ASACUSA Status

Atomic Spectroscopy And Collisions Using Slow Antiprotons

120th Meeting of the SPSC
January 19, 2015

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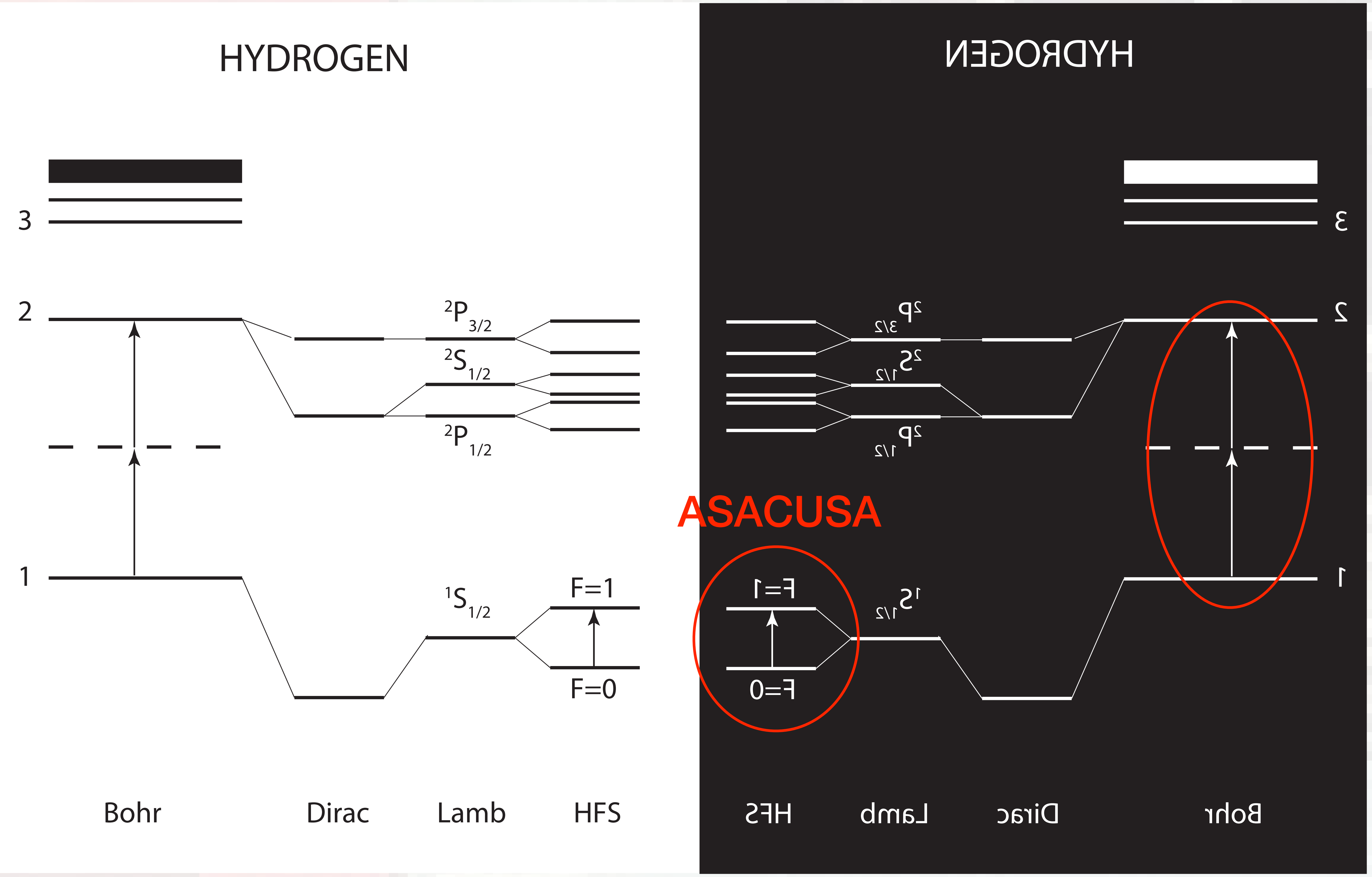
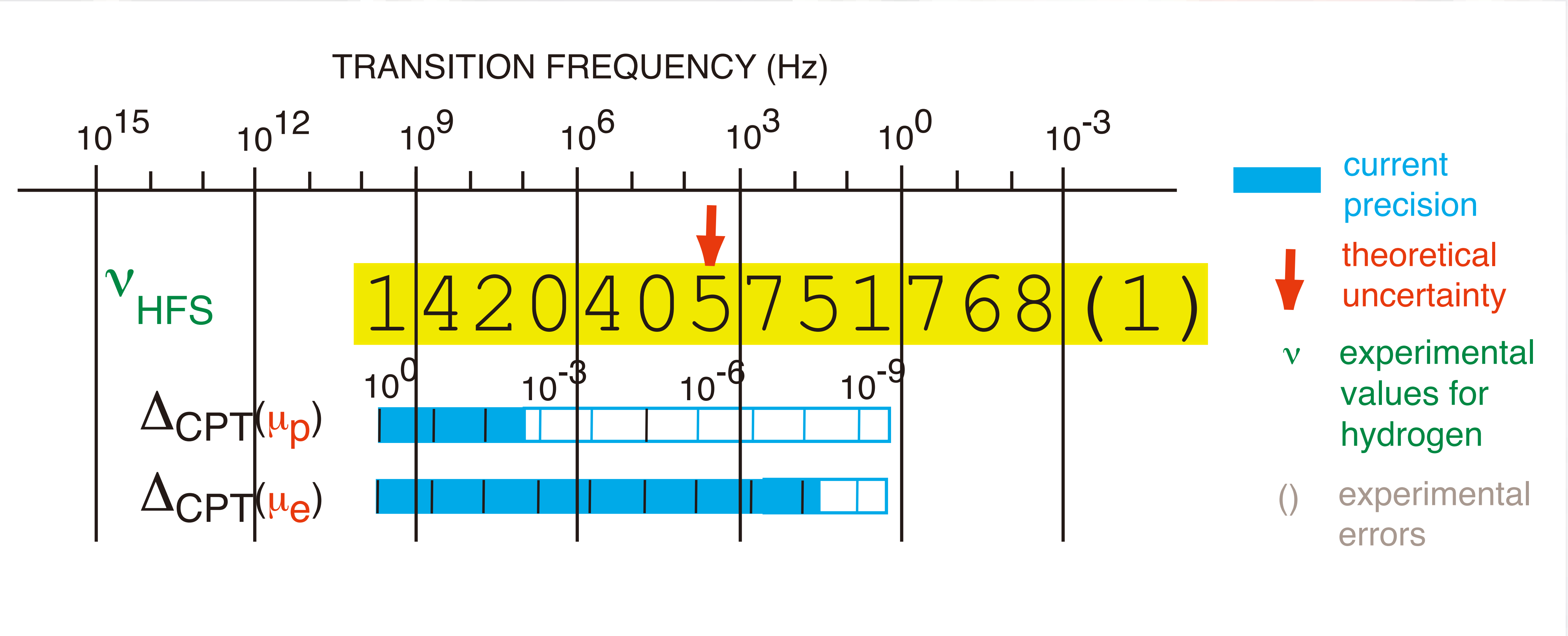
Spokesperson, ASACUSA

1. Toward $\overline{\mathrm{H}}$ GSHFS Spectroscopy ~6 weeks
2. $\overline{\mathrm{p}}$He two-photon laser spectroscopy ~5 weeks
3. $\overline{\mathrm{p}}$-C annihilation cross section at 5.3 MeV ~2 weeks

1. Toward $\bar{H}$ GSHFS Spectroscopy





$\bar{\mathrm{H}}$ GSHFS Spectroscopy: in 2015

1. transportation of 20 eV $\bar{p}$s to the double-cusp trap
2. reconstruction of annihilation vertices with the micromegas detector
3. synthesis of $\bar{\mathrm{H}}$ atoms - formation rate ~15 %
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5. σ_1 hyperfine frequency of ordinary H atoms measured to <10 ppb

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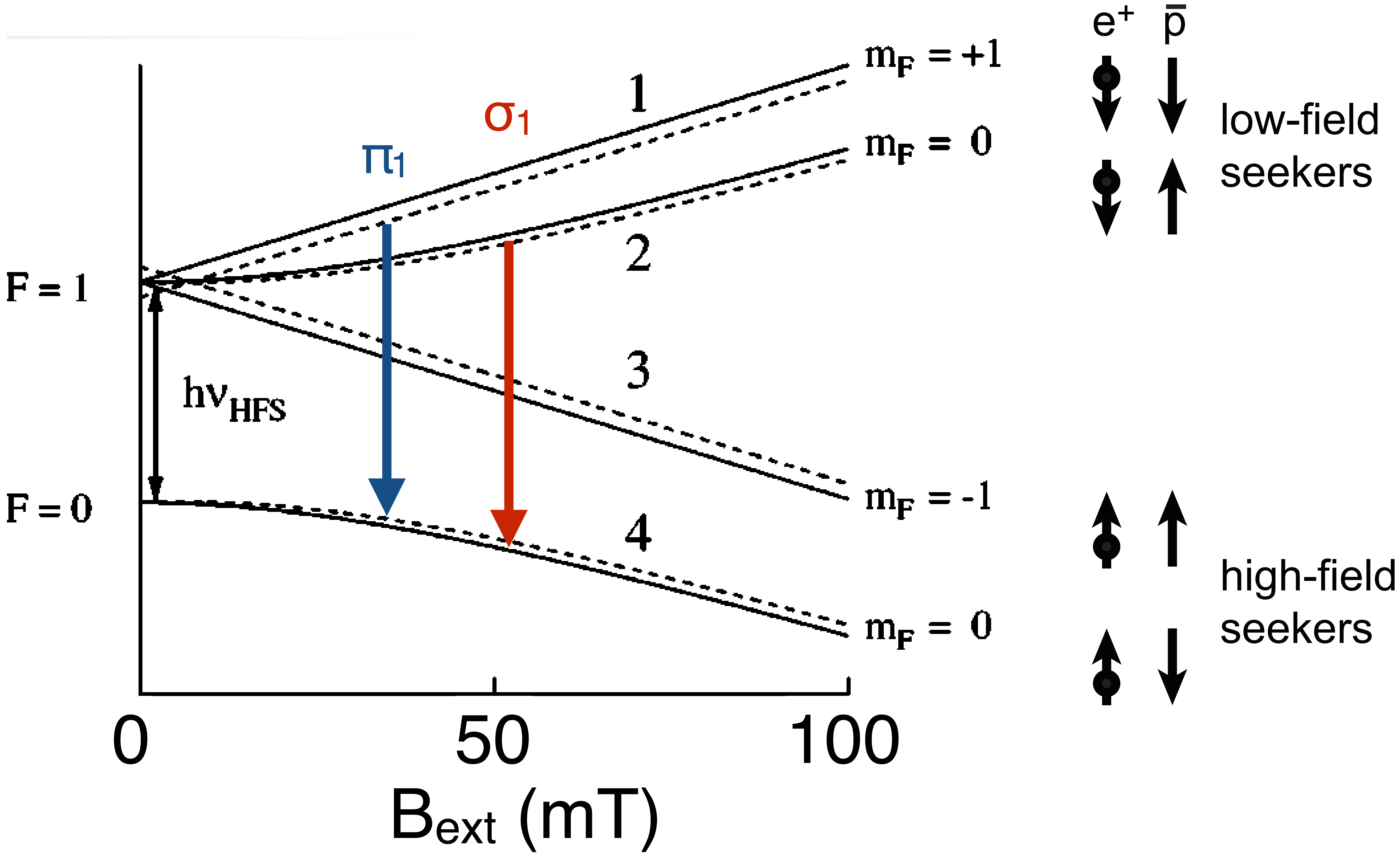
First ↓

5. σ_1 hyperfine frequency of ordinary H atoms measured to <10 ppb

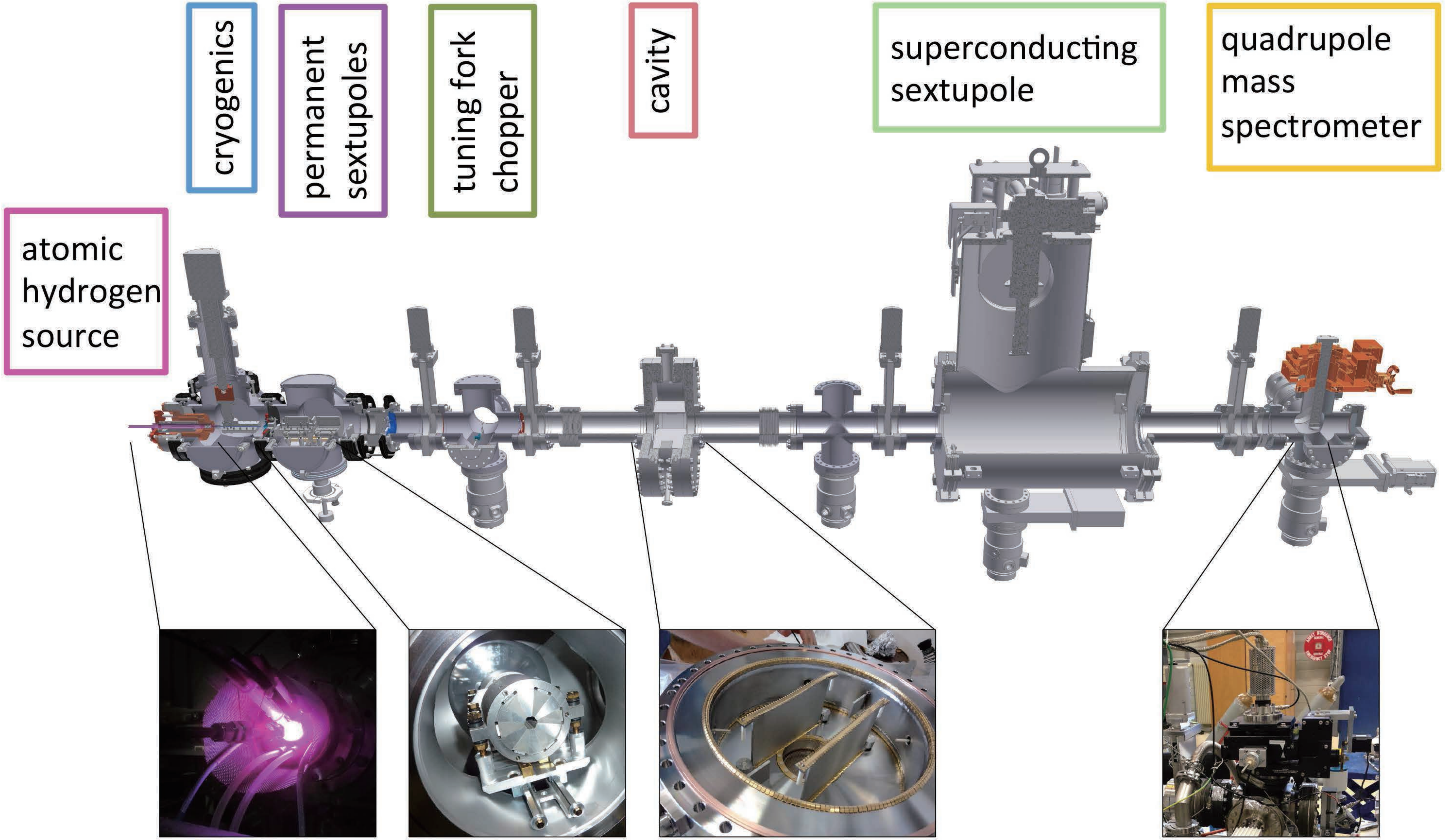
Two accessible transitions, σ_1 & π_1

σ_1 - less sensitive to B_{ext}

π_1 - more sensitive to B_{ext}
& possible CPTV effects

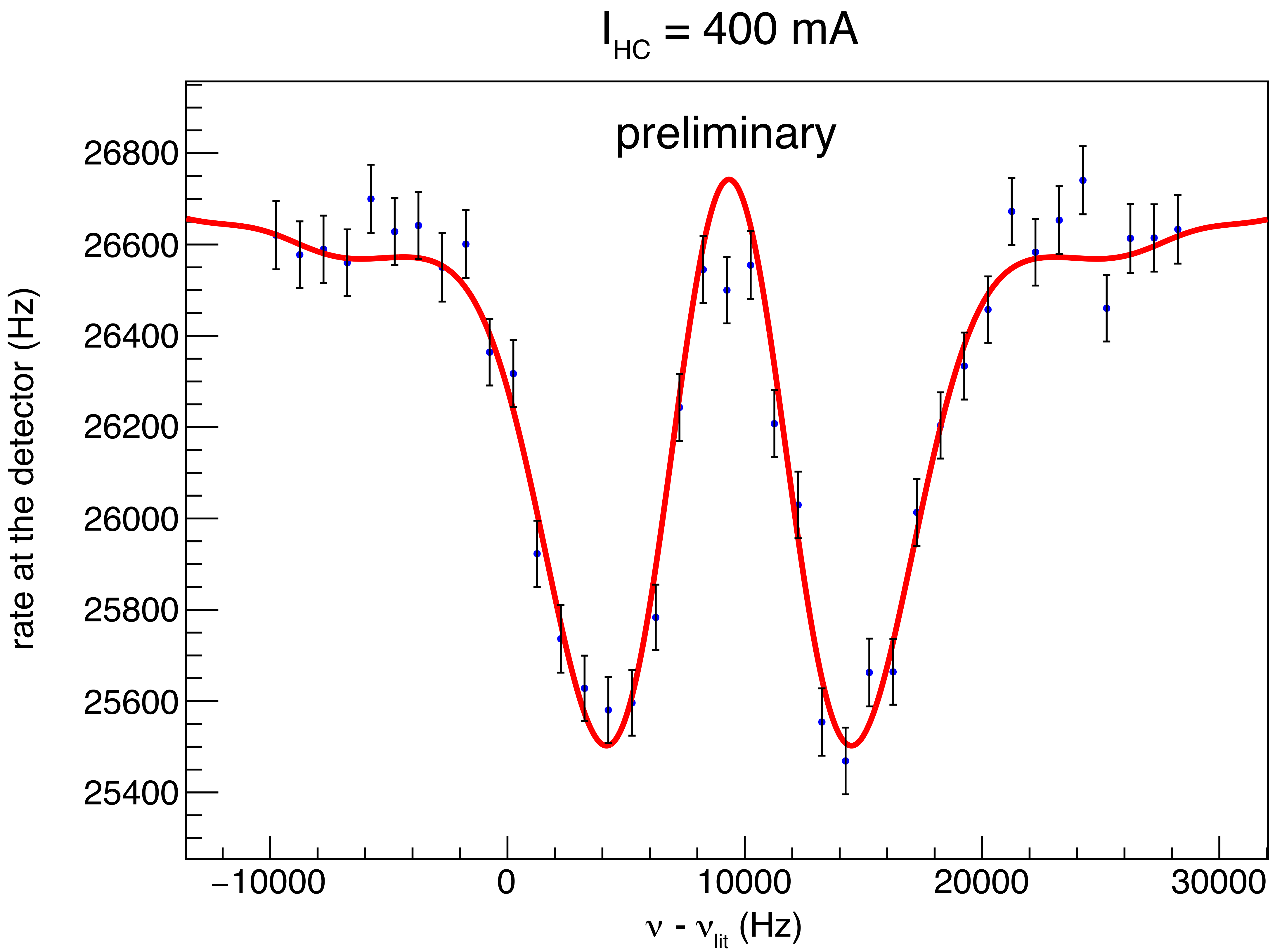


“H” setup (same cavity, same sextupole as the $\bar{H}$ exp)



a typical <u>Hydrogen</u> σ_1 resonance scan

- For each scan, a fixed B-field (-250 ~ 250 μT) applied by Helmholtz coils
- cavity frequency was scanned
- hydrogen detection rate measured with QMS

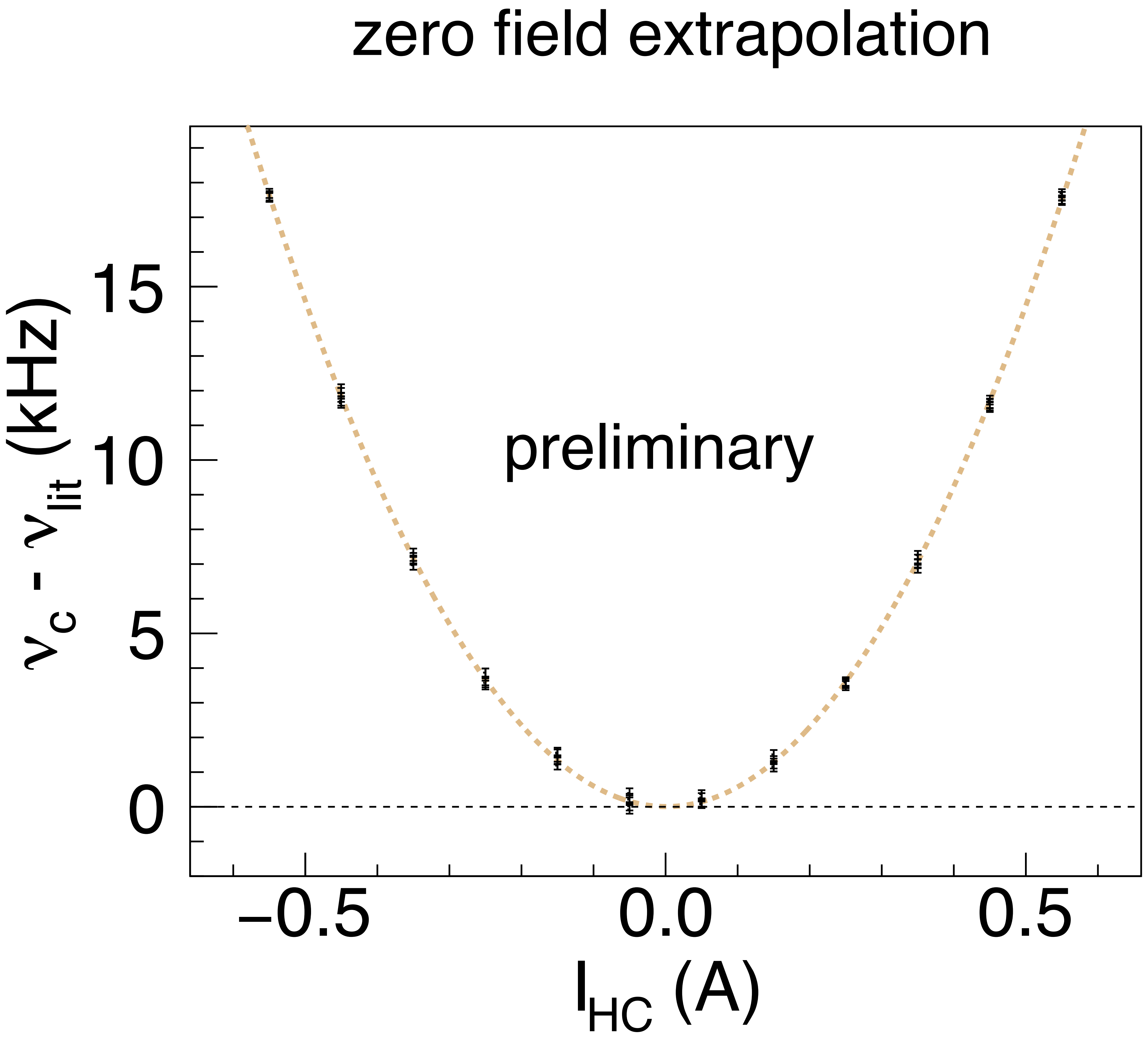


← Fit result

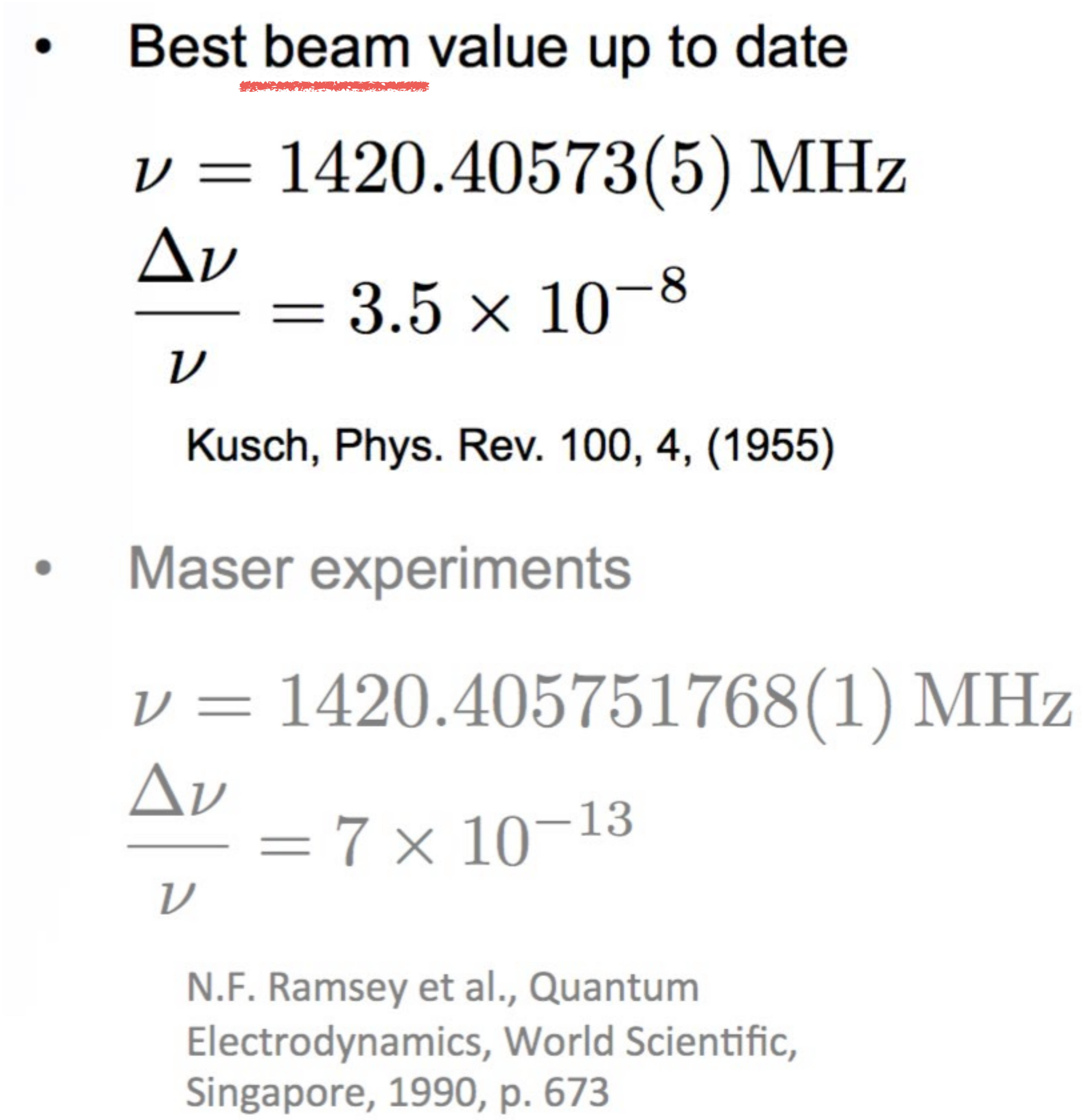
$$\nu_c - \nu_{lit} = 9336 \pm 71 \text{ Hz}$$

zero-field extrapolation

- One of 10 zero-field extrapolation sets
- Fit result: $\nu_0 - \nu_{lit} = 5.7 \pm 23.6$ Hz, χ^2/n.d.f. = 65.3/57



soon to be published



- Best beam value up to date

$$\nu = 1420.40573(5)\,\mathrm{MHz}$$

$$\frac{\Delta\nu}{\nu} = 3.5 \times 10^{-8}$$

Kusch, Phys. Rev. 100, 4, (1955)

- Maser experiments

$$\nu = 1420.405751768(1)\,\mathrm{MHz}$$

$$\frac{\Delta\nu}{\nu} = 7 \times 10^{-13}$$

N.F. Ramsey et al., Quantum Electrodynamics, World Scientific, Singapore, 1990, p. 673

preliminary results:

ν = 1 420.405 7… MHz

statistical error ~3 Hz

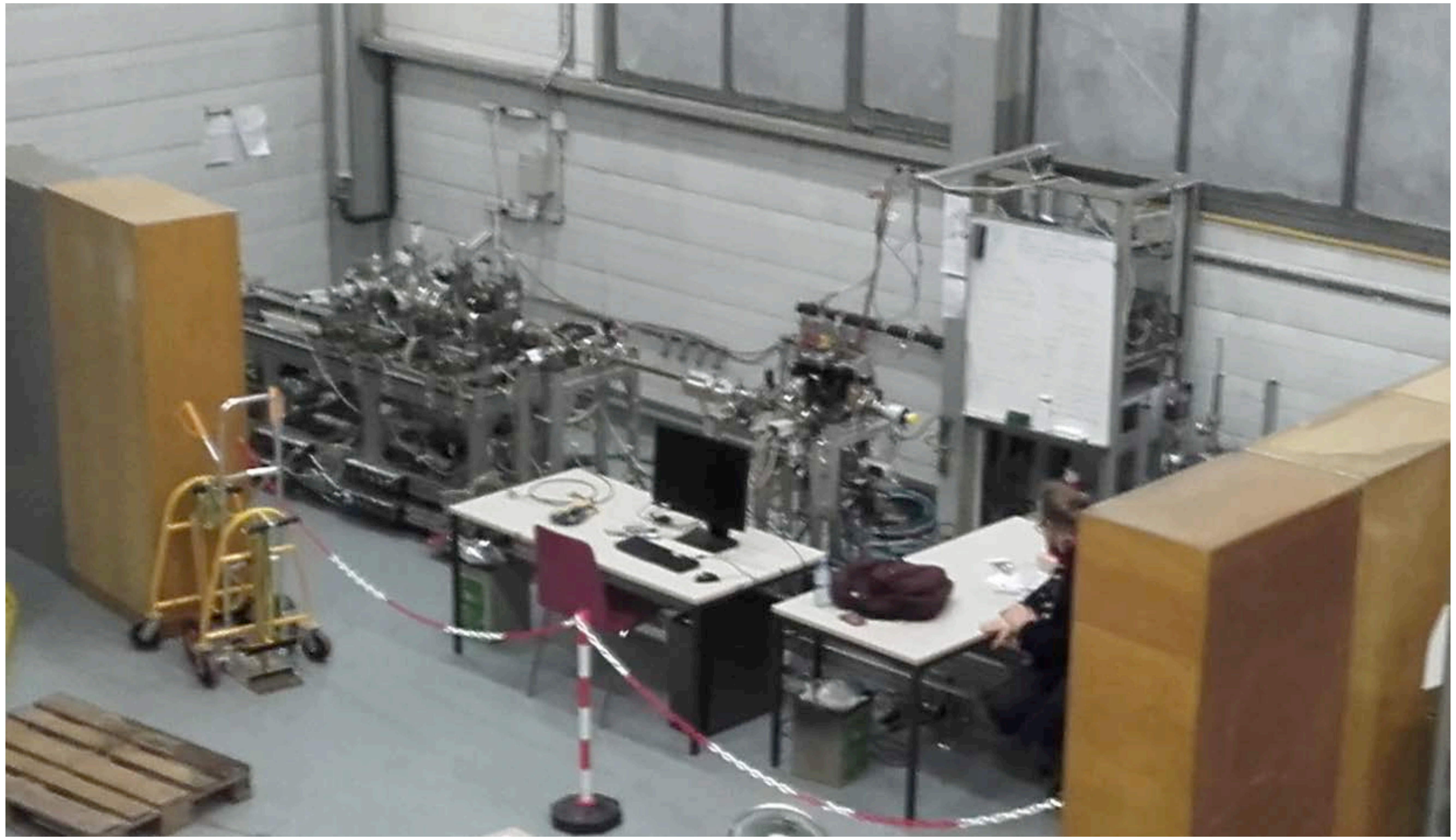
systematic error ~2 Hz

rel. precision: < 3 ppb

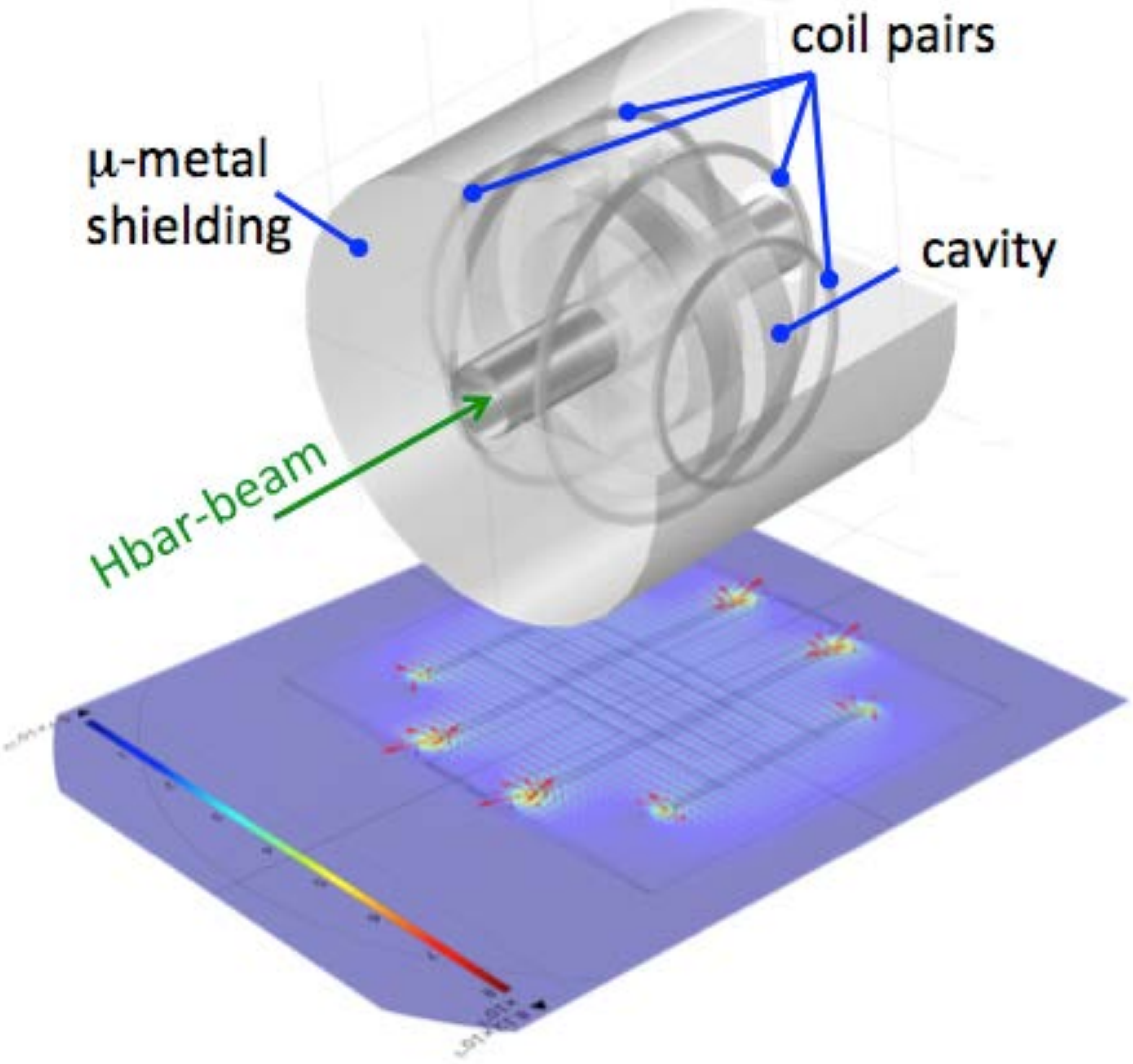
factor >10 better than Kusch et al.

