Physics Beyond Colliders Closeout 5th Annual Workshop

Gianluigi Arduini, Joerg Jaeckel, Gunar Schnell, Claude Vallée

Acknowledgements: All Participants of the Workshop, all PBC Accelerator and Physics Working Groups and collaborators.

(Many slides pictures taken from Workshop. Thanks!)

CERN, 27th March 2024

Good News to start the Workshop

Sticker Available ☺

Good News to start the Workshop

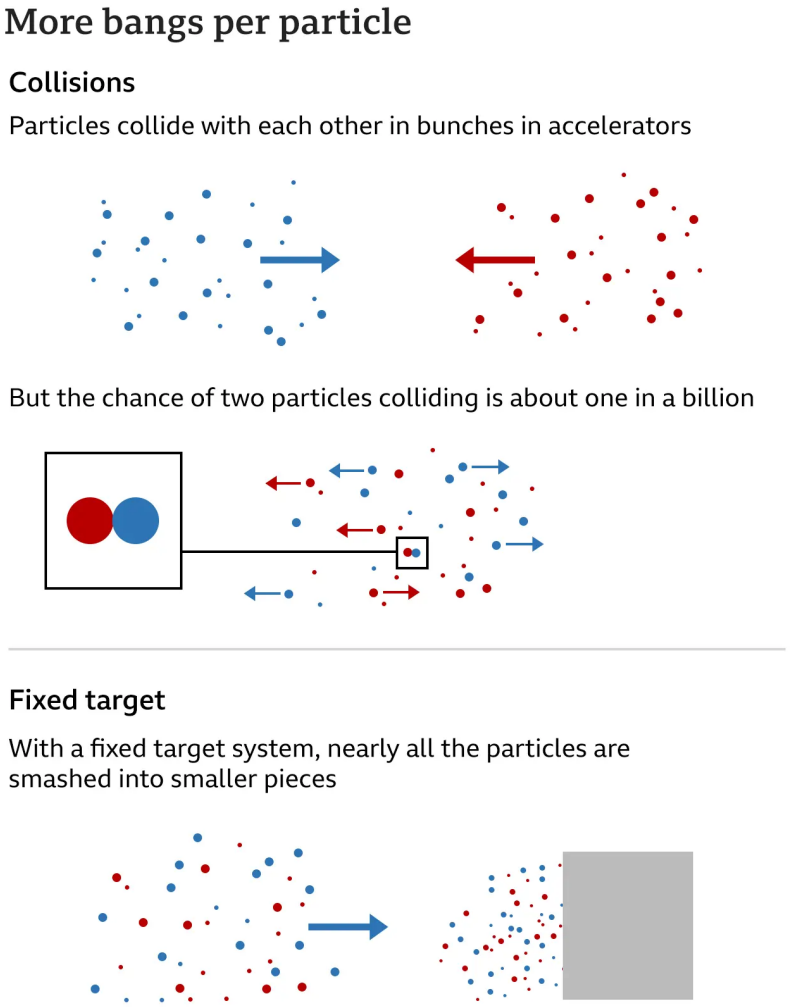
ECN3 High Intensity Programme approved:

SHiP will search for Feebly Interacting Particles at the Beam dump Facility with a physics programme extending beyond the next decade and contributing to maintain an exciting diverse programme in the North Area

ECN3/BDF/SHiP is going to be followed-up by the SPSC and the BDF WG is discontinued

BBC “discovers” Dark Matter and Fixed Targets on Monday

Victor de Schwanberg/Science Photo Library



Both pictures from https://www.bbc.com/news/science-environment-68631692

European Strategy

Council approved timeline for the update of the European Strategy for Particle Physics:

- community input by 31 March 2025
- process to be concluded by June 2026

Diverse physics programme remains one of the ingredients of the strategy preparation

➔ **PBC to contribute**

Forward Physics Facility

Current status and plans

Detectors layout being defined, overall Integration

➔ **Clarify plans with regard to SND**

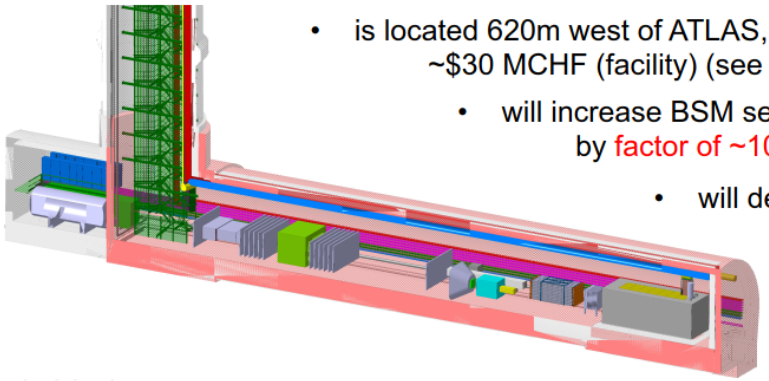
Updated facility document by June 2024

LoI to be submitted early 2025

FORWARD PHYSICS FACILITY

- These experiments have demonstrated the ability to detect thousands of TeV neutrinos and carry out background-free BSM searches with tabletop-size far-forward experiments on time and on budget.
- They have opened a new window at the energy frontier.
- Similar to the discovery of cosmic neutrinos or gravitational waves, the appropriate question is not whether we should follow up on these discoveries, but how can we best exploit this new way of learning about the Universe.

The proposed Forward Physics Facility at the HL-LHC



- is located 620m west of ATLAS, 75m long, 11.5m wide, ~$30 MCHF (facility) (see J. Boyd's talk)
- will increase BSM sensitivity (decay vol * lumi) by factor of ~10,000 over FASER
- will detect ~1000 TeV-energy neutrinos *per day*

Feng 3

Forward Physics Facility

Complementarity with present and approved experiments to be further detailed:

- BSM searches beyond PBC benchmarks
- Neutrino physics
- Potential to have impact on HL-LHC main experiments' programme (PDFs etc.)

➔ Discuss Complementarity between SHiP and FPF considering broader physics case

➔ Quantify impact on BSM searches

➔ Compare to SMOG2 and other measurements of PDFs and investigate complementarity

➔ Quantify systematics at low-x

Large-Angle LLP Searches

Codex-beta: Good progress on construction.

(embedded into LHCb)

(pre-)Anubis: Test setup running. Data taken!

