The kaon identification system in the NA62 experiment at CERN SPS

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on behalf of the NA62 KTAG working group

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Outline:

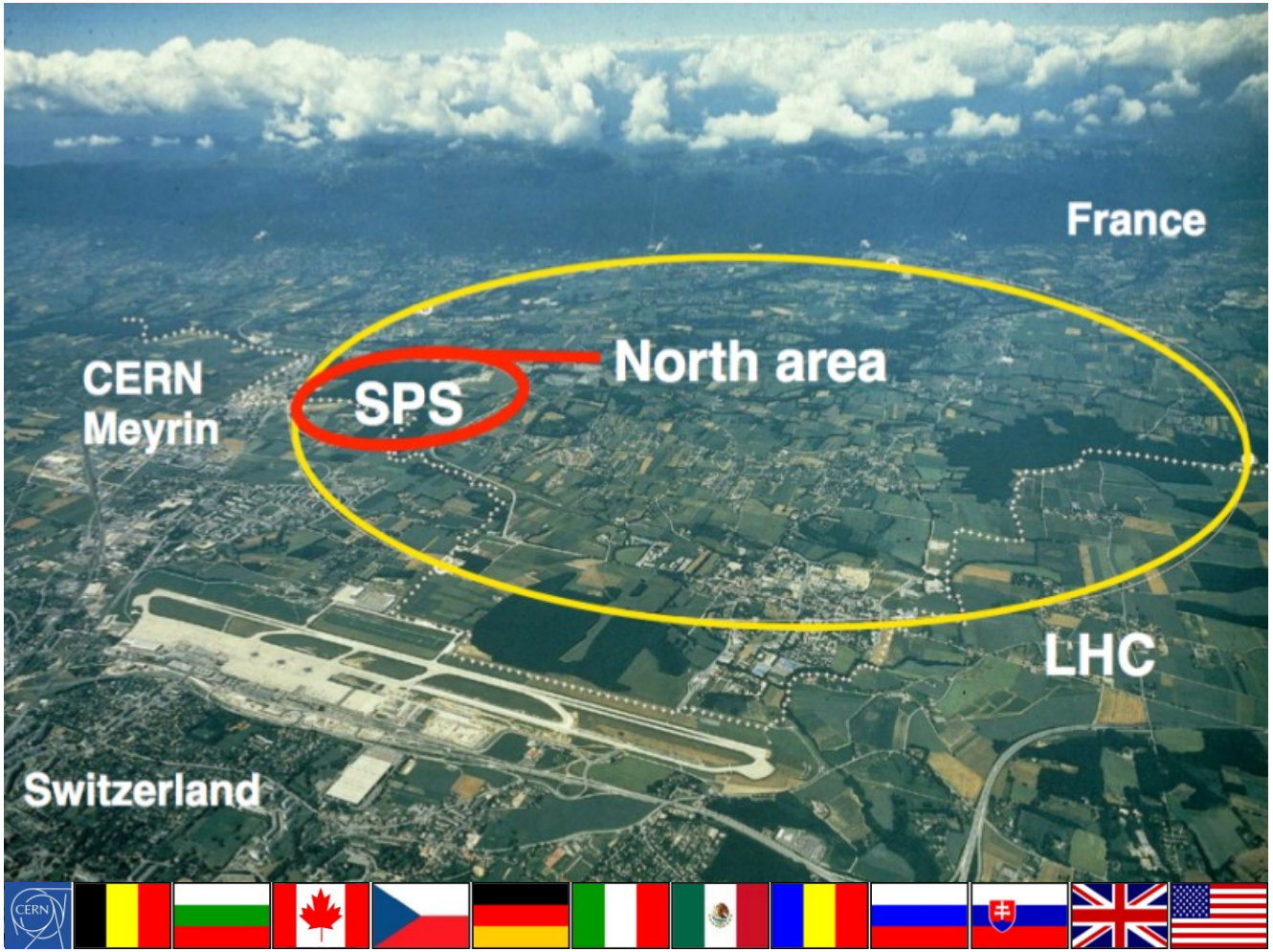
- **Introduction: the NA62 experiment and the $K^+ \to \pi^+ \nu\bar{\nu}$ decay**
- **Kaon identification in NA62: motivations**
- **The CEDAR detector and the KTAG upgrade**
- **Performances of the NA62 Kaon identification system**

38th International Conference on High Energy Physics

Chicago, USA – 06/08/2016

The NA62 experiment @ CERN

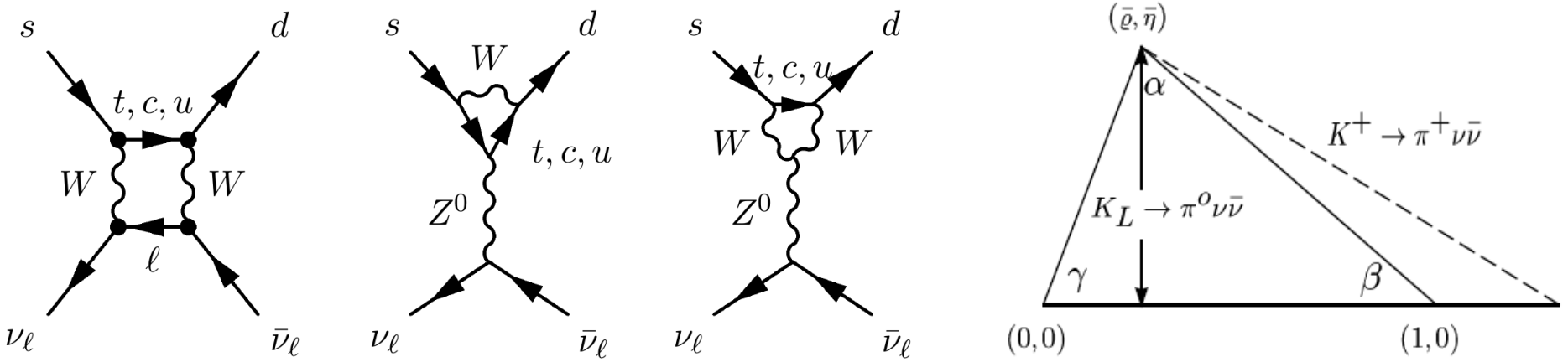
NA62 is the last from a long tradition of fixed-target Kaon experiments in the CERN North Area
[*M. Moulson – Search for $K^+ \to \pi^+ \nu\bar{\nu}$ at NA62*]



