



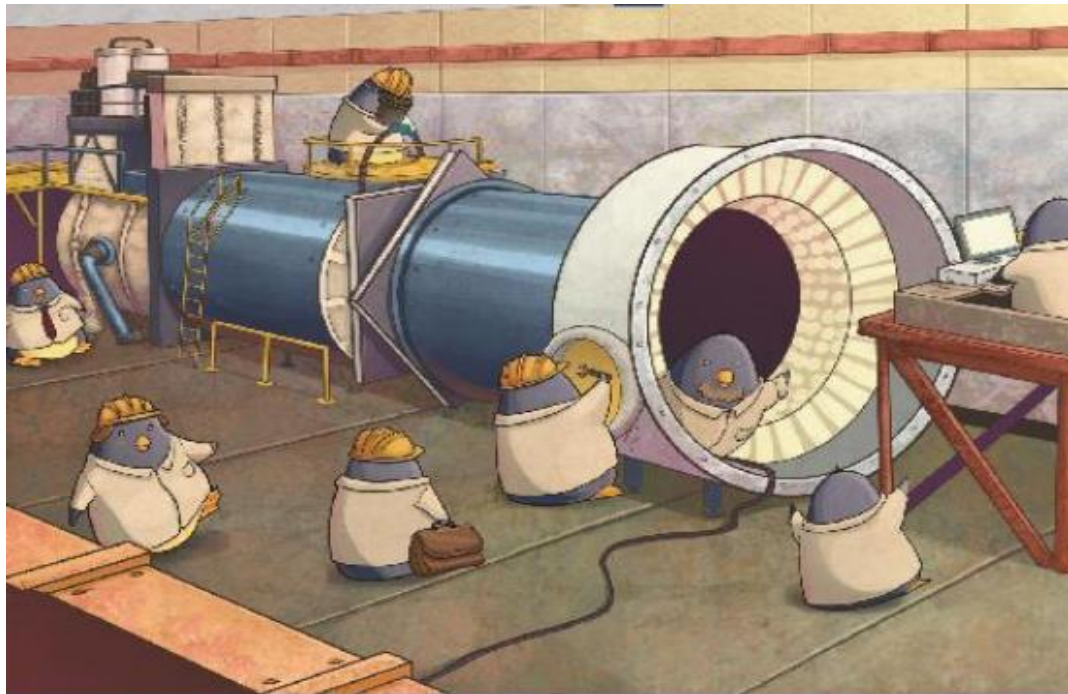
Stato e prospettive dell'esperimento NA62

Riunione Gruppo 1, Napoli 08/01/2016

F. Ambrosino, T. Capussela, M. Corvino, D. Di Filippo, P. Massarotti, M. Mirra,
M. Napolitano, G. Saracino

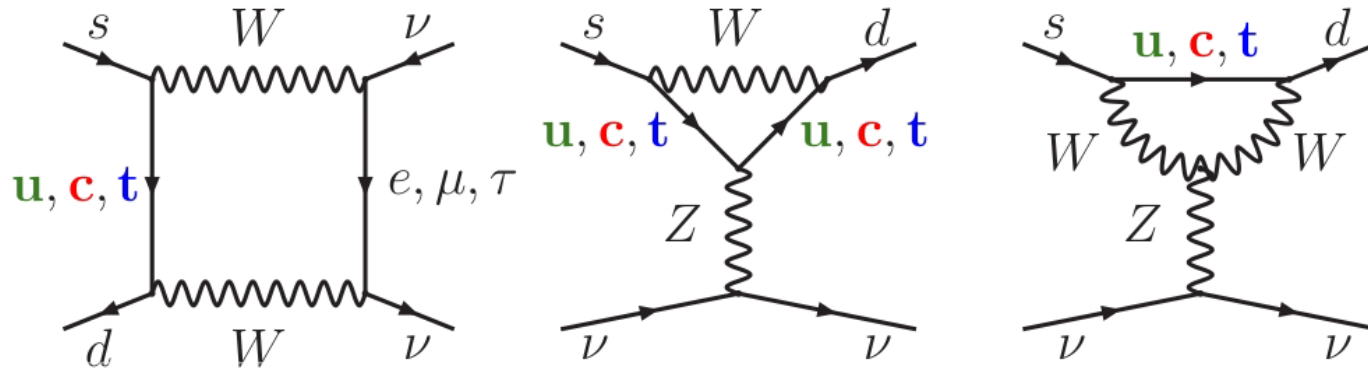
Outline

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay
- NA62: apparato sperimentale
- Attività napoletana in NA62 nel 2015
- Risultati preliminari del run 2015
- Prospettive per il 2016



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

- FCNC loop processes: $s \rightarrow d$ 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 ($K^+ \rightarrow \pi^0 e^+ \nu_e$)

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

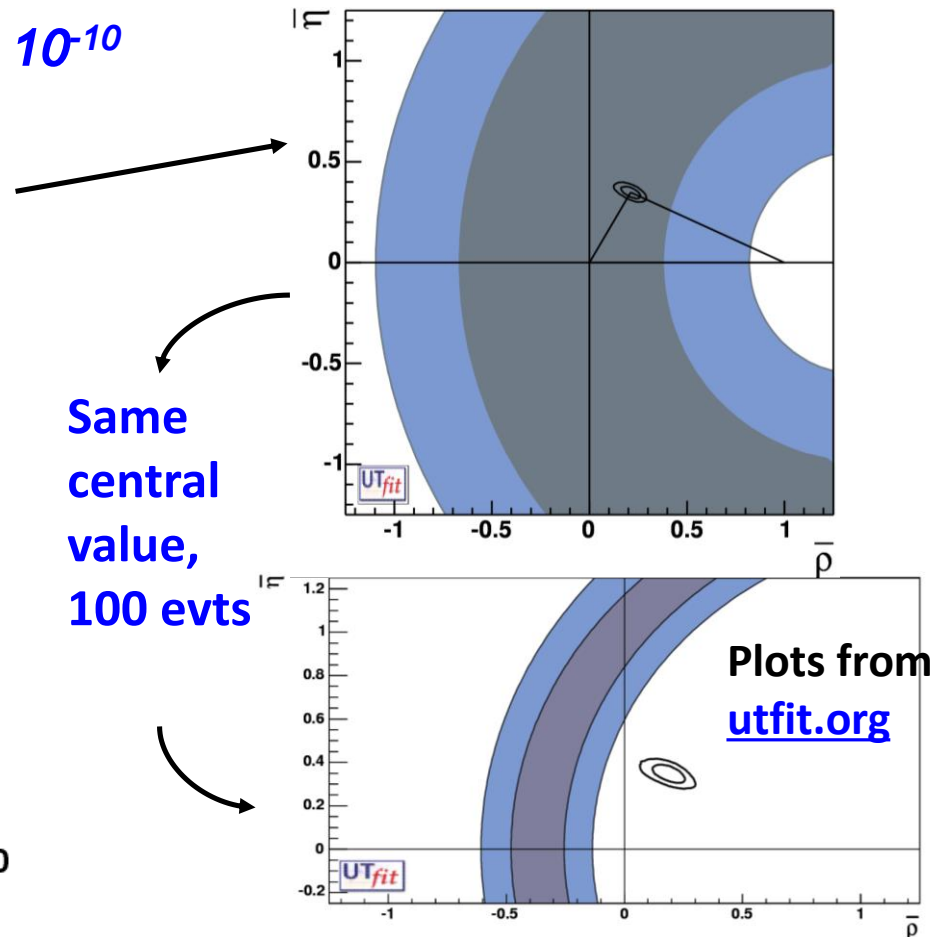
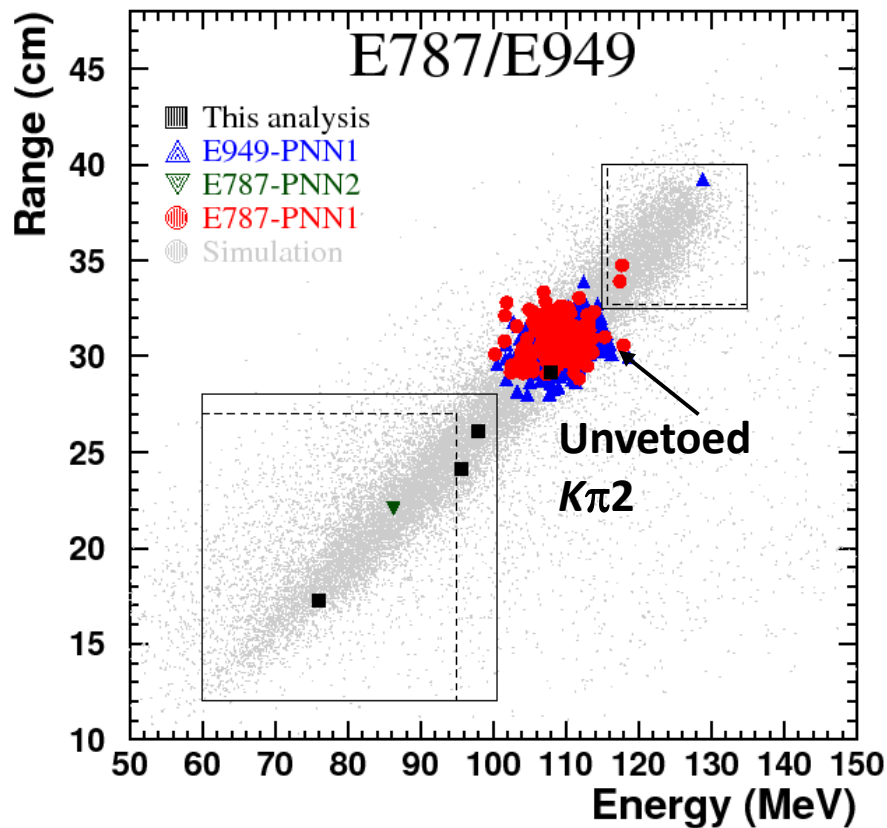
- SM prediction [A.J. Buras et al, 2015 , arXiv:1503.02693]

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

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

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

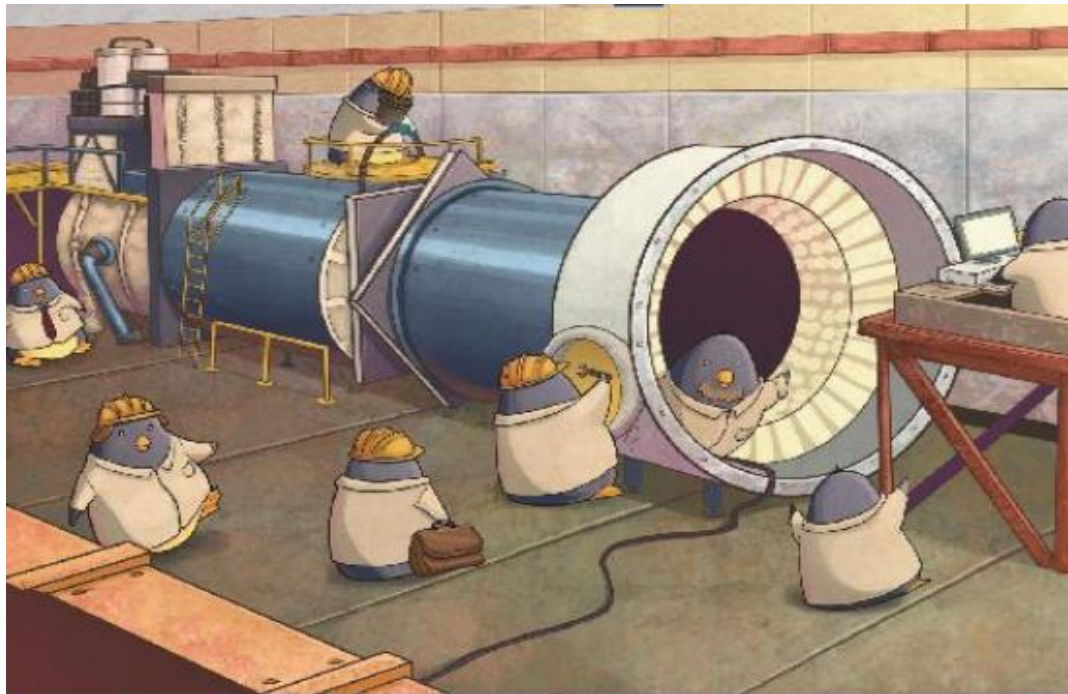
$$BR(K^+ \rightarrow \pi^+ \bar{\nu} \nu) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$