(embedded into ATLAS)

MATHUSLA: re-scoping after P5

factor 10 size reduction to save cost

➔ **Update Physics case in light of SHiP. Highlight complementarity.**

➔ **Investigate physics potential in comparison to main detectors at LHC, (in particular in light of new analysis strategies such as the one proposed for LHCb)**

➔ **Possible Discussion between SHiP/FPF/Large-Angle LLP/NA64 theory to consider benchmarks models and beyond**

LHC Fixed Target

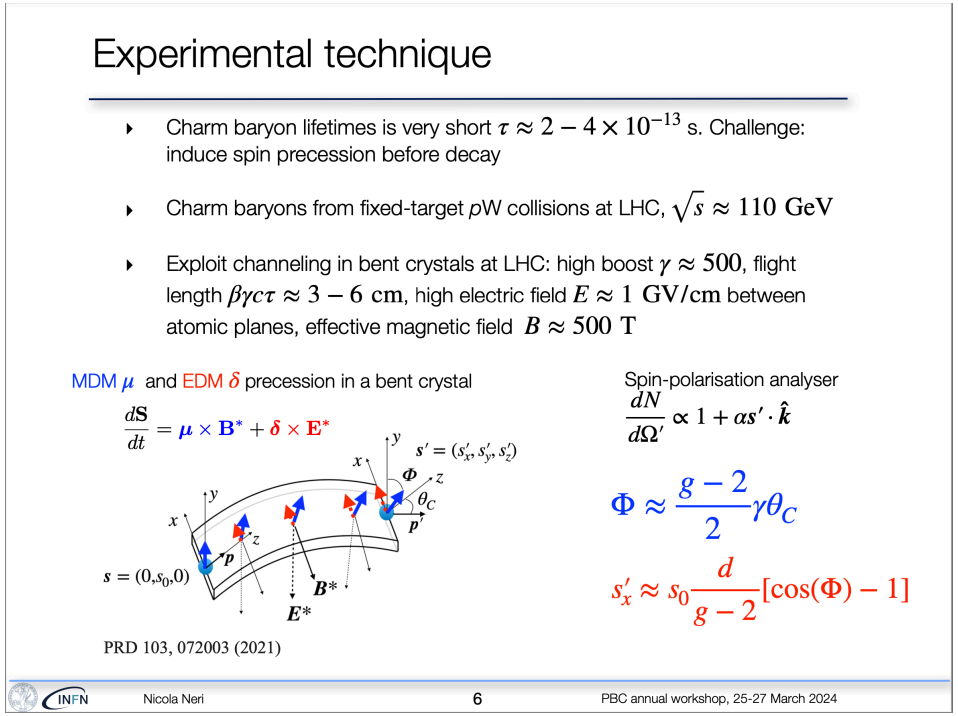
LHCSpin:

- SMOG2 as a successful demonstrator of FT and Collider running simultaneously
- encouraging experimental results for the recombination of polarized Hydrogen atoms into polarized Hydrogen molecules in a carbon coated storage cell ➔ confirmation needed

Crystals: Progress with the preparation of the Proof of Principle tests in LSS3 ➔ Beam tests expected in 2025

- LoI to be submitted to LHCC
- SMOG2 data to provide data for Λ_c

➔ **Investigate E and B in crystal and the uncertainties related to those**



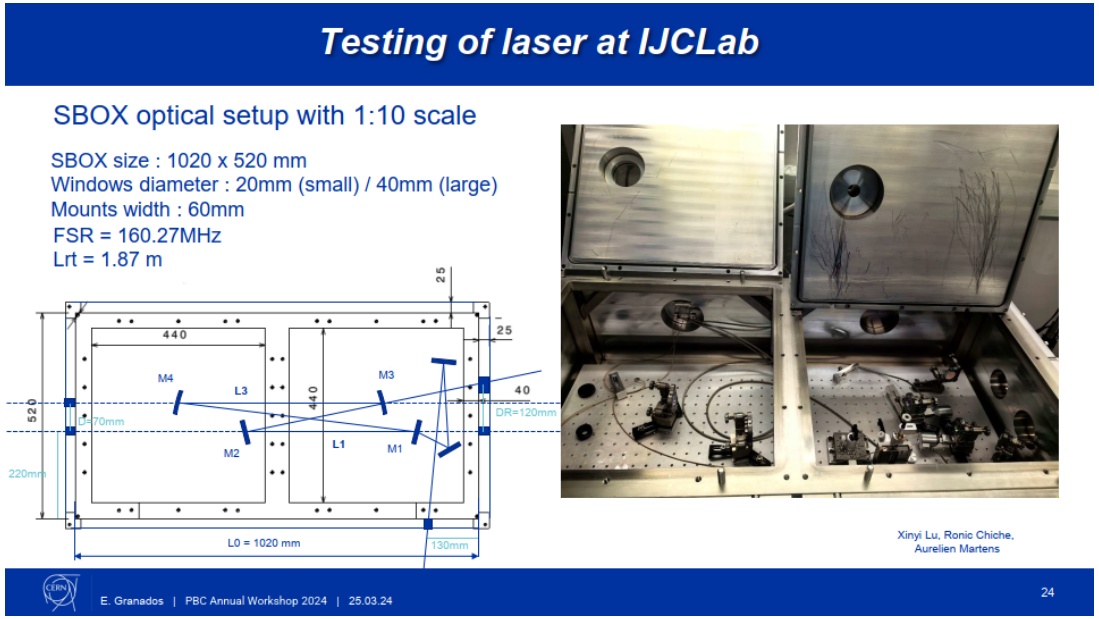
Gamma Factory Proof of Principle

Validation of the main building blocks for a proof of principle experiment (thanks to IJCLab & SY/STI):

- Oscillator with excellent stability/low phase noise
- Locking with high finesse cavity at low power
- Environmental vibration measurements
- Laser line stability investigations ongoing (North Area). End of the year
- Tests at higher power with 4 mirror cavity to come

Simulations to assess the possibility to achieve transverse emittance cooling for ion beams encouraging

➔ **Define clear physics case for Proof of Principle (e.g. Xenon cooling (helpful for ALICE))**



NA Ion Experiments

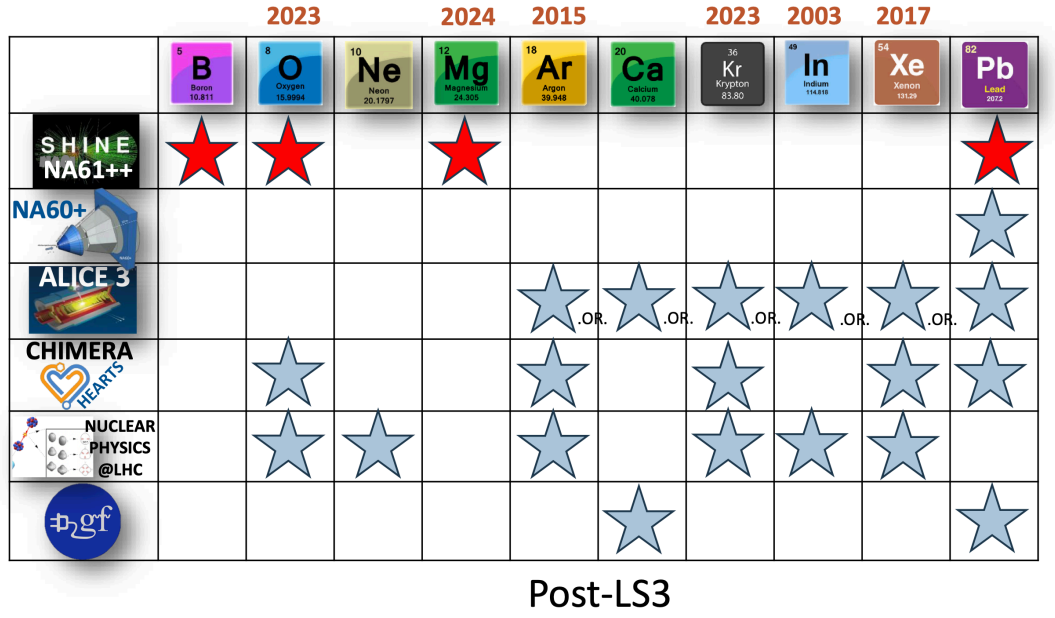
- **Document in preparation**

Ion beams requirements for the North Area Experiments post-LS3

C. Ahdida[1], R. Alemany Fernandez[1], G. Arduini[,1], K. Balazs[1], H. Bartosik[1], D. Boer[&], R. Bruce[1], T. A. Bud[1], N. Charitonidis[1], T. Galatyuk[&], M. Gazdzicki, J. Jaeckel*[,13], M. Kuich, J. Osborne[1], J. Pawlowski[&], T. Prebibaj[1], S. Pulawski, G. Schnell[&,26], E. Scomparin, G. Usai, C. Vallée*[,24], M. Van Dijk[1] (to be finalized)*

