Consiglio di Sezione - July 2024

Low Energy Antimatter

Studies involving antimatter at low (sub-MeV) energy

ALPHA (CERN) with anti-hydrogen

- BRESCIA/PAVIA

AEGIS (CERN) with anti-hydrogen

- TRENTO, MILANO, BRESCIA/PAVIA

ASACUSA (CERN) with anti-hydrogen

- BRESCIA/PAVIA, MILANO

PSYCO with positronium

- TRENTO

QUPLAS with positronium

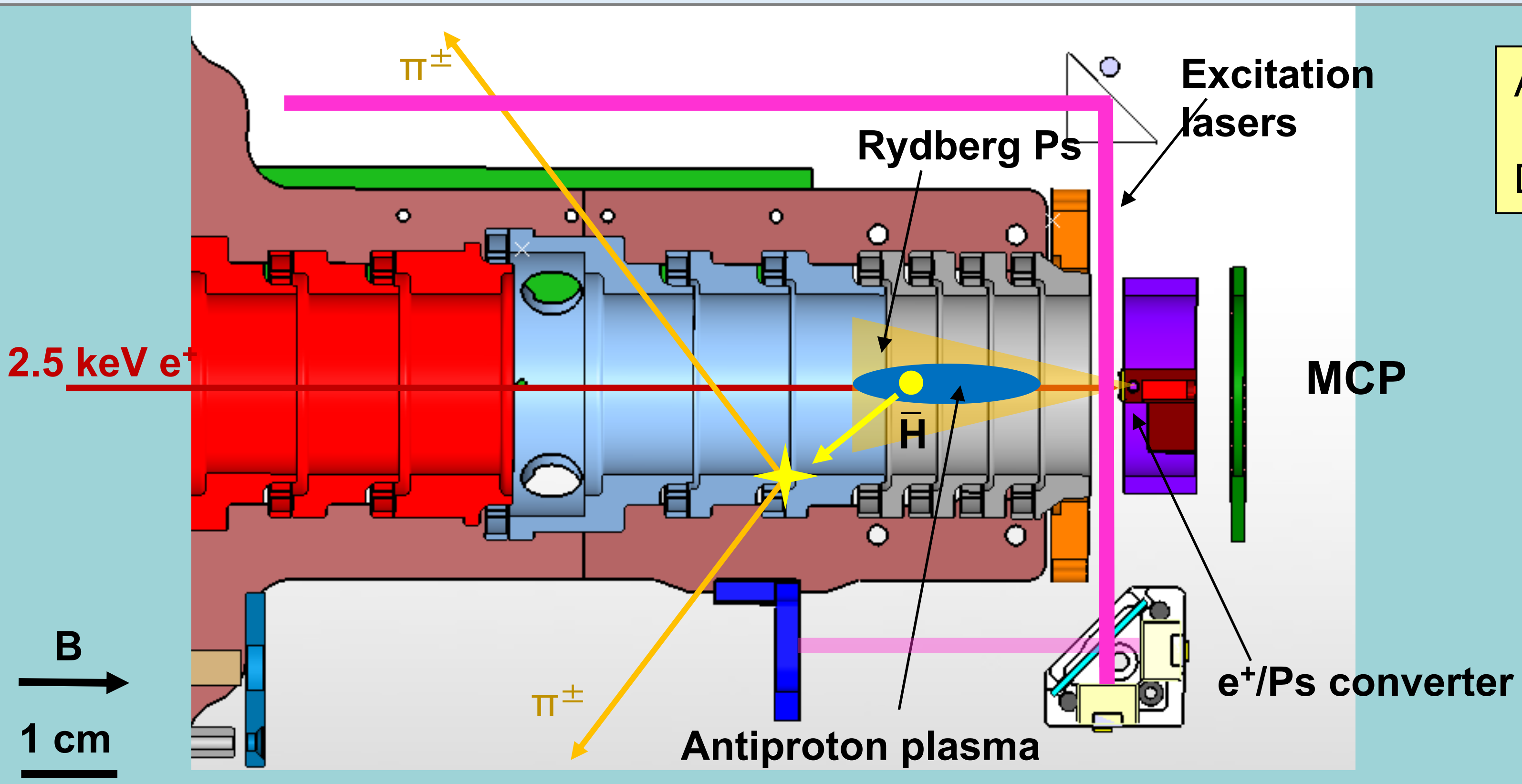
- MILANO , FIRENZE, BRESCIA/PAVIA

A E G I S

QUantum interferometry and gravitation with Positrons and LASers

Recall: the AD/ELENA accelerator system provides for low-energy antiprotons

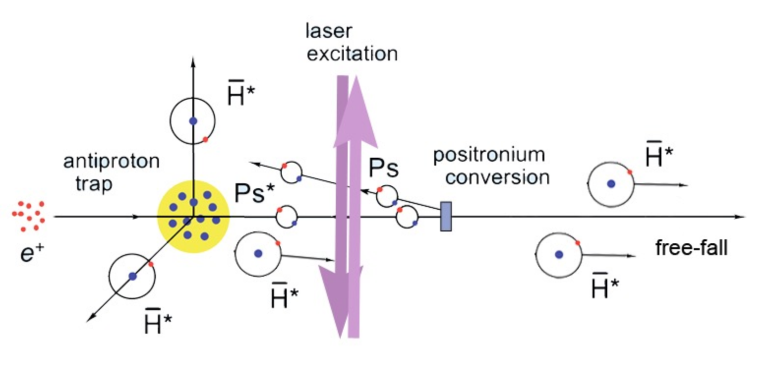
External Scintillation Detector Array (ESDA)



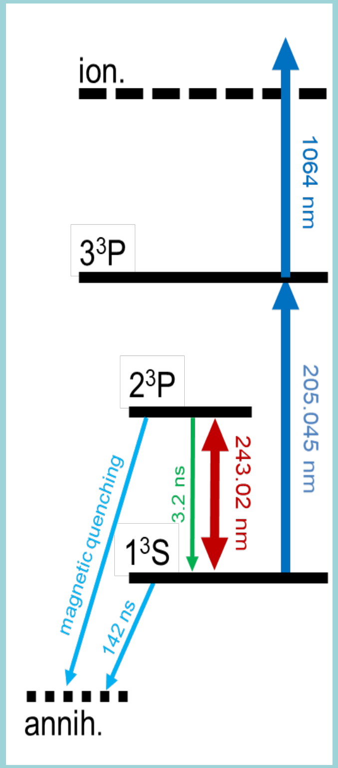
External Scintillation Detector Array (ESDA)

