EIC Silicon Consortium

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on behalf of the EIC Silicon Consortium

ECCE Workshop

11 February 2021

EIC Silicon Consortium

- Building on from the work carried out by the eRD16 (LBNL) and eRD18(Birmingham/RAL) projects, now merged into eRD25, within the EIC Generic Detector R&D meeting since 2016
- EOI: https://indico.bnl.gov/event/8552/contributions/43219/

BERKELEY LAB
UNIVERSITY OF BIRMINGHAM
Science & Technology Facilities Council Rutherford Appleton Laboratory
CENTRAL CHINA NORMAL UNIVERSITY
Jefferson Lab Thomas Jefferson National Accelerator Facility
BROOKHAVEN NATIONAL LABORATORY
OAK RIDGE National Laboratory
Brunel University London
Science & Technology Facilities Council Daresbury Laboratory
UNIVERSITY OF LIVERPOOL

… and more institutes expressing interest/joining

Develop a **well-integrated and large-acceptance** EIC vertex and tracking detector concept, based on Monolithic Active Pixel Sensor (**MAPS**) in a commercial **65 nm** CMOS imaging process

MAPS in 65 nm

- A large effort is emerging to develop new generation MAPS in a commercial 65 nm CMOS imaging technology

- Large interest in the HEP community to develop this process for future experiments: CERN EP R&D programme and ALICE ITS3 project

- This path is very attractive for the development of an EIC MAPS
- With respect to older CMOS imagining technologies (for instance 180 nm), 65 nm offers
  - **Improved performance in terms of granularity and power consumption** that are key for precision measurements at the EIC
  - **Process availability** on the EIC project timescale
  - **Lower cost per area** but higher entry cost and complexity than older technology nodes, however…
- … the EIC SVT development could leverage from the ALICE ITS3 project
  - The ITS3 **sensor specifications and development timescale** are largely compatible with those of the EIC
  - **Non-ALICE members are welcome** to contribute to the R&D to develop and use the technology for other applications
  - See L. Greiner at the EIC Yellow Report Kick-Off meeting https://www.jlab.org/indico/event/348/session/5/material/0/0.pdf

ALICE ITS3 project

- The ALICE ITS3 project aims at developing a new generation MAPS sensor at the 65 nm node with extremely low mass for the LHC Run4 (HL-LHC)

- ITS3 sensor
  - Specifications meet or even exceed the EIC requirements
  - Higher granularity (10 um pixel pitch) and lower power consumption (<20mW/cm^2) with respect to pre-CD0 simulation baseline (that was ITS2/ALPIDE derived)
  - Also integration time, fake hit rate and time resolution better than required at the EIC

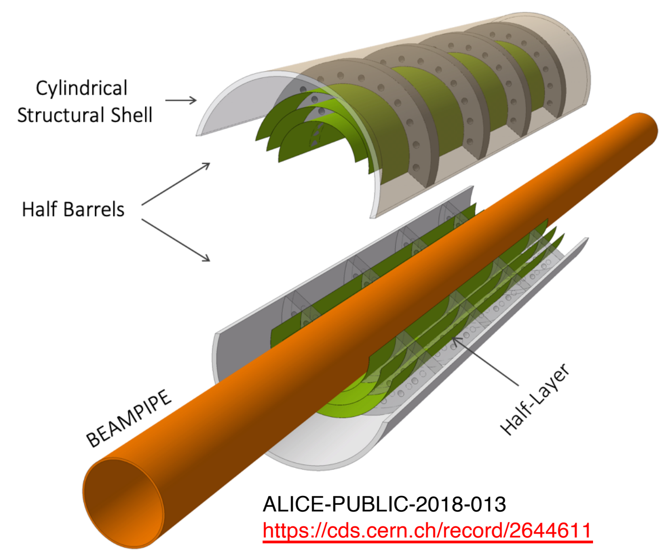
- ITS3 detector
  - Three layers vertex detector, 0.12 m^2
    - Truly cylindrical layers
  - Design and post-processing techniques to reach an extremely low material budget of 0.05% X/X0 per layer
    - Low power, wafer-scale sensor, thinned to 20-40 μm, bent around the beam pipe = air-cooling, support and services outside active area