- **Ion needs and viable scenario for sharing between users with different species**

CURRENT REQUESTS AND SYNERGIES

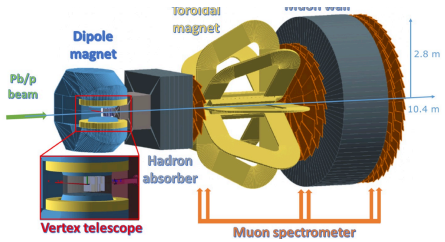


PBC ANNUAL MEETING, R. ALEMANY FERNANDEZ

NA Ion Experiments NA60+ NA61/SHINE

Main physics topics

Caloric curve of QGP	⇨	Measurement of temperature of thermal dimuons vs $\sqrt{s_{NN}}$
Chiral symmetry restoration	⇨	ρ-a_1 mixing in the dimuon channel
Charmonium melting in the QGP	⇨	Charmonium suppression vs $\sqrt{s_{NN}}$ (dimuon decay channel)
QGP transport coefficients and charm hadronization	⇨	Hadronic decays of open HF mesons/baryons



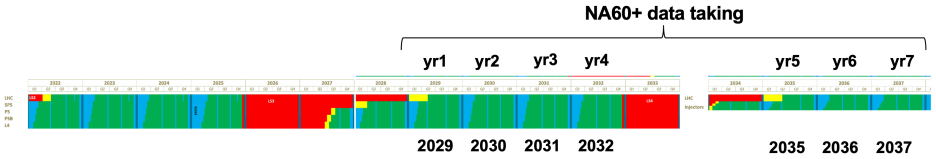
Progress on detector

NA60+ timeline

The plan discussed with SPSC is to have the experiment on the floor by the end of LS3 → **2029**

Roadmap:

- Technical proposal: **2024-2025** → Good progress on fundamental technical points
- Construction and installation: **2026-2028**

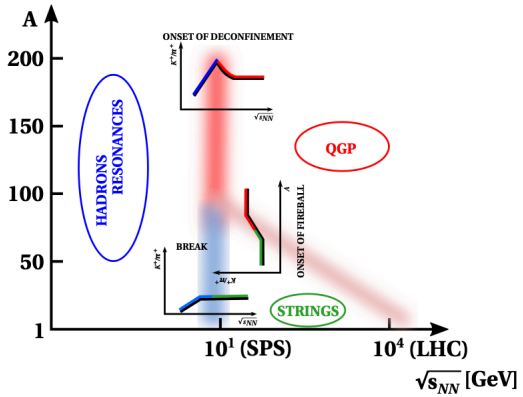


NA61/SHINE program post-LS3

SPS Heavy Ion and Neutrino Experiment

- **Energy scan with light and medium mass ions to study the phase diagram of strongly interacting matter**
- Measurements of heavy hadron resonances in large statistics p+p interactions
- Measurements with antiproton beams
- Measurements of hadron emission from the LBNF and HYPER-K replica targets
- Data for flux predictions in neutrino experiments using very low energy beams

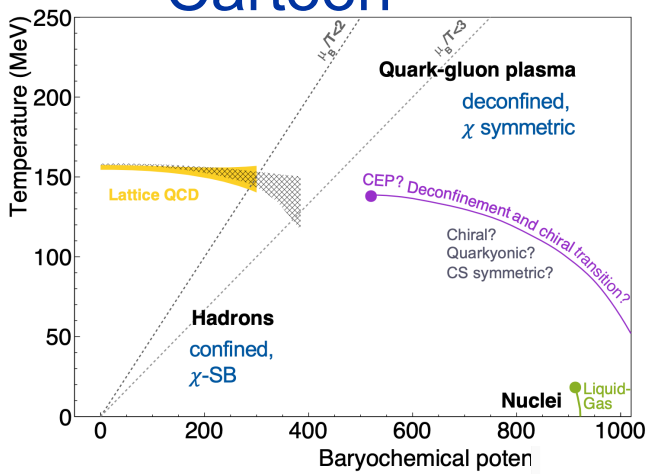
- **New and exciting physics post-LS3**:
  - search for **the onset of fireball** of strongly interacting matter
  - verification of the hypothesis of **large isospin violation** with **N=Z** nuclei (the simplest case).



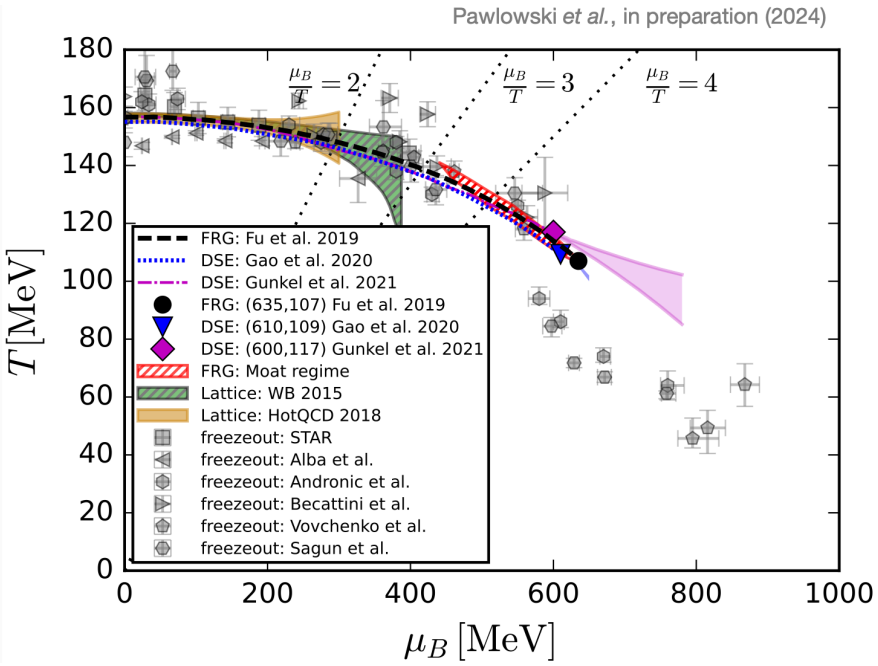
Maja Maćkowiak-Pawłowska
for the NA61/SHINE Collaboration