precision π_1 measurement planned in 2016

Hydrogen beam setup in building B275



π_1 measurement needs better B_{ext} control



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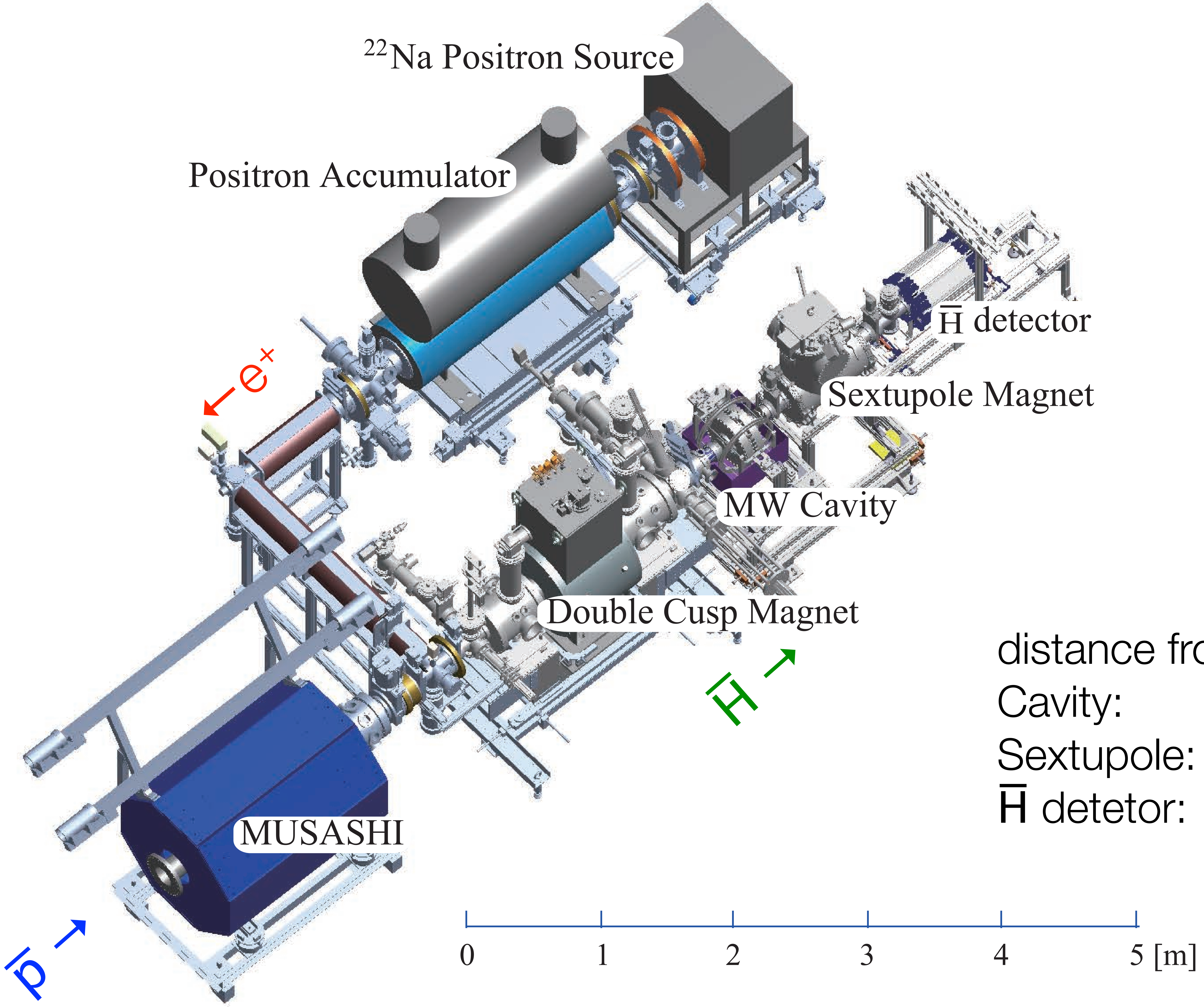


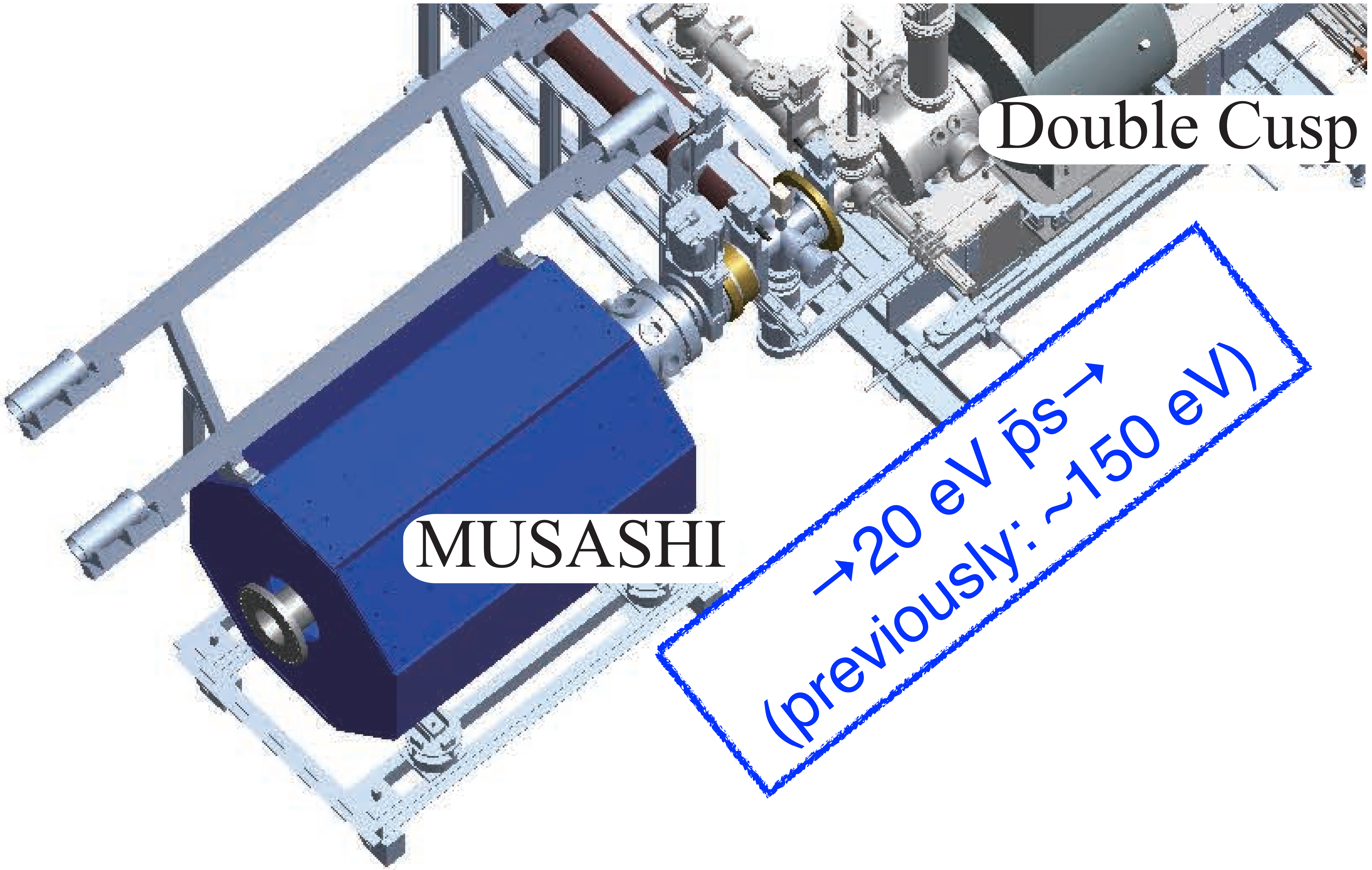
distance from the mixing position

Cavity: +1840mm

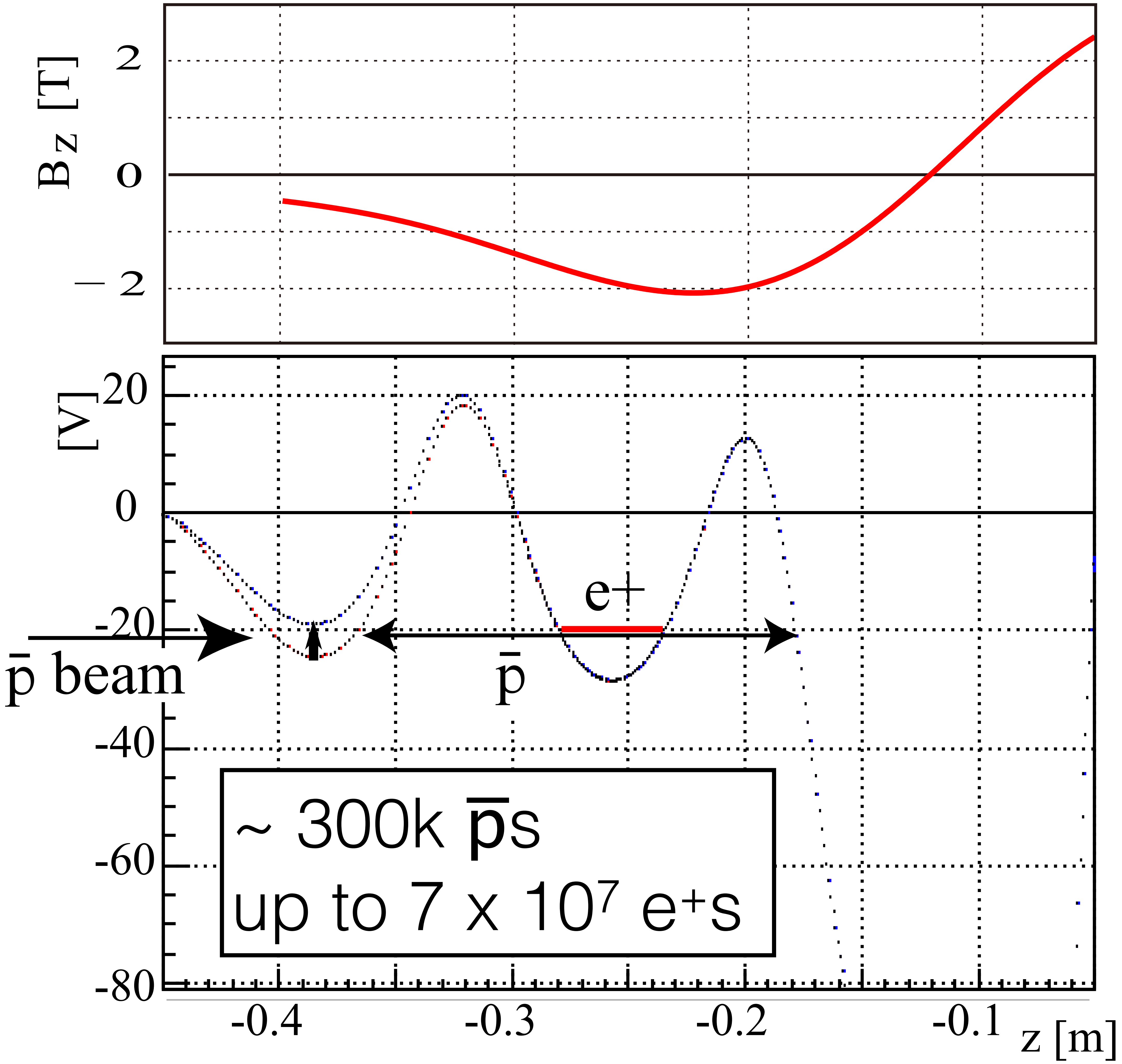
Sextupole: +2628mm

$\overline{\text{H}}$ detetor: +3739mm

minimize energy deposition to the e^+ plasma



→20 eV $\bar{p}$s→
(previously: ~150 eV)



~ 300k $\bar{p}$s
up to 7 x 10^7 e^+s

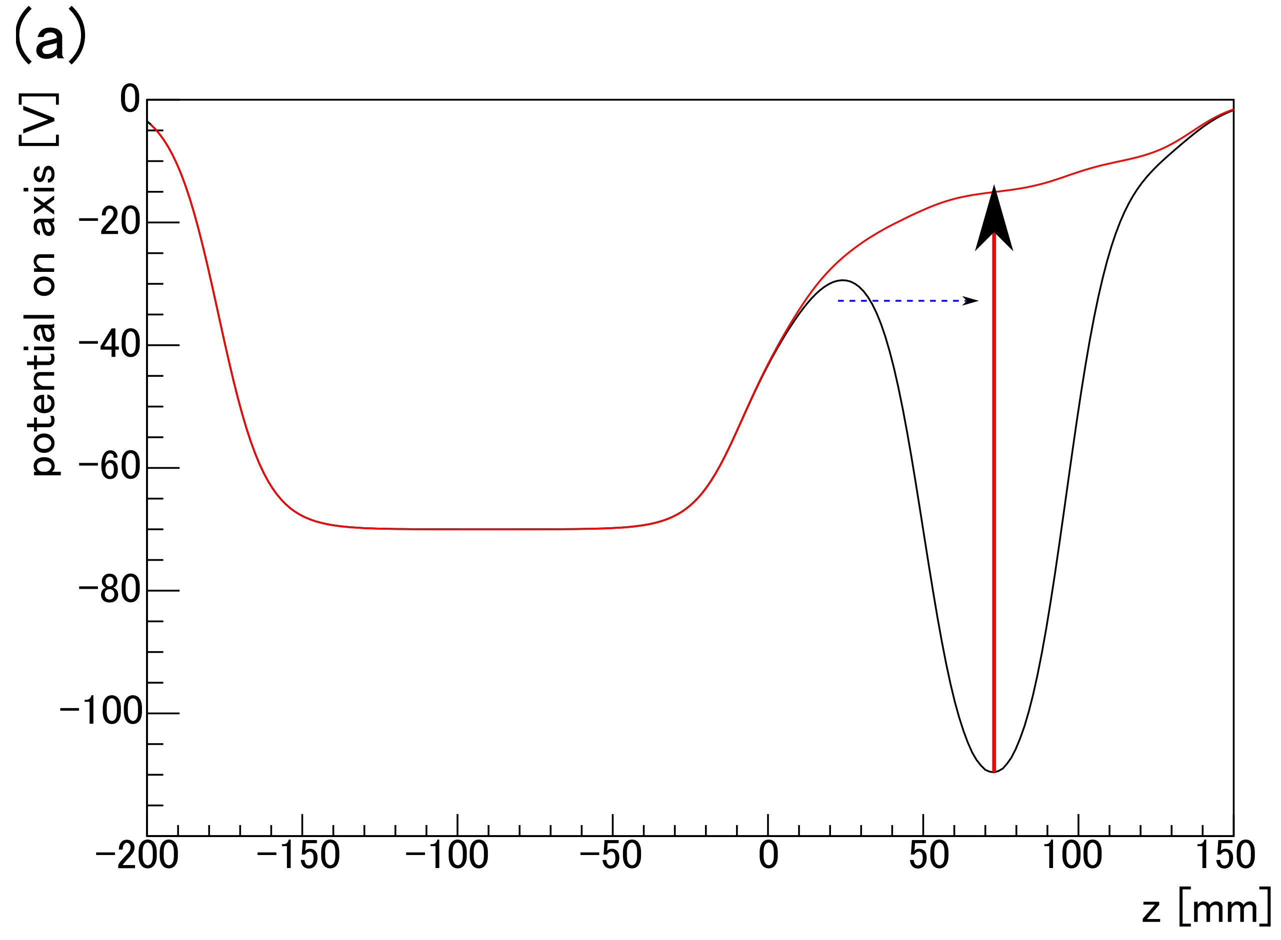
optimizing $\bar{p}$-extraction scheme

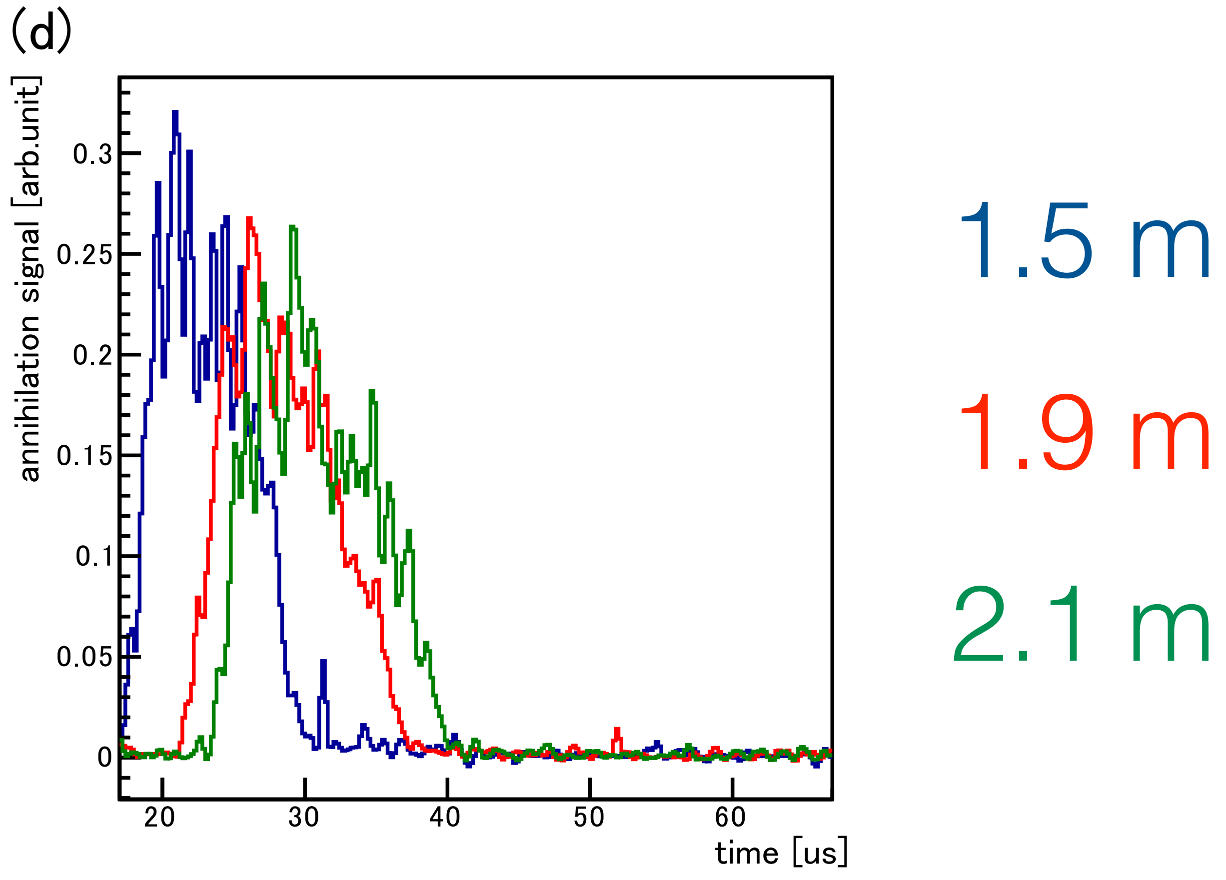
potential in the $\bar{p}$ catching trap

$\bar{p}$ time distribution downstream

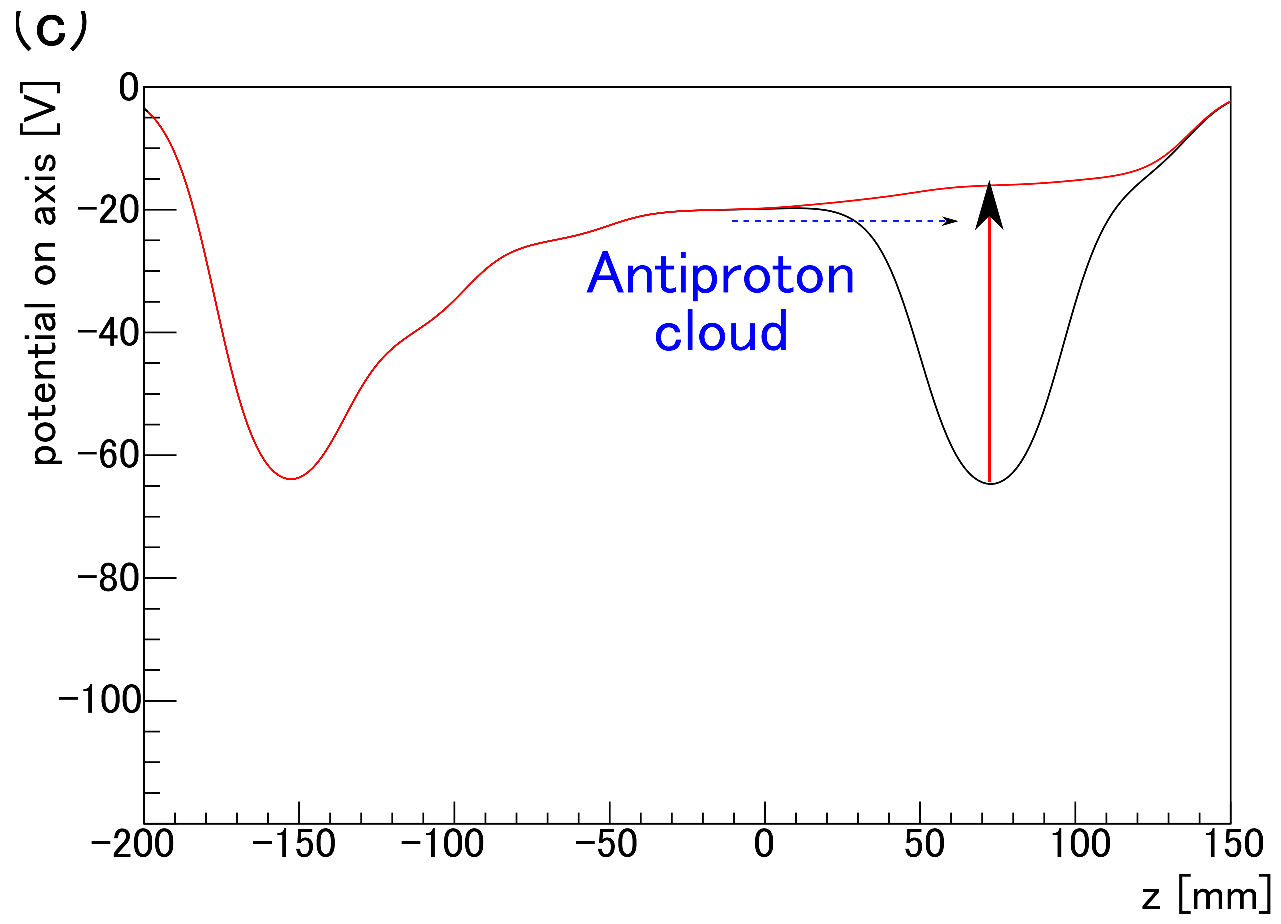
$\bar{p}$ trapping

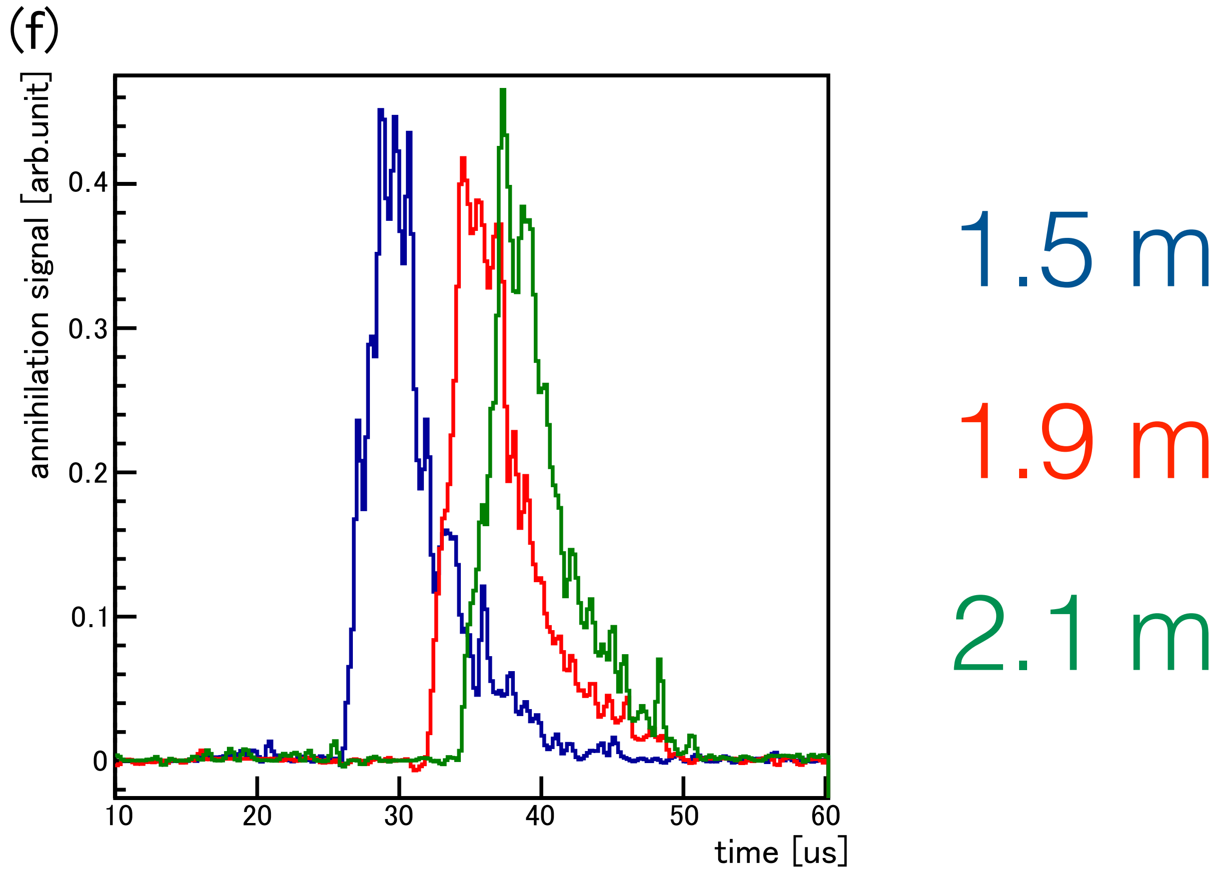
$\bar{p}$ extraction





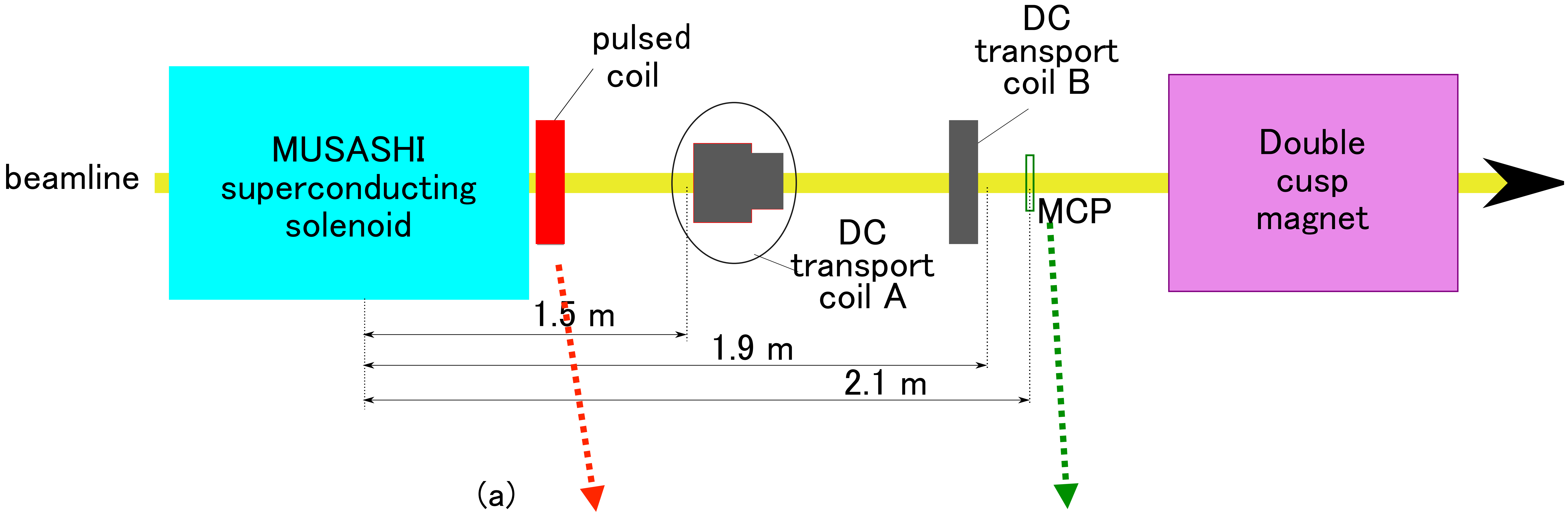
20 eV→



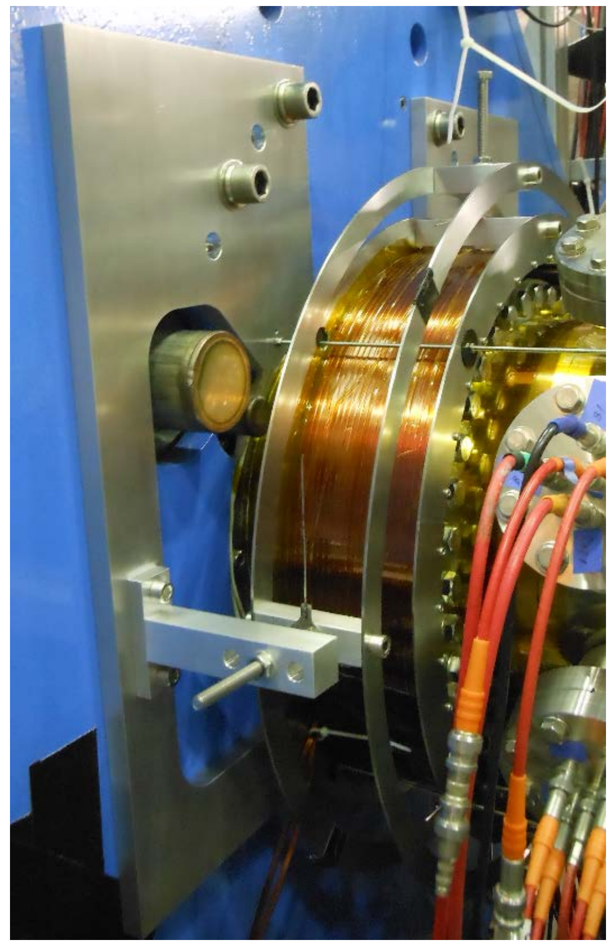


estimated $T_{\bar{p}} \sim 1\text{eV}$

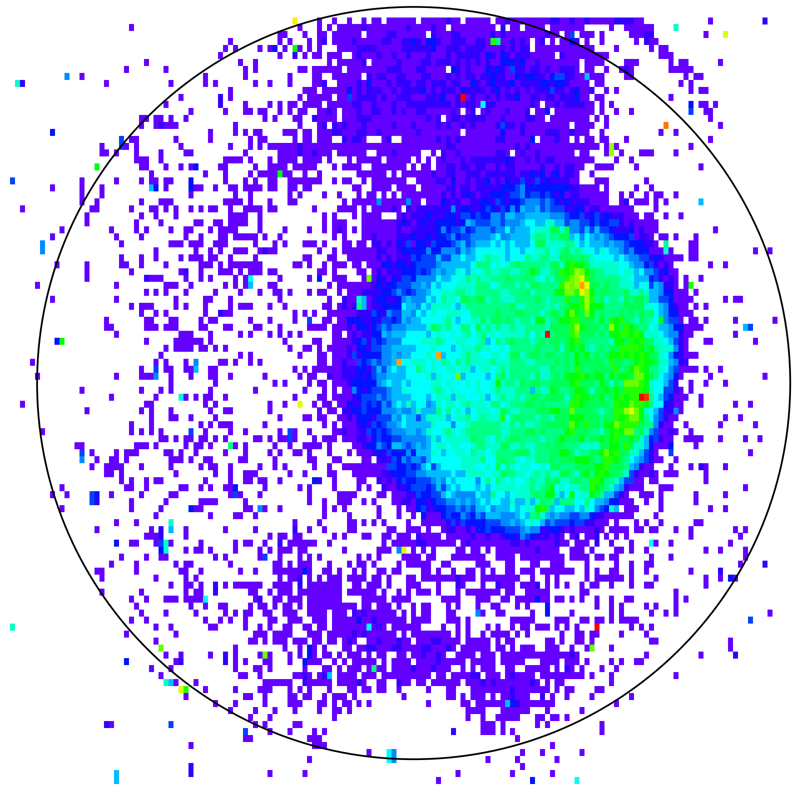
pulsed coil for 20-eV $\bar{p}$ transport



