BINP activities in cosmic-ray experiments

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Outline

1. **TAIGA project**

   - Muon scintillation detector

2. **Direct search of DM**

   - Dark Side -20 K experiment

3. **Conclusion and outlook**

TAIGA

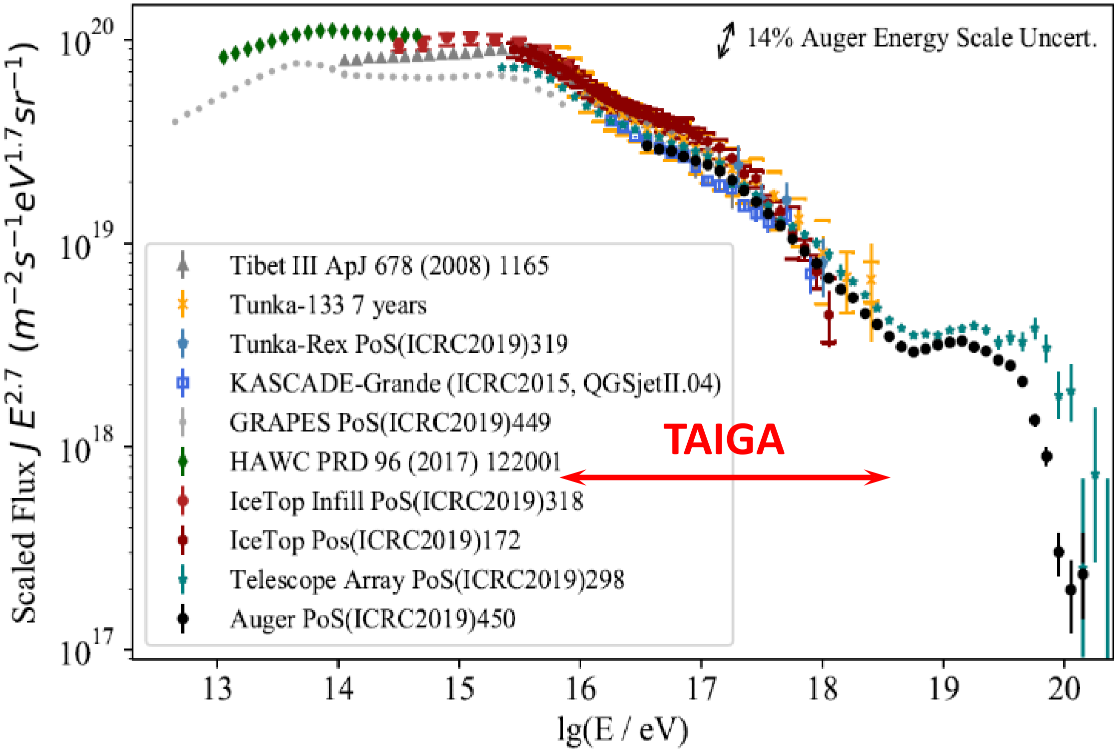
Tunka **A**dvanced **I**nstrument for cosmic rays and **G**amma **A**stronomy

Main goals:

- Search for galactic sources of gamma-quanta with energies higher then 20-30 TeV at the record level of sensitivity
- Search for ”Pevatrons” (ultra-high energy gamma-ray sources) and measure the composition and spectrum of cosmic rays in the transition region from Galactic to Extragalactic origin.
- Studies of high energy part of gamma radiation spectrum from the most bright blazars with aim to study gamma-quanta absorption on intergalactic background radiation (infrared and microwave) and search for axion-photon transitions
- Search for possible violations of Lorenz-invariance and axion-photon transitions which in new approach to search of dark matter in the Universe

TAIGA

Tunka Advanced Instrument for cosmic rays and Gamma Astronomy



Research area:

any cosmic rays

PeV-EeV

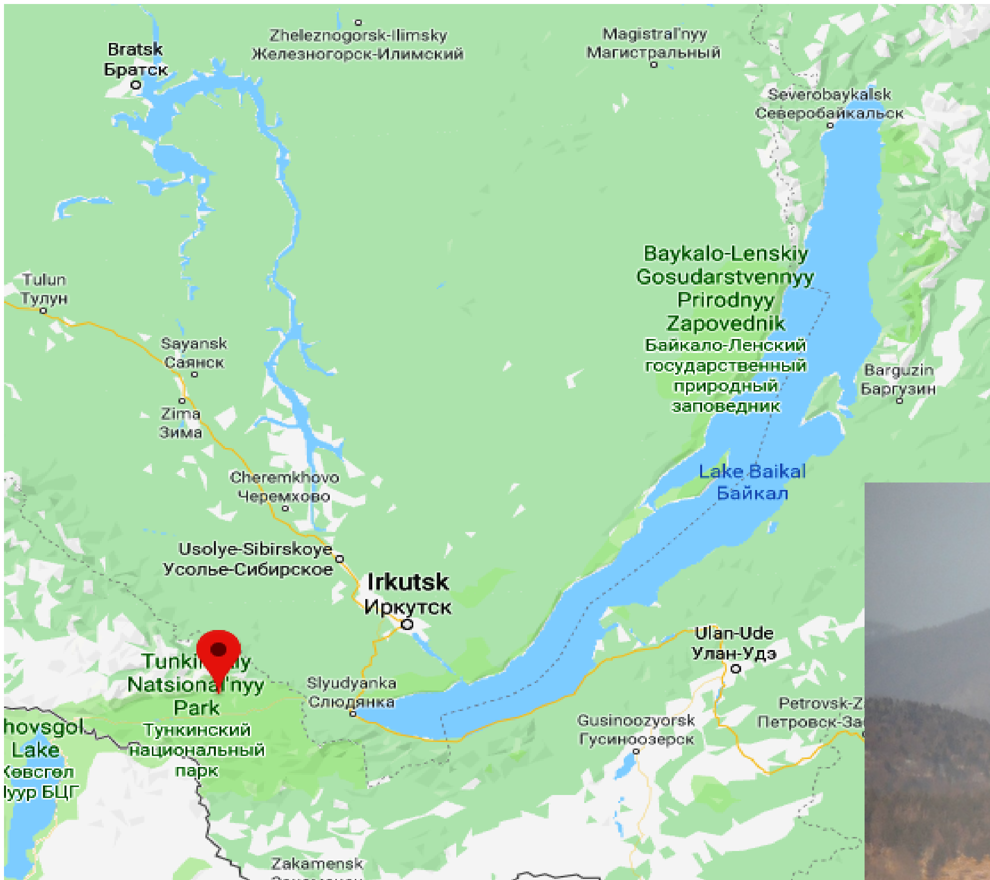
any gamma rays

TeV-PeV

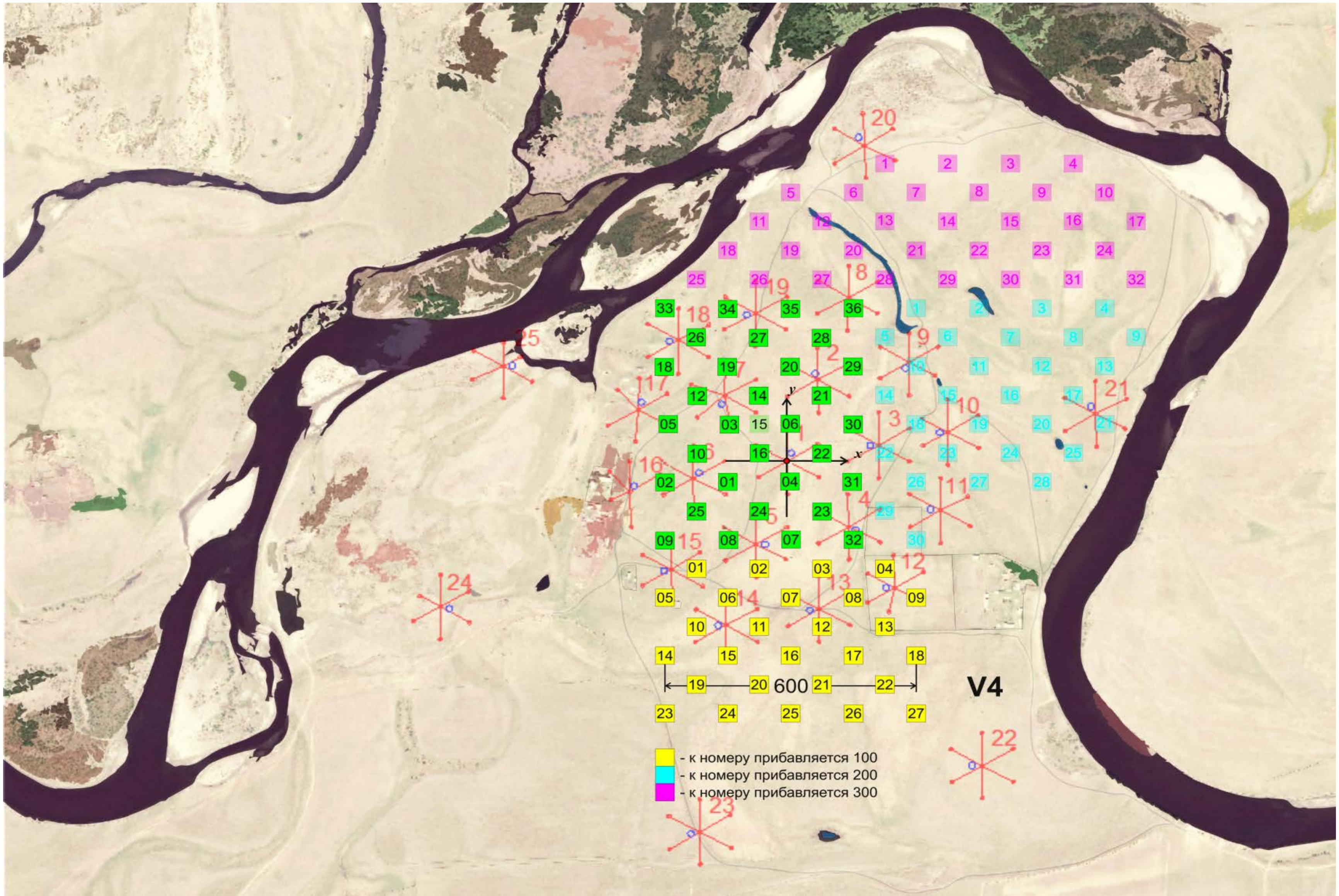
+ their sources

TAIGA

Tunka valley, the Republic of Buryatiya



TAIGA



600
V4
- к номеру прибавляется 100
- к номеру прибавляется 200
- к номеру прибавляется 300

TAIGA (old parts)

Setups for registration of

- Secondary cosmic particles
- Cherenkov light
- Radio emission

from air showers

Tunka-133

Tunka-Grande scintillators

Tunka-Rex antennas

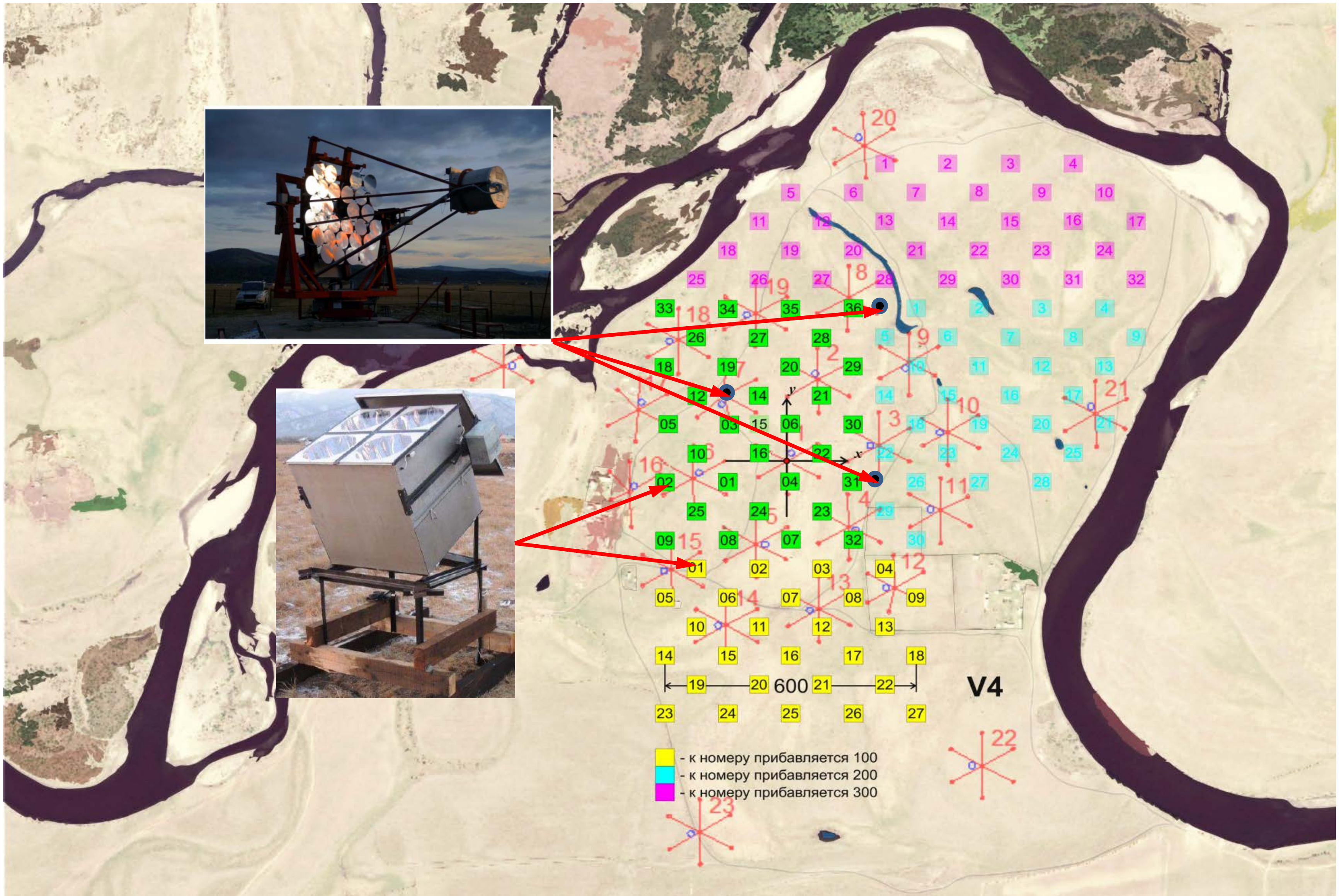
TAIGA (new)