ALICE

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

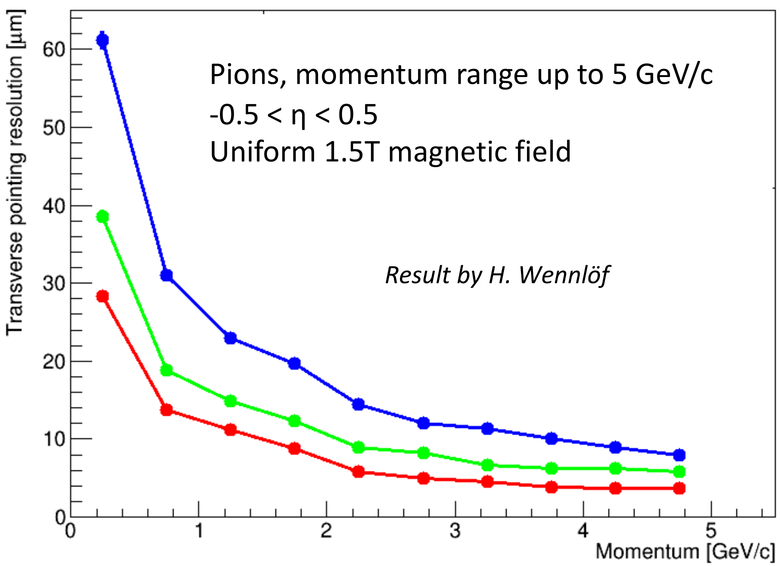
M. Mager | ITS3 kickoff | 04.12.2019 |



ALICE-PUBLIC-2018-013
https://cds.cern.ch/record/2644611

Simulation driven technology choice

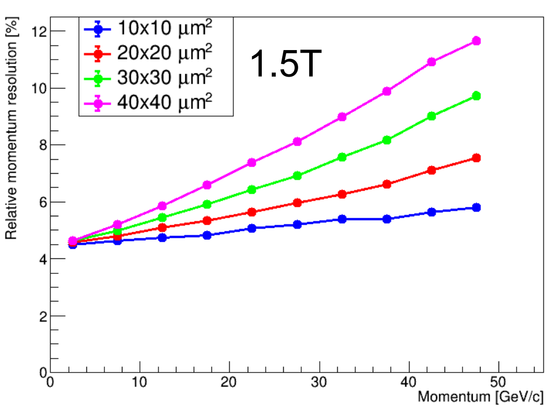
- Initial simulations showed
  - The need for ITS3 like spatial resolution and material budget to reach required vertex resolution

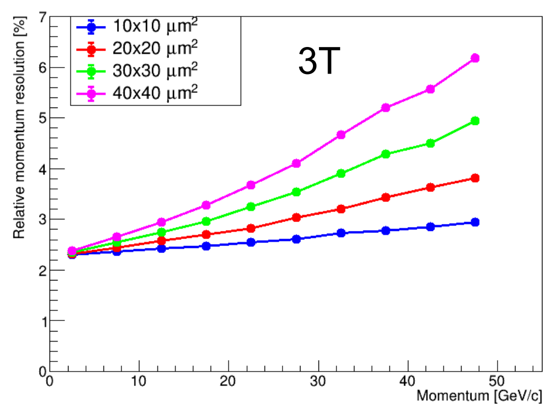


	Green	Blue	Red (ITS3 derived EIC SVT)
Beam pipe radius [mm]	18	**31**	**31**
x/X0 vertex	0.3%	0.3%	**0.05%**
x/X0 tracking layers	0.8%	0.8%	0.8%
Pixel pitch [um]	20	20	**10**

A beam pipe radius of 18 mm and a pixel pitch of 20 um were used in pre-CD0 simulations. Note that a pixel pitch of 20 um is not the ALPIDE, ALPIDE has ~28um pitch. Here binary readout is assumed so the spatial resolution is ~ 6 um (20 um pitch) and ~ 3 um (10 um pitch).

