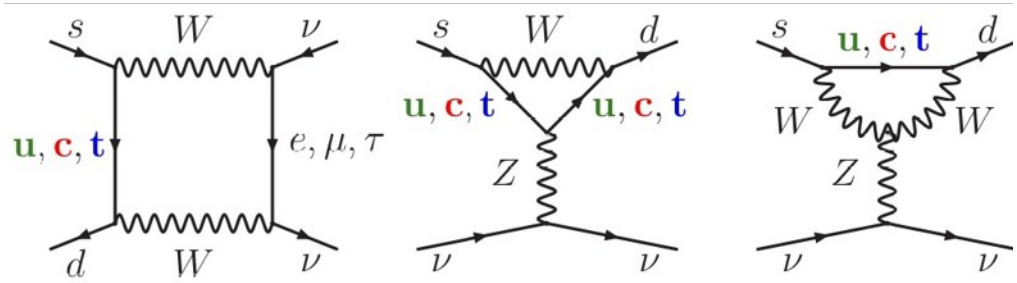
L'esperimento NA62 per la misura di BR($K^+ \to \pi^+ \nu\bar{\nu}$)

Andrea Salamon
andrea.salamon@roma2.infn.it

Roberto Ammendola
roberto.ammendola@roma2.infn.it

Il decadimento $K^+ \to \pi^+ \nu\bar{\nu}$



Niente panico!

- Ultra-rare decays with the highest CKM suppression

➡ Very clean from the theoretical point of view [Buras. et. al., JHEP11 (2015) 033]

  - $BR_{SM}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.6 \pm 0.4) \cdot 10^{-11}$

➡ Previous measurement by E787/E949 at BNL [Artamonov et al.. Phys.Rev.Lett. 101 (2008) 191802], [Artamonov et al., Phys.Rev.D 79 (2008) 092004]

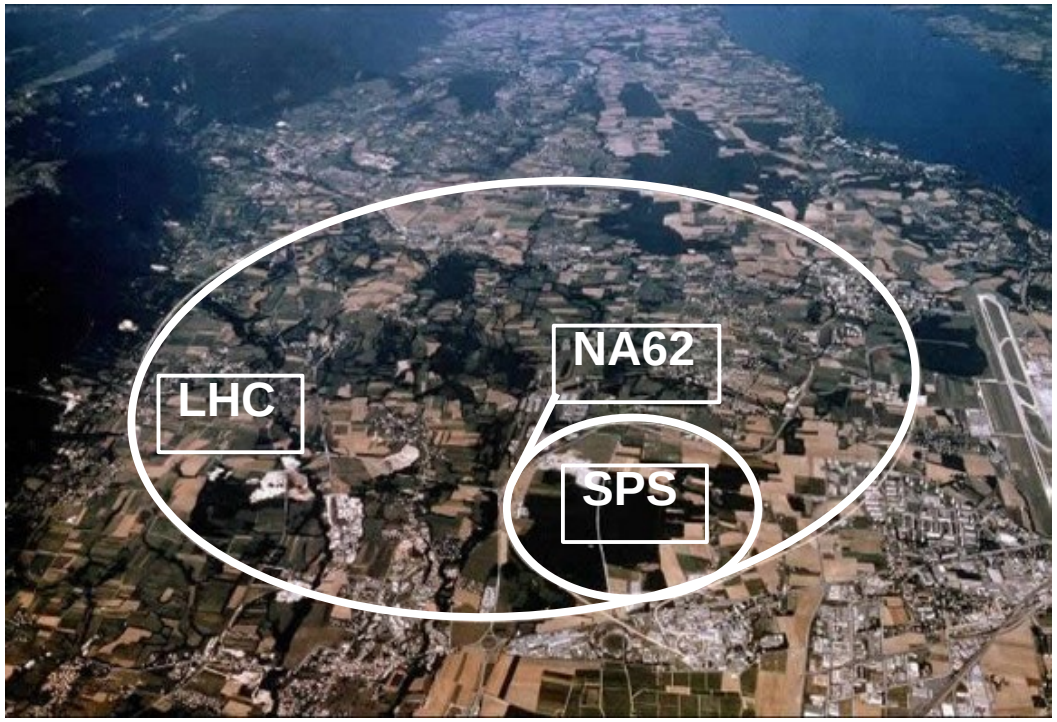
  - $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \cdot 10^{-11}$

➡ Very sensible to many NP models

  - Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
  - MSSM non-MFV [Blazek, Matak, Int.J.Mod.Phys. A29 (2014) no.27],[Isidori et al. JHEP 0608 (2006) 064]
  - Simplified Z, Z' models [Buras, Buttazzo,Knegjens, JHEP11(2015)166]
  - Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, Eur.Phys.J. C76 (2016) 182]
  - LFU violation models [Isidori et al., Eur. Phys. J. C (2017) 77: 618]
  - Leptoquarks [S. Fajfer, N. Košnik, L. Vale Silva, arXiv:1802.00786v1 (2018)]

The NA62 experiment at CERN SPS

NA62 Collaboration (~ 200 participants): Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver (UBC)

