



NUCLEAR EMULSIONS FOR WIMP SEARCH

directional measurement

Giovanni De Lellis

NEWS Collaboration

70 physicists, 14 institutes from 5 countries



news-dm.lngs.infn.it

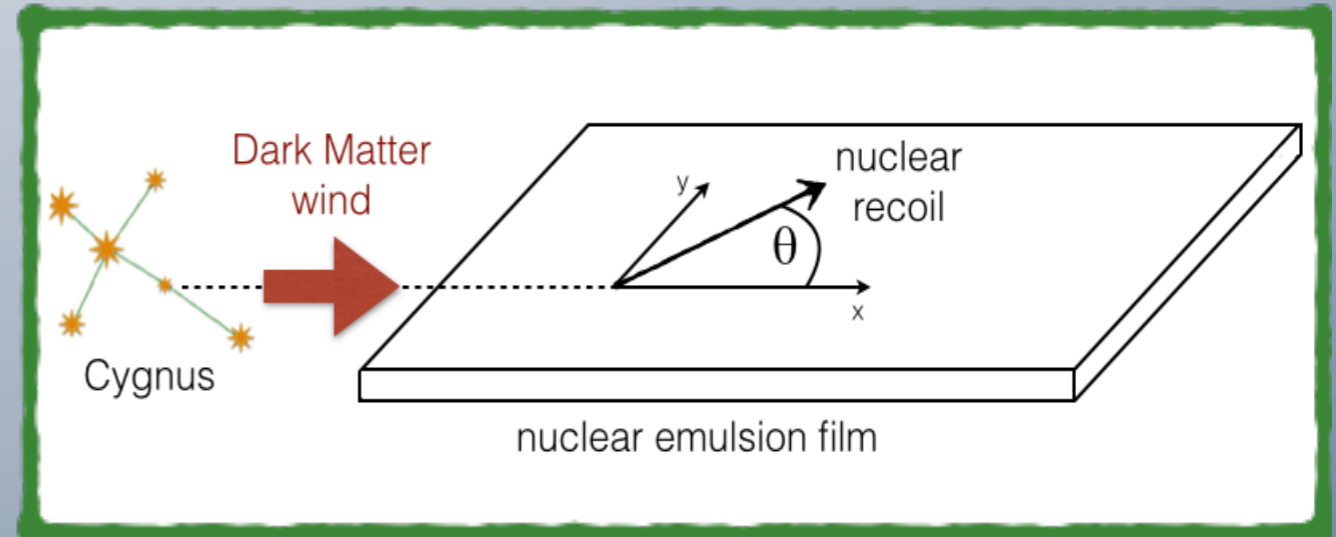
Napoli, 23 May 2017

STATUS OF THE EXPERIMENT

- June 2015: Draft of the Letter of intent submitted to CSN2
- September 2015: Approval of the NEWS R&D phase by CSN2
- October 2015: Letter of Intent submitted to LNGSC Committee
<https://arxiv.org/pdf/1604.04199.pdf>
- 2016-2017 program:
 - Develop a microscope with the required resolution
 - Study the sensitivity to dark matter including the directionality
 - Small scale detector ($\sim 10\text{g}$) in LNGS to measure background in a shielded site
 - Write TDR for kg-scale detector (pilot experiment)
- Most of the items accomplished, some problems at LNGS delayed the experimental program
- CSN2 likely to extend the R&D program to 2018
- Pilot experiment planned after the R&D phase

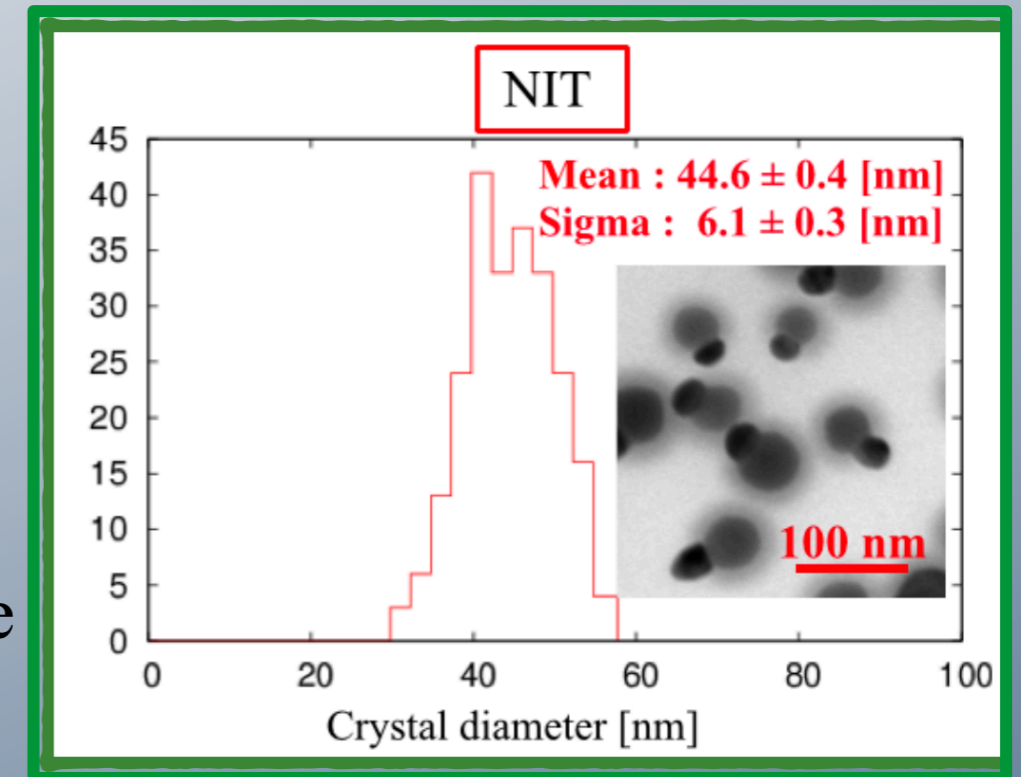
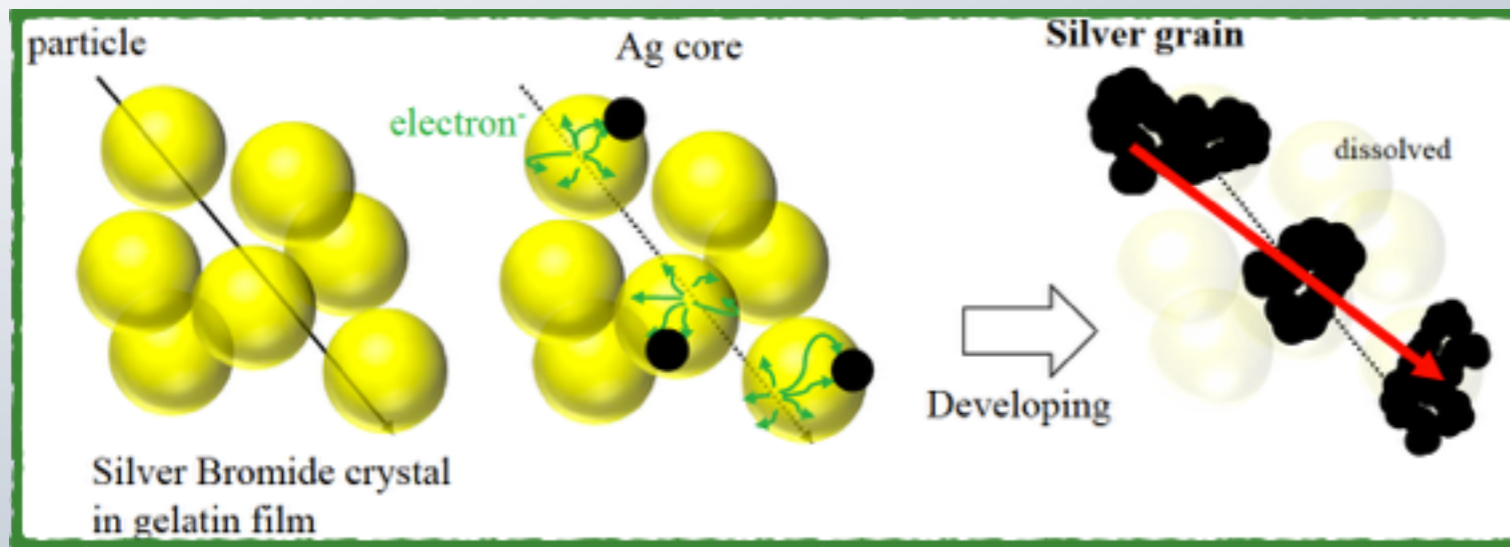
SCIENTIFIC IMPACT

