Search for dark sector physics in missing energy events in the NA64 experiment

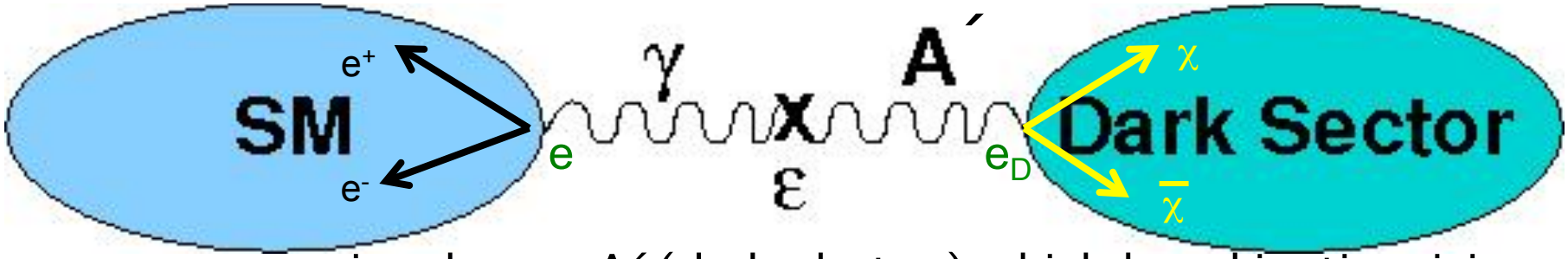
Lomonosov conference
August 2017 Moscow

Outline

- Motivation
- The NA64 experiment
- Runs 2016
- Simulation of the Dark Matter production
- Analysis of the data
- Results
- Conclusion and plans

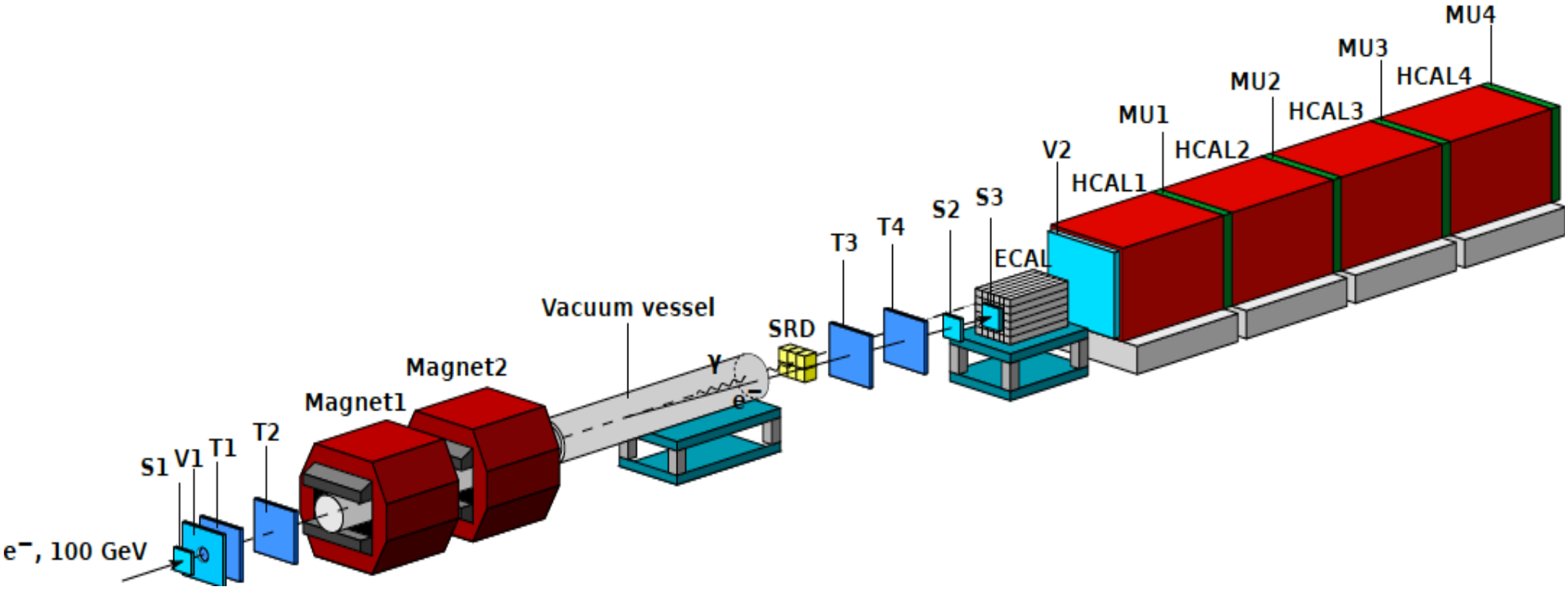
Vector portal to Dark Sector

Okun, Holdom' 86 .. $\alpha_D=e_D^2/4\pi$



- new massive boson A´(dark photon) which has kinetic mixing with ordinary photon: $\Delta L = \varepsilon/2\ F^{\mu\nu}A'_{\mu\nu}$
- GUT prediction for the size of the γ-A´mixing strength ($\varepsilon<<1$): 1-loop: $\varepsilon \sim 10^{-4}$ -10^{-2}; 2 loops: $\varepsilon \sim 10^{-5}$ -10^{-3}, $m_{A'} \sim \varepsilon^{1/2} M_Z$
- Production: A´- bremsstrahlung $e^- Z \rightarrow e^- Z A'$, $\sigma \sim Z^2\varepsilon^2/m_{A'}^2$
- Decays:
  - Visible: $A' \rightarrow e^+e^-, \mu^+\mu^-$, hadrons,..
  - Invisible: $A' \rightarrow \chi\chi$ if $m_{A'} > 2m_\chi$ assuming $\alpha_{DM} \sim \alpha >> \varepsilon$.
    Can explain $(g-2)_\mu$, astrophys. observations
    - Cross section for χ–DM annihilation: $\sigma v \sim \overbrace{[\alpha_{DM}\,\varepsilon^2(m_\chi/m_{A'})^4]}^{y}\ \alpha/m_\chi^2$

