# PID, CALORIMETERS, RICH and SHiP OPTIMISATION vs costs

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# ITEMS

CONSIDERATION FROM THE BACKGROUND POINT OF VIEW

- contribution of PID to

  a) background suppression (Behzad's results) in particular for non-pointing channels

  b) to help deciding on VETO/no VETO (=surround VETO) vs vacuum/which vacuum

CONSIDERATIONS FROM THE SIGNAL POINT OF VIEW

- pointing in the ECAL for $\gamma\gamma$ physics—>requires fine-grained and segmented

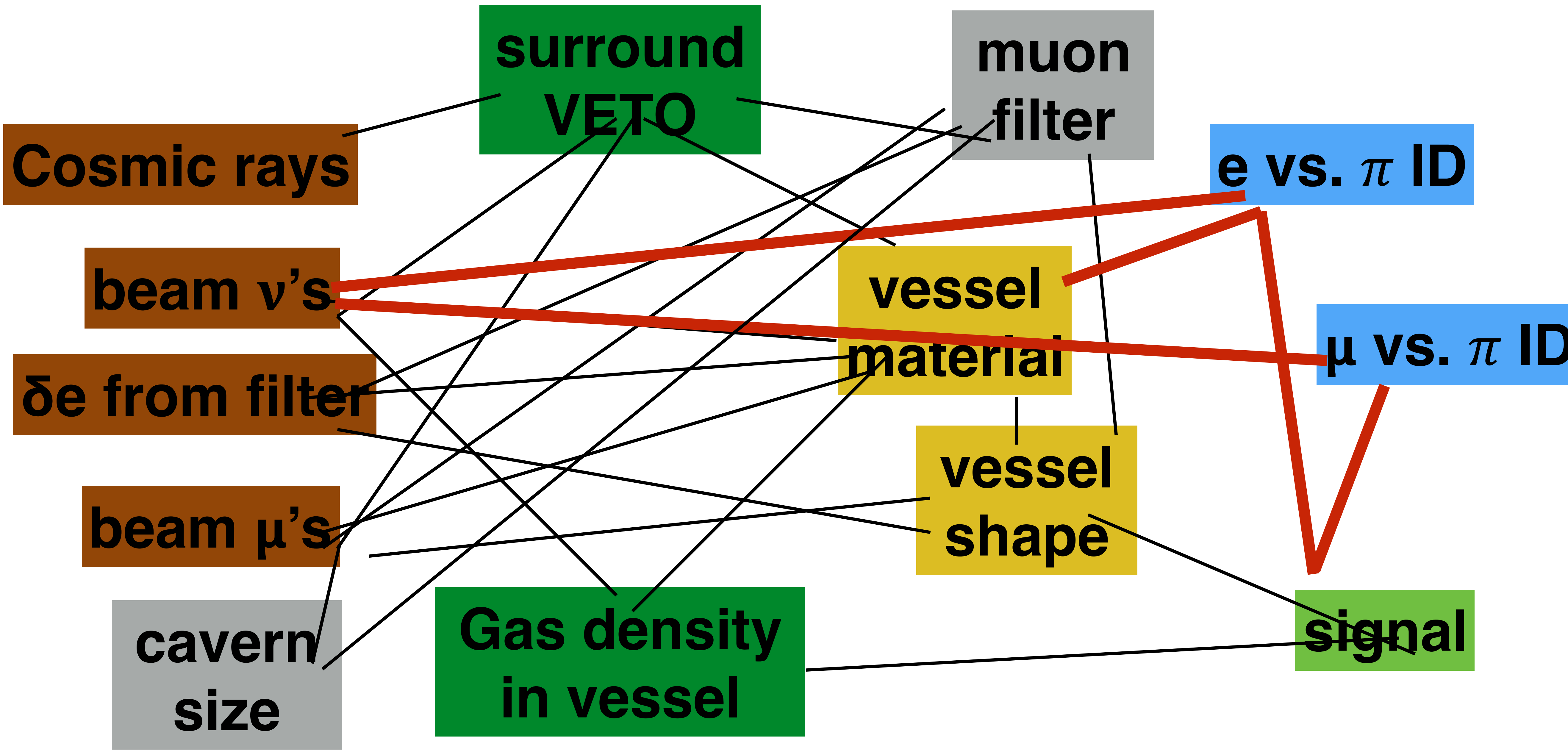
- kaon identification

- $e/\pi$ separation issues

- $\pi/\mu$ separation issues

# Optimisation parameters

## Background level target (channel dependent)




## COST

a) e vs. $\pi$ ID b) µ vs. $\pi$ ID

we do the best we can here optimising essentially for cost

but once a) and b) are defined, they help the overall optimisation

— background suppression, helps relaxing pressure requirements in the decay vessel

I.e. PID can drive the design of the rest rather the opposite

# Signal table

## Efficiency 2body decay selection

## Mass 1 GeV

**Selection cut IP<=10**

| REC → / GEN ↓ | μ-μ | e-e | π-π | μ-π | π-e | μ-e |
|---|---|---|---|---|---|---|
| μ-μ 2 body | 357/361 **98.89%** | | | 4/361 **1.11%** | | |
| e-e 2 body | | 342/346 **98.84%** | 1/346 **0.29%** | | 3/346 **0.87%** | |
| π-π 2 body | | | 311/332 **93.67%** | 8/332 **2.41%** | 13/332 **3.92%** | |
| μ-π 2 body | 4/312 **1.28%** | | 3/312 **0.96%** | 297/312 **95.19%** | | 8/312 **2.56%** |
| π-e 2 body | | 8/328 **2.44%** | 1/328 **0.3%** | | 316/328 **96.34%** | 3/328 **0.91%** |

