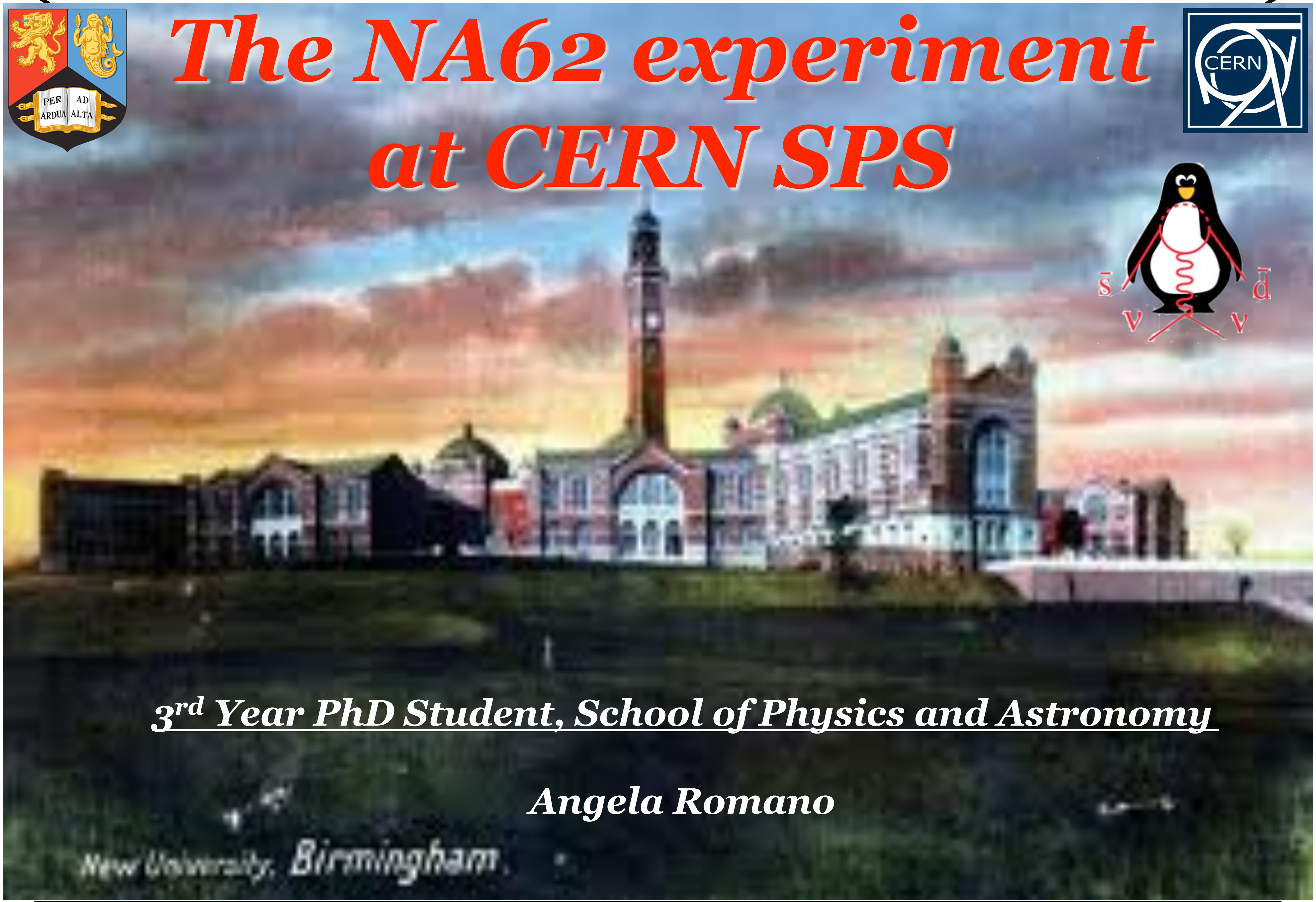
The NA62 experiment at CERN SPS



3rd Year PhD Student, School of Physics and Astronomy

Angela Romano

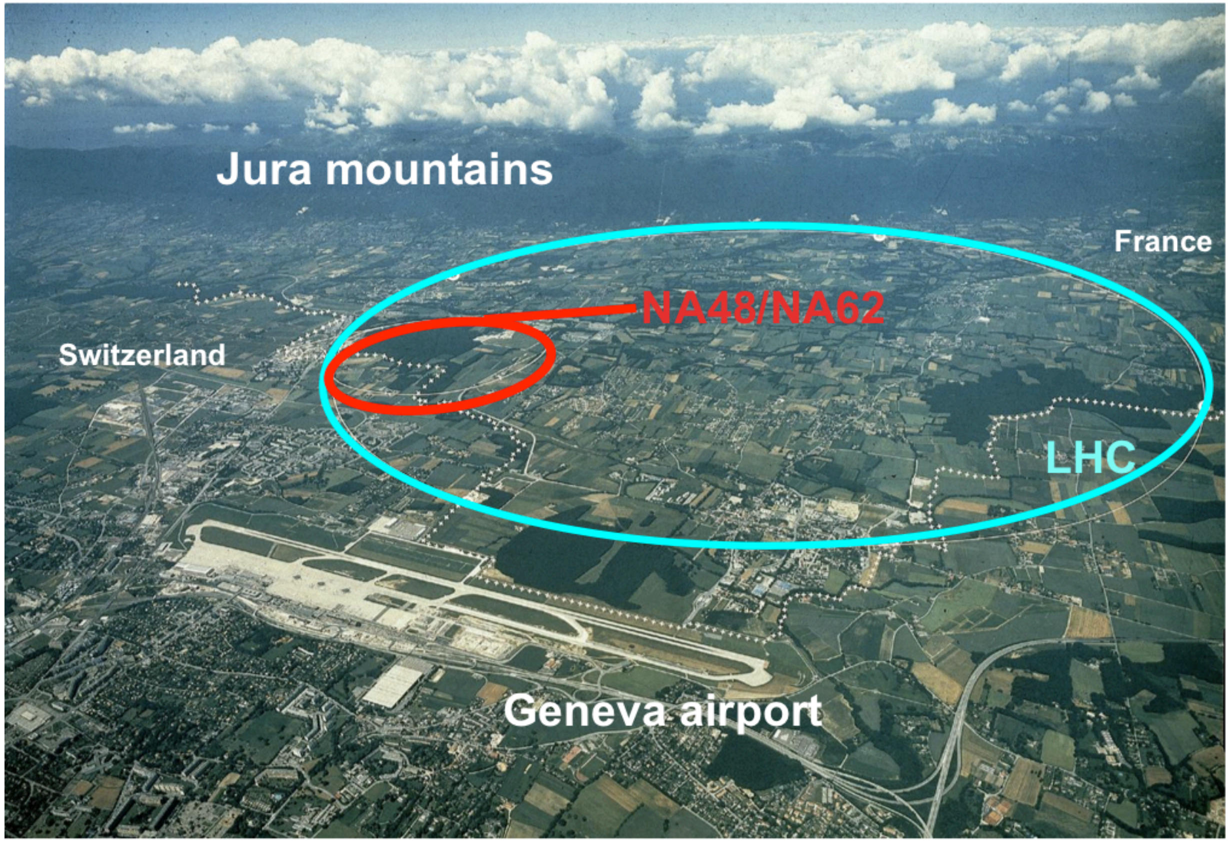
Particle Physics Group Seminar 08/06/11

Outline

- The NA62 collaboration at CERN SPS
- NA62-I: Lepton Flavour Universality Test with $K^+ \to l^+\nu$ Kaon leptonic decays ($l = e,\mu$) **PLB B698 (2011) 105**
- Kaon leptonic radiative decays: $BR(K^+ \to l^+\nu\gamma)$
  - Motivation
  - State of the Art
  - Form Factors Fit
- NA62-II: Ultra Rare Kaon decay Branching Ratio $BR(K^+ \to \pi^+\nu\bar{\nu})$ measurement
- K^+ Identification detector (CEDAR):
  - Application/Usage on NA62-II detector layout
  - Research & Development Status

NA62 at CERN SPS North Area

NA48/NA62 a series of experiments,
present-day CERN Kaon physics programme



NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

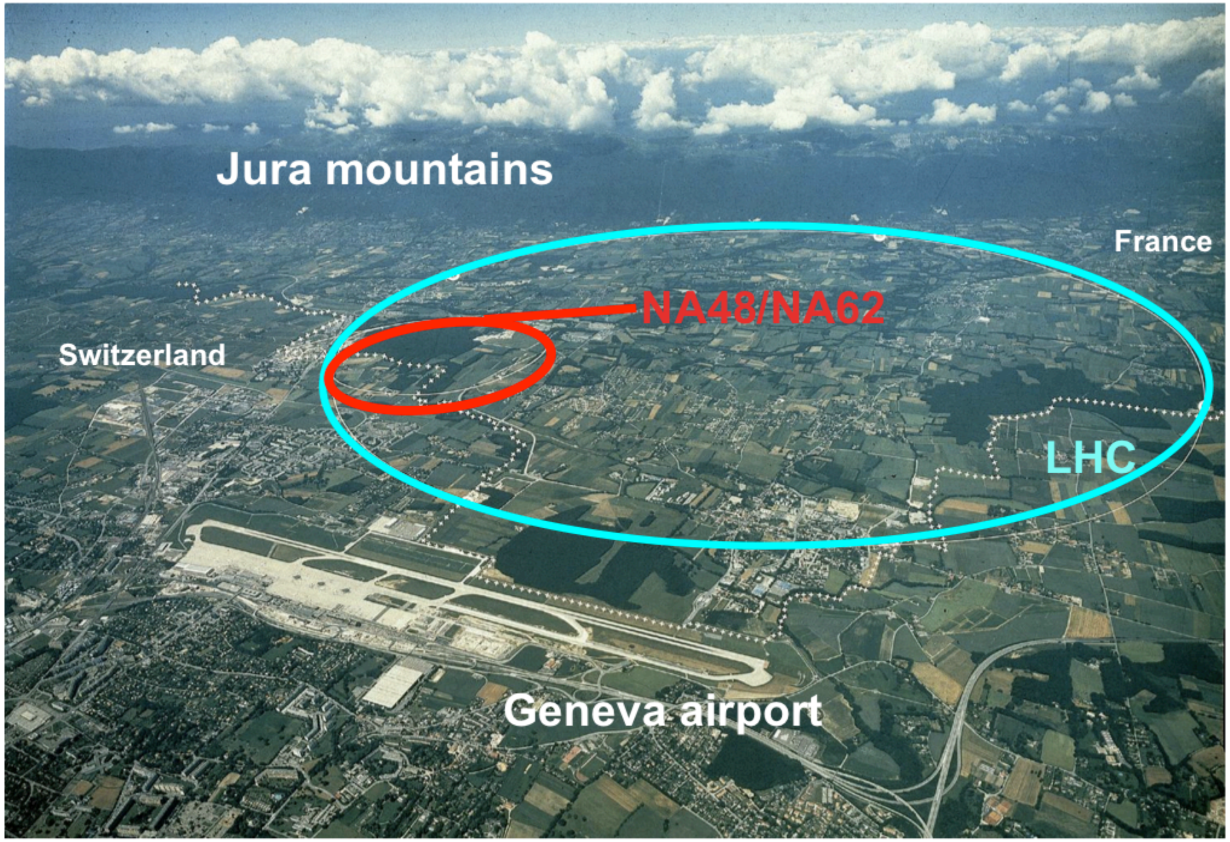
NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

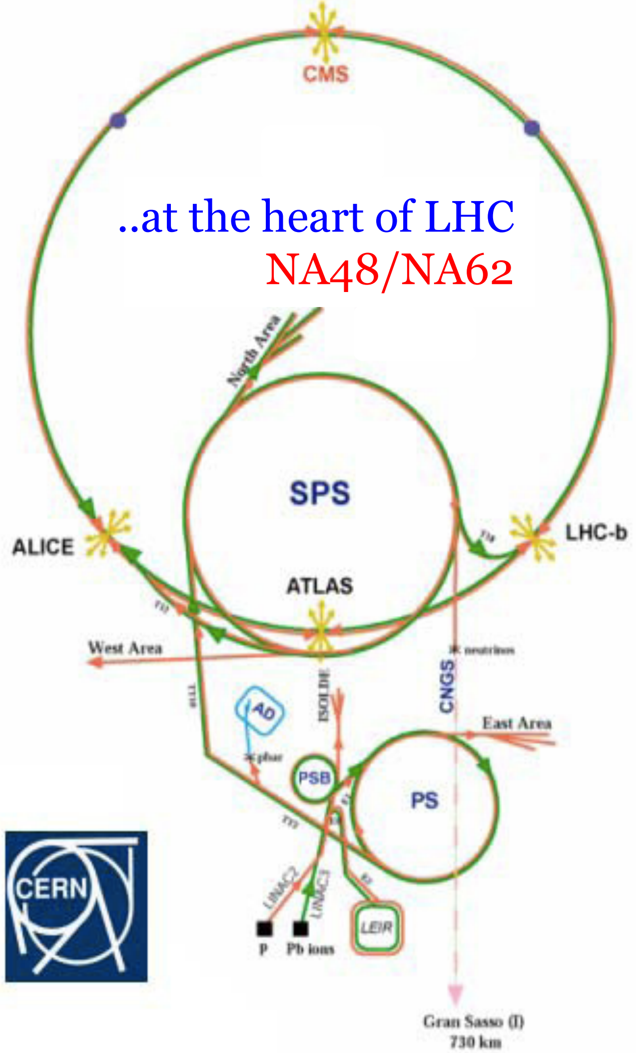
NA62 (phase I)
- 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu2}$
- 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu2}$

NA62 (phase II)
- 2007-2013: design & construction
- 2014-2016: $K^+ \to \pi^+ \nu\bar{\nu}$ data taking

NA62 at CERN SPS North Area

NA48/NA62 a series of experiments, present-day CERN Kaon physics programme





NA62 collaboration:

(Bern ITP, Birmingham, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP Protvino, INR Moscow, Liverpool, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin)

NA62 – I

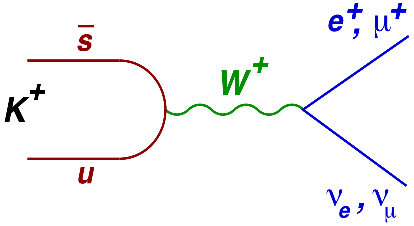
Precision Test of Lepton Flavour Universality with R_K:

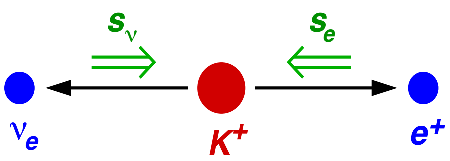
$R_K = \Gamma(K^{\pm} \to e^{\pm}\nu_e)/\Gamma(K^{\pm} \to \mu^{\pm}\nu_{\mu})$

(denoted as: $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$)

R_K in the SM

- Standard Model test
- Hadronic uncertainties cancel in the ratio: $R_K = K_{e2}/K_{\mu 2}$
- Helicity suppression: ~ 10^{-5}





<u>R_K SM expectation</u>:

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)}$$

$$R_K = \underbrace{\frac{m_e^2}{m_\mu^2}}_{\text{Helicity suppression}} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot \underbrace{(1 + \delta R_K^{rad.corr.})}_{\text{Radiative correction (few\%)}}$$

Helicity suppression

Radiative correction (few%)

[V.Cirigliano, I.Rosell JHEP 0710:005 (2007)]

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

Phys. Lett. 99 (2007) 231801

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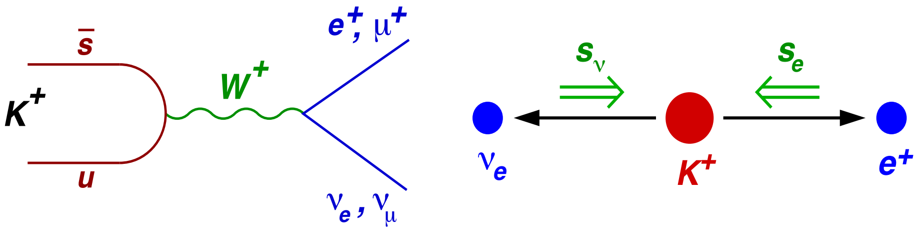

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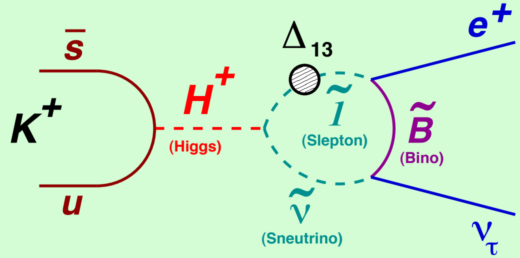
R_K beyond SM

- Indirect search of New Physics
- MSSM scenario: LFV terms (charged Higgs coupling) introduces extra contributions to the SM amplitude
- Up to 1% variation

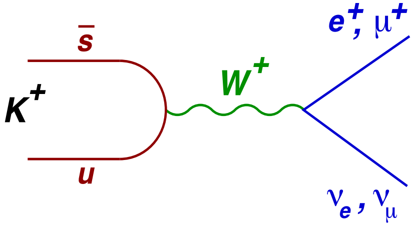


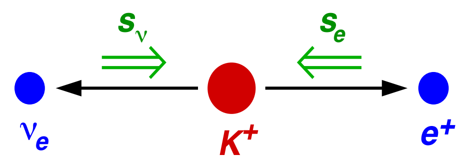
PRD 74 (2006) 011701,JHEP 0811 (2008) 042

$$R_K^{LFV} \approx R_K^{SM}\left[1 + \left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_{13}|^2 \tan^6 \beta\right]$$

R_K in the SM

- ➢ Standard Model test
- ➢ Hadronic uncertainties cancel in the ratio: $R_K = K_{e2}/K_{\mu 2}$
- ➢ Helicity suppression: ~ 10^{-5}





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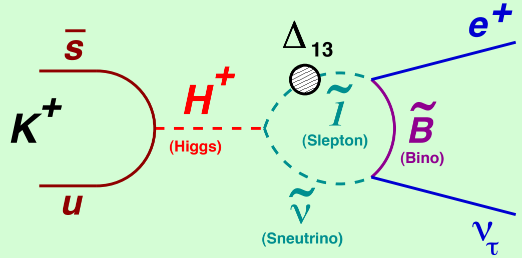

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$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

Phys. Lett. 99 (2007) 231801

Experimental status:

- ➢ PDG'08 average (1970s measurements): -> $R_K = (2.45 \pm 0.11) \times 10^{-5}$ ($\delta R_K/R_K = 4.5\%$)
- ➢ Recent improvement KLOE (Frascati): -> $R_K = (2.493 \pm 0.031) \times 10^{-5}$ ($\delta R_K/R_K = 1.3\%$)