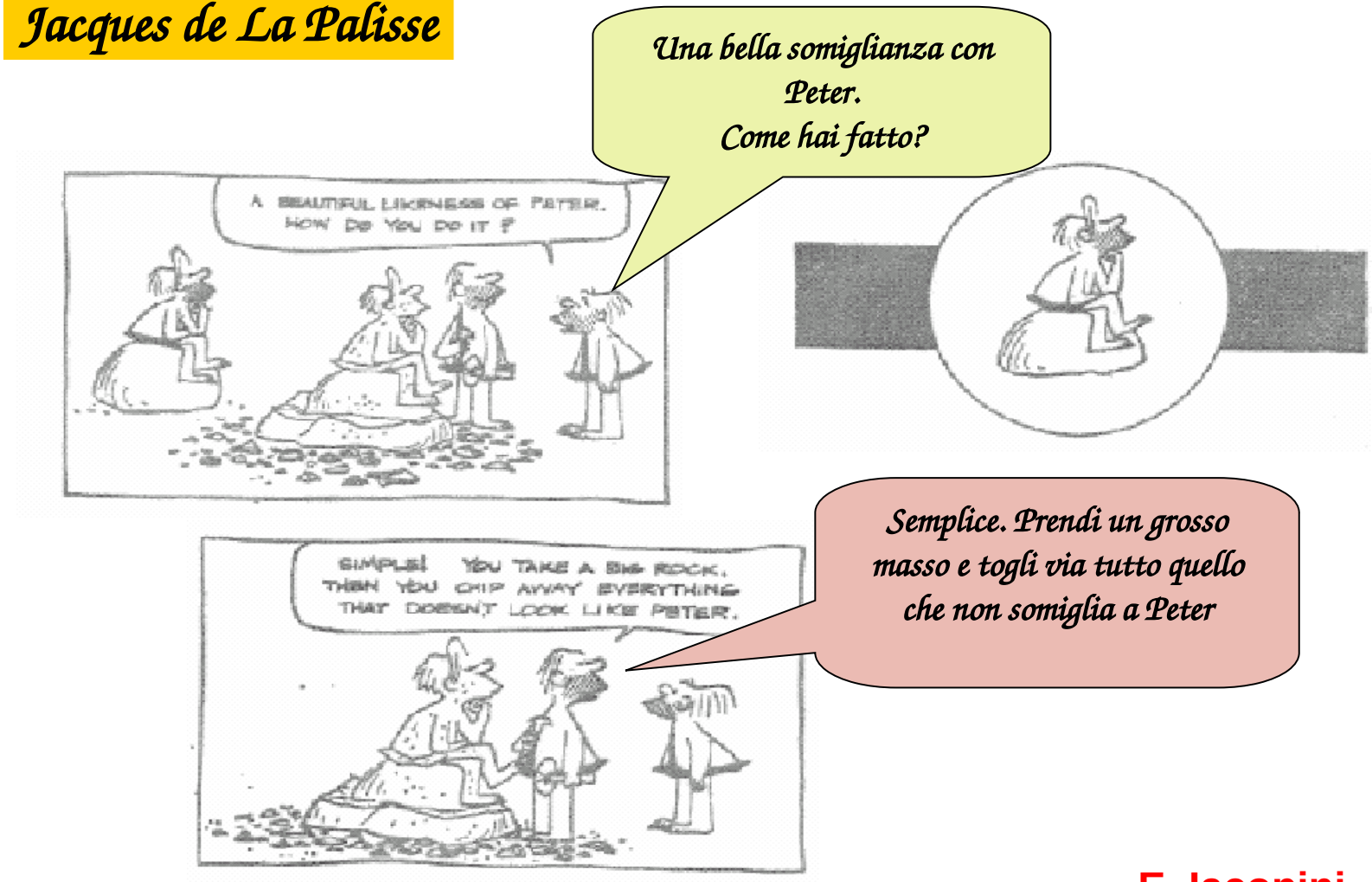


Goal: O(10%) precision measurement of BR($K^+ \to \pi^+ \nu\bar{\nu}$)

- Statistics: O(100) events
- K^+: decays 10^{13}
- Signal acceptance: O(10%)
- Background rejection: > 10^{11}

Come misurare BR($K^+ \to \pi^+ \nu\bar{\nu}$)?

Jacques de La Palisse



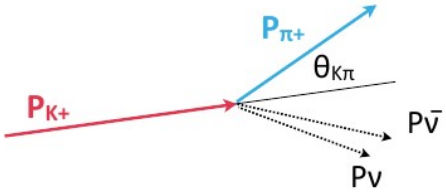
E. Iacopini

Come si traduce in una strategia di analisi?

Identificare una variabile discriminante (la massa mancante dei due neutrini), trovare alcune regioni in cui sia possibile “salvare” gli eventi di segnale e “buttare” gli eventi di background ricordando che il BR che vogliamo misurare è $\sim 10^{-10}$

Selection:

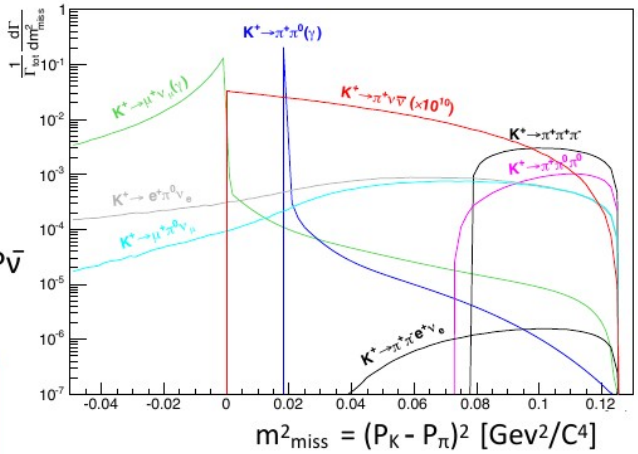
- K^+ - π^+ matching
- π^+ identification
- Photon rejection
- $110 < Z_{vertex} < 165$ m
- $15 < P_{\pi+} < 45$ GeV/c



Performance:

- Kinematic rejection $\sim 10^4$
- μ^+ rejection $> 10^7$
- π^0 rejection $> 10^7$
- $\sigma(m^2_{miss}) = 1 \cdot 10^{-3}$ GeV^2
- $\sigma_T \sim$ O(100ps)

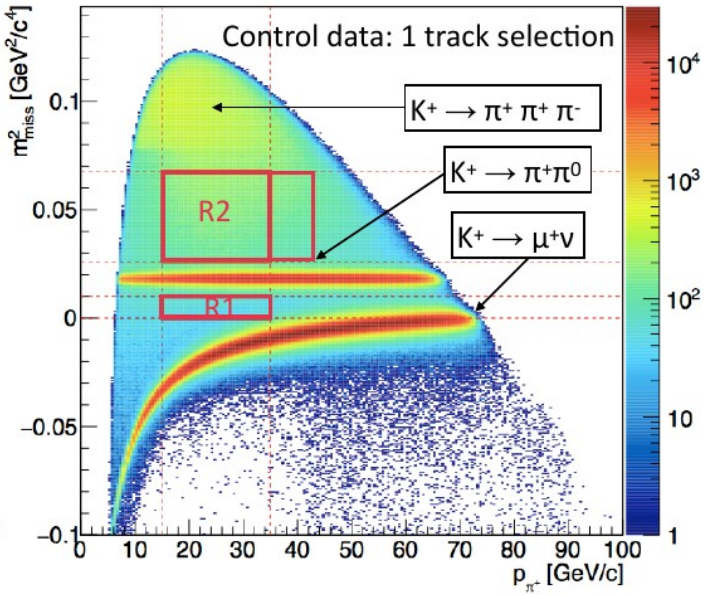
Most discriminating variable:
$m^2_{miss} = (P_{K+} - P_{\pi+})^2$ with m_π hypothesis for the charged daughter



Background sources:

- $K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\nu$
- $K^+ \to \pi^+\pi^+\pi^-$ non gaussian resolution tails
- decays with neutrino in final state
- Upstream interactions

2 signal regions,
on each side of the $K^+ \to \pi^+\pi^0$ peak
(to eliminate 92% of the K^+ width)

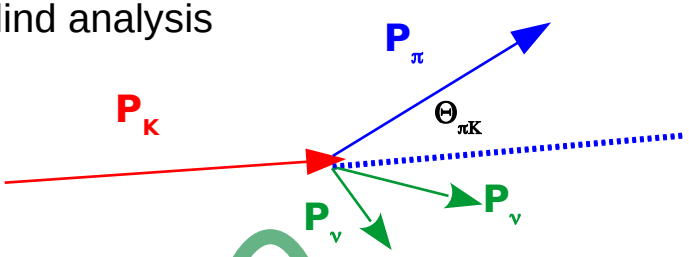


S. Martellotti

The $K^+ \to \pi^+\nu\bar{\nu}$ analysis strategy

New in flight decay technique!

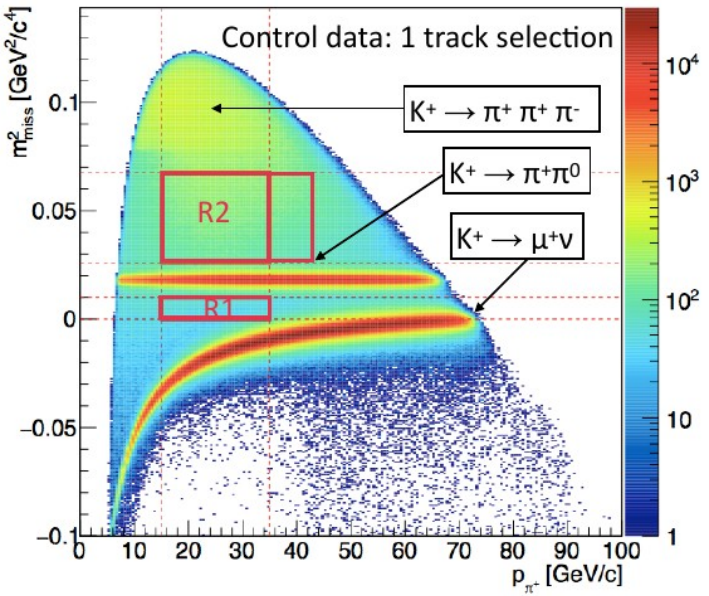
- K^+ - π^+ time and space matching
- Two $m^2_{miss}=(P_K-P_\pi)^2$ regions
- Cut based analysis
- Blind analysis



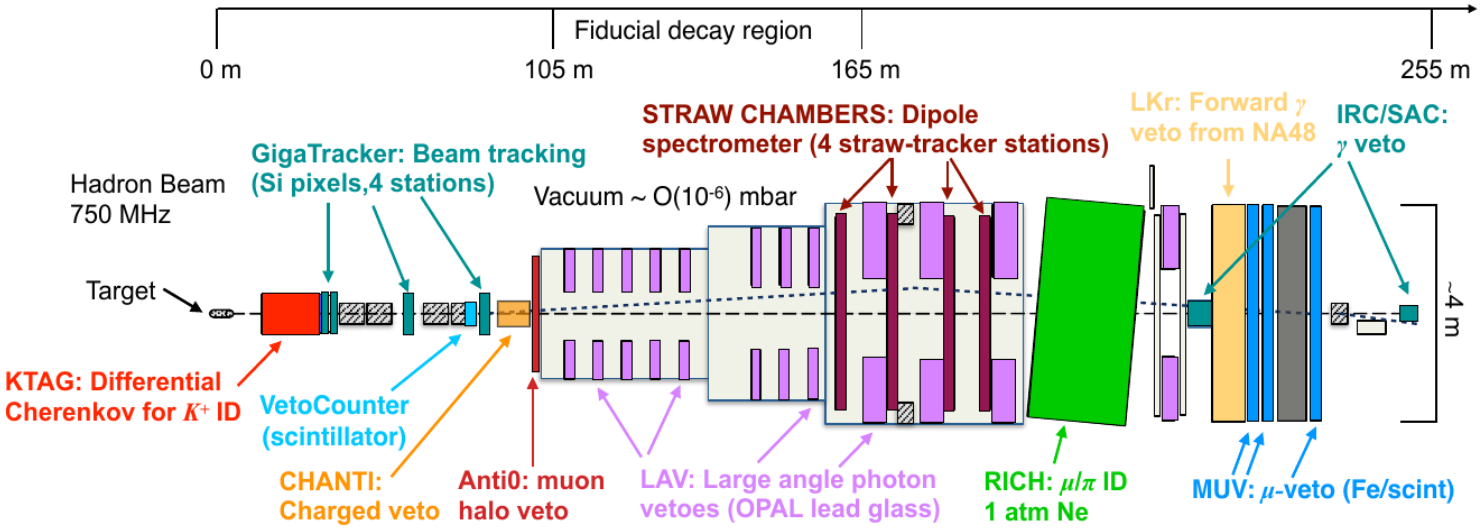
Decay	BR	Rejection
$K^+ \to \mu^+\nu_\mu(\gamma)$	63%	μ-ID + kinematics
$K^+ \to \pi^+\pi^0(\gamma)$	21%	γ-veto + kinematics
$K^+ \to \pi^+\pi^+\pi^-$	6%	multi + kinematics
$K^+ \to \pi^+\pi^0\pi^0$	2%	γ-veto + kinematics
$K^+ \to \pi^0 e^+\nu_e$	5%	e-ID + γ-veto
$K^+ \to \pi^0\mu^+\nu_\mu$	3%	μ-ID + γ-veto

Requirements

- O(100 ps) timing between sub-detectors
- $O(10^4)$ background suppression with kinematics
- $O(10^7)$ μ-suppression $K^+ \to \mu^+\nu$
- $O(10^7)$ γ-suppression $K^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$



The NA62 beam



[NA62 Detector Paper, 2017 JINST 12 P05025]

SPS beam

- 400 GeV/c protons
- 2×10^{12} protons/spill
- 3.5 s spill
- ~10^{18} POT/year

Secondary beam

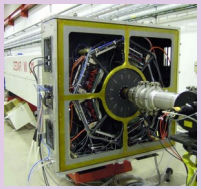
- 75 GeV/c momentum, 1% bite
- 100 μrad divergence (RMS)
- 60x30 mm^2 transverse size
- K^+(6%)/π^+(70%)/p(24%)
- 750 MHz of particles at GTK3

Decay region

- 60 m fiducial region
- ~5 MHz K^+ decay rate
- Vacuum ~10^{-6} mbar

The NA62 detector

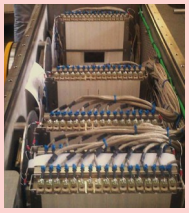
KTAG



Nitrogen filled differential Cherenkov counter to tag beam kaons with 70 ps time resolution.

