СУПЕР С-ТАУ ФАБРИКА: ДЕТЕКТОР

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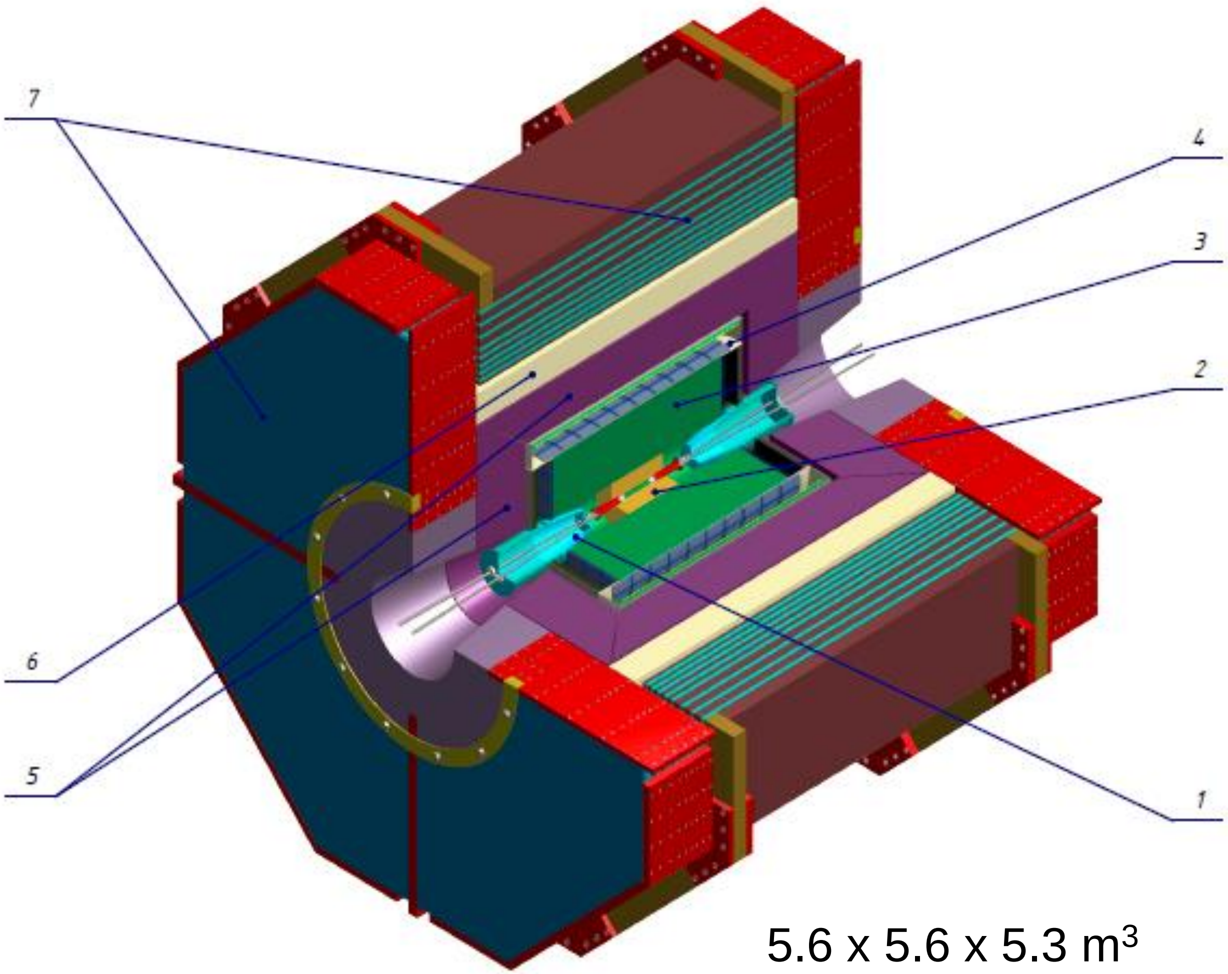
ИЯФ СО РАН

Требования к детектору

- Momentum resolution $\sigma_p/p \leq 0.4\%$ at 1 GeV
- Very symmetric and hermetic
- Able to detect soft tracks ($p_t \geq 50\ MeV/c$)
  - Inner tracker should be able to handle 10^4 tracks/cm^{2}s
- Very good particle identification: $e/\mu/\pi/K$
  - π/K in the whole energy range, e.g. for $D\bar{D}$ mixing
  - μ/π up to 1.5 GeV, e.g. for $\tau \to \mu\gamma$ search
  - dE/dx better than 7%
- Able to detect γ from 10 MeV to 3.5 GeV, good π^0/γ separation
  - Calorimeter energy resolution $\sigma_E/E \leq 1.8\%$ at 1 GeV
  - Calorimeter time resolution $\sigma_t \leq 1$ ns
- Efficient “soft” trigger
- Ability to operate at high luminosity, up to 300 kHz at J/ψ

Общая структура

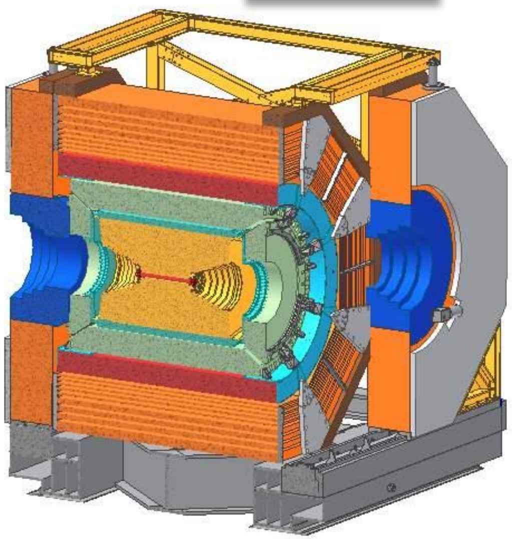


5.6 x 5.6 x 5.3 m^3

1. Vacuum pipe
2. Inner tracker
3. Drift chamber
4. PID
5. Calorimeter
6. SC magnet
7. Muon system

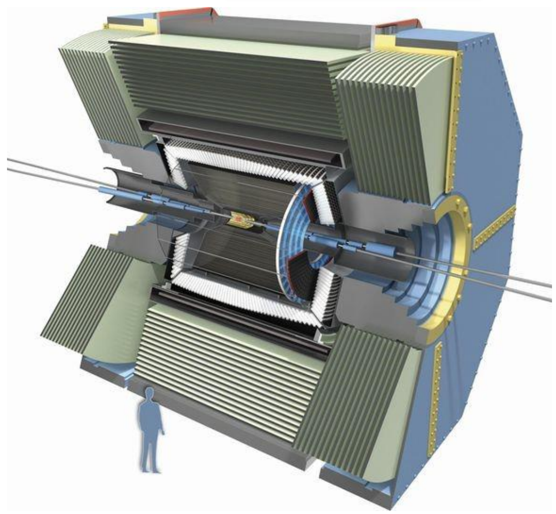
Brothers, sisters and cousins…

BES-3



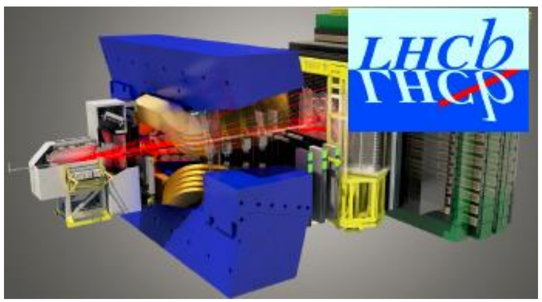
Very similar
1% luminosity

BELLE-2



Super B-factory (10.58 GeV)
5-10x luminosity

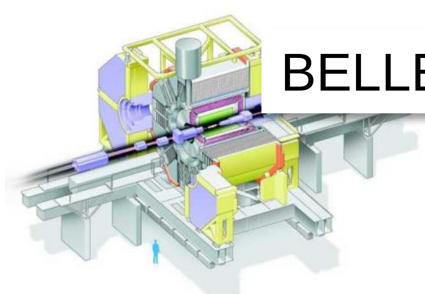
LHCb



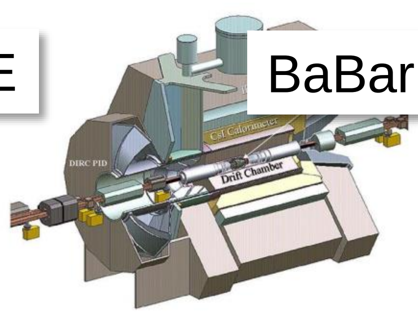
pp collisions

Previous generation:

