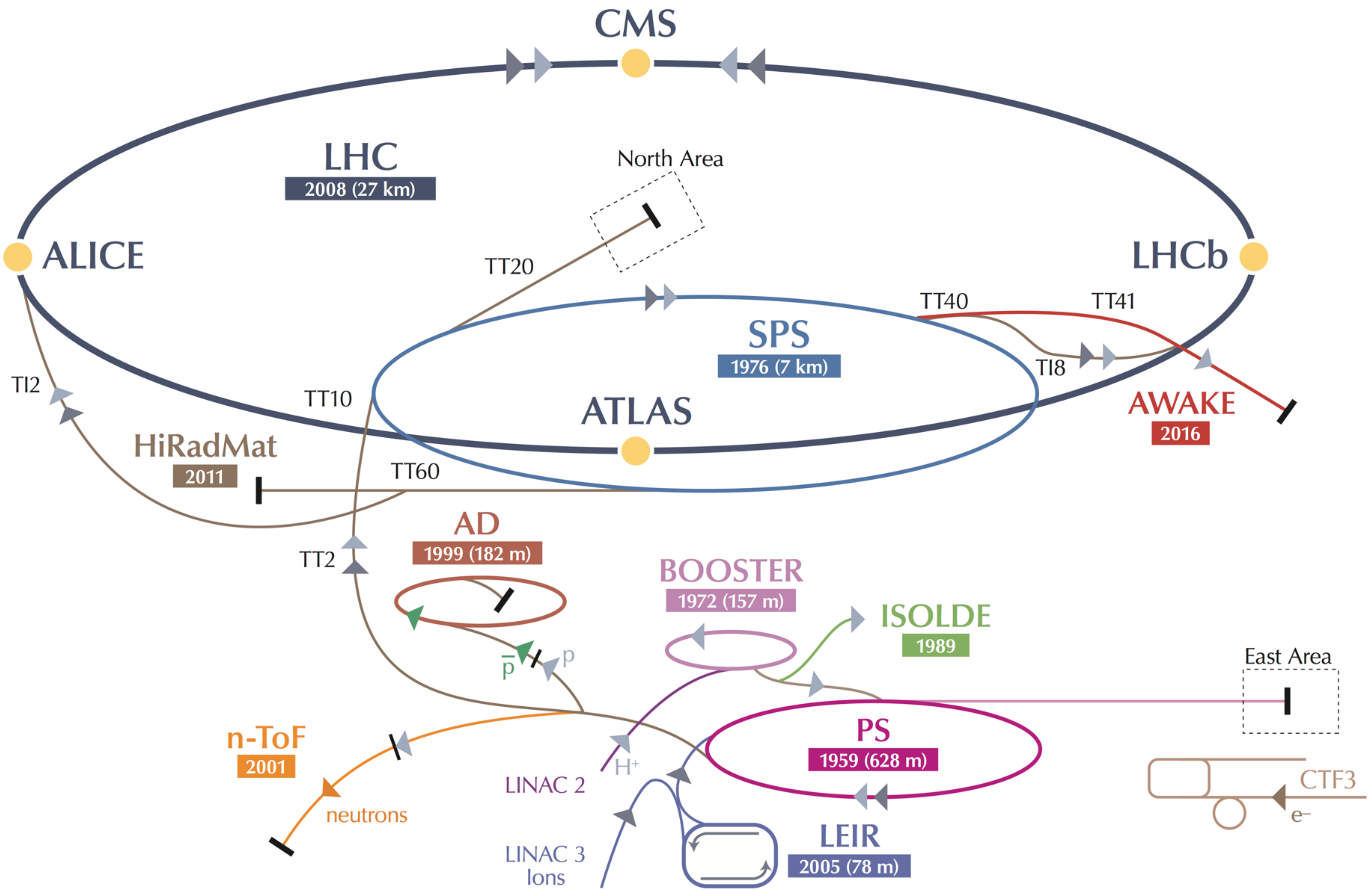
Nuclear Physics at CERN – a selection

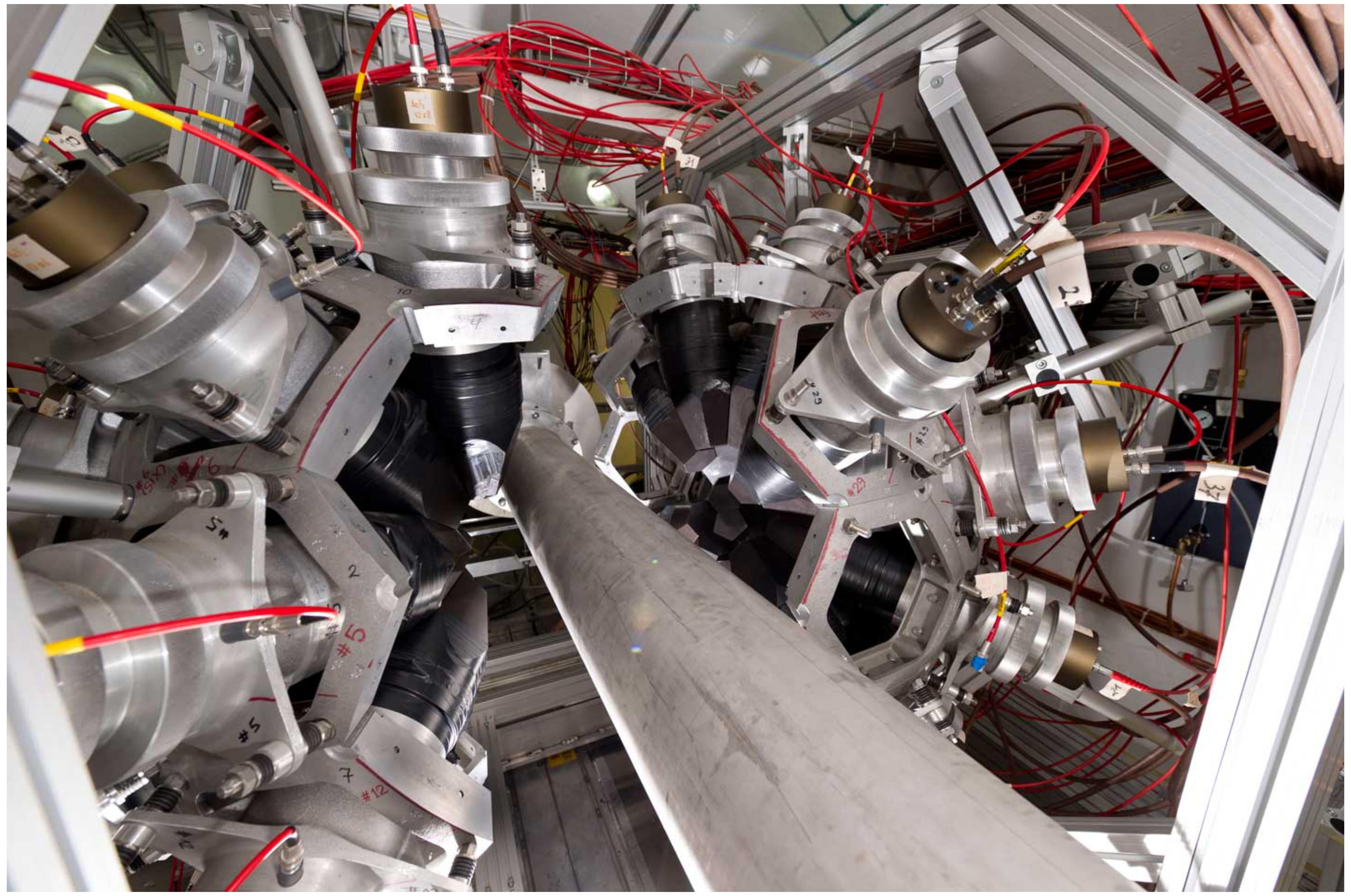
E.Elsen

Large range of accelerators for Nuclear Physics

- ISOLDE
  - HIE-ISOLDE
- nTOF
- PS
- SPS
  - Fixed target
  - HiRADMat
- **LHC**
  - ALICE
  - ATLAS, CMS, LHCb

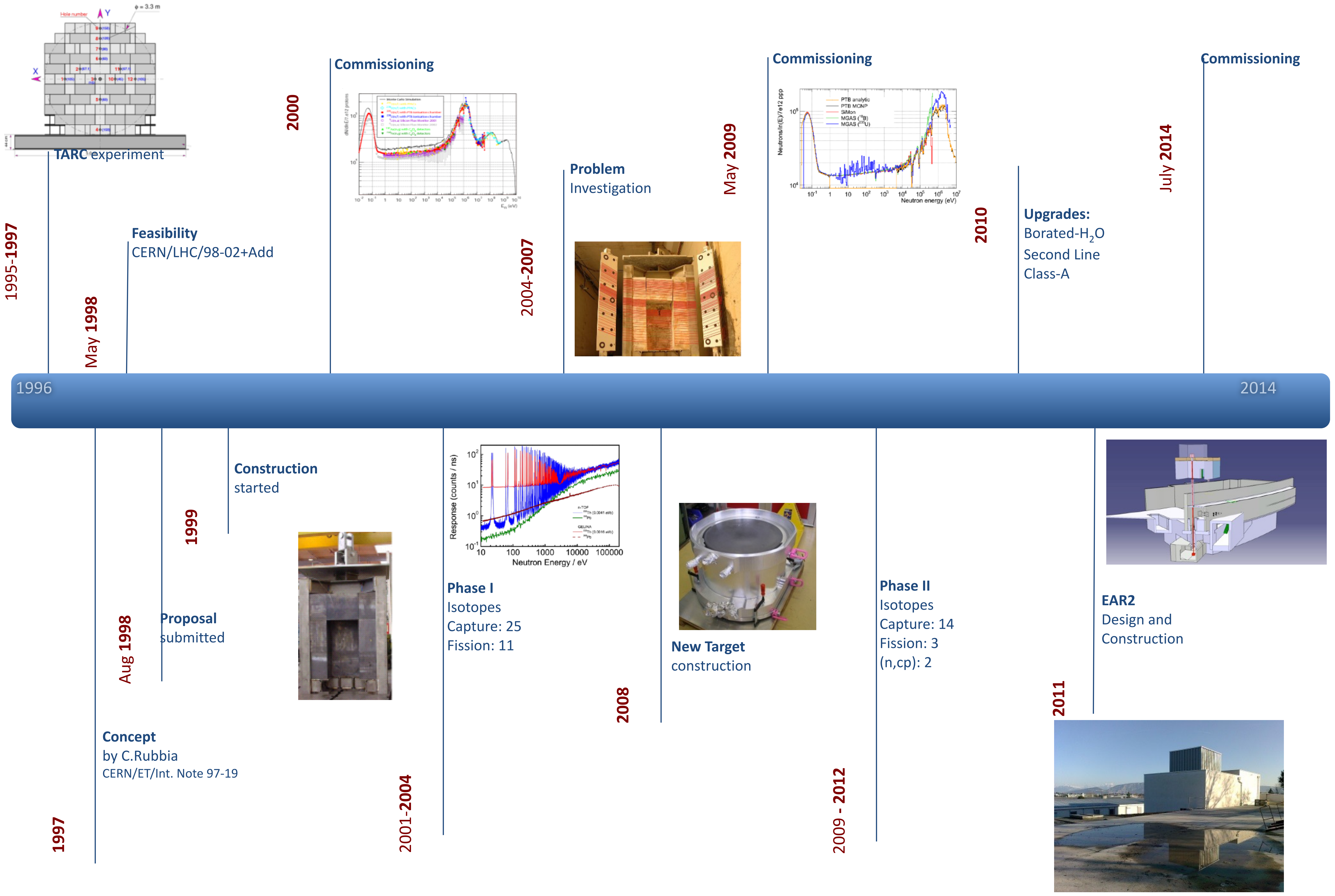


nTOF



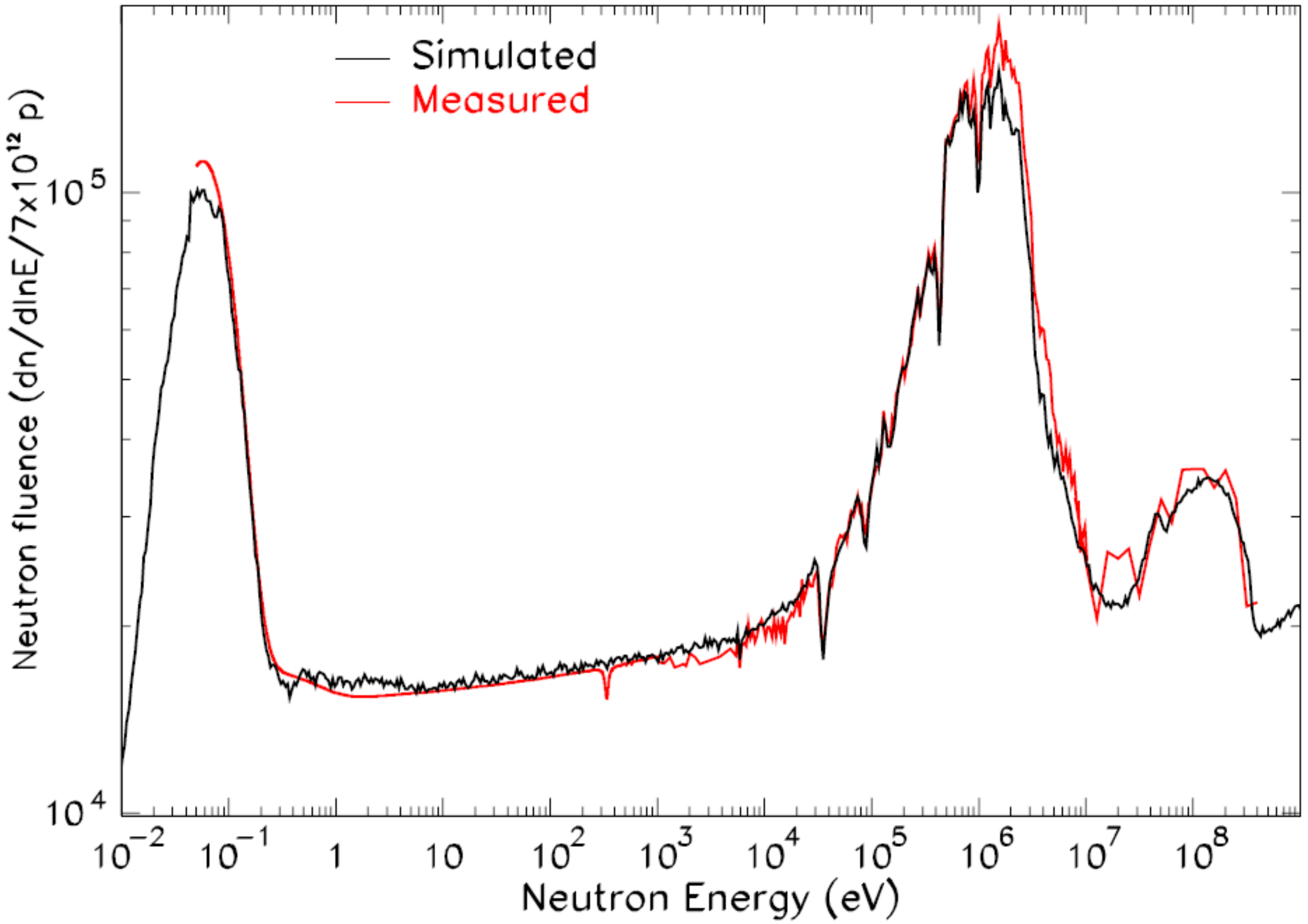
nTOF Goals and Implementation steps

- Goals
  - Nuclear Waste Transmutation
  - Medical Isotopes Production
  - Astrophysics
  - Nuclear Physics

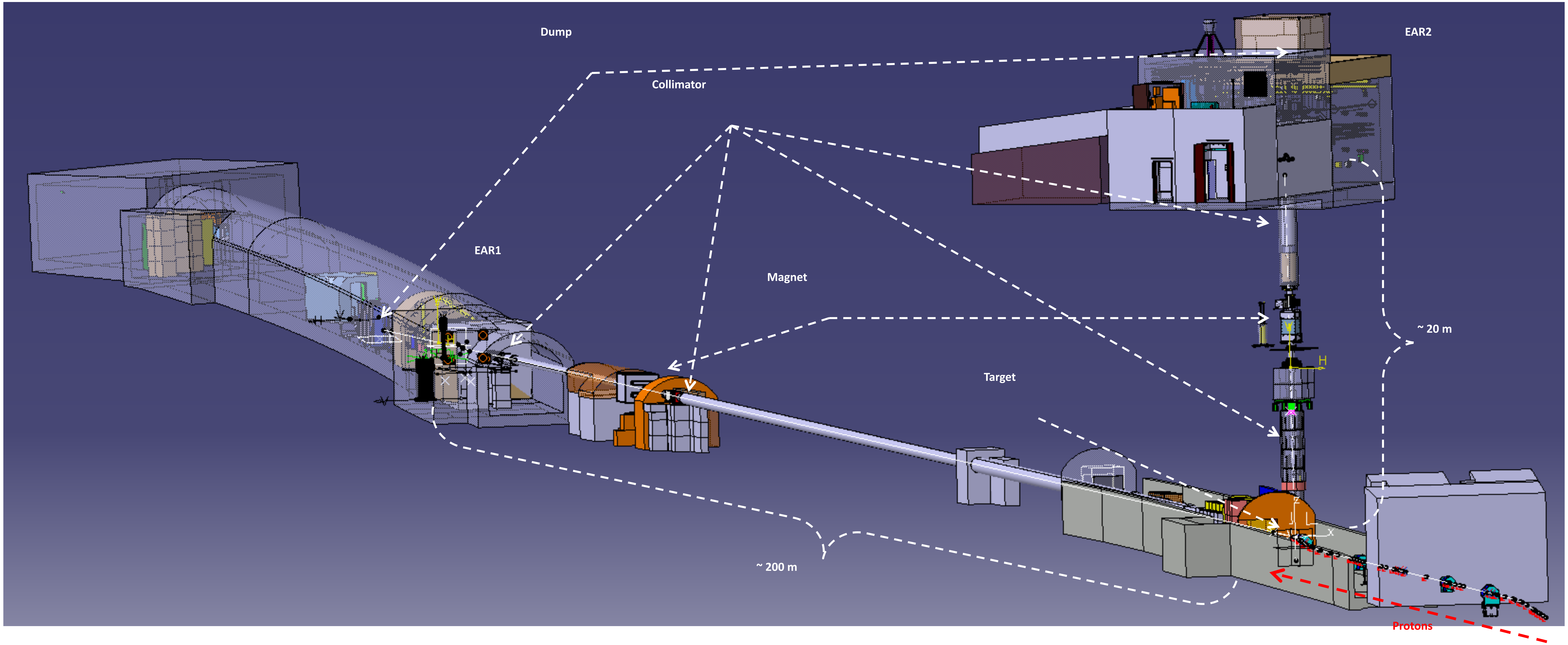


nTOF Features

- High instantaneous neutron flux (10^5 n/cm^2/pulse)
- Unique facility for measurements of radioactive isotopes (maximize S/N)
- High resolution in energy ($\Delta E/E = 10^{-4}$) → study resonances
- Large energy range (25 meV$<E_n<$1 GeV) → measure fission up to 1 GeV
- Low repetition rate (<0.8 Hz) → no wrap-around