TAIGA-IACT
(Imaging Atmospheric Cherenkov Telescope)

TAIGA-HiSCORE
(High-Sensitivity Cosmic ORigin Explorer)

+ TAIGA-Muon

TAIGA


600
V4
- к номеру прибавляется 100
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- к номеру прибавляется 300

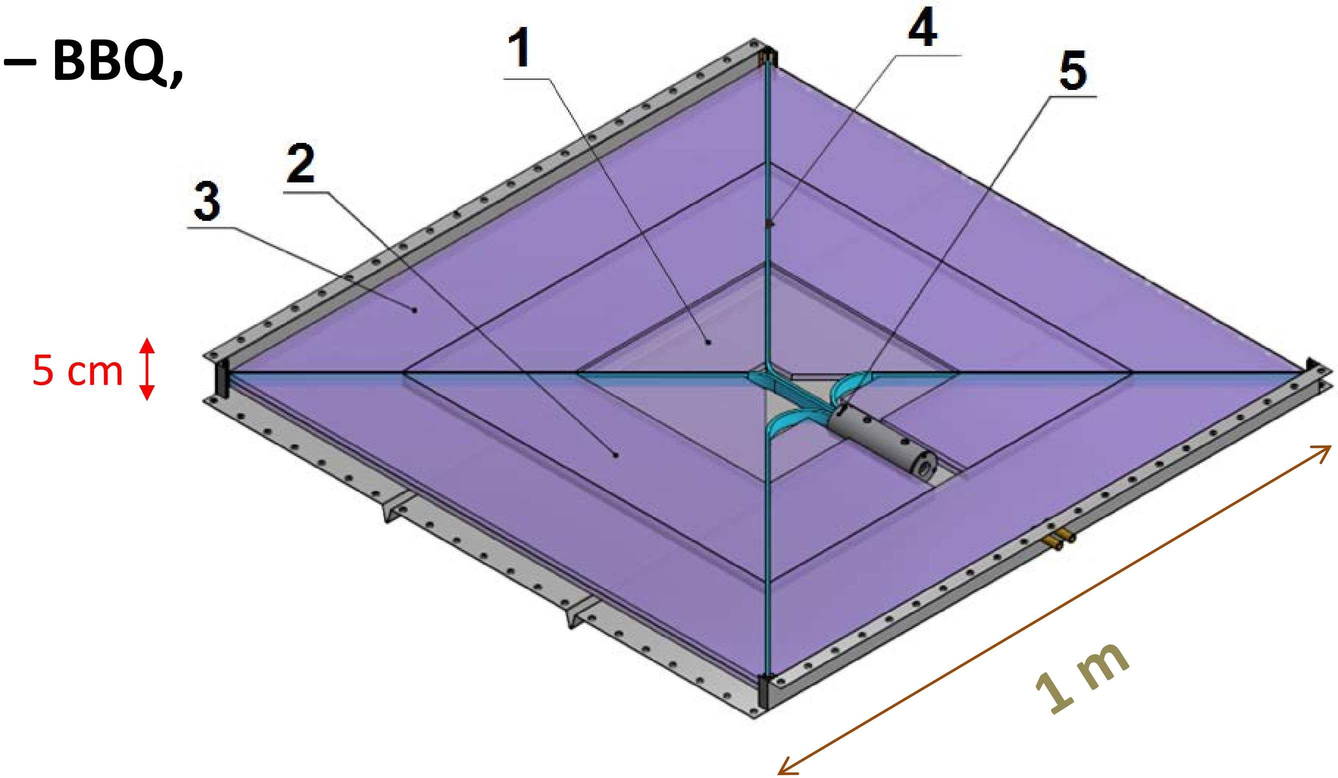
BINP and NSU activities

- Laboratory 3 of Budker INP and Laboratory of New detection technologies PF NSU have developed the muon counter for the TAIGA experiment
- The design of the counter is optimised for operation in severe condition (hermetic, wide temperature diapason ± 50 C);
- The total price of the counter ~ $1500;

Muon scintillation detector

Cross section of the shifters - 5x20 mm²

Reemitting addition – BBQ,
n = 0.1 g/kg



Thickness of

scintillation plates

1,2 – 10 mm

3 - 2x10=20 mm

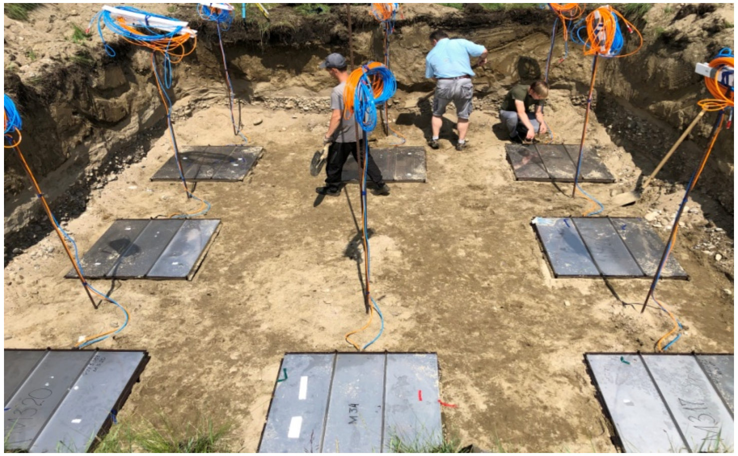
PMT entry window – 25 mm

1, 2, 3 – scintillator (polystyrene + POPOP),
4 – WLS, 5 - PMT

11/21

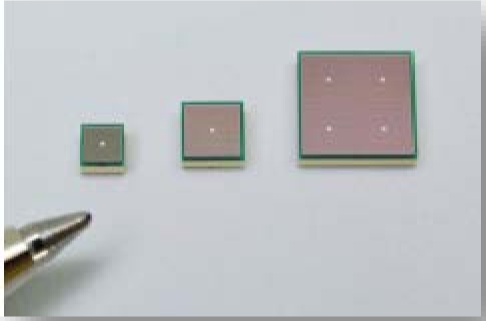
TAIGA-Muon

- Joint project of BINP and NSU
- Installed – 48 counters (3 x 16)
- Total scintillator area-2000 m^2
- Improving of gamma-hadron separation
- Continuous data taking



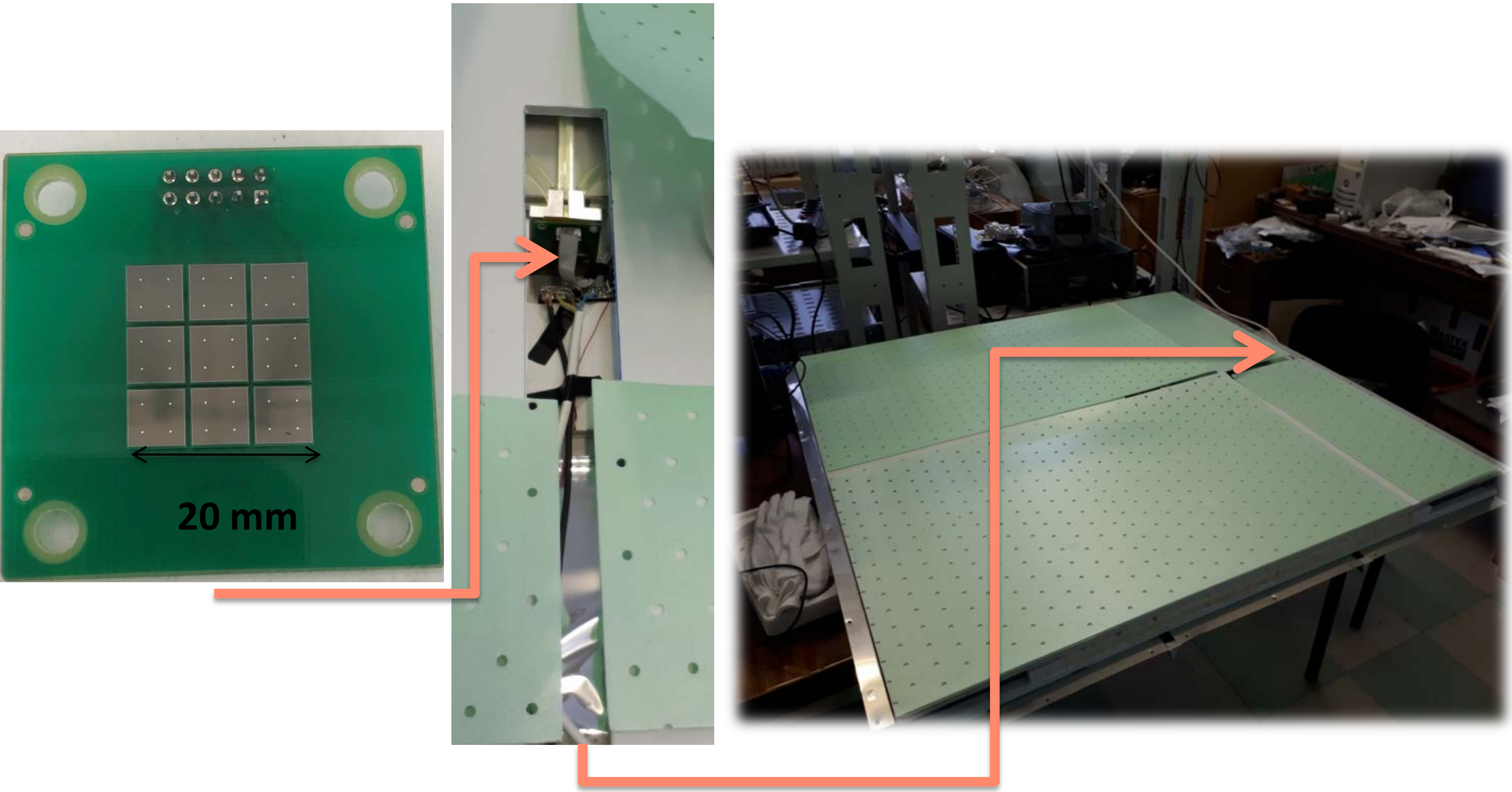
PMT vs SiPM

	PMT	SiPM
Size	10 cm	6 mm
Sensitivity to magnetic fields	yes	no
Operating Voltage	~ 1 kV	~ 50 V
Quantum efficiency	~ 20% (420 nm)	~ 40 %



