Preparation and transport of $\bar{\text{p}}$ in ASACUSA $\bar{\text{H}}$ experiment

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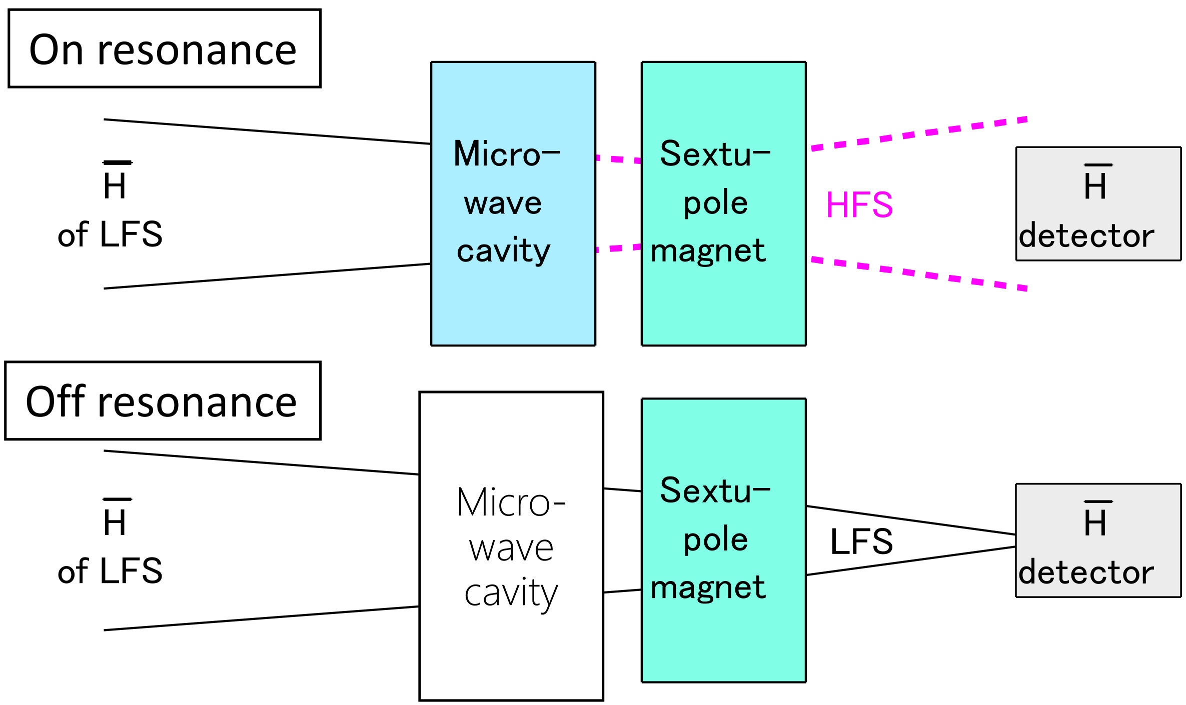
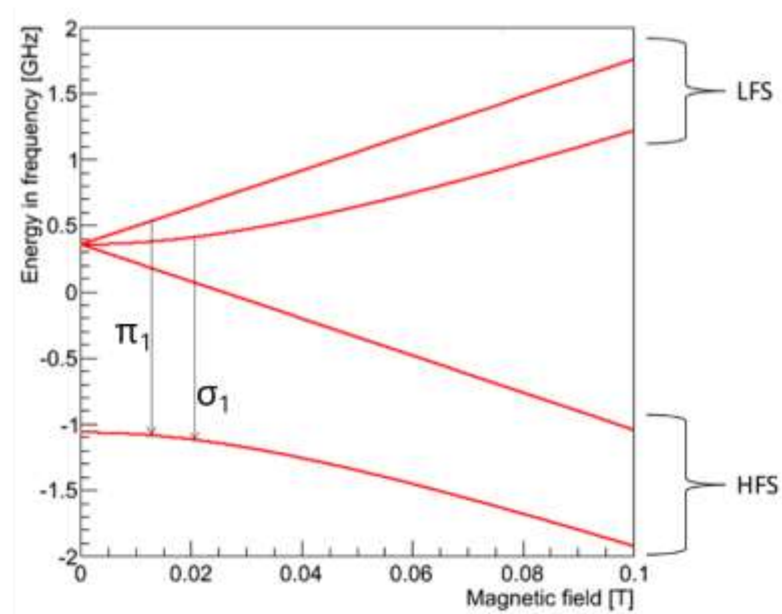
2nd Mini-workshop on GBAR antiproton trap

Feb. 9, 2017

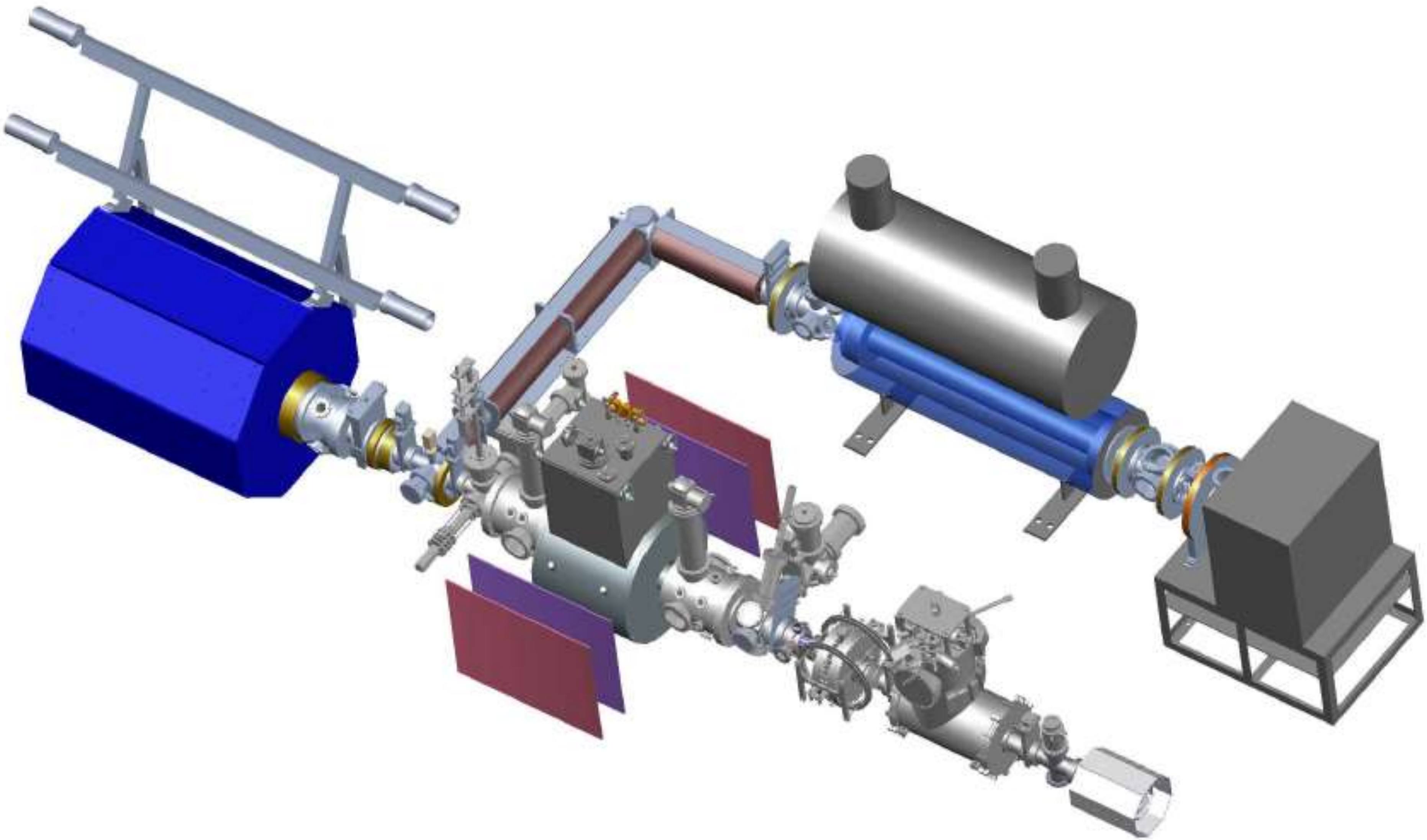
ASACUSA $\overline{\mathrm{H}}$ experiment

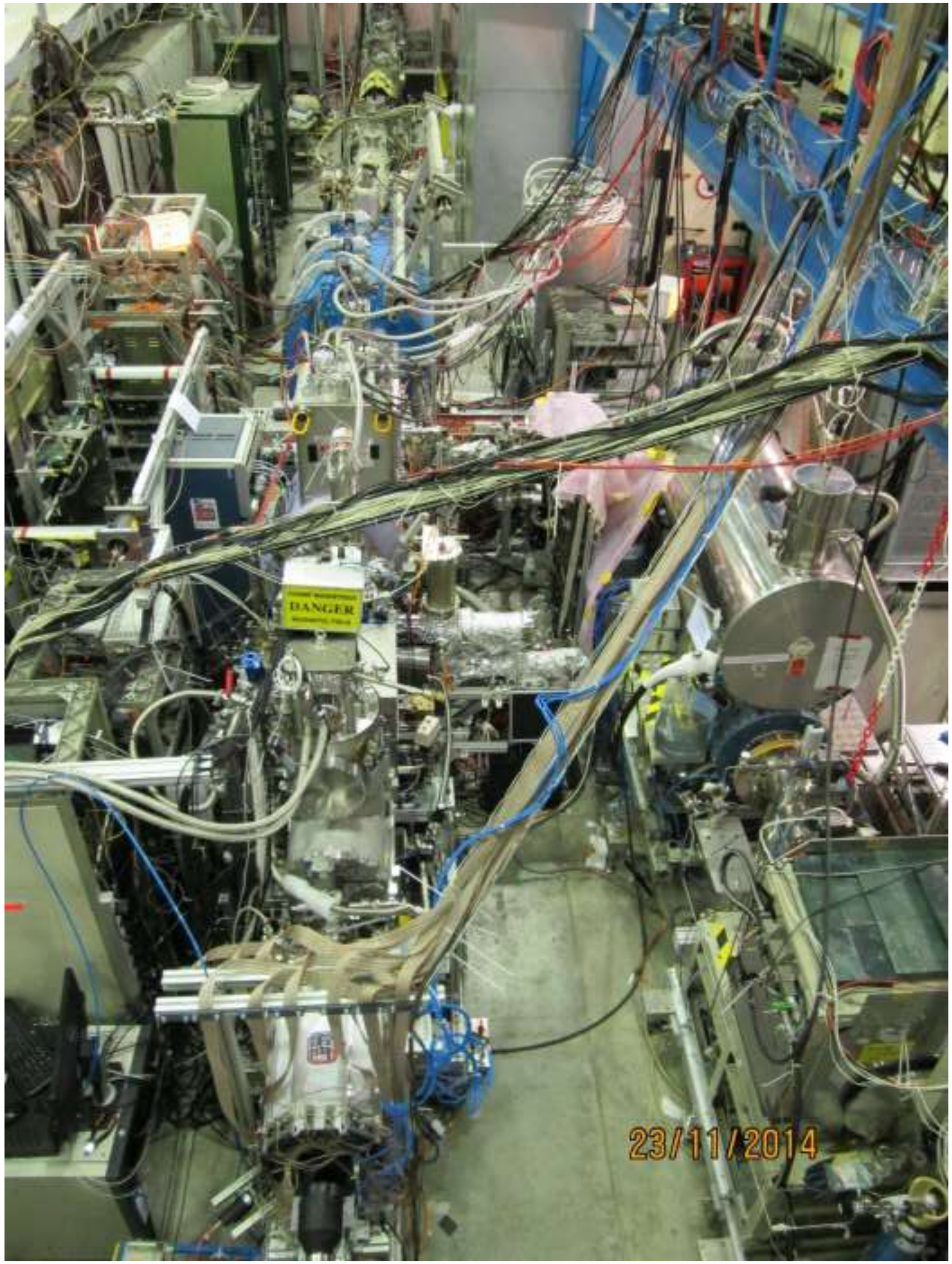
- Test of CPT symmetry by measurement of ground-state hyperfine splitting of $\overline{\mathrm{H}}$
- Slow, intense, polarized $\overline{\mathrm{H}}$ in LFS is required