**see Behzad talk in a while**

# Background table

**from Jaroslava tuples (neutrino only); to be divided by 8 to get events in 2e20pot in Air**

**μ$\pi$ pointing**

**with [w/o] VETO**

**10 [12] events**

**μμ/ee/eμ non-pointing**

**with [w/o] VETO**

**3/1/7[11/9/20]      eμ are the misidentified from $\pi$μ that are dominant —>may be reduced with improved ECAL**

# Background to μρ

with VETO about 20-50 events $\pi$μ non pointing with two neutral clusters —>need to study this in detail after invariant mass and pointing cuts

But we need before to study also the signal (some work done by a student of Jacques)

# First comment on e/$\pi$ and $\mu/\pi$ misidentification

**For $\mu/\pi$ there is a 1.5%-2%/track misidentification due to DIF —> there is basically nothing we can do!**

**For e/$\pi$ there is a 2%-4%/track misidentification due to pion charge exchange reaction; we need longitudinal segmentation/pre-shower —> work of the next months; pre shower already in FairShip**

**What are the options to suppress background? (building a relatively cheap detector)**

**a) Air+VETO(=SBT)**

**b) He+VETO**

**c) He no-VETO**

**d) vacuum $10^{-3}$ no VETO**

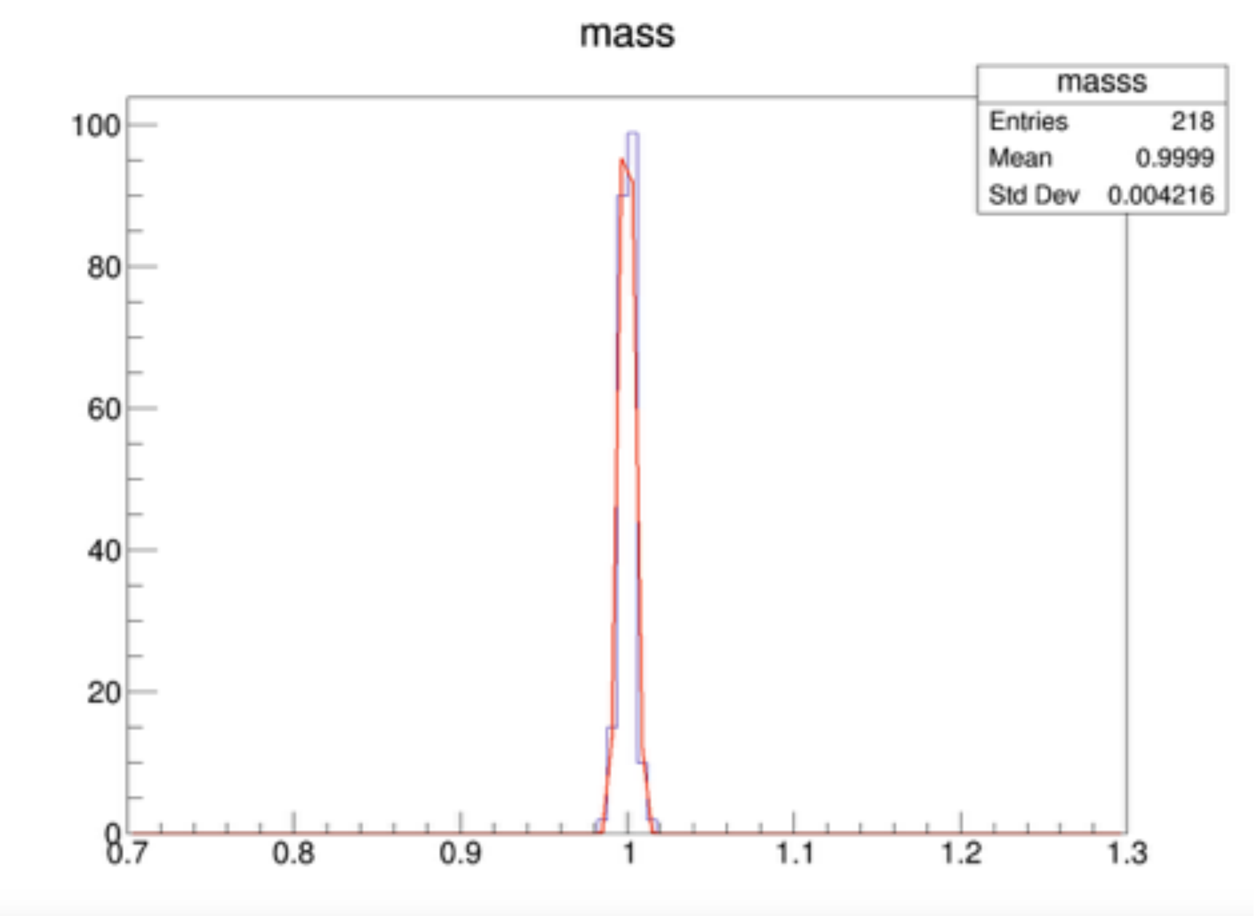
**(for the γγ channel we probably need high vacuum +VETO —> not a cheap detector; this channel would eventually drive the design)**

