Proposal to use NA62 in beam-dump mode to search for hidden particles

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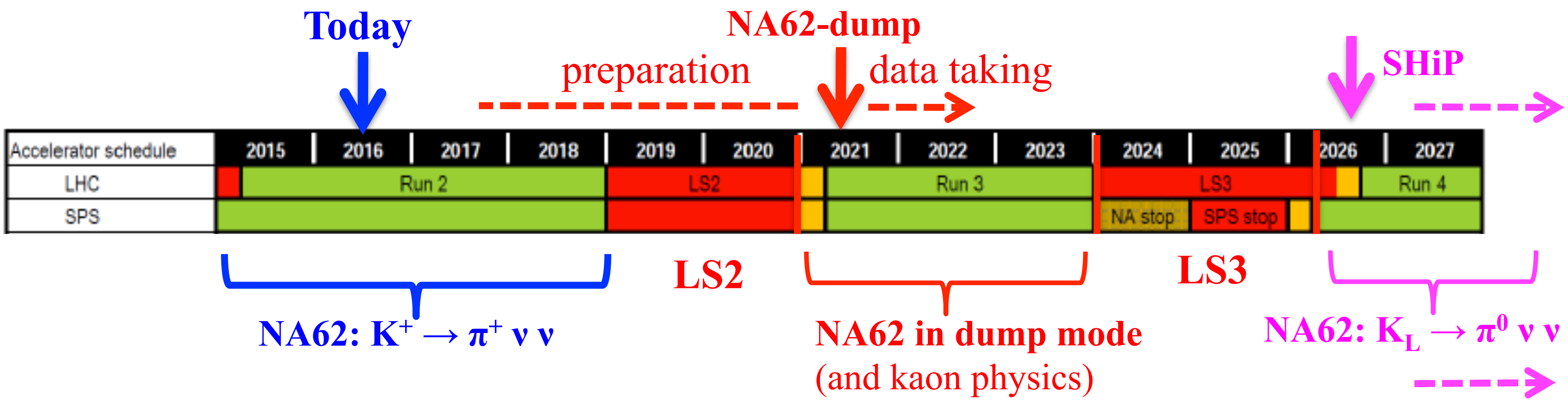
Consiglio dei Laboratori Aperto, June 2016

Preamble – 1/2

- NA62 is officially approved to run until LS2 with the main goal of measuring the BR($K^+ \rightarrow \pi^+ \nu$ anti-ν) with 10% accuracy;

- While the long-term upgrade of the experiment ($K_L \rightarrow \pi^0 \nu$ anti-ν) is currently being discussed within the Collaboration **there is a window of opportunity of using the first year after LS2 (2021) to run NA62 in beam-dump mode to search for hidden particles five years before SHiP.**



Preamble – 2/2

1) NA62 has 2% of the expected SHiP beam intensity and <10% of the SHiP acceptance, hence an overall yield for hidden sector particles which is (at most) 2 per mille of the SHiP one (**no competition**, **SHiP = 500 x NA62**).

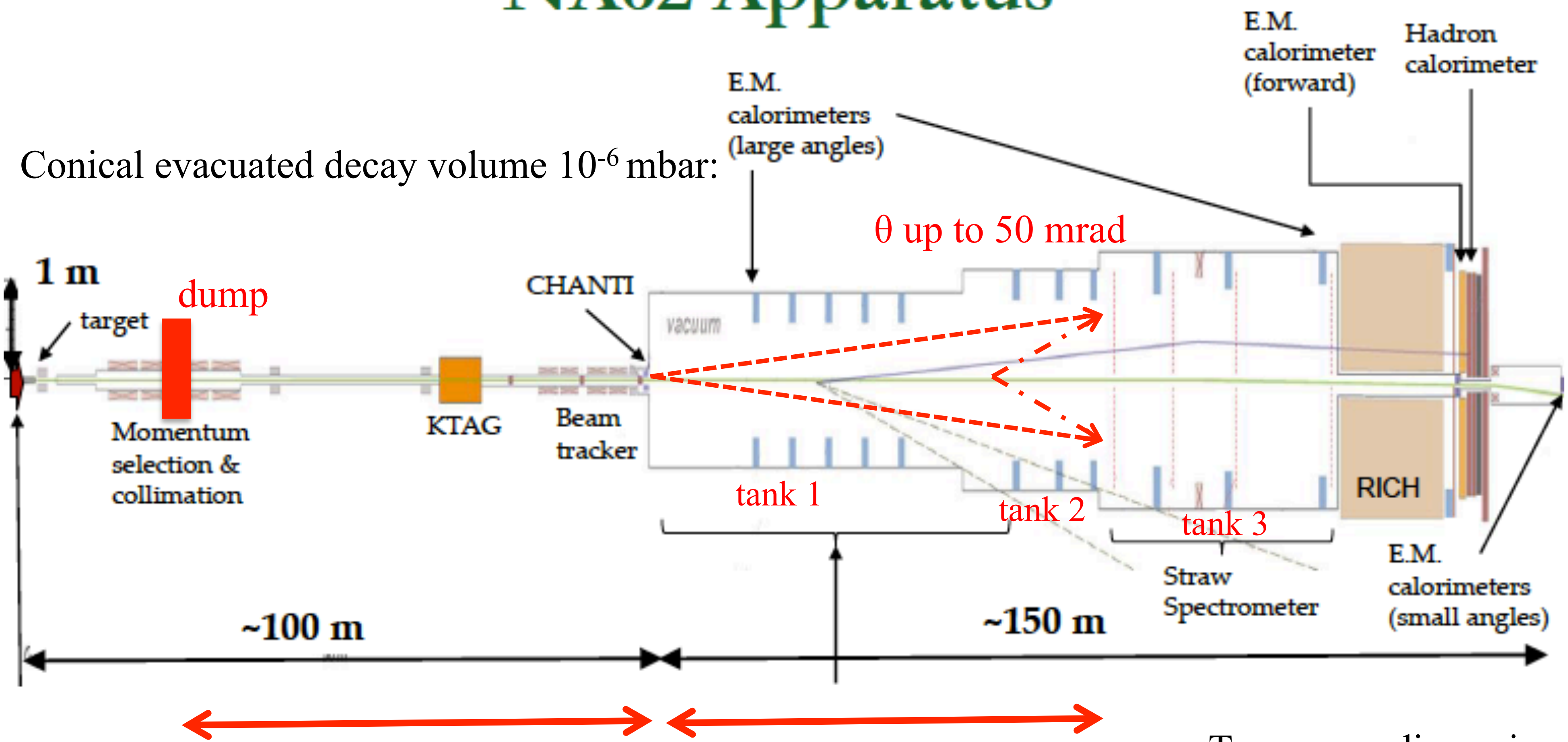
2) However NA62 has the potential to have a better sensitivity of past beam-dump experiments for some of the hidden sector models (see later).

3) This run could also be very useful for SHiP to:
   - study the backgrounds;
   - (further) optimize the detector design;
   - do the R&D for some detectors;
   - exercise the analysis procedures;
   - strengthen the collaboration by having as intermediate goal to produce preliminary (but already competitive) physics results by 2021-2022;

The NA62 experiment in ECN3

NA62 Apparatus

Conical evacuated decay volume 10^{-6} mbar:

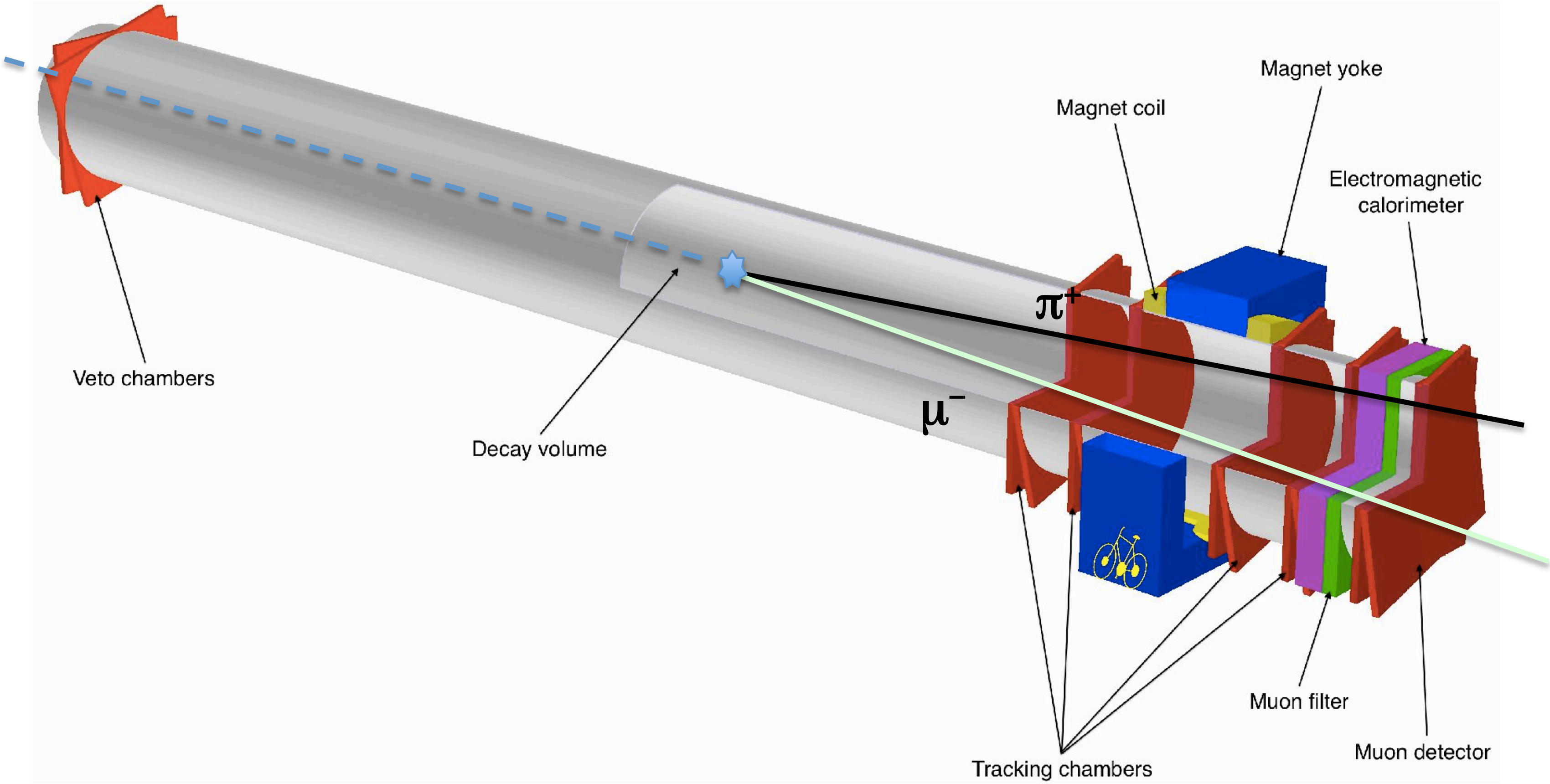


Distance dump-decay volume: **~80 m**
(SHiP TP: **64 m**)