  - Momentum resolution at large eta also strongly affected by spatial resolution





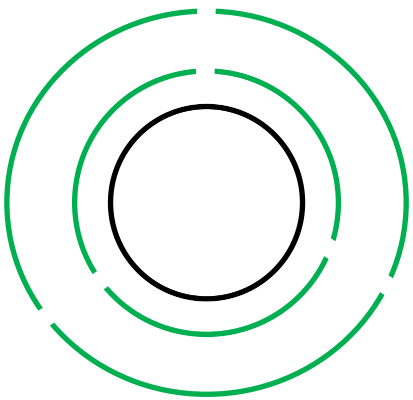
Forward region studied; η = 3
Single electrons fired from centre
Magnetic field: uniform 1.5 T and 3 T
Vertex layers and disks: 0.3% x/X0
Tracking layers: 0.8% x/X0
Beam pipe radius: 18 mm

See H. Wennlöf at https://indico.jlab.org/event/400/contributions/6529/ and http://cern.ch/go/xKk6

ITS3-derived EIC SVT

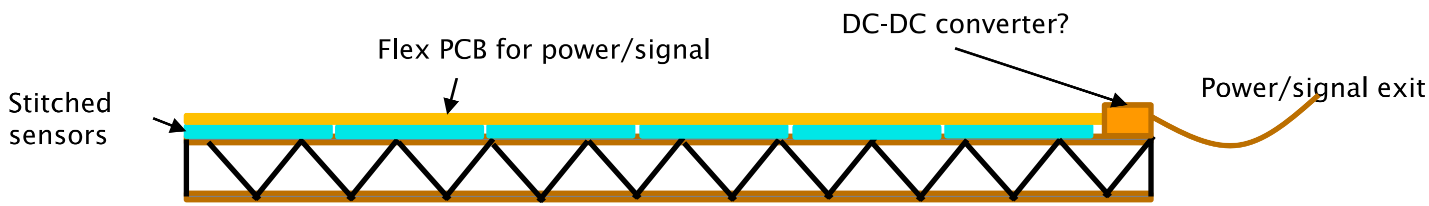
- Vertexing inner layers
  - Use ITS3 sensor
  - Adapt ITS3 detector concept to different length and radii of the EIC vertex layers

EIC strawman design (modification of ITS3)



Reach larger radii by using 3 bent sections. Services exit from both sides of inner layers.

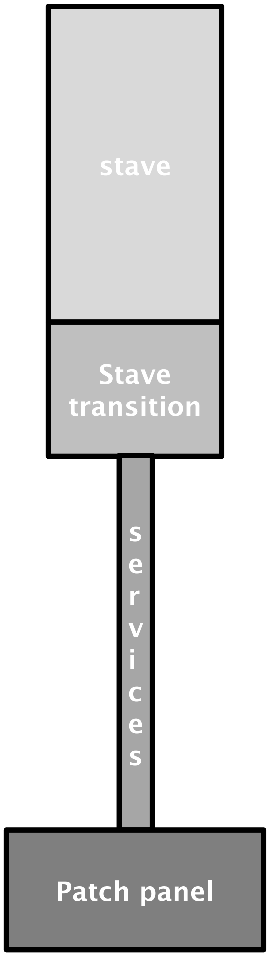
- Tracking layers and disks
  - Staves and discs will be based on a forked EIC specific sensor design based on the ITS3 sensor
  - The primary concern is yield for long rows of stitched sensors. The plan is to assess yield in the first engineering run and adjust the EIC sensors to optimize yield for the number of stitched sensors in a row.
  - Staves and disks will need to optimize the stitched sensor layout on the wafers to provide the right number of stitched sensor lengths to give the proper needed lengths for each stave/disc. This needs study and optimization.



