L’esperimento NA62 per la misura di BR($K^+ \rightarrow \pi^+ \nu\nu$)

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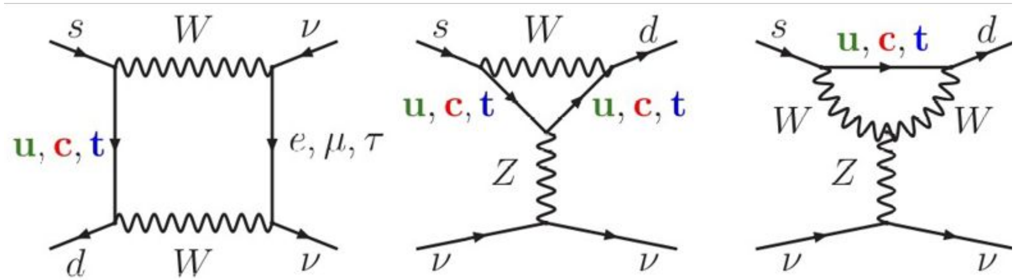
Il decadimento $K^+ \rightarrow \pi^+\nu\nu$

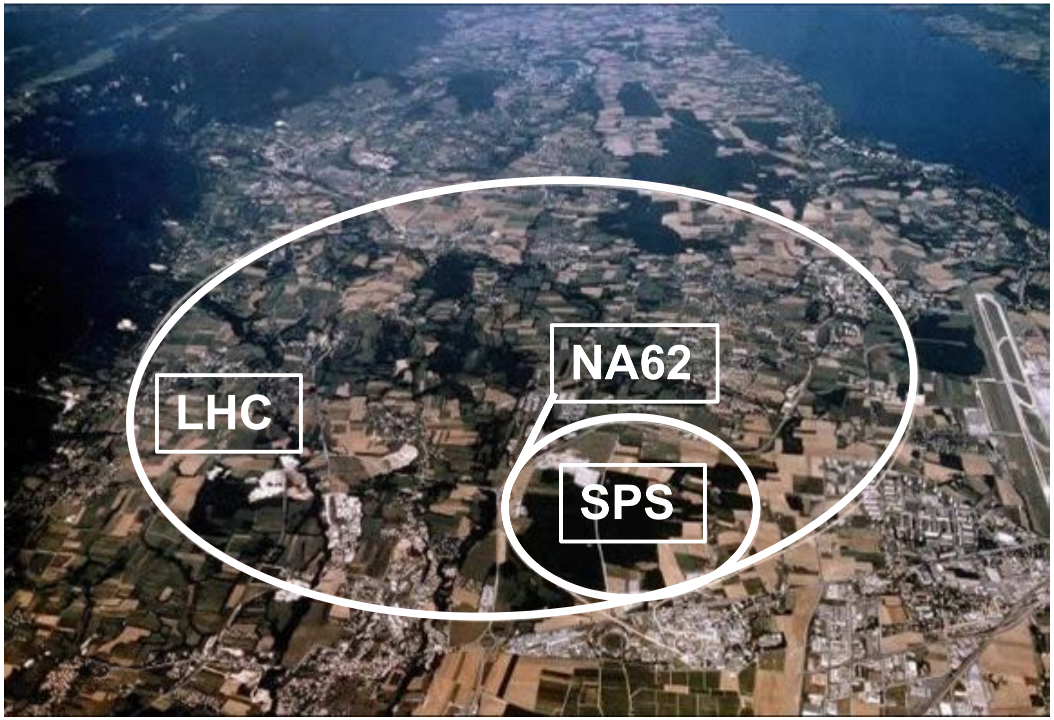


Niente panico!

- Ultra-rare decays with the highest CKM suppression
- Very clean from the theoretical point of view [Buras. et. al., JHEP11 (2015) 033]
  - $BR_{SM}(K^+\rightarrow\pi^+\nu\nu)=(8.6\pm0.4)\cdot10^{-11}$
- 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]
  - $BR(K^+\rightarrow\pi^+\nu\nu)=(17.3^{+11.5}_{-10.5})\cdot10^{-11}$
- 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)



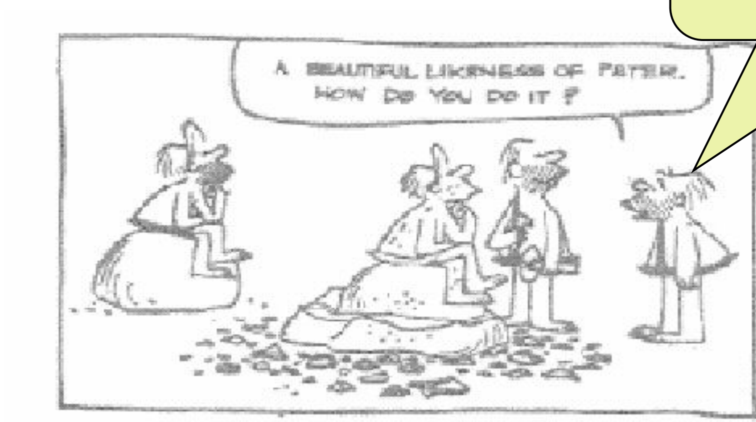
Goal: O(10%) precision measurement of BR($K^+ \rightarrow p^+nn$)

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

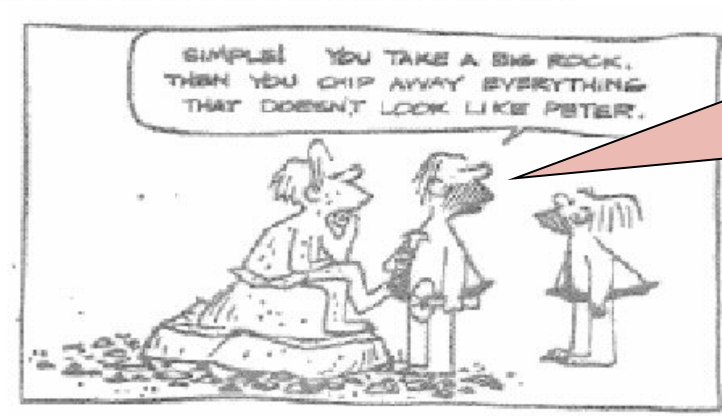
Come misurare BR($K^+ \to \pi^+ \nu\nu$)?

Jacques de La Palisse

Una bella somiglianza con Peter.
Come hai fatto?



