Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN

Marco Mirra - Università degli studi di Napoli Federico II and INFN Napoli on behalf of the NA62 collaboration

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Outline

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay
- NA62 experimental strategy and apparatus
- 2015 data quality
Kaons at CERN SPS

ε′/ε and direct CP violation discovery

**NA48/1 (2002)**
K_{s} rare decay studies

**NA48/2 (2003 – 2004)**
K^{±} precision measurements

**NA62 (2007)**
Lepton universality: K_{e2}/K_{μ2} (using the NA48 apparatus)

**NA62 (2015 – )**
Main goal: BR(K^{+} → π^{+}ν\bar{ν})
Rare decay studies: LFV, LNV decays, search for heavy ν, axions, .

Search for $K^{+} → π^{+}ν\bar{ν}$ at the NA62 experiment at CERN
$K^+ \to \pi^+ \nu \bar{\nu}$ decay in SM

FCNC loop processes: $s \to d$ coupling and highest CKM suppression

\[
\begin{align*}
\lambda &= V_{us} \\
\lambda_c &= V_{cs}^* V_{cd} \\
\lambda_t &= V_{ts}^* V_{td} \\
\end{align*}
\]
\[
x_q \equiv \frac{m_q}{m_W^2}
\]

\[
\text{BR}(K^+ \to \pi^+ \nu \bar{\nu}) = \kappa_+ \left[ \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_t}{\lambda^5} X(x_t) + \frac{\text{Re} \lambda_c}{\lambda} P_c (X) \right)^2 \right] (1 + \Delta_{EM})
\]

\[
\text{BR}(K_L \to \pi^0 \nu \bar{\nu}) = \kappa_L \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2
\]

24/05/2016  M. Mirra  Search for $K^+ \to \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN
**K^+ \rightarrow \pi^+ \nu \bar{\nu} decay in SM**

**FCNC loop processes: s→d coupling and highest CKM suppression**

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\begin{align*}
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**Hadronic matrix element obtained from BR(K_{l3}) via isospin rotation**
\( K^+ \to \pi^+ \nu \bar{\nu} \) decay in SM

FCNC loop processes: \( s \to d \) coupling and highest CKM suppression

\[
\begin{align*}
\text{Loop functions favor top contribution} & \quad \text{Hadronic matrix element obtained from } BR(K_{l3}) \text{ via isospin rotation}
\end{align*}
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\begin{align*}
BR(K^+ \to \pi^+ \nu \bar{\nu}) & = \kappa_+ \left[ \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_t}{\lambda^5} X(x_t) + \frac{\text{Re} \lambda_c}{\lambda} P_c(X) \right)^2 \right] (1 + \Delta_{EM}) \\
BR(K_L \to \pi^0 \nu \bar{\nu}) & = \kappa_L \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 \quad \text{\( \mathcal{CP} \)}
\end{align*}
\]

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\begin{align*}
\lambda & = V_{us} \\
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\lambda_t & = V_{ts}^* V_{td} \\
x_q & \equiv m_q/m_W
\end{align*}
\]
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay in SM

FCNC loop processes: $s \rightarrow d$ coupling and highest CKM suppression

$\lambda = V_{us}$

$\lambda_c = V_{cs}^* V_{cd}$

$\lambda_t = V_{ts}^* V_{td}$

$x_q \equiv m_q^2/m_W^2$

Loop functions favor top contribution

$\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = \kappa_+ \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_t}{\lambda^5} X(x_t) \right)^2 \left(1 + \Delta_{EM} \right)$

$\text{BR}(K_L \rightarrow \pi^0 \nu \bar{\nu}) = \kappa_L \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 \leftarrow \text{CP}$

Hadronic matrix element obtained from $\text{BR}(K_{l3})$ via isospin rotation

QCD corrections for charm diagrams

Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay in SM

FCNC loop processes: $s \rightarrow d$ coupling and highest CKM suppression

$\lambda = V_{us}$
$\lambda_c = V^*_{cs} V_{cd}$
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$x_q \equiv m_q^2/m_W^2$

Loop functions favor top contribution

EM radiative correction

Hadronic matrix element obtained from $BR(K_{l3})$ via isospin rotation

QCD corrections for charm diagrams

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Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay in SM

**FCNC loop processes:** $s \rightarrow d$ coupling and highest CKM suppression

\[ \lambda = V_{us} \]
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\[
x_q \equiv m_q^2/m_W^2
\]

