ON A SEARCH FOR NEW LIGHT CHARGED PARTICLES IN PHOTOPRODUCTION

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1. Motivation
2. Limitations from the muon a.m.m.
3. Earlier attempts
4. A new experiment – status and hopes

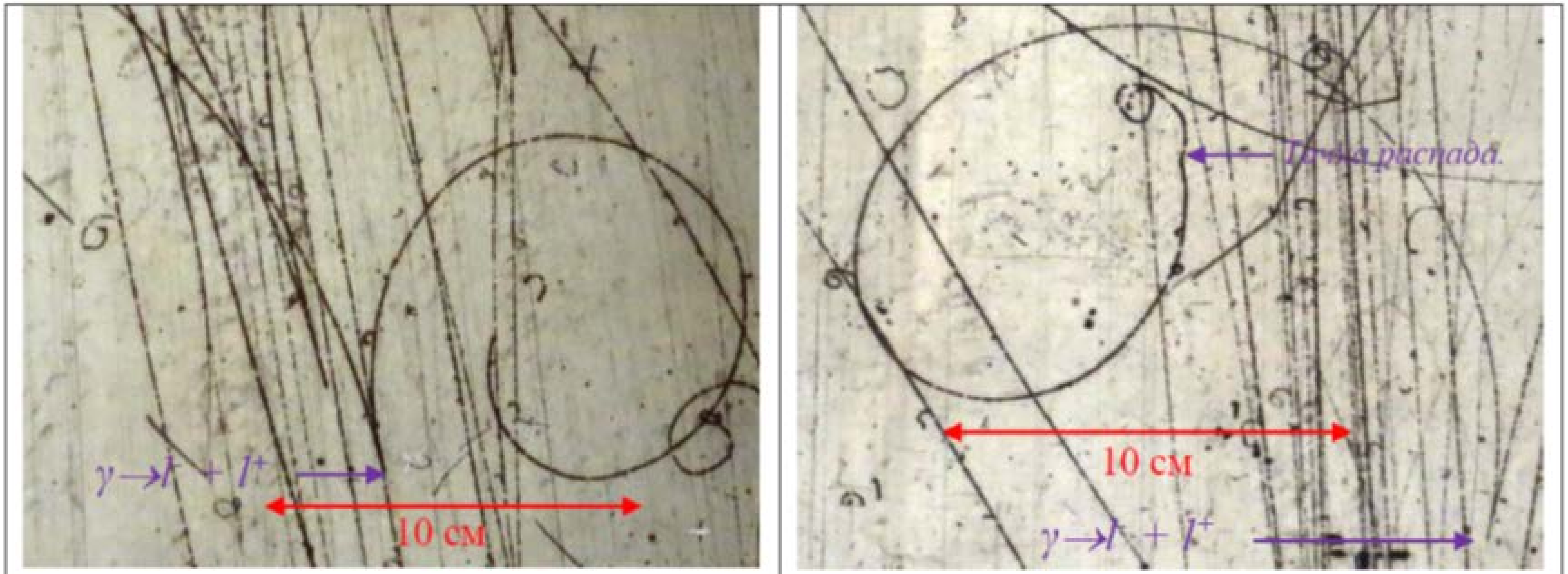
1. Motivation

Sensational data from the 2m propane bubble chamber of JINR LHE
irradiated by 10-GeV protons:

9 tracks of charged particles ($\ell^+\ell^-$) with the mass of ~ 9 MeV are found on about 7000 investigated stereo photos

(first announced by V.A. Nikitin. May 2017).

Presumably these $\ell^+\ell^-$ are formed in the matter by photons from π^0 decays.



Positive lepton | Negative lepton, decays with emitting electron

Mass of the particle is found through curvature of the trajectory and range

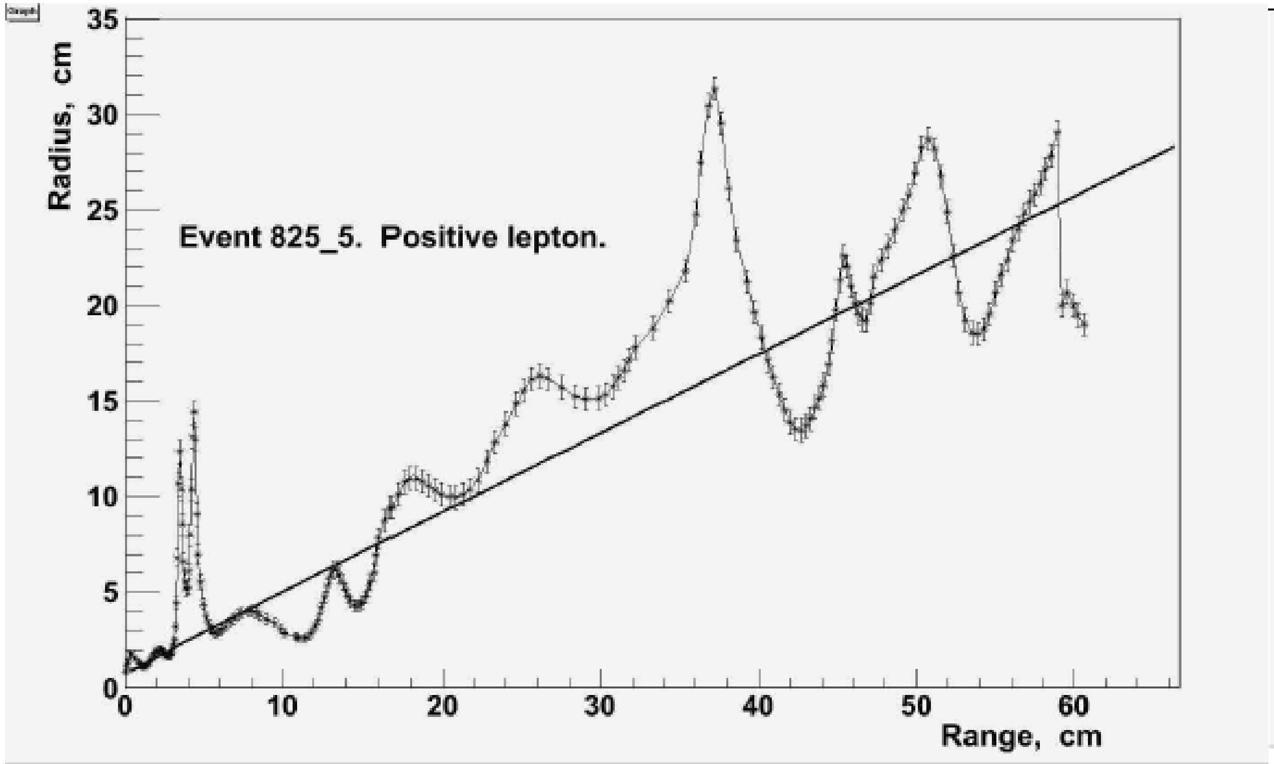
At every point of the trajectory in magnetic field