NA ION Experiments Physics Case

Cartoon



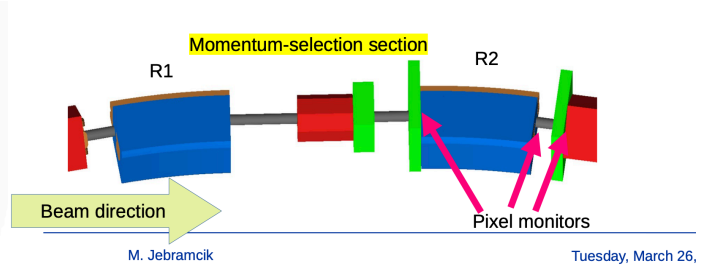
vs Calculation



- ➔ **Make Physics Case simple to understand and picture for non-experts**
- ➔ **Which questions can be answered? How?**
- ➔ **Interplay with other experiments.**

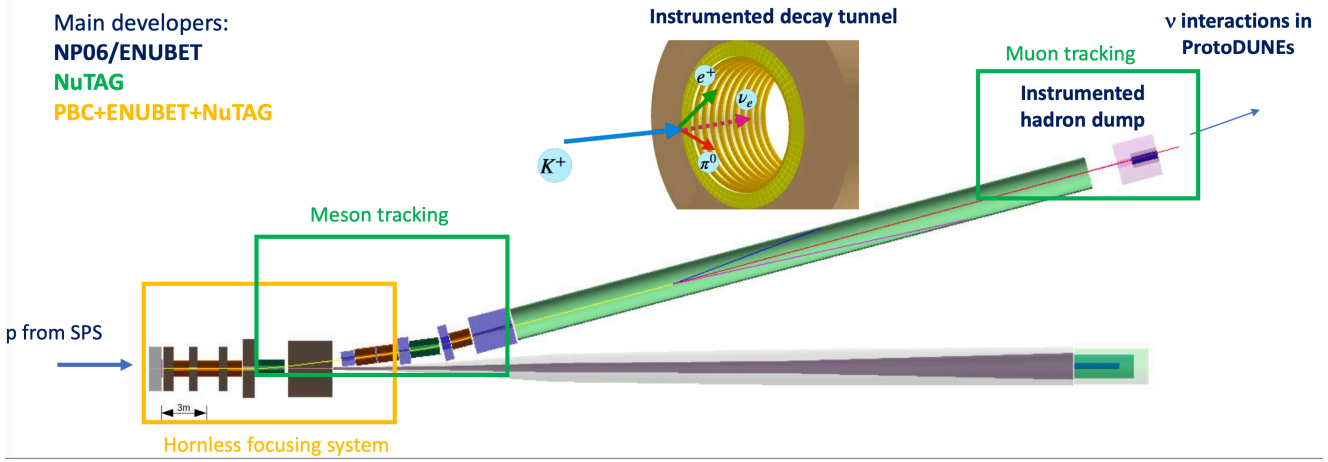
Neutrinos: ENUBET/NuTag SBL

- Neutrino cross sections (dominant systematic for future experiments)
- Know neutrino energy (second leading systematic)



- Merging of the ENUBET and NuTAG proposal have led to a reduction of the required pot by factor 5 to 10

Progress on design



A. Longhin, M. Perrin-Terrin, F. Terranova(*)
on behalf of the ENUBET and NuTAG Collaborations

➔ **Potential sites to be investigated for the strategy?**

NA64

- Data Taking going on ☺.

- Leading Searches for several dark sector particles

	2016-2018	2021	2022	2023	2024	2025	
NA64e	2.84 × 10^{11} EOT	6 × 10^{10} EOT	~6.3 × 10^{11} EOT	~5.1× 10^{11} EOT		~ 3× 10^{12} EOT	LS3
			1.5 x 10^{12} EOT		Improved set-up		

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1057 (**2023**), 168776

	2021	2022	2023	2024	2025	
NA64e+		1x10^{10} E+OT @ 100 GeV	1x10^{11} E+OT @ 70 GeV	@ 40, 60 150 GeV	Tests @ 40 GeV	LS3

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	2021	2022	2023	2024	2025	
NA64mu	2x10^{9} MOT @ 160 GeV	2x10^{10} MOT @ 160 GeV	1.5x10^{11} MOT @ 160 GeV	3x10^{11} MOT @ 100/160 GeV		LS3
			Improved set-up			

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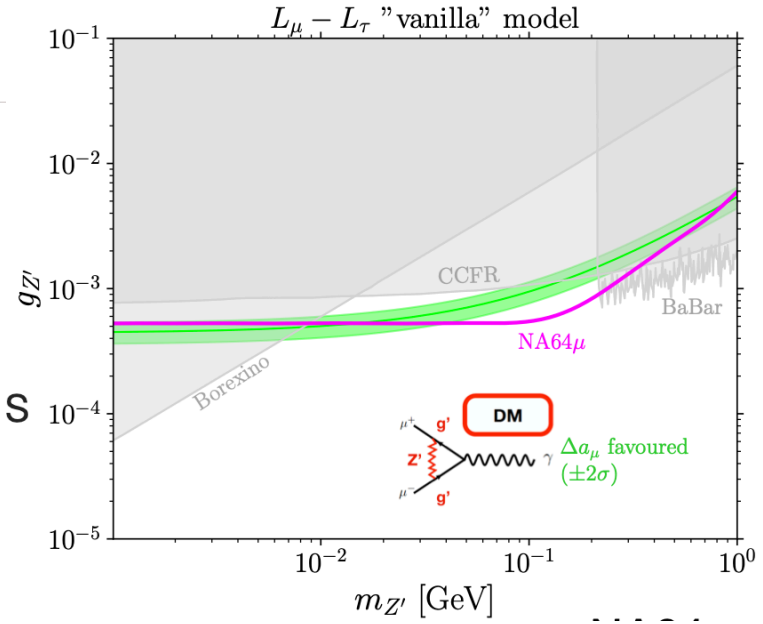
NA64h

- **2022** ~2x10^{9} pions (1 day) -> proof of principle (DS coupled to quarks)
- p+ A -> E_{miss} (S,P,Z', HNL, ..) + X , technique à la NA64e under study



