# NA64 and beam-dump experiments

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# Outline

**Presentation outline:**

- Accessing the parameter space with a beam-dump experiment
- Recent results
- Prospects for the near future
- Conclusions

# Framework

**Dark photon but also ALPs (or dark scalars, HNLs) as a possible NP extension:**

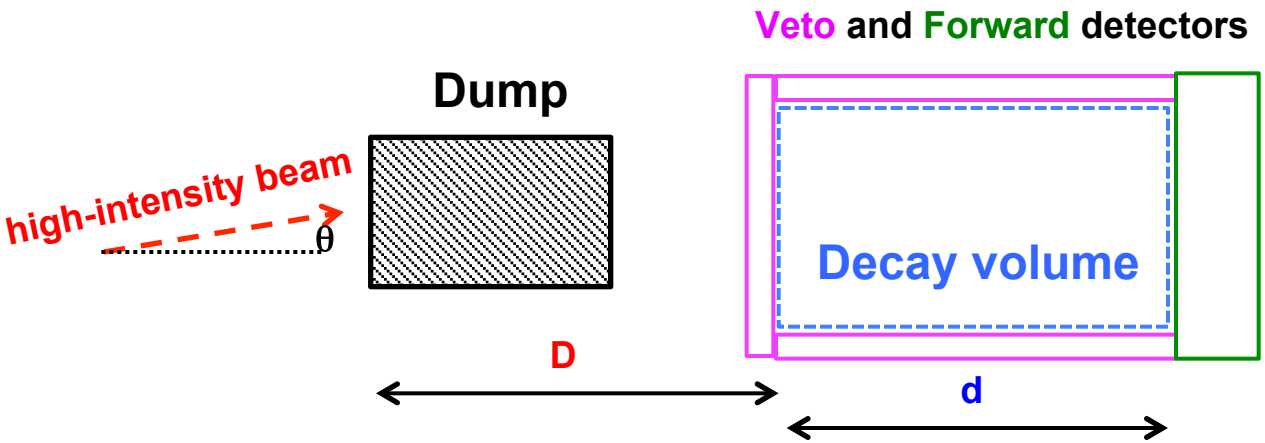
- **More (or less) theoretically justified**
- **If O(10 GeV) mediators produced, decay lengths 10's m – 10's km**

**Many possible models, common treats of the phenomenology:**

- **(At least) mass and coupling to SM fields are free parameters**
- **If O(10 GeV) mediators produced, decay lengths 10's m – 10's km**
- **Different production mechanisms: strahlung and/or meson decays**

**Beam dump setup: pros (high flux, low background), cons (low acceptance for high couplings, uncertainties in the background estimate)**

# Typical features of a beam dump setup




Yield proportional to $e^{-D/\lambda}$ $(1 - e^{-d/\lambda})$, where $1/\lambda \sim M/p\tau$ and $1/\tau \sim \varepsilon^2$

- High coupling $\varepsilon$ region: need large boost / decay volume close to the dump
- Low coupling $\varepsilon$ region: need long decay volume, far from the dump

Beam angle $\theta$ relevant for physics-case optimization:

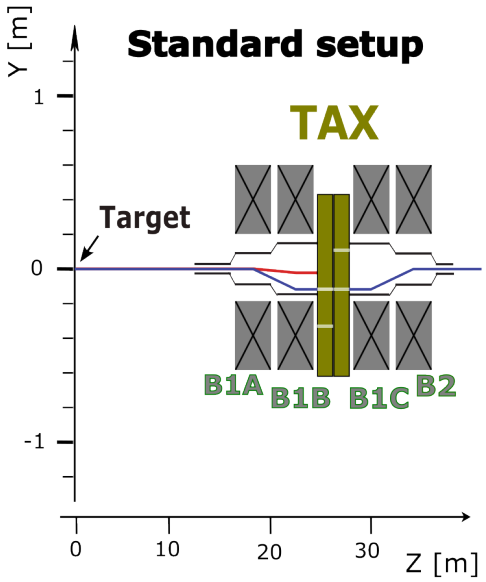
- Low $\theta$ setup: good for dark photon / ALP from light mesons / brems
- High $\theta$ setup: good for HNL / fermion-coupled ALPs from B meson decays

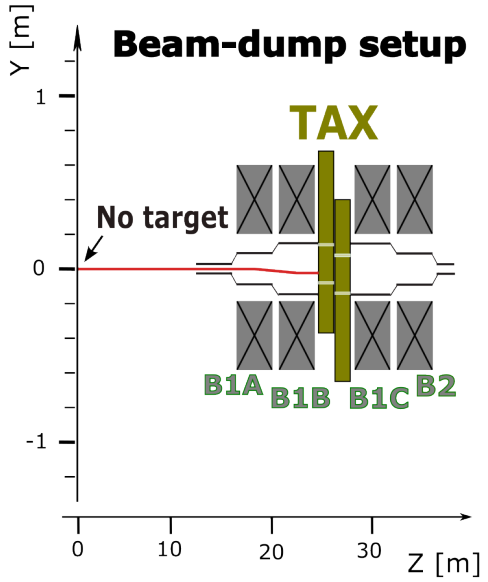
# An example I know well, A’ in NA62-dump

