Discussion of Yellow Report Content - Tracking with focus on two detector baselines

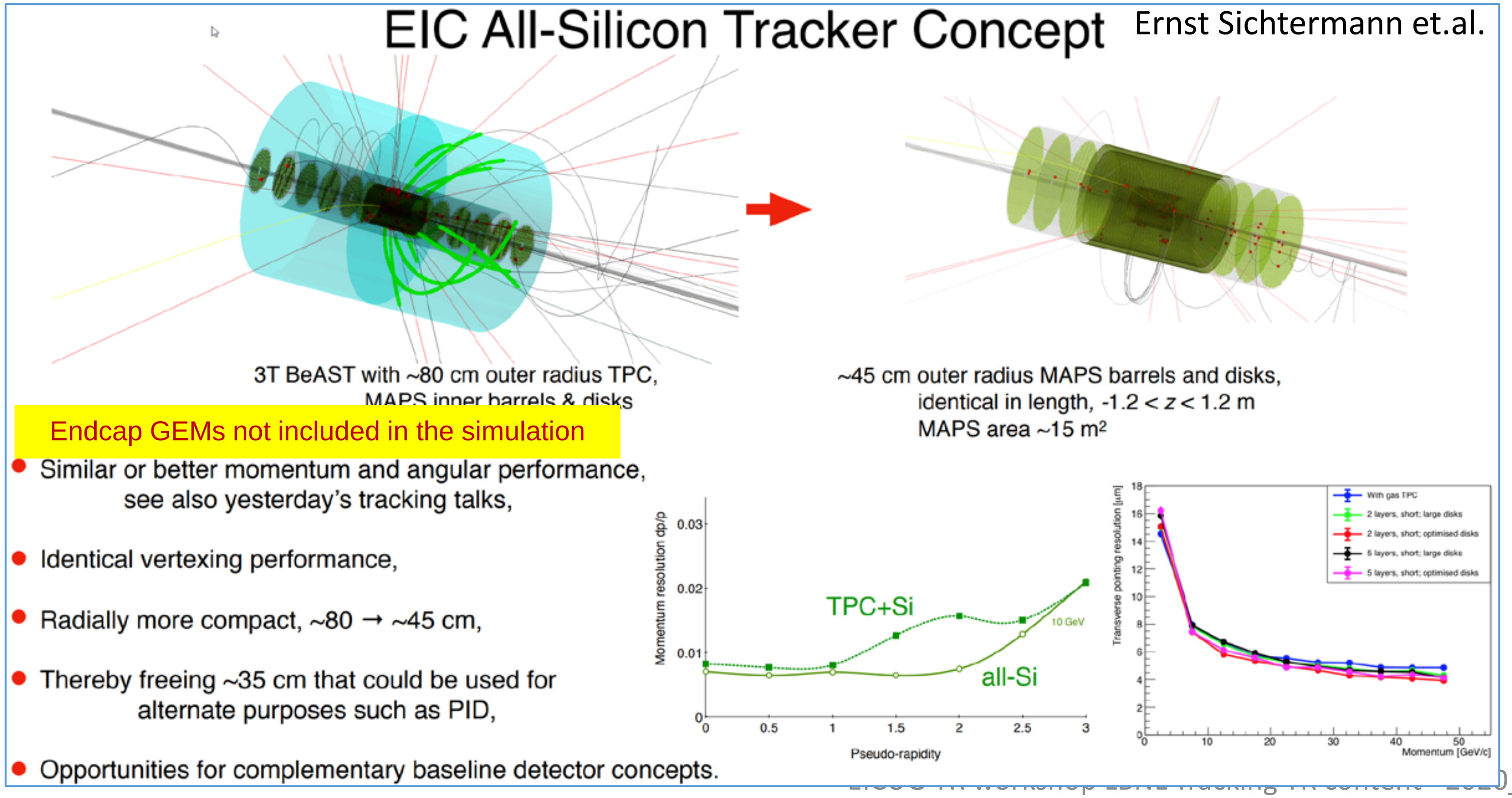
Leo Greiner, Domenico Elia, Kondo Gnanvo

Two baseline detector designs

This is not a new or even original idea – just one worth pursuing

- A "hybrid" tracking detector (silicon + TPC + End Cap GEM layers) is part of the original BEAST concept and is the traditional configuration for general purpose HI collider detectors.
- All silicon tracking options have been proposed since the beginning of EIC development (e.g. TOPSiDE) and developed in ERD16, ERD18 in the MAPS technology.

