NA62 PHYSICS HANDBOOK

MITP, JANUARY 11-23, 2016

NA62 warmly acknowledges the MITP support of this scientific program which happens at a crucial time for the Collaboration

AN EARLY START...

- THE IDEA TO GATHER THE PHYSICS INTO A NA62 HANDBOOK ORIGINATED IN 2008
- THE FIRST (AND LATEST) MEETING TOOK PLACE AT THE END OF 2009
- WE IMMEDIATELY REALIZED THAT THERE WAS PLENTY OF PHYSICS TO DO...
- ...BUT NO DETECTOR...
- ...SO WE LEFT THE HANDBOOK UNFINISHED...
- ... AND WE STARTED TO BUILD A NEW EXPERIMENT!

...AND NOW NA62 EXISTS

5 10^12 K^+ decays / year
7 10^12 pi+ decays/ year
10^12 pi0 decays/ year

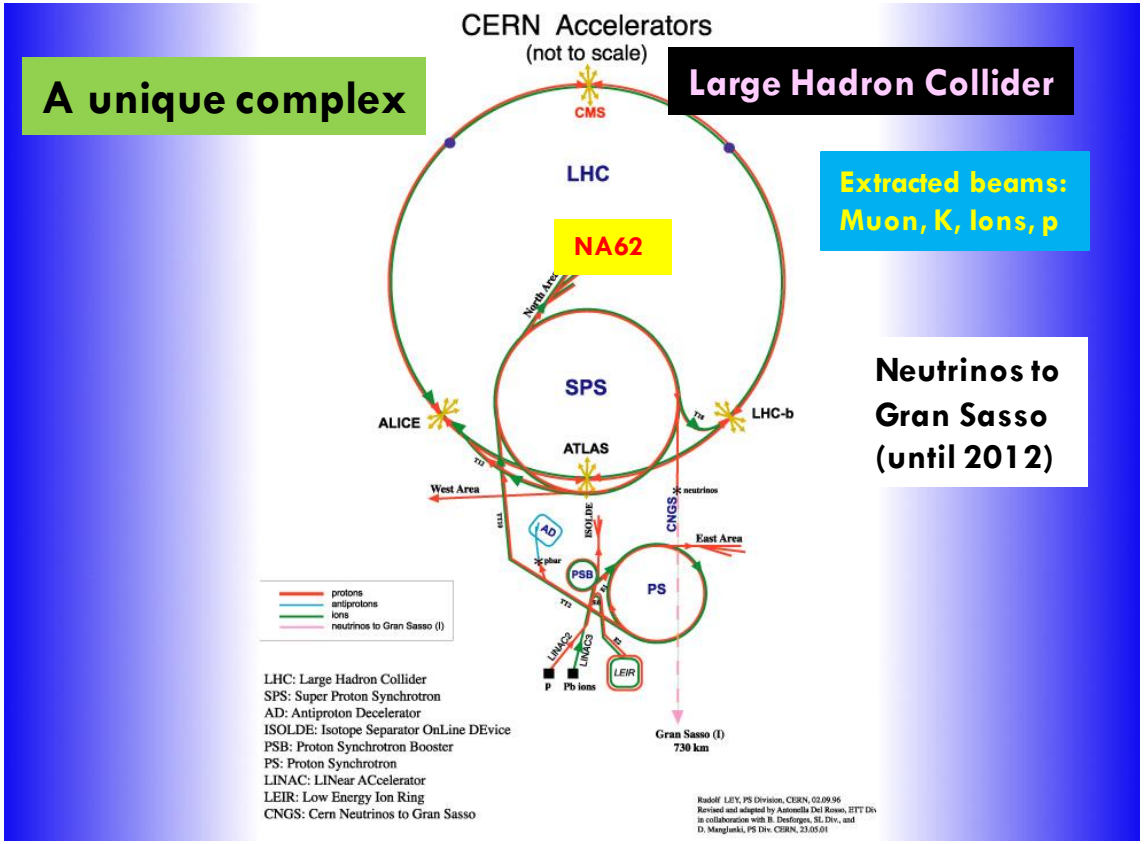
...provided you know what to do with these decays and you can capture them before they disappear (we make so many decays that we cannot simply record all)

WHAT MAKES NA62 UNIQUE

- HIGH MOMENTUM BEAM (75 GEV /C) → ACCEPTANCE AND HIGH YIELD OF K PER PROTON
- CALORIMETRY FOR PRECISE PHOTON RECONSTRUCTION (1% ENERGY RESOLUTION)
- FULL PARTICLE IDENTIFICATION (PION / MUON)
- FAST AND (ALMOST) MASS-LESS TRACKING

