G.Alexeev, JINR PAC, 18.01.2021

Theme/project "**PANDA Experiment at FAIR (JINR Participation)"**

2022-24

- **Main results of the project (2015-20):**
  - Detector description programs, development of Monte Carlo generators, contribution to physical program (Phase C)
  - Magnet (design of superconducting solenoid and its yoke, engineering documentation) -> delivered to Novosibirsk (Budker INP) for production (**the yoke is fully manufactured in 2020**)
  - PANDA Muon System (prototype, beam tests, front-end electronics)
  - Synergy of muon systems of PANDA/FAIR and SPD/NICA projects -> 90-100% (detectors, electronics, PID algorithms, calibration)
  - **Warranty of project financial support from FAIR -> 830 K € (2020)**

- **Proposal of a new project PANDA (2022-24) for main task – production of MDT detectors for Barrel part of PANDA Target Spectrometer**

Authors from JINR:

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1) Dzhelepov Laboratory of Nuclear Problems (DLNP)
2) Veksler and Baldin Laboratory of High Energy Physics (VBLHEP)
3) Bogolyubov Laboratory of Theoretical Physics (BLTP)
4) Laboratory of Information Technologies (LIT)

Total FTE = 21.7. The average age of the JINR PANDA team is 63.4 years. There are: 1 young scientist preparing PhD, 10 engineers, 18 staff members with PhD degree and 9 professors.

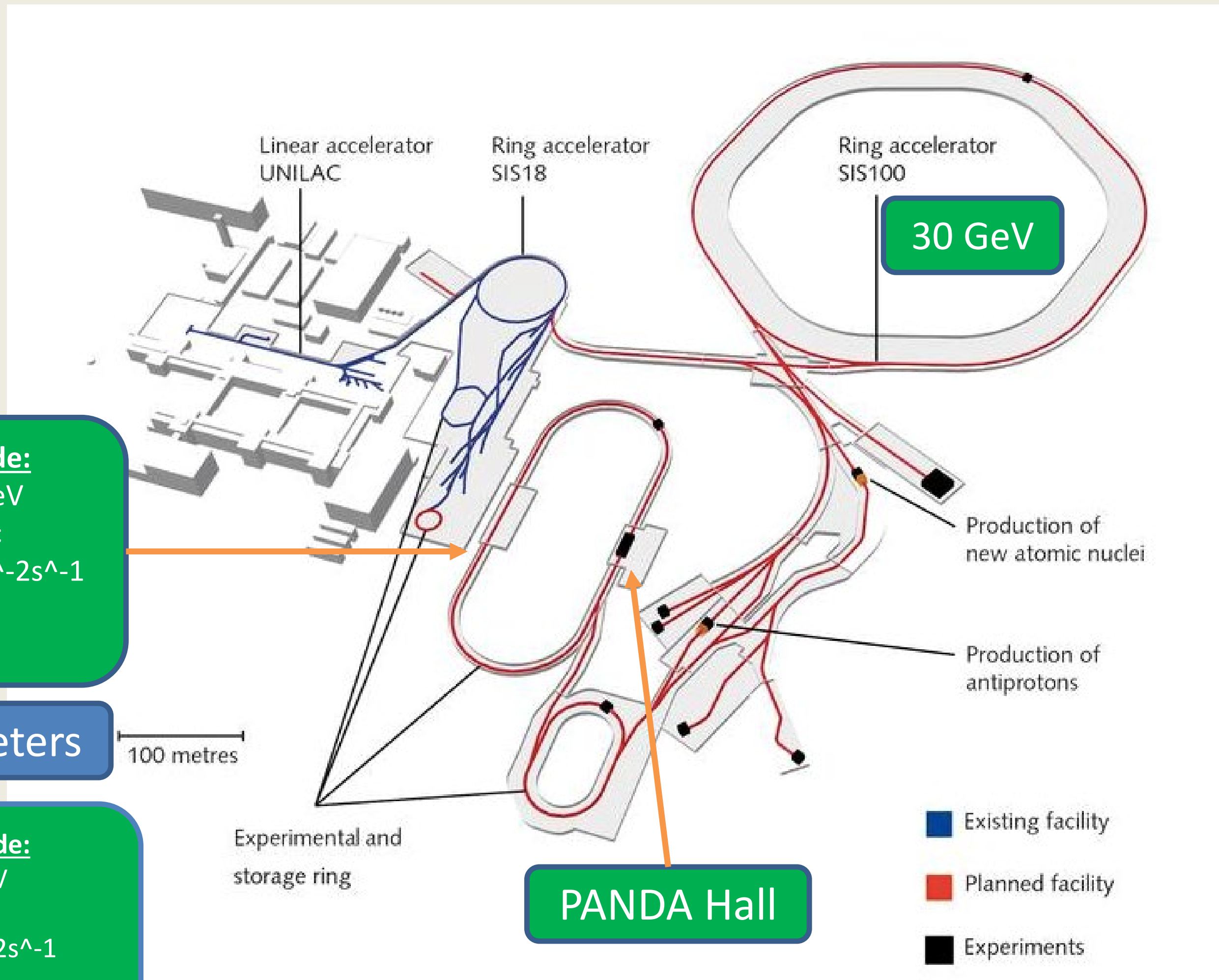
GSI & FAIR Laboratories (areal view)

FAIR Accelerator Complex

High Intensity Mode:
Ecm = (2.5 - 5.5) GeV
p = (1.5 - 15) GeV/c
Lumi: 2x10^32 cm^-2s^-1
Beam dp/p: 10^-4
10^11 antiprotons

HESR parameters

High Resolution Mode:
Ecm = (2.5 - 5.5) GeV
p = (1.5 - 15) GeV/c
Lumi: 2x10^31 cm^-2s^-1
Beam dp/p: 2x10^-5
10^10 antiprotons

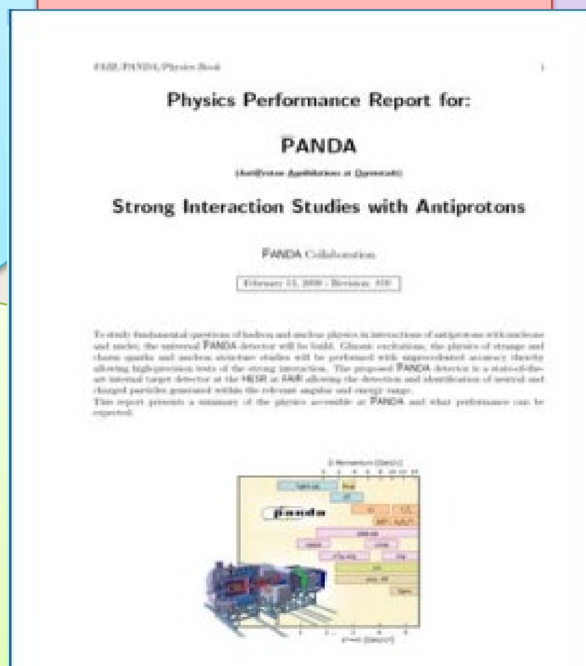


Panda physics overview

Nucleon Structure

Transition Distribution Amplitudes (TDA) (meson production)
Generalised Distribution Amplitudes (GDA) (time-like Compton, hard exclusive processes)
Time-like Electromagnetic Form Factors (Low and high E, e and μ pairs production)
Transverse Parton Distributions (Drell Yan process)

Bound states and Dynamics of strong interactions


Physics Performance Report for:

PANDA

Strong Interaction Studies with Antiprotons

PANDA Collaboration

arXiv:0903.3905v1

Hadron spectroscopy

Production of states of all quantum numbers
Resonance scanning with high resolution
Precision determination of mass, width & quantum numbers J^{PC} of resonances
Charm hadrons: charmonia, D-mesons, charm-baryons –> Understand new XYZ states, $D_s(2317)$ and others
Production of exotic QCD states:
Glueballs, hybrids, multi-quarks

Nuclear Physics

Hypernuclear physics:
Double Λ hypernuclei
γ-spectroscopy of hypernuclei
Hyperon interaction
Antihyperon in Nucleai
Hadrons in nuclei:
Charm and strangeness in the medium

Strangeness

Strange baryons:
Specroscopy
Polarisation

Staging of physics program: flagship showcases

Timeline

Conceptual compilation

2025

✓ **Phase-C:** *reduced setup, <u>proton</u> beam*

- Commissioning of detector components
- Physics in p+p: under investigation

2026

✓ **Phase-1:** *reduced setup, reduced luminosity, <u>antiproton</u> beam*

0.5 fb^{-1}

- light: Electromagnetic form factors in dilepton channel at low energies
- strange: Spin observables in hyperon production: S=1,2 systems
- charm: Exploration of charmonium(like) states; line shape studies

2027

✓ **Phase-2:** *full setup, reduced luminosity, antiproton beam*

1 fb^{-1} total MSV0-3

- light: light-meson spectroscopy: gluonic excitations
- strange: S=2,(3) baryon spectroscopy
- charm: high-spin charmonium spectroscopy

2027+

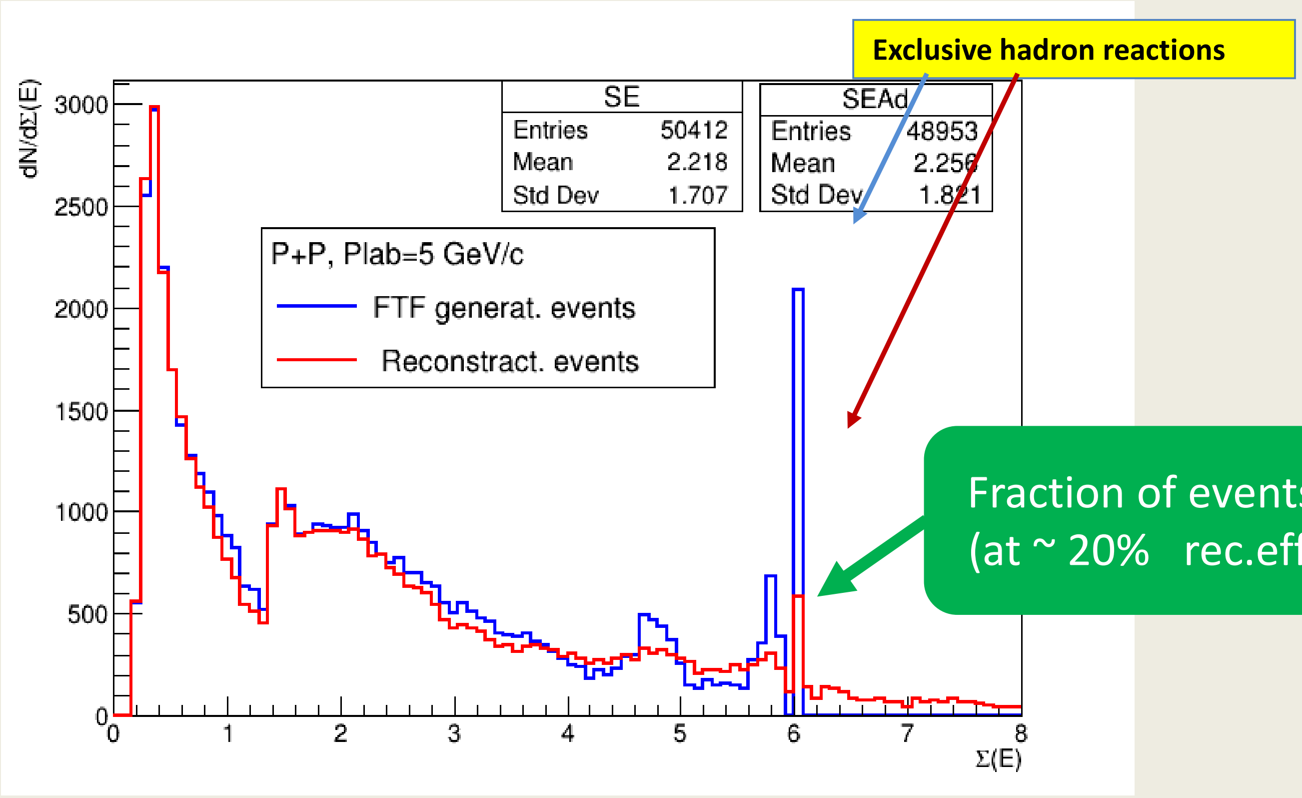
✓ **Phase-3:** *full setup, full luminosity, antiproton beam*