Stave support structure

ITS3-derived EIC SVT – Material budget estimates

- See L. Greiner's talk at the 2nd YR workshop for details
  - https://indico.bnl.gov/event/8231/contributions/37955/



	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	~0.1%	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

YR baseline SVT concepts

- Two tracking detector scenarios developed as YR baseline concepts based on the proposed ITS3-derived EIC SVT
  - Beam pipe for both is a beryllium cylinder of radius of 3.17 cm and thickness of 760 μm

- All-silicon concept
  - See talk from R. Cruz-Torres at this workshop

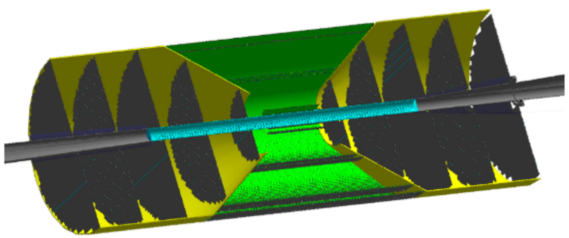


Table 1: Main barrel-layer characteristics.

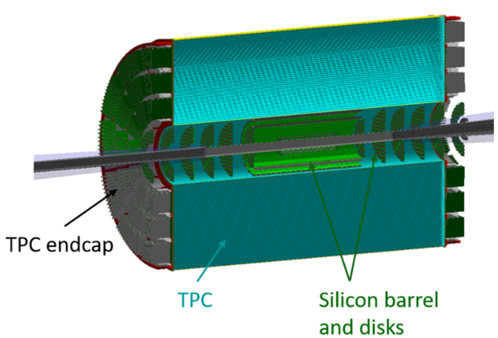
Barrel layer	radius [cm]	length along z [cm]
1	3.30	30
2	5.70	30
3	21.00	54
4	22.68	60
5	39.30	105
6	43.23	114

Table 2: 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

x/X0 vertex	0.3%
x/X0 tracking layers	0.3%
x/X0 disks	0.3%
Pixel pitch [um]	10

- Hybrid: Silicon + gaseous detector tracking
  - Work by H. Wennlöf, https://indico.bnl.gov/event/7919/contributions/43180/ and in YR chapter 11



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

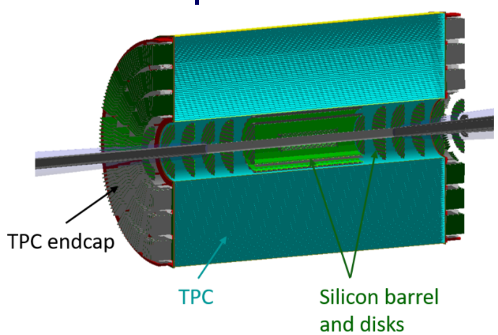
Disk	z position	Inner radius	Outer radius
Disk 1	220 mm	36.4 mm	71.3 mm
Disk 2	430 mm	36.4 mm	139.4 mm
Disk 3	586 mm	36.4 mm	190.0 mm
Disk 4	742 mm	49.9 mm	190.0 mm
Disk 5	898 mm	66.7 mm	190.0 mm
Disk 6	1054 mm	83.5 mm	190.0 mm
Disk 7	1210 mm	99.3 mm	190.0 mm

(b) Disk region

x/X0 vertex	0.05%
x/X0 tracking layers	0.55%
x/X0 disks	0.24%
Pixel pitch [um]	10

YR baseline SVT concepts against physics requirements

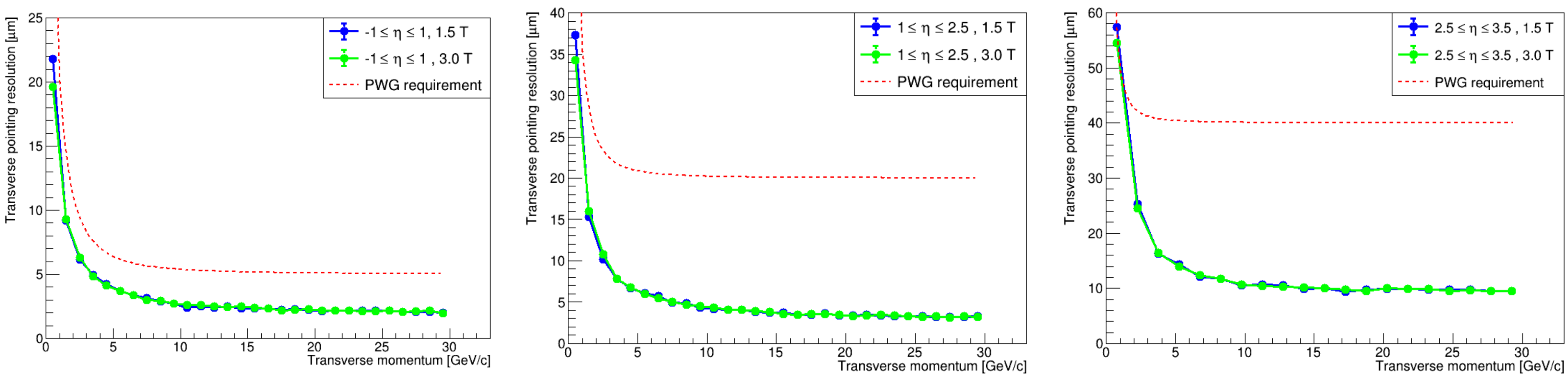
- Both concepts tested against the tracking requirements provided by the YR physics WG
  - Full results published in the YR, here only selected plots for hybrid concept