Semplice. Prendi un grosso masso e togli via tutto quello che non somiglia a Peter



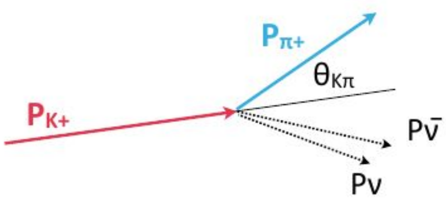
E. Iacopini

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:

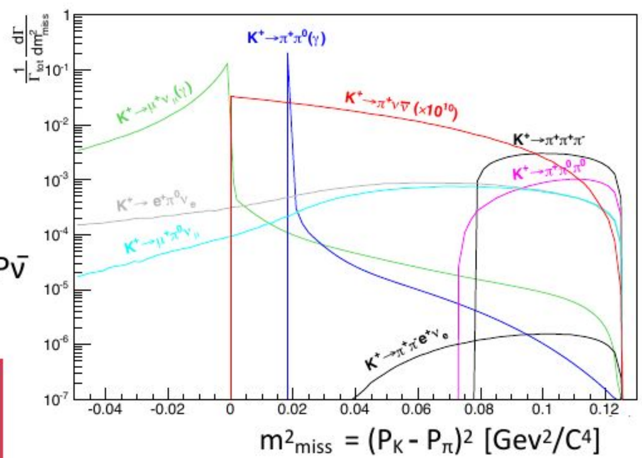
- K^+ - π^+ matching
- π^+ identification
- Photon rejection
- $110 < Z_{vertex} < 165$ m
- $15 < P_{\pi+} < 45$ GeV/c



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
- $\sigma_T \sim O(100ps)$

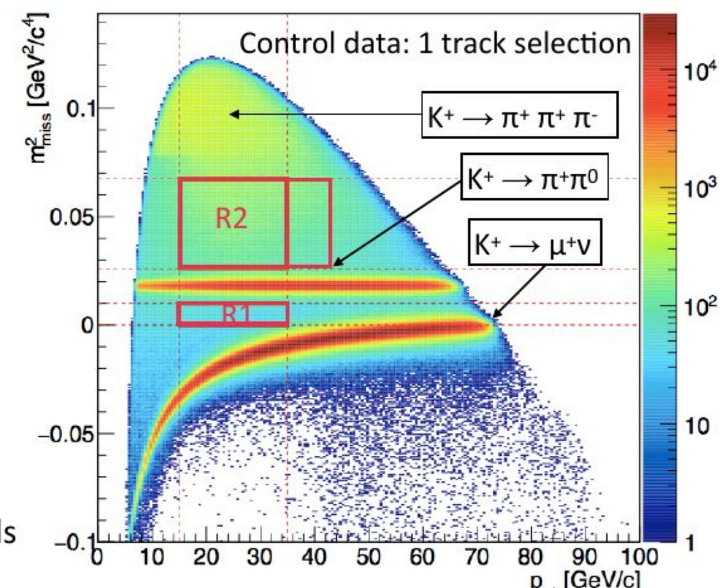
Most discriminating variable:
$m^2_{miss} = (P_{K+} - P_{\pi+})^2$ with m_π hypothesis for the charged daughter



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)

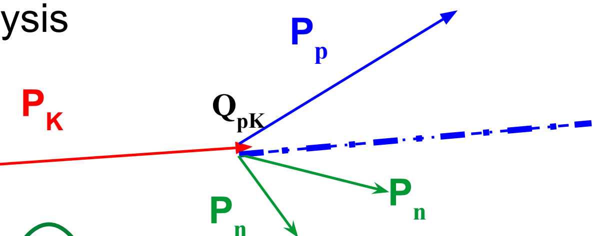


S. Martellotti

The $K^+ \to \pi^+\nu\nu$ analysis strategy

New in flight decay technique!

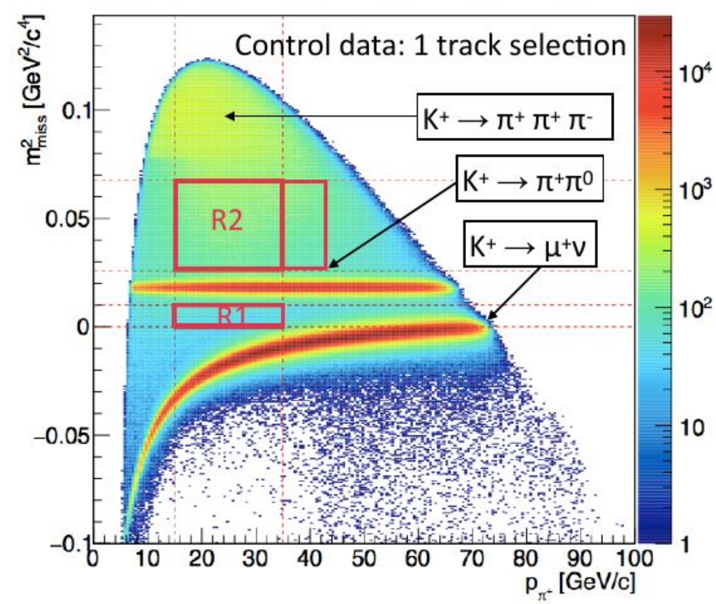
- K^+ - π^+ time and space matching
- Two $m^2_{miss}=(P_K-P_\pi)^2$ regions
- Cut based analysis
- Blind analysis