>10 fb^{-1} with P3

- light: Drell-Yan, GDA's, TDA's
- strange: Spin observables in S=3 hyperon production + CP violation; hypernuclei (S=2)
- charm: Ds scan and open-charm decays & spectroscopy

Reconstruction efficiency for high Pt hadron exclusive reactions at PANDA detector in pp interactions (PandaRoot)

Event total energy distributions for particles with θcms~ 90º ± 45º produced in generated (100 K) and reconstructed PP events



Monte Carlo Event Generator of PANDA

A. Galoyan and V. Uzhinsky, VBLHEP, LIT JINR

1. Creation of DPM – basic fast generator based on Dual-Parton/Quark-Gluon string models aimed for simulation of antiproton-proton interactions (2003 – 2007);

2. Implementation of elastic antiproton-proton scattering in DPM (2008);

3. Enlargement of Geant4 FTF (Fritiof) model by simulation of antiproton-proton and antiproton-nucleus interactions (2009 – 2013);

4. Improving neutron production in hadron-nucleus interactions in FTF (2014-2015);

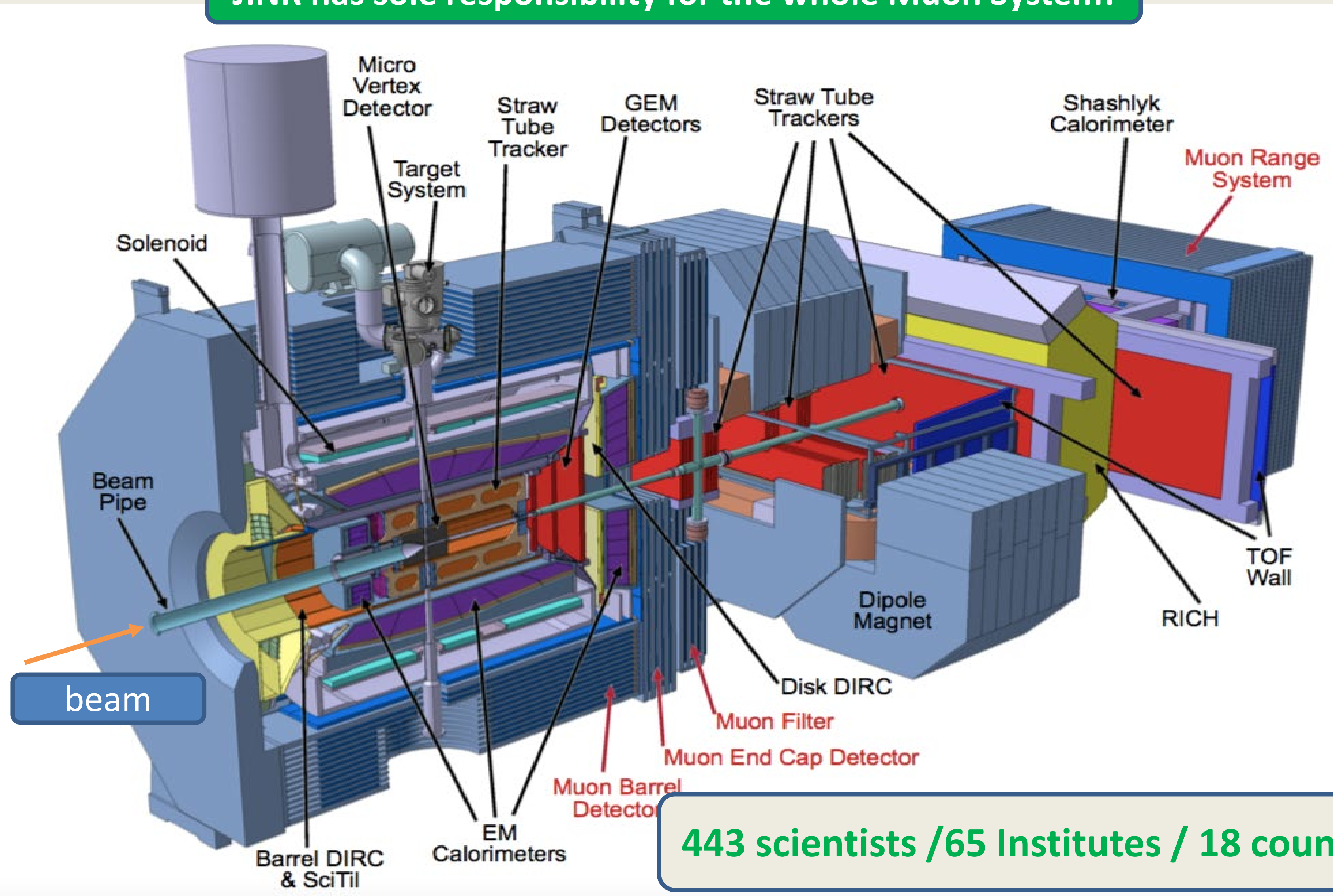
5. Tuning and validation of FTF model for strange meson and hyperon production in antiproton interactions (2015 – 2016);

6. Implementation of smearing of resonance masses in Geant4 FTF (2017);

7. Implementation of charmed and bottom particles in FTF and QGS models (2018 – 2020)

The view of PANDA setup: the Muon System elements (Barrel, End Cap, Filter and Range System) are indicated in red

JINR has sole responsibility for the whole Muon System!



443 scientists /65 Institutes / 18 countries

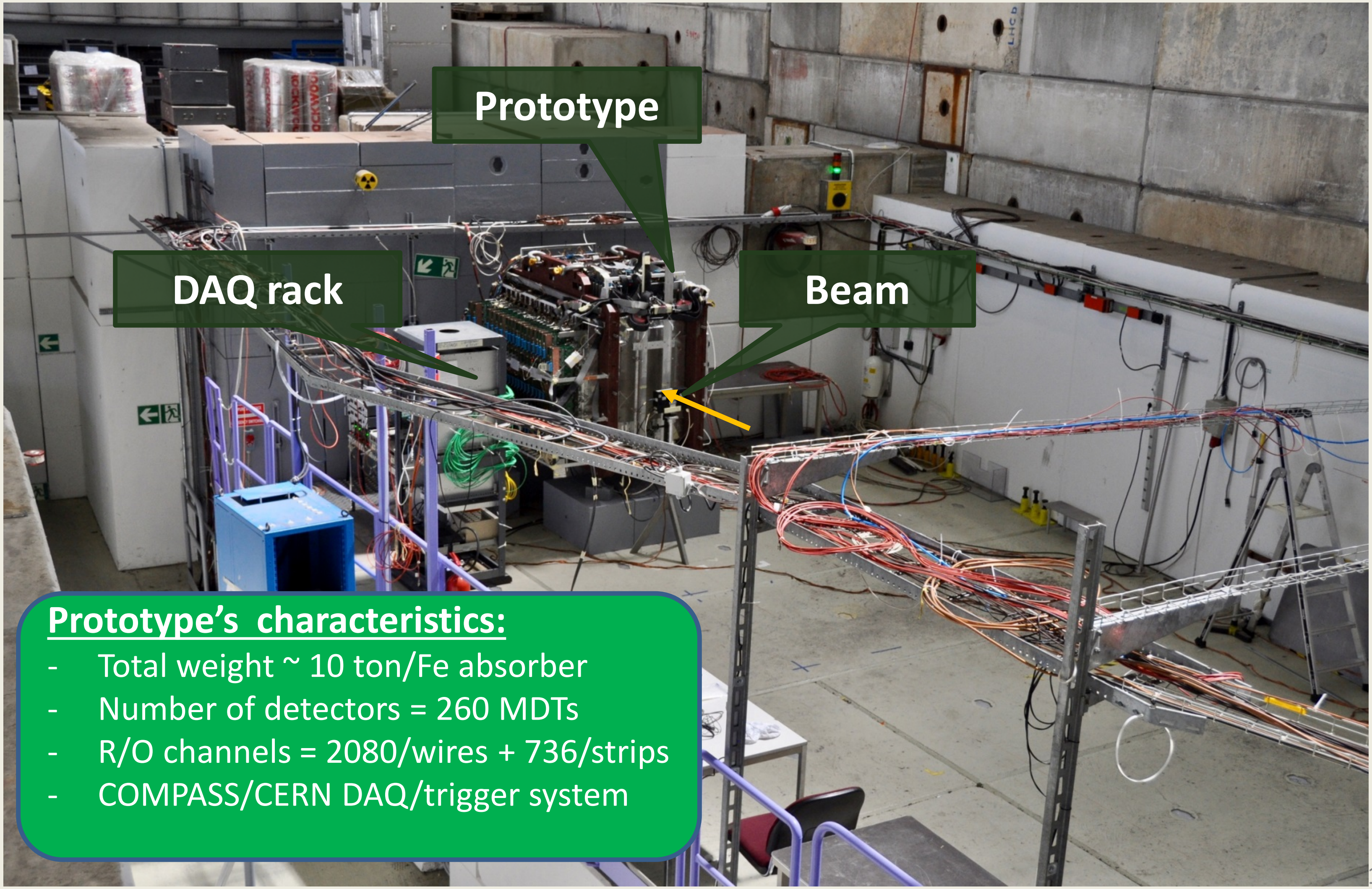
Magnet yoke (serving also as laminated absorber for the Muon System) manufactured at Novosibirsk factory:
(a) Barrel, (b) full assembly with End Cap

(a)

(b)

Laminated structure of the yoke/absorber:
30mm Fe planes with 35mm gaps for MDTs

PANDA Muon System Prototype
@ PS/T9/CERN Beam Line

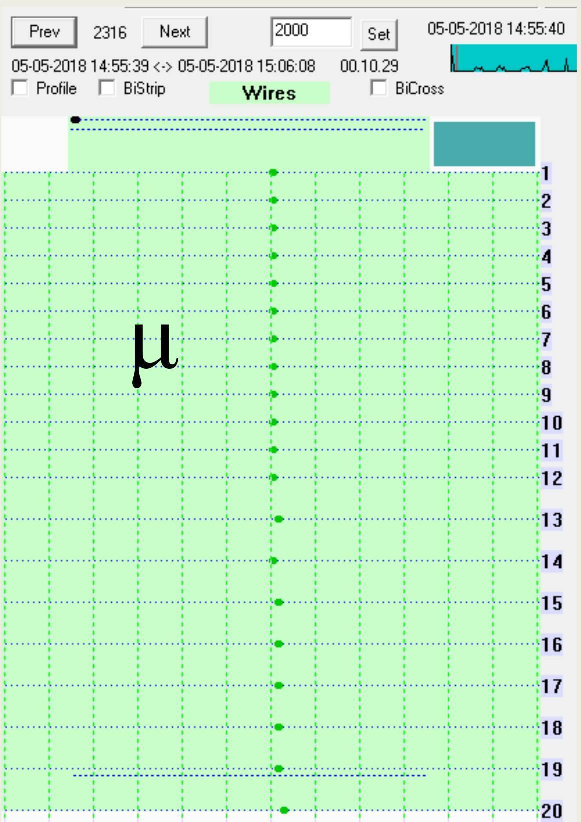


Prototype's characteristics:

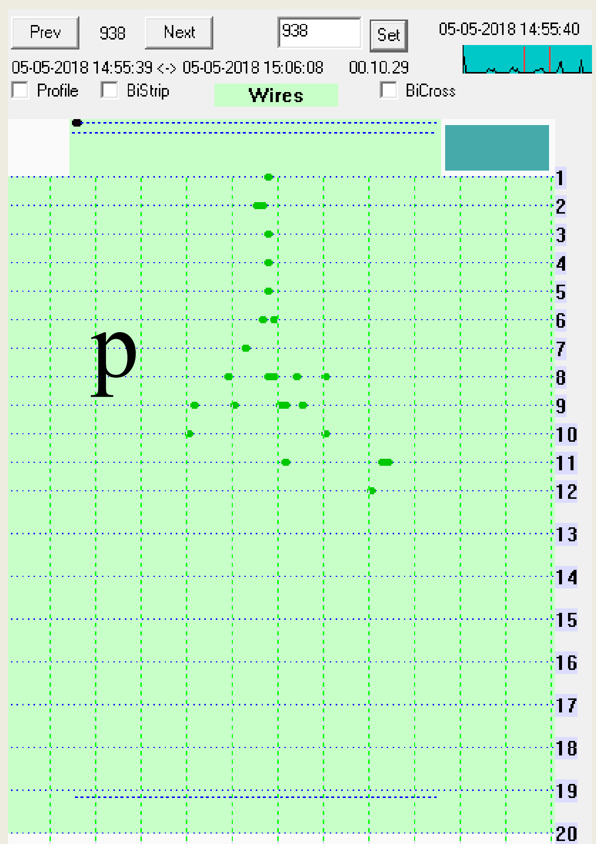
- Total weight ~ 10 ton/Fe absorber
- Number of detectors = 260 MDTs
- R/O channels = 2080/wires + 736/strips
- COMPASS/CERN DAQ/trigger system

Event Examples (P = 5 GeV/c)

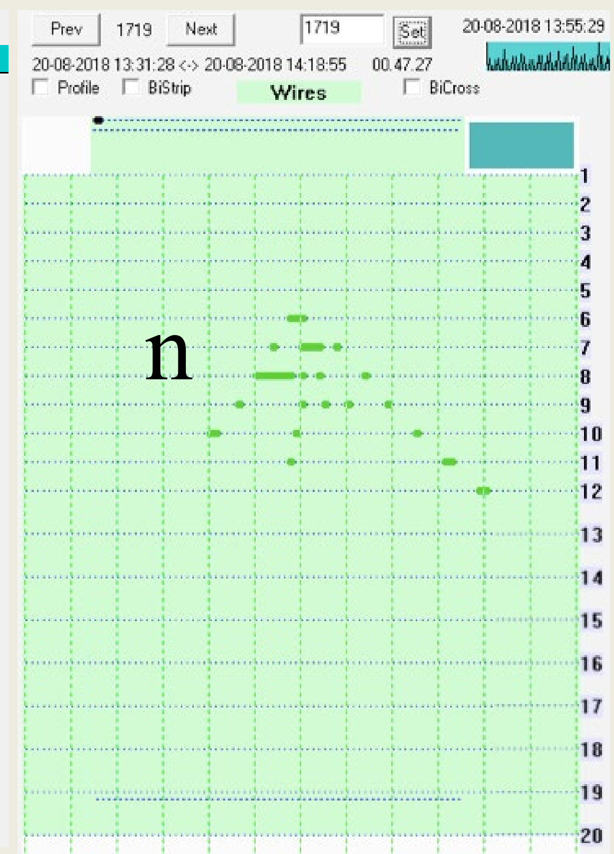
Range System will also be used as a coarse hadron calorimeter – >
very important for neutron registration (the only system in PANDA)!



Run 829



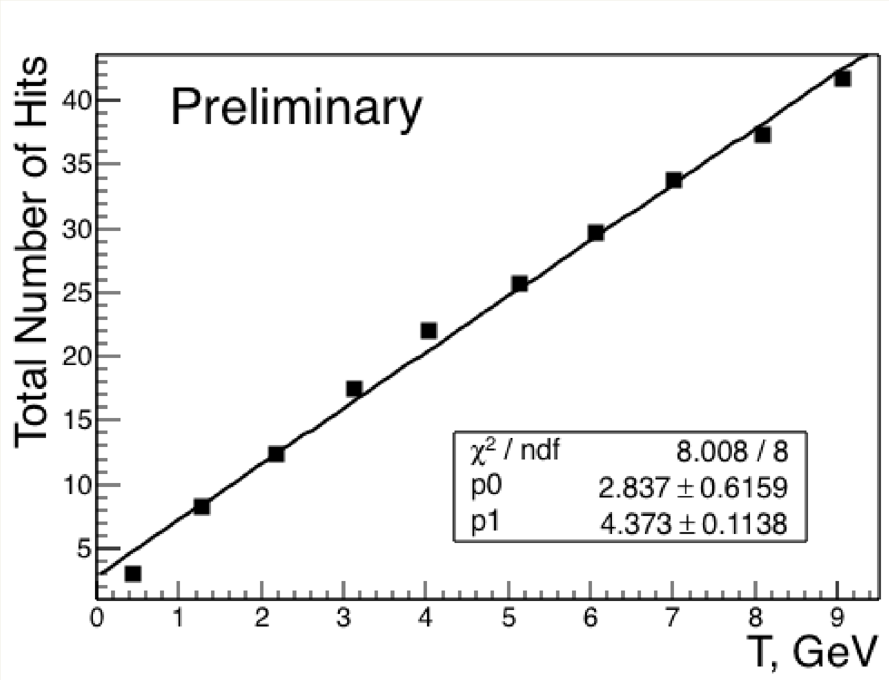
Run 829

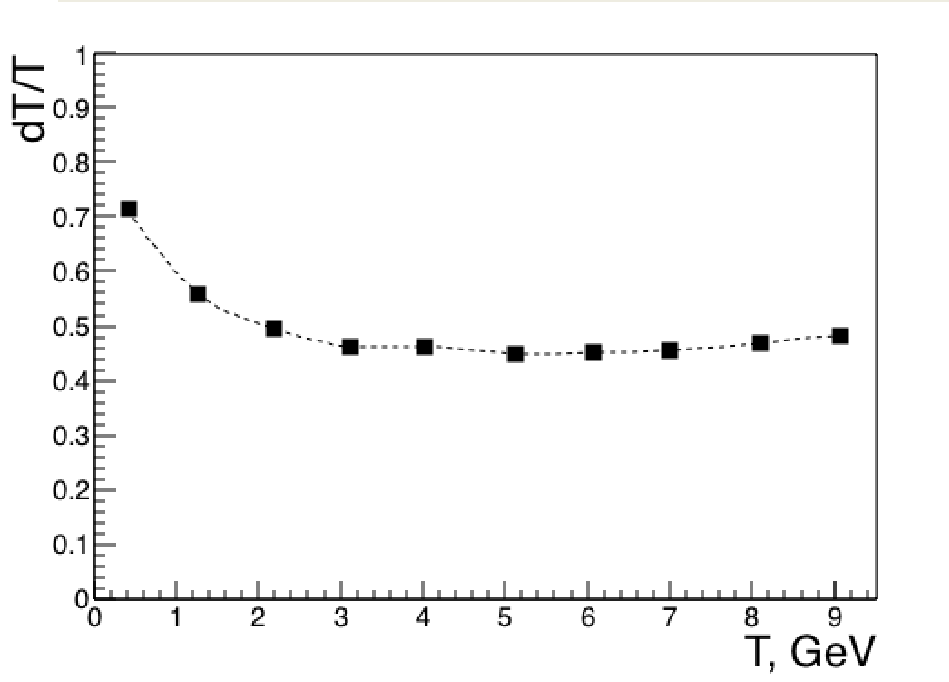


Run 951

Green points represent hit wires (corresponding to 1cm * 1cm in cross-section)