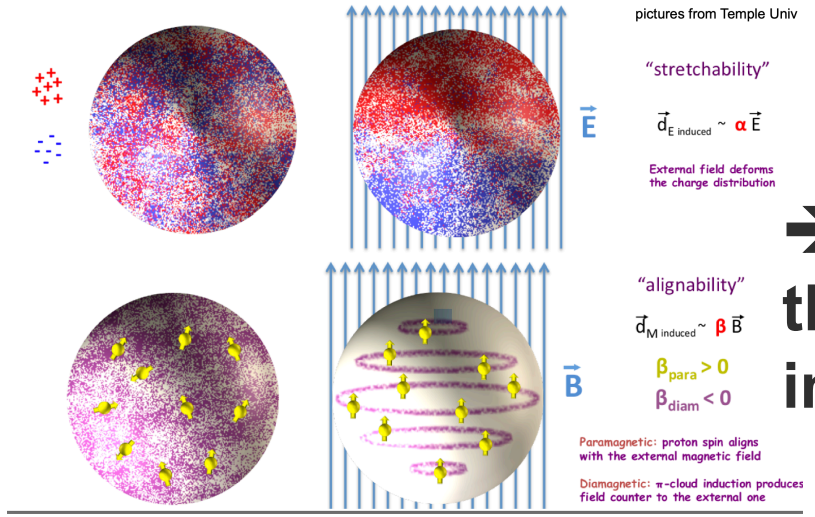
NA64, arXiv:2401.01708

➔Interface with SHiP/FPF etc on benchmark discussion

AMBER

	Beam	Target	Additional Hardware	
Proton radius measurement	100 GeV muons	high pressure Hydrogen	active target TPC, tracking stations (SciFi, Silicon)	Phase 1 (approved)
Antiproton production cross section	50 GeV - 280 GeV protons	LH_2, LHe	Liquid He target	
Drell-Yan measurements with pions	190 GeV charged pions	Carbon, Tungsten		
Drell-Yan measurements with Kaons	~100 GeV charged Kaons	Carbon, Tungsten	vertex detectors, 'active absorber'	Phase 2 (in preparation)
Prompt photon measurements	> 100 GeV charged Kaon/pion beams	LH_2, Nickel	hodoscopes	
K-induced spectroscopy	50 GeV - 100 GeV charged Kaons	LH_2	recoil ToF, forward PID	

Bjoern Seitz
University of Glasgow

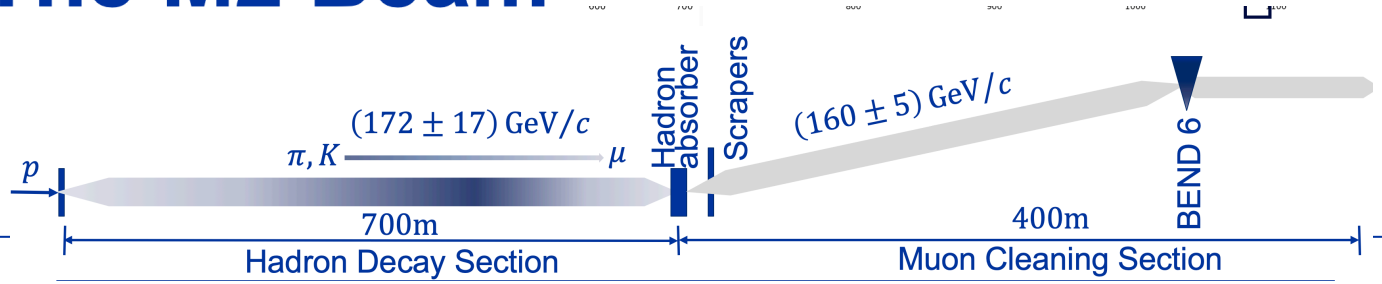


Bjoern Seitz
University of Glasgow

➔ **Quantify theory/experiment interplay**

Kaon beam requirements post LS3 demand for beam line vacuum upgrade and CEDAR refurbishment

The M2 Beam



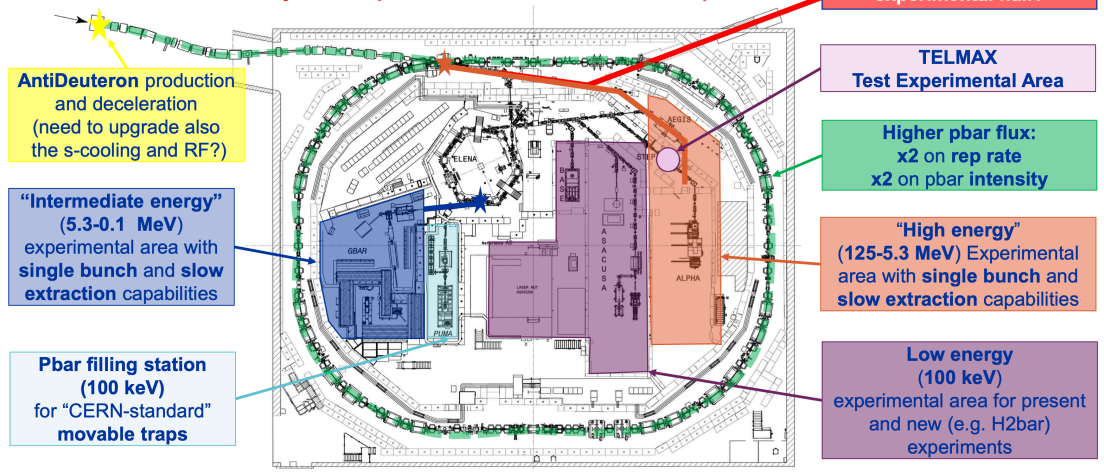
- muon beam
- hadron beam

AD

Elena going strong and looking into the future

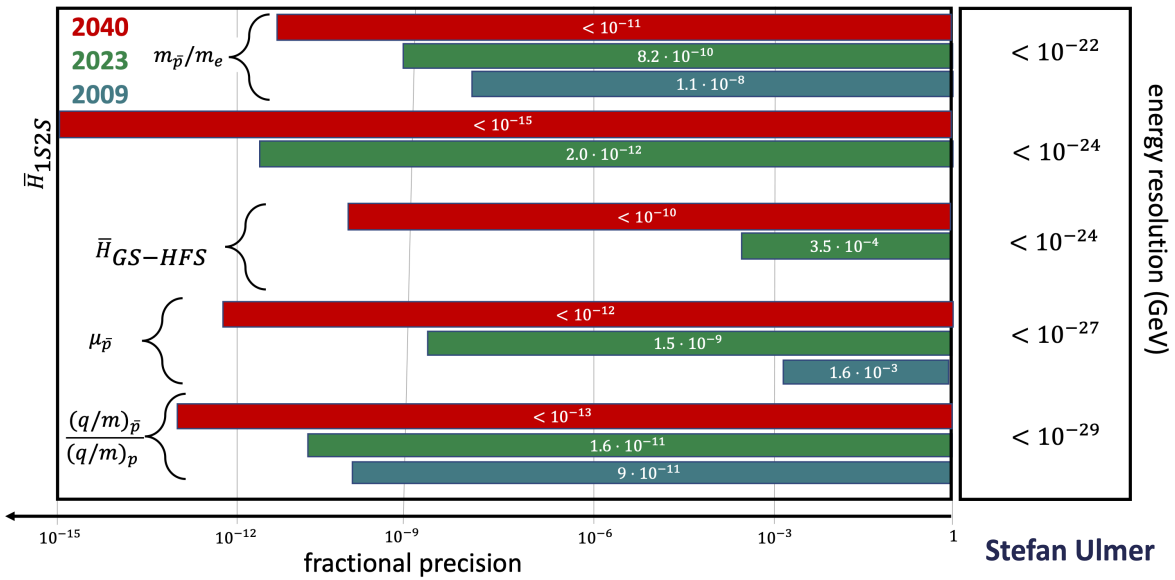
Overview of "Independent" Upgrade Cases

- Any of these (except TELMAX) will require well-defined physics experiment cases!
- The actual cost and feasibility of each option will be evaluated if and when required.



