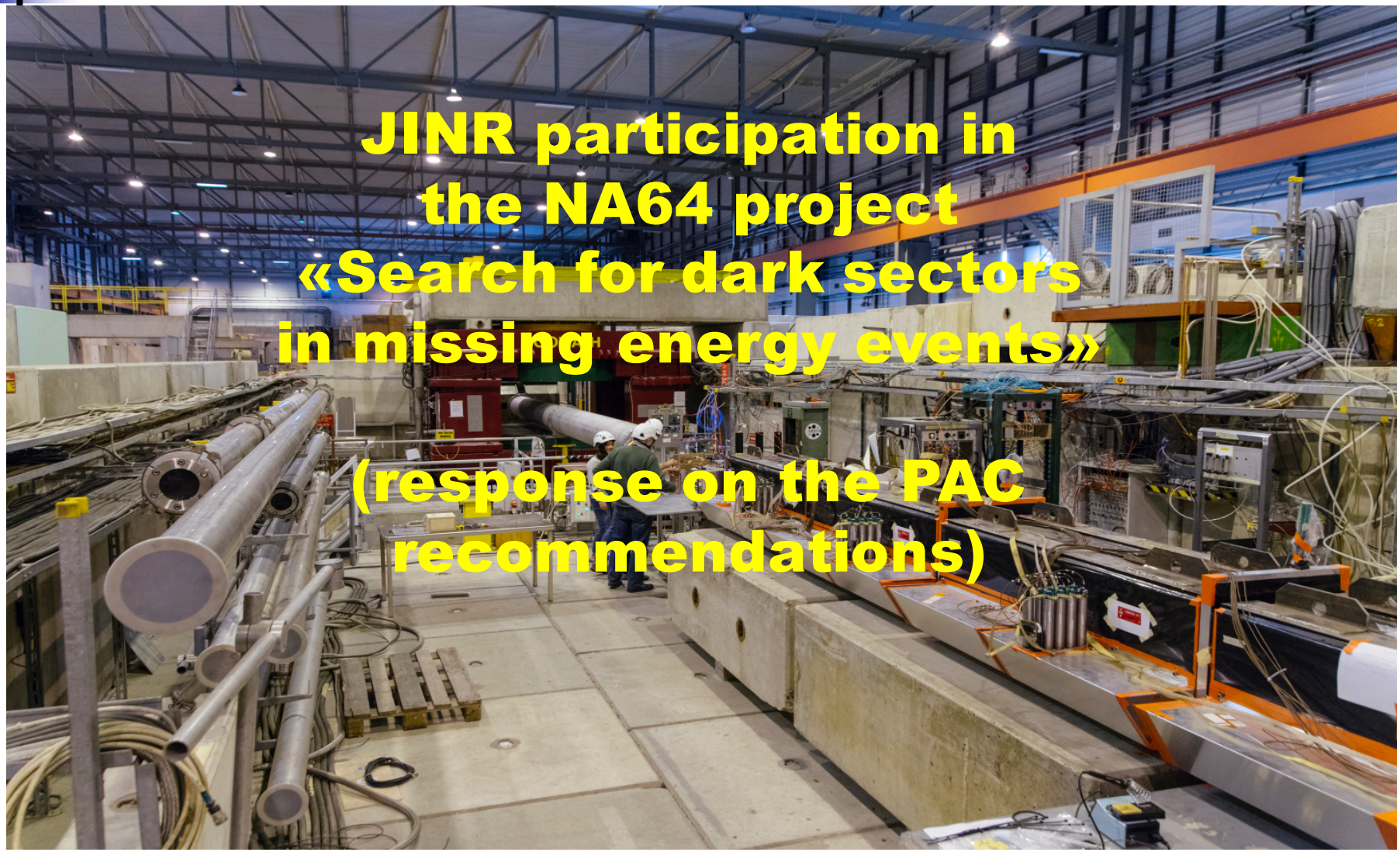


JINR participation in the NA64 project «Search for dark sectors in missing energy events»

(response on the PAC recommendations)

D.Peshekhonov on behalf of the team

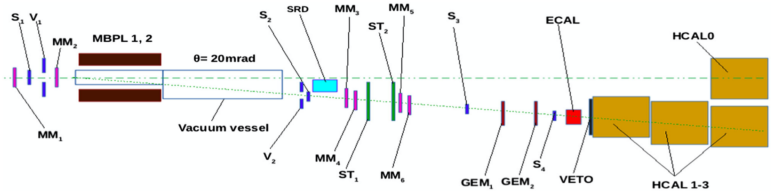
Outline

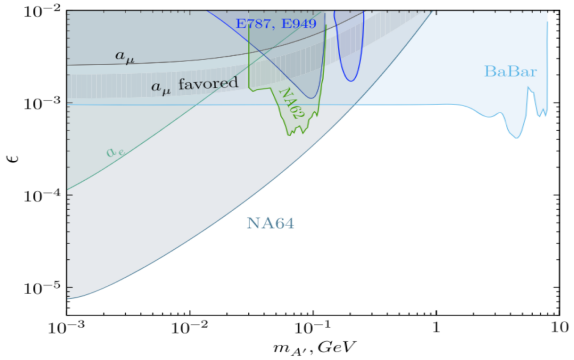
- New NA64 results and publications
  - Light Dark Matter
  - News on the ^{8}Be anomaly
  - Axion-like particles
  - $(g-2)_\mu$ anomaly and a new light Z´
- JINR contribution and participation
- Brief reminder of the report on 51th PAC meeting
- Response on the PAC recommendations