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

Figure 1: Requirements Table

- Transverse pointing resolution
  - 1.5T, 3.0T, PWG requirement



Results by H. Wennlöf

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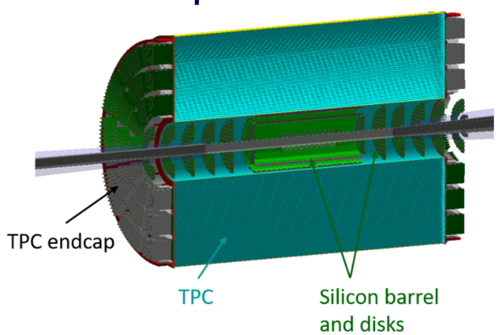
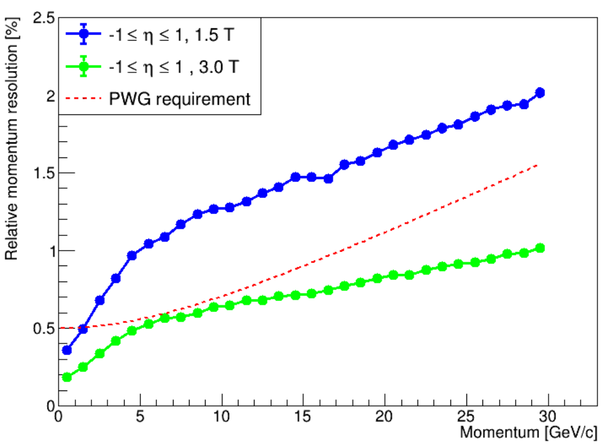
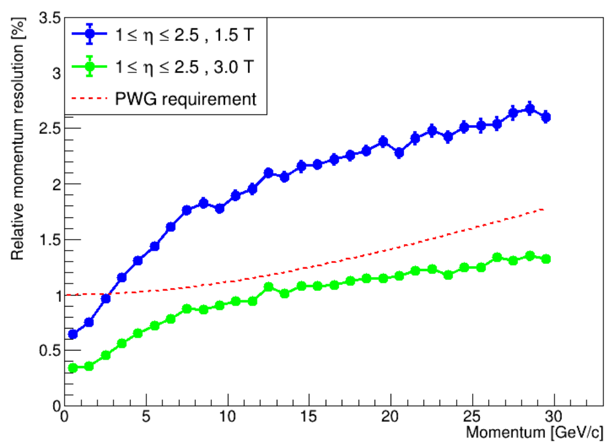


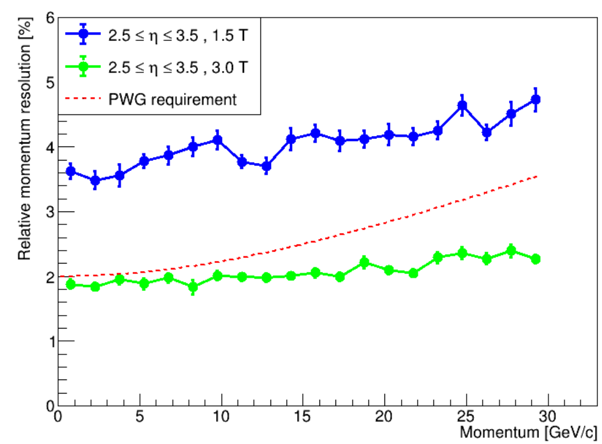
Tracking requirements from PWGs						
η			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
-3.5 to -3.0	Central Detector	Backward Detector	$\sigma_p/p \sim 0.1\% \times p \oplus 0.5\%$	~5% X0 or less	100-150 MeV/c	dca(xy) ~ 30/pT μm ⊕ 40 μm
-3.0 to -2.5					100-150 MeV/c	
-2.5 to -2.0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