(a)



(b)



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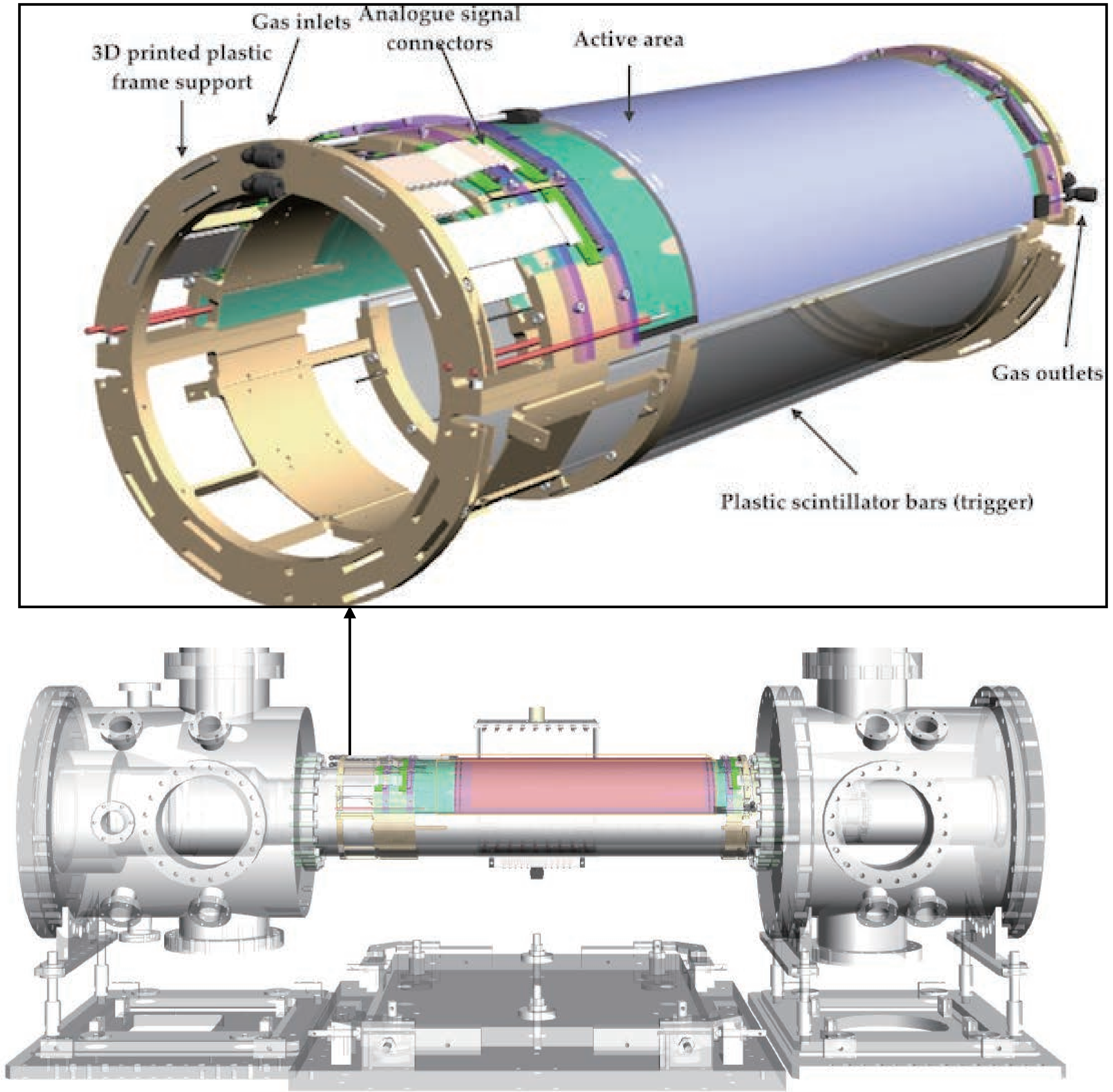
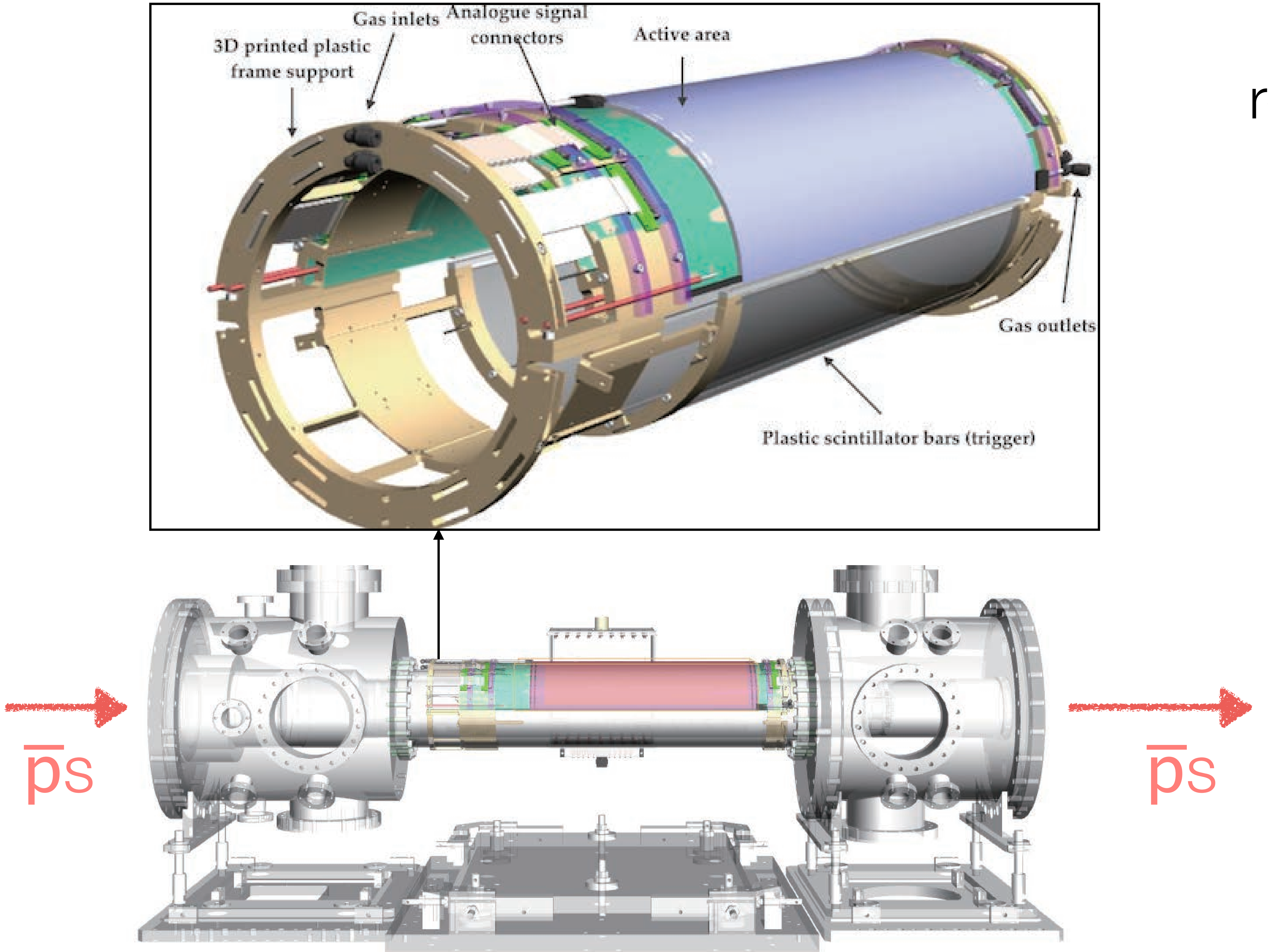
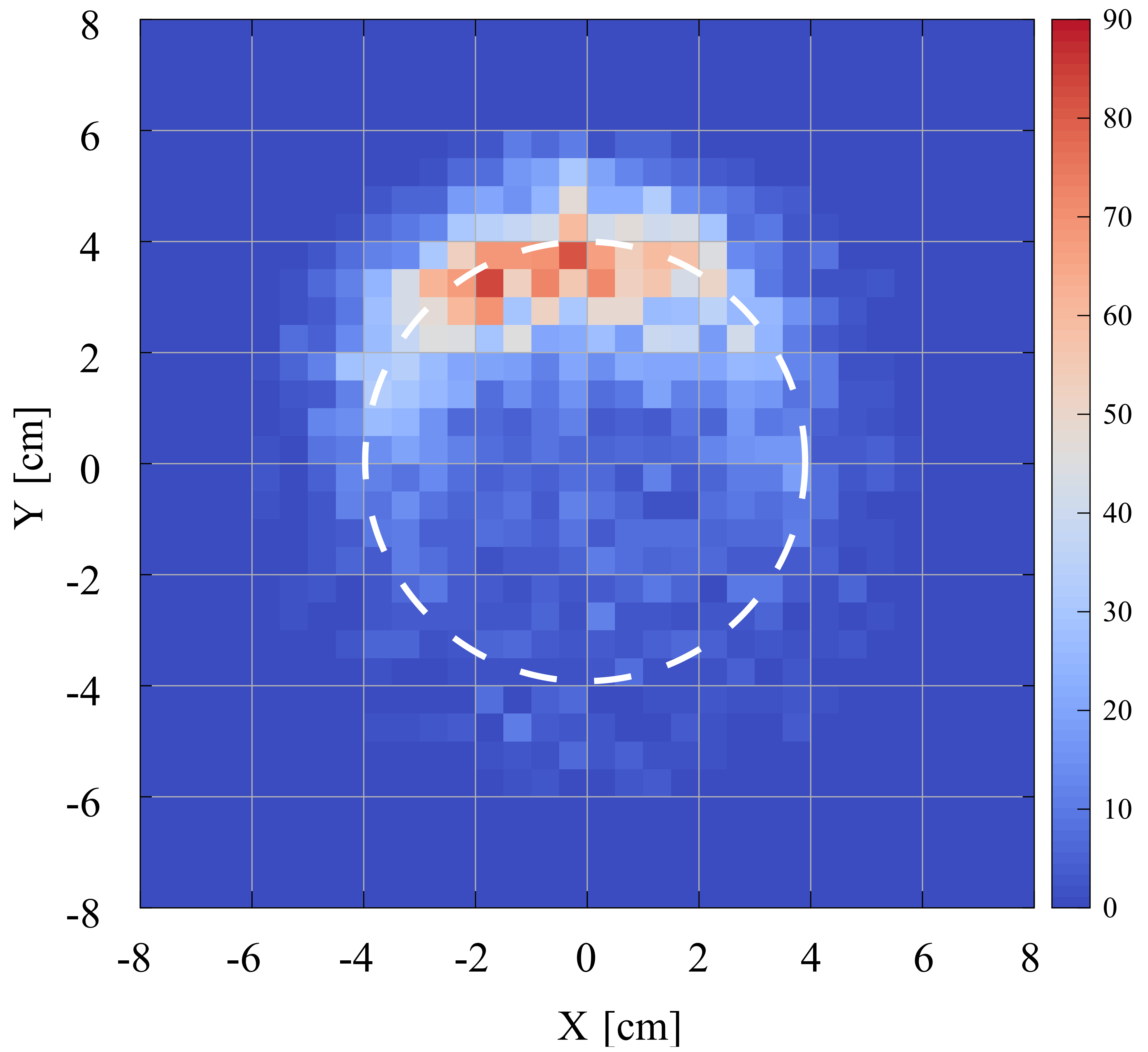
micromegas around the 2-cusp vacuum tube



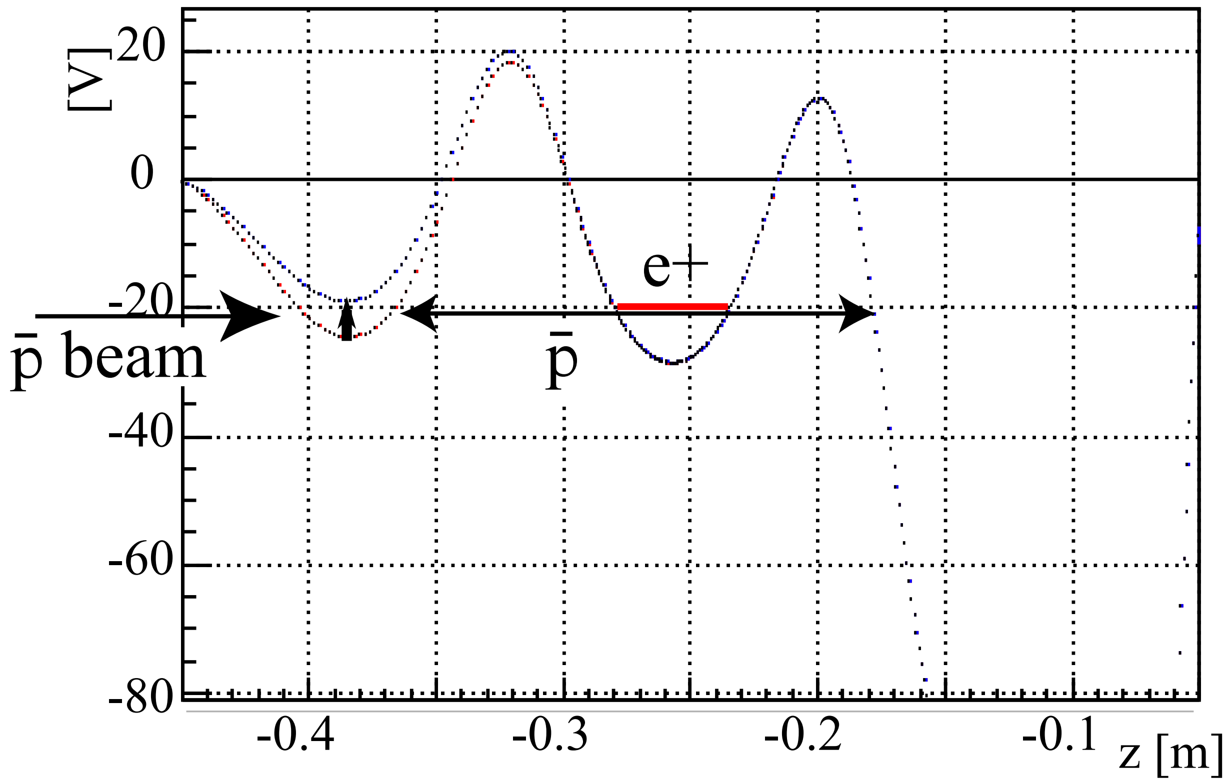
micromegas around the 2-cusp vacuum tube



reconstructed annihilation x-y vertices with slow-extracted $\overline{p}$s



time evolution of annihilation positions during $\bar{p}$-e^+ mixing



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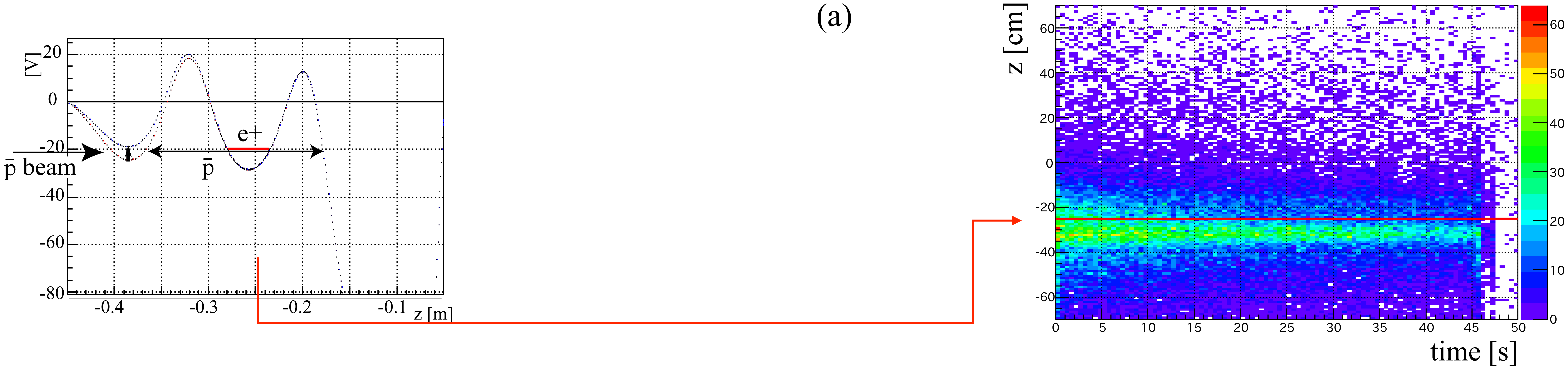

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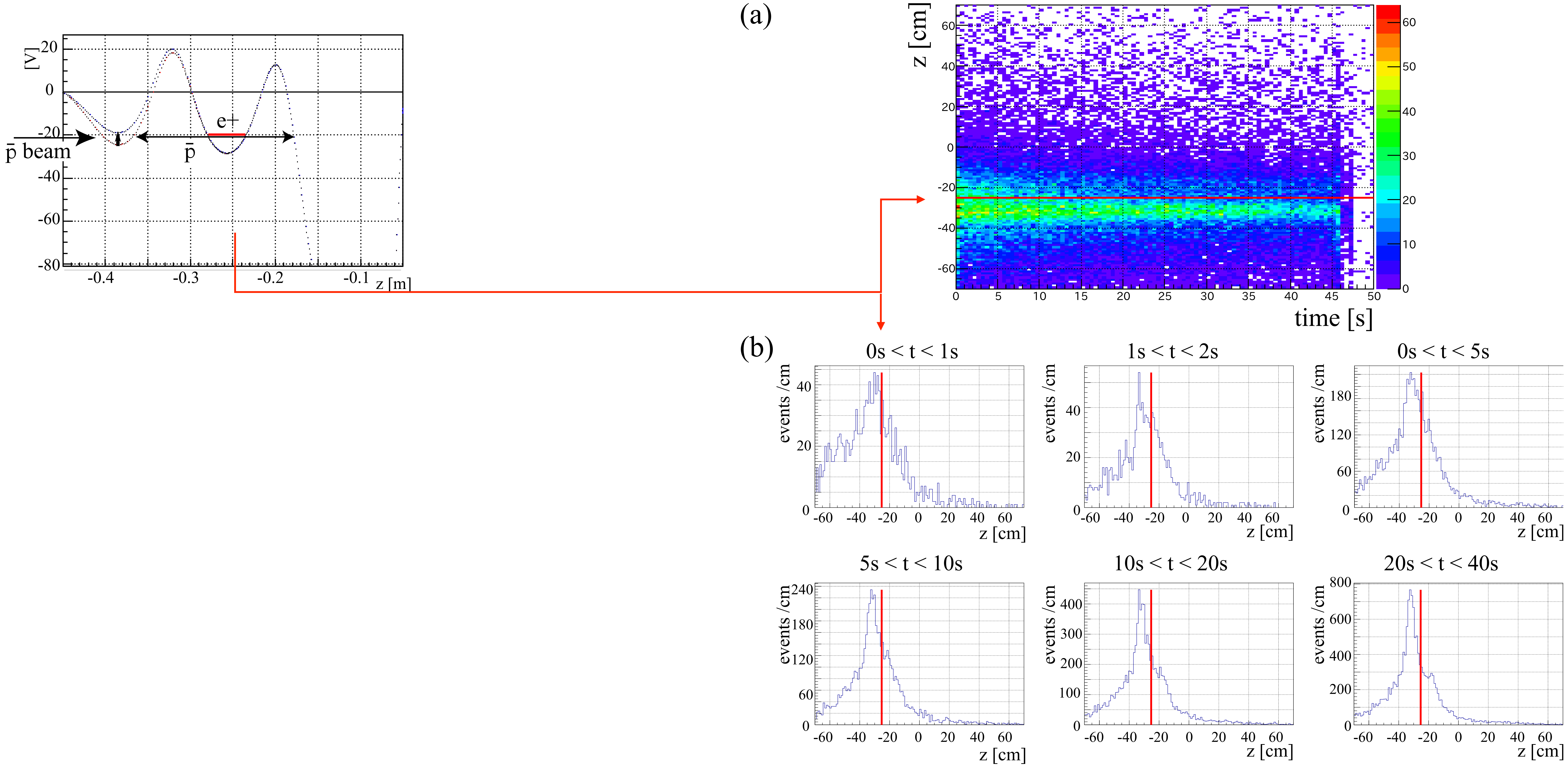

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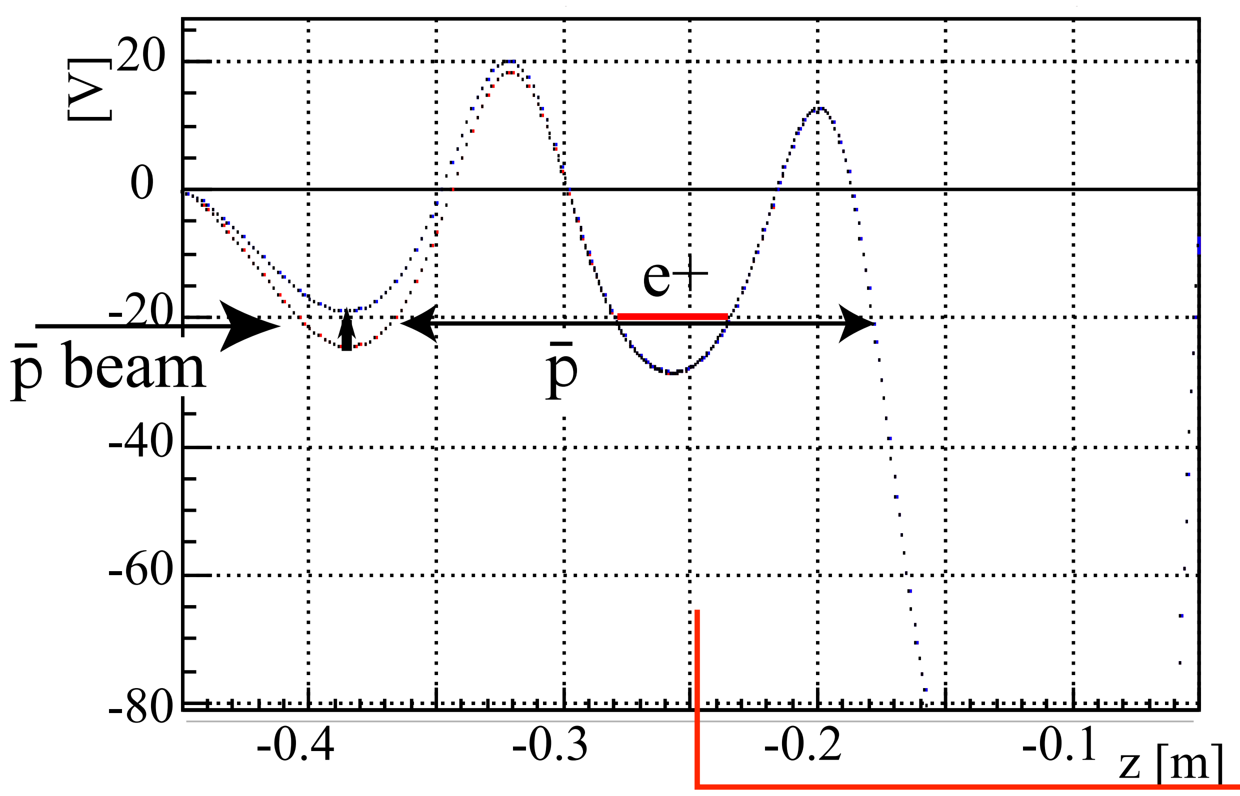

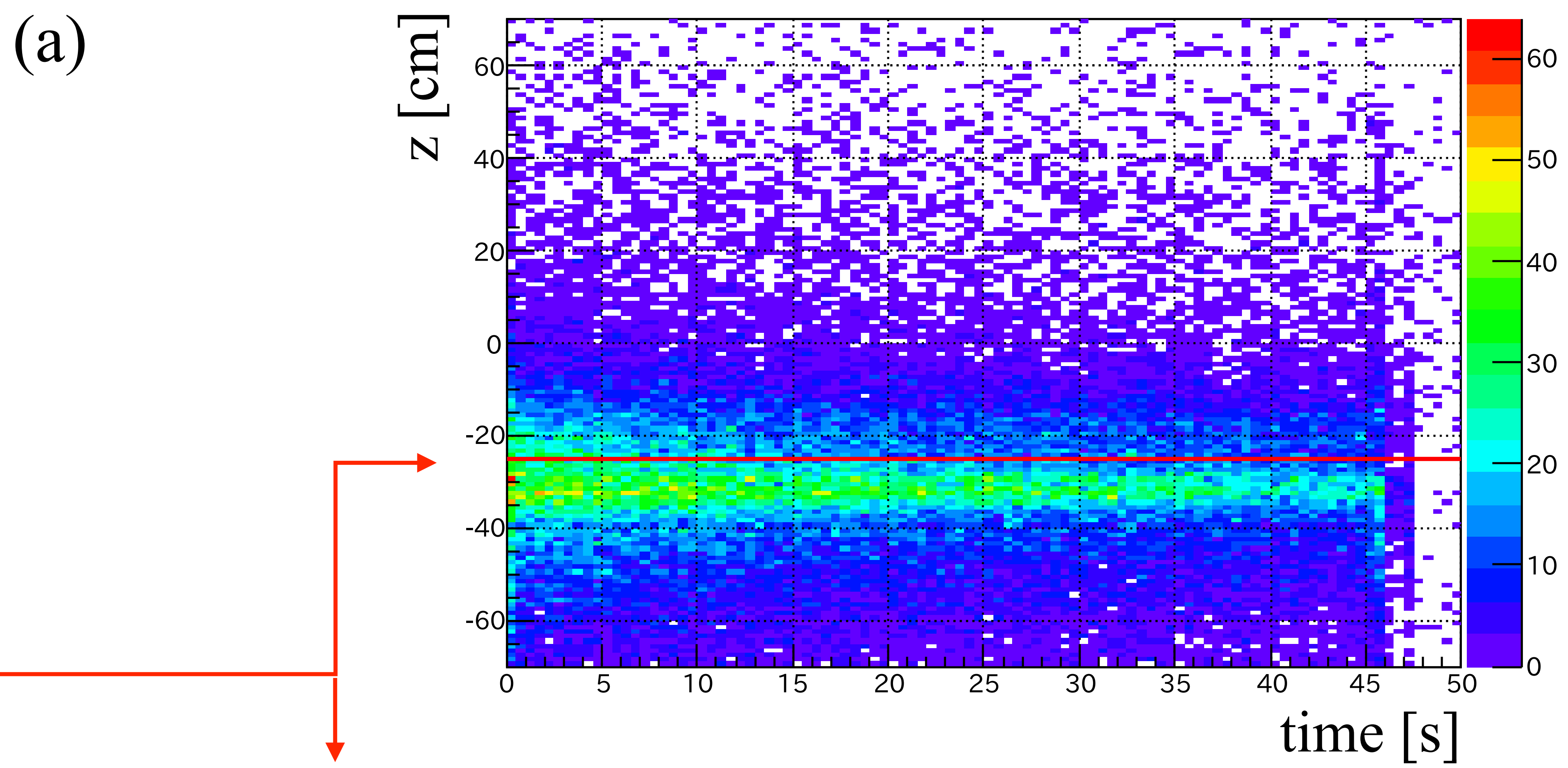

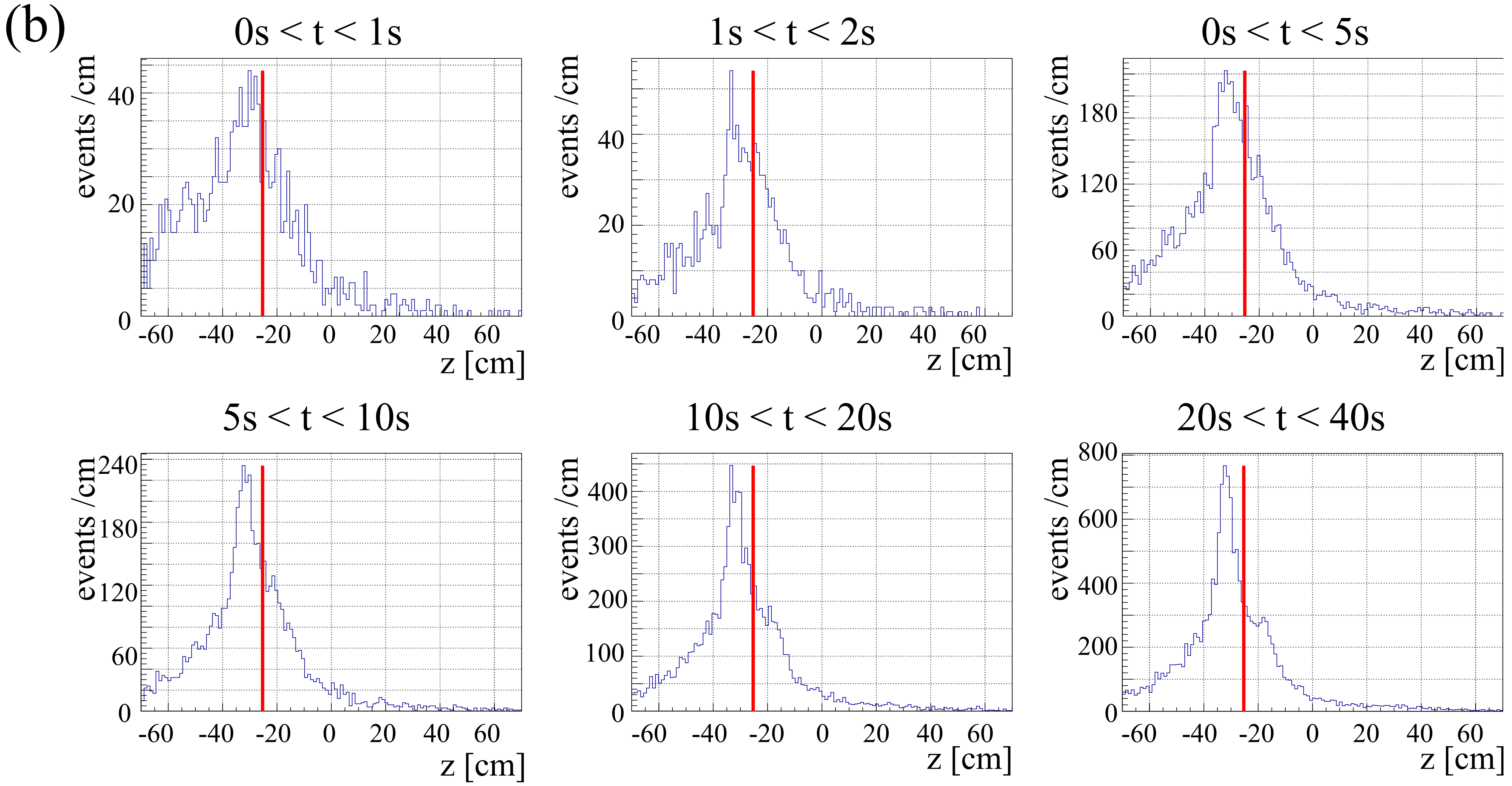

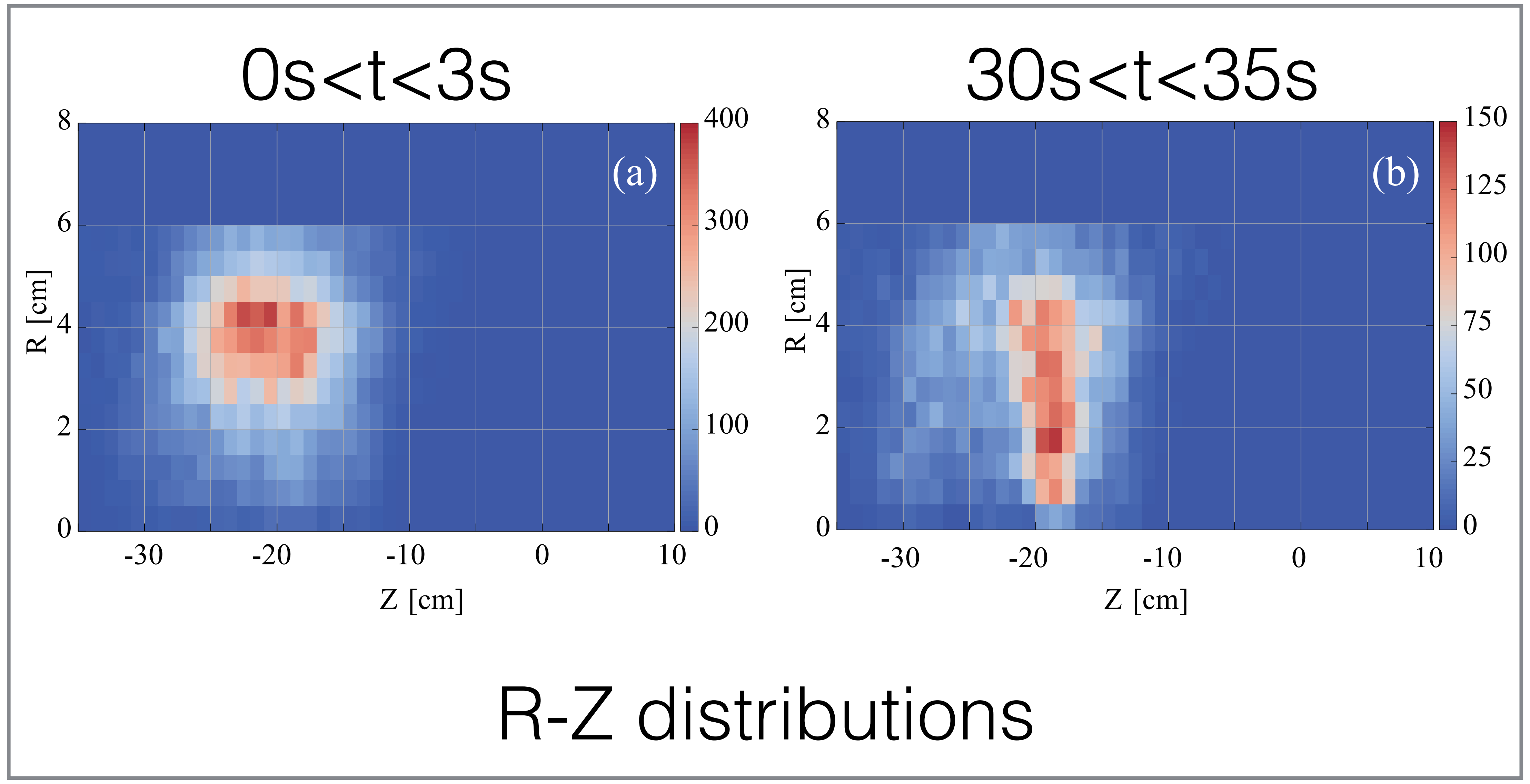

R-Z distributions

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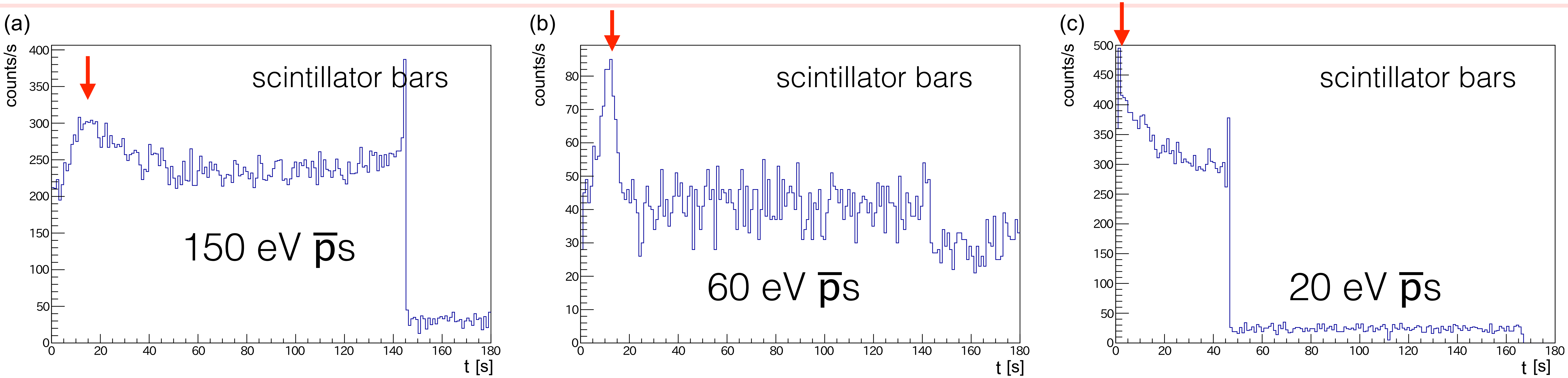
with 20 eV $\bar{p}$s - high $\bar{H}$ formation rate in early times