All experiments have clear plans for the (long-term) future

Future Perspective – Towards 2040 and beyond



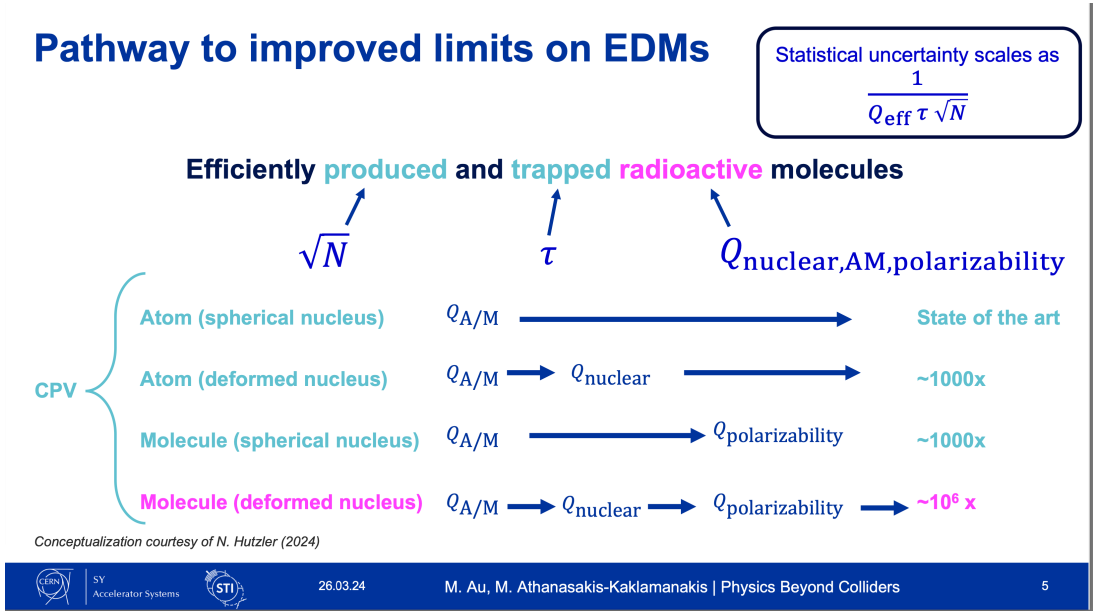
...are looking forward to invitations by the SPSC to submit new proposals (invitation promised for 2024)

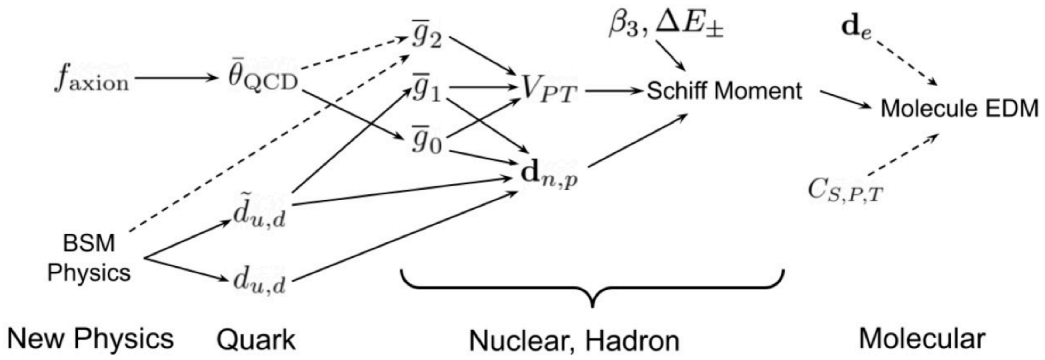
➔ Maybe start discussing theoretical model sensitivities in wider context?

➔ Make contact with FIP community?

ISOLDE

Opportunities to probe Electic Dipole Moments

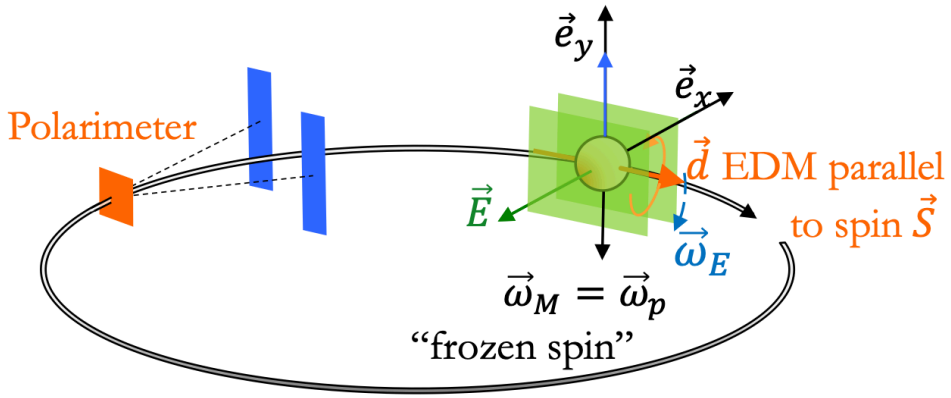




M. Au, M. Athanasakis-Kaklamanakis

➔ Quantify sensitivity and time scale for oscillating EDMs

CP EDM



Sketch of a "magic energy"
cp-EDM Ring

"m" for

Challenges and mitigation...

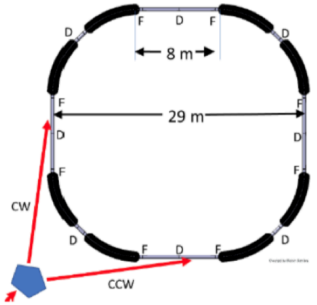
Measurement Principle – Variants of "magic Energy Rings"

- Purely electro-static machine with focusing by electric fields
  - Stray magnetic fields probably the most limiting systematic effect despite state-of-art shielding
  - Counter-rotating beams to control some systematic effects
  - Deflection by average radial magnetic field $\bar{B}_x$ compensate by electric field $\bar{E}_y = -\beta_m c \bar{B}_x$
  - With Thomas-BMT angular frequency $\bar{\omega}_{m,x} = -\frac{q}{m}\frac{G+1}{\gamma_m^2}\bar{B}_x$ (for $\bar{B}_x = 9.3\ aT$ gives $\bar{\omega}_{m,x} = 1.6$ nrad/s)
  - Cannot be disentangled from EDM combining measurements with counter-rotating beams
  - Mitigation using vertical orbit differences by how many orders of magnitude?
- Hybrid cpEDM ring (pursued by team around BNL and KAIST (South Korea))
  - Focusing by magnetic quadrupoles - Radial magnetic stray field compensated by magnetic quad field => no spin rotation proportional to perturbation
  - Vertical electric field from bends generates spin rotations around radial axis => very fast, but can in principle be disentangled from EDM observing counter-rotating beams
  - High periodicity 800 m ring proposed, operation with different polarities
  - Separation of counter-rotating beams and unwanted electric gradients - mitigations proposed
- Possible limitation due to geometric phase effects and other higher order effects to be understood for both variants

