

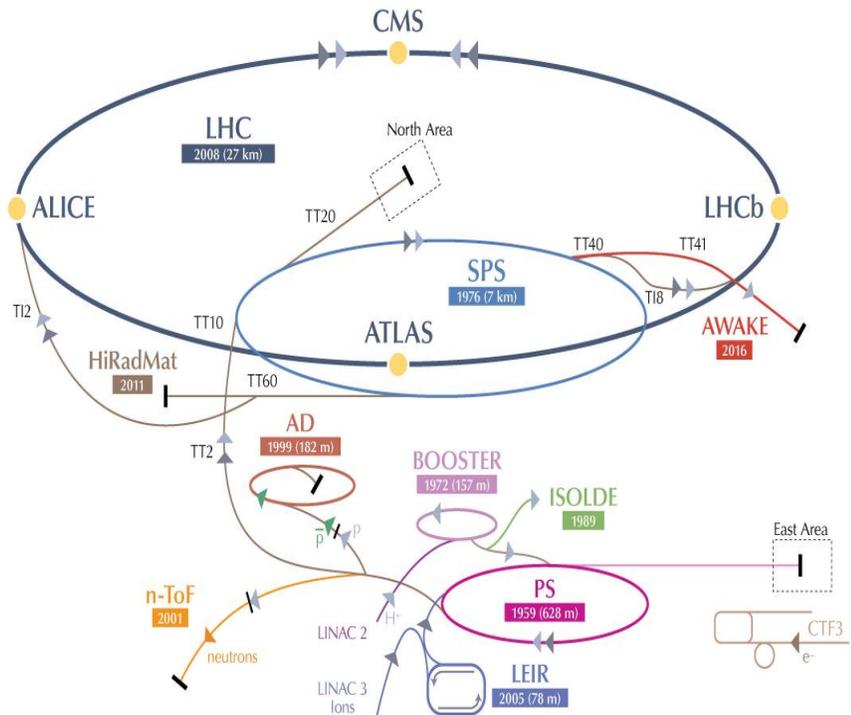


# Applications with AWAKE- like Electron Beams

Studies done within the PBC (Physics Beyond Collider) Working Group.

Edda Gschwendtner, CERN

# Introduction



## AWAKE: Advanced Proton driven Plasma Wakefield Experiment

- First facility that investigates the use of plasma wakefields driven by a proton beam to accelerate electrons to high energies at GeV level.
- Apply scheme to particle physics experiments leading to shorter or higher energy accelerators
- Collaboration of 18 institutes and 2 associate members.
- Approved in 2013
- First beam in 2016

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022/23/24
Proton and laser beam-line	Study, Design, Procurement, Component preparation			Installation	Commissioning	Data taking		Long Shutdown 2 24 months	Data taking	
Experimental area	Study, Design, Procurement, Component preparation			Modification, Civil Engineering and installation		<b>RUN 1</b>			<b>RUN 2</b>	
e <sup>-</sup> source and beam-line	Studies, design		Fabrication	Installation	Commissioning	Phase 2				

Run 1 – until LS2 of the LHC.

After LS2 – proposing Run 2 of AWAKE (during Run 3 of LHC)

**After Run 2: kick off particle physics driven applications**

# Fixed Target Experiments with High Energy Electron Beam

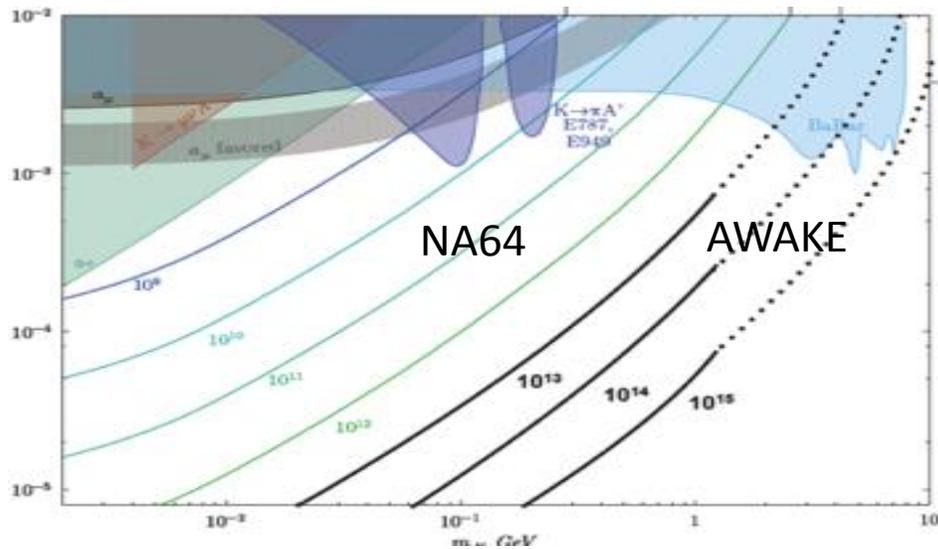
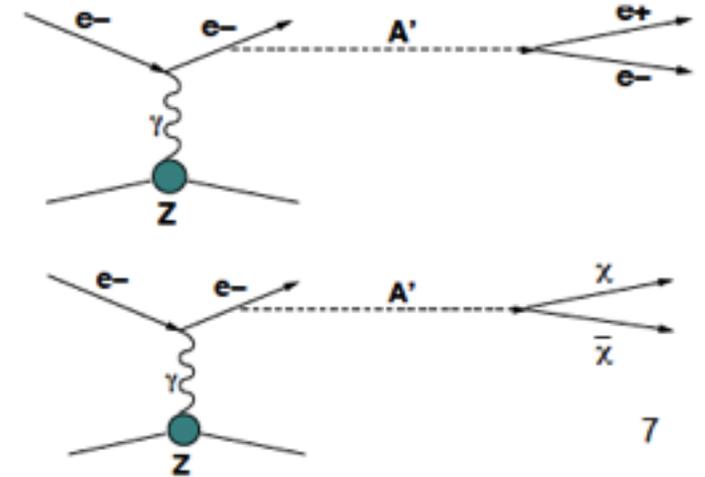
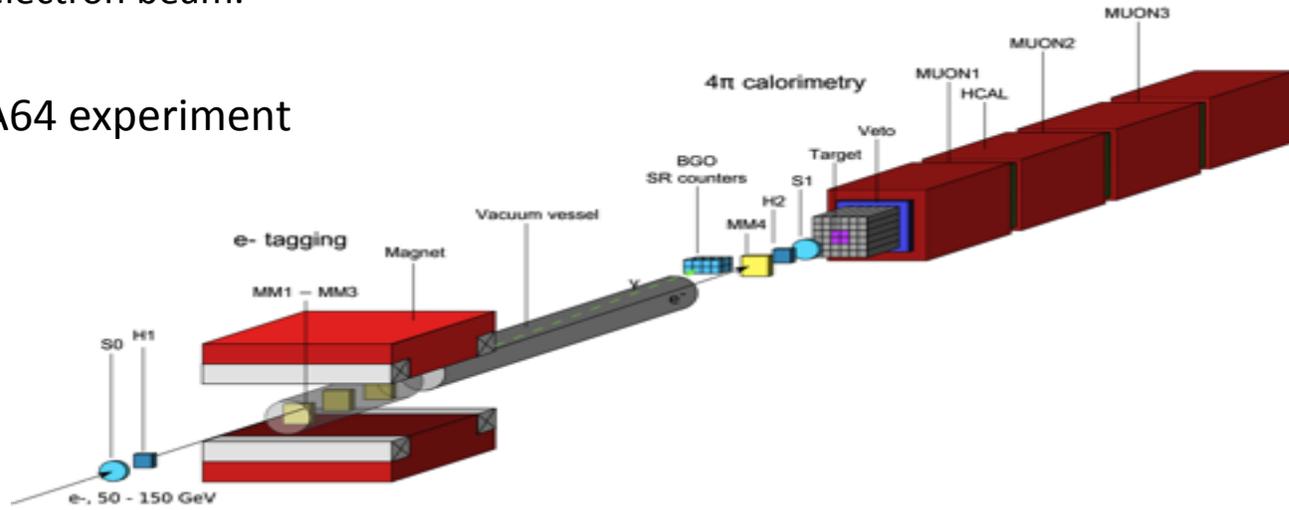
So far, no experimental hints on particle nature of dark matter.