- A' produced by proton interactions in the TAX, 2 mechanisms:

1. Bremsstrahlung: p N → p N A’
[WW approx., JHEP 1602 (2016) 018]

2. Meson decays: p N → M X,
M → A’ $\gamma$ ($\pi^0$), M = $\pi^0$, $\eta$, $\omega$, …
production probability evaluated with PYTHIA 8.2, validation against data [JHEP 05, 213 (2019), JHEP 10, 046 (2020)]

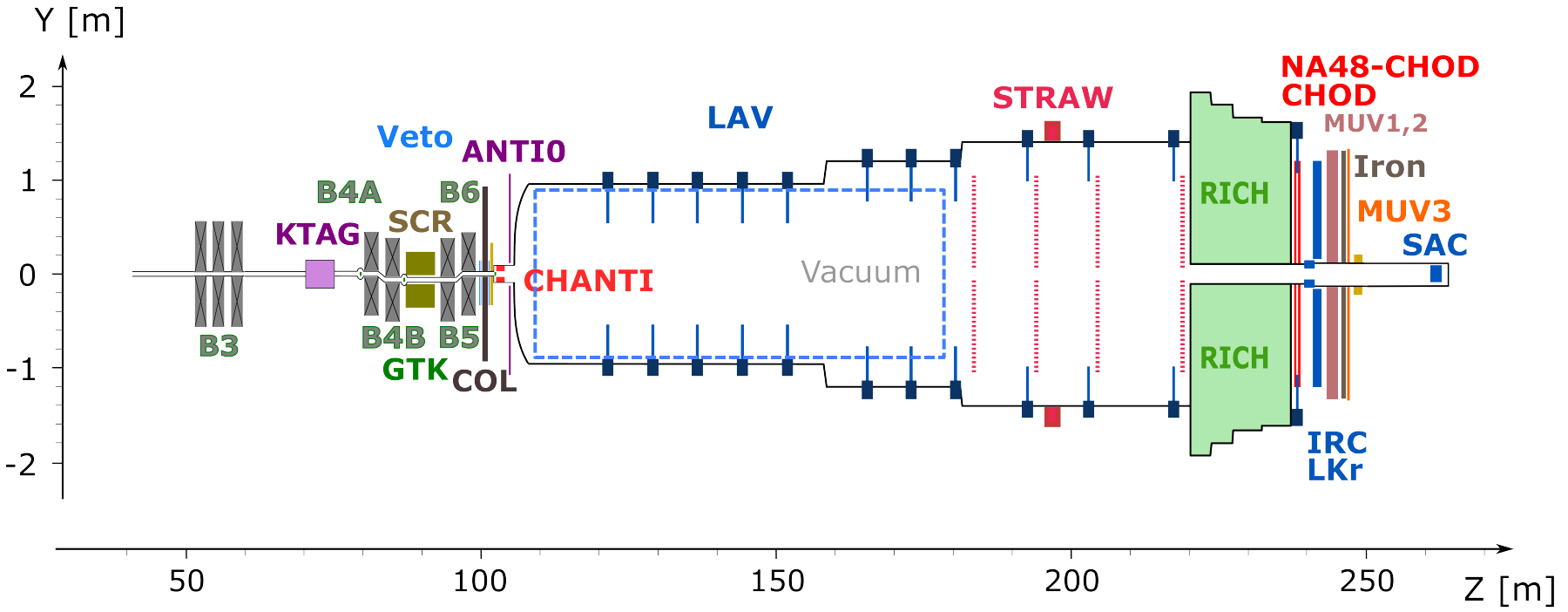



- Decays to lepton pairs dominate up to ~600 MeV

- Data for 1.5 ×$10^{17}$ protons on tax (POT) already acquired, $10^{18}$ planned

