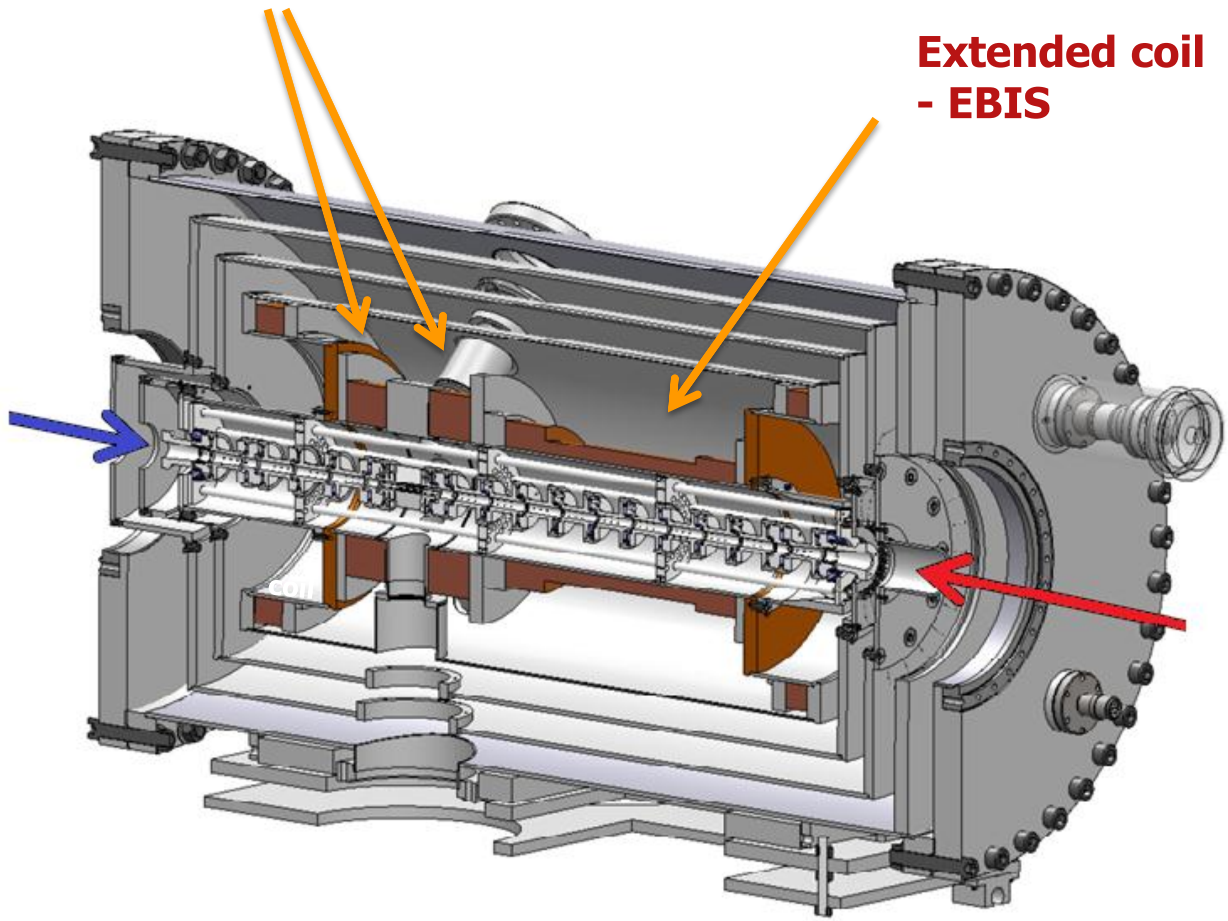
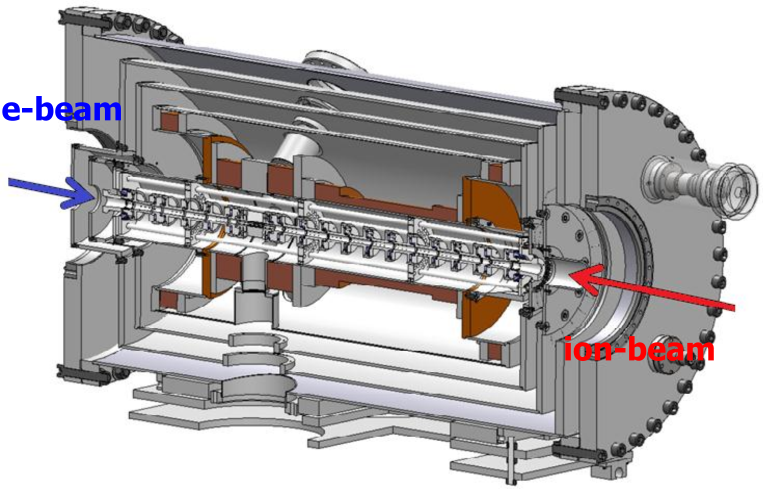
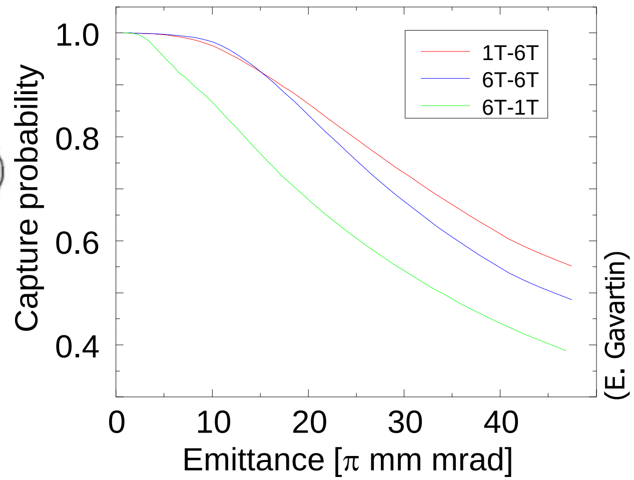
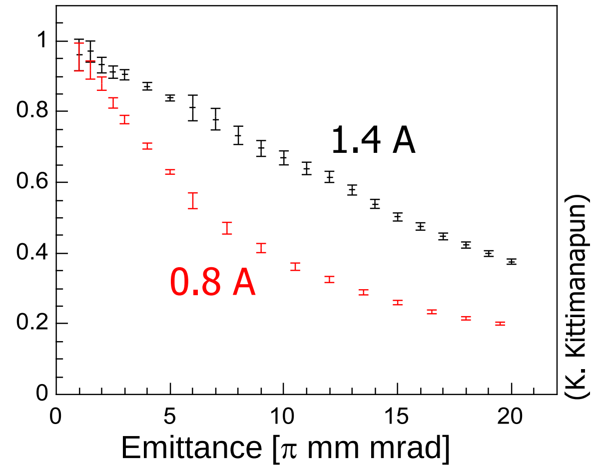
The Helmholtz + solenoid magnet configuration for the NSCL EBIS/T