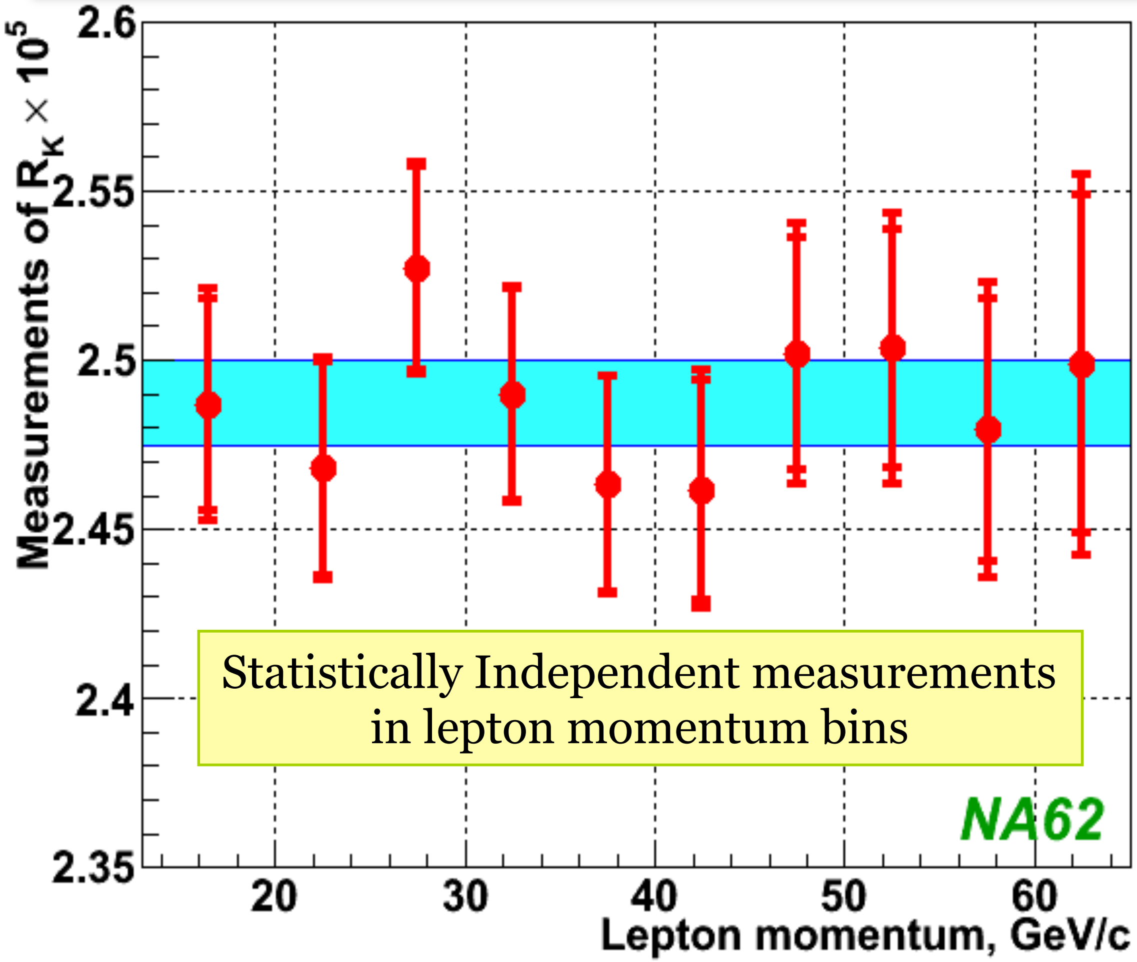
(EPJ C64 (2009) 627)

NA62 - I goal: measurement of R_K with accuracy level below 1% (~0.5%)

NA62-I Result (40% data set)

$R_K = (2.487 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5}$
$= (2.487 \pm 0.013) \times 10^{-5}$

Recently published: PLB B698 (2011) 105



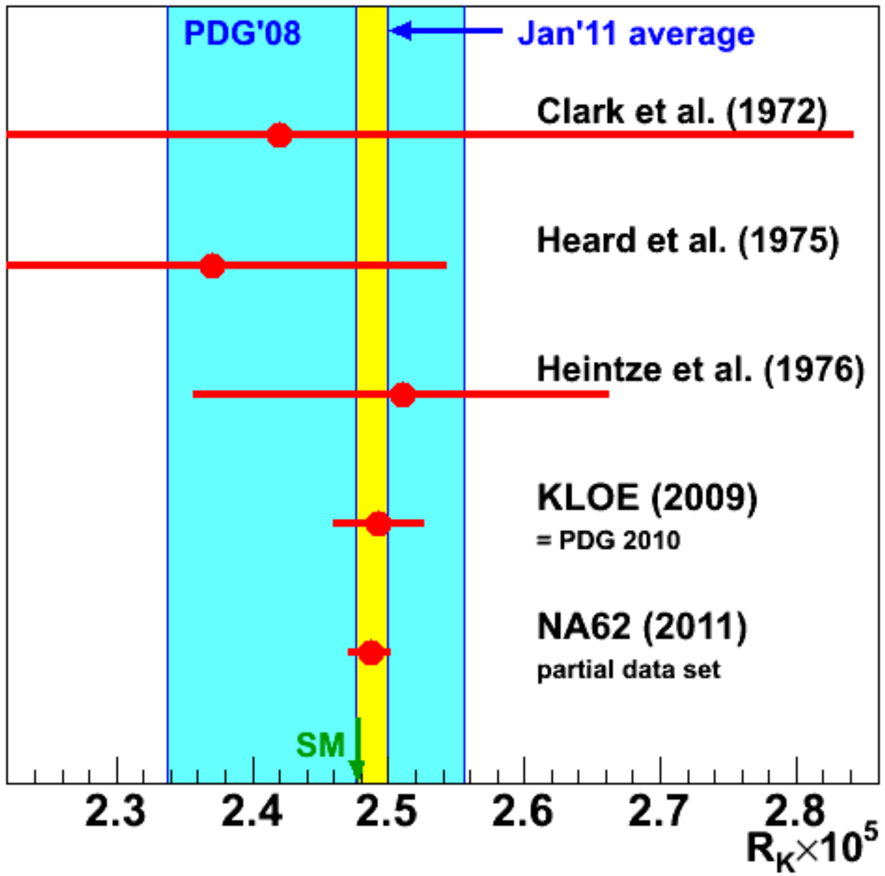
(systematic errors included, partially correlated)

Uncertainties

Source	$\delta R_K \times 10^5$
Statistical	0.011
$K_{\mu 2}$	0.005
$BR(K^+ \to e^+ \nu\gamma\ (SD^+))$	0.001
Helium purity	0.003
Beam halo	0.001
Acceptance	0.002
DCH alignment	0.001
Positron ID	0.001
Lkr readout ineff	0.001
1-track trigger	0.002
Total	0.013

(0.5% precision)

R_K: world average

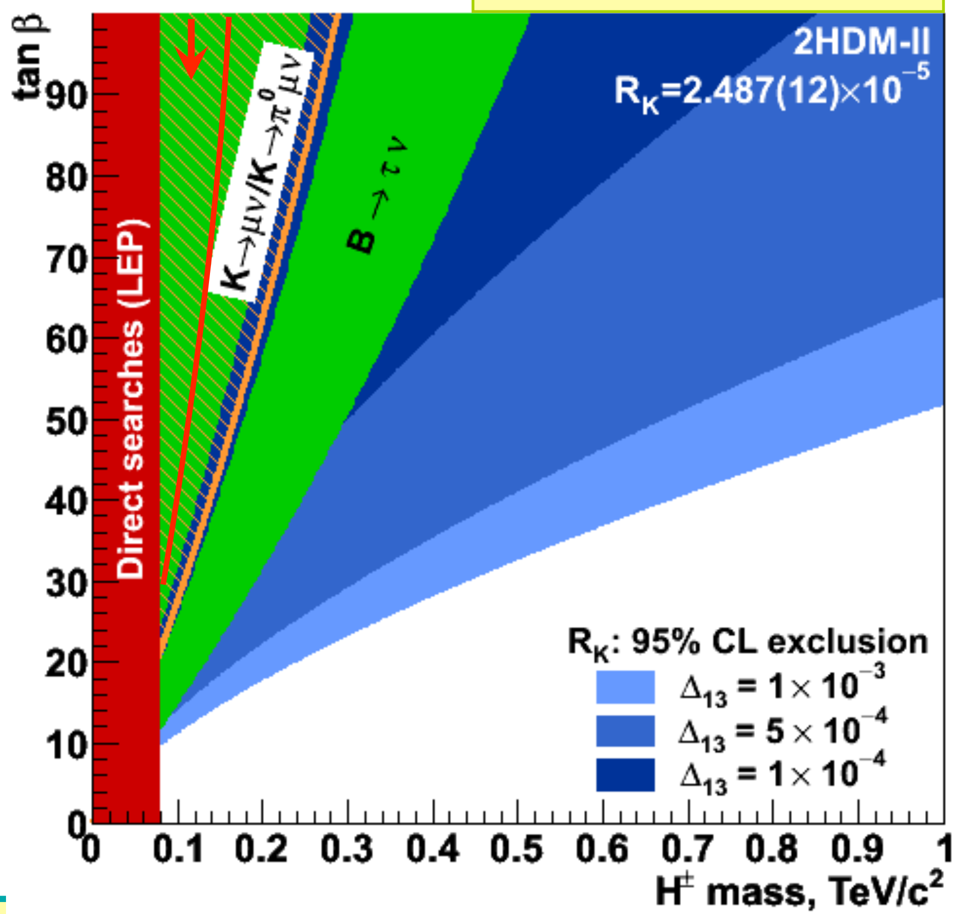


World average	$\delta R_K \times 10^5$	Precision
PDG 2008	2.447±0.109	4.5%
January 2011	2.487±0.012	0.48%

R_K measurements are currently in agreement with the SM expectation at ~1σ.

Tevatron Run II

95% exclusion limits



Any significant enhancement with respect to the SM would be evidence of new physics.

Kaon Leptonic Radiative decay:

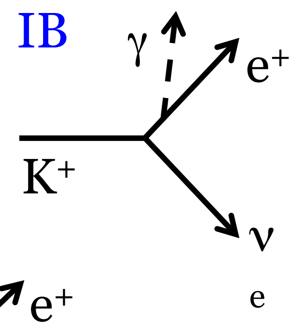
$K^+ \rightarrow e^+ \nu \gamma$ ($K^+_{e2\gamma}$)

$K^{+}_{e2\gamma}$: Theory

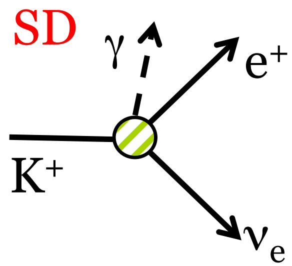
Amplitude M of the decay $K^{+}_{e2\gamma}$ written in terms of three contributions:

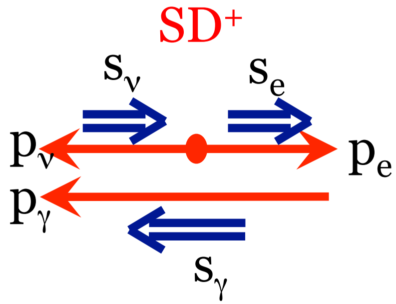
$M = M_{IB} + M_{SD} + M_{INT}$

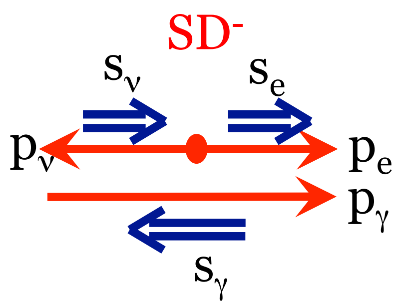
1. "Inner Bremsstrahlung" (IB) component
   - Photon emitted by e^{+} (external leg);
   - Helicity suppressed (e^{+}=R, ν=L for m_e->0);
   - α and **(V-A)** structure as in K_{e2};



2. "Structure Dependent" ($SD^{\pm}$) components
   - Photon emitted at the K^{+} decay vertex;
   - Two non-interfering contributions: positive & negative γ helicity;
   - No helicity suppressed;
   - **(V±A)** structures contributing;







3. Interference ($INT^{\pm}$) components
   - IB & $SD^{\pm}$ interfering contributions;
   - $M_{INT} \propto (m_e/m_K)^2$;
   - Negligible due to the small electron mass;

$K^+_{e2\gamma}$: Motivation & Goal

- SM Test to the Next-to-Leading Order (NLO) in chiral expansions (ChPT $O(p^4)$, ChPT $O(p^6)$) ; (NPB396 (1993) 81)
- Model independent extractions of theoretical Form Factors (FFs);
- Independent measurement with a different technique wrt the one performed by KLOE; (EPJC64 (2009) 627)
- SD^+ component: "key" ingredient for the estimate of the R_K background; (PLB B698 (2011) 105)

Analysis Goals (SD^+ component):

1. Model-independent Decay rate $d^2\Gamma/dxdy$ & Branching Ratio $BR(K^+_{e2\gamma})$ in the kinematic region of interest;
2. Parameters of the model: SD^+ Form Factors; (precision test for ChPT $O(p^6)$);

$K^+_{e2\gamma}$: Kinematics

In the K^+ rest frame, the Kinematics of $K^+_{e2\gamma}$ can be described by two conventional, dimensionless quantities:

$$x = \frac{2E^*(\gamma)}{M_K}; \qquad y = \frac{2E^*(e)}{M_K};$$

$E^*(e)$, $E^*(\gamma)$: electron and photon energy in K^+ rest frame

with their physical allowed regions being:

$$0 \le x \le 1 - r_e; \quad 1 - x + \frac{r_e}{1-x} \le y \le 1 + r_e;$$

where, $r_e = (m_e/m_K)^2$

$$\rho(x,y) = \frac{d^2\Gamma(K^+_{e2\gamma})}{dxdy} = \underbrace{\rho_{IB}(x,y)}_{\text{helicity suppressed}} + \rho_{SD^\pm}(x,y) + \underbrace{\rho_{INT^\pm}(x,y)}_{\text{negligible}}$$

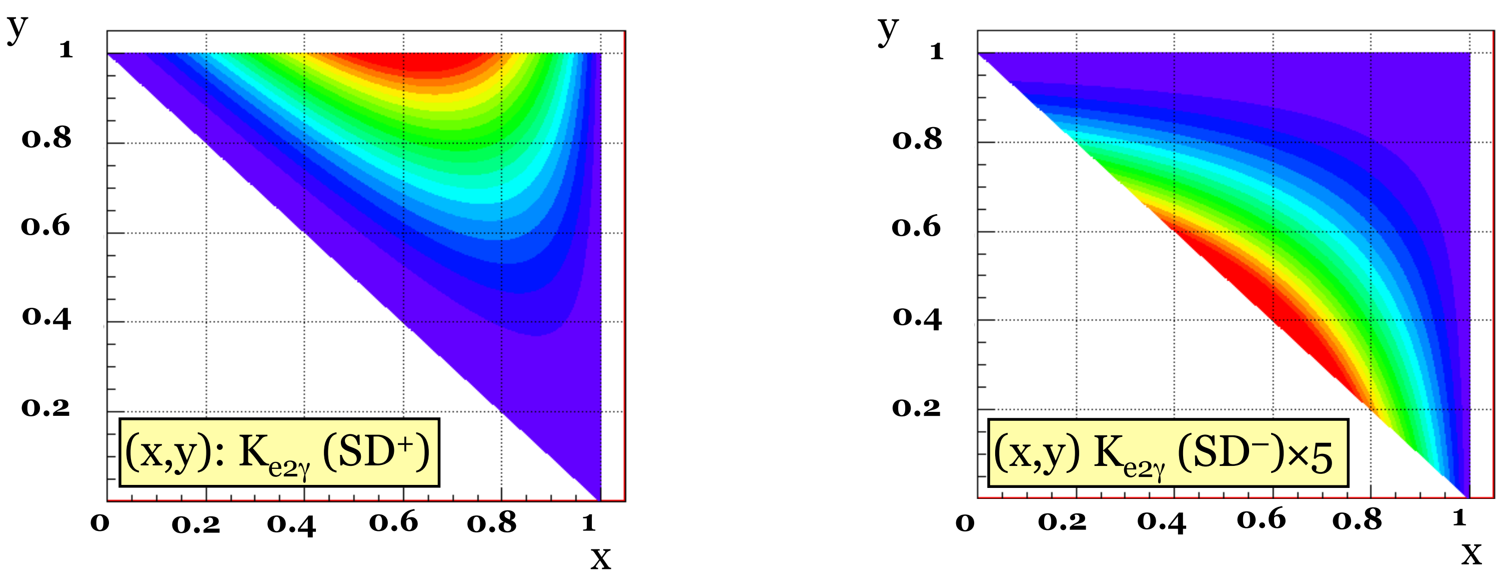
$K^+_{e2\gamma}(SD^+)$: Kinematics

$$\rho_{SD^\pm}(x,y) = \frac{G_F^2|V_{us}|^2\alpha}{64\pi^2} M_K^5[(V+A)^2 f_{SD^+}(x,y) + (V-A)^2 f_{SD^-}(x,y)]$$

V, A: model-dependent vector and axial-vector effective couplings

$$f_{SD^+}(x,y) = (1-x)(x+y-1)^2; \qquad f_{SD^-}(x,y) = (1-x)(1-y)^2;$$

SD^- component is smaller and beyond the kinematical region of the analysis;



$K^+_{e2\gamma}(SD^+)$: Experimental Status & Background

KLOE result (2009):

- ✓ N_{evt}=1484 (p_e>200 MeV/c, in K^+ rest frame)
- ✓ $\Gamma(K_{e2\gamma})/\Gamma(K_{\mu 2}) = (1.438 \pm 0.066_{stat} \pm 0.013_{syst})\times 10^{-5}$
- ✓ $|V+A| = 0.125 \pm 0.007_{stat} \pm 0.001_{syst}$

KLOE measurement of V+A leads to
BR(SD^+, full phase space) = $(1.37\pm 0.06)\times 10^{-5}$
(EPJC64 (2009) 627)

Main Backgrounds:

- ✓ $K^+ \to e^+\pi^0\nu$ (K_{e3}) decay: $\Gamma(K_{e3})/\Gamma(K_{e2\gamma}) \sim 3000$;

  K_{e3} can mimic $K_{e2\gamma}$ decay if the positron is energetic and one photon from the $\pi^0 \to \gamma\gamma$ decay is undetected;
- ✓ $K^+ \to \pi^+\pi^0$ ($K_{2\pi}$) decay: $\Gamma(K_{2\pi})/\Gamma(K_{e2\gamma}) \sim 12000$;