Accumulation of 10 millions antiprotons

Detection of H-bar formation



Laser cooling of positronium

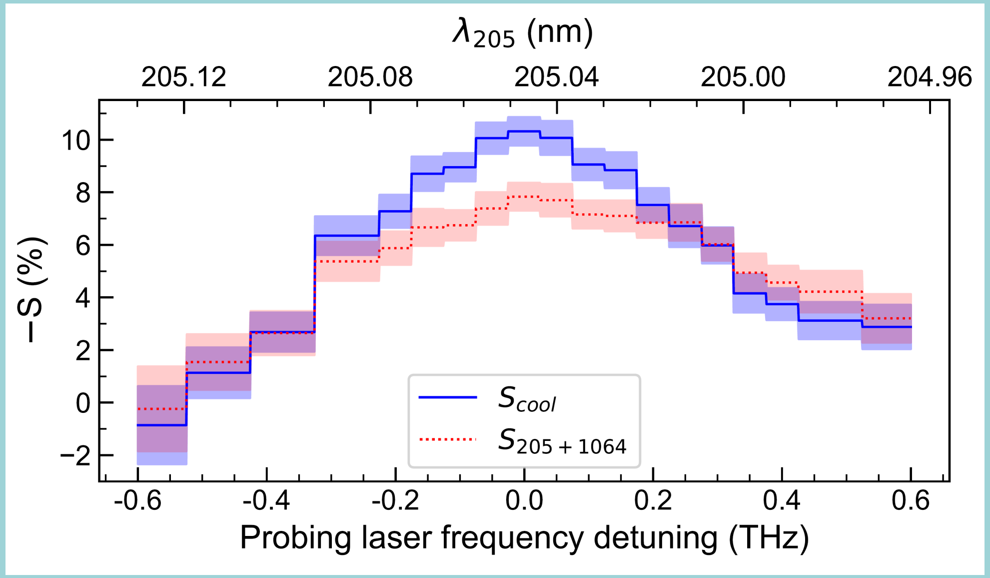


Results: narrowing of the 1^3S – 3^3P line

Probing transition
(1^3S → 3^3P → Ion)

Cooling transition
(1^3S ↔ 2^3P)

Ps cloud cooled from 380 K to 170 K

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Science

Antimatter: Scientists freeze positronium atoms with lasers

L.T. Glogger et al.,
Positronium Laser cooling via the 1^3S-2^3P Transition with a Broadband Laser Pulse
Phys. Rev. Lett., 132, 083402 (2024) doi.org/10.1103/PhysRevLett.132.083402

1. CIRCUS: an autonomous control system for antimatter, atomic and quantum physics experiments
EPJ Quantum Technology 11, 10 (2024) doi.org/10.1140/epjqt/s40507-024-00220-6

2. TALOS: (Total Automation of Labview Operations for Science): a framework for autonomous control systems for complex experiments
Review of Scientific Instrument accepted

3. Real-time antiproton annihilation vertexing with sub-micron resolution
Nature Communication – submitted

Conference	location	date	speaker	subject
ICSLS 2024 26th International Conference on Spectral Line Shapes	Otsu, JAPAN	2 - 7 Jun.	R. Caravita	Ps cooling
EXA/LEAP : INTERNATIONAL CONFERENCE ON EXOTIC ATOMS AND RELATED TOPICS AND CONFERENCE ON LOW ENERGY ANTIPROTONS	Vienna- Austria	26 - 30 Aug	R. Caravita	Antiprotons in AEgIS
SIF	Bologna	9 - 13 Sep.	R. Caravita	Ps cooling
Seminar at the Tokio University	Tokio University-Japan	12 June	R. Caravita	Ps Cooling