- Aim of the experiment: **directional** detection on WIMP-nucleon elastic scattering with nuclear emulsions used both as target and tracking device



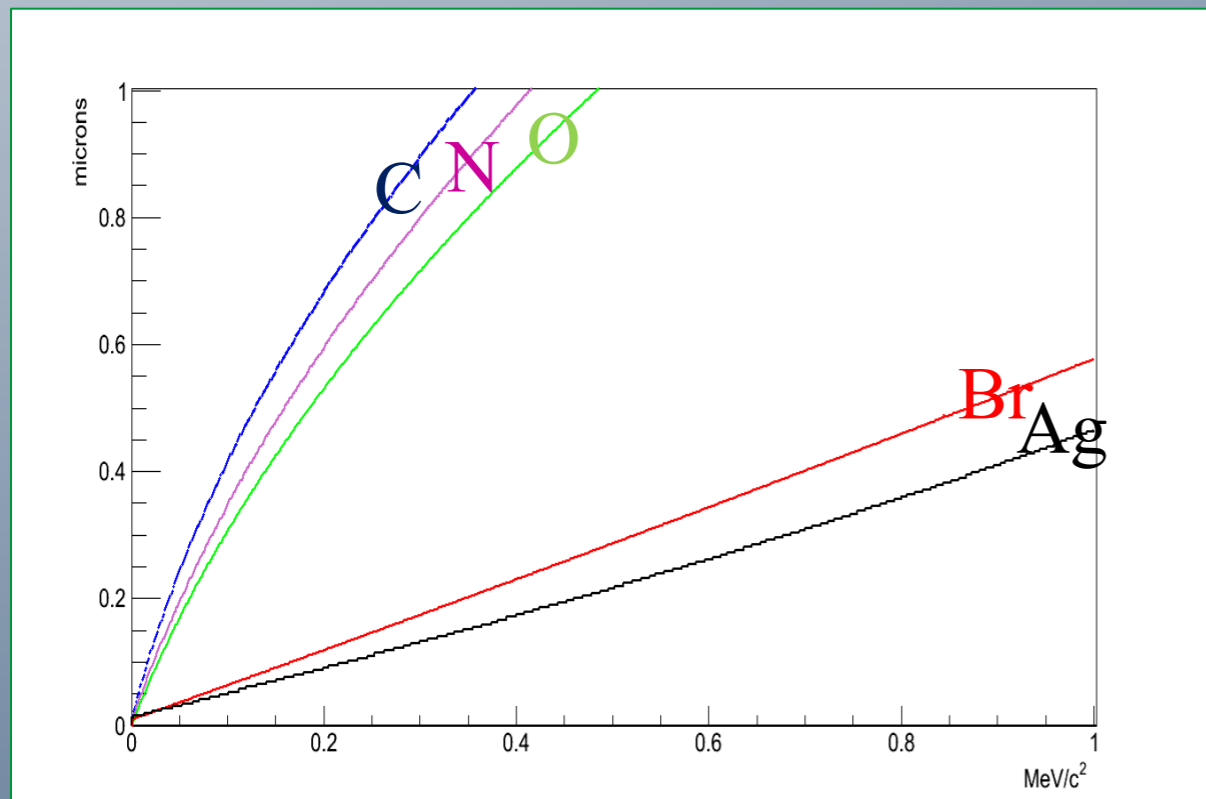
- Power of directionality:
 - unambiguous proof of the galactic origin of Dark Matter
 - unique possibility to overcome the “**neutrino floor**”, where coherent neutrino scattering creates an irreducible background
- Current directional experiment based on gaseous detectors:
 - Very difficult to achieve large target mass
 - sensitivity only to Spin-Dependent WIMP cross-section

NUCLEAR EMULSIONS

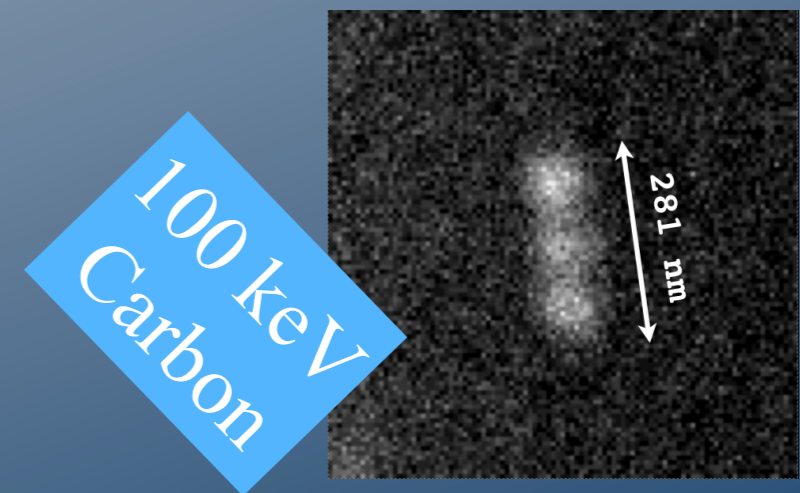


- Nuclear emulsions: AgBr crystals in organic gelatine
- Passage of charged particle produce *latent image*
- Chemical treatment makes Ag grains visible