FEW WORDS ON CERN ACCELERATORS

A unique complex



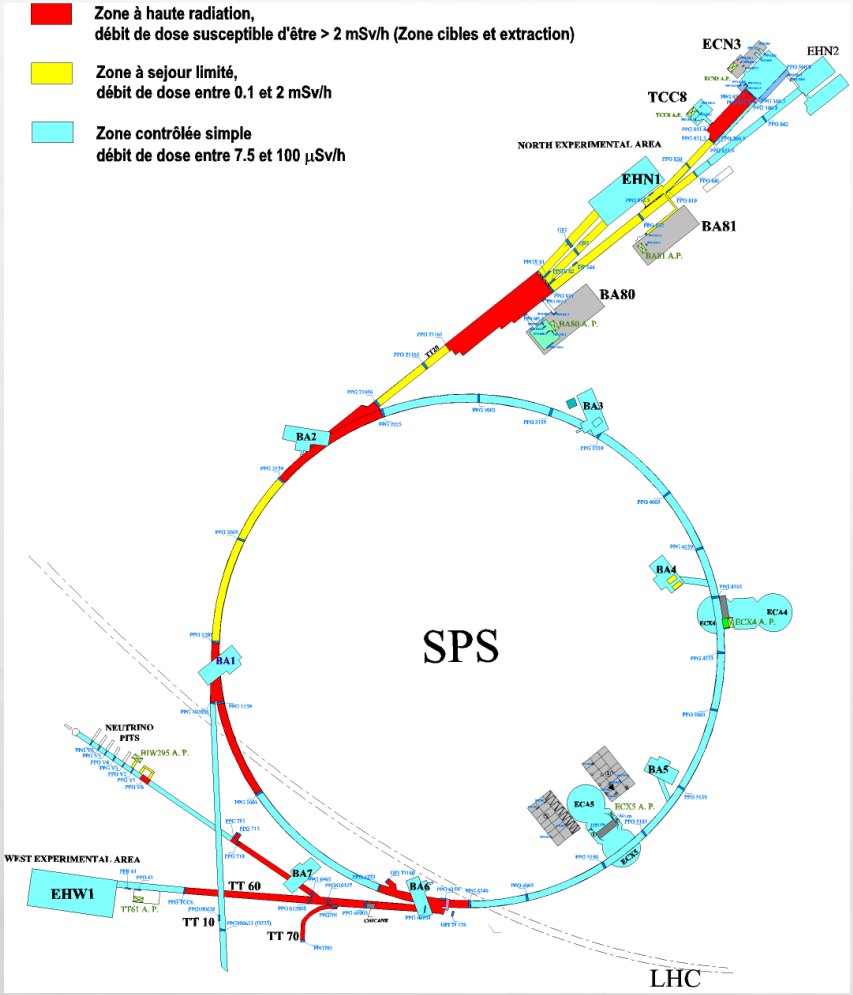
Large Hadron Collider

NA62

Extracted beams: Muon, K, Ions, p

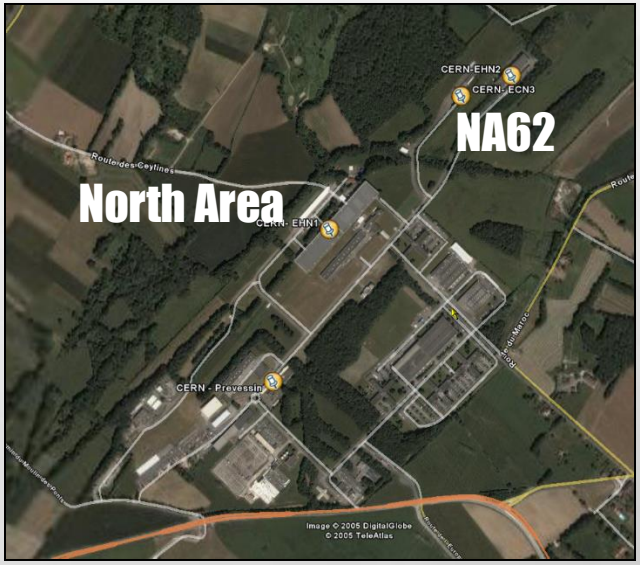
Neutrinos to Gran Sasso (until 2012)

CERN-SPS



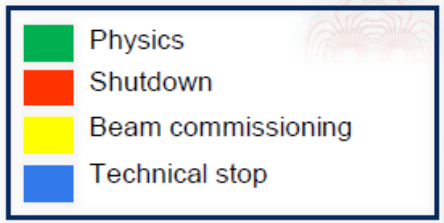
SPS (Super Proton Synchroton) since 1976

