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

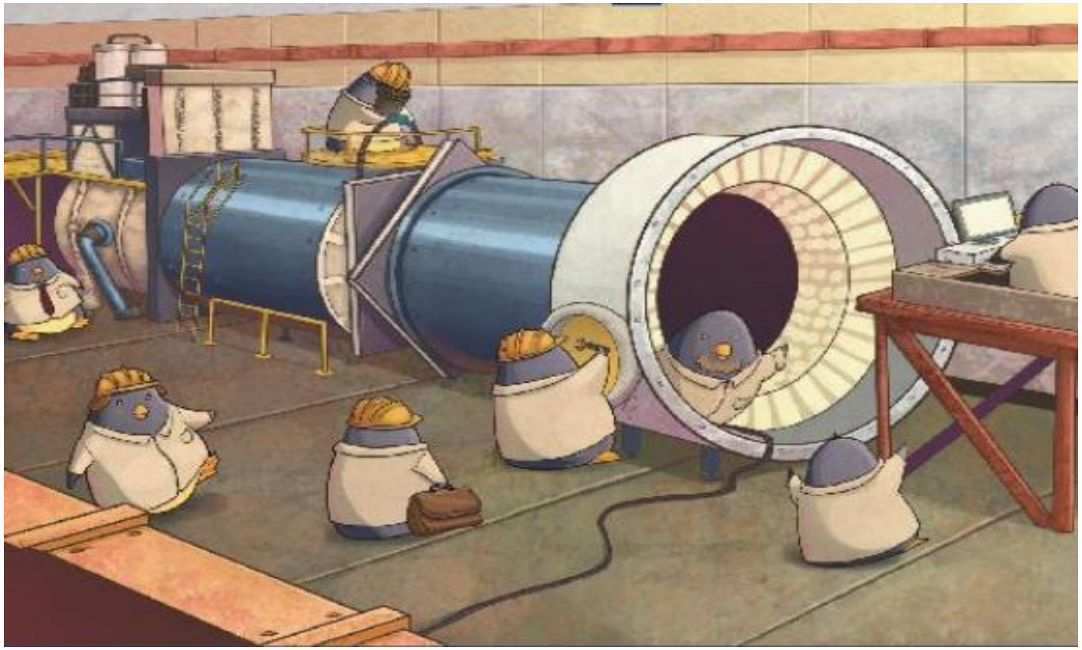
on behalf of the NA62 collaboration

XIIIth International Conference on Heavy Quarks and Leptons

May 24 2016, Blacksburg, Virginia

Outline

- $K^+ \to \pi^+ \nu\bar{\nu}$ **decay**
- **NA62 experimental strategy and apparatus**
- **2015 data quality**



Kaons at CERN SPS

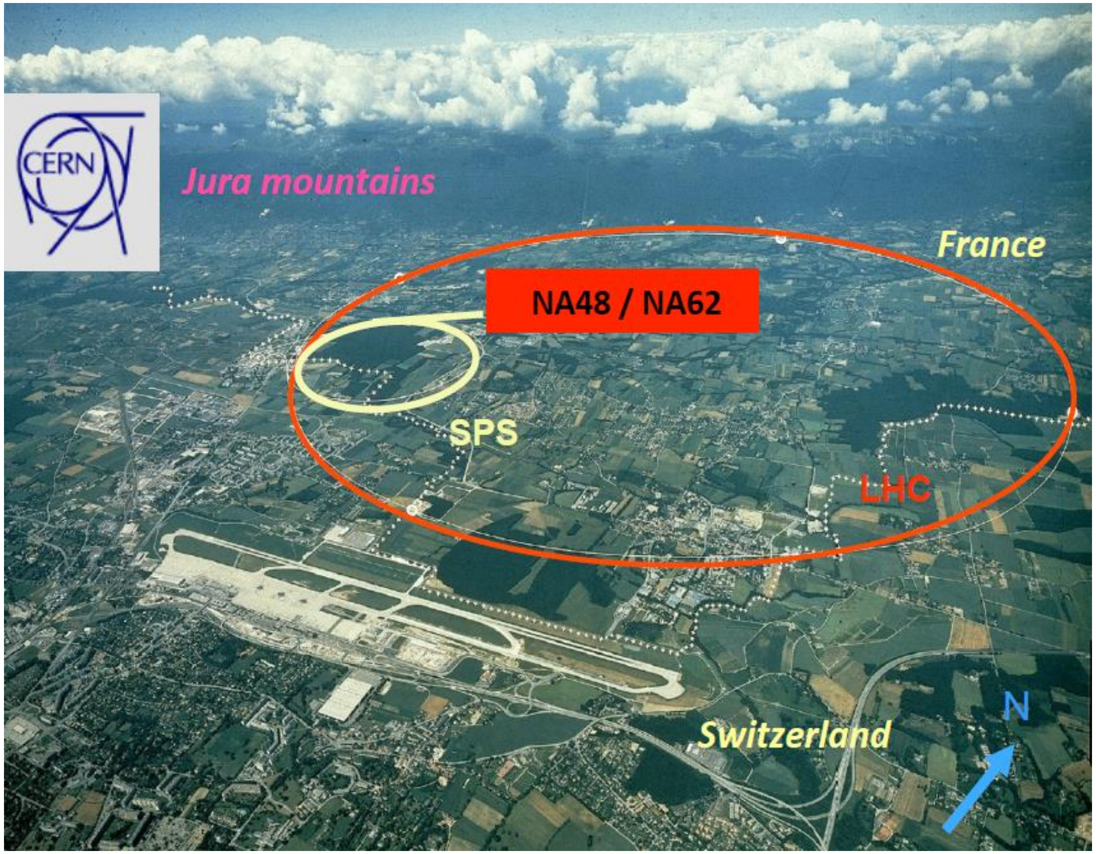
NA48 (1997 – 2001)
ε'/ε and direct CP violation discovery

NA48/1 (2002)
K_s rare decay studies

NA48/2 (2003 – 2004)
$K^{\pm}$ precision measurements

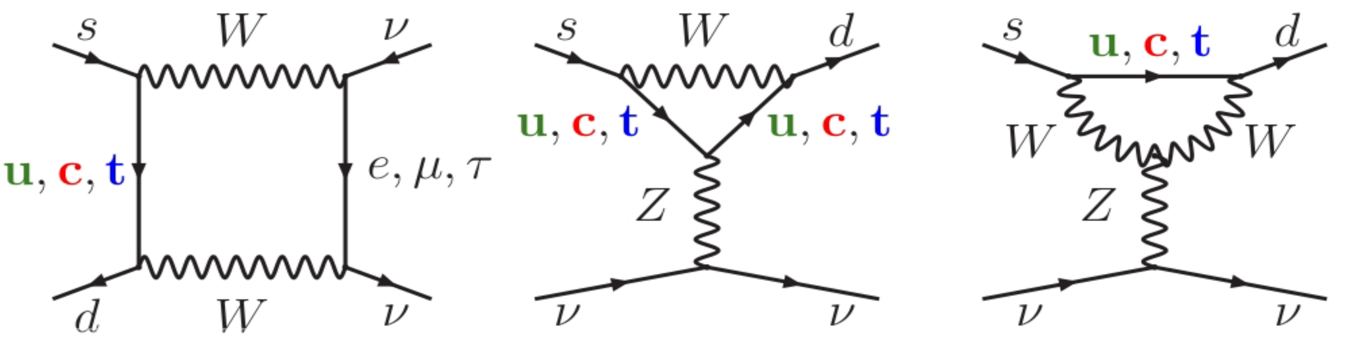
NA62 (2007)
Lepton universality: $K_{e2}/K_{\mu 2}$ (using the NA48 apparatus)

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



$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

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



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$

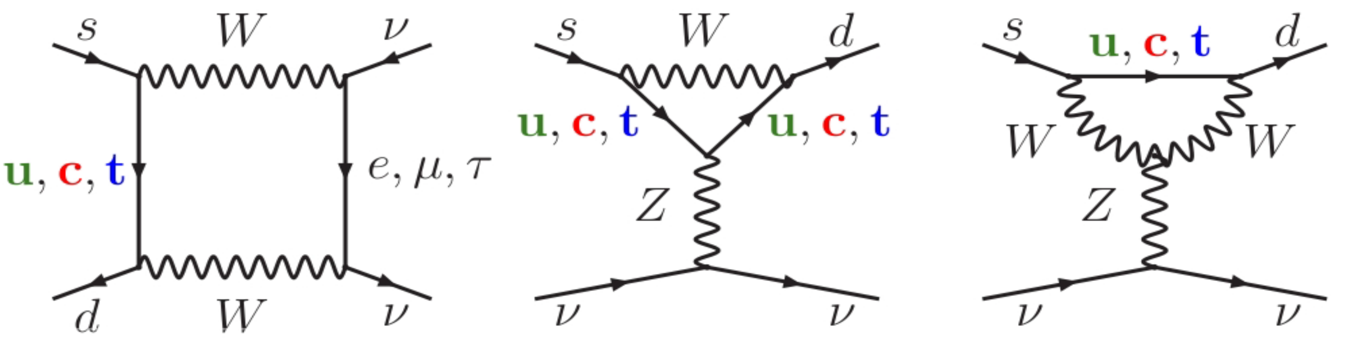
$$x_q \equiv m_q^2 / m_W^2$$

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

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

$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

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



$$\lambda = V_{us}$$
$$\lambda_c = V_{cs}^* V_{cd}$$
$$\lambda_t = V_{ts}^* V_{td}$$

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

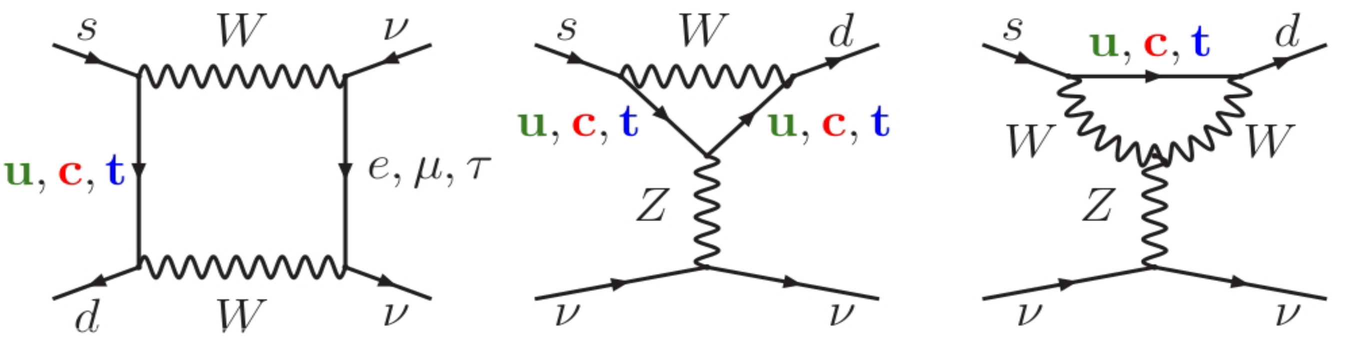
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right] (1 + \Delta_{EM})$$

