Recent results and prospects from NA62

Michal Zamkovsky

Charles University in Prague

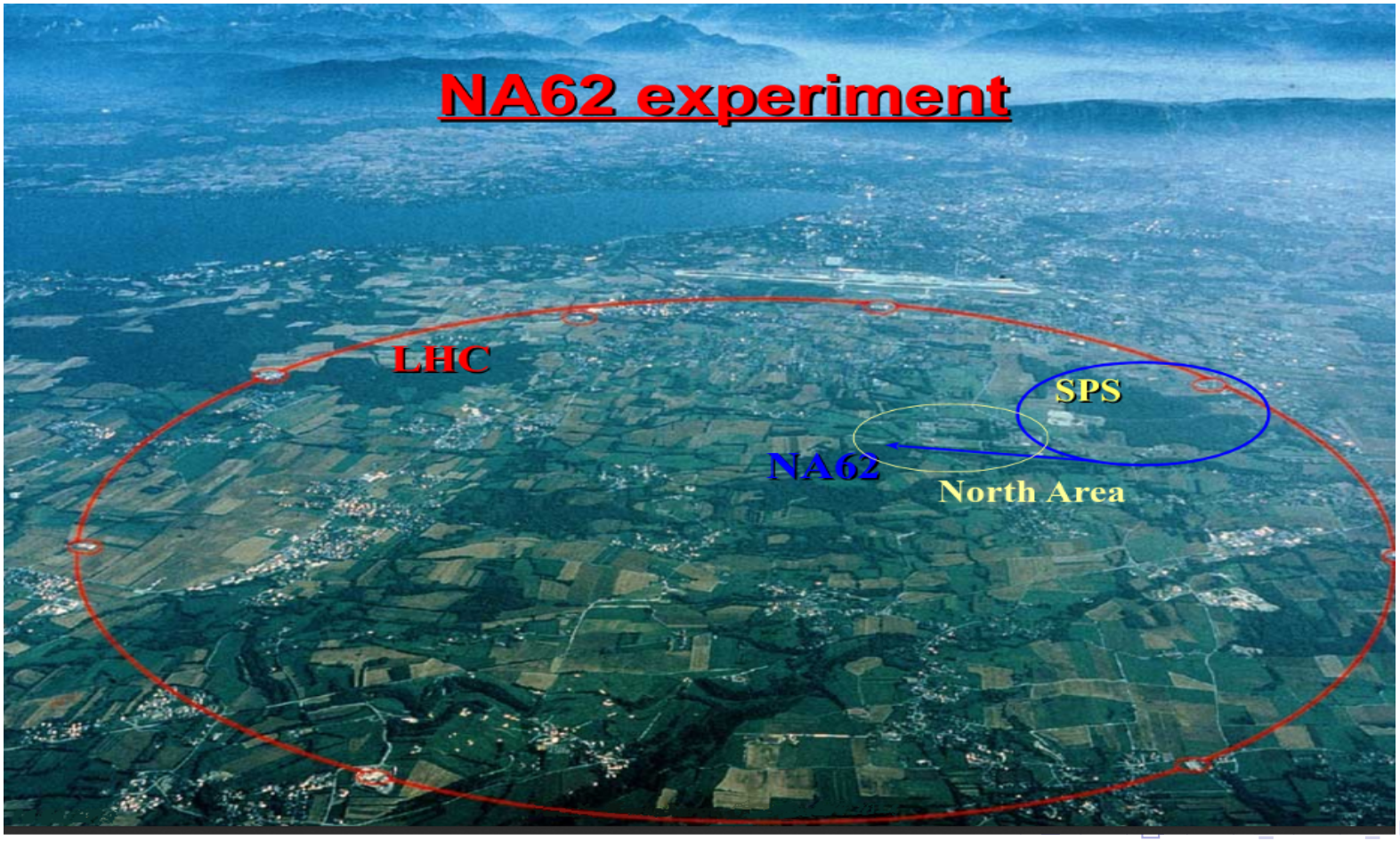
February 25, 2017

Outline

- The NA62-R_K and NA62 experiments at CERN
- Measurement of the π^0 transition form factor on 2007 data
- Heavy neutral lepton search with 2007 and 2015 data
- Future prospects of NA62 experiment
- Summary

Experiment NA62 at CERN

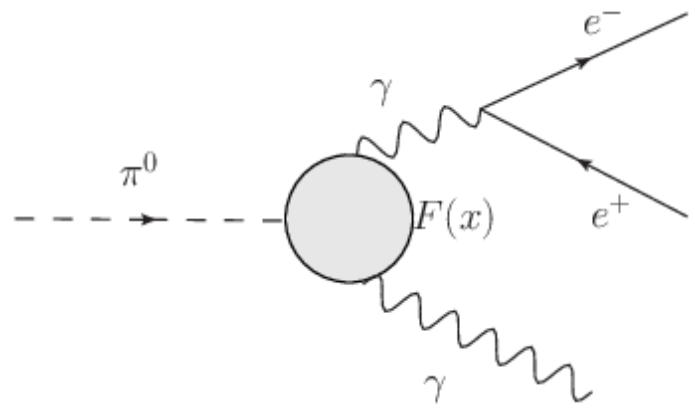
- SPS North Area experiment NA62, Prevessin
- Extracting 74 GeV/c K^+ from 400 GeV/c proton beam
- NA62-$\mathrm{R_K}$ (2007) using NA48 detector setup - π^0 TFF measurement and HNL search