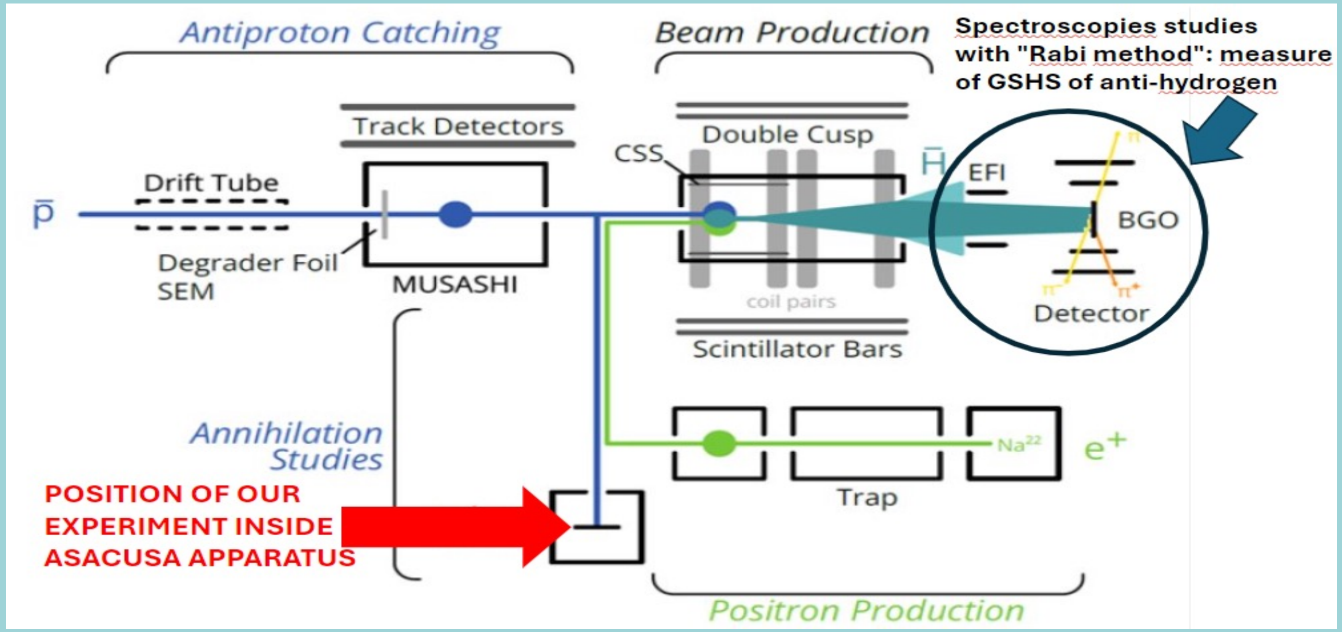
A S A C U S A

QUantum interferometry and gravitation with Positrons and LASers

Historically known for Antiprotonic Helium

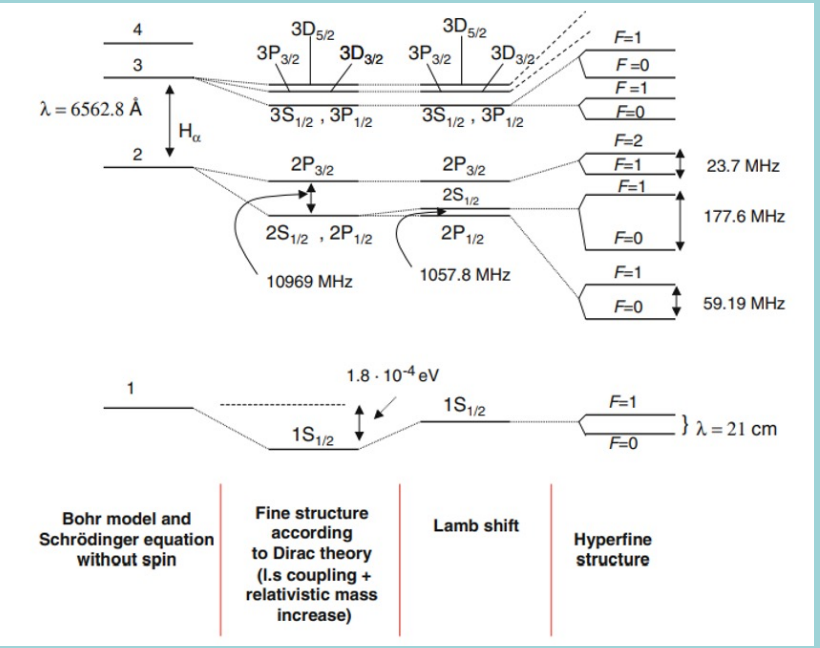
Anti-hydrogen physics part focused on

GSHS of H-bar (CPT test)



Physics in the CUSP

Rabi method to measure GSHS



Tuned up with hydrogen (best result ever, except with MASER)

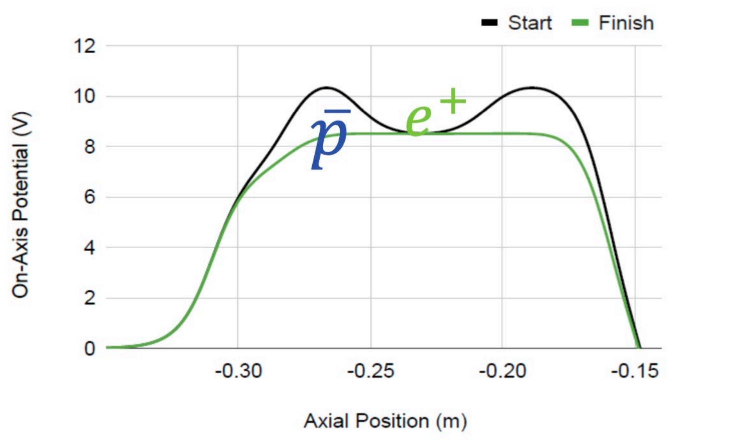
Antiprotons

10^7 catched per AD/ELENA shot

10^6 successfully trapped/cooled in the CUSP

High density ($10^7/cm^3$)

5 x 10^5 anti-hydrogen atoms at 300 K



Positrons (Stacker built in Milano)

3 x 10^7 confined in the CUSP

Obtained temperature of 25 K

E.D. Hunter et al.
SDR, EVC, and SDREVC: Limitations and Extensions
Journal of Plasma Physics 89 (2023) 935890501

D. Murtagh et al.
Slow positron production and storage for the ASACUSA-Cusp experiment
Journal of Plasma Physics 89 (2023) 905890608

A. Lanz et al.
Upgrade of the positron system of the ASACUSA-Cusp experiment
Submitted J. Plasma Phys.

Papers

C. Amsler et al.
Injection and capture of antiprotons in a Penning-Malmberg trap using a drift tube accelerator and degrader foil, NIMA 2014

Papers- submitted or in preparation

C. Amsler et al.
Antiproton annihilation at rest in thin solid targets and comparison with Monte Carlo simulations, submitted to EPJA

Conference, seminars (by Italian people)

2 talk at FuPhy 2024

1 Invited talk at EXA/Leap 2024

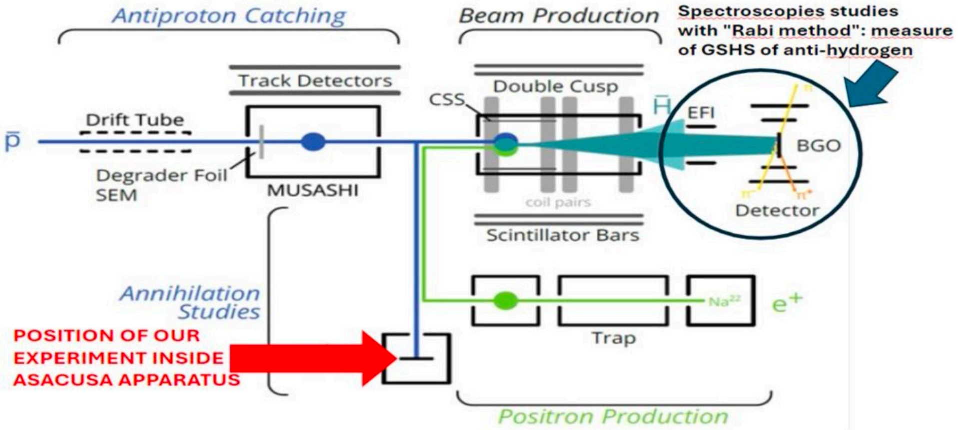
2 posters at EXA/Leap 2024

For LEA (including ASACUSA): 1 invited talk at INFN2024
1 invited talk at SIF2024

INTERFEROMETRY WITH ANTIPROTONS

Motivations for Interfrometry with antiproton:

- Never done before
- Towards the Aharonov-Bohm experiment with antiproton

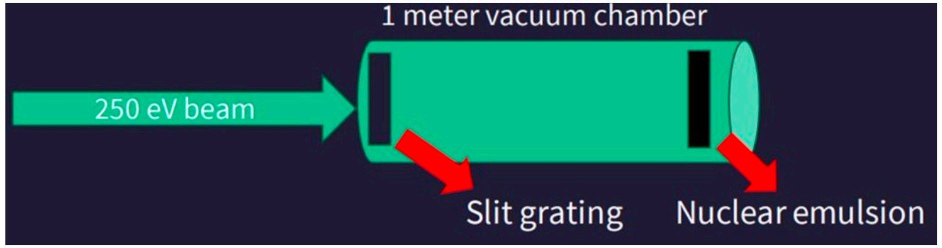


Program

2024 – Exposure test of emulsions

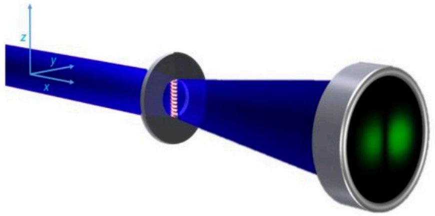
2025 – Realization of Interferometer

2025 – Exposure for Interferometry

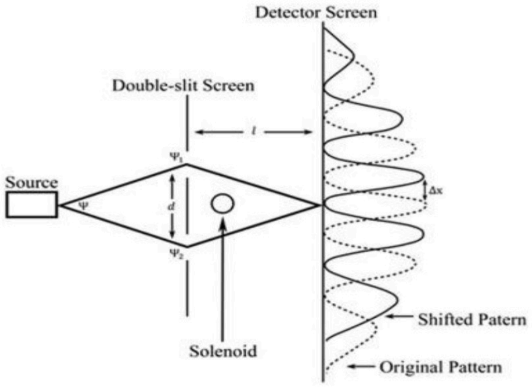


Motivations for Aharonov-Bohm experiment with antiproton:

- Never done with particles different from e-
- Clarification of the potential role in quantum physics
- Existence of the «quantum force»?



Left-right asymmetry seen by the Batelaan group (with e-)



Antimatter Gravitation with Ps

The Alpha Collaboration's recent study on the interaction of antimatter with gravity.

physicsworld TOP 10 BREAKTHROUGH 2023

Antigravitation

- Not a very sound theoretical basis
- A phenomenological motivation

Excluded in a very effective way by the ALPHA measurement

Lorentz violation (→ WEP violation, maybe CPT)

- A very sound theoretical basis (almost a must!)

Most complete Effective Model: SME

1) The coefficients driving Ps gravitation in the SME are DIFFERENT than the ones driving (anti)Hydrogen g
2) The SME being an "effective theory" misses the fundamental level of Ps being made by SM fermions (while the antiproton being a "wave function" primarily made of the QCD color field).
3) Ps gravitation is directly linked to ONE coefficient of Lorentz Violation in the SME (antihydrogen gravitation depends on the combination of 6 parameters)

Positronium Gravitation

$$\frac{\delta g}{g}(Ps)=\frac{8}{3}c_e$$

QUPLAS

QUantum interferometry and gravitation with Positrons and LASers

Physics with positrons (single particle mode)

- QUPLAS-0 (completed)
- QUPLAS Microwave
- QUPLAS Aharonov-Bohm

Ps- production for Gravitation

Gravitational Physics with positronium (Ps)

QUPLAS-Gravitation

- QUPLAS-I: demonstration of Ps interferometry
- QUPLAS-II: measurement of g with Ps interferometry

Terminology

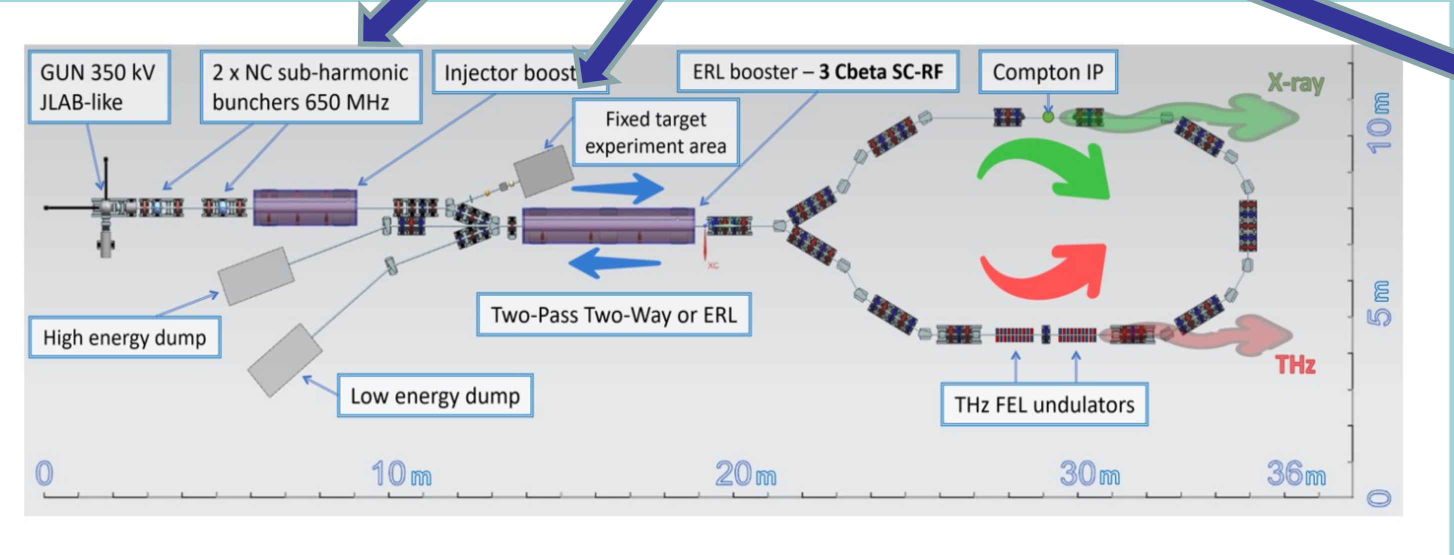
Update of the CDR

Positronium Gravitation strategy

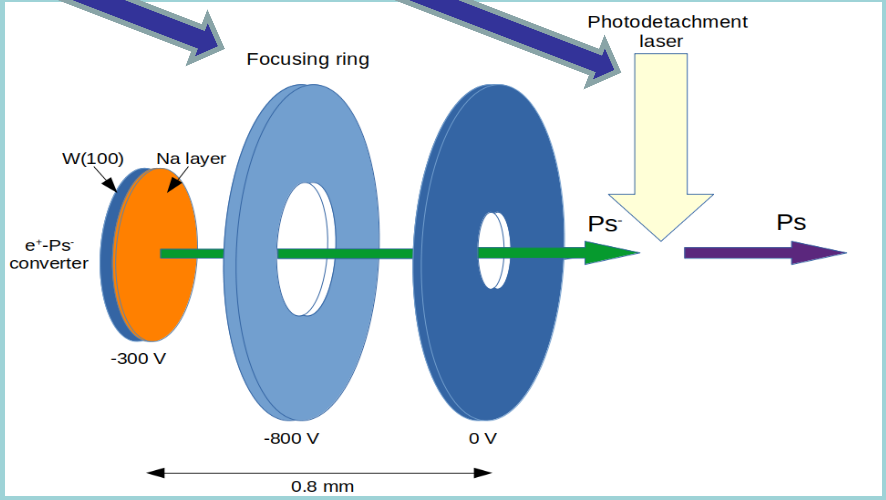
The formation of a High Intensity Collimated neutral Ps beam

