AEḡIS/AD-6
Antihydrogen experiment:
Gravity, Interferometry and Spectroscopy

Status report for 2020

Michael Doser / CERN
on behalf of the AEḡIS collaboration

AEḡIS collaboration

INFN

INRNR

POLITECNICO MILANO

TIFPA Trento Institute for Fundamental Physics and Applications

UNIVERSITÀ DI TRENTO

PAUL SCHERRER INSTITUT PSI

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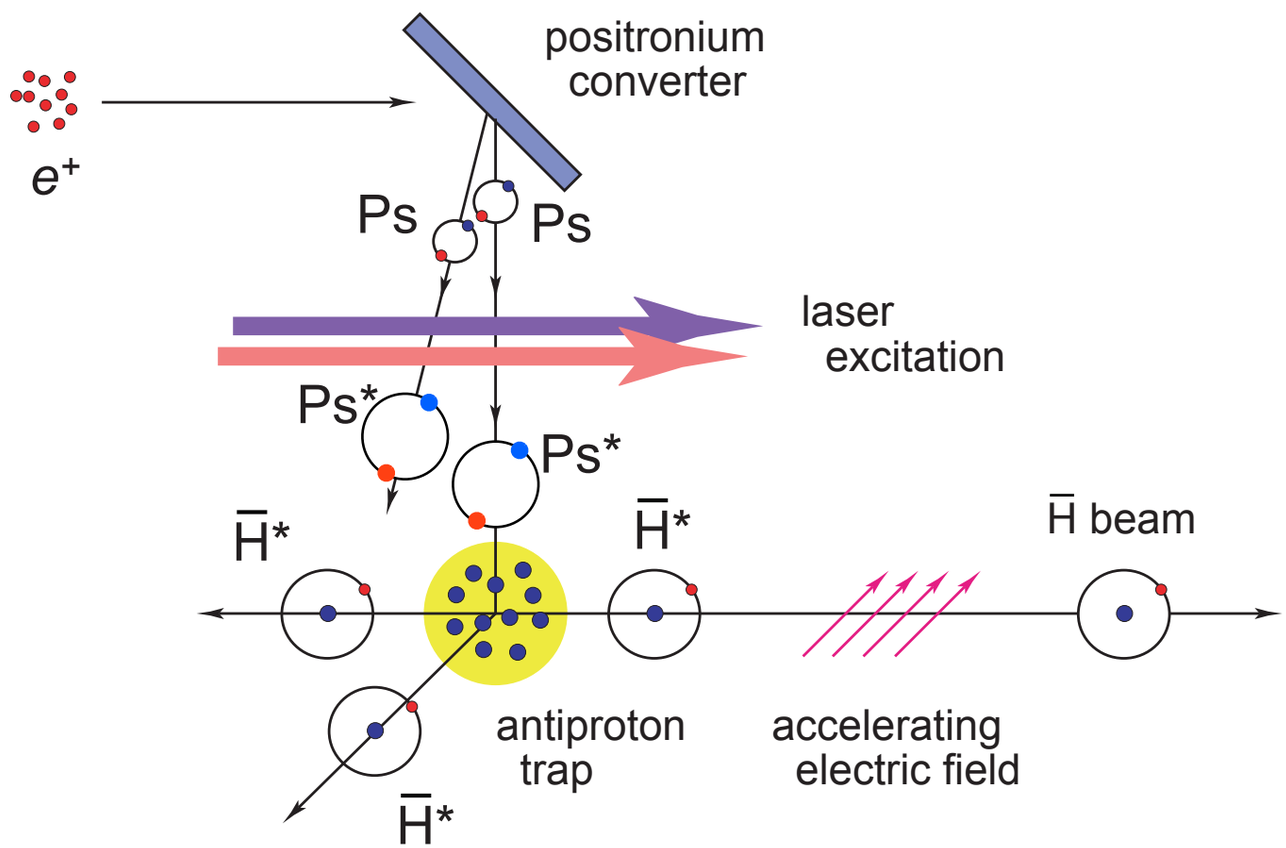
UNIWERSYTET WARSZAWSKI

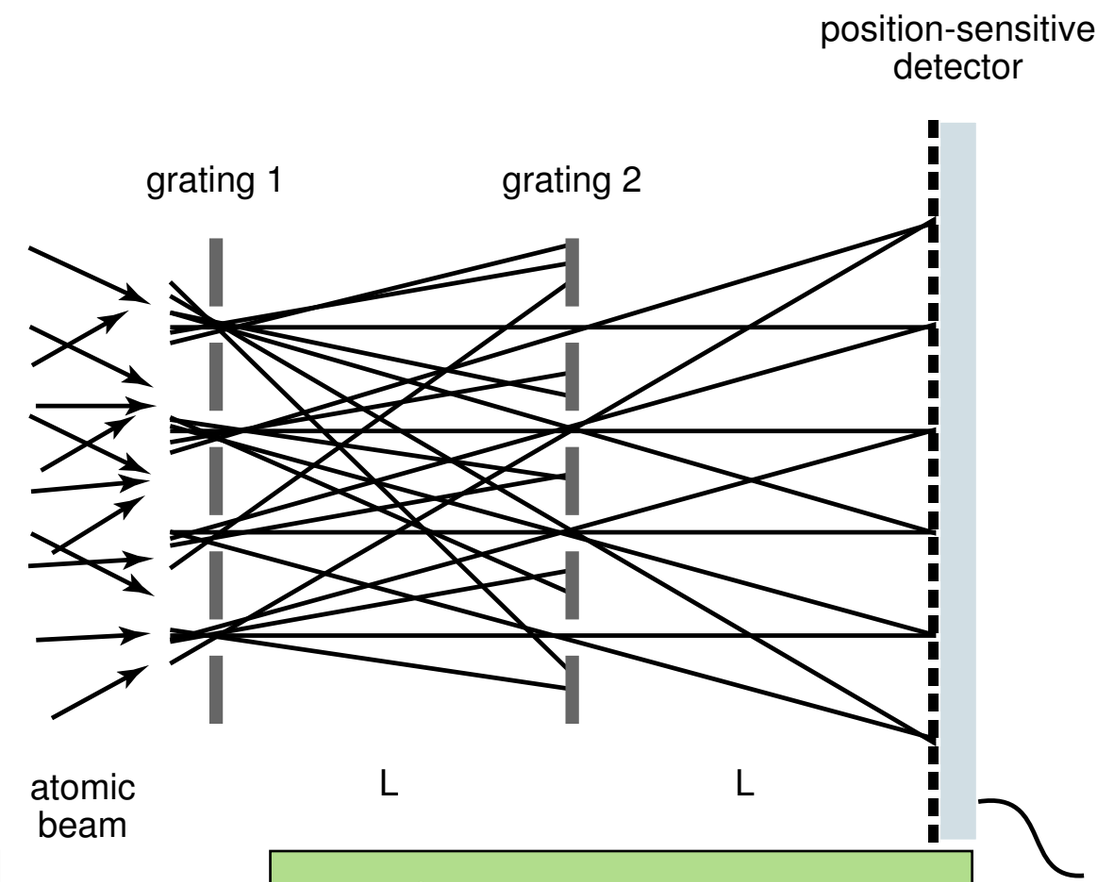
RRI

Overview of experimental approach:

Schematic overview

$$Ps^* + \bar{p} \rightarrow \bar{H} + e^-$$





pulsed production

beam formation

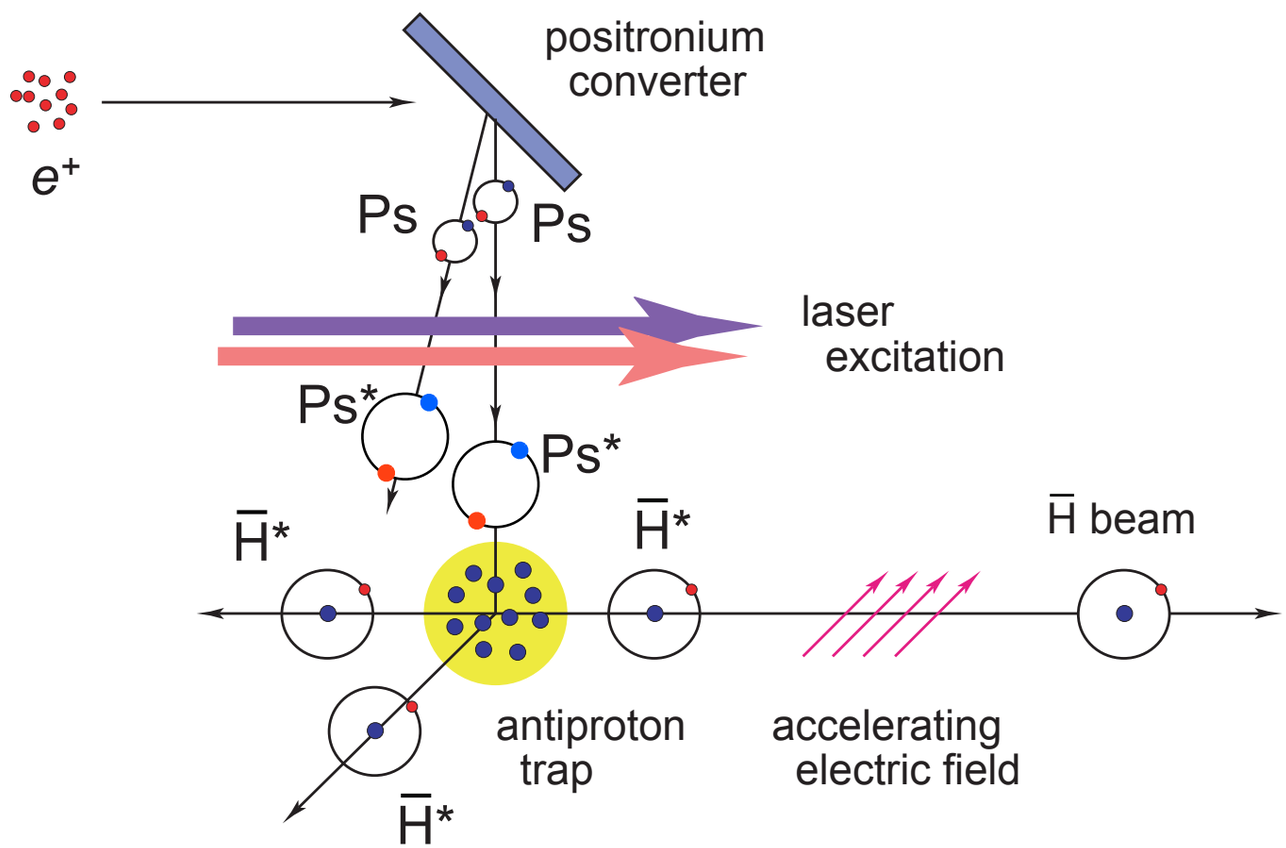
gravity measurement

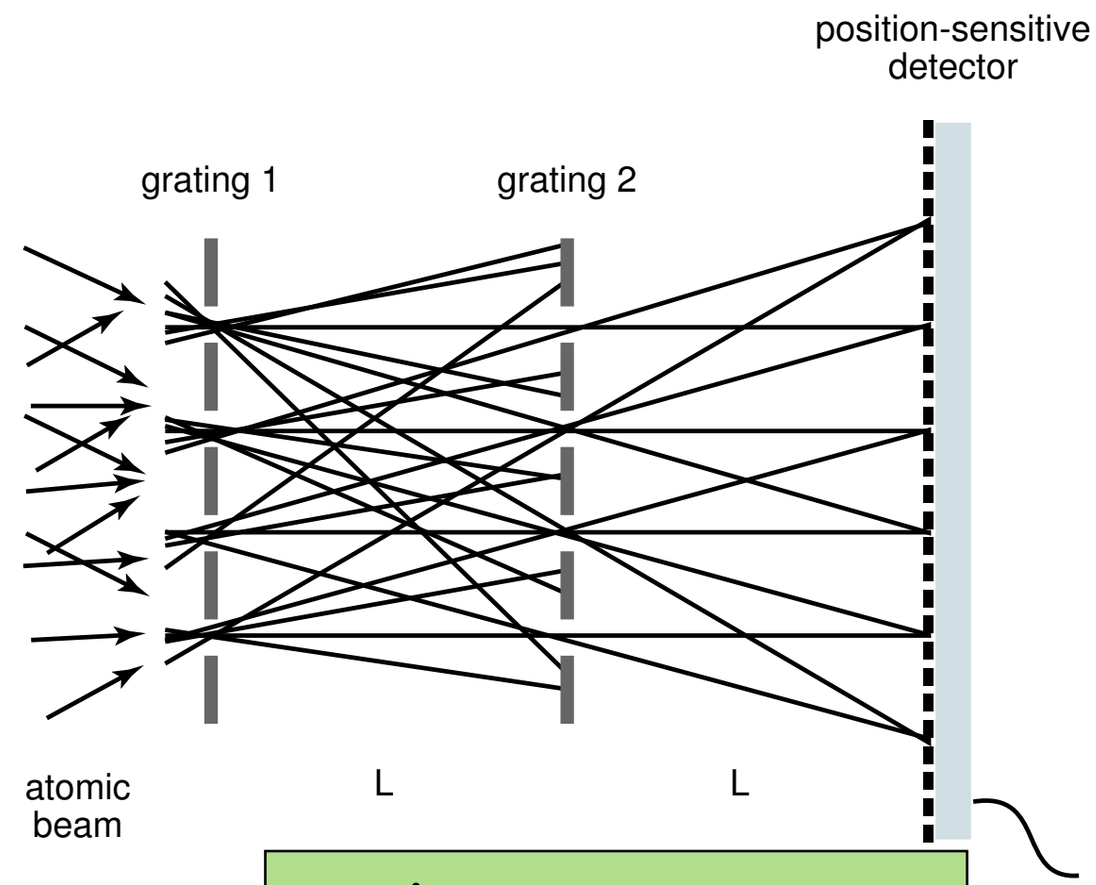
Physics goals: measurement of the gravitational interaction between matter and antimatter, spectroscopy, ...