In YR process, mention made at Pavia meeting:



https://indico.bnl.gov/event/8231/contributions/37776/attachments/28208/43596/Pavia.OpenMIC.Contributions.pdf

Two baseline detector designs

Domenico's talk

- The concept of two possible baseline detectors (all-silicon and hybrid) has continued to be developed during the YR process in the tracking workgroup.
- We now have optimized baseline layouts for both configurations.
- The YR contains both options as baseline detector configurations.
- The simulations for both have been completed in the barrel region ($-1 < \eta < 1$) to a level that allows the performance characteristics to be assessed and compared to the physics derived requirements for most quantities. Preliminary performance studies in the forward/backward regions available, need to be finalized/completed by including further options (MPGDs) in the simulation. Coverage is provided for $|\eta| \leq 3.5$
- The concepts have been simulated based on ALICE ITS3 type sensors.
- A number of options are presented for the gaseous detector in the hybrid versions.

Why present two baseline detector designs?

- Both designs mostly meet the requirements in the physics requirements matrix.
- Selection will likely be based on factors that are an optimization of the whole EIC detector design e.g. magnet size and field, PID considerations, cost, relative importance of compactness in a tracking detector design, etc.
- The different characteristics will be useful in the complementarity studies and in the process of the development of a detector for the second interaction region.
- Based on this, it is worthwhile to take another look at the tracking technology options as they relate to overall detector design.

Technology Options and Attributes

In the Pavia meeting the tracking group presented a technology summary as it relates to complimentarity

(YES – too small to read)

Tracking WG: technology input for complementarity

Tracking Si central detector (vertex + barrel + discs)

Technology: for the vertex, barrel and inner disc detectors, the only identified technology that meets the requirements are MAPS. No currently existing MAPS sensor appears to fully meet all of the EIC requirements (current simulations are based on ALPIDE sensors with a smaller pixel size 20 x 20 um^2). In order to produce a new sensor design that meets the EIC requirements a consortium of EIC groups are joining an ongoing sensor development effort at CERN. There are contingency plans for modification of existing sensor designs to meet EIC requirements should this CERN effort be unsuccessful.
There is general consensus that this is a promising path to pursue to deliver an EIC sensor in the given timeframe. Momentum and pointing resolution performance studies are in progress. EIC requirements seem satisfied.

ITS3 silicon design parameters

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

	Stave X/X0
ITS3 like vertexing	~0.1%
ITS3 like barrel (up to 1.5m length)	0.55 %
ITS3 like disc (up to 60 cm diameter)	0.24%

Si + gaseous detector vs. all silicon

	Si + gaseous	All Si
Attributes for consideration	• dE/dx in gas for PID • Well understood technology - less R&D needed. • Costs less (likely) • Less material in tracking region • Worse single point resolution but more position samples	• Readout faster than TPC • Better momentum resolution than TPC at higher momentum (>~5GeV/c) • Can be made more compact • Less material in endcap regions • Fewer calibration/correction issues • Very high single point resolution

Tracking WG: technology input for complementarity

	TPC + Fast MPGD Layer	Cylindrical MPGD (Micromegas, μRWELL)	Drift Chambers / Straw Tubes	Planar MPGDs (GEM, Micromegas, μRWELL)	Small TGCs	MPGD-TRDs
Barrel region	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Space point & angular res. - Time resolution (< 10 ns) - **Low material in End cap** - **Cost & robustness**	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Alternative to cylindrical MPGDs arrangement in polygons - **Easier fabrication**	N/A	N/A Radiator size
	Cons: - **End cap material** - calibration space charge distortion	Cons: - Momentum res. - Fabrication challenges - **Material budget in barrel**	Cons: - **End cap material** - calibration - Stability issues	Cons: - Momentum res. - Detector space barrel - **Material budget in barrel**		
Hadron End Cap	N/A Only planar option		Pros: - momentum res.; - additional dE/dx; - **cost**	Pros: - Momentum & angular res. - Low material (< 0.4% X/X0 per layer) - **Cost & robustness**	Pros: - Momentum & angular res. - **Cost & robustness**	Pros: - Additional tracking - Angular res. for RICH - **Additional e/π PID**
			Cons: - **Material budget** - calibration - Stability issues	Cons: - **?**	Cons: - **Material budget**	Cons: - Radiator size
Electron End Cap	N/A Only planar option		N/A	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness**	N/A Mainly because of material budget	Pros: - Additional tracking - **Complement main e PID in electron end cap**
				Cons: - **?**		Cons: - Radiator size?

https://indico.bnl.gov/event/8231/contributions/37908/attachments/28346/43620/2020_05_21_tracking_summary.pdf

