ÖAW AUSTRIAN ACADEMY OF SCIENCES

SMI - STEFAN MEYER INSTITUTE

20 Years of Stefan Meyer Institute for subatomic Physics

E. Widmann

Director, Stefan Meyer Institute, Vienna

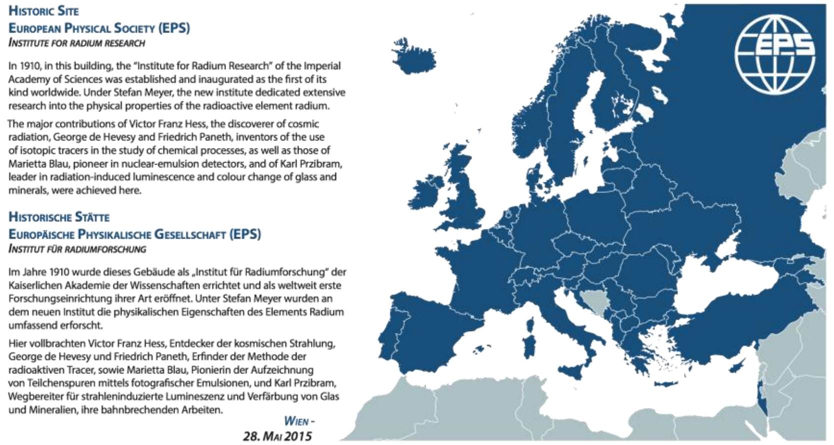
Syposium 20 Years of SMI

Vienna, 11 Nov 2024

Historical note

Stefan Meyer

Boltzmanngasse 3



HISTORIC SITE
EUROPEAN PHYSICAL SOCIETY (EPS)
INSTITUTE FOR RADIUM RESEARCH

In 1910, in this building, the "Institute for Radium Research" of the Imperial Academy of Sciences was established and inaugurated as the first of its kind worldwide. Under Stefan Meyer, the new institute dedicated extensive research into the physical properties of the radioactive element radium.

The major contributions of Victor Franz Hess, the discoverer of cosmic radiation, George de Hevesy and Friedrich Paneth, inventors of the use of isotopic tracers in the study of chemical processes, as well as those of Marietta Blau, pioneer in nuclear-emulsion detectors, and of Karl Przibram, leader in radiation-induced luminescence and colour change of glass and minerals, were achieved here.

HISTORISCHE STÄTTE
EUROPÄISCHE PHYSIKALISCHE GESELLSCHAFT (EPS)
INSTITUT FÜR RADIUMFORSCHUNG

Im Jahre 1910 wurde dieses Gebäude als „Institut für Radiumforschung" der Kaiserlichen Akademie der Wissenschaften errichtet und als weltweit erste Forschungseinrichtung ihrer Art eröffnet. Unter Stefan Meyer wurden an dem neuen Institut die physikalischen Eigenschaften des Elements Radium umfassend erforscht.

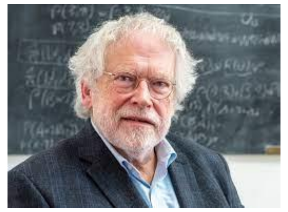
Hier vollbrachten Victor Franz Hess, Entdecker der kosmischen Strahlung, George de Hevesy und Friedrich Paneth, Erfinder der Methode der radioaktiven Tracer, sowie Marietta Blau, Pionierin der Aufzeichnung von Teilchenspuren mittels fotografischer Emulsionen, und Karl Przibram, Wegbereiter für strahleninduzierte Lumineszenz und Verfärbung von Glas und Mineralien, ihre bahnbrechenden Arbeiten.

WIEN - 28. MAI 2015

Viktor Franz Hess
Nobelpreis 1936

Georg v. Hevesy
Nobelpreis 1943

A. Zeilinger
Nobelpreis 2022



- 1910 „**Institut für Radiumforschung**"
  - Boltzmanngasse 3
  - Stefan Meyer was first director
  - Nobel prizes
    - V. Hess (physics): cosmic rays
    - G.v. Hevesy (chemistry): tracer method
    - A. Zeilinger, IQOQI (physics): quantum physics
- 1987 Renamed to „**Institute for Medium Energy Physics**"
- 2004: Institute renamed to "**Stefan Meyer Institute for Subatomic Physics**"
- ***2024: Symposium 20 years***

2021 → Kegelgasse

2023 → PSK

Beginning of SMI: renaming ceremony 29 Oct 2004

- Symposium in Theatersaal
  - In presence of Pierre Radvanyi, Hélène Langevin-Curie and many colleagues

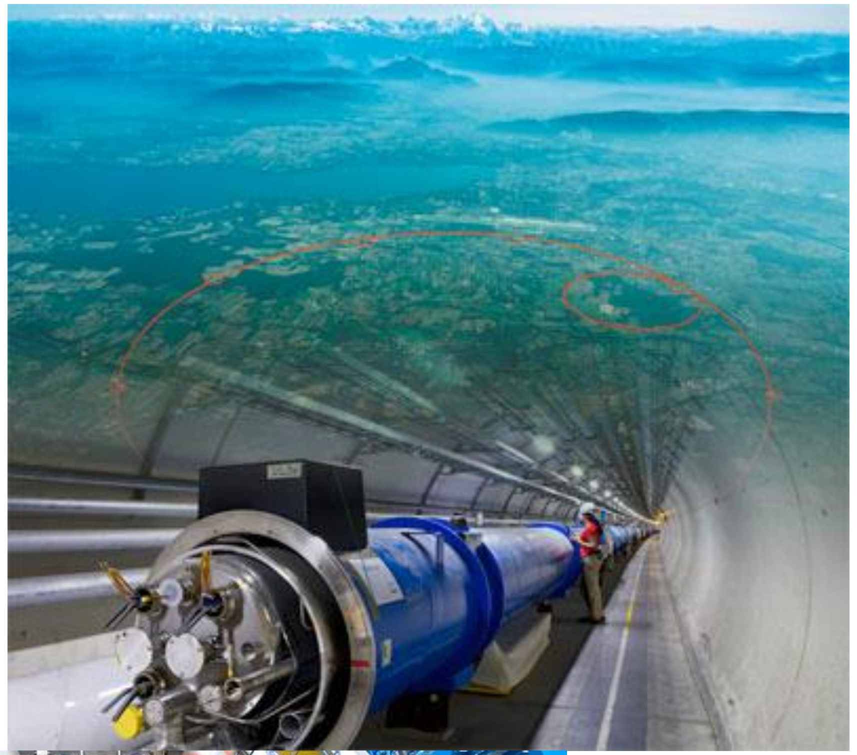
- Unveiling of Honour Plaque in Boltzmanngasse 3

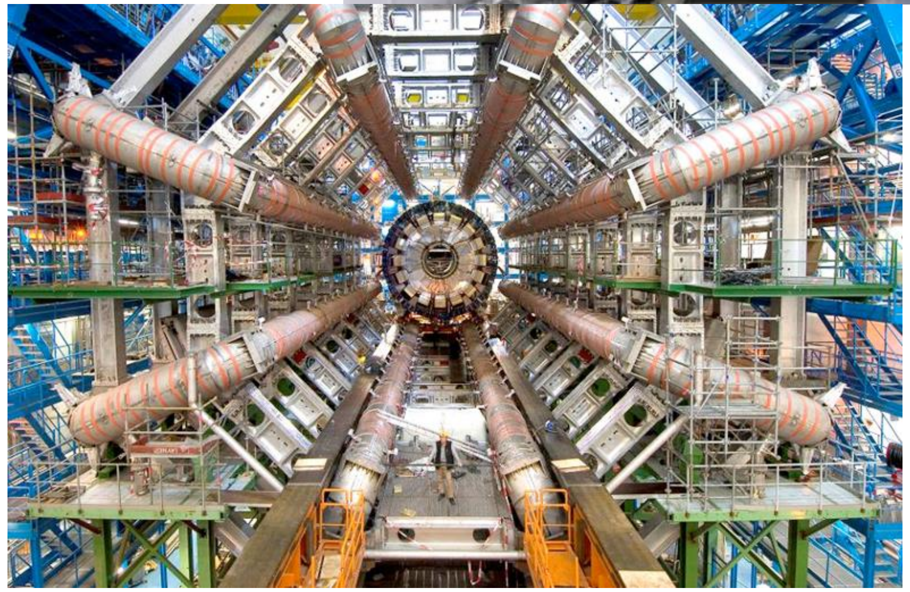
SMI Physics Programme

Fundamental Interactions and Symmetries

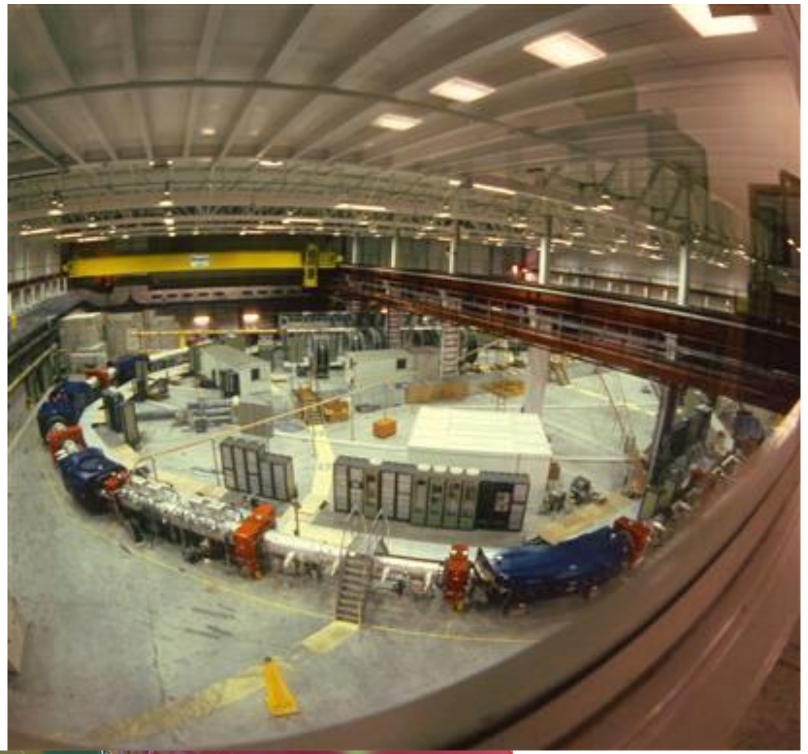
New knowledge in subatomic physics

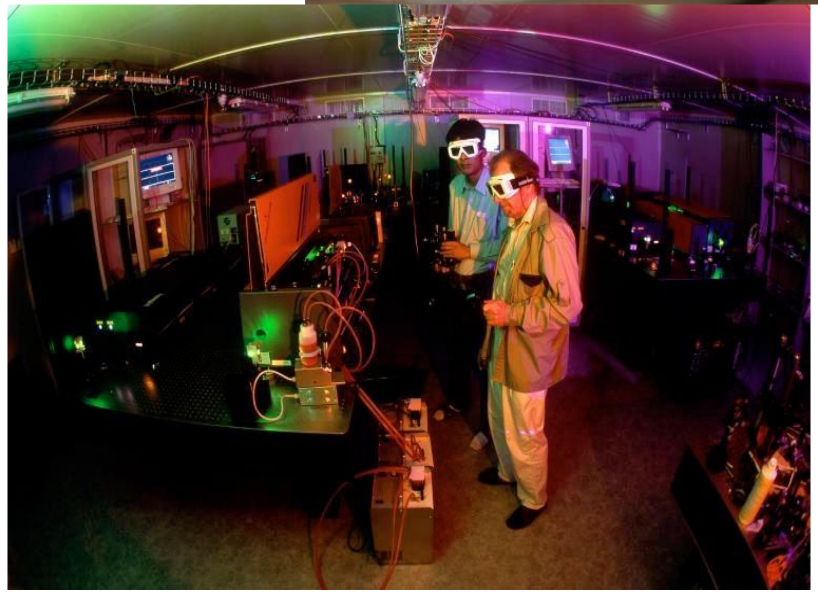
- High energies
  - *Direct observation*





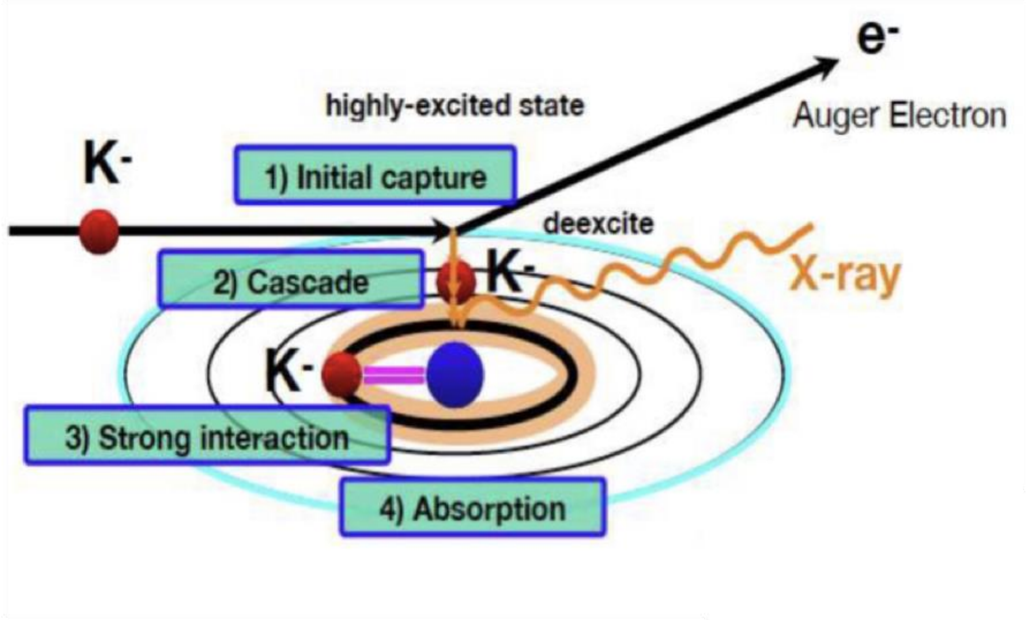
- Low energies
  - *Precision experiments*



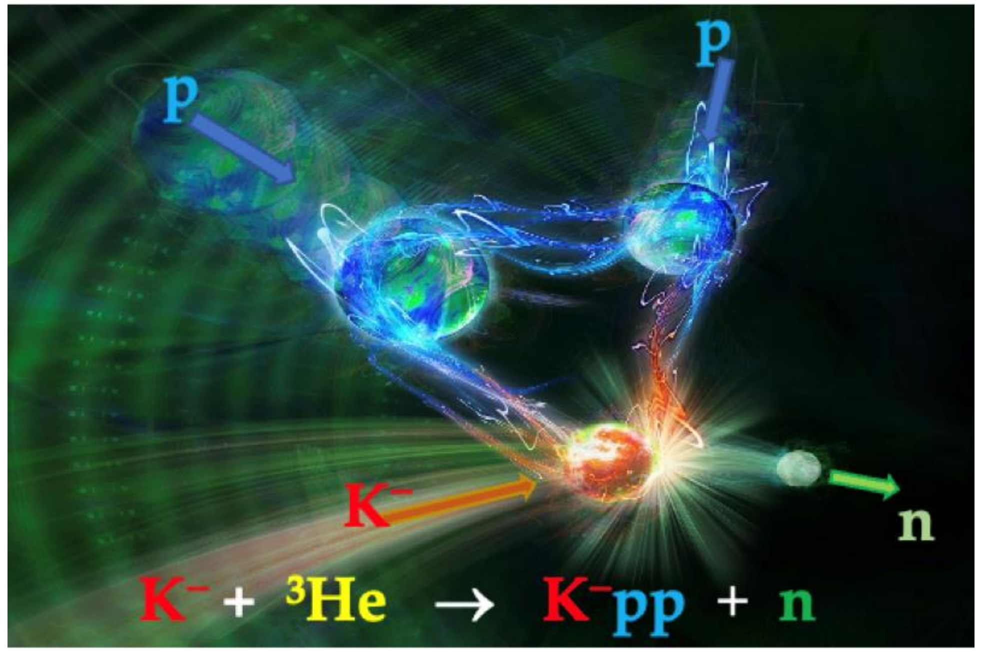


Strong interaction in the non-perturbative regime

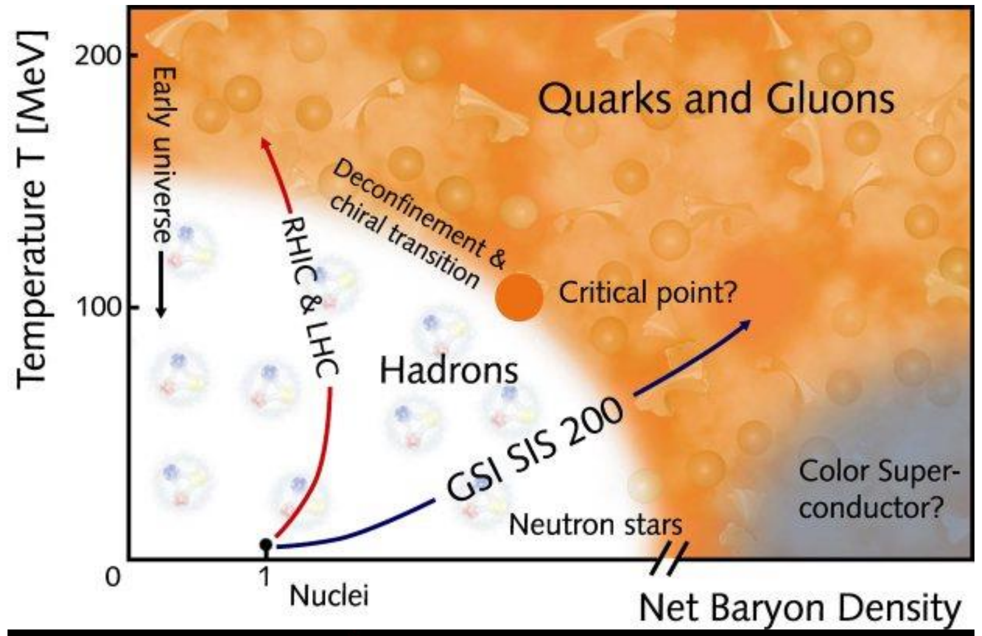
- Kaonic atom

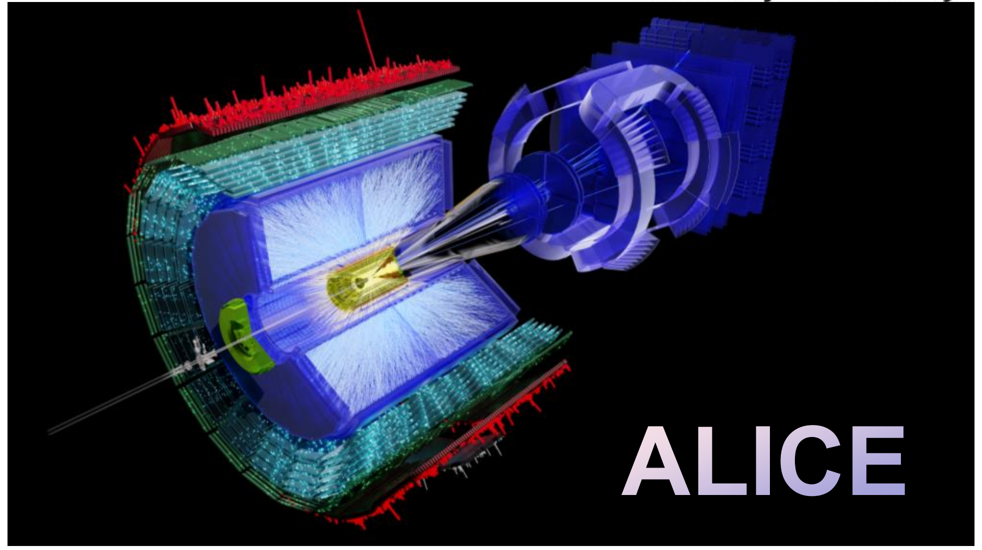


- Kaon nucleon bound states



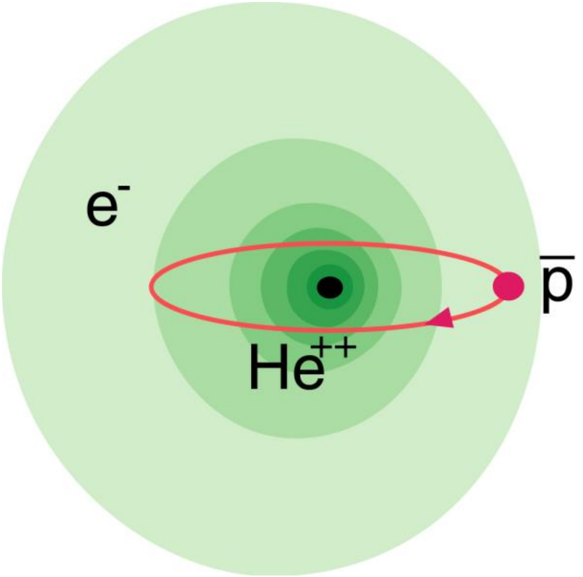
- Phase diagram of strongly interacting matter





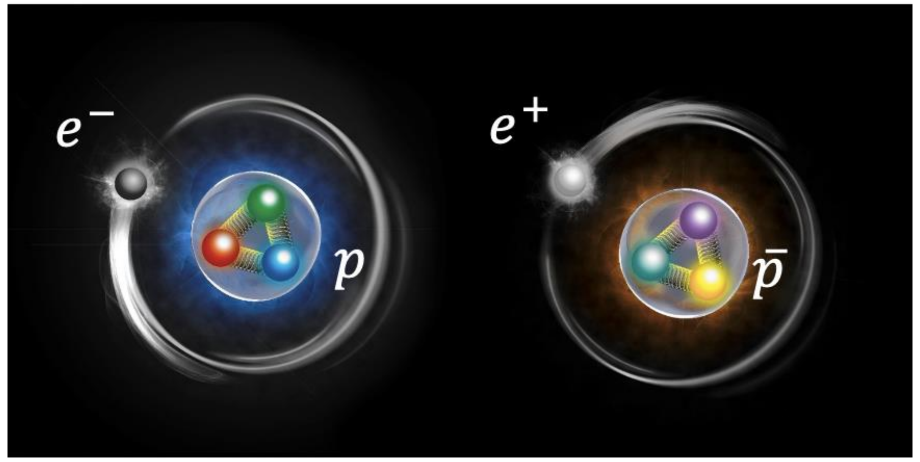
SMI: exotic atoms to study fundamental symmetries and interactions

Antiprotonic helium



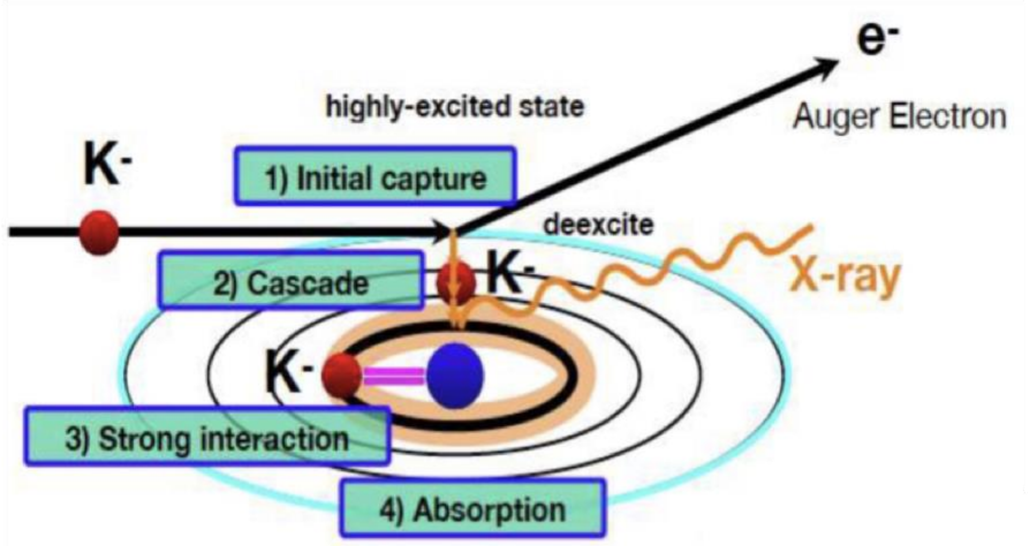
Three-body matter-antimatter system
Easy to make, difficult to calculate
No strong interaction: QED
laser spectroscopy: $m_{\bar{p}}/m_e$, CPT

Antihydrogen



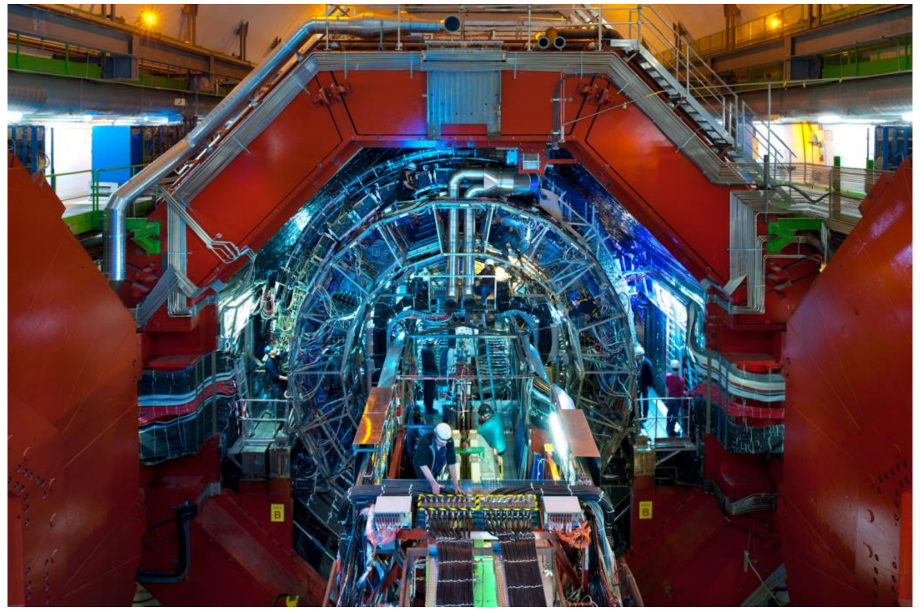
Two-body pure antimatter system
Difficult to make, easy to calculate
Laser & microwave spectroscopy
CPT, QED

Kaonic hydrogen



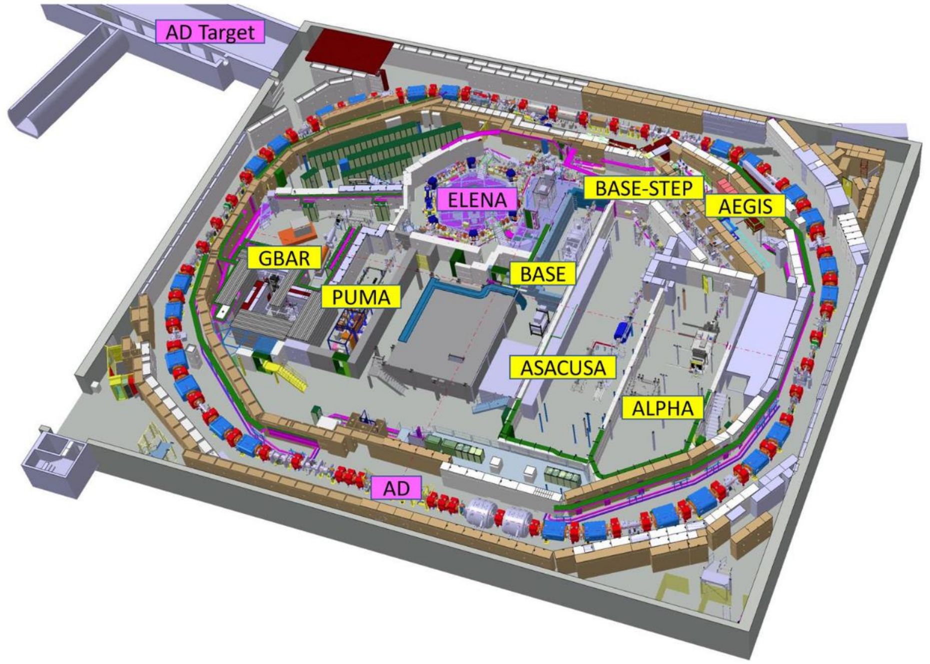
Two-body matter-antimatter system
Easy to make, difficult to calculate
X-ray spectroscopy
QCD