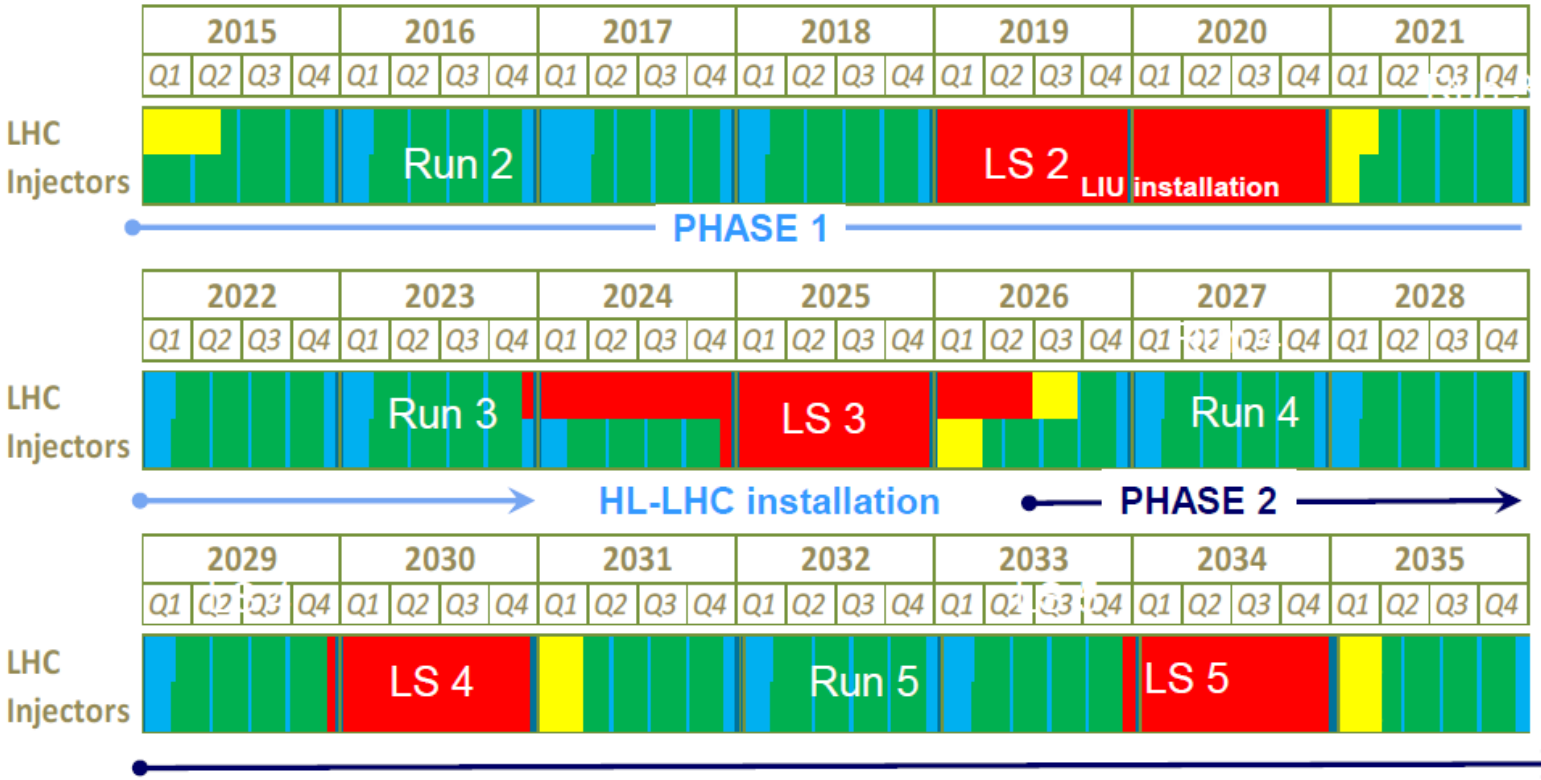
- Circumference : 6.9 km
- 2.5 km of secondary beam lines.
- protons for fixed target physics at 400 GeV/c
- protons for LHC at 450GeV/c
- lead ions for fixed target physics at 400 GeV/c proton equivalent
- Injector for the LHC



LHC Roadmap

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC





THE SPS IS ESSENTIAL FOR LHC OPERATION…SO IT WILL FUNCTION AT LEAST UNTIL 2035

CHARGED K BEAMS

"Stopped"