History of NA48/NA62 experiments		
1997 ↓ 2001	NA48 (K_S/K_L)	Re ε′/ε **Discovery of direct CPV**
2002	NA48/1 (K_S/hyperons)	Rare K_S and hyperon decays
2003 ↓ 2004	NA48/2 (K^+/K^-)	Direct CPV, Rare K^+/K^- decays
2007 ↓ 2008	NA62-R_K (K^+/K^-)	$R_K = K^{\pm}_{e2}/K^{\pm}_{\mu 2}$
2015 ↓ -	**NA62 (K^+)**	**$K^+ \to \pi^+ \nu\bar{\nu}$, Rare K^+ and π^0 decays**

NA62: currently ~ 200 participants, 29 institutions from 12 countries

$K^+ \to \pi^+ \nu\bar{\nu}$: Motivations & Theory



- FCNC forbidden at tree level: 1-loop contributions as leading order
- Highly CKM suppressed: $BR(K^+ \to \pi^+ \nu\bar{\nu}) \sim |V_{ts}^* V_{td}|^2 \sim \lambda^{10}$

} high sensitivity to new physics

- Dominated by short-distance contribution (top quark)
- t quark contribution @ NLO QCD and 2-loop EW corrections, c quark @ NNLO QCD and 1-loop EW corrections
- Hadronic matrix element from $BR(K \to e\pi^0\nu)$

} high-precision theoretical prediction

- Measurement of $|V_{td}|$ complementary to those from $B–\bar{B}$ mixing or $B^0 \to \rho\gamma$
- Constraints on CKM unitary triangle

SM prediction: $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (0.911 \pm 0.072) \times 10^{-10}$
Buras *et al.*, JHEP 11 (2015) 033

Current Experimental result [from 7 events]:
$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$
E787/E949, PRL 101 (2008) 191802

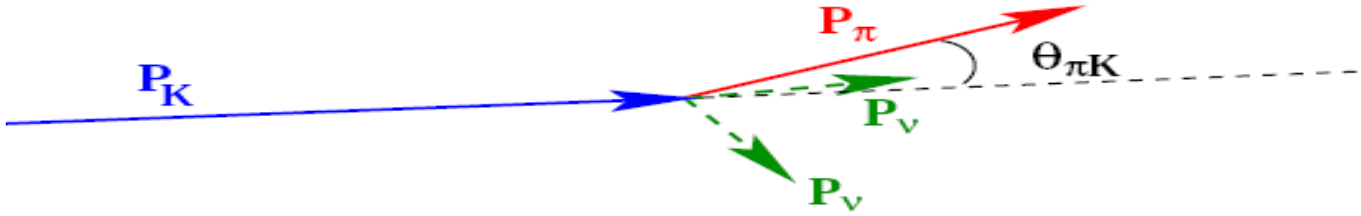
$K^+ \to \pi^+ \nu\bar{\nu}$: Main Backgrounds

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

Kaon track +

Pion track +

NOTHING ELSE



$$m^2_{miss} \approx m^2_K \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m^2_\pi \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$

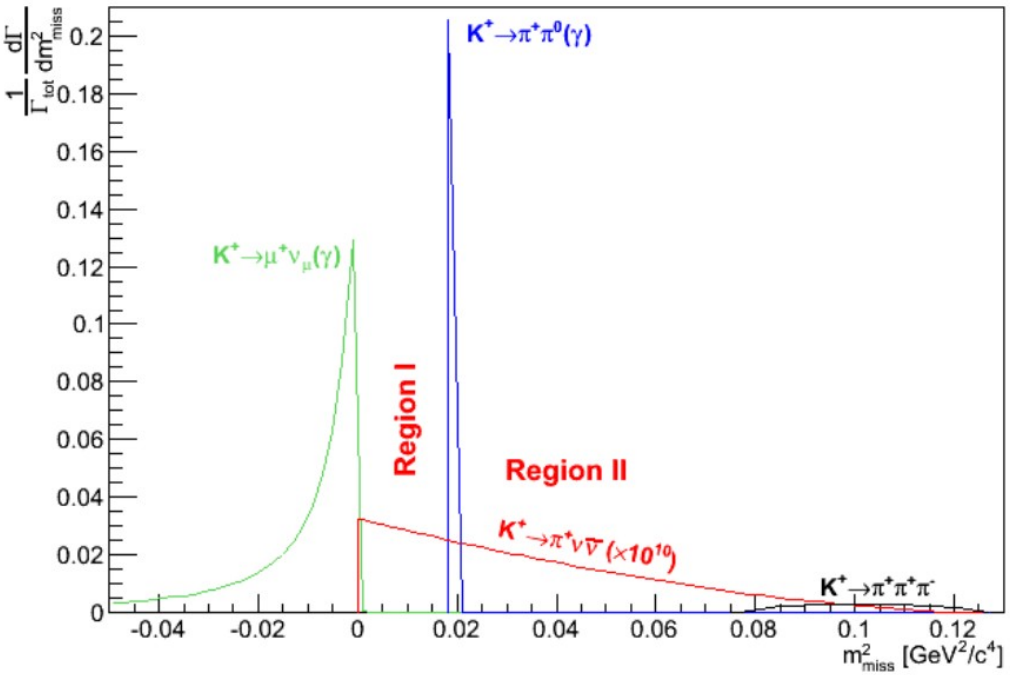
Backgrounds rejection cutting on the M^2_{miss} ~ 92%