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

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

$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

FCNC loop processes: s→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

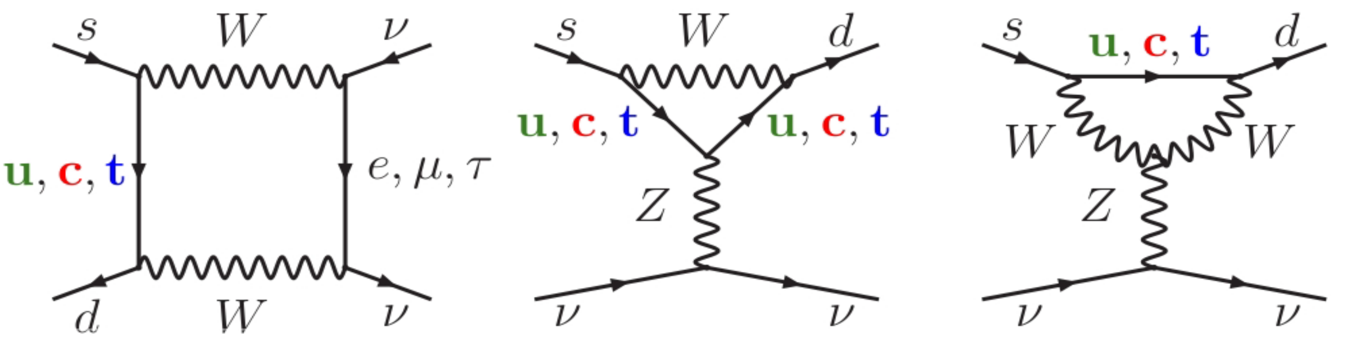
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right] (1 + \Delta_{EM})$$

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

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

$K^+ \to \pi^+\nu\bar{\nu}$ decay in SM

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



$$\begin{aligned} \lambda &= V_{us} \\ \lambda_c &= V^*_{cs}V_{cd} \\ \lambda_t &= V^*_{ts}V_{td} \end{aligned}$$

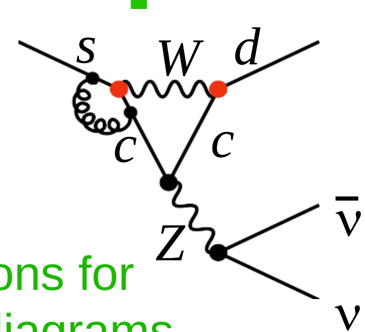
$$x_q \equiv m_q^2/m_W^2$$

Loop functions favor top contribution

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

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

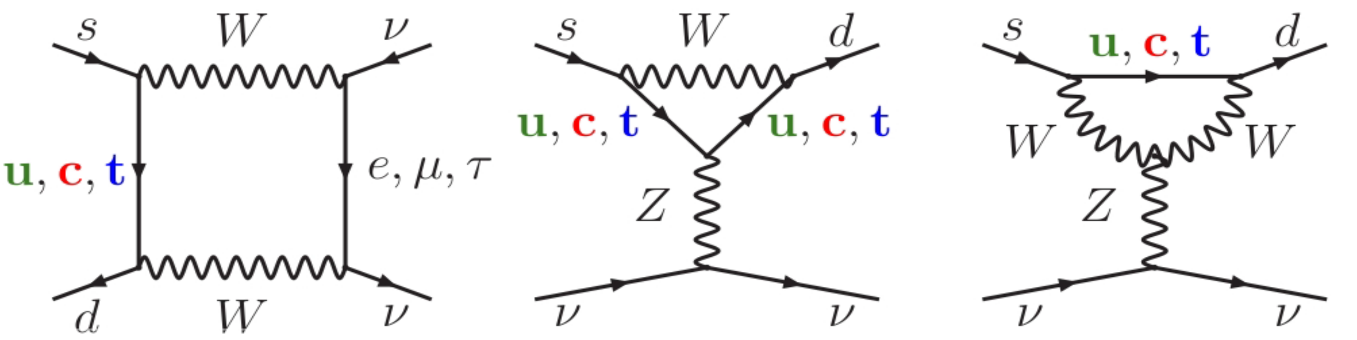
Hadronic matrix element obtained from BR(K_{l3}) via isospin rotation



QCD corrections for charm diagrams

$K^+ \to \pi^+ \nu \bar{\nu}$ decay in SM

FCNC loop processes: s→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

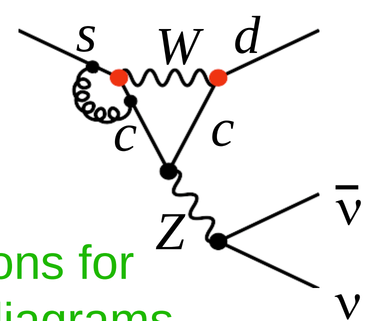
EM radiative correction

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

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

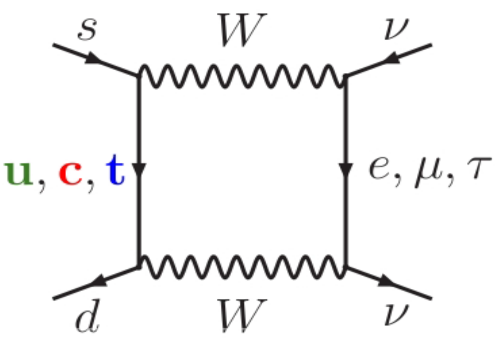
Hadronic matrix element obtained from BR(K_{l3}) via isospin rotation

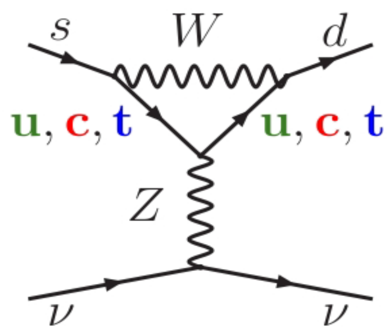
QCD corrections for charm diagrams

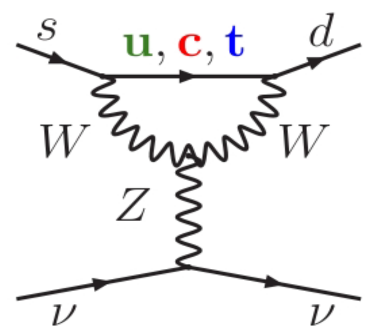


$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

FCNC loop processes: s→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

EM radiative correction

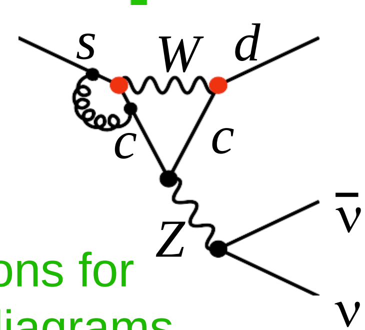
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_t}{\lambda^5} X(x_t) + \frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) \right)^2 \right] (1 + \Delta_{EM}) = 9.11 \pm 0.72$$

$$\mathrm{BR}(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 \leftarrow \cancel{CP} = 3.00 \pm 0.30$$

SM prediction (10^{-11} units)

A.J. Buras et al, 2015,arXiv: 1503.02693

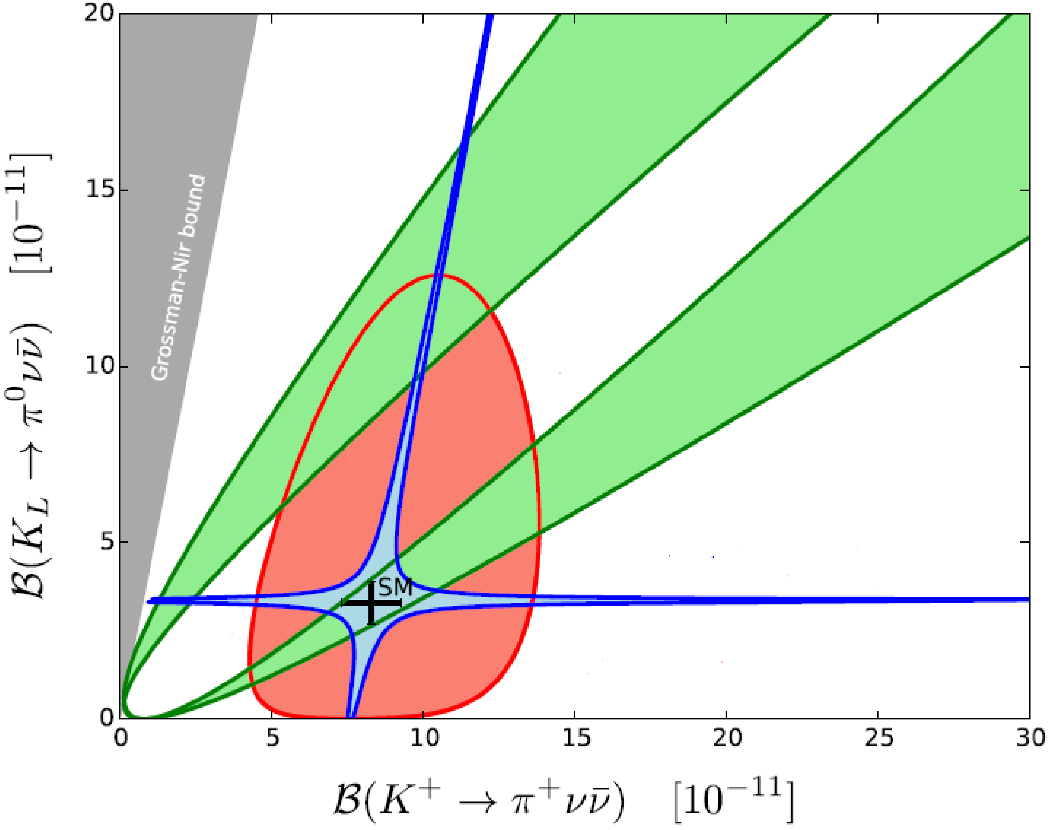
Hadronic matrix element obtained from BR(K_{l3}) via isospin rotation