International accelerator labs



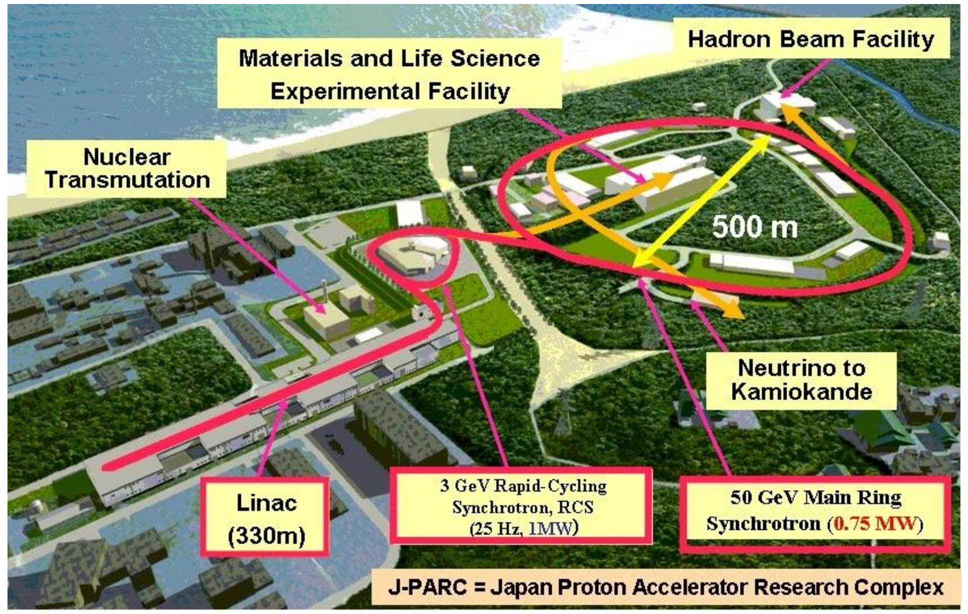
ALICE
@CERN-LHC

DAΦNE
@LNF
Frascati



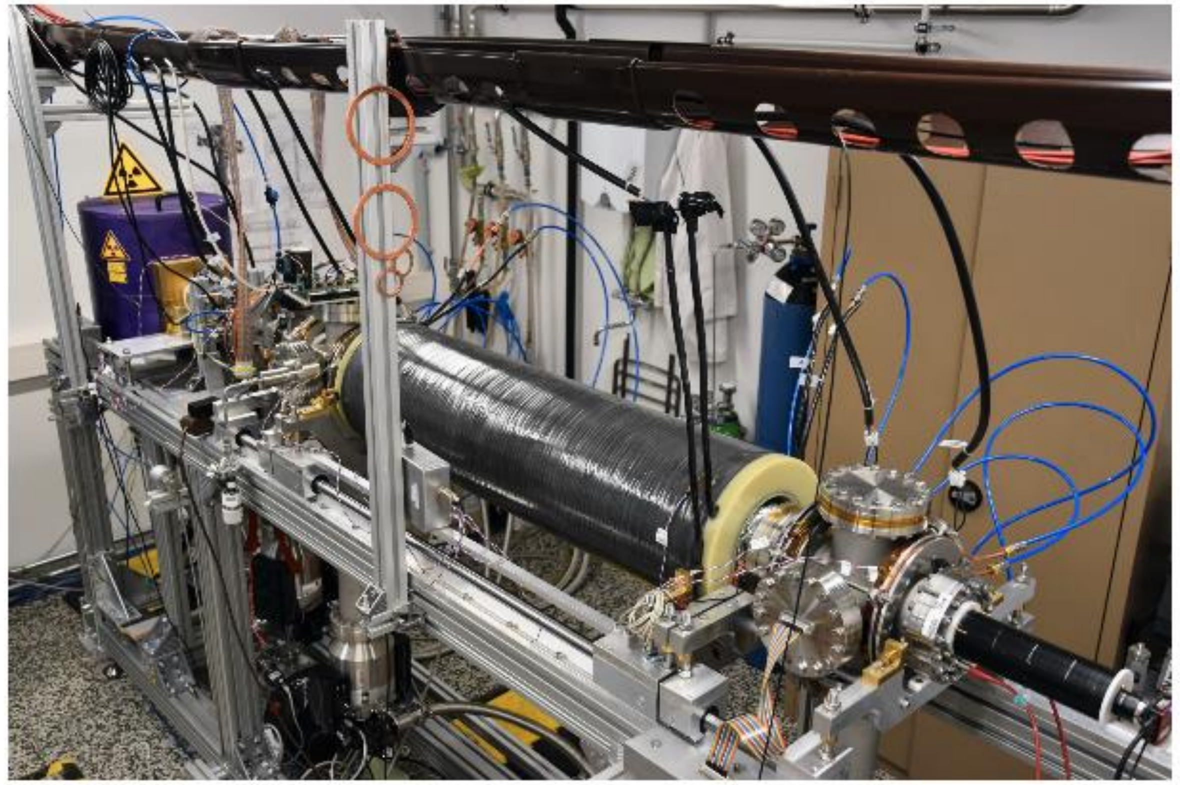
AD/ELENA
@CERN

J-PARC
@Tokai

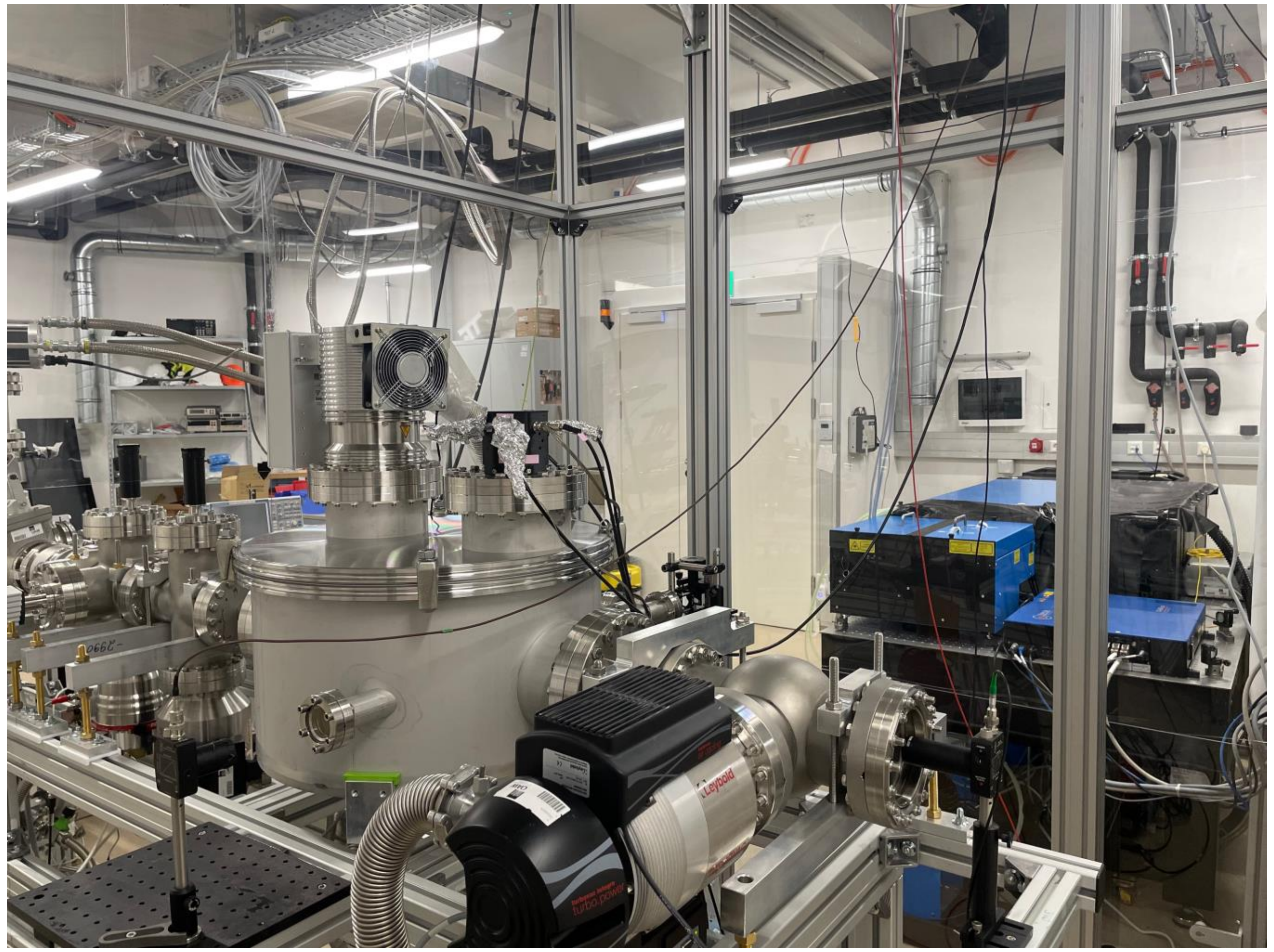


Since move to Kegelgasse: on site experiments

- Positron lab
  - Still located in Kegelgasse



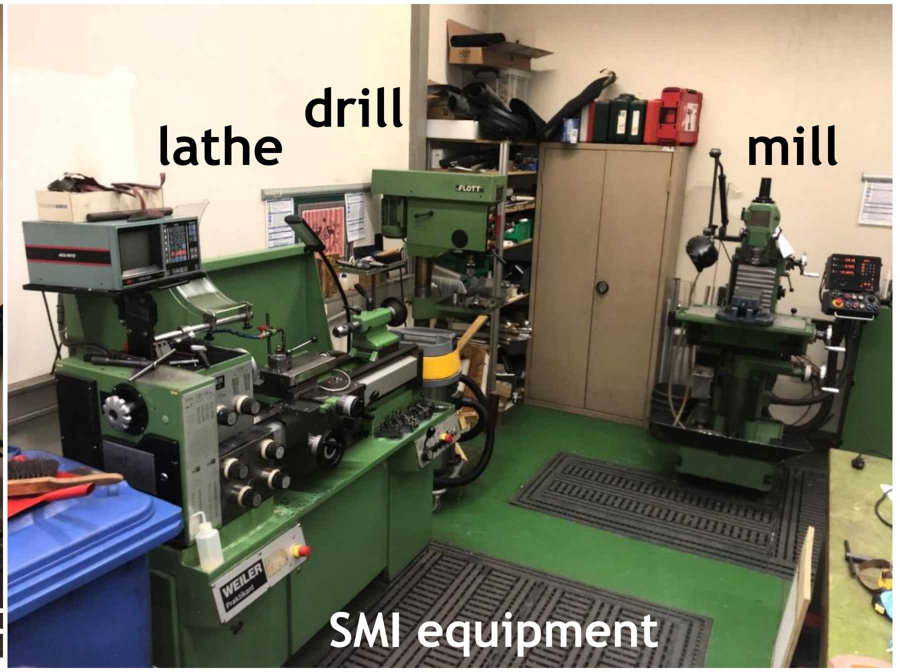
- Hydrogen and deuterium beams



PSK: joint Cryolab with HEPHY

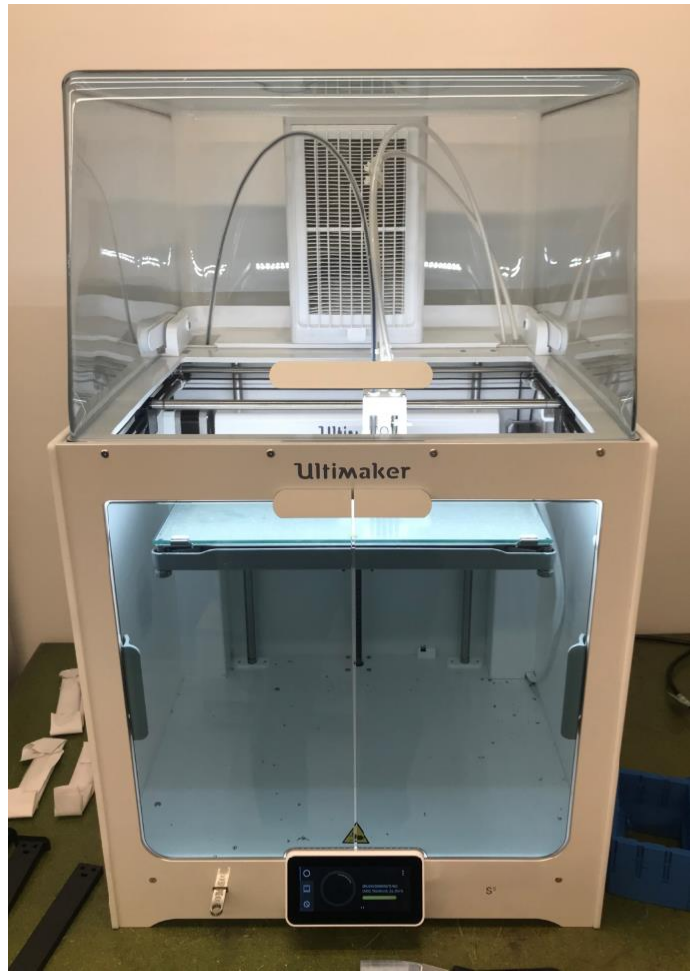
Advanced instrumentation: infrastructure

Mechanical workshop



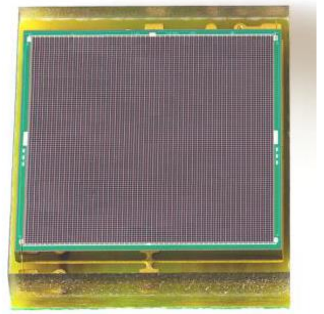
Still in Boltzmanngasse 3
to move 2025 to PSK

Additive manufacturing



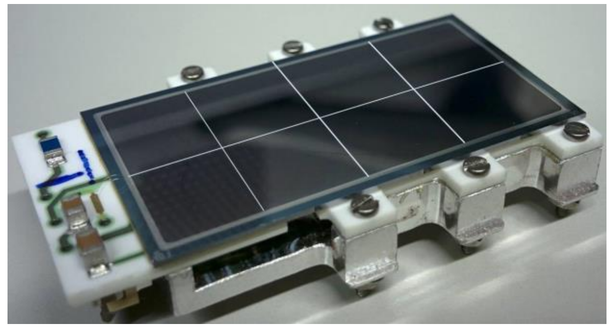
Advanced instrumentation: detectors and experimental setups

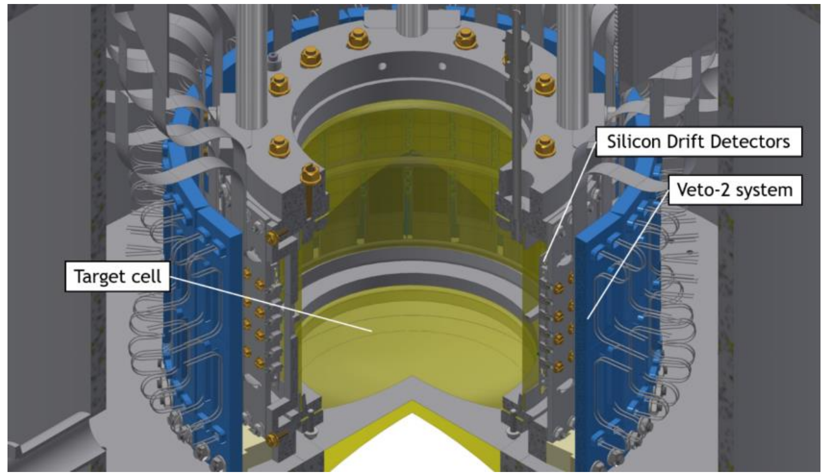
SiPM



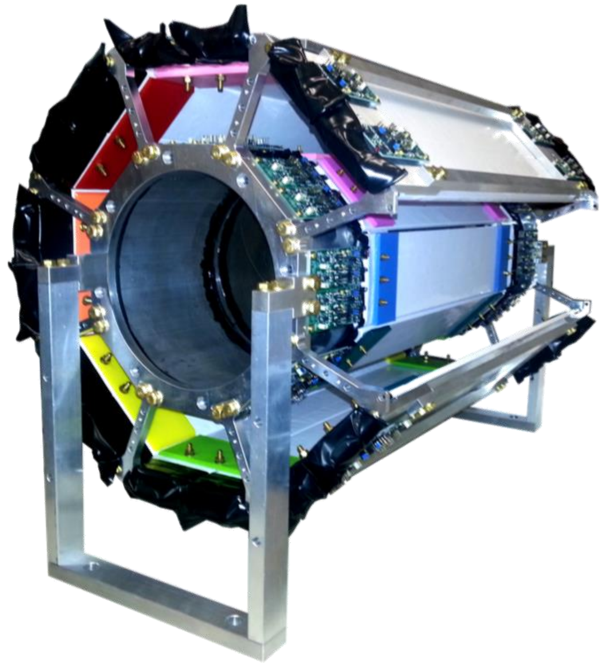
SiPM electronics

SDD

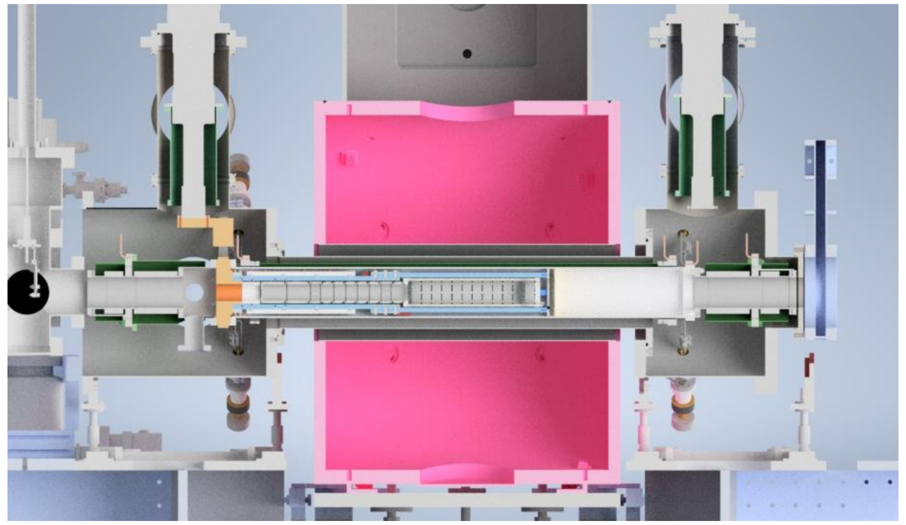




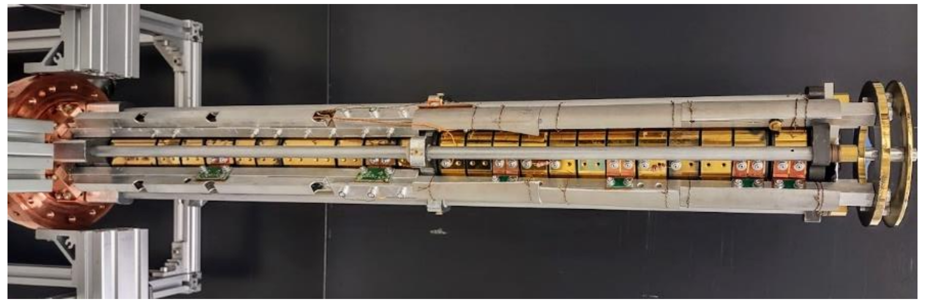
SIDDHARTA-2



Hodoscope



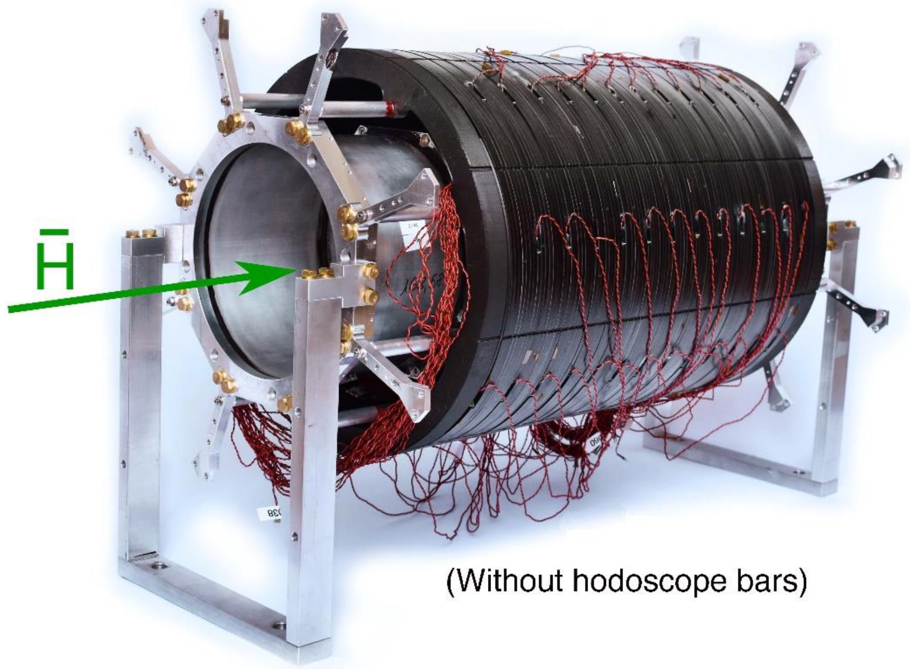
ASACUSA cold bore



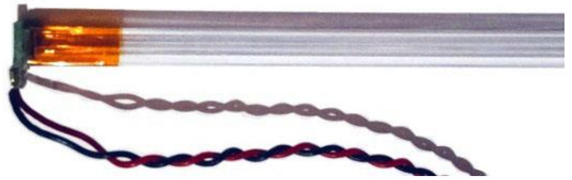
ASACUSA Penning trap

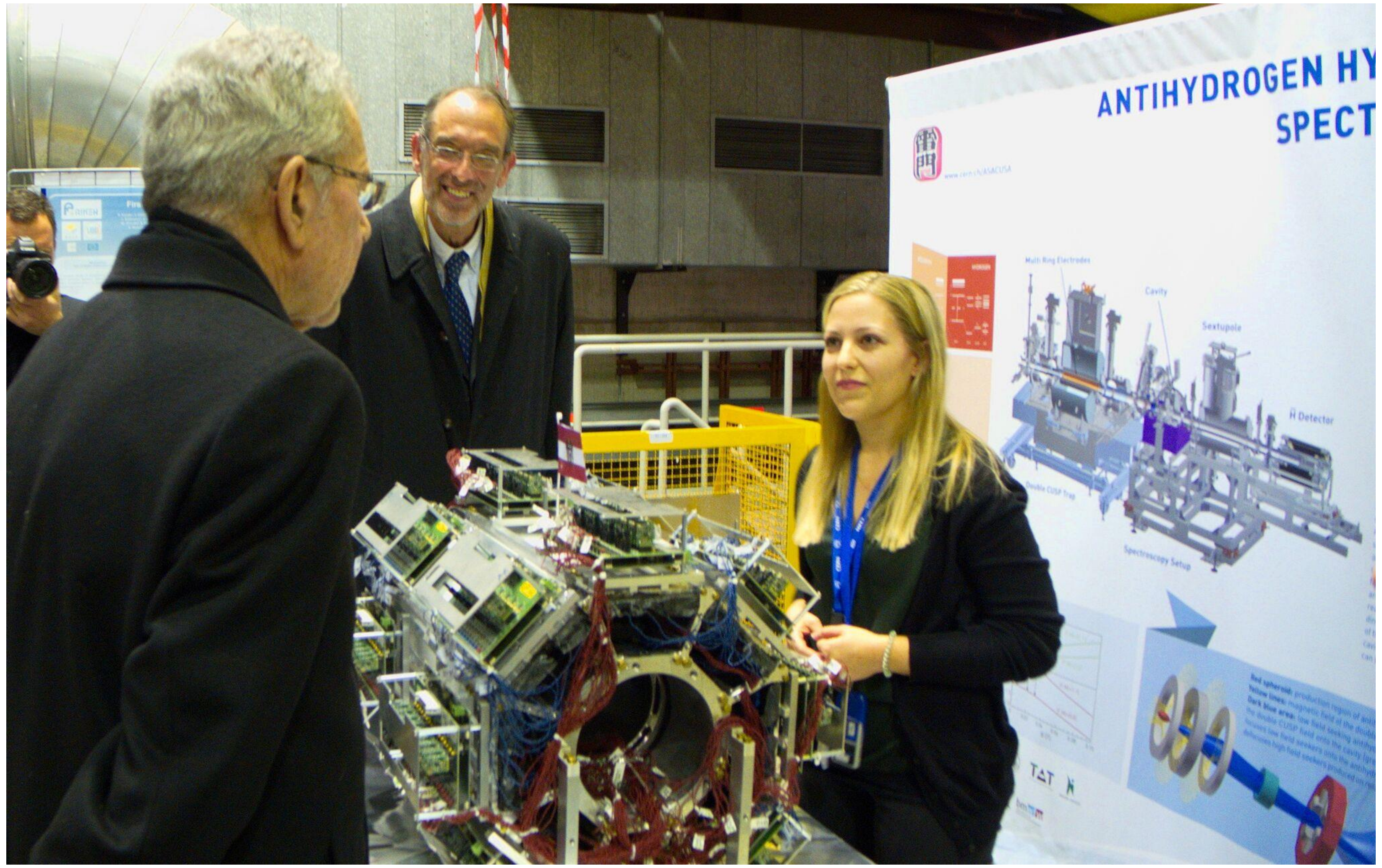
Advanced instrumentation

- Asacusa hodoscope
  - Scintillators, scint. Fibers, SiPM
- Central BGO disk
- Machine learning:
  - Cosmics rejection
    99,7%
  - False positive rate:
    $0.0039\ s^{-1}$
  - $\bar{p}$ efficiency ~ 80%



(Without hodoscope bars)



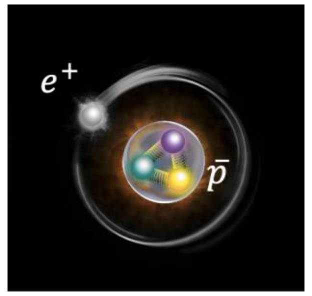


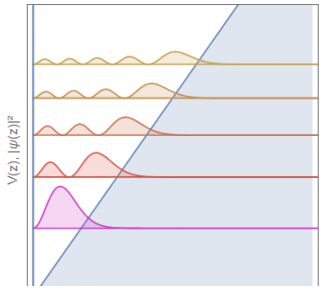
Physics program overview

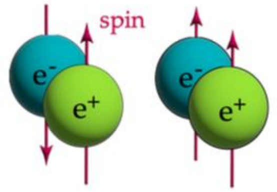
- **Low energy precision experiments** EW, D. Murtagh, M. Simon (50%)
  - ASACUSA@CERN: Antihydrogen hyperfine structure, H and D beams: *CPT & Lorentz invariance tests* ERC 2012

2017~ • GRASIAN: GRAvity, Spectroscopy and Interferometry with ultra-cold Atoms and Neutrons: *ultra-cold H: short-range forces, precision laser and microwave spectroscopy*

2018~ • Positron laboratory: *molecular states involving positronium*, move to PSK in Dec 2024



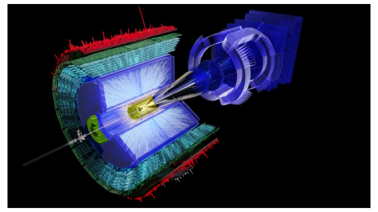


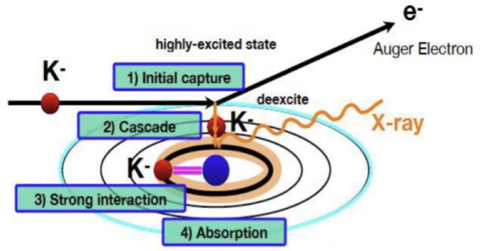


- **Hadron physics** D. Dobrigkeit Chinnellato, P. Bühler

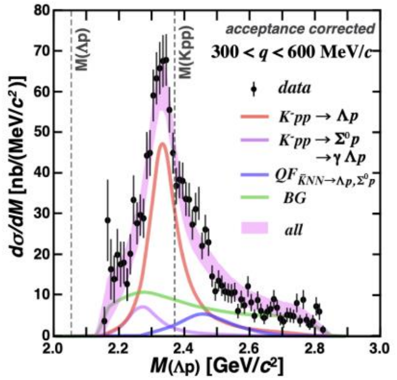
2015~ • ALICE: *Quark Gluon Plasma,* NFG 2015

  - SIDDHARTA-2@LNF, *strong interaction studies at low energies,* J. Zmeskal †
    - E57@J-PARC: *K^-d X-rays,*
    - J-PARC E31 Λ(1405), E15 *K^-pp* finished, E80@J-PARC $\bar{K}$NNN





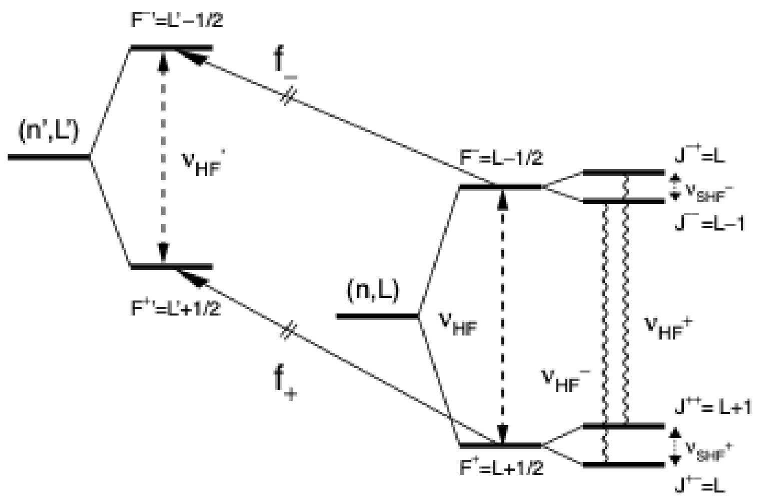
- **Advanced Instrumentation** (service unit) M. Simon (50%)

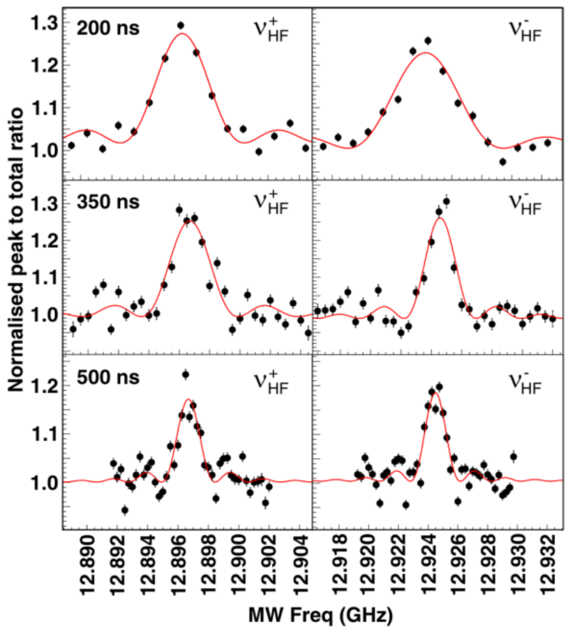


Projects since 2004, *others (PANDA, VIP, NoMoS NFG 2015 discontinued)*

ASACUSA: antiprotonic He hyperfine spectroscopy

- $\bar{p}^4$He: determination of $\bar{p}$ magnetic moment (2009)



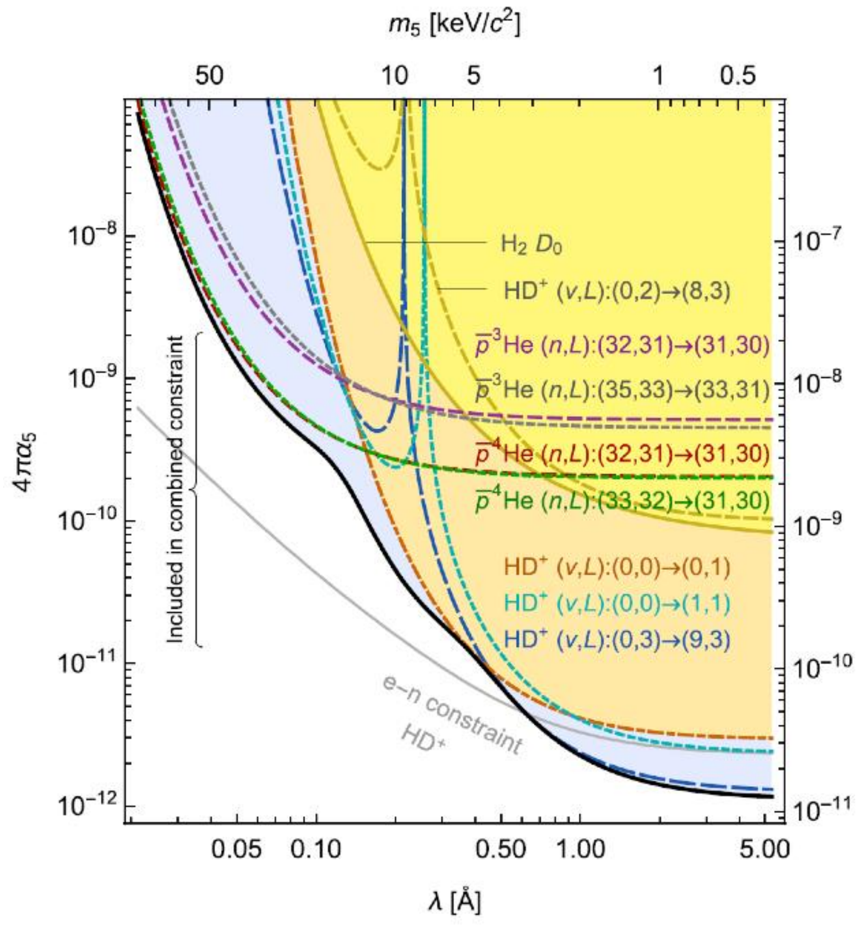


$$\frac{\mu_p - |\mu_{\bar{p}}|}{\mu_p} = (2.4 \pm 2.9) \times 10^{-3}.$$

- $\bar{p}^3$He (2011)
  - Limits on spin-dependent exotic forces

F. Ficep et al., PRL 120, 183002 (2018)

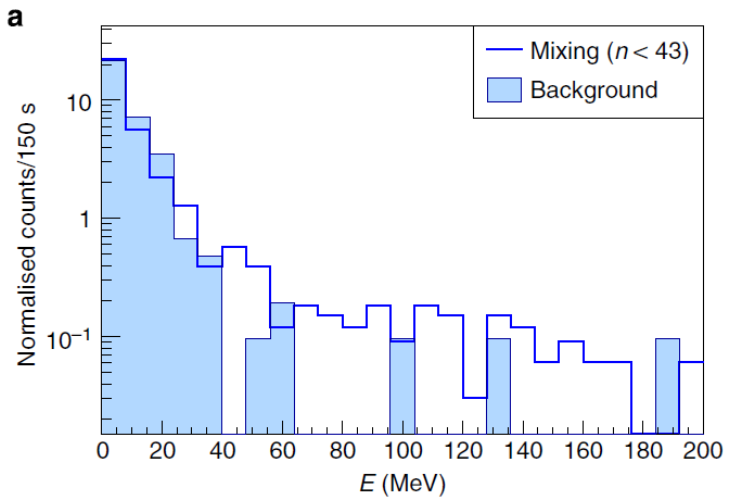
- Limits on 5th force



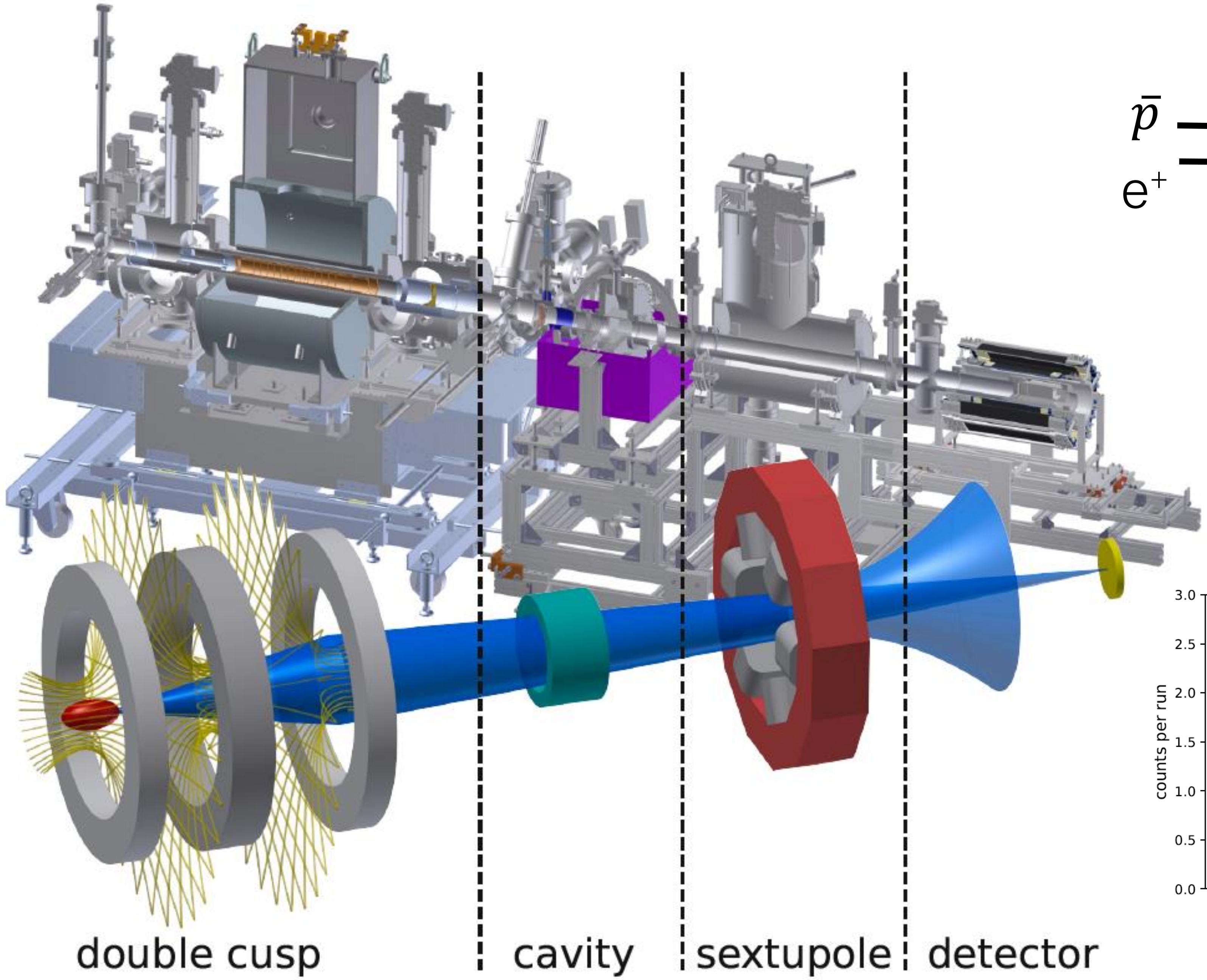
M. Germann et al., Phys Rev Research 3, L022028 (2021)

