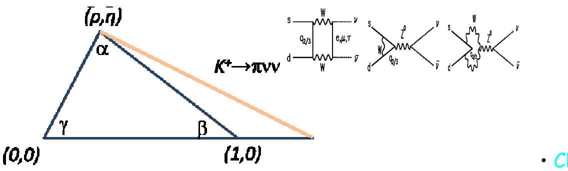
Silicon Photo Multipliers as readout for the NA62 CEDAR Detector

The NA62 Collaboration

(Bern ITP, Birmingham, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Louvain, Mainz, Menlo Park, Merced, Moscow, Naples, Perugia, Pisa, Protvino, Rome I&II, S.Luis Potosi, Sofia, Turin, Vancouver)

THEORY

- $K^+ \to \pi^+ \nu\bar{\nu}$ BR measures one side of CKM triangle
- Theoretical prediction depending on top (dominant) and charm contributions in loops

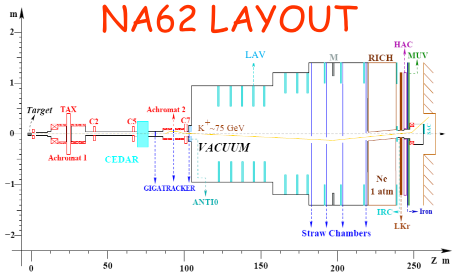


$BR(K^+ \to \pi^+ \nu\bar{\nu})_{THEORY} = (8.22 \pm 0.84) \cdot 10^{-11}$

$BR(K^+ \to \pi^+ \nu\bar{\nu})_{EXP} = (1.73^{+1.15}_{-1.05}) \cdot 10^{-10}$ (7 candidates)

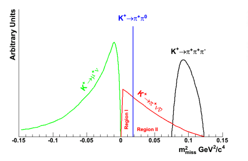
E787/E949, Phys.Rev.Lett.101, 191082(2008)

NA62 LAYOUT

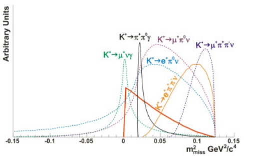


- CEDAR: On-beam Kaon tagging through Cherenkov effect
- GIGATRACKER: hi-res P_K measurement, sub-ns resolution
- VETOES: 12 stations to veto particles from BG decays
- STRAW CHAMBERS: Track momentum at <% resolution

- LKR: γ rejection at $[10^{-3}\text{-}10^{-5}]$ level for $E\gamma$=[2.5-10] GeV
- HAC/MUV: μ^+ reco (MUV), $E(\pi^+)$ deposit analysis (HAC)



Constrained BG (~92%)



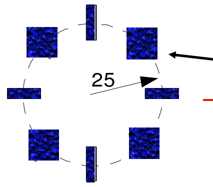
Unconstrained BG (~8%)

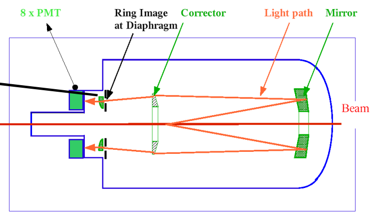
NA62 GOALS

- Collect ~ 100 $K^+ \to \pi^+ \nu\bar{\nu}$ events with ~10% BG in 2 years
- High efficiency in rejecting photons and muons from Kaon decays

CEDAR(ChErenkov Differential counter with Achromatic Ring focus)

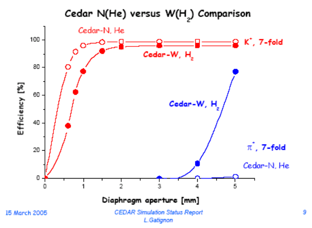
- Used at CERN since 70s to tag on-beam particles
- Optics condenses light into 8 spots (1x3 cm^2 each)
- 6(or 7)/8 spot coincidence





CHANGES FOR NA62:

- Hydrogen filling to reduce multiple scattering
- Readout and electronics to be renewed



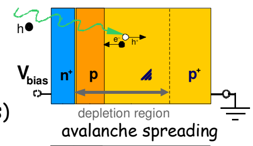
READOUT REQUIREMENTS

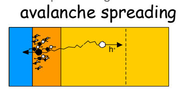
- R_{Kaon} ~50 MHz (R_{TOT}~1 GHz)
- R_γ ~2 MHz/mm^2 (on spots)
- Kaon tag Eff. > 95%
- Contamination < 10^{-6}
- Time resolution < 100 ps

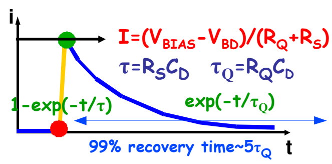
SPAD (Single Photon Avalance Diods)

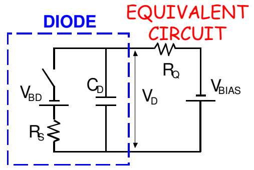
Diodes working in the discharge (Geiger) regime