QCD corrections for charm diagrams

$K^+ \to \pi^+ \nu\bar{\nu}$ beyond SM

Possibility to distinguish among different models



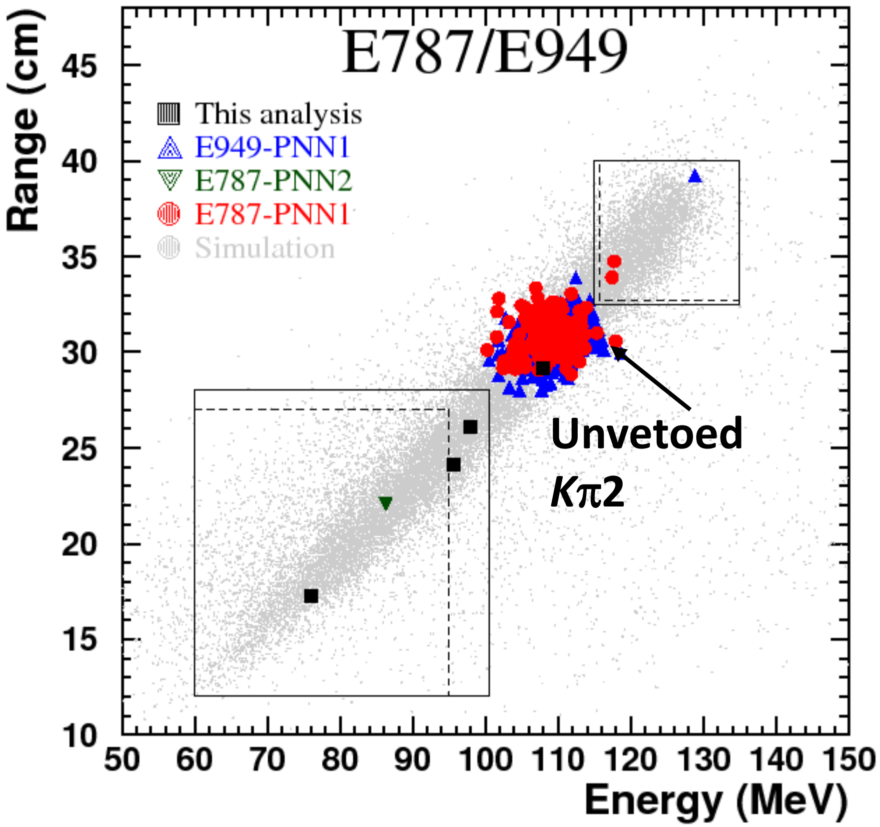
- **Models with a CKM-like structure of flavour interactions (e.g. MFV)**
- **Models with new flavour and CP-violating interactions in which either left or right handed currents fully dominate (e.g. Z or Z' FCNC scenarios)**
- **More specifics NP models like Randall-Sundrum**

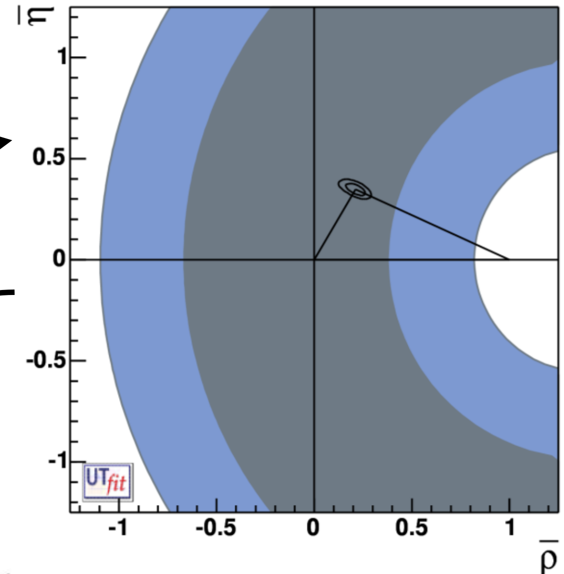
[A. J. Buras, D. Buttazzo, and R. Knegjens, arXiv:1507.08672, Nov 2015]

$K^+ \to \pi^+ \nu\bar{\nu}$ decay: experimental status

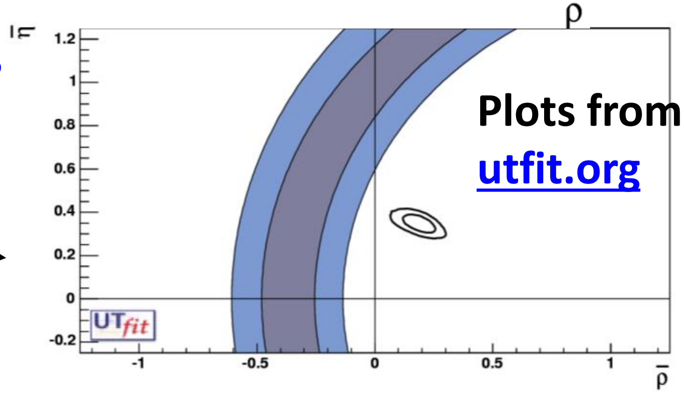
In 2008, combine E787 (1995-8 runs) & E949 (12-weeks run in 2001) results

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





Same central value, 100 evts



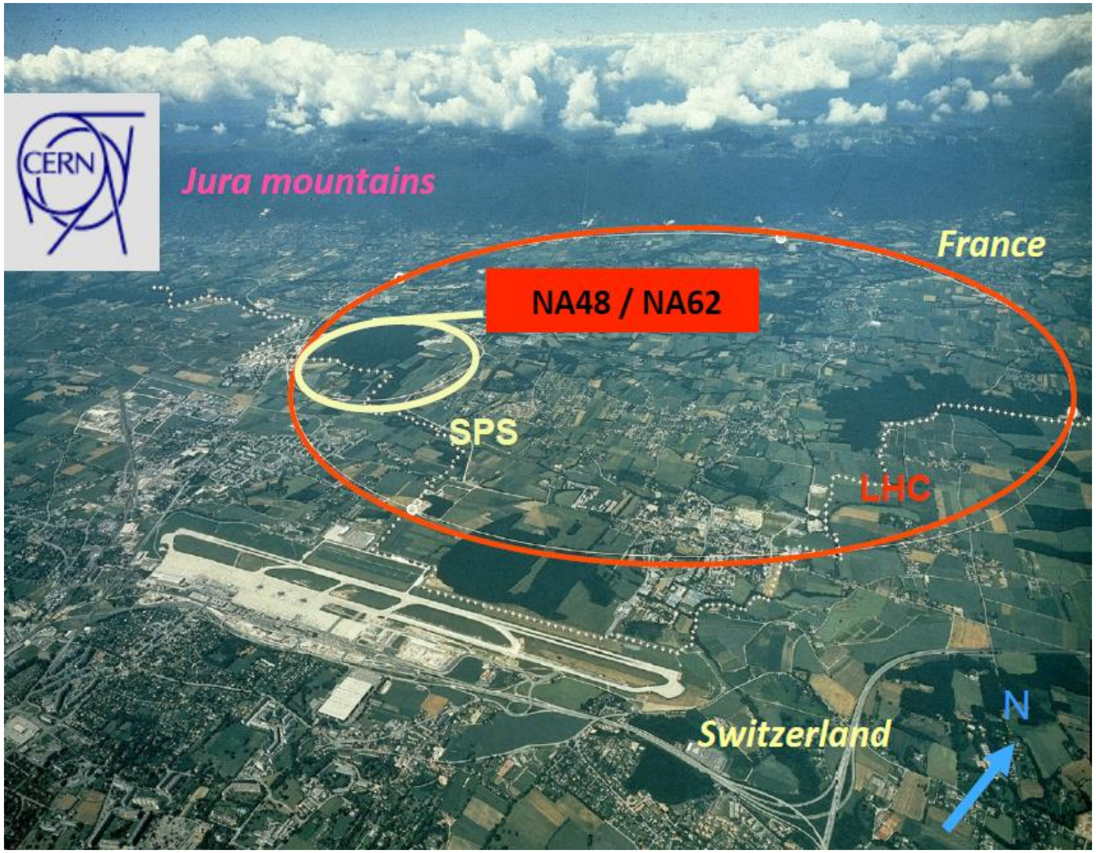
Plots from utfit.org

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 450GeV/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

NA62 beam

Primary SPS proton beam:

- p = 400 GeV protons
- Proton on target 1.1×10^{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 π
- 170 MHz p
- 45 MHz K

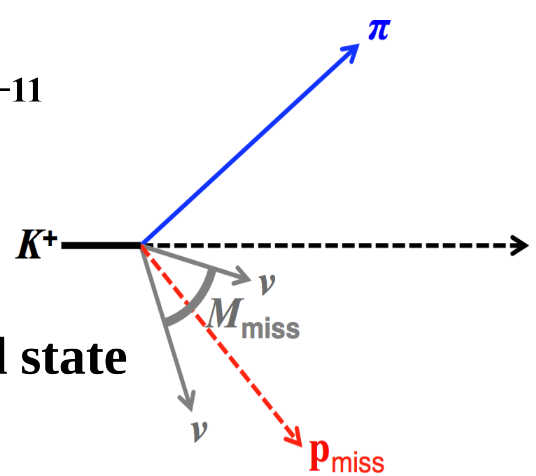
$K^+ \to \pi^+ \nu\bar{\nu}$ decay: signal and background

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

Technique:
K decay in flight

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

K^+ track in
π^+ track out
No other particles in final state



Requirements:

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

Decay backgrounds

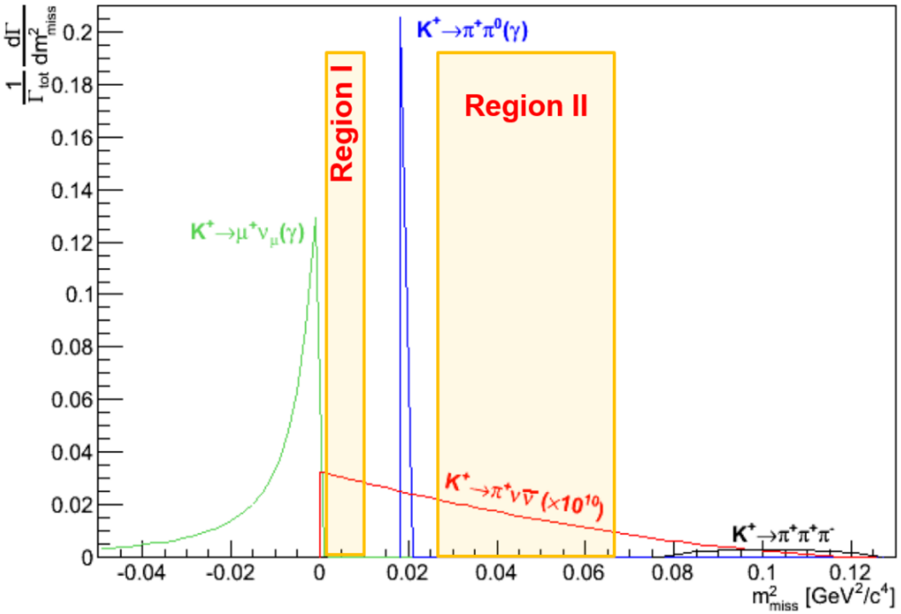
Mode		BR
$\mu^+\nu(\gamma)$	$K_{\mu 2}$	63.5%
$\pi^+\pi^0(\gamma)$	$K_{2\pi}$	20.7%
$\pi^+\pi^+\pi^-$	$K_{3\pi}$	5.6%
$\pi^0 e^+ \nu$	K_{e3}	5.1%
$\pi^0 \mu^+ \nu$	$K_{\mu 3}$	3.3%
$\pi^+\pi^- e^+ \nu$	$K_{e4}(+-)$	4.1×10^{-5}
$\pi^0\pi^0 e^+ \nu$	$K_{e4}(00)$	2.2×10^{-5}
$\pi^+\pi^- \mu^+ \nu$	$K_{\mu 4}$	1.4×10^{-5}
$e^+\nu(\gamma)$	K_{e2}	1.5×10^{-5}

