



# Searches for the light invisible hypothetical pseudoscalar in the $K^+ \rightarrow \pi^+ \pi^0 P$ decay at the OKA setup

**Speaker:** A. Okhotnikov

30/08/2022

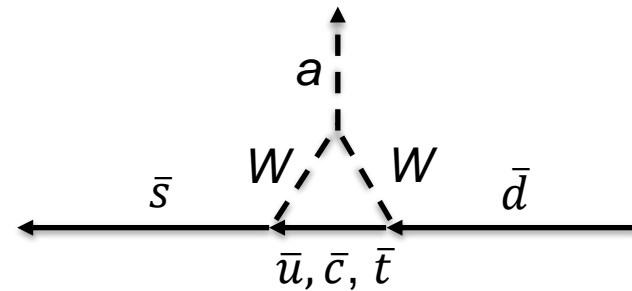
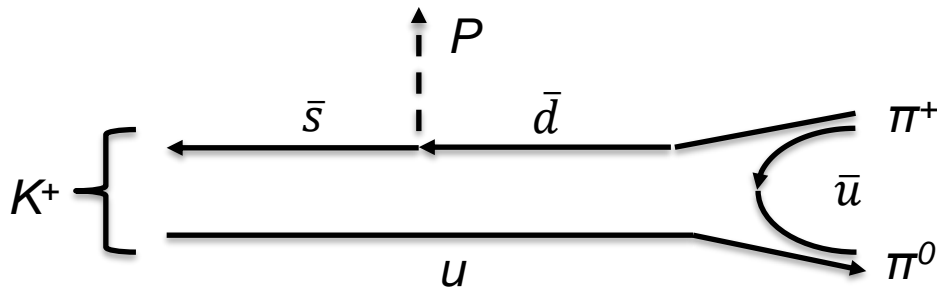
Moscow International School of  
Physics 2022

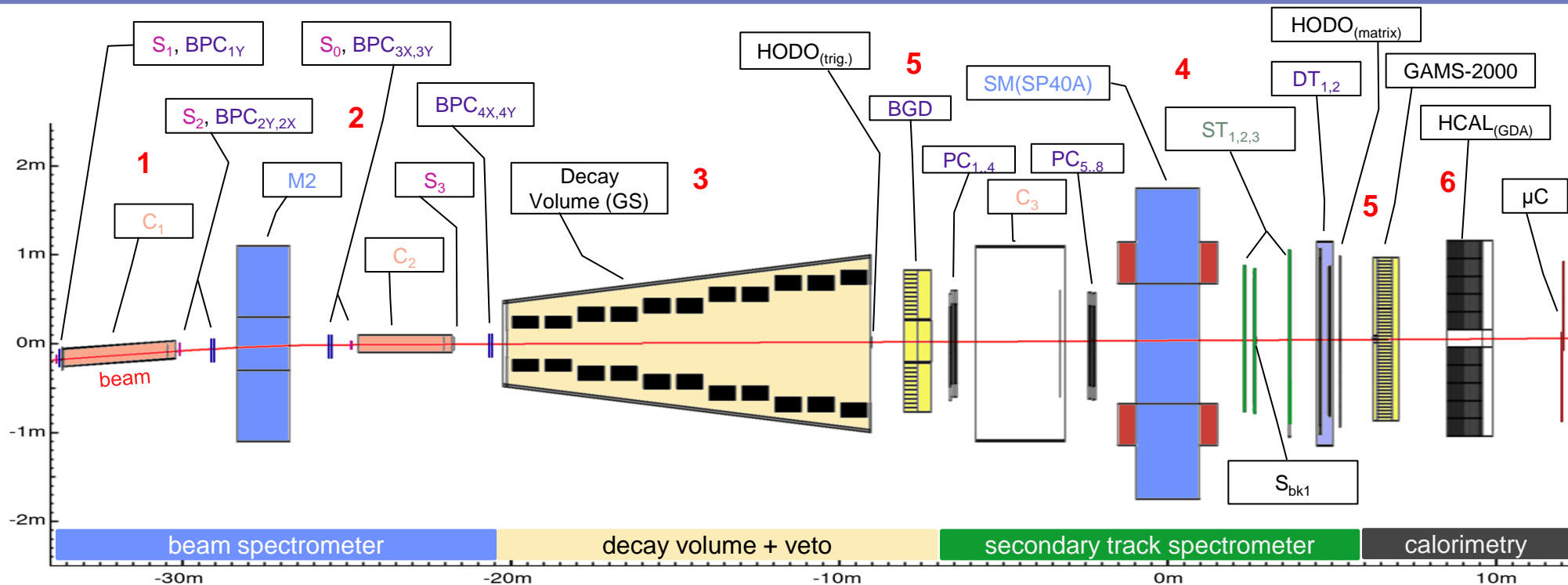
The spontaneous supersymmetry breaking models should include superpartners of the Goldstone fermion: pseudoscalar  $P$  and scalar  $S$  sgoldstino.

$K^+ \rightarrow \pi^+ \pi^0 P$  studies at ISTRA+ setup showed no signal at a  $BR(K^+ \rightarrow \pi^+ \pi^0 P) < 10^{-5}$  level. (e.g. **Phys. Lett. B** 602(2004), p.149-156)

Also a point of interest is a  $K^+ \rightarrow \pi^+ \pi^0 a$  search with an axial-vector axion coupling in FCNC models (more in **CERN-NA62-22-01**).

A registration efficiency and an estimated upper limit depends on a supposed model of a hypothetical process (its matrix element). Here both versions are shown.