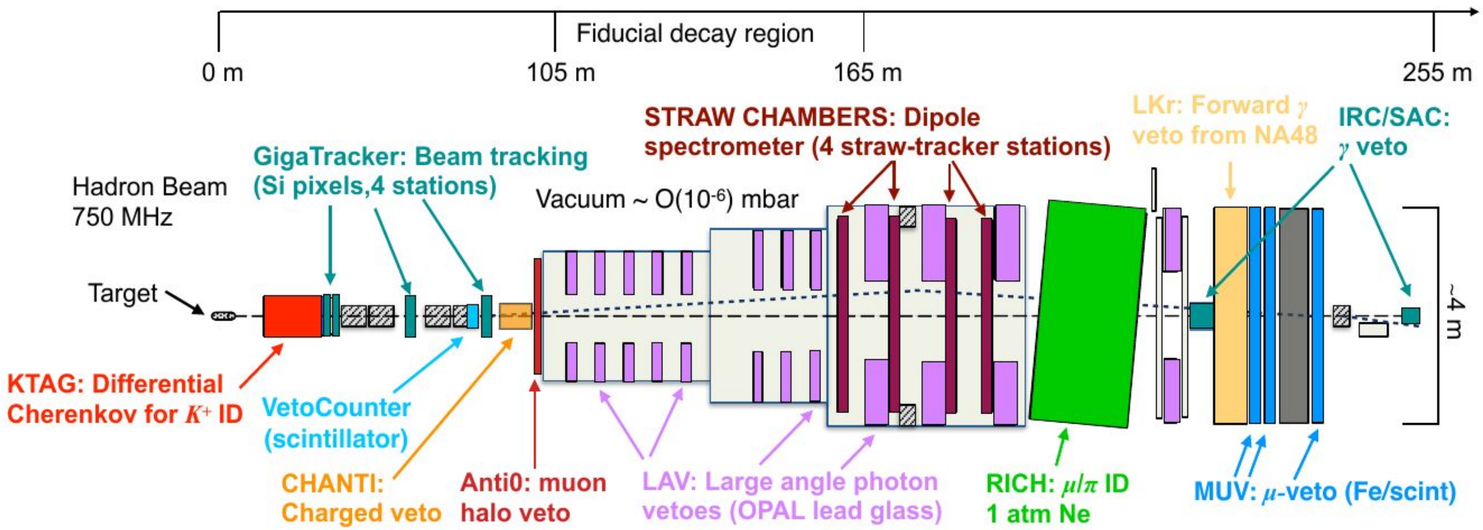
Requirements

- 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 $K^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$

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



The NA62 beam



[NA62 Detector Paper, 2017 JINST 12 P05025]

SPS beam

- 400 GeV/c protons
- 2x10^{12} protons/spill
- 3.5 s spill
- ~10^{18} POT/year

Secondary beam

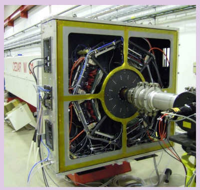
- 75 GeV/c momentum, 1% bite
- 100 μrad divergence (RMS)
- 60x30 mm^2 transverse size
- K^+(6%)/π^+(70%)/p(24%)
- 750 MHz of particles at GTK3

Decay region

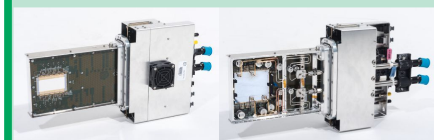
- 60 m fiducial region
- ~5 MHz K^+ decay rate
- Vacuum ~10^{-6} mbar

The NA62 detector

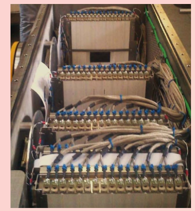
KTAG Nitrogen filled differential Cherenkov counter to tag beam kaons with 70 ps time resolution.



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

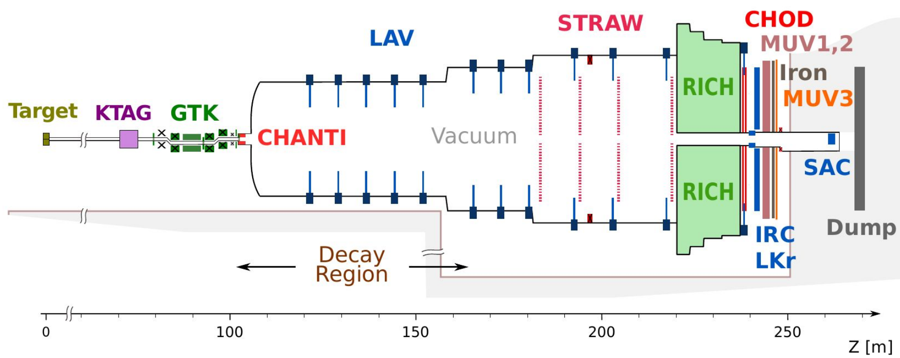


CHANTI Guard ring polystirene-based scintillator bars to veto beam induced inalastic interactions and muon halo close to the beam.



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

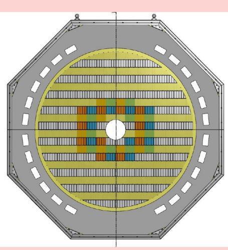
MUV MUV1 (25 layers) and MUV2 (23 layers) iron-plastic scintillator calorimeters from NA48. MUV3: after 80 cm iron, 5cm thick single layer scintillator tiles.



[NA62 Detector Paper, 2017 JINST 12 P05025]

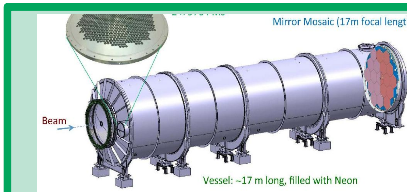
STRAW Precision low-mass straw spectrometer operating in vacuum (4 chambers, 4 views each) to measures trajectories and momenta of charged particles produced in kaon decays.

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.



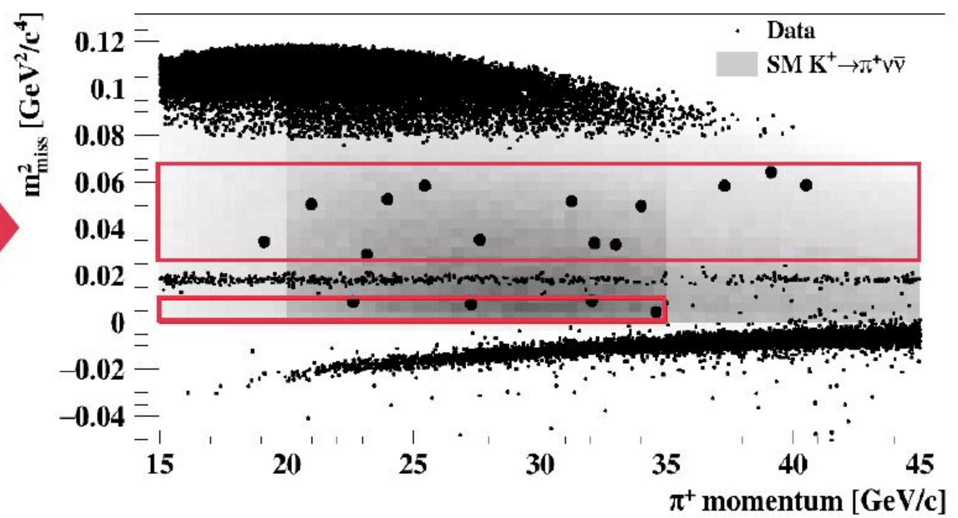
RICH Neon gas RICH counter with better than 100 ps time resolution for π/μ separation.

