A Detector for the LHeC

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DIS2011, Newport News
Parallel Session 2: Accelerator Design Plans
12th of April 2011

Preliminary

- Detector Layout
  - Experiment Magnet(s)
  - Beam Pipe
  - Tracker
  - Calorimeter
- Detector Requirements - Physics Motivated

  Physics Issues discussed in Parallel Session 9: LHeC Physics (i) Anna Stasto, Paul Newman, Brian Cole, Tobias Toll
  Parallel Session 10: LHeC Physics (ii) Voica Radescu, Olaf Behnke, Uta Klein
- Physics ↔ Detector Design ↔ Interaction Region (beam optics / SR)

  see talks Overview of the LHeC Project - Max KLEIN (Liverpool) Parallel Session 1: Project Overviews
  LHeC Linac-Ring Design - Alex BOGASZ (JLab) Parallel Session 2: Accelerator Design Plans
  LHeC Ring-Ring Design - Miriam FITTERER (CERN) Parallel Session 2: Accelerator Design Plans
- Detector Design ← Machine Option Impacts

Aim of present studies

- Prove together with Physics & Machine WG the feasibility and the physics potential.
- Establish the Machine and the Interaction Region constrains
  - Magnets, Beam-Pipe, Synchrotron Radiation.
- Detector baseline within reach of currently available and established technologies.
- Verify that the generic solution already fulfills the physics requirements, e.g. Calorimetry:

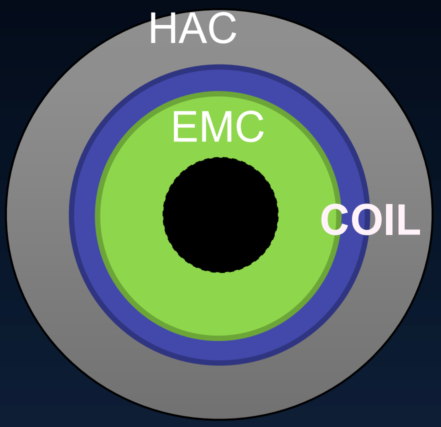
Summary of calorimeter kinematics and requirements for the default design energies

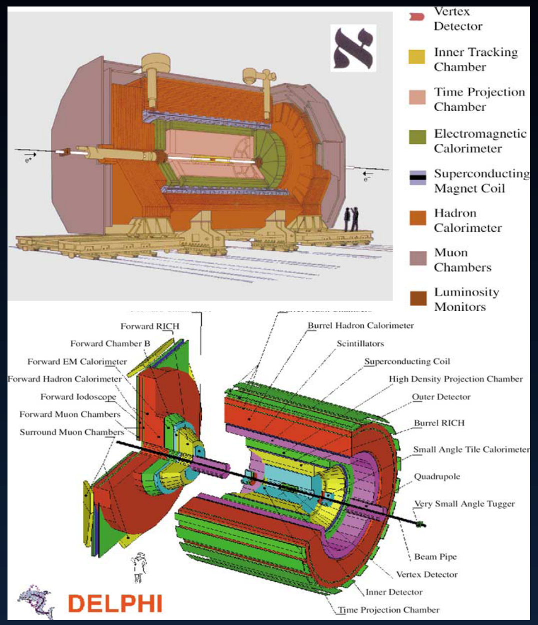
region of detector approximate angular range / degrees	backward 179 - 135	barrel 135 -45	forward 45-1
scattered electron energy/GeV	3-100	10-400	50-5000
x_e	$10^{-7} - 1$	$10^{-4} - 1$	$10^{-2} - 1$
elm scale calibration in %	0.1	0.2	0.5
elm energy resolution $\delta E/E$ in $\% \cdot \sqrt{E/GeV}$	10	15	15
hadronic final state energy/GeV	3-100	3-200	3-5000
x_h	$10^{-7} - 10^{-3}$	$10^{-5} - 10^{-2}$	$10^{-4} - 1$
hadronic scale calibration in %	2	1	1
hadronic energy resolution in $\% \cdot \sqrt{E/GeV}$	60	50	40

Solenoid Options

Small Coil - Default

- Smaller Solenoid placed between EMC and HAC
- Convenient: placement of Solenoid and Dipoles in same cold vacuum vessel (Linac-Ring)
- Smaller return flux (less iron required)
- Muon p, p_t measurement compromised

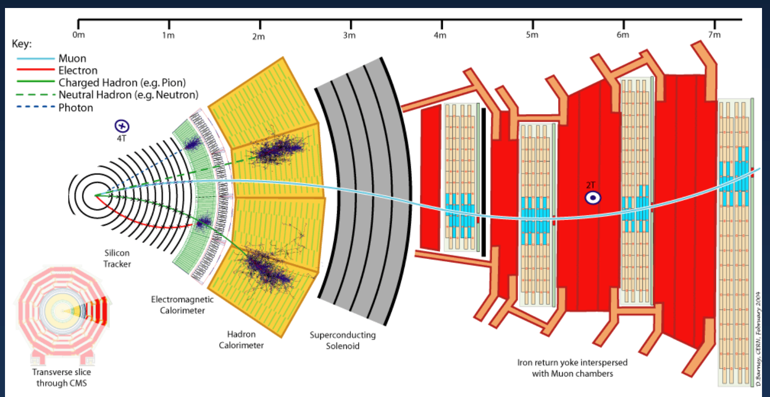




Option Two

- Large Solenoid containing the Calorimeters
- more expensive
- 3.5 T Solenoid similar to CMS/ILC
- Precise Muon measurement
- Sizable return flux needed either enclosed with instrumented Iron or

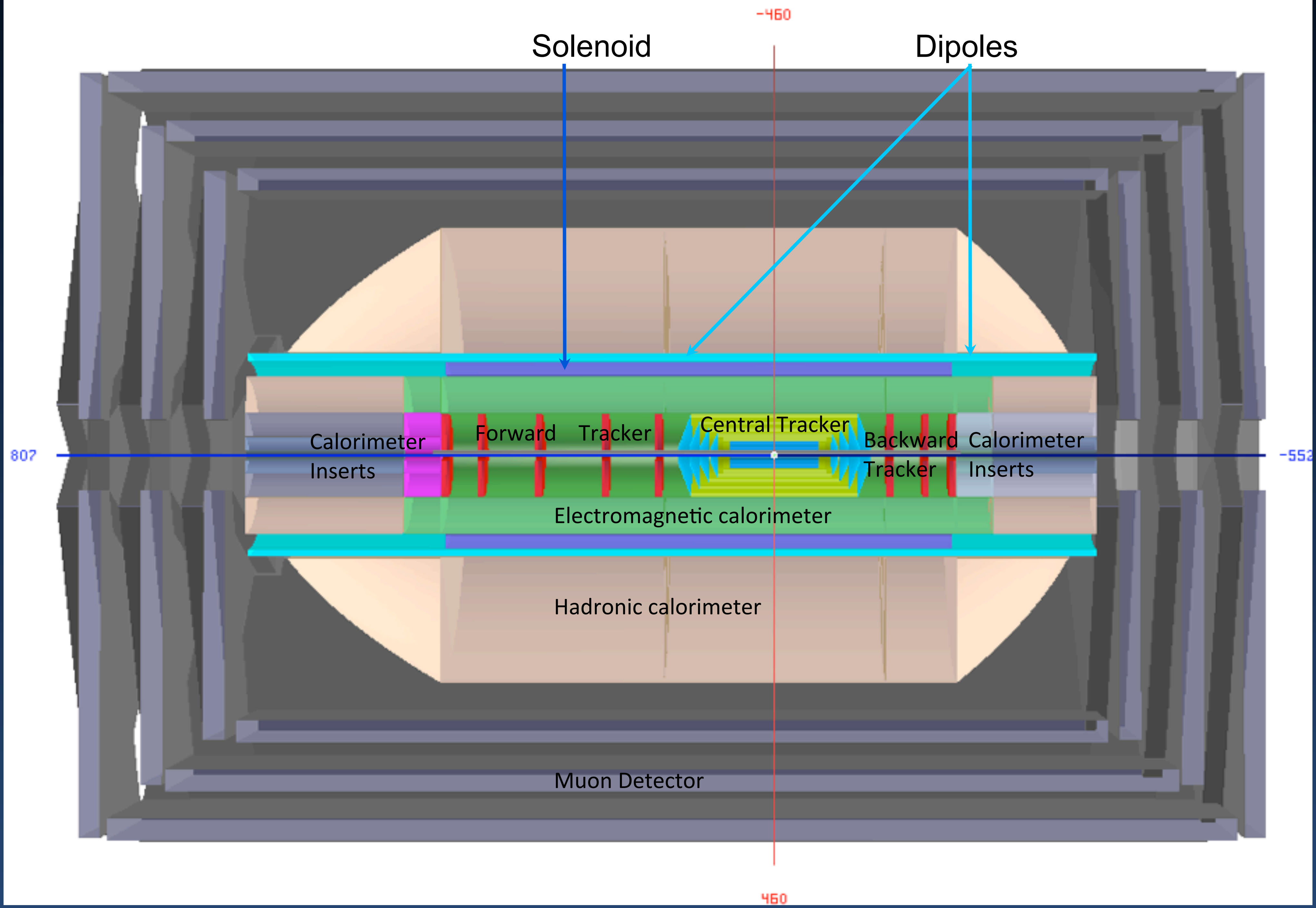
Option of active B shielding with 2nd solenoid



General parameters	
Magnetic length	12.5 m
Free bore diameter	6.3 m
Central magnetic induction	4 T
Total Ampere-turns	41.7 MA-turns
Nominal current	19.14 kA
Inductance	14.2 H
Stored energy	2.6 GJ
Cold mass	
Layout	Five modules mechanically and electrically coupled
Radial thickness of cold mass	312 mm
Radiation thickness of cold mass	3.9 X_0
Weight of cold mass	220 t
Maximum induction on conductor	4.6 T
Temperature margin wrt operating temperature	1.8 K
Stored energy/unit cold mass	11.6 kJ/kg
Iron yoke	
Outer diameter of the iron flats	14 m
Length of barrel	13 m
Thickness of the iron layers in barrel	300, 630 and 630 mm
Mass of iron in barrel	6000 t
Thickness of iron disks in endcaps	250, 600 and 600 mm
Mass of iron in each endcap	2000 t
Total mass of iron in return yoke	10 000 t

Small Solenoid (default) High Acceptance LR Option

- Size of detector: 14 x $9m^2$



Small Solenoid (default)
High Acceptance LR Option

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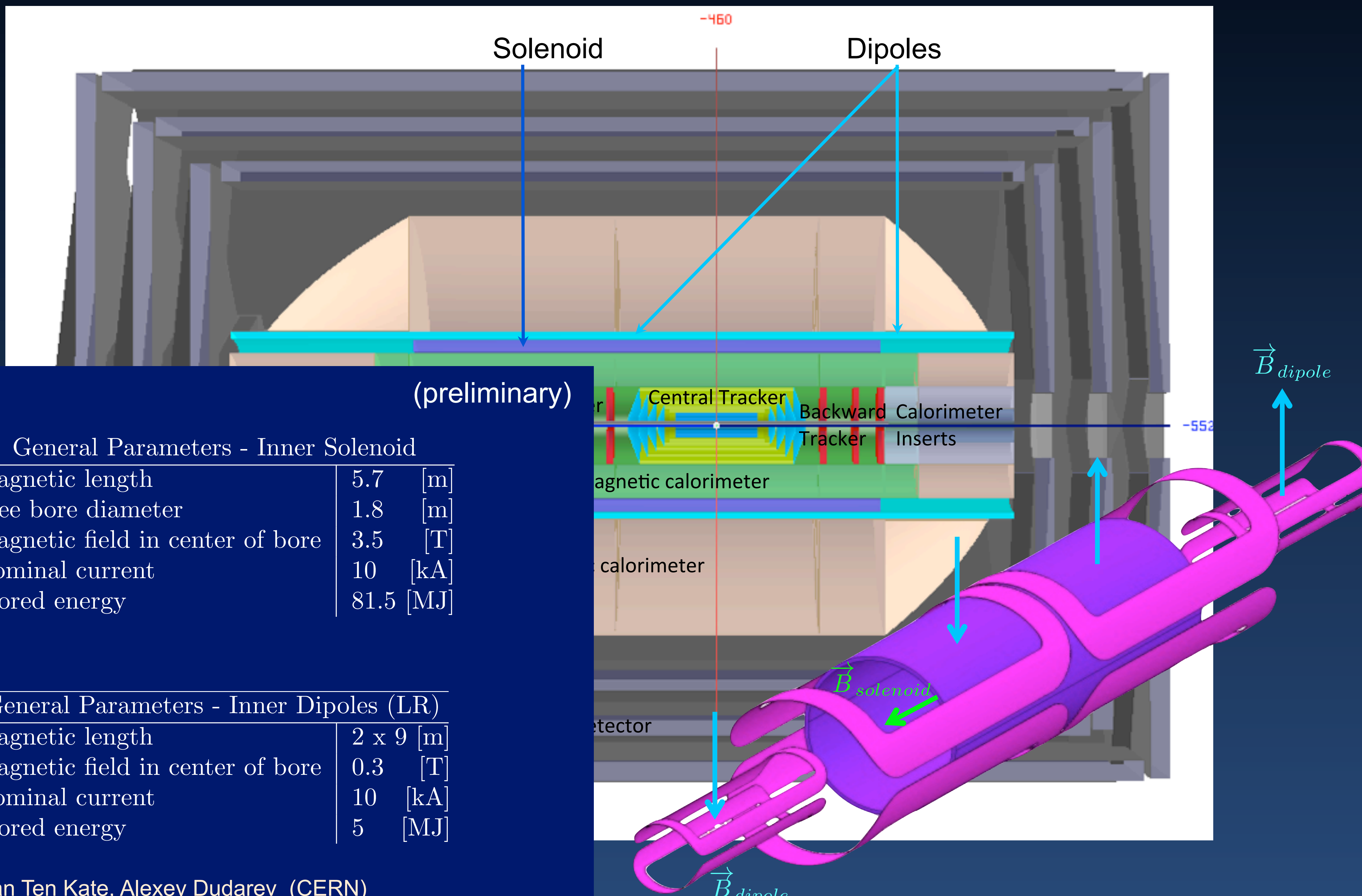


- Magnets: (preliminary)