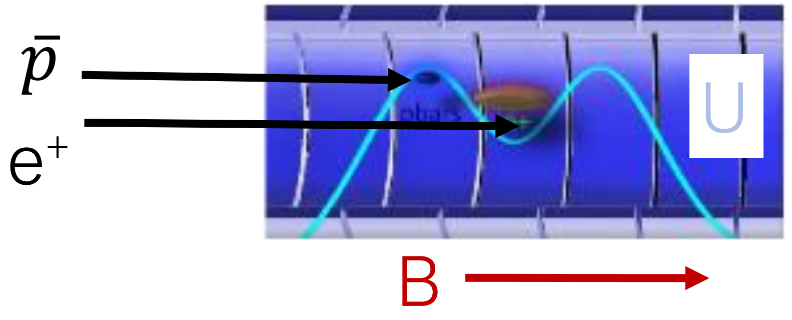
ASACUSA antihydrogen beam for HFS

- $\overline{\mathrm{H}}$ production 1st time in **2010** in nested Penning trap
  - Three body recombination (→Rydberg states)
- 1st observation of beam in field free region **2014**
  - n≤43: 6 $\overline{H}$/15 min
  - n≤29: 4 $\overline{H}$/15 min

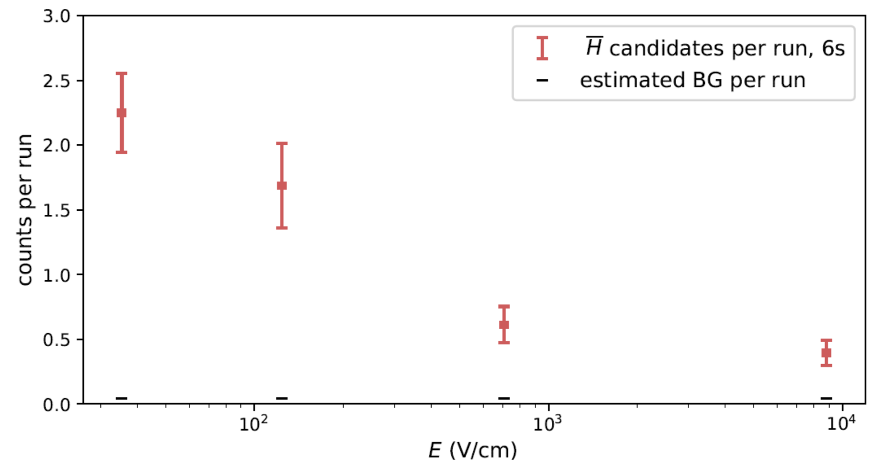


N. Kuroda et al, *Nat. Commun.* **5,** 3089 (2014).





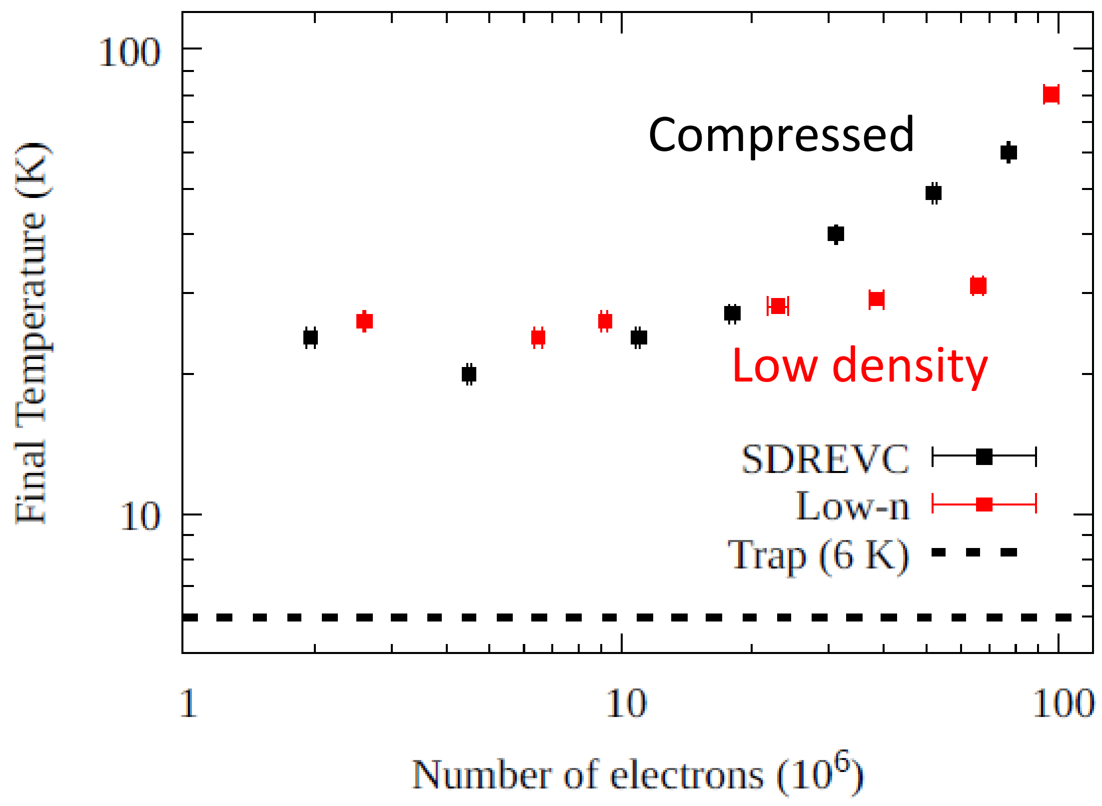
- Measurement of n distribution **2021**



B. Kolbinger et al. *EPJ D* 75, (2021) 91.

Recent milestones

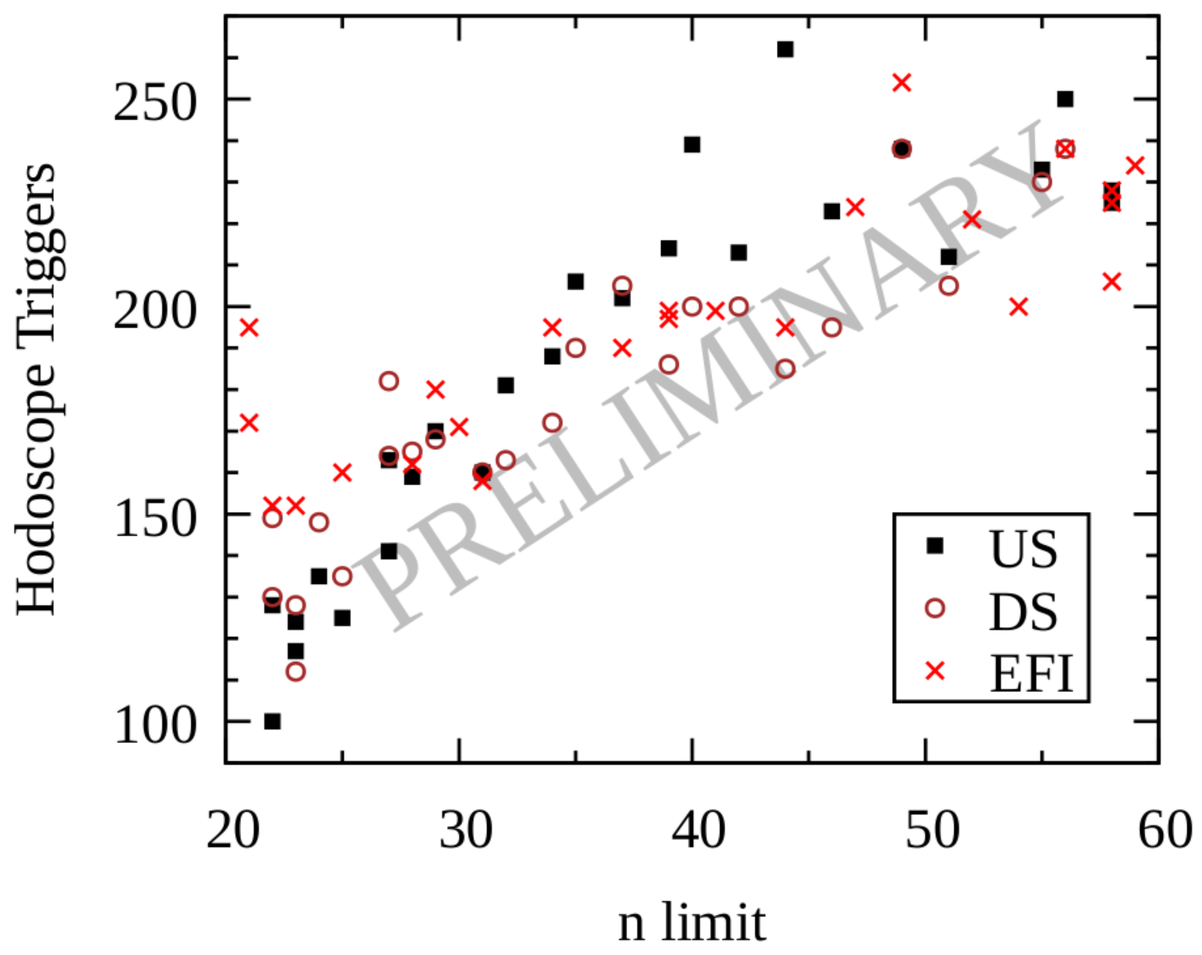
- 100 K colder electron plasmas compared to before



E. Hunter et al. EPJ Web Conf. 262 01007 (2022)
C. Amsler et al. arXiv:2203.14890 [physics.plasm-ph]

- Quantum number distribution of $\bar{H}$

- Factor 100 increase
- Clear beam component observed



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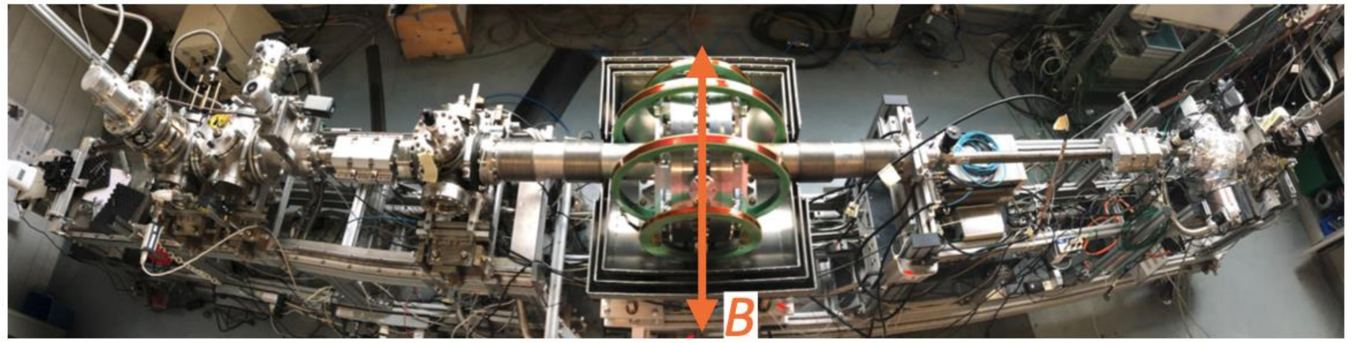
Hydrogen and Deuterium beam experiments

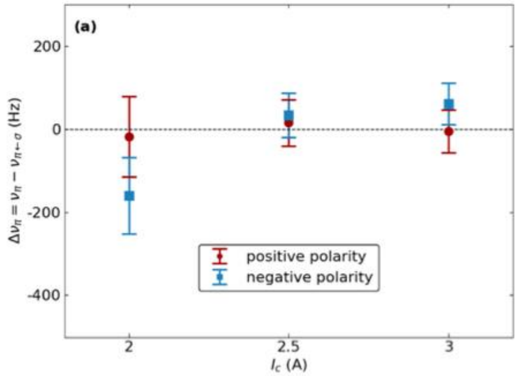
Hydrogen beam: orientation dependence



π transition

- $\nu_\pi(\vec{B}) - \nu_\pi(-\vec{B})$ is proportional to SME coefficients
  V.A.Kostelecký & A.J. Vargas, PRD 92, 056002, (2015).
  - Error 51 Hz
- Simultaneous measurement of ν_σ, ν_π yields improved value for zero field hyperfine splitting
  - $\delta\nu_{HF} = 0.63$ Hz (440 ppt)

I_c	2.0 A	2.5 A	3.0 A
B_{stat}	0.46 mT	0.57 mT	0.68 mT



Coefficient $\mathcal{K}$	Constraint on $\lvert\mathcal{K}\rvert$
proton	
$H^{NR(0B),Sun}_{p010}, g^{NR(0B),Sun}_{p010}$	$< 1.2\times10^{-21}$ GeV
$H^{NR(1B),Sun}_{p010}, g^{NR(1B),Sun}_{p010}$	$< 5.8\times10^{-22}$ GeV
$H^{NR(0B),Sun}_{p210}, g^{NR(0B),Sun}_{p210}$	$< 8.4\times10^{-11}$ GeV^{-1}
$H^{NR(1B),Sun}_{p210}, g^{NR(1B),Sun}_{p210}$	$< 4.2\times10^{-11}$ GeV^{-1}
$H^{NR(0B),Sun}_{p410}, g^{NR(0B),Sun}_{p410}$	< 1.2 GeV^{-3}
$H^{NR(1B),Sun}_{p410}, g^{NR(1B),Sun}_{p410}$	< 0.6 GeV^{-3}
electron	
$H^{NR(0B),Sun}_{e010}, g^{NR(0B),Sun}_{e010}$	$< 7.7\times10^{-19}$ GeV
$H^{NR(1B),Sun}_{e010}, g^{NR(1B),Sun}_{e010}$	$< 3.8\times10^{-19}$ GeV
$H^{NR(0B),Sun}_{e210}, g^{NR(0B),Sun}_{e210}$	$< 5.5\times10^{-8}$ GeV^{-1}
$H^{NR(1B),Sun}_{e210}, g^{NR(1B),Sun}_{e210}$	$< 2.8\times10^{-8}$ GeV^{-1}
$H^{NR(0B),Sun}_{e410}, g^{NR(0B),Sun}_{e410}$	$< 8.0\times10^{2}$ GeV^{-3}
$H^{NR(1B),Sun}_{e410}, g^{NR(1B),Sun}_{e410}$	$< 4.0\times10^{2}$ GeV^{-3}

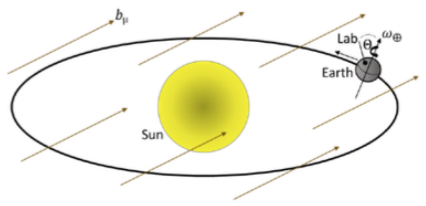
First limits on this type of coefficients
Nowak, L. et al. arXiv.2403.17763

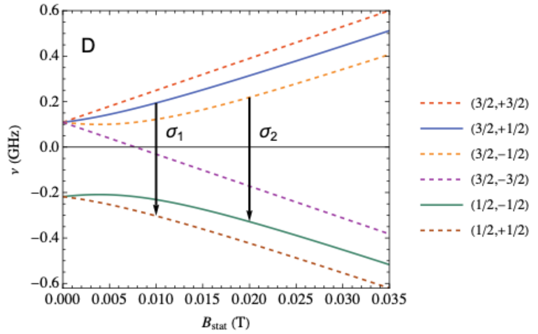
Deuterium beam: sidereal variations

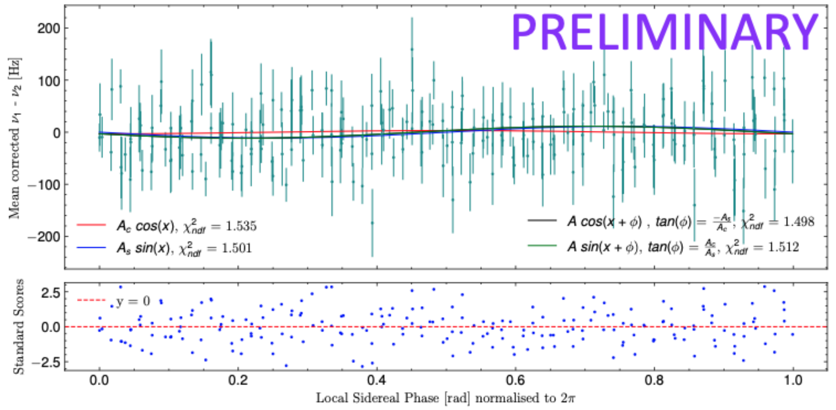
LABORATOIRE Aimé Cotton — cnrs PHYSIQUE — université PARIS-SACLAY

Deuterium hyperfine structure

- Increased sensitivity due to relative momentum p-n in d
- Important for coefficients at higher order in momentum







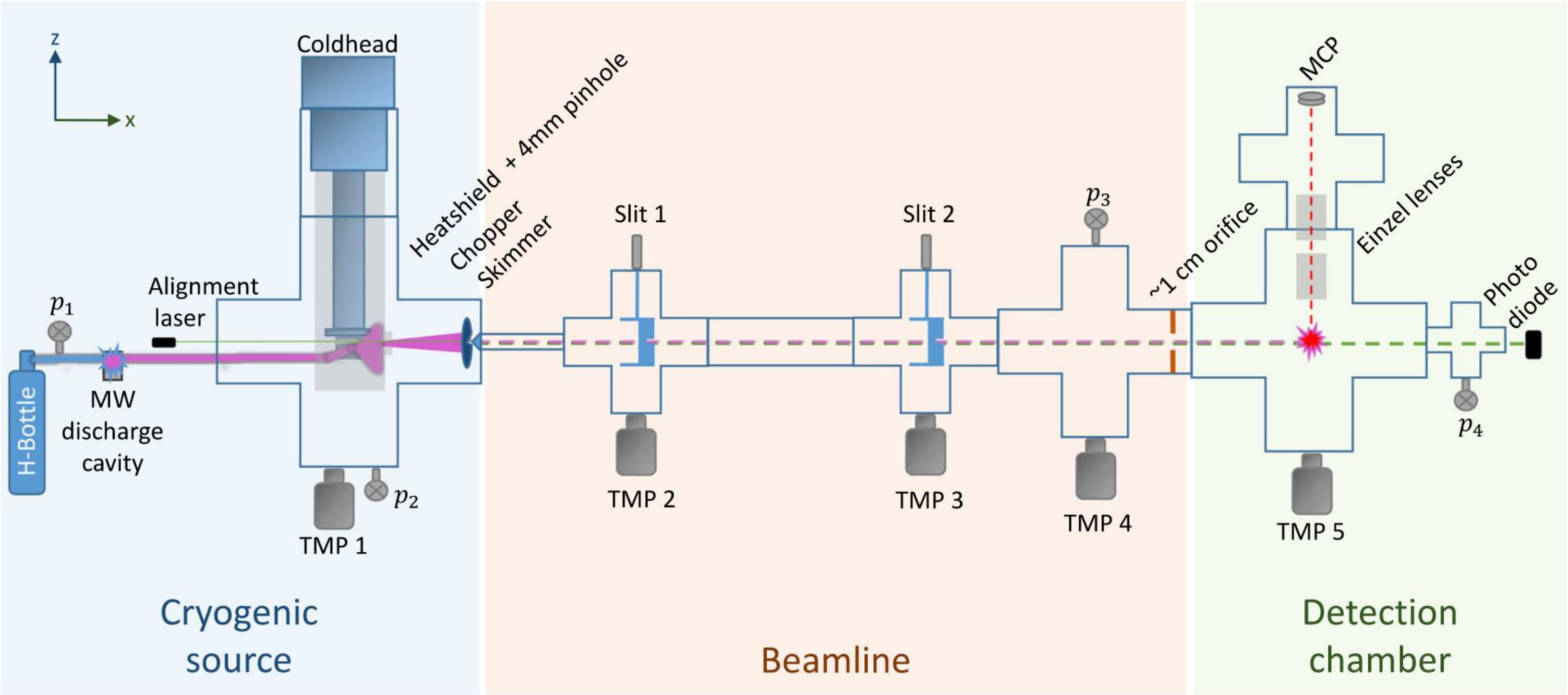
Coefficient $\mathcal{K}$	Constraint on $\lvert\mathrm{Re}\,\mathcal{K}\rvert, \lvert\mathrm{Im}\,\mathcal{K}\rvert$
$H^{NR(0B),Sun}_{w011}, g^{NR(0B),Sun}_{w011}$	$< 4\times10^{-22}$ GeV
$H^{NR(1B),Sun}_{w011}, g^{NR(1B),Sun}_{w011}$	$< 2\times10^{-22}$ GeV
$H^{NR(0B),Sun}_{w211}, g^{NR(0B),Sun}_{w211}$	$< 3\times10^{-20}$ GeV^{-1}
$H^{NR(1B),Sun}_{w211}, g^{NR(1B),Sun}_{w211}$	$< 6\times10^{-20}$ GeV^{-1}
$H^{NR(0B),Sun}_{w411}, g^{NR(0B),Sun}_{w411}$	$< 7\times10^{-20}$ GeV^{-3}
$H^{NR(1B),Sun}_{w411}, g^{NR(1B),Sun}_{w411}$	$< 2\times10^{-19}$ GeV^{-3}
$c^{NR,Sun}_{w221}, a^{NR,Sun}_{w221}$	$< 4\times10^{-20}$ GeV^{-1}
$c^{NR,Sun}_{w222}, a^{NR,Sun}_{w222}$	$< 6\times10^{-20}$ GeV^{-1}
$c^{NR,Sun}_{w421}, a^{NR,Sun}_{w421}$	$< 2\times10^{-19}$ GeV^{-3}
$c^{NR,Sun}_{w422}, a^{NR,Sun}_{w422}$	$< 4\times10^{-19}$ GeV^{-3}

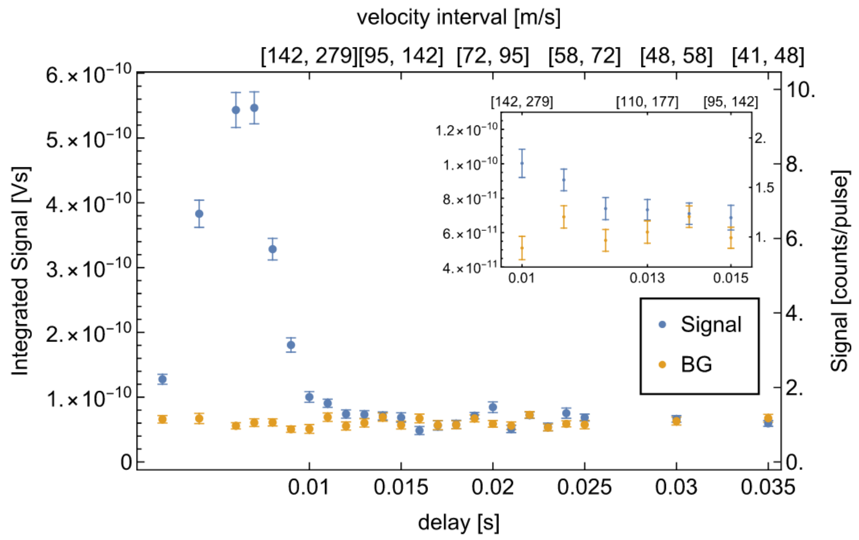
Expected sensitivity for $\Delta\nu \sim 10$ Hz
*A.J. Vargas, Phys. Rev. D **109**, 055001 (2024)*

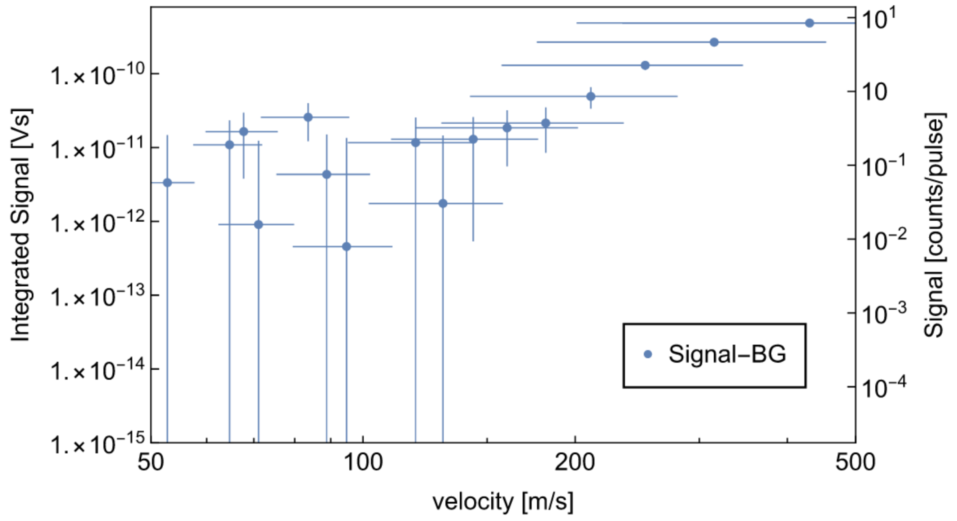
Nowak, L., et al. *Physics Letters B* 858 (November 1, 2024): 139012.

GRASIAN *GRAvity, Spectroscopy and Interferometry with ultra-cold Atoms and Neutrons*

- Quest for coldest hydrogen source
  - Longer interaction time → higher precision in laser or microwave spectroscopy
  - Lowest energies: gravitational quantum states (analogy neutrons): $v \sim cm/s$
  - Quantum reflection from van der Waals/Casimir-Polder potential
  - Also possible for antihydrogen
  - Other applications: search for short-range forces

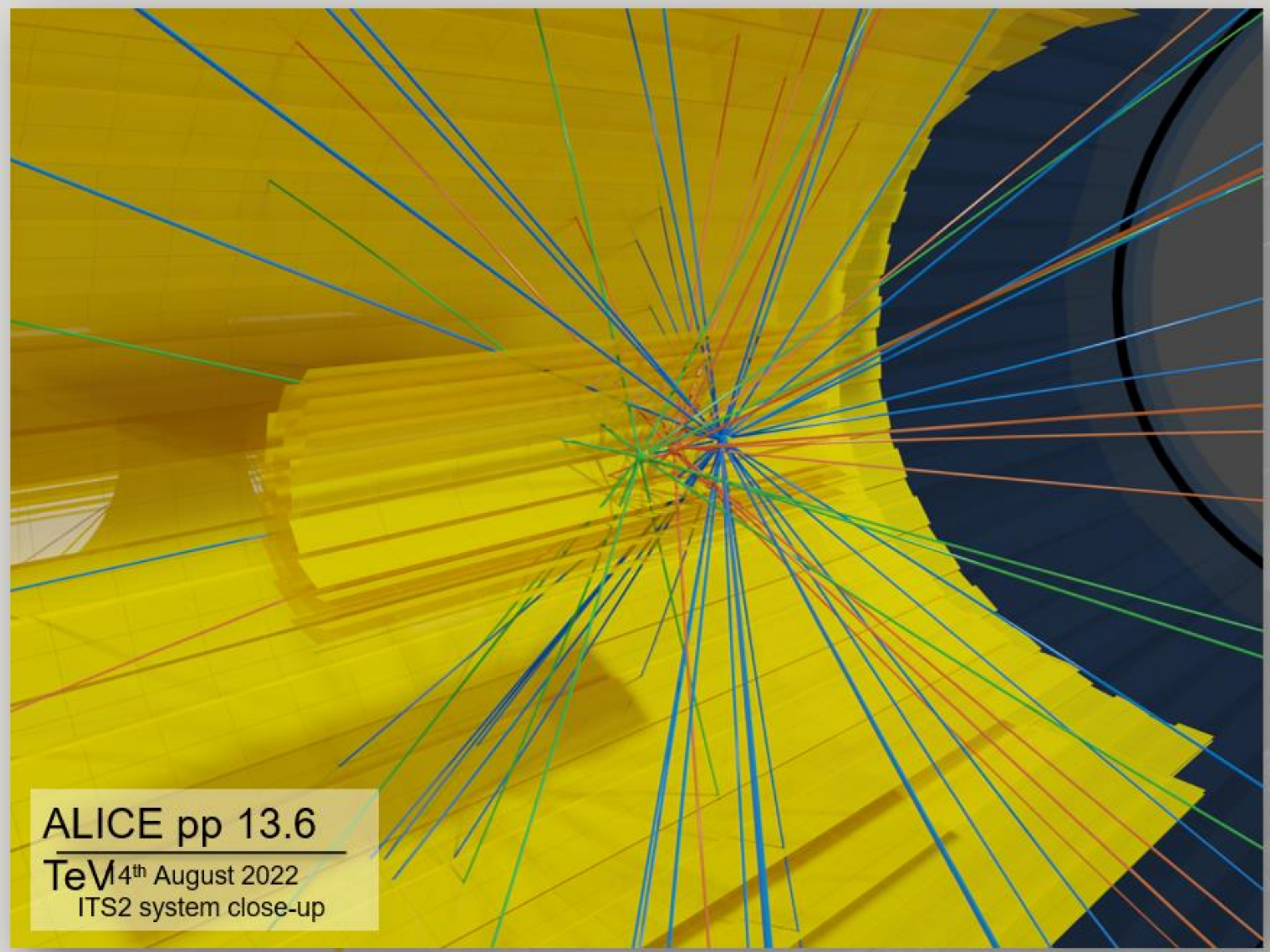






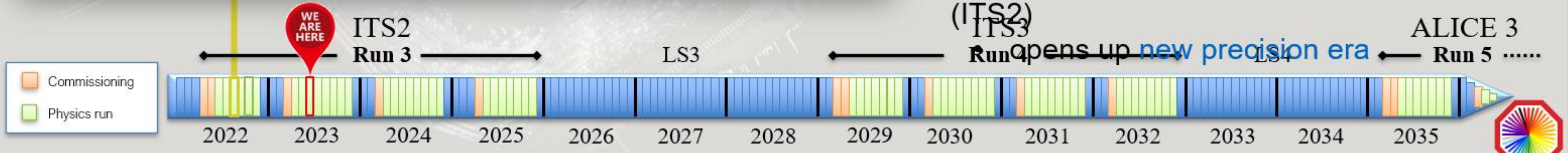
Killian, Carina, et al.
The European Physical Journal D 78(2024): 132.