NA64 experiment setup



NA64 collaboration

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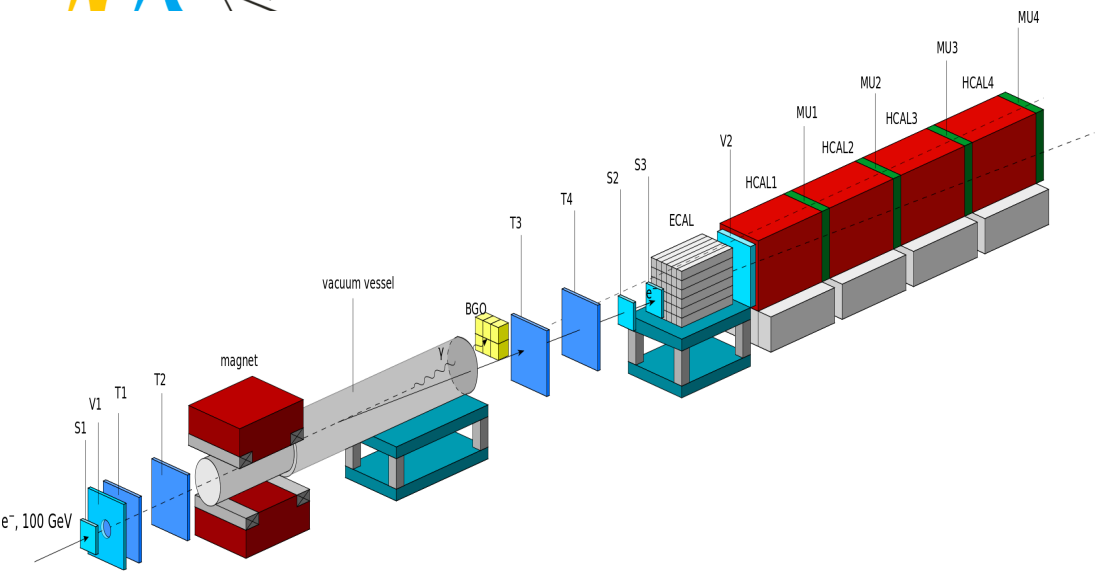
47 researchers from 12 Institutes
Proposed in 2014, first test beam in 2015 (2 weeks)

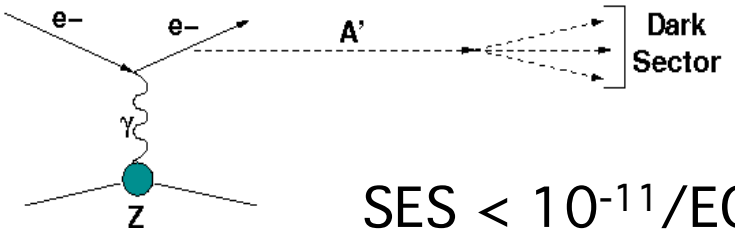
Search for A´->invisible decays at CERN SPS



S.Andreas et al., arXiv: 1312.3309
S.G., PRD(2014)

Main components :

- clean 100 GeV e- beam
- e- tagging system: tracker+SRD
- fully hermetic ECAL+ HCAL



SES < 10^{-11}/EOT

Signature:

- in: 100 GeV e- track
- out: $E_{ECAL} < E_0$ shower in ECAL
- no energy in Veto and HCAL

Background:

- μ, π, K decays in flight
- Tail < 50 GeV in the e- beam
- Energy leak from ECAL+HCAL

Summary of the 2016 runs

- **First run period, 29.06-13.07, 2 w**

  $Tr_{A'} = \Pi s_i$ x V1 x PS($E>E_{PS}$) x ECAL($E<E_{ECAL}$)

  - **0.88×10^9 eot, 0.3×10^6 e^-/spill, BGO run**
  - **1.87×10^9 eot, 1.3×10^6 e^-/spill, PbSc run**
  - **Total number ~ 2.75×10^9 eot**
  - **Result published**