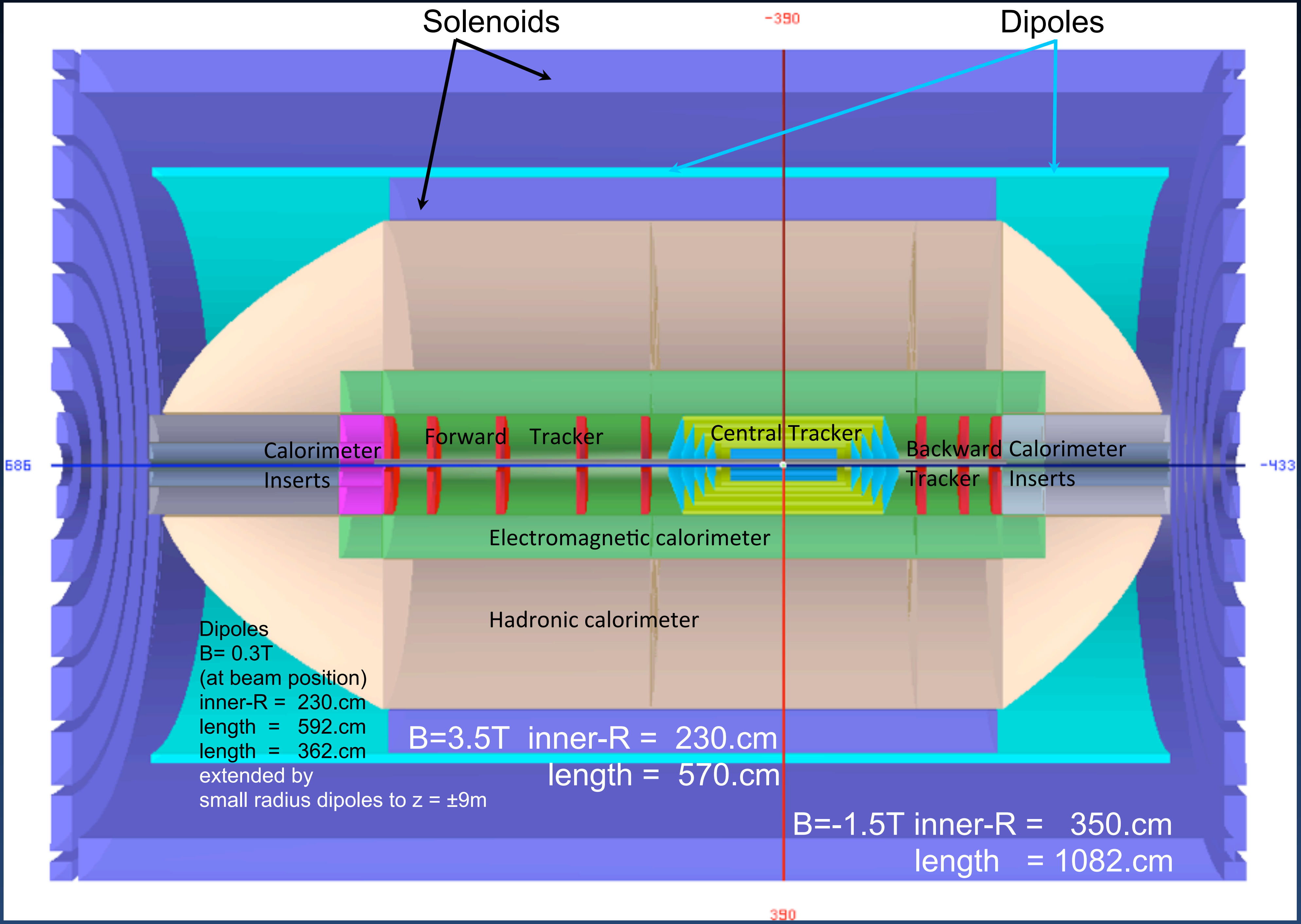
General Parameters - Inner Solenoid		
Magnetic length	5.7	[m]
Free bore diameter	1.8	[m]
Magnetic field in center of bore	3.5	[T]
Nominal current	10	[kA]
Stored energy	81.5	[MJ]

General Parameters - Inner Dipoles (LR)		
Magnetic length	2 x 9	[m]
Magnetic field in center of bore	0.3	[T]
Nominal current	10	[kA]
Stored energy	5	[MJ]

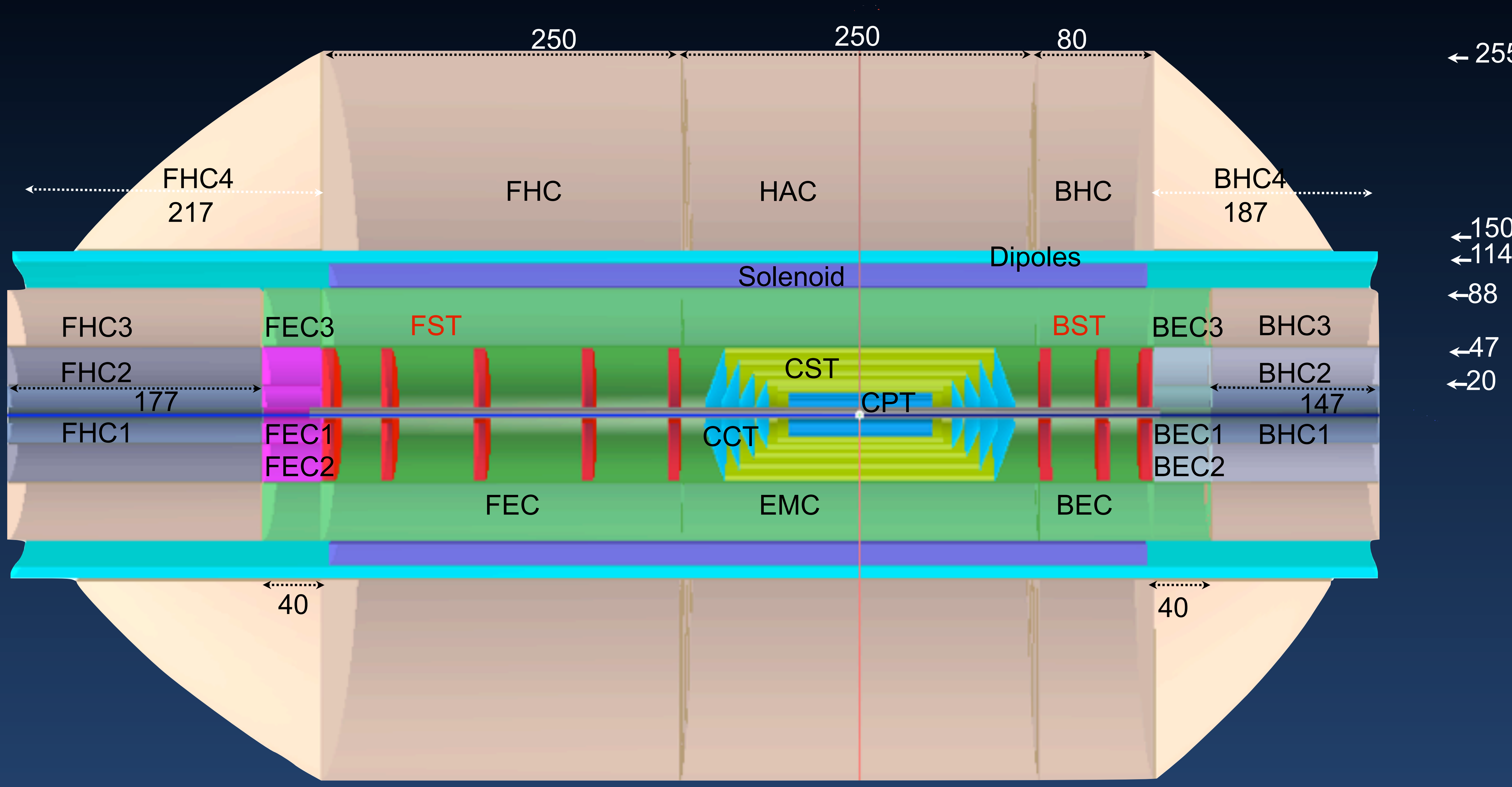
Expertise: Herman Ten Kate, Alexey Dudarev (CERN)

Dual Solenoid High Acceptance LR Option

- Size of detector: 11 x $8m^2$



The Detector - High Acceptance - LR

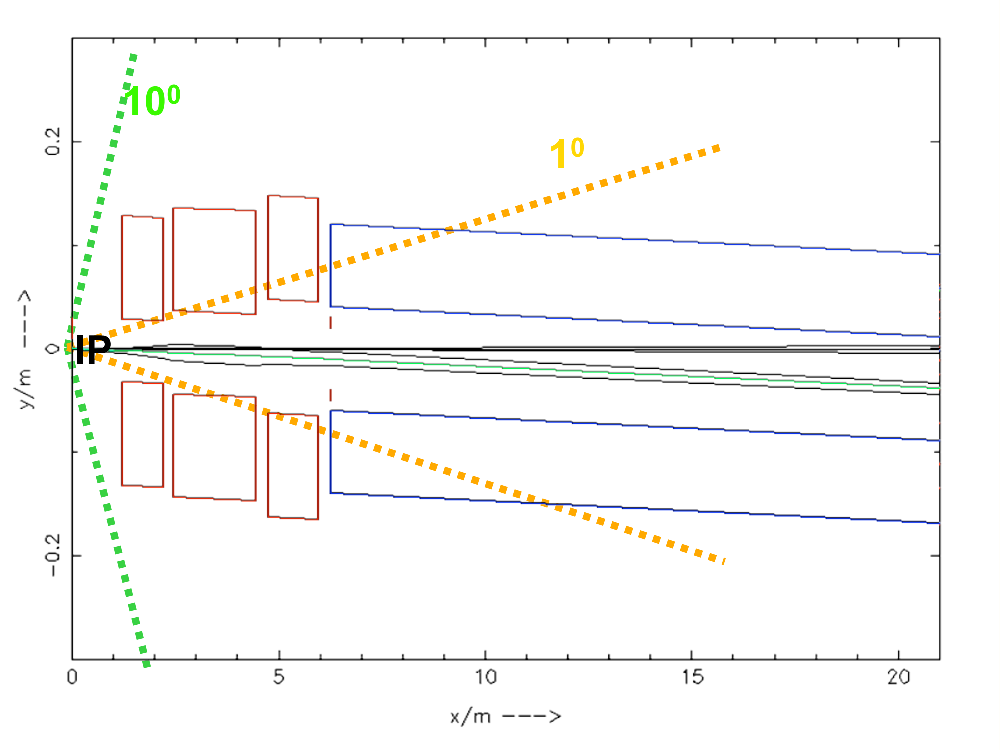


Fwd/Bwd asymmetry in energy deposited and thus in geometry and technology [W/Si vs Pb/Si...]
Dimensions - incl. muon det.: LxD =14x9m^2 [CMS 21 x 15m^2, ATLAS 45 x 25 m^2]

RR - Beam Optics and Detector Acceptance

Consequences on detector design:

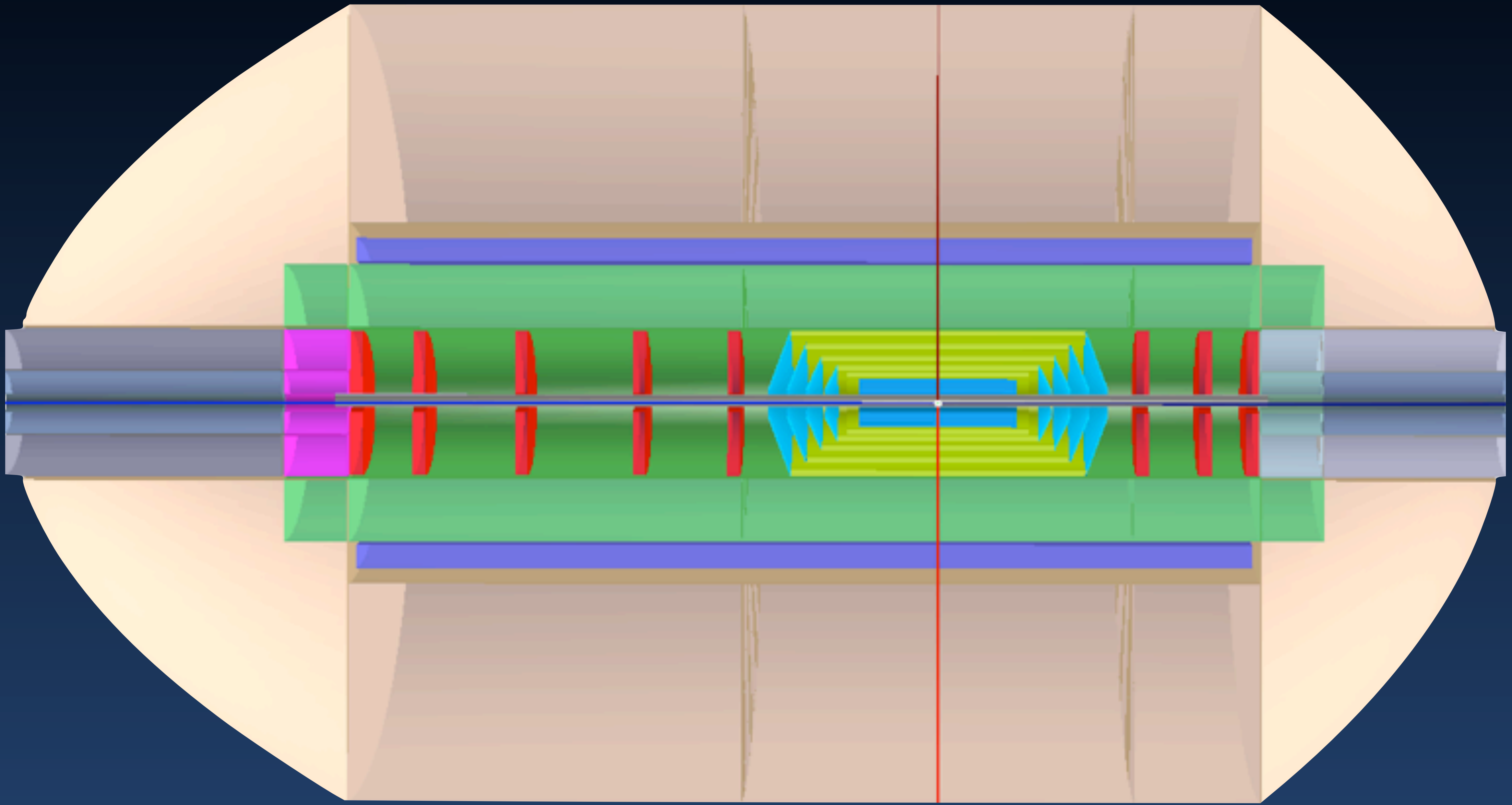
- low β* magnets near the IP for High Luminosity (at z= ± 1.2m)
- High Acceptance without low β* magnets



Bernhard Holzer (CERN)