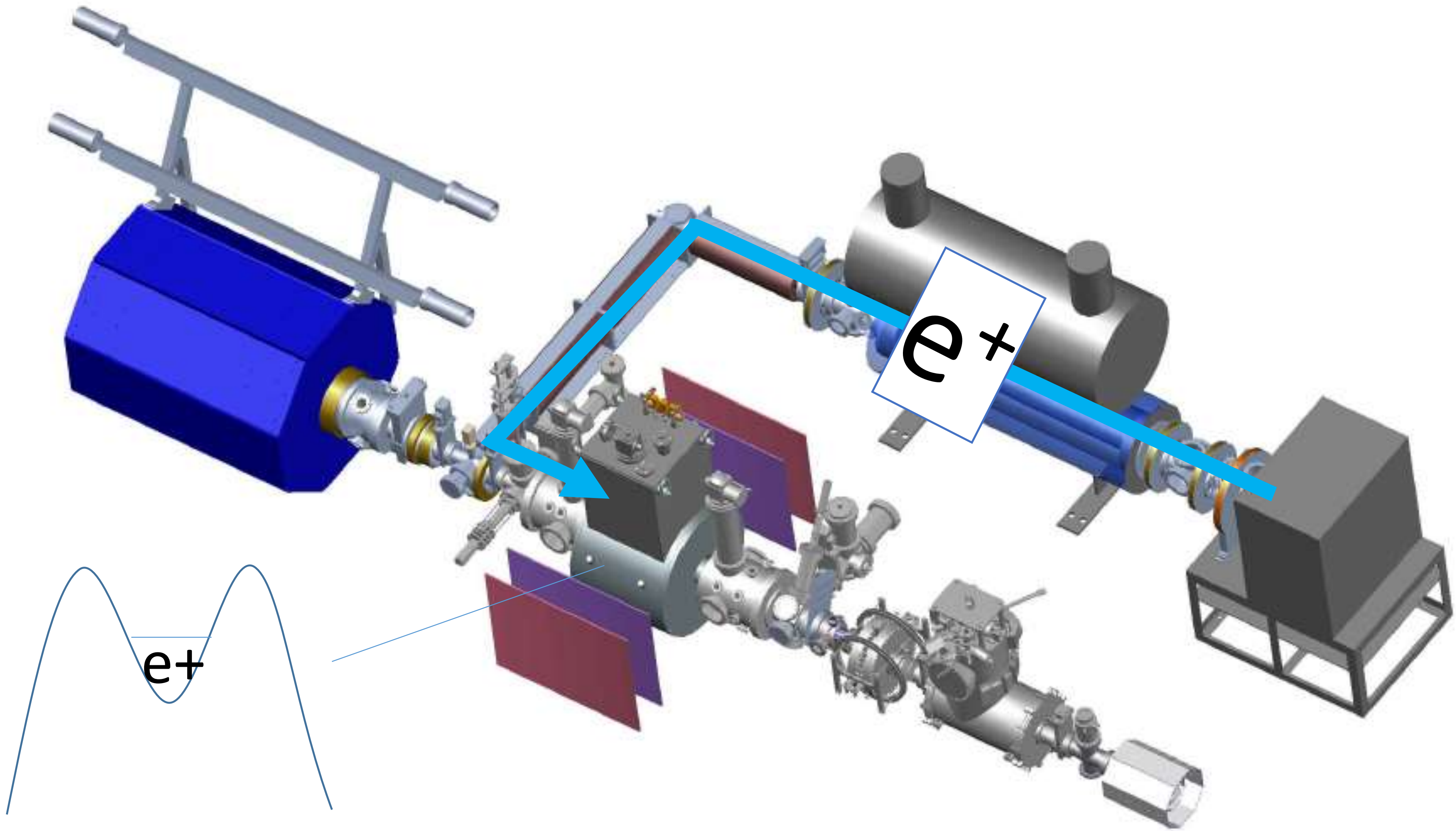


Setup for ASACUSA $\overline{\mathrm{H}}$ experiment

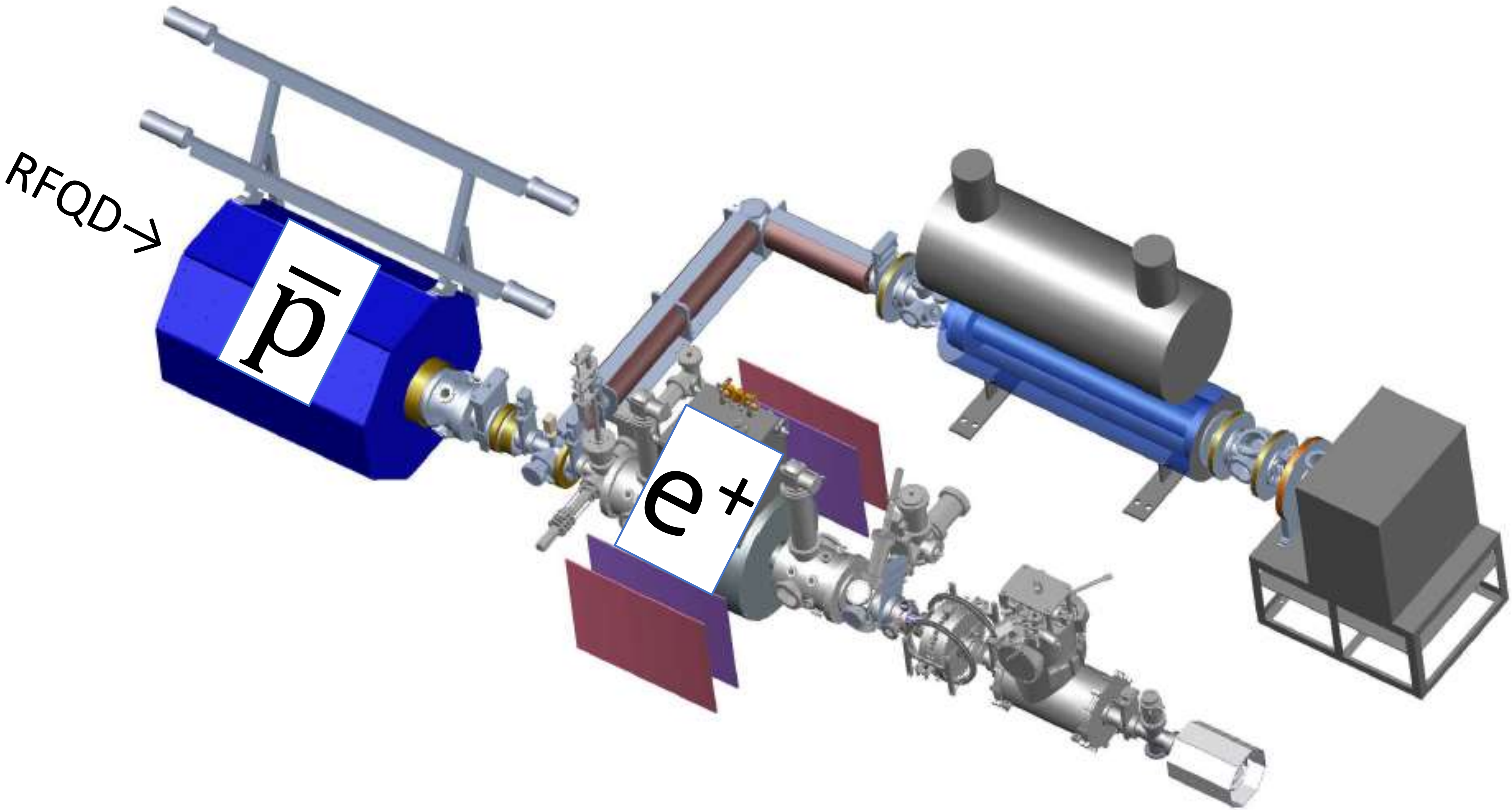



DANGER
23/11/2014

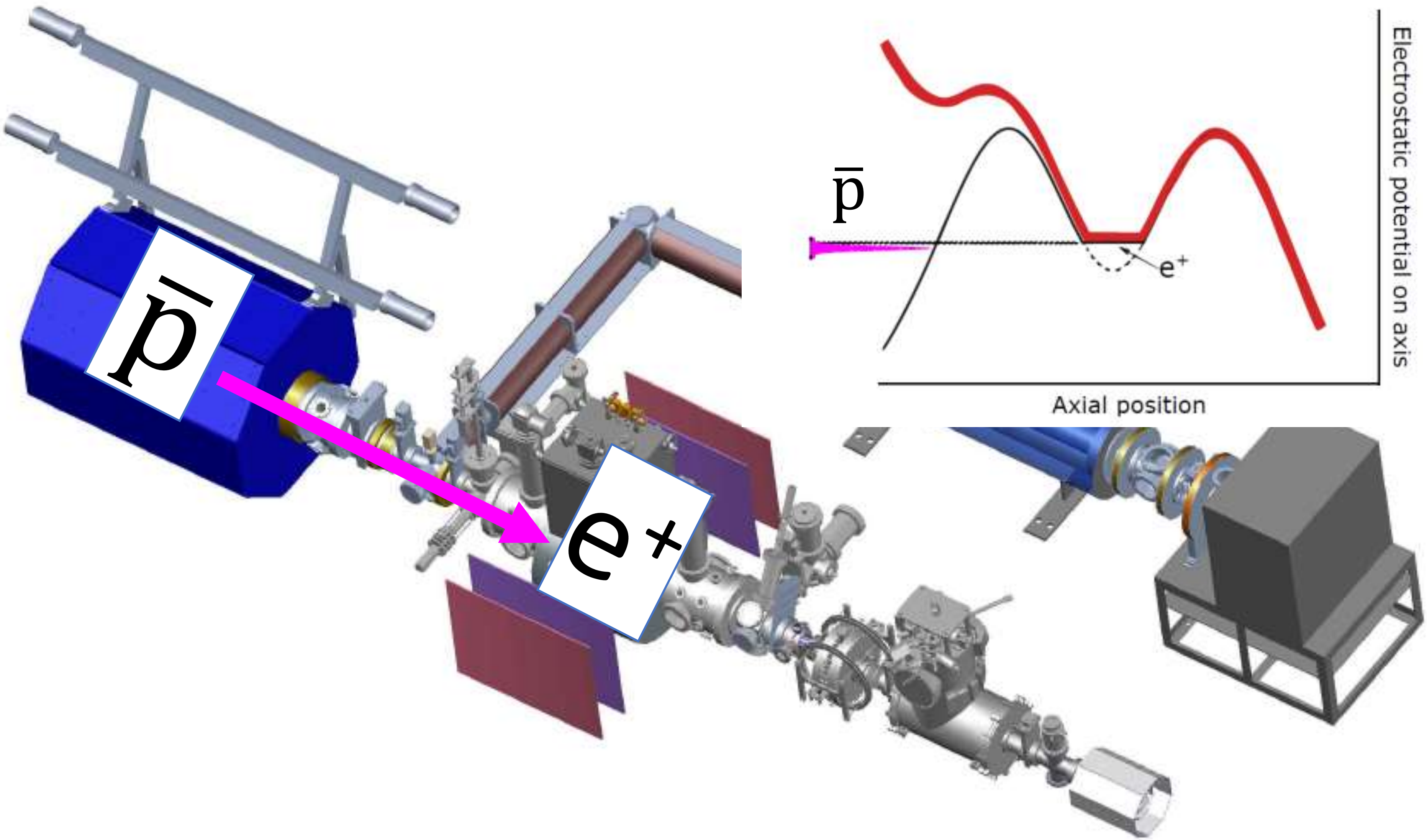
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



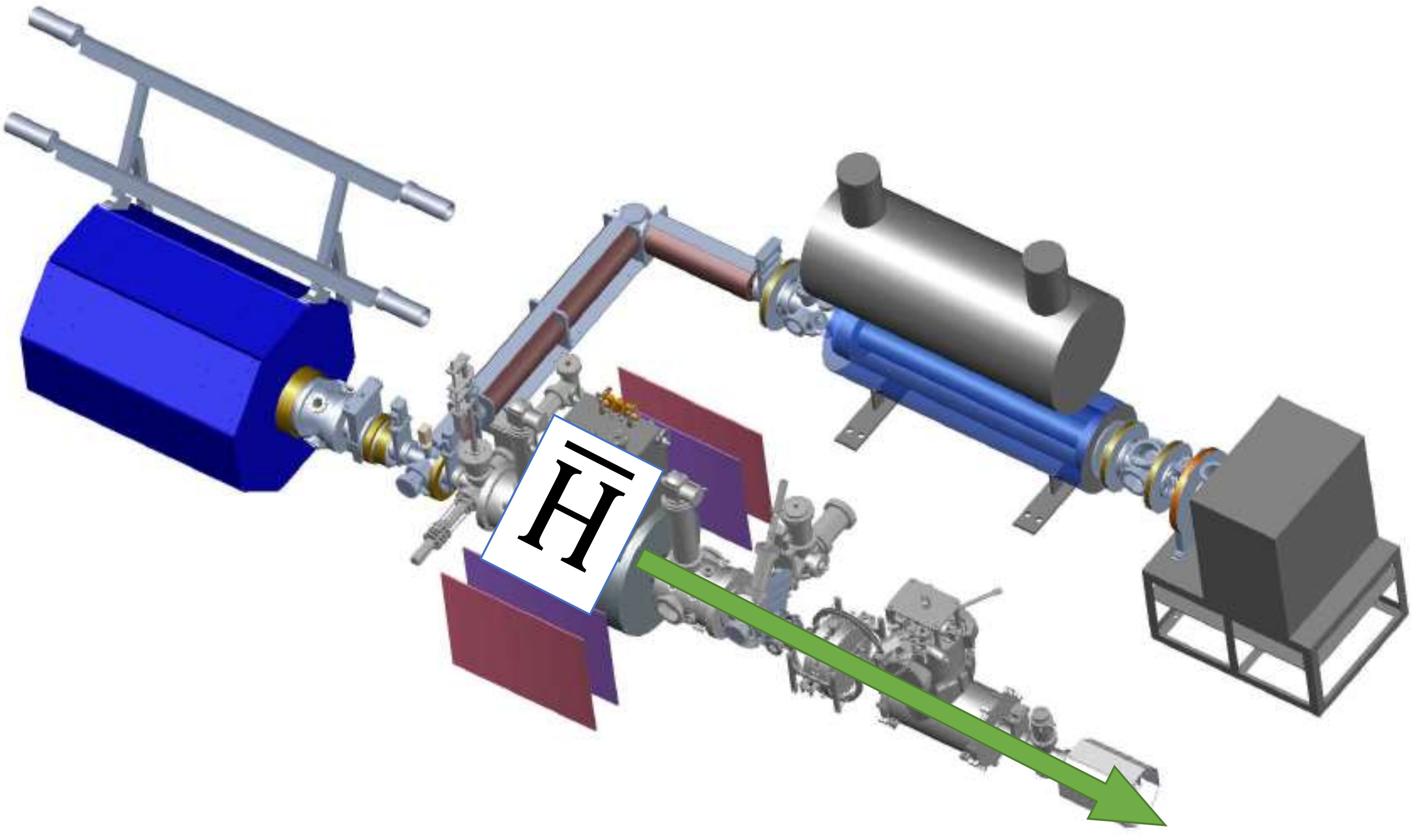
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



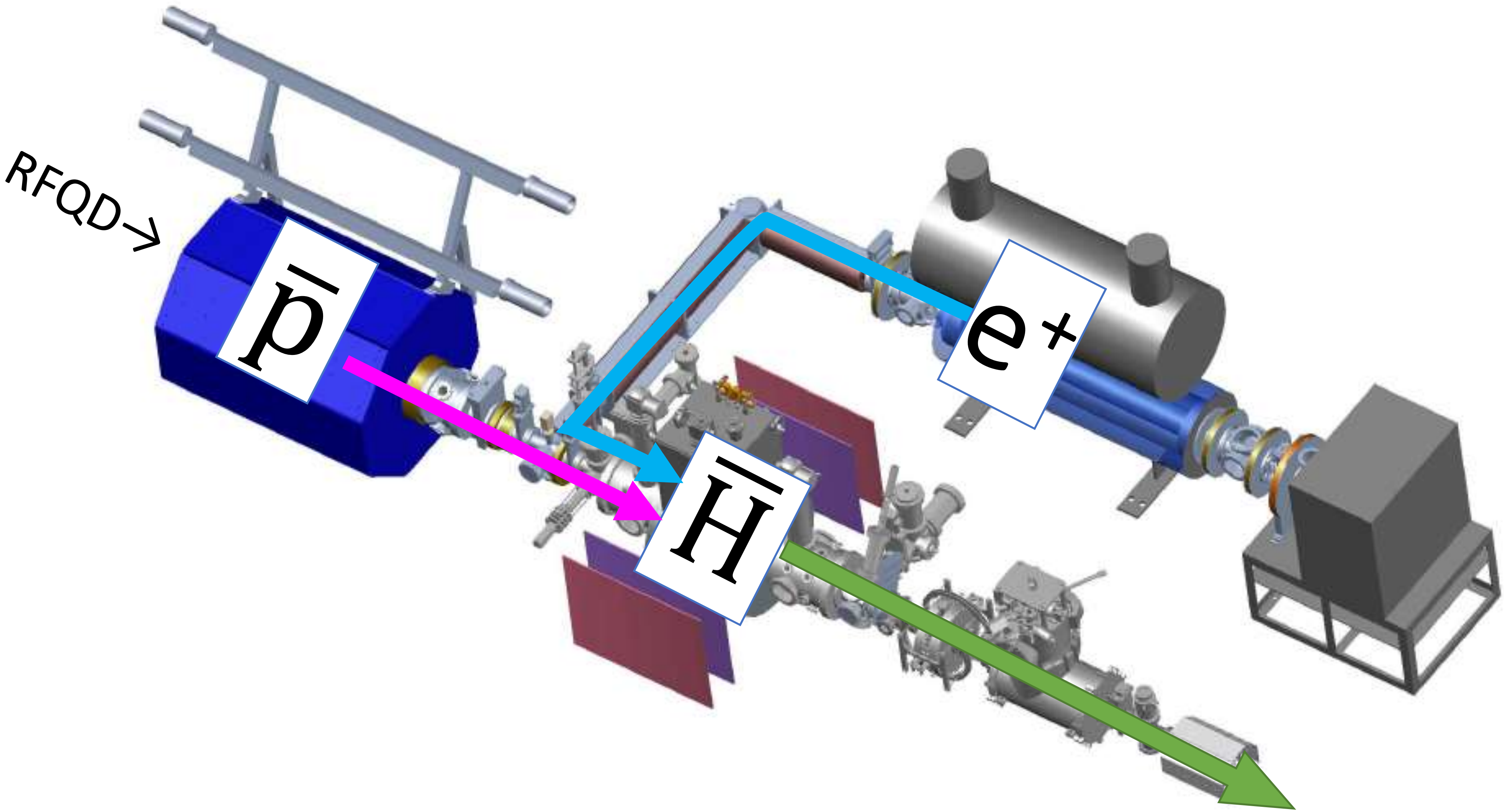
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