Calorimetry for protons: PANDA Barrel Structure

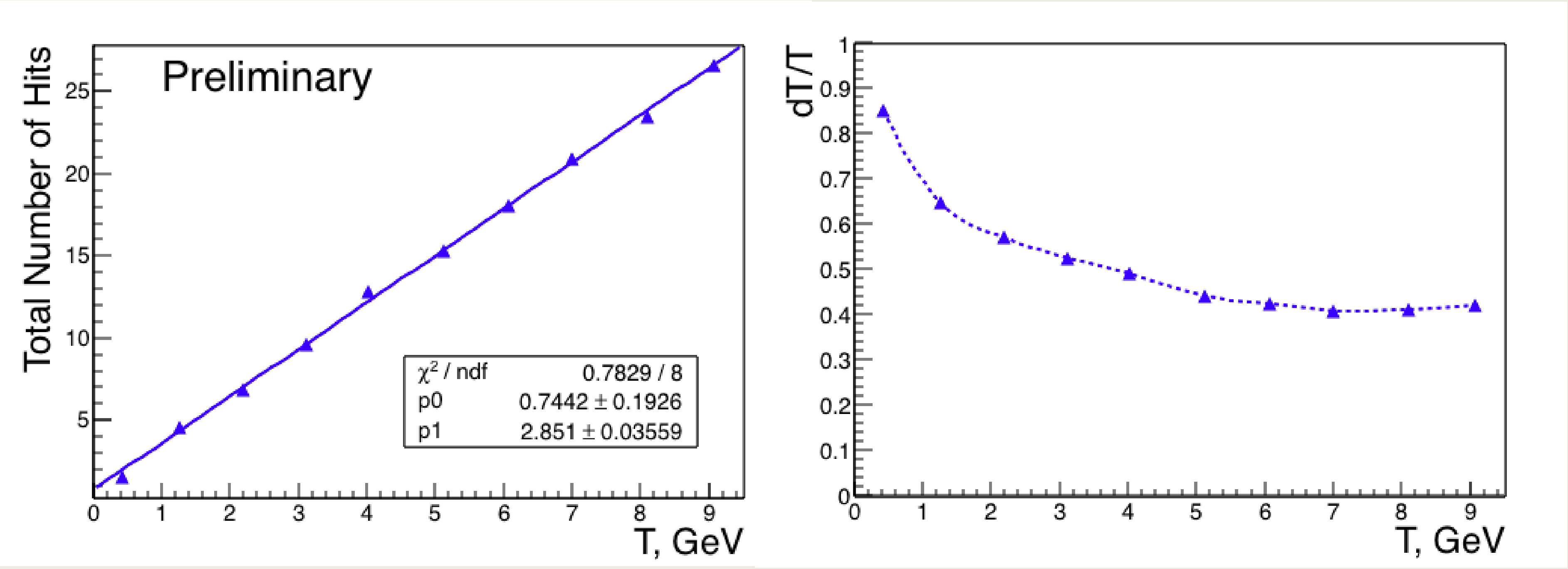




Sampling: 30 mm / Fe

Nuclear interaction length $\lambda_I \approx 2.3$

Calorimetry for protons:
PANDA MF+EC Structure

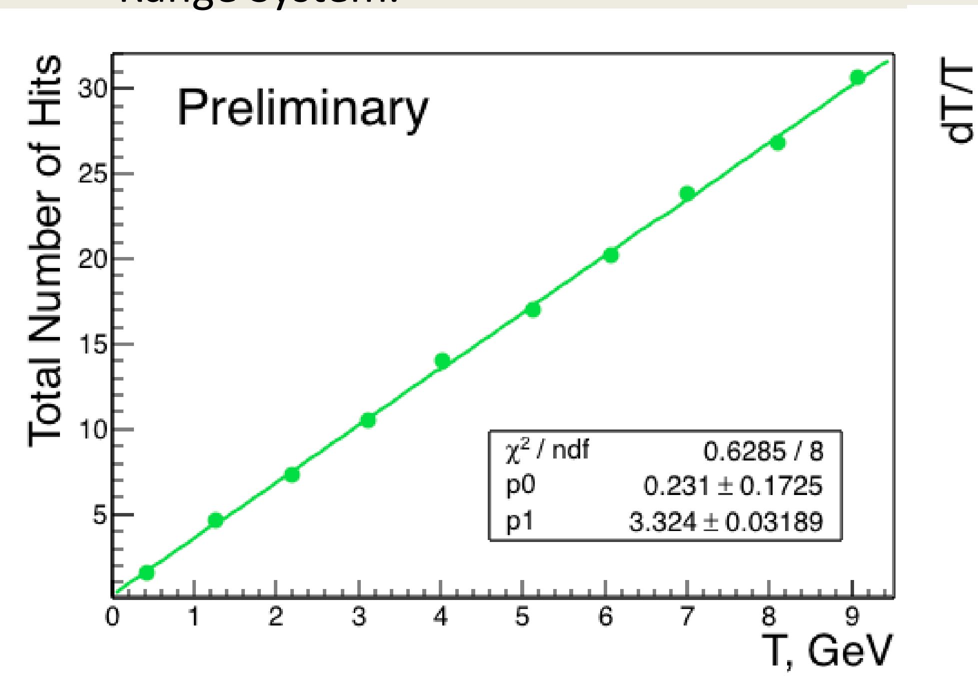


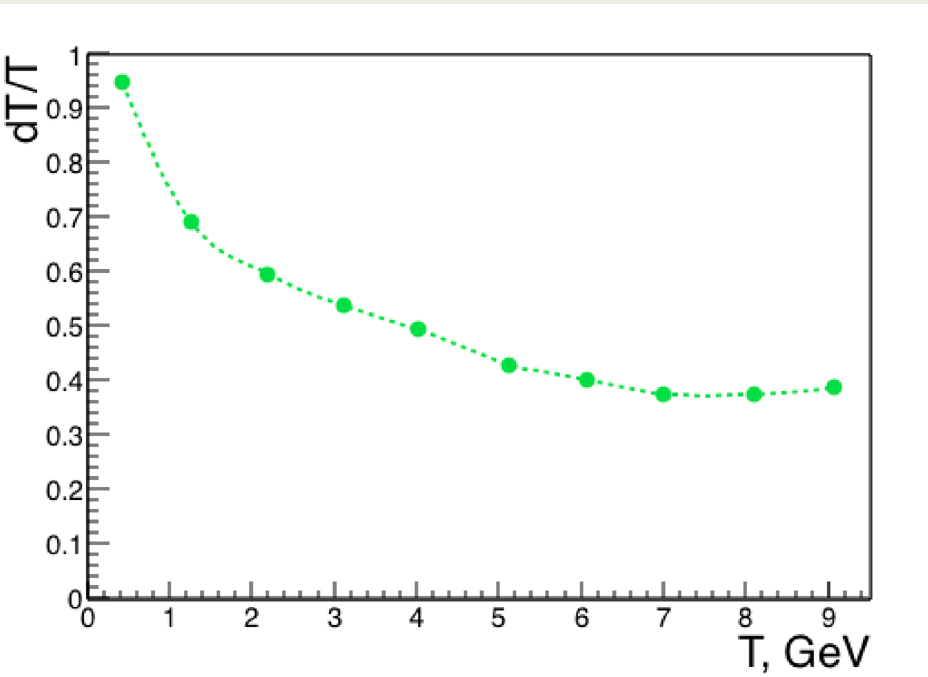
Sampling: 60 mm / Fe

Nuclear interaction length $\lambda_I \approx 3.4$

Calorimetry for protons: PANDA FRS Structure

Various combination of layers can be used to simulate different parts of Muon Range System.

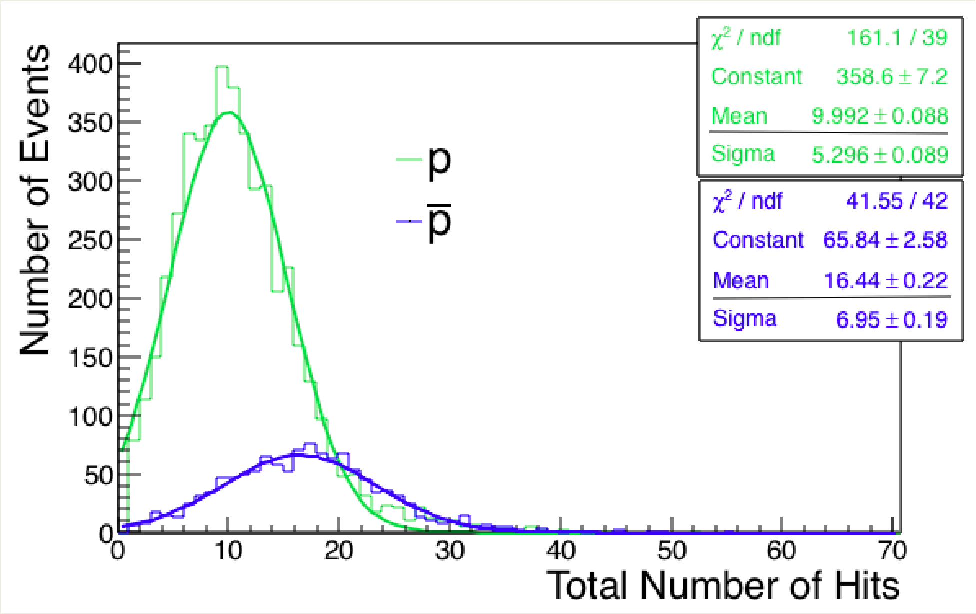


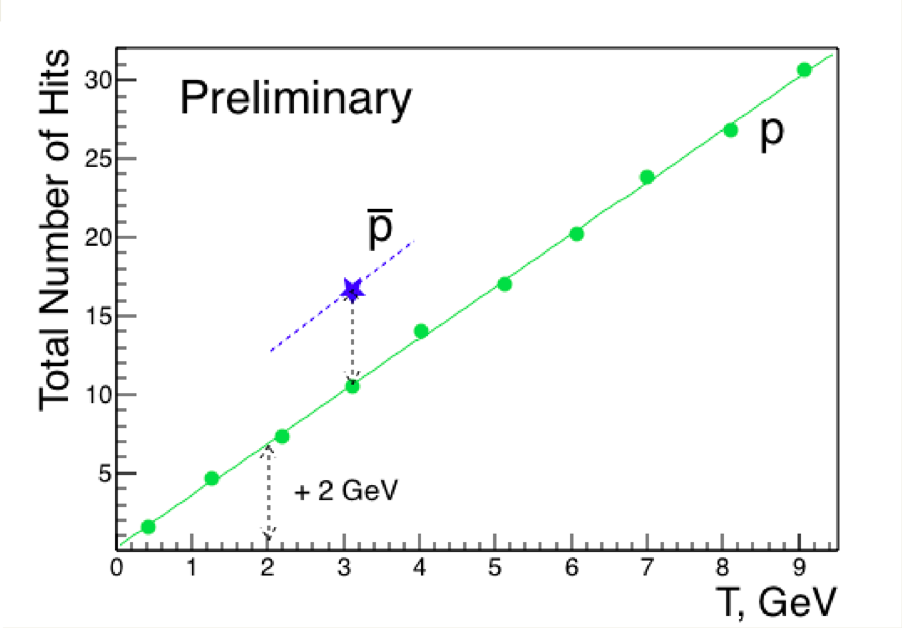


Sampling: 60 mm / Fe

Nuclear interaction length $\lambda_I \approx 5.2$

Protons vs Antiprotons

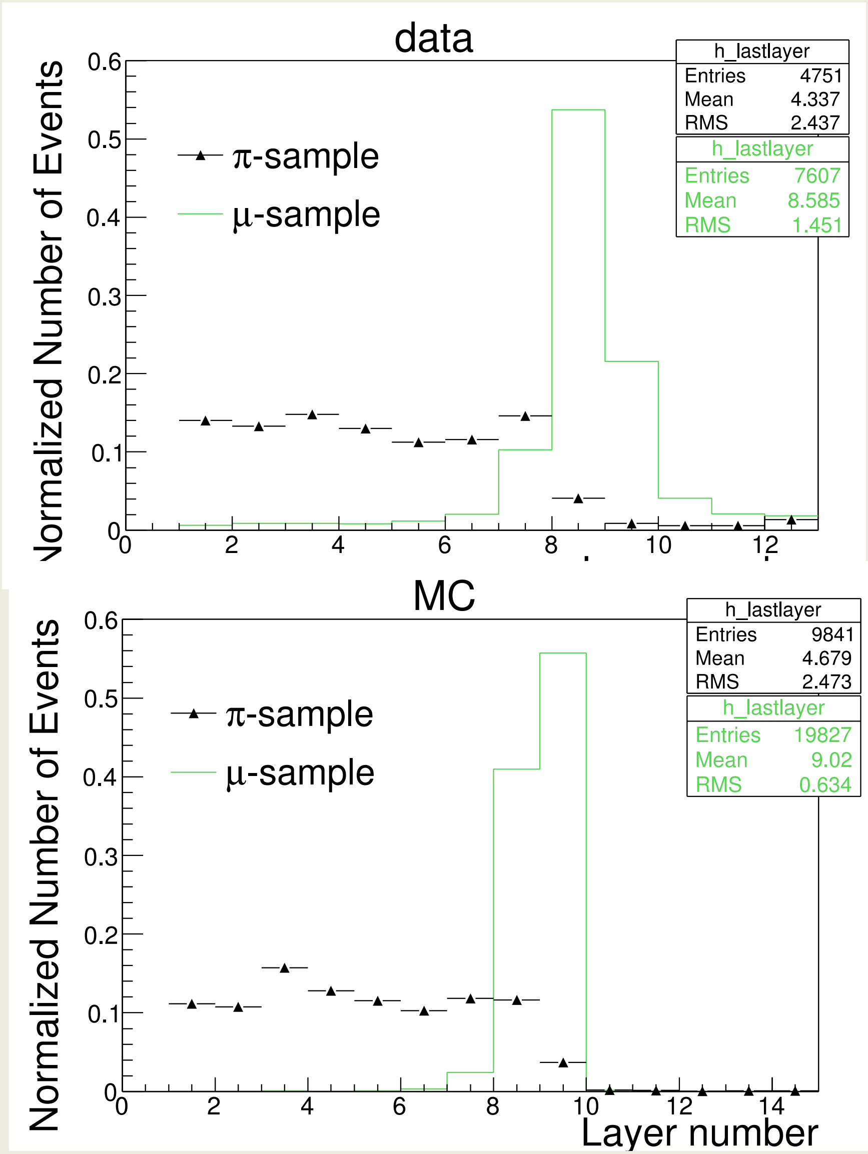




PANDA FRS Structure, T = 3.1 GeV (P = 4 GeV/c)