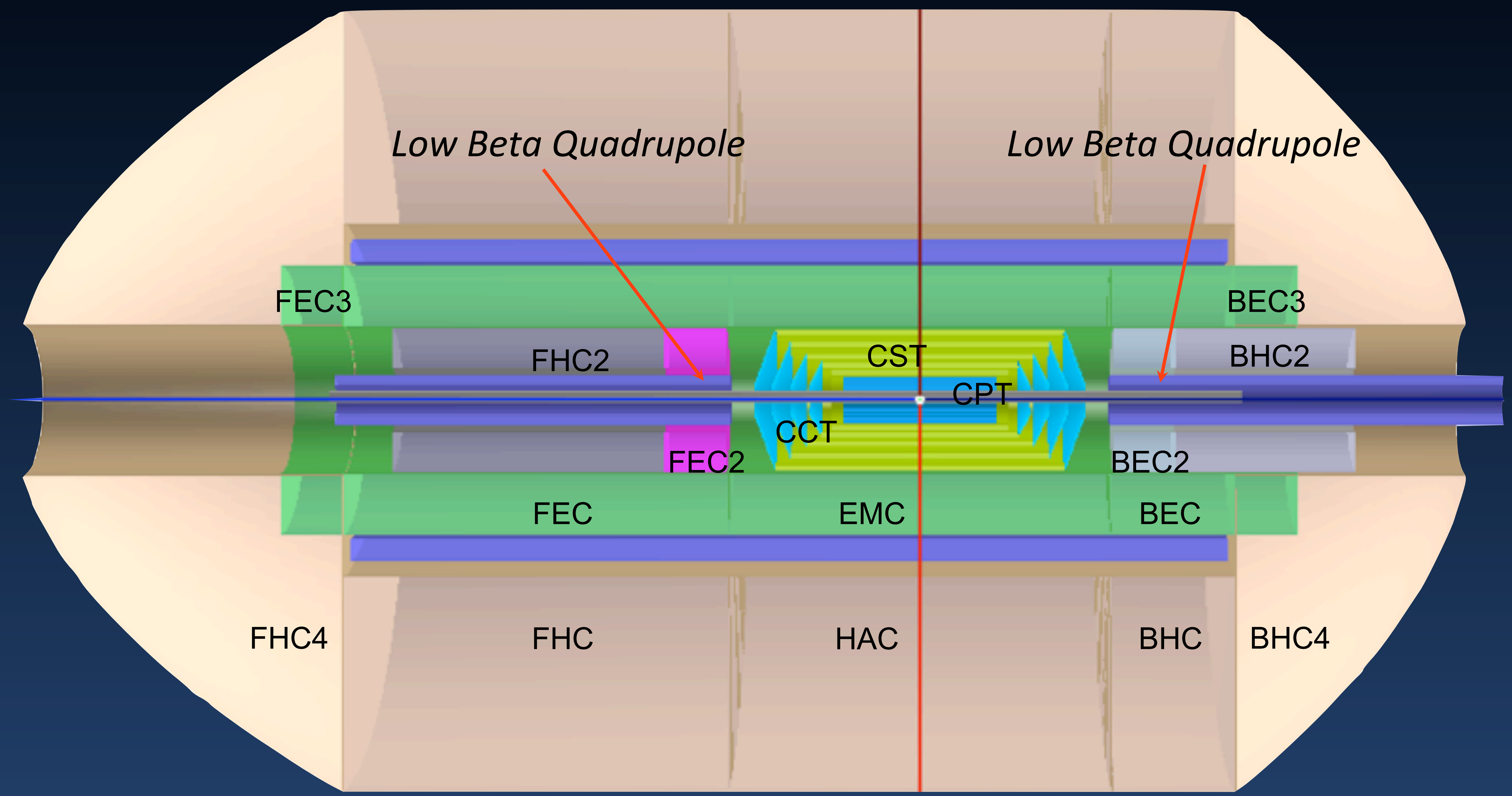
- Lumi: 10° < θ < 170°: ~ 1.3×10^{33} cm^{-2} s^{-1}
  1° < θ < 179°: ~ 7.3×10^{32} cm^{-2} s^{-1}
  RR: 1mrad crossing angle (25ns);
  LR: head on, dipoles for beam separation
  Synchronous *ep* and *pp* operation at LHC - LHC *p* beams provide ~100 x $\text{Lumi}_{\text{HERA}}$
- Lower Lumi, Low Q2 access → High Acceptance detector 1° - 179°
- Higher Lumi, High Q2 access → High Luminosity detector 10° - 170° aperture

The Detector - High Luminosity - RR



➔Aim of current evaluations: RR machine - avoid detector split in two experiment phases - High Lumi / High Acceptance - time and effort

The Detector - High Acceptance - RR



→Aim of current evaluations: RR machine - avoid detector split in two experiment phases - High Lumi / High Acceptance - time and effort

LR Interaction Region

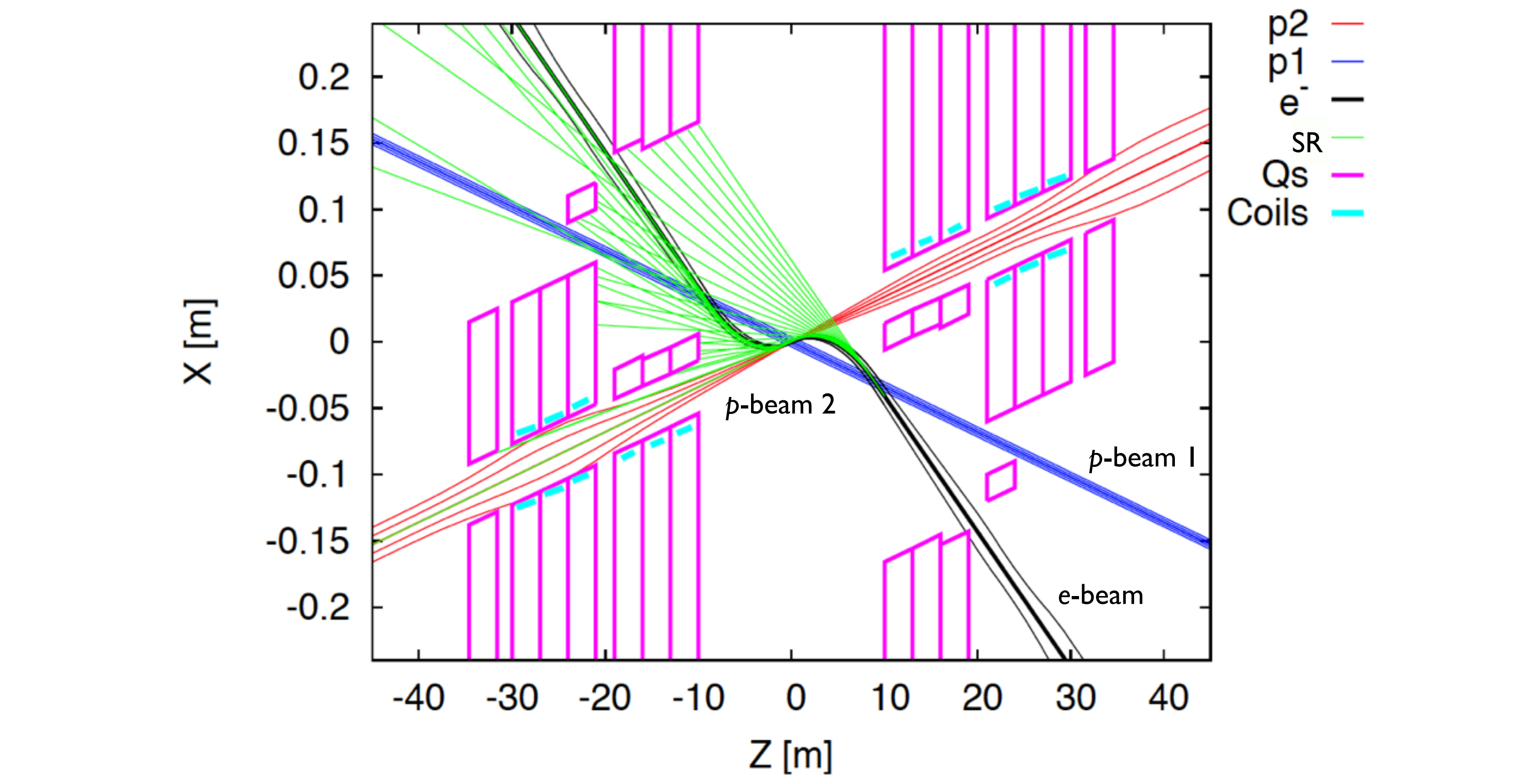
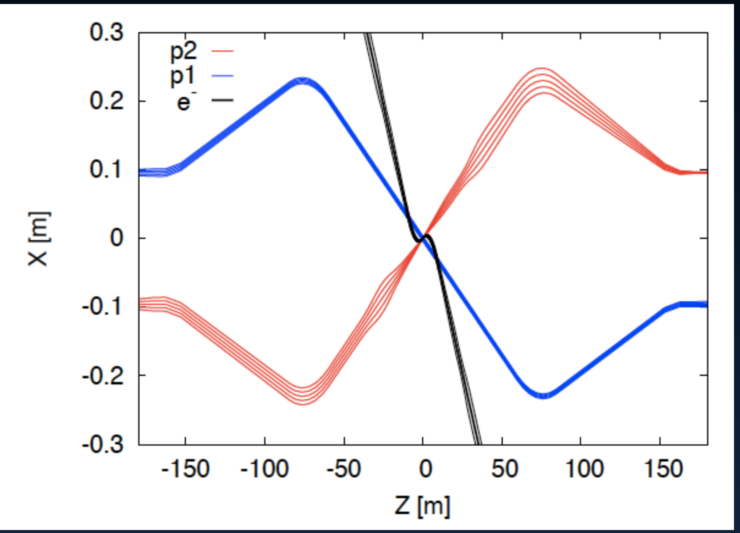


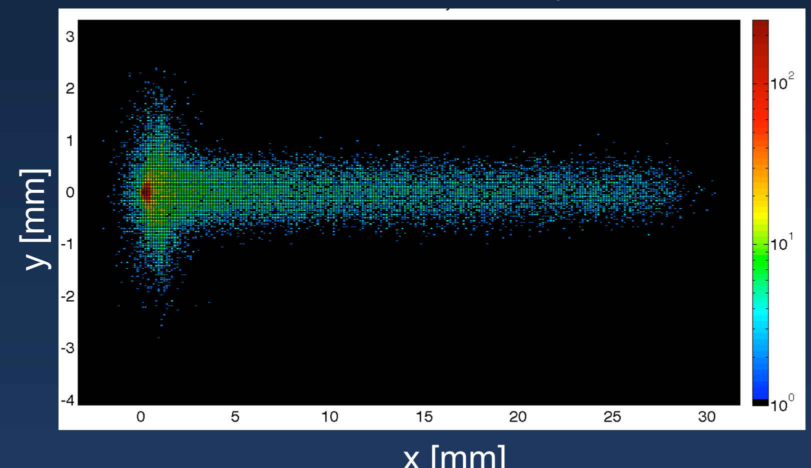
Figure 9.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam trajectories with 5σ and 10σ envelopes are shown.

Rogelio Tomas - CERN

3 beams, head-on collisions



Photon Number Density at the IP



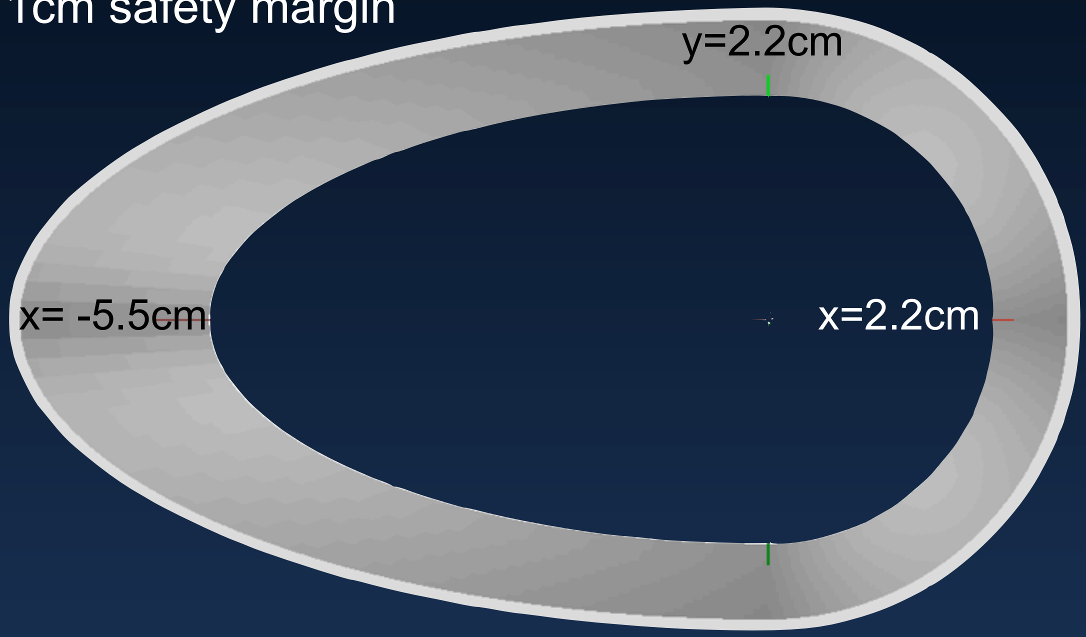
Nathan Bernard - CERN/UCLA

- Dipoles around the IP - make electrons collide head-on with *p-beam 2* & safely extract the disrupted electron beam.
- GEANT4 - simulate the SR load in the IR and design absorbers / masks shielding SR from backscattering into the detector & from propagating with $e^{\pm}$ beam.
  - SR in LR case: 49 kW, E_c= 718keV (due to large dipole field) ;
  - SR produced in RR setup: high lumi 33kW, E_c=126keV ; high acceptance 51kW, E_c=163keV.
- Beam pipe design - space for SR fan - tracking remains close to the IP / beam line (goal: 1°-179°)