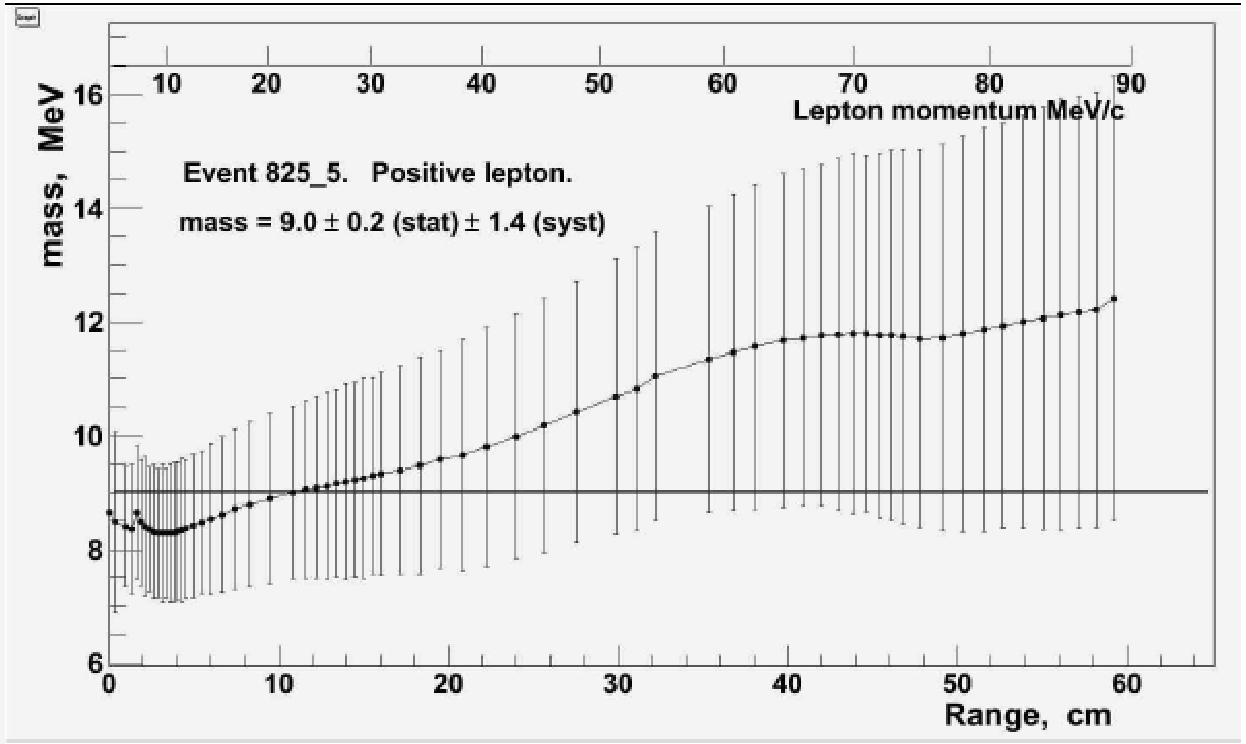
$p = (e/c)\ B\ R$

$p^2 = E^2 - M^2 \quad \rightarrow \qquad dp/dx = (1/\beta)\ \ dE/dx$

Mass $\quad M = p\ /\ (\beta\gamma)$

The energy is found instead through the range $\qquad l(E_k, m) = c1 \dfrac{E_k^2}{E_k^{c2} + m}$



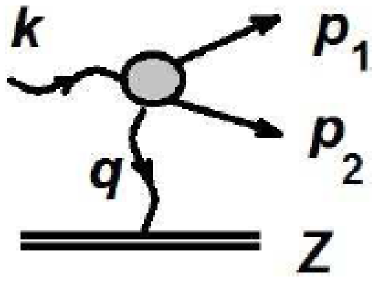


Quantum numbers of the "anomalous lepton"

Decays are seen $\ell \to e + ?$ i.e. $\ell \to e + \nu$ or $\ell \to e + \gamma$

Simplest possibilities:
- spin = 0
- spin = ½
- spin = 1

Due to their electric charge pairs of such particles can be produced by photons on nuclei through Bethe-Heitler mechanism

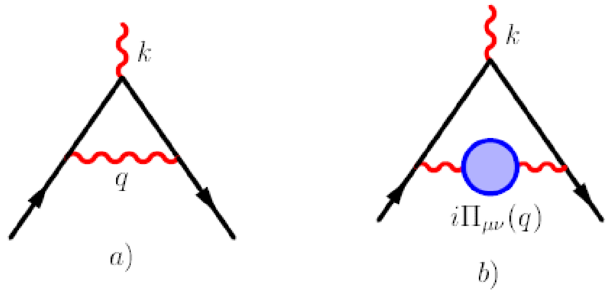


2. Standard model and limitations from the muon a.m.m.

Almost no space in SM for additional particles!

PDG-2018

$$a = \frac{g-2}{2} = a^{\text{QED}} + a^{\text{EW}} + a^{\text{hadr}}$$



$$a^{\text{exp}} = \left(\frac{g-2}{2}\right)^{\text{exp}} = 0.001\ 165\ 920\ 91\ (54_{\text{stat}})\ (33_{\text{sys}})$$

$$a^{\text{SM}} = \left(\frac{g-2}{2}\right)^{\text{SM}} = 0.001\ 165\ 918\ 23\ (1_{\text{weak}})\ (34_{\text{LO hadr}})\ (26_{\text{NLO hadr}})$$

$$a^{\text{QED}} = \left(\frac{\alpha}{2\pi}\right) + 0.765857425(17)\left(\frac{\alpha}{\pi}\right)^2 + 24.05050996(32)\left(\frac{\alpha}{\pi}\right)^3 + 130.8796(63)\left(\frac{\alpha}{\pi}\right)^4 + 753.3(1.0)\left(\frac{\alpha}{\pi}\right)^5 + \ldots = 0.001\ 165\ 847\ 19$$

$$a^{\text{hadr}}[\text{LO}] = 0.000\ 000\ 069\ 31(34)$$ $\leftarrow$ **Here might be anomalous leptons**

$$\Delta a = a^{\text{exp}} - a^{\text{SM}} = (2.68 \pm 0.63_{\text{exp}} \pm 0.43_{\text{th}}) \times 10^{-9}$$