Loop functions favor top contribution

EM radiative correction

\[
\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = \kappa_+ \left[ \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left( \frac{\text{Re} \lambda_t}{\lambda^5} X(x_t) \right)^2 + \frac{\text{Re} \lambda_c}{\lambda} P_c(X) \right] (1 + \Delta_{EM}) = 9.11 \pm 0.72
\]

\[
\text{BR}(K_L \rightarrow \pi^0 \nu \bar{\nu}) = \kappa_L \left( \frac{\text{Im} \lambda_t}{\lambda^5} X(x_t) \right)^2 = 3.00 \pm 0.30
\]

SM prediction (10^{-11} units)


Hadronic matrix element obtained from BR($K_{l3}$) via isospin rotation

QCD corrections for charm diagrams
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ beyond SM

Possibility to distinguish among different models

- Models with a CKM-like structure of flavour interactions (e.g. MFV)
- Models with new flavour and CP-violating interactions in which either left or right handed currents fully dominate (e.g. Z or Z' FCNC scenarios)
- More specifics NP models like Randall-Sundrum

In 2008, combine E787 (1995-8 runs) & E949 (12-weeks run in 2001) results

\[ BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10} \]

Expected bkg 2.6 events, prob. all 7 obs. evts are bkg is \( \sim 10^{-3} \)
NA62 experiment at CERN

NA62 is located in the North Area at CERN. It uses the SPS accelerator complex:

- Circumference: 6.9 km
- Injector of protons for LHC at 450 GeV/c
- Protons for fixed target physics at 400 GeV/c

~200 participants from 29 institutions

- 2006: Proposal
- 2009: Approved
- 2010: Technical Design
- 2012: Technical Run
- 2014: Pilot run
- 2015-2018: Physics run
Primary SPS proton beam:
- $p = 400$ GeV protons
- Proton on target $1.1 \times 10^{12}$/s

High-intensity, unseparated secondary beam
- Momentum selection chosen to optimize $K$ decays
- $p = 75$ GeV/c (1.4× more $K^+$ than NA48/2)
- $\Delta p/p \sim 1\%$ (3× smaller than NA48/2)

Total rate 750 MHz
- 525 MHz $\pi$
- 170 MHz $p$
- 45 MHz $K$
\[ K^+ \rightarrow \pi^+ \nu \bar{\nu} \] decay: signal and background

**NA62 Main Goal:**
10% precision BR\( (K^+ \rightarrow \pi^+ \nu \bar{\nu}) \) measurement

**Technique:**
K decay in flight

**Signal:**
\[ BR_{SM} \sim (9.11 \pm 0.72) \times 10^{-11} \]

- \( K^+ \) track in
- \( \pi^+ \) track out
- No other particles in final state

**Requirements:**
- \( \sim 100 \) SM events
- \( 10^{13} \) \( K^+ \) decays (signal acceptance \( \sim 10\% \))
- background rejection \( \sim 10^{12} \)
- background known to \( \sim 10\% \)

**Decay backgrounds**

<table>
<thead>
<tr>
<th>Mode</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu^+\nu(\gamma) )</td>
<td>( K_{\mu2} )</td>
</tr>
<tr>
<td>( \pi^+\pi^0(\gamma) )</td>
<td>( K_{2\pi} )</td>
</tr>
<tr>
<td>( \pi^+\pi^+\pi^- )</td>
<td>( K_{3\pi} )</td>
</tr>
<tr>
<td>( \pi^0e^+\nu )</td>
<td>( K_{e3} )</td>
</tr>
<tr>
<td>( \pi^0\mu^+\nu )</td>
<td>( K_{\mu3} )</td>
</tr>
<tr>
<td>( \pi^+\pi^-e^+\nu )</td>
<td>( K_{e4}(+-) )</td>
</tr>
<tr>
<td>( \pi^0\pi^0e^+\nu )</td>
<td>( K_{e4}(00) )</td>
</tr>
<tr>
<td>( \pi^+\pi^-\mu^+\nu )</td>
<td>( K_{\mu4} )</td>
</tr>
<tr>
<td>( e^+\nu(\gamma) )</td>
<td>( K_{e2} )</td>
</tr>
</tbody>
</table>

**Other backgrounds**

- Upstream interactions
NA62 experimental strategy

Most discriminating variable: $m_{miss}^2 = (P_K - P_\pi)^2$

Experimental principles:

- Precise kinematic reconstruction: 2 signal regions in $m_{miss}^2$
- Low $\pi$ momentum ($15 < p_\pi < 35$ GeV/c) to allow enough «missing» energy to be detected by hermetic $\gamma$ veto detectors (mainly for $K_{2\pi}$ and semileptonic modes with $\pi^0$)
- PID: K upstream, $e/\mu/\pi$ downstream
- Beam inelastic event suppression
- Sub-ns timing

Expected 45 SM signal events / year with < 10 background
Large angle photon vetoes
OPAL lead glass

Forward \gamma \nu veto
NA48 LKr

Dipole spectrometer
4 straw-tracker stations

Fiducial volume \sim 60m
10^{-6} mbar

Differential Cerenkov for \( K^+ \) ID in beam

Charged veto

Beam tracking
Si pixels, 3 stations

GIGATRACKER

\gamma \nu veto
IRC

CHOD
Hodoscope

\mu \nu veto
Fe/scint
Experimental status

- **NA62 took data in 2014 and 2015**
- **Beam commissioned up to nominal intensity**
- **Tracker:**
  - Beam tracker (Gigatracker) partially commissioned
  - Straw spectrometer commissioned
- **Cherenkov detectors:**
  - Beam Kaon ID (KTAG) commissioned
  - RICH commissioned
- **All the other detectors commissioned**
- **Trigger:**
  - L0 commissioned; L1(2) partially commissioned.
- **Data samples for data quality study (mainly from 2015):**
  - Low intensity data taken with a minimum bias trigger (this talk)
  - Samples at half and full intensity taken with a calorimeter trigger
One track selection (OTS):
- Single downstream track topology
- Beam track matching the downstream track
- Downstream track matching energy in calorimeters

K+ ID
Downstream track origin in the fiducial volume

Not K+ ID

K+ → π^+ π^0

K^+ → μ^+ ν_μ

Search for K^+ → π^+ ν̅ν at the NA62 experiment at CERN
2015 data quality: kinematics

**Technique:** Si-pixel tracker and Straw tube tracker in vacuum

**Goal:** $O(10^4 \div 10^5)$ kinematic suppression factor required for main backgrounds

Resolution on $m^2_{miss}$ close to the design

$O(10^3)$ kinematic suppression factor in 2015
2015 data quality: downstream particle ID

**Technique:** RICH and calorimeters

**Goal:** $O(10^7) \, \mu/\pi$ separation to suppress mainly $K^+ \to \mu^+ \nu_\mu$

80% $\pi^+$ efficiency in RICH with $O(10^2) \, \mu/\pi$ separation

Simple cut analysis on calorimeters provides $(10^4 \div 10^6) \, \mu$ suppression, with $(90\% \div 40\%) \, \pi^+$ efficiency. Room for improvements.
2015 data quality: photon rejection

**Technique:** EM calorimeters with different angles range

**Goal:** $O(10^8)$ rejection $\pi^0$ from $K^+ \to \pi^+ \pi^0$

Measured on data using $K^+ \to \pi^+ \pi^0$ selected kinematically

$O(10^6)$ $\pi^0$ rejection already obtained

2015 rejection measurement statistically limited
Summary from 2015 data quality studies

- **Time resolution:**
  Close to the design

- **Kinematics:**
  Resolution close to the design.
  Prospects to reach the designed signal – background separation.

- **Pion – muon ID:**
  Separation with RICH close to expectations.
  Study of the separation with calorimeters on going. Results from simple cut analysis promising.

- **Photon veto:**
  O(10^6) \(\pi^0\) rejection already obtained. More statistics needed to push the study at the design sensitivity.
NA62 physics programme

- **Standard Kaon Physics Precision:**
  - 10% precision $\text{BR}(K^+ \to \pi^+ \nu \bar{\nu})$ measurement
  - $\chi$PT studies: $K^+ \to \pi^+ \gamma \gamma, K^+ \to \pi^+ \pi^0 e^+ e^-, K^+ \to \pi^0(+) \pi^0(-) l^+ \nu$
  - Precision measurement of $R_K = \Gamma(K^+ \to e^+\nu_e)/(K^+ \to \mu^+\nu_\mu)$

- **LFV with kaons:**
  - $K^+ \to \pi^+ \mu^\pm e^\mp, K^+ \to \pi^- \mu^+ e^+, K^+ \to \pi^- l^+ l^+$

- **Heavy neutrino searches**
  - $K^+ \to l^+ \nu_h$
  - $\nu_h$ from K, D decays and $\nu_h \to \pi l$

- **Pion decay:**
  - $\pi^0 \to 3/4 \gamma, \pi^0 \to \text{invisible}$

- **Dark sector:**
  - long living dark photon, produced by $\pi^0/\eta/\eta'/\Phi/\rho/\omega$, decaying in $l^+l^-$
  - long living axion, produced in a beam-dump configuration, decaying in $\gamma\gamma$
Conclusion

- Commissioning of the NA62 experiment for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is almost completed. Tested up to the nominal intensity.

