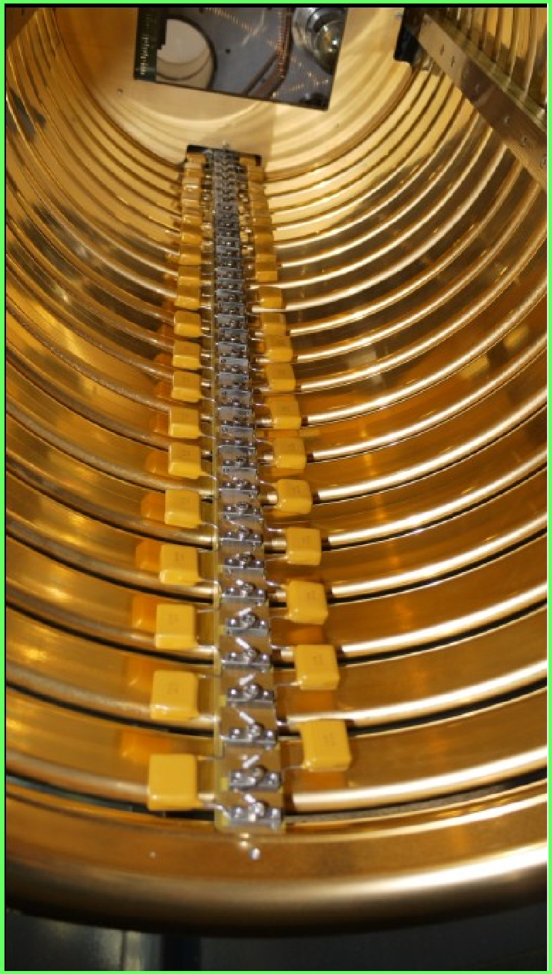
Detector R&D in Switzerland



CHIPP
Swiss Institute of Particle Physics

SWICH April 2018

3-6 April 2018
Schweizerische Bundesbahnen SBB Centre Loewenberg
Europe/Zurich timezone

Igor Kreslo

University of Bern

UNIVERSITÄT BERN
AEC
ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

Detector R&D in Switzerland

Based on Slides provided by:

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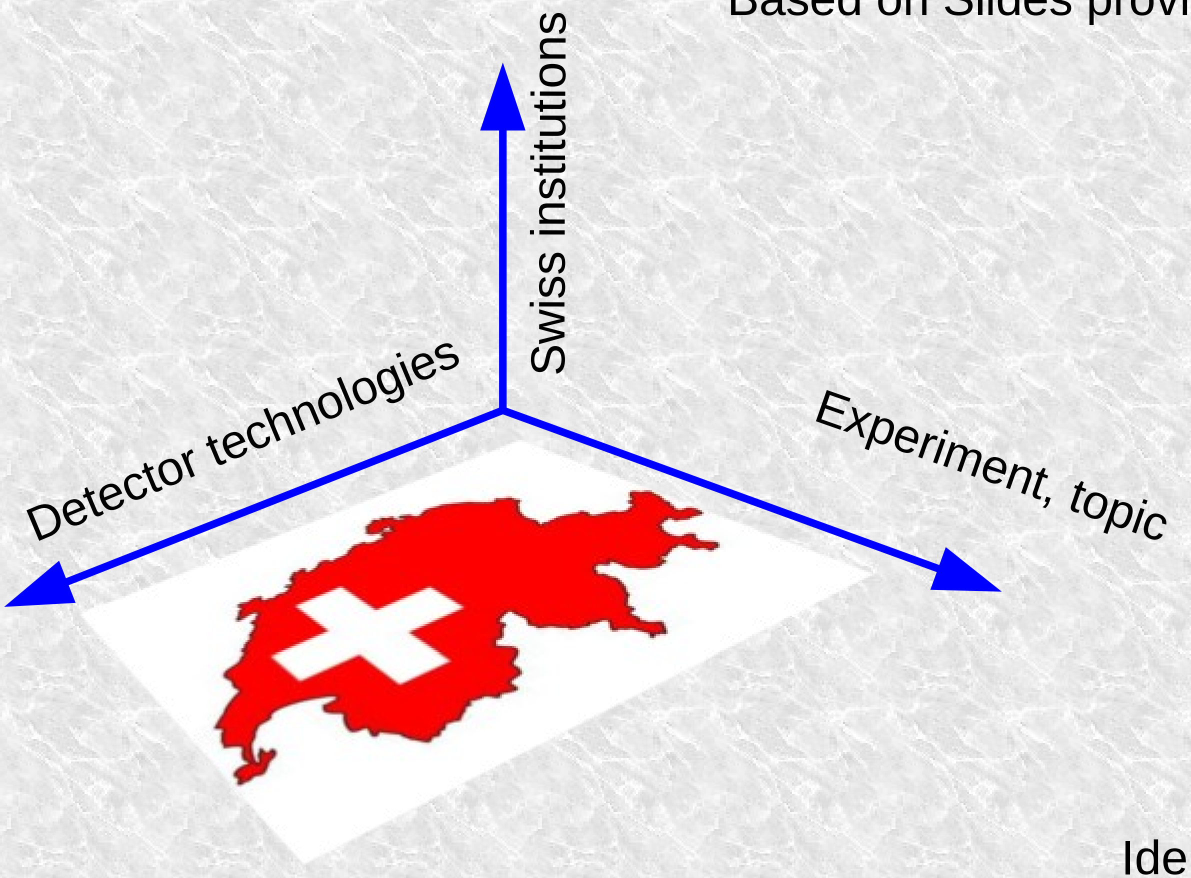
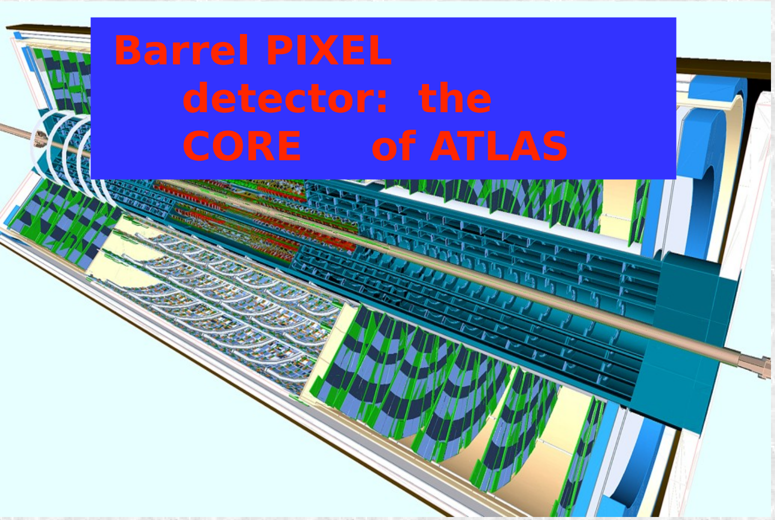


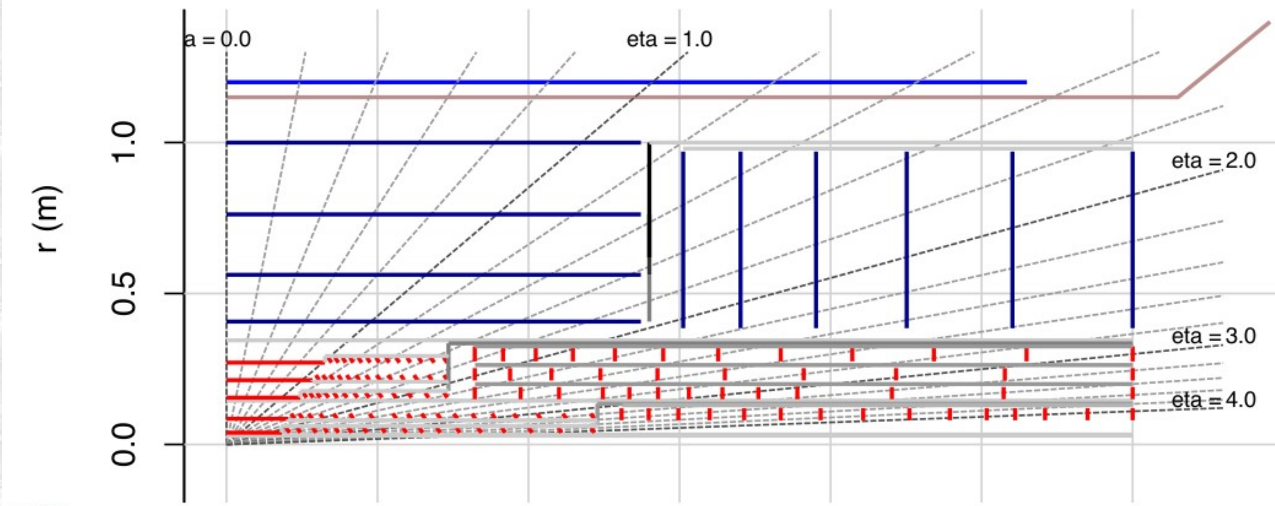
Identify flowering technologies

Identify deficits

Develop reccomendations

Frontiers (ATLAS)





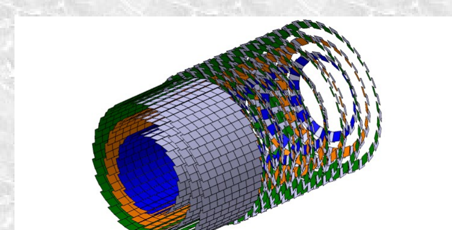
5 pixel layers + 4 strip (double) layers Tilted geometry at intermediate η

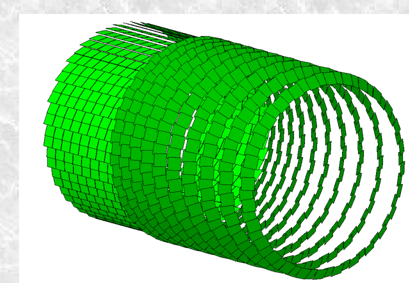
|η| < 4

Swiss contribution: outer three barrel layers

High degree of innovation

- Central flat sections
- inclined sensors at intermediate angles
- introduces a new concept for cooling

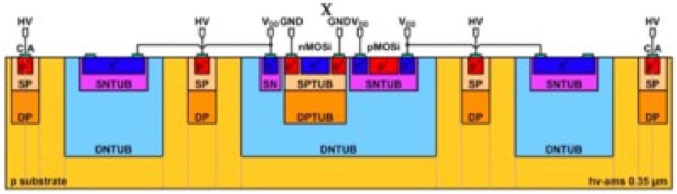


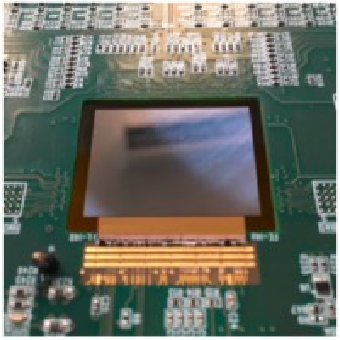


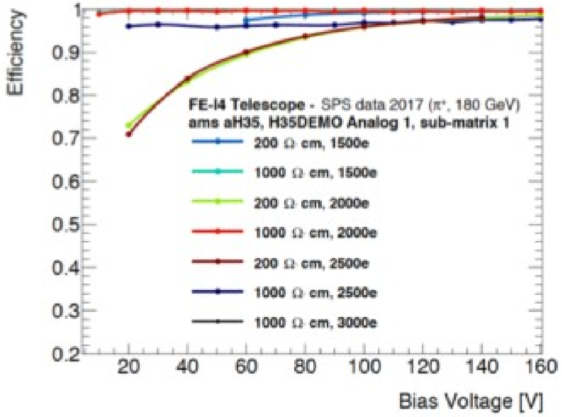
Si pixels/strips

Frontiers (ATLAS)

- Strong Swiss R&D effort toward a new generation of silicon pixel sensors,Advantages:
  - ➡ use of CMOS standard industrial processes (cost, high throughput, reliability)
  - ➡ possibility to go "monolithic" (no need for expensive bump bonding of expensive sensors to readout CMOS chips)







- ◆ qualification of precise glueing
- ◆ sensor efficiency in test beams
- ◆ sensor radiation hardness

Some of the peer-reviewed papers:
Testbeam telescope: JINST 11 (2016), P07003
Testbeam unirradiated: JINST 11 (2016) P07019
Testbeam irradiated: JINST 13 (2018) P02011
Full digital and analog matrices, 1712.08338

Si Radiation hardness R&D

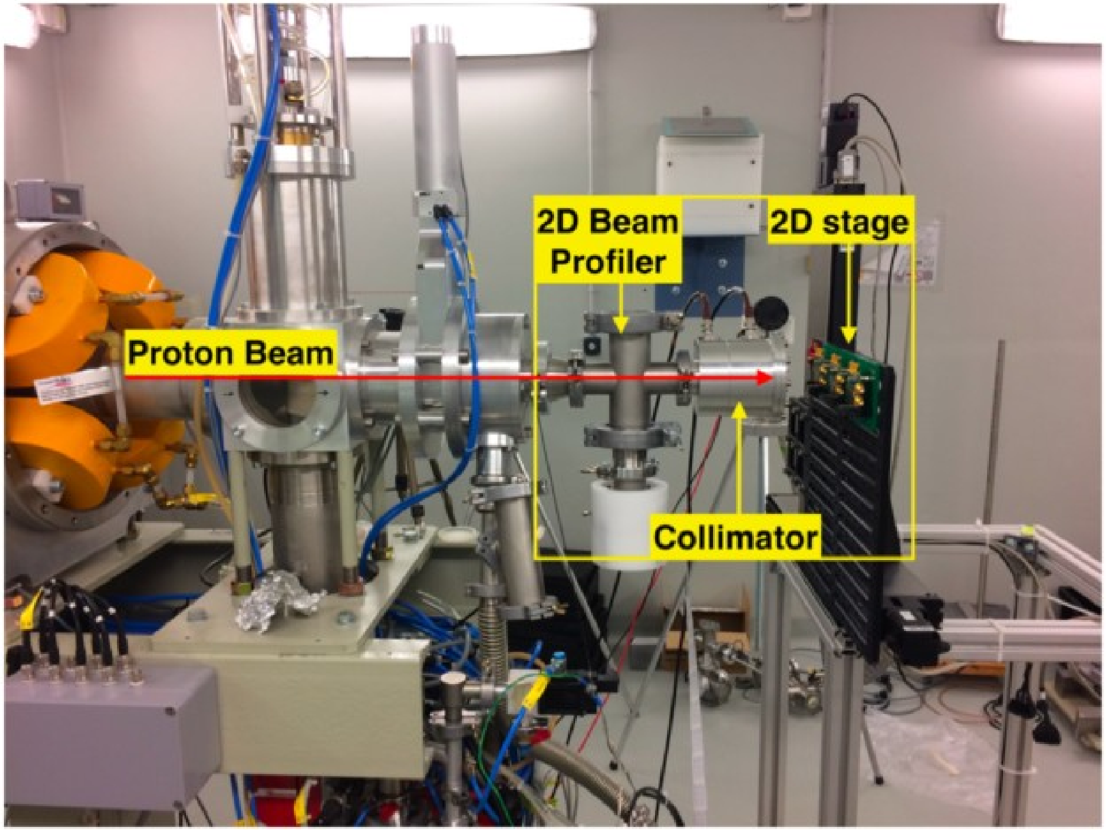
Medical cyclotron (18 MeV)

