First Results from beta-SRF - testing SRF samples at high parallel field

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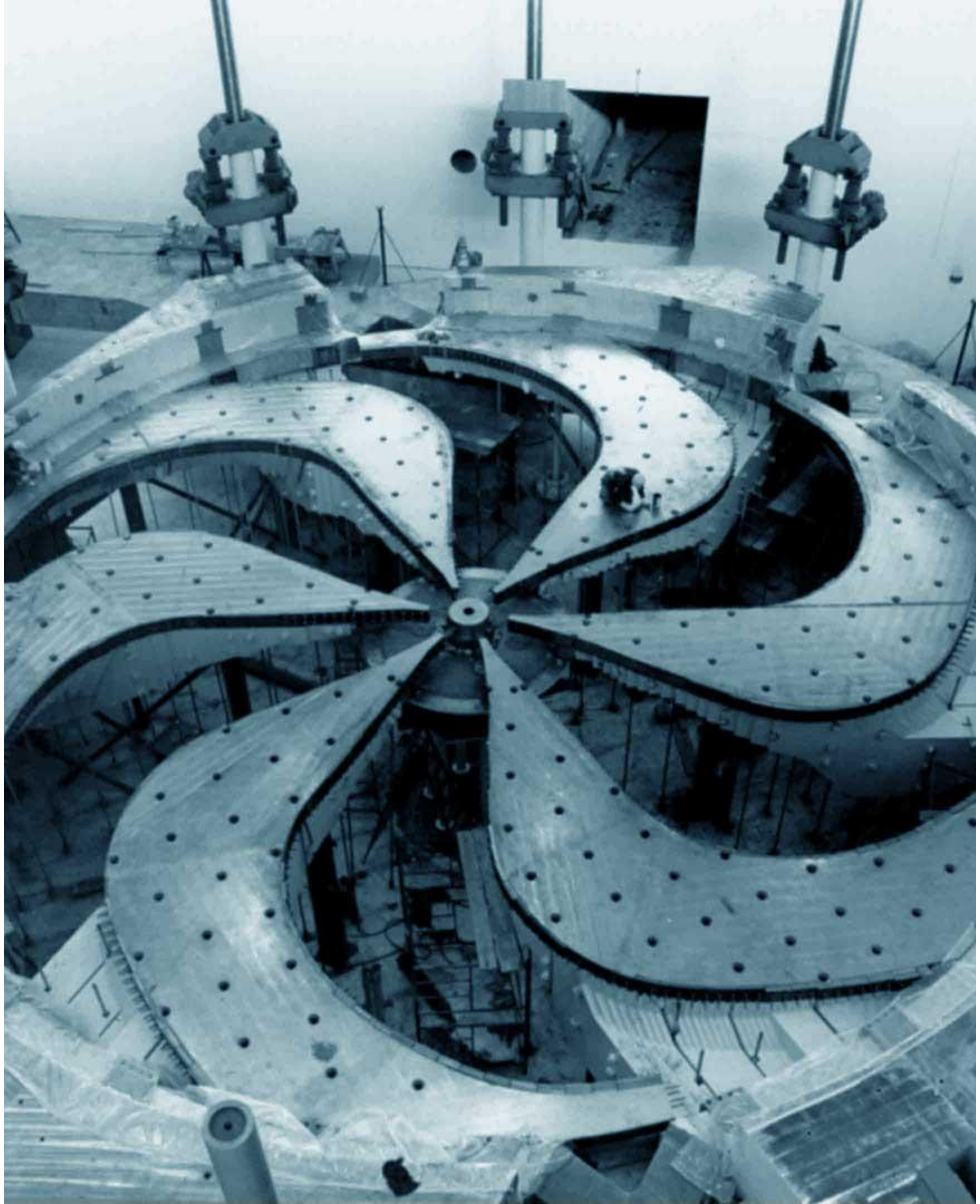
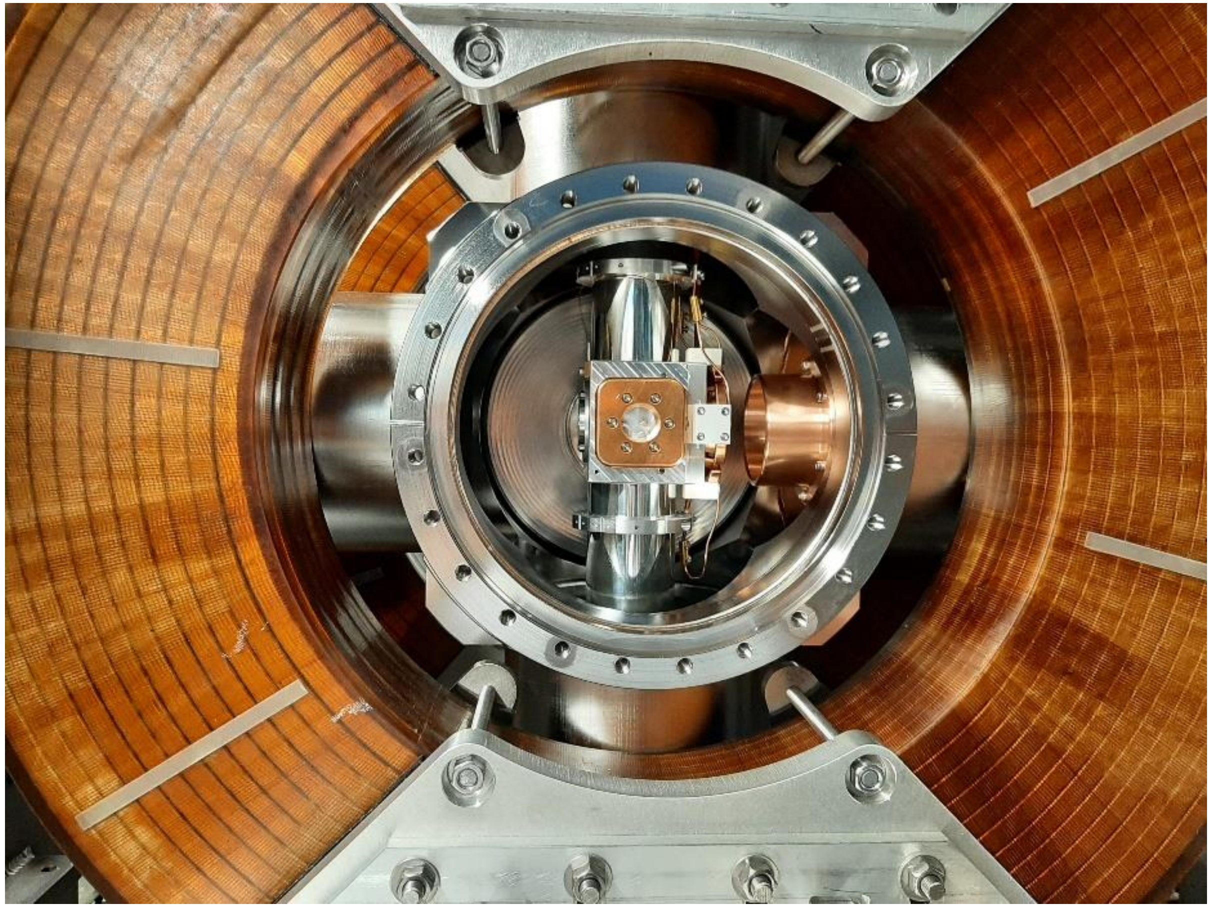


Discovery, accelerated

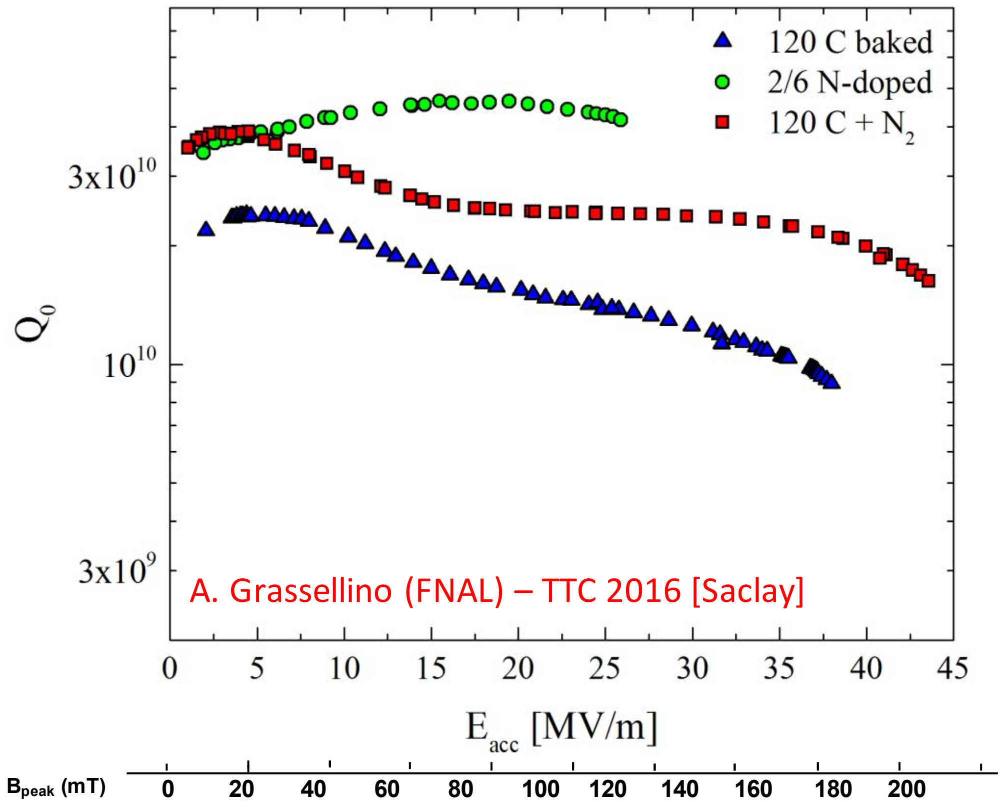
Outline

- Introduction/Motivation
- The beta-NMR Technique
- The New beta-SRF Facility
- Experimental Results
- Summary

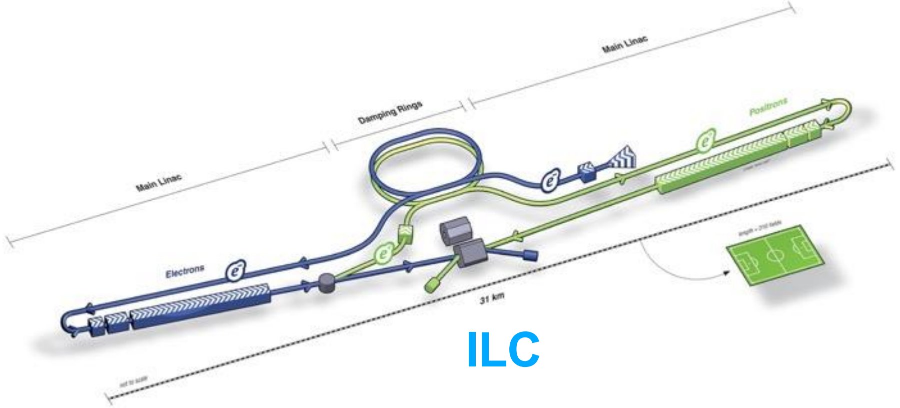


SRF Global Status

- **SRF Frontier** is **high Q** and **high gradient** → support existing + future project
- **Various Recipes**:
  - **Proven effective → Empirical**
  - **Modify the near surface**
- **Underlying mechanism ?**
  - **Develop better recipes**



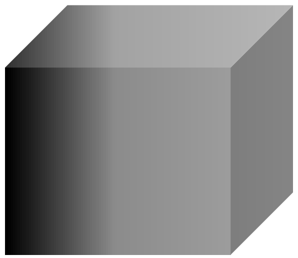
LCLS-II



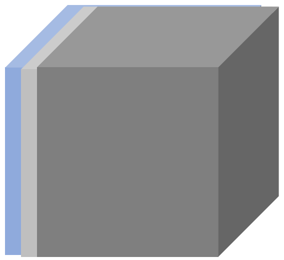
ILC

Role of the Surface

- For high gradient we need a material that can **withstand magnetic vortex penetration** (maintain **Meissner state)** up to a **high rf magnetic field** (**~200 mT**)
- Depends on surface modifications**:**
  - Customized **heat treatments** are being developed that alter the near surface
  - **Layered structures** are proposed to increase the field of first vortex penetration

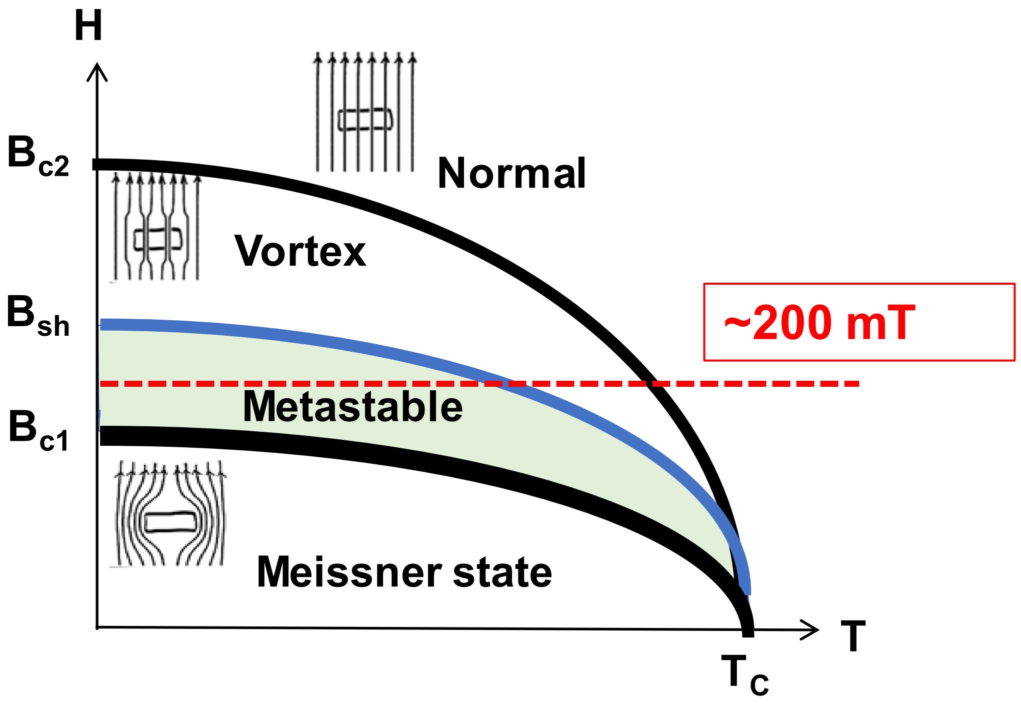


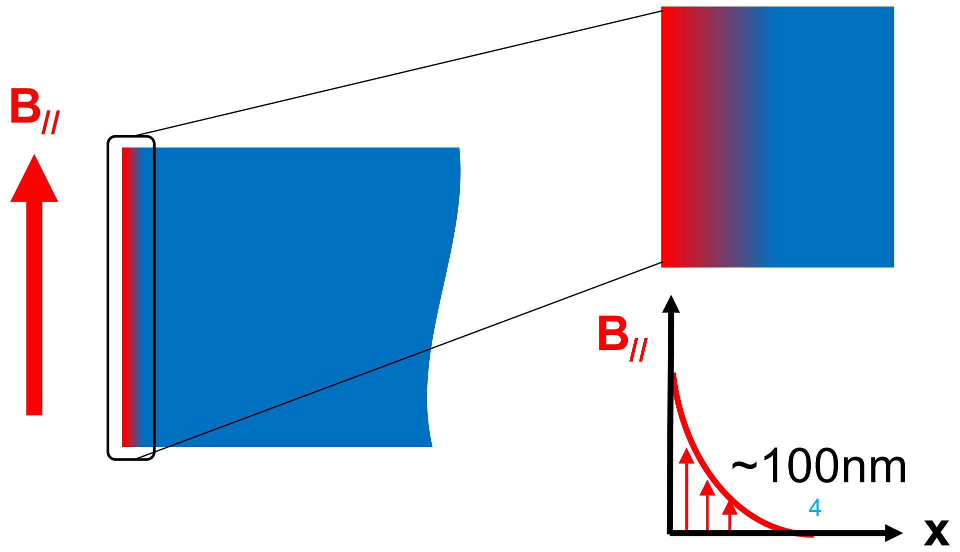
Heat treatments



Layers

Need a surface probe that can diagnose magnetic screening in the London layer (~100 nm) at fields up to 200 mT