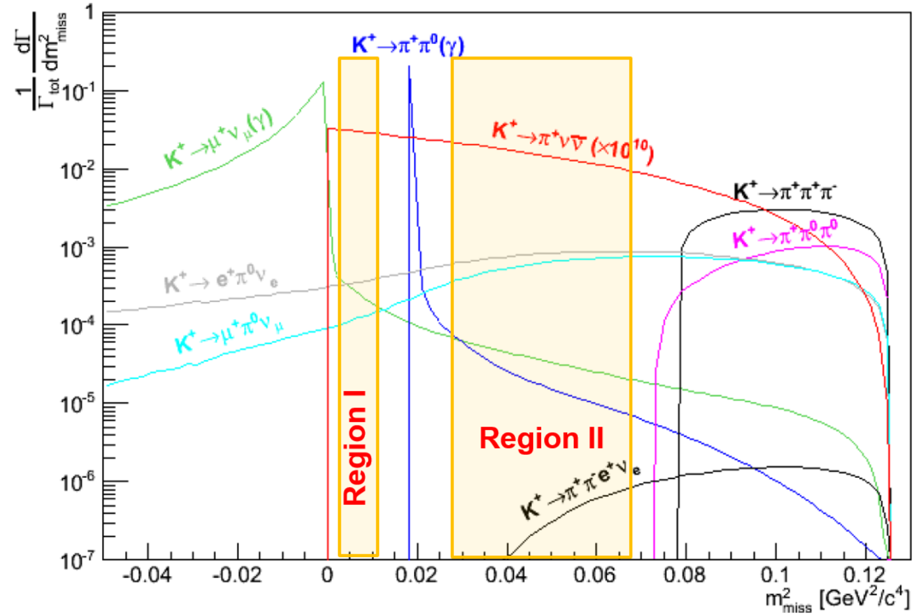
Other backgrounds

Upstream interactions

NA62 experimental strategy

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



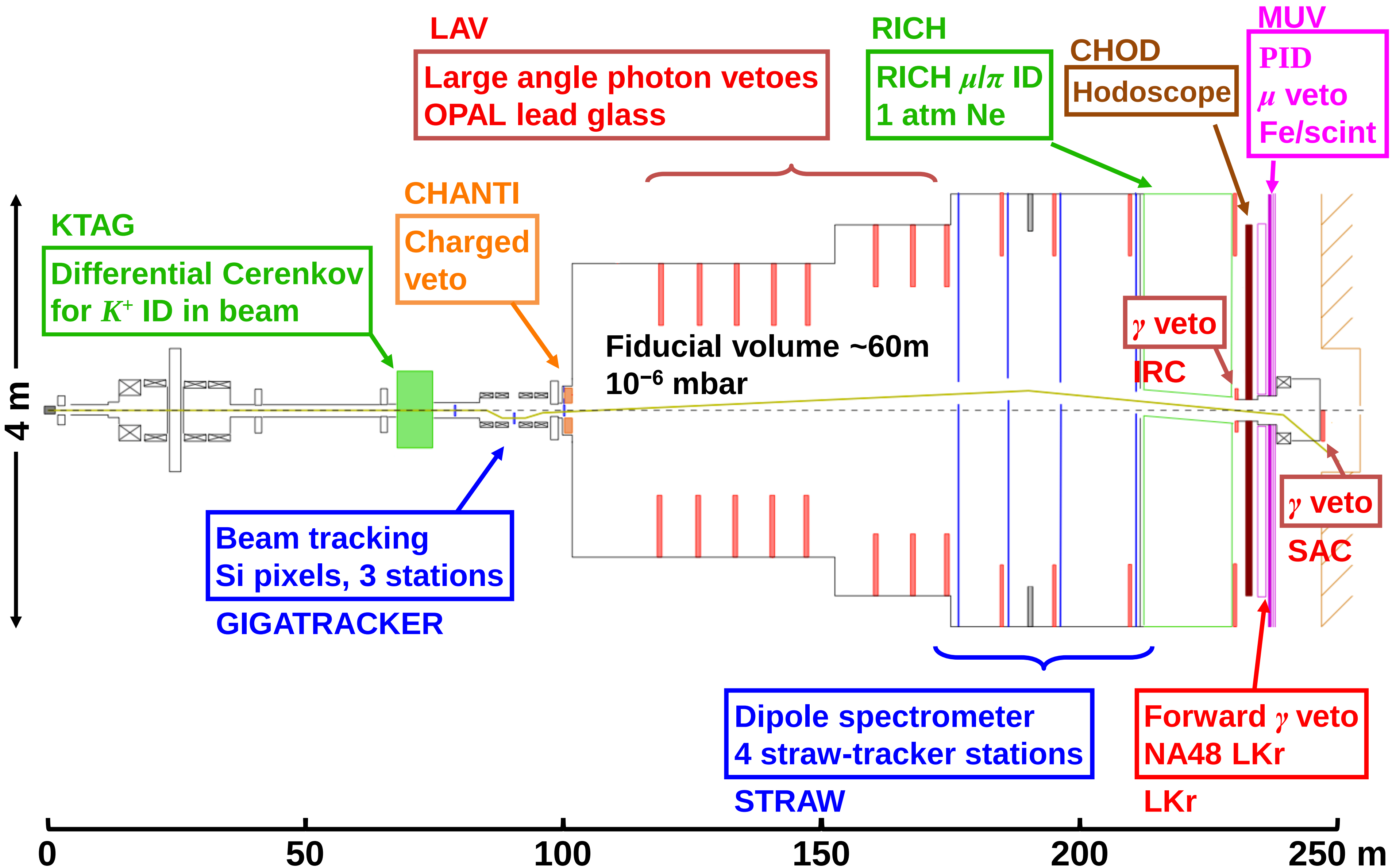


Experimental principles:

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

Expected 45 SM signal events / year with < 10 background

NA62 setup

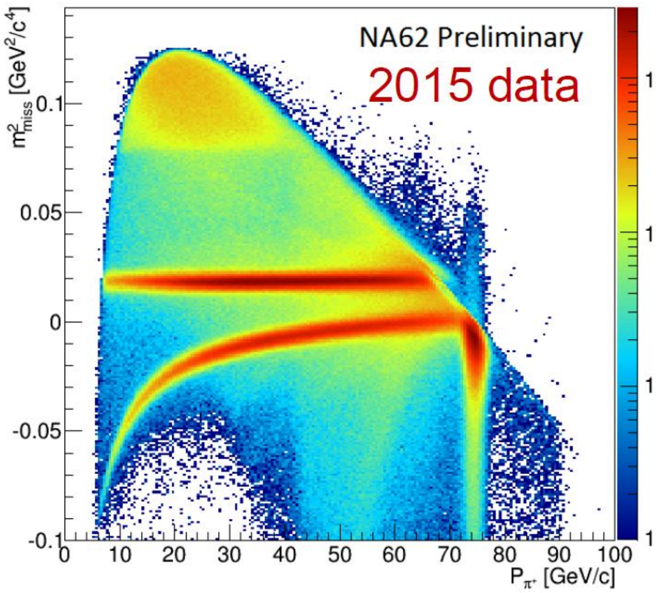


LAV
Large angle photon vetoes
OPAL lead glass
RICH
RICH μ/π ID
1 atm Ne
CHOD
Hodoscope
MUV
PID
μ veto
Fe/scint
KTAG
Differential Cerenkov
for K^+ ID in beam
CHANTI
Charged
veto
4 m
Fiducial volume ~60m
10^{-6} mbar
γ veto
IRC
γ veto
SAC
Beam tracking
Si pixels, 3 stations
GIGATRACKER
Dipole spectrometer
4 straw-tracker stations
STRAW
Forward γ veto
NA48 LKr
LKr
0
50
100
150
200
250 m

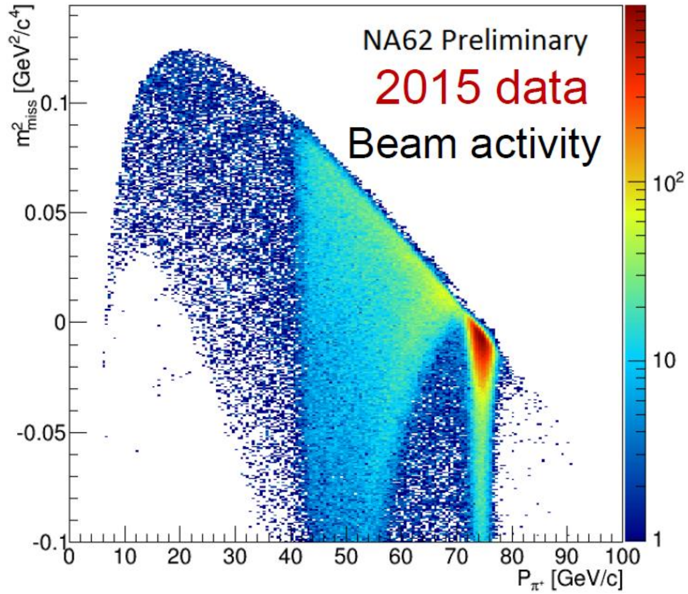
Experimental status

- **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

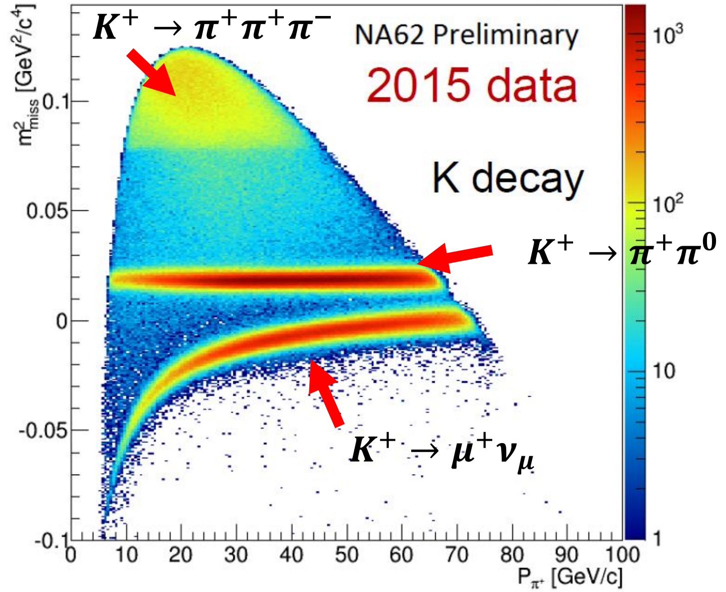
2015 data quality: signal topology and K^+ ID