Precise beam current monitor

Large dynamic range

Operation of the sensors in-situ during irradiation

Associated characterization alboratory

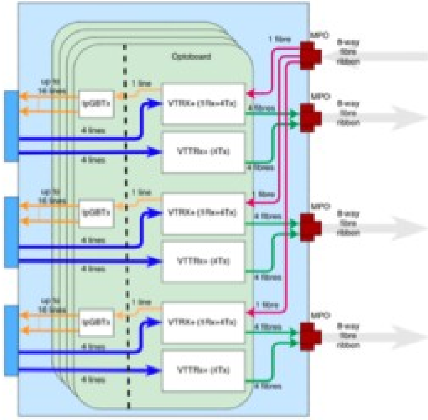


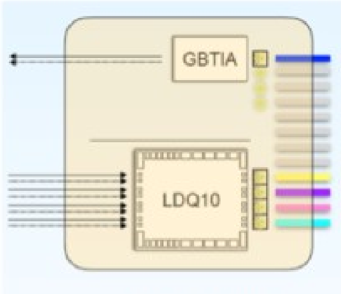
Si pixel readout electronics

Experience with optical transceivers from current Pixel detector

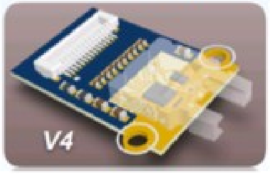
New ~5 Gbit link modules being implemented for upgrade

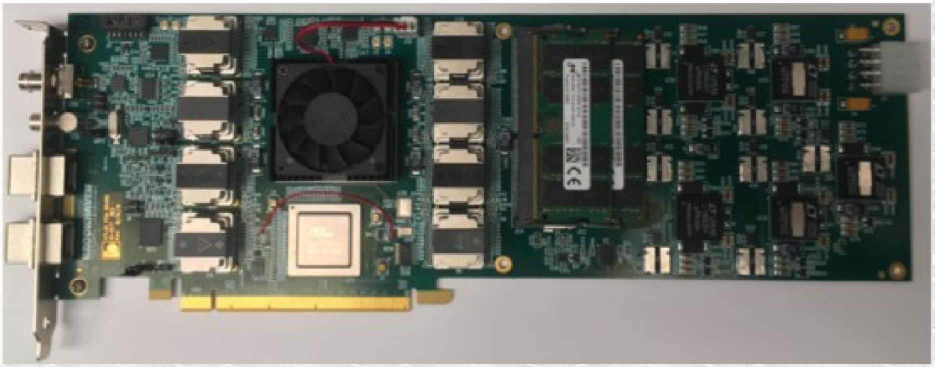
Felix readout system to be used for up to 48 optical links





4Tx & 1 Rx





Frontiers (LHCb)

SciFi technology for the LHCb upgrade (during LHC Long Shutdown 2 (LS2))

The tracking system behind the dipole magnet (silicon Inner Tracker + straw-tube Outer Tracker) will be replaced with a SciFi tracker.

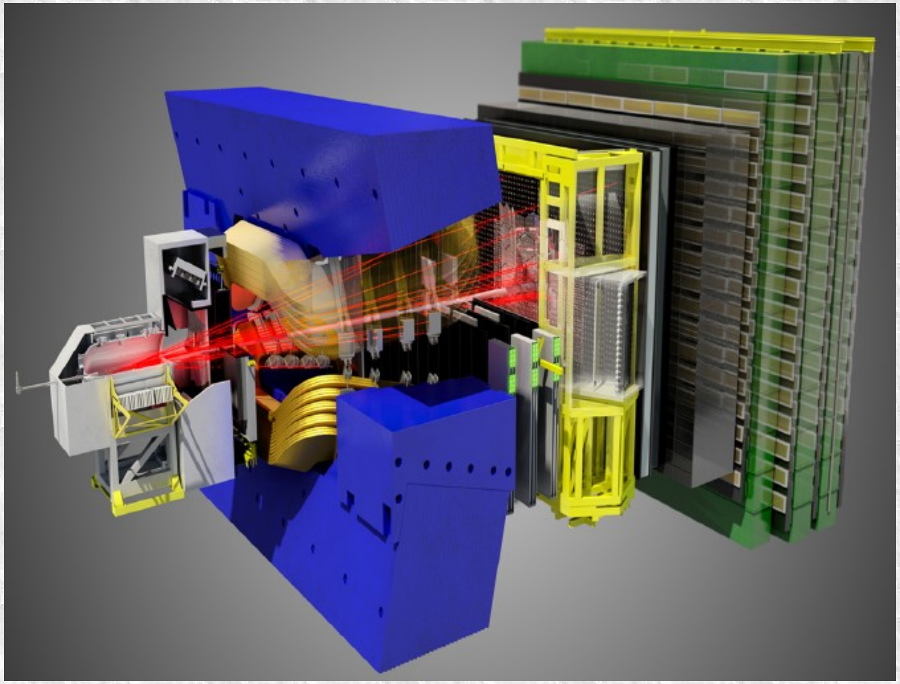
Customized 128-channel SiPM arrays

In-house capability of producing fibre arrays to be assembled into modules.

Further R&D in fibre transparency, radiation hardness, timing.

R&D on the interface between fibre and SiPM (more efficient light collection).

Upgrade 2 of the LHCb tracking system would perhaps not be feasible with SciFi only, but require silicon.

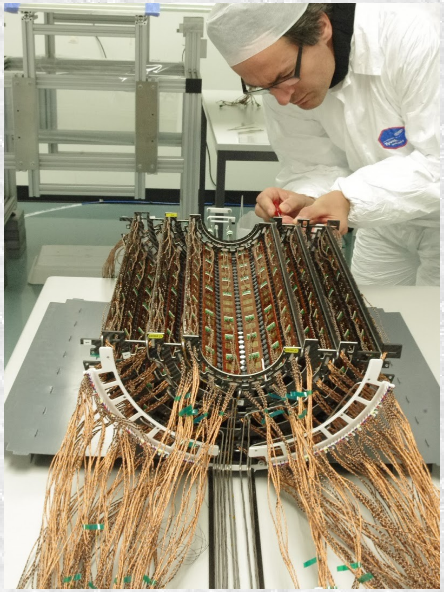


Silicon detectors
Sci Fibers
SiPM

Frontiers (CMS)

- heavily involved in R&D, design and construction of the CMS barrel pixel detector:
  readout chip, sensor, bump bonding,
  module production, assembly and integration

- “phase-0” detector installed 2008
  “phase-1” detector installed 2017



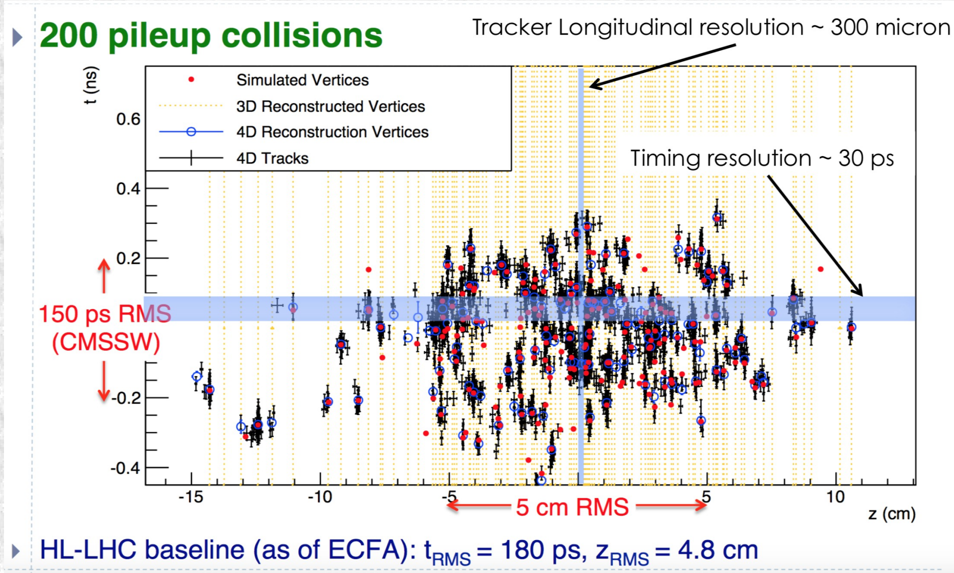
- Phase-2 pixel upgrade for the HL-LHC
  - development of the pixel module design
  - module construction and testing for barrel pixel layers & endcap pixel disks
  - mechanics and service cylinder design of the endcap disks

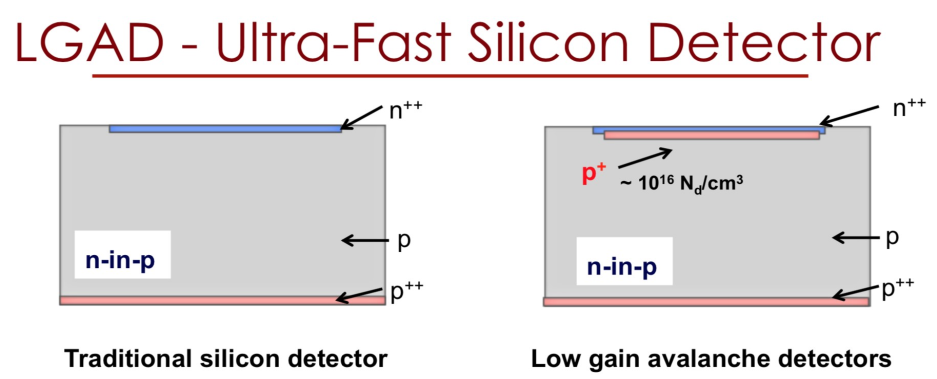
- HV MAPS technology
  - R&D project to develop HV MAPS detector which could be used for pixel detectors at larger radii (lower data rates and radiation doses)

- Mu3e experiment
  - construction of the pixel detector
  - development of the upgraded version of pixel detector

Si pixels/strips

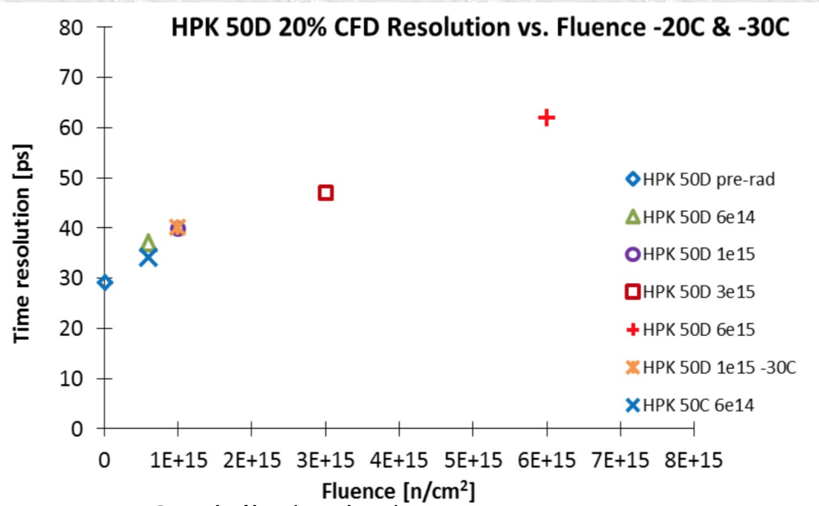
Frontiers (CMS)



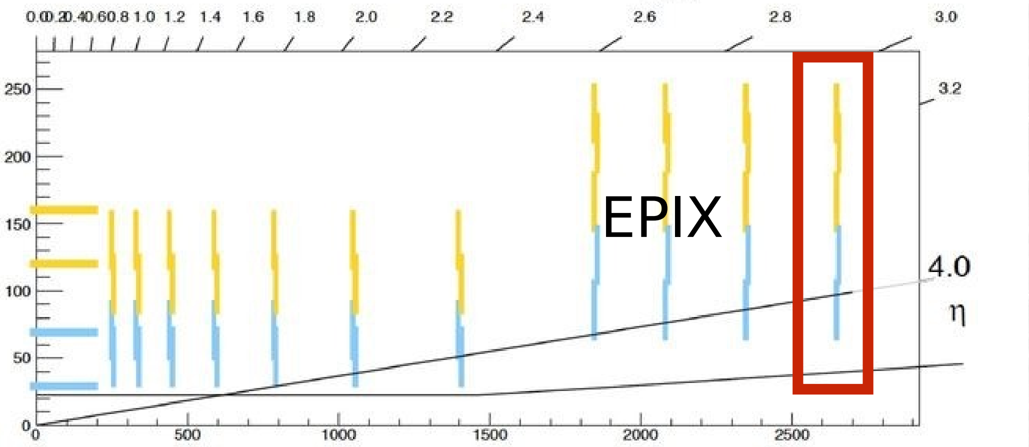


In CMS Phase 2 :

