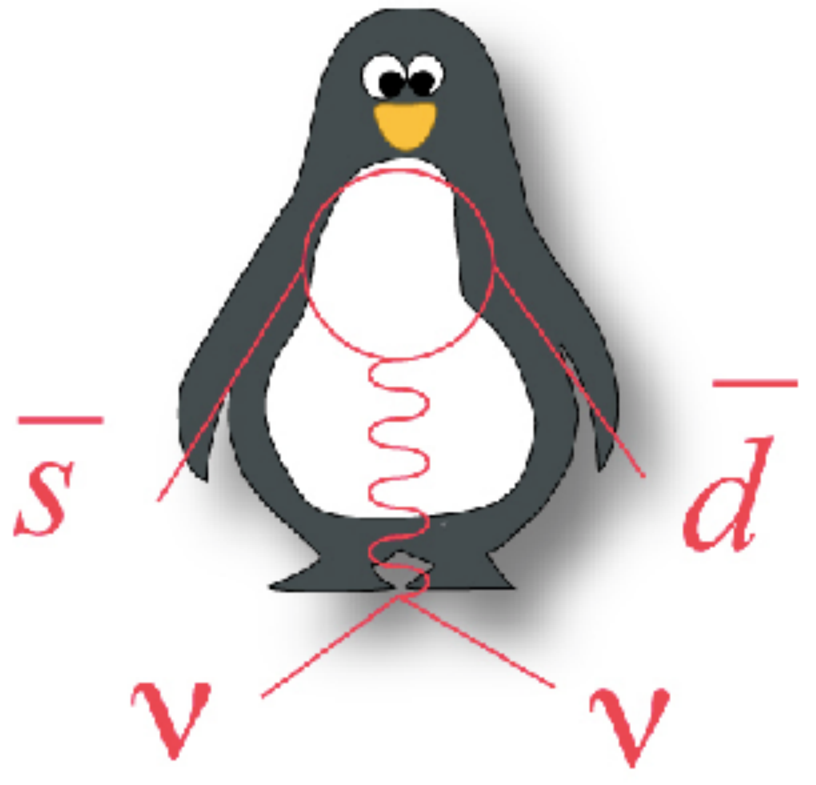


NA62

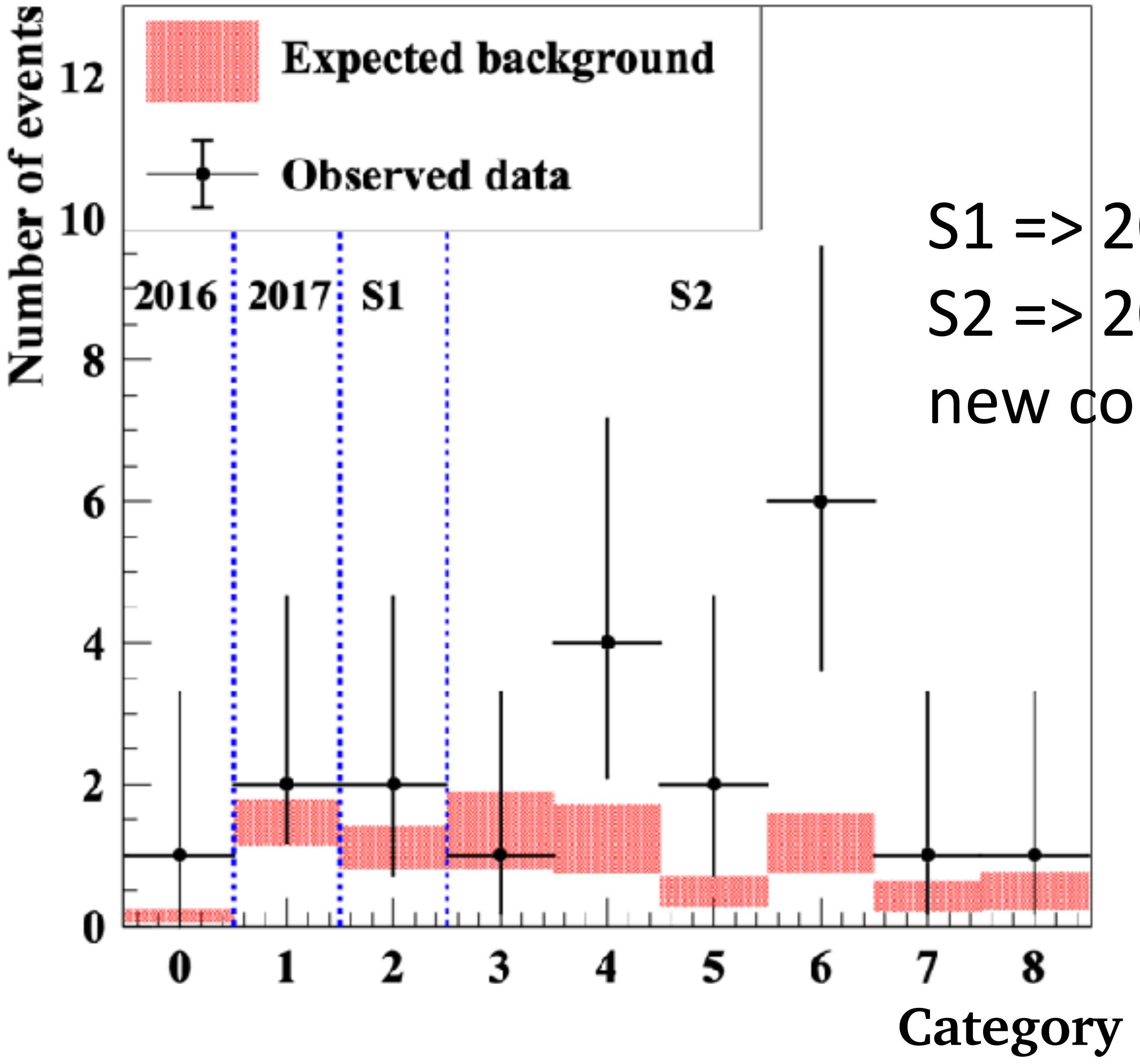
Consiglio dei Laboratori - Preventivi 2024

Silvia Martellotti, 6 Luglio 2023

NA62 result from Run 1 (2016-2018)

$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9_{\text{syst}}) \times 10^{-11} \quad 68\% \text{ CL}$$

JHEP06(2021)093



S1 => 2018
S2 => 2018 with new collimator

$$N^{\text{exp}}_{\pi\nu\bar{\nu}} = 10.01 \pm 0.42_{\text{syst}} \pm 1.19_{\text{ext}}$$

$$N^{\text{exp}}_{\text{bkg}} = 7.03^{+1.05}_{-0.82}$$

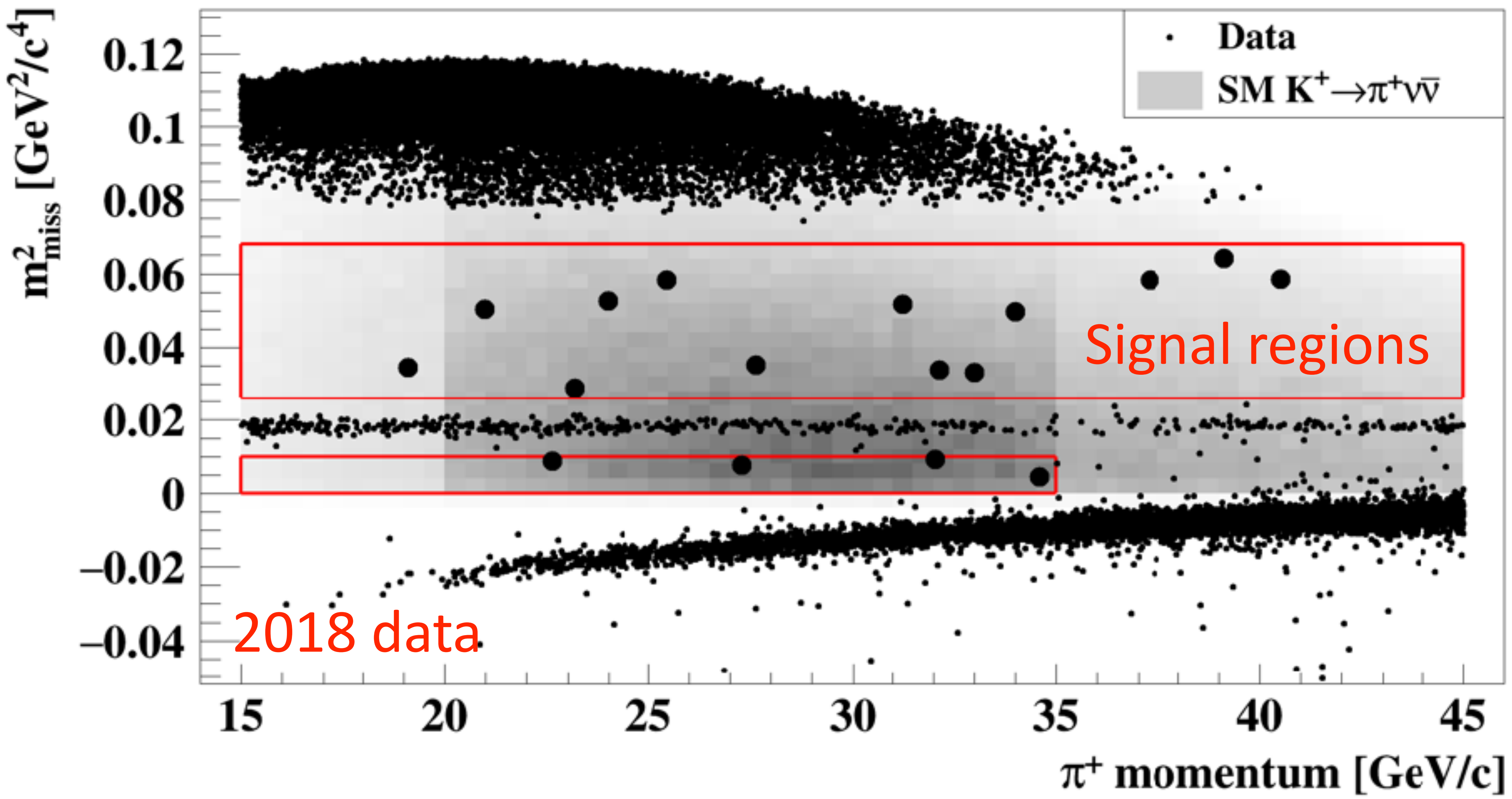
$$N_{\text{obs}} = 20$$

NA62 performance

- O(100 ps) timing
- ~10^3 kinematic bkg suppression
- ~10^8 μ^+ suppression
- ~10^8 π^0 suppression

Recorded Intensity:
Tot PoT ~ 2.2 x 10^{18}

$$m^2_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$$

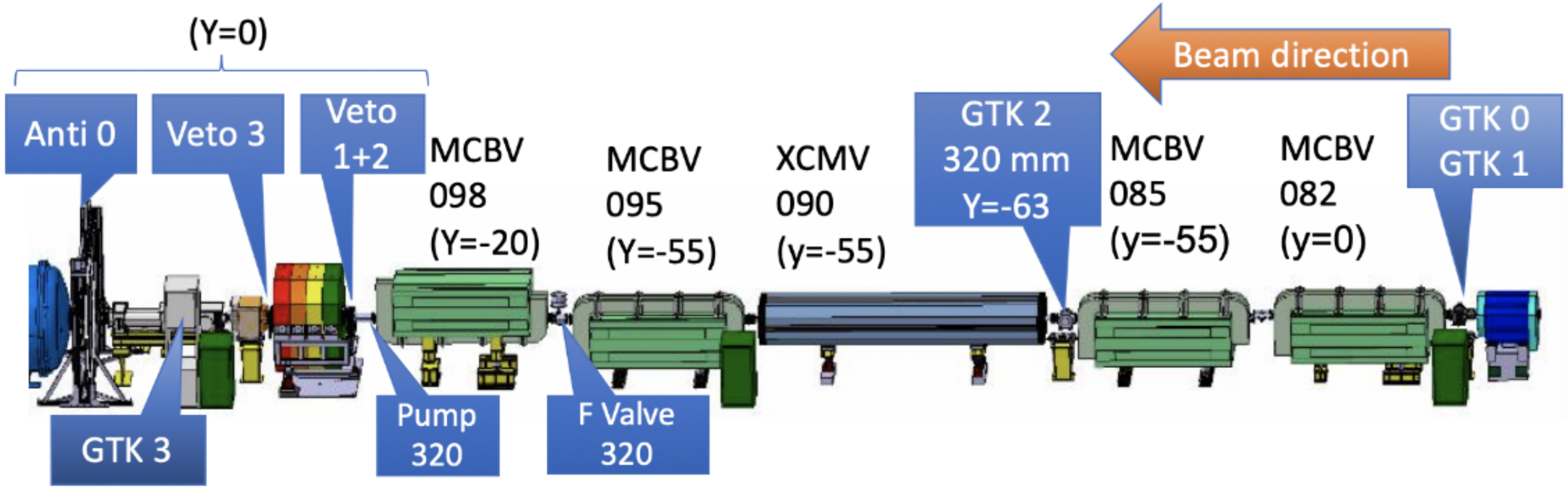


NA62 Run 2 (2021-2025)