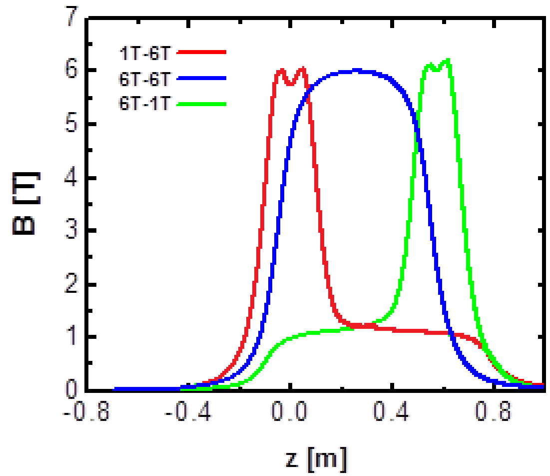
EBIS/T design – hybrid trap



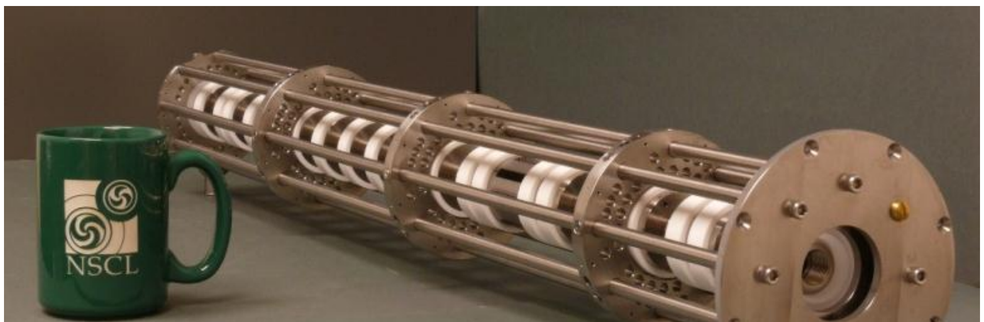




Moderate compression + large e-beam current
+ longer trap needed = good acceptance
→ **Two traps for high acceptance and fast breeding**