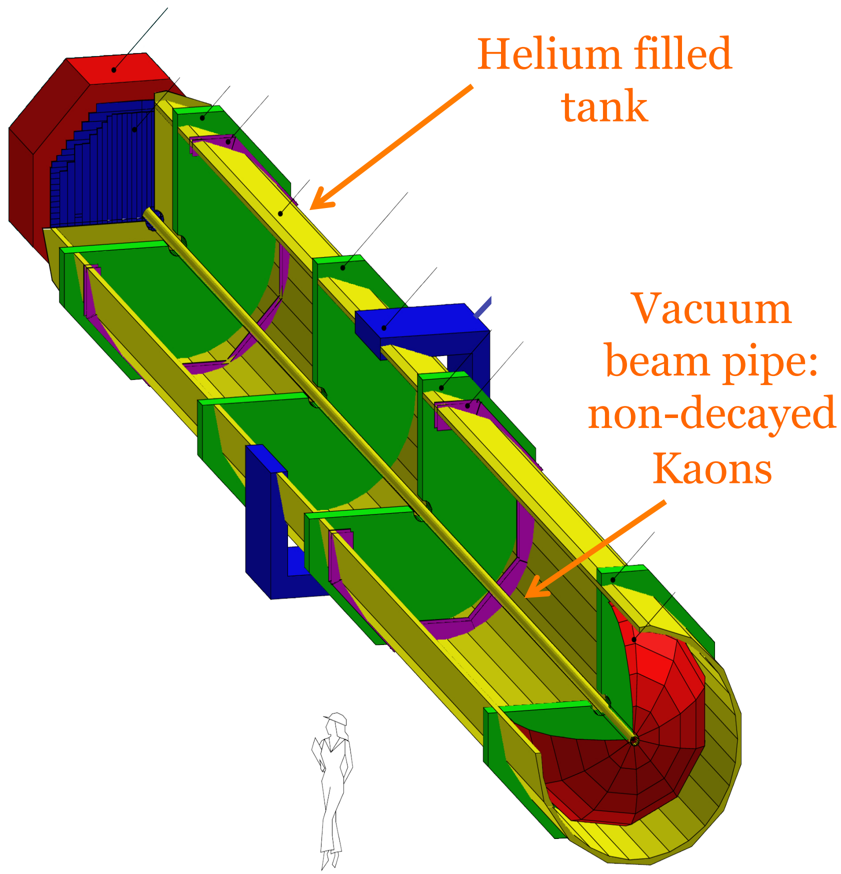
  $K_{2\pi}$ can mimic $K_{e2\gamma}$ decay if the pion is mis-ID as a positron (~10^{-3} probability) and one photon from the $\pi^0 \to \gamma\gamma$ decay is undetected;

Data Taking and Detector

- Four months in 2007:
  ~ 400K SPS spills, 300TB of raw data
- Two weeks in 2008:
  special data sets allowing reduction of the systematic uncertainties.

Principal subdetectors (NA48 beam line):

Secondary Beam composition:
$K^{+}(\pi^{+}) = 5\%(63\%)$



Decay volume is upstream

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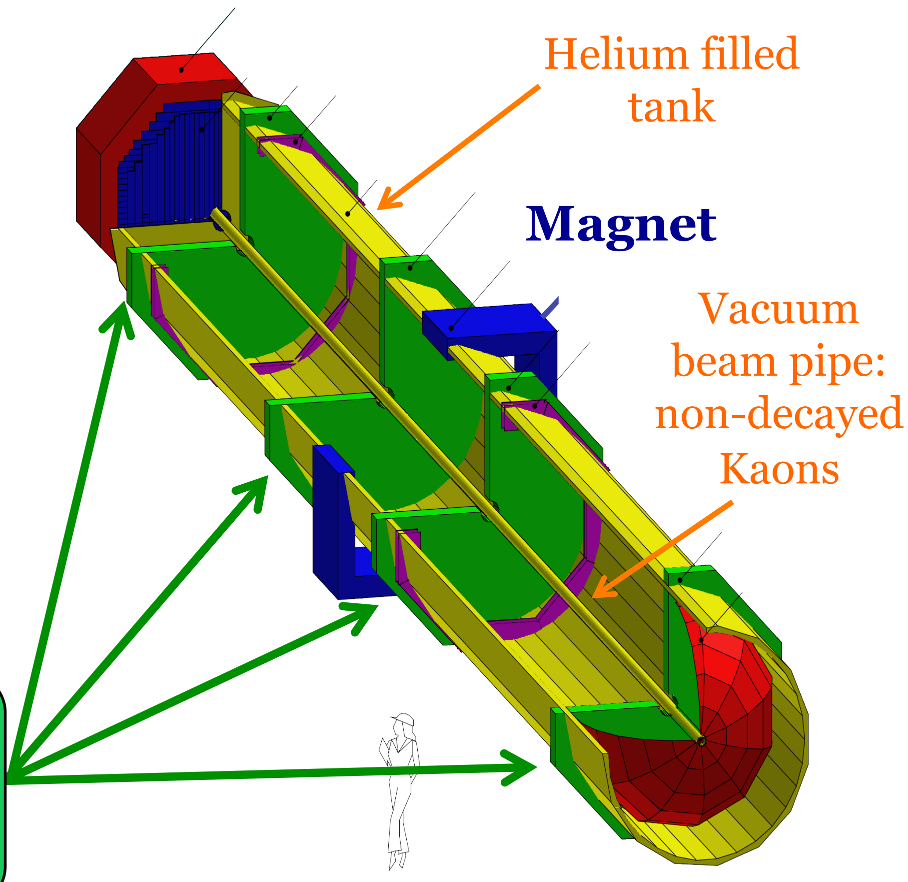

Spectrometer (4 DCHs + Magnet):
4 views/DCH ⇒ high efficiency;
$\sigma_p/p = 0.47\% + 0.02\% \cdot p$ [GeV/c]

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Principal subdetectors:

Hodoscope:
fast trigger, precise time measurement (150ps)

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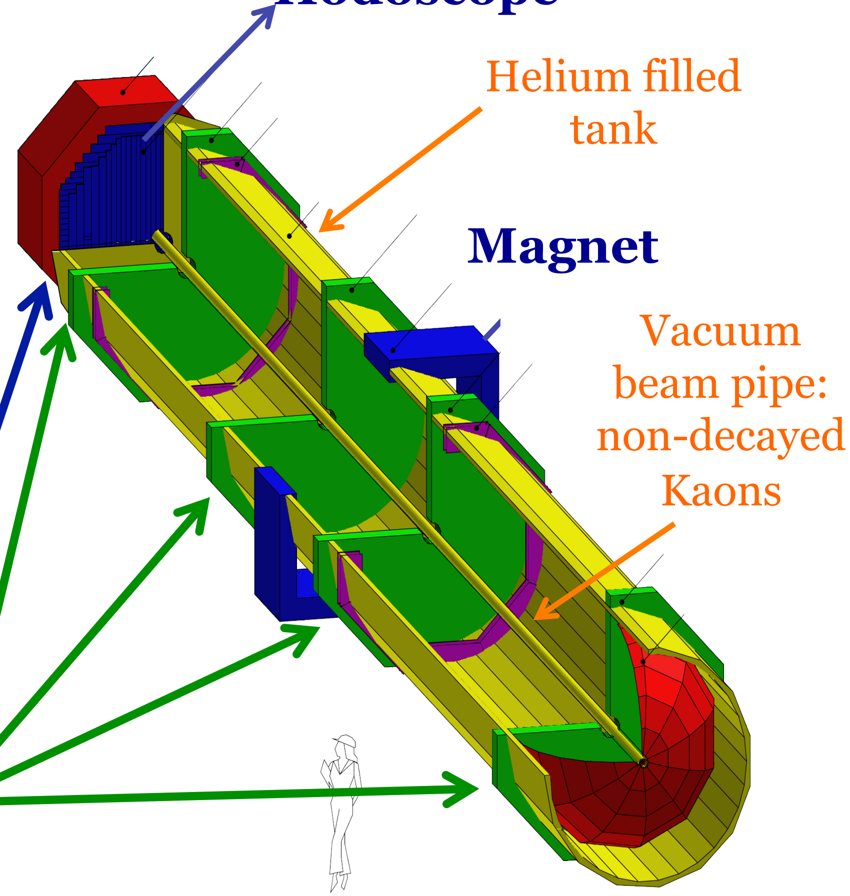

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Data Taking and Detector

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- <u>Two weeks in 2008:</u>
  special data sets allowing reduction of the systematic uncertainties.

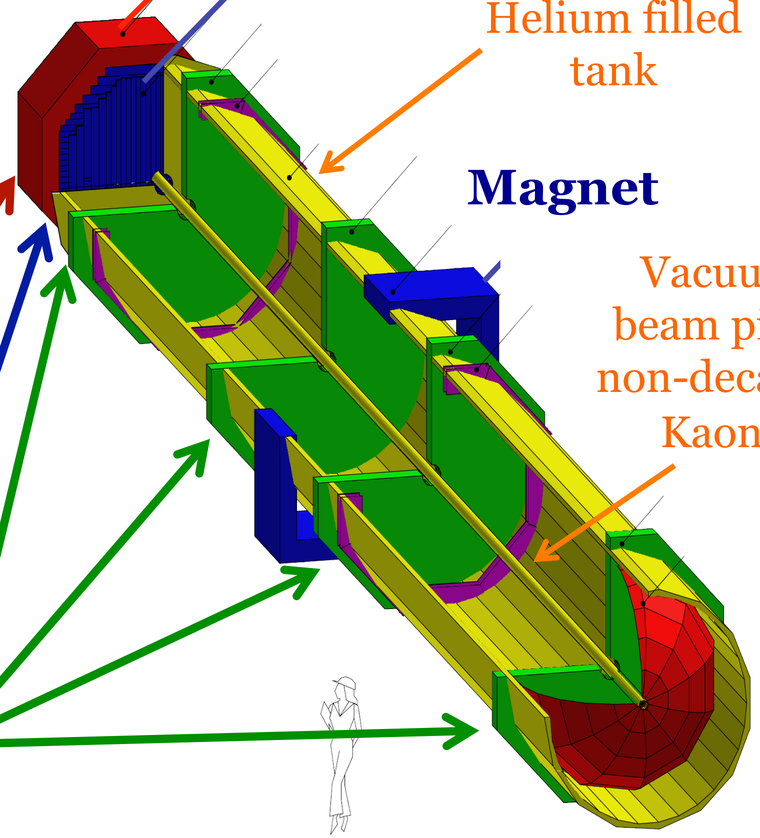
Secondary Beam composition:
$K^+(\pi^+) = 5\%(63\%)$

Principal subdetectors:

Liquid Krypton EM calorimeter (LKr):
High granularity, quasi-homogeneous;
$\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]
$\sigma_x=\sigma_y=0.42/\sqrt{E} + 0.6$mm (1.5mm@10GeV)

Hodoscope:
fast trigger, precise time measurement (150ps)

Spectrometer (4 DCHs + Magnet):
4 views/DCH ⇒ high efficiency;
$\sigma_p/p = 0.47\% + 0.02\%\cdot p$ [GeV/c]



Decay volume is upstream

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$K^+ \to e^+\nu\gamma$ (SD^+)

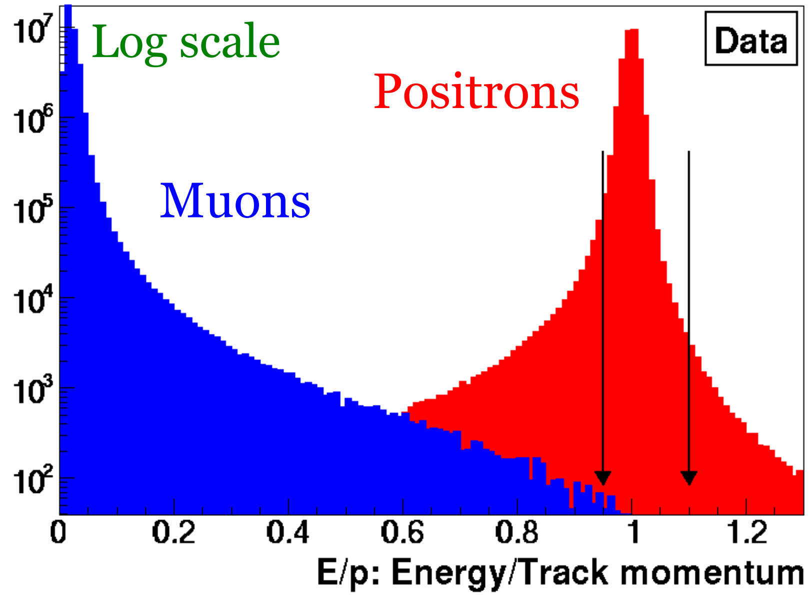
Analysis Strategy

$K^+ \to e^+\nu\gamma$ (SD^+) selection

Positron Selection:

Common part with Ke2:

- one reconstructed track;
- positive charge;
- geometrical acceptance cuts;
- K decay vertex: closest distance of approach between track & kaon axis;
- $0.95 < E/p < 1.10$ (positron);
- track momentum: $10 GeV/c < p < 55 GeV/c$

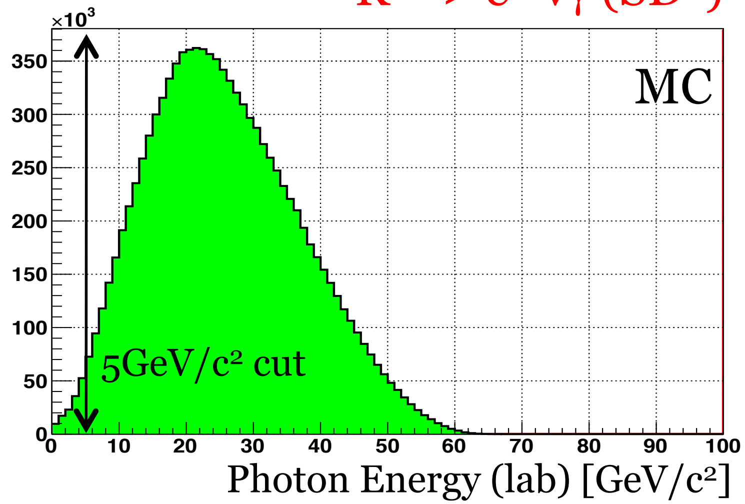


Photon Selection:

Specific part for radiative decay:

- one extra LKr energy deposition cluster;
- isolated and good;
- LKr geometrical acceptance cuts;
- in time with the track;
- photon energy: $E > 5\ GeV/c^2$

$K^+ \to e^+ \nu\gamma$ (SD^+)



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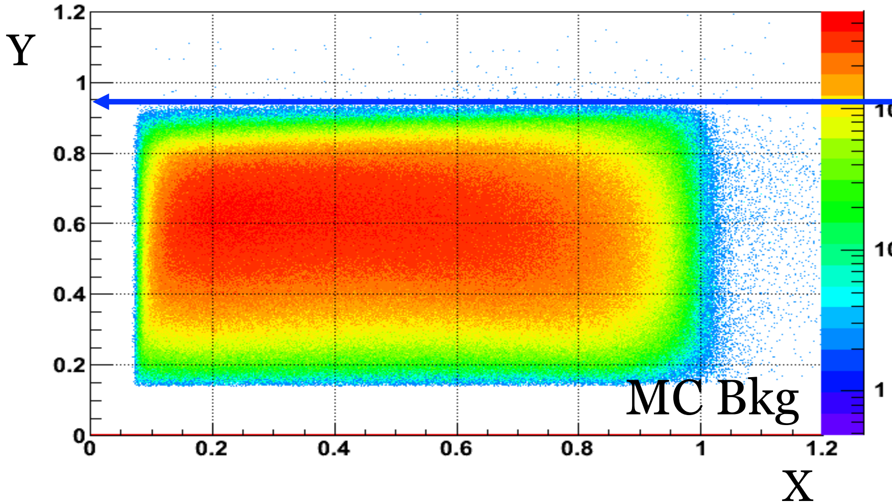
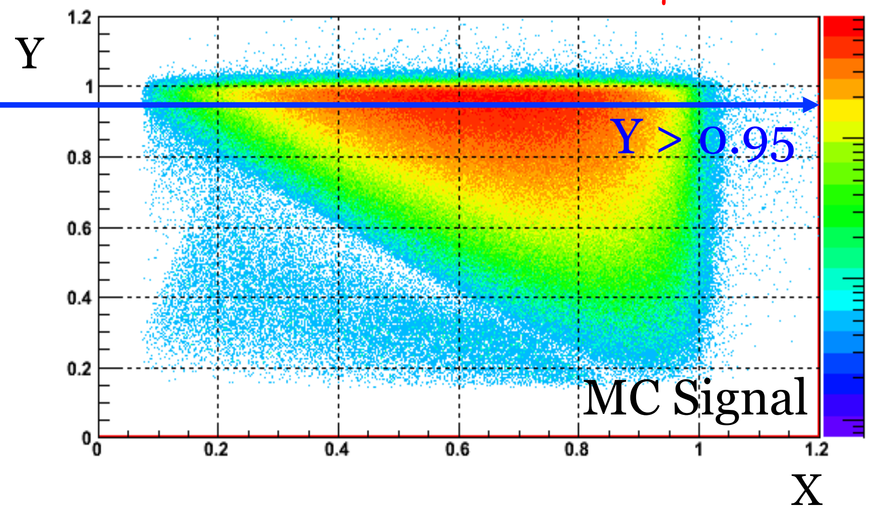
Reconstructed Signal-Bkg