# An example I know well, NA62-dump

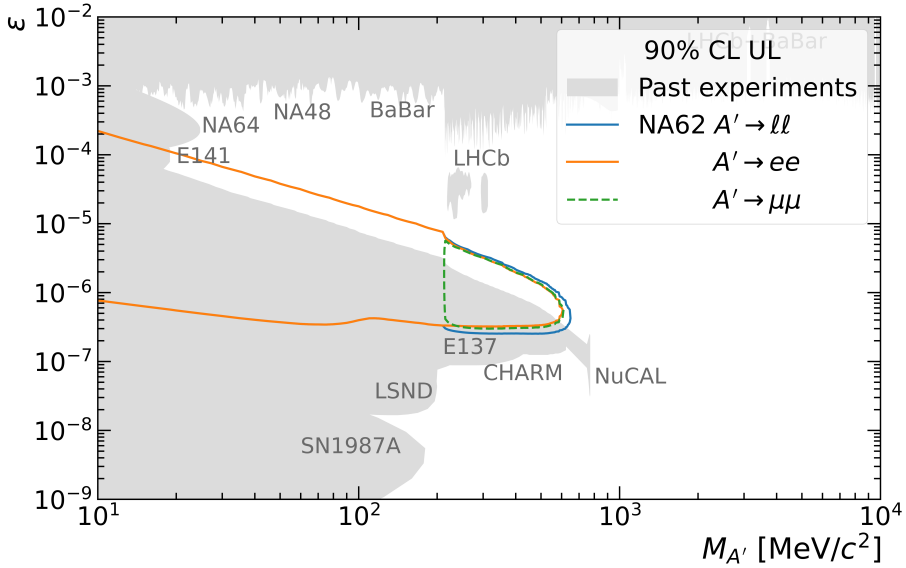


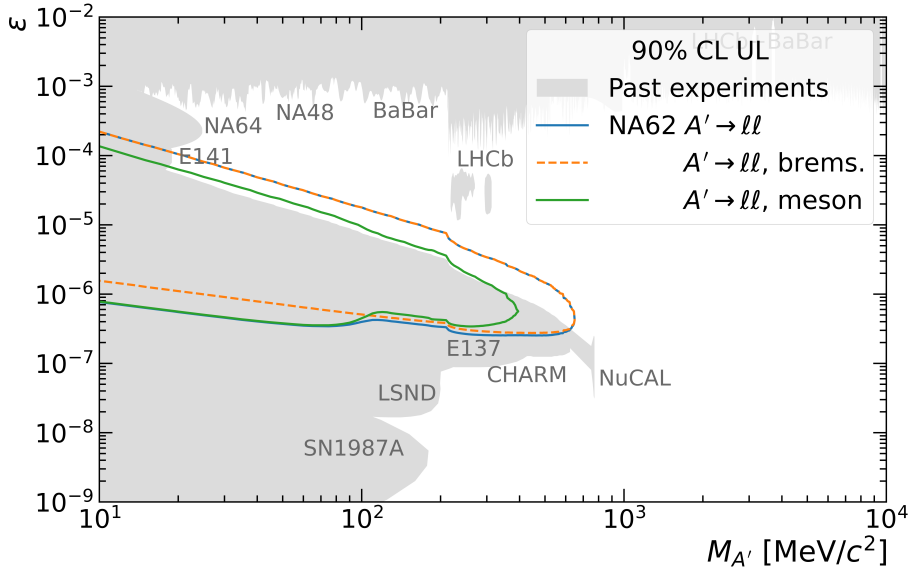

- Distance dump to decay volume D = 82 m, decay volume length d = 75 m

# NA62 expected sensitivity, kinetic-mixing A'

**Expected bkg < 0.05 events either in $\mu^+\mu^-$ (arXiv:2303.08666) or $e^+e^-$ (Moriond 2023 QCD) final states: if no signal, 0 events expected at 90% CL**