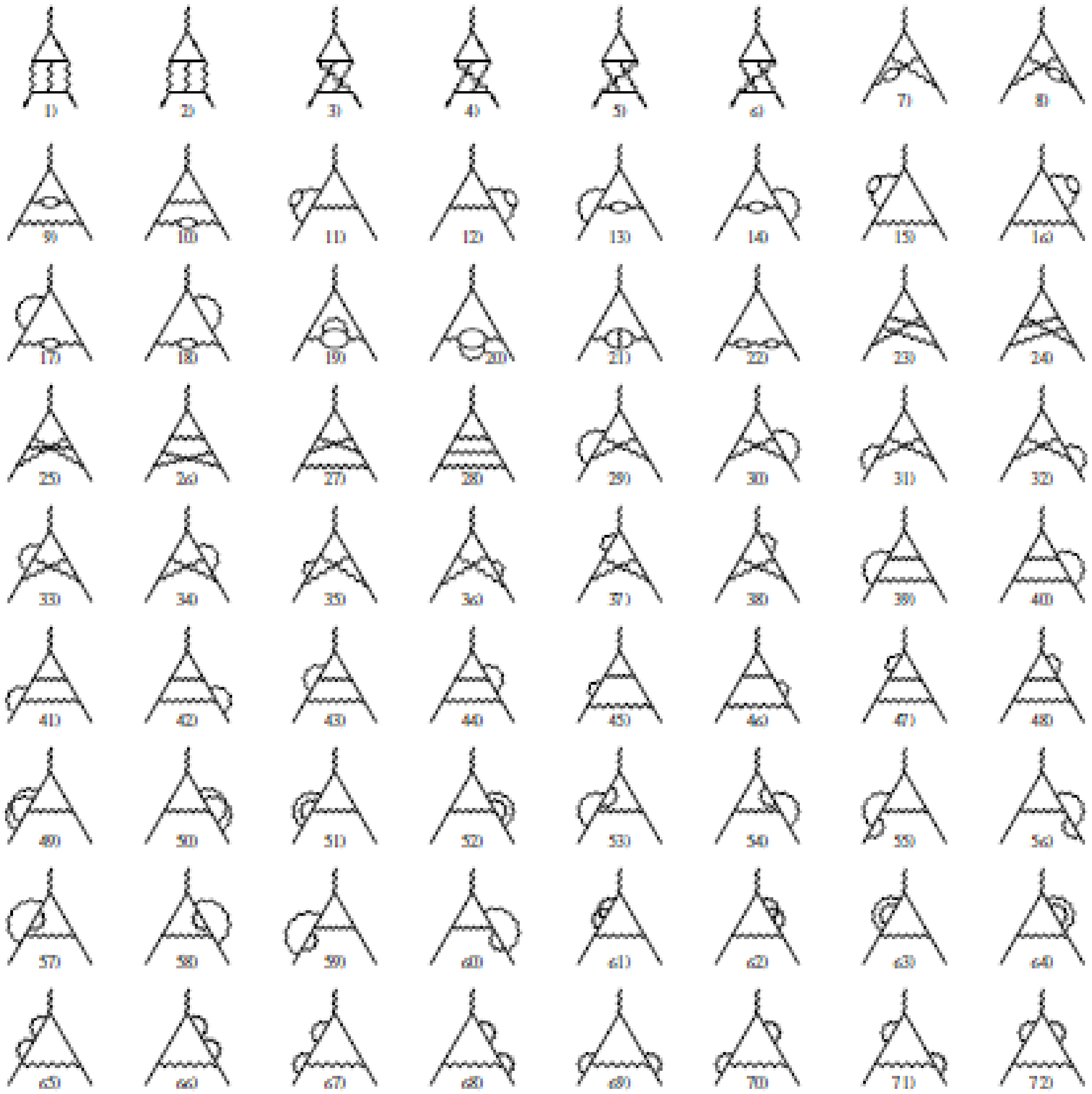
Complexity of the calculation:
Kinoshita group (borrowed from A. Nyffeler)

Pure QED (for electron)
1-loop 1 diagram
2-loop 7 diagrams
3-loop 72 diagrams
4-loop 891 diagrams
5-loop 12672 diagrams

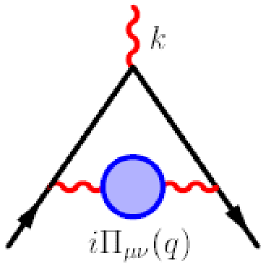
Electroweak
1-loop 3 diagrams
2-loop 1678 diagrams

Hadrons

Light-by-light scattering



2a. Contribution of anomalous leptons to a.m.m. ("hadron")



$$\Pi_{\mu\nu} = (q_\mu q_\nu - q^2 g_{\mu\nu})\Pi(q^2)$$

$$\text{a.m.m.} = \int \frac{d^4 q}{(2\pi)^4} \frac{q^2 \Pi}{q^2 \ q^2} \, (\Gamma S \Gamma S \Gamma)$$

Unsubtracted dispersion relation is usually applied:

$$\text{If } \Pi(t)/t \to 0 \text{ at } t \to \infty \qquad \frac{\Pi(q^2)}{q^2} = \frac{1}{\pi} \int \frac{\operatorname{Im}\Pi(t)}{t} \frac{dt}{t - q^2 - i0}$$

Then

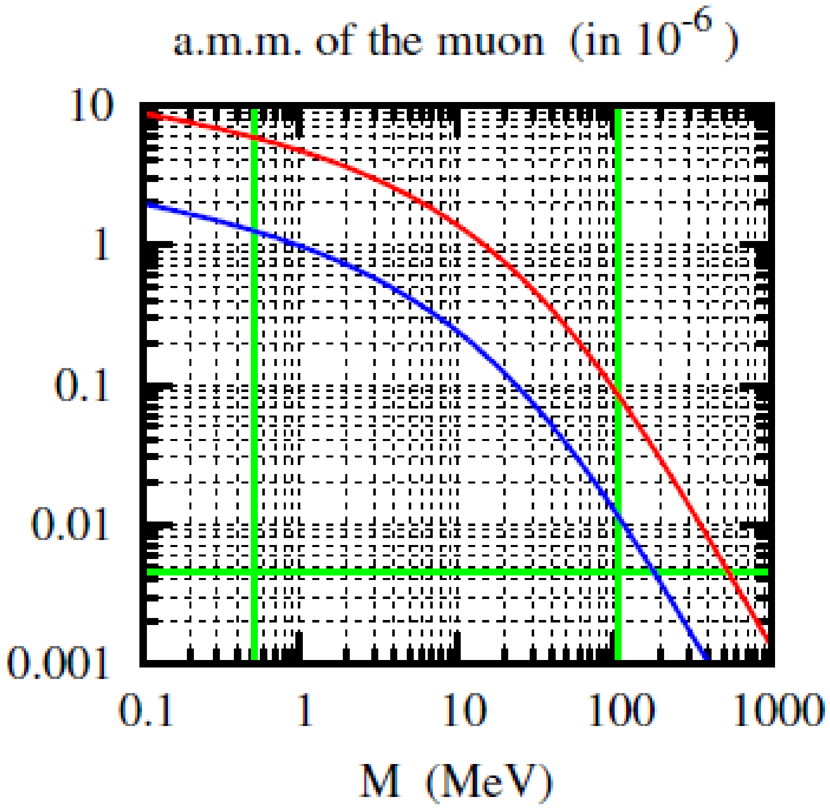
$$\text{a.m.m.} = \frac{1}{\pi} \int \frac{\operatorname{Im}\Pi(t)}{t} K(t)\, dt \qquad K(t) = \frac{\alpha}{\pi} \int_0^1 \frac{x^2(1-x)\, dx}{x^2 + (t/m_\mu^2)(1-x)}$$

Polarisation operator and comtributions to a.m.m.

$$\text{spin } 0: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{12}\Big(1 - \frac{4M^2}{t}\Big)^{3/2}$$

$$\text{spin } 1/2: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{3}\Big(1 - \frac{4M^2}{t}\Big)^{1/2}\Big(1 + \frac{2M^2}{t}\Big)$$

$$\text{spin } 1: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{12}\Big(1 - \frac{4M^2}{t}\Big)^{3/2}\Big(3 + \frac{t}{M^2}\Big)$$



Blue = spin 0
Red = spin ½

Available space from (SM – Exp) = 4.2×10^{-9} (2σ)
Therefore limits:

Spin 0 M > 190 MeV
Spin ½ M > 550 MeV
(update of Dedenko, Domogatsky, Zheleznykh, Petrunkin. 1973)

Special case spin 1.