Overview of experimental approach:

Schematic overview

$Ps^* + \bar{p} \rightarrow \bar{H} + e^-$





pulsed production

beam formation

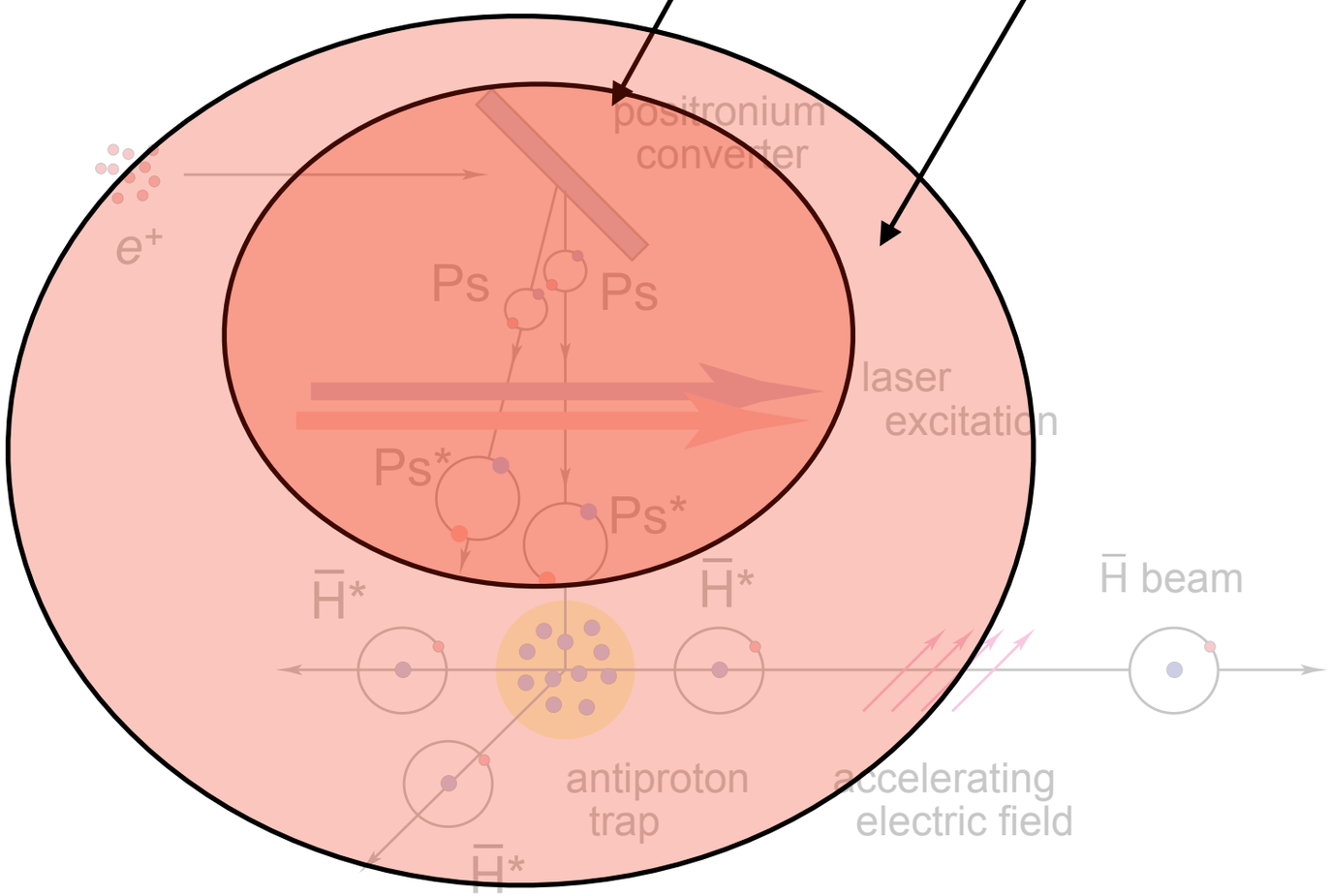
gravity measurement

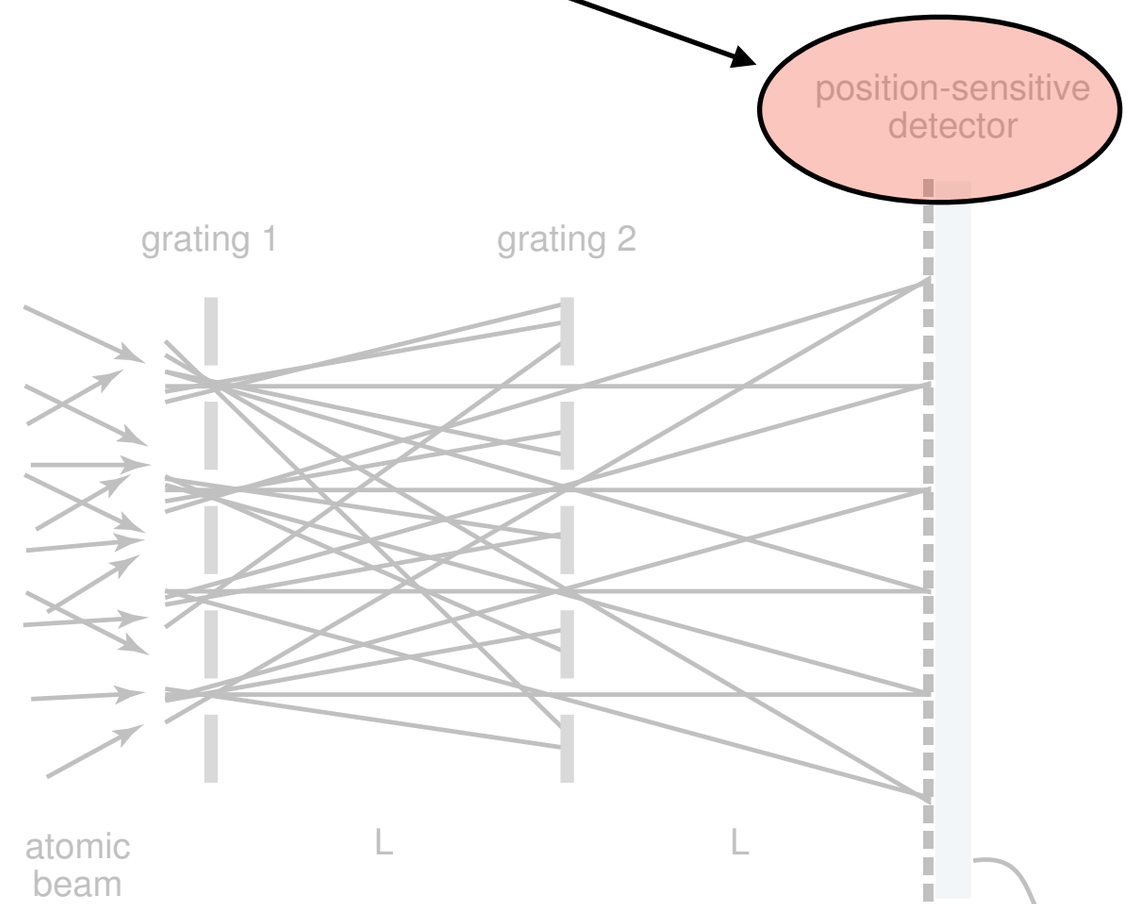
<u>Technical steps</u>: cold $\bar{p}$; pulsed Ps and Ps* formation ; pulsed production of $\bar{H}$; beam formation ; deflectometer

Program for 2020: Ps & upgrades

Schematic overview

$Ps^* + \bar{p} \rightarrow \bar{H} + e^-$





pulsed production

beam formation

gravity measurement

<u>Technical steps</u>: cold $\bar{p}$; pulsed Ps and Ps* formation ; pulsed production of $\bar{H}$; beam formation ; deflectometer

Program for 2020: Ps & upgrades

1) Ps: work towards laser-cooling of Ps

a)
- optimization of the Ps source and laser system
- first Doppler-free saturated absorption spectroscopy of Ps on 1^3S-3^3P
- concurrent Ps laser excitation / probing

b) position-sensitive detector: for Ps studies (but also for $\bar{H}$)

2) Upgrades:

zone layout:

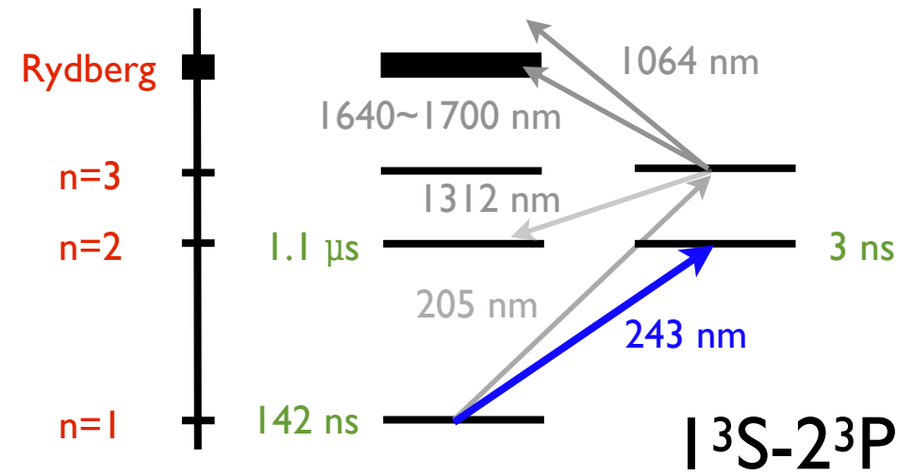
$\bar{H}$ formation region:

adapting to ELENA:

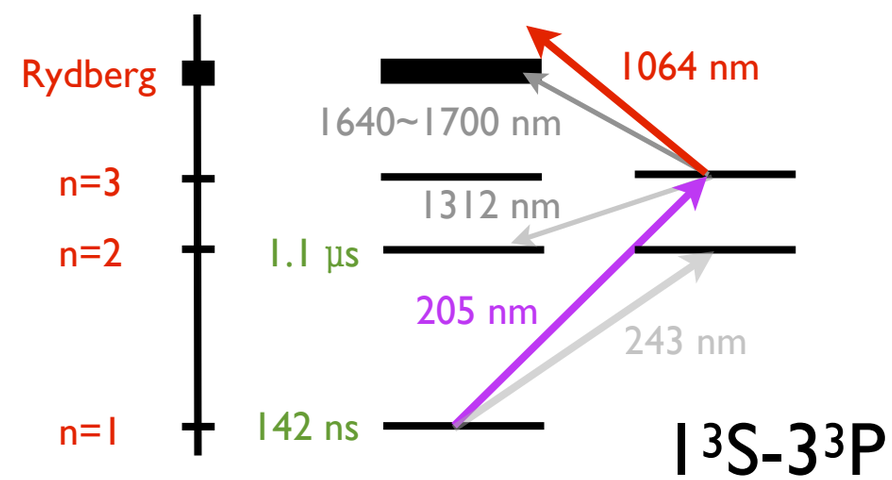
towards laser-cooling of Ps

two independent laser systems are available → combine them!

1 interact laser pulse @ 243 nm (pulse length currently 24 ns; with another laser being prepared, can extend to 100 ns)



2 after cooling, Ps Doppler-profile to extract velocity distributions (transverse, longitudinal)



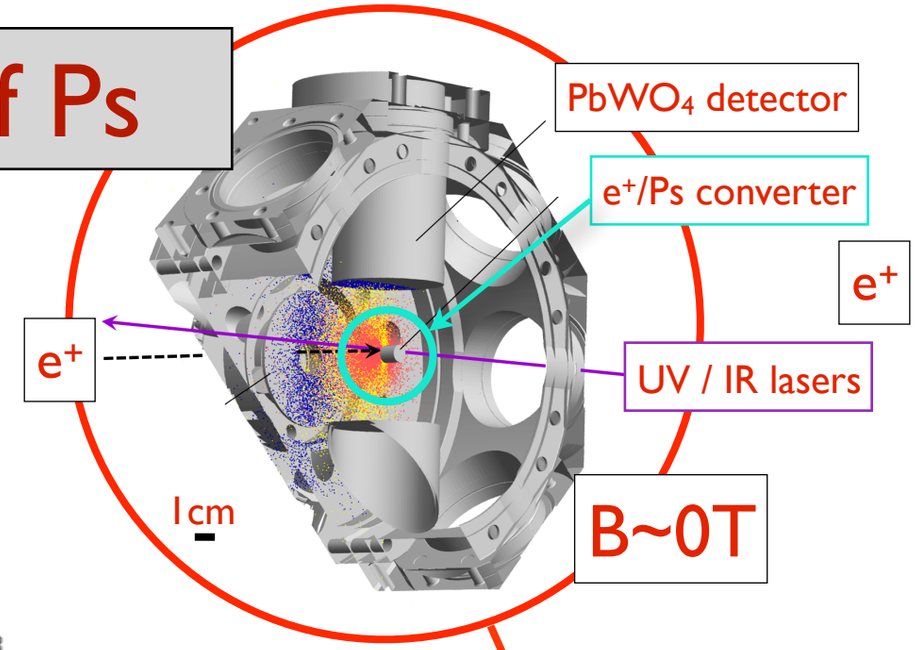
first however: establish a Doppler-sensitive detection method

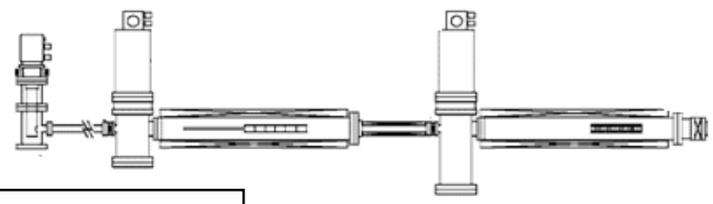
in parallel: develop kinetic MC for Ps in E,B,laser fields