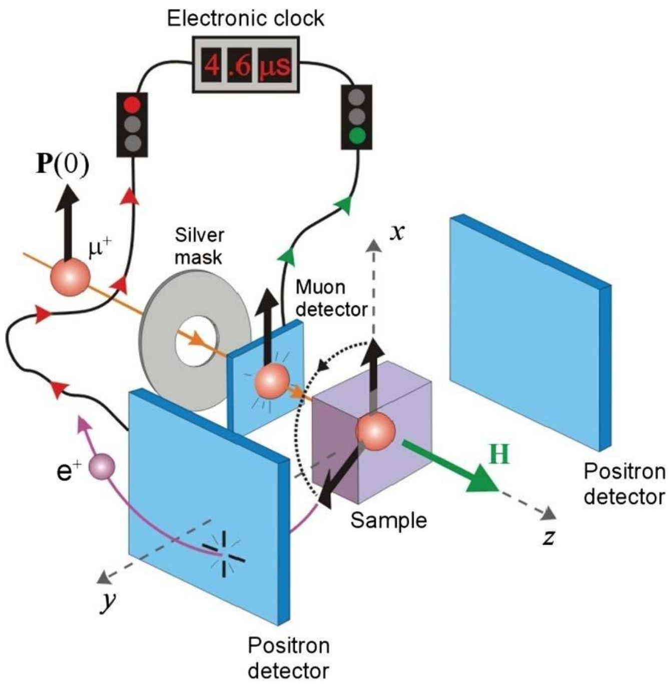


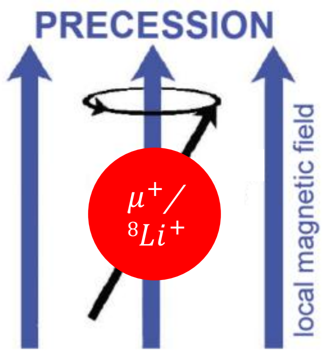
Material Probes – μSR & β-NMR

- TRIUMF has **<u>two world class material science probes</u>** in **<u>μSR and β-NMR</u>**
- Similarities:

  embed a beam of polarized muons or 8Li ions + monitor the β-decay as probes of local magnetic fields.

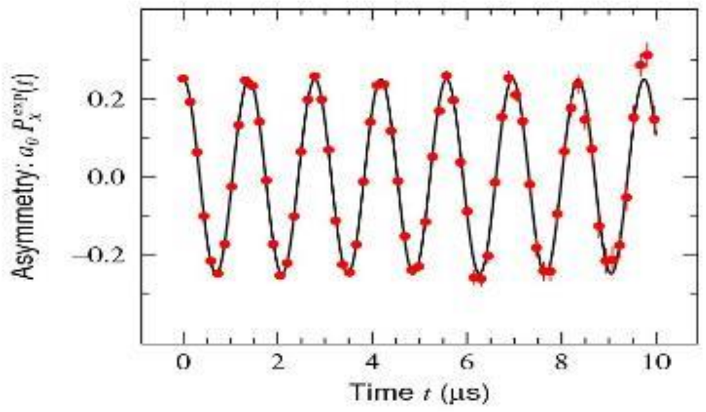
- Different capabilities:
  - TRIUMF HE-μSR: bulk probe (100μm)
  - TRIUMF β-NMR: surface probe (0 – 100nm)





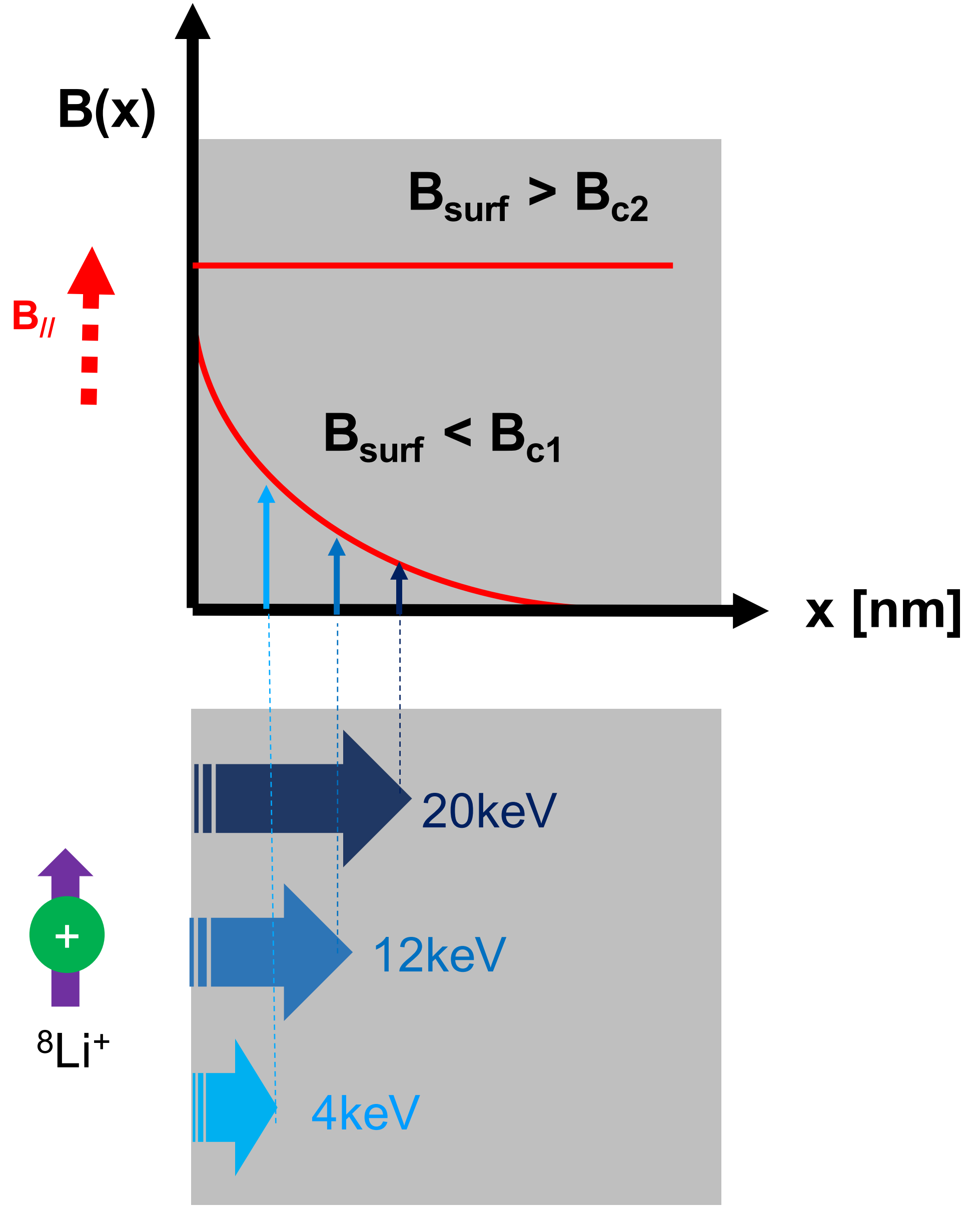
$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$^{8}\mathrm{Li}^+ \rightarrow e^- + \nu_e + {}^{8}\mathrm{Be}$



The beta-NMR Method

βNMR Facility: Depth controlled probe of local magnetic field



Measure field screening in surface layer:

- Implanting spin-polarized $^{8}Li^{+}$ (vary E)
- Monitor rate of at which spin depolarizes → depends on local fields

Available facilities before upgrade:

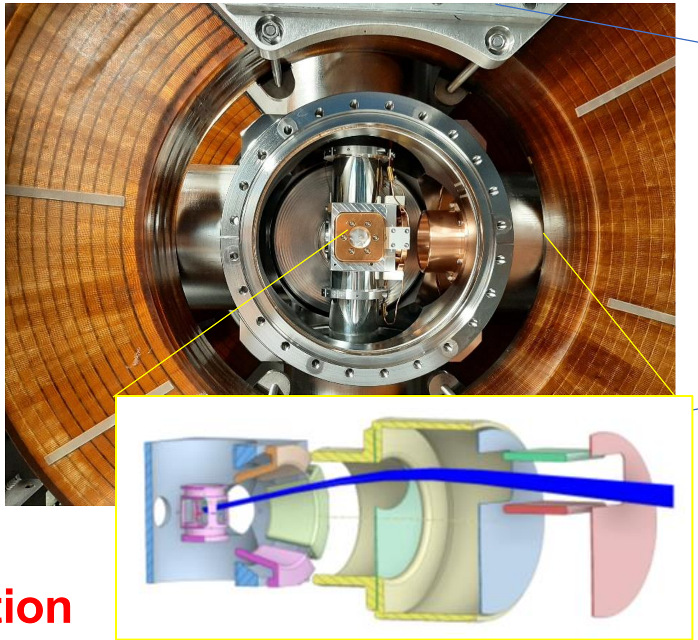
- *β*NMR (and LE-muSR PSI)
  - ✓ Depth-control (nm) scale by varying ion energy
  - χ Limited to Low (parallel) fields: ~ 24-30 mT

Upgrade challenge:

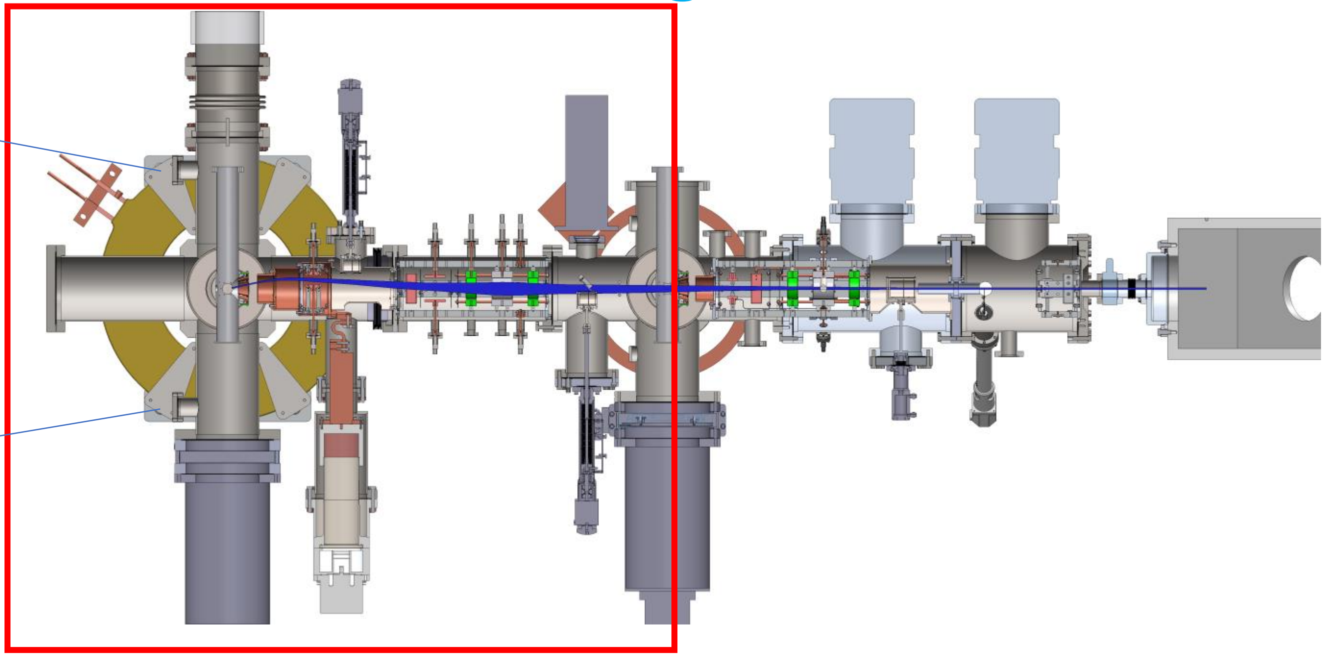
- Want high parallel fields near B_{c1} of Nb → 200 mT
- Low energy beam (depth-control) + strong fields parallel to sample surface → **large transverse deflection (much more difficult with LE-μSR)**

βNMR High-parallel-field Upgrade & Commissioning

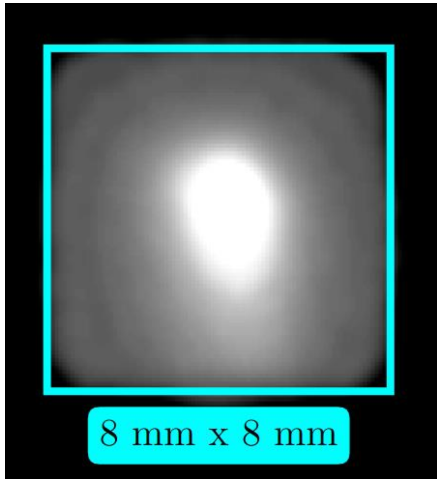
200 mT Magnet



Strong deflection



Added ~1 m beamline



Upgrade for SRF Studies:

- New 200 mT coils
- Transverse deflection compensation: new beamline optics + diagnostics

Depth-resolved measurements now possible at high-parallel-field.

