Stato e prospettive dell'esperimento NA62

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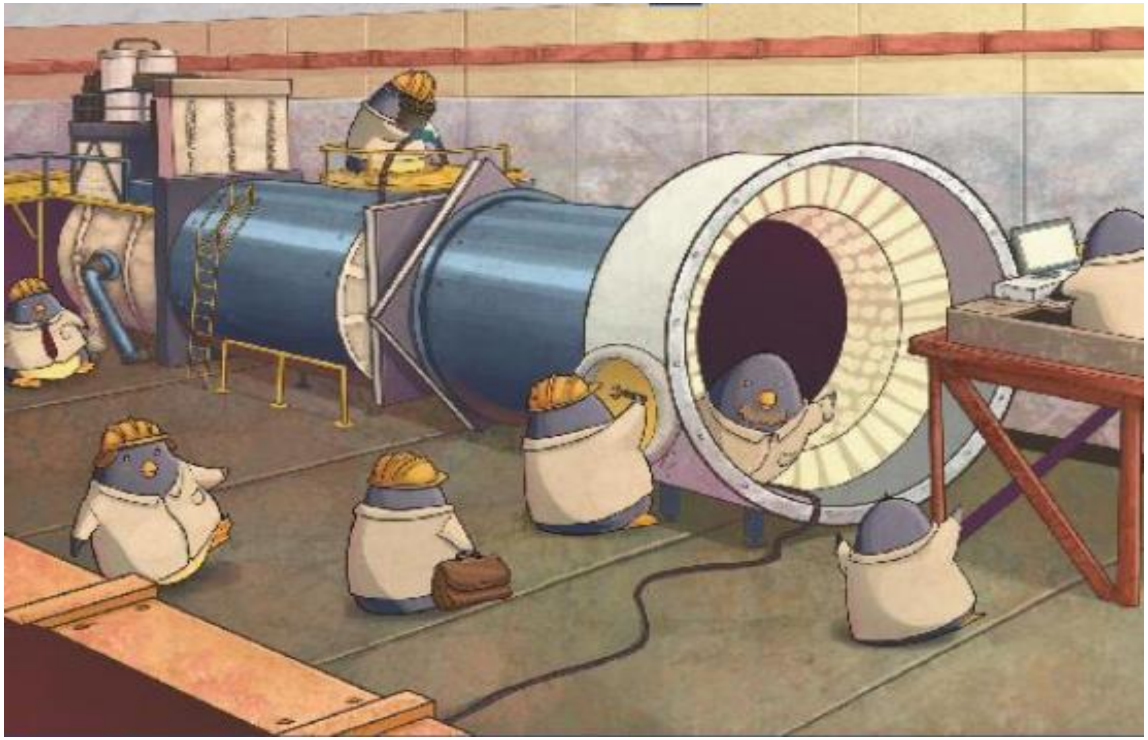
Riunione Gruppo 1, Napoli 19/12/2016

Outline

- $K^+ \to \pi^+ \nu\bar{\nu}$
- NA62: strategia ed apparato sperimentale
- NA62 nel run 2016
- Attività napoletana in NA62
- Conclusioni



Rare decays: motivation

A Journey to the Very Short Distance Scales:

1676 - 2046

Microuniverse	10^{-6}m	Bacteriology Microbiology
Nanouniverse	10^{-9}m	Nanoscience
Femtouniverse	10^{-15}m	Nuclear Physics Low Energy Elementary Particle Physics
Attouniverse	10^{-18}m	High Energy Particle Physics (present)
High Energy Proton-Proton Collisions at the LHC	$5\cdot10^{-20}$m	Frontiers of Elementary Particle Physics in 2010´s
High Precision Measurements of Rare Processes (Europe, Japan, USA)	10^{-21}m	Zeptouniverse

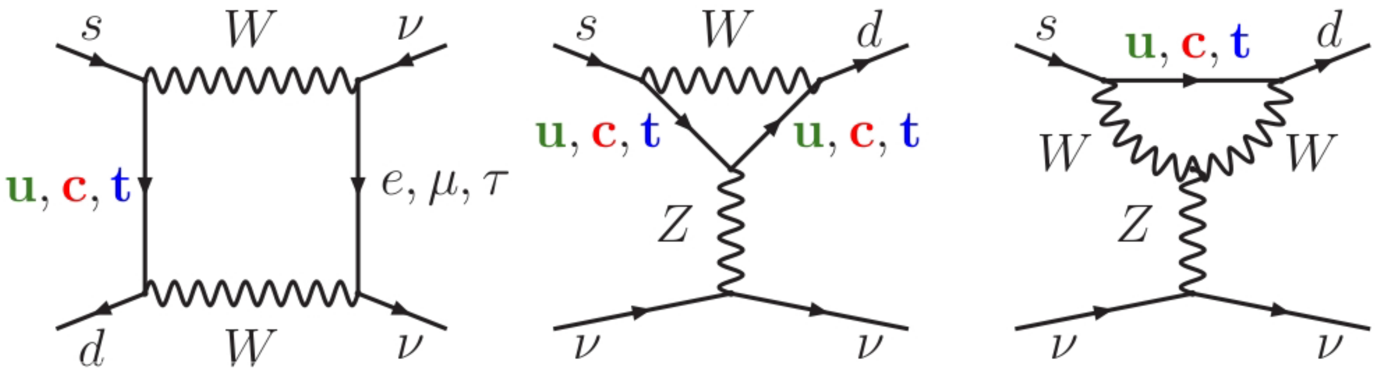
7 Stockholm2013

A. Buras@EPS 2013

The 100 TeV scale will only be accessible with rare decay studies up to > 2035

$K^+ \to \pi^+ \nu\bar{\nu}$ 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** $(K^+ \to \pi^0 e^+ \nu_e)$

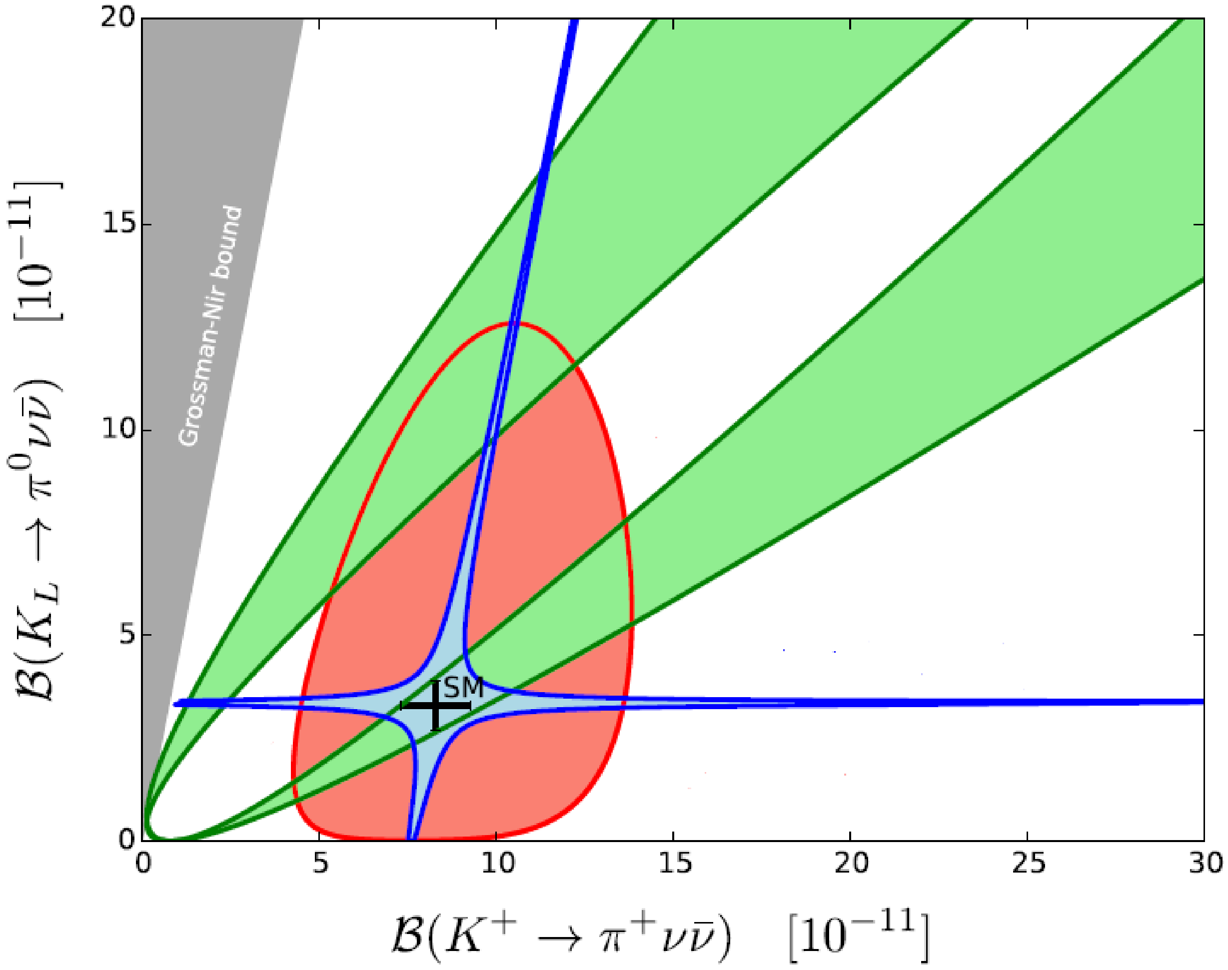
- **BR proportional to** $|V_{ts}{}^* V_{td}|^2$

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

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

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

Possibility to distinguish among different models

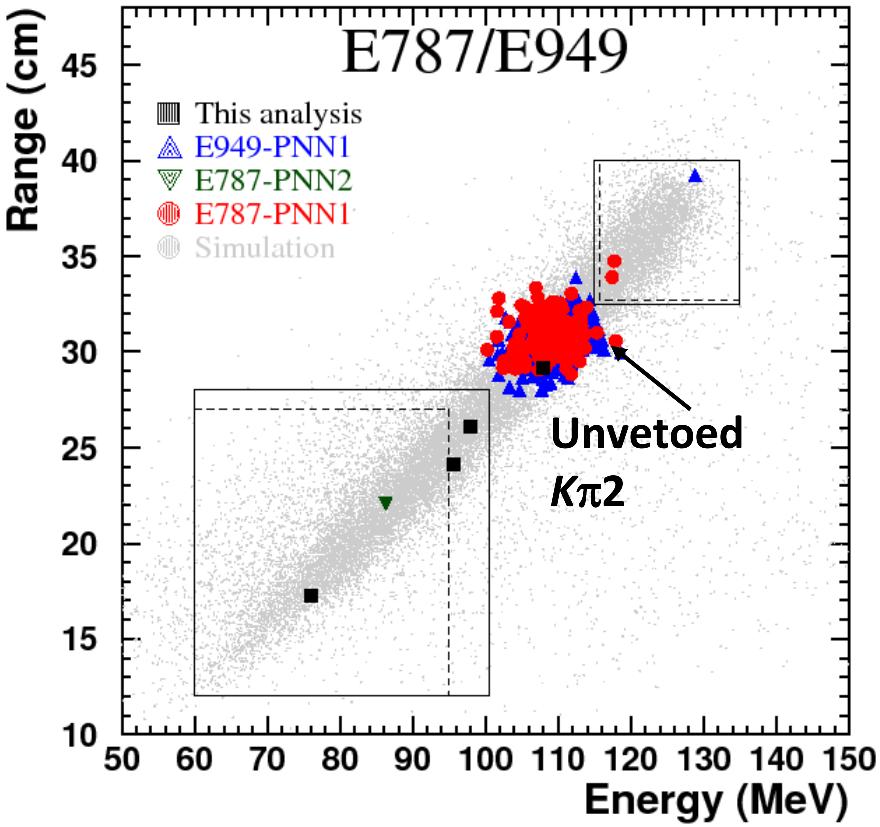


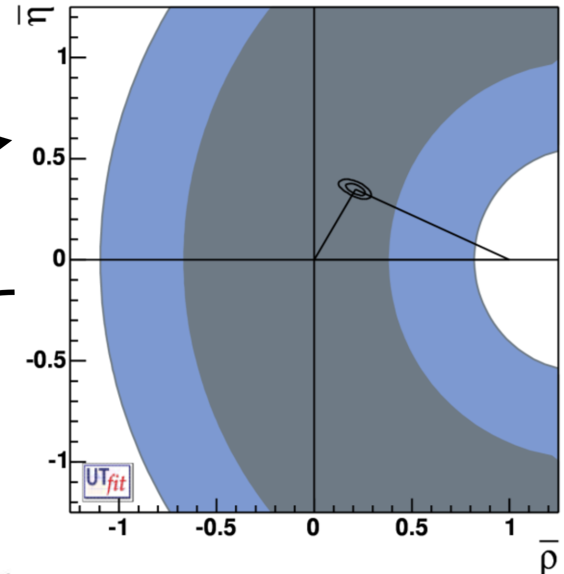
- Models with a CKM-like structure of flavour interactions (e.g. MFV)
- Models with new flavour and CP-violating interactions in which either left or right handed currents fully dominate (e.g. Z or Z' FCNC scenarios)
- Models like Randall-Sundrum