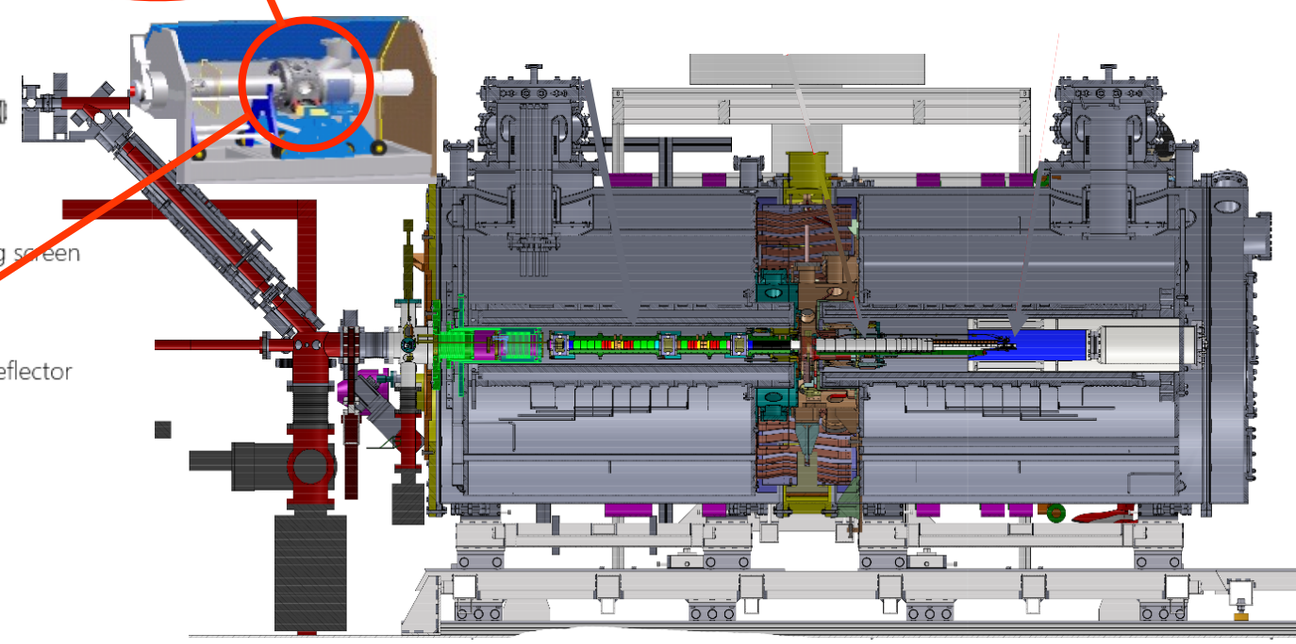
towards laser-cooling of Ps

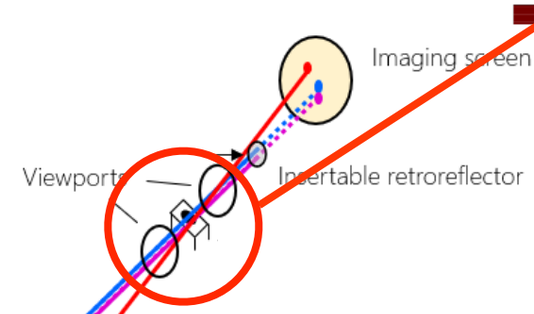
σ_{205nm} = (110 ± 30) GHz

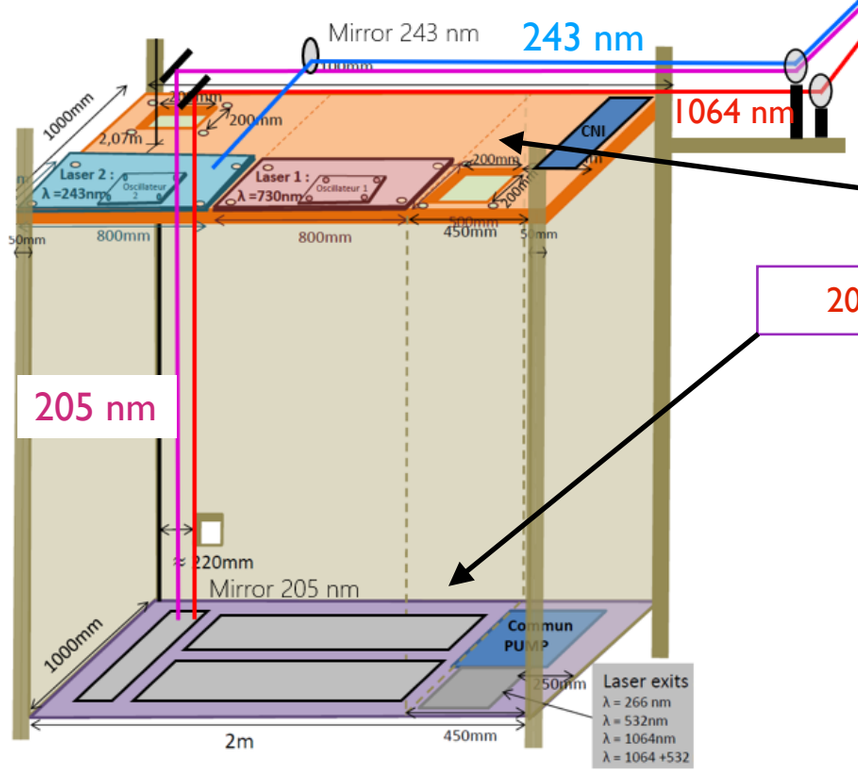
σ_{243nm} = (55 ± 13) GHz

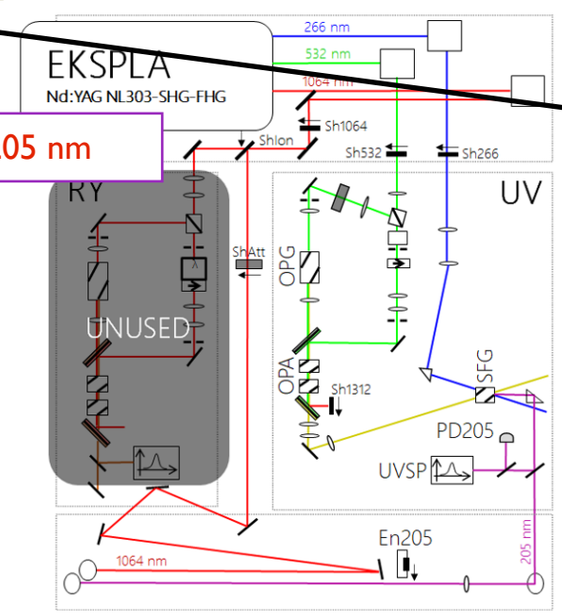


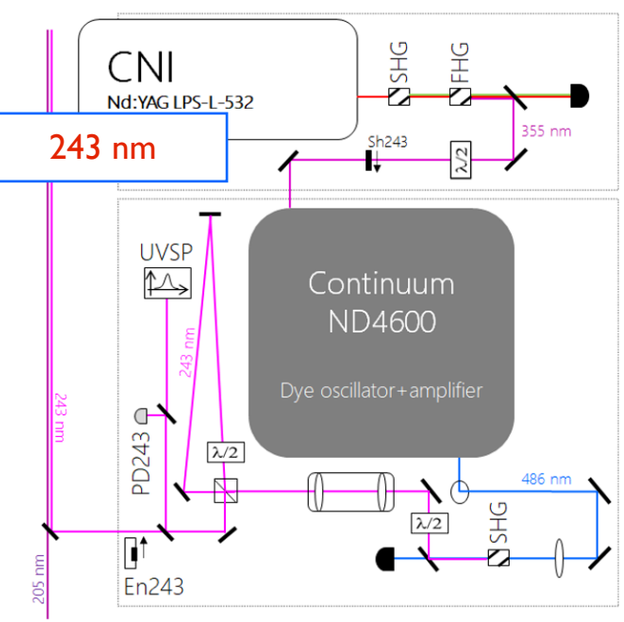












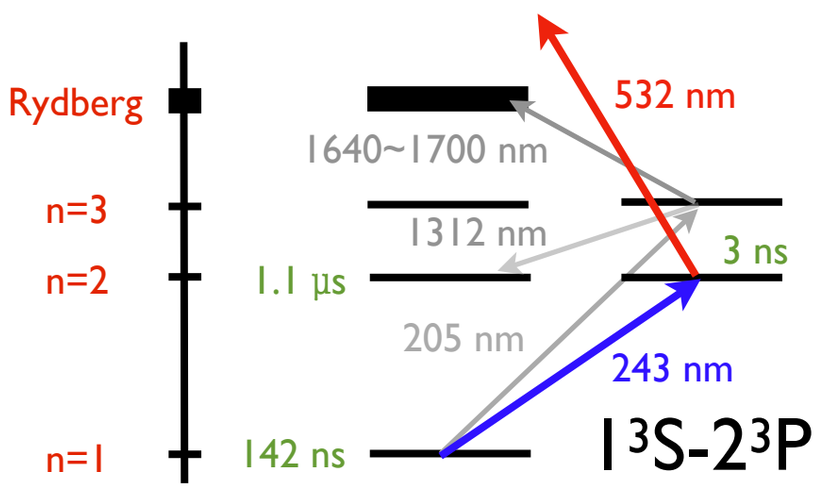
first however: establish a Doppler-sensitive detection method

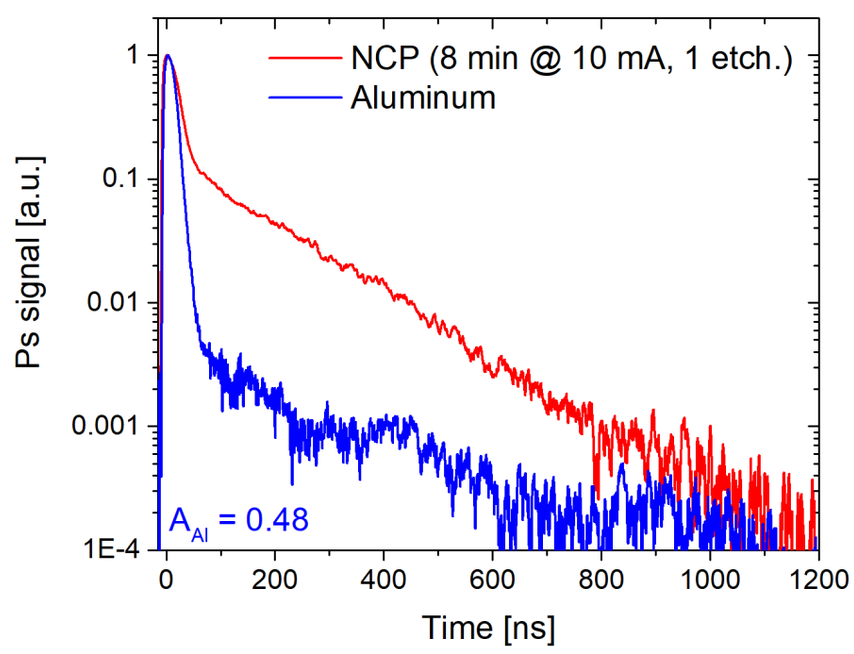
many improvements to the laser system (concurrent burst mode, independent control of timing & detuning, calibration to << 10 pm) and to the Ps target (optimized procedure for maximal yield - 40% - and Ps thermalization - 300 K)

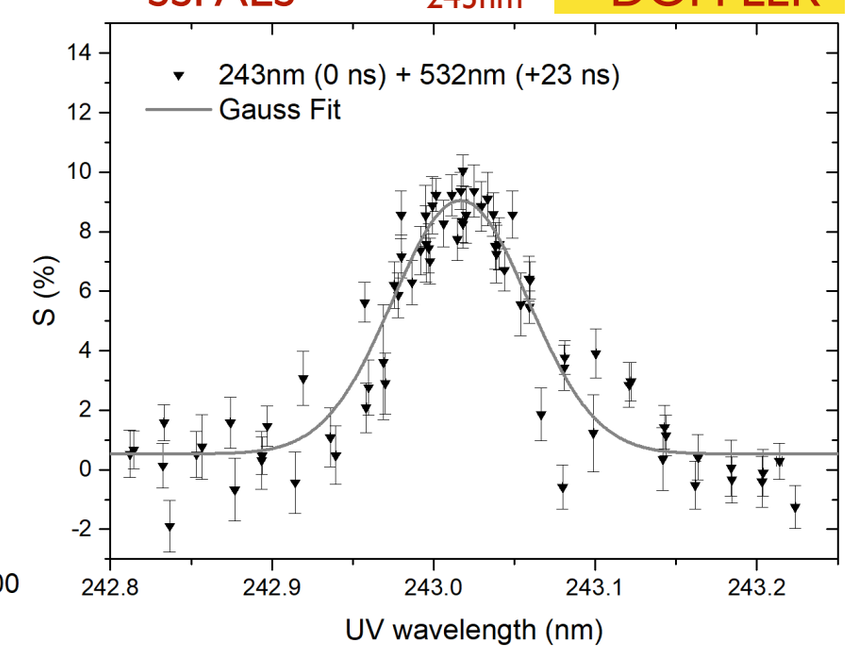
characterization of the transverse velocity distribution of Ps by SSPALS

reduction of 1^3S Ps annihilation rate (λ_{243})

$\sigma_{SSPALS} = \sigma_{243nm} \otimes \sigma_{DOPPLER}$







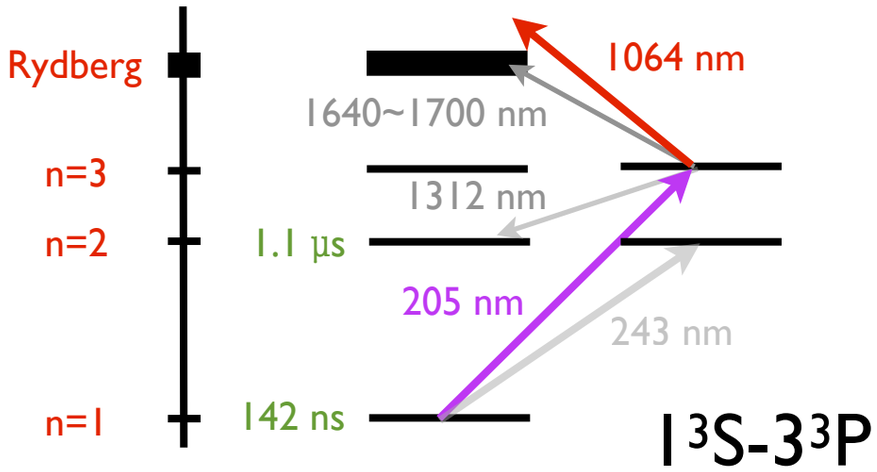
$\sigma_{243nm} = (55 \pm 13)$ GHz

Yield = 40%

$\sigma_{DOPPLER} = (39.6 \pm 2.8)$ pm

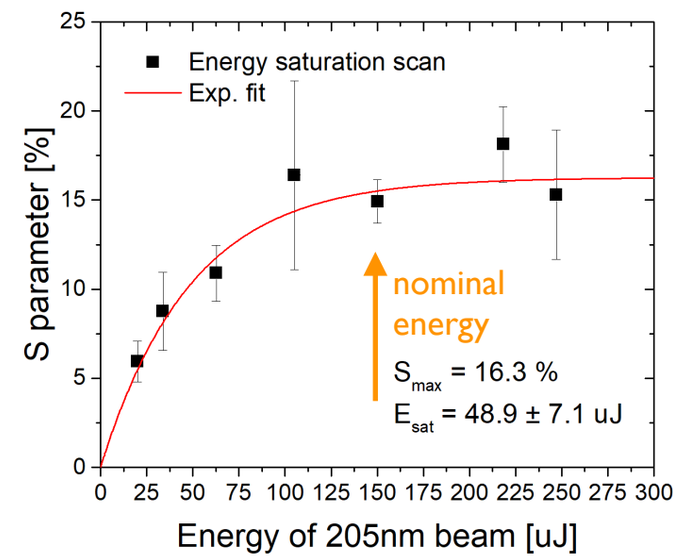
$T_{Ps} = (291 \pm 46)$ K

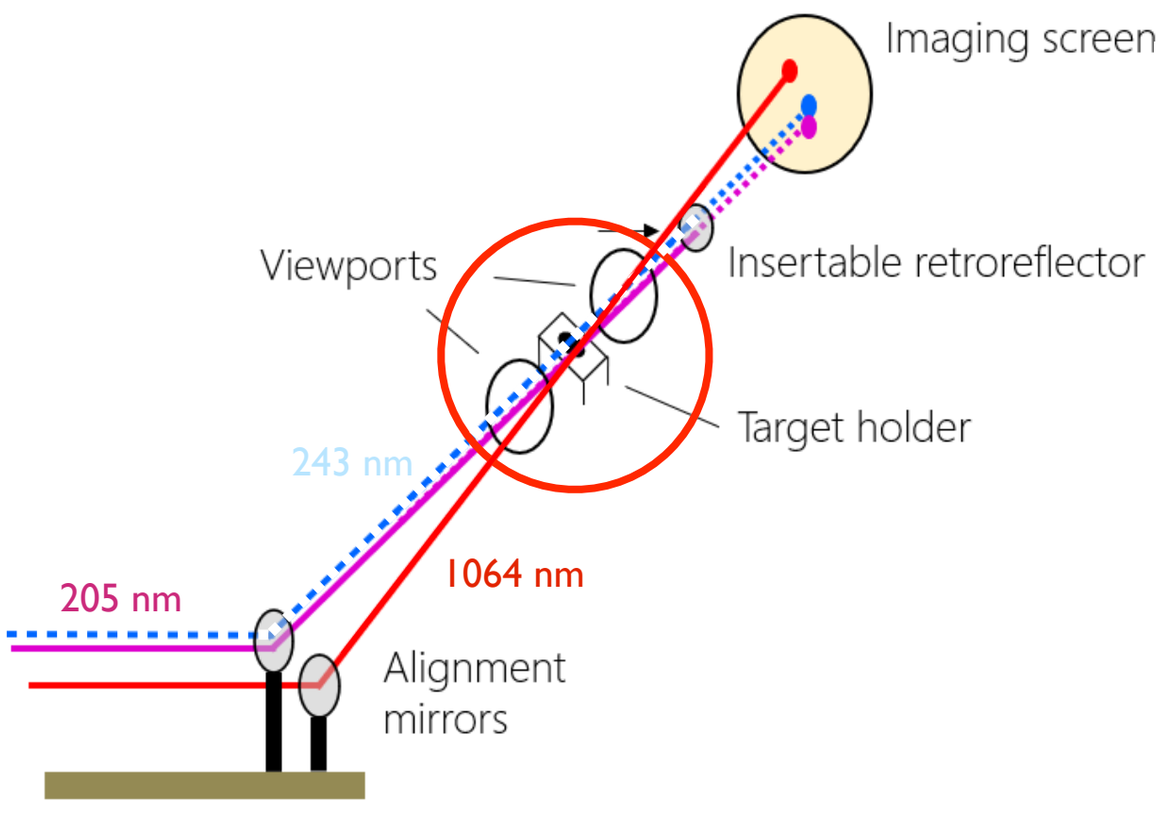
first Doppler-free spectroscopy of the Ps 1^3S-3^3P transition