Beam Pipe / Profile - SR Fan

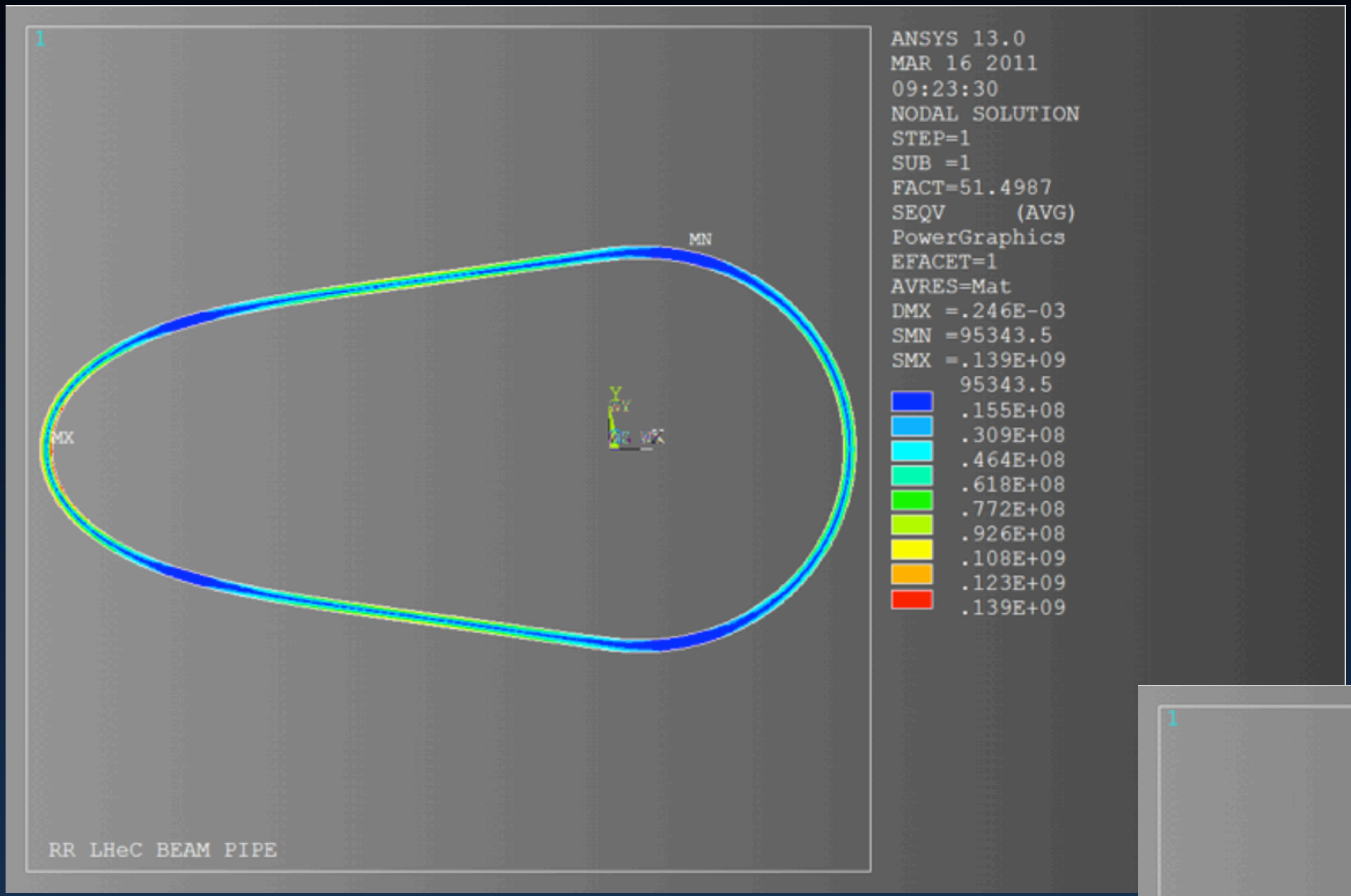
RR - Inner dimensions (masks at 6, 5, 4m - primary SR shield)
Circular(x)=2.2cm (LHC upgrade); Elliptical(-x)=-5.5, y=2.2cm

beam pipe dimensions reduced - possible using static / movable masks;
housing beam/SR envelopes + 1cm safety margin



LR - Inner Dimensions
Circular(x)=2.2cm; Elliptical(-x)=-10., y=2.2cm

Beam Pipe - ANSYS Stress Test



RR

material Be - 1.5mm wall thickness

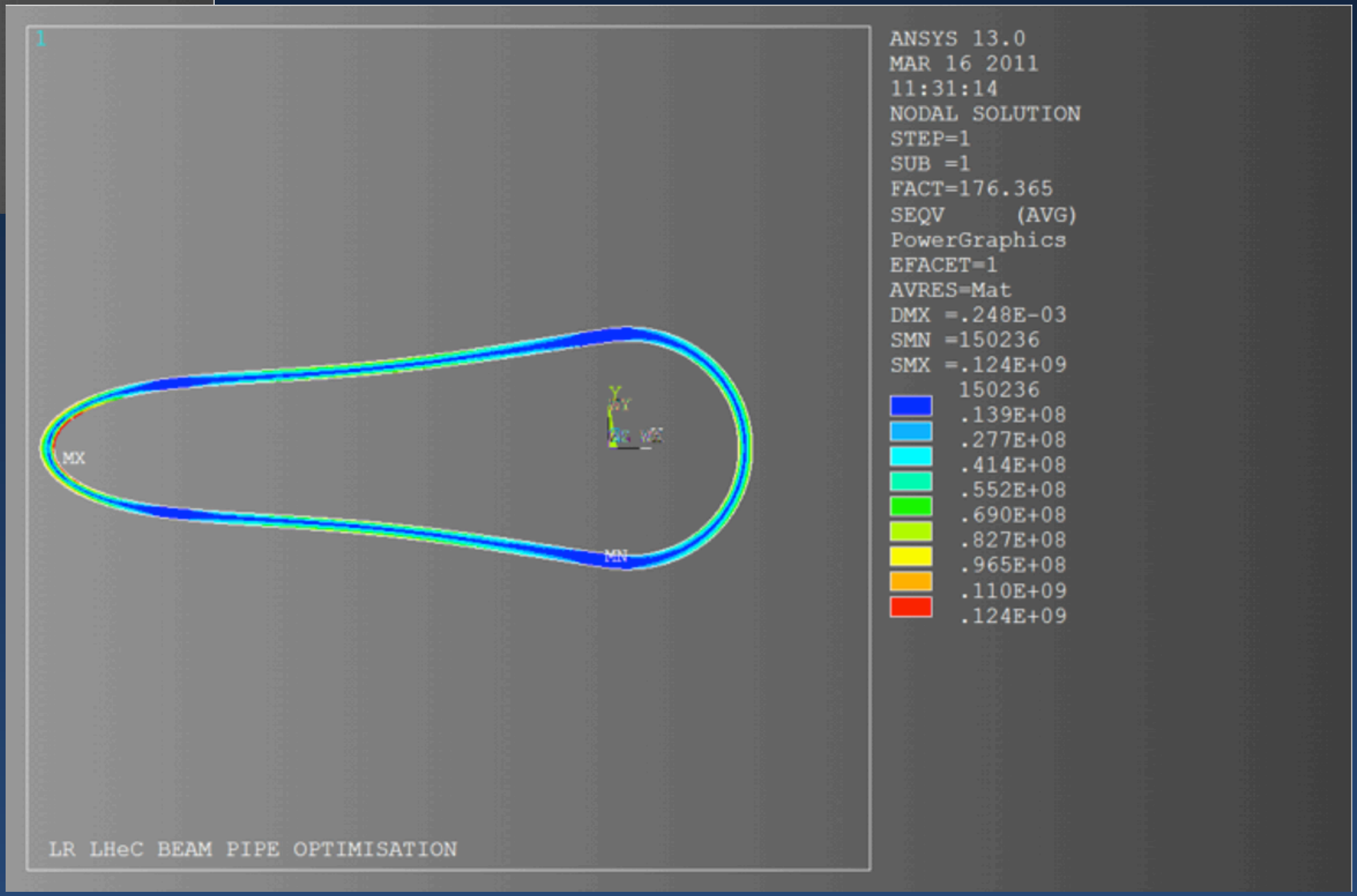
R&D: composite beampipe structures at CERN
→ smaller radiation length X_0

LR

material Be - 3mm wall thickness

Stress Test's:
Pipes would be sufficient to resist the external pressure

BUT 1^0 track passing 1.5mm thick Be wall - X/X_0=25% → R&D important



Expertise: Raymond Veness, Jonathan Bosch (CERN)

Machine Options - Impacts

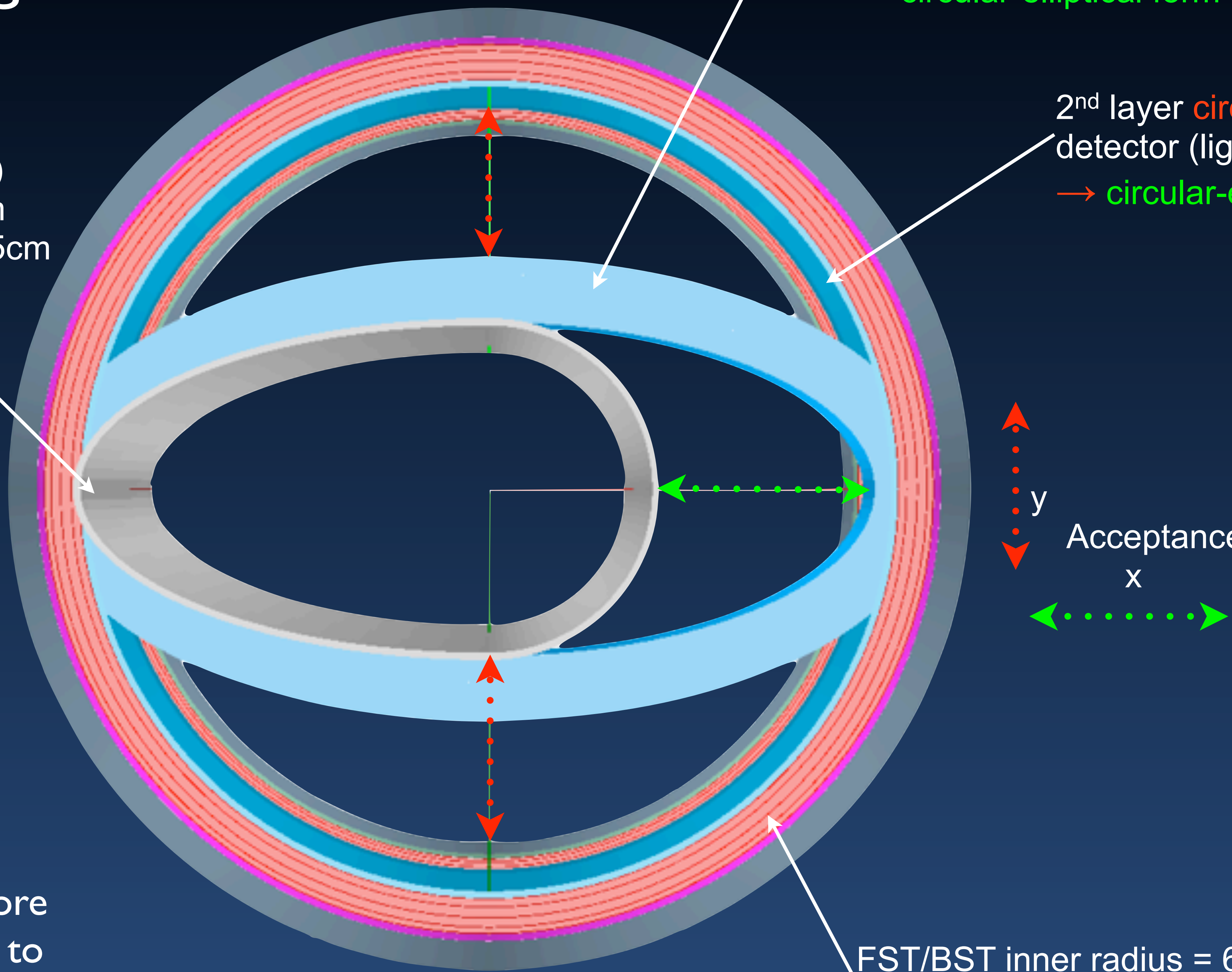
- Linac-Ring (LR)
  - 2 x 9m 0.3 T dipole over full detector length (and beyond)
- Ring-Ring (RR)
  - High Acceptance

    High Lumi option - low β-quadrupoles near to the Interaction Point

    → Detector modular / removable
    forward / backward tracker & calorimeter end-caps
- Beam Optics / Synchrotron Radiation
  - beam pipe circular-elliptical - aperture φ-dependent
    → detector design - follow BP shape

Tracker - Inner Dimensions

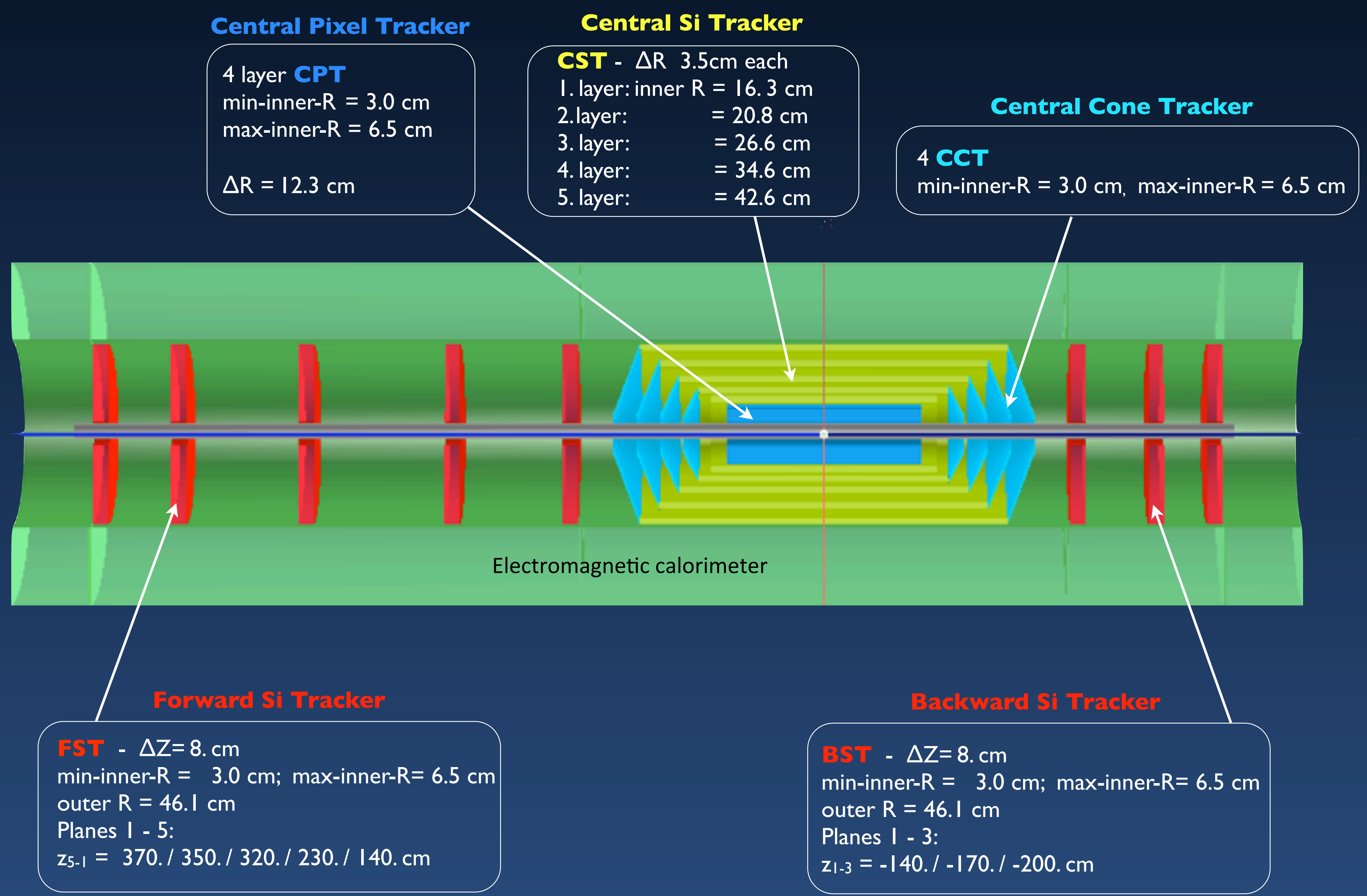
Ring-Ring



Lineaar-Ring more challenging due to extended SR fan

Tracking - High Acceptance

- Dominant forward production of dense jets; backward measurements relaxed



Tracker Dimensions

Central Tracker Barrel	CPT1	CPT2	CPT3	CPT4	CST1	CST2	CST3	CST4	CST5
Min. Inner Radius R $[cm]$	3.0	8.3	10.8	13.3	16.3	20.8	26.6	34.6	42.6
Min. Polar Angle θ $[^0]$	3.4	9.4	12.1	14.9	15.7	18.0	19.8	22.4	24.4
Max. Pseudorapidity $\|\eta\|$	3.5	2.4	2.2	2.0	1.8	1.6	1.3	1.1	0.8
ΔR $[cm]$	2	2	2	2	3.5	3.5	3.5	3.5	3.5
$\pm z$-length $[cm]$	25	25	25	25	29	32	37	42	47
Sensor Area $[m^2]$	1.3				12.4				
Central Tracker Cone-Inserts						CCT1	CCT2	CCT3	CCT4
Min. Inner Radius R $[cm]$						3.0	3.0	3.0	3.0
Min. Polar Angle θ $[^0]$						2.5	2.2	1.9	1.7
at $\pm z_{inner-R}$ [cm]						68	79	90	101
Max. Pseudorapidity $\|\eta\|$						3.8	4.0	4.1	4.2
Δv $[cm]$						3.5	3.5	3.5	3.5
Sensor Area $[m^2]$						1.5			
Forward Tracker Planes	FST1	FST2	FST3	FST4	FST5				
Min. Inner Radius R $[cm]$	3.0	3.0	3.0	3.0	3.0				
Min. Polar Angle θ $[^0]$	1.3	0.9	0.65	0.52	0.46				
at z [cm]	130	190	265	330	370				
Max. Pseudorapidity η	4.5	4.8	5.2	5.4	5.5				
Outer Radius R $[cm]$	46.1	46.1	46.1	46.1	46.1				
Δz $[cm]$	8	8	8	8	8				
Sensor Area $[m^2]$	13.1								
Backward Tracker Planes	BST1	BST2	BST3						
Min. Inner Radius R [cm]	3.0	3.0	3.0						
Max. Polar Angle θ $[^0]$	178.8	179.	179.14						
at z [cm]	-130	-170	-200						
Min. Pseudorapidity η	-4.5	-4.7	-4.9						
Outer Radius R $[cm]$	46.1	46.1	46.1						
Δz $[cm]$	8	8	8						
Sensor Area $[m^2]$	7.9								