SPSC has approved NA62 run up to the LS3 end
Goal is to measure BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) with a precision matching the theoretical one (O(10%))

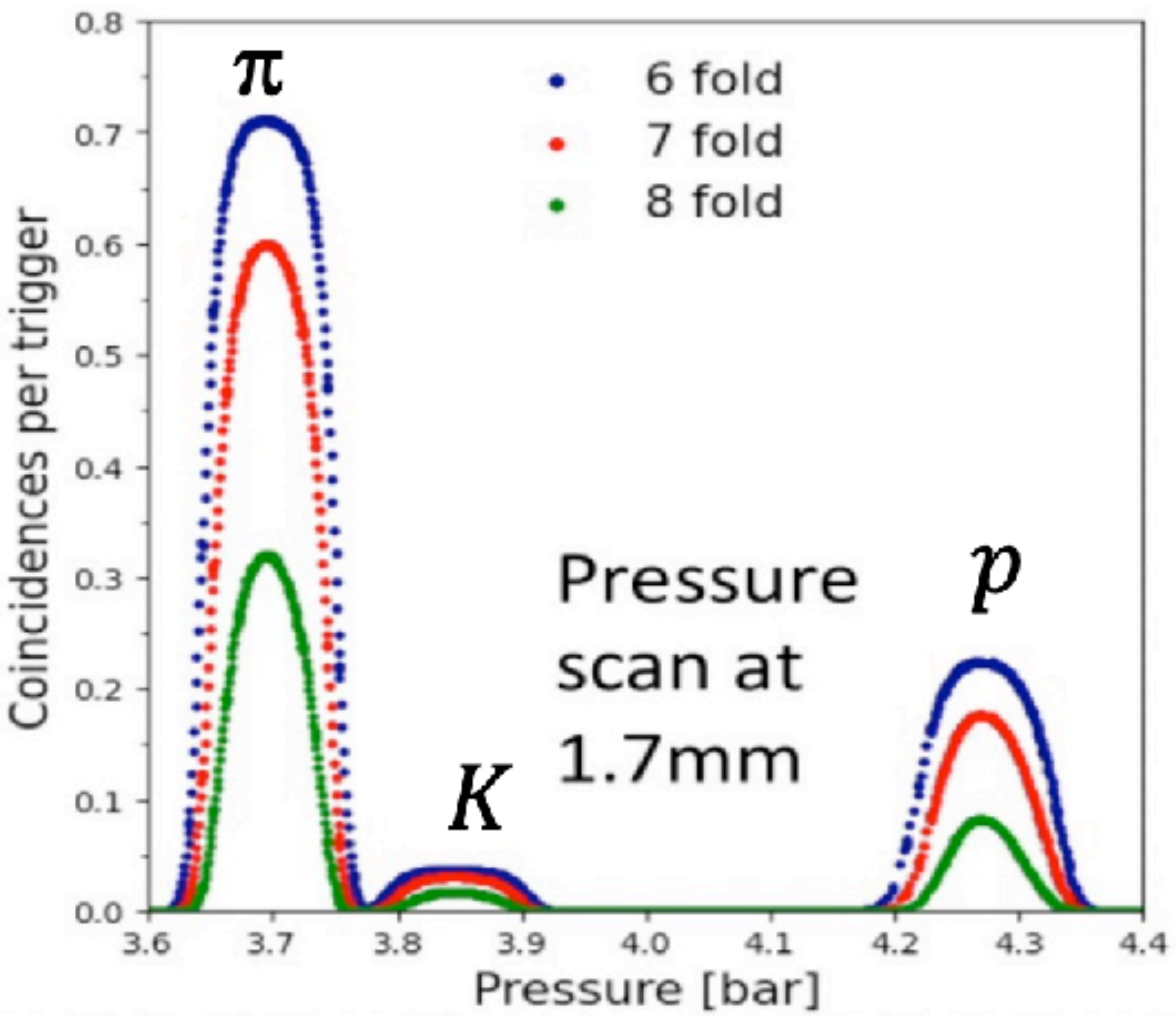
Upgrade from 2021

- A 4th GTK station (**GTK0**) to improve efficiency, time resolution and K-π matching
- VetoCounter detectors upstream (**Veto 1+2** and **Veto 3**) to reduce upstream background
- Veto detector at the beginning of the Fiducial Volume (**Anti 0**) for muon halo
- Small calorimeter downstream (**HASC**) to improve rejection of photons from conversions in the RICH pipe



Upgrade from 2023

- **Cedar-H** (instead of Nitrogen) to reduce material along the beam line
- **L0TP+** new trigger processor



NA62 Run 2 (2021-2025)

Year	Weeks	Bursts	Good Bursts	Beam intensity	PNN/good burst
2022	29	403 k	320 k	100% of nominal	$O(2.5 \times 10^{-5})$
2021	18	145 k	120 k	100% of nominal	WIP
2018	31	520 k	450 k	65 % of nominal	1.7×10^{-5}
2017	24	300 k	254 k	50% of nominal	0.8×10^{-5}
2016	8	84 k	67 k	40% of nominal	0.4×10^{-5}

2023:
22 weeks …

Expected events in signal region:

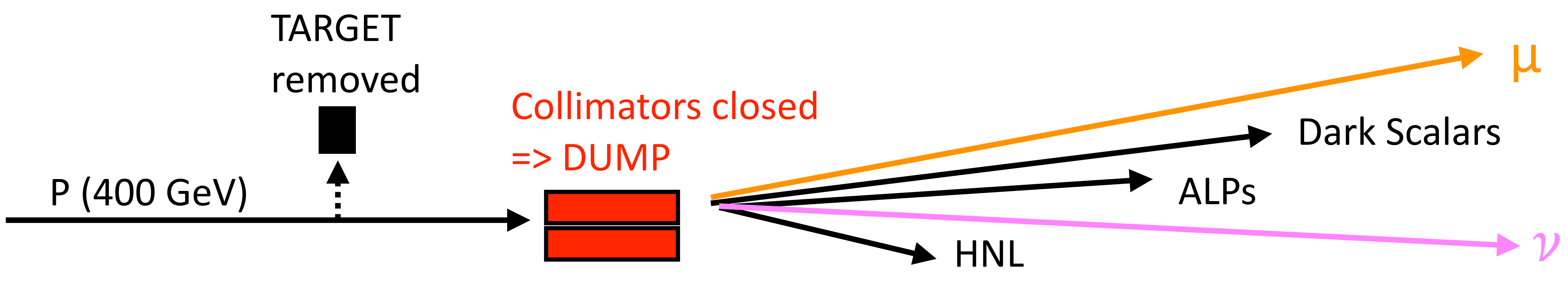
Process	2018	2022	
$K^+ \to \pi^+\pi^0(\gamma)$	0.75 ± 0.05	0.82 ± 0.03	$\longrightarrow$ Data driven
$K^+ \to \mu^+\nu(\gamma)$	0.64 ± 0.08	0.74 ± 0.06	$\nearrow$
$K^+ \to \pi^+\pi^+\pi^-$	0.22 ± 0.08	0.09 ± 0.02	$\longrightarrow$ Data + MC
$K^+ \to \pi^+\pi^- e^+\nu$	0.51 ± 0.10	0.31 ± 0.16	$\longrightarrow$ MC
Upstream	$3.30^{+0.98}_{-0.73}$	WIP	
$K^+ \to \pi^+\nu\bar{\nu}$ (SM)	7.58 ± 0.85	8.00 ± 1.1	

47% increase of $\pi\nu\nu$/burst w.r.t. 2018:

$$\underbrace{1.45}_{\text{Intensity}} \times \underbrace{1.2}_{\text{Acceptance}} \times \underbrace{0.95}_{\text{Reconstruction}} \times \underbrace{0.90}_{\text{Trigger/DAQ efficiency}} = 1.49$$

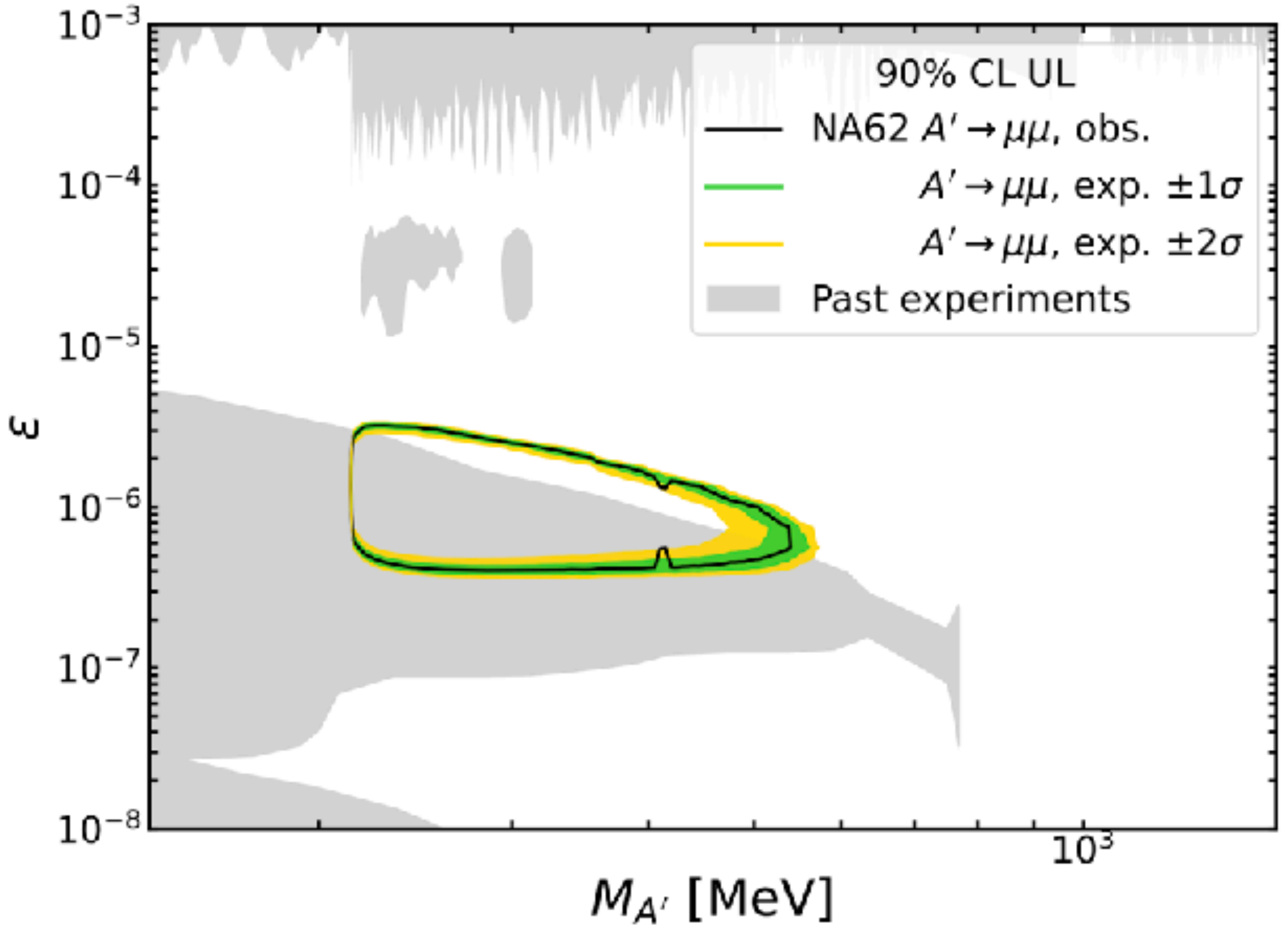
New result based on 2021+2022 data (with analysis improvement with respect to the past) hopefully by end-2023

