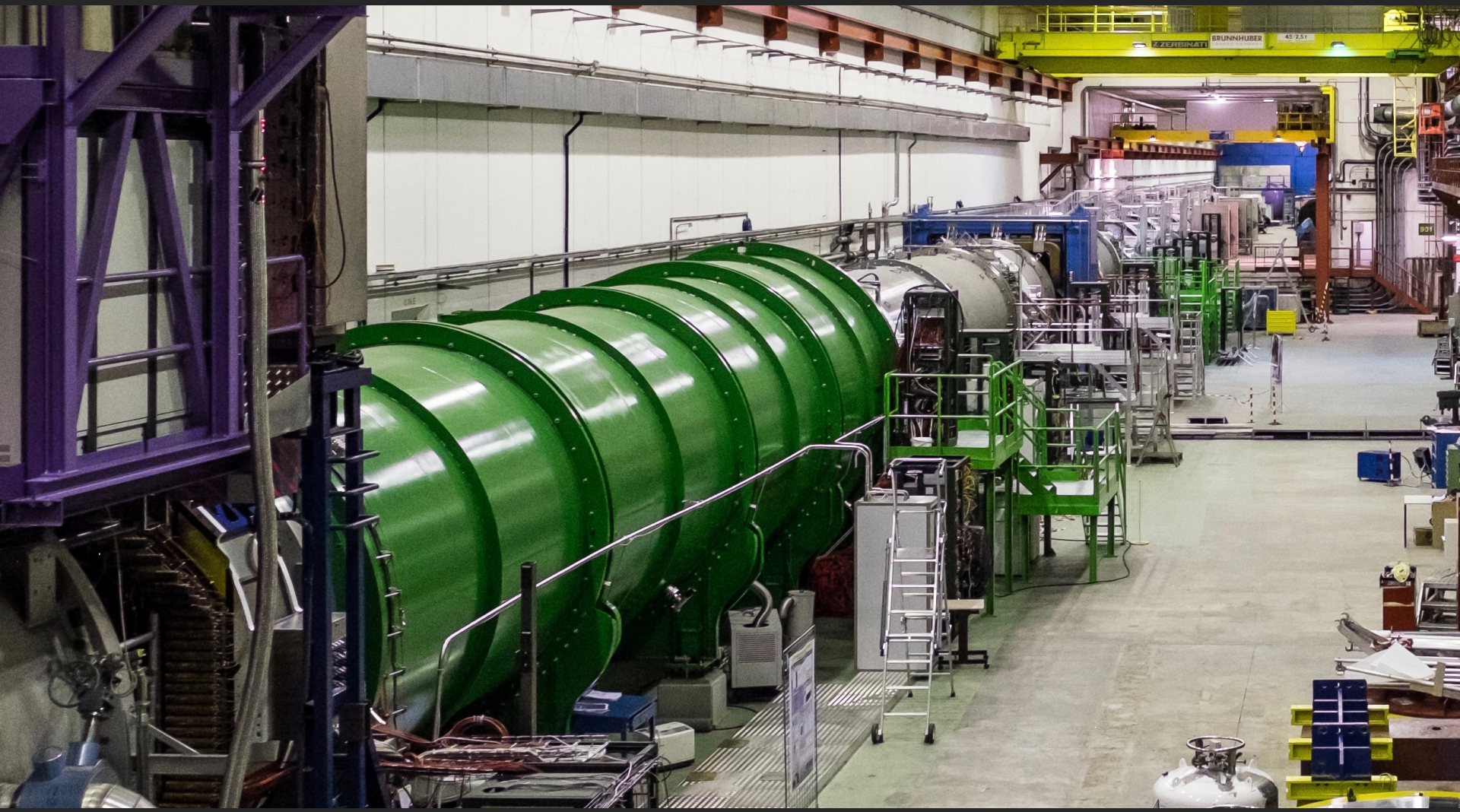
# NA62: Present and future

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**Laboratori Nazionali di Frascati**
07 July 2020

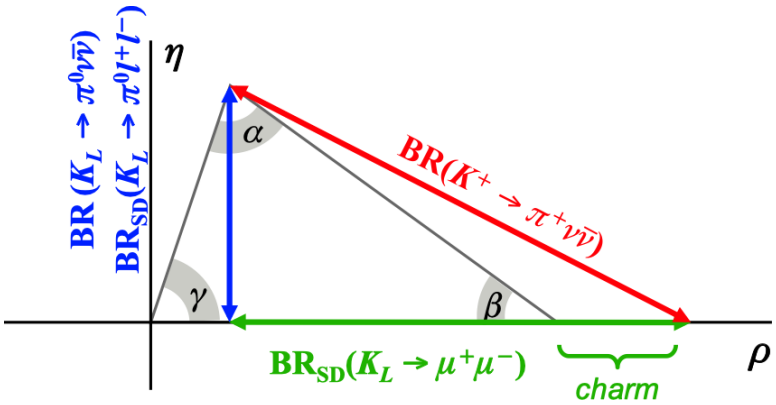
# New physics in $K \to \pi\nu\bar{\nu}$ decays

**Extremely rare decays with rates very precisely predicted in SM:**

| | SM predicted rates* | Experimental status |
|---|---|---|
| $K^+ \to \pi^+\nu\bar{\nu}$ | **BR = (8.4 ± 1.0) × $10^{-11}$** | 7 evts from BNL787, 3 evts from **NA62**<br>Goal: BR to 20% from **NA62** by end of Run 3 |
| $K_L \to \pi^0\nu\bar{\nu}$ | **BR = (3.4 ± 0.6) × $10^{-11}$** | Only limits at present<br>**KOTO** (JPARC): ~ few SM events by 2025 |