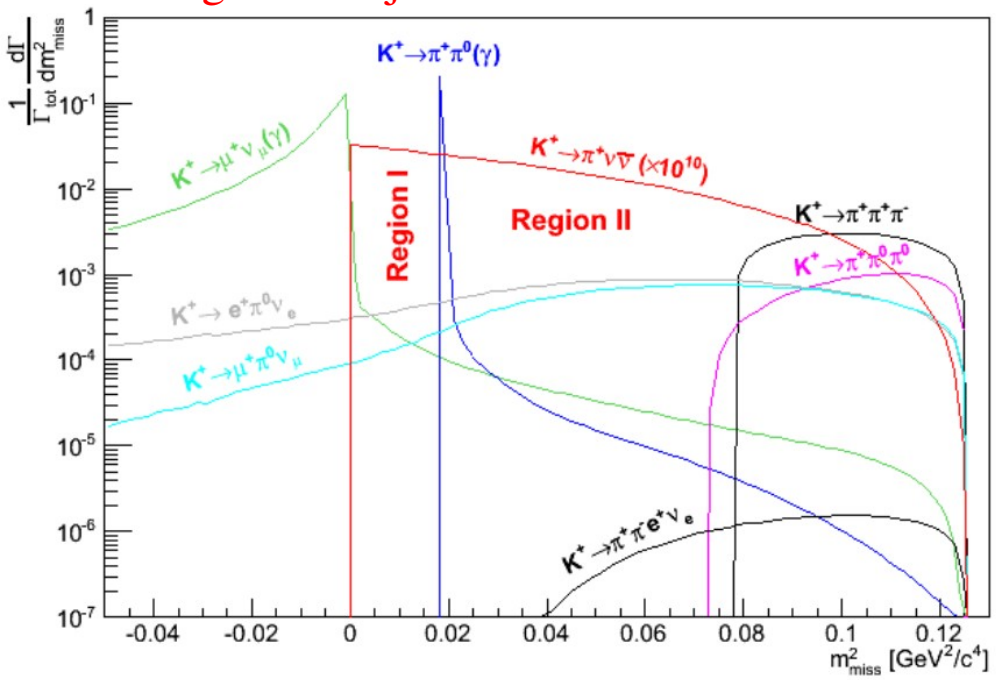
→ Relying on correct K-π association

Required Photon veto inefficiency ~ 2×10^{-4}

Required Muon mis-ID probability ~ 10^{-7}

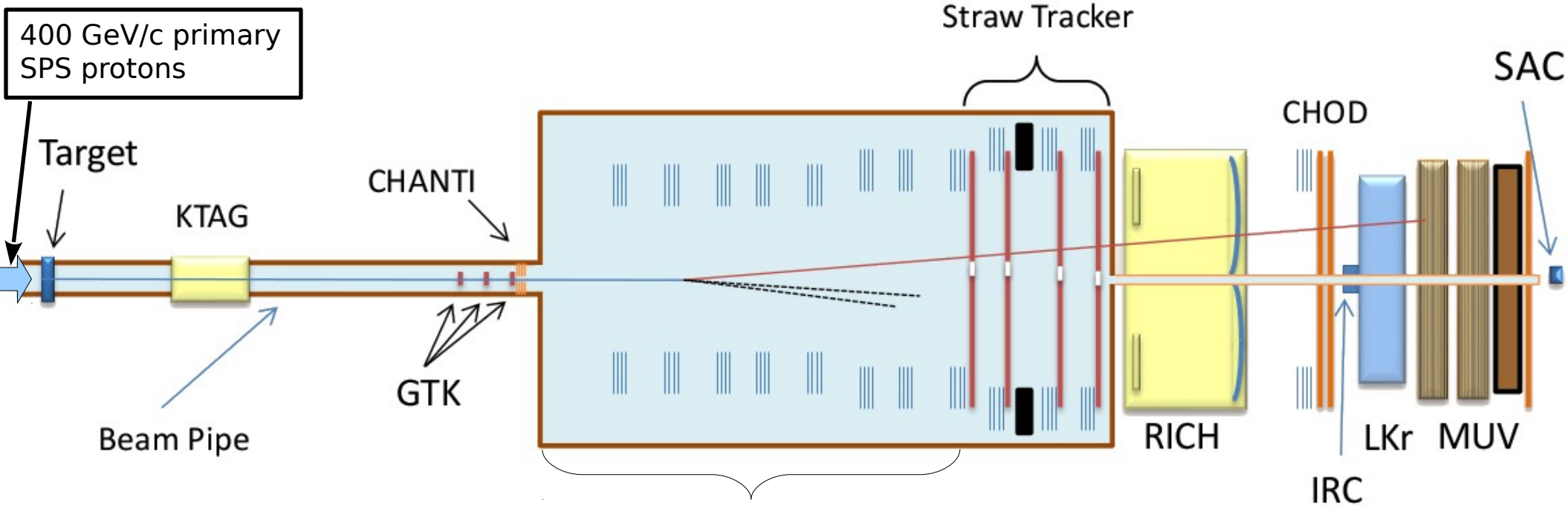
Background rejection at ~ 10^{11} level





The NA62 detector

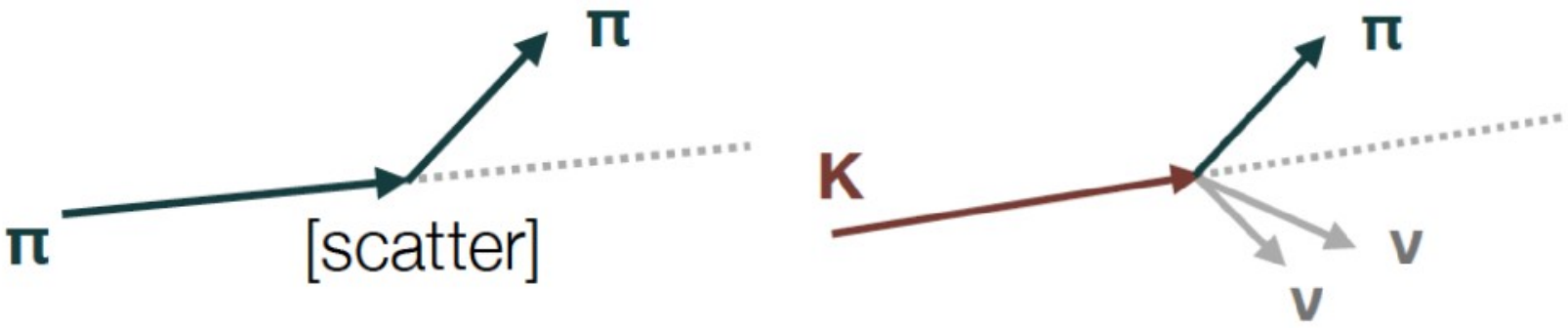
75(±1%) GeV/c unseparated secondary hadron (K / p / π) beam
Kaon decays in flight technique
750 MHz beam; 45 MHz Kaons (~6%); ~10 MHz L0 rate



Total Length 270m

Kaon identification in NA62: Motivations

- Interaction of beam particles in the residual gas in the decay volume:
  → Signature similar to the signal. Negligible if pressure < 10^{-8} mbar (not feasible!)