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

Outline

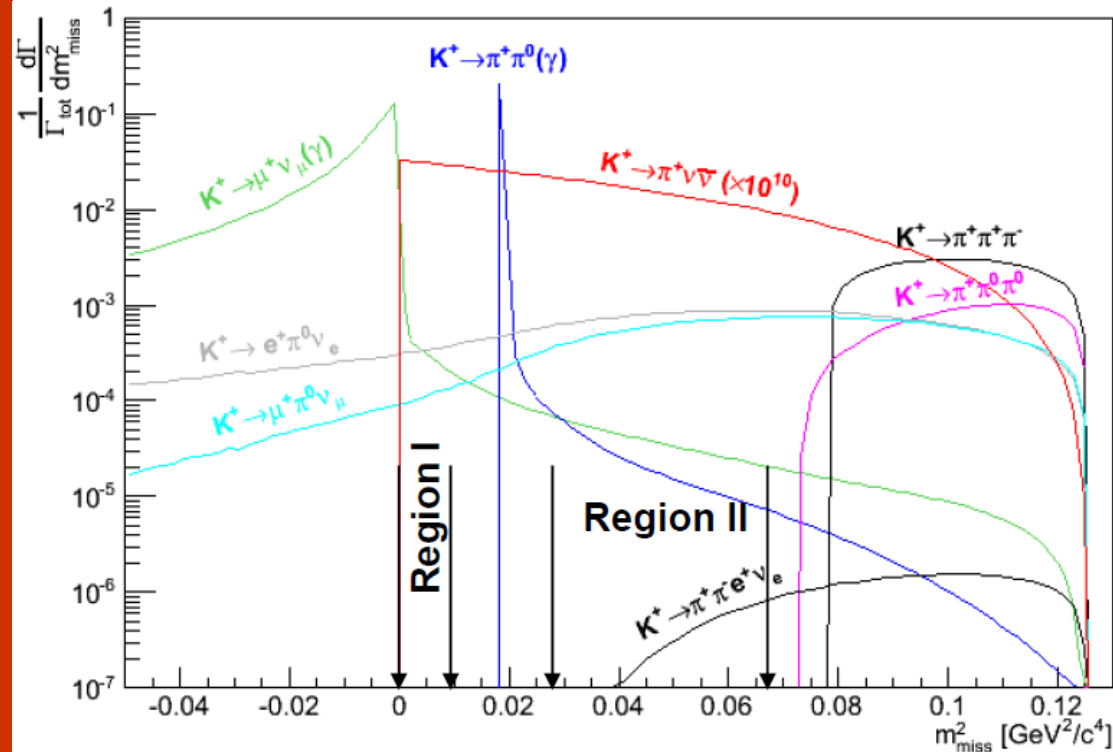
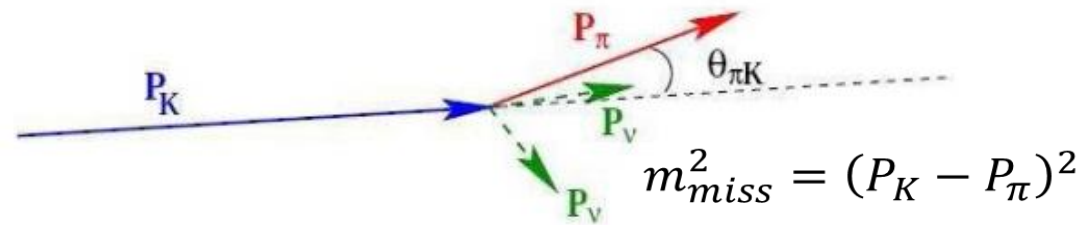
- $K^+ \rightarrow \pi^+ \nu \nu$ decay
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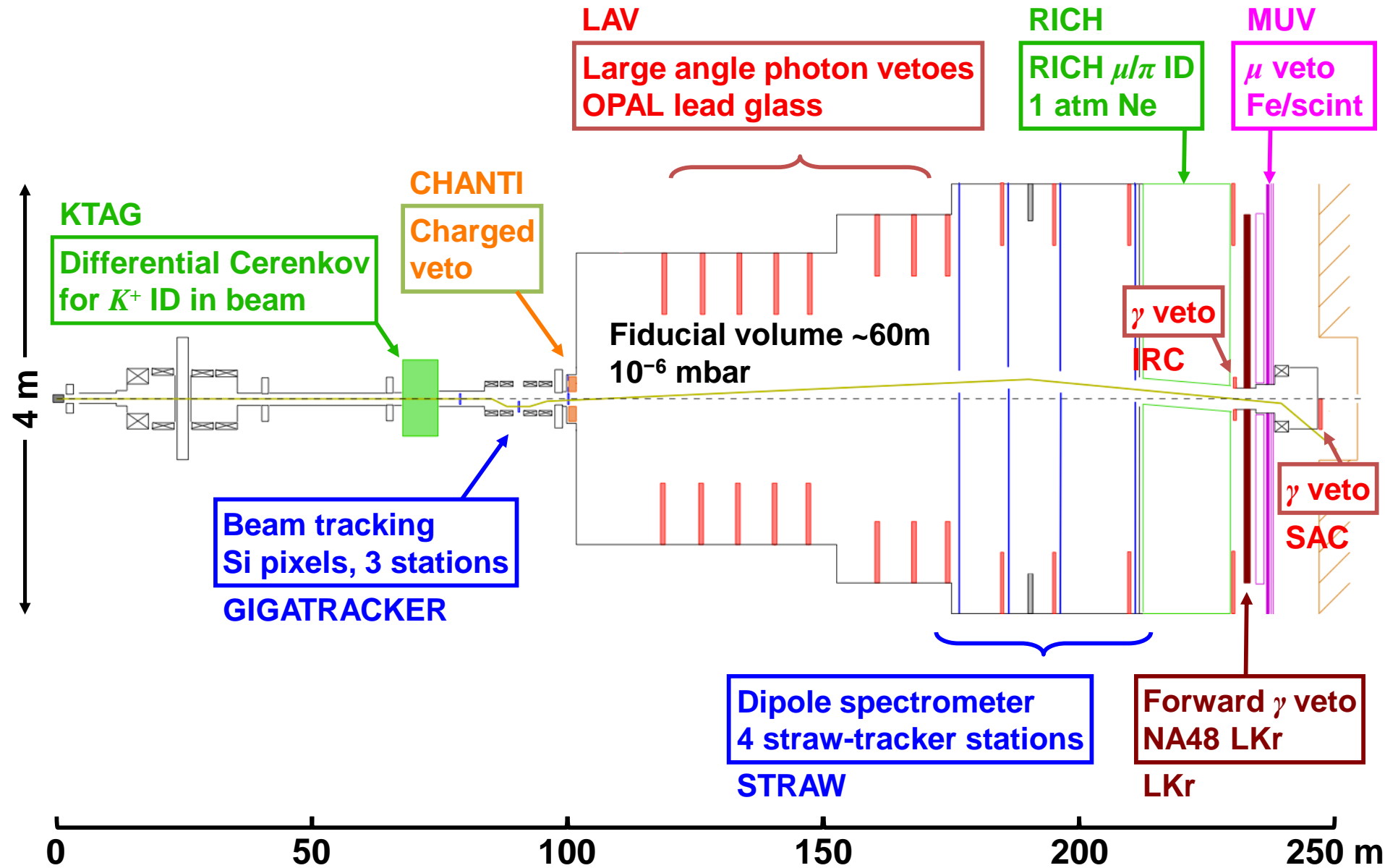
NA62 experimental strategy

Main goal: Detect ~ 100 SM $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decays with O(10%) precision BR measurement

- High K momentum (in flight technique)
- Kinematical rejection w lightweight spectrometers (GTK, STRAW)
- Low π momentum to allow enough «missing» energy to be detected by hermetic veto detectors (LAV,IRC,SAC,LKr)
- Particle identification (RICH, MUV)
- Beam particle identification and inelastic event suppression (KTAG, CHANTI)

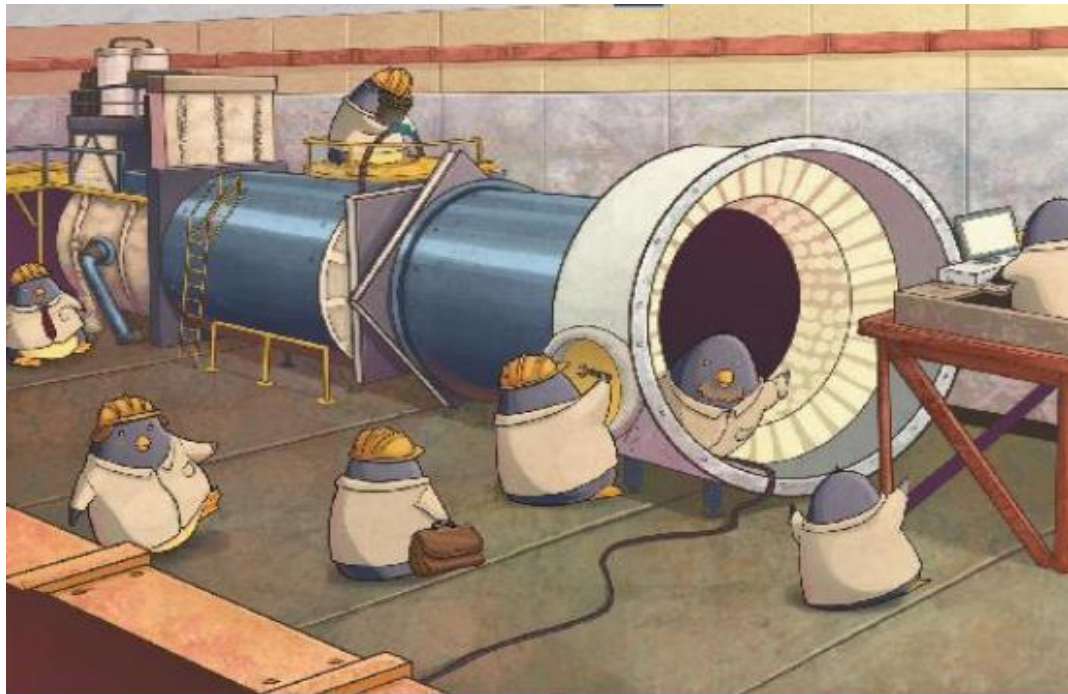


NA62 setup



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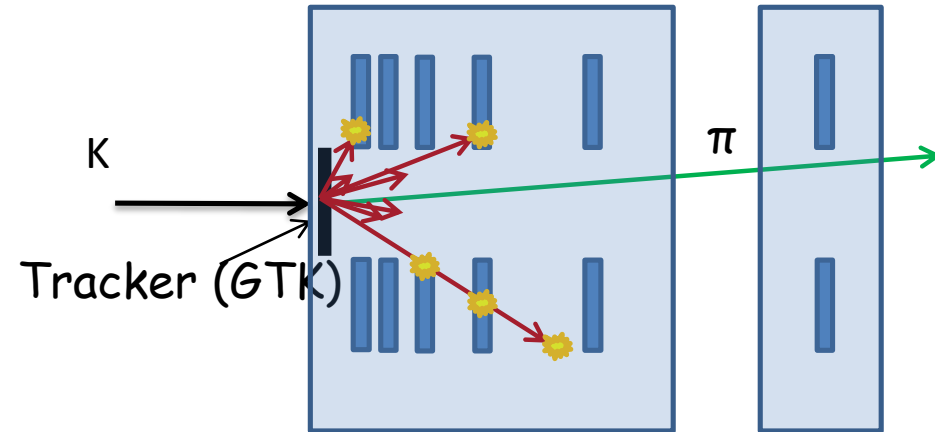


CHANTI postcard

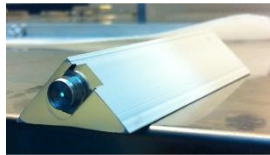
Rivelatore 100% napoletano fin dalla proposta e dal progetto.