Dalitz Decay: $\pi^0 \to e^+e^-\gamma$

- π^0_D decay - kinematic variables x, y :

$$x = \frac{(p_{e^+} + p_{e^-})^2}{m^2_{\pi^0}}, \quad y = \frac{2p_{\pi^0} \cdot (p_{e^+} - p_{e^-})}{m^2_{\pi^0}(1-x)}$$



- Differential decay width ($r^2 = (2m_e/m_{\pi^0})^2 \equiv m_{min}$):

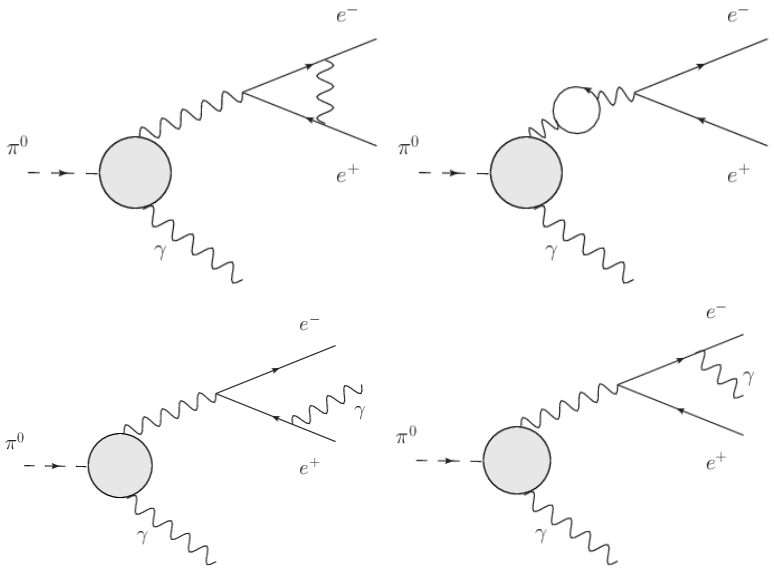
$$\frac{1}{\Gamma(\pi^0_{2\gamma})}\frac{d^2\Gamma(\pi^0_D)}{dxdy} = \frac{\alpha}{4\pi}\frac{(1-x)^3}{x}(1 + y^2 + \frac{r^2}{x})(1 + \delta(x,y))|F(x)|^2$$

$$F(x) \approx 1 + ax \qquad a: \ \textit{TFF slope parameter}$$

- π^0 TFF slope measurement at NA62 (Kaon decay experiment)
  - $\mathrm{K}^\pm \to \pi^\pm\pi^0$ decay: source of tagged π^0 decays (BR($K_{2\pi}$) $\approx 21\%$)
  - NA62 in 2007: data taking conditions optimized for $e^\pm$ from $\mathrm{K}^\pm \to e^\pm\nu_e$
    $\to$ large and clean sample of $\mathrm{K}^\pm \to \pi^\pm\pi^0$; $\pi^0 \to \gamma e^+e^-$ decays