- Plan considered for region 3 < |η| < 2
- UZH looking into smaller sensors for 4 < |η| < 3



From N. Cartiglia (Torino)



Status:

- Testing doped sensors (Ga, B+C, Ga+C) for improved rad-hardness
- Constructing smaller sensors for EPIX

Silicon

Dark Matter & Neutrino

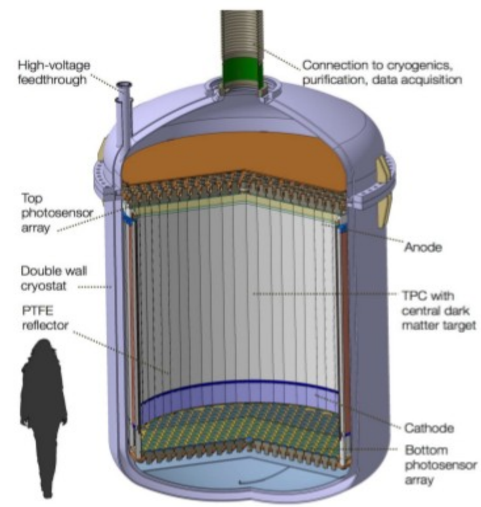
Overview of U-Zurich activities in the field

- Dark matter searches with xenon TPCs: XENON1T (taking data), XENONnT (in construction, to start 2019) and DARWIN (R&D and design stage; to start ~2025)
- Searches for the neutrinoless double beta decay with HPGe detectors (^{76}Ge) in liquid argon and with xenon (^{136}Xe) TPCs: GERDA (taking data), LEGEND (planning stage, to start in 2021) and DARWIN
- R&D studies (see next slides) and material radio-assay with HPGe detector (Gator) at LNGS

First results:
Phys. Rev.Lett. 119 (2017)

Instrument description:
Eur. Phys. J. C77 (2017) no.12, 881

Recent results:
Nature 544 (2017) 47

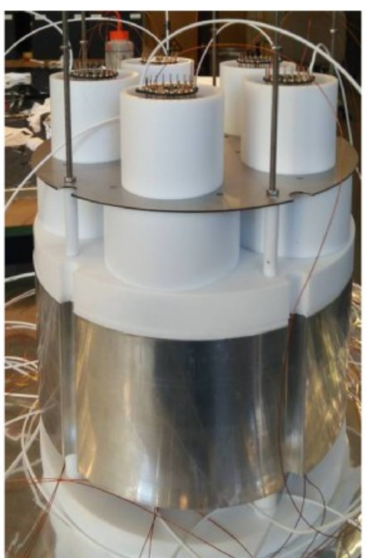


JCAP 1611 (2016) no.11, 017

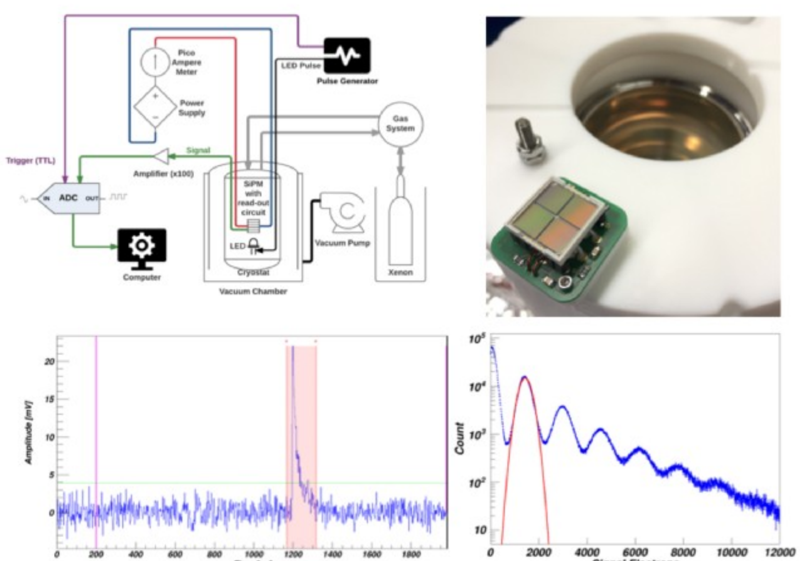
LAr / LXe
HPGe

New photosensors for LAr and LXe detectors

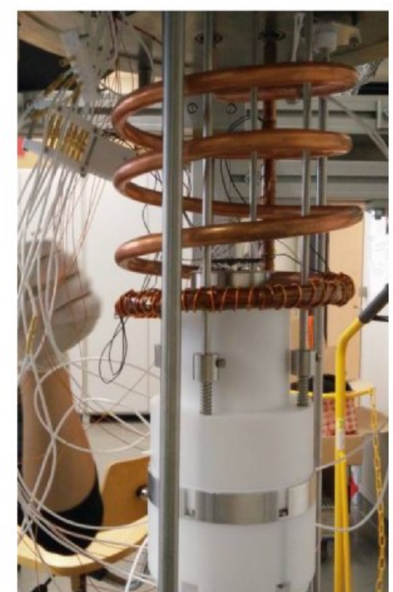
- Development (with Hamamatsu) of ultra-low radioactivity, high QE (at 175 nm) PMTs and evaluations in liquid xenon Eur. Phys. J. C75 (2015) no. 11, 546
- Tests of VUV sensitive SiPM arrays in liquid argon and xenon TPCs (manuscript in preparation)
- Development of cold and warm electronics for PMTs and SiPMs



MarmotX PMT test facility



Test of SiPM arrays (12 x 12 mm2) with LArS

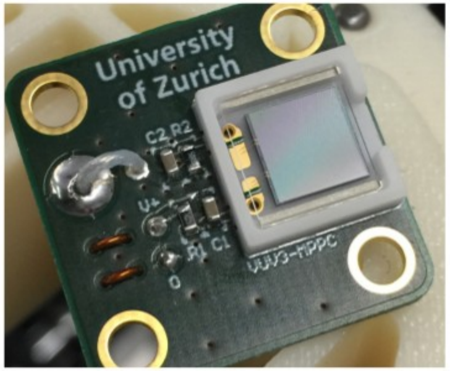


LArS SiPM array test facility

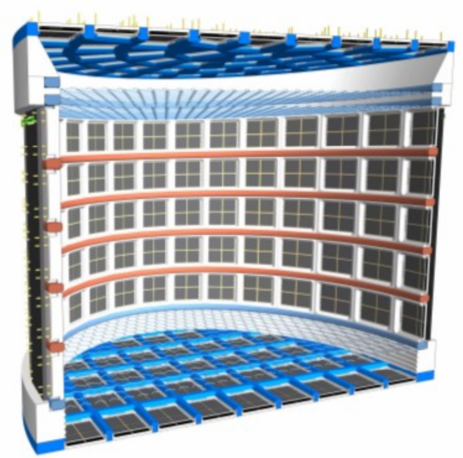
LAr / LXe
SiPM, PMT
Electronics

TPCs for future dark matter detectors (DARWIN)

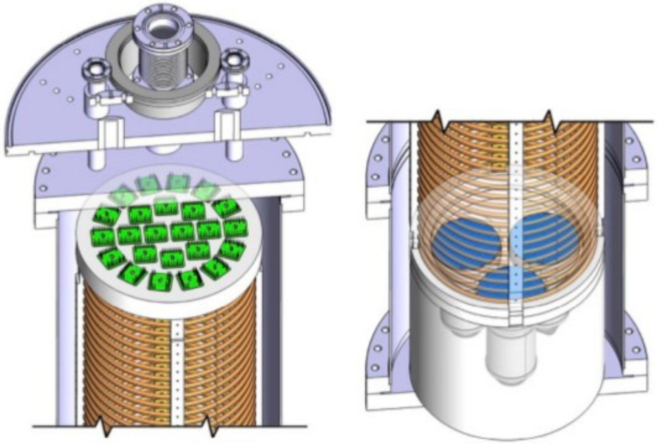
- TPC schemes with 4-π light readout (top and bottom array of photosensors and SiPM array rings at the walls, largely replacing PTFE)
- DARWIN demonstrator with 2.6 m long TPC (actual length of the DARWIN TPC, to show e-drift, liquid xenon purity etc)
- Funded by the ERC advanced grant Xenoscope (2017-2022)



SiPM test board developed at UZH



A 4-π readout xenon TPC

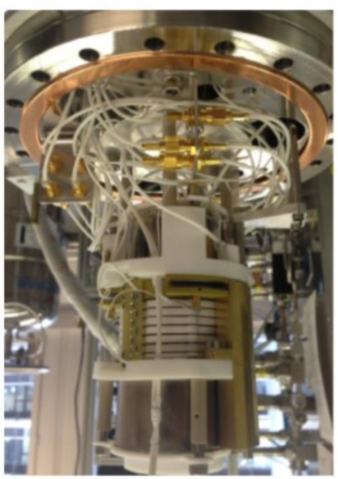


A 2.6 m xenon TPC, as DARWIN demonstrator

LAr / LXe
SiPM, PMT
Electronics

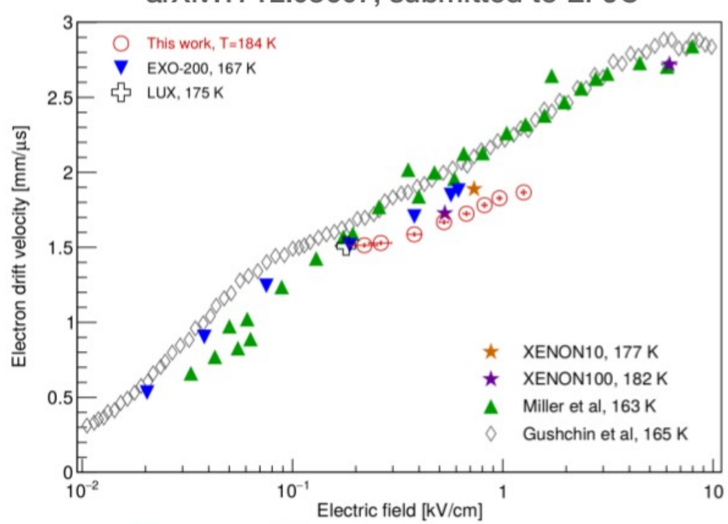
Properties of LXe as radiation detection medium

- Small liquid xenon TPC (Xürich) operated with fast neutrons from D-D generator and various external and internal gamma and beta sources (^{137}Cs, ^{22}Na, ^{83m}Kr, ^{37}Ar)
- Upgrade with top/bottom SiPM array planned for 2018 (for x-y position resolution)
- First tests of SiPM arrays in TPC environment (so far, all tests in single-phase)

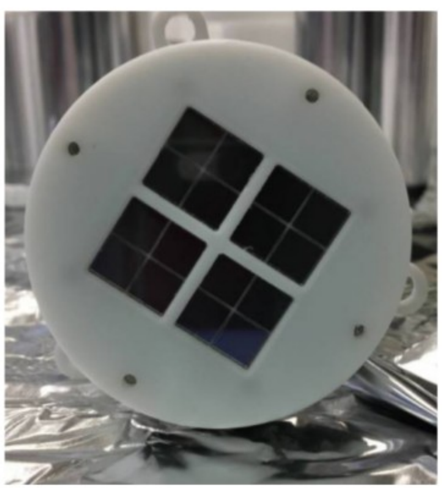


The Xürich detector

arXiv:1712.08607, submitted to EPJC

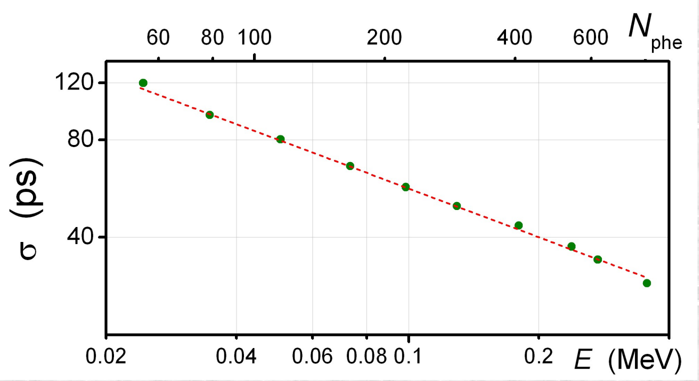


Electron drift velocity measurements

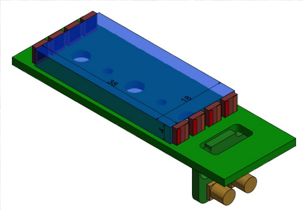


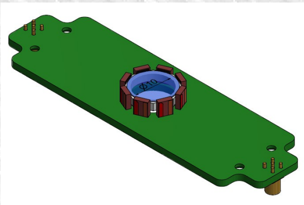
Top SiPM array to replace 2-inch PMT

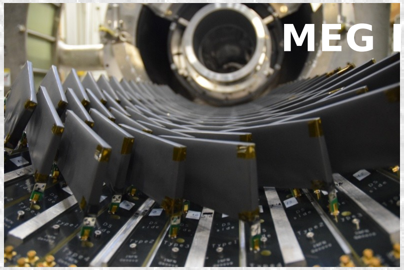
Lepton and neutron physics

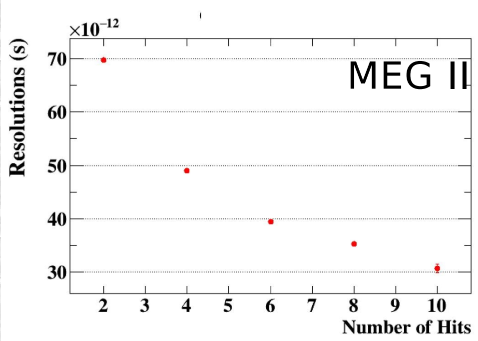


- fast timing plastic scintillation detectors:
  - fundamental studies to achieve best timing resolution:
    $\rightarrow \sigma = \sigma_{1MeV} / E^{0.5}$, with $\sigma_{1MeV} \approx 20$ ps·MeV$^{0.5}$
  - → applications:
    - ▫ pixelated Timing Counter of MEG II experiment
    - ▫ μSR instrumentation