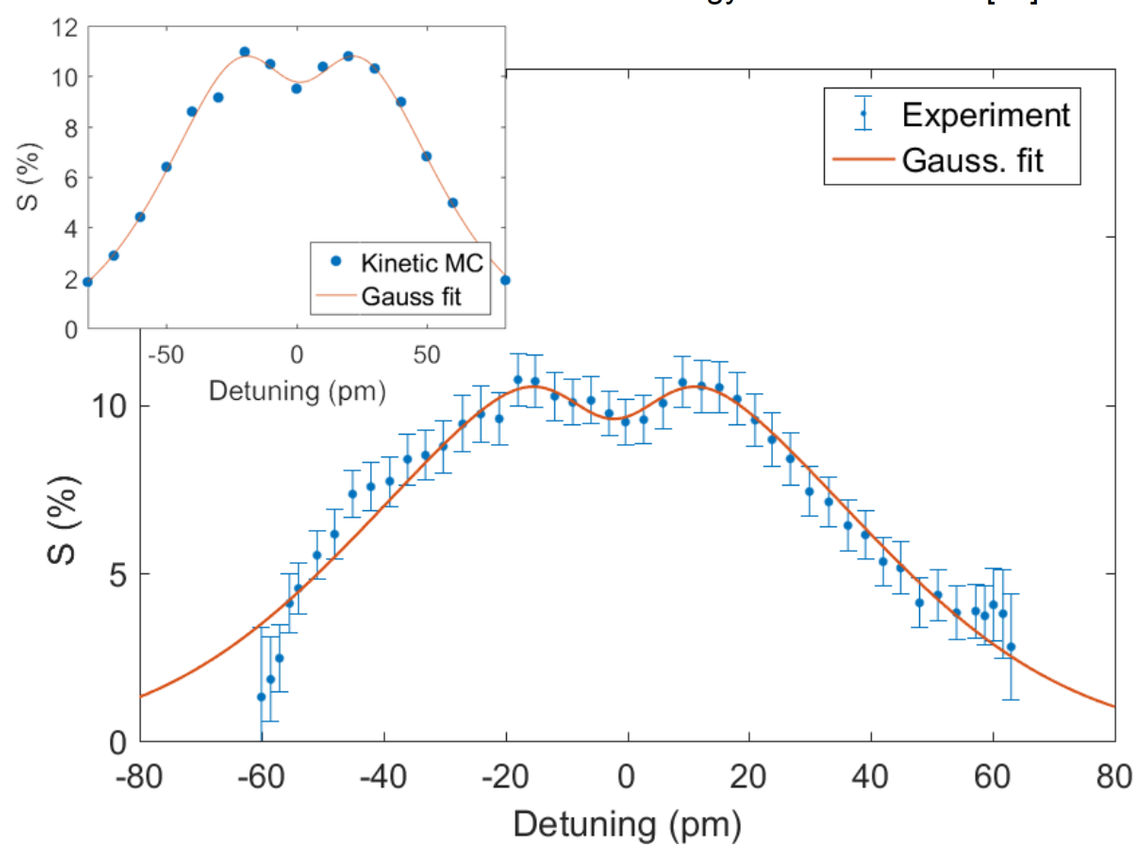


σ_{205nm}= (110 ± 30) GHz

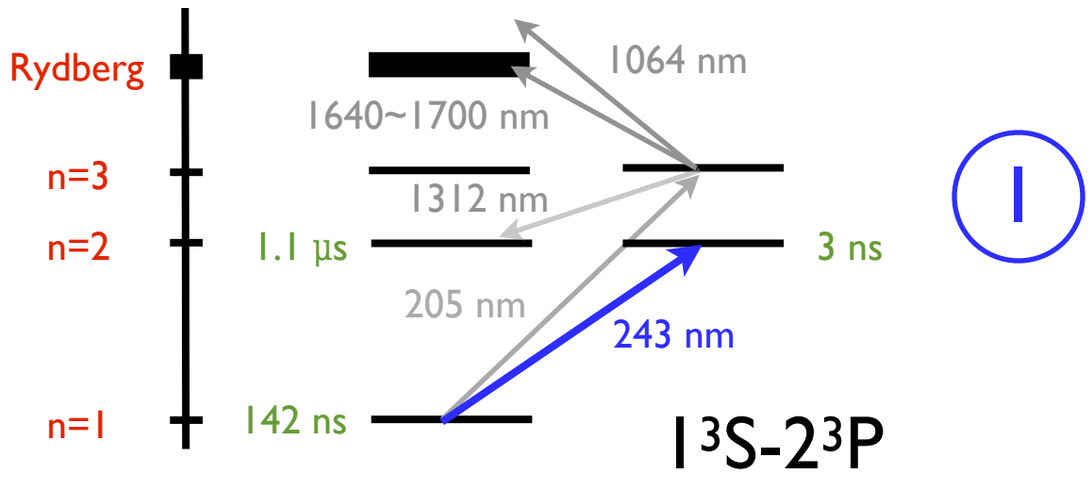
relies on counter-propagating 205 nm beams and saturation spectroscopy → Lamb dip

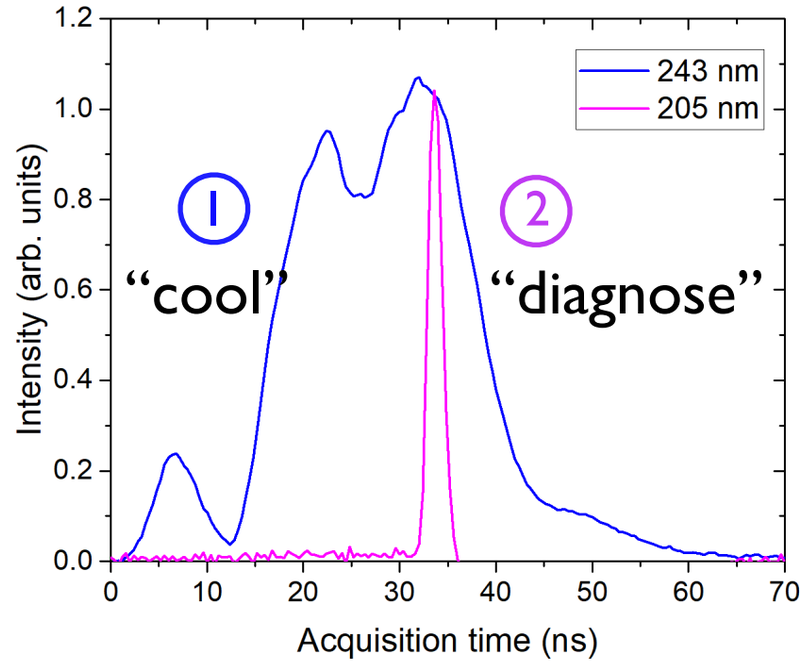


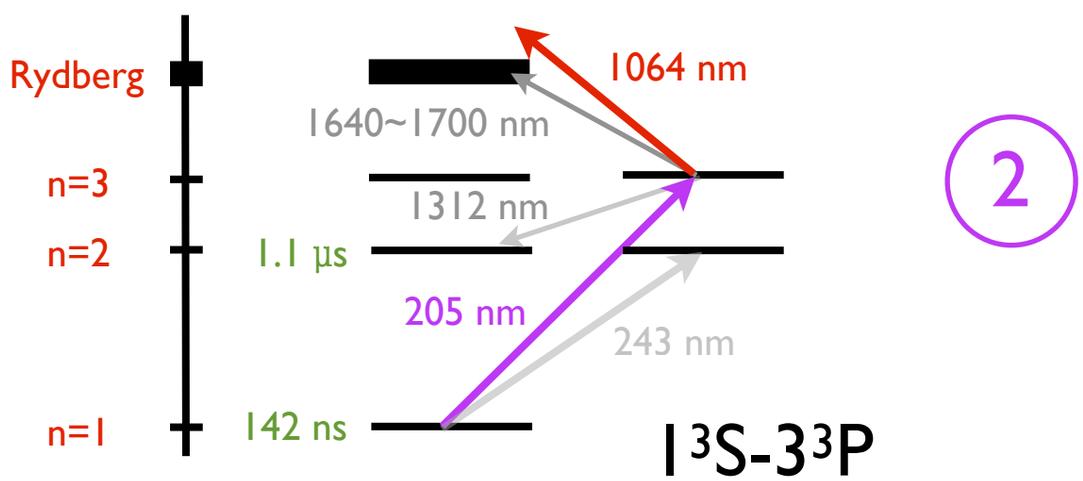


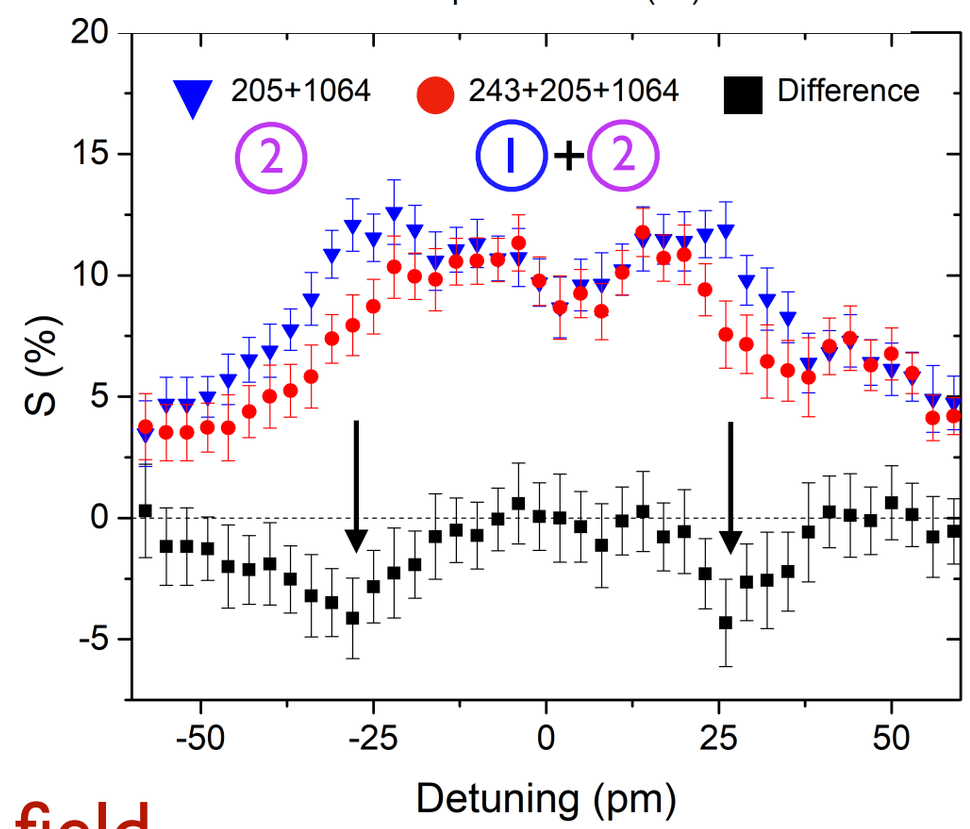


concurrent Ps 1^3S-2^3P and 1^3S-3^3P laser excitation: towards Ps laser cooling





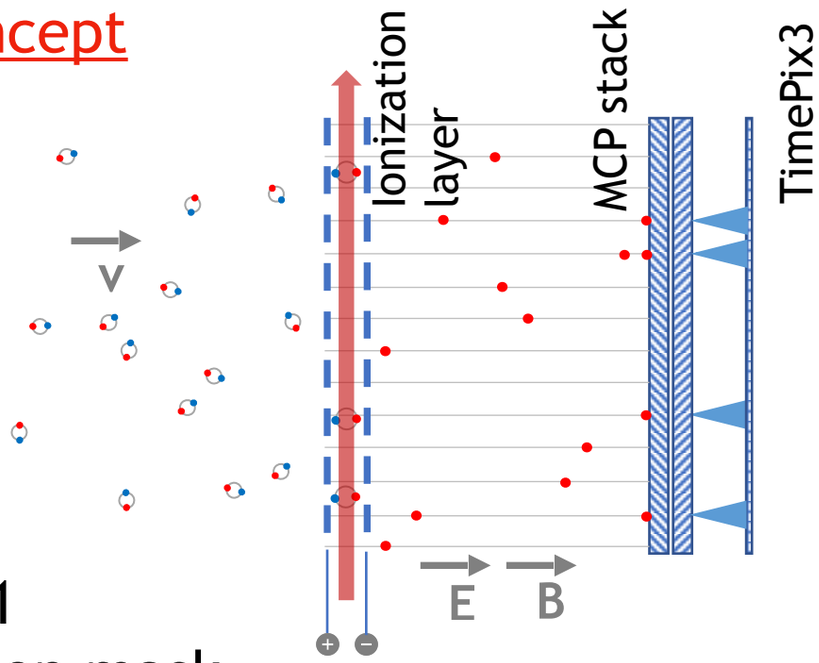




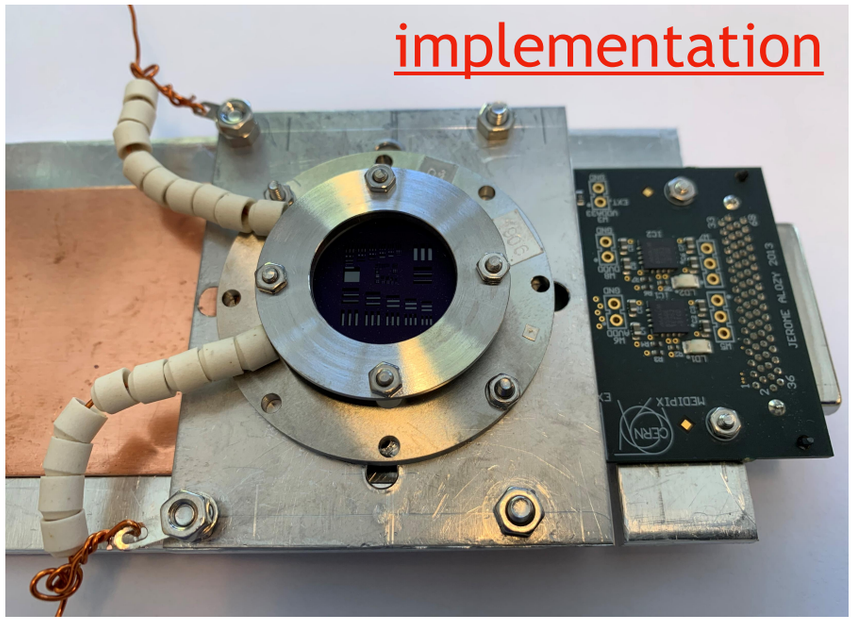
dips: magnetic quenching during 1 ;
still need to address 180 G e^+ transport field
before Ps laser cooling can be established

high-resolution position-sensitive detector for $\bar{H}$ / Ps

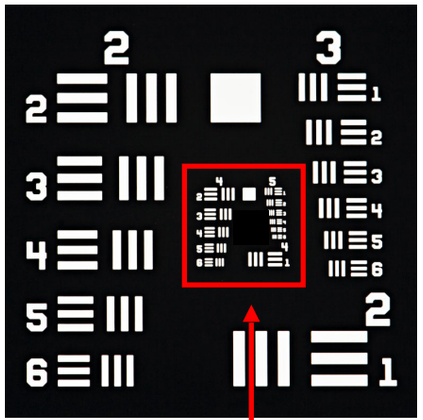
concept



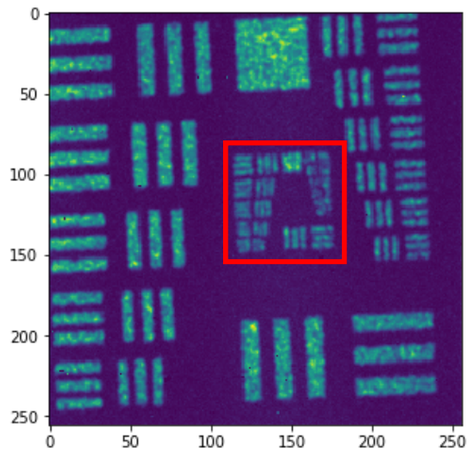
implementation



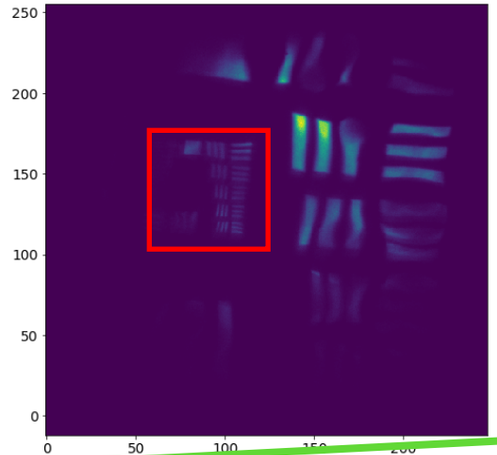
USAF-51 resolution mask



smallest feature size ~35 μm

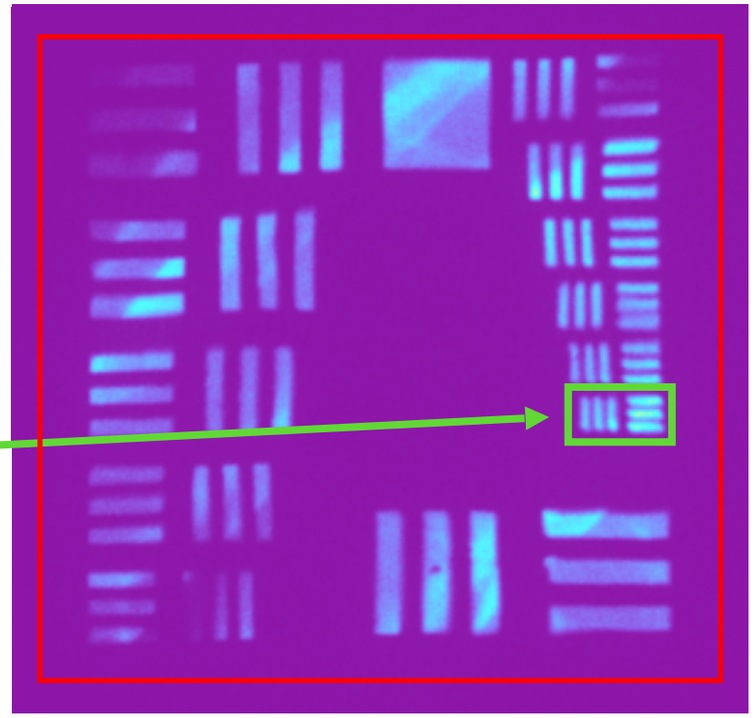


Am-241 source on TPX3 (ASIC + Si sensor + Al layer)