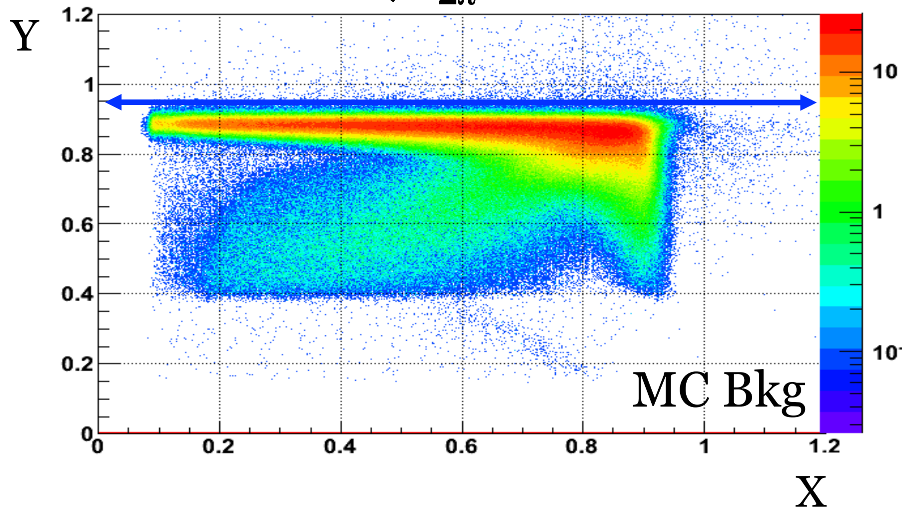
$K^+ \to e^+ \pi^0 \nu \ (K_{e3})$



$K^+ \to e^+ \nu \gamma \ (SD^+) \ (K_{e2\gamma})$



$K^+ \to \pi^+ \pi^0 \ (K_{2\pi})$

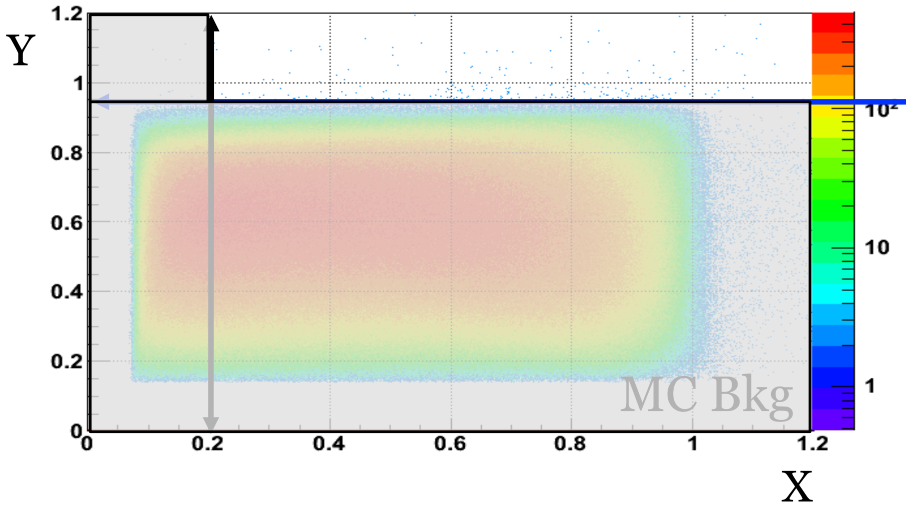


$$X = \frac{2E^*(\gamma)}{M_K}; \qquad Y = \frac{2E^*(e)}{M_K};$$

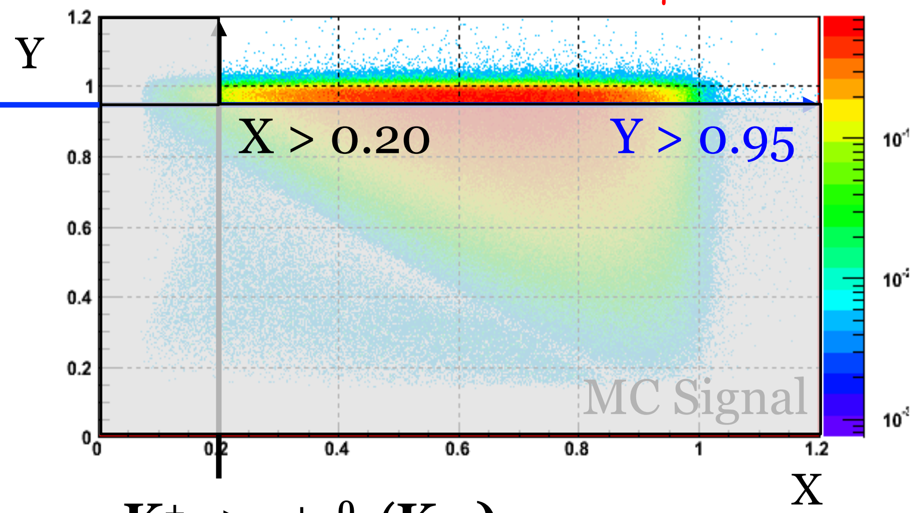
$$Y_{K_{e3}}^{\max} = 0.923 < Y_{K_{e2\gamma}}^{\max} = 1$$

Reconstructed Signal-Bkg

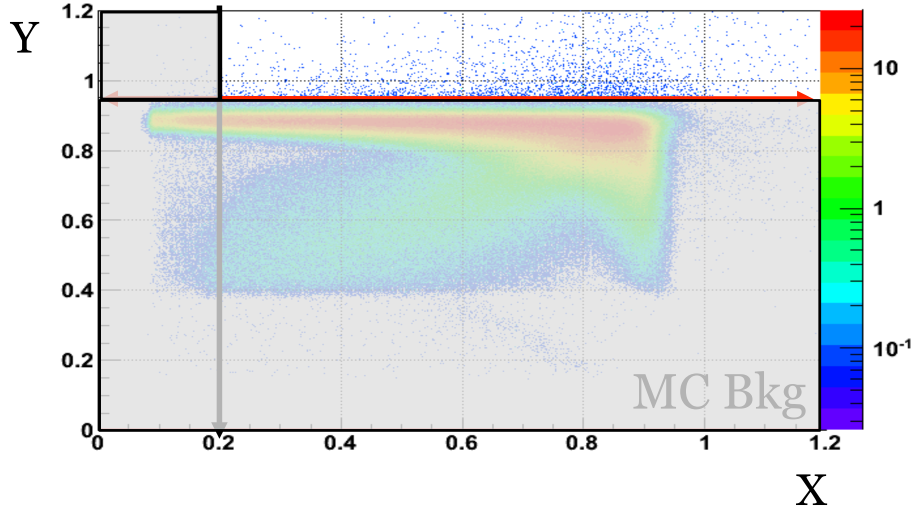
$K^+ \rightarrow e^+ \pi^0 \nu$ (K_{e3})



$K^+ \rightarrow e^+ \nu \gamma$ (SD^+) ($K_{e2\gamma}$)



$K^+ \rightarrow \pi^+ \pi^0$ ($K_{2\pi}$)



$$Y^{max}_{K_{e3}} = 0.923 < Y^{max}_{K_{e2\gamma}} = 1$$

$$X > 0.20; \quad Y > 0.95;$$

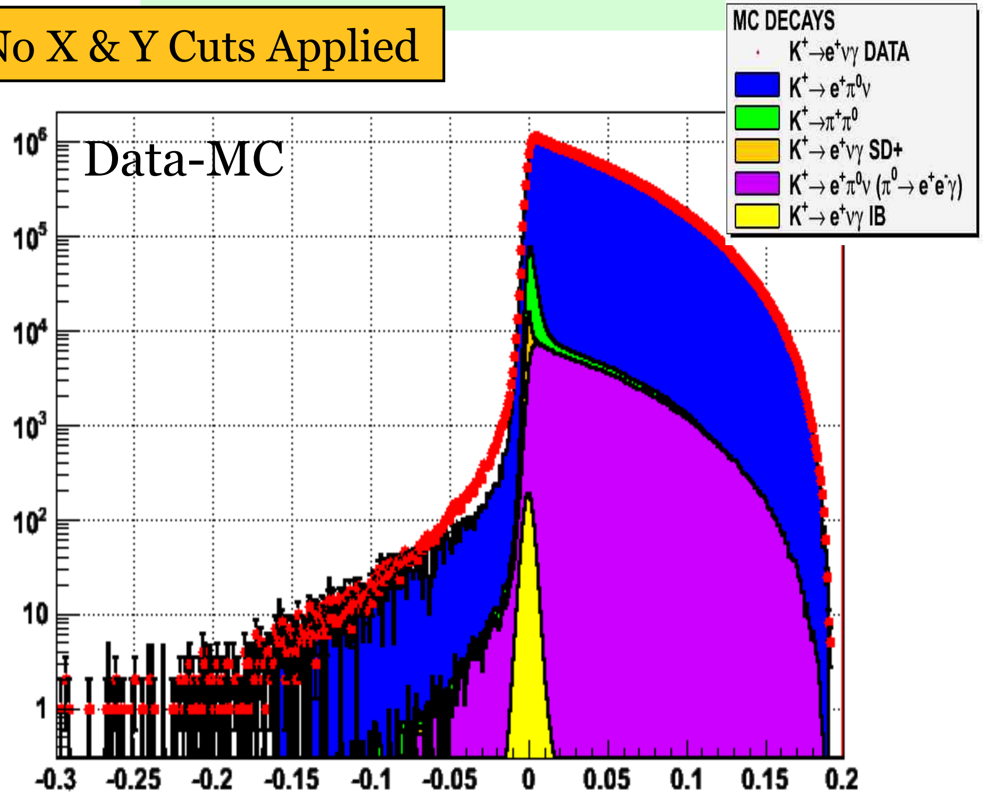
The X cut has been optimised for minor sources of background;

$K^+ \to e^+\nu\gamma$ (SD+) selection

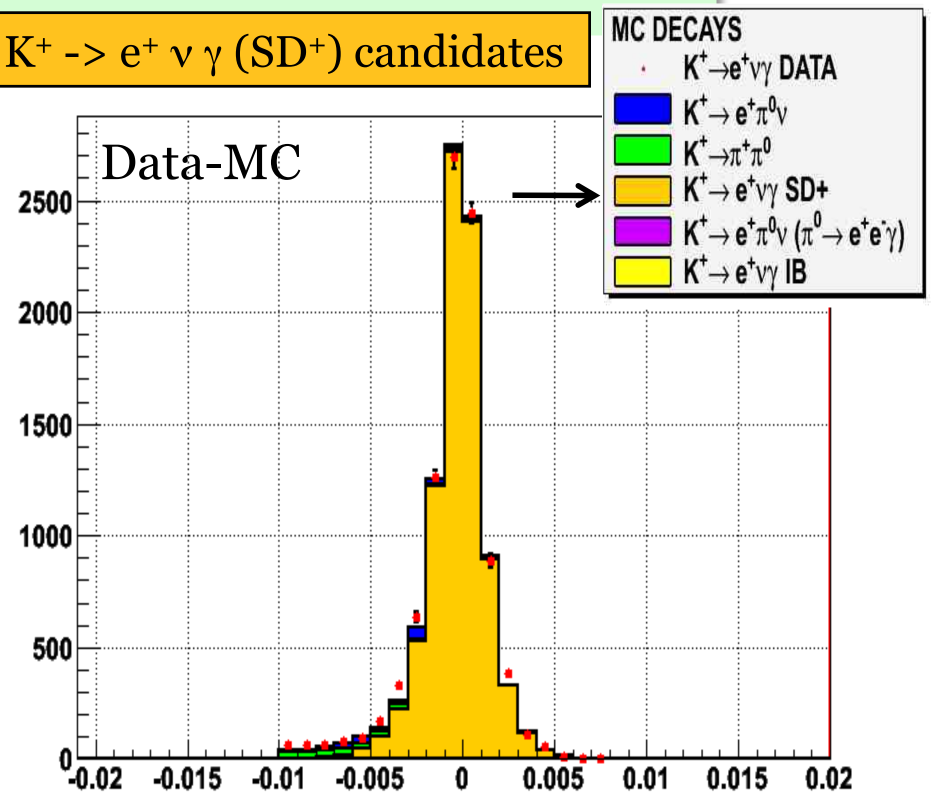
Kinematic identification:

- Three body decay: $M^2_{miss}(e^+\gamma) = |(P_{K^+} - P_{e^+} - P_\gamma)^2| < 0.01\ GeV^2/c^4$

No X & Y Cuts Applied



K+ -> e+ ν γ (SD+) candidates



$Acc\ (K^+_{e2\gamma}) = N^{MC}_{final}(K^+_{e2\gamma})/N^{MC}_{TOT}(K^+_{e2\gamma})$
$Acc\ (K^+_{e2\gamma})\ \sim 7\%$

$\sim$ 10k $K^+_{e2\gamma}$(SD+) candidates
Bkg/Data ~ 5% (mainly K_{e3})

Form Factors Fit

A χ^2 fit has been performed to the measured X spectrum using the distribution expected from the ChPT models;

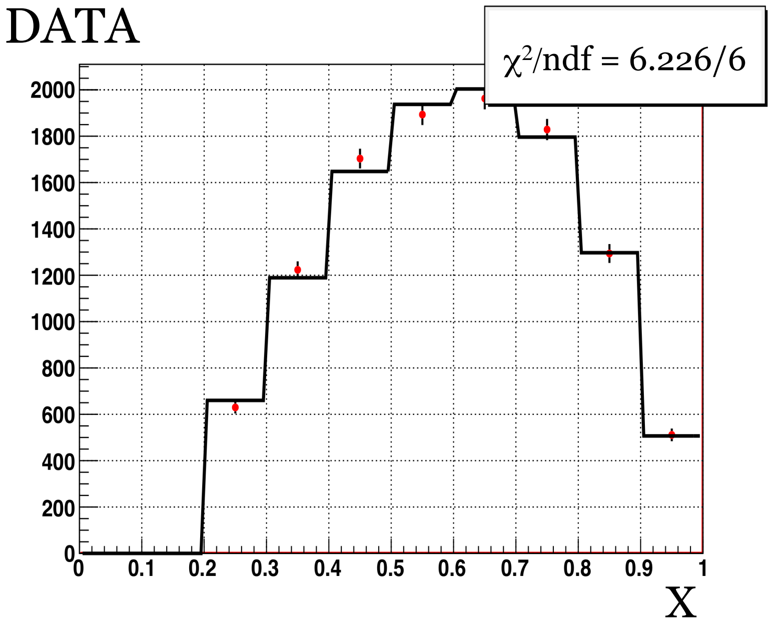
$$\frac{d^2\Gamma(K^+ \to e^+\nu\gamma)}{dxdy} = \frac{G_F^2 \sin^2\theta_c M_K^5 \alpha}{64\pi^2}(V+A)^2(1-x)(x-y-1)^2$$

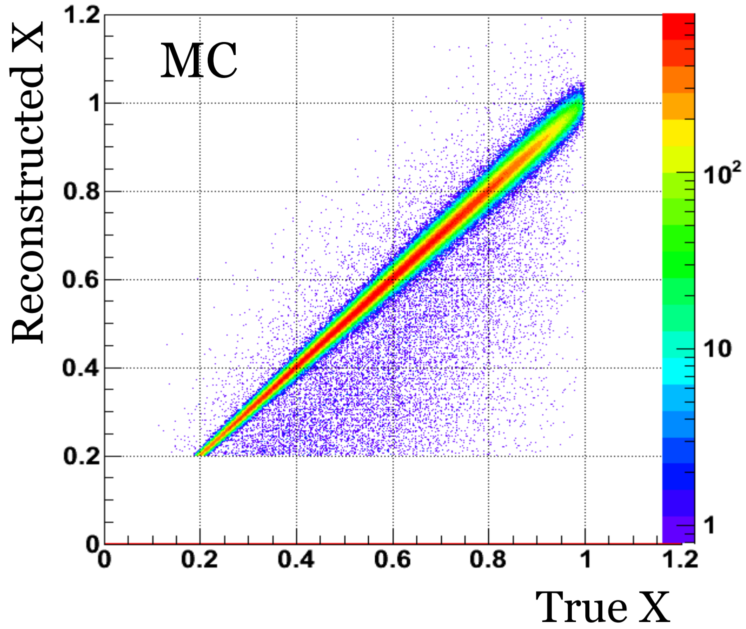
Axial and Vector effective couplings used:

A=0.034, as given by ChPT O(p^6); (PRD77 (2008) 014004)

V=V_0(1+λ(1-X)); (EPJC64 (2009) 627)

Smearing effects due to the detector acceptance, resolution and mis-reconstruction are convoluted with the theoretical distribution;





Fit Results

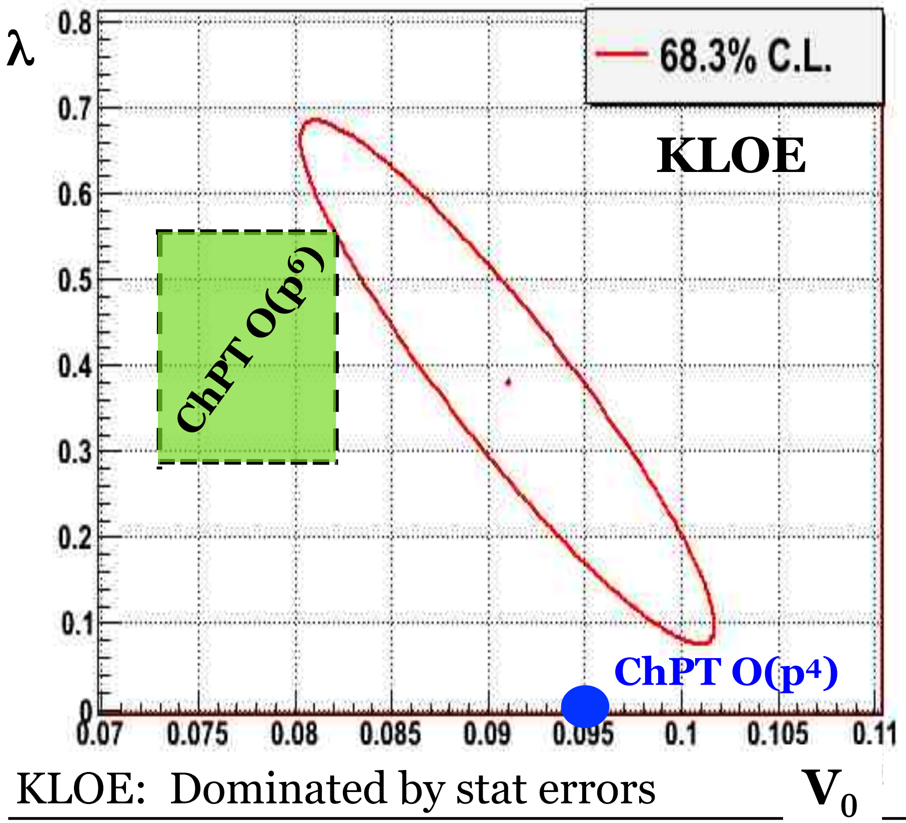
Form Factor parameters with their uncertainties and the correlation coefficient represented with the standard error ellipse (68% C.L.)