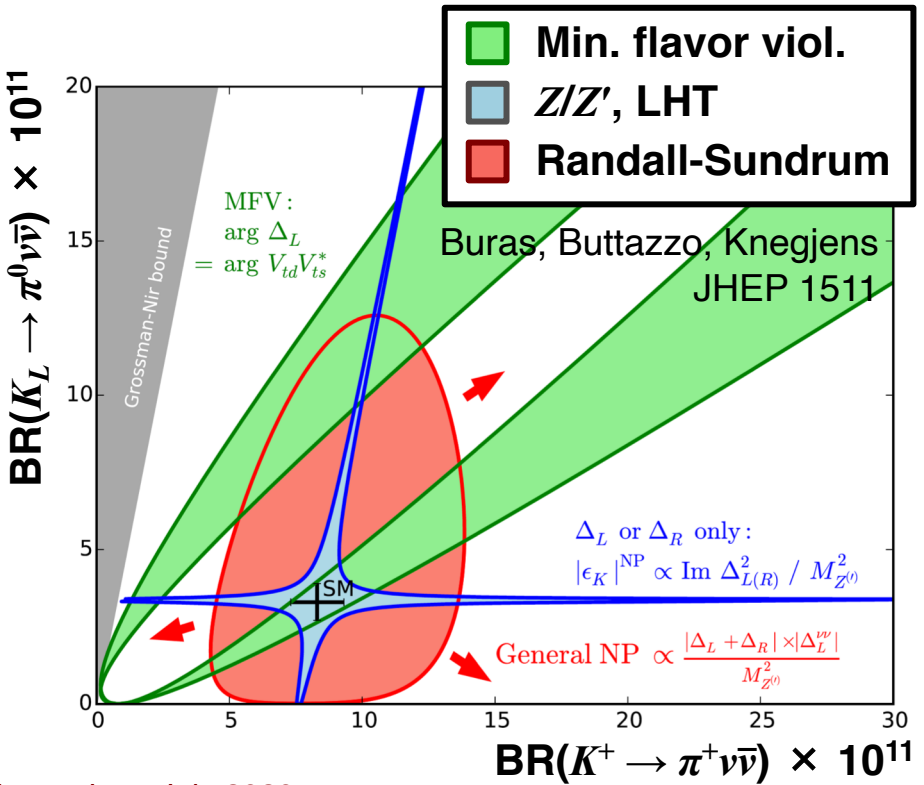
Buras et al, JHEP 1511*

**$K^+$ and $K_L$ BRs completely determine unitarity triangle:**




**New physics affects $K^+$ and $K_L$ BRs differently**

Can discriminate among different models

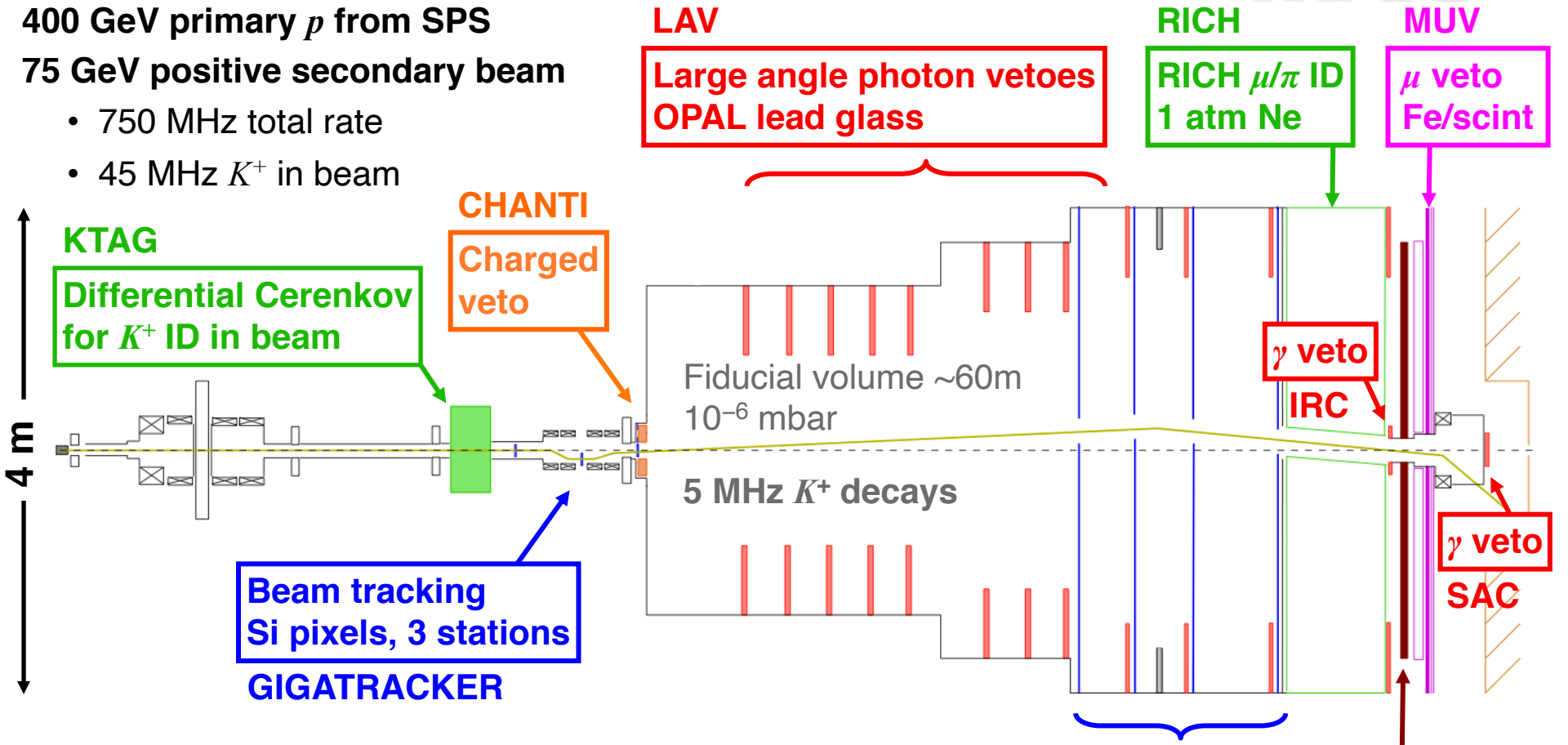


# The NA62 experiment at the SPS

**400 GeV primary $p$ from SPS**

**75 GeV positive secondary beam**

- 750 MHz total rate
- 45 MHz $K^+$ in beam




- **High-rate, precision tracking**
- **Redundant particle ID & $\mu$ vetoes**
- **Hermetic photon vetoes**
- **High-performance EM calorimeter**