- Work in Kaon frame
- High Kaon purity (Electro-Magneto-static Separators)
- Compact Detectors

"In-Flight"

- Decays in vacuum (no scattering, no interactions)
- RF separated or Unseparated beams
- Extended decay regions

Exp	Machine	Meas. or UL 90% CL	Notes
	Argonne	$< 5.7 \times 10^{-5}$	Stopped; HL Bubble Chamber
	Bevatron	$< 5.6 \times 10^{-7}$	Stopped; Spark Chambers
	KEK	$< 1.4 \times 10^{-7}$	Stopped; $\pi^+ \rightarrow \mu^+ \rightarrow e^+$
E787	AGS	$(1.57^{+1.75}_{-0.82}) \times 10^{-10}$	Stopped
E949	AGS	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	Stopped; PPN1+PPN2
NA62	SPS		In-Flight; Unseparated

NA62 Collaboration

29 Institutes, 233 Collaborators

NA62 MAIN GOAL

- We aim to measure to 10% or better

$$Br(K^+ \to \pi^+ \nu\bar{\nu})$$

with in-flight kaon decays

- State of the art:

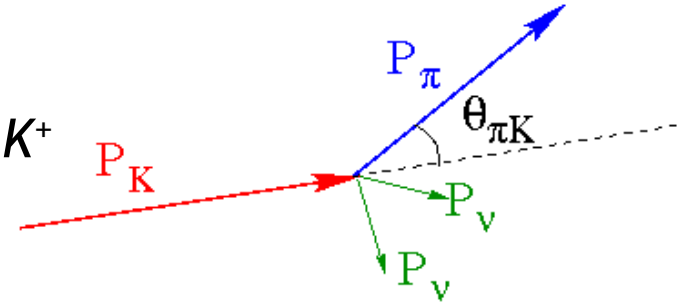
Decay	Branching Ratio ($\times 10^{10}$)	
	Theory (SM)	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}(\gamma)$	0.911 ± 0.072 [1]	$1.73^{+1.15}_{-1.05}$ [2]

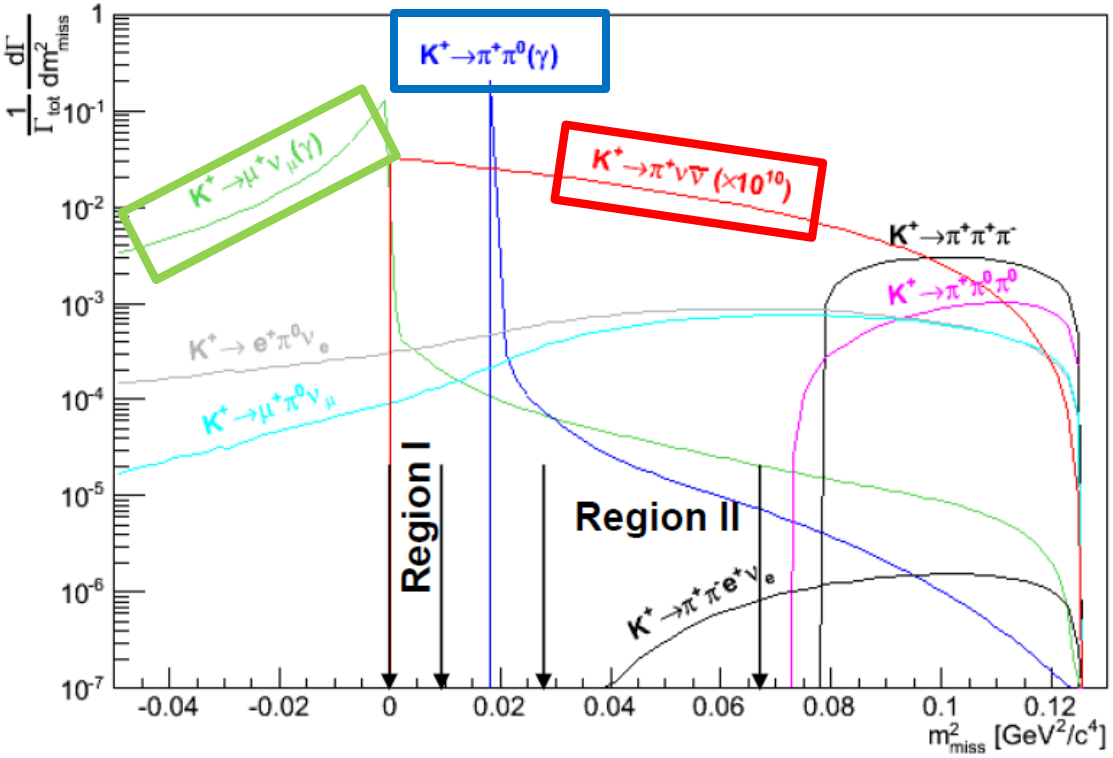
[1] A.J. Buras, D. Buttazzo, J. Girrbach-Noe and R. Knegjens arXiv:1503.02693