**Sensitivities as regions excluded @ 90%CL (here, geom. acceptance only)**

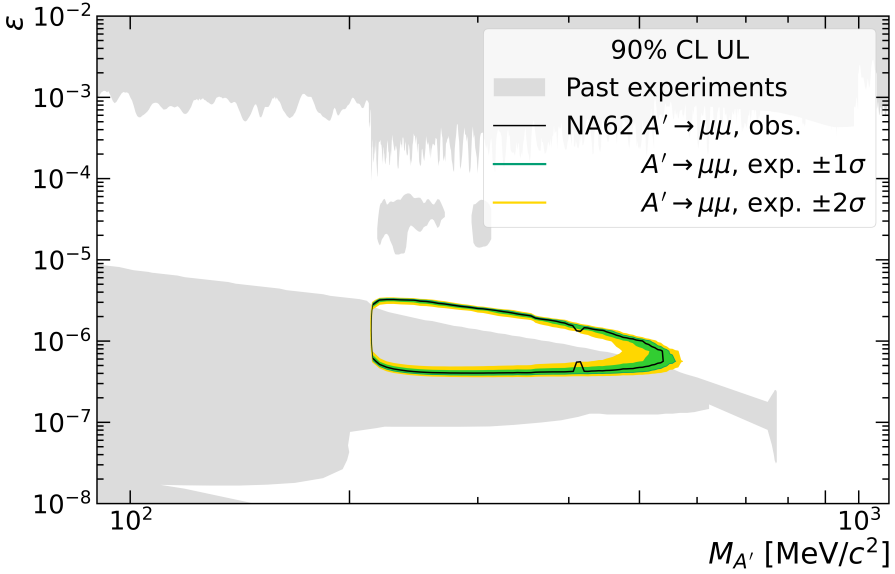


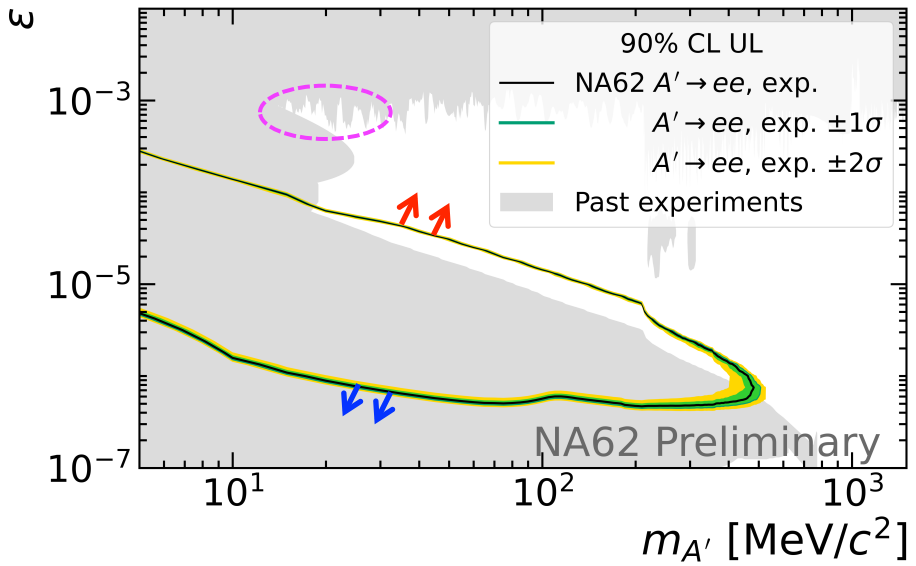



# NA62 excluded regions, kinetic-mixing A’

**No evidence of a new-physics signal**

**Nominal 20% POT uncertainty affects more high masses / low couplings**



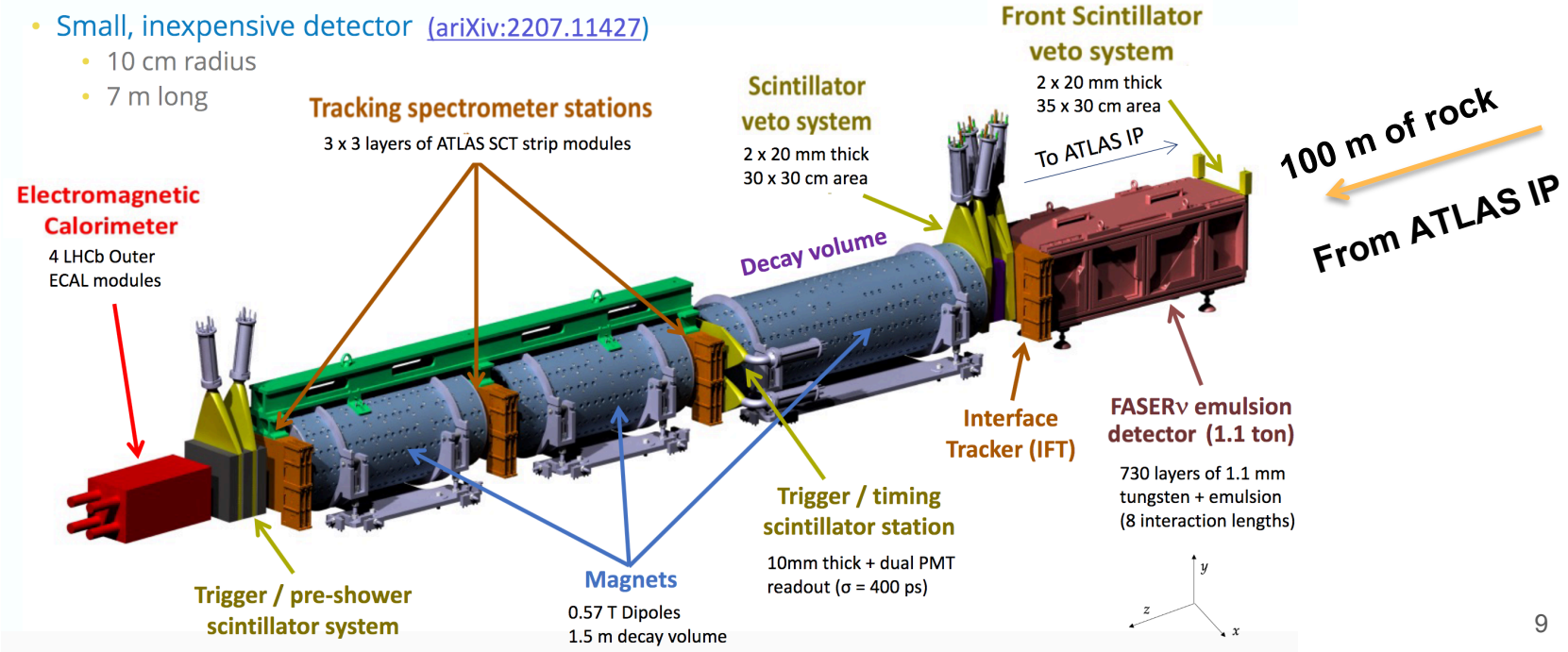

**In the upper boundary signal yield scales as exp(-ε²) (in lower b., *A – B* ε²)**

**Cannot be sensitive to the interesting region for X(17)**

# The