Figure 1: Requirements Table

- Relative momentum resolution
  - 1.5T, 3.0T, PWG requirement



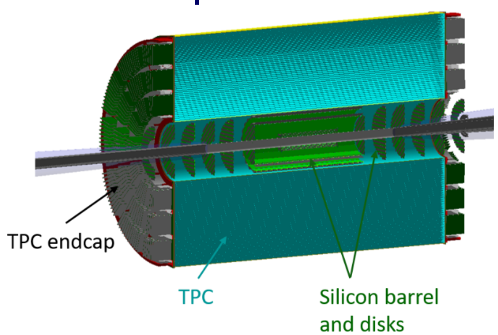




Results by H. Wennlöf

YR baseline SVT concepts against physics requirements

- Both concepts tested against the tracking requirements provided by the YR physics WG
    - Full results published in the YR, here only selected plots for hybrid concept

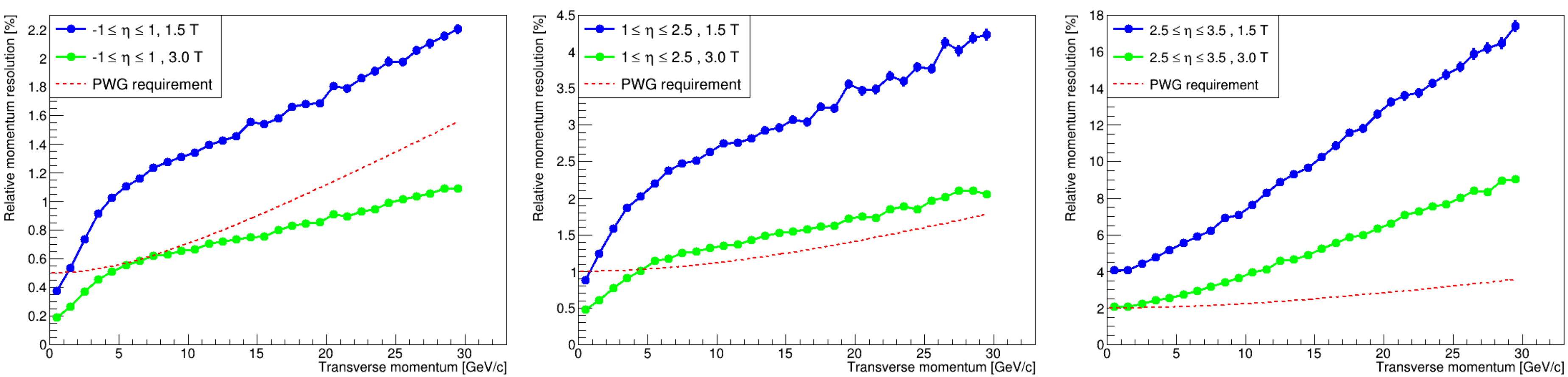


Tracking requirements from PWGs

η			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
-3.5 to -3.0			σp/p ~ 0.1%×p ⊕ 0.5%		100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0		Backward Detector			100-150 MeV/c	
-2.0 to -1.5			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5						
-0.5 to 0	Central Detector	Barrel	σp/p ~ 0.05%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5					100-150 MeV/c	
1.5 to 2.0			σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
2.0 to 2.5		Forward Detector			100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 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