- **Second run period, 12.10-09.11, 4 w**

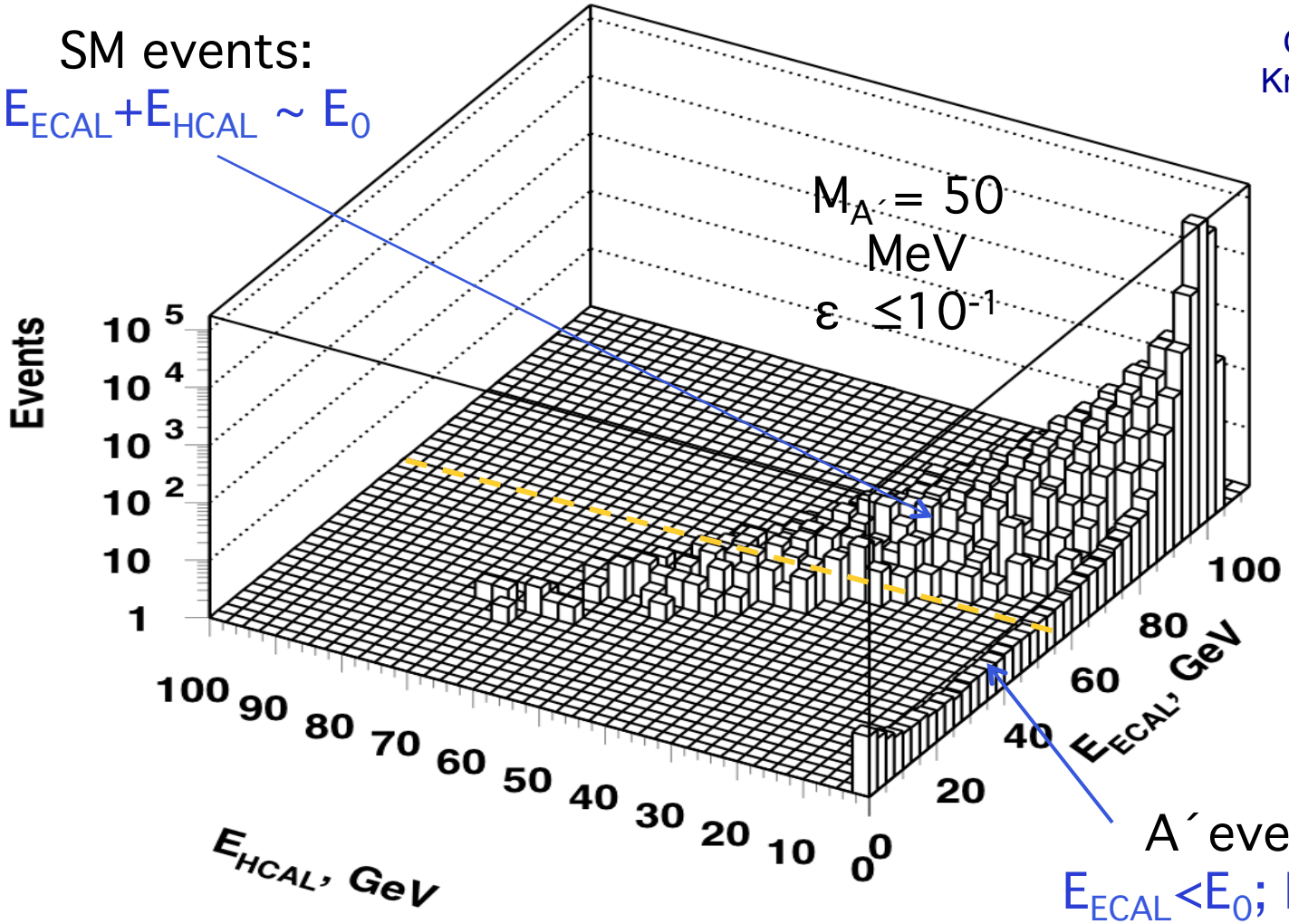
  - **23 October → start data taking;**
  - **Total accumulated electrons ~2×10^{10}, S_0 rate $1.5 \div 2.2 \times 10^6$;**
  - **Total accumulated electrons ~1.5×10^{10}, S_0 rate $2.4 \div 3.2 \times 10^6$;**
  - **Total accumulated electrons ~1.0×10^{10}, S_0 rate $4.6 \div 5.0 \times 10^6$; ~0.6 day**
  - **Total number ~ 4.5×10^{10} eot**

  05.11-09.11 ^{8}Be anomaly test

  - **Test visible mode, second tungsten electromagnetic calorimeters, additional veto counters were installed downstream of vacuum pipe;**
  - **Data taking, ~ 5×10^9 eot, $2.8 \div 3.0 \times 10^6$ e-/spill (2 days)**

Simulation of eZ->eZA´; A´-> invisible @ BG

GEANT4 + code for A´emission in the process of e-m shower development. σ(e^-Z->$e^-ZA´$) from Bjorken et al. 2009

