Title: New ALP probes from light meson decays

Speakers: Stefania Gori

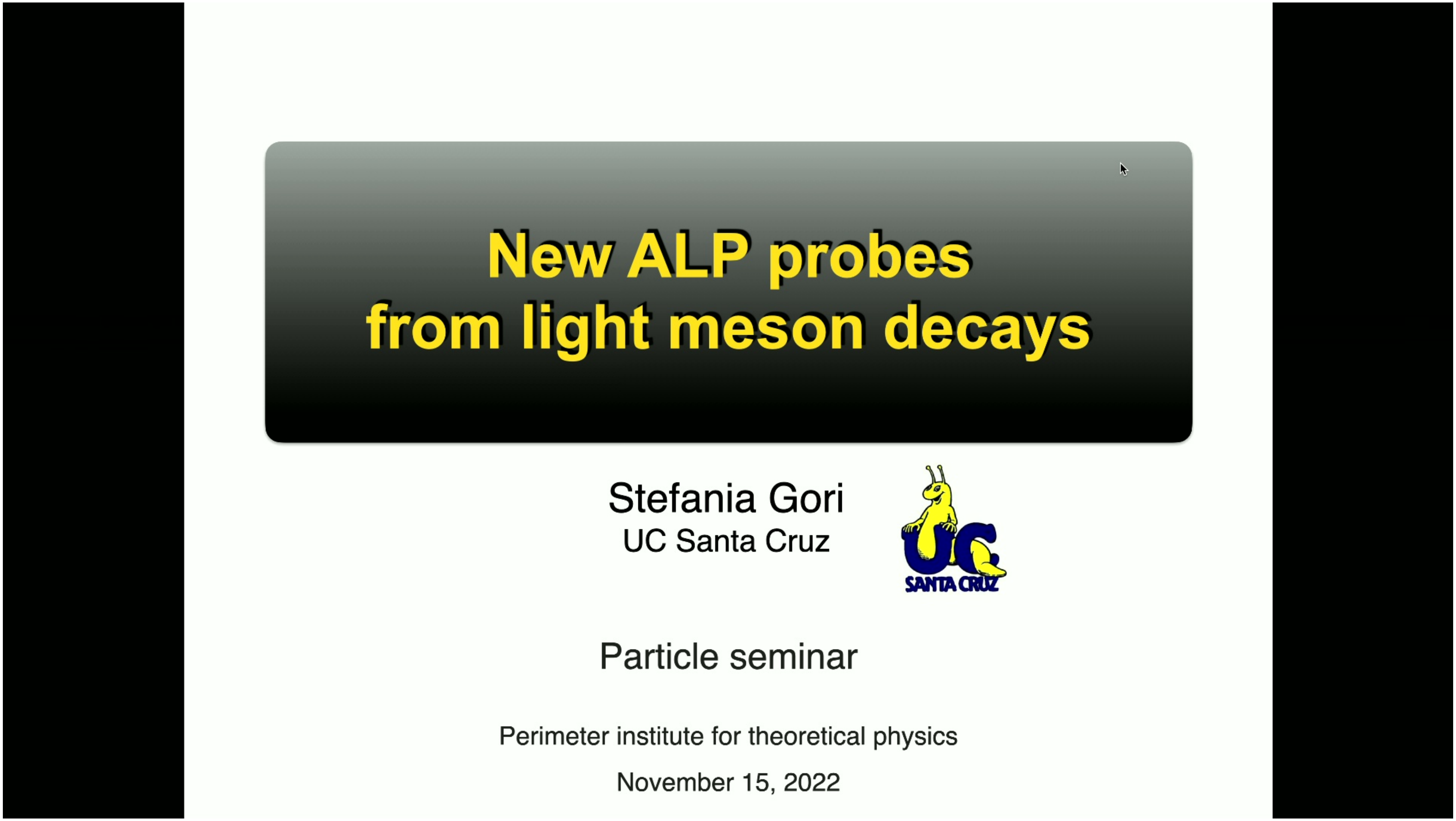
Series: Particle Physics

Date: November 15, 2022 - 1:00 PM

URL: https://pirsa.org/22110056

Abstract: Rare meson decays are among the most sensitive probes of both heavy and light new physics. Among them, new physics searches using kaons and pions benefit from their small total decay widths and the availability of very large datasets. In this talk, we first give an overview of new opportunities to search for axion-like particles (ALPs) in light meson decays. Second, we revisit the theory and constraints on ALPs interacting with leptons, pointing out the relevance of charged current meson and W decays to ALPs. This is particularly prominent in models where the ALP couples in an isospin-violating way. Finally, we highlight the role of the future PIONEER experiment in probing these new charged current pion decays to ALPs.

Zoom Link: https://pitp.zoom.us/j/98376159809?pwd=eDNHd1NhTUlVTmV4Y1RONjllNTNPdz09



New ALP probes from light meson decays

Stefania Gori
UC Santa Cruz

Particle seminar

Perimeter institute for theoretical physics

November 15, 2022

Outline of the seminar

1. Introduction

- Meson factories and axion-like-particles (ALP) from meson decays

Neutral current meson decays

Charged current meson decays

2. Neutral current meson decays

- Benchmark: ALPs coupled to W bosons
- Highlight: ALPs at **Kaon** factories

3. Charged current meson decays

- Benchmark: (1) ALPs mixing with Standard Model pions
  (2) ALPs coupled to leptons
- Highlight: ALPs at **pion** factories

Main references for this talk

Altmannshofer, SG, Robinson, 1909.00005
SG, Perez, Tobioka, 2005.05170
Altmannshofer, Dror, SG, 2209.00665

Focus on processes, experiments, and models not explored before

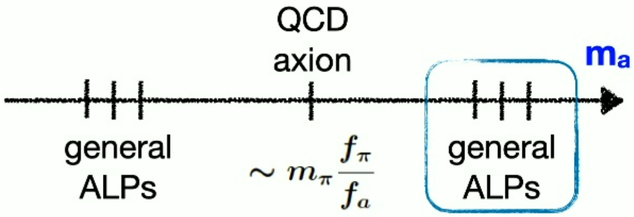
Axion-like-particles (ALPs)

Scalar with an approximate shift symmetry

(Possibly) connected to the Strong CP problem:
why is the QCD θ parameter so small?

$$\mathcal{L}_{\rm QCD} \supset \bar{\theta} \frac{g^2}{32\pi^2} G_{\mu\nu}\tilde{G}^{\mu\nu}$$

Mass can be protected by
a Peccei-Quinn symmetry
➡ ALPs below the EW scale?



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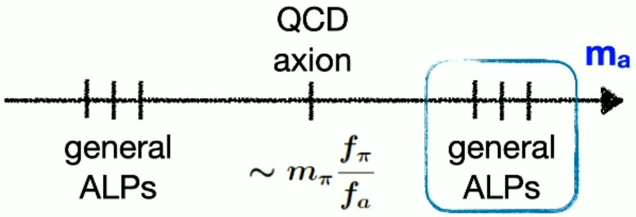
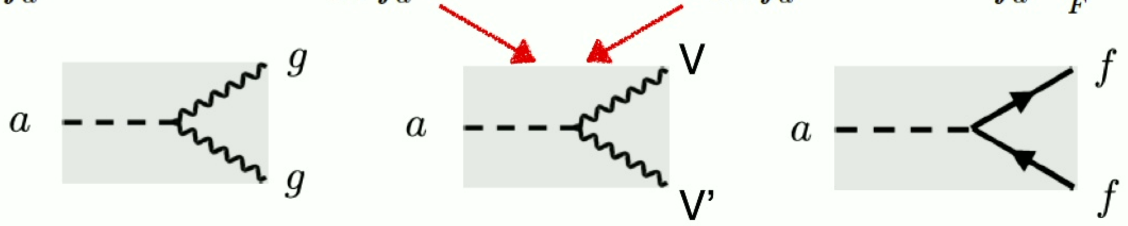


$$\mathcal{L} \supset c_{GG} \frac{\alpha_s}{4\pi} \frac{a}{f_a} G^a_{\mu\nu} \tilde{G}^{\mu\nu,a} + c_{WW} \frac{\alpha_2}{4\pi} \frac{a}{f_a} W^A_{\mu\nu} \tilde{W}^{\mu\nu,A} + c_{BB} \frac{\alpha_1}{4\pi} \frac{a}{f_a} B_{\mu\nu} \tilde{B}^{\mu\nu} + \frac{\partial_\mu a}{f_a} \sum_F \bar{\psi}_F C_F \gamma_\mu \psi_F$$



In particular, a ALP-photon coupling
is generated in the broken phase

by far the most studied

Broad program of ALP searches at meson factories?