Setup for ASACUSA $\overline{\mathrm{H}}$ experiment

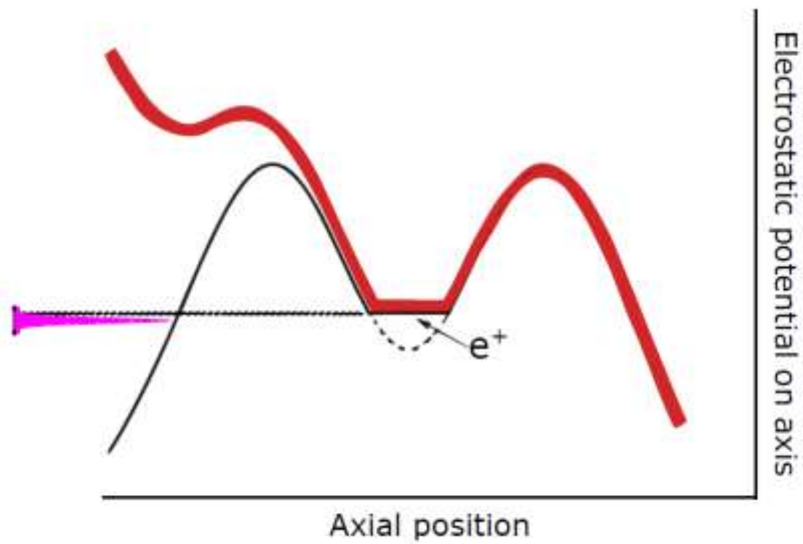


Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



For a desirable $\overline{\mathrm{H}}$ beam…

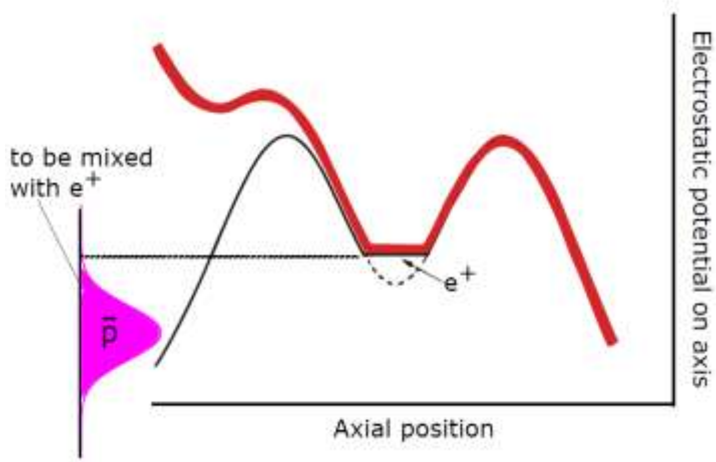
For slow & intense $\overline{\mathrm{H}}$ beam, injection of $\bar{p}$ with a small energy spread is really important.



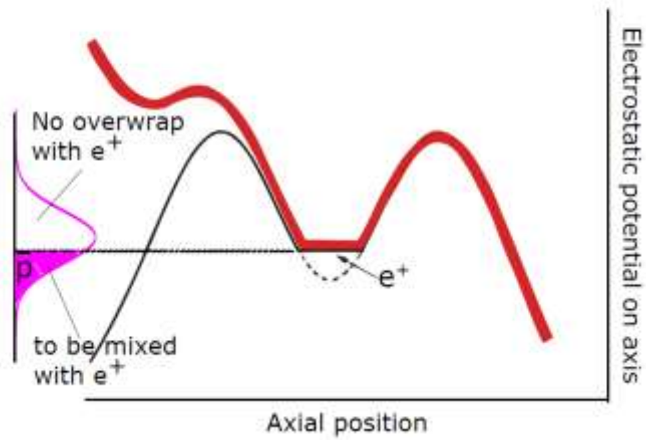
For a desirable $\overline{\mathrm{H}}$ beam…

For slow & intense $\overline{\mathrm{H}}$ beam, injection of $\bar{\mathrm{p}}$ with a small energy spread is really important.

If the energy spread is large…



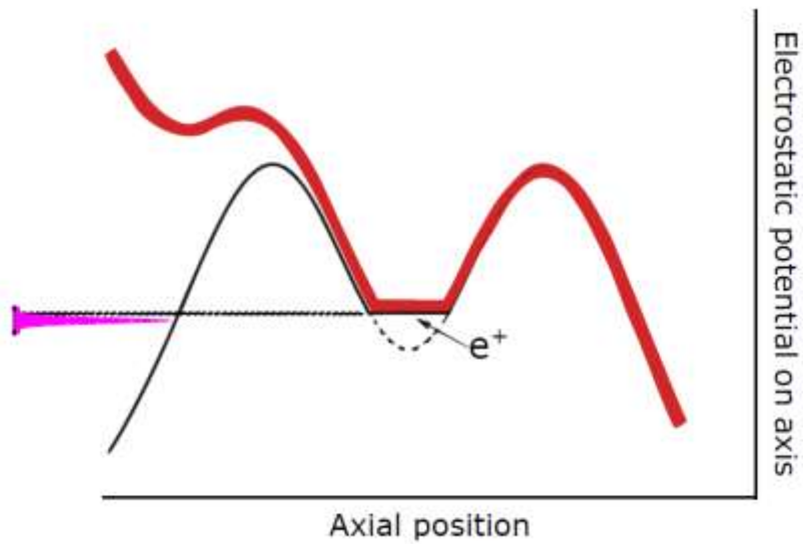
heating of e+



less $\bar{\mathrm{p}}$

For a desirable $\overline{\mathrm{H}}$ beam…

For slow & intense $\overline{\mathrm{H}}$ beam, injection of $\bar{\mathrm{p}}$ with a small energy spread is really important.



But it was not achieved by our old scheme.

For a desirable $\overline{\mathrm{H}}$ beam…

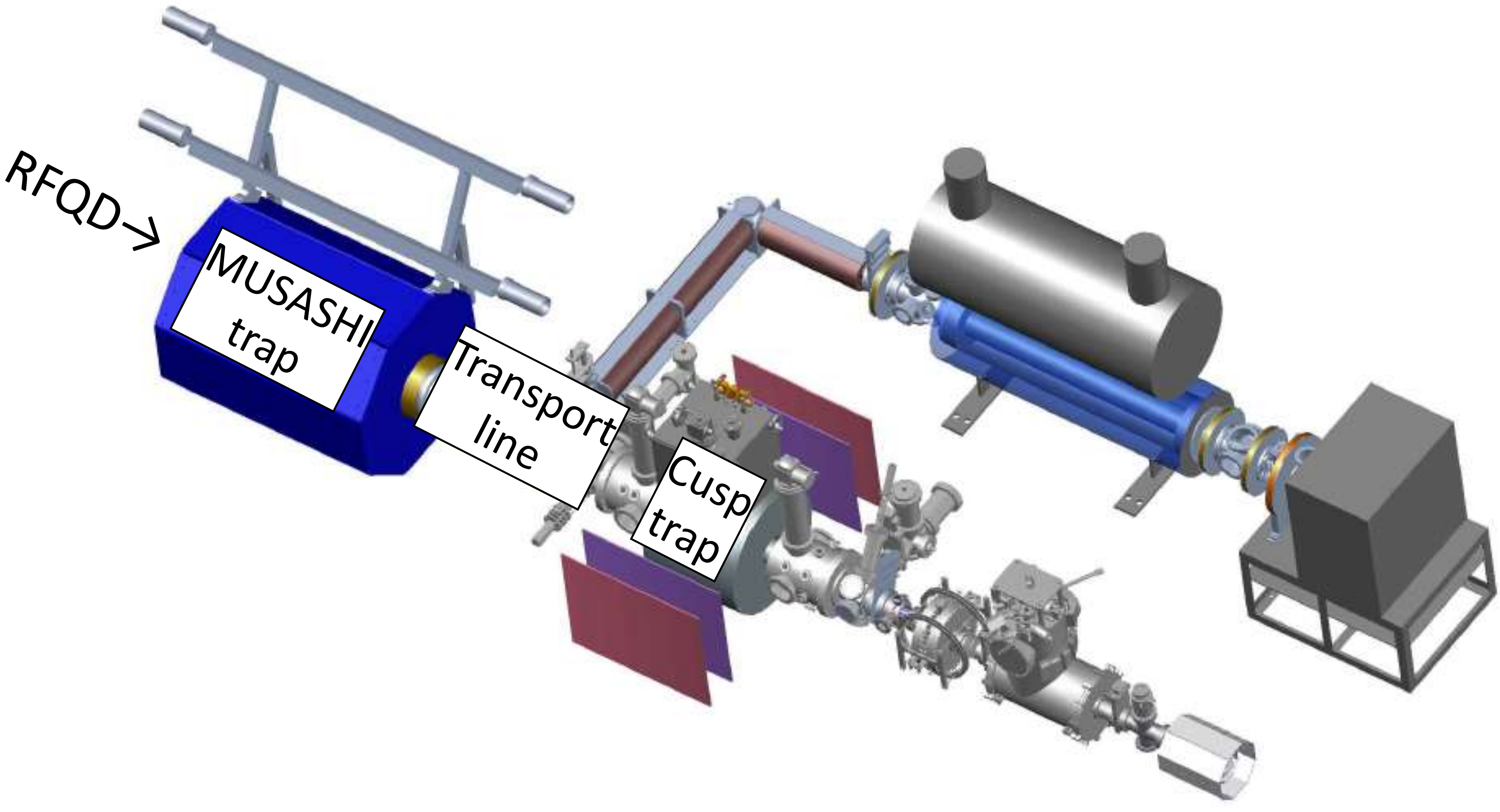
For slow & intense $\overline{\mathrm{H}}$ beam, injection of $\bar{\mathrm{p}}$ with a small energy spread is really important.

But it was not achieved by our old scheme.

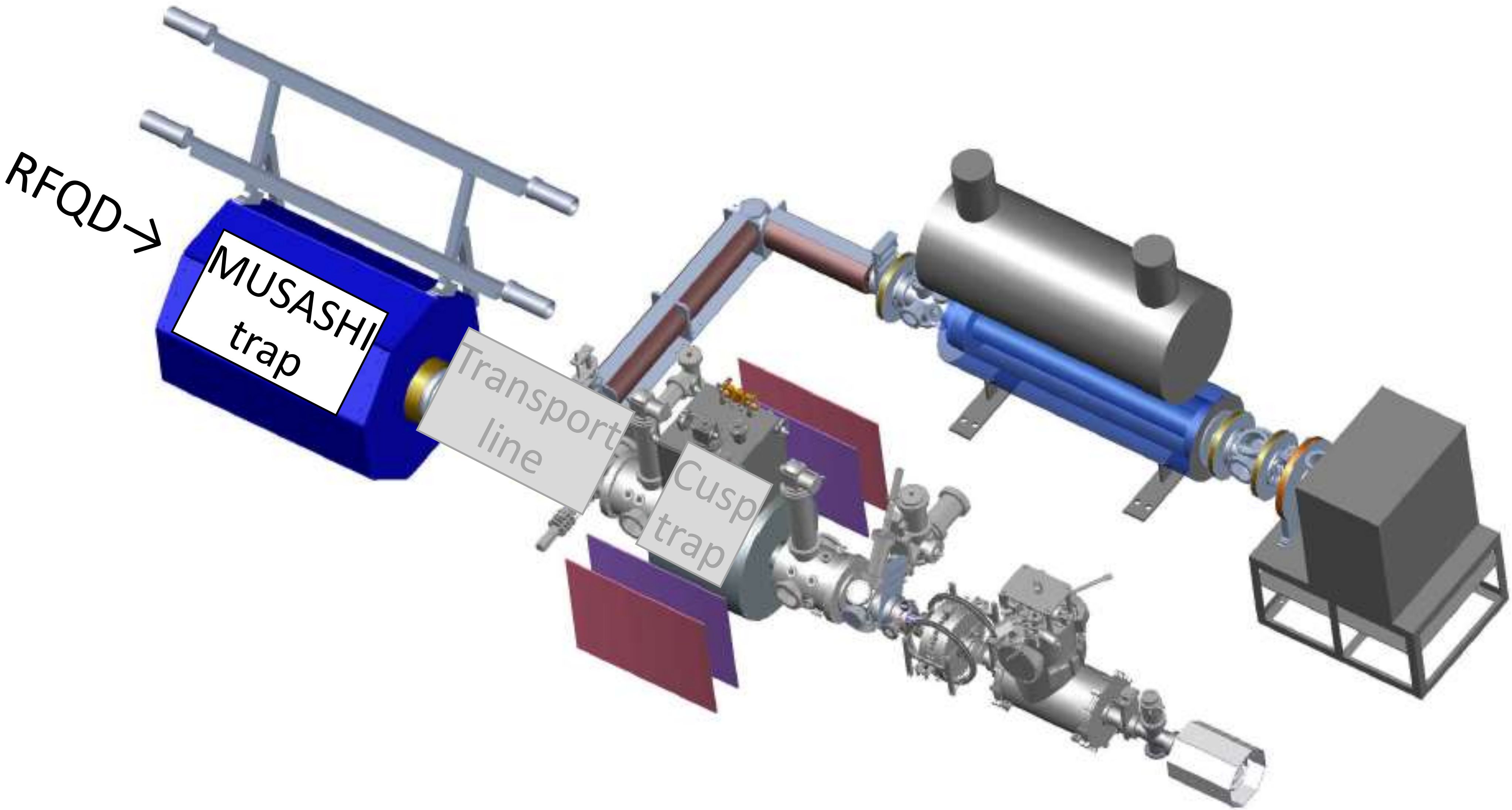
Then in recent years, we have tried

- to prepare and extract a cold $\bar{\mathrm{p}}$ cloud --- making the initial (before transport) energy spread small,
- to transport it adiabatically --- keeping the small energy spread after transport.