[2] AGS-E787/E949 PRL101 (2008) 191802, arXiv:0808.2459

NA62 IN-FLIGHT TECHNIQUE

- Calorimetry to veto extra particles
- Very light trackers to reconstruct the K^+ and the π^+ momenta
- Full particle identification





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

$K^+ \to \pi^+ \nu\bar{\nu}$ Analysis Sensitivity (MC)

Decay	event/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+(\mu^+) \nu$, others	negligible
Total background	< 10

Further NA62 K Physics Program

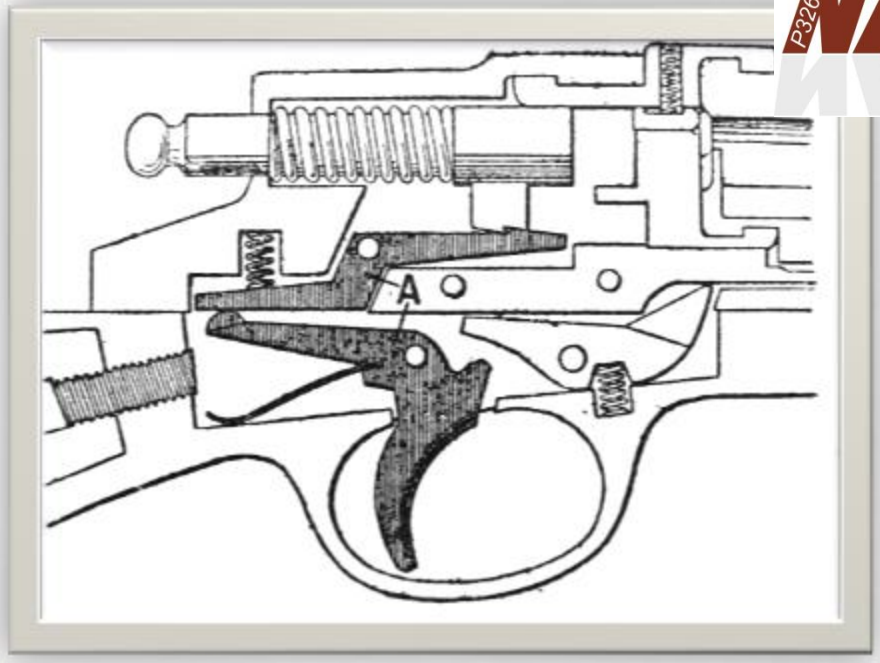
Decay	Physics	Present limit (90% C.L.) / Result	NA62
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	0.7×10^{-12}
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	0.7×10^{-12}
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	0.7×10^{-12}
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	2×10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	0.4×10^{-12}
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	$5.9\times10^{-11}\ m_{X^0}=0$	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)

FURTHER NA62 PROGRAM

- WHICH ULTIMATE PRECISION TO BE TARGETED?
- IS THERE A COMPELLING K-LONG PROGRAM?
- WHAT ABOUT THE DARK SECTOR?
- WHAT ELSE WAS OVERLOOKED?
- CHARGED PIONS? (OPTIMIZING ACCEPTANCE REDUCING THE BEAM MOMENTUM)
- NEUTRAL PIONS?