GTK Three hybrid silicon pixel detector stations (<0.5% X0) with 100 ps time resolution..

CHANTI

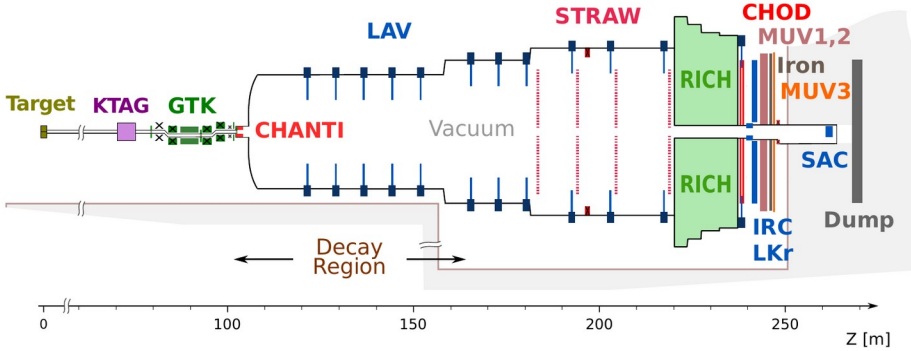


Guard ring polystirene-based scintillator bars to veto beam induced inalastic interactions and muon halo close to the beam.

LAV

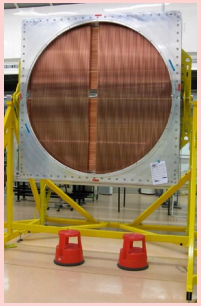
12 stations with 4/5 lead glass rings (from OPAL) in vacuum covering angular region 8.5-48 mrad.

MUV MUV1 (25 layers) and MUV2 (23 layers) iron-plastic scintillator calorimeters from NA48.
MUV3: after 80 cm iron, 5cm thick single layer scintillator tiles.



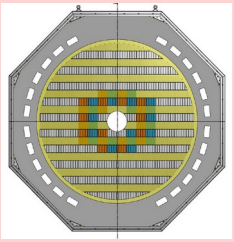
[NA62 Detector Paper, 2017 JINST 12 P05025]

STRAW



Precision low-mass straw spectrometer operating in vacuum (4 chambers, 4 views each) to measures trajectories and momenta of charged particles produced in kaon decays.

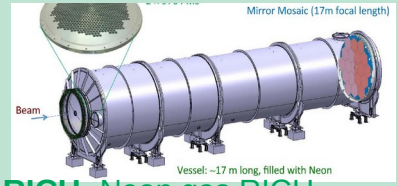
CHOD



Plastic scintillator charged particles odoscope for fast triggering.

IRC/SAC Inner Ring Calorimeter and Small Angle Calorimeter (lead plastic scintillators) for angular region below 1 mrad.

LKR 20 T liquid krypton calorimeter (from NA48) as forward photon veto in the angular region 1-8.5 mrad.



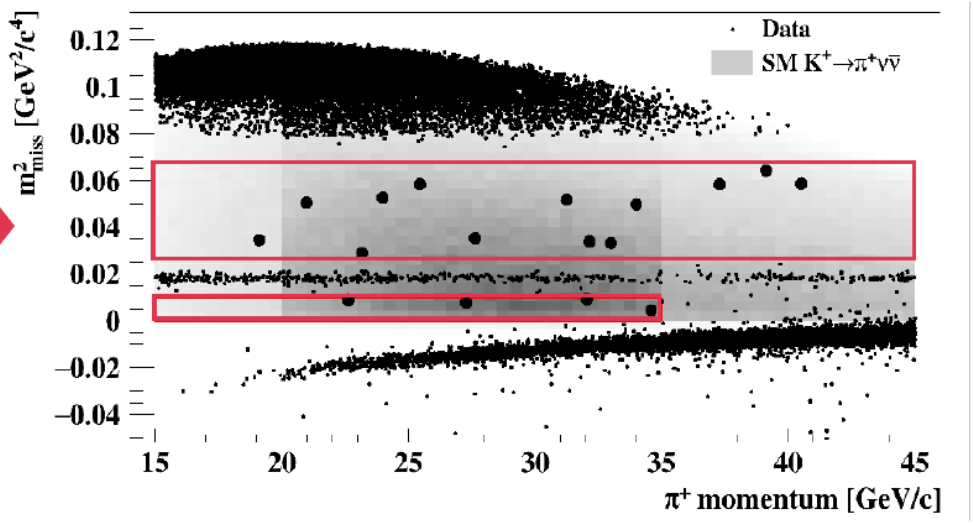
RICH Neon gas RICH counter with better than 100 ps time resolution for π/μ separation.

NA62: a che punto siamo?

Process	Expected events in R1+R2
$K^+ \to \pi^+\nu\bar{\nu}$ (SM)	$7.58 \pm 0.40_{syst} \pm 0.75_{ext}$
$K^+ \to \pi^+\pi^0(\gamma)$	0.75 ± 0.04
$K^+ \to \mu^+\nu(\gamma)$	0.49 ± 0.05
$K^+ \to \pi^+\pi^- e^+\nu$	0.50 ± 0.114
$K^+ \to \pi^+\pi^+\pi^-$	0.24 ± 0.08
$K^+ \to \pi^+\gamma\gamma$	$0 < 0.01$
$K^+ \to l^+\pi^0\nu_l$	$0 < 0.001$
Upstream background	$3.3^{+0.98}_{-0.73}$
Total background	$5.28^{+0.99}_{-0.74}$

2018 data

Observed 17 $K^+ \to \pi^+\nu\nu$ candidates



2016 + 2017 + 2018 data

Observed 20 (1+2+17) $K^+ \to \pi^+\nu\nu$ candidates

$\mathrm{SES} = (8.39 \pm 0.53_{syst}) \times 10^{-12}$

Expected signal: $10.01 \pm 0.42_{syst} \pm 1.19_{ext}$

Expected background: $7.03^{+1.05}_{-0.82}$

$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = (10.6^{+4.0}_{-3.4\,stat} \pm 0.9_{syst}) \times 10^{-11}$$

3.4 σ significance most precise measurement to date!