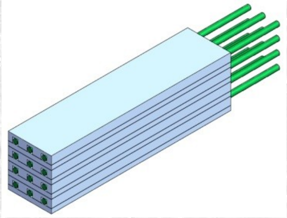


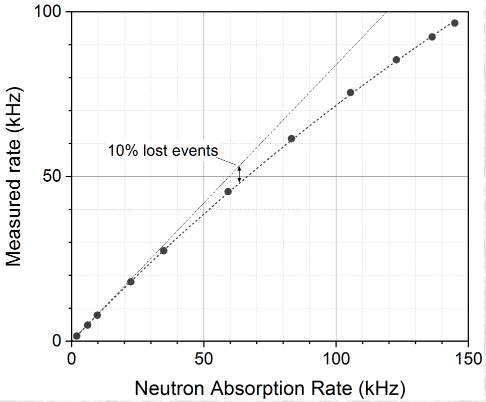






- thermal neutron ZnS scintillation detectors:
  - ZnS:^{6}LiF scintillator and embedded WLS fibres allow high neutron absorption efficiency
  - each channel: individual SiPM and dedicated (FPGA-based) signal processing allow high count rate capability
  - → applications:
    - ▫ neutron scattering instrumentation, e.g. SINQ, ESS
    - ▫ fast neutron detector (e.g. homeland security)



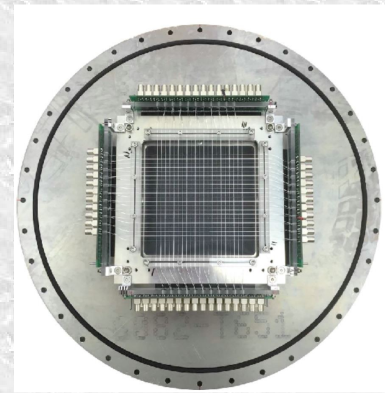


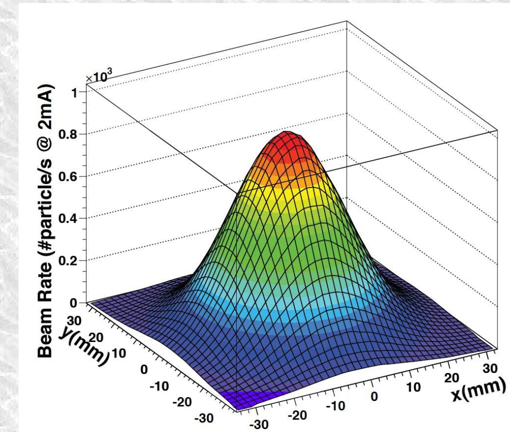
SiPMs
Crystal scintillators

Lepton physics

- fibre beam profile monitor:
  - real-time beam 2D profiles and rates
  - quasi non-invasive
  - high rate capable
  - particle ID

  → applications:
    - tuning tool for secondary beam lines PSI, test beam lines at other facilities
    - conceivable as permanent installation in MEG II, Mu3e, ...

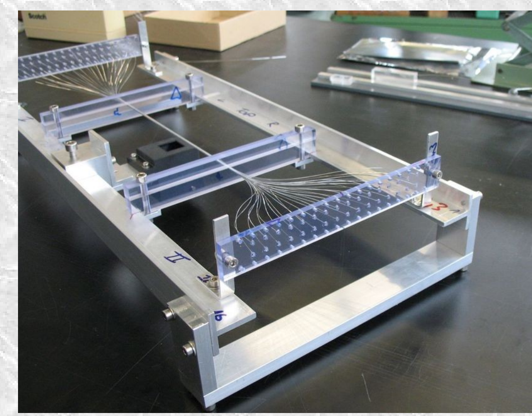




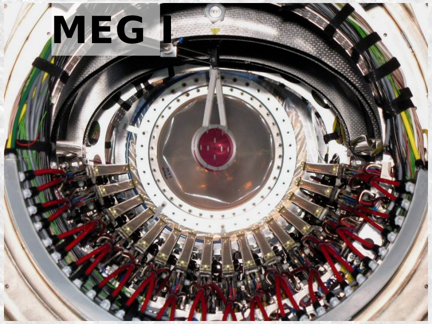
- fibre arrays for fast timing tracking detector:

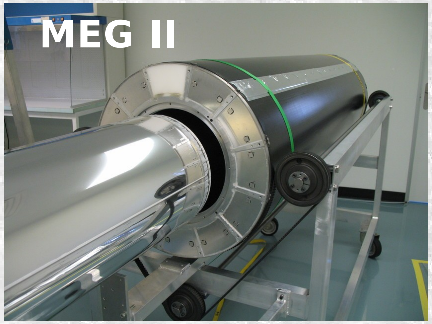
  → aiming for:
    - 3-4 layers of 250 μm fibres, $X/X_0 \leq 0.5\%$
    - high efficiency ≥ 95%
    - timing resolution ~500 ns

  → applications:
    - Scintillating Fibre Tracker in Mu3e Experiment
    - single layer squared fibres conceivable as active target, radiative decay counter in MEG II experiment



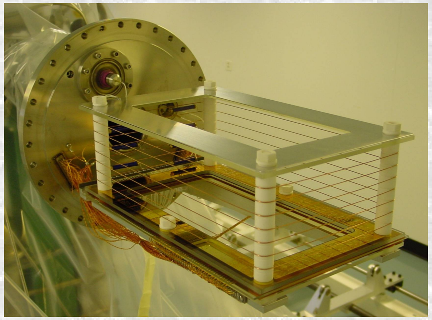
Lepton physics





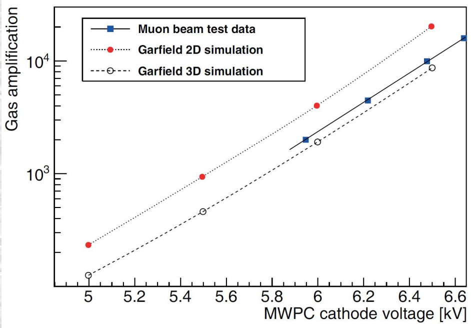
- low material budget proportional chambers:
  - He-based gas mixtures
  - thin metallised electrodes (12 μm polyimide foil, ~250 nm Al in MEG I), Cu/Be- or Al- wires, Rohacell, C-fibre structures

→ applications:
  - MEG experiment: $X_{0,\text{e-track}} = 2.0 \times 10^{-3}$
  - MEG II experiment: $X_{0,\text{e-track}} = 1.6 \times 10^{-3}$

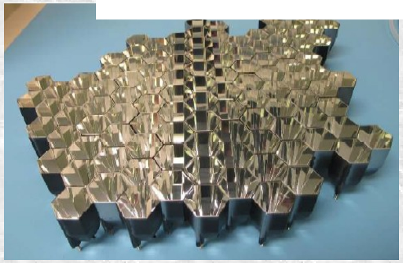


- high pressurised hydrogen proportional chambers:
  - low outgassing, high electrical fields
  - challenging properties concerning gaseous electronics (no quenching)

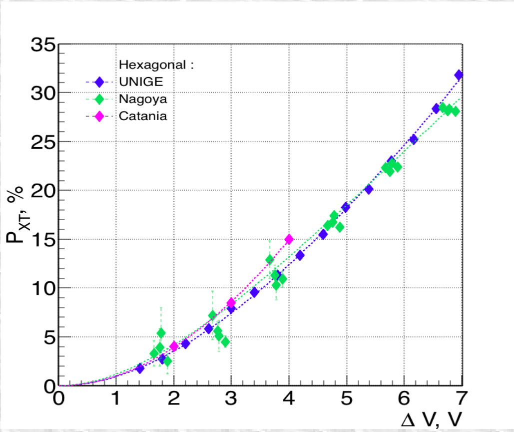
→ applications:
  - TPC and MWPC for MuCap experiment
  - experiments using hydrogen filling operated as active target and detector

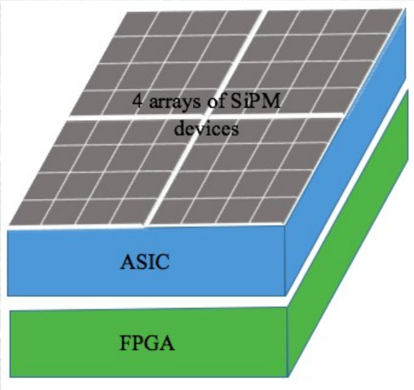


Astroparticle physics

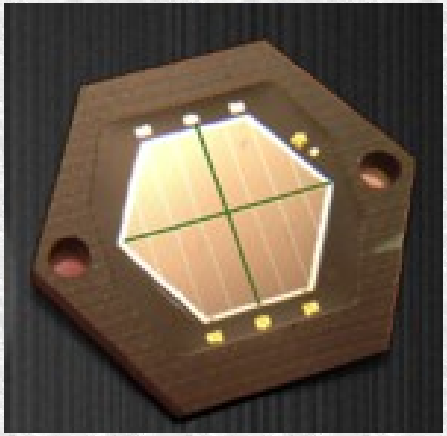


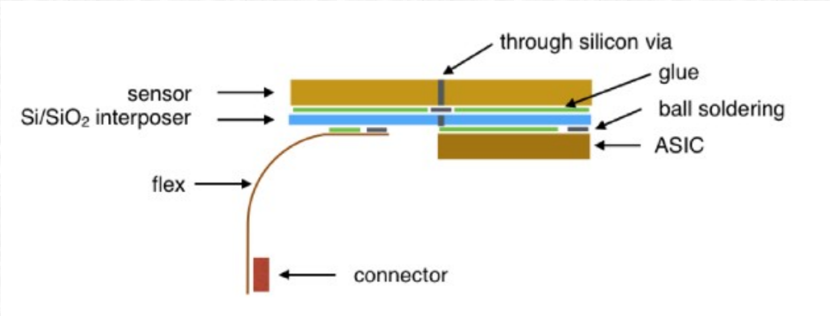
- **CTA R&D:**
  - SiPM development of largest available hexagonal monolithic sensor (EPJC77 (2017) 47)
  - UV-blue Lightguides (also used in LHAASO, China)
  - associated electronics and slow control
  - Dichroic coatings and filters (with ThinFilmPhysics, Zürich)
- **SENSE FET-OPEN:**
  - Roadmap: https://www.sense-pro.org/documents/roadmap
  - Collaborative R&D (UniGE, MPIK, KIT, DESY, UBarcelona, IFAE, Nagoya, Heidelberg): setups of various sensor and optical elements (light guides, filters, etc…) qualification in different institutes for establishment of methods and errors on measurements
  - measurement of all recent sensors from the various manufacturers in the field, characteristics and performance to be stored in an on-line data base with open access
- **New Proposals and R&D activities.**
  - fully integrated plug-and-play photosensor with high level of integration and low power consumption
  - Intra-operative beta probe lego-brick with active background rejection proposed   to SNF-Croatia cooperative projects





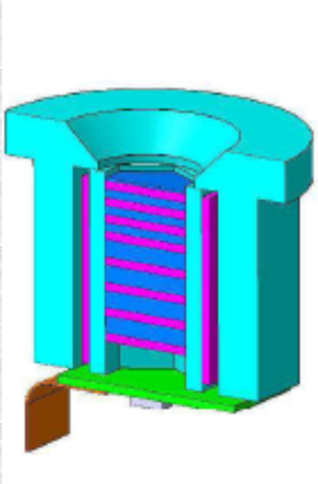
SiPMs
Optics
Integrated sensors
ASICs
FPGA



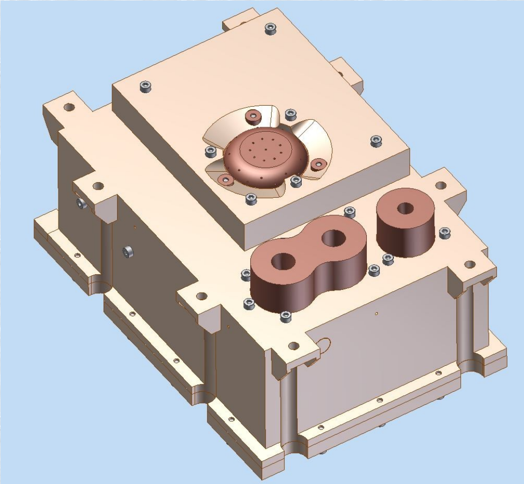


Space particle physics

- spaceborne radiation environment monitors:
  - based on long-lasting, close collaboration with space industry:
    Radiation Environment Monitor (REM)
    Standard Radiation Environment Monitor (SREM)
  - current development: Radiation Hard Electron Monitor (RADEM)
    - stacks of alternating silicon sensors and absorbers
    - electron detector: 0.1 to 40 MeV, up to 10^9 e/cm^2/s
    - proton detector: 5 to 250 MeV, up to 10^8 p/cm^2/s
    - heavy ion detector: particle separation from Helium up to Oxygen



→ applications:
  - ESA JUICE mission to Jupiter (launch 2022): characterisation of particle environment of Jupiter



