INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

Congresso 3-4 febbraio 2022

Dipartimento Interateneo di Fisica "M. Merlin"

Detector developments for future experiments

Alessandra Pastore (INFN Bari)
on behalf of many others

Designing our future ….

- Future detector developments: global perspectives
- Research and developments @ INFN Bari
- Summary and outlooks

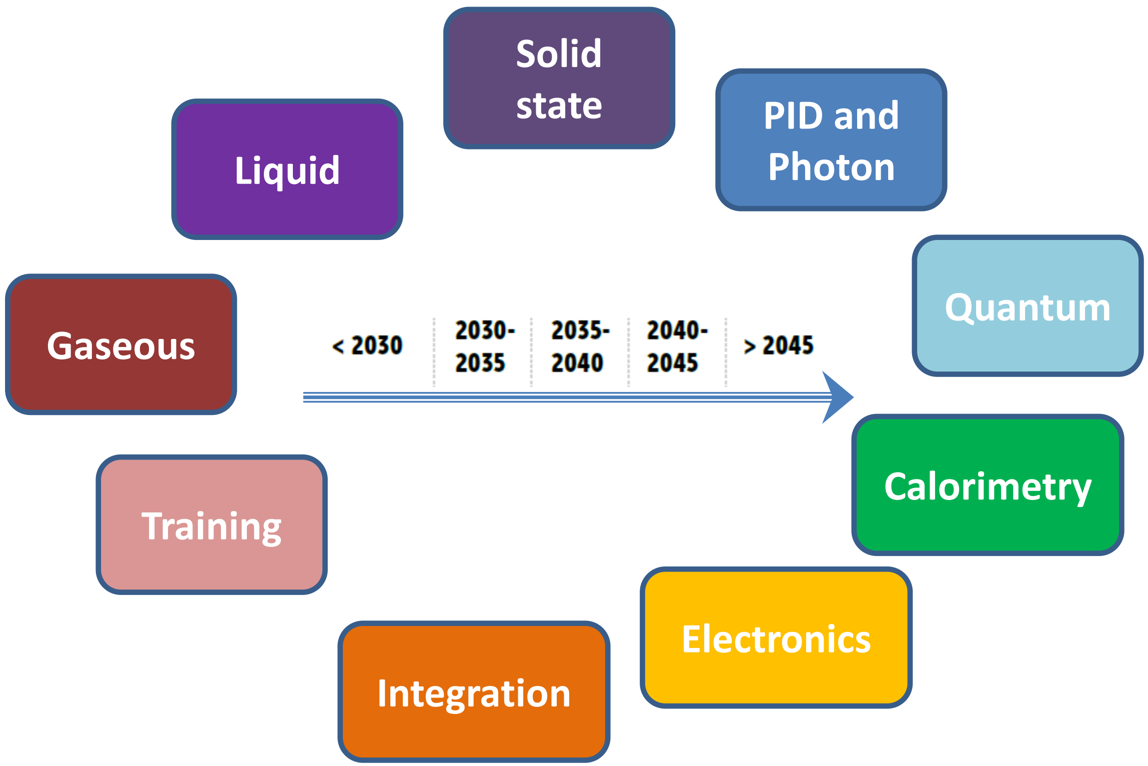
The 2021 ECFA European Detector R&D roadmap

https://cds.cern.ch/record/2784893

May 2020 → EPPSU mandate to ECFA

develop a roadmap for detector R&D efforts in Europe, with a bottom-up approach

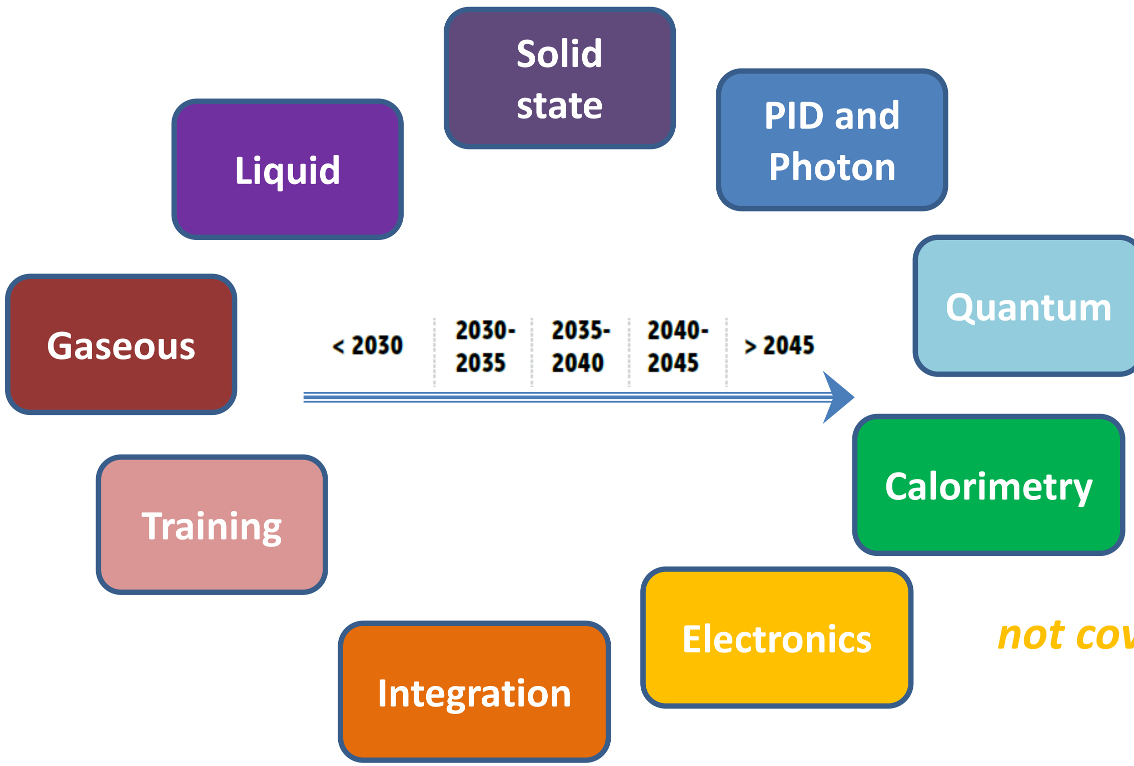
coordination between several communities (ECFA, APPEC, NuPECC, LEAPS, LENS, ESA)



Detector R&D roadmap: focus on INFN Bari

https://cds.cern.ch/record/2784893

- several R&D activities started or ready to start locally
- focus on future experiments (medium-long term)
- well integrated into the ECFA roadmap



not covered by this talk

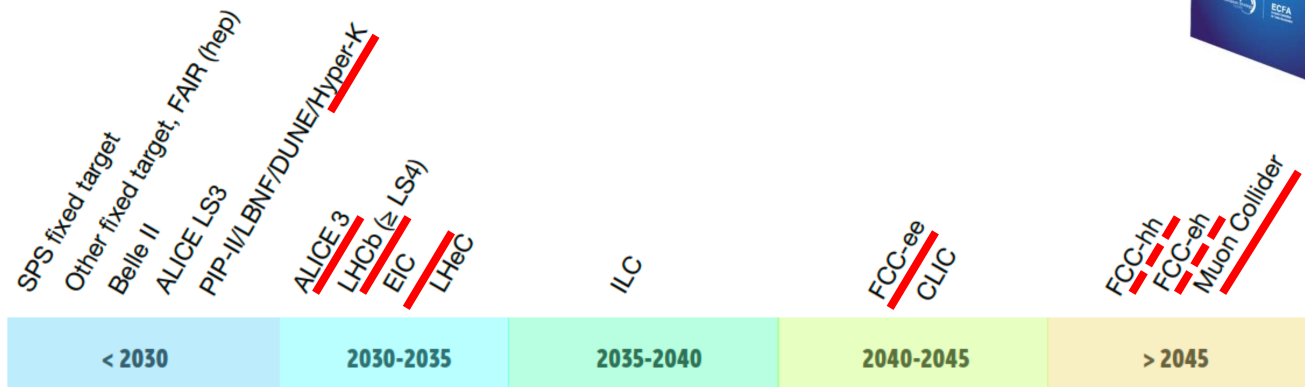
not covered by this talk

Detector R&D roadmap: focus on INFN Bari

An indication of the earliest feasible start dates is given

https://cds.cern.ch/record/2784893

Large Accelerator Based Facility/Experiment



Smaller Accelerator and Non-Accelerator Based Experiments (not exhaustive)

R&D @ INFN Bari on Gaseous detectors

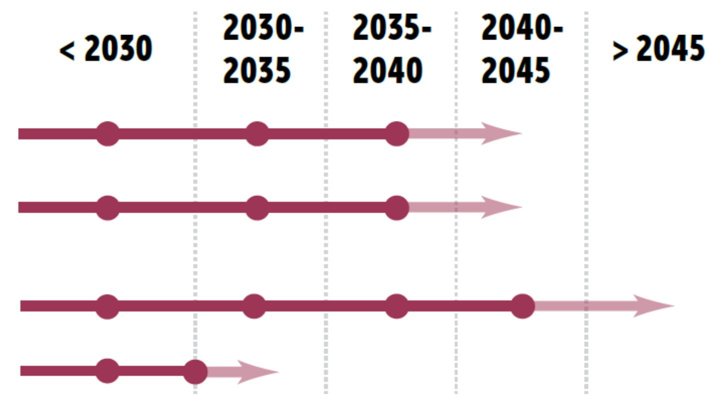
Gaseous

DRDT 1.1 Improve time and spatial resolution for gaseous detectors with long-term stability

DRDT 1.2 Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes

DRDT 1.3 Develop environmentally friendly gaseous detectors for very large areas with high-rate capability

DRDT 1.4 Achieve high sensitivity in both low and high-pressure TPCs



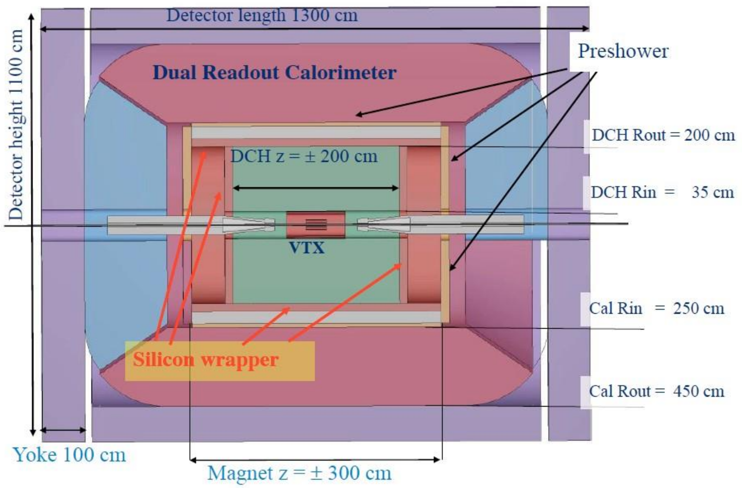
focus on:

R&D @ INFN Bari on Gaseous detectors

The IDEA detector at e^+e^- colliders

FCC-ee
at CERN

CEPC
at IHEP-China



Innovative Detector for Electron-Positron Accelerators

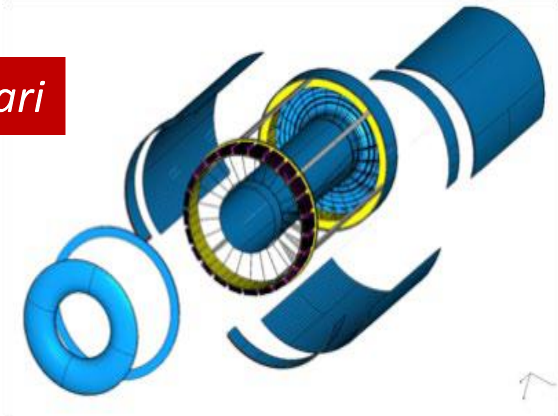
electron-positron collisions in a wide energy range

measure the Higgs boson σ_{prod} and most of its properties with precisions far beyond achievable at the LHC

Central tracker:

IDEA-Bari

- silicon pixel vertex detector
- large-volume ultra-light drift chamber
- silicon strip detectors in both barrel and forward regions



Ultra – light cylindrical DC:
4 m long, r = 35-200 cm,
112 layers, 343968 wires in total
90% He – 10% i-C4H10 gas mix
ε_{trk} ~ 1 @ θ > 260 mrad

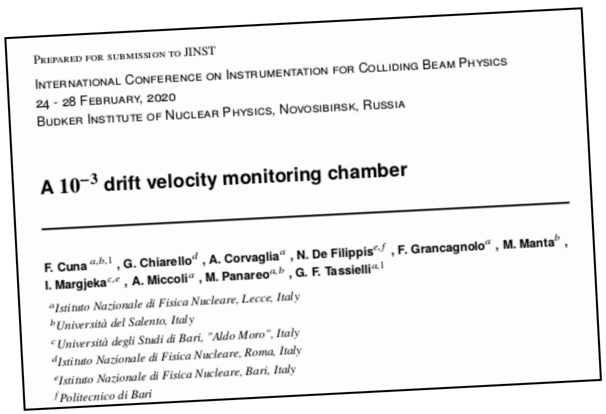
New concept of construction
material reduced to ≈ 10^{-3} X0 (barrel)
and to a few x 10^{-2} X0 (end-cap)

R&D @ INFN Bari on Gaseous detectors

IDEA-Bari:

- Focus on the ultra-light drift chamber project
- Design, test and characterization of a small chamber as drift velocity monitoring device
- Geant4 simulation of the drift chamber
- test beam activity at CERN to test the “cluster counting” technique for PID

Design, test and characterization of a small chamber for monitoring the drift velocity


Prepared for submission to JINST

International Conference on Instrumentation for Colliding Beam Physics
24 - 28 February, 2020
Budker Institute of Nuclear Physics, Novosibirsk, Russia

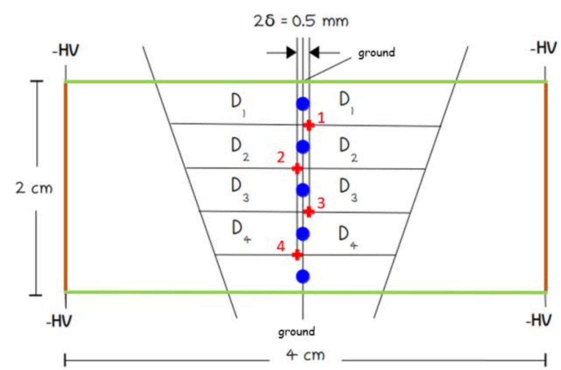
A 10^{-3} drift velocity monitoring chamber

F. Cuna[a,b,1], G. Chiarello[d], A. Corvaglia[a], N. De Filippis[e,f], F. Grancagnolo[a], M. Manta[b], I. Margjeka[c,e], A. Miccoli[a], M. Panareo[a,b], G. F. Tassielli[a,1]

[a] *Istituto Nazionale di Fisica Nucleare, Lecce, Italy*
[b] *Università del Salento, Italy*
[c] *Università degli Studi di Bari, "Aldo Moro", Italy*
[d] *Istituto Nazionale di Fisica Nucleare, Roma, Italy*
[e] *Istituto Nazionale di Fisica Nucleare, Bari, Italy*
[f] *Politecnico di Bari*

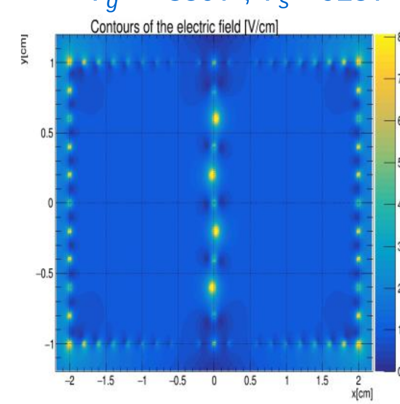
continuous monitoring of the quality of gas →
install a small drift chamber that allows to measure electron v_{drift} variations at the 10^{-3} level, in < 1 min


Detector to be installed and tested in the INFN Bari lab



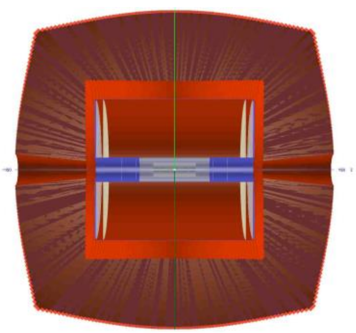
Simulation studies with Garfield++

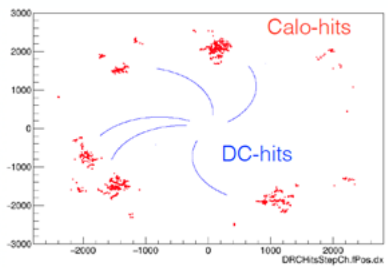
Electric field configuration with $V_g = -350V$, $V_s = 925V$



R&D @ INFN Bari on Gaseous detectors

Geant4 simulation of the drift chamber



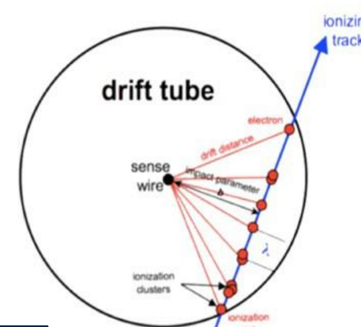


DC simulated at a good level of geometry details, including detailed description of the endcaps

hit creation and track reconstruction code available

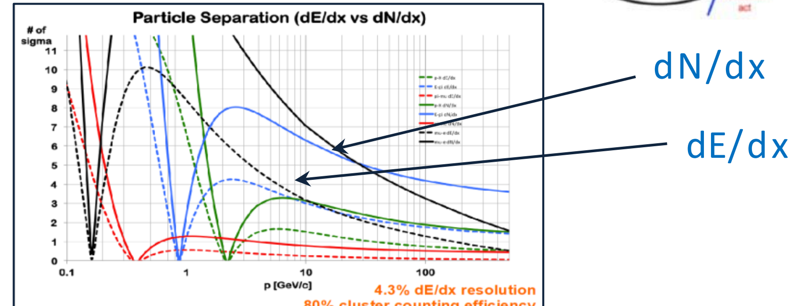
full simulation for the IDEA detector going to be ported in the FCC framework