CERN DG New year presentation Jan 14, 2020: Highlight on NA64

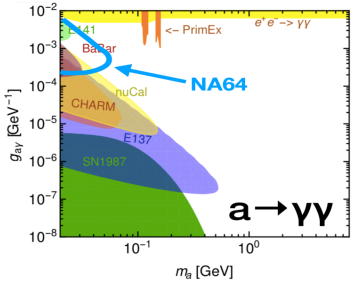
Selected Beam Dump Experiment: NA64

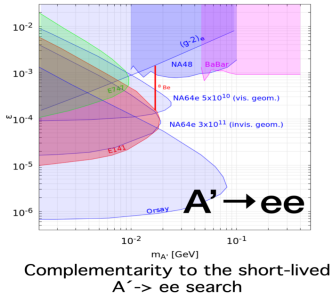
NA64 e-beam dump experiment
- active target
- search for dark photons





preliminary results on a→γγ and A'→ee





Complementarity to the short-lived A´-> ee search

Eventually plan to run with μ to explore second generation.

Vice-DG E. Elsen: *....From a wide variety of fixed-target experiments, I chose NA62 and NA64 as the most indicative in terms of the potential for discovering new physics at SPS... Analysis of data collected during 2016-2018 with electrons allowed NA64 to achieve a record sensitivity for the region of light dark matter parameters, as well as significantly advance in the search for other new weakly interacting particles. The plan is also to run with muons to explore potential for new physics with second generation.*

"2019 in Review" Jan 29, 2020: Highlight on NA64

January 29th article "2019 in Review" by DG was published in the Bulletin for the CERN Community.

DG F. Gianotti:

"...Highlights from the fixed-target programme include progress in the study of the extremely rare $K^+ \to \pi^+ \nu\nu$ decay from NA62 and new results on searches for dark photons from the NA64 beam dump experiment. Both are promising avenues to search for new physics in ways that are complementary to high-energy colliders.."

2019 in review

By Fabiola Gianotti

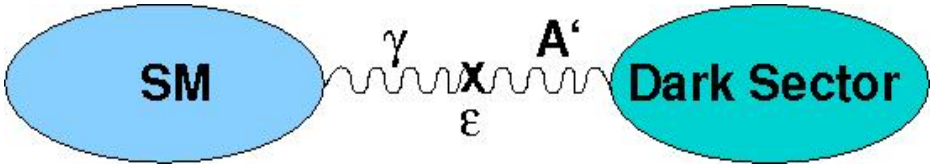
5-6 minutes

Fabiola Gianotti is the Director-General of CERN.

NA64 experiment at the CERN SPS

- Primary goal: searching for Dark Sector Physiscs:
  Light Dark Matther (LDM), new feebly interacting particles, ...
  with the first and second lepton generations at the CERN SPS
- Proposed in 2014, pilot-run and feasibility tests in 2015
- Recommended and approved by RB as NA64 in March 2016
- Plan to accumulate **$5\times10^{12} - 10^{13}$** EOT after LS2
- Active member of the CERN Physics Beyond Colliders platform:
  - Spokesperson is a member of the PBC BSM working group,
  - Submission of Input to European Strategy Group on Particle Physics
- Currently ~ 60 participants representing institutes from Germany, Greece, Chile, Russia, Switzerland, UK, USA, and CERN and JINR.

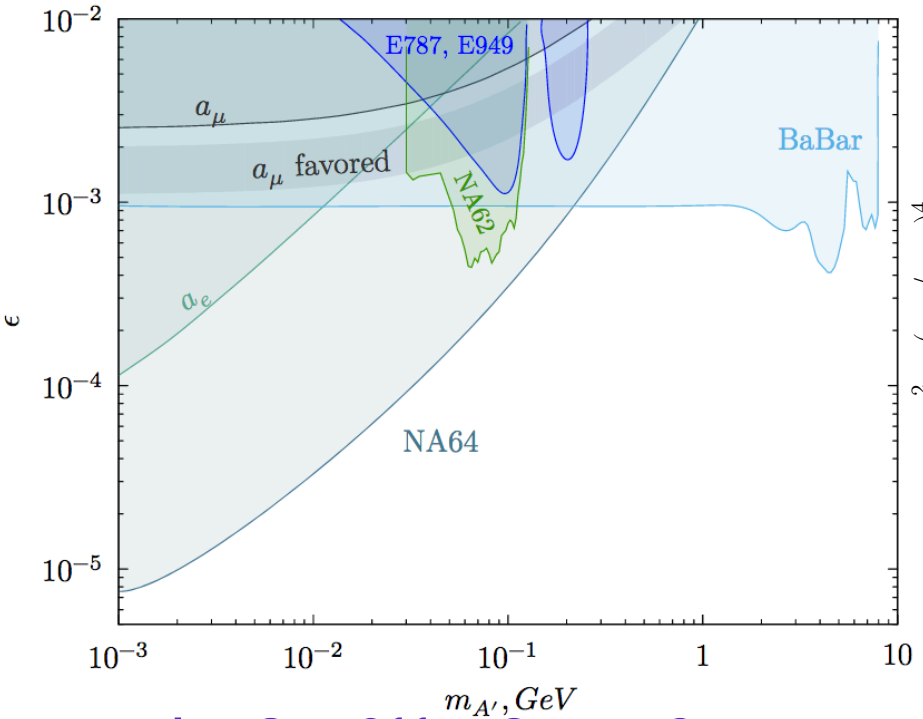
2016-18 runs: LDM search, 2.84x10^{11} EOT

