$K^+ \rightarrow \pi^+ \nu \nu$ and New Physics searches @ NA62 experiment

In Pursuit of New Particles and Paradigms

Dario Soldi on behalf of NA62 collaboration
A general purpose experiment

Search for **New Physics** at the EW scale with sizeable coupling to SM particles *via* indirect effects in loops

Search for **lepton flavour and number violation**, rare and forbidden decays

Search for **New Physics** below the EW scale (MeV-GeV) feebly-coupled to SM particles *via* direct detection of long-lived particles

**Flavour Physics**

**Hidden sector Physics**

**BR(K⁺→π⁺νν)**

**LFV, LNV**

**Heavy Neutral Lepton (HNL)**

**Dark Photon (DP), ALPs**
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NA62 Main Goal

The $K^+ \rightarrow \pi^+\nu\nu$ decay is extremely suppressed flavor-changing neutral current quark transition $s \rightarrow d\nu\nu$ forbidden at tree level

**Clean theoretical prediction:** QCD corrections, electroweak corrections, hadronic matrix element related to $K^+ \rightarrow \pi^0 e^+\nu e$ decay.

**SM theoretical prediction:**

$$\text{BR}(K^+ \rightarrow \pi^+\nu\nu)_{\text{SM}} = (8.4 \pm 1.0) \times 10^{-11}$$

Previous measurement: E787 and E949 @ BNL (7 events)

$$\text{BR}(K^+ \rightarrow \pi^+\nu\nu)_{\text{EXP}} = (17.3 + 11.5 - 10.5) \times 10^{-11}$$

Gap between theoretical precision and large experimental error motivates a strong experimental effort. Significant new constraints can be obtained.
New Physics from $K\rightarrow\pi\nu\nu$

many BSM scenarios:

- **Simplified Z, Z’ models** [Buras, Buttazzo,Knegjens, JHEP 1511 (2015) 166]
- **Littlest Higgs with T-parity** [Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]
- **Custodial Randall-Sundrum** [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- **LFU violation models** [Isidori et al., Eur. Phys. J. C (2017) 77]

Tree-level flavour changing $Z'$, LH+RH couplings

$K\rightarrow\pi\nu\nu$ is uniquely sensitive to high mass scales, up to 2000 TeV: NA62 complementary to the LHC experiments and the B factories
the North Area the SpS extraction line is delivers the charged hadron beam with the required $K^+$ intensity.

- 400 GeV/c primary proton beam
- $3 \times 10^{12}$ protons/pulse
- 40 cm beryllium target
- 75 GeV/c unseparated hadrons beam: $\pi^+, K^+ (6\%)$, protons ($\Delta p/p \pm 1\%$)
- $4.8 \times 10^{12}$ $K^+$ decays/year
NA62 Apparatus

270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Kaon Tag (KTAG):
- Differential Cherenkov detecting Kaons;

Beam Spectrometer (GigaTracker - GTK):
- 3 stations of Silicon pixel detectors inside an achromat;
NA62 Apparatus

270 m long region starting about 100 m downstream of the beryllium target. Detector diameters go from 20 to 400 cm.

Downstream tracks - Kinematics

Straw Spectrometer:
- 4 straw chambers in vacuum;

RICH:
- Cherenkov detector filled with Neon;
- distinguish $\pi/\mu/e$

NA48 CHOD
- Plastic scintillators;
- Control Trigger

CHOD:
- Plastic tile scintillators;
- Decay topology detection;
NA62 Apparatus

270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Large Angle Vetoes (LAV):
- 8.5 – 50 mrad
- 12 stations along the vacuum tank;

Liquid Krypton Calorimeter (LKr):
- Electromagnetic calorimeter
- photon veto coverage 1÷8.5 mrad;

Small Angle Vetoes (SAV):
- very small angle <1 mrad;

Photon vetoes
270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Muon Veto 1,2
- hadron calorimeter to complete the LKr-electromagnetic calorimeter information;

Muon Veto 3
- Placed after an iron wall;
NA62 Timescale

2016: 40% of nominal intensity: $13 \times 10^{11}$ proton on target: $\sim 5 \times 10^{11}$ $K^+$ decays recorded

2017 + 2018: 60% of nominal intensity: $> 8 \times 10^{12}$ $K^+$ decays on tape
  - better data quality assessment
  - higher data taking efficiency