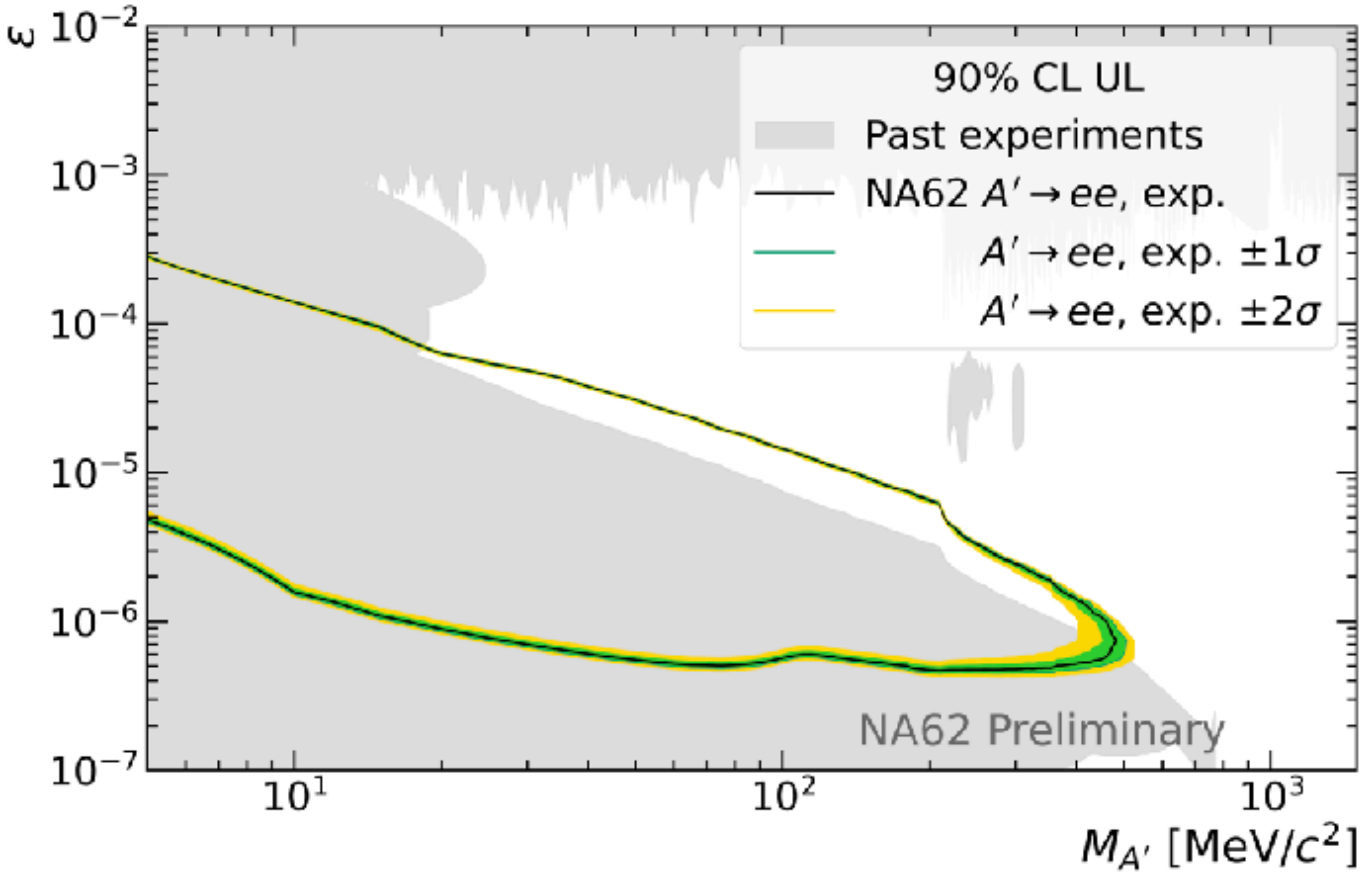
NA62 in beam dump mode



- Target removed
- 3.2 m Cu-Fe collimators put in the p beam path
- ~ 1.5 x nominal beam intensity

2021 data: $(1.4 \pm 0.28) \times 10^{17}$ PoT, from a cut-based counting experiment blind analysis a 90% CL upper limit has been set for $A' \to \mu^+\mu^-$ and $A' \to e^+e^-$ exploring a new region of the parameter space





Papers in preparation T.Spadaro (WG coordinator) et al…

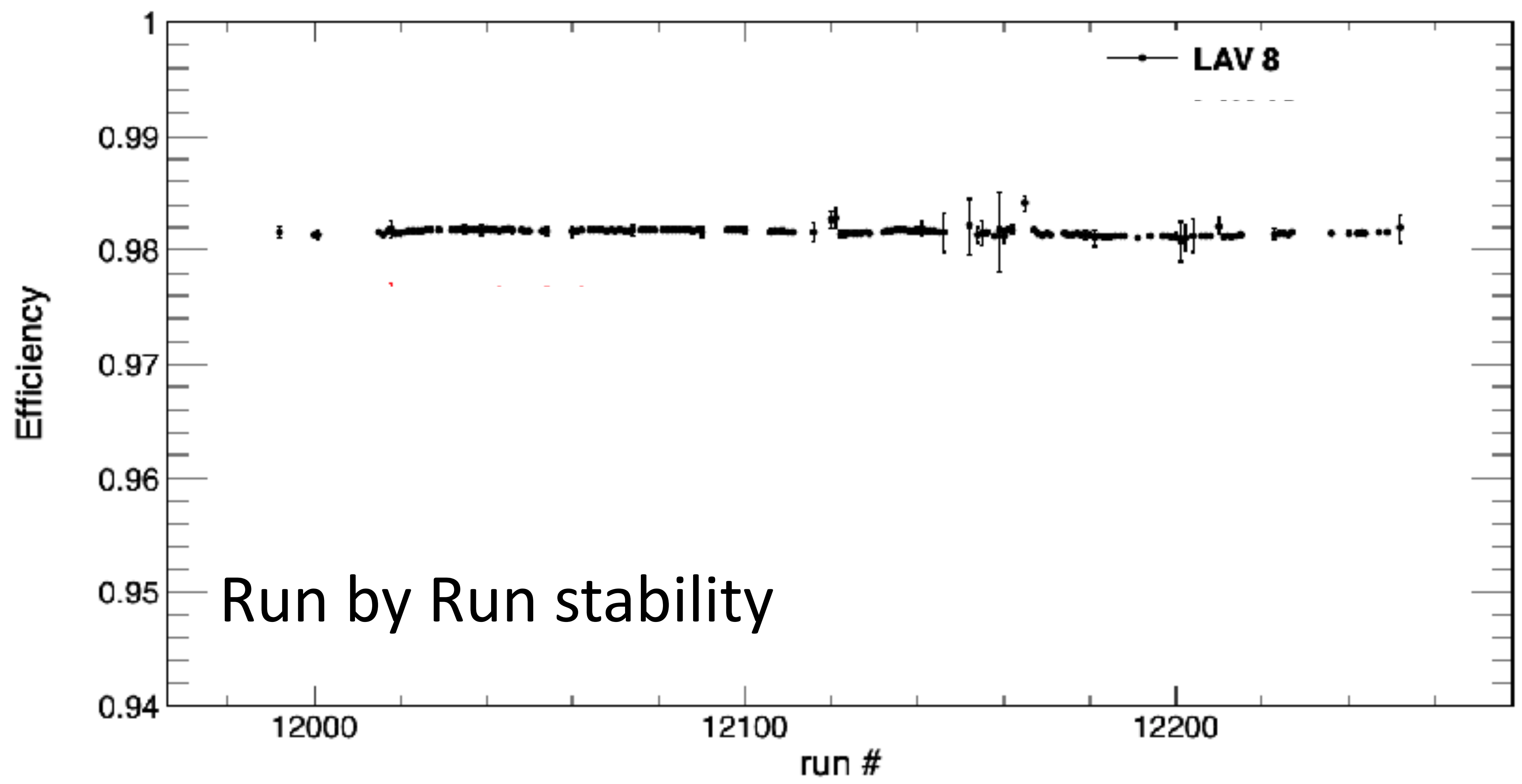
10^{17} PoT in beam dump mode foreseen for 2023 —> **10^{18} PoT in Run2**

- Expected background in SR: 0.016 ± 0.002 events
- 1 event observed (2.4σ significance)

- Expected background in SR: $0.0094^{+0.049}_{-0.009}$ events
- No event observed

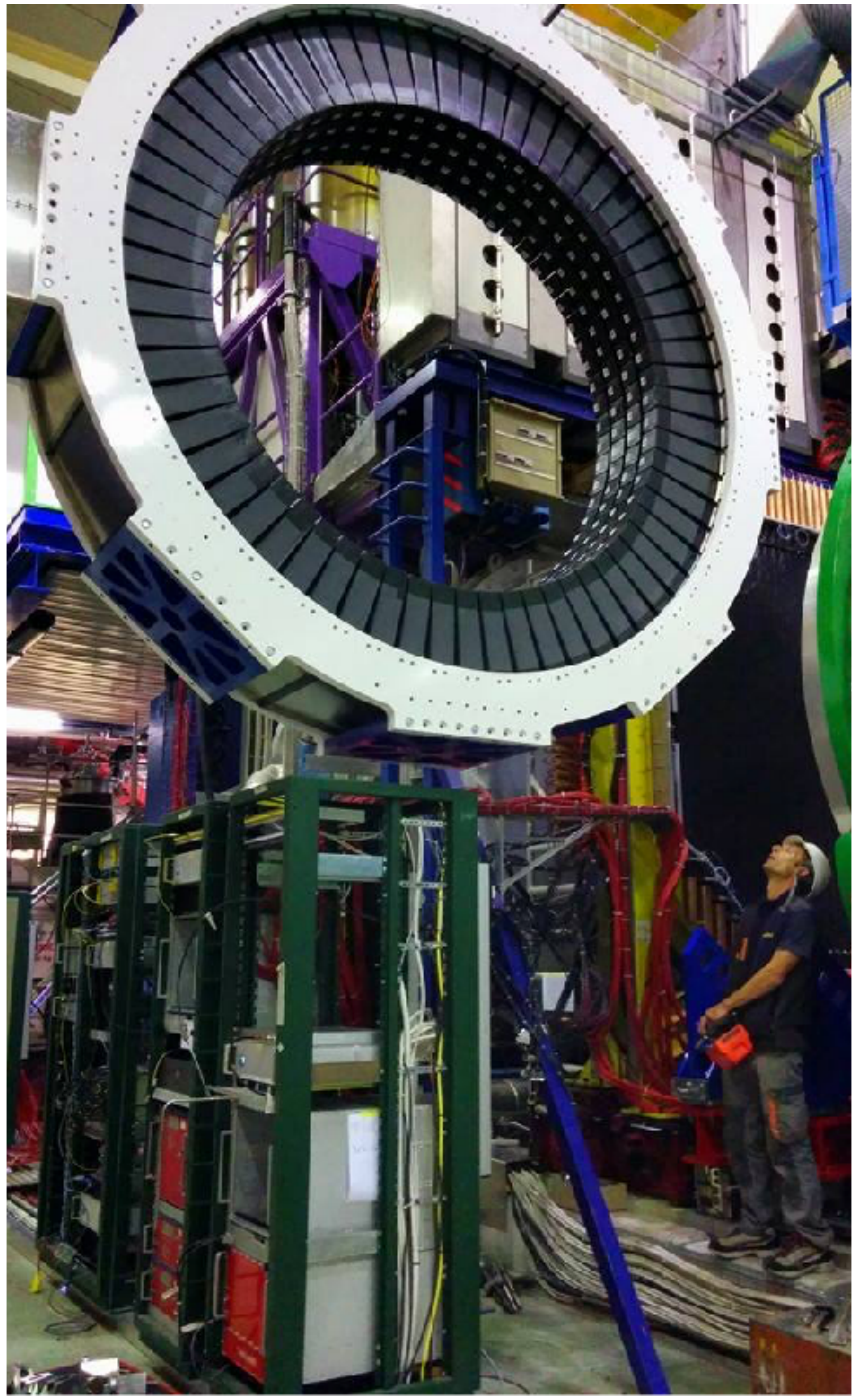
NA62 - LNF group

- Maintenance, operation, and analysis of data from two of the experiment’s main photon detection systems, the Large-Angle Veto (LAV) system and the Small-Angle Veto (SAV) system. Online and offline data quality
- General support to the experiment, assisting with run planning and coordination, and participating in data taking: continuous on-call expert support throughout the entire period
- Analysis of data acquired in 2021-2022 and measurement of system performance