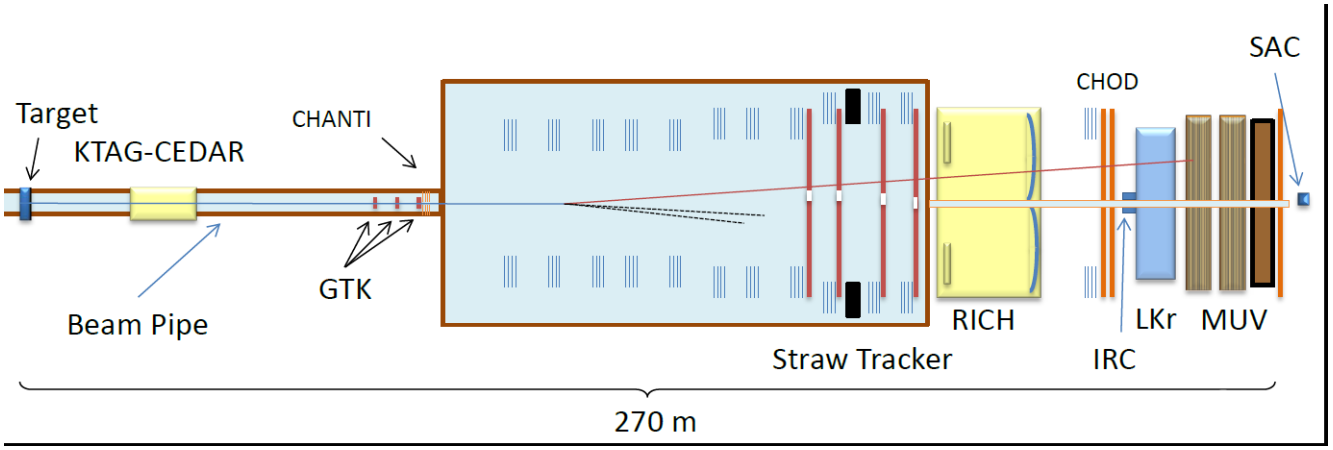
THIS WORKSHOP

THE TRIGGER



- BETWEEN A REACH WEALTH OF DATA AND NA62 STANDS THE TRIGGER
- WE CANNOT SIMPLY WRITE ON TAPE ALL KAON DECAYS
- WE NEED TO USE VERY FAST ALGORITHMS TO REJECT THE UNWANTED DECAYS
- THE TRIGGER MUST BE MOSTLY BLIND TO MUONS (70% OF THE SINGLES RATE IN NA62 IS MUONS)
- FOR INSTANCE THERE IS AN OBVIOUS CONFLICT SELECTING A PI+ AND NOTHING ELSE OR PI+ AND TWO PHOTONS