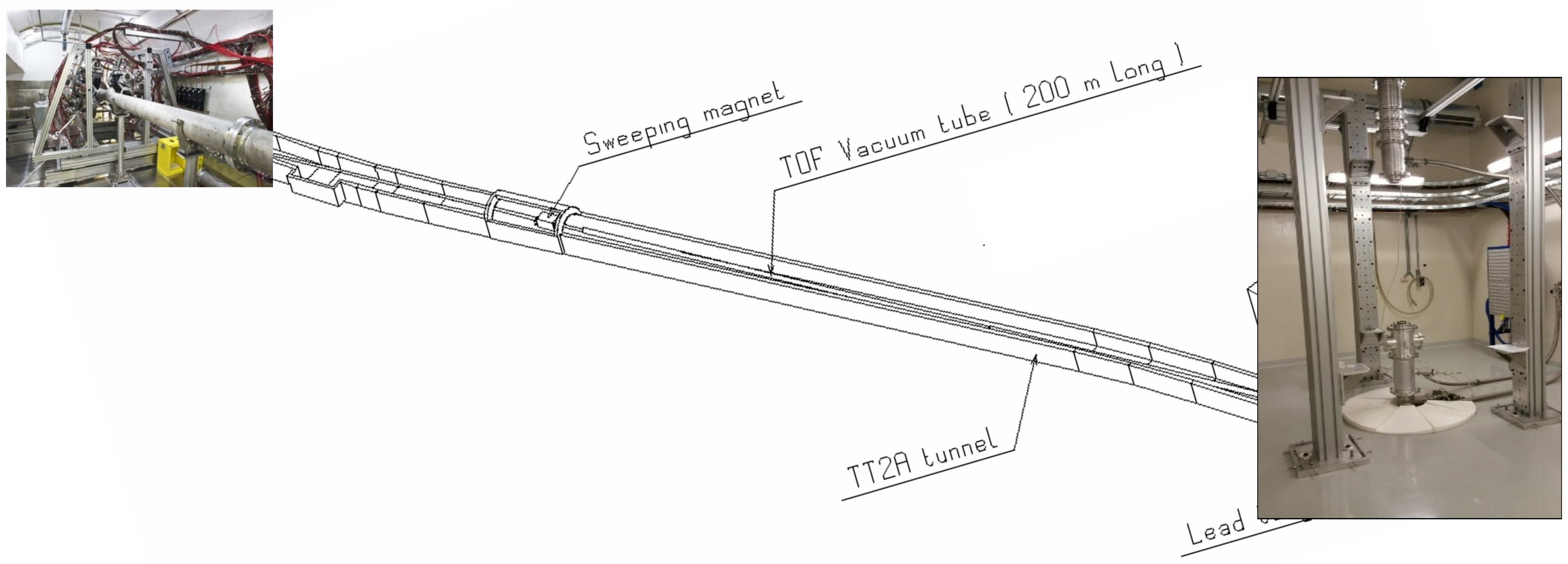
nTOF - Layout of Experimental Area 2 (EAR2)



nTOF

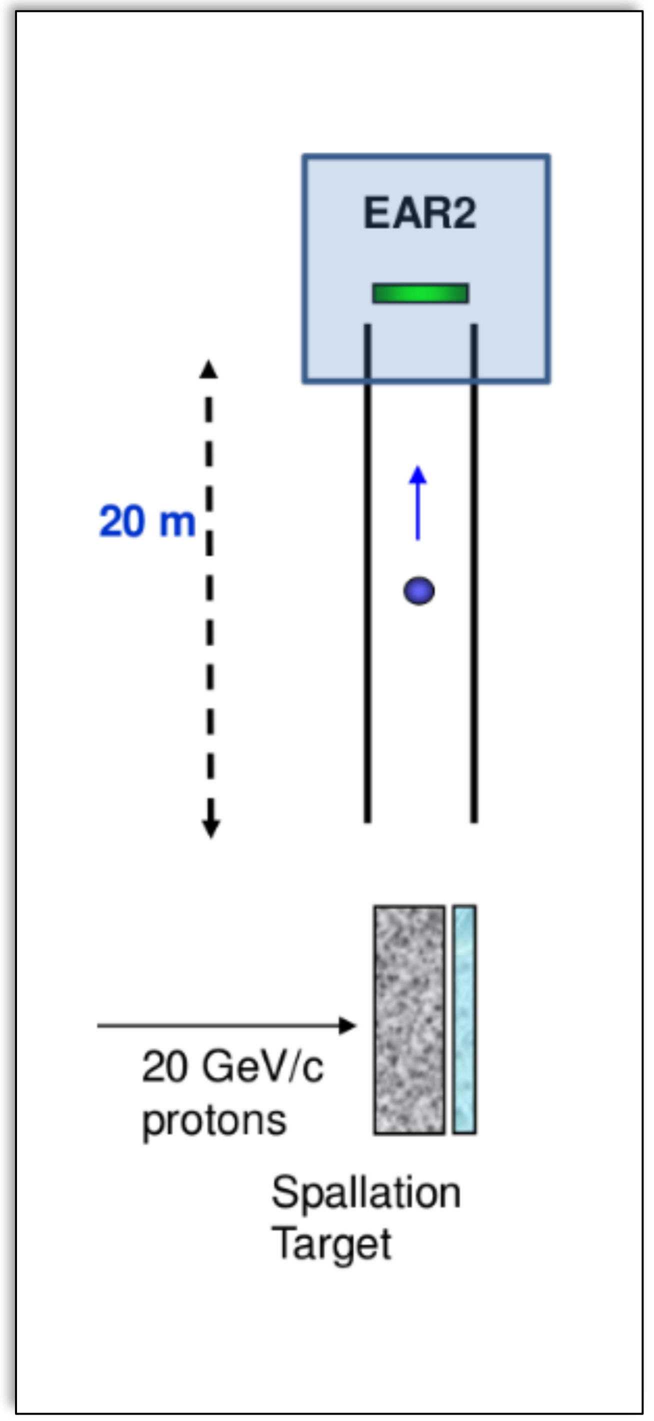
- EAR
  - Horizontal flight path:
    - EAR1 at 182.5 m
  - Vertical flight path:
    - EAR2 at 18.2 m

Both beam lines have:
– 1st collimator:
  halo cleaning + first beam shaping.
– Filter station.
– Sweeping magnet
– 2nd collimator: beam shaping.



Addressing the cosmological Lithium problem via ^{7}Be(n,cp)

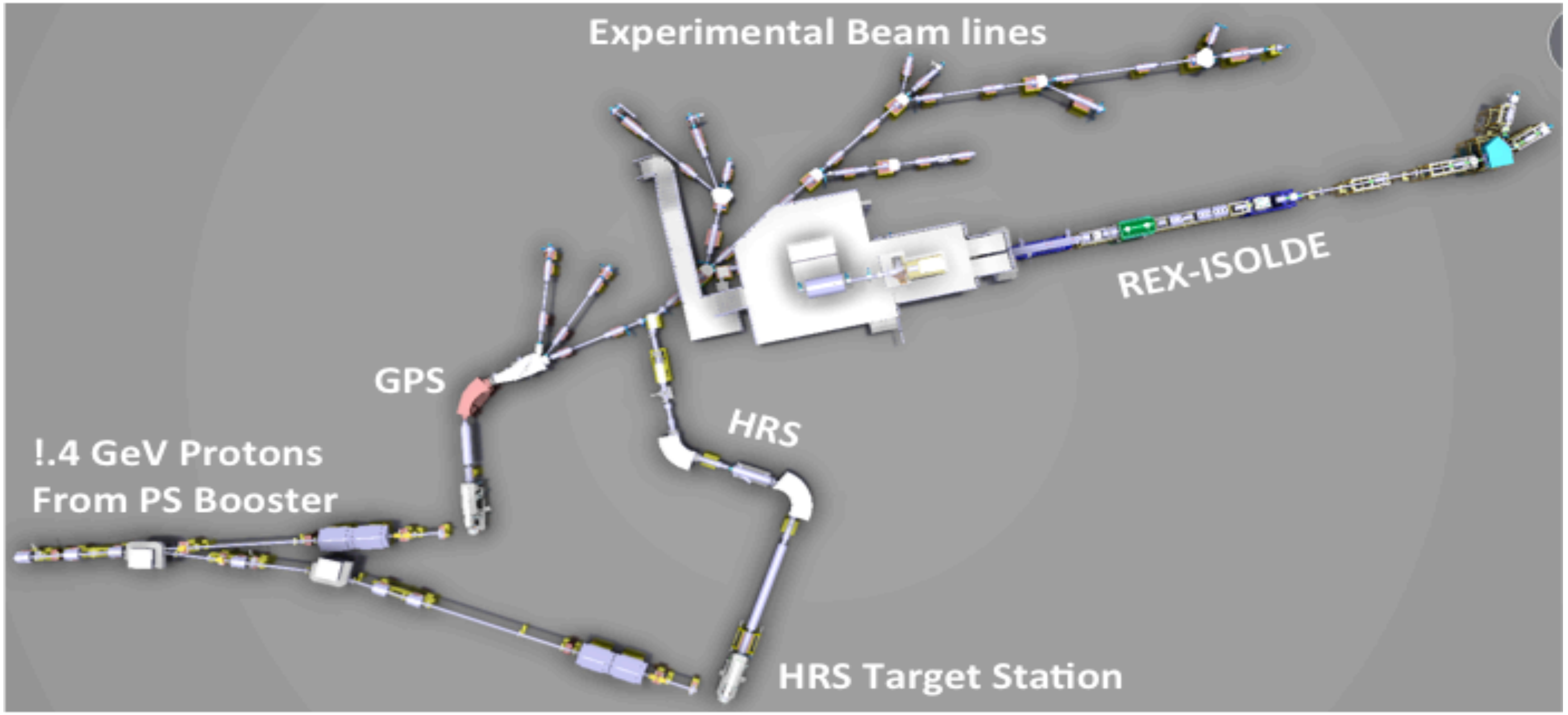
- ^{7}Be decay
  - n+^{7}Be → α + α (~2.5%)
    nTOF result 2015
  - n+^{7}Be → p + ^{7}Li (~97%)
    nTOF result 2016
- possible because of
  - high n rate and
  - small sample masses



95% of primordial ^{7}Li from Electron Capture decay of ^{7}Be ($T_{1/2}$ = 53.2 d)

^{7}Li problem persists

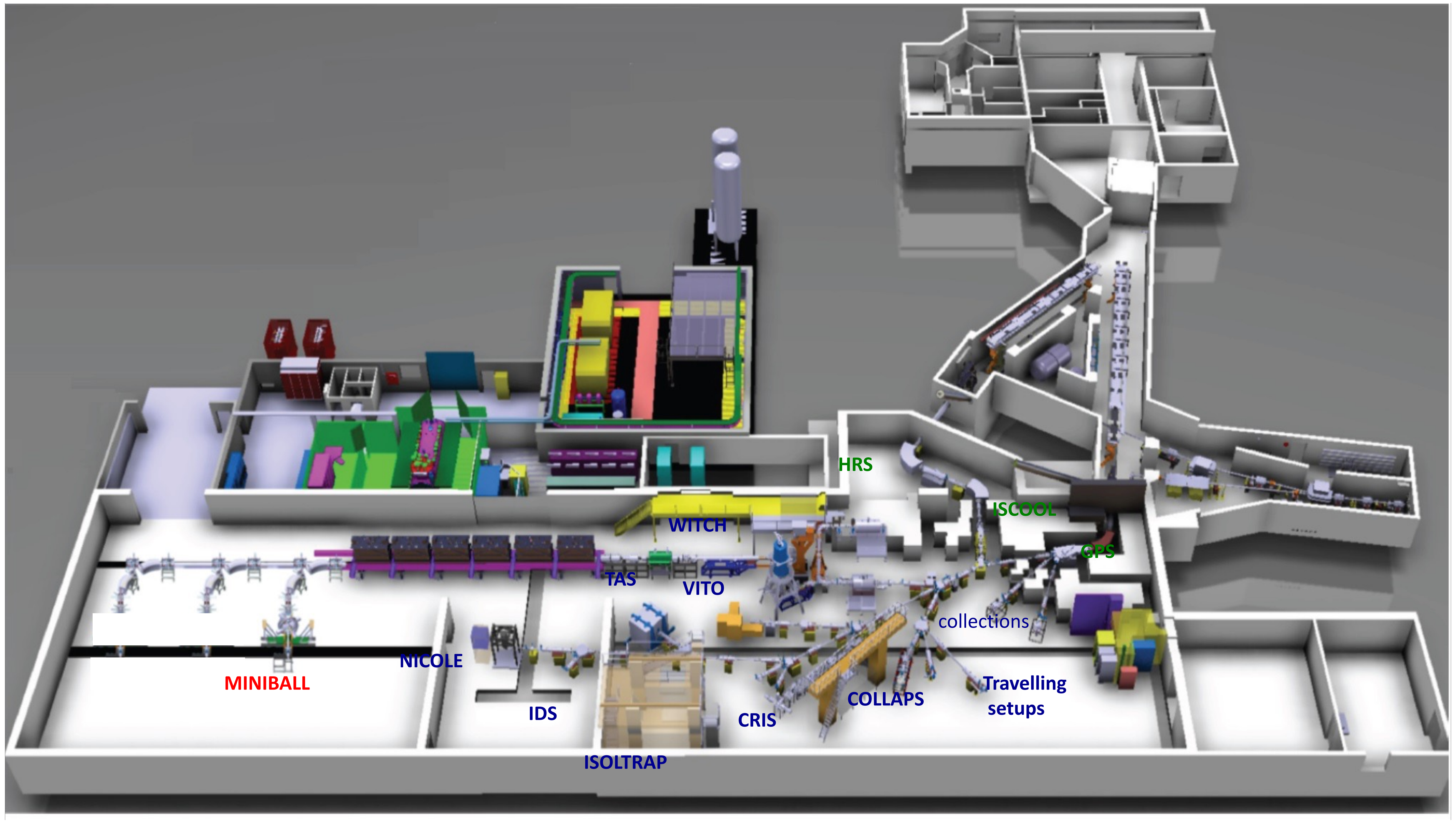
ISOLDE



see talk by Maria Borge

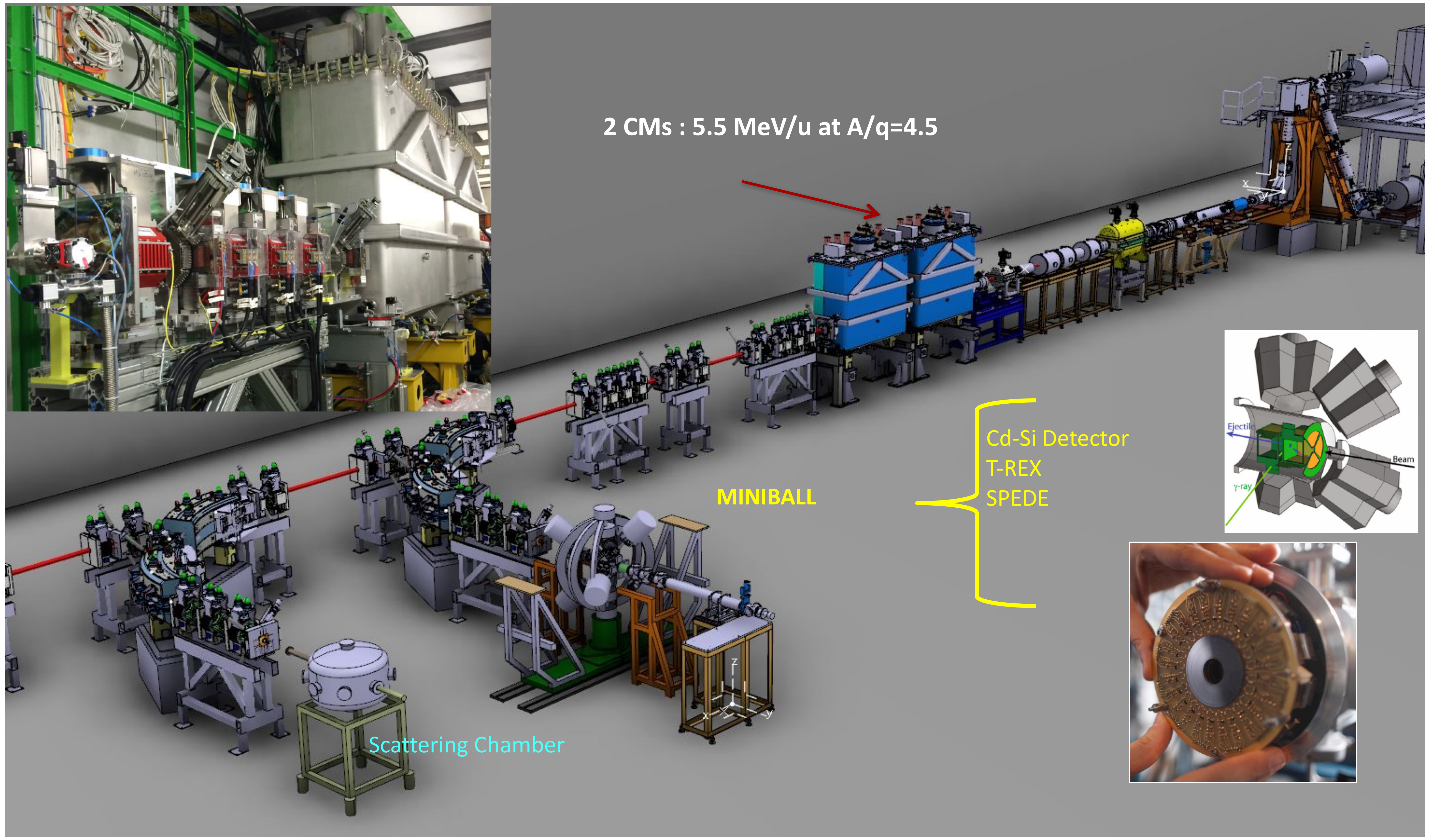
ISOLDE

- Decay spectroscopy (IDS, TAS,..)
- Coulomb excitation (MINIBALL)
- Transfer reactions (T-REX, Scattering)
- Electromagnetic Properties (COLLAPS, CRIS, NICOLE)
- Polarized Beta-NMR (VITO, COLLAPS)
- Masses (ISOLTRAP)
- Applications:
  - Solide state (Collections)
  - Life Science (collections & VITO)