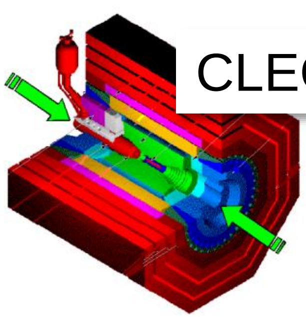
BELLE



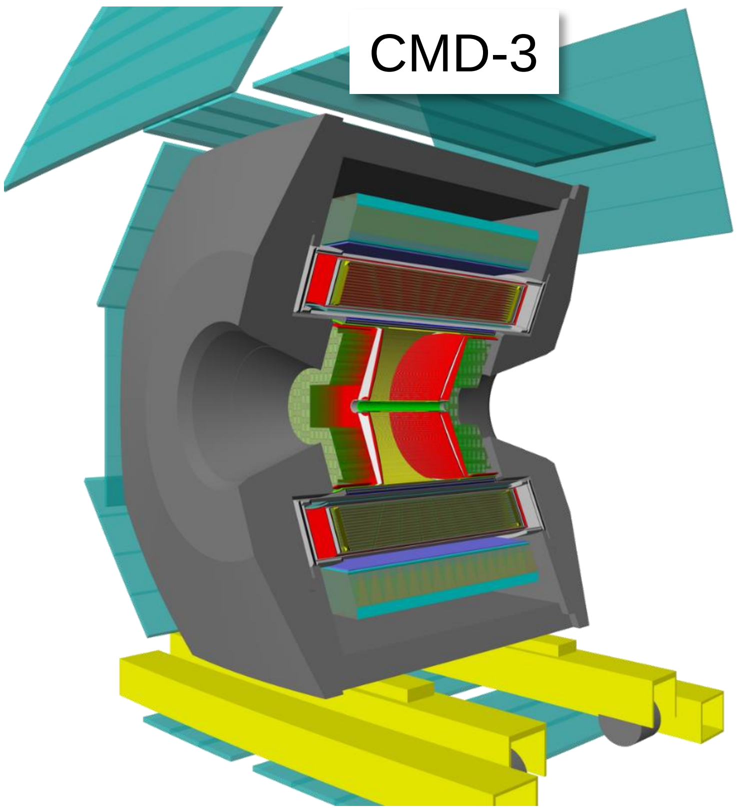
BaBar

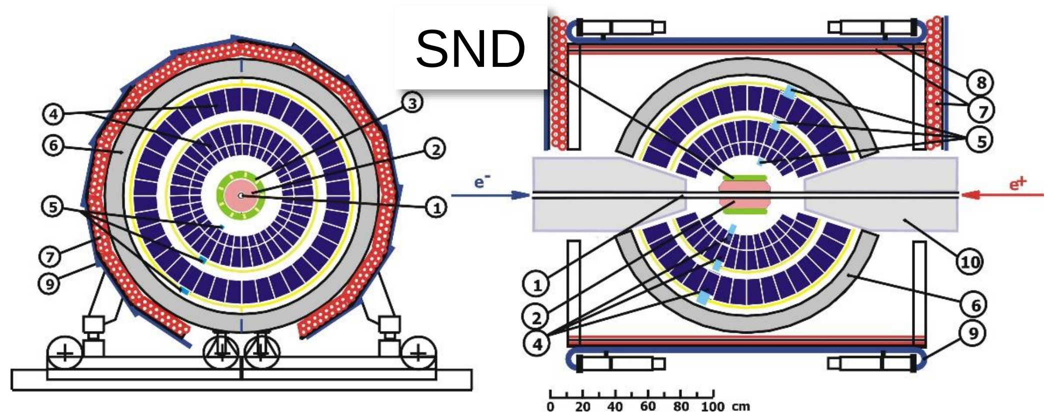


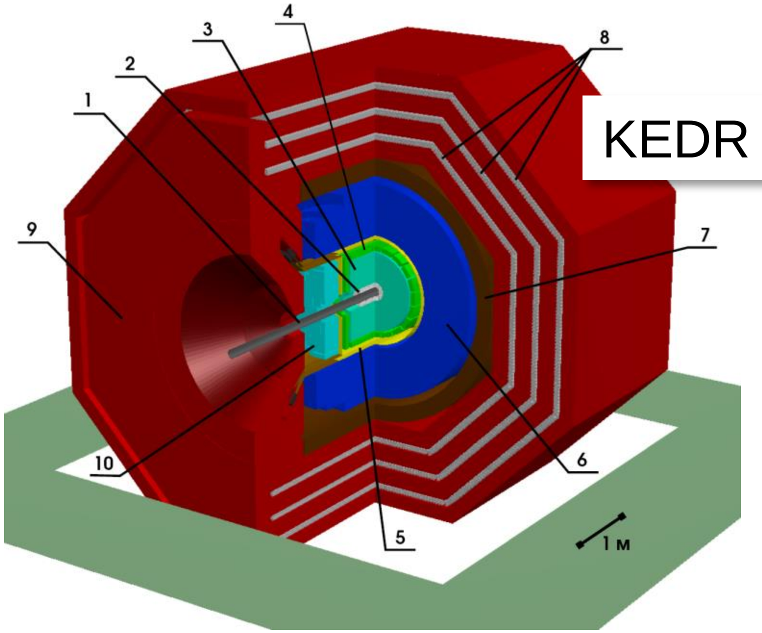
CLEO-c



In-house (Novosibirsk) cousins

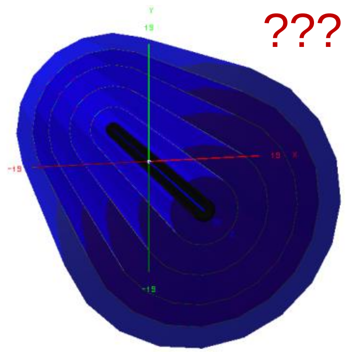






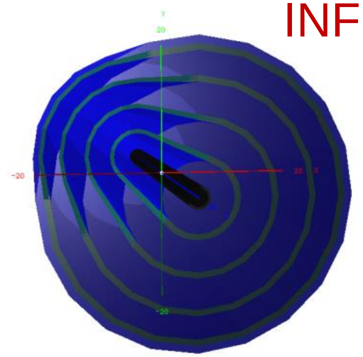
Внутренний трекер

???



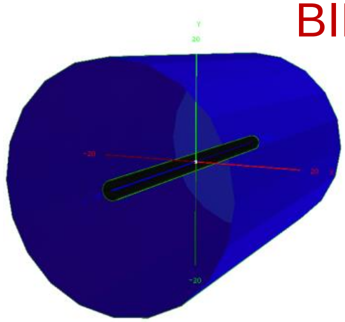
4-layer Si-strip

INFN



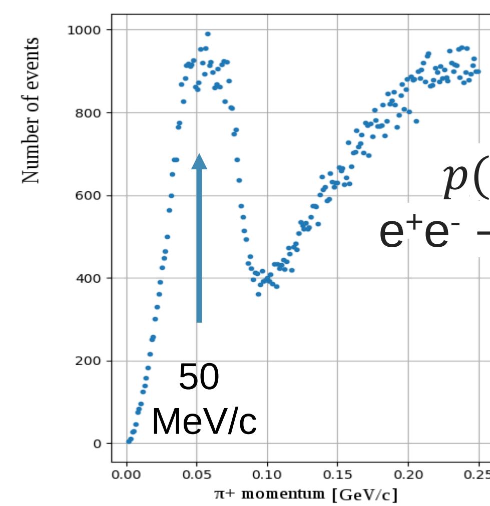
Cylindrical MPGD

BINP



Time Projection Chamber (TPC)

- Работает как независимая система (треки, не вылетающие в ЦДК), так и совместно с ЦДК
- Измеряет параметры треков и координаты вершин распадов
- Разрешение сравнимо с ЦДК ($\sim 100\ \mu$)
- Способна регистрировать «мягкие» частицы ($p_t \sim 50$ MeV/c)
- Способная работать в условиях большой загрузки
- Приблизительные размеры: Ø (40-400) x 600 мм

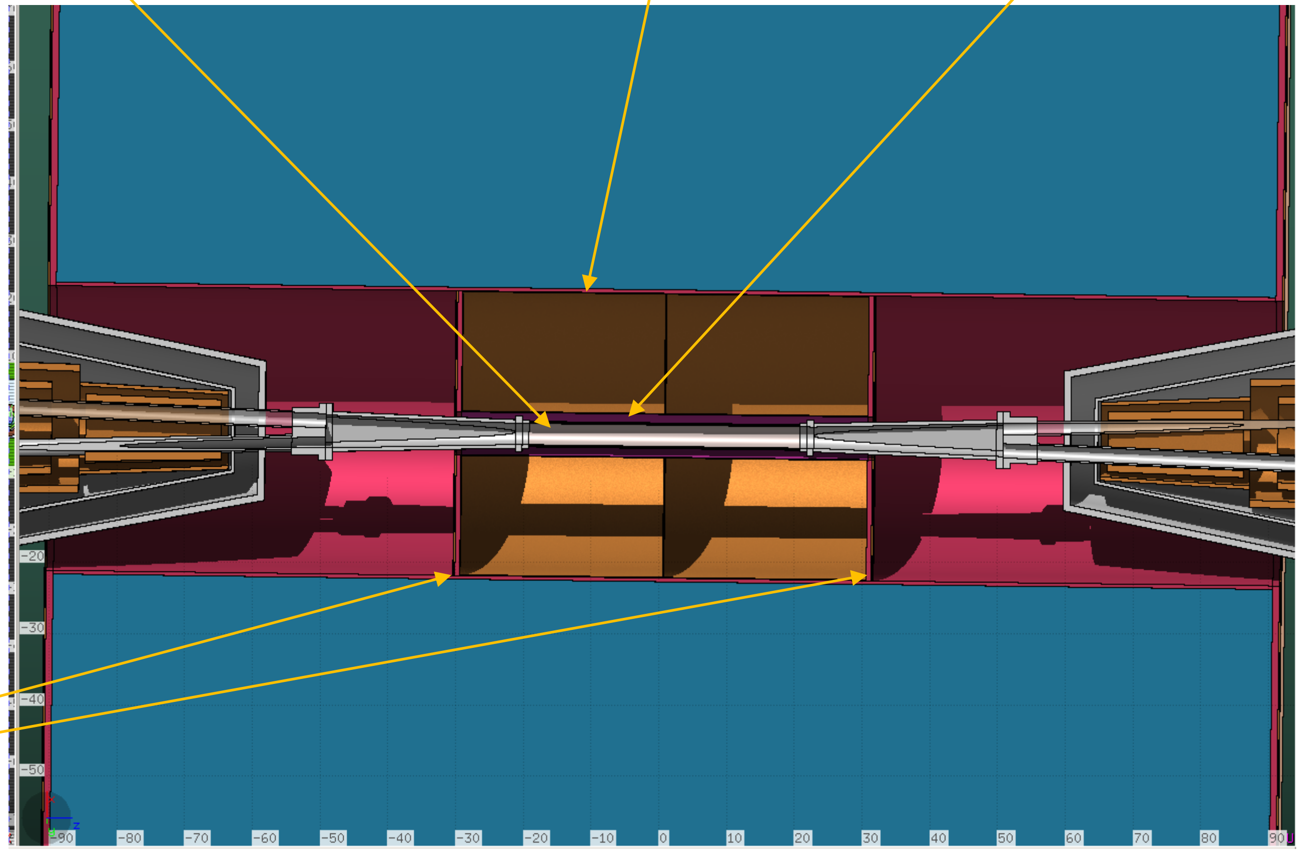


Inner Tracker: TPC

Beam pipe, inner radius 1.5 cm

Outer radius 20 cm

Inner radius 3 cm



TPC advantages:

- Highest number of hits per track
- Great dE/dx measurement

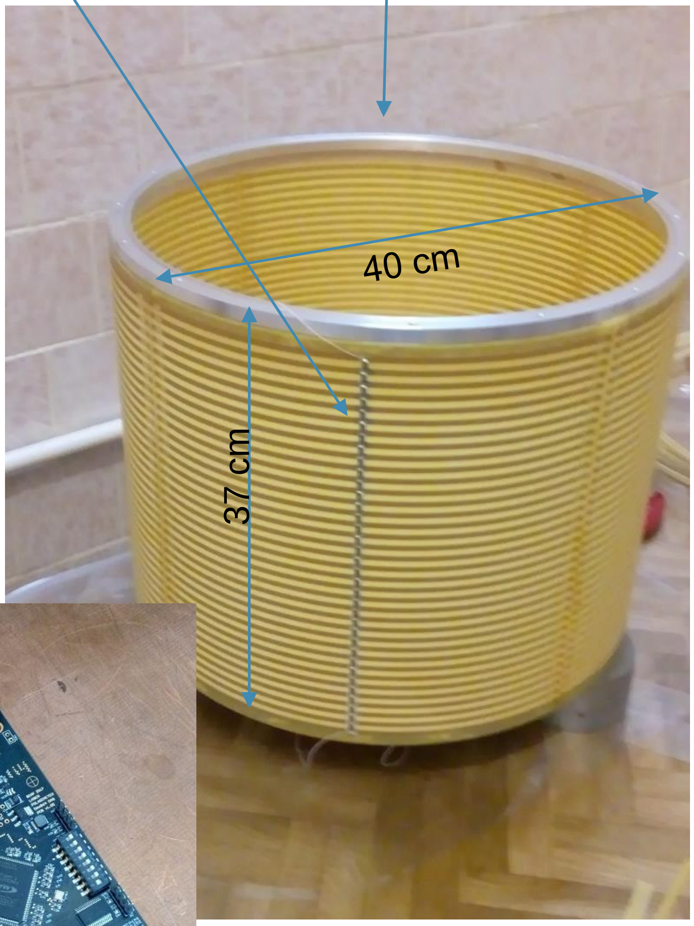
-30 cm < Z < 30 cm

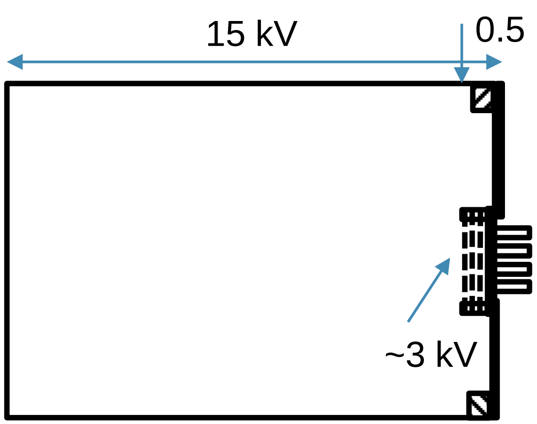
TPC prototype

Ability to operate in high flux (including reconstruction) have to proved

Field cage is ready. Design of the end-cap detector is going on.