Not K^+ ID



K^+ ID
Downstream track origin in the fiducial volume

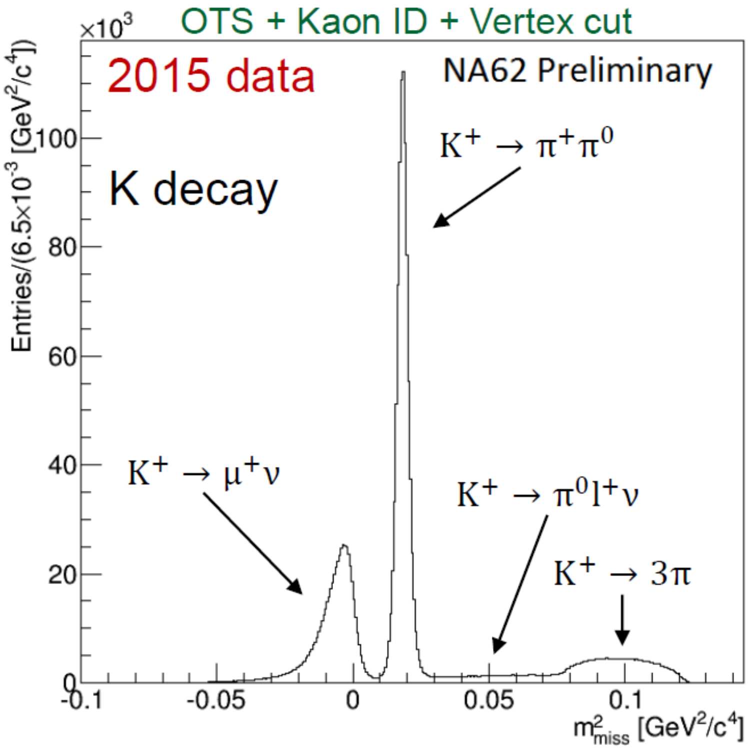


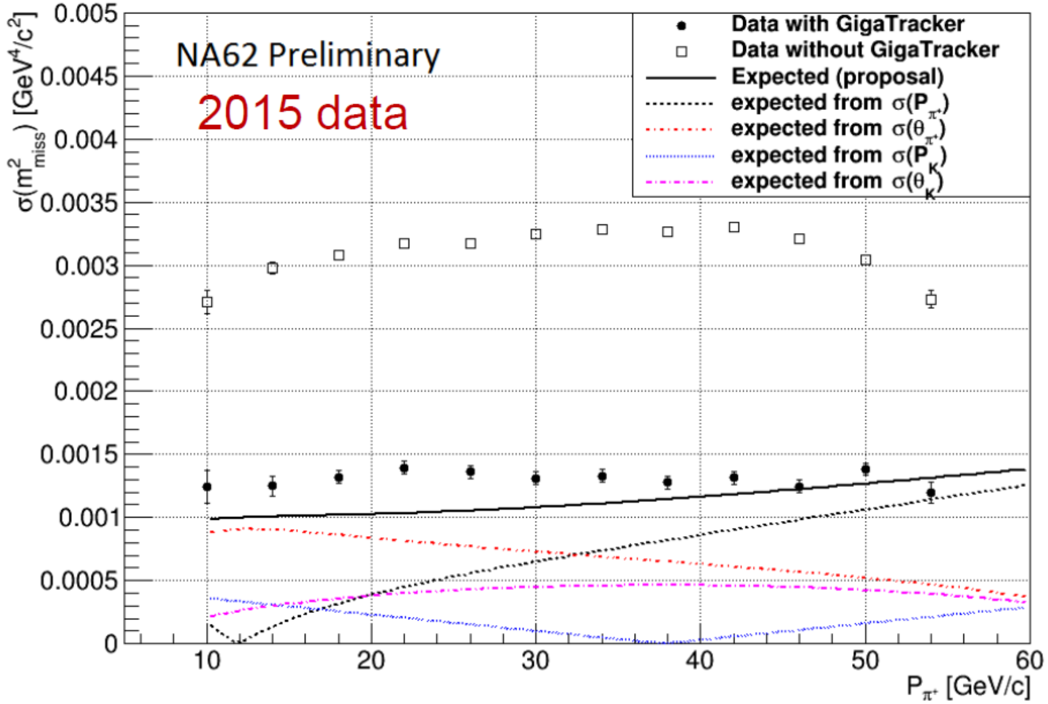
One track selection (OTS):
- Single downstream track topology
- Beam track matching the downstream track
- Downstream track matching energy in calorimeters

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



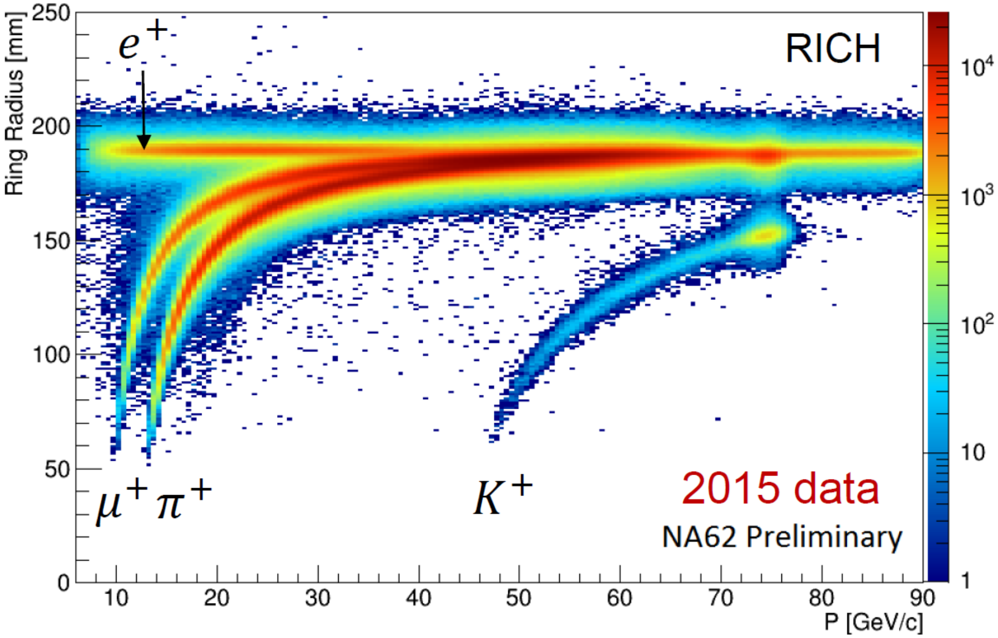


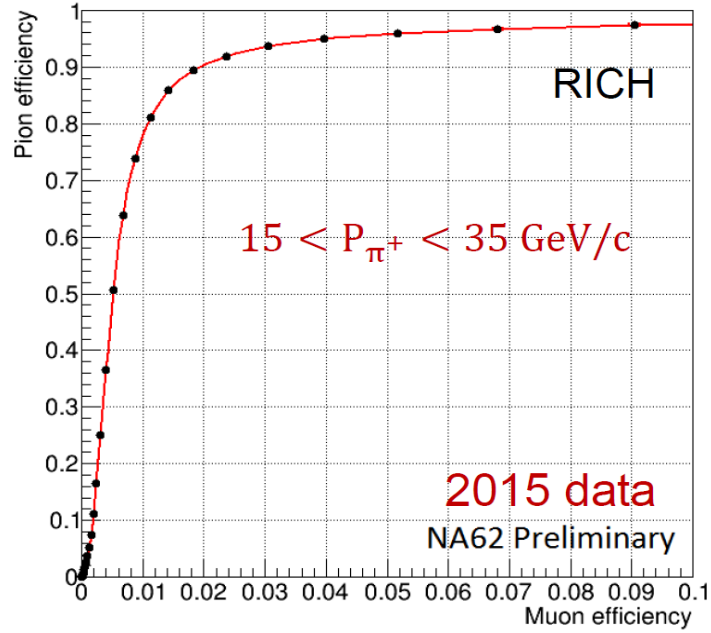
Resolution on m^2_{miss} close to the design

O(10^3) kinematic suppression factor in 2015

2015 data quality: downstream particle ID

Technique: RICH and calorimeters
Goal: $O(10^7)$ μ/π separation to suppress mainly $K^+ \to \mu^+ \nu_\mu$





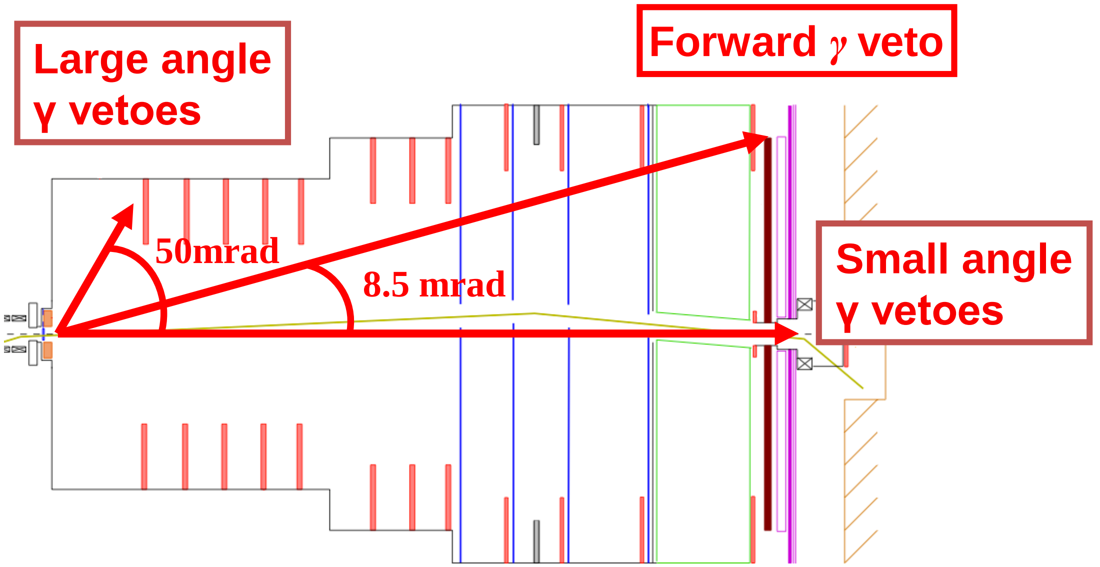
80% π^+ efficiency in RICH with $O(10^2)$ μ/π separation

Simple cut analysis on calorimeters provides ($10^4 \div 10^6$) μ suppression, with (90%÷40%) π^+ efficiency. Room for improvements.