Test beam results (preliminary)

EPJ WoC, Volume 177 (2018) 04001



Run 605, autumn 2017

momentum = 0.5 GeV/c

Selection -> after layer #7:

22% - pion contamination and

93% - muon efficiency

FairBoxGenerator, PandaROOT

E = 0.5 GeV/c

Selection -> after layer #7:

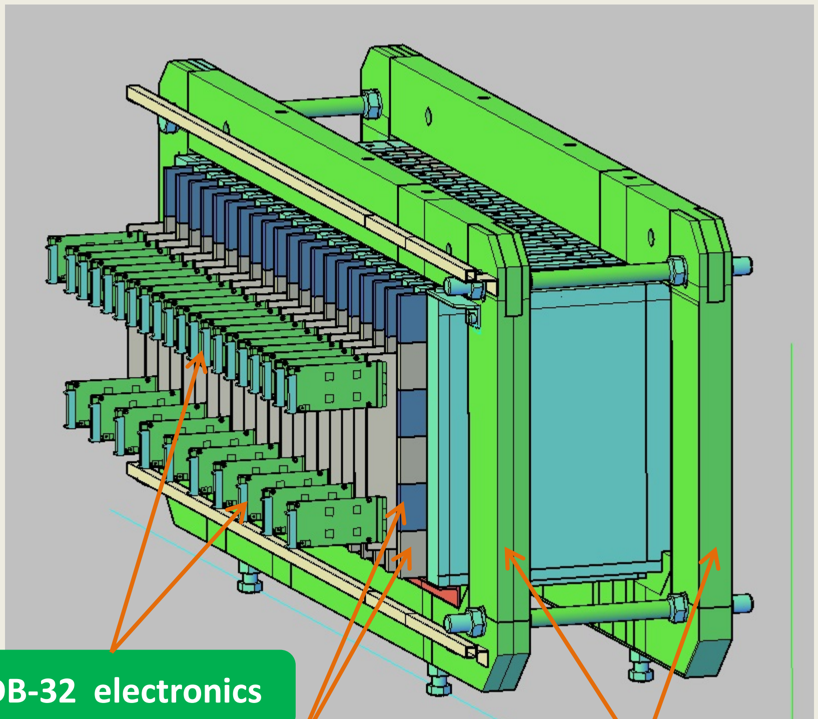
27% - pion contamination and

99% - muon efficiency

PANDA spin-off -> SPD/NICA Range System Prototype

(to be used at SPD test area at Nuclotron)

3D model of SPD Muon (Range) System Prototype



ADB-32 electronics

6 MDTs per plane

Support frame

96 MDTs, 768 wire & 256 strip R/O channels

Prototype absorber (1.5 ton) manufactured at DLNP/JINR

Fe absorber plates:
60mm + 15 layers x 30 mm + 60 mm;
total thickness ~ 3.5λ

Synergy between PANDA/FAIR & SPD/NICA muon systems:

- MDT detectors -> 100%
- Analog electronics -> 100%
- Digital electronics (FPGA based) -> ~ 90%
- Beam tests -> 100%
- Algorithms of pattern recognition -> 100%

CONCLUSION: ALMOST FULL SYNERGY !

Plans for 2022 – 2024

0) Signing of FAIR-JINR contract (830 K€) for Barrel detectors production ……… 2021

1) Preparation of production workshop for MDT detectors ………….. 2021-22
2) **Production of MDT detectors ……………………….………….. 2022-23(*)**
3) R&D on electronics ……..……………………………………… 2021-22
4) Production of analog front-end electronics ………………………. 2022-23
5) Beam tests with the prototype at CERN ………………………… 2022-24
6) Mounting of the Muon System (detectors and electronics) at FAIR 2023-24
7) Software and physics development ……………………………... 2022-24

***)**

- **Total number of Barrel detectors (with spares) = 1800 MDTs**
- **Workshop productivity = 20/day (experience of D0/FNAL and COMPASS/CERN)**
- **Expected time for production (not including logistics for the parts) = 18 weeks only!**

МЕЖДУНАРОДНАЯ МЕЖПРАВИТЕЛЬСТВЕННАЯ ОРГАНИЗАЦИЯ
INTERNATIONAL INTERGOVERNMENTAL ORGANIZATION

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ
JOINT INSTITUTE FOR NUCLEAR RESEARCH

Дубна Московской области Россия 141980 Dubna Moscow Region Russia 141980
Fax: (7-495) 632-78-80 **Tel.:** (7-49621) 6-50-59 **AT:** 205493 WOLNA RU **E-mail:** post@jinr.ru http://www.jinr.ru

Professor Dr. Paolo Giubellino
Scientific Managing Director of GSI and FAIR

Date 08.06.2020
Ref. № 010-16/206

Dear Dr. Giubellino,

On behalf of JINR I am writing to you to express our readiness to share our long-term experience with GSI in constructing detectors for FAIR.

JINR is prepared to provide GSI with the Muon System of PANDA detector (presently, for the Barrel part) in the framework of the collaboration contract between FAIR and JINR (of the cost book value including an inflation correction coefficient).

This proposal has the following PSP Number: 1.4.1.13.1.1 (Target Spectrometer Barrel Muon Detector Chambers). The cost book value of this item amounts to 591,000.00 € in 2005 costs.

If you require any further information, please feel free to ask.

We look forward to your reply.

Yours sincerely,

Academician Victor Matveev
Director of JINR

The letter of JINR director, confirming the interest of JINR to participate in PANDA/FAIR project and conditions for the production of the starting part of the PANDA Muon System (detectors for the Barrel of the Target Spectrometer). The cost of this part at present (2020), including the inflation factor, equals to 830 K€. This amount is part of the full cost 3,480 M€ (see Appendix II below), and will be deducted from that cost at later stage in framework of the next contract.

МЕЖДУНАРОДНАЯ МЕЖПРАВИТЕЛЬСТВЕННАЯ ОРГАНИЗАЦИЯ
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Дубна, Московская область, Россия 141980 Dubna Moscow Region Russia 141980
Fax: (7-495) 632-78-80 **Tel.:** (7-49621) 6-50-59 **AT:** 205493 WOLNA RU **E-mail:** post@jinr.ru
http://www.jinr.ru

To Research Director of FAIR
Prof. Dr. Günther Rosner

19.05.2014 010-27/171

Dear Prof. Rosner,

The Joint Institute for Nuclear Research (JINR, Dubna) is interested to implement its long term experience for the construction detectors of the Facility for Antiproton and Ion Research (FAIR).

Our Institute is ready to provide the Muon System of PANDA detector in framework of Collaboration Contract between our Institute and FAIR GmbH (for the cost-book price including an inflation correction coefficient). This proposal comprises the following PSP Number of the cost-book: 1.4.1.13.

The cost-book value for this item amounts to 2,318,000.00 €.

Kind regards,

Academician V. A. Matveev
Director

The letter of JINR director, confirming the interest of JINR to participate in PANDA/FAIR project and conditions for the production of the full PANDA Muon System. The cost of the Muon System at present (2020), including the inflation factor, equals to 3,480 M€.

Backup slides

Referee report (I.A. Tyapkin)

The FAIR laboratory, now being constructed at Darmstadt, promises very large variety of studies in the field of hadron and nuclear physics. The PANDA experiment will use the unique antiproton beam of High Energy Storage Ring (HESR) with high luminosity and energy homogeneity. The experiment makes emphasis on research of possible exotic states (hybrids, glue-balls, etc.) and structure of nucleons. It is important to point out that PANDA will complement information about nuclear matter features from analyses of heavy ion collisions, which will be obtained in collider experiments MPD and SPD at NICA/JINR, as well as in the fixed target experiment CBM, also at FAIR.

The JINR group is developing several interesting tasks suggested by our scientists for the PANDA physics program: measurement of proton structure functions (quark and gluon distributions) in a new kinematical region, measurement of elastic and deep inelastic antiproton-nuclei processes (tensor glue-balls and effects of nucleon polarized strangeness and others.) It is also worth mentioning the development of Monte-Carlo generators being used in simulation with PANDAroot (improved FTF and DPM models of Geant4 toolkit).

The hardware contribution of JINR group to the PANDA experiment went through serious changes: from participation in R&D works on several technologies to concentration on two very important items (the solenoidal superconducting magnet and the muon system), and finally, the full responsibility for the muon system. Now the JINR group defines totally the design and production of the PANDA muon system. Keeping in mind that the system is based on Mini-Drift Tubes technology developed in JINR and the previous experience of the group in constructing the big muon systems (D0/FNAL and COMPASS/CERN), one may be sure that JINR group will successfully realize the PANDA muon system project.

The R&D results obtained by the group demonstrate high degree of project readiness. The following achievements should be mentioned: direct calibration of the muon system prototype response to muons and hadrons in full PANDA energy range, observation of antiproton and neutron signals, successful test of FPGA-based digital front-end electronics (for data acquisition system).

Very important feature of this project is high degree of synergy between muon systems of PANDA and SPD/NICA. Most of results obtained by the JINR group during execution of PANDA project are fully applicable to the design of SPD.

The requested resources needed to construct the muon system look adequate to the task.
I fully support this project and recommend approving its extension with high priority for the next period.

07.11.2020 I.A. Tyapkin

Doctor of physical and mathematical Sciences, Leading scientist of VBLHEP JINR

Referee report (A.E. Dorokhov)

The Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany, builds on the experience and technological developments of the existing GSI laboratory, and provides unique possibilities for a new generation of hadron-, nuclear-, atomic- and plasma physics experiments. The future fixed-target experiment PANDA at FAIR, which features a modern multipurpose detector, offers a broad physics program with an emphasis on various aspects of hadron physics. The antiproton beams of High Energy Storage Ring (HESR) with momenta ranging from 1.5 to 15 GeV/c allow using a wide variety of physics channels. Understanding the strong interaction in the non-perturbative regime remains one of the greatest challenges in contemporary elementary particle physics and, to that end, the hadron beams provide several important advantages. Furthermore, the high-intensity low-energy domain of PANDA experiment will be suitable for Standard Model tests on the high-precision frontier.

Currently, the JINR physicists at PANDA develop a number of important areas. The most urgent of them are related to the detector construction and JINR has commitments on making the Muon System, very important part of PANDA detector.
PANDA Physics Pillars include study of: 1) the nucleon structure and its characteristics GDAs and TDAs, EMFFs; 2) the strangeness physics, such as hyperon production, spectroscopy and decays; 3) the physics of charm and exotics, such as glueballs, hybrids and multiquarks; 4) hadrons in nuclei: color transparency at intermediate energies, short-distance structure of the nuclear medium, influence of the nuclear potential on hadron properties.