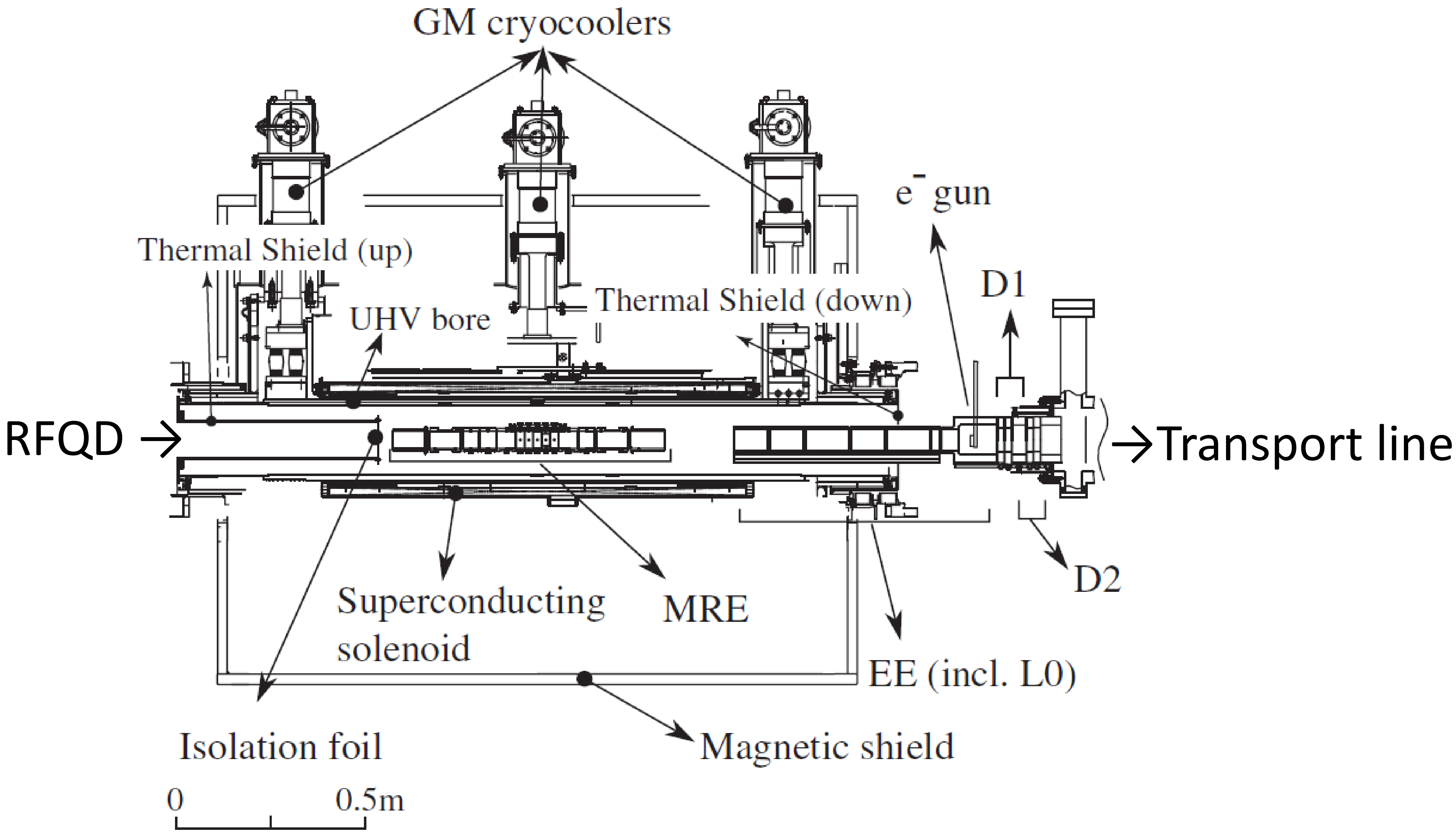
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



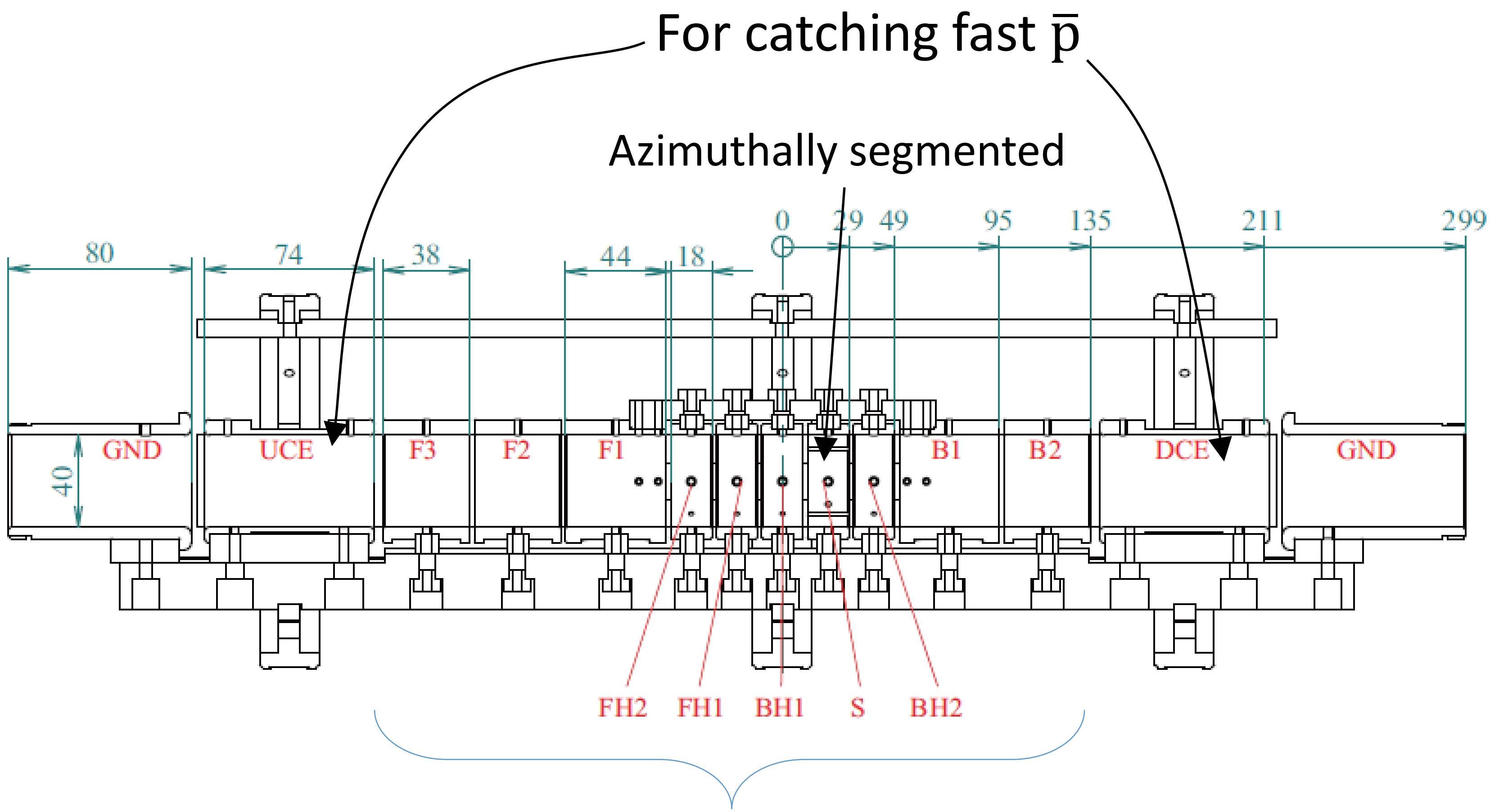
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



MUSASHI trap



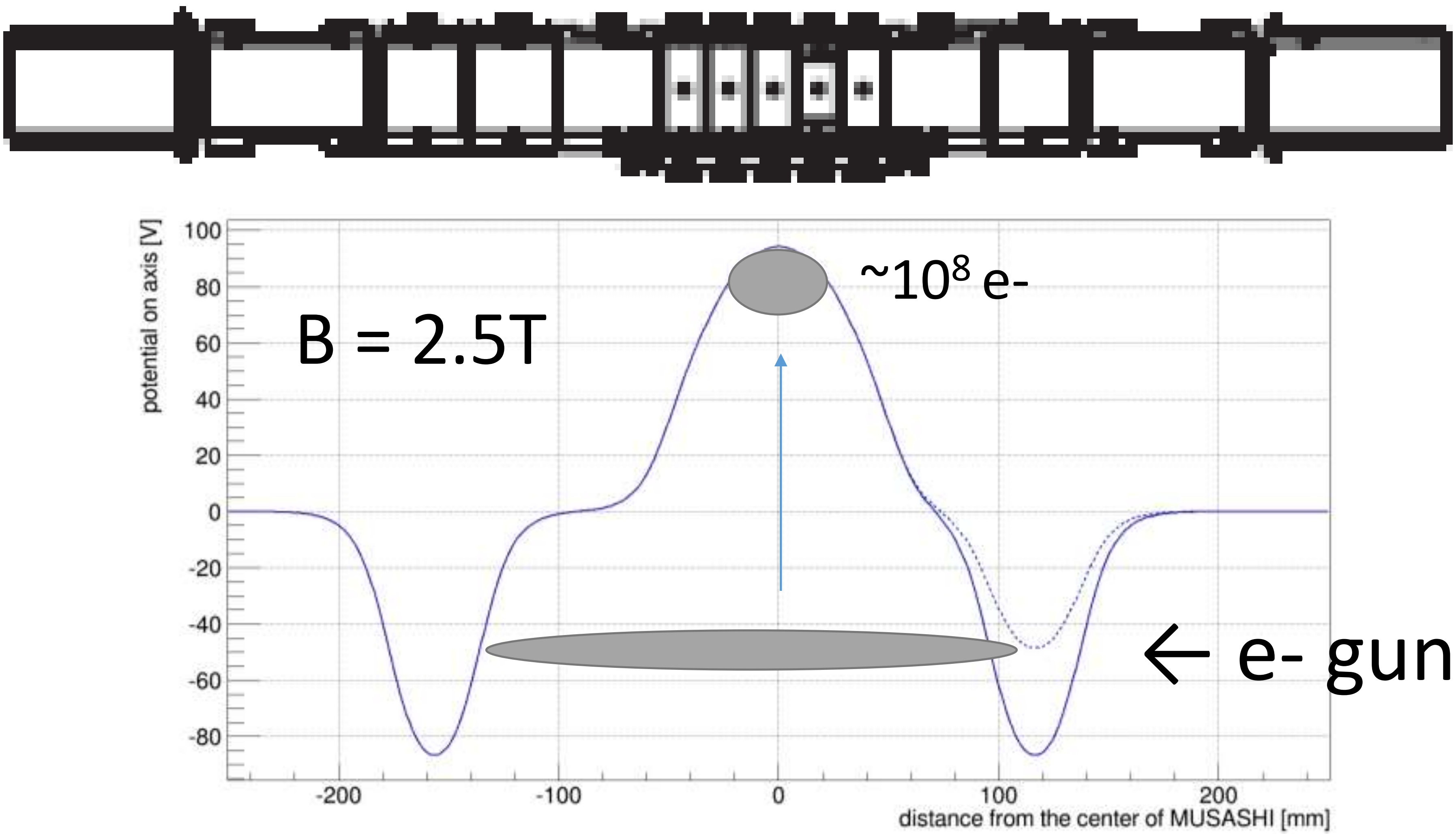
MUSASHI MRE



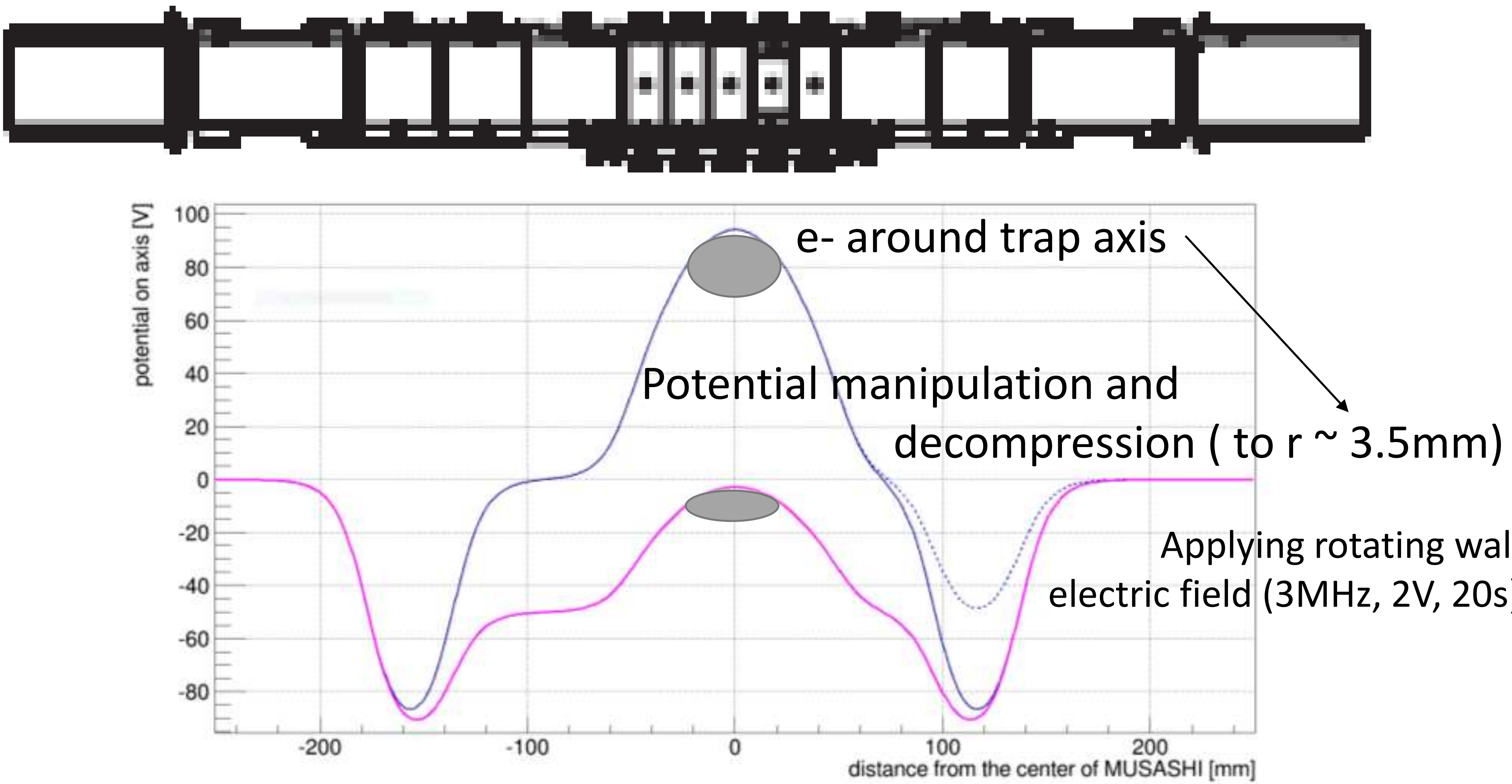
10 electrodes are used for a fine potential manipulation.

By floating MRE as a whole, the energy of $\bar{p}$ can be changed.