2015 data quality: photon rejection

Technique: EM calorimeters with different angles range

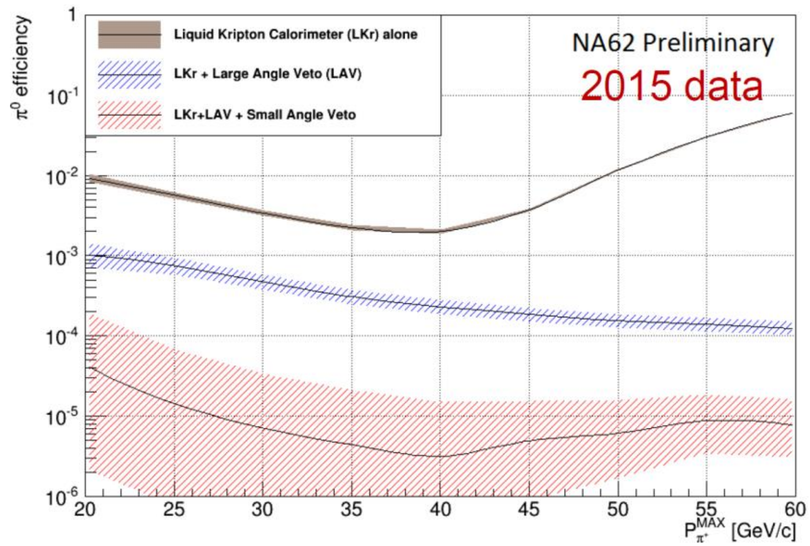
Goal: $O(10^8)$ rejection π^0 from $K^+ \to \pi^+\pi^0$



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

$O(10^6)$ π^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) π^0 rejection already obtained. More statistics needed to push the study at the design sensitivity.

NA62 physics programme

- **Standard Kaon Physics Precision:**
  - 10% precision BR($K^+ \to \pi^+ \nu\bar{\nu}$) measurement
  - χPT 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**
  - $K^+ \to l^+ \nu_h$
  - ν_h from K, D decays and $\nu_h \to \pi l$

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

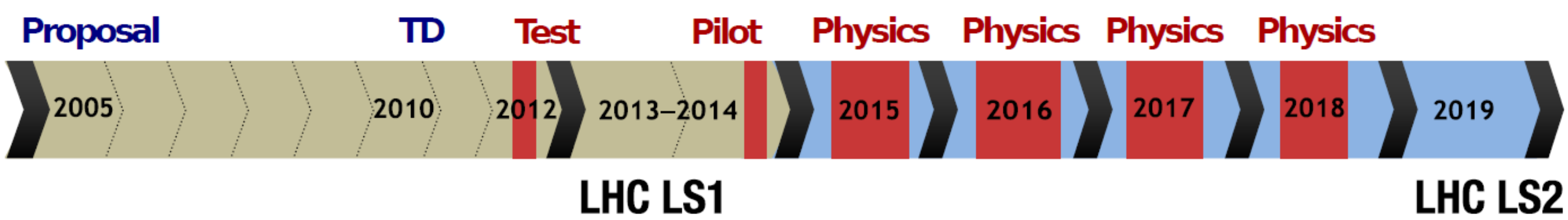
- **Dark sector:**
  - long living dark photon, produced by $\pi^0/\eta/\eta/\Phi/\varrho/\omega$, decaying in $l^+ l^-$
  - long living axion, produced in a beam-dump configuration, decaying in $\gamma\gamma$

Conclusion

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

- Preliminary study of the quality of the data taken at low intensity:
  - **Physics sensitivity** for $K^+ \to \pi^+ \nu\bar{\nu}$ 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

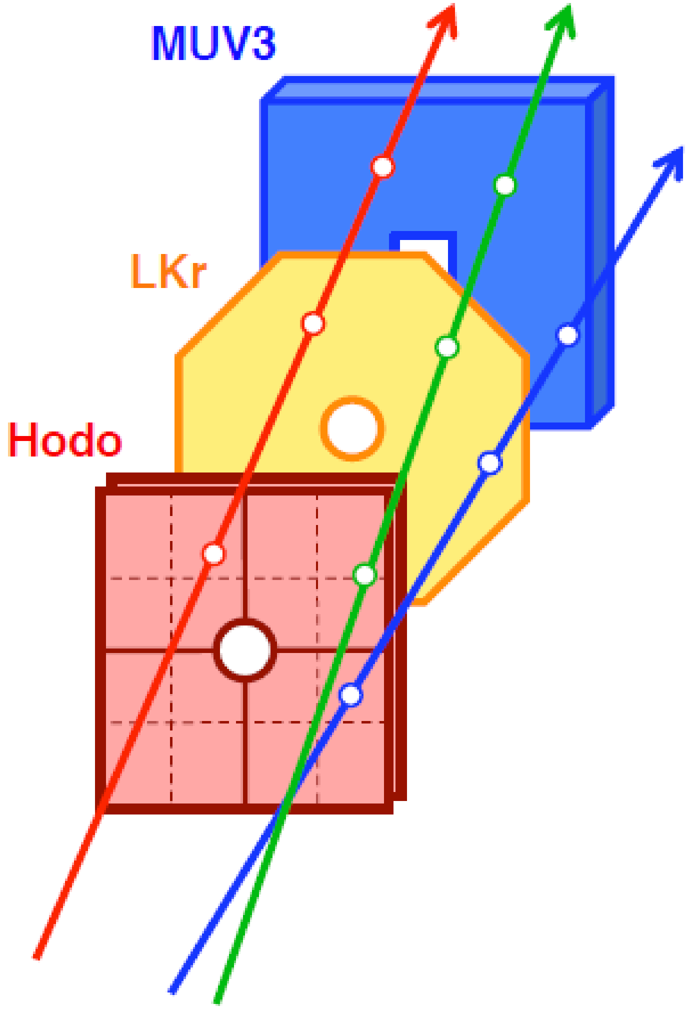


Backup Slide

Decay	Physics	Present limit (90% C.L.) / Result	NA62
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	0.7×10^{-12}
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	0.7×10^{-12}
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	0.7×10^{-12}
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	2×10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	0.4×10^{-12}
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	5.9×10^{-11} $m_{X^0}=0$	10^{-12}
$\pi^+\chi\chi$	New Particle	–	10^{-12}
$\pi^+\pi^+e^-\nu$	$\Delta S\neq\Delta Q$	1.2×10^{-8}	10^{-11}
$\pi^+\pi^+\mu^-\nu$	$\Delta S\neq\Delta Q$	3.0×10^{-6}	10^{-11}
$\pi^+\gamma$	Angular Mom.	2.3×10^{-9}	10^{-12}
$\mu^+\nu_h, \nu_h\to\nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h}=350\ MeV$	
R_K	LU	$(2.488\pm0.010)\times10^{-5}$	>×2 better
$\pi^+\gamma\gamma$	χPT	< 500 events	10^5 events
$\pi^0\pi^0e^+\nu$	χPT	66000 events	$O(10^6)$
$\pi^0\pi^0\mu^+\nu$	χPT	-	$O(10^5)$

Trigger for LFN modes in NA62

640 kHz 3-track decays upstream of trigger hodoscope vs. **~1 MHz** design rate for L0 trigger



Definitions of level-0 trigger primitives:

Q_n	Hits in at least n Hodo quadrants
$LKR_n(x)$	At least n LKr clusters with energy $E > x$ GeV
MUV_n	Hits in at least n MUV3 pads

Level-0 triggers for LFNV searches:

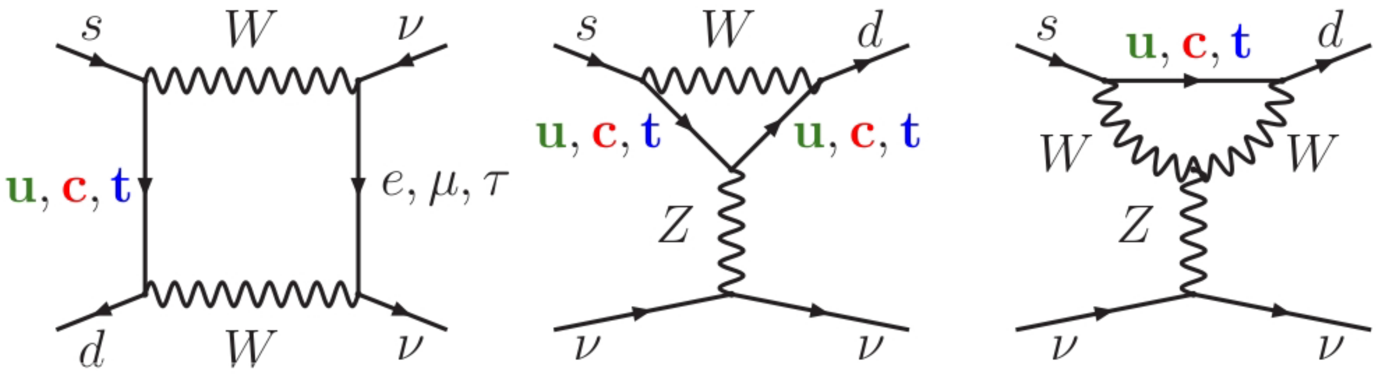
ee pair	$Q_2 \cdot LKR_2(15)$
$e\mu$ pair	$Q_2 \cdot LKR_1(15) \cdot MUV_1$
$\mu\mu$ pair	$Q_2 \cdot MUV_2$

Total rate ~few × 10 kHz

Dominantly from $K_{\pi 3}$, $K \rightarrow \pi\pi^0{}_{\mathrm{D}}$

$K^+ \to \pi^+ \nu\bar{\nu}$ decay in SM

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



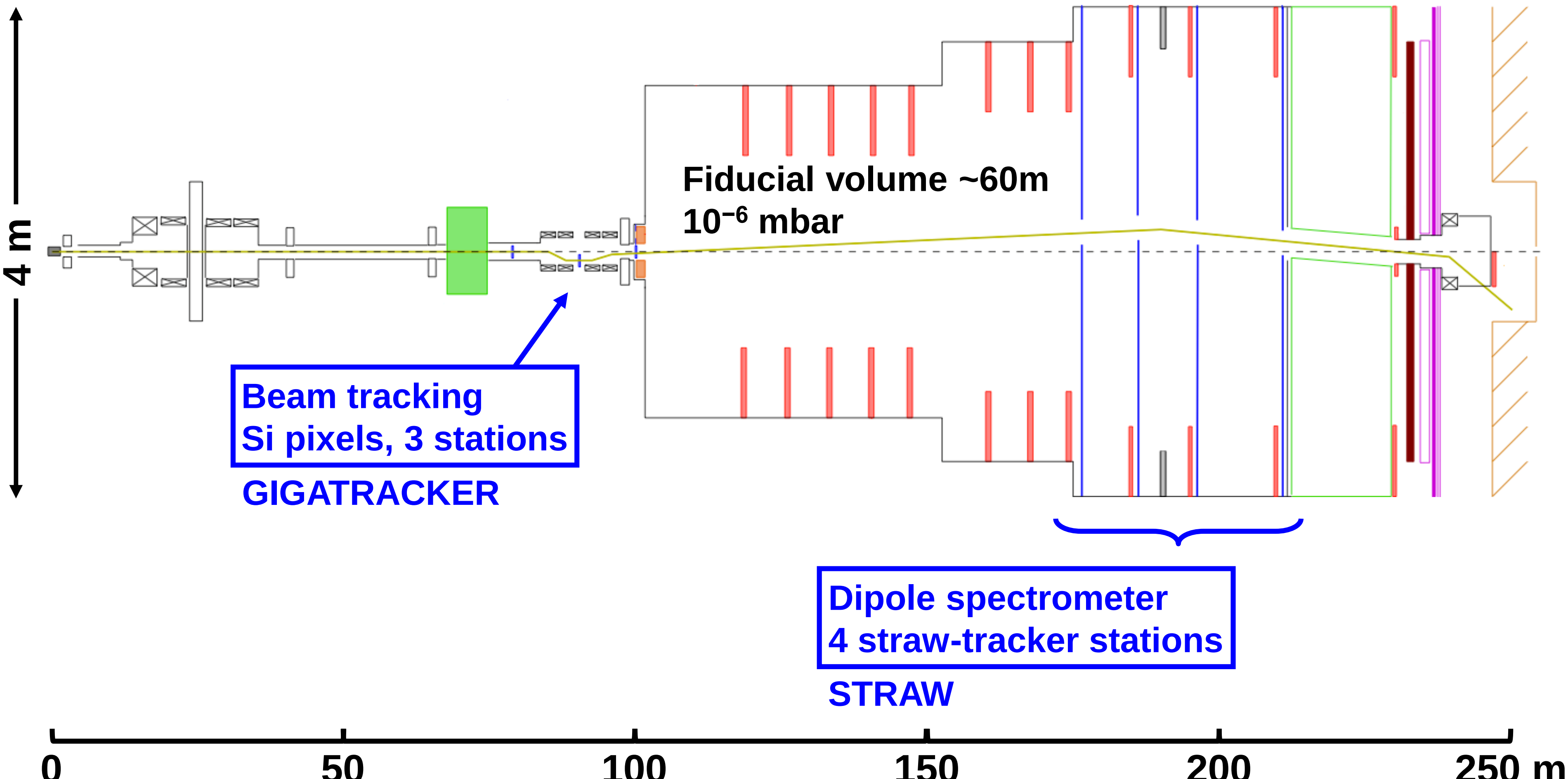
- **Very clean theoretically:**
  - **SD contribution dominate** $A_q \sim \frac{M_q^2}{M_W^2} V_{qs}^* V_{qd}$
  - **Hadronic matrix element related to the precisely measured BR** $(K^+ \to \pi^0 e^+ \nu_e)$