[JHEP06 (2021) 093]

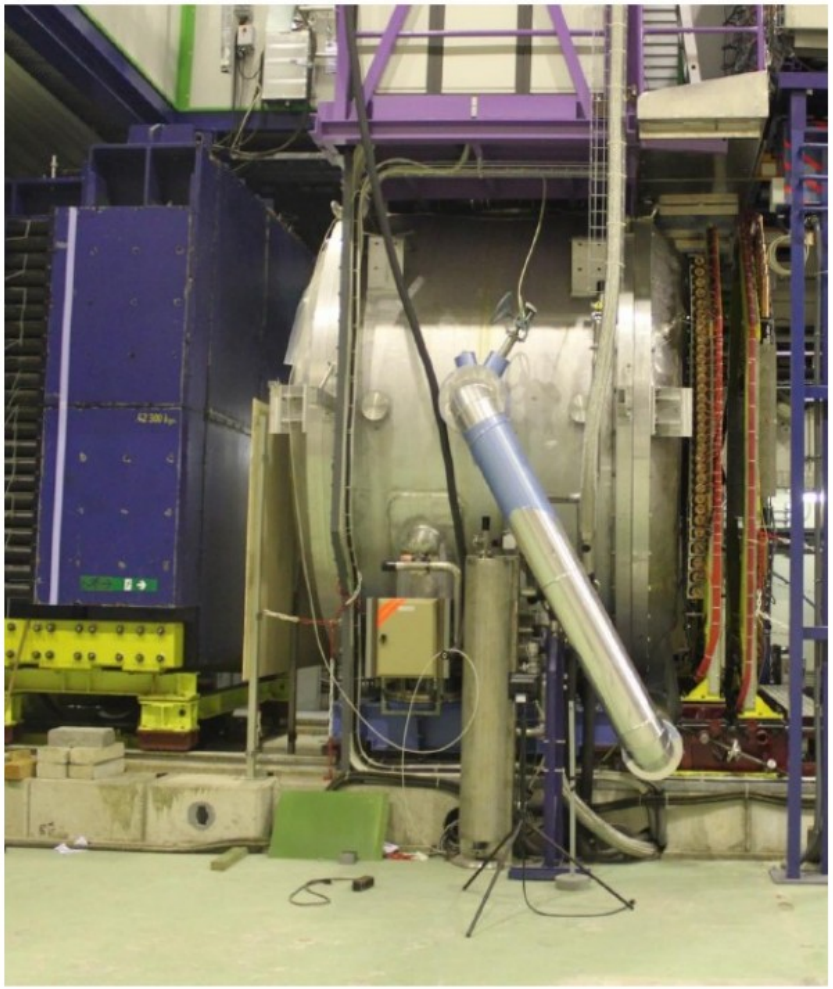
S. Martellotti

The NA62 **kaon factory** physics program

Oltre alla misura principale c'è un vasto programma di fisica da esplorare...

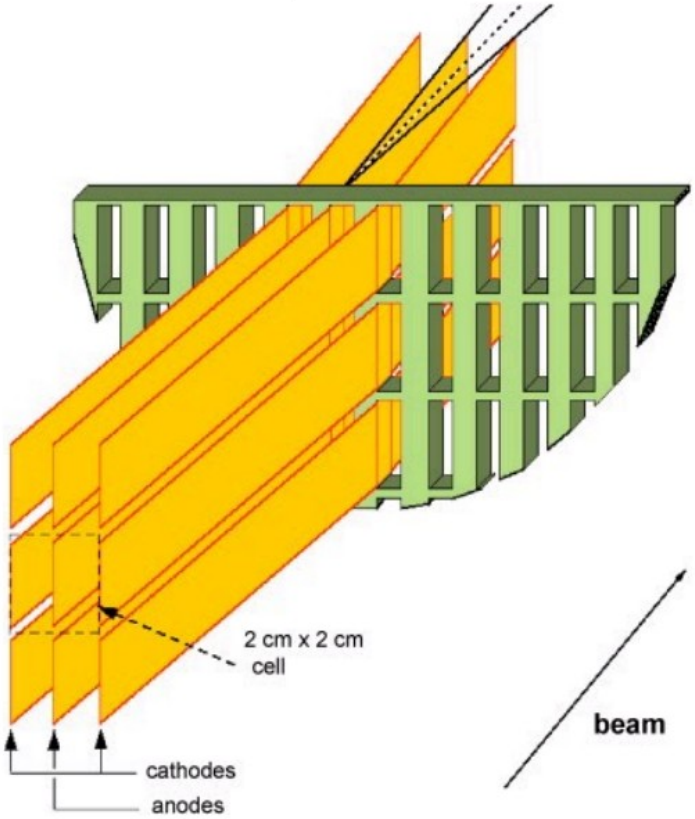
- Main goal: O(10%) precision measurement of **BR($K^+ \to \pi^+ \nu\bar{\nu}$)**
- Standard kaon physics:
  - Branching fraction measurements of all main K^+ decay modes
  - χ_{PT}: $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\pi^0 e^+e^-$
  - Lepton universality: $R_K = \Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu)$
- Rare and forbidden K^+ and π^0 decays:
  - K^+ physics: $K^+ \to \pi^+ l^+ l^-$, $K^+ \to \pi^+\gamma l^+ l^-$, $K^+ \to l^+\nu\gamma$, [l = e, μ]
  - LNV/LFV searches: $K^+ \to \pi^+\mu^{+-}e^{-+}$, $K^+ \to \pi^-\mu^+e^+$, **$K^+ \to \pi^- l^+ l^+$ [l = e, μ]**
  - π^0 physics: $K^+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^-$, $\pi^0 \to e^+e^-e^+e^-$, $\pi^0 \to \gamma\gamma\gamma(\gamma)$
- Exotics searches:
  - Heavy Neutral Lepton (HNL) production: $K^+ \to l^+\nu h$
  - Dark photon (A'): $K^+ \to \pi^+\pi^0$, $\pi^0 \to A'\gamma$, A' → invisible

A Tor Vergata: veto per fotoni



$K^+ \to \pi^+ \pi^0$ VETO

For $K^+ \to \pi^+ \pi^0$ decays in the decay fiducial region and for $E_\pi < 35$ GeV 80% of the photons are in the Lkr acceptance