Measurement of $BR(K^+ \rightarrow \pi^+\nu\nu)$ with 2016 Data Analysis (4 weeks of data taking) will be here presented

New Strategy:
   Kaons with high momentum.
   Decay in flight technique.
   Signal signature: $K^+$ track + $\pi^+$ track

Data Sample:
   $\pi\nu\nu$ Trigger
   - 1 track
   - $\gamma/\mu$ veto

Control Trigger:
   $K^+ \rightarrow \pi^+\pi^0$, $K^+ \rightarrow \mu^+\nu$,
   $K^+ \rightarrow \pi^+\pi^+\pi^-$ samples for background estimation
2 signal regions, on each side of the $K^+ \rightarrow \pi^+\pi^0$ peak

Theoretical $m^2_{\text{miss}}$ distribution for signal and backgrounds of the main $K^+$ decay modes: (signal is multiplied by a factor $10^{10}$).

Main background sources:

<table>
<thead>
<tr>
<th>Decay</th>
<th>BR</th>
<th>Main Rejection Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \mu^+\nu_\mu(\gamma)$</td>
<td>63%</td>
<td>$\mu$-ID + kinematics</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^0(\gamma)$</td>
<td>21%</td>
<td>$\gamma$-veto + kinematics</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^+\pi^-$</td>
<td>6%</td>
<td>multi-track + kinematics</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^0\pi^0$</td>
<td>2%</td>
<td>$\gamma$-veto + kinematics</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^0\mu^+\nu_\mu$</td>
<td>5%</td>
<td>$e$-ID + $\gamma$-veto</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+\nu_\mu$</td>
<td>3%</td>
<td>$\mu$-ID + $\gamma$-veto</td>
</tr>
</tbody>
</table>

- O(100 ps) **timing** between sub-detectors
- O($10^4$) background suppression with **kinematics**
- O($10^7$) **$\mu$-suppression** ($K^+ \rightarrow \mu^+\nu_\mu$)
- O($10^7$) **$\gamma$-suppression** (from $K^+ \rightarrow \pi^+\pi^0$, $\pi^0 \rightarrow \gamma\gamma$)

- The analysis is mostly cut based
- Blind analysis procedure: signal and control regions kept masked for the whole analysis
Kinematic selection of signal regions

$K^+$ decays with a single charged particle in final state and vertex between tracks reconstructed in the fiducial region

$m^2_{\text{miss}} = (P_K - P_\pi)^2$ with $m_\pi$ hypothesis

Selection:
- Single track in final state topology
- $\pi^+$ identification
- Photon rejection
- $110 < Z_{\text{vertex}} < 165$ m
- $15 < p_{\pi^+} < 35$ GeV/c (to leave at least 40 GeV of $E_{\text{mis}}$)

Performances:
- $\varepsilon(\mu^+) = 1 \cdot 10^{-8}$ (64% $\pi^+$ efficiency)
- $\varepsilon(\pi^0) = 3 \cdot 10^{-8}$
- $\sigma(m^2_{\text{miss}}) = 1 \cdot 10^{-3}$ GeV$^2$/c$^4$
- $\sigma T \sim O(100)$ ps
Single Event Sensitivity

Kabala:
- Nk from K⁺ → π⁺π⁰ control trigger: (1.21 ± 0.02) x 10¹¹
- K⁺ → π⁺νν acceptance: (4.0 ± 0.1) x 10⁻²
- Random Veto Efficiency: 0.76 ± 0.04
- Trigger Efficiency: 0.87 ± 0.2

\[ SES = \frac{1}{N_K} \sum_j (A_{\pi\nu\nu}^j \cdot \epsilon_{RV}^j \cdot \epsilon_{trig}^j) \]

\begin{align*}
\text{Expected SM } K^+ &\rightarrow \pi^+\nu\bar{\nu} \\
&= \frac{(3.15 \pm 0.01_{\text{stat}} \pm 0.24_{\text{syst}}) \cdot 10^{-10}}{0.267 \pm 0.001_{\text{stat}} \pm 0.020_{\text{syst}} \pm 0.032_{\text{ext}}} \text{ Error on the SM BR}
\end{align*}