Beamline + Optics Commissioned

- Beam successfully transported up to 200 mT

Measurements Completed

- First SRF measurements up to 200 mT

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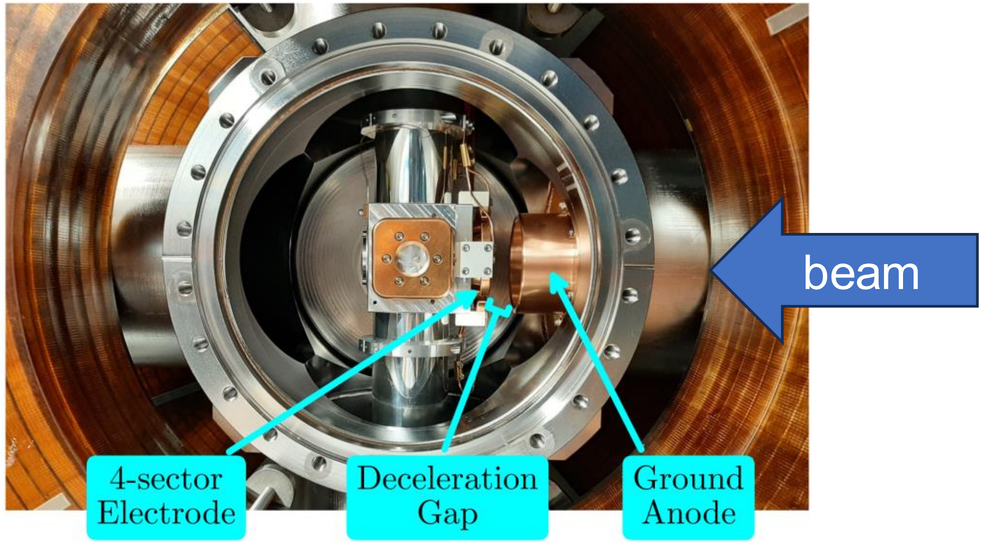
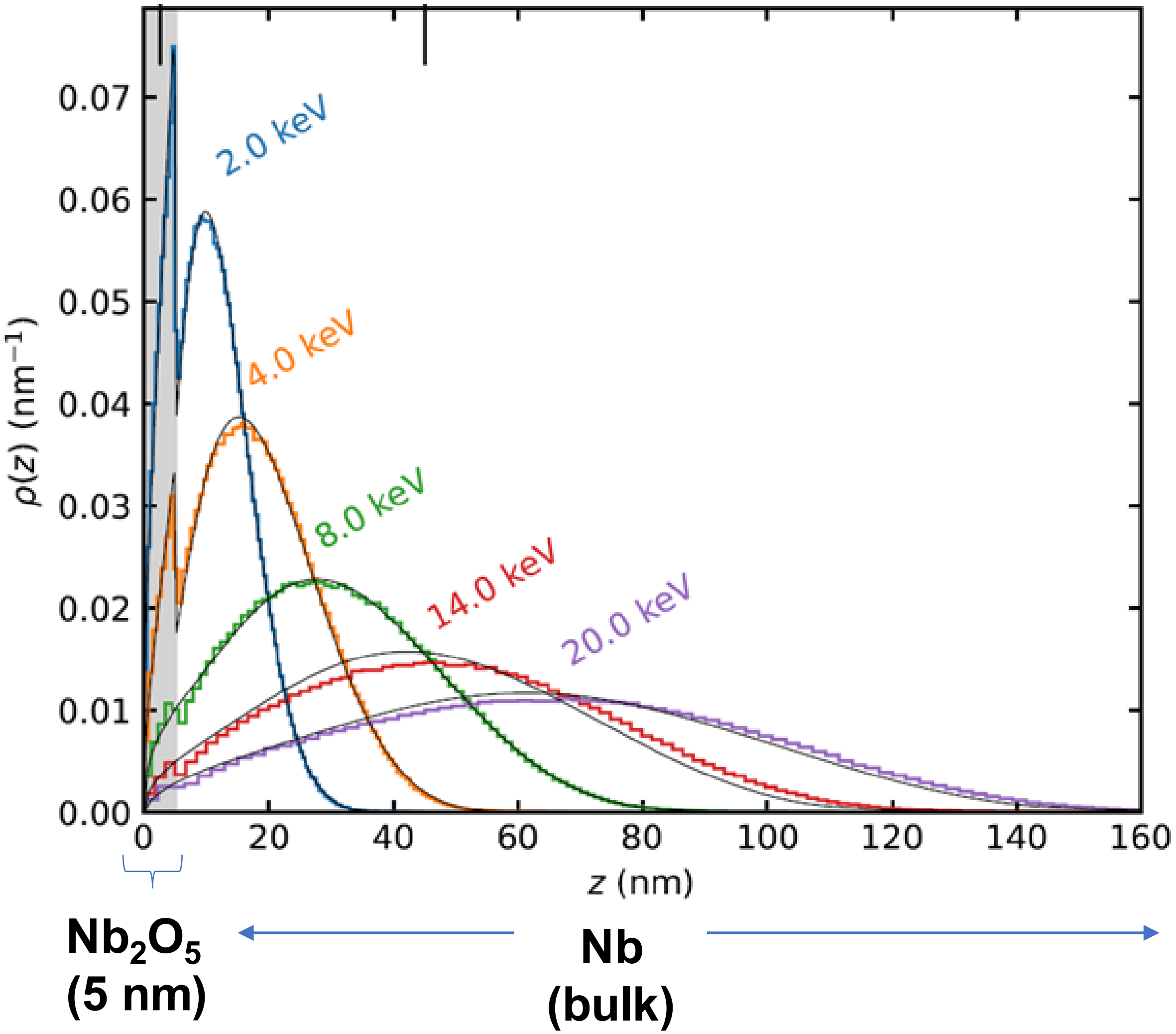
Depth Resolved: Beam Implantation

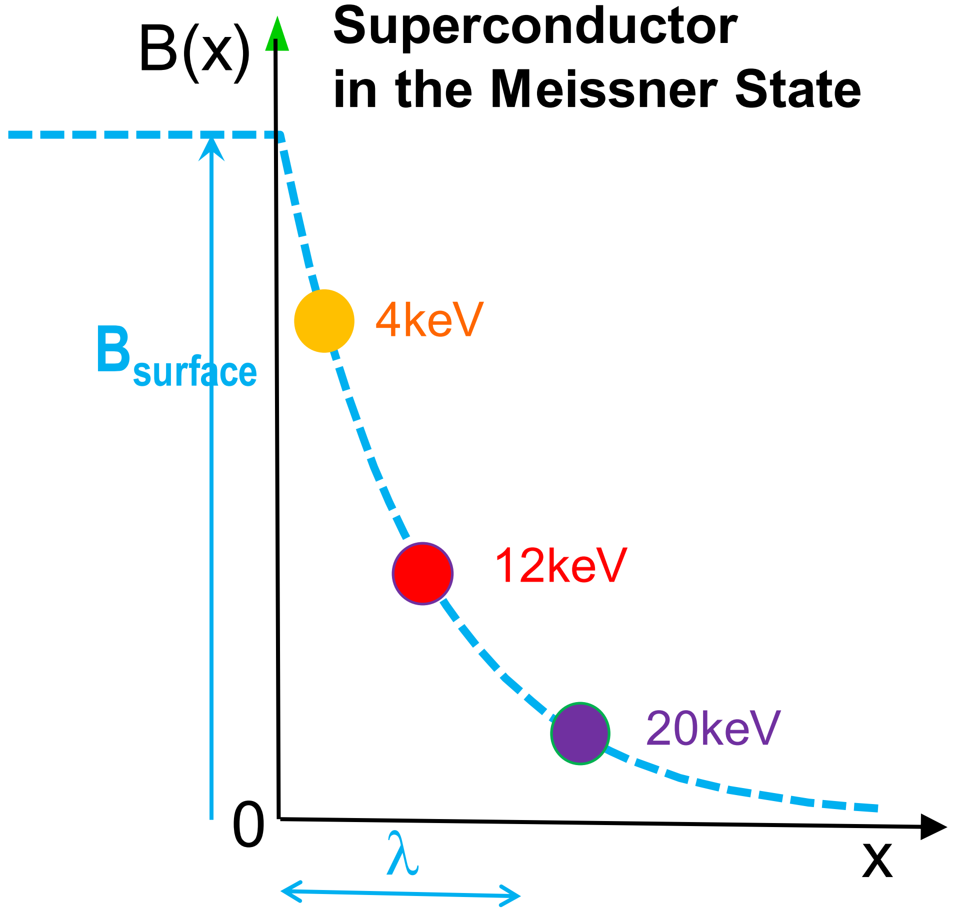
Depth control:

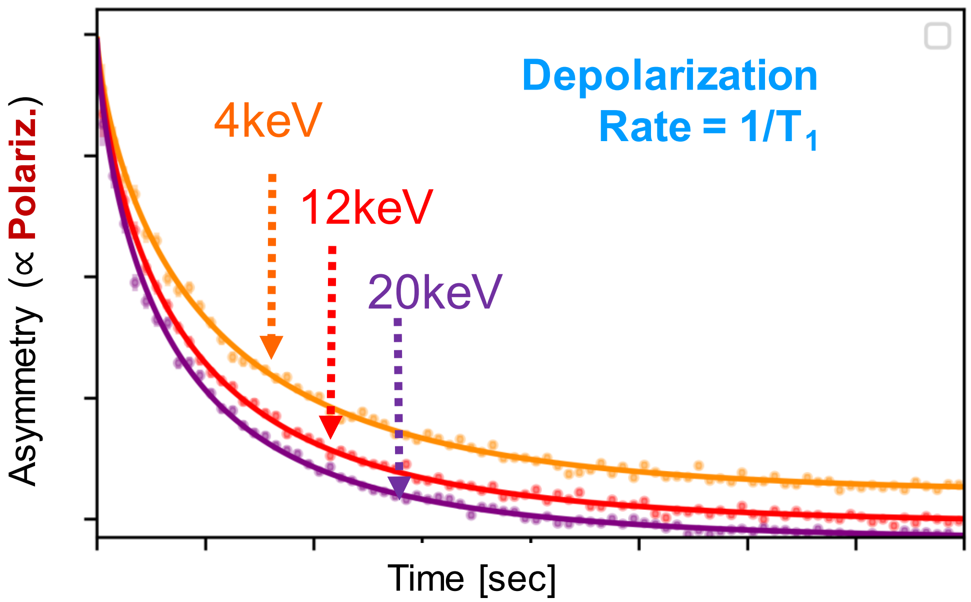
- Incoming (radioactive) beam with constant Energy, e.g., 20 keV
- Samples are HV biased.

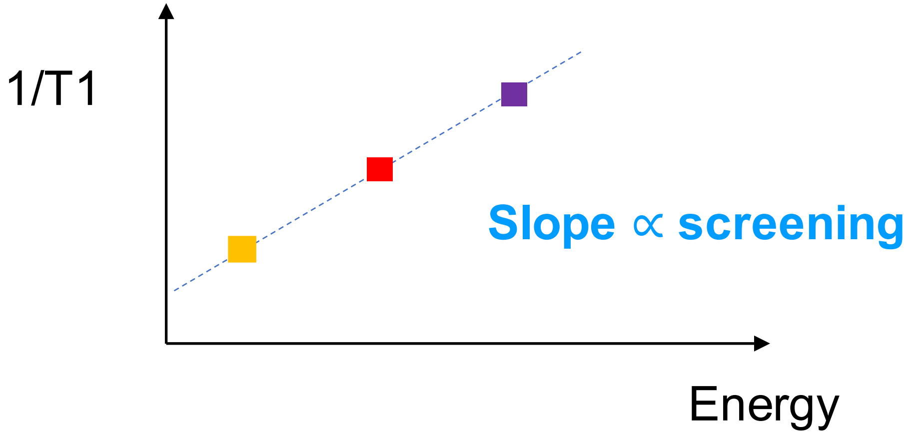




Local Field: Spin-Lattice-Relaxation







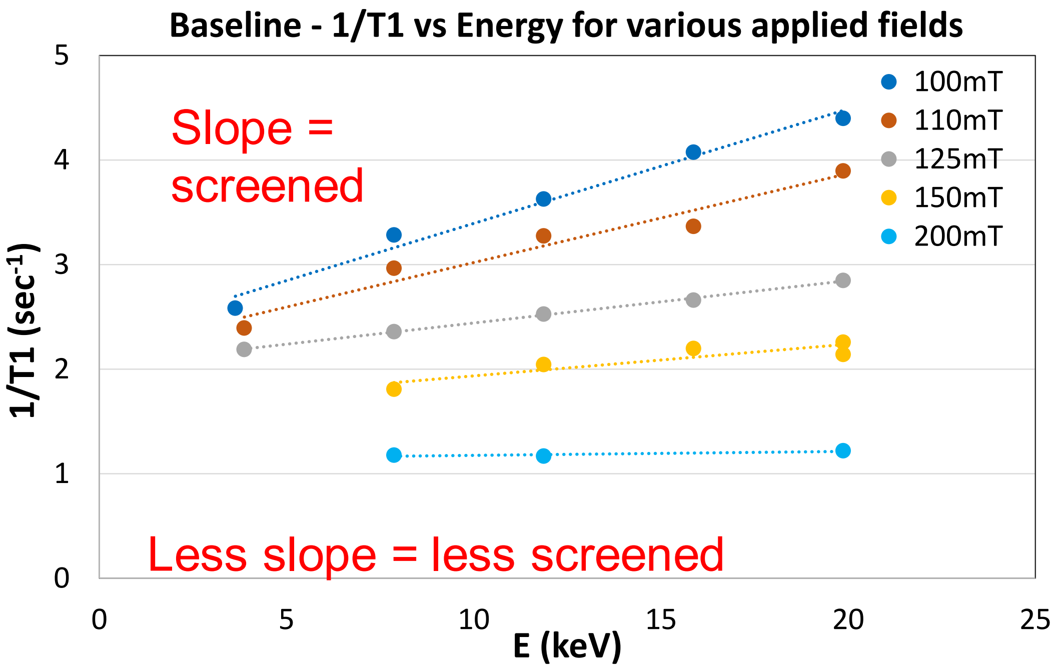
$$\frac{1}{T1} = \frac{a}{b + < B_{loc} >^2}$$