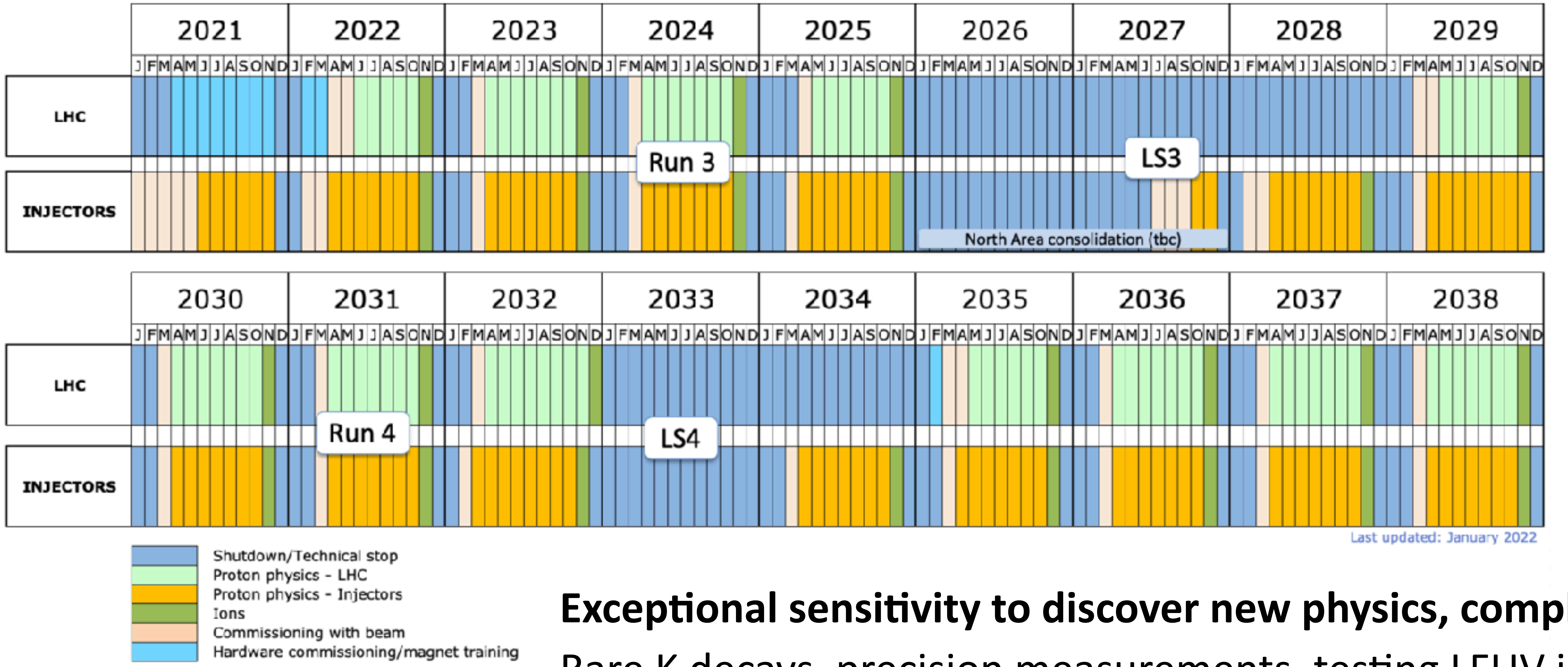
LAV Photon efficiency measured offline with $\pi^+\pi^0$

- Studies for $\pi\nu\nu$ analysis improvement. LAV random veto reduction, GTK reconstruction with machine learning
- New LAV veto trigger algorithm at L1



Future program after LS3

- In EU Strategy document 2020 (CERN-ESU-014) “Rare kaon decays at CERN” are mentioned in “Other essential activities for particle physics” .
- An integrated program with multiple phases, K^+ + K_L beams and dump mode is widely studied and discussed inside Physics Beyond Colliders working group



Fixed target runs could be planned to accompany LHC running from 2028-29

Exceptional sensitivity to discover new physics, complementary to LHC:
Rare K decays, precision measurements, testing LFUV in K decays, complementary to B physics and with comparable sensitivity, exotic particles in K/dump

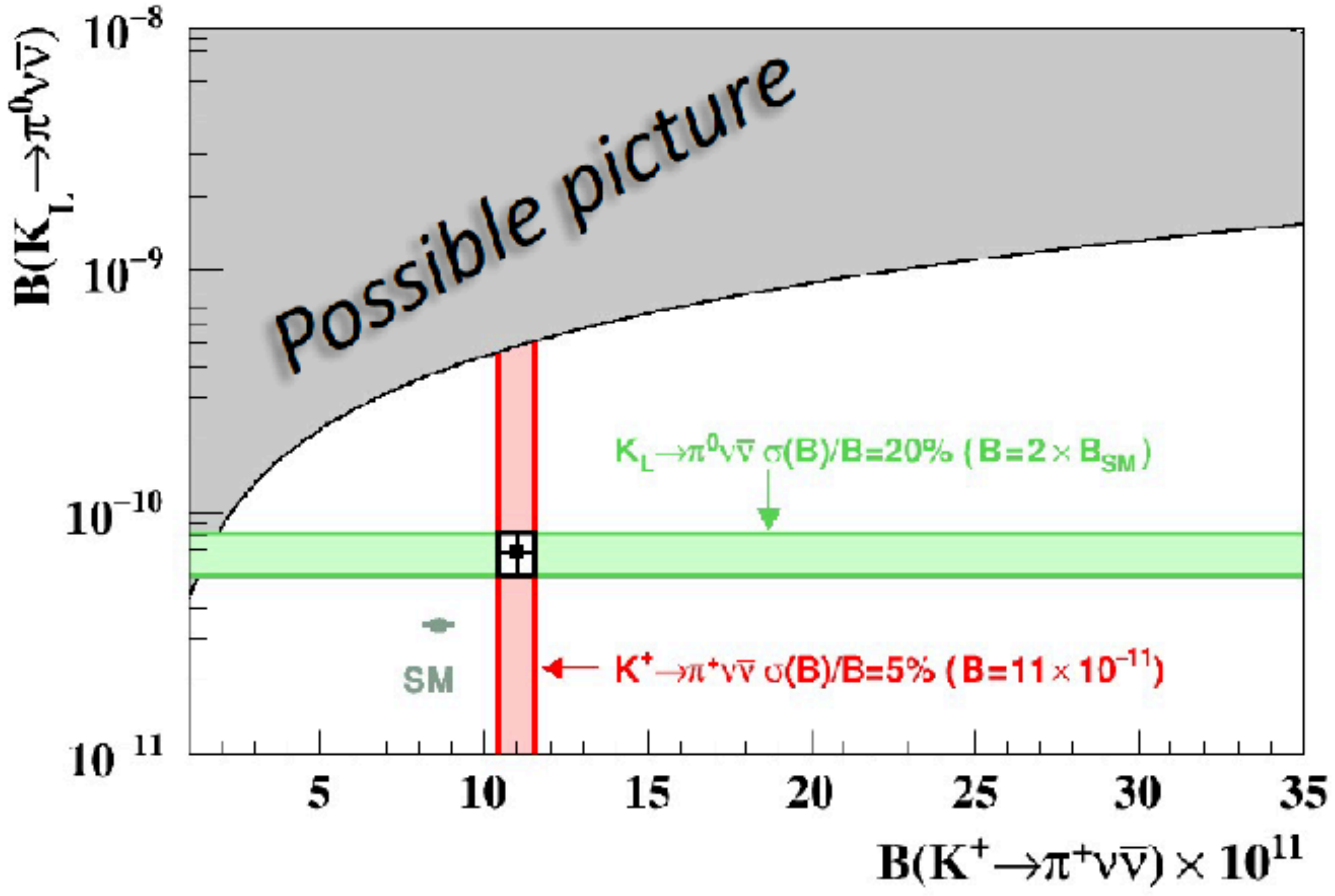
HIKE: High Intensity Kaon Experiment

Multi stage program: NA62x4 + KLEVER

- **K^+ at 4x NA62 intensity**: 500 $K^+ \to \pi^+ \nu\nu$ decays (after LS3 -2029)
- Transitional program: K_L beam, downstream tracking & PID like NA62.
- **K_L at 6x NA62 intensity**: 60 $K_L \to \pi^0 \nu\nu$ decays (after LS4 - 2035)
- Periodic runs in **beam dump mode** (10^{19} POT)

K^+ phase (NA62x4)		
$K^+ \to \pi^+ \nu\bar{\nu}$	$\sigma(\mathrm{BR}) \sim 5\%$	New physics in FCNC decays
$K^+ \to \pi^+ l^+ l^-$	For factors at $\sim 1\%$ level	LFUV
$K^+ \to \pi \mu e, \pi^- l^+ l^+$	$O(10^{-12})$ sensitivity	LFV, LNV
$R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$	$R_K \sim 0.1\%$	LFUV
$K^+ \to \pi^+ \gamma\gamma, \pi^+ \pi^0 \gamma, \pi^+ \pi^0 e^+ e^-$	as best as possible	Chiral parameters (LECs)
Hybrid phase		
$K_L \to \pi^0 l^+ l^-$	Observation	New physics in FCNC decays
$K_L \to \mu^+ \mu^-$	$\sigma(\mathrm{BR}) < 1\%$	New physics in FCNC decays
$K_L \to \mu^\pm e^\mp, \pi^0 \mu^\pm e^\mp$	$O(10^{-12})$ sensitivity	LFV
$K_L \to \gamma\gamma, \pi^0 \gamma\gamma$	as best as possible	Ancillary to $K_L \to \mu^+ \mu^-$ LECs
K_L phase (KLEVER)		
$K_L \to \pi^0 \nu\bar{\nu}$	$\sigma(\mathrm{BR}) \sim 20\%$	New physics in FCNC decays

Advantage: common upgrades for intensity and detectors , more flexibility on schedule



Decision Timeline for the ECN3 facility

- Candidate experiments for ECN3 have submitted a Letter of Intent (LoI) in November 2022 before the SPSC meeting

*"SPSC recognizes that the intensity upgrade of ECN3 opens up unique opportunities for potential high-impact particle physics programs at CERN. Therefore, the SPSC strongly recommends, in an experiment-agnostic way, the **intensity upgrade of ECN3**"*

- Research Board (RB) meeting on 13th March: support for a physics agnostic intensity upgrade of the ECN3 facility subject to Scientific Policy Committee endorsement and Medium Term Plan (MTP) funding. MTP approved with cost estimation of 60 MCHF
- Last step: approval at the June Scientific Policy Committee (CERN Council)

Which experiment will use ECN3 area? Decision expected by the end of 2023

- A detailed proposal has been asked by the SPSC to the candidate experiments by the end of August 2023
- Proposals will be discussed at September and November SPSC meetings with room for interaction with the referees. On November 2023 SPSC will chose the experiment and will recommend it to the RB for final decision.