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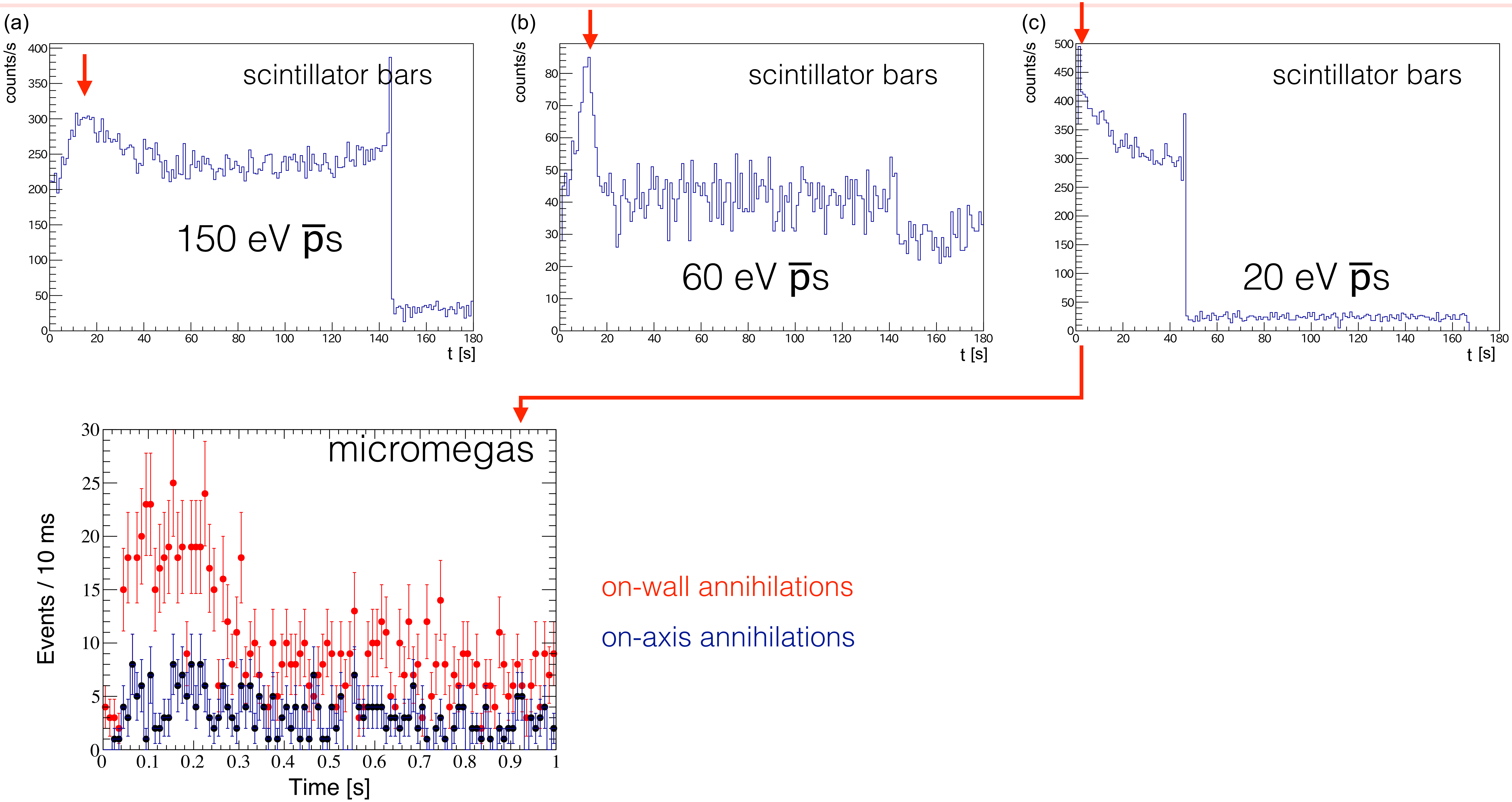
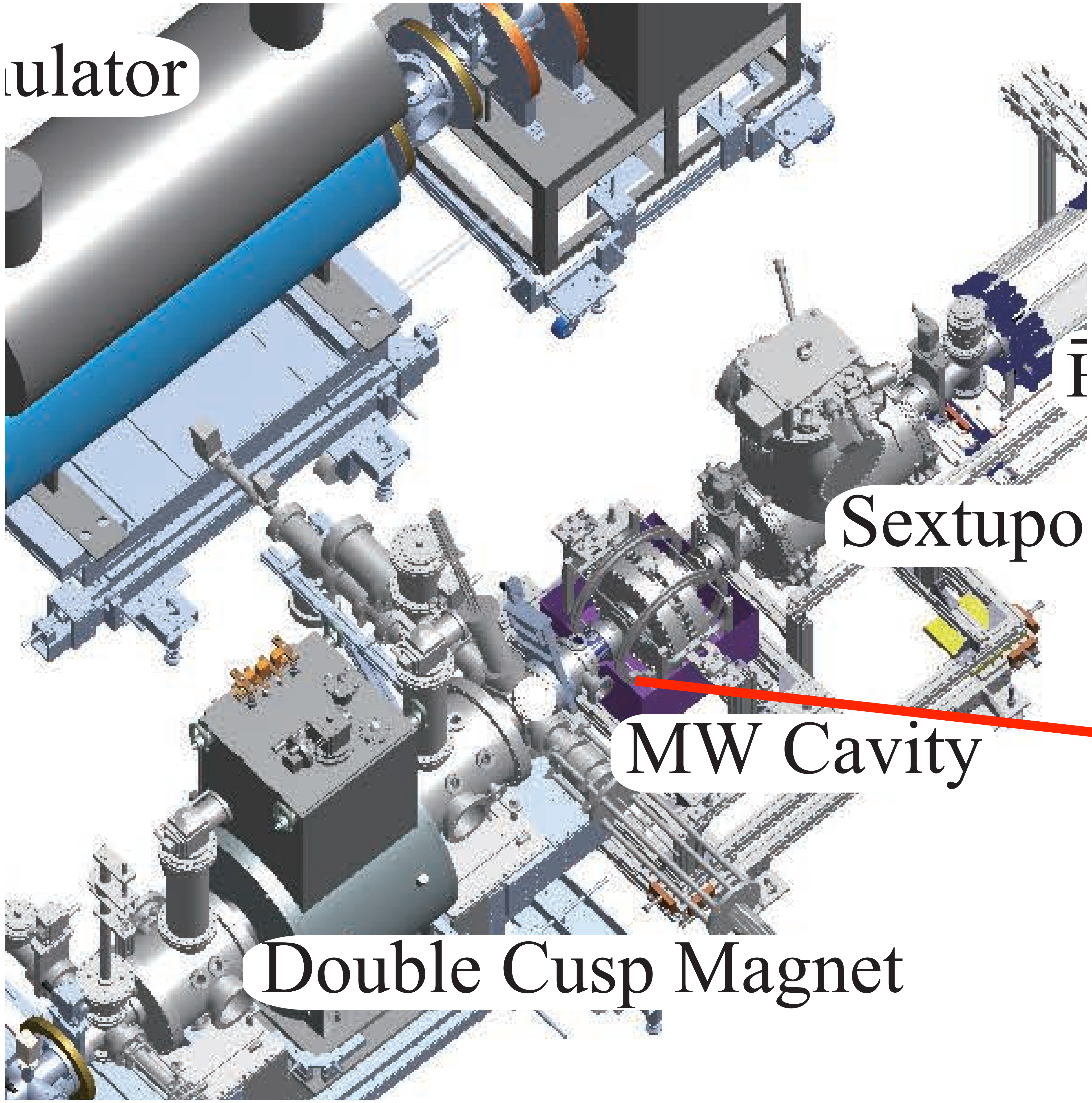
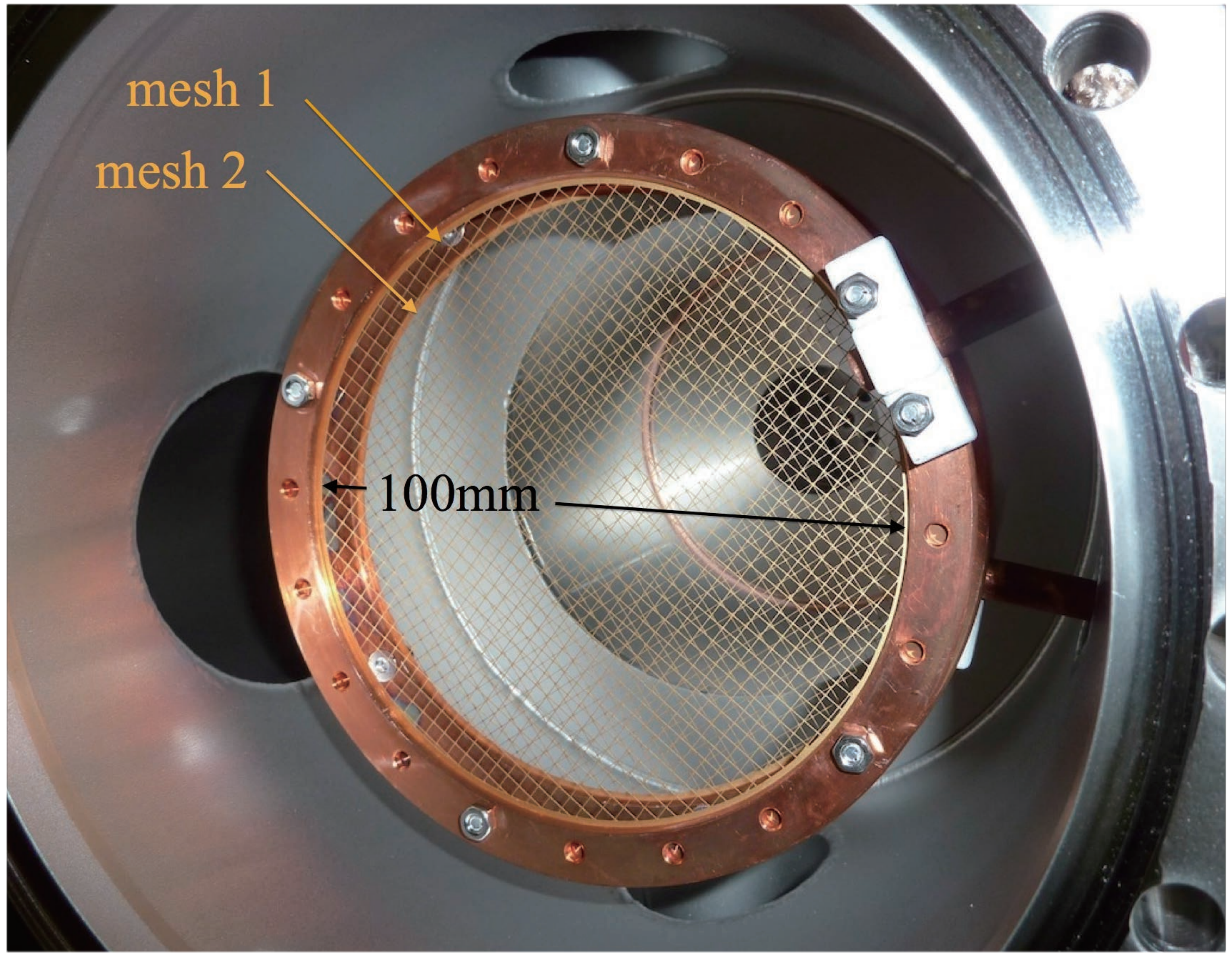


Field ionizer chamber between cusp & cavity



±8.7 kV →17.4 kV/cm
→n ≥12 ionized



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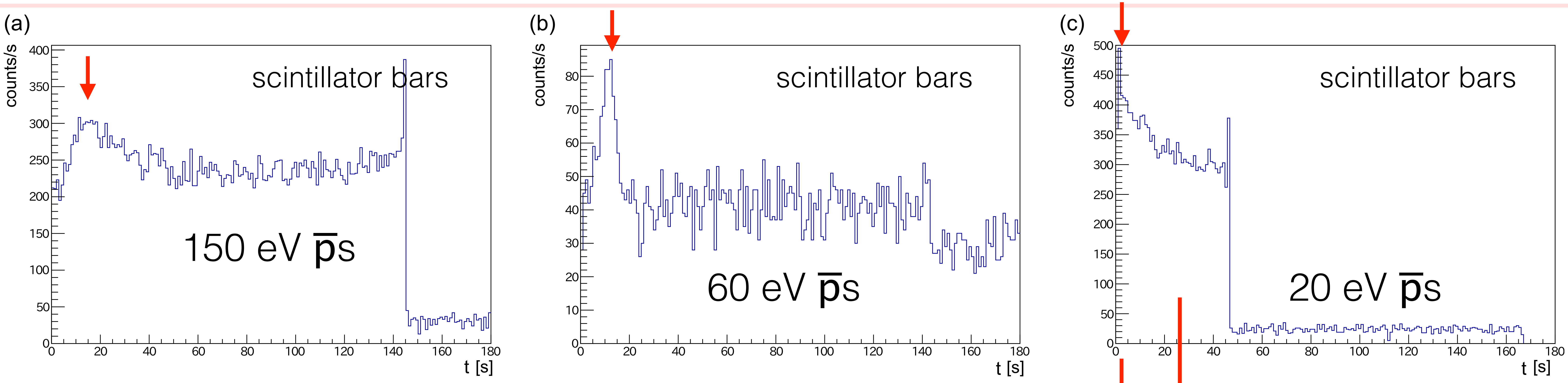

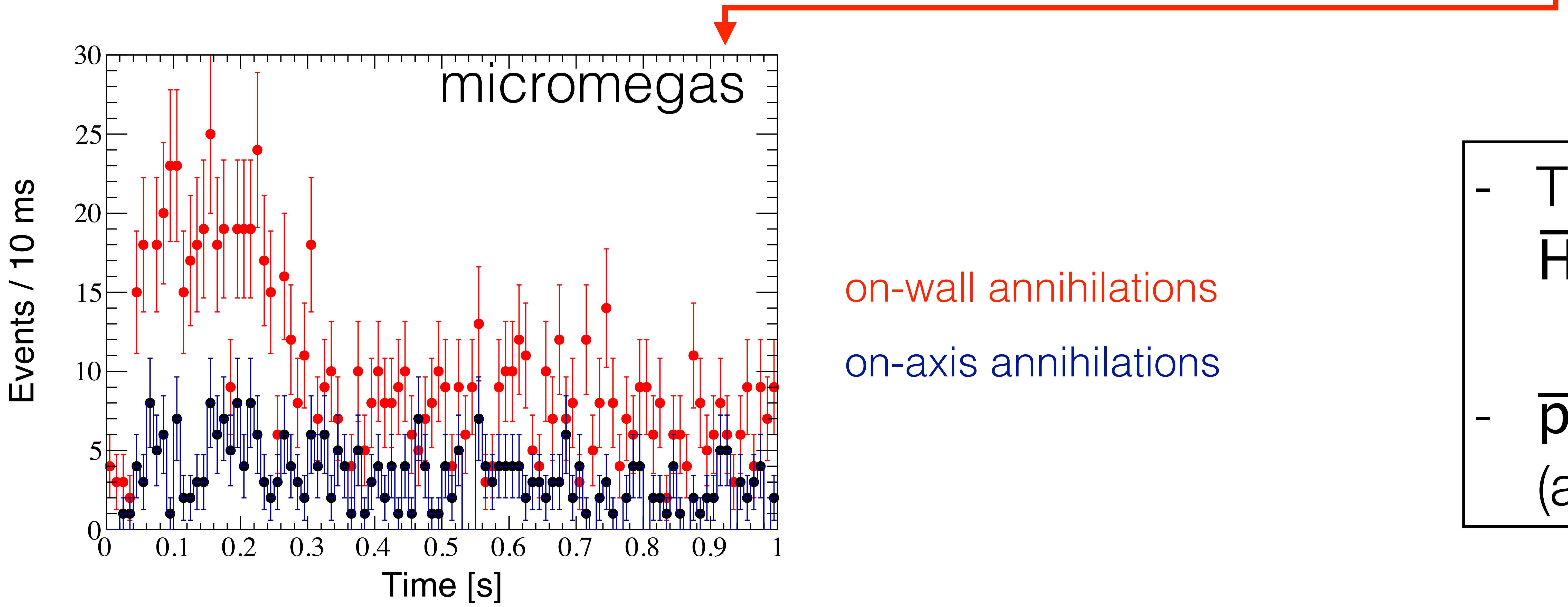

on-wall annihilations

on-axis annihilations

- The total number of field-ionized $\bar{H}$s ~ 390 (in 40 s)
- $\bar{p} \rightarrow \bar{H}$ efficiency ~16% (assuming isotropic emission)

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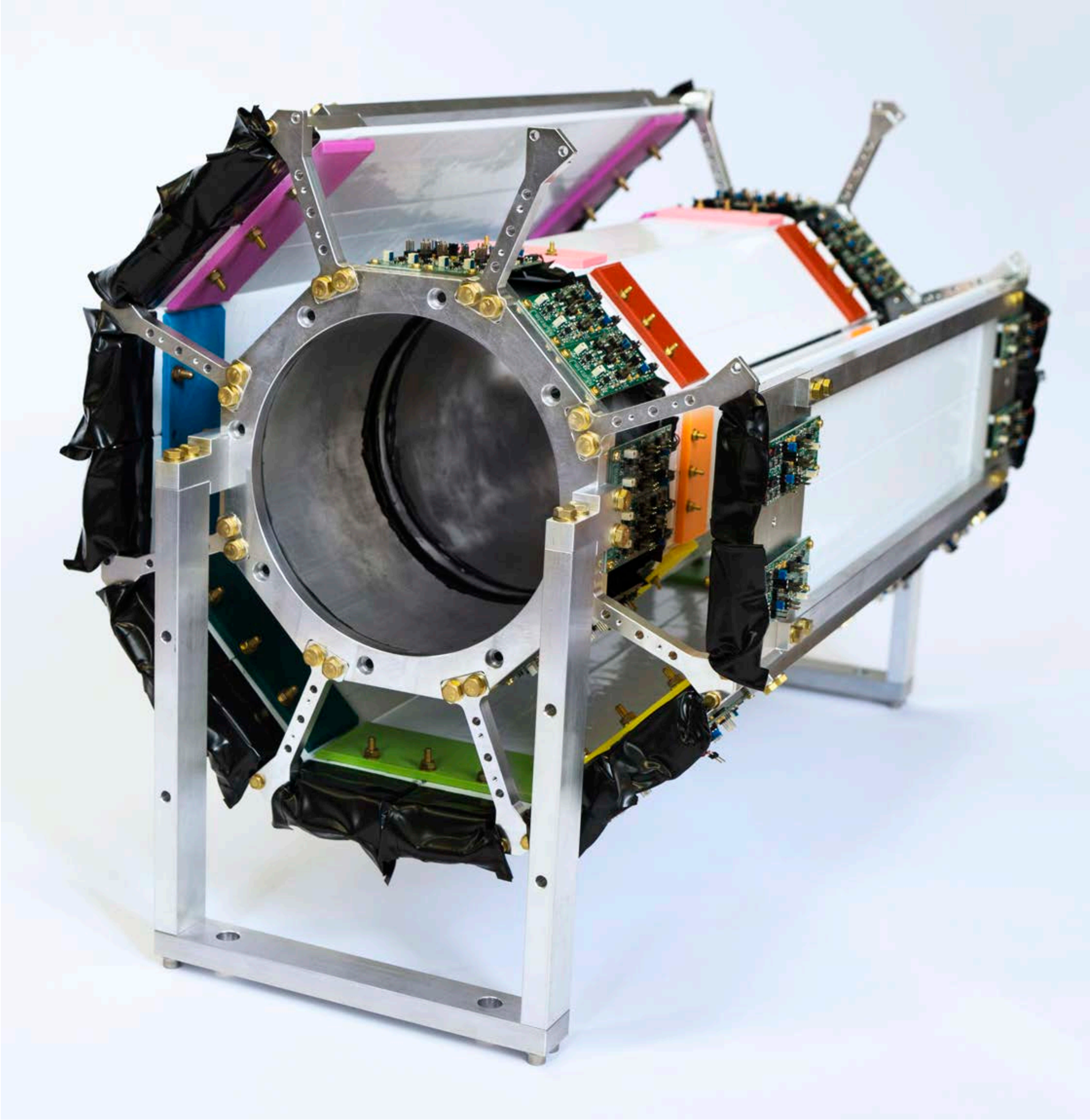
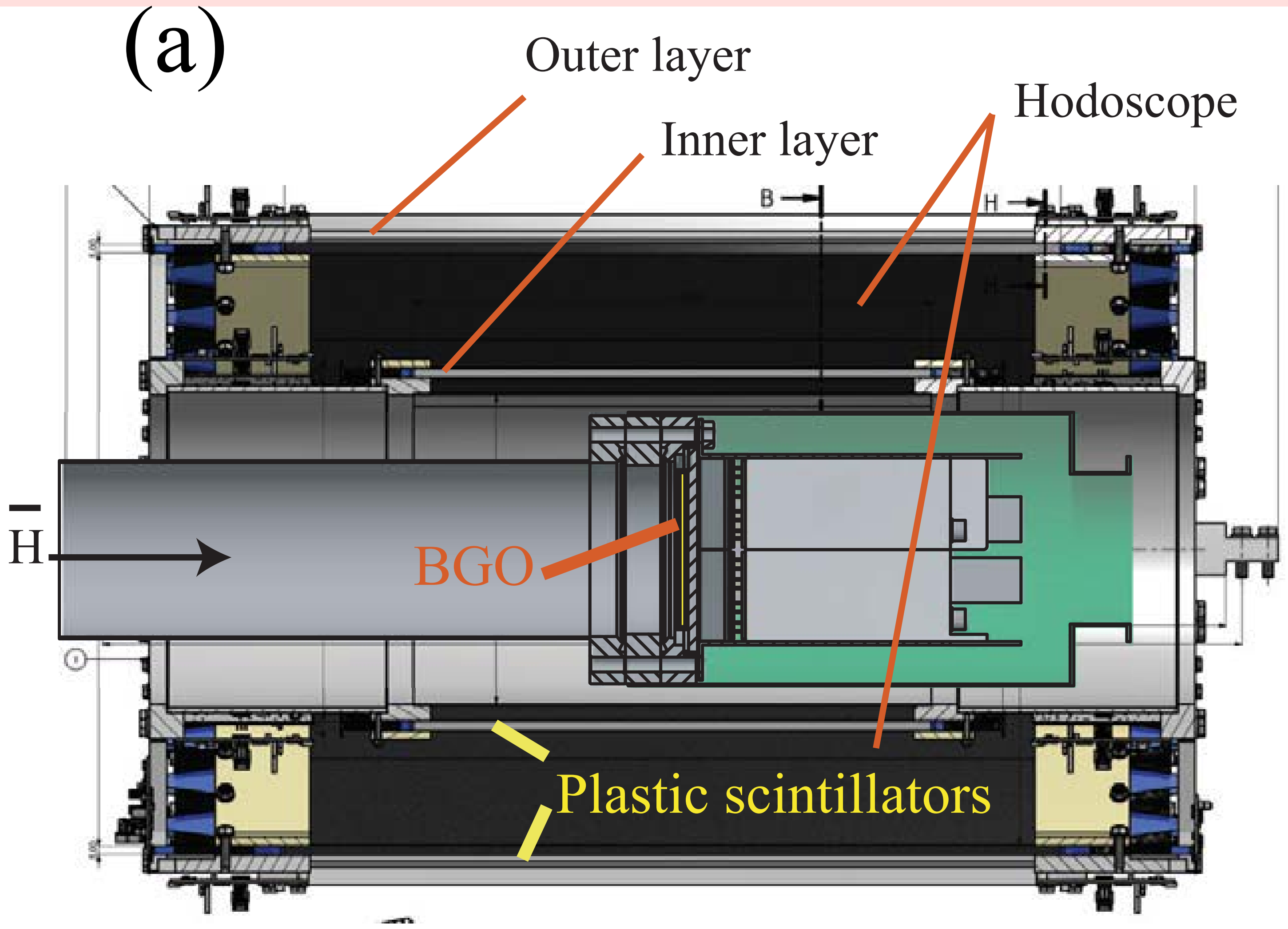
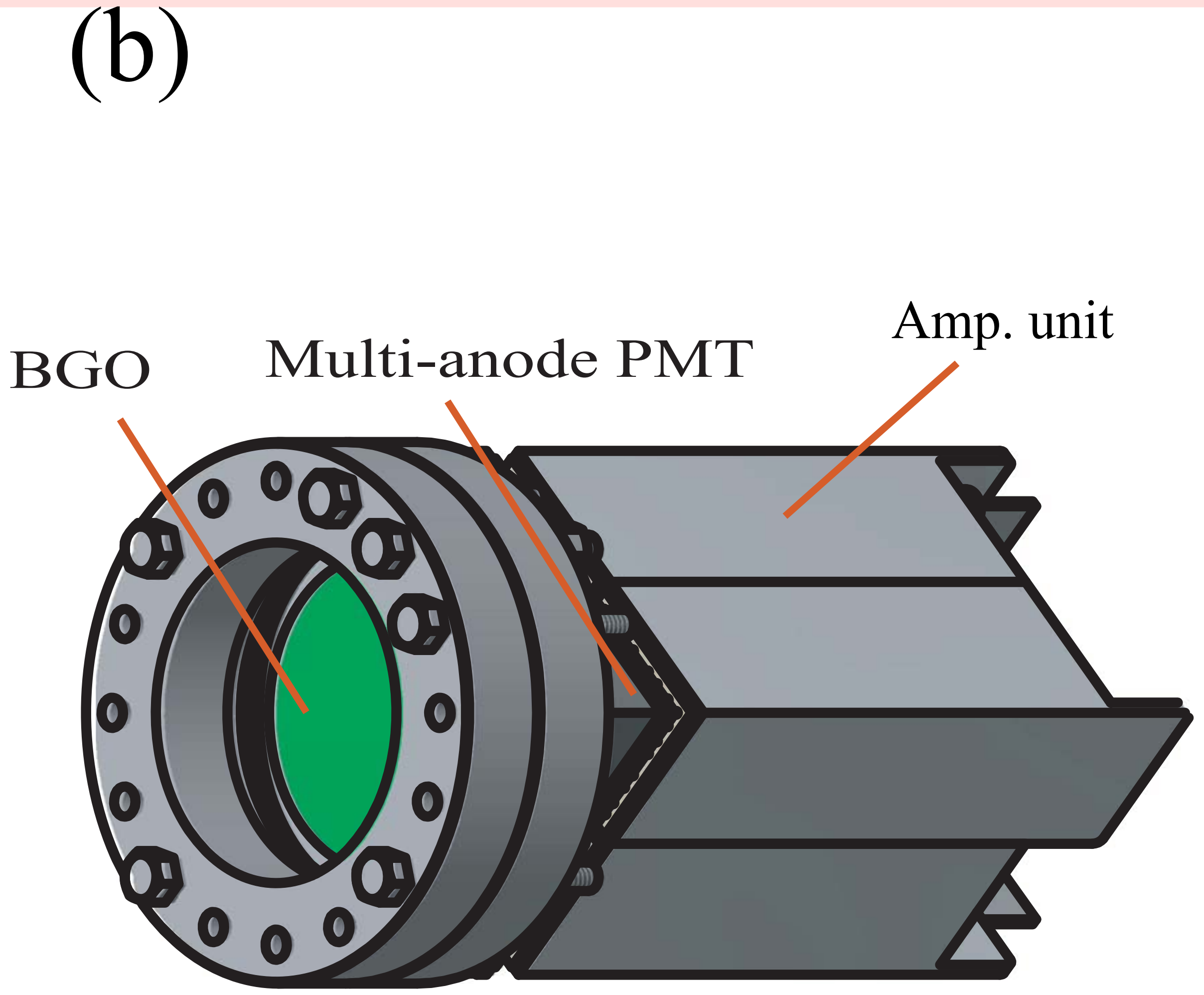
$\bar{H}$ detector @ 3.7m (Solid angle ~0.004%)







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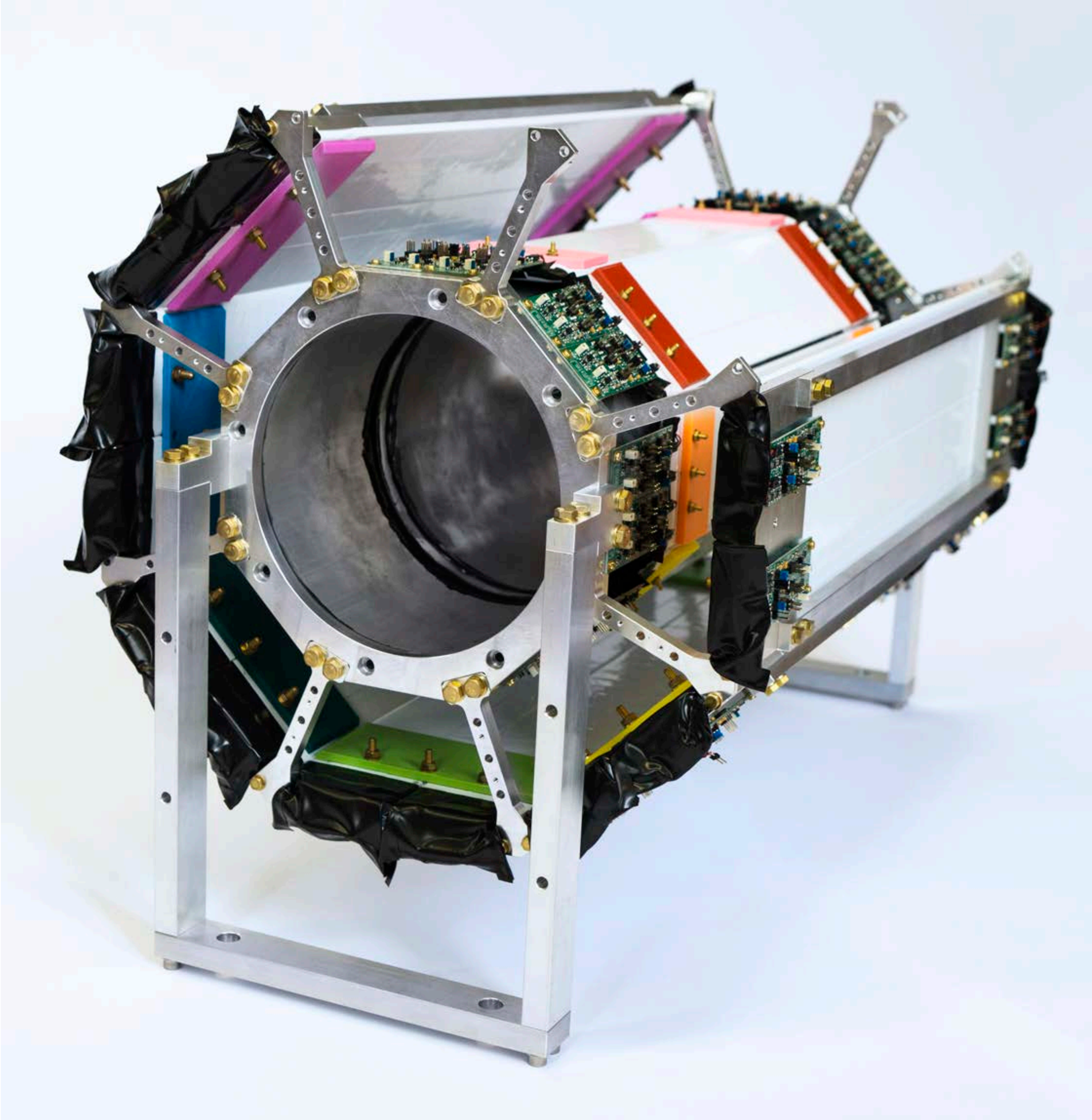