### Delta SES

<table>
<thead>
<tr>
<th>Source</th>
<th>δ SES (10⁻¹⁰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random veto</td>
<td>±0.17</td>
</tr>
<tr>
<td>Definition of π⁺π⁰ region</td>
<td>±0.10</td>
</tr>
<tr>
<td>Simulation of π⁺ interactions</td>
<td>±0.09</td>
</tr>
<tr>
<td>N_K</td>
<td>±0.05</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>±0.04</td>
</tr>
<tr>
<td>Extra activity</td>
<td>±0.02</td>
</tr>
<tr>
<td>GTK pileup simulation</td>
<td>±0.02</td>
</tr>
<tr>
<td>Momentum spectrum</td>
<td>±0.01</td>
</tr>
<tr>
<td>Total</td>
<td>±0.24</td>
</tr>
</tbody>
</table>
Data after selection:

**Process** | Expected events in R1+R2
---|---
$K^+ \to \pi^+ \nu \bar{\nu}$ (SM) | $0.267 \pm 0.001_{\text{stat}} \pm 0.020_{\text{syst}} \pm 0.032_{\text{ext}}$
Total Background | $0.15 \pm 0.09_{\text{stat}} \pm 0.01_{\text{syst}}$
$K^+ \to \pi^+ \pi^0(\gamma)$ IB | $0.064 \pm 0.007_{\text{stat}} \pm 0.006_{\text{syst}}$
$K^+ \to \mu^+ \nu(\gamma)$ IB | $0.020 \pm 0.003_{\text{stat}} \pm 0.003_{\text{syst}}$
$K^+ \to \pi^+ \pi^- e^+ \nu$ | $0.018_{-0.017}^{+0.024}_{\text{stat}} \pm 0.009_{\text{syst}}$
$K^+ \to \pi^+ \pi^+ \pi^-$ | $0.002 \pm 0.001_{\text{stat}} \pm 0.002_{\text{syst}}$
Upstream Background | $0.050_{-0.030}^{+0.090}_{\text{stat}}$
**Validation**

Events observed in $\pi^+\pi^0$ CR2: \textbf{1}

Events observed in $\pi^+\pi^0$ CR1: \textbf{0}

Events observed in $\mu\nu$ CR: \textbf{2}

<table>
<thead>
<tr>
<th>CR</th>
<th>$\pi^+\pi^0$</th>
<th>$\mu^+\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>$0.52 \pm 0.08_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
<td>$1.02 \pm 0.16_{\text{stat}}$</td>
</tr>
<tr>
<td>CR2</td>
<td>$0.94 \pm 0.14_{\text{stat}} \pm 0.05_{\text{syst}}$</td>
<td></td>
</tr>
</tbody>
</table>
Result
Result

1 event in R2

Likelihood value under different mass hypothesis

$P_{\pi^+} = 15.3$ GeV
Conclusions from $K \rightarrow \pi \nu \nu$ 2016 data taking

- *The NA62 decay-in-flight technique works*
- SM sensitivity for $K^+ \rightarrow \pi^+ \nu \nu$ reached with the 2016 data analysis
- **One** event observed in 2016 data compatible with SM prediction

$$BR(K^+ \rightarrow \pi^+ \nu \nu) = \leq 14 \times 10^{-10} \text{ @ 95\% CL}$$

NA62 collaboration arXiv:1811.08508 (submitted to PLB)

- $\sim 8.5 \times 10^{12}$ $K^+$ decays collected in the whole NA62 Run1 (2016-2018).

  Analysis in progress…

- Focus on improvements:
  - increased signal acceptance
  - better reconstruction efficiency
  - higher background suppression
  - probability based analysis

**Data taking after LS2 (2021-2023) in approval stage**
A general purpose experiment

Flavour Physics
- Search for **New Physics** at the EW scale with sizeable coupling to SM particles **via indirect effects in loops**
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Hidden sector Physics
- Search for **New Physics below the EW scale** (MeV-GeV) feebly-coupled to SM particles via direct detection of long-lived particles

**BR(K^{+} \rightarrow \pi^{+}\nu\nu)**

**LFV, LNV**

Heavy Neutral Lepton (HNL), Dark Photon (DP), ALPs
Lepton Flavour Violation

Conservation of $L$ and $L_e$, $L_\mu$, $L_\tau$ is an ‘emergent’ property of SM – not required during construction.