- Quad-GEMs, then 2(3)GEMs-muRWELL
- Readout structure with several groups of pads with different size 1-4 mm
- Electronics based on DMXG64B ASIC (CSA+100 cells of analogue memory)

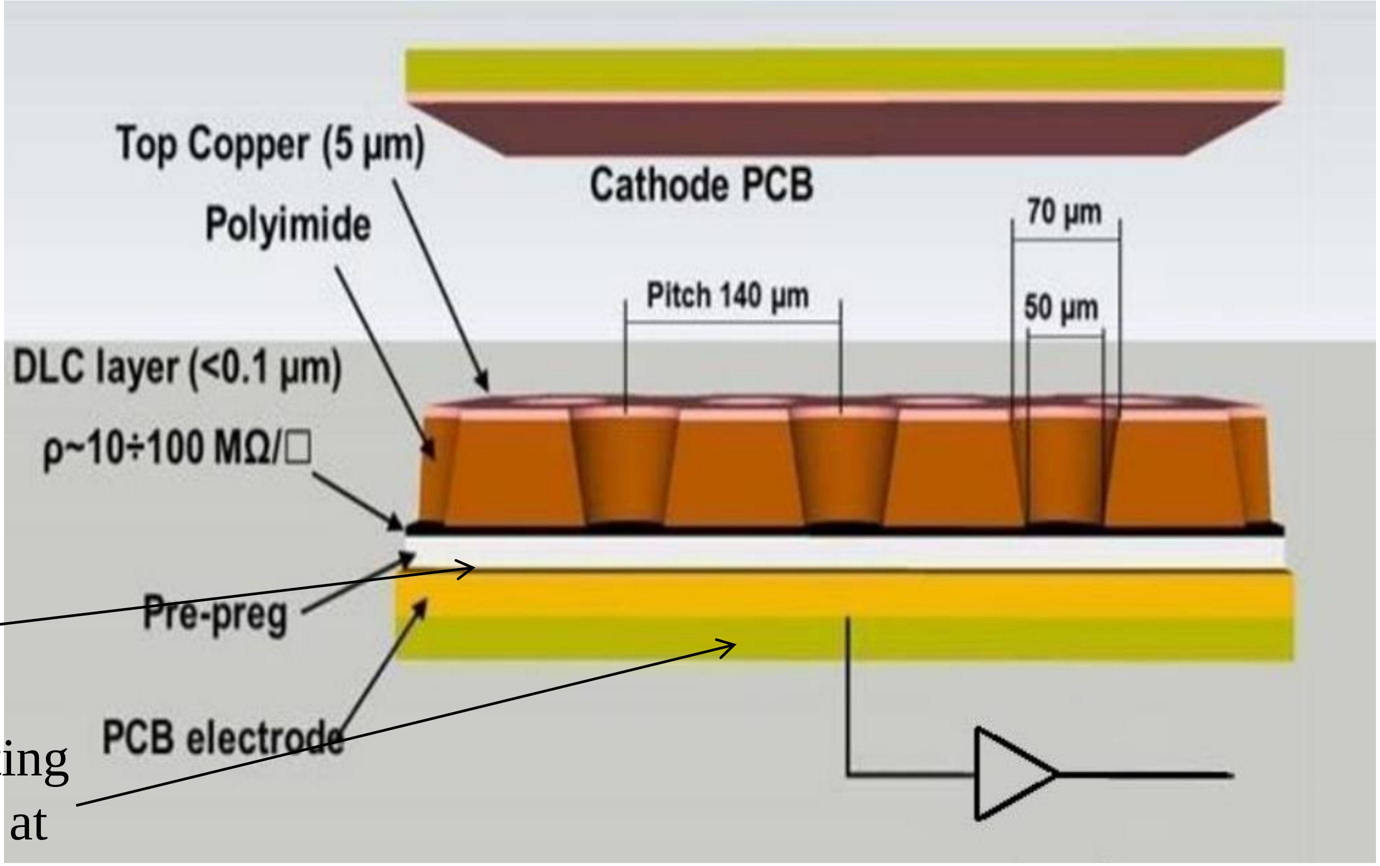




128-channel board

Resistive micro-WELL

GEM on top of resistive layer and on top of readout PCB



Two readout layers

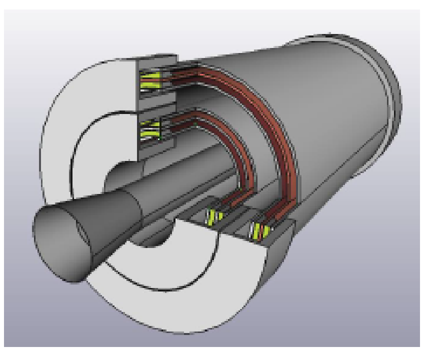
Multilayer PCB, rooting signals to connectors at the edge

Inner Tracker: C-mRWELL

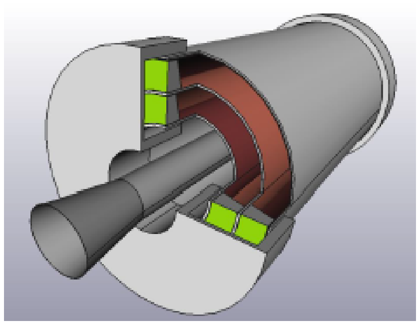
The Cylindrical u-RWELL

The **two schemes** under study are both based on a **B2B layout** (a **double radial TPC – with a central cathode**), characterized by **low material budget** and **modular roof-tile shaped active device**

"2 - B2B small drift gap" cylindrical detector	"1 - B2B large drift gap" cylindrical detector



micro-TPC readout mode allowing **space resolution** of O(**100 µm**) for **inclined tracks** (on the radial view)



N.2 small gap B2B C+layers → 1.72% X0
2 × 1 cm gas gap/B2B device
4 cm global sampling gas

N.1 large gap B2B C+layers → 0.86% X0
2 × 1 cm gas gap/B2B device
10 cm global sampling gas

Further **material budget reduction** by using:

- **high module FR4**
- **low resistivity DLC cathode**
- **aluminum Faraday-Cage/shielding**

1.46 % X0 ← → **0.75 % X0**

C-mRWELL prototype

The C+RWELL prototype

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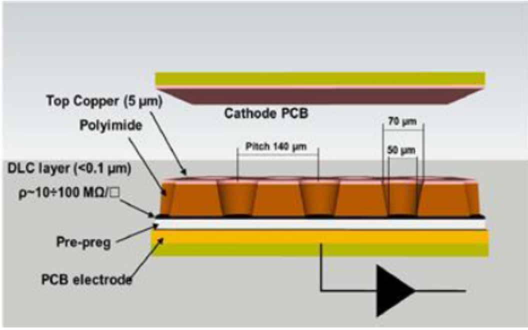
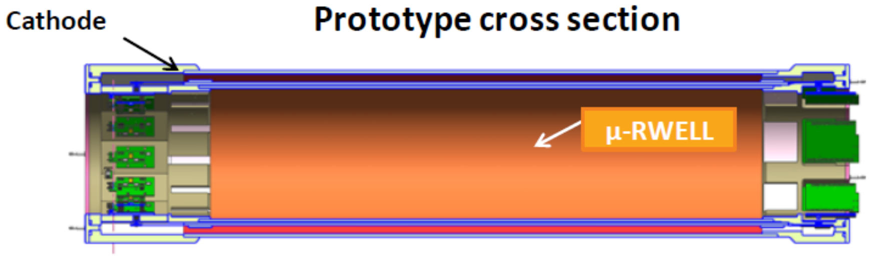
Connecting Russian and European Measures for Large-scale Research Infrastructures

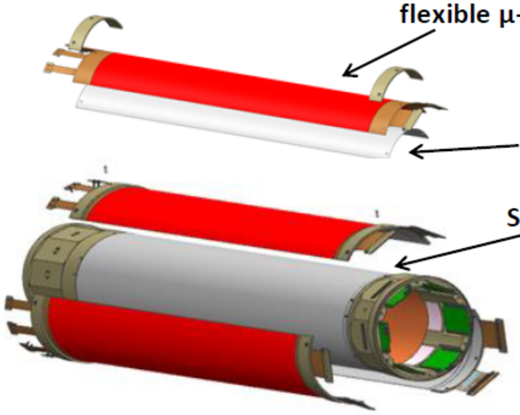
To validate the concept we are designing a single-layer small drift-gap (1 cm) C+RWELL prototype



- From standard **micro-RWELL technology on rigid PCB supports** we are developing a **full flexible detector tile**
- **Three of such flexible detector tiles** will be **glued** on **composite/foam roof-tiles**, then mounted on the **anode cylindrical support**
- **A full cylindrical-cathode will close (externally) the detector**

Prototype cross section





Prototype size

- external diameter ≈20cm
- global length ≈ 100cm
- active length≈ 60cm

C-mRWELL prototype

INFN LNF-DDG

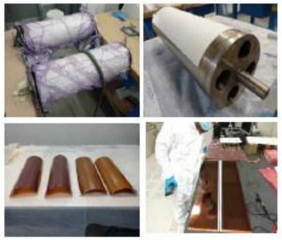
Cremlin+ → the C+RWELL progress (II)

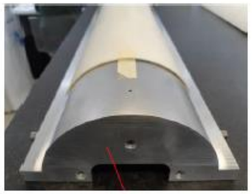
CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

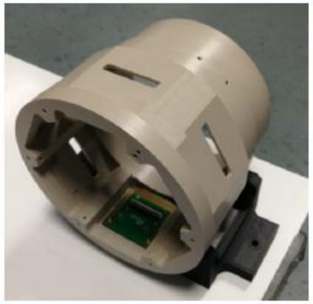
The **design** of the prototype has been **completely revised and finalized**

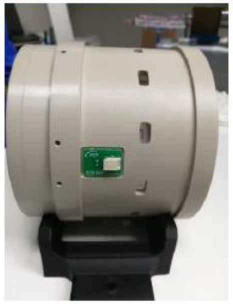
- Orders of **flex-detector tiles** (CERN – Rui) done → delivery by the end of November
- Orders of **mechanics/tools** (anode/cathode, end-caps, plugs, tiles) done → **construction in progress (@LOSON):**

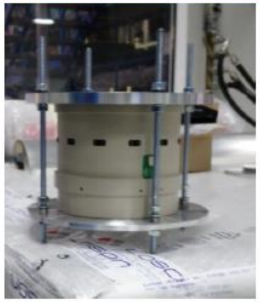
- **anode mould** **DONE**
- **cathode mould** **DONE**
- **end-caps/plugs in peek →** **DONE**
- **tiles (still) under test →** **DONE**
- **HV, signal interface boards →** **DONE**
- **Detector assembly →** **Nov – Dec 2021**











Центральная дрейфовая камера

Measurement of momentum and dE/dx (PID)

- Spatial resolution ~100 μ
- Small cell
- Minimal material (reduce MS)
- Approximate size: Ø (400-1600) x 1800 mm

"Traditional" option BINP	**"Beyond-traditional" option** INFN
Babar, BES-3, Belle-2	KLOE, MEG-2, IDEA
Axial and stereo superlayers	Full stereo
Traditional dE/dx	dE/dx by cluster counting
Feed-through wiring	Robotic wiring

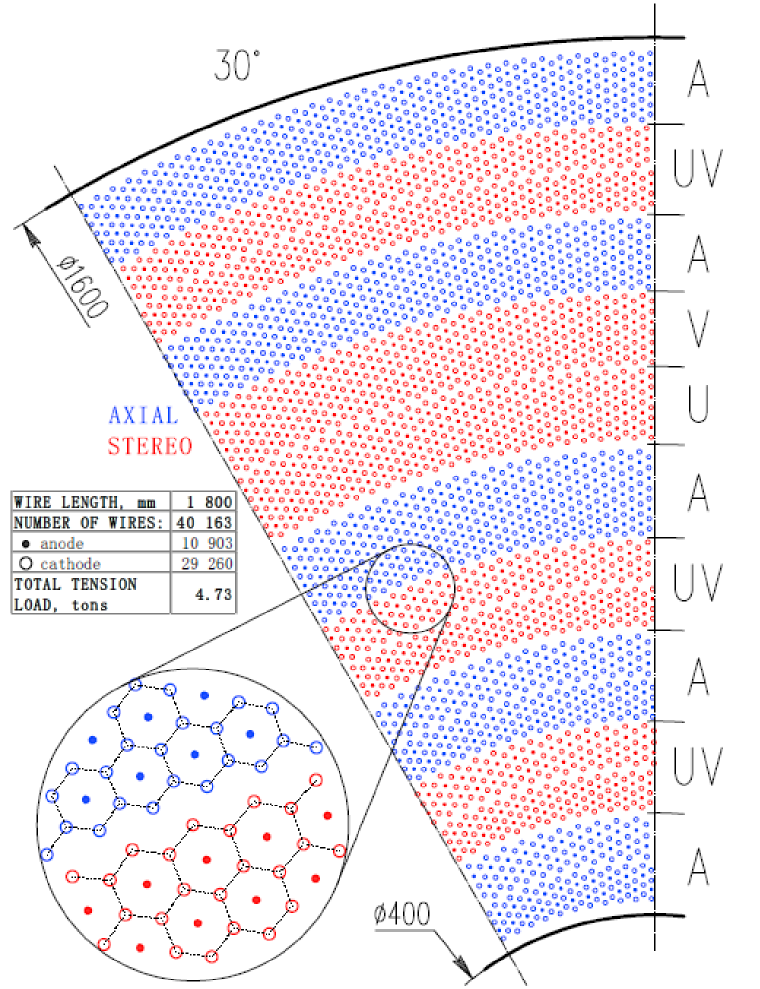
Drift chamber: “traditional” option (BINP)

- ~40000 wires
  - 11k sensitive, W-Rh(Au)
  - 29k field, Al(Au)
- Hexagonal cell, 6.3-7.5 mm
- 41 layers
- 60% He + 40% C_3H_8
- 330 ns drift time (1.5 T)

$$\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.21\%^2 p_t^2 + 0.31\%^2}$$