Interest in low-mass particle solutions increasing; e.g., **dark photons**.

Light shining through walls experiments ...

Here, use electron beam.

NA64 experiment



**NA64:** expect  $10^6$  electrons/spill;  $10^{12}$  electrons for 3 months

# NA64, $A' \rightarrow \chi\chi$ Invisible Channel

2016 July: No event observed in the signal region  $\rightarrow$  exclusion of most of the g-2 muon favored region

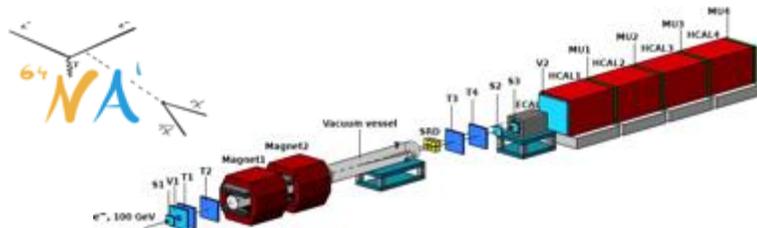
- $2.75 \times 10^9$  eot,  $1.4 \times 10^6$  e-/spill, 1.5 cm (FWHM) diameter beam.

$\rightarrow$  NA64 collaboration, Phys. Rev. Lett. 118, 011802 (2017)

2016 October: No event observed in the signal region  $\rightarrow$  exclusion of large parameter space for dark photons  $\rightarrow$  new limits also on pseudo-Dirac and Majorana type of light thermal DM

- $4 \times 10^{10}$  eot, up to  $5 \times 10^6$  e-/spill, 1.5 cm (FWHM) diameter beam.

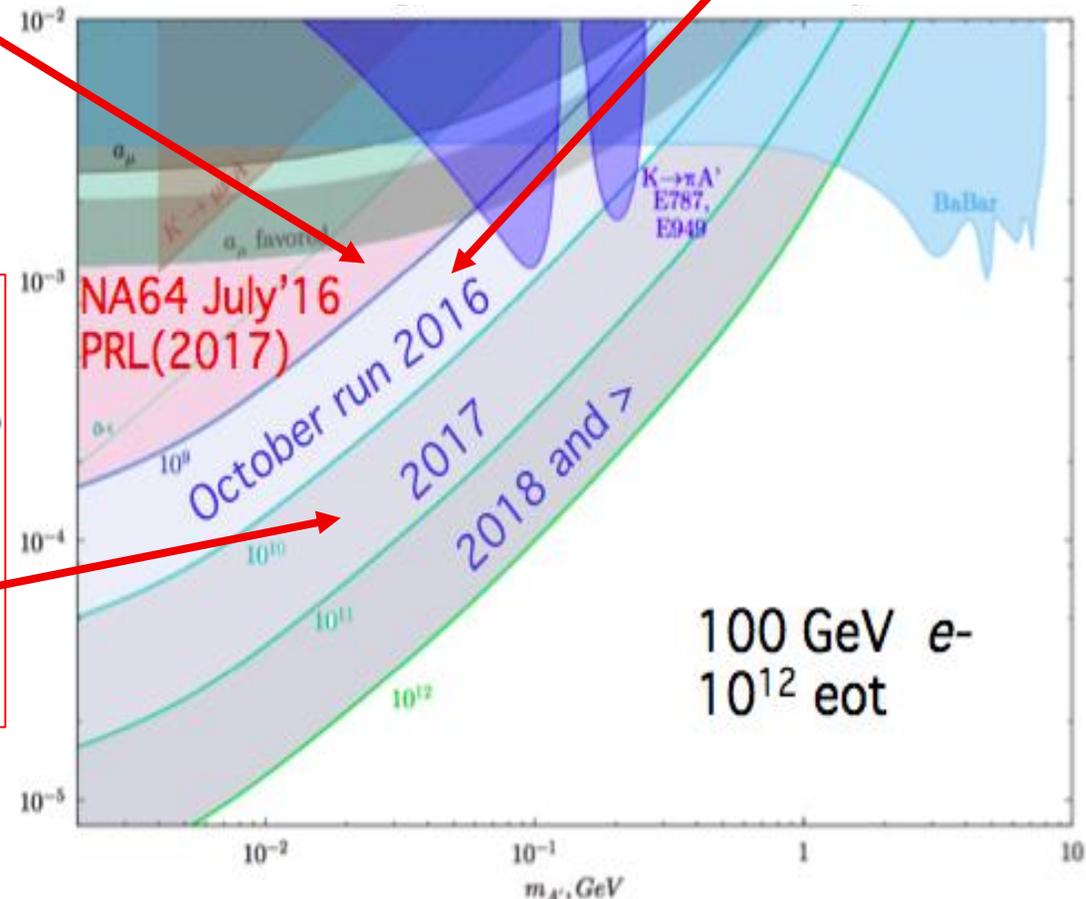
$\rightarrow$  Latest results: arXiv:1710.00971