Am-241 source on TPX3 (ASIC) + MCP stack

dedicated e^+ beam test



Positron beam on TPX3 (ASIC) + MCP stack

→ can resolve structures well below 20 μm

Program for 2020: Ps & upgrades

1) Ps: work towards laser-cooling of Ps

a)
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- first Doppler-free saturated absorption spectroscopy of Ps on 1^3S-3^3P
- concurrent Ps laser excitation / probing

b) position-sensitive detector:

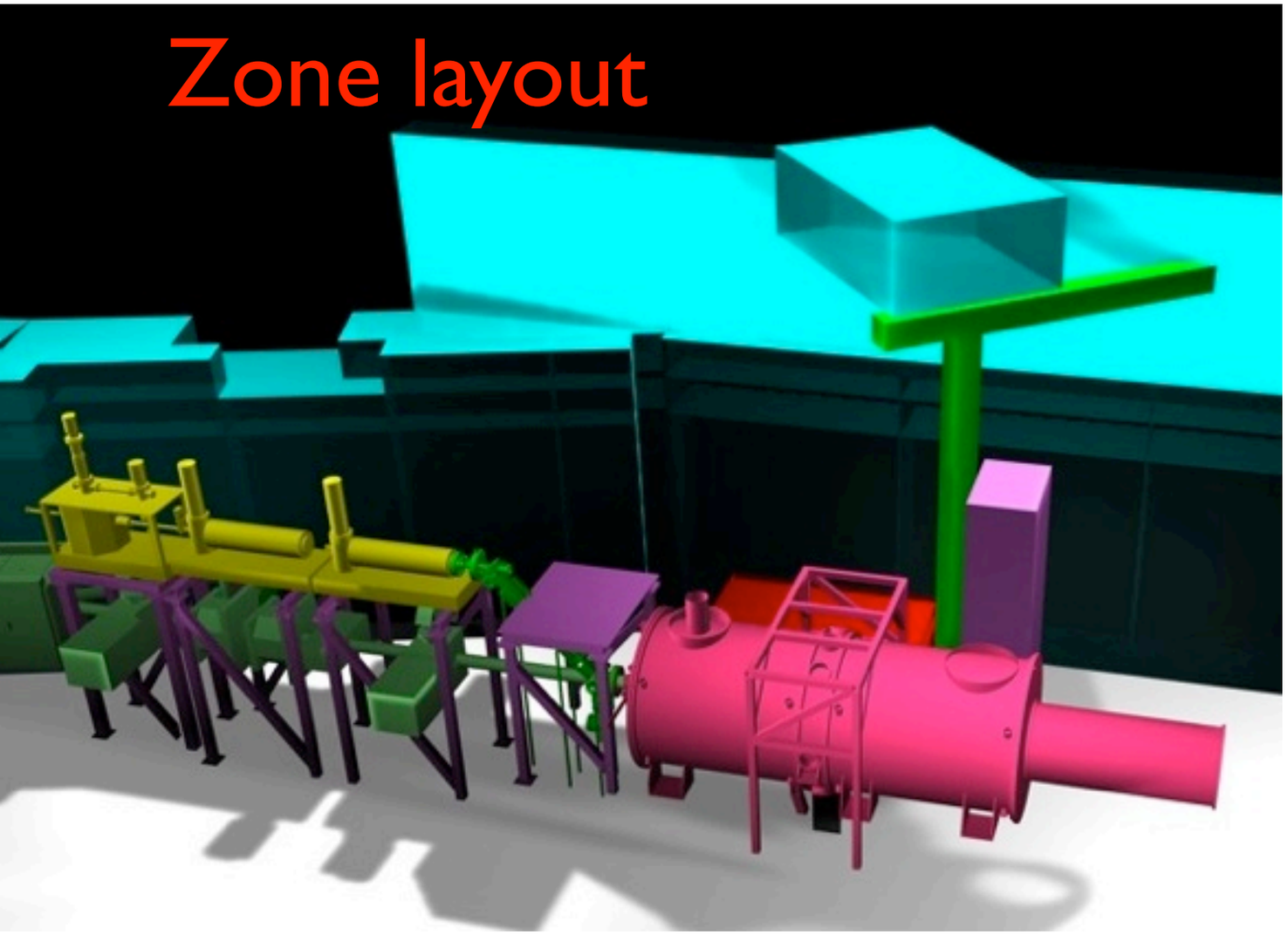
2) Upgrades:

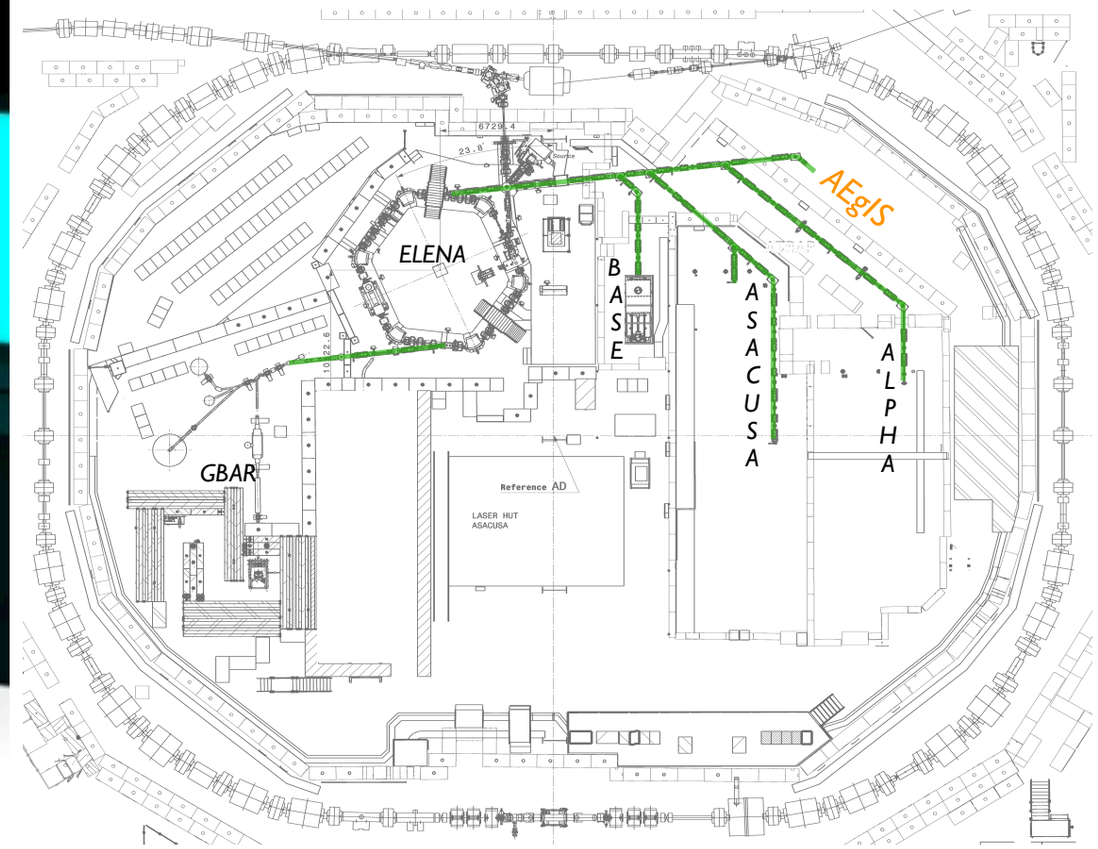
zone layout:

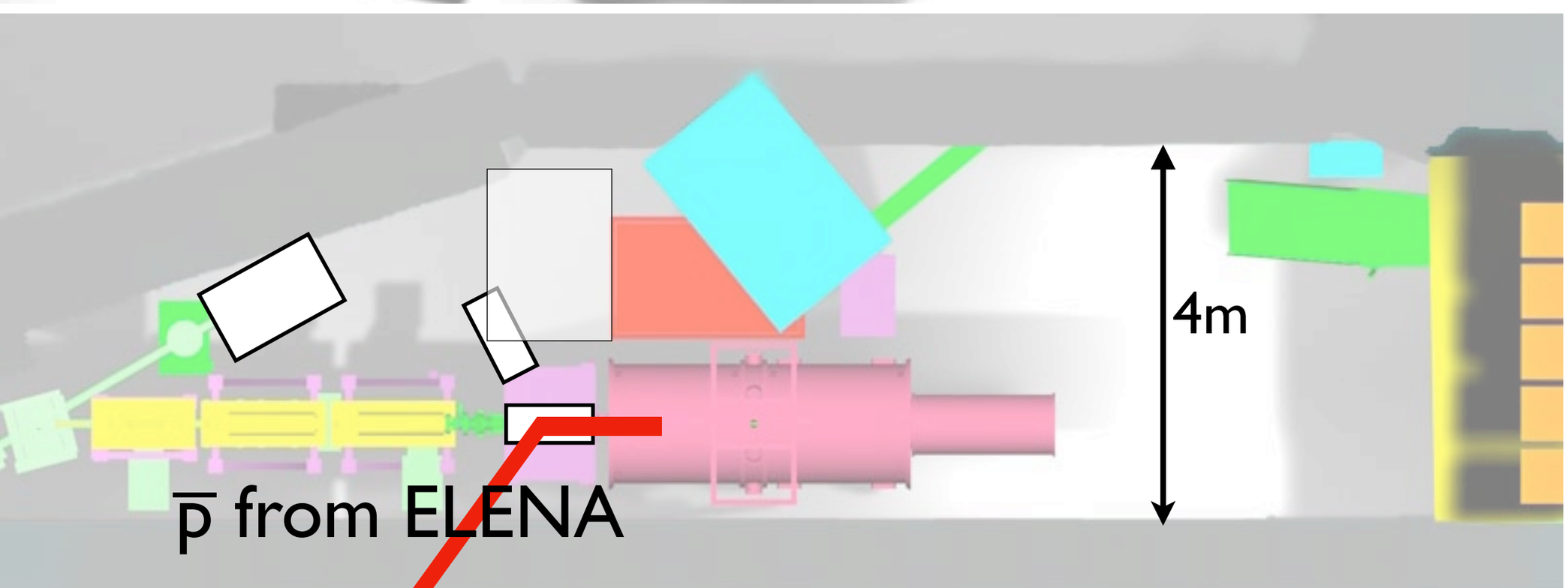
$\bar{H}$ formation region:

adapting to ELENA:

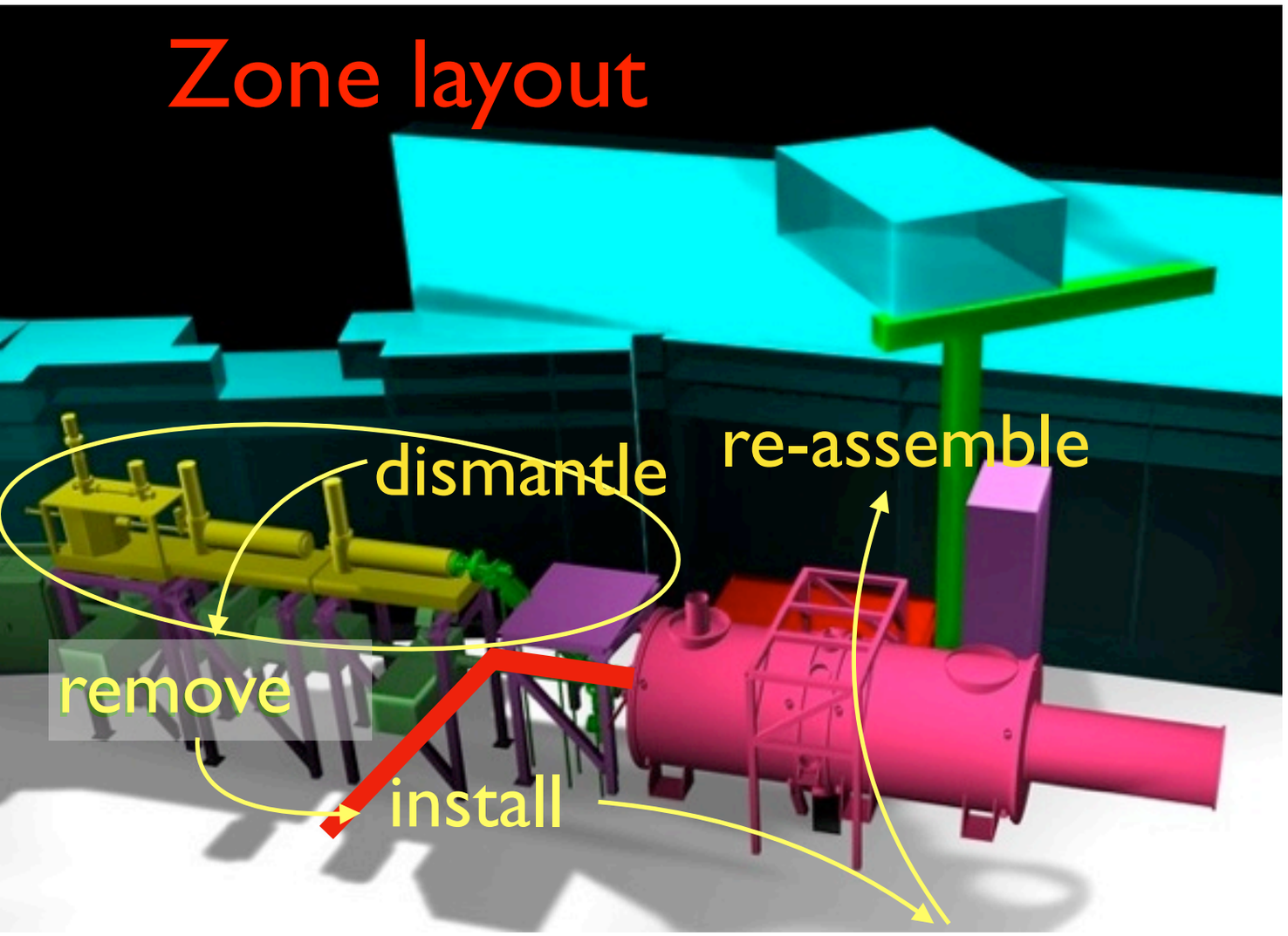
Zone layout

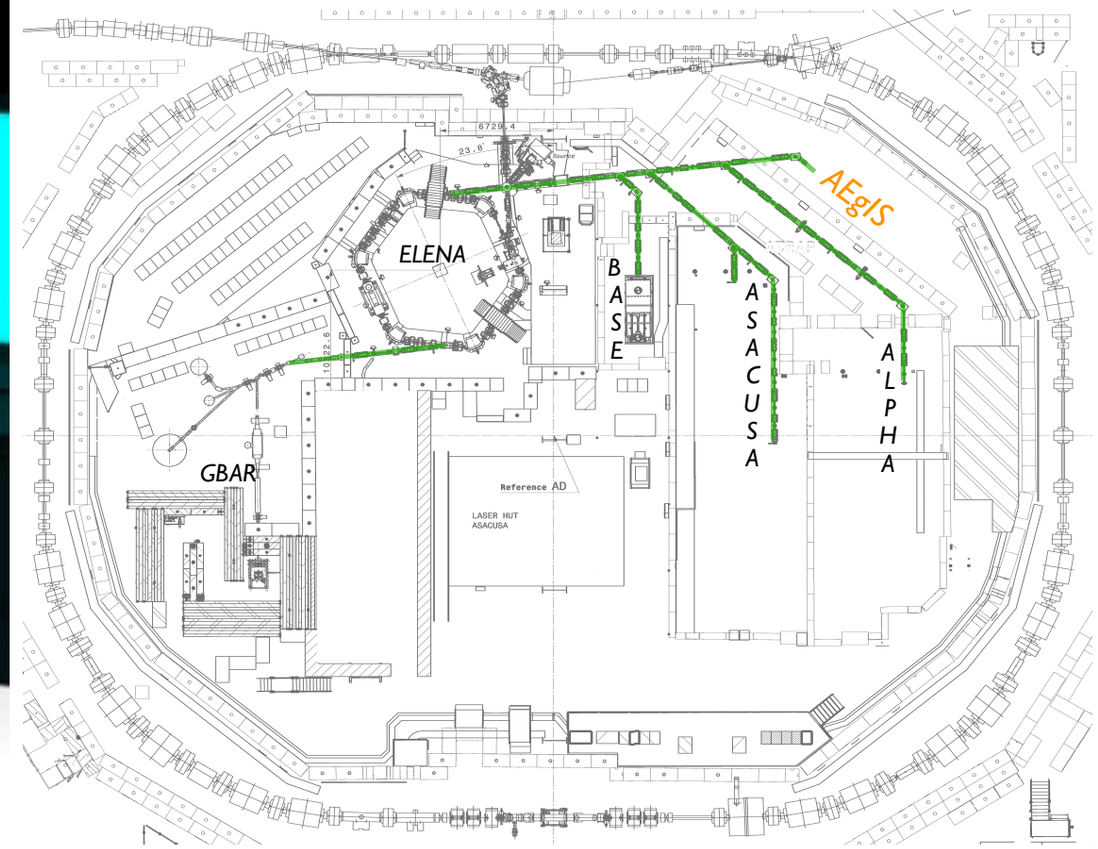


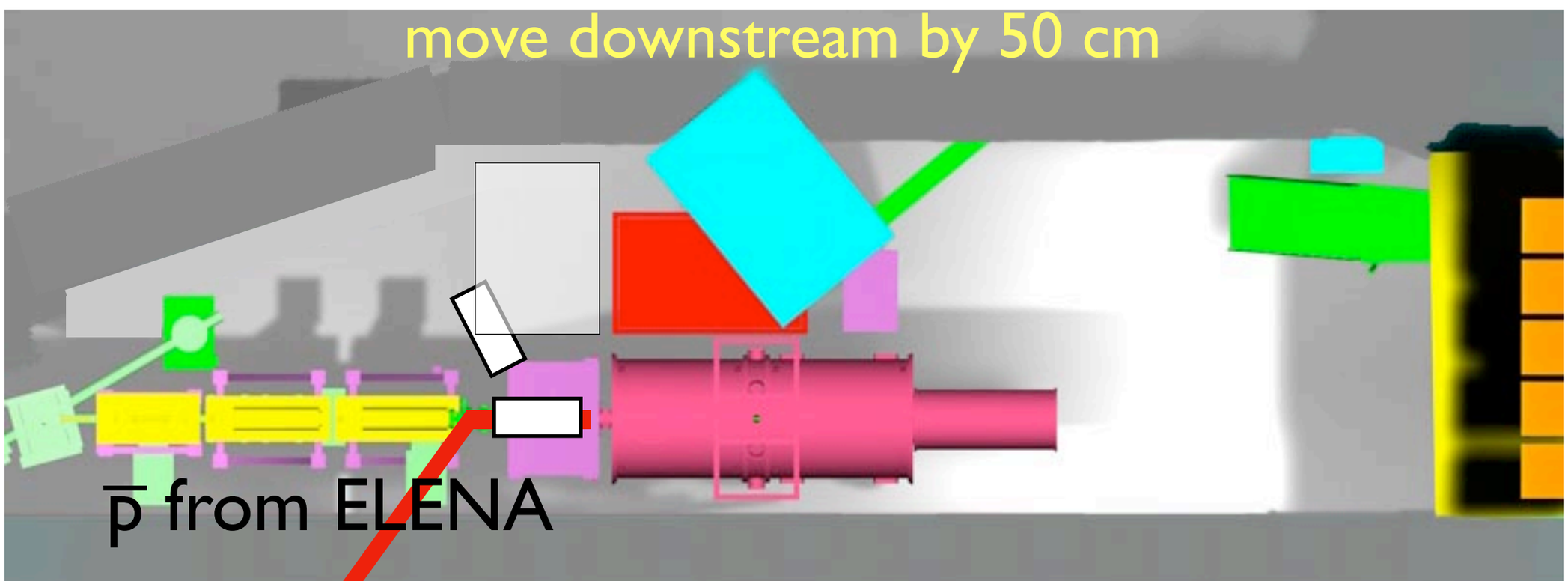

ELENA
GBAR
BASE
ASACUSA
ALPHA
AEgIS
Reference AD
LASER HUT
ASACUSA


4m
p̄ from ELENA

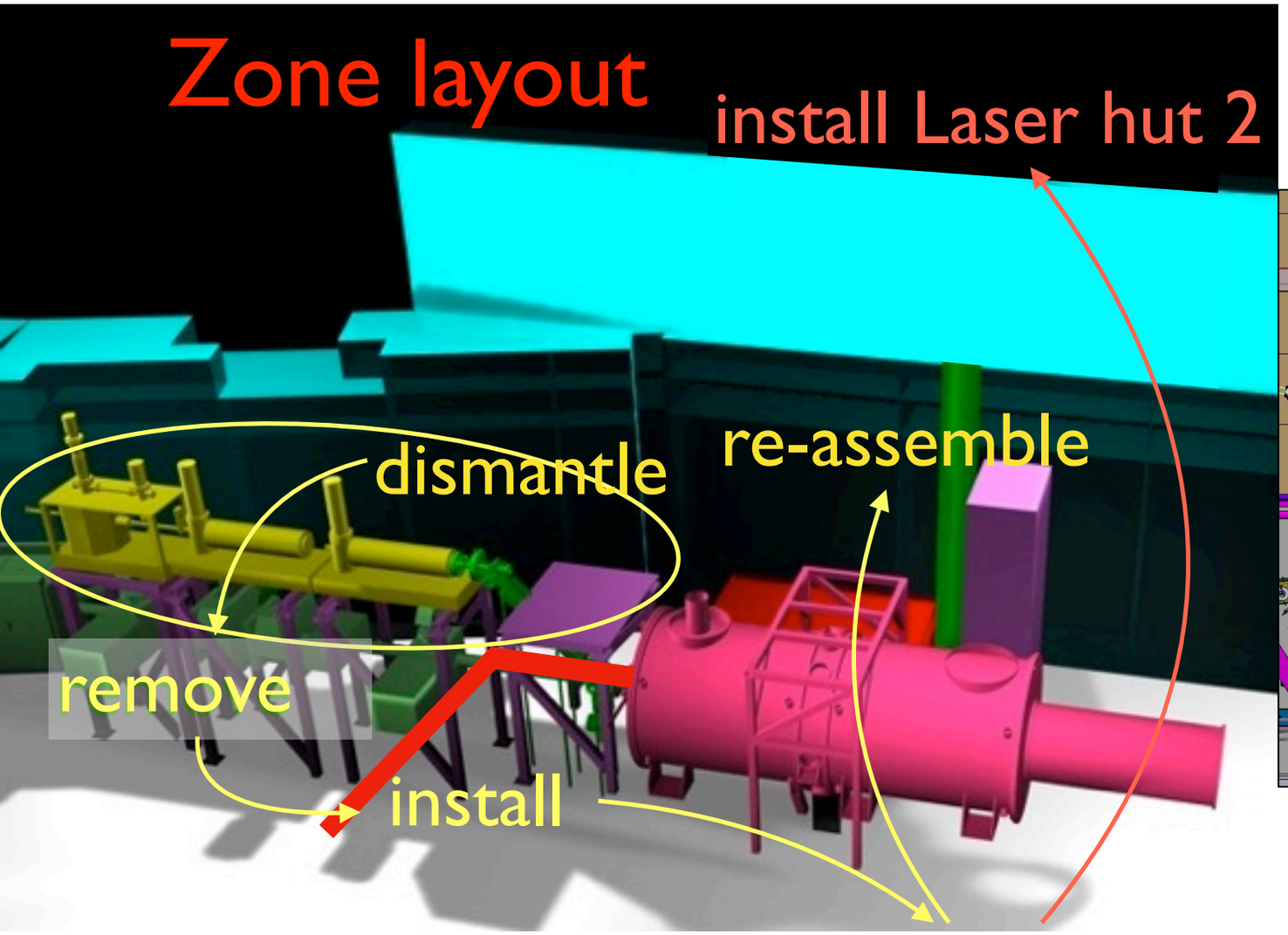
Zone layout


dismantle
re-assemble
remove
install

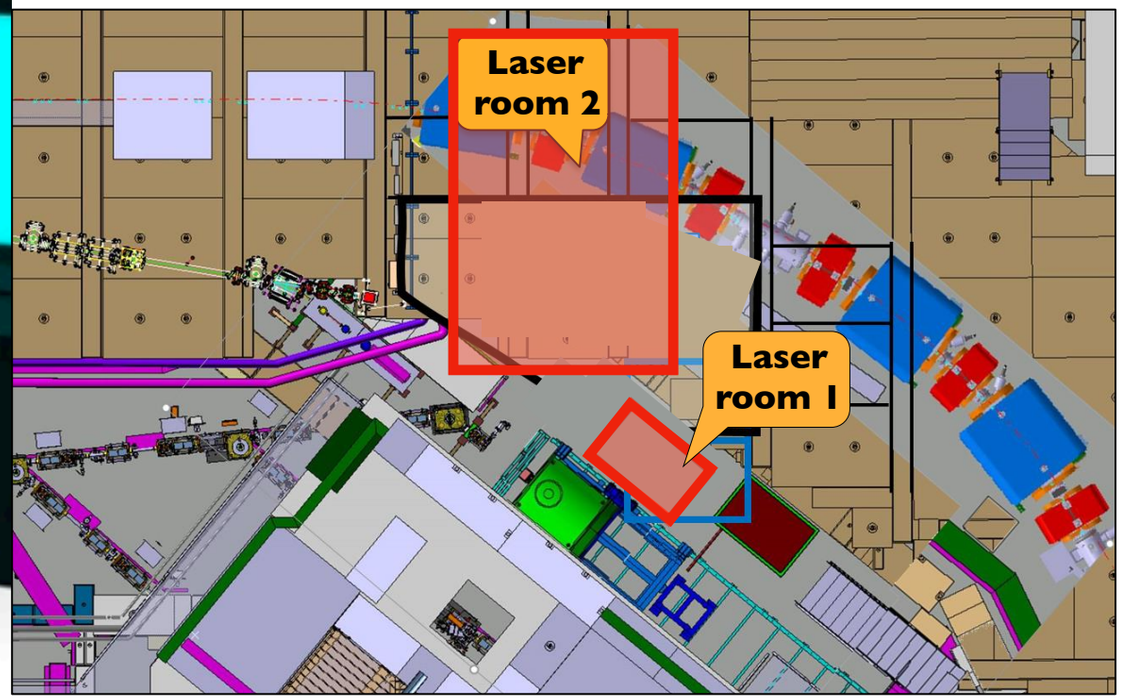

ELENA
GBAR
BASE
ASACUSA
ALPHA
AEgIS
Reference AD
LASER HUT
ASACUSA

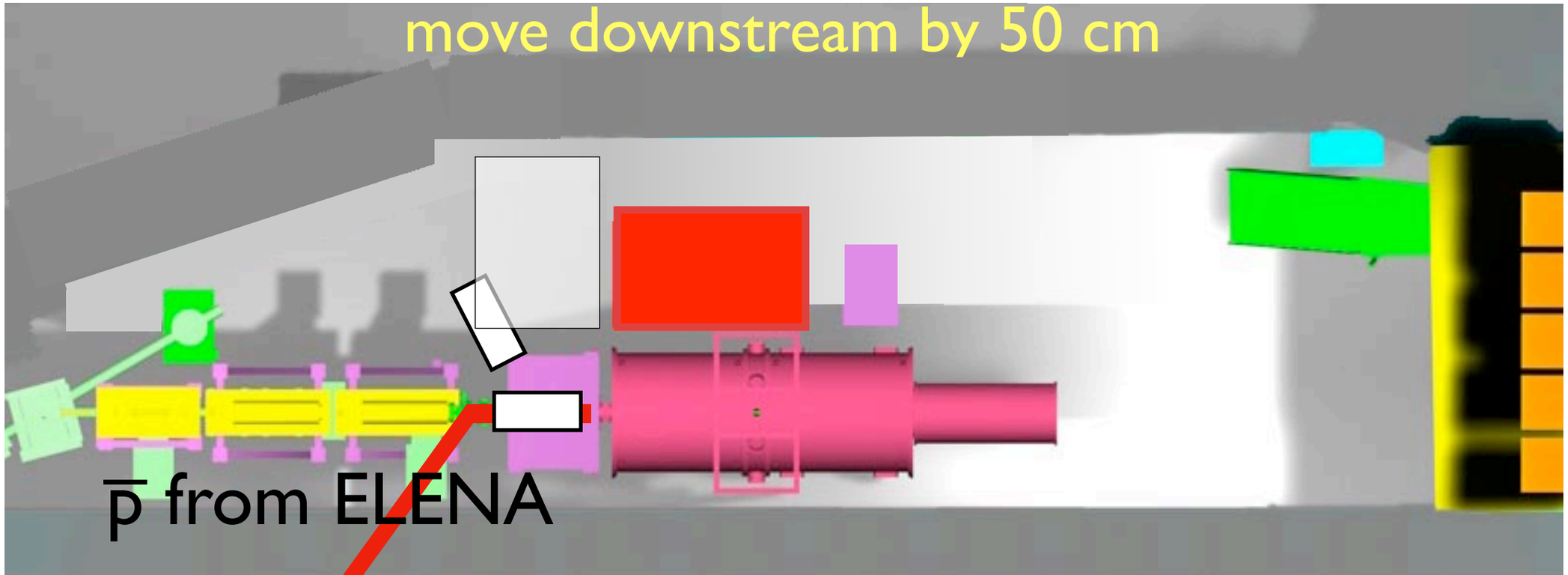

move downstream by 50 cm
p̄ from ELENA

Zone layout

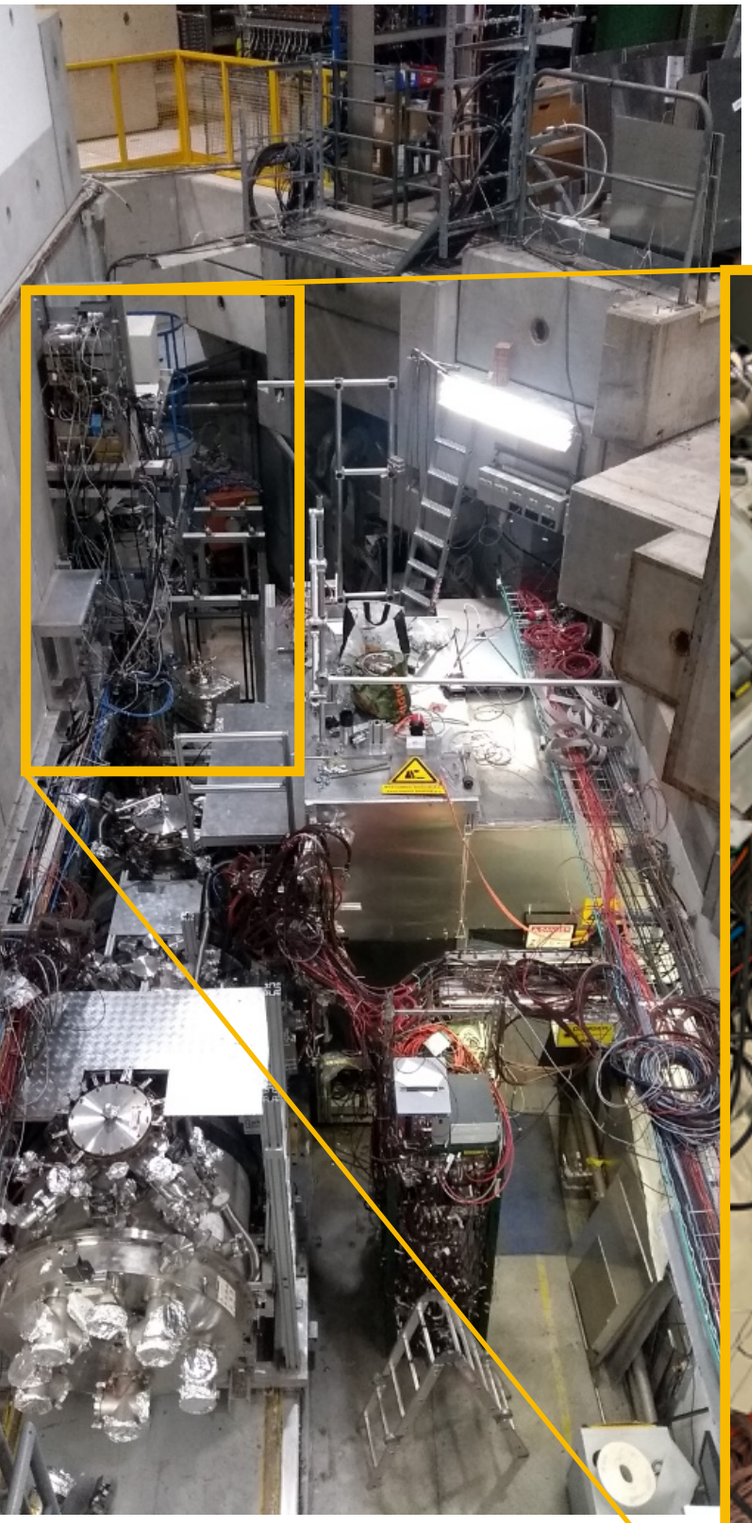


Order placed for Laser room 2

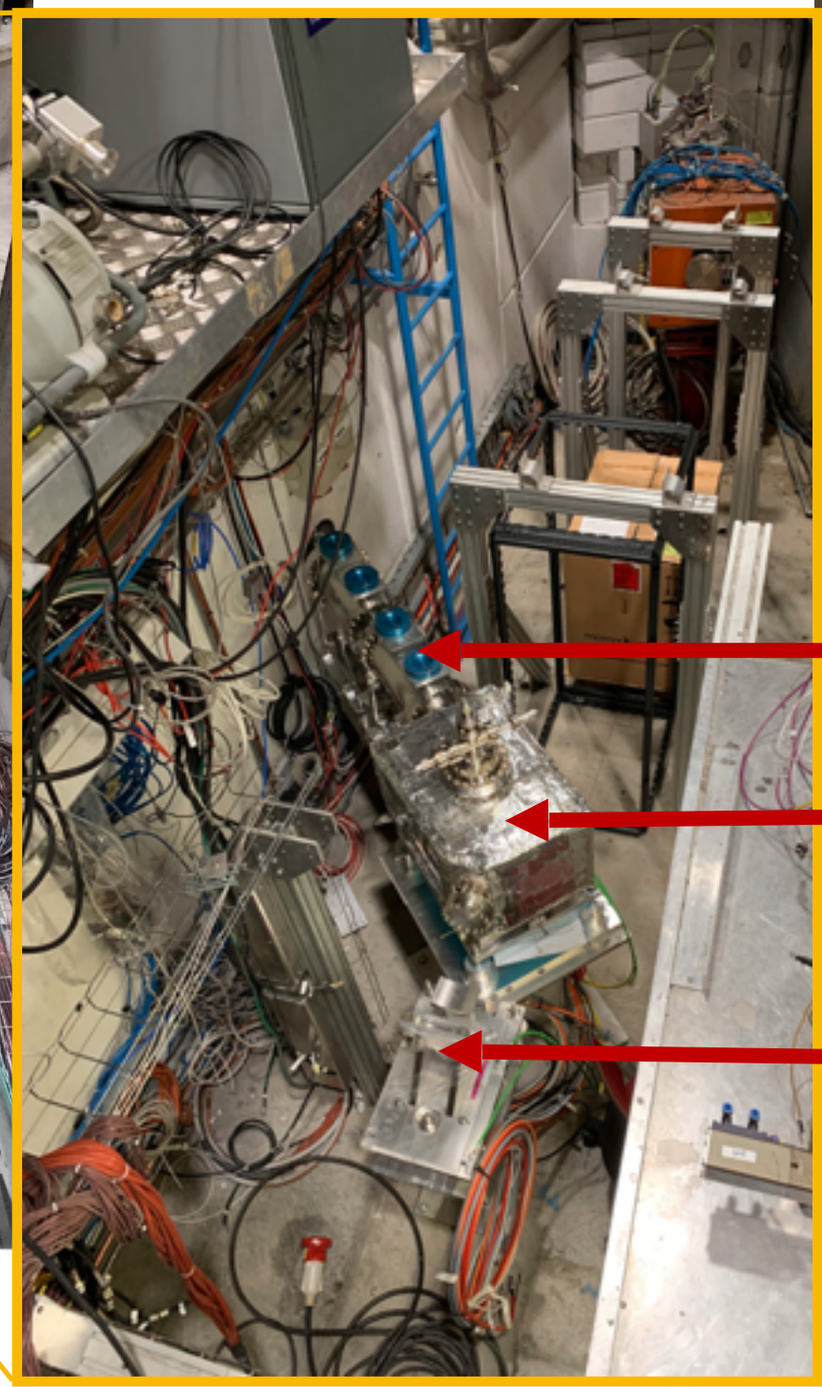




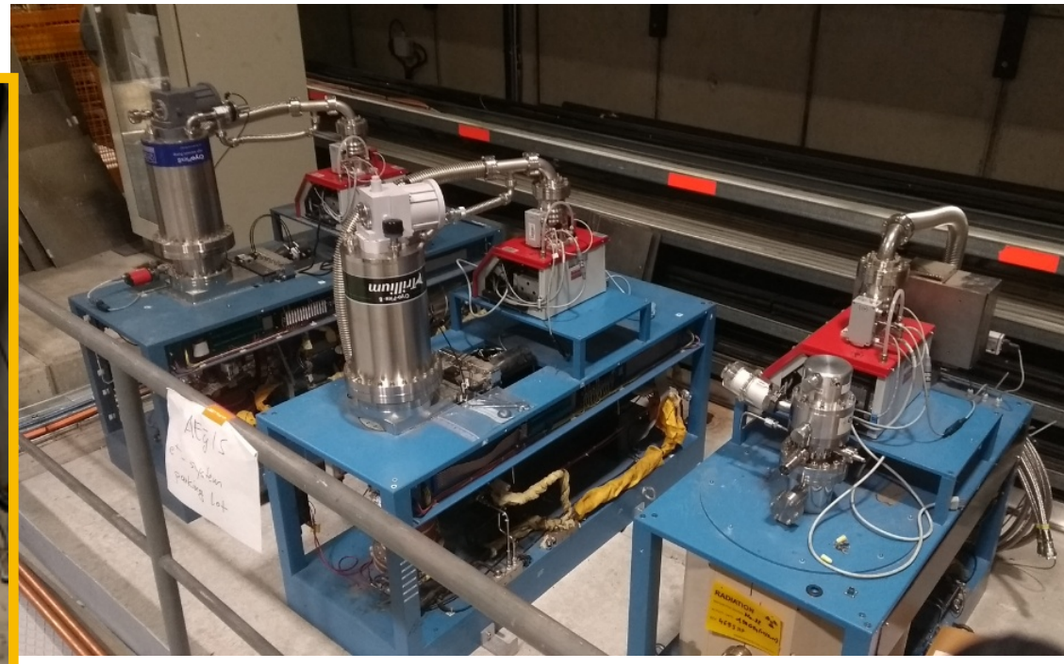
status on Dec 19th