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

Breaking news 2024

CERN Press release :

CERN Accelerating science

NA62 experiment at CERN observes ultra-rare particle decay

In the Standard Model of particle physics, the odds of this decay occurring are less than one in 10 billion

25 SEPTEMBER, 2024

INFN Press release :

INFN Istituto Nazionale di Fisica Nucleare

25 SETTEMBRE 2024

CERN: L'ESPERIMENTO NA62 OSSERVA UN PROCESSO RARISSIMO

UKRI Press release : UK Research and Innovation

CERN reports first observation of ultra-rare particle decay

Scientific American :

SCI AM

OCTOBER 1, 2024 | 5 MIN READ

A One-in-10-Billion Particle Decay Hints at Hidden Physics

Physicists have detected a long-sought particle process that may suggest new universe

le Scienze
edizione italiana di Scientific American

CLIMA GENETICA FISICA NOBEL ASTRONOMIA INTELLIGENZA ARTIFICIALE

02 ottobre 2024

Il decadimento di una particella su 10 miliardi suggerisce una fisica nascosta

di Clara Moskowitz/Scientific American

Una fase di allestimento dell'esperimento NA62 al CERN di Ginevra (©CERN) ()

Al CERN di Ginevra i fisici hanno rilevato un processo cercato da molti anni che potrebbe suggerire l'esistenza di nuove forze e particelle nell'universo

ANSA
Evento rarissimo al Cern, potrebbe aprire alla nuova fisica
Grazie alla collaborazione NA62, coordinata da un italiano (ANSA)
1 mese fa

Università degli studi di Ferrara
Alla ricerca di una "nuova fisica" | Il contributo di Unife all'esperimento NA62 del CERN
Come si producono e si misurano i kaoni al CERN. L'esperimento NA62 è stato progettato specificamente per misurare un decadimento...
1 mese fa

Scienze Notizie
Rarissimo evento osservato al CERN: i dettagli dell'esperimento NA62
Protagonista dell'osservazione è la particella "kaone" ... L'esperimento che ha consentito di osservarlo è il NA62, frutto di una collaborazione...
1 mese fa

Unina
Al CERN presentato un nuovo risultato con il contributo di fisici federiciani
L'esperimento NA62 del CERN, cui partecipa un gruppo di fisici dell'Ateneo federiciano e della Sezione di Napoli dell'Istituto Nazionale di...
1 mese fa

Grandenapoli.it
Napoli frontiera della fisica moderna grazie all'esperimento NA62
L'esperimento NA62 osserva un processo rarissimo: una scoperta rivoluzionaria che porta luce sulla comunità scientifica partenopea. ... L'...
1 mese fa

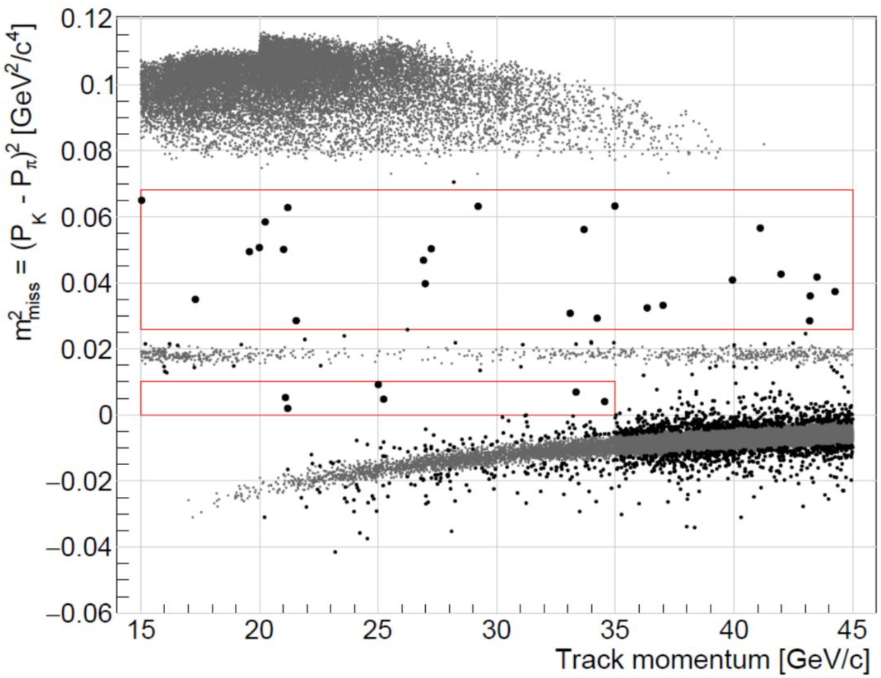
Positano News
L'esperimento NA62 del CERN ha il cuore napoletano. I dettagli di un esperimento che potrebbe cambiare la Fisica
L'Università Federico II, infatti, ha avuto un ruolo importante in un esperimento tenutosi al CERN di Ginevra. L'esperimento NA62 ha osservato...
1 mese fa

Il Mattino
La nuova fisica è targata Napoli: è napoletana la scoperta della particella che muta una volta ogni 10 miliard
L'esperimento NA62 condotto nei laboratori del Cern.
1 mese fa

Università degli studi di Ferrara
Fisica e Modello Standard | Raro decadimento osservato da NA62 al Cern. Il contributo Unife
Fisica e Modello Standard | Raro decadimento osservato da NA62 al Cern. Il contributo Unife ... Un altro fondamentale obiettivo per mettere alla...
31 lug 2020

assodigitale.it

PNN: Opening Signal Regions (2021+22)