Overlapping & double wafer design - taken into account calculating sensor areas - all preliminary

Tracker Dimensions

Central Tracker Barrel		CPT1	CPT2	CPT3	CPT4	CST1	CST2	CST3	CST4	CST5
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$\pm z$-length	$[cm]$	25	25	25	25	29	32	37	42	47
Sensor Area	$[m^2]$		1.3					12.4		
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Min. Polar Angle θ	$[^0]$						2.5	2.2	1.9	1.7
at $\pm z_{inner-R}$	[cm]						68	79	90	101
Max. Pseudorapidity $\|\eta\|$							3.8	4.0	4.1	4.2
Δv	$[cm]$						3.5	3.5	3.5	3.5
Sensor Area	$[m^2]$								1.5	
Forward Tracker Planes		FST1	FST2	FST3	FST4	FST5				
Min. Inner Radius R	$[cm]$	3.0	3.0	3.0	3.0	3.0				
Min. Polar Angle θ	$[^0]$	1.3	0.9	0.65	0.52	0.46				
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Outer Radius R	$[cm]$	46.1	46.1	46.1	46.1	46.1				
Δz	$[cm]$	8	8	8	8	8				
Sensor Area	$[m^2]$			13.1						
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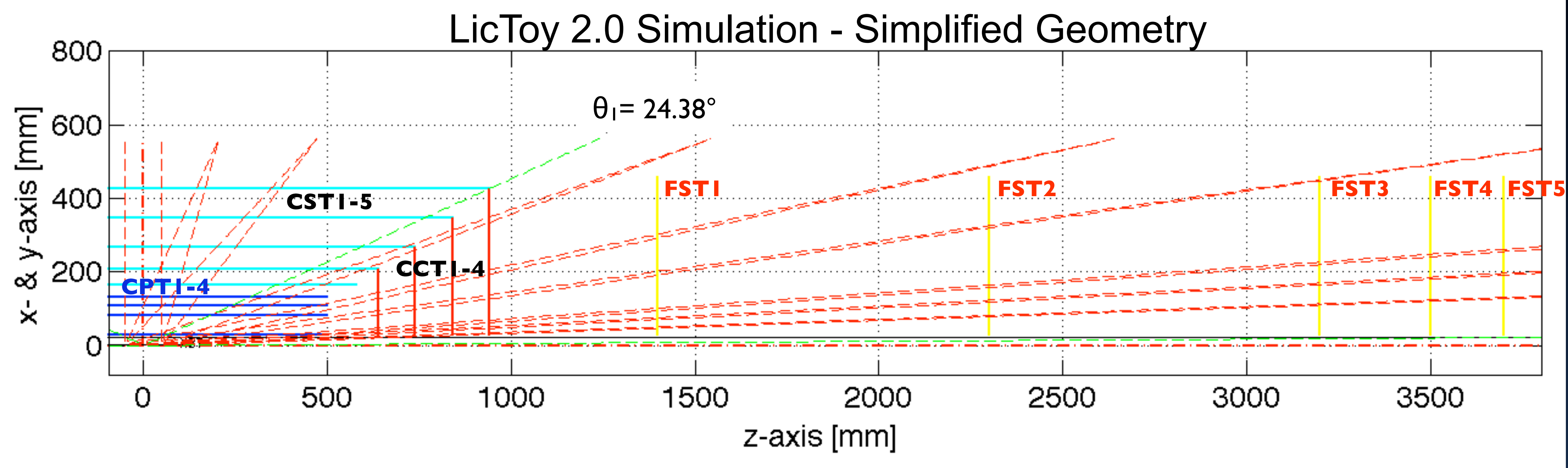
Outer Radius R	$[cm]$	46.1	46.1	46.1						
Δz	$[cm]$	8	8	8						
Sensor Area	$[m^2]$		7.9							

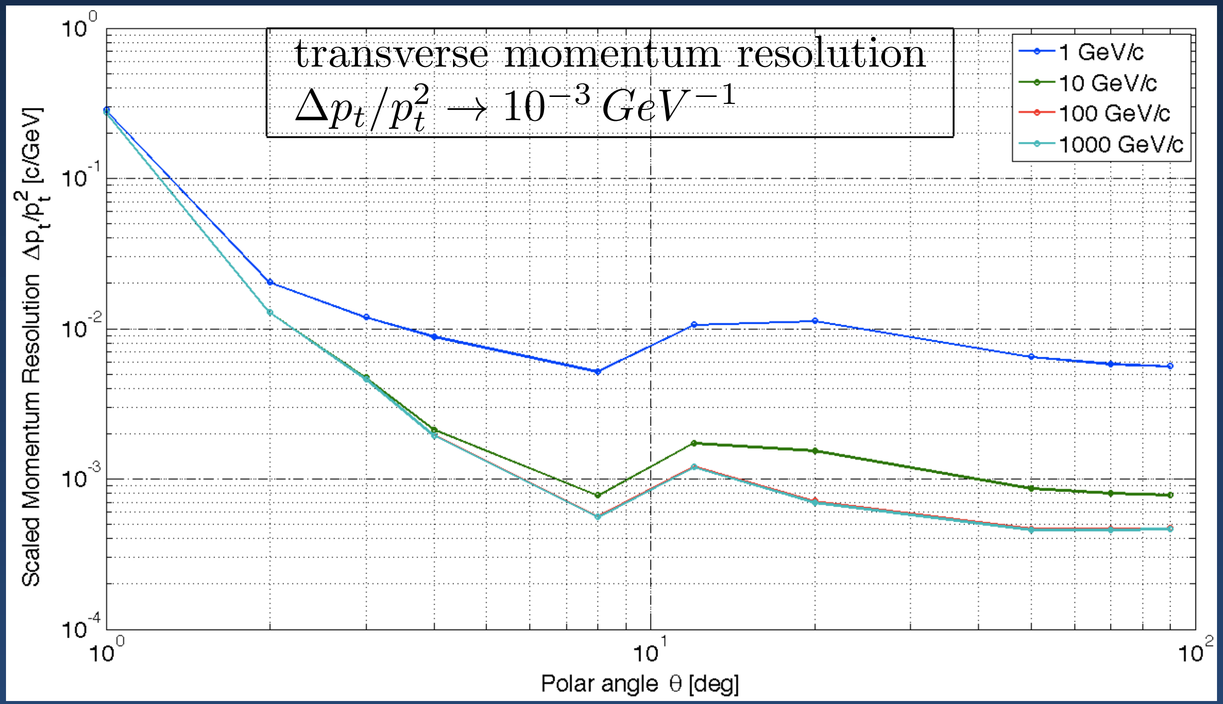
$$\sum = 36.2\,m^2$$

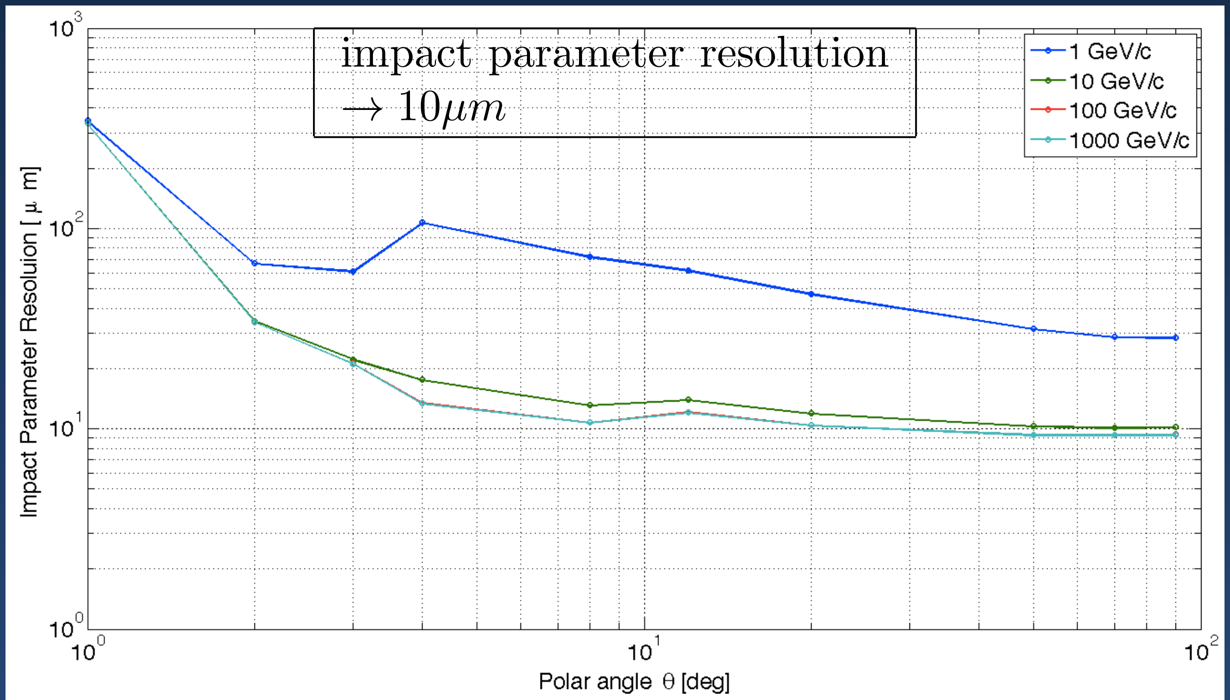
Overlapping & double wafer design - taken into account calculating sensor areas - all preliminary

Tracker Simulation

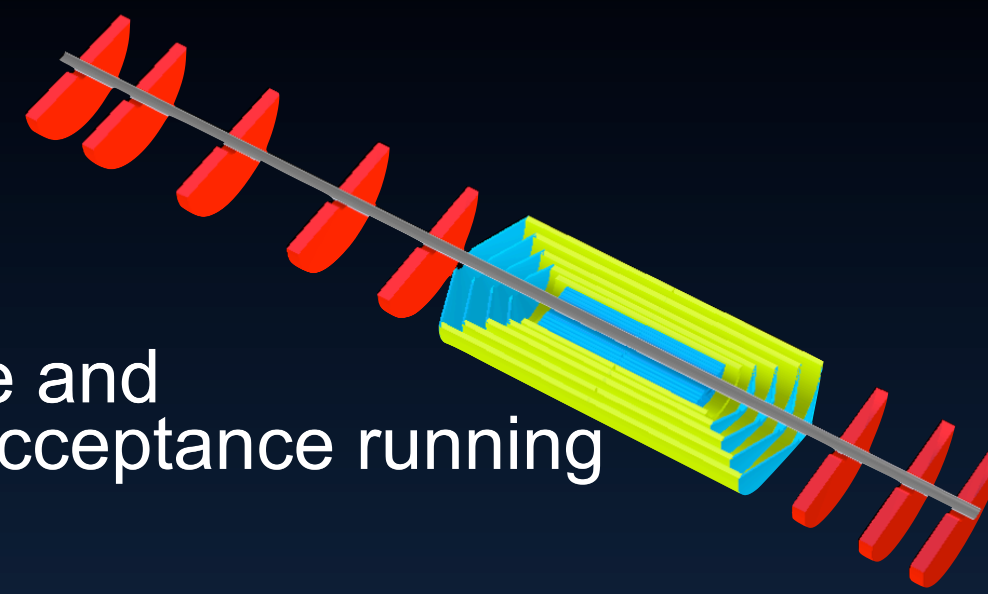
http://wwwhephy.oeaw.ac.at/p3w/ilc/lictoy/UserGuide_20.pdf







Tracking - Pixel



- Tracker technology … available today !

- Modular structure for replacement / maintenance and detector adoption: RR high luminosity / high acceptance running

- Pixel Detector*) (CPT I-4)
  barrel pixel ($1.3 m^2$ sensor area - hybrid single plane Si, overlaps incl.)
  → sensor & R/O electronic bump bonded.

  n-in-p (sLHC) or n^+-in-n (2-3x expensive) - CMS / ATLAS / LHCb

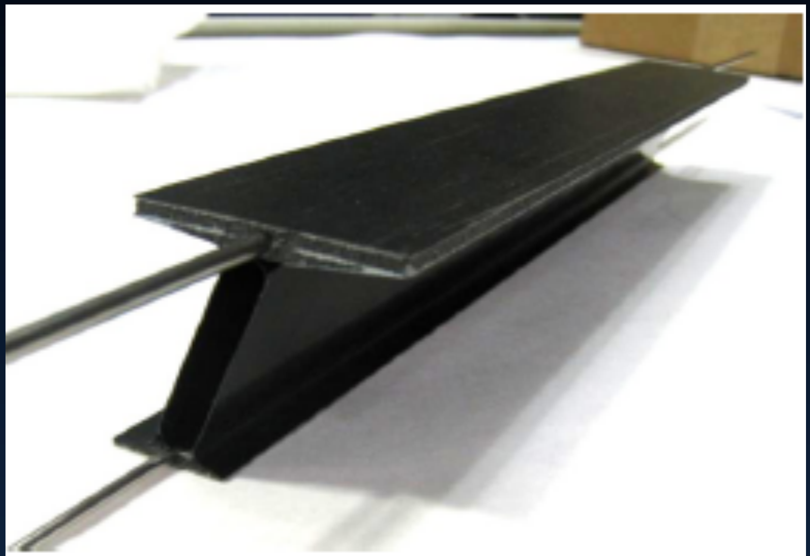
  CPT I-4 - 50μm x 250μm pixel size (FE-14 - ATLAS) or
  100μm x 150μm (ROC - CMS)

- Part of FST - pixel equipped - likely for $\Theta \leq 4°$
  Decision on inner radius FST blade equipement after detailed radiation - / track density simulation (being prepared - FLUKA/GEANT4).