• Violation of these conservation laws predicted in BSM models:
  
  • E.g. $K^+ \rightarrow \pi^+ l^+ l^+$: $\Delta L = 2$ and $\Delta L_\mu = 2$ or $\Delta L_e = 2$ via Majorana neutrinos $U$ (analogue to $v_0\beta\beta$ decays) [JHEP 0905 (2009) 030], [Phys.Lett. B491 (2000) 285-290]

<table>
<thead>
<tr>
<th>Trigger Name</th>
<th>Description</th>
<th>Use in LNV/LFV Searches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di-Muon</td>
<td>3 tracks with 2 $\mu$ candidates (MUV3)</td>
<td>Collect SM $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ &amp; LNV $K^+ \rightarrow \pi^- \mu^+ \mu^+$</td>
</tr>
<tr>
<td>Multi-Track $e$</td>
<td>3 tracks with 20 GeV energy deposit in LKr</td>
<td>Collect SM $K^+ \rightarrow \pi^+ e^+ e^-$ &amp; LNV $K^+ \rightarrow \pi^- e^+ e^+$</td>
</tr>
<tr>
<td>Multi-Track</td>
<td>Minimum bias 3-track trigger</td>
<td>Control samples for background studies</td>
</tr>
</tbody>
</table>

Previous Experimental results:

\[ BR(K^+ \rightarrow \pi^- e^+ e^+) < 6.4 \times 10^{-10} \text{ @ 90\% } CL \text{ (BNL E865: PRL 85 2877 (2000))} \]
\[ BR(K^+ \rightarrow \pi^- \mu^+ \mu^+) < 8.6 \times 10^{-11} \text{ @ 90\% } CL \text{ (CERN NA48/2: PL B769 67 (2017))} \]
Lepton Flavour Violation

New NA62 upper limits: 3 months of data taking in 2017! ~3 times more data still to analyse

<table>
<thead>
<tr>
<th>Decay</th>
<th>$BR$ UL @ 90% CL</th>
<th>PDG UL @ 90% CL</th>
</tr>
</thead>
<tbody>
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<td>$K^+ \to \pi^- e^+ e^+$</td>
<td>$2.2 \times 10^{-10}$</td>
<td>$6.4 \times 10^{-10}$</td>
</tr>
<tr>
<td>$K^+ \to \pi^- \mu^+ \mu^+$</td>
<td>$4.2 \times 10^{-11}$</td>
<td>$8.6 \times 10^{-11}$</td>
</tr>
</tbody>
</table>
**Dark Photons**

New $U(1)$ gauge-symmetry sector, with a vector mediator field $A'$; In a simple realization of such a scenario, $A'$ would interact with the SM photon through a “kinetic mixing” lagrangian:

$$\mathcal{L} = \varepsilon A'_{\mu\nu} F_{\mu\nu}$$


The lagrangian might be accompanied by further interactions, both with SM matter and with a secluded, hidden sector of possible dark-matter candidates.

Missing-energy signature might reveal its presence.

NA62 is looking for:

$$K^+ \rightarrow \pi^+ \pi^0 \text{ with } \pi^0 \rightarrow A'\gamma$$

$$A' \rightarrow \text{invisible}$$

$$M^2_{\text{miss}} = (P_K - P_\pi - P_\gamma)^2$$

Exploiting extreme photon-veto capability and high resolution tracking while sustaining a high-rate environment makes the dark photon analysis synergic with and parasitic to the $K^+ \rightarrow \pi^+\nu\nu$ measurement.
Search for $\pi^0 \to \gamma A', A' \to \text{invisible}$

- Search parasitic to $\pi \nu \nu$-trigger
  - (“1 track” + small forward energy)
- Signal signature: 1 track, 1 $\gamma + E_{\text{mis}}$
- Data driven background estimation.
- Dominant background:
  - $\pi^0 \to \gamma \gamma$ with 1 $\gamma$ missing

Analysis with data from 2016:
$\sim 1.5 \times 10^{10}$ K$^+$ (~5% of 2016 statistics)

No signal observed, 90% CL UL within expected statistical uncertainty band
HNL from K decays

Search for HNL produced in $K^+ \rightarrow e^+ \nu_H$ and $K^+ \rightarrow \mu^+ \nu_H$ decays: peaks $m_{miss}^2$ spectra

