Dark sector searches at the CERN high-intensity kaon beam facility

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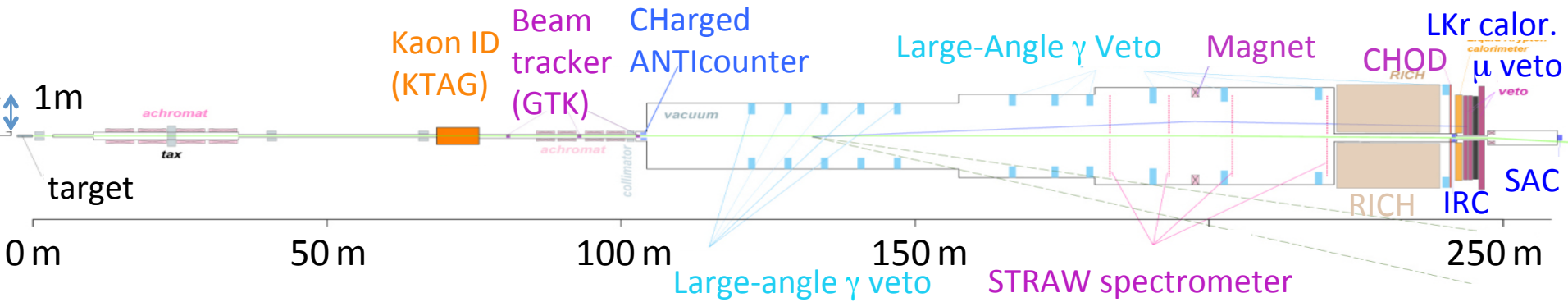
on behalf of the NA62 and KLEVER collaborations

NA62: a high-intensity setup

High-intensity secondary charged hadron beam produced from SPS proton beam:

1.1 10^{12} 400-GeV protons/s from ~3 s SPS spills onto a Be target

Secondary 75-GeV beam selected: 1% momentum bite, X,Y divergence < 100 μrad



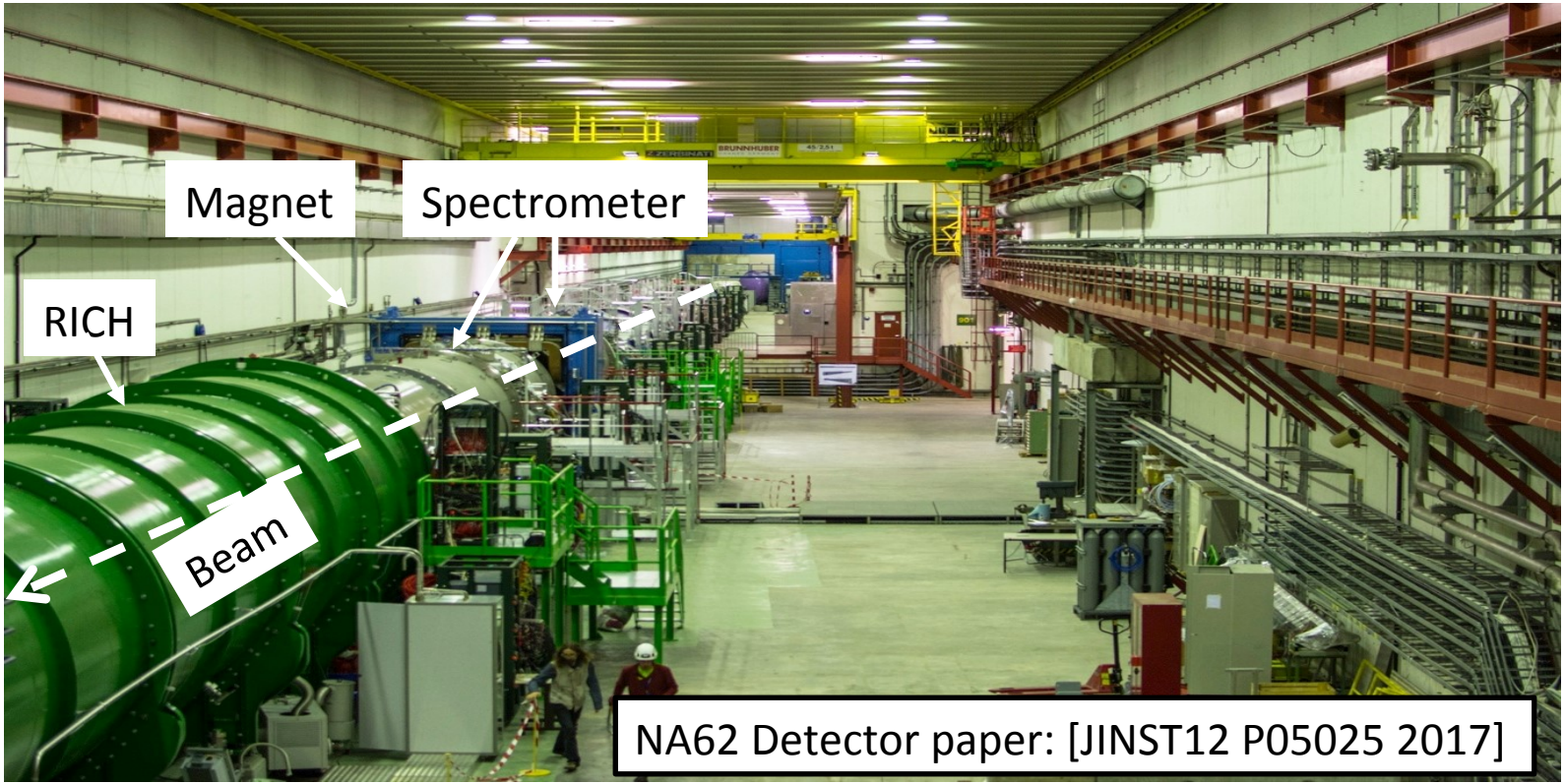
Can **track 750 MHz beam** (6% K^+) and sustain ~5 MHz K^+ decay in a **60-m long FV in vacuum**