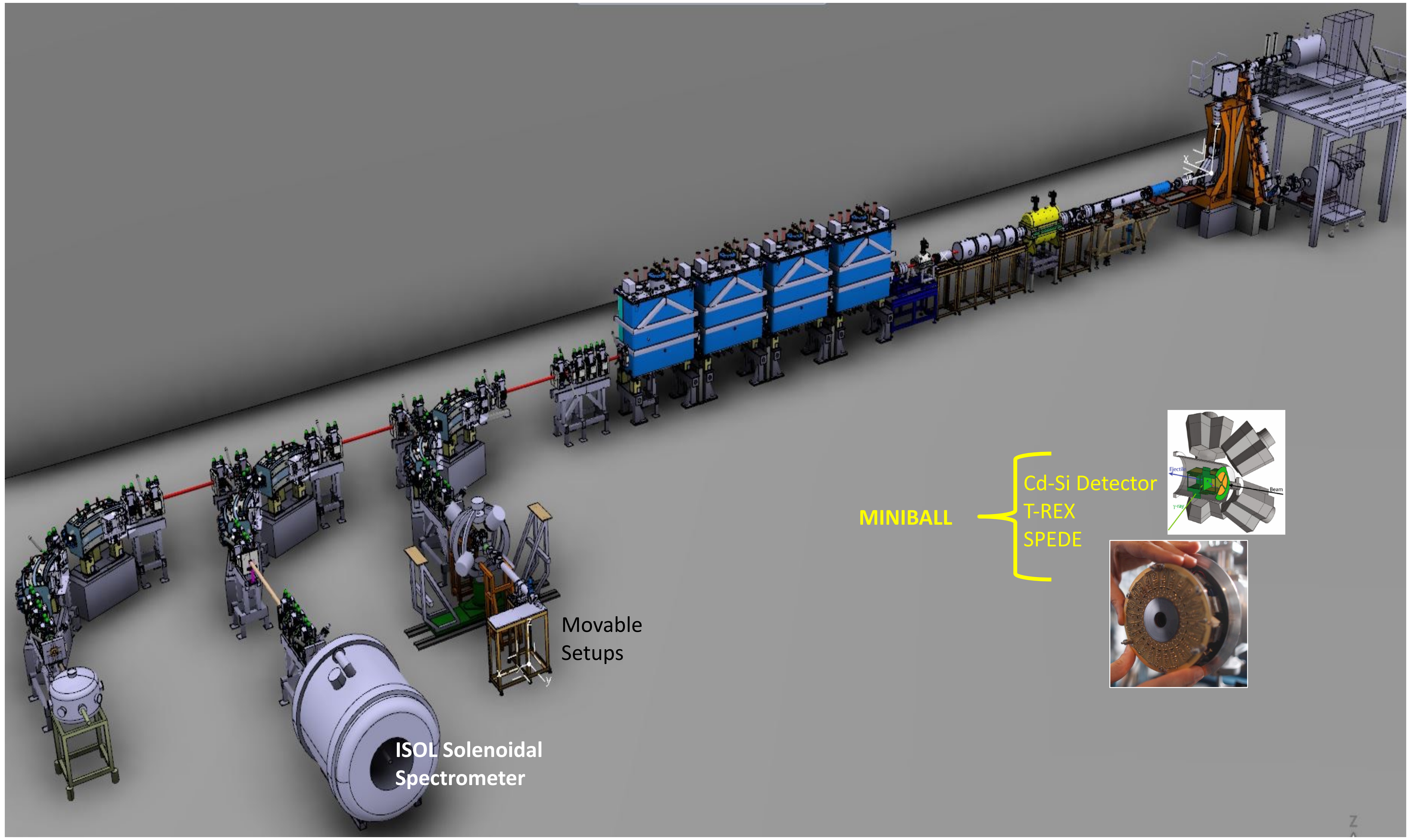
HIE-ISOLDE (phase 1)

- 2 cryomodules
  - 5.5 MeV/u at
    - A/q = 4.5



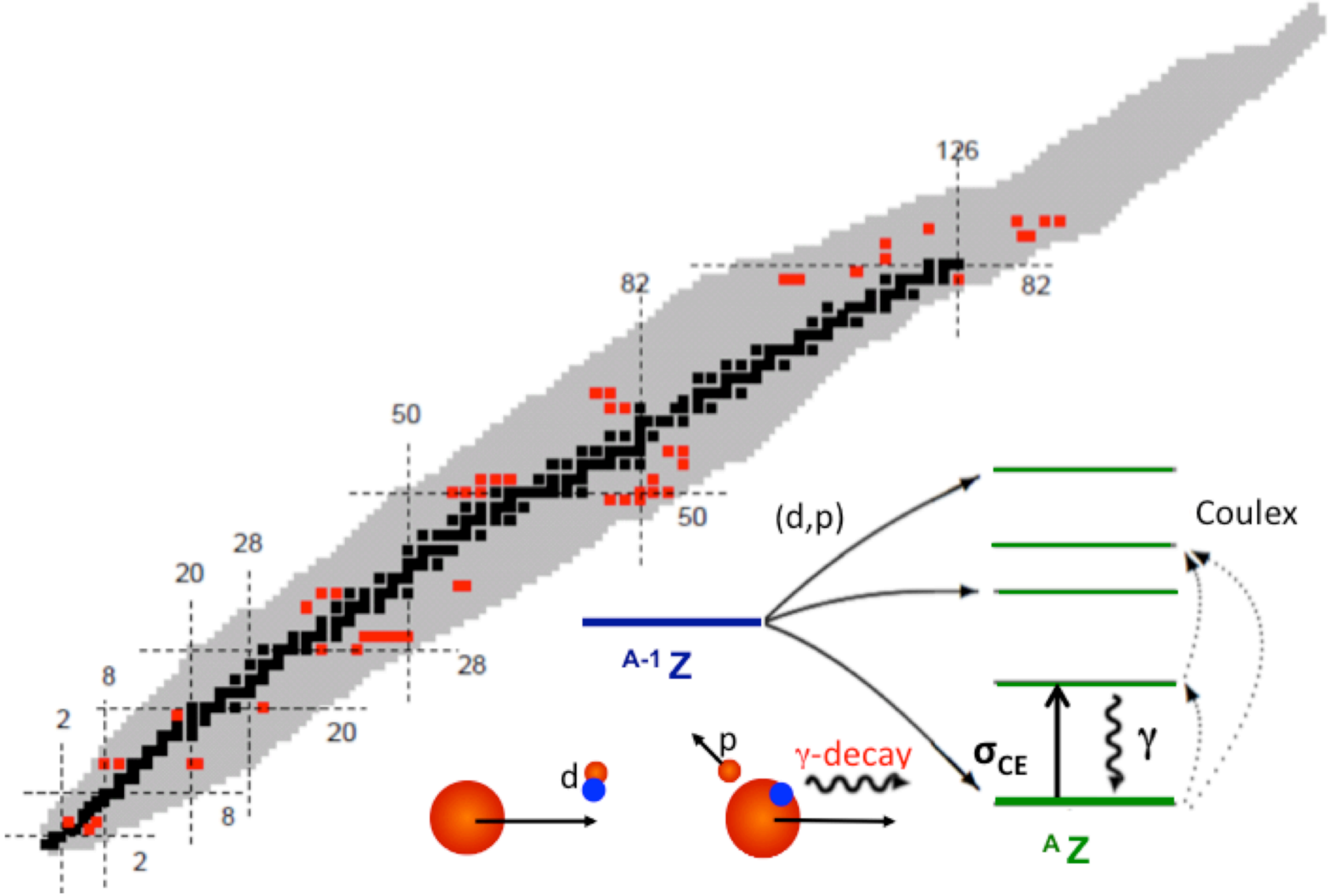
HIE-ISOLDE (phase 2)

- 10 MeV/u
- 3 beamlines

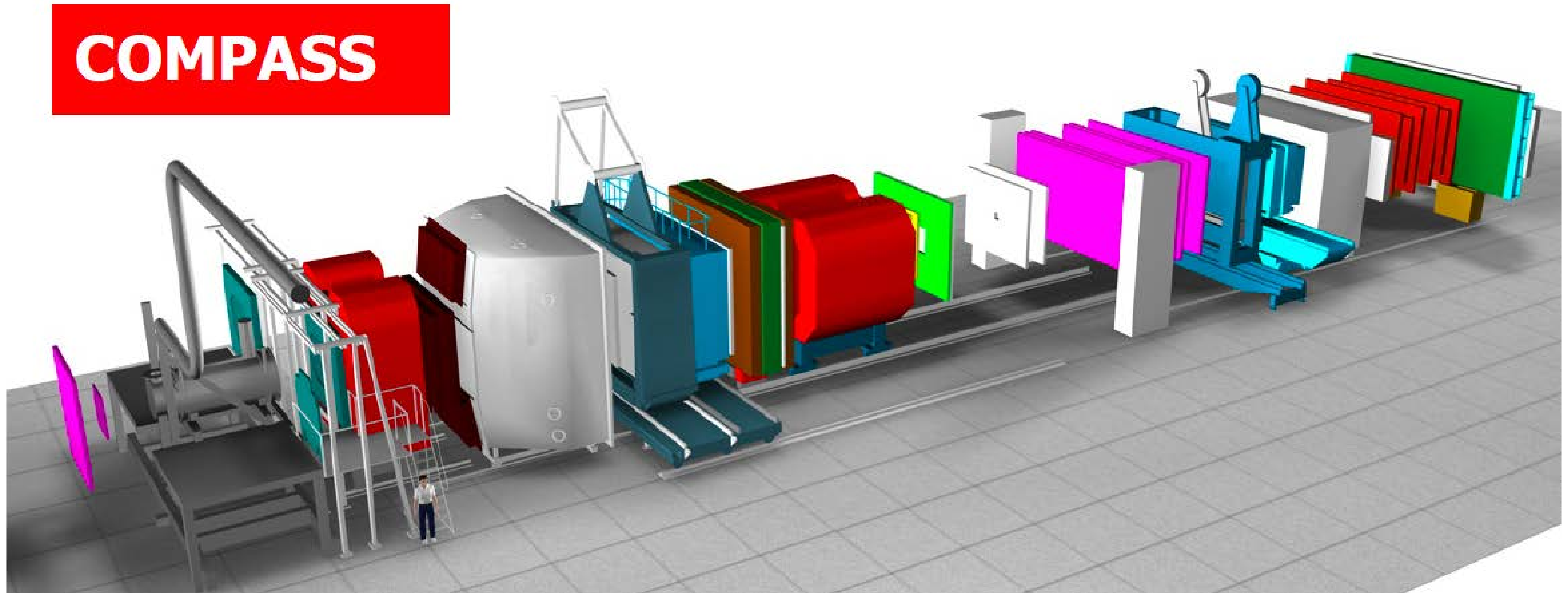


HIE-ISOLDE programme

- Isospin symmetry
- Magic numbers far from stability
- Collectivity versus Single Particle
- Shape Coexistence
- Reaction for nucleo-synthesis studies



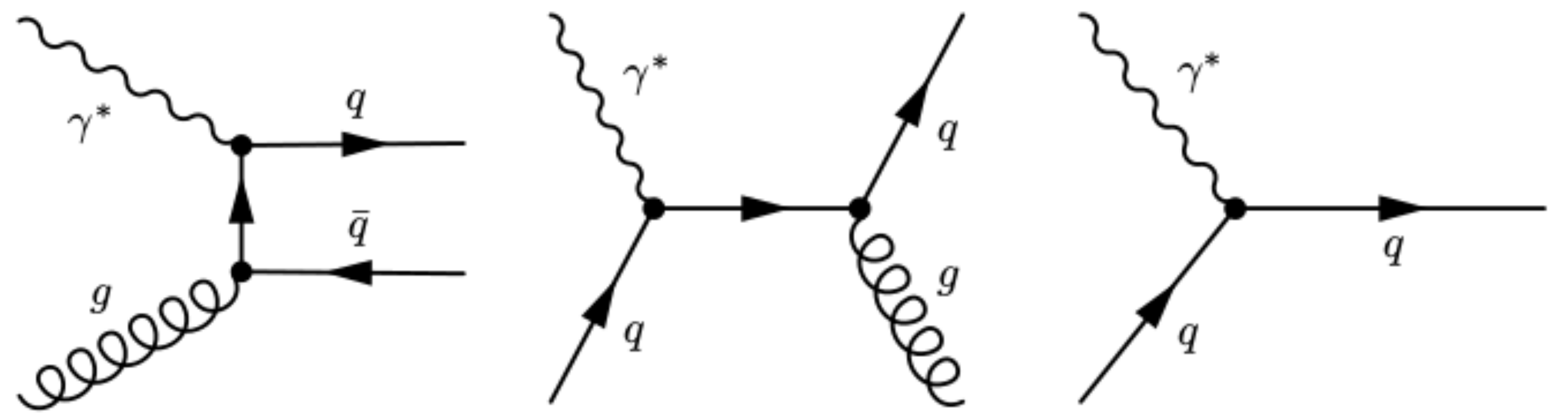
COMPASS

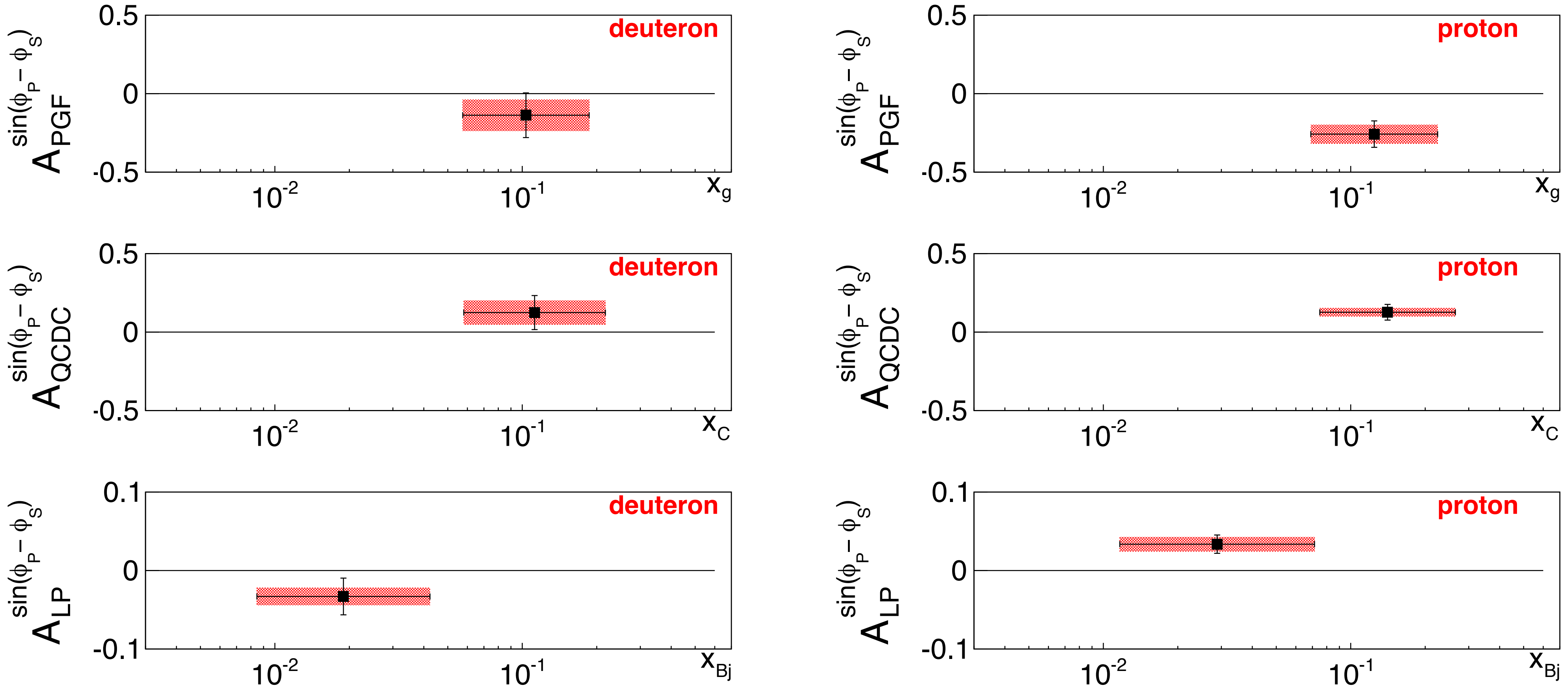


COMPASS Programme

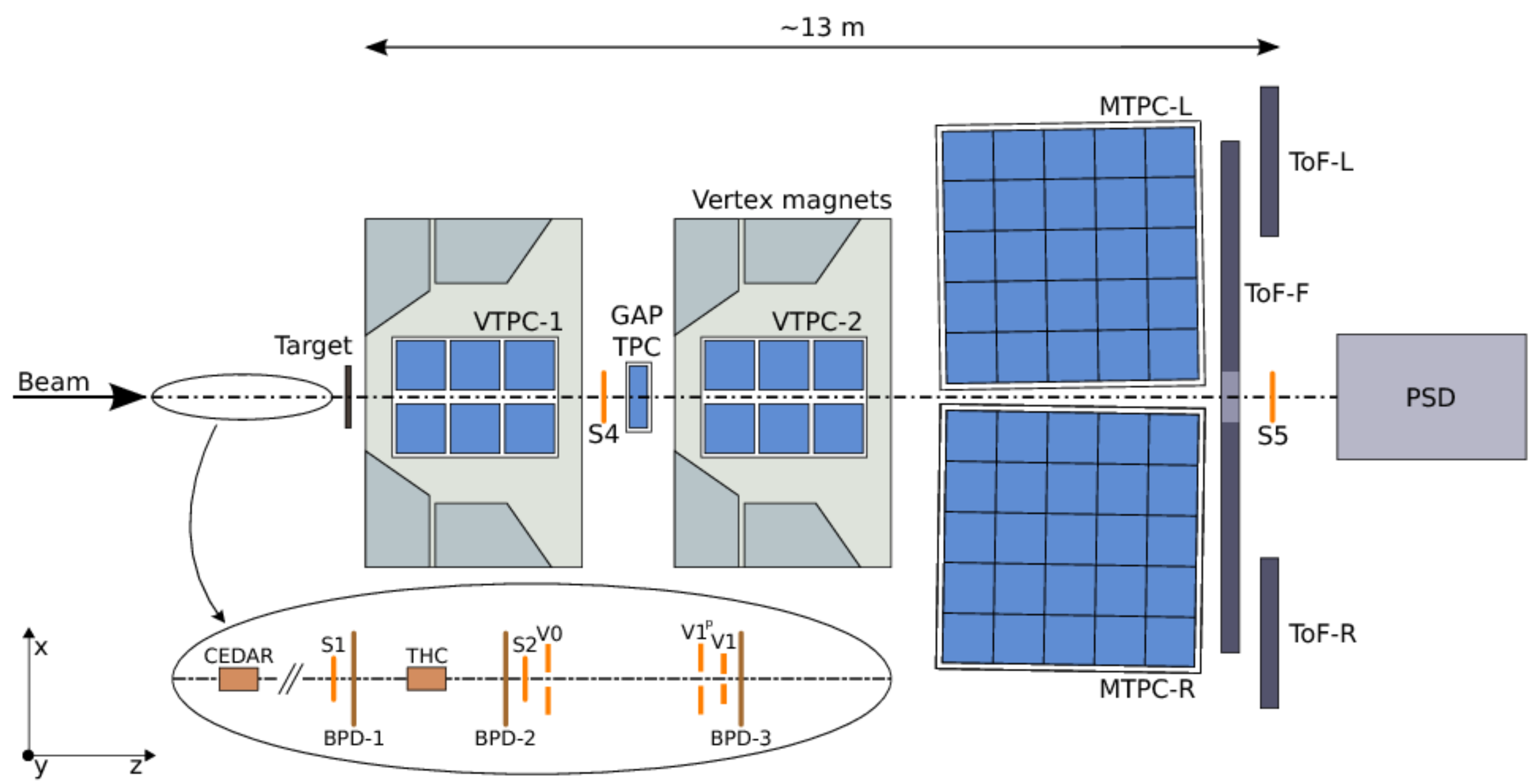
- legacy DIS
- Drell Yan processes
- polarized targets
    - Spin crisis