other players in the present and near future

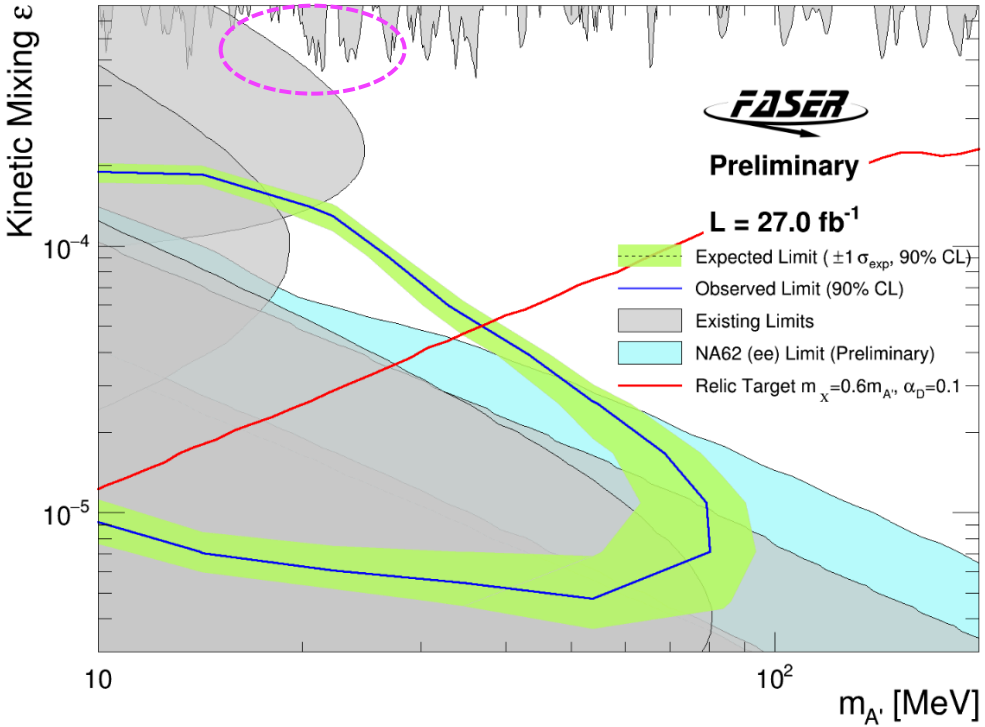
**Other proton dumps (SeaQuest/DarkQuest at BNL, a number of long baseline neutrino experiments, LDMX proposed experiment)**

**FASER, on axis ($\eta$ > 9) and 480 m downstream from the ATLAS IP**



# FASER first dark-sector physics results

**FASER first physics results using ~ 30 $fb^{-1}$ @ Moriond 2023 search not background limited ($\pi^0 \rightarrow A' \gamma$, $A' \rightarrow e^+e^-$, well below 0.01 events expected)**