Kinematics, rejection of main K modes 10^4—10^5 via kinematic reconstruction

PID capability, μ vs π rejection of O(10^8) for 15 < p(π^+) < 35 GeV

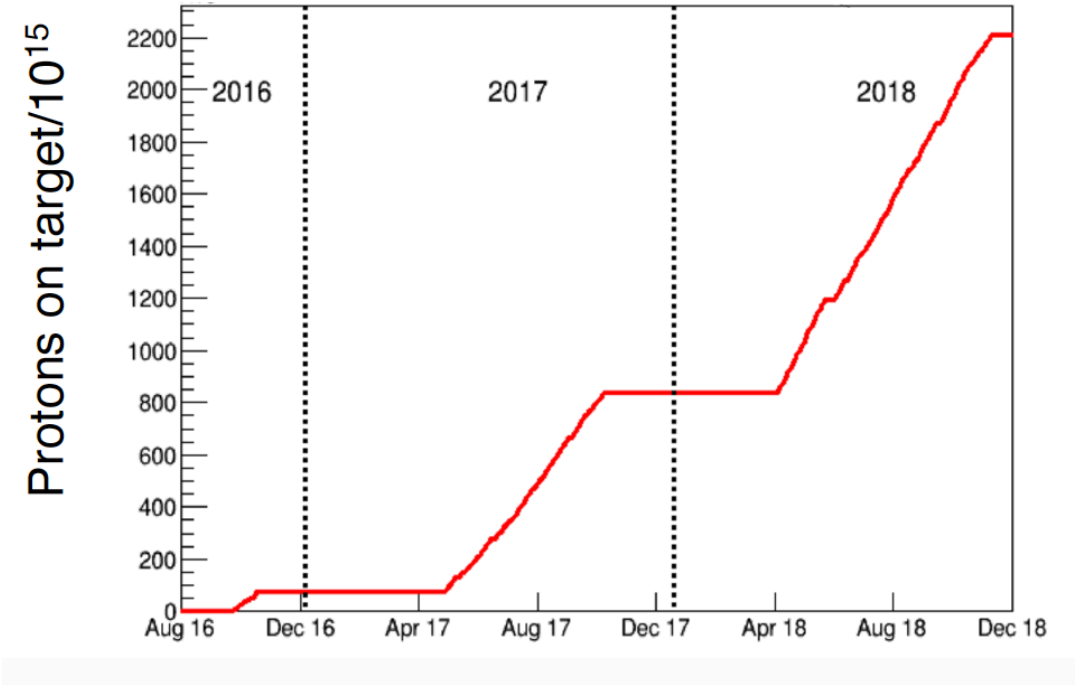
High-efficiency veto of additional photons, O(10^8) rejection of π^0's for E(π^0) > 40 GeV