Limits from heavy neutrino production searches

- KEK (1984)
- $K^+ \rightarrow \mu^+ \nu$, $K^+ \rightarrow e^+ \nu$
- TRIUMF (1992)
- $\pi^+ \rightarrow e^+ \nu$
- PIENU (2017)
- $\pi^+ \rightarrow e^+ \nu$
- E949 (2015)
- $K^+ \rightarrow \mu^+ \nu$
- $K^+ \rightarrow \mu^+ \nu$
- NA62-2015
- $K^+ \rightarrow \mu^+ \nu$, $K^+ \rightarrow e^+ \nu$

**Range mass from $\pi$-mass to K-mass**

**NA62 2007 data**

Extends the mass range for upper limits on $|U_{\mu 4}|^2$


**NA62 2015 data with minimum bias trigger @ 1% intensity, 5 days, i.e., K+ decays in FV:**

$N_K = (3.01 \pm 0.11) \times 10^8$ for $K^+ \rightarrow e^+ \nu_H$

$N_K = (1.06 \pm 0.12) \times 10^8$ for $K^+ \rightarrow \mu^+ \nu_H$

Reached $10^{-6}$-$10^{-7}$ limits for $|U_{\mu 4}|^2$ in HNL (170,448) MeV/c$^2$ mass range


Best world limit above 300 MeV/c2

**Full 2016-2018 data set analysis will explore $|U_{\mu 4}|^2 \approx 10^{-8}$ range**

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NA62 as a dump experiment

- NA62 has the possibility to **dump the entire beam** by closing TAX (~$10^{12}$ p/s) and removing target;
- Copper TAX $\rightarrow$ coherent $Z^2$ enhancement with charge;

NA62 looking for
- Axion Like Particles (ALPs)
- Heavy Neutral Leptons (HNLs)
NA62 potential for Axion Like Particles

Study Axion Like Particle (ALP) production from interaction onto collimator, ⇒ search must be performed in beam-dump mode

Search for $\gamma\gamma$ fusion via Primakoff effect [JHEP 1602 (2016) 018] for ALP production and subsequent decay to $\gamma\gamma$ in NA62 fiducial volume

- account for geometrical acceptance
- zero-background assumption
- evaluate expected 90% C.L. exclusion contours

1 day of run in real beam-dump mode: $\sim 1.3 \times 10^{16}$ POT’s

NA62 → small D, large E: one day runtime as ‘dump’ is sensitive to new physics (90% confidence at 0 background)

Analysis of $2 \times 10^{16}$ POT collected in dump mode in 2017-2018 in progress....
Potential for HNL from beam dump

The HNLs may be also produced in beam dump mode:

From leptonic decays $D(D_s) \rightarrow l^+\nu_H$ soon after production in the target (mass up to $\sim 1.7$ GeV)

$$|\text{sterile neutrino coupling to } \mu|^2$$

Assume $2 \times 10^{18}$ POT

- $\nu_H \rightarrow \pi e$, $\nu_H \rightarrow \pi \mu$:
- 2 oppositely-charged, in-time, tracks reconstructed as originating from the 60-m long fiducial volume, 1-lepton final states
- Invariant mass should reconstruct HNL mass
- Include trigger/acceptance/selection efficiency
- Assume zero-background.

$$U^2_e:U^2_\mu:U^2_\tau = 1:16:3.8$$

Analysis of $2 \times 10^{16}$ POT collected in dump mode in 2017-2018 in progress....
Conclusions

The NA62 decay in flight technique to measure $\text{BR}(K^+ \rightarrow \pi^+\nu\nu)$ works!
- 1 event observed in 2016 data
- $\text{BR}(K^+ \rightarrow \pi^+\nu\nu) < 14 \times 10^{-10}$ @ 95% CL

First results on Dark Photons and HNL searches

First results on LFV physics

NA62 potential has been shown

Running after LS2 (2021-2023) will allow to fully exploit the physics reach with the current NA62 setup, with minimally upgraded detector and modified beam line
THANK YOU for your ATTENTION!
$K \rightarrow \pi \nu \nu$ and the Unitary Triangle

Stringent test of the SM and possible evidence for New Physics $\rightarrow$ complementary to LHC!

Example of CKM constraints:
- $\text{BR}(K^+ \rightarrow \pi^+ \nu \nu)$ to $\pm 10\%$
- $\text{BR}(K_L \rightarrow \pi^0 \nu \nu)$ to $15\%$

Overconstrain CKM matrix $\rightarrow$ reveal New Physics?