Dubna group' studies give significant contribution to the physics program. The results obtained in the simulation of the standard benchmark process of the "muon-antimuon" pair production and its background modeling allowed to work out the requirements and geometric parameters of the proposed muon system of the PANDA detector. Currently, the more in-depth study of the backgrounds for the Drell-Yan process is being conducted to estimate the possibility of studying this process at the PANDA. A complete geometric description/model of the muon system has been accomplished and now it is ready to be implemented in the PANDARoot package. The development and improvement of the FTF model, implemented in Geant4 with cross-checking with experimental data from other experiments, allows to study charmed quark, strange quark-antiquark and diquark-antidiquark pair production, which is especially important for the initial phase of PANDA physics program. This model is also used for modeling and analyzing inelastic and elastic proton-proton interactions with 2, 4, 6 hadrons in the final states with large transverse momentum. In addition, simulation of proton interactions with C, Al, Cu and W nuclei was done using Geant4 FTF model, results of which can be useful in developing the p/bar-nucleus physical program in the energy range of the PANDA experiment. Development of research program of the exotic multiquark states at PANDA is also being carried out. JINR PANDA group as well involved in the preparation of the LoI for the 'Phase-C' of PANDA, which is devoted to the study the high Pt physics during commissioning of the PANDA setup. This list of physical activities of the JINR group complements the experimental achievements of the group on the construction of the PANDA muon system. Finally, let us hope to see the successful start of the PANDA experiment.
I suggest that the Program Advisory Committee should approve the prolongation of the proposed project on JINR group participation in the PANDA experiment for the years 2022-2024.

05.11.2020 A.E. Dorokhov

Doctor of physical and

REFEREE's REPORT on the PROJECT

"PANDA experiment at FAIR (JINR participation)"

JINR's participation in PANDA is unique for two reasons. One is that PANDA's research program covers most of the hot problems in high-energy physics, the second is in the complementarity of the FAIR and NICA's physical programs.

The Facility for Antiproton and Ion Research (FAIR) in Darmstadt is based on the experience and technological developments of the existing GSI laboratory. The future fixed-target experiment PANDA at FAIR, featuring a modern multipurpose detector, offers a broad physics program with emphasis on various aspects of hadron physics. The antiproton beams of High Energy Storage Ring (HESR) with momenta ranging from 1.5 to 15 GeV/c will make possible the use of a wide variety of physics channels.

The most important part of JINR's team in PANDA is related to the construction of the detector in the Muon System. PANDA's Physics program includes, in particular: 1) studies of the nucleon structure; 2) strangeness and charm physics physics, glueballs, hybrids and multiquarks; 4) hadrons in nuclei; 5) developing Monte-Carlo generators.

The JINR group is developing several tasks suggested by JINR scientists for the PANDA, namely: measurement of proton structure functions (quark and gluon distributions) in a new kinematical region, measurement of elastic and deep inelastic antiproton-nuclei processes (tensor glueballs etc.).

The hardware contribution of JINR group to the PANDA experiment has undergone significant changes: from participation in the R&D technologies to the solenoidal superconducting magnet and the muon system.

Among the R&D the following results are worth mentioning: direct calibration of the muon system prototype response to muons and hadrons in full PANDA energy range, observation of antiproton and neutron signals, successful test of FPGA-based digital front-end electronics. An important feature of this project is the high degree of synergy between muon systems of PANDA and SPD/NICA. Most of the results obtained by the the JINR group are applicable to the design of SPD.

The JINR team is involved in the design and production of the PANDA muon system. The system, based on Mini-Drift Tubes technology developed in JINR and the previous experience of the group will realize the PANDA muon system project. The following issues are worth to mention: direct calibration of the muon system prototype response to muons and hadrons in the whole PANDA energy range; observation of antiproton and neutron signals; successful test of digital front-end electronics (for the data acquisition system).

The presentation of the Project is not free from some technical flaws, raising the following questions and remarks:

1. Overlap/complementarity in the scientific programs and potentials of FAIR and NICA should be better highlighted;
2. Production of glueballs is among PANDA's priorities. The advantage of PANDA (if any) compared to central diffractive production at the LHC is worth to estimate and comment;
3. The main theoretical tool is referred to as the "modified FTC MC". It should have been better explained what does "modified" mean as well as compare it with alternative theoretical approaches;
4. Small technical flaws: a) the first appearance of abbreviations should be explained/expanded; b) units of money (probably EU) miss from Table ("Cost estimate") on p. 5.

All this does not affect my appreciation of the Project. I fully support it and recommend its extension with high priority for the next period. The requested resources are adequate to the task.

L. Jenkovszky

Prof. László Jenkovszky (jenk@bitp.kiev.ua),
BITP, Kiev; Member of the Hungarian Academy of Sciences

Answers to the questions of Prof. László Jenkovszky

1. Overlap/complementarity in the scientific programs and potentials of FAIR and NICA should be better highlighted

Very close conditions for operation of PANDA and SPD detectors make physical programs not only overlapping and complementary but open the doors for close cooperation during the detector production. Both detectors have: working luminosity up to ~ 10^{32} cm^{-2} s^{-1}; registration solid angle ~ 4π; PID for all particles (including neutron registration by the Range/Muon System which will be produced by JINR for both detectors); energy scan with precision ~$\delta E/E \approx 10^{-5}$; unique beams $\bar{p}$ at PANDA and polarized proton and deuteron beams at SPD. These conditions will open possibility to provide absolutely unique investigations of the exclusive hadron reactions when all particle in the final state are produced in high p_T region ($p_T \geq 0.5$ GeV/c).

The unique characteristics of the PANDA and SPD detectors make it possible to supplement the physical program with research aimed to study the laws of QCD in the nonperturbative region. This region to define the possibilities to exist the exotic **constituent** components (**diquark** and **multiquark**) in the structure of baryons and ordinary nuclei. The proof of existence for diquarks and definition of their properties is between key questions which will be realized at these detectors.

For example, the exclusive hadron reactions NN (N$\bar{N}$) → B + B$'$($\bar{B}$) and NN (N$\bar{N}$) → B + B$'$($\bar{B}$) + M +M' where N nucleon, B baryon ($\bar{B}$ baryon-bar) and M meson will give information about:

- the proof of existence, probabilities and properties (flavors and spin states) of diquark components of the nucleon wave function;
- the characteristics of constituent quark-quark(quark-bar), quark-diquark (diquark-bar) and diquark-diquark(diquark-bar) interaction vertexes;

Answers to the questions of Prof. László Jenkovszky (cont'd)

- the parameters of the elementary interaction of nucleons with kaons and lambda hyperons (very important for the hyper-nuclei physics and existence of strange matter inside the massive stars);
- the proof of existence of the pentaquarks and tetraquarks in the light quark sector (u,d and s) using reactions of direct production which can't be realized in other experiments;
- the nature of the high hyperon polarization which is produced with high p_T momenta ($p_T \geq 1.0$ GeV/c) in nonpolarized pp- and pA-interactions.

The above items (with the same proton beams as at SPD) can be realized at PANDA. During the Phase-C at PANDA the opportunity will be to provide investigation of pp, dd and pA interactions some time in advance of SPD operation.

2. Production of glueballs is among PANDA's priorities. The advantage of PANDA (if any) compared to central diffractive production at the LHC is worth to estimate and comment

In the paper **PANDA Phase One** which is in preparation for publication in **EPJ, p.20 (2021)** indicated the main goal of glueball investigations: "Glueballs (gg or ggg) are formed due to the self-coupling of the color-charged gluons. This unique feature of the strong interaction is of particular interest since the glueball mass has no contribution from the Higgs mechanism. Instead, it is completely dynamically generated by the strong interaction. Most glueballs predicted by QCD or phenomenological models have the same quantum numbers as mesons and hence they can mix. **As a consequence, it is a challenge to unambiguously identify an observed 1500 hadronic state as a glueball.**"

Answers to the questions of Prof. László Jenkovszky (cont'd)

3. The main theoretical tool is referred to as the "modified FTC MC". It should have been better explained what does "modified" mean as well as compare it with alternative theoretical approaches;

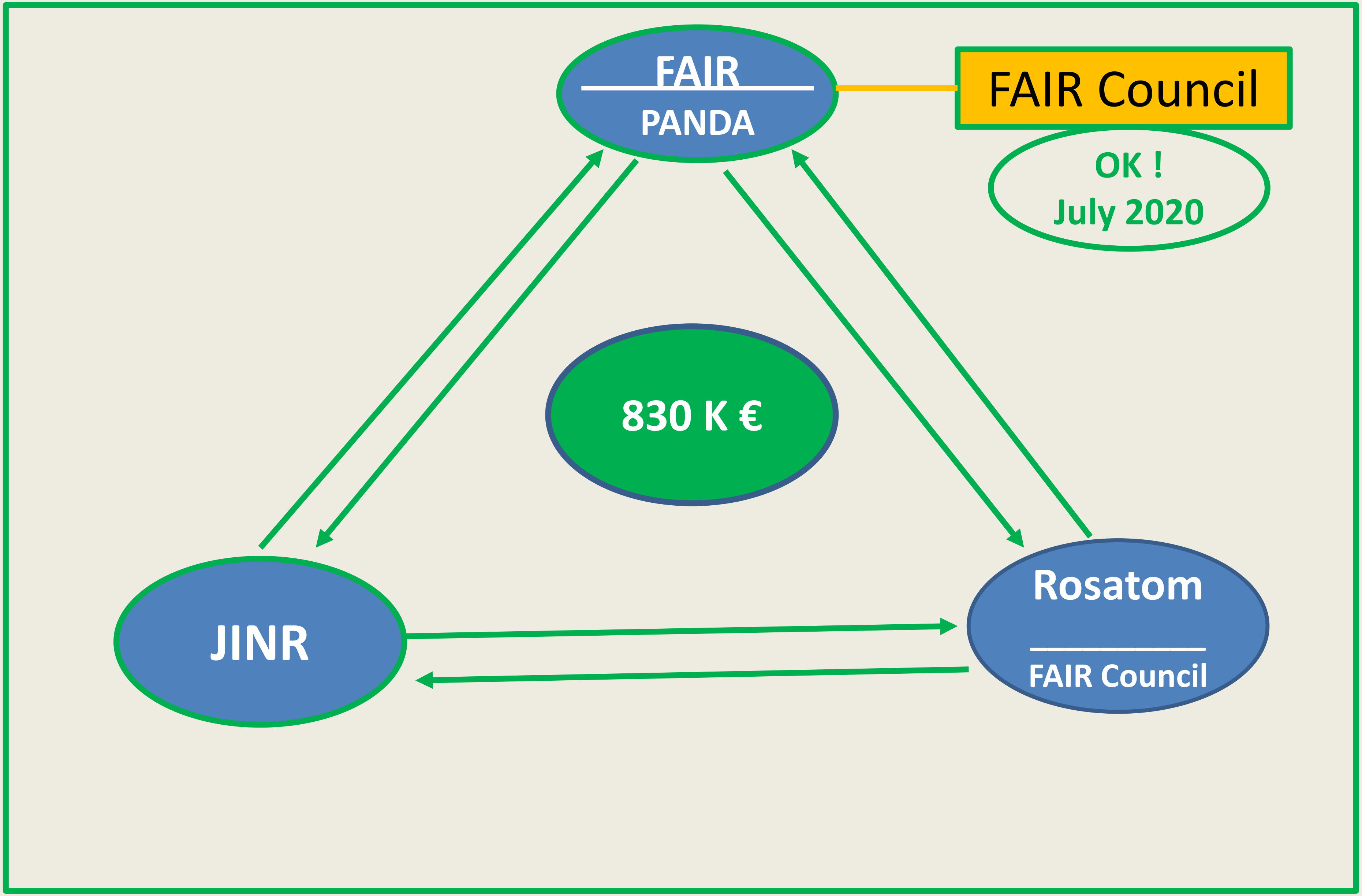
I guess that "modified FTC MC" is miss-typed FTF, which is Fritiof - well-known MC program of the LUND University. The Fritiof model was essential improved in the Geant4 package by our JINR/PANDA co-workers - A. Galoyan and V. Uzhinsky. A detailed description of the Geant4 Fritiof (FTF) model implementation is presented at Geant4 WEB-page in the Physics Reference Manual.