Decay volume: **~65 m**
(SHiP TP: **50 m**)

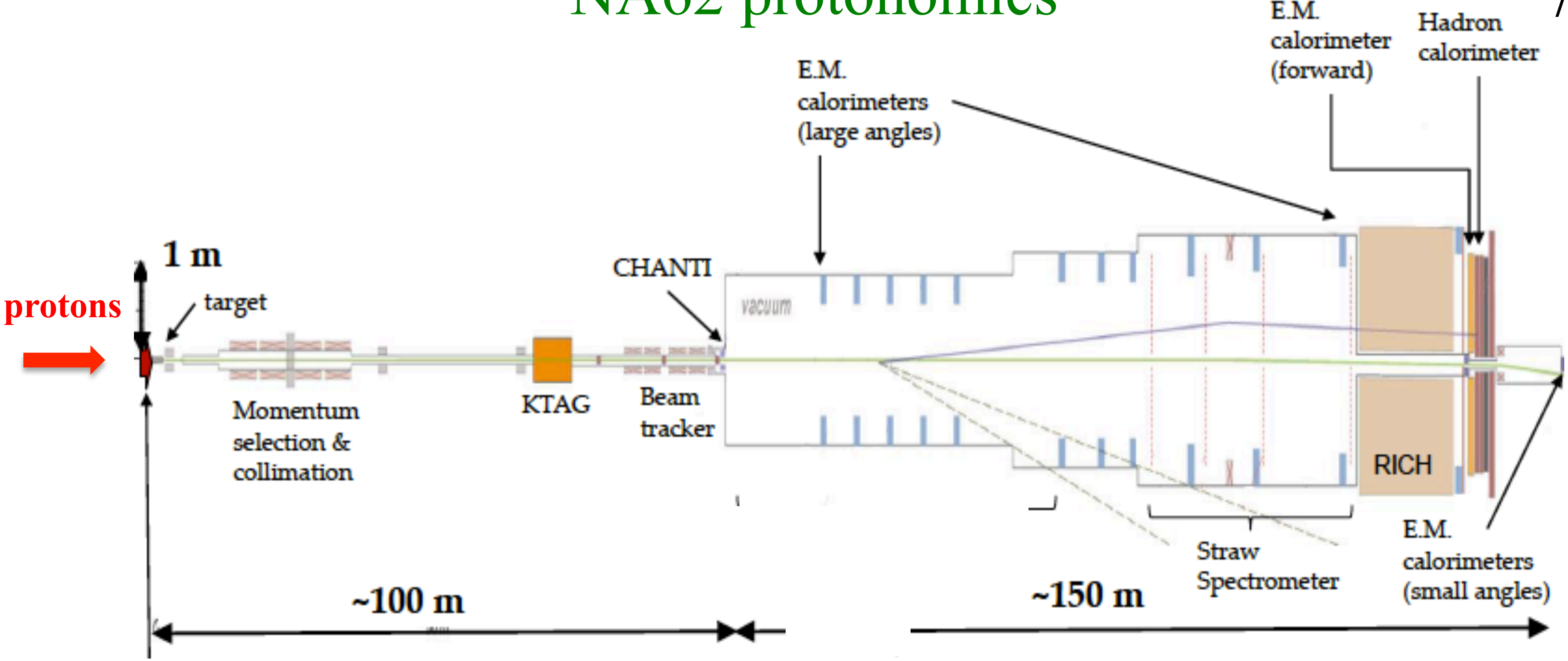
Transverse dimensions of the spectrometer:
~ 3-m diameter
(10% of the SHiP area)

The SHiP Experiment



NA62 is a small SHiP detector on a similar (but less intense) beam line.

NA62 protonomics

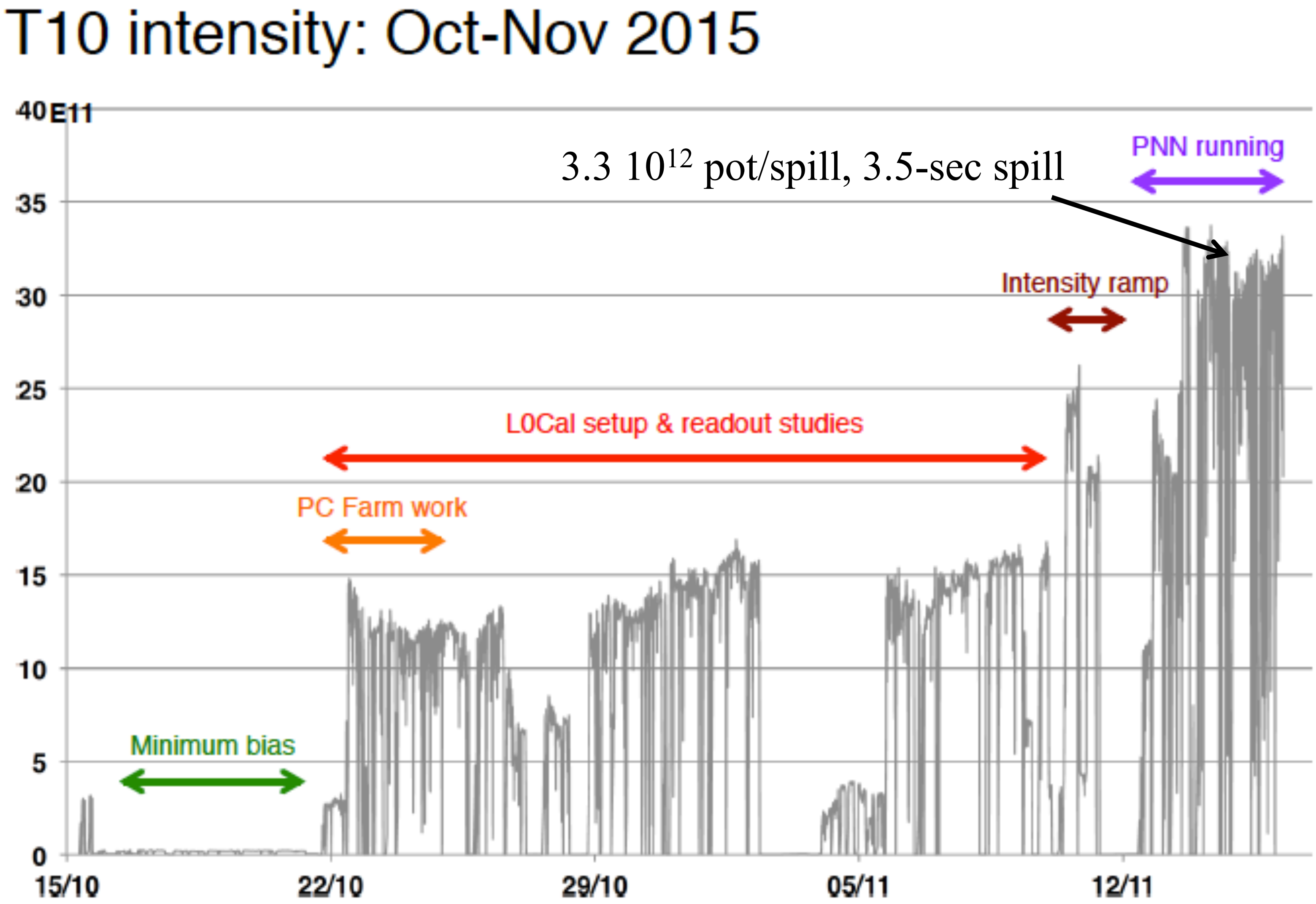


SPS proton
400 GeV
10^{12} p/s
3.5 s spill

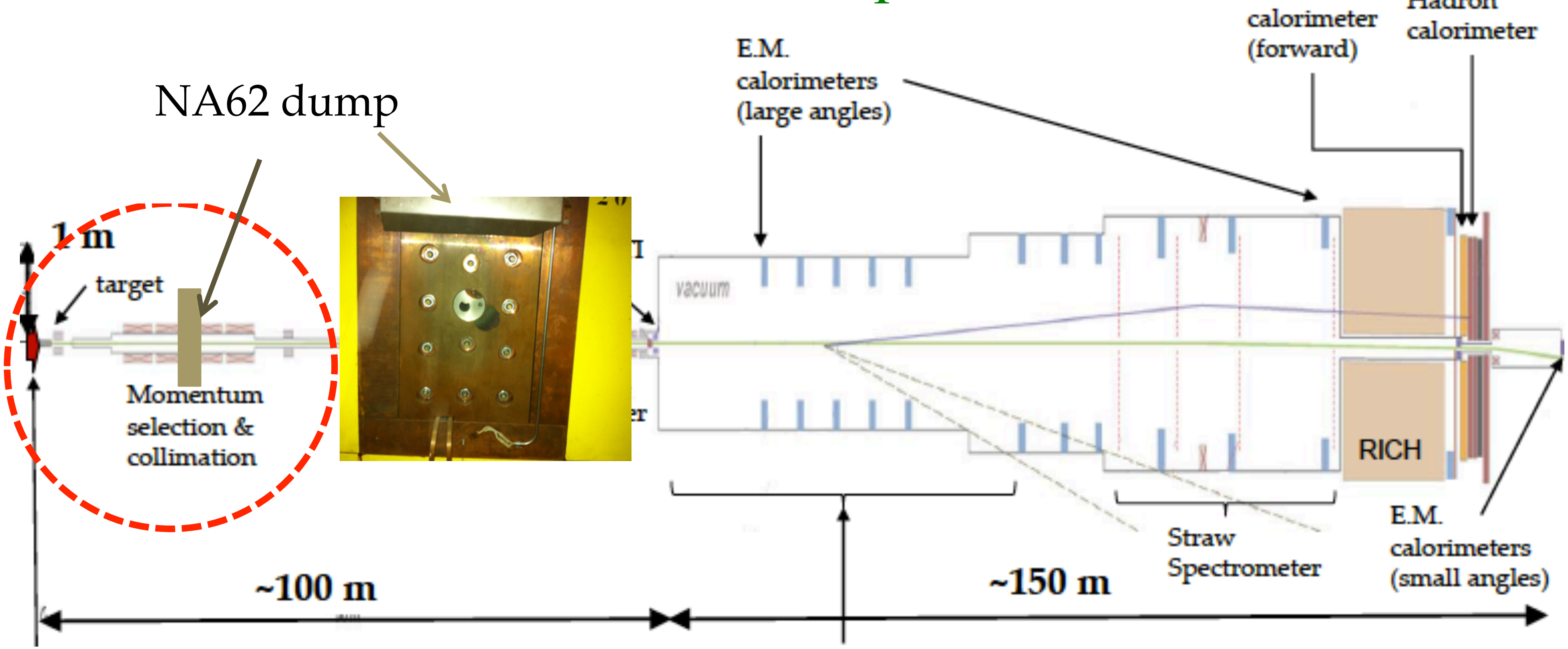
The primary protons, transported via the P42 beam line, are focused and directed at zero angle onto a 400-mm long, 2-mm diameter, beryllium target. This is suspended between thin aluminium foils and is cooled by forced convection of air in the T10 target station.