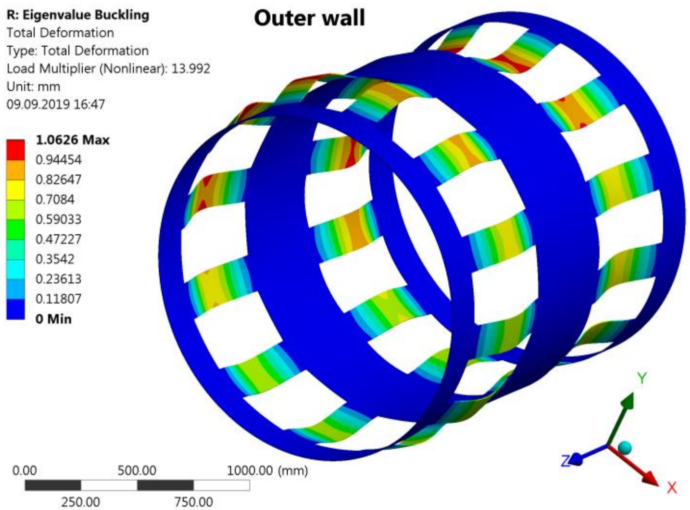
≈0.4% at 1 GeV

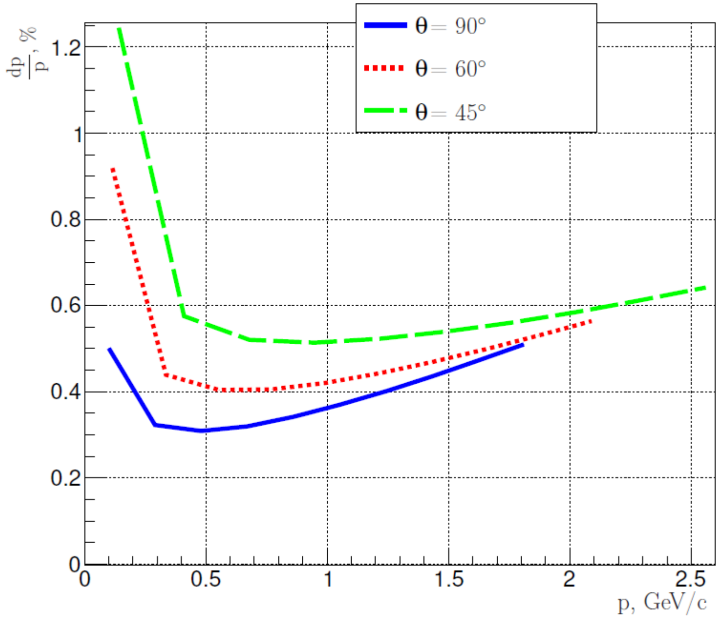
$$\frac{\sigma_{dE/dx}}{dE/dx} \approx 6.9\%$$



I.Yu.Basok et al., NIM A1009 (2021) 165490

Drift chamber: “traditional” option (BINP)





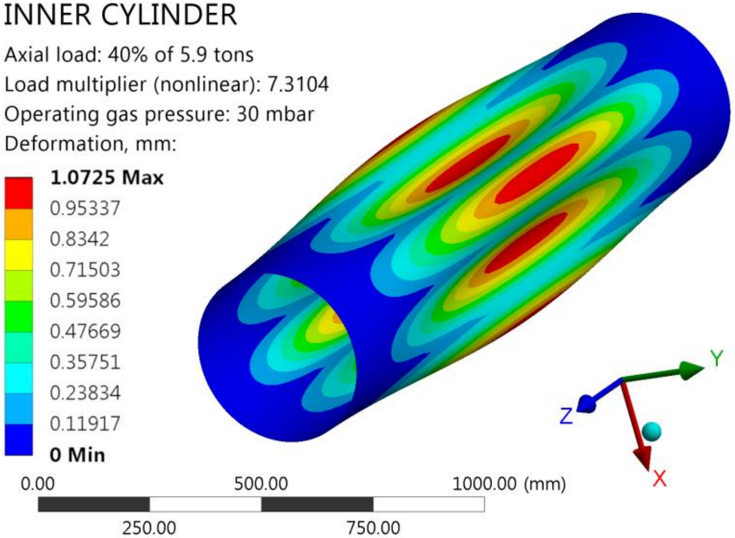
INNER CYLINDER

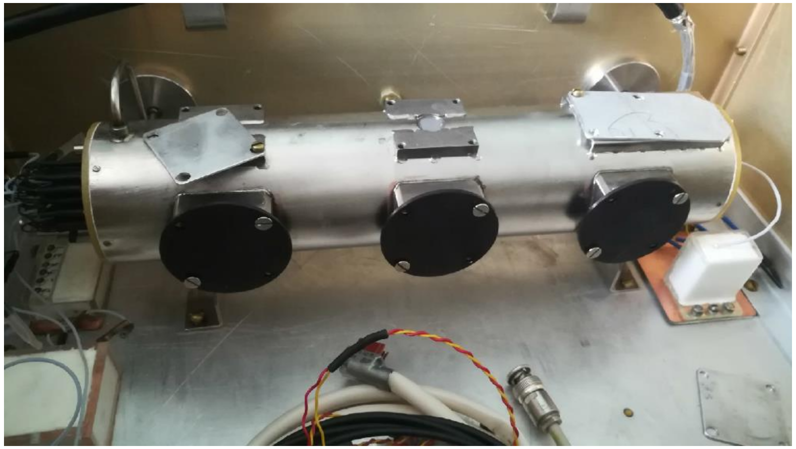
Axial load: 40% of 5.9 tons

Load multiplier (nonlinear): 7.3104

Operating gas pressure: 30 mbar

Deformation, mm:





Drift chamber: TraPid option (INFN)

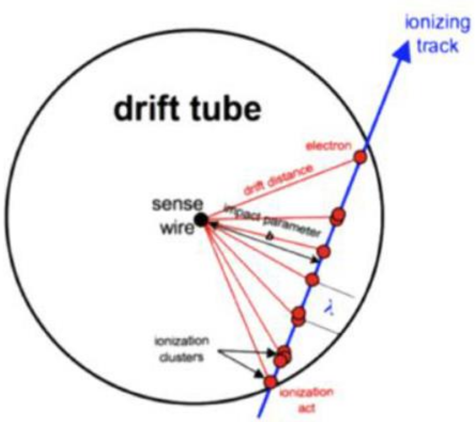
- ~141000 wires
  - 23k sensitive, W
  - 117k field, Al (→ C)
- Square cell, 7.2-9.1 mm
- 64 layers
- 90% He + 10% iC_4H_{10}

$$\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.078\%^2 p_t^2 + 0.18\%^2}$$

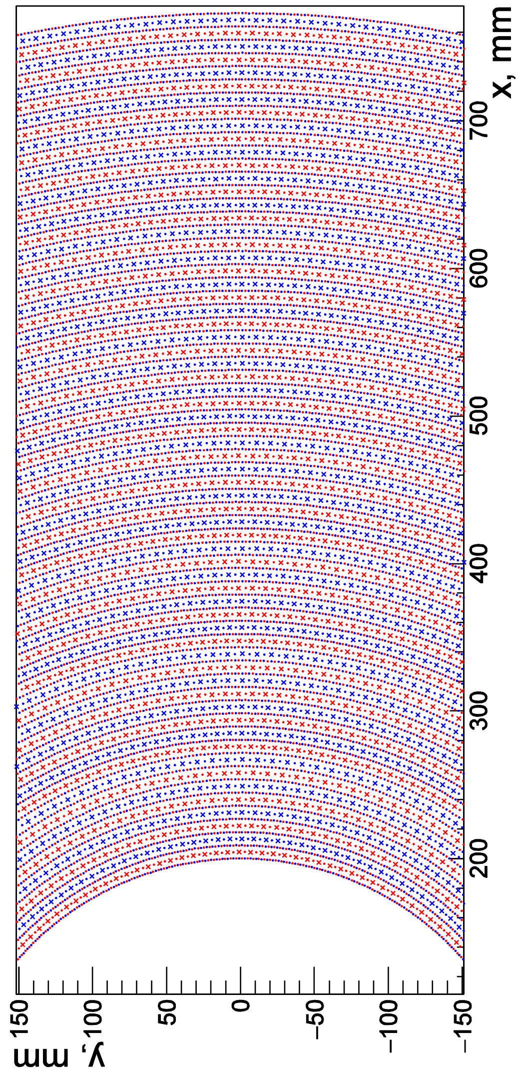
≈0.2% at 1 GeV

$$\frac{\sigma_{dN/dx}}{dN/dx} \approx 3.6\%$$

With room for improvement!



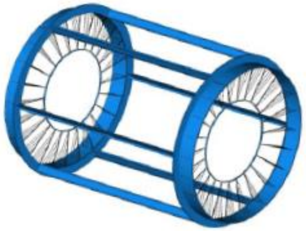
Measurement of individual clusters improves time and dE/dx resolution



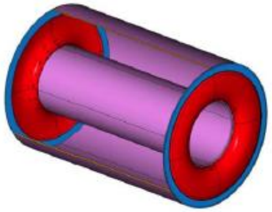
MEG-2 drift chamber

The MEG2 drift chamber

- Separation of the wire anchoring function from the mechanical and wire containment



Wire cage structure not subject to differential pressure can be light and feed-through-less.



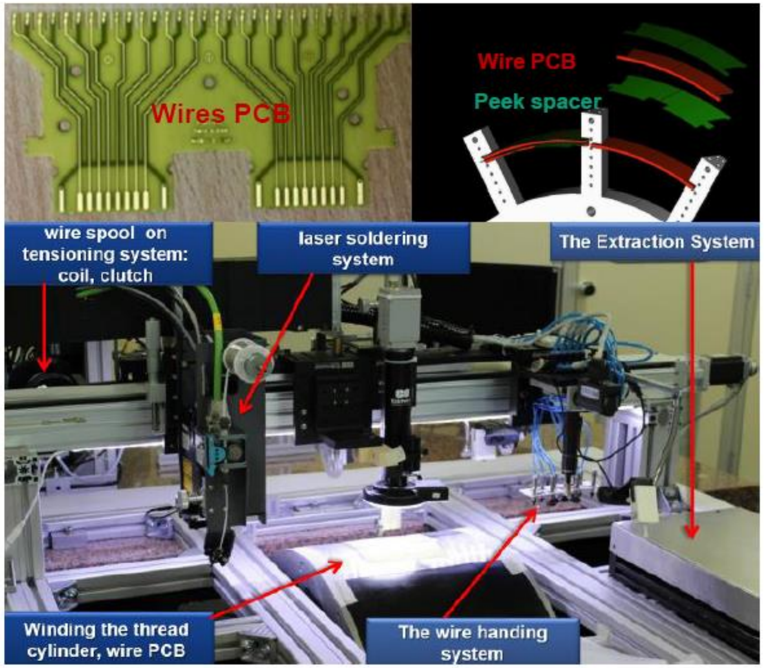
Gas envelope can freely deform without affecting the internal wire position and tension.

- Wire PCB

The high wires density (12 wires/cm^2) imposes the use of ***wires PCBs*** where the wires are accurately positioned and strung at the correct mechanical tension.

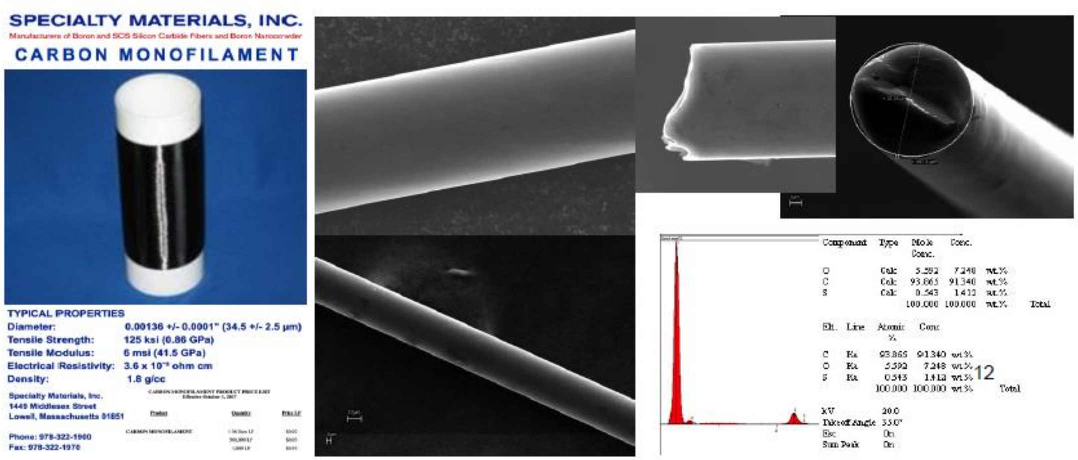
- Wiring robot

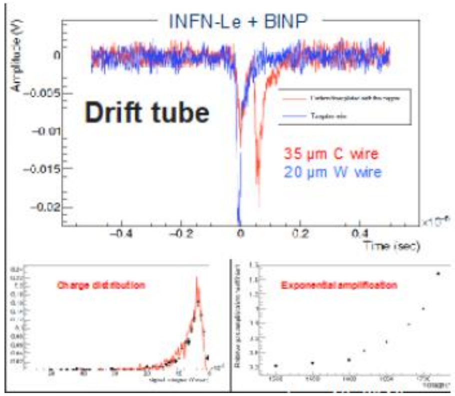
Stringent requirements on the precision of wire position and on the uniformity of the wire mechanical tension impose the use of an automatic system (Wiring Robot), to operate the wiring procedures.