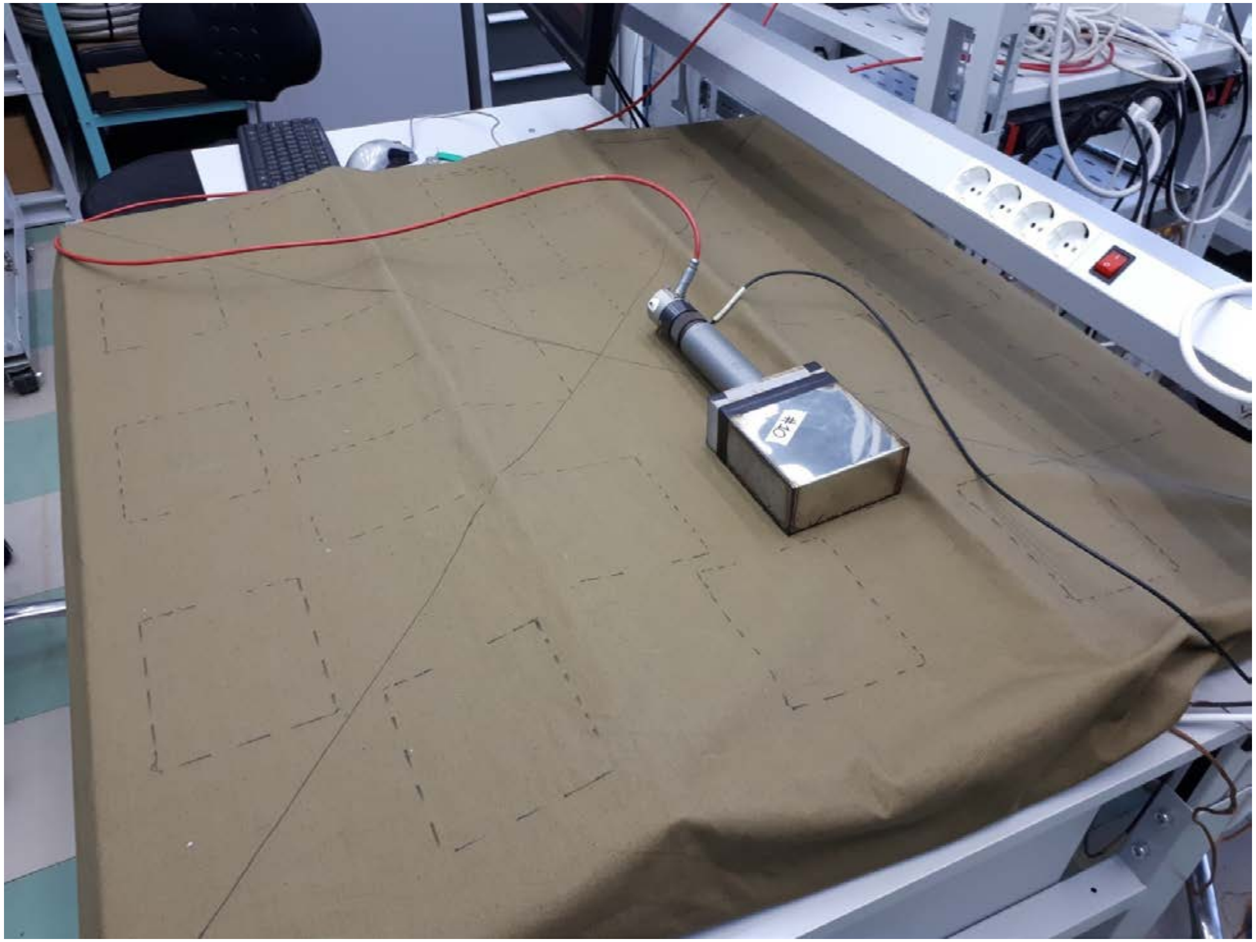
- **SiPM has a long service life, higher rata capabilities and wider spectral range**

Laboratory tests



Hamamatsu S13360-6050VE

Laboratory tests

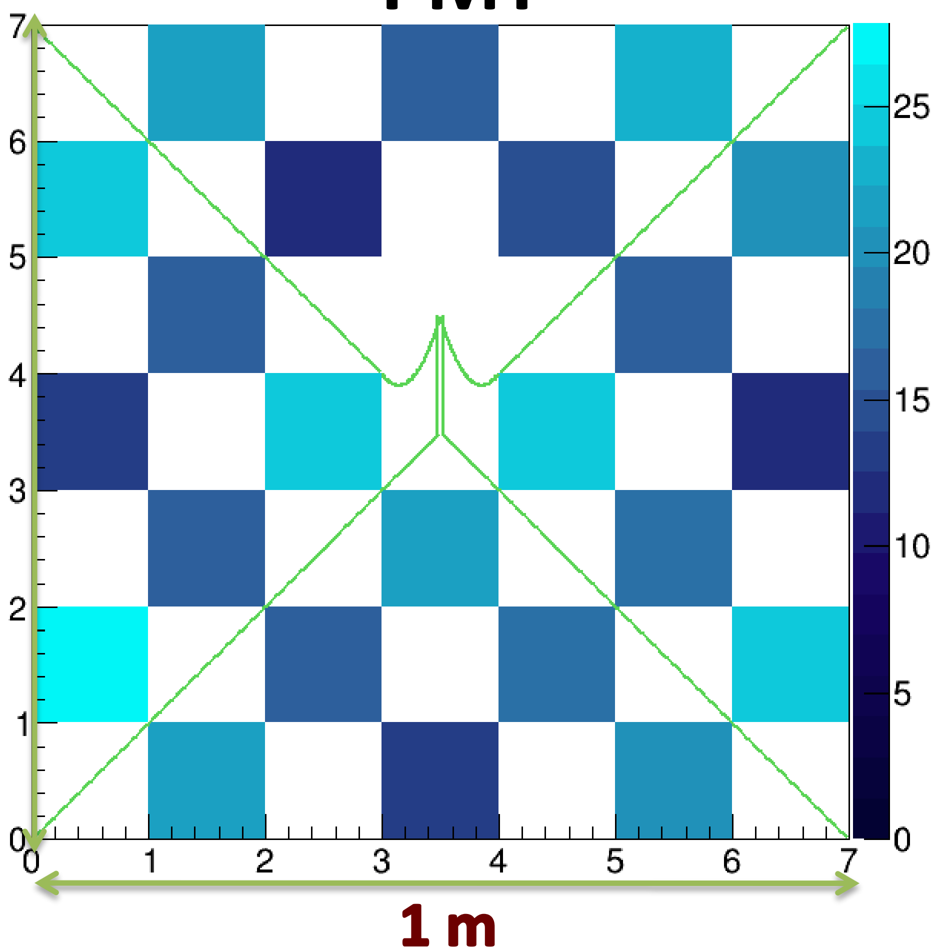


Test results

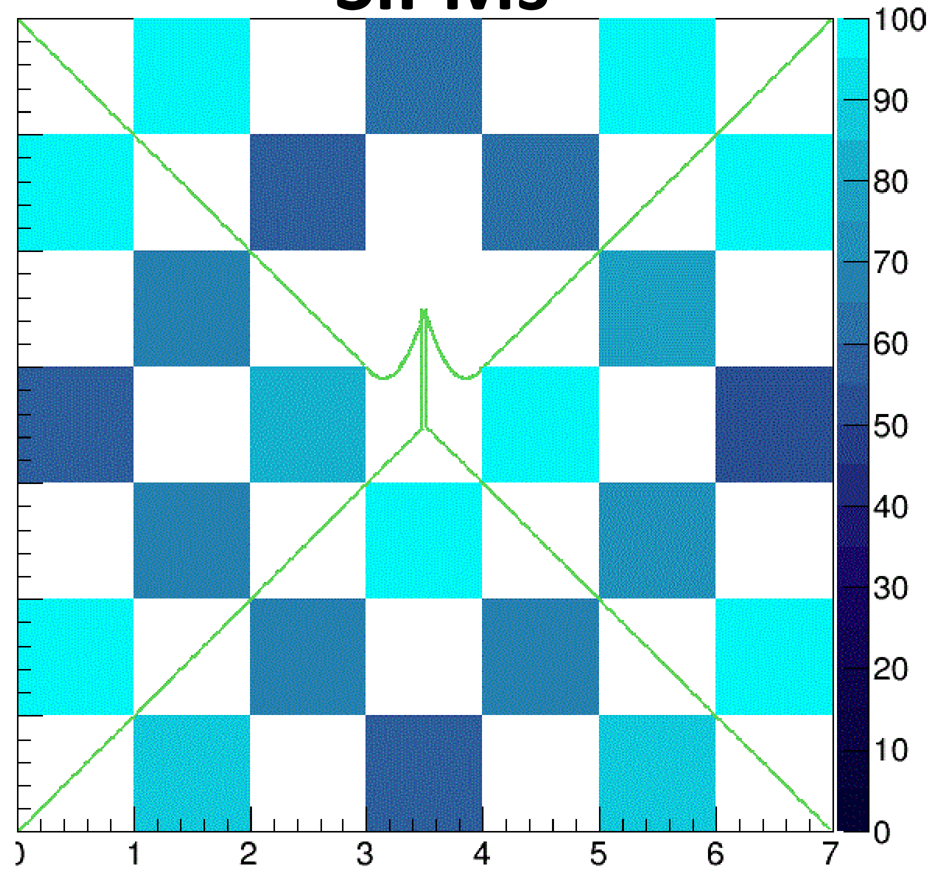
$N_{pe} = Ampl\_{muon} \; / \; Ampl\_{calibration}$

Number of photoelectrons (2D histogram)