2017: 5 weeks September: upgrade of sub-detectors

- $5 \times 10^{10}$  eot collected for the invisible mode, up to  $8 \times 10^6$  e-/spill
- $6 \times 10^{10}$  eot collected for visible mode  $\rightarrow$  confront  $^8\text{Be}$  decay anomaly which could be explained by 17 MeV X boson (J. Feng et al., PRD 95, 035017 (2017))

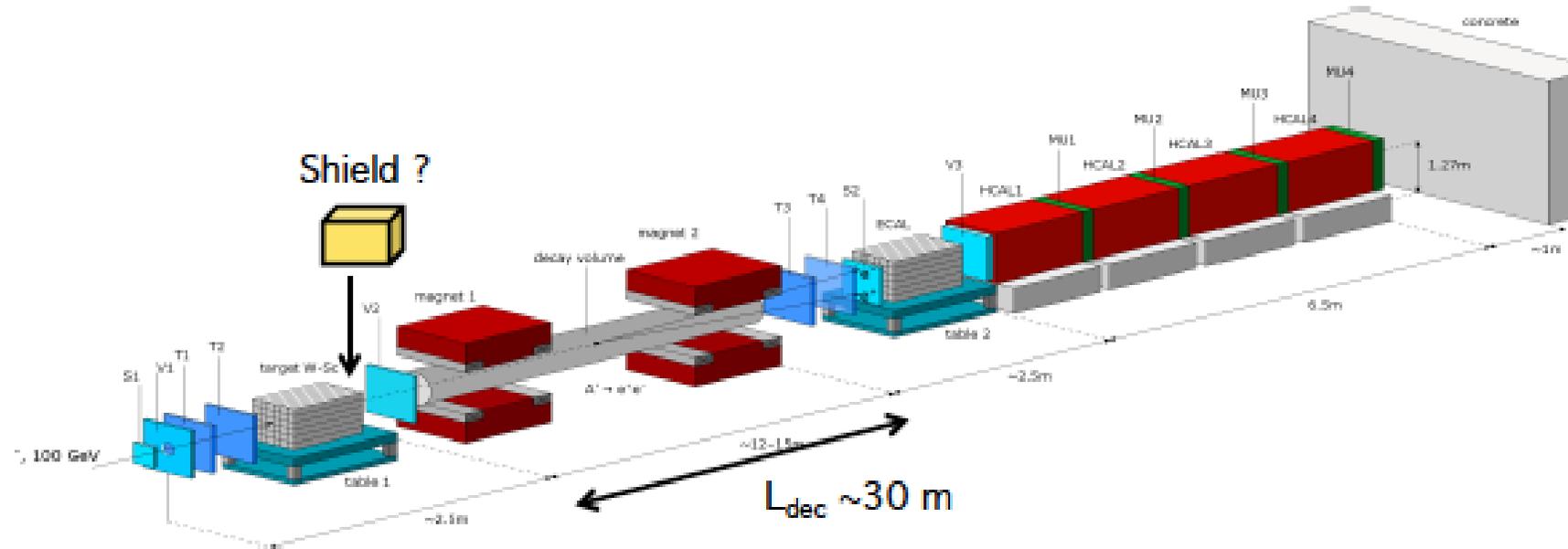
$\rightarrow$  analysis is in progress



# AWAKE for NA64 Experiment

- NA64 today:  $\sim 10^6$  electrons / 4.8 s spill
    - $N_e \sim 10^{12}$  for 3 months running
  - AWAKE:  $\sim 10^9$  electrons / 100 fs (cycle length of  $\sim 5$ s)
    - $N_e \sim 10^{15}$  for 3 months running
- ➔ Experiment with an **AWAKE-like electron beam** has an increase of intensity by a **factor of 1000** wrt NA64 experiment.
- NA64 invisible-like experiment requires tagging of single electrons
- ➔ not compatible with AWAKE time structure
- Investigate **visible mode  $A' \rightarrow e^+e^-$**
- ➔ **fixed target experiment** ➔ compatible with AWAKE time structure