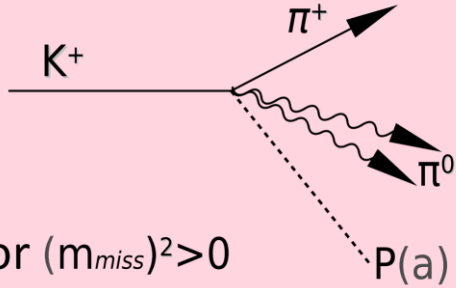




1. Trigger (scint. 6mm  $S_0$ , 2mm  $S_{1,3}$ ) and beam Cherenkov counters ( $C_1$ ,  $C_2$ ).
2. Beam spectrometer: M2 magnet + 7 BPCs (1mm step, ~1500 ch.).
3. Decay Volume (He) with veto system «GS» 670 Pb-Sc (200 ADC ch.).
4. Secondary track spectrometer: SP40A magnet, 8 PCs (2mm step, ~5000 ch.), straw (~1000 ch.), DTs (~300 ch.), HODO.
5. EM calorimeters: GAMS-2000 (~2300 ch., 4x4 cm<sup>2</sup>), BGD (~1050 ch., 5x5 cm<sup>2</sup>).

# $K^+ \rightarrow \pi^+ \pi^0 P$ and background processes' topology

We search for  $K^+ \rightarrow \pi^+ \pi^0 P$

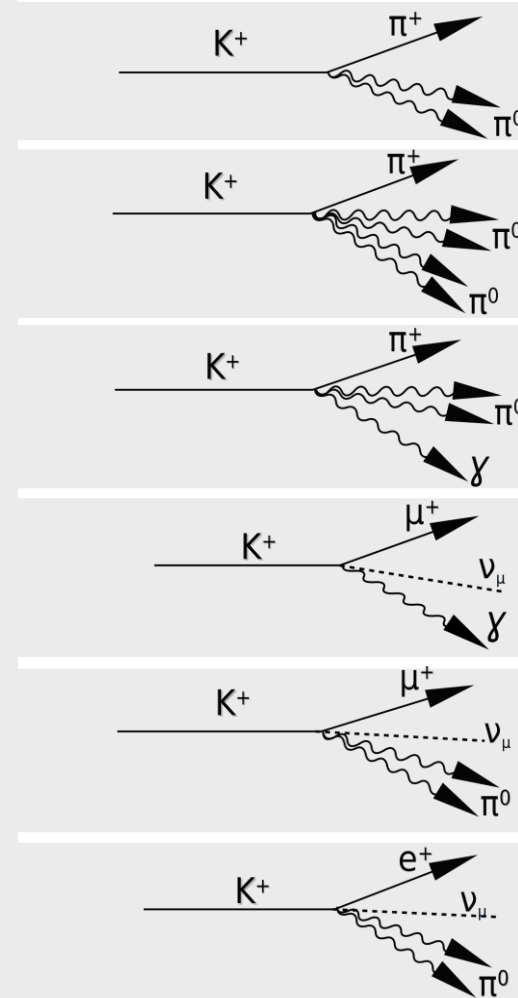


1) Cuts:

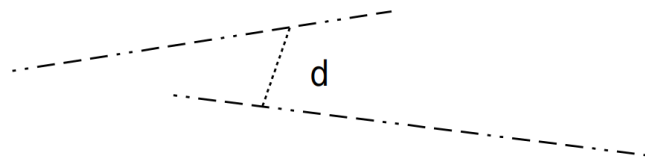
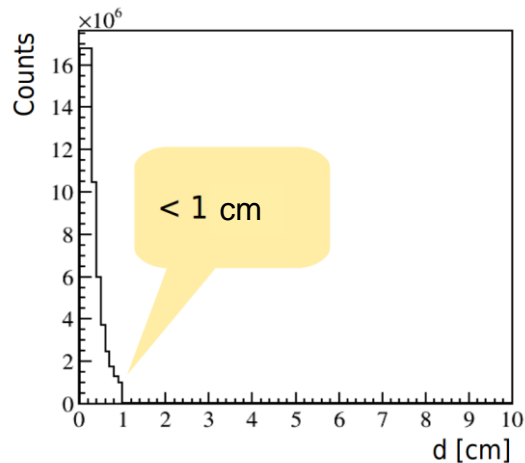
- One track events.
- Kaon momentum  $\sim 17.7$  GeV.
- Secondary track is a charged pion.
- 2 photons in GAMS+BGD.
- High track quality.

2) Modelling and spectra subtracting of all background processes.