Sivers asymmetry for gluons from SIDIS data

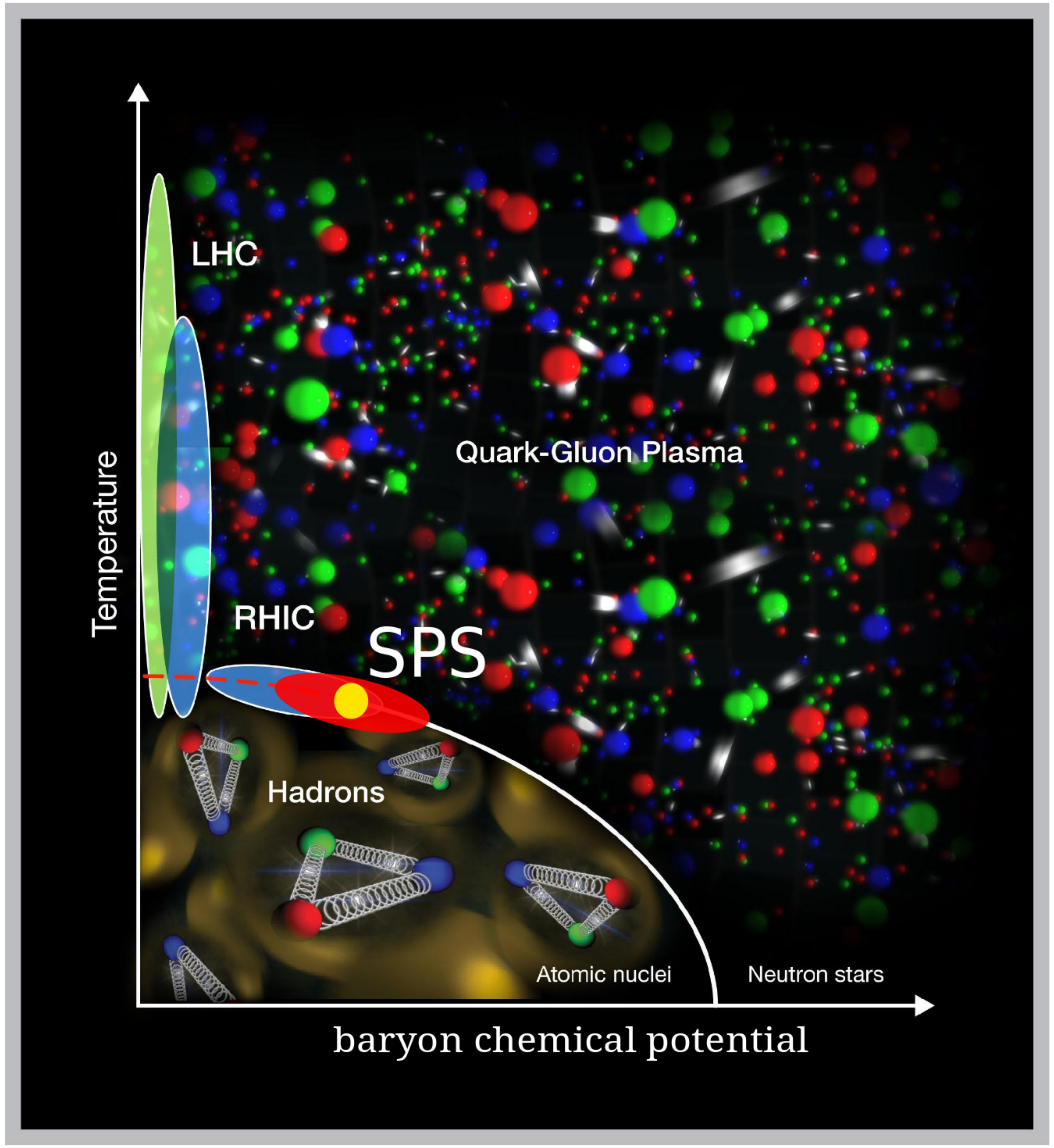


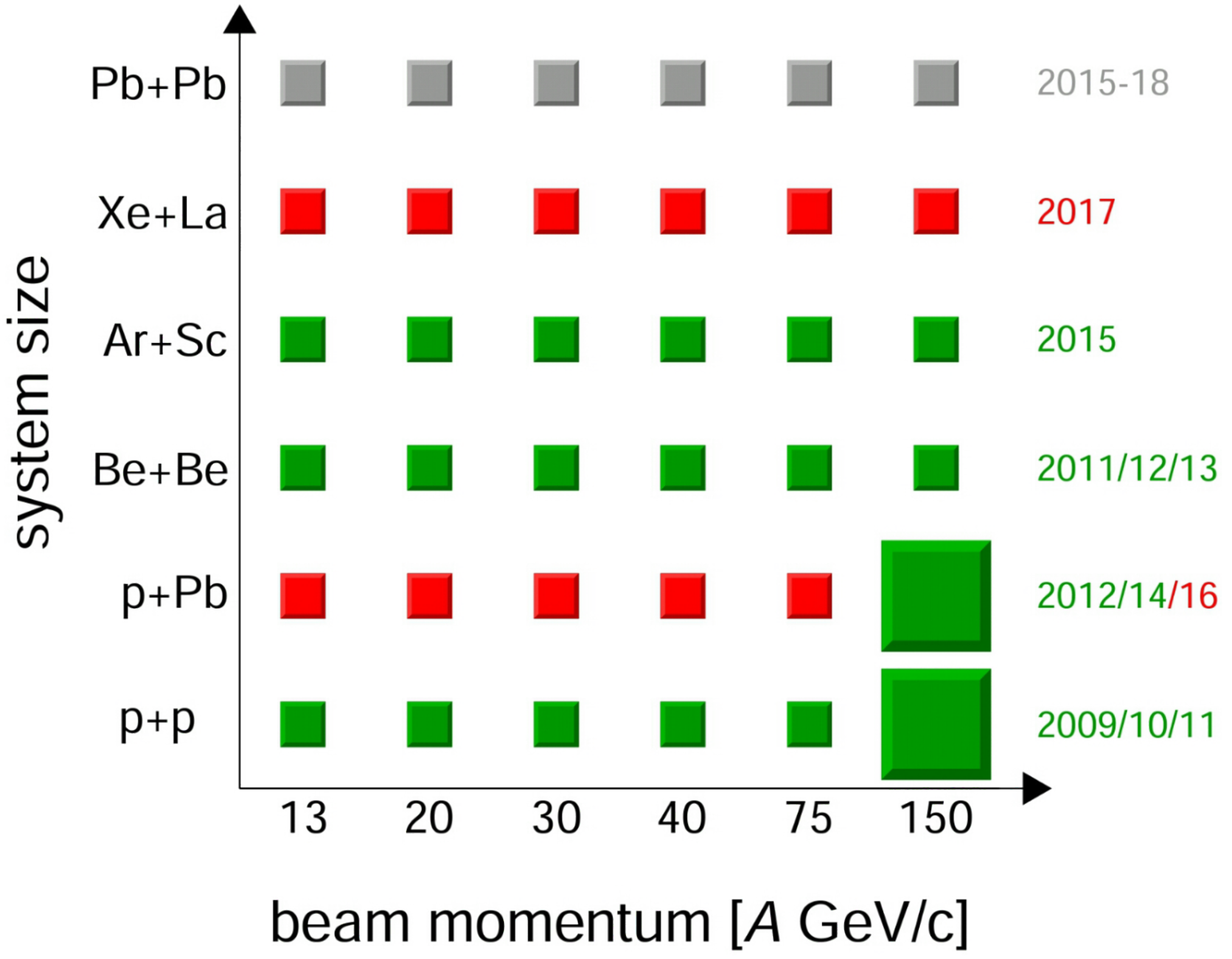


NA61 / Shine


~13 m
MTPC-L
ToF-L
Vertex magnets
ToF-F
VTPC-1
GAP
TPC
VTPC-2
Target
Beam
S4
S5
PSD
CEDAR
S1
THC
S2
V0
V1
BPD-1
BPD-2
BPD-3
MTPC-R
ToF-R
x
y
z

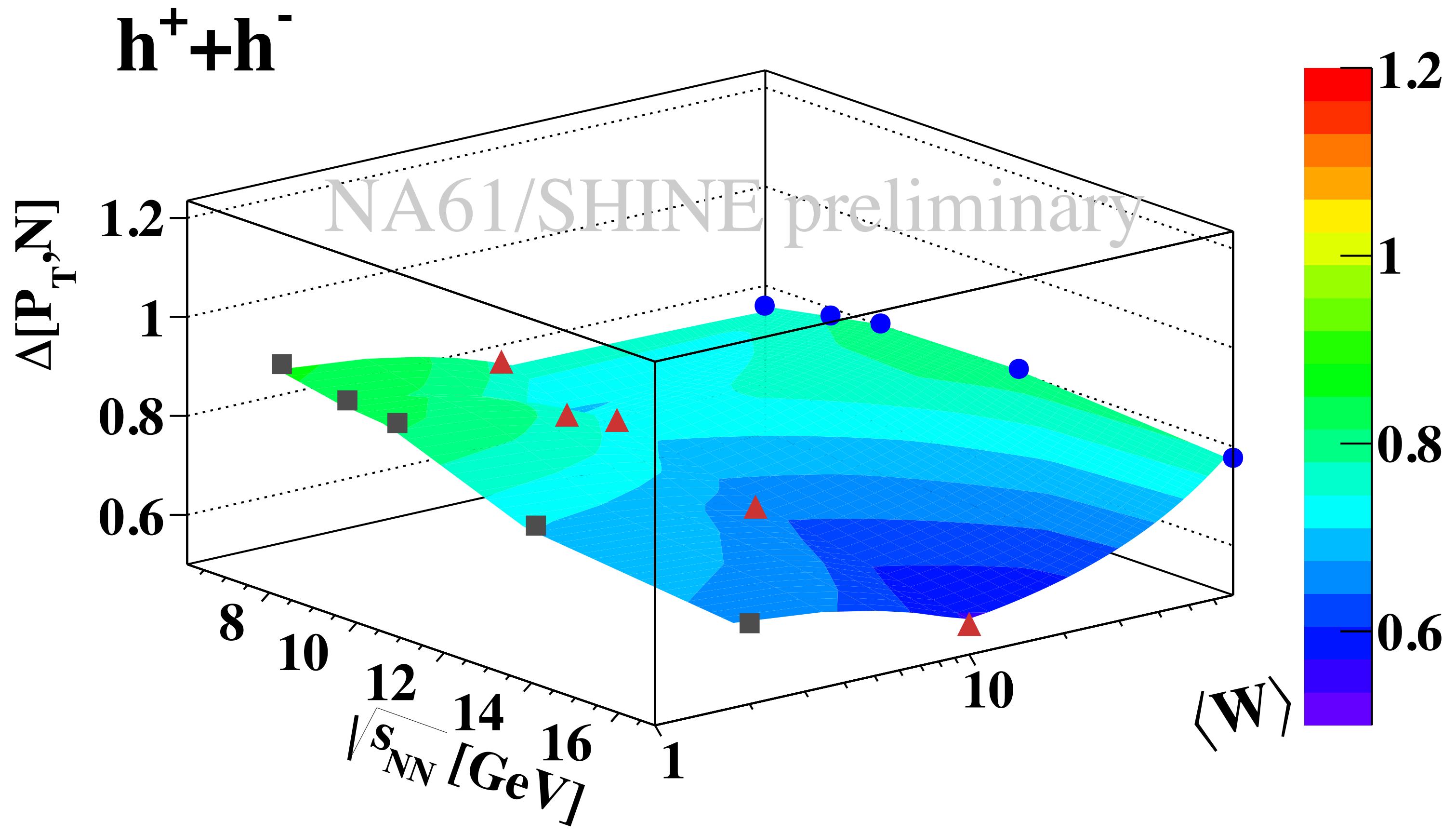
NA61 – Systematic exploration of QGP phase transition