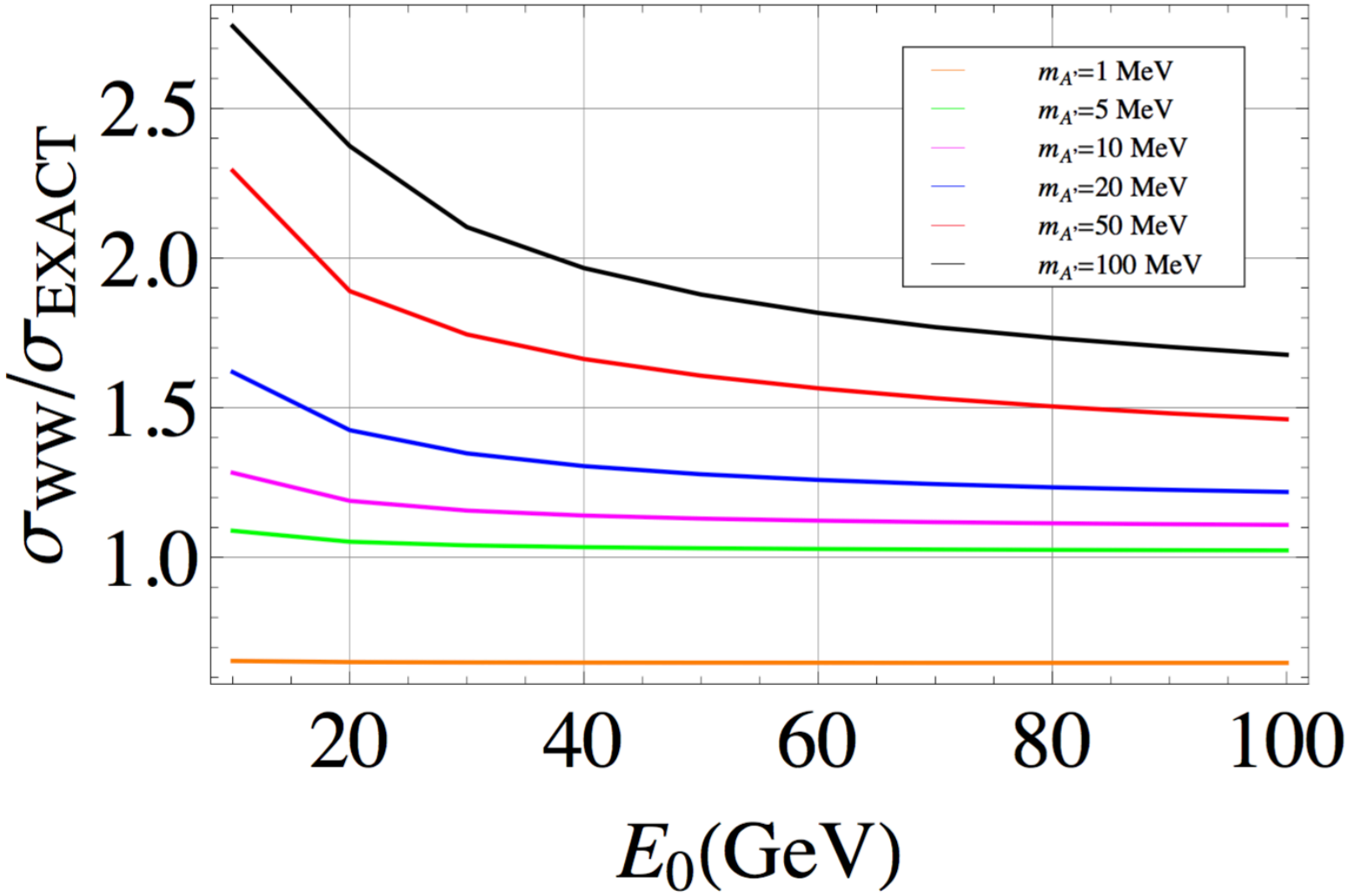


Gninenko, Kirsanov, Krasnikov, Kirpichnikov PRD(2016)

Simulation of eZ->eZA´

- The signal process is simulated using simplified Weizsaecker – Williams (WW) approximation (Bjorken et al., 2009)
- More exact calculations that use the full matrix element were performed recently (2016, 2017)
- We started to use these calculations this year
- They are implemented as K-factors to the total cross section. The latter can be decreased by as much as factor 15 w.r.t. the simplified WW approximation at $M_A \sim 1$ GeV
- The differential cross section (essentially the distribution of the energy fraction transferred to A') from WW is used. The difference is small because both WW and exact are strongly peaked near 1. The A' spectrum is determined mainly by the EM shower development

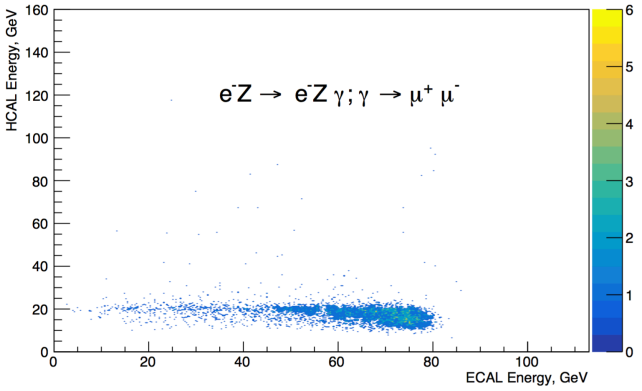
K-factors to eZ->eZA´



Reconstruction: key moments

- Synchrotron Radiation detectors (SRD) made as lead – scintillator sandwiches suppress pions and other particles heavier than electrons that are present in the beam by a factor of 10^{-5}
- The shower profile in ECAL is compared to the profile of true electrons in order to further suppress wrong particles.
- Micromegas track detectors are used to reconstruct the momentum of electron before the ECAL in order to suppress small fraction of soft electrons from interactions on beam line elements.

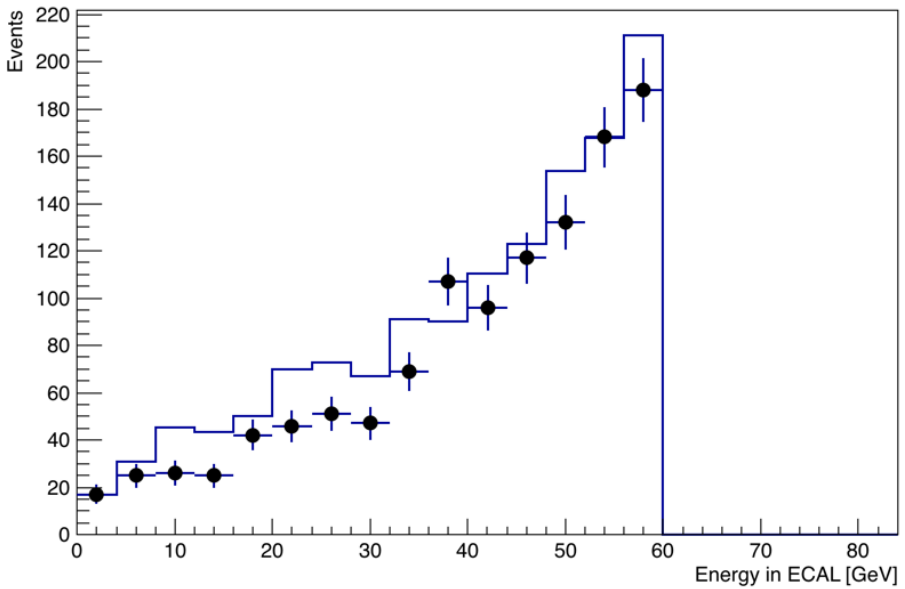
Dimuon production as a reference process