Highly suppressed
Very well predicted

90% CL SM prediction

PDG - 2017

BNL-787
BNL-949

$\text{BR}(K \rightarrow \pi \nu \nu)$ to $\pm 10\%$

Prospective study on rare Kaons
A General purpose experiment

The high-intensity setup, trigger system flexibility, and detector performance as

- high-frequency tracking of beam particles;
- redundant PID;
- ultra-high-efficiency photon vetoes;

make NA62 particularly suitable for searching for new-physics effect from different scenarios:

Standard Kaon Physics

- Measurements of the BR of all the main $K^+$ decay modes
- ChPT studies: $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\pi^0e^+e^-$, $K^+ \to \pi^0(+)\pi^0(-)l^+\nu$
- Precision measurement of $R_K = \frac{\Gamma(K^+\to e^+\nu_e)}{\Gamma(K^+\to \mu^+\nu_\mu)}$

Rare/forbidden $K^+$ and $\pi^0$ decays at SES $\sim 10^{-12}$

- $K^+$ physics: $K^+ \to \pi^e e^e(\gamma)$, $K^+ \to \pi^\mu^+\mu^+(\gamma)$, $K^+ \to \gamma l^+\nu$
  (sensitivity x 100 wrt the past results)
- $\pi^0$ physics: $\pi^0 \to e^+e^-$, $\pi^0 \to e^+e^-e^+e^-$, $\pi^0 \to \gamma\gamma\gamma$, $\pi^0 \to \gamma\gamma\gamma\gamma$, $\pi^0 \to \nu\nu$, ...
- LFV-LNV searches: $K^+ \to \pi^+\mu^e\mp(\gamma)$, $K^+ \to \pi^-\mu^+e(\gamma)$, $K^+ \to \pi^-l^+l^+$, ...

Searches for exotic particles from hidden sector
NA62 potential for $A'$ visible decays

Study Dark Photon production from interaction onto target

- search for di-lepton decays $A' \to e^+e^-$, $A' \to \mu^+\mu^-$ in NA62 fiducial volume
- account for acceptance/trigger/selection efficiency
- Assume zero-background

Sensitivity expected to be higher than shown:
- including direct QCD production of $A'$
- Including $A'$ production in the collimator (here, only target)

**Acquired in 2016-2018:**
- $\sim 10^{18}$ POT with $\mu\mu$-parasitic trigger,
- $\sim 5 \times 10^{16}$ POT with ee-parasitic trigger
  ... to be analyzed

**Assume** $10^{18}$ POT

$|A'$ coupling to ordinary $\gamma|^2$
270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Kaon Tag (KTAG):
- Differential Cherenkov detecting Kaons;
- ~80 ps time precision;

Beam Spectrometer (GigaTracker - GTK):
- 3 stations of Silicon pixel detectors inside an achromat;
- Time: $\sigma \approx 130$ ps per station;
- Direction: $\sigma_{dx,dy} \approx 0.016$ mrad, Momentum: $\Delta P/P < 0.4%$;
**NA62 Apparatus**

270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Straw Spectrometer:
- 4 straw chambers in vacuum;
- Each chamber measuring 4 coordinates (views);
- High accuracy: 130 µm/view;

RICH:
- Cherenkov detector filled with Neon;
- 70 ps of time resolution;

**NA48 CHOD**
- Plastic scintillator hodoscope;
- ~200 ps time resolution;

**CHOD:**
- Plastic tile scintillator;
- <1 ns time resolution;
- Decay topology detection;

Downstream tracks - Kinematics
NA62 Apparatus

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Detector diameters go from 20 to 400 cm

Large Angle Vetoes (LAV):
- 8.5 – 50 mrad
- 12 stations along the vacuum tank;

Liquid Krypton Calorimeter (LKr):
- Electromagnetic calorimeter
- photon veto coverage 1÷8.5 mrad;

Small Angle Vetoes (SAV):
- very small angle <1 mrad;

Photon vetoes
NA62 Apparatus

270 m long region starting about 100 m downstream of the beryllium target
Detector diameters go from 20 to 400 cm

Muon Vetoes

Muon Veto 1,2
- Readout with LKr electronics;
- Can be used in level-0 as hadron trigger to complete the LKr-electromagnetic calorimeter information;

Muon Veto 3
- Placed after an iron wall;
- Rate: > 10 MHz muons.
- Used in level-0 trigger to veto muons;