Background processes

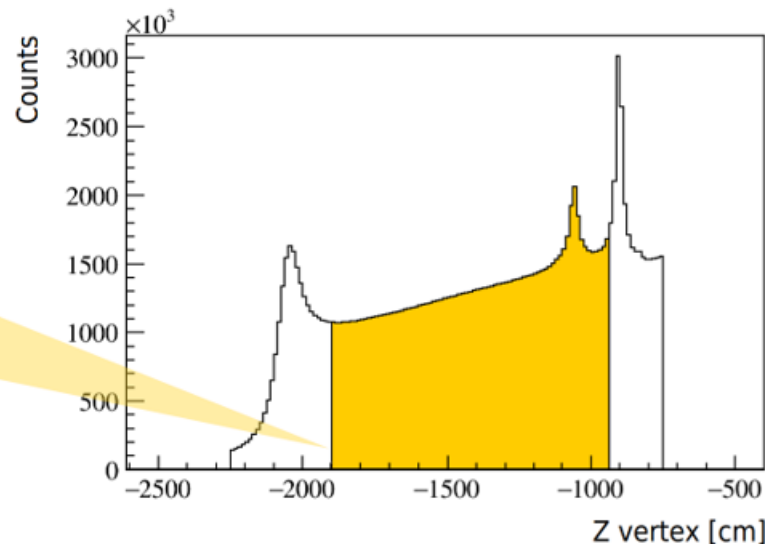


# Review of cuts: the decay vertex

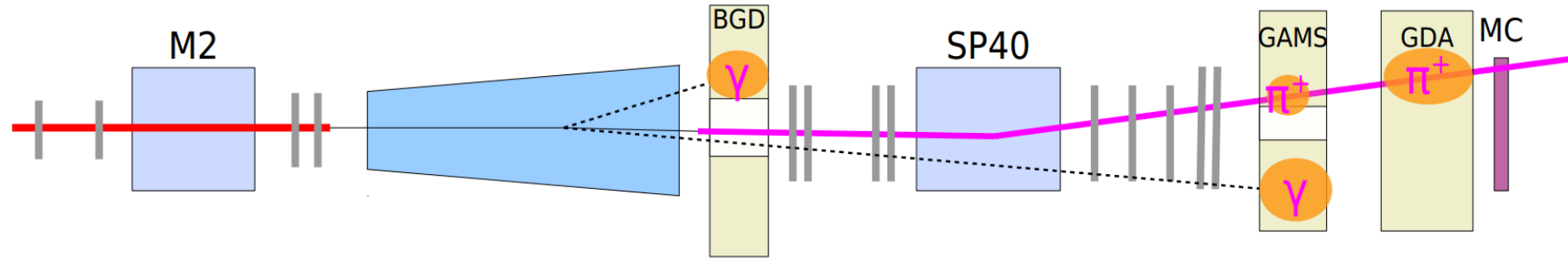


$d$  – a distance between beam and secondary tracks' reconstructed segments

We choose Z vertices located beyond entry/exit windows



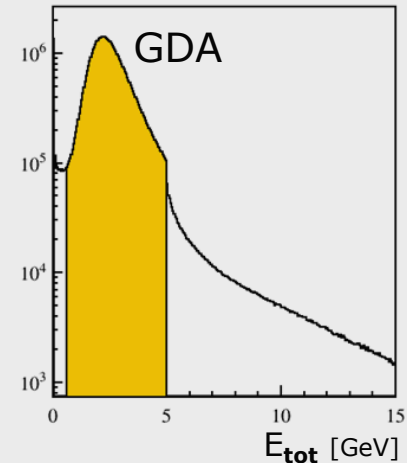
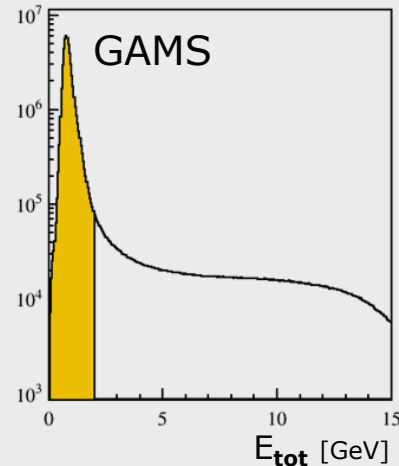
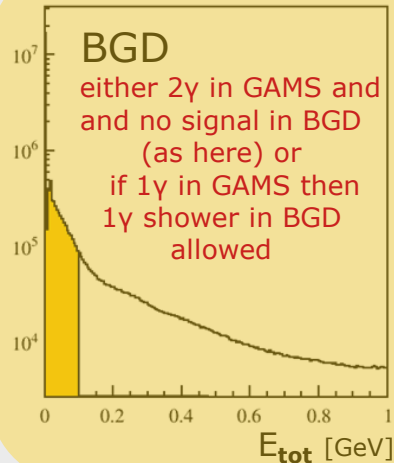
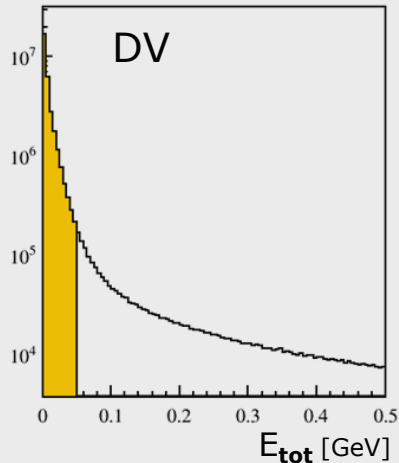
GOAL: an event with **one track before the DV** and **one after**.



- $\pi^0$  search: an event should have 2 EM showers with a total  $m_{\text{inv}} \approx m_{\pi^0}$  in EM calorimeters (GAMS+BGD system).
- $\pi^+$  identification: there are clusters associated with the track in each of GAMS and GDA detectors, which are not of  $e^+$  and  $\mu^+$  type.

We exclude any tracks and gammas in DV veto and BGD, (1 gamma allowed in BGD)

We exclude any signals (tracks, gammas) except energy release from one  $\pi^0$  in GAMS/BGD and  $\pi^+$  in HCAL



1. An event with **one track before the DV** and **one after**.
2.  $\pi^0$  search: an event should have 2 EM showers with a total  $m_{inv} \approx m_{\pi^0}$  in EM calorimeters (GAMS+BGD system).
3.  $\pi^+$  identification: there are clusters associated with the track in each of GAMS and GDA detectors, which are not of  $e^+$  and  $\mu^+$  type.
4.
  - a) BGD cluster is not on a central hole edge.
  - b) Secondary particle track does not cross BGD.
  - c) Number of hits per track, good chi-square for both beam and secondary tracks.
  - d) Beam particle's reconstructed momentum  $\sim 17.7$  GeV/c.
  - e) Decay vertex is inside the DV.

By this moment  $1.67 \cdot 10^7$   $K^+ \rightarrow \pi^+ \pi^0$  ( $K^+ \rightarrow \pi^+ \pi^0 P$ ) candidates were chosen.