- Most beam particles (~94%) are not Kaons ("only" 45 MHz out of 750 MHz)

  → <u>Use a detector to identify Kaons within the unseparated beam</u>

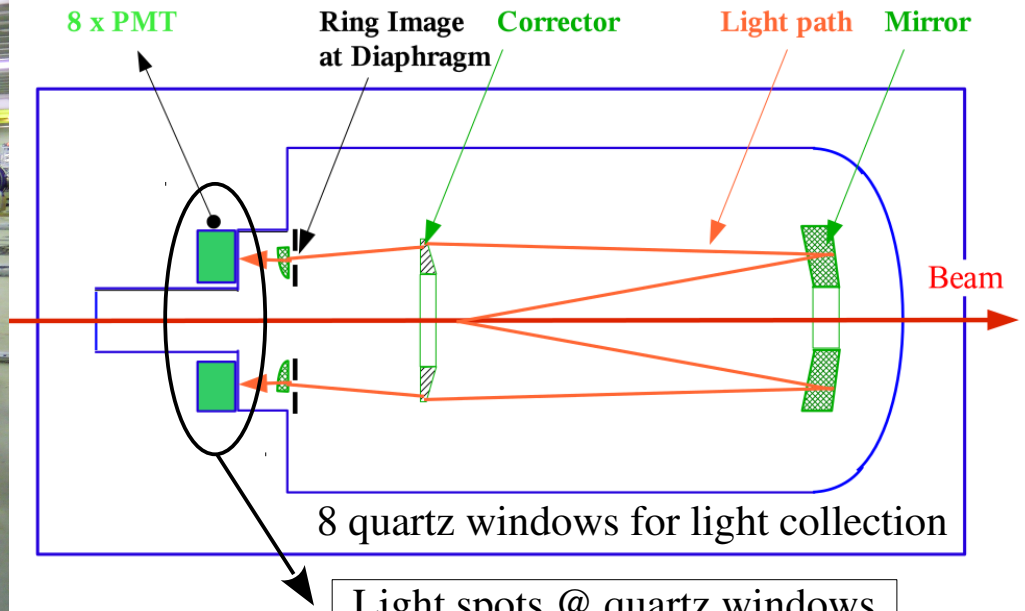
- The Kaon identification must satisfy the following requirements:
  - Kaon identification efficiency of at least 95%
  - Pion mis-identification probability < 10^{-4}
  - Kaon time resolution < 100 ps, to have accidental coincidence with a π at few %
  - Sustain a ~ 45 MHz kaon rate

The CEDAR detector

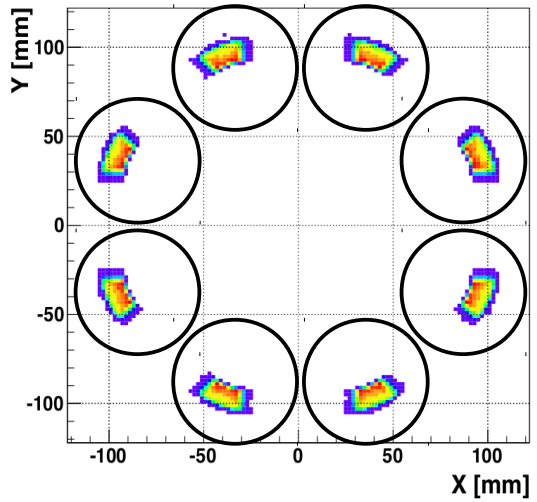
CEDAR: ChErenkov Differential counter with Achromatic Ring focus

CEDAR characteristics:

- 1.1 m³ of Nitrogen @ 1.7 bar as radiator
- Adjustable diaphragm aperture (0 → 20 mm)



Light spots @ quartz windows



Kaon ID system requirements vs CEDAR:

- Kaon ID efficiency of at least 95% ✓
- Pion Mis-ID probability < 10^{-4} ✓
- Kaon Time resolution < 100 ps ✗
- Sustain a ~ 45 MHz kaon rate ✗

The KTAG upgrade

For more details: E. Goudzovski *et al.*, NIM A (2015) 86

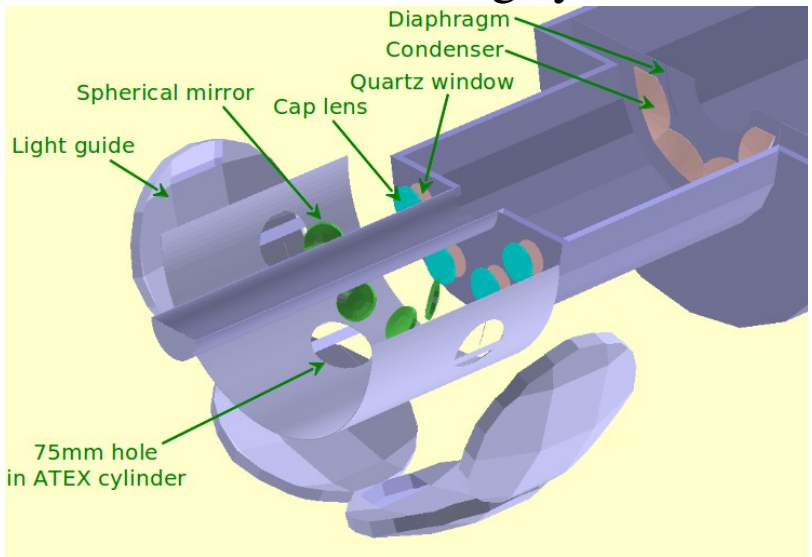
Funded by Grant ERC-2010-AdG Project 268062

KTAG system working conditions:

- Kaon Rate (average) ~ 45 MHz
- Light Yield (@ Quartz Windows) ~ 200 photons/Kaon
- Rate of detected photon on single PMT ~ 4 MHz

KTAG characteristics:

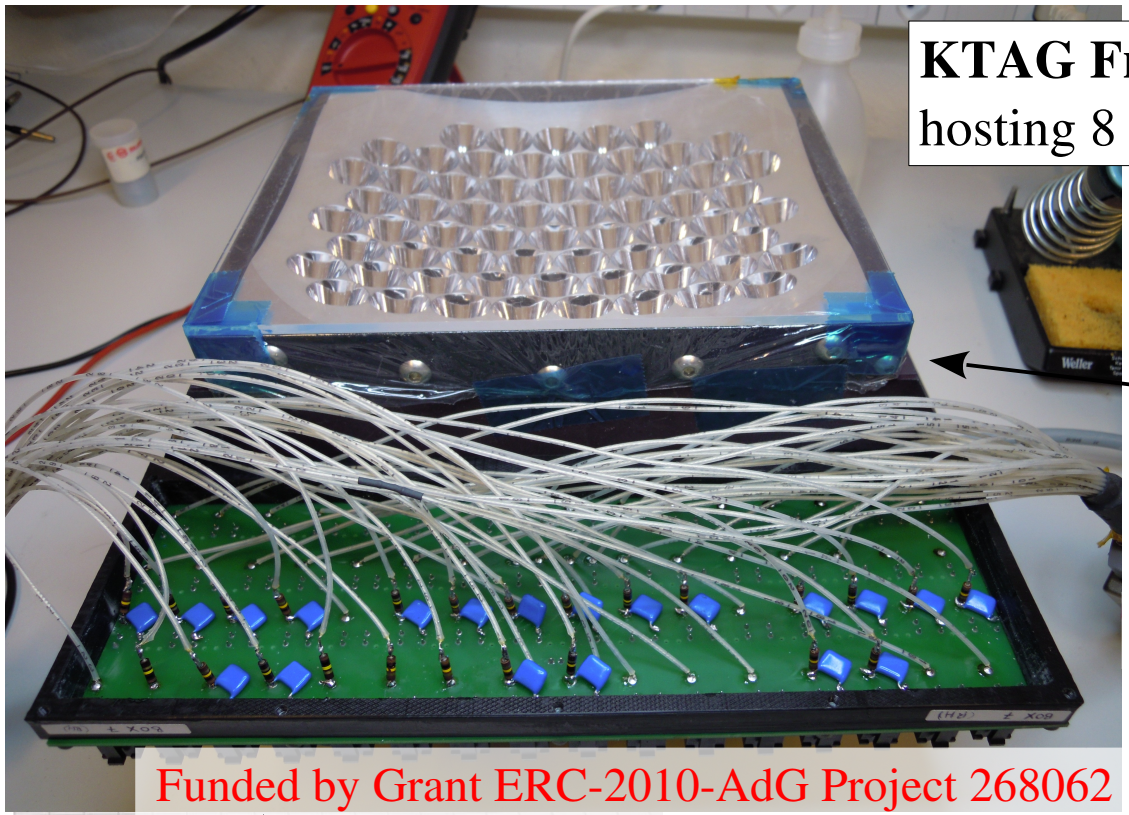
- 8 light boxes with 48 PMTs each (Hamamatsu, 32 R9880-110 + 16 R7400)
- KTAG enclosure flushed with Nitrogen (for possible use of Hydrogen as radiator)
- Electronics water-cooling system



Kaon ID system requirements vs CEDAR/KTAG:

- Kaon ID efficiency of at least 95% ✓
- Pion Mis-ID probability < 10^{-4} ✓
- Kaon Time resolution < 100 ps ✓
- Sustain a ~ 45 MHz kaon rate ✓

The KTAG Electronics



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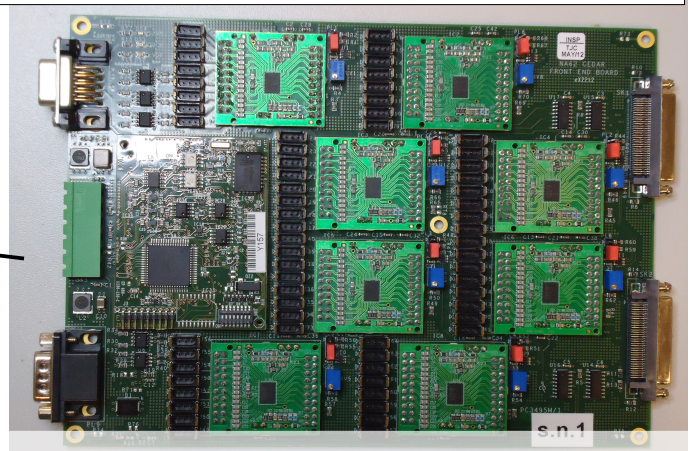
KTAG Front End Board: 64 channels mother board hosting 8 NINO ultra-fast amplifiers/discriminators

1 board inside each lightbox



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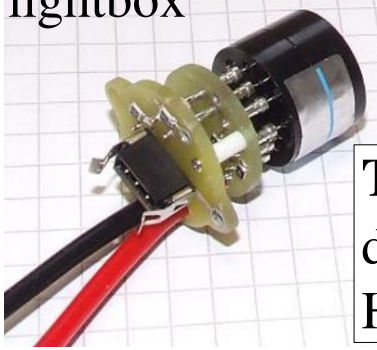
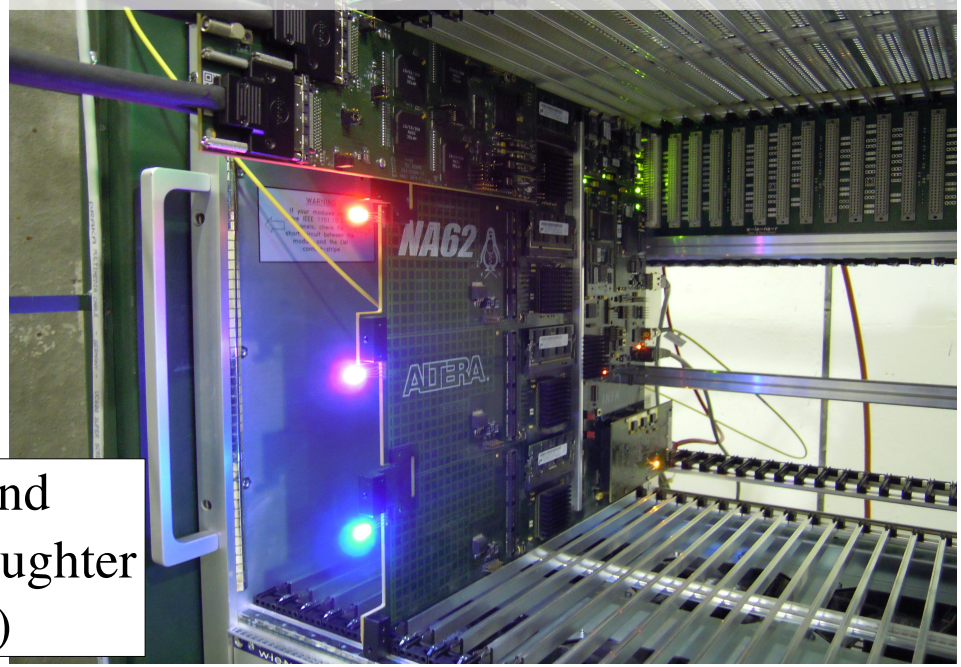
48 PMTs in each lightbox



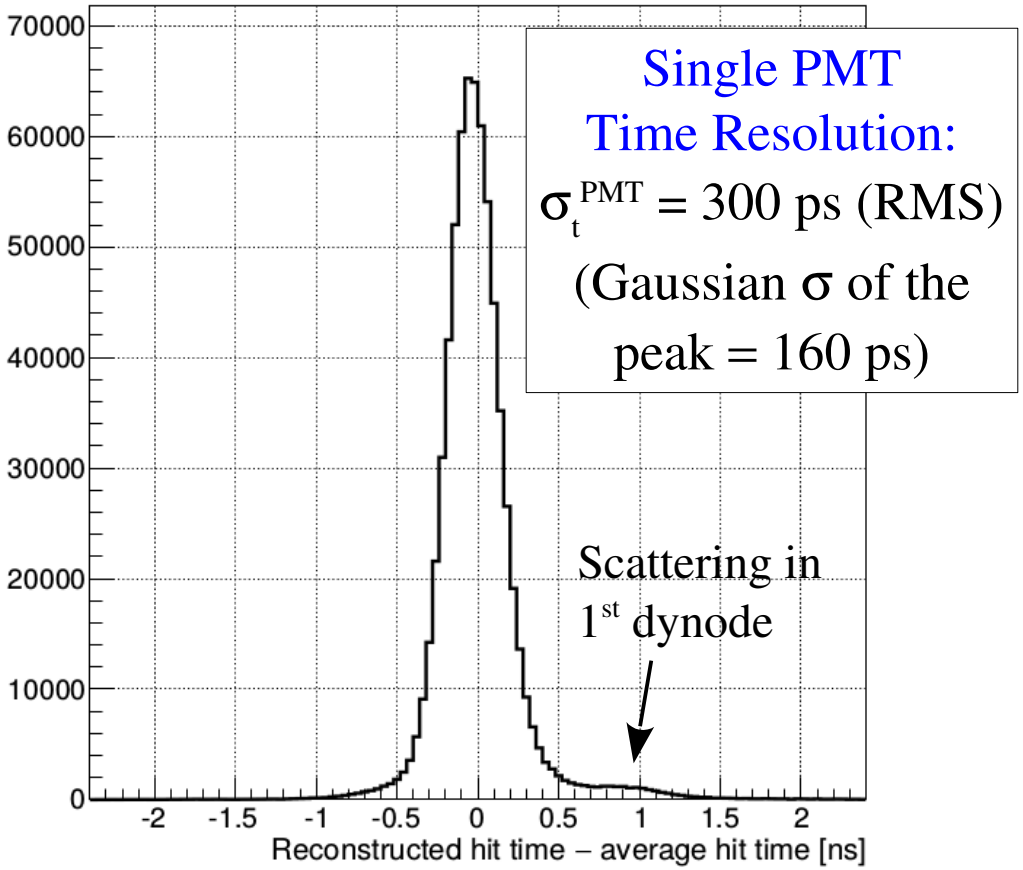
PMT with customised socket:

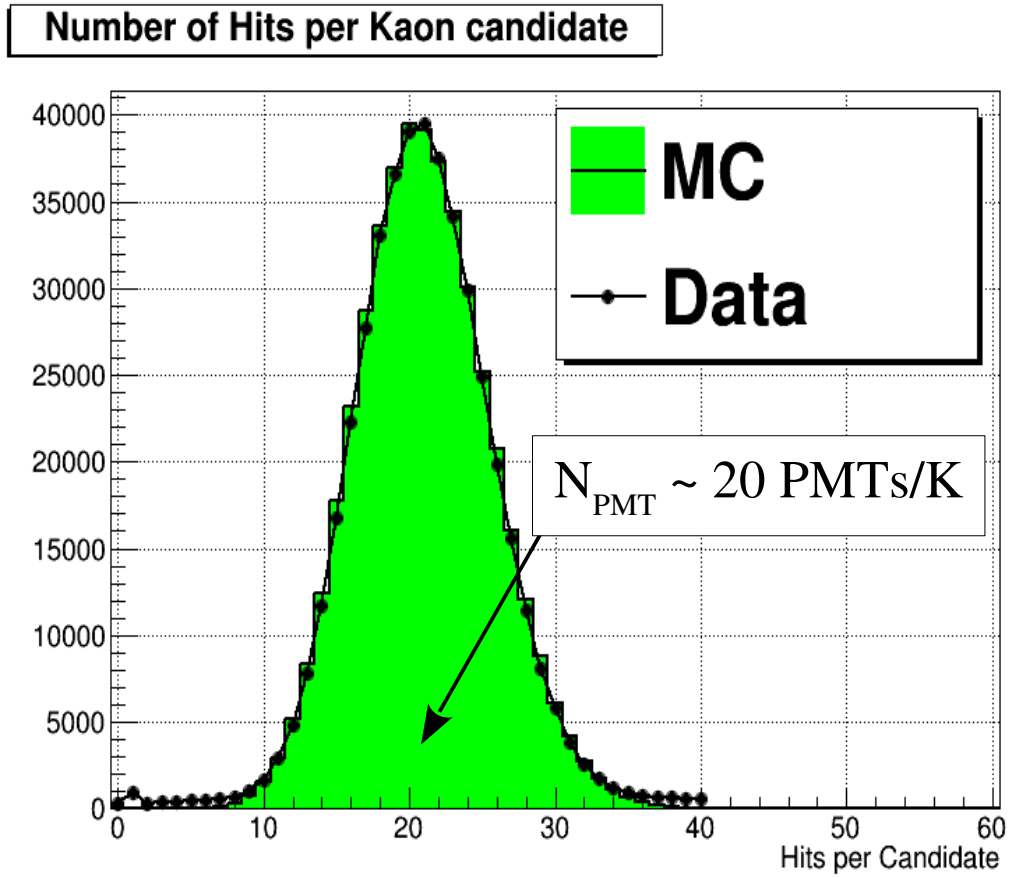
- Differential Output
- Lower power dissipation



TEL62 Board: Integrated trigger and data acquisition board, hosting 4 daughter HPTDC boards (128 channels each)

