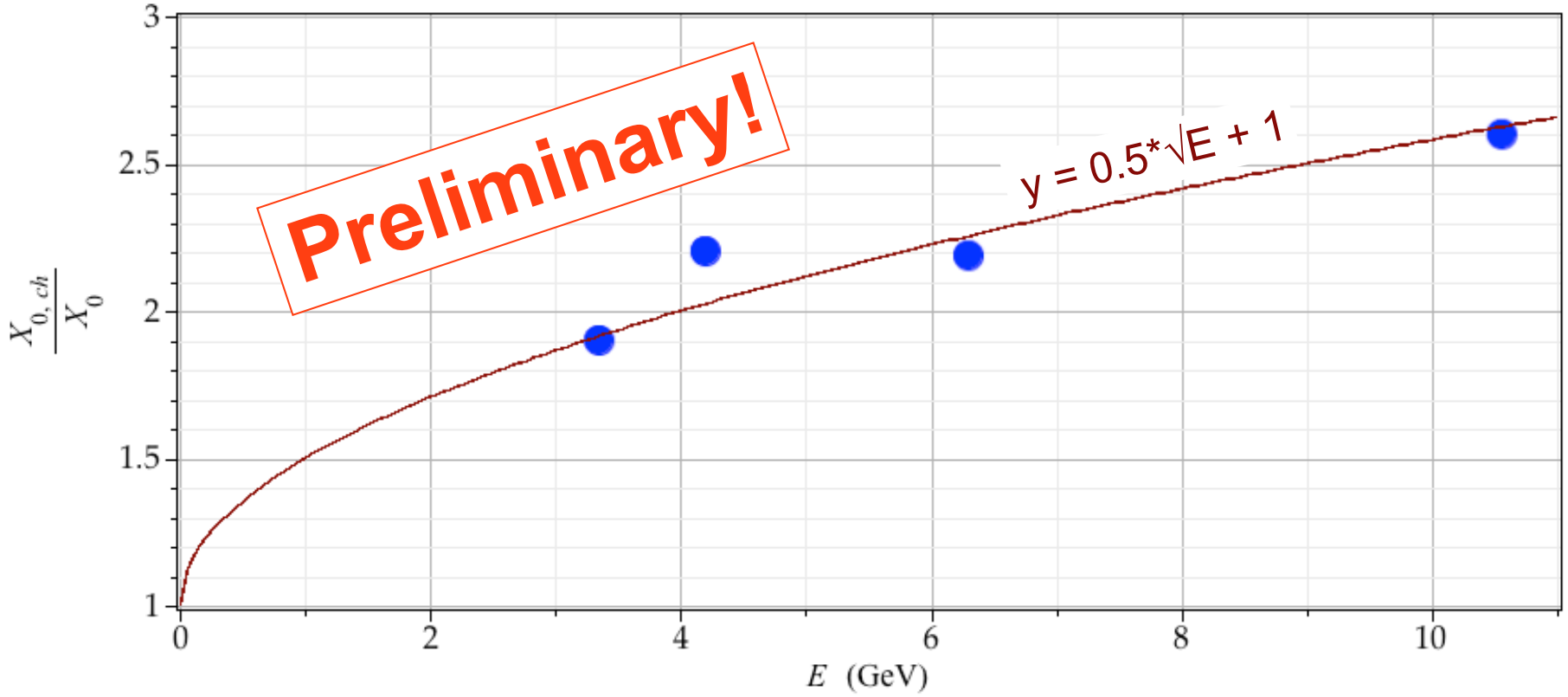




Scattering of Channeled Beam *vs* Energy

SLAC

- Widening of channeled beam/main beam
  - if multiple scattering, use modification of X_0 to parametrize
  - suggestive of √E relation, but not enough data to make claim