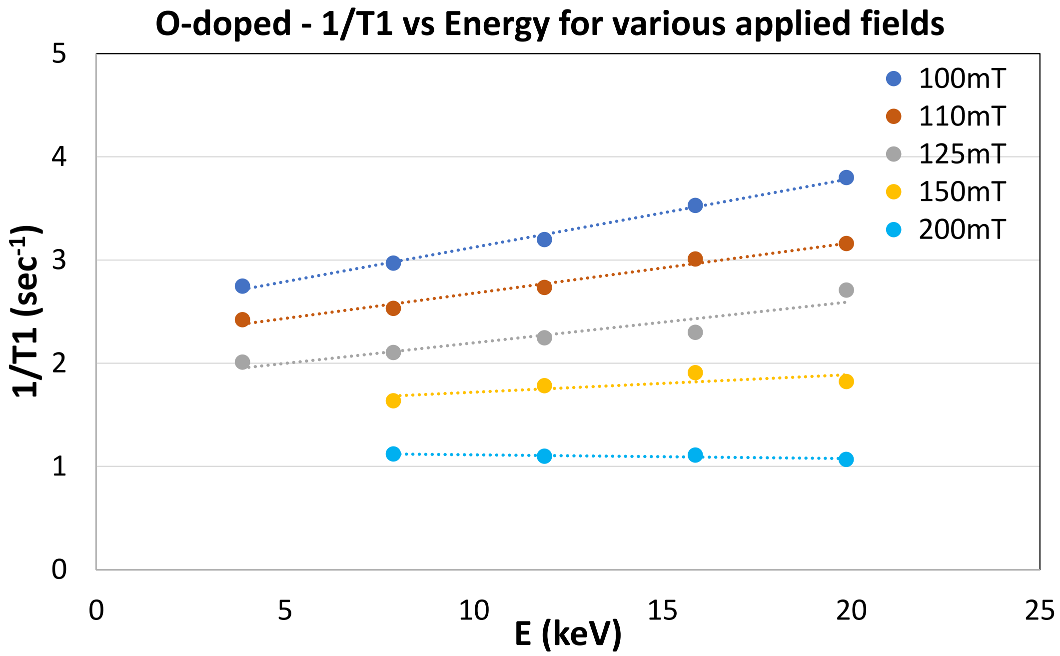
Experimental Results

Field Scans up to 200 mT

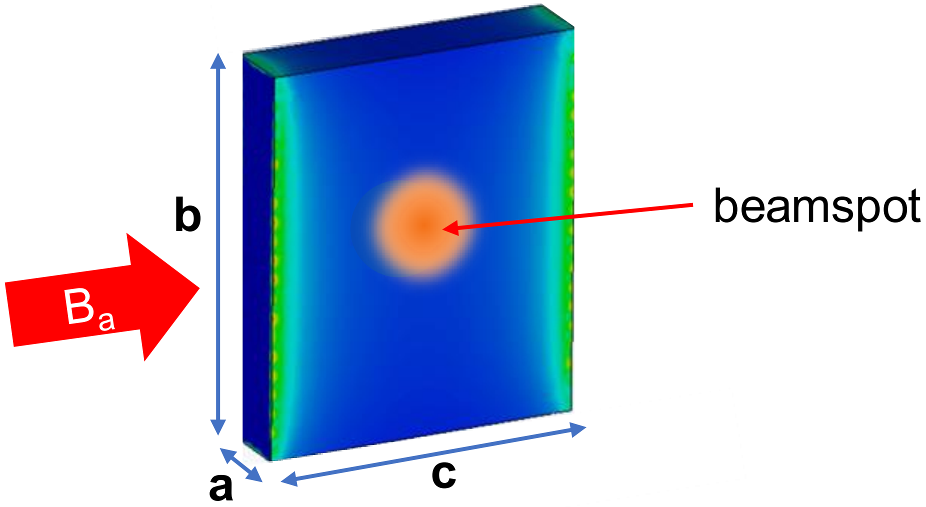
- **Two Nb samples:** RRR Niobium
  - **Baseline**: 1400 ^{o}C annealing for 4 hours + BCP
  - Custom treated with mid-T bake (“**oxygen doping**”): Same as baseline **+ 400^{o}C for 3 hours**
- **Field screening profile measured as a function of the applied field**
  - **B(x; $B_{applied}$ = 100 → 200)**

Sample ladder





Sample 1: Baseline

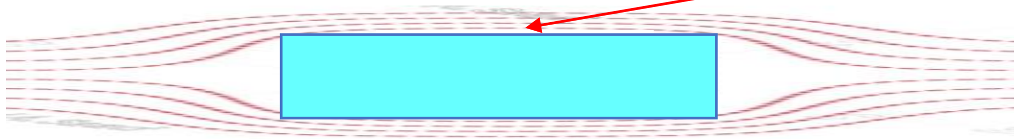


Geometry effects

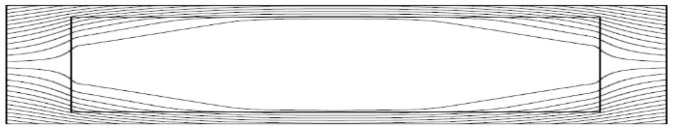
- **Slabs**
  - w/ dimensions: a x b x c = 1.8 x 8.1 x 9.8 mm
- **Surface enhancement**
  - over a 4 mm beam spot - $\mathbf{B_{surface}} / B_{applied} = 1.07$
- **Flux entry**
  - expected at $\mathbf{B_{entry}} = B_{c1} \times tanh\left(\sqrt{0.36 * c/a}\right) = 0.885\, B_{c1}$ (E.H. Brandt, Physica C, 2000)

➢ Assuming @ T=0K: B_{c1}=180mT

→ @ T=4.5K: B_{c1}=137mT and $\mathbf{B_{entry}}$=121mT

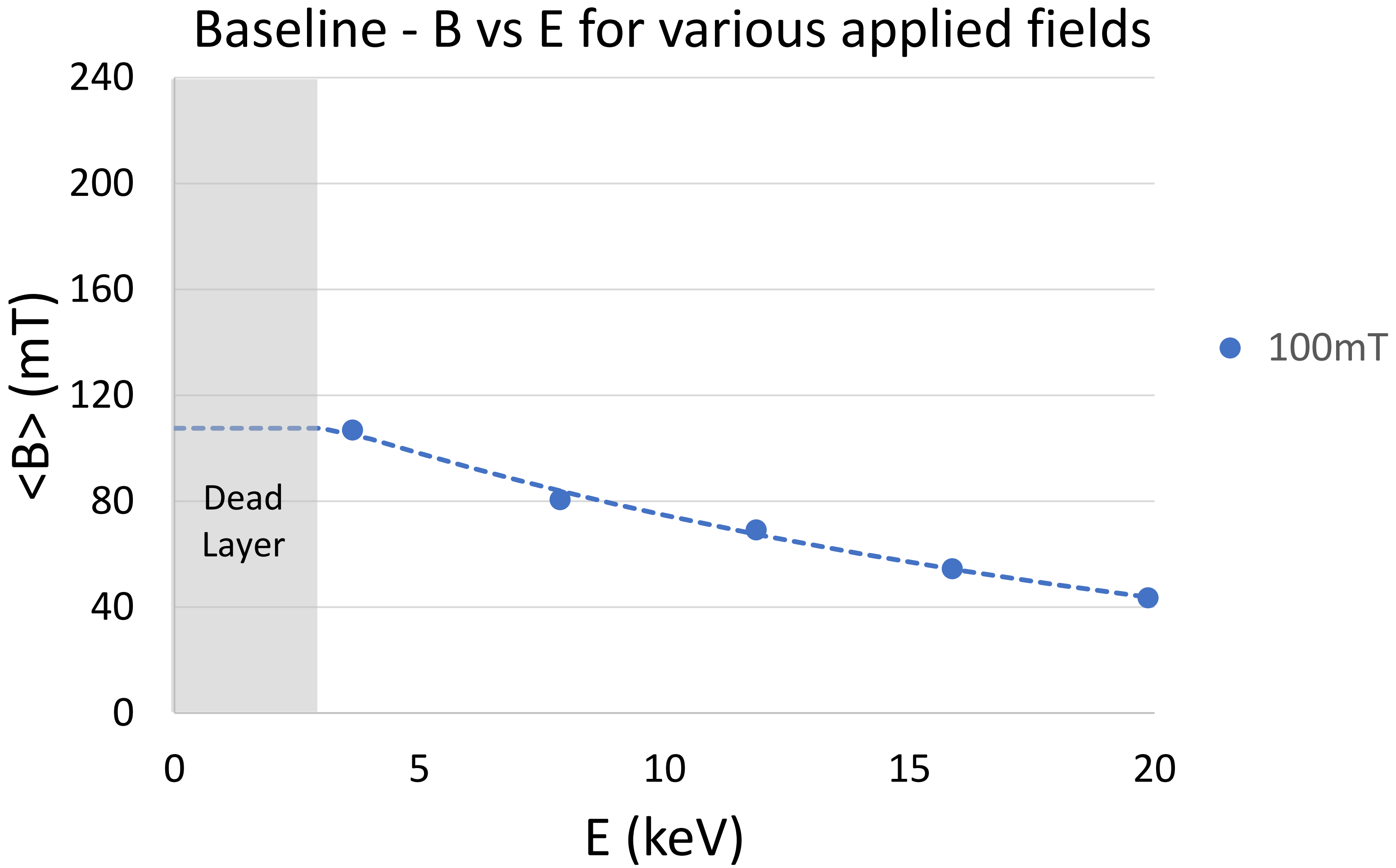


$B_{applied} < B_{entry}$



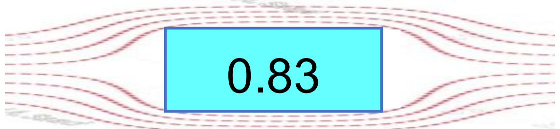
$B_{applied} = B_{entry}$

Sample 1: Baseline



B_{app}	B_{surf}/B_{app}	B_{app}/B_{entry}	SPD
(mT)	-	-	(nm)
100	1.07	0.83	40

SPD = Screening profile depth



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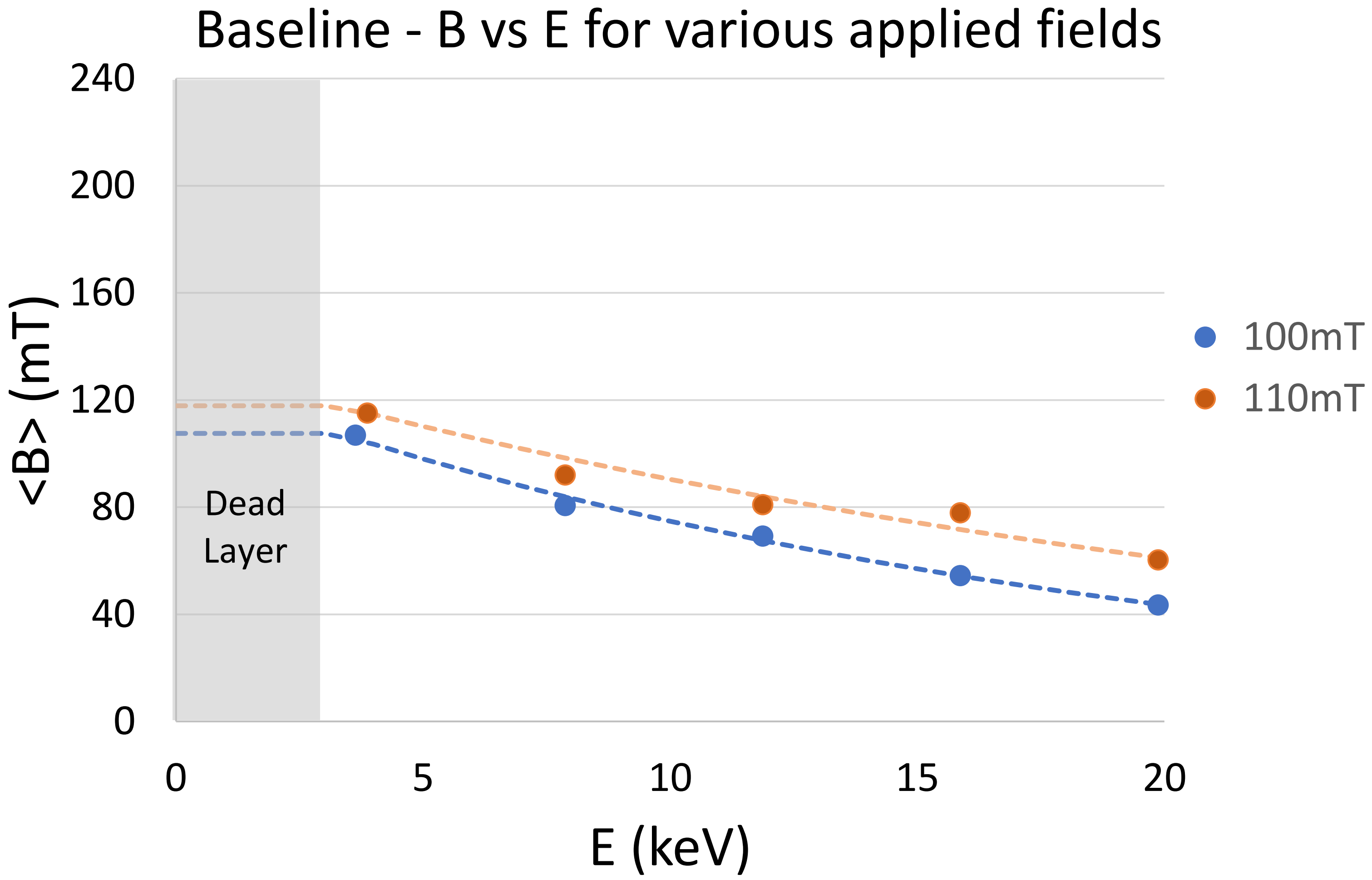
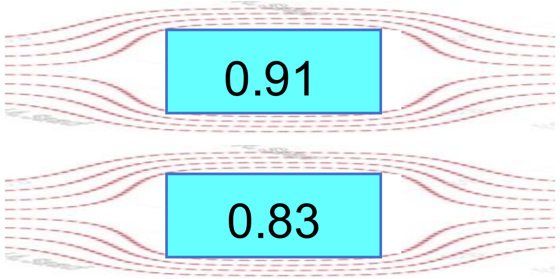


B_{app}	B_{surf}/B_{app}	B_{app}/B_{entry}	SPD
(mT)	-	-	(nm)
100	1.07	0.83	40
110	1.07	0.91	59