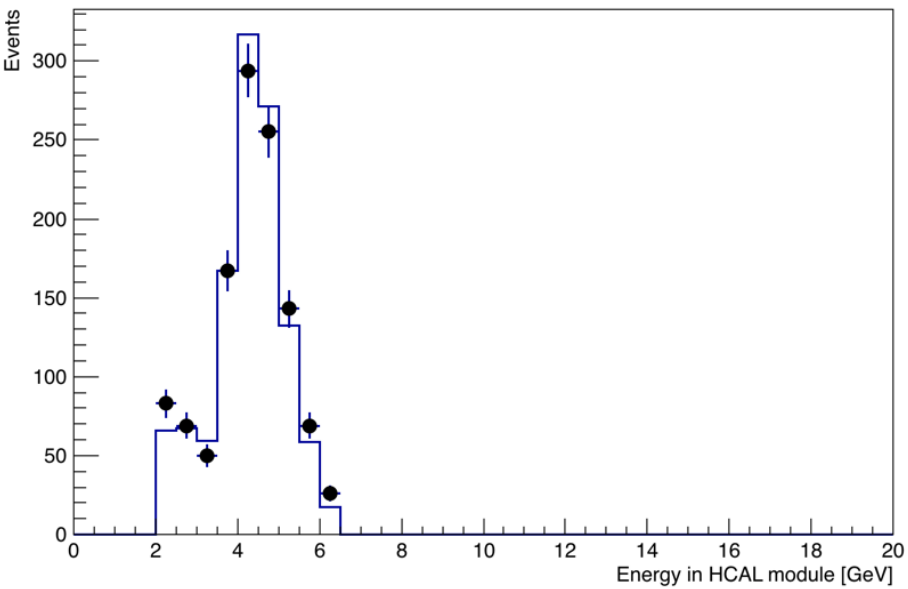


- There is an excellent reference process: gamma to muons conversion. It is rather rare and has many similarities with our signal
- Several 10^4 dimuon pairs with both muons reaching all HCAL modules are registered in the 2016 runs
- The process is available in GEANT4, off by default
- We bias the cross section in GEANT4 by a factor of 200 in order to have good statistics with reasonable CPU time.
- Good agreement DATA - MC