$K^+ \rightarrow \pi^+ \pi^0 P$  selection:

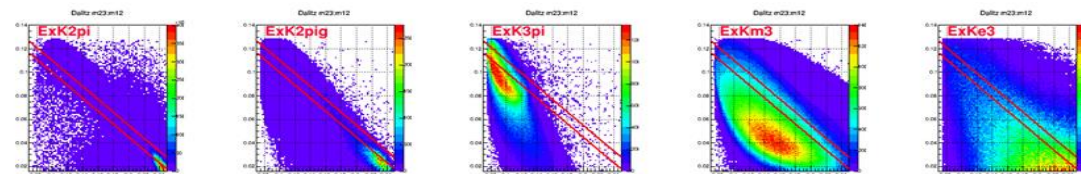
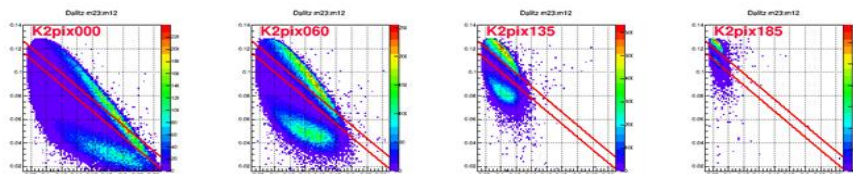
1. We demand  $E_{miss} = E_{K^+} - E_{\pi^+} - E_{\pi^0} > 2.5$  GeV.
2. We also demand  $p_{\pi^0} < 150$  MeV/c (in a kaon rest frame).



# Dalitz plots' analysis for a $K^+ \rightarrow \pi^+ \pi^0 P(a)$ signal including the matrix element and background processes

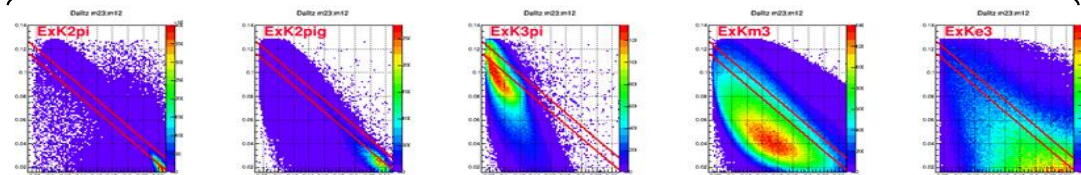
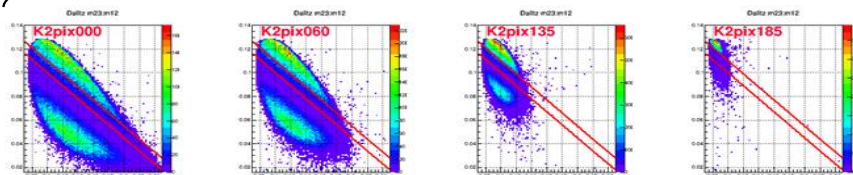
Expected signal for the **sgoldstino** mass 0, 65, 135, 185 MeV

Background processes being misidentified



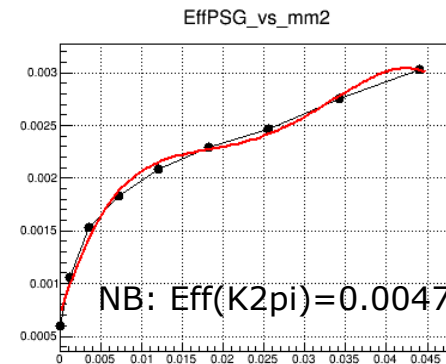
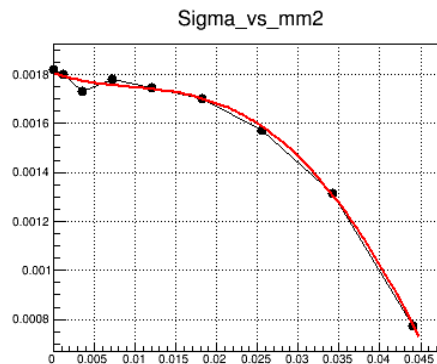
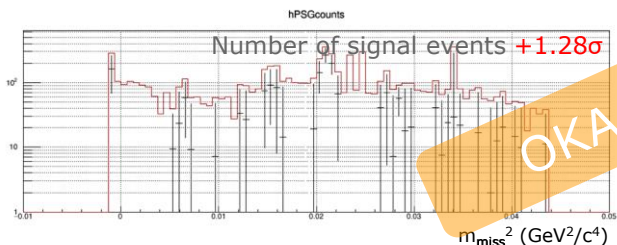
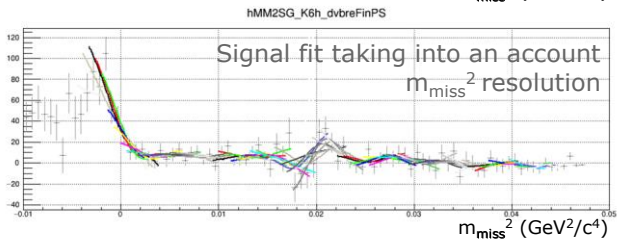
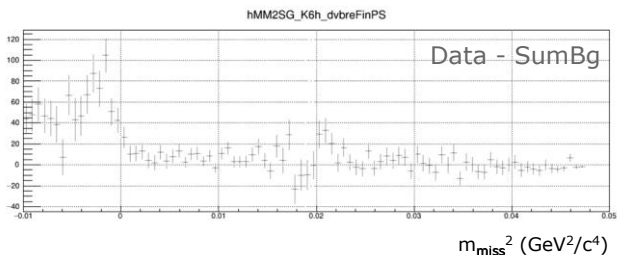
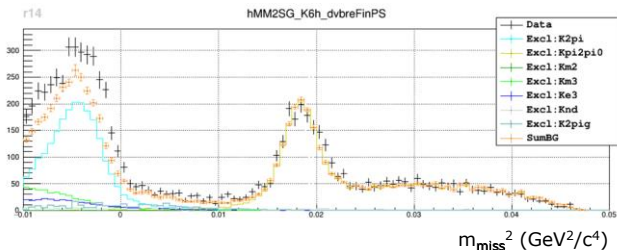
Expected signal for the **axion** mass 0, 65, 135, 185 MeV