- Diode Bias V_{BIAS} above V_{BD}
- Photoelectron triggers avalanche
- I quenching through R_Q (>> Rs) required to detect other p.e.
- It is a BINARY (trigger) system
- Gain = $C_D(V_{BIAS}-V_{BD})/q_e$





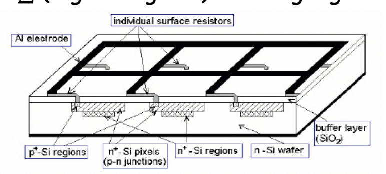


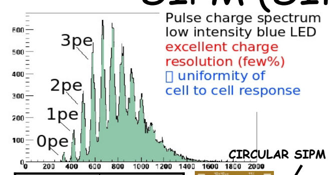


SIPM (SIlicon PhotoMultiplier)

A SIPM is a MATRIX of SPADS

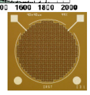
- Single SPADs (cells) independent, give the same signal when hit by a γ
- Several hundred cells/mm^2
- Output charge proportional to Nγ
- Small % of dead surface
- ∑ (digital signals) = analog signal

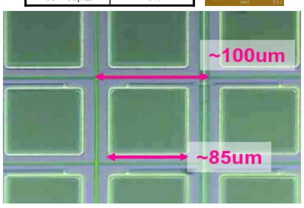




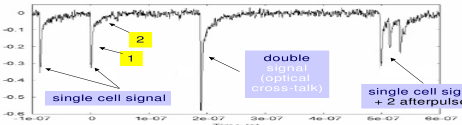
CIRCULAR SIPM

CELL SIZE	FILL FACTOR
40x40 μm^2	44%
50x50μm^2	50%
100x100μm^2	76%





NOISE



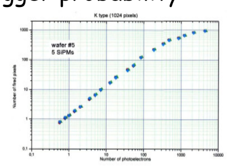
- Dark count: free carriers can trigger avalanches, depends on N_{CELL}/SIPM, R_{DC}~1 MHz
- Afterpulse: Due to carrier releasing by traps, increases with radiation
- Cross-Talk: Signal in a cell triggers neighbour cells

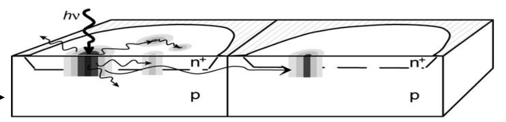
EFFICIENCY

~70% for SIPMs, depends on dead material, quantum eff. and shower trigger probability

DYNAMICAL RANGE

Output proportional to Nγ unless Nγ < $\#_{CELLS}$

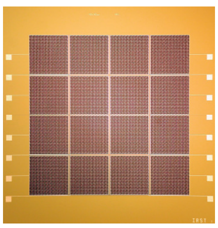




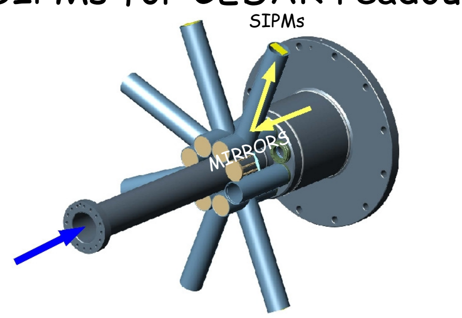
SIPMs for CEDAR readout

Assuming to place on each CEDAR spot a 4x4 matrix of 3x3 mm^2 and 900 channel SIPM one gets:

- PDE x 3 wrt using normal PMs (but SIPMs are less sensible to UV); PDE is a function of spectrum
- 10 Cherenkov photons @ 50 MHz, i.e. 3 photoelectrons/spot, i.e. 10MHz/channel (single γ)
- Detection efficiency for 3 p.e./spot and using 6(7)/8 coincidence method is >> 95%



Even though full recovery time of a single cell is ~100 ns, the high number of channels allows to stand a rate of ~100 MHz/mm^2 (single γ)



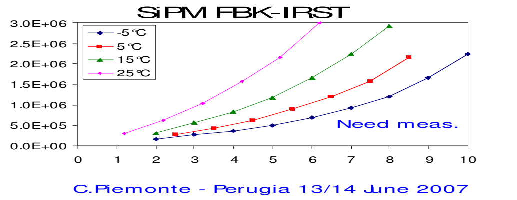
Cherenkov light can be redirected far from the quartz window using mirrors to:

- reduce radiation damages
- concentrate Ch. light on a smaller surface to reduce the SIPM dimensions

NOISE

DARK CURRENT: 500 KHz/mm^2 @ T=300K

- Moderate cooling (T=250/200K) required
- Lower gain (lower V_{BIAS}) to reduce DC
- Larger cells, coincidences among them



AFTER-PULSES: not an issue (+1 MHz/spot)

CROSS-TALK: well below 1%

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