Integral is divergent, so the contribution to a.m.m. depends on high momenta where the used vertices and interactions (actually it was the Proca theory) may not work for evaluation of the polarization operator…

???? Further analysis is needed.

Preliminary conclusion is that “anomalous leptons” of the mass of order 9 MeV might be vector particles. At least this possibility seems to be not fully excluded by information on the muon a.m.m.

3. An early experiment on photoproduction of “anomalous leptons”

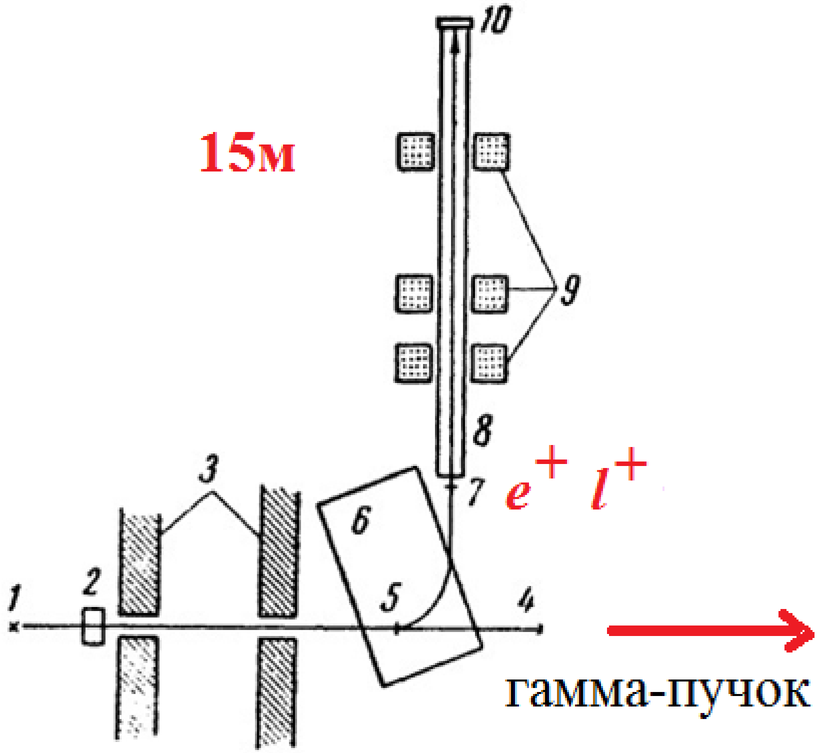
Журнал экспериментальной и теоретической физики

Т. 37 *1959* *Вып. 6(12)*

ПОИСКИ ЧАСТИЦ С МАССАМИ ОТ 6 ДО 25 ЭЛЕКТРОННЫХ МАСС

А. С. Белоусов, С. В. Русаков, Е. И. Тамм, П. А. Черенков

Описываются эксперименты, поставленные с целью выяснить, генерируются ли γ-квантами частицы с массами M от 6 до 25 электронных масс с сечениями, следующими из электромагнитной теории образования пар. Для этой цели, с помощью быстрых схем совпадений, измерялось время пролета частицами с заданным импульсом расстояния между двумя сцинтилляционными счетчиками. Частицы генерировались в свинцовой мишени, помещенной в пучок тормозного излучения синхротрона. Сравнивались рассчитанные теоретически и полученные экспериментально скорости счета совпадений для параметров установки, отвечающих регистрации частиц с ожидаемой массой. В каждой серии опытов измерялось также отношение скорости счета электронов к скорости счета фона. Полученные результаты показывают, что под действием γ-квантов частицы с единичным зарядом, спином $^1/_2$ и массами от 6 до 25 m_e не образуются с сечениями, следующими из электромагнитной теории.



Геометрия опыта: *1* — мишень синхротрона, *2* — мониторная камера, *3* — свинцовые коллиматоры, *4* — направление пучка тормозного излучения, *5* — свинцовая мишень, *6* — магнит, *7* — сцинтилляционный счетчик, *8*—вакуумная труба, *9* — фокусирующие линзы, *10* — сцинтилляционный счетчик

From V.A. Nikitin's talk-2017: parameters of found anomalous tracks

mass MeV	range, cm	range g/cm2	momentum MeV/c	charge	
11,4	20	10	35	-	
9,2	44	22	58	-	decay
11,4	24	12	38	+	decay
7,5	26	13	42	+	
8,9	26	13	40	+	
8,1	35	18	50	-	
7,4	25	13	45	-	
10,3	49	25	88	-	
9,0	63	32	95	+	

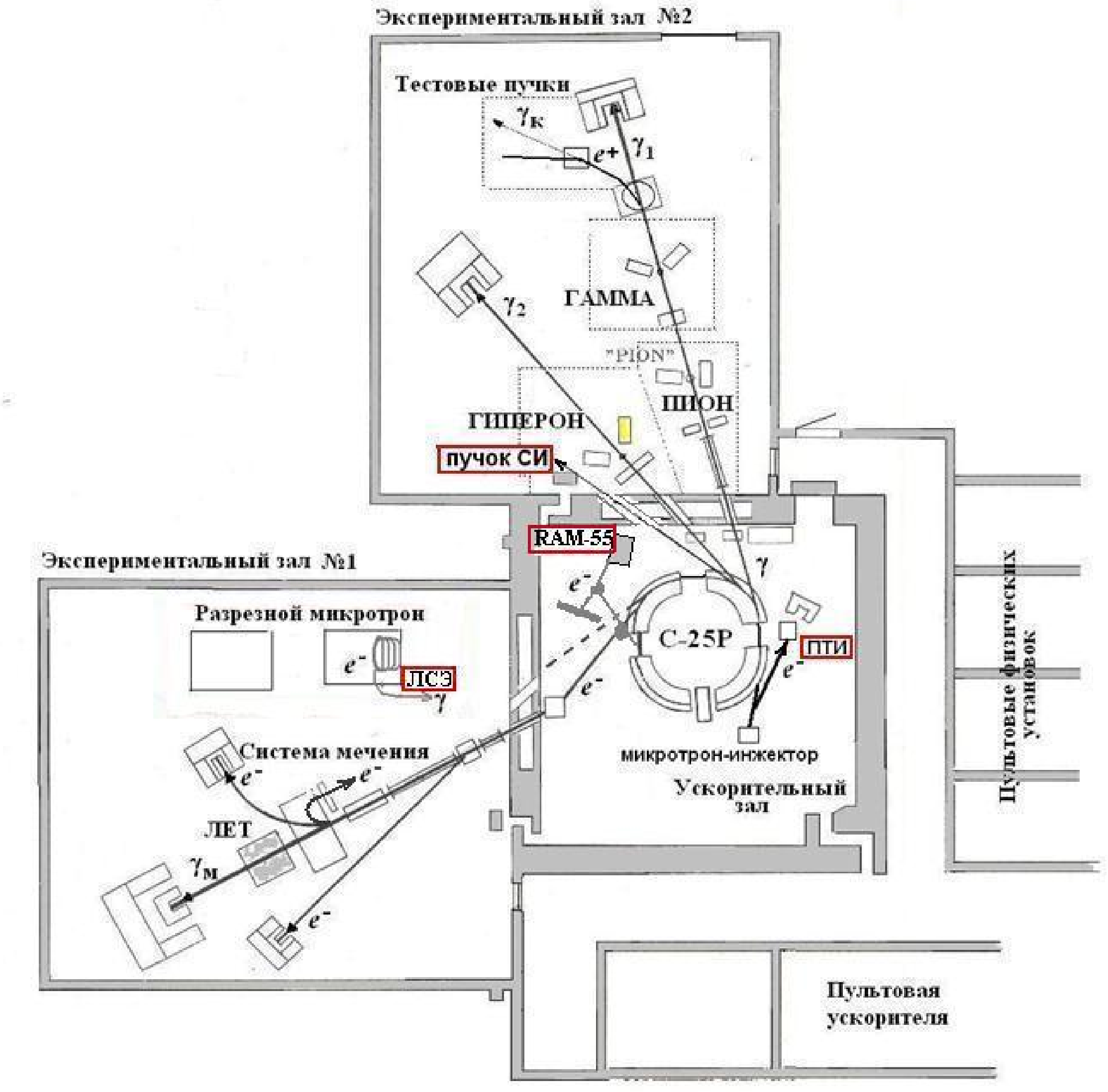
Sum of all track lengths = 312 cm and 2 decays are seen.
One may expect to have twice as much at the lepton momentum ~20 MeV/c
hence with the average length ("length of life") ~ 70 cm ($\rightarrow$ size of the set up!)