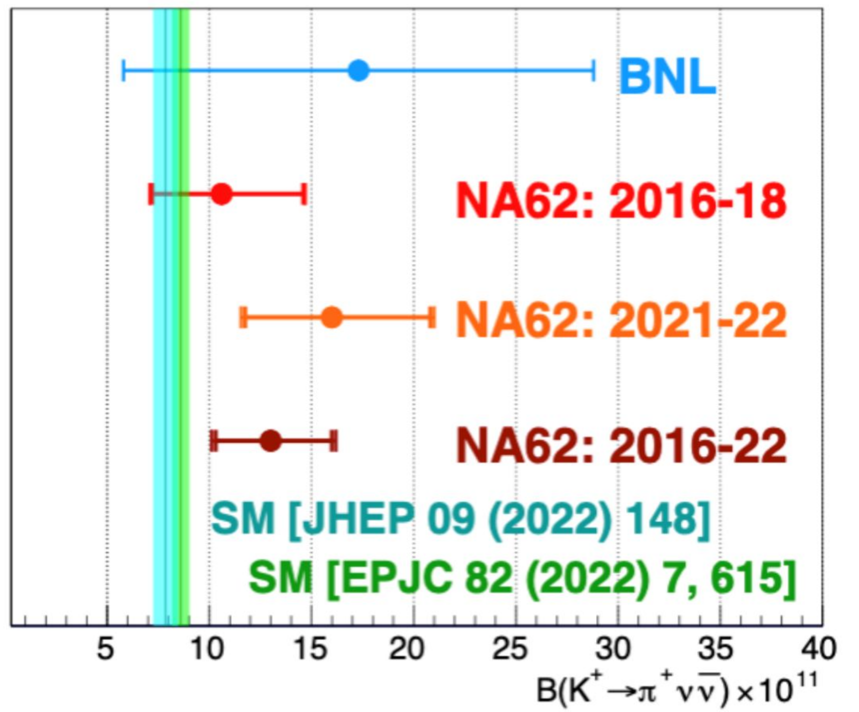
	Number of events
Expected signal	10.00 ± 0.34
Expected background	$11.0^{+2.1}_{-1.9}$
Total expected	$21.0^{+2.2}_{-1.9}$
Observed	**31***

PNN: Result RUN1+RUN2 (21+22)

$$\mathcal{B}_{\pi\nu\bar{\nu}}^{RUN1} = \left(10.6^{+4.1}_{-3.5}\right) \times 10^{-11}$$

$$\mathcal{B}_{\pi\nu\bar{\nu}}^{RUN2} = (16.0^{+5.0}_{-4.5}) \times 10^{-11}$$

$$\mathcal{B}_{\pi\nu\bar{\nu}}^{NA62} = (13.0^{+3.2}_{-2.9}) \times 10^{-11}$$

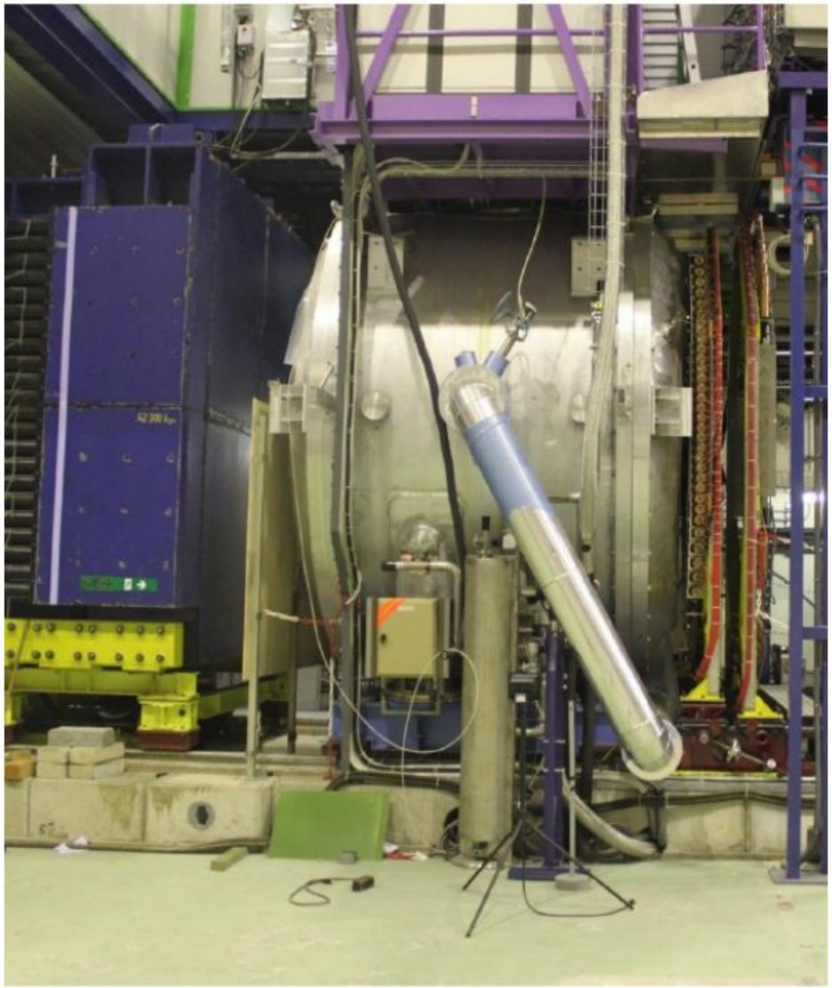


The NA62 **kaon factory** physics program

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

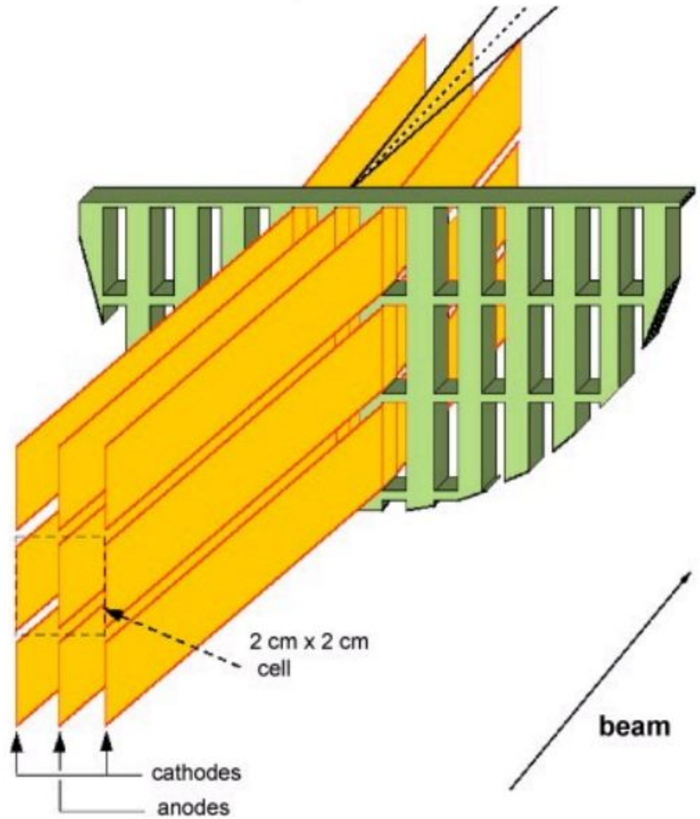
- Main goal: O(10%) precision measurement of **$BR(K^+ \rightarrow \pi^+ \nu\nu)$**
- Standard kaon physics:
  - Branching fraction measurements of all main K^+ decay modes
  - χ_{PT}: $K^+ \rightarrow \pi^+\gamma\gamma$, $K^+ \rightarrow \pi^+\pi^0 e^+ e^-$
  - Lepton universality: $R_K = \Gamma(K^+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