NA62 SCHEMATIC LAYOUT

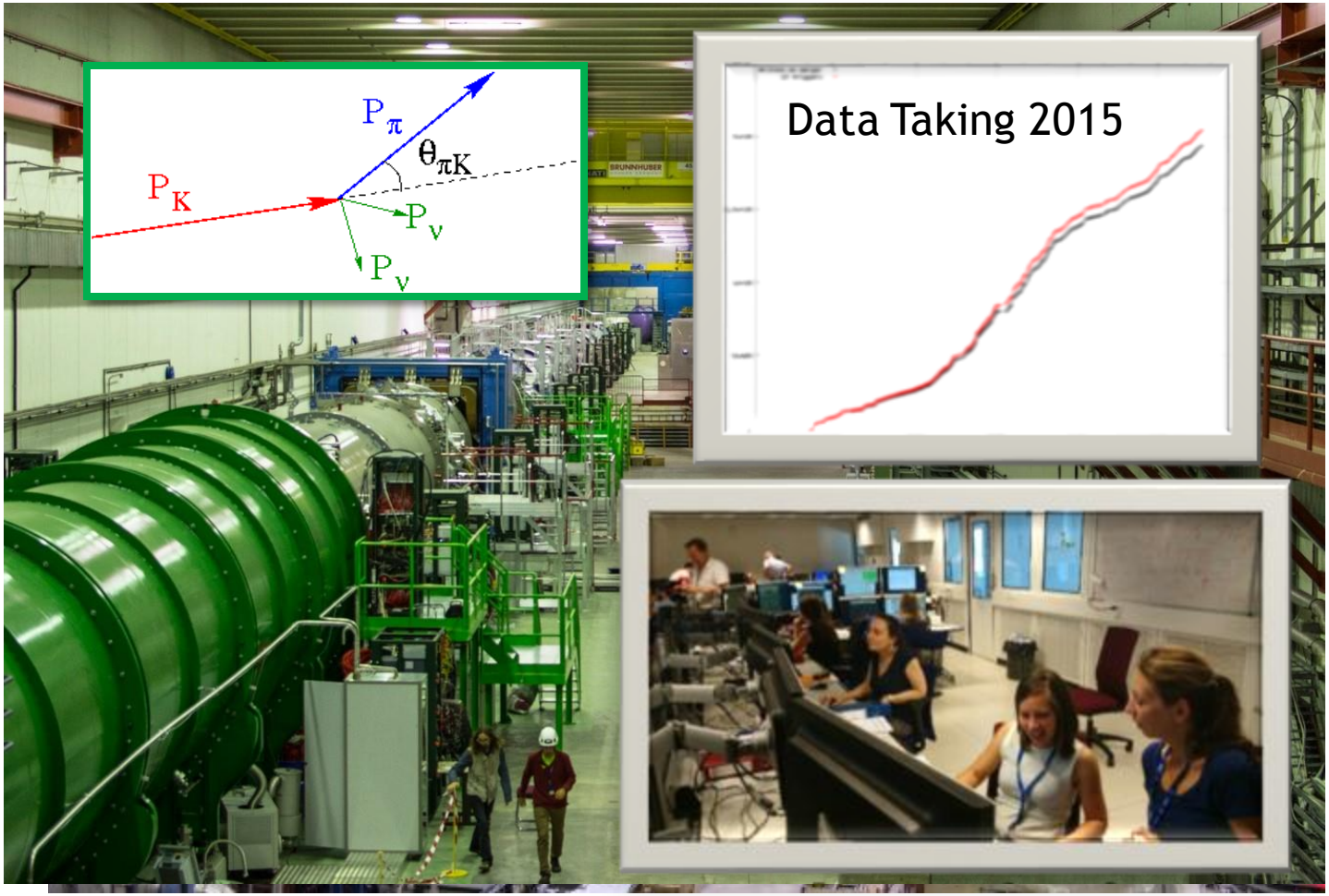


10^{12} / s protons from SPS (400 GeV/c) on Be target (~1 λ)

750 MHz secondary beam: 75 GeV/c
- **Positive polarity**
- **Kaon fraction ~6%**
- **Δ p/p ~ 1%**
- **Useful kaon decays ~10% (5 MHz)**

NA62 is designed for a specific "silver bullet" measurement. This requires high beam rate, full PID, hermetic coverage, very light, high-rate tracking and state-of-the-art trigger and DAQ. It paves the way to a broad physics program

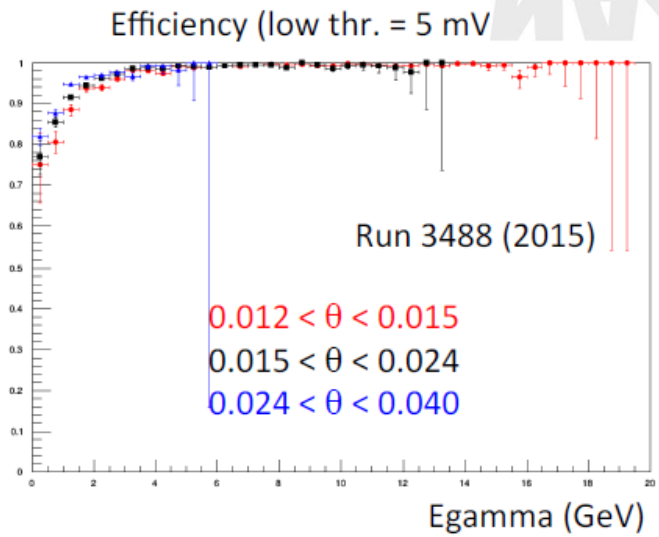
NA62:STATUS



- Beam time 2015: June 22 – November 15
- ~2 10^{10} triggers on tape
- reached nominal beam intensity by the end of the run

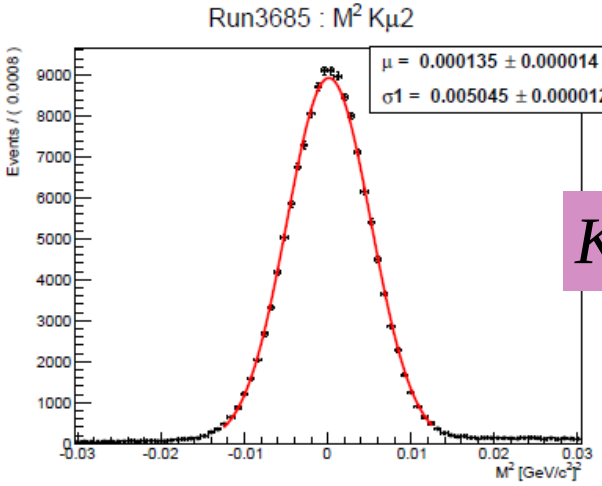
SOME NA62 2015 HIGHLIGHTS

- Large Angle Veto (LAV) photon detection efficiency



- Missing mass resolution (Straw + Gigatracker)