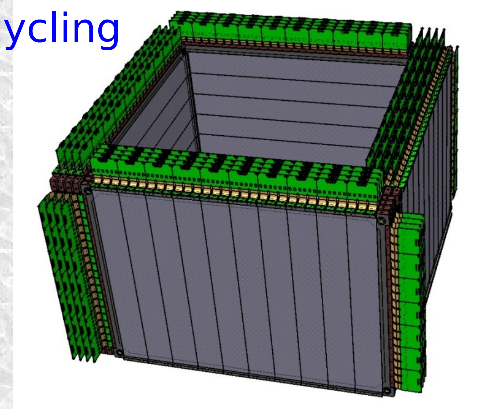
Silicon

Swiss Institute of Particle Physics

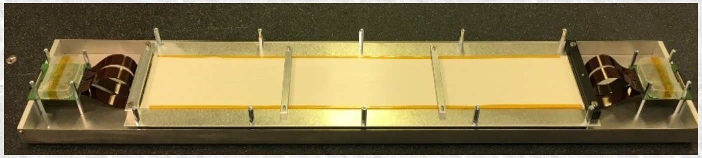
UNIVERSITÉ DE GENÈVE

Space particle physics

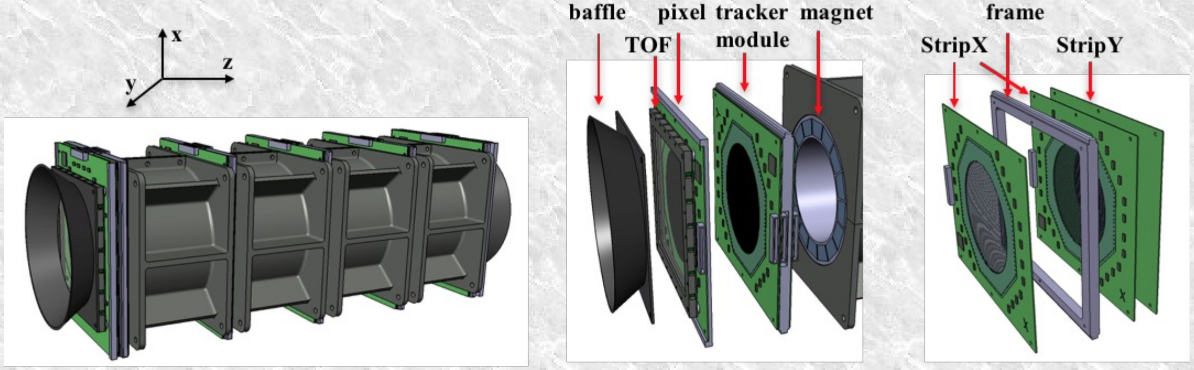
- Specific requirements for particle detectors in space
  - Low mass, low power, vacuum operation, long life (>10 years), radiation resistant (<10 kRad/year with 1mm Al shielding)
  - Survive launching condition: vibration, shock, acceleration, thermal cycling



- **HERD Fiber tracker (FIT)**
  Based on fiber mat and SiPM of LHCb/EPFL
  272 mats (112/160 long/short)
  - 816 MPPC + 408 HDR MPPC, ~157k channels
  - ~11.2 m2 mats, ~ 560 km fiber



- **PAN Instrument**
  Light weight (20 kg) low power (20 W) spectrometer with permanent magnet
  5 tracker modules (Si), 2 TOF modules (Sci+SiPM), 2 pixel modules (Si)



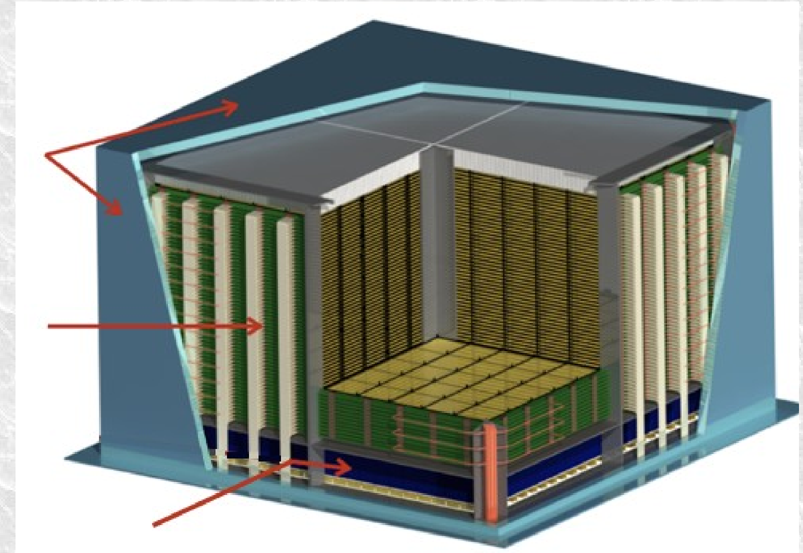
a) b) c)

Silicon
Sci + SiPM

Space particle physics

eASTROGAM proposal to ESA M5Anti-Coincidence System to veto charged particles

plastic scintillators readout by Si PMs + Time of Flight



Tracker – Double-sided Si strip detectors for spectral resolution & 3-D resolution 1m2 area, 0.3 Xo deep

4 towers, 56 layers of 5×5 DSSDs

DSSD: 9.5×9.5 cm², 500 µm thick, 240 µm pitch

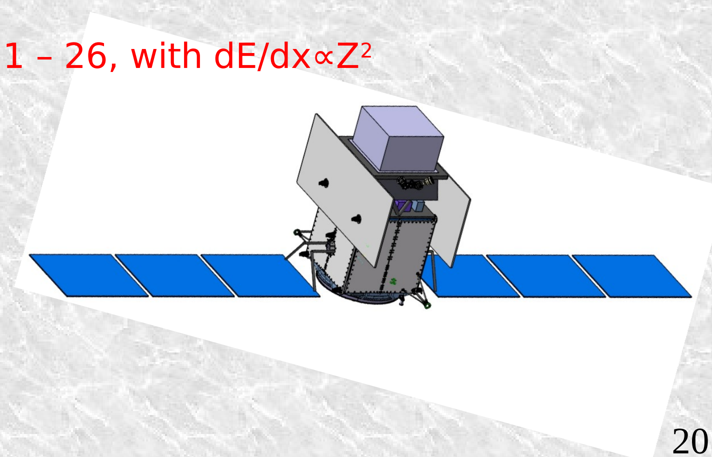
Calorimeter – CsI(Tl) crystals

readout by Si drift detectors for best energy resolution

8 cm thick (4.3 Xo)

R/O ASIC requirements:

- High density: 64-128 channels/chip
- Low power: <0.3 mW/channel
- Low noise: for best position resolution with analog readout
- High dynamic range: in space tracker also used to measure Z, from 1 – 26, with $dE/dx \propto Z^2$
- For Si strip (long or short) and SiPM
- Radiation resistant, up to ~100 kRad
- Typically low rate, $\lesssim$ MHz



Silicon
Crystal / Plastic Sci + SiPM
ASIC !

Neutrino physics with water Cerenkov

Swiss Institute of Particle Physics

UNIVERSITÉ DE GENÈVE

Magnetized Iron Neutrino Detector

Design goals
-- adaptable to rectangular geometries (LBNO)
-- efficient to low enegy muons (>300 MeV)
-- magnetic charge separation
-- momentum by range
-- as high field as possible
-- low power consumption
-- low cost

Collaboration
initially in Neutrino Factory (-> 100 kton!) AIDA
then LBNO … but not needed for DUNE
→ spectrometer for WAGASCI in T2K ND280
2015: CERN NP05 project
spokes Blondel, Kudenko, PM: Etam Noah
2018 taking data in T2K
First ν events in NP experiment!

Baby MIND

WAGASCI
(water scintillator target)

Physics goals
-- Water cross-sections at different off-axis angles
– access «neutrino energy response function»

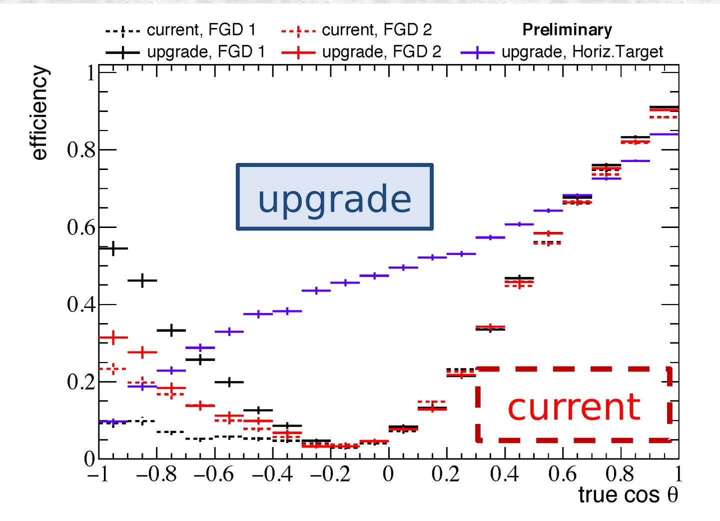
-- an important step in the T2K campaign against systematic errors!

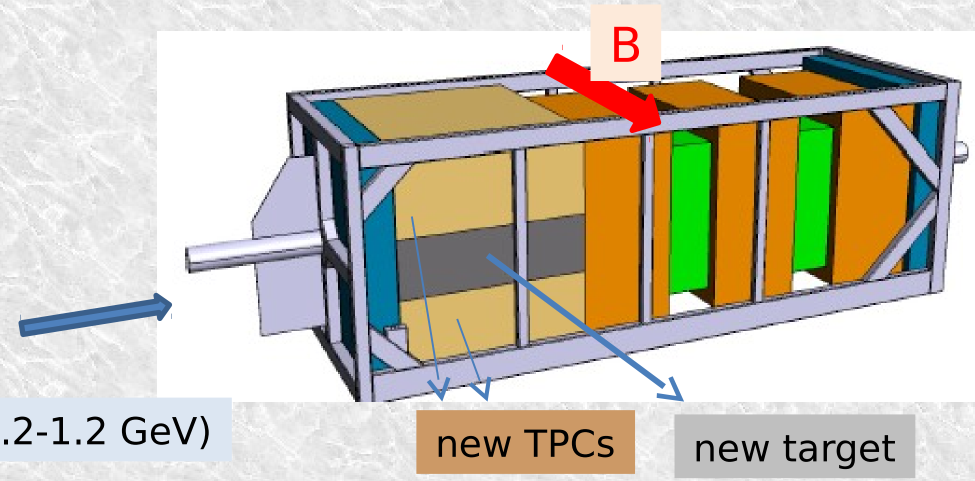
-- joint T2K/Wagasci-baby-MIND analysis
-- integration in T2K collaboration

Scintillator +WLSFi + SiPM

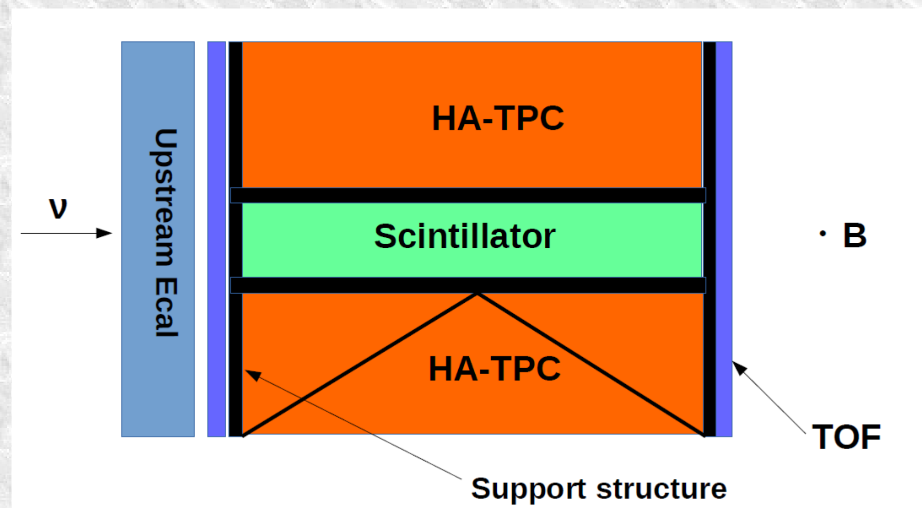
Neutrino physics with water Cerenkov

T2K ND280 upgrade





The current near detector of T2K has relatively poor acceptance at large angle, in contrast with SuperK (the far detector)
➔ systematic errors.
Improve to <3% with a new horizontal target situated between large angle TPC trackers and surrounded by a TOF system
(you saw the first idea by AB at CHIPP2015)
➔ ND280 upgrade study launched spring 2016
➔ T2K project spring 2017 (CERN EOI-015)
➔ Proposal CERN-P357 (219 Authors)
➔ CERN Neutrino group joined T2K upgrade



UNIGE: TOF (Mermod, like SHIP timing)
+electronics design and mechanical integration
very challenging electronics integration
within small gap between TPC and SFGD

Neutrino physics with water Cerenkov

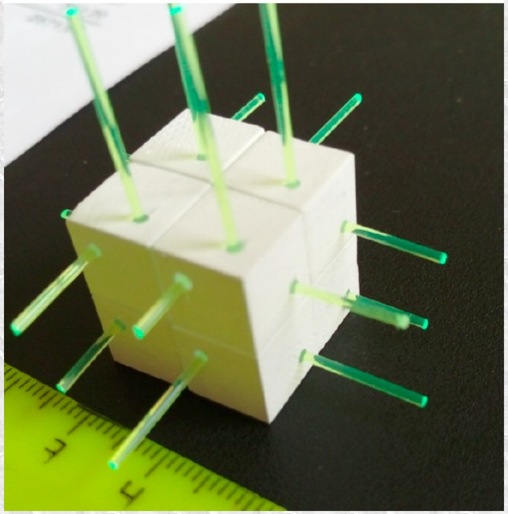
T2K ND280 upgrade

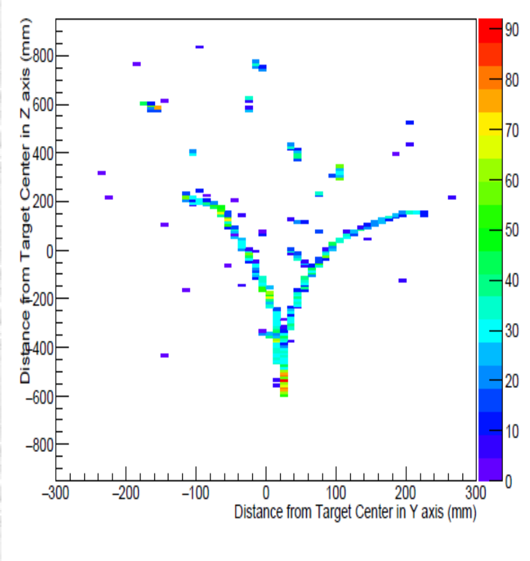
The new target (SuperFGD)
JINST 13 (2018) no.02, P02006
Aims :
Full scattering angle acceptance
Detection of energy around the vertex and low energy protons
-- fully active 3D detector
Detection of electron-neutrinos
➔ e/γ separation

Choice of 1cm³ cubes of scintillator readout by 3 WLS fibers MPPC readout
2 million cubes, 55’000 channels
1Mip ~40 p.e. for each direction/cube
(test of 3x3x3 prototype in Oct.2017)

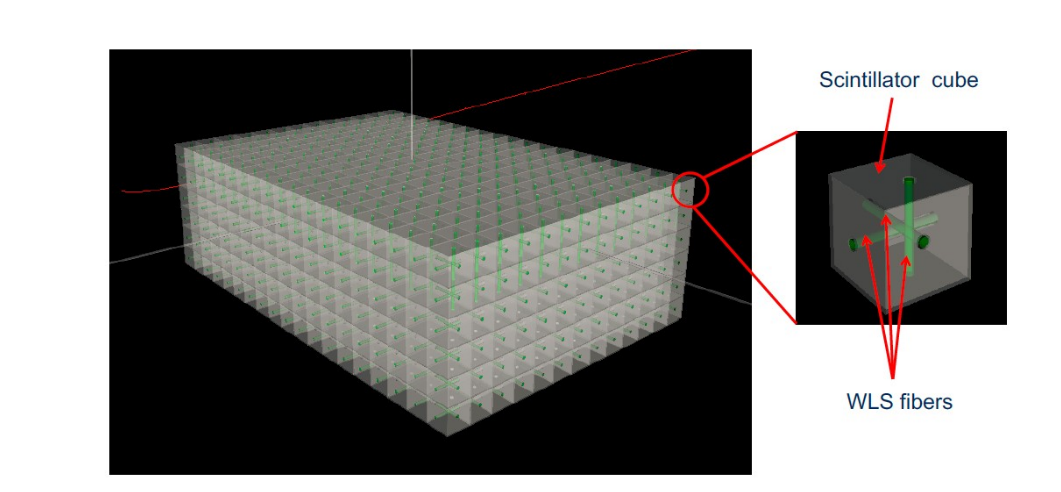
Presently designing MPPC+electronics to be integrated on surface of detector.
+ integration mechanics
Test beam in June-September 2018.
1736 channel prototype . Will use baby-MIND electronics.