PMT



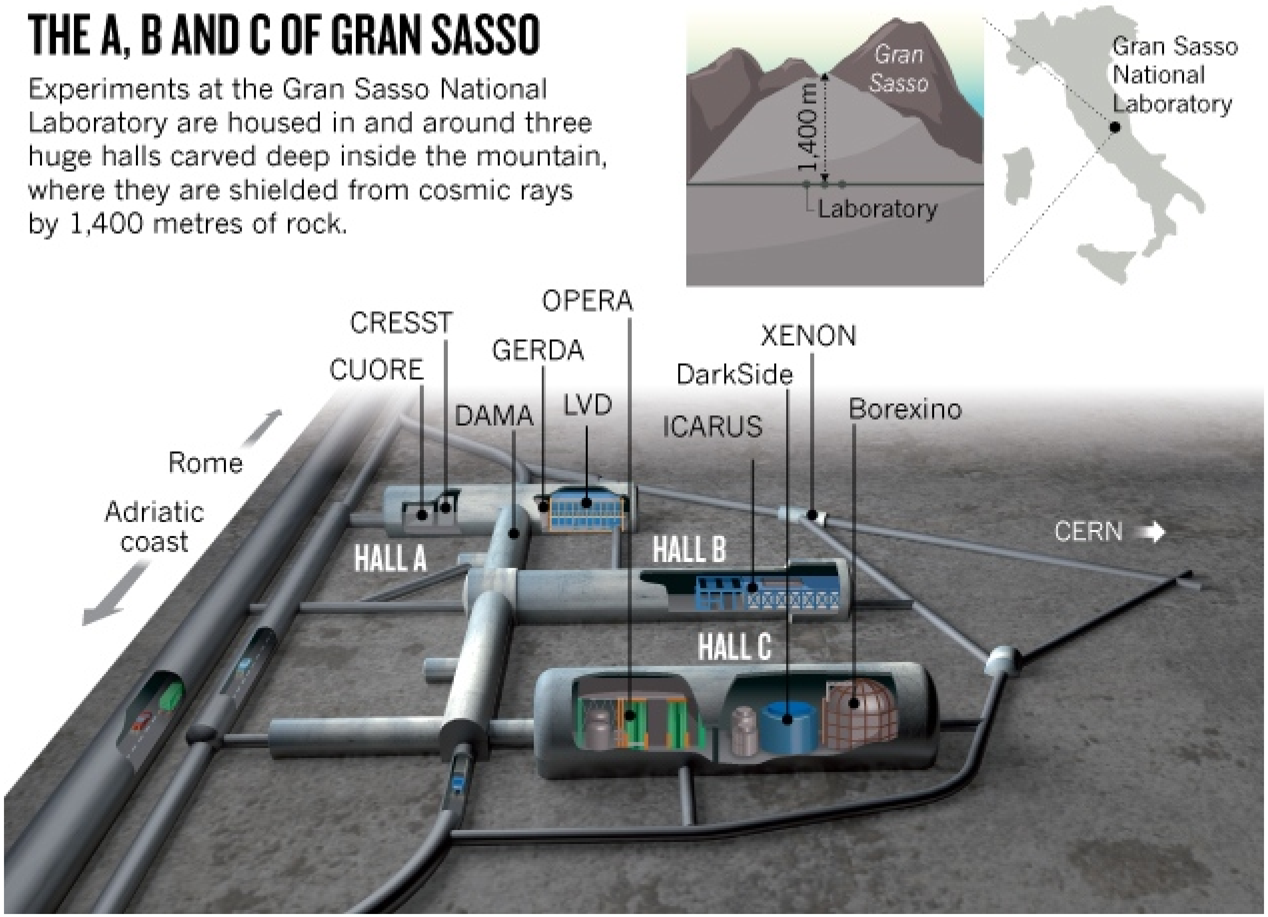
SiPMs



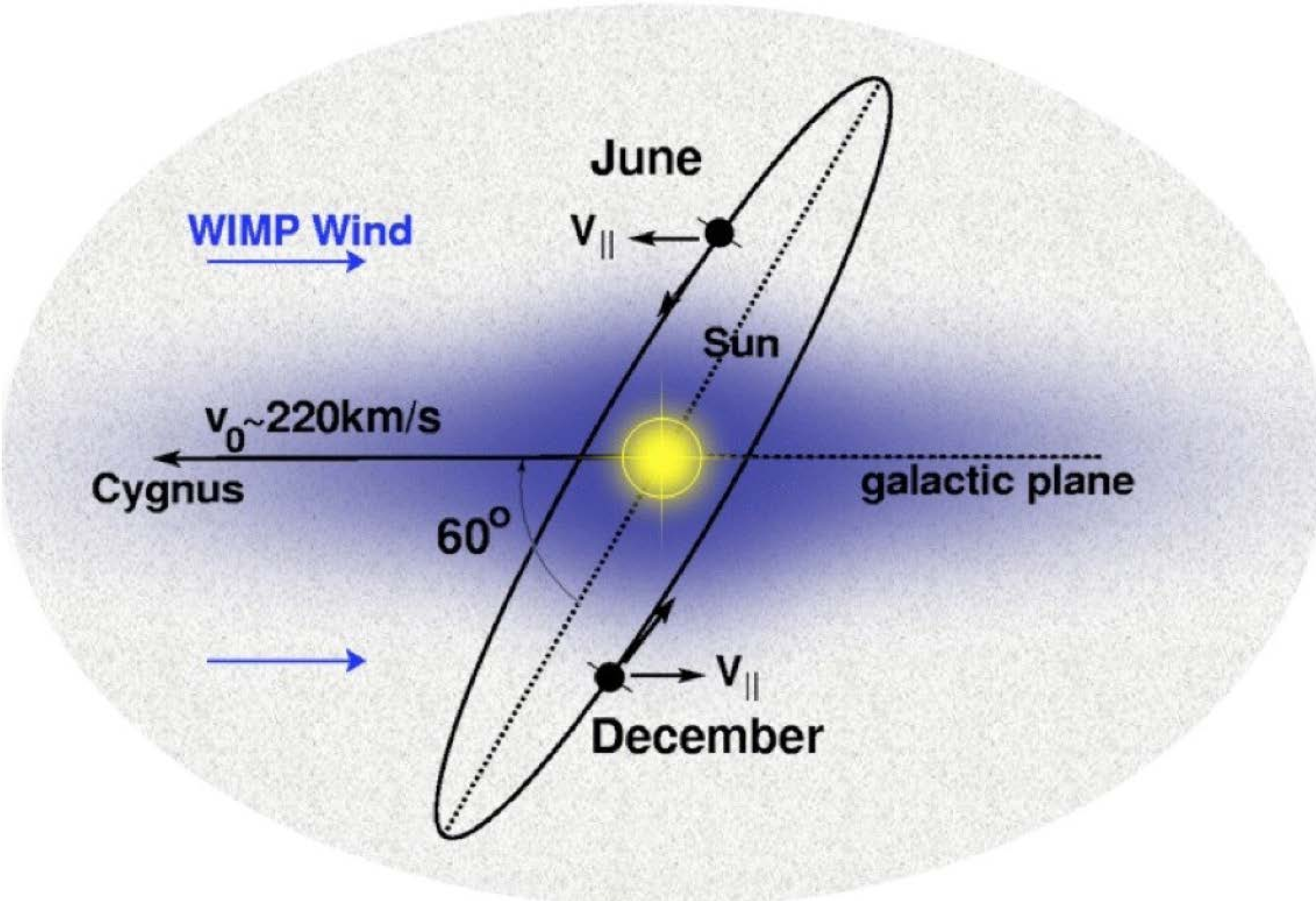
Dark Side experiment

The existence of this “dark matter” is consistent with evidence from large-scale galaxy surveys and cosmic microwave background measurements, which indicate that the majority of matter in the universe is non-baryonic.
The nature of this non-baryonic component is still totally unknown, and the resolution of the “dark matter puzzle” is of fundamental importance to cosmology, astrophysics, and elementary particle physics.

Gran Sasso Underground laboratory

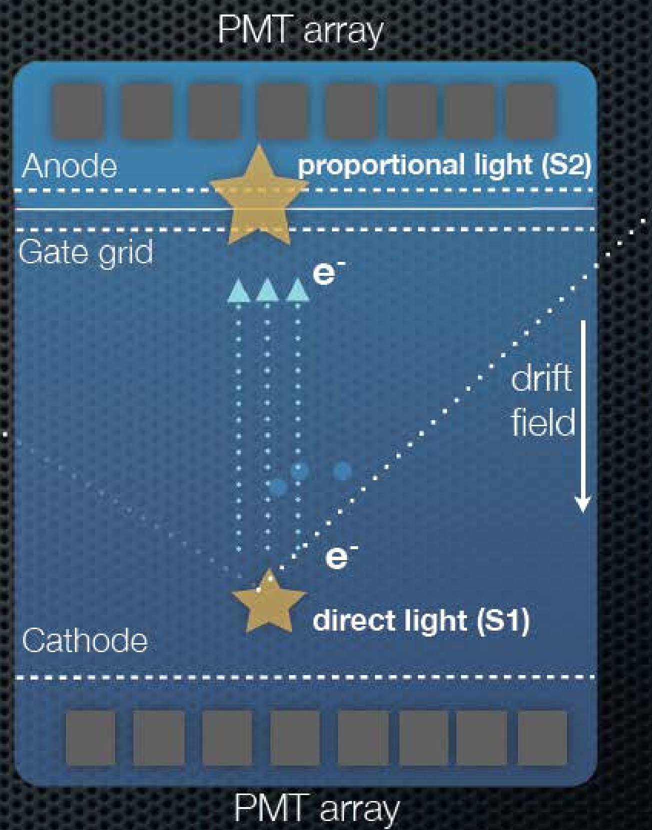


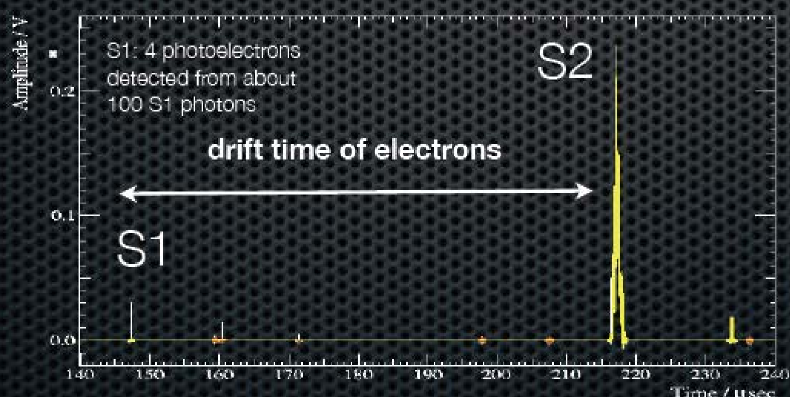
Direct Dark Matter search experiments: principles of detection



Two-phase detectors for rare-event experiments: principles of operation

- *Prompt (S1)* light signal after interaction in the active volume
- Charge is drifted, extracted into the gas phase and detected as *proportional light (S2)*
- *Charge/light depends on dE/dx: particle identification*
- *3D-position resolution: fiducial volume cuts*



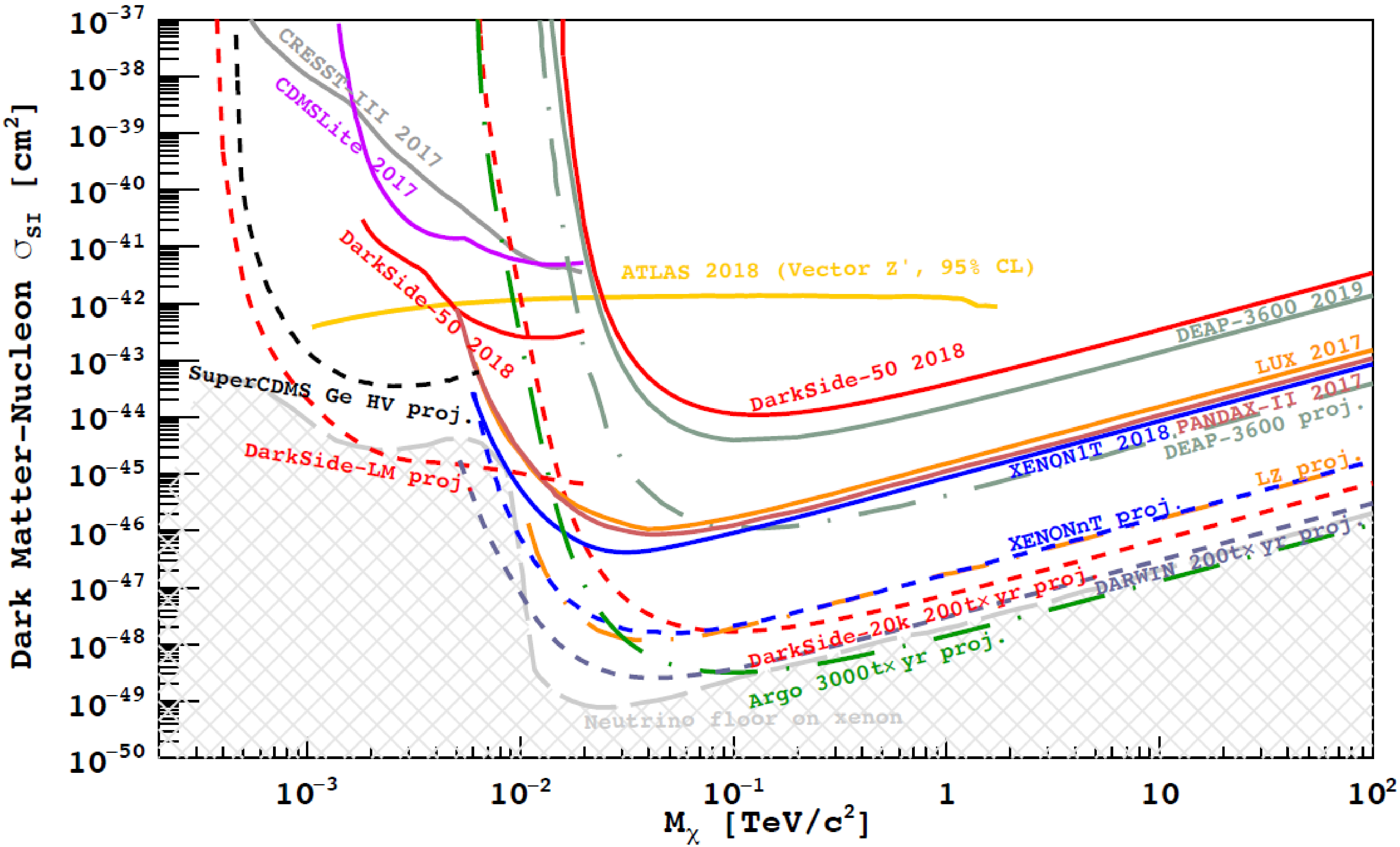


- S2: 645 photoelectrons detected from 32 ionization electrons which generated about 3000 S2 photons