SPD = Screening profile depth



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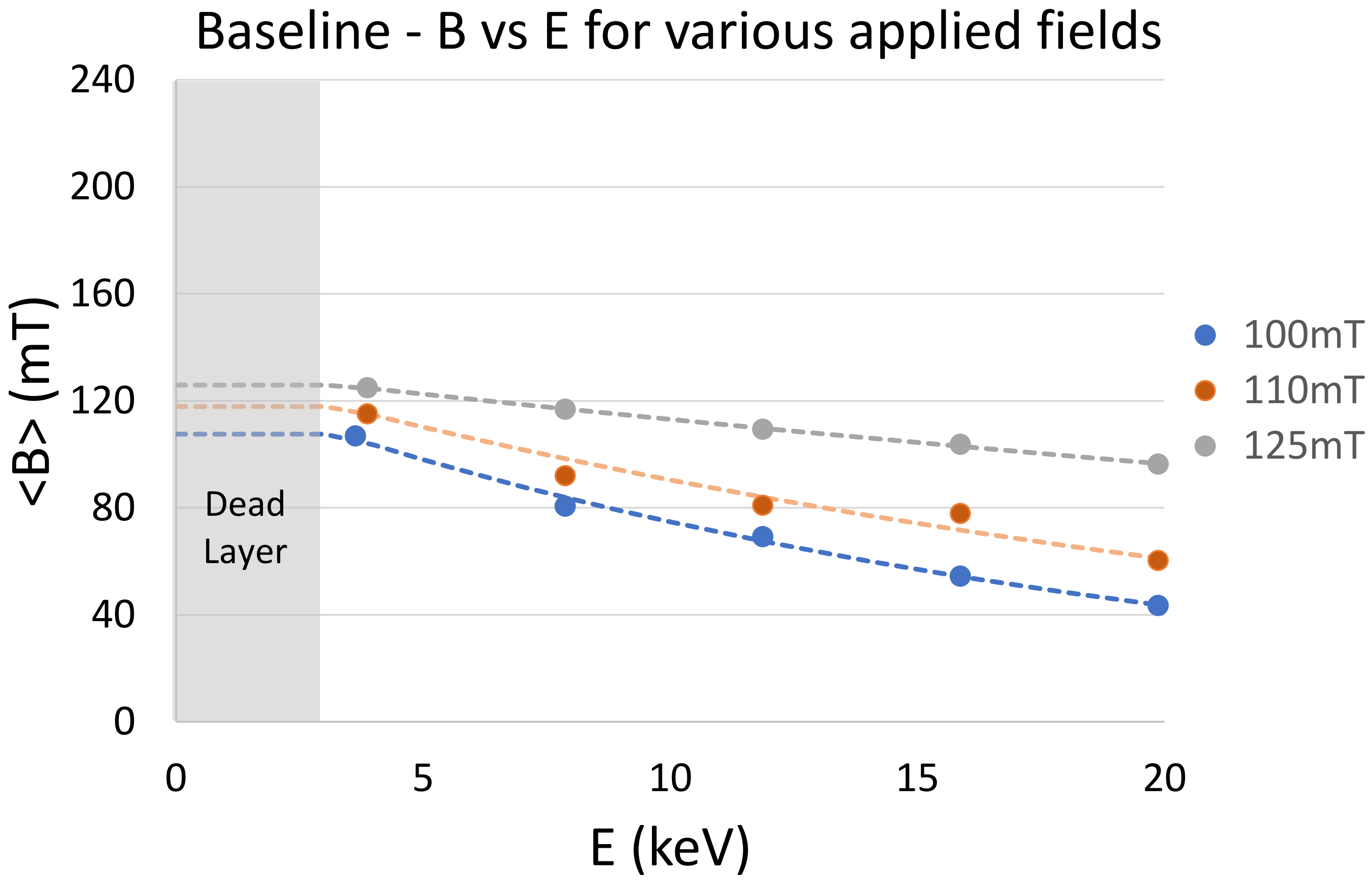

B_{app}	B_{surf}/B_{app}	B_{app}/B_{entry}	SPD
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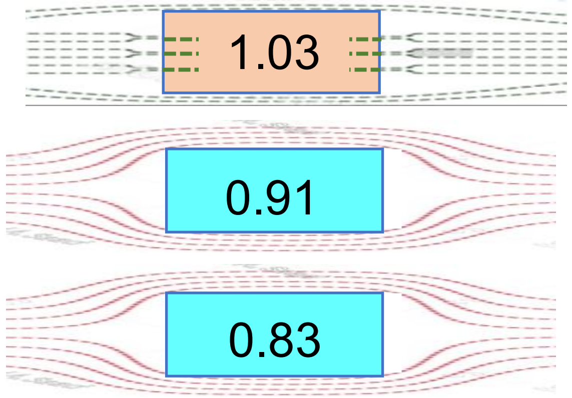
100	1.07	0.83	40
110	1.07	0.91	59
125	1.01	1.03	167

SPD = Screening profile depth



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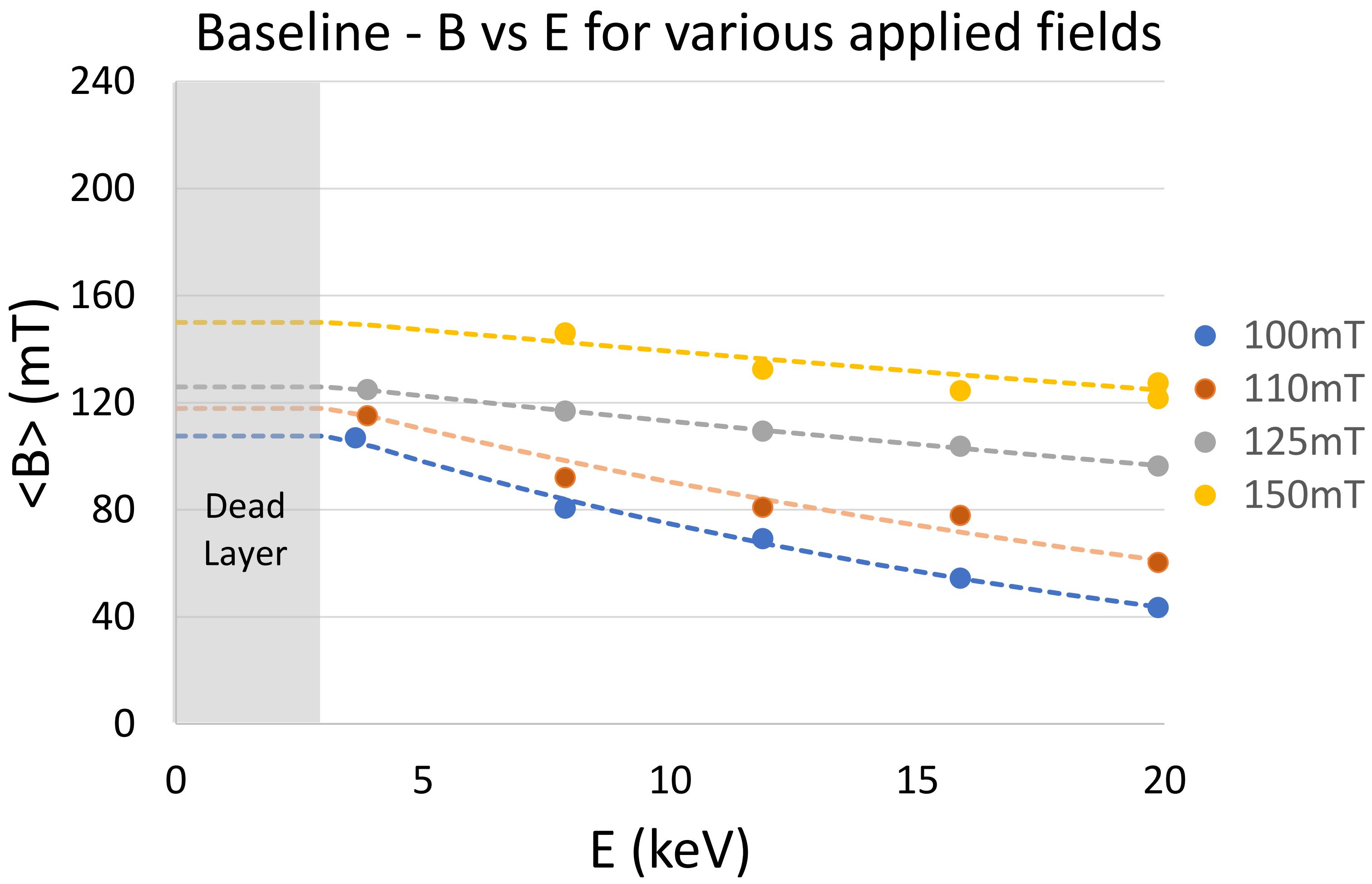
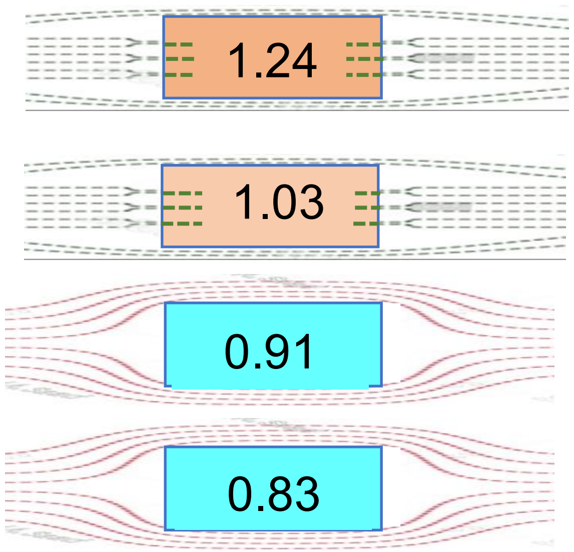
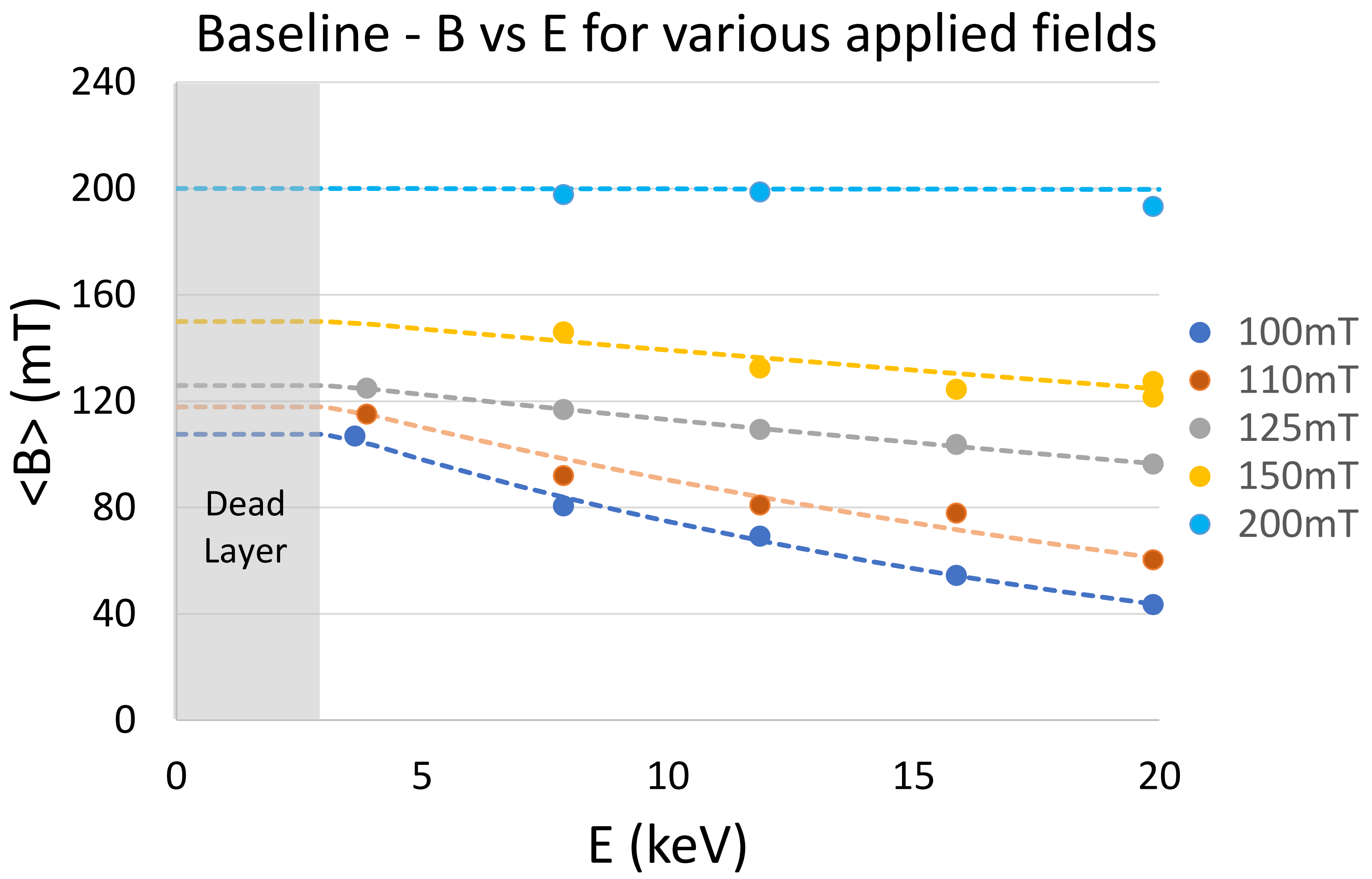


B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.07	0.83	40
110	1.07	0.91	59
125	1.01	1.03	167
150	1.00	1.24	250

SPD = Screening profile depth

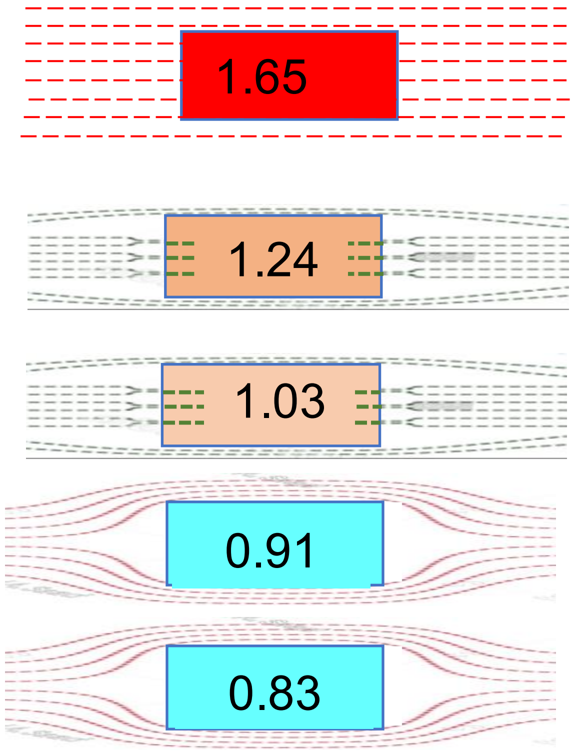


Sample 1: Baseline



B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.07	0.83	40
110	1.07	0.91	59
125	1.01	1.03	167
150	1.00	1.24	250
200	1.00	1.65	NA