Trap: ~ 0.8m long

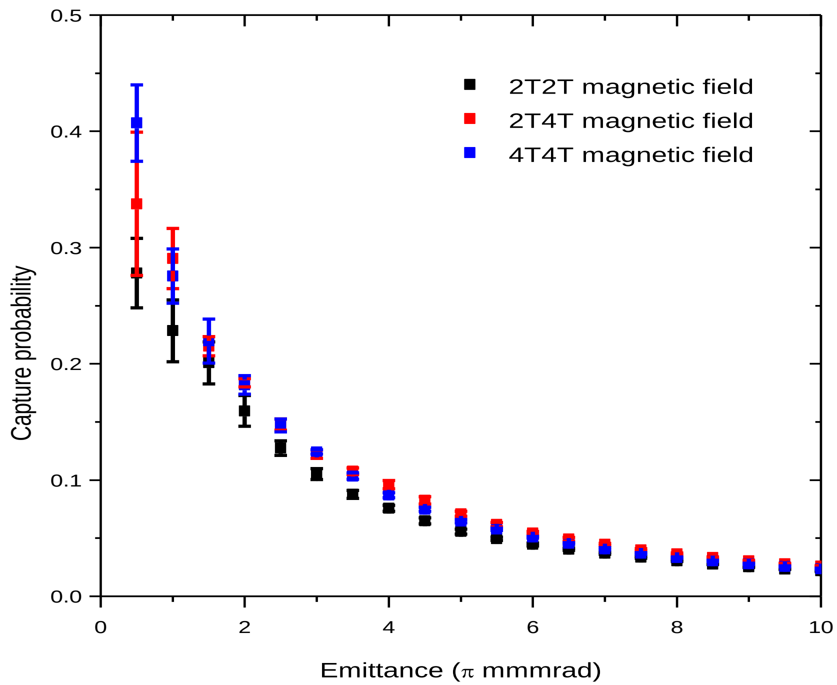


– 21 segments for flexibility
– Center electrode 8fold split

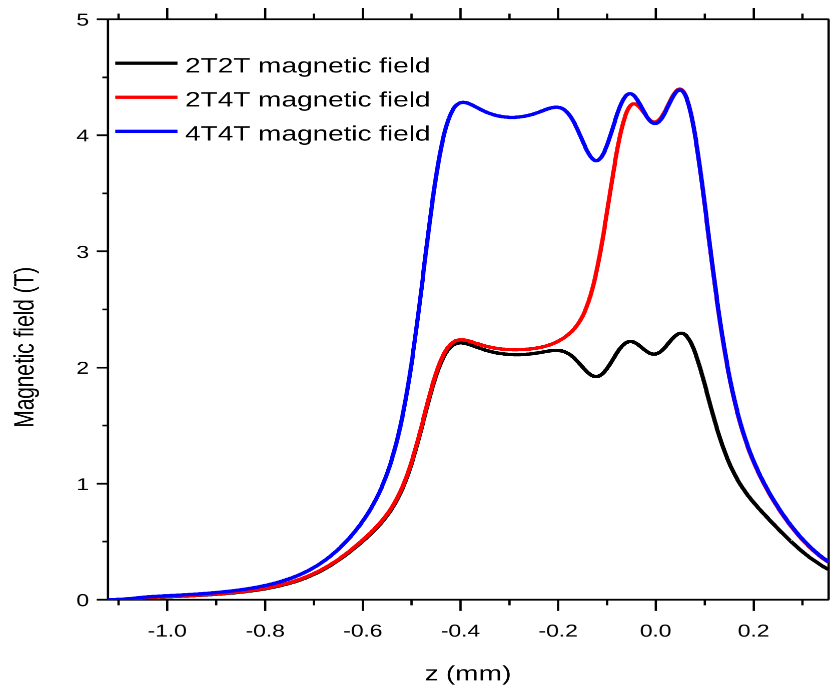
Does the field really matter?