Background processes being misidentified

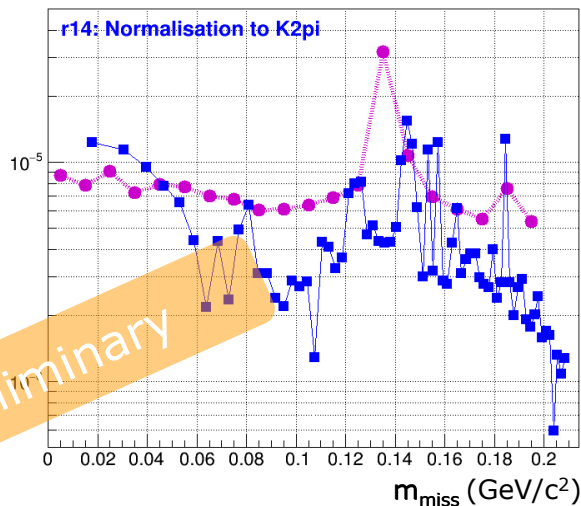


$m_{n+n0}^2 \text{ GeV}^2$

# R14: upper limit (90% CL) for $BR(K^+ \rightarrow \pi^+ \pi^0 P)$



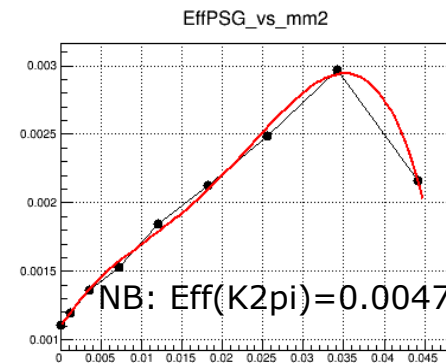
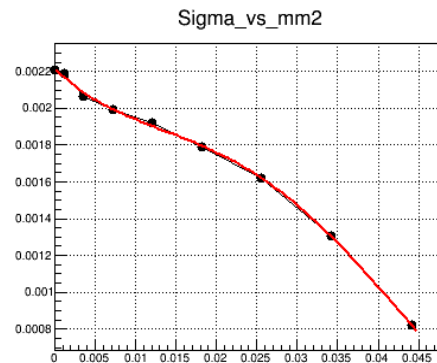
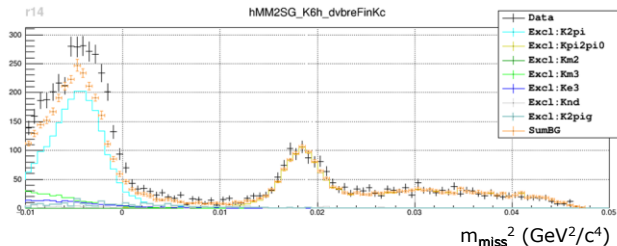
$BR(K^+ \rightarrow \pi^+ \pi^0 P)$



R14: upper limit on a  $Br(P)$  CL  $\sim 90\%$  after the selection on the Dalitz plot

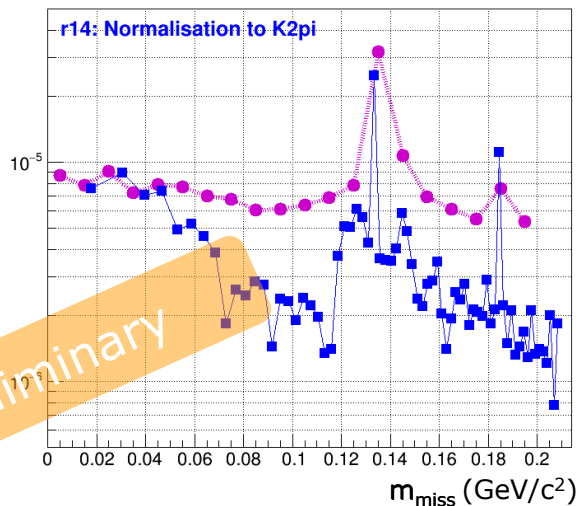
OKA preliminary

# R14: upper limit (90% CL) for $BR(K^+ \rightarrow \pi^+ \pi^0 a)$



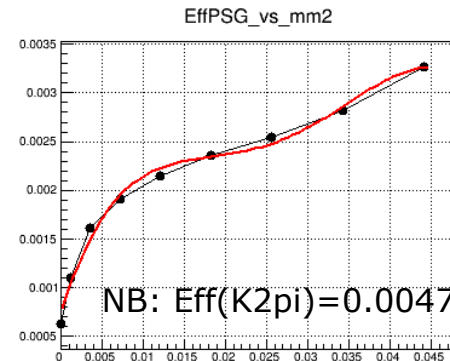
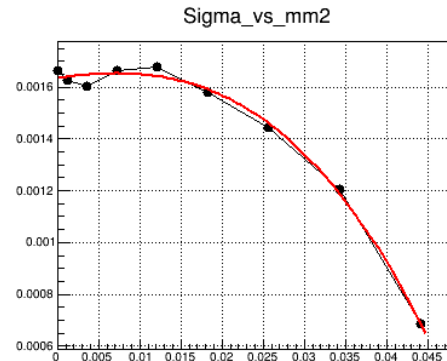
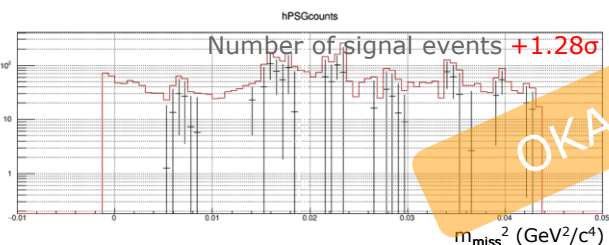
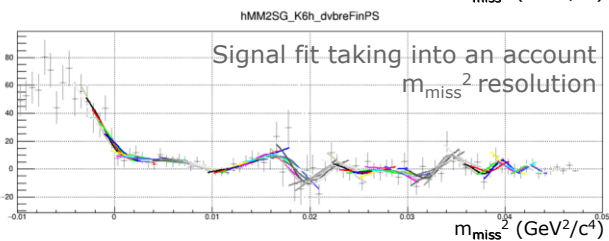
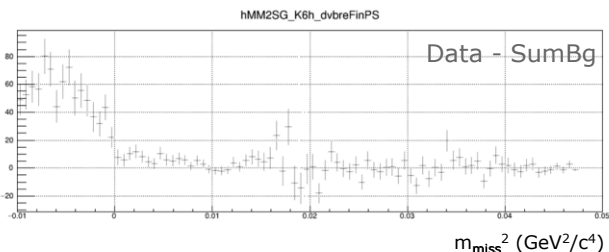
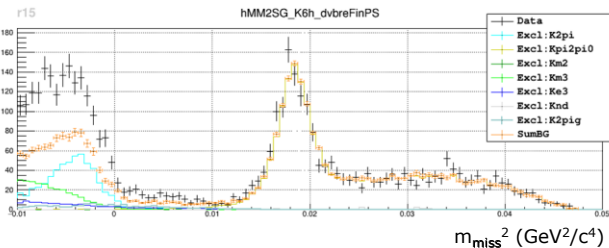
$BR(K^+ \rightarrow \pi^+ \pi^0 a)$