Laura Baudis, University of Zurich, VCI2013, Vienna

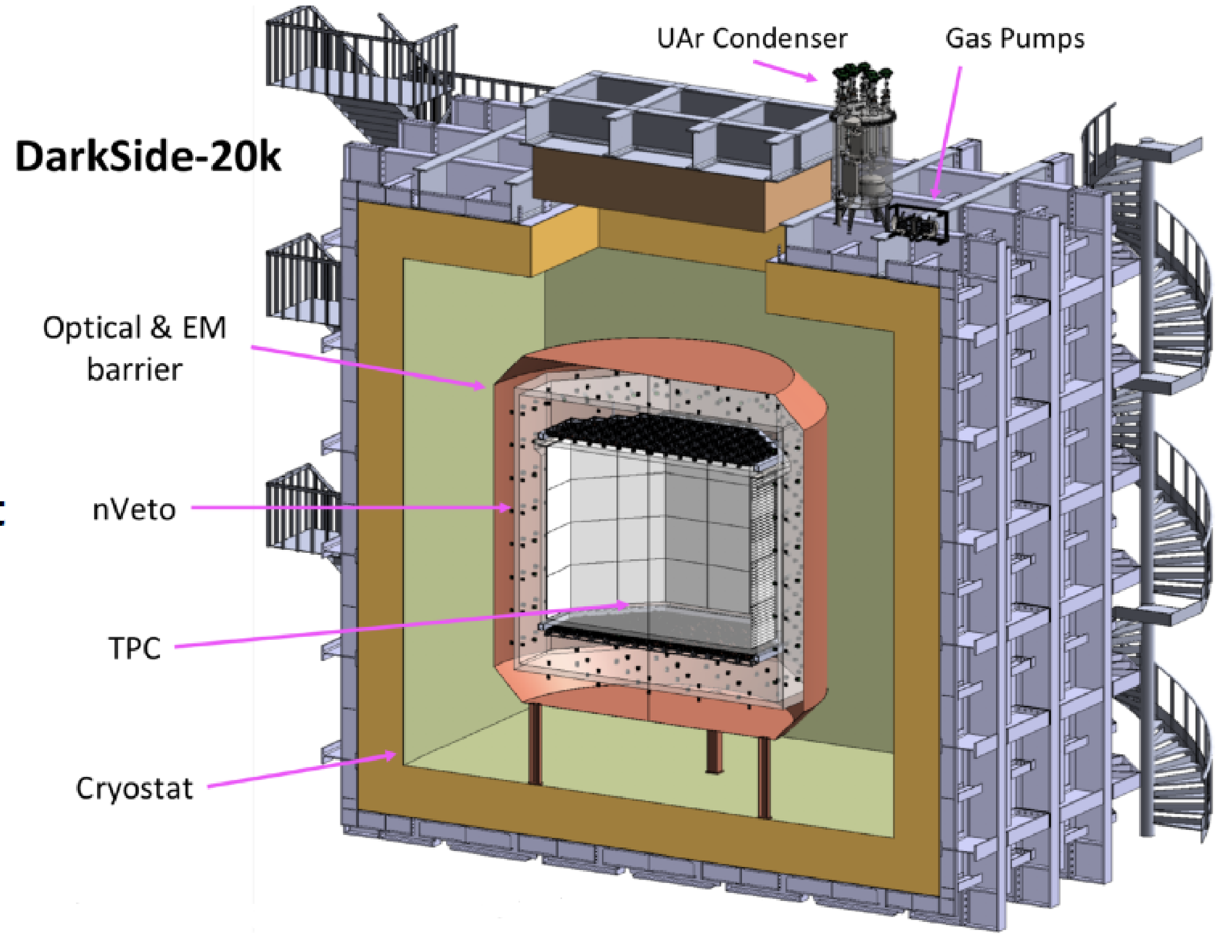
L. Baudis, VCI 2013 talk

Sensitivity



DarkSide-20k

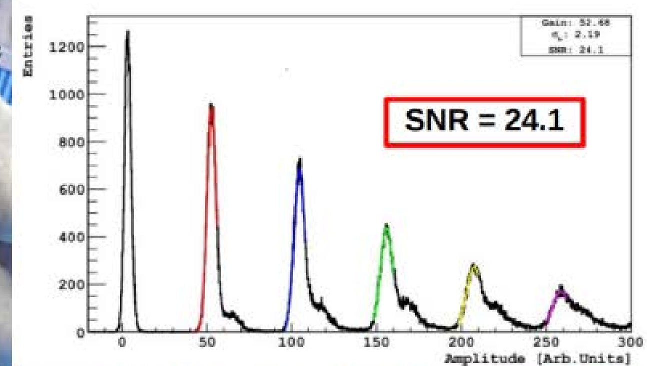
- Sealed acrylic TPC filled with Underground Argon (UAr): 50 tonnes in total
- Membrane cryostat filled with Atmospheric Argon (AAr): based on the ProtoDUNE cryostat
- 2% Gd doped acrylic panels as neutron veto
- SiPMs as photosensors: 8280 channels in TPC, ~3000 channels in Veto



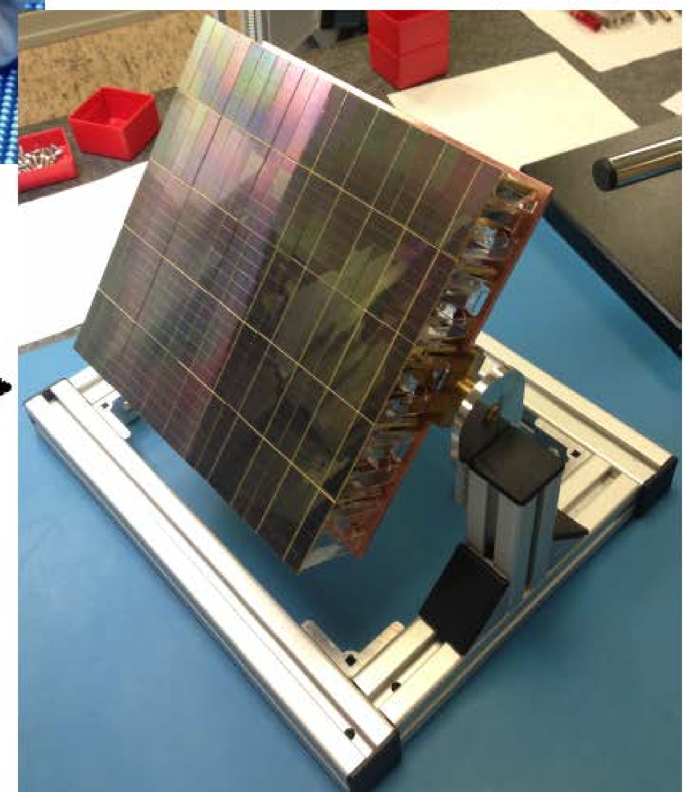
SiPMs as the photosensors

- Compact, increase the coverage
- PDE ~50%
- Good performance at LAr temperatures
- SiPM customization for cryogenic temperatures (FBK)
- SiPM Mass production (LFoundry)
- Packaging of the tiles and the cold electronics (NOA, L'Aquila)
- Full production chain largely funded by Regione Abruzzo, Italy

5cm x 5cm

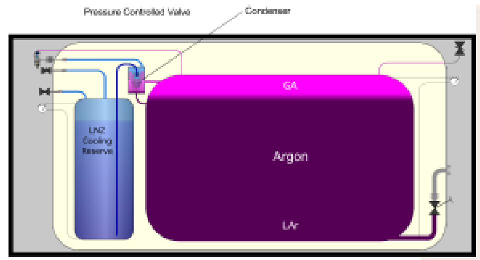


25 PDMs in one motherboard

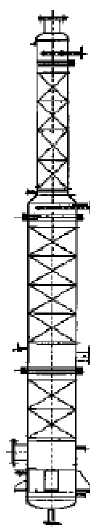


Underground Ar for DS-20k

- URANIA
- Procurement of 50 tonnes of UAr from same Colorado source as for DS-50
- Extraction of 250 kg/day, with 99.9% purity, 90 tonnes / year for the longer term
- UAr transported to Sardinia for final chemical purification at Aria



Seruci-0
Picture was taken during the installation



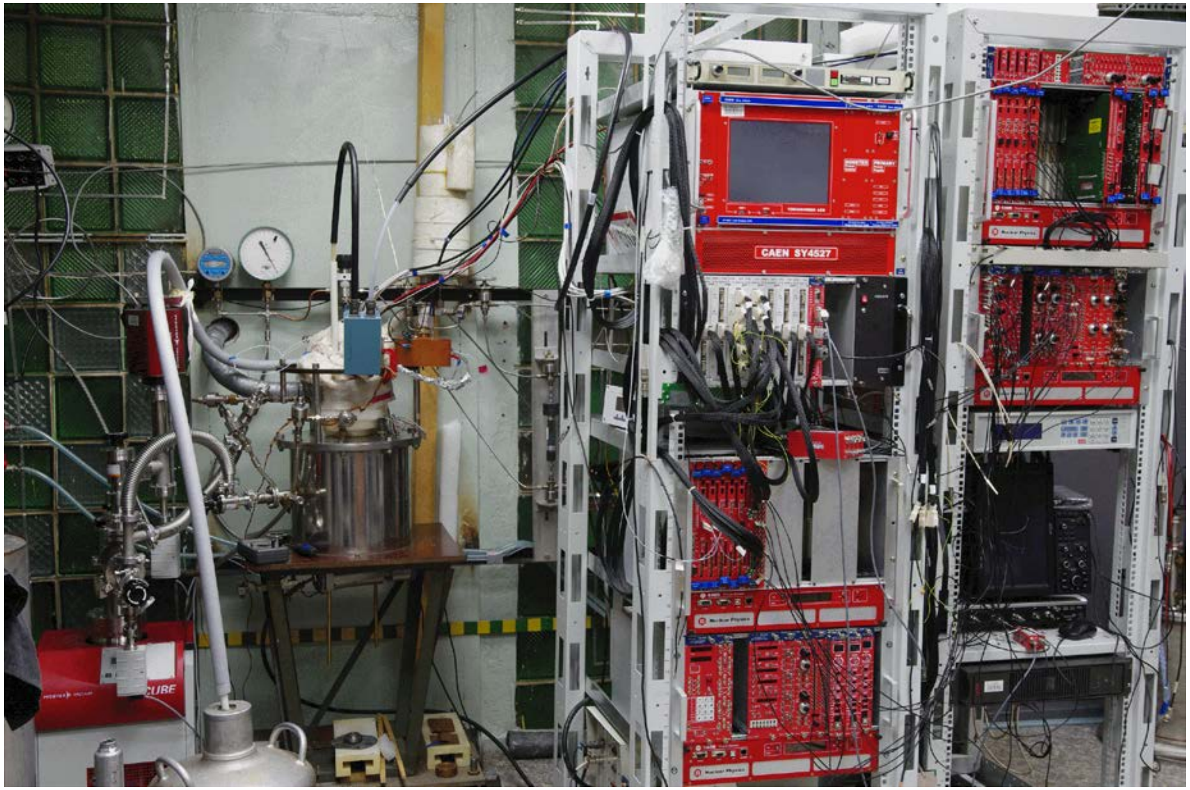
Seruci-I
Seruci-II

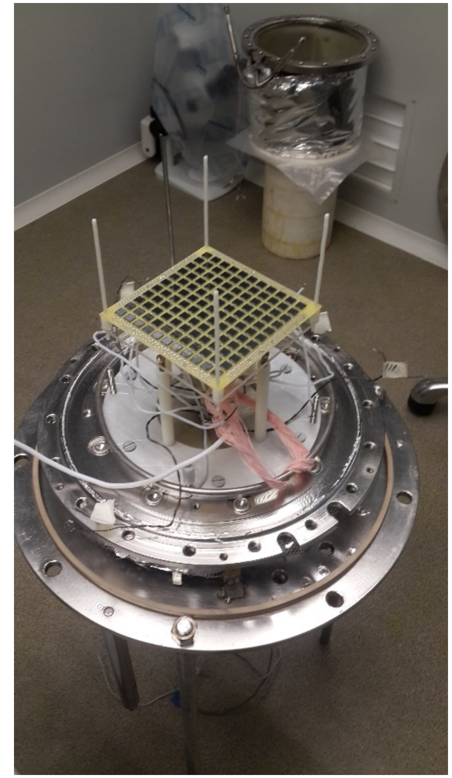
- ARIA
- Big cryogenic distillation column in Seruci, Sardinia, Italy
- Final chemical purification of the UAr
- Process O (1 tonne / day) with 10^3 reduction of all chemical impurities
- Isotopically separate ^{39}Ar from ^{40}Ar

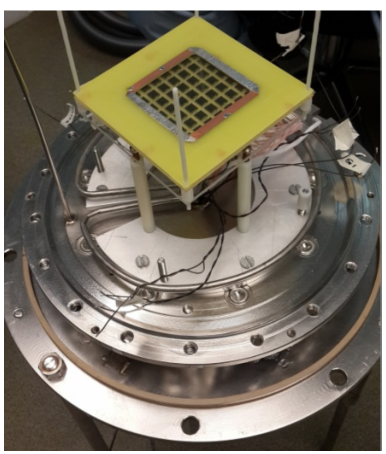
BINP and NSU activities

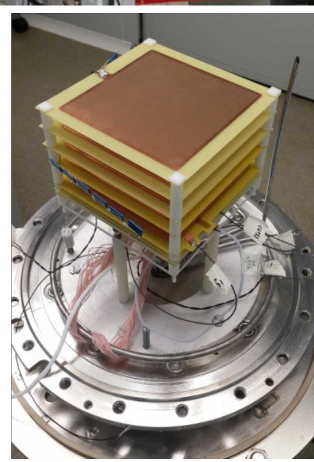
- Laboratory 3 of Budker INP and Laboratory of Cosmology and Elementary Particles PF NSU have 20 year experience in the development of the dual phase xenon and argon calorimeters for the low background experiment.
- We developed an original optical readout technique and made a pioneering studies of the GEM operation in the pure noble gas vapors at the cryogenic temperatures.
- We join the DarkSide-20K collaboration 3 years ago and doing the R’n’D studies for that experiment.