Ion trajectory calculations with MC–style ionization – low beam current

Capture probability vs. beam emittance



Axial field distribution



(K. Kittimanapun)

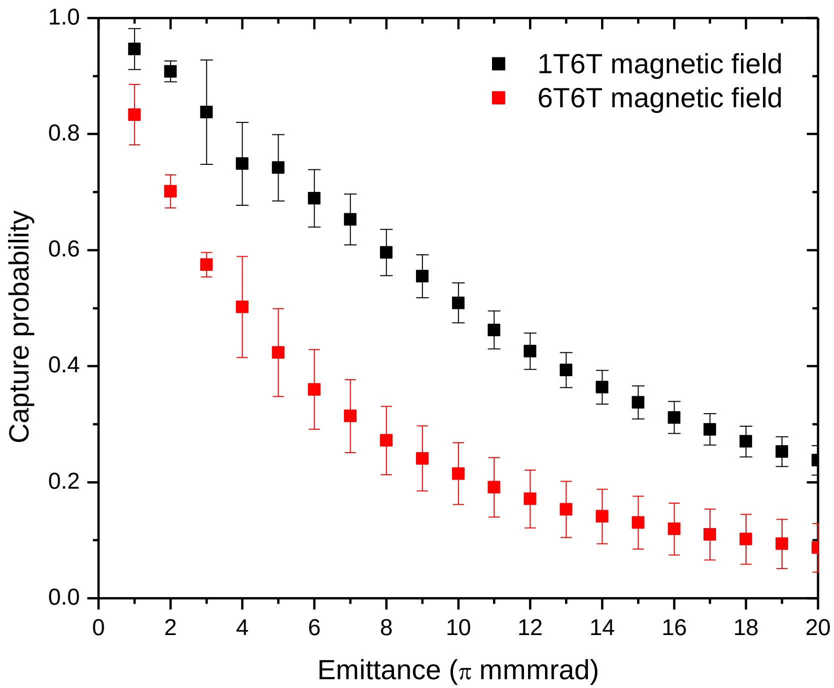
- Ion beam K-39
- Extraction energy 29.306 keV
- Trap length 0.75 m
- Electron beam current 0.1 A
- Electron beam energy 19.545 keV

→ At low beam current: Not so much

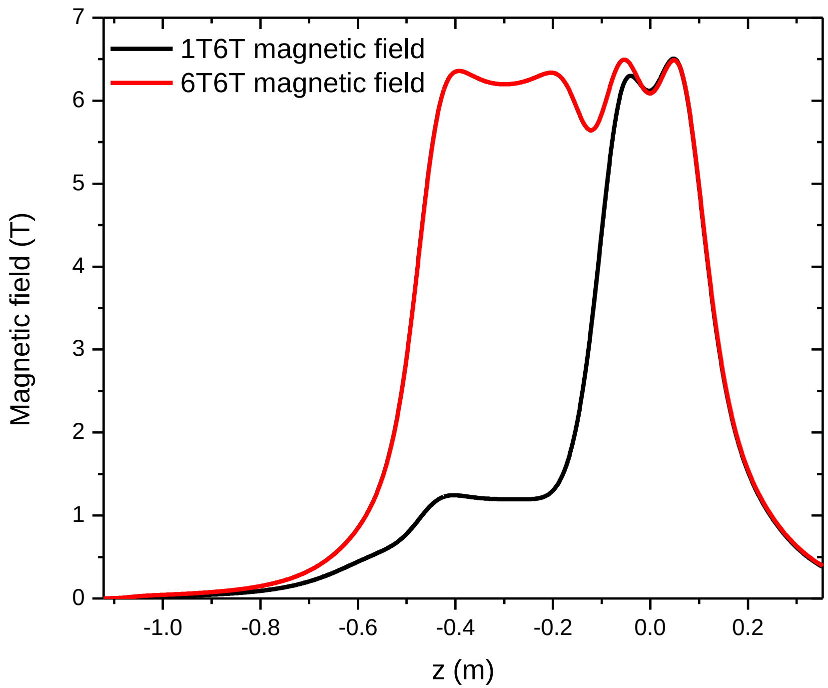
Does the field really matter?

Ion trajectory calculations with MC–style ionization – high beam current

Capture probability vs. beam emittance



Axial field distribution



(K. Kittimanapun)

- Ion beam ^{56}Fe
- Extraction energy 60 keV
- Trap length 0.75 m
- Electron beam current 1 A
- Electron beam energy 12.5 keV
- Electron beam current density
  - 1.6 x 10^3 A/cm^2 at 1T region
  - 1.2 x 10^4 A/cm^2 at 6T region

→ At high beam current: Yes

Don't like lengthy MC calculations?