**Dipole spectrometer**
**4 straw-tracker stations**
**STRAW**

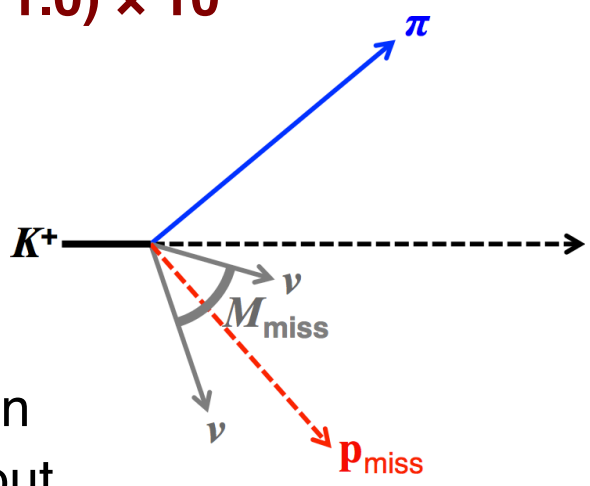
**Forward $\gamma$ veto**
**NA48 LKr**
**LKr**

0 50 100 150 200 250 m

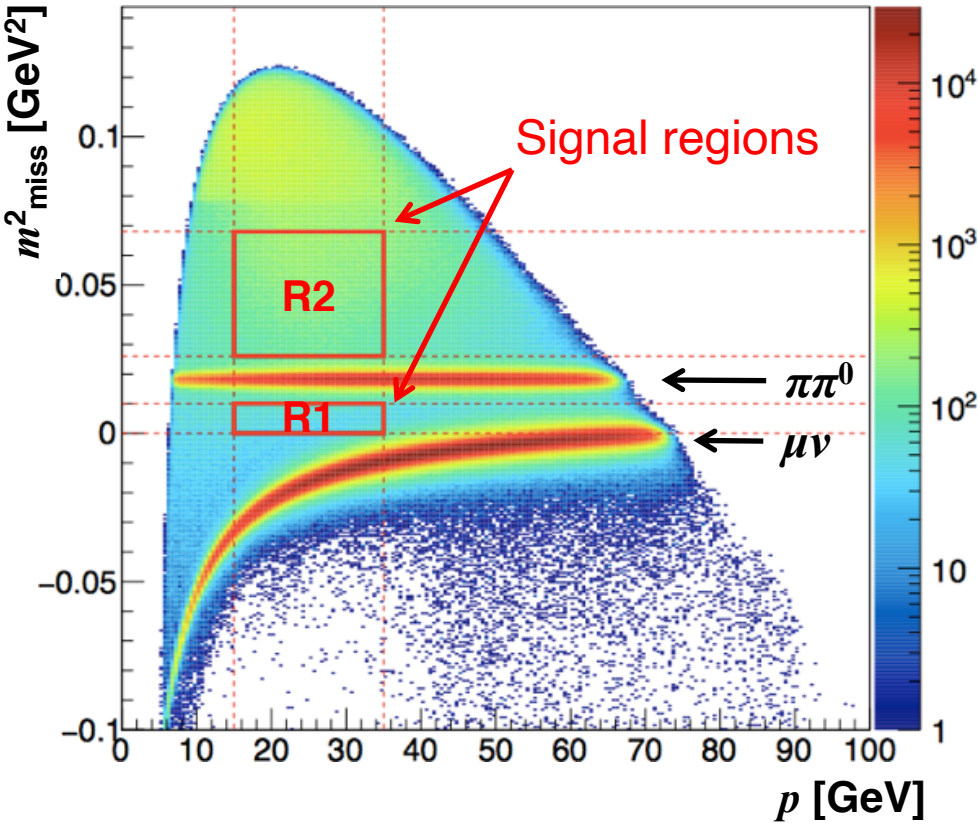
# $K^+ \to \pi^+ \nu\bar{\nu}$ with decay in flight

**Signal:**

**BR = (8.4 ± 1.0) × $10^{-11}$**




- $K$ track in
- $\pi$ track out
- No other particles in final state
- $M^2_{\text{miss}} = (p_K - p_\pi)^2$




**Main backgrounds:**

| | |
|---|---|
| $K^+ \to \mu^+ \nu(\gamma)$ | **BR = 63.5%** |
| $K^+ \to \pi^+ \pi^0(\gamma)$ | **BR = 20.7%** |