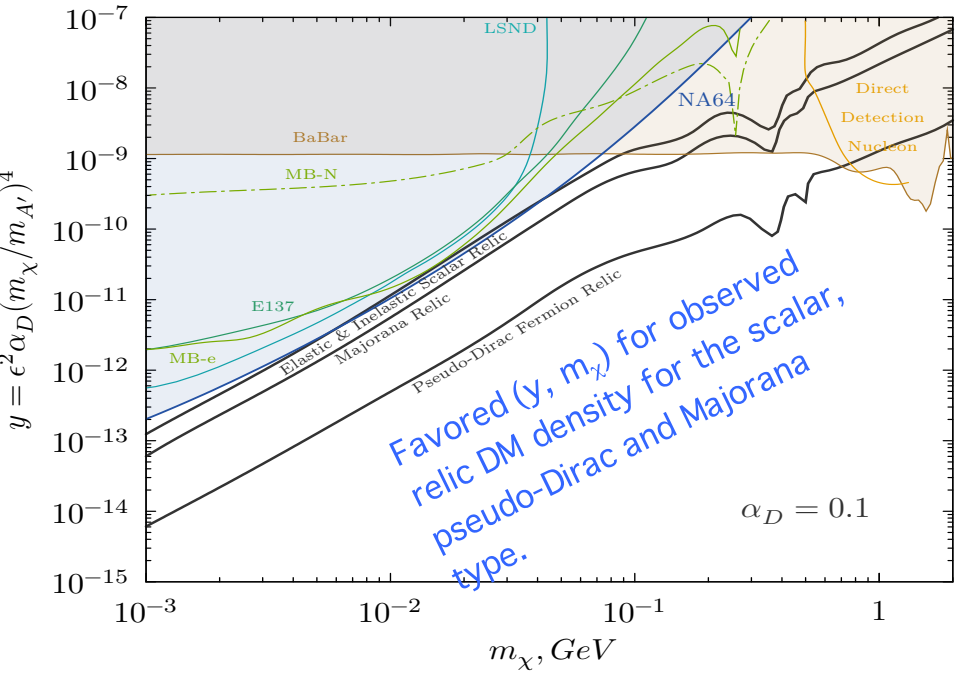


Best limits on $\gamma - A'$ mixing strentghs

First probing of scalar LDM parameter space

$m_{A'} = 3m_{\chi}$





Favored (y, m_χ) for observed relic DM density for the scalar, pseudo-Dirac and Majorana type.

With ~3x10^{11} EOT NA64 superseded bounds from LSND, MiniBooNE, and SLAC, obtained with ~10^{22}, 10^{20} POT and 10^{19} EOT!

With ~5x10^{12} EOT NA64 will cover almost the full parameter space !

Combined 2016-2018 result on LDM search

Highlighted by PRL as Editor's Suggestion

PHYSICAL REVIEW LETTERS **123,** 121801 (2019)

Editors' Suggestion

Dark Matter Search in Missing Energy Events with NA64

D. Banerjee,[4,5] V. E. Burtsev,[2] A. G. Chumakov,[13] D. Cooke,[6] P. Crivelli,[15] E. Depero,[15] A. V. Dermenev,[7] S. V. Donskov,[11] R. R. Dusaev,[13] T. Enik,[2] N. Charitonidis,[4] A. Feshchenko,[2] V. N. Frolov,[2] A. Gardikiotis,[10] S. G. Gerassimov,[8,3] S. N. Gninenko,[7,*] M. Hösgen,[1] M. Jeckel,[4] A. E. Kameyeu,[7] G. Kekelidze,[2] B. Ketzer,[1] D. V. Kirpichnikov,[7] M. M. Kirsanov,[7] I. V. Konorov,[8,3] S. G. Kovalenko,[14] V. A. Kramarenko,[2,9] L. V. Kravchuk,[7] N. V. Krasnikov,[2,7] S. V. Kuleshov,[12] V. E. Lyubovitskij,[13,14] V. Lysan,[2] V. A. Matveev,[2,7] Yu. V. Mikhailov,[11] L. Molina Bueno,[15] D. V. Peshekhonov,[2] V. A. Polyakov,[11] B. Radics,[15] R. Rojas,[14] A. Rubbia,[15] V. D. Samoylenko,[11] D. Shchukin,[8] V. O. Tikhomirov,[8] I. Tlisova,[7] D. A. Tlisov,[7] A. N. Toropin,[7] A. Yu. Trifonov,[13] B. I. Vasilishin,[13] G. Vasquez Arenas,[14] P. V. Volkov,[2,9] V. Yu. Volkov,[9] and P. Ulloa[14]

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(Received 5 June 2019; published 18 September 2019)

A search for sub-GeV dark matter production mediated by a new vector boson A', called a dark photon, is performed by the NA64 experiment in missing energy events from 100 GeV electron interactions in an active beam dump at the CERN SPS. From the analysis of the data collected in the years 2016, 2017, and 2018 with 2.84×10^{11} electrons on target no evidence of such a process has been found. The most stringent constraints on the A' mixing strength with photons and the parameter space for the scalar and fermionic dark matter in the mass range $\lesssim 0.2$ GeV are derived, thus demonstrating the power of the active beam dump approach for the dark matter search.