- New kind of emulsion for DM search
- Smaller crystal size

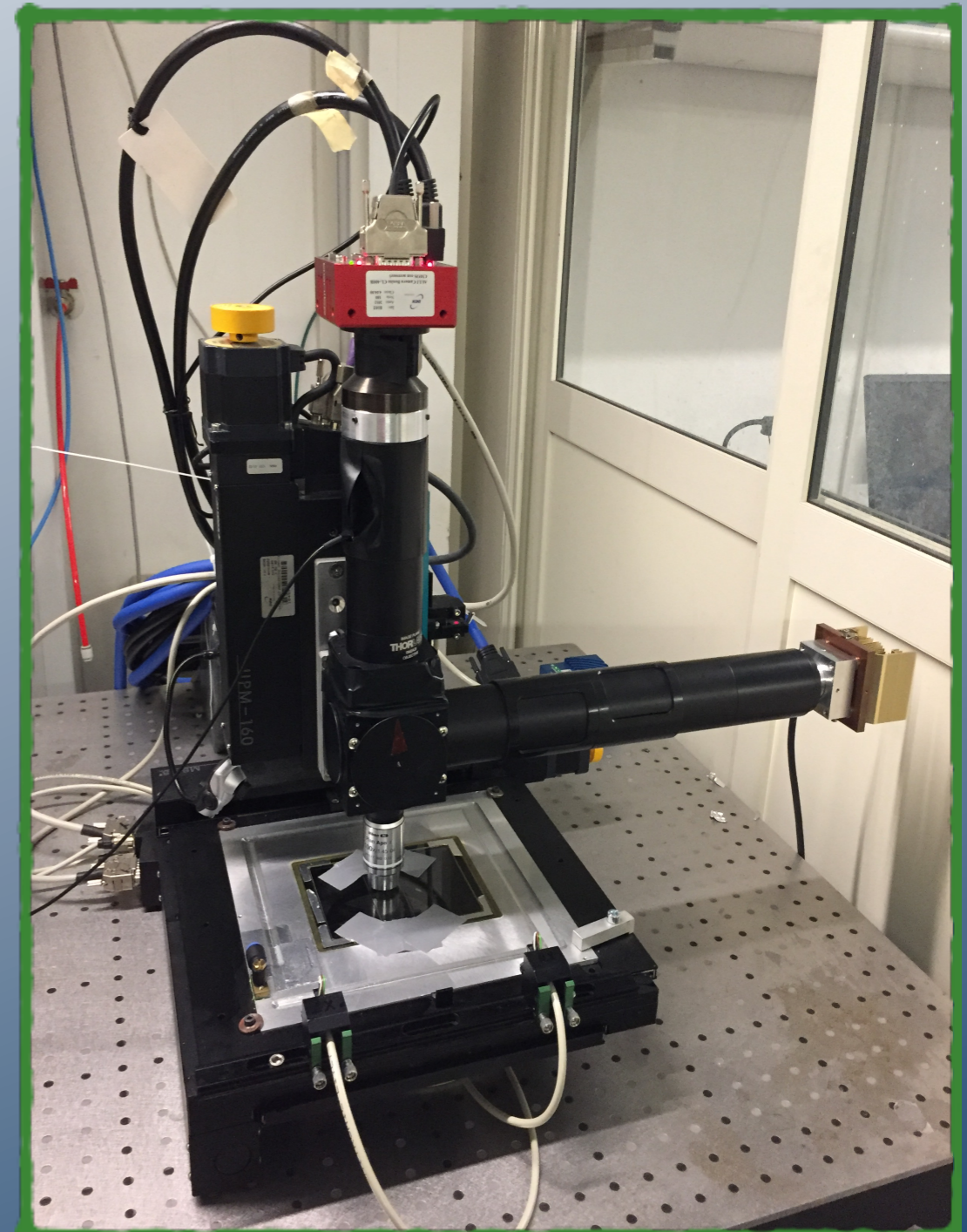


Both light and heavy nuclei



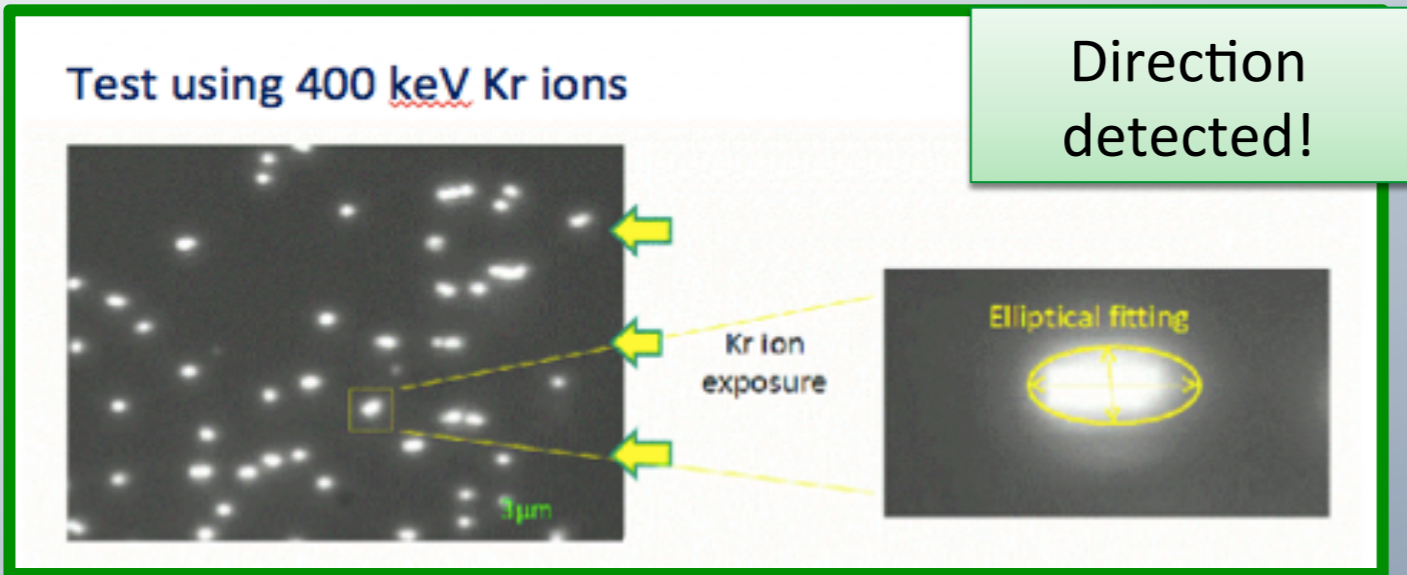
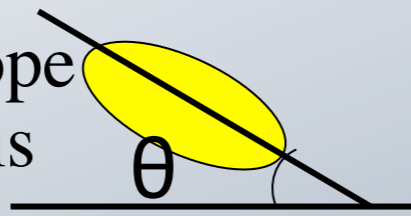
CORE ACTIVITIES (I)

- Development of high resolution and high speed microscopy for the analysis of nanometric nuclear emulsions