Npot/year = 10^{12} p/s x 10^{7} sec (~100 days) x 20% duty cycle x 60% SPS efficiency =
= 1.2 x10^{18} pot/year (SHiP: 4 10^{19} pot/year)

NA62 reached the nominal beam intensity in November 2015:



NA62 in dump mode



The target is followed 25-m downstream by a 1.6-m long, water-cooled, copper collimators, `Target Attenuator eXperimental areas' (TAXes) offering a choice of bores of different apertures. **The TAXes can act as a dump (10.7 λ_I) :**

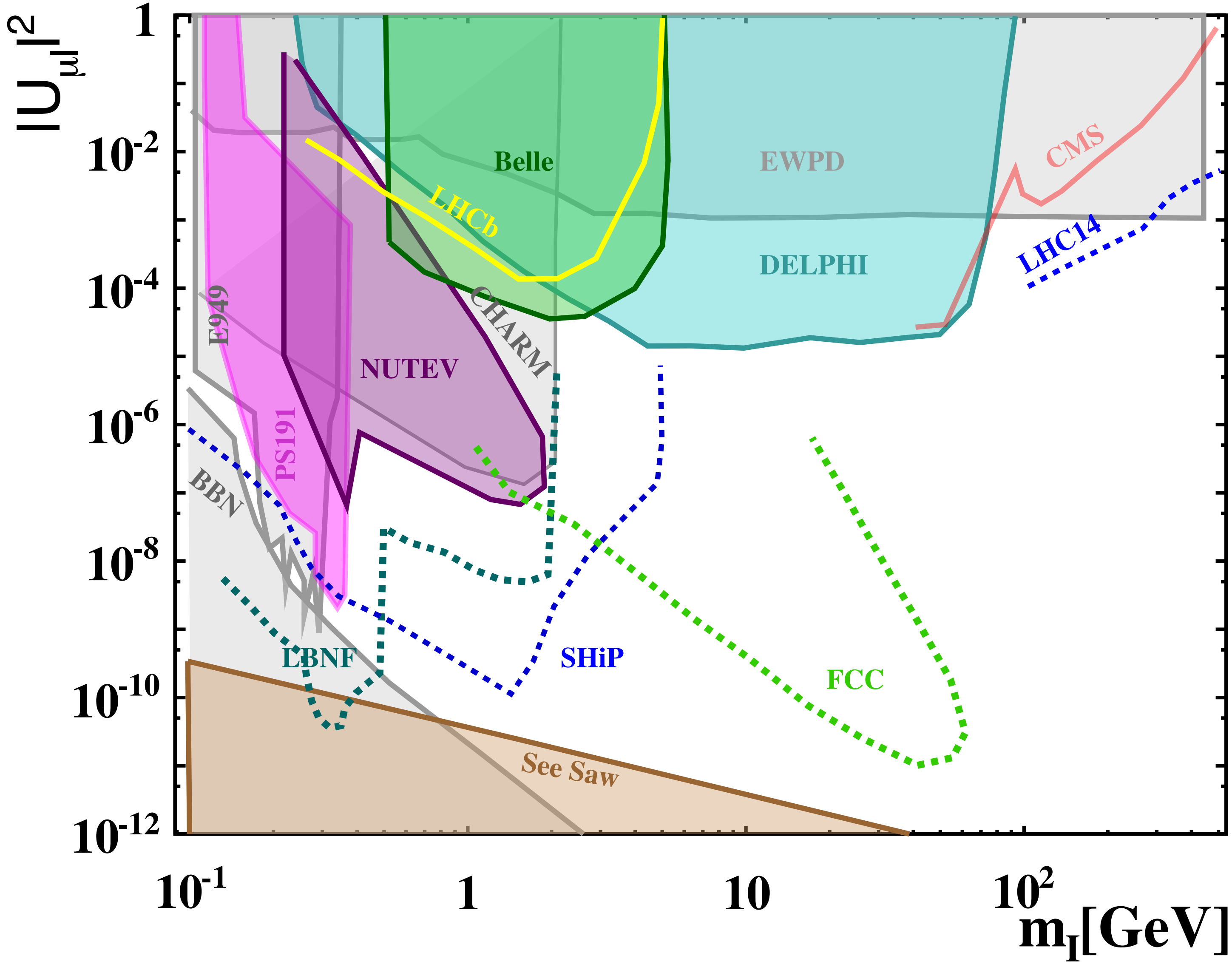
-in dump mode the target can be moved away from the beam and the beam let impinging on the copper.

- no problem with radioprotection issues at this intensity with a dump Cu-based.

Preliminary sensitivities for hidden sector searches

Assume 1 year of data taking, acceptance&selection efficiencies, zero background

HNL : sensitivity to $U_{\mu I}$



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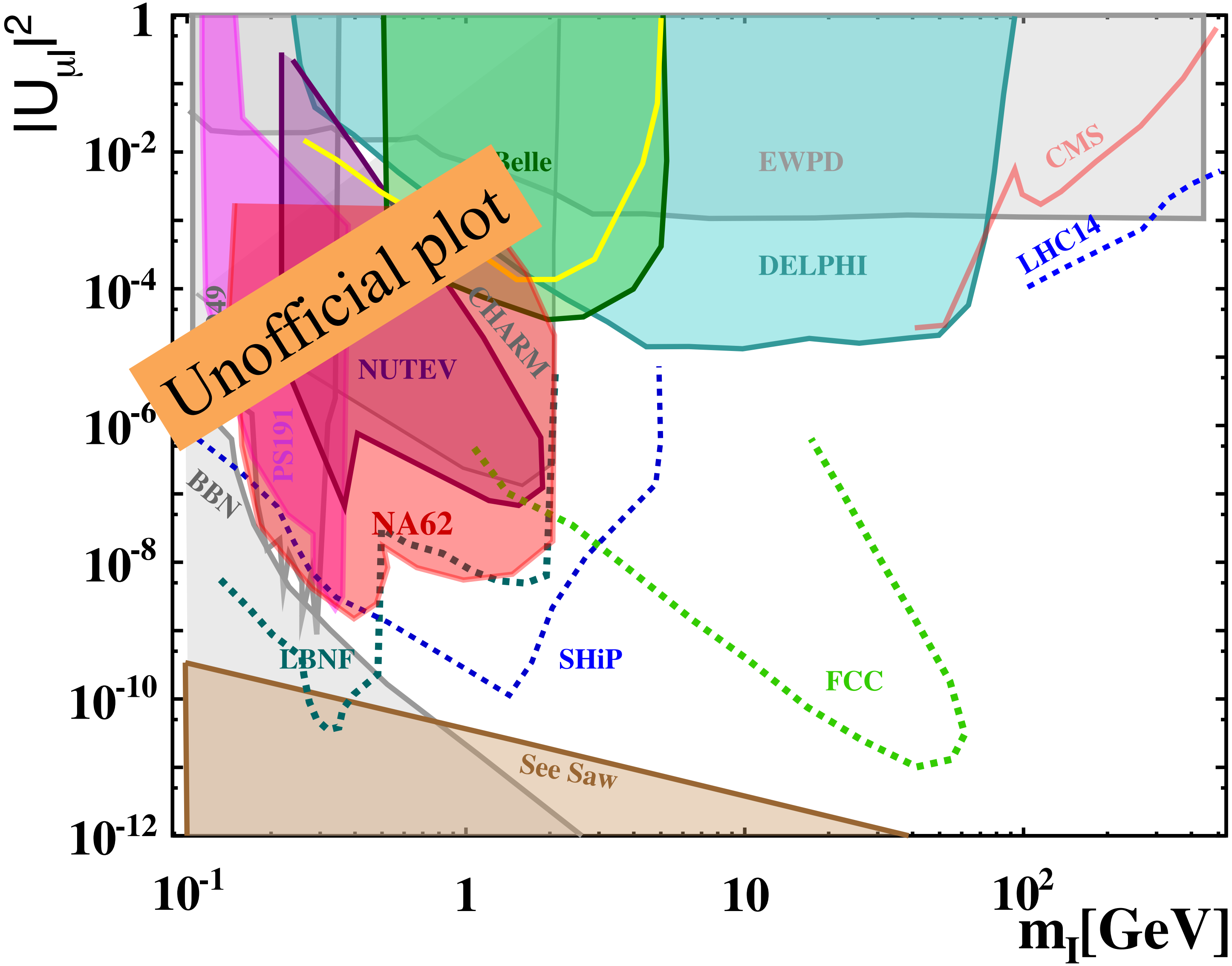
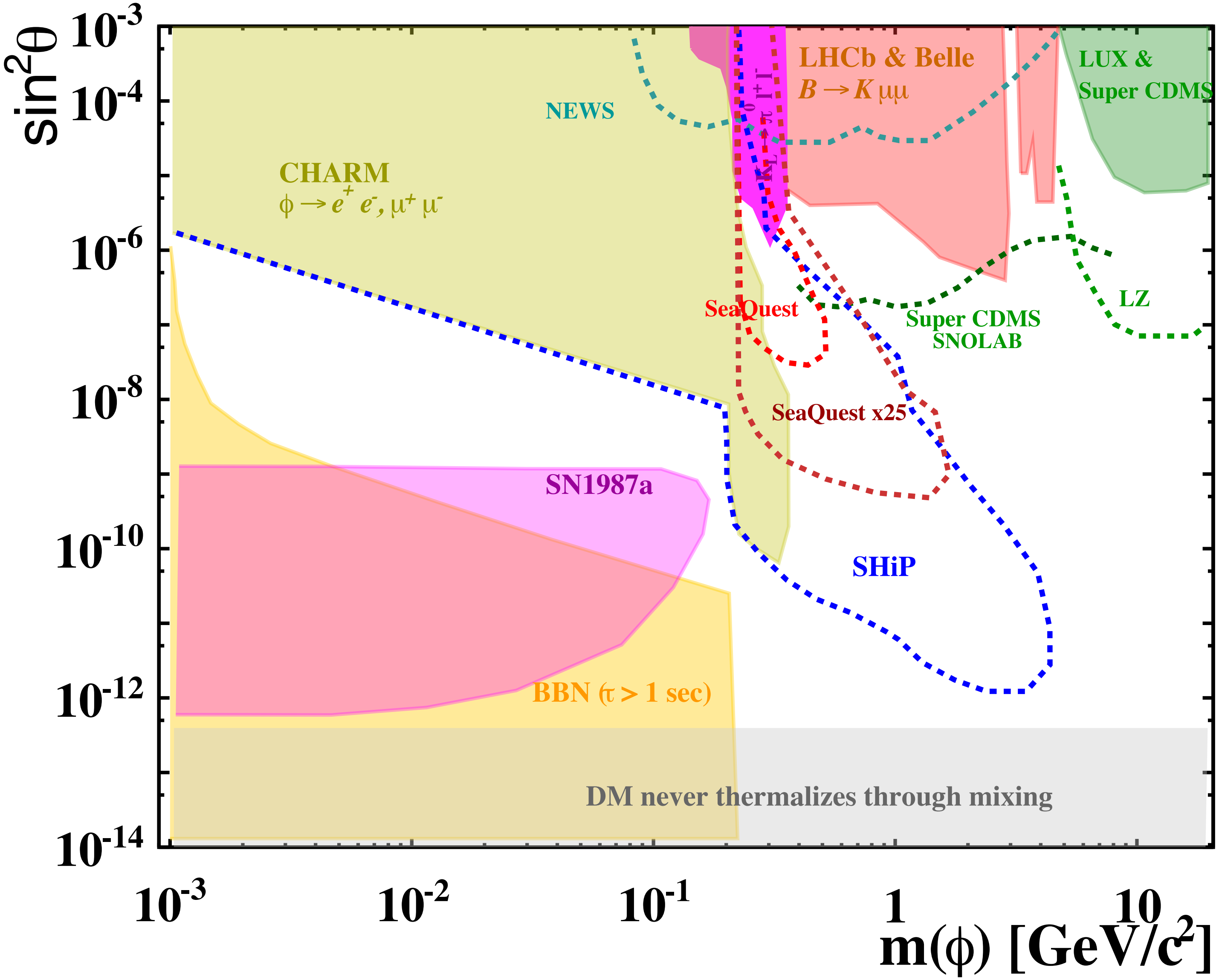