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

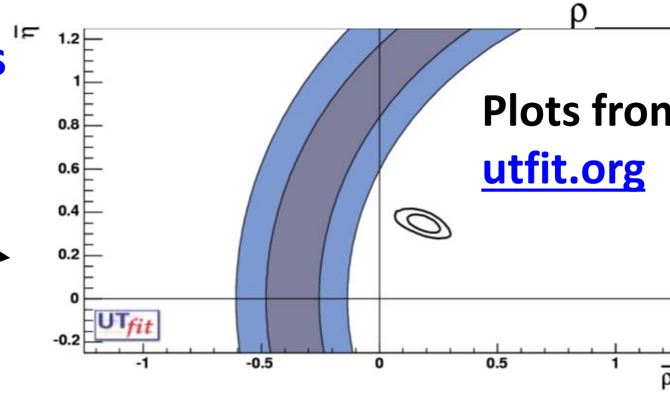
In 2008, combine E787 (1995-8 runs) & E949 (12-weeks run in 2001) results

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





Same central value, 100 evts



Plots from utfit.org

Expected bkg 2.6 events, prob. all 7 obs. evts are bkg is $\sim 10^{-3}$

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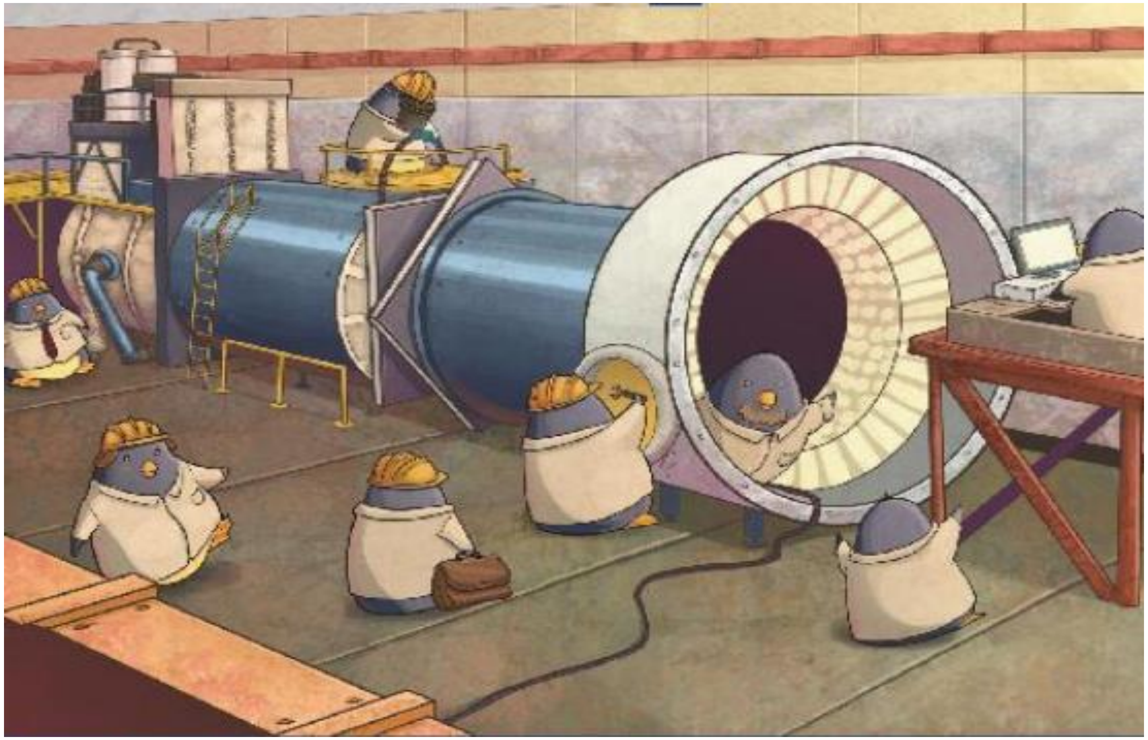
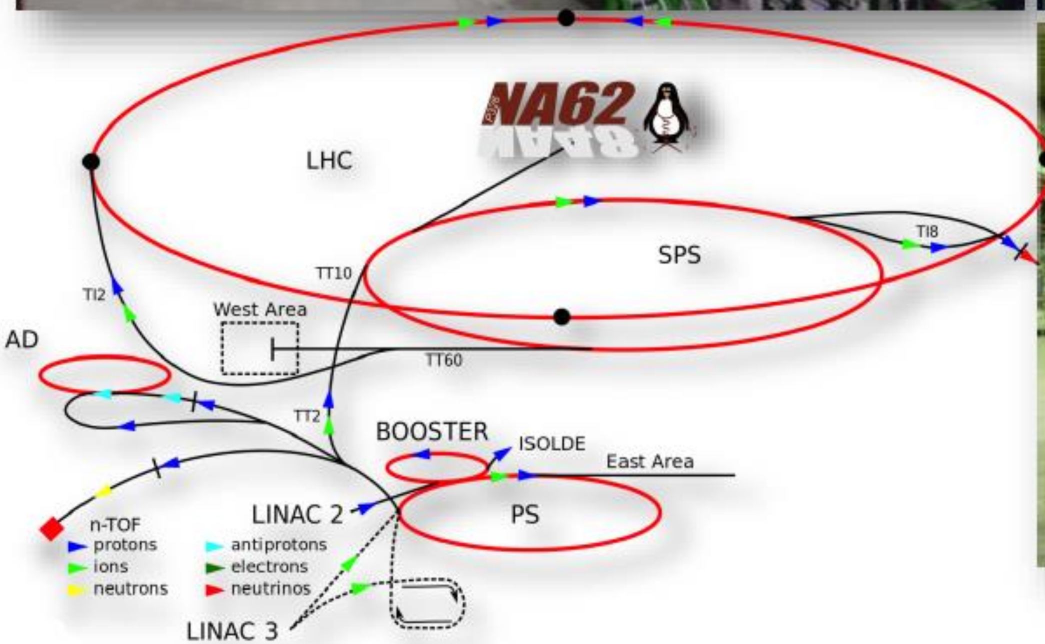


NA62 at CERN SPS



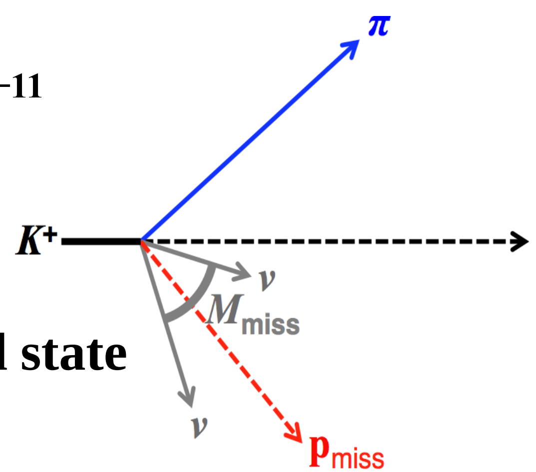
$K^+ \to \pi^+ \nu\bar{\nu}$ decay: signal and background

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

Technique:
75 Gev/c 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

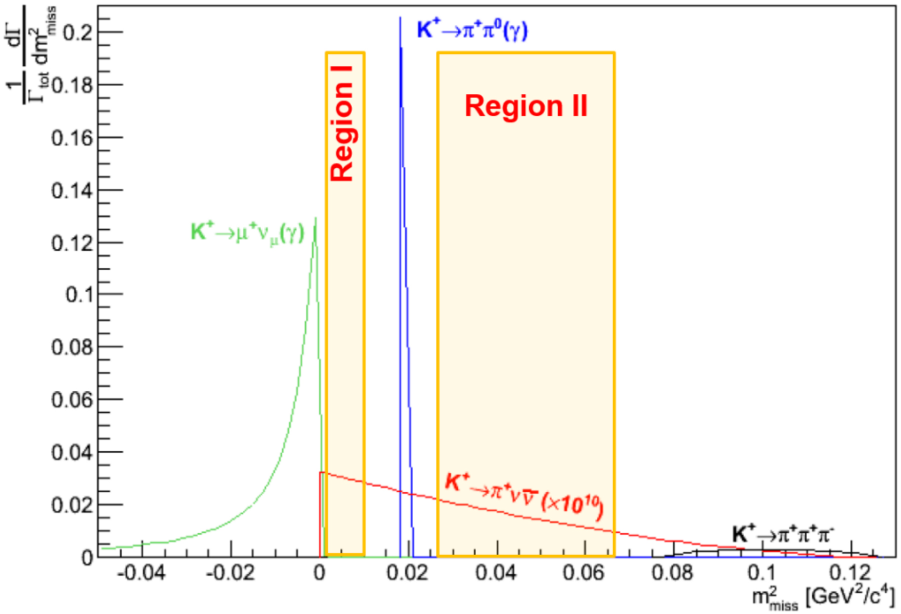
Mode		BR
$\mu^+\nu(\gamma)$	$K_{\mu2}$	63.5%
$\pi^+\pi^0(\gamma)$	$K_{2\pi}$	20.7%
$\pi^+\pi^+\pi^-$	$K_{3\pi}$	5.6%
$\pi^0 e^+\nu$	K_{e3}	5.1%
$\pi^0\mu^+\nu$	$K_{\mu3}$	3.3%
$\pi^+\pi^- e^+\nu$	$K_{e4}(+-)$	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$	$K_{e4}(00)$	2.2×10^{-5}
$\pi^+\pi^-\mu^+\nu$	$K_{\mu4}$	1.4×10^{-5}
$e^+\nu(\gamma)$	K_{e2}	1.5×10^{-5}

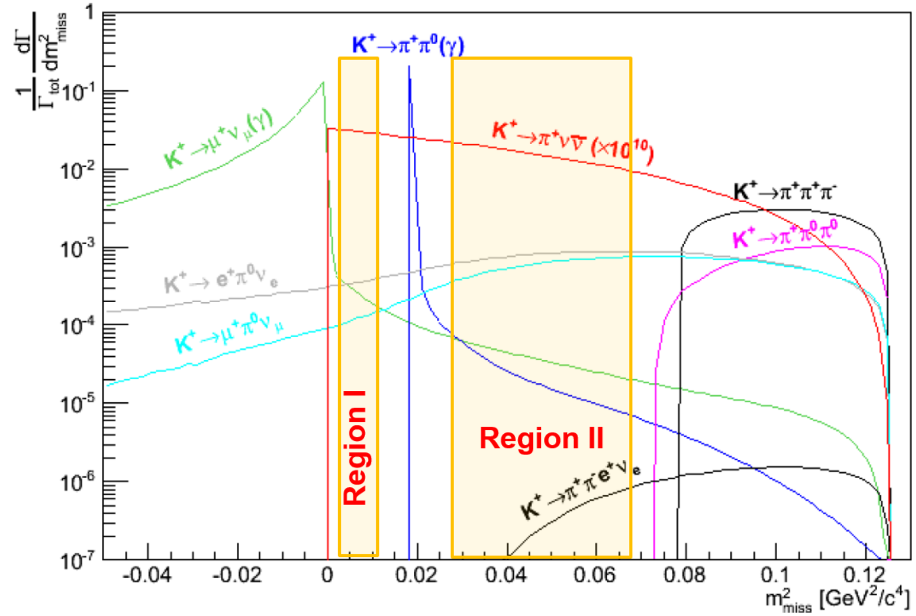
Other backgrounds

Upstream interactions

NA62 experimental strategy

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



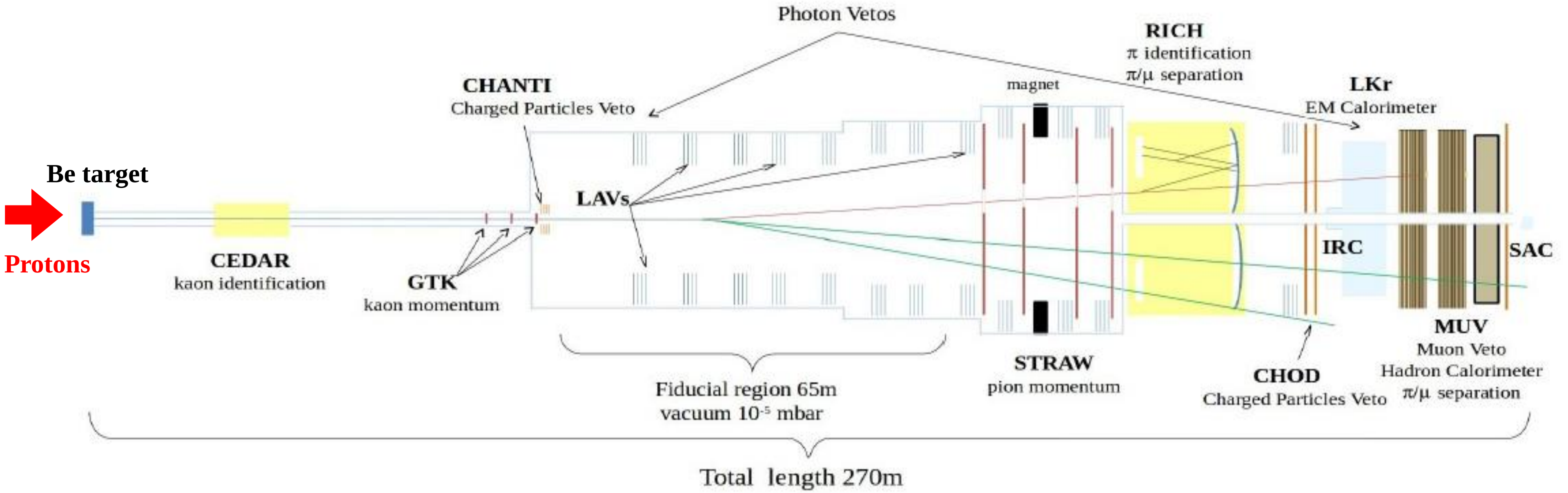


Experimental principles:

- ✓ Precise kinematic reconstruction: 2 signal regions in m_{miss}^2
- ✓ Low π momentum (15<p_π<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



Primary SPS proton beam:

- p = 400 GeV protons
- Proton on target 1.1×10^{12} /s
- Protom beam interacts with a beryllium target

High-intensity, unseparated secondary beam

- p = 75 GeV/c
- $\Delta p/p$ ~ 1%

Total rate 750 MHz

- 525 MHz π
- 170 MHz p
- 45 MHz K

Detectors commissioned up to nominal intensity in 2015

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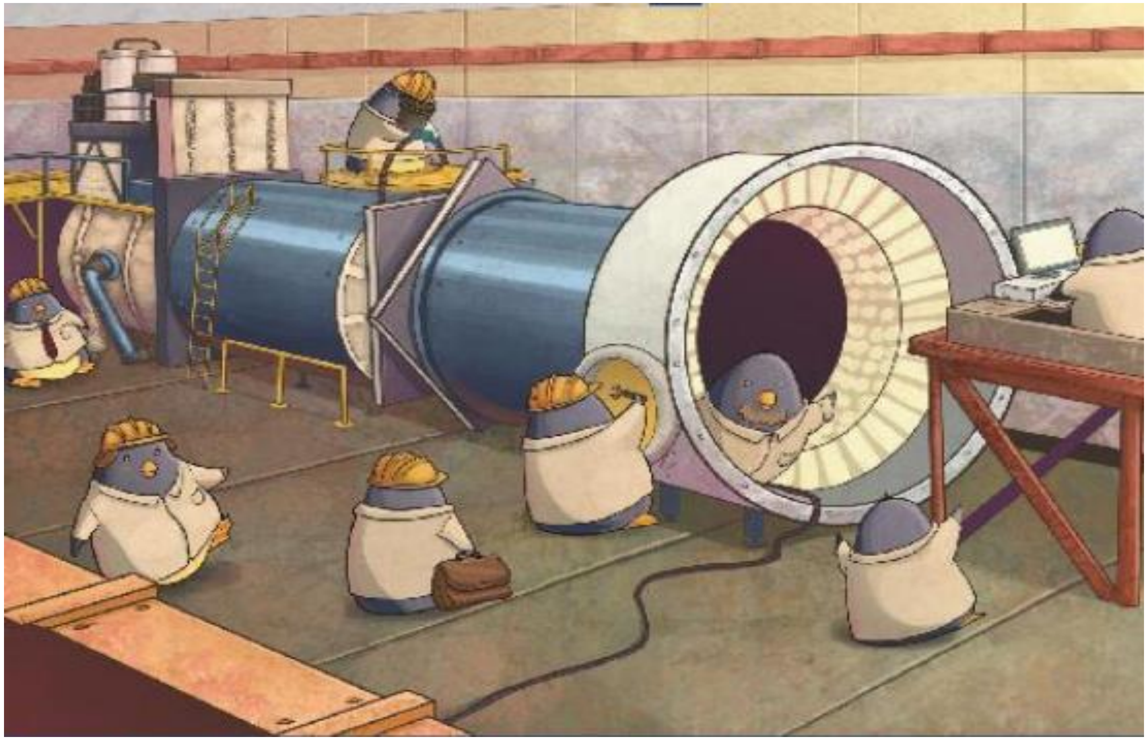
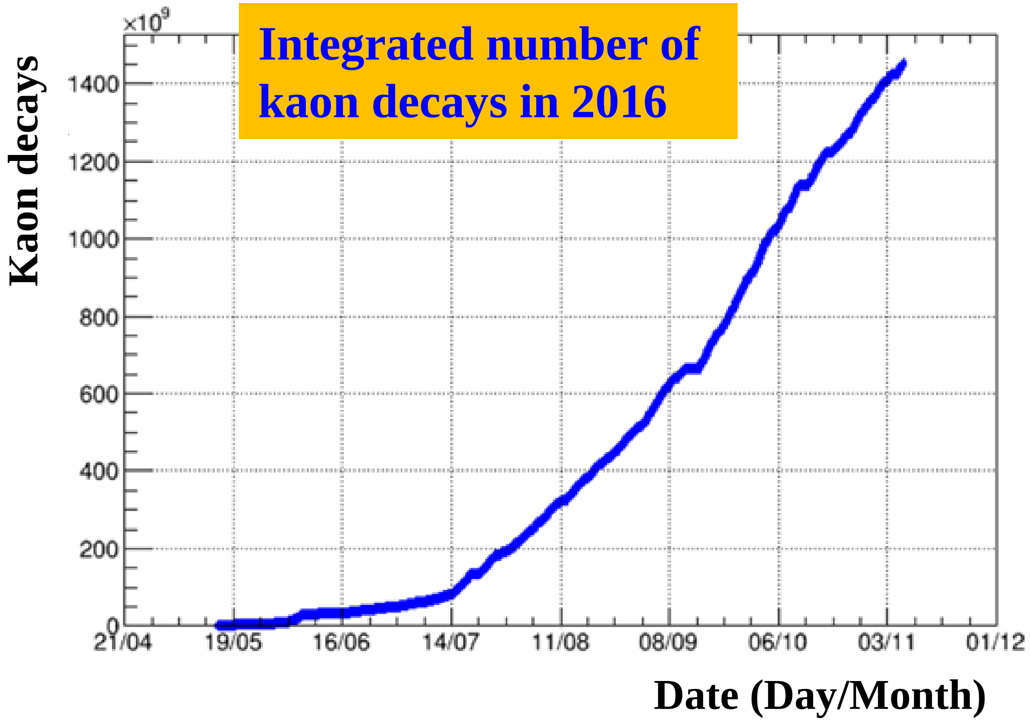


Where NA62 is now

- 2014: detector commissioning
- 2015: trigger commissioning, beam line commissioning up to the nominal intensity, detector performance studies
- 2016: high level software trigger commissioning, full commissioning of the beam tracker



K-decays: extrapolation to end of 2018:
$5 \cdot 10^{11}$ / month * 12 months ~ $6 \cdot 10^{12}$

Running consistently at about **40% of nominal intensity:**

- Limited by beam "Structures"
- Data taking for PNN + RARE/EXOTICS simultaneously
- Three full GTK working (no noise, 30/30 chips) since September 15

With improved extraction and incremental improvements to the efficiency we can reach our target of 10^{13} K decays before LS2

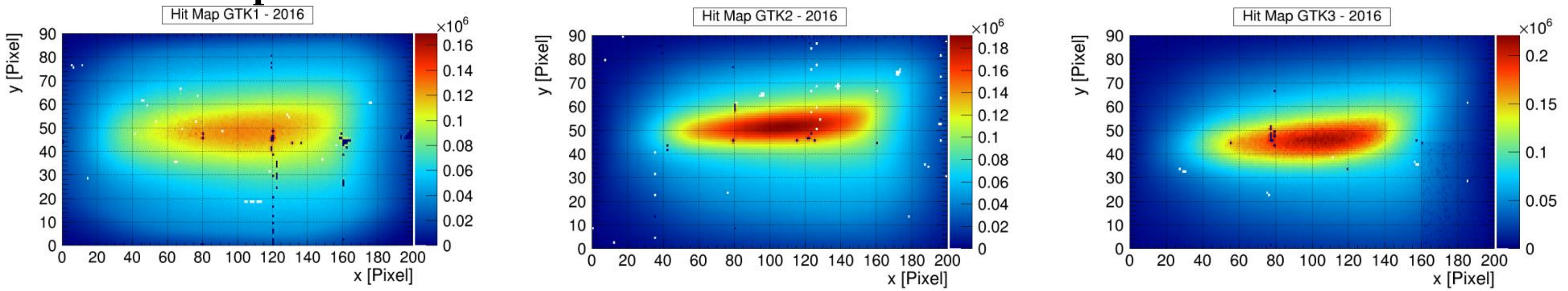
One track selection

- **Downstream particle selection**
  - ✓ **Loop on each of the straw track: not vertex with any other track**
  - ✓ **Good positive track, within detectors' geometrical acceptance**
  - ✓ **Momentum of track between 15 and 35 GeV/c**
  - ✓ **Track matching with CHOD candidates, LKr and MUV1,2 cluster and a RICH ring**

- **Upstream particle selection**
  - ✓ **K in KTAG in time with the CHOD time**
  - ✓ **Spectrometer –Gigatracker track matching**
  - ✓ **Cut on Z of the reconstructed vertex between 105 and 165 m**

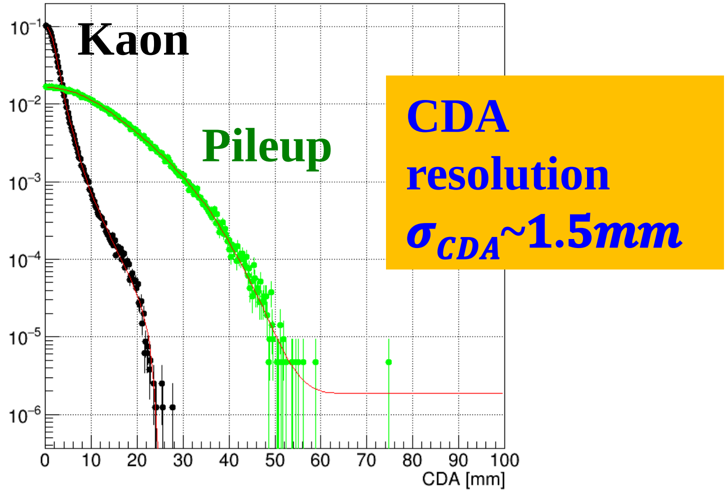
Track matching in 2016 data

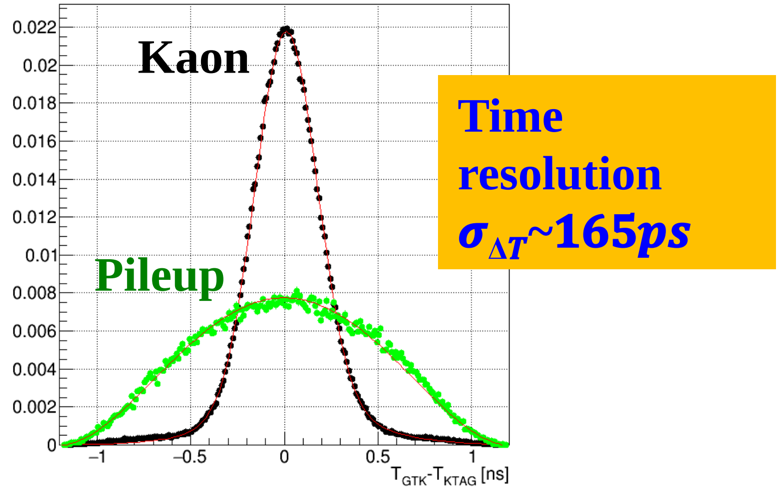
3 stations of Silicon pixel detectors (300 x 300 µm^2), operating in the evacuated beam pipe inside an achromat. Active area ≈ 60 (X) * 27 (Y) mm^2; overall rate 750 MHz, in the beam centre 140 kHz/pixel



GTK Kaon tracks sample: for each $K_{3\pi}$, all GTK triplets (in time with KTAG) compatible with a beam particle; kaon candidate selected using $K_{3\pi}$ downstream

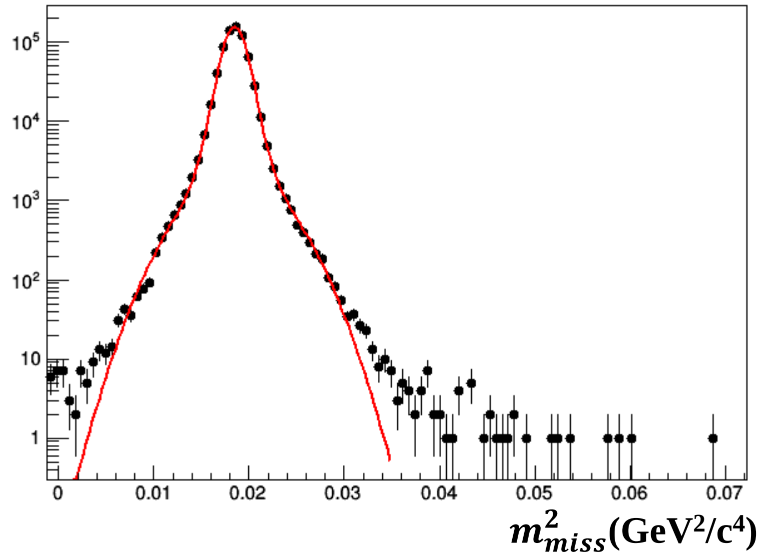
GTK Pileup tracks sample: same as above using triplet from out-of-time hits wrt KTAG.