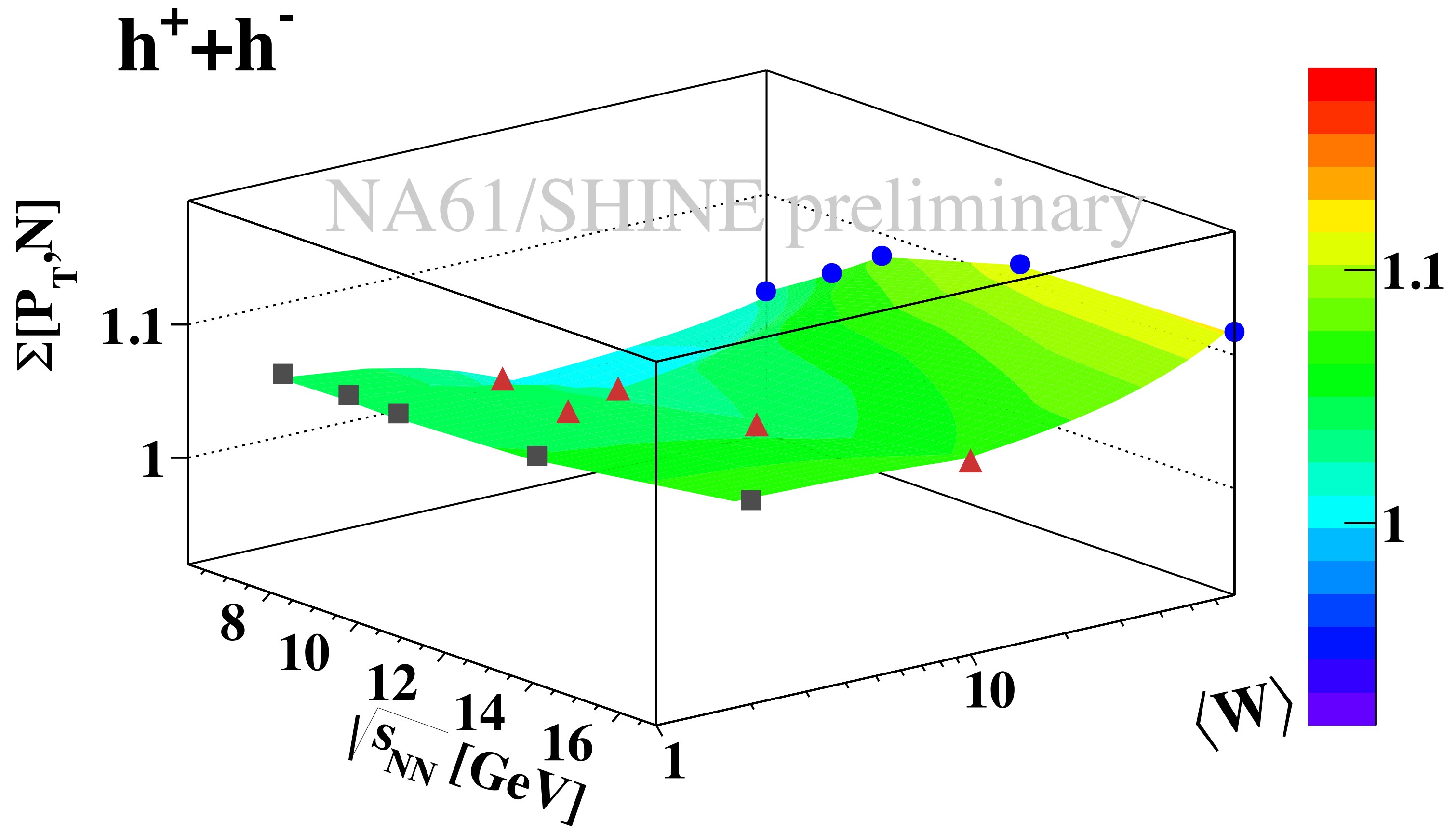




Initial observation

- no indication of a critical point so far

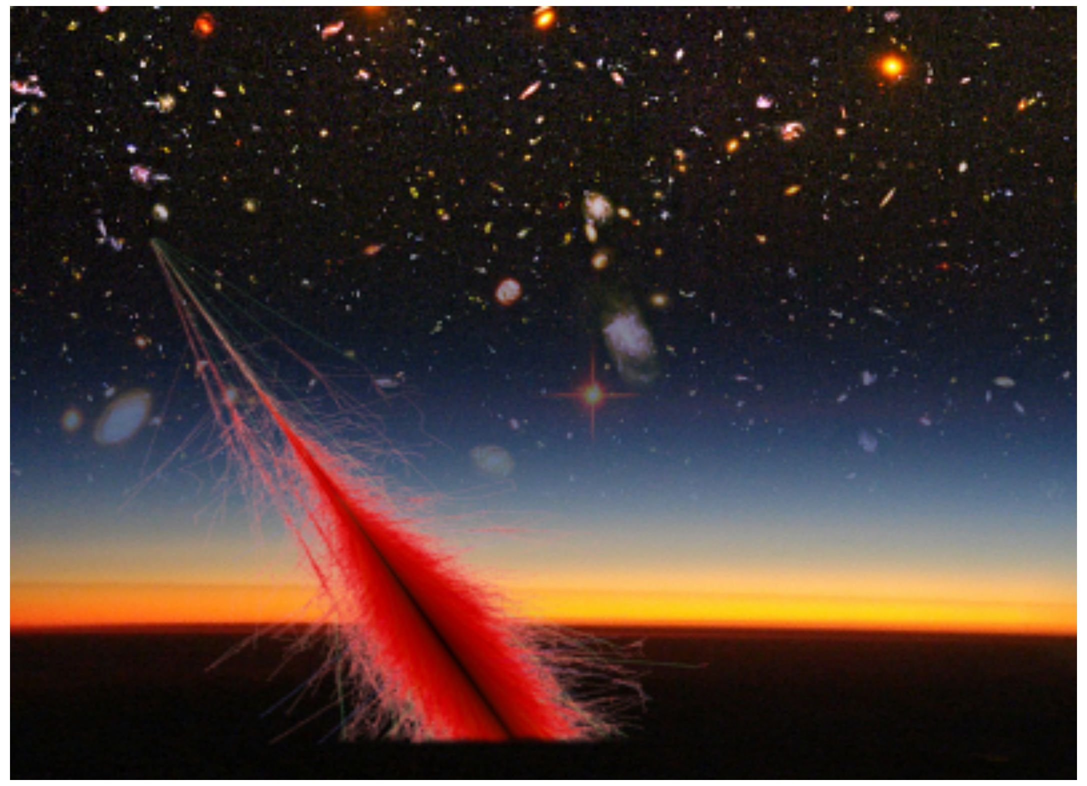




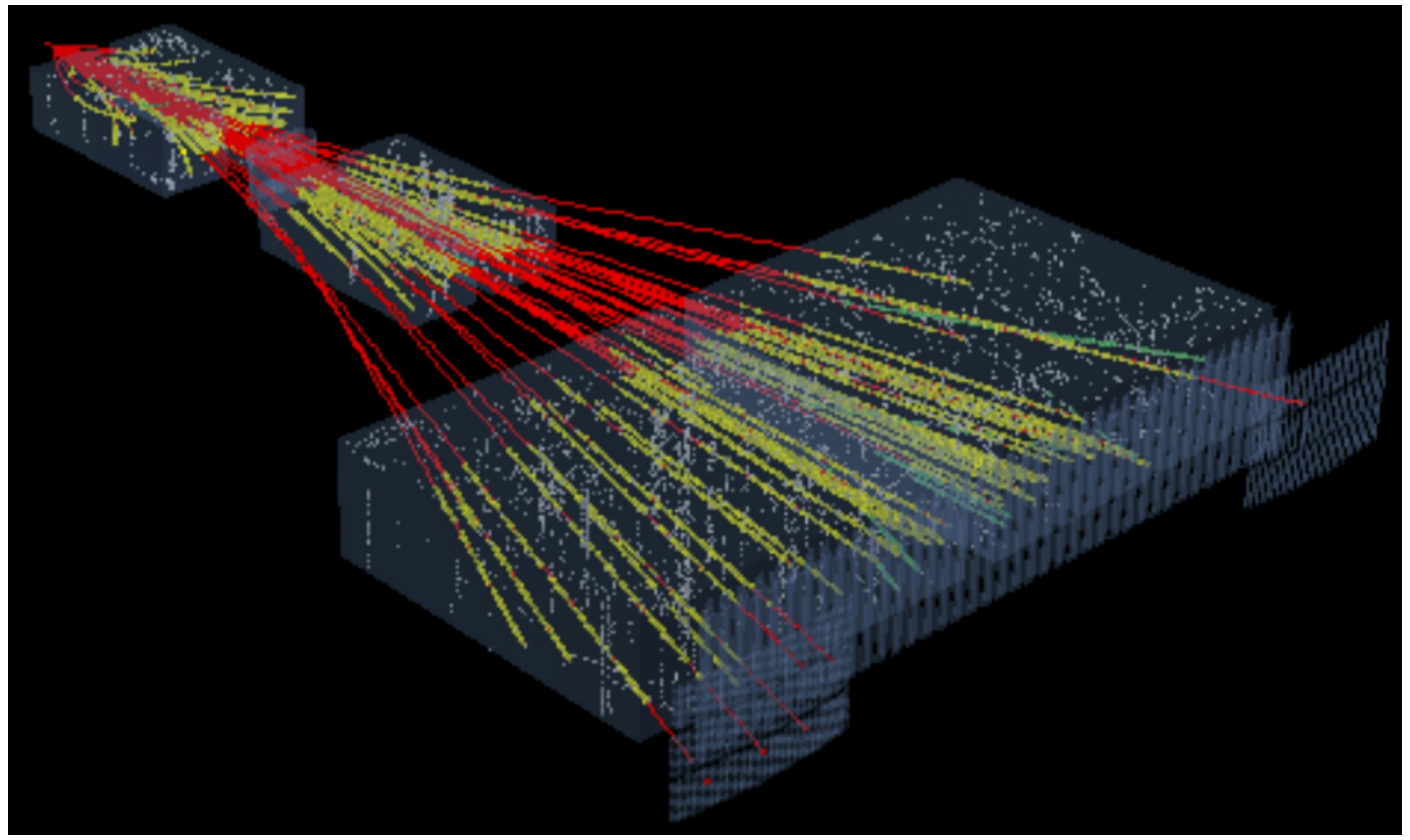
- exploration continues with more nuclei

NA61 / Shine

- Measurement of cross sections for cosmic ray studies



- Measurement of target properties for neutrino physics



LHC

Beams of

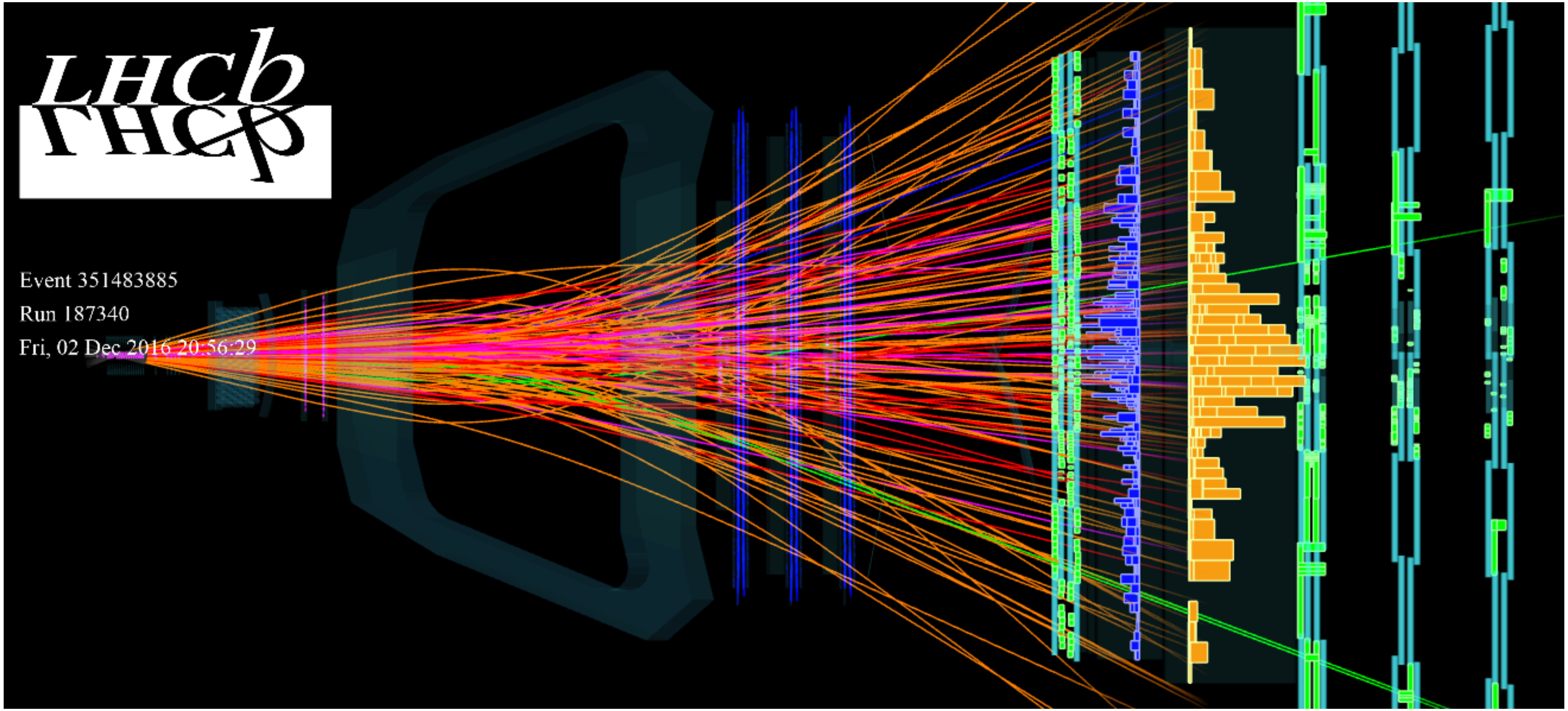
- pp
- pA
- AA

Comprehensive experimental approach independent of theoretical assumptions

Superb performance of LHC in 2016 – also in p-Pb run

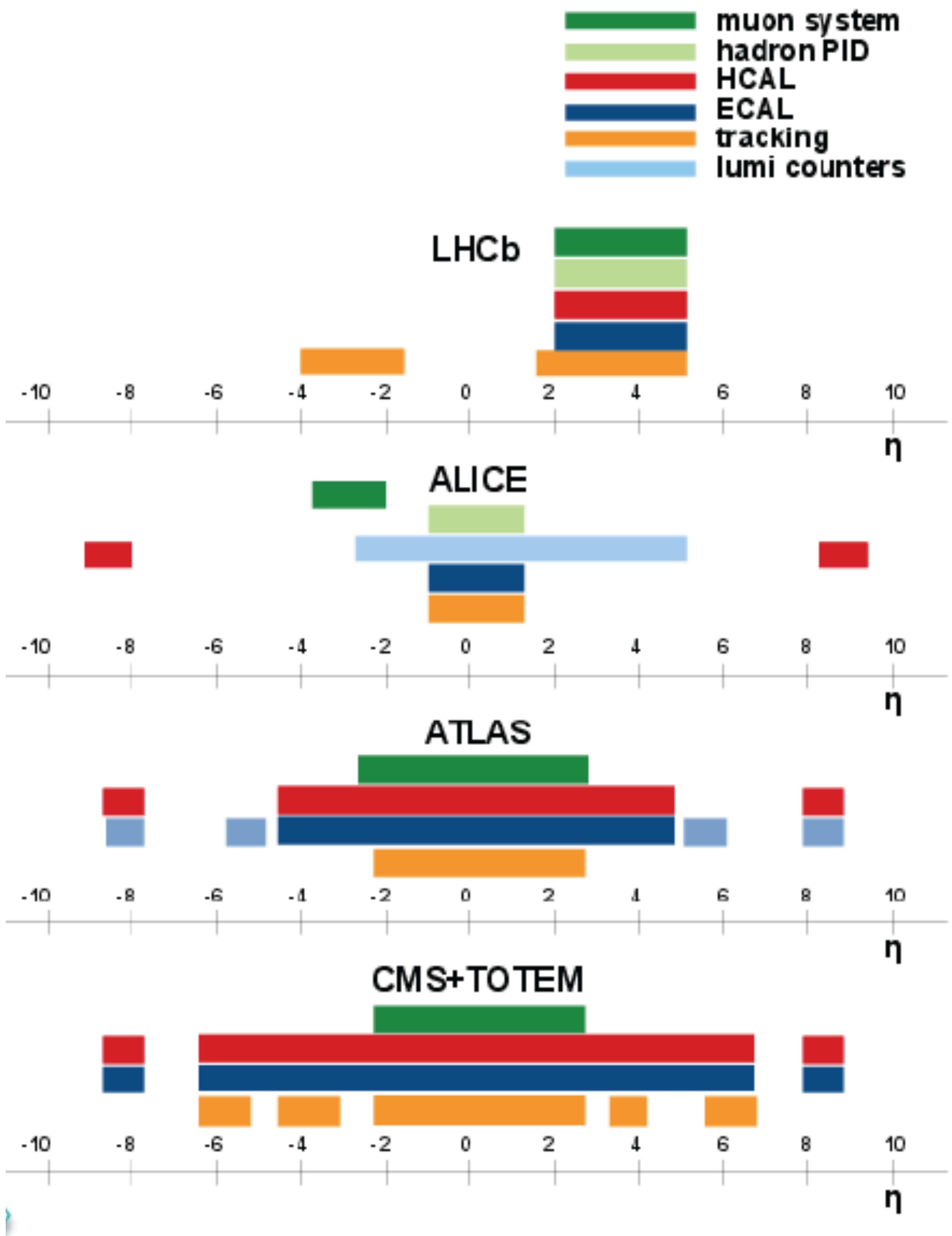
Configuration	Goal		Achieved
5 TeV p-Pb	ALICE	700×10^6 min bias events	**780×10^6**
8 TeV p-Pb	ATLAS - CMS	50 nb^{-1}	**69.5 - 65.5 nb^{-1}**
	LHCb - ALICE	10 nb^{-1}	**14 - 13 nb^{-1}**
	LHCf	9-12 h at $10^{28}\ cm^{-2}s^{-1}$	**9.5 h**
8 TeV Pb-p	ATLAS - CMS	50 nb^{-1}	**124 - 118 nb^{-1}**
	ALICE - LHCb	10 nb^{-1}	**25 - 19 nb^{-1}**

p-Pb lead collisions in LHCb

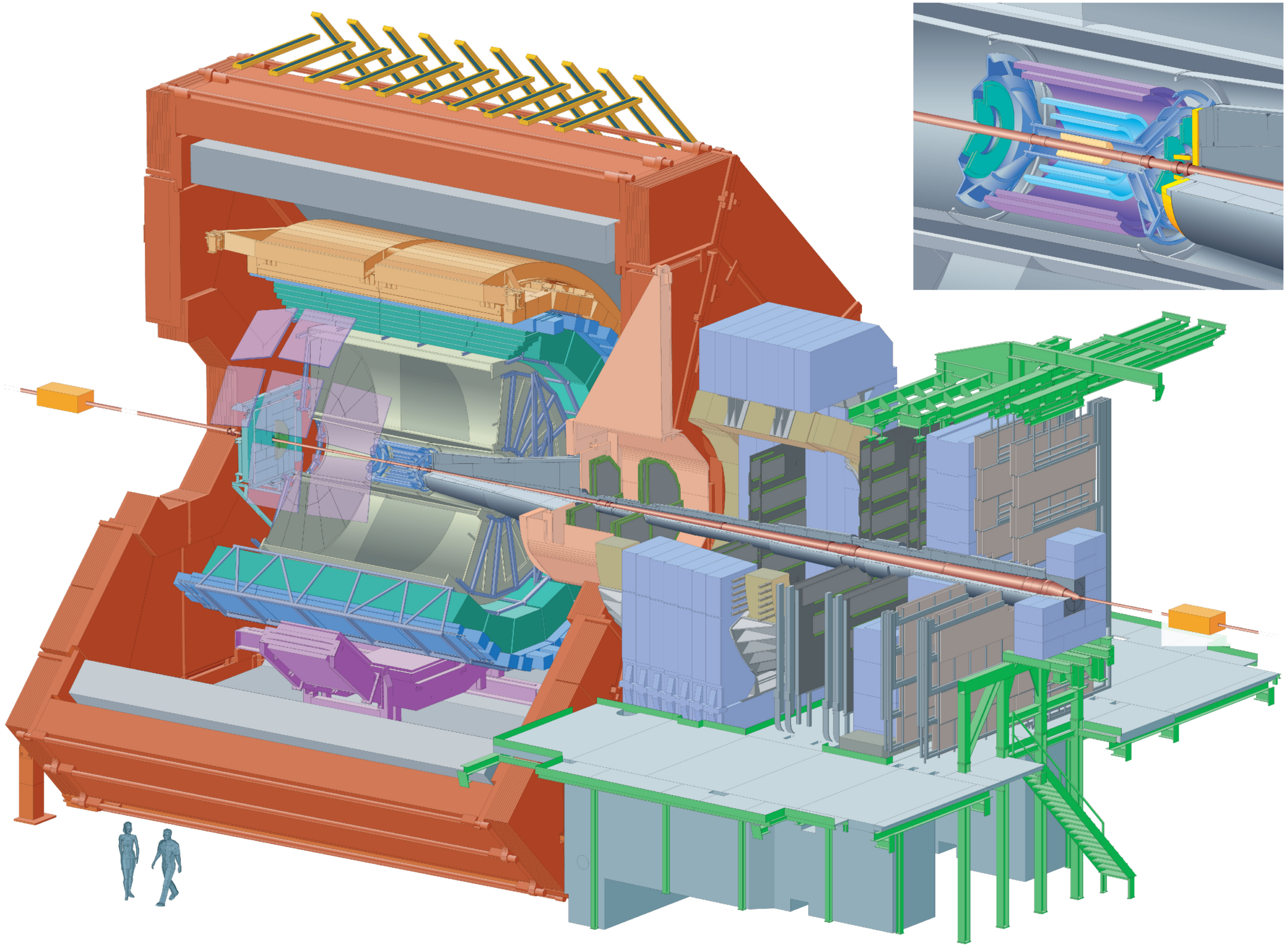


All 4 experiments contributing to Heavy Ion Programme

- Specific rapidity coverage
- ALICE specialising on low momentum particles and particle identification
- LHCb full coverage in forward direction
- ATLAS and CMS typically place harder momentum selection