4. Present experiment:
photoproduction of lepton pairs at the bremsstrahlung photon beam

LPI electron synchrotror
C-25R in Troitsk
in the energy regime
up to 300 (500) MeV.

Identification:
TOF, magnetic field,
NaI

Aim: among paticles
with selected
Momentum identify
slower (heavier) ones.



синхротрон
γ до ~850 МэВ
e⁻ до ~650 МэВ
γ СИ (ВУФ, МР)

микротроны
e⁻ 7-11 МэВ
e⁻ 7-35 МэВ

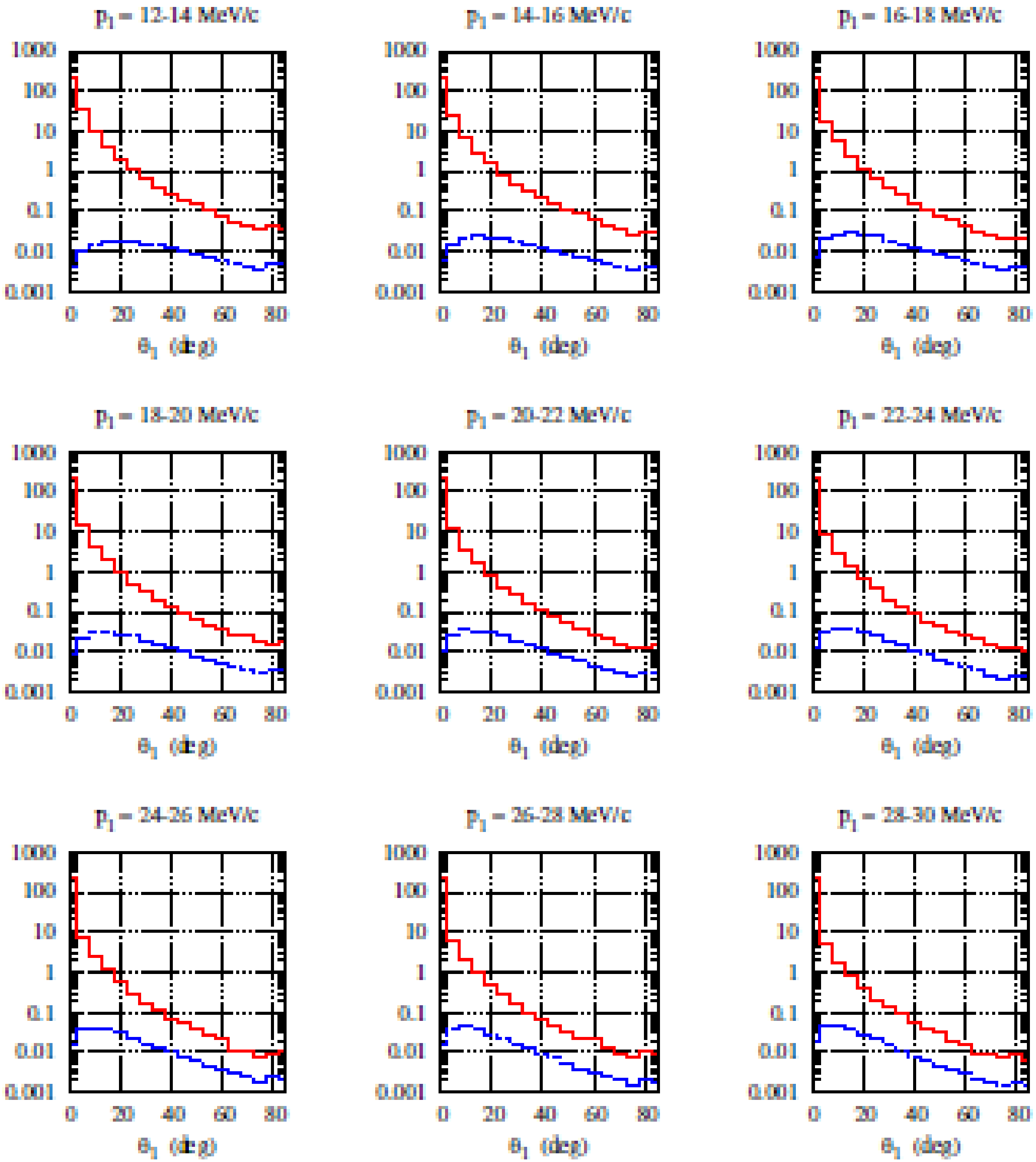
γ ЛСЭ (терагерц)

Special kinematics

1) Produced e+e- pairs are mainly emitted at forward angles, whereas heavier leptons have bigger angles.

Simulation of yields of e+e- and 9-MeV leptons (of spin ½) produced by 300 MeV bremsstrahlung photon beam (10^8 photons/sec) off 1mm copper target.
Red cures = electrons,
Blue curves = heavy leptons.