NA62: a high-intensity setup



The NA62 data taking

Overall ~2.2 × 10^{18} protons on target (POT) in Run 1, three rounds of K→πνν analysis



2016 40% of nominal intensity
0.12 × 10^{12} K^+ decays in FV
PLB 791 (2019) 156-166

2017 60% of nominal intensity
1.5 × 10^{12} K^+ decays in FV
ArXiv:2007.08218 [hep-ex]
(submitted to JHEP)

2018 60-70% of nominal intensity
2.6 × 10^{12} K^+ decays in FV
Preliminary @ ICHEP 2020

Physics goal of the LoI

Exploring dark-sector scenarios in the MeV-GeV from the high-intensity NA62 setup

1. **From K^+ decays: ~ 5×10^{12} in the FV from Run 1, expect × 3 from Run 2**

- production of a dark scalar S in $K^+ \rightarrow \pi^+ S$ decays;
- production and decay of a MeV-scale ALP: $K^+ \rightarrow \pi^+ a$, $a \rightarrow e^+ e^-$ prompt;
- production of dark scalar or vector particles in $K^+ \rightarrow \mu^+ \nu X$, X invisible or $X \rightarrow \mu^+ \mu^-$, $e^+ e^-$, or $\gamma\gamma$ prompt;
- production of massless dark photons or invisible light ALPs in $K^+ \rightarrow \pi^+ \pi^0 X$;
- production of long-lived heavy neutral leptons in $K^+ \rightarrow (\pi^0)\ e^+ N$ and $K^+ \rightarrow \mu^+ N$;
- production and decay of short-lived heavy neutral leptons, e.g. $K^+ \rightarrow \mu^+ N$, $N \rightarrow e^+ e^- \nu$ with a displaced vertex

Physics goal of the LoI

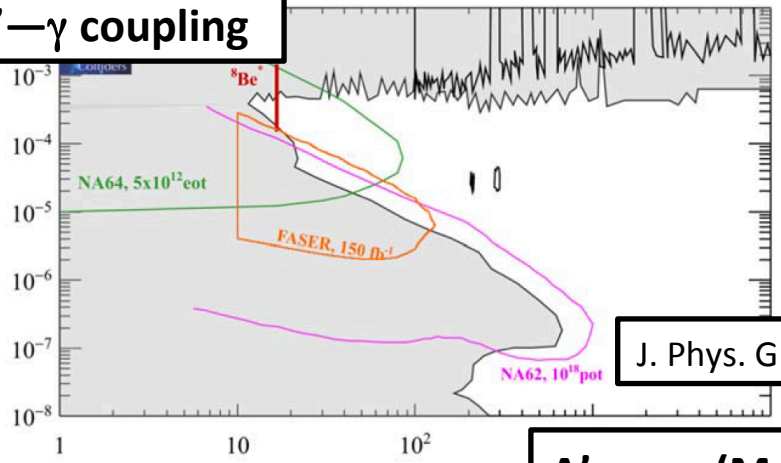
Exploring dark-sector scenarios in the MeV-GeV from the high-intensity NA62 setup

2. From ultra-rare K decays → See M. Moulson's talk in RF2

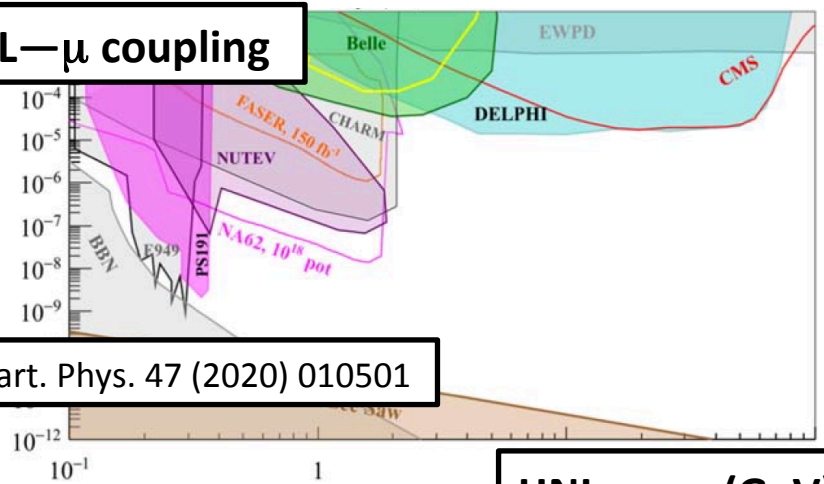
3. With dedicated runs in beam-dump mode: sensitivity to most final states