- Preliminary study of the quality of the data taken at low intensity:
  - Physics sensitivity for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ measurement in line with the design.
  - A further compelling physics program is going to be addressed.
  - Analysis of data at higher intensity on going.

- NA62 started to collect new data at the end of April (~200 days of data taking for 2016). The data taking will continue in 2017 and 2018.
Backup Slide
<table>
<thead>
<tr>
<th>Decay</th>
<th>Physics</th>
<th>Present limit (90% C.L.) / Result</th>
<th>NA62</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\mu^+e^-$</td>
<td>LFV</td>
<td>$1.3 \times 10^{-11}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\mu^-e^+$</td>
<td>LFV</td>
<td>$5.2 \times 10^{-10}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-\mu^+e^+$</td>
<td>LNV</td>
<td>$5.0 \times 10^{-10}$</td>
<td>$0.7 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-e^+e^+$</td>
<td>LNV</td>
<td>$6.4 \times 10^{-10}$</td>
<td>$2 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\pi^-\mu^+\mu^+$</td>
<td>LNV</td>
<td>$1.1 \times 10^{-9}$</td>
<td>$0.4 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\mu^-ve^+e^+$</td>
<td>LNV/LFV</td>
<td>$2.0 \times 10^{-8}$</td>
<td>$4 \times 10^{-12}$</td>
</tr>
<tr>
<td>$e^-\nu\mu^+\mu^+$</td>
<td>LNV</td>
<td>No data</td>
<td></td>
</tr>
<tr>
<td>$\pi^+X^0$</td>
<td>New Particle</td>
<td>$5.9 \times 10^{-11}$ $m_{X^0} = 0$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\chi\chi$</td>
<td>New Particle</td>
<td></td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\pi^+\pi^+e^-\nu$</td>
<td>$\Delta S \neq \Delta Q$</td>
<td>$1.2 \times 10^{-8}$</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>$\pi^+\pi^+\mu^-\nu$</td>
<td>$\Delta S \neq \Delta Q$</td>
<td>$3.0 \times 10^{-6}$</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td>$\pi^+\gamma$</td>
<td>Angular Mom.</td>
<td>$2.3 \times 10^{-9}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>$\mu^+\nu_h, \nu_h \rightarrow \nu\gamma$</td>
<td>Heavy neutrino</td>
<td>Limits up to $m_{\nu_h} = 350$ $MeV$</td>
<td></td>
</tr>
<tr>
<td>$R_K$</td>
<td>LU</td>
<td>$(2.488 \pm 0.010) \times 10^{-5}$</td>
<td>$\times2$ better</td>
</tr>
<tr>
<td>$\pi^+\gamma\gamma$</td>
<td>$\chi$PT</td>
<td>$&lt; 500$ events</td>
<td>$10^5$ events</td>
</tr>
<tr>
<td>$\pi^0\pi^0e^+\nu$</td>
<td>$\chi$PT</td>
<td>$66000$ events</td>
<td>$O(10^6)$</td>
</tr>
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<td>$\pi^0\pi^0\mu^+\nu$</td>
<td>$\chi$PT</td>
<td>-</td>
<td>$O(10^5)$</td>
</tr>
</tbody>
</table>
Trigger for LFN modes in NA62

3-track decays upstream of trigger hodoscope vs. \( \sim 1 \text{ MHz} \) design rate for L0 trigger

Definitions of level-0 trigger primitives:

- \( Q_n \)  
  Hits in at least \( n \) Hodo quadrants

- \( \text{LKR}_n(x) \)  
  At least \( n \) LKr clusters with energy \( E > x \) GeV

- \( \text{MUV}_n \)  
  Hits in at least \( n \) MUV3 pads

Level-0 triggers for LFNV searches:

- \( ee \) pair  
  \( Q_2 \cdot \text{LKR}_2(15) \)

- \( e\mu \) pair  
  \( Q_2 \cdot \text{LKR}_1(15) \cdot \text{MUV}_1 \)

- \( \mu\mu \) pair  
  \( Q_2 \cdot \text{MUV}_2 \)