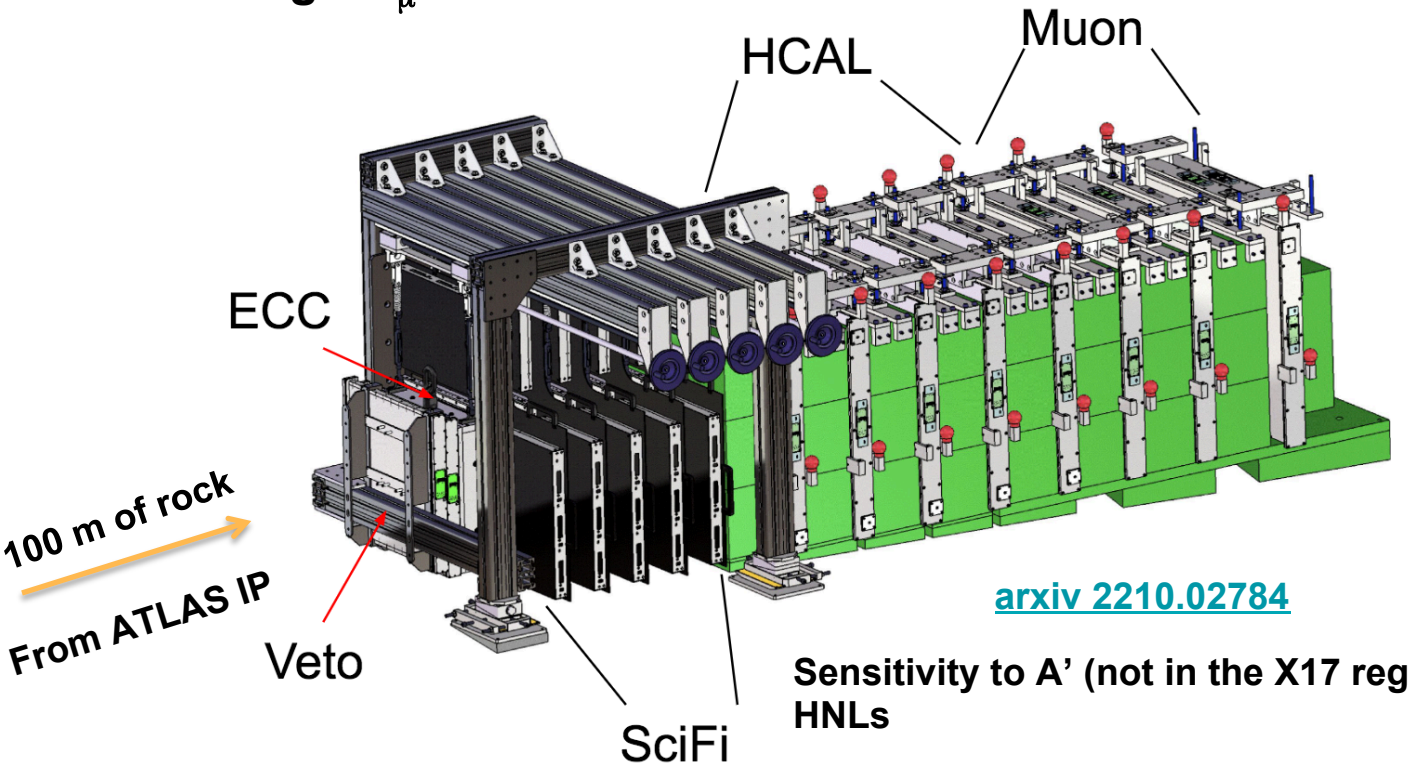

CERN-FASER-CONF-2023-001

**Not sensitive to the interesting region for X(17), moreover not sensitive to proto-phobic dark-photon scenarios**

# The SND experiment

**SND: off axis ($7.2 < \eta < 8.4$) and 480 m from the ATLAS IP, ~ 40 $fb^{-1}$ recorded**

**Started observing 8 $\nu_\mu$ CC candidates**




arxiv 2210.02784

**Sensitivity to A' (not in the X17 region) dark scalars, HNLs**

# The NA64 experiment – A' visible setup (2017 run)

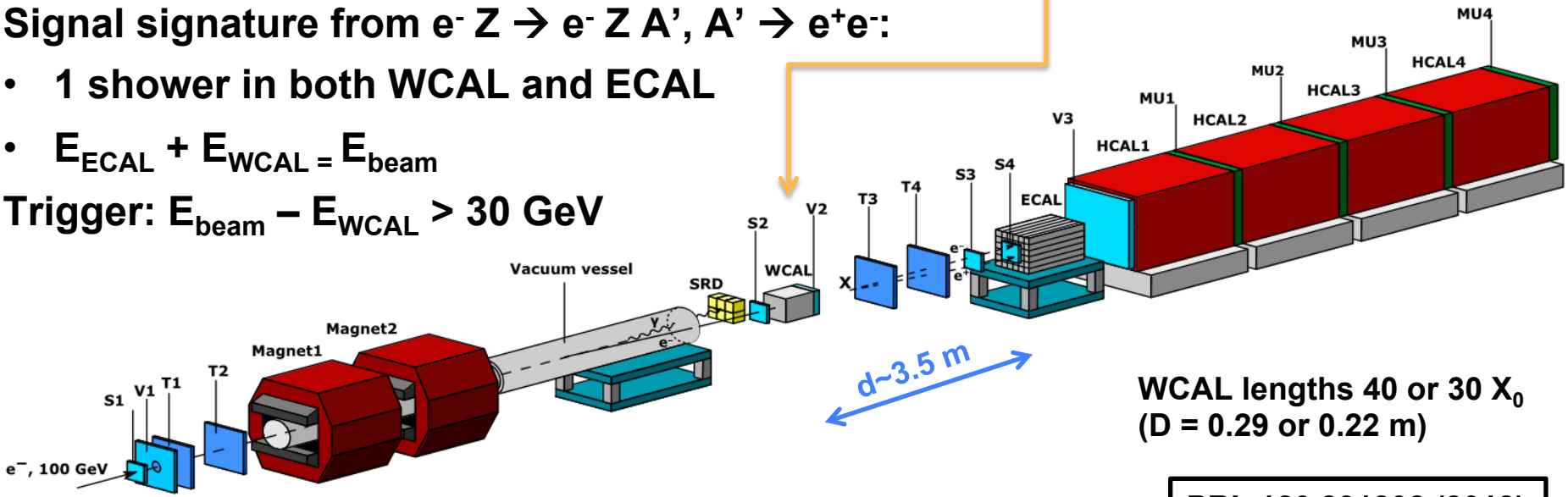
**Dump $5.4\times10^{10}$ $e^-$ from the 100 GeV H4 beam into an active dump (WCAL)**