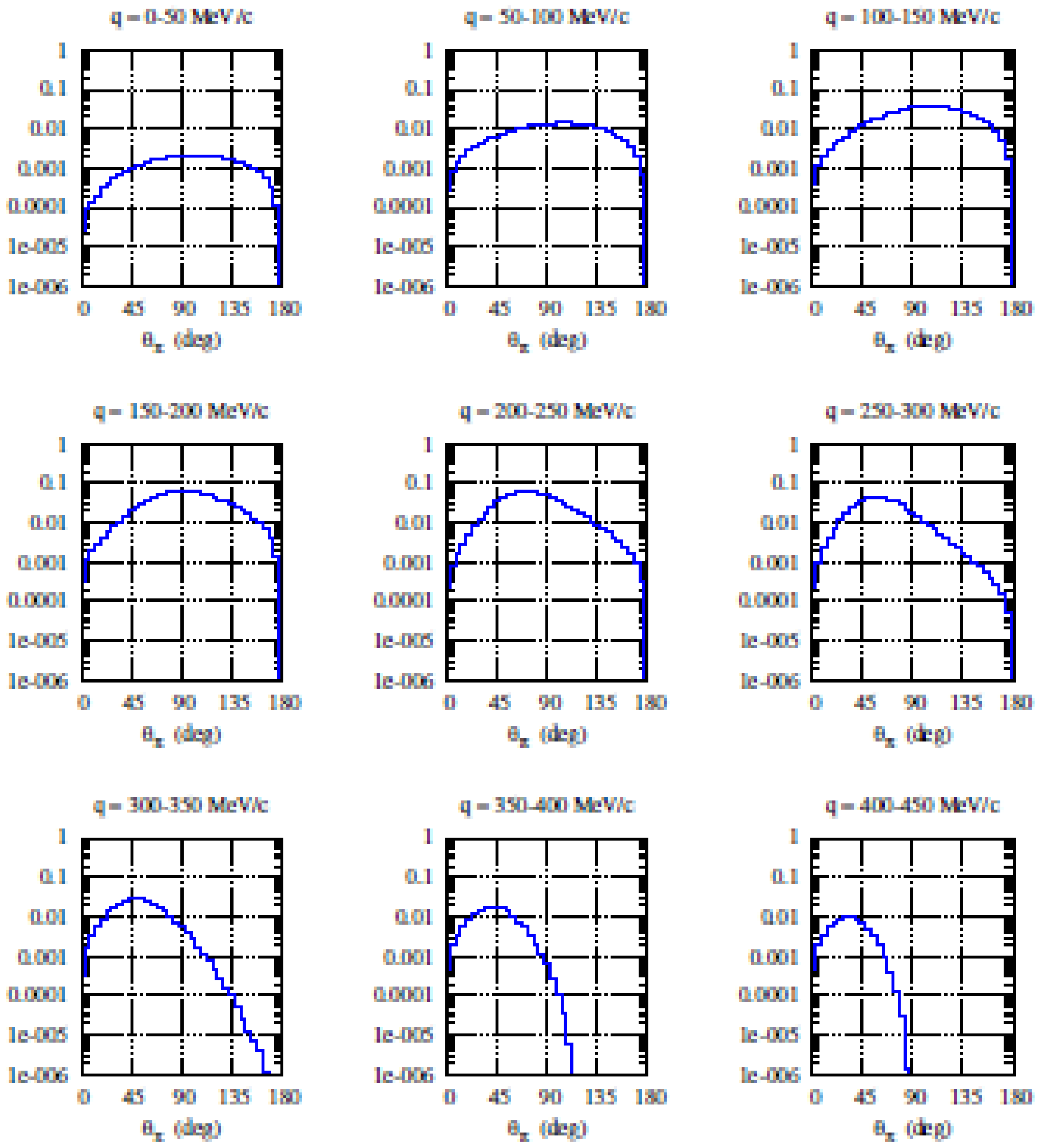
At medium angles leptons/electrons ~ 10%.



Pion background

This is background of charged
pions produced off the copper
target at angles of order 40 deg.

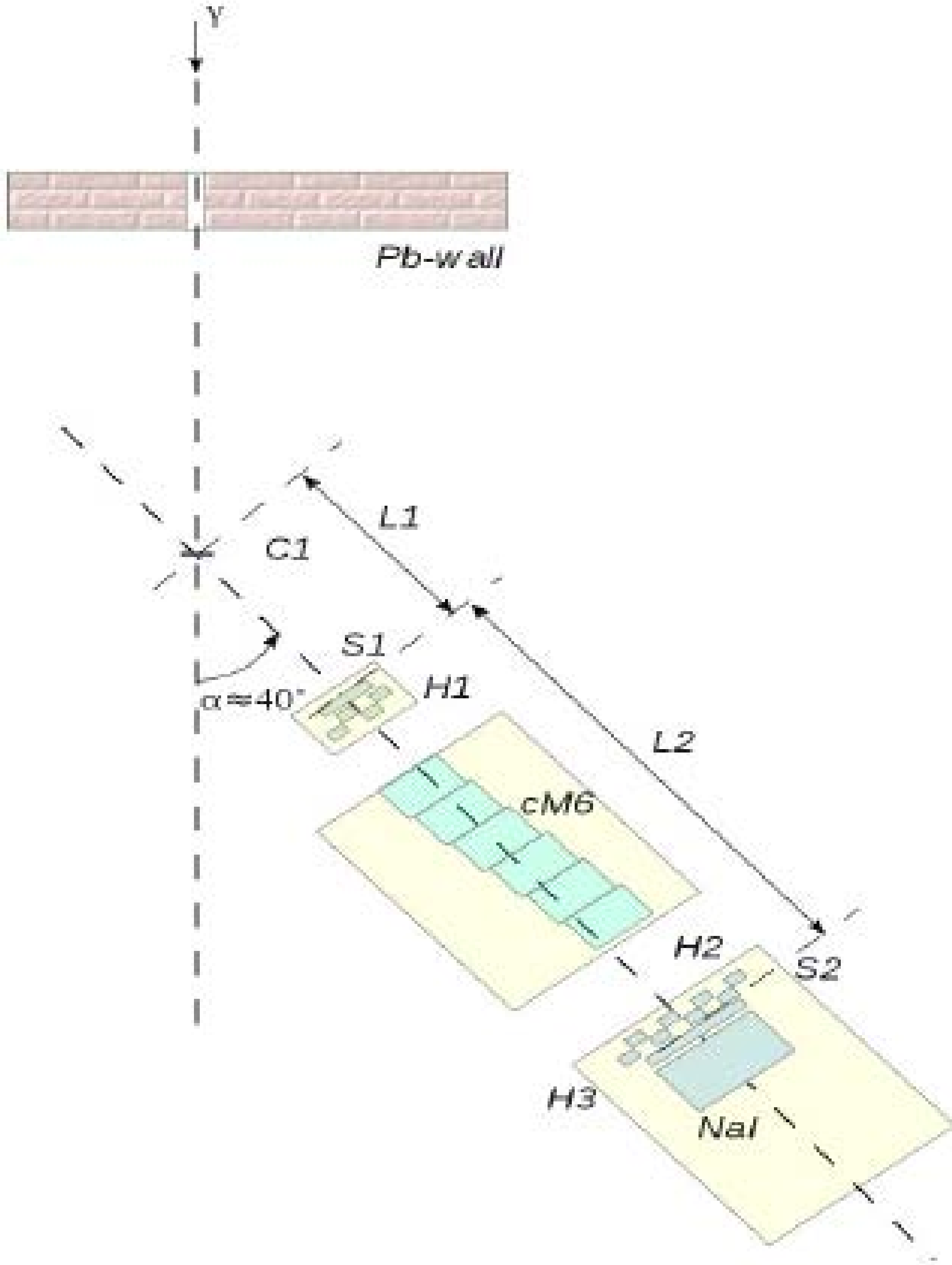
To the moment it was estimated
theoretically, In the Fermi gas model.
The simulation predicts that the fraction of
soft pions with momenta below 50 MeV/c
Is not large and the pion background
Is less than the expected yield of
heavy leptons.