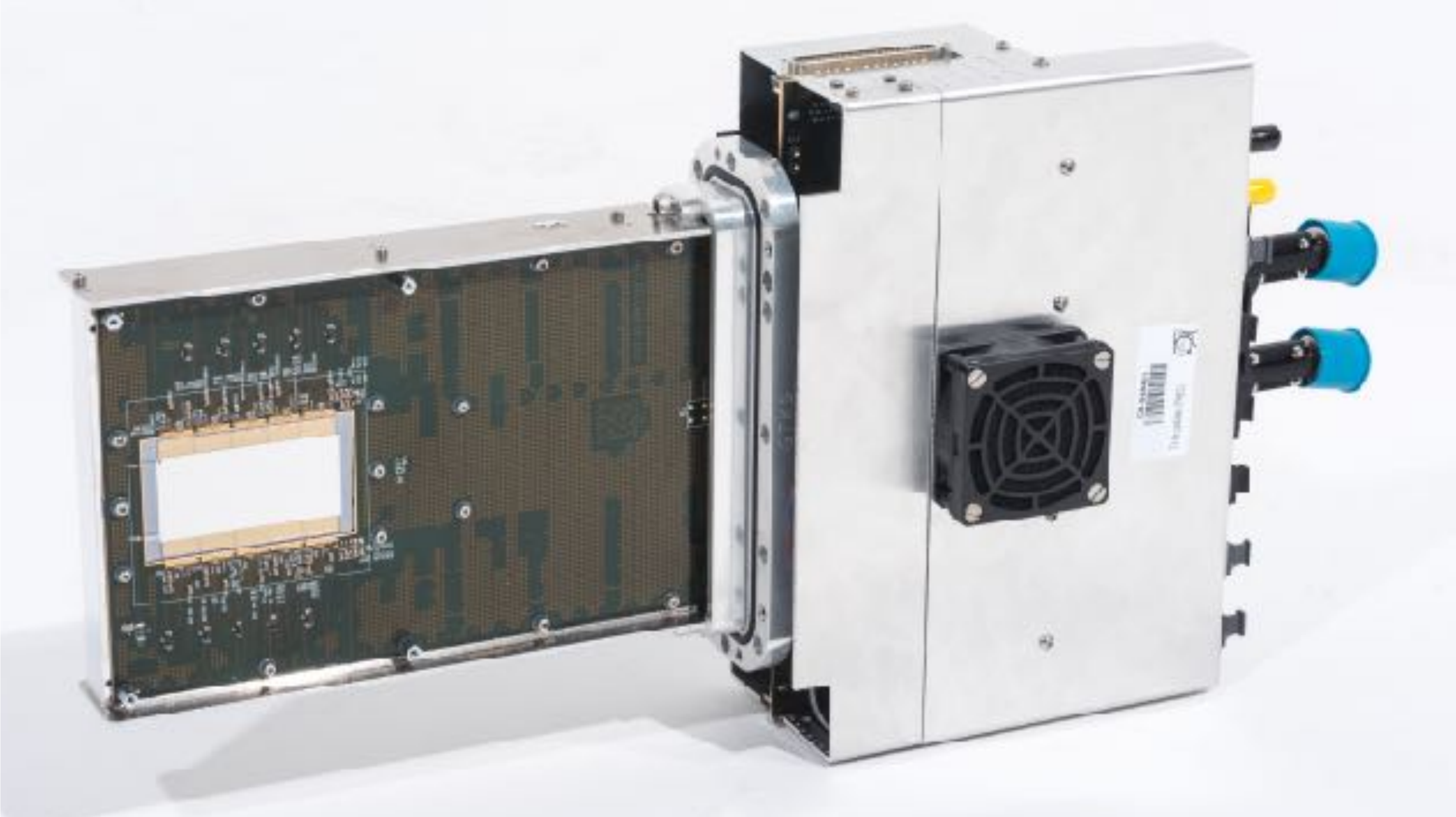
NA62x4 - K^+

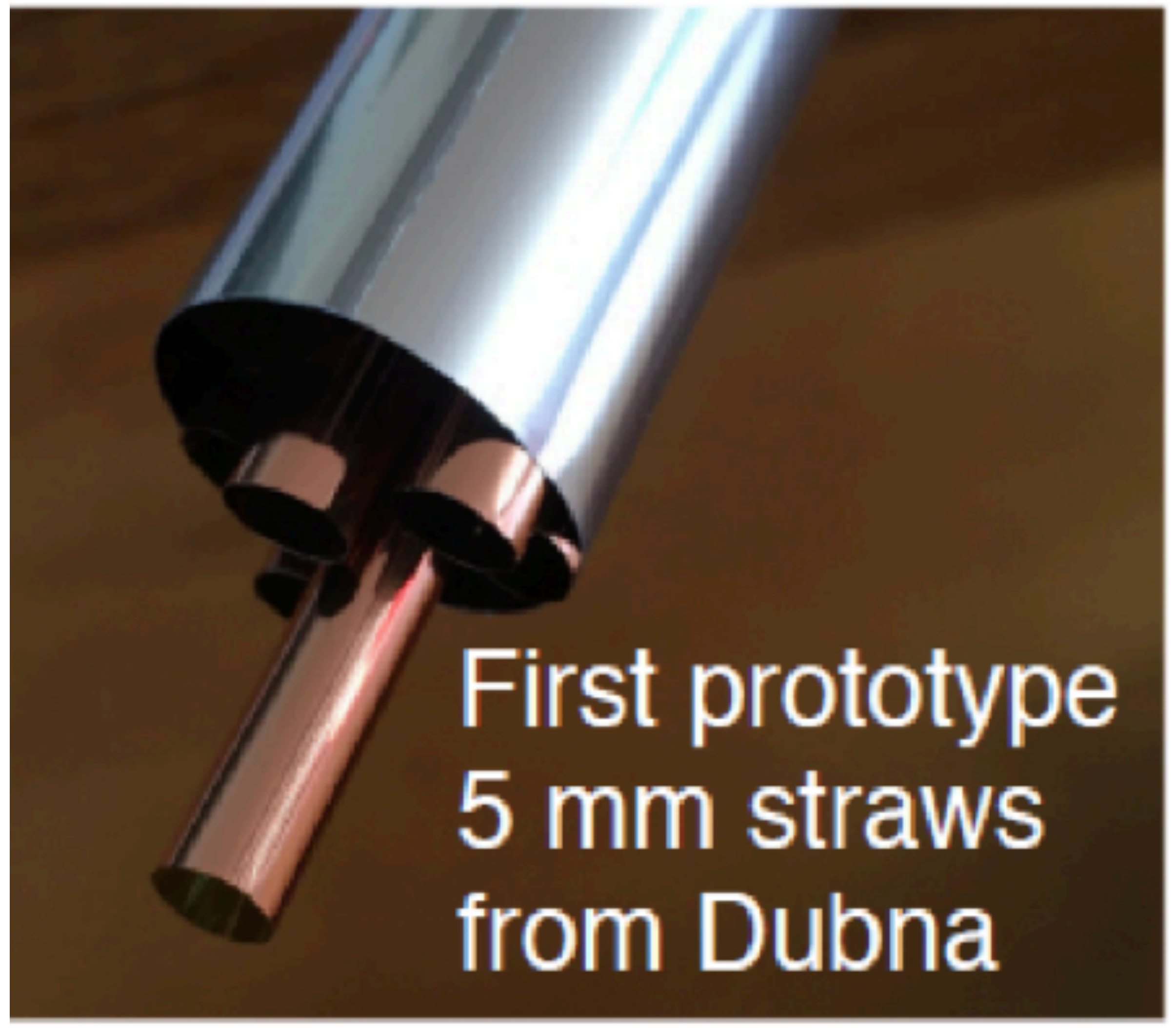
The NA62 upgrade for x4 intensity is based on the well consolidated NA62 running experience.
Challenge: **20–40 ps time resolution** for key detectors to keep random veto under control, while maintaining all other NA62 specifications. Appropriate modifications to the current design to cope with higher intensity

Key detectors upgrade and R&D:

GTK:

increase time resolution < 50 ps, beam intensity: 3 GHz over ~3x6 cm^2 (maximum 8 MHz/mm^2, radiation resistance: 2×10^{15} neq/cm/200days). Promising: TimeSpot ,GTK group in contact with Cagliari





STRAW:

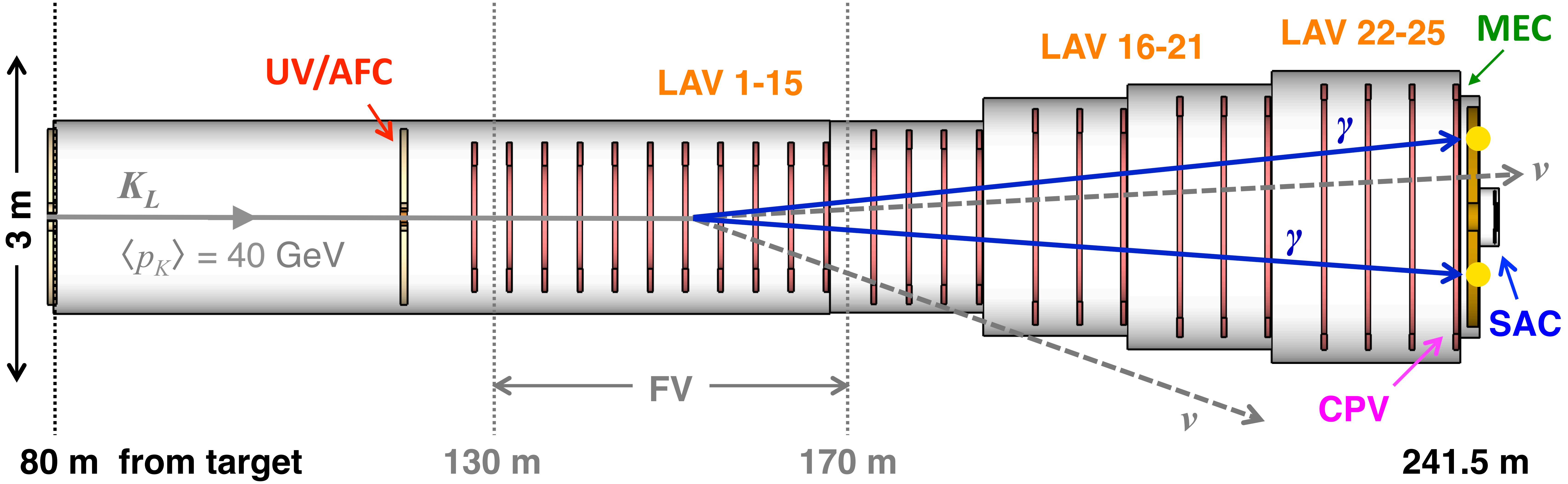
5 mm diameter (instead of 9.8 mm).
Improved trailing time resolution: 6 ns. Rate capability increased by factor 6-8. Reduced wall thickness (less material budget). Pre-production tests: Au/Cu coated Mylar film 5 m long straws with a 19 µm wall thickness have successfully been produced (CERN & Dubna)

All Calorimeters in common with K_L phase

KLEVER - K_L

Target sensitivity: measure BR($K_L \rightarrow \pi^0 \nu\nu$) with (O(20%)) precision.

~ 60 SM events in Run4 (5 years) with S/B ~1



Main detector/veto systems:

UV/AFC Upstream veto/Active final collimator

LAV 1-25 Large angle vetoes (25 stations)

MEC Main electromagnetic calorimeter

SAC Small angle calorimeter

CPV Charged particle veto

Main Italian group interest (led by Frascati, M.Moulson)

Well consolidated design (start on 2012 with PRIN project), detailed simulation of the beam line and detectors.
Input to the 2020 update of the European Strategy for Particle Physics

Beam line for KLEVER needs to be extended by ~150 m to mitigate Λ background.
Optimization on-going to improve signal efficiency

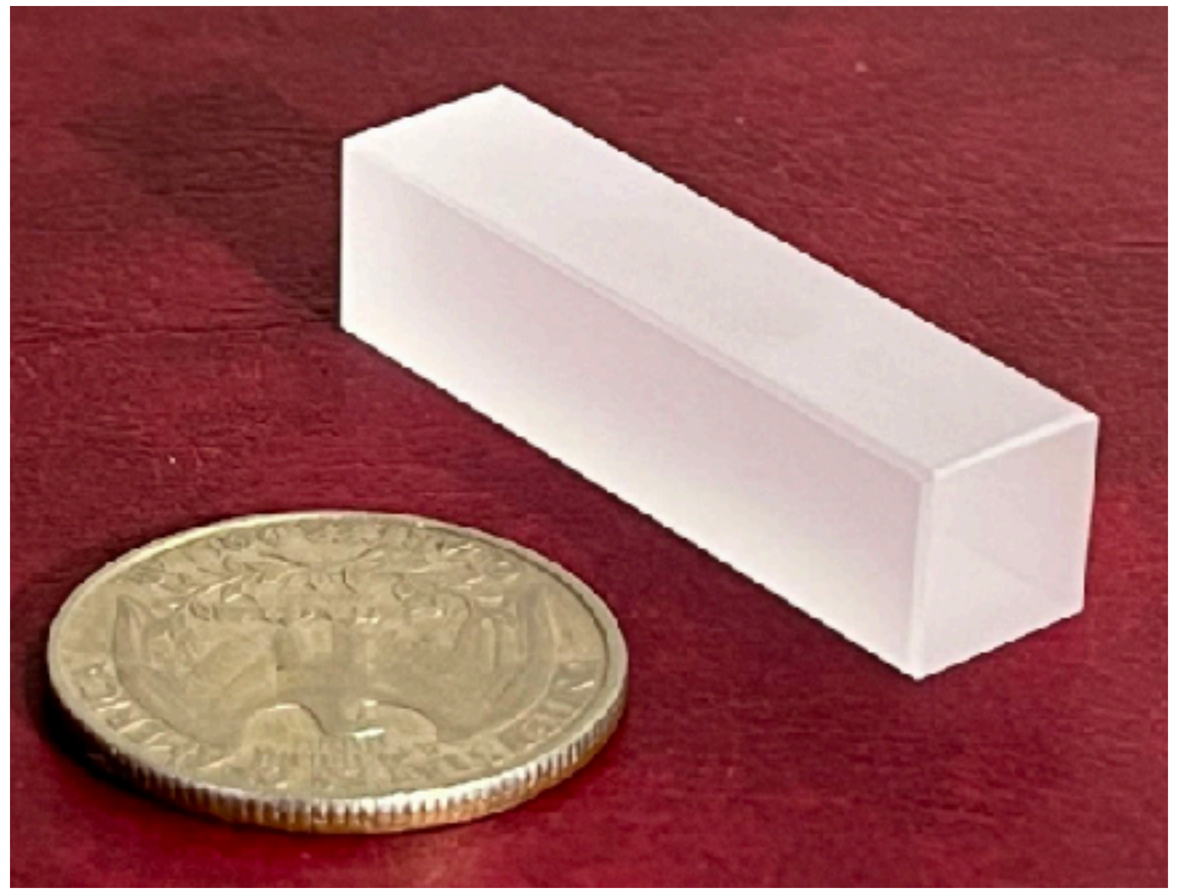
Small Angle Calorimeter (SAC)