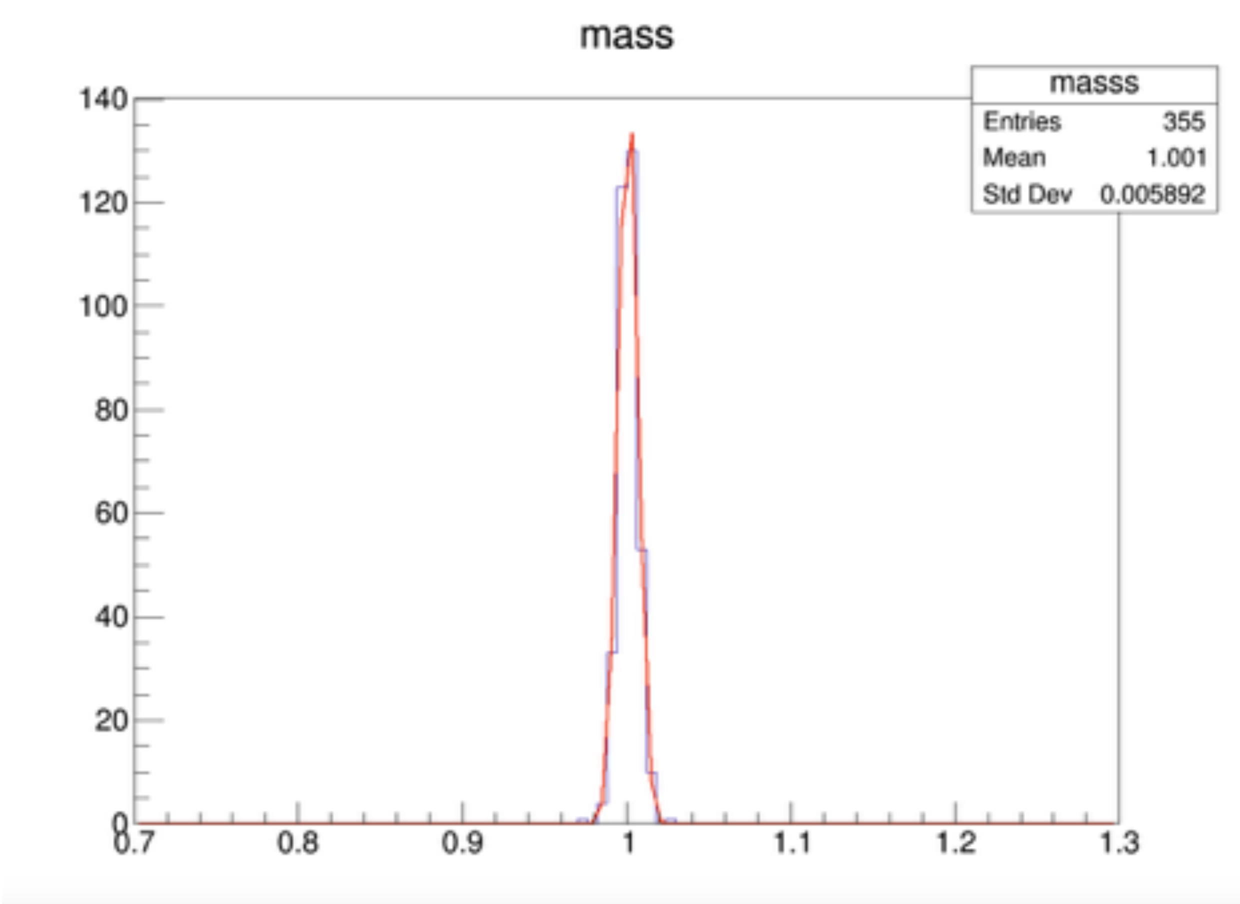
## Toy MC for determining discovery sensitivity

**Indeed one can calculate 5$\sigma$ such that the observed signal has P<3x$10^{-7}$ of being an artefact of the statistical fluctuation of the background**

**so we generate random background configurations according to the findings of the full simulations and calculate how many events we need to observe to reject that hypothesis**

# Mass resolution




**HNL m=1GeV      40MeV bin  includes most events**

**(6 standard deviations)**

**2body $\pi\mu$ pointing (the other channels much less of a problem)**

**10 background events in flat mass region between 0.5 and 3GeV with 100% systematics**

**mass bin resolution 40MeV**

**5events in one bin is 5$\sigma$ with Air**

**4events in one bin is 5$\sigma$ with He (with 1 of background 3 events would be enough)**

**veto ON or OFF small effect**

**2body μμ non-pointing VETO ON [OFF]**

**3 [11] background events in flat mass region between 0.5 and 3GeV with 100% systematics**

**no mass reco —>1bin**

**9[17]events in one bin is 5$\sigma$ with Air**

**5[7]events in one bin is 5$\sigma$ with He! almost at the level of being fine without VETO! the difference is really small**

**with vacuum $10^{-3}$ —> 3[4] events —> no need of VETO!**

2body eμ non-pointing VETO ON [OFF] (remember these events come from e misid—>will probably the reduced to <half)

7 [20] background events in flat mass region between 0.5 and 3GeV with 100% systematics

no mass reco —>1bin

14[25]events in one bin is 5$\sigma$ with Air

6[9]events in one bin is 5$\sigma$ with He! almost at the level of being fine without VETO! the difference is really small

with vacuum $10^{-3}$ —> 3[4] events —> no need of VETO!