R14: upper limit on a  $Br(a)$  CL  $\sim 90\%$  after the selection on the Dalitz plot

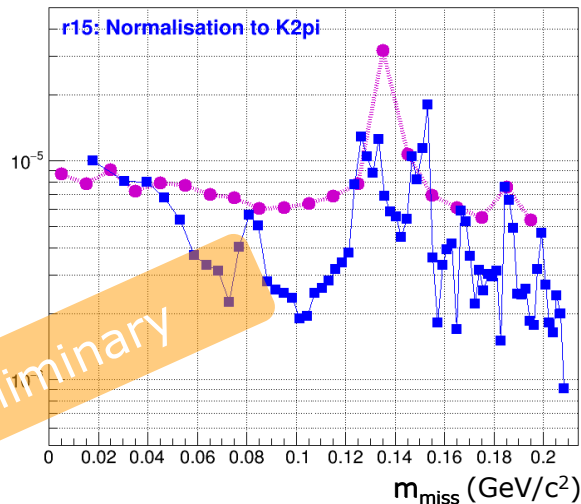


# R15: upper limit (90% CL) for $BR(K^+ \rightarrow \pi^+ \pi^0 P)$

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$BR(K^+ \rightarrow \pi^+ \pi^0 P)$

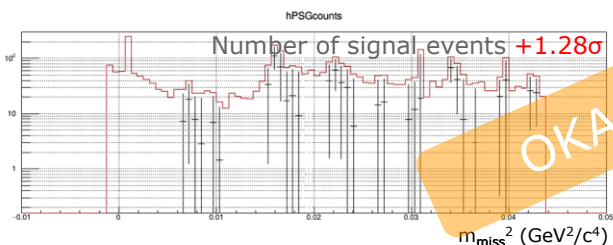
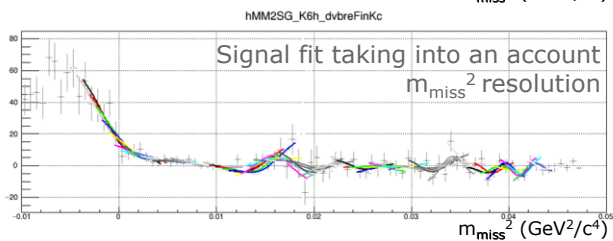
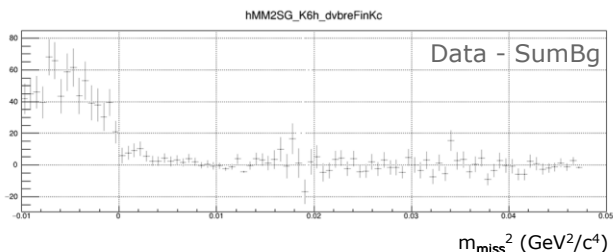
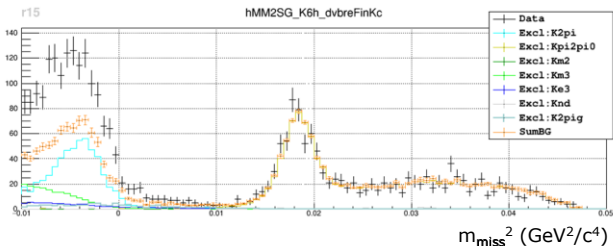


R15: upper limit on a  $Br(P)$  CL  $\sim 90\%$  after the selection on the Dalitz plot