The precision frontier @ flavor factories

A big jump in luminosity is expected in the coming years

	Past/Present	Future
Pion-factories	**PIENU experiment** at TRIUMF: ~10^{11} pi$^+$	**PIONEER experiment** at PSI (phase 1 approved. Data in ~2028(?)): ~10^{12} pi$^+$
Kaon-factories	**E949** at BNL: ~10^{12} K$^+$ (decay at rest experiment); **E391** at KEK: ~10^{12} K$_L$	**NA62** at CERN: ~10^{13} K$^+$ by the end of its run (decay in flight experiment); **KOTO** at JPARC: ~10^{14} K$_L$ by the end of its run
B-factories	**LHCb:** more than ~ 10^{12} b quarks produced so far; **Belle** (running until 2010): ~10^9 BB-pairs were produced.	**LHCb:** ~40 times more b quarks will be produced by the end of the LHC; **Belle-II:** ~50 times more BB-pairs will be produced.

The PIONEER experiment

W. Altmannshofer,[1] H. Binney,[2] E. Blucher,[3] D. Bryman,[4,5] L. Caminada,[6]
S. Chen,[7] V. Cirigliano,[8] S. Corrodi,[9] A. Crivellin,[6,10,11] S. Cuen-Rochin,[12]
A. DiCanto,[13] L. Doria,[14] A. Gaponenko,[15] A. Garcia,[2] L. Gibbons,[16] C. Glaser,[17]
M. Escobar Godoy,[1] D. Göldi,[18] S. Gori,[1] T. Gorringe,[19] D. Hertzog,[2] Z. Hodge,[2]
M. Hoferichter,[20] S. Ito,[21] T. Iwamoto,[22] P. Kammel,[2] B. Kiburg,[15] K. Labe,[16]
J. LaBounty,[2] U. Langenegger,[6] C. Malbrunot,[5] S.M. Mazza,[1] S. Mihara,[21] R. Mischke,[5]
T. Mori,[22] J. Mott,[15] T. Numao,[5] W. Ootani,[22] J. Ott,[1] K. Pachal,[5] C. Polly,[15]
D. Počanić,[17] X. Qian,[13] D. Ries,[23] R. Roehnelt,[2] B. Schumm,[1] P. Schwendimann,[2]
A. Seiden,[1] A. Sher,[5] R. Shrock,[24] A. Soter,[18] T. Sullivan,[25] M. Tarka,[1] V. Tischenko,[13]
A. Tricoli,[13] B. Velghe,[5] V. Wong,[5] E. Worcester,[13] M. Worcester,[26] and C. Zhang[13]

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[2] Dpt Phys. University of Washington
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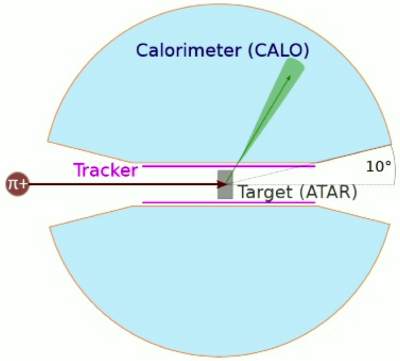
[4] University of British Columbia
[5] TRIUMF
[6] Paul Scherrer Institute
[7] Tsinghua University
[8] Institute for Nucl. Theory, University of Washington
[9] Argonne National Laboratory
[10] University of Zurich
[11] CERN
[12] Tec de Monterrey
[13] Brookhaven National Laboratory
[14] PRISMA+ Cluster of Excellence, University of Mainz
[15] Fermilab
[16] Cornell University
[17] University of Virginia
[18] ETH Zurich
[19] University of Kentucky
[20] University of Bern
[21] KEK
[22] University of Tokyo
[23] University of Mainz
[24] Stony Brook University
[25] University of Victoria
[26] Inst. Div, BNL

Proposal in 2203.01981



Experiment approved
last summer for PSI

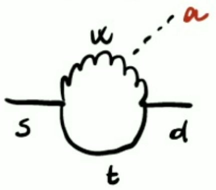
Phase I: ~2 x 10^{12} pions
Phase II/III: ~7 x 10^{13} pions

Neutral & charged current meson decays to ALPs

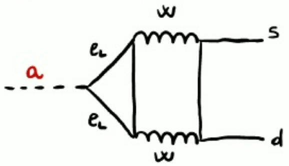
Flavor changing neutral current

They arise in models with

- ✱ ALPs mixed with SM neutral pions
  (e.g. $K^+ \to \pi^+\pi^0 \Rightarrow K^+ \to \pi^+ a$)
- ✱ ALPs coupling to W or tops



- ✱ ALPs coupling to leptons
  (higher loop)



$$\begin{array}{ccc} K_L & \to & \pi^0 a \\ K^+ & \to & \pi^+ a \\ B & \to & K a \end{array}$$

- ✱ Flavor violating ALPs

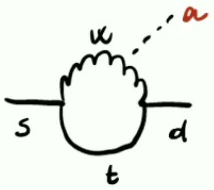
Somewhat studied in the literature but pieces are missing

Neutral & charged current meson decays to ALPs

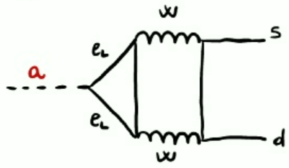
Flavor changing neutral current

They arise in models with

- ALPs mixed with SM neutral pions
  (e.g. $K^+ \to \pi^+\pi^0 \Rightarrow K^+ \to \pi^+ a$)
- ALPs coupling to W or tops



- ALPs coupling to leptons
  (higher loop)



$$\begin{aligned} K_L &\to \pi^0 a \\ K^+ &\to \pi^+ a \\ B &\to K a \end{aligned}$$

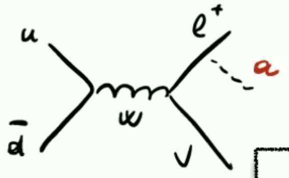
- Flavor violating ALPs

Somewhat studied in the literature but pieces are missing

Charged current

They arise in models with

- ALPs mixed with SM neutral pions
  (e.g. $\pi^+ \to \ell^+\nu\pi^0 \Rightarrow \pi^+ \to \ell^+\nu a$)
- ALP coupling to leptons

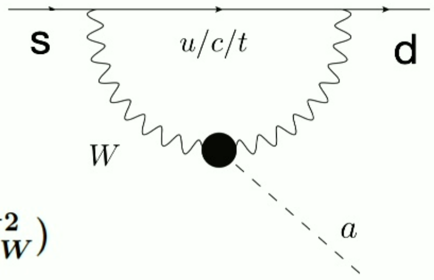


$$\begin{aligned} \pi^+ &\to a\ell^+\nu \\ K^+ &\to a\ell^+\nu \\ B^+ &\to a\ell^+\nu \end{aligned}$$

Not studied in the literature

ALP coupling to W bosons

$$\frac{g_{aW}}{4}\, a\, W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$$



$$g_{ads} \equiv -\frac{3\sqrt{2}G_F M_W^2 g_{aW}}{16\pi^2}\sum_{\alpha\in c,t} V_{\alpha d}V^*_{\alpha s}\, f(M_\alpha^2/M_W^2)$$

$$\Gamma(K_L\to\pi^0 a) = \frac{M^3_{K_L}}{64\pi}\left(1-\frac{M^2_{\pi^0}}{M^2_{K_L}}\right)^2 \mathrm{Im}(g_{asd})^2\,\lambda^{1/2}_{\pi^0 a}$$

This coupling will induce the decay of the ALP into two photons:

$$\frac{g_{a\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu},\quad g_{a\gamma}=g_{aW}\sin^2\theta$$

Due to isospin, we expect an effect also in the K^+ decay. Indeed:

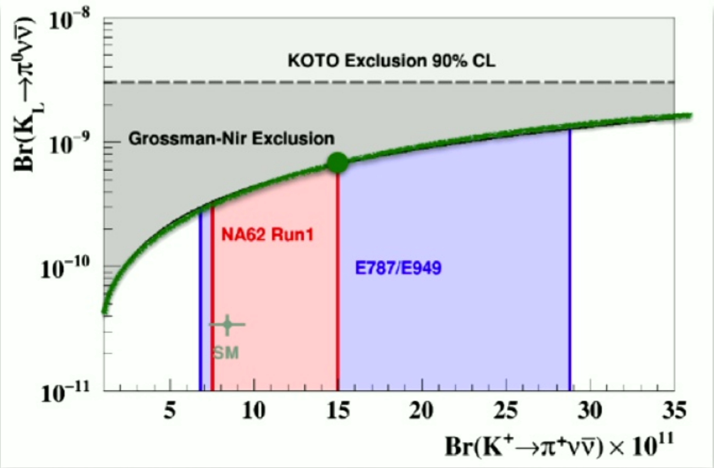
$$\Gamma(K^+\to\pi^+ a) = \frac{M^3_{K^+}}{64\pi}\left(1-\frac{M^2_{\pi^+}}{M^2_{K^+}}\right)^2|g_{asd}|^2\,\lambda^{1/2}_{\pi^+ a}$$

A side note: the Grossman-Nir (GN) bound

Beyond the Standard model theories can easily induce a New Physics (NP) effect in these very rare Kaon decays.