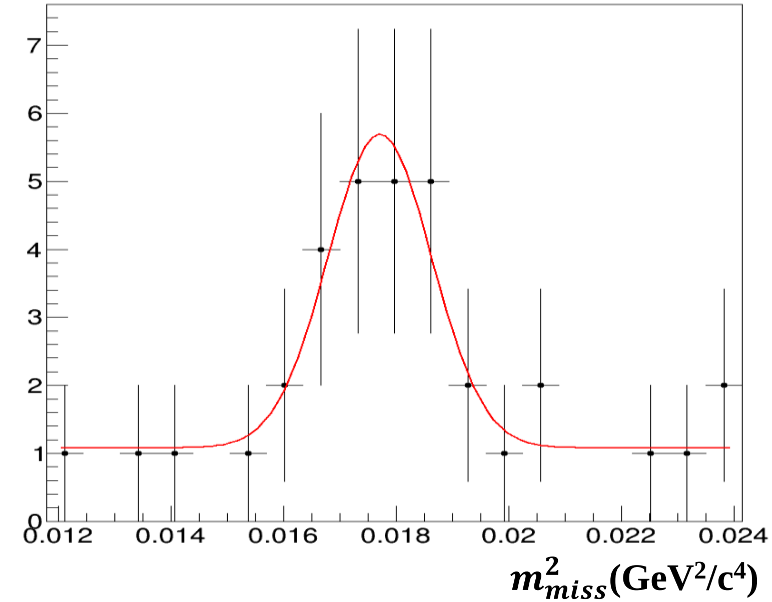


Photon rejection

Dedicated $K^+ \rightarrow \pi^+\pi^0$ selection
Missing mass peak resolution: 1x10^{-3}



LAV, LKr, SAC and IRC in veto

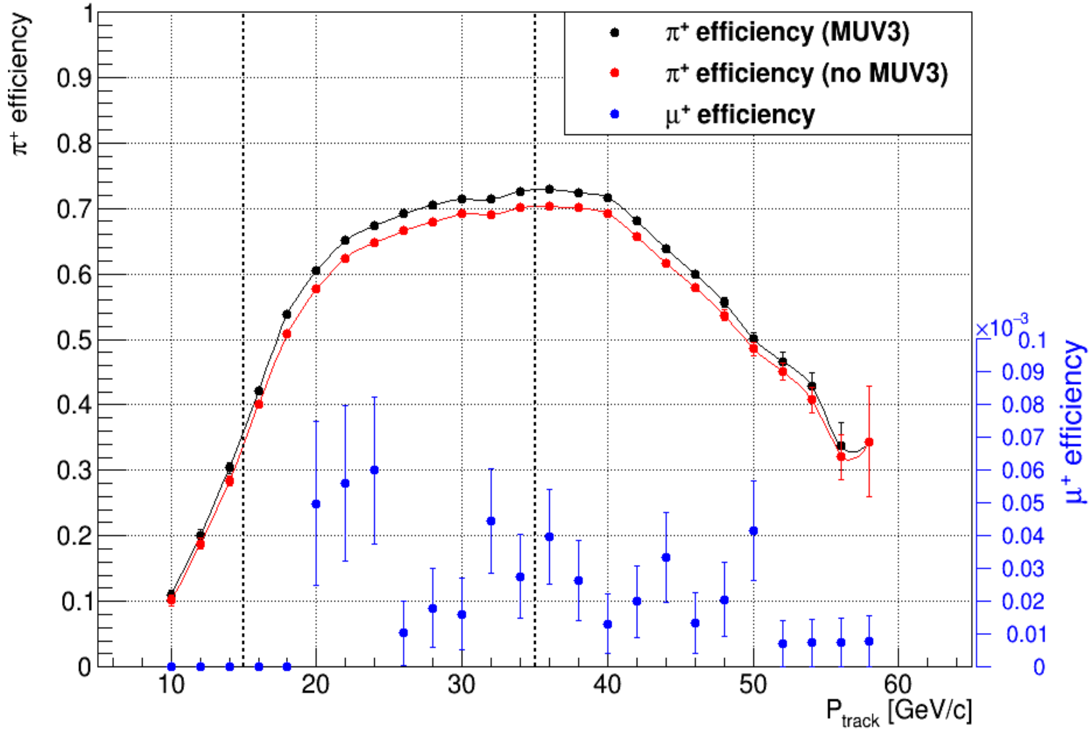


$\pi^+\pi^0$ photon rejection
(6±2) x 10^{-7}

PID with calorimetric information

Cut and count method using samples of muons and pions (purity of samples to be evaluated).
Info used:

- **MUV3**
- **Total energy (LKr+MUV1+MUV2) and Total energy / P**
- **Energy sharing among calo: ratio of the energies in MUV1,2 wrt total energy**
- **Shape of the energy depositions in LKr, MUV1,2**



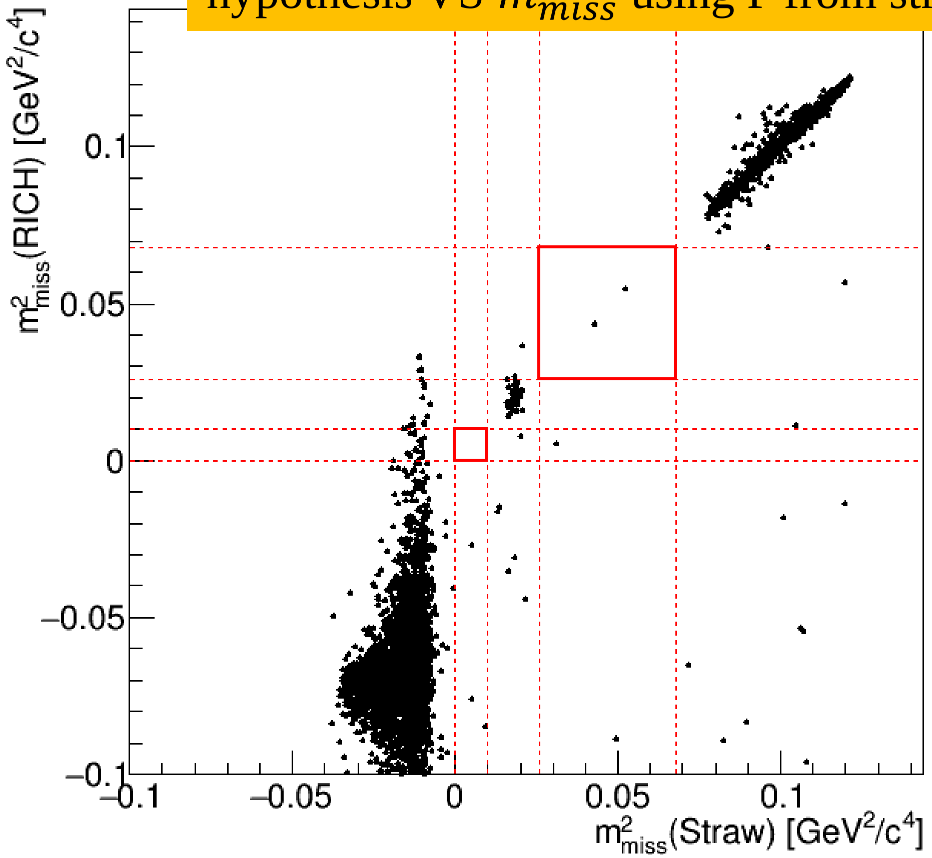
Muon acceptance (15-35)GeV/c: $2.9 \pm 0.6 \times 10^{-5}$

Pion efficiency (15-35)GeV/c: 65% (including 3% of MUV3 random veto)

$K^+ \to \pi^+ \nu\bar{\nu}$ selection preliminary study

Not a blind analysis in one run with 5×10^9 kaon decays (rough estimation)

m^2_{miss} using momentum from RICH under pion hypothesis VS m^2_{miss} using P from straw spectrometer



Residual events in region 2 are:

- 3 pion (improvement of multi-charged particle suppression)
- Beam background

Sensitivity in the range
$10^{-8} \div 4\times10^{-9}$

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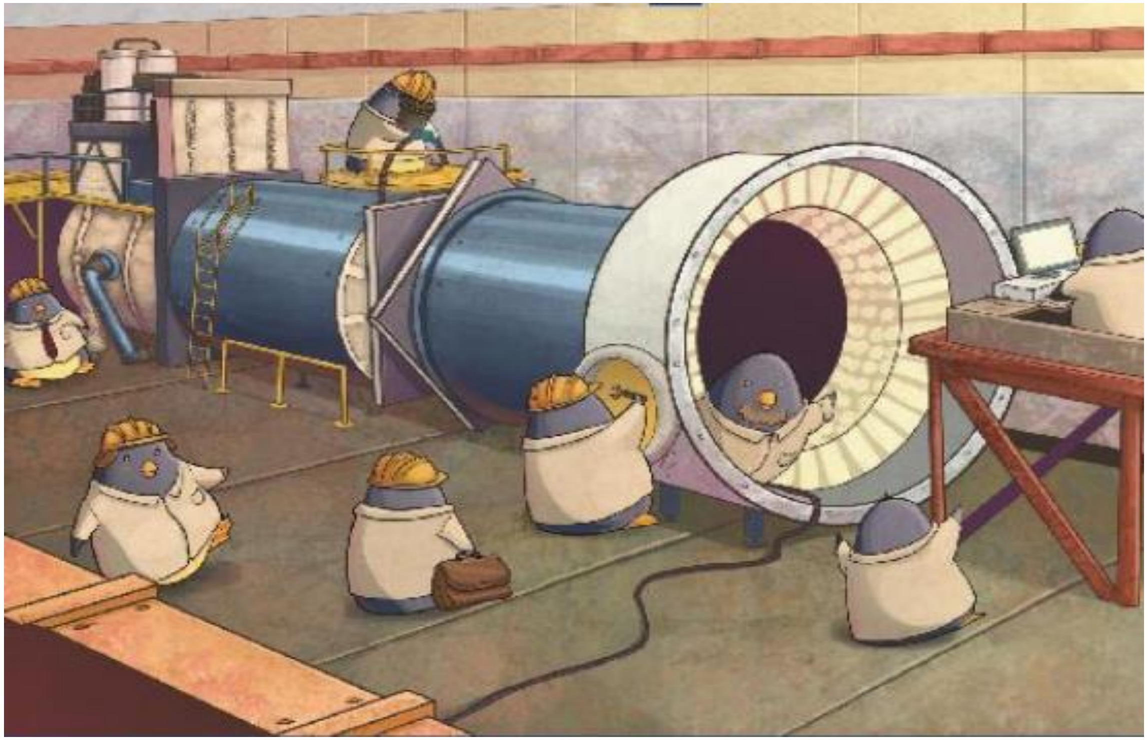
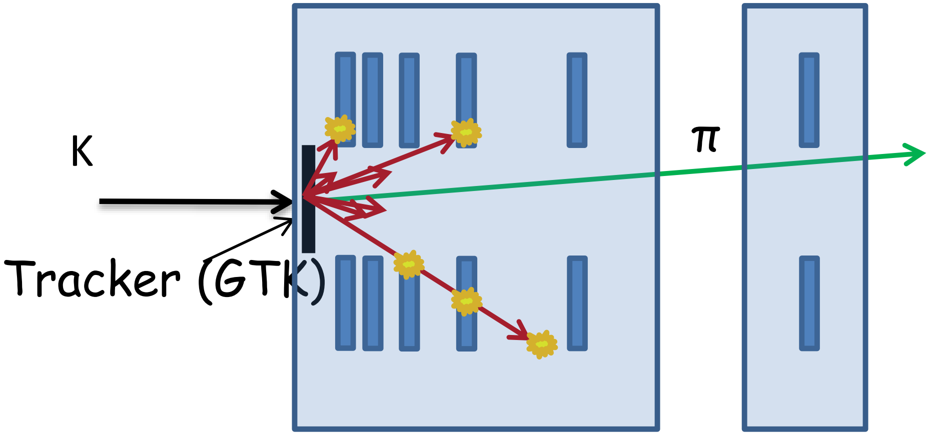
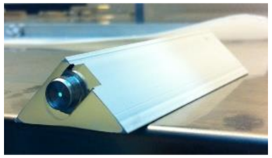


CHANTI postcard

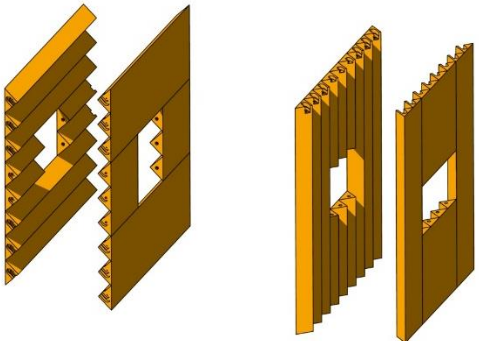
Rivelatore 100% napoletano fin dalla proposta e dal progetto.
Sei anelli di guardia per vetare le interazioni inelastiche dei K sul GTK
Barre di scintillatori a sezioni triangolare letti tramite fibre WLS e SiPM, montate in modo da avere un piano X e uno Y per ogni stazione