"cluster counting" technique for PID



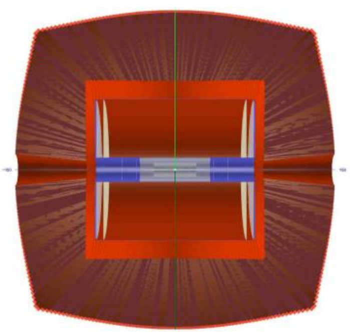
Counting dNcl/dx (# of ionization acts per unit length) → make possible to identify particles (P.Id.) with a better resolution than dE/dx

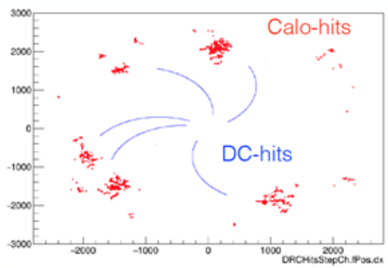
dN_{cl}/dx δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track → **σ ≈ 2.0%**



R&D @ INFN Bari on Gaseous detectors

Geant4 simulation of the drift chamber





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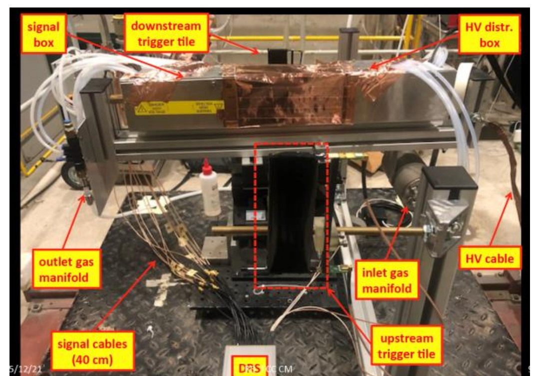
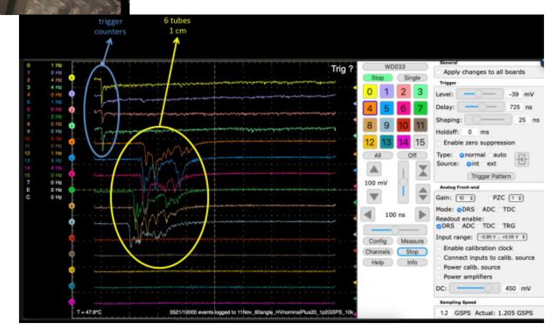


Test beam at CERN/H8 in 2021 to test the technique:

- Need to demonstrate the ability to count clusters
- Establish the limiting parameters for an efficient cluster counting(cluster density , space charge, gas gain saturation)
- In optimal configuration, measure the relativistic rise as a function of βγ, both in dE/dx and in dN_{cl}/dx, by scanning the muon momentum from the lowest to the highest value



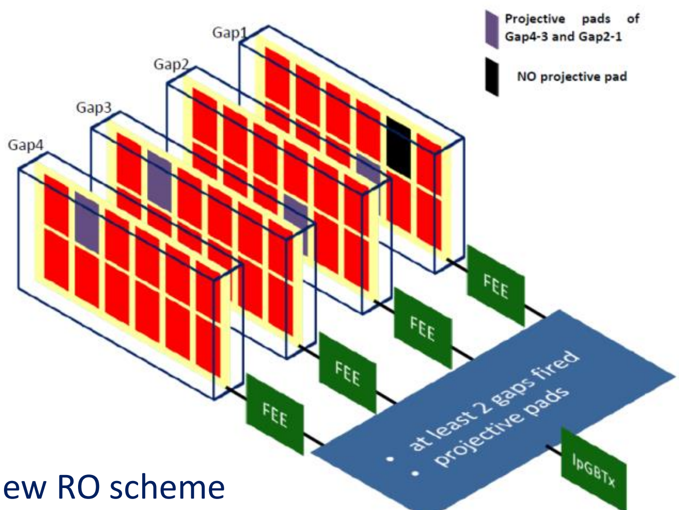
R&D @ INFN Bari on Gaseous detectors

LHCb Upgrade II (≥ LS4), FTDR to be published in March 2022

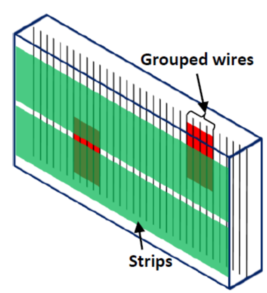
Future Muon Detector: Bari Group is actively involved in

- simulation and optimization studies of the Muon Detector design
- R&D on new generation RPCs with eco-friendly gas mixtures
- new FE electronics (*INFN Bari Electronics Service*)

Baseline option: MWPC + μRWELL (R1-R2)
RPCs or SCI-Tiles in R4 (exp. rate *several* kHz/cm^2)



new RO scheme
for the baseline option



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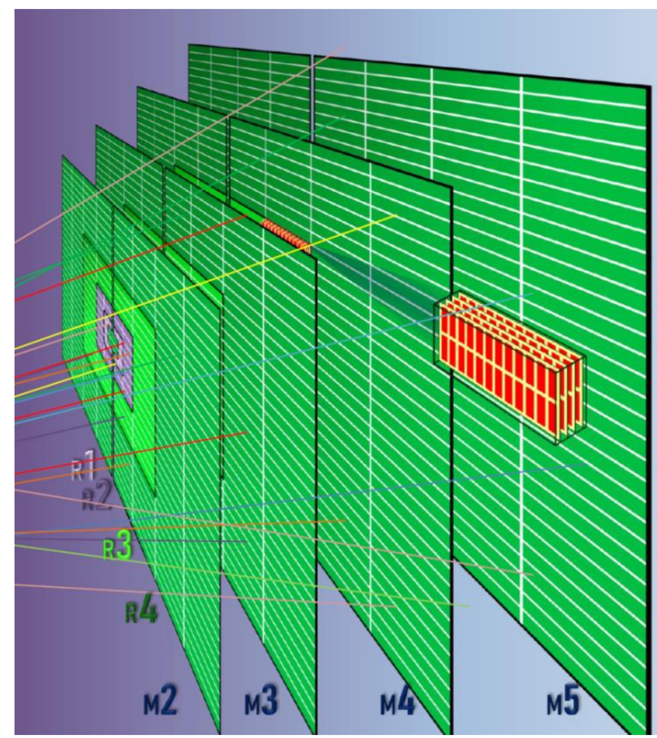
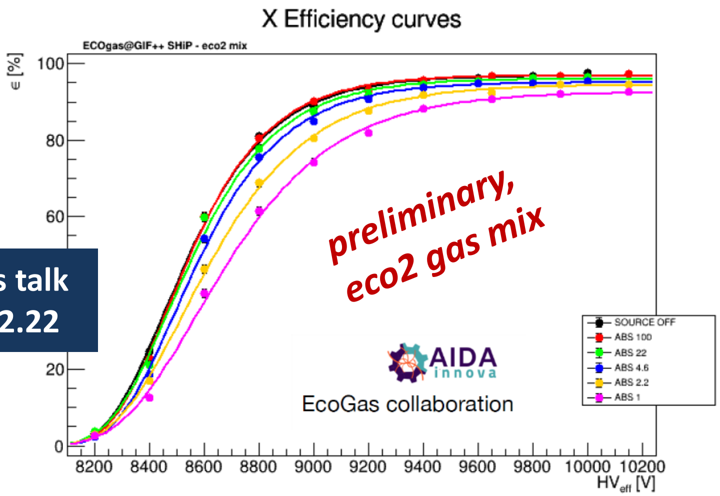


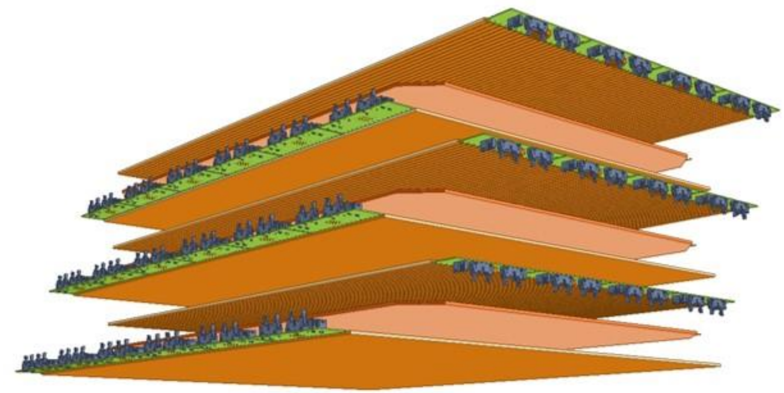
R&D @ INFN Bari on Gaseous detectors

R&D on new generation RPCs with eco-friendly gas mixtures



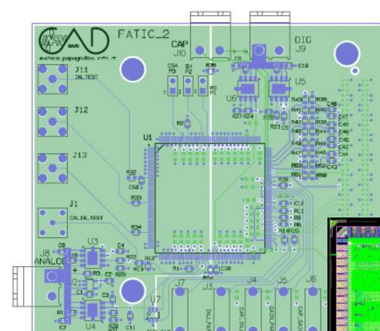
see Piet's talk on 03.02.22

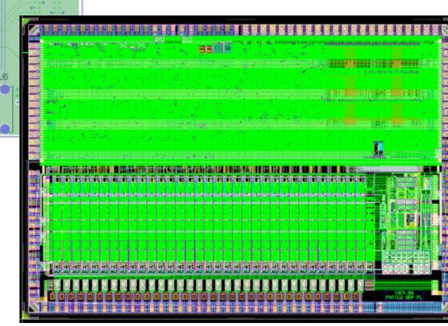
Performance studies on RPCs with different gap and electrodes thickness, operated with eco-friendly gas mixtures on-going in Bari and at CERN GIF++



prototype of a RPC-triplet
(INFN Bari Mechanics Service)

new FE electronics (*INFN Bari Electronics Service*)



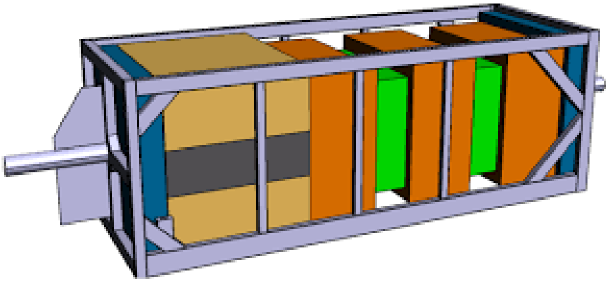


Development of a new version of the FATIC2 chip to meet LHCb requirements for μRWELL, MWPC and RPC options

R&D @ INFN Bari on Gaseous detectors

ND280 upgrade for T2K phase II and Hyper-K

Group activities:
- Electric field simulation inside the field cages
- Construction of new generation TPCs with micro-pattern gas detector readout
- Gas system design, implementation and maintenance



Goal of this new detector: increase the phase space coverage of the current ND280 up to 4π → increase the ND280 constraint on x-section models in order to improve oscillation analyses

AIDA-INNOVA (WP 7.4)

Group activities:
- Simulation and construction of a High-pressure TPC prototype with hybrid readout (optical+MPGD)
- Study different gas mixtures as a target for neutrino interactions

Goal of this new detector: increase our knowledge on neutrino x-section models (extremely important for the next generation of neutrino oscillation experiments, as HK)

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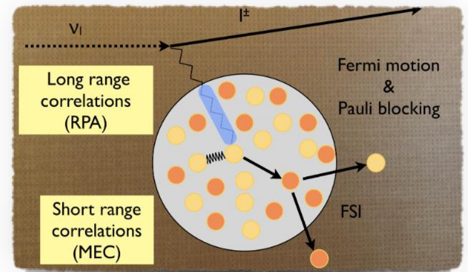
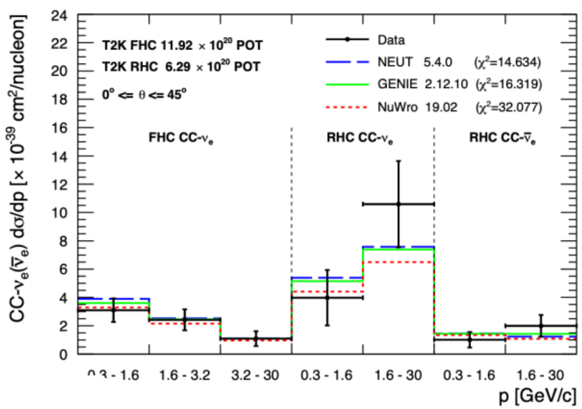
R&D @ INFN Bari on Gaseous detectors

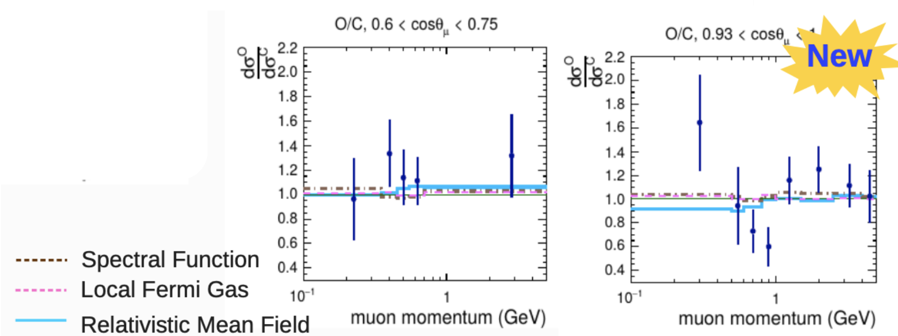
AIDA-INNOVA (WP 7.4)

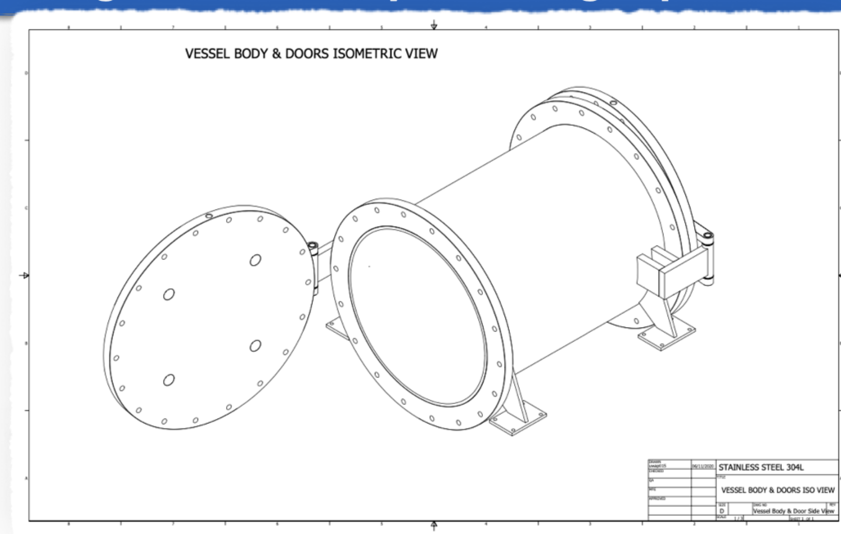
- At low energies the main kind of interactions are **CCQE-like**
  - Other neutrino interactions with production of **pions** in the final state are important as well
  - There are large discrepancies between different theoretical models
  - Neutrino x-sec are not completely understood at low energies



- **A dedicated experiment is needed** in order to reduce the systematic uncertainty related to the neutrino x-section model **(today the largest systematic uncertainty in the neutrino oscillation analyses)**
- **AIDA-Innova project (HPTPC with hybrid readout) started in Bari since April 2021**
- **Vessel design will be done by our CAD group here in Bari**



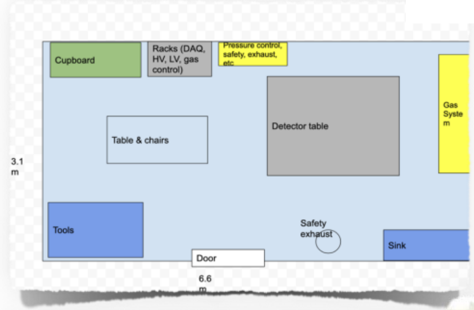


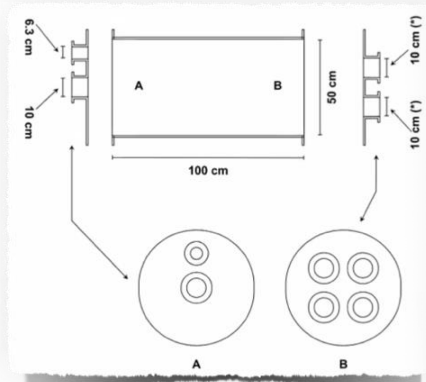


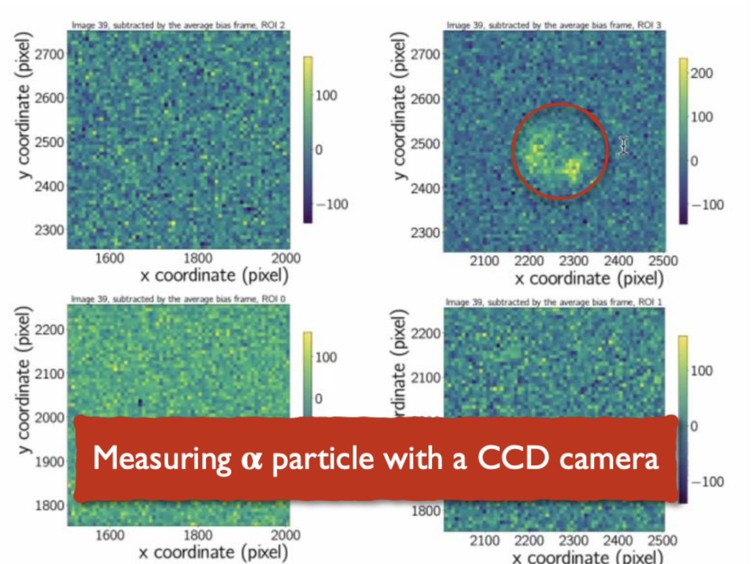
R&D @ INFN Bari on Gaseous detectors

AIDA-INNOVA (WP 7.4)
Ideal schedule

- ***High-pressure Lab. in our department***
  - High pressure flowmeter will be installed in late spring
- ***Design and construction of the prototype***
  - will be done in Bari by using CAD design and Mechanical workshop (this year)
- ***Test and data taking with the prototype (2023-2024)***
  - different pressure values, different gas and different readout techniques can be checked