Generically, the NP effects in the **K^+ and in the K_L decay are highly correlated**.

This is the reason that it is hard to get huge NP effects at KOTO ($K_L \to \pi^0\bar{\nu}\nu$) while being consistent with measurements at NA62 ($K^+ \to \pi^+\bar{\nu}\nu$)



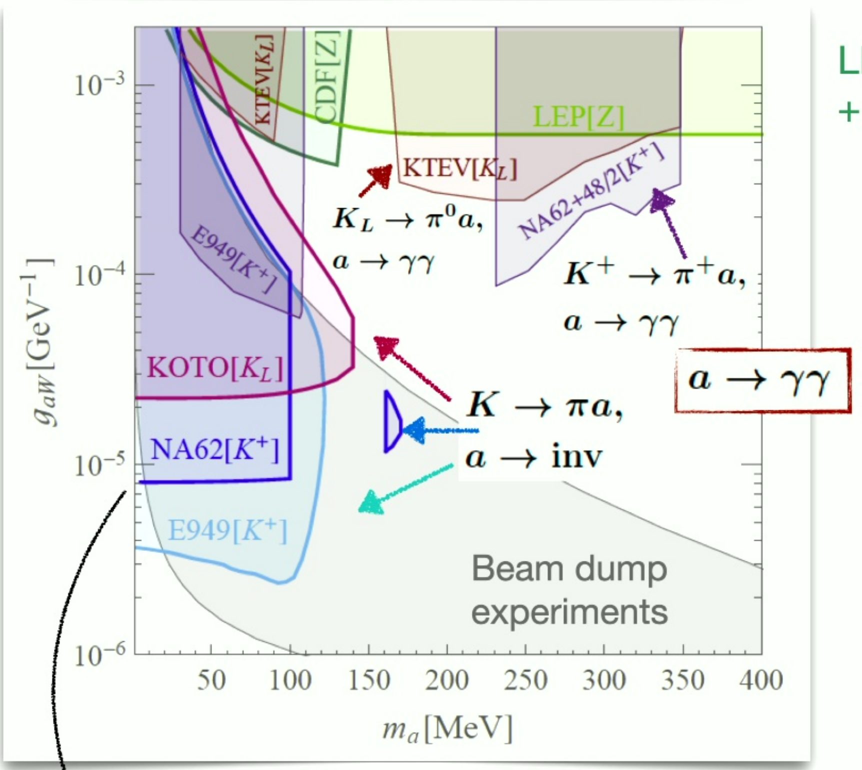
Marchevski talk @ ICHEP, 2020

Grossman-Nir bound (~model independent):

$$\frac{\mathrm{BR}(K_L \to \pi^0\nu\bar{\nu})}{\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu})} < 4.3$$

hep-ph/9701313

$aW\tilde{W}$ at Kaon experiments



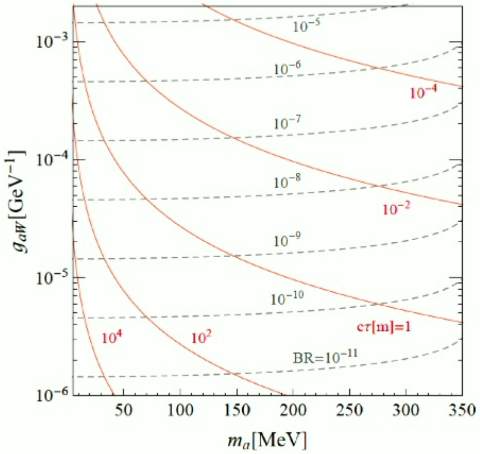
SG, G. Perez, K. Tobioka, 2005.05170

using measurements of $K \to \pi\nu\bar{\nu}$

LEP ($e^+e^- \to \gamma$ a or Z $\to \gamma$ a $\to \gamma\gamma(\gamma)$)
+ CDF (Z $\to \gamma$ a $\to \gamma\gamma$)

ALP lifetime (in meters)

BR($K_L \to \pi$ a)



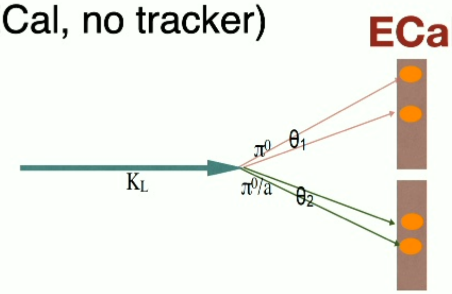
BR($K^+ \to \pi^+$ a) ~ 1.8 BR($K_L \to \pi$ a)

Additional searches for NA62 and KOTO?

$\boxed{K_L \to \pi^0 X \to 4\gamma}$ Our new proposed search for KOTO

Challenges of the search:

- the decay point is unknown (only ECal, no tracker)
- combinatorics of γγ pairs



Main ingredients :

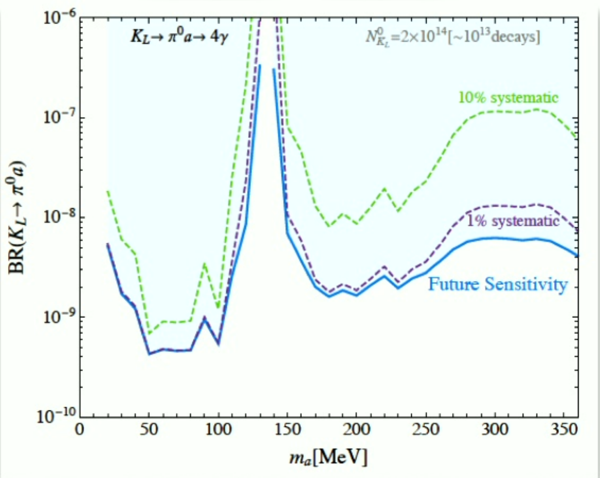
1. We derive the K_L decay vertex location of the 6 possible di-photon pair combinations, assuming
$$m^2_{\gamma_i\gamma_j} = m^2_{\pi^0}$$
2. Require $m_{4\gamma} \simeq m_{K_L}$ to find a correct pair

Importance of a good vertex resolution! (~5cm) and small energy smearing (~2%)

We simulate the main sources of background:

$K_L \to \pi^0\pi^0$, $K_L \to \pi^0\gamma\gamma$

mainly for $m_a \sim m_{pion}$



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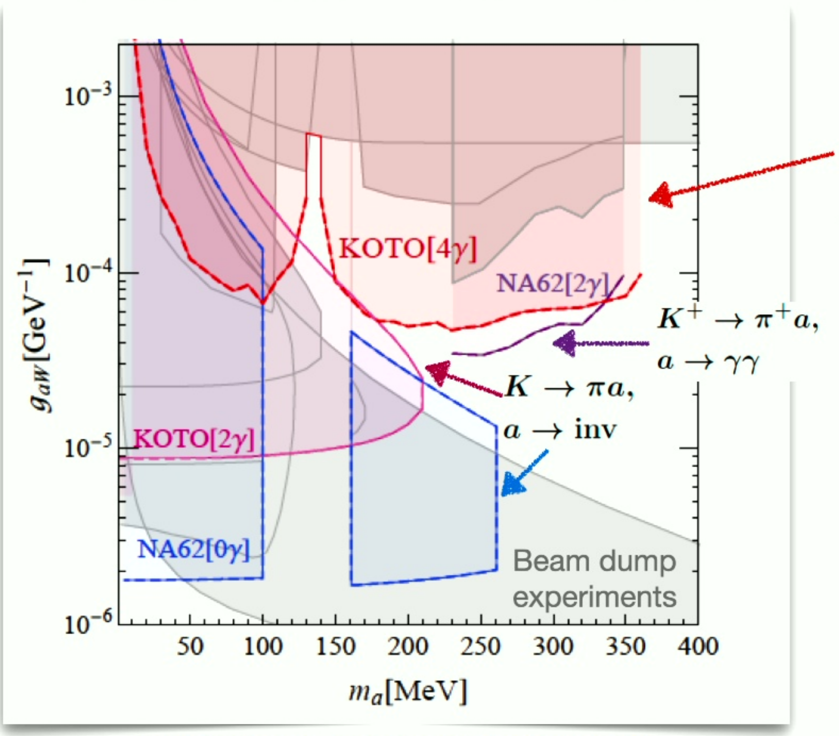
SG, G. Perez, K. Tobioka, 2005.05170