Possible with the Na-22 source but the optimal solution would be a LINAC

e^- beam → e^+ beam → Ps^- beam → Ps beam → Ps interferometry



The possible use of a high-intensity electron beam (e.g. BriXSinO)



Ps ion (Ps-) intermediate state

Milano – Como

Problema della sorgente in fase di soluzione

Produzione di Ps- I studio

Firenze

Cavità per il photodetachment in fase di sviluppo

Articoli pubblicati

F. Castelli et al., Loss and revival of coherence in the interaction between a positron beam and a photon field - Journal of Plasma Physics 89 (2023) 935890603

G. Vinelli et al., A large-momentum-transfer matter-wave interferometer to measure the effect of gravity on positronium - Classical and Quantum Gravity 40 (2023) 205024

M. Sacerdoti et al., Montecarlo simulations towards the formation of a positronium coherent beam - submitted and /arxiv.org/abs/2307.12894

References

[1] Davisson C and Germer L H 1927 *Phys. Rev.* **30** 705
[2] Sala S, Ariga A, Ereditato A, Ferragut R, Giammarchi M, Leone M, Pistillo C and Scampoli P 2019 *Sci. Adv.* **5** eaav7610
[3] Rauch H, Treimer W and Bonse U 1974 *Phys. Lett.* A **47** 369
[4] Cronin A D, Schmiedmayer J and Pritchard D E 2009 *Rev. Mod. Phys.* **81** 1051
[5] Arndt M, Nairz O, Vos-Andreae J, Keller C, Van der Zouw G and Zeilinger A 1999 *Nature* **401** 680–2

Presentazioni conferenze

R. Ferragut "16th International Workshop on Slow Positron (SLOPOS-16)" Orleans, France (July 16th – 21st, 2023). Positronium interferometry to measure the effect of gravity.

- M. Giammarchi – De Broglie Foundation Paris 2023 – Antimatter Interferometry
- M. Giammarchi – XXI Lomonosov Conference on Elementary Particle Physics Moscow (Russia) Antimatter Gravitation and Fundamental Laws

LEA MILANO 2025

	LEA	QUPLAS	ASACUSA	AEGIS	
Castelli	80%	40%	-	40%	
Ferragut	90%	60%	30%		
Bayo	100%	60%	40%		
Consolati	40%	-	-	40%	
Giammarchi	70%	50%	20%		
Maero	50%	20%	30%		
Prelz	20%	-	-	20%	
Romè	50%	20%	30%		
Toso	20%	10%	10%		
Assegnista	100%	100%	-		(bando di concorso uscito)
Dottorando (?)	100%	-	100%		(partecipa sia a Milano che a Bs – ASACUSA)

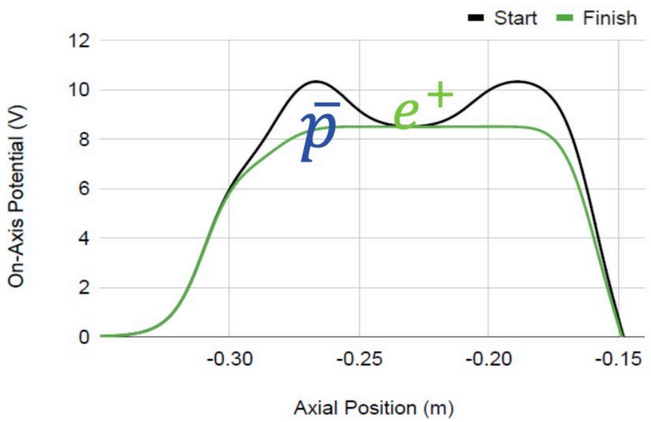
	LEA	QUPLAS	ASACUSA	AEGIS
C. Apparati	32	25	7	
Missioni	34.5	8	17	9.5

Backup slides

2023 main results 2/2

MIXING AND ANTIHYDROGEN PRODUCTION

- rotating wall is used to tune densities: **1×10^7 cm^{-3} for antiprotons** and **2×10^8 cm^{-3} for e+**.
  This antiproton density is among the highest so far reported (partly due to the large number of antiprotons, 10^6)
- **e+ temperature = 25 K** (maintained throughout the 60 s mixing cycle).
- **Up to 3×10^7 e- have been cooled to 25 K** in the Cusp. However, only 4×10^6 e+ were used for mixing in 2023 because the stronger Na-22 source not yet arrived. (With the old source, it takes over an hour to accumulate 3×10^7 e+ in the Cusp.)
- antiprotons and e+ are then merged by slowly ramping the trapping voltages
- In ASACUSA developed new methods **to reduce the e+ temperature** (2 times better than ALPHA-2)