- Design and installation of a prototype microscope in Napoli equipped with liquid crystal polarizer: 10 nm position resolution achieved
- Signal characterization with test beam data
- Measurement of intrinsic resolution
- Design of a microscope for nanometric 3D readout
- Measurement of intrinsic neutron background in nuclear emulsions

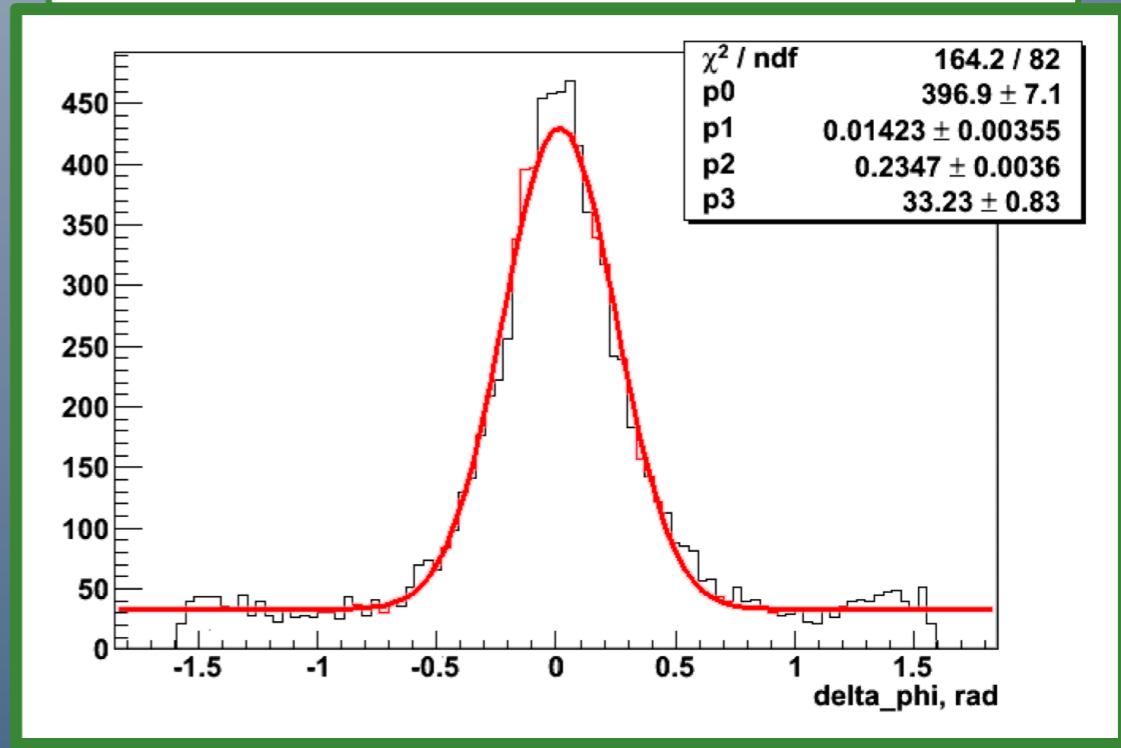
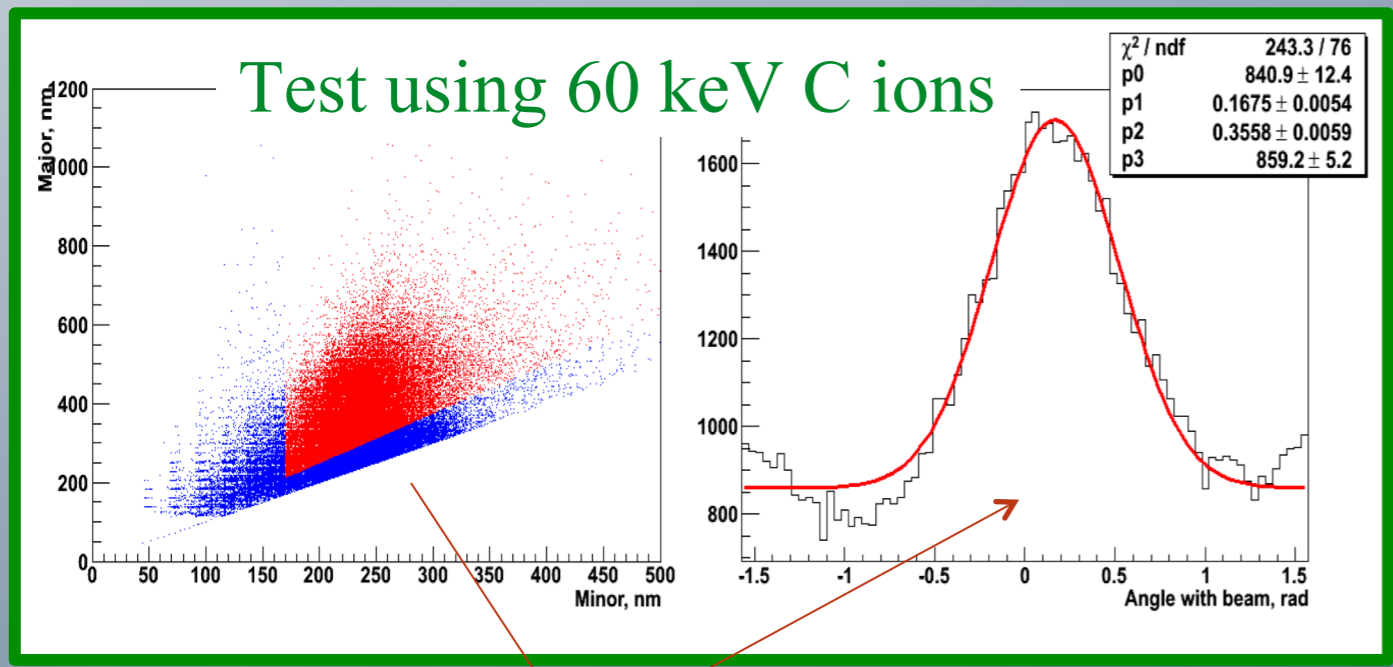
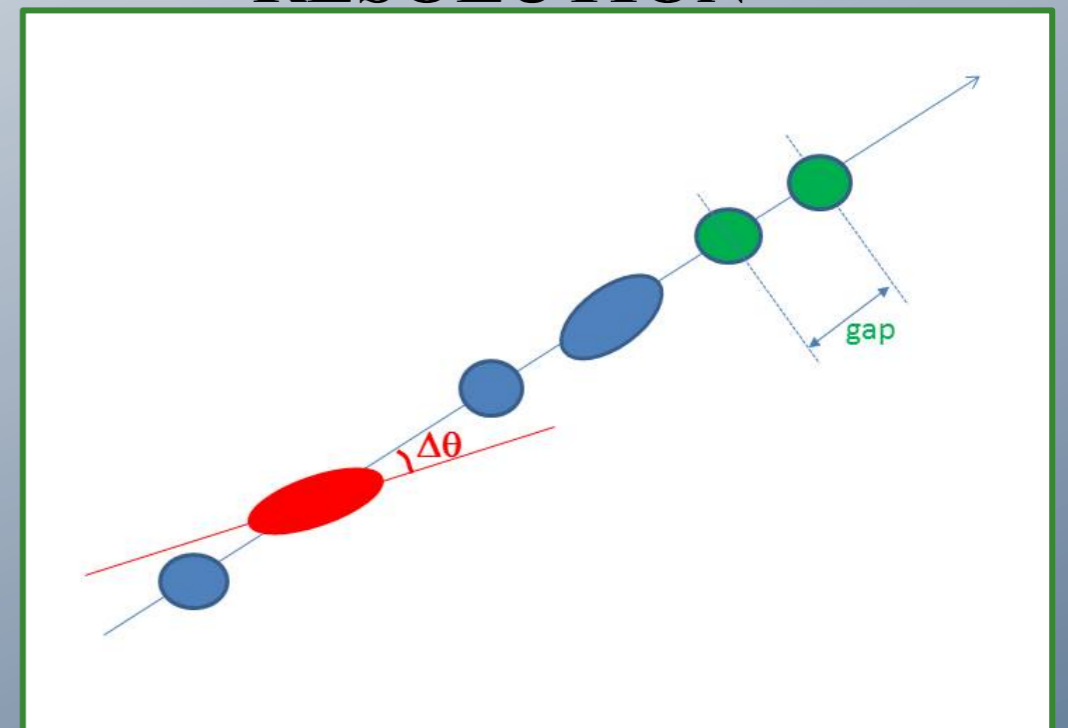