Scintillator +WLSFi + SiPM





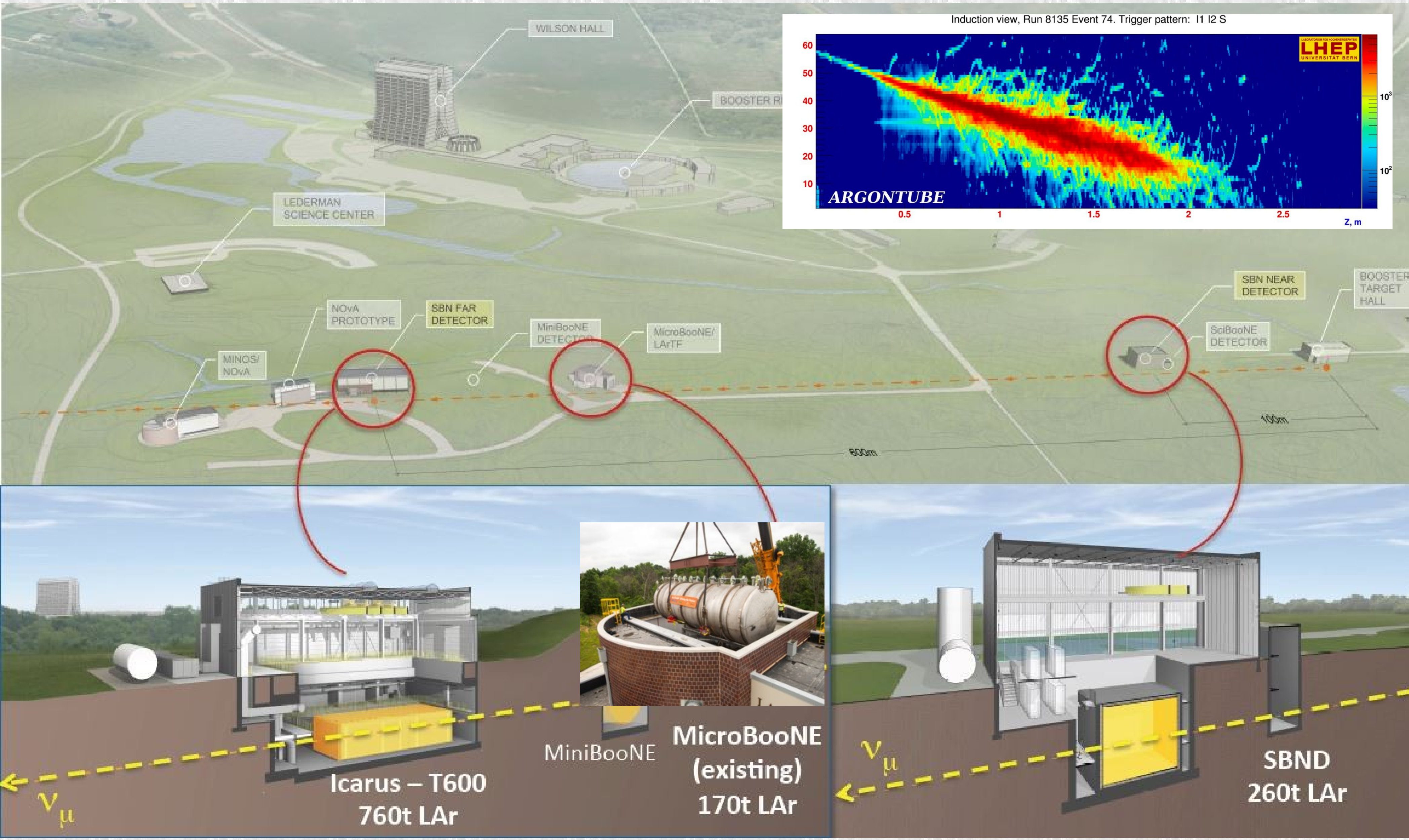
γ pair conversion in SFGD



Swiss Institute of Particle Physics

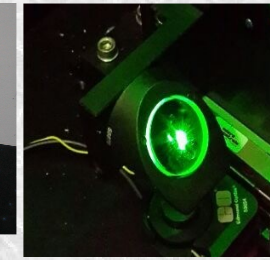
Neutrino physics with LAr: SBN

UNIVERSITÄT BERN



Neutrino physics with LAr : SBN

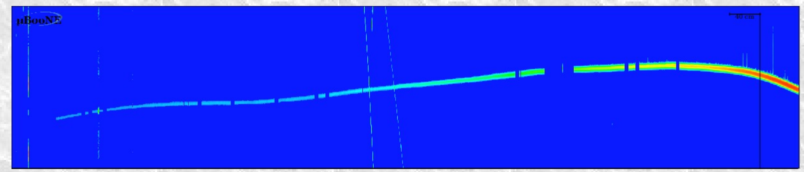
MicroBooNE & SBND :

- Laser Field Calibration System

  Correction of field distorsions with straight ionization track from pulsed UV laser

  A. Ereditato et al., JINST 9, P11010 (2014)
  A. Ereditato et al., JINST 9, T11007 (2014)



- Scintillating Cosmic Ray tagger

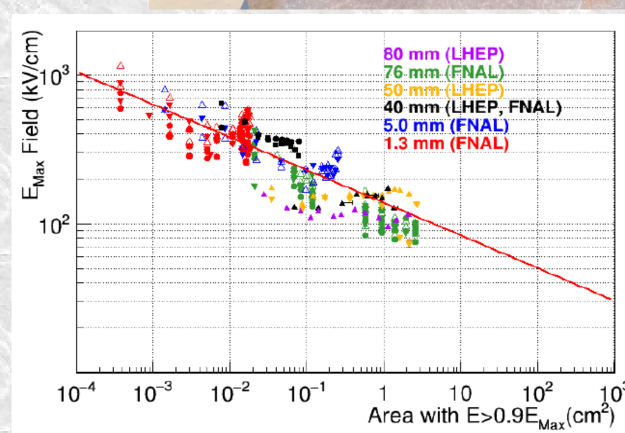
  Tagging cosmics with scintilator coverage

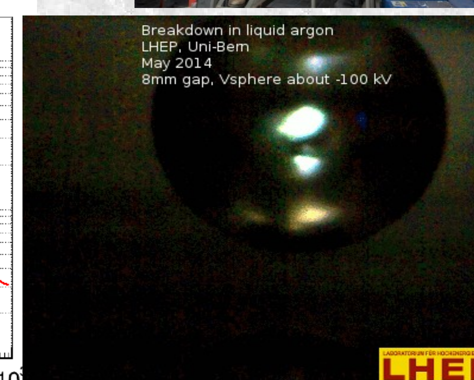
  M. Auger et al., Instruments 1 (2017) no.1, 2
  M. Auger et al., JINST 11 (2016) no.10, P10005

- HV in noble liquids

  Dicovery of anomalous breakdown limit

  M. Auger et al., JINST 9, P07023 (2014)
  A. Blatter et al., JINST 9, P04006 (2014)
  M. Auger et al., JINST 11, P03017 (2016)

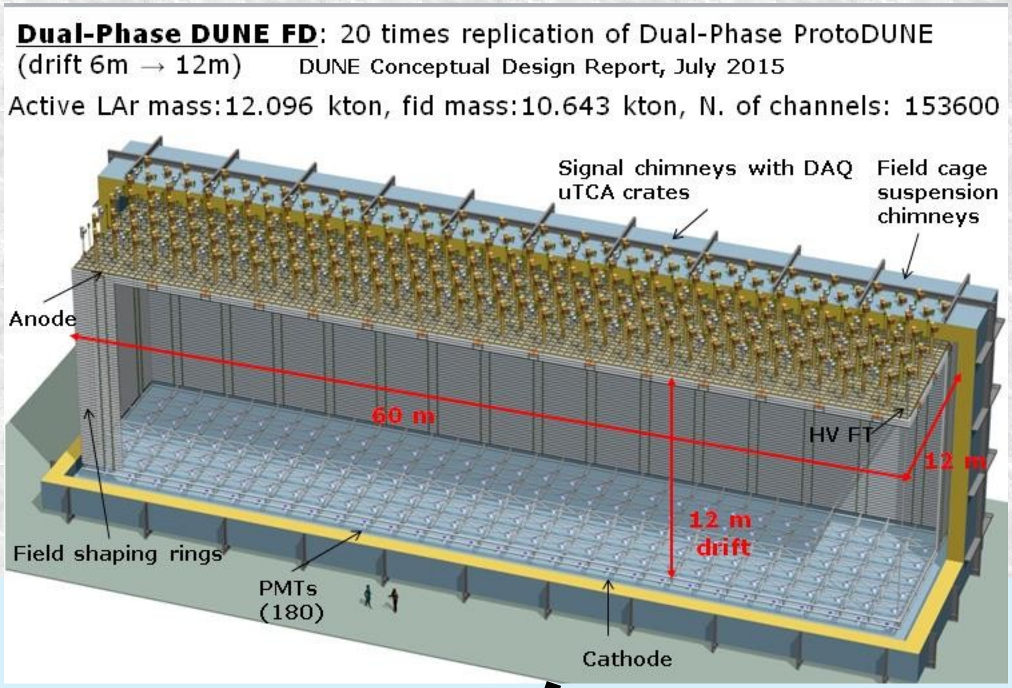




LAr
Sci+WLS Fi
SiPM
Electronics

CH - recognized leader in the know-how and technology

Neutrino physics with LAr: DUNE

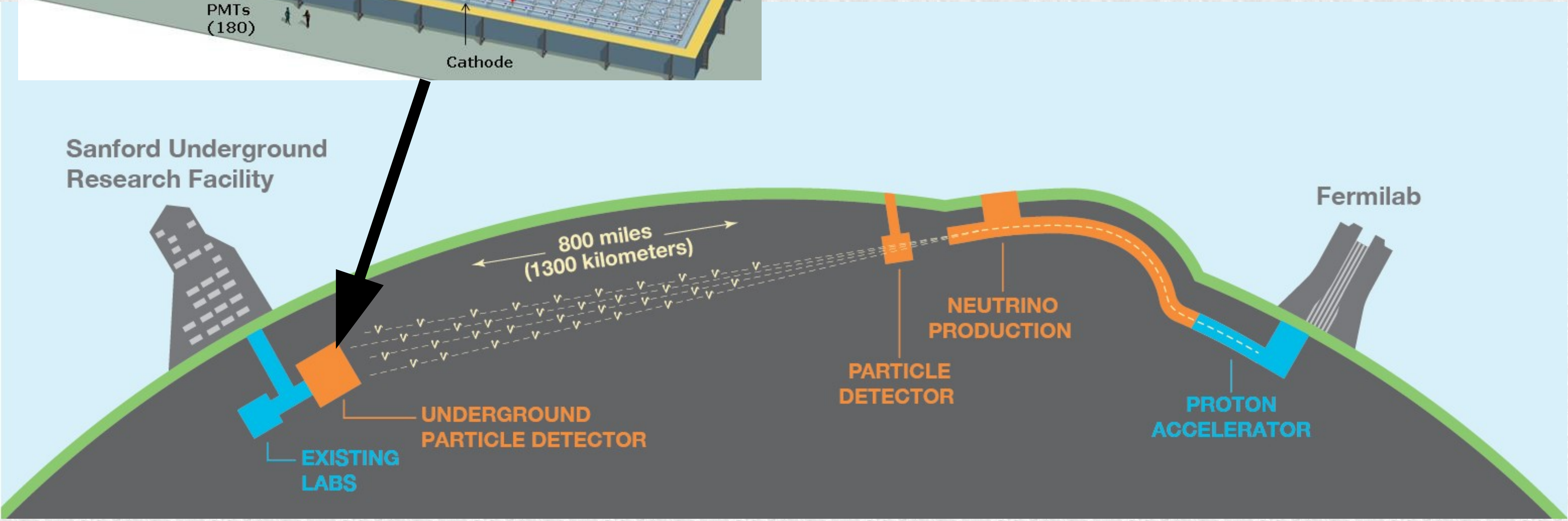


Far detector (FD)