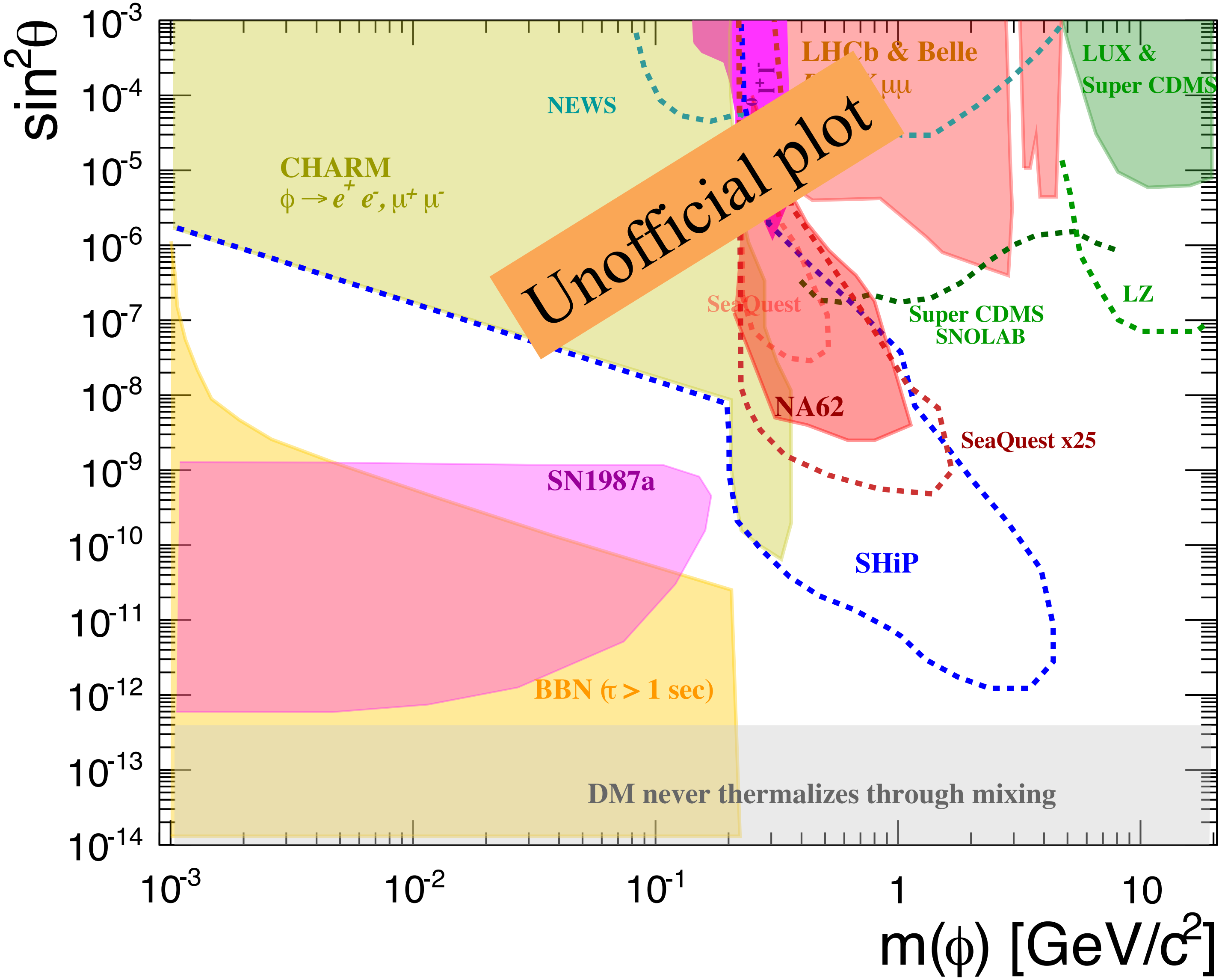
Limit improved by two orders of magnitude with respect to past experiments between the kaon and the charm mass (and comparable to LBNF).

Dark Scalar:



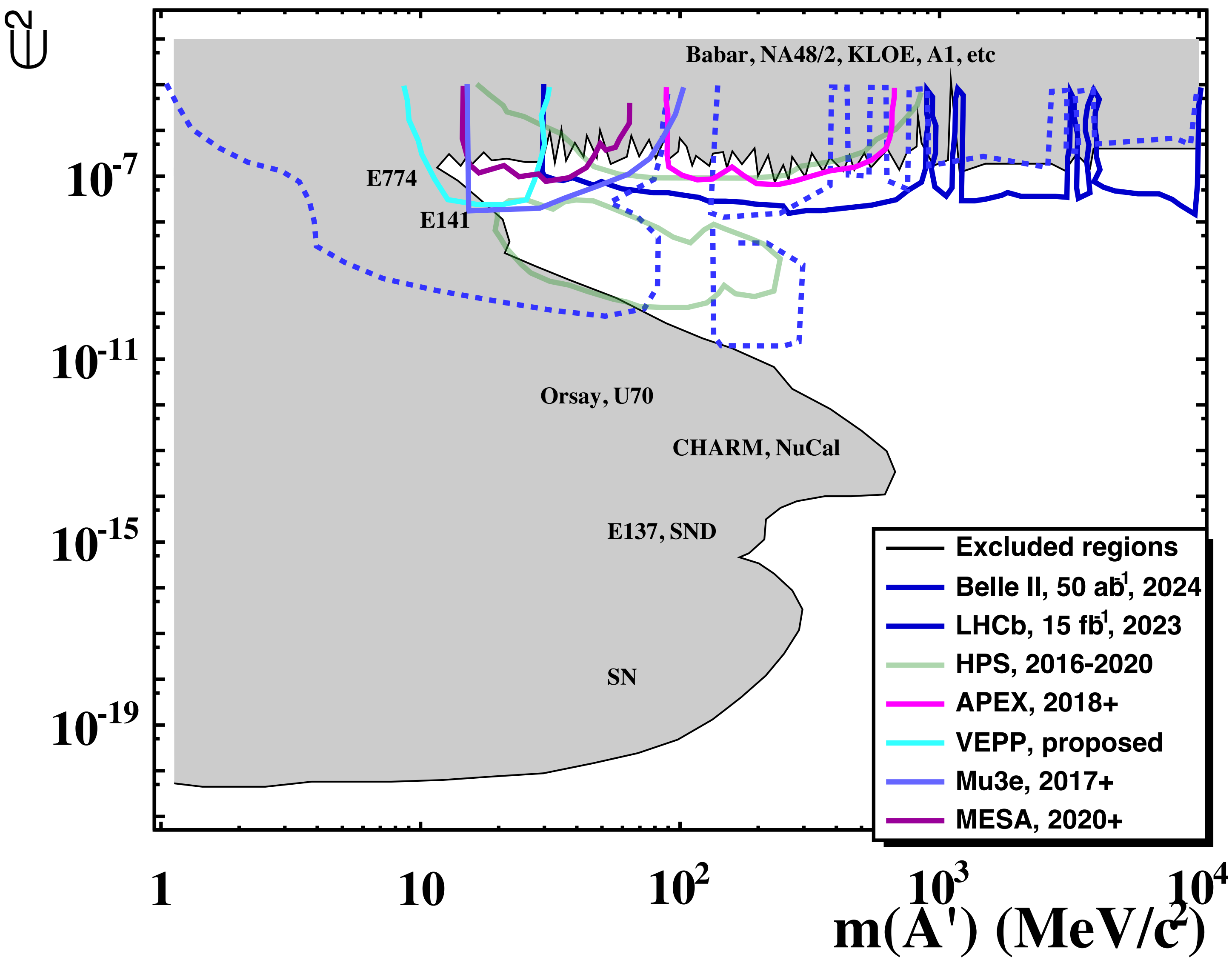
sin²θ
10⁻³
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10⁻¹²
10⁻¹⁴
NEWS
CHARM
φ → e⁺ e⁻, μ⁺ μ⁻
LHCb & Belle
B → K μμ
LUX &
Super CDMS
SeaQuest
Super CDMS
SNOLAB
LZ
SeaQuest x25
SN1987a
SHiP
BBN (τ > 1 sec)
DM never thermalizes through mixing
10⁻³
10⁻²
10⁻¹
1
10
m(φ) [GeV/c²]

Dark Scalar:



Limit improved by three orders of magnitude between the kaon and the charm mass. Much better than SeaQuest proposed at FNAL.

Dark Photon into visible final states



Existing limit (grey) and projected sensitivities (color).