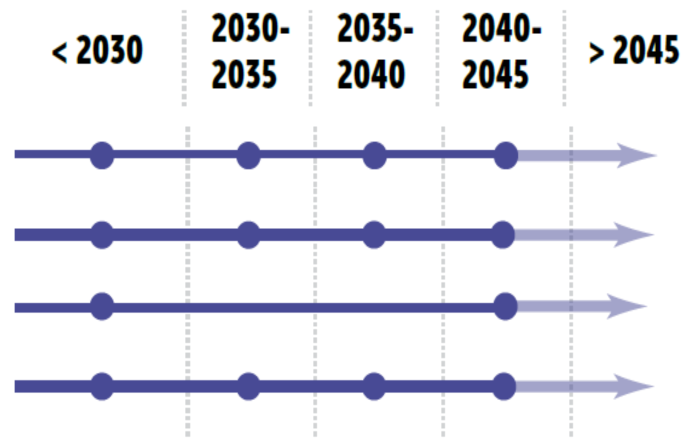


- **Some optical readout possibility already tested in UK:**
  - A FLI Proline PL09000 CCD camera is mounted on the window flange
  - A Nikon f/1.2 50 mm focal length lens is used to focus on the amplification region from the cathode side.
  - The camera images an area of 71 × 71 cm^2 and provides a granularity of 3056 x 3056 pixels → **effective readout segment sizes of 230 µm length possible**
- **Triple-GEM or resistive MicroMegas can be used as MPGD readout**

R&D @ INFN Bari on Solid State detectors

Solid state

- **DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- **DRDT 3.2** Develop solid state sensors with 4D-capabilities for tracking and calorimetry
- **DRDT 3.3** Extend capabilities of solid state sensors to operate at extreme fluences
- **DRDT 3.4** Develop full 3D-interconnection technologies for solid state devices in particle physics



focus on:

ALICE 3

AMEGO All-sky Medium Energy Gamma-ray Observatory

& related projects ..

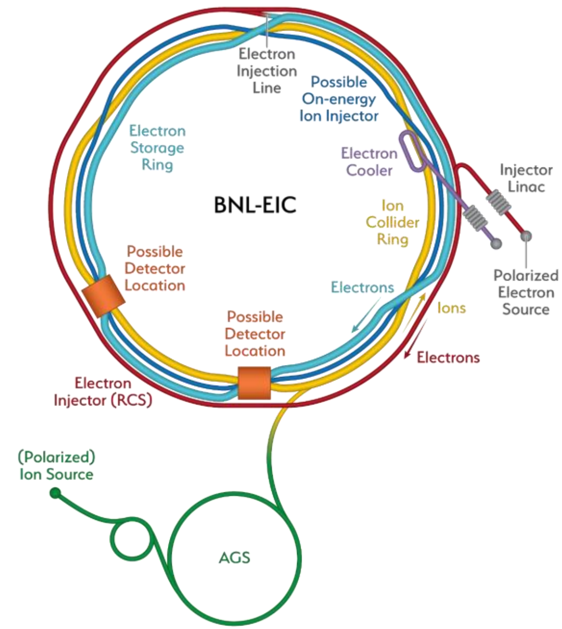
R&D @ INFN Bari on Solid State detectors

The Electron-Ion Collider (EIC) in US:

a new, innovative, large-scale particle accelerator facility planned for construction **at BNL** in the 2020s

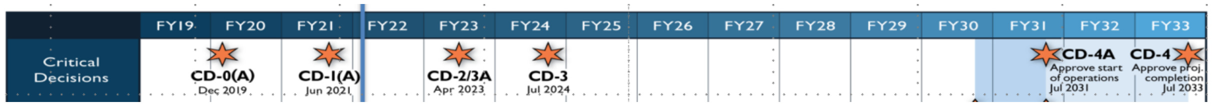
The EIC will study protons, neutrons and atomic nuclei with the most powerful electron microscope, in terms of versatility, resolving power and intensity, ever built.

The resolution and intensity is achieved by colliding high-energy electrons with high-energy protons or (a range of different) ion beams



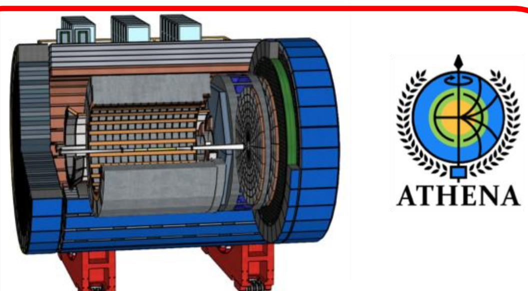
• Center of Mass Energies	20 GeV – 140 GeV
• Maximum Luminosity	10^{33}-10^{34} $cm^{-2}s^{-1}$
• Hadron Beam Polarization	70%
• Electron Beam Polarization	70%
• Ion Species Range	p to Uranium
• Number of interaction regions	up to two

R&D @ INFN Bari on Solid State detectors

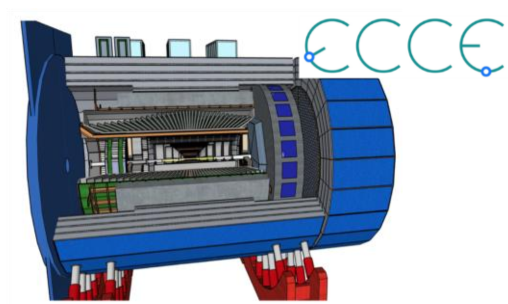


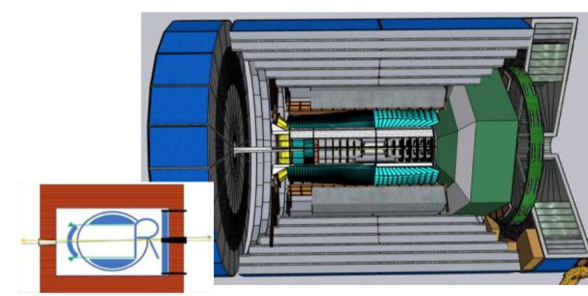
Main steps in the recent EIC path

- July 2018: endorsement by US NAS (National Academy of Science)
- January 2020: CD0 (mission need approval) and site selection (BNL)
- February 2021: EIC CDR: https://doi.org/10.2172/1765663
- March 2021 Yellow Report released: https://arxiv.org/abs/2103.05419
- March 2021: Call for detector proposals: https://www.bnl.gov/eic/CFC.php
- June 2021: CD-1 (completion of Definition Phase and the conceptual design)
- **December 2021: proposals sent to DoE (ATHENA, ECCE, CORE): feedback expected in March 2022**



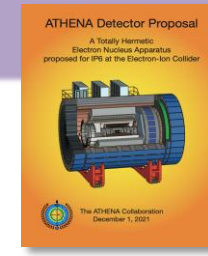
INFN contribution



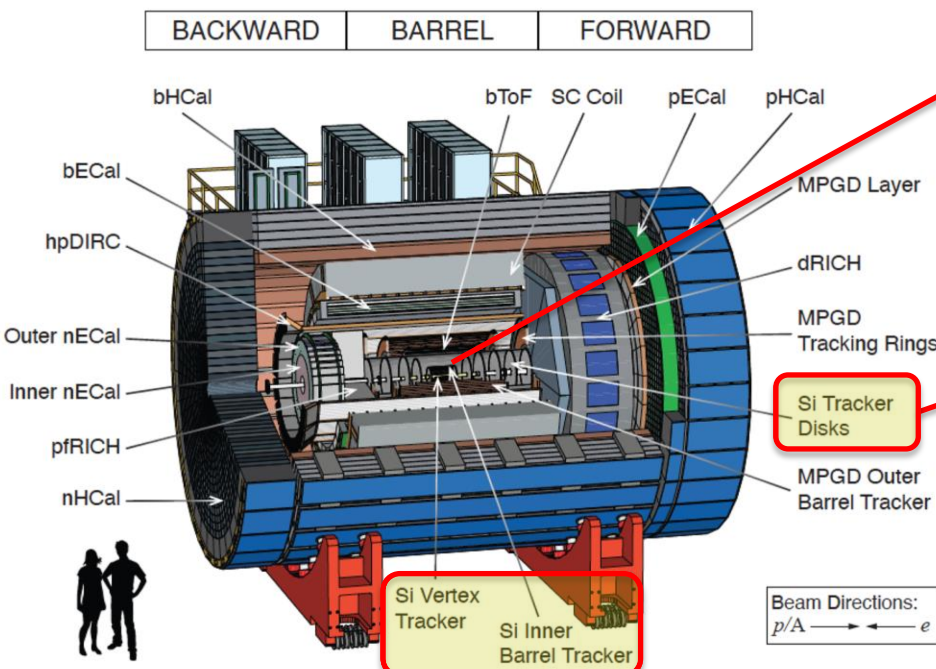


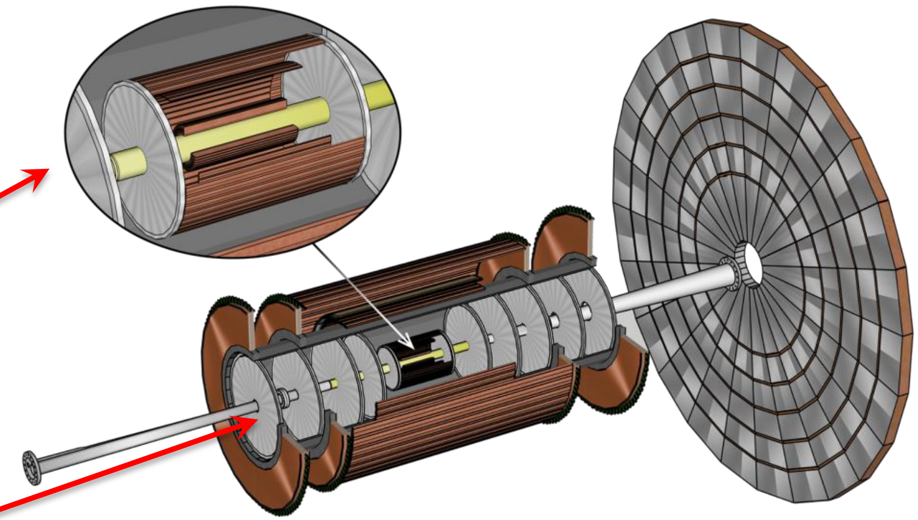
- ✓ **ATHENA is general purpose for IP6 with new 3T solenoidal magnet (and large bore diameter)**
- ✓ ECCE is general purpose detector for IP6 re-using 1.4 T Babar magnet (bore diameter 2.8)
- ✓ CORE is a more "compact" proposal, potentially for IP8 (3T solenoid as well)

R&D @ INFN Bari on Solid State detectors



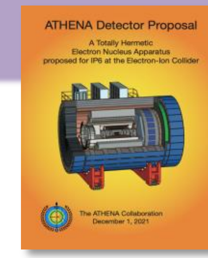
EIC-Bari: *Tracking system in ATHENA@EIC*





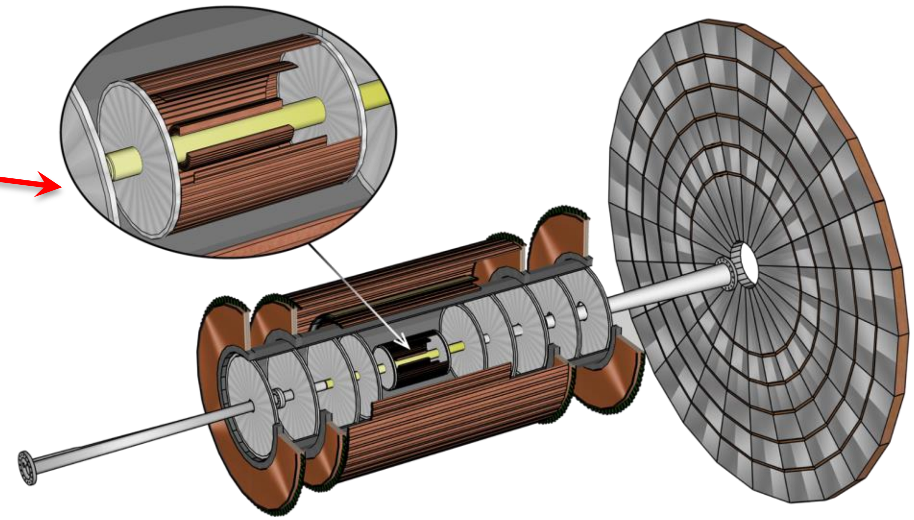
Non-symmetric configuration
optimized for low material budget
in the backward direction

R&D @ INFN Bari on Solid State detectors



EIC-Bari: *Tracking system in ATHENA@EIC*

- Si Vertex Tracker: 3 layers
  - ✓ first layer @ R~33 mm
  - ✓ material 0.05% X_0 per layer
- Si inner barrel Tracker: 2 layers
  - ✓ material 0.55% X_0 per layer
- FW and BW Si Tracker disks
  - ✓ material 0.24% X_0 per disk



✓ existing experience from eRD16/eRD18/eRD25 US projects

✓ targeting the 65 nm MAPS technology (10 μm pitch, < 20 mW cm^{-2}) being developed for ALICE ITS3

→ R&D **synergies EIC/ALICE (for INFN in Bari and Trieste)**

see talk by D. Colella

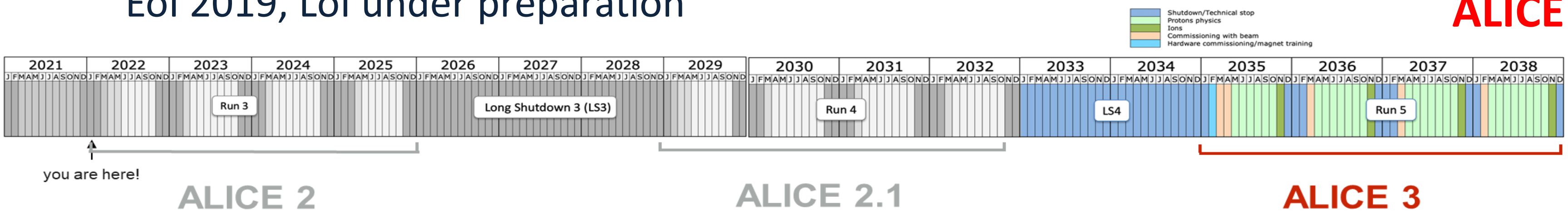
- Tracking WG coordination for YR (2020) and ATHENA proposal (2021): INFN Bari
- EIC Silicon Consortium leadership representatives: INFN Bari and Trieste

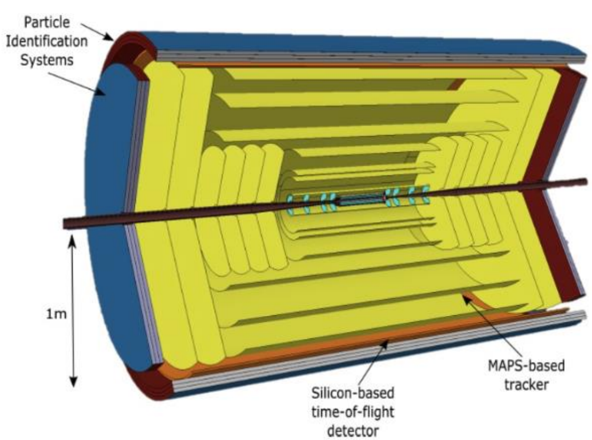
R&D @ INFN Bari on Solid State detectors

ALICE 3

ALICE3 : a rich heavy ion programme at the HL-LHC

EoI 2019, LoI under preparation





A next-generation Heavy Ion experiment

» Ultra-lightweight silicon tracker with excellent vertexing

→ 12 tracking barrel layers + disks based on MAPS

see talk by D. Colella

» Particle identification

→ TOF determination (20 ps time resolution), Cherenkov, pre-shower/calorimeter

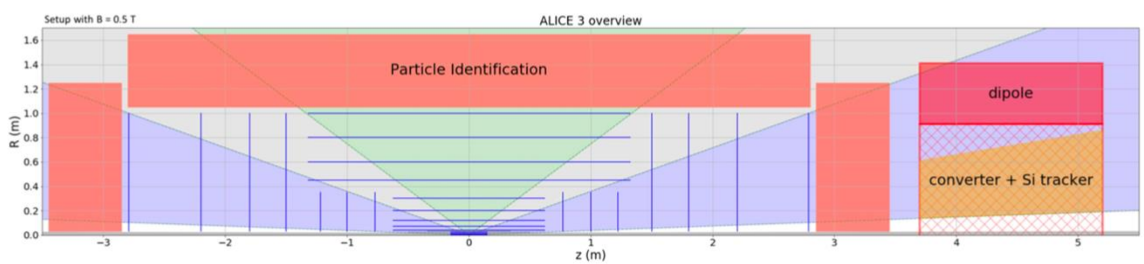
» Dedicated forward detector for soft photons (conversion + Si tracker)

» Further detectors under study (e.g. muon ID)

» Fast to profit from higher luminosity (x20 - x50 higher than in ALICE 2)