## Conclusion for discovery (without γγ)

vacuum $10^{-3}$ bar is ideal [4events] and probably needs no surround VETO

He is a bit worse and would need the VETO to perform best

Air is not good

Before concluding on this we need to address the issue of the μp channel

**An internal note is in preparation by Behzad**

## Coming back to ECAL

# ECAL requirements other than PID

**Energy resolution requirements moderate:**

**only neutral clusters need an energy measurement**

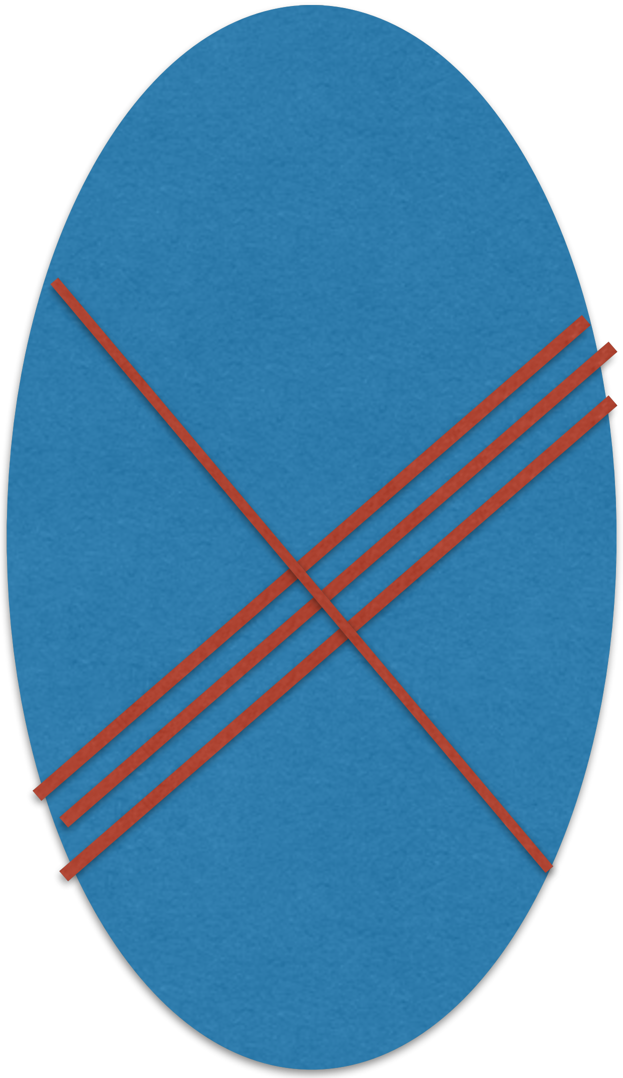
**- dominant only for determining the mass of HNL—>ρ+l candidates and DP—>$\pi$+$\pi$-$\pi$0**

**- for photon only decays all dominated by vertex resolution**

**probably 20%/sqrt(E) enough**

# Possible new designs

# Extruded scintillator




**extruded scintillator with WLS fibres read by sides —> if it works, large cost reduction in machining, # of sensors**

**allows longitudinal segmentation —> shower angle**

**needs analog readout with TDC readout from both sides**

Another possibility: DIGITAL GAS CALORIMETRY

# Calorimeter HARGD

- High Angural Resolution Gamma Detector
- Accuracy on shower direction much more interesting than accuracy on energy

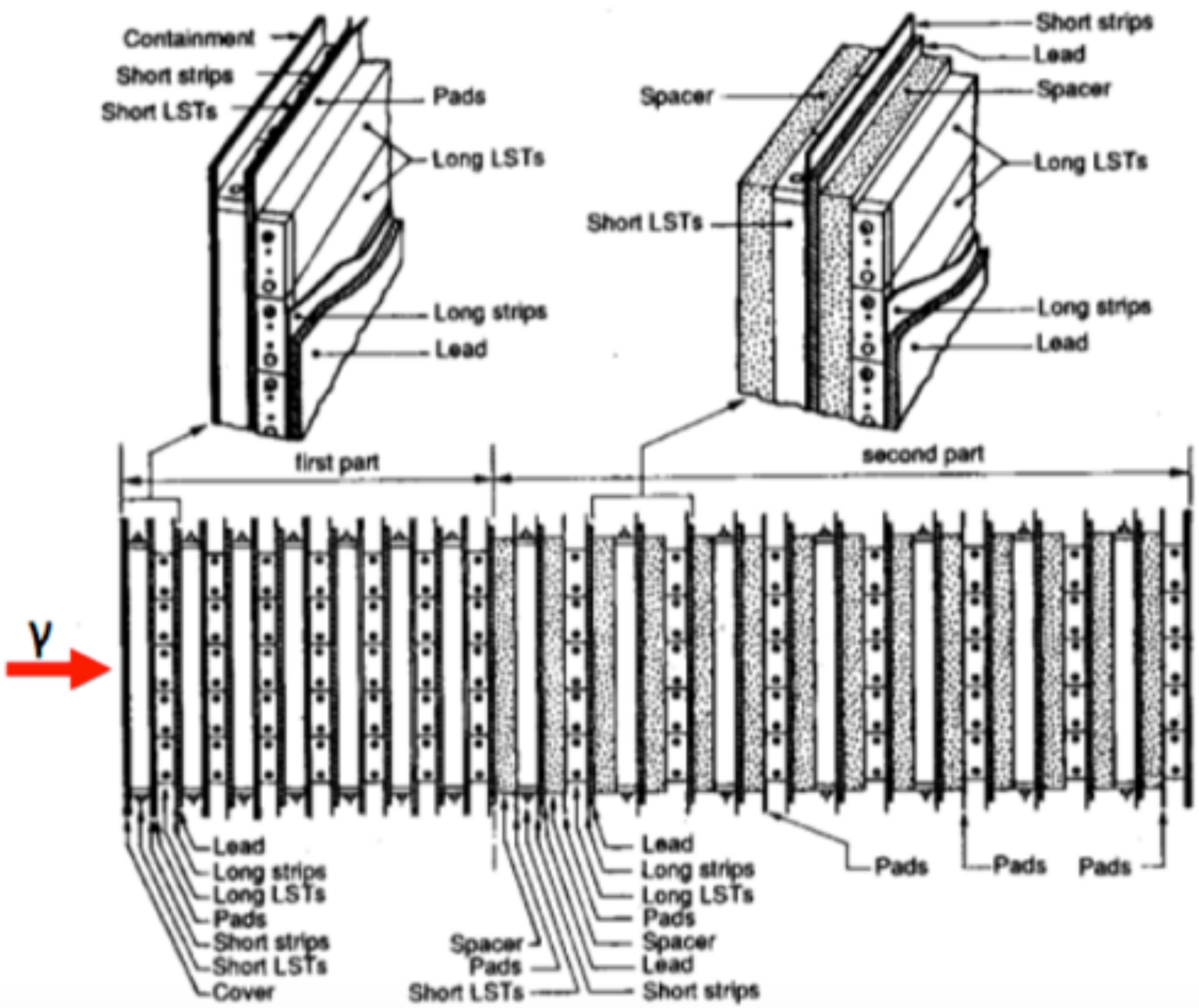



Fig. 2. Electromagnetic calorimeter stratigraphy.