A Tor Vergata: veto per fotoni



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

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



A Tor Vergata: veto per fotoni

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

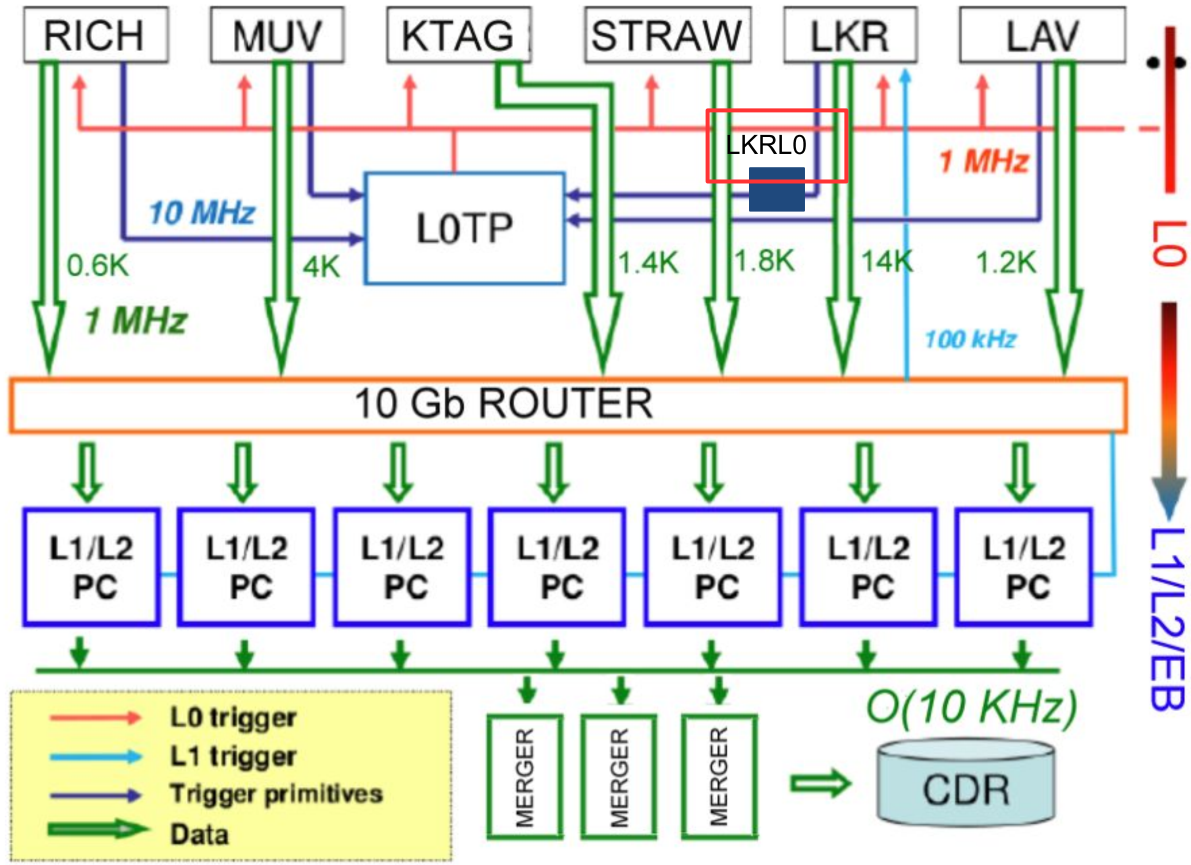
Inefficiency < 10^{-5} for E_γ > 10 GeV

NA62 TDAQ system

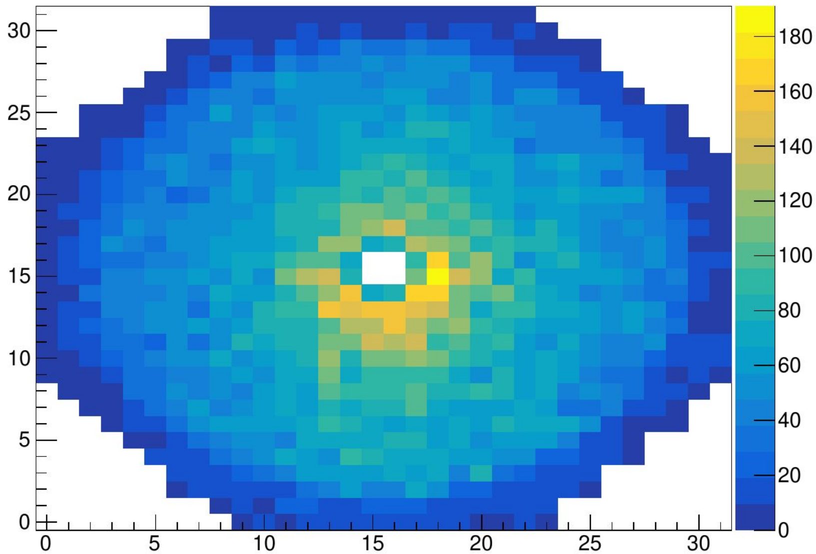
NA62 is a Trigger-based acquisition system