https://grasian.eu/



A bright future ahead at the LHC

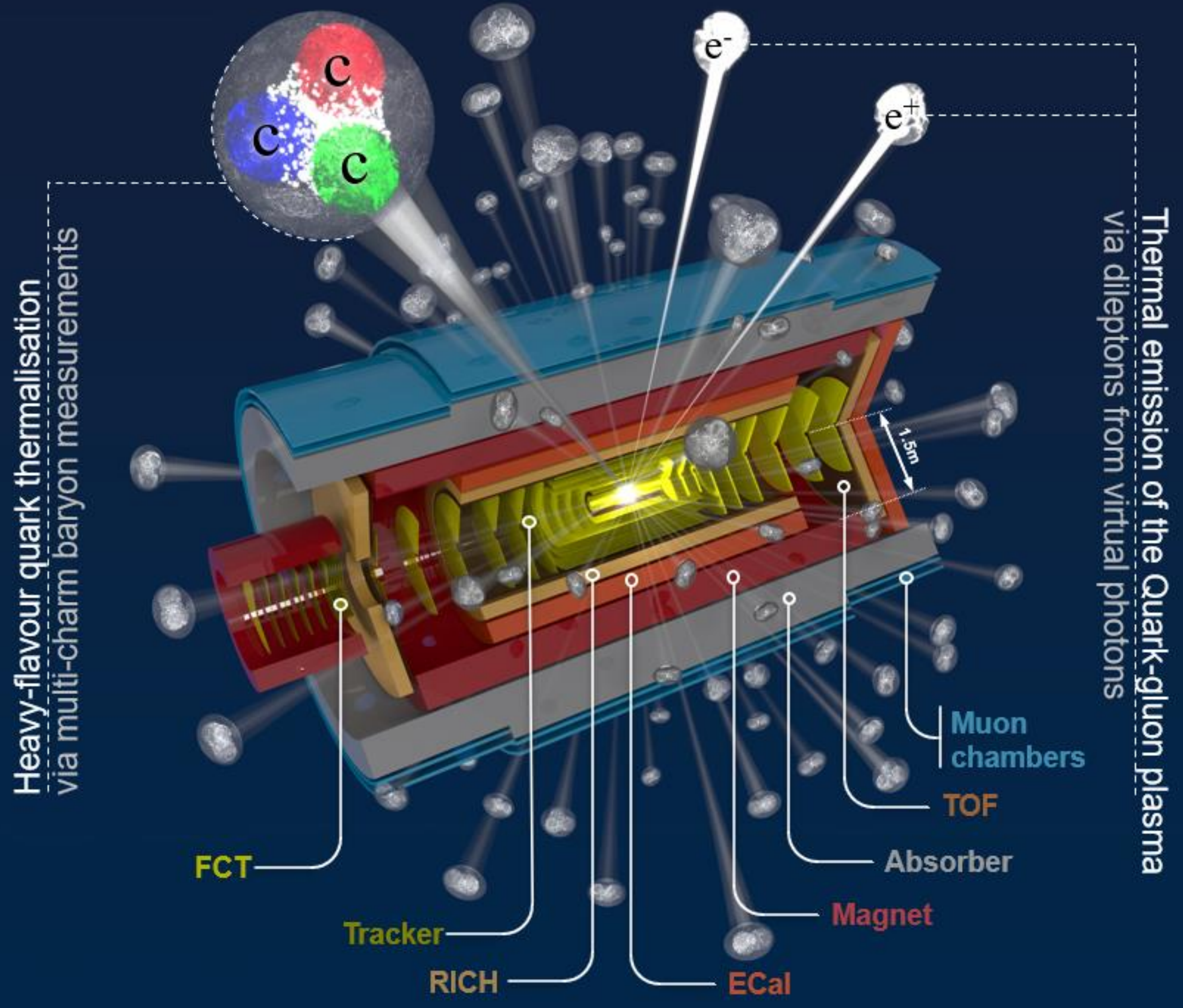
- Run 3: detector redesigned for very high rates
  - **500 kHz** in pp
  - **50 kHz** Pb-Pb
- Completely redesigned software: O^2
  - Necessary to meet new challenges
  - Powering the next generation of analyses!
  - SMI has leading roles:
    - Paul Bühler: PWG-UD convener
    - David Chinellato: Analysis Coordinator
- Fully silicon-pixel-based inner tracker system (ITS2) opens up new precision era



ALICE

SMI/SAB Meeting - 20th July 2023 - D.D. Chinellato 6

ALICE 3: a next-generation experiment for the 2030s

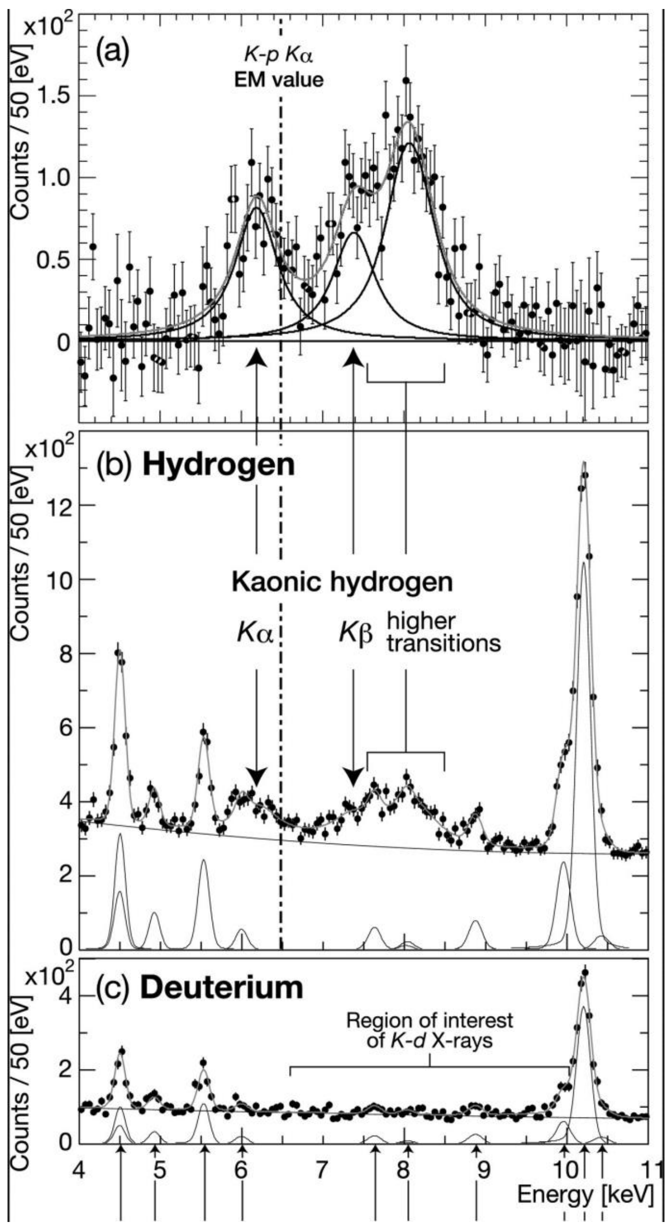


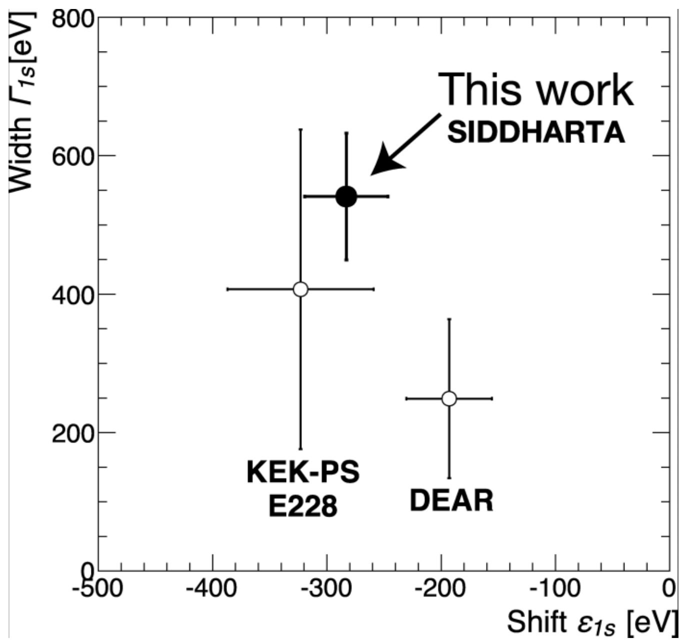
- All-silicon, large-acceptance tracker
  - High rate: 5x bigger luminosity, exploit LHC
  - Momentum precision of $\sigma_p/p \sim 1\%$
  - $\sim 10\% \ X_0$ overall material budget
- State-of-the-art particle identification
  - Silicon-based TOF and RICH
  - Muon identification
- Very high vertexing precision
  - First layer at 5 mm from interaction point
  - Impact parameter resolution:
    - ~10 µm at p_T ~200 MeV/c
    - ~3 µm at p_T > 1 GeV/c

The heavy flavour angle: new frontier beyond simple thermalization

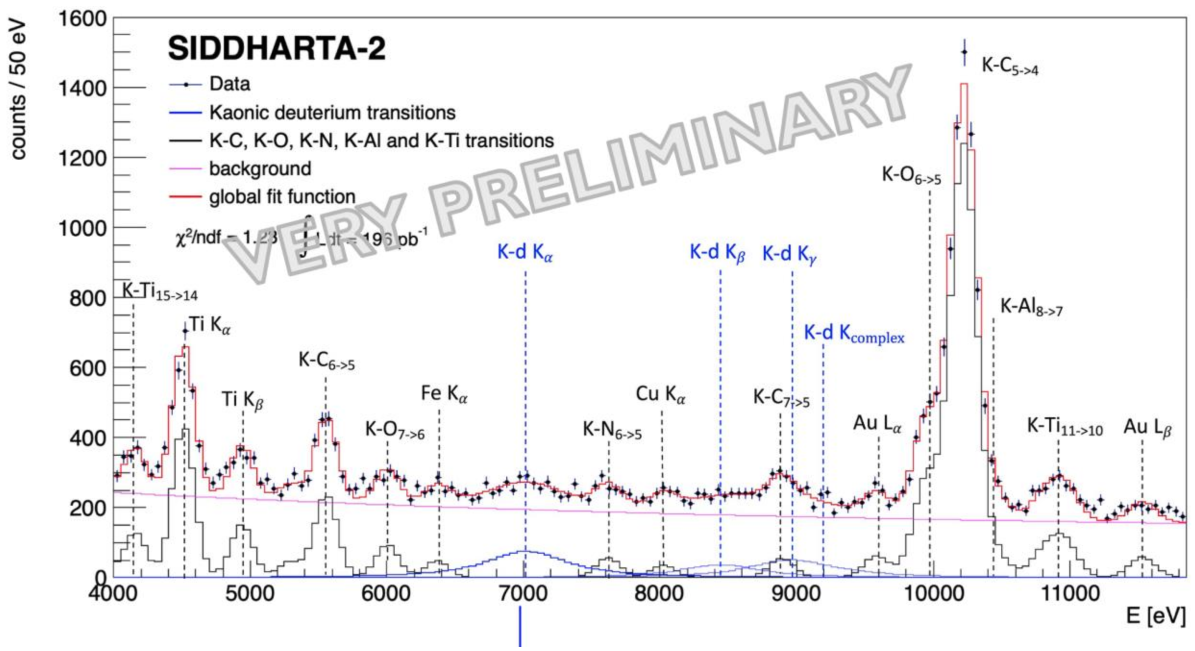
Required: state-of-the-art detector and analysis techniques ⇄ **new opportunities**!

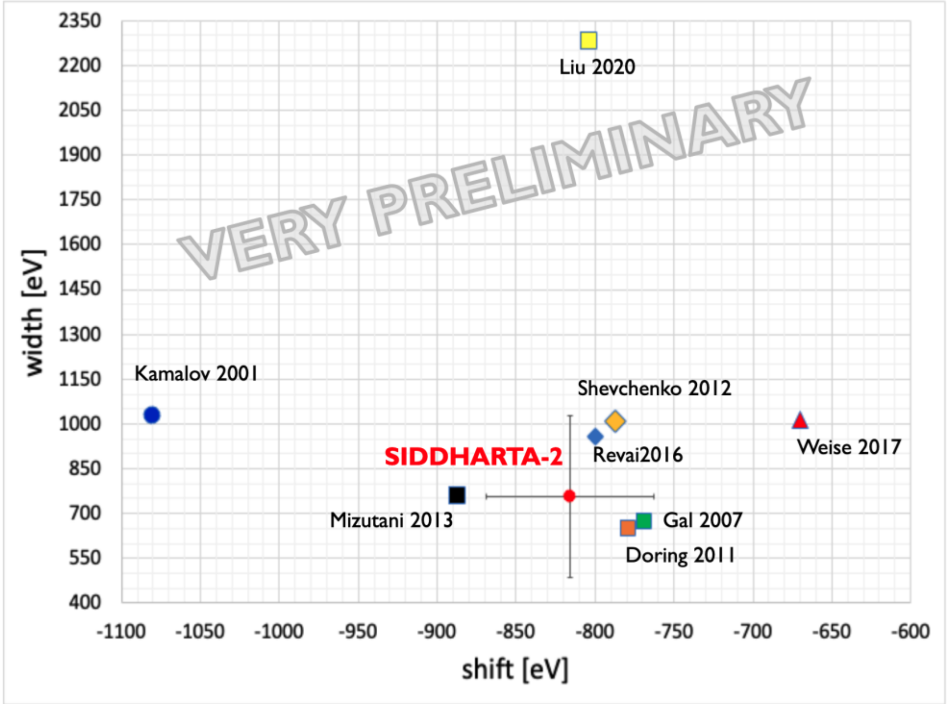
SIDDHARTA: X-ray measurement of K⁻p and K⁻d





Bazzi, M., et al. *Physics Letters B* 704, (2011): 113–117

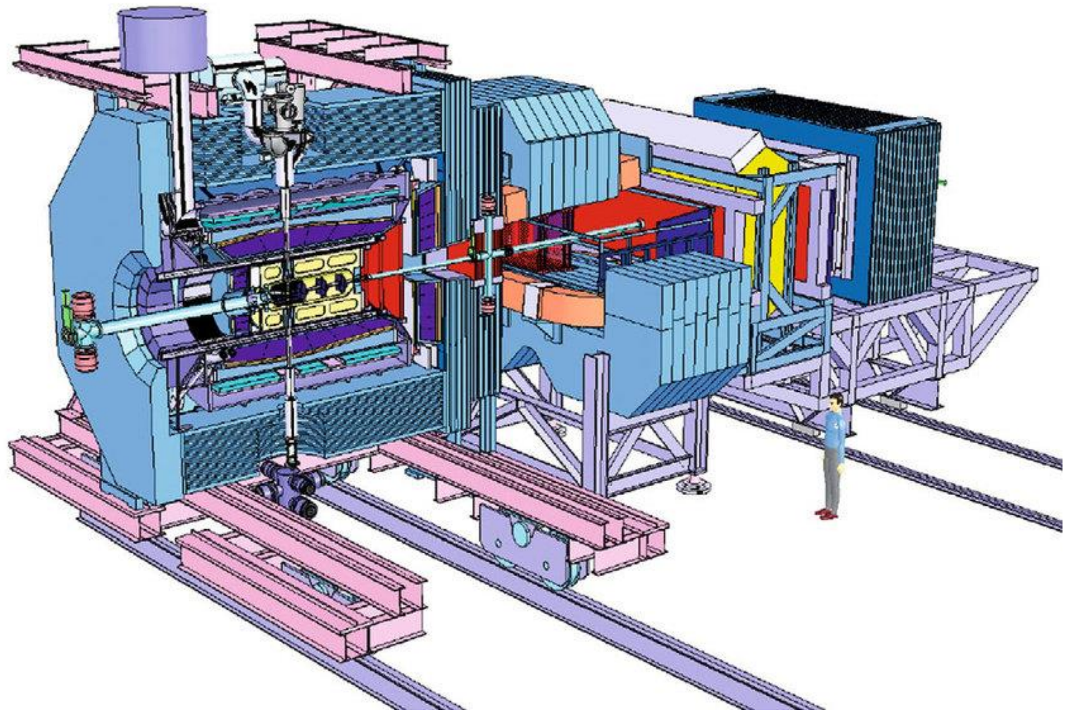


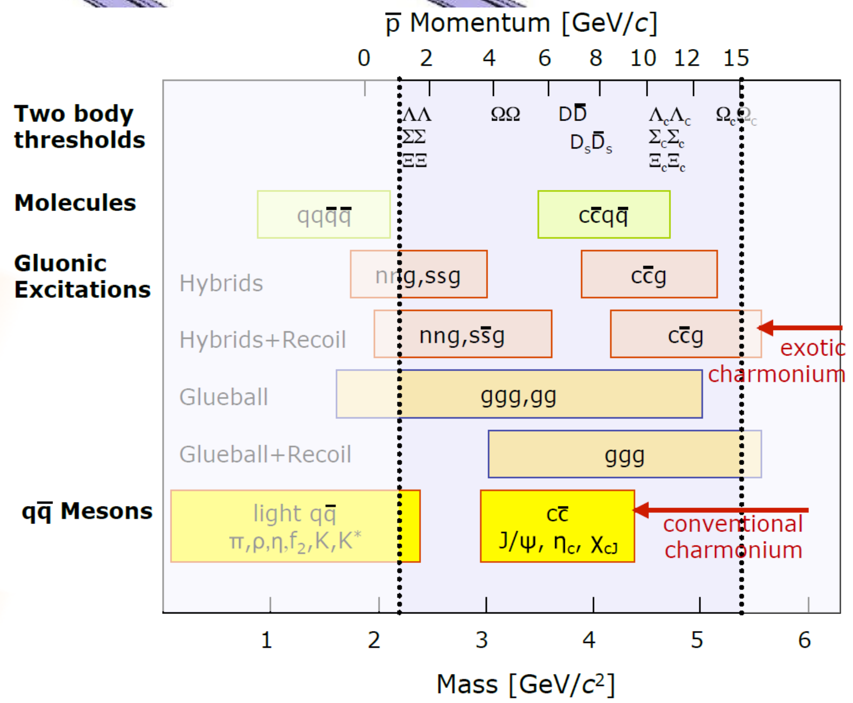


F. Sgaramella, talk at EXA/LEAP2024

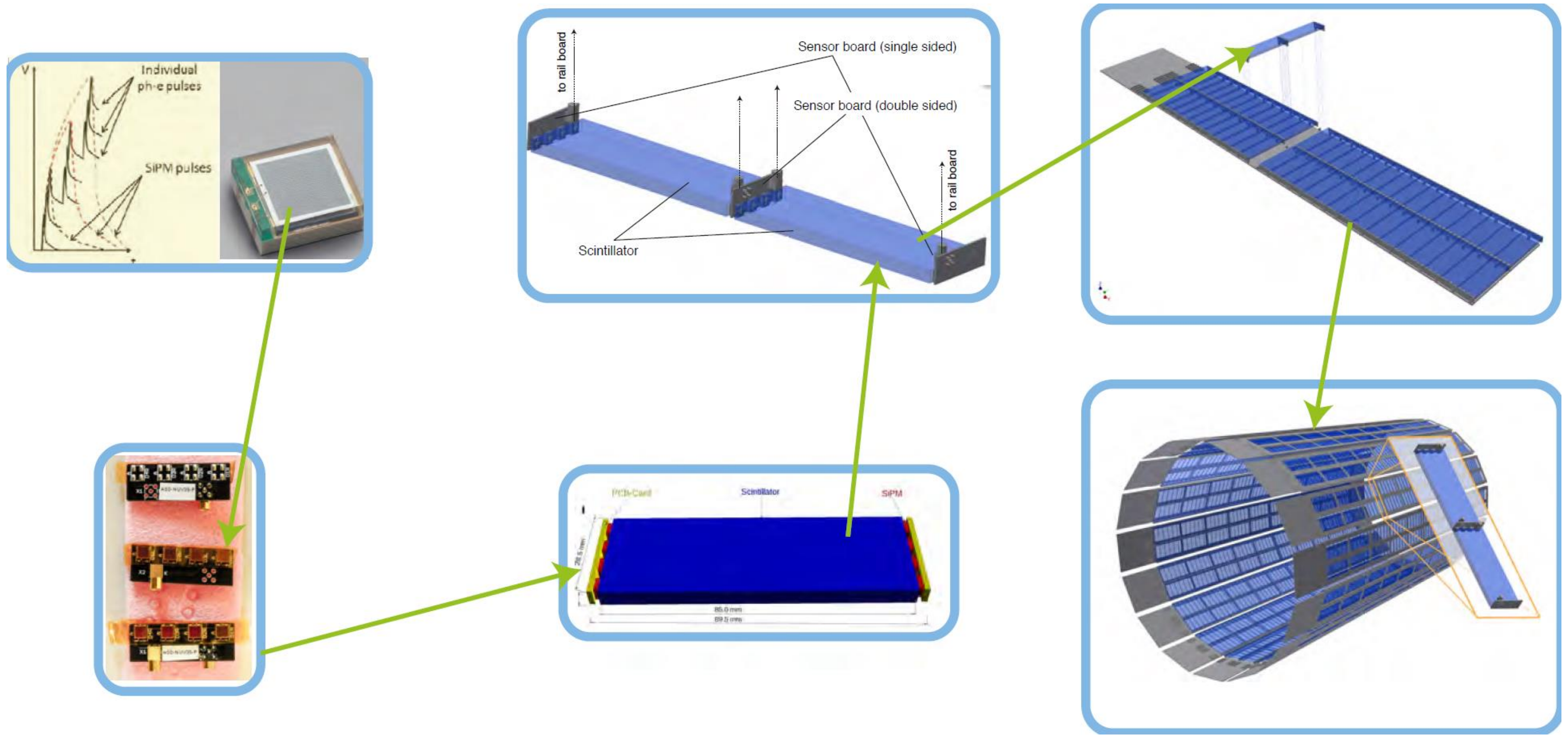
PANDA@FAIR: *discontinued at SMI*

Start delayed to 203x



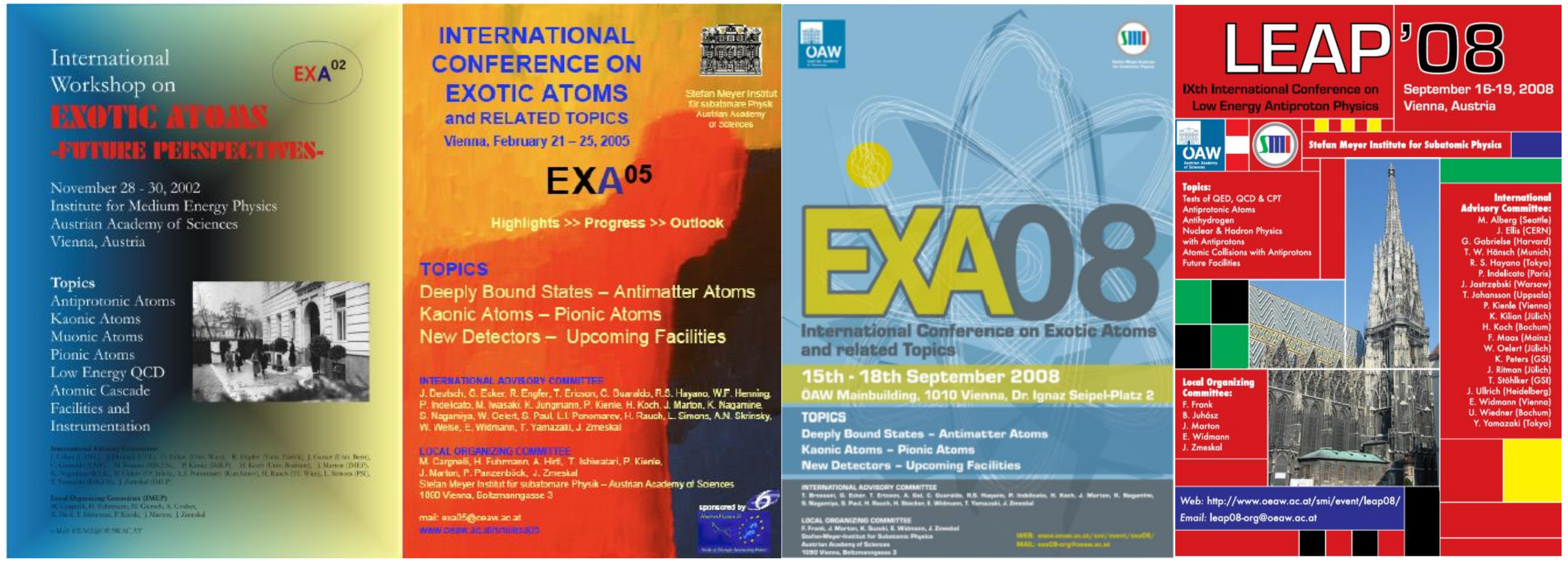


- Barrel TOF detector:
  - Time resolution < 100 ps
  - TDR written at SMI, approved
  - Construction funding pending



EXA and other conferences

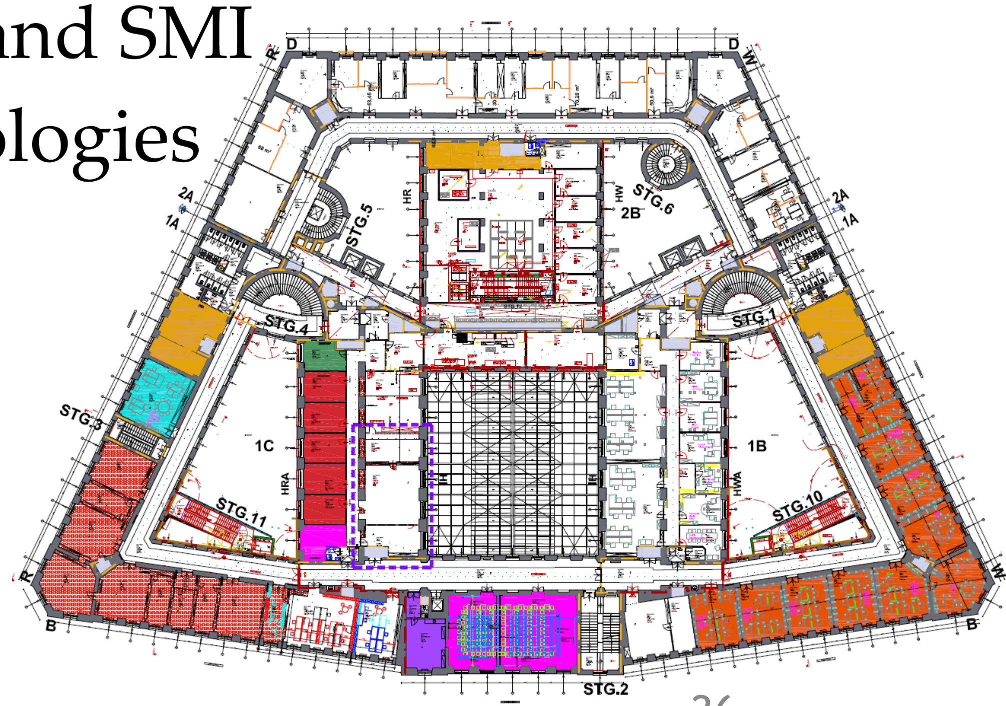
after 2021



Staff members 2004 and 2024

What's next

- ASACUSA
  - 1st sign of antihydrogen beam
  - Rabi hyperfine spectroscopy
  - Ramsey hyperfine spectroscopy
  - New beam creation schemes
- GRASIAN
  - First experiments with slow beam imminent
  - Towards ultra-cold hydrogen ($v < 1$ m/s)
  - Precision spectroscopy and gravity
  - Application to antiyhdrogen
- ALICE
  - Current experiment runs until LS4
  - Upgrade to ALICE-3
- Institutional
  - Fusion of HEPHY and SMI
  - Synergies in technologies and physics



Spares

Hadron Physics at Belle

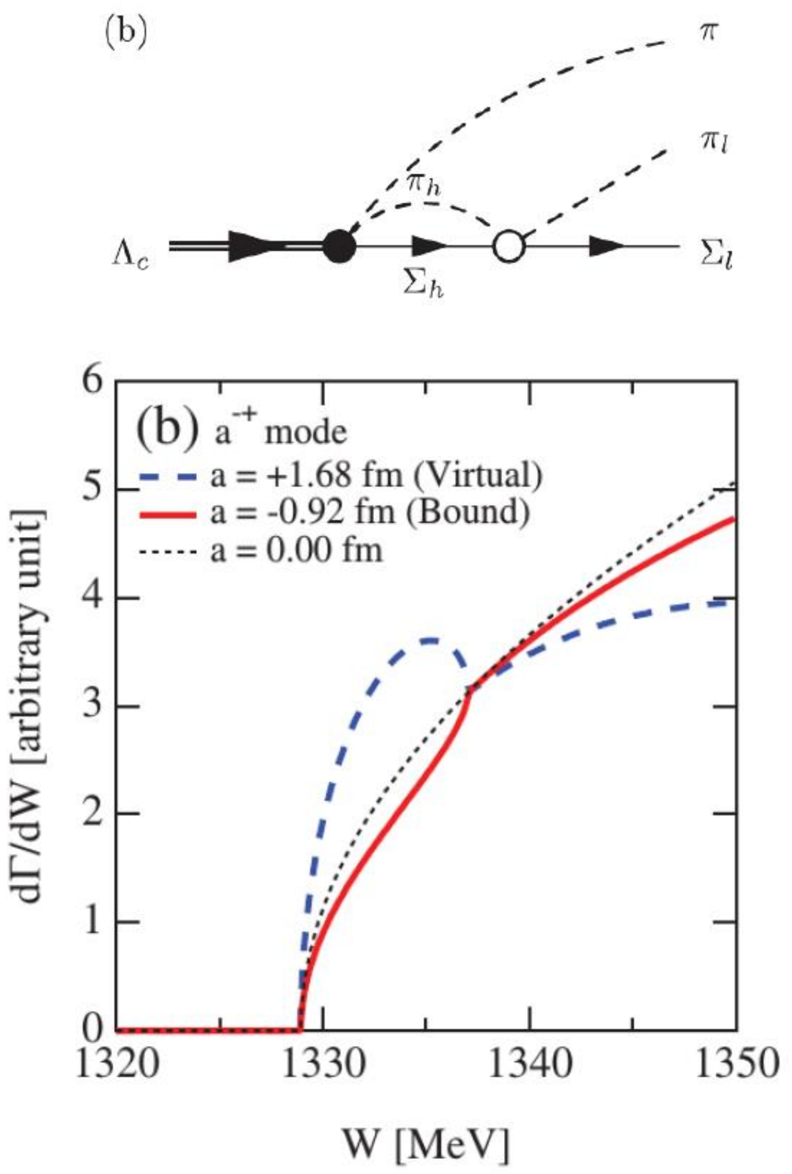
- $\Sigma\pi$ scattering lengths based on "Cabibbo's method"
- Measure the $\mathcal{B}(\Sigma\pi\pi)$ relative to $pK^-\pi^+$
- Study intermediate resonances.