Connection to ELENA



Positron source, trap and accumulator (storage)



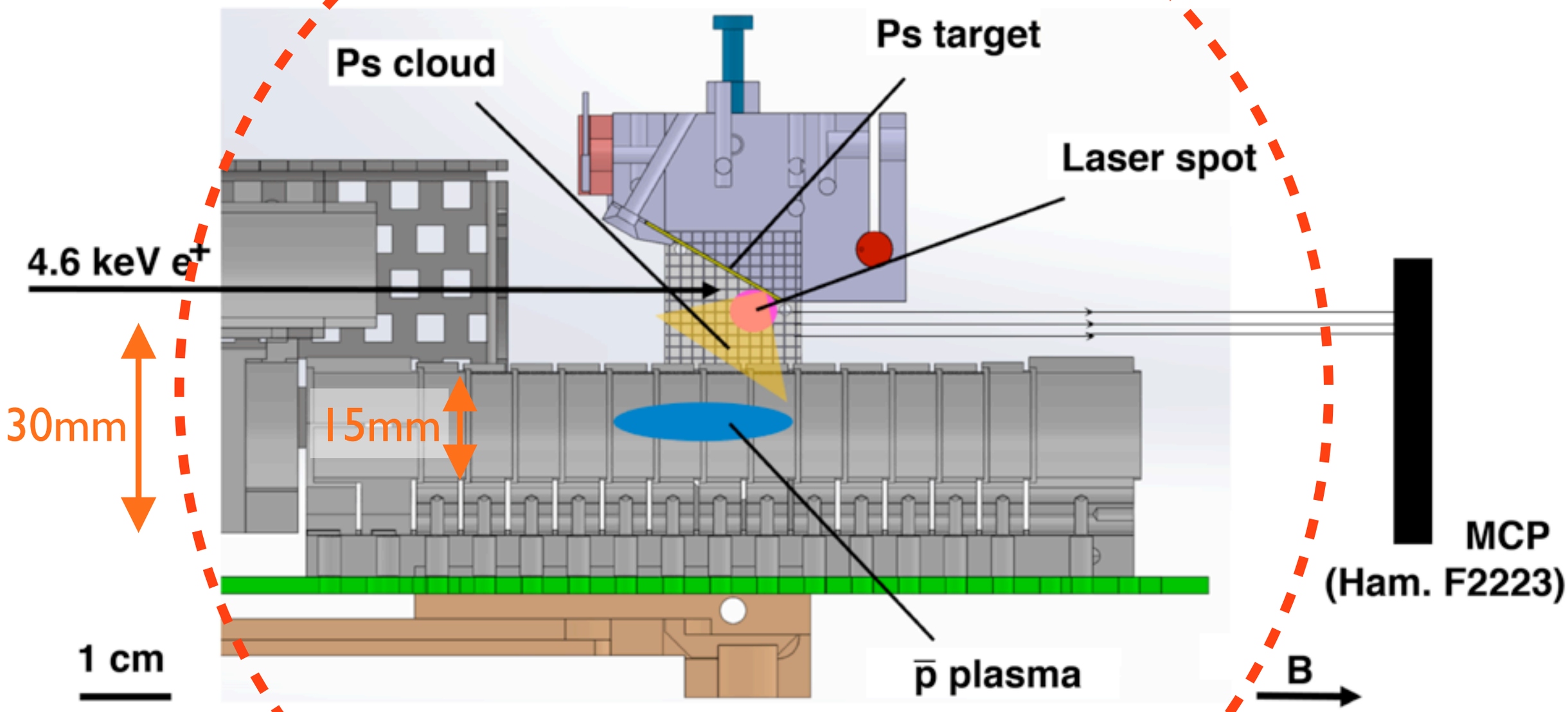
Quadrupoles

Bending electrode

Position of “AD” gate valve

pulsed production of $\bar{H}$ (former geometry)

Pulsed production of $\bar{H}$, S. Aghion et al., Comm. Phys. 2020 (in press)



limitations:

- Ps* moves transverse to $\vec{B}$
- distance of travel of Ps*
- sensitivity of $\bar{p}$ to geometry
- alignment ($\overrightarrow{trap}$,$\vec{B}$)

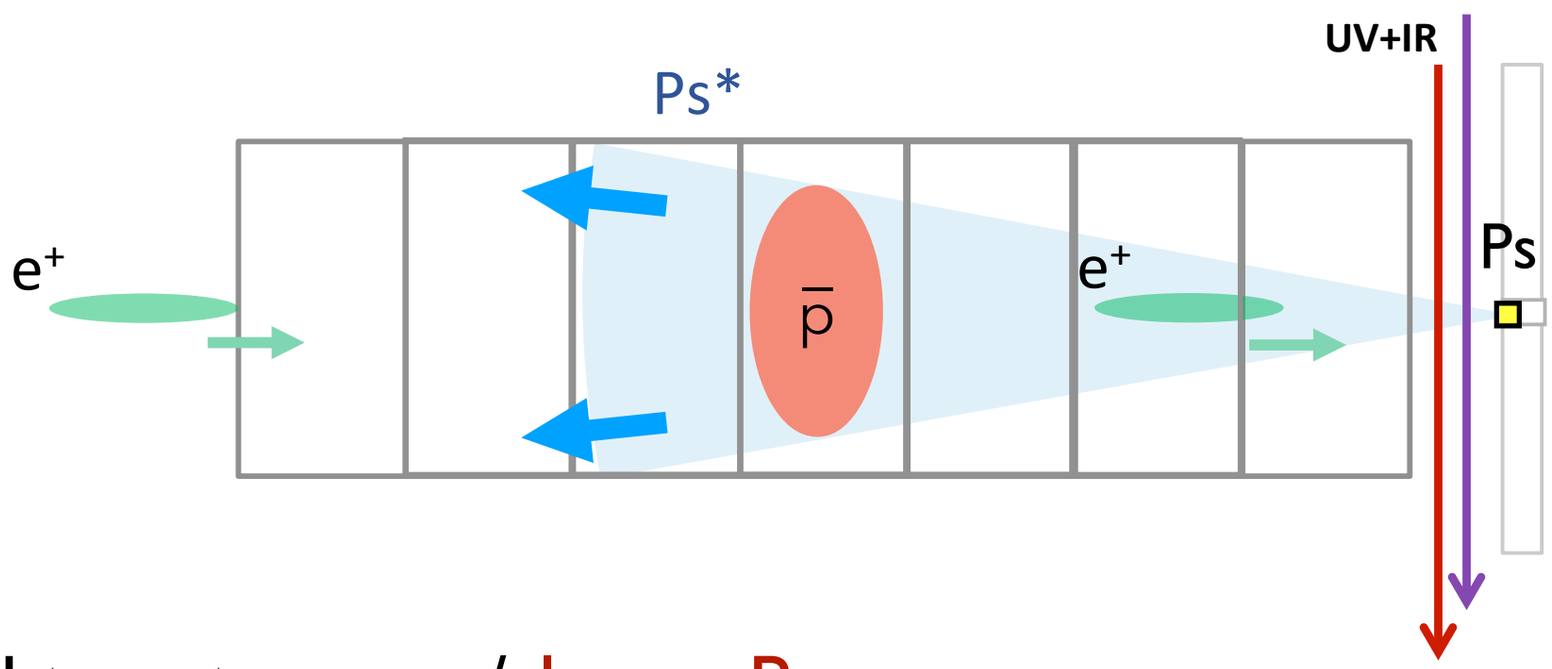
Higher $\bar{H}$ formation rate

- increased numbers of antiprotons from ELENA → scales ~ linearly

unchanged: (variable thickness) degrader procedure, with
of course a much thinner degrader (few 100 nm ~ 1 μm)