» Kinematic range down to very low p_T: 50 MeV/c (central barrel), 10 MeV/c (forward dedicated detector)

» Large acceptance: barrel + end-caps $\Delta\eta$ = 8



R&D @ INFN Bari on Solid State detectors

ALICE 3

ALICE3-Bari: *Inner and Outer Silicon Trackers*

Inner tracker

→ ultra-thin layout: flexible wafer-scale sensors (MAPS/ITS3)

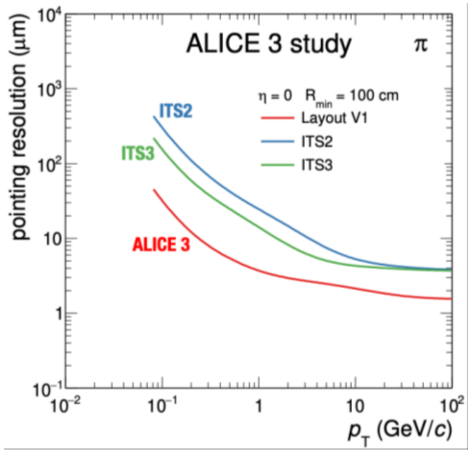
→ minimal distance from IP requires retractable detector

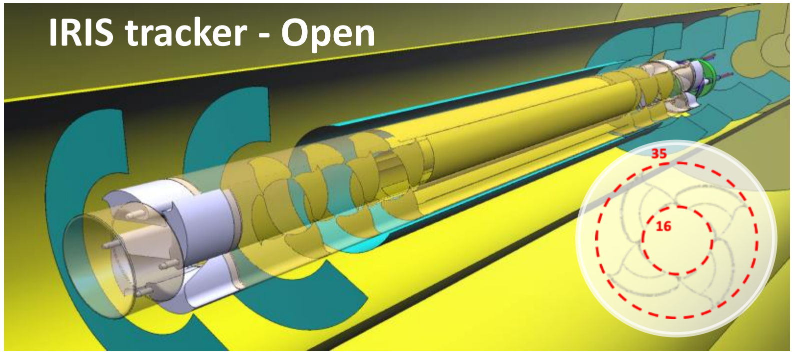
→ position resolution O(1 μm) requires small pixel pitch

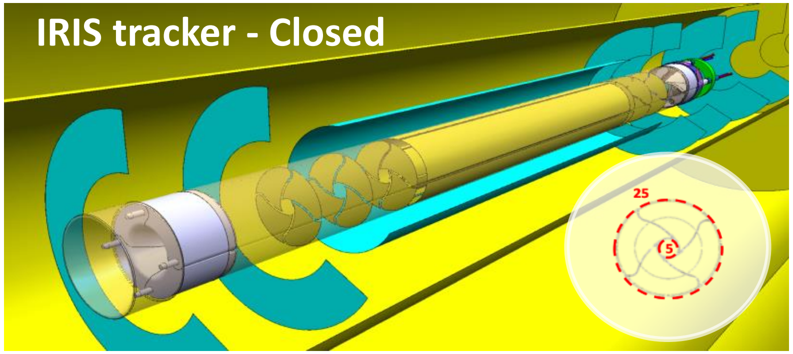
Outer tracker

→ large areas to instrument O(100 m^2): develop cost-effective sensors

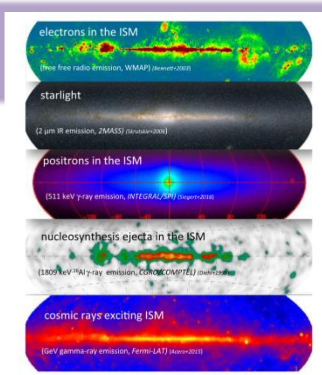
→ low material budget requires low-weight support and services







R&D @ INFN Bari on Solid State detectors

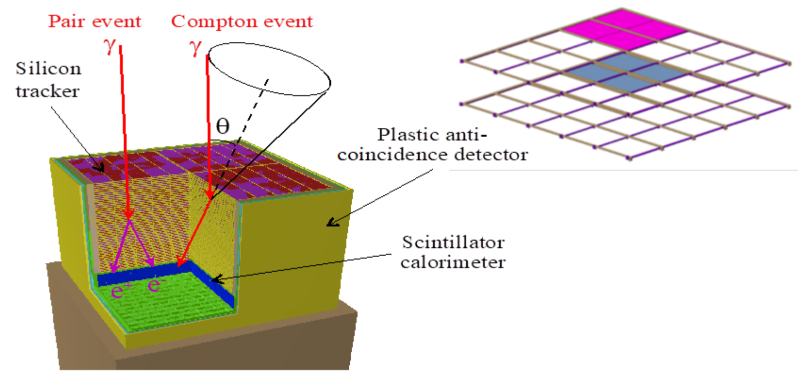


Medium size Gamma-ray telescopes based on Si strip/pad detectors

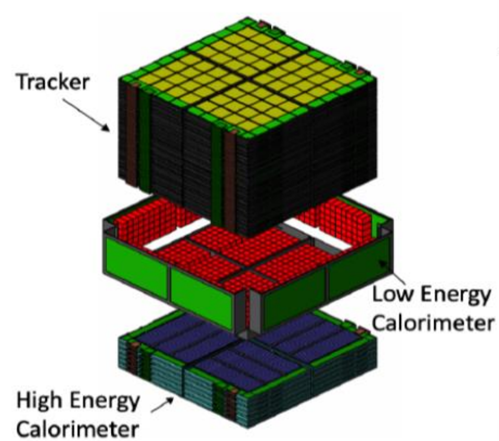
- Next MeV-GeV satellite generation:
  - Enable Compton regime reconstruction

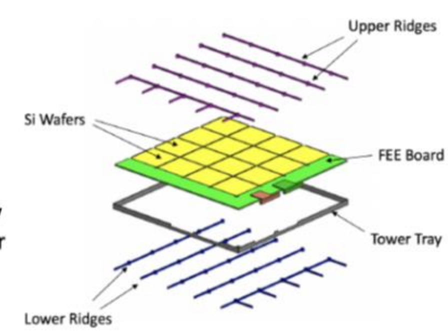
see talk by R. Pillera

- ASTROGAM M5-Esa call (2016-2018) (INFN PI):
  - nearly 56 m^2 of double-sided Si strip detectors (DSSDs)
  - 4 towers, 56 layers of 5×5 DSSDs
    - 5600 DSSDs
  - Each DSSD wafer has a cross section of 9.5×9.5 cm^2, a thickness of 500 µm and a pitch of 240 µm (384 strips per side)



- AMEGO Probe mission NASA call (2019-2021) (NASA PI):
  - 4 towers, 60 layers of 4×4 DSSDs
    - 4800 DSSDs
  - DSSD wafers 9.5 cm wide, 500 µm thick and pitch of 500 µm (190 strips per side)
- DSSDs wire-bonded on both sides to form 2-D views
  - Bonding machines should be able to work on large area planes, as the strips in both direction need to be connected
  - Non-trivial ladder mechanic support to avoid wire bonding paths





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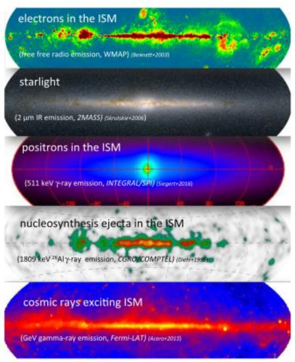
R&D @ INFN Bari on Solid State detectors

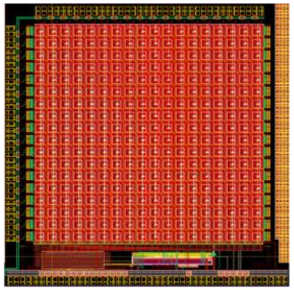


Recent NASA MIDEX call

- Astrophysics Explorers Program 2021 Medium Explorer (MIDEX)
  - Release: Aug 2021
  - Proposal due: Dec 9, 2021
  - Selection: early 2024
  - Launch Readiness: late 2028

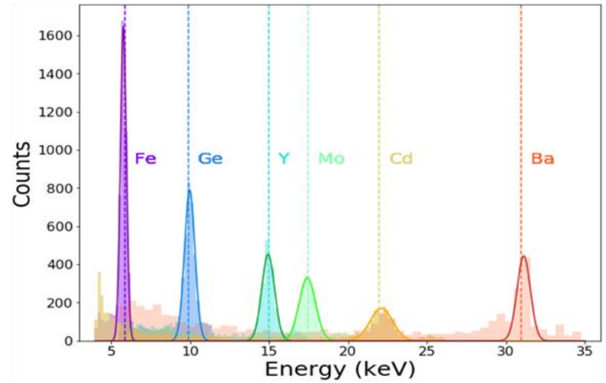
2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Phase A		Phase B	Phase C		Phase D			Phase E	

- AMEGO-X proposal submitted (NASA PI):
  - A reduced layout of AMEGO instrument
  - Large pixel pad-based tracker
    - Pixel size 500×500 μm²
    - Si thickness 500 μm
    - Good energy resolution at low energy
  - AstroPix NASA grant on going based on the ATLAS pixel
    - AstroPix v1 version under test
      - Pixel size 200×200 μm²
      - For more details see https://arxiv.org/abs/2109.13409
  - INFN activities for the pixel development to be discussed



(a) Top level view of the AstroPix V1 sensor matrix. The matrix is 18 by 18 pixels, each pixel 200 μm^2, with digital readout for each row and column.

(b) Picture of the AstroPix V1 detector on a carrier board.



R&D @ INFN Bari on PID and Photon detectors

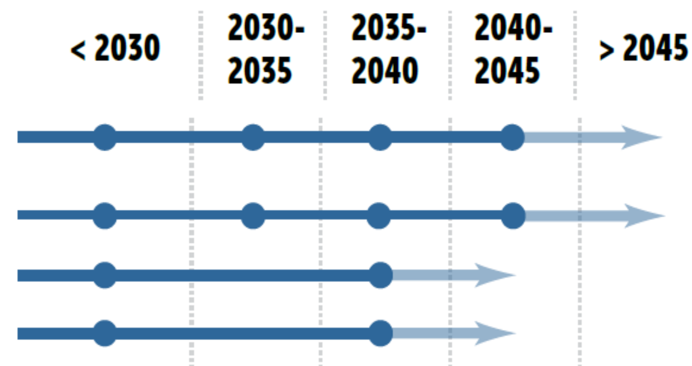
PID and Photon

DRDT 4.1 Enhance the timing resolution and spectral range of photon detectors

DRDT 4.2 Develop photosensors for extreme environments

DRDT 4.3 Develop RICH and imaging detectors with low mass and high resolution timing

DRDT 4.4 Develop compact high performance time-of-flight detectors



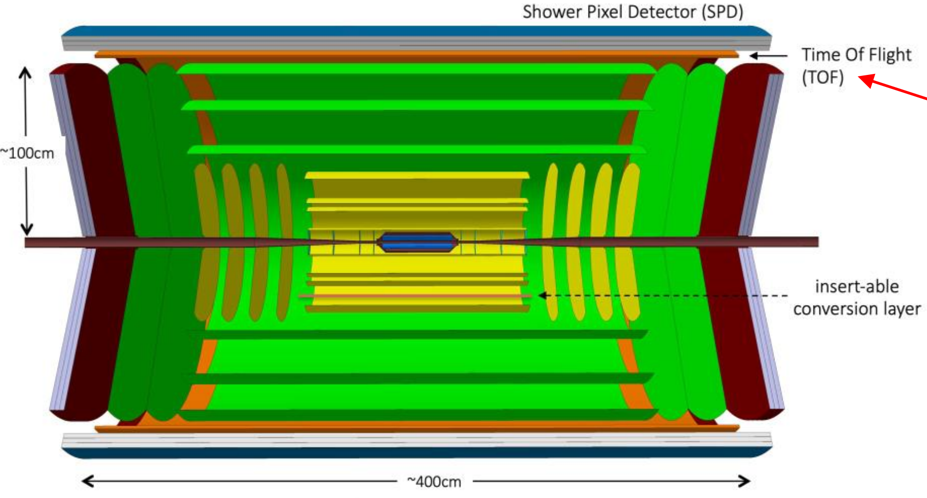
focus on:

ALICE 3

R&D @ INFN Bari on PID and Photon detectors

ALICE 3

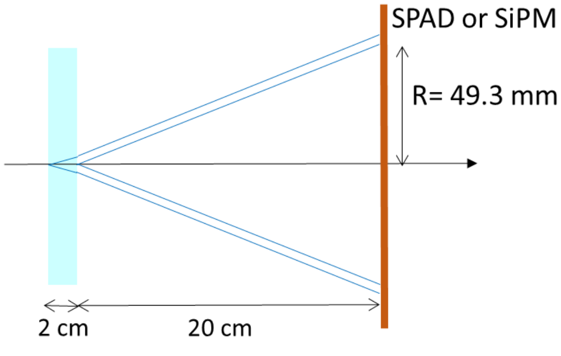
ALICE3-Bari: *Aerogel – RICH barrel to complement TOF PID*



- Increase radius of TOF layer(s) by 22 cm to insert 2 cm of aerogel Cherenkov radiator + 20 cm expansion gap
- Implement single-photon detection in TOF layer (using SPADs or SiPM) for Cherenkov radiation, sensitivity in the visible range is necessary
- Exploit both information from Cherenkov angle and Cherenkov photons timing to complement TOF PID.

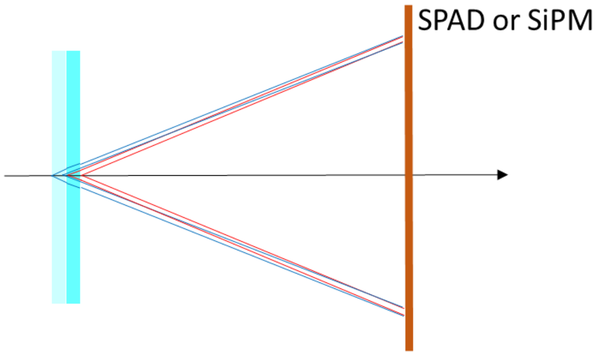
detector design options

Single layer aerogel



n=1.03

Double layer aerogel -> focusing, reduced geometric aberration

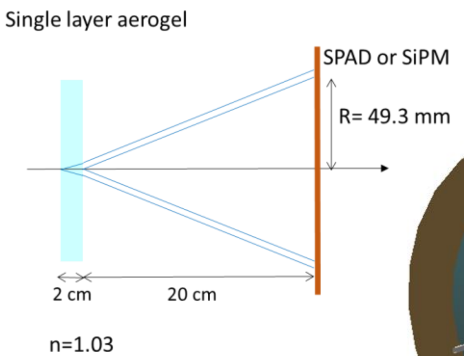


n_1=1.03 < n_2=1.0326

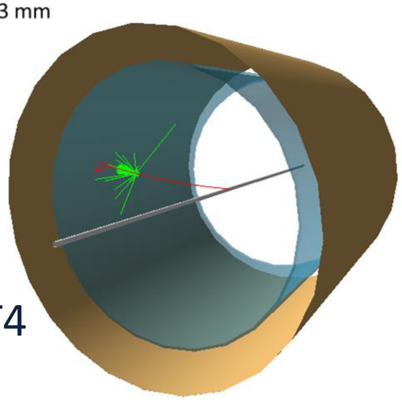
R&D @ INFN Bari on PID and Photon detectors

ALICE 3

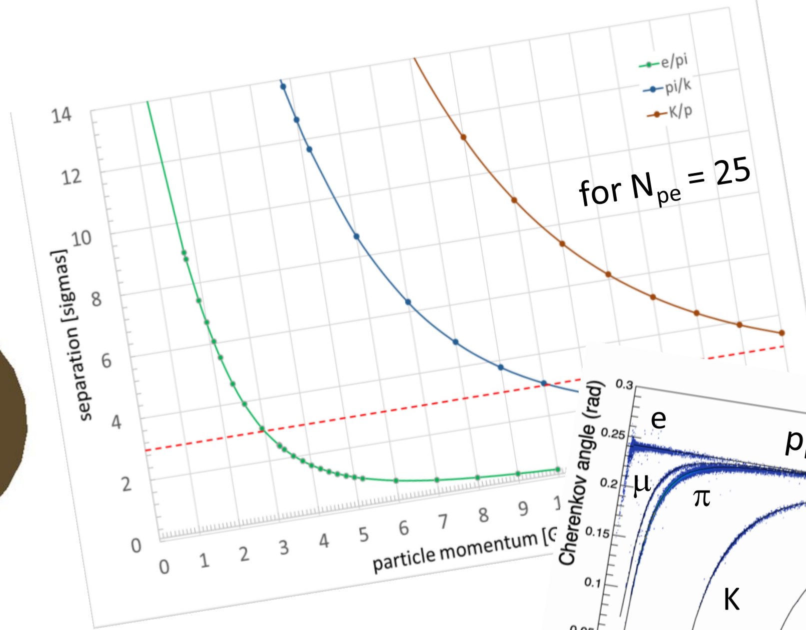
ALICE3-Bari

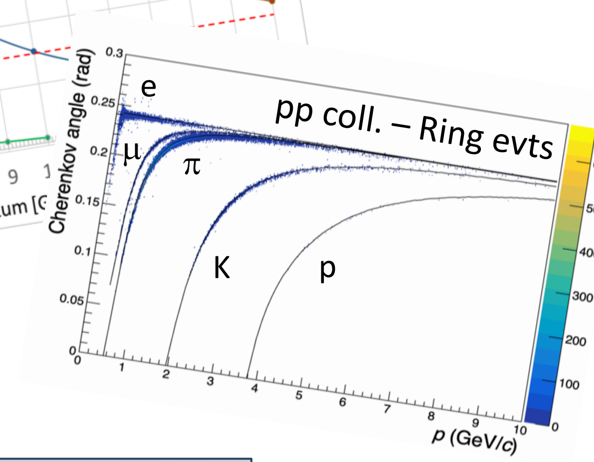


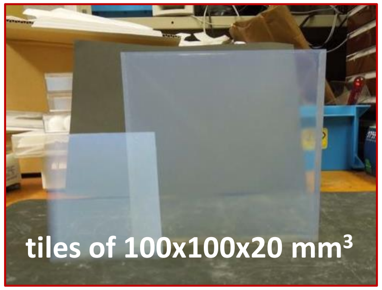
Detector simulation and performances studies