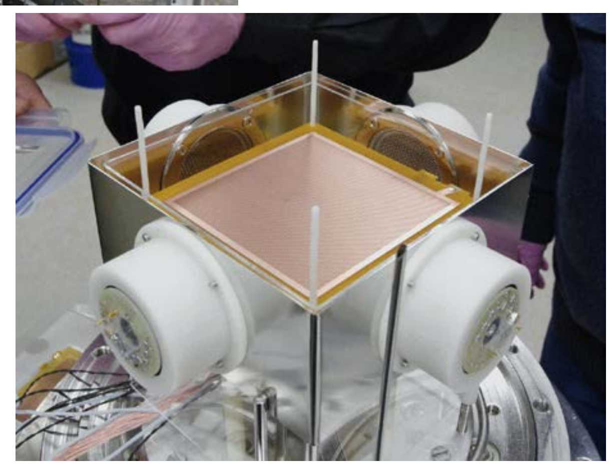
Experimental setup



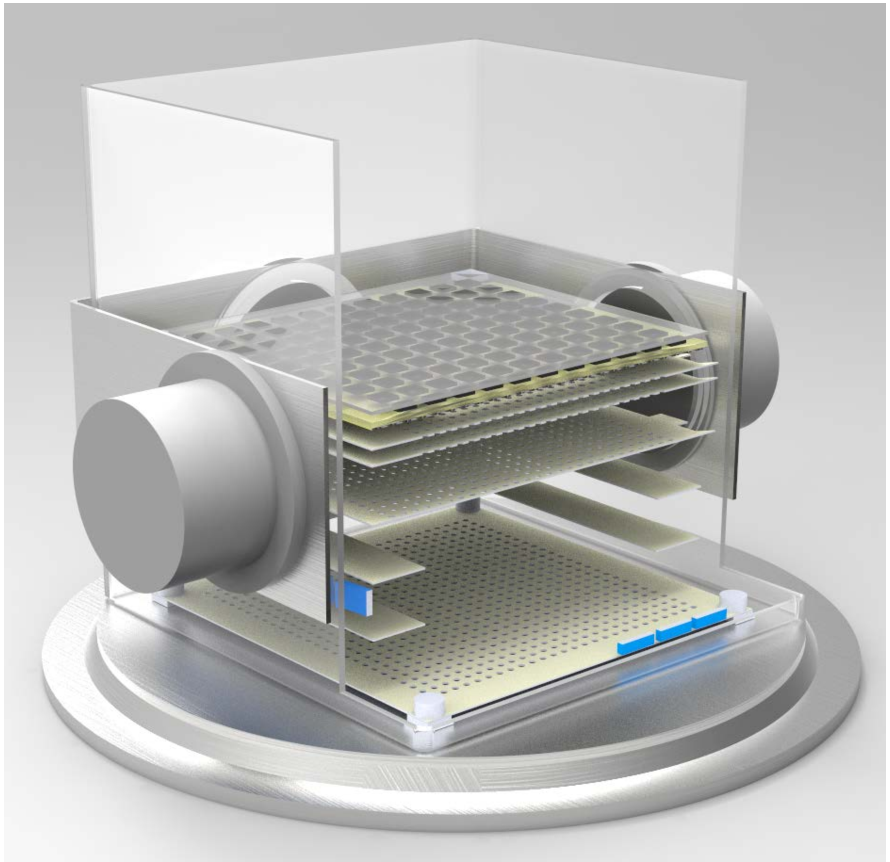


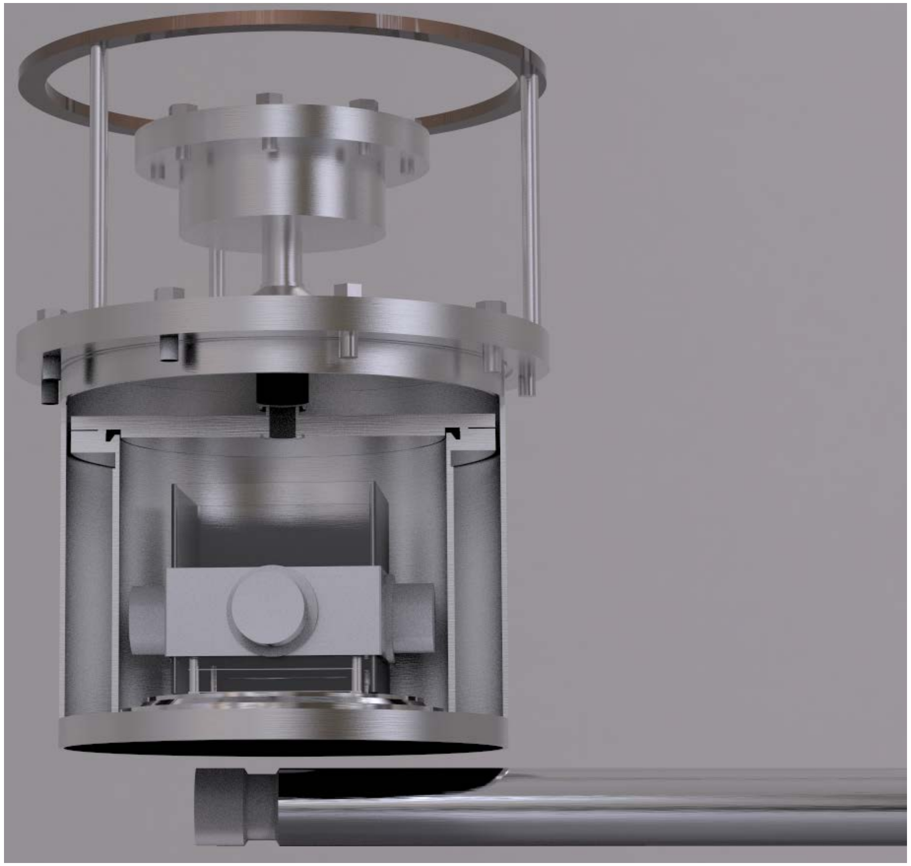




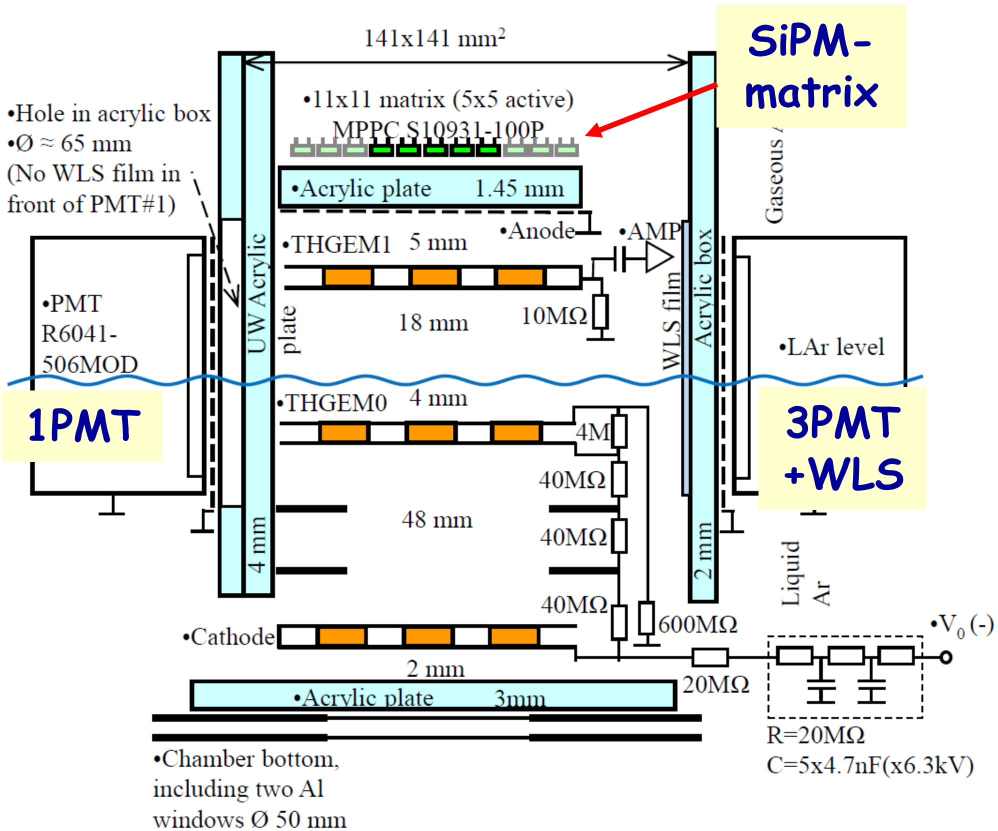


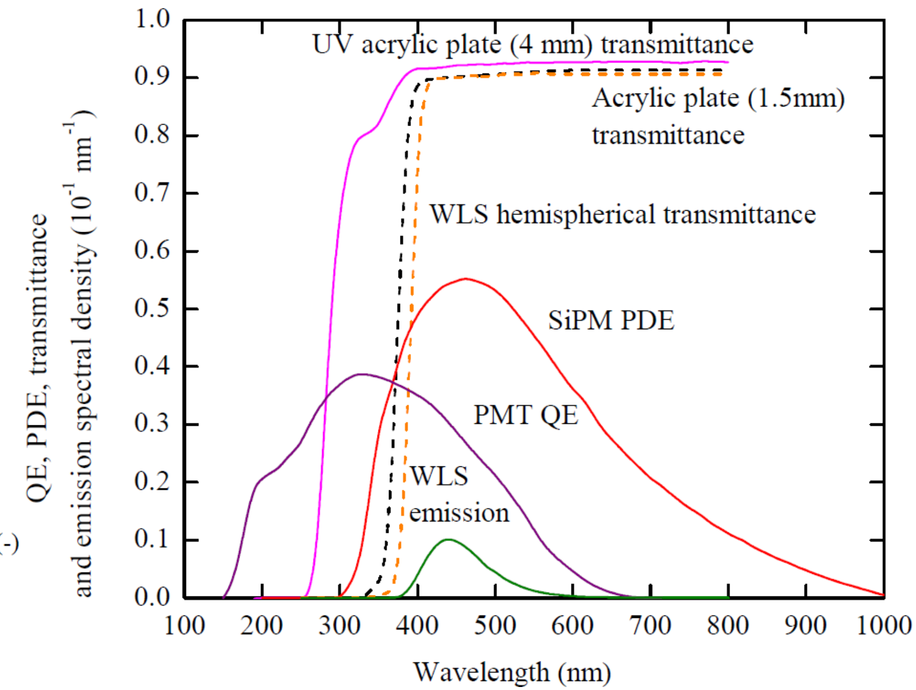
Experimental setup





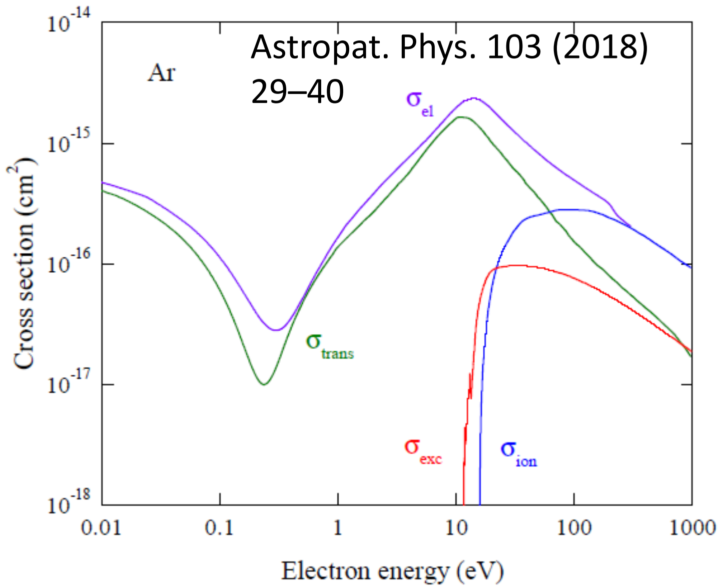
Experimental setup





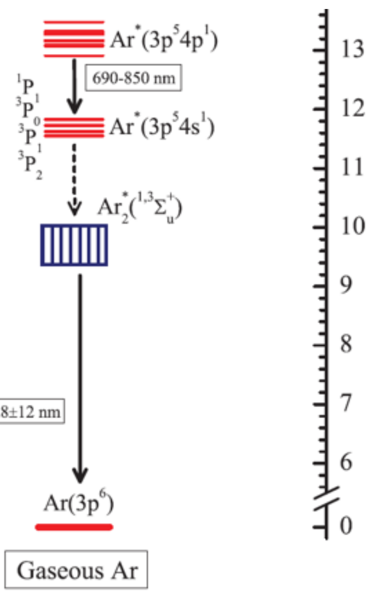
Taking into account light propagation through acrylic plates and WLS, the detectors were sensitive in the following wavelength regions:
1PMT (bare PMT): 300-650 nm (via direct recording)
3PMT+WLS: 100-650 nm (at <400 nm via re-emission in WLS, at >400 nm via direct recording)
SiPM-matrix: 400-1000 nm (via direct recording)

Ordinary mechanism of proportional electroluminescence

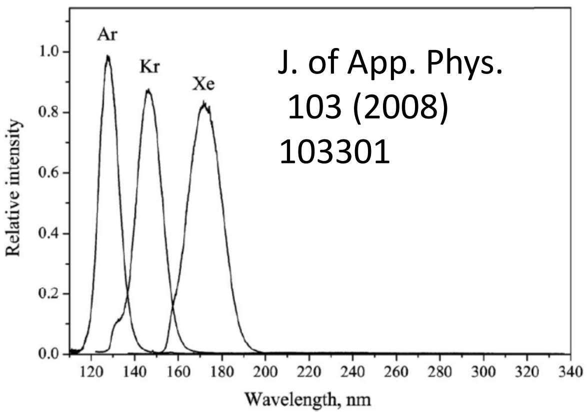


- **Between collisions with atoms, drifting electrons are accelerated by an electric field and their kinetic energy increases.**
- **At a reduced field of more than 4Td (1Td = 0.87 kV/cm at 87K), electrons excite atoms to the group of lower excited levels $3p^5 4s^1$.**
- **As a result of triple collisions, excimers are formed - excited molecules Ar_2^*.**
- **Excimers decay with emission in VUV with an average wavelength of 128 nm.**