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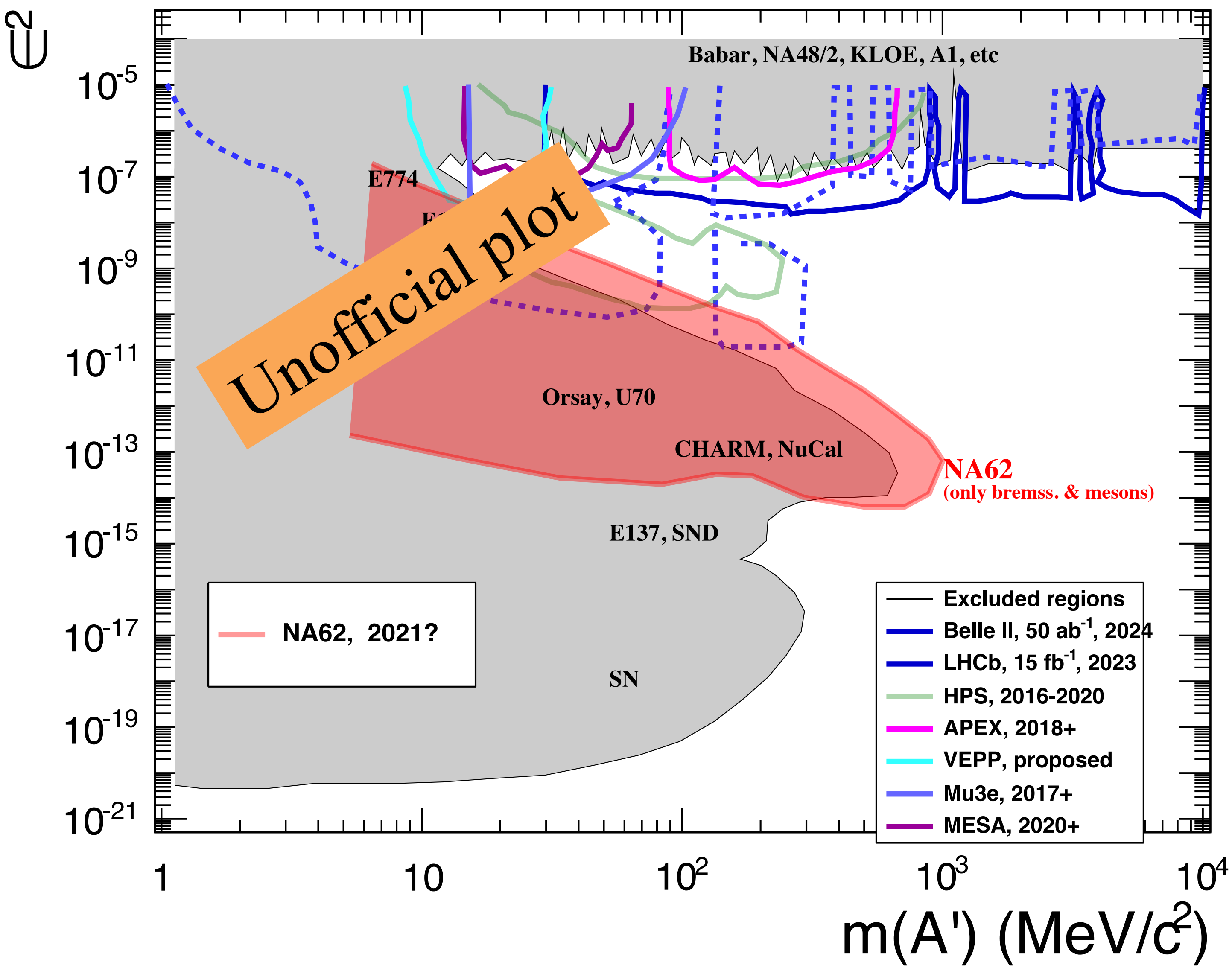

Unique sensitivity in the $\varepsilon^2 = 10^{-10} - 10^{-14}$ range.

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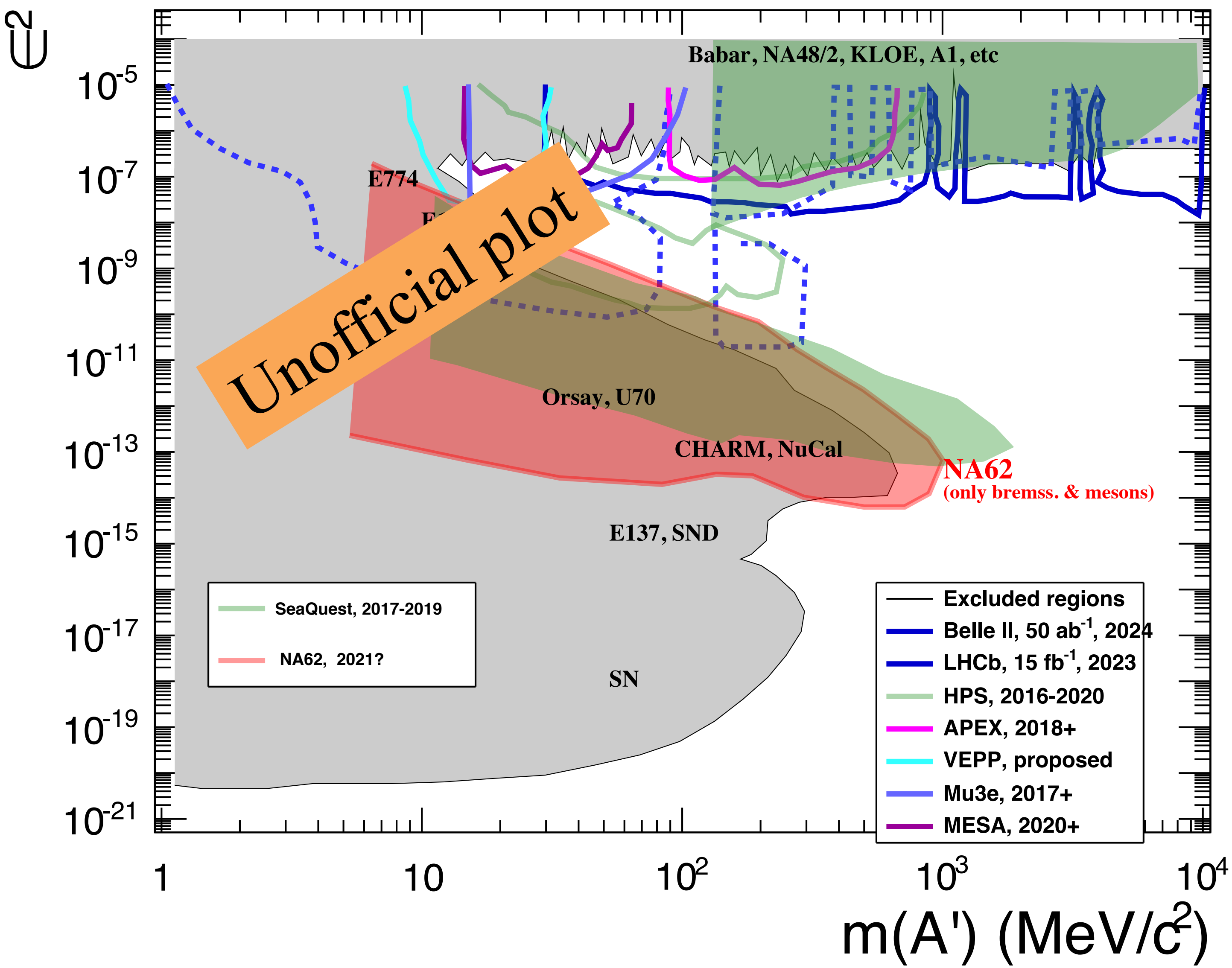
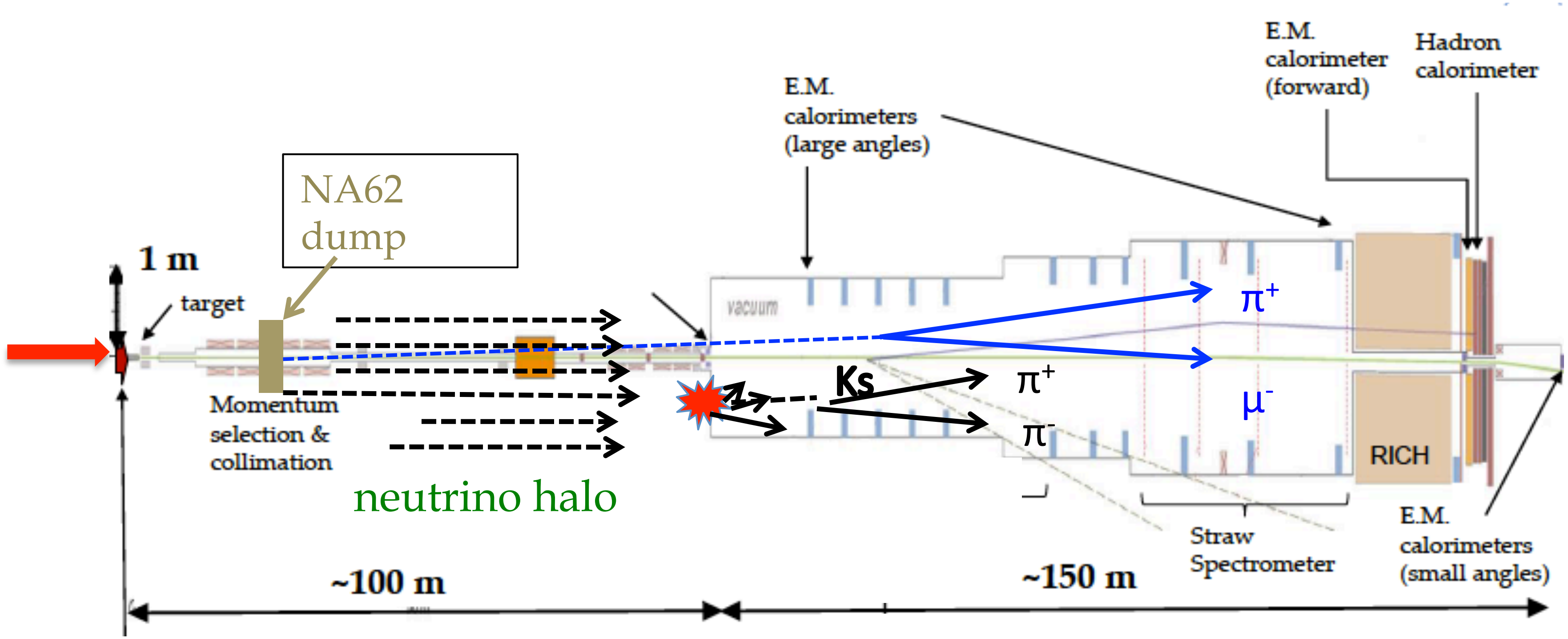


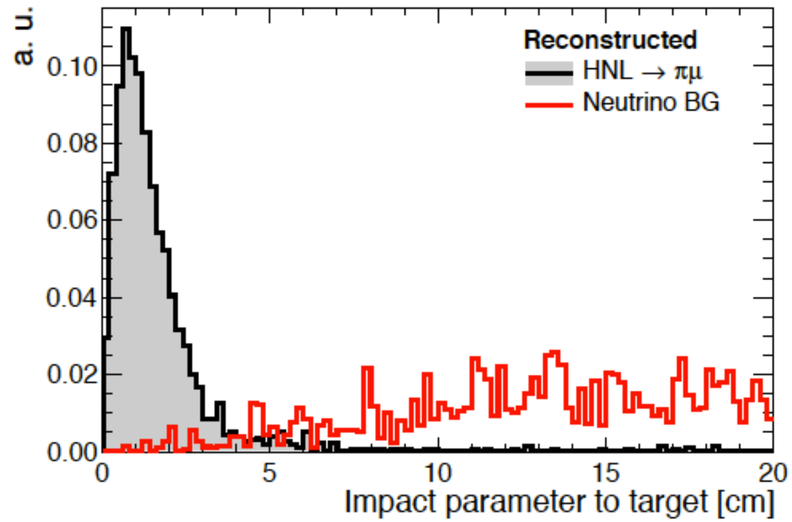
Unique sensitivity in the $\varepsilon^2 = 10^{-10}$ and 10^{-14} range.
Comparable with SeaQuest.