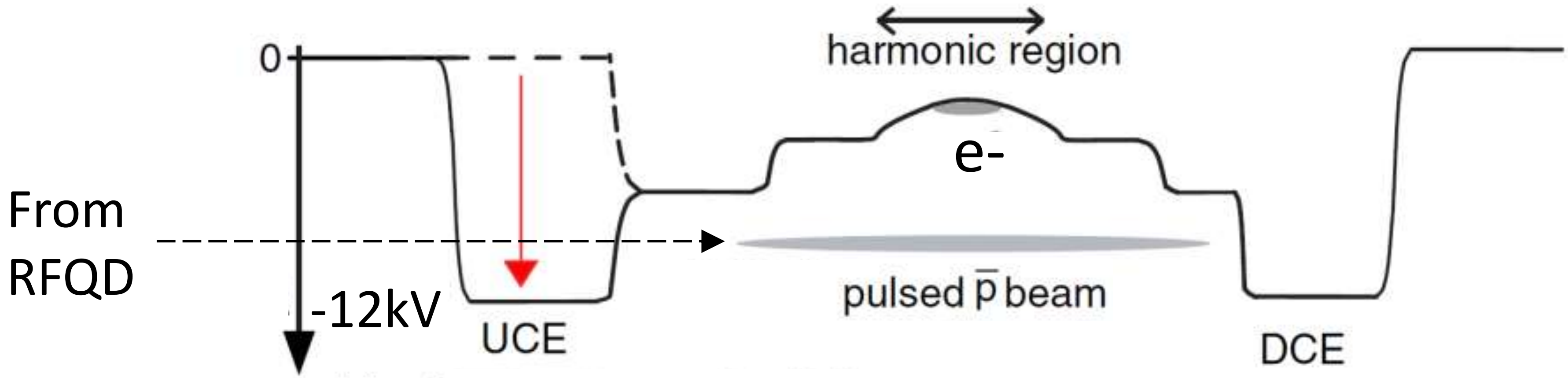
Preparation of e- cloud



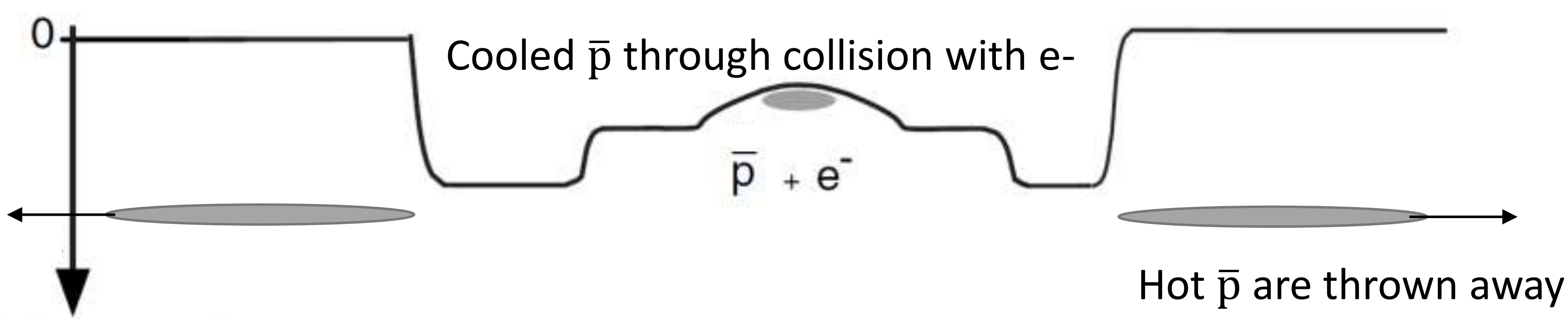
Preparation of e- cloud



$\bar{p}$ injection and electron cooling

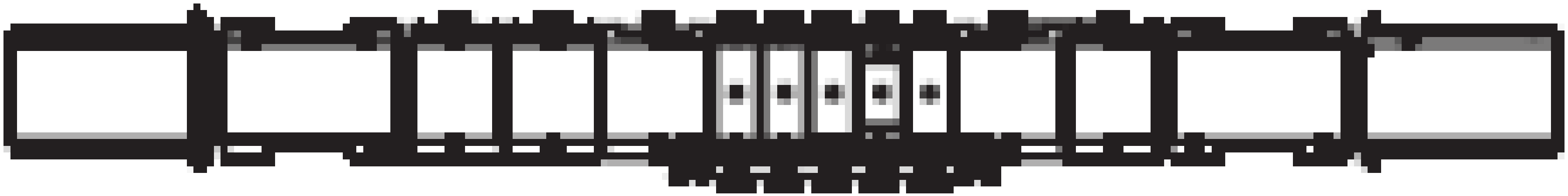


Cooling for 40 s

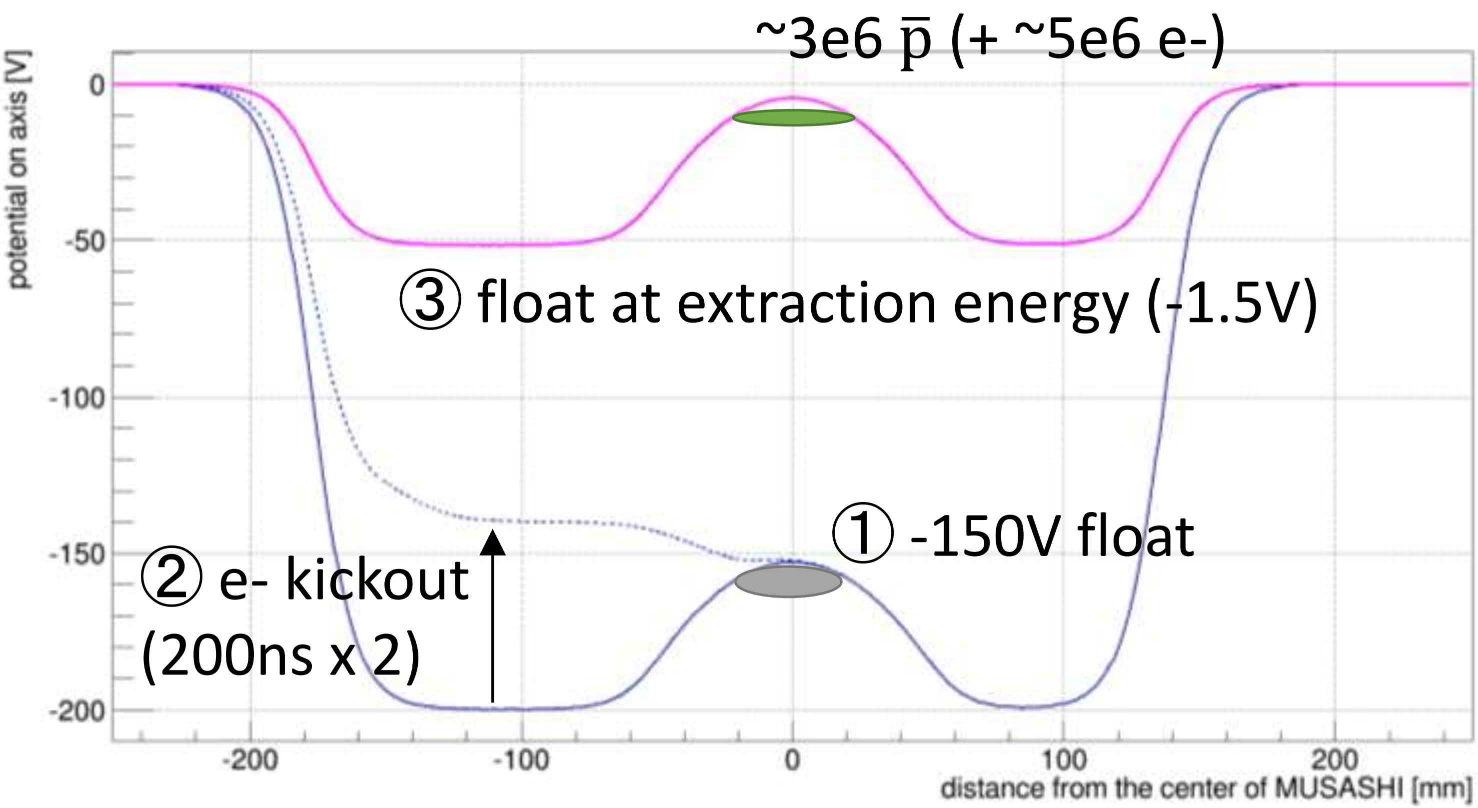


Typically 4 AD shots are accumulated (~3e6 $\bar{p}$).

Preparation of $\bar{p}$

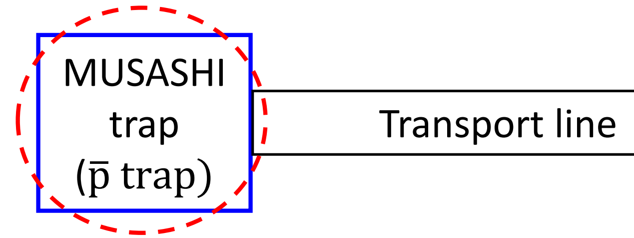


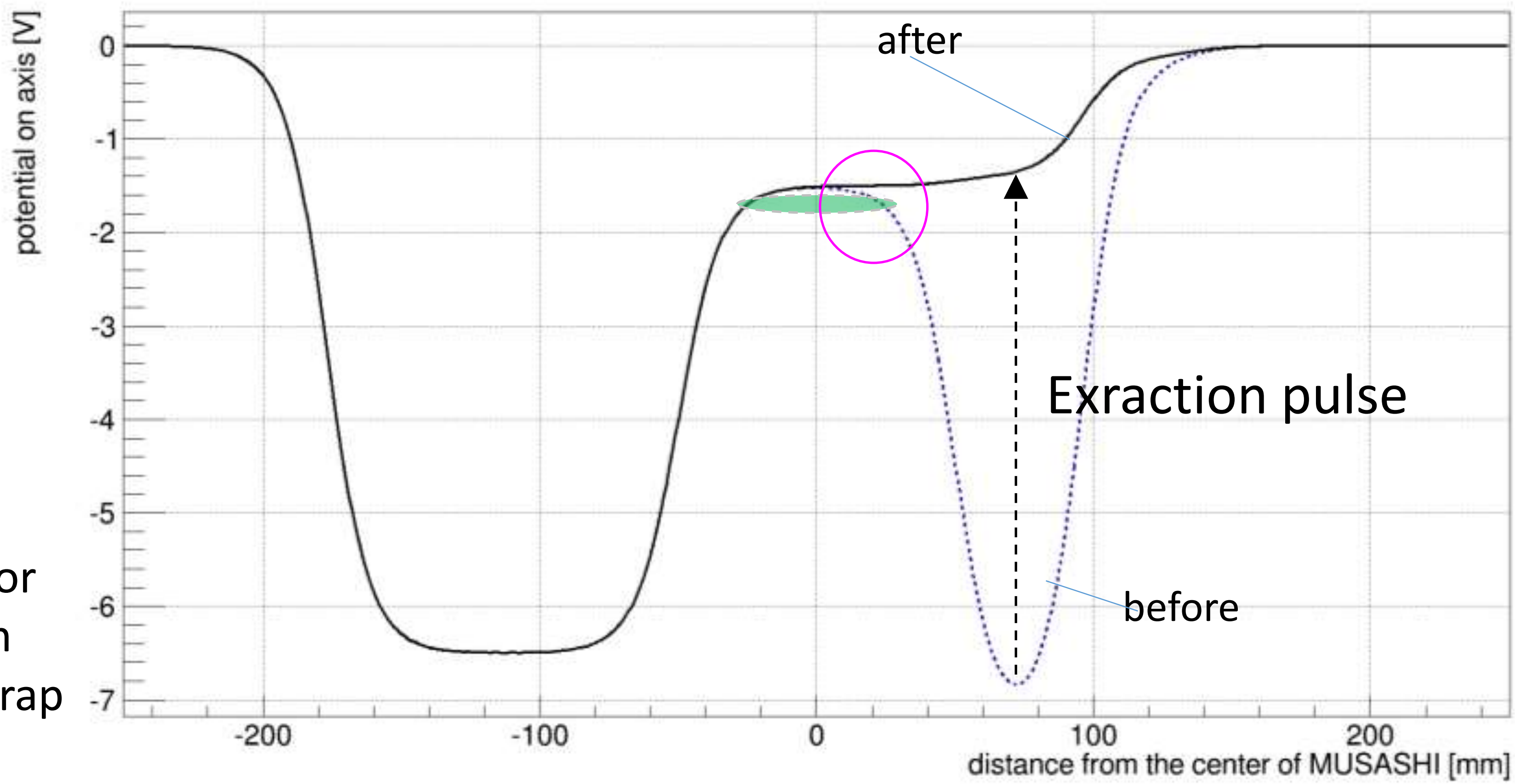
④ Compression (RW 247kHz, 0.3V, 120s)



Extraction scheme from the MUSASHI trap

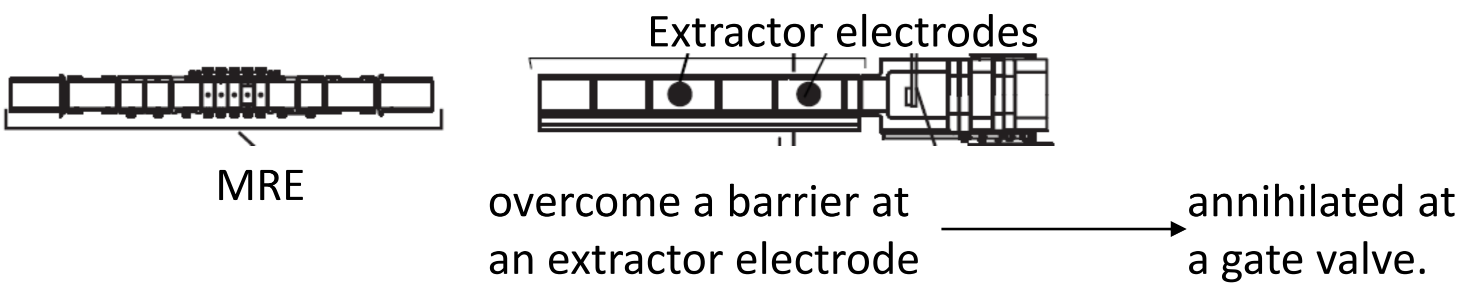
The extraction scheme is optimized to minimize potential change where antiprotons exist.