These assessments have been updated and are on the following slides

Gaseous tracking technology options

	TPC + Fast MPGD Layer	Cylindrical MPGD (Micromegas, µRWELL)	Drift Chambers / Straw Tubes	Planar MPGDs (GEM, Micromegas, µRWELL)	Small TGCs	MPGD-TRDs
Barrel region	**Pros:** - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	**Pros:** - Space point & angular res. - Time resolution (< 10 ns) - **Low material in End cap** - **Cost & robustness**	**Pros:** - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	**Pros:** - Alternative to cylindrical MPGDs arrangement in polygons - **Easier fabrication**	N/A	N/A Radiator size
	Cons: - **End cap material** - calibration space charge distortion	**Cons:** - Momentum res. - Fabrication challenges - **Material budget in barrel**	**Cons:** - **End cap material** - calibration - Stability issues	**Cons:** - Momentum res. - Detector space barrel - **Material budget in barrel**		
Hadron End Cap	N/A Only planar option		**Pros:** - momentum res.; - additional dE/dx; - **cost**	**Pros:** - Momentum & angular res. - Low material (< 0.4X0 layer) - **Cost & robustness**	**Pros:** - Momentum & angular res. - **Cost & robustness**	**Pros:** - Additional tracking - Angular res. for RICH - **Additional e/π PID**
			Cons: - **Material budget** - calibration - Stability issues	**Cons:** - **?**	**Cons:** - **Material budget**	**Cons:** - Available space i.e. radiator thickness
Electron End Cap	N/A Only planar option		N/A	**Pros:** - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness**	N/A Mainly because of material budget	**Pros:** - Additional tracking - **Complement main e PID in electron end cap**
				Cons: - **?**		**Cons:** - Available space i.e. radiator thickness

Inner Tracking Silicon technology options

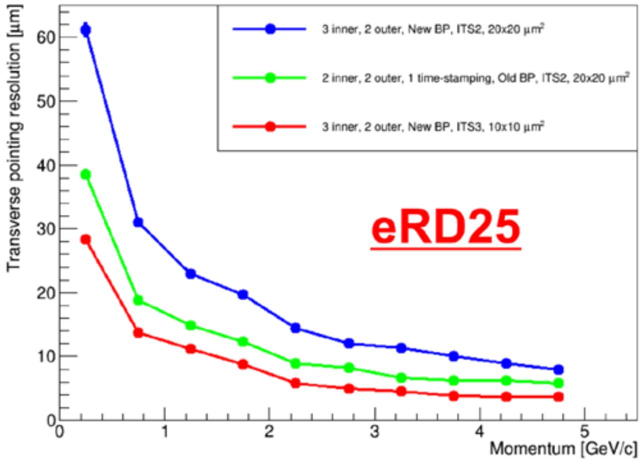
Tracking WG: technology input for complementarity - Silicon

- For the vertex, barrel and inner disc detectors, the only identified technology that meets the requirements are MAPS.
- ALPIDE is the only existing MAPS sensor candidate that is available for use now or with planned availability within the next 1-2 years. All others are in prototype status. No currently existing MAPS sensor appears to fully meet all of the EIC requirements (early simulations were based on ALPIDE sensors with a smaller pixel size 20 um^2, current are 10 um^2).
- In order to produce a new sensor design that meets the EIC requirements a consortium of EIC groups have joined the ongoing sensor development effort for ALICE ITS3 at CERN.
- There are contingency (paths in both ITS3 and EIC Silicon Consortium) plans for modification of existing sensor designs to meet EIC requirements should this CERN effort be unsuccessful. Until the project reaches the point where it needs to commit to a particular sensor, it is prudent to monitor sensor progress in other technologies (180nm MAPS, SOI, LGAD, etc.) in order to be in a position to make the best sensor choice for EIC tracking. This is detailed in YR Ch. 14.

ITS2 vertex layers & old beam pipe: 20 μm pixel pitch, 0.3% X/X0

ITS2 vertex layers & new beam pipe: 20 μm pixel pitch, 0.3% X/X0

ITS3 vertex layers & new beam pipe: 10 μm pixel pitch, 0.05% X/X0



Studies have been carried out in the tracking workgroup on the effects of pixel size on pointing and momentum resolution for a variety of pixel sizes.

https://wiki.bnl.gov/conferences/images/1/1c/ERD25-proposal-Jul20.pdf

Inner Tracking Silicon technology options

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Tracking detector component	Stave X/X0
ITS3 like vertexing	0.05-0.1%
ITS3 like barrel (up to 1.5 m length)	0.55%
ITS3 like disc (up to 60 cm diameter)	0.24%

	Si + gaseous	All Si
Attributes for consideration	• dE/dx in gas for PID (TPC) • Well understood technology - less R&D needed. • Costs less (likely) • Less material in tracking region but more in the endcap region. • Worse single point resolution but more position samples	• Readout faster than TPC • Better momentum resolution than TPC at higher momentum (>~5GeV/c) • Can be made more compact • Less material in endcap regions • Very high single point resolution

Mix and Match for overall detector optimizations

All of these considerations are linked and require optimizations to drive the particular complementarity in the physics topics that will be addressed.