cpEDM PBC annual Workshop, 26th March 2024

Stage 2

prototype ring



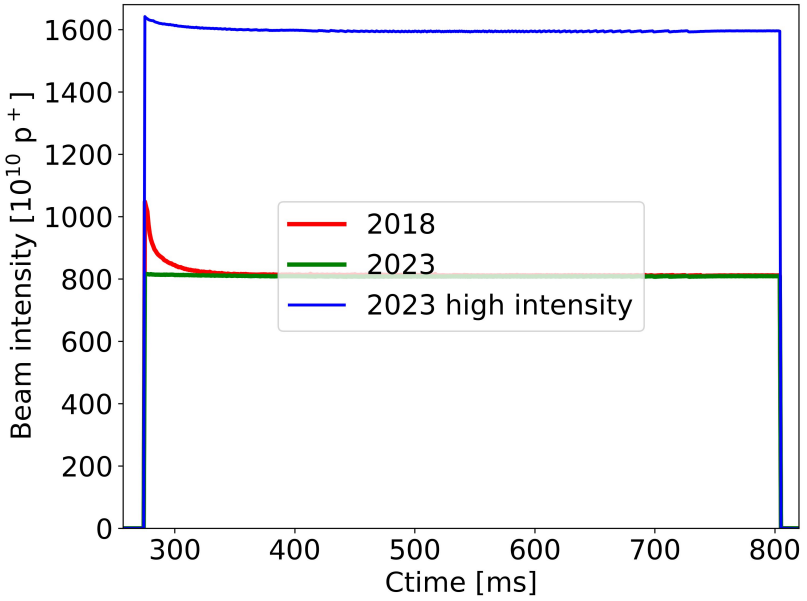
- electrostatic storage ring
- simultaneous ↻ and ↺ beams

5 years

C. Carli on behalf of the cpEDM Collaboration

Beams present and future

- **LIU upgrade successful**
- **Improved intensity and energy**



FCC-injectors

FCC-ee injector beam parameters

Running mode	Z	WW	ZH	ttbar	Unit
Beam energy at exit of injector	20				GeV
Number bunches/collider ring	11200	1780	380	56	
Number bunches/booster cycle	1120	980	380	56	
Booster cycle length	3.64	5.95	6.3	4.66	s
Maximum bunch charge	≥ 4	1.6	1.6	1.6	nC
Maximum bunch intensity	≥ 2.5	1	1	1	10^{10}
Number of bunches per pulse	2	2	2	2	
Linac repetition rate	200	100 (200)	50 (200)	50	Hz
Norm. emittance (x, y) (rms)	<10,10				mm mrad
Bunch length (rms)	~1				mm
Energy spread (rms)	~0.1				%
Bunch spacing from injector	25				ns
Injector duty cycle for FCC-ee	76	74 (37)	60 (15)	12	%

FCC PBC Annual Workshop, 27.03.2024, CERN FCC-ee injector scheme Hannes Bartosik

~ 0.25-0.85 fraction available

➔ **AWAKE connection?**

tirsi.prebibaj@cern.ch

➔**Full exploitation of new opportunities?**

➔**Competition from Jefferson-Lab and Co?**

Technology WG

- Active gateway for many experiments

All experiments & proposals linked with Tech WG

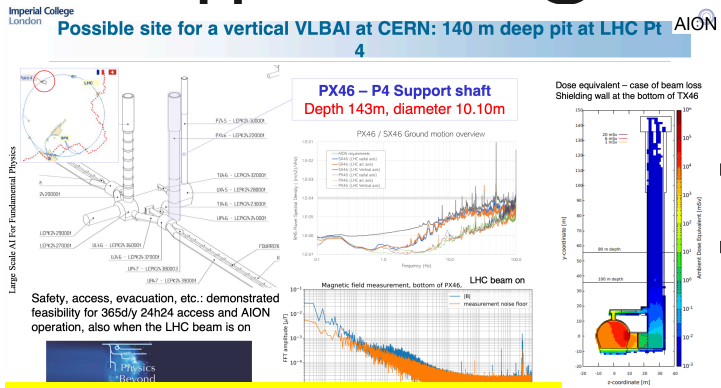
Updated list after reaching out to all experiments

- **ALPS-II (Joern Schaffran) -> axion search light-shining-through-wall with lasers**
- **BabyIAXO (Matthias Mentink, Igor Garcia Irastorza) -> axion search from the sun**

- **GrAHal (Pierre Pugnat) -> axion search with RF cavities**
- **RADES/HTS (Jessica Golm) -> axion search with HTS RF cavities**
- **Advanced-KWISP (Giovanni Cantatore) -> search for Short Range Interactions**
- **Axion Heterodyne Detection (TBC) -> axion search with two-mode RF cavities**
- **AION-100 @ CERN (Oliver Buchmuller, Richard Hobson) -> vertical atom interferometer**

- **NEW: FLASH (Claudio Gatti) - > axion search with RF cavities**

AION opportunities @ CERN



Cost Estimate for required refurbishment of shaft is rather modest! Oliver Buchmueller

➔Clarify timeline

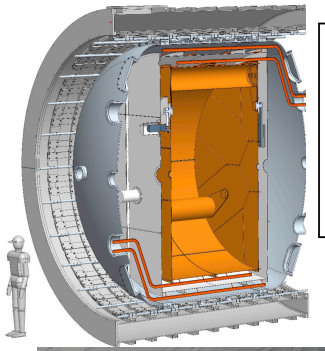
➔Simple picture physical layout of detector

HETERODYNE DETECTION OF AXION DARK MATTER

(*) loaded non-funable mode

FLASH
Finuda magnet for
Light Axion SearcH

Galactic axion search at 100 MHz (0.5-1.5 μeV)



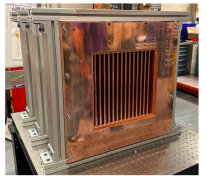
(*) $Q \simeq 3.5 \times 10^4$

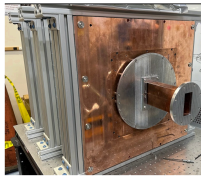
$V \simeq (0.48 \times 0.46 \times 0.46)\,\mathrm{m}^3$

$T \simeq 300\,\mathrm{K}$

$\epsilon_{1d} \simeq 10^{-3}$

$\omega \simeq 3\,\mathrm{GHz}$





Raffaele Tito D'Agnolo - CEA IPhT Saclay and ENS Paris

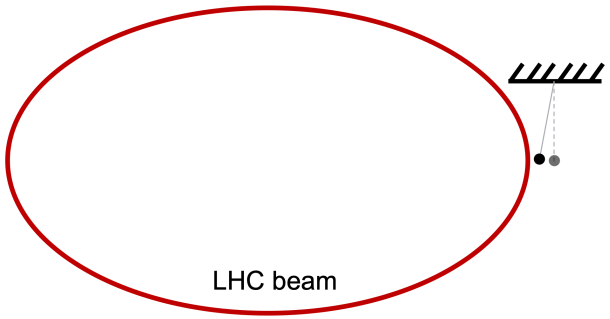
Claudio Gatti - LNF

Connects to Quantum Technology Initiative

New Ideas

Measuring the gravitational field of the LHC beam - Daniel Braun et al.