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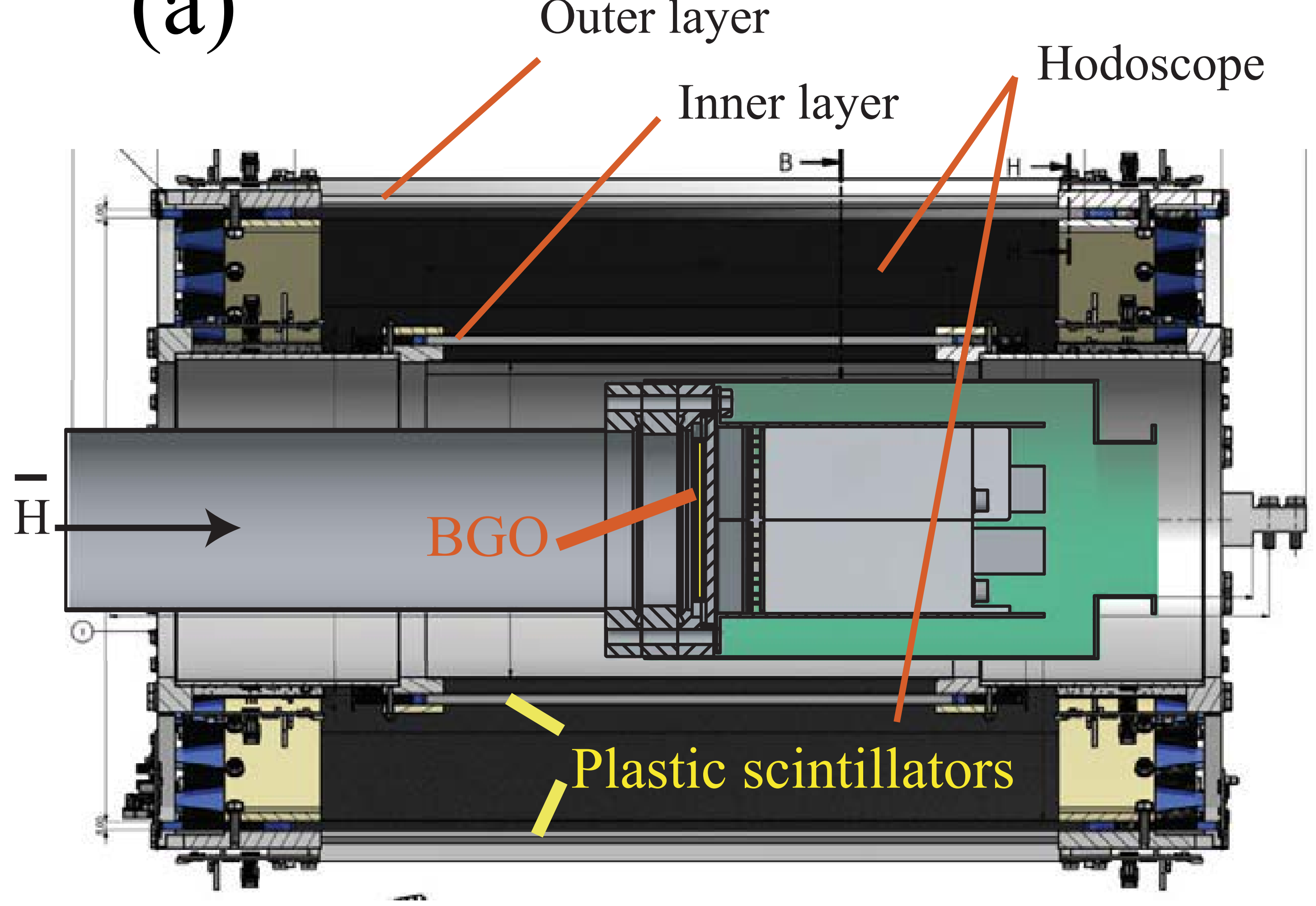

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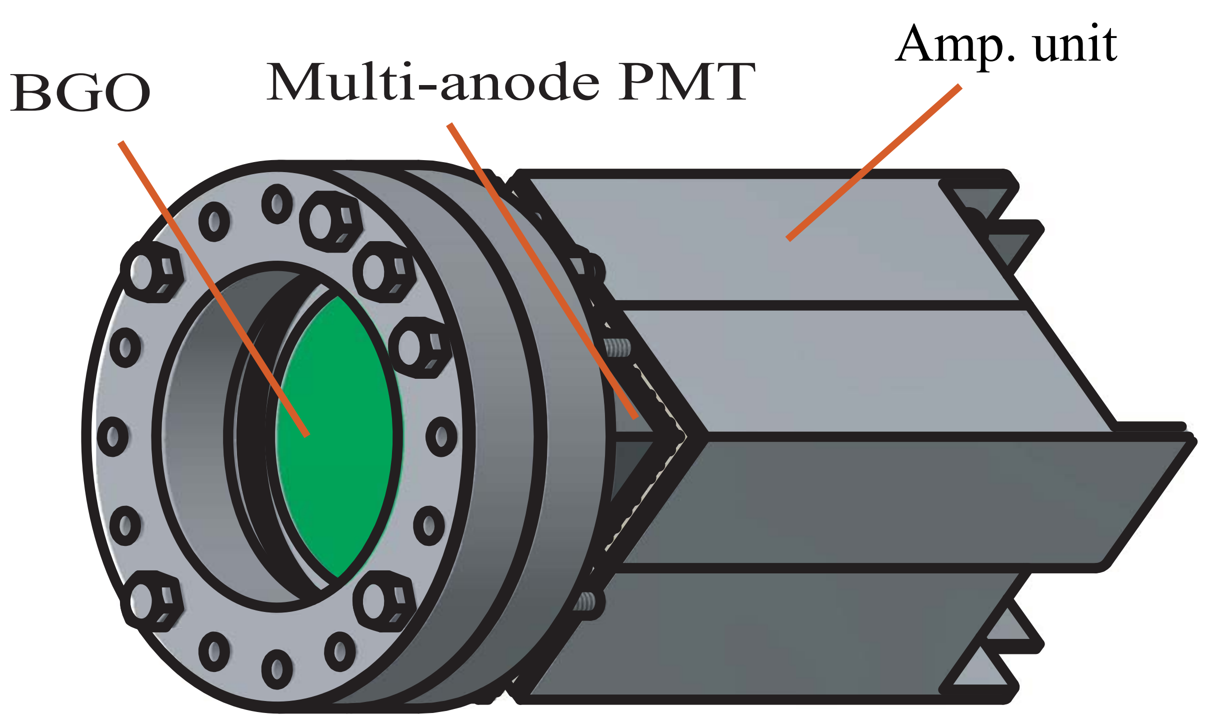
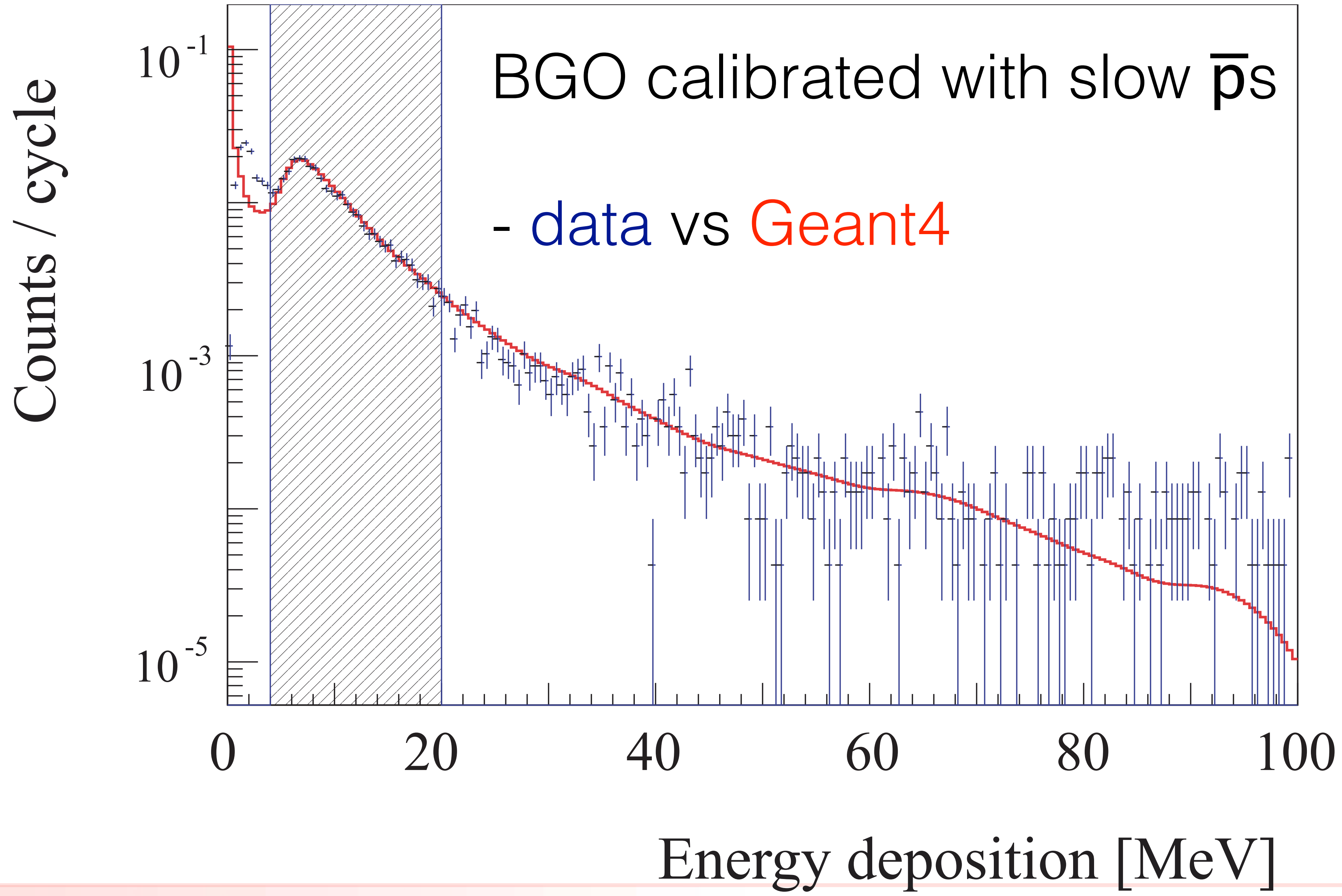
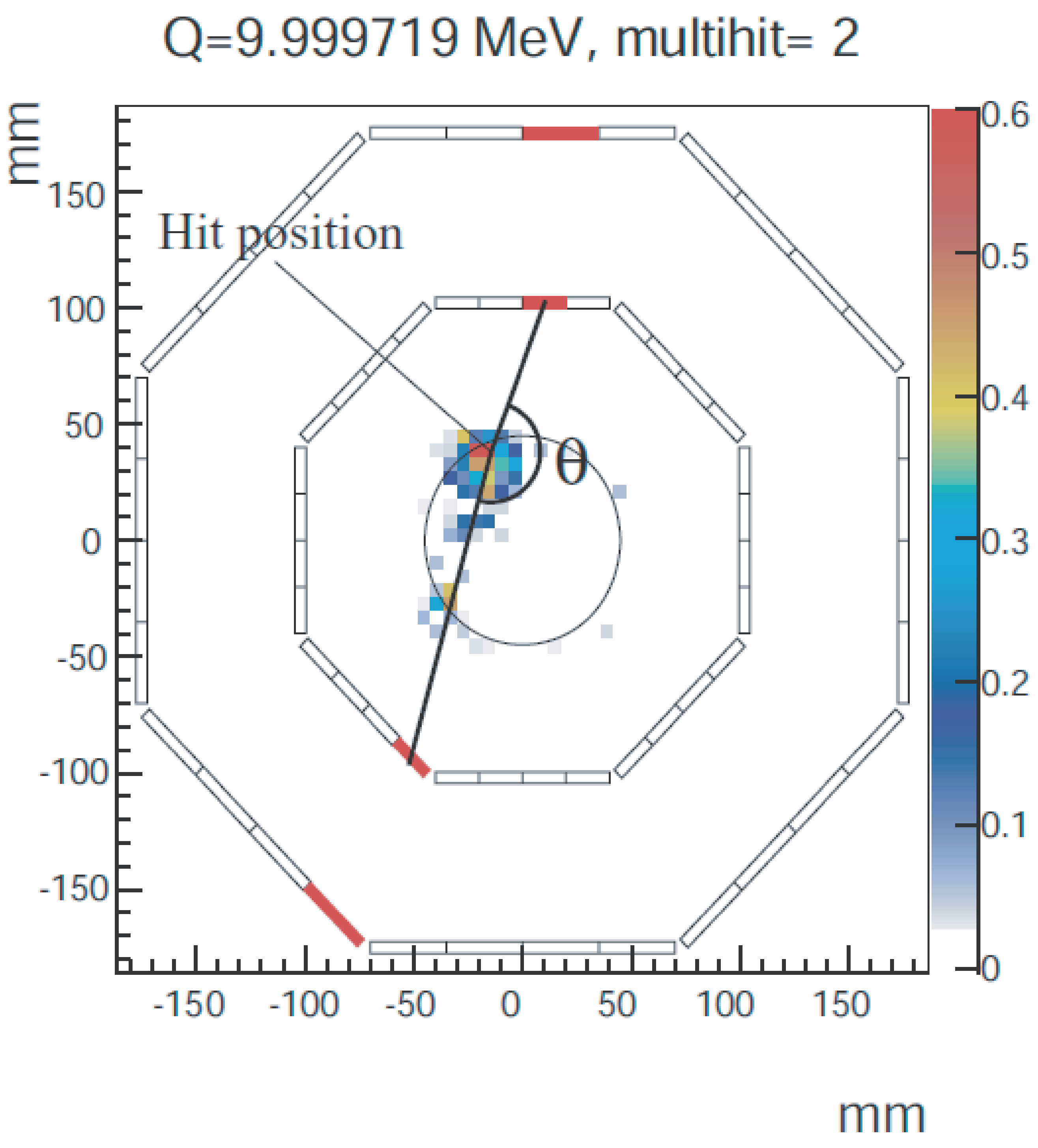
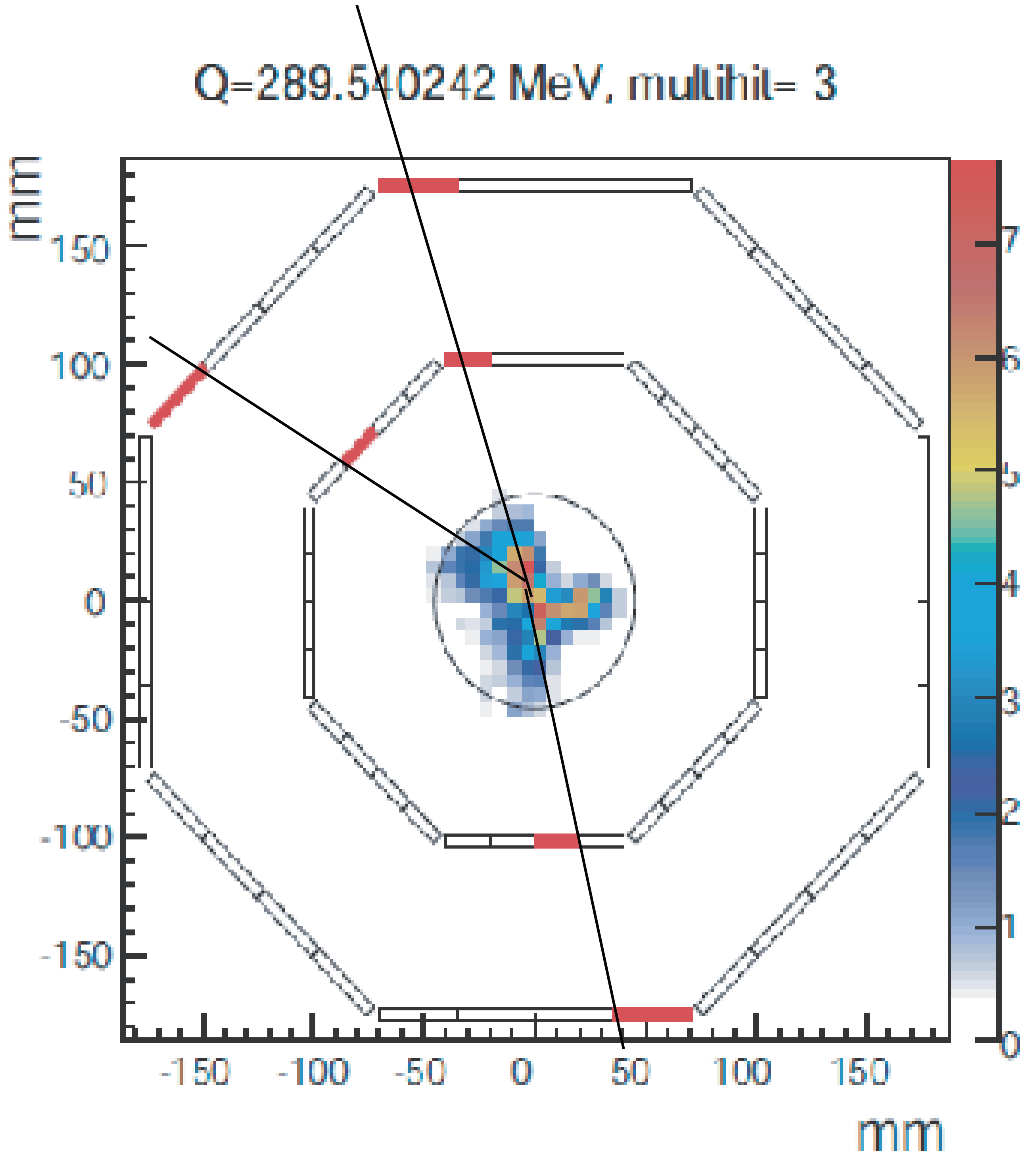




cosmic vs $\bar{H}$ ($\bar{p}$)

BGO energy deposit and hodoscope opening angle





$\overline{\mathrm{H}}$ GSHFS Spectroscopy: 2015 summary

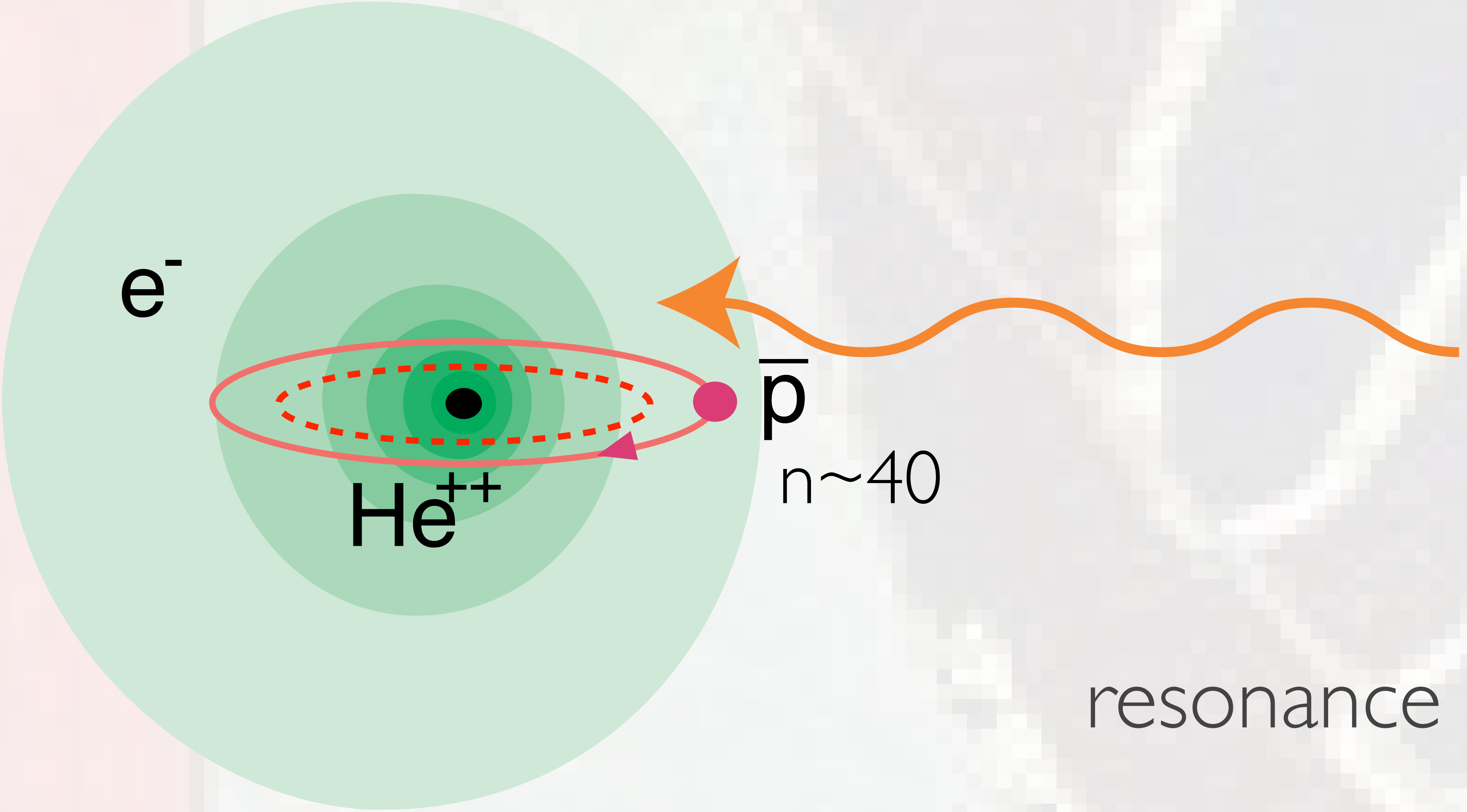
1. $\overline{\mathrm{H}}$ atom formation rate ~15 % with 300k $\overline{\mathrm{p}}$s at 20 eV
   & $7\mathrm{x}10^7$ e^+s

2. $\overline{\mathrm{H}}$ detection scheme perfected

3. σ_1 hyperfine frequency of ordinary H atoms
   measured to <10 ppb

4. Currently, ~1 $\overline{\mathrm{H}}$ detected / mixing cycle (~15 min)
   x10 $\overline{\mathrm{H}}_{gs}$ rate needed for spectroscopy

2. Antiproton-to-electron mass ratio



laser pulse changes the $\bar{p}$ orbit

resonance detection via $\bar{p}$ annihilation

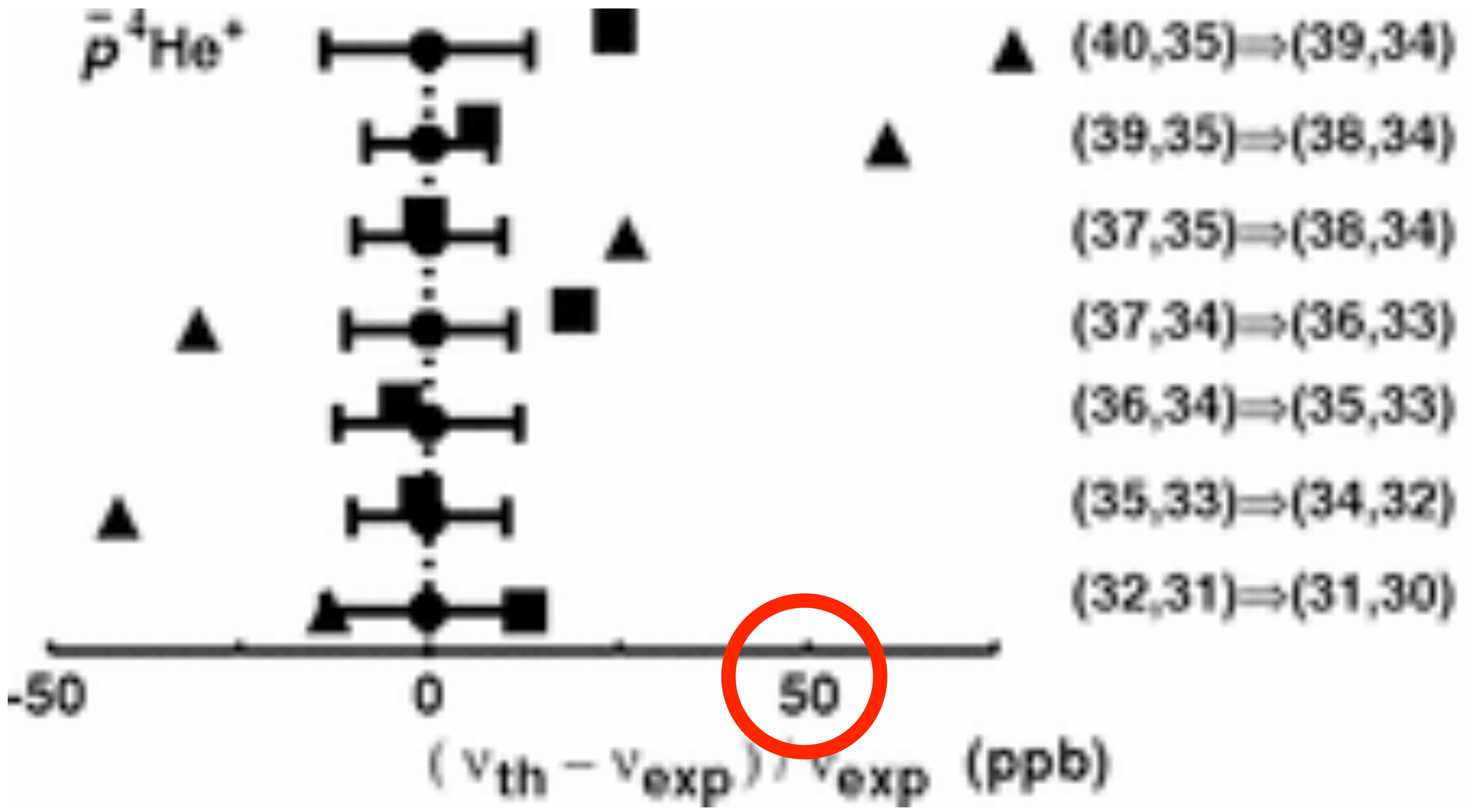
Frequency

$$\boxed{\nu_{n,\ell\rightarrow n',\ell'}} = Rc\boxed{\frac{m^*_{\bar{p}}}{m_e}} Z^2_{\mathrm{eff}}\left(\frac{1}{n'^2}-\frac{1}{n^2}\right) \quad +QED$$

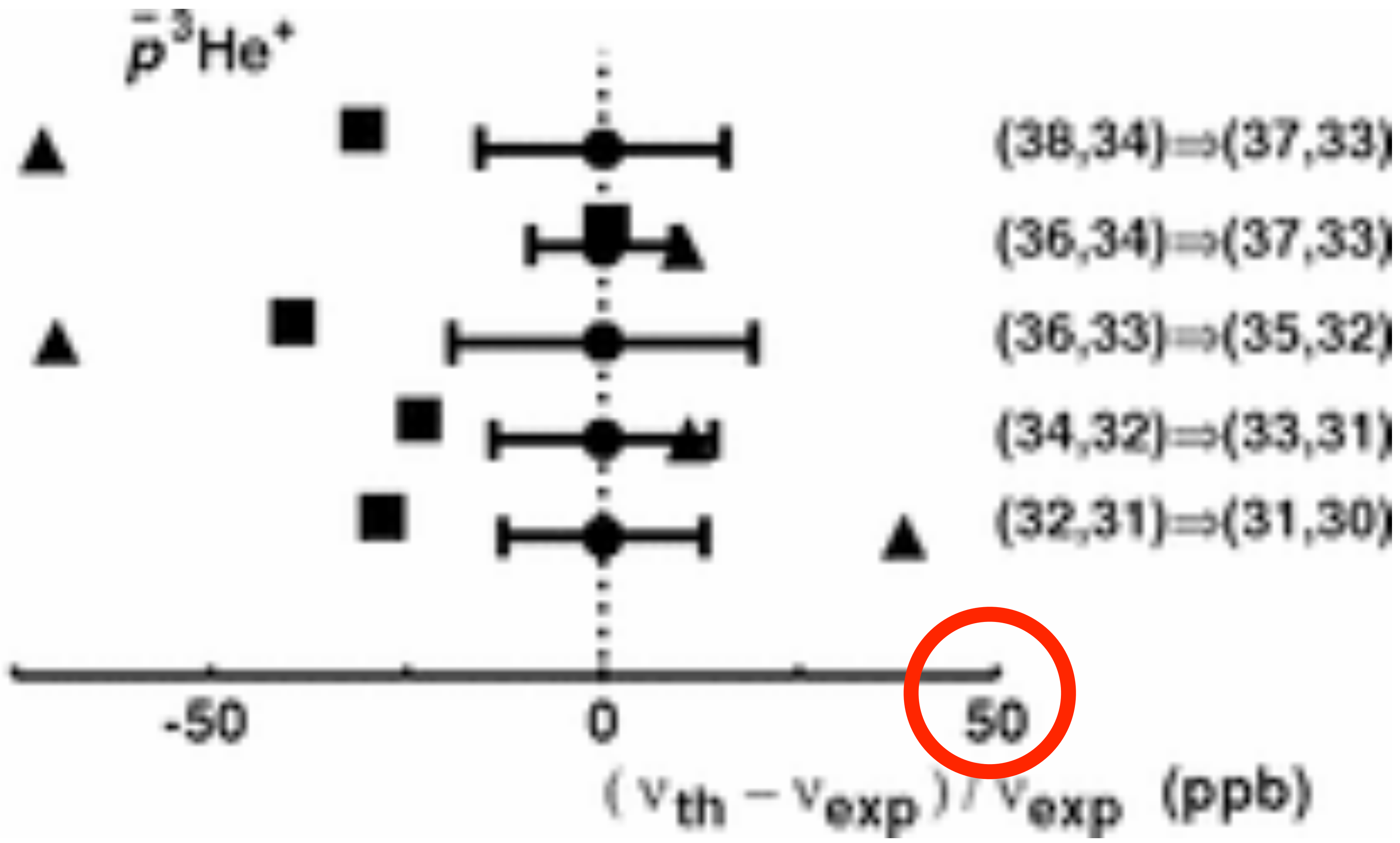
$\bar{p}$ (p) - e mass ratio

Theory

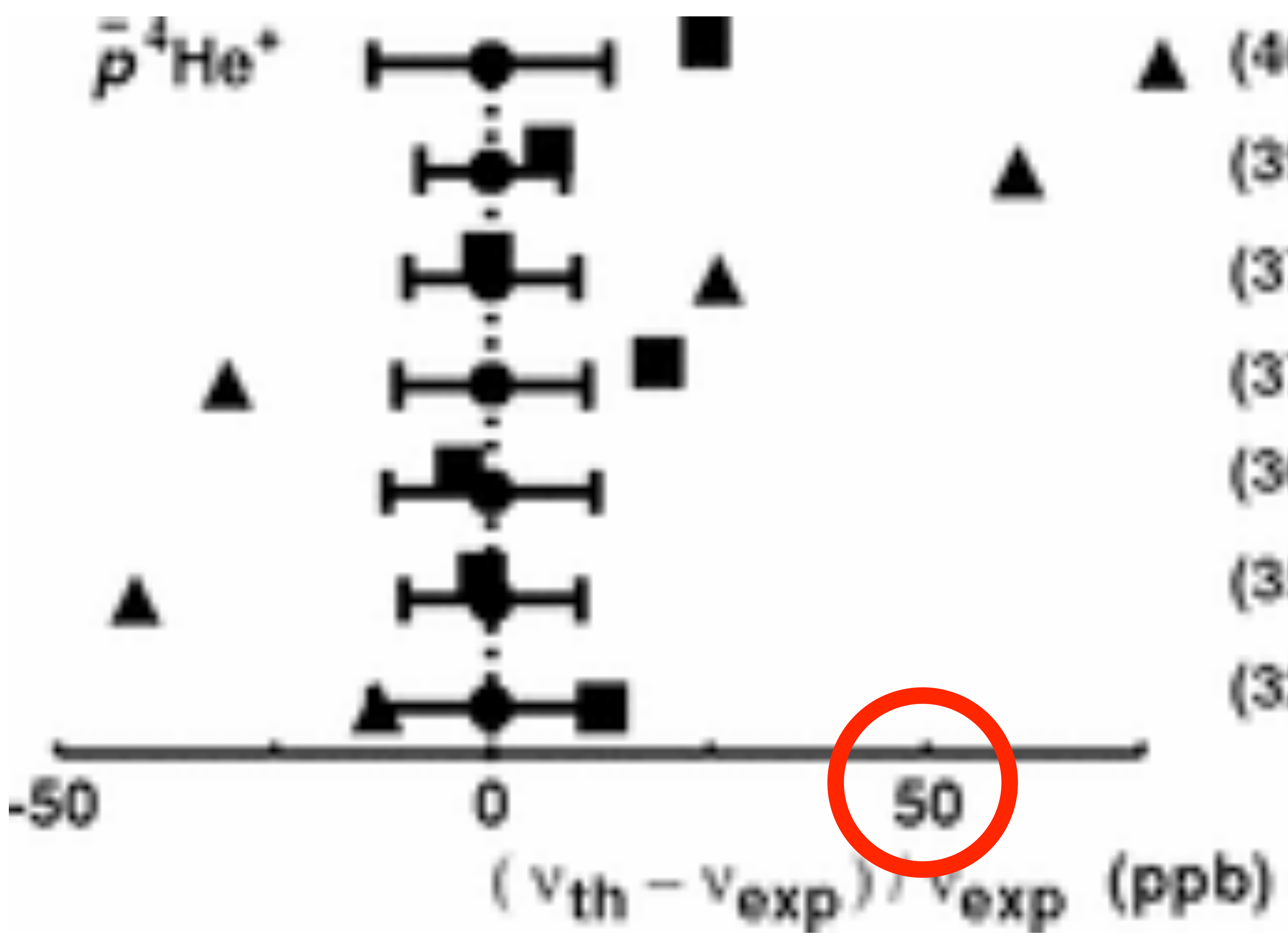
ASACUSA single photon (final)