- Sampling calorimeter.
- Converter: lead
- Active: Limited streamer tubes (1cm pitch)
- Dual reading: on strips and or pads
- Digital: hit/not hit
- 10 Xo
- Spatial accuracy below 3 mm (-> 2 mrad)

**Mauro Villa**

ıetry

## the γγ final state

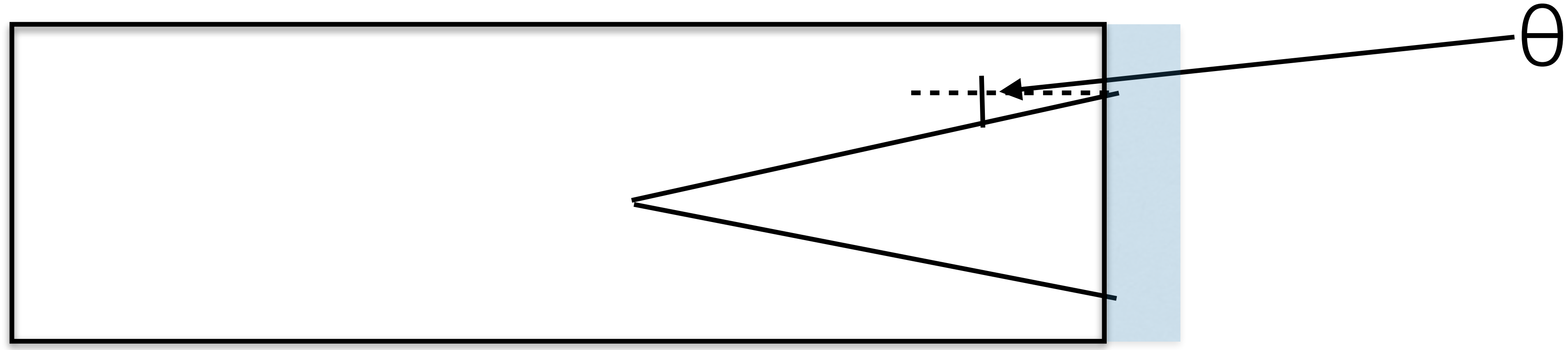
**performed full simulation of neutrino background (with VETO and vacuum) —> only residual background from coherent $\pi$ production**

**this channel would probably become the “design” requirements channel (we have to rerun the simulation of background without VETO to check)**

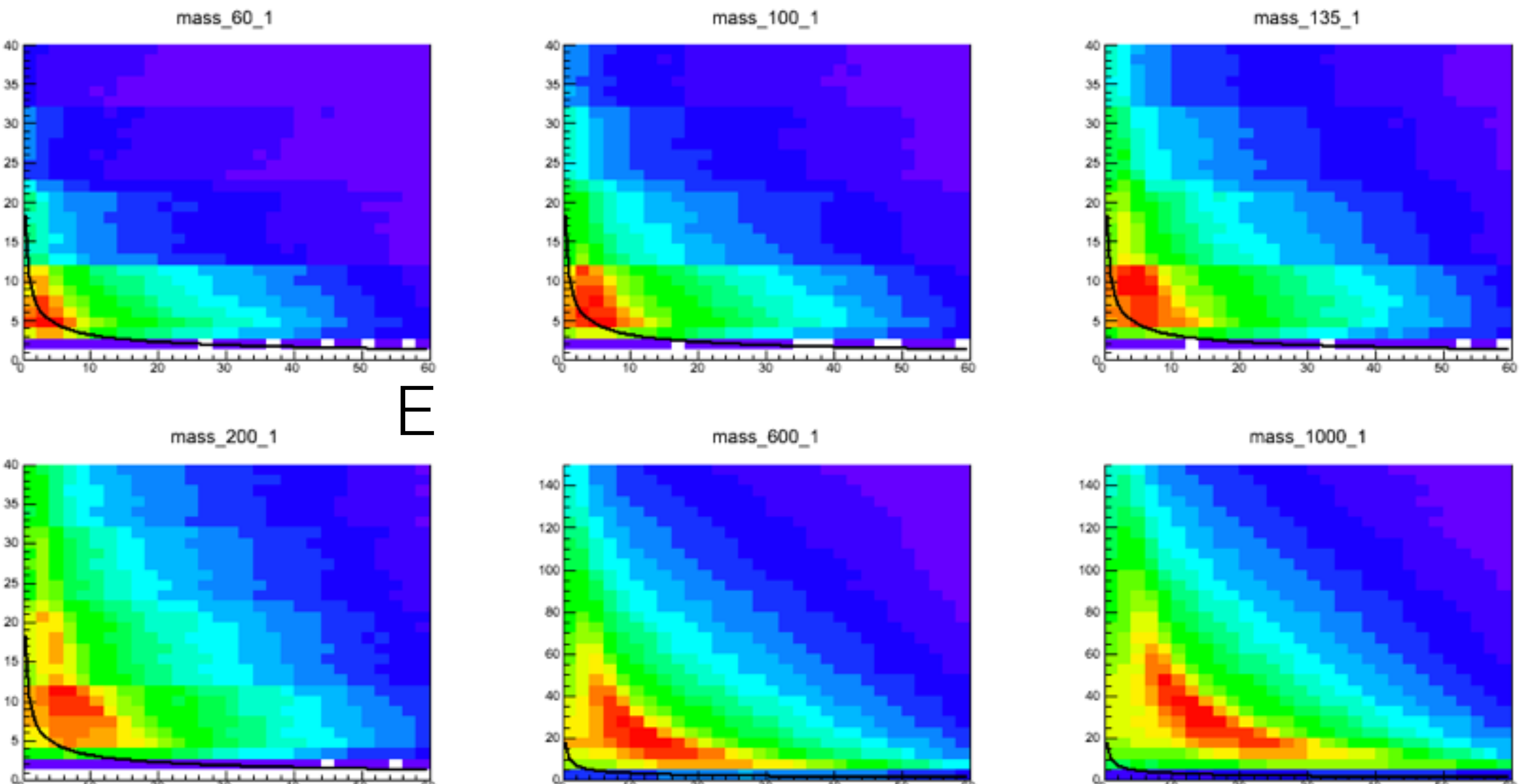
**if we wanted to reconstruct the mass, using the directional information of showers (and something nobody did so far) it requires a complex and expensive ECAL**