Ultimate target mass 40 kton

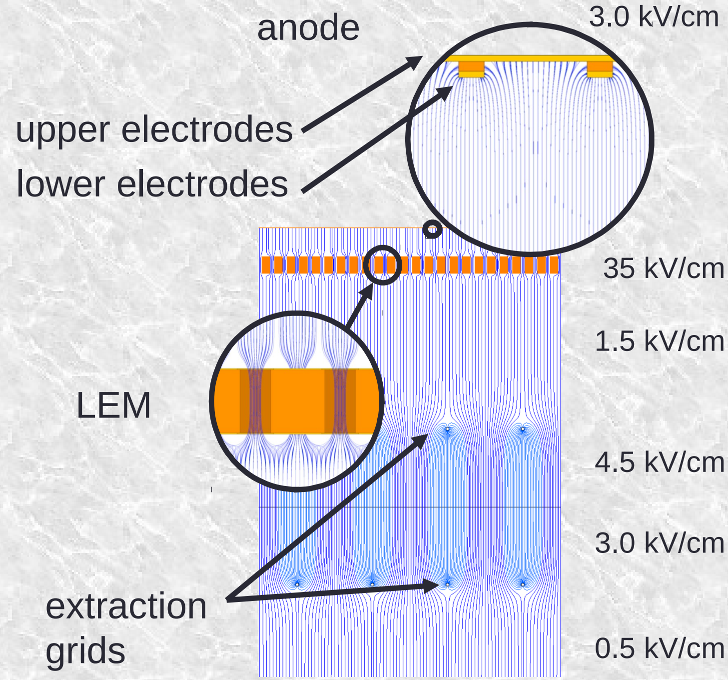
Single Phase Module(s) (SP)

Dual Phase Module(s) (DP)



The Dual Phase LArTPC concept (DP)

1.) Ionization electrons drift towards the liquid argon surface
2.) Drift electrons are efficiently emitted into the gas phase
3.) Charge multiplication in the holes of the Large Electron Multiplier (LEM)
4.) Charge collection on a 2D anode readout (symmetric unipolar signals with two orthogonal views)



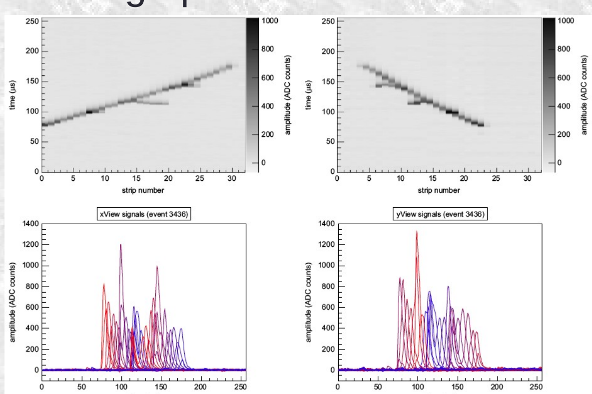
Results from a 10x10 cm2 prototype

charge sharing test of the 2D anode

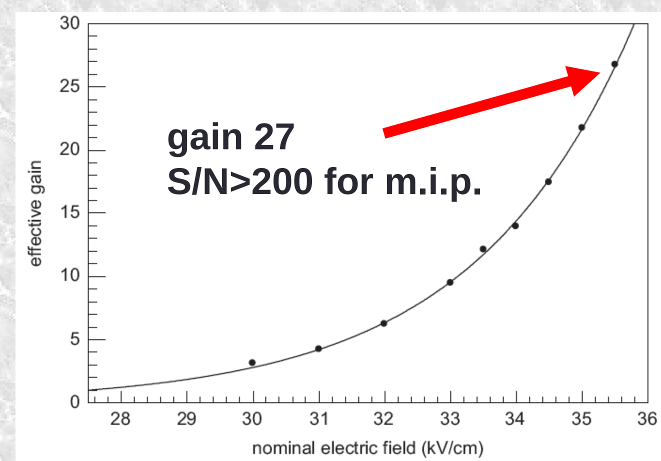
- signal shape of x and y view identical
- charge sharing verified:

(x-y)/<x+y> better than 5%

- design parameters verified



gain curve



NIM A 641 (2011) 48-57

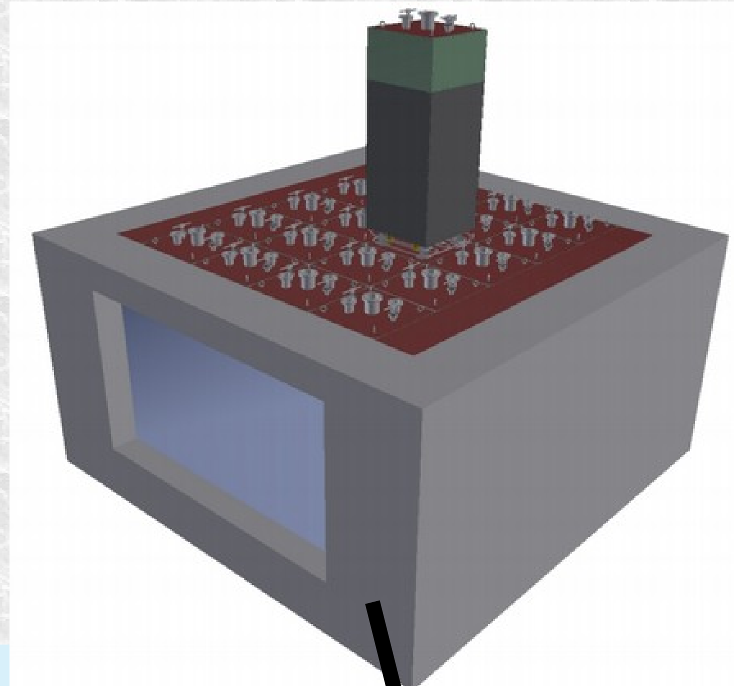
LAr Electronics

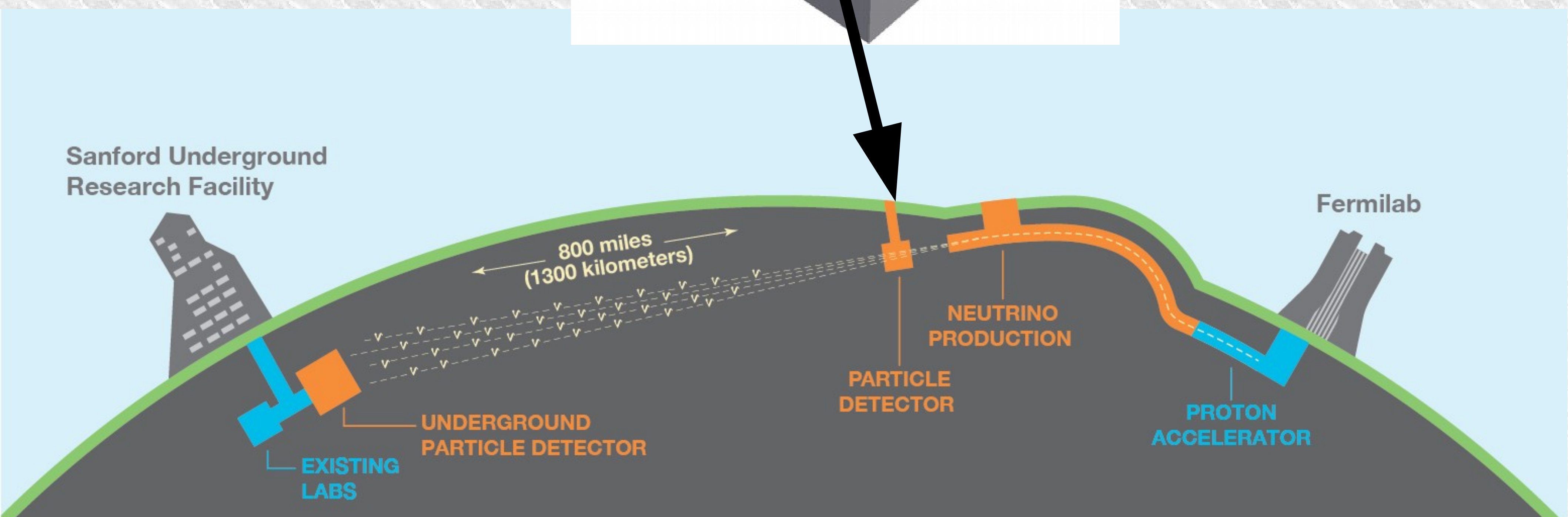
Neutrino physics with LAr: DUNE

Near detector (ND)

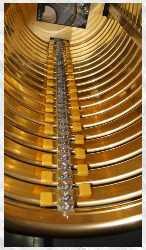
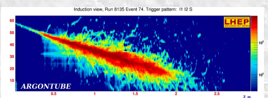
Target mass 80 tons

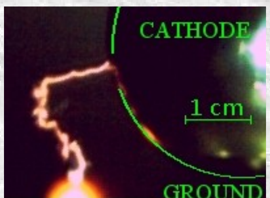
ArgonCUBE design

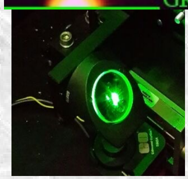
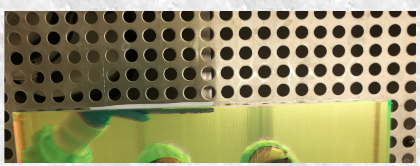
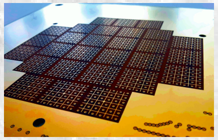
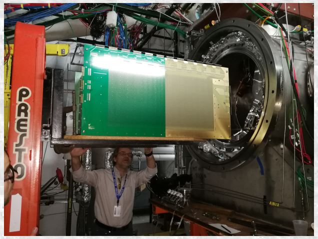




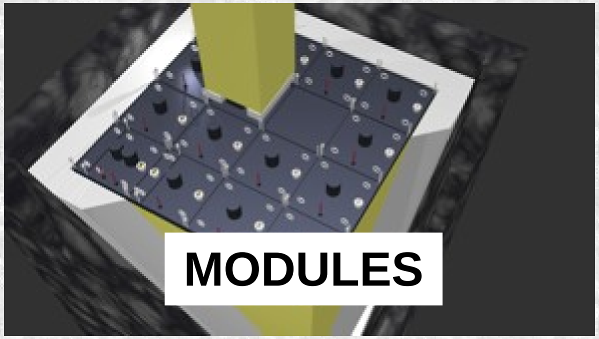
Neutrino physics with LAr: DUNE ND (ArgonCUBE)

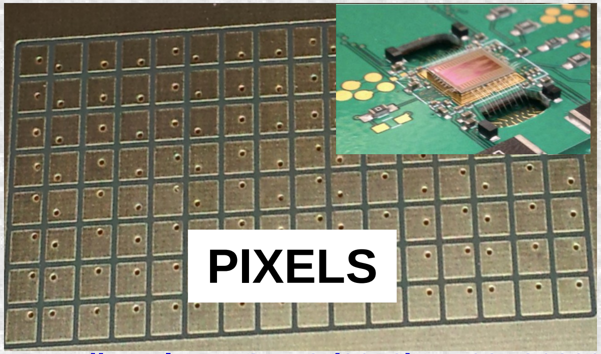





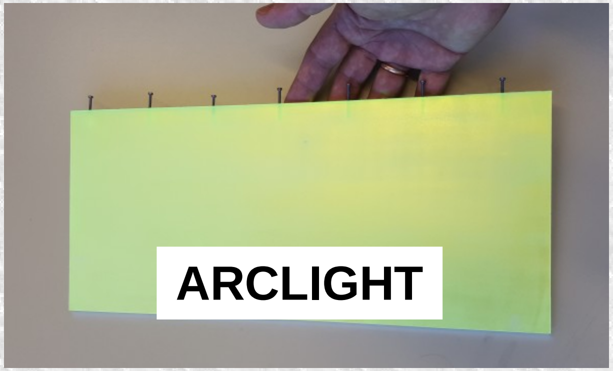





LAr
Sci+WLS
SiPM
Cryo-ASICs
Electronics



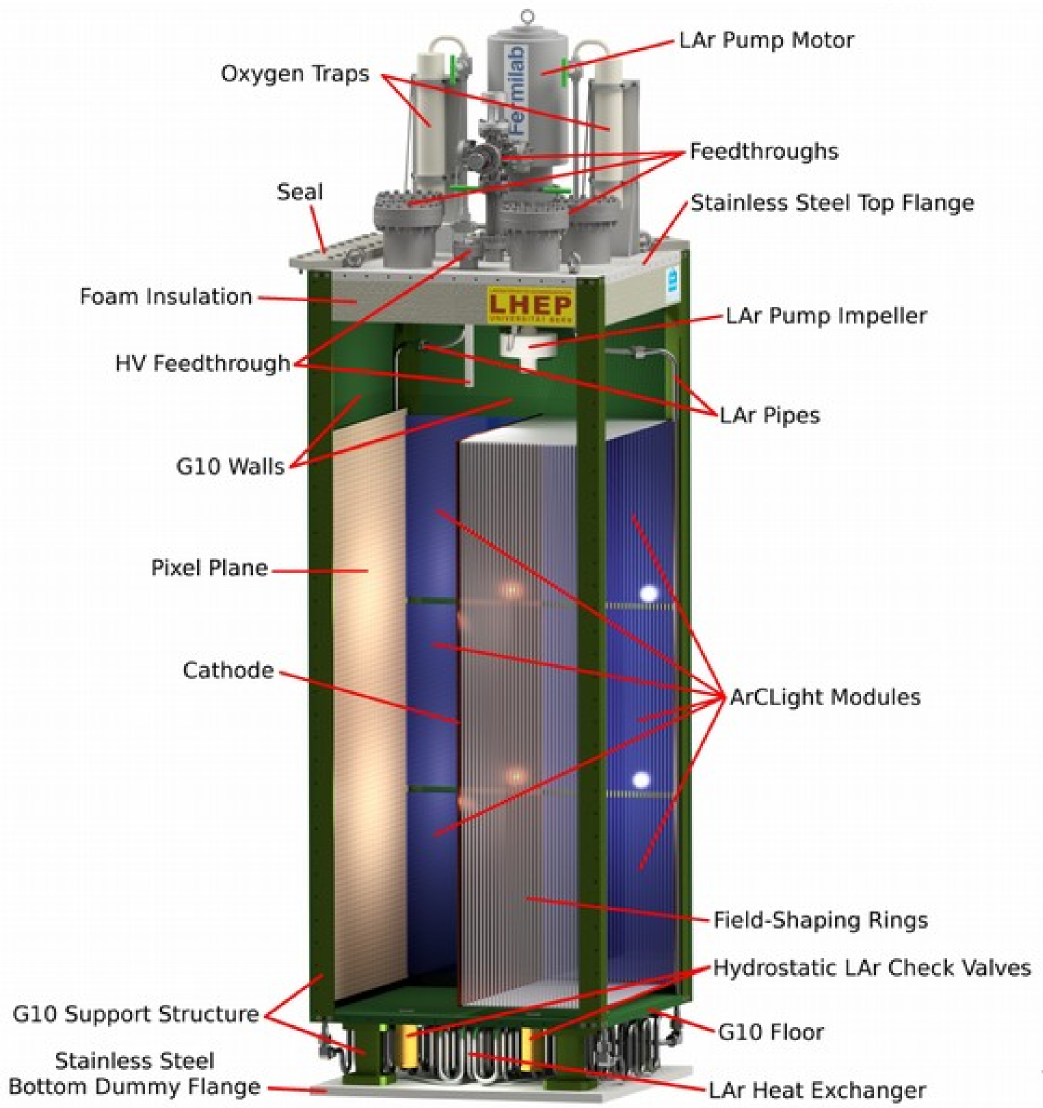


J. Asaadi et al., JINST 13 (2018) no.02, C02008



M. Auger et al., Instruments 2 (2018) no.1, 3

Neutrino physics with LAr: DUNE ND (ArgonCUBE)