Visible decay modes at Belle:

$$\Lambda_c \rightarrow \Sigma^+\pi^-\pi^+(4.57 \pm 0.29\%)^*$$
$$\Lambda_c \rightarrow \Sigma^0\pi^+\pi^0(2.3 \pm 0.9\%)^*$$
$$\Lambda_c \rightarrow \Sigma^+\pi^0\pi^0(\text{unknown})$$

- Goal: Σπ scattering length
- 1st step: determination of $B(\Sigma\pi\pi)$

M. Berger at al. arXiv:1802.03421 (submitted to PRD)

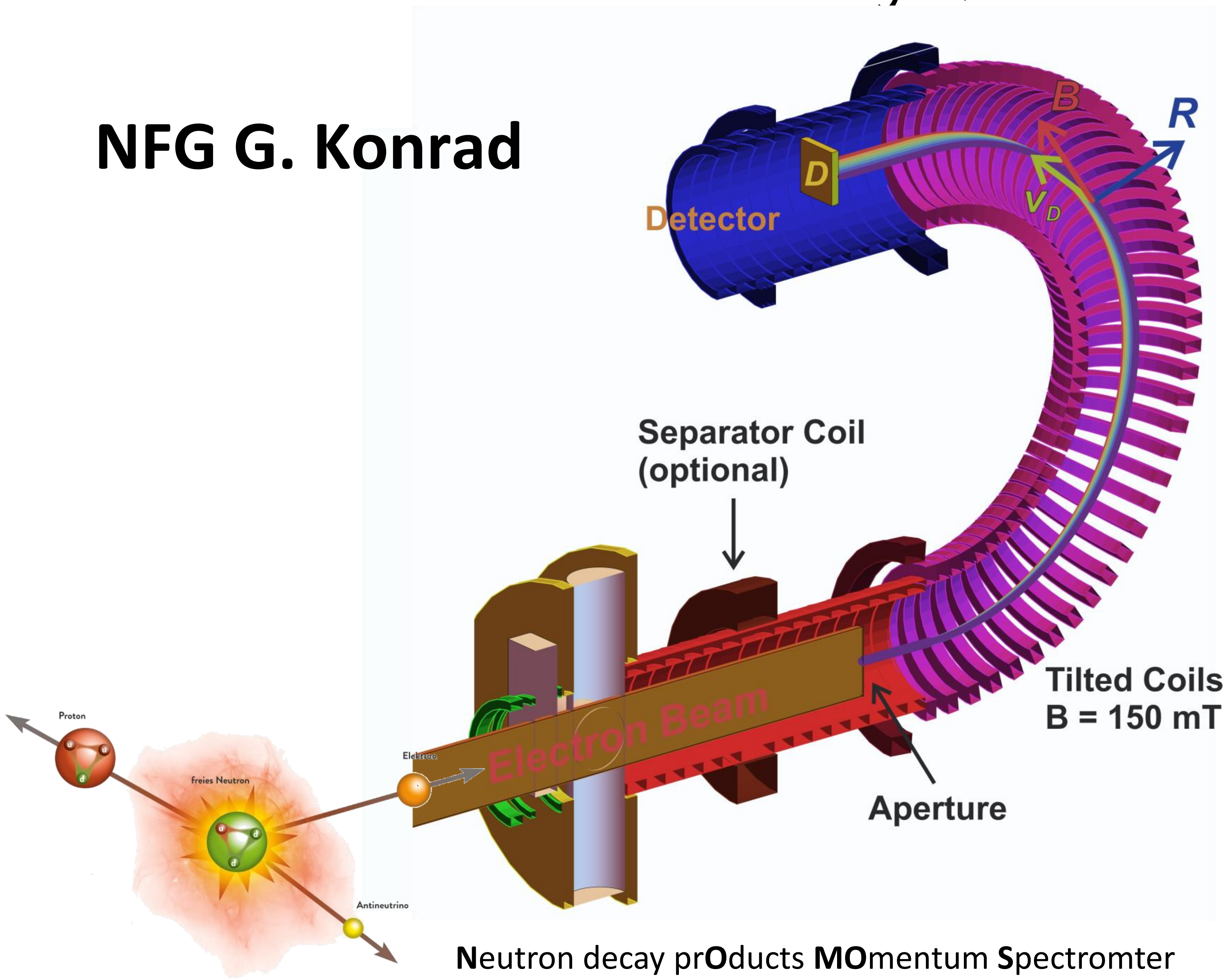


K. Miyahara, T. Hyodo, E. Oset, Phys. Rev. C. 92, 055204 (2015)

NoMoS – Beyond the Standard Model in Neutron Decay (FRM-II/ILL)

NFG G. Konrad

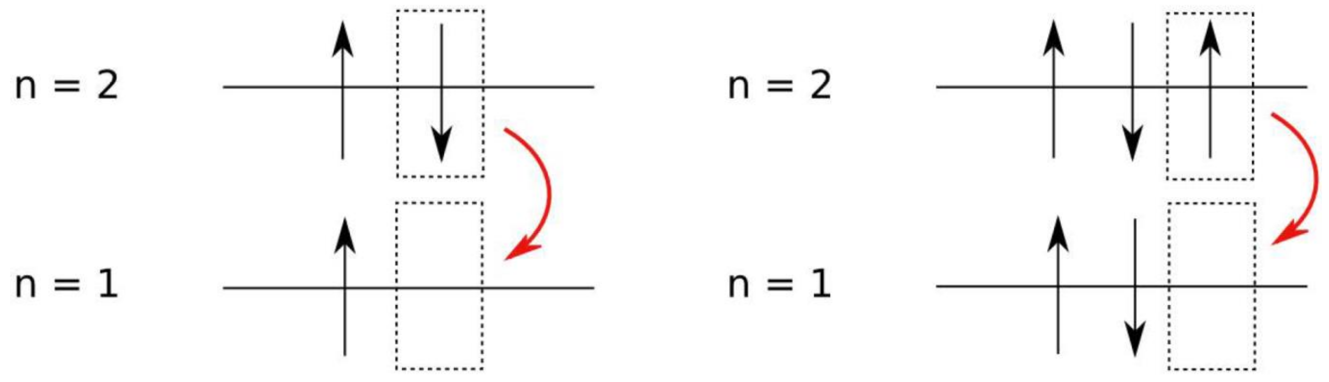
- Comprehensive physics programme:
  - Study structure of weak interaction
  - Test unitarity of CKM matrix
  - Search for new physics beyond Standard Model
  - Test Lorentz invariance
- Goal:
  - Electron and proton spectroscopy on
  - 10^{-4}- respectively 10^{-3}-level
- Further activities:
  - aSPECT experiment @ ILL Grenoble
  - PERKEO III-C experiment @ ILL Grenoble
  - New PERC facility @ FRM II Munich (under construction)
  - Proposed ANNI instrument @ ESS Lund (resubmission planned)

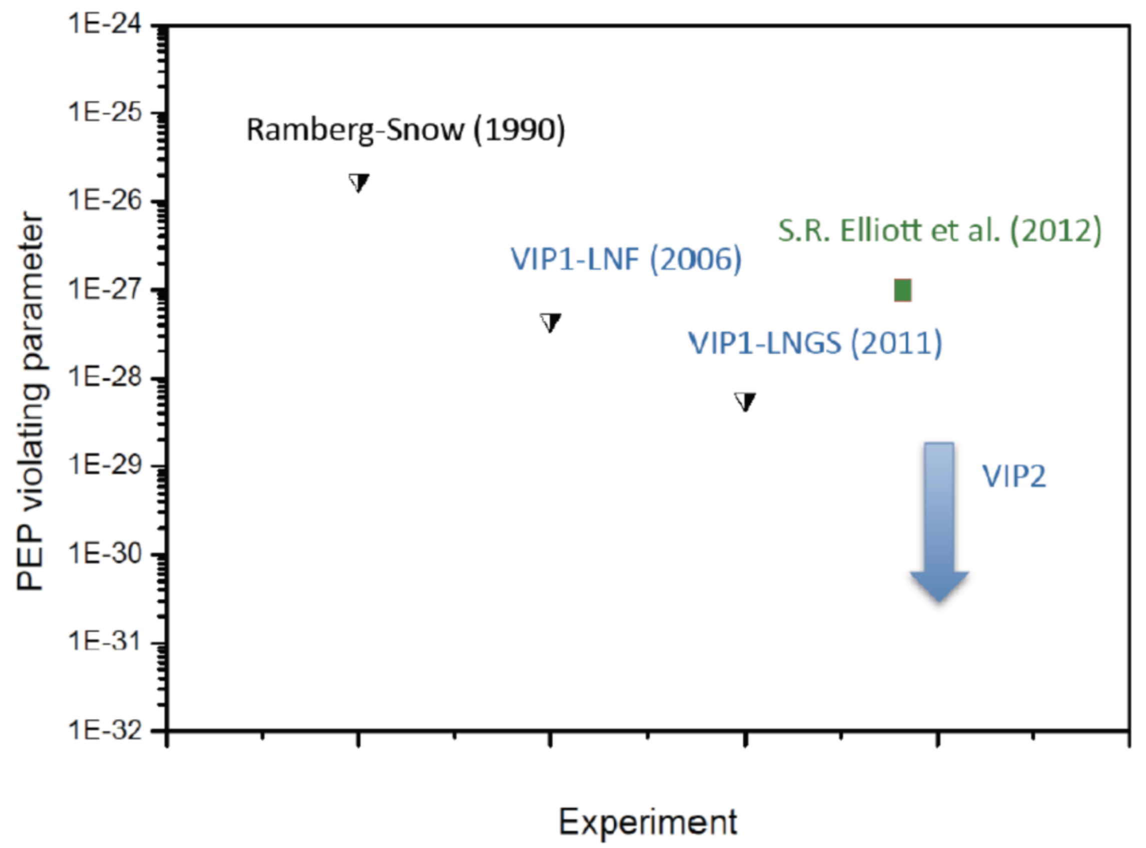


Neutron decay pr**O**ducts **MO**mentum **S**pectromter

VIP – VIolation of thr Pauli principle (LNGS)

- Tests the Pauli Exclusion Principle (PEP) and thereby the Spin-Statistics connection
- PEP governs the behaviour of fermions
- Search for atomic states in copper, which violate PEP
  - These states are not completely antisymmetric, but have a symmetric admixture with respect to the exchange of two particles
- The states can be identified by PEP-forbidden transitions, which have a slightly different energy than normal transitions
- Photons form these transitions are recorded by Silicon Drift Detectors
- The VIP2 experiment will lower the upper limit on the probability that the PEP is violated by two orders of magnitude





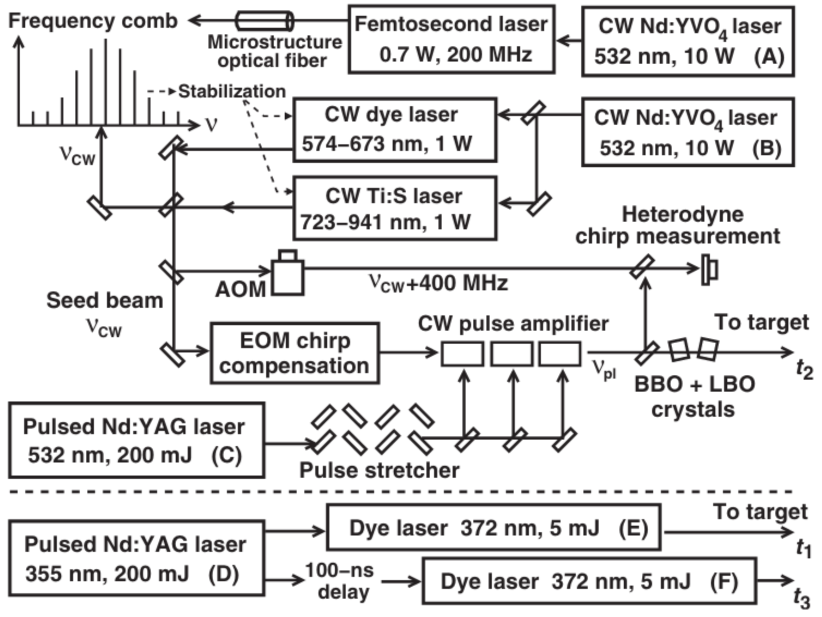
Highlights

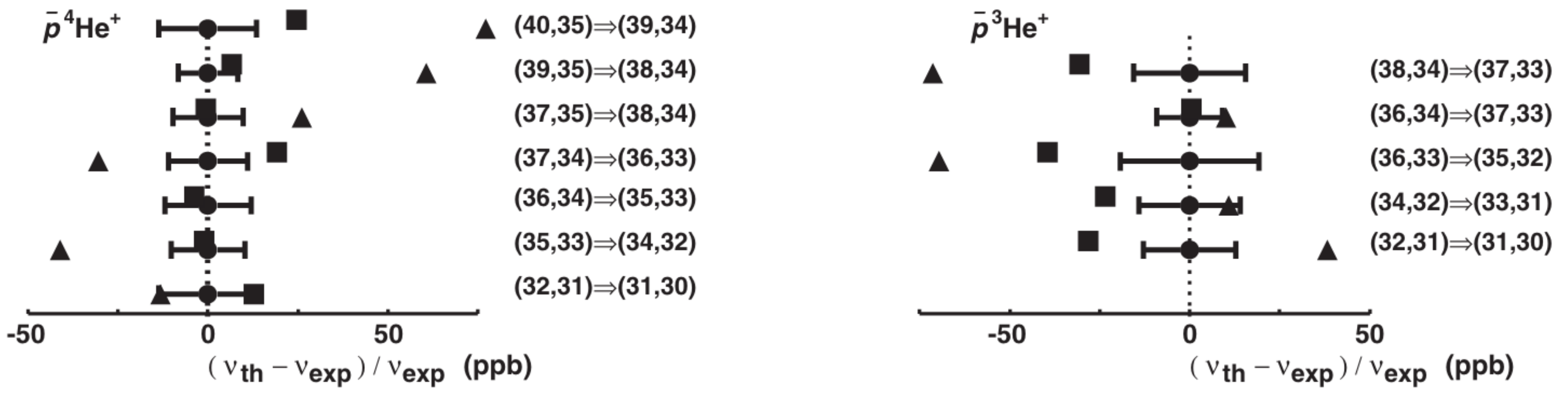
- 2012: ERC AdG HbarHFS for ASACUSA
- 2015: 2 NFG Groups: ALICE, NoMos
  - One became a permanent topic of SMI

Time lines

- 2004 – 2011
  - ASACUSA: antiprotonic helium spectroscopy
  - SIDDHATA: K^-p
- After
  - ASACUSA: antihydrogen
  - SIDDHARTA-2
- 2015 –
  - ALICE
  - NoMoS till 2020
- 2004 – 2018
  - PANDA, BELLE, FLAIR
  - AEgIS

ASACUSA: antiprotonic He laser spectroscopy





$$\frac{m_{\bar{p}} - m_p}{m_p} = \frac{q_{\bar{p}} - q_p}{q_p} < 2x10^{-9}$$

Current level (2016): $5x10^{-10}$

PRL **96,** 243401 (2006) PHYSICAL REVIEW LETTERS week ending 23 JUNE 2006

Determination of the Antiproton-to-Electron Mass Ratio by Precision Laser Spectroscopy of $\bar{p}$He$^+$

M. Hori,[1,2] A. Dax,[2] J. Eades,[2] K. Gomikawa,[2] R. S. Hayano,[2] N. Ono,[2] W. Pirkl,[2] E. Widmann,[3] H. A. Torii,[4] B. Juhász,[5,3] D. Barna,[6,2] and D. Horváth[6]

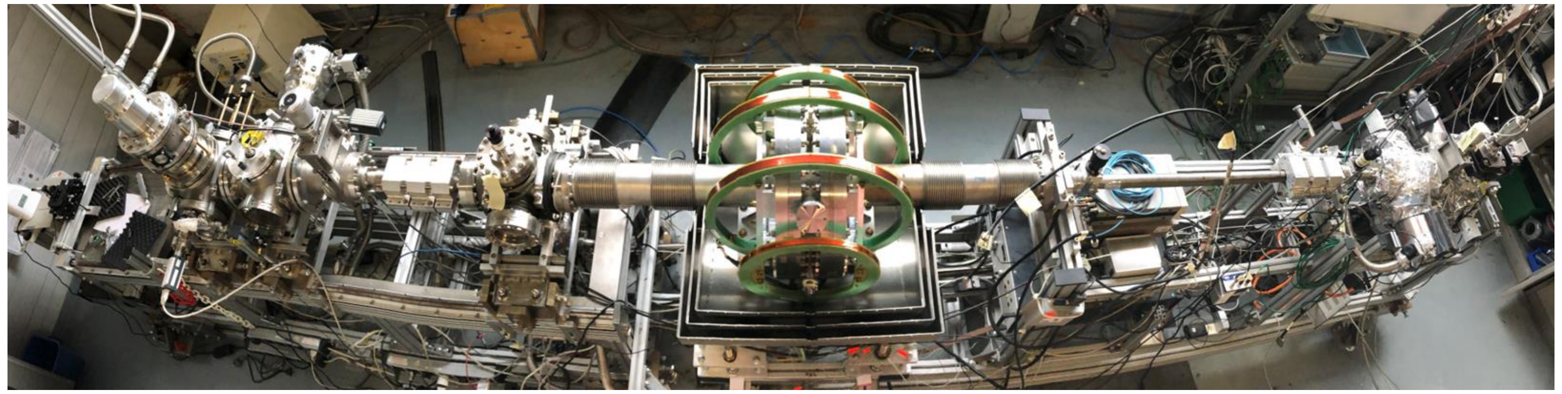
Narrative

- History
  - Umbenennung
  - IMEP: SIDDHARTA, PANDA, piH
  - New: ASACUSA, KNN, FLAIR
  - Later more …
    - J-PARC, FOPI, AEgIS, NoMoS, Hydra, GRASIAN,
- Physics
  - Start: exotic atoms - > slide
    - Fundamental symmetries: pbarHe, Hbar, Hydra, GRASIAN
    - Strong interaction πp, Kp,Kd
  - Later: higher energy strong interaction
    - J-PARC, PANDA@FAIR, ALICE
- Define phases?
  - Exotic atoms
  - Exotic nuclear matter
  - Stop of PANDA
  - ERC grant for ASACUSA: move to Hbar
  - H, D beams
  - Positron lab
  - GRASIAN
- Highlights
  - 2012 ERC AdG EW
  - 2015 2 NFGs, 1 remained

Experimental infrastructure

- Activities at partner institution
  - H beam at ETH Zürich


  - D beam at LAC Paris-Saclay



- Local activities at PSK

Detector lab TP

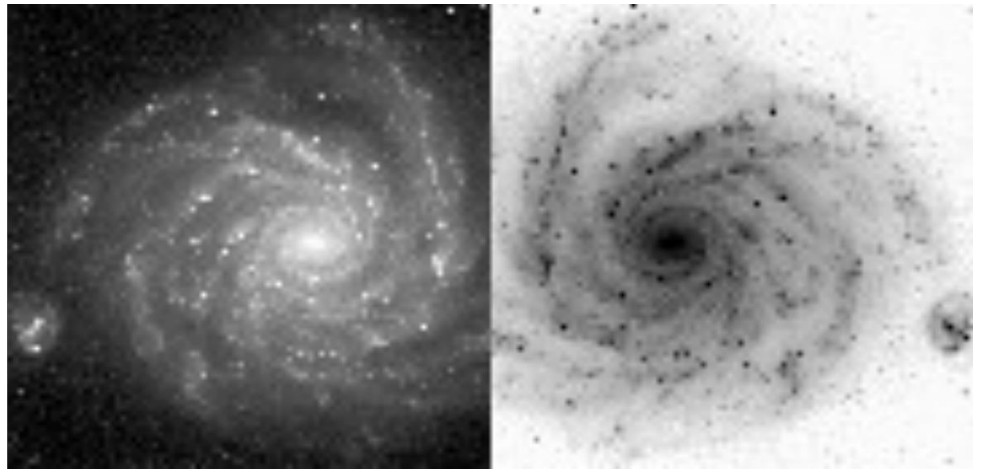
Laser lab TP

Positron lab Kegelgasse -> PSK

Cryolab with HEPHY OK

Matter-antimatter symmetry

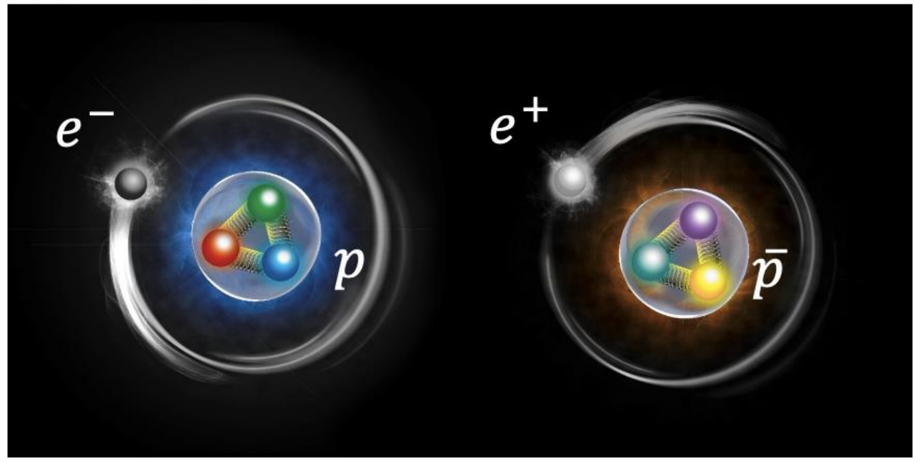
- **Baryon Asymmetry** in the observable universe: almost everything we see is matter. Where did all the antimatter go?

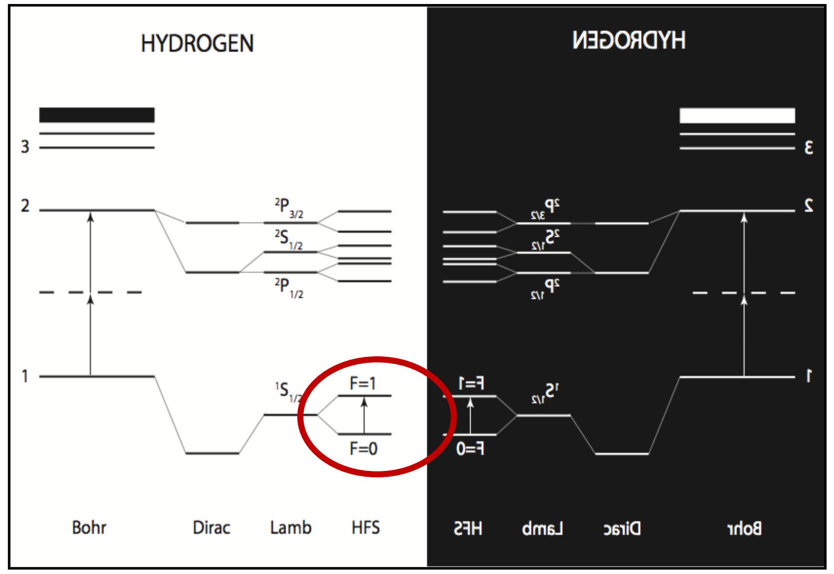


$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} \sim 6.1\ x\ 10^{-10}$$

- **Standard Model**: CPT and Lorentz symmetry

- **Antihydrogen**: H is one of the best measured matter systems

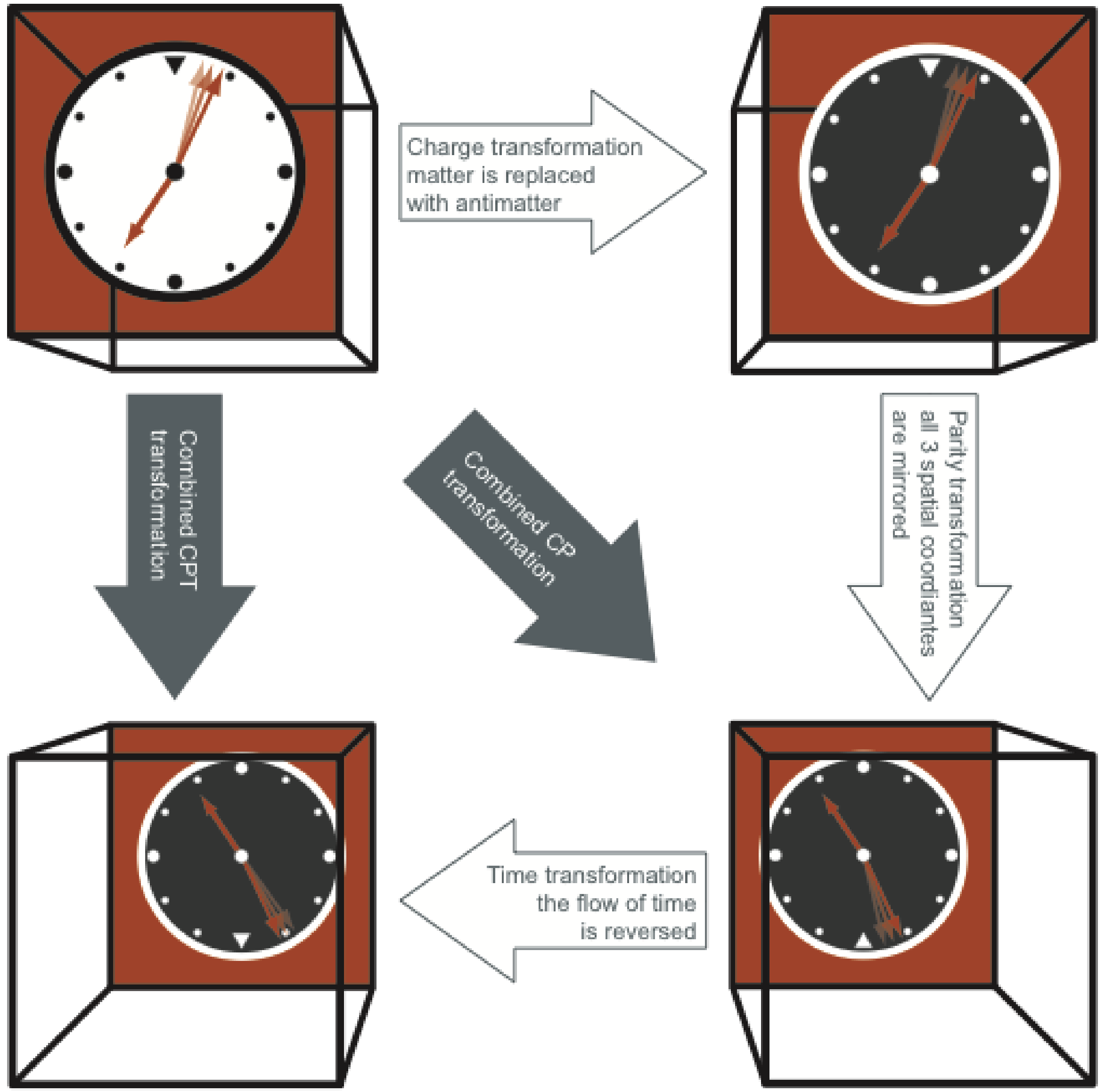




$$\frac{\Delta\nu_{HF}}{\nu_{HF}} < 10^{-12}$$

Fundamental symmetries C, P, T

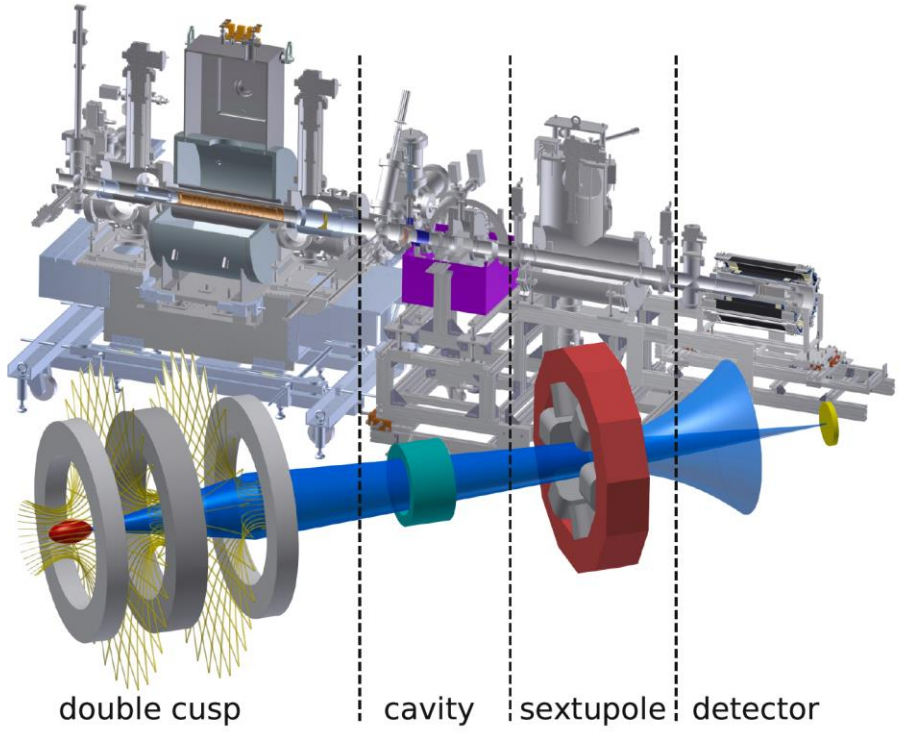
- **C**: charge conjugation particle - antiparticle
- **P**: parity: spatial mirror
- **T**: time reversal
- **CPT** theorem: consequence of
  - Lorentz-invariance
  - local interactions
  - unitarity
    - Lüders, Pauli, Bell, Jost 1955
- all QFT of SM obey CPT
- not necessarily true for string theory: CPT tests are sensitive tests of BSM physics

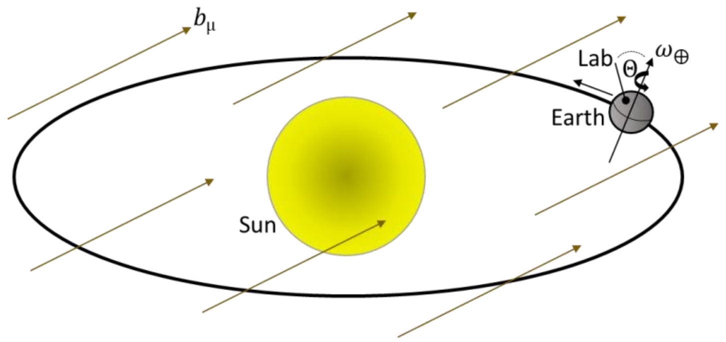


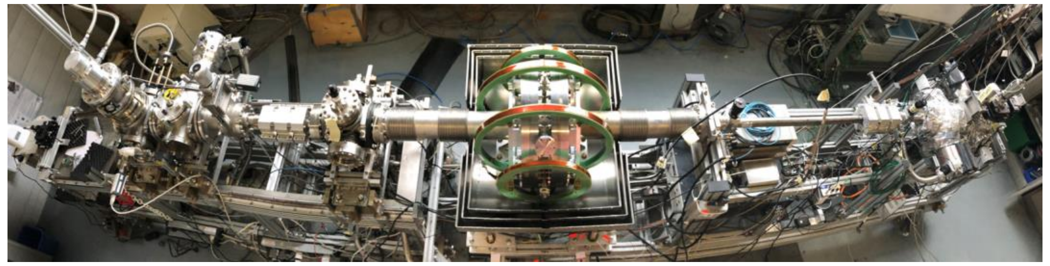
CPT → particle/anitparticle: same masses, lifetimes, g-factors, |charge|,...