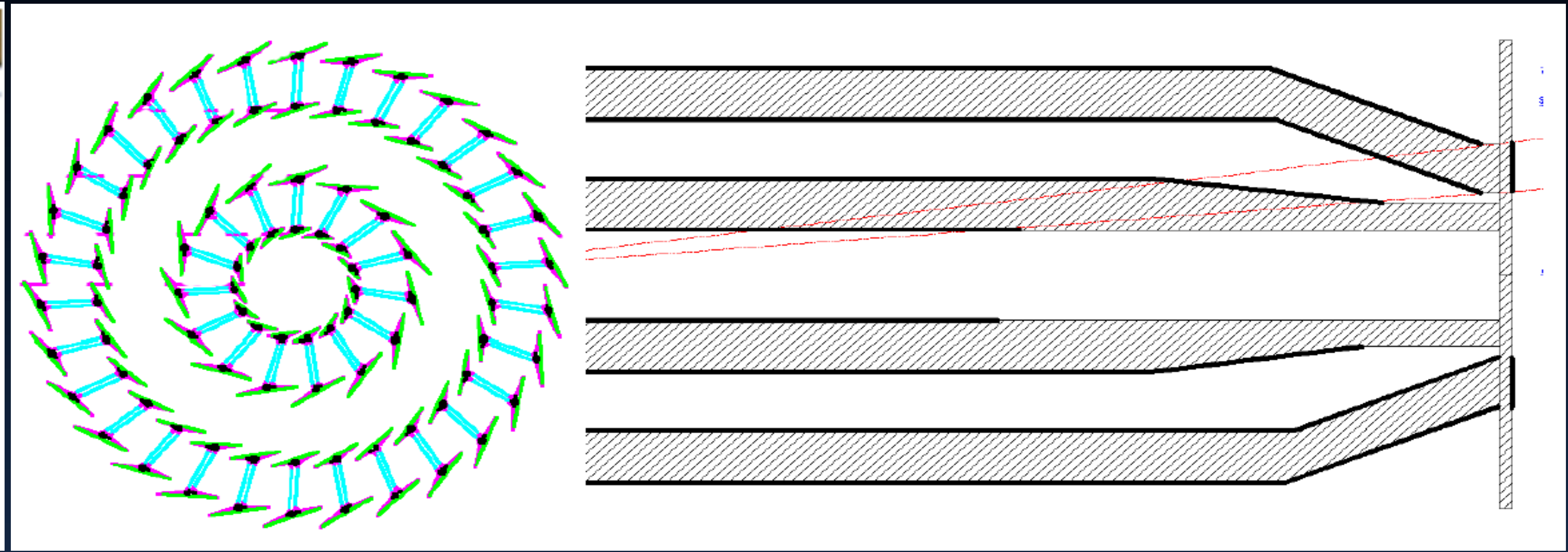
- Low power consum. & low noise & “easy” handling & ASICs available

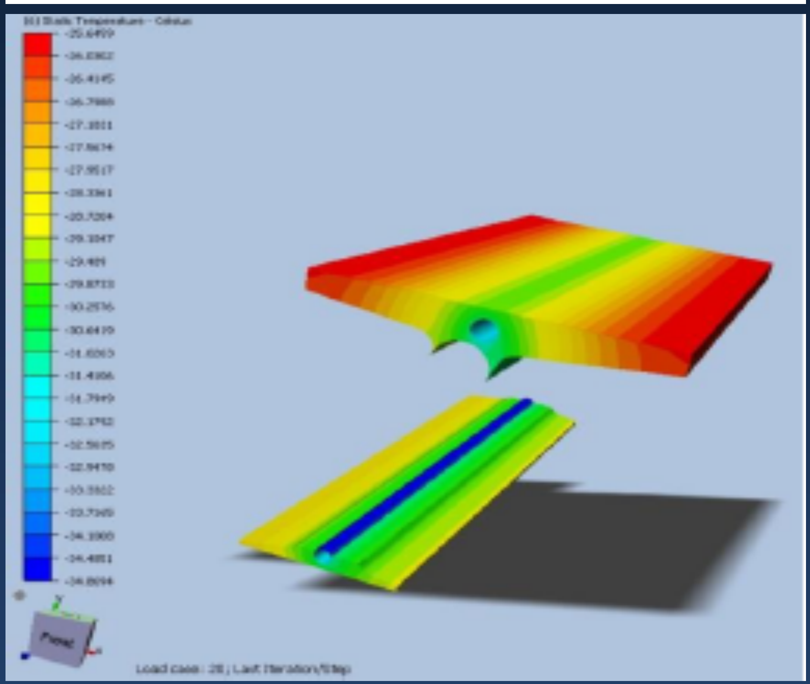
*) discussed by N.Wermes (1st CERN-ECFA Workshop on the LHeC - 2008): Silicon Pixel detectors for Tracking;
R.Horrisberger (CMS Tracker Week La Biodola, Isola d’ Alba - 2010: Tracking at Phase II - Pixel, Strixel & Strips;
P.Allport (3rd CERN-ECFA-NuPECC Workshop on the LHeC - 2010: “Conventional” Silicon Pixel/Strip Tracker; …

Material Reduction (ATLAS Upgrade)



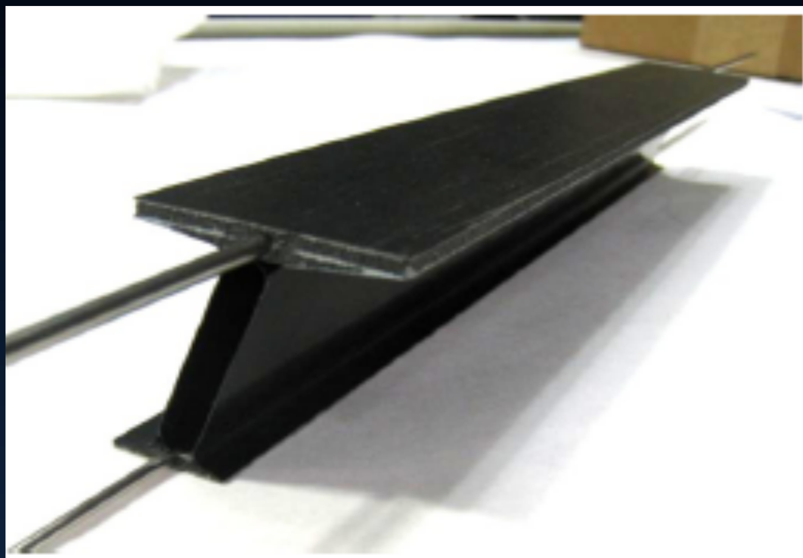
I-beam prototype, LBNL 2010



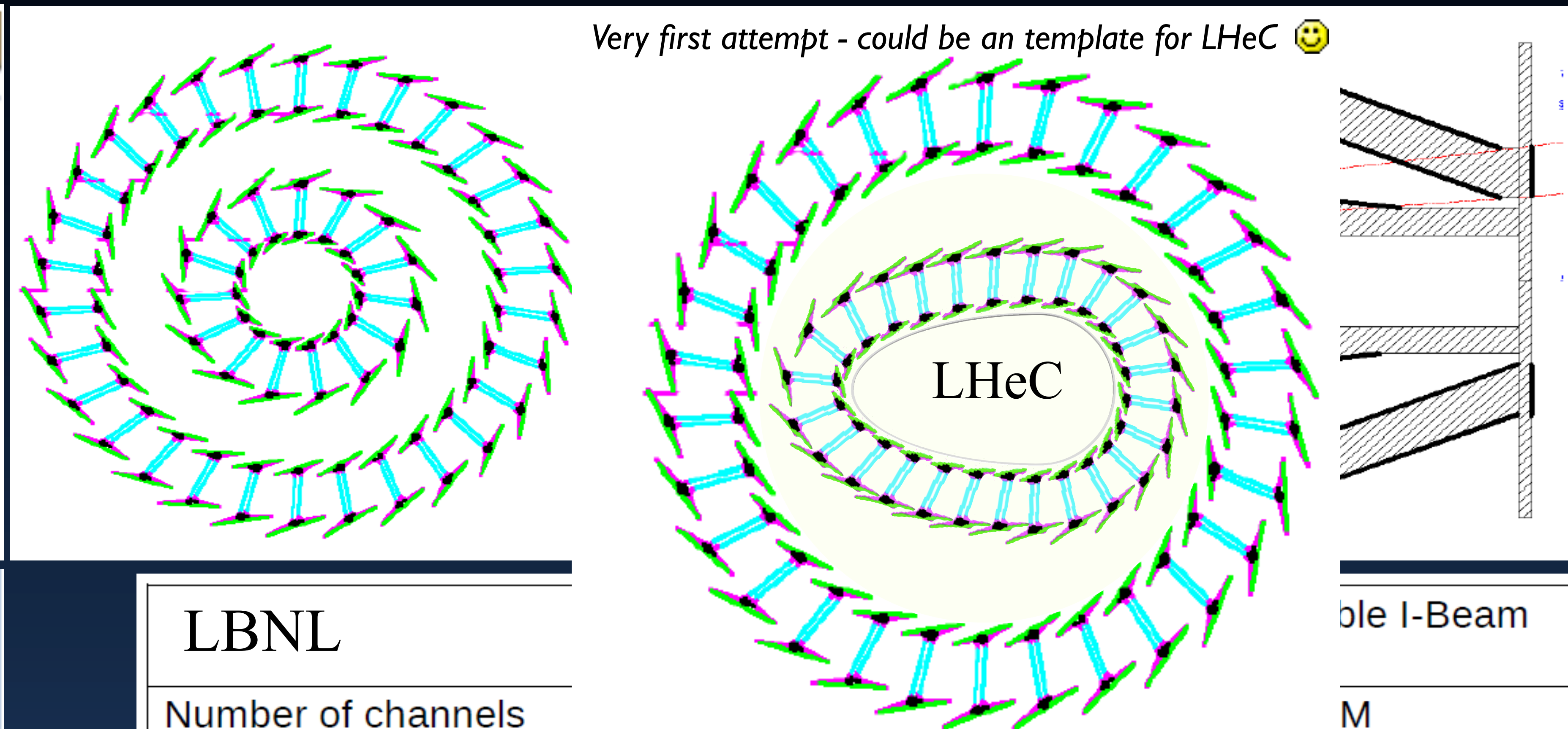


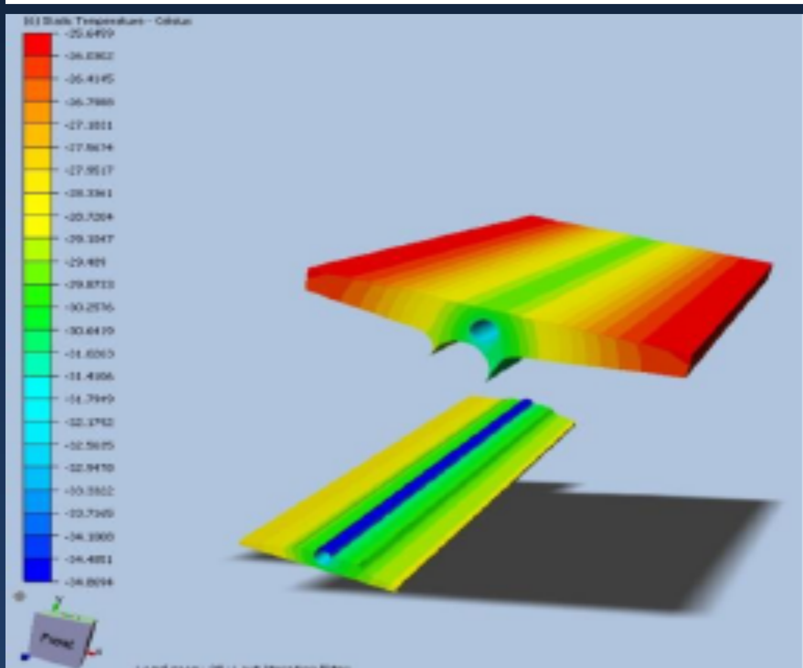
LBNL	Present detector + IBL	Double I-Beam
Number of channels	92 M	276 M
Global supports mass	8.3 kg	2.1 kg
Local supports mass	6.6 kg	5.6 kg (meas.)
Silicon mass equivalent of all mechanics	5.7 kg	2.8 kg
Sensor + chip mass	2.9 kg	4.4 kg (*)
Total silicon equivalent	8.7 kg	7.2 kg

Material Reduction (ATLAS Upgrade)



I-beam prototype, LBNL 2010





LBNL		ble I-Beam
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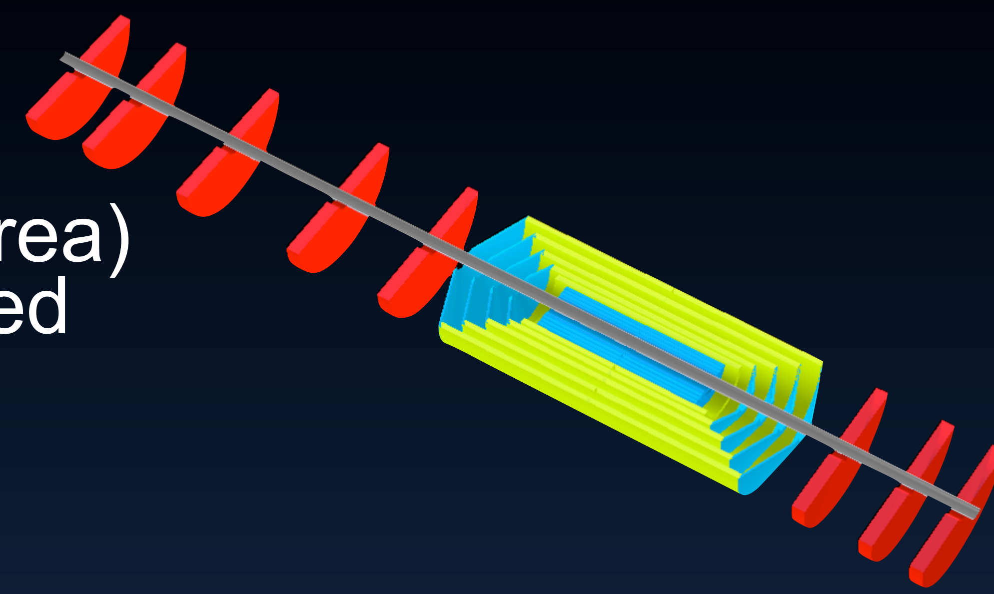
Central Tracking - Strip