4. With dedicated parasitic triggers: sensitivity to di-muon, lepton-muon final states

A'—γ coupling



HNL—μ coupling



J. Phys. G: Nucl. Part. Phys. 47 (2020) 010501

Sensitivity to dark photons @ 10^{18} POT

Sensitivity to HNLs μ-coupled @ 10^{18} POT

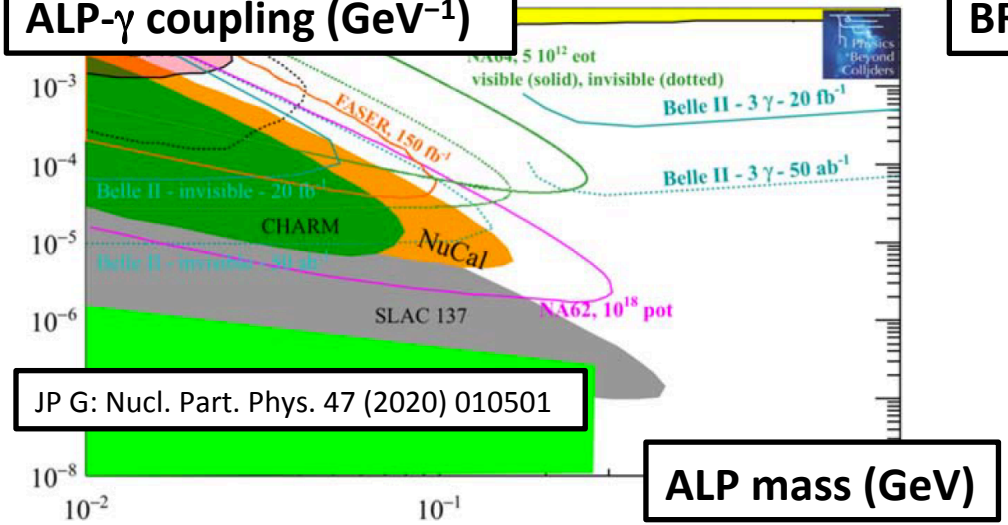
Physics goal of the LoI

Exploring dark-sector scenarios in the MeV-GeV from the high-intensity NA62 setup

3. Data taken in beam-dump mode: 2×10^{16} POT in Run 1, 10^{18} POT foreseen in Run 2

4. Parasitic mode: 7×10^{17} POT for $\mu\mu$, 2×10^{17} POT for $\pi\mu$ final states in Run 1

ALP-γ coupling (GeV^{-1})



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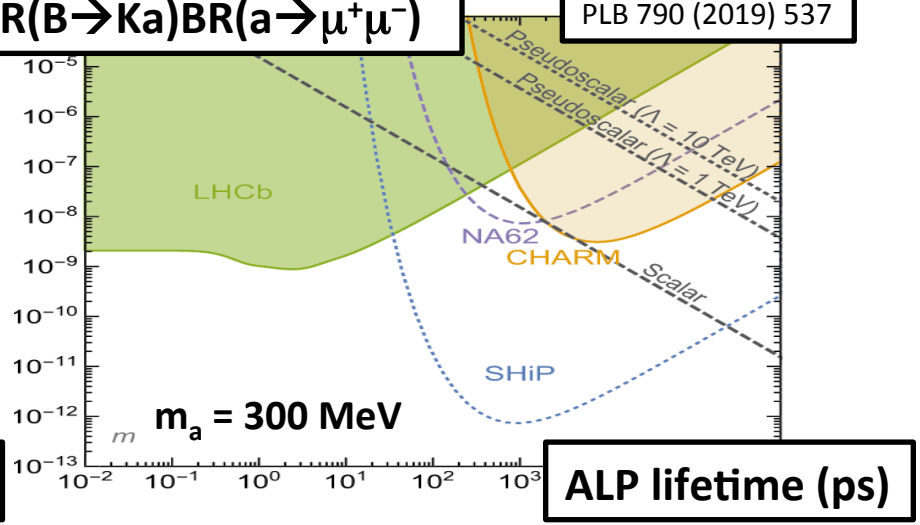
ALP mass (GeV)