**Selection criteria:**

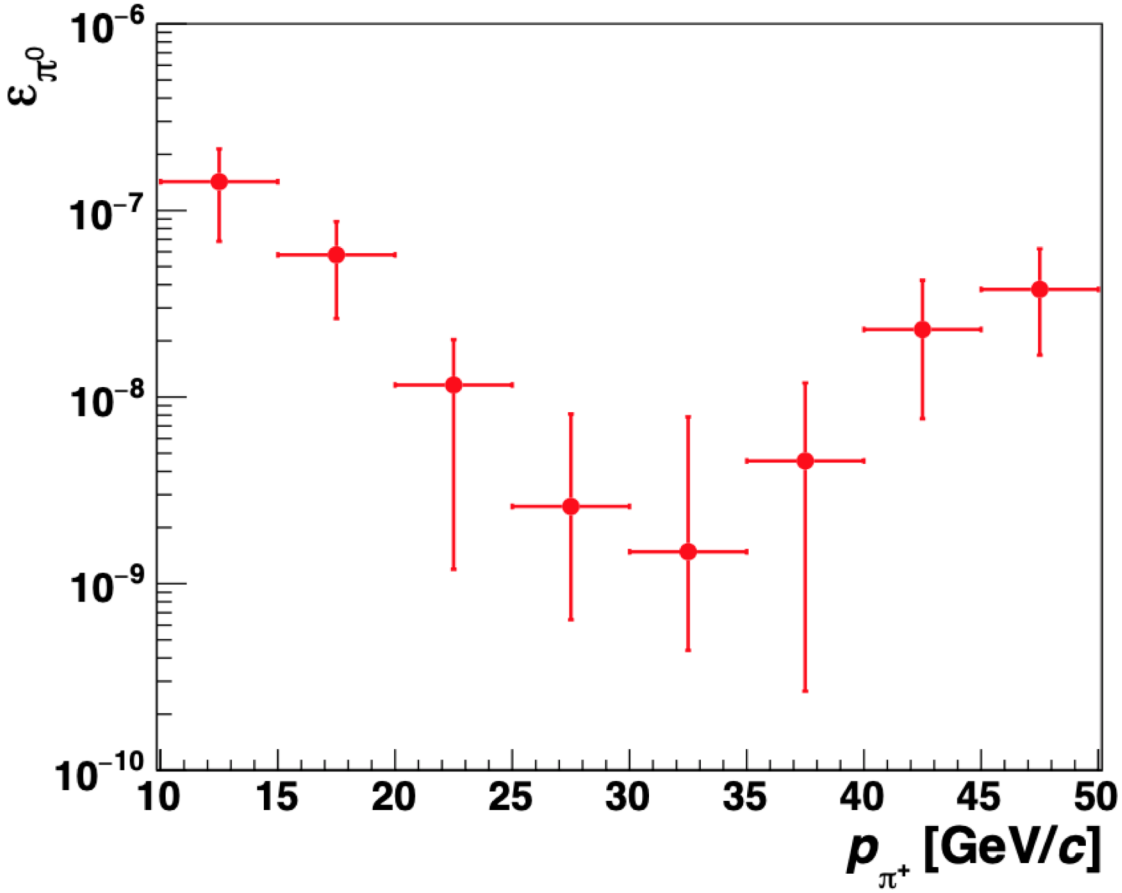
- $K^+$ beam identification
- Single track in final state
- $\pi^+$ identification ($\varepsilon_\mu \sim 10^{-8}$)
- $\gamma$ rejection ($\varepsilon_{\pi 0} \sim 10^{-8}$)

# Photon efficiency: $\pi^0 \to$ invisible

Evaluation of $\pi^0$ rejection from single-photon detection efficiency measurements
Use $K^+ \to \pi^+\pi^0$ events from $K^+ \to \pi^+\nu\nu$ control sample ($0.015 < m^2 < 0.021$ GeV$^2$)

- Single-$\gamma$ detection efficiency from data by tag-and-probe
- Overall $\pi^0$ rejection from single-$\gamma$ efficiencies by convolution with MC
- Expected $\pi^0$ rejection:
  **$2.8^{+5.0}_{-2.1} \times 10^{-9}$**
  25 GeV $< p_{\pi^+} <$ 40 GeV
- Background expected:
  $10^{+22}_{-8}$ $K^+ \to \pi^+\pi^0$
- Events observed: 12

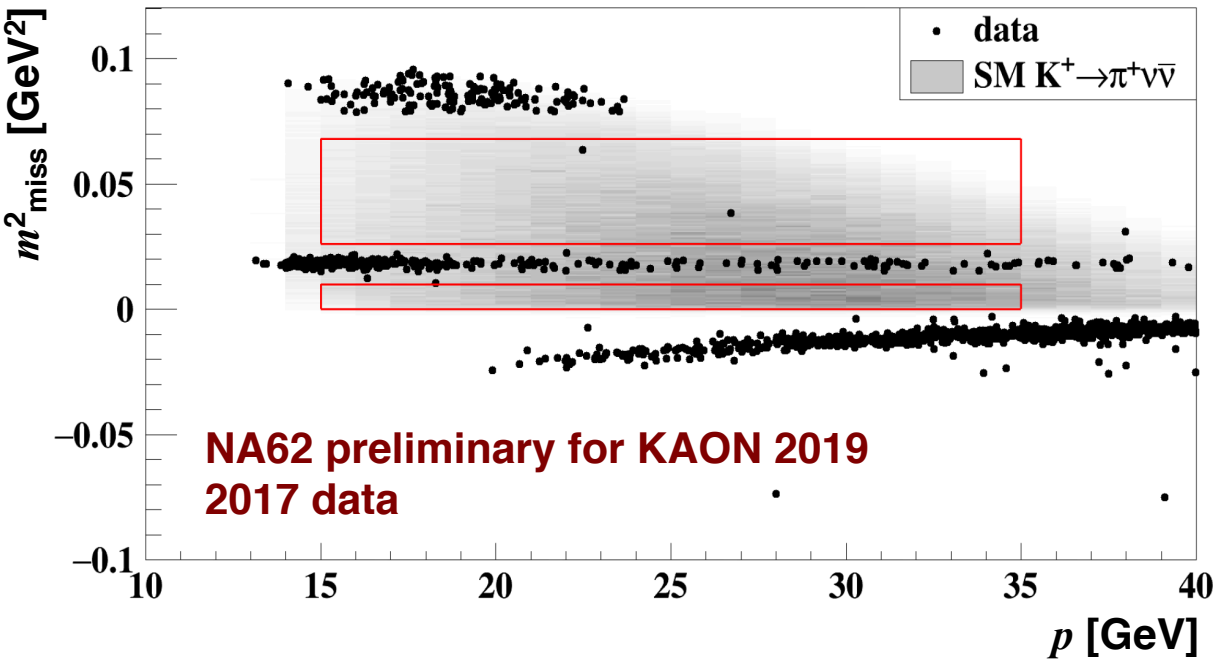
**Article in preparation**




**BR($\pi^0 \to$ invisible): $< 4.4 \times 10^{-9}$ (90%CL)**

60x more stringent than previous best result

# BR($K^+ \to \pi^+ \nu\bar{\nu}$) from 2016-17 data




| Run | $K^+$ decays |
|---|---|
| 2016 | $1.2 \times 10^{11}$ |
| 2017 | $2 \times 10^{12}$ |
| 2018 | $4 \times 10^{12}$ |