Mikaelian and Smith

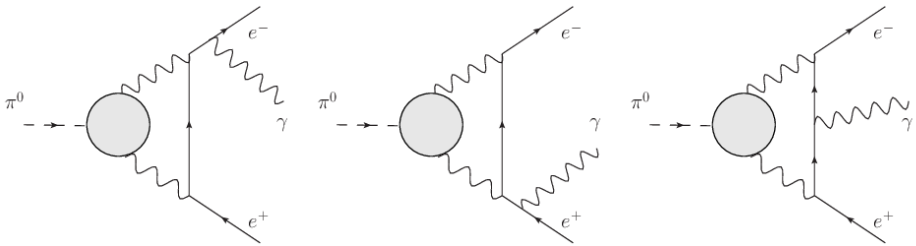
Phys. Rev. D5(1972) 1763



$\delta_{virt} + \delta_{BS}$ corrections

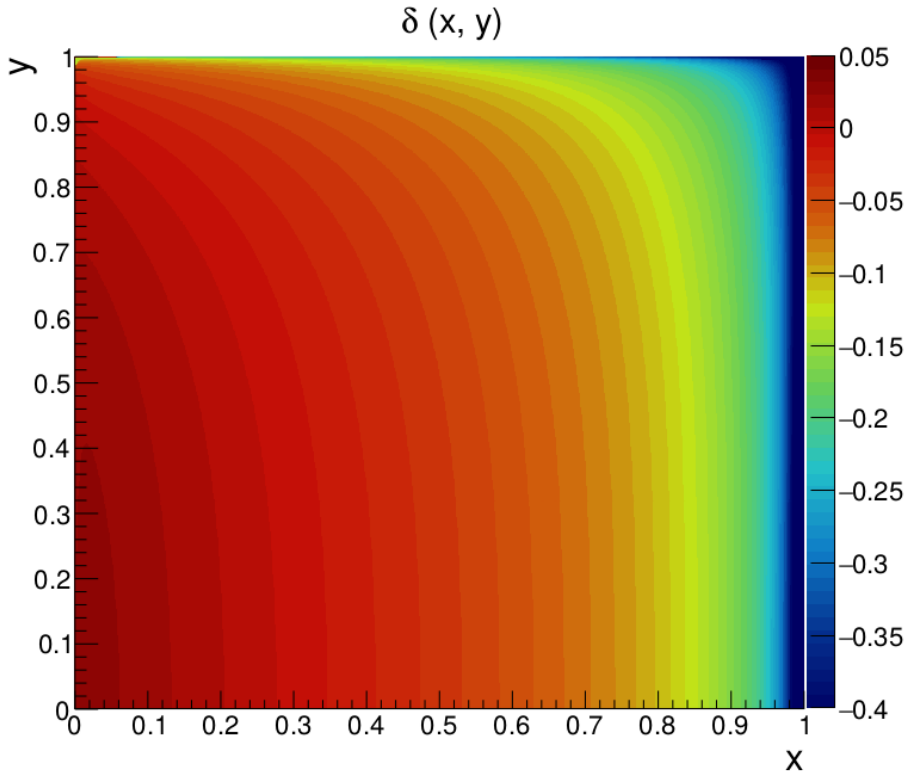
Husek, Kampf and Novotny

Phys. Rev. D92(2015) 5, 054027



$\delta_{1\gamma \mathrm{IR}}$ correction

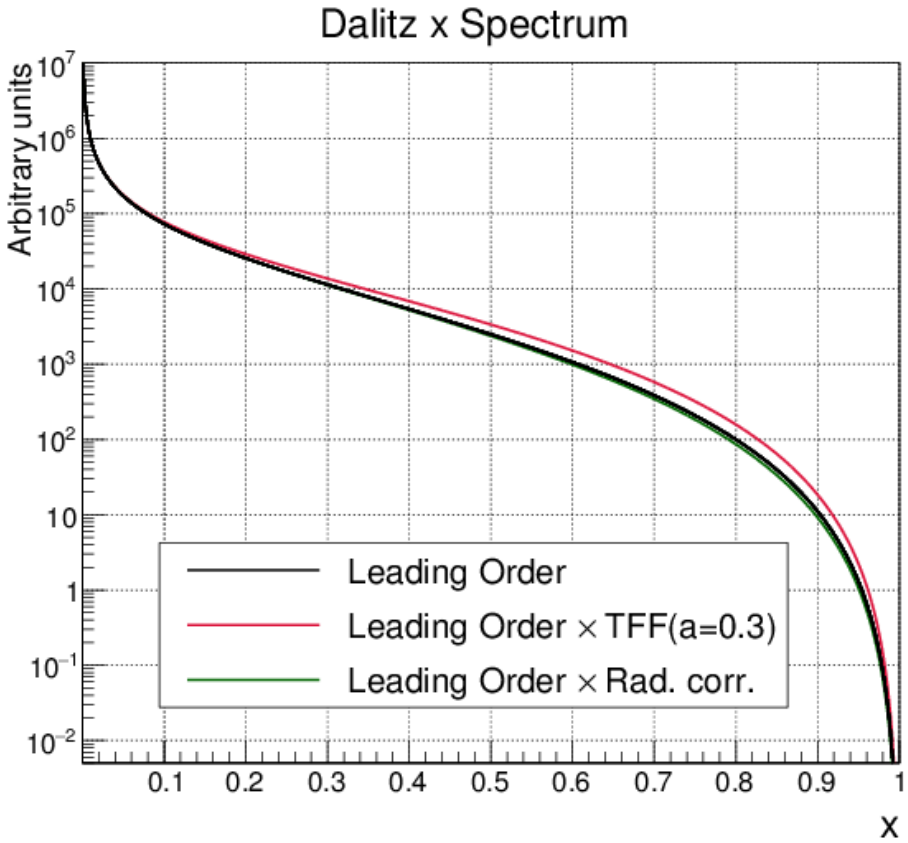
$$\frac{d^2\Gamma}{dxdy} = \left(\frac{d^2\Gamma}{dxdy}\right)_0 (1 + \delta(x, y))$$