ASACUSA@CERN-AD

- Test of CPT and Lorentz invariance
- Antihydrogen hyperfine structure measurement in a beam
  - No stray fields: highest precision
- $\bar{H}$ production greatly improved, beam production, rate and quantum state needs improvement
- e+ conditions essential, recent progress
- H-HFS done with same apparatus with 2.7 ppb accuracy
- 1st goal for $\bar{H}$: ppm measurement
- Continuation of H,D beam spectroscopy
  - Standard Model Extension (SME)

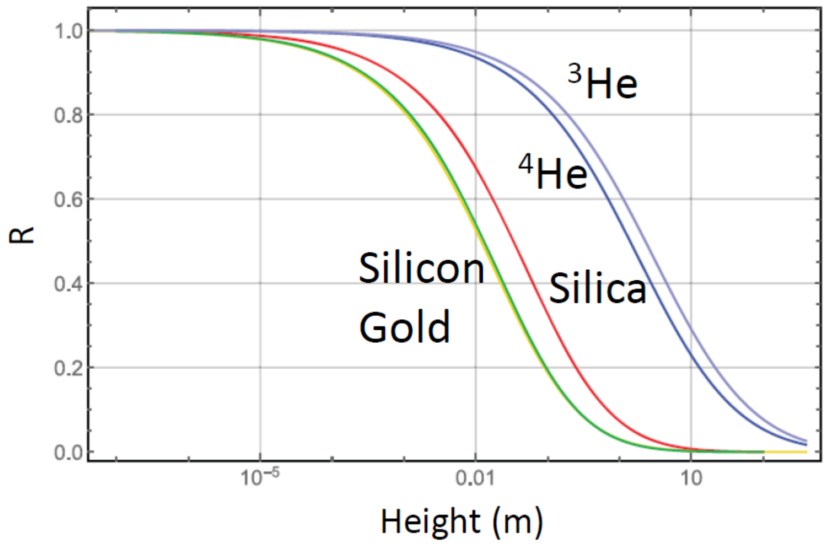




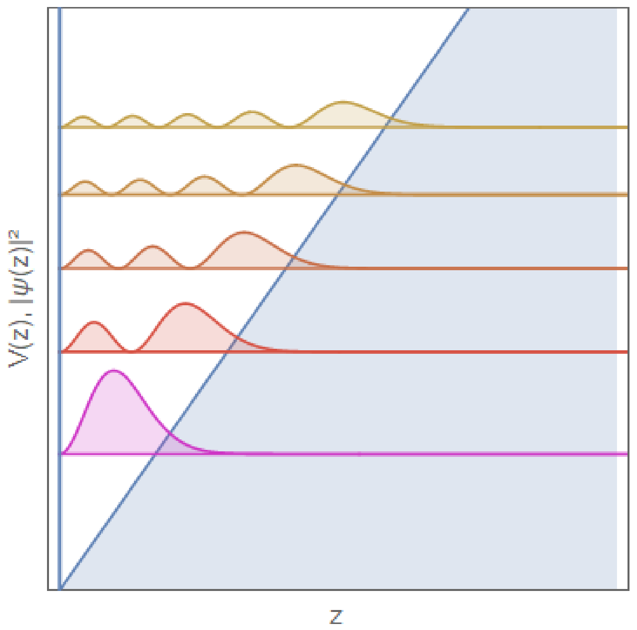


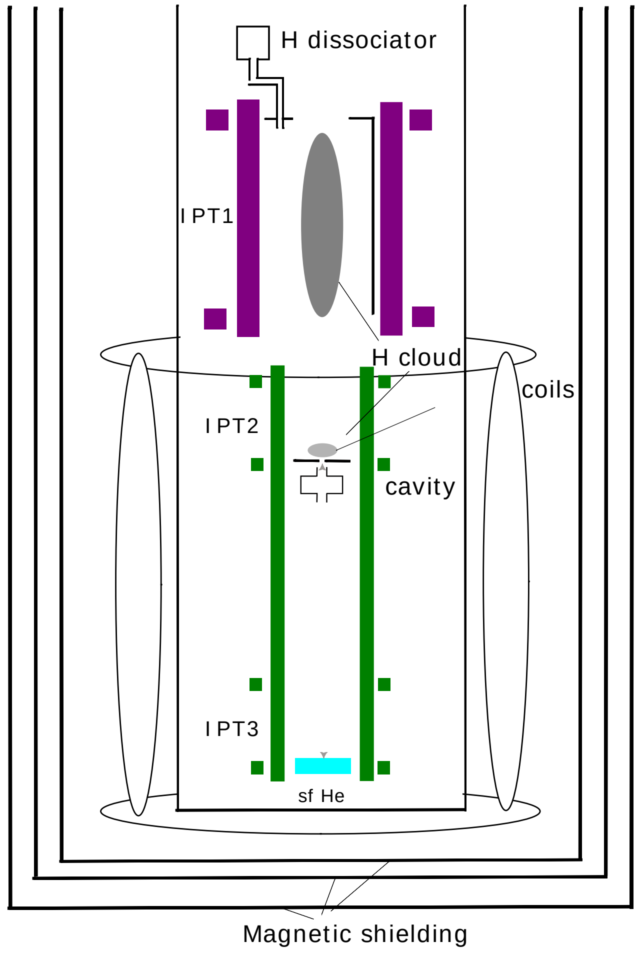
GRASIAN *GRAvity, Spectroscopy and Interferometry with ultra-cold Atoms and Neutrons*

- Quest for coldest hydrogen source
  - Longer interaction time → higher precision in laser or microwave spectroscopy
  - Lowest energies: gravitational quantum states (analogy neutrons): *v~cm/s*
  - Quantum reflection from van der Waals/Casimir-Polder potential
  - Highest reflectivity: superfluid He
  - Bouncing H: Ramsey hyperfine spectroscopy, 1s-2s laser spectroscopy
  - Also possible for antihydrogen
  - Other applications: short-range forces



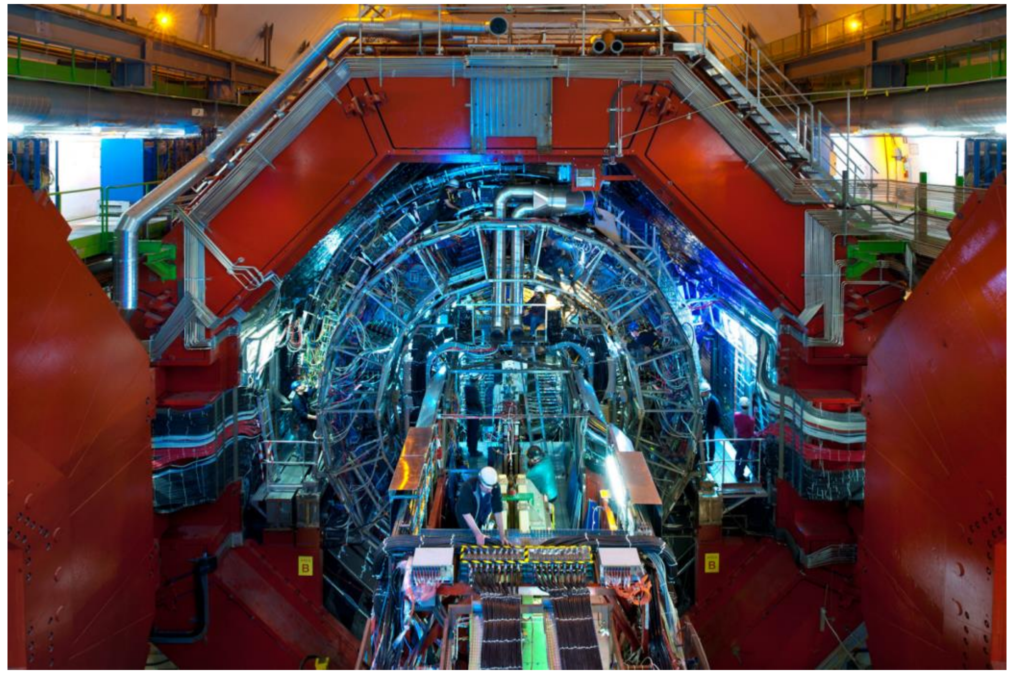
Crépin, P. P. *et al.* *EPL* **119**, 3301–3301 (2017).



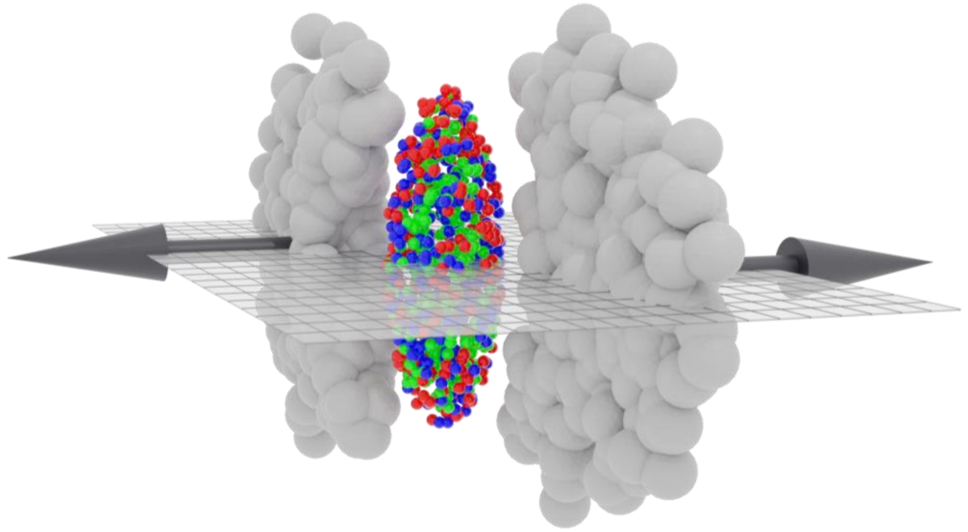


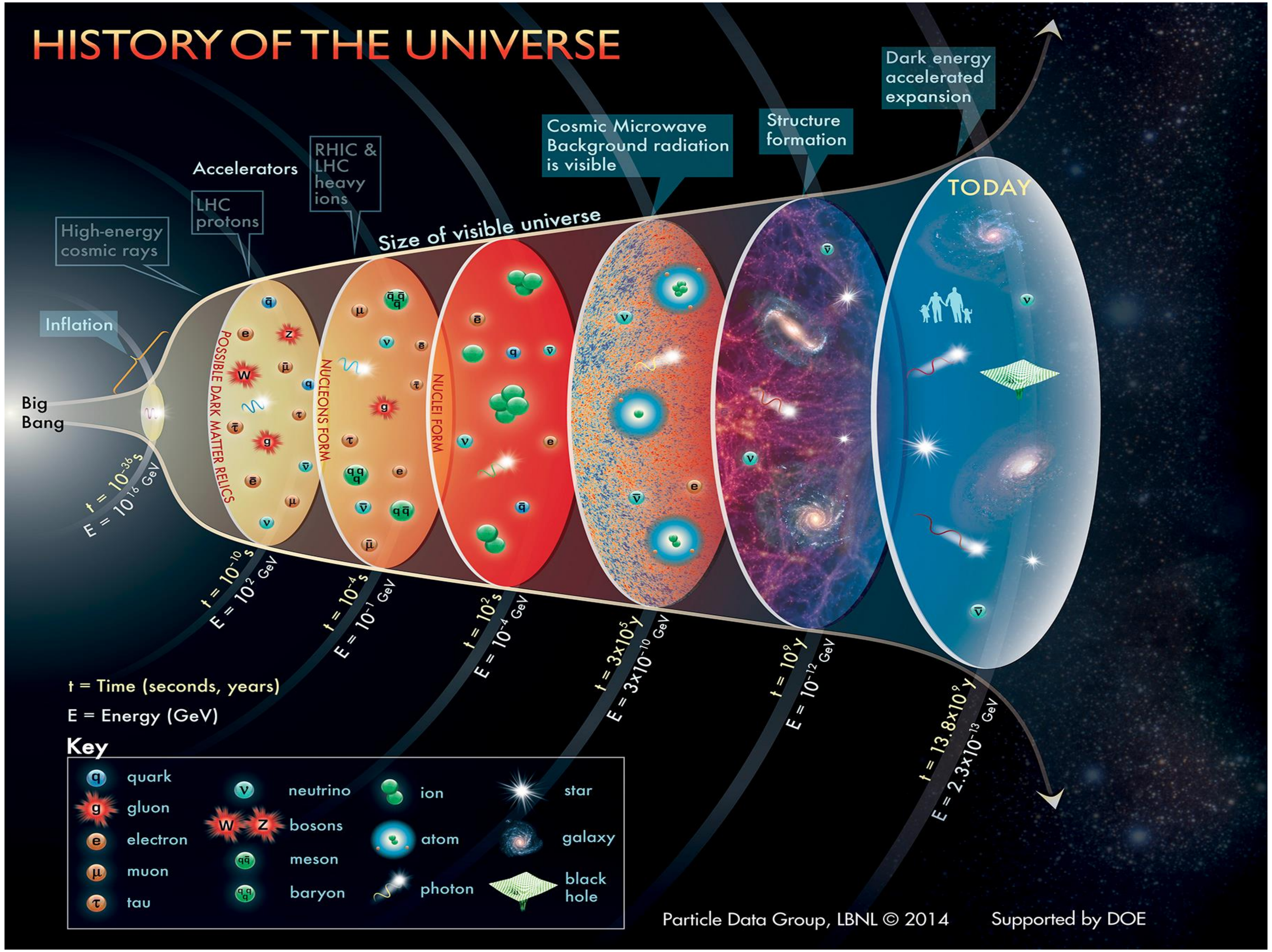
https://grasian.eu/

ALICE@CERN-LHC



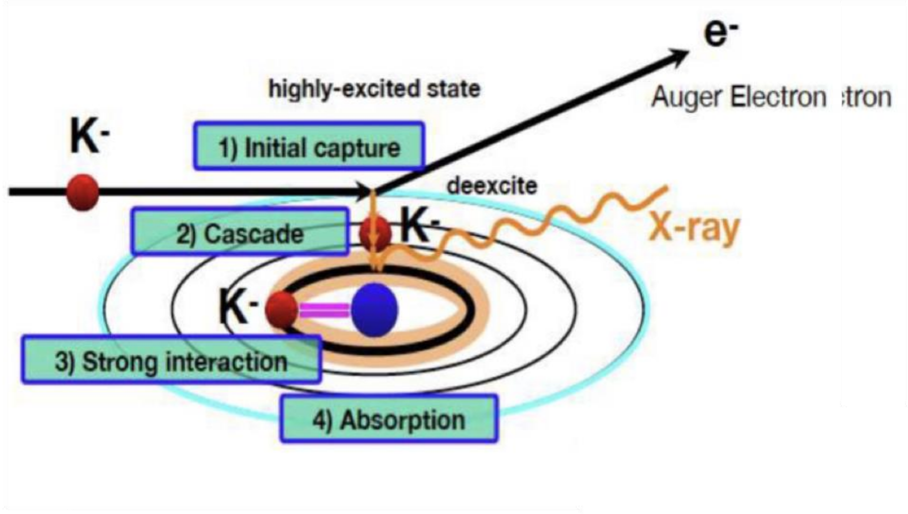
- **High-density QCD matter studies** using the large hadron collider (LHC)
  - Do we understand the strongest force in the universe and how it confines quarks and gluons?
  - Under which conditions do we recover a primordial soup such as the one created in the big bang?
- **ALICE@SMI expertise:**
  - **Identified particle production measurements** from light to heavy flavour hadrons allow to understand system evolution and hadronisation
  - **Ultraperipheral collisions** literally shine light inside protons and lead nuclei and allow for direct studies of nuclear inner structures of gluons at energies never seen before, testing nuclear PDFs, perturbative QCD and Beyond Standard Model theories.

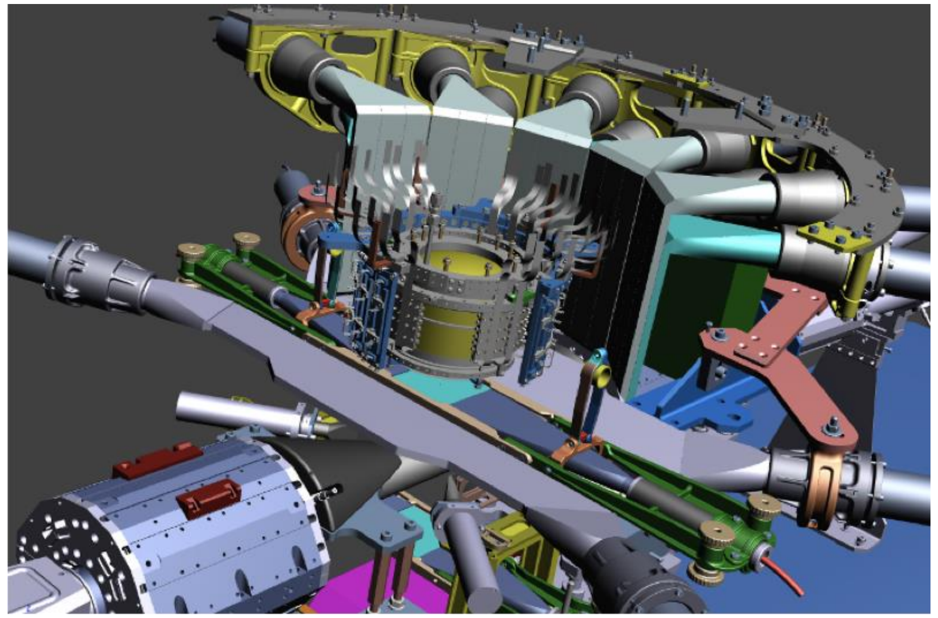


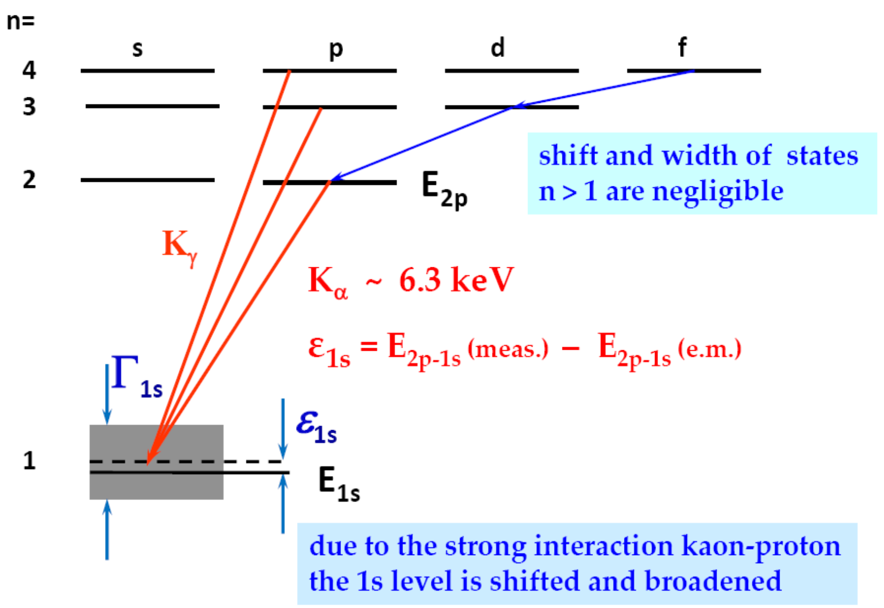

HISTORY OF THE UNIVERSE
Dark energy accelerated expansion
Structure formation
Cosmic Microwave Background radiation is visible
RHIC & LHC heavy ions
Accelerators
LHC protons
High-energy cosmic rays
Size of visible universe
TODAY
Inflation
Big Bang
POSSIBLE DARK MATTER RELICS
NUCLEONS FORM
NUCLEI FORM
t = 10^-36 s E = 10^16 GeV
t = 10^-10 s E = 10^2 GeV
t = 10^-4 s E = 10^-1 GeV
t = 10^2 s E = 10^-4 GeV
t = 3x10^5 y E = 3x10^-10 GeV
t = 10^9 y E = 10^-12 GeV
t = 13.8x10^9 y E = 2.3x10^-13 GeV
t = Time (seconds, years)
E = Energy (GeV)
Key
quark
gluon
electron
muon
tau
neutrino
bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL © 2014
Supported by DOE

Exotic kaonic bound states: strong interaction

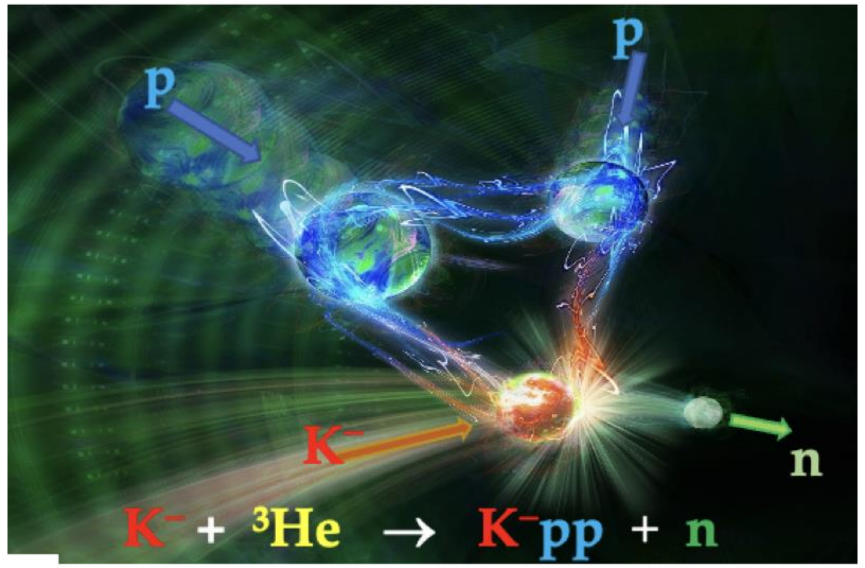
- Kaonic atom: X-ray spectroscopy

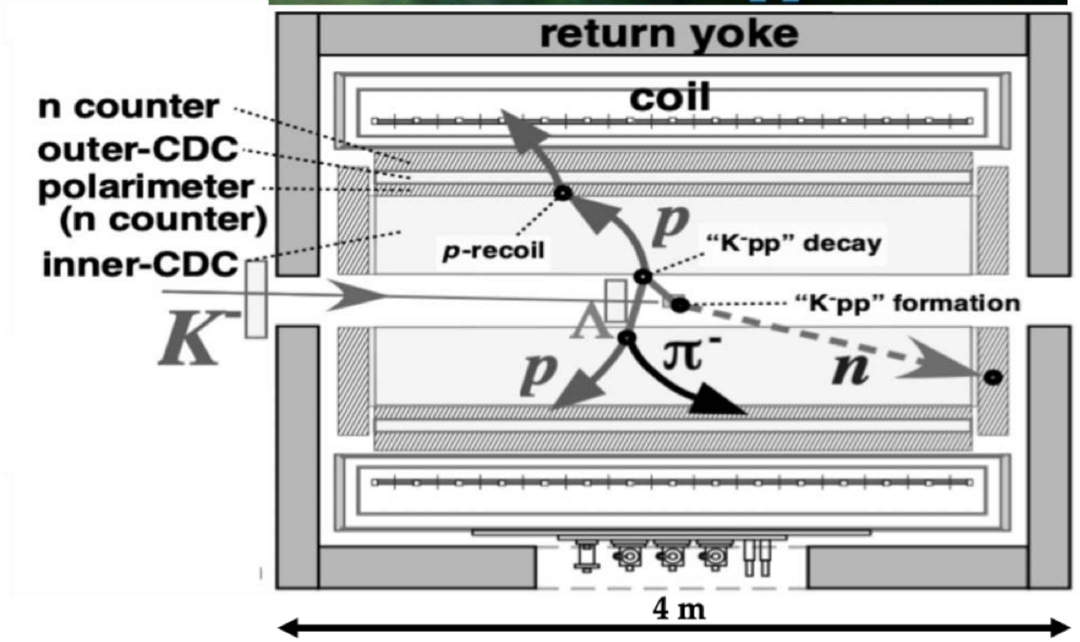






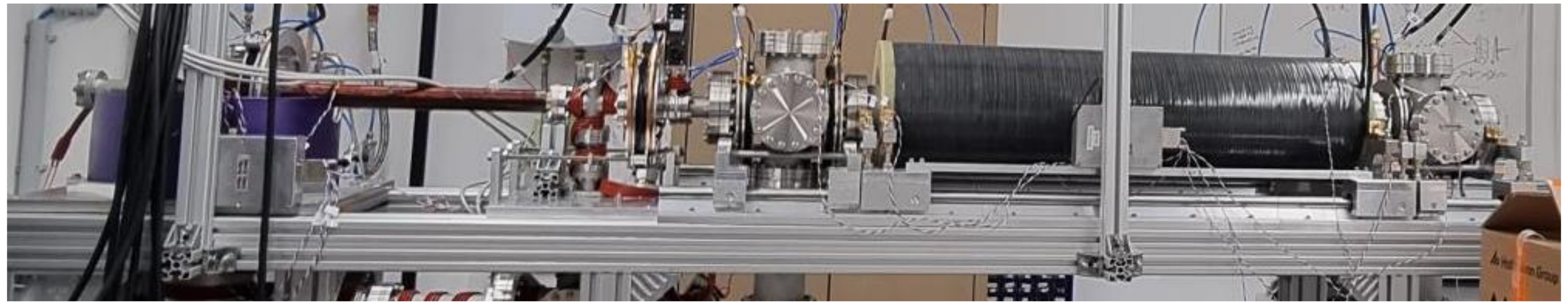
- Kaonic nuclear bound states

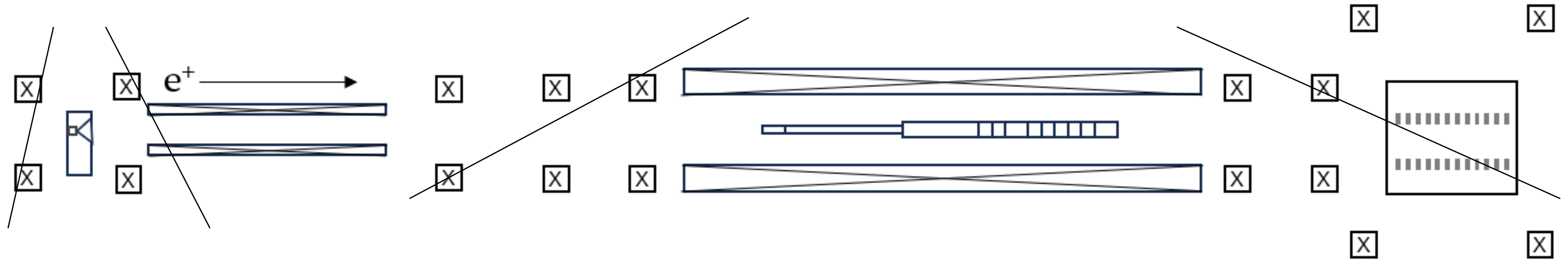




Positron Lab at SMI Kegelgasse *(until May/June)*

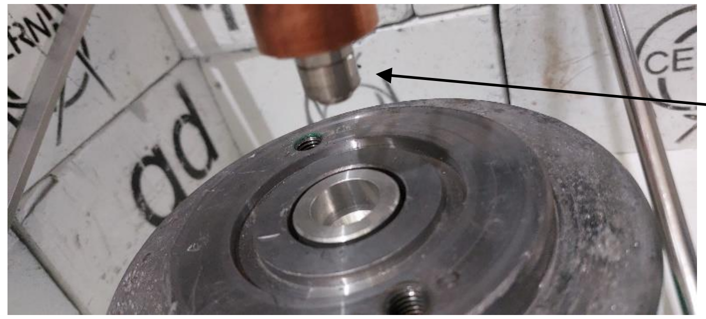
- A new Ne moderated positron beam and buffer gas trap apparatus have been constructed at SMI
- We will soon be producing positron bunches with thermal energy spreads
- The first planned experiments will measure the binding energy of molecular states involving positronium atoms (e.g. PsH, PsOH)
- For this measurement an ion spectrometer is currently under final simulation and will be constructed soon.





Moderator cone

Trap stack



Sodium-22 Source

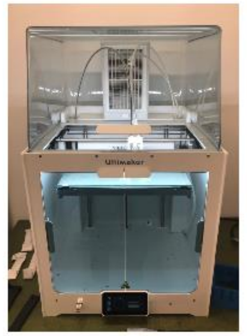
Advanced Instrumentation

Still in Boltzmanngasse 3

Mechanical workshop

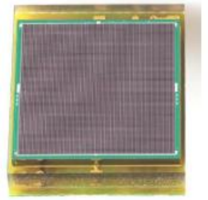
Additive manufacturing





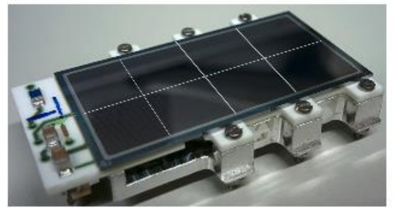
Detectors and experimental setups

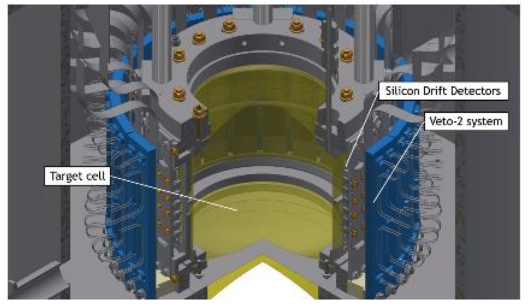
SiPM



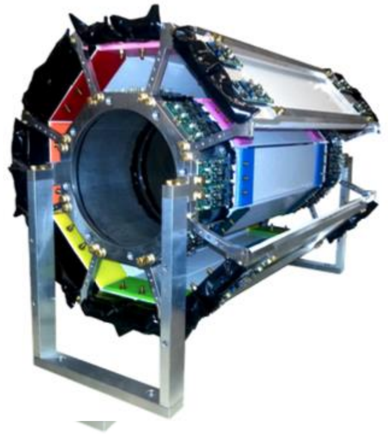
SiPM electronics

SDD

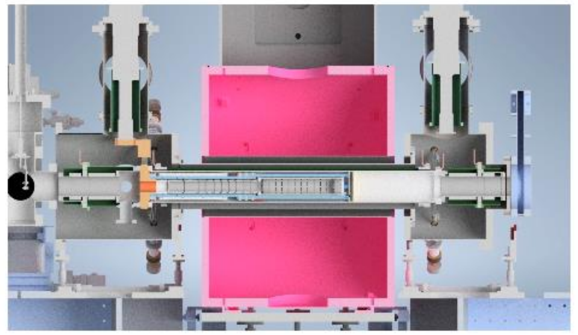




SIDDHARTA-2



Hodoscope



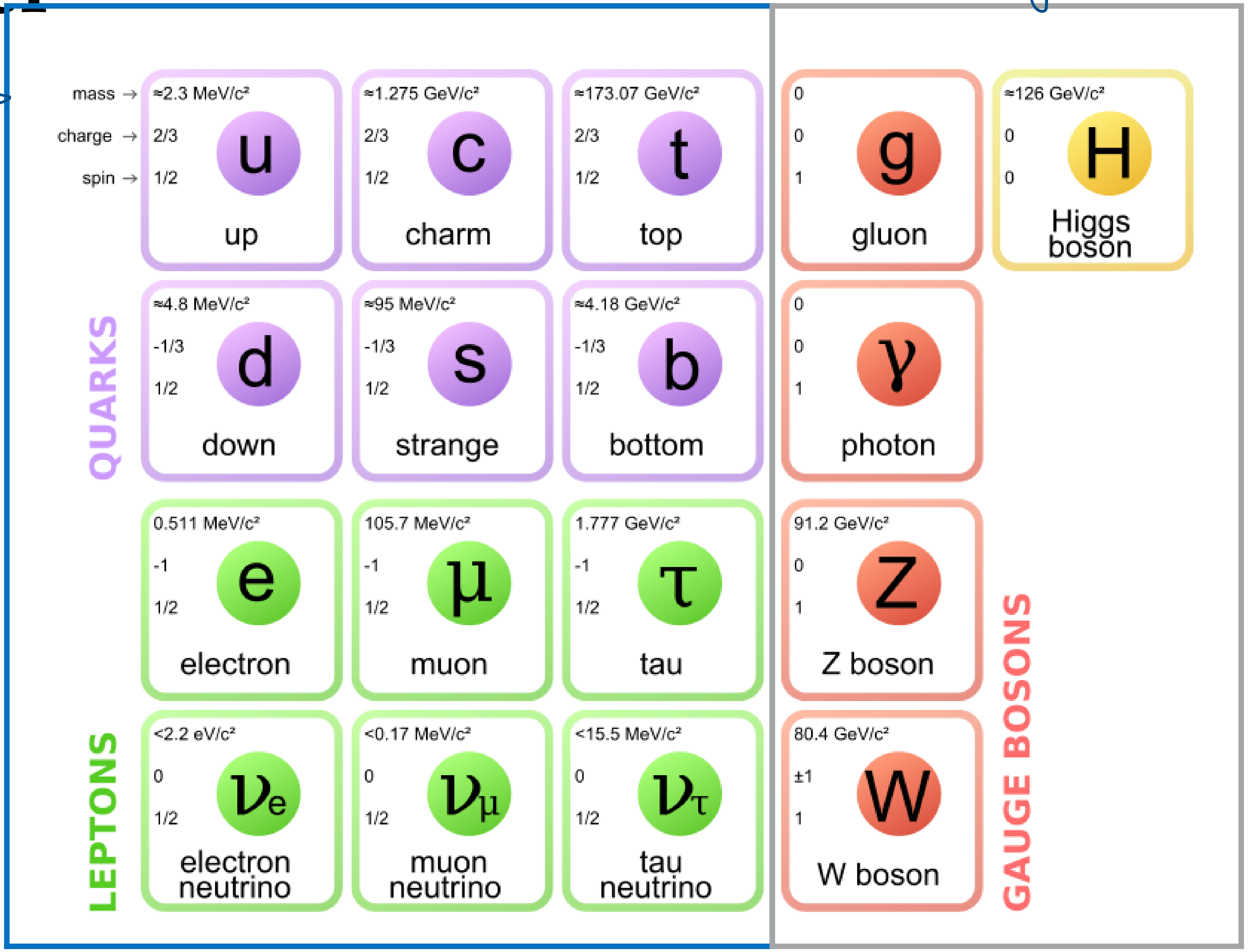
ASACUSA cold bore

ASACUSA Penning trap

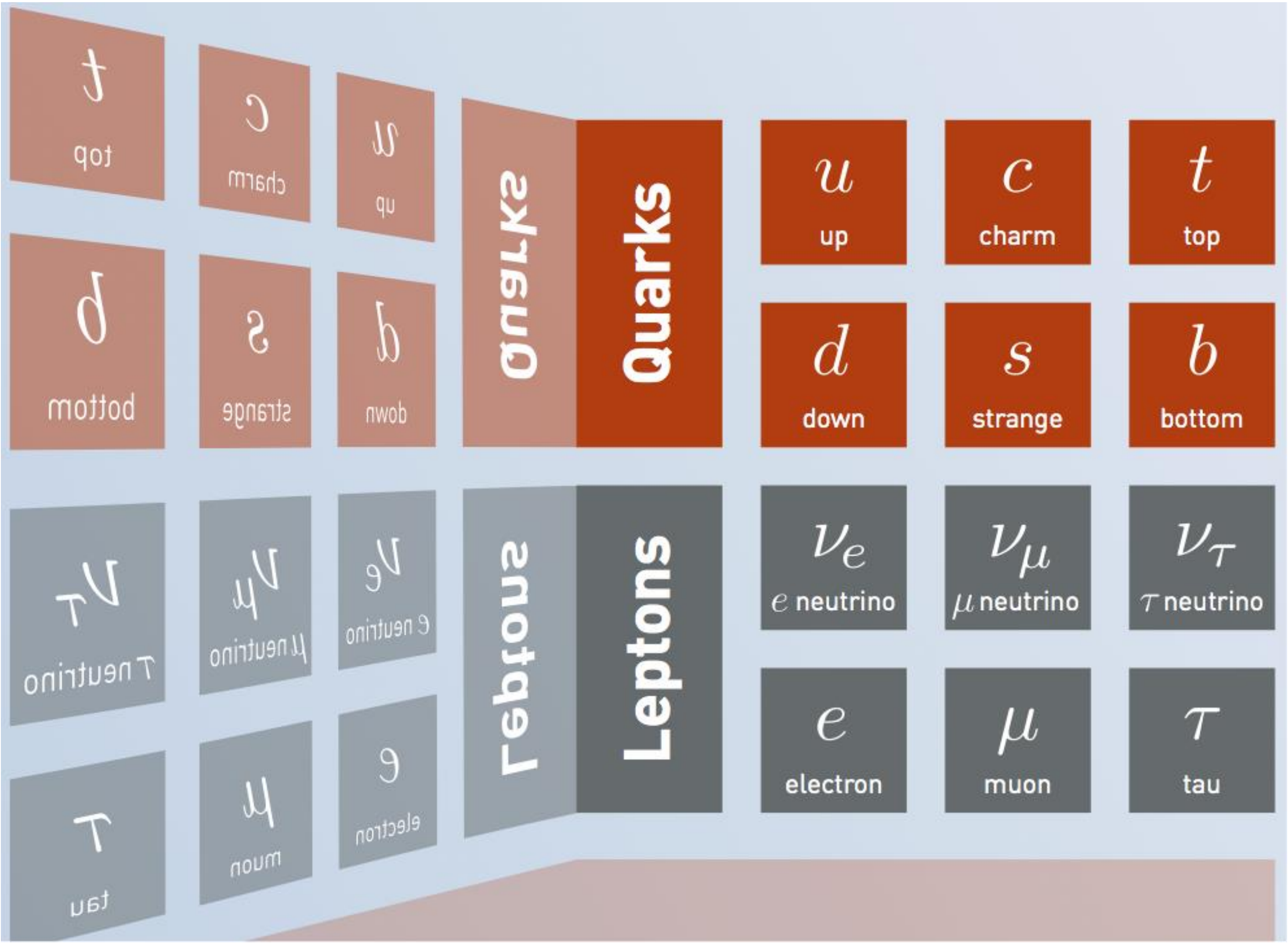
1.3 The standard model

exchange bosons

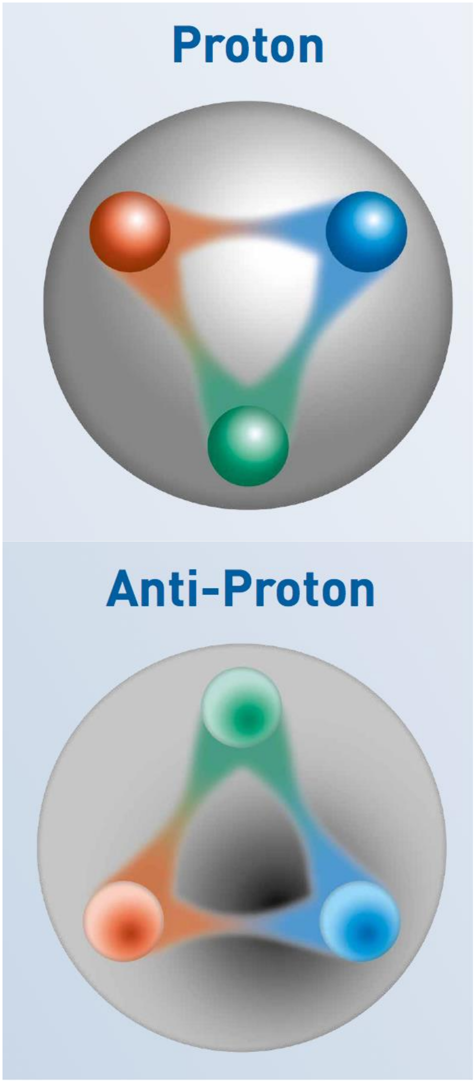
- fundamental fermions
- Leptons
  - e: stable
  - μ: 2.2 μs
  - τ: 2.9x10^{-13}s
  - ν: m=0 (not true!)
- quarks
  - fractional charges
  - 3 colors
  - no free quarks
  - p: uud, n: ddu
- universe: e, u, d