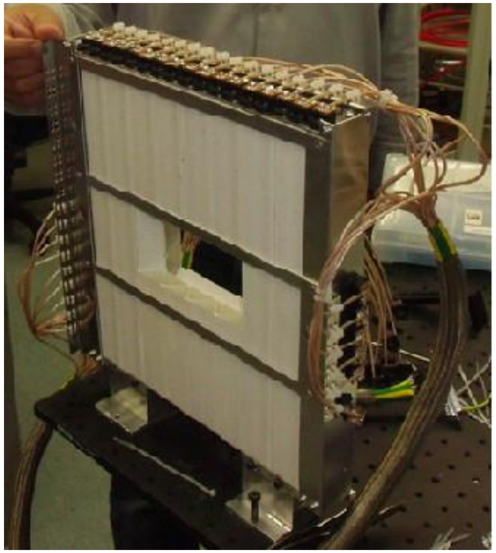
Barra di scintillatore



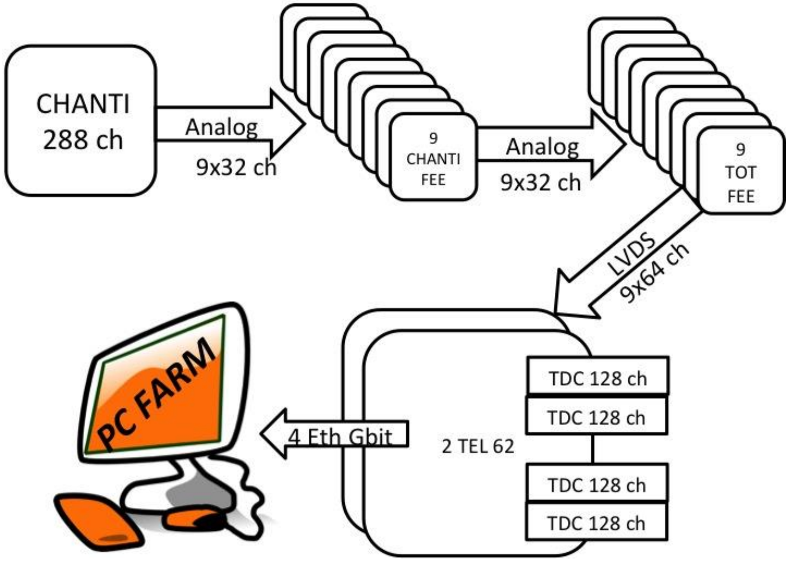
Layout dei layer X/Y



Stazione cablata



Elettronica di FE



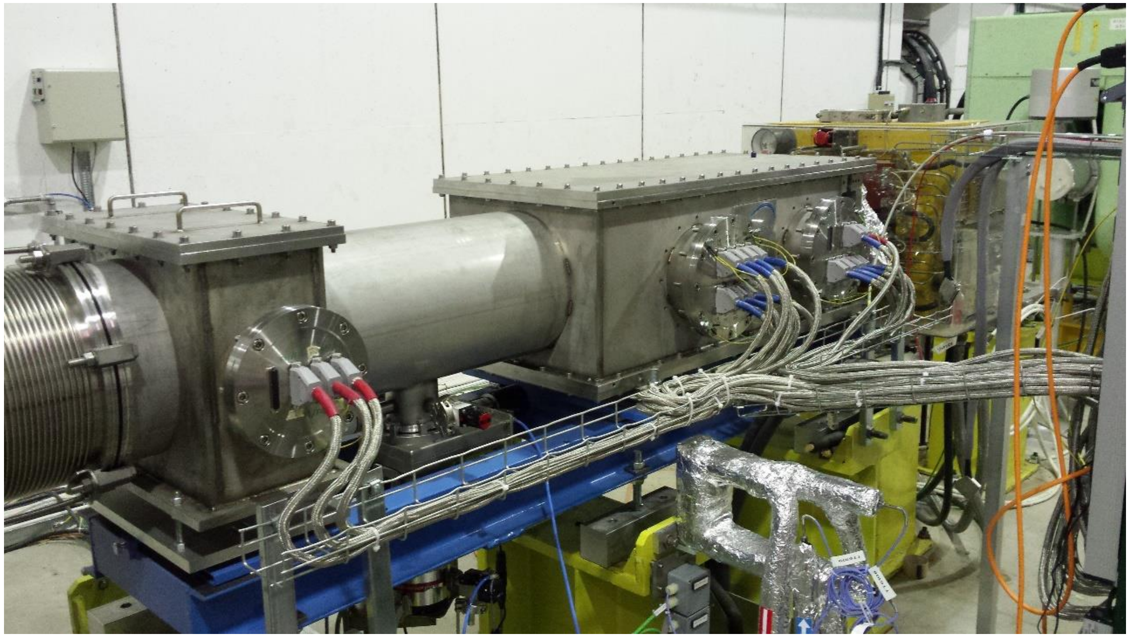
CHANTI in NA62

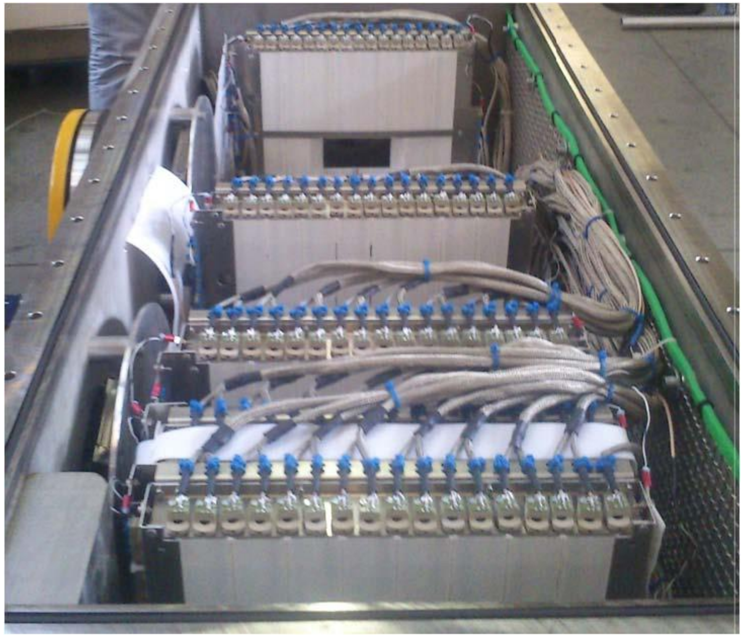
Run 2014 - Completata la costruzione e installato con test sull'elettronica

Run 2015 - Valutazione delle performance del rivelatore sul fascio (risoluzione temporale, efficienza di rivelazione, risoluzione spaziale, veto accidentale introdotto)

Run 2016 - Stabilmente in presa dati

F.Ambrosino et al. , *CHANTI: a Fast and Efficient Charged Particle Veto Detector for the NA62 Experiment at CERN*, Journal of Instrumentation, Volume 11, P03029, March 2016, http://dx.doi.org/10.1088/1748-0221/11/03/P03029





Beam background responsibility

Summary of $\pi\nu\nu$ analysis

- Full analysis on 2015 data: D. Brymann, J. Fu, A. Conovaloff
- Full analysis on 2016 data: R. Marchevsky, G.R., D. Brymann, B. Velghe
- GTK – Straw matching (coordinated by M. Perrin-Terrin): Z.Kucerova, B. Velghe, J. Swallow, D. Moise
- PID with calorimeters: R. Aliberti, M. Zamkovsky
- PID with RICH: R. Volpe, S. Duk, J. Engelfried
- Photon rejection: T. Spadaro, L. Peruzzo, G.R., B. Velghe
- Beam background: M. Mirra
- Trigger efficiency: D. Soldi
- ... many items to be covered yet

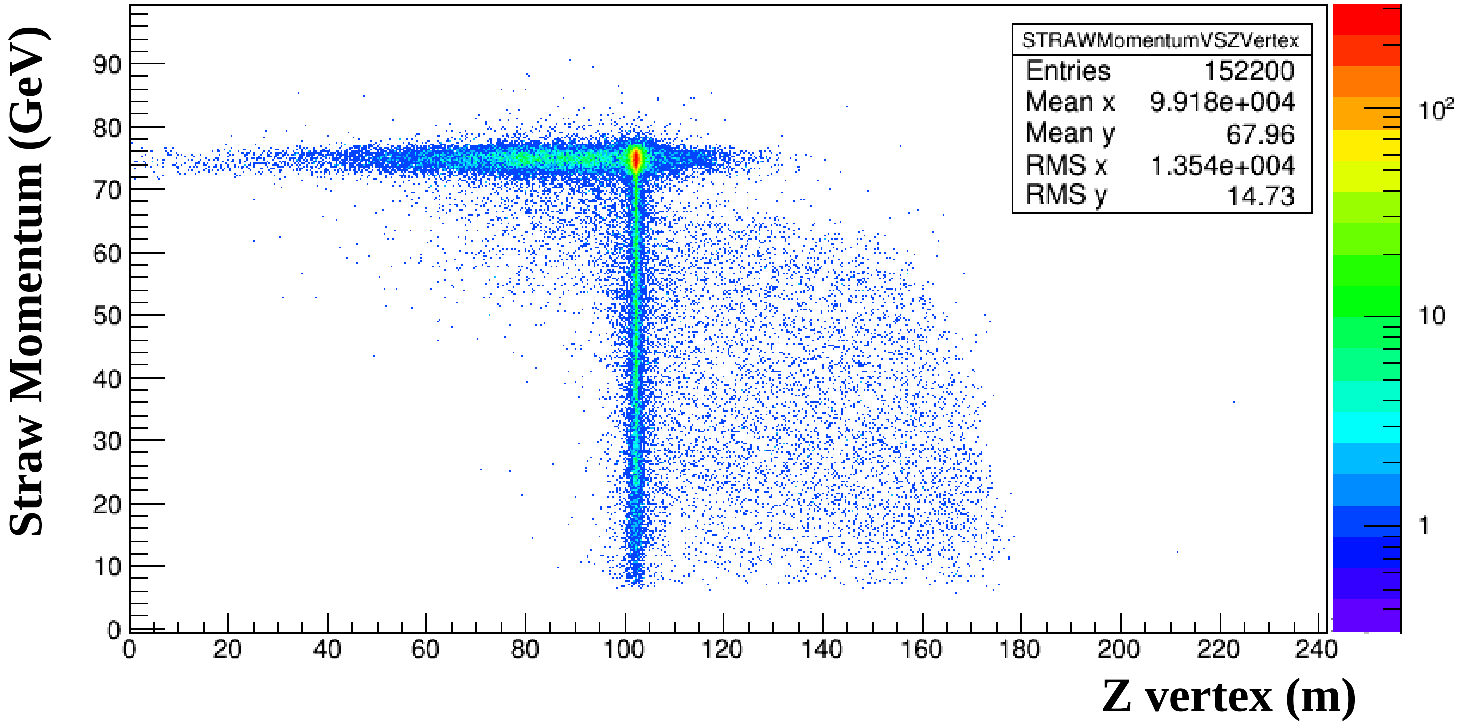
Names are preliminary

14/12/2016 Giuseppe Ruggiero - Physics Analysis Meeting 9

Sample of inelastic interactions

Using pions, instead of kaons, in order to study inelastic interactions. Sample definition:

- ✓ **Single track event in STRAW: one track(positive charge) in geometrical acceptance of downstream detectors**
- ✓ **One CHOD candidate matching in time and space the track**
- ✓ **GTK track in time forming a good vertex (CDA cut) with the downstream track**
- ✓ **KTAG condition in veto**
- ✓ **No MUV3 candidate in time with CHOD and space matching with the track**
- ✓ **Cut on E/P of the π^+ candidate**

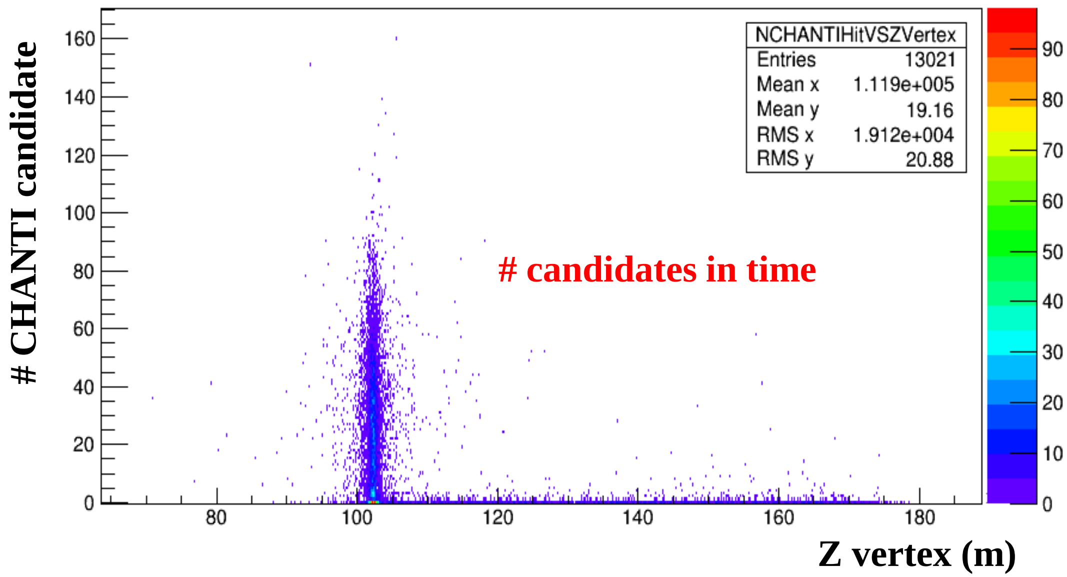


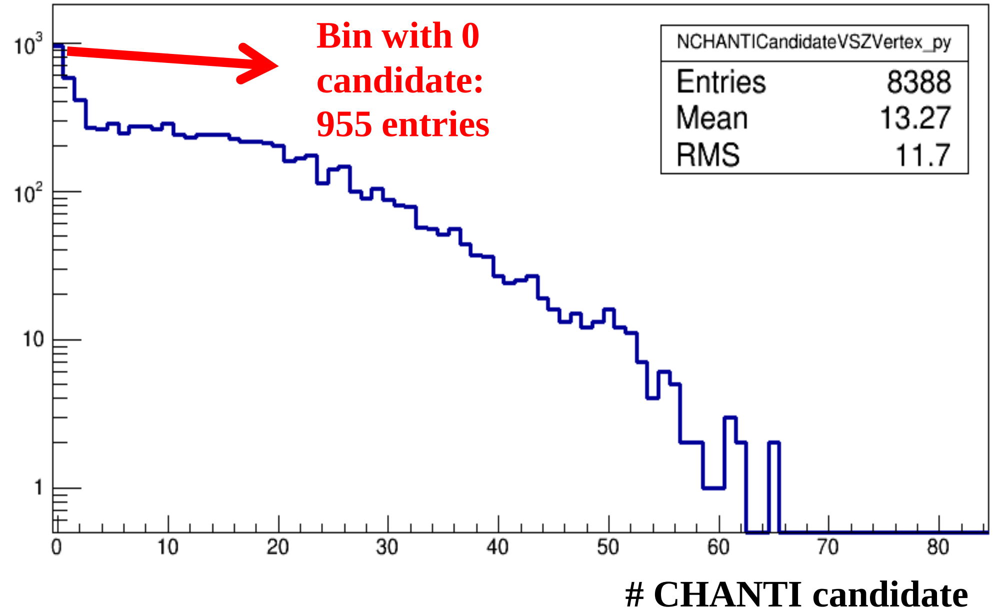
Inelastic detection efficiency

Subtracting the number of pion decays evaluated with pol0 fit in the fiducial volume, the detection efficiency is ~90%.