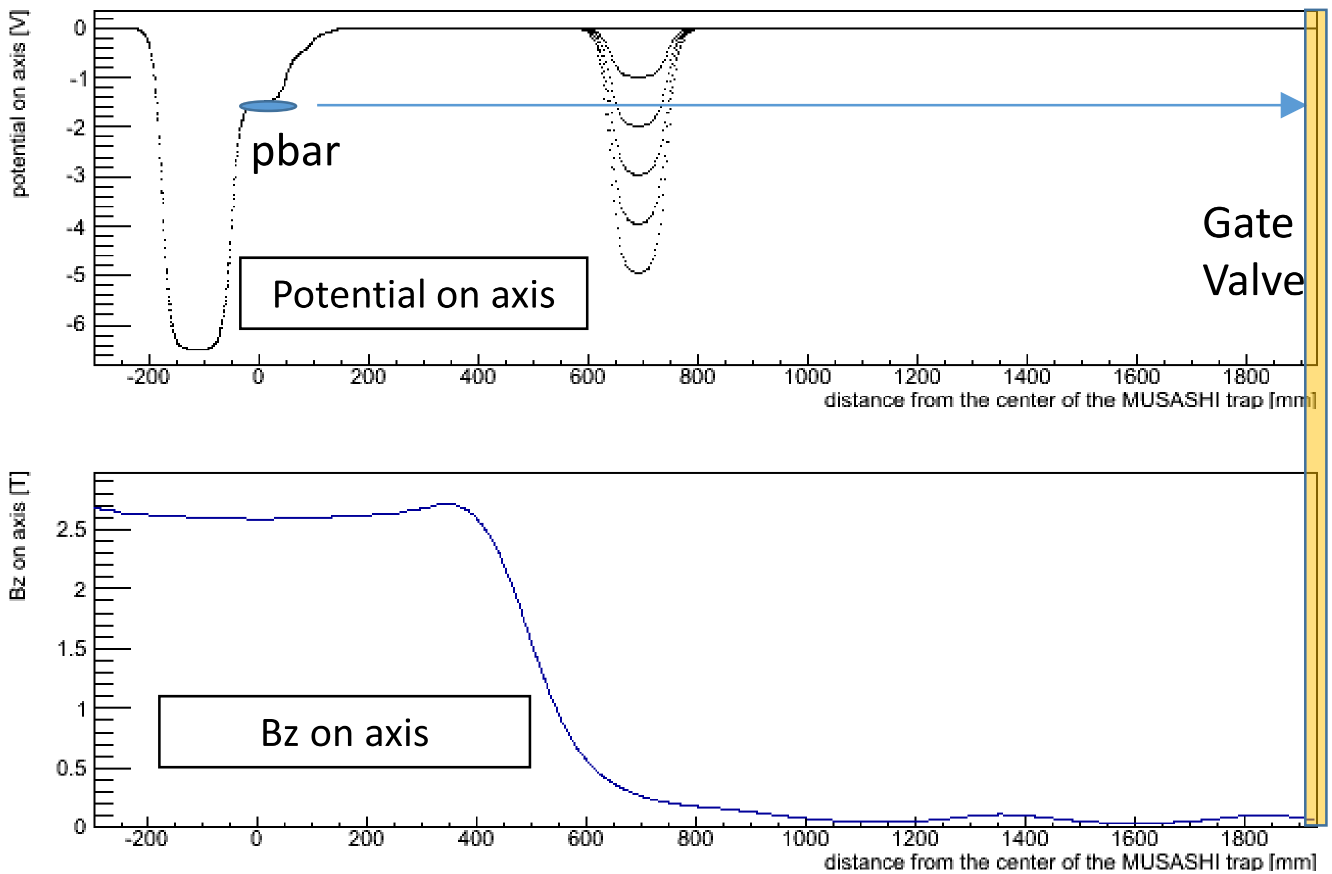




Potential manipulation for extraction from the MUSASHI trap

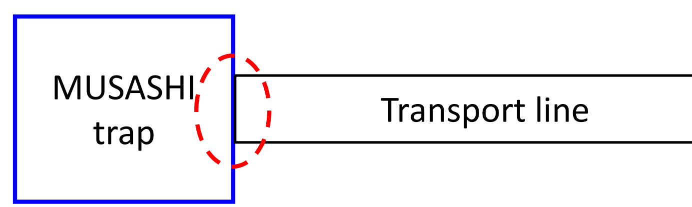
Axial energy distribution @ the exit of the MUSASHI trap





How to measure?

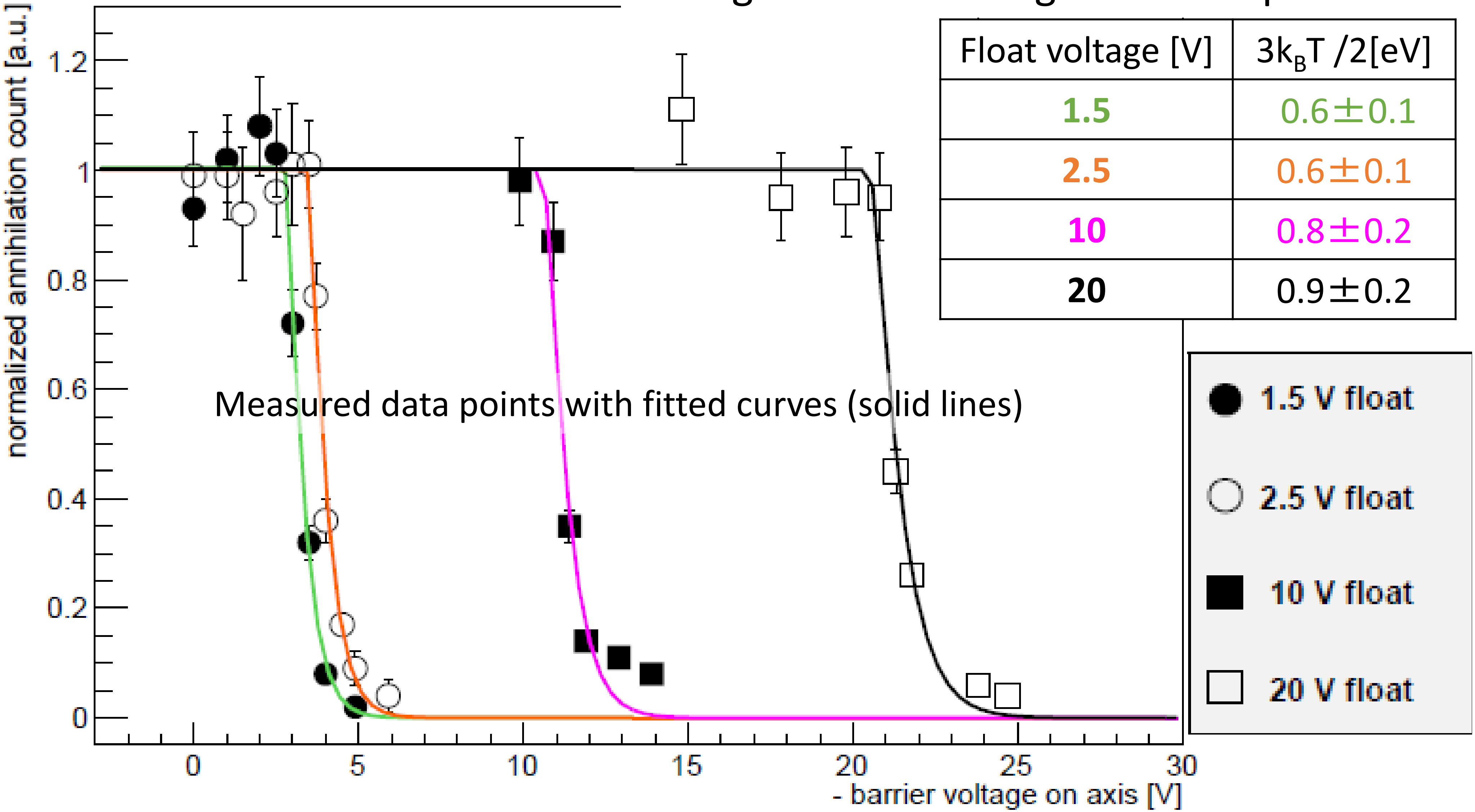
- Change the height of the barrier.
- Plot the # of antiprotons traveling through the barrier, as a function of the barrier's height.



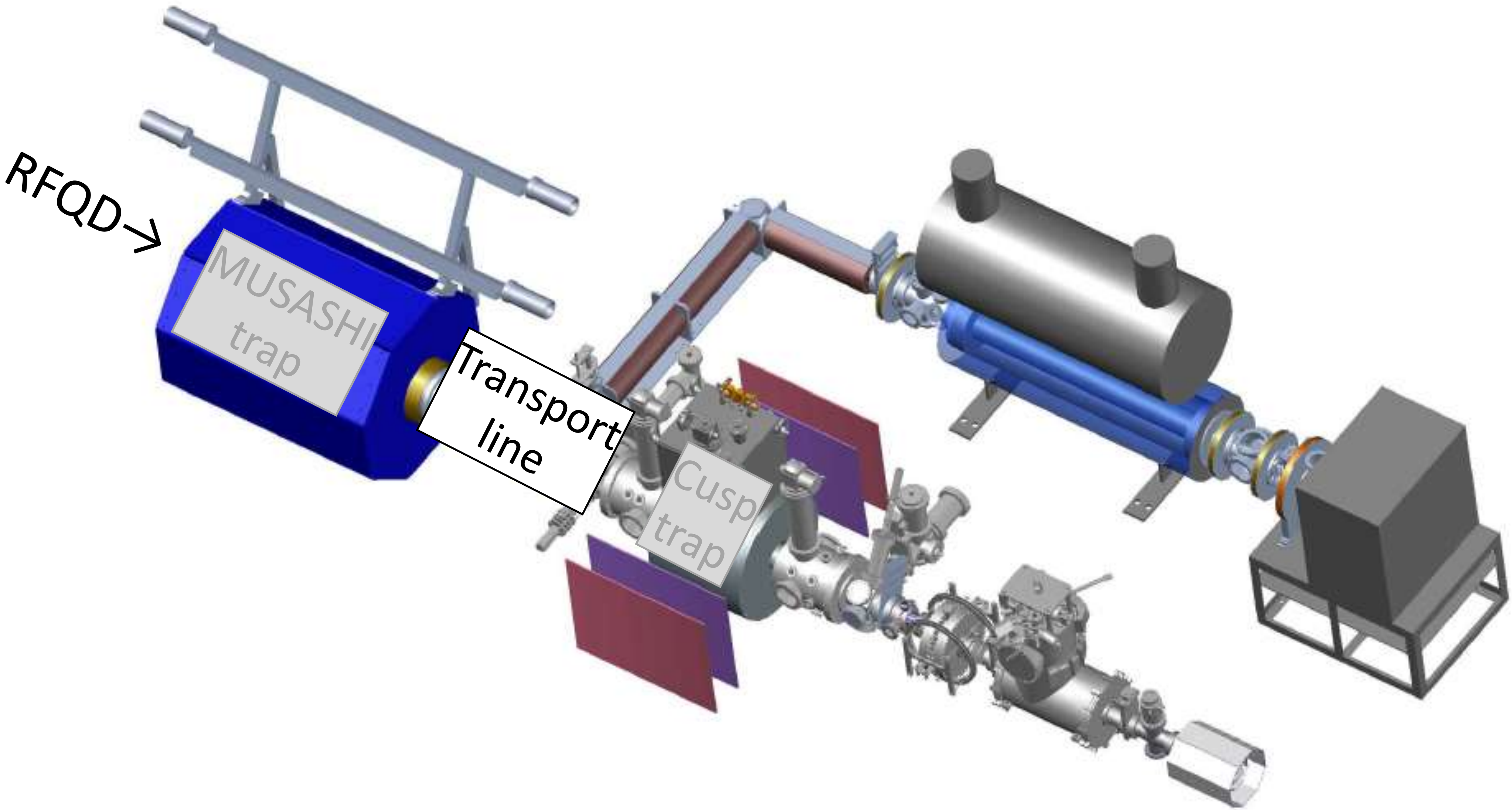
Energy distribution @ the exit of the MUSASHI trap

Fitting result assuming thermal equilibrium.

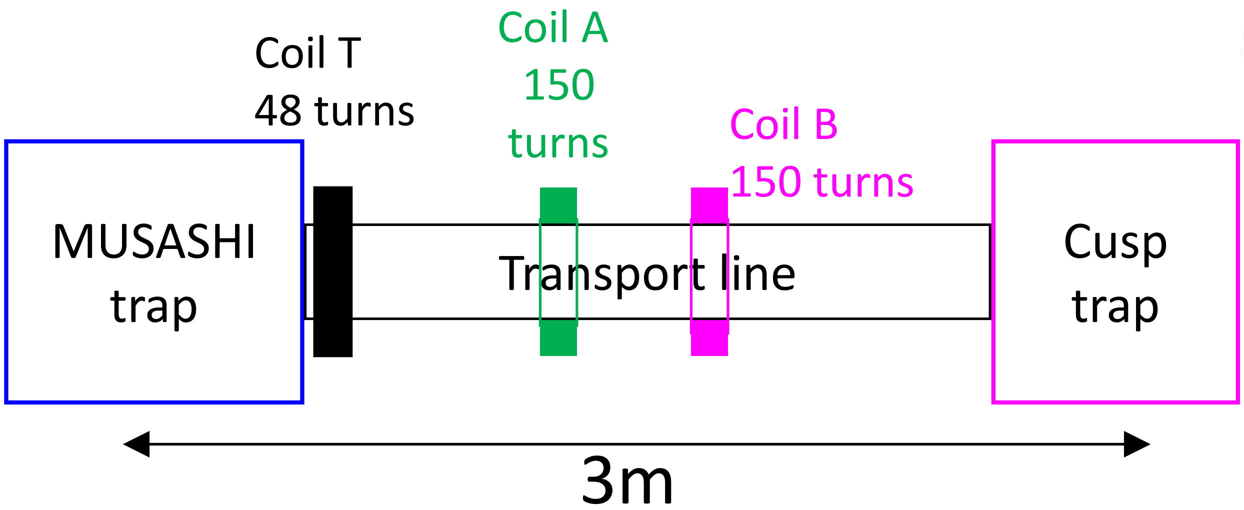
Float voltage [V]	$3k_BT/2$[eV]
1.5	0.6±0.1
2.5	0.6±0.1
10	0.8±0.2
20	0.9±0.2

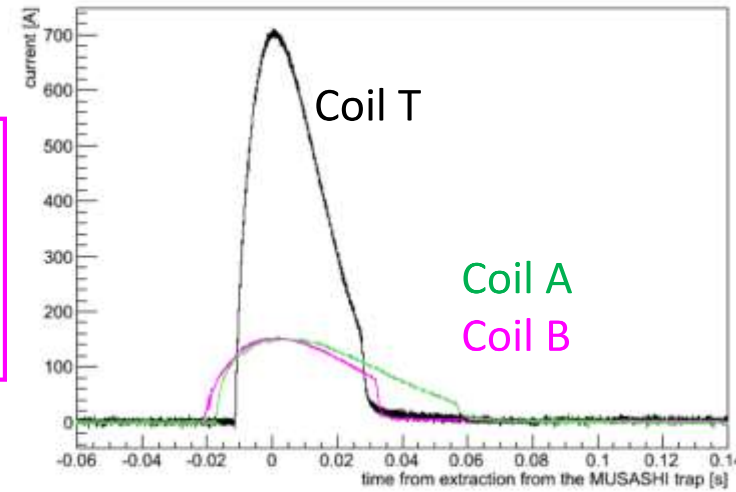


Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



Transport line



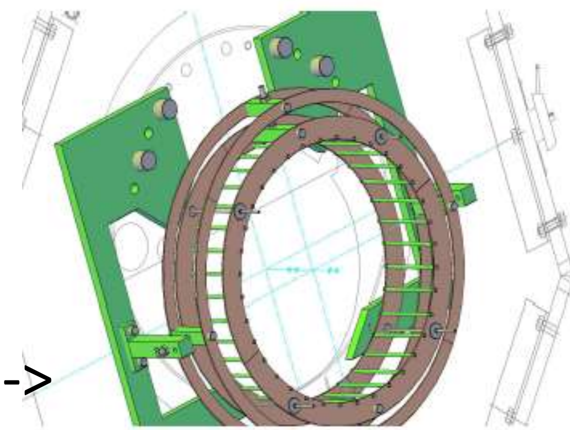


There are 3 pulse coils along the transport line to improve transport.