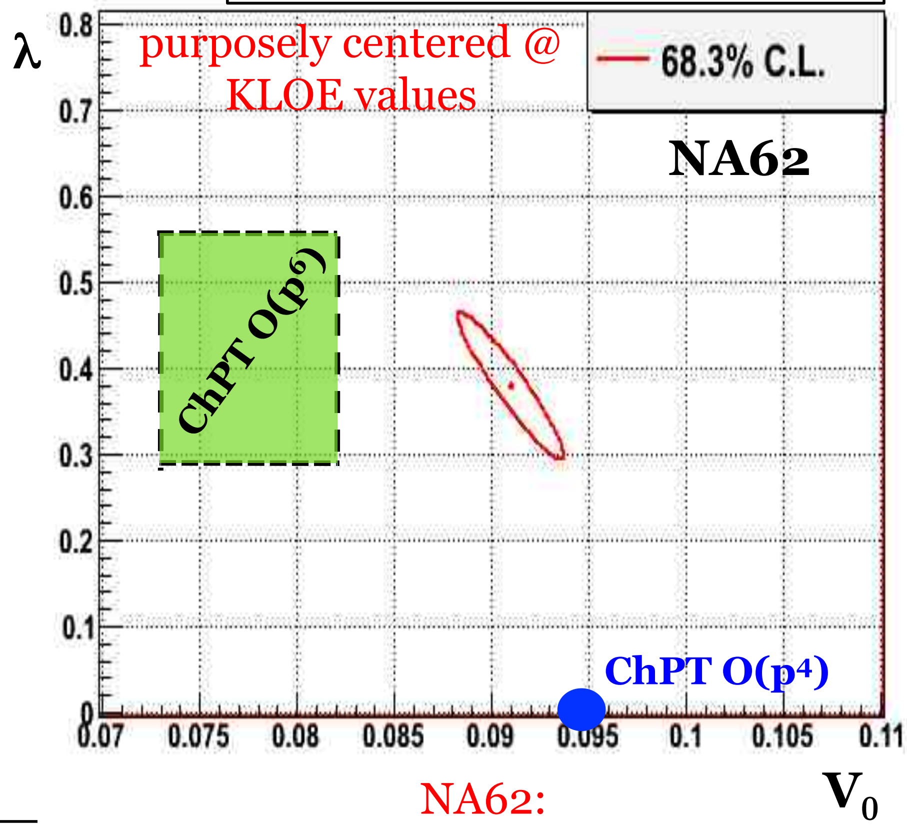
Analysis phase space region (K rest frame):

KLOE: $p_e > 200\text{MeV}/c$, $E_\gamma > 10\text{MeV}/c^2$;

NA62: $E_e > 235\text{MeV}/c^2$, $E_\gamma > 50\text{MeV}/c^2$;

NA62/KLOE statistics ~ 10
NA62/KLOE ellipse axis ~ 33%





KLOE: Dominated by stat errors

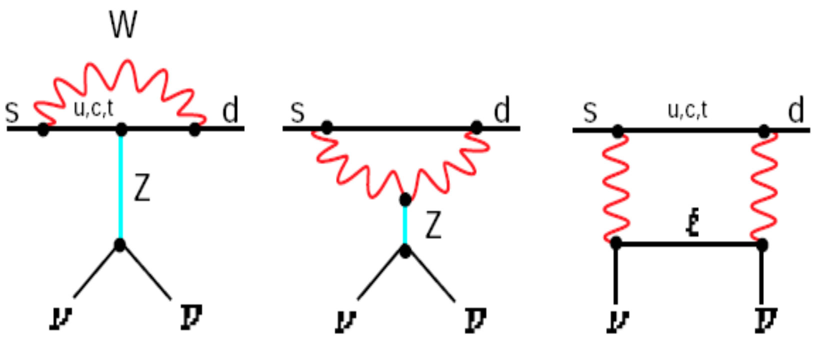
(EPJC64 (2009) 627), (NPB684(2004281))

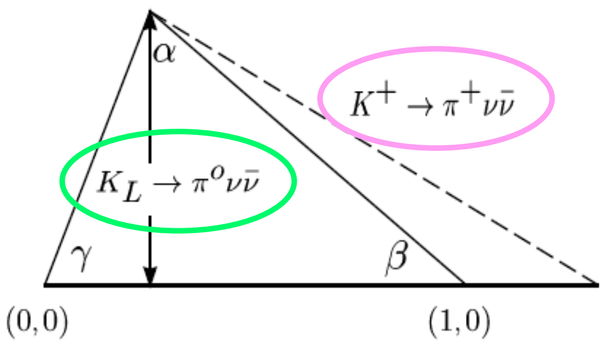
NA62:
Significant systematic uncertainty expected

NA62-II:

BR($K^+ \to \pi^+ \nu\nu$)

Motivations





	Short distance	Irreducible error	BR_{SM}
K_L->$\pi^0\nu\nu$	>99%	1%	$3\cdot10^{-11}$
K^+->$\pi^+\nu\nu$	***88%***	***<3%***	***$8\cdot10^{-11}$***
K_L->$\pi^0e^+e^-$	38%	15%	$3.5\cdot10^{-11}$
K_L->$\pi^0\mu^+\mu^-$	28%	30%	$1.5\cdot10^{-11}$

BR(K^+->$\pi^+\nu\nu$):

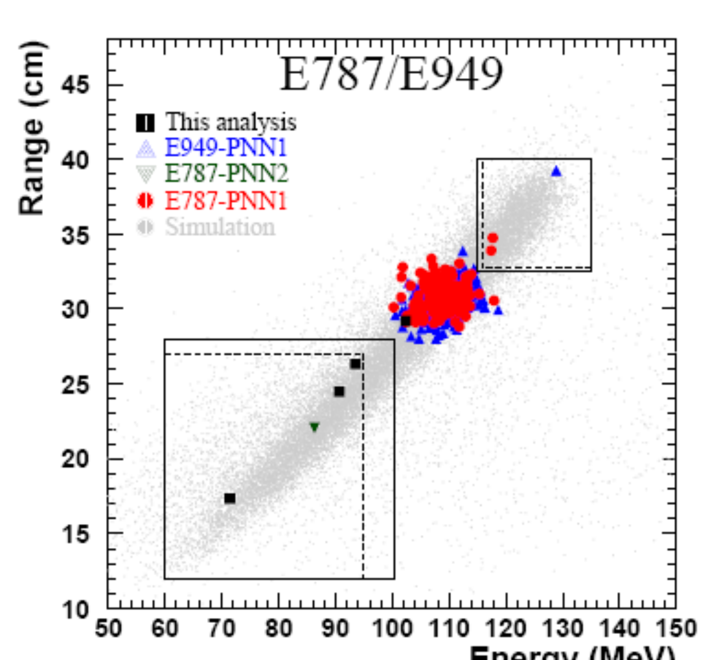
✓FCNC process forbidden at tree level;
✓Only one-loop contributions: box & penguin diagrams;
✓Dominated by Top quark contribution;

✓Very clean theoretical prediction: hadronic matrix element extracted from BR($K \to \pi e \nu$);
✓Cleanest way to extract V_{td} and to give independent determination of the kaon unitarity triangle;

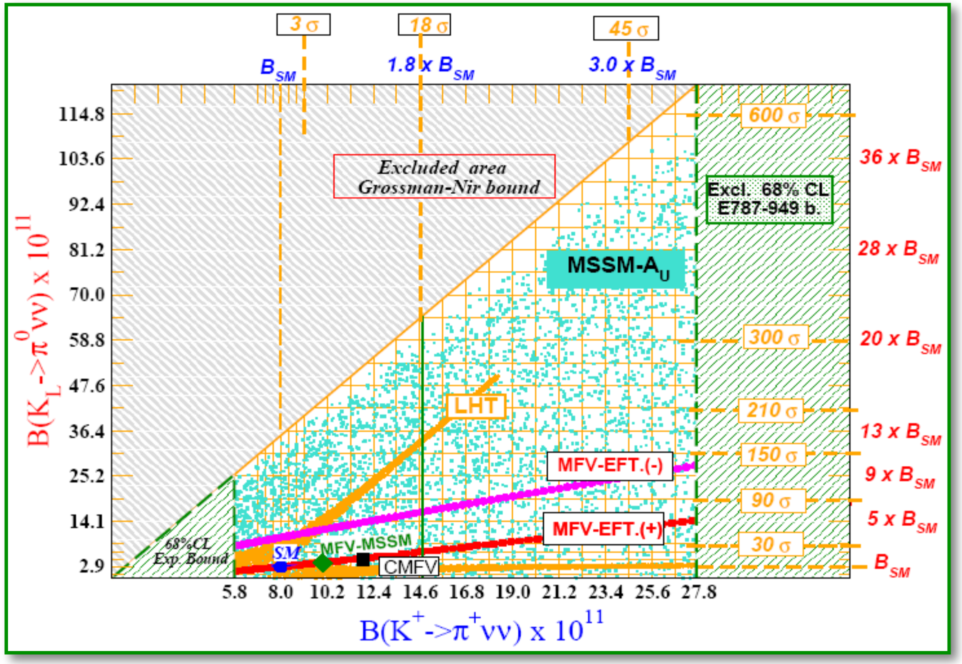
✓Complementarity with B physics;
✓Very sensitive to New Physics;

NP -Experimental Status

- Several NP models: SUSY, MSSM (with or without new sources of CPV or FV), 5-dim split fermions, topcolor, multi Higgs, light sgoldstino, extra-dimensions …
- Possibility to distinguish among different models



(7 candidates E787+E949)



$$BR(K^+\to\pi^+\nu\nu)_{THEORY} = (0.85 \pm 0.07) \times 10^{-10}$$

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

(based on 7 events)

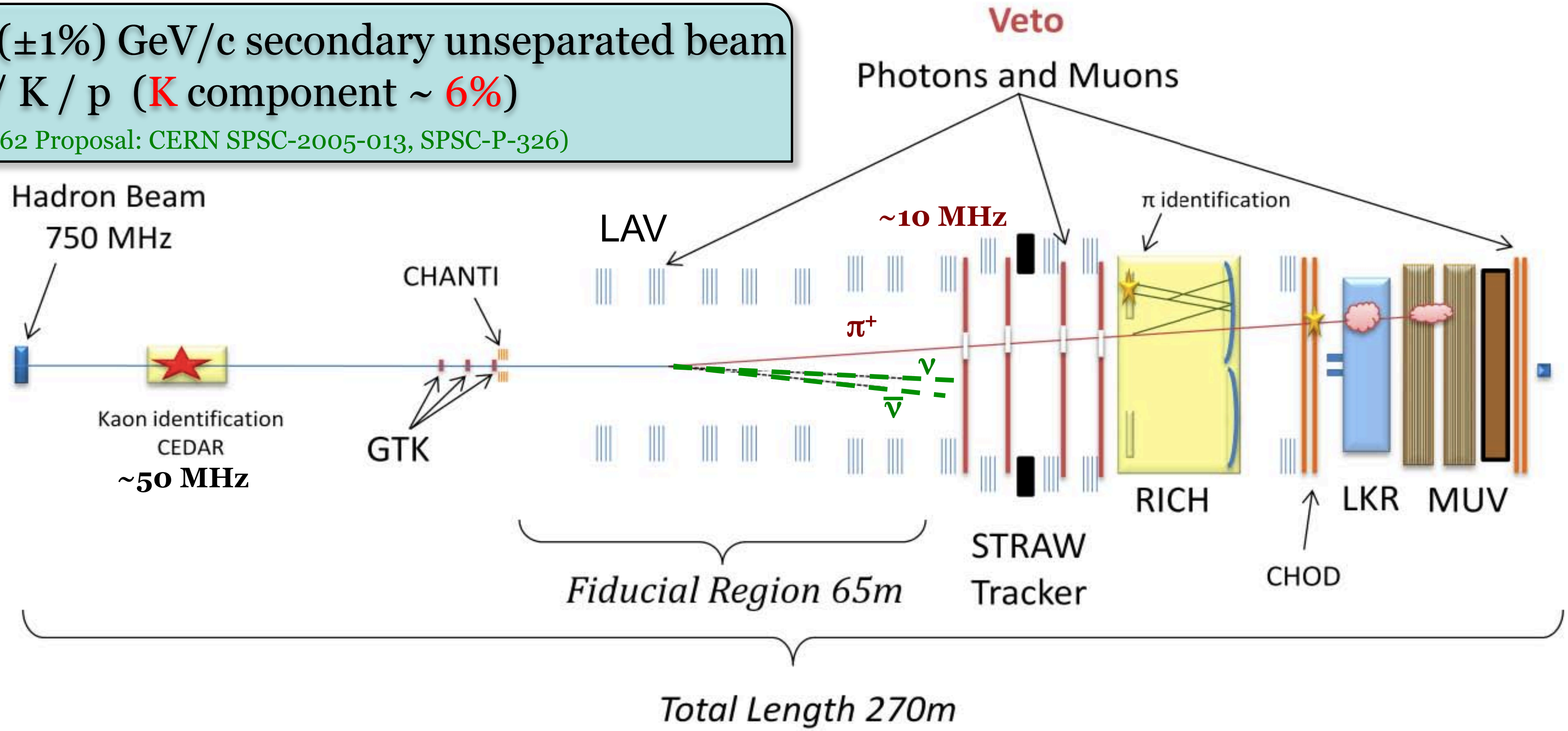
(E787/E949, Phys.Rev.Lett.101, 191082(2008))

$K^+\to\pi^+\nu\nu$ probe of unique sensitivity for NP BSM

NA62 Detector Layout

SPS primary protons on target: 400 GeV/c (3×10¹² ppp)

75(±1%) GeV/c secondary unseparated beam
π / K / p (K component ~ 6%)
(NA62 Proposal: CERN SPSC-2005-013, SPSC-P-326)

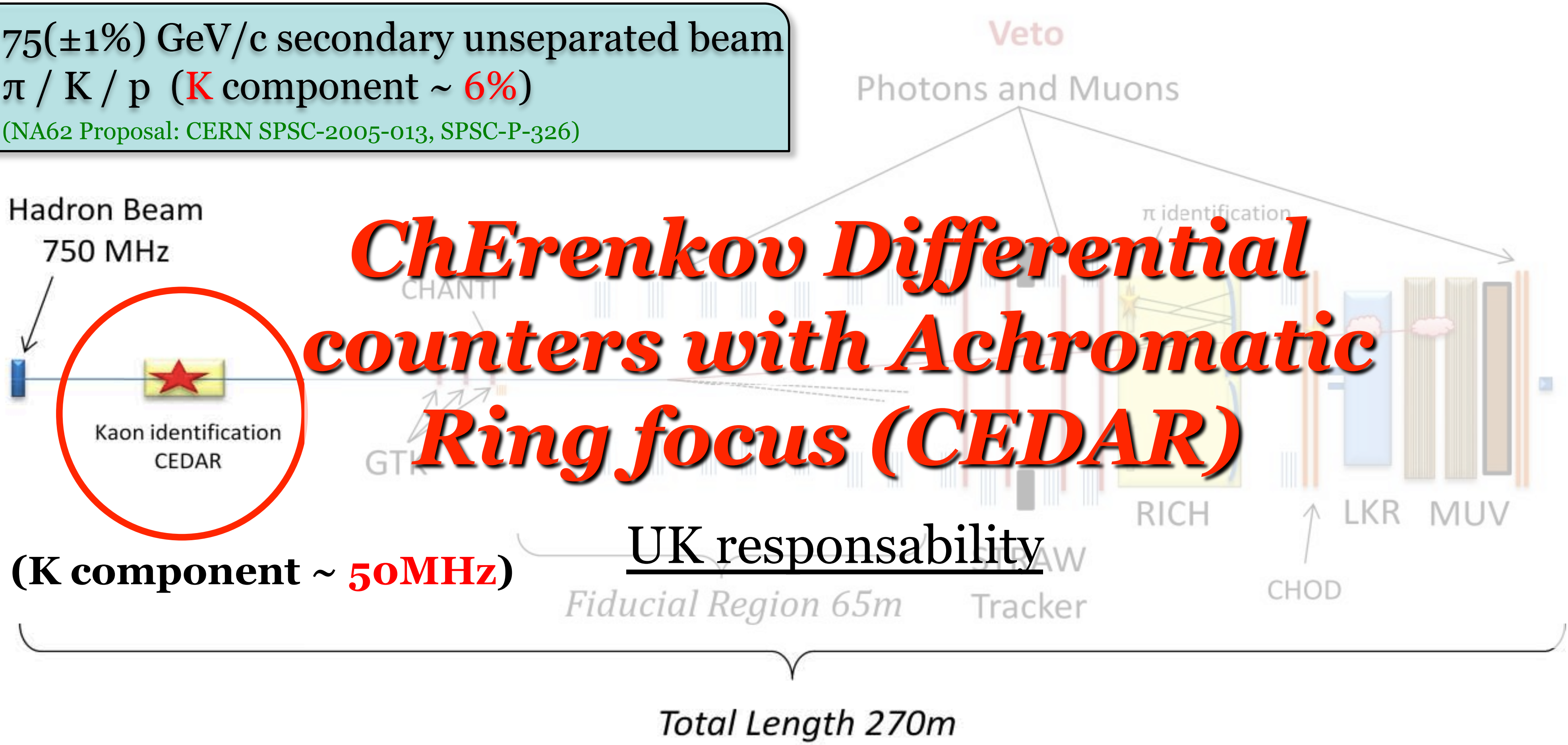


- ✓ Kaon decays in flight to avoid scattering and bkg induced by the stopping target;
- ✓ High momentum beam to improve bkg rejection;
- ✓ **NA62-II Goal: BR($K^+ \to \pi^+ \nu\nu$) measurement with ~10% accuracy;**

NA62-II Strategy: Collect O(100) events $K^+ \to \pi^+ \nu\nu$ with ratio Signal/Bkg ~ 10;

75(±1%) GeV/c secondary unseparated beam
π / K / p (K component ~ 6%)
(NA62 Proposal: CERN SPSC-2005-013, SPSC-P-326)

ChErenkov Differential counters with Achromatic Ring focus (CEDAR)

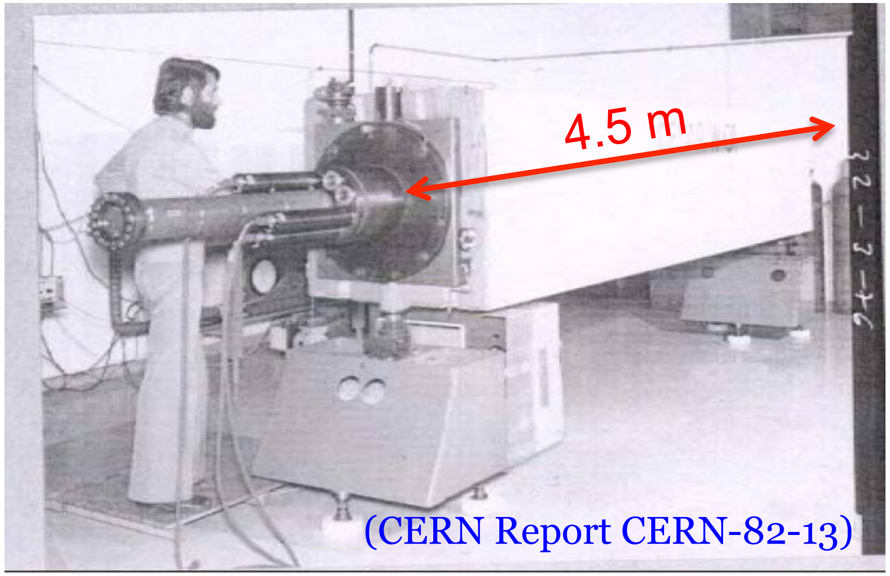


UK responsability

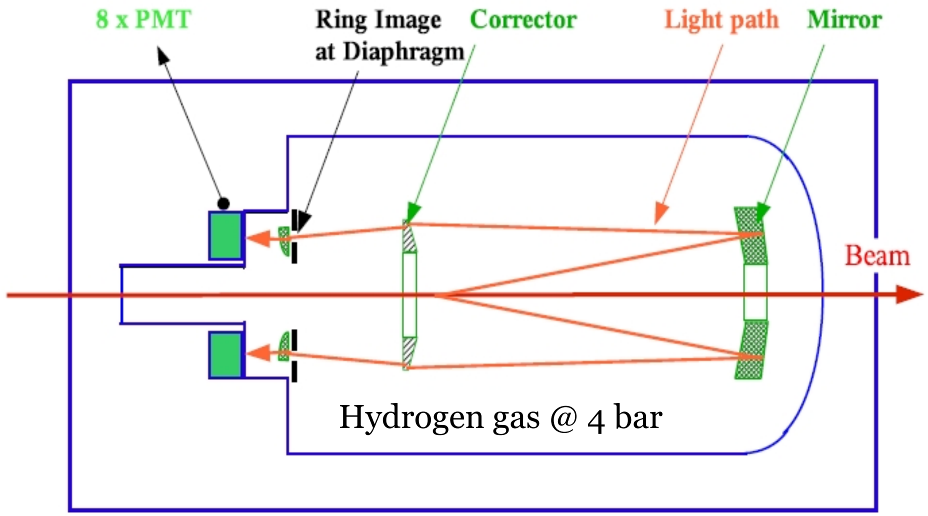
(K component ~ 50MHz)

The CEDAR detector

The Kaon identification detector for the NA62 rare Kaon decay experiment at CERN



Upgraded form of the CEDAR built for the SPS secondary beams.