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



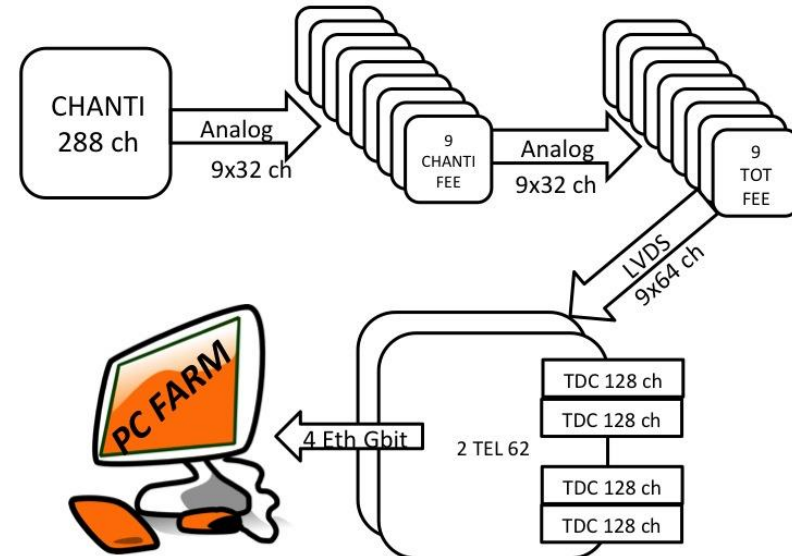
Barra di scintillatore



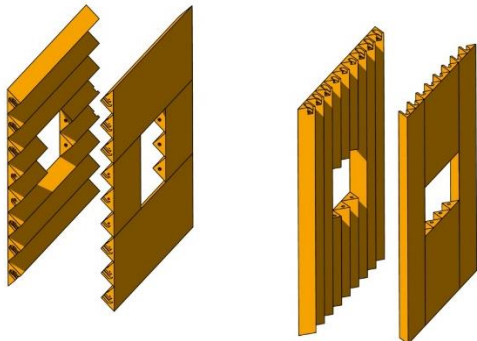
Stazione cablata



Elettronica di FE



Layout dei layer X/Y

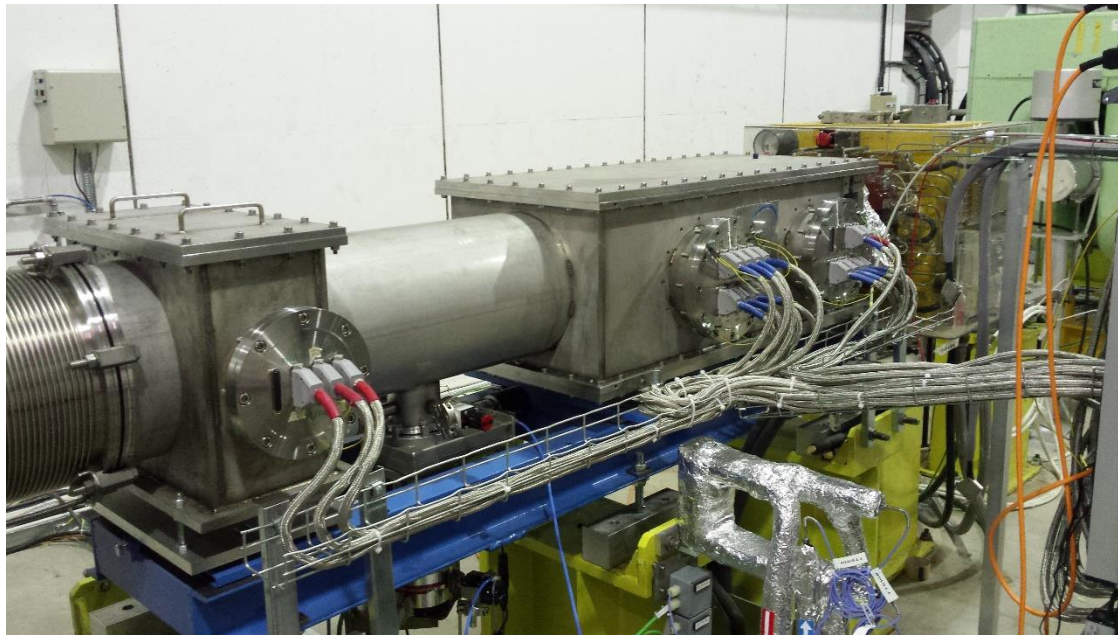


CHANTI in NA62

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)

F.Ambrosino et al. , *CHANTI: a Fast and Efficient Charged Particle Veto Detector for the NA62 Experiment at CERN*, arXiv:1512.00244 e
sottomesso su JINST Journal

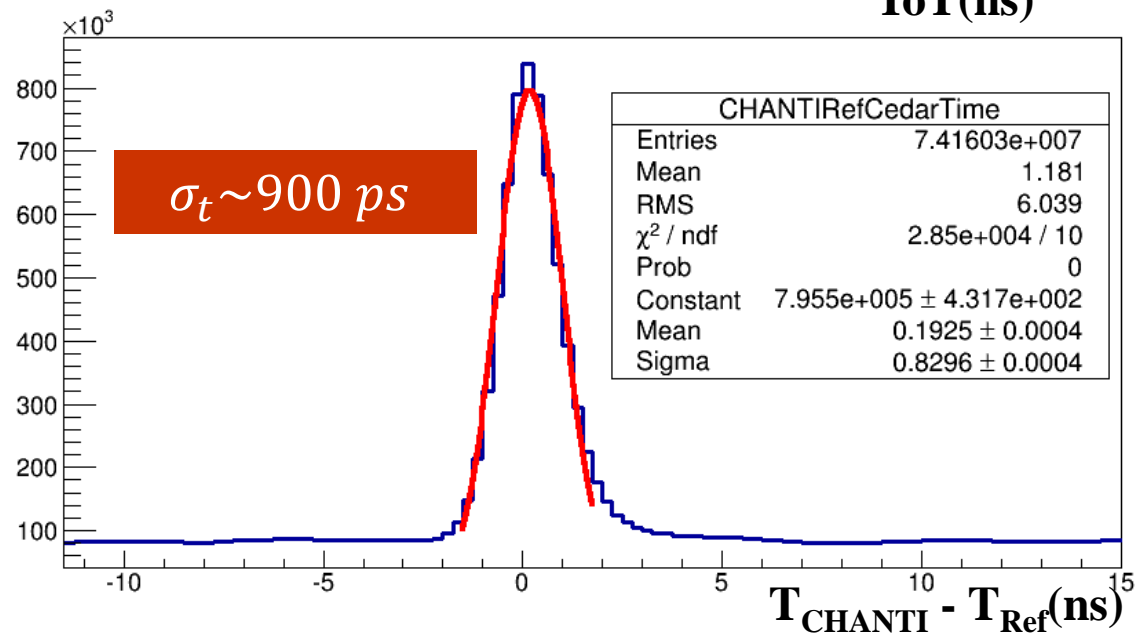
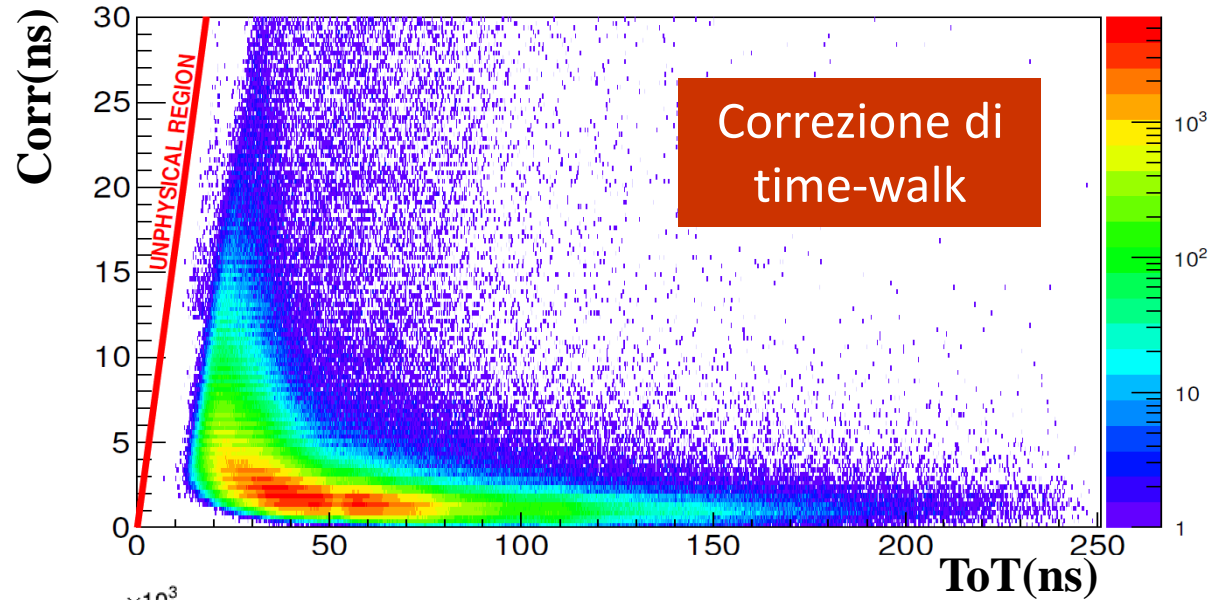


CHANTI: risoluzione temporale

Risoluzione temporale: tempo di un candidato CHANTI rispetto a un tempo di riferimento.

Il candidato CHANTI è un cluster di barre appartenenti alla stessa stazione.

I tempi provenienti dalle hit di ciascuna barra sono corretti per il time-walk (estr. lineare o correzione media)



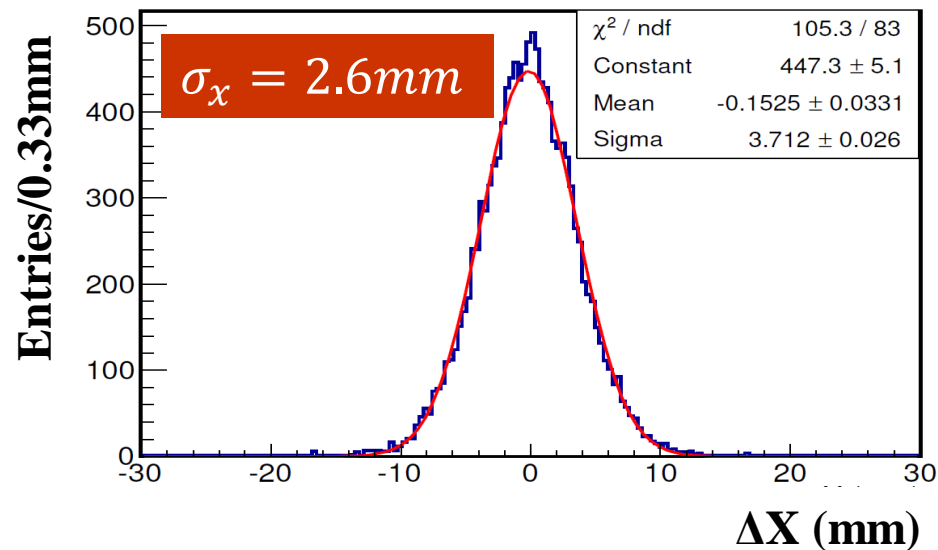
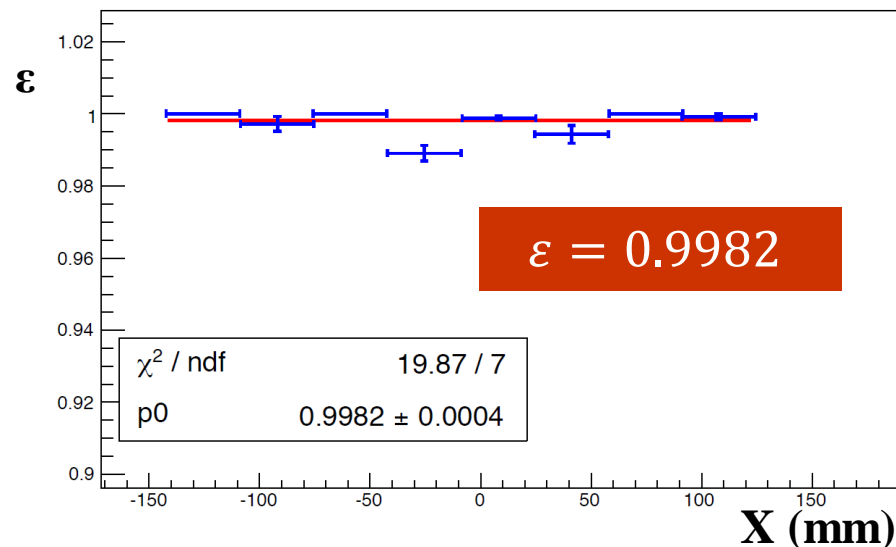
CHANTI: efficienza e risoluzione spaziale

Run di muoni paralleli alla linea di fascio utilizzato per valutare 'ε' e 'σ_x'

Efficienza valutata separatamente per i layer X e Y.