Future prospects to test $aW\tilde{W}$



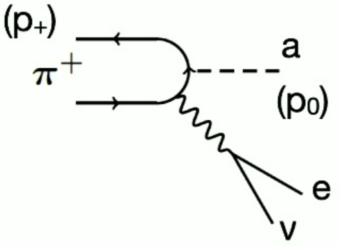
$K^+ \to \pi^+ a,$
$a \to \gamma\gamma$

$K \to \pi a,$
$a \to \text{inv}$

KOTO proposed search:
$K_L \to \pi^0 a,$
$a \to \gamma\gamma$

SG, G. Perez, K. Tobioka, 2005.05170

Sec. 1: ALP-pion mixing scenario



$$\begin{aligned}\mathcal{A}^\mu &\simeq \langle a|\pi^{0*}\rangle\langle\pi^{0*}|\bar{d}\gamma^\mu u|\pi^+\rangle \\ &\equiv \sin\vartheta\langle\pi^{0*}|\bar{d}\gamma^\mu u|\pi^+\rangle \\ &\equiv \sin\vartheta\; c_\pi\left[f_+(p_+^\mu+p_0^\mu)+(f_0-f_+)\frac{m_+^2-m_0^2}{q^2}\underbrace{(p_+^\mu-p_0^\mu)}_{q^\mu}\right]\end{aligned}$$

ALP mass

form factors

$f_+(q^2)\simeq 1$ as long as q^2 is small → m_0>~10 MeV

Theory: more understanding of form factors would be needed to get precision constraints for lighter ALPs

$$\frac{\mathrm{BR}[\pi^+\to ae^+\nu]}{\mathrm{BR}[\pi^+\to e^+\nu]}\sim\frac{m_0^4\sin^2\vartheta}{f_\pi^2 m_e^2(1-m_e^2/m_+^2)^2}\times\int_1^{\frac{(m_0^2+m_+^2)}{2m_0m_+}}(w^2-1)^{3/2}dw$$

no helicity suppression

Once produced, the ALP can

- decay to photons: $g_{a\gamma}^{\text{eff}}=\sin\vartheta\frac{\sqrt{2}\alpha}{8\pi f_\pi}+g_{a\gamma}$
- be invisible to our detectors

Possible UV contribution

Signatures

- $\pi^+\to ae^+\nu\to(\gamma\gamma)e^+\nu$
- $\pi^+\to ae^+\nu\to e^++\text{inv}$

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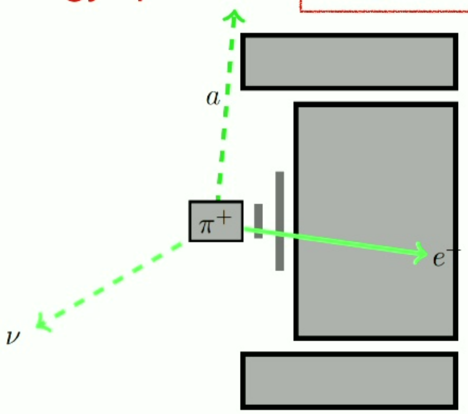
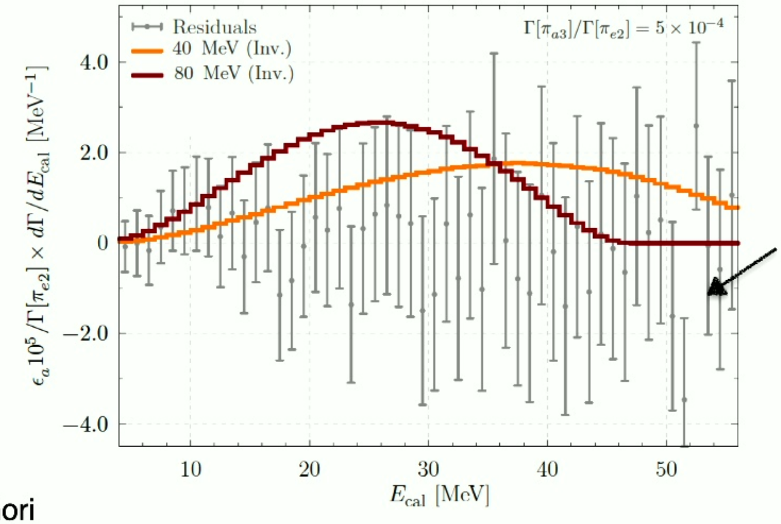
ALPs at PIENU

PIENU experiment @ TRIUMF: Most precise measurement of the SM $\pi^+ \to e^+\nu$

The production of the ALP will affect the measured energy spectrum $\boxed{\pi^+ \to ae^+\nu}$

1. Invisible regime: the energy spectrum of the positron depends on the ALP mass.





residuals from
PIENU collaboration, 1712.03275
(search for sterile neutrinos: $\pi^+ \to e^+N$)

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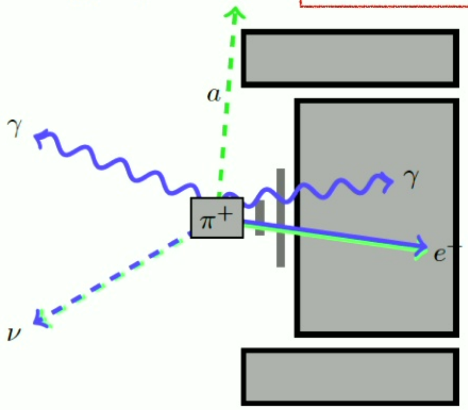
ALPs at PIENU

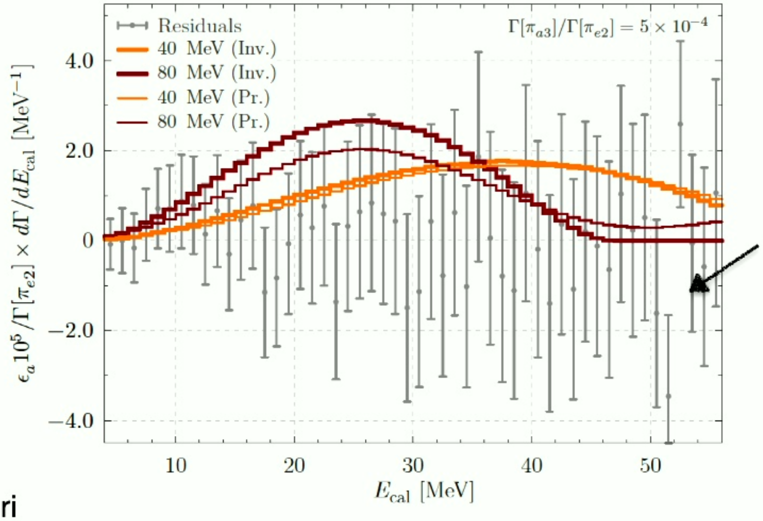
PIENU experiment @ TRIUMF: Most precise measurement of the SM $\pi^+ \to e^+\nu$

The production of the ALP will affect the measured energy spectrum $\boxed{\pi^+ \to a e^+\nu}$

1. Invisible regime: the energy spectrum of the positron depends on the ALP mass.

2. Prompt regime: the energy measured by the calorimeter can get a contribution from the photons produced from the ALP decay.