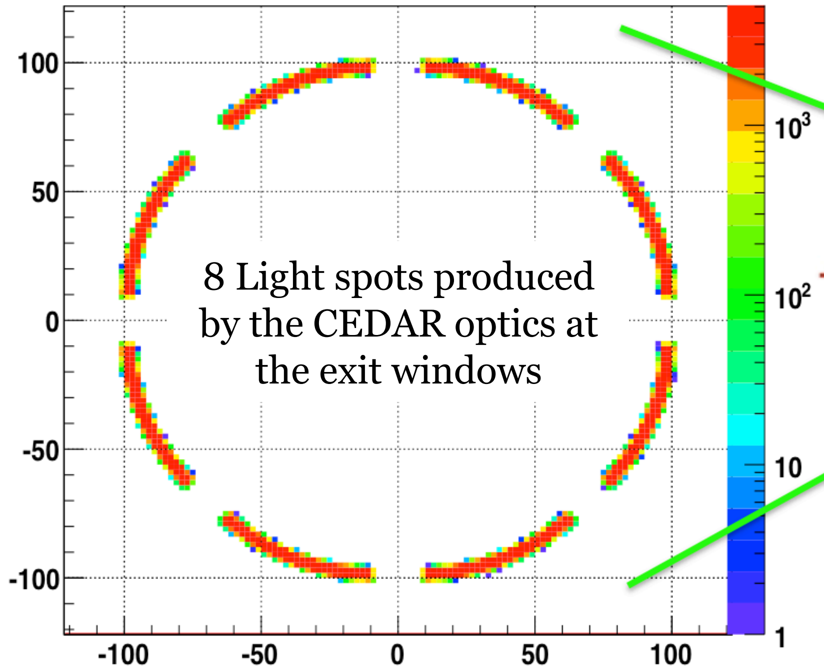


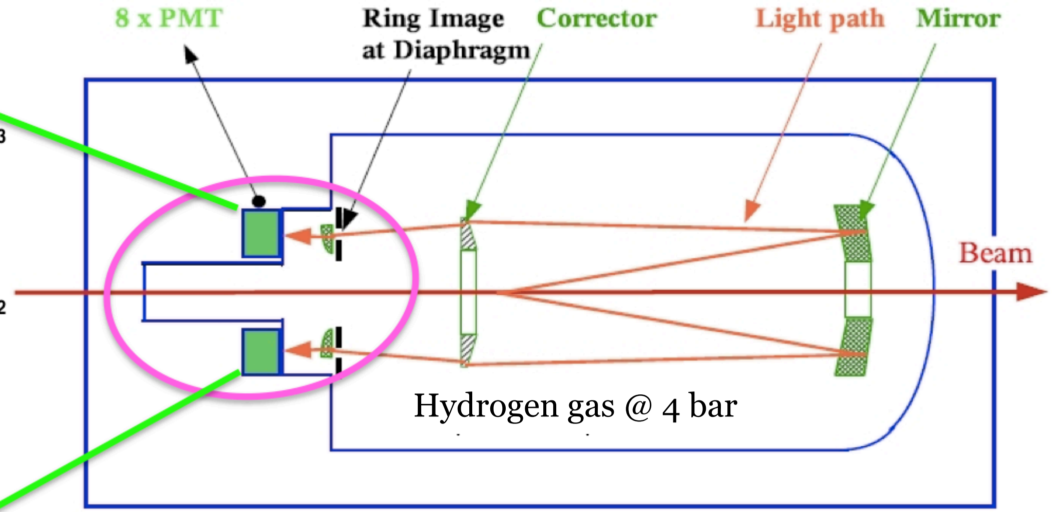
CEDAR challenge:
High Intensity ~ 800 MHz incoming hadron beam

- ✓ The CEDAR is used to identify Kaons in the beam using Cherenkov light;
- ✓ The CEDAR is blind to all particles except Kaons (i.e. the wanted type);
- ✓ A diaphragm blocks the light from other particles;
- ✓ Nevertheless the rate is very high ~ 50 MHz (average);

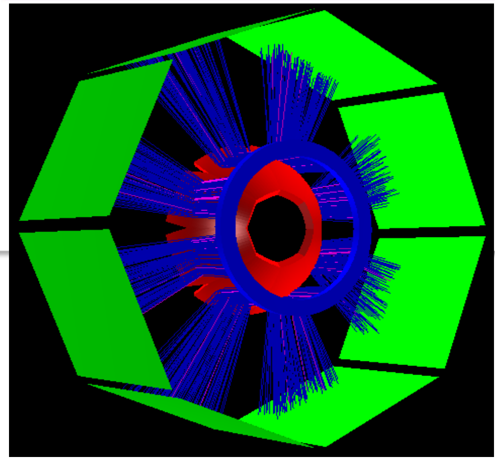
CEDAR: Optics

Existing photon detectors and associated readout are not suitable and need to be replaced





Projection of Cherenkov light from the exit windows to the photo-detector (PMT) planes

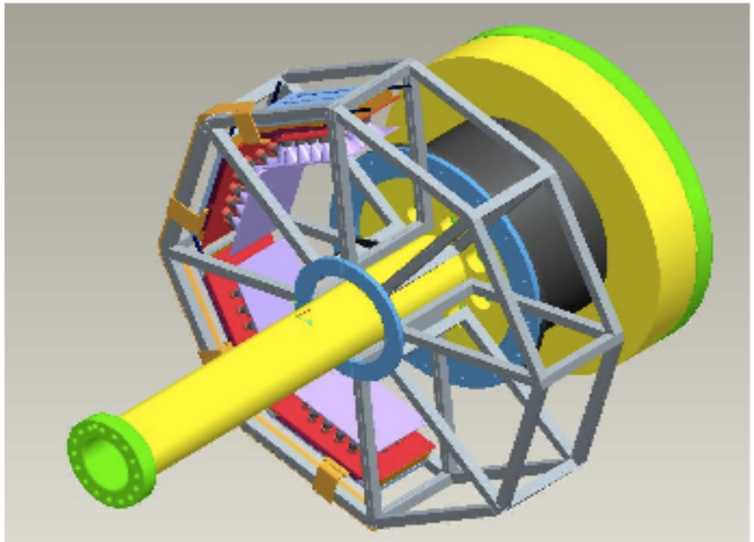


New CEDAR concept: light spots enlarged to spread the photon rate on bigger areas

Exit windows
Spherical mirrors
PMT planes

CEDAR: Requirements

- ✓ K^+ particle ID in a high-intensity hadron beam;
- ✓ K^+ ID efficiency of at least 95%;
- ✓ Resolution on K^+ crossing time ~ 100 ps;



Real world (average values):

- K^+ beam ~ 50 MHz;
- Cherenkov light yield
  at the Exit windows ~ 250 γ /K;

New Photo-Detector system:

- ✓ High Cherenkov light collection efficiency;
- ✓ Fast Response;
- ✓ Limited Anode current (due to rate on PMT);

CEDAR: Simulation

A simulation based on a Montecarlo to decide for the best PMT configuration optimizing the CEDAR performances

The MC includes:

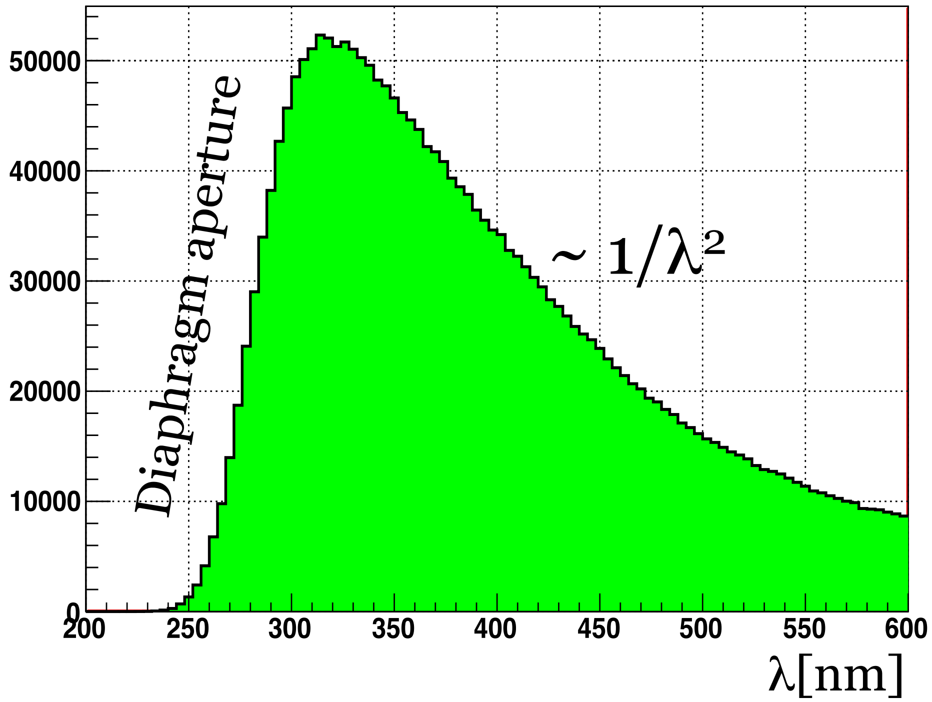
- Averaged Kaon Rate (50MHz);
- Cherenkov Photon production and tracking through optics;
- Reflection in a spherical mirror + projection on PMT plane;
- Light collection system + Photo-Detector layout;
- PMT Quantum Efficiency as a function of Cherenkov λ;
- Inefficiency due to pile-up events, electronics dead time and limitation of the readout system;
- Estimate of Kaon ID Inefficiency & Time resolution;

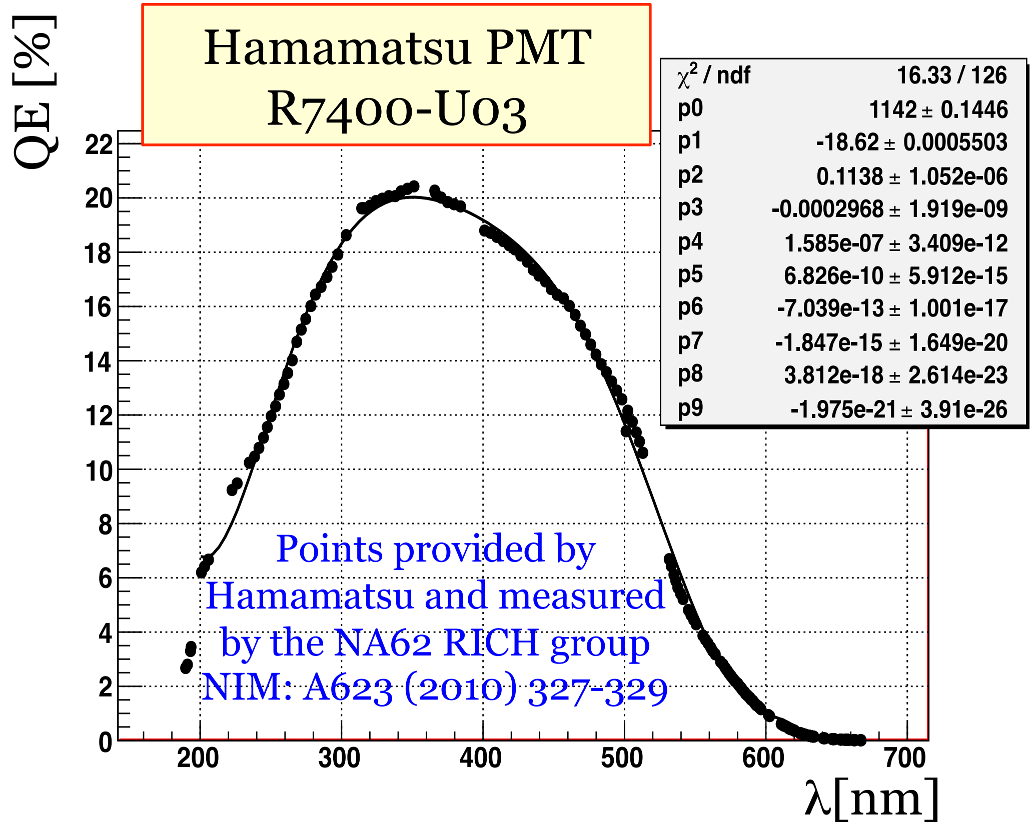
MC: Input Parameter

Cherenkov Photons generated according to:

- ✓ Cherenkov radiation trajectory: $\cos\theta_c = 1/\beta n;$
- ✓ Frank Tamm equation: $\frac{d^2N}{d\lambda dx} = \frac{2\pi\alpha}{\lambda^2} \cdot \sin^2\theta_c;$
- ✓ Wavelength spectrum ~ $1/\lambda^2$ in the range [200,600]nm;

Photon Wavelength at the exit windows





MC: Model Evaluation

✓Reflection in a spherical mirror + projection on PMT plane;
✓Light collection efficiency ~ 85%;
✓PMT (Hamamatsu R7400-U03) QE(λ);

Photon XY distribution on PMT plane

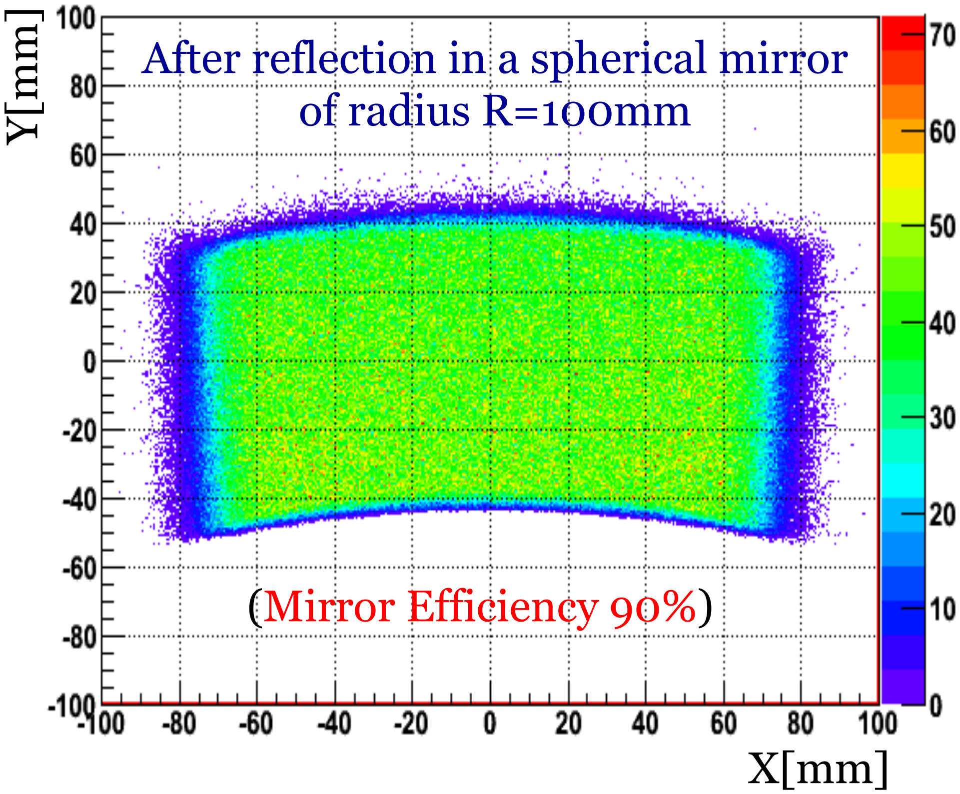
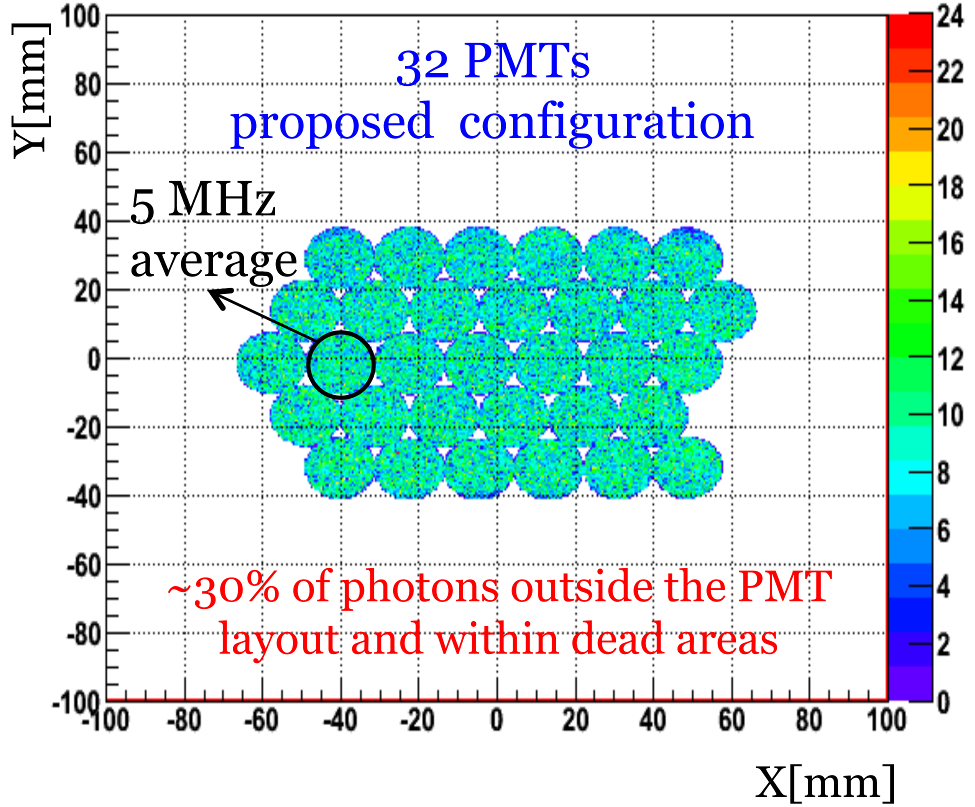