Evento di muone attraverso il CHANTI: almeno una hit in due barre adiacenti e nelle corrispondenti barre di altre 4 stazioni; viene valutata l'efficienza della sesta stazione

Coordinata X/Y determinata dalla media pesata con i ToT, della barre accesse durante il passaggio di un muone. Differenza della coordinata X/Y tra le stazioni 3 e 4 per valutare la risoluzione spaziale



CHANTI: veto accidentale

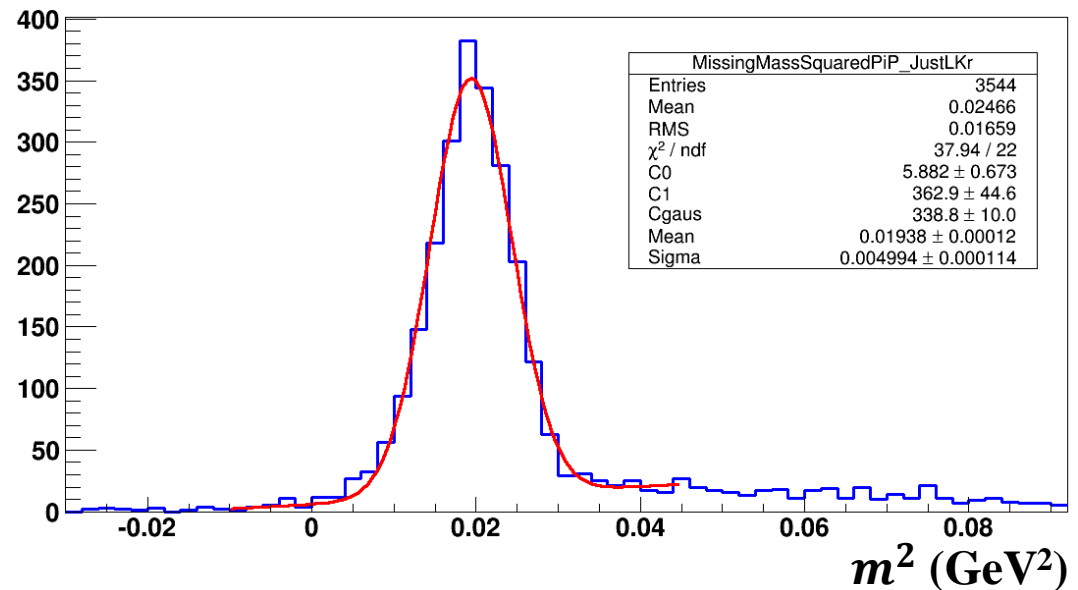
Selezione di un campione $K^+ \rightarrow \pi^+ \pi^0$ usando CHOD, LKr e KTAG

- Un candidato nel CHOD che fornisce il tempo di riferimento. I candidati degli altri detector in tempo con quello del CHOD
- KTAG identifica positivamente il K^+
- Ricerca di 2 sciami em nel LKr. Nell'ipotesi che i due sciami em provengano dai γ del π^0 e usando il momento nominale del K^+ è possibile ricostruire il vertice di decadimento e tagliare sulla variabile

$$m^2 = (P_{K^+} - P_{\pi^0})^2$$

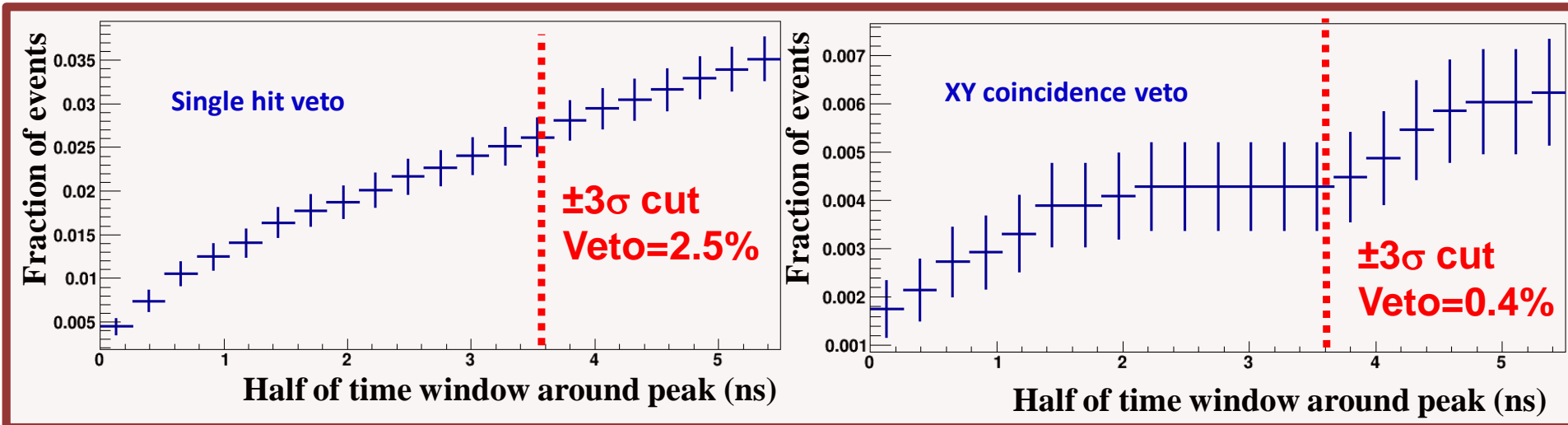
**Fit gaussiano (segnale) più
funzione lineare (fondo) in
diverse condizioni del beam**

**Campione $K^+ \rightarrow \pi^+ \pi^0$
selezionato mantenendo
costante il rapporto
segnale/rumore**

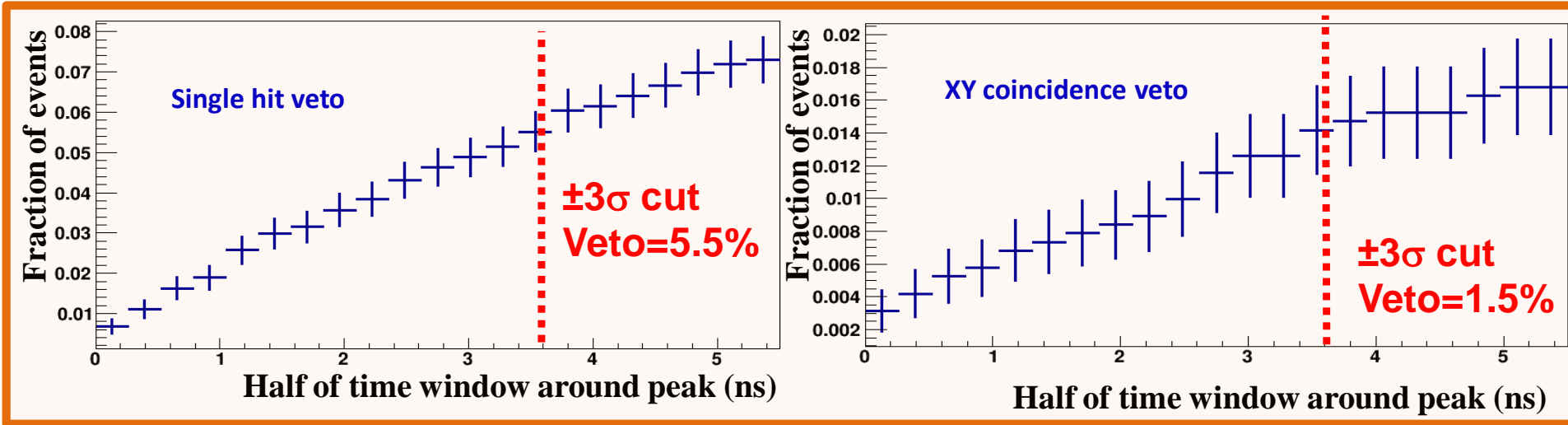


CHANTI: veto accidentale

Run 2015: fascio al 10% dell'intensità nominale



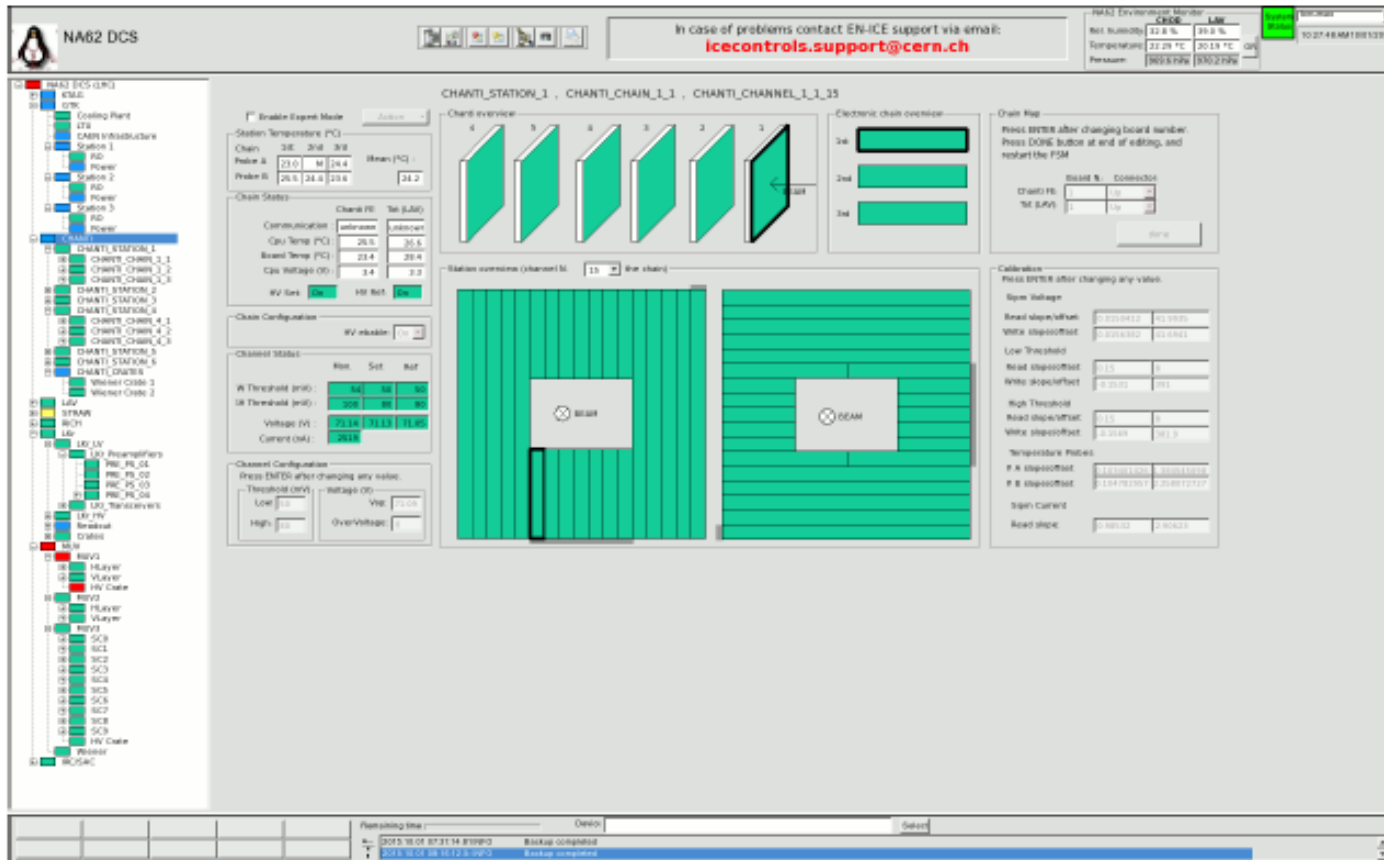
Run 2015: fascio al 40% dell'intensità nominale



CHANTI DCS

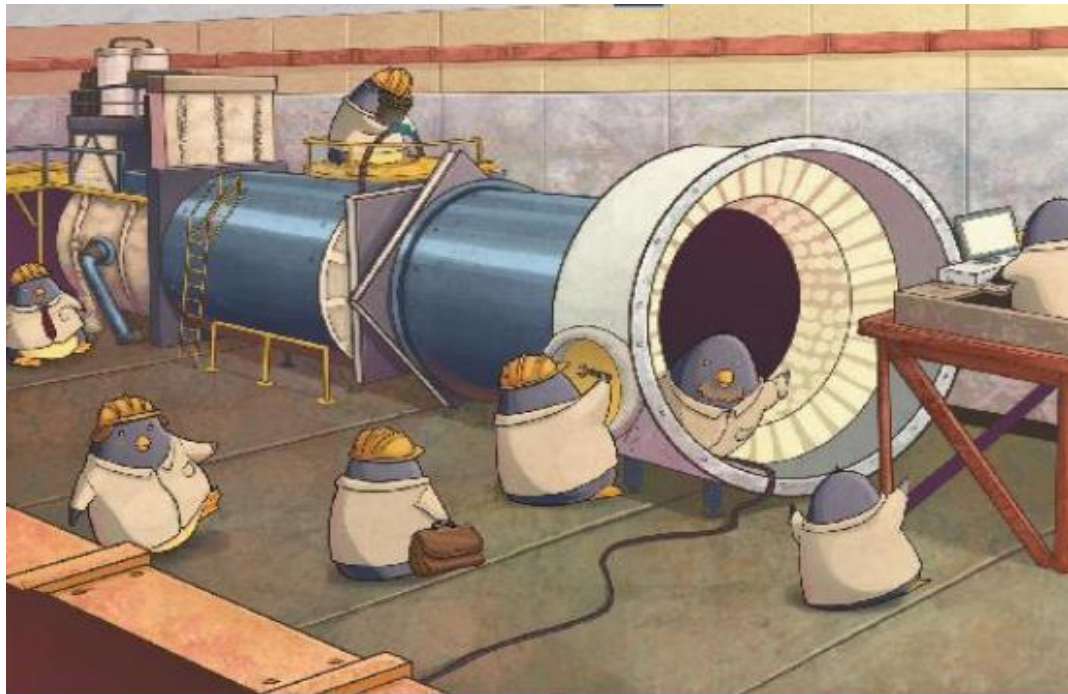
Sistema di controllo del CHANTI integrato nel DCS generale di NA62

- Controllo/lettura delle soglie applicate al segnale dei SiPM
- Controllo/lettura della tensione di bias dei SiPM
- Lettura corrente dei SiPM
- Lettura delle temperature delle PT100
- ...