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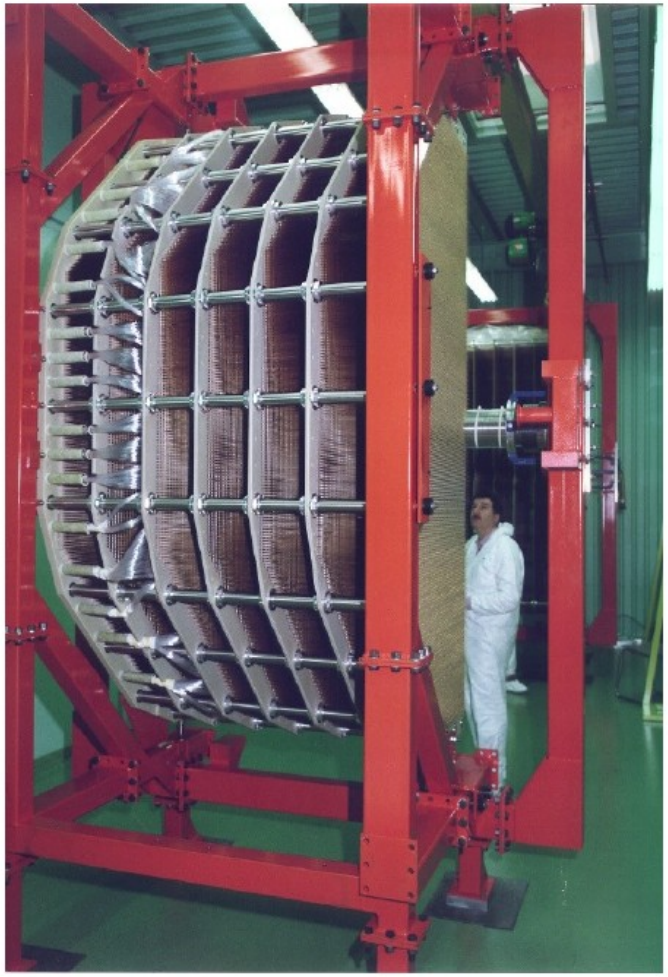


13248 channels

27 X_0

$$\frac{\sigma_E}{E} = \frac{0.032}{\sqrt{E}} + \frac{0.09}{E} + 0.0042$$

$$\sigma_{X,Y} = \frac{0.42}{\sqrt{E}} + 0.06$$

$$\sigma_t = \frac{2.5}{\sqrt{E}}$$

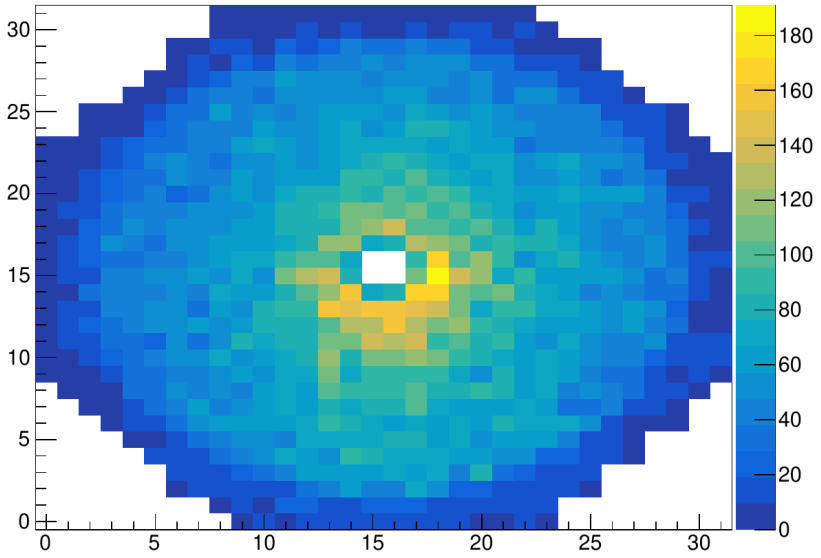
(GeV, cm and ns)

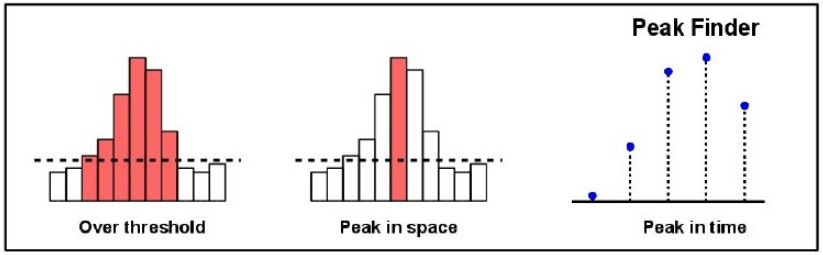
Photon veto in the angular decay region 1-8.5 mrad

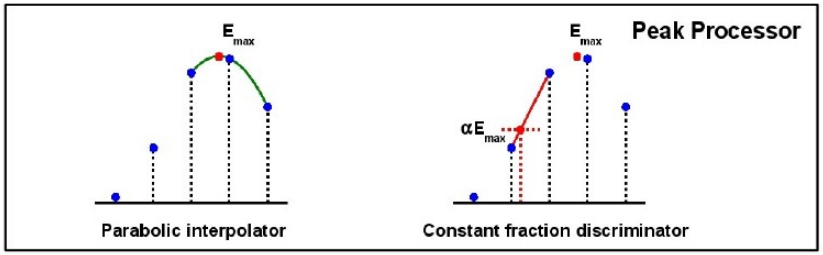
For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for E_π < 35 GeV 80% of the photons are in the Lkr acceptance