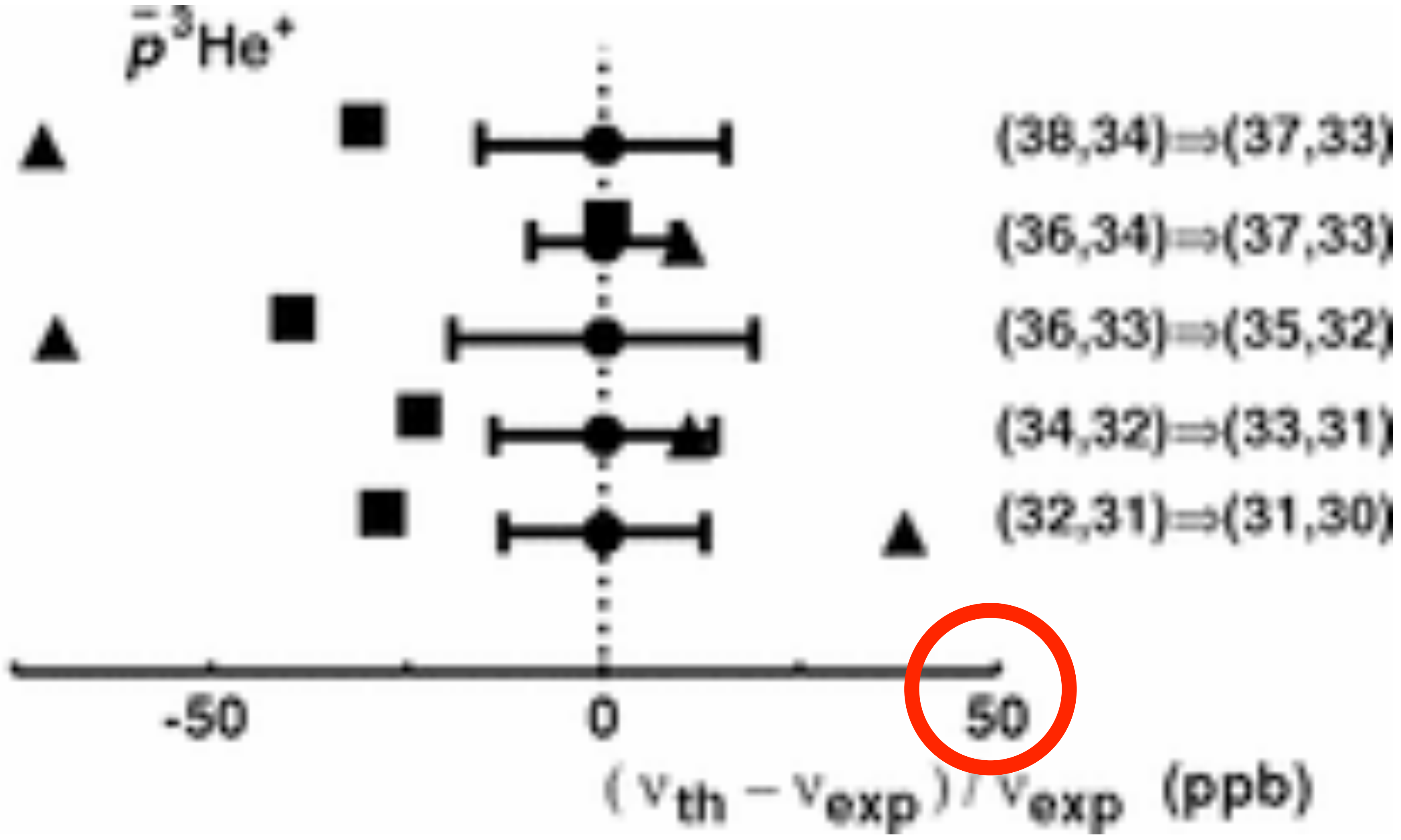


2006
~15 K

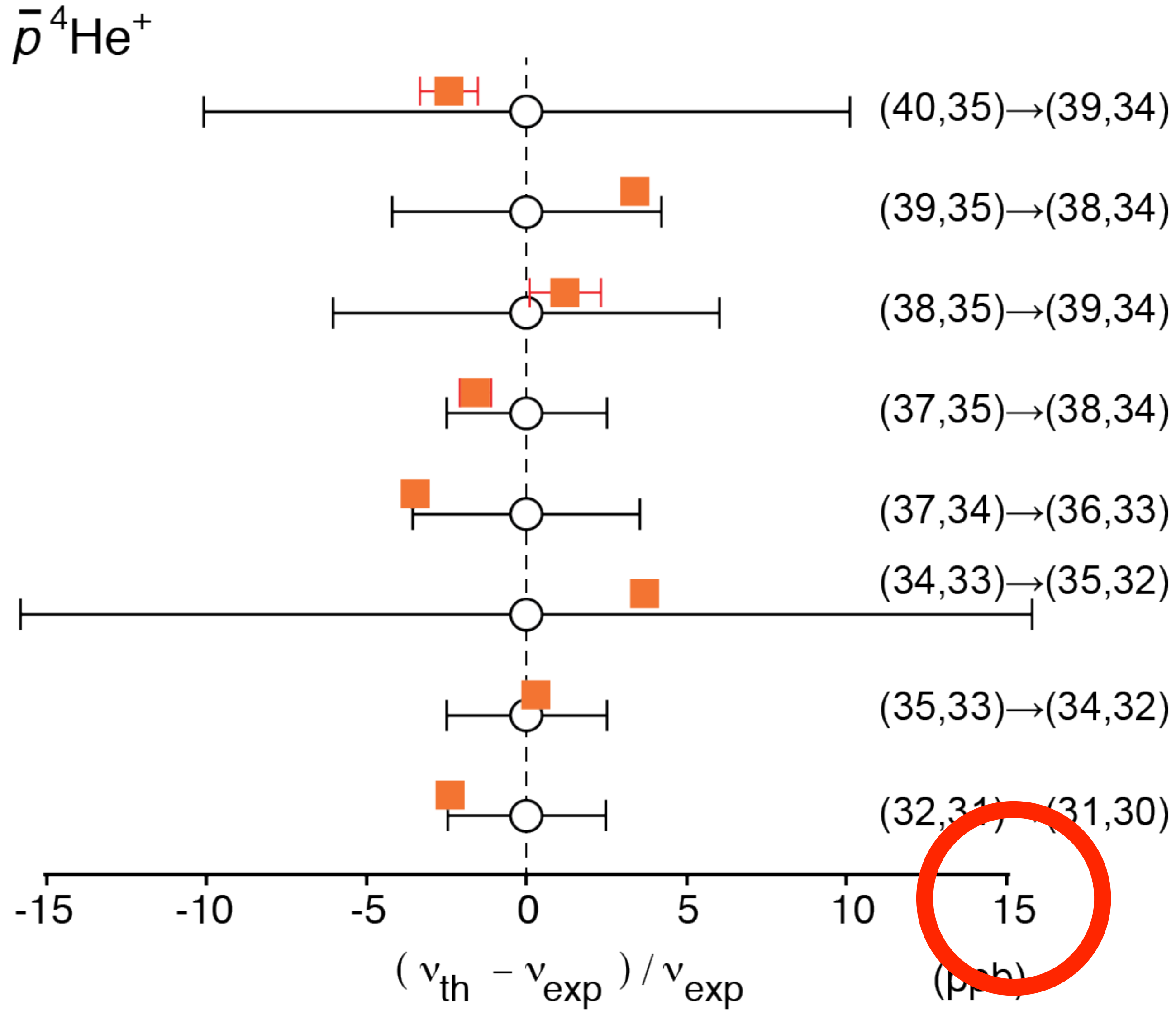


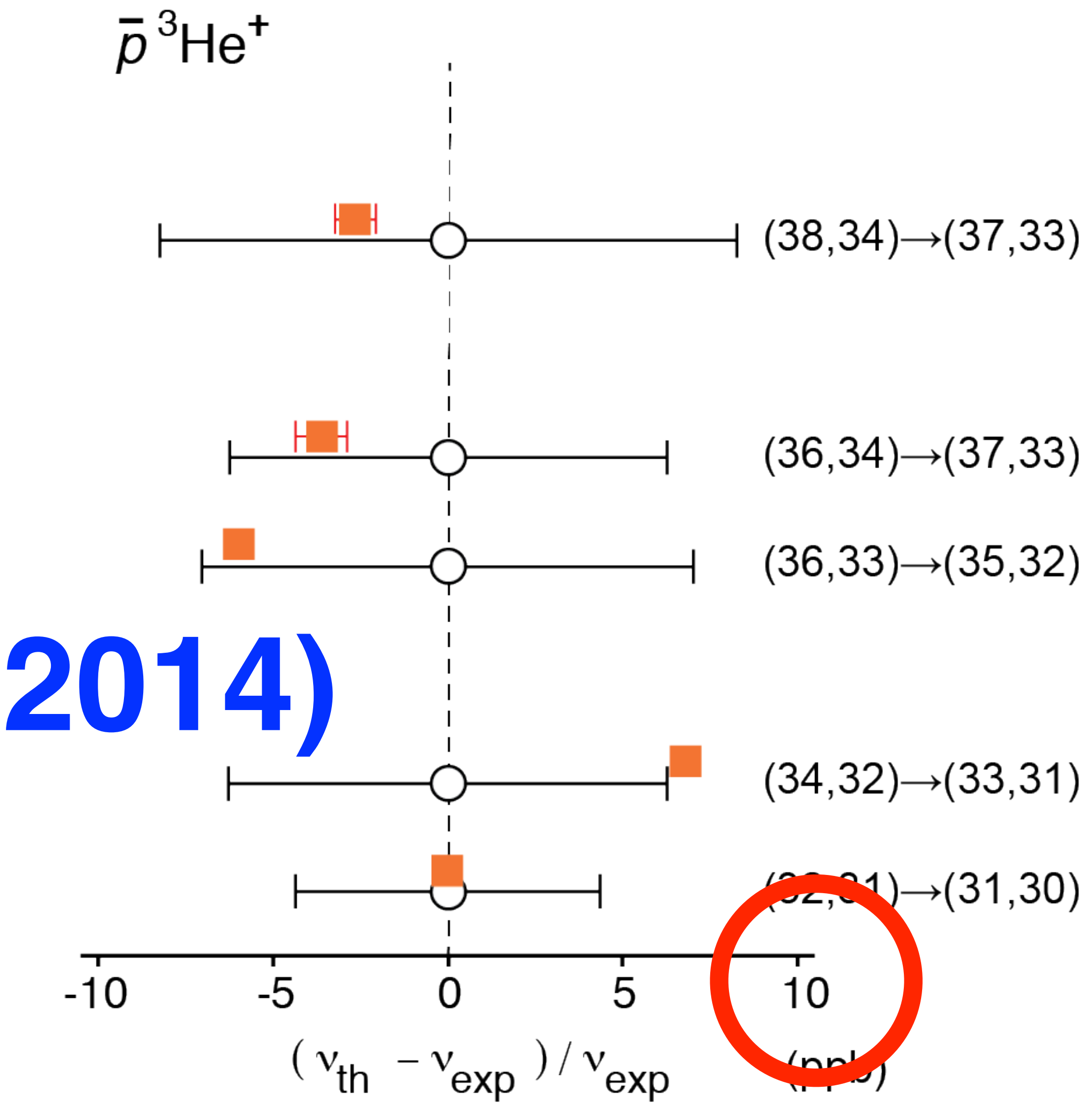
ASACUSA single photon (final)





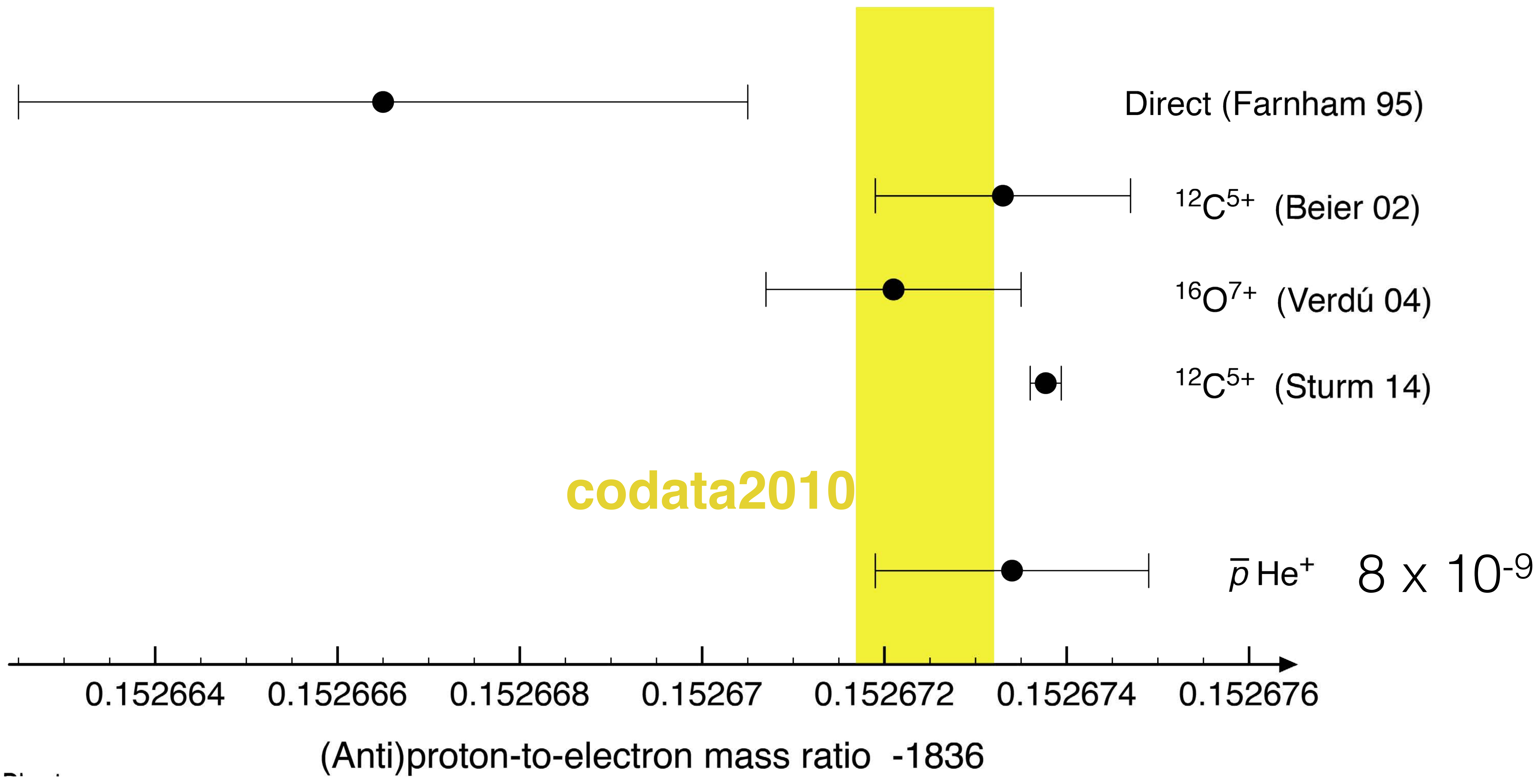
2006
~15 K





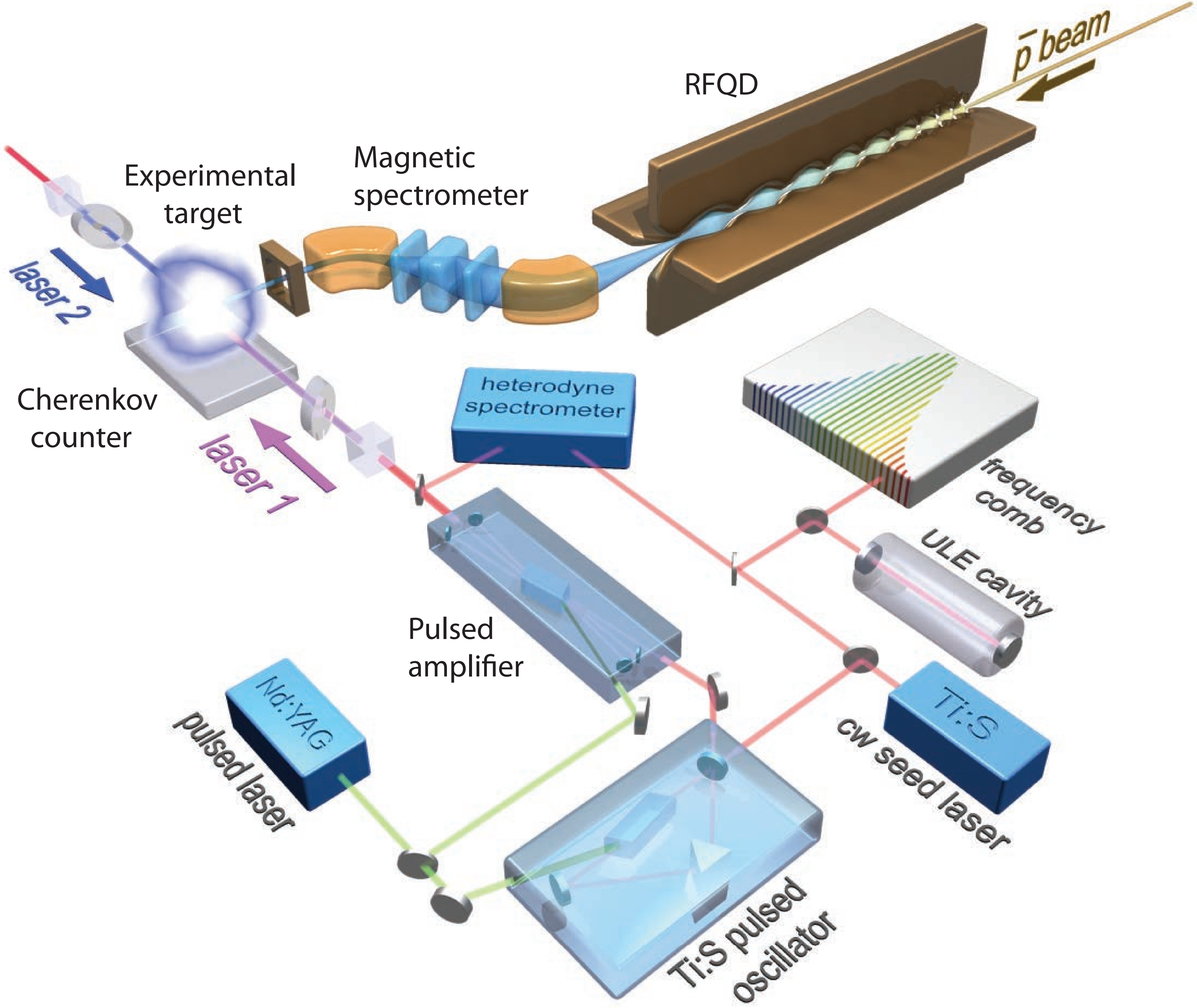
2015
~1.5K
(contributed to CODATA2014)

ASACUSA single photon (final)



Experimental improvements in 2012-2015

2-photon



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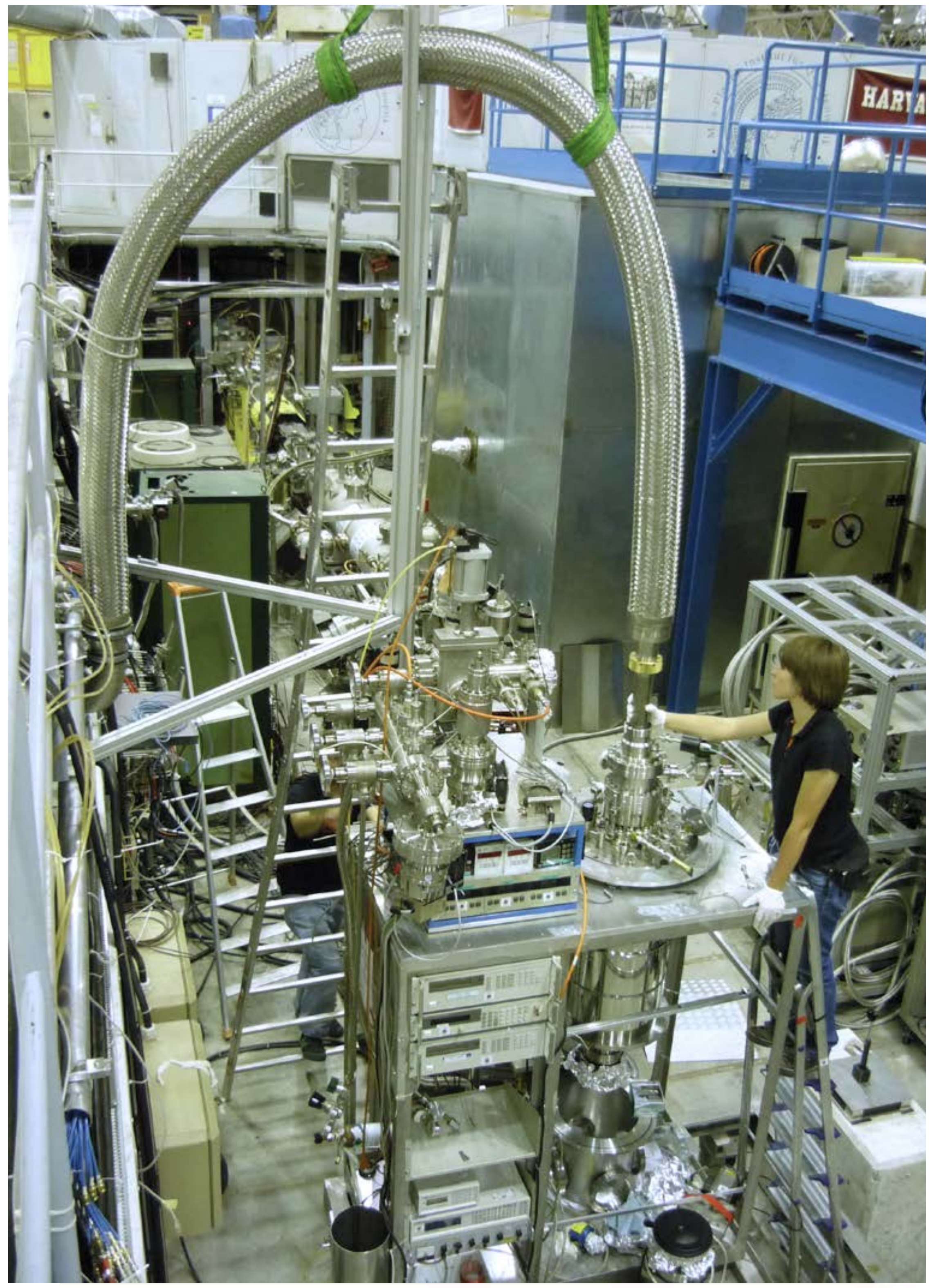
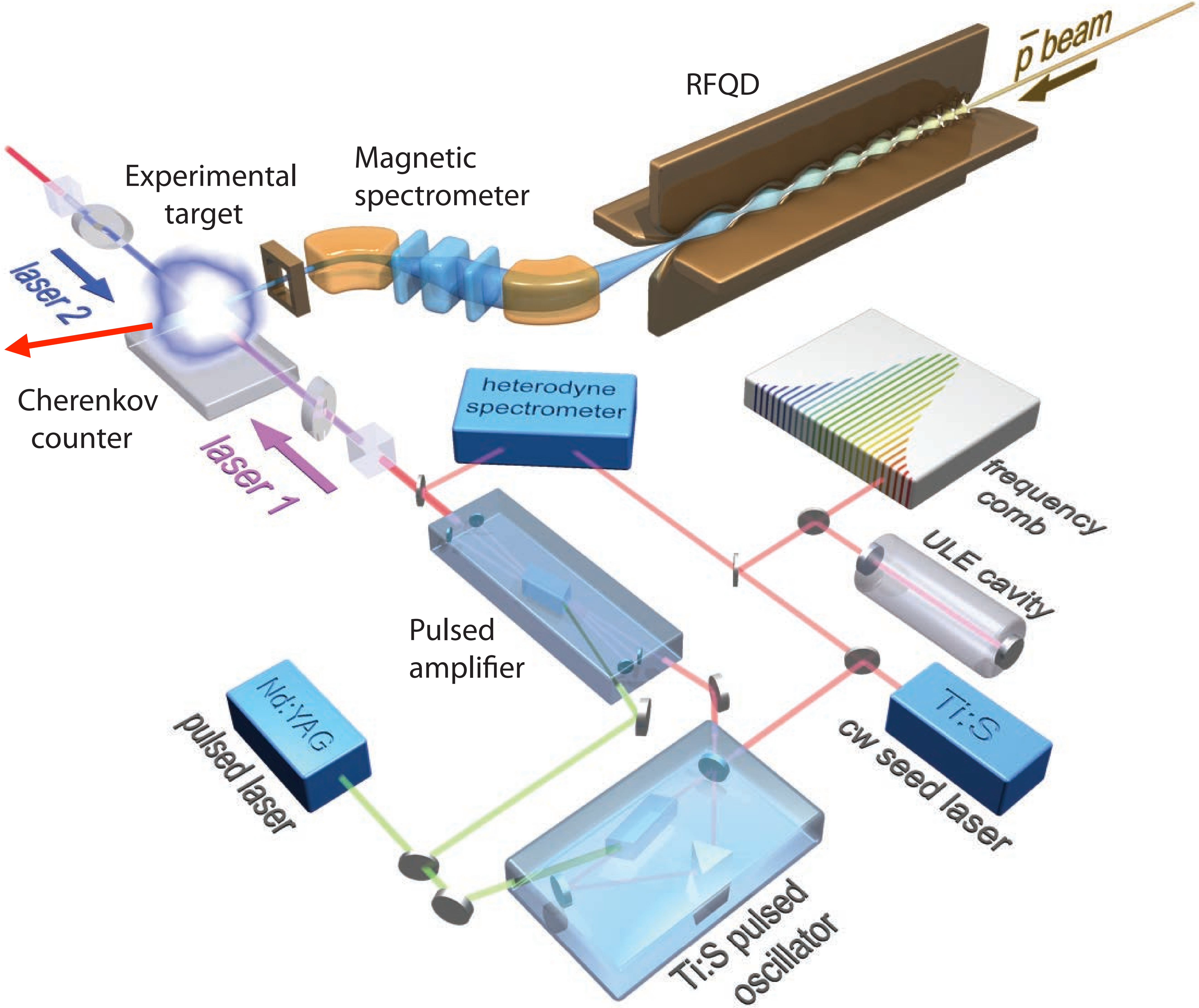


$\overline{p}$He cooled to 1.5K



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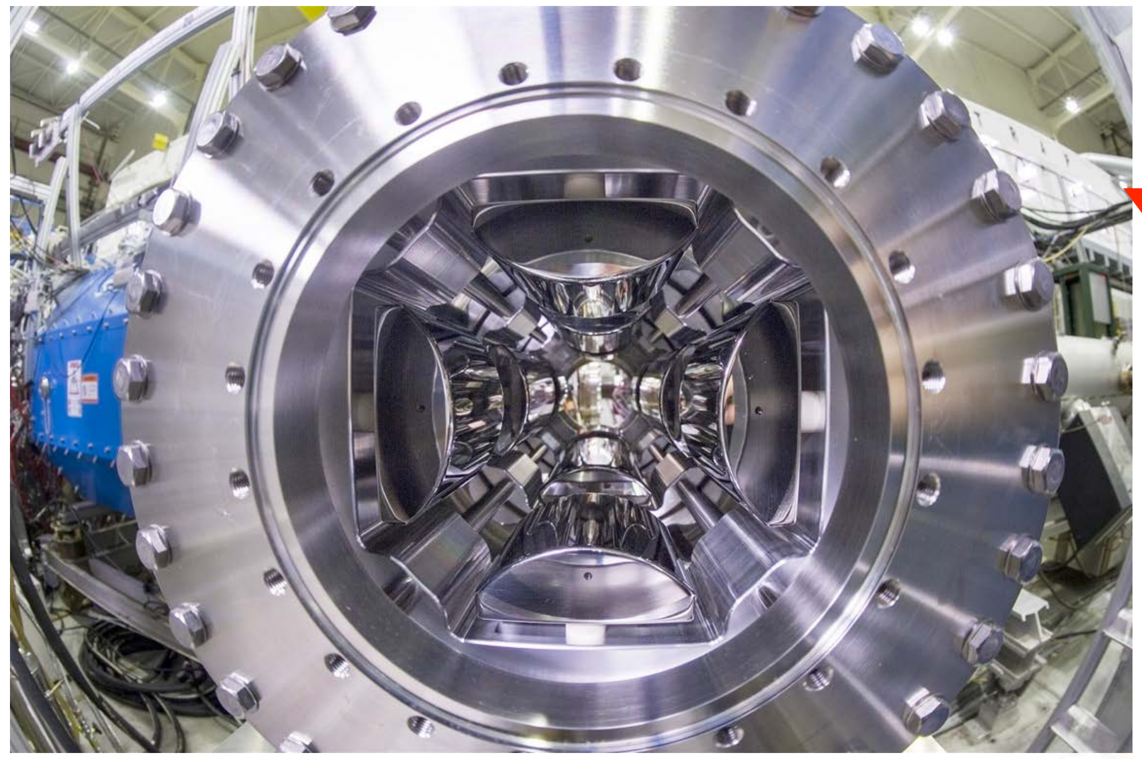
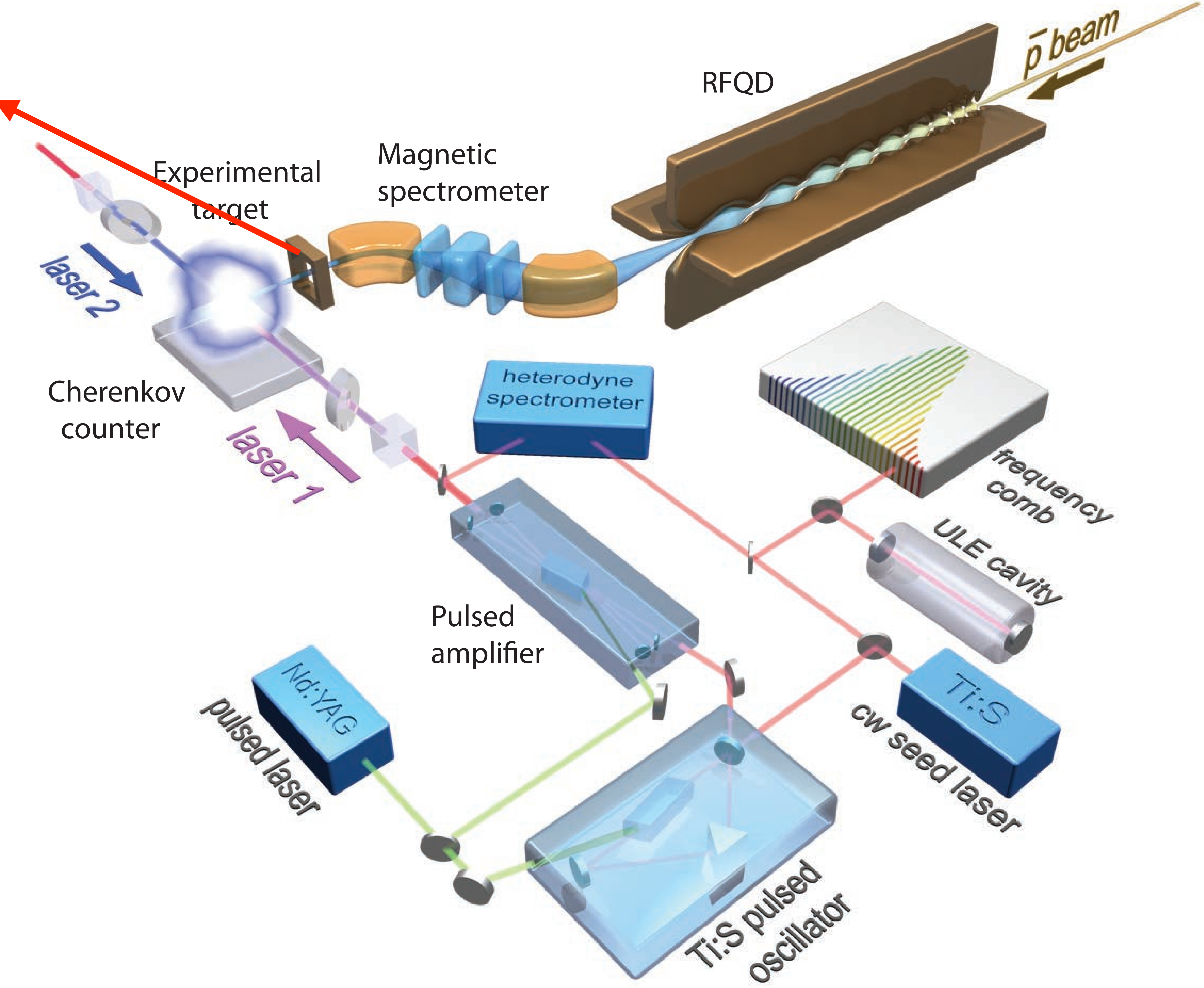
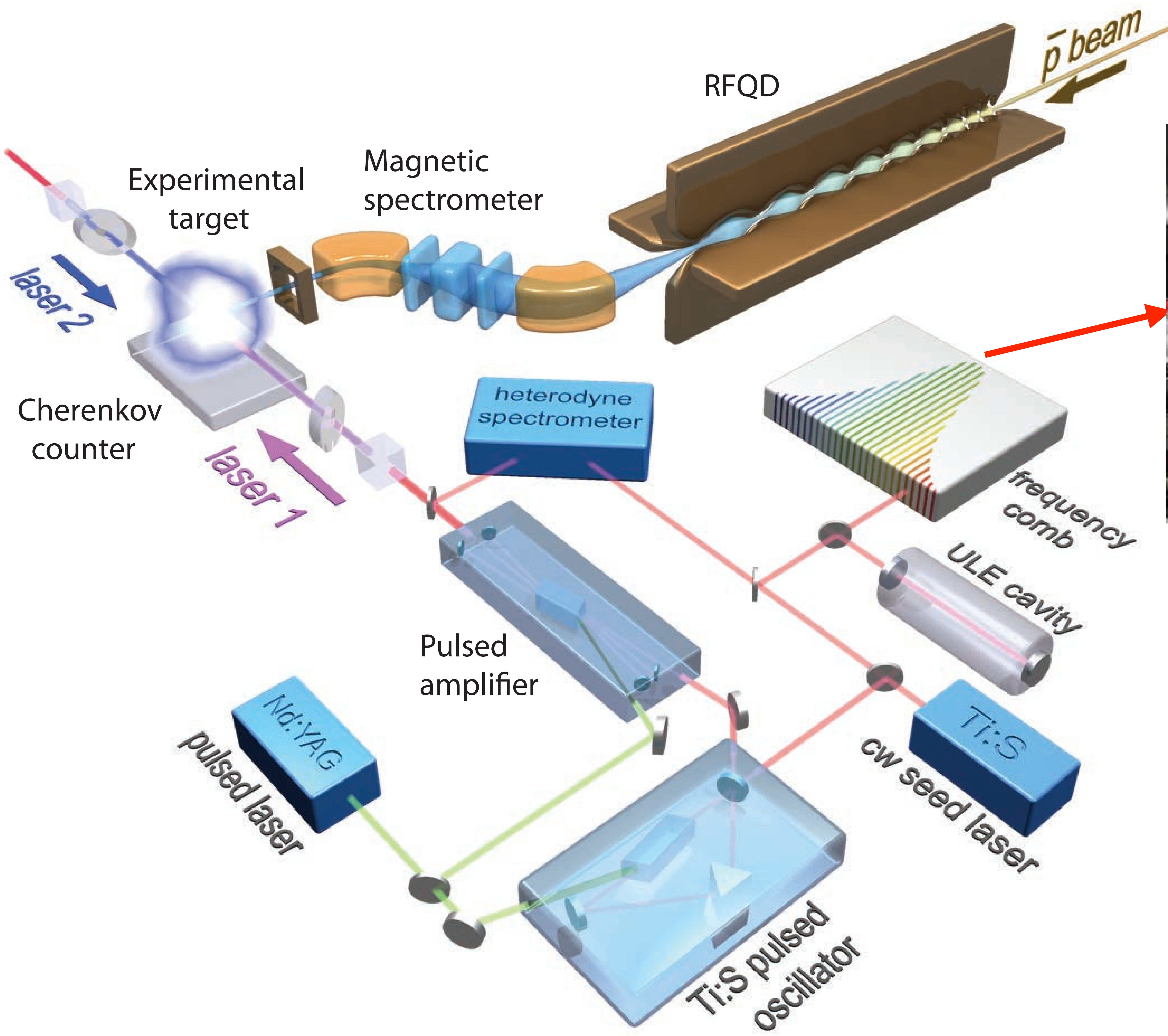
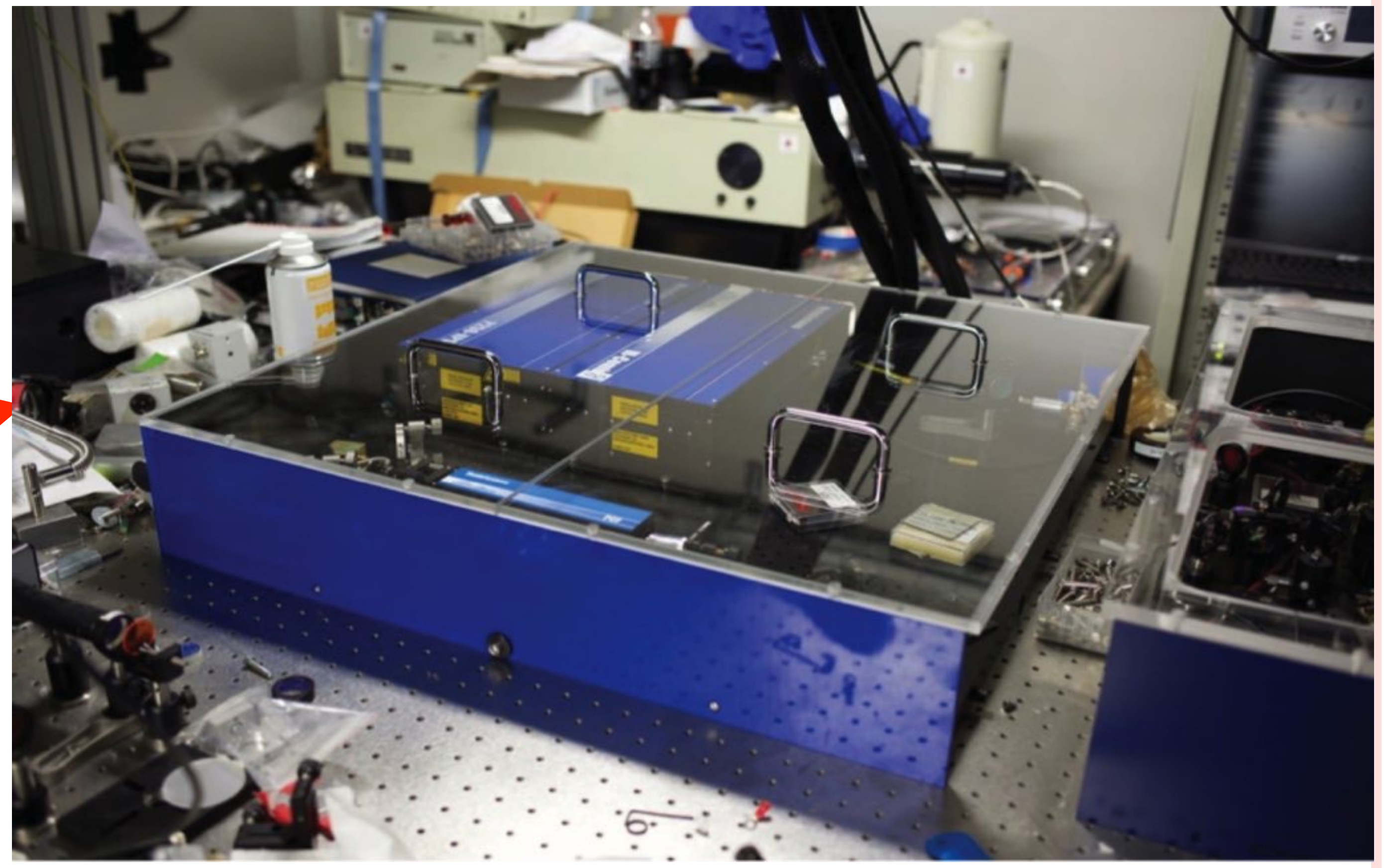