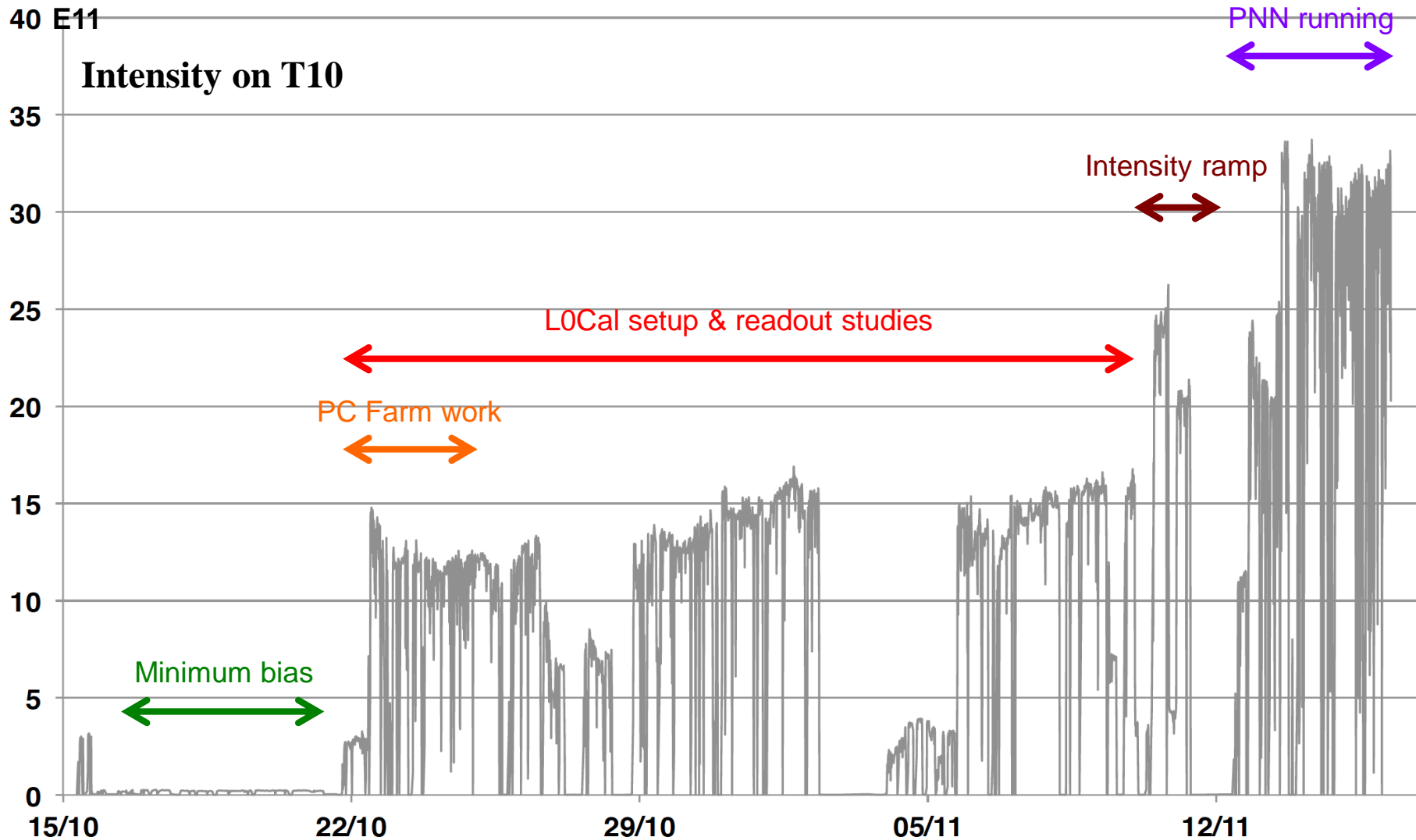
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NA62: il run del 2015

Una buona quantità di dati raccolta per valutare le performance dei rivelatori, studiare sistematici e cominciare una vera analisi

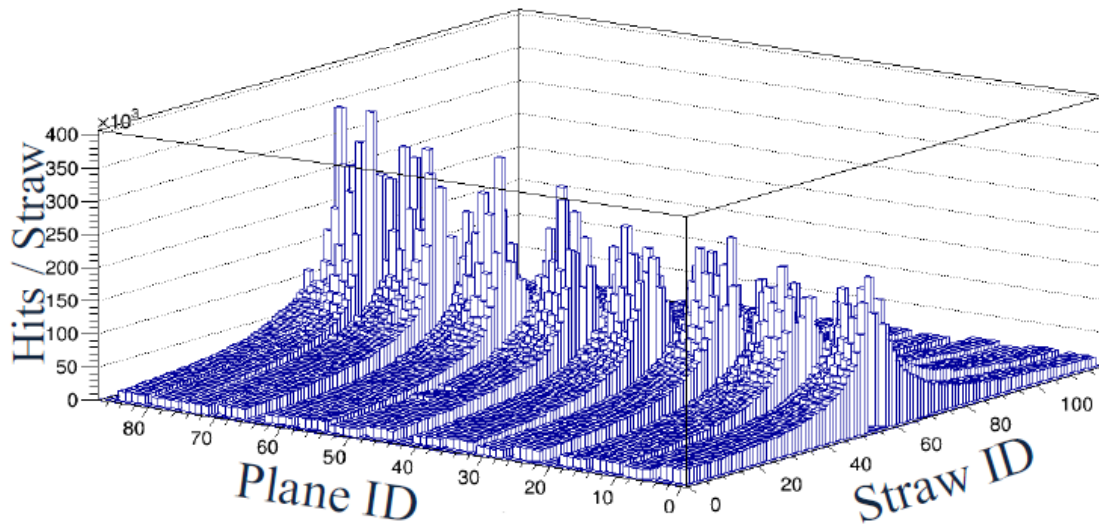
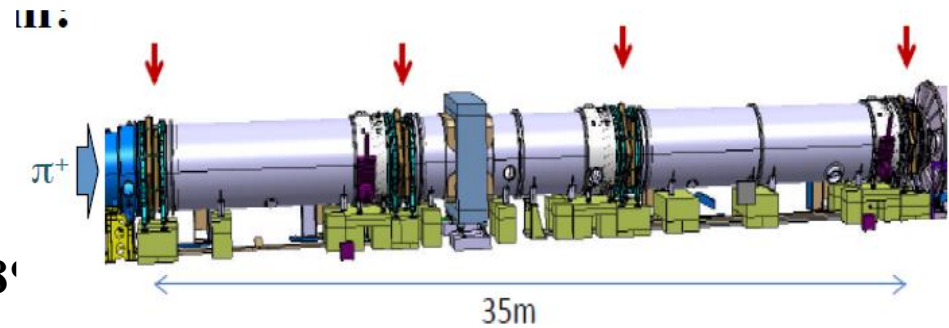


NA62: pion tracking

Straw-tracker

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

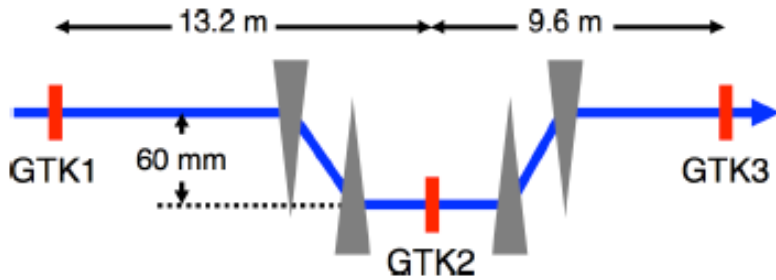
$\sigma \leq 130 \mu\text{m}$ (1 view) $\sigma_p/p = 0.32\% \oplus 0.008\%$
0.45 X_0 per chamber $\sigma_{\theta(K\pi)} = 20\text{-}50 \mu\text{rad}$



NA62: beam tracker

Gigatracker

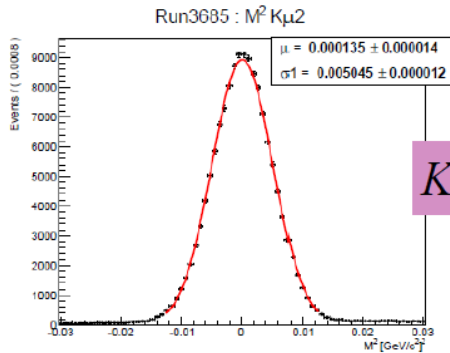
Tracks particles in the unseparated beam with 3 planes of Si pixel detectors



On site bump bonded readout chip 0.13 μm CMOS tech
(200+100 μm \sim 0.5% X_0)
Pixel size 300x300 μm^2 , $\sigma_\theta \sim 30$ μrad

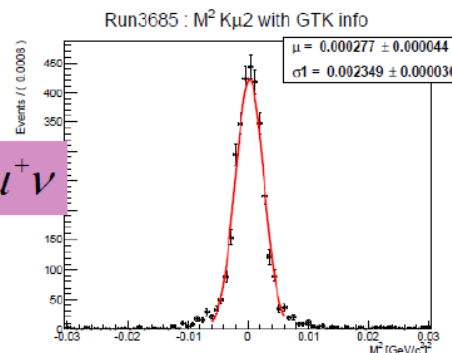


Without Gigatracker

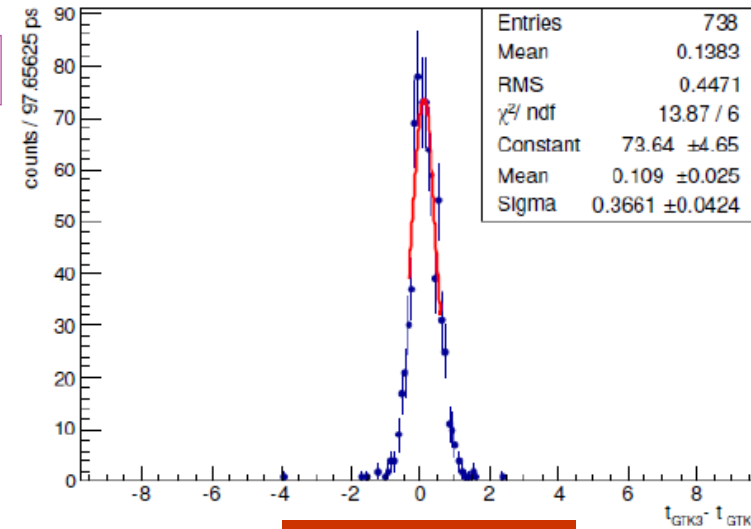


$$\sigma = 0.0050 \text{ (GeV}/c^2)^2$$

With Gigatracker



$$\sigma = 0.0023 \text{ (GeV}/c^2)^2$$



$$\sigma_t \sim 260 \text{ ps}$$

NA62 beam identification

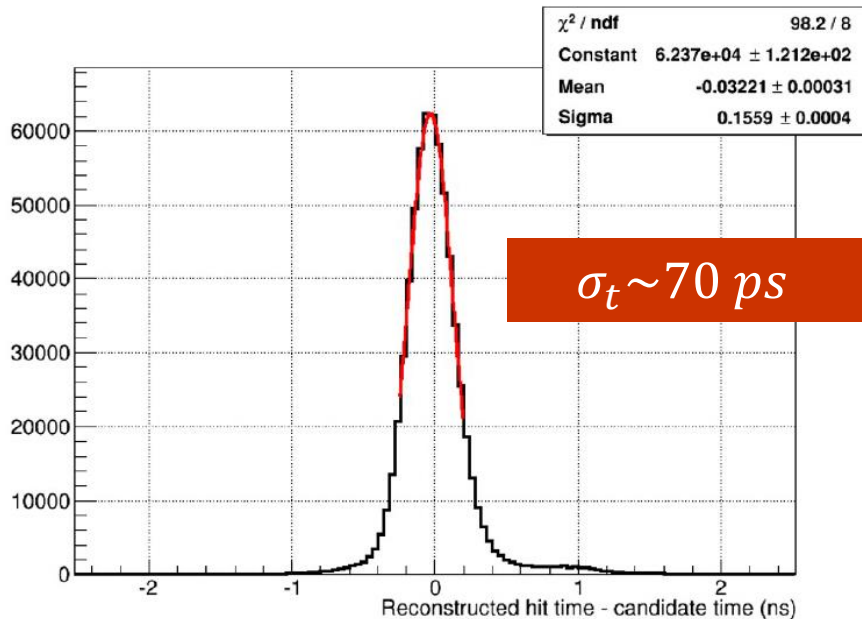
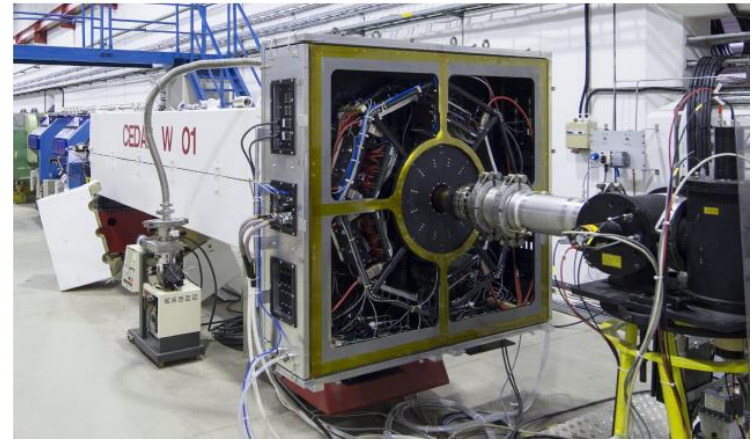
KTAG

Identifica 45 MHz di K^+ in un fascio adronico di 750 MHz.