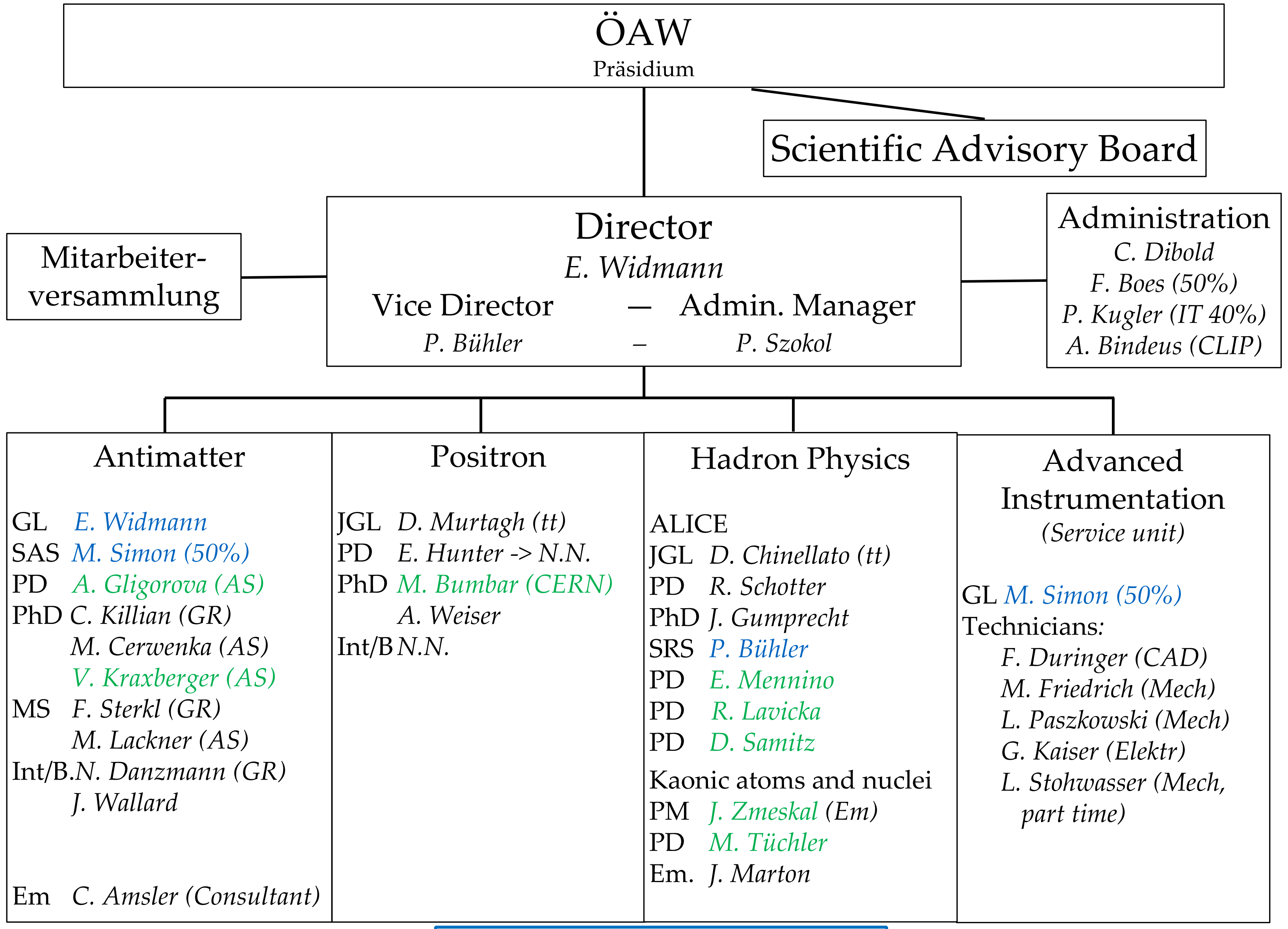
Antimatter



- Matter definition
  - Positive hadron
  - Negative lepton
- For this lecture:
  - **Neutral** antimatter



SMI structure and staff



AS: ASACUSA, GR: GRASIAN, tt: tenure track

Scientists *permanent / third-party funded*

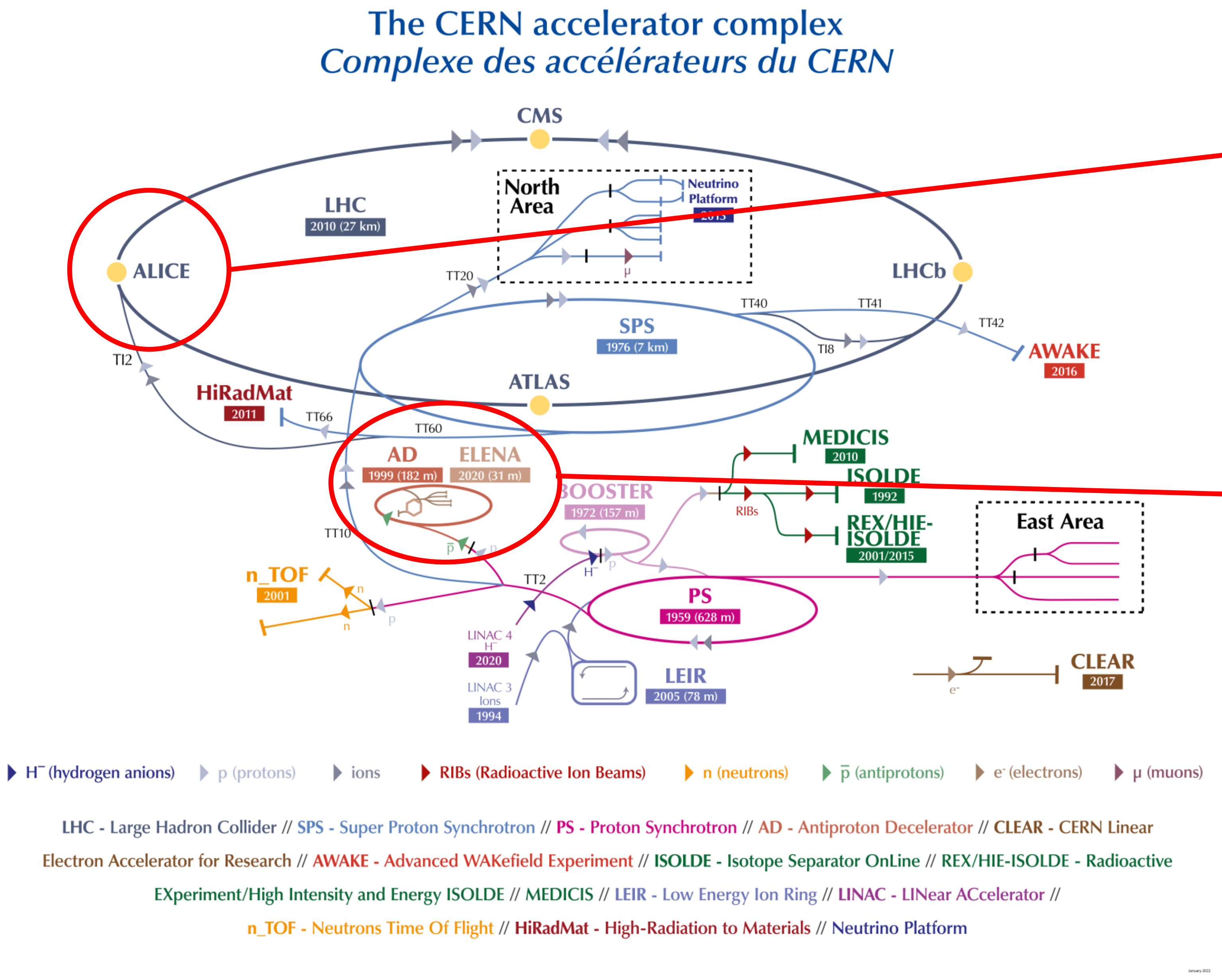
Feb 2024

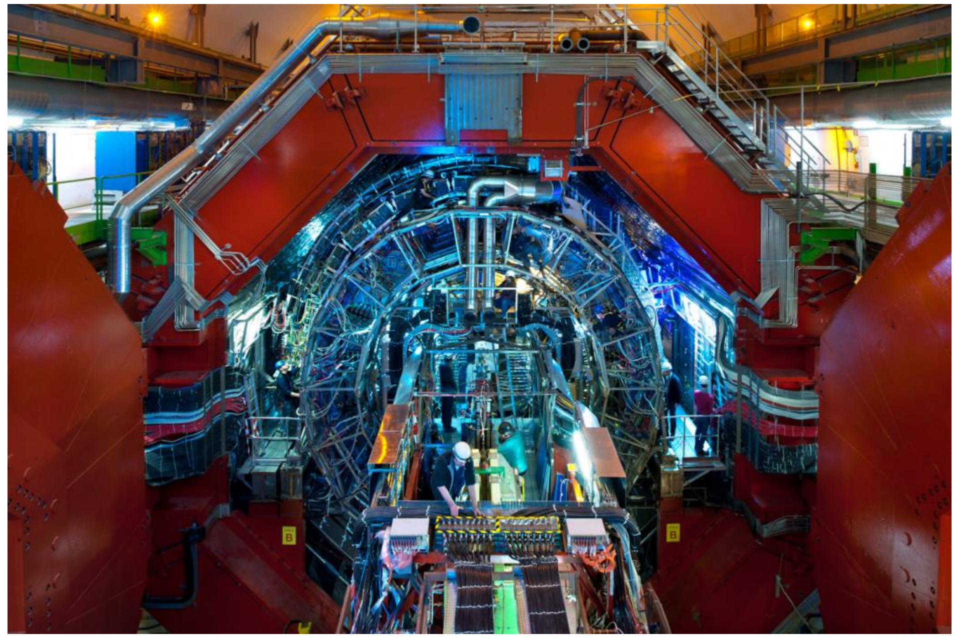
Senior scientists/GL	3	3 permanent, EW → EoS
JGL (*tenure track*)	2	Positron group, ALICE
Postdoc	7	1 JG positron (open), 1 JG ALICE, 5 FWF
Ph.D. students	7	5 intern (2 finishing 2024), 1 FWF, 1 CERN
M.Sc. Students	2	Number fluctuates, from both Uni & TU Wien
B.Sc. Students and interns	3	Number fluctuates
Administration	2.5 FTE	
IT support	1.4 FTE	1 first level, 1 CLIP
Technicians	4	2 mechanical, 1 electronics engineer, 1 drafts(wo)man
Emeriti, Consultants	3	1 PI FWF grant (JZ)

25 FTE without undergrad students, emeriti

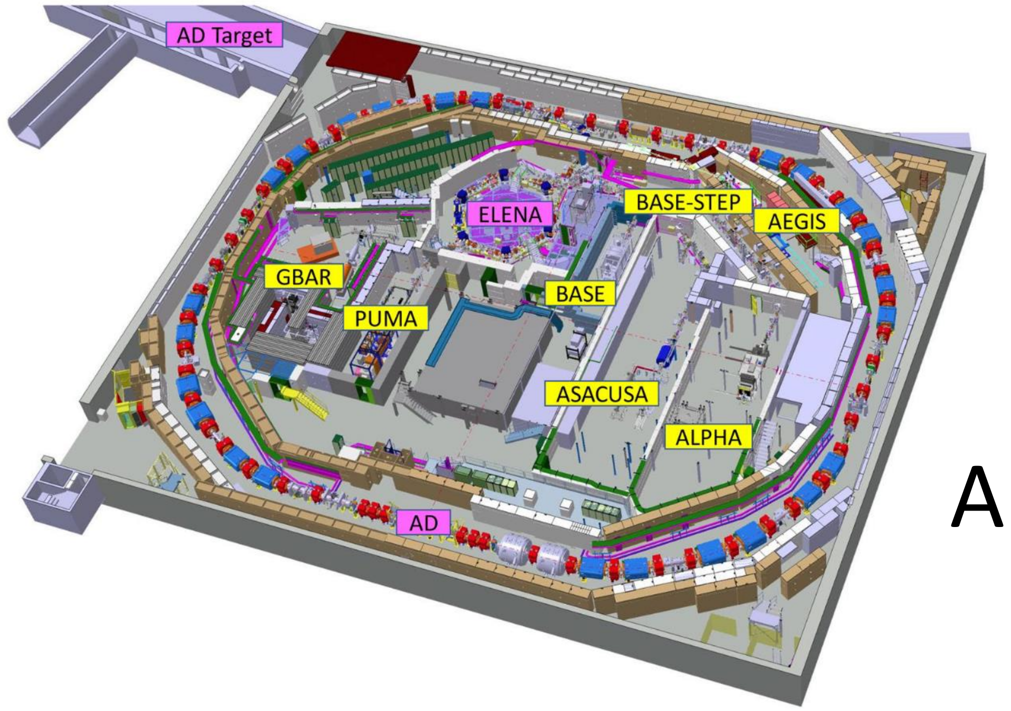
As of Feb 2024

Infrastructures: CERN





ALICE



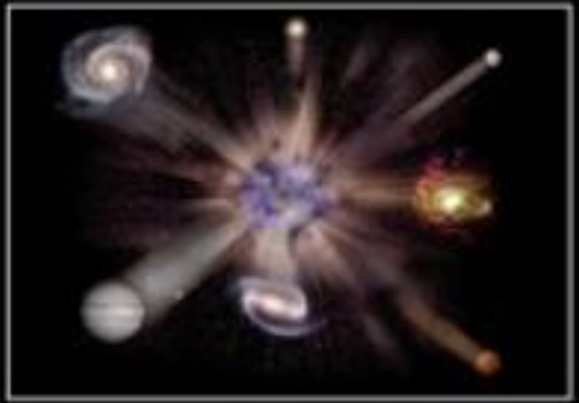
AD/ELENA

Big open questions in particle physics

Unsolved Mysteries

Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, microscopic black holes, and/or evidence of string theory.

Why is the Universe Accelerating?



The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?

Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

What is Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Are there Extra Dimensions?

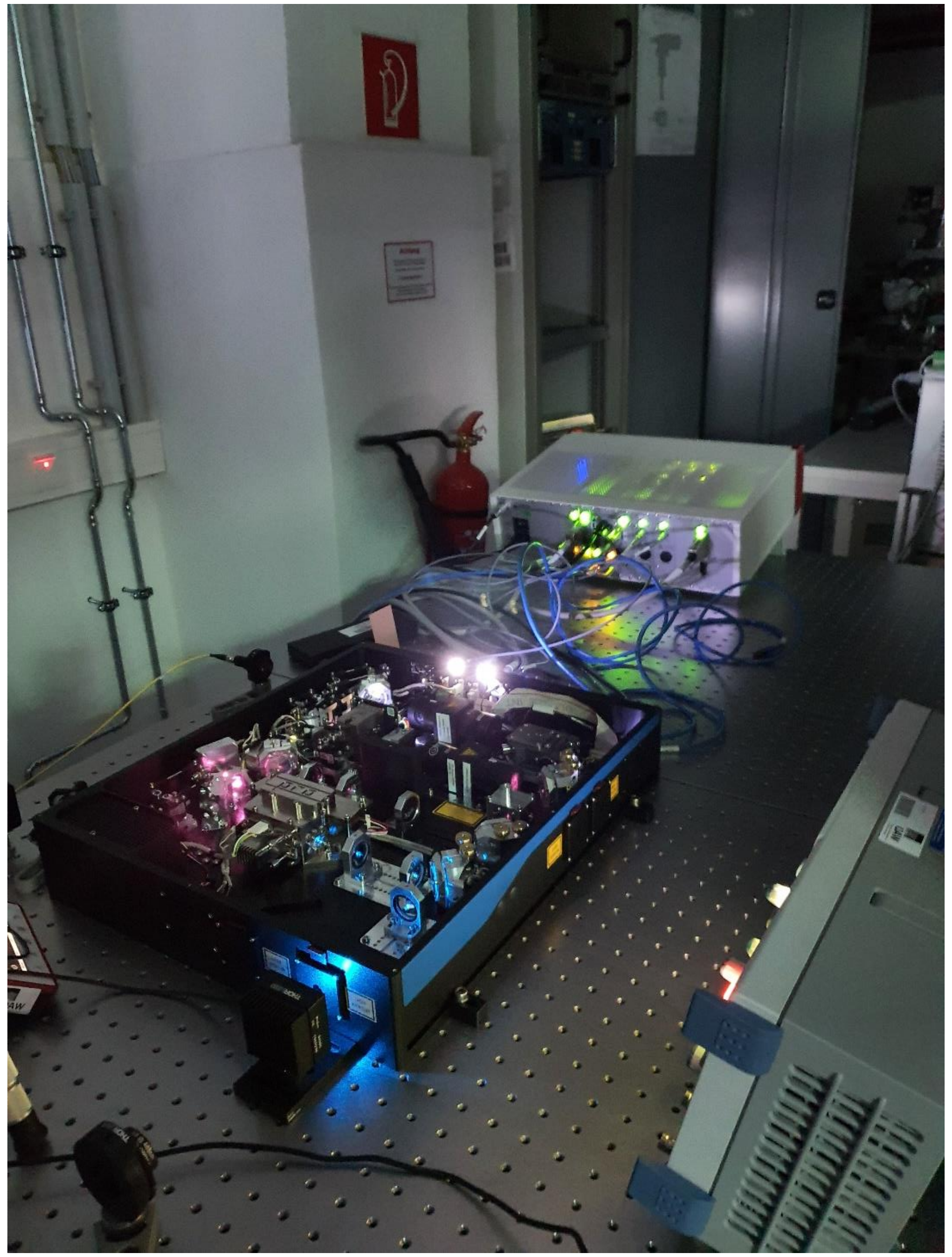
An indication for extra dimensions may be the extreme weakness of gravity compared with the other three fundamental forces (gravity is so weak that a small magnet can pick up a paper clip overwhelming Earth's gravity).

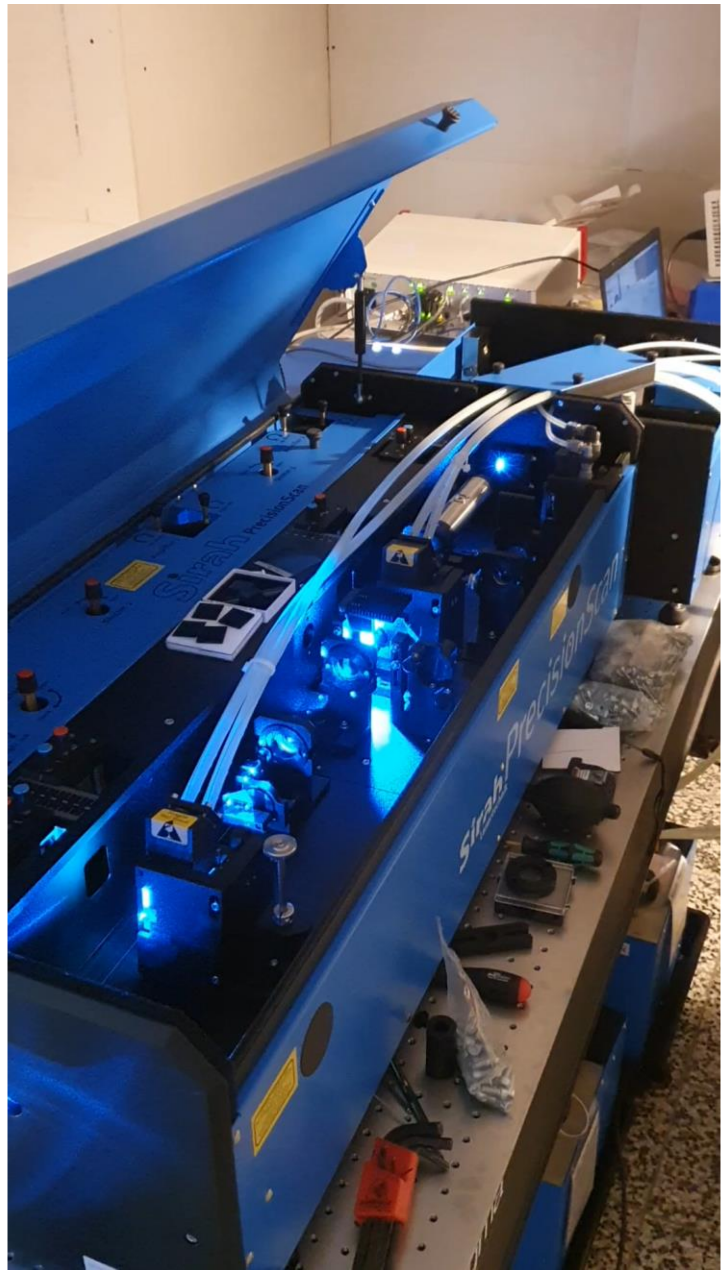
Situation of experiments, labs, workshop

- Move to **Kegelgasse** during Covid
- slow setup of labs due to restrictions of people present, delivery times
  - Delay in installation of new laser system and laser hut
  - ^{22}Na source availability delays ASACUSA and positron lab
- Ps lab to stay in KG → end 2023

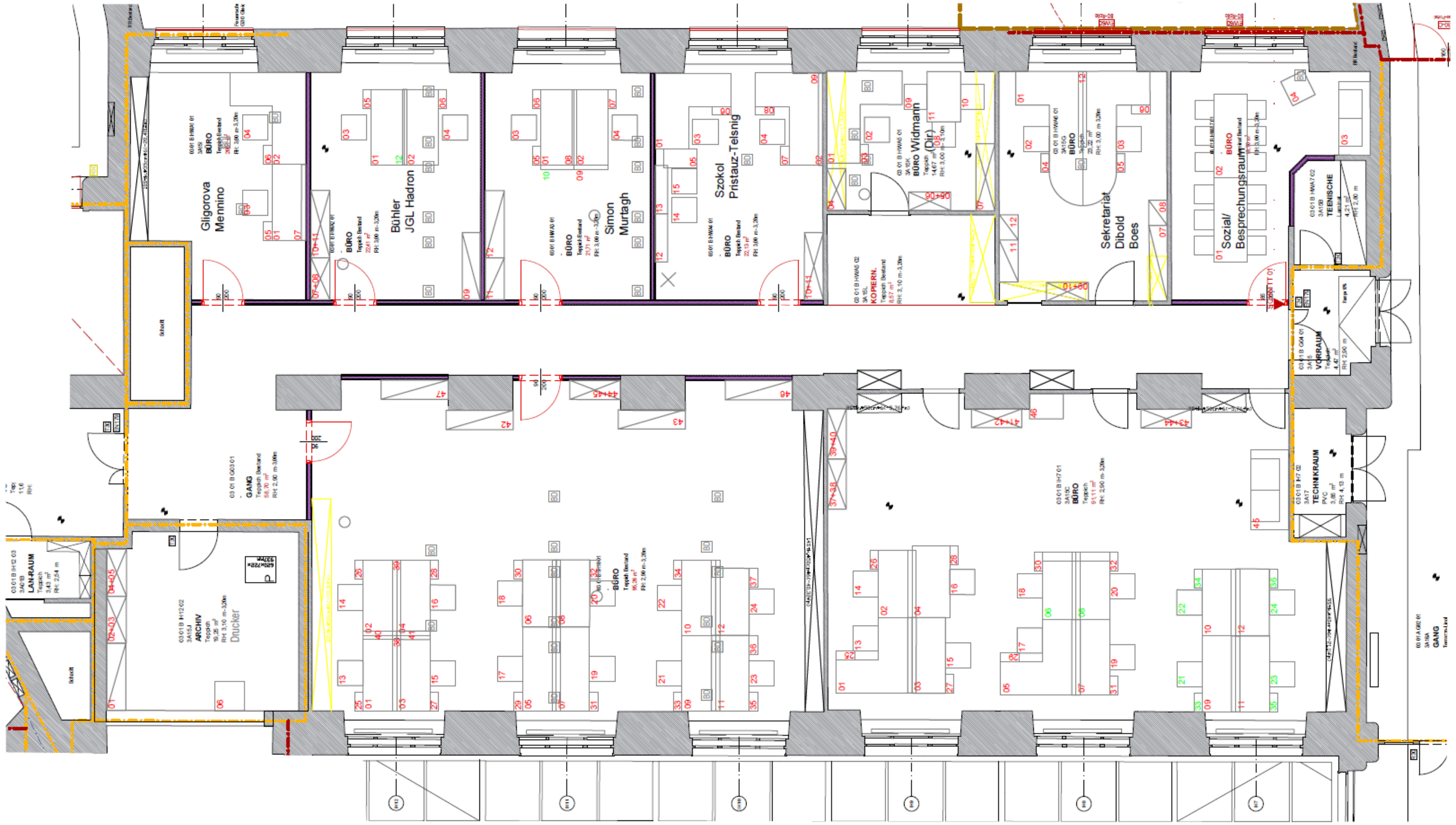
- Move to **PSK**
- Two H/D beam setups needed to be installed outside SMI
  - ETH: Laser system for H detection, return 2024
  - LAC Paris-Saclay: D beam, longer lasting collaboration envisaged
- Mechanical workshop to stay in Boltzmanngasse (IQOQI) until HEPHY moves (end 2024/25)

Laser system for H/D detection



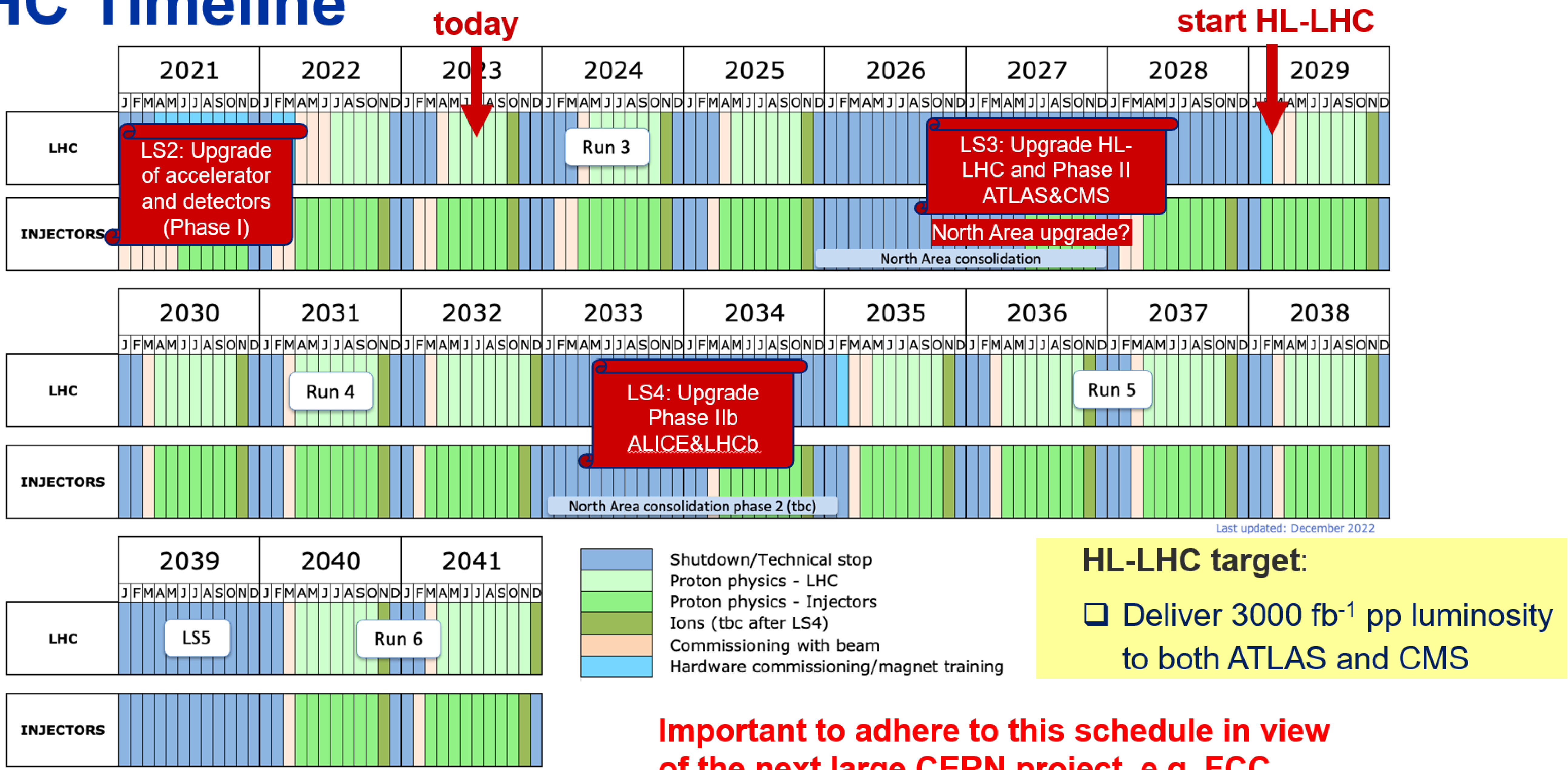


Office layout



- GL/JGL/PDs in 2-room offices
- Two offices with 12+ persons each
  - Acoustic separation needed (“zoom boxes”)
- Only one social / meeting room, others shared