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

- **SM prediction [A.J. Buras et al, 2015 , arXiv:1503.02693]**

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (9.11 \pm 0.72)\times 10^{-11}$$

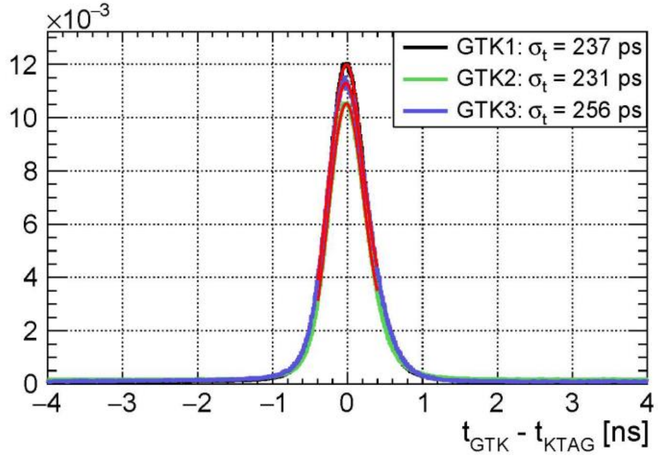
NA62 setup: Gigatracker and Straw tracker

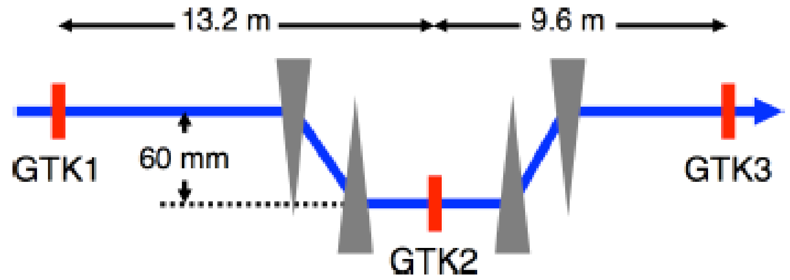


NA62 setup: Gigatracker and Straw tracker

Giga-tracker

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





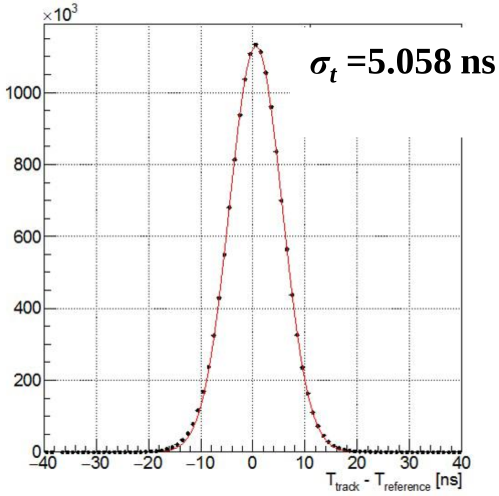
In 2015 the detector was partially commissioned with σ_t~250ps, σ_θ~16 μrad

Straw-tracker

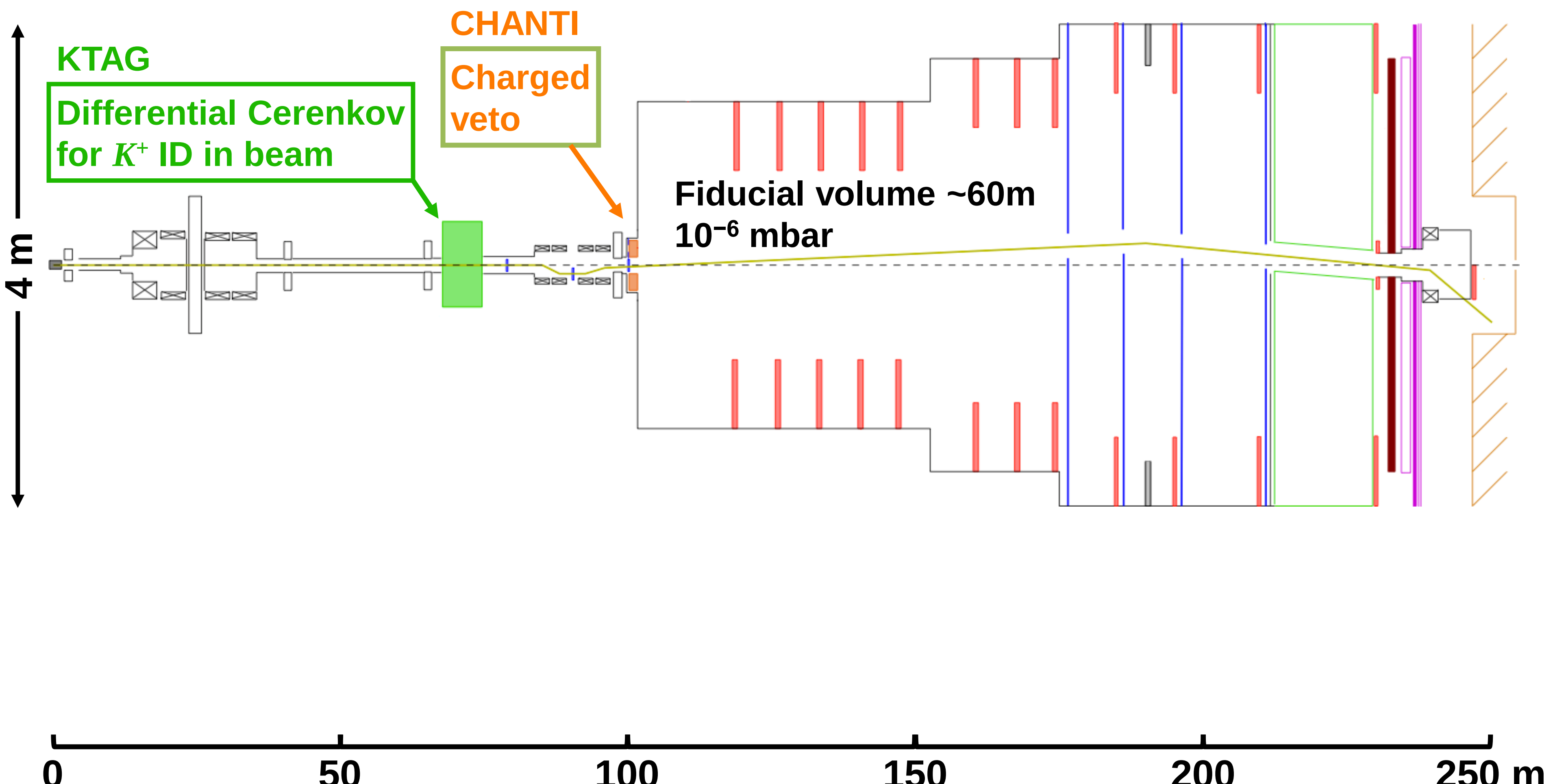
4 chambers, 2.1 m in diameter
16 layers (4 views) of straws per chamber

$\sigma \leq 130$ μm (1 view) $\sigma_p/p < 1\%$
$0.45X_0$ per chamber $\sigma_{\theta(K\pi)} < 60$μrad

Detector fully commissioned in 2014 run

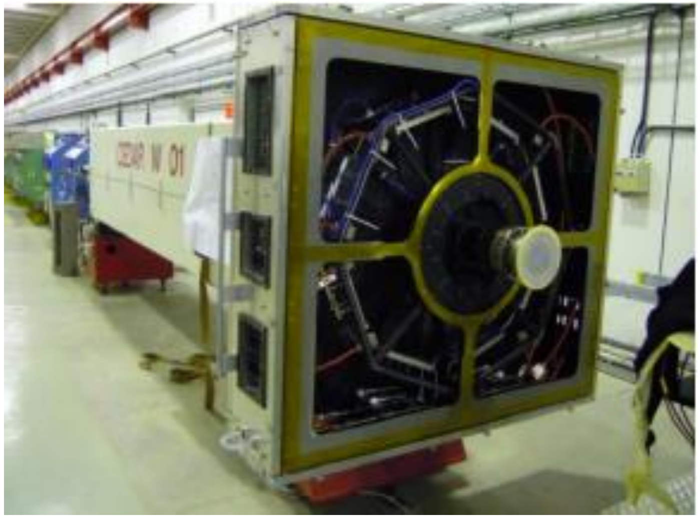


NA62 setup: KTAG and CHANTI



NA62 setup: KTAG and CHANTI

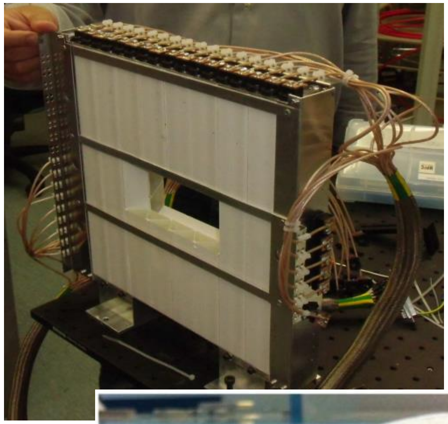
KTAG

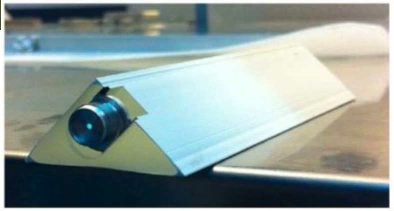


Identifies 45 MHz of K^+ in 750 MHz of unseparated beam
Running with N_2 at 1.74 bar