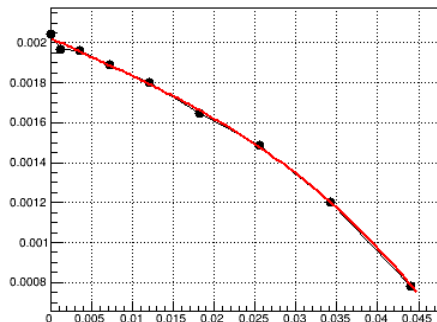
OKA preliminary

# R15: upper limit (90% CL) for $BR(K^+ \rightarrow \pi^+ \pi^0 a)$

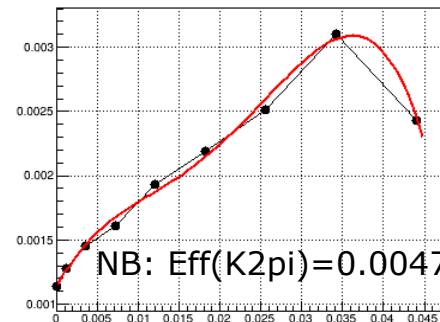
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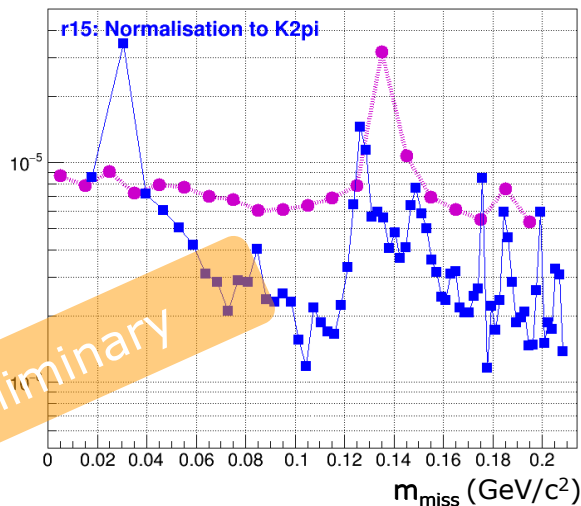
Sigma\_vs\_mm2



EffPSG\_vs\_mm2



$BR(K^+ \rightarrow \pi^+ \pi^0 a)$



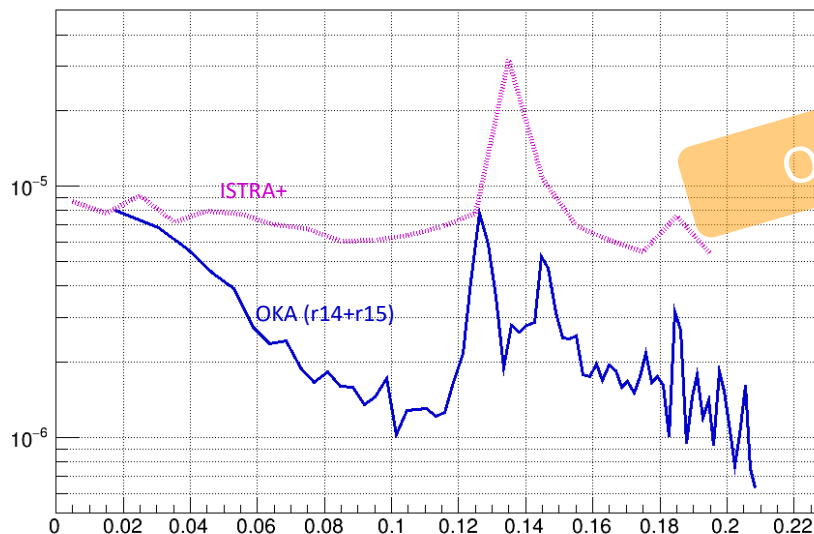
R15: upper limit on a  $Br(a)$  CL  $\sim 90\%$  after the selection on the Dalitz plot



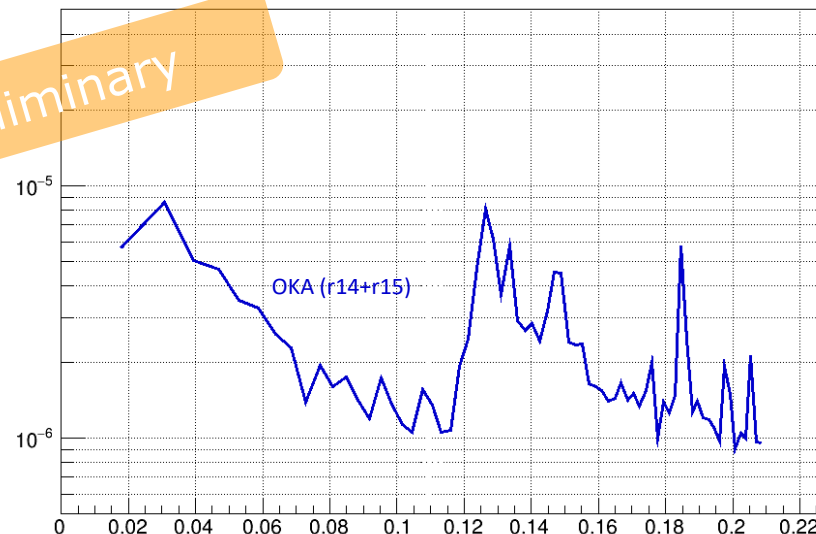
R14+R15: upper limit on a  $Br(a)$  CL  $\sim 90\%$   
according to a selection on a Dalitz plot

$$x_{\text{наил}} = \frac{\sum_{i=1}^N w_i x_i}{\sum_{i=1}^N w_i},$$
$$w_i = 1/\sigma_i^2$$

UL on a  $Br(P)$  at CL 90%



UL on a  $Br(a)$  at CL 90%



**Thank you for your attention!**

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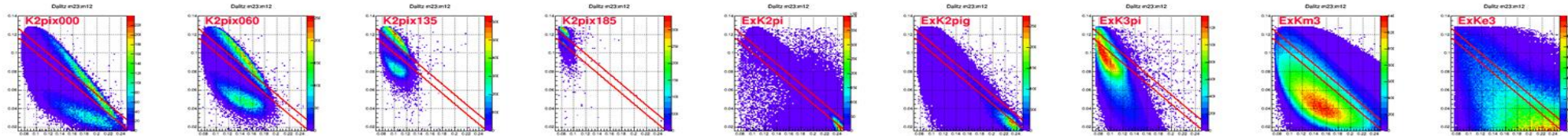
# Dalitz plots' analysis for a $K^+ \rightarrow \pi^+ \pi^0 P$ signal including the matrix element and background processes

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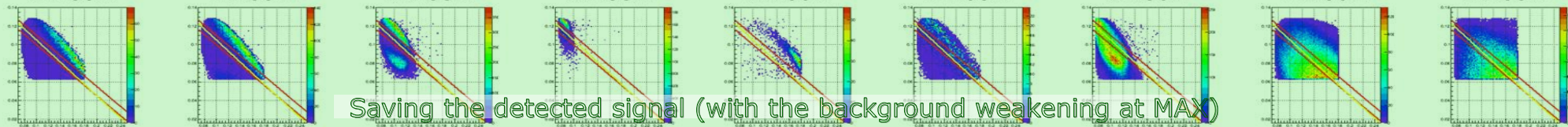