- Corrections included in the simulation
- Radiative photon emission simulated

π^0_D : $d\Gamma/dx$ and Transition Form Factors

$$\frac{1}{\Gamma(\pi^0_{2\gamma})}\frac{d\Gamma(\pi^0_D)}{dx} = \frac{2\alpha}{3\pi}\frac{(1-x)^3}{x}\left(1+\frac{r^2}{2x}\right)\sqrt{1-\frac{r^2}{x}}\left(1+\delta(x)\right)(1+ax)^2$$



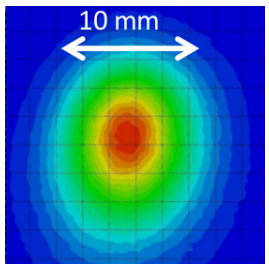
- π^0 TFF slope expectation from Vector Meson Dominance model: $a \approx 0.03$
- π^0 TFF theoretical models enter hadronic light-by-light scattering (HLbL) contribution to $(g-2)_\mu$
- See recent overview and references in: A. Nyffeler, arXiv:1602.03398 [hep-ph]
  $\rightarrow$ Comparison of TFF slope prediction with model independent measurement: important test of the theory models

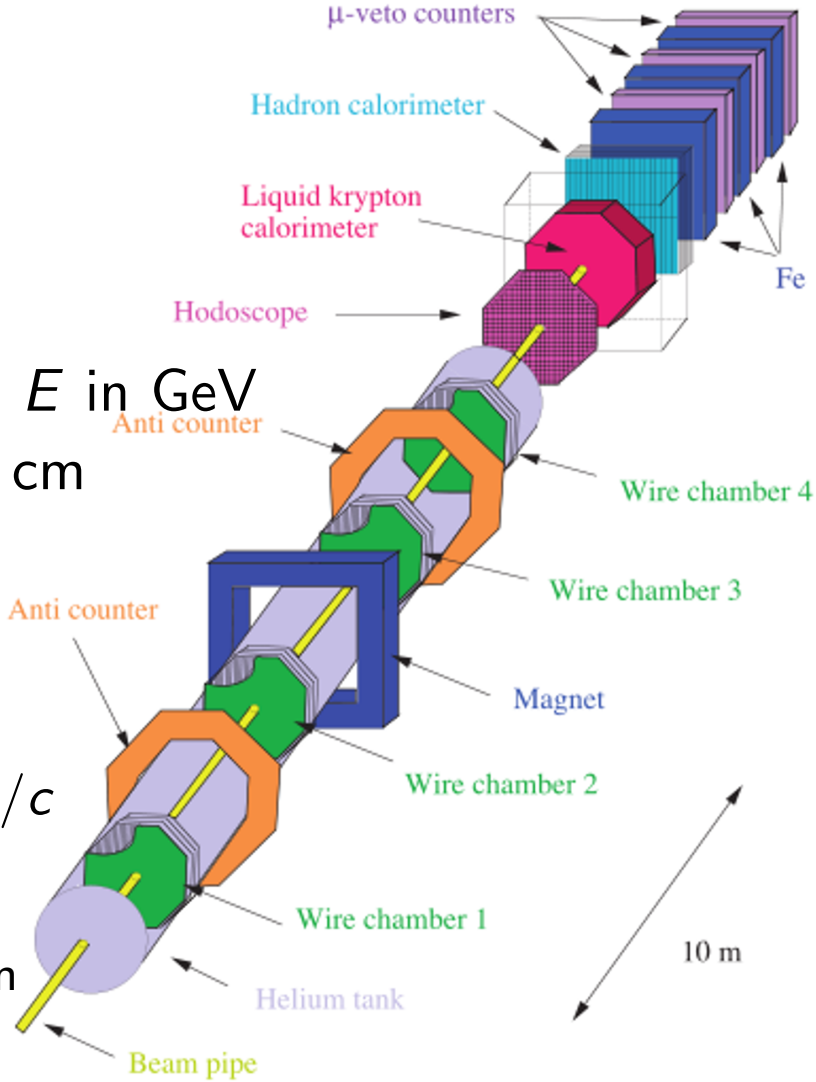
Experimental setup in 2007 NA62

- Detector performances and resolutions:

DCH	$\sigma_x = \sigma_y = 90\mu\text{m}$ $\sigma_p/p = (0.48 \oplus 0.009 \cdot p)$
HOD	$\sigma_t \sim 150$ ps
LKr	$\sigma_E/E = (3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42)\%$ E in GeV $\sigma_x = \sigma_y = (0.42/\sqrt{E} \oplus 0.06)$ cm