# NA64 Visible Mode: $A' \rightarrow e^+e^-$



## Main components :

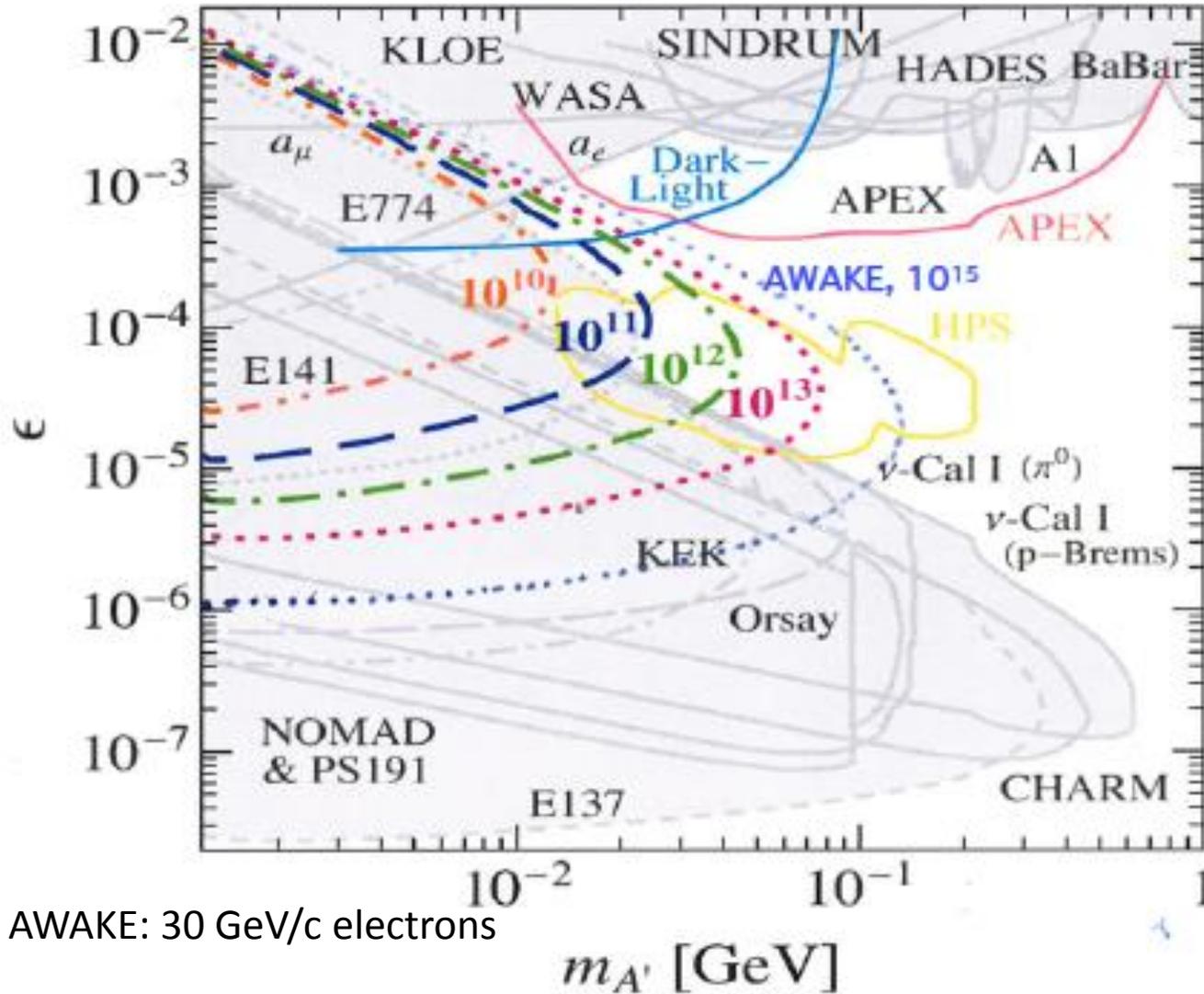
- clean, mono-energ. 100 GeV  $e^-$  beam
- passive beam-dump target
- Shield + magnet 1
- vertex recon. with  $e^+e^-$  Si tracker + magnet 2
- PS+ECAL:  $e^+e^-$  ID, HCAL:  $\mu^+\mu^-$  pair ID

## Signature:

- $e^+e^-$ ,  $\mu^+\mu^-$  pair from the vertex in vacuum
- no Veto after ECAL
- Sensitivity  $\sim \epsilon^4$

S.N. Gninenko, NA64-AWAKE meeting, CERN, June 7, 2017

# Possible AWAKE Limits for $A' \rightarrow e^+e^-$

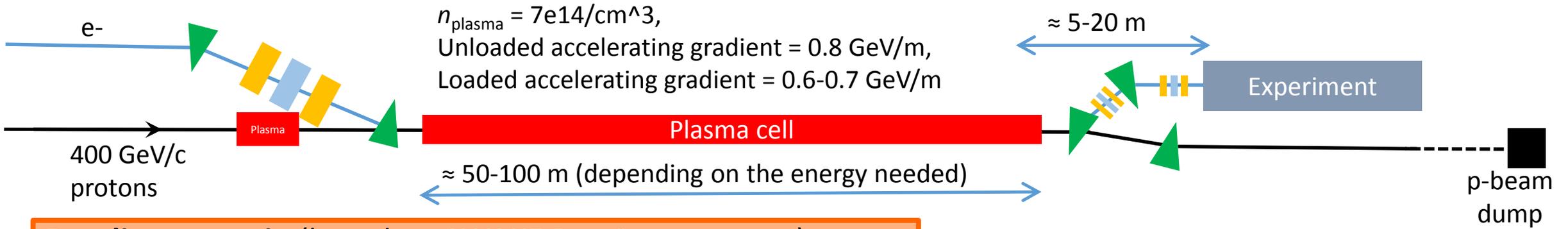


AWAKE: 30 GeV/c electrons

NA64 G4 simulation available

- $A' \rightarrow e^+e^-$
- $A' \rightarrow \mu^+\mu^-$
- Background sources e.g. from  $\mu^+\mu^-$  to be studied