**it is related to some “expensive” SHiP version**

# Toy MC developed: discussed in PID talk June SHiP meeting




θ(mRad)




E

**$\sigma(\theta)=10\mathrm{mrad}/\sqrt{E}$**

# Preliminary conclusion of the toyMC

Coherent background can be suppressed by kinematic requirements without directional information

Mass reconstruction is possible with directional information in 2d with O(10mrad/sqrt(E)) resolution, with uncertainty <50% for 200MeV-1GeV

O(mRad) resolution —> O(1mm) position resolution on 1m lever arm

- pre shower with fine segmentation + ECAL with precise shower position reconstruction or all in one ECAL…

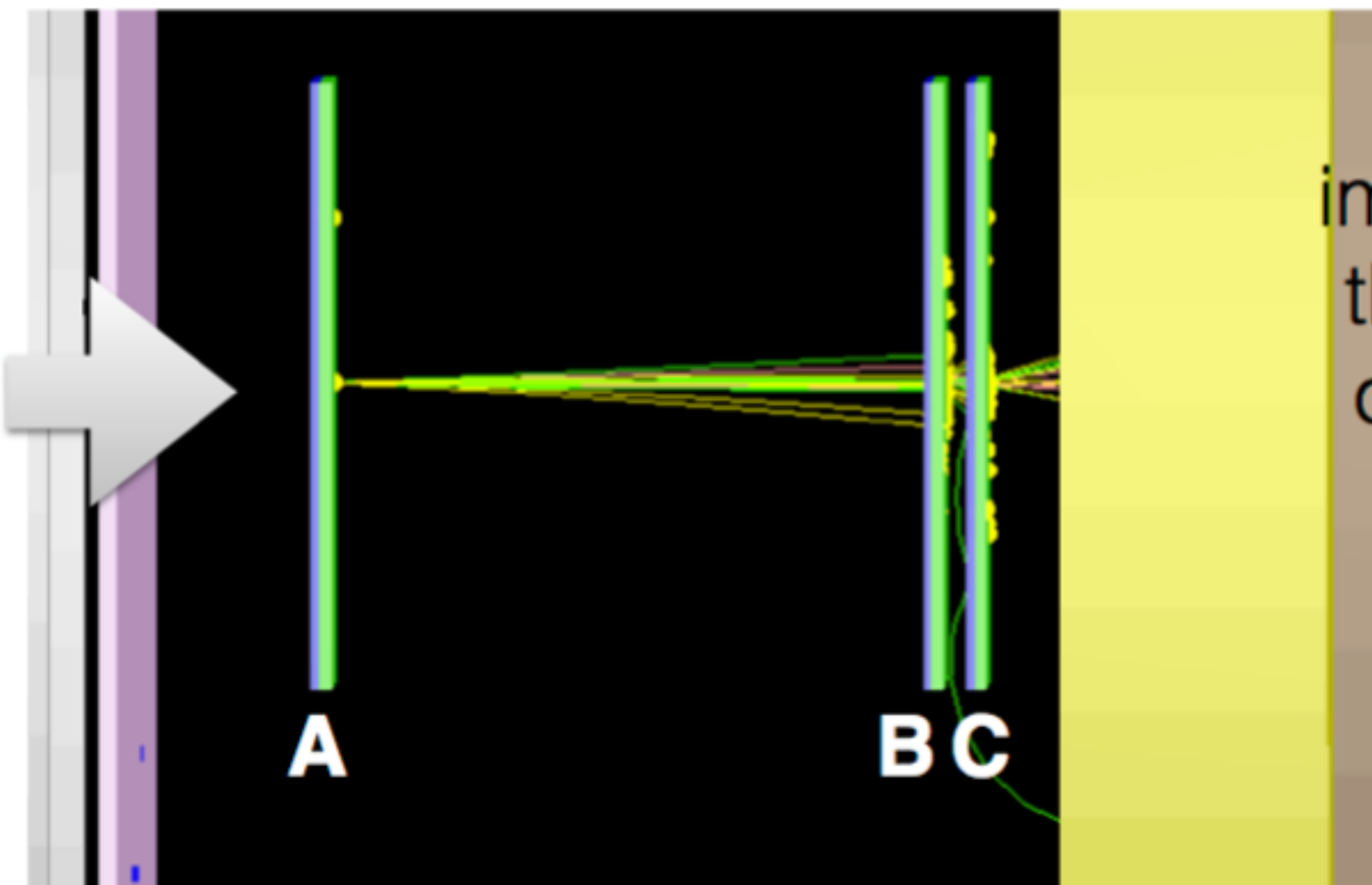
- new idea: using uWELLS as active detector

# Some trials

**With FairSHiP:**

**3 layers of scintillator : one sampling the shower at the beginning (2.5X0) and two after another 1.5X0 (as if they were sampling INSIDE the ECAL); 1m lever arm**

**20GeV γ**
**θ=0**




important to have thin exit window of VV like NA62 (He..)