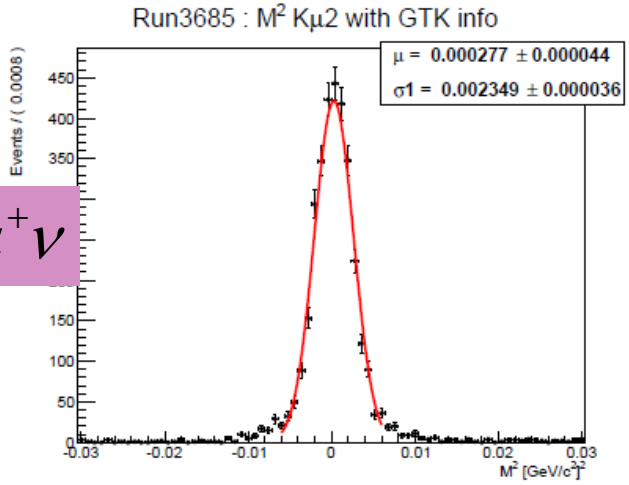
Without Gigatracker



σ=0.0050 (GeV/c^2)^2

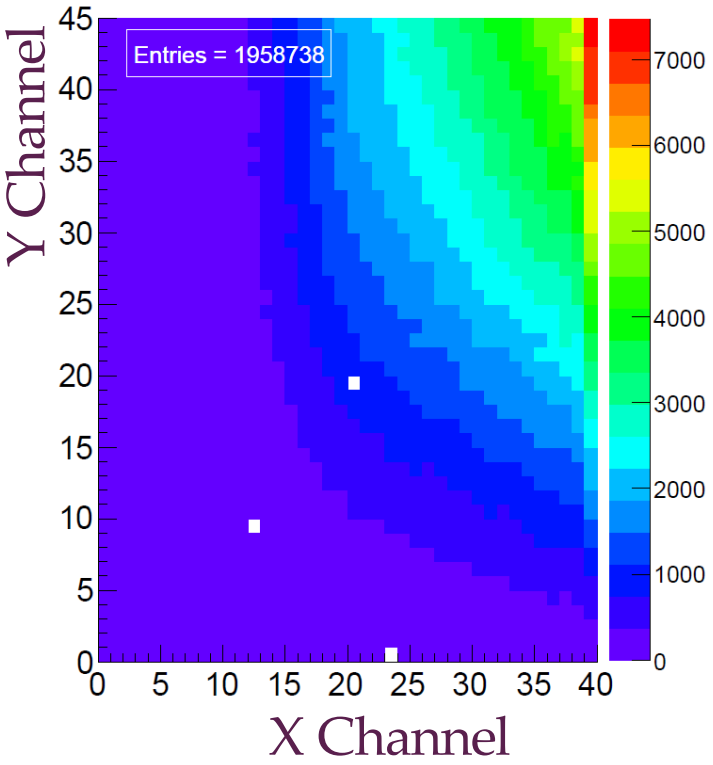
$K^+ \to \mu^+ \nu$

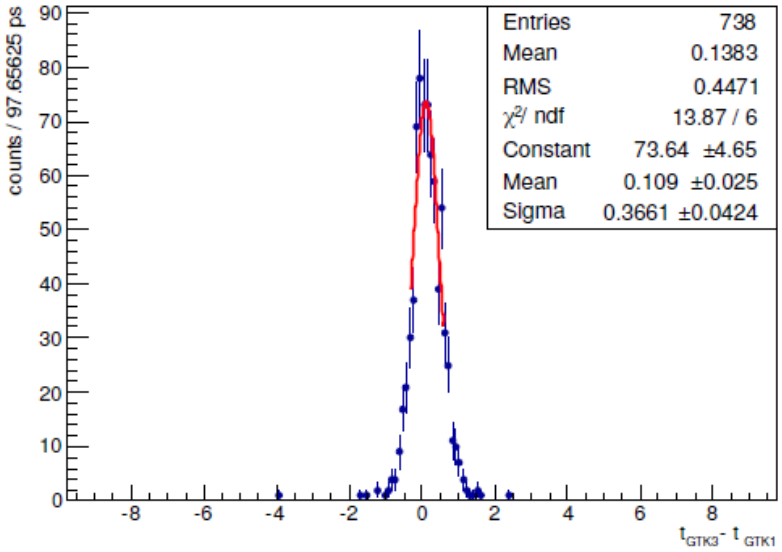
With Gigatracker



σ=0.0023 (GeV/c^2)^2

GIGATRACKER PERFORMANCE





After ToT correction

Time resolution~ 260 ps /station
In line with expectations for
HV= 200 V

K12 Beam; Illumination of one GTK chip

STATUS OF NA62: OUTLOOK

- 2015 was instrumental to collect a first significant sample of kaon decays with the complete detector
- Immediate Goal: Accumulate and analyze O(10^{13}) good kaon decays before LS2 to make a O(10%) measurement of $Br(K^+ \to \pi^+ \nu\bar{\nu})$
- Define a physics driven program of data taking after LS2
- The “NA62 Kaon Physics Handbook” is a great opportunity