OPTICAL MICROSCOPE READ-OUT: STEP 1

Scanning with optical microscope and shape recognition analysis



INTRINSIC ANGULAR RESOLUTION



Signal selection:

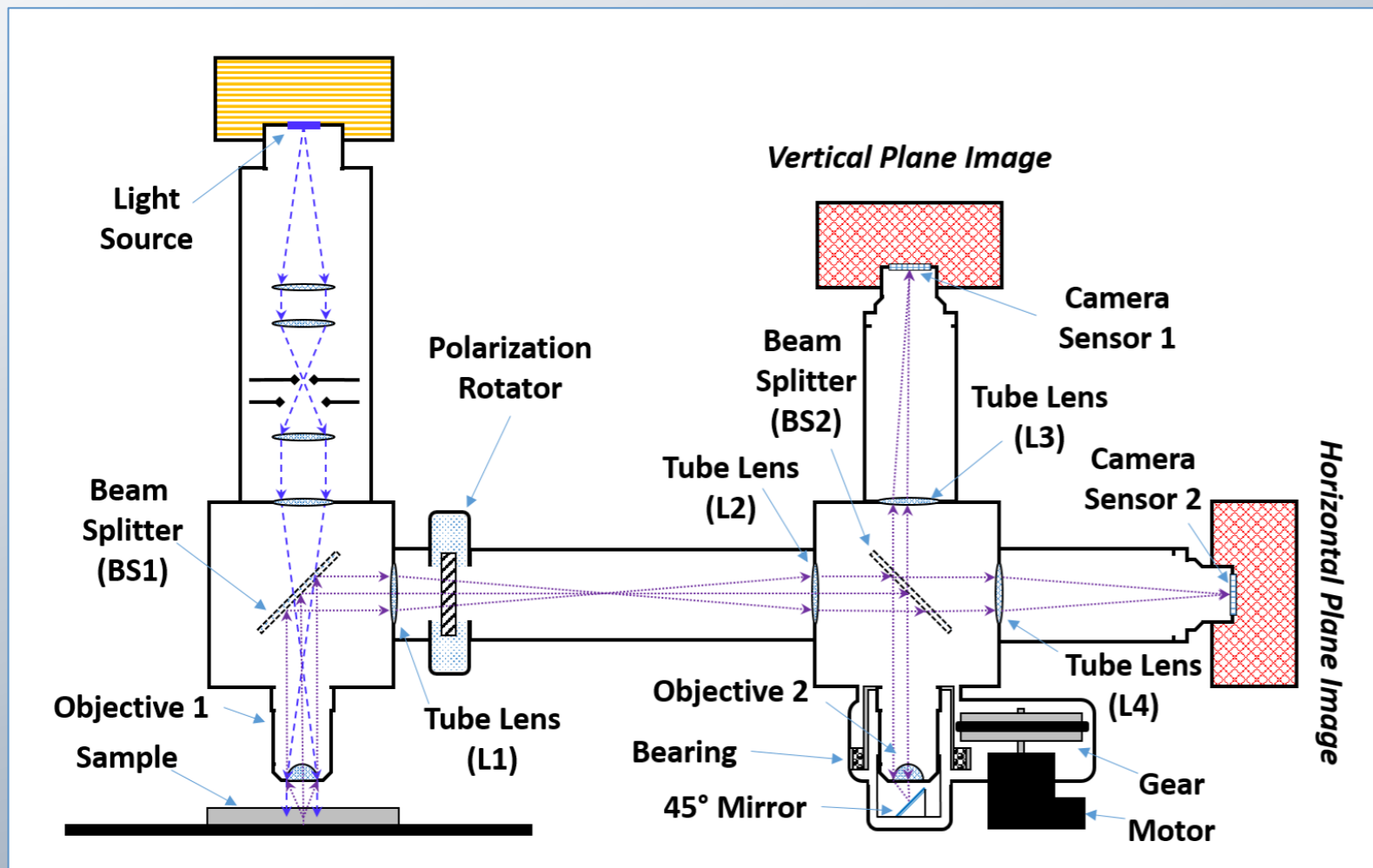
- Major/minor > 1.25
- minor > 170 nm

$$\sigma^2 = \sigma^2_{\text{intrinsic}} + \sigma^2_{\text{scattering}}$$

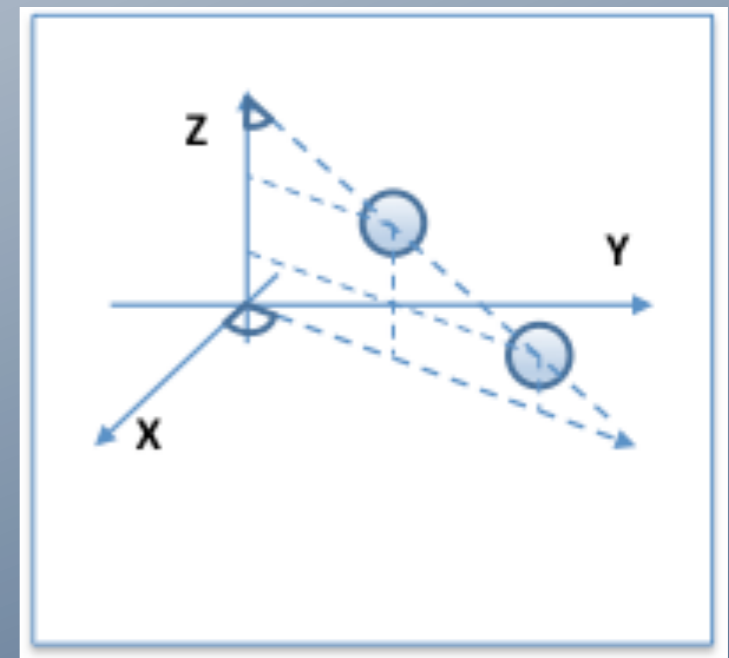
$$\sigma = 360 \text{ mrad}$$

$$\sigma = 235 \text{ mrad} = 13^\circ$$

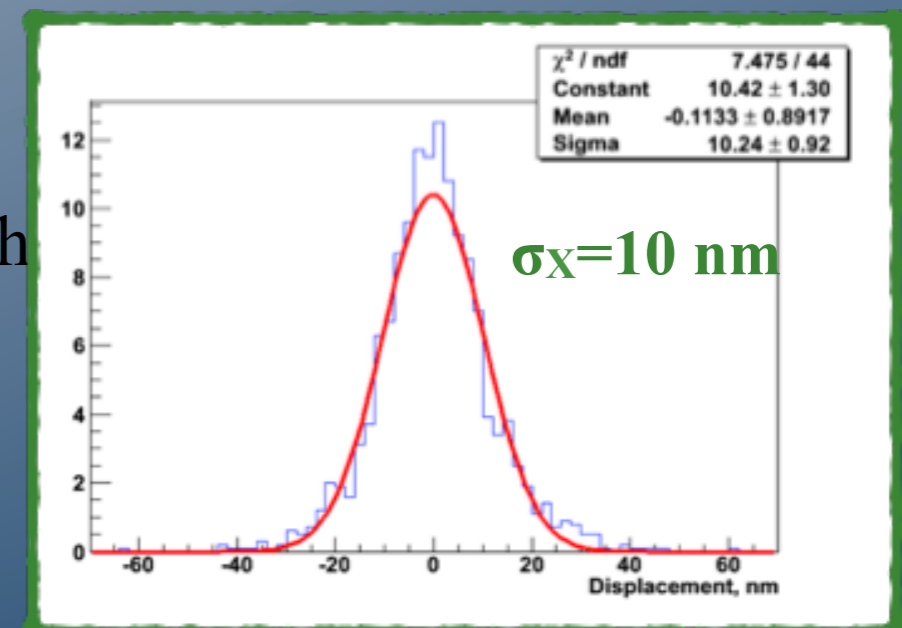
3D NANOMETRIC READOUT



Patented in Dec 2016
 N. 102016000132813
 A. Alexandrov, GDL, V.
 Tioukov, N. D'Ambrosio

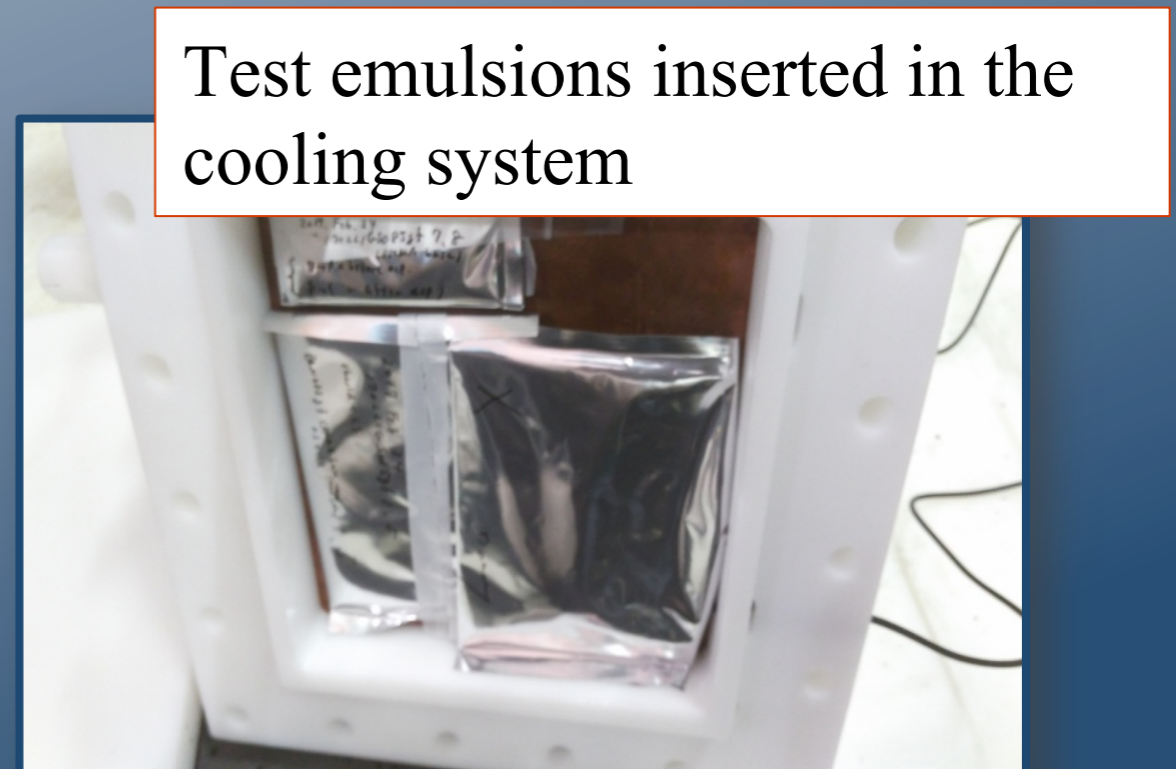
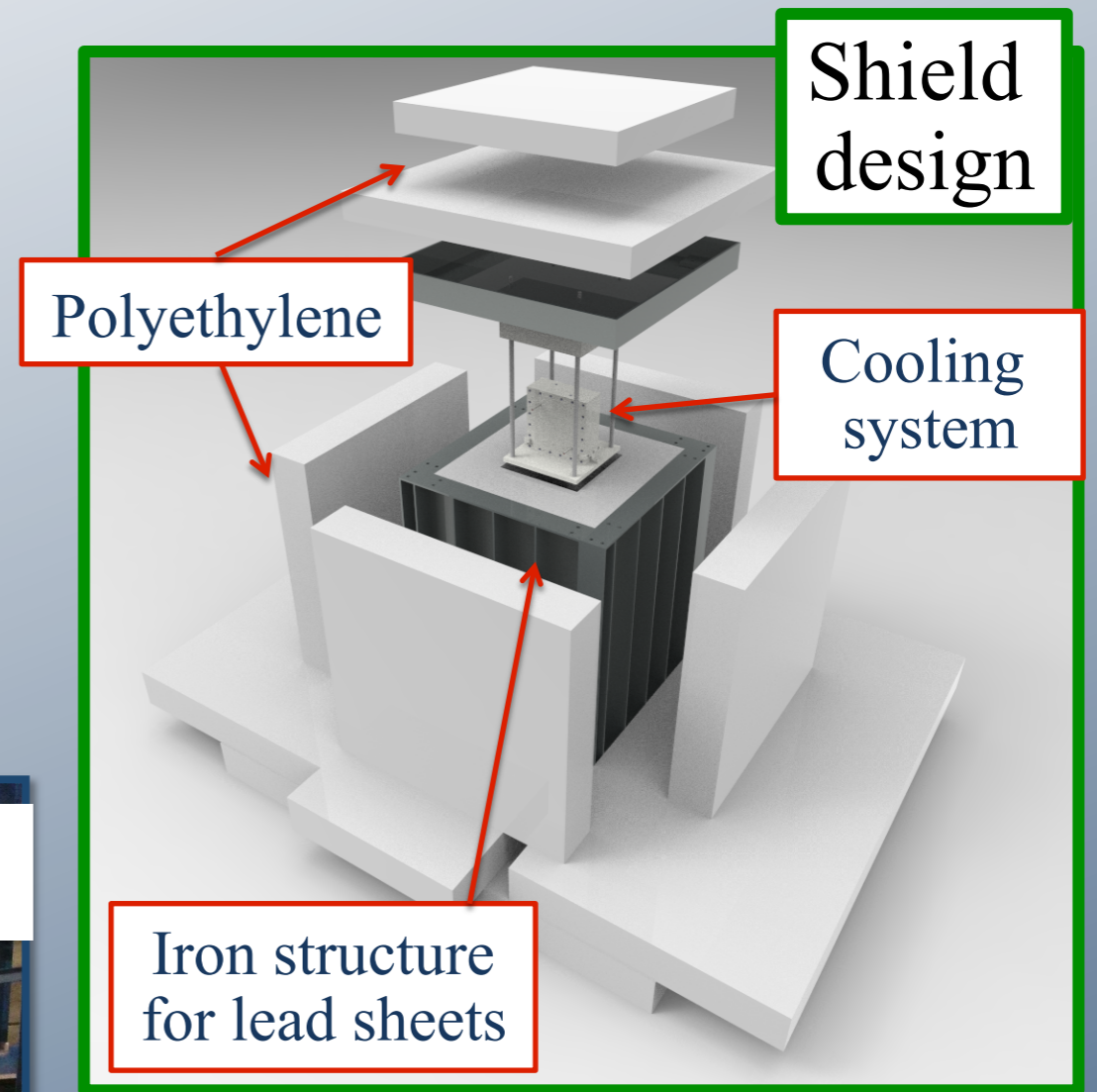