**To be continued…quite some work to do!**

**we will restart CALO meetings bi-weekly to discuss!**

# Thoughts on Pion-Kaon ID
# (before we discuss any detector)

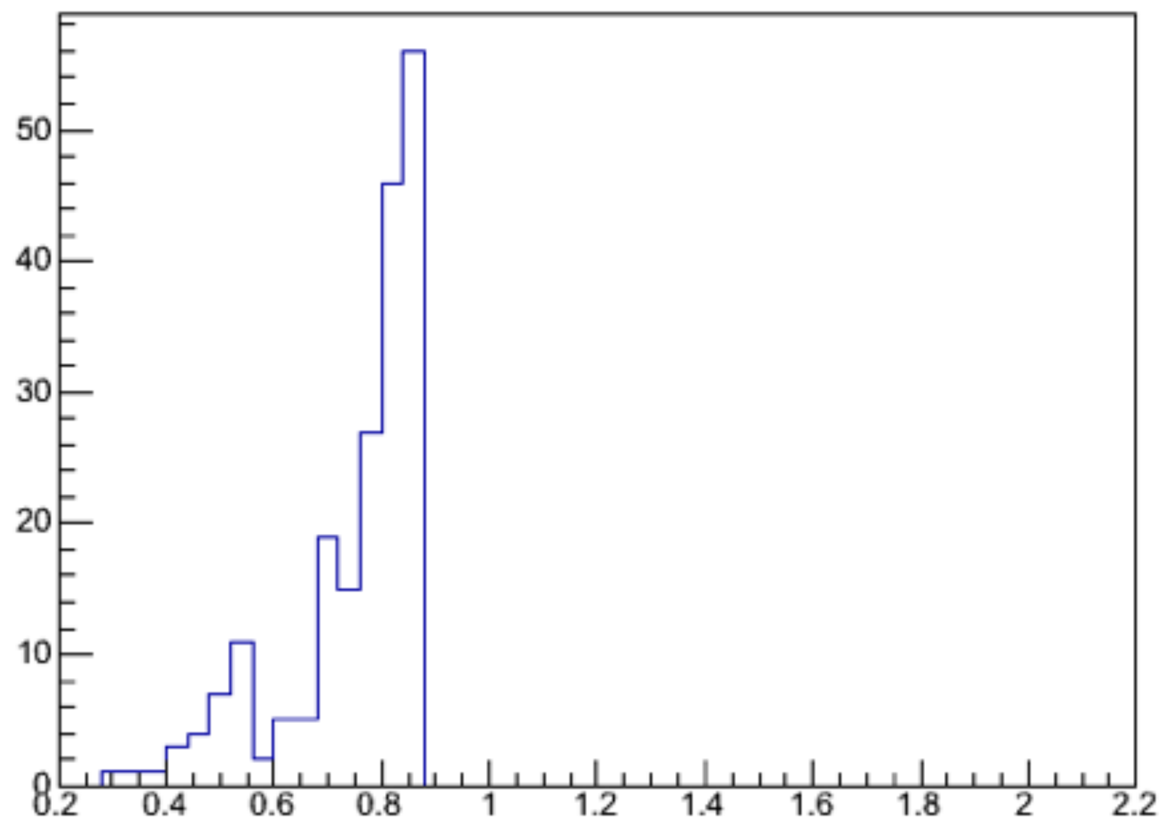
**In decays of LLP with at least one hadron one does not know a priori if the hadron is a Kaon or a Pion.**

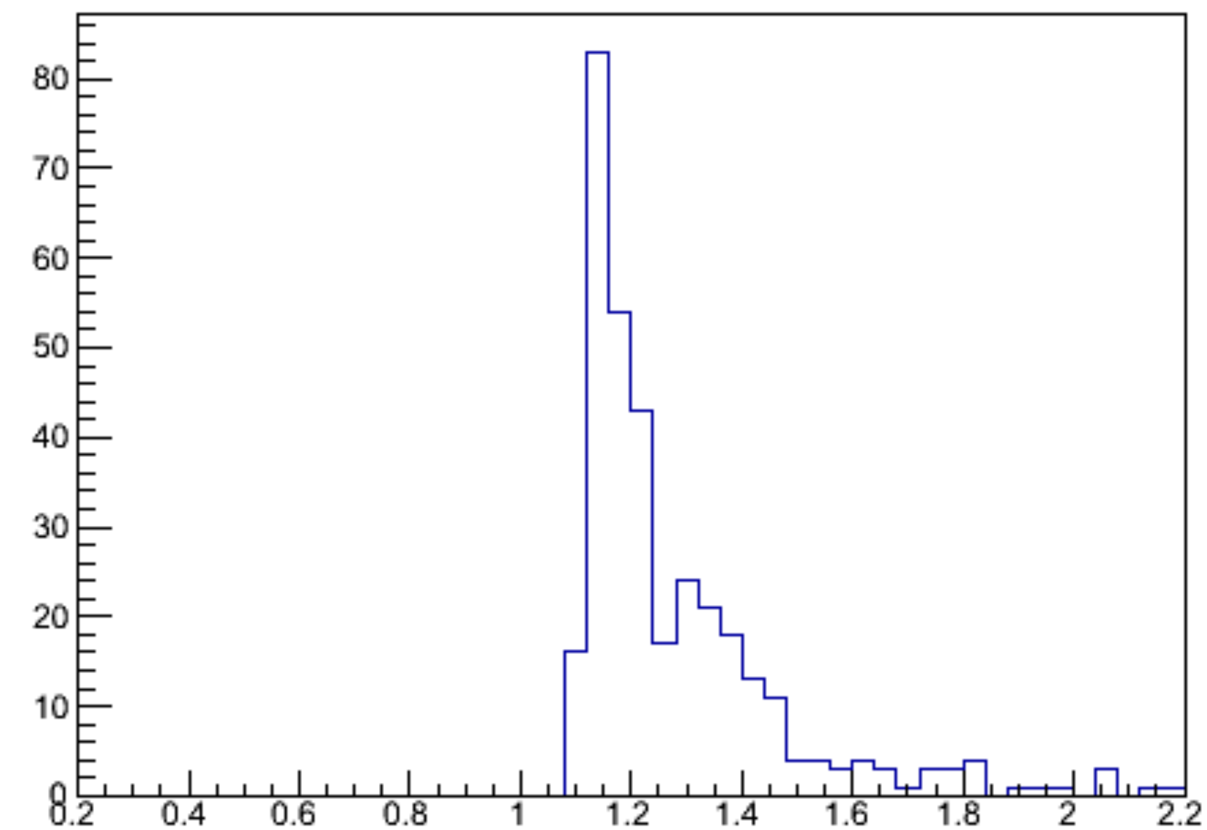
**If we find more than 1 candidate (and as shown before you need >=3 to give a 5$\sigma$ discovery) in principle it is possible to test the different hypotheses and see weather there is clustering around some invariant mass value or not**