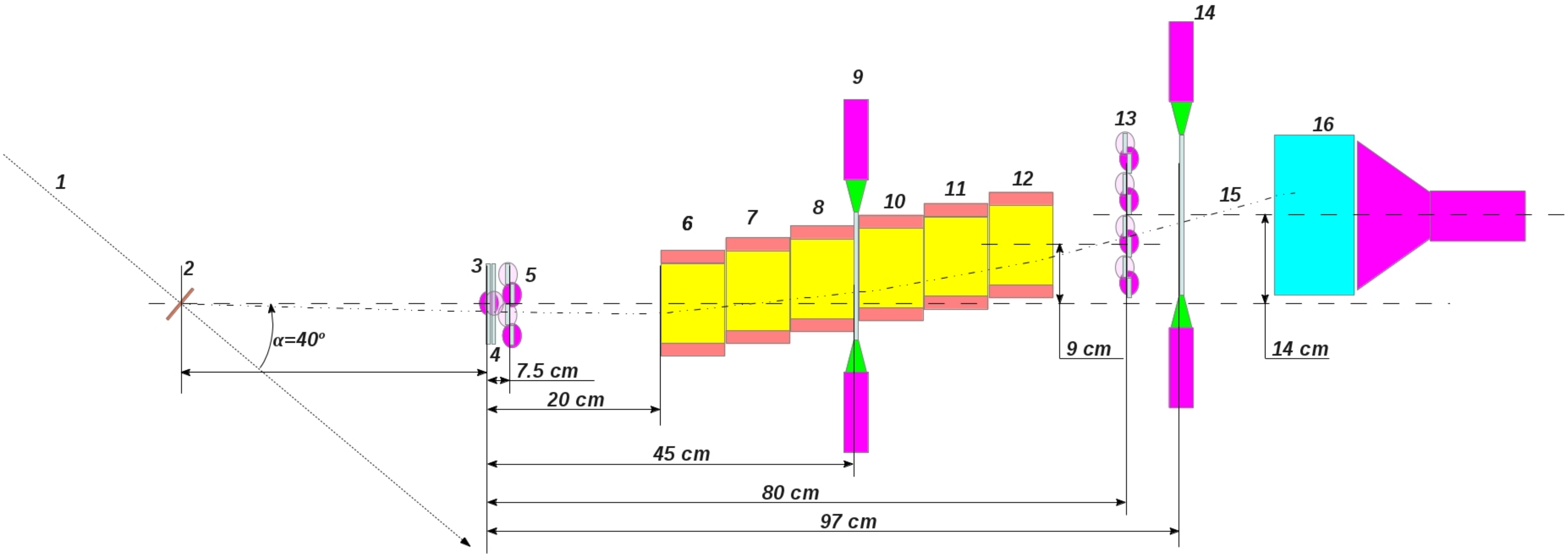
The layout of the experimental setup
(as of May 2018).
The detector arm is set at 40 deg
with respect to the photon beam.

Magnetic field of 1.6 kGs is made of
constant magnets. It is optimized to
trace positive-charge particles with the
Momenta near 20 MeV/c.
(Such a low momentum Is selected in
order to have a better TOF discrimitation
of positrons and heavier particles.

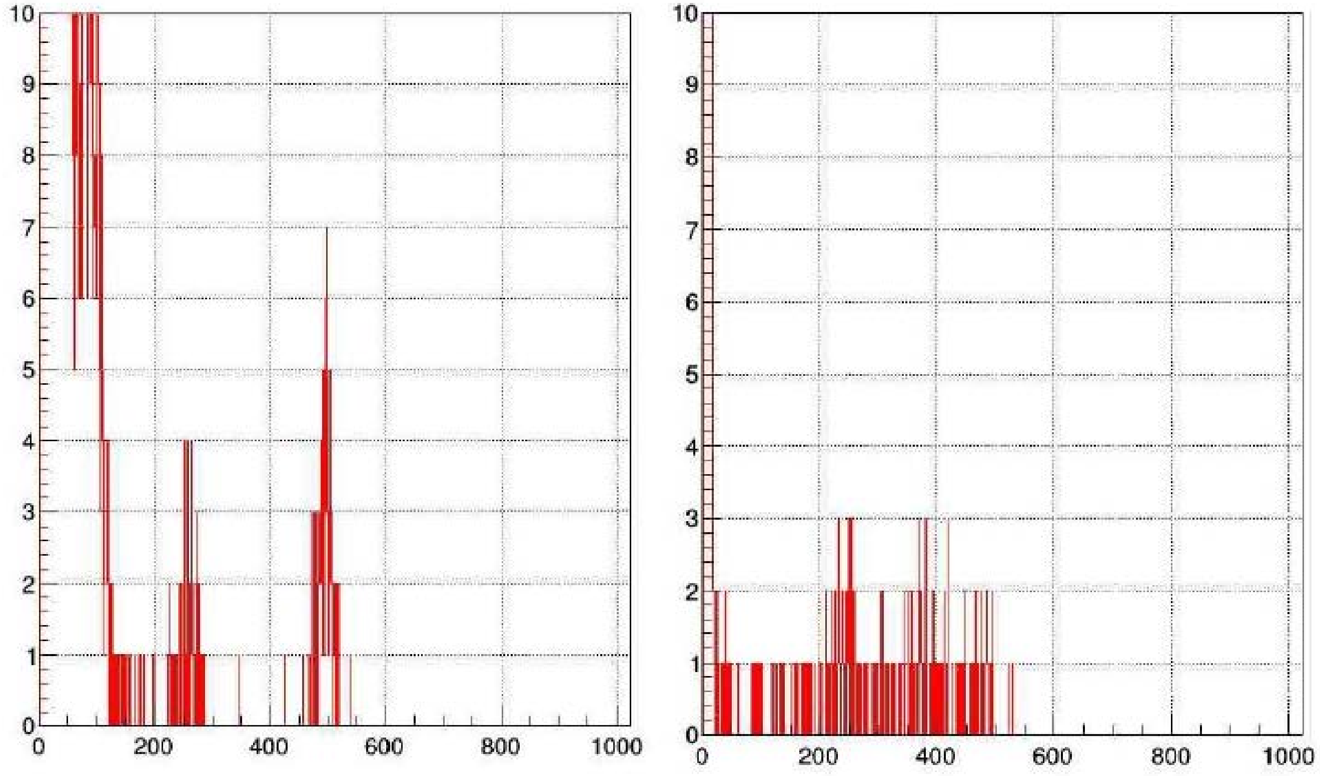
NaI of $\varnothing 20 \times 10$ cm is used to select particles
having (at the same momentum) lesser kinetic
energy.
The setup includes start-stop counters and coordinate hodoscopes.