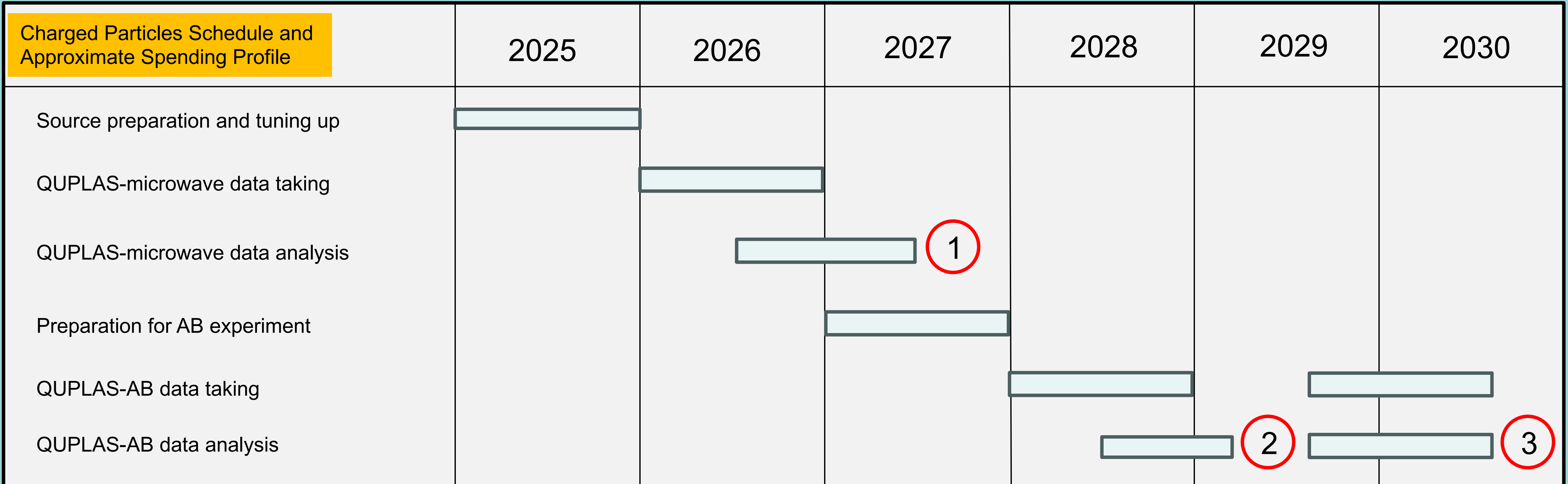


ALPHA-like “slow merge” scheme employed in 2023 for antihydrogen production. Antiprotons begin in the left well and are gradually pushed into the positrons at −0.23m

$$\bar{p} + e^+ + e^+ \rightarrow \bar{H} + e^+$$

- **antihydrogen yield** monotonically increases with mixing time, from **50% for 500 ms** mixing to **80% for 60 s** mixing (**250 - 400 k** antihydrogen atoms)
- **total antihydrogen yield is at least 5 times greater than has been reported elsewhere** (due to the number of antiprotons is higher than before, 4×10^5 after evaporative cooling)

Charged Particles Schedule and Approximate Spending Profile

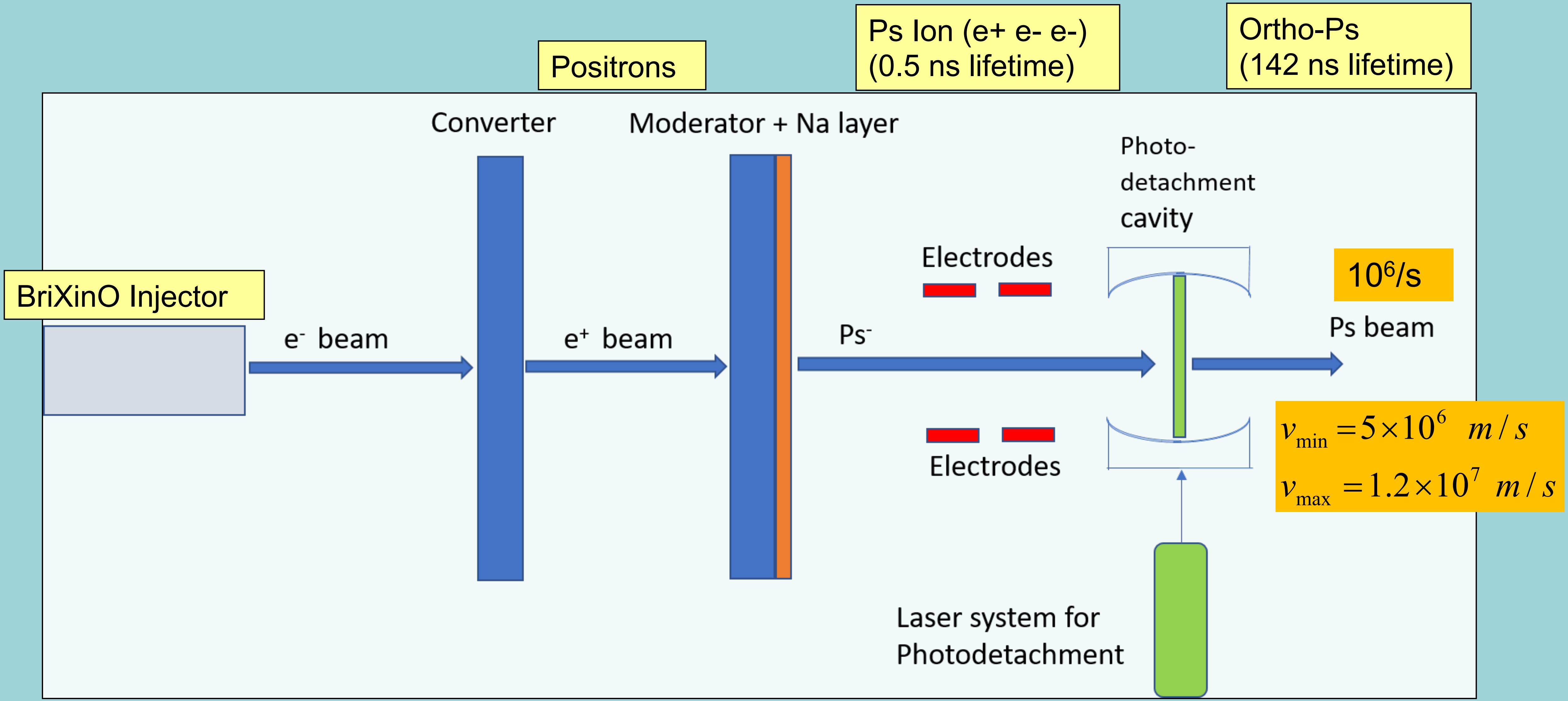


	2025	2026	2027	2028	2029	2030
Approx Funding Profile		10	25	10	10	
Approx Co-Funding Profile	10		10		10	