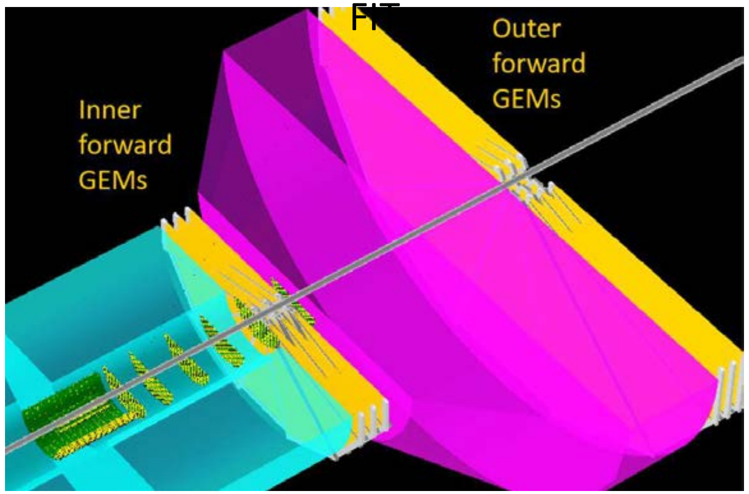
In addition to the two baseline tracking detector configurations addressed in the YR we could consider:

- All silicon option in existing Babar magnet with additional PID (possibly high pressure gas Cerenkov in the space gained from the more compact silicon tracking)
- Compact new magnet at 2-3 Tesla using all silicon option – smaller detector overall (possible cost savings) better momentum performance, may limit some PID options, etc.
- Etc., etc., etc.
- This is a large parameter space just in tracking and when the other detector systems are included it becomes too large and interrelated to present in a slide format.
- The approach of the tracking group was to deliver baseline simulations for the two different optimized detector configurations and at two magnetic field settings so that the strengths/weaknesses of various large feature combinations could be judged in the context of prioritized physics goals.

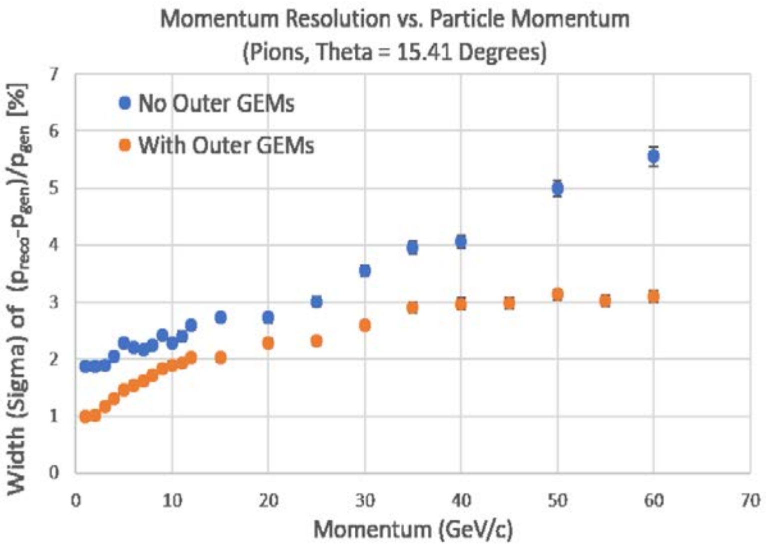
“Final” configurations again will be driven by what overall detector optimizations make sense in the context of performance in specific physics topics and complementarity. We hope that the inclusion of the baseline performance simulations will help stimulate this discussion.

The Case for MPGD Trackers behind the dRICH in the Hadron End Cap

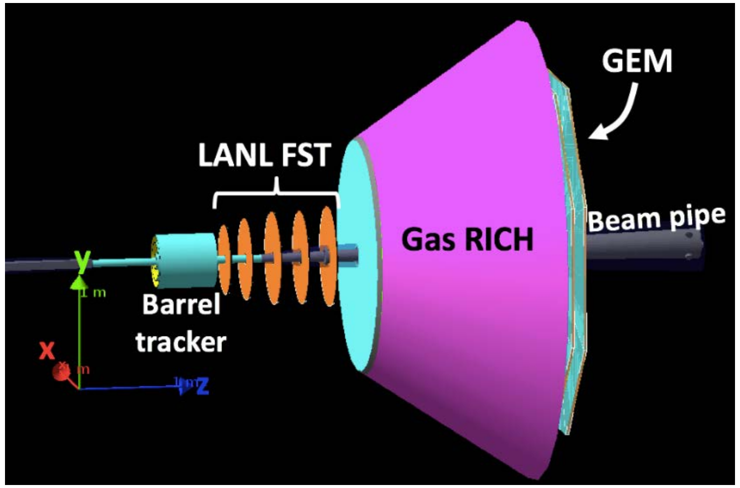
Hybrid option: Preliminary studies at FIT