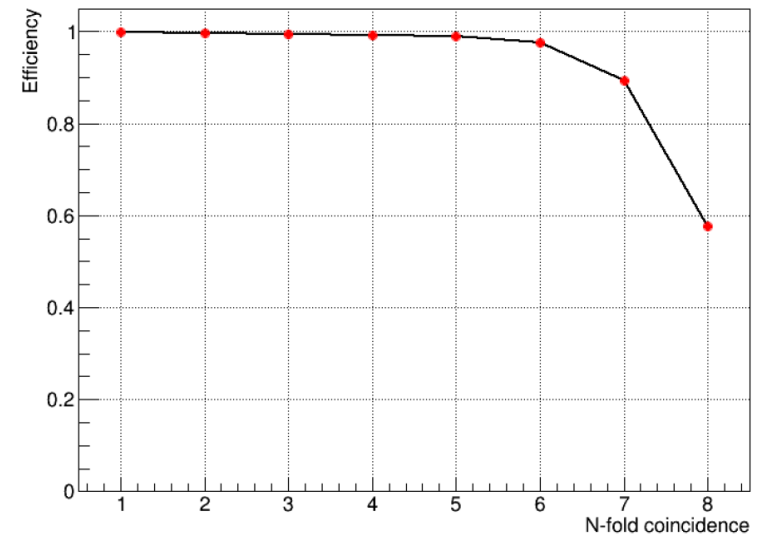
Opera con N_2 a 1.1 bar o H_2 a 3 bar

Efficienza del detector valutata

considerando un campione di $K^+ \rightarrow \pi^+ \pi^0$;
un pione è identificato erroneamente come un K con una probabilità dell'ordine di 10^{-4}



Efficiency VS N-fold coincidence



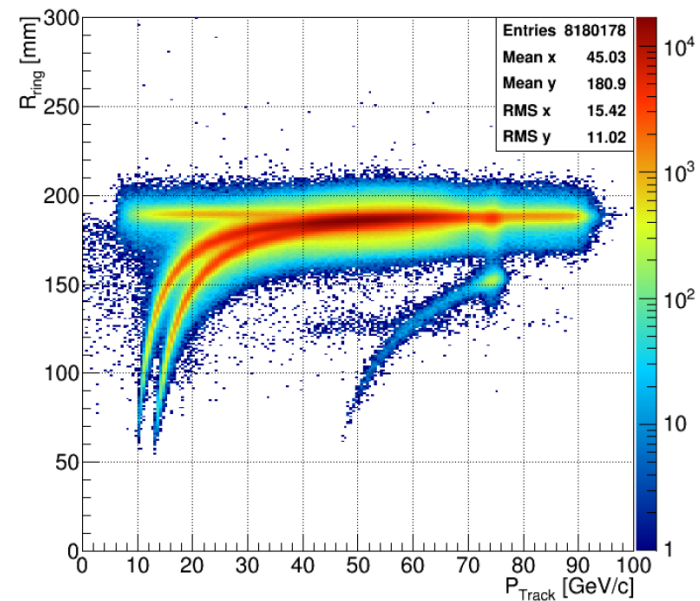
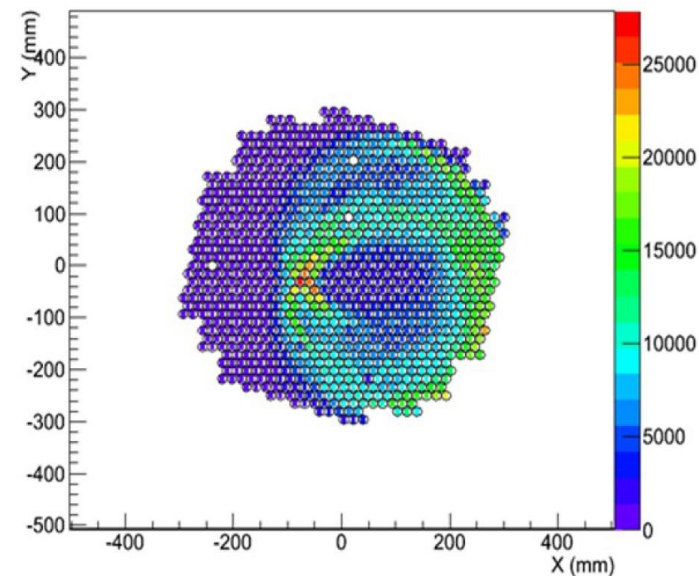
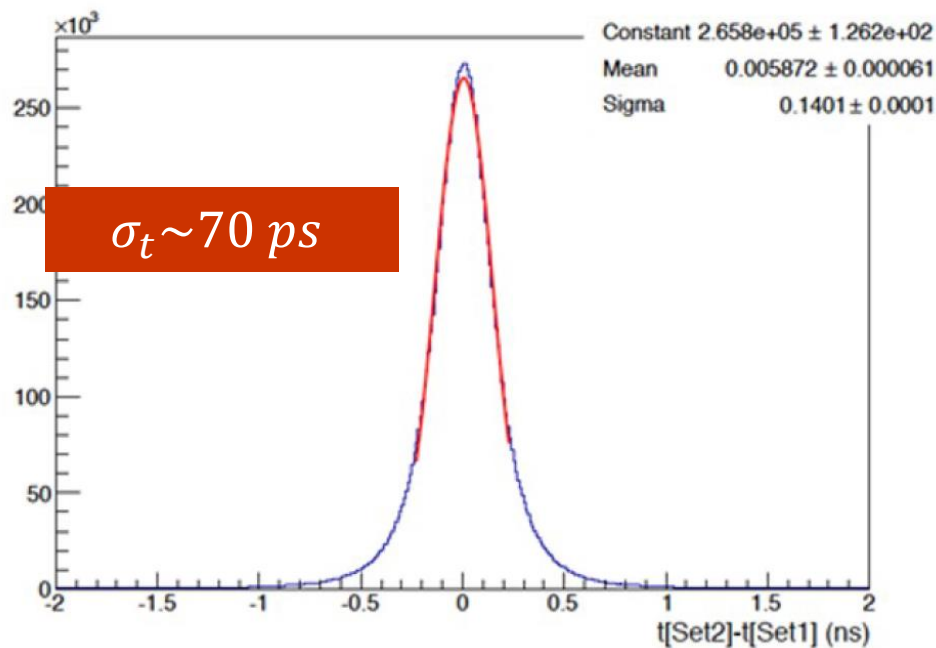
RICH

μ/π separation better than 1% for $15 < p < 35 \text{ GeV}$

Risoluzione temporale dell'ordine di 70ps

Durante il 2015 ha fornito un L0 trigger per particelle cariche

Ne gas a 1 atm



NA62 photon veto detectors

Large angles vetoes (LAV) $8.5 < \theta < 50$ mrad

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

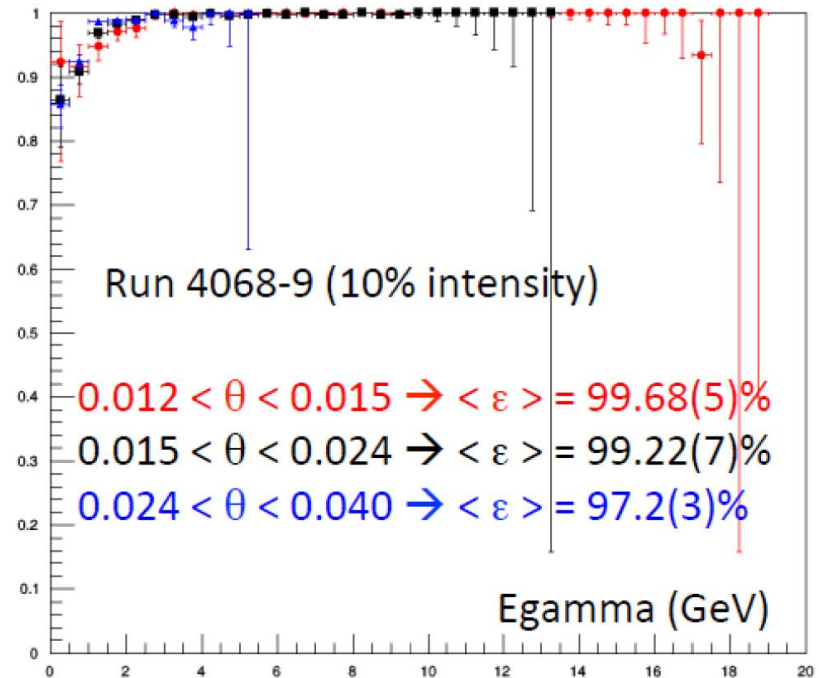
Ogni stazione ha 4-5 anelli di blocchi al vetro-piombo

Napoli ha partecipato alla costruzione a LNF e l'installazione 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



Large angles vetoes (LAV)

Discharges observed on air-side of all HV vacuum flanges. Symptoms of discharges:

- Tripped channels (single channels or clusters)
- Unstable HV boards: inability to control many channels
 - Generally, access required to reseal board
 - Possible to try rebooting HV crate remotely, but not always effective and generally difficult to restart OPC server

New flanges and connectors being installed – tight schedule of work but problem should be solved for 2016 run

NA62 photon veto detectors

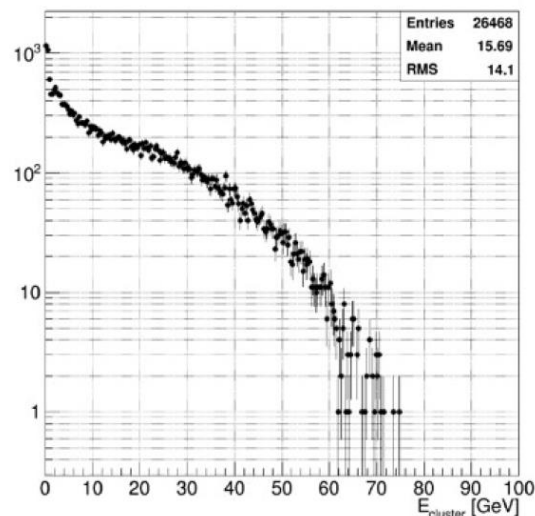
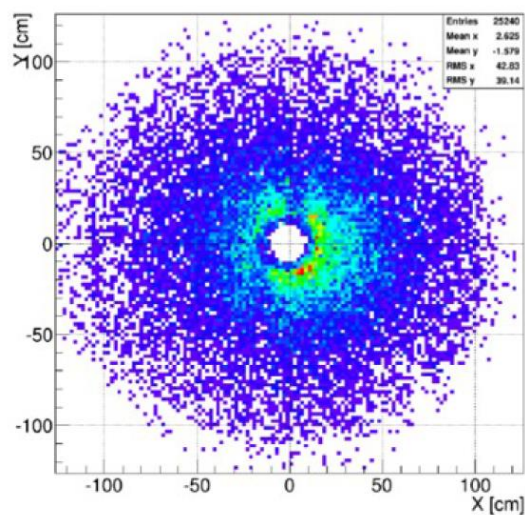
Liquid krypton calorimeter (LKr) $1 < \theta < 8.5$ mrad

Quasi-homogeneous calorimeter

Readout towers 2×2 cm² - 13248 channels

Depth 127 cm = $27 X_0$

$1 - \epsilon$ for γ with $E > 10$ GeV: $< 8 \times 10^{-6}$

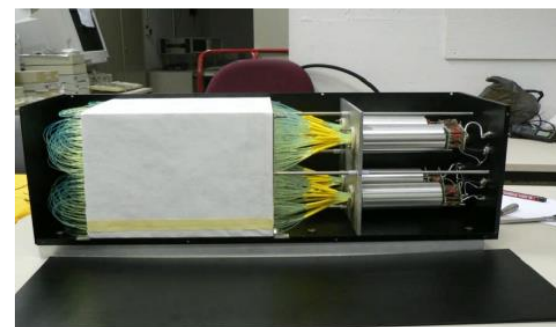


IRC and SAC ($\theta < 1$ mrad)