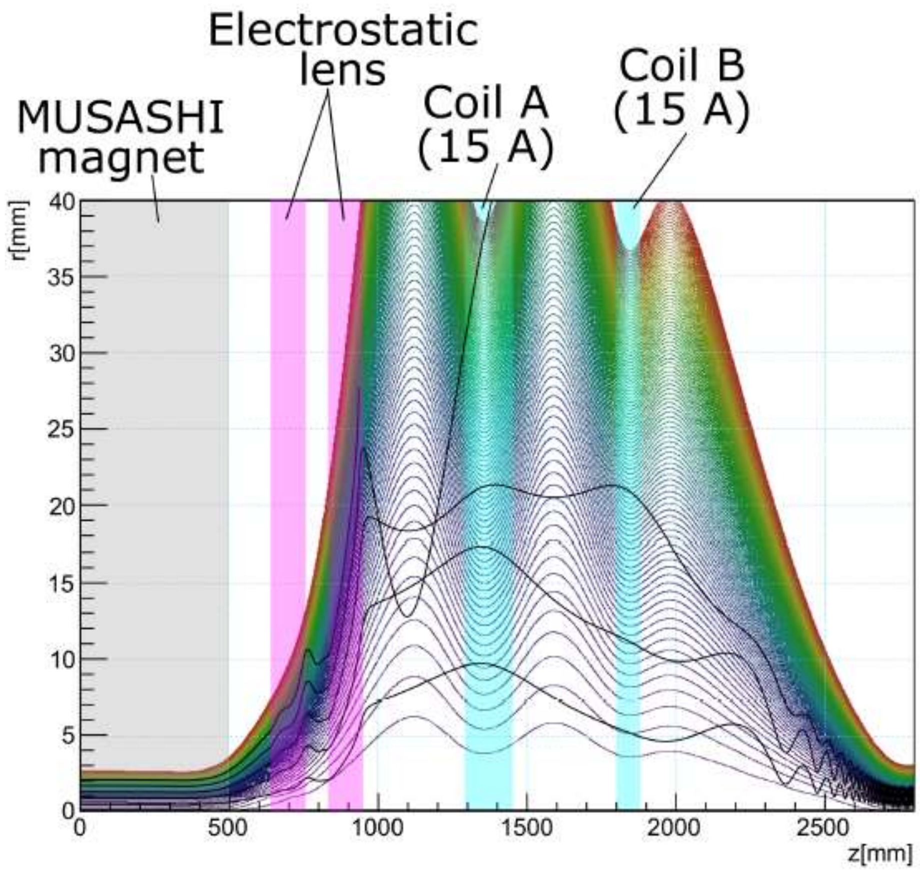
Coil A&B : ~ 1200 gauss on axis @ maximum

Coil T : ~ 1600 gauss on axis @ maximum

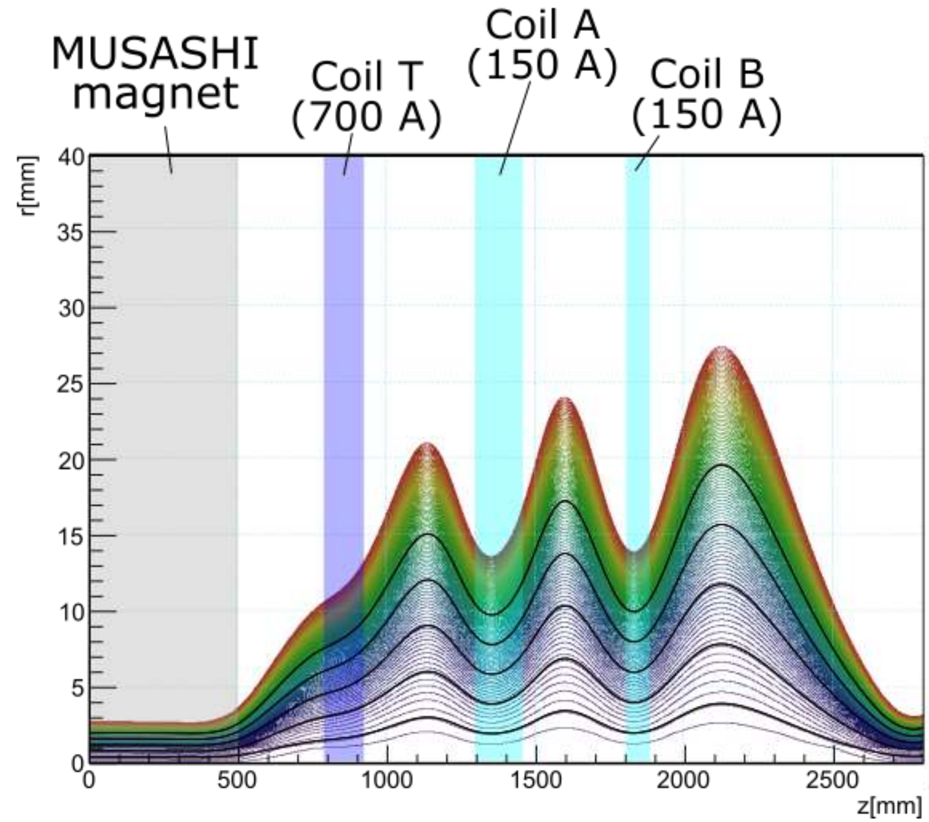
A support structure for the coil T ->



Transport line



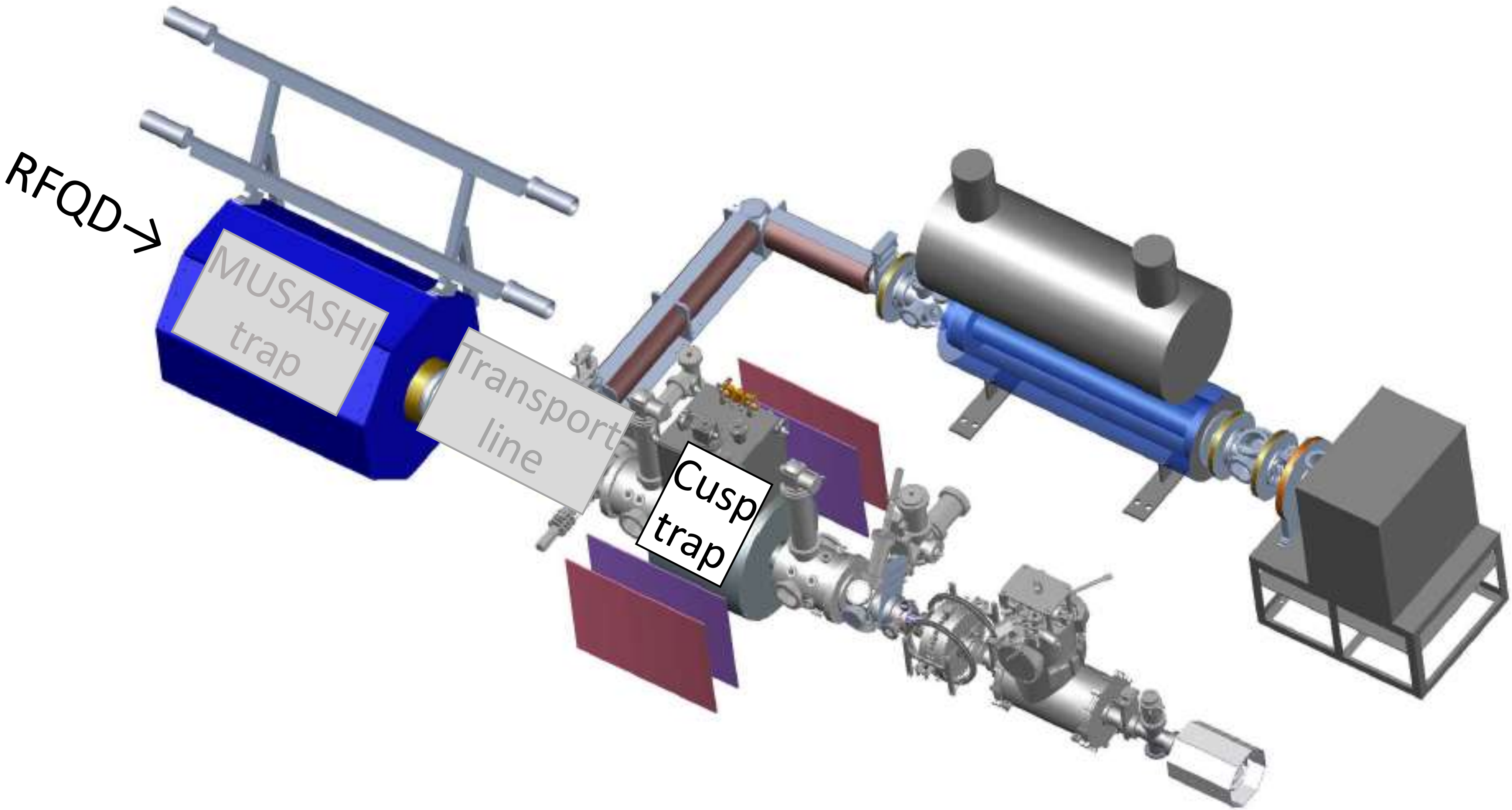
[Old transport]



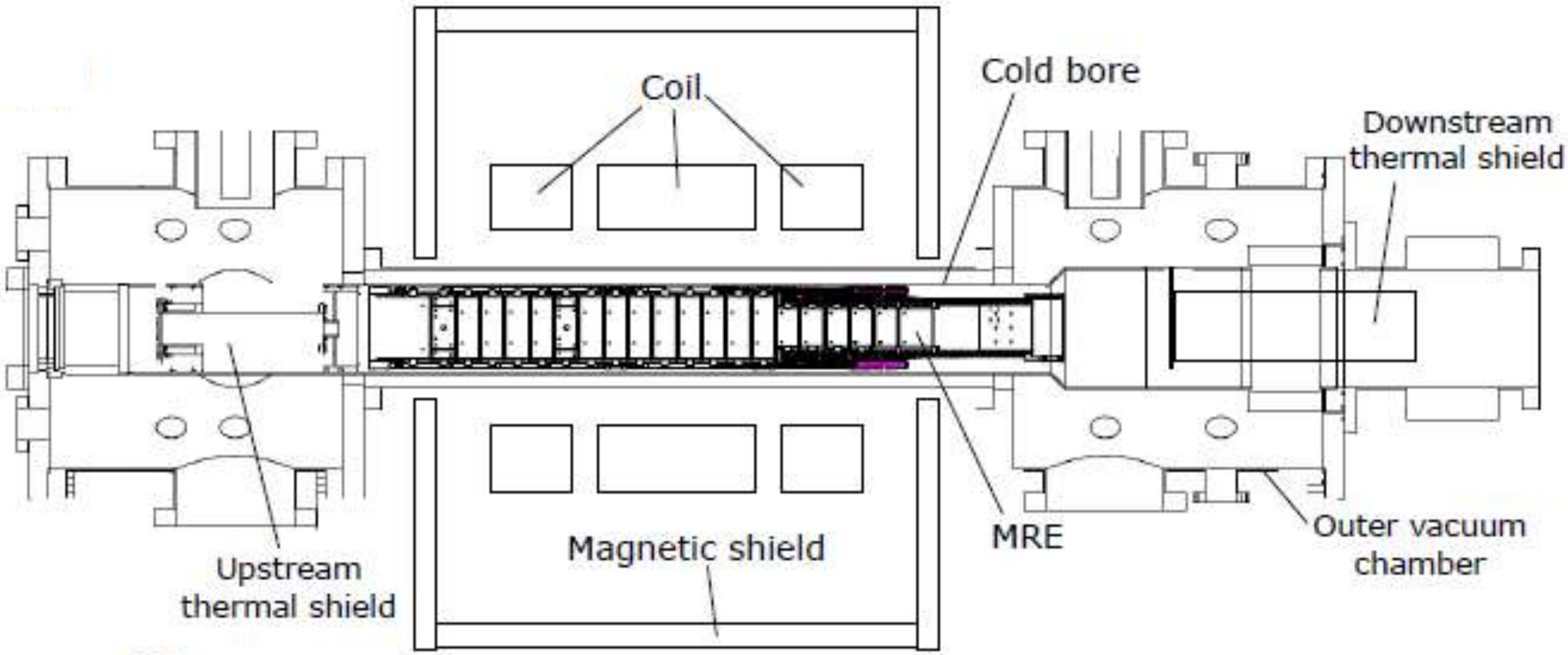
[Modified transport](2016)

Divergence of magnetic field lines is greatly suppressed and trajectories are along the field lines in the modified transport compared to the old transport.

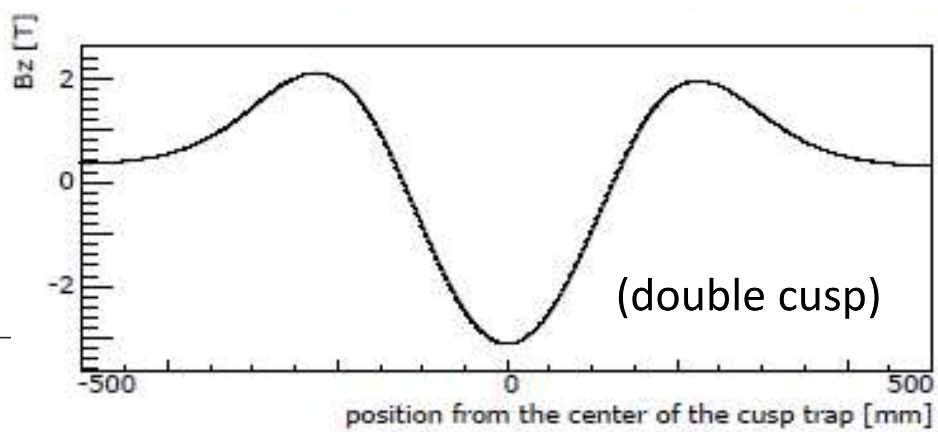
Setup for ASACUSA $\overline{\mathrm{H}}$ experiment



The cusp trap ($\overline{\mathrm{H}}$ production region)

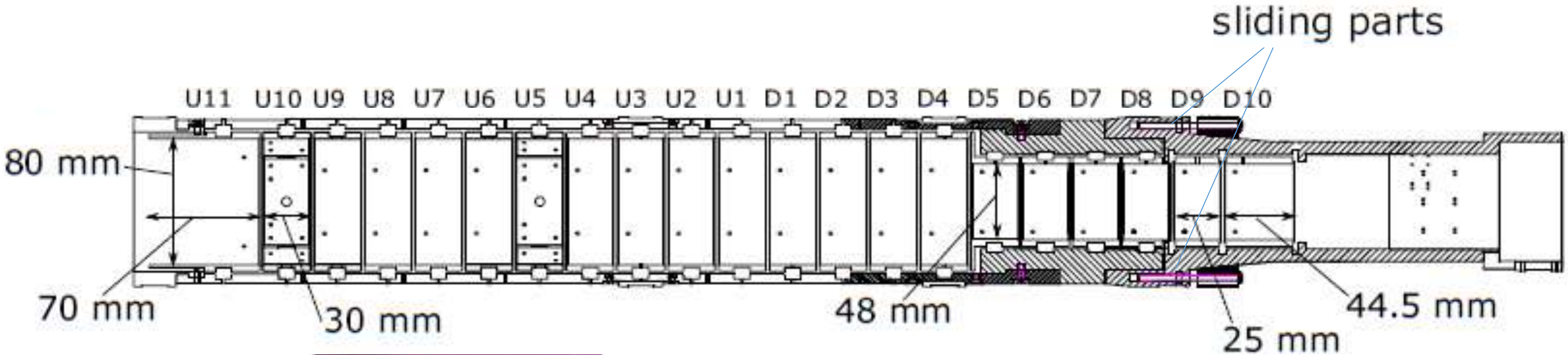


(single cusp)