**Only problem: kinematic reflections, i.e. when the wrong mass assignment occurs inside the mass resolution of the correct assignment**

**Let us do the exercise in a model independent way, final state by final state**

# Mass swap



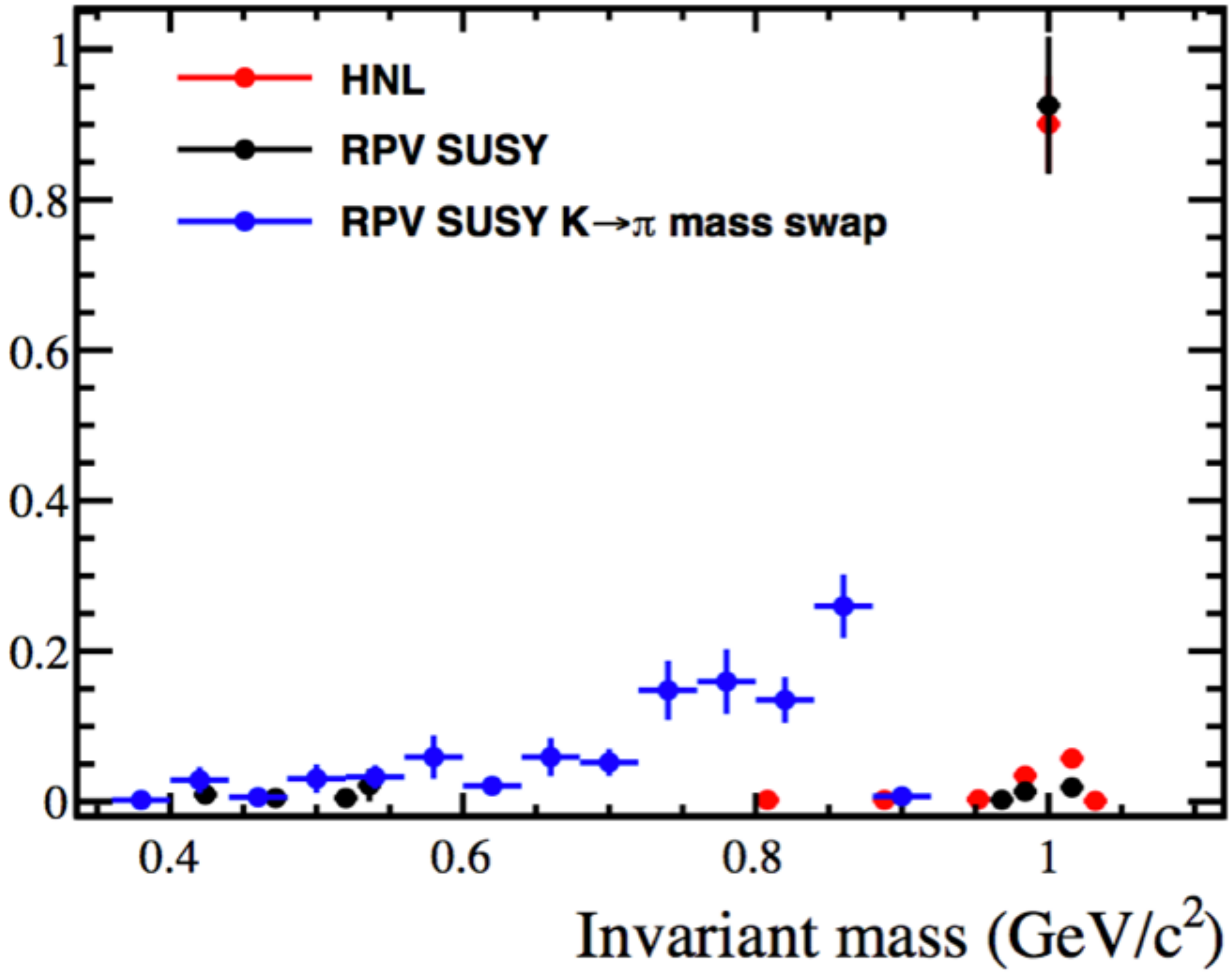




**μK with the μ$\pi$ hypothesis**

**HNL m=1GeV**

**μ$\pi$ with the μK hypothesis**

# From Kostas, 22/9



Probability of 2-3-4 events occurring in the same mass bin

| | HLN->μK (K->$\pi$) | HLN->μ$\pi$ ($\pi$->K) |
|---|---|---|
| P(2) | 28% | 22% |
| P(3) | 8.9% (5.5%) | 4.9% (2.9%) |
| P(4) | 2.9% | 1.1% |

In black 40MeV window, in red 30MeV window

**What do u think? does this indicate the need of a RICH?**

**Remember: as Jacques showed, we already have some discrimination potential at low momentum thanks to the timing detector**

**Even more complicated if we find 2 different Hidden Sector particles**

# Conclusions

**Some directions are clear:**

**1) present ECAL expensive and lacks longitudinal segmentation**

**2) needs longitudinal segmentation or pre shower**

**3) needs optimise $\pi\mu$ separation detectors (a different topic!)**

**We have to "decide" what direction to take on:**

**- having or not a RICH**

**- study an "expensive" ECAL to measure photon direction to mRad for $\gamma\gamma$ physics together with VETO plus tight vacuum**