Rejects photons from $K_L \rightarrow \pi^0 \pi^0$ escaping through beam hole, operates inside neutral beam: as insensitive as possible to 430 MHz of neutron. **Baseline solution:**

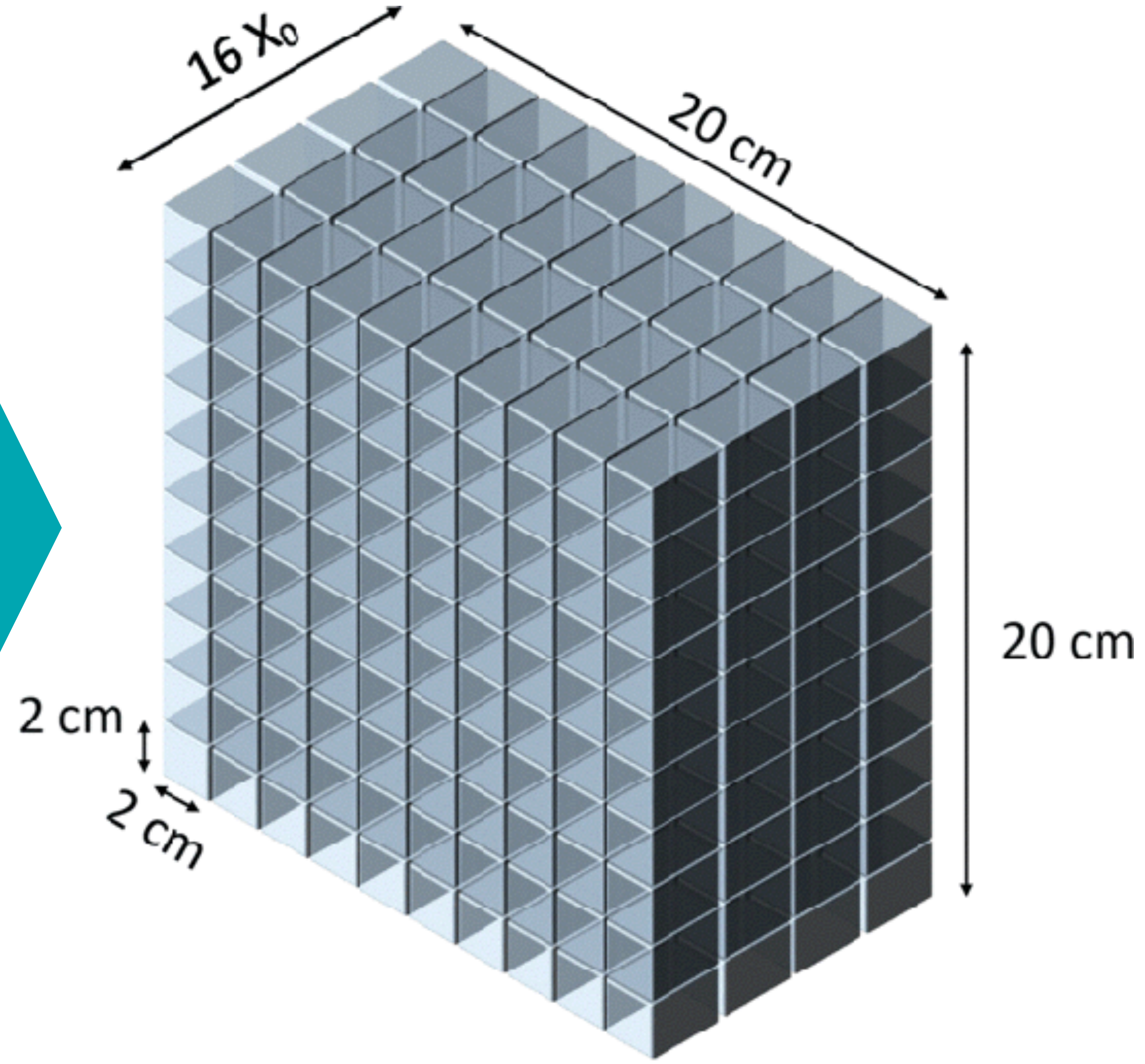
Highly segmented, homogeneous calorimeter with dense, **high-Z crystals** providing very fast light output

- **PbF_2** : Cherenkov radiator that provides very fast signal
- **Ultra fast PWO** (PWO-UF): scintillator with good light yield and high radiation tolerance (higher than PbF_2)
- **$\sigma_t < 100$ ps, 2-pulse separation** at ~1 ns
- Readout with **SiPMs** would facilitate a compact SAC design (minimize leakage)
- Explore idea of exploiting **coherent interactions in crystals** to reduce thickness

An R&D work on the KLEVER SAC is currently being carried out in synergy with the **CRILIN** group (Muon Collider calorimeter with similar performance requirement)



Example of high-Z crystals with both transverse and longitudinal segmentation



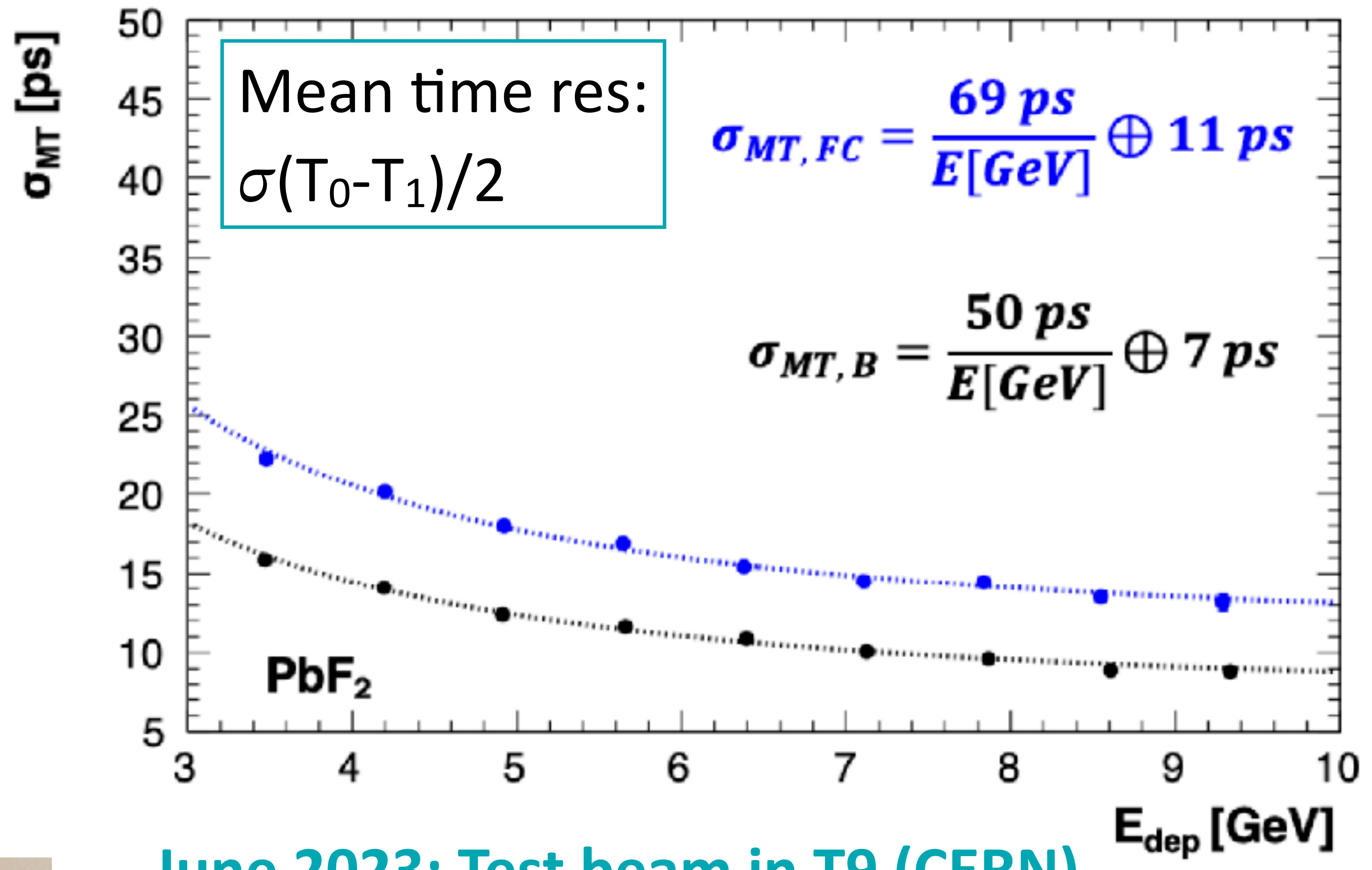
R&D CRILIN

2021 & 2022: Test beam in H2 (CERN)
e- 120 GeV, MIP 150 GeV

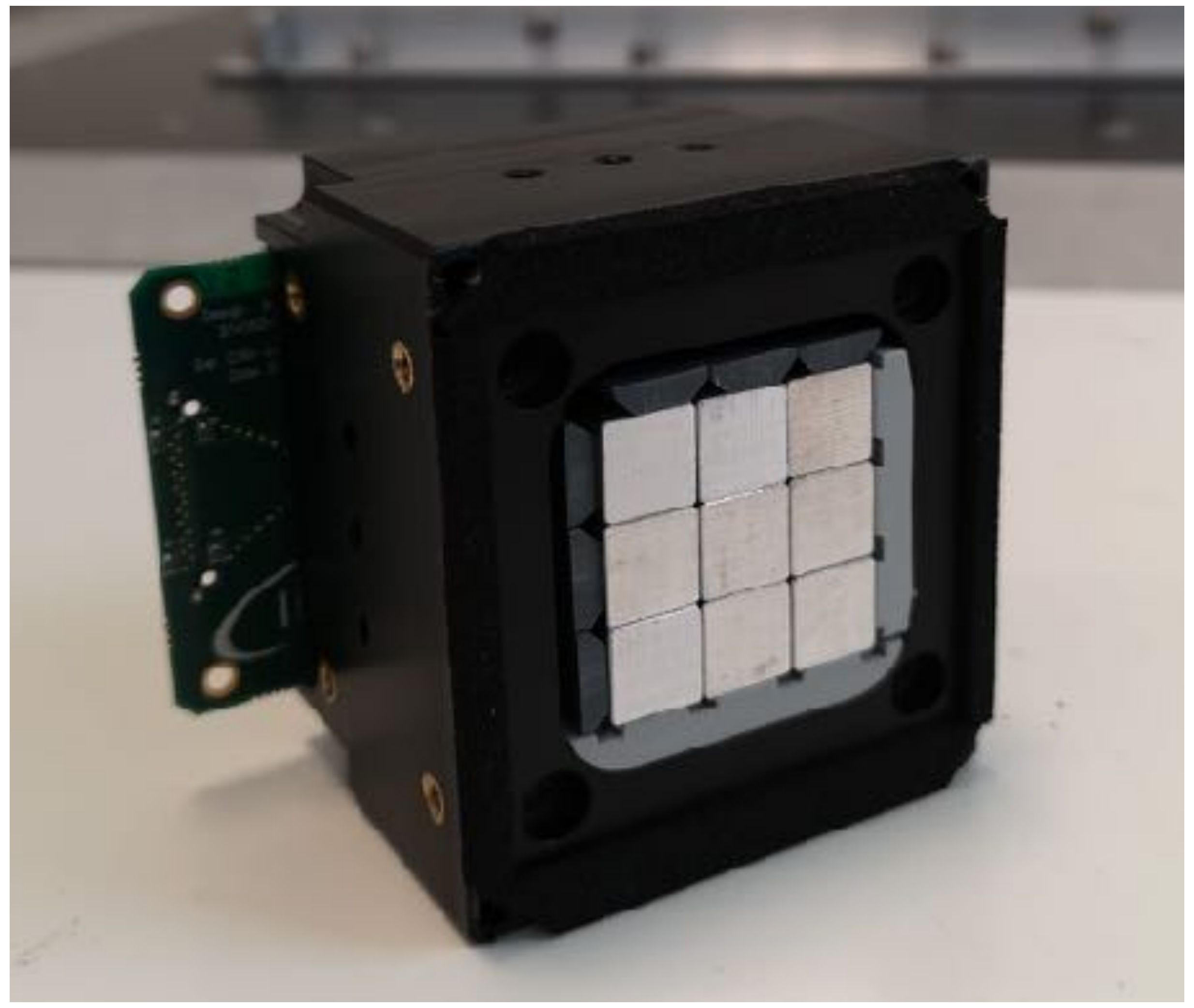
- 1 PWO-UF or PbF_2 crystal
- 4x4 mm², 10 µm pixel size SiPMs
- 4 SiPM/crystal (2x 2-series connection)