To measure the gravitational near field of the LHC proton beam



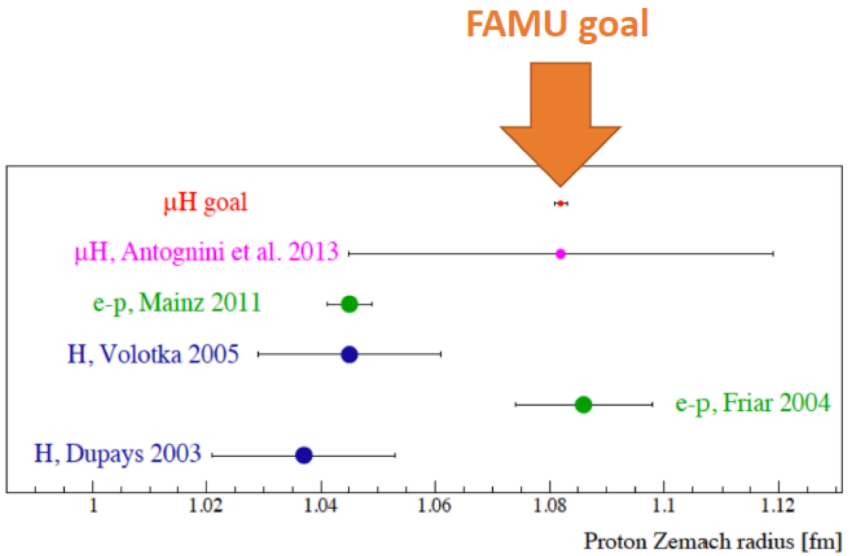
ultra-sensitive opto-mechanical acceleration sensor

1. The science case
2. Why LHC?
3. How?
4. Technical challenges
5. Links to other proposals

!!!

FAMU experiment

Aim: measurement of *hfs* in μH with 10^{-5} relative uncertainty, in order to obtain r_Z with uncertainty of around 1%.



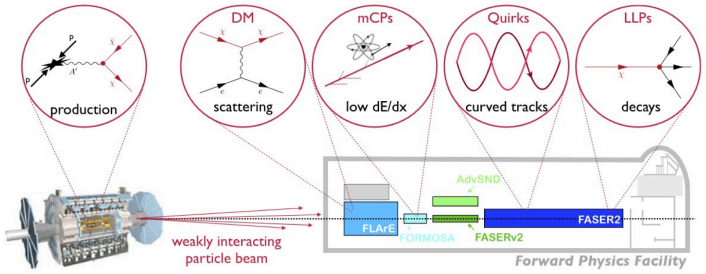
M. Bonesini

➔ Clarify CERN benefits?

BSM Vision

Towards new benchmark scenarios

- Need to re-consider the case for LHC LLP experiments
- Identify FIP models that are inaccessible for SHiP
  - Quirks
  - Inelastic dark matter
  - …?
- Take these models seriously!
- What are constraints from other experiments, astrophysics and cosmology?



The future of PBC Beyond Standard Model

- FIP Physics Centre more important than ever!
- Need input from young physicists (and CERN theory group) to maintain (and increase) momentum
- PBC BSM working group requires readjustment
  - Reduced importance of flavour physics?
  - Increasing importance of neutrino physics?
  - What about low-energy precision measurements?

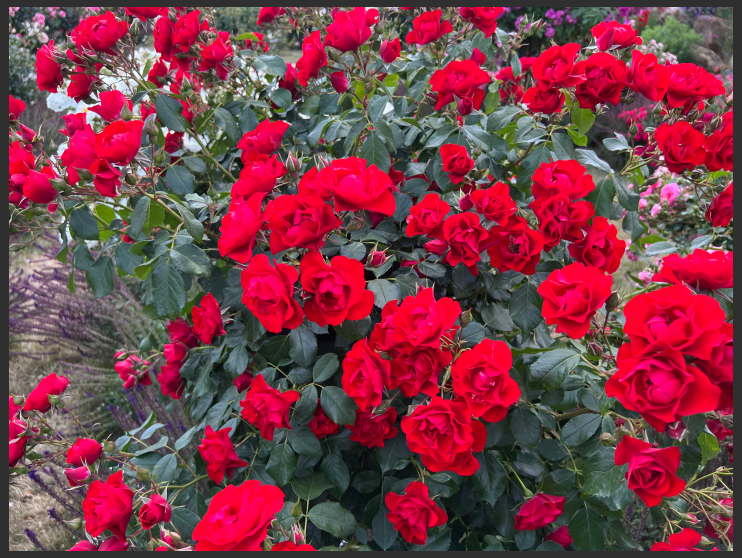
General Things

- NA Ion report
- General strategy input from PBC
- BSM group and FPC re-organisation after ECN3 decision to fit future progress and projects such as FPF
- PDF study group?
  BSM impact study?
- Mandate to be updated

Most Importantly….

What remains to be said...

Thank You Claude!!!



What remains to be said...

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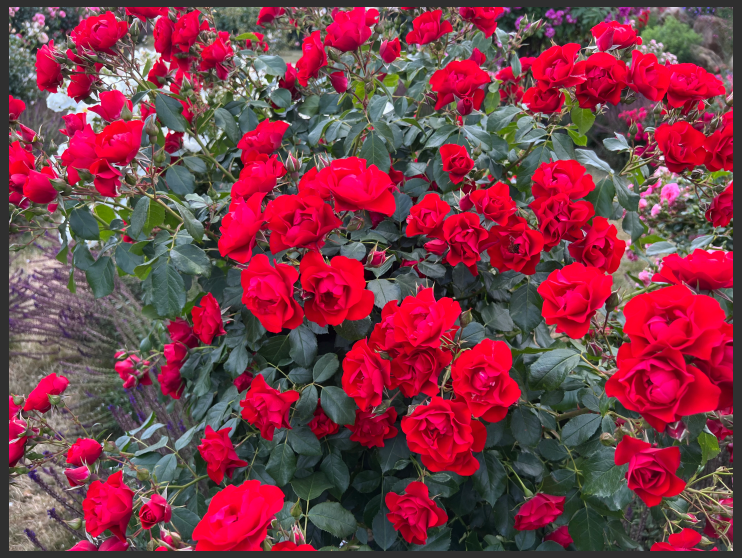
Thank You Claude!!! and again

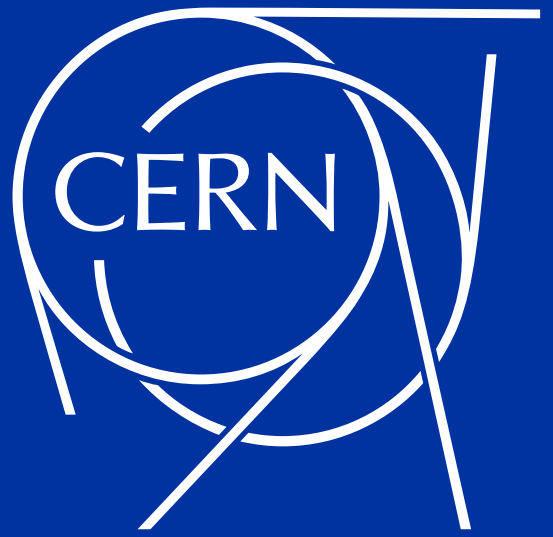


What remains to be said...

Thank You Claude!!!

and again

and some More ☺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