Dimuon reconstruction

HCAL module 3





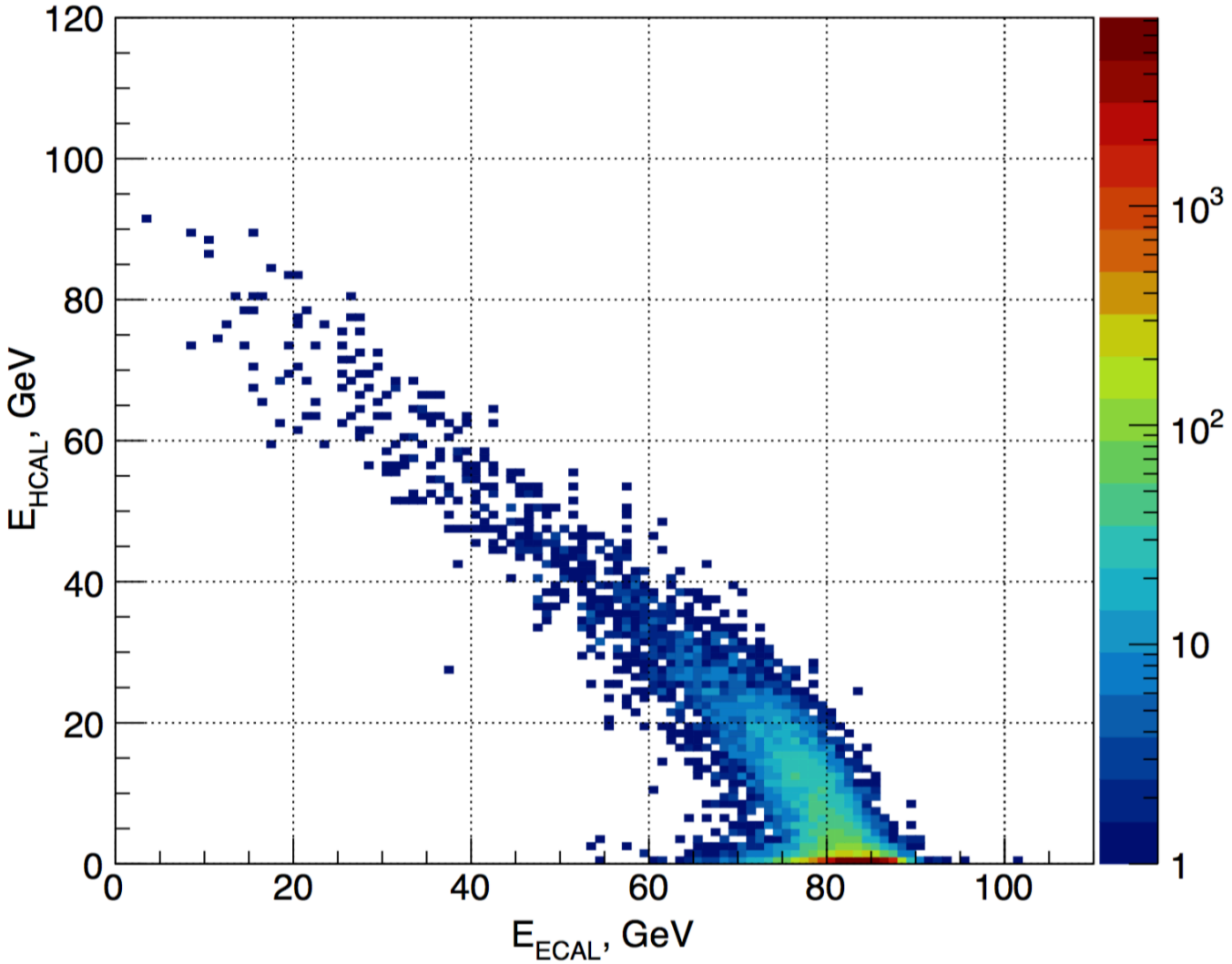
Dimuons selection: $E_{ECAL} < 60$ GeV

$2.5 < E_{HCAL1} < 6.35$

$2 < E_{HCAL3} < 6.35$

Left plot: number of dimuons in DATA ~ 0.92 of MC prediction -> efficiency correction

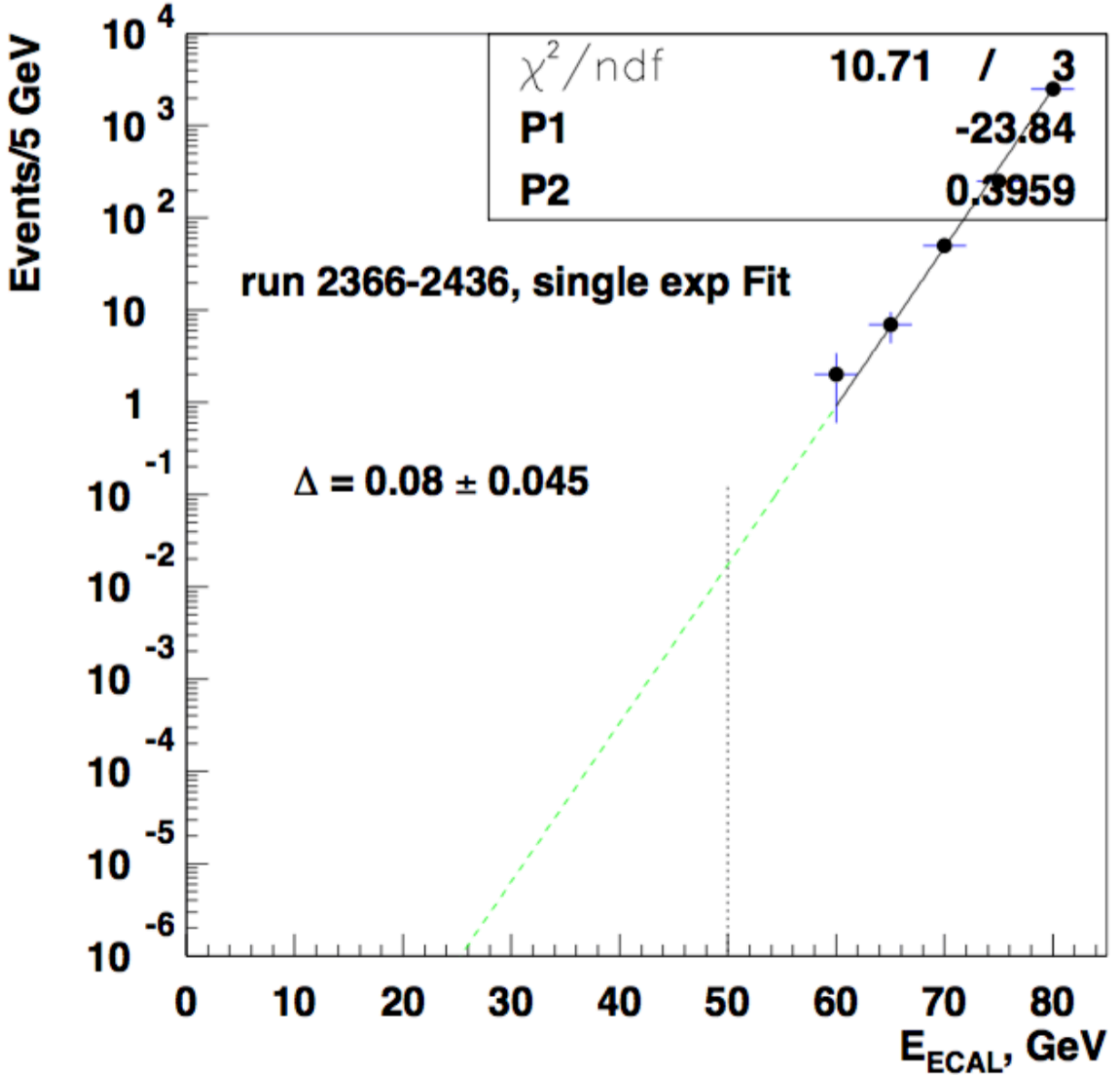
Background


120
100
80
60
40
20
0
0
20
40
60
80
100
E_{HCAL}, GeV
E_{ECAL}, GeV
10^3
10^2
10
1

Background

- As mentioned above, the sources of background are decays in flight and various impurities of the beam (softer electrons etc.)
- The BG from decays was estimated by biasing the life times in GEANT4
- The second BG is higher and difficult to simulate. We estimated it using extrapolation from the “side bin” , i.e. from what we see beside our “signal box” preliminarily defined as “$E_{ECAL} < 50$ GeV”