# Possible Beam Scenario



## Baseline scenario (based on AWAKE Run 2 parameters)

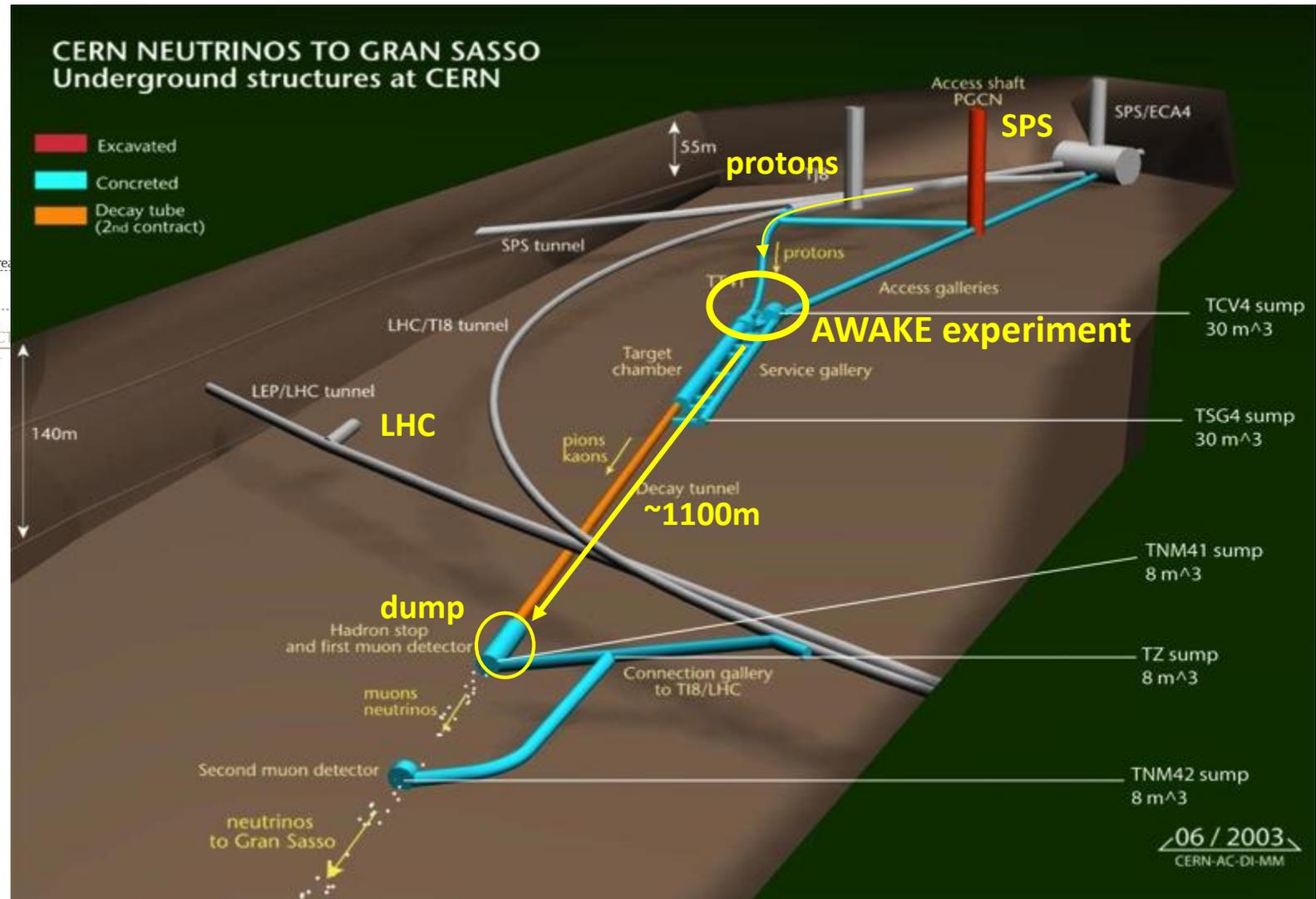
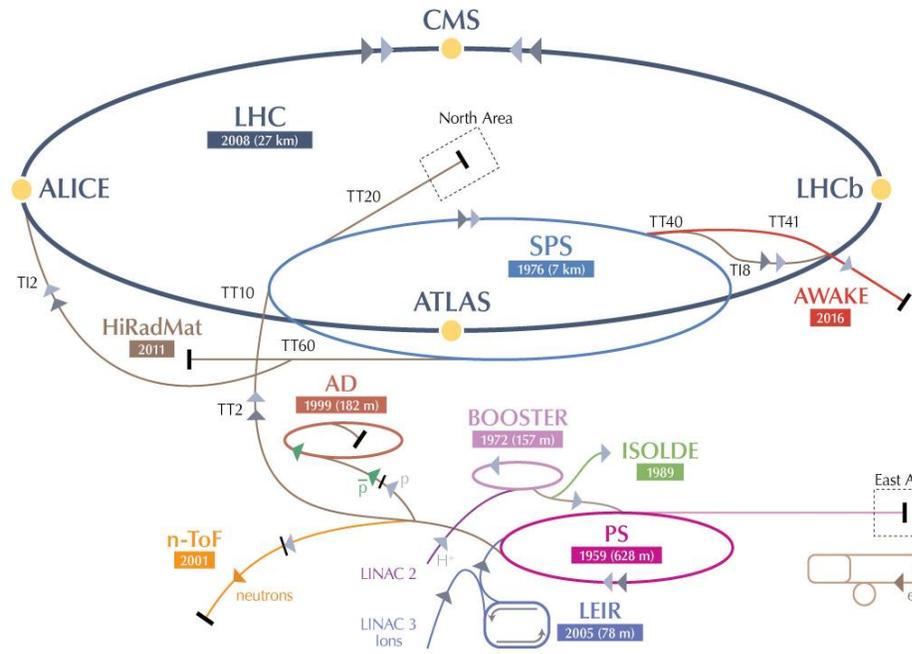
- 50 m long plasma accelerator
- 33 GeV/c electrons,  $\Delta E/E = 2\%$ ,  $\sim 100$  pC
- For 100 m accelerator: 53 GeV/c e,  $\Delta E/E=2\%$ ,  $\sim 130$  pC