Backgrounds

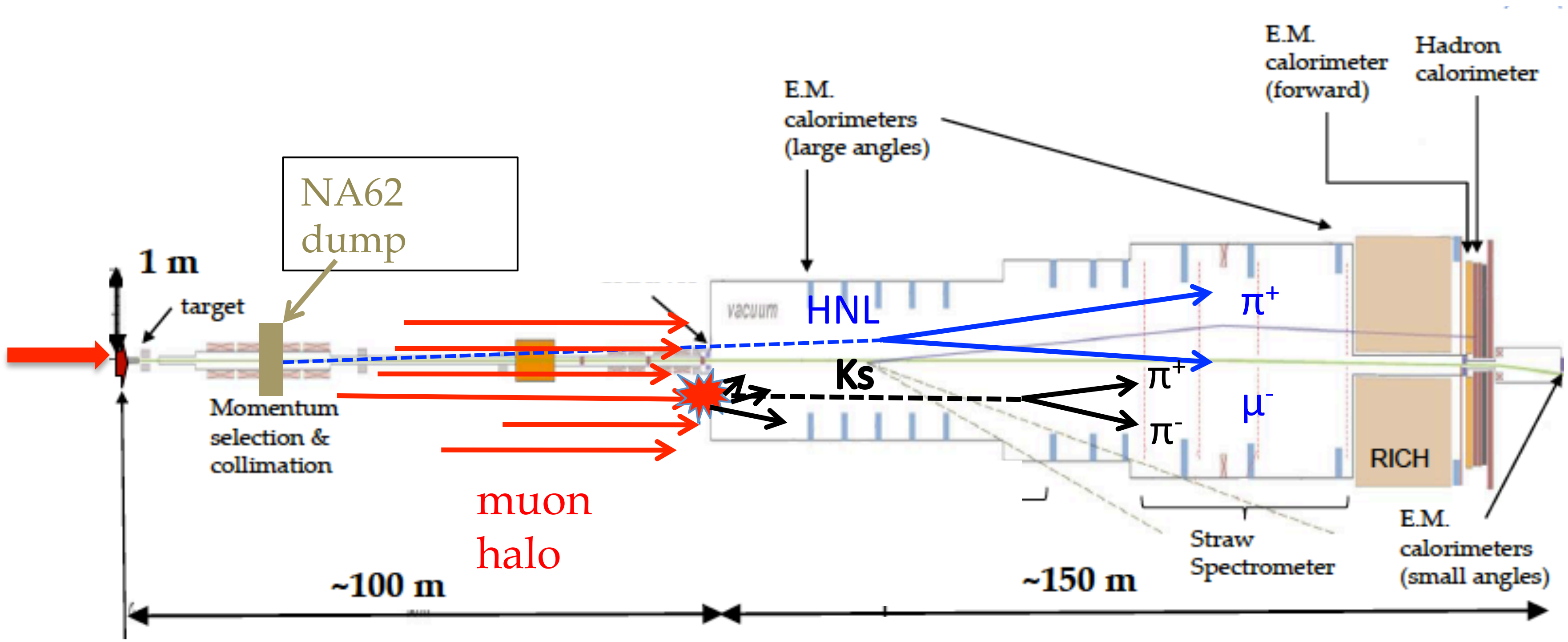
Background: **neutrino halo** from the dump



~ 10 GHz of active neutrinos from the dump are expected in nominal conditions which can make inelastic interactions in the material of the decay vessel creating V^0s and other tracks that can mimic signal signature.
In general this background does not point to the target.



Background: **muon halo** from the dump



~ 5 MHz of muons from the dump are expected in nominal conditions

Two types of background expected:

- muon inelastic interactions with the material of the decay vessel producing V^0s (similar signature of the neutrino inelastic interactions);

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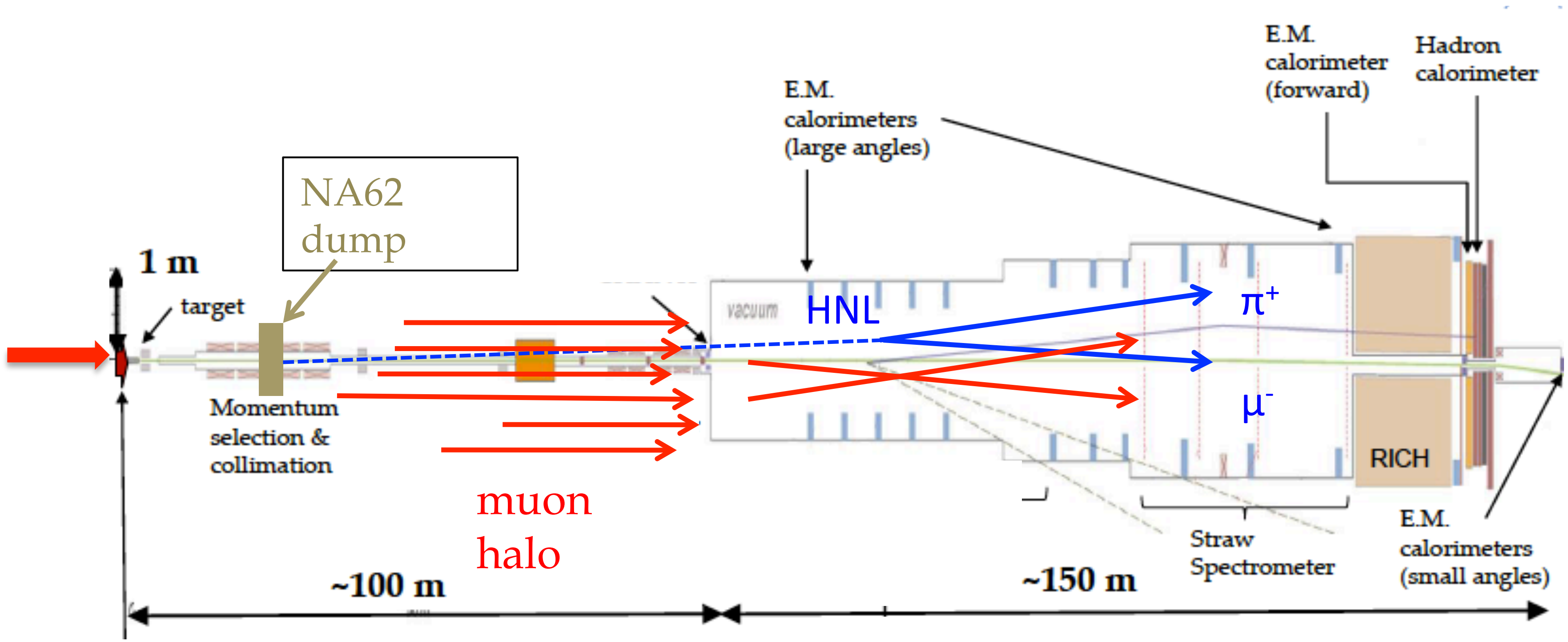

~ 5 MHz of muons from the dump are expected in nominal conditions

Two types of background expected:

- muon inelastic interactions with the material of the decay vessel producing V0s
- muon random combinations inside the decay volume;

Both backgrounds can mimic signal signature:

- a vertex in the decay volume with 2 or more tracks and nothing else.

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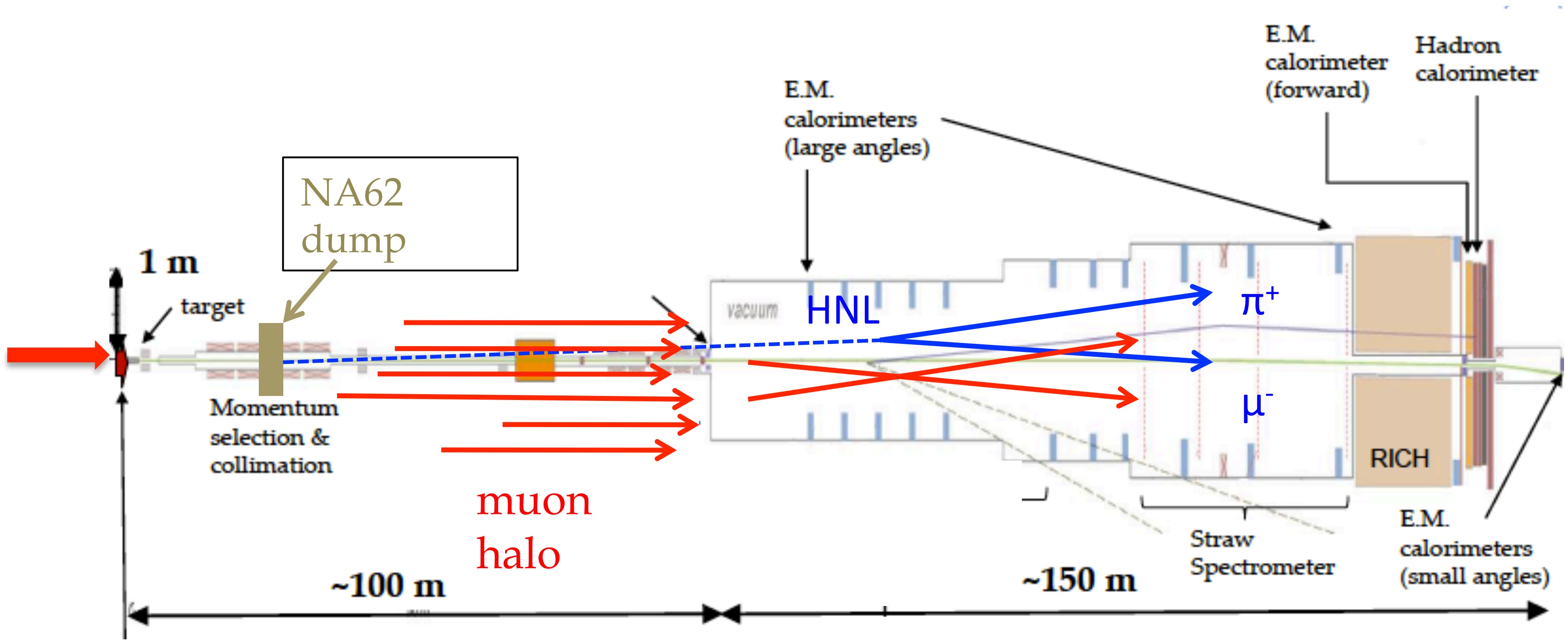