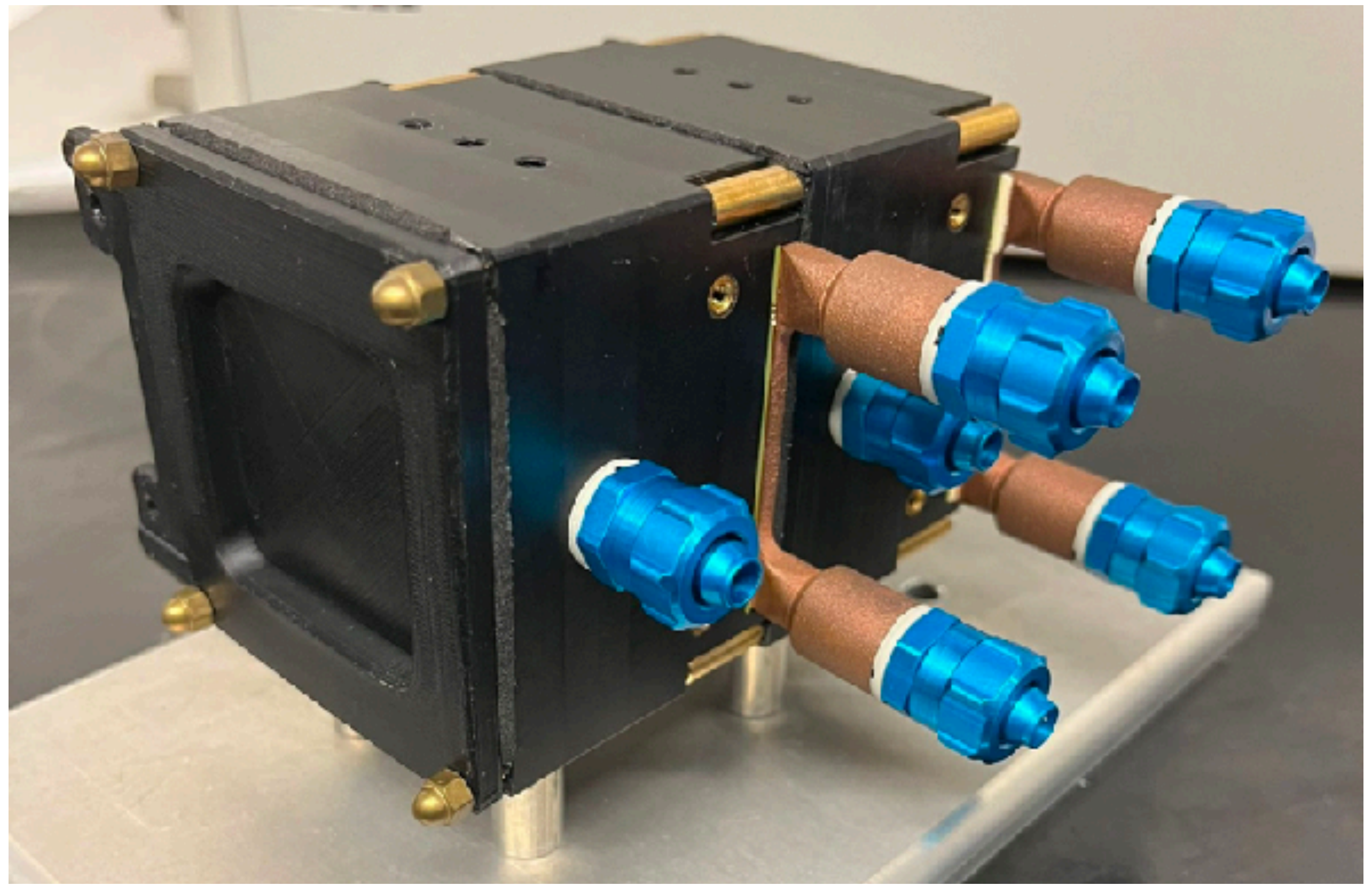
Time resolution and light transport studies: publication under review

CRILIN prototype 0



CRILIN prototype 1





June 2023: Test beam in T9 (CERN)
e- 5 GeV, MIP 4 GeV

- 3x3 2 layers array (18 crystals)
- 4 SiPMs/crystal (2x2 series or parallel connection - 2 independent channels per crystal): 36 electronic channels

This week: test beam in BTF
August 2023: test beam at H2

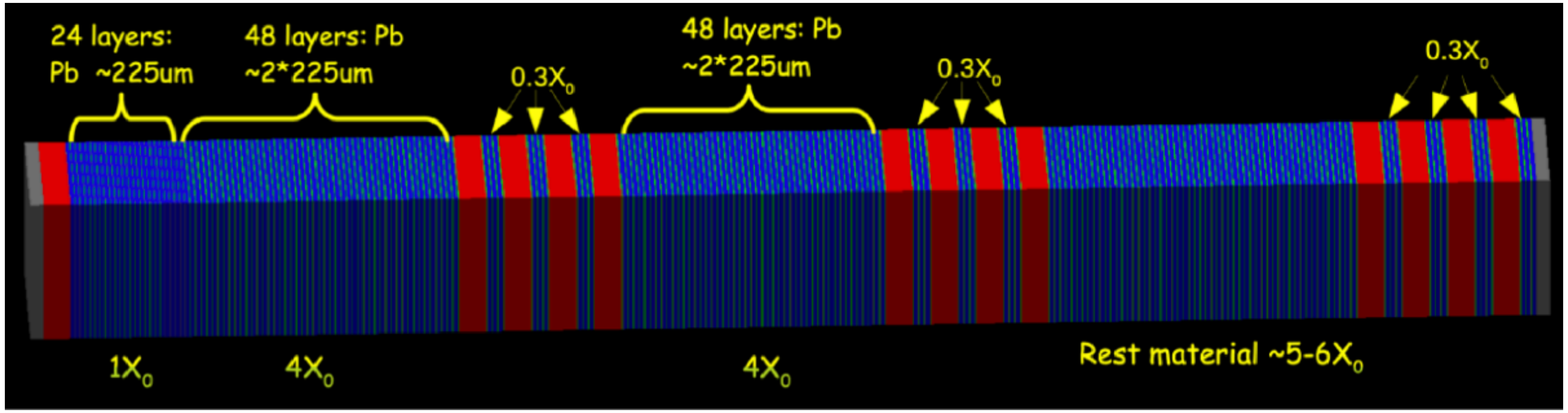
Main Electromagnetic Calorimeter(MEC)

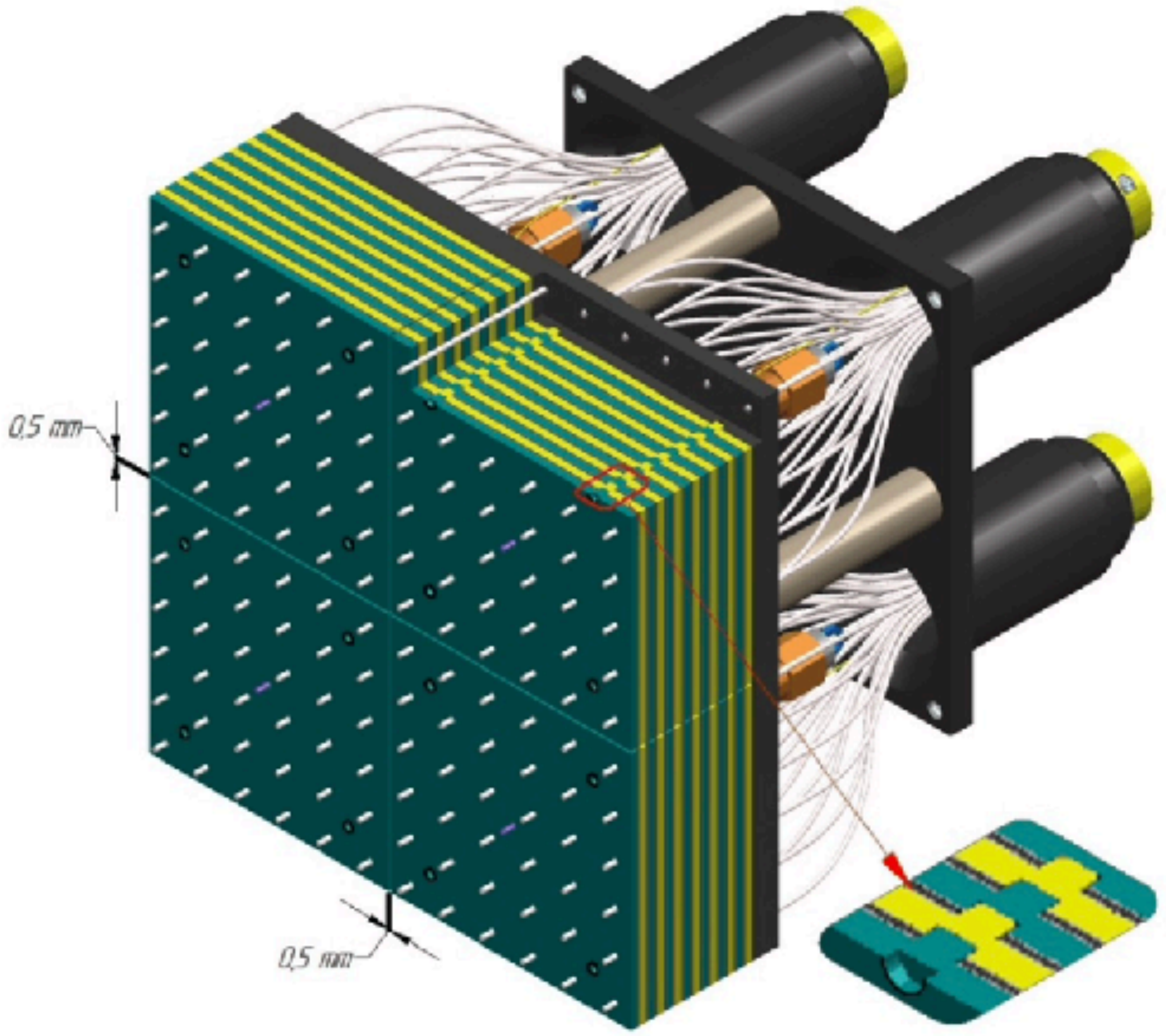
Requirements: excellent efficiency, time resolution ~100 ps, good 2 clusters separation.