Background: example of extrapolation

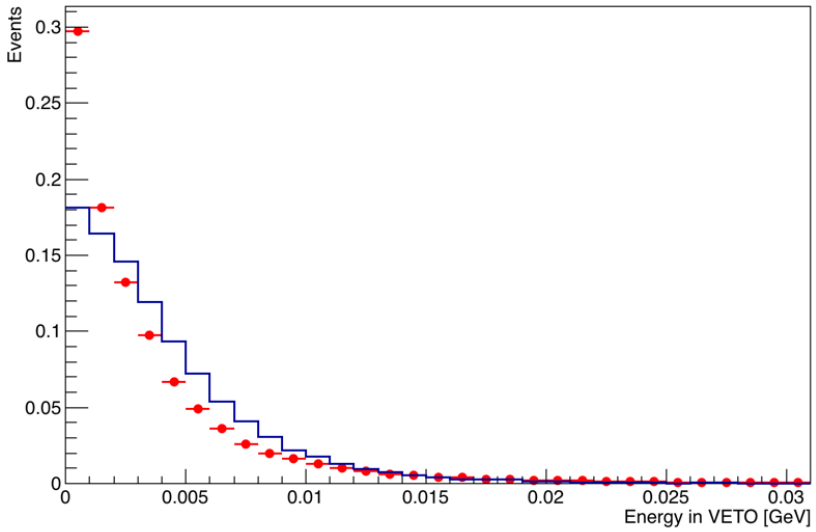


Total predicted background ~0.17

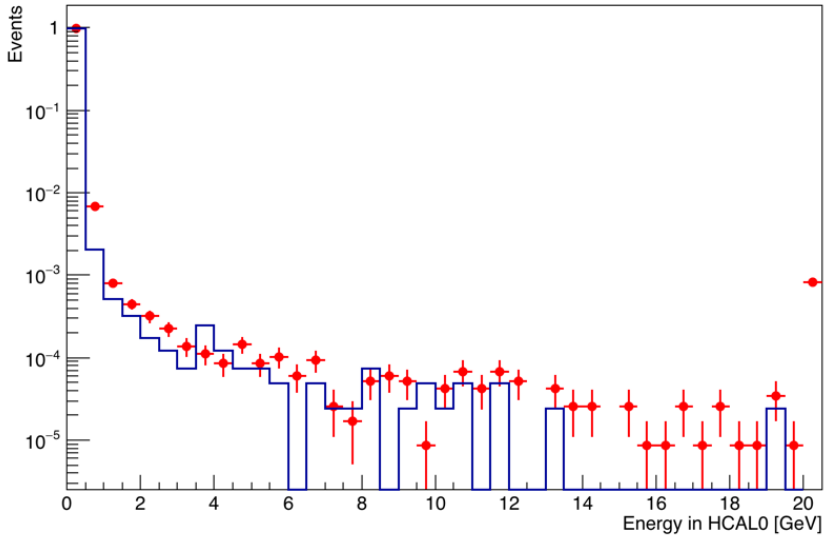
Analysis: efficiency corrections and uncertainties

Efficiency type	Method	Efficiency	uncertainty
Trigger and SRD selection, DAQ	Dimuons analysis	0.91	10%
VETO cut	Comparison MC - data in calib. runs	1	5%
HCAL cut	Comparison MC - data in calib. runs	0.99	5%