- **CST** - 5 barrel layer strip (13.1 m^2 sensor area)
  → sensor & R/O electronic wire bonded

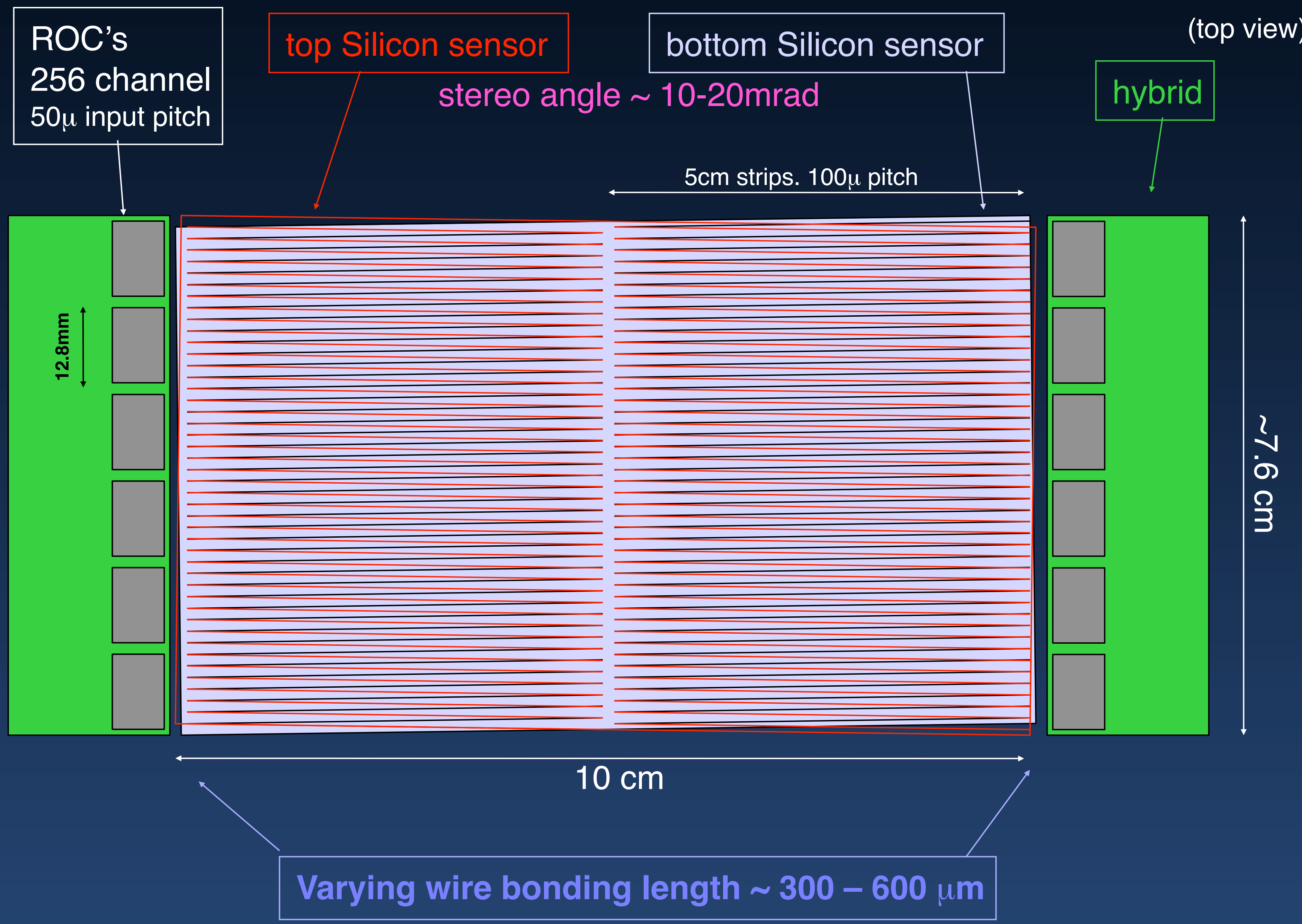
- 100µm pitch, 5cm strip length

- "Two-in-One" Strip - Modules - CMS:

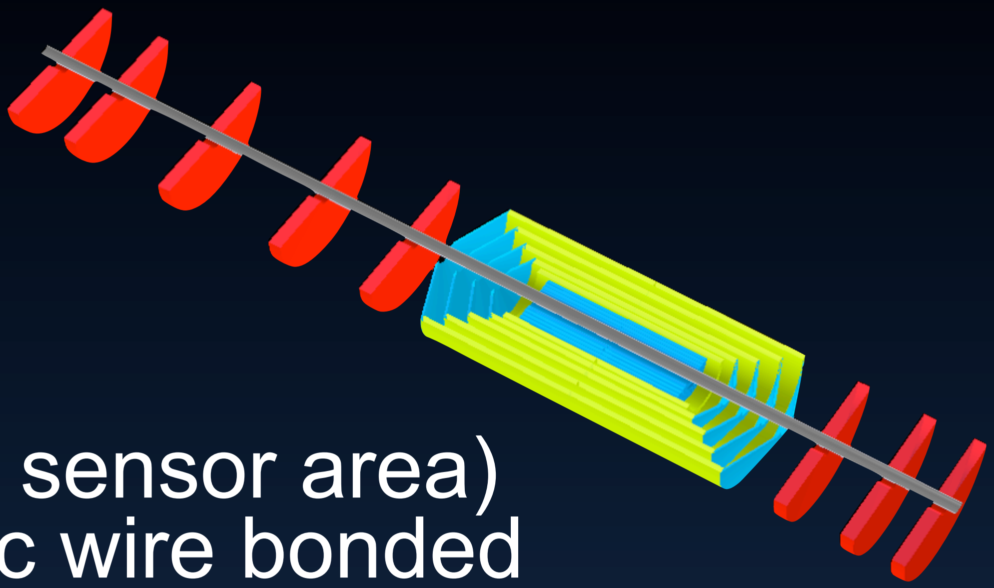
  - Cost of a normal TOB module (~40 CHF/cm^2) → extra Si-detector < +8 CHF/cm^2)
  - "Two-In-One" TOB modules can be configured as pt-triggering or stereo layers
  - Connectivity for upper to lower sensor signals solved with no extra power
  - Low mass construction by double use of hybrid infrastructure (power, cooling, . .)
  - Wire-bond construction very conventional and simple → technology at hand
  - Low power pt-signal correlation due to local neighbour channel communication
  - CBC short Strip ROC with binary signals would be perfect for this job.

Roland Horrisberger (PSI), CMS Tracker Week La Biodola, Isola d' Alba - 2010: Tracking at Phase II - Pixel, Strixel & Strips

"Two-In-One" Design as Stereo modules



Forward/Backward Tracking - Strip



- FST / BST - 5 / 3 disk strip (12.4 m^2 sensor area)
  → sensor & R/O electronic wire bonded

  Part of FST - pixel equipped - likely for $\Theta \leq 4°$
  Decision on inner radius FST blade equipement after detailed radiation - /track density simulation.

- 100µm pitch, 5cm strip length

- "Two-in-One" Strip - Modules - CMS inspired as for CST

Mechanics of Disks

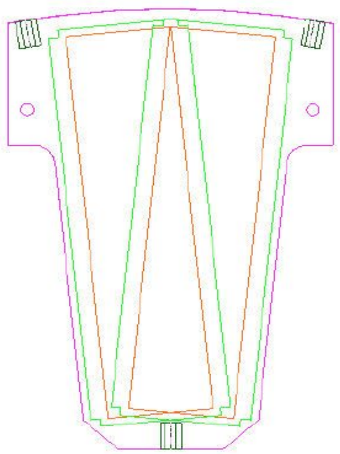
Inner & outer ring of blades

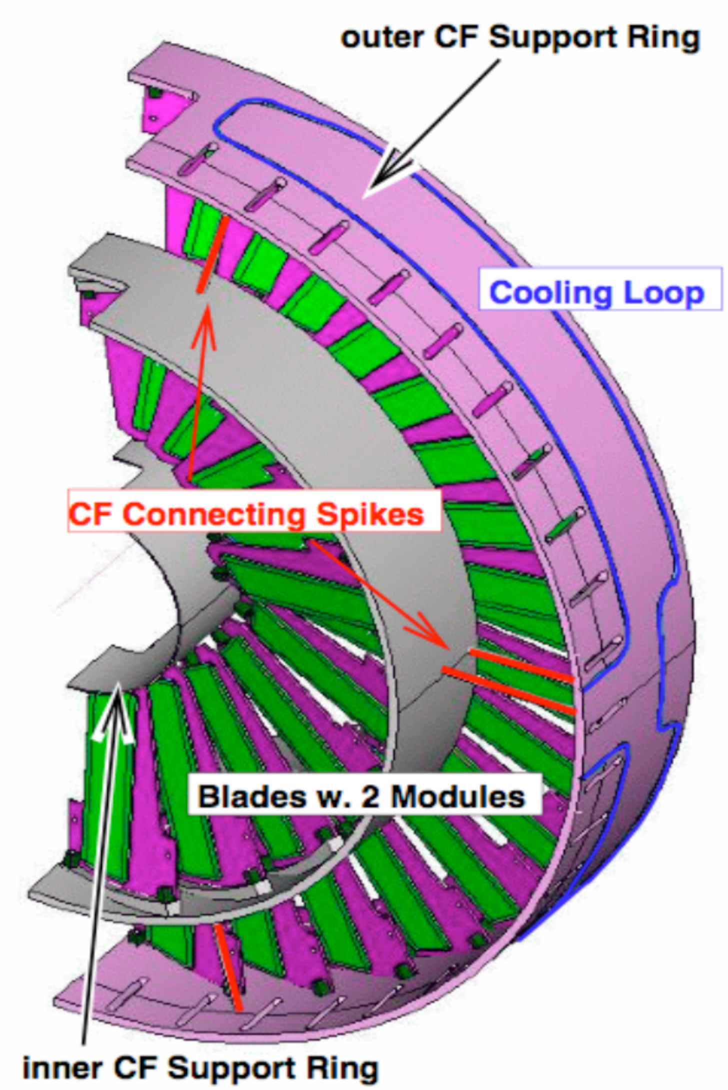
CO_2 tubes embedded in half disk support:

- support cylinder:
  - Carbon carbon
  - Grooves for cooling tube
  - Stainless steel tube:
  - 1.8mm OD, 100μm wall

Blades:

- all identical
- Rotated by 20° radial
- Tilted by 12° (inner ring)
- 2 modules per blade (ϕ overlap)
- individually replaceable





Shapes towards BP: half circular / half elliptical

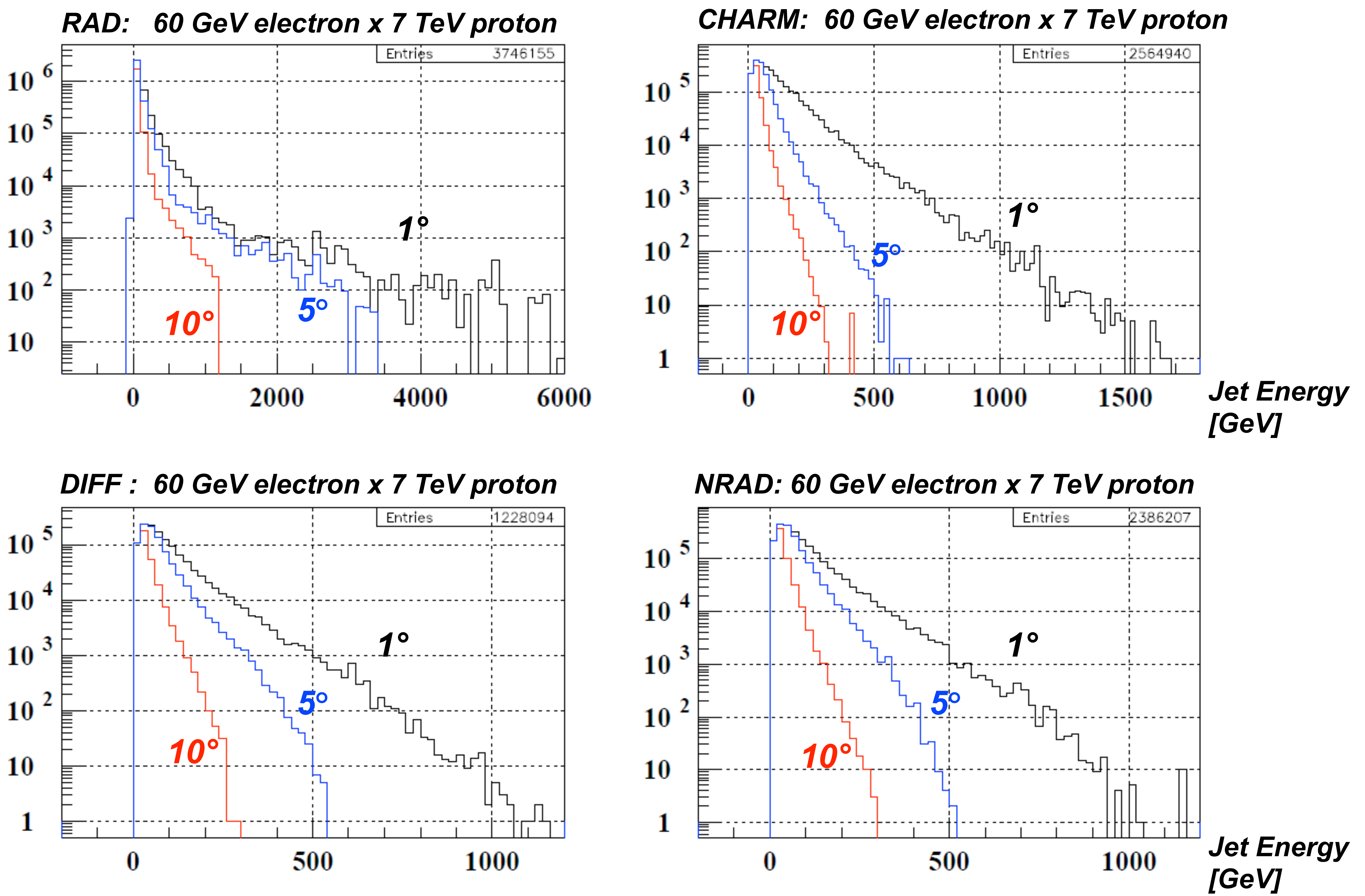
Reminder (fwd energy)

RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

HzTooL-4.2 (H.Jung et.al. - http://projects.hepforge.org/hztool/)

selection: q^2.gt.5

→ **Highest acceptance desirable**



Design Arguments

- Electron
  - final state: high resolution for final states
  - DIS: precision calibration employing over-constrained kinematics
    $10\%/\sqrt{E}$ calibrated using the kinematic peak
  - acceptance: large angle acceptance to measure at low $Q^2 \geq 1$ GeV^2