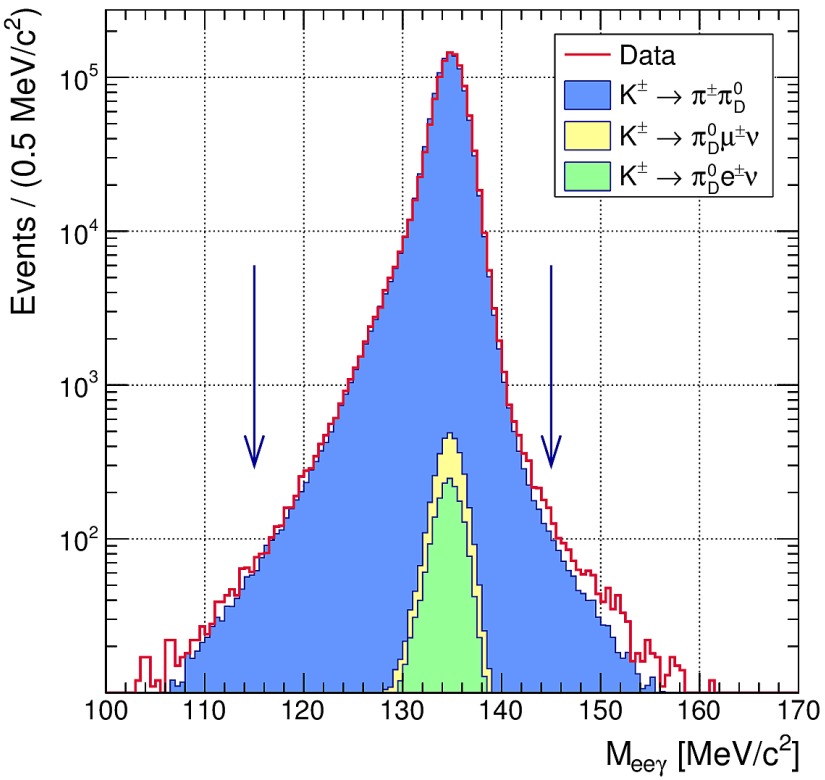
- Narrow momentum band $\mathrm{K}^{\pm}$ beams: $\mathrm{P_K} = 74$ GeV/c, $\delta\mathrm{P_K}/\mathrm{P_K} \sim 1\%$ (rms).
- Beam: simultaneous K^+ and K^- with a central momentum (74 ± 2) GeV/c
  - Focused at DCH1 with ~ 10 mm transverse size
  - Superimposed beam axes within 1 mm

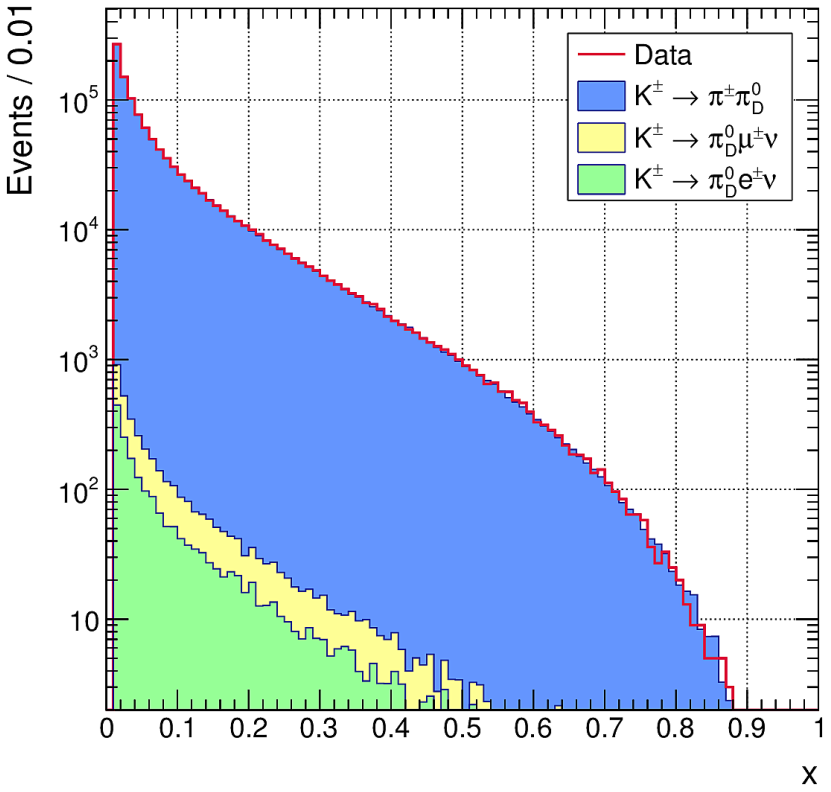




π^0_D : *TFF Selection*

- Selection: 3-track topology, photon in LKr, full kinematic closure, $x > 0.01$
- 1.05×10^6 fully reconstructed $\pi^0 \to \gamma e^+ e^-$
- TFF obtained by adjusting the simulation to the data x spectrum