ALICE at LHC – setup till Long Shutdown 2



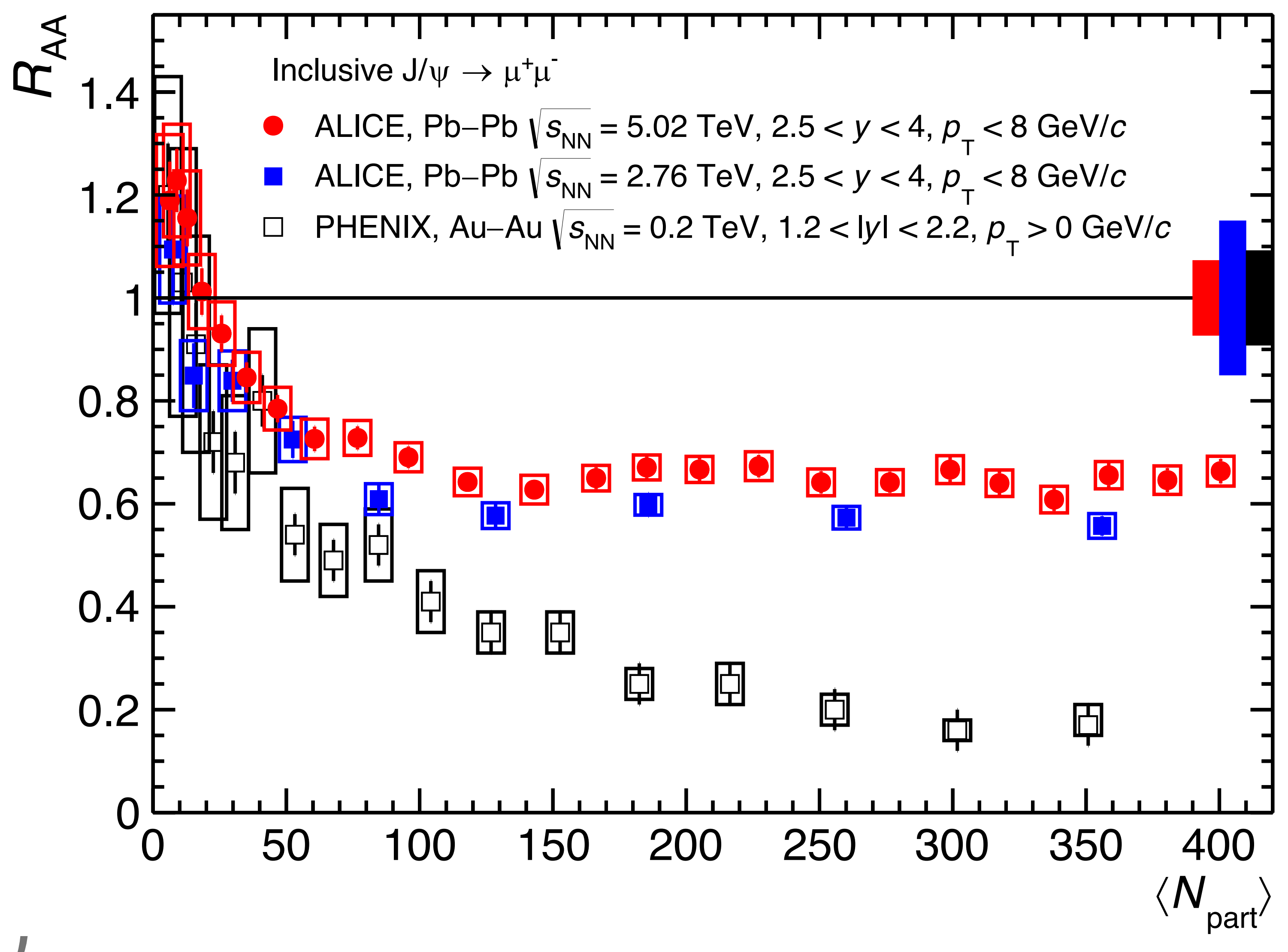
Pb-Pb: J/ψ suppression at 5 TeV

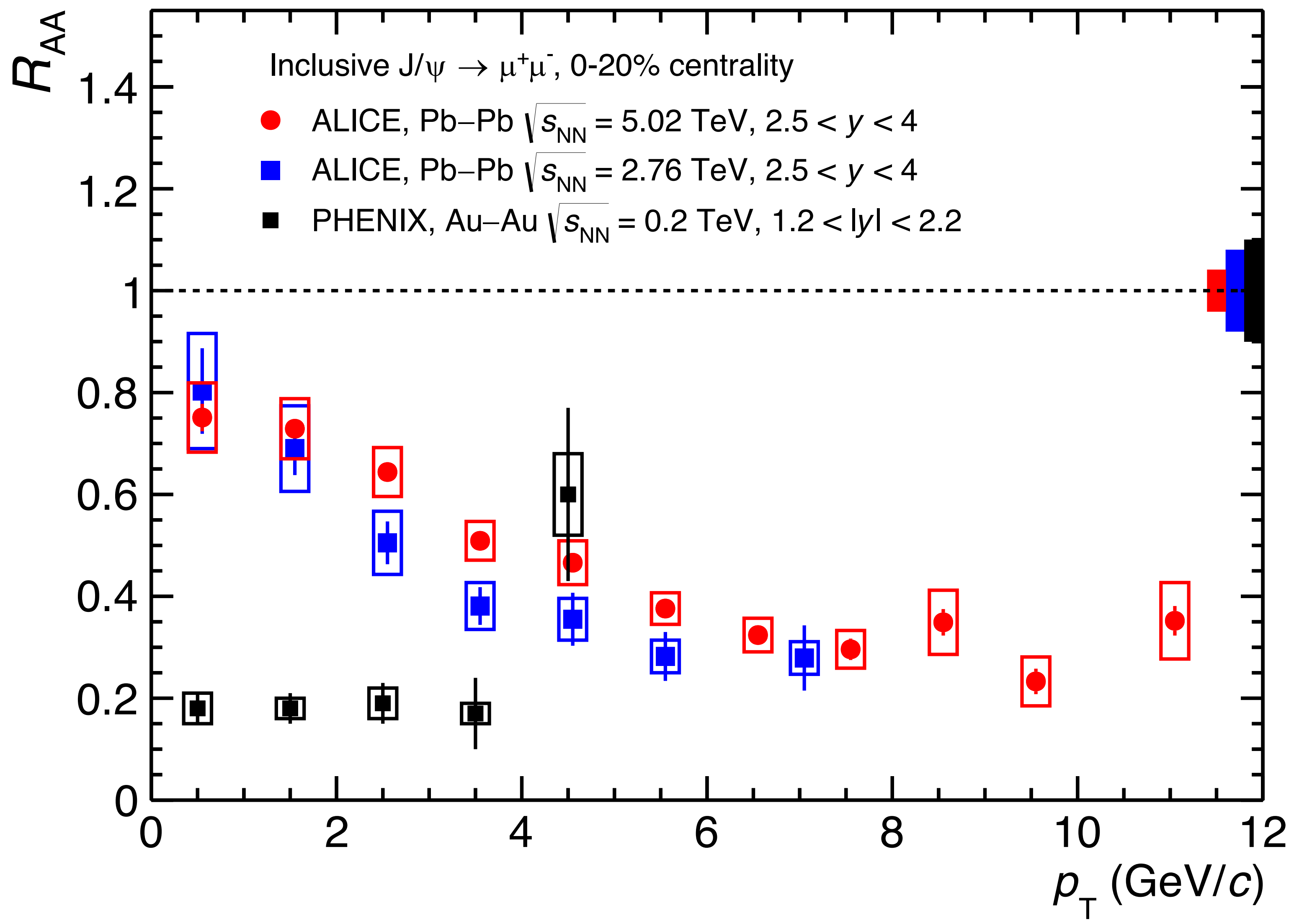
ALICE

- nuclear modification factor R_{AA}:

$$R_{AA} = \frac{N(J/\psi)_{AA}}{\langle N_{bin} \rangle N(J/\psi)_{pp}}$$

- very different behaviour between LHC and RHIC (vs both centrality and p_T)
- most straightforward explanation: c-cbar recombination at LHC



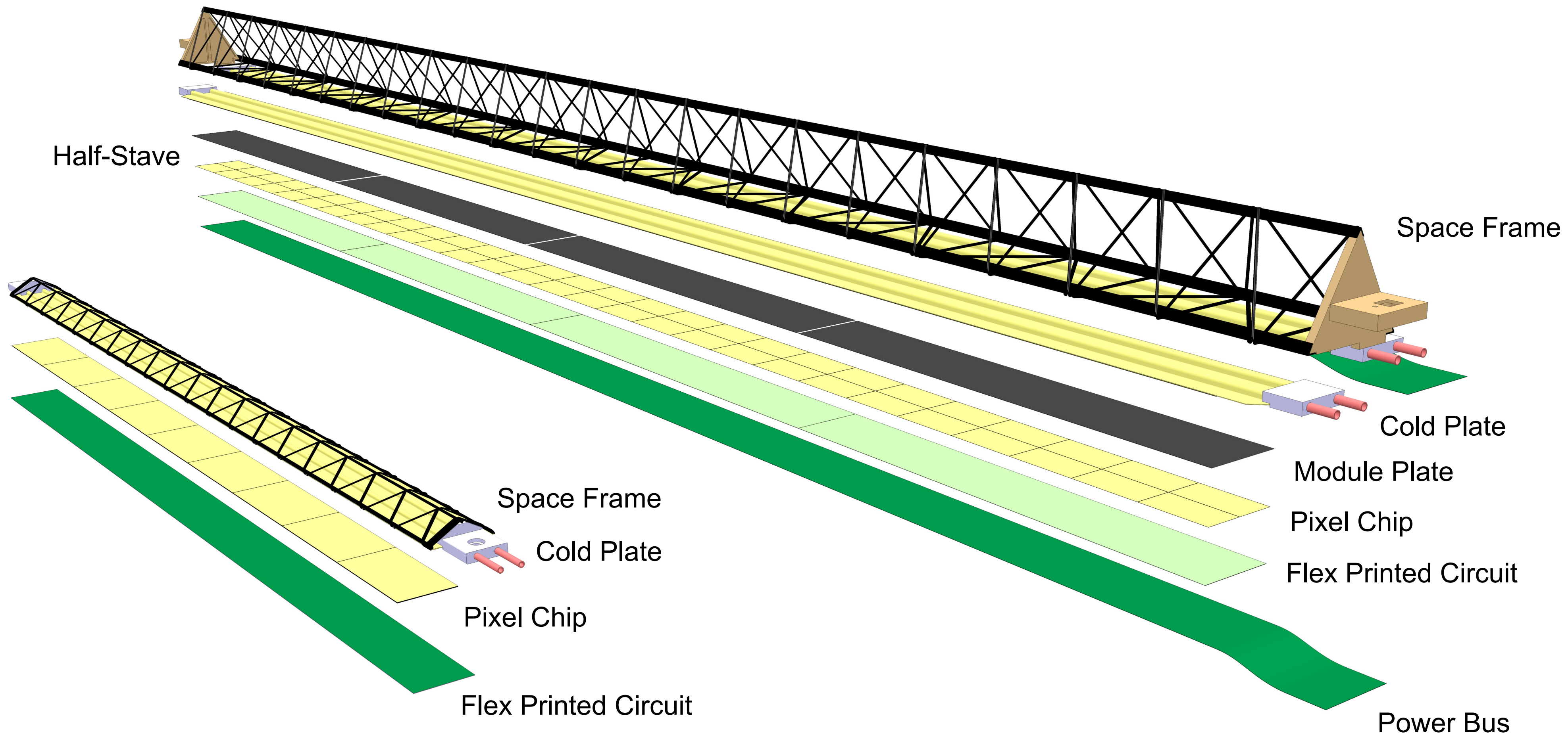


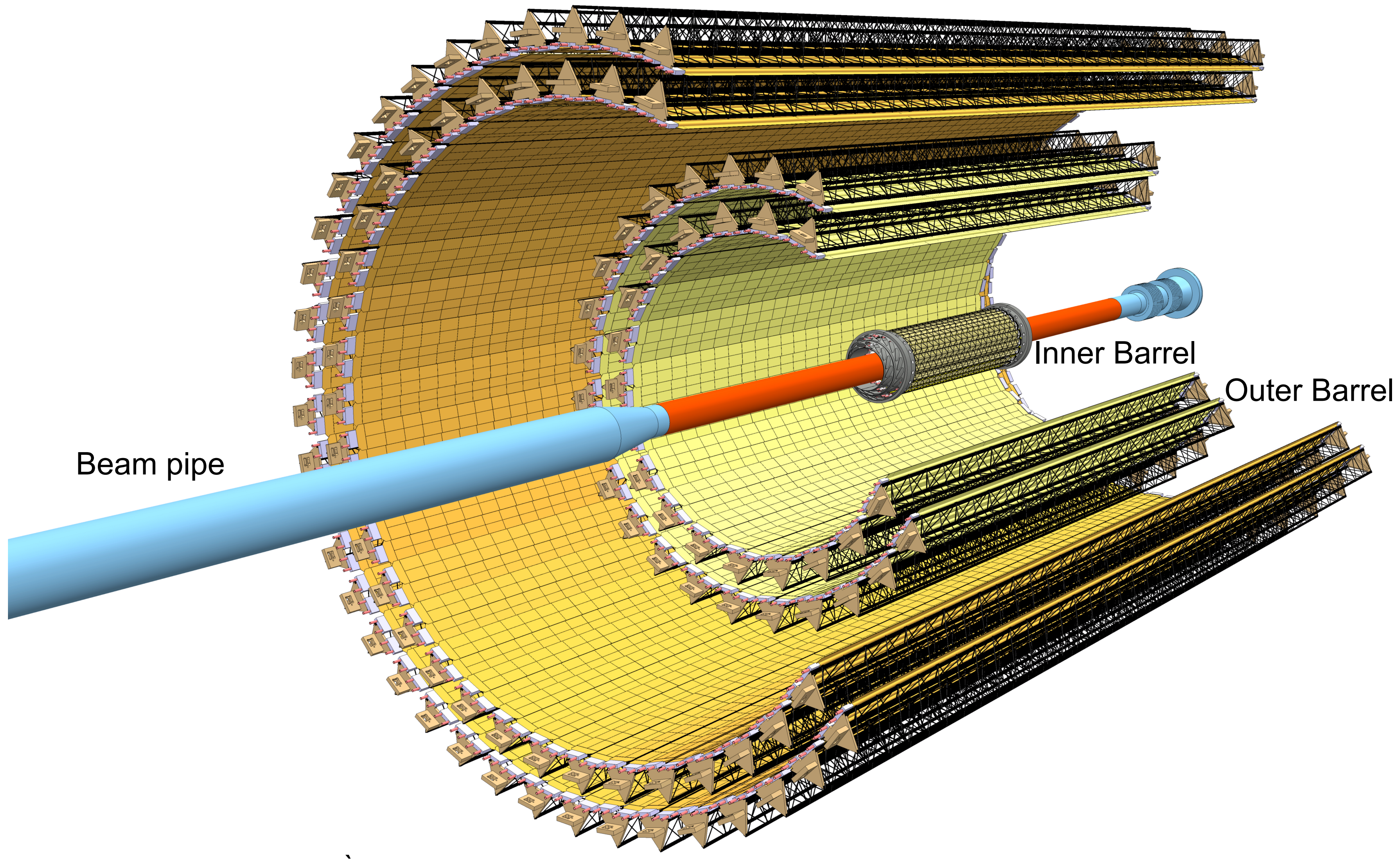
New and precise 5 TeV data support even further increase

ALICE after Long Shutdown 2

- **Motivation**: Focus on high-precision measurements of rare probes at low p_T
  - can not be selected with hardware trigger
  - need to record large sample of events
- **Target**: Pb-Pb recorded luminosity: $\geq 10\ nb^{-1}$
  - gain in statistics: factor 100 for selected probes!
  - plus pp and pA data
- **Strategy**:
  - read out all Pb-Pb interactions at a maximum rate of 50 kHz with a minimum-bias trigger or continuously (TPC)
  - perform online data reduction

ALICE ITS

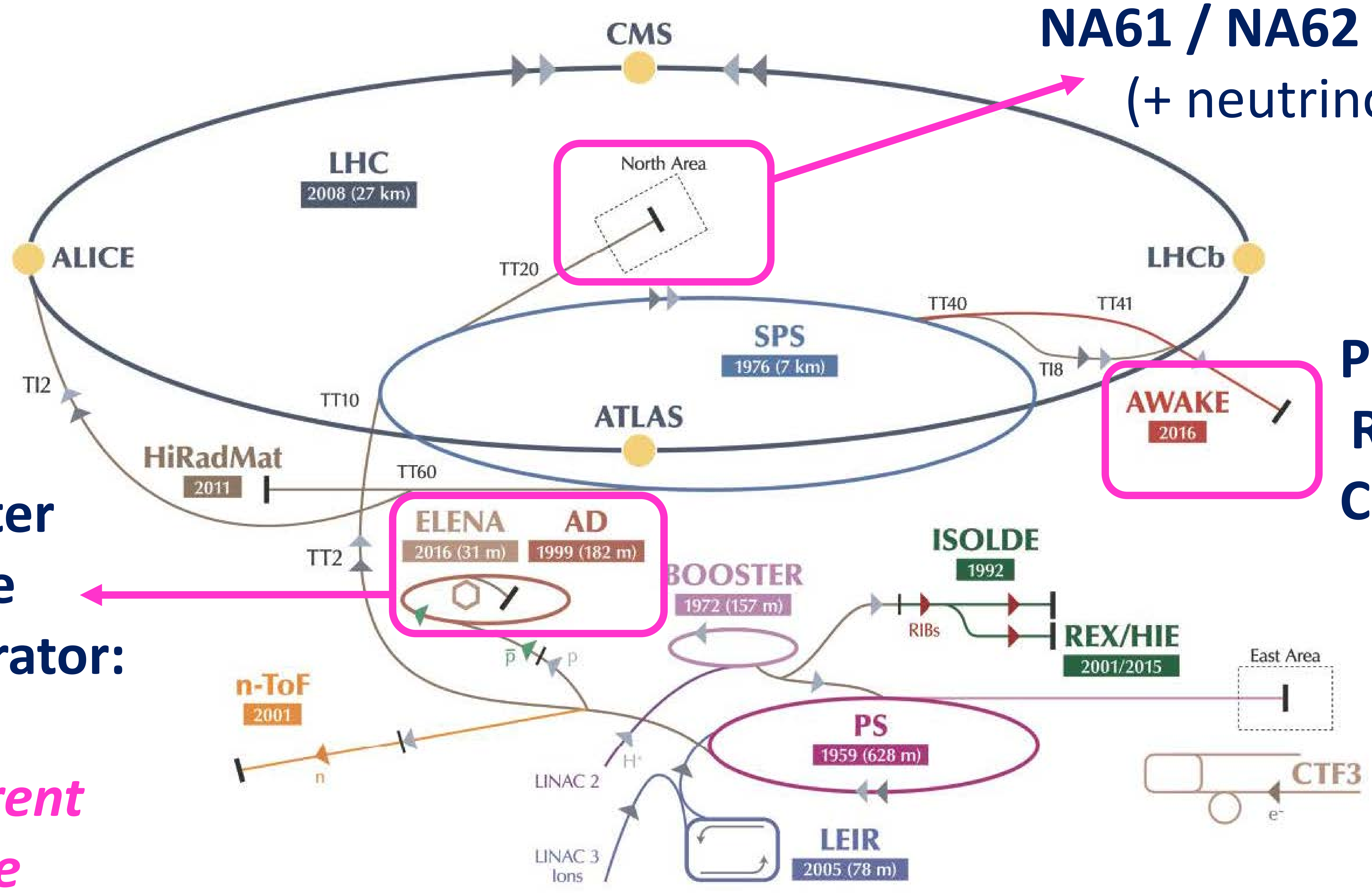

Half-Stave
Space Frame
Cold Plate
Module Plate
Pixel Chip
Flex Printed Circuit
Power Bus
Space Frame
Cold Plate
Pixel Chip
Flex Printed Circuit


Inner Barrel
Outer Barrel
Beam pipe

Physics-Beyond-Colliders (PBC)

- Workshop 6-7 Sep 2016
- Convened by
  - C Vallee, J Jäckel, M Lamont
- with 342 registered participants
- Will contribute to ESPP update

Particle Physics Programme on LHC injectors



NA61 / NA62 / NA64 / COMPASS
(+ neutrino platform R&D)