GEANT4

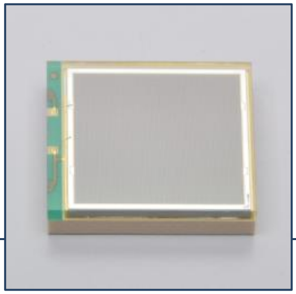






25 m² of aerogel required factor 10 increase wrt existing and planned RICH systems

Detector challenges: sinergy with EIC - dRICH (dual RICH)



Main requirements for SiPM/ SPAD:

- Single photon sensitivity in the visible range (PDE ~ 40-50%)
- Fill factor > 80-90%
- Pixel ~ 3x3 mm² (up to 5x5 mm²)
- **Area coverage ~ 30 m² → CMOS SPADS under investigation**

R&D @ INFN Bari on PID and Photon detectors

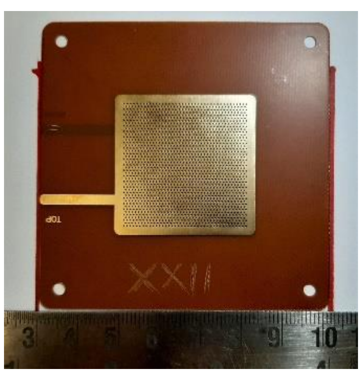
Nanodiamond photocathodes
for MPGD-based single photon detectors at future EIC

Main key requirements for hadron ID@EIC with RICH:

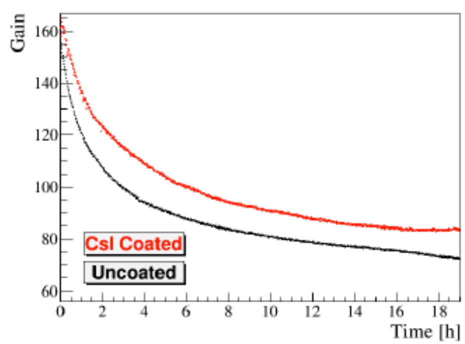
compact geometry and high space resolution
→ reduced pad size

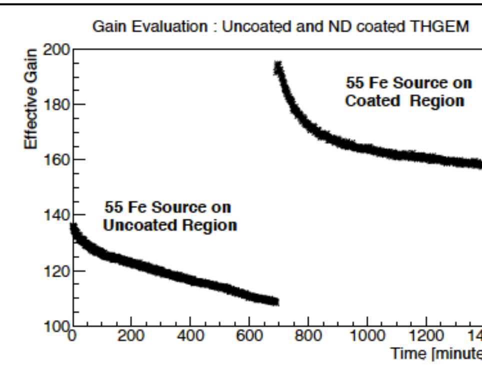
radiation hardness
→ need for a robust photocatode

CsI	Nanodiamond (ND)
> Low electron affinity > 0.1 eV	> Low electron affinity > 0.35 – 0.5 eV
> Wide band gap > 6.2 eV	> Wide band gap > 5.5 eV
> Typical Quantum Efficiency > 35 – 50% @ 140 nm	> Preliminary measured QE > 30 – 40% @ 140 nm for Hydrogenated ND.
> CsI has hygroscopic nature	> Chemically inert
> Aging > Ion Accumulation > Degradation in QE of PC	> Radiation hard
	> Good thermal conductivity



R&D ongoing on
ThickGEM-based counters
for single photon detection





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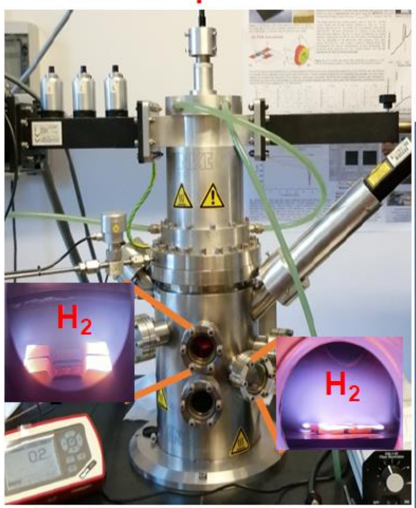
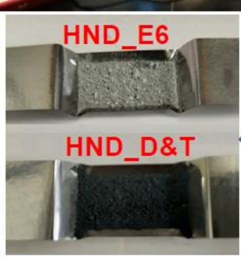
R&D @ INFN Bari on PID and Photon detectors

Nanodiamond photocathodes for MPGD-based single photon detectors at future EIC

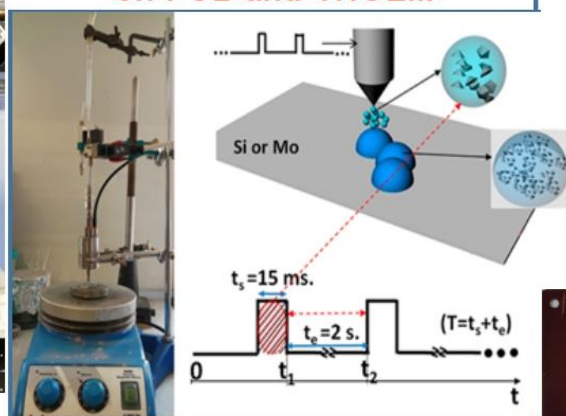
H_2 plasma for treatment of ND particles

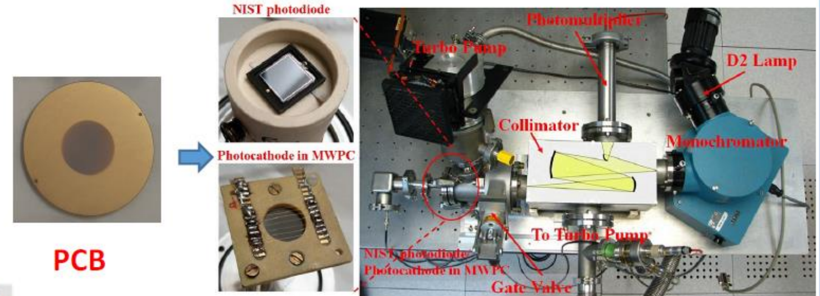




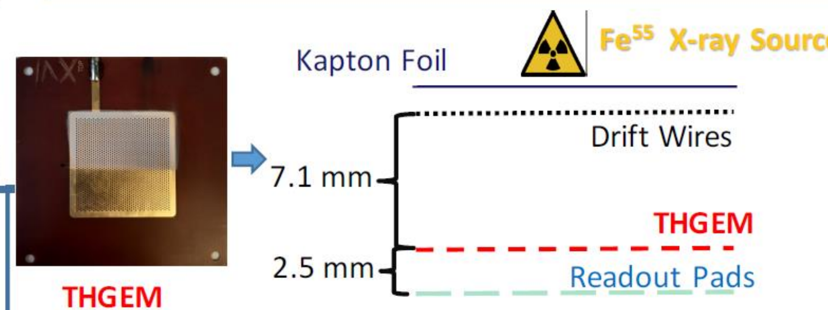
HND PARTICLES

Pulsed spray depositon on PCB and THGEM





Apparatus for QE measurements



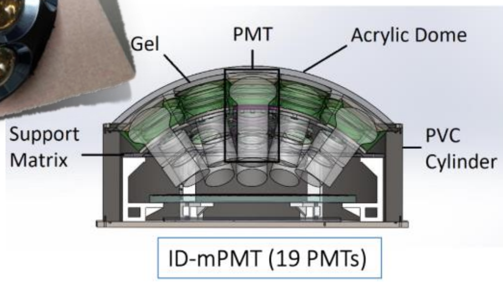
Schematic Diagram of the Chamber

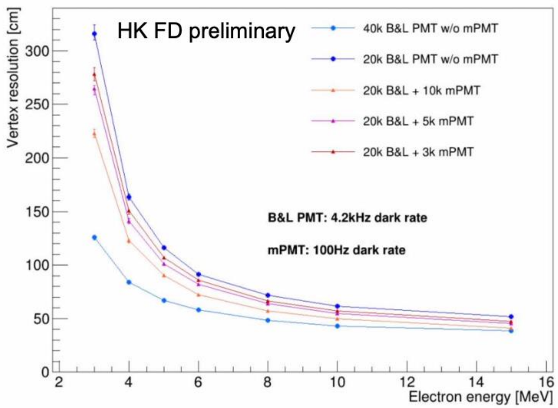
R&D @ INFN Bari on PID and Photon detectors

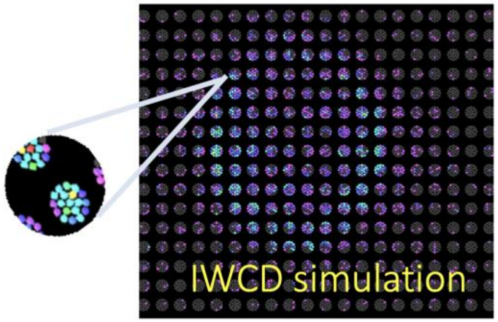
Multi-PMT for the Hyper-K multi-purpose Water-Cherenkov detector

Group activity:
multi-PMTs design with the INFN Bari CAD group
simulations of the mechanical stress of multi-PMT under pressure

Goal of this new detector: improve performances on vertex resolution and directional sensitivity with respect to the current SK PMTs







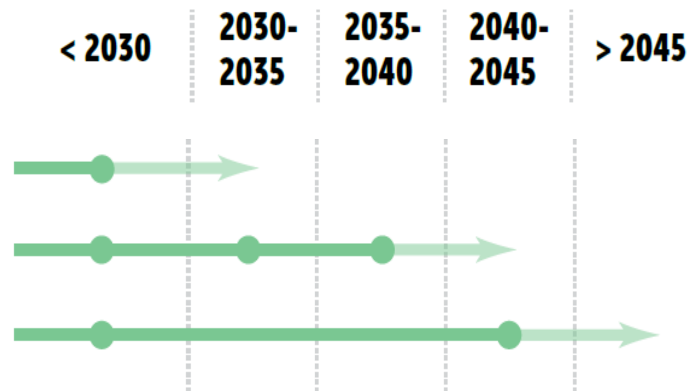
Advantages of a mPMT technology

- Superior photon counting → improved sensitivity for low energy events!
- Improved angular acceptance
- Local coincidence
- Photodetectors and electronics in a pressure resistant vessel → reduce risk of broken photo detectors
- ~ ns time resolution
- High rate tolerance and low background
- Increased granularity → improved sensitivity for multi-ring events!

R&D @ INFN Bari on Calorimetry detectors

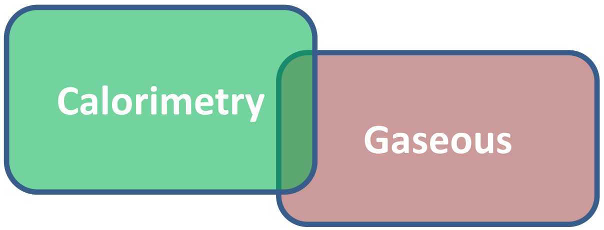
Calorimetry

- **DRDT 6.1** Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
- **DRDT 6.2** Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
- **DRDT 6.3** Develop calorimeters for extreme radiation, rate and pile-up environments



focus on:

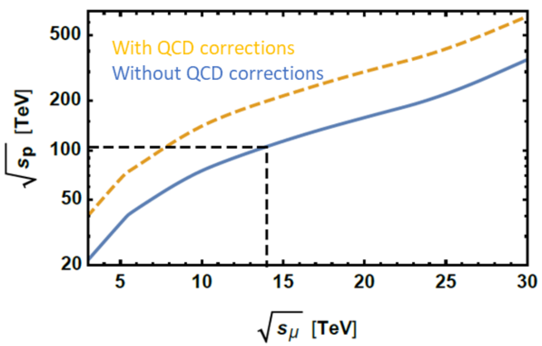
International MUON Collider Collaboration



R&D @ INFN Bari on Calorimetry detectors

The multi-TeV Muon Collider concept :

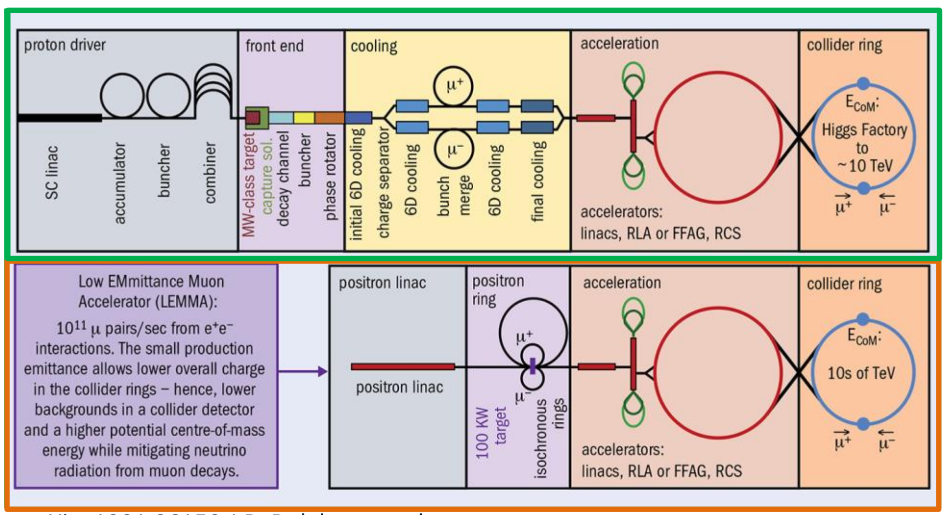
a unique next-generation lepton-collider facility at the high-energy frontier



Muon Collider can be used both as **direct exploration** and **precision** machine

critical technologies required to produce, capture, accelerate and store intense beams of μ

μ production options: MAP vs LEMMA



arXiv: 1901.06150 J.P. Delahaye et al.

MAP

US **M**uon **A**ccelerator **P**rogram, 2011

Proton driver scheme, producing μ ($\mathbf{10^{13}}$-$\mathbf{10^{14}}\boldsymbol{\mu/sec}$)

- as tertiary particles, at low energy
- with large emittance -> quick cooling and confinement

LEMMA (INFN proposal)

Low **E**mittance **M**uon **A**ccelerator, 2013

Positron driver scheme, producing μ ($\mathbf{10^{11}}\boldsymbol{\mu}$ pairs/$\boldsymbol{sec}$)

- from e+e- collisions , at mean energy ~ 22 GeV
- with small emittance -> no cooling or confinement

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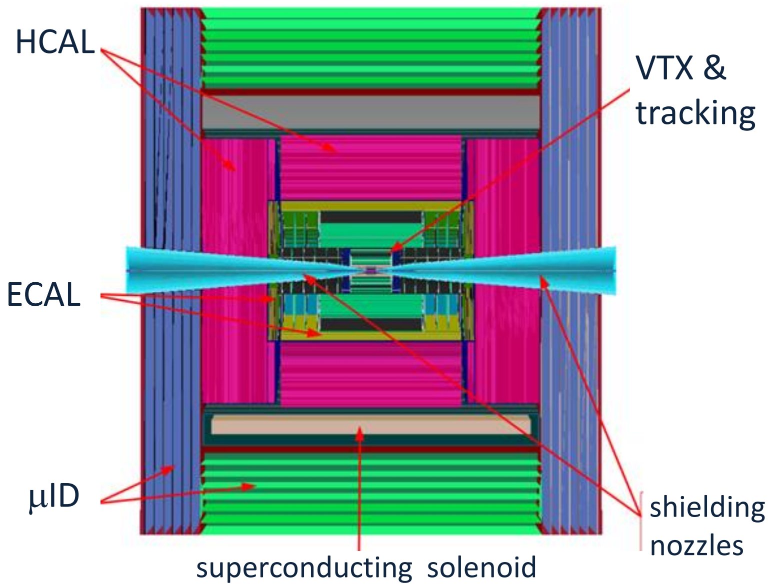
R&D @ INFN Bari on Calorimetry detectors



Simulation studies to define the design of the detector on going

Geometry, event simulation and reconstruction are currently implemented in the CLIC's software ILCSoft

Muon Collider-Bari

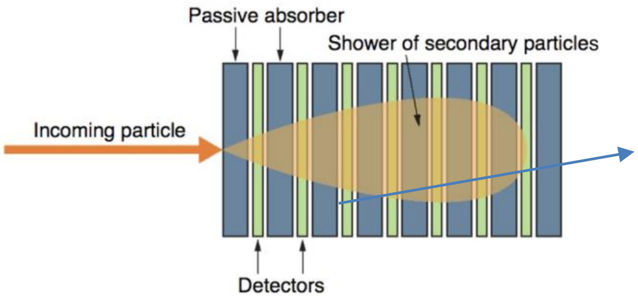
- **HCAL design**: proposal of a sampling of absorber + MPGD (as active layer)
  - Standalone simulation in GEANT4 for quick studies with particle guns
  - Simulation studies (full apparatus) with physics channels as benchmark for determining its final design
- Participation **to test beam activities to assess the LEMMA option**, mostly focused on the study of the emittance and ee → μμ cross section measurements
- **Design study and optimisation** of the Muon Collider **target** zone (ν Factory, HARP data used in MAP)

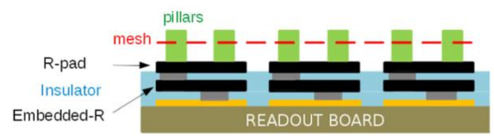
R&D @ INFN Bari on Calorimetry detectors