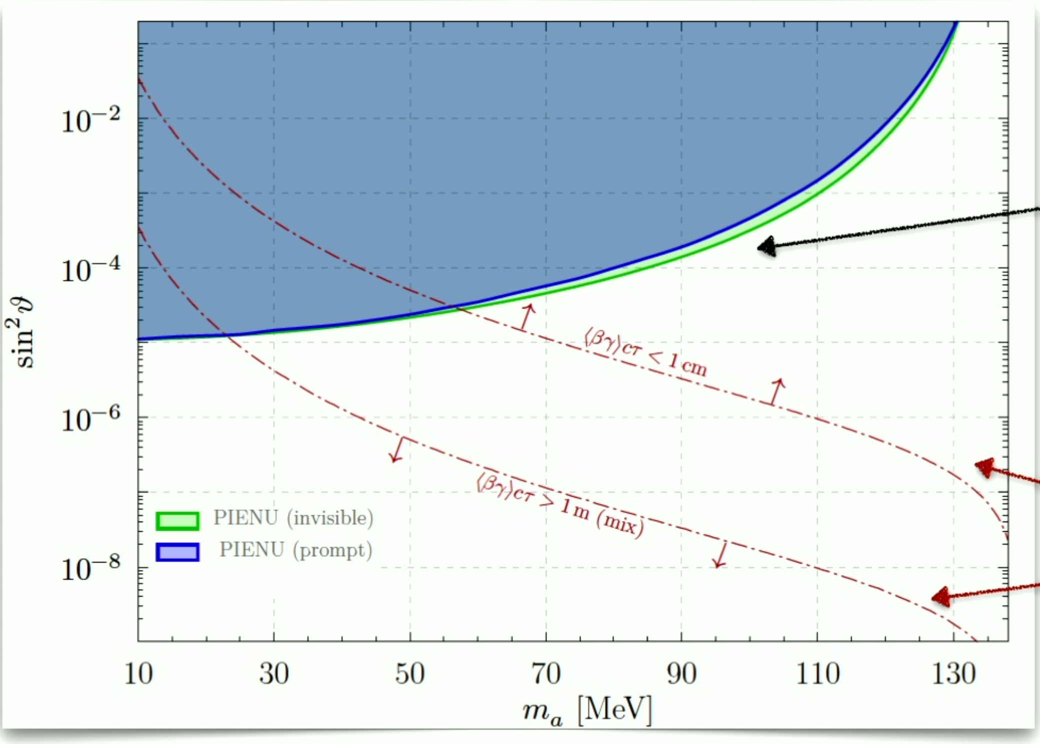




residuals from
PIENU collaboration, 1712.03275
(search for sterile neutrinos: $\pi^+ \to e^+ N$)

ALP bound from PIENU

Fitting the residuals…



This bound corresponds to

$$\mathrm{BR}(\pi^+ \to a e^+ \nu) \sim \mathcal{O}(10^{-8})$$

Life time in the mixing scenario

$$g_{a\gamma}^{\mathrm{eff}} = \sin\vartheta \frac{\sqrt{2}\alpha}{8\pi f_\pi}$$

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ALPs at PIBETA

PIBETA experiment @ PSI: Most precise measurement of the SM $\pi^+ \to \pi^0 e^+ \nu$

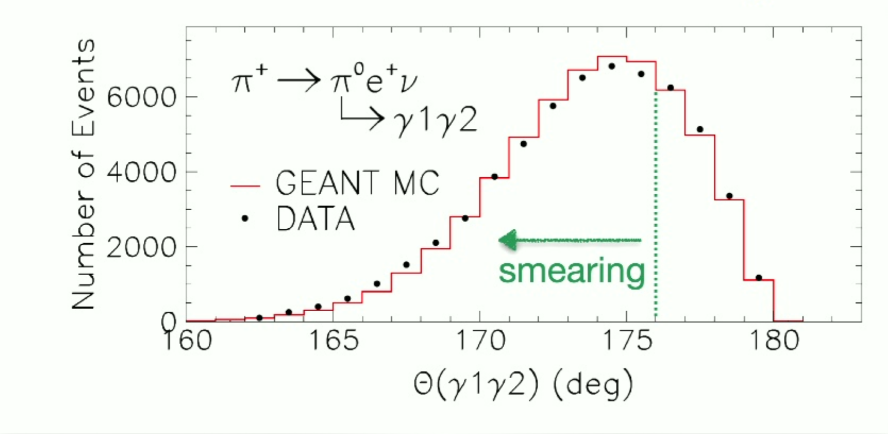
The production of the ALP will affect the measured photon angle $\boxed{\pi^+ \to a e^+ \nu}$

$\boxed{\pi^+ \to \pi^0 e^+ \nu}$

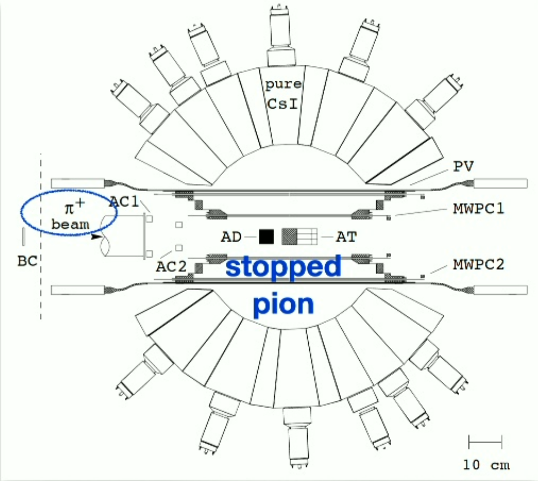
π^0 is produced (almost) at rest

→ $\gamma\gamma$ will be produced ~ back to back

from 0312030



smearing

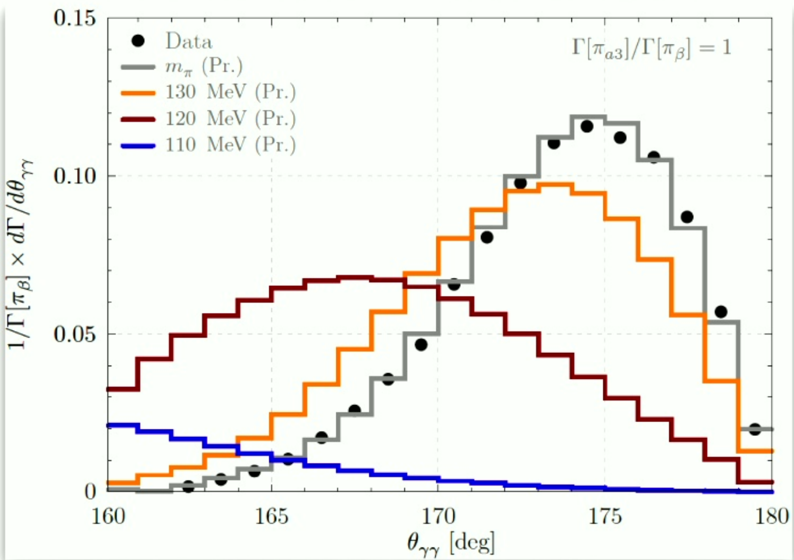


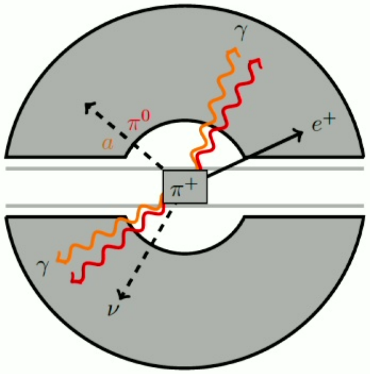
stopped pion

$$-1 \leq \cos\theta_{\gamma\gamma} \leq -1 + 2\left(\frac{m_{\pi^+}^2 - m_{\pi^0}^2}{m_{\pi^+}^2 + m_{\pi^0}^2}\right)^2$$

Photon distribution at PIBETA

$\boxed{\pi^+ \to a e^+ \nu}$ The spectrum of the photons will change:



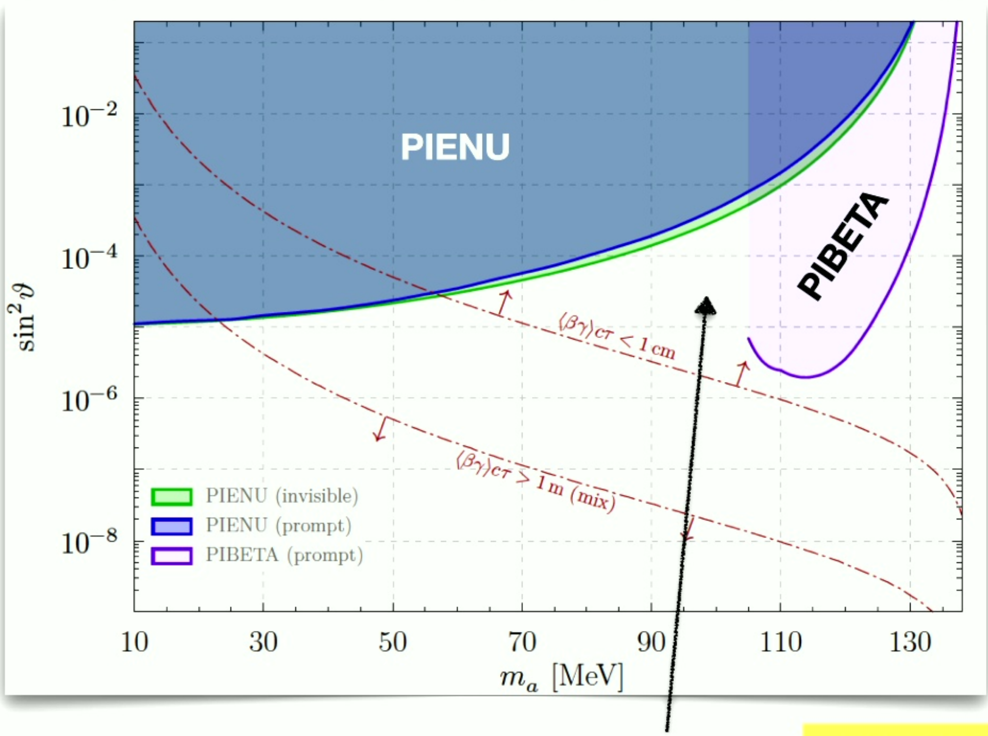


$$-1 \le \cos\theta_{\gamma\gamma} \le -1 + 2\left(\frac{m_{\pi^+}^2 - m_a^2}{m_{\pi^+}^2 + m_a^2}\right)^2$$

Unfortunately the PIBETA collaboration does not report residuals.

We require the integrated contribution in (160-180) deg
is smaller than the experimental uncertainty in the $\mathrm{BR}(\pi^+ \to \pi^0 e^+ \nu)$

ALP bound from PIENU and PIBETA



Possibility to go to lower masses
at future experiments
(data at smaller angles!)

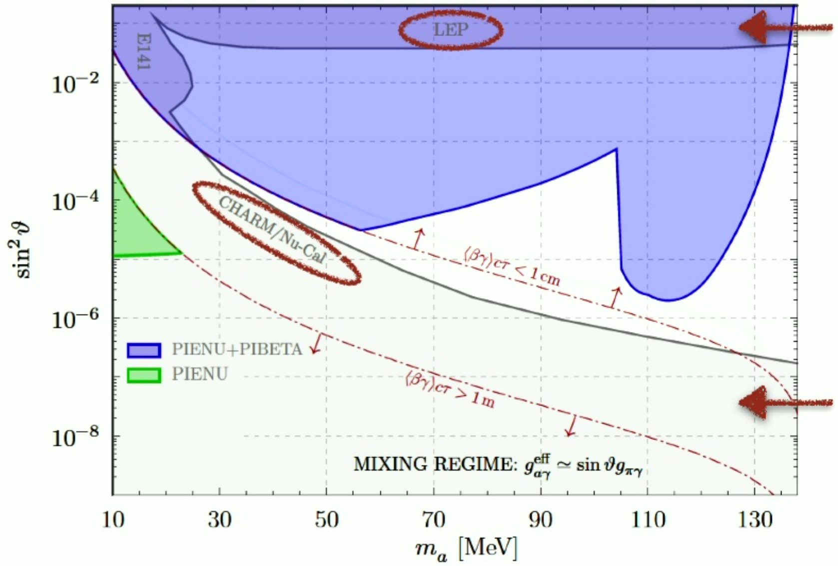
Reach at PIONEER?
Phase I: ~2 x 10^{12} pions
Phase II/III: ~7 x 10^{13} pions

Comparison with other experiments

(model dependent!)

- If we assume a theory with no extra contribution to the diphoton coupling (mixing regime) then $\Gamma_{a\gamma\gamma} = \sin^2\vartheta \frac{\alpha^2 m_a^3}{32\pi^3 f_\pi^2}$
  (decay & production of the ALP depend only on the mixing angle and on its mass)

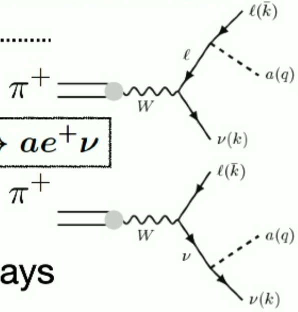
- We can directly compare the PIENU, PIBETA bounds with LEP and old fixed target experiments:



Sec. 2: Lepton-coupled ALP scenario

$$\frac{(\partial_\mu a)}{m_e}\left[\bar{e}\gamma^\mu\left(\bar{g}_{ee}+g_{ee}\gamma_5\right)e+g_\nu\bar{\nu}\gamma^\mu P_L\nu\right]$$

$$\boxed{\pi^+\to ae^+\nu}$$



- ✱ Because of the conservation of lepton number, one combination of couplings does not contribute at LO to pion decays
- ✱ It is not true that the vector coupling is “unphysical”

$$\begin{aligned}\mathrm{BR}(\pi^+\to e^+a\nu) = \;& \frac{1}{384\pi^2}\frac{m_\pi^4}{m_e^2 m_\mu^2}\left(1-\frac{m_\mu^2}{m_\pi^2}\right)^{-2}\Bigg[(\overbrace{g_{ee}-\bar{g}_{ee}+g_\nu}^{\text{0 if SU(2) conservation}})^2 f_0\left(\frac{m_a^2}{m_\pi^2}\right)\\ &+\frac{4m_e^2}{m_\pi^2}\Bigg(3(g_{ee})^2 f_3\left(\frac{m_a^2}{m_\pi^2}\right)+3(\bar{g}_{ee}-g_\nu)^2 f_4\left(\frac{m_a^2}{m_\pi^2}\right)\\ &+2g_{ee}(\bar{g}_{ee}-g_\nu)f_5\left(\frac{m_a^2}{m_\pi^2}\right)\Bigg)+\mathcal{O}\left(\frac{m_e^3}{m_\pi^3}\right)\Bigg]\end{aligned}$$

Helicity suppression is lifted only in the case of SU(2) violation

SU(2) (or weak) violation:
$\bar{g}_{ee}-g_{ee}-g_\nu\neq 0$

(SU(2) violation can be generated e.g. by $\partial^\mu a(HL)^\dagger\gamma_\mu(HL)$)

S.Gori

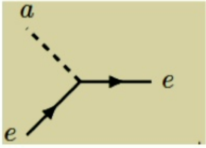
A change of basis for the ALP interactions

$$\mathcal{L} = -a\partial_\mu j^\mu_{PQ}$$

$$\partial_\mu j^\mu_{\rm PQ} = g_{\ell\ell}(\bar{\ell} i\gamma_5 \ell)$$

“Standard” vertex

the one considered in the literature



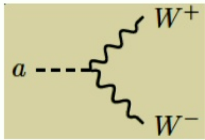
$$+ \frac{e^2}{16\pi^2 m_\ell}\frac{\bar{g}_{\ell\ell} - g_{\ell\ell} + g_{\nu_\ell}}{4s_W^2} W^+_{\mu\nu}\tilde{W}^{-,\mu\nu}$$

$$+ \frac{e^2}{16\pi^2 m_\ell}\frac{\bar{g}_{\ell\ell} - g_{\ell\ell}(1-4s_W^2)}{2c_W s_W} F_{\mu\nu}\tilde{Z}^{\mu\nu} - g_{\ell\ell}F_{\mu\nu}\tilde{F}^{\mu\nu} +$$

$$+ \frac{e^2}{16\pi^2 m_\ell}\frac{\bar{g}_{\ell\ell}(1-4s_W^2) - g_{\ell\ell}(1-4s_W^2+8s_W^4) + g_\nu}{8s_W^2 c_W^2} Z_{\mu\nu}\tilde{Z}^{\mu\nu}$$

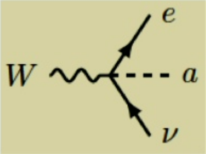
$$+ \frac{ig}{2\sqrt{2}m_\ell}(g_{\ell\ell} - \bar{g}_{\ell\ell} + g_{\nu_\ell})(\bar{\ell}\gamma^\mu P_L \nu)W^-_\mu$$

Anomaly terms



Weak vertex

(only present for weak violating models)