This is probably mainly due to geometrical acceptance (efficiency, checked on muons in 2016, is >99% single view. The inelastic detection does not include LAV (covering a complementary geometrical region with respect to the CHANTI)

Moreover no GTK information are used (ToT and multiplicity of hits in GTK3)





CHANTI accidental veto

Sample definition:

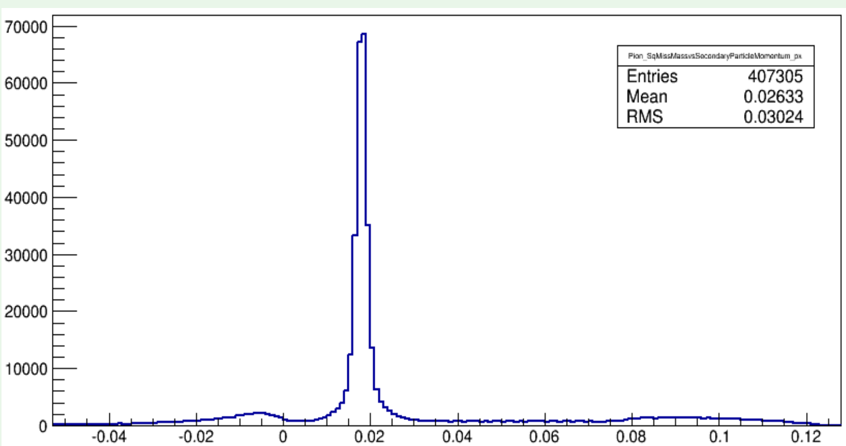
- ✓ One track(positive charge) in geometrical acceptance of downstream detectors
- ✓ One CHOD candidate matching in time and space the track
- ✓ GTK track in time forming a good vertex (CDA cut) with the downstream track
- ✓ KTAG condition to identify kaon
- ✓ Cut on E/P of the π^+ candidate

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

No MUV3 candidate in time with CHOD and space matching with the track

Cut on the missing mass

$$m^2_{miss} = (P_{K^+} - P_{\pi^+})^2$$



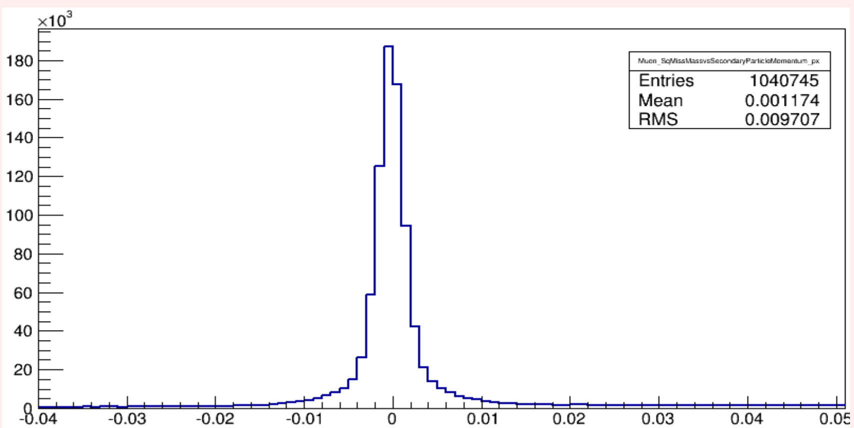
m^2_{miss}(GeV^2/c^4)

$K^+ \rightarrow \mu^+\nu_\mu$ sample

MUV3 candidate in time with CHOD and space matching with the track

Cut on the missing mass

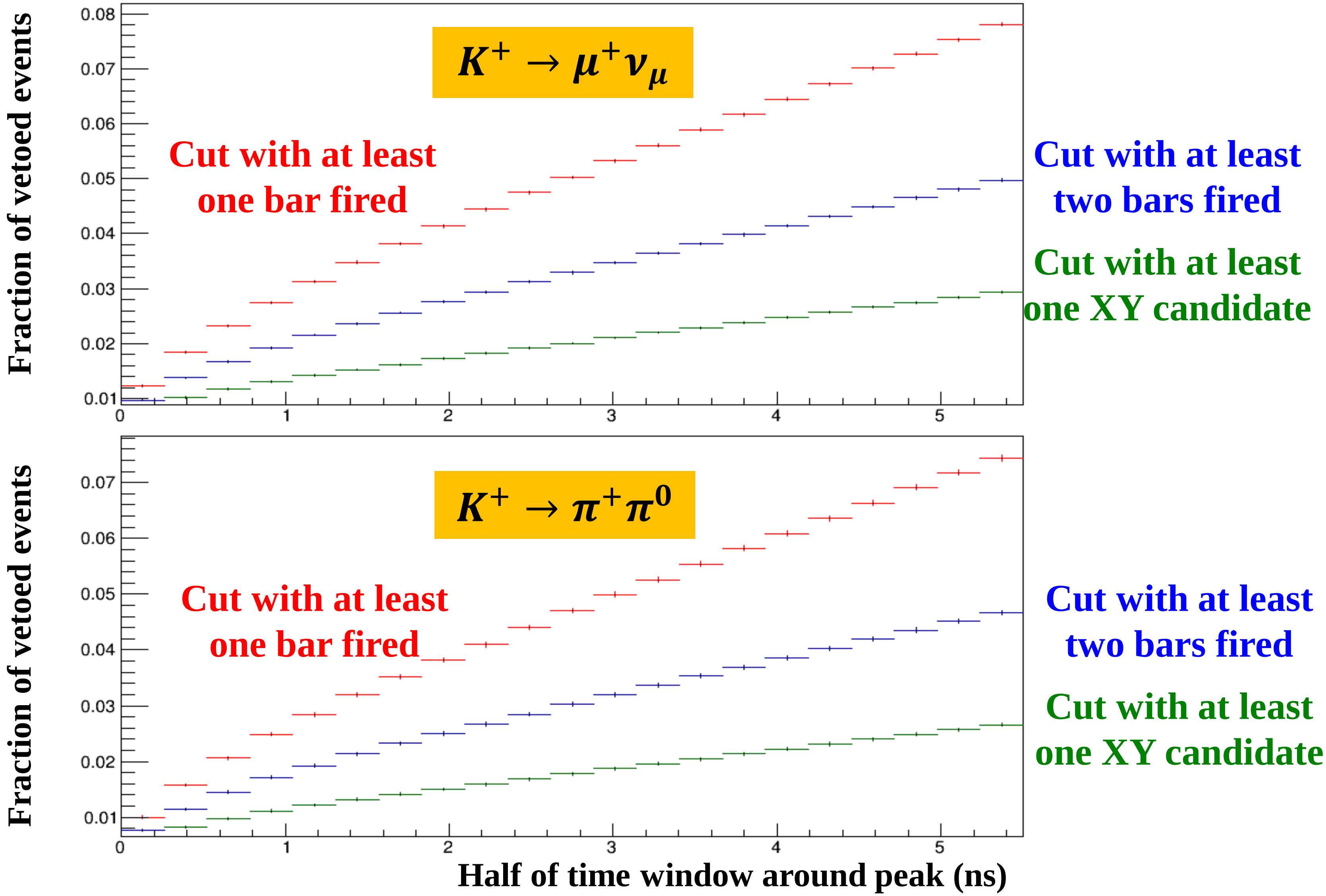
$$m^2_{miss} = \left(P_{K^+} - P_{\mu^+}\right)^2$$



m^2_{miss}(GeV^2/c^4)

CHANTI accidental veto

Fraction of events rejected by CHANTI vs. time window around event time



Large angle vetoes efficiency

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

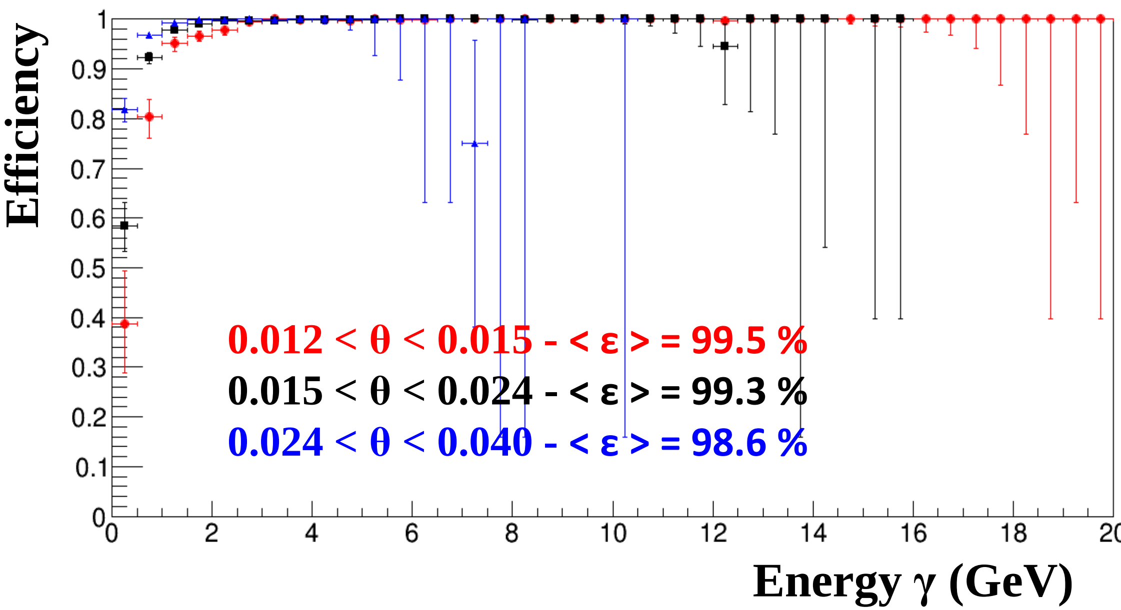
12 stazioni a intervalli di ~10m lungo la linea di fascio

Ogni stazione ha 4-5 anelli di blocchi al vetro-piombo

Napoli ha partecipato alla costruzione a LNF e l'istallazione al CERN dei LAV

Efficienza

- **Metodo**: selezione di un campione di $K^+ \rightarrow \pi^+\pi^0$ richiedendo 1 traccia e un γ nel LKr, in modo da predire la posizione dell'altro γ nel LAV
- **Eventi efficienti**: c'è almeno un blocco acceso in corrispondenza del γ atteso nel LAV entro 5ns dal tempo di riferimento



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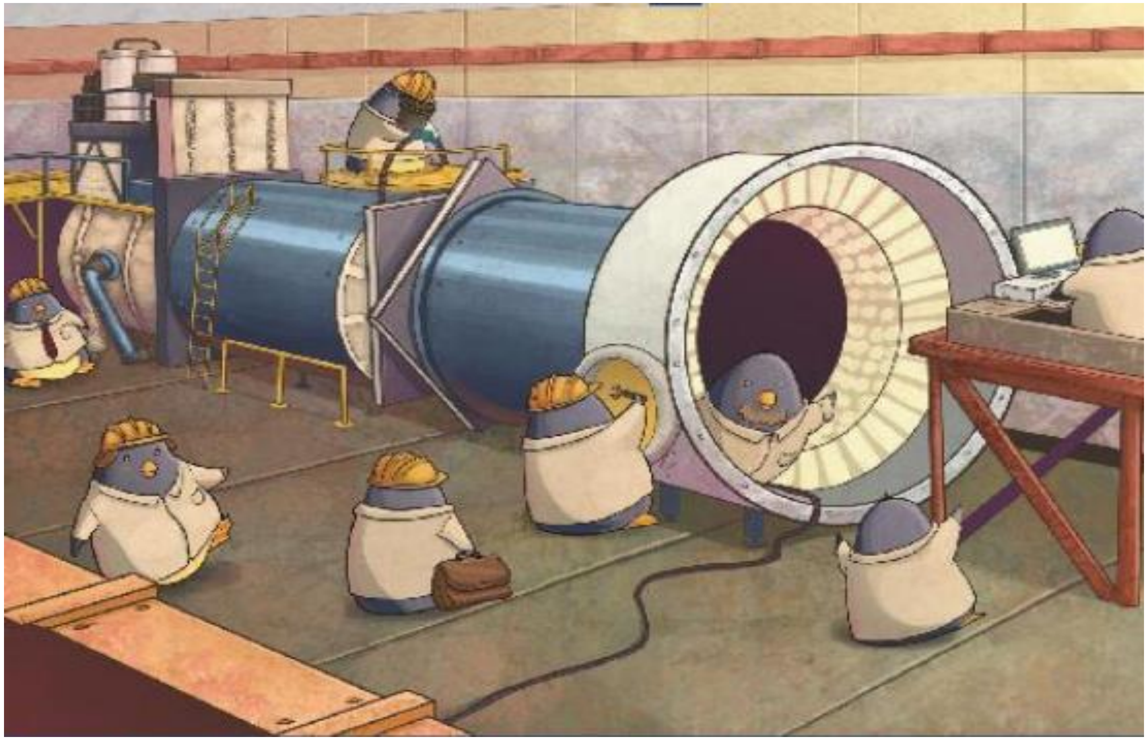
- ➢ NA62: strategia ed apparato sperimentale
- ➢ NA62 nel run 2016
- ➢ Attività napoletana in NA62
- ➢ **Conclusioni**