electrostatic quadrupole lens (ELENA R&D)



Experimental improvements in 2012-2015

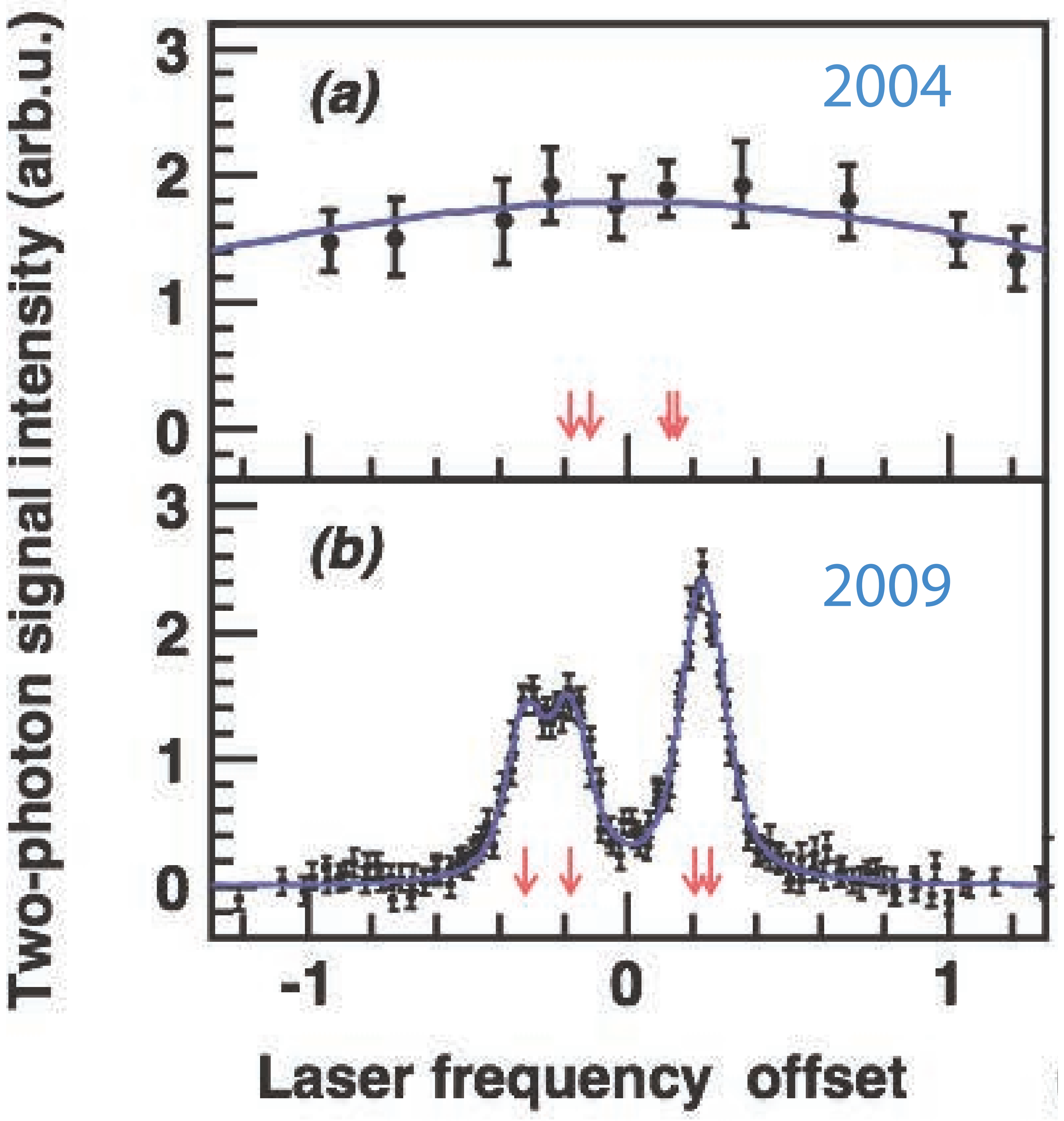


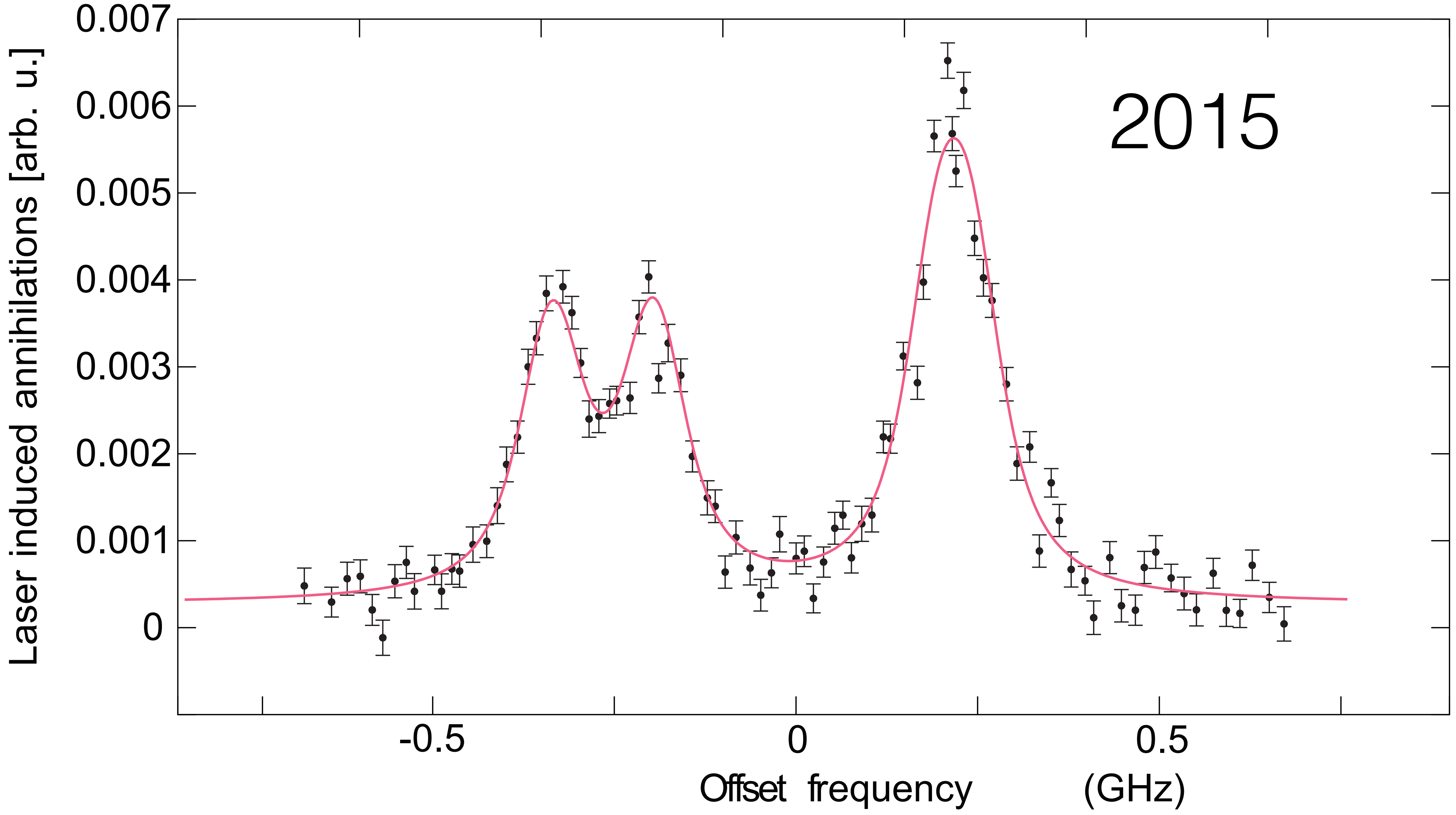


erbium fiber frequency comb

NEW in 2015

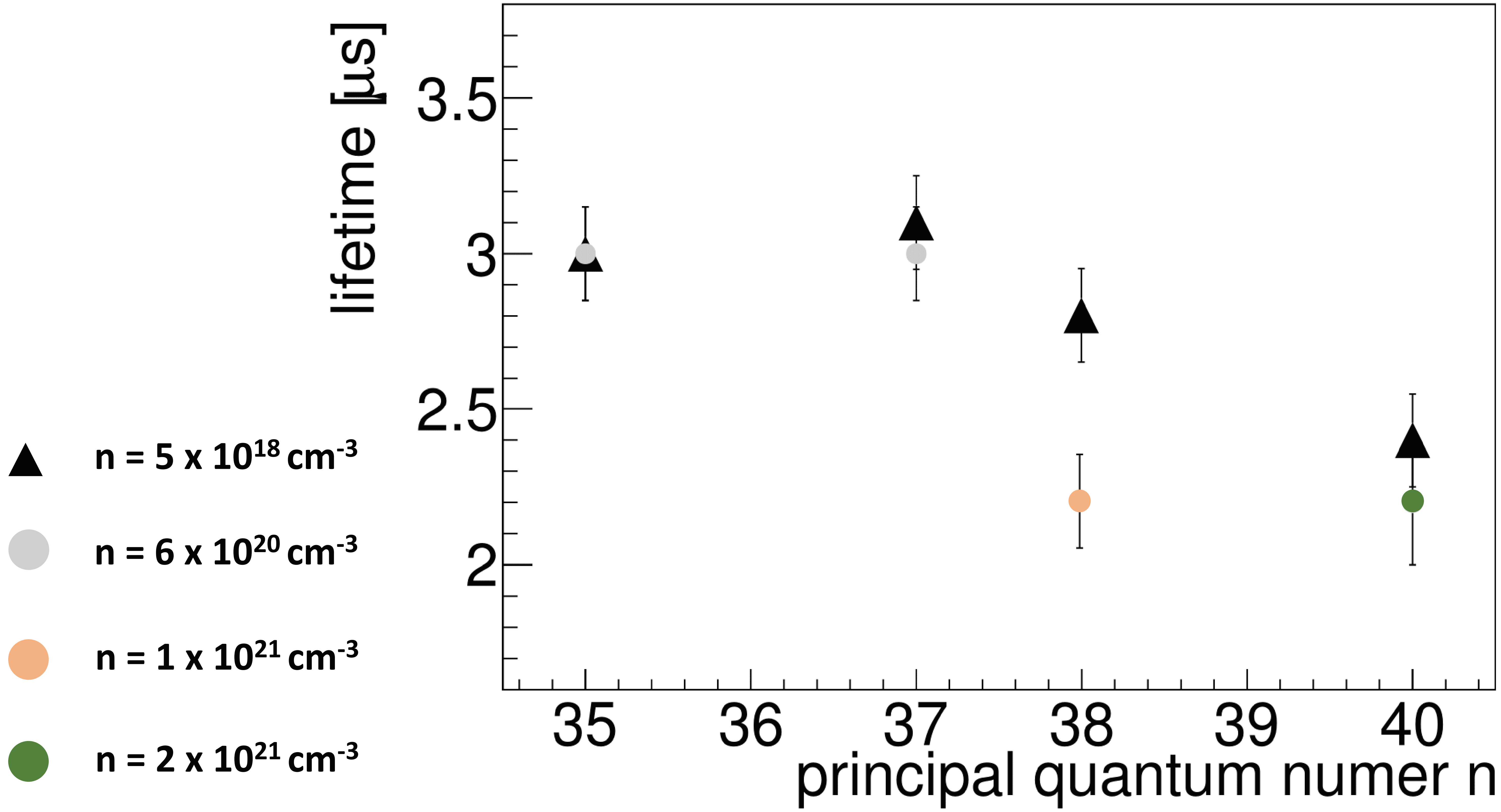
two-photon resonance $\overline{p}^4$He (36,34)→(34,32)





- New frequency comb improved experimental stability
- Leak in target→higher temperature
  → slight deterioration of resolution
  (will be fixed in 2016)

Population evolution T=1.5 K $\bar{p}$He at low densities



State lifetimes are unchanged even when the densities are reduced by factor 100-200

In 2016, continuation of $\overline{p}$He two-photon

$\overline{p}{}^4$He

(n,l)=(36,34)→(34,32)

(n,l)=(31,30)->(30,29)

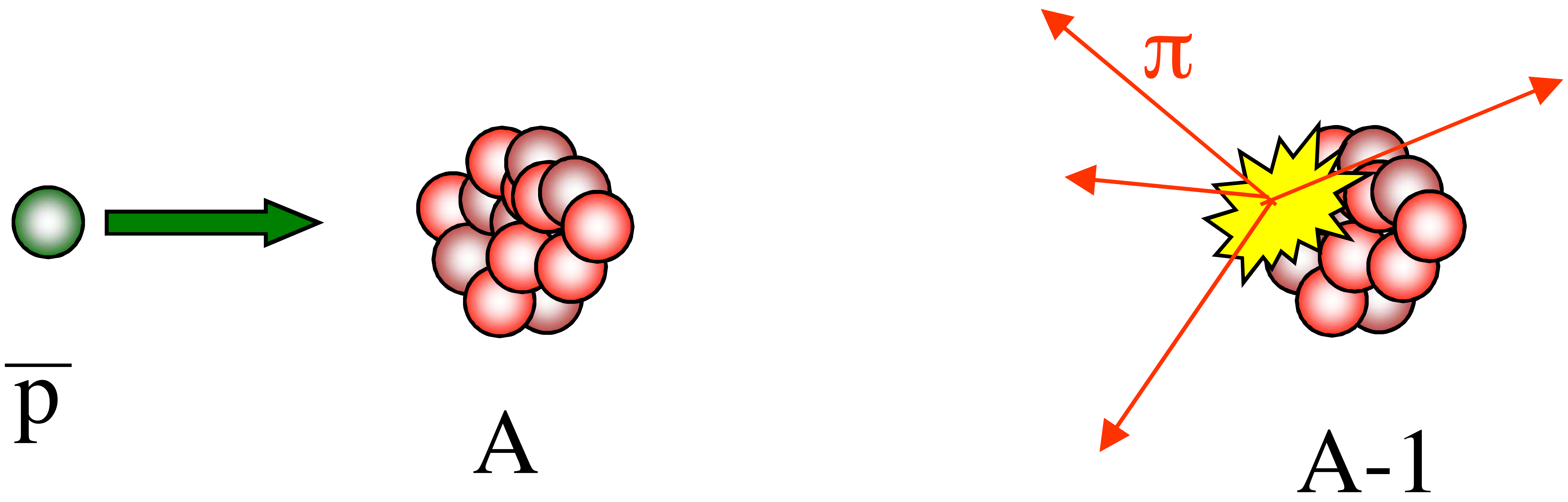
$\overline{p}{}^3$He

(n,l)=(30,29)->(29,28)

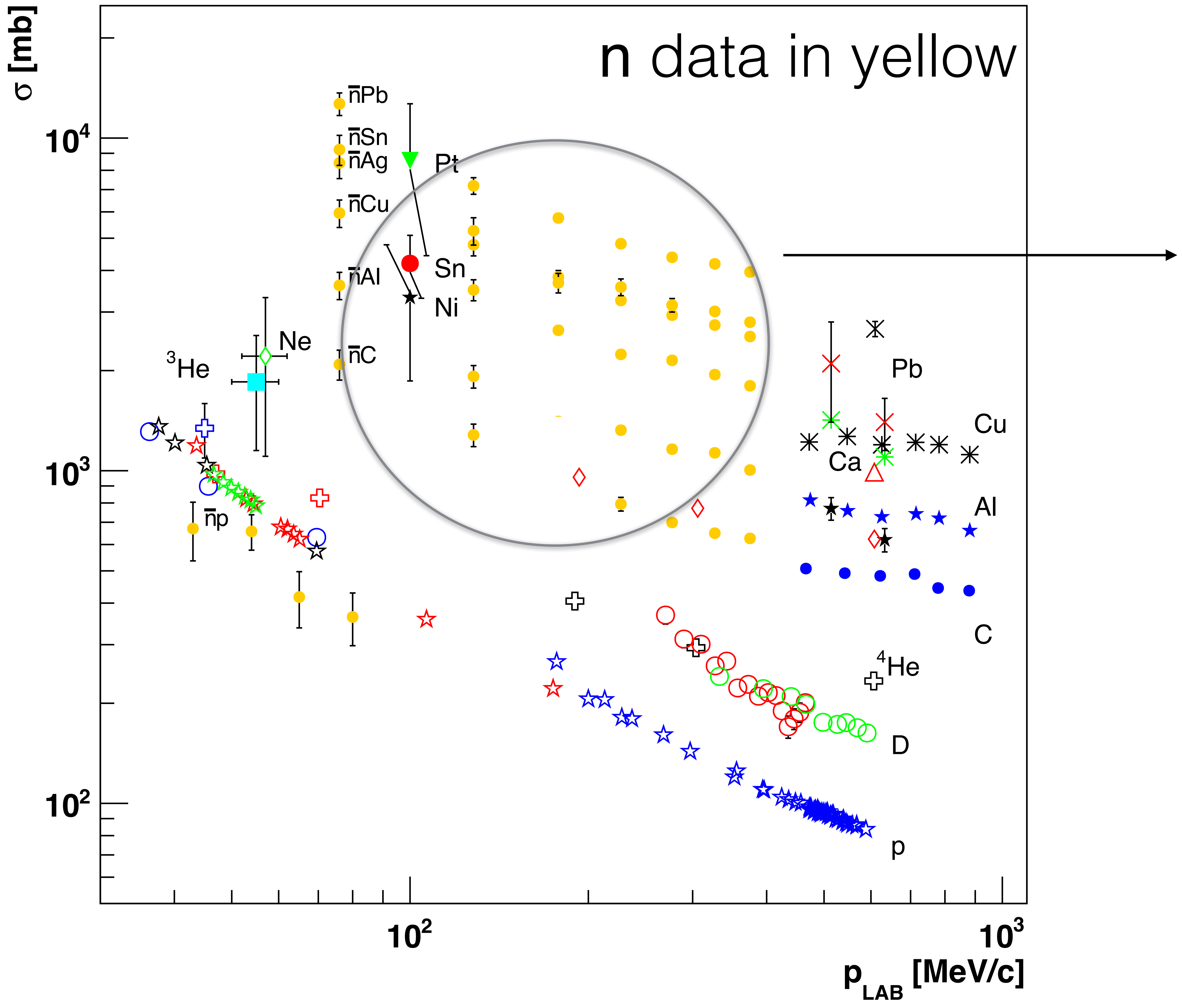
Goal: antiproton-to-electron mass ratio $<3\times10^{-10}$

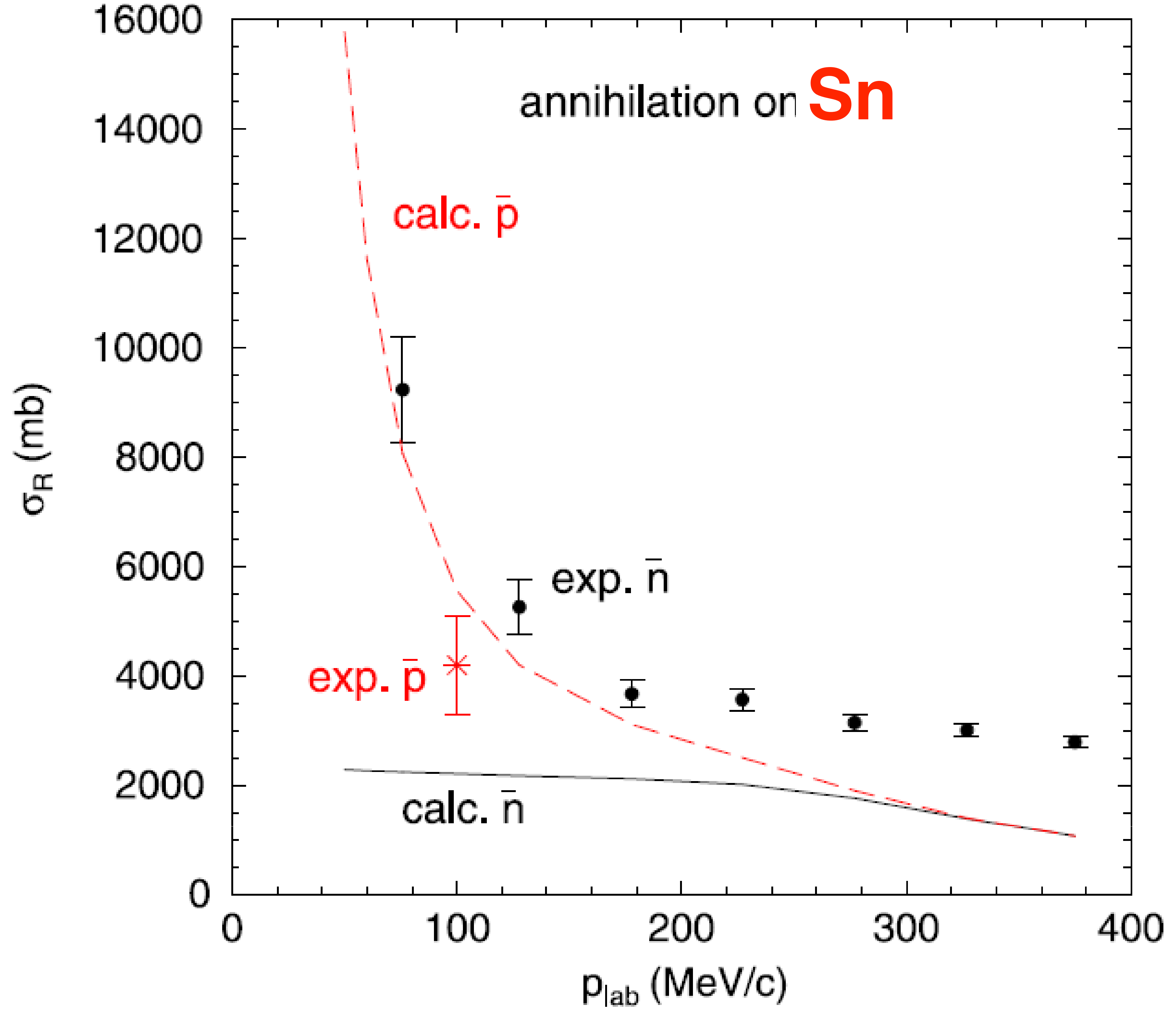
($<1 \times 10^{-10}$ at ELENA)

3. $\bar{p}$ annihilation σ at 5.3 MeV



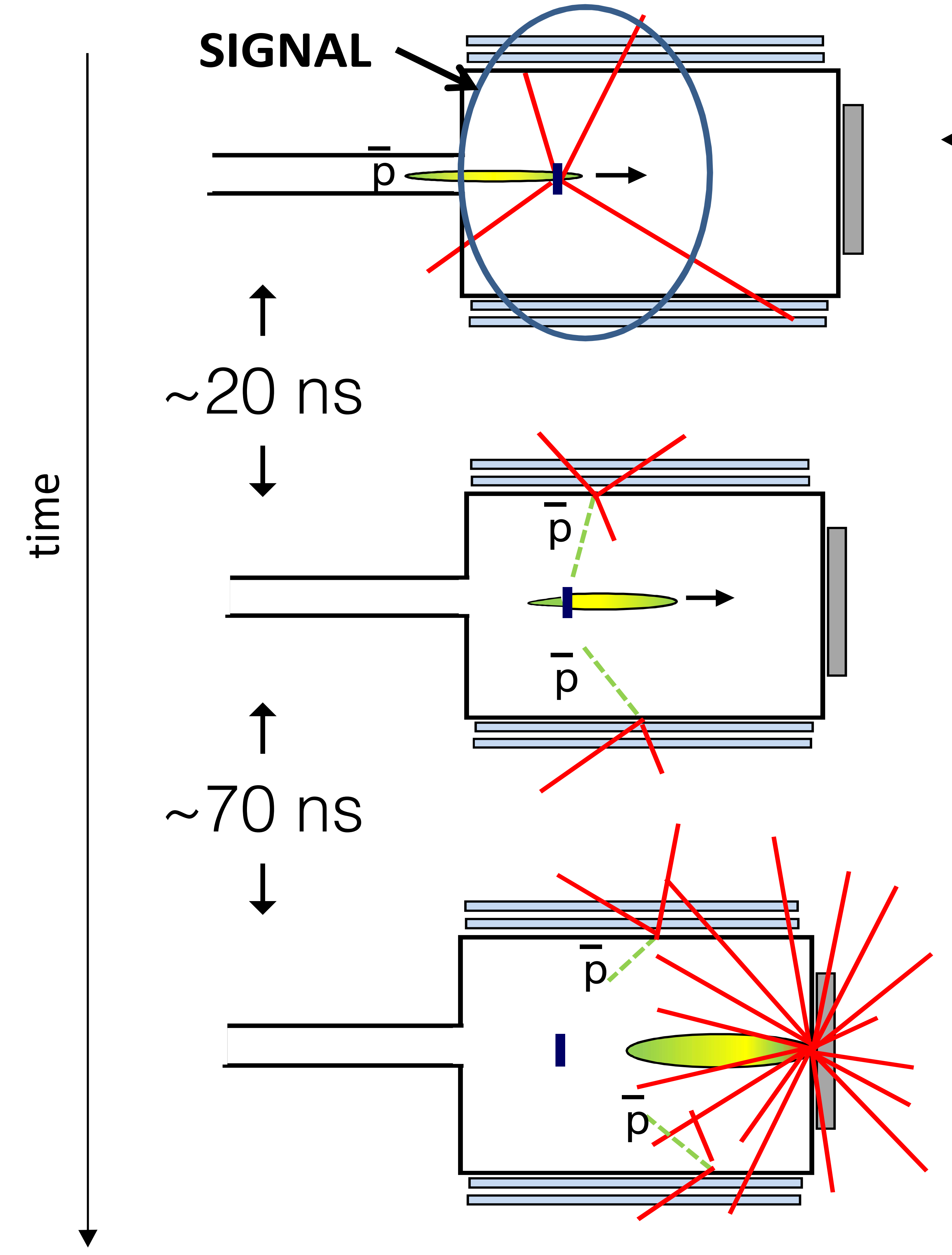
Existing data



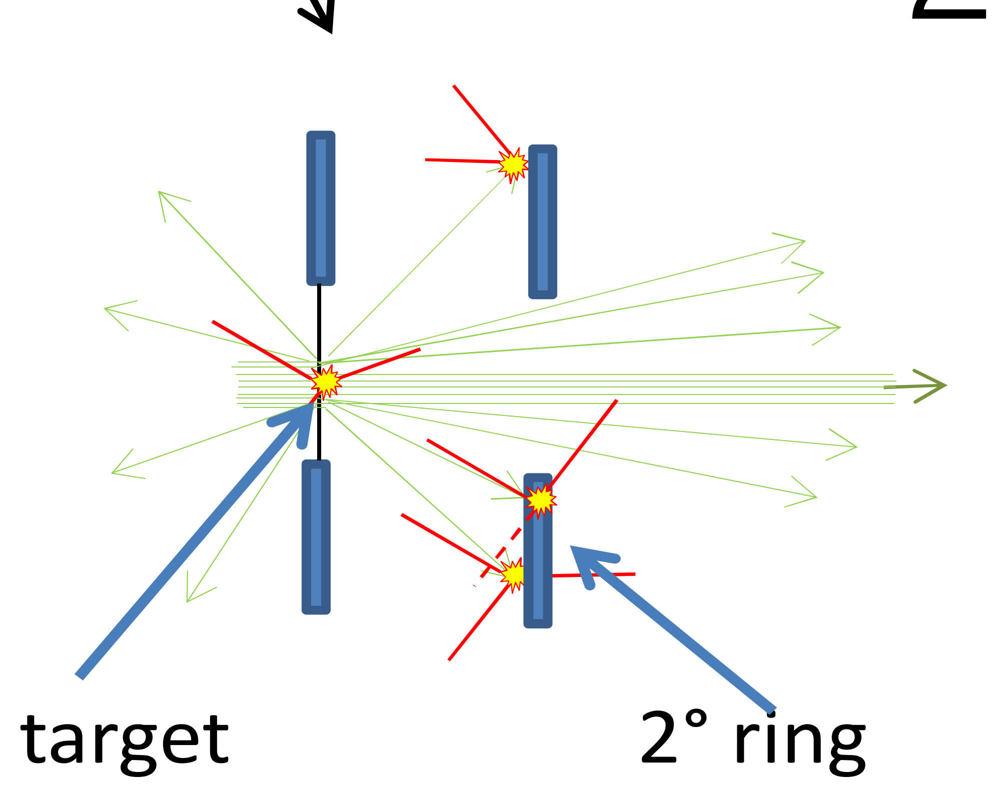


why $\bar{n}$ behaving like $\bar{p}$?
puzzling behavior at ~ 5 MeV

$\overline{p}$ on C at 5.3 MeV, σ precision <10%

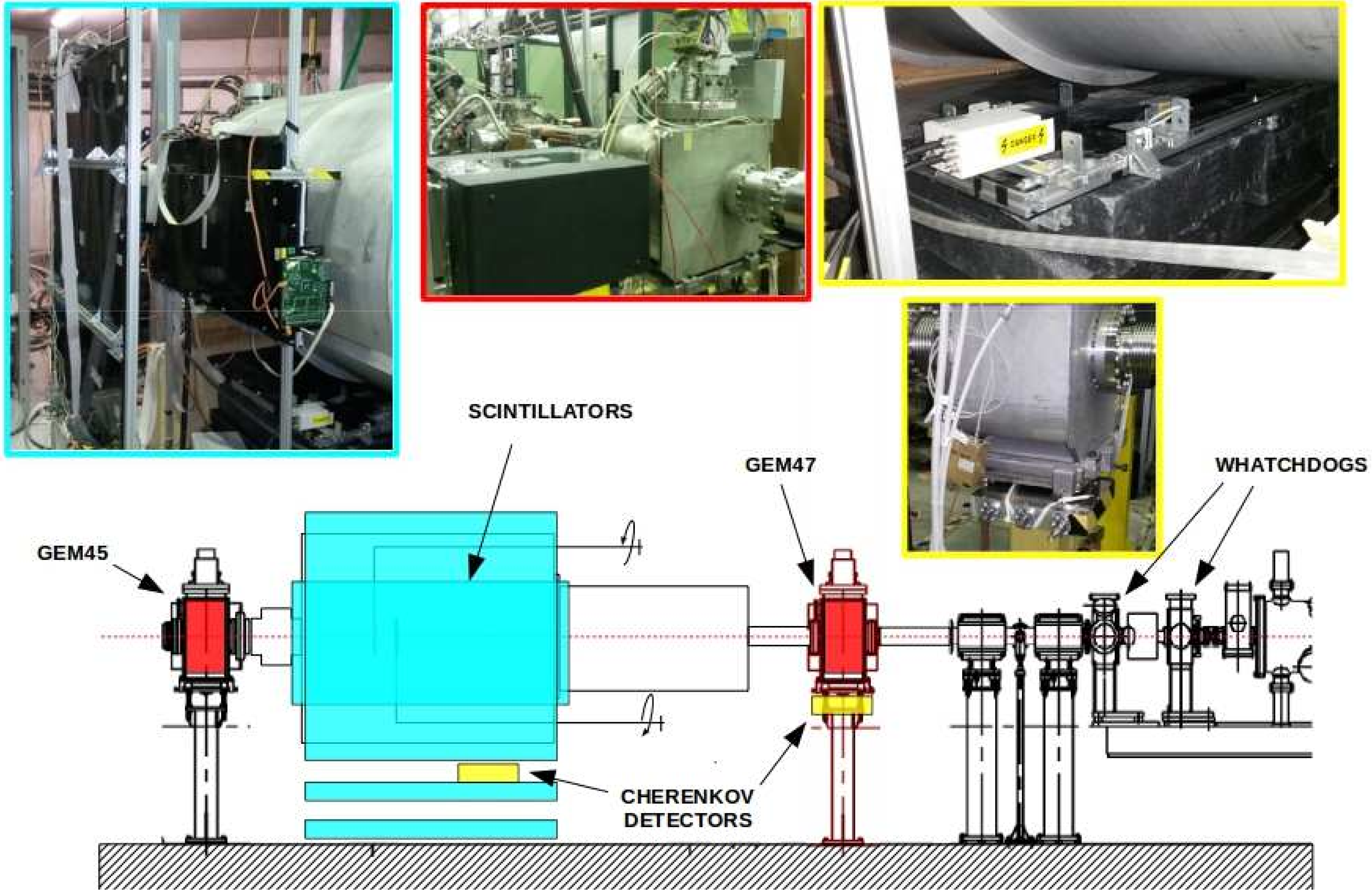


$$\sigma_{ann}(\overline{p}A) \propto \frac{N_{events}}{N_{beam}}$$



1. use timing to separate signal from background
2. use 2nd ring (Rutherford) to obtain absolute σ