**2016-17 preliminary KAON 2019**

**SES = (3.46 ± 0.17) × $10^{-11}$**

**Expected signal 2.43 ± 0.29**

**Expected bkgd 1.65 ± 0.31**

**3 events observed in R2**

**NA62 preliminary: 2017 data**

| Background source | Expected events R1 + R2 |
|---|---|
| **$K^+ \to \pi^+ \nu\nu$ (SM)** | **$2.16 \pm 0.12_{stat} \pm 0.26_{ext}$** |
| $K^+ \to \pi^+\pi^0(\gamma_{IB})$ | $0.29 \pm 0.03_{stat} \pm 0.03_{sys}$ |
| $K^+ \to \mu^+\nu(\gamma_{IB})$ | $0.11 \pm 0.02_{stat} \pm 0.03_{sys}$ |
| $K^+ \to \pi^+\pi^-e^+\nu$ | $0.12 \pm 0.05_{sys} \pm 0.03_{sys}$ |
| Upstream background | $0.9 \pm 0.2_{stat} \pm 0.2_{sys}$ |
| **Total background** | **$1.5 \pm 0.2_{stat} \pm 0.2_{sys}$** |

**BR($K^+ \to \pi^+ \nu\nu$)**

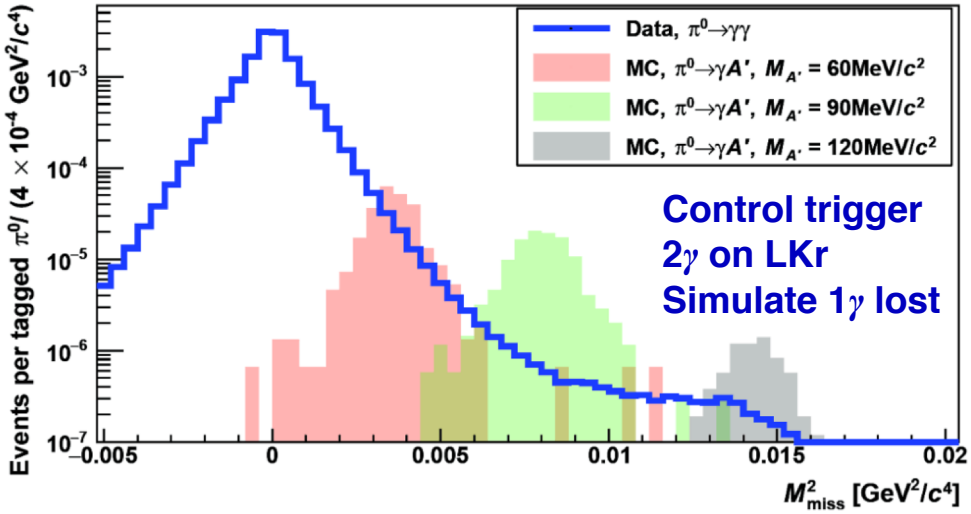
**< 18.5 × $10^{-11}$ (90%CL)**

- **Article in preparation**
- Preliminary update with 2018 data expected soon
- 2016-2018 sensitivity O(10) SM $K^+ \to \pi^+ \nu\nu$ events

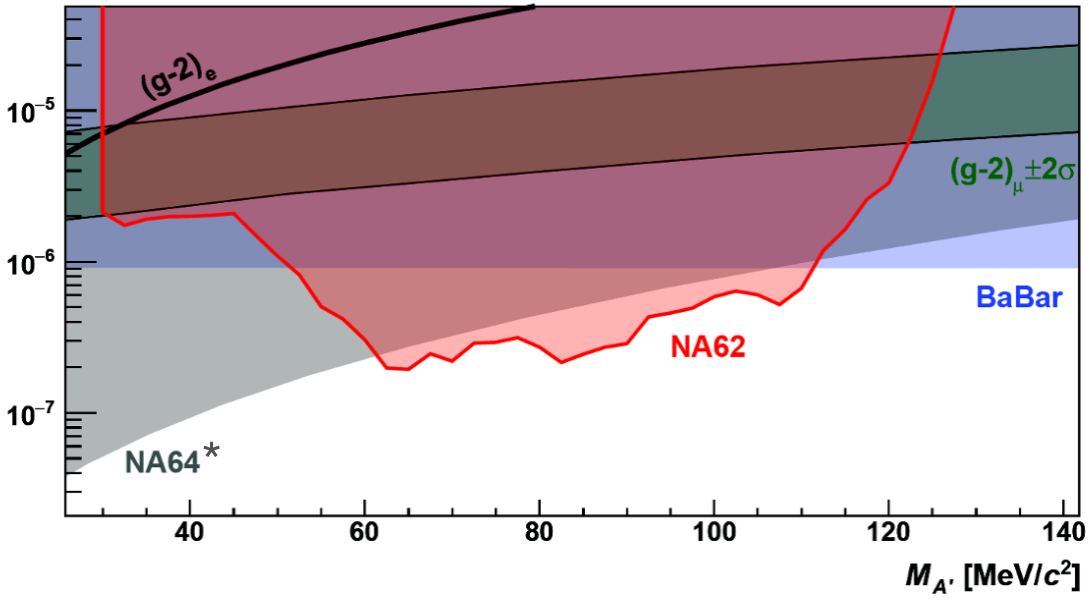
# Dark photons with invisible decays

**Search for $K^+ \to \pi^+\pi^0$ with $\pi^0 \to \gamma A'$ and $A'$ invisible**

- Sensitivity for $m_{A'} < m_{\pi 0}$
- Signal: 1 track + 1 $\gamma$ + missing energy
- Search for missing mass peak corresponding to $A'$
- Main background: $\pi^0 \to \gamma\gamma$ with 1 $\gamma$ lost