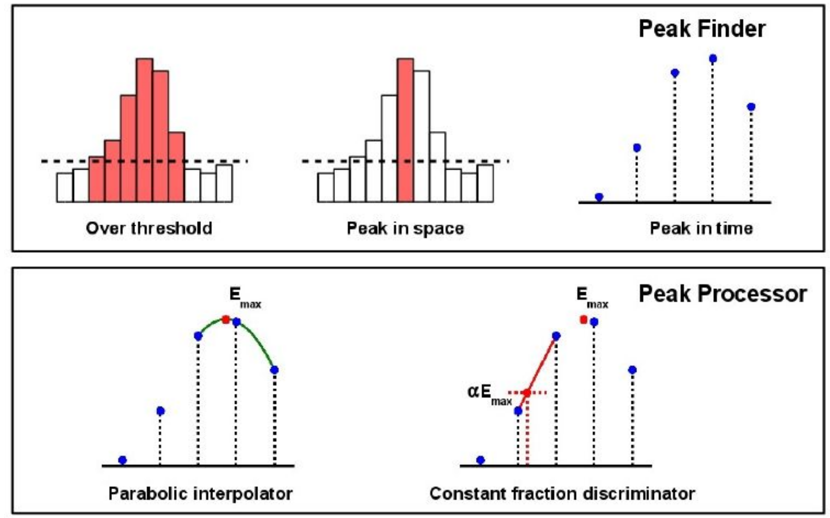
Three levels of trigger

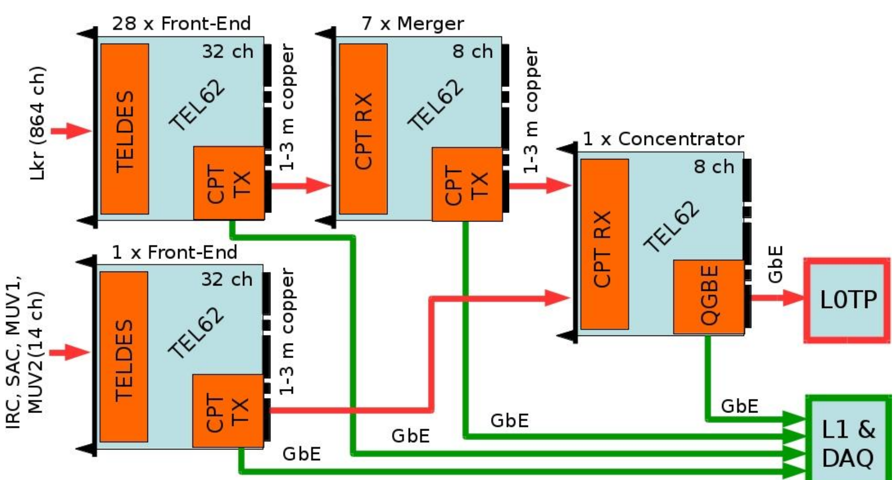
- L0: Hardware level, reduce event rate from 10 MHz to 1 MHz with max latency of 1 ms
- L1: Software level, single detector event selection, reduce from 1 MHz to 100 kHz, latency O(1s)
- L2: Software level, complete event reconstruction, event rate O(10kHZ) latency 1 burst O(10s).

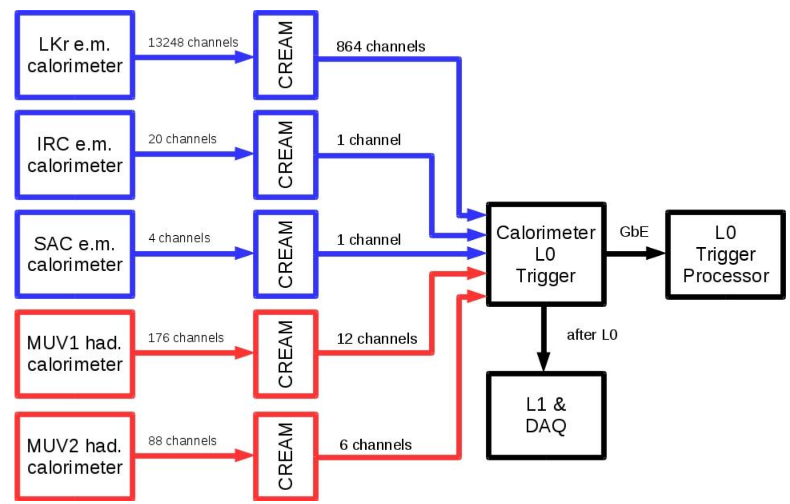


A Tor Vergata: veto per fotoni



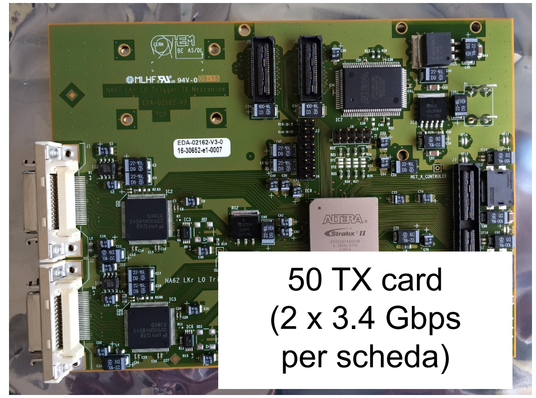




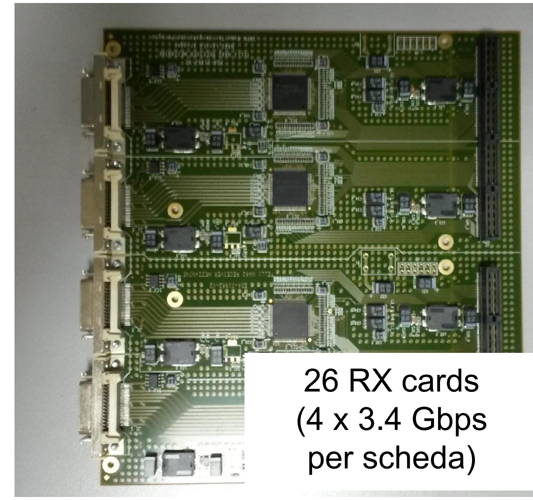


A Tor Vergata: veto per fotoni

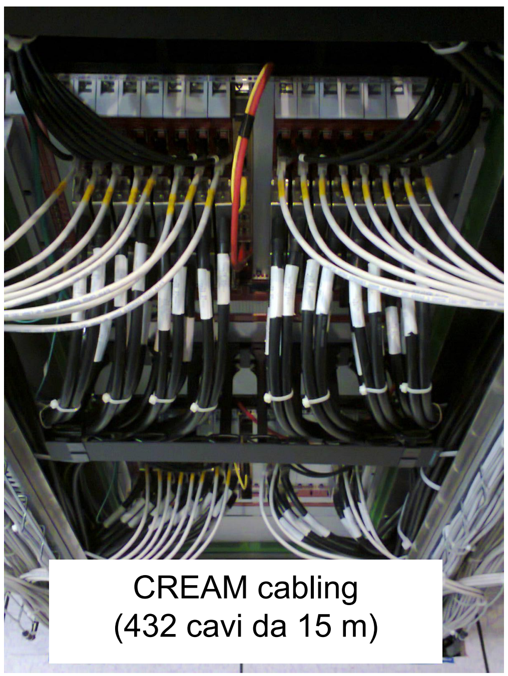
70 deserializer cards
(collaborazione con INFN Pg)