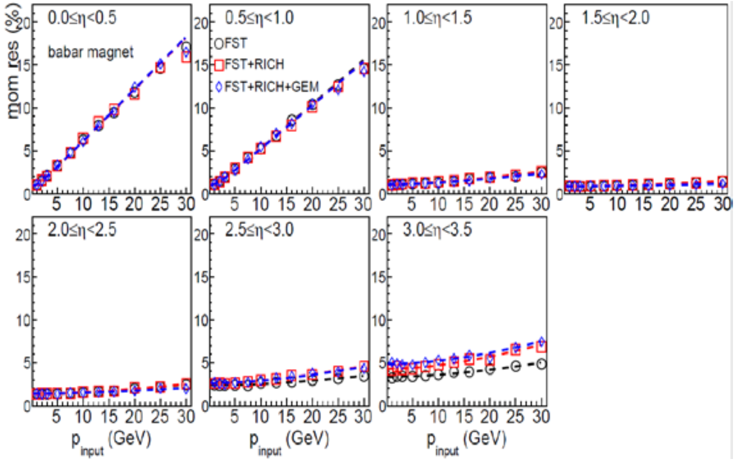
Improved momentum resolution



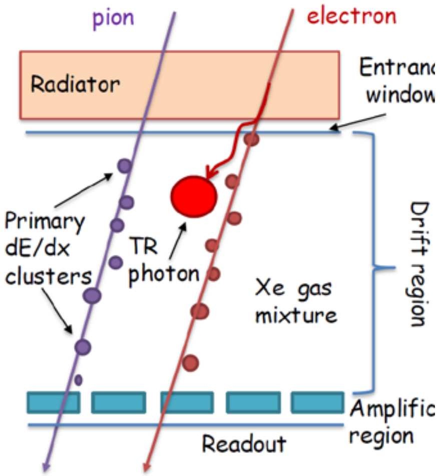
"All Silicon" option: LANL studies at FIT