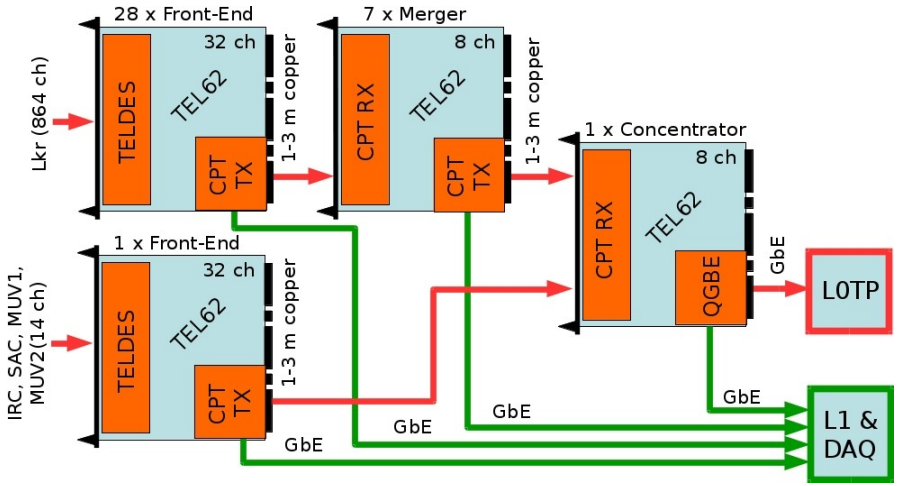
Inefficiency < 10^{-5} for E_γ > 10 GeV

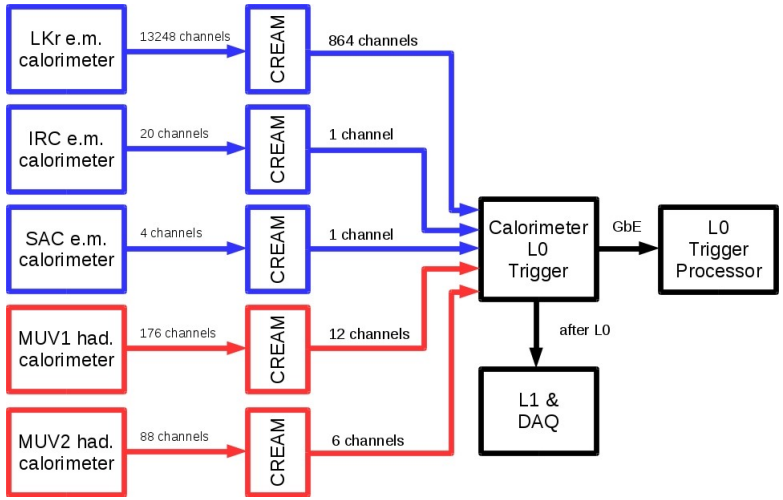
A Tor Vergata: veto per fotoni





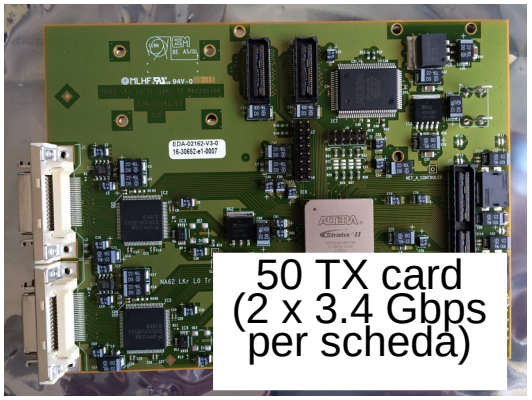




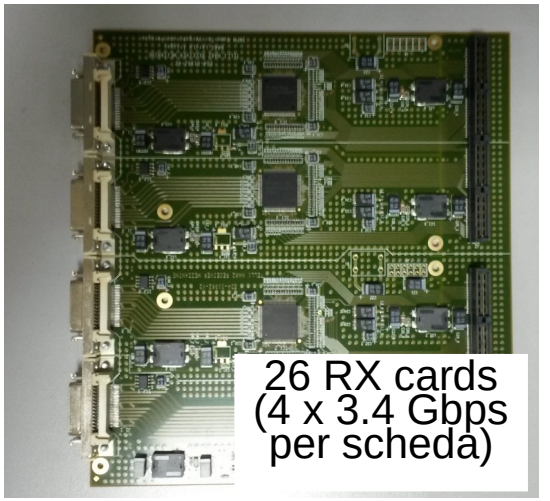


A Tor Vergata: veto per fotoni

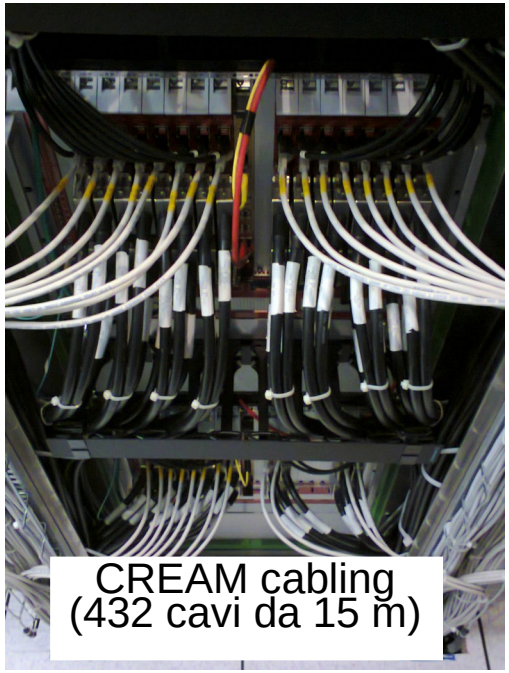
70 deserializer cards
(collaborazione con INFN Pg)



50 TX card
(2 x 3.4 Gbps
per scheda)

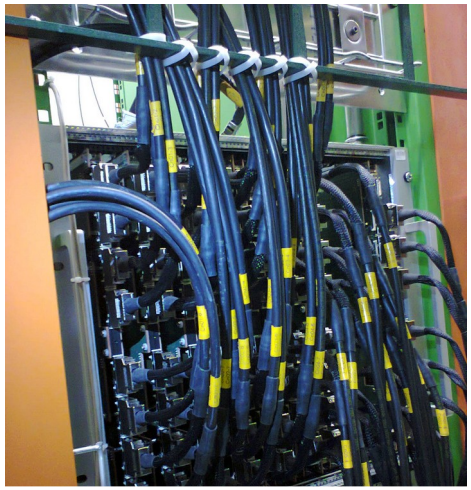


26 RX cards
(4 x 3.4 Gbps
per scheda)



CREAM cabling
(432 cavi da 15 m)

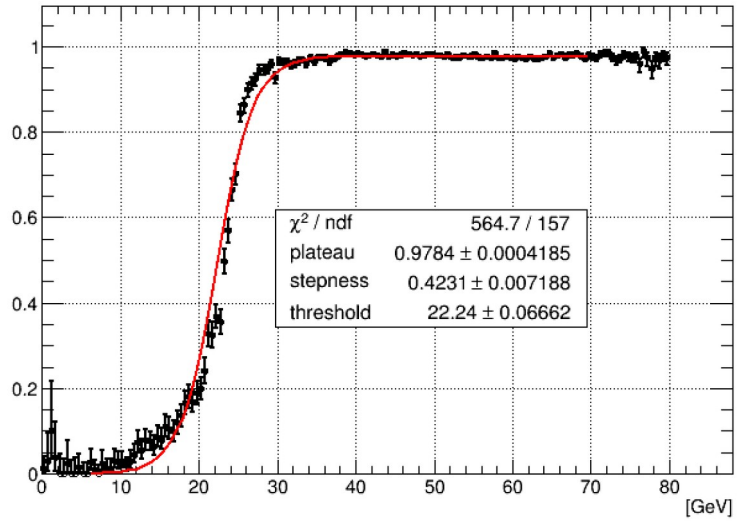
Front-End cabling
(2 crate 9U, 964 pad)