There were no annihilation processes in the original model. Our co-workers have added the annihilation. In a short, the implementation is based on the ideas of the Quark-Gluon-String (QGS) model proposed by A. Kaidalov, K. Ter-Martirosyan and A. Capella. Regge parametrizations of anti-proton - proton cross sections (diffraction, annihilation and non-annihilation processes) are used in the FTF implementation. Additional to this, right fragmentation functions of quark and di-quark according to QGS were added.

4. Small technical flaws: a) the first appearance of abbreviations should be explained/expanded; b) units of money (probably EU) miss from Table ("Cost estimate") on p. 5

The currency unit of this Table is $, contrary to the rest of the project (which is costed in Euro due to the main currency of the partner). This table appeared for the first time in the set of required documents from the accounts department, which uses only official JINR foreign currency – USA dollars. I have overlooked this moment, unfortunately.

Financial status of PANDA/JINR project (in FAIR budget)



Form No. 26

Schedule proposal and resources required for the implementation of the Project PANDA Experiment at FAIR

Expenditures, resources, financing sources		Costs (k€) Resource require.	Proposals of the Laboratory on the distribution of finances and resources (k€)		
			1st year	**2nd year**	**3rd year**
Main units and equipments	1. Construction of detectors for the PANDA Muon System (**Barrel part**)	830	480	300	50
	2. R&D, international scientific and technical cooperation	170	40	50	80
	Total	**1000**	**520**	**350**	**130**
Financing sources	JINR/DLNP budget	60			60
	Contribution of Germany (BMBF) to JINR budget	110	40	50	20
	BMBF-JINR contract (construction of detectors for the PANDA Barrel Muon System)	830	480	300	50
	Total	**1000**	**520**	**350**	**130**

Form No. 29

Estimated expenditures for the Project PANDA Experiment at FAIR

№№	Expenditure items	Full cost, k€	**1st year**	**2nd year**	**3rd year**
1.	Construction of detectors for the PANDA Muon System (**Barrel part**)	830	480	300	50
2.	R&D	50	30	20	
3.	Scientific and technical cooperation:				
	- JINR Member States	5	5		
	- other States	115	5	30	80
	Total (k€)	**1000**	**520**	**350**	**130**

SWOT Analysis

	Helpful	Harmful
Internal	**STRENGTHS** • The experience of JINR team in production and running of big muon systems for D0/FNAL and COMPASS/CERN detectors • Possibility to produce all components of the project (MDT detectors, analog and digital electronics, infrastructure elements) mostly at JINR and its Member-States • Serious theoretical support available for further development of PANDA physics program	**WEAKNESSES** • Temporary absence of free space a JINR to deploy the MDTs productior workshop • Tight time-schedule for production ir Dubna and assembly of the system at FAIR
External	**OPPORTUNITIES** • Participation in excellent physical program of PANDA/FAIR • Allocation of adequate amount of money by Rosatom/Russia to FAIR budget for constructing the full Muon System • Planned start of PANDA running in 2025	**THREATS** • Absence of signed FAIR-JINR contract on production of the Muor System • Possible further delays with start of PANDA project at FAIR

Muon System as PID

* PANDA Muon System based on range system technique is a good PID system for muon-to-hadron separation
* It works in full energy range of secondary particles at PANDA (0,5 ~ 10 GeV)
* It resolves muons and hadrons with ~ 100% efficiency (zero hadron contamination) above ~ 1 GeV by obviously different response pattern
* Separation of muons vs pions (the main rival) below 1 GeV is less efficient and requires test beam measurements for calibration
* Fake muons from pion-to-muon decay may not be recognized as such by Muon System working in 'stand along' mode !
* Range system will be used as a coarse hadron calorimeter – > very important for neutron registration (the only system in PANDA)!

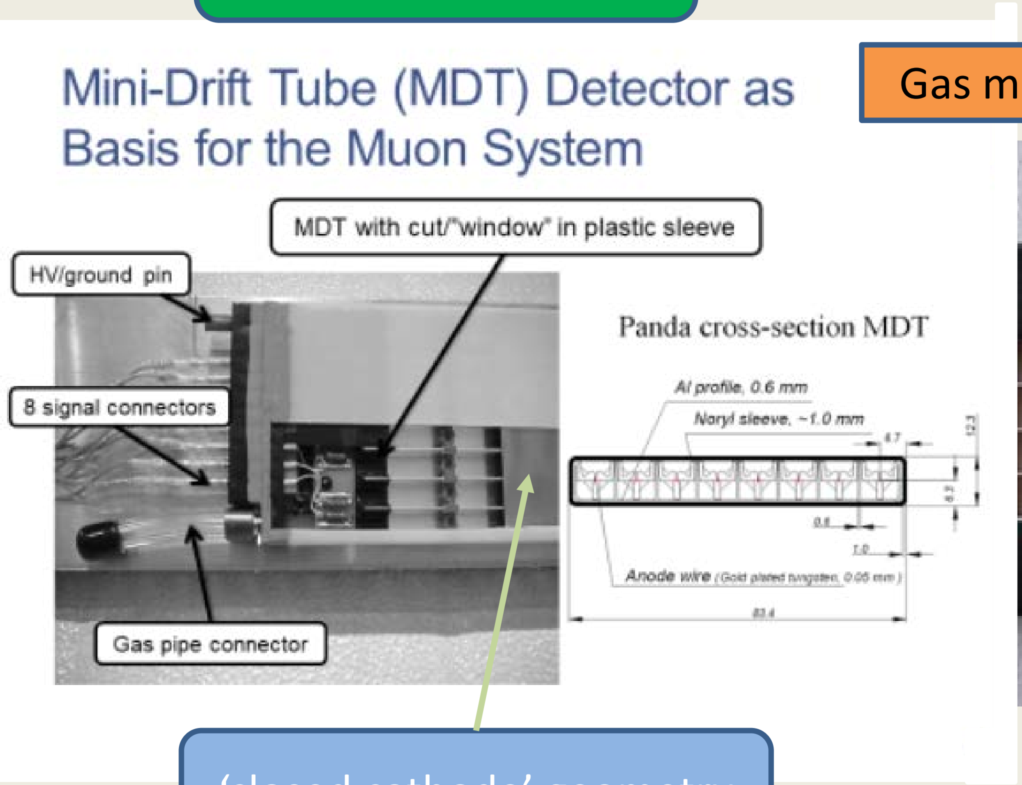
Mini Drift Tube (MDT) detectors

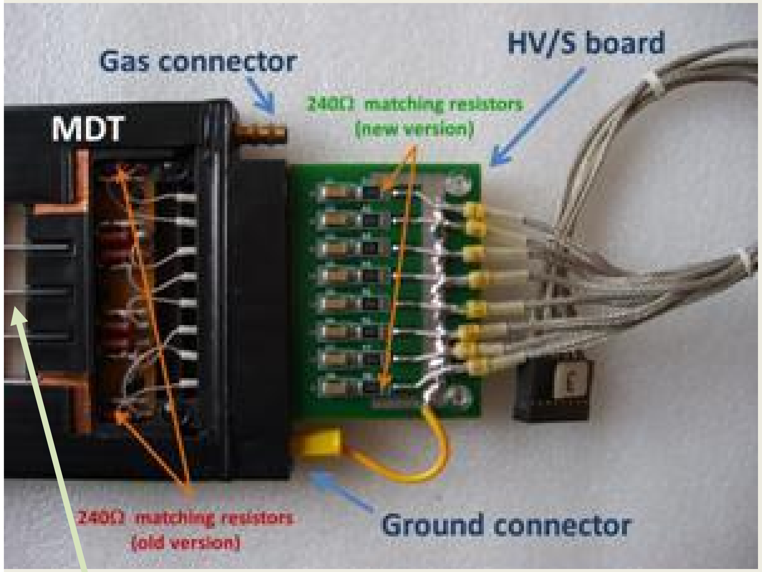
(D0/FNAL&COMPASS/CERN-wire R/O (left), PANDA/FAIR&SPD/NICA – wire&strip R/O (right)

- HV on ALU cathode

+ HV on the wires

Gas mixture -> Ar:CO_2 = 70:30





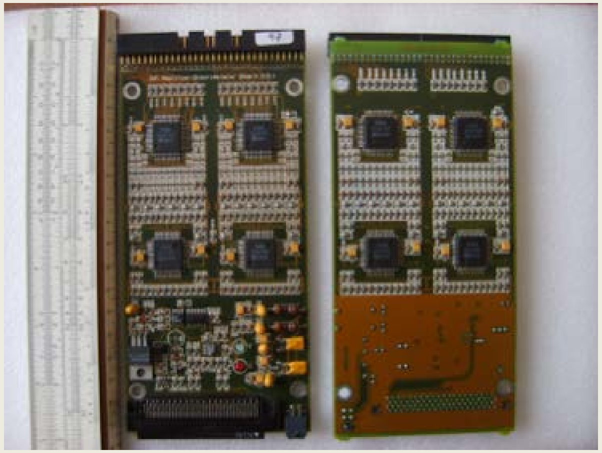
'closed cathode' geometry

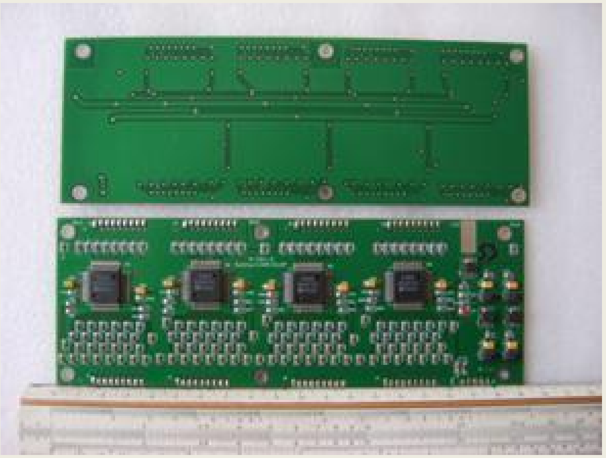
'open cathode' geometry

Analog Front End Electronics (FEE) cards
(conservative approach – D0/FNAL & COMPASS/CERN)