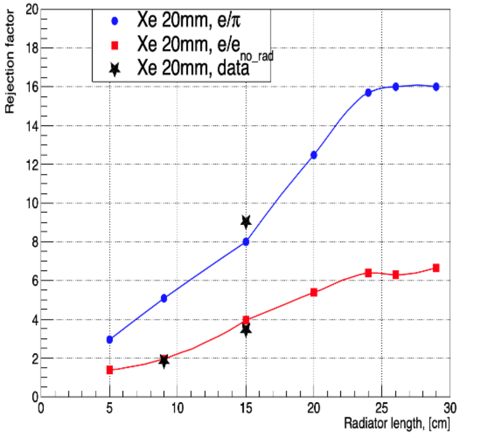


Replacing Si-disks with GEM: no negative impact on momentum resolution

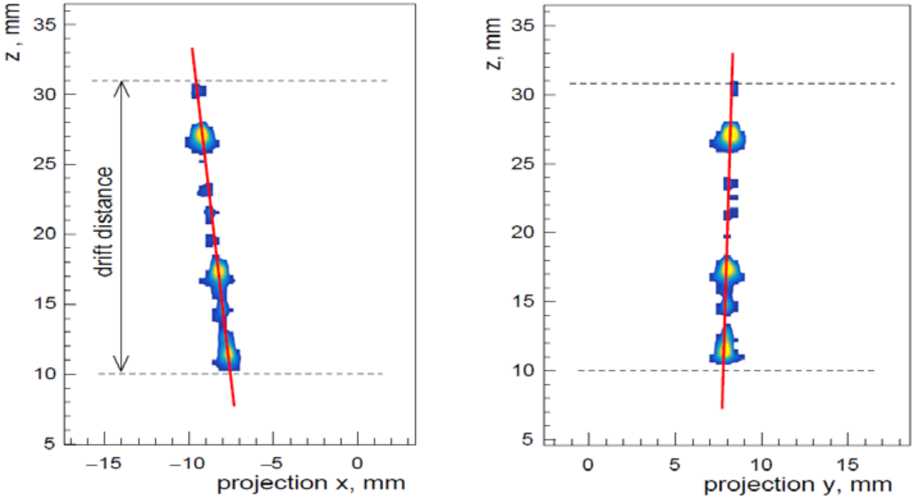


GEM-TRD-T: e-π separation - JLab test beam





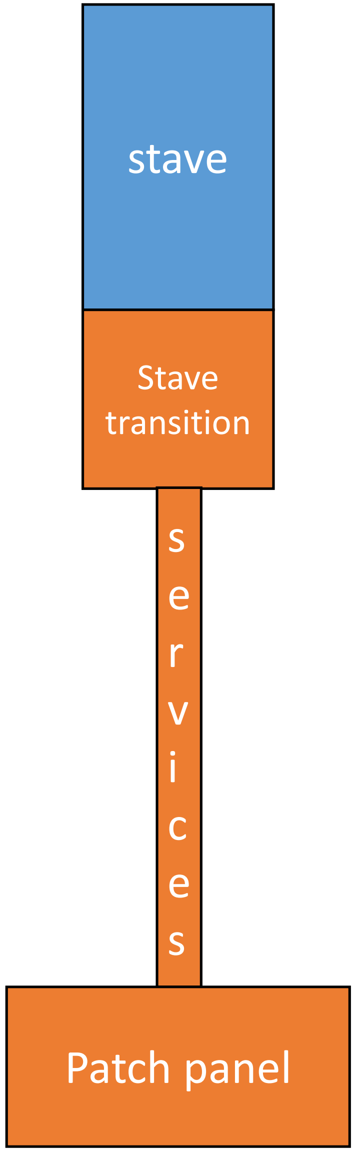
Provide additional Tracking in µTPC mode



Tracking Section Contents

backup

Summary of ITS3 like Si tracking



	Stave X/X0	Stave transition (per 100 cm^2 of Si surface)	Services (per 100 cm^2 of Si surface)	Patch panel (per 100 cm^2 of Si surface)
ITS3 like vertexing	~0.5 – 0.1%	6.66 cm^3 of material with X/X0 of 0.031 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.002 per traversed cm	4.32 cm x 1cm x 1 cm with 0.03423 X/X0 per traversed cm
ITS3 like barrel (up to 1.5m length)	0.55 %	4.286 cm^3 of material with X/X0 of 0.0306 per traversed cm	1.905 cm^2 cross section with X/X0 of 0.002 per traversed cm	2.778cm x 1cm x 1 cm with 0.03423 X/X0 per traversed cm
ITS3 like disc (up to 60 cm diameter)	0.24%	6.66 cm^3 of material with X/X0 of 0.031 per traversed cm	2.96 cm^2 cross section with X/X0 of 0.002 per traversed cm	4.321 cm x 1cm x 1 cm with 0.03423 X/X0 per traversed cm

Hybrid detector baseline detector layout

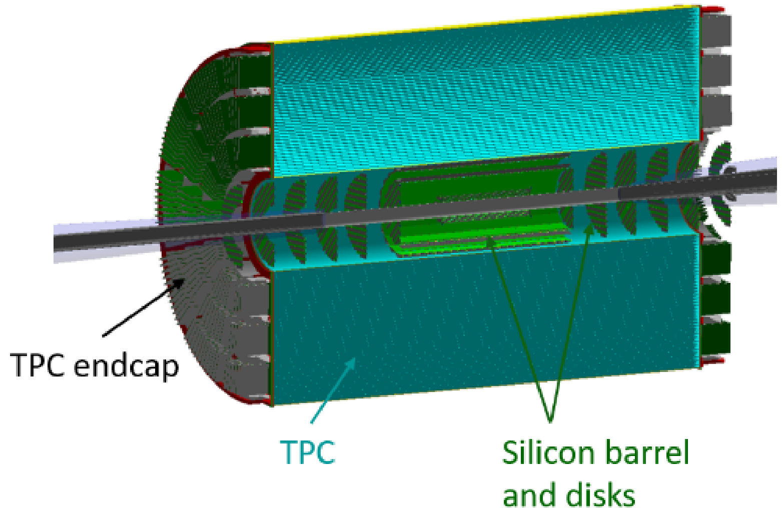


Figure 23: New hybrid baseline layout. The silicon layers and disks are shown in green, and the TPC in light blue.

Layer	Length	Radial position
Layer 1	420 mm	36.4 mm
Layer 2	420 mm	44.5 mm
Layer 3	420 mm	52.6 mm
Layer 4	840 mm	133.8 mm
Layer 5	840 mm	180.0 mm
TPC start	2110 mm	200.0 mm
TPC end	2110 mm	780.0 mm

(a) Barrel region

Disk	z position	Inner radius	Outer radius
Disk 1	220 mm	36.4 mm	71.3 mm
Disk 2	430 mm	36.4 mm	139.4 mm
Disk 3	586 mm	36.4 mm	190.0 mm
Disk 4	742 mm	49.9 mm	190.0 mm
Disk 5	898 mm	66.7 mm	190.0 mm
Disk 6	1054 mm	83.5 mm	190.0 mm
Disk 7	1210 mm	99.3 mm	190.0 mm

(b) Disk region

Table 8: Positions and lengths of detector parts in the barrel region and the disk region. In the disk region, the seven disks in the forward region are shown, but this layout is symmetric so it is the same with reversed sign on the z position in the backward region.