Photo-Electron XY distribution on PMT plane



Photon Collection Efficiency

Detected photons ~ 12% of total photons at the exit windows;

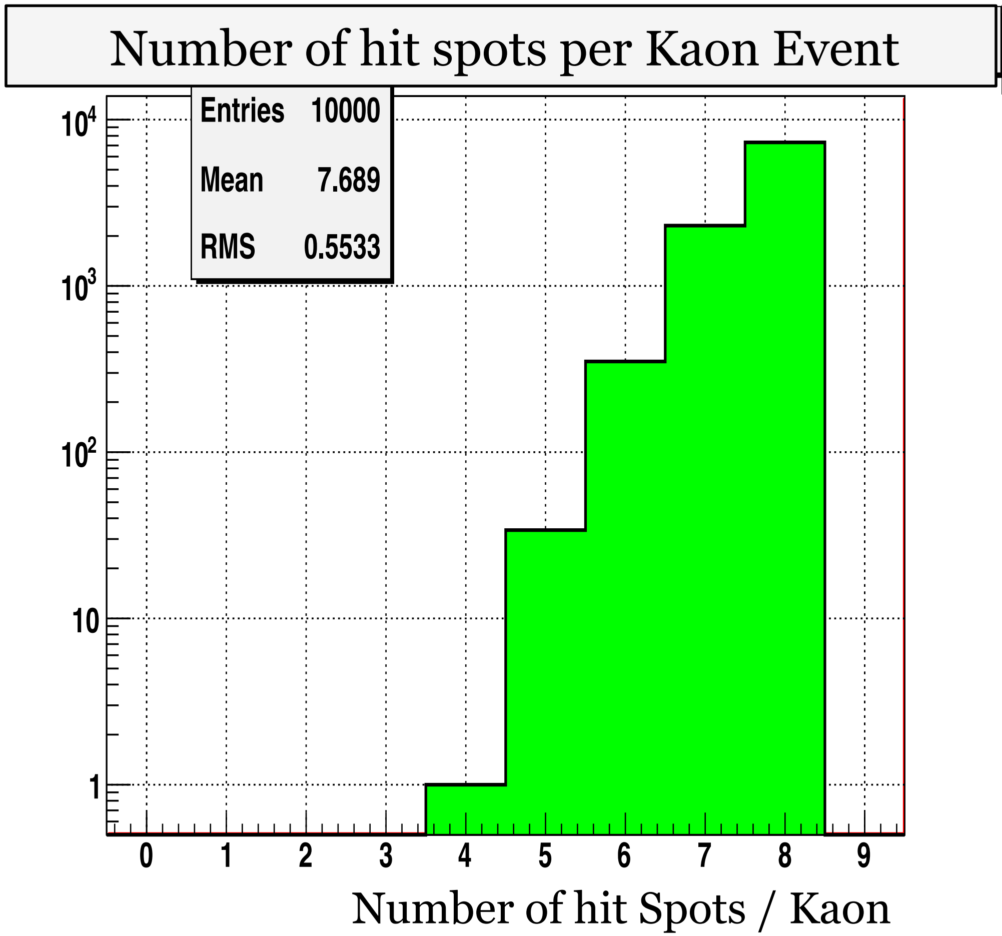
- **Efficiencies affecting**:
  - 0.90 (Mirror Efficiency);
  - 0.70 (PMT layout geometrical Acceptance);
  - 0.85 (Light Guide Efficiency);
  - PMT QE(λ);

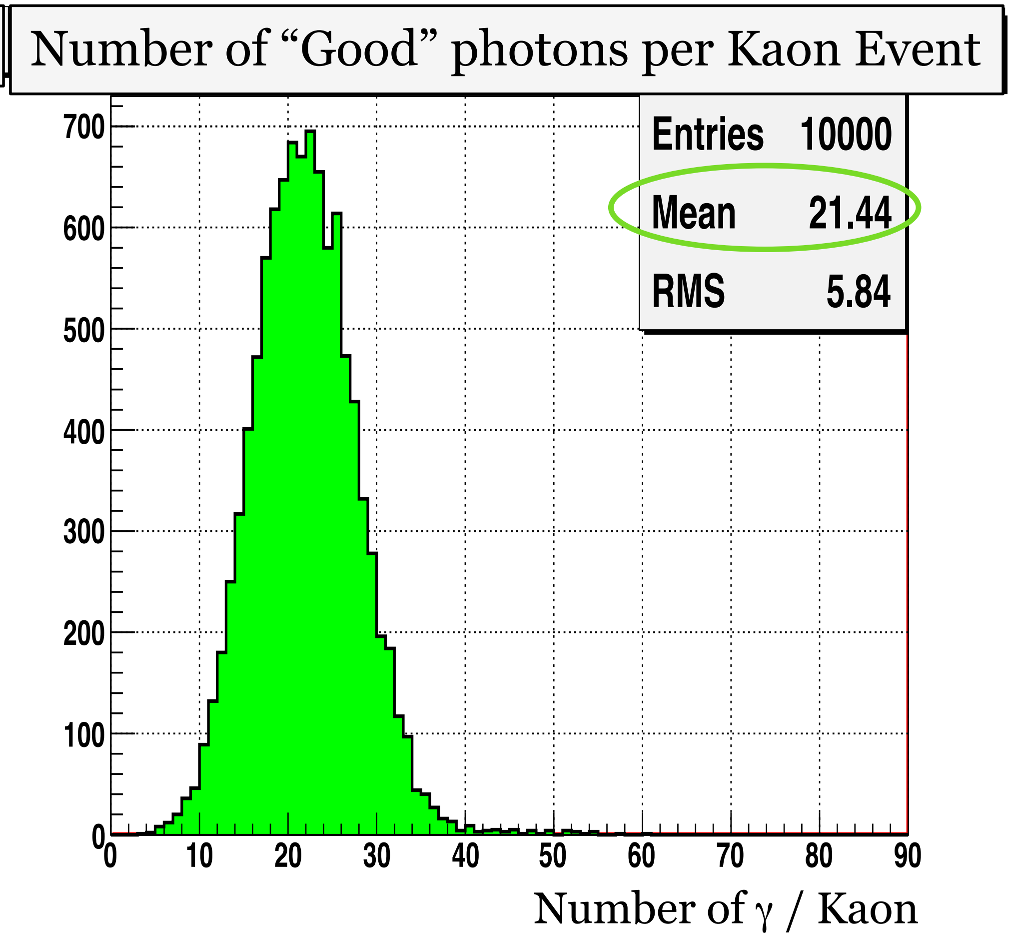
Detected photons are classified as:

- **"Inefficient"**:
  - if overlap on PMT within the same Kaon Event ~ 5%
  - if overlap on PMT from different Kaons with $\Delta t < T_{dead}$ (~ 20ns) ~ 6%

Mc: Results

Number of "Good" Photons and Hit Spots, obtained after the considered inefficiencies, are used to evaluate the Kaon identification (ID) Inefficiency.





Kaon ID Inefficiency & Time resolution

The probability to have a number of “Good” photons $N < N_{min}$;

N_{min} ensuring:

-A number of hit spots suitable for the Kaon ring reconstruction;

-A number of photons necessary to achieve the Kaon Time Resolution (σ_{TK}):

$$\sigma_{TK} = \frac{\sigma_{T\gamma}}{\sqrt{N_{min}}}$$

Considering NA62 RICH test results on R7400U3 PMTs -> $\sigma_{T\gamma}$ ~ 300ps

AND	# photons ≥ 9 ($\sigma_T(K)$ ~ 100 ps)	# photons ≥ 10 ($\sigma_T(K)$ ~ 95 ps)	# photons ≥ 11 ($\sigma_T(K)$ ~ 90 ps)
# hit spots ≥ 5	0.61 %	1.12 %	1.84 %
# hit spots ≥ 6	0.72 %	1.23 %	1.93 %
# hit spots ≥ 7	2.74 %	3.19 %	3.80 %

Required Inefficiency < 5%

Kaon Time Resolution ~ 100 ps

Conclusions

NA62 Phase I:

- The $R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$ precise measurement (~0.5%) is a very powerful tool to constrain new physics parameters in case of presence of LFV mediators;
- A comprehensive analysis of the radiative process $K^+ \rightarrow e^+ \nu \gamma$ is being performed using the same data sample;
- Model independent BR(SD^+, NA62 phase space) can be evaluated ~2% precision;

NA62 Phase II:

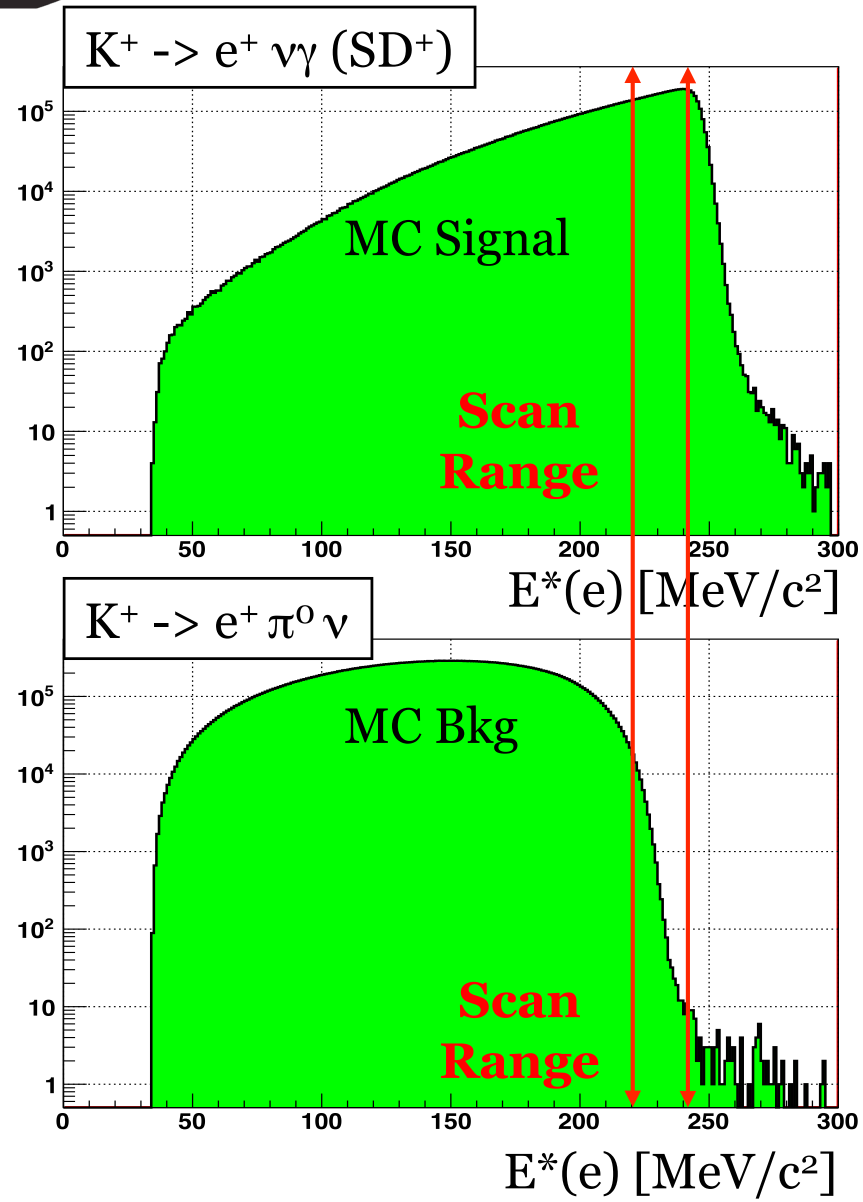
- The study of the $K^+ \rightarrow \pi^+ \nu \nu$ decay is a good opportunity to find NP or to distinguish among different models;
- The positive Kaon identification will be achieved with a Cherenkov counter (CEDAR);
- R&D of new optics, photodetectors and readout electronics is in progress;

Spares

3rd Year PhD Student, School of Physics and Astronomy

Angela Romano

Kaon Rest Frame Kinematics



Electron Energy in Kaon Rest Frame $E^*(e)$ [MeV/c²]

Used to reject background coming from $K^+ \to e^+ \pi^0 \nu$ decay channel.

To decide for a lower CUT value a scan of E^*_{min} was performed.

Looking at the Electron Energy distributions in the Kaon Rest the **scan range** was set between:

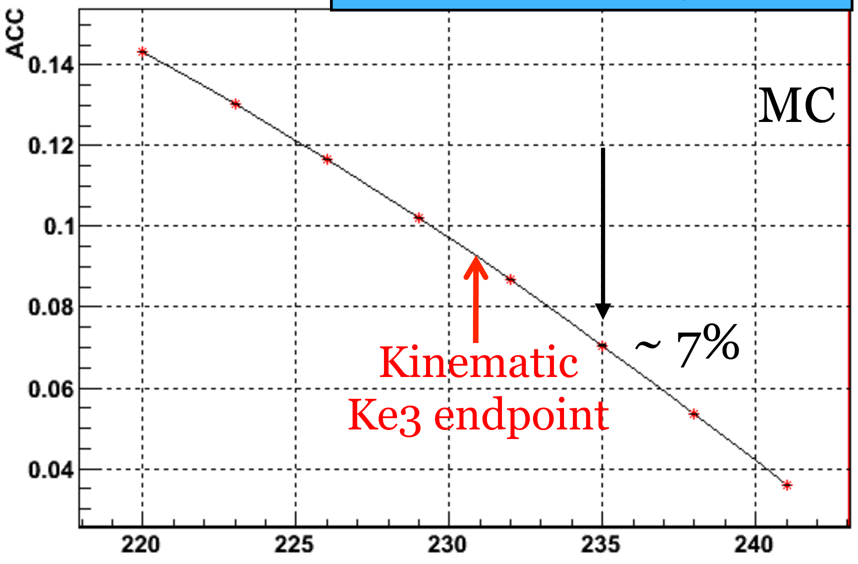
(220 < E*min(e) < 241) MeV/c²

Kaon Rest Frame Kinematics

Acceptance: Acc (i) = $N_{final}(i)/N_{TOT}(i)$ where $N_{final}(i)$ are N(i) which pass the selection

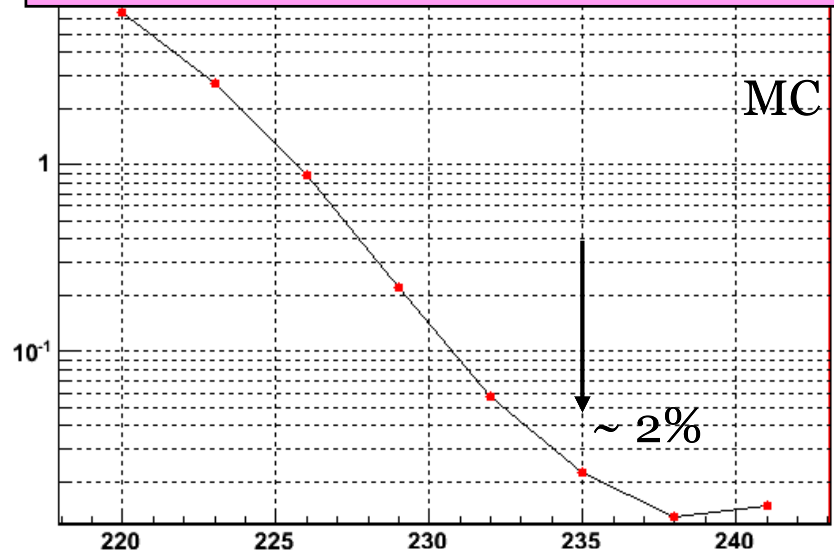
Background-Signal ratio:
$B(j)/S(i) = N_{final}(j)/N_{final}(i)$,
- j is the background channel
- i is the signal channel

Acc ($K^+ \to e^+ \nu\gamma$ (SD))



$E^*_{min}(e)$ cut [MeV/c²]

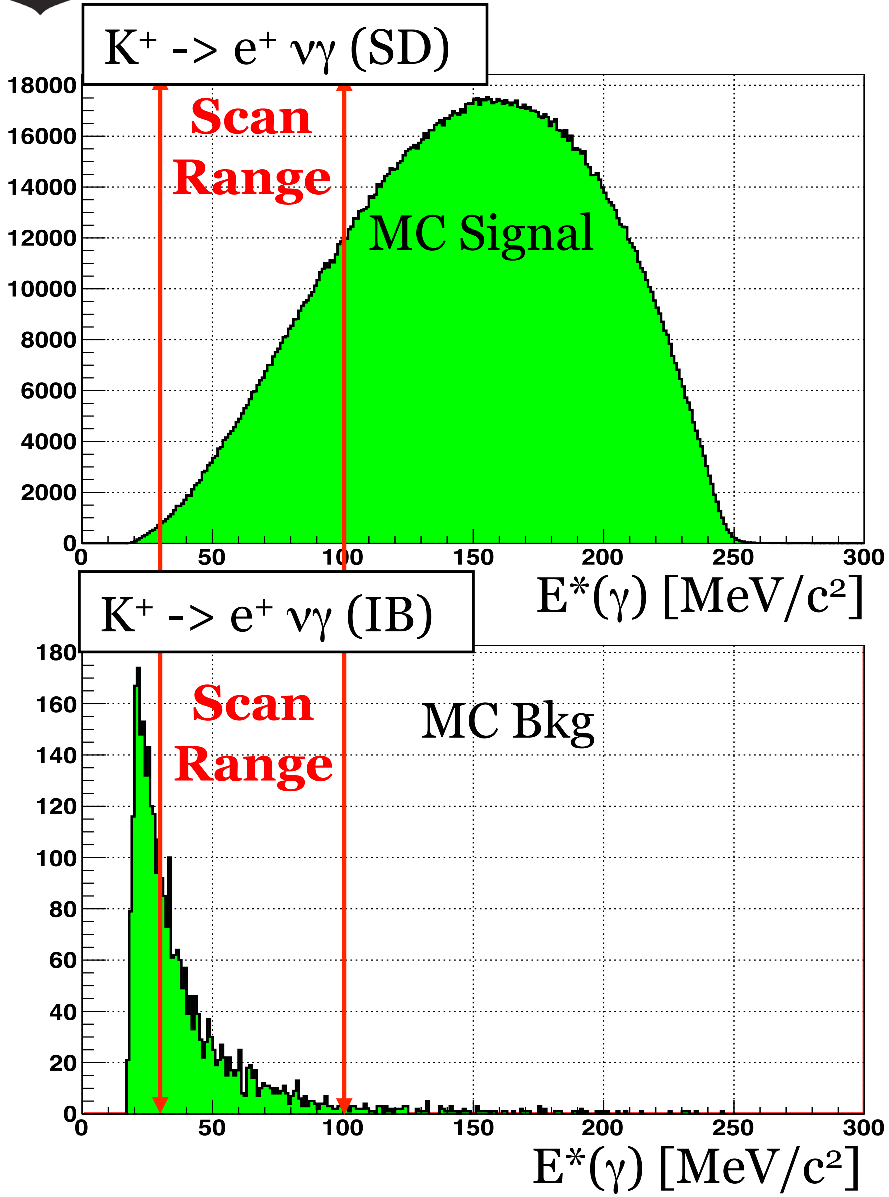
B ($K^+ \to e^+ \pi^0 \nu$)/ S($K^+ \to e^+ \nu\gamma$ (SD))



$E^*_{min}(e)$ cut [MeV/c²]

Kaon Rest Frame Electron Energy lower cut: $E^*_{min}(e)$ = 235 MeV/c²

Kaon Rest Frame Kinematics



Photon Energy in Kaon Rest Frame $E^*(\gamma)$ [MeV/c²]

Used to reject background coming from $K^+ \to e^+\nu\gamma$ (IB) decay channel

To decide for a lower CUT value a scan of E^*_{min} was performed.