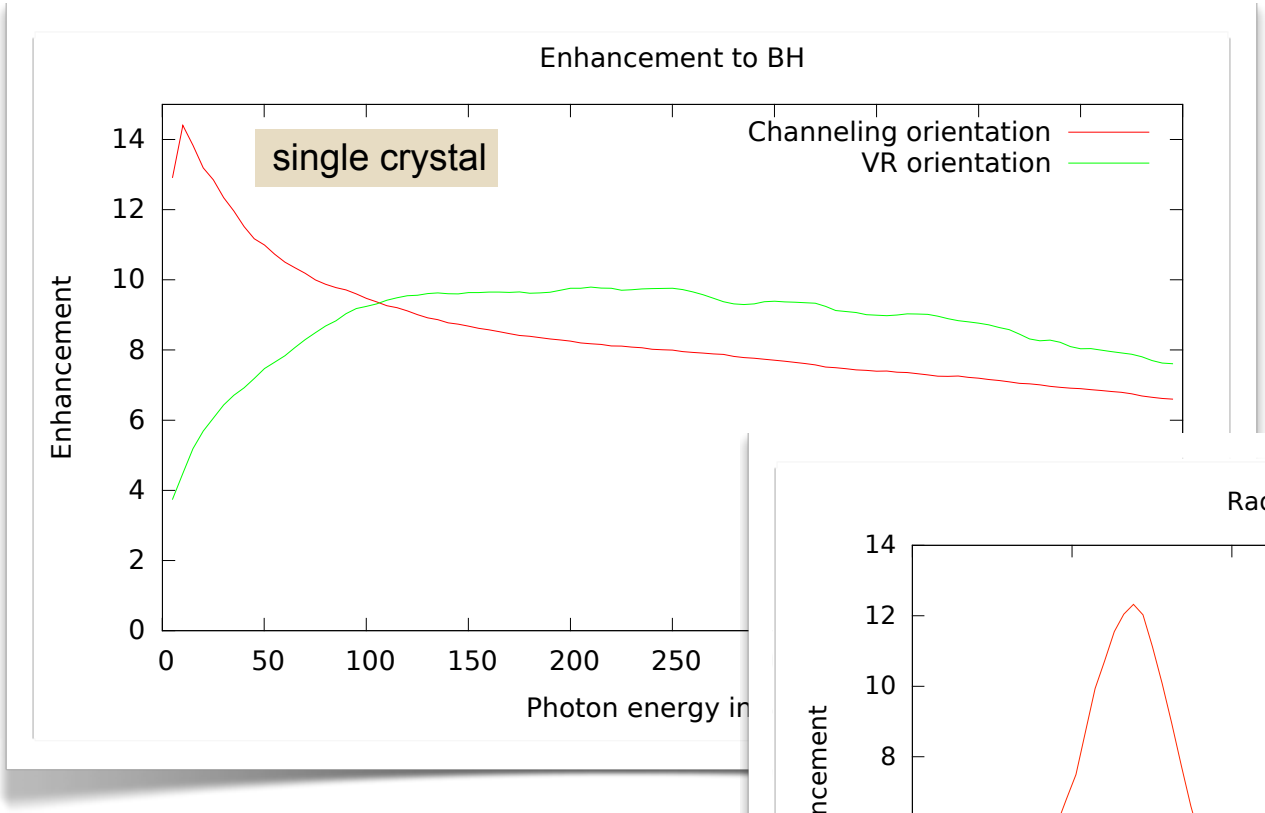
Summary of T513 Results

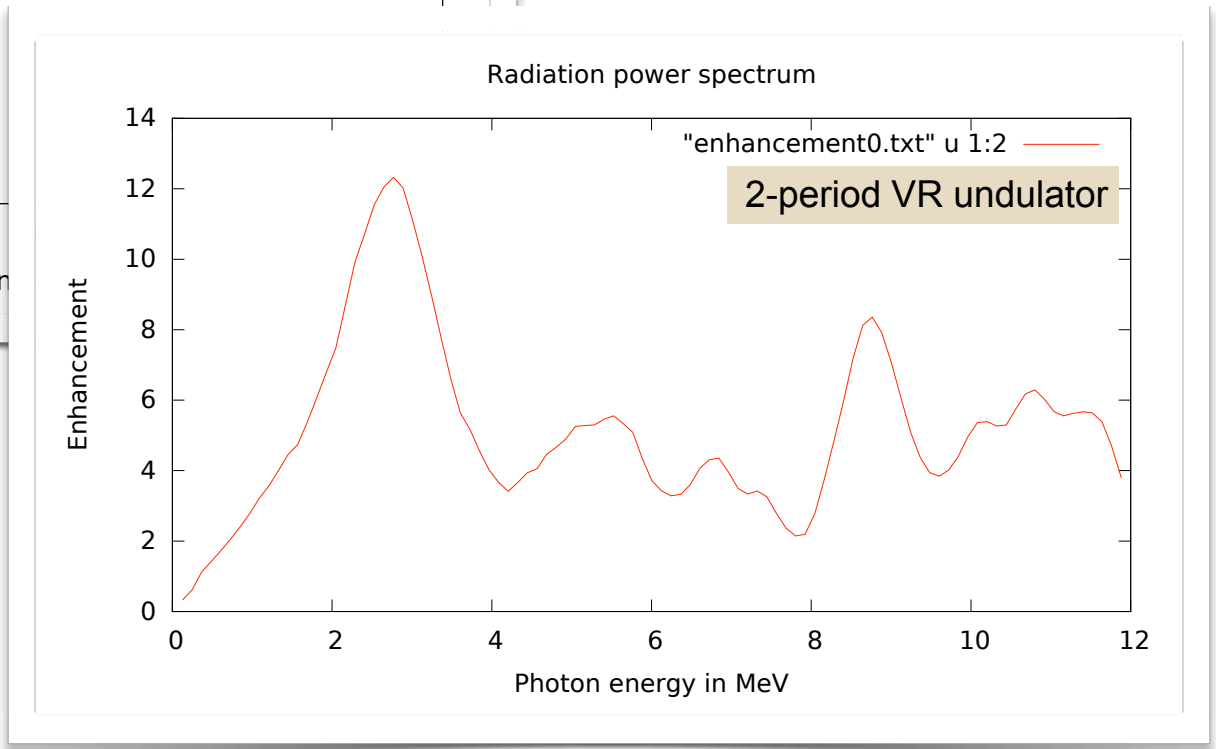
- Channeling efficiency ≈ 22 %, VR up to 95%
- Dechanneling length ≈ 30…40 μm
  - seem to be relatively independent of the beam energy
  - data suggest 2^{nd} component, nearly flat, re-channeling effect?
- Surface transmission 57% (6.3 GeV)…65% (3.35 GeV)
  - calc: 57% @ 6.3 GeV (Wistisen)
- Scattering seems enhanced in the vertical plane for channeled particles
  - In units of X_0: Factor 1.9 @ 3.35 GeV, 2.6 @ 10.5 GeV
    - positive correlation with energy
-

Plans

- There are two somewhat separate thrusts of T-513 successor experiments:
  - **e^- Beam collimation demonstration using a VR array**
    - Conceptually simple experiment but needs new crystals
      - good right at the edge
    - Additional stages being bought
  - **Radiation generation, characterize channeling and VR radiation** with an eye towards a γ-ray undulator.
    - T-513 crystal suitable for first exploration
    - need to come up with a suitable γ-ray detector.

Radiation Spectrum (6.3 GeV e^-, T. Wistisen)





Conclusion

- T-513 successfull beyond our initial expectations
  - Quantitative data suitable for benchmarking simulations etc.
- Promising avenues for successor experiments:
  - VR collimation
  - Radiation generation
    - Beam time promised, likely early 2015
- Synergy with E212 (Uggerhøj) @ FACET