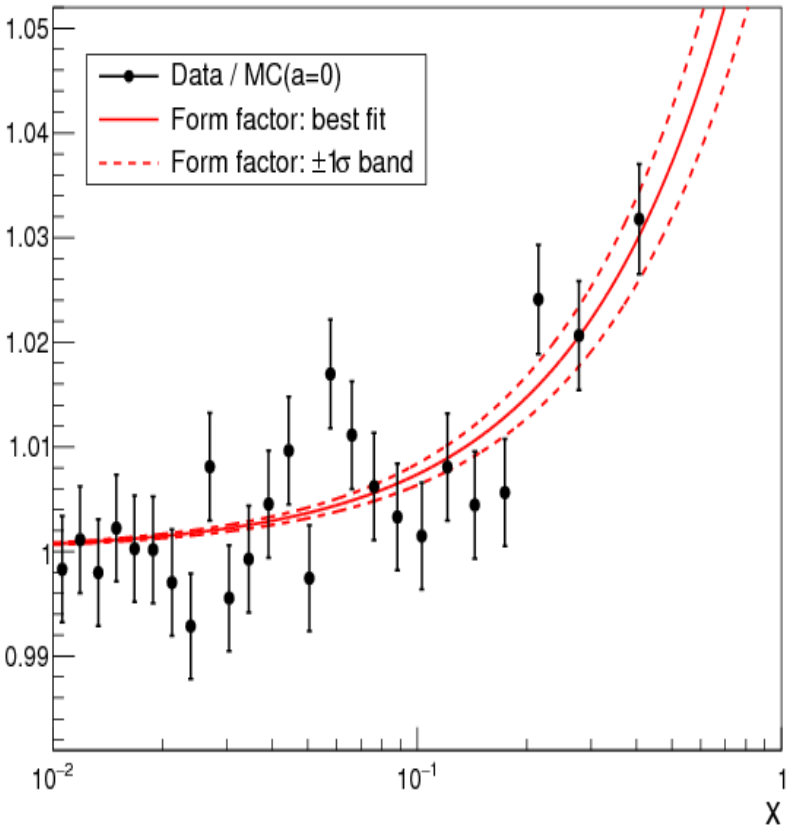
π^0_D : *Systematic Uncertainties*

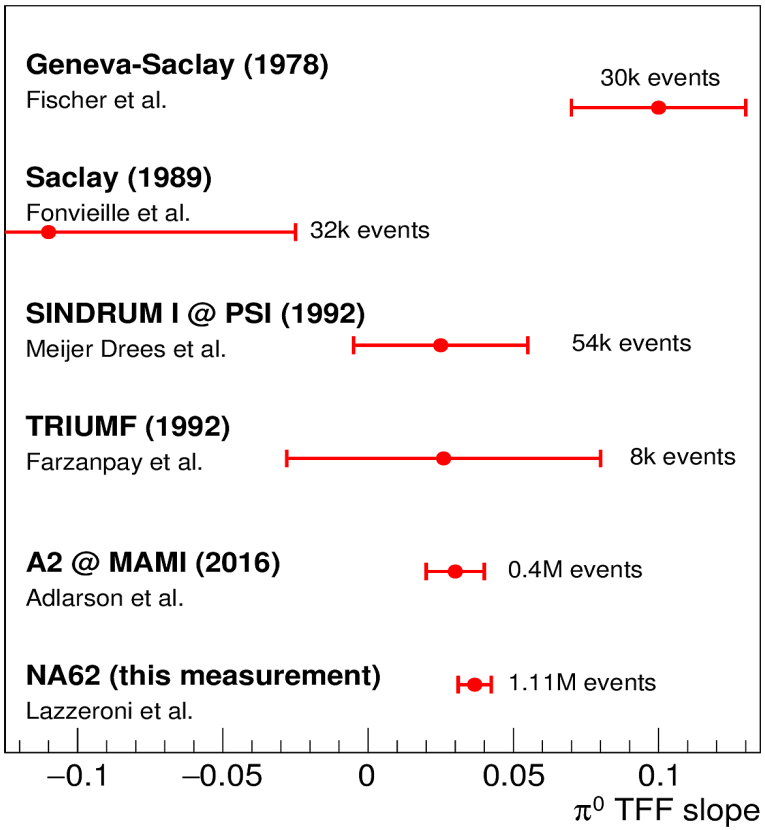
Source	$\delta a(\times 10^2)$
Statistical-Data	0.48
Statistical-MC	0.18
Spectrometer momentum scale	0.16
Spectrometer resolution	0.05
LKr calibration	0.04
Beam momentum spectrum simulation	0.03
Calorimeter trigger inefficiency	0.06
Accidental background	0.15
Particle mis-ID	0.06
Neglected π^0_D sources in MC	0.01
Higher order radiative contributions	$<$0.01

NA62 final result on π^0 TFF slope parameter:

$$a = (3.68 \pm 0.51_{stat} \pm 0.25_{syst}) \times 10^{-2}$$

$\pi^0 \to \gamma e^- e^+$ *TFF: Final results*





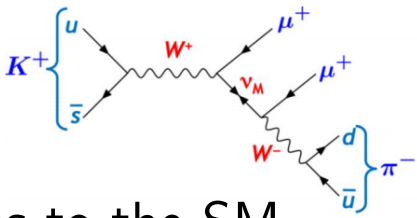
TFF Theory expectations:

- $a = (2.90 \pm 0.50) \times 10^{-2}$, χPT, *[K. Kampf et al. EPJ C46 (2006), 191]*
- $a = (3.07 \pm 0.06) \times 10^{-2}$, dispersion theory, *[M. Hoferichter et al. EPJ C74 (2014), 3180]*
- $a = (2.92 \pm 0.04) \times 10^{-2}$, two-hadron saturation, *[T. Husek et al. EPJ C75 (2015) 12, 586]*

NP searches in $K^+ \to \pi\mu\mu$ *decays*

- Search for Majorana neutrinos in LNV $K^+ \to \pi^- \mu^+ \mu^+$ decays

  [Asaka-Shaposhnikov model (νMSM) [PLB 620 (2005) 17]]



  - DM + Baryon Asymmetry + low mass of SM ν can be explained by adding three sterile Majorana neutrinos to the SM
  - Current limits set by NA48/2 *[submitted to Physics Letters B; arXiv:1612.04723]*

$$\mathrm{BR}(K^\pm \to \pi^\mp \mu^\pm \mu^\pm) < 8.6 \times 10^{-11} \quad @ \quad 90\%\ \mathrm{CL}$$

- Search for resonances (N, X, etc.) in the opposite-sign muons sample

  [Shaposhnikov-Tkachev model [PLB 639 (2006) 414]]

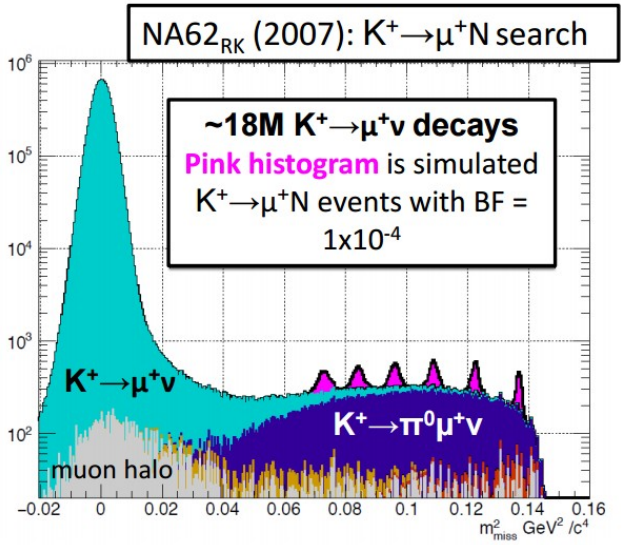
  - νMSM + real scalar field (inflaton X) with scale invariant couplings
  - Explains universe homogeneity and isotropy on large scales/structures on smaller scales
  - Current limits:
    - HN peak search in $K^+ \to \mu^+(\pi^+\mu^-)$
    - Inflatons peak peak search in $K^+ \to \pi^+(\mu^-\mu^+)$

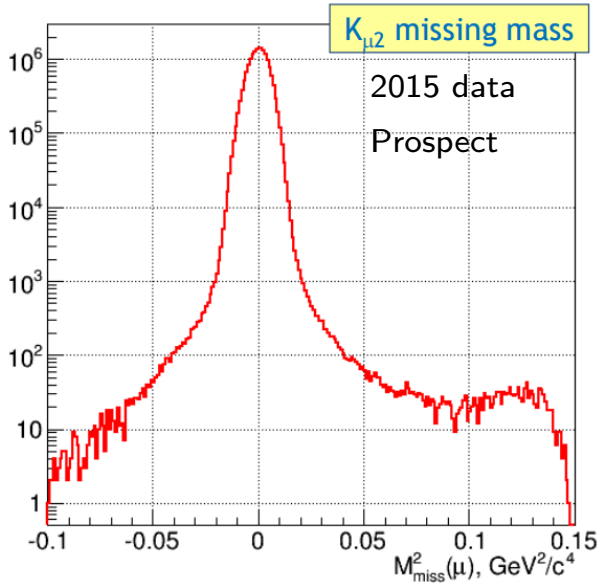
Limits set at $\sim 10^{-9}$ (90% CL) by NA48/2