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

CHANTI

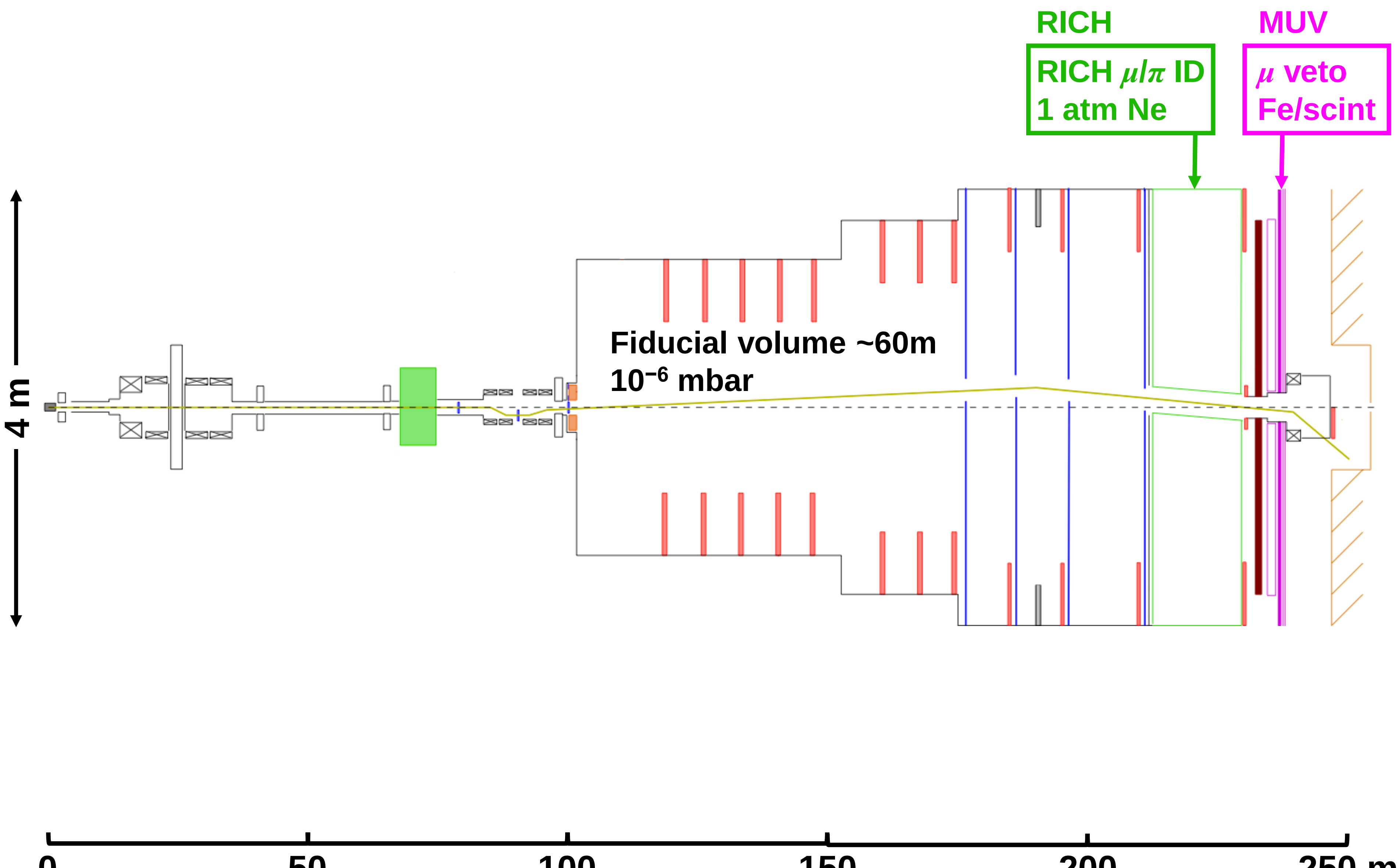




Detection of particles from inelastic interactions in GTK mimicking a pion in time with a kaon
6 stations hermetic to charged particles between 49 mrad and 1.31 rad
Each station is made of 24 scintillation bars in each view (X & Y), readout with WLS fibers and SiPMs

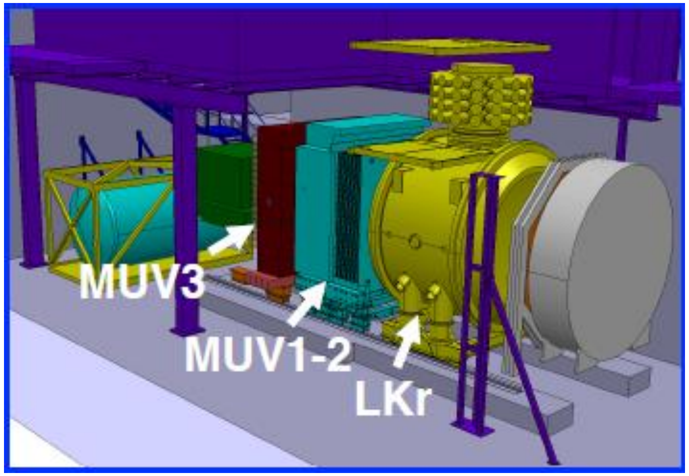
Detector commissioned with
- ✓ $\sigma_t \sim 900$ps
- ✓ Single layer efficiency > 0.99

NA62 setup: downstream particle identification



NA62 setup: downstream particle identification

MUV system: π/μ identification & trigger



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

MUV3: Fast μ identification for trigger
- **Vetoes μ online at 10 MHz**

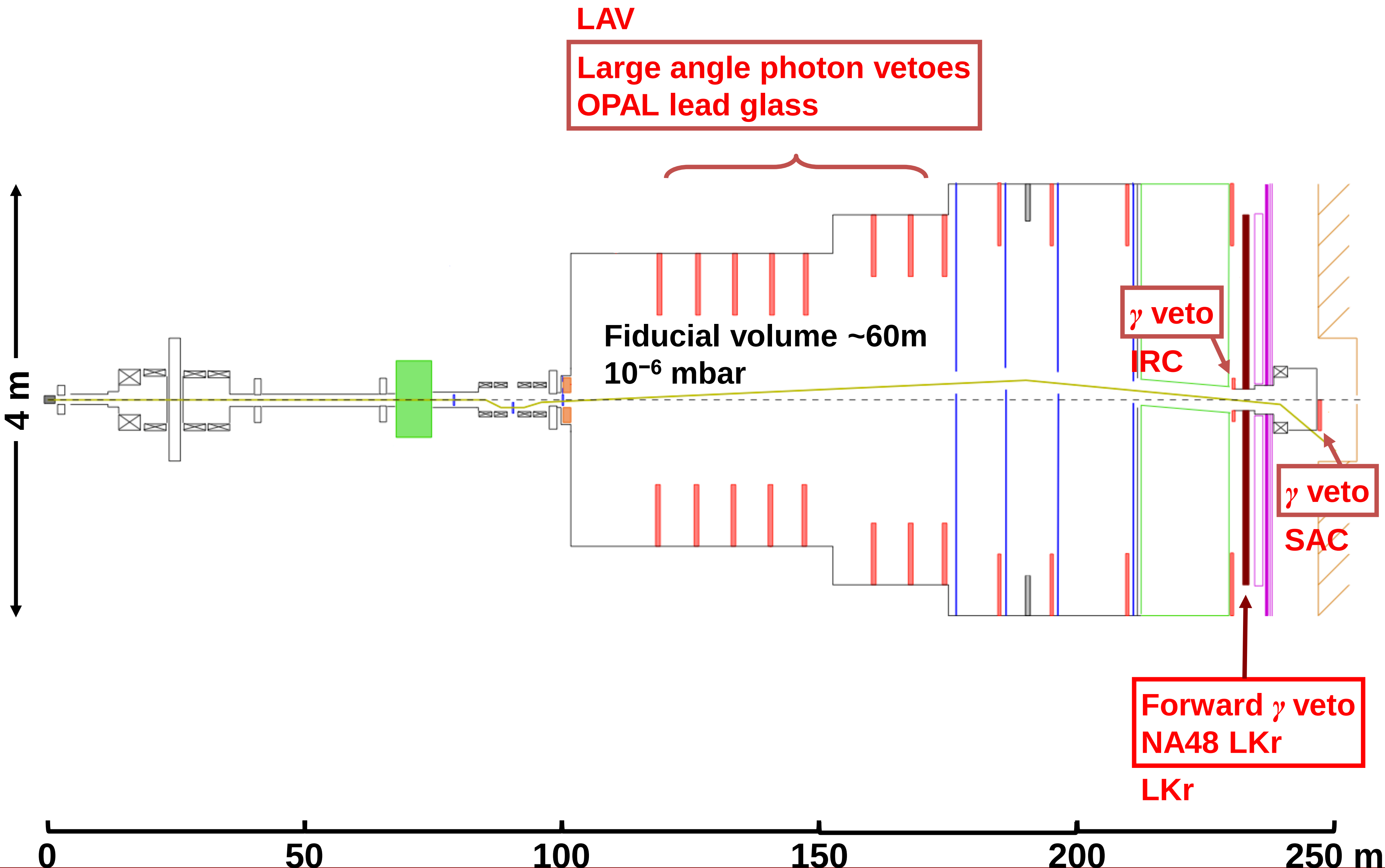
Detector commissioned; MUV3 σ_t ~ 420ps

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

μ/π separation ~ 1% for 15<p< 35GeV
Provides L0 trigger for charged particles
Ne gas at 1 atm
2000 8-mm PMTs on upstream flanges

RICH fully commissioned with σ_t ~ 70ps

NA62 photon veto detectors



NA62 photon veto detectors

Large angles vetoes (LAV) 8.5 < θ < 50 mrad

12 stations at intervals of ~10m along decay volume
Each station has 4-5 rings/station of lead glass blocks
$1-\varepsilon$ for e^- at 200 MeV: ~ 10^{-4}

LAV fully commissioned with σ_t ~ 1ns

Liquid krypton calorimeter (LKr) 1 < θ < 8.5 mrad

Quasi-homogeneous ionization calorimeter
Readout towers 2×2 cm^2 - 13248 channels
Depth 127 cm = 27 X_0
$1-\varepsilon$ for γ with E > 10 GeV: < 10^{-5}

**LKr from NA48 setup.
Commissioned with:**

- σ_t ~ 500ps
- Space resolution 1mm
- $1-\varepsilon < 10^{-5}$ for 10 GeV γ

SAC & IRC: very small angle veto Shashlik calorimeters

SAC: γ 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 σ_t ~ 1ns