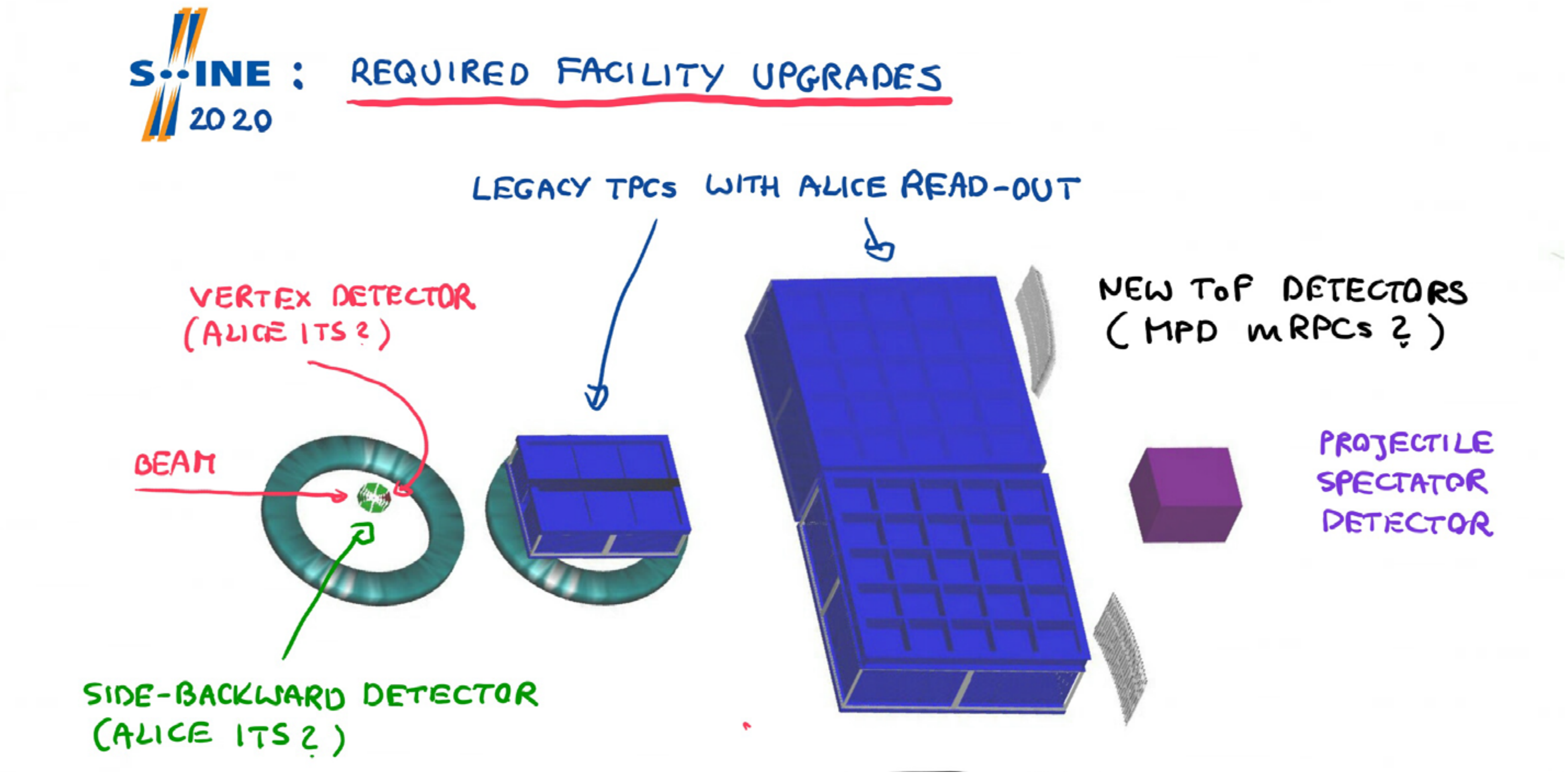
Plasma acceleration R&D on the former CNGS extraction line

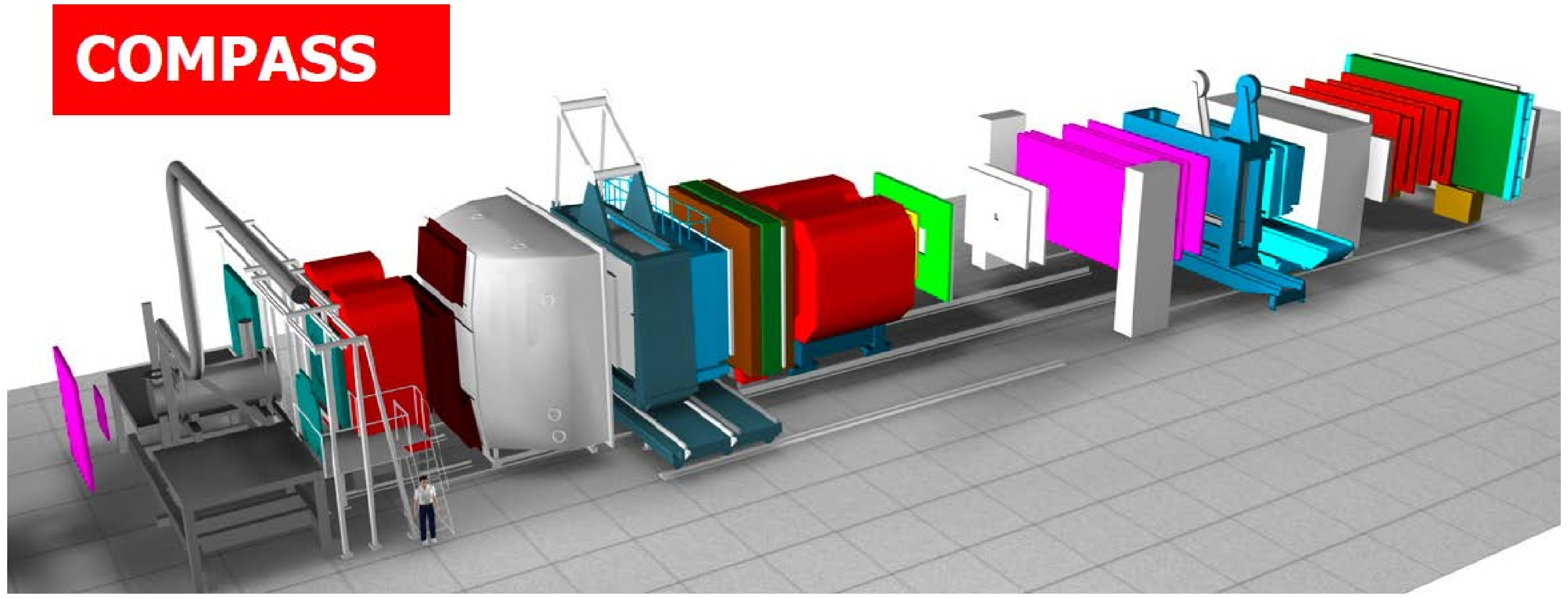
Vibrant antimatter program on the Antiproton Decelerator:
bright future secured with current ELENA upgrade

NB: recent stop of major programs (e.g. CNGS) leaves room for new significant initiatives

Fixed Target Programme

- NA61
  - Charm deconfinement
  - support for ν-programme
- COMPASS
  - Drell-Yan with anti-p and K-beams

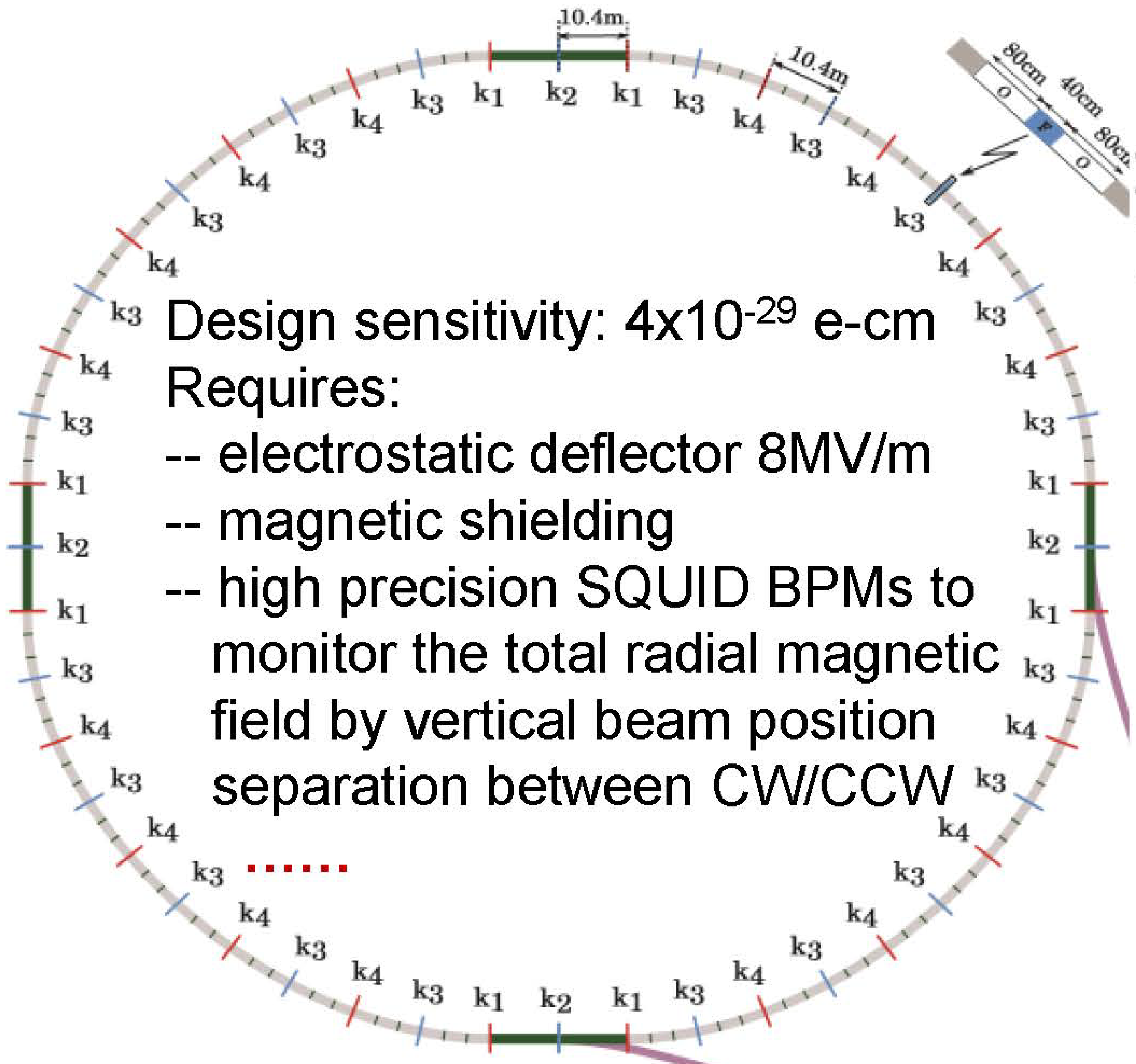




Precision EDM Measurements using electrostatic ring

10^{-29} e-cm sensitivity would correspond to 100 TeV for new physics energy scale.

Pure electrostatic ring applicable to proton only



Design sensitivity: 4×10^{-29} e-cm

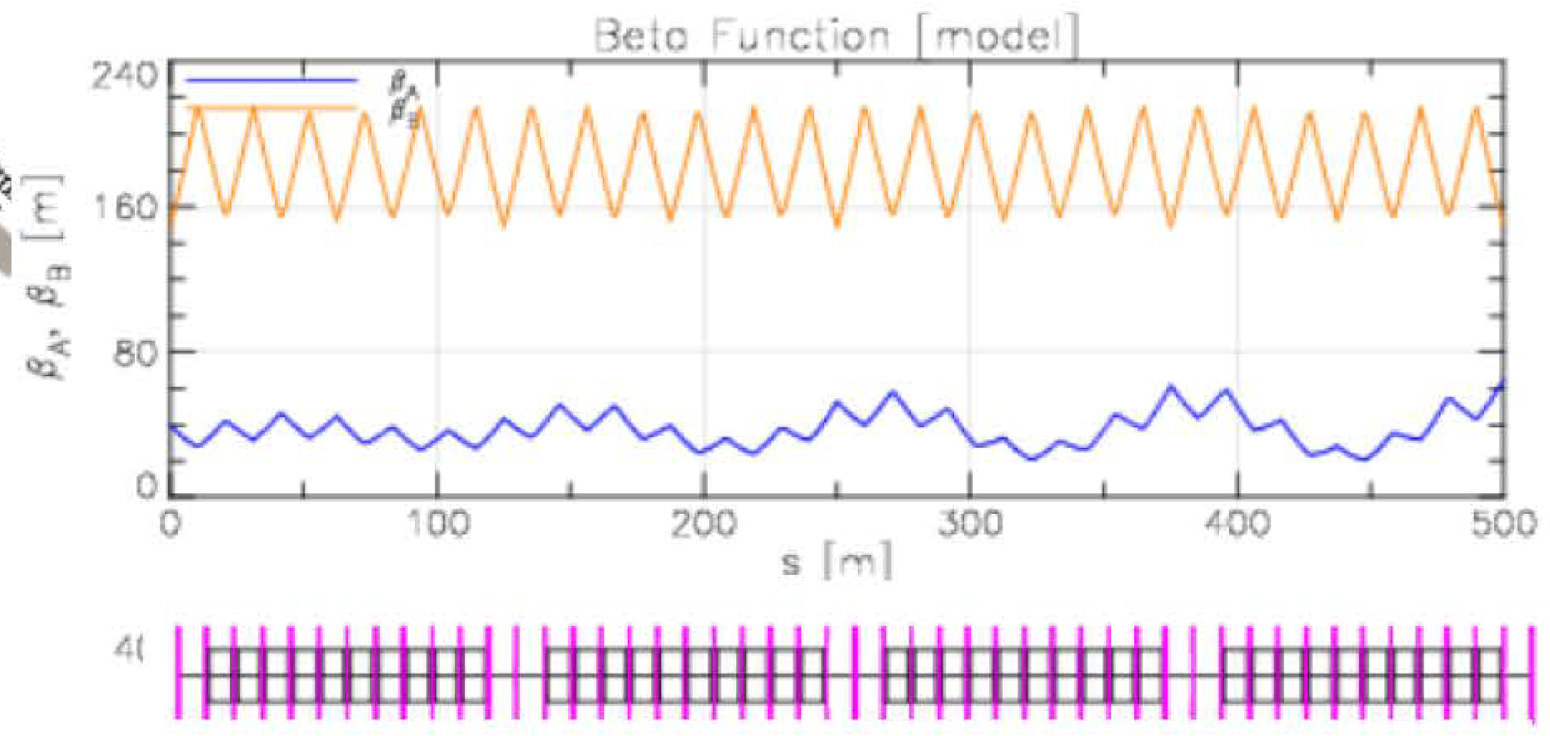
Requires:

-- electrostatic deflector 8MV/m

-- magnetic shielding

-- high precision SQUID BPMs to monitor the total radial magnetic field by vertical beam position separation between CW/CCW

......

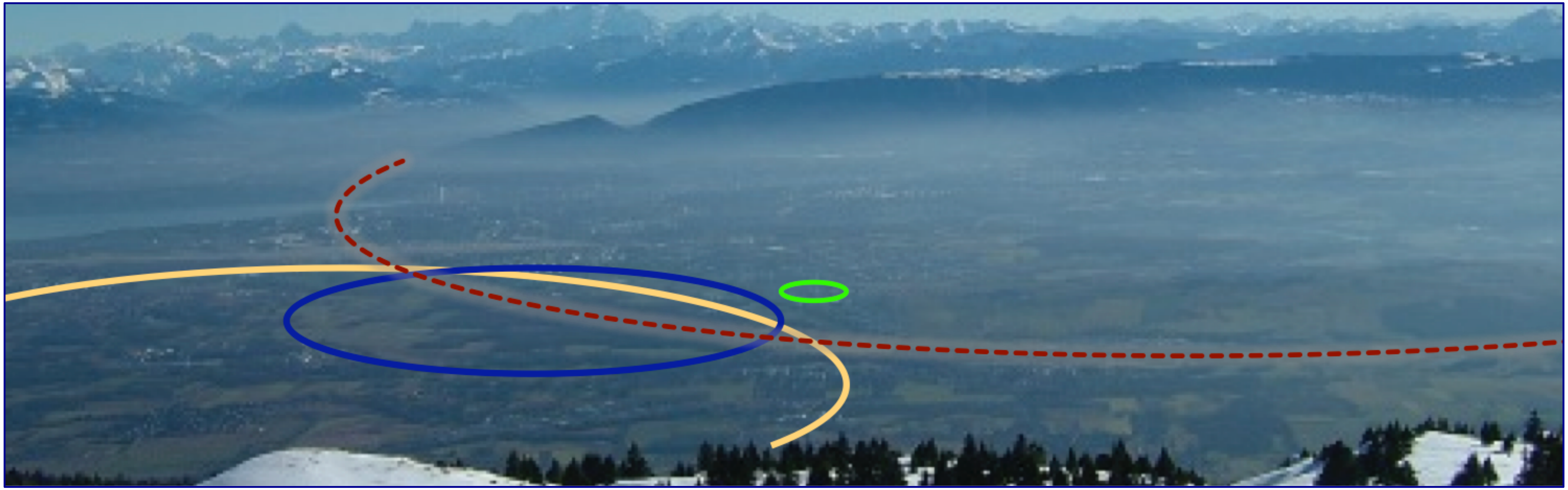


Bending radius	52.3 m
circumference	500 m
Electrode spacing	3 cm
Deflector shape	cylindrical
Harmonic, RF[MHz]	100, 35.878
Q_x, Q_y	2.42, 0.44
ε_x , ε_y [mm-mrad]	17, 3.2
maximum $\frac{dp}{p}$	4.6×10^{-4}
Dispersion, max [m]	30 m