Module: an independent TPC

- Individual thermal/purity management

- Cathode bias (-100 kV) supplied via HV feed-through
- Relatively low voltage => breakdown-free setup
- Electrically transparent container => low dead volume

- Drift time ~ 0.5 ms => reduced purity requirements

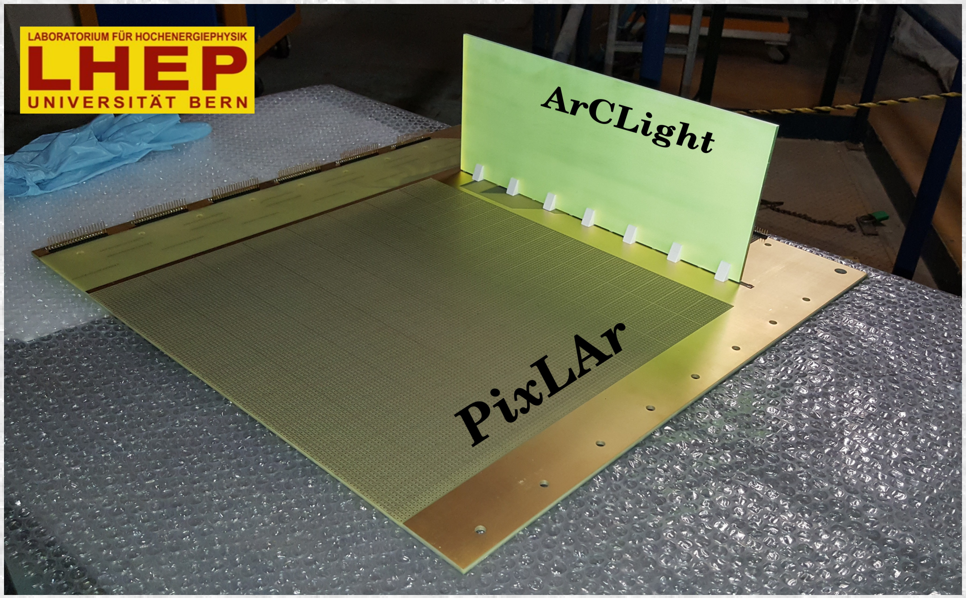
- Mechanically robust production technology
- Low failure cost

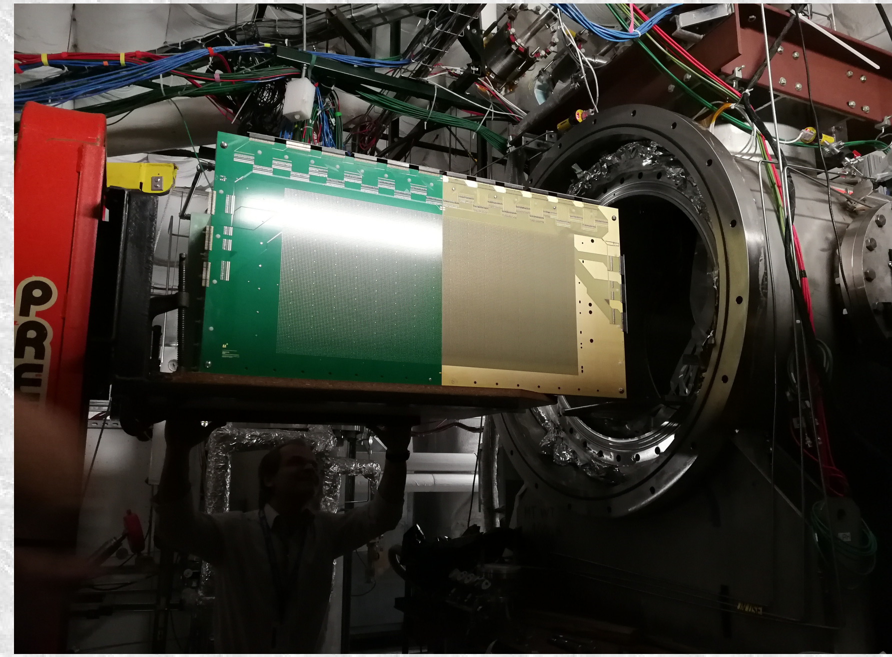
- Charge readout: pad arrays, *e.g.* 4x4 mm^2 pads
- Light readout via WLS light guides & SiPMs

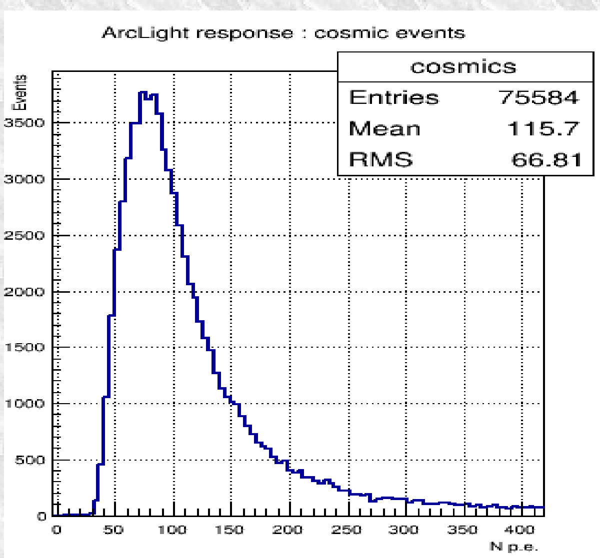
Reliable/repairable self-contained unit

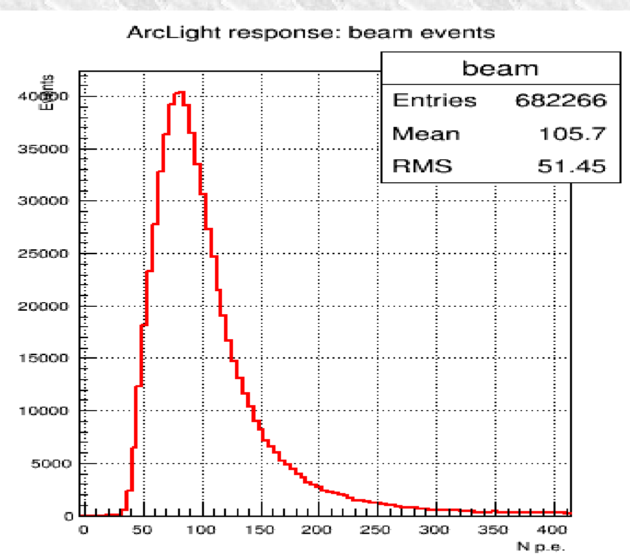
Neutrino physics with LAr: DUNE ND (ArgonCUBE)

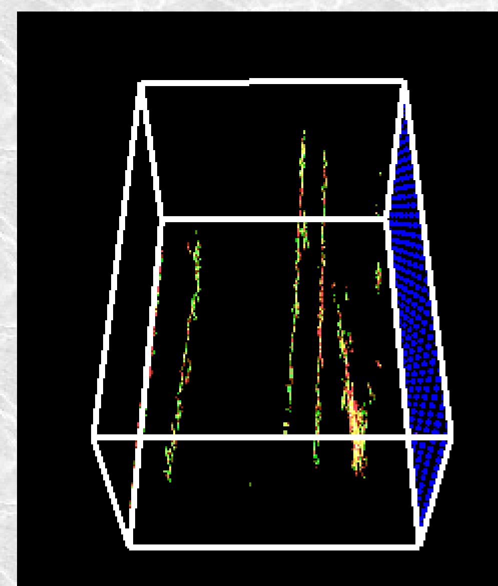
Test of PixelPlane and ArcLight in the LArIAT beam



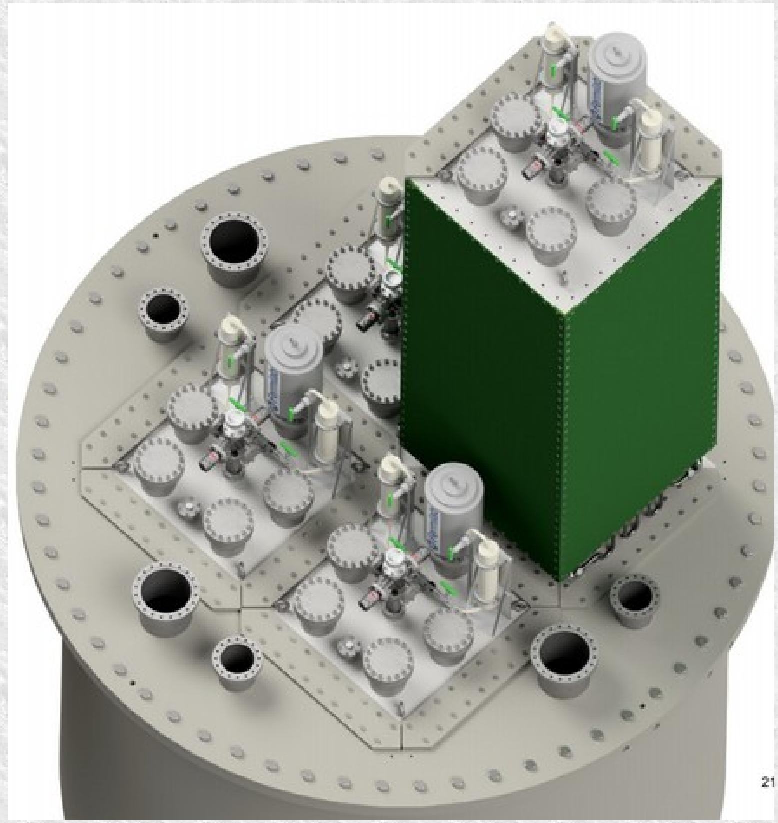


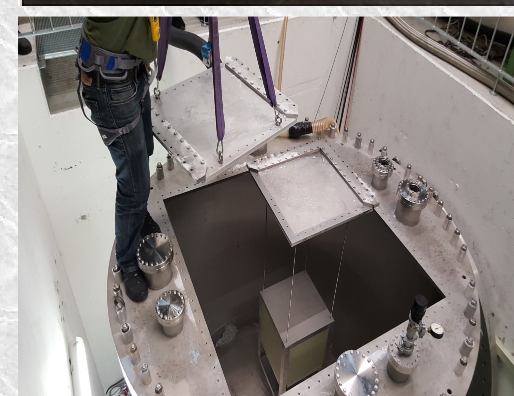






Neutrino physics with LAr: DUNE ND (ArgonCUBE)





LAr + Cryogenics
Sci+WLS
SiPM
Cryo-ASICs
Electronics

Detector R&D in Switzerland

Frontiers (LHC):
R&D: Silicon detectors, SiPM arrays, SciFi, electronics, ASICs, rad. hardness

Dark Matter Search : XENON(s), DARWIN
R&D: Radiopure materials, advanced photon detectors & electronics (SiPM, hybrid), 4-pi TPC readout, LAr, LXe TPC

Astroparticle physics: CTA
R&D : Low Light Level sensors (SiPM, hybrid, within EU SENSE roadmap), integrated sensors (Silicon+ASIC+FPGA)

Neutron physics (n-imaging, homeland security)
R&D :Thermal and fast neutron imagers, Scintillators+SiPMs

X-ray physics (wide application spectrum)
R&D: Fast pixel X-ray detectors (fs) and associated electronics (with DECTRIS)

Lepton physics (MEG, Mu3e)
R&D: Fast timing scintillating counters and trackers, SiPM, fiber beam profilers, low-material gas chambers

Space physics: planets exploration program
R&D: Silicon-based spaceborne rad sensors (RADEM)

Space particle physics: HERD,eASTROGAM,PAN,POLAR2,eXTP
R&D: Silicon strips, Sci Fi and Bars, SiPMs,

Neutrino physics: GERDA, LEGEND, DARWIN.
R&D: Radiopure materials, advanced electronics, WLS, 4-pi TPC readout, LAr TPC

Neutrino physics: T2K
R&D: Magnetized Iron+Scintillators (BabyMIND), SciFi+SiPMs

Neutrino physics: DUNE
R&D: LAr TPC (SP & DP): LEM, true 3d pixelized readout, modular, advanced scint. Detectors, SiPM

Detector R&D in Switzerland
Dry residual

Various technologies !!!

Most popular are:

Silicon : strips/pixels, direct / charge transfer (ccd)

SiPMs and associated electronics

Scintillators (crystal/plastic, fibers/bars)

Cryogenic noble liquids (LAr / LXe)

Strong request: **ASIC**s design, warm and cold !