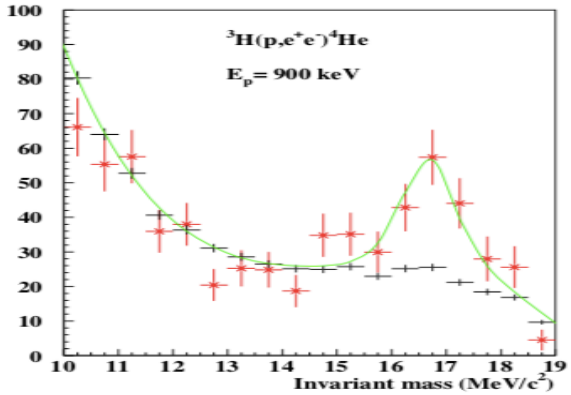
A´, X17->e+e- decay search in 2017-18 runs

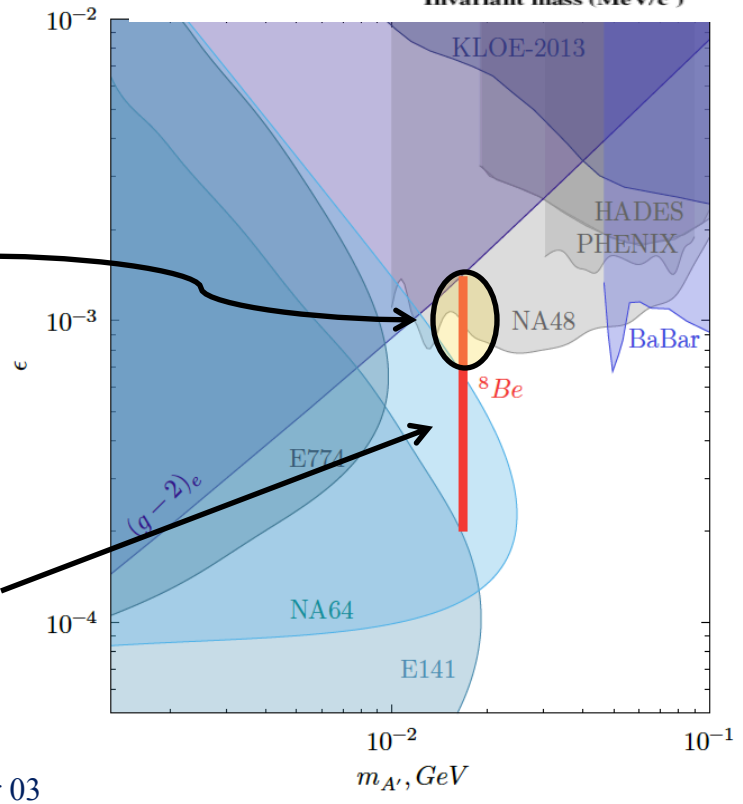
- Primary goal: searching for a 17 MeV X-boson, which could explain the ^{8}Be-^{4}He anomaly – an ~6-7 σ excess in the invariant mass of e^+e^- pairs and dark photon A´ ->e^+e^- decays.

- A´, X produced in e-Z->e-Z+A´, X from 150 GeV e- reaction in a short active WCAL dump with subsequent A´, X ->e^+e^- decays

- Plans to cover the remaining parameter space of the e-X coupling with a **few10^{12}** EOT after LS2 by using also reconstruction of invariant mass of the decay e^+e^- pairs

ATOMKI 2019, ^{4}He anomaly





Exclusion region from 2017-18 runs for the e- A´ couplings vs A´ mass

Red strip is the region of allowed e-X couplings for mass 17 MeV

^{8}Be – ^{4}He anomaly (subm. to PRD(R))

Improved limits on a hypothetical $X(16.7)$ boson and a dark photon decaying into e^+e^- pairs

D. Banerjee,[4,5] J. Bernhard,[4] V. E. Burtsev,[2] A. G. Chumakov,[13] D. Cooke,[6] P. Crivelli,[15] E. Depero,[15] A. V. Dermenev,[7] S. V. Donskov,[11] R. R. Dusaev,[13] T. Enik,[2] N. Charitonidis,[4] A. Feshchenko,[2] V. N. Frolov,[2] A. Gardikiotis,[10] S. G. Gerassimov,[8,3] S. N. Gninenko,[7] M. Hösgen,[1] M. Jeckel,[4] V. A. Kachanov,[11] A. E. Karneyeu,[7] G. Kekelidze,[2] B. Ketzer,[1] D. V. Kirpichnikov,[7] M. M. Kirsanov,[7] V. N. Kolosov,[11] I. V. Konorov,[8,3] S. G. Kovalenko,[14] V. A. Kramarenko,[2,9] L. V. Kravchuk,[7] N. V. Krasnikov,[2,7] S. V. Kuleshov,[12] V. E. Lyubovitskij,[13,14] V. Lysan,[2] V. A. Matveev,[2] Yu. V. Mikhailov,[11] L. Molina Bueno,[15] D. V. Peshekhonov,[2] V. A. Polyakov,[11] B. Radics,[15] R. Rojas,[14] A. Rubbia,[15] V. D. Samoylenko,[11] D. Shchukin,[8] V. O. Tikhomirov,[8] I. Tlisova,[7] D. A. Tlisov,[7] A. N. Toropin,[7] A. Yu. Trifonov,[13] B. I. Vasilishin,[13] G. Vasquez Arenas,[14] P. V. Volkov,[2,9] V. Yu. Volkov,[9] and P. Ulloa[14]