The setup as of September 2018.
Currently test and calibration runs are carried out.

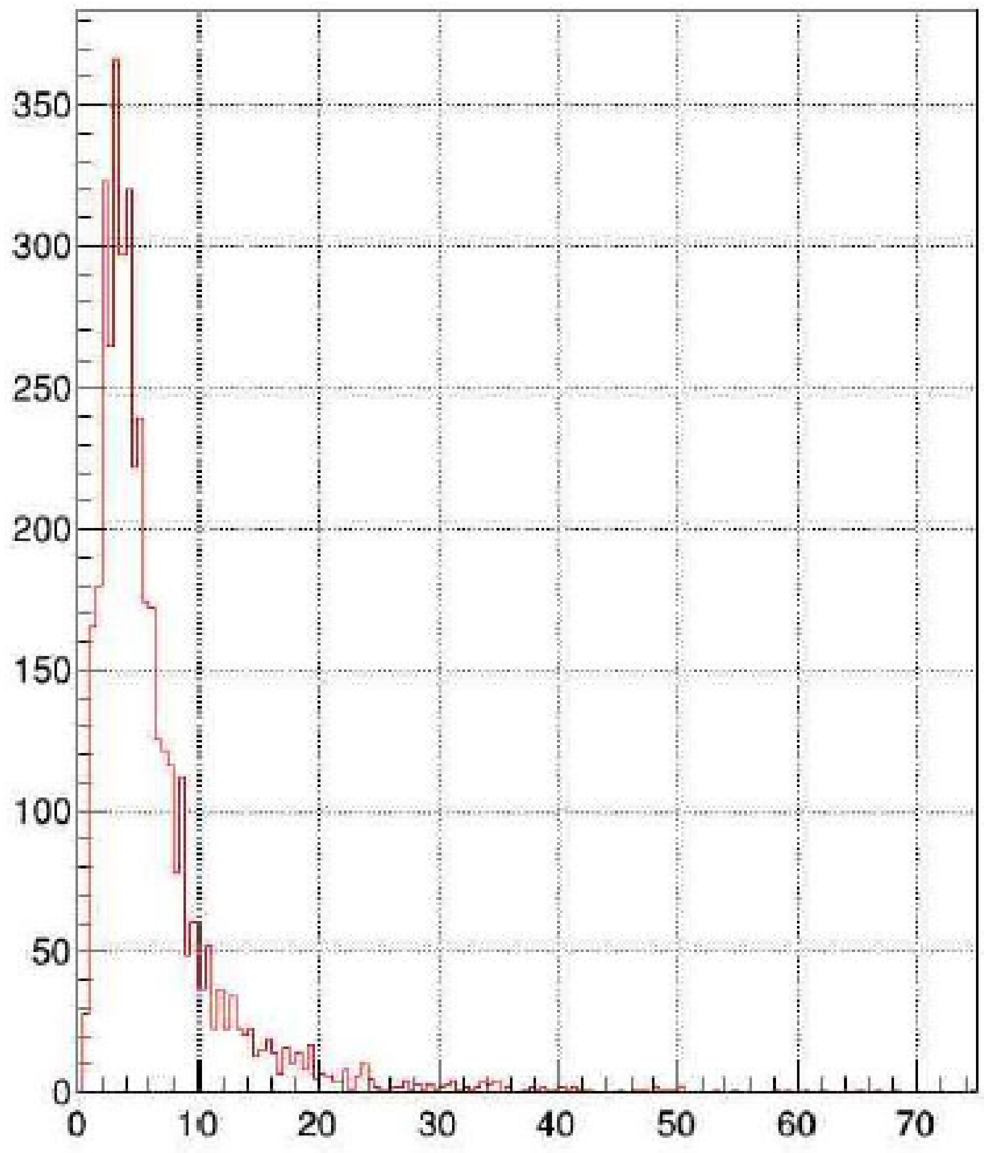


First calibrations of NaI with Co^{60} at voltage at FEU-49 1800 V and 1400 V.



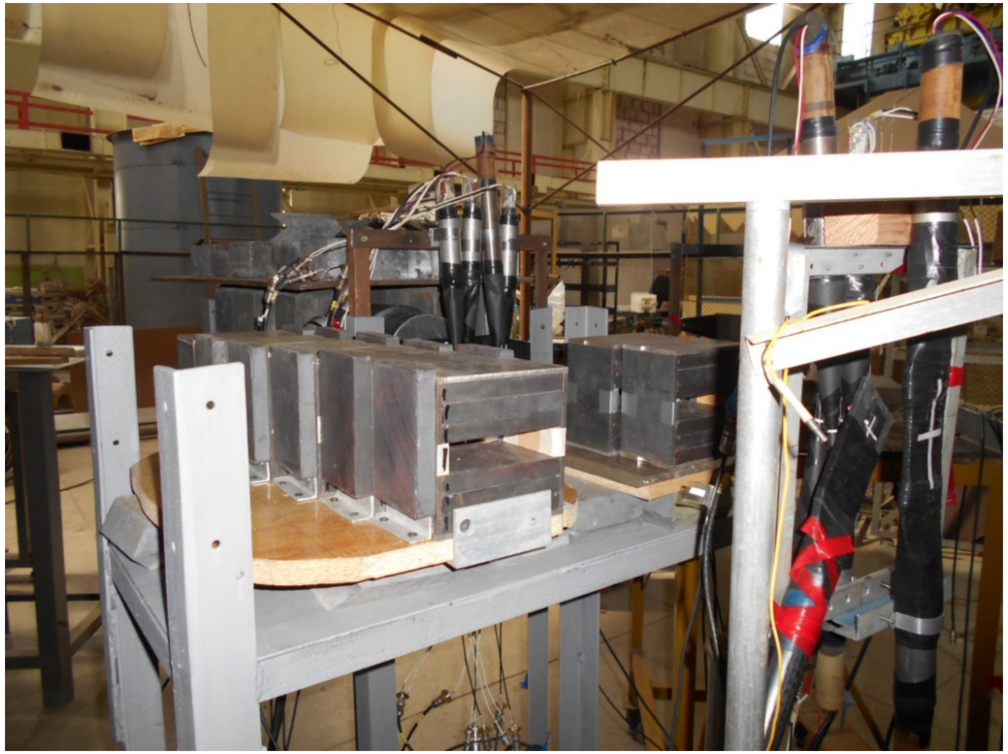
NaI counts (MeV) at 1200 V
from TOF trigger. Bin = 0.5 MeV

September 2018.



As of 4 June, 2018

The setup for searching «anomalous leptons»



Conclusion

The experiment is under way. Everything is working (including the synchrotron itself). Chances to find new physics are minimal but we hope to establish better limits for “heavy” particle photoproduction in comparison with older experiments…