Baseline solution: fine-sampling **Shashlyk** based on PANDA forward EM calorimeter produced at Protvino (0.275 mm Pb + 1.5 mm scintillator): **σ_t ~ 72 ps, $\sigma_E/\sqrt{E}$ ~ 3%, σ_x ~ 13 mm** (/√E in GeV)

Longitudinal shower information from spy tile

- PID information: identification of μ, π, n interactions
- Shower depth information: improved time resolution for EM shower





Semiconductor nano-structures can be used as sensitizers/emitters for ultrafast, robust scintillators:

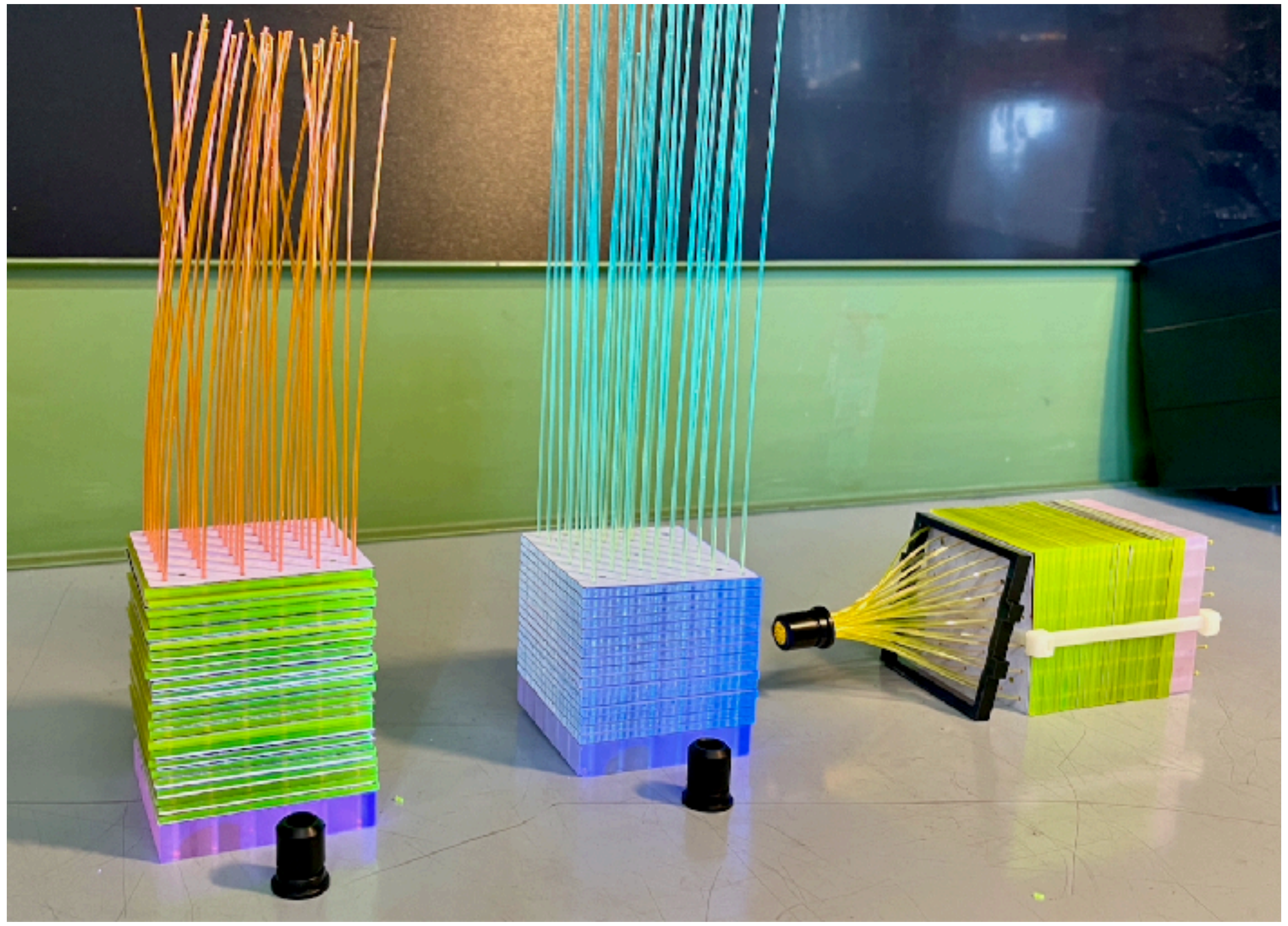
Perovskite (ABX_3) nanocrystals cast with polymer.

Nanocrystal: emission wavelength, decay time…

Composite: high concentration of nanocrystals shorter radiation length

- Decay times down to **O(100 ps)**
- Radiation hard to **O(1 MGy)**

R&D NanoCal (AidaInnova)

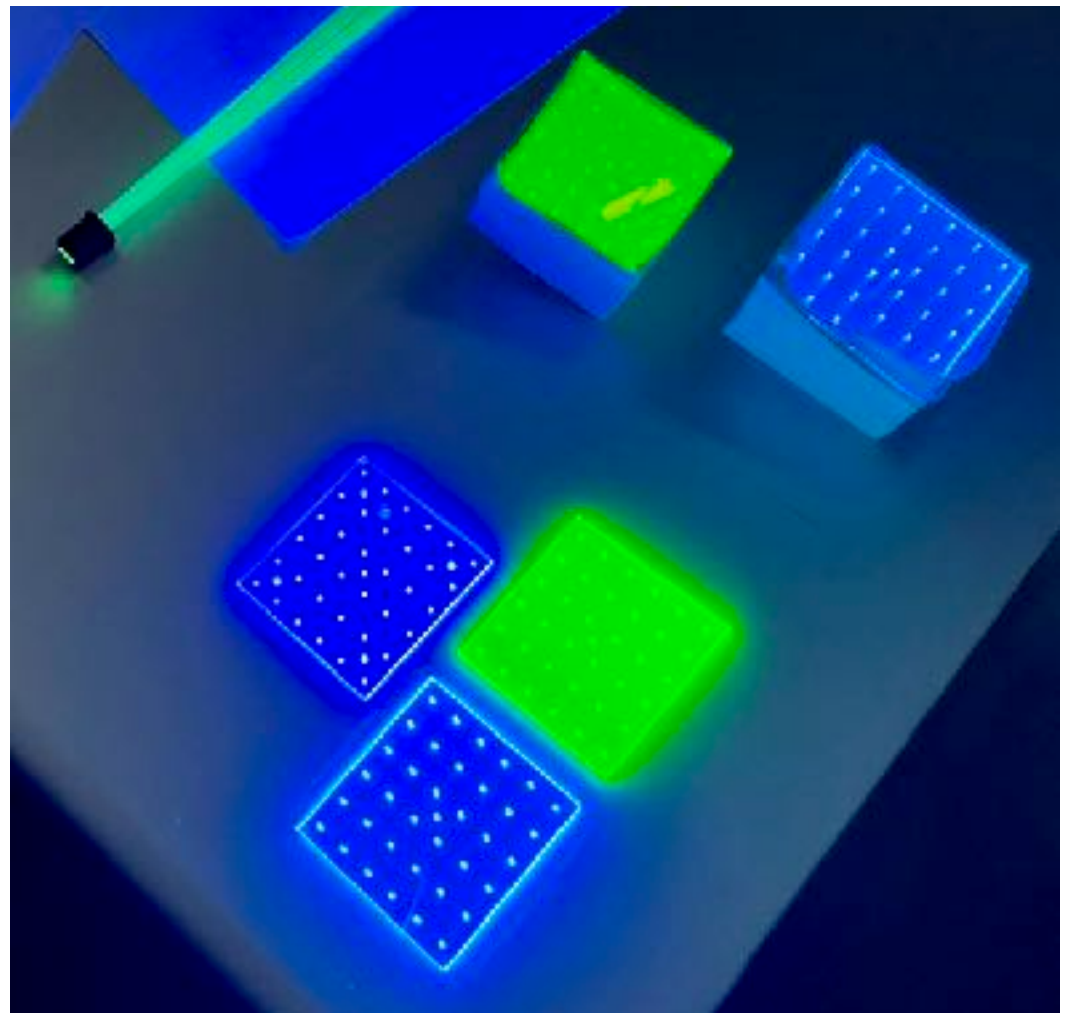


Shashlyk calorimeter with nanostucture tiles

- 0.2% $CsPbBr_3$ in PMMA with O-2 (commercial orange) fibers
- 0.2% $CsPbBr_3$ in PMMA with NCA-1 (custom orange) fibers
- 0.2% $CsPb(Br,Cl)_3$ in PMMA with coumarin-6 WLS and NCA-1 fibers

Conventional

- Protvino PS scintillator with Y-11 (green) fibers
- Custom PVT scintillator with Y-11 (green) fibers



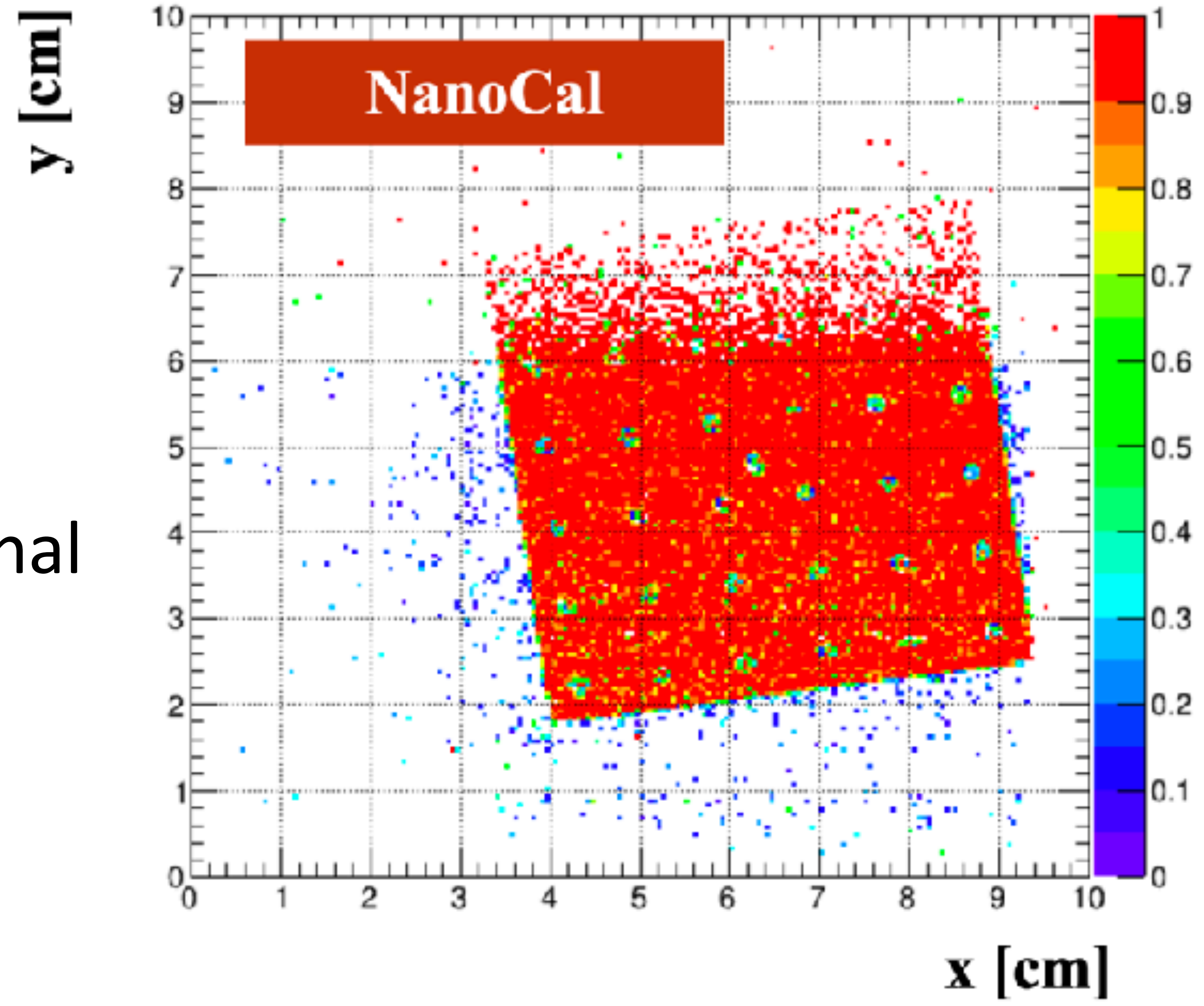
2022: Test beam in H2

- First test of fibers, tiles, SiPMs
- Light yield ~10x less than conventional scintillator
- Time resolution same as or better than conventional

June 2023: Test beam in T9

- Data analysis started …

New Test beam in October



Conclusions

NA62 is taking data at full intensity with an upgraded detector, aiming to reach a BR($K^+ \to \pi^+ \nu\nu$) measurement at 10% precision, comparable to the theoretical one

- Data analysis is ongoing with promising indications for improvement
- Run in dump mode for exotic search: first results based on 1.4x 10^{17} POT. 10^{18} POT will be collected by the end of RUN2

Proposal and R&D for longer term high-intensity kaon beam experiments are under development

- LNF is the focus of conception and R&D for the future detectors. If HIKE will be approved we will need spaces and resources

NA62 Frascati group has grown in the last year

- 6.4 FTE NA62 + 1.6 FTE synergic projects
- 2 more AdR (Mattia Soldani & Joel Swallow)

- NanoCal and Crilin mechanics: Alessandro Russo, Daniele Pierluigi, Emiliano Paoletti, Roberto Tesauro
- Front-end Crilin: Sergio Ceravolo