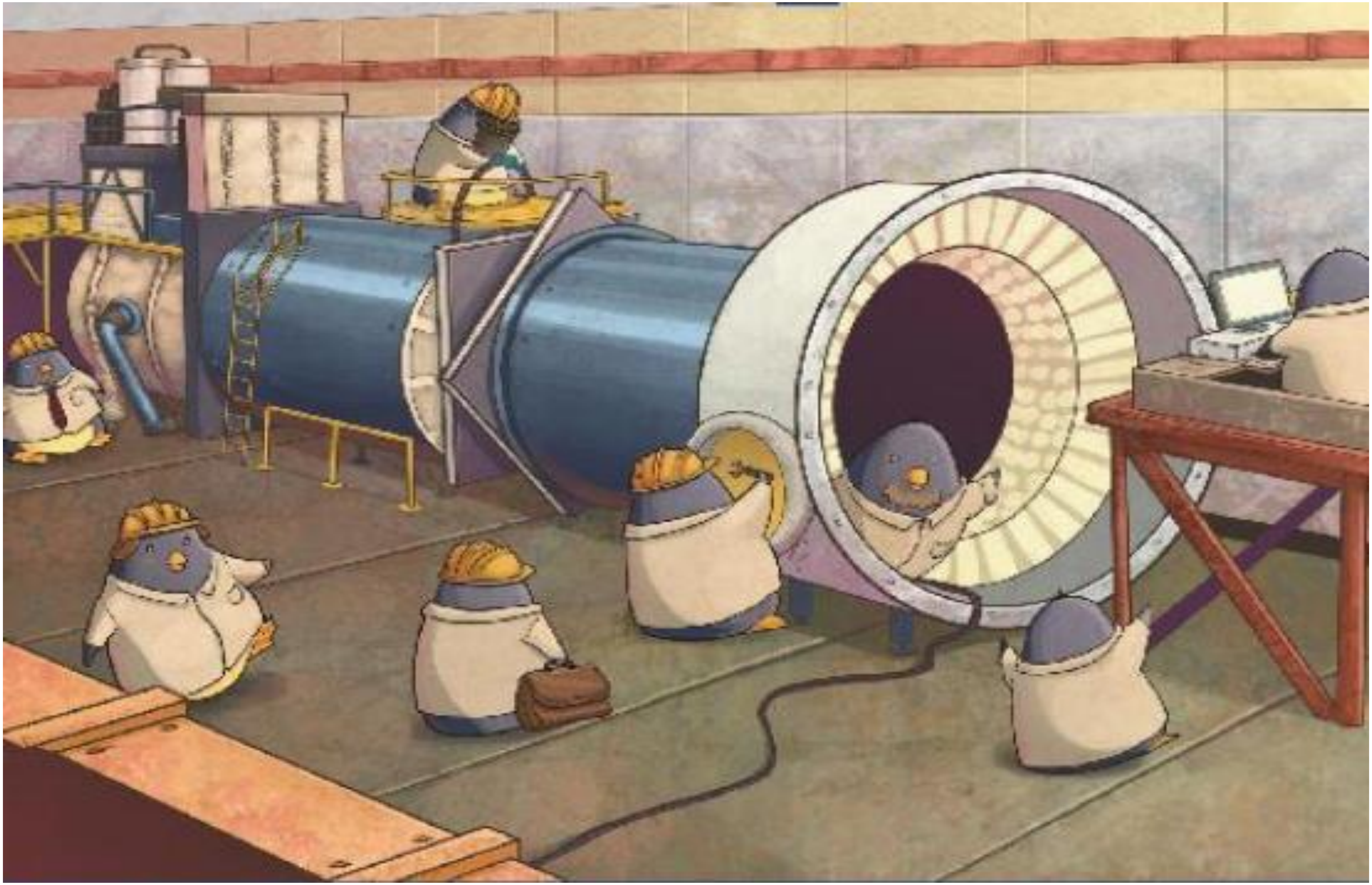


Conclusions

- **Run (2015-2018): focused on the "golden mode" $K^+ \to \pi^+ \nu\bar{\nu}$**
  - With 2016 data O(SM) sensitivity for $K^+ \to \pi^+ \nu\bar{\nu}$, in 2017/18 10% BR measurement
  - Trigger bandwidth for other physics is limited.
  - Several measurements at nominal **SES~10^{-12}**: $K^+ \to \pi^+ A'$, $\pi^0 \to inv$
  - A few measurements do not require extreme SES: " $K^+ \to l^+ \nu_H$ …
  - In general, limited sensitivities for most rare/forbidden decays (**SES~10^{-10}** to **~10^{-11}**, similar to NA48/2 and BNL-E865).
  - A proof of principle for a broad rare/forbidden decay programme.

- **Run (2021-2024): programme is under discussion.** ***[Presented at the "Physics Beyond Colliders" workshop, CERN, Sep 2016]***
  - Existing apparatus, different trigger logic: no capital investment.
  - Rare/forbidden K^+ and π^0 decays at **SES~10^{-12}**:
    - ✓ K^+physics: $K^+ \to \pi^+ l^+ l^-$, $K^+ \to \pi^+ \gamma\gamma$, $K^+ \to l^+ \nu\gamma$, ...
    - ✓ π^0 physics: $\pi^0 \to e^+ e^-$, $\pi^0 \to e^+ e^- e^+ e^-$, $\pi^0 \to 3\gamma$, $\pi^0 \to 4\gamma$…
    - ✓ Searches for LFV/LNV: $K^+ \to \pi^- l^+ l^+$, $K^+ \to \pi^+ \mu e$, $\pi^0 \to \mu e$…
  - Dump mode: hidden sector searches (long-lived HNL, DP).
  - Possibly further $K^+ \to \pi^+ \nu\bar{\nu}$ data collection.
  - Possibly K_L rare decays (**SES~10^{-11}**), including $K_L \to \pi^0 \nu\bar{\nu}$ [CPV].

Spares



A broad kaon/pion physics programme

3-charge tracks events

- LFV and Majorana neutrino search from 2l final states
- Search for dark higgs from 3l final states
- Short-lived dark photos searched from 2l final states

2-charge tracks events

- One lepton: searches for long-lived heavy neutral leptons from target production and/or decays from beam particles
- Two leptons: search for long-lived dark photons from target production and/or decays from beam particles.

1-charge track events

- Peak searches in $K^+ \to \pi^+ X, \mu^+ Y$ with X a dark pion or a $\chi\chi$ pair and Y a heavy neutral lepton
- Studies of rare π^0 decays

0-charge tracks events

- Searches for neutral resonances and axions

Physics at NA62 in run 3

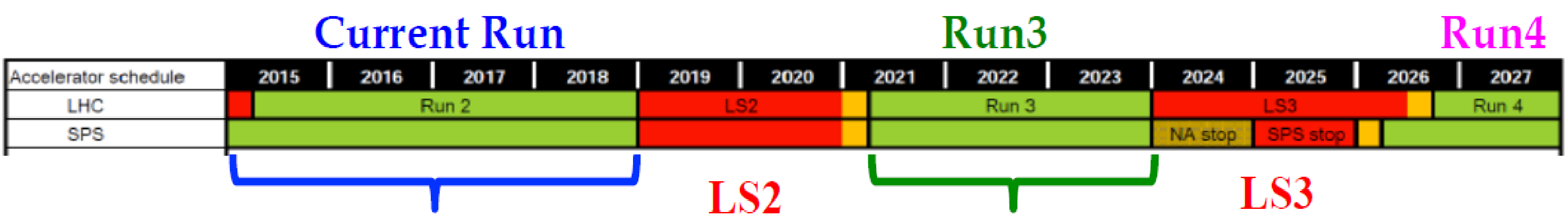
A rich field to be explored with minimal/no upgrades to the present setup

1. Present setup for K^+ beam + dedicated triggers: complete LFV/LNV high-sensitivity studies based on K^+/π^0:

$K^+ \to \pi^+\mu^\pm e^\mp$, $K^+ \to \pi^-\mu^+ e^+$, $K^+ \to \pi^- e^+ e^+$, $K^+ \to \pi^-\mu^+\mu^+$ (+ radiative modes)

$\pi^0 \to \mu e$, 3γ, 4γ, ee, $eeee$

2. Year-long run in "beam-dump" mode, new program of NP searches for MeV-GeV mass hidden-sector candidates: Dark photons, Heavy neutral leptons, Axions/ALP's, etc.



NA62: $K^+ \to \pi^+ \nu \nu$, LNV/LFV decays, hidden sector searches in K decays

LFV/LNV @ ultimate sensitivity, hidden sector searches (beam dump)

NA62 perfectly suited for hidden sector

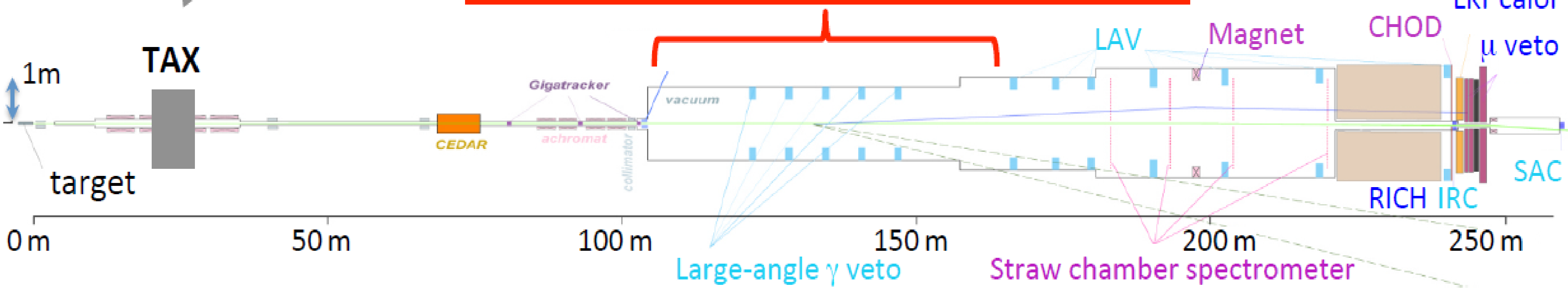
High-intensity 400-GeV proton beam → boost charm/beauty, other meson production

10^{18} POT / nominal year: 10^{12} POT/sec on spill, 3.5-s/16.8 s, 100 days/year, 60% run efficiency

10^{15} $D_{(s)}$, 10^{14} K, 10^{18} $\pi^0/\eta/\eta'/\Phi/\rho/\omega$ with ratios 6.4/0.68/0.07/0.03/0.94/0.95 (& B mesons, too)

Compact beam dump: ~11 λ_I Cu-based beam-defining collimator (TAX)
radioprotection-compliant even if target removed