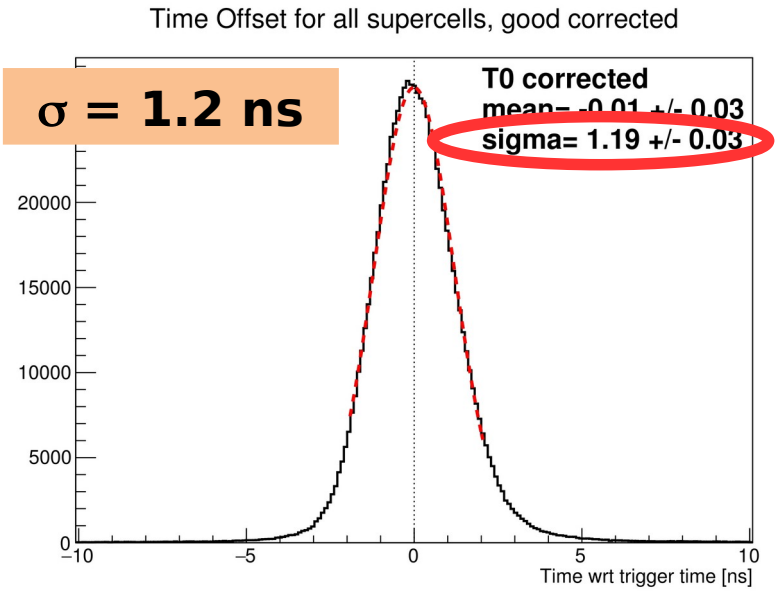
TX-RX cabling
(1 crate 9U, 64 cavi,
3.4 Gbps per cavo)

A Tor Vergata: veto per fotoni

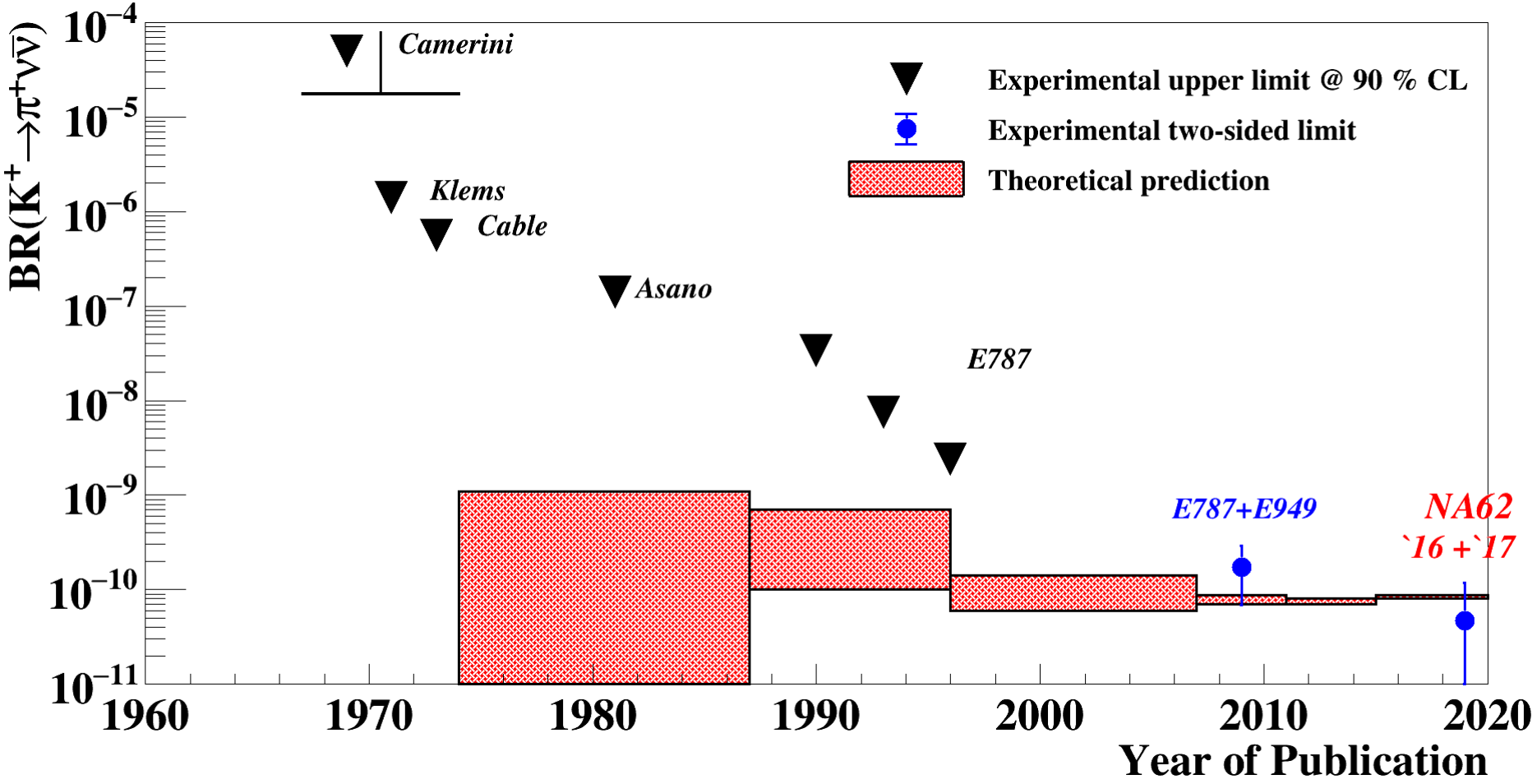
Soglia picchi 560 MeV



σ = 1.2 ns



Grazie per l’attenzione!


BR(K+→π+νν̄)
10−4
10−5
10−6
10−7
10−8
10−9
10−10
10−11
1960
1970
1980
1990
2000
2010
2020
Year of Publication
Camerini
Klems
Cable
Asano
E787
E787+E949
NA62
`16 +`17
Experimental upper limit @ 90 % CL
Experimental two-sided limit
Theoretical prediction