σ_{ann} setup 2015 (5.3 MeV beam)



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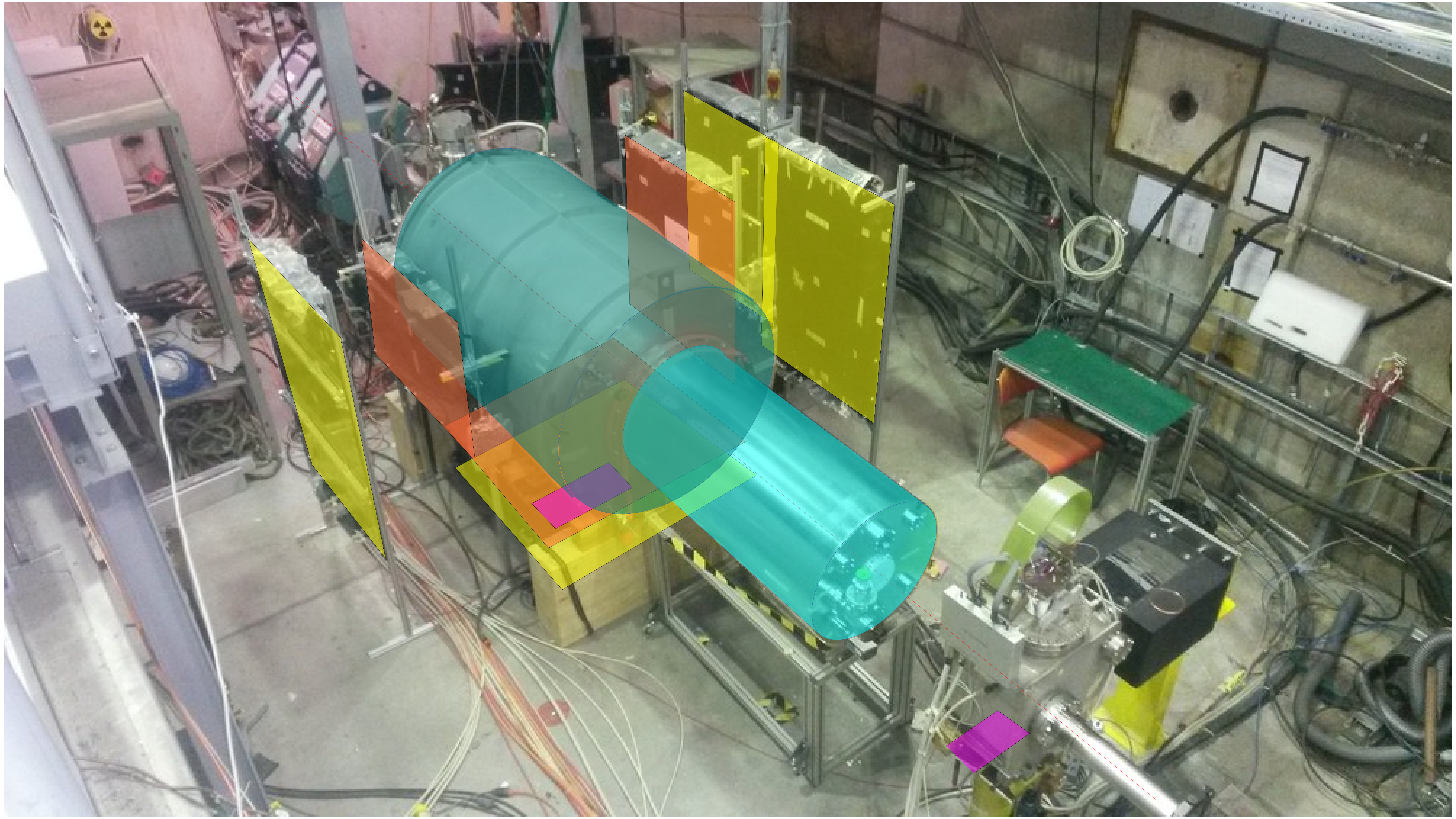
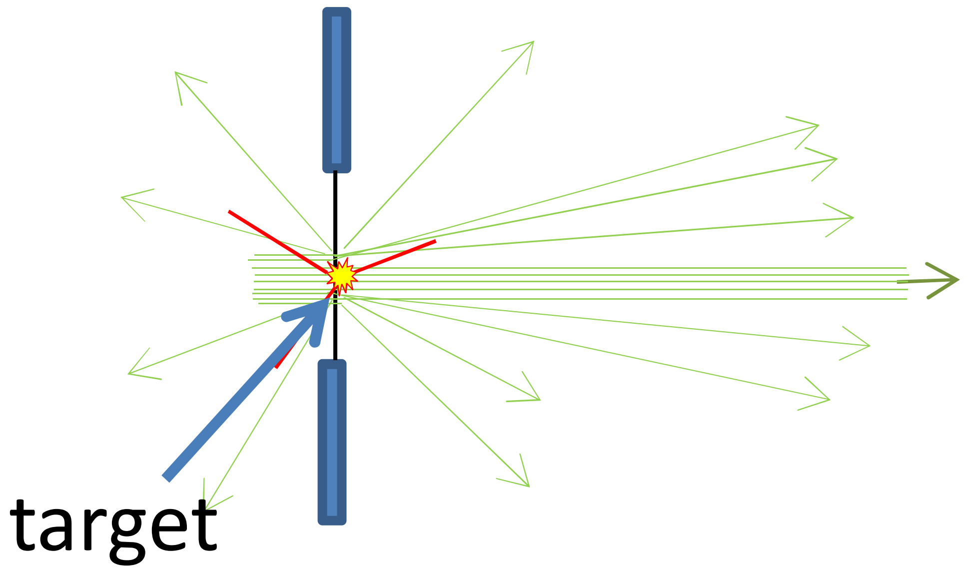
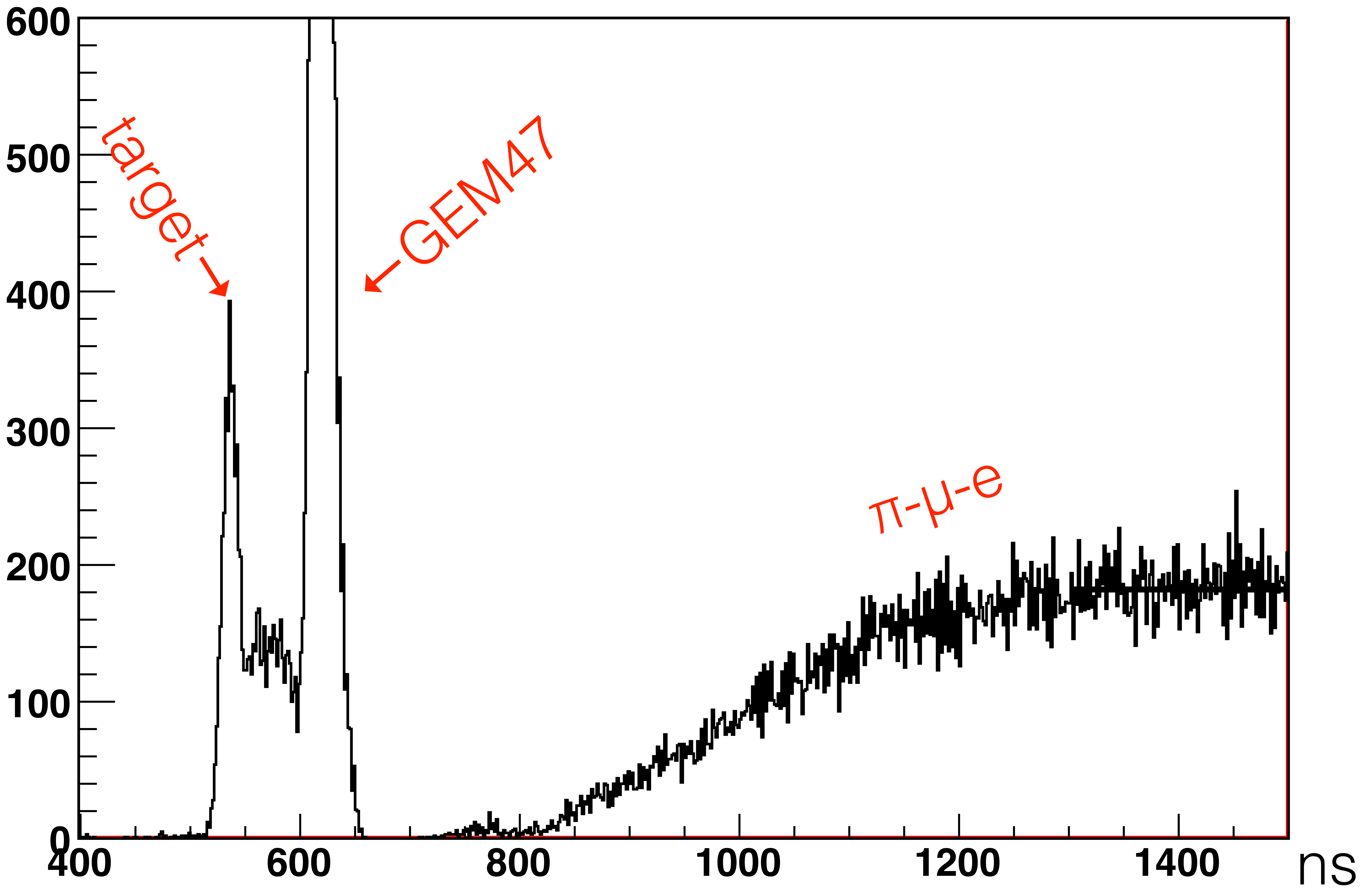
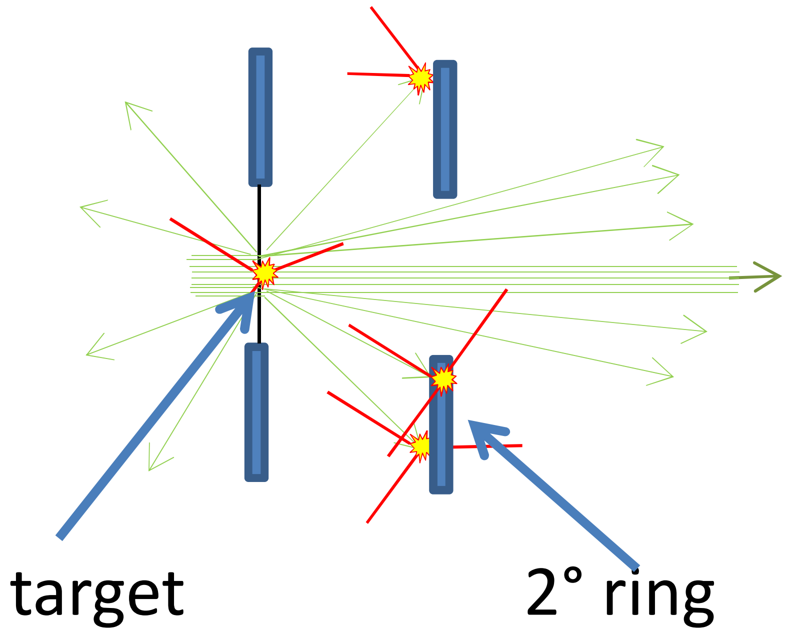


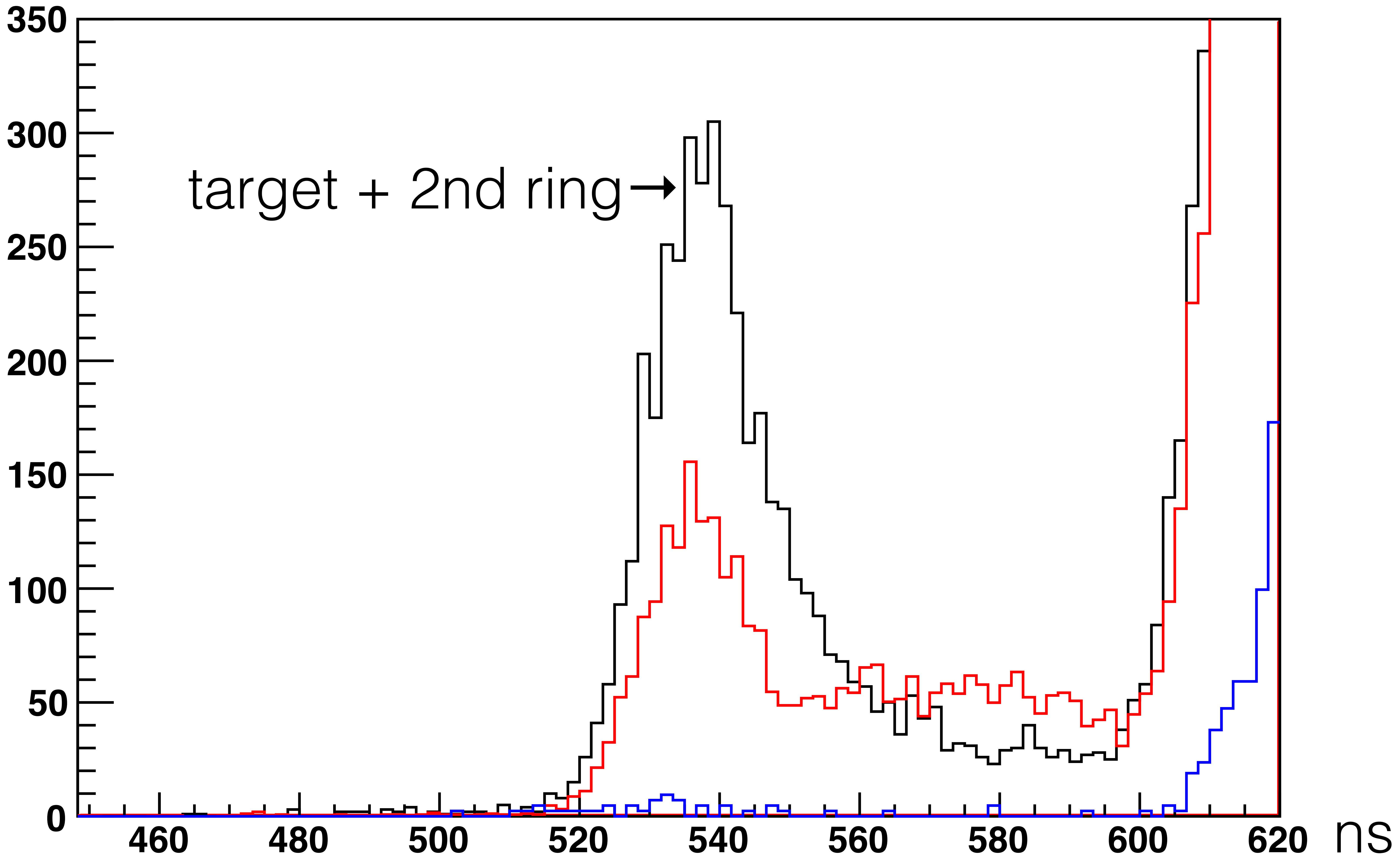
$\bar{p}$ annihilation time distribution





annihilation on the target clearly separated





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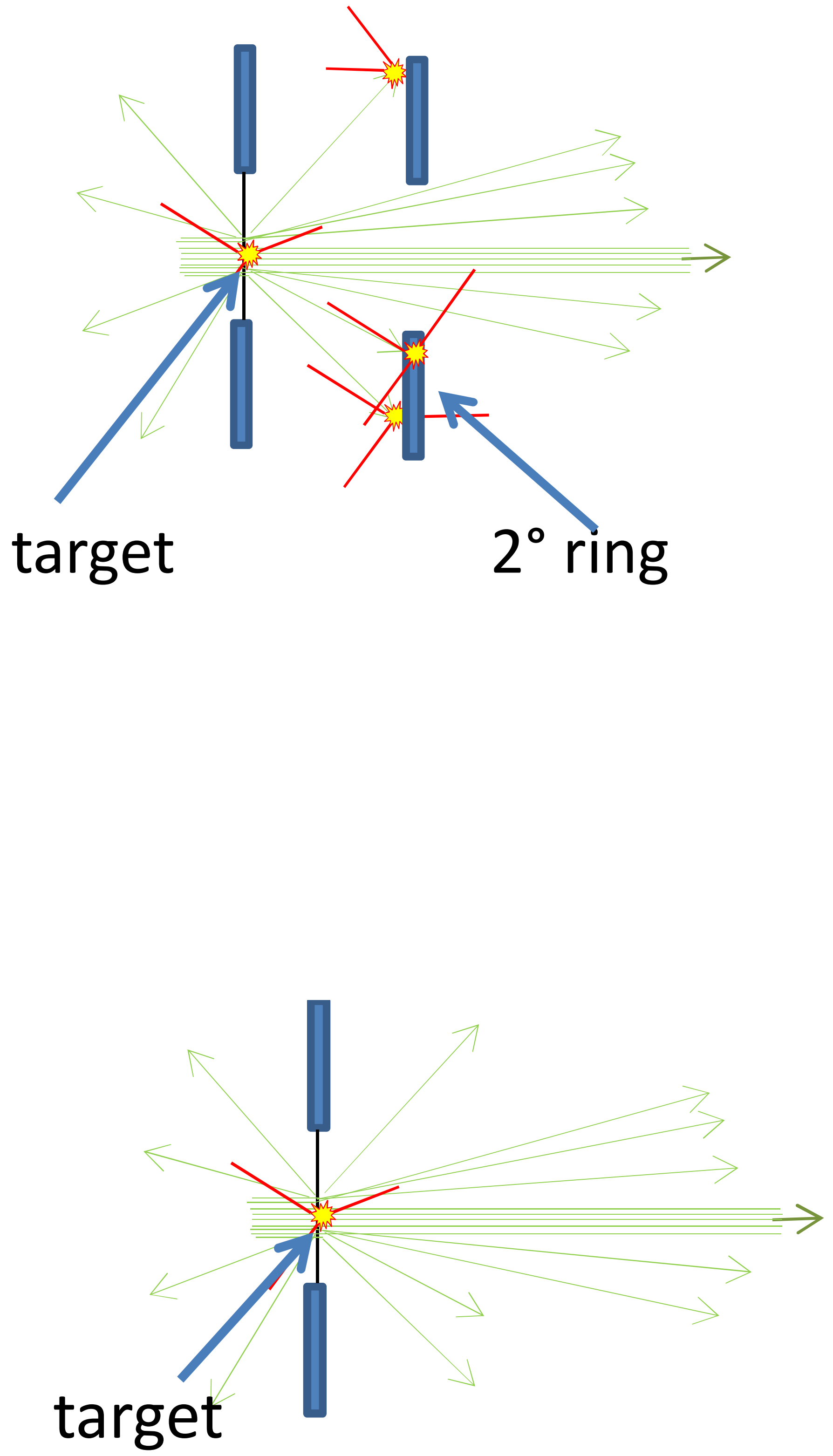
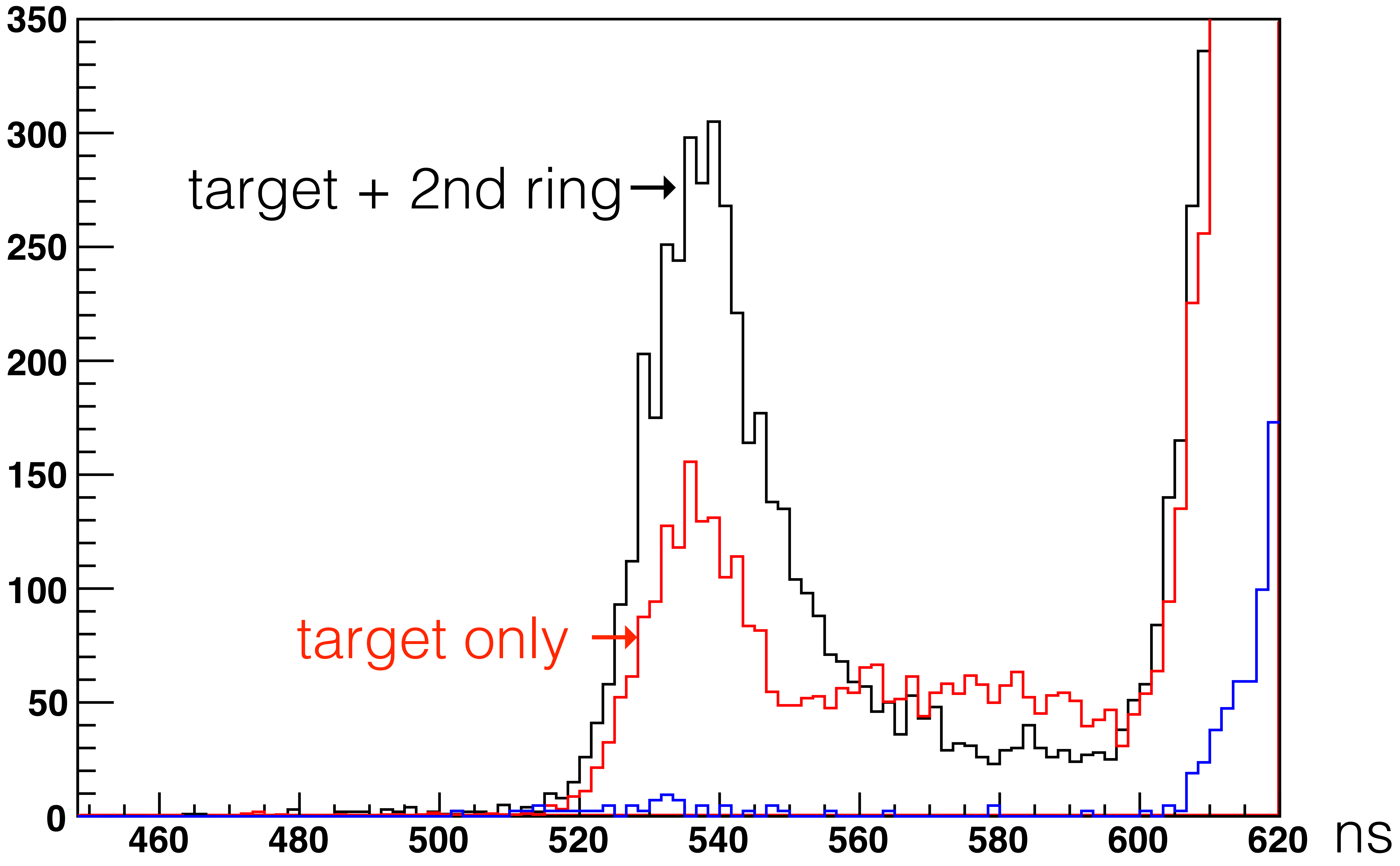
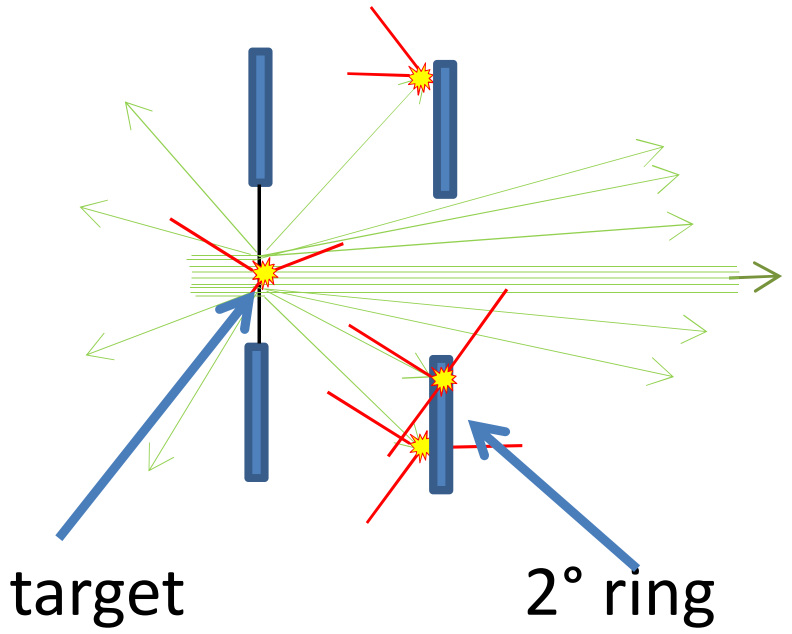
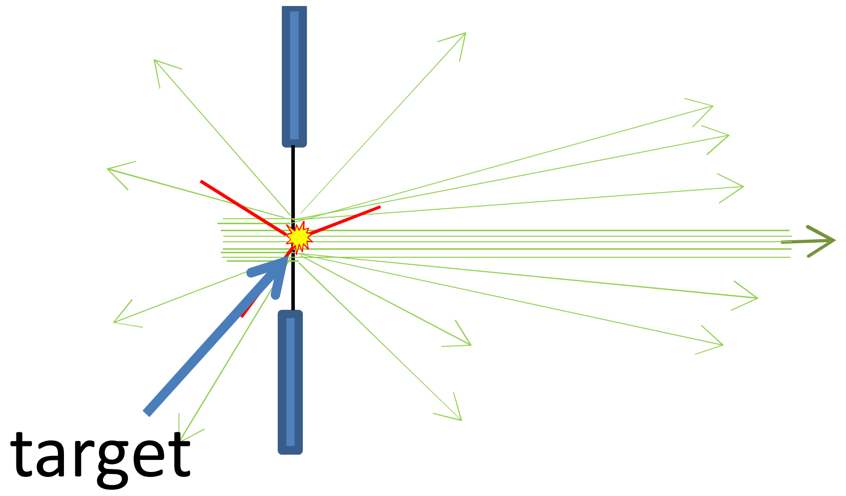
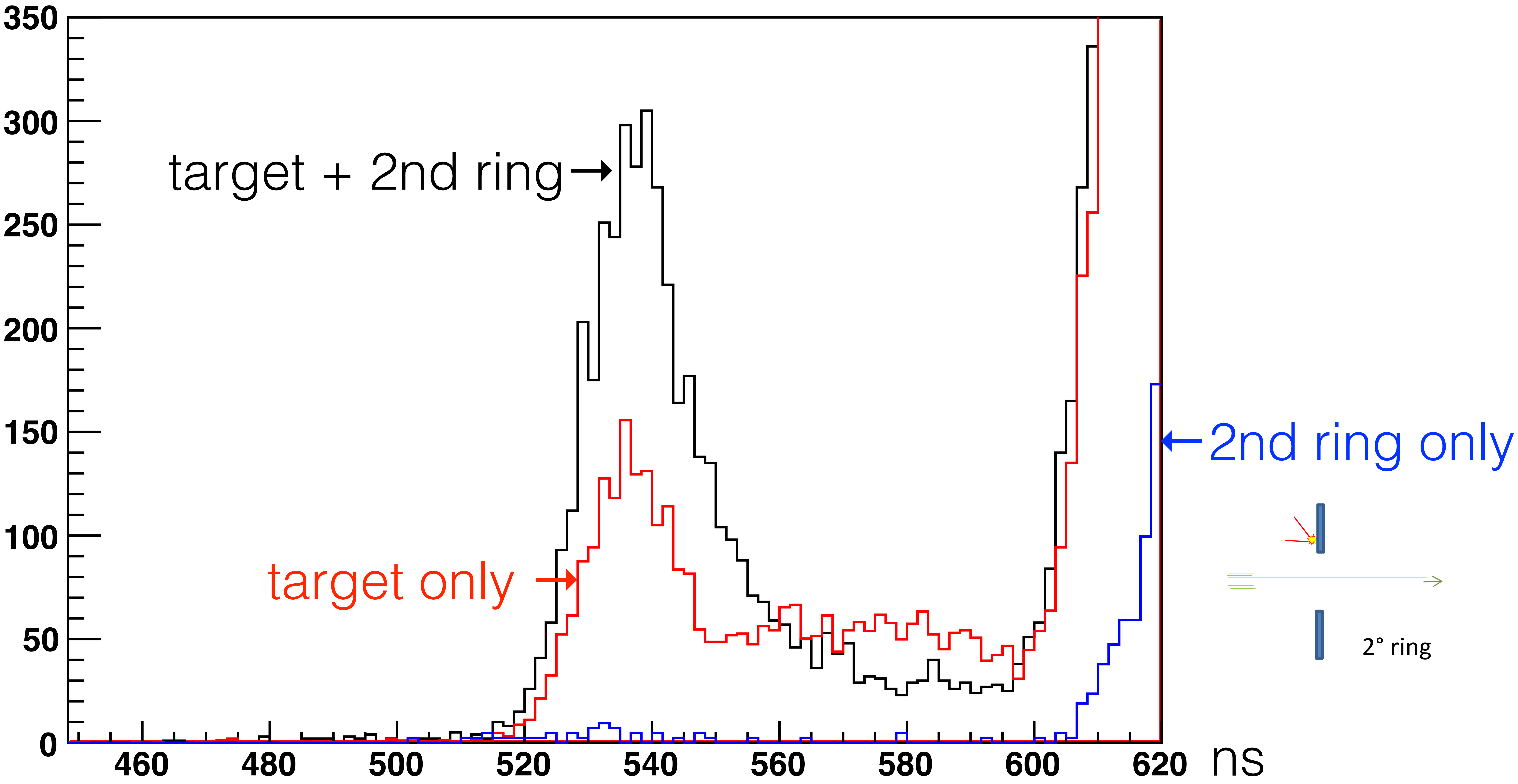




annihilation on the target clearly separated







$\overline{p}$ annihilation σ at 5.3 MeV, Summary

- Good data for $\overline{p}$-carbon annihilation at 5.3 MeV collected
  a benchmark to understand $\sigma_{ann}(E, A)$ at low energies

- The data are being analyzed
  we do not plan to use the $\overline{p}$ beam in 2016.

Conclusions

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  - continuation of two-photon laser spectroscopy of $\bar{p}$He