## Possibilities to increase electron energy, while keeping same plasma accelerator length:

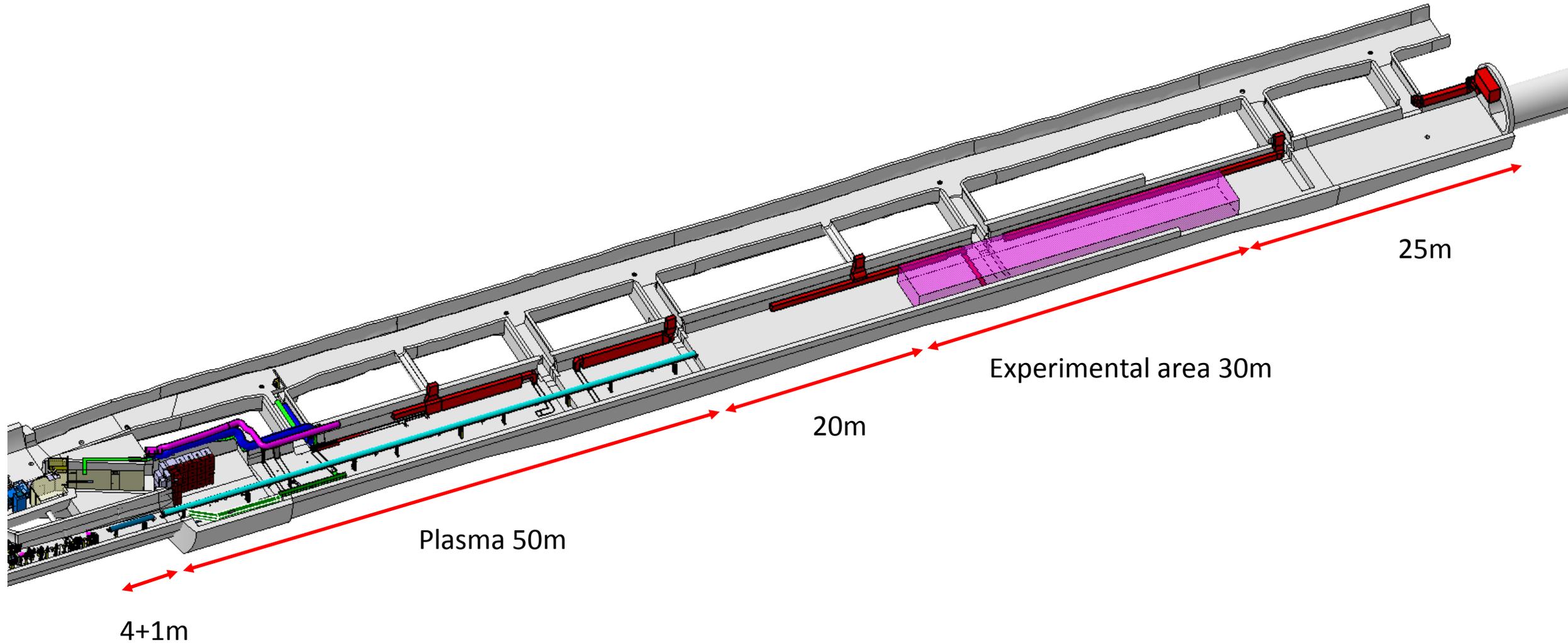
- Use higher plasma density with existing SPS proton beam
- Improve SPS beam transverse emittance: 2x lower emittance  $\rightarrow$  4x higher beam density. With 4x denser plasma  $\rightarrow$  gives 2x higher wakefield ( $\rightarrow$  after LIU upgrade).
- Use more efficient micro-bunching techniques.

**Study electron – proton separation:** proton energy  $\sim 10x$  higher  $\checkmark$ , electron final focus required?

# AWAKE at CERN



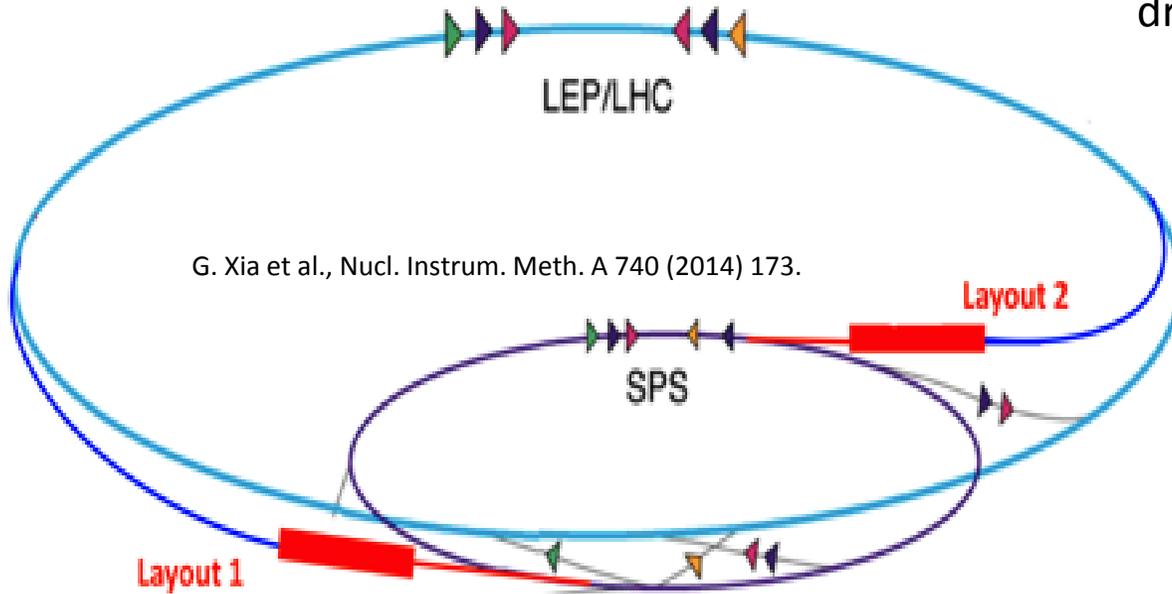
# Layout NA64@AWAKE



# Physics with an Electron-Proton or Electron-Ion Collider

## PEPIC: Plasma Electron Proton/Ion Collider:

Create  $\sim 50$  GeV electron beam within 50–100 m of plasma driven by SPS protons, But luminosity  $< 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$ .