- Perform plasmon analysis in horizontal plane
 - Measure ϕ angle
- Rotate mirror to make the vertical plane coincide with the prediction's direction (ϕ)
- Perform plasmon analysis in vertical plane
 - Measure θ angle
 - Measure 3D length



CORE ACTIVITIES (II)

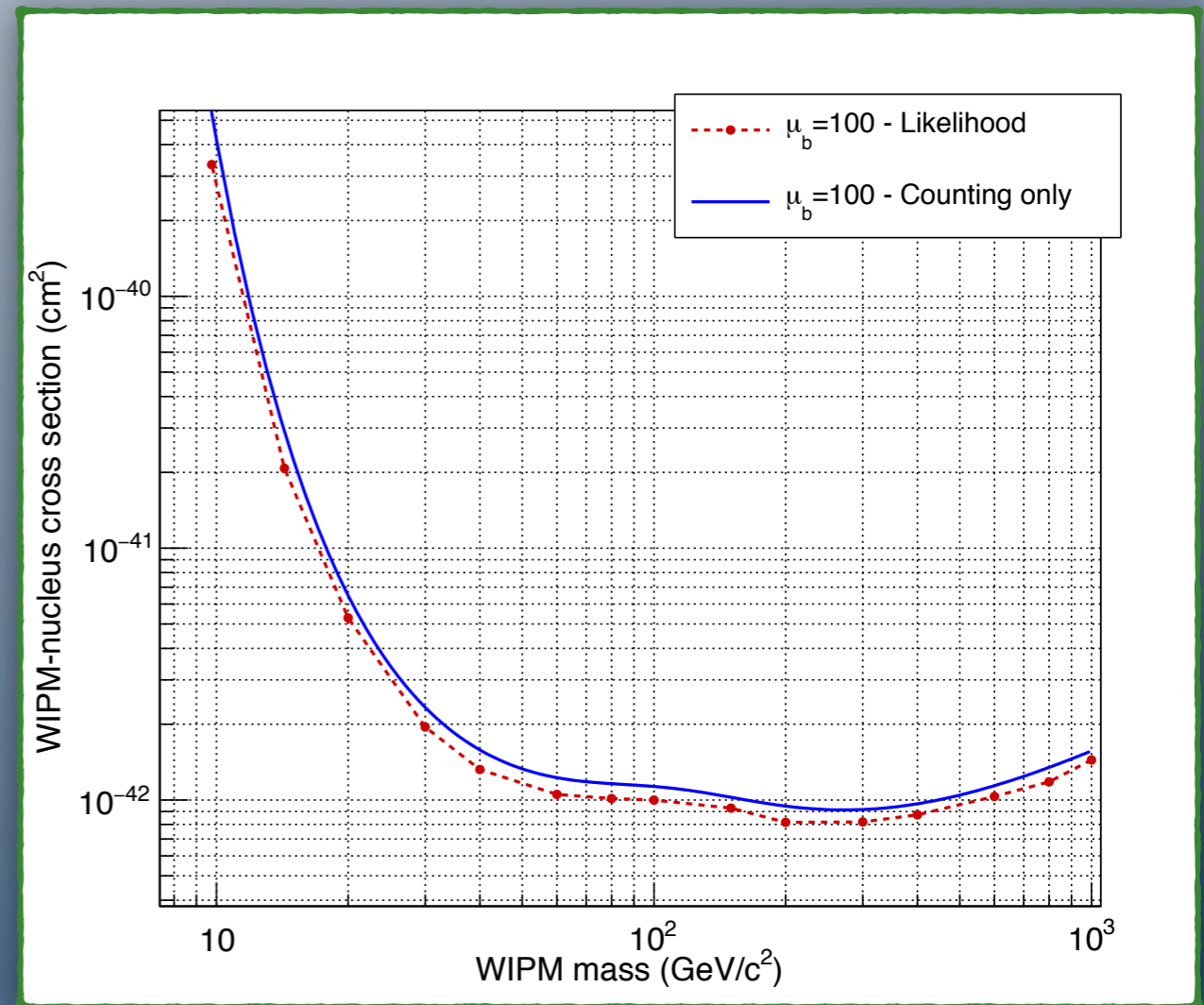
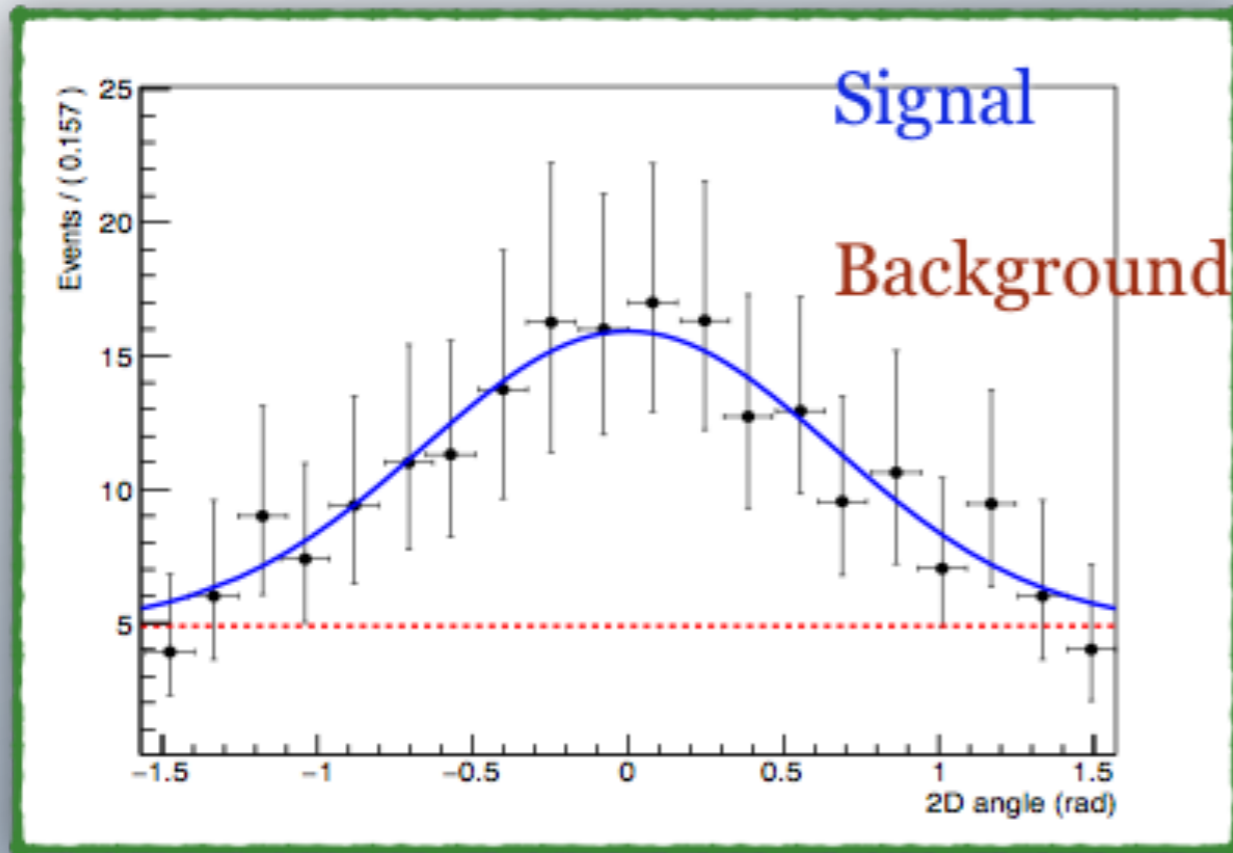
- Design of the shield for the 10g test
- Construction and installation of the shield at LNGS in Hall B and first technical test started in February 2017