Варианты полевых проволок

Development of a new type of field and sense wires





- 40 μm and 50 μm "bare" (uncoated) Al5056 as new solution for field wires, to be coated by BINP magnetron.
- 35 μm Carbon monofilament, to be coated by BINP magnetron, to be used either as field.
- small single cell drift chamber prototypes are being designed to test operatively new wire proposals.
- 10 μm and 15 μm Molybdenum wires as sense wires (instead of Tungsten) to be used in conjunction with 35 μm Carbon as field.

Drift chamber: TraPid option (INFN)

INFN teams

INFN Bari

M. Abbrescia
R. Aly
N. De Filippis
D. Diacono
G. Donvito
W Elmetanawee
G. Iaselli
M. Maggi
I. Margjeka

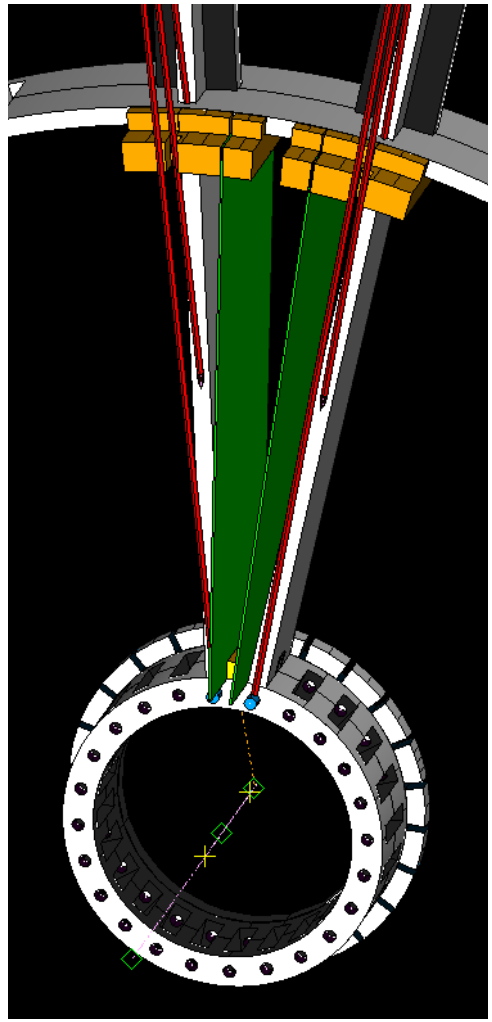
INFN Lecce

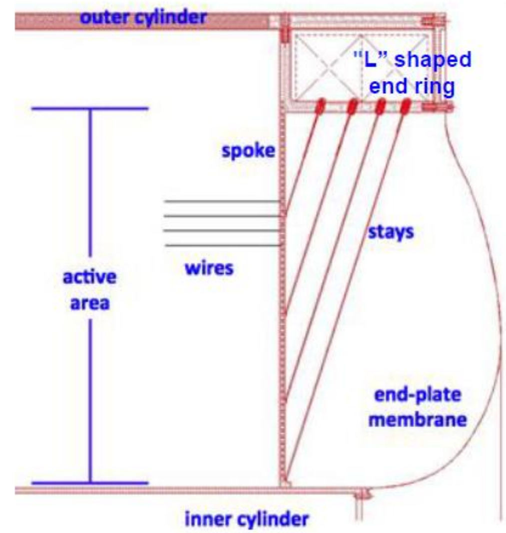
A. Corvaglia
G. Chiarello
F. Cuna
E. Gorini
F. Grancagnolo
A. Miccoli
M. Panareo
M. Primavera
G. Tassielli
A. Ventura

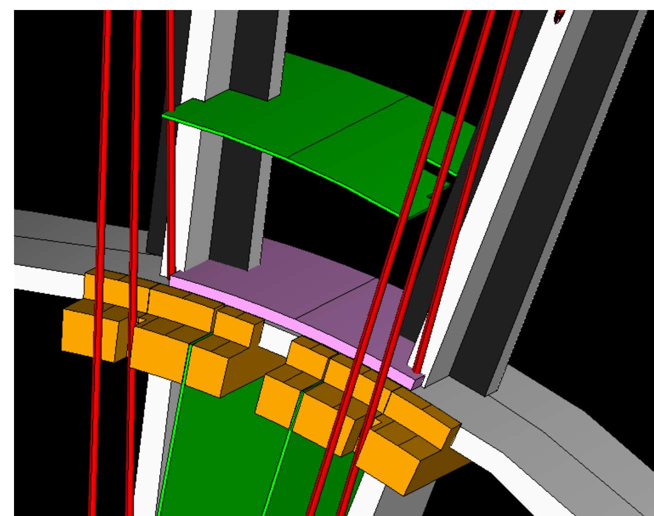
Mechanics, wiring, test beam, simulations…

BINP

Preamp ASIC, wire coating, simulations,…







Plan to create smaller-size DC for CMD-3 as a prototype

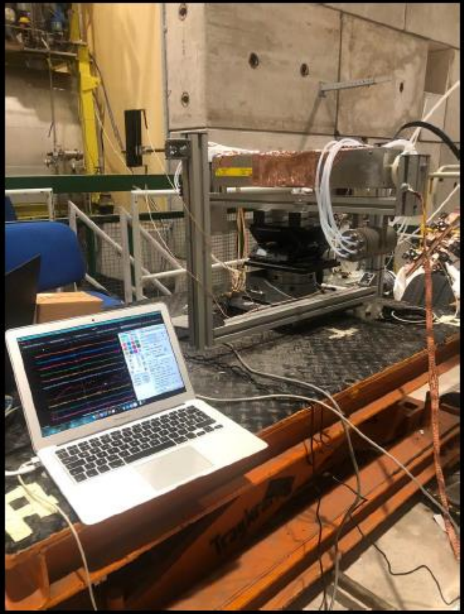
Test beam at CERN

Purpose

- **Demonstrate the ability to count clusters at a fixed βγ (e.g. muons at a fixed momentum – 165 GeV/c) by changing:**
  - the cell size (1 – 3 cm)
  - the track angle (0° to 60°)
  - the gas mixture (90/10: 12 cl/cm, 80/20: 20 cl/cm, for m.i.p.)
- **Establish the limiting parameters for an efficient cluster counting:**
  - cluster density as a function of impact parameter
  - space charge (by changing gas gain, sense wire diameter, track angle)
  - gas gain stability
- **Train different cluster counting algorithms**

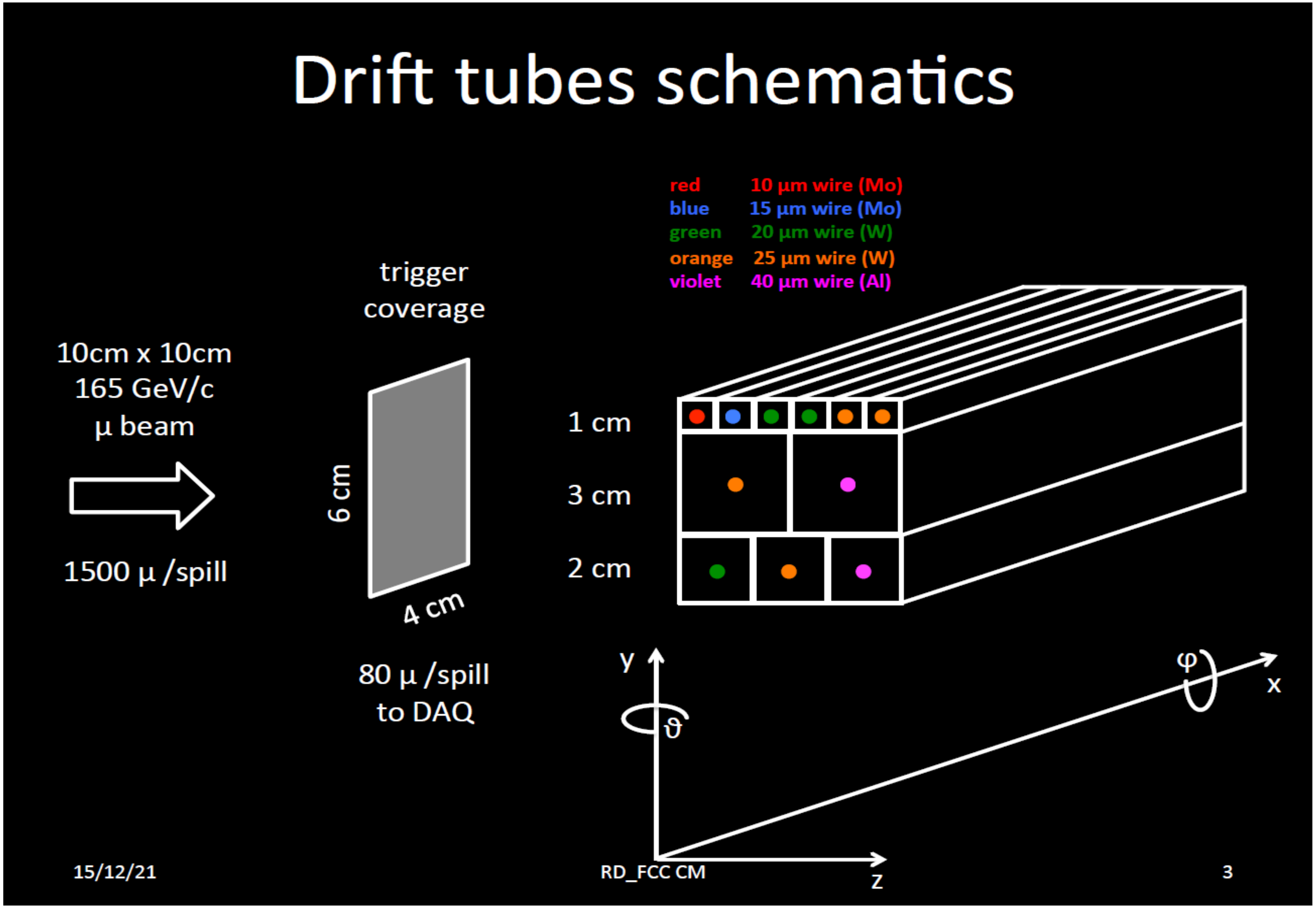
SHIFTERS

Claudio CAPUTO	UC Louvain
Federica CUNA	INFN Lecce
Nicola DE FILIPPIS	INFN Bari
Francesco GRANCAGNOLO	INFN Lecce
Matteo GRECO	INFN Lecce
Sergey GRIBANOV	BINP Novosibirsk
Kurtis JOHNSON	U of Florida
Sasha POPOV	BINP Novosibirsk
Angela TALIERCIO	UC Louvain
Shuiting XIN	IHEP Beijing