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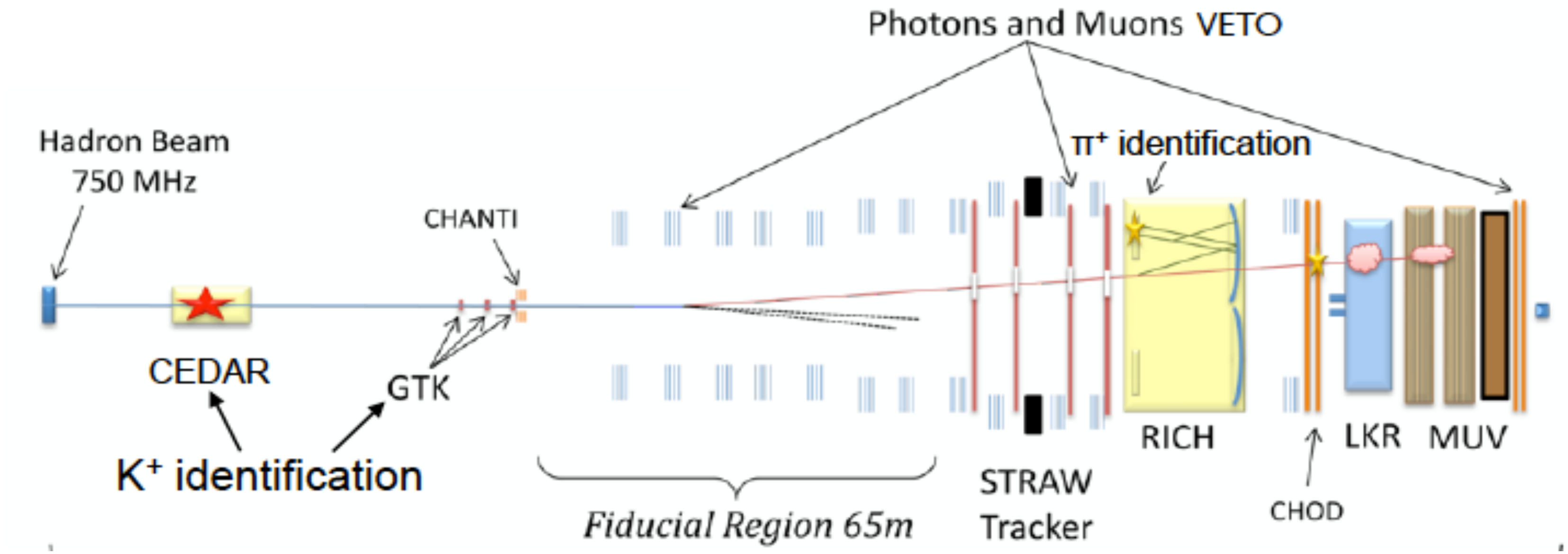
Where can we improve over the current NA62 detector?



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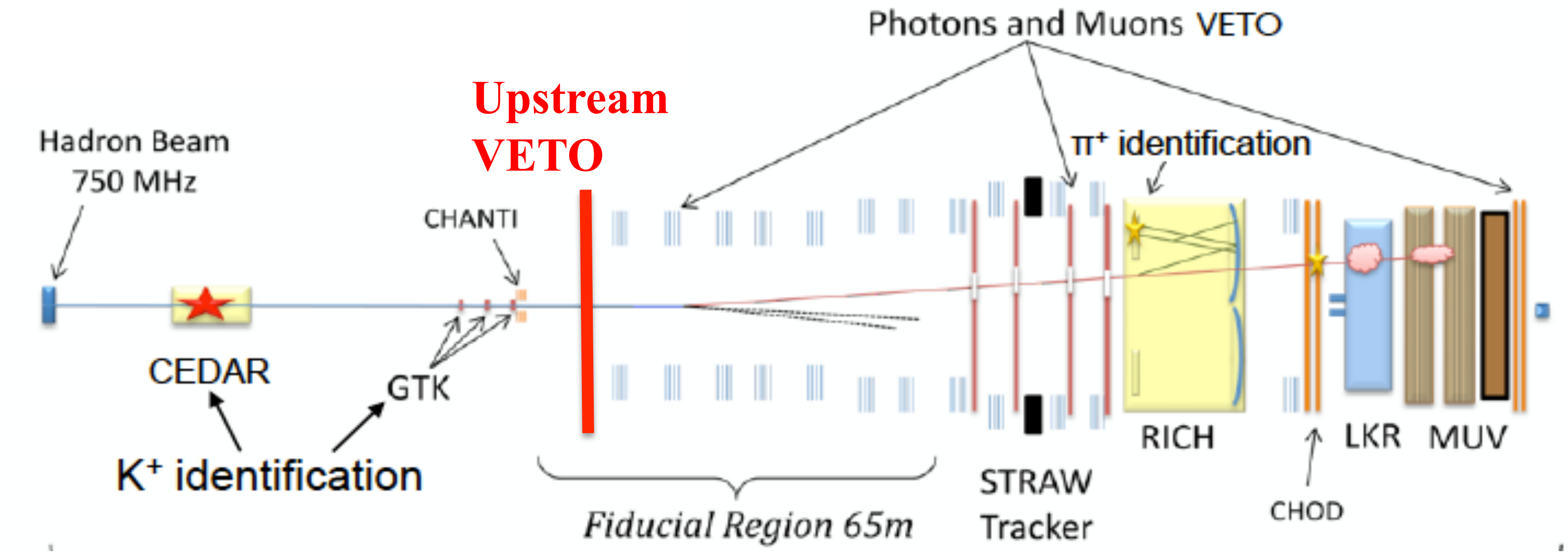

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→ to veto beam-induced muons from the dump

→ 99% efficiency gives a rejection factor of 10^4 on muons pairs

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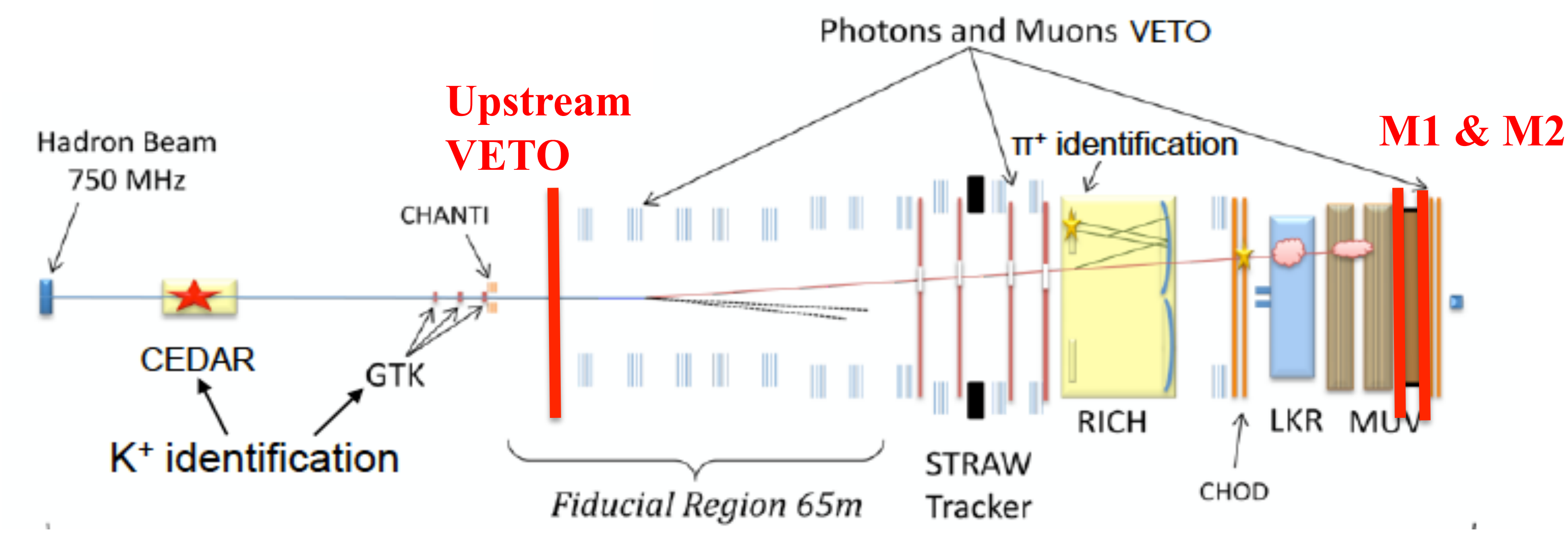

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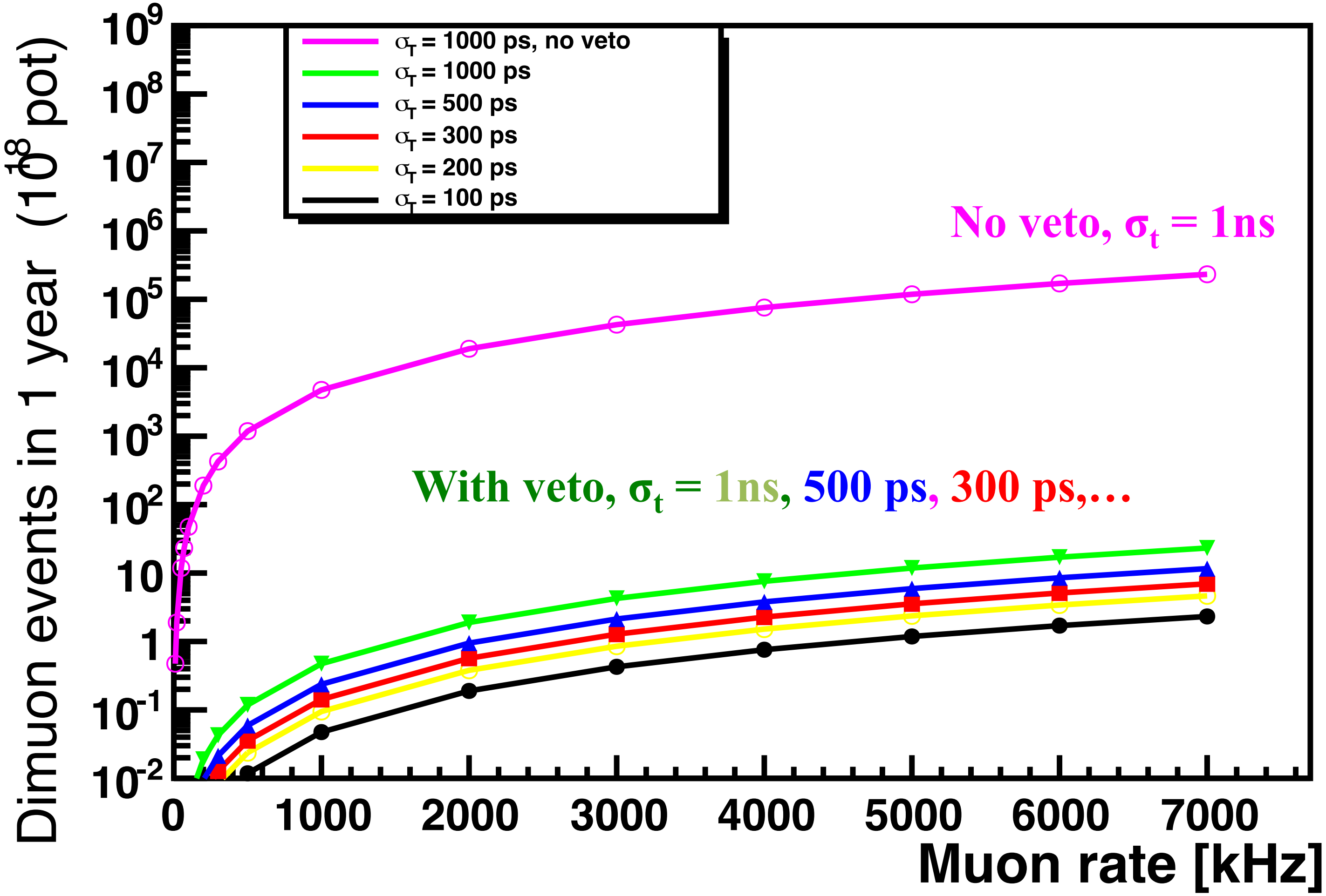
2) Other ideas under study (but not for now):

→ **two muon stations M1&M2** between MUV2 and MUV3 (currently filled with 80 cm of iron) to positively identify muons and time-stamp them.