**$e^-$ PID: track $e^-$ (MMs $T_{1,4}$ ), detect synchrotron rad. to reduce $e/\pi \sim 10^{-6}$**

**Signal signature from $e^- Z \rightarrow e^- Z A'$, $A' \rightarrow e^+e^-$:**

- **1 shower in both WCAL and ECAL**
- **$E_{ECAL} + E_{WCAL} = E_{beam}$**

**Trigger: $E_{beam} - E_{WCAL} > 30$ GeV**




**WCAL lengths 40 or 30 $X_0$ (D = 0.29 or 0.22 m)**

**PRL 120 231802 (2018)**

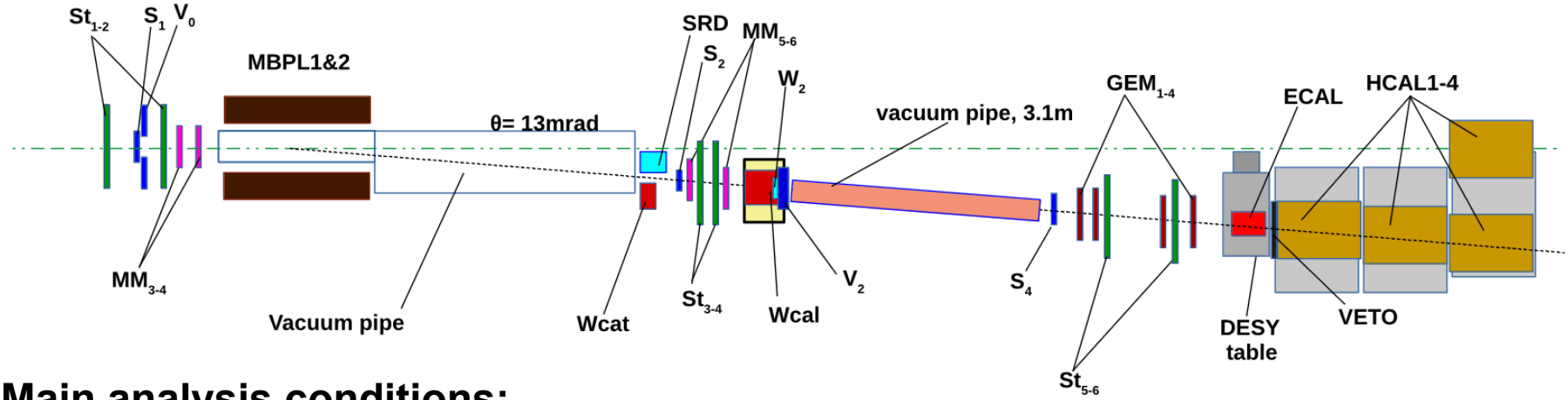
**Expected bkg: 0.07 ± 0.03, systematic uncertainty on $N_{A'}$ ~ 25%, no error from EOT**

# The NA64 experiment – A' visible setup (2018 run)

**150 GeV $e^-$ beam at CERN H4 (2018 run, $3x10^{10}$ EOT)**

**Thinner veto W2, additional tracking between WCAL and ECAL**

**Use a decay volume in vacuum, increase distance between WCAL and ECAL**




## Main analysis conditions:

- E(W2) < 0.7 MIP
- E(S4) > 1.5 MIP (invert with < 0.5 MIP for "neutral" events, e.g. $K_S$)
- E(ECAL) + E(WCAL) ~ Ebeam
- E(ECAL) > 25 GeV, cluster shape condition in ECAL