Veto: cut at 0.01 GeV



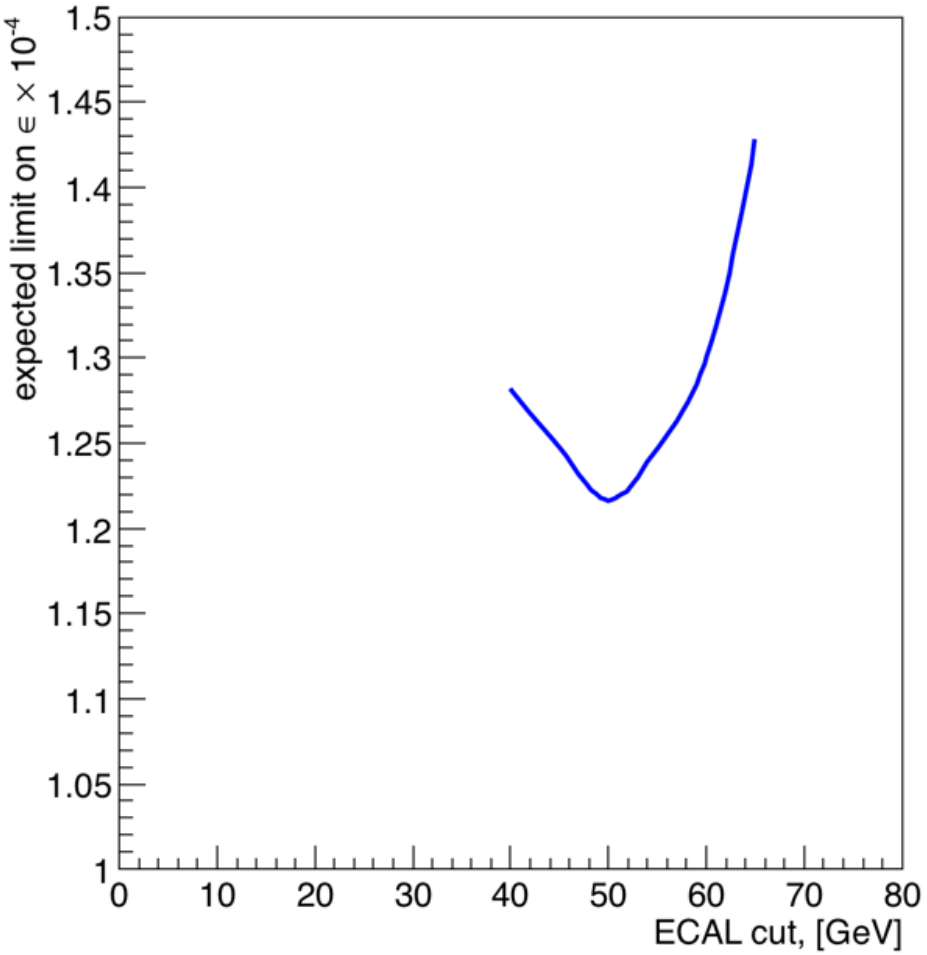
HCAL0: cut at 1 GeV



Analysis

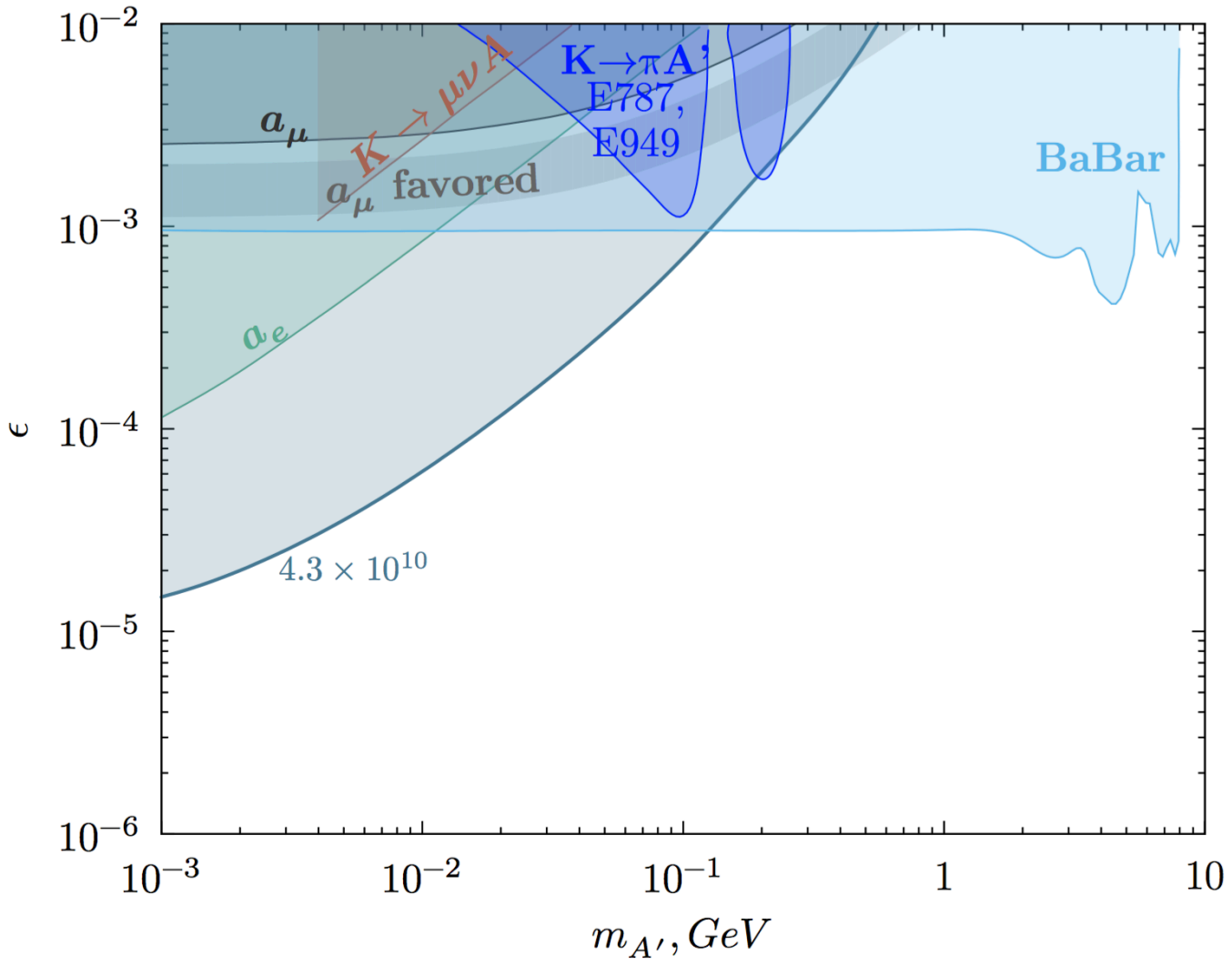
- Data collected in the automn 2016 run are divided in 3 bins: low, medium and high intensity
- For each bin the background, efficiency corrections and their uncertainties are estimated
- The expected sensitivity was calculated with ProfileLikelihood method
- The limits are calculated with CL_S method

Analysis: optimization



The optimization confirmed the preliminary choice of the E_{ECAL} cut: 50 GeV

Results


10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
ϵ
10^{-3}
10^{-2}
10^{-1}
1
10
$m_{A'}, GeV$
a_μ
$K \to \mu\nu A'$
a_μ favored
a_e
4.3×10^{10}
$K \to \pi A'$
E787,
E949
BaBar

Conclusion

- A search is performed for sub-GeV dark photons (A′) mediated production of dark matter by the NA64 experiment with $4.3*10^{10}$ 100 GeV electrons on target
- No evidence for such events is found. This allows to derive an upper limit on the A′ − γ mixing strength in the A′ mass range from 1 to 500 MeV and allows to exclude a vector mediator particle solution to the g-2 anomaly. For the masses ~10 MeV the limits on the mixing parameter are about 10^{-4}: improved by a factor ~3 w.r.t. last year publication
- NA64 plans to increase statistics in the nearest future and extend the searches for dark matter and other new physics at the CERN SPS beams