Looking at the Photon Energy distributions in the Kaon Rest Frame the **scan range** was set between:

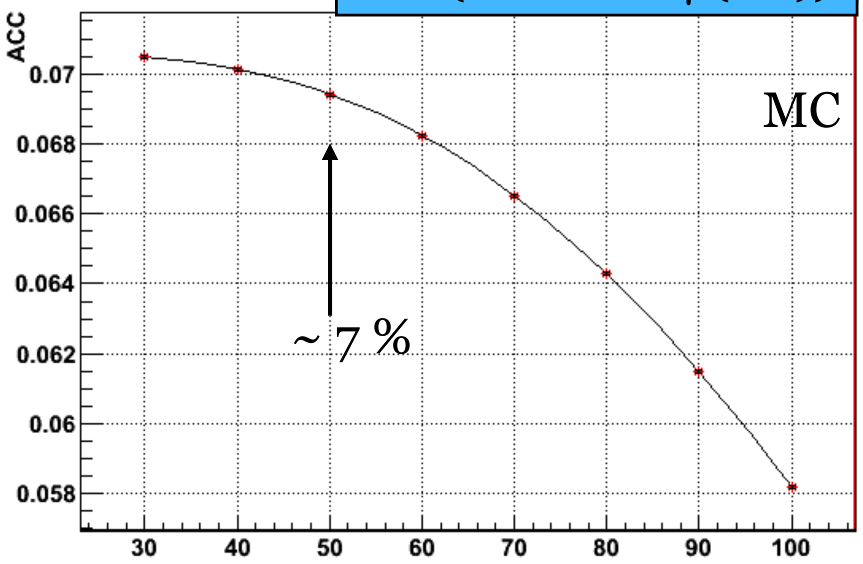
$(30 < E^*min(\gamma) < 100)$ MeV/c²

Kaon Rest Frame Kinematics

Acceptance: Acc (i) = $N_{final}(i)/N_{TOT}(i)$ where $N_{final}(i)$ are N(i) which pass the selection

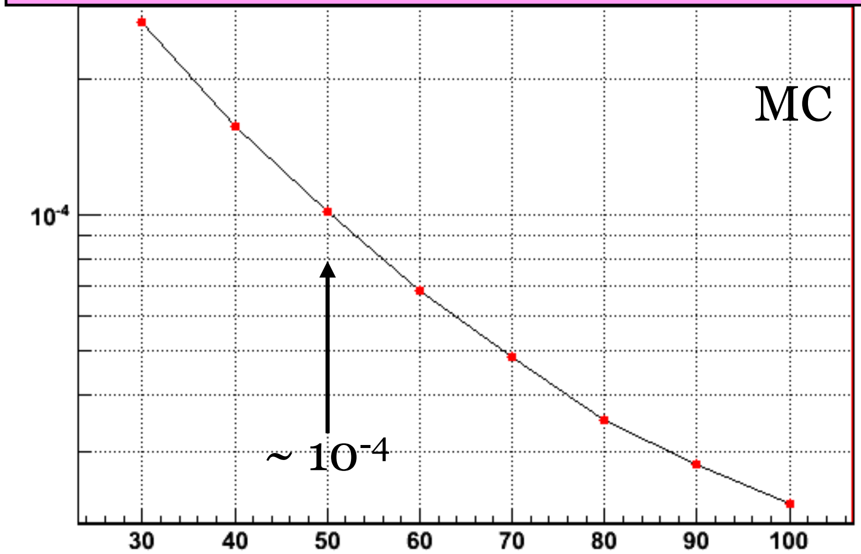
Background-Signal ratio:
$B(j)/S(i) = N_{final}(j)/N_{final}(i)$,
- j is the background channel
- i is the signal channel

Acc ($K^+ \to e^+ \nu\gamma$ (SD))



$E^*_{min}(\gamma)$ cut [MeV/c²]

B($K^+ \to e^+ \nu\gamma$ (IB))/ S($K^+ \to e^+ \nu\gamma$ (SD))



$E^*_{min}(\gamma)$ cut [MeV/c²]

Kaon Rest Frame Photon Energy lower cut: $E^*_{min}(\gamma)$ = 50 MeV/c²

Conclusions $K^+ \to e^+\nu\gamma(SD^+)$

- A comprehensive study of the process $K^+ \to e^+\nu\gamma(SD^+)$ is being performed;
  - About 10k candidate events with a ~5% background contamination;
- Total uncertainty is dominated by the background subtraction (mainly K_{e3});
  - signal kinematic region is affected by non gaussian tails above the K_{e3} kinematic endpoint: $y_{K_{e3}}^{max} = 0.923 < y_{K_{e2\gamma}}^{max} = 1$
- Model independent BR(SD^+, NA62 phase space) can be evaluated with a ~2% precision;
- SD^+ FFs and extraction of V,A effective coupling:
  - KLOE results are in agreement with the expectations from ChPT and confirm at ~2σ the presence of a slope in V (as predicted in $O(p^6)$)
  - NA62 results will get advantages from the large data sample providing that the background is kept reasonably under control

NA62 Strategy

Event Reconstruction (Acc ~ 10%)

Detectors upstream the decay region on unseparated beam (~800 MHz)

CEDAR: Diff Cherenkov counter for K^+ tagging and time measurement;

GIGATRACKER: Beam spectrometer for Kaon momentum, time and angular measurements;

Detectors downstream the decay region (~10 MHz)

STRAW: Magnetic Spectrometer for direction and momentum measurements of charged decay products;

RICH: Ring Image Cherenkov for m/p separation and pion crossing time measurement;

Bkg rejection (at ~ 10^{12} level)

LAV: Counters surrounding the vacuum tank providing full coverage for photons at large angles;

LKR: Electromagnetic calorimeter built for the NA48 experiment for the photon veto in the forward region;

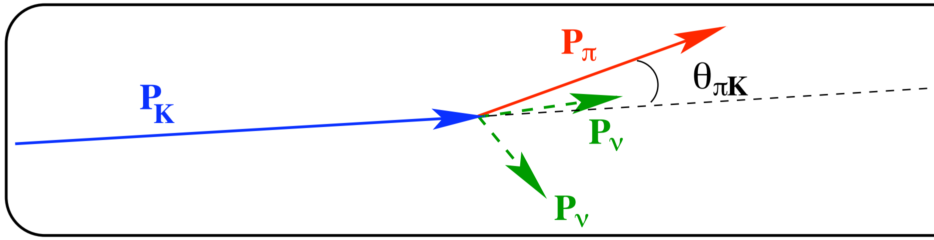
IRC/SAC: Photon veto at small and intermediate angles;

ANTI-0: Ring counters to veto charged particles coming from the collimator;

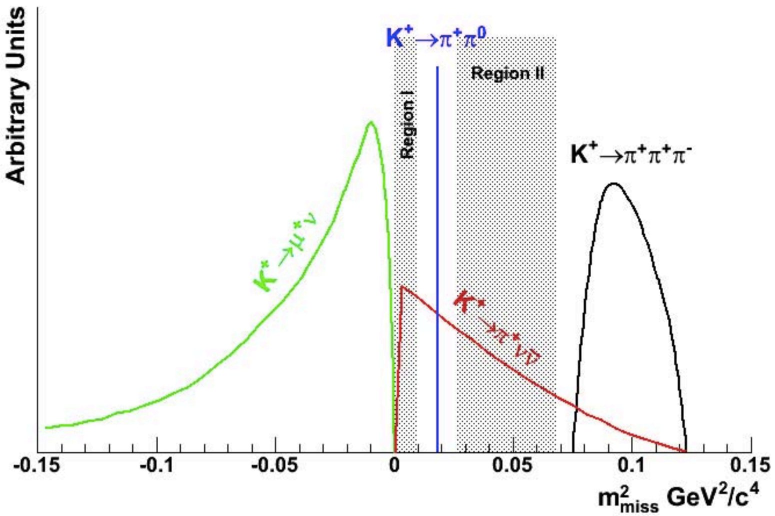
HAC/MUV: Hadron calorimeter and Muon veto detector;

Experimental Strategy

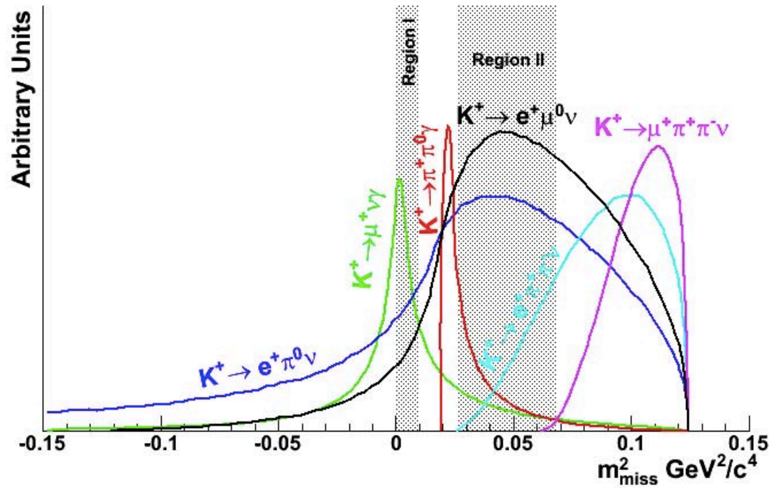
Sensitivity is NOT limited by protons flux !
Sensitivity is limited by backgrounds..



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



92% Kinematically constrained bkg



8% Not kinematically constrained bkg

NA62 Strategy: Collect O(100) events $K^+\to\pi^+\nu\nu$ with ratio Signal/Bkg ~ 10;

Experimental Principles

- ✓ **Kaon Flux**: K decays/year 4.8×10^{12};
- ✓ **Systematics** < 10%;
- ✓ **Kinematical Rejection:** (P_{π}, P_K, $\theta_{\pi K}$);

  Low mass tracking (GigaTracker (GTK) +Straw Chamber Spectrometer)
- ✓ **Particle Identification (PID)**: (K_{ID}, π_{ID});

  K/π (CEDAR), π/μ (RICH)
- ✓ High efficiency **Vetoes**:

  γ (Large Angle Veto (LAV) + Liquid Kripton Cal (LKR) (NA48) + Small Angle Cal (SAC) + CHANTI;

  μ (Muon Veto (MUV))
- ✓ **Precise timing**: association of daughter particle (π^+) to the correct incoming parent particle (K^+) in a ~800 MHz beam;

  (GTK, CEDAR & RICH time resolution, σ(t) ~ 100 ps)

Background Rejection

Main Backgrounds:

- $K^+ \to \mu^+\nu$ (BR ~ 63%);
- $K^+ \to \pi^+\pi^0$ (BR ~ 21%);

Signal Signature:

- ✓ Incoming high momentum (75 GeV/c) K^+ ;
- ✓ Outgoing low momentum (< 35 GeV/c) π^+ ;

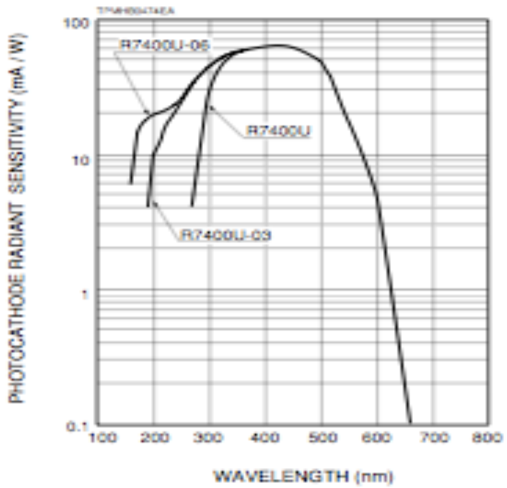
For $K^+ \to \pi^+\pi^0$ decay: p_{π^0} > 40 GeV/c -> Photons hardly undetected ☺

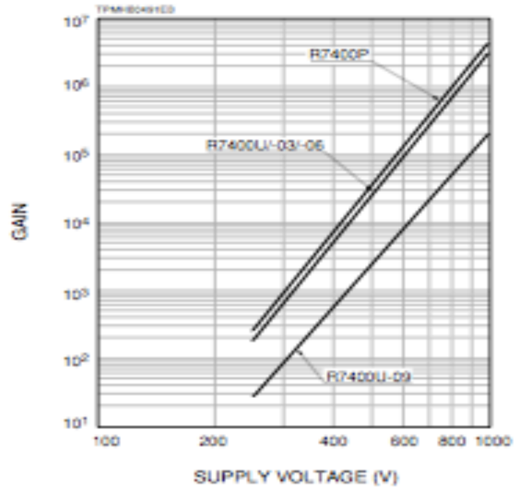
Background rejection @ level ~ 10^{-12}:

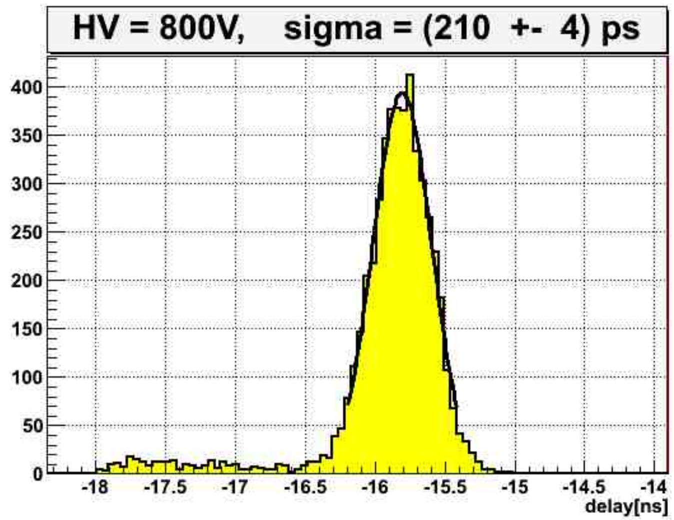
- Kinematics ~ 10^{-5}
- Vetoes ~ 10^{-5}
- PID ~ 5×10^{-3}

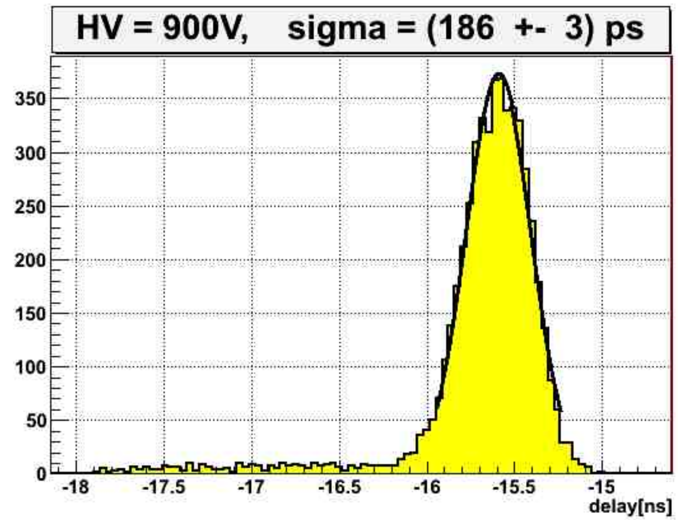
Hamamatsu Photomultiplier Tube: R7400-U03

- Metal package tube
- 16mm dd
- 8mm active dd
- 185nm–650nm
- 420nm peak sensitivity
- UV glass window
- Bialkali cathode
- Gain: $7x10^5$
- Transit time: 5.4ns
- Transit time spread: 0.28ns
- Number of dynodes: 8
- Applied Voltage: 800V (1000Vmax)









Very powerful for Single photoElectron Response (SER) measurements: $\sigma_{T,\gamma} \simeq 2.36 *$ sigma

sigma = standard deviation of the SER time distribution

PMT Anode Current & Rate

PMT channels rate ~ (130γ x 0.25)/(8 x 36)
~ 0.1γ @ 50MHz
~ 5MHz

Photo-Electron Rate/mm² ~ (130γ x 0.25 x 50MHz)/(8x14400mm²)
~ 14KHz/mm²

Average/Peak Anode Current α (PE Rate/mm² x Gain)

Anode Current = PE rate/mm² x q(PE)
~ 14KHz/mm² x 200fC ~ 2.8 nA/mm²
~ 0.14 μA per PM device

where 200fC = 1PE x G x q(E) = $1 \times 10^{6} \times 1.6 \times 10^{-19}$

Anode Average Current for R7400U3 PMTs is limited to 0.1mA
(-> from datasheet)