**PRD 101 071101( R ) 2020**

# The NA64 experiment – A' visible setup

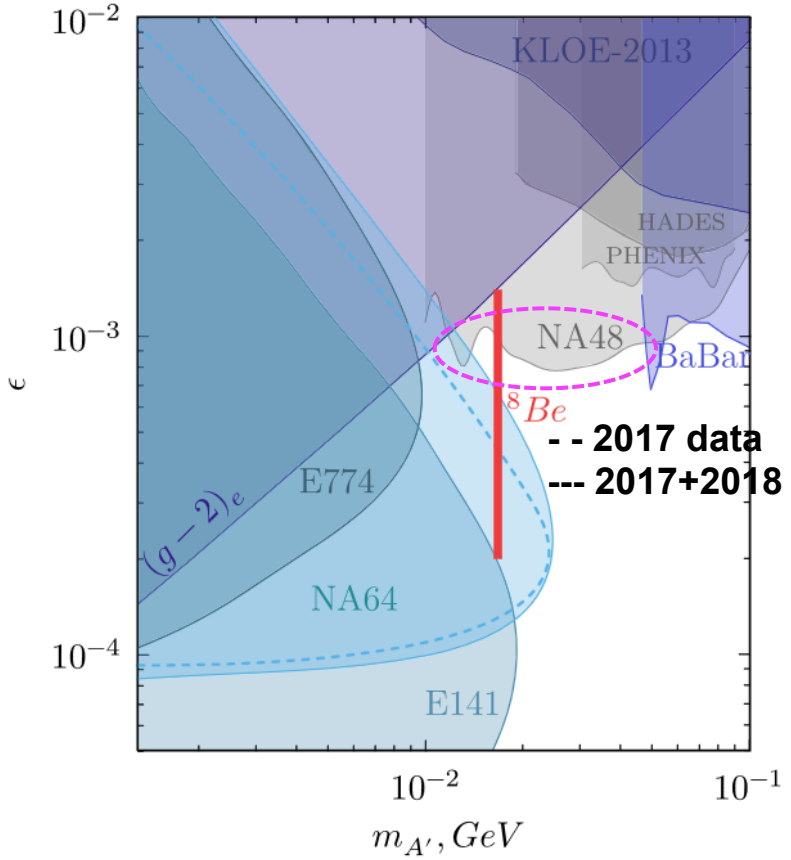
**Total error on the yield at 25%, will affect mostly "the nose"**

**Uncertainties in NA48 will affect the lower boundary ($\pi^0$ -> $\gamma$A', A' →$e^+e^-$ suppressed in proto-phobic scenarios)**

**About the $(g\text{-}2)_e$ bound: see Raggi's talk**

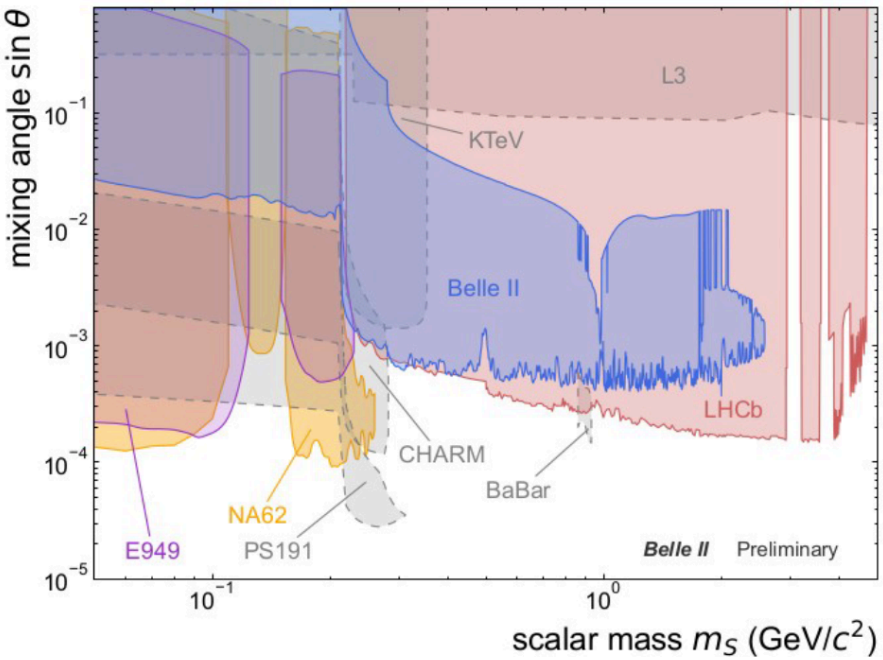
**To further probe the X(17) region significant detector upgrades needed (see L. Marsicano, ICHEP 2022 PoS):**

- **Thinner active dump**
- **Magnetic spectrometer for $e^+/e^-$ tracking and separation**
- **Statistics of $7\times10^{11}$ EOT needed**



# The other players in the present and near future

**BELLE-II latest physics results using ~ 190 $fb^{-1}$ @ Moriond 2023 search for LLP (dark scalars), B→KS, S→$x^+x^-$**




**They might obtain results for dark photons (prompt or displaced) using 430 $fb^{-1}$ already collected data**

**Difficult to probe the X17 region, need to distinguish e+/e- tracks which tend to be at low opening angle**

**Many other players "from above" (high-intensity exps (LHCb, NA62), exp at colliders such as BES-III), etc.**

# Conclusions

**Search for X(17) timely and relevant**

**Beam-dump experiments limited “from above” by geometrical acceptance**

**In the active dump approach from the NA64 collaboration, only part of the parameter space has been accessed (marginally for the ALP case, see M. Raggi’s talk)**

**Other approaches at colliders involving displaced vertices might be competitive**