International MUON Collider Collaboration

Muon Collider-Bari

A MPGD-based HCAL



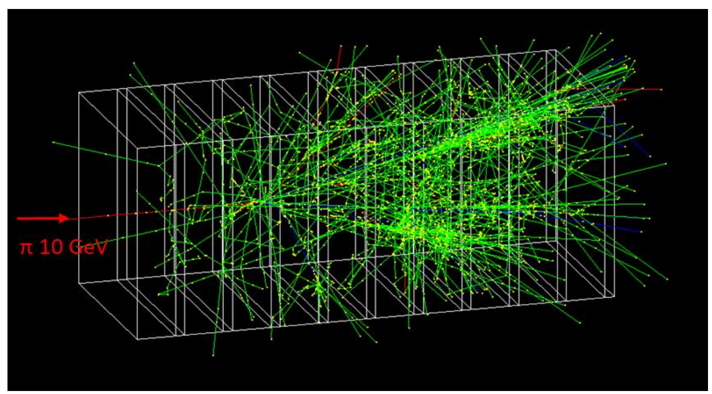


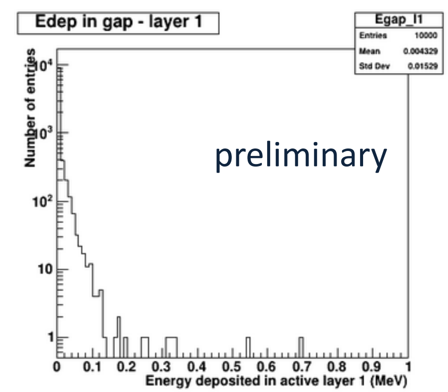
- radiation hard technology (BIB)
- high granularity and fast response (S/N)
- design and/or technology optimisation to improve jet reconstruction while suppressing the BIB

R&D supported by a RD51 (GRANT P. Verwilligen)

First studies performed in standalone GEANT4 environment with simple geometry:

- 10 layers
  - 2cm of Fe (absorber)
  - 5 mm of Ar (active gap)
- 10x10 cm^2 transverse surface

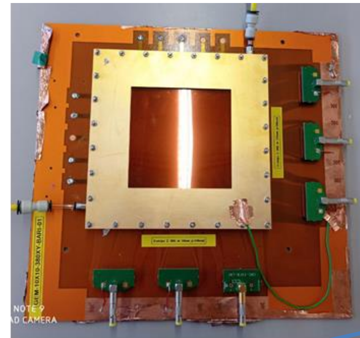


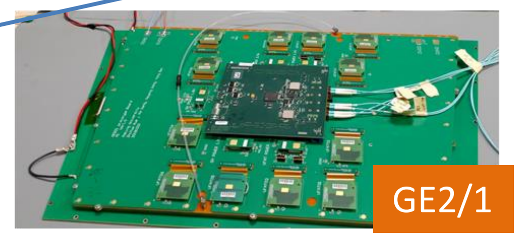


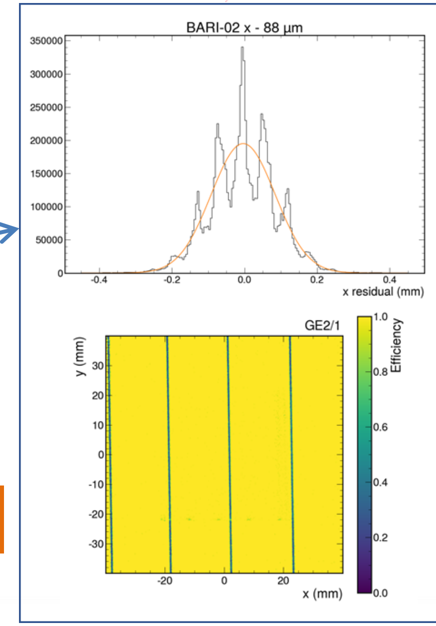
R&D @ INFN Bari on Calorimetry detectors

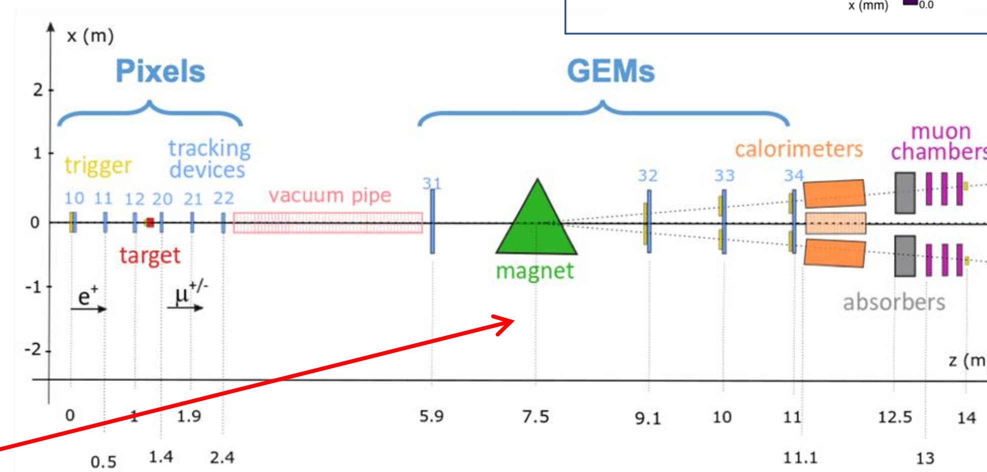
Full characterization of **high spatial resolution triple GEM,** as a first candidate to build a small calo-cell prototype

- Preliminary test in Bari lab
- **Test beam at CERN NA, Fall 2021: ongoing analysis, preliminary results available** (efficiencies > 95%, spatial resolution~75 μm)
  - Further goal reached: GE2/1 CMS detectors successfully tested and operated with final **CMS electronics (VFAT3 chips + OptoHybrid) and DAQ**
    + custom compact back-end based on commercial FPGA (CVP-13)
  - **Also provided** a test of **integration and performance** of **GEM detectors** in view of LEMMA TB (2023) to measure the e+e- →μ+μ- cross section and muon beam emittance at μ production threshold (**Bari participation: muon spectrometer with triple-GEM**)





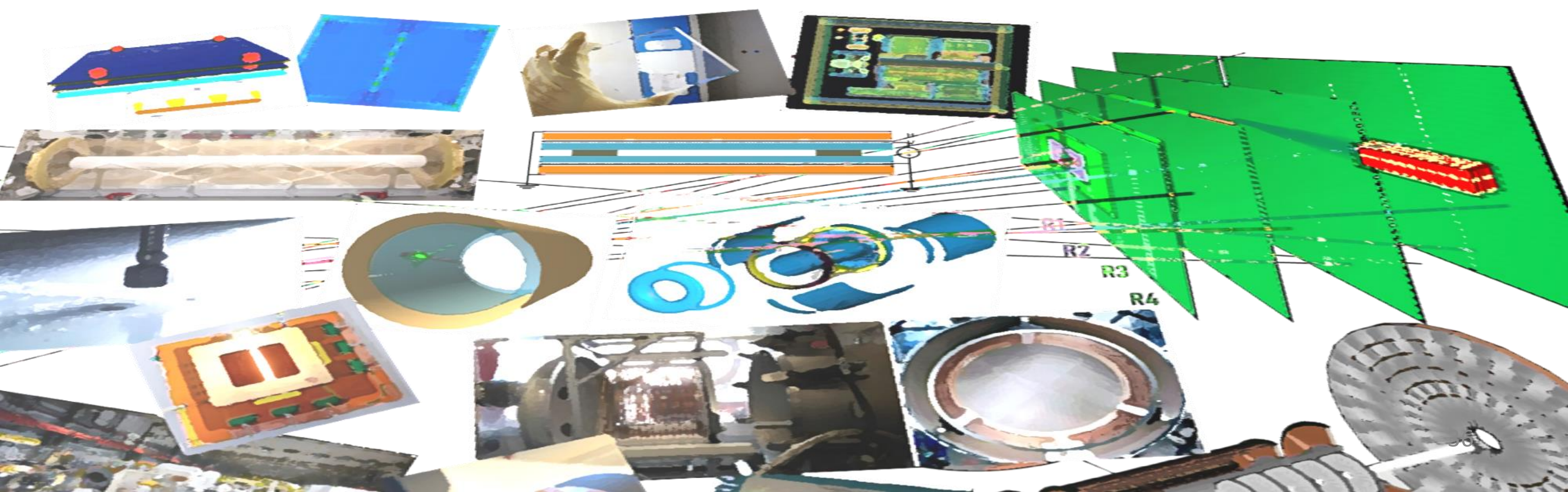




Conclusion and outlook

- 2021 set a globally agreed roadmap for the future of particle physics
- a variety of ideas, design studies and R&D activities carried on locally, dedicated to future experiments
- focus on some of them, but many others on-going (to be described soon…)
- a lot of work, and a lot of fun in our near future !

Last but not least, a big thanks to all of you,
who have directly and undirectly contributed to this talk



Backup

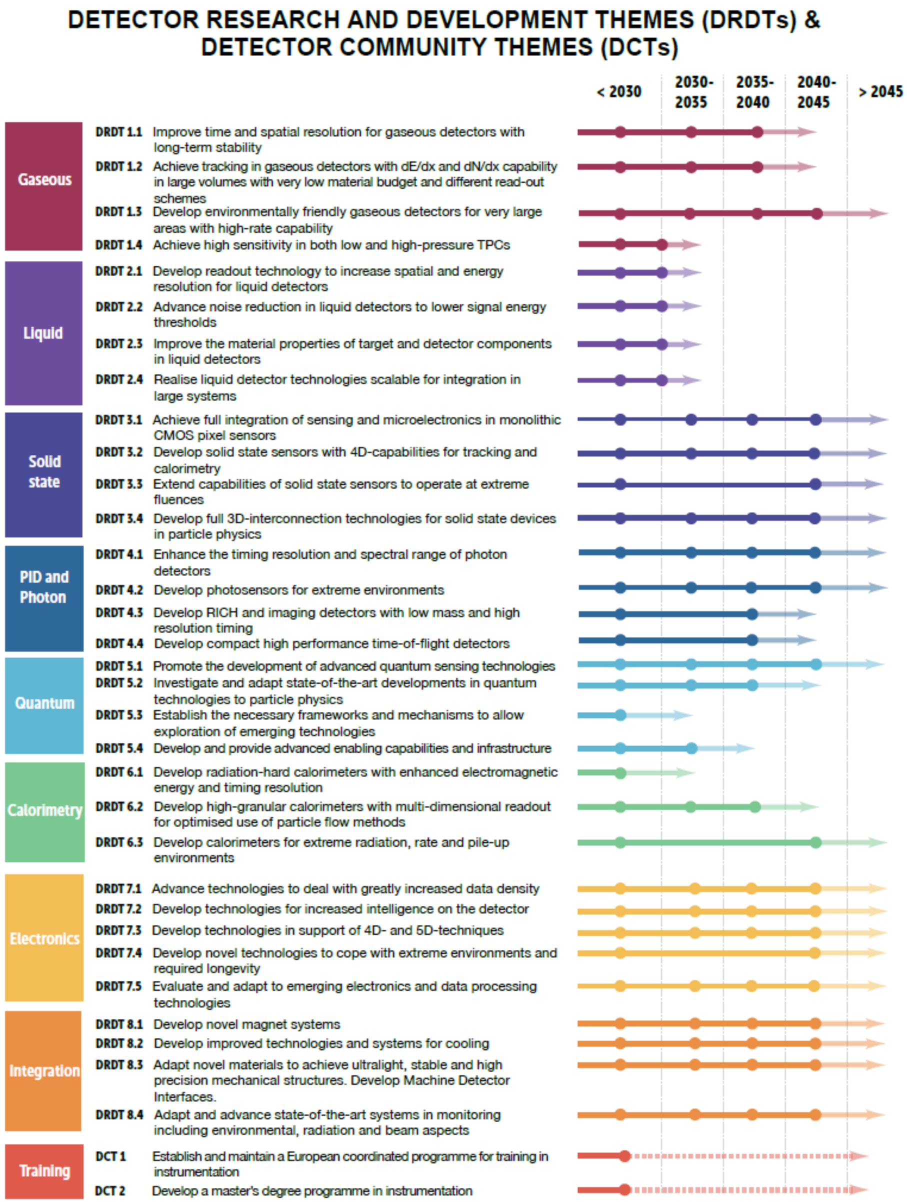


Figure 11.1: Detector R&D Themes (DRDTs) and Detector Community Themes (DCTs). Here, except in the DCT case, the final dot position represents the target date for completion of the R&D required by the latest known future facility/experiment for which an R&D programme would still be needed in that area. The time from that dot to the end of the arrow represents the further time to be anticipated for experiment-specific prototyping, procurement, construction, installation and commissioning. Earlier dots represent the time-frame of intermediate "stepping stone" projects where dates for the corresponding facilities/experiments are known. (Note that R&D for Liquid Detectors will be needed far into the future, however the DRDT lines for these end in the period 2030-35 because developments in that field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D. Similarly, dotted lines for the DCT case indicate that beyond the initial programmes, the activities will need to be sustained going forward in support of the instrumentation R&D activities).

Challenges of tracking at future e^+e^- colliders

High Lumi e^+e^- colliders:

- EW factories (3×10^{12} $e^+e^- \rightarrow Z$, 10^8 $e^+e^- \rightarrow W^+W^-$)
- $t\bar{t}$ and Higgs boson factories (10^6 $e^+e^- \rightarrow t\bar{t}$, 10^6 $e^+e^- \rightarrow HZ$)
- flavor factories (5×10^{12} $e^+e^- \rightarrow b\bar{b}$, $c\bar{c}$, 10^{11} $e^+e^- \rightarrow \tau^+\tau^-$)

FCC-ee parameters		Z	W^+W^-	ZH	ttbar
$\sqrt{s}$	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	230	28	8.5	1.7
Bunch spacing	ns	19.6	163	994	3000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section (Z)	pb	40,000	30	10	8
Event rate	Hz	92,000	8.4	1	0.1
"Pile up" parameter [μ]	10^{-6}	1,800	1	1	1

Physics rates up to 100 kHz (at Z pole) → fast detectors and electronic

Tracker:

- High momentum ($\delta p/p^2 \leq$ few x 10^{-5}) and angular resolution $\Delta\vartheta \leq 0.1$ mrad (to monitor beam spread) for charged particle momenta ranging at the Z pole from a few hundred MeV/c to several tens of GeV/c
- Large angular coverage
- Large tracking radius to recover momentum resolution since magnetic field is limited to ~ 2 T to contain the vertical emittance at Z pole
- High transparency due to the low momentum particles from Z, H decays → Multiple Scattering (MS) contribution to the resolution is not negligible!
- Particle identification → to distinguish identical topology final states

Vertexing:

- Few μm track impact parameter resolution
- High transparency

M. Primavera
INFN-Lecce

2nd FCC France Workshop, 20-21 January 2021

IDEA Tracking System

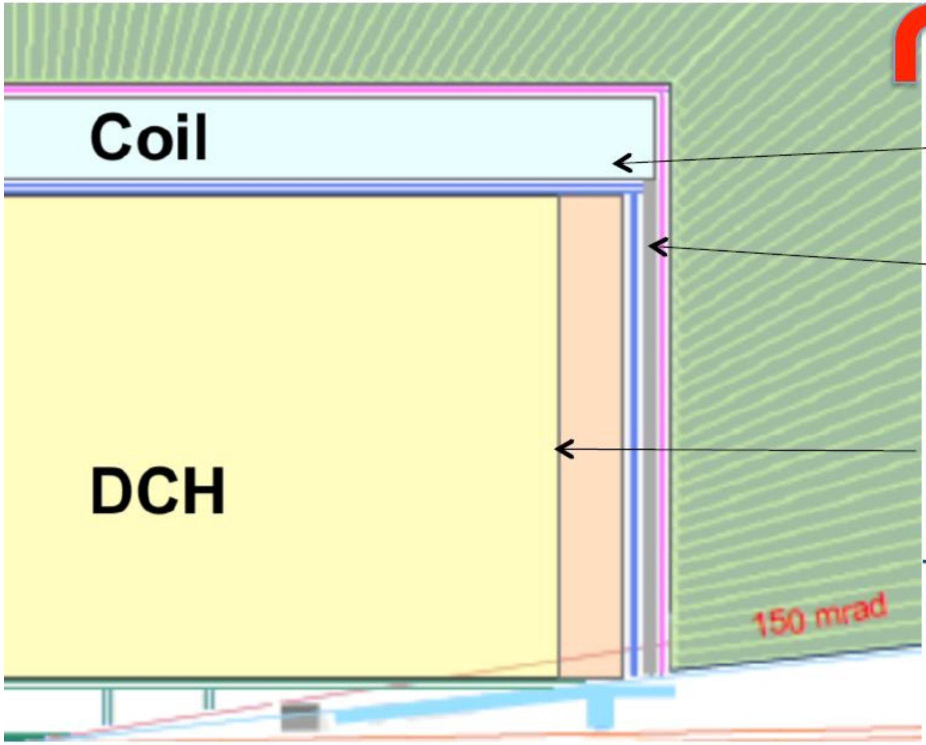
M. Primavera
INFN-Lecce

2nd FCC France Workshop, 20-21 January 2021

IDEA → Innovative Detector for Electron-positron Accelerators (Details in the D. Contardo's talk in this Workshop)

FCC-ee at CERN

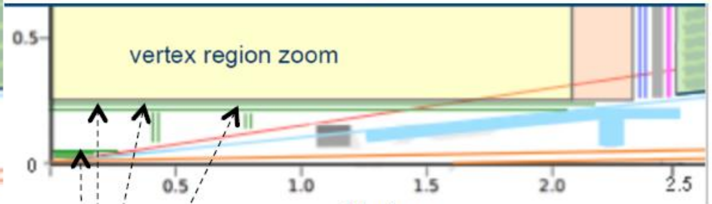
CEPC at IHEP-China



Solenoid: 2 T, length = 5 m, r = 2.1-2.4 m, 0.74 X_0, 0.16 λ @ 90º

Si Wrapper:
2 layers of μ-strips (50 μm x 10 cm) in both barrel and forward regions

Drift Chamber : 4 m long, r = 35-200 cm, 112 layers, He based gas mixture (90% He – 10% i-C_4H_{10})

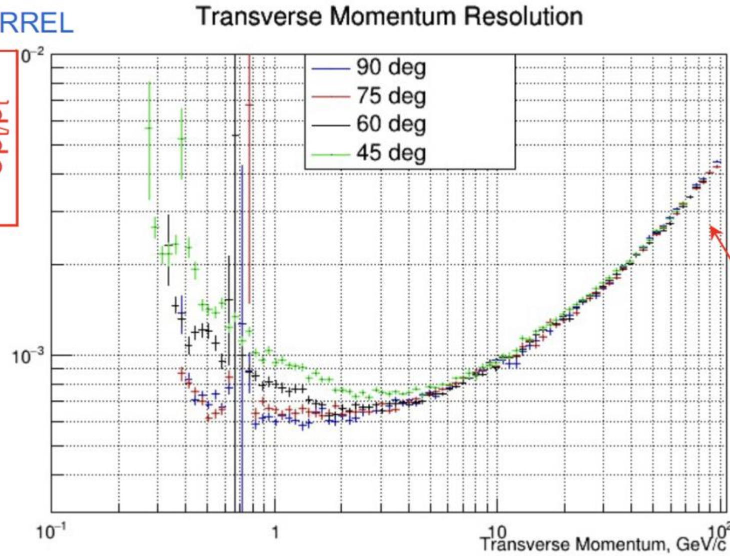


Vertex:
inner: 3 Si pixel (20 μm x 20 μm) layers, 0.3% X_0
outer: 2 Si pixel (50 μm x 1mm) layers, 0.5% X_0
forward: 4 Si pixel (50 μm x 50 μm) layers, 0.3% X_0

Ion backflow and space charge buildup → no TPC-like detector in tracking system!!