+ beam position monitor

- transverse target → limit to n(Ps*) through motional Stark effect (ionization)

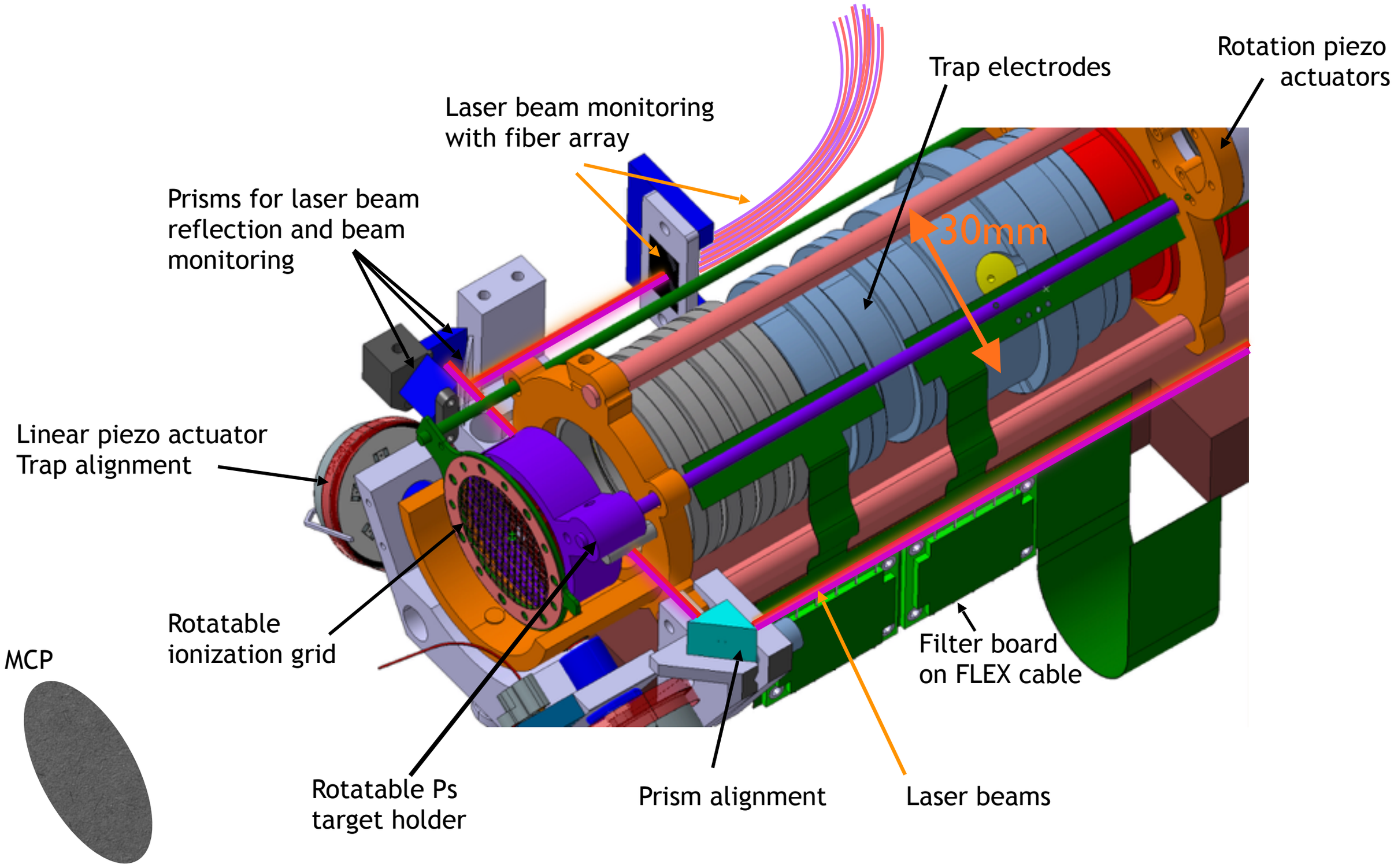


bigger & alignable target → colder $\bar{p}$

improved target: more/slower Ps
on-axis geometry: higher n(Ps*)
→ much higher $\bar{H}$* formation cross section

formation rate of $\bar{H}$* should be greatly enhanced ~ O(10/cycle)

pulsed production of $\overline{H}$ (new geometry)



modifications required for 100 keV $\bar{p}$

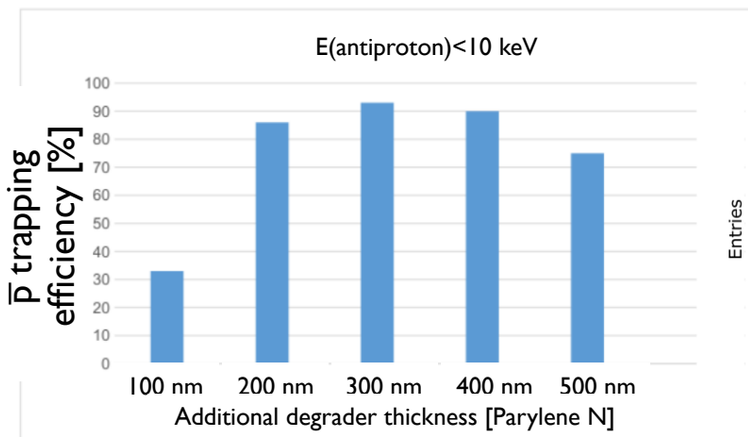
- need to degrade $\bar{p}$ energy from 100 keV to < 10 keV
- need to monitor beam spot (formerly 50 μm Si pixel detector)

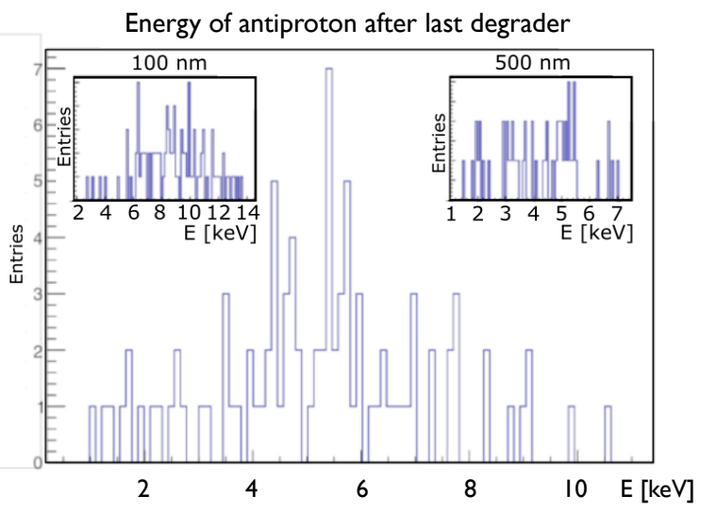
→ lowest Z material: parylene N, can be made in 100 nm thin foils

→ segmented zones via metal-vapor deposition

Geant4 simulations:

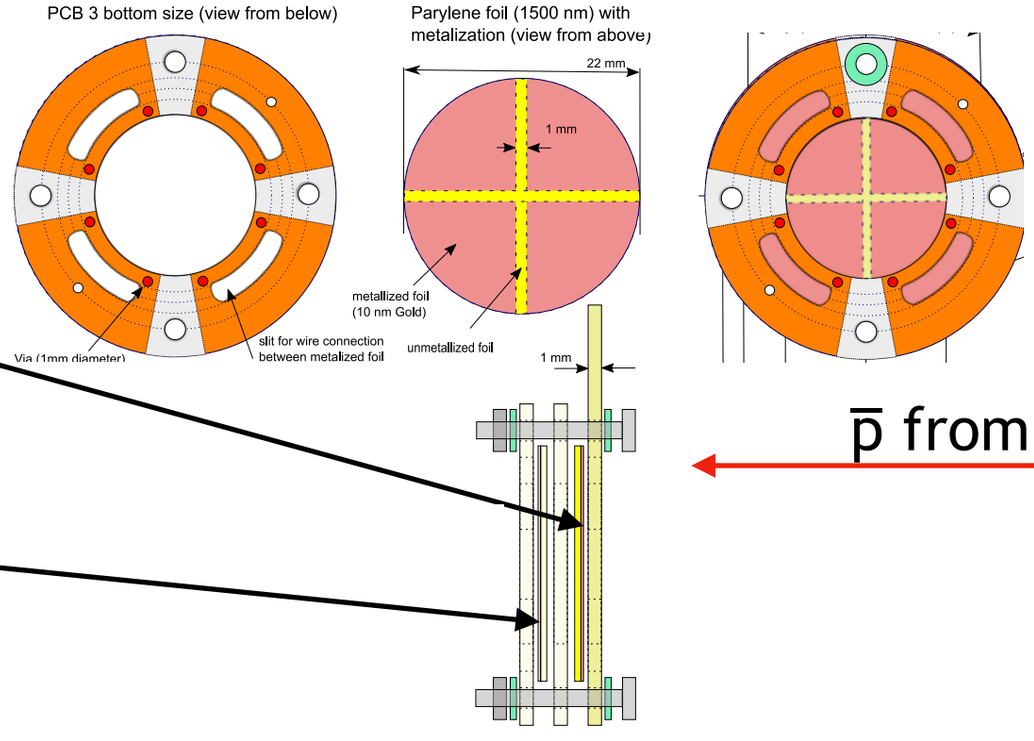
overall thickness required:
1900 nm Parylene N (C_8H_8)
thin metalization: 20 nm Al





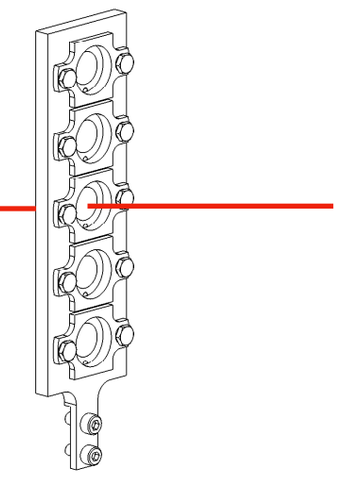
main degrader and
beam position monitor
(1500 nm + 10 nm Al)

final degrader and
Faraday cup
(100 nm + 10 nm Al)



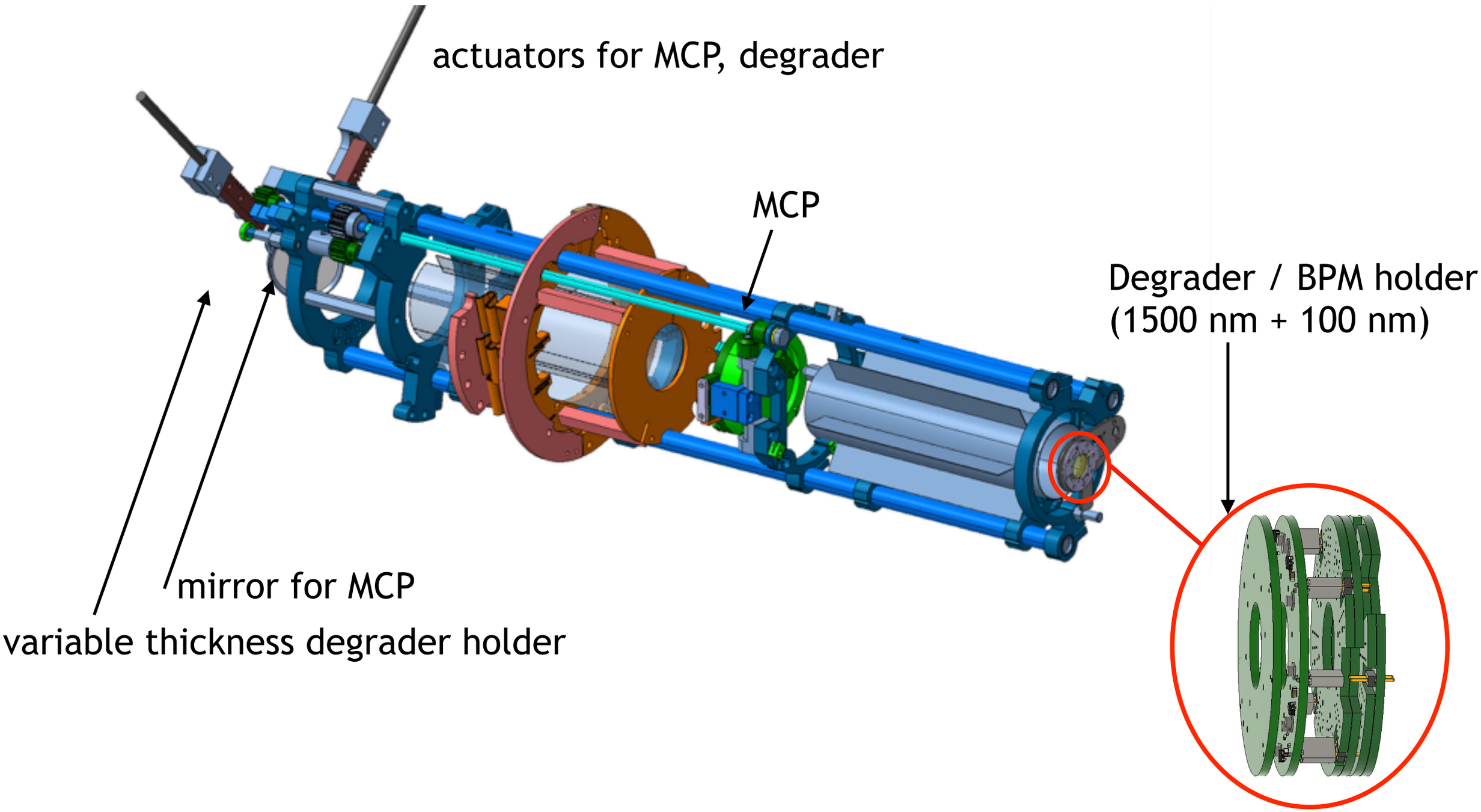
$\bar{p}$ from ELENA

tuneable degrader:
0 nm - 500 nm
(in 100 nm steps)



modifications required for 100 keV $\overline{p}$

rebuild complete entrance region to improve reliability and to minimize thermal load to the inside traps (production has started and will take 2 months)



Conclusion and outlook

Covid-19 has had a major impact on our program in 2020, resulting in delays on several fronts, which we have attempted to mitigate

Building on Ps experimental physics program in 2019, work on Ps continued for around 6 months of 2020:
→ first results on Doppler-free measurement of Ps 1^3S-3^3P transition; close to establishing laser-cooling of Ps

In parallel: redesigns, modifications and improvements to the apparatus and the experimental area (with the potential for major improvements / gains) are being implemented, and will keep us busy for the next 6 months

Goal for 2021: reestablish all steps for pulsed antihydrogen production in AE$\bar{g}$IS & pursue work with Ps towards a pulsed beam of metastable Ps

We expect to be ready for $\bar{p}$ beam by its scheduled arrival in August

request for 2021: pro-rata access to ELENA (in parallel running mode)

End of slides