Hybrid tracking detector layout taken from the current draft of the YR.

All-silicon baseline detector design

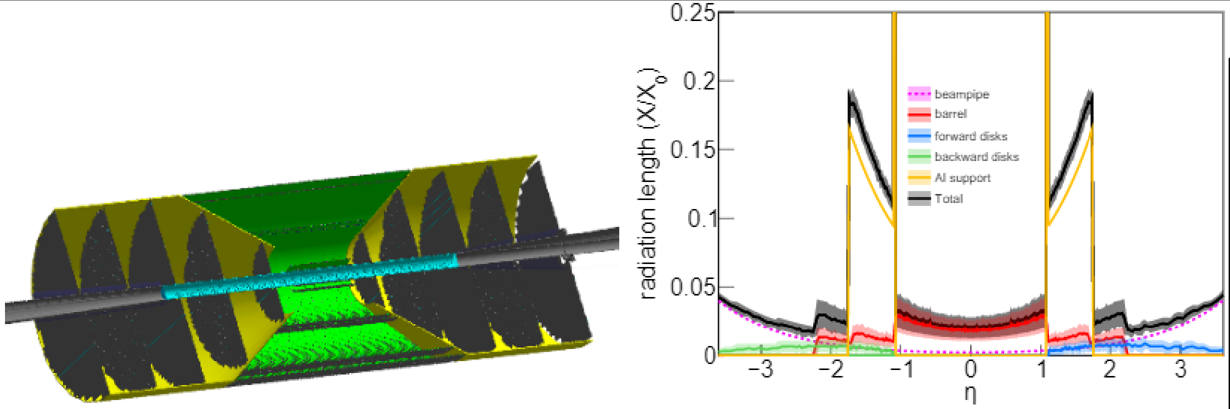


Figure 12: All-silicon tracker geometry. Left: Geant-4 schematic of the tracker cross section. The barrel, disks, and support structure correspond to the green, dark-gray, and yellow components, respectively. The beryllium section of the beam pipe is shown in cyan. The rest of the beam pipe, which takes into account the expected electron-hadron-beam crossing angle is shown in light-gray. Right: Detector material scan. The dashed line describes the baseline material budget from the beam pipe. The red, blue, and green curves correspond to the barrel, forward, and backward components of the detector, respectively. The uncertainty band defines the minimum and maximum amounts of material found in a given η as the material is scanned around ϕ. The yellow curve describes the aluminum support structure. See text for details.

Table 2: Main barrel-layer characteristics.

Barrel layer	radius [cm]	length along z [cm]
1	3.30	30
2	5.70	30
3	21.00	54
4	22.68	60
5	39.30	105
6	43.23	114

Table 3: Main disk characteristics.

Disk number	z position [cm]	outer radius [cm]	inner radius [cm]
-5	-121	43.23	4.41
-4	-97	43.23	3.70
-3	-73	43.23	3.18
-2	-49	36.26	3.18
-1	-25	18.50	3.18
1	25	18.50	3.18
2	49	36.26	3.18
3	73	43.23	3.50
4	97	43.23	4.70
5	121	43.23	5.91

All-silicon tracking detector layout taken from the current draft of the YR.

Comparison with requirements

ALL-SILICON tracking system:

Tracking performance (All-silicon concept, B = 3 T)						
			Momentum res.		**Transverse pointing res.**	
η			Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$	$\sigma_p/p \sim 0.1\% \times p \oplus 0.5\%$	dca(xy) ~ 60/pT µm ⊕ 20 µm	
-3.0 to -2.5						dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$	$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						
-1.5 to -1.0						
-1.0 to -0.5		Barrel	$\sigma_p/p \sim 0.02\% \times p \oplus 0.5\%$	$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$	$\sigma_p/p \sim 0.05\% \times p \oplus 1\%$	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$	$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$	dca(xy) ~ 60/pT µm ⊕ 20 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						dca(xy) ~ 30/pT µm ⊕ 60 µm

Comparison with requirements

ALL-SILICON tracking system:

Tracking performance (All-silicon concept, B = 1.5 T)						
			Momentum res.		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma p/p \sim 0.2\% \times p \oplus 5\%$	$\sigma p/p \sim 0.1\% \times p \oplus 0.5\%$	dca(xy) ~ 60/pT µm ⊕ 20 µm	
-3.0 to -2.5						dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			$\sigma p/p \sim 0.04\% \times p \oplus 2\%$	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						
-1.5 to -1.0						
-1.0 to -0.5		Barrel	$\sigma p/p \sim 0.04\% \times p \oplus 1\%$	$\sigma p/p \sim 0.05\% \times p \oplus 0.5\%$	dca(xy) ~ 30/pT µm ⊕ 5 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	$\sigma p/p \sim 0.04\% \times p \oplus 2\%$	$\sigma p/p \sim 0.05\% \times p \oplus 1\%$	dca(xy) ~ 40/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0			$\sigma p/p \sim 0.2\% \times p \oplus 5\%$	$\sigma p/p \sim 0.1\% \times p \oplus 2\%$	dca(xy) ~ 60/pT µm ⊕ 20 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						dca(xy) ~ 30/pT µm ⊕ 60 µm