The IDEA detector at e^+e^- colliders

BARREL



DCH + SVX but no Si-Wrapper

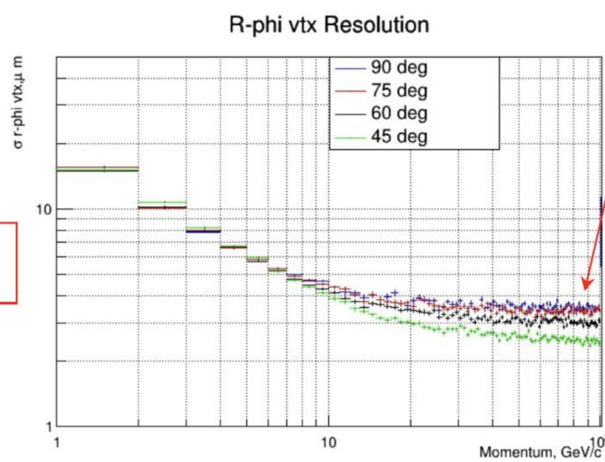
Recent studies with

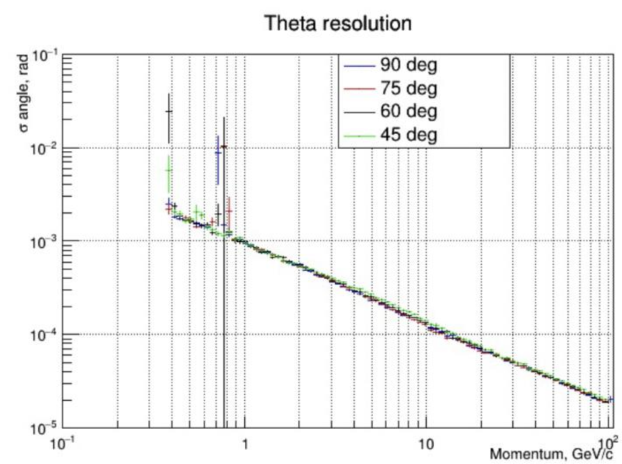
$\sigma(p_t)/p_t$ (100 GeV) = $3x10^{-3}$

$\sigma(d_0)$ (100 GeV) = $2\mu m$

BARREL

impact parameter





Moreover (internal news)...

→ "First FCC-Italy workshop" che si terra' a Roma il 21 e 22 Marzo

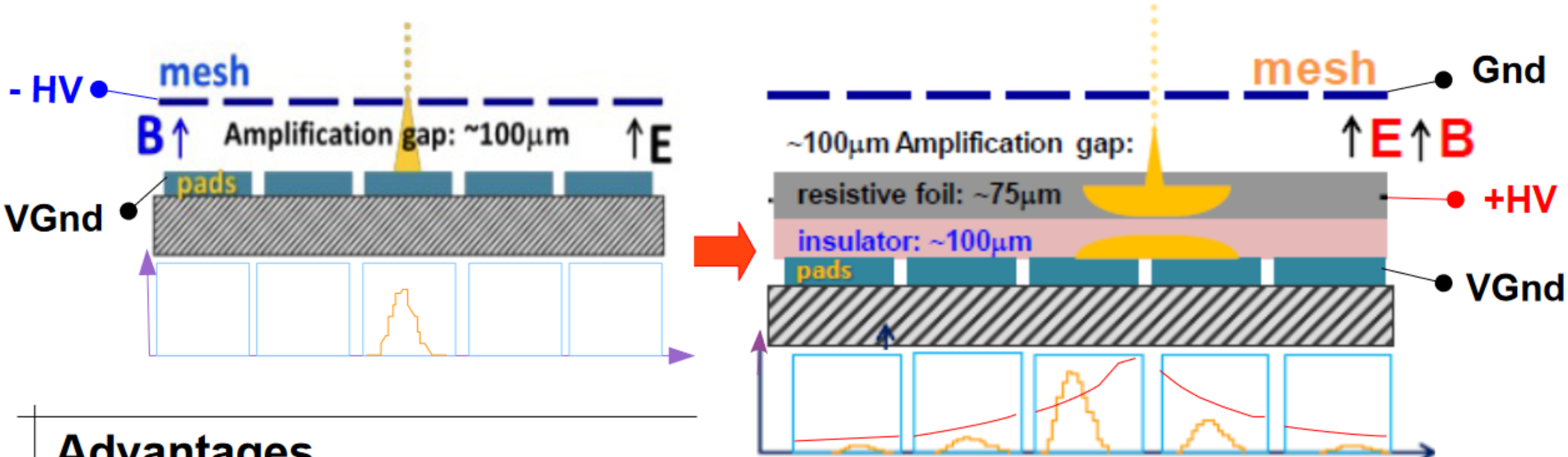
→ For first time, PJAS LHC/FCC both Collaboration at 50% .

→ 1/04/22 Reham Aly at 50%/50% CMS-FCC

Anode readout → Resistive Micromegas

P.Colas (CEA Saclay Irfu/DPhP)
CERN workshop 2017/11

Micromegas detector configuration:
encapsulated resistive anode with grounded mesh



Advantages

- Charge spreading → better space point resolution
  → with less electronics channels
- Target resistivity R ~ 0.4 MΩ/square + C ~ O(pF/mm2)
  → shaping time O(100ns) & spread O(3mm)

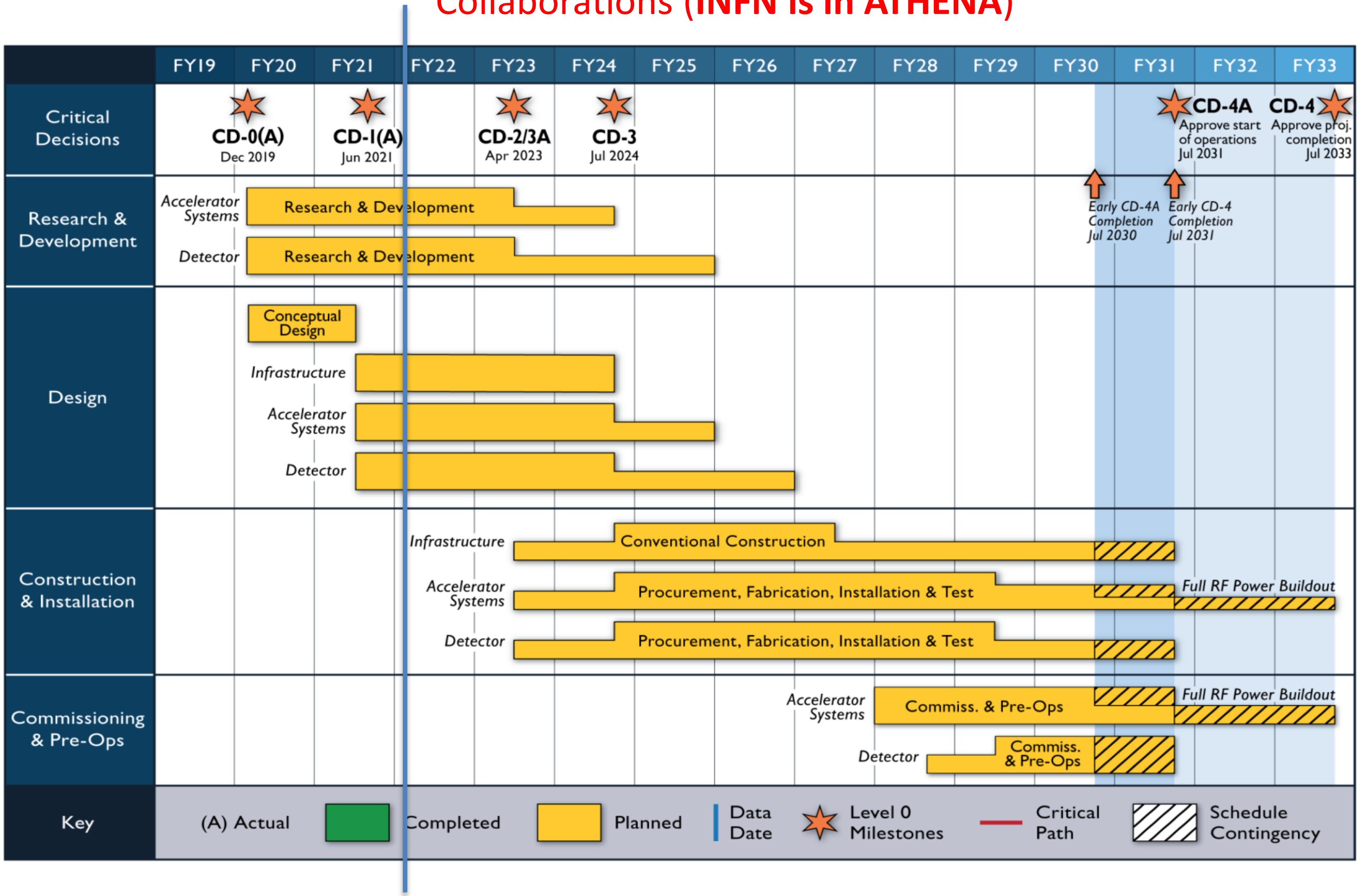
$$\rho(r,t) = \frac{RC}{2t} e^{-r^2 RC/(4t)}$$

- Resistive layer prevents charge build-up, ie sparks:
  → operation at higher gain & lighter Font End cards
- Mesh potential at ground and insulation of Resistive layer
  → potentially better field homogeneity → reduced track distortions
- Less sensitive to electric noise due to shielding effect of resistive foil

EIC Project in US

EIC timeline

Extremely intense work carried out between March and December 2021 towards preparation of detector proposals by the three proto-Collaborations (**INFN is in ATHENA**)



Status and plans for Si-tracker R&D

ALICE ITS3 as a solution for EIC

The ALICE ITS3 project aims at developing **a new generation MAPS sensor at the 65 nm CMOS node with extremely low mass for the LHC Run 4 (HL-LHC)**

ITS3 sensor *(from the EIC point of view)*

- Specifications meet or even exceed the EIC requirements
- Satisfactory granularity (now targeting 20μm pixel pitch) and power consumption (<20mW/cm^2)
- Also, integration time, fake hit rate and time resolution better than required at the EIC
- Sensor design optimized for high yield, stitched sensor to reach wafer-scale size (up to 28 x 10 cm^2)
- Development schedule well aligned with EIC timeline

ALICE

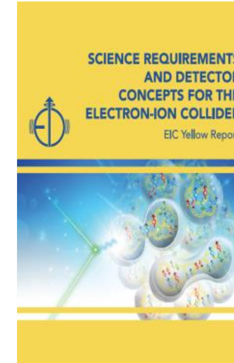
ITS3 Specifications

Parameter	ALPIDE (existing)	Wafer-scale sensor (this proposal)
Technology node	180 nm	65 nm
Silicon thickness	50 μm	20-40 μm
Pixel size	27 x 29 μm	O(10 x 10 μm)
Chip dimensions	1.5 x 3.0 cm	scalable up to 28 x 10 cm
Front-end pulse duration	~ 5 μs	~ 200 ns
Time resolution	~ 1 μs	< 100 ns (option: <10ns)
Max particle fluence	100 MHz/cm^2	100 MHz/cm^2
Max particle readout rate	10 MHz/cm^2	100 MHz/cm^2
Power Consumption	40 mW/cm^2	< 20 mW/cm^2 (pixel matrix)
Detection efficiency	> 99%	> 99%
Fake hit rate	< 10^{-7} event/pixel	< 10^{-7} event/pixel
NIEL radiation tolerance	~3 x 10^{13} 1 MeV n_{eq}/cm^2	10^{14} 1 MeV n_{eq}/cm^2
TID radiation tolerance	3 MRad	10 MRad

M. Mager | ITS3 kickoff | 04.12.2019 |

ATHENA vertex & tracking

Tracking requirements for physics @ EIC

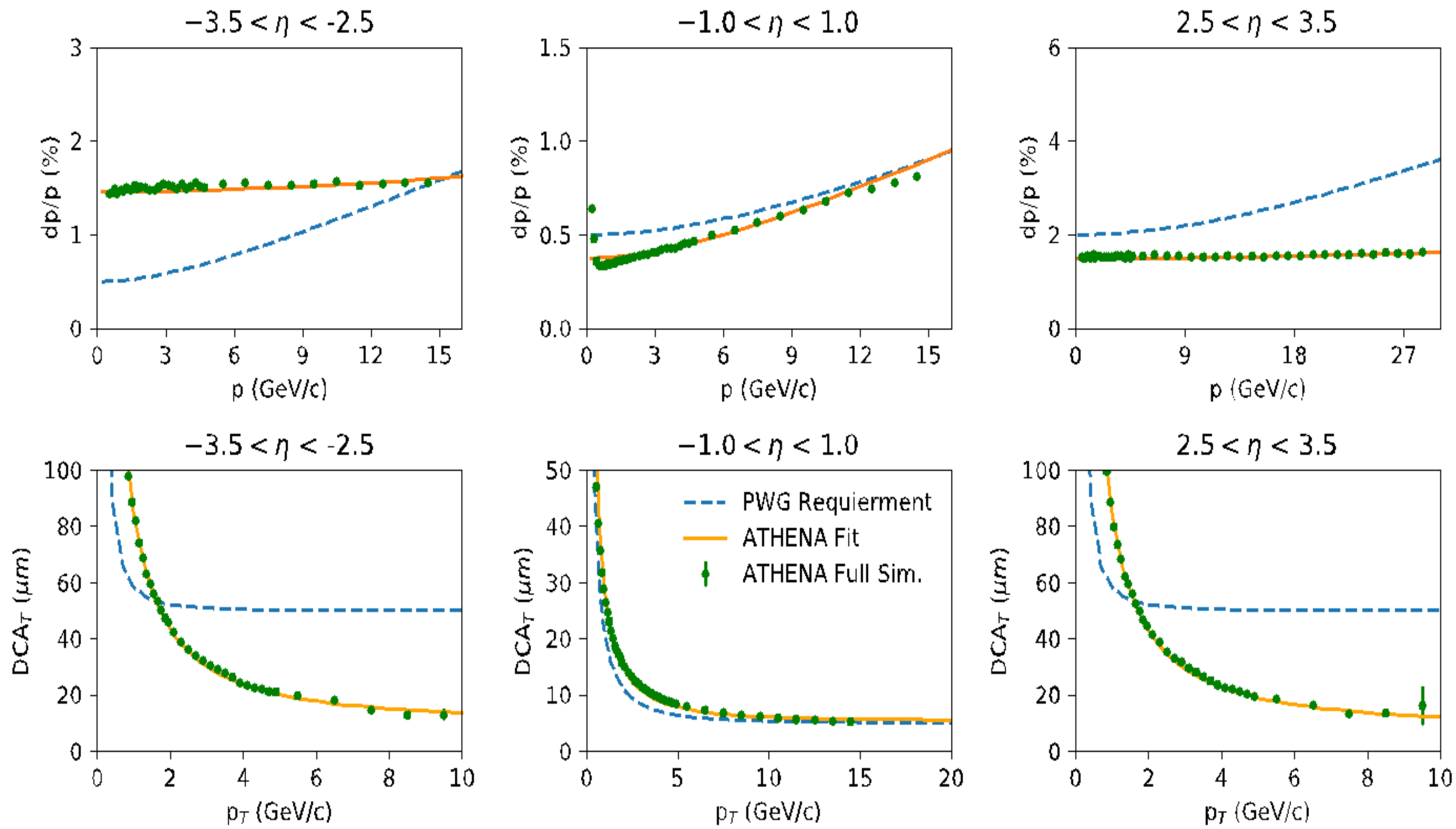


PWG requirements in the YR:

https://arxiv.org/abs/2103.05419

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0			$\sigma p/p \sim 0.1\% \times p \oplus 0.5\%$		100-150 MeV/c	
-3.0 to -2.5		Backward Detector			100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 40 μm
-2.5 to -2.0			$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 20 μm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 20/pT μm ⊕ 5 μm
-0.5 to 0	Central Detector			~5% X0 or less		
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	$\sigma p/p \sim 0.05\% \times p \oplus 1\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 20 μm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			$\sigma p/p \sim 0.1\% \times p \oplus 2\%$		100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 40 μm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 60 μm