**JHEP 1905 (2019) 182**



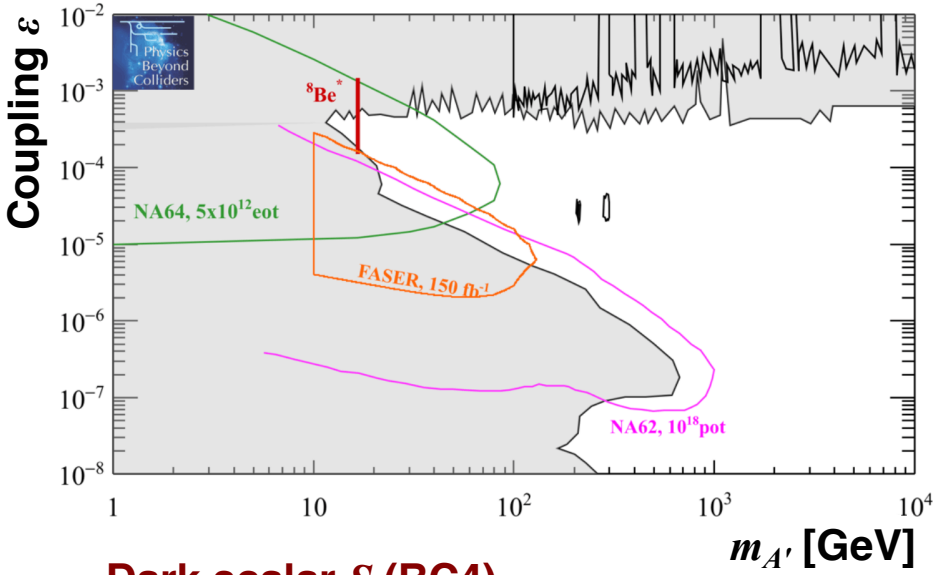

**Result from 2016 subsample (1% of NA62 data)**

- **$4.1 \times 10^8$ $\pi^0$ decays**
- Background from negative $m_{\text{miss}}$ resolution tail from control data
- No significant excess observed
  90% CL UL within expected statistical uncertainty band

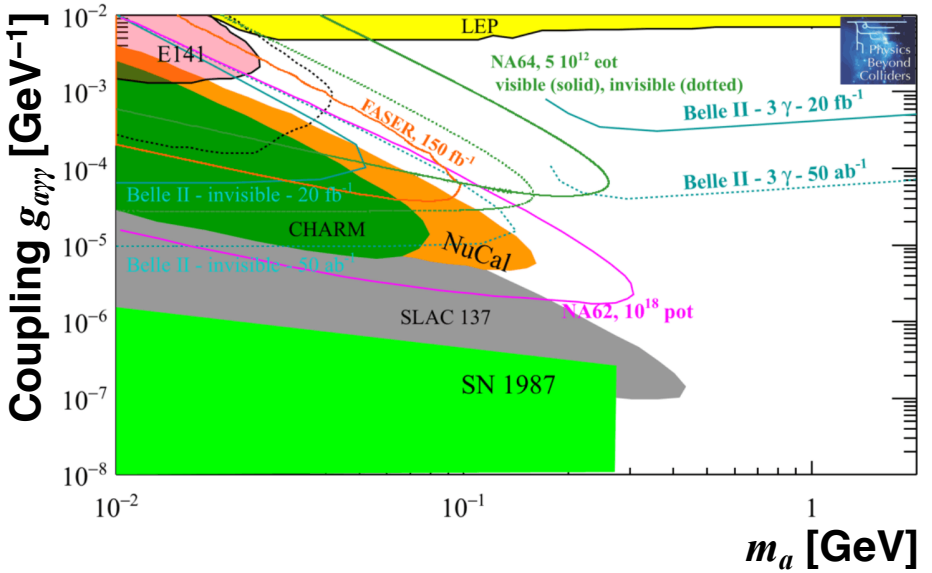
* NA64 UL since updated, but prospects for future NA62 limits remain competitive

# Physics reach with beam dump

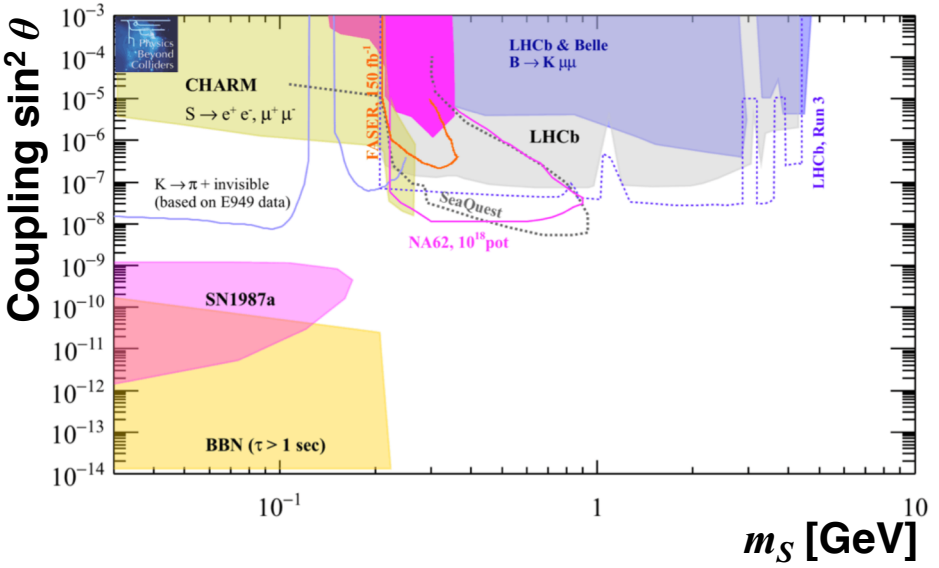
## Dark photon $A'$ with visible decays (BC1)




## ALP $a$ coupled to photons (BC9)




## Dark scalar $S$ (BC4)




**LNF group coordinates exotic physics program**

**Sensitivity estimates for exotic particle searches in beam dump mode**

- Assumes $10^{18}$ pot in dump mode
  = few months dedicated run in Run III
- Validated with $3 \times 10^{16}$ pot taken in Run II
- Calculated for Physics Beyond Colliders
  **J. Phys. G 47 (2019)**

# $K \to \pi\nu\bar{\nu}$ in Run III and beyond

## Data taking in Run III: July 2021 – end of 2024

- Collect $10^{18}$ pot in beam-dump mode to search for exotic particles
- Suppress background from upstream decays and interactions
  - Modifications to beamline
  - Add 4th station to GTK beam tracker
  - New counters to veto background from beam activity
- Run at maximum beam intensity (possibly higher in beam dump mode)
- **Expect to measure BR($K^+ \to \pi^+\nu\nu$) to < 20%**