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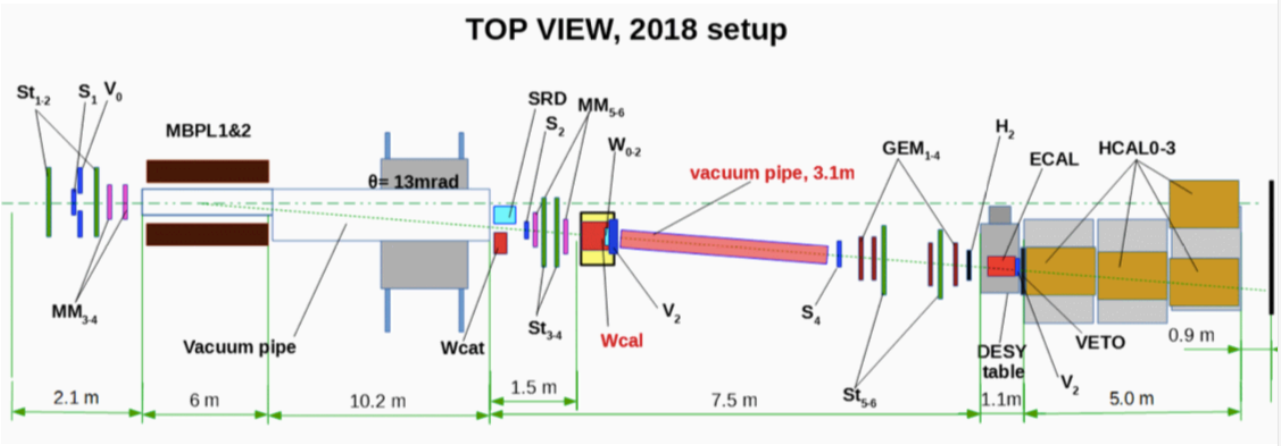
[13] *Tomsk State Pedagogical University, 634061 Tomsk, Russia*
[14] *Universidad Técnica Federico Santa María, 2390123 Valparaíso, Chile*
[15] *ETH Zürich, Institute for Particle Physics and Astrophysics, CH-8093 Zürich, Switzerland*

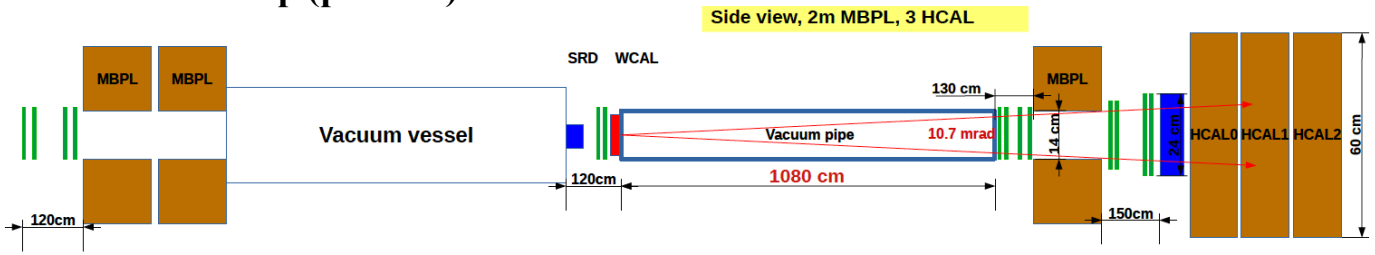
The improved results on a direct search for a new $X(16.7$ MeV) boson which could explain the anomalous excess of e^+e^- pairs observed in the excited ^{8}Be* nucleus decays ("Berillium anomaly") are reported. Due to its coupling to electrons, the X boson could be produced in the bremsstrahlung reaction $e^-Z \to e^-ZX$ by a high-energy beam of electrons incident on active target in the NA64 experiment at the CERN SPS and observed through its subsequent decay into e^+e^- pair. No evidence for such decays was found from the combined analysis of the data samples with total statistics corresponding to 8.4×10^{10} electrons on target collected in 2017 and 2018. This allows to set the new limits on the $X - e^-$ coupling in the range $1.2 \times 10^{-4} \lesssim \epsilon_e \lesssim 6.8 \times 10^{-4}$ excluding part of the parameter space favored by the Berillium anomaly. We also set new bounds on the mixing strength of photons with dark photons (A') from non-observation of the decay $A' \to e^+e^-$ of the bremsstrahlung A' with a mass $\lesssim 24$ MeV.