Kaon Time resolution in NA62





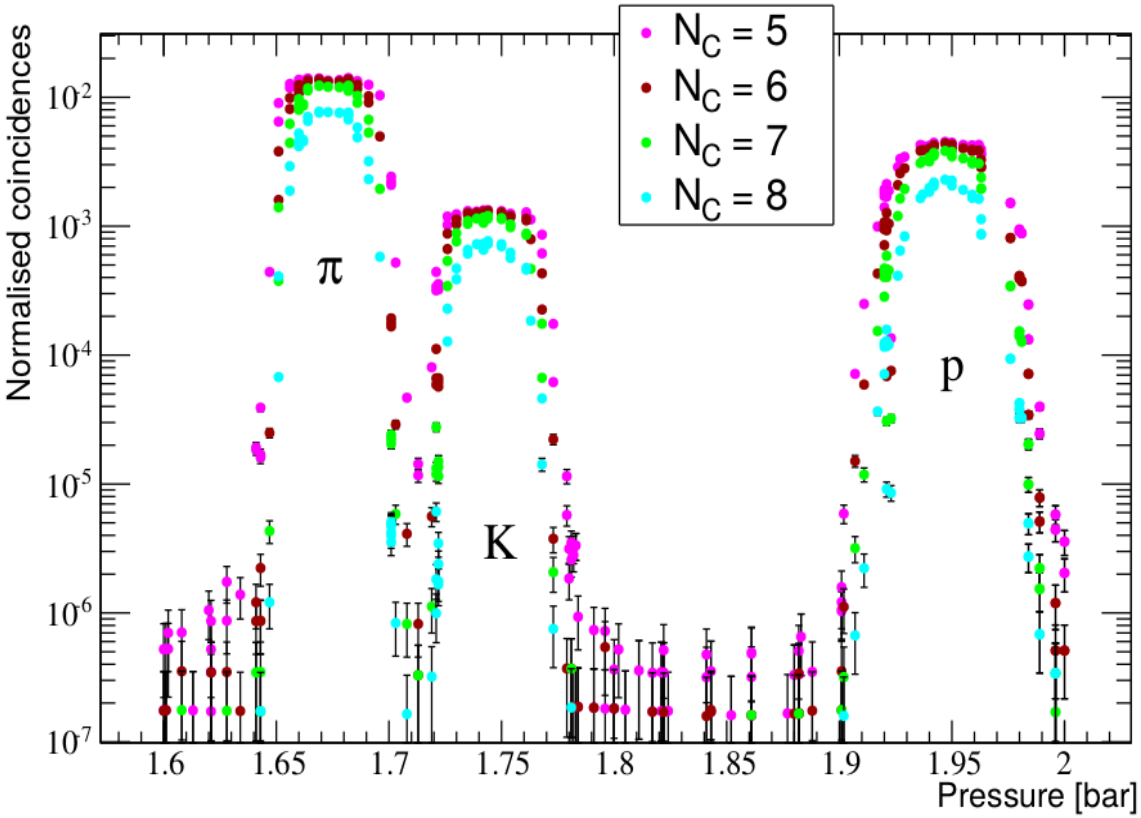
Measured Kaon Time Resolution:

$$\sigma_t^{(K)} = \frac{\sigma_t^{PMT}}{\sqrt{N_{PMT}}} \simeq 70\ ps\,(RMS)$$

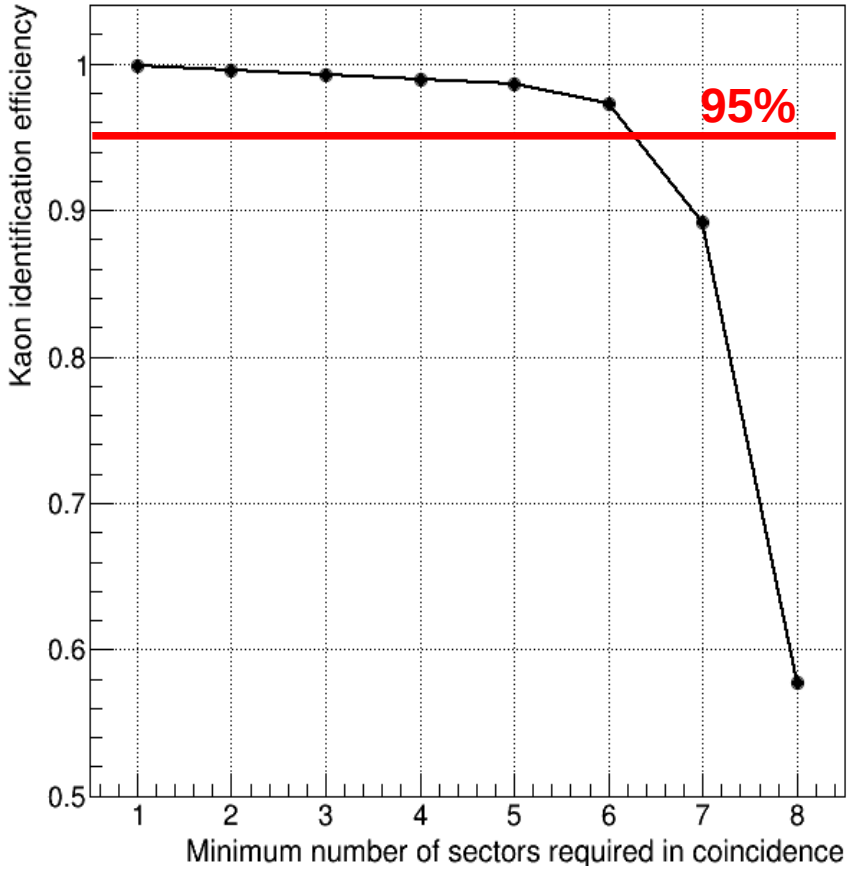
Kaon identification efficiency in NA62

Varying the pressure, the CEDAR is sensitive to the different particle types in the beam

Peak heights are proportional to beam composition



Pressure ~ 1.75 bar set during NA62 data taking



Coincidences	Measured Efficiency
≥ 4	98.9%
≥ 5	98.6%
≥ 6	97.3%
≥ 7	89.2%
8	57.7%

Conclusions

- NA62 beam line fully commissioned, NA62 detector installation completed
- Kaon identification is essential to achieve the proposed level of sensitivity
- The CEDAR/KTAG system provides the Kaon timing to NA62 experiment
- NA62 Kaon identification system preliminary results:
  - Kaon time resolution ~ 70 ps
  - Kaon identification efficiency > 95% for ≥ 6 sectors in coincidence
  - Pion mis-ID probability < 10^{-4} for ≥ 6 sectors in coincidence

  → **Required performances are reached**
- NA62 physics data taking started in 2015, data are being analysed