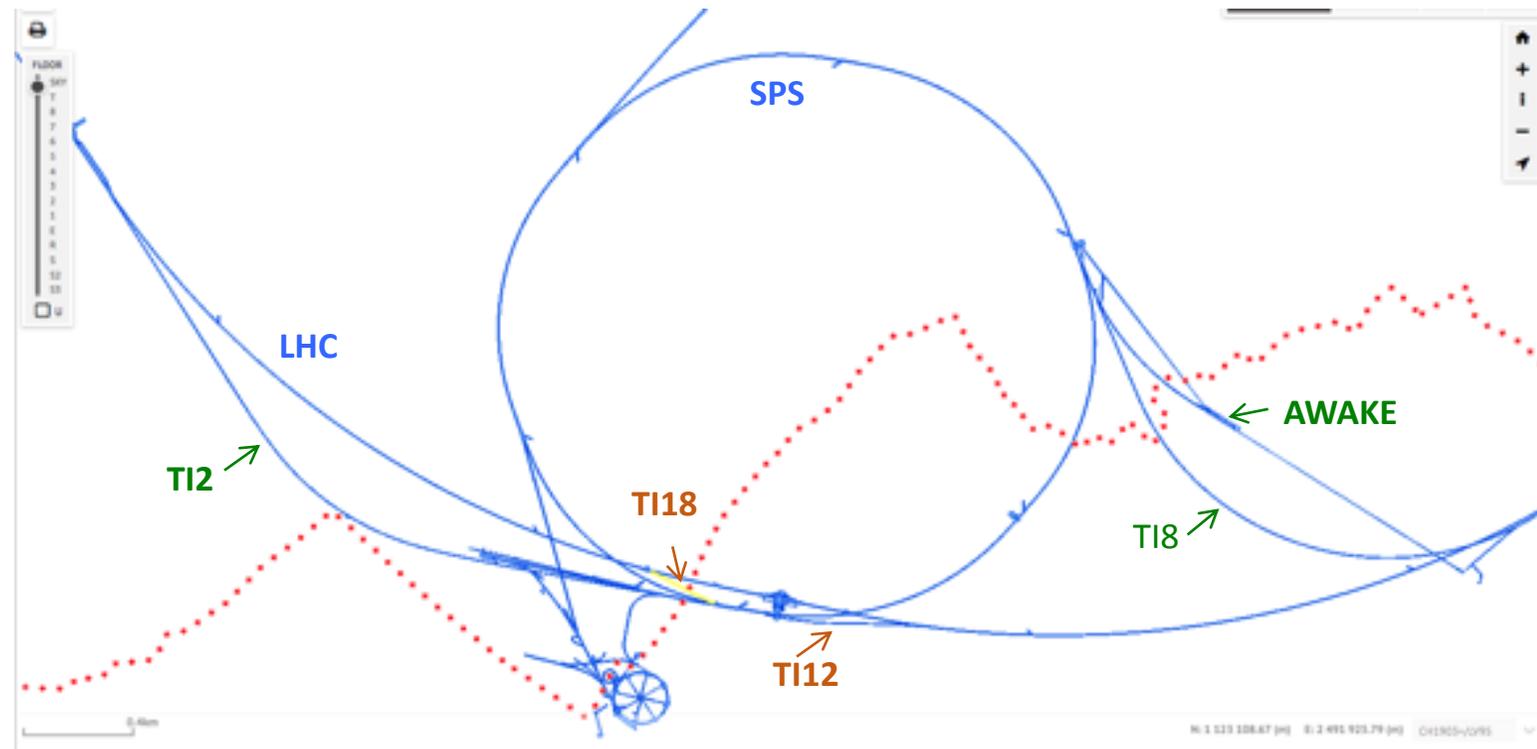


- What is the electron energy, e.g.  $E_e \sim 100\text{--}150$  GeV in 200m?
- Which luminosity can we reach?
- What is the physics programme, e.g focus on QCD and low-x physics?

- **Focus on QCD:** Large cross sections  $\rightarrow$  low luminosity enough (HERA level)
- Many open physics questions !
  - $\rightarrow$  High energy ep collider:  $E_e$  up to  $O(50 \text{ GeV})$ , colliding with LHC proton;
  - $\rightarrow$  e.g.  $E_e = 10 \text{ GeV}$ ,  $E_p = 7 \text{ TeV}$ ,  $\sqrt{s} = 530 \text{ GeV}$  already exceeds HERA cm energy.

# Possible locations for PEPIc plasma acceleration stage

- Possible locations for pe- collider experiment would be either ALICE or LHCb.
- Since p beam is produced in the SPS a natural location for the plasma cell(s) would be in one of the transfer tunnels from the SPS to the LHC:
  - TI 2 SPS -> LHC beam 1
  - TI 8 SPS -> LHC beam 2
  - TI 12 old e- TL from SPS to LEP
  - TI 18 old e+ TL from SPS to LEP
- LHC needs to stay fully operational as pp collider
- PEPIc equipment needs to share space with existing equipment in LHC/TI2/TI8



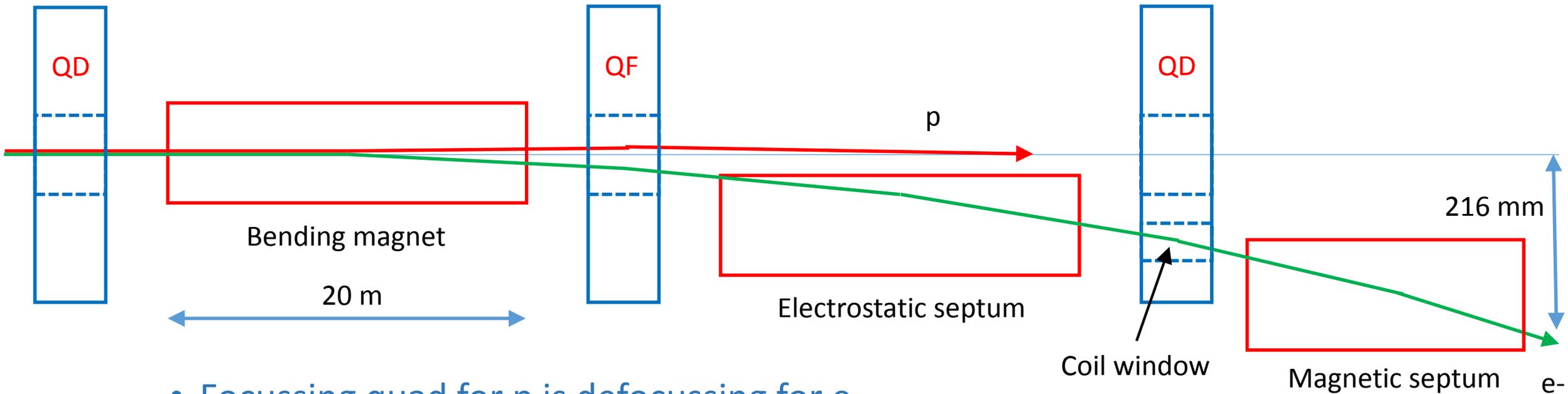
# TI 2 transfer line

- The TI 2 transfer line has a 540 m long straight section, close to its end.
- This sections contains only quadrupoles, correctors and beam instrumentation elements in a regular FODO lattice with 30 m half cell length.