LHC Timeline



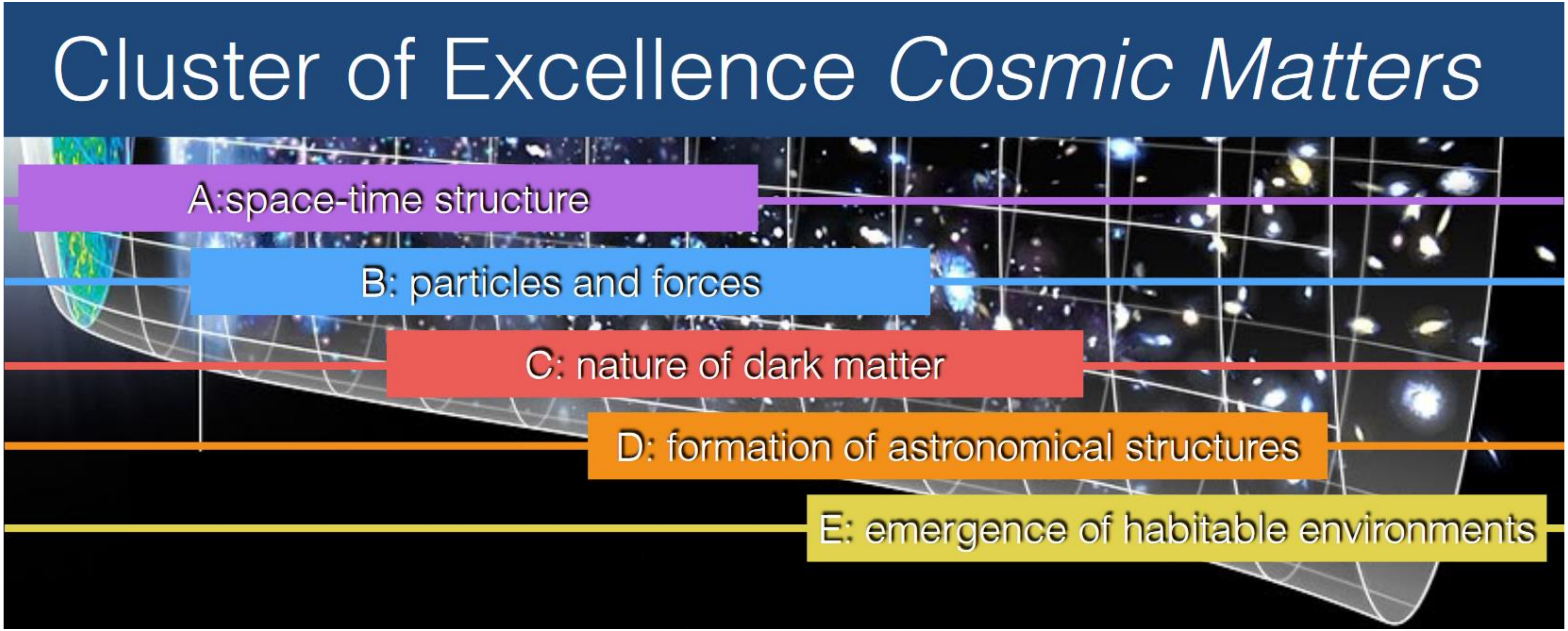
HL-LHC target:

- Deliver 3000 fb^{-1} pp luminosity to both ATLAS and CMS

Important to adhere to this schedule in view of the next large CERN project, e.g. FCC

New grant scheme excellent = austria

- Custers of Excellence
- **Cosmic Matters**:
  - ÖAW, Uni Wien, TU Wien, U Graz, U Innsbruck
  - 35 M€ / 5 years, additonal 5 years possible after evaluation
  - All particle physics and astrophysics groups in Austria
  - 30+ key researchers
  - CERN, ESO, ESA
  - *Director of Research EW*
- SMI contributions
  - ASACUSA: RA A
  - ALICE: RA B
  - GRASIAN: RA A, B, C
- Infrastructure
  - Cryolab
  - Austrian Silcion Lab (CMOS det.)
- Procedure
  - 15 Dec 2021 pre-proposal
    - *If successfull*
  - 17 Oct 22 full proposal
  - Final decision end of Mar 2023

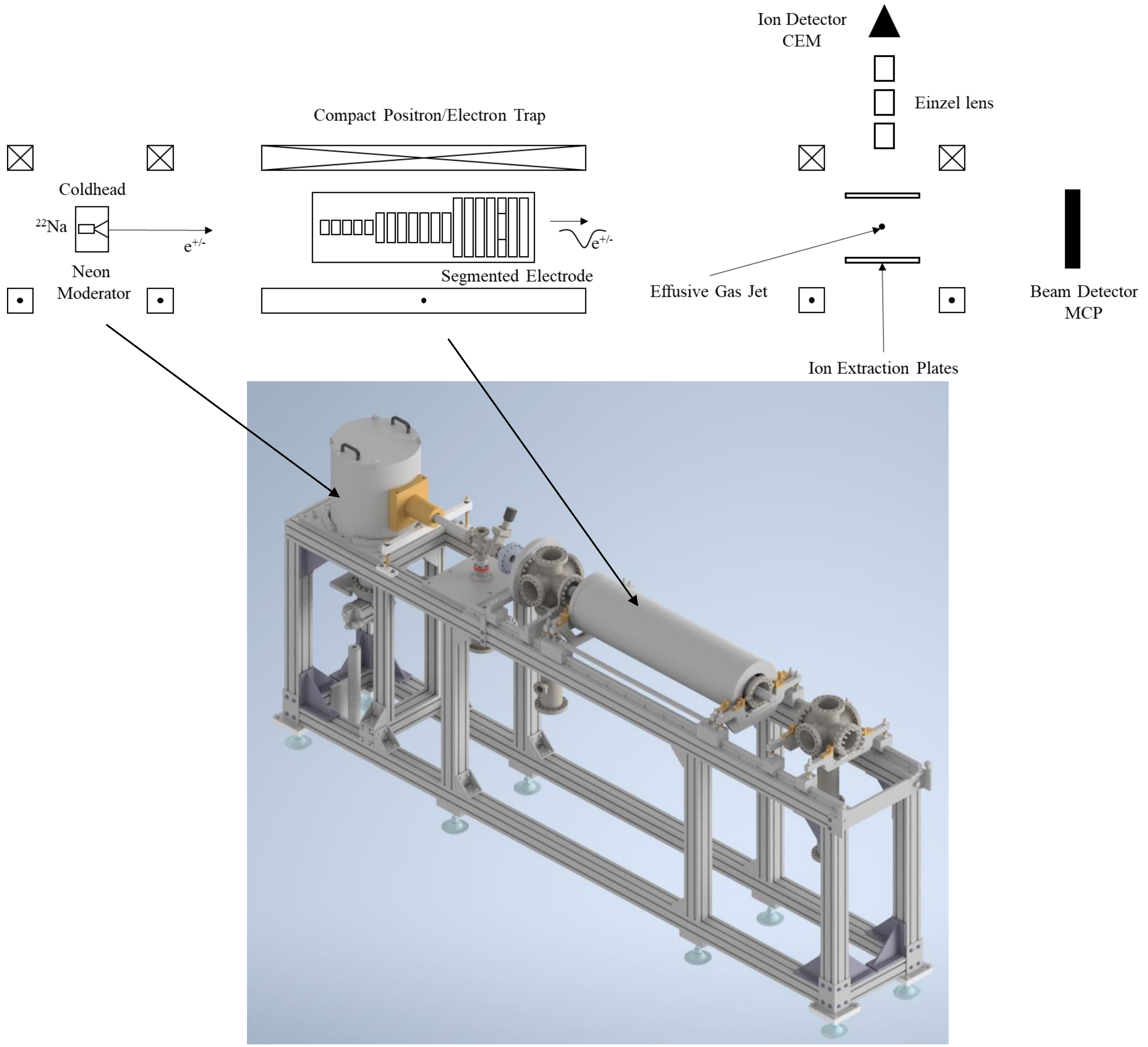

Cluster of Excellence *Cosmic Matters*
A:space-time structure
B: particles and forces
C: nature of dark matter
D: formation of astronomical structures
E: emergence of habitable environments

Physics program overview

- Introduction
- Low energy precision experiments
  - ASACUSA@CERN
  - NoMoS *(in collaboration with ATI)*
  - VIP@LNGS
- Hadron physics
  - Kaon-nucleon interaction
  - Belle *(in collaboration with HEPHY)* and PANDA
  - ALICE
- Advanced Instrumentation

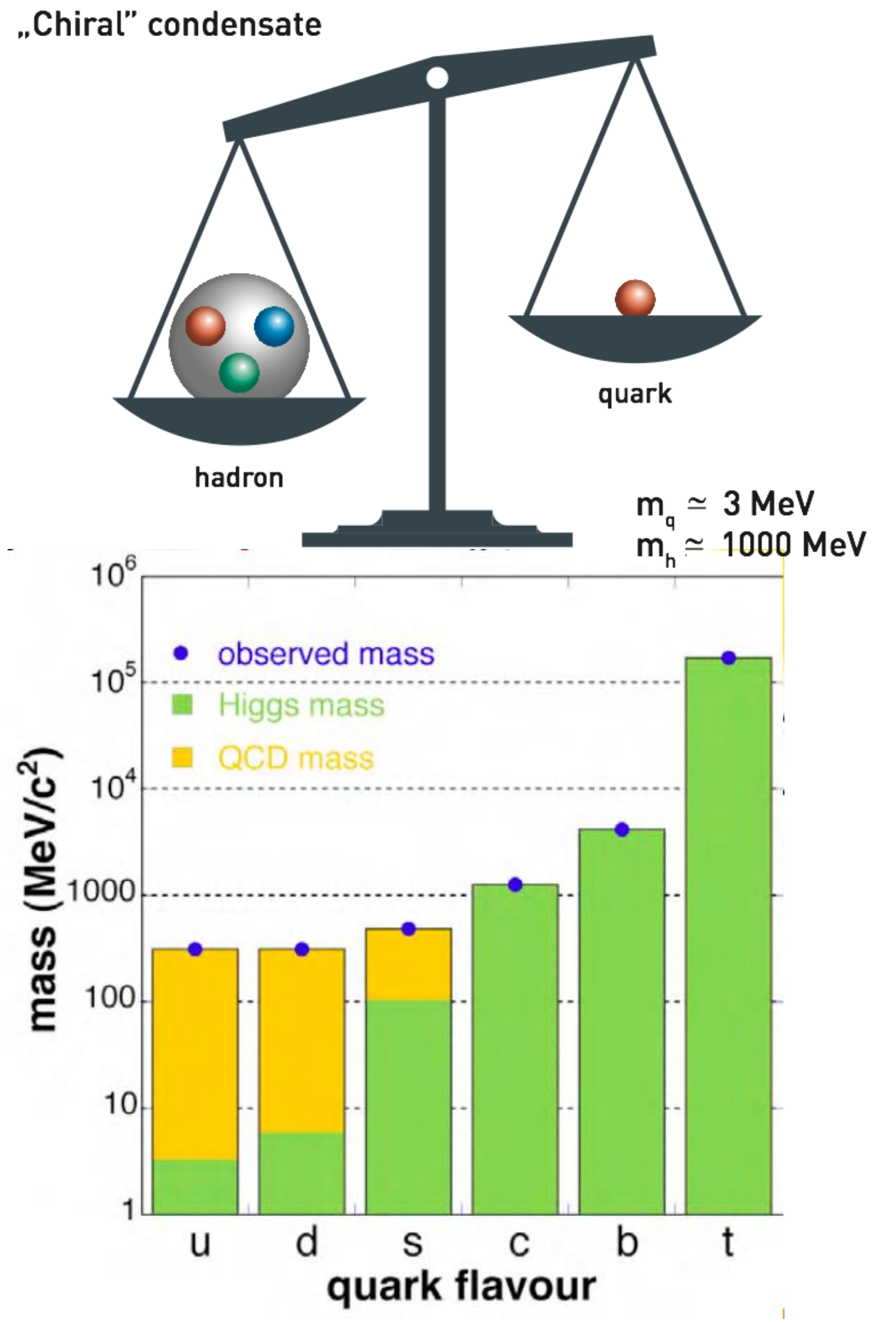
Positron Lab at SMI

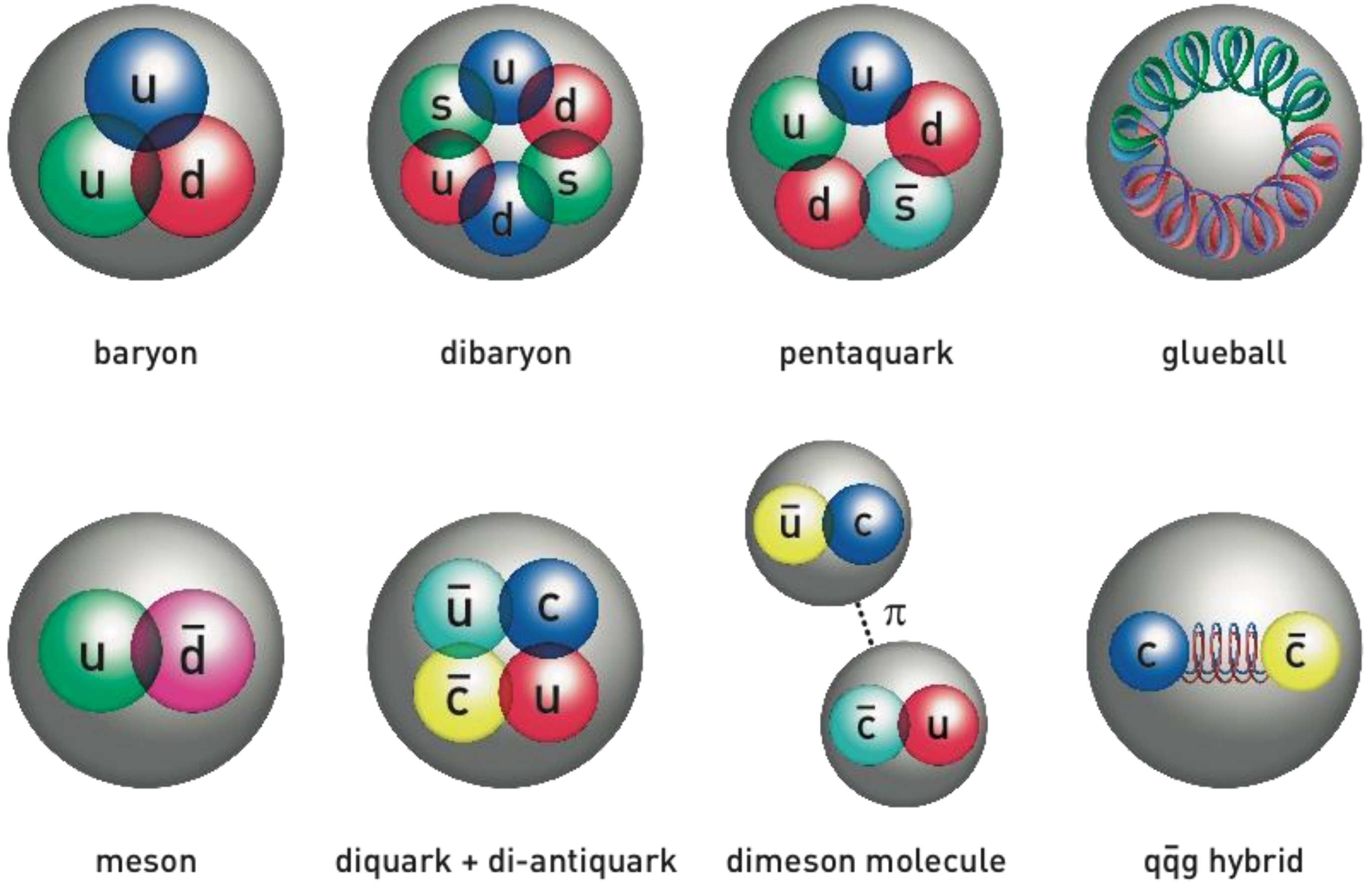
- A new Ne moderated positron beam and buffer gas trap are under construction at SMI
- By the end of 2021 we will be producing pulses of positrons with thermal energy spreads for experiments here at the institute
- The first planned experiments will look for the formation of molecular states involving positronium such as positronium hydride (PsH), positronic water (PsHO) and positronium sulphide (PsS)
- The binding energy of these systems will be investigated using ion spectroscopy to identify the production of dissociation fragments below their formation energy



Hadron physics in non-perturbative regime

- Hadrons: first level of complexity
- Mass generation by dynamic processes
- Not all predicted states are observed
- New states so far unexplained





Summary

- Subatomic physics at accelerators and underground labs
- Mostly long-term projects
- Subjects in NuPECC LRP
- Funded by
  - ÖAW
  - FWF
  - ERC
  - Marie Curie (IF, ITN)
  - IA HadronPhysics 1-3 (FP6,7), Strong2020 (H2020, submitted)
  - bmbwf
  - ffg, COST

- Funding scheme for contributions to large experiments missing
  - ÖAW: commission GROFO

Grants – active

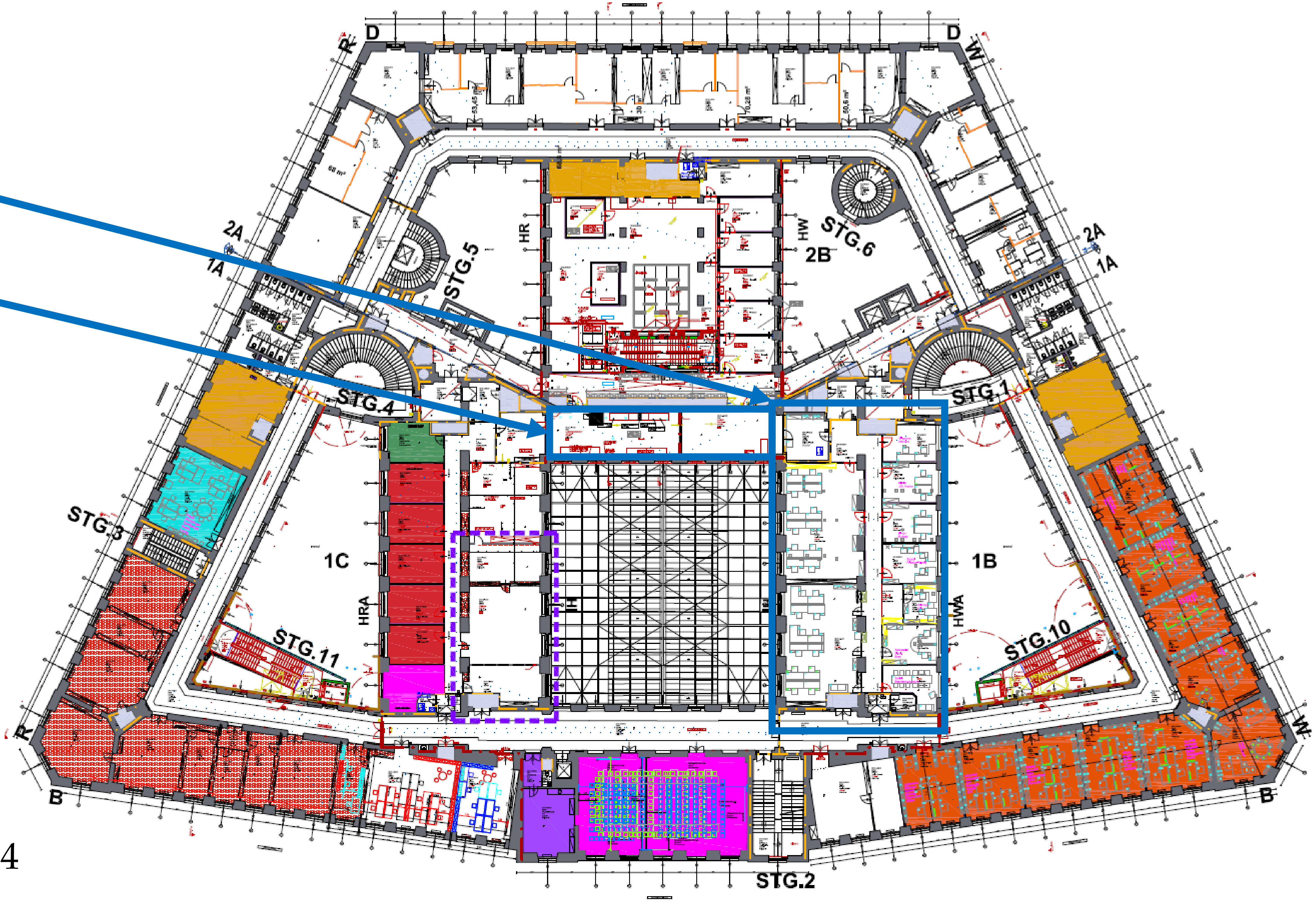
- FWF
  - FWF stand-alone projects
    - SIDDHARTA-2, E57 (*Zmeskal*) →*11/24*
    - ASACUSA p̄ annihilation (*Gligorova*) →*06/24*
    - ALICE dileptons (*Meninno*) →*10/25*
    - ALICE tau magnetic moment (*Bühler*) →*07/25*
- Horizon2020
  - Strong2020 (*Zmeskal*) →*07/24*
- ÖAW Innovation Fund
  - *D-Rabi approved (Simon, one-time invest)*

- In evaluation
  - FWF Start QGP (*K. Boguslavski, theory TU Wien*)
  - ANR-FWF joint project GRASIAN *(EW)*
  - Marie Curie Doctoral Network ALICE *(Chinellato)*

others

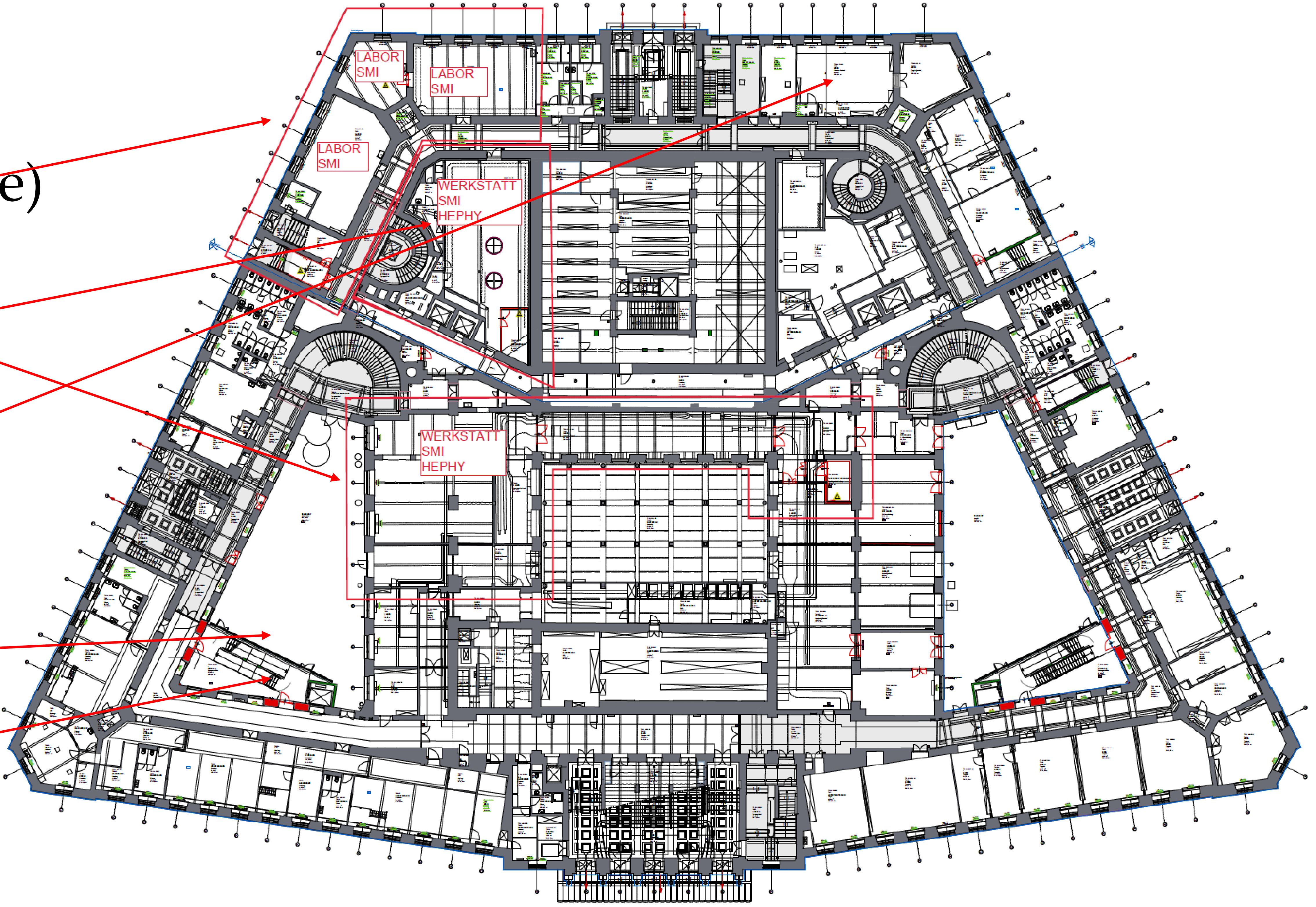
- Planned
  - FWF Stand-alone project for J-PARC *(Zmeskal)*
  - FWF Schrödinger Fellowship *(F. Hechenberger, theory TU Wien)*
  - FWF Stand-alone project ALICE *(Chinellato)*
  - FWF Stand-alone project for Ramsey spectroscopy with hydrogen and antihydrogen (Simon)
  - FWF Stand-alone project ALICE *(Bühler)*
  - ERC Synergy Grant GRASIAN *(EW)*
    - 2019 *approved but not funded, resubmission planned for* 2024/2025
  - ERC Consolidator Grant *(Chinellato, 2024/2025)*
  - Cryo4ppp infrastructure call FFG together with HEPHY
    - *once on reserve list but not selected, resubmission planned*
  - PhD student cotutelle SMI/LKB Sorbonne funded, 2nd cotutelle in preparation (GRASIAN)
- Graduate school
  - *Vienna Doctoral School in Physics VDSP (EW)*

- Moved in Sep 2023
- Offices on 3rd floor
  - Electronics lab, small mechanical workshop
- Labs on ground floor
  - Same as Kegelgasse
- Common workshop with HEPHY (*during 2024*)
- Cryolab in basement
  - New; jointly used with HEPHY
- Main issues
  - Acoustic cross-talk between offices
  - Seminar room infrastructure
  - *Financing of safety installations in labs, zoom boxes (solved?)*
  - Workshop stays in BG till middle 2024



Labs

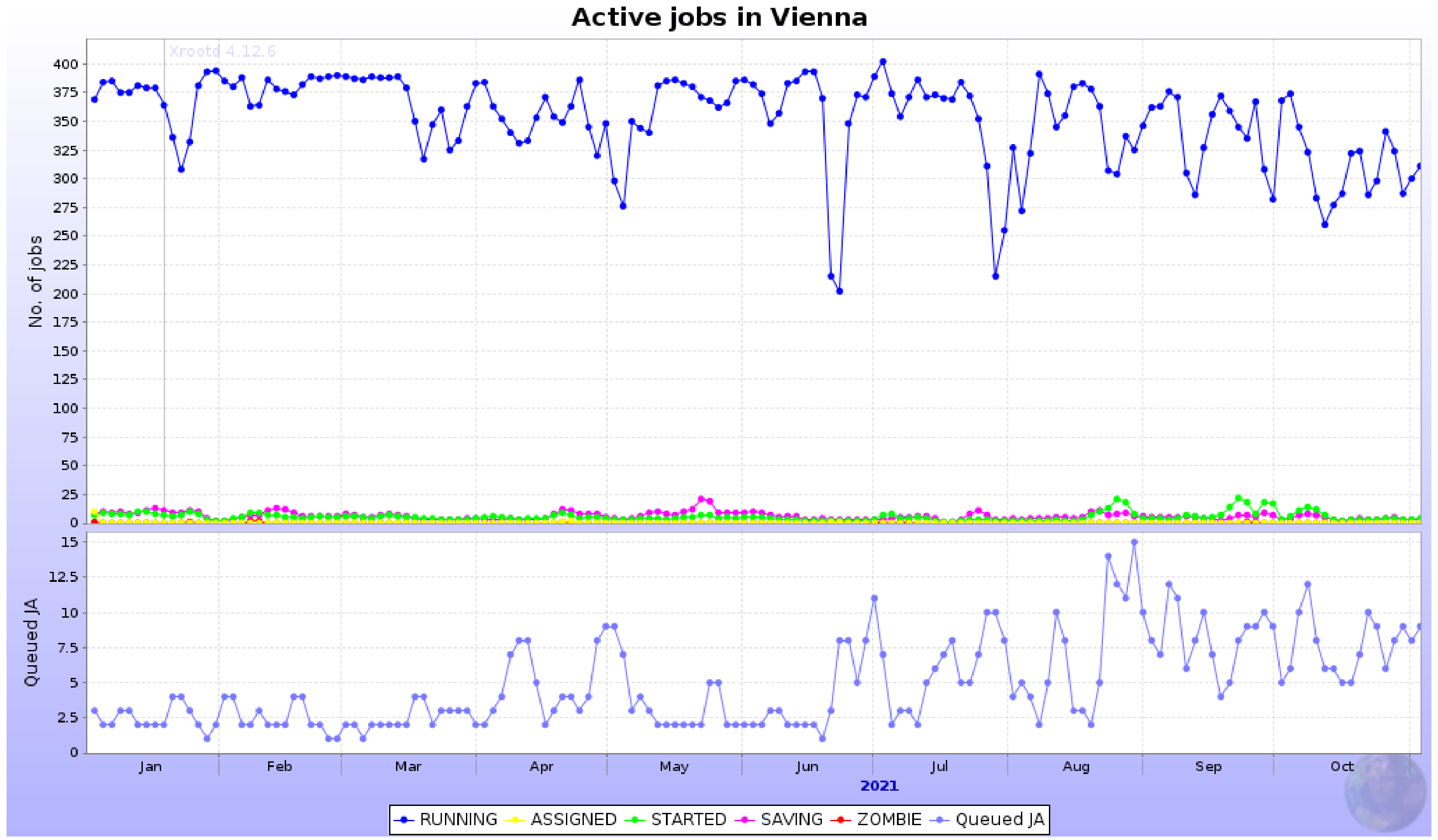
- Ground floor (Tiefparterre)
  - Labs
  - Mechanical workshop
    - Jointly with HEPHY
  - Offices of technicians
- Basement (Oberkeller)
  - CNC milling machine
  - Cryolab
    - Jointly with HEPHY
  - Laser lab



CLIP

- High Performance Data Analysis infrastructure: *CLIP – Center for Life Science and Physics*
  - GMI, IMBA, IMP, HEPHY, SMI
  - Grid (CMS, Belle, ALICE) working since summer 2020
  - Non-grid usage still weak
  - Usage will increase because of ALICE expansion
    - Additional invest: disks, CPUs

ALICE grid jobs (predominantly)



Renaming ceremony 29 Oct 2004

- *Jean-Pierre Blaser*, Cooperation of the Austrian Academy of Sciences and the Swiss Institute for Nuclear Research
- *Carlo Guraldo*, Kaon Physics at Laboratori Nazionale di Frascati (LNF)
- *Carlo Guaraldo*, The DEAR-SIDDHARTA Project at Laboratori Nazionale di Frascati (LNF)
- *Sydney Gales*, The FAIR-Project at GSI-Darmstadt - A European Perspective
- *Volker Metag*, Perspectives of Hadron Physics at FAIR
- *Paul Kienle*, Our fields of research