50 TX card
(2 x 3.4 Gbps
per scheda)

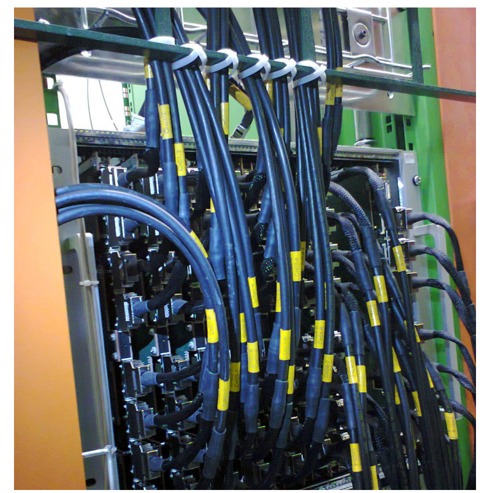


26 RX cards
(4 x 3.4 Gbps
per scheda)



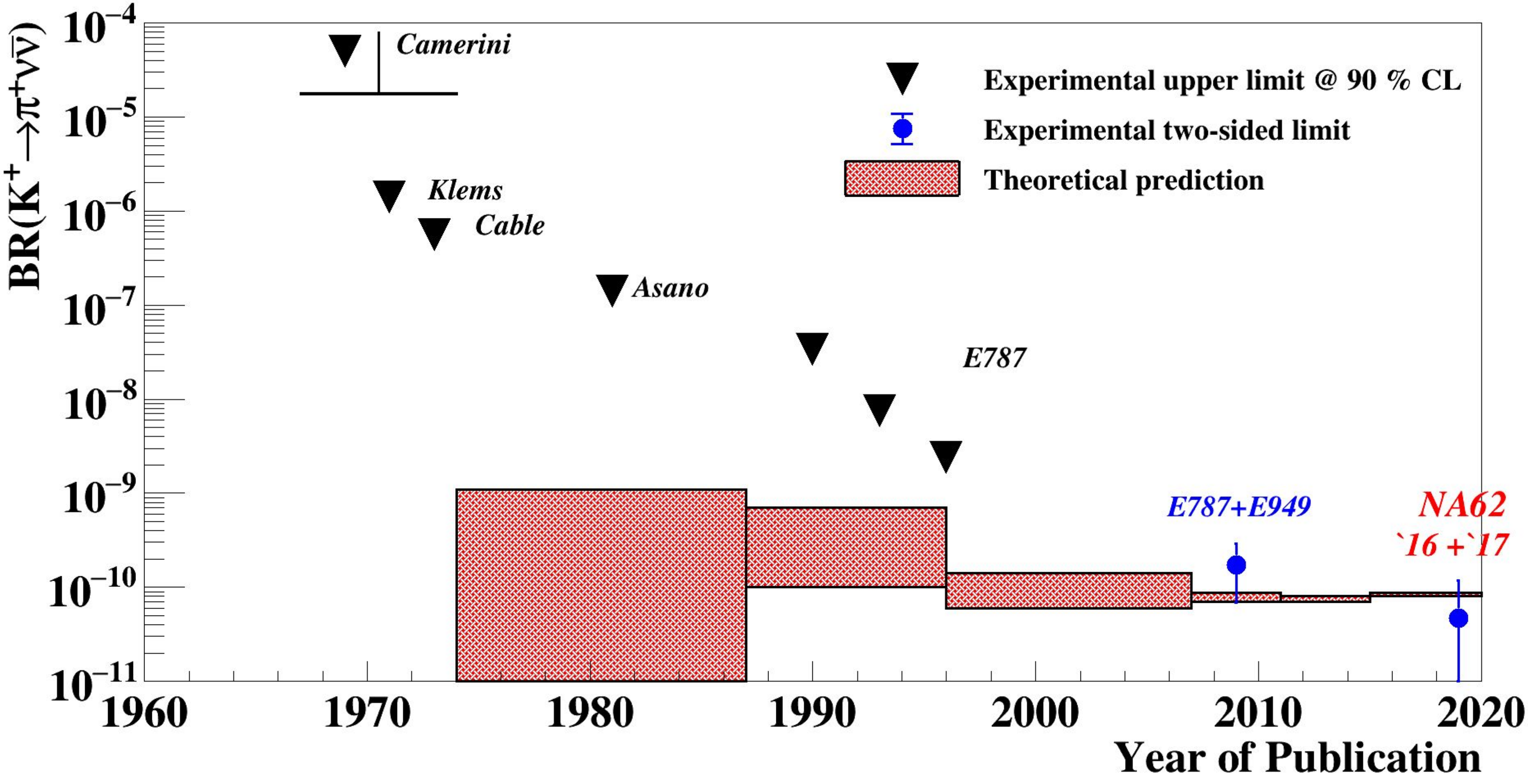
CREAM cabling
(432 cavi da 15 m)

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



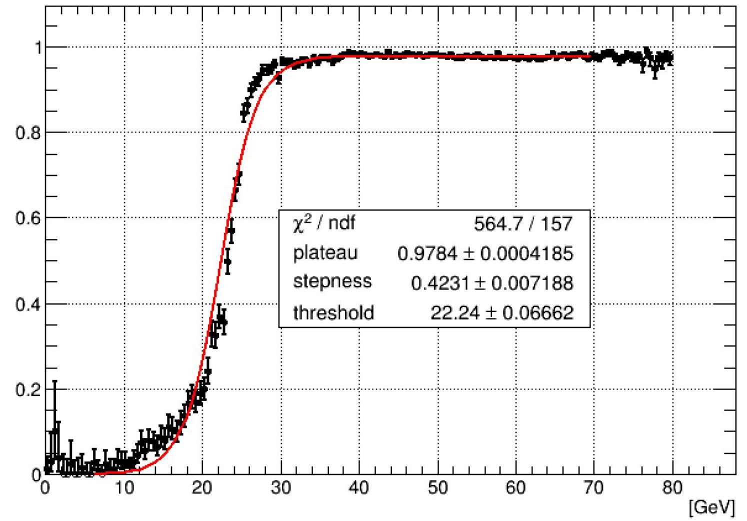
TX-RX cabling
(1 crate 9U, 64 cavi,
3.4 Gbps per cavo)

Grazie per l’attenzione!


$BR(K^+ \to \pi^+ \nu \bar{\nu})$
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
Camerini
Klems
Cable
Asano
E787
E787+E949
NA62
`16 +`17
Experimental upper limit @ 90 % CL
Experimental two-sided limit
Theoretical prediction
1960
1970
1980
1990
2000
2010
2020
Year of Publication

A Tor Vergata: veto per fotoni

Soglia picchi 560 MeV



σ = 1.2 ns