SPD = Screening profile depth



Sample 2: O-doped (mid-T)

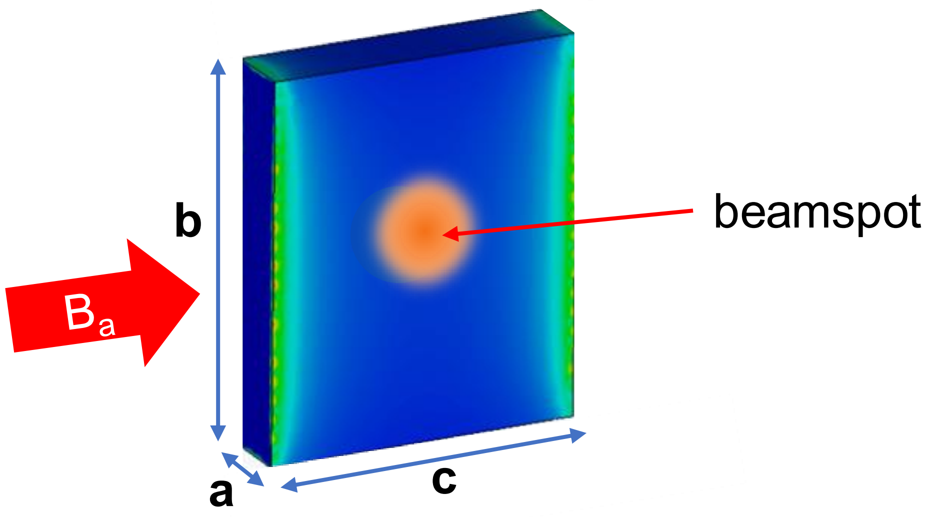
Geometry effects:

Same analysis, slightly different geometry

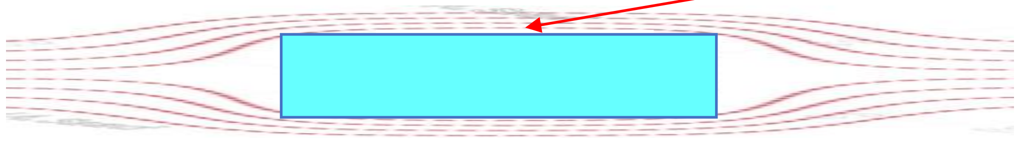
- **Slabs**
  - w/ dimensions: a x b x c = 1.7 x 12.5 x 12.6 mm
- **Surface enhancement**
  - over a 4 mm beam spot - $\mathbf{B_{surface}}$ / $B_{applied}$ = 1.04
- **Flux entry**
  - expected at [(E.H. Brandt, Physica C, 2000)]:
    $\mathbf{B_{entry}} = B_{c1} \times \; tanh\left(\sqrt{0.36 * c/a}\right) = 0.926\, B_{c1}$

➢ Assuming @ T=0K: B_{c1}=180mT

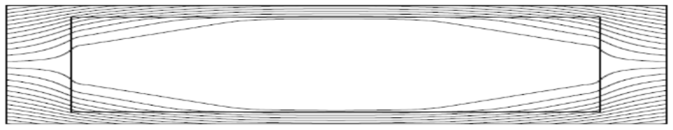
→ @ T=4.5K: B_{c1}=137mT and $\mathbf{B_{entry}}$=127mT



$\mathbf{B_{surf}}$
(at beamspot)

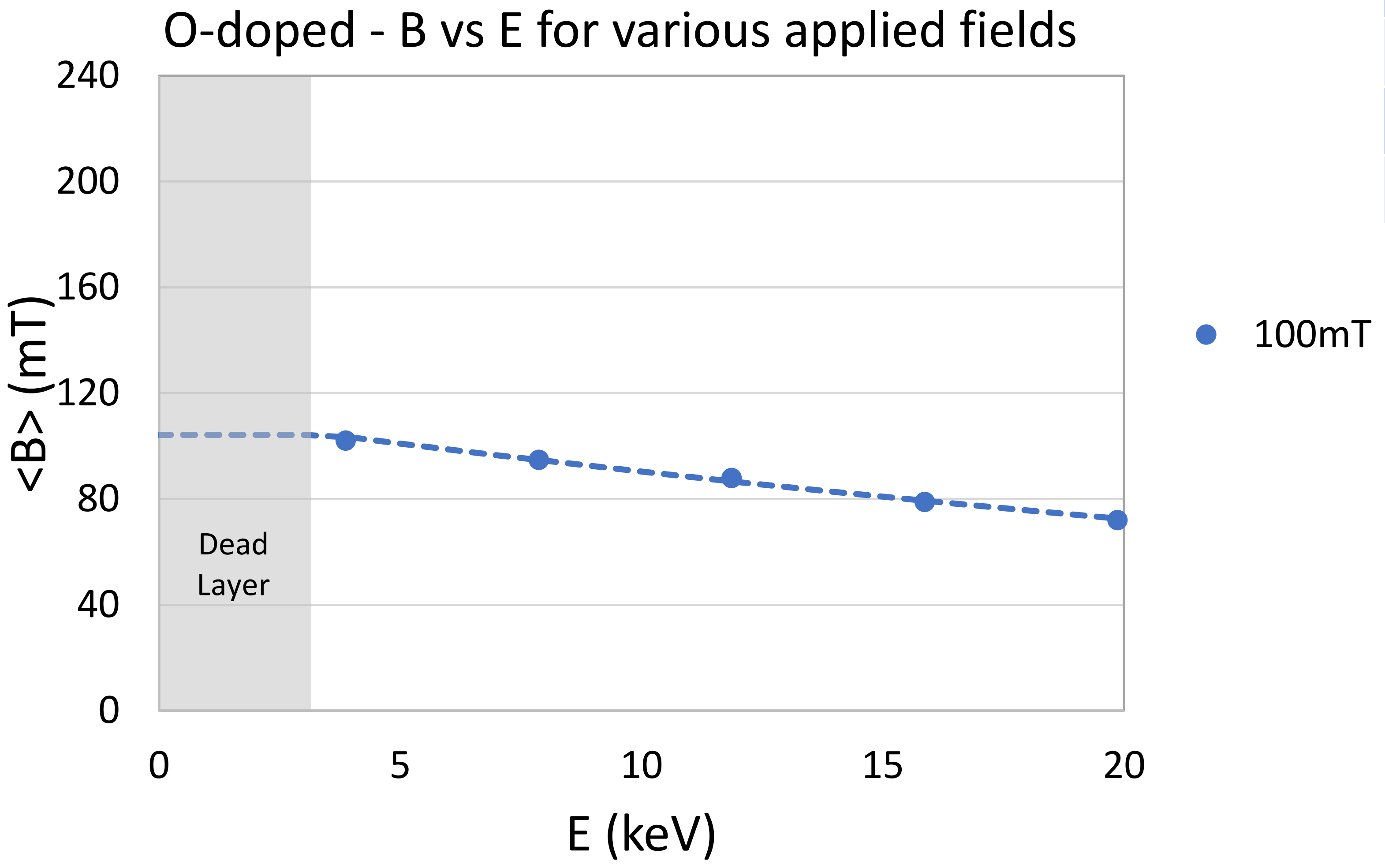


$\mathbf{B_{applied} < B_{entry}}$



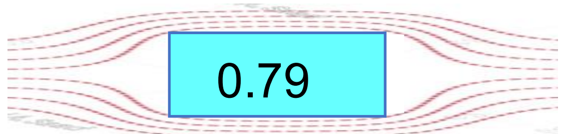
$\mathbf{B_{applied} \rightarrow B_{entry}}$

Sample 2: O-doped (mid-T)



B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.04	0.79	117

SPD = Screening profile depth



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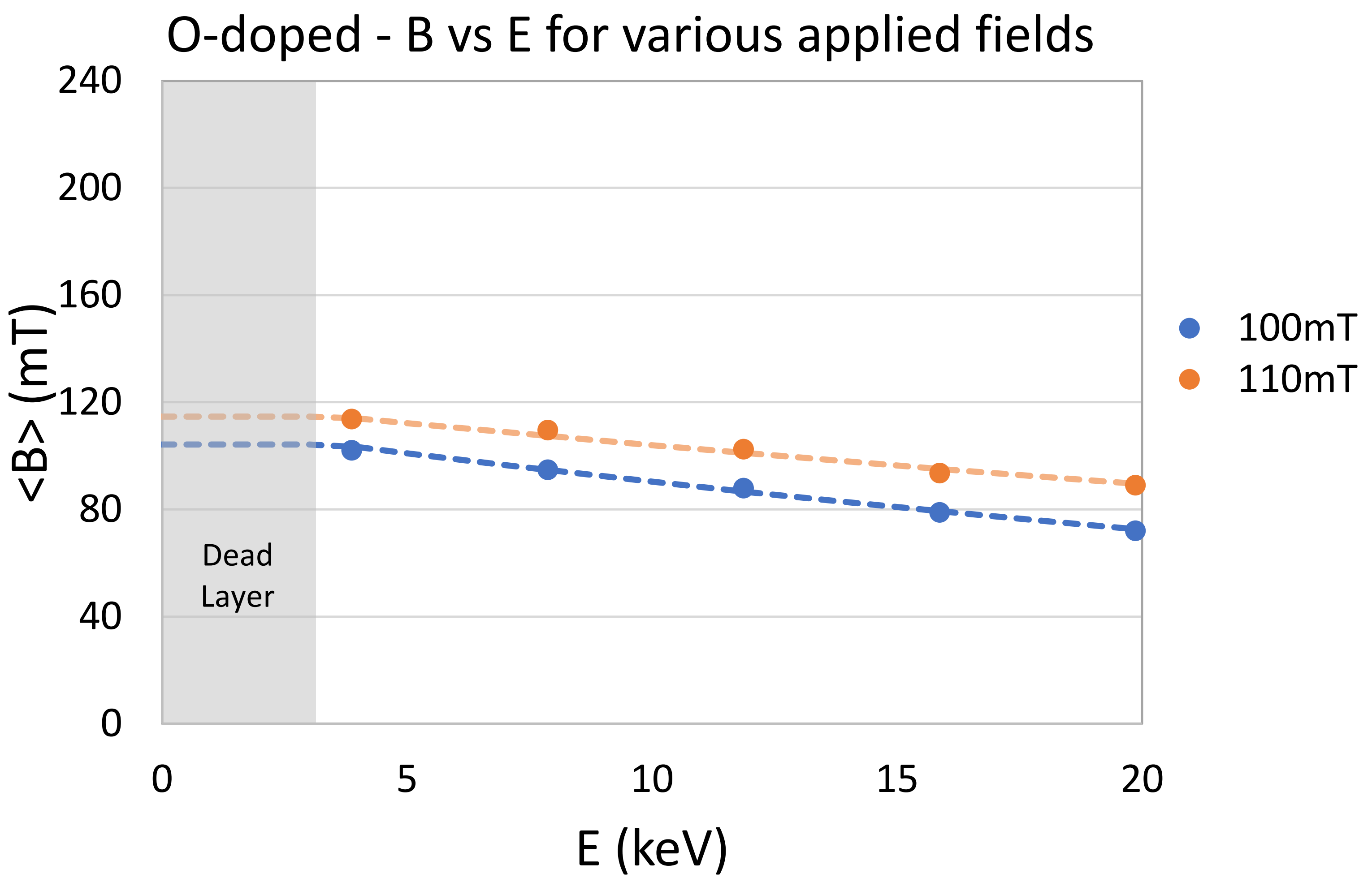
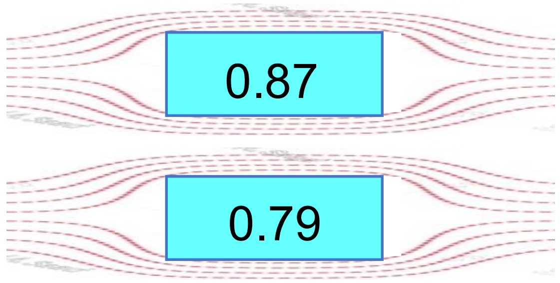
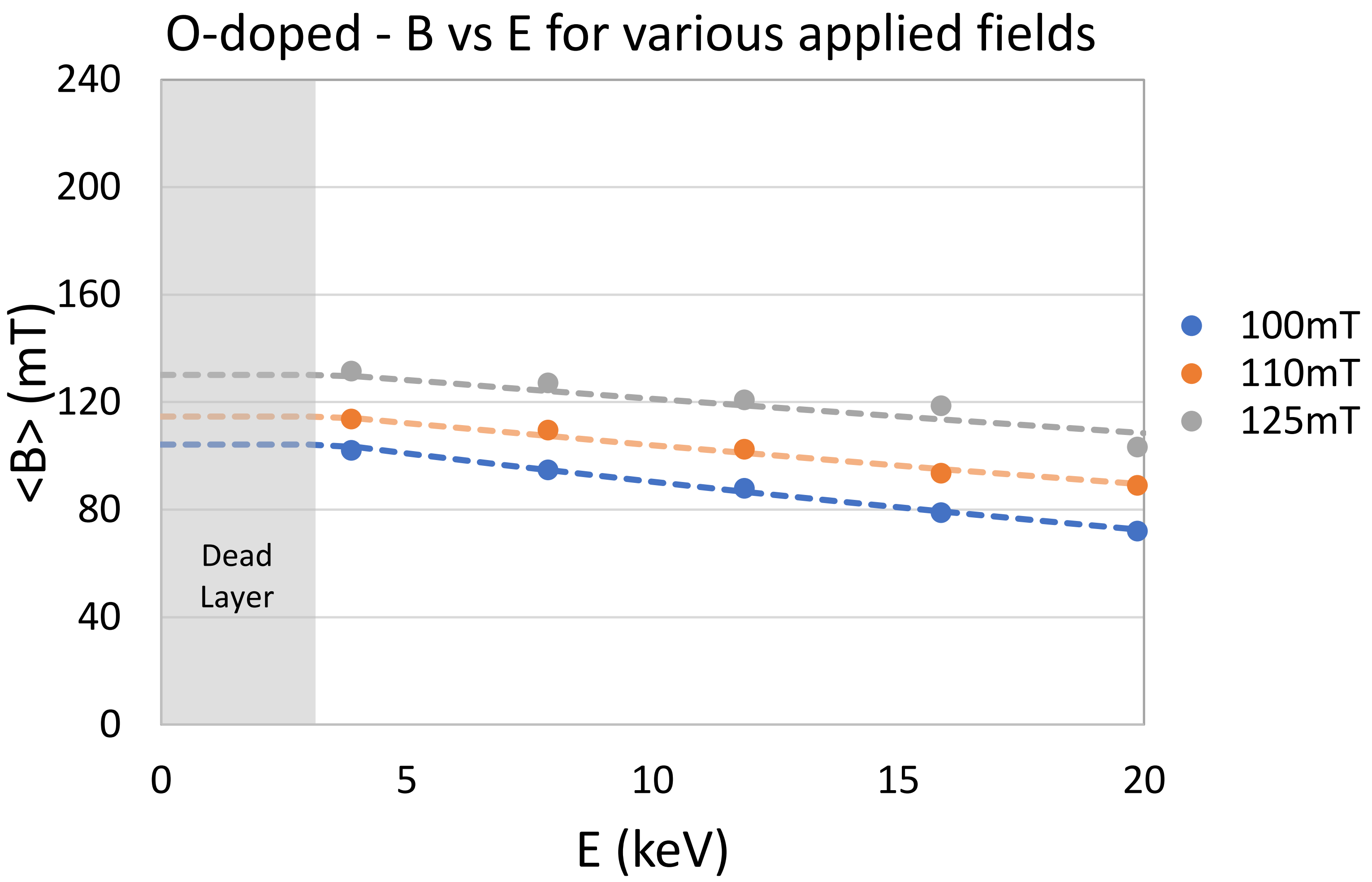