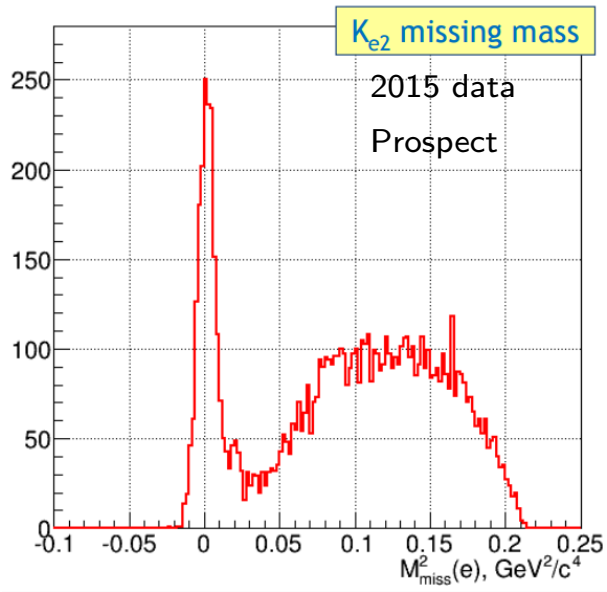
- Can also search for HNL in $K^+ \to l^+ N$ with undecayed N
  - $K^+ \to l^+ N$ events would appear as peaks in the $K^+ \to l^+ \nu$ m^2_{miss}
  - Searches are model independent

Heavy neutral leptons in $K^+ \to l^+N$

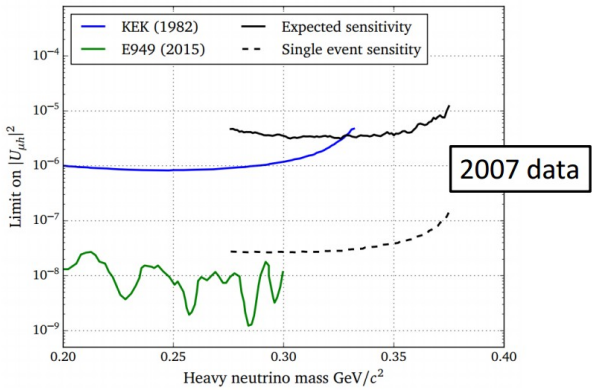
- The mass resolution at NA62 is better by a factor ∼2 compared to NA48/2
- NA62 can potentially improve by two orders of magnitude the NA48/2 results







- Current experimental status:
  most stringent constraints from kaon measurements
- Expected SES with 2015 NA62 data at the level of 10^{-8} (similar for $K \to eN$ and $K \to \mu N$)
- Analysis underway with NA62 data from 2015.



NA62 physics programme

- Run 2 (2015-2018): focused on the "golden mode" $K^+ \to \pi^+ \nu\bar{\nu}$.
  - Trigger bandwidth for other physics is limited.
  - Several measurements at nominal SES$\sim 10^{-12}$: $K^+ \to \pi^+ A'$, $\pi^0 \to \nu\nu$.
  - A few measurements do not require extreme SES: $K^+ \to l^+ \nu_H$, ...
  - In general, limited sensitivities for most rare/forbidden decays (SES$\sim 10^{-10}$ to $\sim 10^{-11}$, similar to NA48/2 and BNL-E865).
  - A proof of principle for a broad rare/forbidden decay programme.
- Run 3 (2021-2024): programme is under discussion.

  [Presented at the "Physics Beyond Colliders" workshop, CERN, Sep 2016]
  - Existing apparatus, different trigger logic: no capital investment.
  - Rare/forbidden K^+ and π^0 decays at SES$\sim 10^{-12}$:
    - K^+ physics: $K^+ \to \pi^+ l^+ l^-$, $K^+ \to \pi^+ \gamma l^+ l^-$, $K^+ \to l^+ \nu\gamma$, $K^+ \to \pi^+ \gamma\gamma$, ...
    - π^0 physics: $\pi^0 \to e^+ e^-$, $\pi^0 \to e^+ e^- e^+ e^-$, $\pi^0 \to 3\gamma$, $\pi^0 \to 4\gamma$, ...
    - Searches for LFV/LNV: $K^+ \to \pi^- l^+ l^+$, $K^+ \to \pi^+ \mu e$, $\pi^0 \to \mu e$.
  - Dump mode: hidden sector searches (long-lived HNL, DP, ALP).
  - Possibly further $K^+ \to \pi^+ \nu\bar{\nu}$ data collection.
  - Possibly K_L rare decays (SES$\sim 10^{-11}$), including $K_L \to \pi^0 l^+ l^-$[CPV].

Conclusions

- World best measurement of the π^0 transition form factor slope (NA62 2007 data):

$$a = (3.68 \pm 0.51_{stat} \pm 0.25_{syst}) \times 10^{-2}$$

  - The result is based on the NA62 2007 data statistics
  - The selected neutral pions are produced from $\mathrm{K}^{\pm} \to \pi^{\pm}\pi^0$ decays
  - About 1 million π^0 Dalitz decays have been fully reconstructed
  - The precision of the TFF measurement has been improved in the time-like momentum region
  - Final result accepted by Physics Letters B, *arXiv:1612.08162 [hep-ex]*
- Reported progress in the HNL searches
  - Draft in preparation for 2007 data (improved KEK limit above 320 MeV/c in the muon mode)
  - Possible improvement of current best results from NA48/2 experiment by two orders of magnitude with new data
  - Analysis underway with NA62 data from 2015.