Try something less time-consuming instead:

1: Use: 'Geometrical acceptance' (see F. Wenander, CERN report)
= maximum emittance of ion beam caught inside e-beam

$$\alpha_{\max} = \pi \frac{r_{ebeam}}{\sqrt{2U_{ext}}} \cdot \left(Br_{ebeam}\sqrt{\frac{q}{m}} + \sqrt{\frac{qB^2 r_{ebeam}^2}{4m} + \frac{\rho_l}{2\pi\varepsilon_0}} \right)$$

= f(e-radius r_{ebeam}, acceleration voltage U_{ext}, magnetic field strength B, longitudinal SC density ρ_l)

With Herrmann-formula for e-beam radius

$$r_h = r_b \sqrt{\frac{1}{2} + \frac{1}{2}\sqrt{1 + 4\left(\frac{8kT_c r_c^2 m}{e^2 r_b^4 B^2} + \frac{B_c^2 r_c^4}{B^2 r_b^4}\right)}}$$

➔ Partial efficiency given by ε_{beam} in relation to α_{max}

2: Calculate t_{12} from $1^+ \rightarrow 2^+$ x-section. E.g. use f(E) ~ $E^{-0.75}$

➔ Partial efficiency given by time-in-trap compared to t12: ~ 1-exp($-t_{trap}$ / t_{12})

→ Easy analytical estimate for capture probability of DC beam!

Depends on :
- ion beam emittance, trap magnetic field, e-current, trap length
- E-energy, mean ion energy in trap, ion extraction energy,
- e-gun parameters: B_c, T_c, r_c

→ Even Excel can do it!

F. Wenander's emittance formula → acceptance

Capture probability = f(trap length, electron energy, B-field, emittance) using F. Wenander's formula + Lotz' X-section

cathode radius	rc	mm	3.18
e-energy	Ee	keV	20
mean energy in trap	Eion	eV	100
Ionization x-section	$\sigma_{1->2}$	A^2	0.03340
mean velocity in trap	$<v_t>$	m/s	22232.5

Color code:
- affected by acceptance
- affected by time in trap / j
- affected by both
- >99%

Capture probability [%]

↓ current / trap length →

I [A] = 0.1

↓ ε / B →	dz [m] 0.16: 1	2	4	6	dz [m] 0.4: 1	2	4	6	dz [m] 1.2: 1	2	4	6 T
3	2.2	4.3	6.2	7.6	5.4	10.5	14.4	17.1	15.4	28.2	35.2	38.0
10	0.9	1.3	1.9	2.3	2.2	3.1	4.3	5.1	6.3	8.5	10.5	11.4
30	0.3	0.4	0.6	0.8	0.7	1.1	1.4	1.7	2.1	2.8	3.5	3.8
50	0.2	0.3	0.4	0.5	0.5	0.6	0.9	1.0	1.3	1.7	2.1	2.3

I [A] = 1.5

↓ ε / B →	dz [m] 0.16: 1	2	4	6	dz [m] 0.4: 1	2	4	6	dz [m] 1.2: 1	2	4	6 T
3	24.7	46.3	72.7	86.2	50.9	78.8	96.1	99.3	88.1	99.1	100.0	100.0
10	24.7	46.3	57.4	55.5	50.9	78.8	75.9	63.9	88.1	99.1	79.0	64.4
30	13.8	17.5	19.1	18.5	28.3	29.8	25.3	21.3	49.0	37.4	26.3	21.5
50	8.3	10.5	11.5	11.1	17.0	17.9	15.2	12.8	29.4	22.5	15.8	12.9

I [A] = 2.4

↓ ε / B →	dz [m] 0.16: 1	2	4	6	dz [m] 0.4: 1	2	4	6	dz [m] 1.2: 1	2	4	6 T
3	33.6	61.0	86.8	95.5	64.1	90.5	99.4	100.0	95.4	99.9	100.0	100.0
10	33.6	61.0	86.8	78.0	64.1	90.5	99.4	81.6	95.4	99.9	100.0	81.6
30	24.9	29.9	29.1	26.0	47.4	44.3	33.4	27.2	70.5	48.9	33.6	27.2
50	14.9	17.9	17.5	15.6	28.4	26.6	20.0	16.3	42.3	29.3	20.2	16.3