Measurements

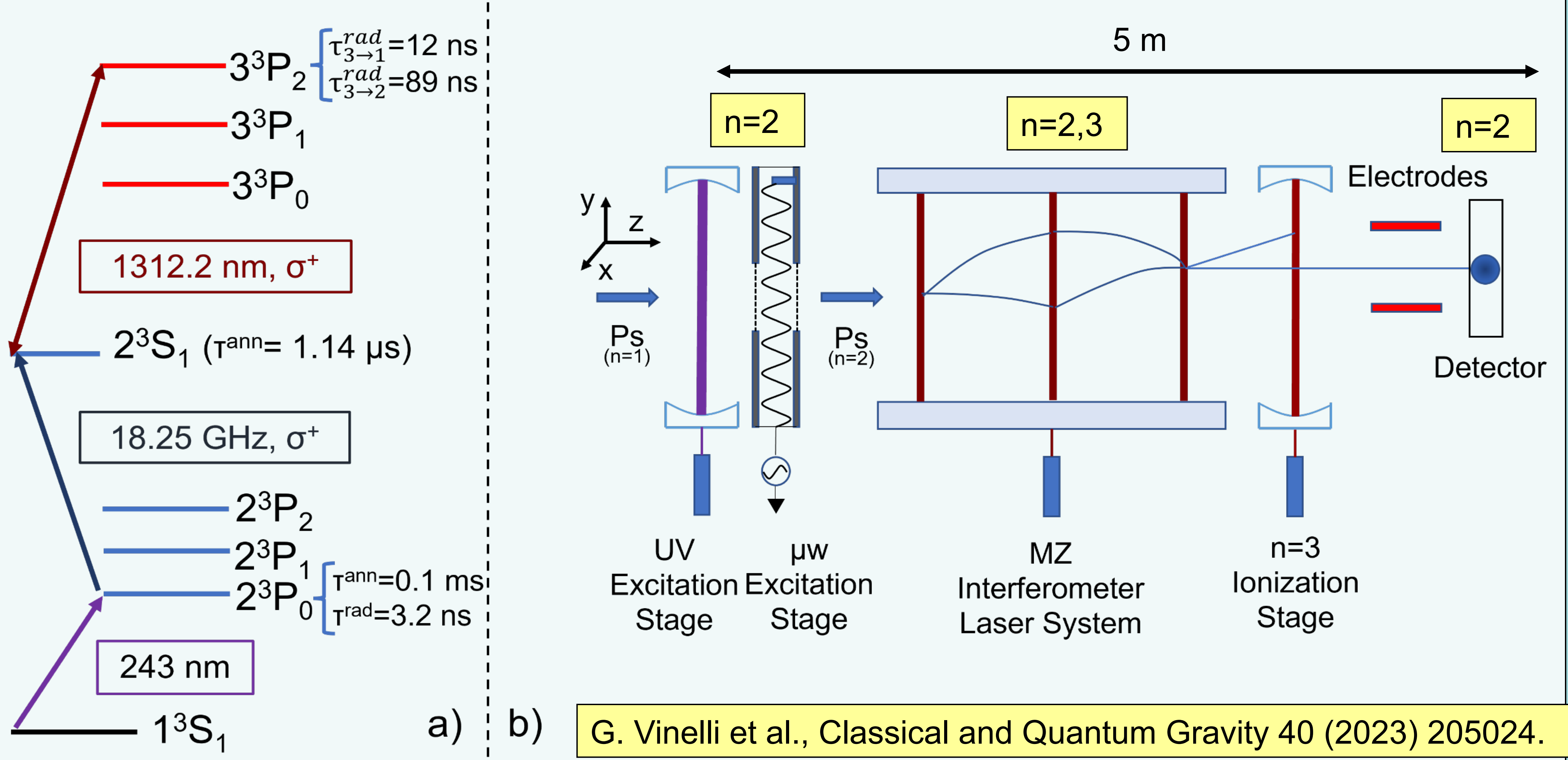
1) Observation of the Quantum Revival Effect
2) Observation of the Aharonov-Bohm Effect for the positron
3) Detection of the “quantum force”

Formation of a Ps (high intensity, good collimation, neutral)



Gravitation: the LMT – Interferometer

$$\Delta\phi = k_{eff}\, g\, T^2$$



G. Vinelli et al., Classical and Quantum Gravity 40 (2023) 205024.

The effect of Gravitation is «written» on the phase of the wave function governing the oscillation between n=2 and n=3 states

$$\Delta\phi = k_{eff}\, g\, T^2$$

The very same technique was used by our group in the MAGIA experiment to measure gravitation with atoms