Recently, the search for new light bosons weakly coupled to SM particles was additionally inspired by the observation in the ATOMKI experiment by Krasznahorkay et al. [1, 2] of a $\sim 7\sigma$ excess of events in the invariant mass distributions of e^+e^- pairs produced in the nuclear transitions of excited ^{8}Be* to its ground state via internal pair creation. It has been shown that this anomaly can be interpreted as the emission of a new protophobic gauge boson X with a mass of 16.7 MeV decaying into e^+e^- pair [3, 4]. This explanation of the anomaly was found to be consistent with

NA64 & ^{8}Be – ^{4}He anomaly after LS2



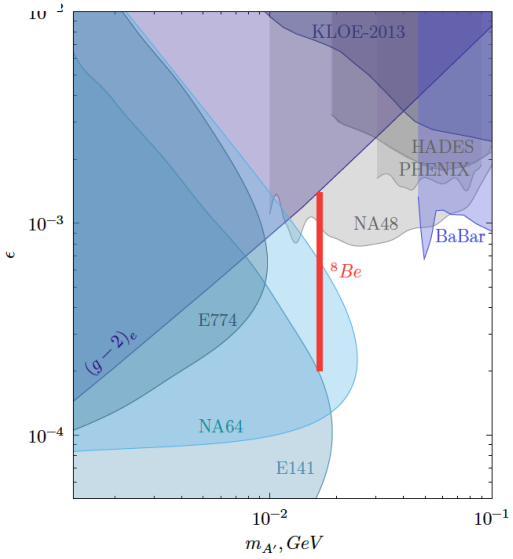
2021 setup (possible)



Running time estimation for registration of the 2.3 signal events with 150 GeV electron beam and intensity 3 10^6 e^-/spill, 4 10^3 good spills/day.

ε_e	10^{-3}	1.2 10^{-3}	1.4 10^{-3}
time	11 days	1.5 months	10 months

Low material budget tracker providing precise 2 track separation for the invariant mass of the decay e+e- pairs reconstruction becomes very important (GEMs, Micromegas, 2mm Straw)



Meeting with SPSC referees Jan 20, 2020

Preliminary plans for 2021

-two-weeks run at the spring
-six-weeks run in the autumn

Autumn 2021 run scenarios:

-½ for A' -> invisible; ½ for A'-> visible with the focus on the Be-anomaly
-The full run for A' -> visible with focus on the Be anomaly

-28th of January 2020 SPSC136 Report

> The SPSC **recommends** the requested pilot run in 2021 in the M2 beam-line with the goal to commission the NA64μ detector and to probe for the first time the coupling strengths and masses $M_{Z\mu}$<200 MeV that could explain the muon $(g-2)_\mu$ anomaly.

Run with a muon beam is expected to be approved by RB (Research Board)

LHCb and FASER plan obtain data on the Be anomaly in 2023

Plans for 2021-2024

NA64e, 100 GeV e-

•Accumulate **$n_{eot} \sim 5 \times 10^{12}$ EOT** to probe the parameter space of the Light Dark matter models (scalar, Majorana, pseudo-Dirac). Assuming the beam rate ~10^7 e^-/spill and ~4000 good spills/day, about at least 8 months of data taken are requested

•Accumulate **$n_{eot} \sim 10^{12}$ EOT** to probe the remaining parameter space of the X17 from the ^{8}Be-^{4}He anomaly

• It is scheduled to upgrade facility for more efficient operation with a high beam intensity. During 2021 run we plan to register **~5*10^{11} - 10^{12}** events for further searches **for both A' and X-boson decays**

NA64μ, 150 GeV μ-

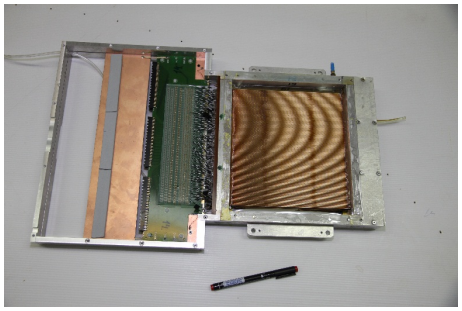
• To perform first measurements in the pilot-run 2021 at M2 muon line

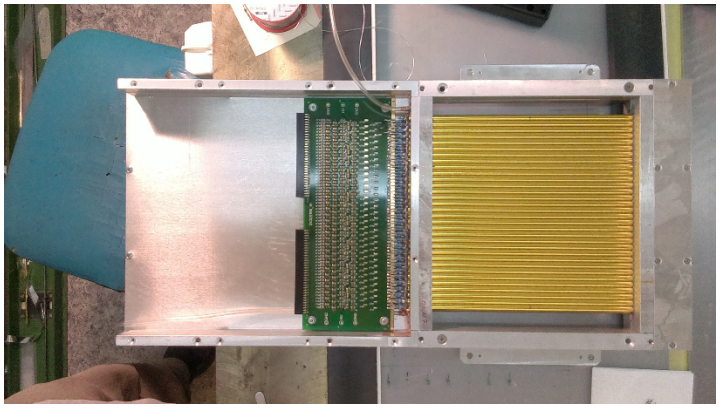
Request to the JINR group:

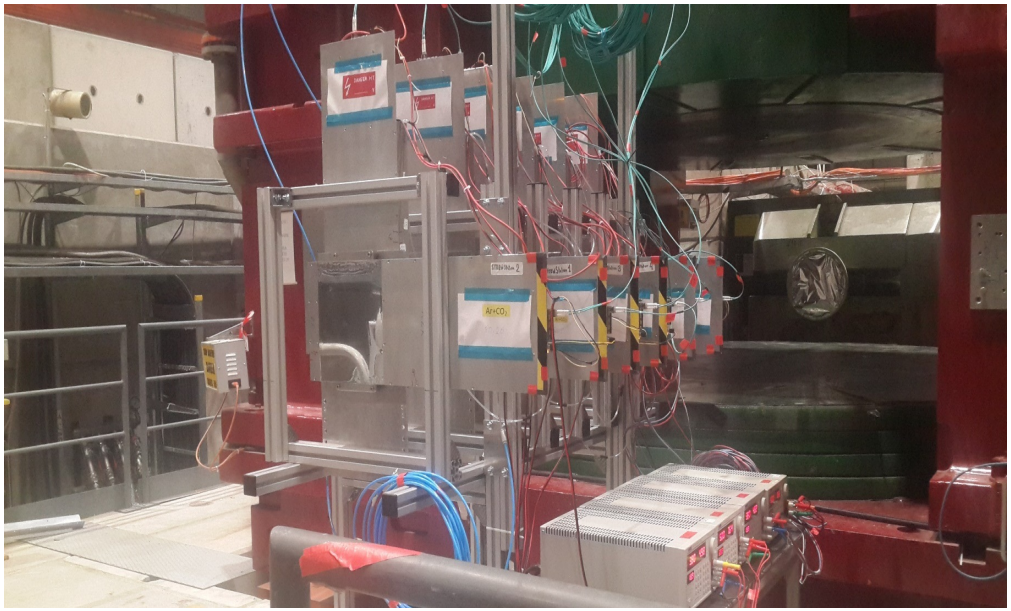
Manufacturing of 7 double layer 6mm straw chambers with a size 1200x600 мм^2 and equip them by electronics (responsibility of SRI NP BSU, Belarus)

JINR responsibility and participation

- Manufacturing, operation and support of the straw tube drift chambers for the spectrometer tracker.
- Development software for the effective track reconstruction
- Participation in the data analysis
- Study of the possibility to use 2 mm Straw for the double-track separation







Run 2018 NA64 experimental zone: 6 stations (XXYY) of 6mm straw tube detectors

Straw tube detector

ISSN 1063-7796, Physics of Particles and Nuclei, 2015, Vol. 46, No. 1, pp. 94–122. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © V.D. Peshekhonov, 2015, published in Fizika Elementarnykh Chastits i Atomnogo Yadra, 2015, Vol. 46, No. 1.

Coordinate Detectors Based on Thin-Wall Drift Tubes

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Abstract—Design features and basic parameters of the detectors based on straw trackers are reviewed using the example of the studies and development of trackers in a number of operating and proposed accelerator experimental facilities. The results of methodological studies aimed at qualitatively improving the spatial/time resolution and high rate capability of the detector and enhancing the performance capabilities of such detectors used for particle detection in a high multiplicity environment (and in high-luminosity experiments) are presented.

DOI: 10.1134/S1063779615010062

Письма в ЭЧАЯ. 2019. Т. 16, № 6(225). С. 627–642

МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

СТРОУ-КАМЕРЫ ДЛЯ ЭКСПЕРИМЕНТА NA64

В. Ю. Волков [а], *П. В. Волков* [б], *Т. Л. Еник* [б], *Г. Д. Кекелидзе* [б, 1], *В. А. Крамаренко* [б], *В. М. Лысан* [б], *Д. В. Пешехонов* [б], *А. А. Солин* [в], *А. В. Солин* [в]

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Целью настоящей работы является описание характеристик и свойств созданных в ОИЯИ по технологии склеенных строу-трубок трековых детекторов для эксперимента NA64 на выведенном пучке электронов SPS (ЦЕРН), физической задачей которого является поиск проявлений темного сектора и темной материи.

The aim of this work is to describe the properties of tracking detectors created at JINR on the technology of glued straw tubes for the experiment NA64 on the extracted electron beam of the CERN SPS. The physical task of the experiment is to search the phenomenon of the dark sector and dark matter.

PACS: 07.07.Df

Required resources

Expenditure items	Full cost	1st year	2nd year	3rd year…
Direct expenses for the Project				
6. Materials	145k$	45	45	10
	common funds	15	15	15
7. Equipment	95k$	45	30	30
8. Construction/repair of premises	k$			
9. Payments for agreement-based research	k$			
10. Travel allowance, including:	120k$			
a) non-rouble zone countries		40	40	40
b) rouble zone countries				
c) protocol-based				
Total direct expenses	360	145	130	85
* including Belarus contribution	105*	50*	45*	10*

Summary (51st PAC)

- JINR team successfully fulfilled obligations on the straw tube detectors, participated in development of the on-line monitoring and analysis software, as well as in the development and support of DAQ and electronics.
- Contributed to the data analysis and plans to expand the participation
- JINR team ready to fulfil new obligation on the manufacturing of the 7 new straw tube double planes.
- New participants attracted (SRI NP BSU)

- SPSC approved data taking with electron beam on the period 2021-2024, new NA64 experimental area is in preparation (CERN investment 400к SFr);
- SPSC approved 30 days pilot run with the muon beam (preliminary) at the beginner of 2022, the proposal of the experiment with a muon beam is under consideration.