V. Gentile & V. Tioukov

CORE ACTIVITIES (III)

- Estimation of NEWS discovery potential using directionality
- Sensitivity
- Dark Matter identification
- Upper limit



expected number of WIMP events μ_x expected number of background events μ_b signal pdf f_x background pdf f_b

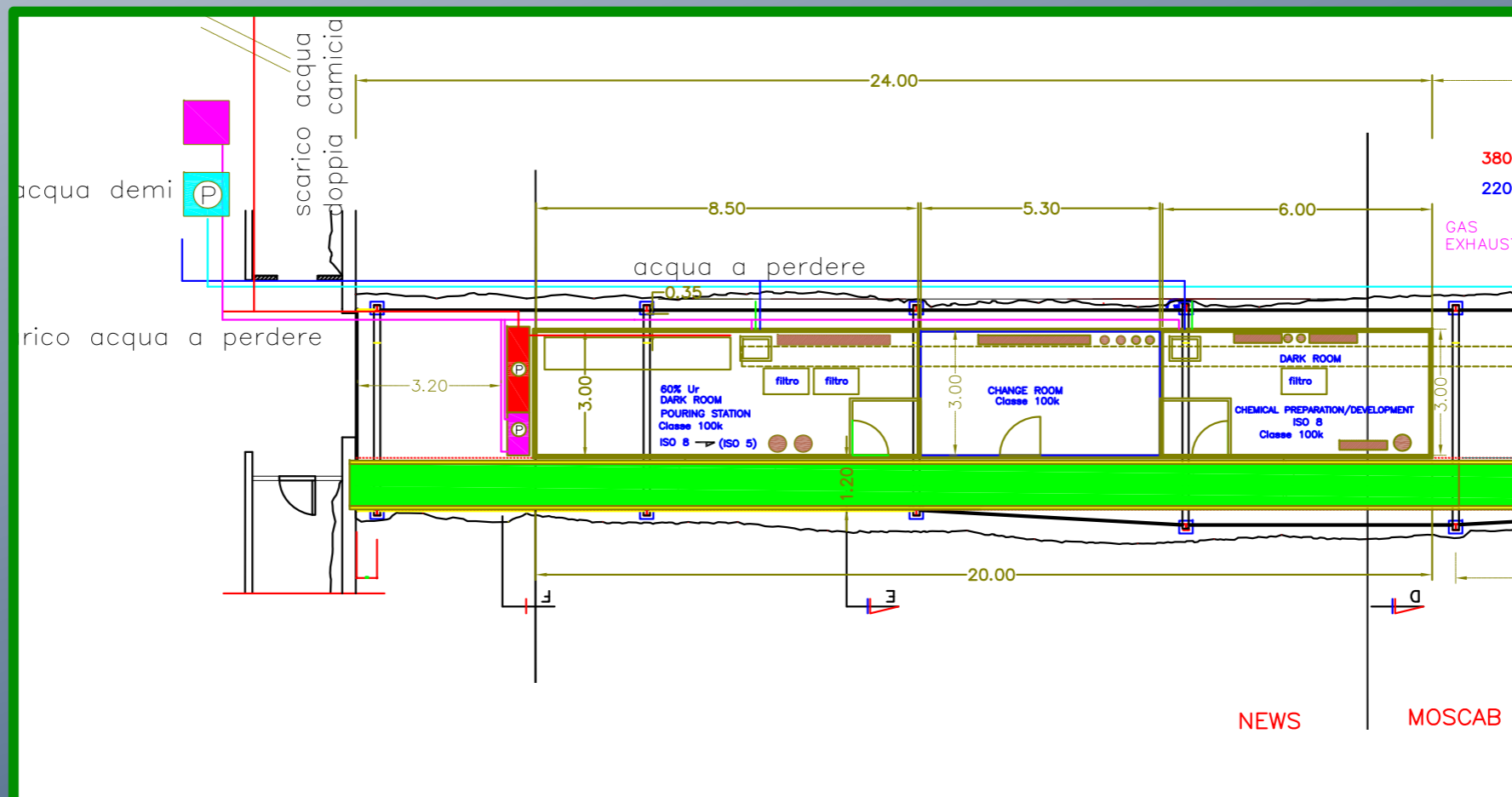
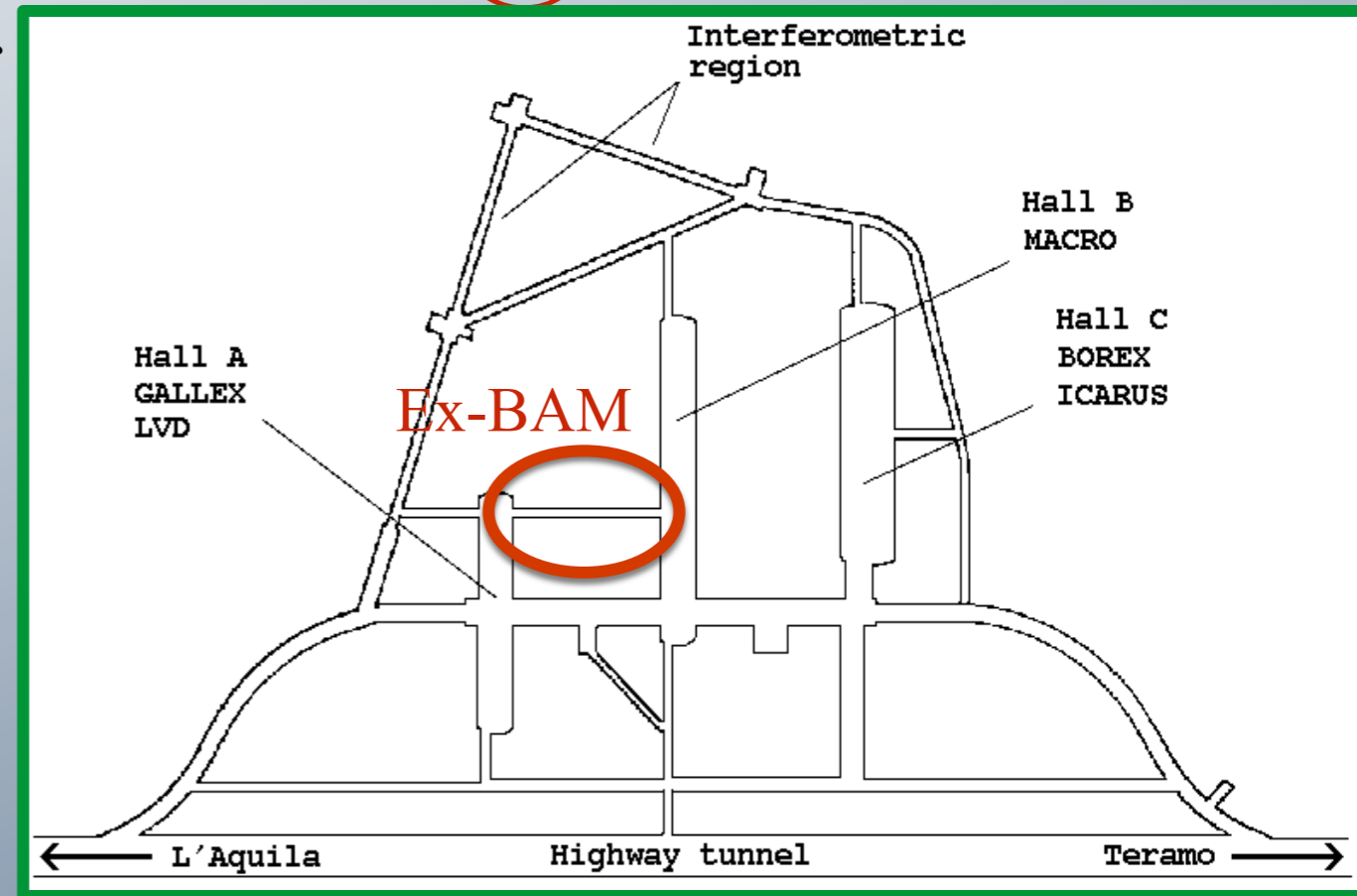
$$\mathcal{L}(\sigma_{\chi-n}, R_b) = \frac{e^{-(\mu_x + \mu_b)}}{N!} \times \prod_{i=1}^N [\mu_x f_x(\vec{q}_i; t_i) + \mu_b f_b(\vec{q}_i)]$$