SAC: γ detection along the beamline (after beam deflection)

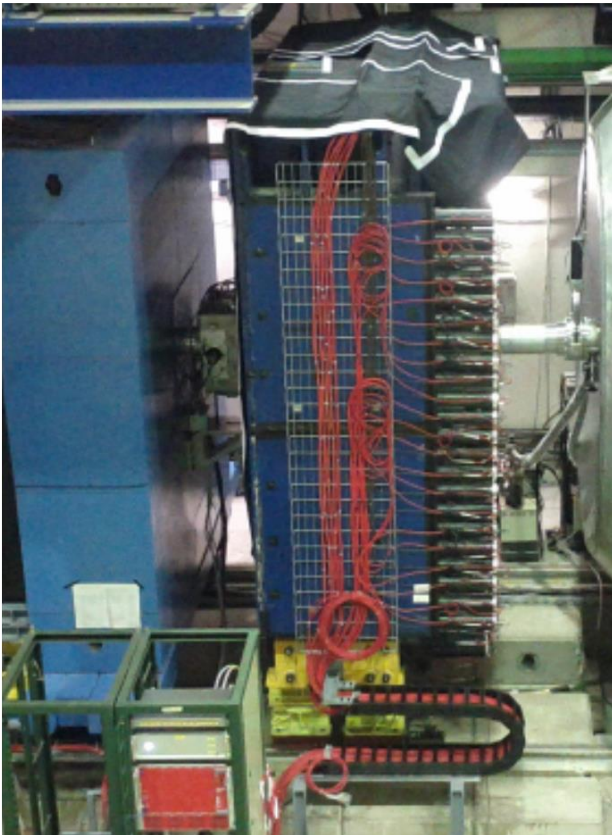
IRC: detection of photons at very low angle in front of the LKr

WLSs+PMTs used for both detectors



MUV1 & MUV2: calorimetri adronici

- 2 moduli di piani ferro/scintillatori (128+64 canali)
- FADC readout



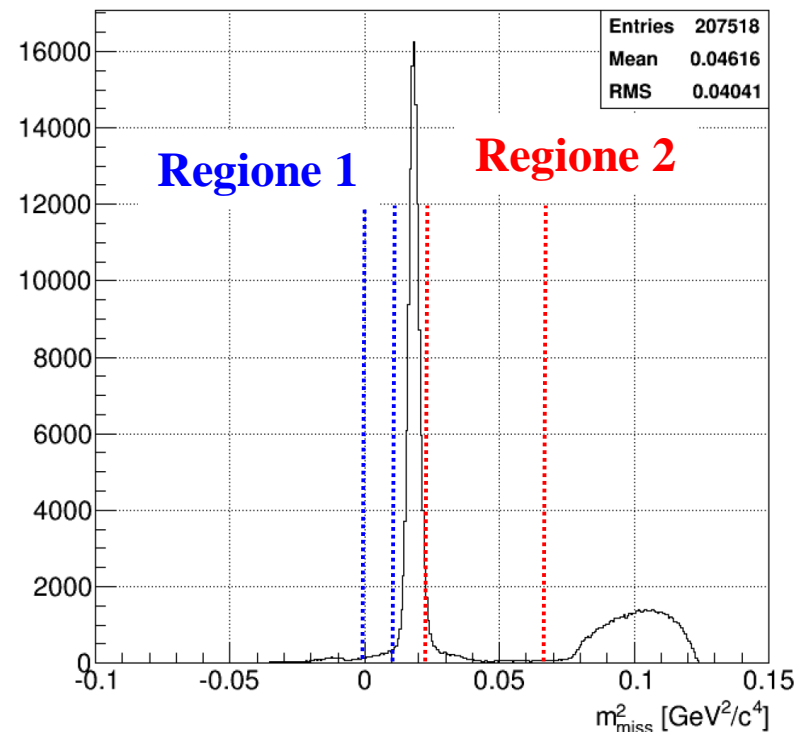
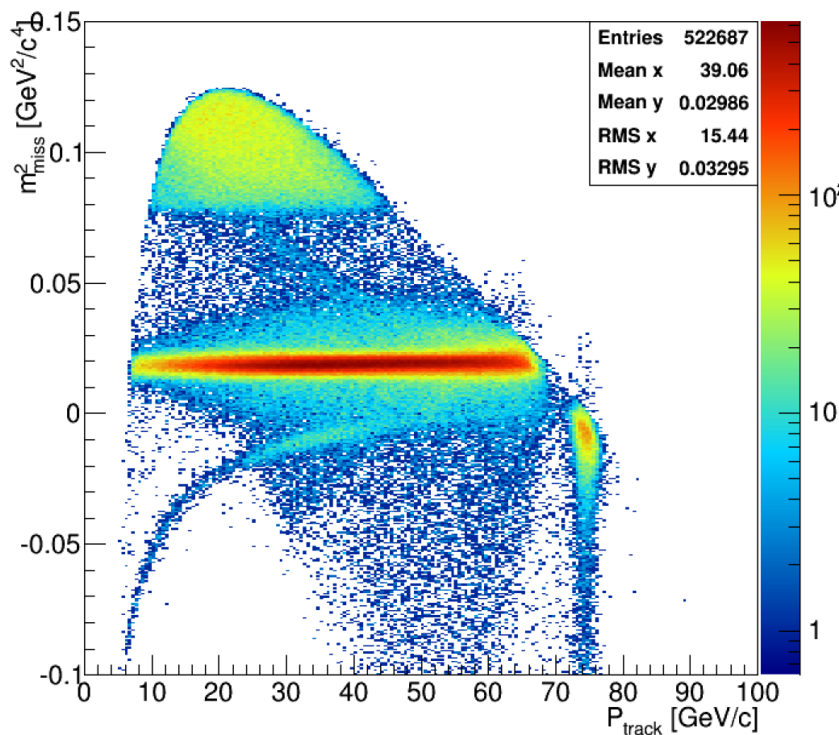
MUV3: veto di muoni

- 2 148 tile di scintillatore
- CFD + TDC readout
- Risoluzione temporale < 500ps



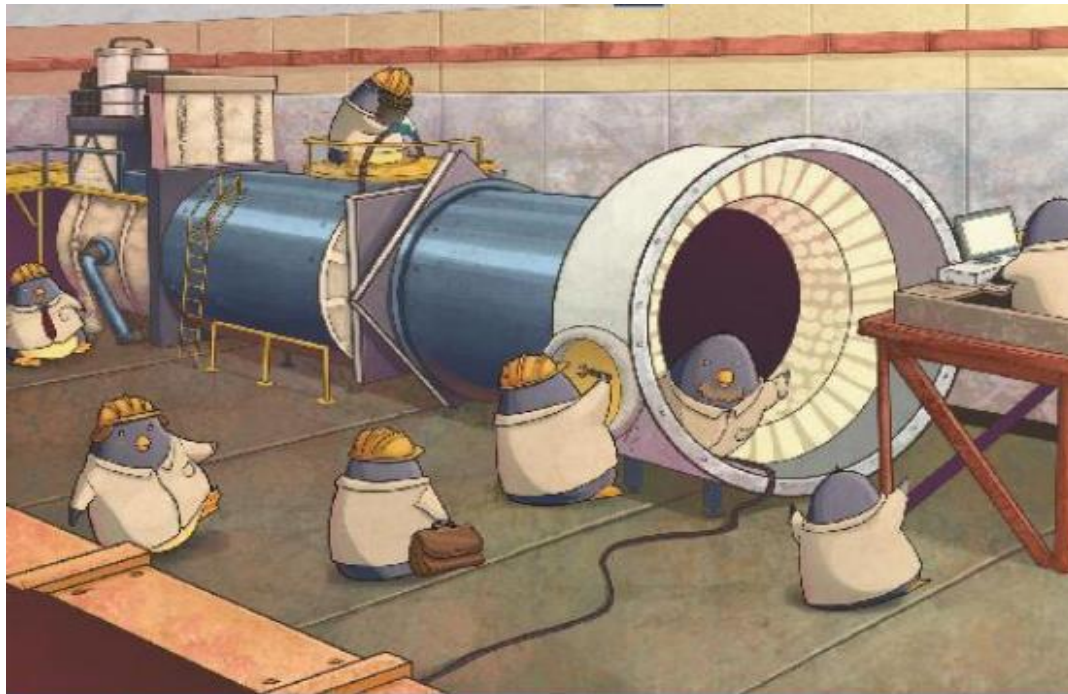
NA62: analisi preliminare dei dati

- Spettrometro a straw: eventi in cui esiste una traccia singola, ossia una traccia che non forma un vertice con un'altra traccia individuata dalla straw stessa
- Matching in spazio e tempo della traccia (estrapolata) con un candidato nel CHOD, LKr, RICH, MUV1 e MUV3.
- Individuazione del candidato GTK tramite taglio temporale rispetto al tempo di riferimento e il CDA del vertice ricostruito
- Richiesta di matching temporale con un candidato KTAG individuato come K



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NA62 nel 2016

Beam

- Fascio di protoni disponibile dal 18 Aprile al 14 Novembre; NA62 ha richiesto l'intero periodo per la presa data

✓ 2006	Proposal
✓ 2009	Approved
✓ 2010	Technical Design
✓ 2012	Technical Run
✓ 2014	Pilot run (almost full commissioning)
✓ 2015...2018	Physics run

Analisi dati del 2015

I dati del 2015 devono essere analizzati per poter individuare la giusta strategia di analisi per il run del 2016. Diversi canali da studiare:

- Decadimenti rari del K (analisi principale $K^+ \rightarrow \pi^+ \nu \bar{\nu}$)
- Ricerca di nuova fisica

Proposal per ricerca di nuova fisica

3-charge tracks events

- LFV and Majorana neutrino search from 21 final states
- Search for dark higgs from 31 final states
- Short-lived dark photons searched from 21 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 $K^+ \rightarrow \pi^+ X$, $\mu^+ Y$ 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

Proposal per ricerca di nuova fisica

Decay	Physics	Present limit (90% C.L.) / Result	NA62 Potential
$\pi^+\mu^+e^-$	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}
$\mu^-ve^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	$5.9 \times 10^{-11} m_{X^0} = 0$	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}
$\mu^+\nu_h, \nu_h \rightarrow \nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h} = 350 \text{ MeV}$	
R_K	LU	$(2.488 \pm 0.010) \times 10^{-5}$	$> \times 2$ better
$\pi^+\gamma\gamma$	χ PT	< 500 events	10^5 events
$\pi^0\pi^0e^+\nu$	χ PT	66000 events	$O(10^6)$
$\pi^0\pi^0\mu^+\nu$	χ PT	-	$O(10^5)$

- **Mantenere la responsabilità CHANTI (nel 2015 detector experts: F. Ambrosino, T. Capussela, D. Di Filippo, P. Massarotti, M. Mirra, G. Saracino)**
- **Completamento MC CHANTI**
- **Identificare un campione di eventi di anelastico per poter ottimizzare il taglio da applicare con il CHANTI**
- **Entrare nei gruppi di analisi dati: CHANTI fondamentale per il $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, altre strade aperte ...**
- **Napoli insieme con LNF, Perugia, Ferrara, Firenze, Pisa, Roma TV, Torino richiederà un finanziamento con il PRIN per l'analisi e la ricerca nel dark sector e lo studio di trigger dedicati aventi come obiettivo la ricerca di decadimenti rari / nuova fisica**

Conclusioni

- **Il 2015 è stato un anno cruciale per NA62**
- **Il rivelatore CHANTI ha funzionato fin da subito secondo le prestazioni attese. Alcuni problemi da risolvere riguardanti il readout, già diverse idee su come agire**
- **Tutti i rivelatori hanno fornito delle risposte importanti nell'ultima presa dati; ora l'obiettivo è collezionare $O(10^{13})$ decadimenti del K prima del LS2**

TEL62s (both TDAQ readout and L0Cal):

- Symptom: Stop sending data
- Frequency: Many times/day
- Remedy: Board reload, ~ 5 minutes downtime

CREAMs:

- Symptom: Stop sending data
- Frequency: Few times/day
- Remedy: Board reload, < 5 minutes downtime

Ethernet switches (both on floor and in EB):

- Symptom: Lost connection with elements in rack, including readout
- Frequency: 1/day
- Remedy: Manual reset, access required, > 20 minutes downtime

CAEN A4531 HV primary power supplies:

- Symptom: HV lost on detector (LAV, KTAG, MUV)
- Frequency: Random, up to a few times/week
- Remedy: Replacement: > 20 minutes downtime if spare available
- Problem seems to be failure of one particularly sensitive MOSFET; CAEN is working on a robust replacement