Total rate \( \sim \) few \( \times 10 \) kHz

Dominantly from \( K_{\pi^3}, K \rightarrow \pi\pi^0_D \)
$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

• FCNC loop processes: $s\to d$ coupling and highest CKM suppression
  
  ![FCNC loop processes](image)

• Very clean theoretically:
  - SD contribution dominate $A_q \sim \frac{M_q^2}{M_W^2} V^*_{qs} V_{qd}$
  - Hadronic matrix element related to the precisely measured BR ($K^+ \to \pi^0 e^+ \nu_e$)

• BR proportional to $|V_{ts} V_{td}|^2$


$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$$
Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN
NA62 setup: Gigatracker and Straw tracker

Giga-tracker
3 stations of Si pixels matching the beam dimensions placed in vacuum (5400 pixels, 10 read out chips)

Straw-tracker
4 chambers, 2.1 m in diameter
16 layers (4 views) of straws per chamber

\[ \sigma \leq 130 \, \mu m \text{ (1 view)} \quad \sigma_p/p < 1\% \]
\[ 0.45X_0 \text{ per chamber} \quad \sigma_{\theta(K\pi)} < 60 \mu rad \]

Detector fully commissioned in 2014 run

In 2015 the detector was partially commissioned with \( \sigma_t \sim 250\)ps, \( \sigma_\theta \sim 16 \mu rad \)
Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN

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NA62 setup: KTAG and CHANTI

KTAG
Identifies 45 MHz of $K^+$ in 750 MHz of unseparated beam
Running with $N_2$ at 1.74 bar

Detector commissioned with
✓ $\sigma_t < 70$ps
✓ K-ID efficiency > 95%
✓ K mis-ID < 10$^{-3}$

CHANTI
Detection of particles from inelastic interactions in GTK mimicking a pion in time with a kaon
6 stations hermetic to charged particles between 49 mrad and 1.31 rad
Each station is made of 24 scintillation bars in each view (X & Y),
readout with WLS fibers and SiPMs

Detector commissioned with
✓ $\sigma_t \sim 900$ps
✓ Single layer efficiency > 0.99
Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the NA62 experiment at CERN
MUV system: $\pi/\mu$ identification & trigger

MUV1-2: Fe/scintillator hadron calorimeter
- Used offline to provide principal veto for $K \to \mu\nu$

MUV3: Fast $\mu$ identification for trigger
- Vetoes $\mu$ online at 10 MHz

Detector commissioned; MUV3 $\sigma_t \sim 420\text{ps}$

RICH provides additional $10^{-2}$ $\mu$ rejection to exclude $K \to \mu\nu$

- $\mu/\pi$ separation $\sim 1\%$ for $15<p<35\text{GeV}$
- Provides L0 trigger for charged particles
- Ne gas at 1 atm
- 2000 8-mm PMTs on upstream flanges

RICH fully commissioned with $\sigma_t \sim 70\text{ps}$
NA62 photon veto detectors

Large angle photon vetoes
OPAL lead glass

Fiducial volume ~60m
10^{-6} mbar

Forward \gamma veto
NA48 LKr

\gamma veto
IRC

\gamma veto
SAC

\gamma veto

LKr

Fiducial volume ~60m
10^{-6} mbar

4 m

0
100
200
250 m
NA62 photon veto detectors

Large angles vetoes (LAV) $8.5 < \theta < 50$ mrad
12 stations at intervals of ~10m along decay volume
Each station has 4-5 rings/station of lead glass blocks
$1-\epsilon$ for $e^-$ at 200 MeV: $\sim 10^{-4}$

LAV fully commissioned with $\sigma_t \sim 1$ns

Liquid krypton calorimeter (LKr) $1 < \theta < 8.5$ mrad
Quasi-homogeneous ionization calorimeter
Readout towers $2 \times 2$ cm$^2$ - 13248 channels
Depth 127 cm = 27 $X_0$
$1-\epsilon$ for $\gamma$ with $E > 10$ GeV: $< 10^{-5}$

LKr from NA48 setup.
Commissioned with:
• $\sigma_t \sim 500$ps
• Space resolution 1mm
• $1-\epsilon < 10^{-5}$ for 10 GeV $\gamma$

SAC & IRC: very small angle veto Shashlik calorimeters

SAC: $\gamma$ detection along the beamline (after beam deflection)
IRC: detection of photons at very low angle in front of the LKr
WLSs+PMTs used for both detectors

Both commissioned in 2015 with $\sigma_t \sim 1$ns