G. Rosi et al., Nature 510 (2014) 518

Key measurements

4) Demonstration of Ps- ion production

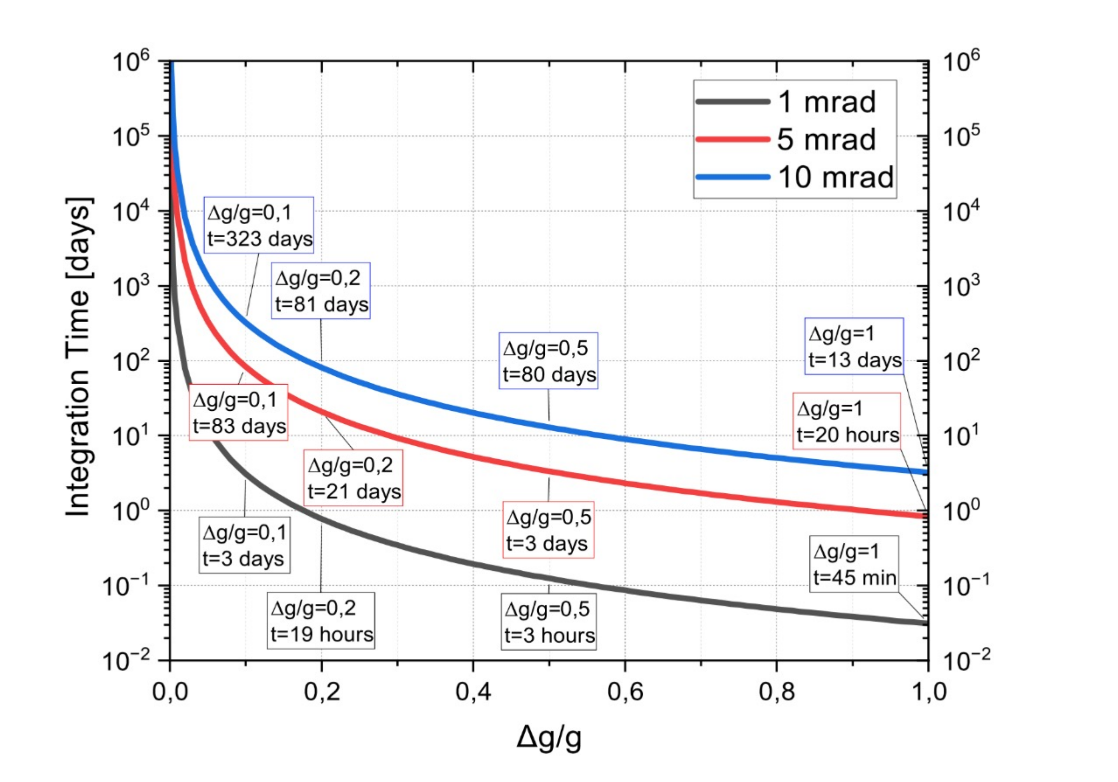
5) Demonstration of photodetachment

6) n=2 excitation system

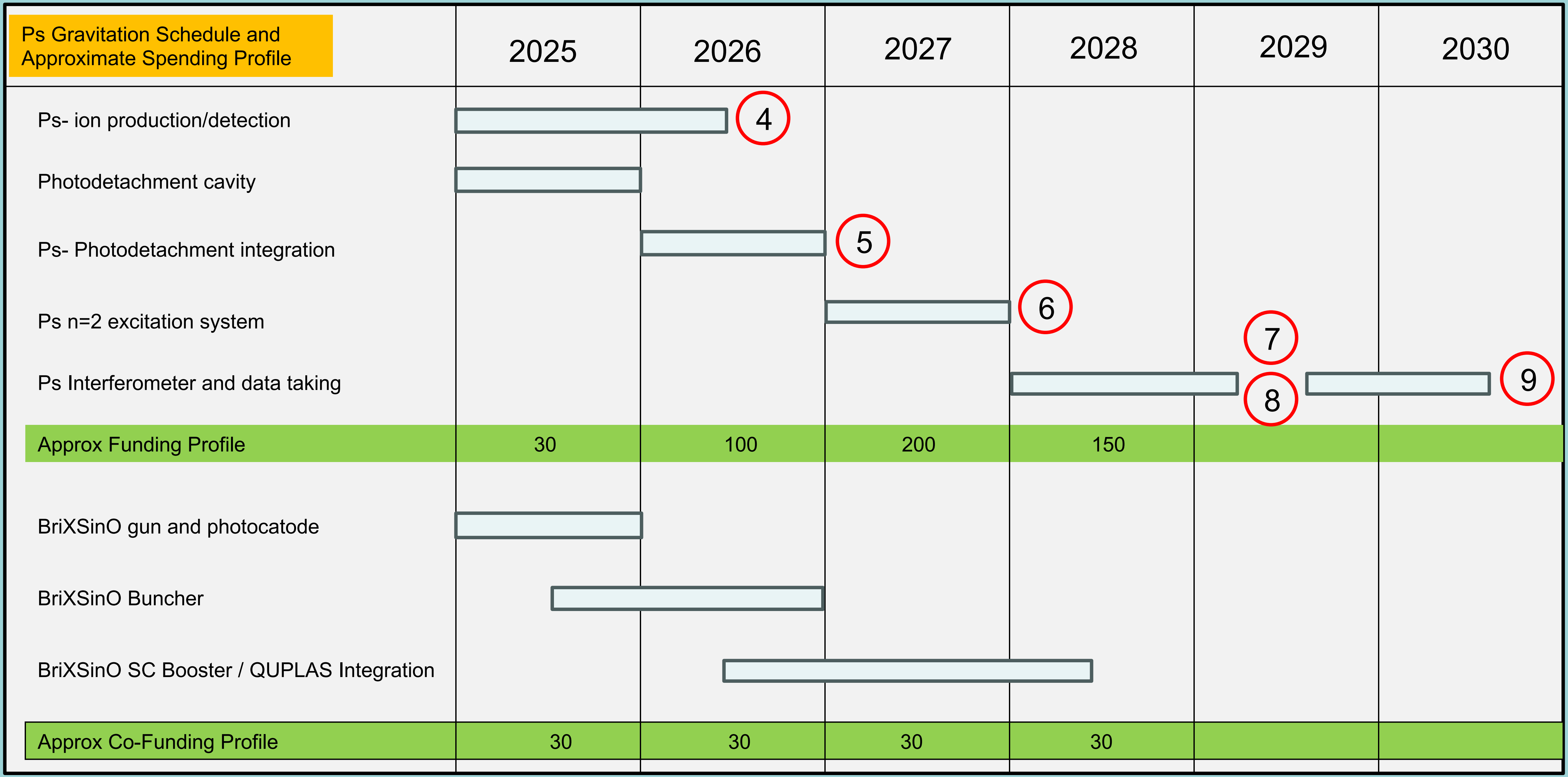
7) Develpoment of the LMT Mach-Zehnder interferometer

8) Ps interferometry demonstration

9) Ps gravitation measurement



Sensitivity diagram as a function of the collimation of the final Ps beam


Ps Gravitation Schedule and Approximate Spending Profile
2025
2026
2027
2028
2029
2030
Ps- ion production/detection
4
Photodetachment cavity
Ps- Photodetachment integration
5
Ps n=2 excitation system
6
7
Ps Interferometer and data taking
8
9
Approx Funding Profile
30
100
200
150
BriXSinO gun and photocatode
BriXSinO Buncher
BriXSinO SC Booster / QUPLAS Integration
Approx Co-Funding Profile
30
30
30
30

QUPLAS

QUPLAS/LEA INFN Group (~4-5 FTE)

Politecnico di Milano @ Como
R. Ferragut, M. Bayo, M. Leone

Univ di Milano & Infn
1 Ass Ric! 1 Phd?
F. Castelli, M. Giammarchi, G. Maero, M. Romé, V. Toso

Univ Firenze & LENS
G. Rosi, L. Salvi, G.M. Tino, G. Vinelli

Univ Bescia, Infn Pavia
S. Migliorati, L. Venturelli

External collaborating Groups

CNR – Istituto Fisica Plasmi Milano
A. Simonetto

Univ Napoli Federico II & LGS
G. De Lellis, N. Dambrosio

A. Asada
Tohu University - Japan

Univ Modena-Reggio, CNR Nanoscience
M. Beleggia, G. Gazzadi, V. Grillo, S. Frabboni, G. Pozzi

INFN BriXinO group at the LASA Laboratory
A. Bacci, S. Cialdi, I. Drebot, D. Giove,
B. L. Serafini, M. Rossetti-Conti

QUPLAS 2024

- Sblocco sj di 35 kEuro + cofinanziamento per sorgente
- 35 + 15 (Polimi-cofin) + 11 (cofin)
- 13.5 kEuro sblocco per Ps- (su 30 richiesti)
- 2 kEuro missioni

Milestone 2024 (end of the year)

Aggancio della cavità per il photodetachment (bassa potenza)

QUPLAS 2025

Missioni

Milano 8 kE:
1) Viaggi a LNGS attività emulsioni 4 kEuro
2) PostDoc viaggi a Firenze 4 kEuro

Firenze: 2 kE viaggi

Apparati

Milano: 25 kE
1) Pompa ionica obsolescente 15
2) Ottica per diagnostica Ps- 10

Firenze: 12 kE
1) 2 Traslatori verticali

Milestones to be reassigned

Completamento cavità photodetachment

Prima evidenza Ps- ?