B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.04	0.79	117
110	1.04	0.87	178

SPD = Screening profile depth

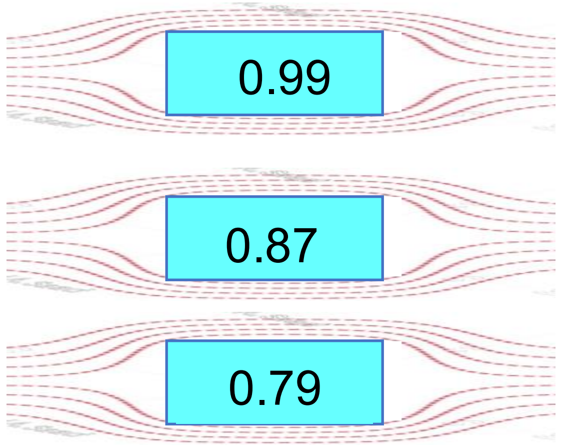


Sample 2: O-doped (mid-T)



B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.04	0.79	117
110	1.04	0.87	178
125	1.04	0.99	248

SPD = Screening profile depth



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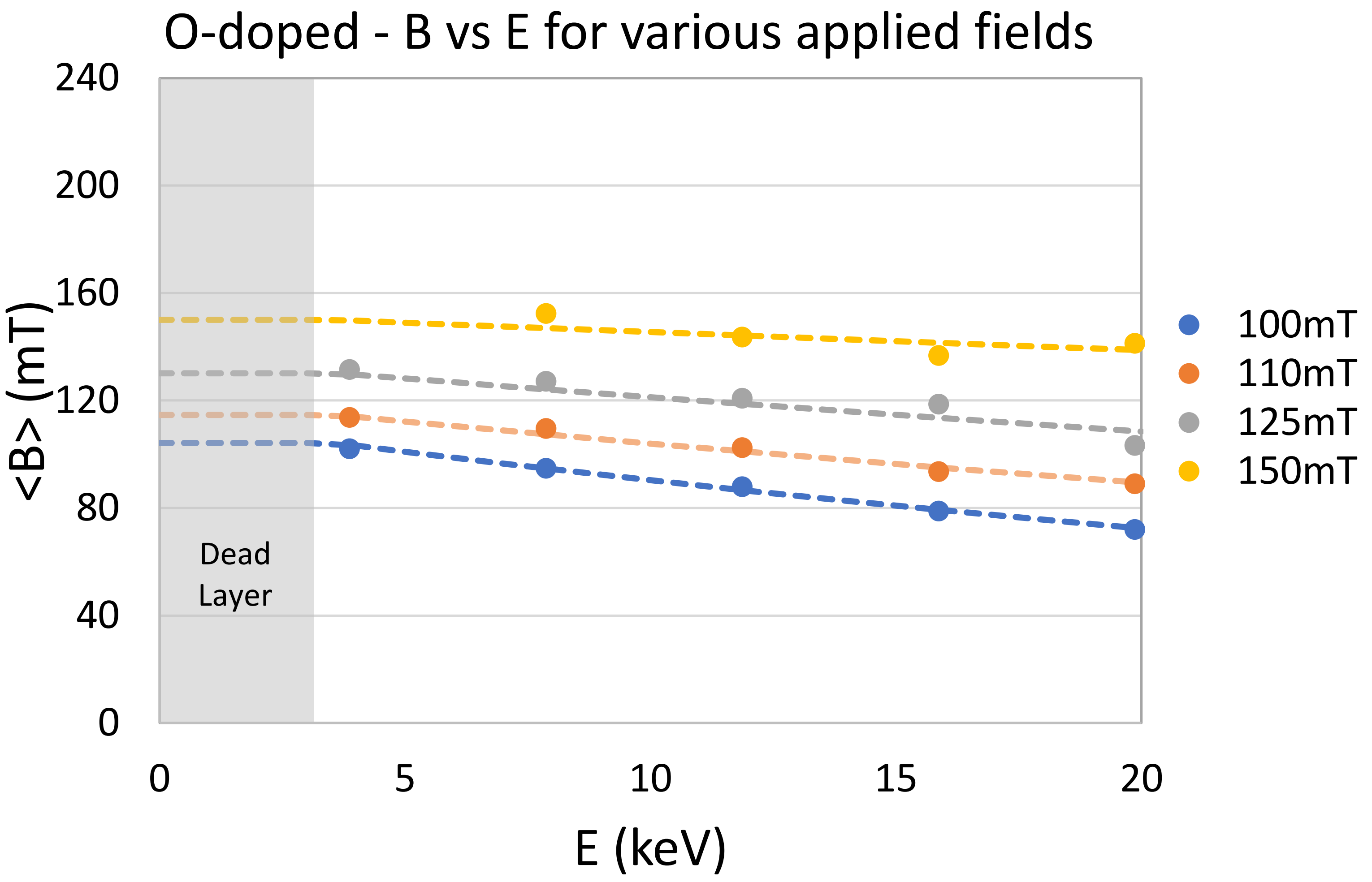
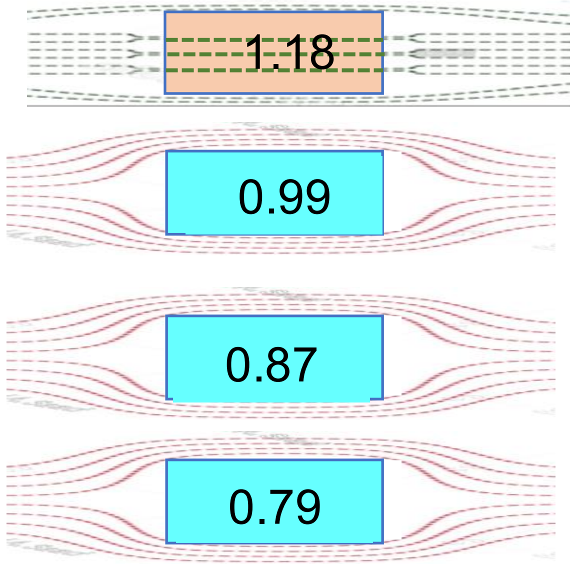


B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.04	0.79	117
110	1.04	0.87	178
125	1.04	0.99	248
150	1.00	1.18	600

SPD = Screening profile depth



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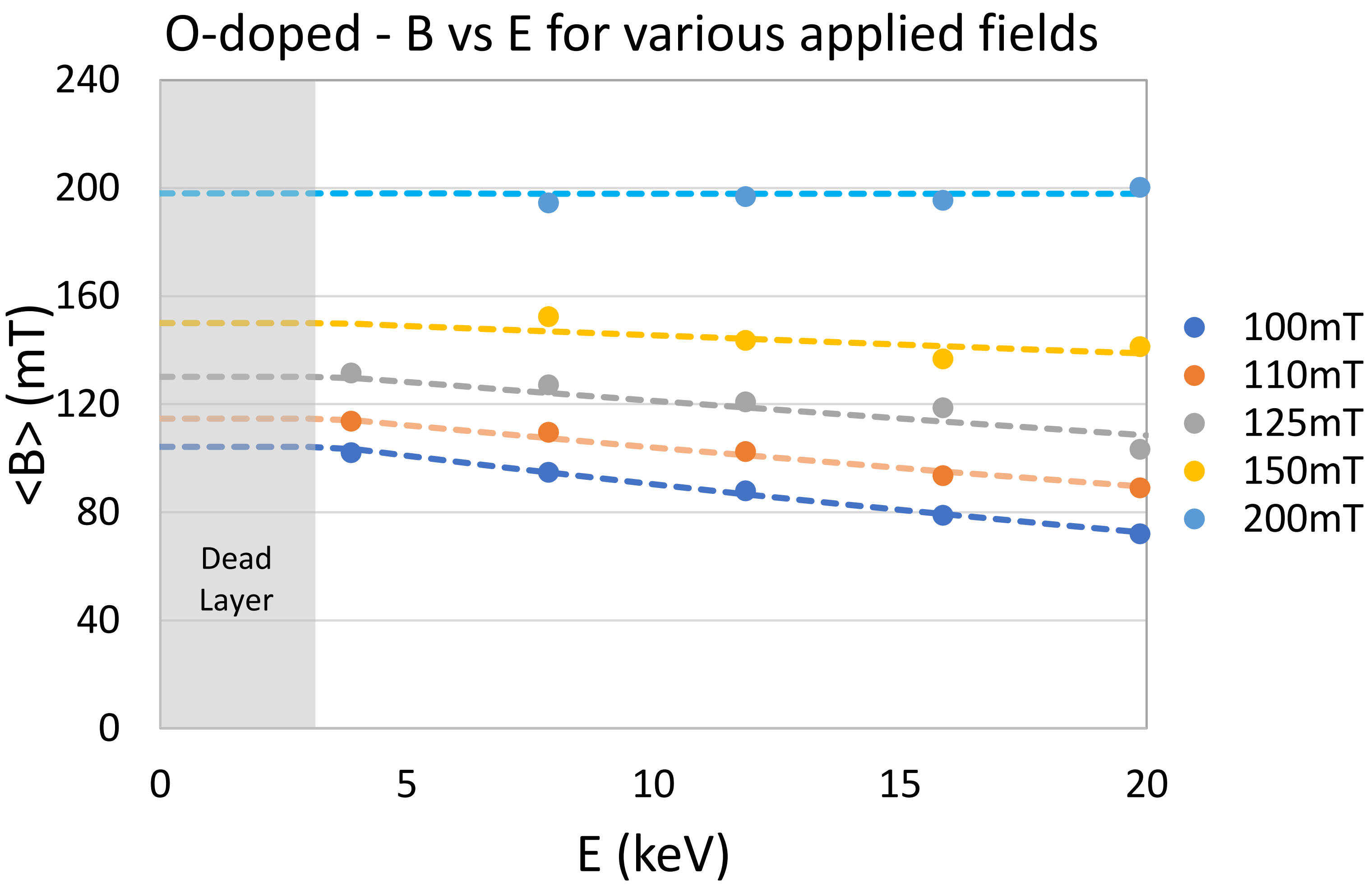
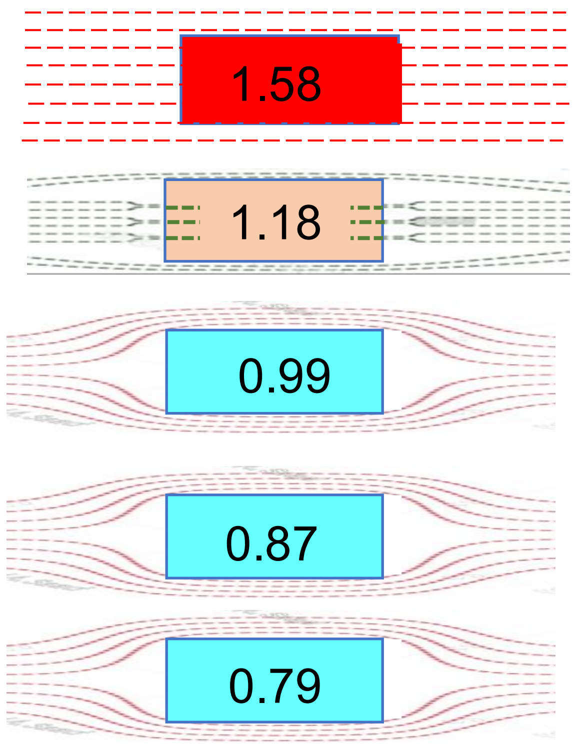


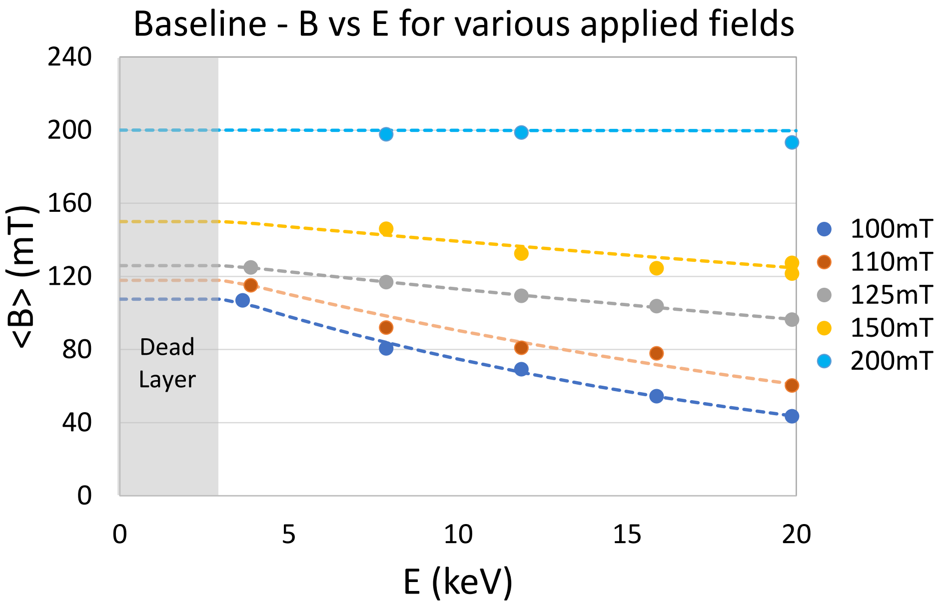
B_{app}	B_{surf}/B_{app}	H_{app}/H_{entry}	SPD
(mT)	-	-	(nm)
100	1.04	0.79	117
110	1.04	0.87	178
125	1.04	0.99	248
150	1.00	1.18	600
200	1.00	1.58	NA