# TI 2 transfer line

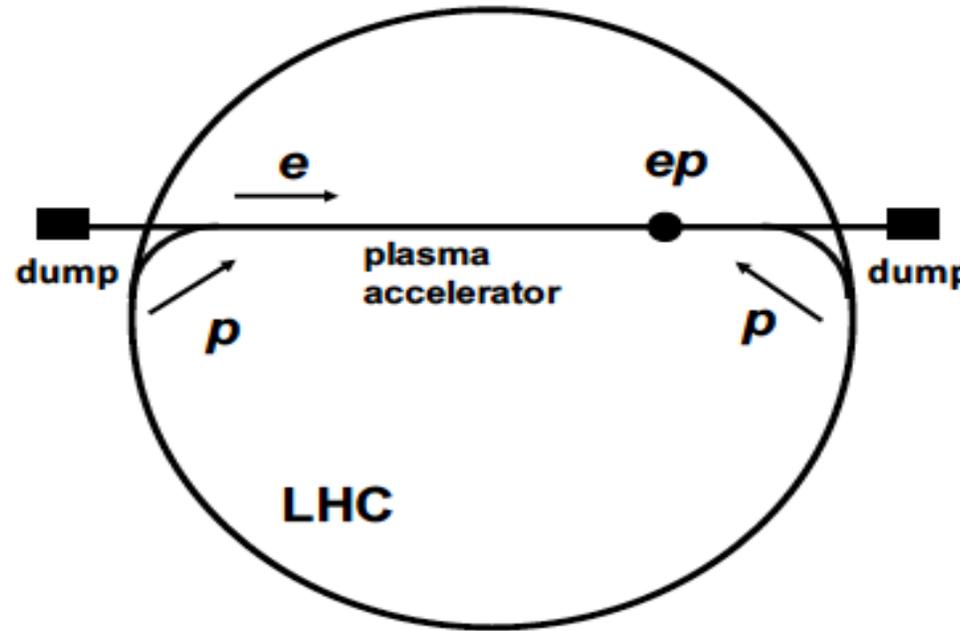
- Separation scheme over multiple half cells:



- Focussing quad for p is defocussing for e-
- Reduced energy loss for e- beam and reduced synchrotron radiation power.
- Reduced deflection of p beam. It might be able to transport p beam to TED.
- To be studied more in detail

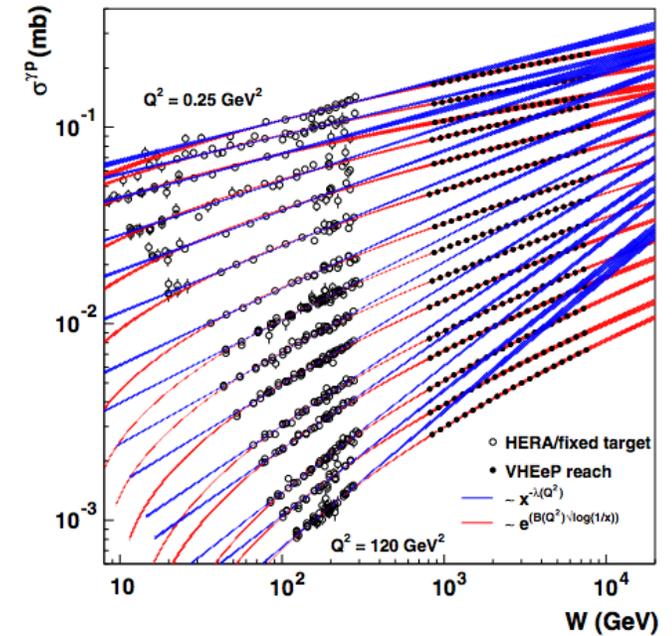
# Physics with an Electron-Proton or Electron-Ion Collider

VHEeP:



VHEeP: A. Caldwell and M. Wing, Eur. Phys. J. C 76 (2016) 463

Eur. Phys. J. C (2016) 76:463



**Fig. 8** Measurements (*open points*) of  $\sigma^{\gamma P}$  versus  $W$  for  $0.25 < Q^2 < 120 \text{ GeV}^2$  from HERA and fixed-target experiments. The *blue lines* show fits to the data, performed separately for each  $Q^2$  value, of the form given in Eq. 8. The *red lines* show fits of the form given in Eq. 9. The reach of VHEeP is shown as projected data points (*closed points*). The points are placed on the *red curve*. The uncertainties are assumed to be of order 1 %, given the increased cross section expected and similar systematics to those at HERA and are not visible as *error bars* on this plot

- Choose  $E_e = 3 \text{ TeV}$  as a baseline and **with**  $E_p = 7 \text{ TeV}$  yields  $\sqrt{s} = 9 \text{ TeV}$ . Can vary.
- Centre-of-mass energy  $\sim 30$  higher than HERA.
- Reach in (high)  $Q^2$  and (low) Bjorken  $x$  extended by  $\sim 1000$  compared to HERA.
- Opens new physics perspectives
- Luminosity  $\sim 10^{28} - 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$  gives  $\sim 1 \text{ pb}^{-1}$  per year.

# Summary

- Studies for application of AWAKE-like electron beam done within the PBC (Physics Beyond Collider) Working Group.
- Identified a physics case for a fixed target experiment with AWAKE-like electron beam.
  - NA64 visible mode:  $A' \rightarrow e^+e^-$  : extend into regions not covered by current limits.
- First studies on the plasma wakefield accelerated electron beam for this experimental configuration.
  - Baseline scenario: 50 m plasma accelerator  $\rightarrow$  33 GeV/c electrons,  $\Delta E/E=2\%$ .
- First studies on integration of an NA64-like experiment in the AWAKE facility.
  - Clean out the CNGS target area to make space for the experiment.
- Identified study program for PEPIC (Plasma Electron Proton/Ion Collider).