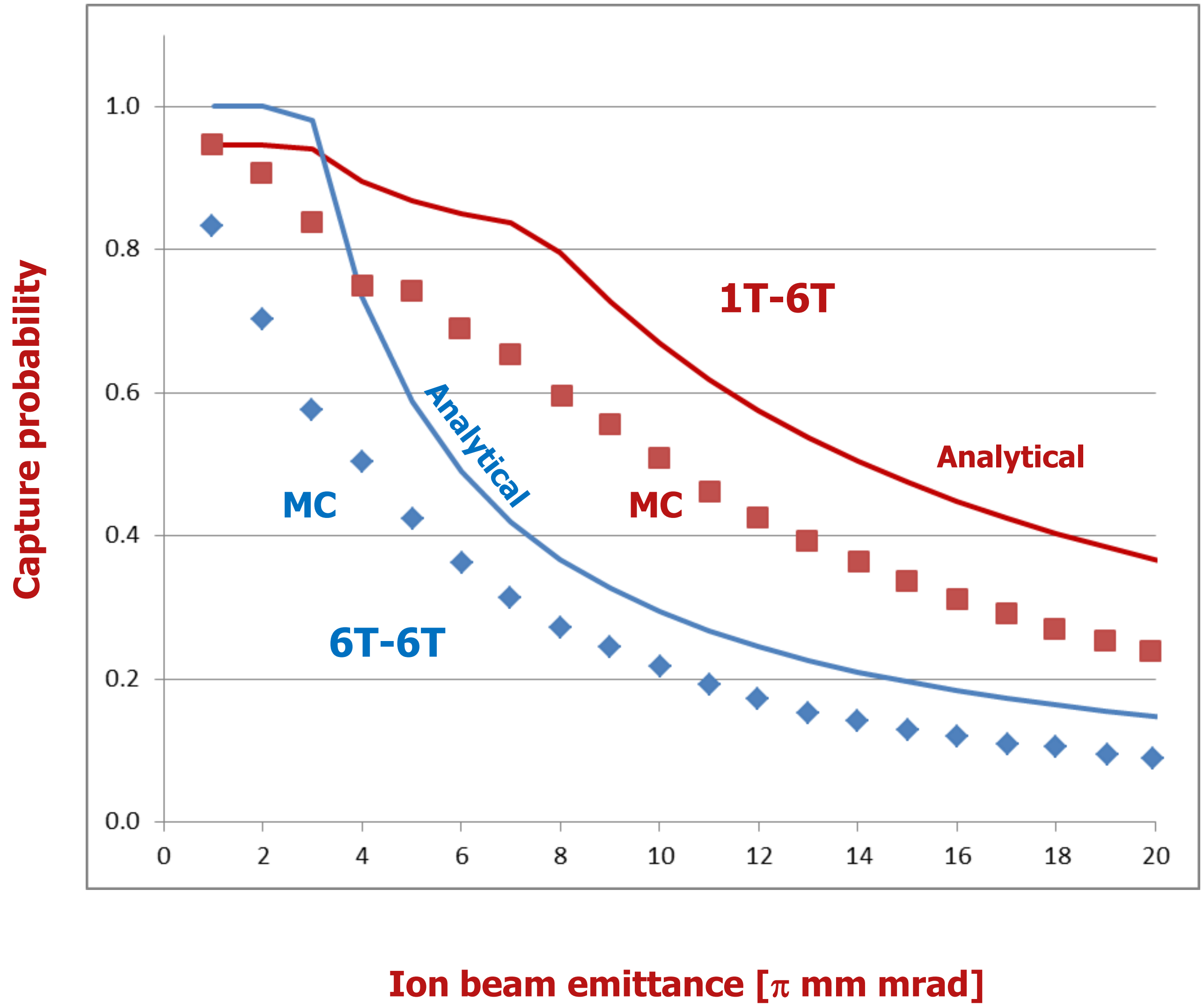
I [A] = 5

↓ ε / B →	dz [m] 0.16: 1	2	4	6	dz [m] 0.4: 1	2	4	6	dz [m] 1.2: 1	2	4	6 T
3	47.4	81.5	98.0	99.8	80.0	98.5	100.0	100.0	99.2	100.0	100.0	100.0
10	47.4	81.5	98.0	99.8	80.0	98.5	100.0	100.0	99.2	100.0	100.0	100.0
30	47.4	61.8	49.1	39.9	80.0	74.8	50.1	40.0	99.2	75.9	50.1	40.0
50	34.9	37.1	29.4	24.0	58.8	44.9	30.0	24.0	73.0	45.5	30.0	24.0