Basic performance from full simulation

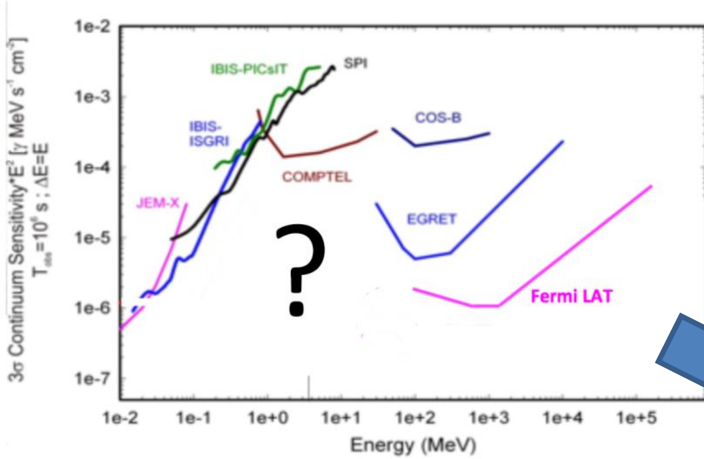


Tracking performance meets or exceeds the momentum resolution requirements stated in the EIC YR, except for the most backward region (needs combination with eCAL, further reduction of material budget etc)

Sensitivity for currently available measurements in MeV-GeV γ-rays

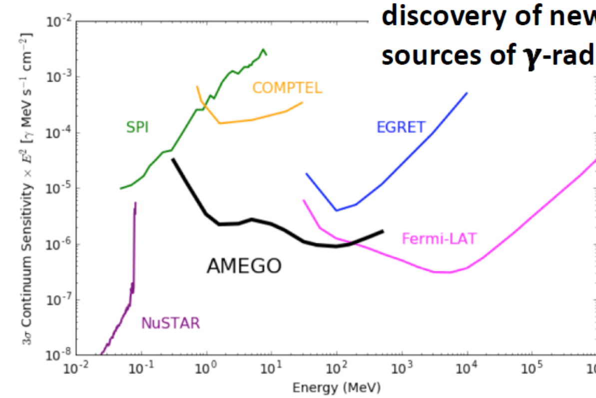
AMEGO All-sky Medium Energy Gamma-ray Observatory

Motivation

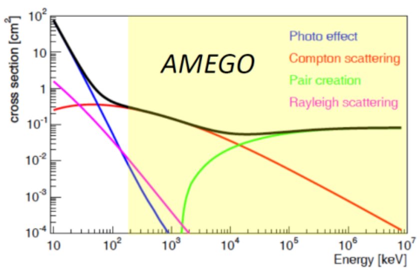


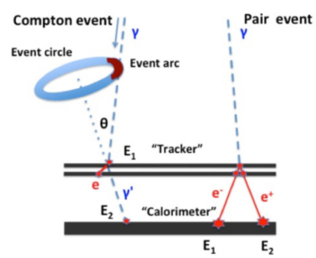
Guaranteed discovery space!
But why this gap ?

(considering only discovery of new sources of γ-radiation)



A lot of interesting science, but difficult to accurately measure: "Impossible energy range"





Energy Range	200 keV -> 10 GeV
Angular resolution	2.5° (3 MeV), 1.5° (5 MeV), 2° (100 MeV)
Energy resolution	<1% (< 2 MeV), 1-5% (1-100 MeV), ~10% (1 GeV)
Field of View	2.5 sr (20% of the sky)
Line sensitivity	<1x10⁻⁶ ph cm⁻² s⁻¹ for the 1.8 MeV ²⁶Al line in a 5-year scanning observation
Polarization sensitivity	<20% MDP for a source 1% the Crab flux, observed for 10⁶ s
Continuum sensitivity (MeV cm⁻² s⁻¹)	2x10⁻⁶ (1 MeV), 1x10⁻⁶ (100 MeV), 5 years

- From 1 to ~100 MeV two photon – matter interaction processes compete: Compton scattering and pair-production
- To fill the "MeV Gap" we need to consider both Compton Scattering and Pair Production
- At low energy pair-production components (e^+ and e^-) suffer large multiple scattering, causing large uncertainty in the incident photon direction reconstruction
- Materials undergo activation on orbit by cosmic rays: artificial background below ~10 MeV

AMEGO: All-sky Medium Energy Gamma-ray Observatory

Alexander Moiseev
CRESST/NASA/GSFC and University of Maryland, College Park
for the *AMEGO* team

ARICH simulation parameters

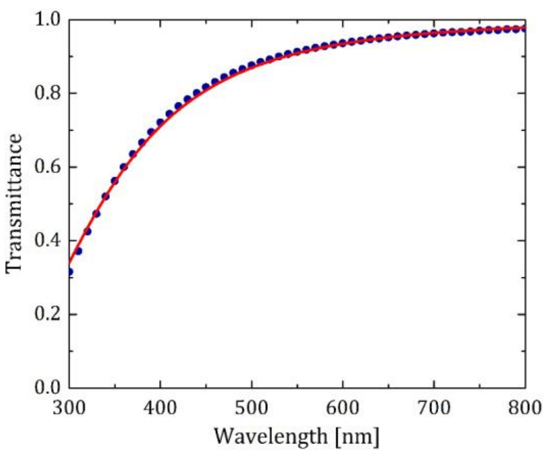
ALICE 3

AEROGEL

- Last generation hydrophobic aerogel from Chiba University with excellent optical properties in the refractive index range 1.03-1.05
- Considered only Rayleigh scattering for the moment, forward scattering has smaller impact on angle resolution and will be added later

PHOTO-DETECTOR

- SiPM HPK 13360 3050CS, 3.x3 mm^2 pixel
- Dark count rate ~ 50 kHz/mm^2
- Assumed 50 ps time resolution



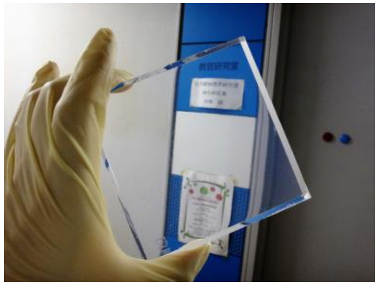
Rayleigh scattering

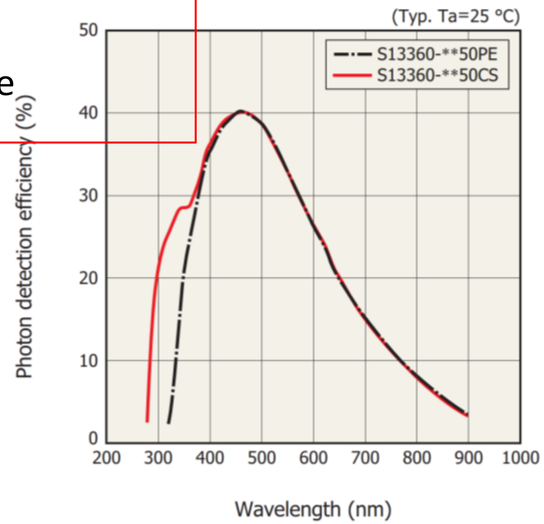
$$T = A\, e^{-CL/\lambda^4}$$

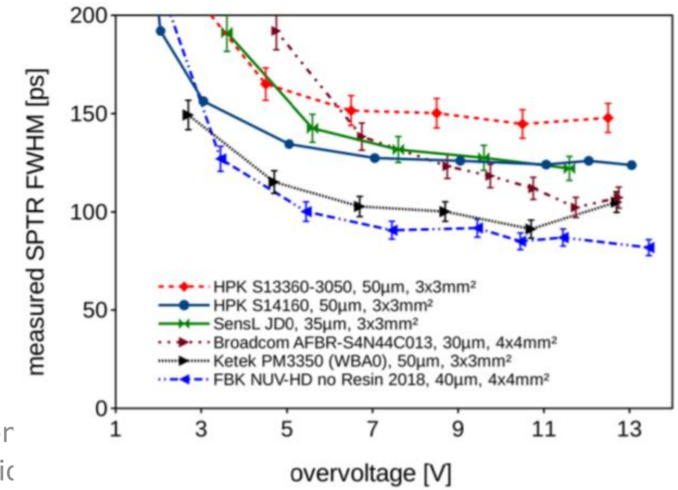
A=1

C=0.00435 μm^4/cm

L= 2 cm







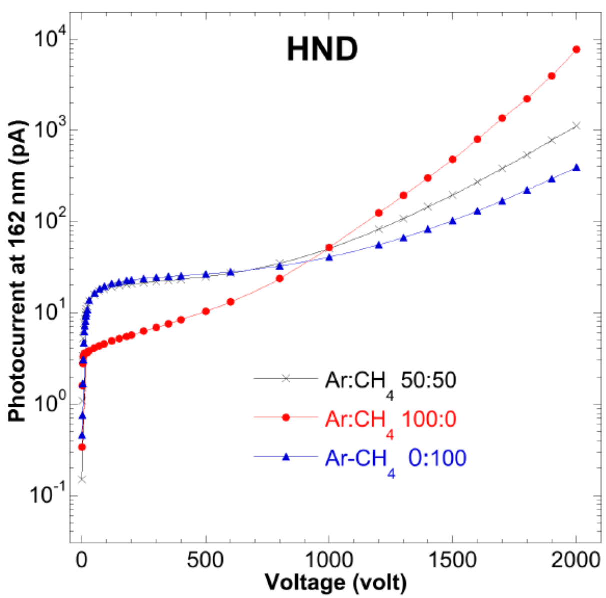
Nanodiamond photocathodes for MPGD-based single photon detectors at future EIC

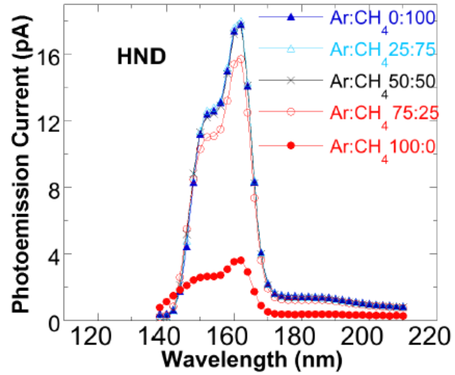
G.Cicala, A.Valentini, T.Ligonzo

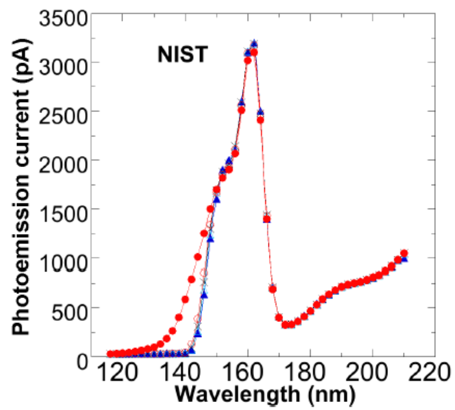
Istituto Nazionale di Fisica Nucleare SEZIONE DI BARI

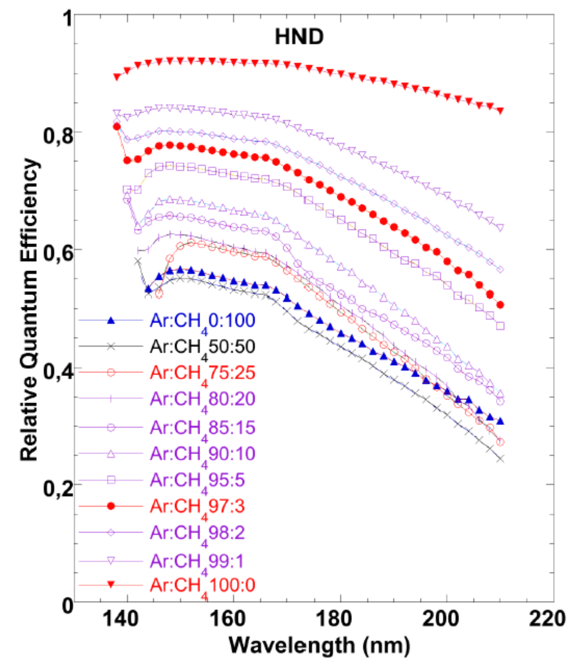
ISTP Consiglio Nazionale delle Ricerche

Photoemission measurements in various Ar-CH_4 gas mixtures





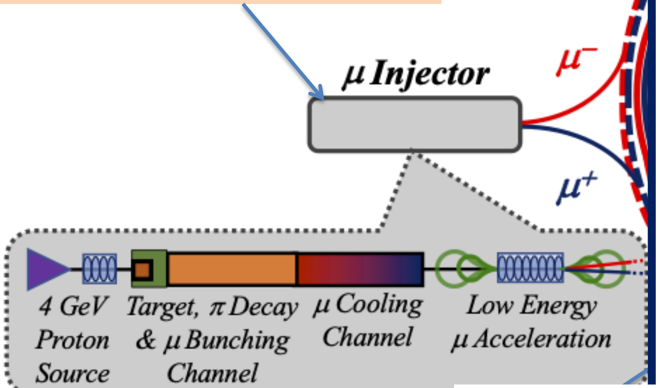




Bari 4 Febbraio 2022

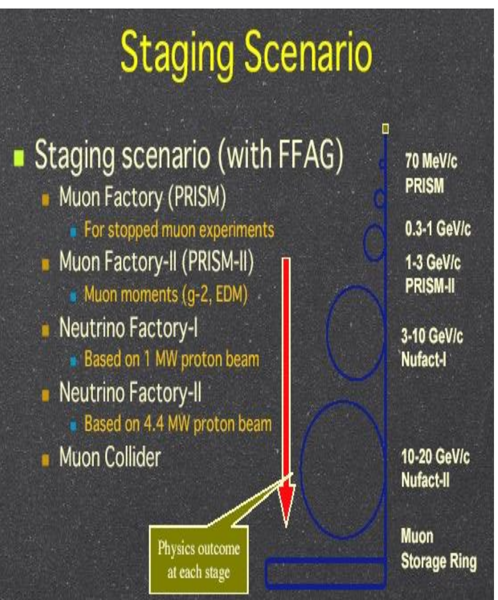
Proton targets @ Muon Collider (E.Radicioni, M.G.Catanesi)

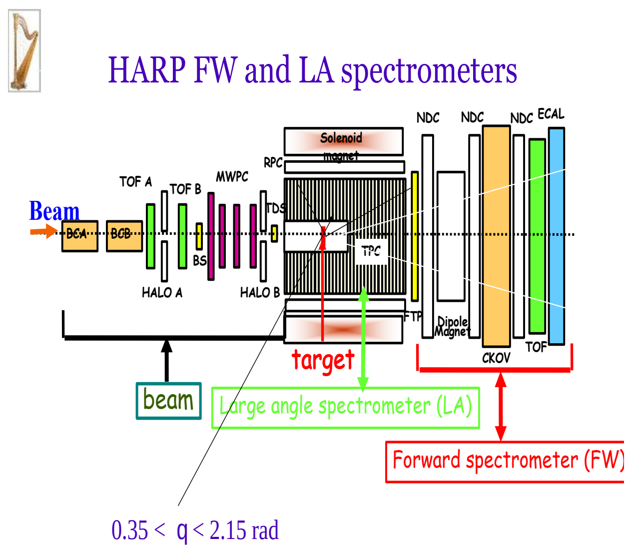
Drives the **beam quality**
quite detailed MAP design
still challenging design with
challenging components
optimise as much as possible

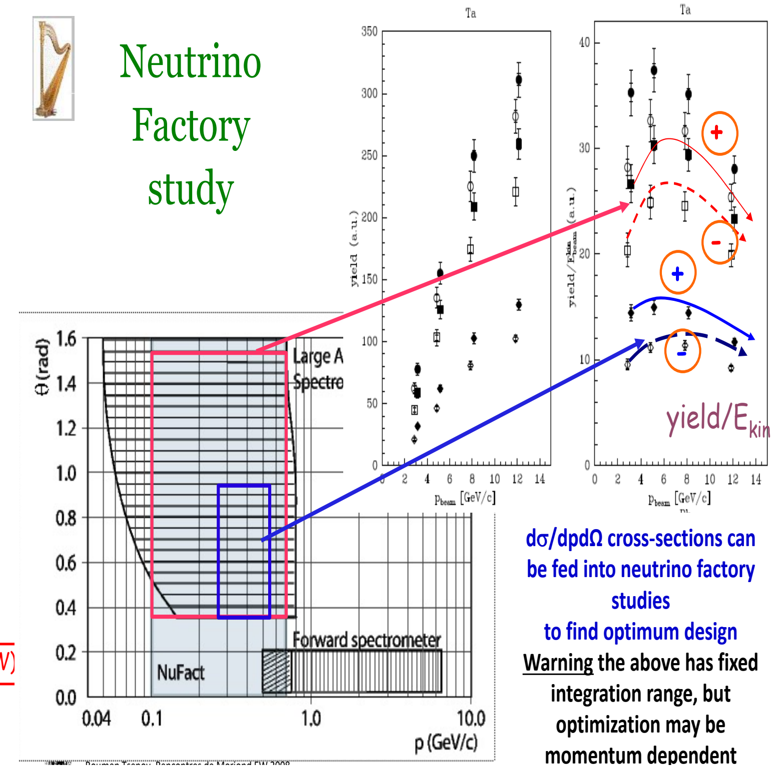


In continuita’ con gli studi effettuati per MAP nell’ambito dell’esperimento HARP , siamo interessati nel ....

- Design study and optimisation (materials, energy, phase space, π cross-sections) of the Neutrino Factory/Muon Collider target zone (WP4)
- Long Term possible activities
  - Test facility at CERN (development of beam monitor detectors)
  - Additional high precision Hadron production measurements if needed







Target and Energy optimisation with HARP data used in MAP