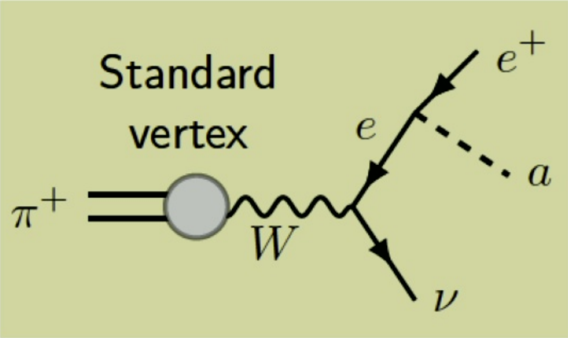


Our work:

- **importance of the weak vertex**
- new bounds on the “standard” vertex

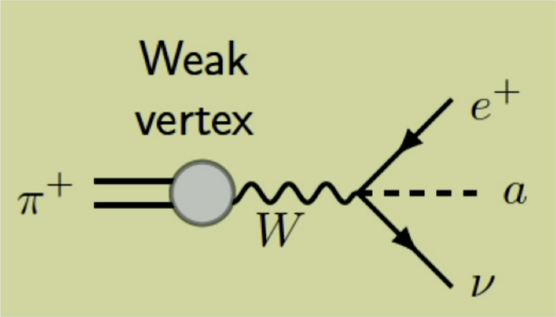
$$\boxed{\frac{(\partial_\mu a)}{m_e}\left[\bar{e}\gamma^\mu\left(\bar{g}_{ee} + g_{ee}\gamma_5\right)e + g_\nu\bar{\nu}\gamma^\mu P_L\nu\right]}$$

Rate for pion to ALP decays



(only term in) weak preserving models

e.g. $2 g_{ee} \frac{(\partial_\mu a)}{m_e} \bar{e}\gamma^\mu P_R e$



(most important term in) weak violating models

$$g_{ee} \frac{(\partial_\mu a)}{m_e} \bar{e}\gamma^\mu \gamma_5 e$$

$$\Gamma_{\pi^+ \to e^+ \nu a} \propto g_{ee}^2 \frac{m_\pi^3 f_\pi^2}{m_W^4}$$

$$\frac{\mathrm{BR}(\pi^+ \to e^+ \nu a)}{10^{-11}} \simeq \left(\frac{g_{ee}}{3.1 \cdot 10^{-5}} \right)^2$$

$$\Gamma_{\pi^+ \to e^+ \nu a} \propto \frac{m_\pi^2}{m_e^2} g_{ee}^2 \frac{m_\pi^3 f_\pi^2}{m_W^4}$$

$$\frac{\mathrm{BR}(\pi^+ \to e^+ \nu a)}{10^{-11}} \simeq \left(\frac{g_{ee}}{4.6 \cdot 10^{-7}} \right)^2$$

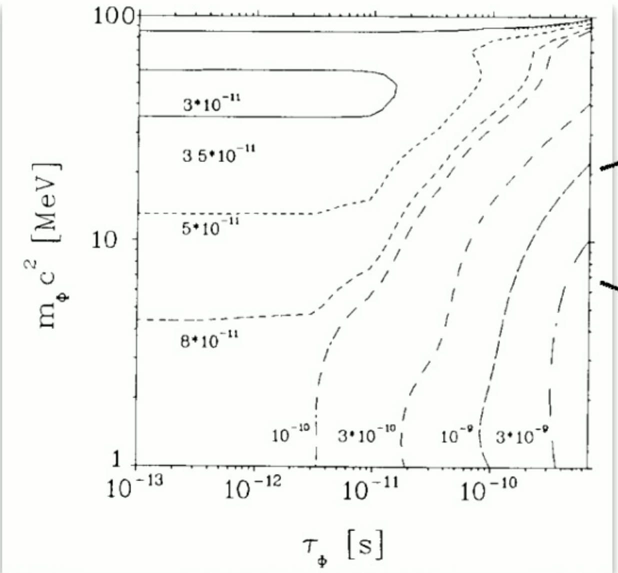
The past search for $\pi^+ \to e^+\nu(a \to e^+e^-)$

In the late ‘80s,
the SINDRUM experiment at CERN:

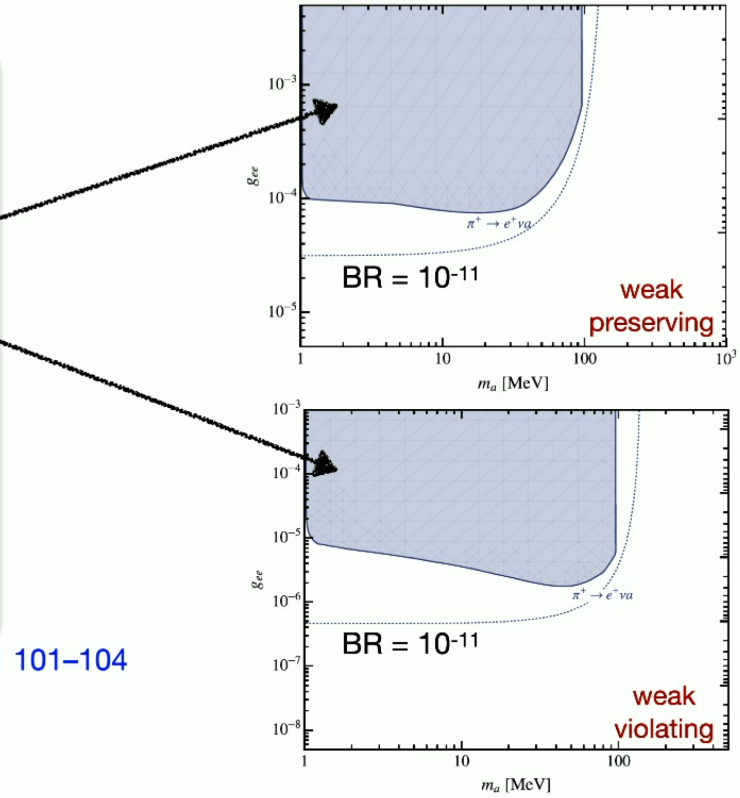
Almost background free search

Reach at PIONEER?

improvement by an order of magnitude?



Eichler et al. Physics Letters B 175 (1986), no. 1 101–104



Complementarity with other charged current decays

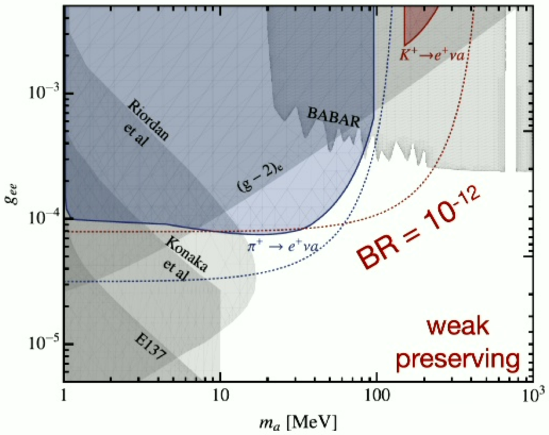
Kaon decays

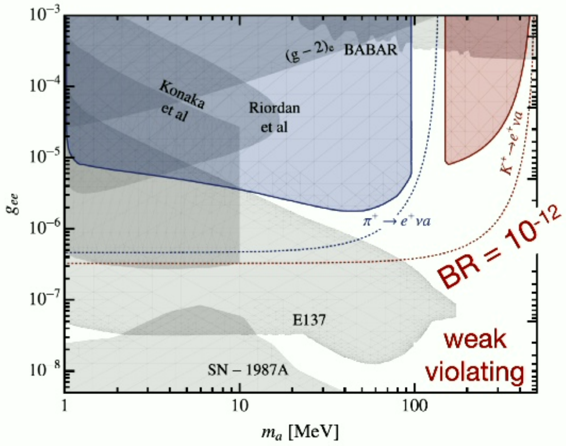
$$\frac{\mathrm{BR}(K^+ \to e^+ \nu a)}{10^{-10}} \simeq \begin{cases} \left(\frac{g_{ee}}{3.3 \cdot 10^{-7}}\right)^2 & \text{weak violating} \\ \left(\frac{g_{ee}}{7.9 \cdot 10^{-5}}\right)^2 & \text{weak preserving} \end{cases}$$

hep-ex/0204006, E865 at BNL:

BR measured for $m_{ee} < 150$ MeV

No dedicated search





S.Gori

Complementarity with other charged current decays

Kaon decays

$$\frac{\mathrm{BR}(K^+\to e^+\nu a)}{10^{-10}} \simeq \left\{\begin{array}{ll} \left(\dfrac{g_{ee}}{3.3\cdot 10^{-7}}\right)^2 & \text{weak violating} \\ \left(\dfrac{g_{ee}}{7.9\cdot 10^{-5}}\right)^2 & \text{weak preserving} \end{array}\right.$$

hep-ex/0204006, E865 at BNL:

BR measured for $m_{ee} < 150$ MeV

No dedicated search

W boson decays

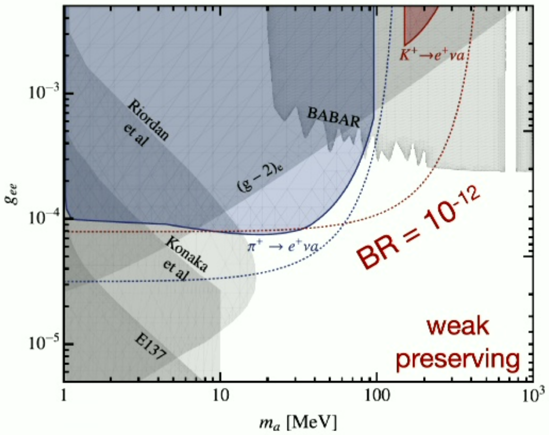
$$\frac{\mathrm{BR}(W^+\to \ell^+\nu_\ell a)}{\mathrm{BR}(W^+\to e^+\nu)} = \frac{3}{1024\pi^2}\frac{m_W^2}{m_\ell^2}\left(g_{\ell\ell}-\bar{g}_{\ell\ell}+g_{\nu_\ell}\right)^2$$

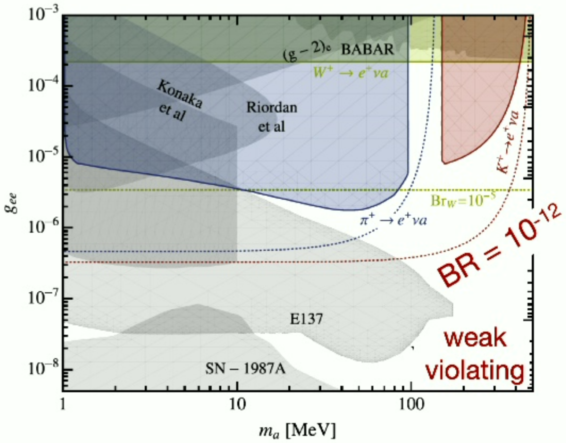
➡ $\mathrm{BR}(W^+\to e^+\nu_e a) \simeq \left(\dfrac{g_{ee}}{10^{-3}}\right)^2$ (only for) weak violating

No dedicated search

We impose:

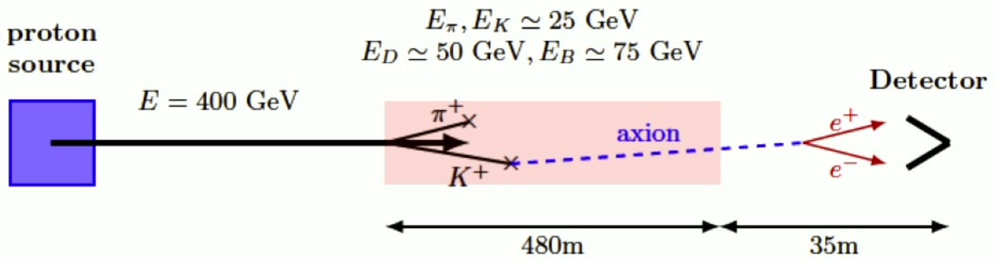
the new width < exp uncertainty on W width





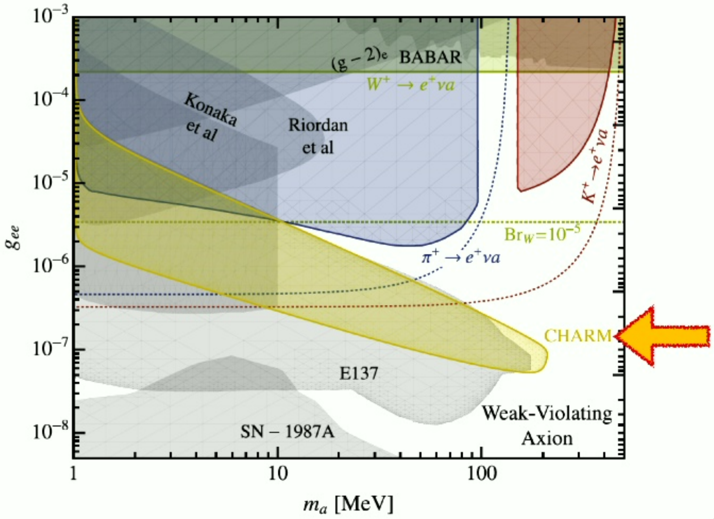
Beam dump experiments & charged currents

CHARM experiment (late 80s at CERN)



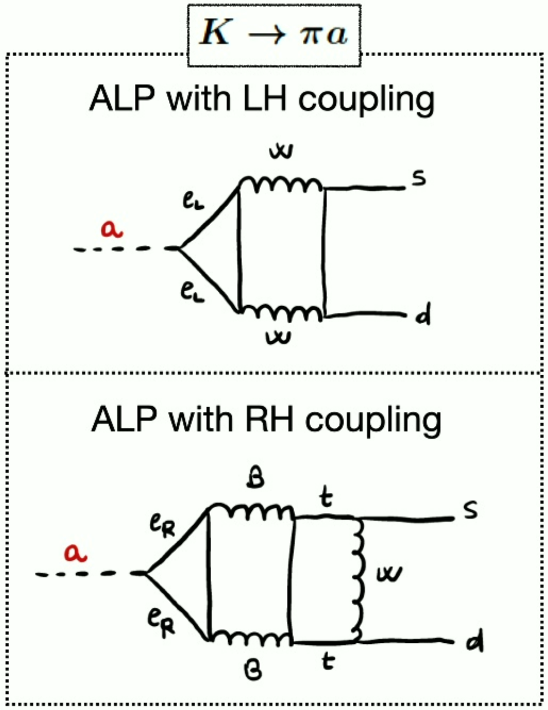
What's new in our study?

- First use of D, D_s, B_c mesons
- Introduction of charged current meson decays



Complementarity with neutral current decays

Neutral current meson decays are also generated at the 2 or 3-loop level (suppressed by CKM elements as well)

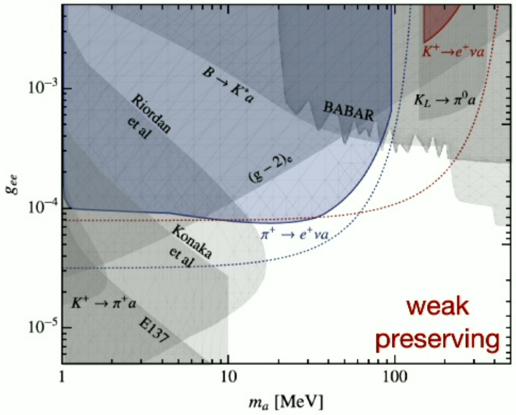


$K \to \pi a$

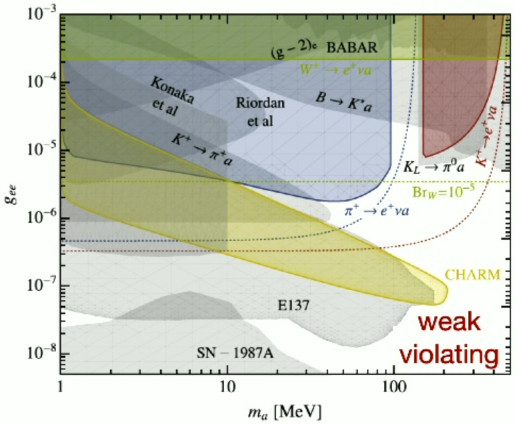
ALP with LH coupling

ALP with RH coupling

Similar diagrams for $B \to K^{(*)} a$



weak preserving



weak violating

S.Gori

Conclusions & Outlook

Interesting times for flavor physics:
anomalies+several experiments ramping up

Plenty of opportunities to test dark sectors at these experiments

For this talk:
testing ALPs at (light) meson factories
(New approved experiment: PIONEER)

Direct searches for $\pi \to a\, e\, \nu$ can probe un-explored ALP parameter space.

In general, enhancement of charged current meson decays in weak violating models

Complementarity with Kaon experiments, B-factories, and beam dump experiments