Decay volume ~ 60 m long (in vacuum):
reasonable acceptance to long-lived states



High-resolution tracking, PID, vetoing: high sensitivity to closed signatures

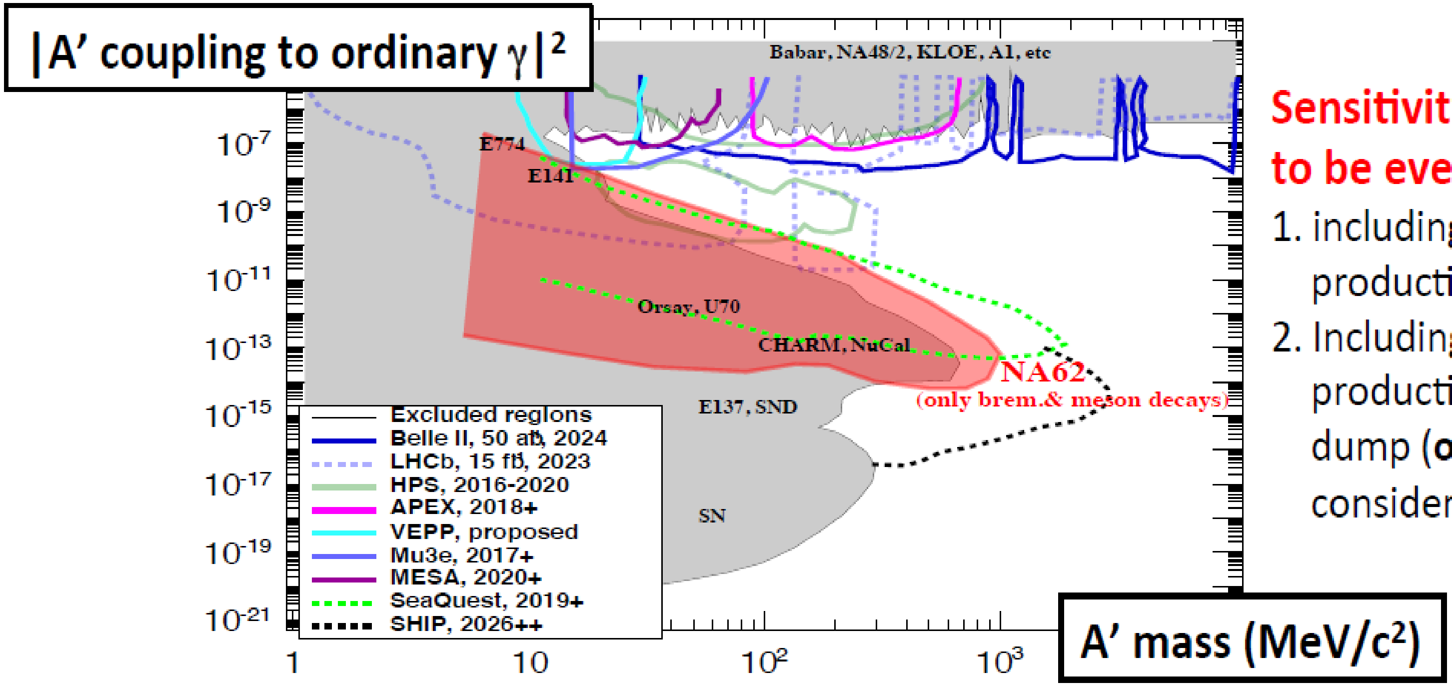
Search for visible decays of long lived A’

Assume 2x10^{18} 400-GeV POT:

search for displaced, dilepton decays of dark photons, A’ → ee, μμ

include trigger/acceptance/selection efficiency

assume zero-background, evaluate expected 90%-CL exclusion plot



Sensitivity expected to be even higher:

1. including direct QCD production of A’
2. Including A’ production in the dump (**only target** considered here)

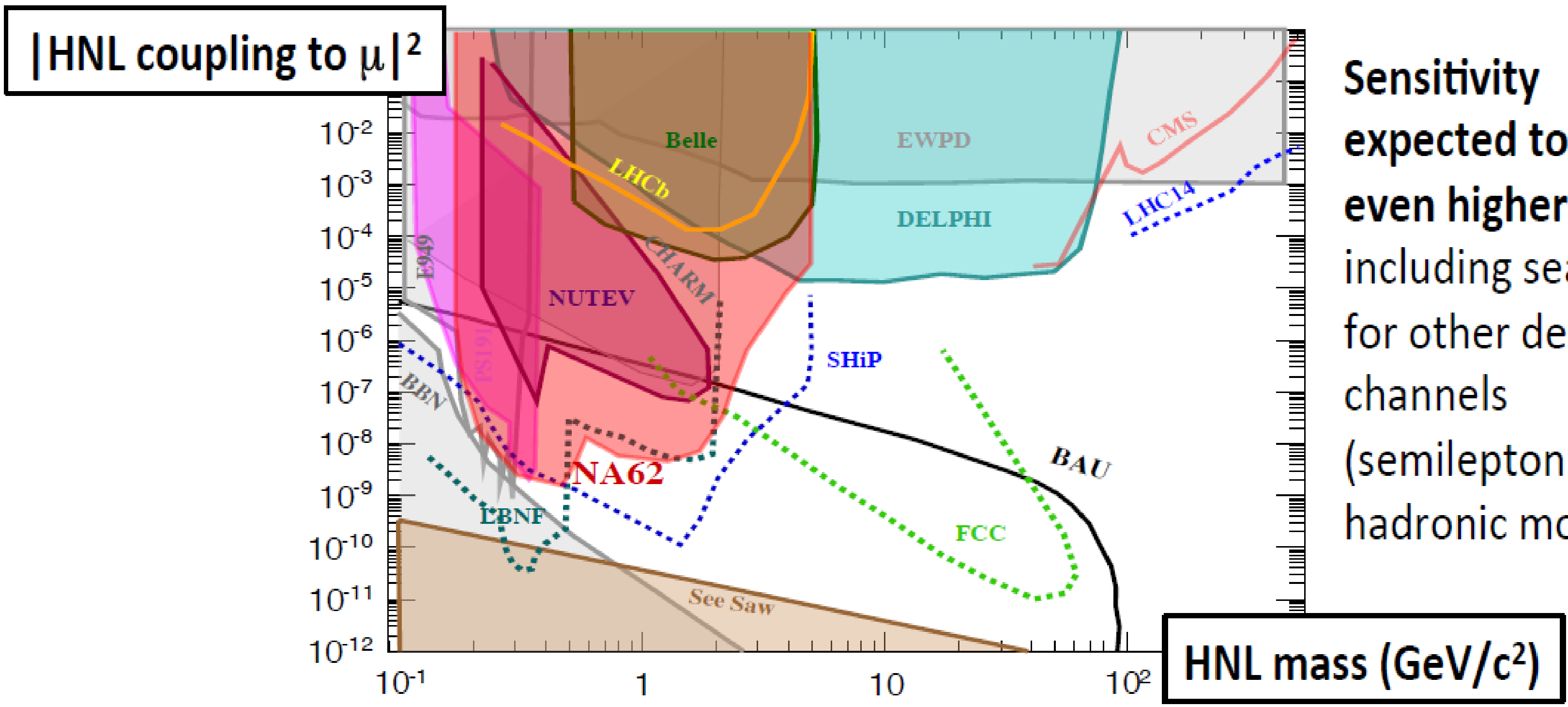
Search for visible decays of HNL

Assume 2 10^{18} 400-GeV POT:

search for displaced, leptonic decays HNL → πe, πμ

include trigger/acceptance/selection efficiency

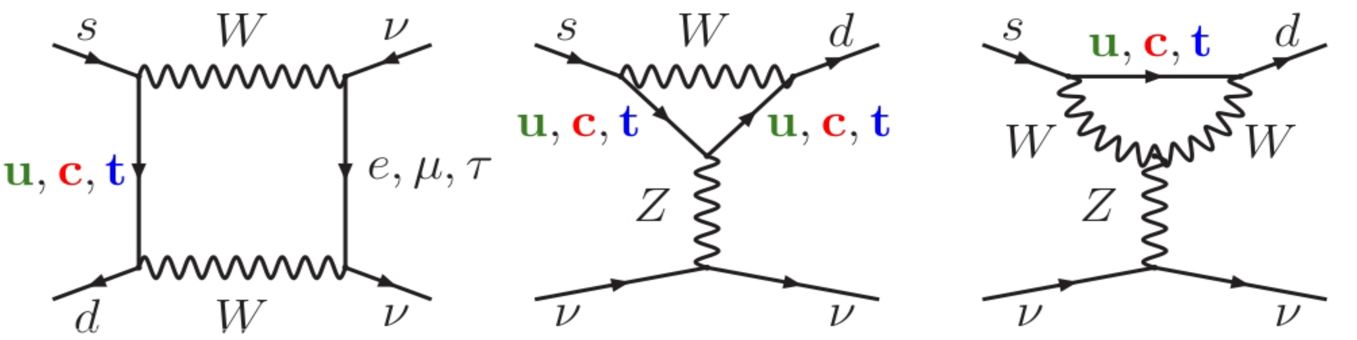
assume zero-background, evaluate expected 90%-CL exclusion plot



Sensitivity expected to be even higher after including search for other decay channels (semileptonic, hadronic modes)

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

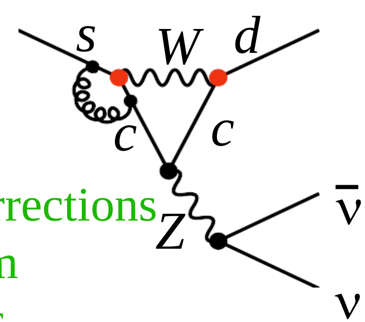
$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \left[\left(\frac{\text{Im } \lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\text{Re } \lambda_t}{\lambda^5} X(x_t) + \frac{\text{Re } \lambda_c}{\lambda} P_c(X) \right)^2 \right] (1 + \Delta_{EM}) = 9.11 \pm 0.72$$

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

← CP̸

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

QCD corrections for charm diagrams

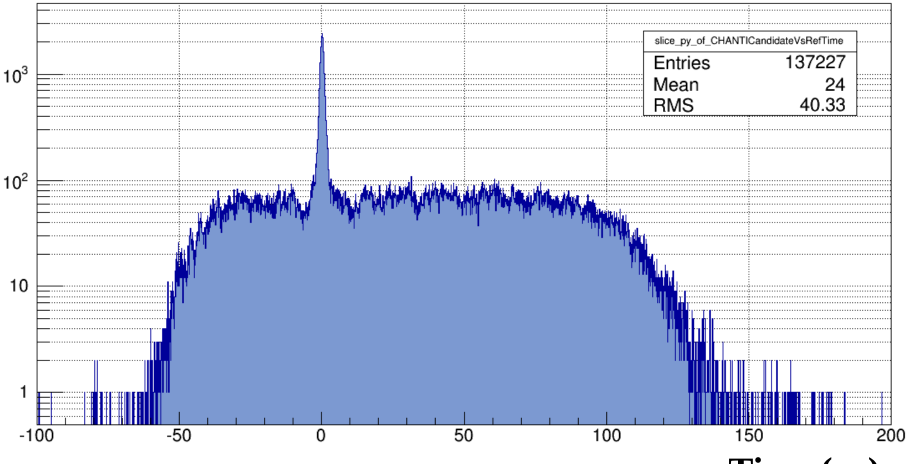


SM prediction (10^{-11} units)

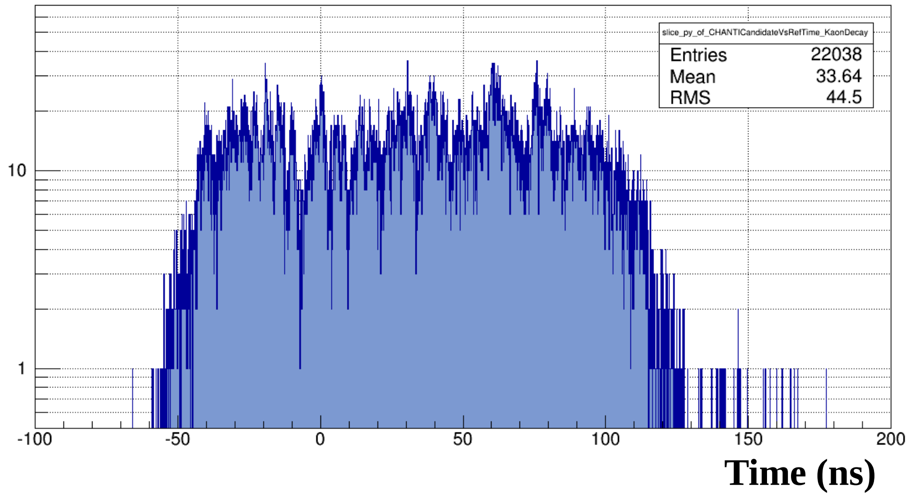
A.J. Buras et al, 2015, arXiv: 1503.02693

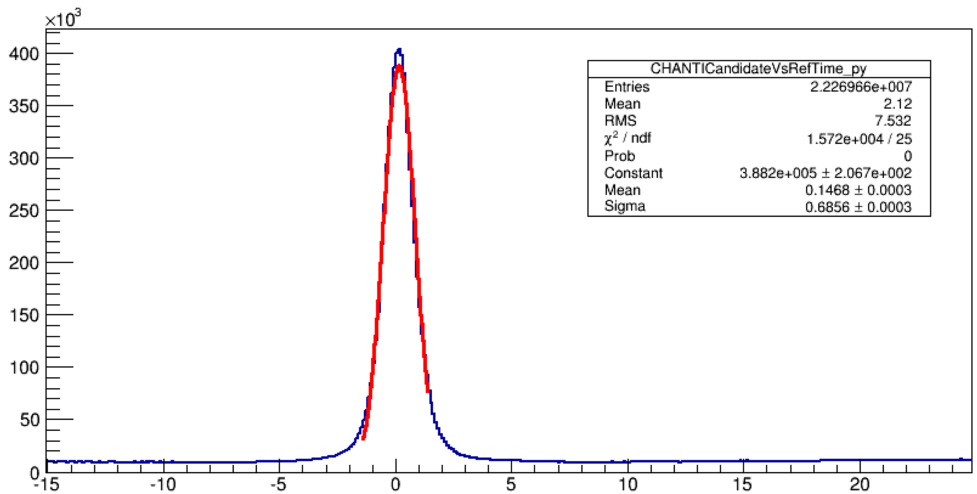
CHANTI time distribution

CHANTI candidate time (with respect to the CHOD) with control trigger and one STRAW track for one burst:



CHANTI candidate time (with respect to the CHOD) with a kaon decay for one burst:





CHANTI candidate time (with respect to the CHOD) with control trigger and one STRAW track for all the bursts