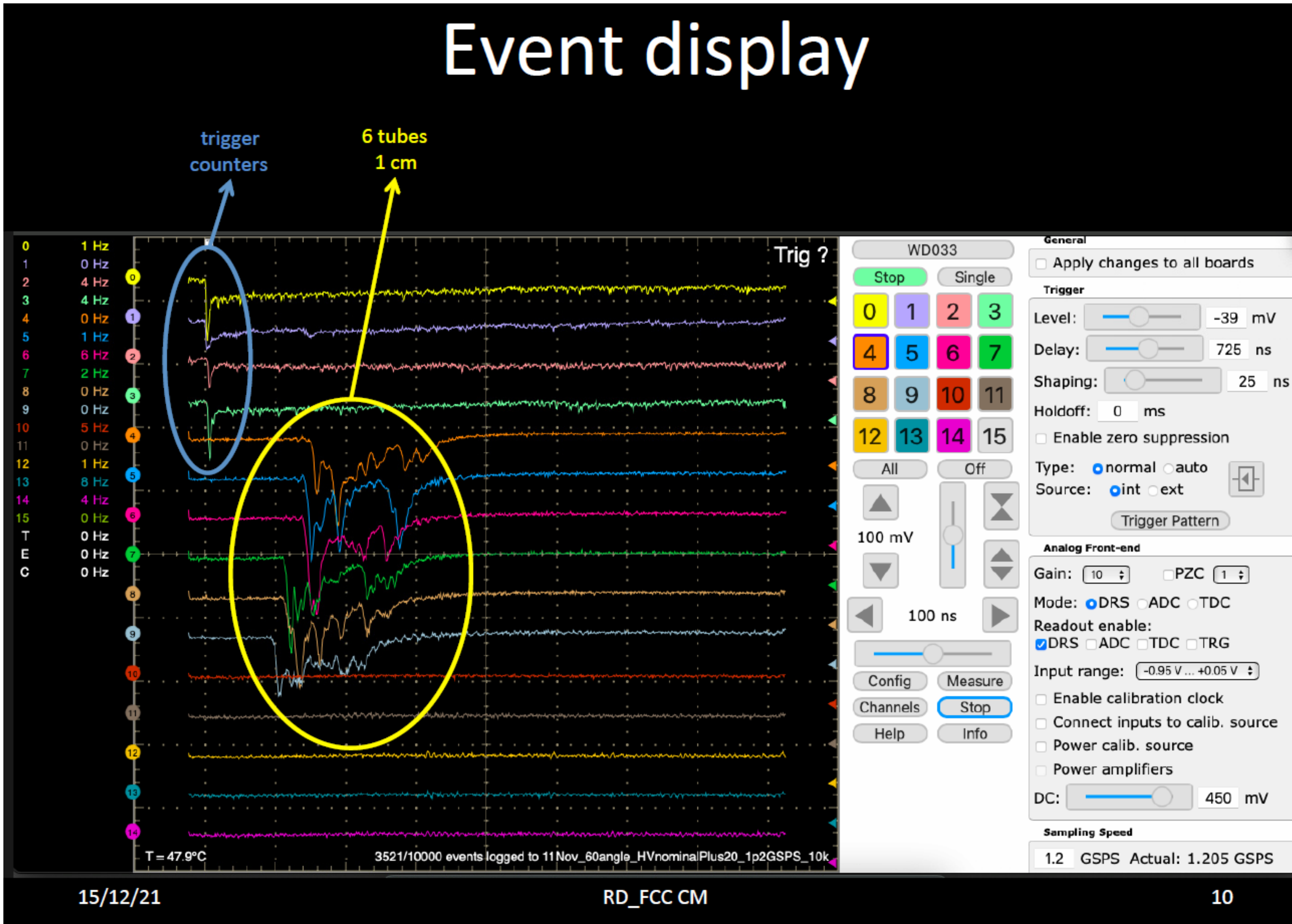


15/12/21 RD_FCC CM 2

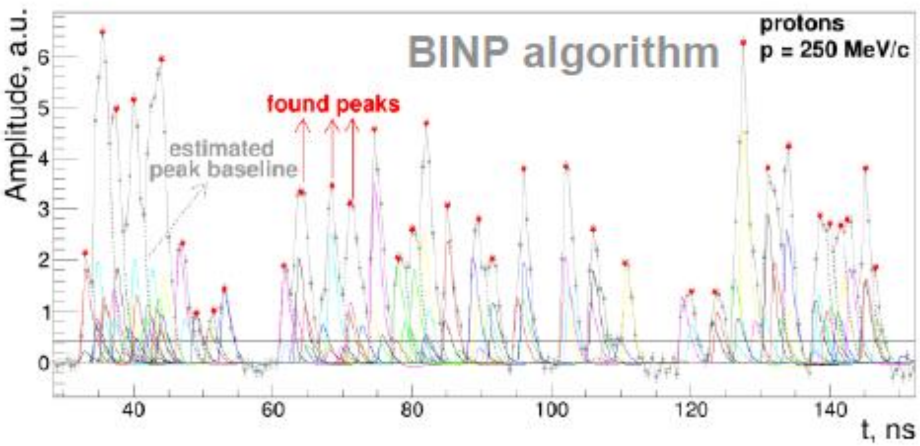
Test beam at CERN

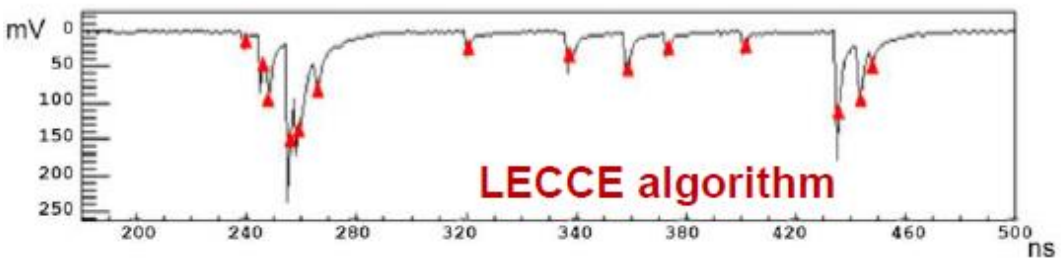


Test beam at CERN



Reconstruction algorithms





Система идентификации

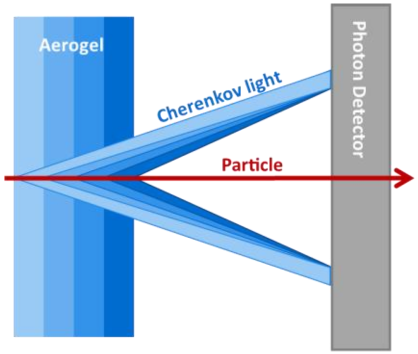
Requirements for PID system

- π/K separation $> 4\sigma$ up to 2.5-3.5 GeV/c
  TOF (BES-3): 3σ at 0.9 GeV/c, DIRC (BaBar): 4σ at 2.5 GeV/c
  ASHIPH (KEDR): 4σ at 1.5 GeV/c
- μ/π suppression <1/40 for to 0.5-1.2 GeV/c
- good μ/π separation at low momentum

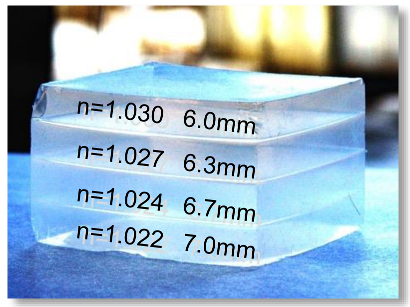
Several option are being considered:

FARICH, ASHIPH, TOF, FDIRC

PID: FARICH option (BINP)

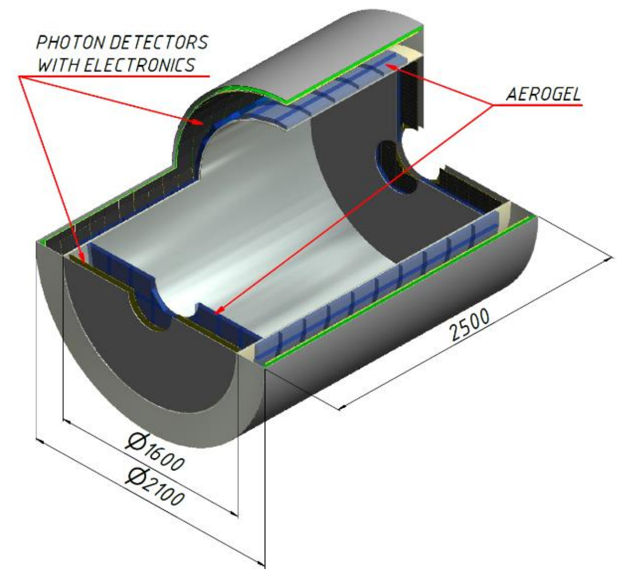


First 4-layer aerogel



Variable n allows to increase N_{pe} using thicker radiator without compromising $\sigma_{\Theta c}$

First detector: Belle-II (ARICH)

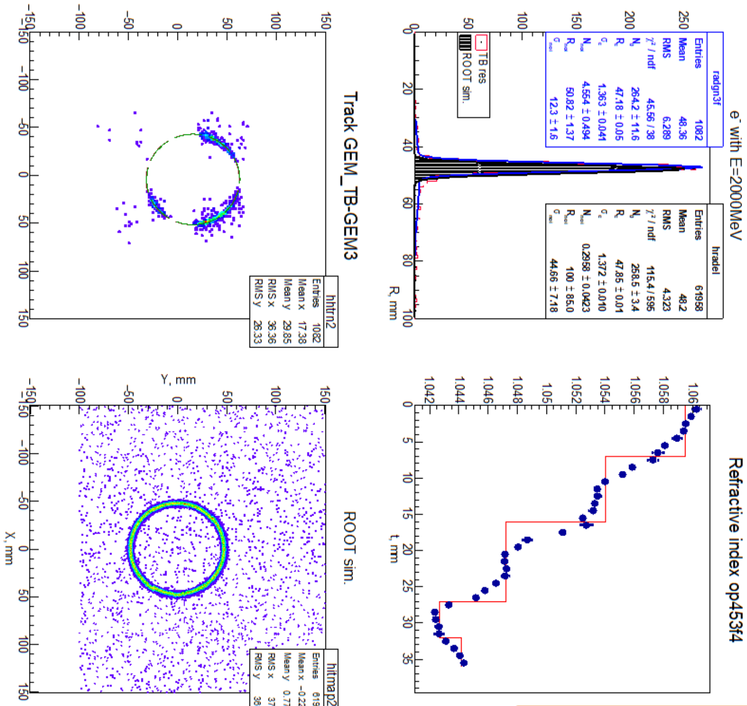


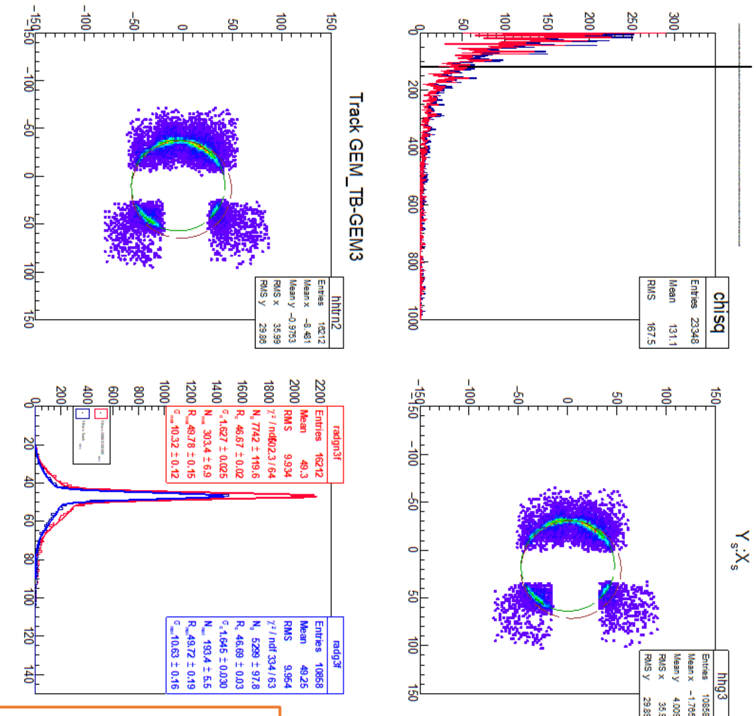
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70
A.Yu. Barnyakov, et al., NIM A 732 (2013) 35

- Proximity focusing RICH
- 4-layer or gradient aerogel radiator n_{max} = 1.05 (1.07?), thickness 35 mm
- 21 m^2 total photon detector area
  - SiPMs in barrel (16 m^2)
  - MCP PMTs in endcaps (5 m^2)
- ~10^6 pixels with 4 mm pitch

2012 test beam: μ/π separation ≥3σ at P=1 GeV/c is demonstrated

FARICH beam tests (2021)