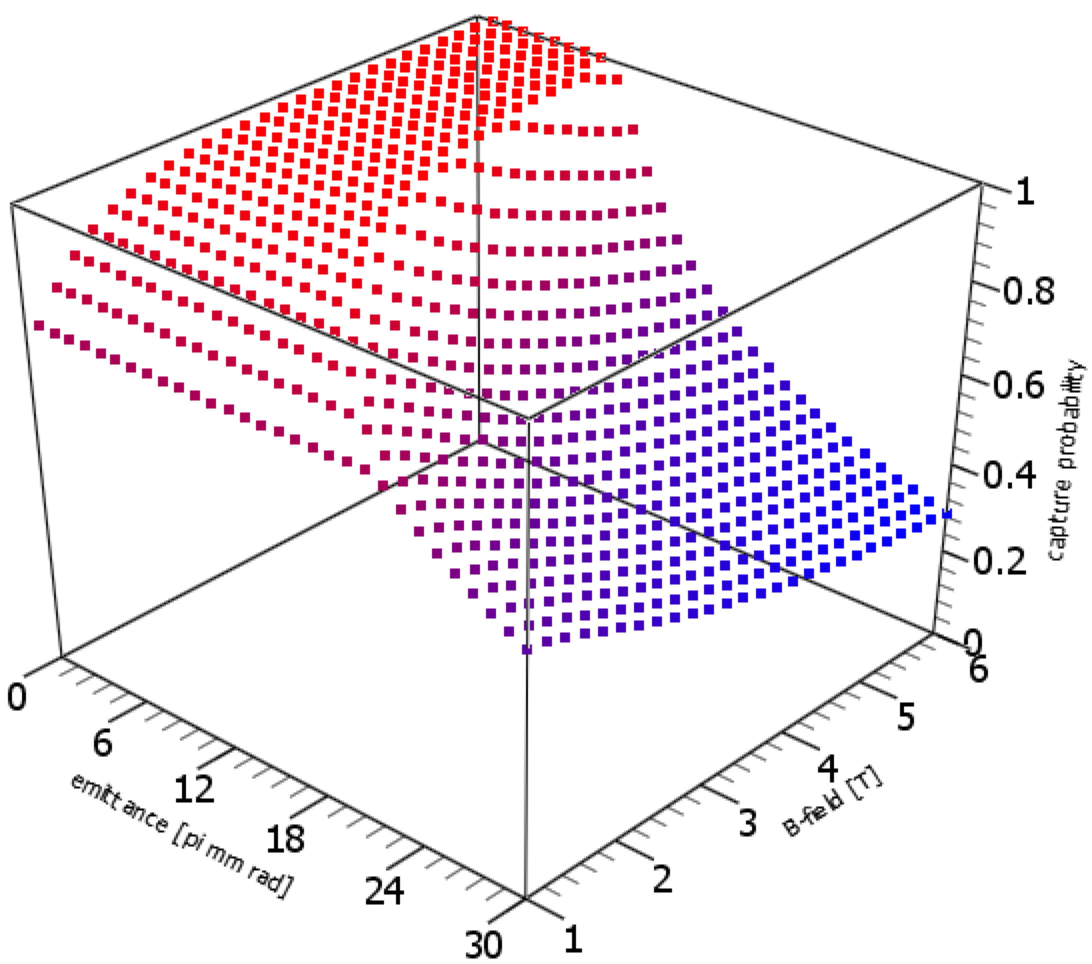
π mm mrad

Wenander et al. - REXEBIS - the Electron Beam Ion Source for the REX-ISOLDE Project, *Design and Simulations* CERN 1999

Comparison with MC calculation



Another view …



Again:
At low emittance:
B does not matter so much,
if you have sufficient I !!

^{56}Fe , mass 56 u
e current [A] 2.5
trap length [m] 1

e energy [keV]: 15
mean ion E in trap [eV]: 300
ion extraction E [keV]: 60
Bc [G]: 20
Tc [T]: 1000
rc [mm]: 6.3