Preparation of the new (permanent) zone at H4 is in progress

Joint session recommendations

NA64. The NA64 experiment is a fixed-target experiment at the CERN SPS specially designed for a direct search for the dark photon decay process A' → invisible. The JINR group is responsible for the design, production, tests and installation of 14 straw tube chambers, together with their data acquisition software, raw data decoding, online monitoring and visualization, reconstruction and Monte-Carlo simulation. The members of the group participated in the data taking runs and took care of the operation of the straw tube detector. Excellent progress has been made by the team in the process leading to the installation and final preparation for the data taking stage. However, it would be most encouraging to see a plan put forward for potential student participation leading to PhD theses. It would also be encouraging to see the JINR team playing a leading role in physics analyses. Furthermore, the relative number of FTE (4.7 for the team of 13) should be higher for a visible and more efficient impact.

51th session recommendation

The PAC took note of the report on the NA64 experiment at the SPS CERN, presented by D. Peshekhonov. The PAC notes the relevance of the research programme and its potential in the quest for dark matter. The PAC recognizes the excellent role played by the JINR team in the design, production, test and installation of the straw tube chambers, together with their data acquisition software, online monitoring and visualization,

reconstruction and Monte-Carlo simulation. The PAC also notes that the recommendations made by the PAC for Particle Physics and the PAC for Nuclear Physics at their joint session in January 2019, to improve the ratio of FTE to participants, to attract students and to get involved in data analysis are not properly addressed in the presented material.

Recommendation. The PAC decides to postpone any recommendation on the project till the authors present to the PAC, not later than at the next session in January 2020, a revised proposal including an action plan where the previous recommendations mentioned above are addressed. Till then, if needed, the PAC recommends that the JINR management provide sufficient resources to the group to allow continuation of their work and commitments.

FTE & number of participants

Detector

G.Kekelidze (0,4 – detector expert), V.Kramarenko (**0,4 – ½** position, detector expert), V.Lysan (**0,8** – detector expert), A.Savenkov (0,3 - technition), I.Zhukov (**0,8**- technition), T.Enik (0,2 – detector expert), V.Burtsev (0,5 – electronics expert), *E.Martovitsky (0,5 – detector & electronics)*

Theory

V.A.Matveev (0,1) and N.V.Krasnikov (**0,5** – ½ position 100%)

Analysis and MC simulation

P.Volkov (**0,5 – ½ position 100%**), D.Peshekhonov (0,3) *E.Mosolova **(0,5 – ½ position 100%)**, E.Kasianova **(1,0 - 100%)**, R.Akhunzianov (0,5)*

Management and support

V.A.Matveev is the JINR team leader

N.Krasnikov - responsibility on the theory in the NA64 Collaboration Board (CB)

D.Peshekhonov responsibility on the ST in the NA64 CB and JINR team co-leader

V.Frolov (0,2) NA64 experiment DAQ expert

In total: FTE – 7,5 persons – 16 (14)

2017: FTE – 4,7 persons - 13

Young researchres

E.Mosolova – is a MS student (StP univ.) - analysis,
E.Kasianova - just graduated from the university, potential PhD student - analysis,
R.Akhundzianov - qualified young researcher (COMPASS), potential PhD student - analysis,
E.Matrovitsky – young researcher, potential PhD student - electronics & detectors,
V.Burtsev – young researcher, potential PhD student – electronics,
P.Volkov – young researcher (½ MSU), analysis,
A.Solin – young researcher, JINR collaborant from Belarus State University, electronics

6 (+1) young researches, 4 new,
3 of them join to the analysis,
almost all are potential PhD students.

S.Gertsenberger is going to join analysis team (currently participates in HyperNIS project)

Conferences and team publicaions

International conference reports: **NEC2019 "Electronics options for the straw tracker"**
52th PAC poster session
Publications: **"Straw chambers for the NA-64 experiment", PEPAN Letters**

Summary

1. FTE and number of participants ratio

FTE/number_of_participants_ratio were improved. Initially it was **4,7/13** while now we came to **7,5/16(14).**

2. **Young researchers attracting & potential PhD students involvement**

- **Four new** young researches were attracted, now team has **6** (+ one more collaborator from BSU).
- All are potential PhD students (data analysis, electronic & detector development).
- Current contribution of the young researchers is **3,5** FTE.
- We plan to expand participation in MC simulation and physical analysis.

3. **Participation in physics analysis**

- We contributed to the 2018 data analysis.
- We join
  - work on the MC simulation for the upgrade and modernization of NA64 setup (visible and invisible modes)
  - simulation of the new setup for operation with the muon beam

- We plan to participate in the analysis of the new data

4. **Detector**

- Ready to fulfill obligation on the new 6mm straw tube duble planes
- Work on the 2mm straw tube planes as an option for the precise tracker

JINR participation in the NA64 project
«Search for dark sectors in missing energy events»

G.Kekelidze, *V.Kramarenko,* V.Lysan, A.Savenkov, I.Zhukov, T.Enik, V.Burtsev, E.Martovitsky, V.A.Matveev, *N.V.Krasnikov, P.Volkov*, D.Peshekhonov, E.Mosolova, E.Kasianova, R.Akhunzianov, V.Frolov

Thank you