Amplifier-Discriminator Board, 32 channels,
ADB-32 for wire R/O

Preamplifier Board, 32 channels,
A-32 for strips R/O

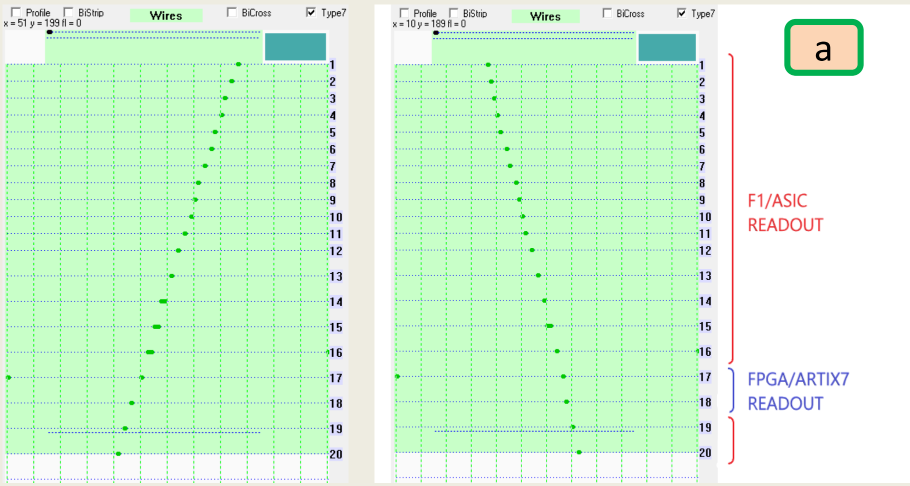


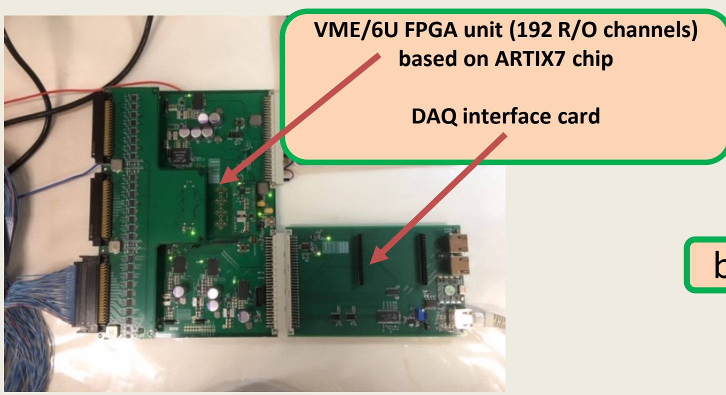


FPGA digital readout test

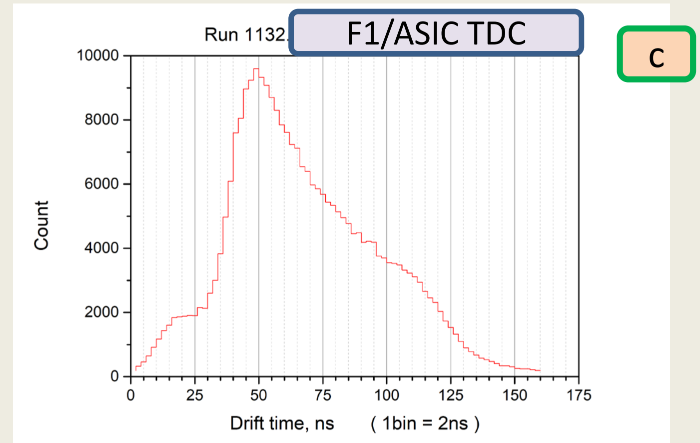
(a) - prototype's wires R/O, (b) - VME/FPGA R/O unit, (c,d) – comparison of time spectra (ASIC vs FPGA)

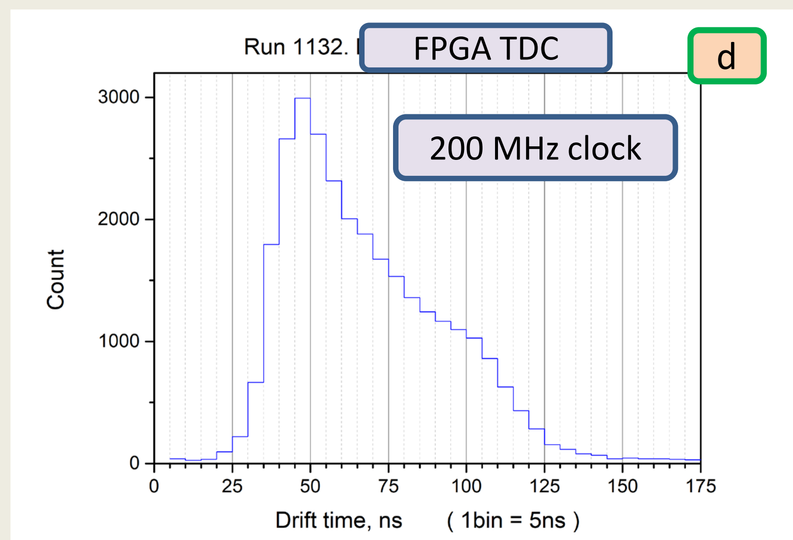
Typical cosmic events





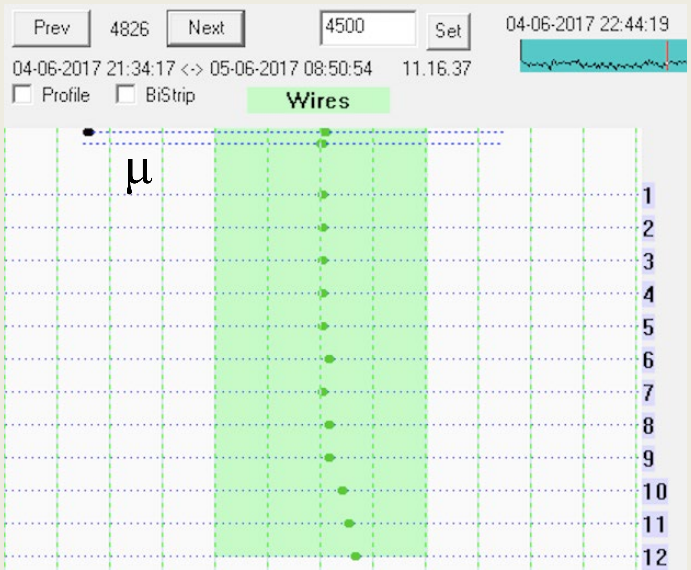
b

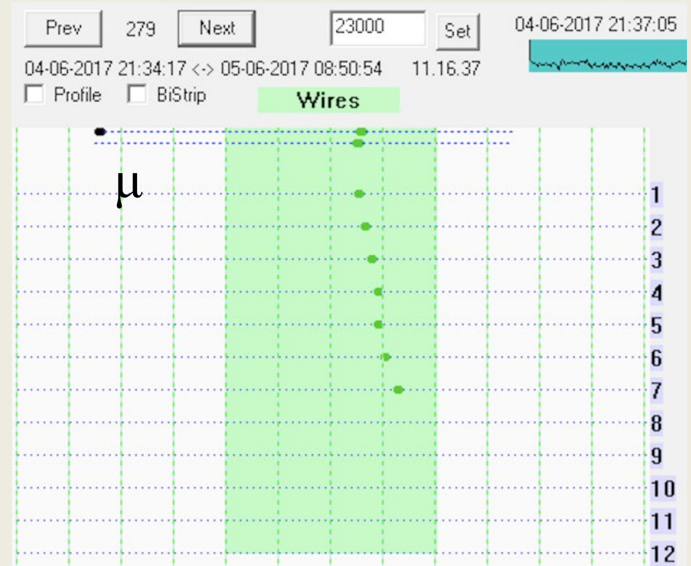


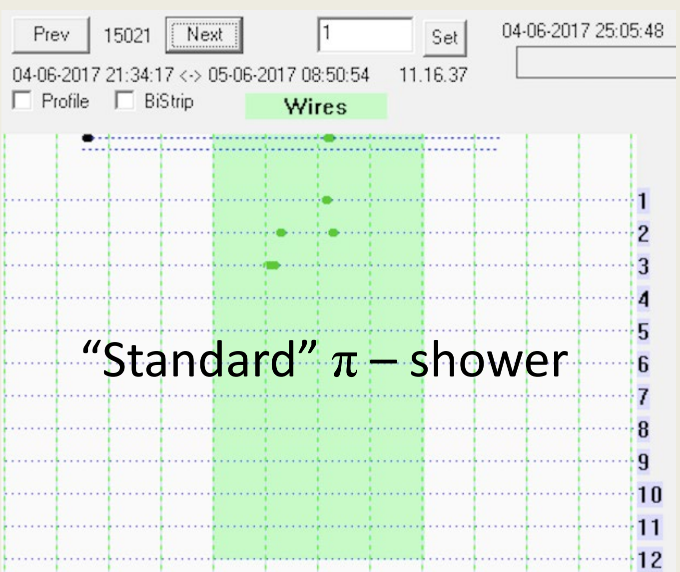


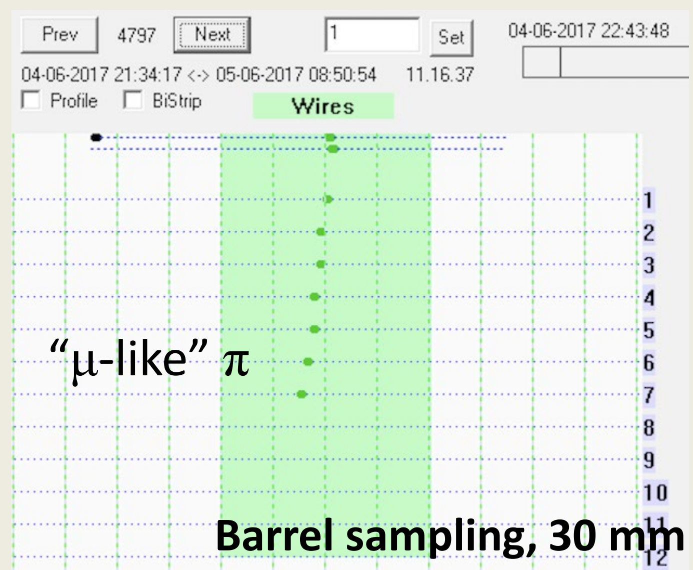
Prototype Data (μ vs π)
Barrel, 0.5 GeV/c

Run 605
P = 0.5 GeV/c



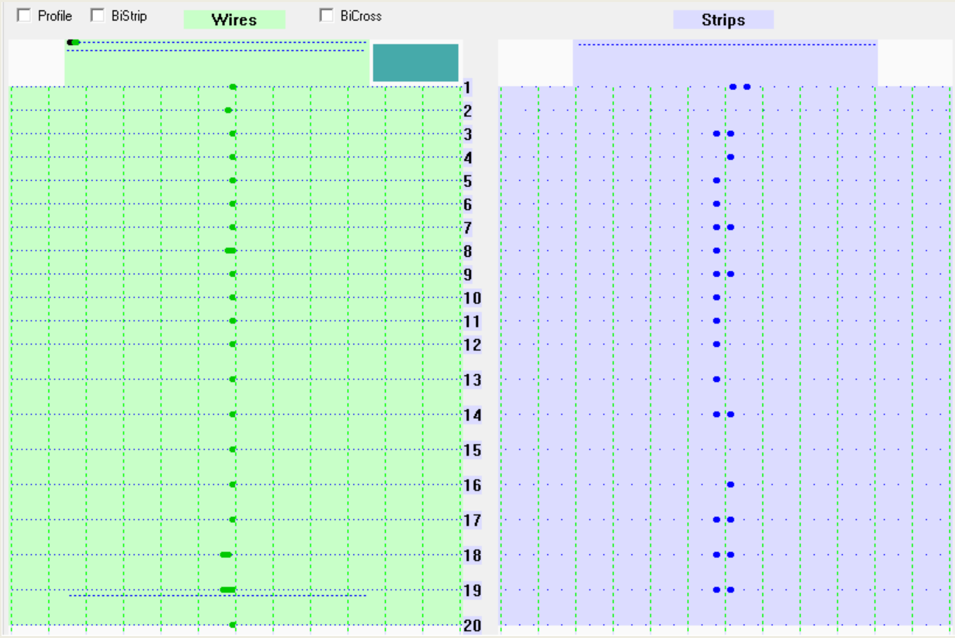






Barrel sampling, 30 mm

Muon 10 GeV: Wires (left) and Strips (right)



Pion 10 GeV: Wires (left) and Strips (right)