Figure 1: Requirements Table

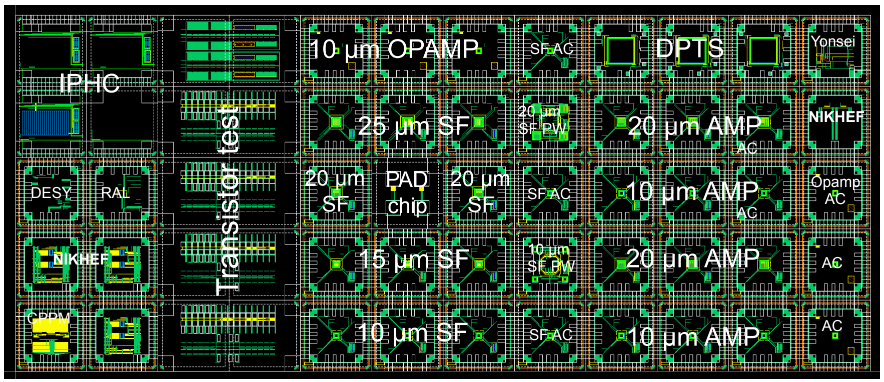
- Transverse relative momentum resolution
    - 1.5T, 3.0T, PWG requirement

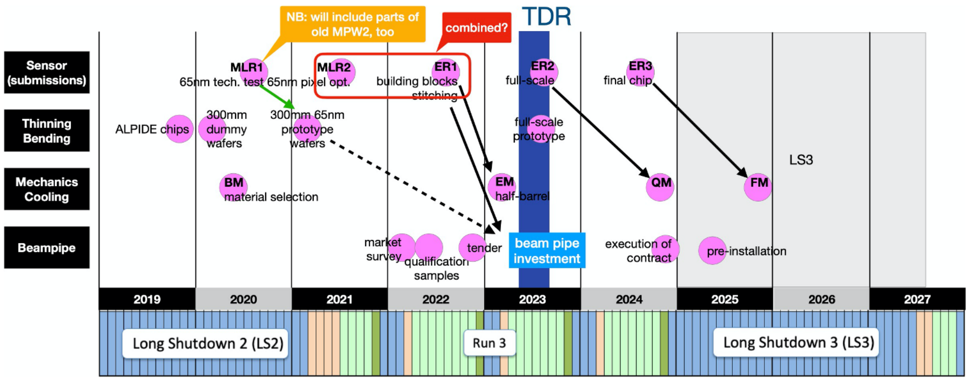


Results by H. Wennlöf

EIC Silicon Consortium status

- Sensor development
  - RAL/Birmingham/LBNL already involved in first 65 nm submission with ITS3 Work Package 2
  - More groups signing NDA and collaboration agreement to join
  - Second submission now plans to start implementing stitching already





- Simple extrapolation of material budget into staves/discs based on ITS3 sensor specification exists (slide 7)
- A document on EIC tracker powering options has been produced
  - Detector/power system requirements
  - DC-DC conversion and serial powering
  - Material budget and development time
- Physics performance simulations continue
- Started EIC SC monthly meeting; assigning groups to tasks and tasks to work packages; discussions ongoing with ITS3 for EIC SC groups to join relevant work packages beyond WP2

Some more references

- Description of ITS3 R&D project and silicon survey at EICUG YR meeting at Temple
  - L. Greiner https://indico.bnl.gov/event/7449/contributions/35955/
  - L. Gonella https://indico.bnl.gov/event/7449/contributions/35954/
- eRD25
  - Proposal talk https://wiki.bnl.gov/conferences/images/1/1c/ERD25-proposal-Jul20.pdf
  - Full proposal and progress report https://wiki.bnl.gov/conferences/images/6/6d/ERD25-Report-FY21Proposal-Jun20.pdf
- Talks at EIC SVT workshop
  - L. Gonella https://indico.jlab.org/event/400/contributions/6533/
  - G. Contin https://indico.jlab.org/event/400/contributions/6536/
  - L. Greiner https://indico.jlab.org/event/400/contributions/6541/
  - A. Collu https://indico.jlab.org/event/400/contributions/6544/
  - I. Sedgwick https://indico.jlab.org/event/400/contributions/6535/
  - H. Wennlöf https://indico.jlab.org/event/400/contributions/6529/
  - R. Cruz-Torres https://indico.jlab.org/event/400/contributions/6532/
  - E. Sichterman https://indico.jlab.org/event/400/contributions/6519/