BR(B→Ka)BR(a→$\mu^+\mu^-$)

PLB 790 (2019) 537



ALP lifetime (ps)

Sensitivity to ALPs γ-coupled @ 10^{18} POT **and to ALPs fermion-coupled @ 10^{18} POT**

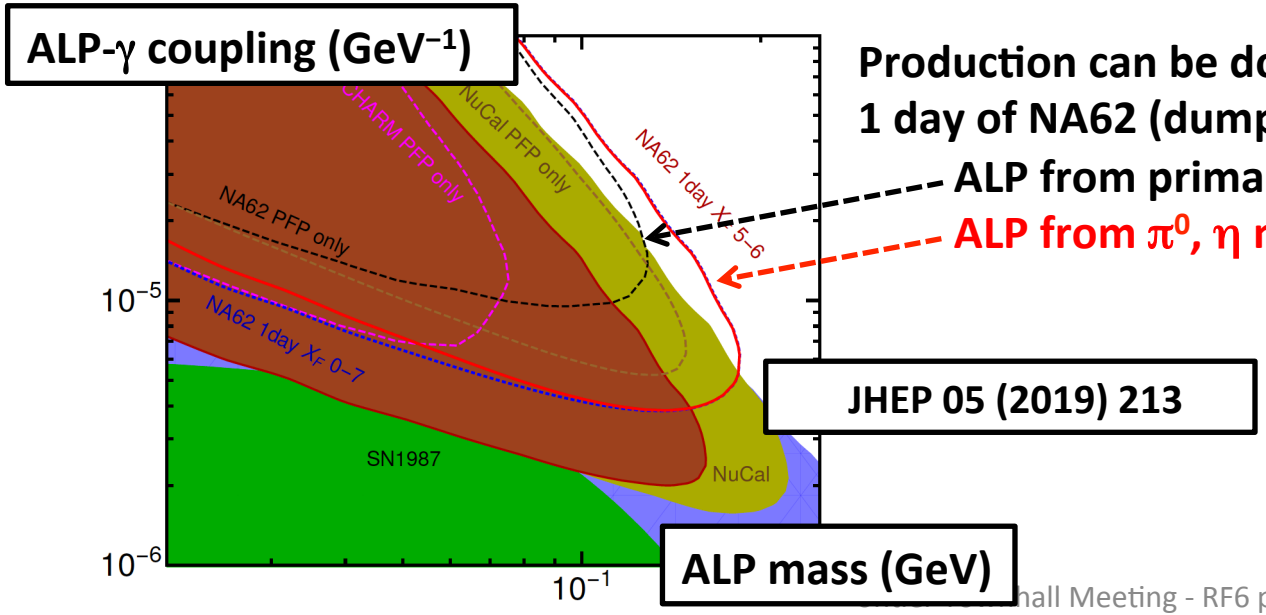
The production mechanism

The proton beam interacts in a dump producing mesons, strange, charmed, beauty particles which decay producing dark-sector particles…

… feebly interacting enough to reach and decay a sensitive volume beyond beam dump

Feeble interaction: ultra-suppressed production rate, **very** long-lived states

E.g.: M(HNL) = 1 GeV, $\tau \sim 10^{-5}$--10^{-2} s, $\lambda \sim$ 10--10000 Km at SPS, production suppression 10^{-7}--10^{-10}



Production can be dominated by soft-QCD, e.g.:
1 day of NA62 (dump mode):
ALP from primakoff production
ALP from π^0, η mesons