EPL, 117 (2017) 39002

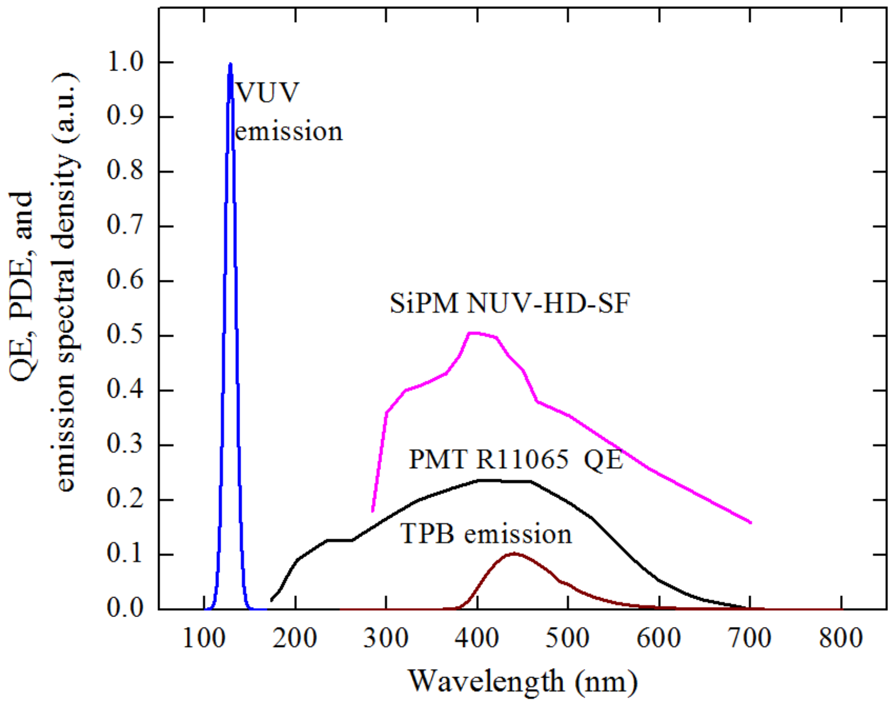


$$e^- + Ar \rightarrow e^- + Ar^* ,$$
$$Ar^* + 2Ar \rightarrow Ar_2^* + Ar ,$$
$$Ar_2^* \rightarrow 2Ar + h\nu .$$



J. of App. Phys. 103 (2008) 103301

Ordinary mechanism of proportional electroluminescence



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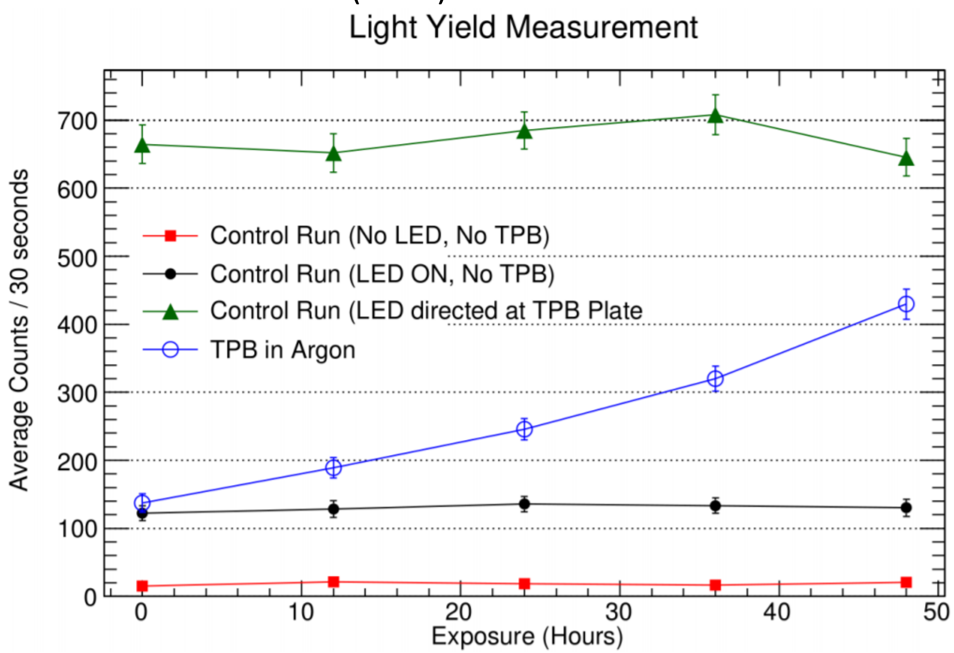
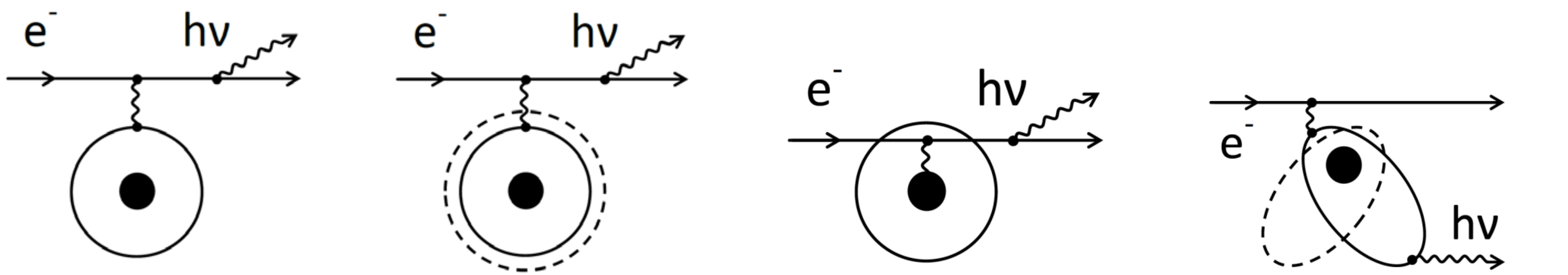


- Since PMTs and SiPMs are not sensitive to the VUV range, for recording the radiation one has to use wavelength shifter (WLS) to convert VUV radiation into visible light.
- There are some problems with WLS: decrease in re-emission efficiency, dissolution in LAr and detachment from surfaces - these effects lead to signal instability.
- For example, it was shown in one paper that S1 signal increases with time due to TPB dissolution in LAr and as a consequence increasing of light collection.
- Thus, the question arises: is it possible to refuse WLS?

Types of bremsstrahlung

Neutral bremsstrahlung is produced by *slow* (~10 eV) electrons when they are scattered (elastically or inelastically) on neutral atoms.

$e^- + A \rightarrow e^- + A + h\nu$ $\quad$ $e^- + A \rightarrow e^- + A^* + h\nu$



Neutral bremsstrahlung in elastic scattering — Neutral bremsstrahlung in inelastic scattering — Ordinary bremsstrahlung — Polarization bremsstrahlung

At such electron energies, the contribution of ordinary bremsstrahlung (produced in the Coulomb field of a nucleus) and polarization bremsstrahlung (produced by atoms due to their time-dependent polarization) is negligible.

Mechanism of neutral bremsstrahlung (NBrS)

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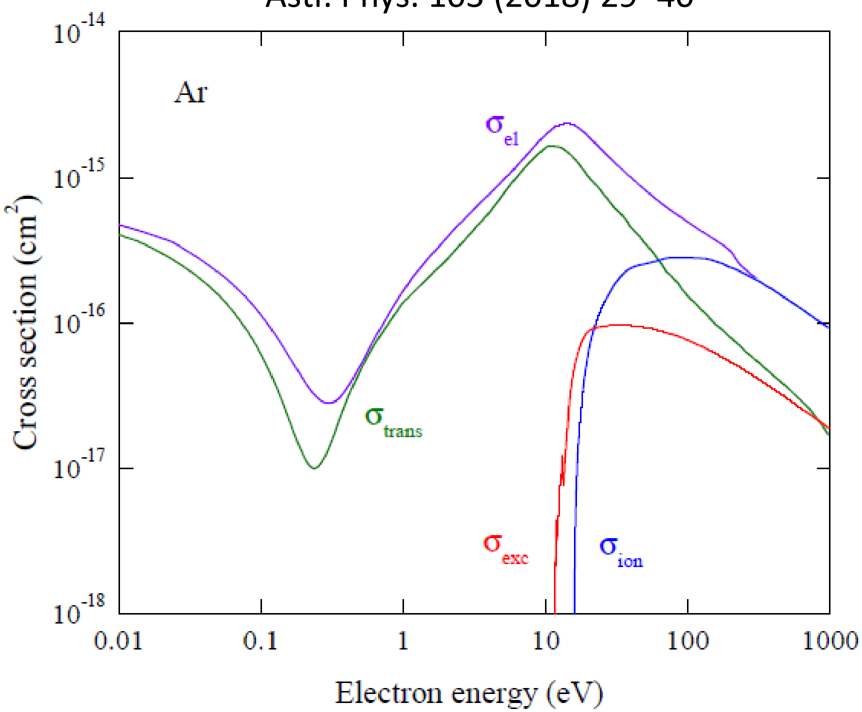

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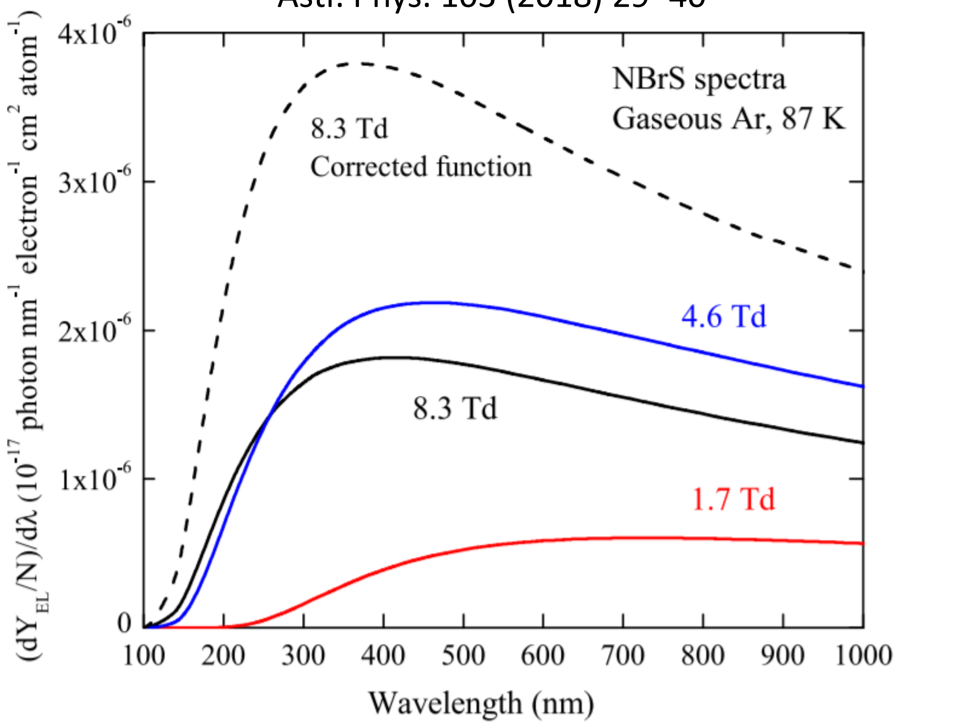
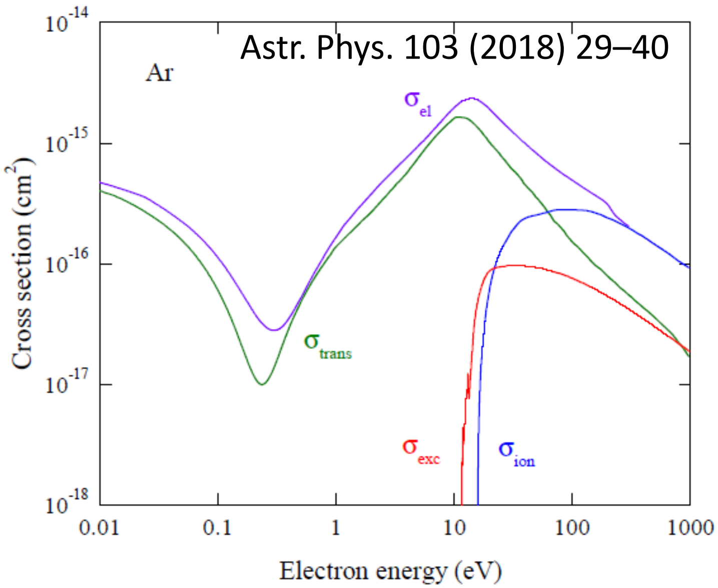
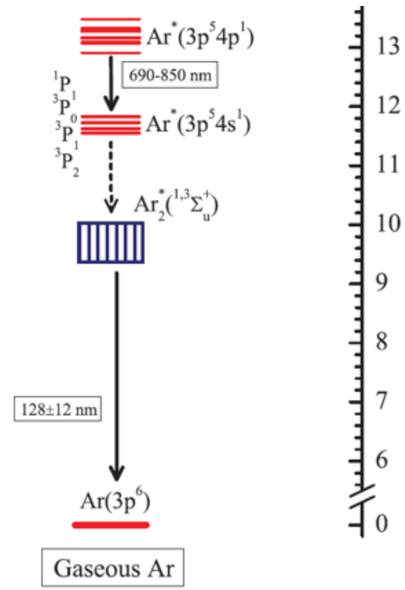
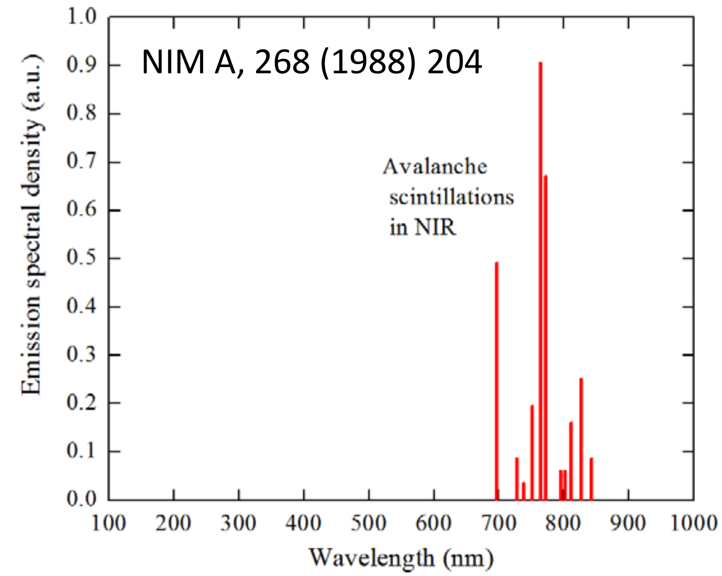