V. Anastassopulos et al, https://arxiv.org/abs/1502.04317

Energy Frontier

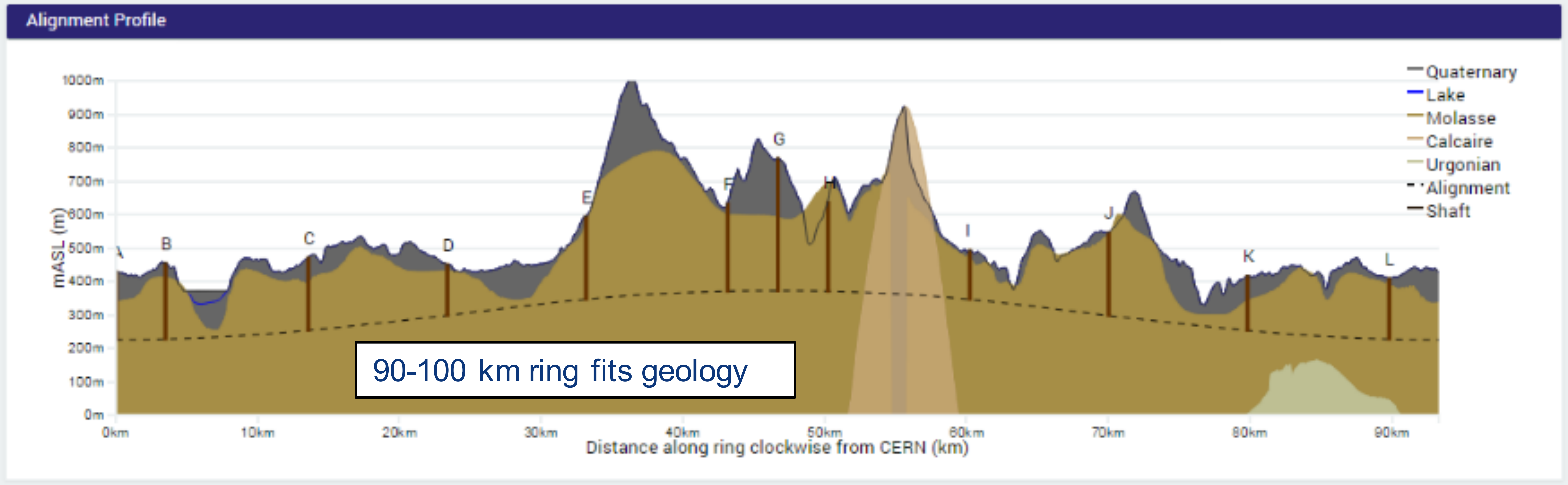
Future Circular Collider FCC



- European Design Study
- ~100 TeV pp in a ~100 km ring

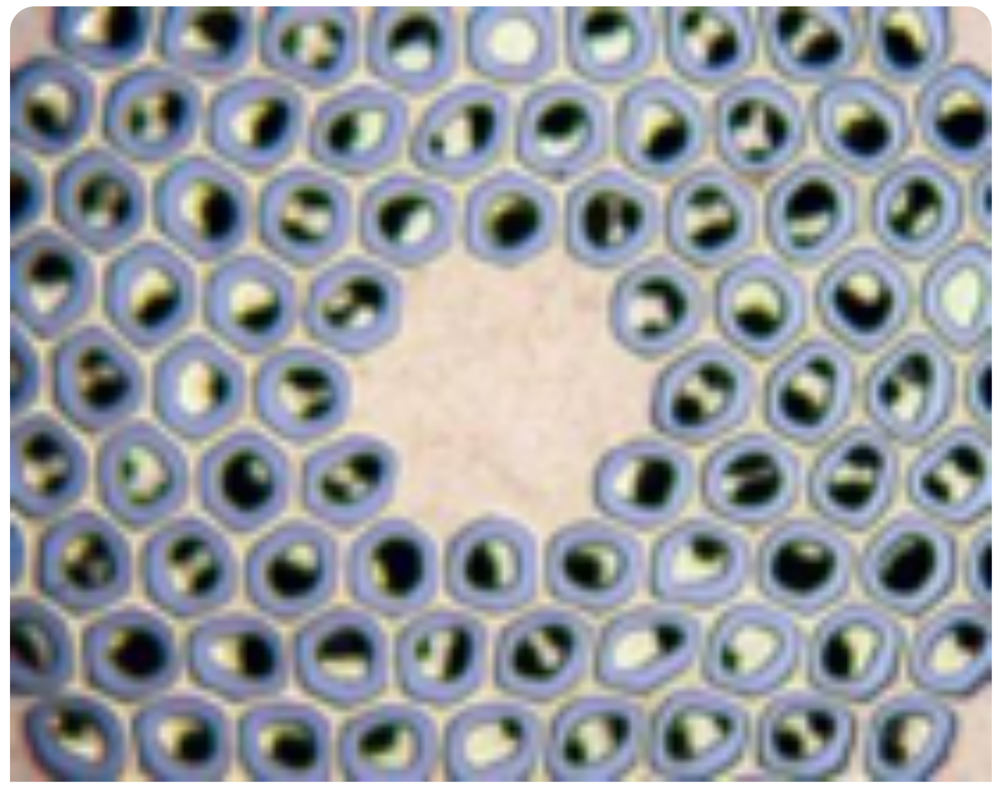
Site investigations @ CERN

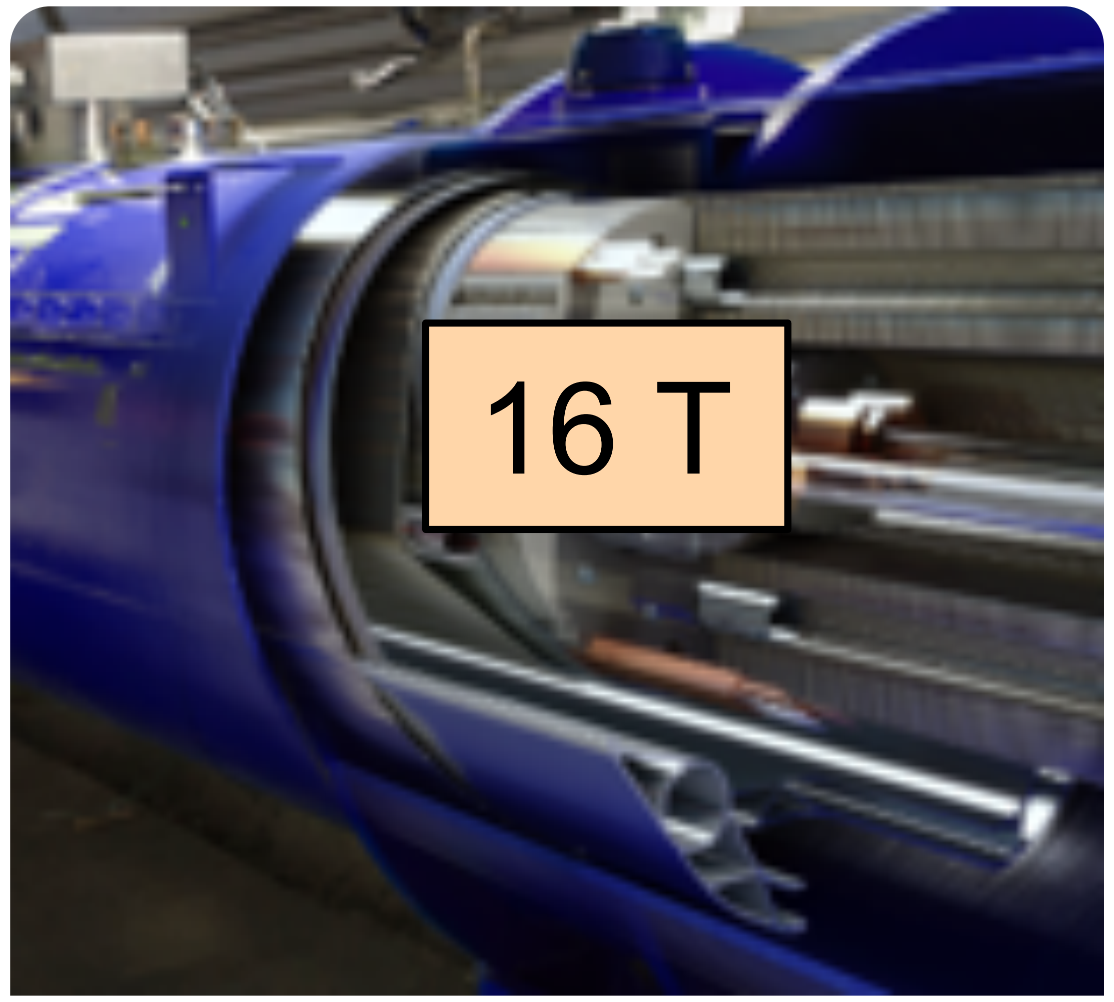
- Studies are a priori site independent. – FCC@CERN benefits from existing infrastructure.



Magnet R&D

- LHC: nominal 8.3 T; exercise 9 T (being studied)
- HL-LHC:
  - 11 T dipoles in dispersion suppression collimators
  - 12-13 T low-β quadrupoles ATLAS and CMS IR's

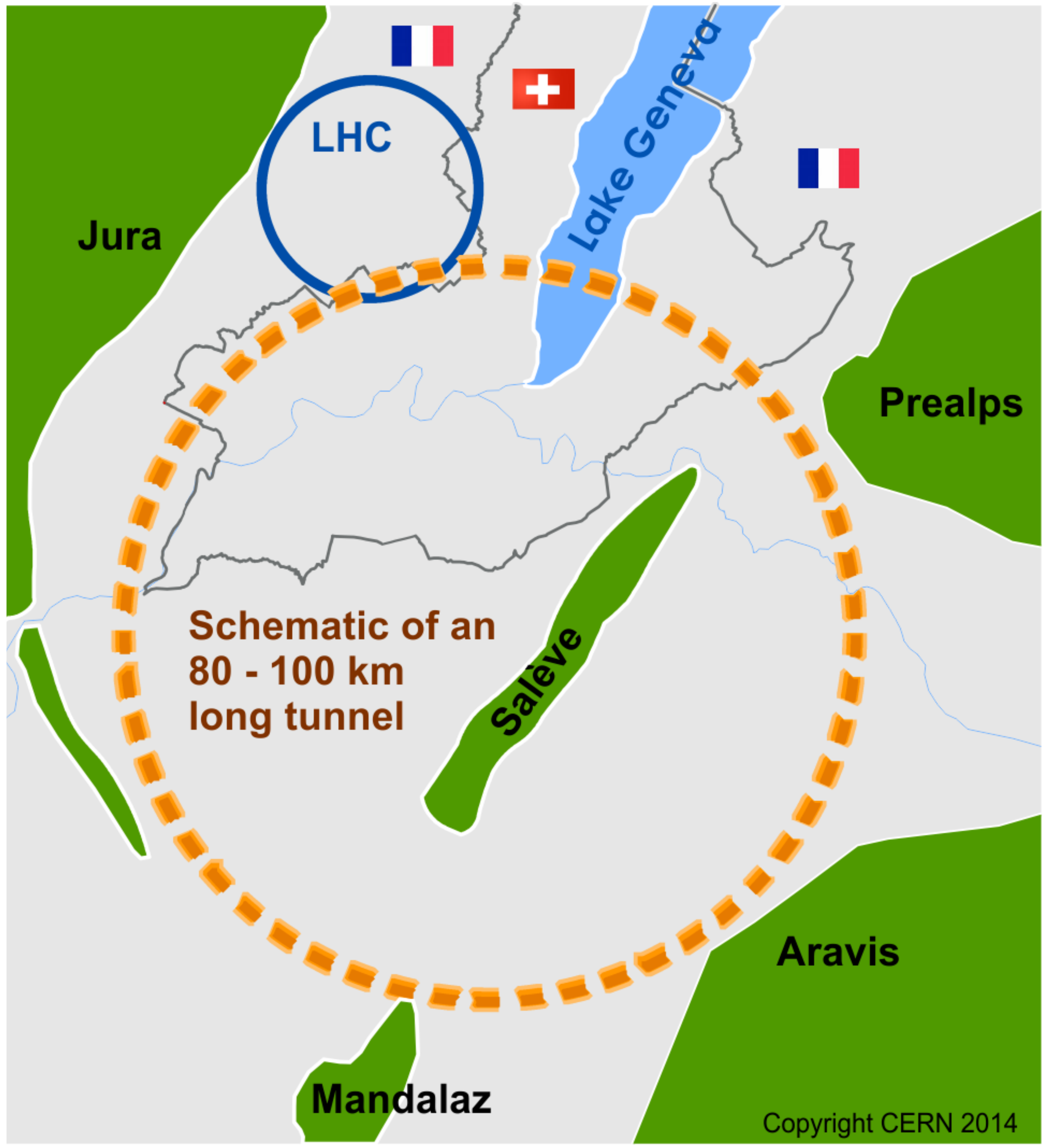




Dec 2015: 2 in 1 dipole of 1.8 m length reaches nominal 11.3 T.

Conceptual Design Report by end 2018

- **pp-Collider (FCC-hh) – sets the boundary conditions**
  - **100 km ring, $\sqrt{s}$=100 TeV, L~2x10^{35}**
  - **HE-LHC is included (~28 TeV)**
- e^+e^--Collider as a possible first step
  - $\sqrt{s}$= 90 - 350 GeV,
    L~1.3x10^{34} at high E
- eh-Collider as an option
  - $\sqrt{s}$=3.5 TeV, L~10^{34}

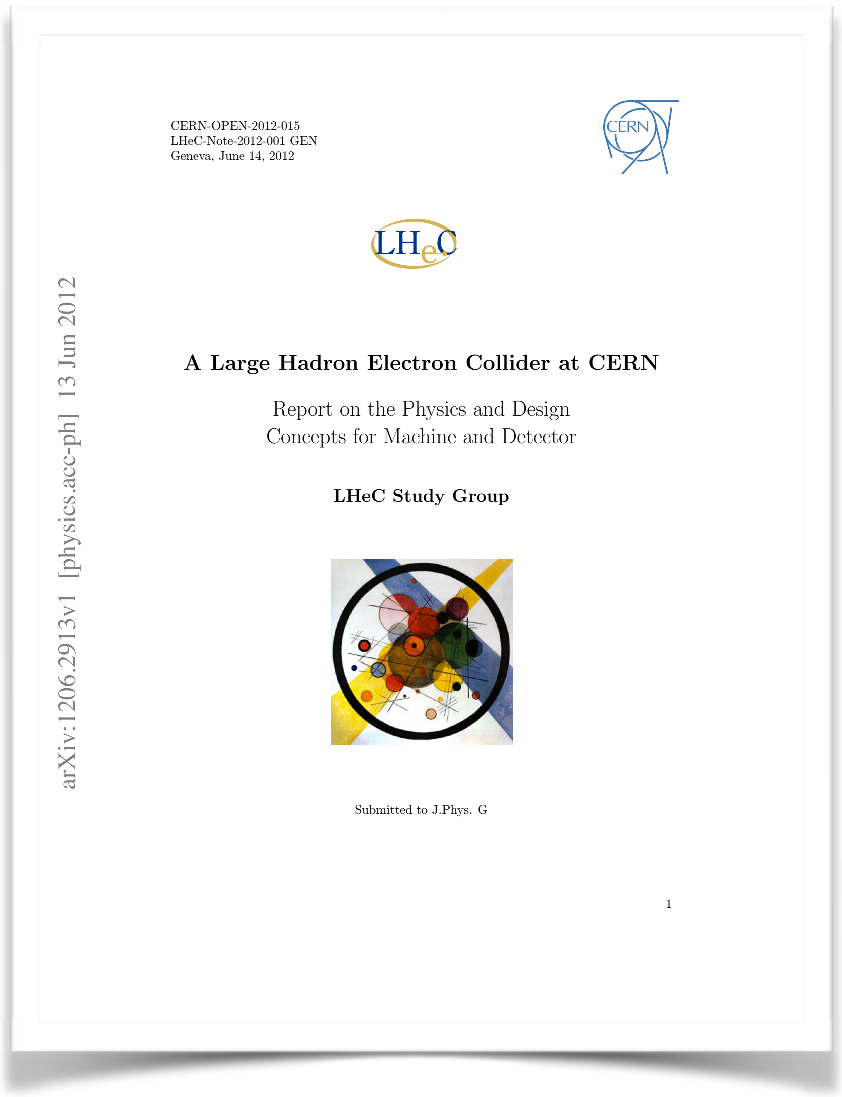


FCC-hh Parameters

Parameter	FCC-hh		SppC	LHC	HL LHC
collision energy cms [TeV]	100		71.2	14	
dipole field [T]	16		20	8.3	
# IP	2 main + 2		2	2 main + 2	
bunch intensity [10^{11}]	1	1 (0.2)	2	1.1	2.2
bunch spacing [ns]	25	25 (5)	25	25	25
luminosity/Ip [10^{34} $cm^{-2}s^{-1}$]	5	~25	12	1	5
events/bunch crossing	170	~850 (170)	400	27	135
stored energy/beam [GJ]	8.4		6.6	0.36	0.7
E-loss/turn synchrotron radiation/beam	5 MeV 3 MW		2 MeV 5.8 MW	7 keV 5.4 kW	7 keV 9.5 kW

FCC eh

- eh option included in FCC study
  - emerged from LHeC study



CERN-OPEN-2012-015
LHeC-Note-2012-001 GEN
Geneva, June 14, 2012

arXiv:1206.2913v1 [physics.acc-ph] 13 Jun 2012

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group

Submitted to J.Phys. G

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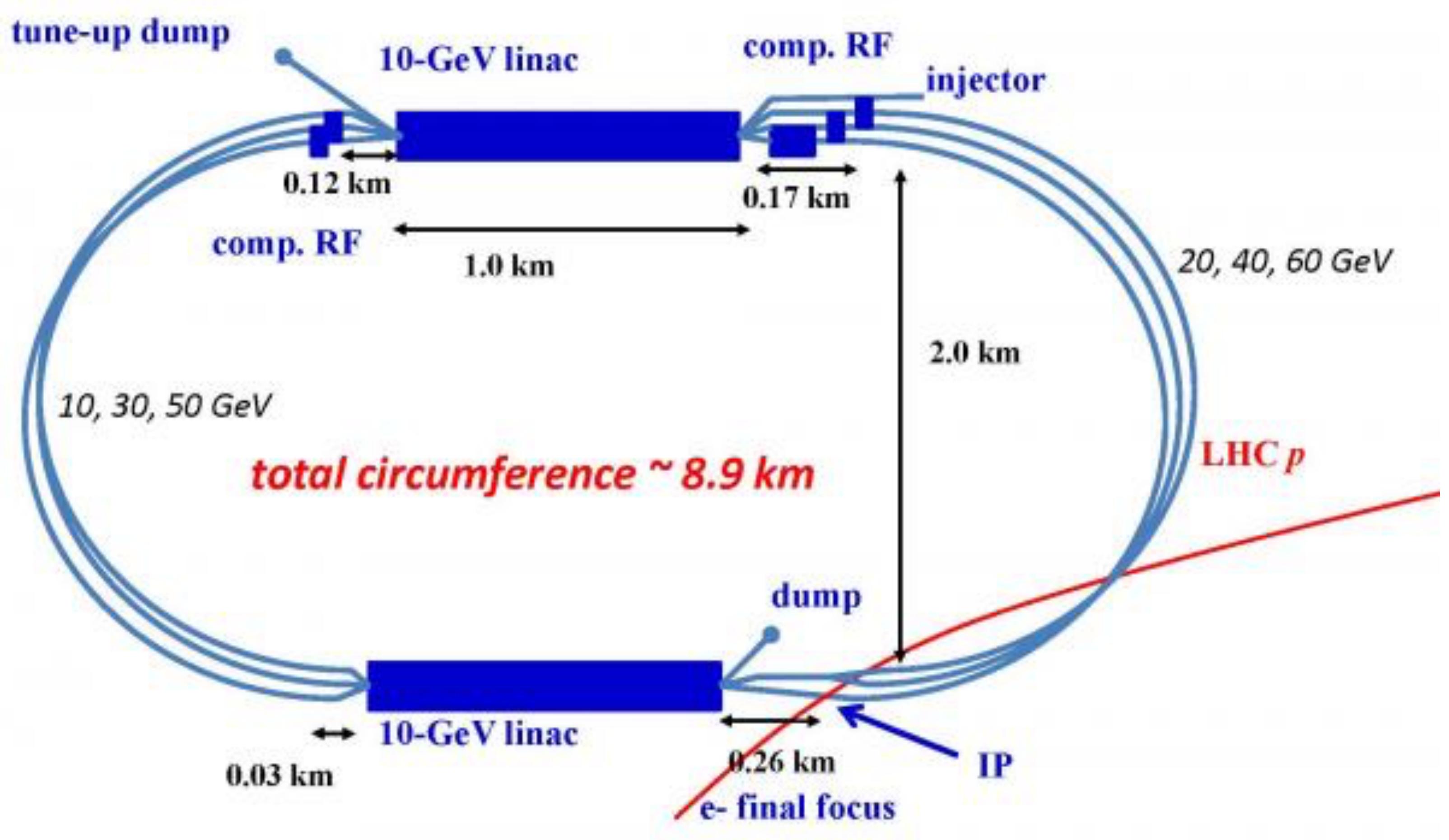
ERL option for LHeC



Goal of FCC study

- Design report by end of 2018
  - including cost
- Includes High-Energy LHC study
  - use of high field magnets in existing LHC ring
- Serves as input for Update of European Strategy of Particle Physics that is to conclude by May 2020

Conclusion

- Broad and rich Nuclear Physics Programme in place at CERN
- ALICE is the dedicated Heavy Ion Experiment at CERN
  - Upgrade during LS2 – ready for 50 kHz operation with 10 nb^{-1} goal
  - all four LHC experiments take part in Heavy Ion runs
- Further options explored for fixed target programme (PBC-study)
- eh-programme also examined for FCC-study