JHEP 05 (2019) 213

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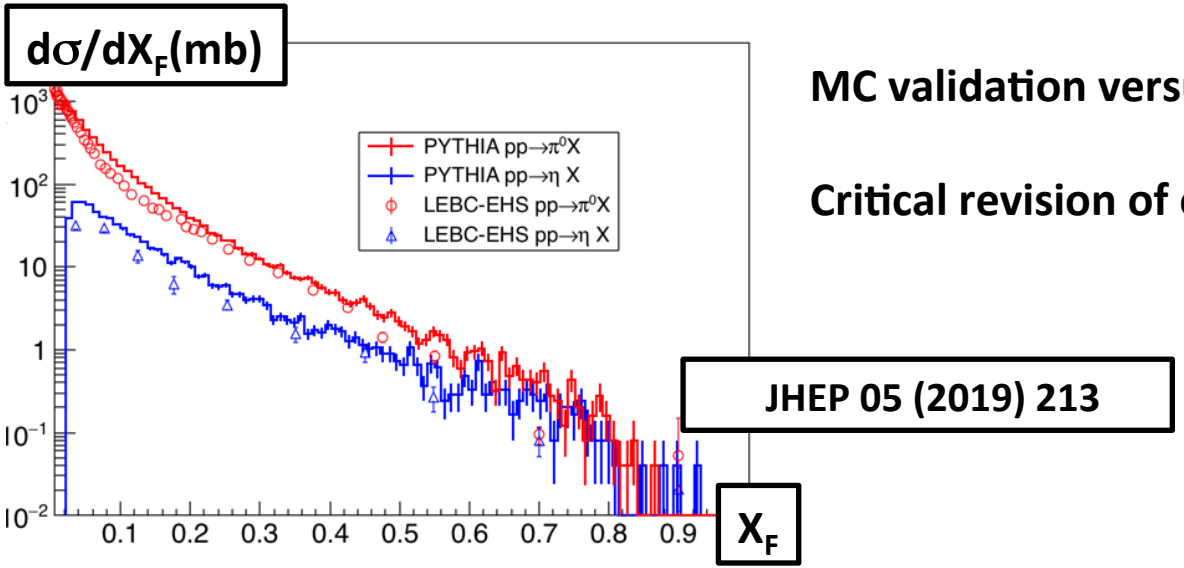

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MC validation versus data of π^0 and η production

Critical revision of experimental data performed

A joint phenomenological effort

Expected production cross section usually evaluated on a case-by-case basis for each proposal

A common framework would allow a coherent comparison of the expected sensitivities:

- **Soft-QCD effects**
- **Secondary/tertiary production of strange, charmed, beauty particles in hadronic showers**
- **Polarization effects**

A validation campaign for any MC in low-energy regime ($\sqrt{s} < 30$ GeV) would be useful

Existing proposals/running experiment with sensitivity in the MeV-GeV from the use of fixed-target hadron beam would profit of such an effort, e.g.: 1, 10, 120, 400 GeV proton beams

Perspectives and timeline

Results from NA62 Run 1 expected for Q2 2021, e.g.: γ-coupled ALP → $\gamma\gamma$, fermionic ALP → $\mu\mu$

Basis for exotics searches in Run 2, with 10^{18} POT planned in beam-dump mode

Parasitic trigger lines will be kept insofar compatible with the main physics programme

Major hardware improvements in the NA62 setup for Run 2:

Installation of an anti-halo hodoscope just upstream of the decay region

Improved redundancy and sweeping performance of second achromat for K beam tracking

Installation of an additional veto calorimeter just upstream of the Kaon-beam dump

Continuation of exotics searches with parasitic triggers possible, depending on results from other dedicated experiments and compatibility with main programme

Future program with high-intensity K's and the KLEVER project, see M. Moulson @ RF2

Spare slides

Future plans after Run 2

NA62 high-intensity K^+ discussion, Jan 19:

- **Goal: Measure BR($K^+ \to \pi^+ \nu\nu$) to 5%**
- **4x primary intensity ("NA62x4"),** based on feasibility studies for KLEVER beam
- Technological challenges, esp. beam and spectrometer tracking
  Adopt calorimetry and veto designs from KLEVER
- Significant interest from NA62 collaboration and community

Outcome of European Strategy Update:

- Support for intensity frontier physics reaffirmed
  Rare kaon decays explicitly mentioned in supporting document
- Physics Beyond Collider programs generally supported
- SPS beam dump facility judged to be to expensive

CERN-ESU-014 June 2020

es and

Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board. Among the proposals for larger-scale new facilities investigated within the Physics Beyond Colliders study, the Beam Dump Facility at the SPS emerged as one of the frontrunners. However, such a project would be difficult to resource within the CERN budget, considering the other recommendations of this Strategy.