- It is based on bremsstrahlung of drifting electrons scattered on neutral atoms.
- e- + A -> e- + A + hν.
- This radiation mechanism does not have an energy threshold.
- NBrS electroluminescence has a continuous emission spectrum, extending from the UV to the visible and NIR range

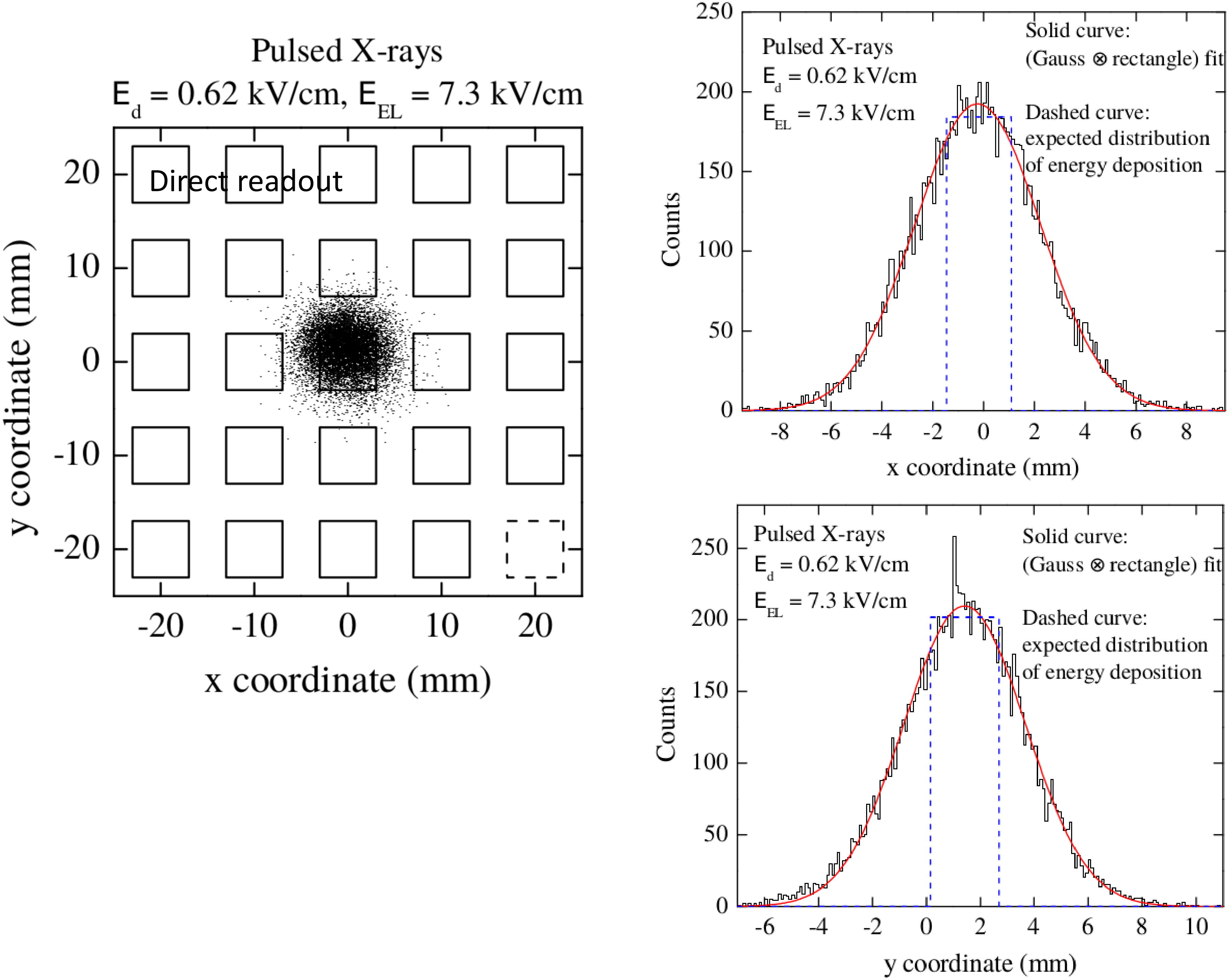
Mechanism of electroluminescence in NIR







- When the electric field in a gas exceeds 8 Td, additional mechanism arises, namely EL in the NIR range, due to transitions between 2 groups of excited levels – $3p^54p^1$ and $3p^54s^1$.
- Such EL has a linear spectrum in the NIR range.
- This mechanism is particularly noticeable at even higher fields, above 20 Td, where the avalanche multiplication of the electrons takes place, accompanied by corresponding secondary scintillations: by so-called "avalanche scintillations".



Pulsed X-rays
E_d = 0.62 kV/cm, E_{EL} = 7.3 kV/cm
Direct readout
y coordinate (mm)
x coordinate (mm)
Pulsed X-rays
E_d = 0.62 kV/cm
E_{EL} = 7.3 kV/cm
Solid curve:
(Gauss ⊗ rectangle) fit
Dashed curve:
expected distribution
of energy deposition
Counts
x coordinate (mm)
Pulsed X-rays
E_d = 0.62 kV/cm
E_{EL} = 7.3 kV/cm
Solid curve:
(Gauss ⊗ rectangle) fit
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Counts
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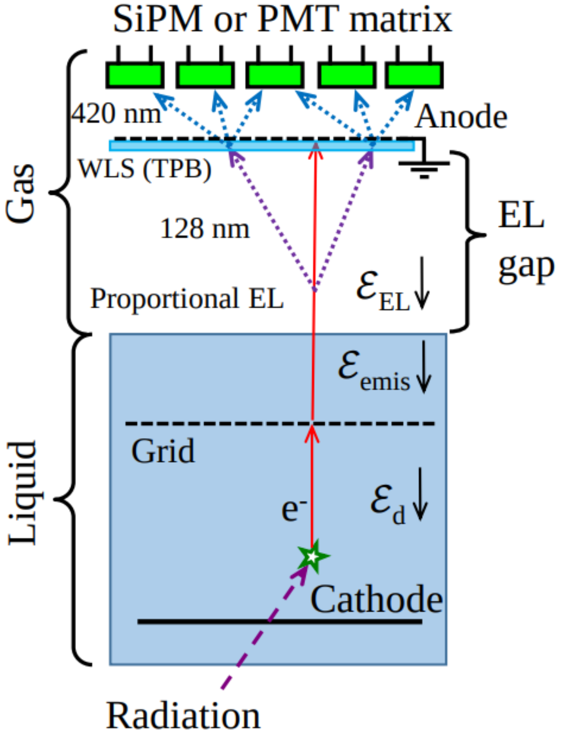
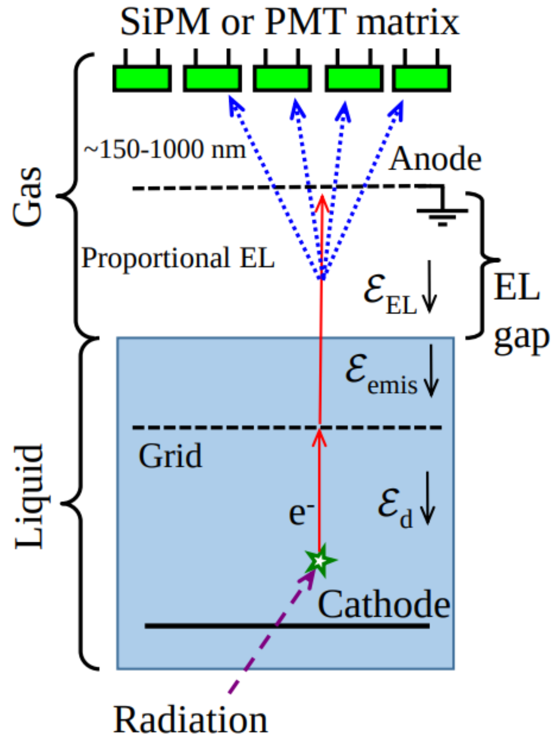
Readout concepts

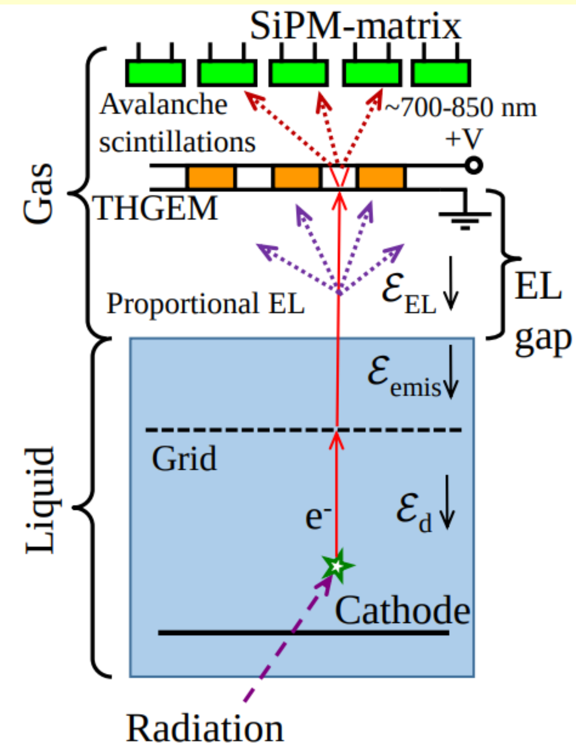
"Standard" concept



Concept of direct readout



THGEM/SiPM-matrix readout



- Three readout concepts (conceptual designs of the detector) can be distinguished, which correspond to the three EL mechanisms.
- In "standard" concept WLS must be used (ordinary mechanism of EL).
- In concept of direct readout WLS can just be removed (mechanism of NBrS).
- In concept based on THGEM/SiPM-matrix readout Thick Gas Electron Multiplier is used to create high field (mechanism of avalanche scintillations).

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Revealing neutral bremsstrahlung in two-phase argon electroluminescence

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ABSTRACT

Proportional electroluminescence (EL) in noble gases has long been used in two-phase detectors for dark matter search, to record ionization signals induced by particle scattering in the noble-gas liquid (S2 signals). Until recently, it was believed that proportional electroluminescence was fully due to VUV emission of noble gas excimers produced in atomic collisions with excited atoms, the latter being in turn produced by drifting electrons. In this work we consider an additional mechanism of proportional electroluminescence, namely that of bremsstrahlung of drifting electrons scattered on neutral atoms (so-called neutral bremsstrahlung); it is systemically studied here both theoretically and experimentally. In particular, the

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Neutral bremsstrahlung in two-phase argon electroluminescence: further studies and possible applications

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ABSTRACT

We further study the effect of neutral bremsstrahlung (NBrS) in two-phase argon electroluminescence (EL), revealed recently in Buzulutskov et al. (2018). The absolute EL yield due to NBrS effect, in the visible and NIR range, was remeasured in pure gaseous argon in the two-phase mode, using a two-phase detector with EL gap read out directly by cryogenic PMTs and SiPMs. Possible applications of the NBrS effect in detection science are discussed, including those in two-phase dark matter detectors.

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SiPM-matrix readout of two-phase argon detectors using electroluminescence in the visible and near infrared range

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Abstract

Proportional electroluminescence (EL) in noble gases is used in two-phase detectors for dark matter search to record ionization signals in the gas phase, induced by particle scattering in the liquid phase (S2 signals). The "standard" EL mechanism is considered to be due to noble gas excimer emission in the vacuum ultraviolet (VUV). In addition

Conclusions

- Budker INP is actively participating in the cosmic-ray experiments
- The mass production of the muon detectors for TAIGA experiment is started
- BINP group is participated in the R’n’D studies for the future DarkSide-20k experiment