Comparison with requirements

HYBRID tracking system:

Tracking performance (Hybrid concept, B = 3 T)								
			Momentum res.		Minimum pT		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 50/pT µm ⊕ 10 µm	
-3.0 to -2.5					160-220 MeV/c	100-150 MeV/c		dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 25/pT µm ⊕ 3 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5						100-150 MeV/c		
-1.5 to -1.0					300 MeV/c	100-150 MeV/c		
-1.0 to -0.5		Barrel	σp/p ~ 0.11%×p ⊕ 0.2% (0-5 GeV/c) σp/p ~ 0.03%×p ⊕ 0.5% (5-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 0.5%	400 MeV/c (90% acceptance)	100-150 MeV/c	dca(xy) ~ 15/pT µm ⊕ 2 µm	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0								
0 to 0.5								
0.5 to 1.0								
1.0 to 1.5		Forward Detector	σp/p ~ 0.11%×p ⊕ 0.4% (0-8 GeV/c) σp/p ~ 0.04%×p ⊕ 1% (8-30 GeV/c)	σp/p ~ 0.05%×p ⊕ 1%	300 MeV/c	100-150 MeV/c	dca(xy) ~ 25/pT µm ⊕ 3 µm	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					160-220 MeV/c	100-150 MeV/c		
2.0 to 2.5						100-150 MeV/c		
2.5 to 3.0			σp/p ~ 0.05%×p ⊕ 2%	σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 50/pT µm ⊕ 10 µm	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5						100-150 MeV/c		dca(xy) ~ 30/pT µm ⊕ 60 µm

Comparison with requirements

HYBRID tracking system:

Tracking performance (Hybrid concept, B = 1.5 T)								
			Momentum res.		Minimum pT		Transverse pointing res.	
η			Performance	Requirements	Performance	Requirements	Performance	Requirements
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma_p/p \sim 0.1\% \times p \oplus 4\%$	$\sigma_p/p \sim 0.1\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 50/pT μm ⊕ 10 μm	
-3.0 to -2.5					70-130 MeV/c	100-150 MeV/c		dca(xy) ~ 30/pT μm ⊕ 40 μm
-2.5 to -2.0			$\sigma_p/p \sim 0.24\% \times p \oplus 1\%$ (0-8 GeV/c) $\sigma_p/p \sim 0.07\% \times p \oplus 2\%$ (8-30 GeV/c)	$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$		100-150 MeV/c	dca(xy) ~ 25/pT μm ⊕ 3 μm	dca(xy) ~ 30/pT μm ⊕ 20 μm
-2.0 to -1.5						100-150 MeV/c		
-1.5 to -1.0					150 MeV/c	100-150 MeV/c		
-1.0 to -0.5		Barrel	$\sigma_p/p \sim 0.21\% \times p \oplus 0.3\%$ (0-5 GeV/c) $\sigma_p/p \sim 0.06\% \times p \oplus 1\%$ (5-30 GeV/c)	$\sigma_p/p \sim 0.05\% \times p \oplus 0.5\%$	200 MeV/c (90% acceptance)	100-150 MeV/c	dca(xy) ~ 15/pT μm ⊕ 2 μm	dca(xy) ~ 20/pT μm ⊕ 5 μm
-0.5 to 0								
0 to 0.5								
0.5 to 1.0								
1.0 to 1.5		Forward Detector	$\sigma_p/p \sim 0.24\% \times p \oplus 1\%$ (0-8 GeV/c) $\sigma_p/p \sim 0.07\% \times p \oplus 2\%$ (8-30 GeV/c)	$\sigma_p/p \sim 0.05\% \times p \oplus 1\%$	150 MeV/c	100-150 MeV/c	dca(xy) ~ 25/pT μm ⊕ 3 μm	dca(xy) ~ 30/pT μm ⊕ 20 μm
1.5 to 2.0					70-130 MeV/c	100-150 MeV/c		
2.0 to 2.5						100-150 MeV/c		
2.5 to 3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 4\%$	$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$		100-150 MeV/c	dca(xy) ~ 50/pT μm ⊕ 10 μm	dca(xy) ~ 30/pT μm ⊕ 40 μm
3.0 to 3.5						100-150 MeV/c		dca(xy) ~ 30/pT μm ⊕ 60 μm