Pixel ø1 mm
$\sigma_R = 1.36 \pm 0.04\ mm$

$$\sigma_R^{calc}(■3\text{mm}) = \sqrt{1.36^2 + \left(\frac{3}{\sqrt{12}}\right)^2} = 1.613\ mm$$

Beam test results in May-Dec of 2021 show us that we are very close to target resolution $\sigma_R(■3\text{ mm}) = 1.4\ mm$ (from G4 simulation)

Pixel ■3 mm
$\sigma_R = 1.63 \pm 0.03 mm$

PID: FDIRC options (JLU, Giessen)

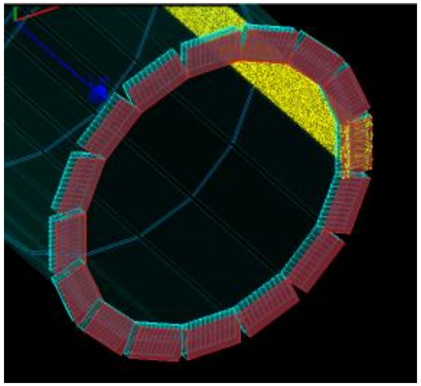
FDIRC option

- Inspired by design from BaBar, SuperB, Belle II, and PANDA
- For PANDA $\sigma_{\Theta_c} \approx 2.1$ mrad/track is achieved for π/K with 3σ@4 GeV/c
- For SCTF $\sigma_{\Theta_c} \approx 0.7$ mrad/track is required for μ/π with 3σ@1.5 GeV/c

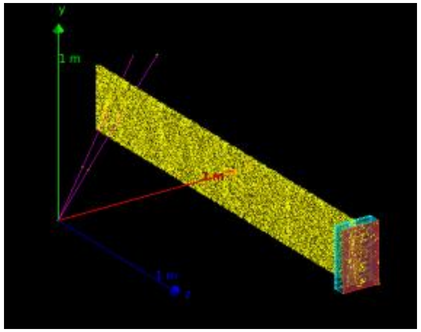
Main parameters:

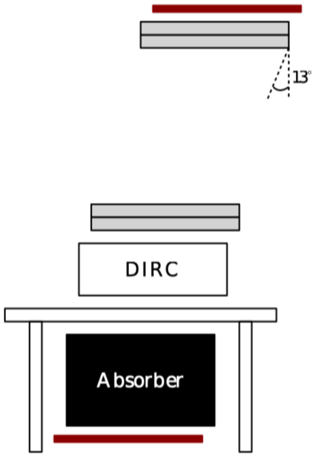
- Synthetic fused silica:
  Barrel: 2×16 plates 110×32×1.5 cm
  Endcap: 2×4 sectors 1÷2 cm thick
- Focusing optics: innovative rad-hard 3-layer spherical lens
- MCP-PMT or SiPM with $\sigma_t \leqslant$100 ps
  Barrel:
  - □2÷3 mm pixel
  - $2.56 \div 1.14 \cdot 10^5$ readout channels

  Endcap:
  - 16×0.5 mm pixel
  - $2.88 \cdot 10^4$ readout channels

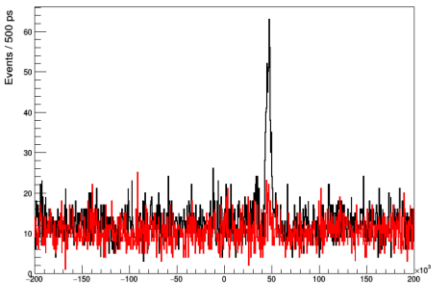


2×16 plates 110×32×1.5 cm^3 and 2×16 expansion volumes 32×20×10 cm^3



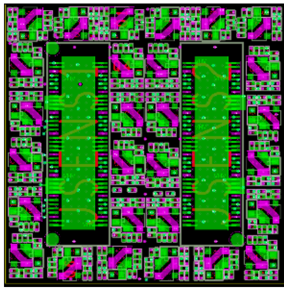


Giessen cosmic station (GCS)

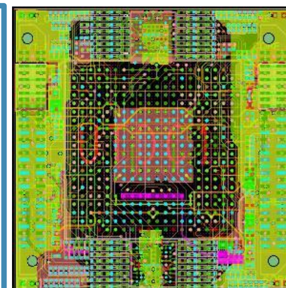


Сотрудничество в рамках CREMLIN+ и Panda

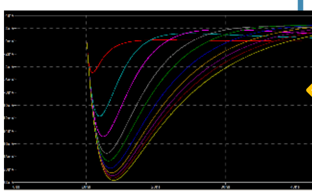
Compact FEE for FARICH/DIRC



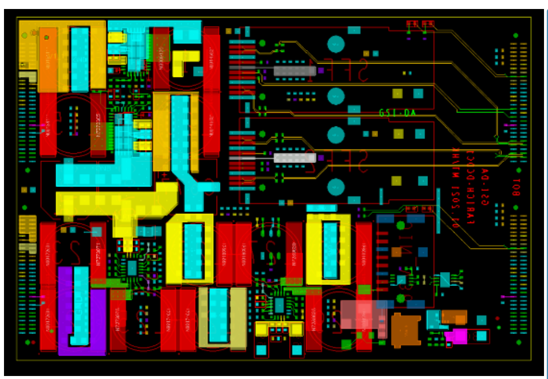
Amplifier board
- 27×27 mm² size
- 14-layer PCB
- 30x gain, 64 channels
- couples to KETEK 8×8 SiPM array



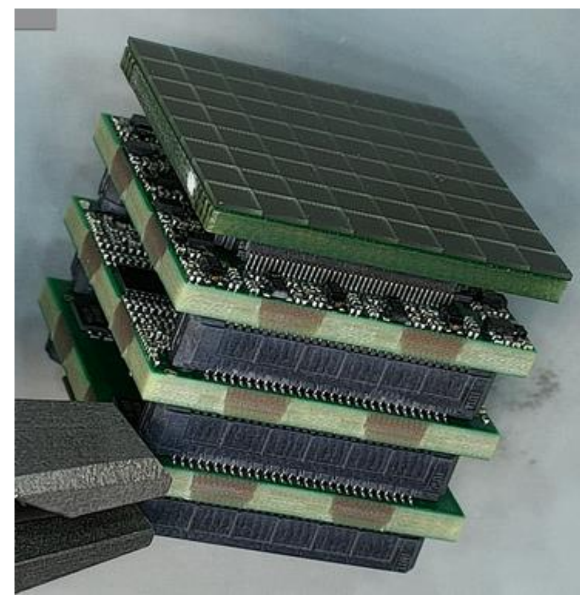
TDC board
- 64 channels
- 2 TDC + 4 threshold FPGAs
- 10ps precision



Simulated single photon pulse shapes from amplifier for different input resistance. ~ 22mV amplitude can be achieved.



DC-DC convertor board
- goes behind the backplane
- 51×84 mm² size
- provides power to SiPMs, amplifiers, FPGA
- uses air inductive coils to operate in the detector magnetic field
- power, trigger & clock connectors



Calorimeter

Baseline:

BELLE/BELLE-2-like electromagnetic crystal calorimeter

Scintillator:

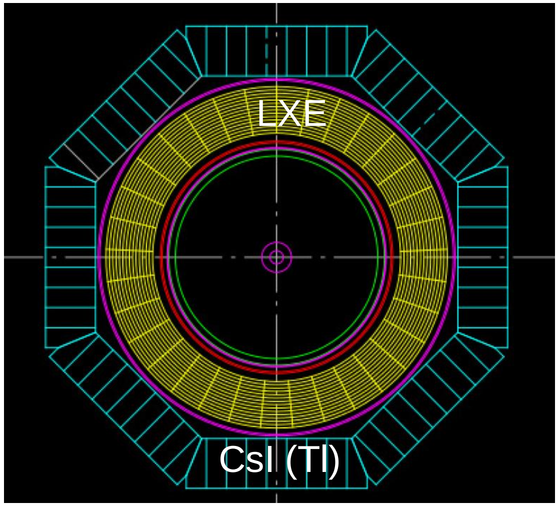
CsI(Tl) has large light yeild, “cheap”, very popular – but slow

LSO, LYSO, etc. – have large LY, very fast – but very expensive (x10)

pure CsI – good compromise: reasonable LY, 30 ns component, reasonable price

Other options being considered:

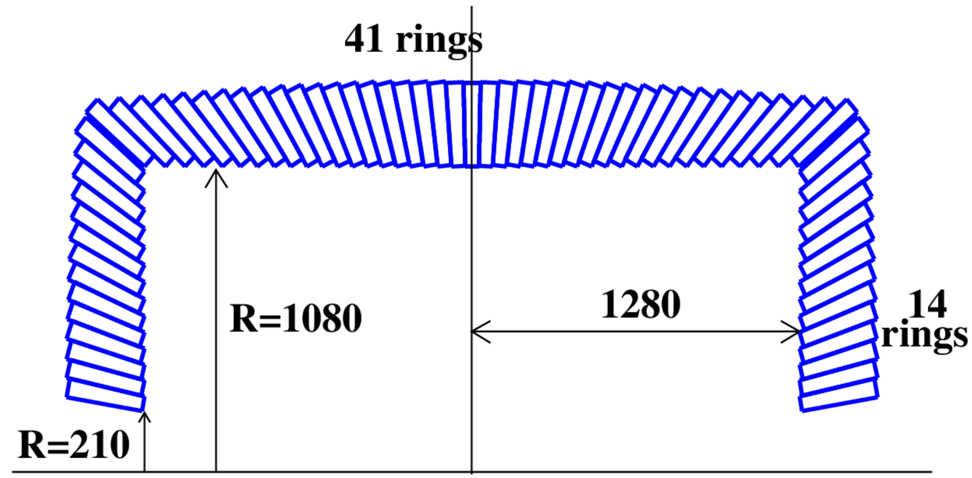
LXe calorimeter, combined LXe + crystal calorimeter (CMD-3: LXe+CsI(Tl))



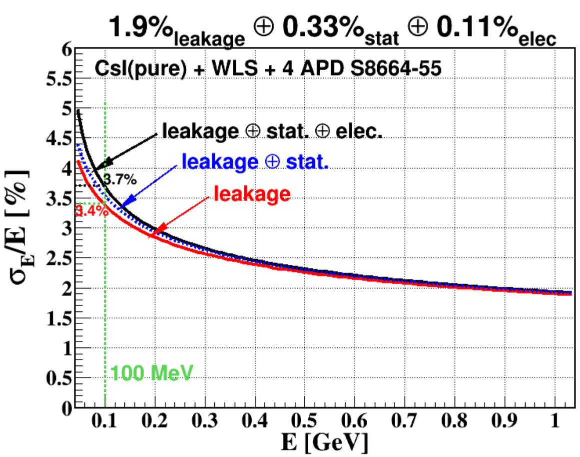
CMD-3 calorimeter

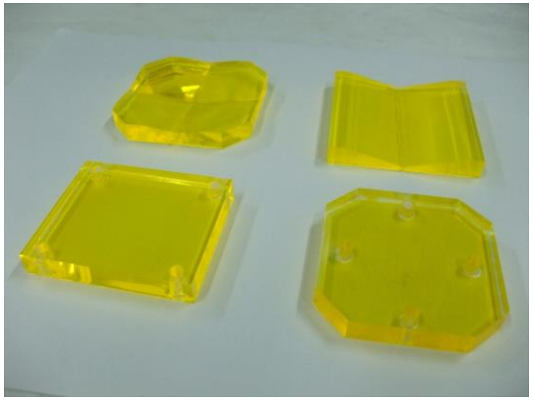
Calorimeter: pCsI option

- 7424 crystals, 16/18 X_0
  - 5248 in barrel
  - 2176 in endcap
- 5.5 x 5.5 x 30(34) cm
- **I. pCsI + 1 photopentode**
- II. pCsI + WLS + 4 APD



$$\frac{\sigma_E}{E} \approx \frac{1.7\%}{\sqrt[4]{E(GeV)}} \oplus \frac{0.33\%}{\sqrt{E}} \oplus \frac{0.11\%}{E}$$