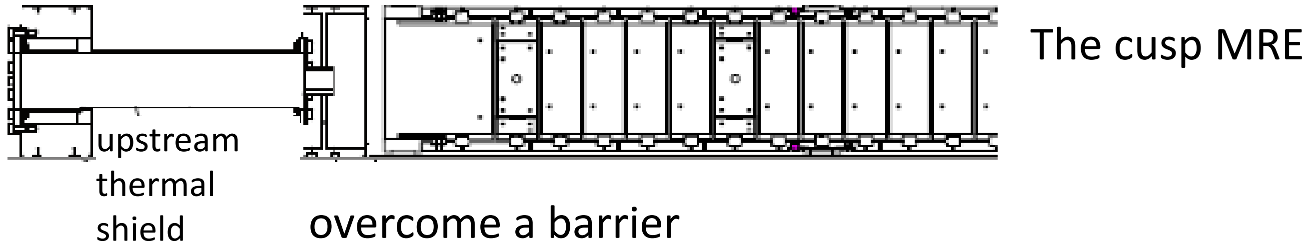


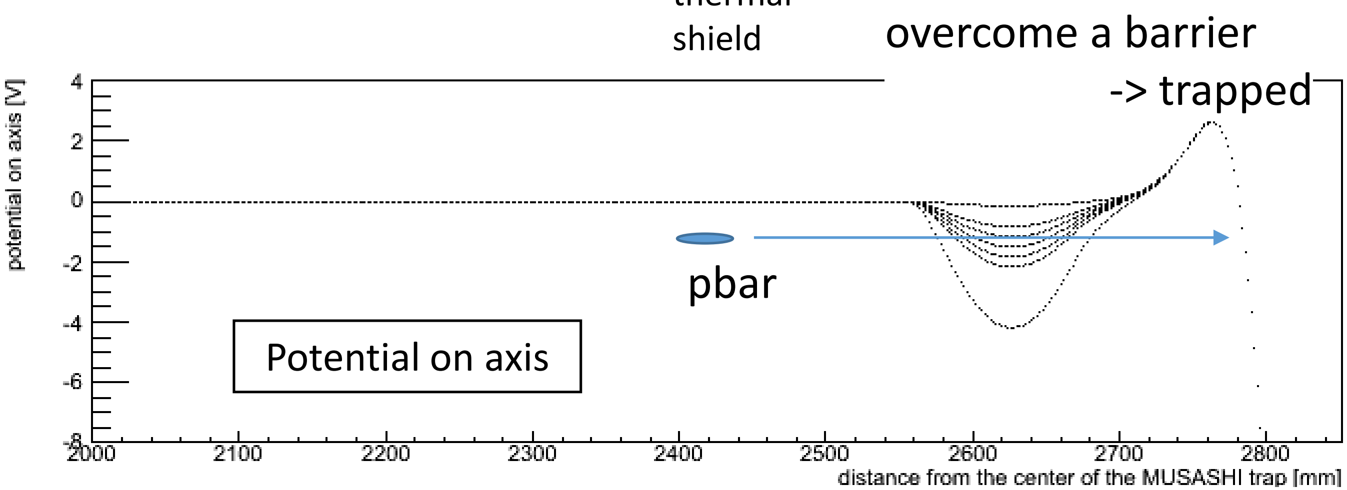
<- Bz on axis.
Better focusing effect for $\overline{\mathrm{H}}$ beam than a single cusp configuration.

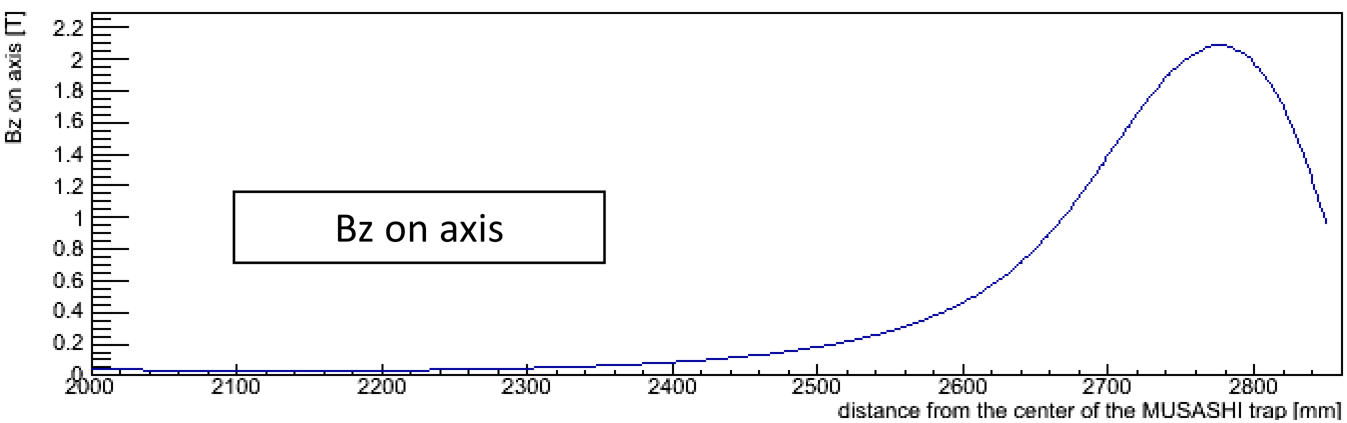
The cusp MRE


sliding parts
U11
U10
U9
U8
U7
U6
U5
U4
U3
U2
U1
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
80 mm
70 mm
30 mm
48 mm
25 mm
44.5 mm

Energy distribution @ the entrance of the cusp trap

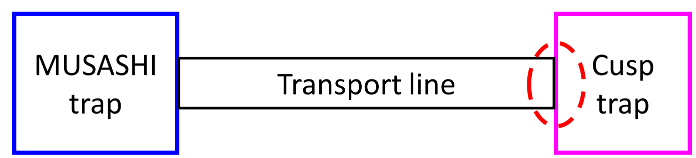




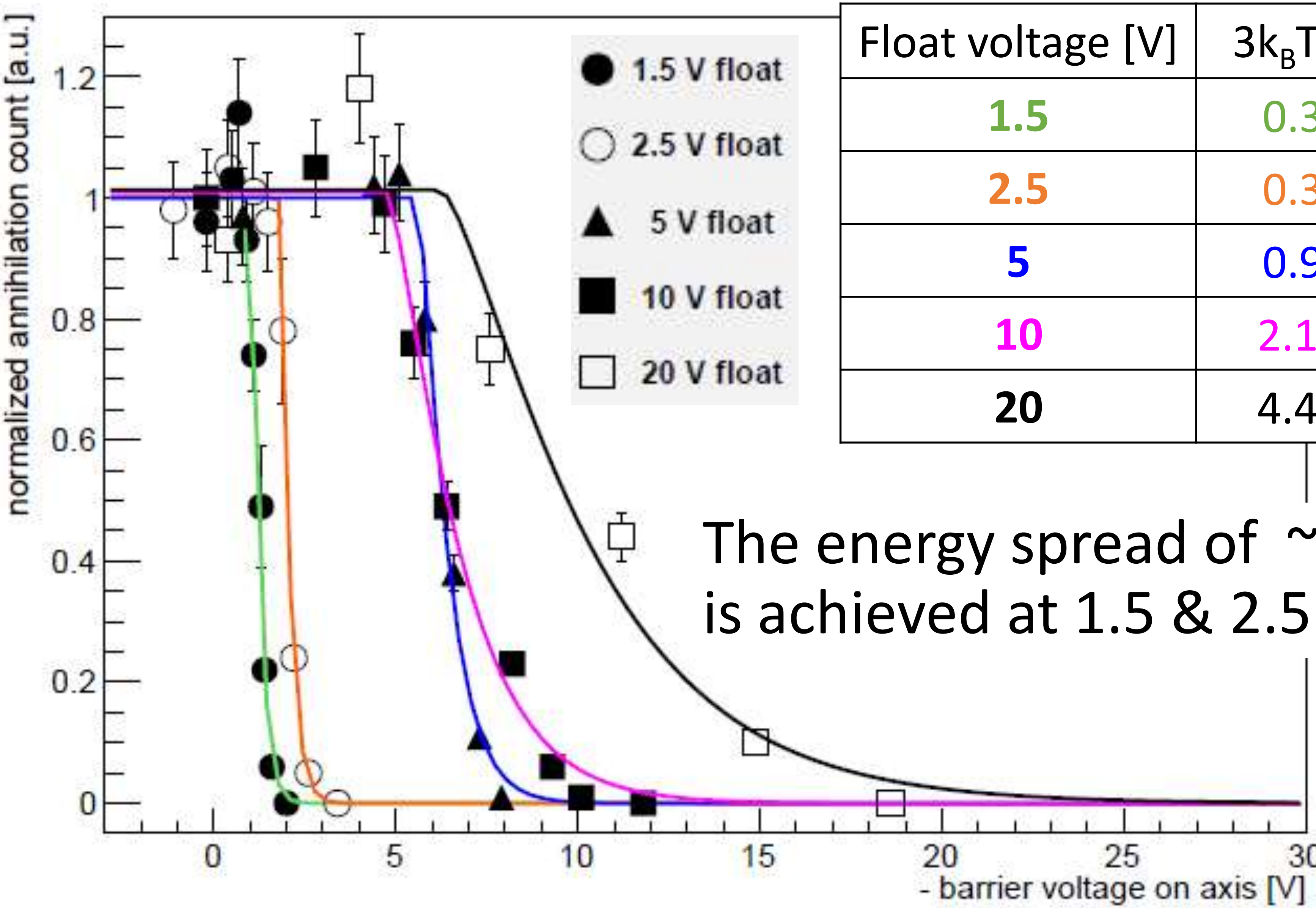


How to measure?

- Change the height of the barrier at the entrance of the cusp trap.
- # of the trapped antiprotons as a function of the height of the barrier.



Energy distribution @ the entrance of the cusp trap

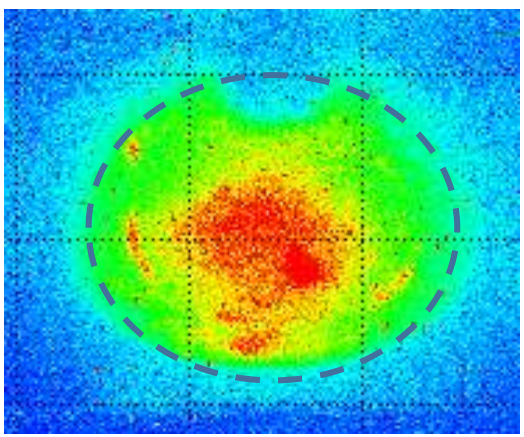


Float voltage [V]	$3k_BT/2$ [eV]
1.5	0.3±0.1
2.5	0.3±0.1
5	0.9±0.1
10	2.1±0.3
20	4.4±0.4

The energy spread of ~0.3eV is achieved at 1.5 & 2.5 V float.

Summary

	Float	Trapping efficiency	Energy spread @ cusp entrance ($3k_BT/2$)
Modified transport (2016)	1.5 V	~ 20 % (typical#: 600k)	~ 0.3 eV



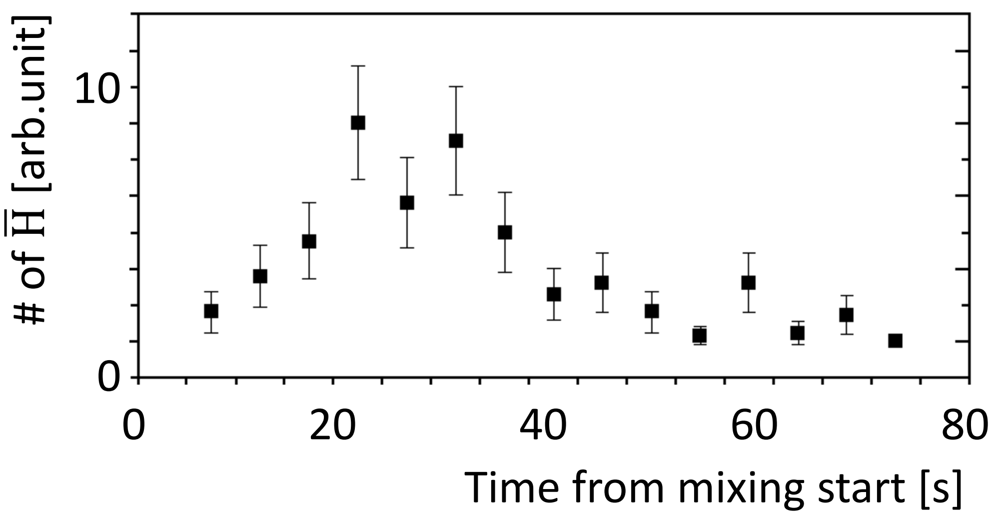
- $\bar{p}$ profile @ MCP-PS in the transport line.
- The core part (r ~ 1mm) and a halo is observed.

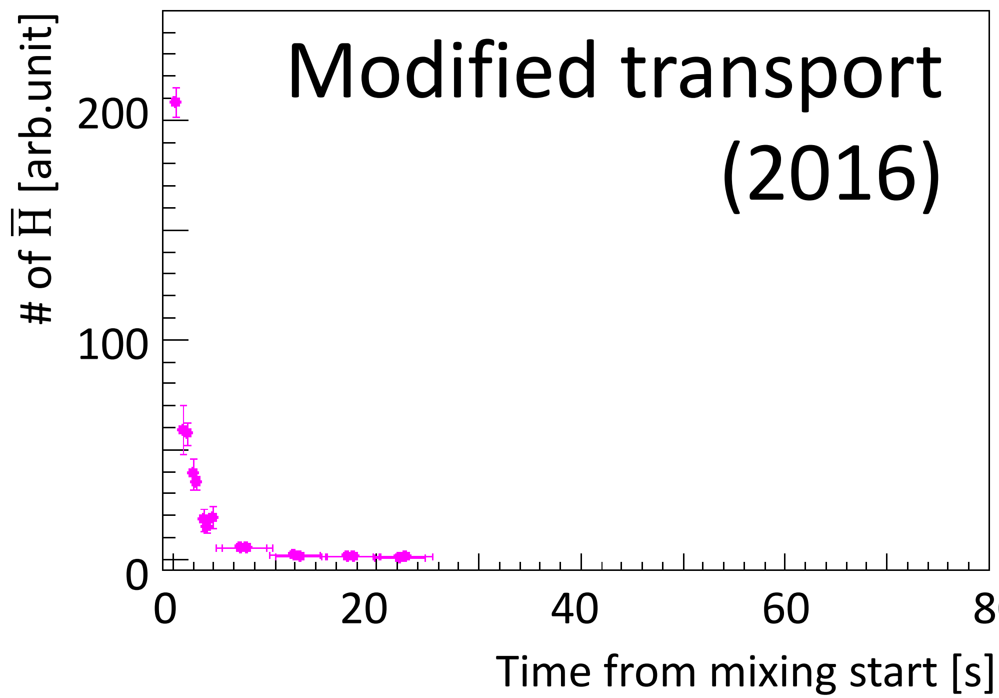
Time structure of $\overline{\mathrm{H}}$ production

Heating of e+ is suppressed because of the small energy spread

-> $\overline{\mathrm{H}}$ production starts just after the mixing.

Old transport





To do

- For a colder antiprotons in cusp, further cooling of antiprotons in the MUSASHI trap is a possibility.
  - Evaporative cooling.
  - Electron kickout by selective excitation by RF.
- For a higher trapping efficiency,
  - A bit higher injection energy within the range of a small energy spread at the cusp trap.
  - Radial compression of $\overline{\mathrm{p}}$.
- For a higher $\overline{\mathrm{H}}$ yield,
  - Counteract separation between antiprotons $\overline{\mathrm{p}}$ and e+.
  - Radial compression of $\overline{\mathrm{p}}$.

Thank you very much for your attention!