Expected signal for the **sgoldstino** mass 0, 65, 135, 185 MeV

Background processes being misidentified

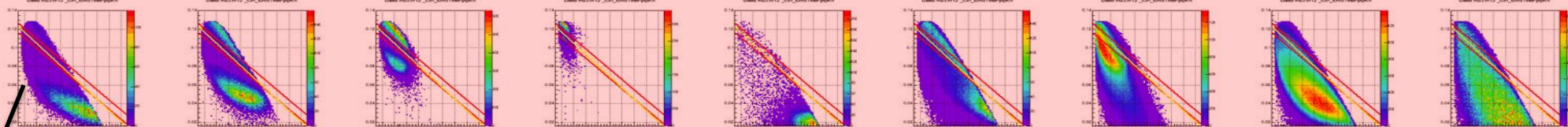


Selection by  $\pi^0$  momentum in a kaon rest frame and  $m_{inv}(\pi^+, \pi^0)$

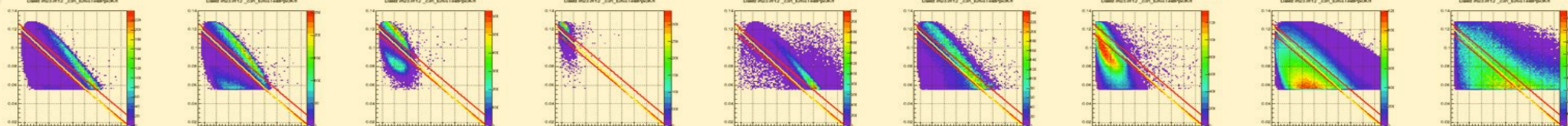


Saving the detected signal (with the background weakening at MAX)

Selection by  $\pi^+$  momentum in a kaon rest frame



Selection by  $\pi^0$  momentum in a kaon rest frame



For the low mass sgoldstino a signal loss in a free-from-background space is critical

$m_{n+n0} \text{ GeV}^2$

$m_{2n0P} \text{ GeV}^2$



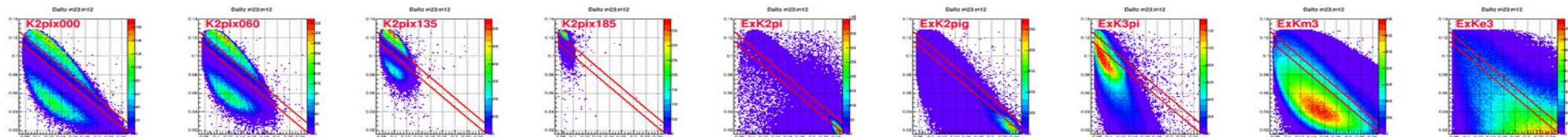
# Dalitz plots' analysis for a $K^+ \rightarrow \pi^+ \pi^0 P$ signal including the matrix element and background processes

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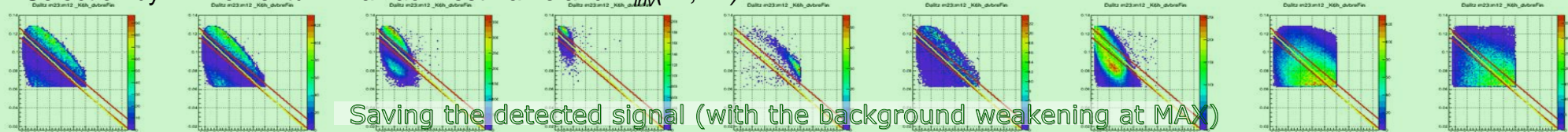


Expected signal for the **axion** mass 0, 65, 135, 185 MeV

Background processes being misidentified

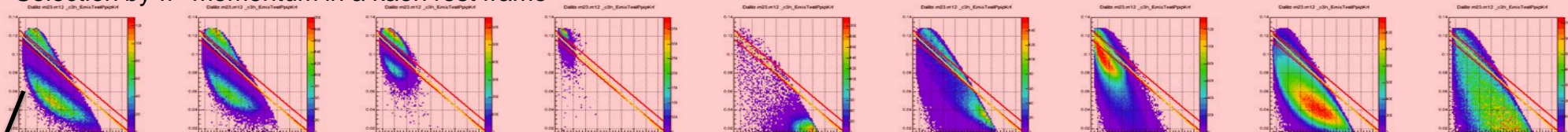


Selection by  $\pi^0$  momentum in a kaon rest frame and  $m_{inv}(\pi^+, \pi^0)$

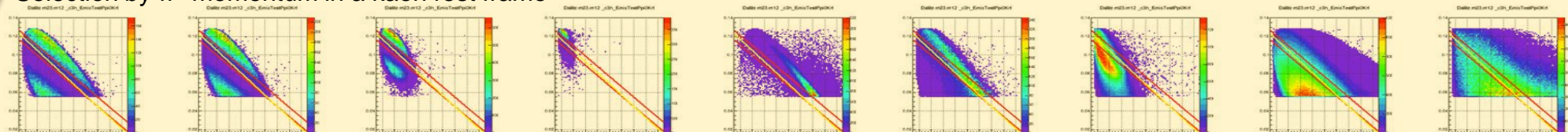


Saving the detected signal (with the background weakening at MAX)

Selection by  $\pi^+$  momentum in a kaon rest frame



Selection by  $\pi^0$  momentum in a kaon rest frame



For the low mass axion a signal loss in a free-from-background space is not so critical but is also sensitive

$(m_{\pi^+ \pi^0})^2 [\text{GeV}^2/c^4]$

$(m_{\pi^+ \pi^0})^2 [\text{GeV}^2/c^4]$