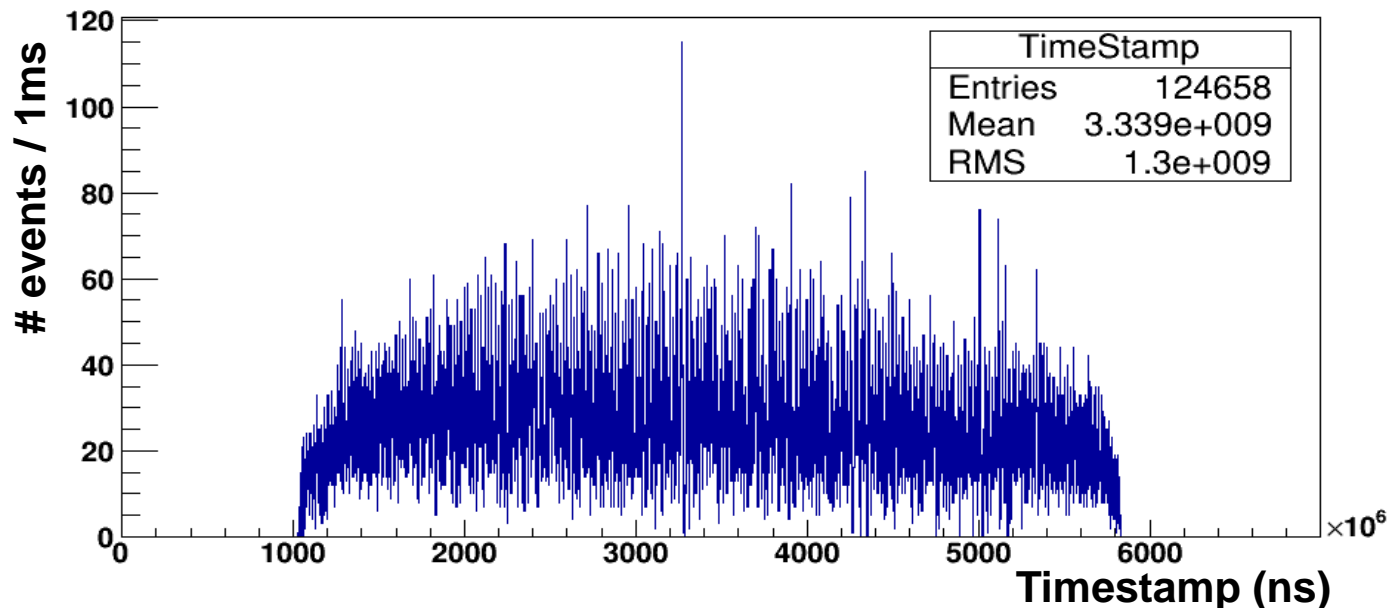
NA62 issues

Trigger condition

- At intensity below 50% data taken with a CHOD*!MUV3 trigger. At higher intensity problems with CHOD trigger; data collected with L0cal (LKr<4/5Gev & MUV1>5/6 GeV)

Frame limiters set for various TELs at restart of 40% program:

- Limit is applied to words stored per TDC per 6.4 us frame
- Initially for L0 TELs: RICH, CHOD, MUV3
- As intensity edged to 50%, also KTAG, CHANTI
- Above 60% intensity at end of run, also LAVs 1, 2



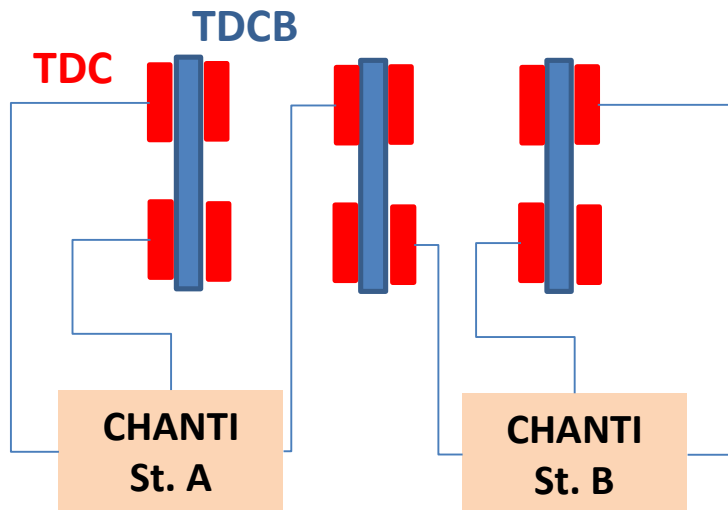
CHANTI cabling for the 2016 run

Present status: 2 tel62, each with 3 TDCBs. Just 3 TDCs of each TDCB are used (1 TDCB corresponds to 1 CHANTI station)

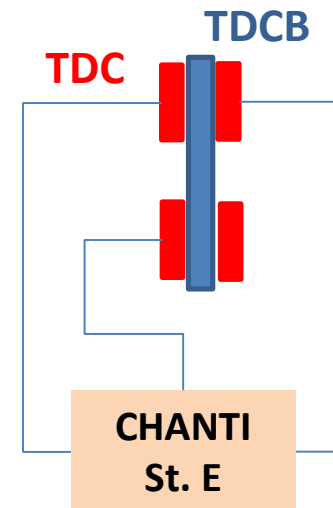
New configuration: 2 tel62, each with 4 TDCBs.

In 6 TDCBs just 2 TDCs will be used in order to connect the st. A,B,C and D (the ones with the highest rates).

In the other 2 TDCBs, 3 TDCs will be used in order to connect st. E and F.



limiter set to 500 word in 6.4us



limiter set to 350 word in 6.4us

It's possible to implement split of LVDS signal



Primary SPS proton beam:

- $p = 400$ GeV protons
- Proton on target 1.1×10^{12} /s
- Simultaneous beam delivery to LHC

High-intensity, unseparated secondary beam

- Momentum selection chosen to optimize K decays
- $p = 75$ GeV/c
- $\Delta p/p \sim 1\%$

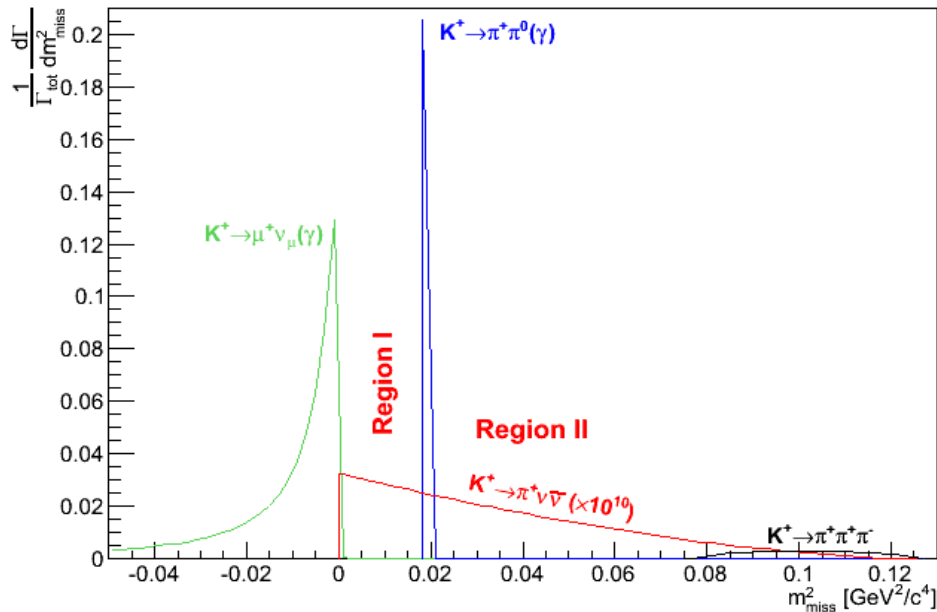
Total rate
750 MHz

- 525 MHz π
- 170 MHz p
- 45 MHz K

Decay volume

- 60m long, starting at 102m from target
- 10% of K^+ decay in FV ($\beta\gamma c\tau = 560m$)
- 4.5×10^{12} K^+ decays/yr

Performance for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$



Acceptance: ~12%

3% in Region I

9% in Region II

50% loss from momentum cut

Detector inefficiencies included

45 signal events/yr

- 1 track with $15 < p_\pi < 35$ GeV and π PID in RICH
- No γ in LAV, LKr, IRC, SAC
- No μ in MUV
- 1 beam particle in Gigatracker with K PID by KTAG
- No activity on CHANTI
- $Z_{\nu\tau x}$ in 60m fiducial region

Expected backgrounds

$K^+ \rightarrow \pi^+ \pi^0$	11%
$K^+ \rightarrow \pi^+ \pi^0 \gamma_{IB}$	3%
$K^+ \rightarrow \mu^+ \nu$	2%
$K^+ \rightarrow \mu^+ \nu \gamma_{IB}$	1%
$K^+ \rightarrow \pi^+ \pi^+ \pi^-$	< 2%
K^+_{e4} , other 3 track decays	< 2%
$K^+_{e3}, K^+_{\mu 3}$	negligible
Total	< 20%

NA62 sensitivity for LFNV decays

High fluxes and PID/veto capabilities of NA62 well suited to look for Lepton Flavor/ Lepton Number Violation modes in both kaon and pion decays:

Decays in FV in 2 years of data $\left\{ \begin{array}{l} 1 \times 10^{13} K^+ \text{ decays} \\ 2 \times 10^{12} \pi^0 \text{ decays} \end{array} \right.$ Single-event sensitivity $1/(\text{decays} \times \text{acceptance})$

Mode	UL at 90% CL	Experiment	NA62 acceptance*
$K^+ \rightarrow \pi^+ \mu^+ e^-$	1.3×10^{-11}	BNL 777/865	~10%
$K^+ \rightarrow \pi^+ \mu^- e^+$	5.2×10^{-10}	BNL 865	
$K^+ \rightarrow \pi^- \mu^+ e^+$	5.0×10^{-10}	BNL 865	~10%
$K^+ \rightarrow \pi^- e^+ e^+$	6.4×10^{-10}	BNL 865	~5%
$K^+ \rightarrow \pi^- \mu^+ \mu^+$	1.1×10^{-9}	NA48/2	~20%
$K^+ \rightarrow \mu^- \nu e^+ e^+$	2.0×10^{-8}	Geneva Saclay	~2%
$K^+ \rightarrow e^- \nu \mu^+ \mu^+$	no data		~10%
$\pi^0 \rightarrow \mu^+ e^-$	3.6×10^{-10}	KTeV	~2%
$\pi^0 \rightarrow \mu^- e^+$			

* From fast Monte Carlo simulation with flat phase-space distribution. Includes trigger efficiency.

NA62 single-event sensitivities: $\sim 10^{-12}$ for K^+ decays
 $\sim 10^{-11}$ for π^0 decays

Rare π^0 decays in NA62

2×10^{12} π^0 decays in FV in 2 years of data will allow substantial improvement of results in many channels

Mode	Current knowledge	Experiment	Expectation in SM	Physics interest
Neutral modes				
$\pi^0 \rightarrow 3\gamma$	$BR_{90CL} < 3.1 \times 10^{-8}$	Crystal Box	Forbidden	Violates C
$\pi^0 \rightarrow 4\gamma$	$BR_{90CL} < 2 \times 10^{-8}$	Crystal Box	$BR \sim 10^{-11}$	Scalar states $\pi^0 \rightarrow SS$
$\pi^0 \rightarrow \text{inv}$	$BR_{90CL} < 2.7 \times 10^{-7}$	BNL 949	$BR < 10^{-13}$ (cosm. limit)	N_ν , LFV
Charged modes				
$\pi^0 \rightarrow e^+e^-e^+e^-$	$BR = 3.34(16) \times 10^{-5}$	KTeV	$3.26(18) \times 10^{-5}$	Off-shell vectors
$\pi^0 \rightarrow e^+e^-\gamma$	$BR_{95CL}(\pi^0 \rightarrow U\gamma)$: $< 1 \times 10^5, M_U = 30 \text{ MeV}$ $< 3 \times 10^6, M_U = 100 \text{ MeV}$	WASA/COSY	Null result	Dark forces

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

- Z' gauge boson mediating FCNC at tree level
- [A.J.Buras et al., JHEP 1302 (2013) 116; A.J.Buras et al. Eur. Phys. J. C74 (2014) 039]
- Littlest Higgs with T-parity [M. Blanke et al., Acta Phys. Polon. B 41 (2010) 657]
- Custodial Randall-Sundrum [M. Blanke et al., JHEP 0903 (2009) 108]
- Best probe of MSSM non-MFV (still not excluded by LHC) [G. Isidori et al., JHEP 0608 (2006) 088]

Z' model

Randall - Sundrum

Littlest Higgs

LHS2, Cyan: 5TeV, Blue: 10TeV, Purple: 30TeV