## Beyond Run III: 2026+

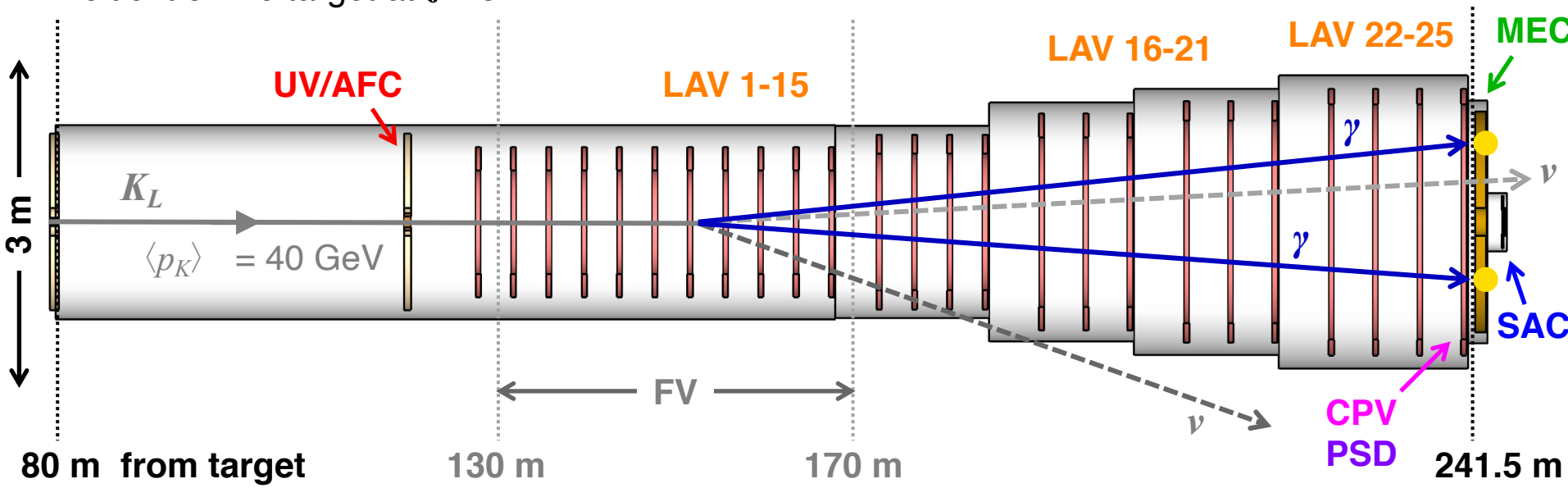
- Fixed target runs planned to accompany LHC running through 2035
- Support from European Strategy for fixed-target running, including $K$ physics
- Measuring all rare $K$ decay modes—charged and neutral—can give clear insight about flavor structure of new physics

Need an ***integrated program*** with ambitious ***new detector:***

1. **"NA62x4": BR($K^+ \to \pi^+\nu\nu$) to 5% with 4x current beam intensity**
2. **KLEVER: BR($K_L \to \pi^0\nu\nu$) to 20% with 6x current beam intensity**
3. **$K_L \to \pi^0\nu\nu$ and other rare and forbidden $K_L$ decays**

# A $K_L \to \pi^0 \nu\bar{\nu}$ experiment at the SPS

400-GeV SPS proton beam ($2 \times 10^{13}$ pot/16.8 s)
incident on Be target at $z$ **= 0 m**




**KLEVER target sensitivity:**
**5 years starting Run 4**

**60 SM $K_L \to \pi^0 \nu\nu$**
**$S/B \sim 1$**

**$\delta$BR/BR($\pi^0 \nu\nu$) ~ 20%**

**Main detector/veto systems:**

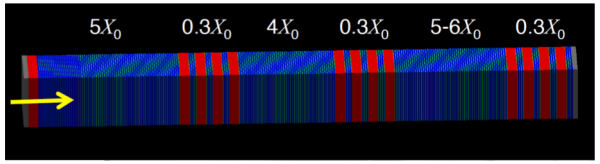
| | |
|---|---|
| **UV/AFC** | Upstream veto/Active final collimator |
| **LAV1-25** | Large-angle vetoes (25 stations) |
| **MEC** | Main electromagnetic calorimeter |
| **SAC** | Small-angle vetoes |
| **CPV** | Charged particle veto |
| **PSD** | Pre-shower detector |

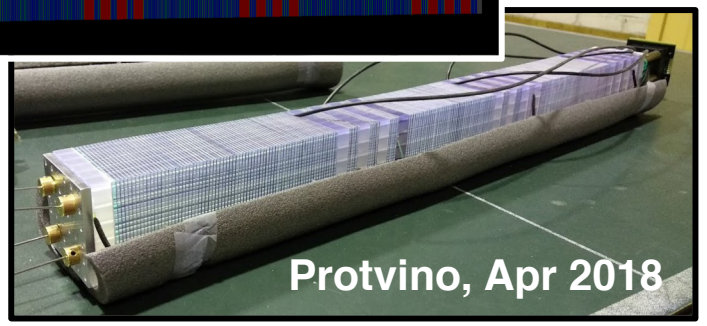
# Planned future activity at Frascati

## Photon efficiency measurements at BTF-2 will be key to KLEVER R&D

- Precision measurements of detection efficiency with single electrons
- Development of techniques for efficiency measurements with tagged photons

## BTF test of shashlyk calorimeter with spy tiles (MEC) for 2021



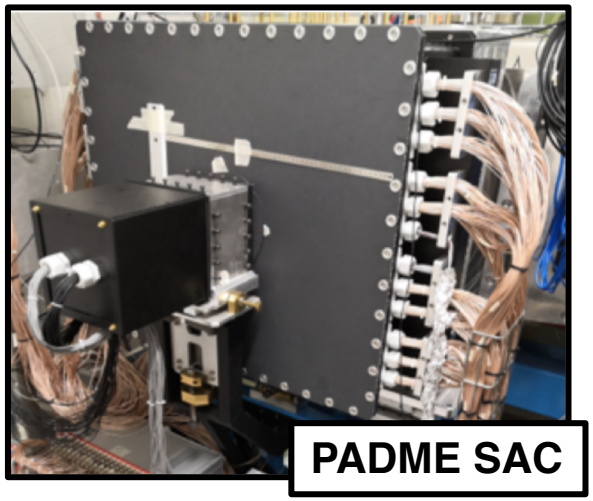




Fine-sampling: 0.275 mm Pb + 1.5 mm scintillator

Spy tiles measure longitudinal shower development:

- Identification of $\mu$, $\pi$, $n$ interactions
- Improved time resolution for EM showers

## Development of ultra-fast calorimeter to intercept beam exit (SAC)




**Synergy with PADME SAC upgrade for future running with continuous beam: AIDAinnova project**

Desired characteristics:

- > 100 MHz sustained rates
- $\sigma_t$ < 100 ps; 2-pulse separation at ~ 1 ns
- Good radiation resistance

Could use $PbF_2$, but validation required for use at continuous high rates and high radiation doses

# Richieste CSN1 per il 2021

| Sigla | Ric | Tec | FTE | MISS | CON |
|---|---|---|---|---|---|
| **NA62** | **9** | **0** | **6.8** | **91.5 kE*** | **20.5 kE*** |

* Stime ancora in fase di discussione con coordinamento nazionale

**Anagrafica:**

| | |
|---|---|
| Antonella Antonelli | 100% |
| Gaia Lanfranchi | 20% |
| Silvia Martellotti | 100% |
| Matteo Martini | 30% |
| Matthew Moulson | 100% |
| Tommaso Spadaro | 80% |
| Gemma Tinti | 100% |

***Associati: Sofia***

| | |
|---|---|
| Venelin Kozhuharov | 50% |
| Vanessa Stoyanova | 100% |

**Servizi:**

**2020:**

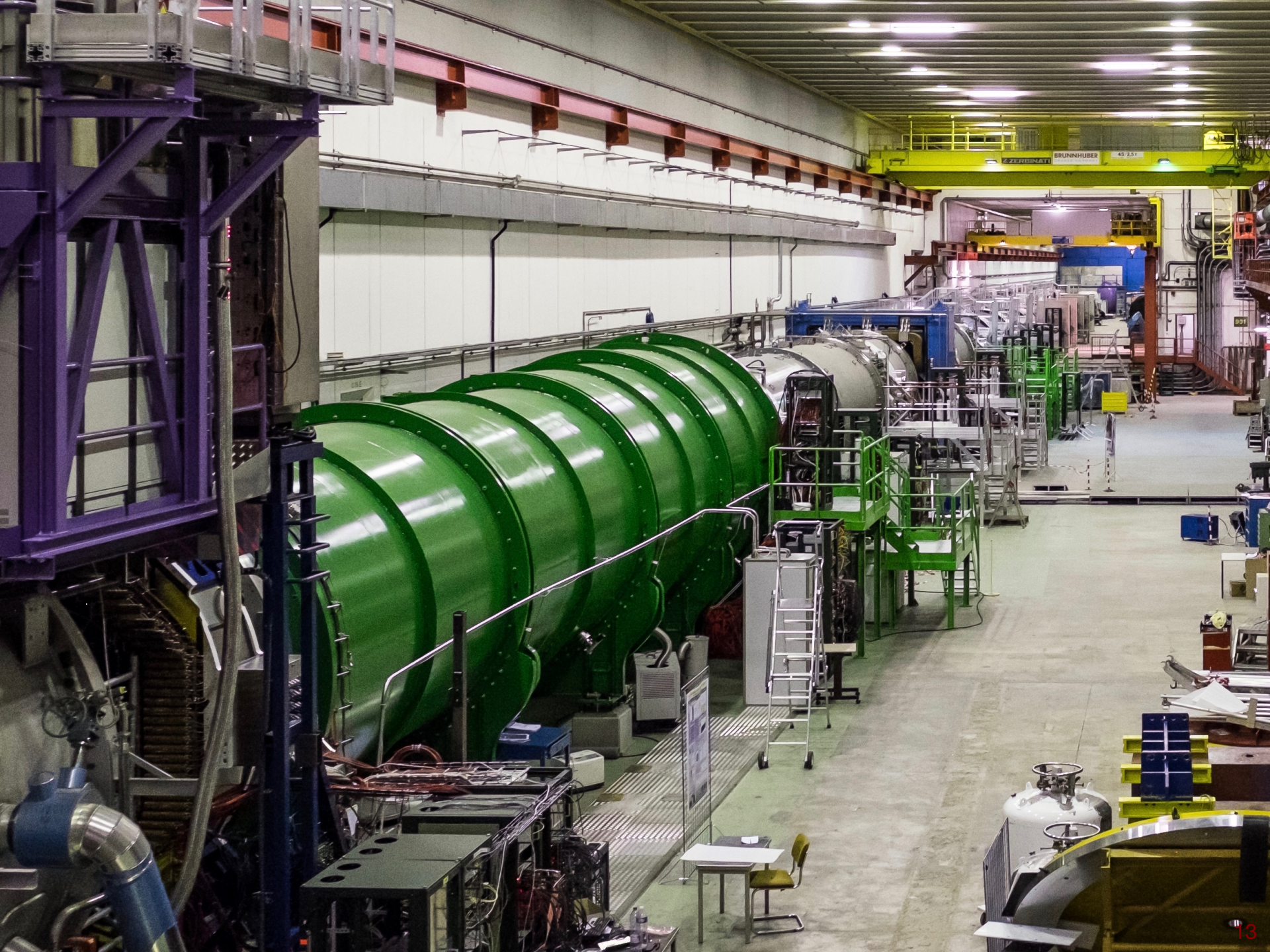
**Servizio Elettronica & Automazione 2MU**

Manutenzione LAV e istallazione sistema di calibrazione in preparazione per ripartenza luglio 2021

**2021 (stimata):**

**Servizio Elettronica & Automazione 2MU**

Perfezionamento preparativi e supporto run 2021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