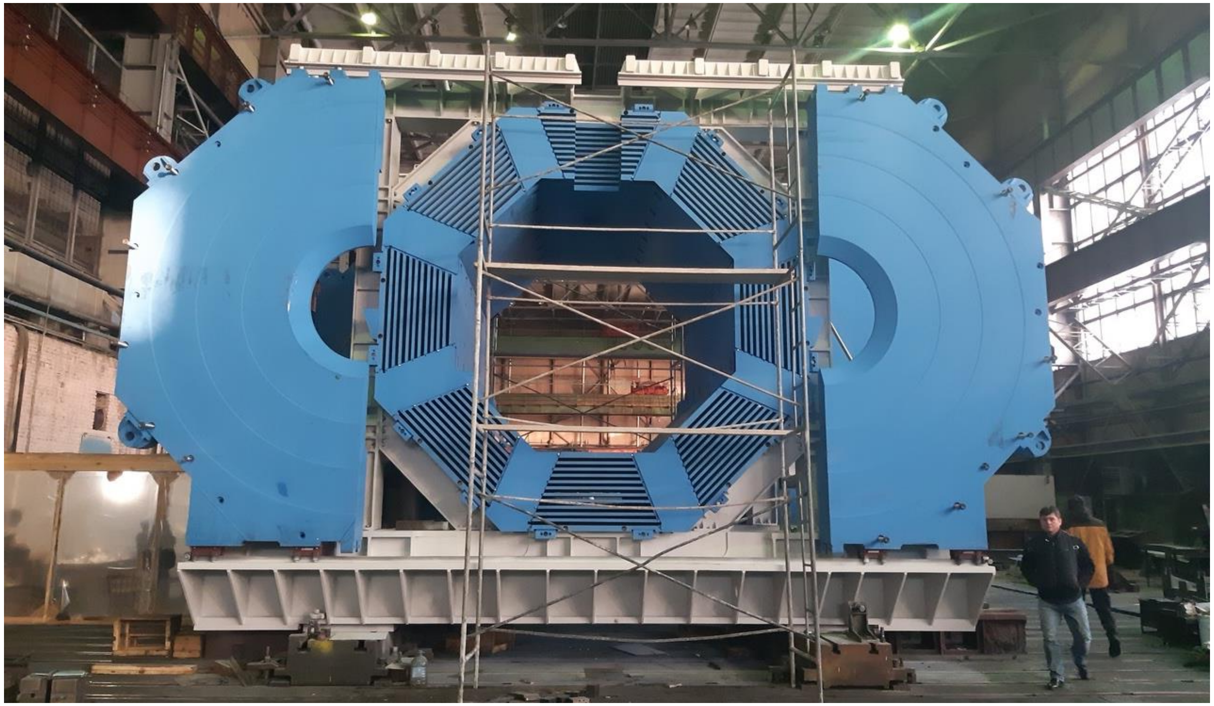




Option (I) was tested successfully ~18 years ago, project parameters were achieved.
Option (II) is being prototyped and optimized, still notable improvements are necessary.

Magnet

- BINP is now building SC magnet for PANDA detector
  - Yoke is finished
  - Technology for cable production is being developed (in Russia)
- SCTF magnet is very similar in size and design



Muon system

- detect muons
  - mult.scat. of O(1cm)
- μ/π separation
- K_L detection

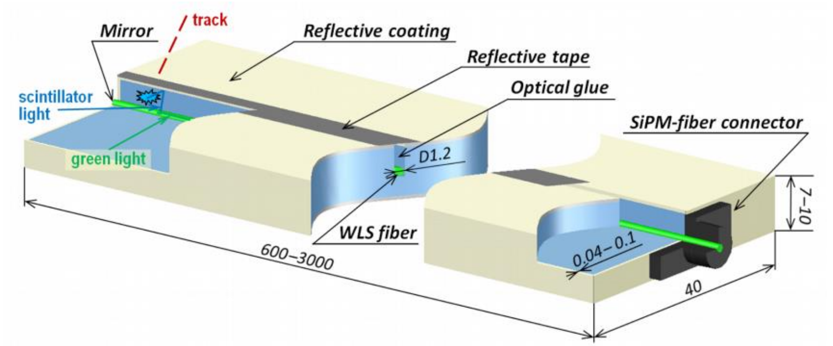
Baseline option:

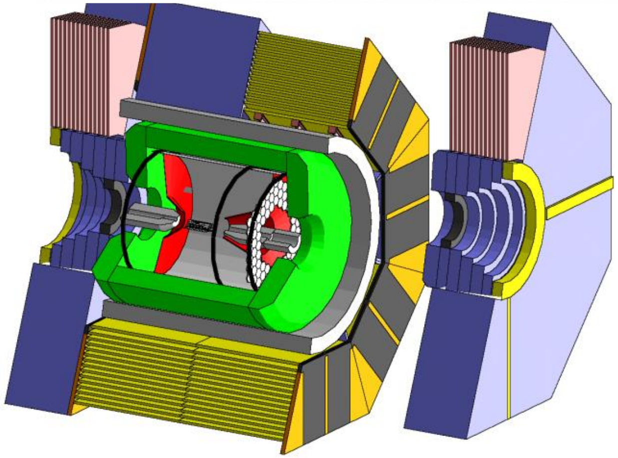
scintillator strips + WLS fiber + SiPM

(BELLE-2, CMD-3)

8-9 layers inside iron yoke

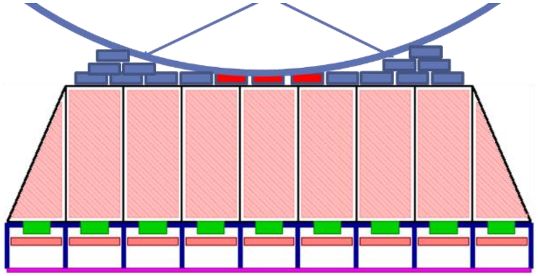
~1500 m^2



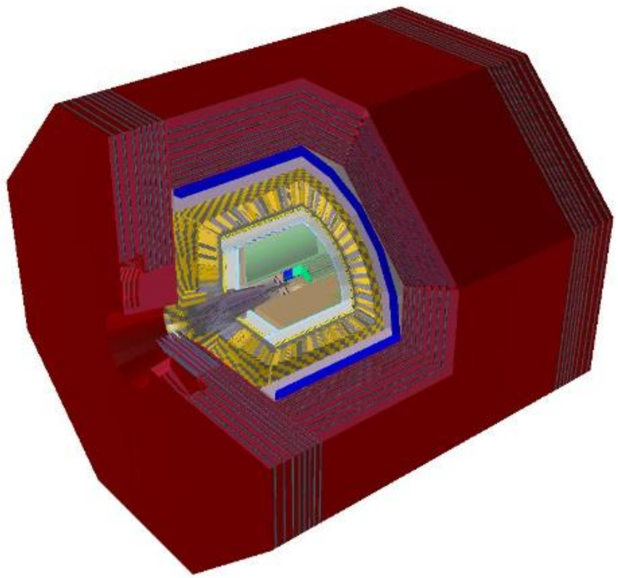


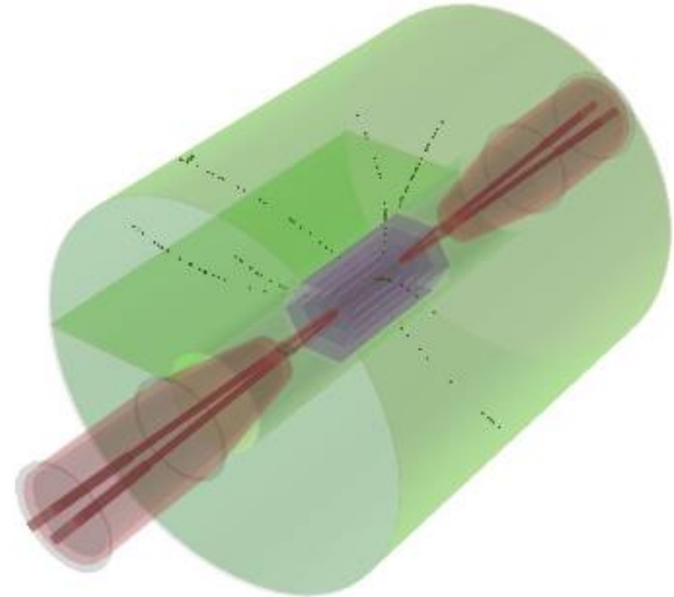
BELLE-2

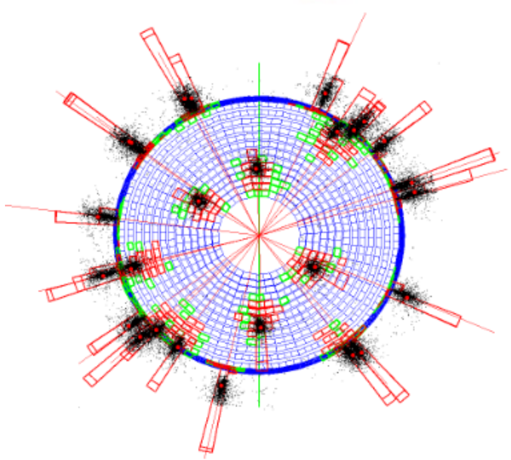
CMD-3

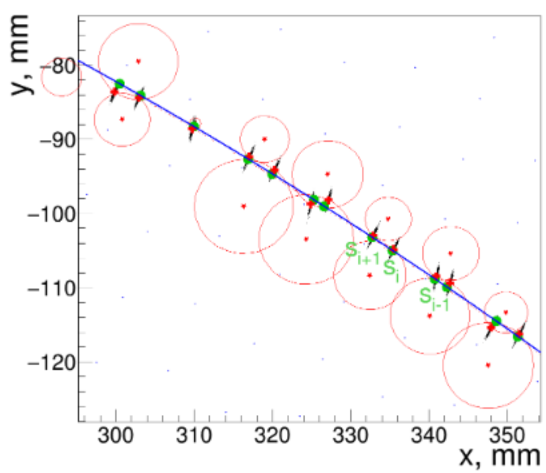


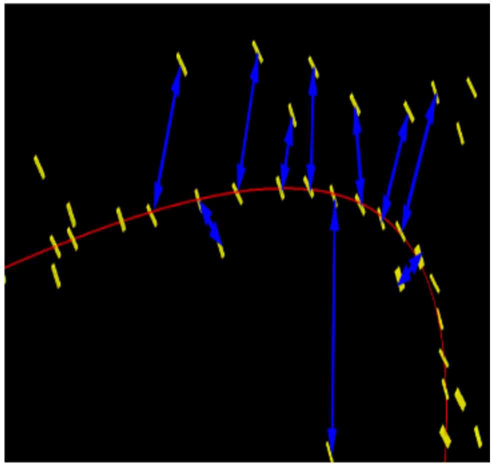
Моделирование











ПО моделирования

«Полное» моделирование

Моделирование рождения первичных частиц (продуктов аннигиляции e^+ и e^-) → Моделирование прохождения частиц через вещество детектора → Моделирование отклика систем детектора (включая электронику) → Моделирование реконструкции данных

используем эффективную модель

«Параметрическое» моделирование

Разработано ПО для параметрического моделирования всего детектора и полного моделирования ЦДК, калориметра, мюонной системы (частично – внутреннего трекера и системы идентификации)

Детектор: от CDR к TDR

- Есть четкий план развития некоторых подсистем
  - Внутренний трекер: две опции
  - Центральная дрейфовая камера: две опции
  - Система идентификации: две опции
  - Сверхпроводящий магнит
  - Мюонная система
  - Скорость разработки ограничена количеством людей и наличием ресурсов
- Есть интересные идеи, но нет ресурсов для их разработки
  - Комбинированный калориметр
  - Внутренний трекер на полупроводниковых сенсорах
  - Дополнительные варианты системы идентификации
  - Нет людей для разработки этих идей
- Совсем не проработаны некоторые системы
  - ASIC-и для предварительной электроники
  - Электроника сбора данных
  - Online компьютинг
  - Нет людей и недостаточно существующих компетенций

Вместо заключения

Проект Супер с-тау фабрики активно развивается

- Ускорительный проект
  - Есть концептуальный проект
  - Текущая задача: достижение проектных параметров с учетом нелинейной динамики (final focus)
  - Синергия с FCC-ee и Super KEKB
- Детектор
  - Есть концептуальный проект
  - По основным системам ведется прототипирование и детальное проектирование опций, развивается полное моделирование систем
  - Сложилась и расширяется коллаборация
- Физическая программа
  - Есть детальный концептуальный проект (физическая программа)
  - Расширяется детальное моделирование отдельных процессов, цель - Physics book в 2023
  - Расширяется круг людей, вовлеченных в обсуждение физической программы (международные совещания, Партнерство, Snowmass,…)
- Финансирование
  - Строительство Супер с-тау фабрики активно обсуждается в рамках программы развития НЦФМ (г.Саров)