(preliminary) estimate of the number of combinatorial muon background events in 1 year of data taking with NA62-dump

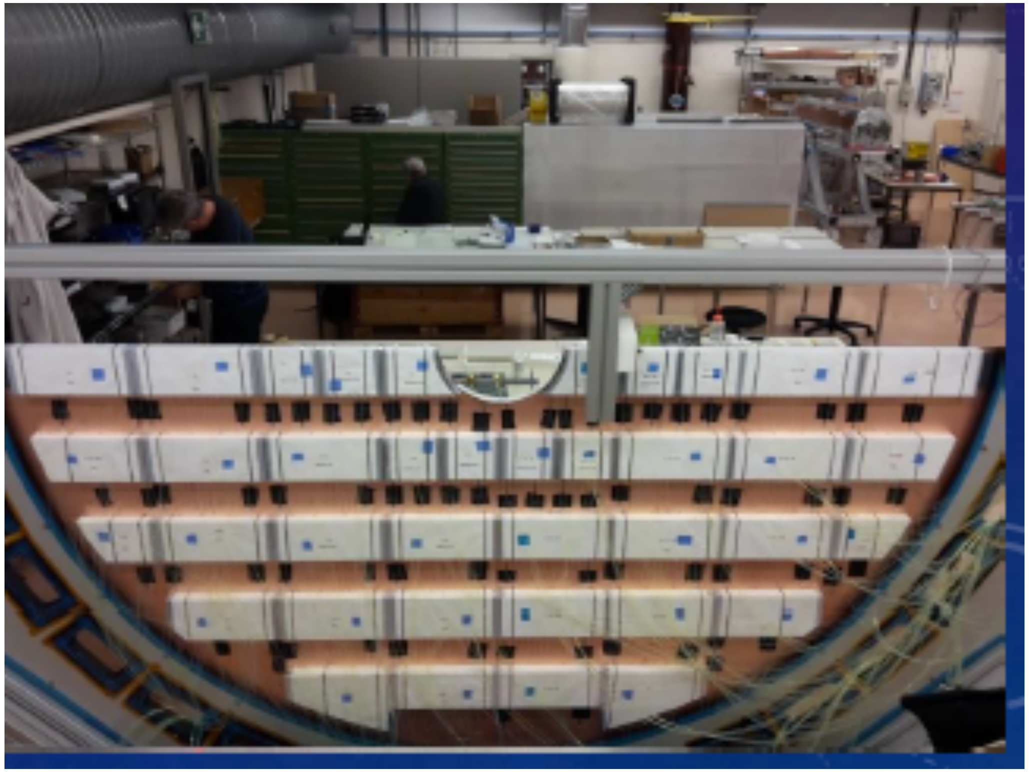
(with kinematic cuts and within a time window of 3.24 σ_t)

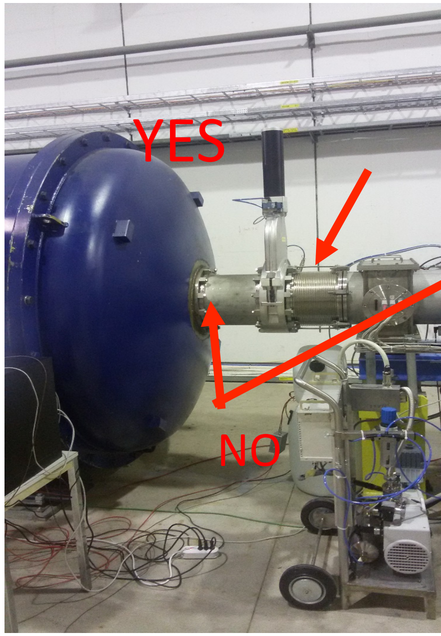


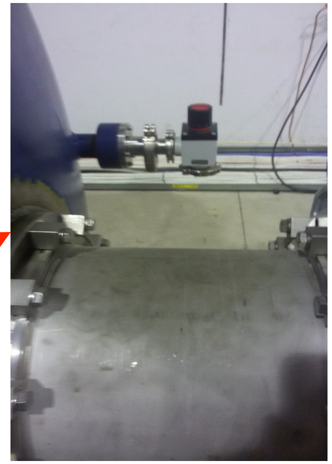
The upstream veto

Based on scintillating tiles and WLS fibers and SiPM readout;
Follow the design of the brand-new installed newCHOD in NA62:
- 152 tiles, 3cm-thick, covering an area of ~8 m^2;
- signals with time information and time resolution ~ o(300-400) ps.

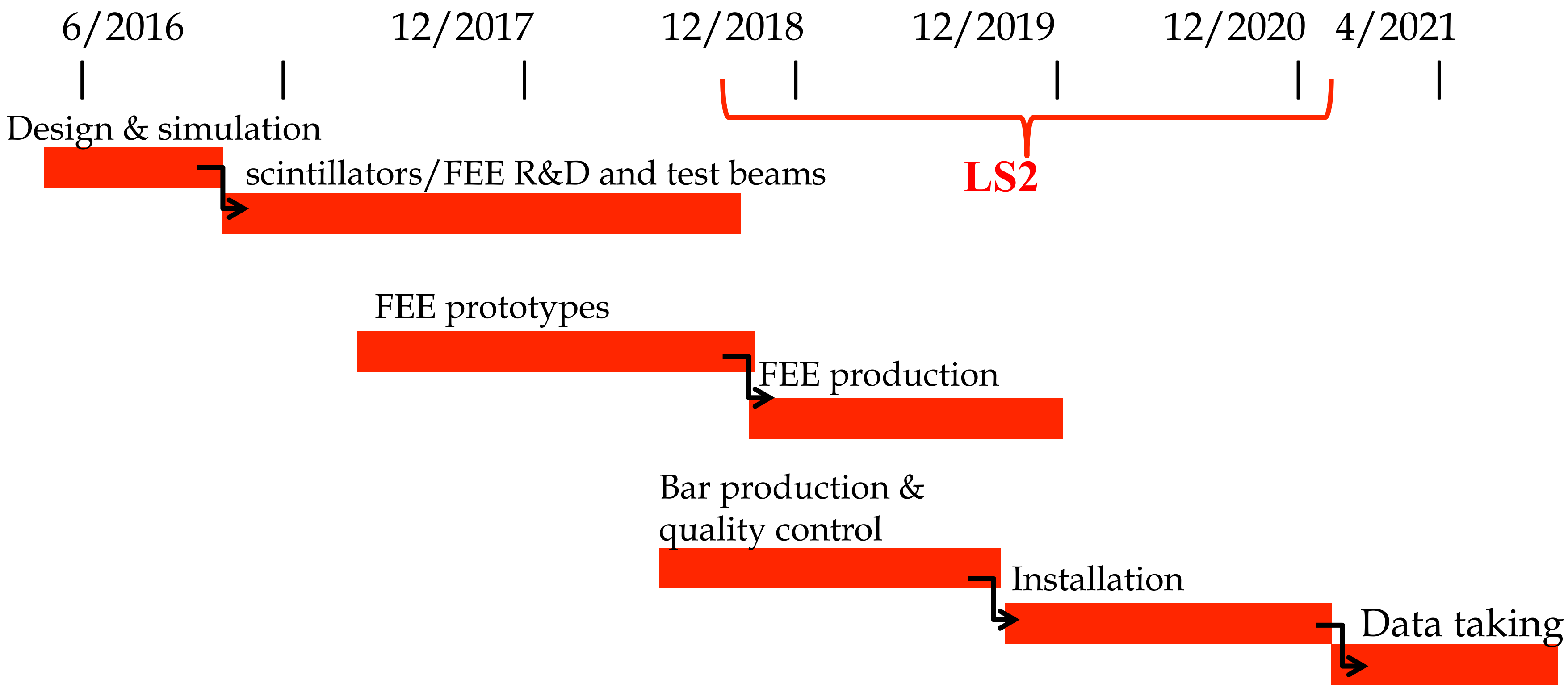
Use also the expertise gained in the tests for the SHiP muon detector.







Project timeline



2017 simulation, R&D for FEE & tiles, and mechanical design:
- 4 MU requested for SEA (in agreement with P. Ciambrone);
- 1 test beam at the end of 2017 to test different tiles configurations;
- 15% of Alessandro Saputi (mechanical design) (in SHiP quota).

2018-2019: production. Can be shared with Ferrara&INR if not enough resources at LNF;
2020: installation.

If we want to catch the LS2 time window for the installation we need to start now.

Team and resources for the Upstream Veto:

Team:

LNF: G. Lanfranchi, A. Paoloni, A. Calcaterra, P. Ciambrone (electronics design),
A. Saputi (mechanical design);
Ferrara: W. Baldini and technicians;
INR-Russia: Yu.Kudenko and his (very experienced) team.
Bologna SHiP Muon group: FEE R&D and Test beams in synergy with SHiP activities.

Resources:

In agreement with Nadia and the NA62 national representative,
the project will be funded in 2017 under dotazioni Gruppo1 @ LNF.
For 2017 we ask:
10 kEuro for FEE R&D
2 kEuro for instrumenting few tiles with fibres/SiPMs
with the goal of having a test beam end of 2017;
3 kEuro di missioni for test beam (hope to get extra-funding via AIDA-2020 as for SHiP).

Richieste ai servizi for 2017 (progettazione elettronica e meccanica):

4 MU per l'elettronica (SEA);
15% di Alessandro Saputi (in quota SHiP).

The **CERN** point of view:

The SPSC has recommended the SHIP collaboration **[CERN-SPSC-2016-011]**
*“**to explore the potential benefit of inputs from NA62 to strengthen the experimental evaluation of backgrounds and systematic uncertainties**”*.

Conclusions: the project landscape

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In 2015 the Advanced ERC "*NuBSM: From Fermi to Planck: a bottom up approach*" has been assigned to prof. M. Shaposhnikov (EPFL, Lausanne):
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The **Collaborations'** point of view:

The NA62 and SHiP collaborations are currently discussing ways of possible synergies.
Dedicated talks held at the NA62 collaboration week in June at CERN (T. Spadaro) and at the SHiP collaboration week in June in London (G. Lanfranchi).

→ **A talk including the run of NA62 in dump mode will be presented at the Physics Beyond Collider Workshop at CERN**, September 6-7 (T. Spadaro).

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The **INFN** point of view:

→ **A discussion on the project is foreseen in the Gruppo1 meeting in November.**
→ **A budget has been allocated in agreement with Nadia under DTZ-GR1 at LNF.**