total number of observed events N set of observables $\{\vec{q}_i, t_i\}$

A. Di Crescenzo

EMULSION FACILITY @LNNGS

- BAM-tunnel assigned to NEWS for emulsion production/handling/development activities
- Emulsion facility not yet ready due to LNNGS delays
- Japanese groups funded a machine for the emulsion production to be installed at LNNGS end of 2017

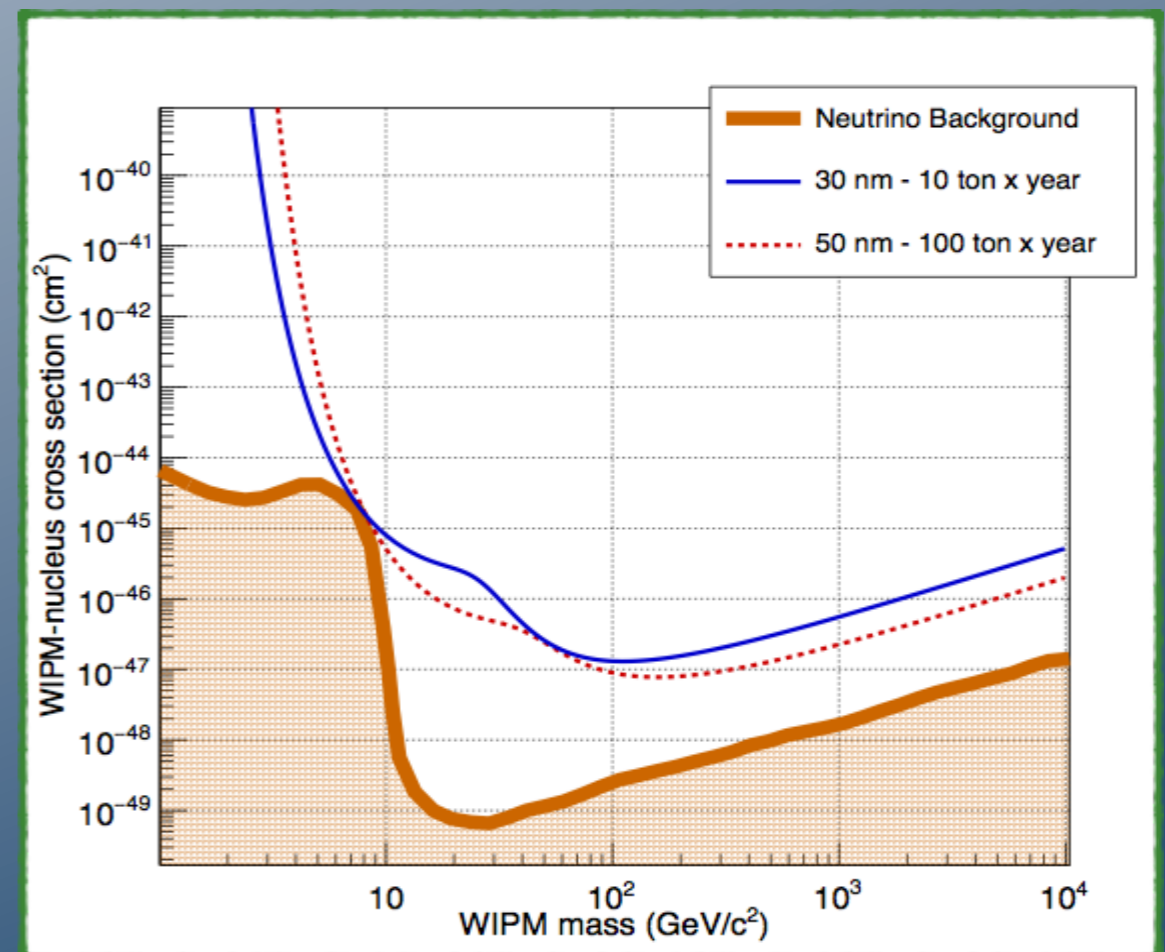


PERSPECTIVES

- Complete 10g exposure test at LNGS
- Confirmation of a negligible background will pave the way for the construction of a **pilot experiment** with an exposure on the \sim **kg year** scale
- Submission of TDR for the pilot experiment



- Pilot experiment as a demonstrator to further extend the mass range and sensitivity toward the “neutrino floor”



ADDITIONAL HUMAN RESOURCES

- Innovative Training Network (H2020) recently approved
 - Project coordinator: G. Cowan (Royal Holloway)
 - Naples University unit: G. De Lellis
 - Topic of our unit: machine learning techniques applied to nuclear emulsions for dark matter search and neutrinos
 - Funds for a Marie Curie Ph.D.
- Alex Rogozhnikov and Andrey Ustyuzhanin from the Yandex School of Data Analysis are visiting researchers in Naples to apply machine learning techniques to the image analysis
- The Japan Society for the Promotion of Science funded a 2 year post-doc as visiting researcher in Naples, entirely devoted to NEWS from June 1st 2017

SCIENTIFIC PRODUCTION

4 published + 2 under review

- **Developments in microscopy**
 - A new fast scanning system for the measurement of large angle tracks in nuclear emulsions
JINST 10 (2015) no.11, P11006 - (14 authors)
 - A new generation scanning system for the high-speed analysis of nuclear emulsions
JINST 11 (2016) no.06, P06002 - (11 authors)
 - The continuous motion technique for a new generation of scanning systems
Submitted to a Journal– under review - (13 authors)
- **Measurement of intrinsic neutron background in nuclear emulsions**
 - Intrinsic neutron background of nuclear emulsions for directional Dark Matter searches
Astroparticle Physics 80 (2016) 16 - (27 authors)
- **NEWS sensitivity with the directional approach**
 - Discovery potential for directional Dark Matter detection with nuclear emulsions
Submitted to a Journal - under review (arXiv: 1705.00613) - (56 authors)
- **Nuclear emulsion technique included in a wider effort for directional dark matter search with different technologies (Cygnus Collaboration)**
 - Readout technologies for directional WIMP Dark Matter detection
J.B.R. Battat et al., Physics Reports 662 (2016) 1 - (93 authors)

RESPONSIBILITIES

- Spokesman of the experiment - G. De Lellis
- Leading role in optical microscopy – A. Alexandrov
- Patent for 3D nanometric readout - A. Alexandrov, N. D’Ambrosio, G. De Lellis, V. Tioukov
- Key role in the analysis - A. Di Crescenzo, corresponding author of the sensitivity paper

SYNERGIES

- Nuclear emulsion technique and optical microscope technology
- Wide range of applications: neutrino physics in SHiP (CSN1), directional dark matter search (CSN2), hadron fragmentation for medical applications (CSN3)
- Technological challenges and human resources shared between different topics

NAPOLI GROUP ACTIVITIES

	SHiP (CSN1)	NEWS (CSN2)	FOOT (CSN3)	OPERA
A. Alexandrov		*		
T. Asada		*		
A. Buonaura	*			
S. Buontempo	*			
R. De Asmundis	*			
G. De Lellis	*	*	*	*
V. Gentile		*		
L. Lista	*			
A. Di Crescenzo	*	*	*	
G. Galati				*
M. Iacovacci	*			
A. Lauria			*	*
S. Meola	*			
M.C. Montesi		*	*	
A. Rogozhnikov	*	*		
V. Tioukov	*	*	*	*
A. Ustyuzhanin	*	*		
E. Voevodina	*	*		

+ undergraduate students, support from engeneering staff 15