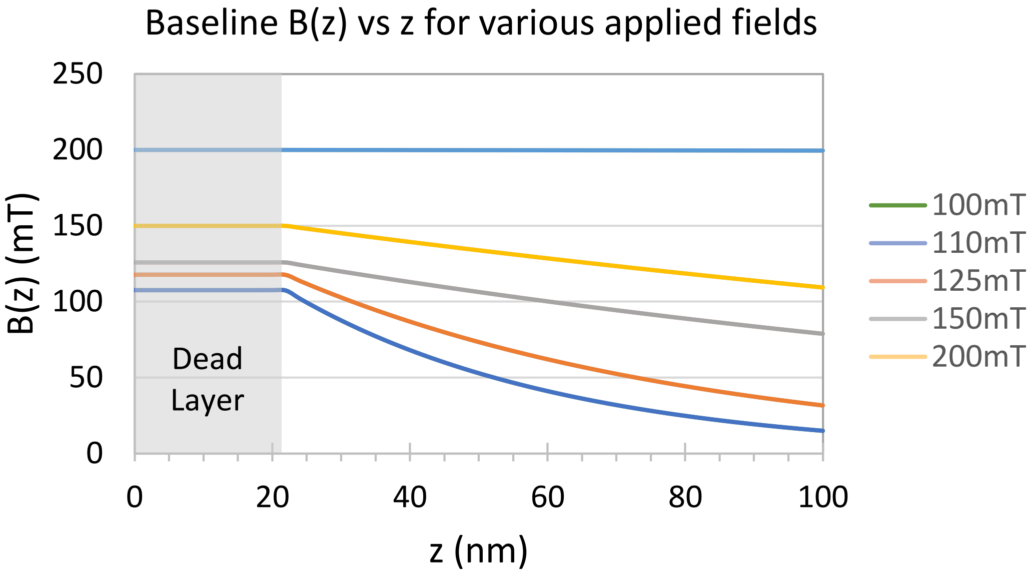
SPD = Screening profile depth



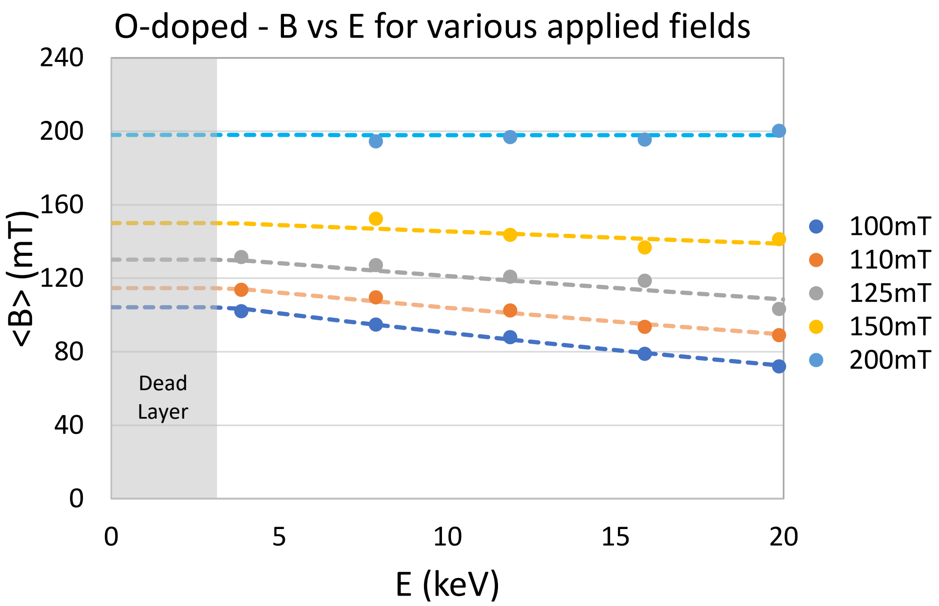
Field Profile: $B(z; B_{app} \rightarrow 200\text{ mT})$

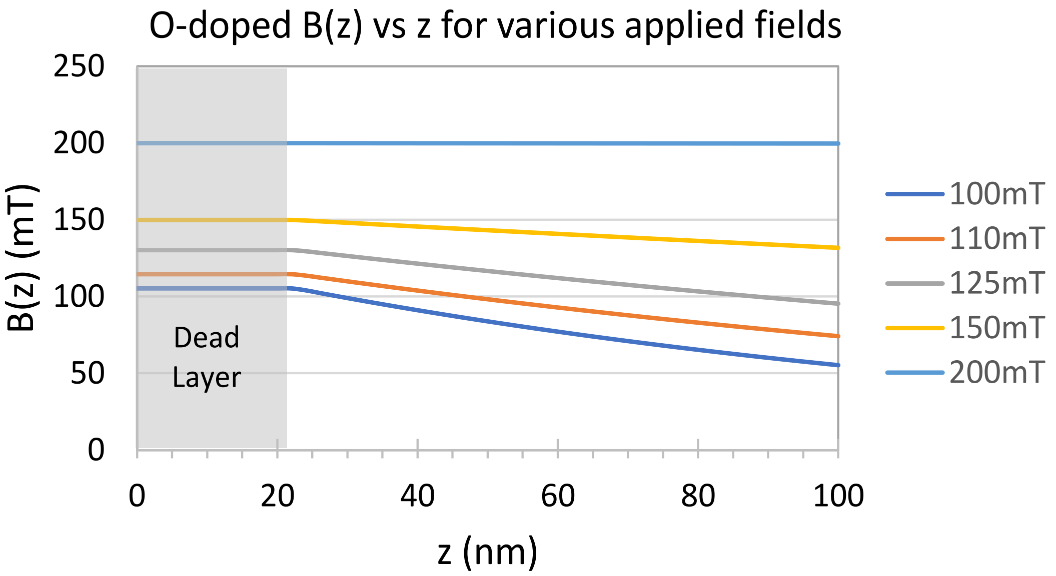
Baseline





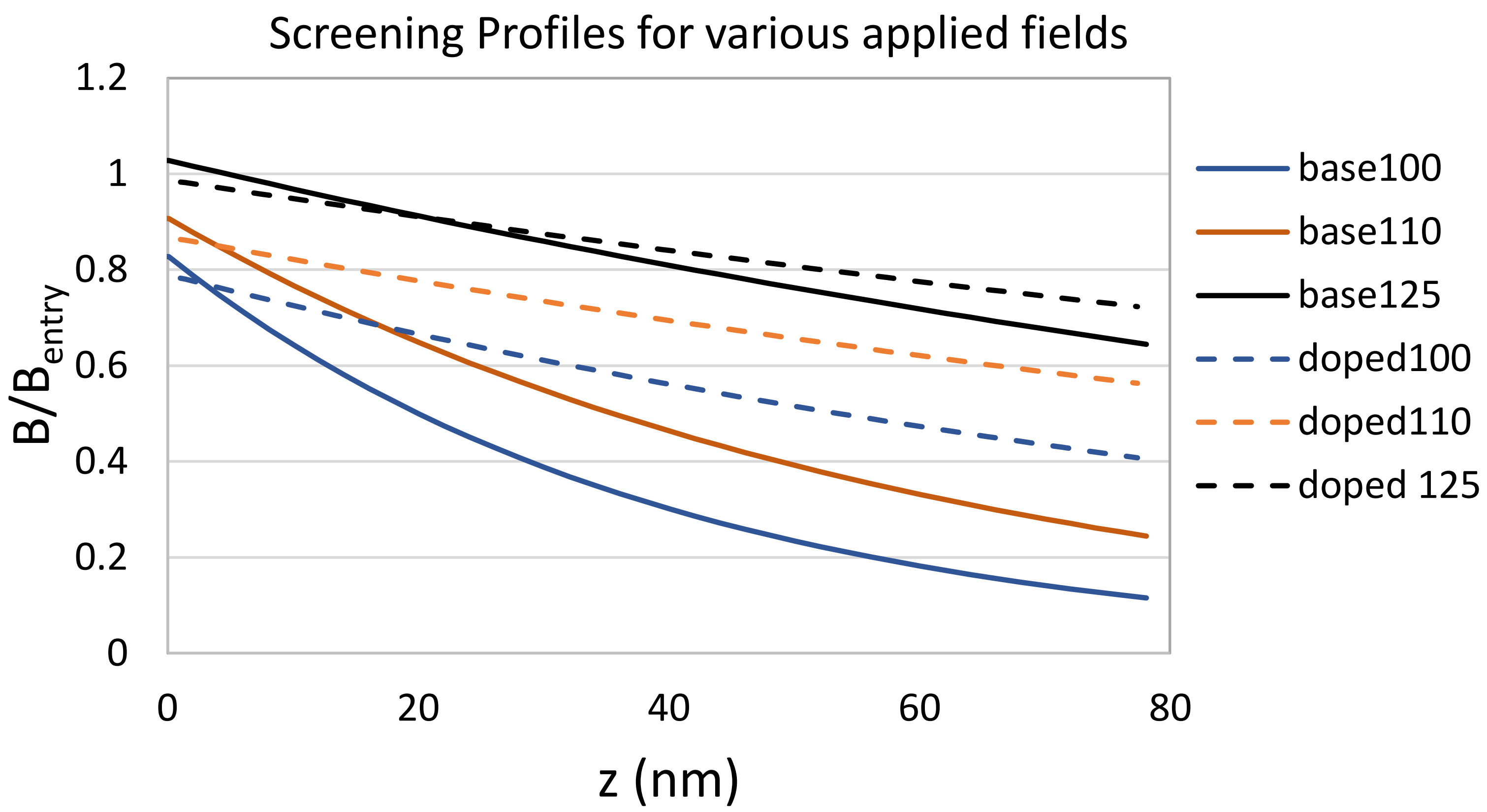
O-Doped





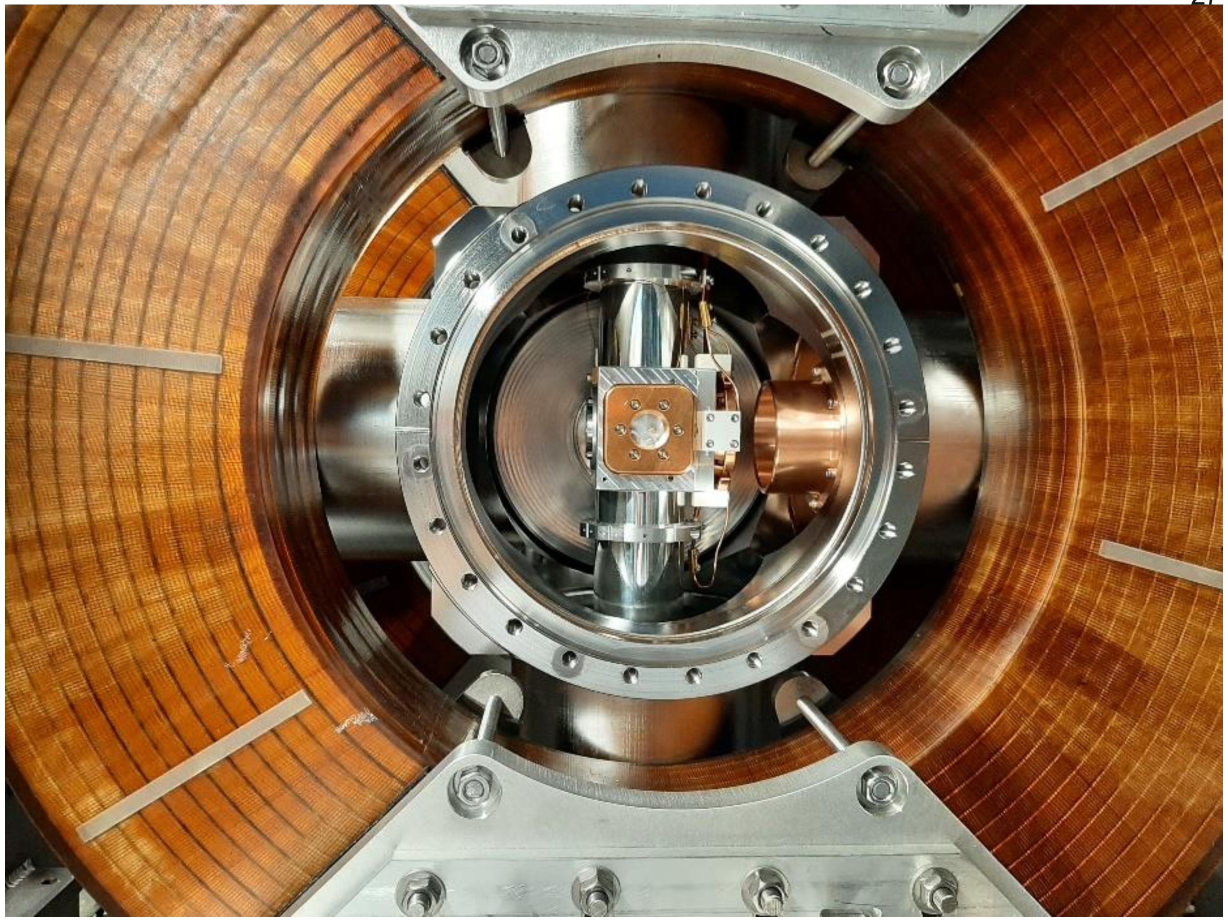
Findings

- **Screening profile is significantly longer in the doped sample** compared to the baseline
- Screening profile in the Meissner state near B_{c1} **increases with applied field**
- Clear slope change in screening profile when the **Meissner state begins to break down**



Summary

- We have successfully completed a verification experiment at the new beta-SRF facility at TRIUMF with parallel fields up to 200mT for two samples, baseline and O-doped
- Beta-SRF is a **unique facility for probing the surface layer** of SRF samples
- The high parallel field near Hc1 and variable implantation depth makes it **ideal for characterizing new treatments**, **new materials and layered structures**



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Thank you
Merci

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