- Hadrons
  - jets: few TeV in forward direction
  - DIS: precision calibration of E_h (p_{th} / p_{te} balance at low y)
    $40\%/\sqrt{E}$ (or better) calibrated with p_{th} /p_{te} to 1% accuracy
  - acceptance: measure hadronic energy down to few degrees

- Heavy Flavour Physics
  - efficient c and b tagging towards large $|\eta|$
- Diffractive Processes and eD
  - forward tagging of p, n, d

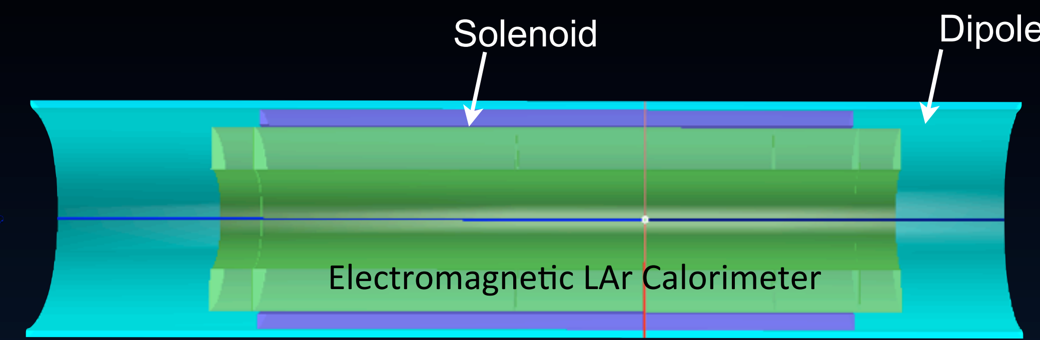
- accurate luminosity measurement (difficult) and efficient e/γ tagging in backward direction

Calorimeter Dimensions

E-Calo Parts Barrel			FEC3	FEC	EMC	BEC	BEC3		
Inner Radius [cm]			48	48	48	48	48		
Outer Radius [cm]			88	88	88	88	88		
z-length [cm]			40	250	250	80	40		
Volume $[m^3]$					11.3				
E-Calo Parts Inserts	FEC1	FEC2						BEC2	BEC1
Inner Radius [cm]	6	21						21	6
Min. Polar Angle θ $[^0]$	0.91	3.2						5.8	1.6
Max. Pseudorapidity η	+4.8	+3.6						3.6	4.8
Outer Radius [cm]	20	46						46	20
z-length [cm]	40	40						40	40
Volume $[m^3]$	0.3							0.3	
H-Calo Parts barrel			FHC4	FHC	HAC	BHC	BHC4		
Inner Radius [cm]			115	115	115	115	115		
Outer Radius [cm]			255	255	255	255	255		
z-length [cm]			217	250	250	80	187		
Volume $[m^3]$					118.6				
H-Calo Parts Inserts	FHC1	FHC2	FHC3				BHC3	BHC2	BHC1
Inner Radius [cm]	6	21	48				48	21	6
Min. Polar Angle θ $[^0]$	0.82	2.9						176.3	175.1
Max/Min Pseudorapidity η	+4.9	+3.7						-3.2	-4.4
Outer Radius [cm]	20	46	88				88	46	20
z-length [cm]	177	177	177				147	147	147
Volume $[m^3]$		1.2						0.8	

tentative: $\sum = 132\,m^3$

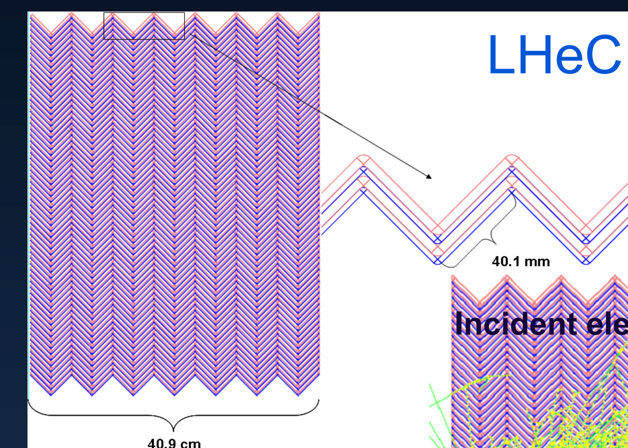
LHeC EM Calorimeter

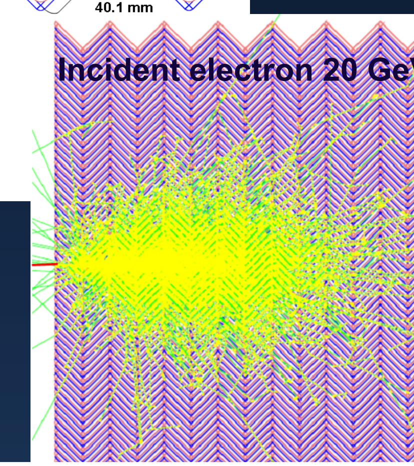


Baseline Electromagnetic Calorimeter

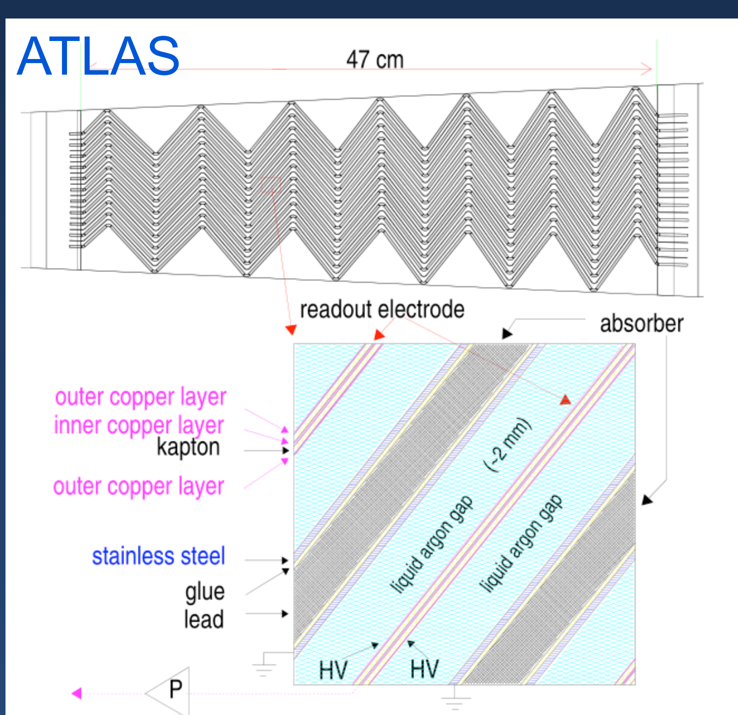
barrel cryostat being carefully optimized - pre-sampler optimal
3 different granularity sections longitudinally

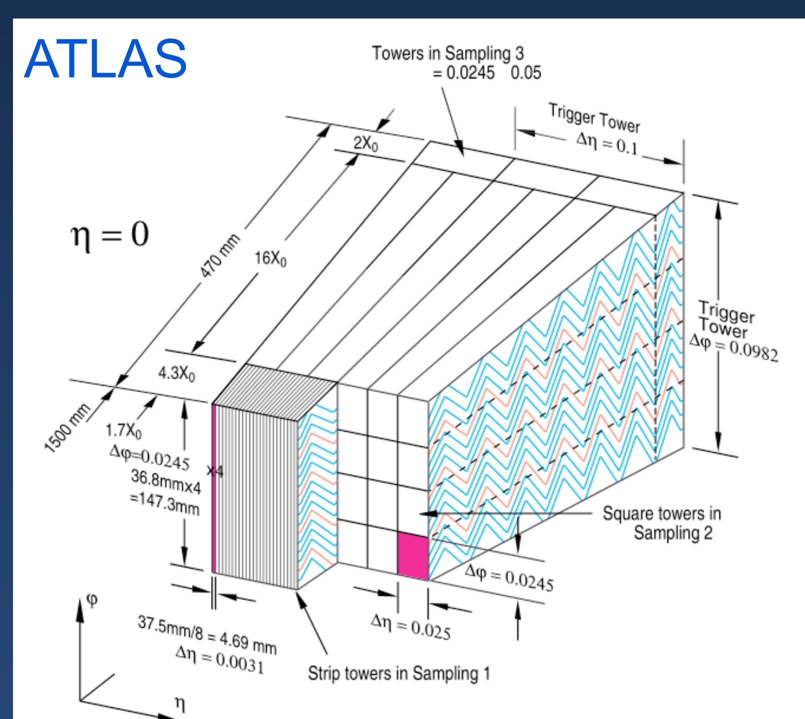
- LAr for barrel EMC calorimetry - ATLAS (~25-30 X_0)
  - Advantage: same cryostat used for solenoid and dipoles
  - cryostat → trickily routing of services for inner detector (tracker)
  - GEANT4 simulation
  - Simulation results compatible with ATLAS

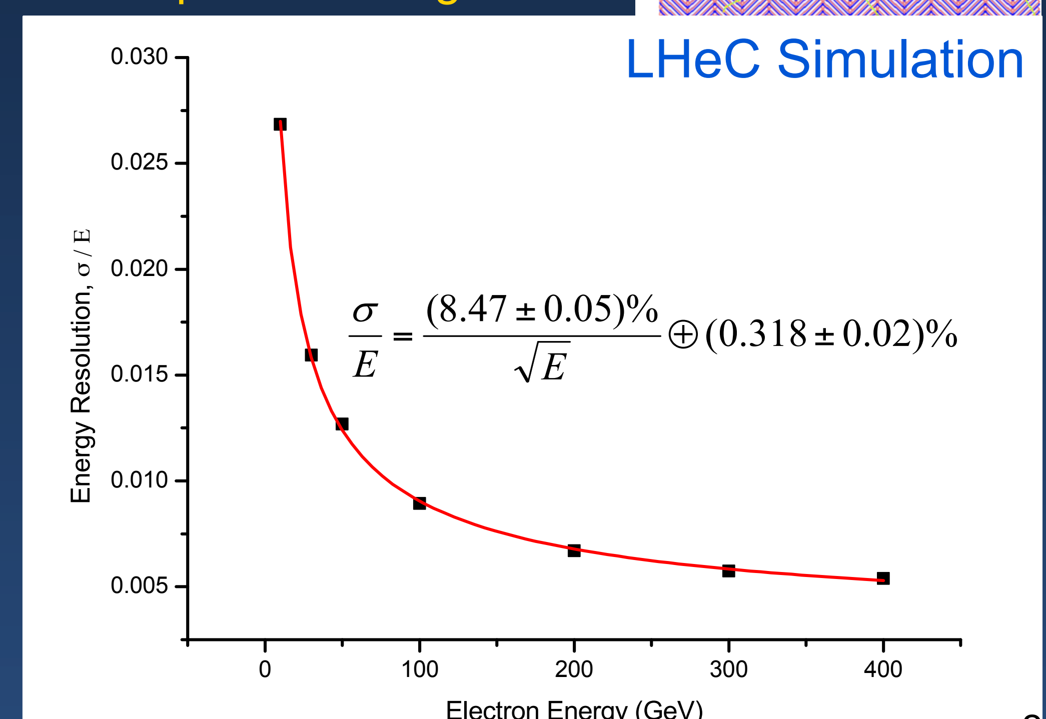




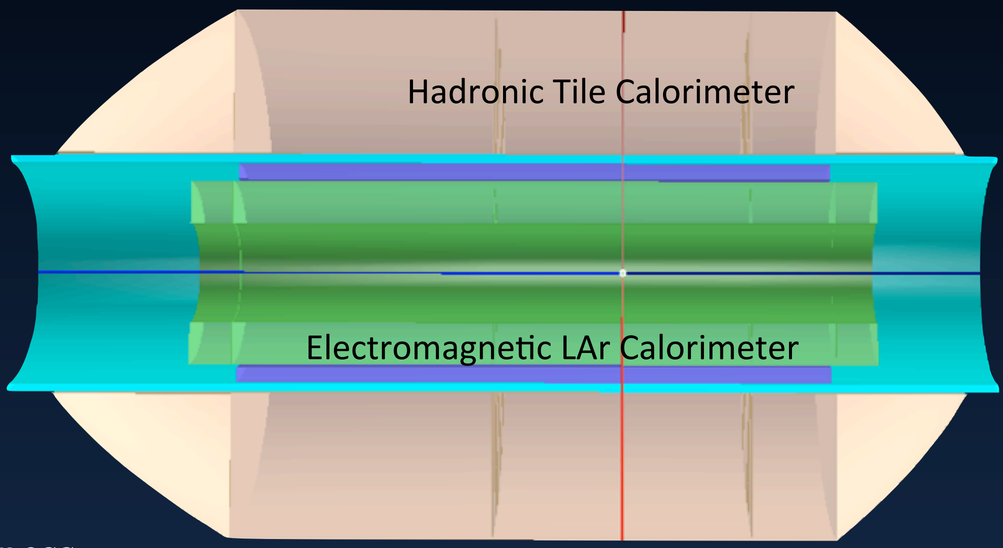
Fatma Kocak,
Ihan Tapan Uludag Univ.







LHeC HA Calorimeter



Baseline Hadronic Calorimeter

- HAC iron absorber (magnet return flux)
  + scintillating plates (similar to ATLAS TILE CAL)
  Interaction Length: ~7-9 λ_I

  Setup:

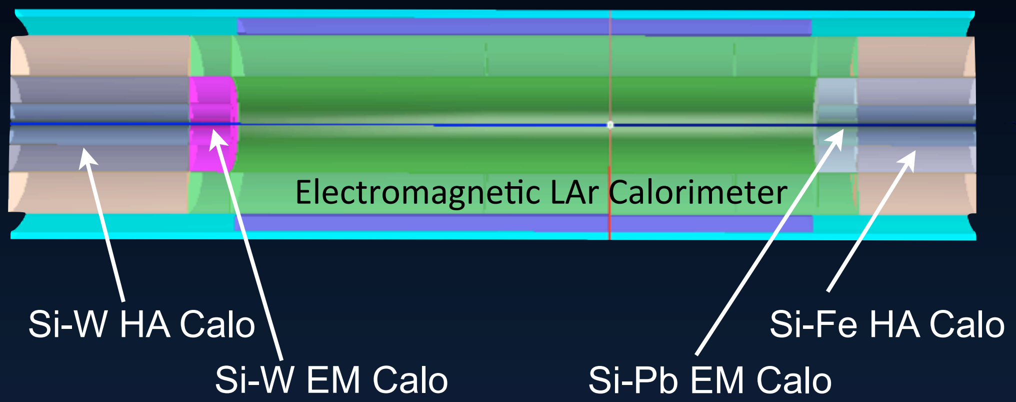
Tile Rows	Height of Tiles in Radial Direction	Scintillator Thickness
1-3	$97mm$	$3mm$
4-6	$127mm$	$3mm$
7-11	$147mm$	$3mm$

- GEANT4 simulation*)
  - performance optimization
    containment, resolution, combined HAC & EMC response -
    solenoid/dipole/cryostat in between

*) Fatma Kocak, Ilhan Tapan - Uludag University

LHeC End-Cap Calorimeters

Baseline
Very Forward/Backward Calorimeters



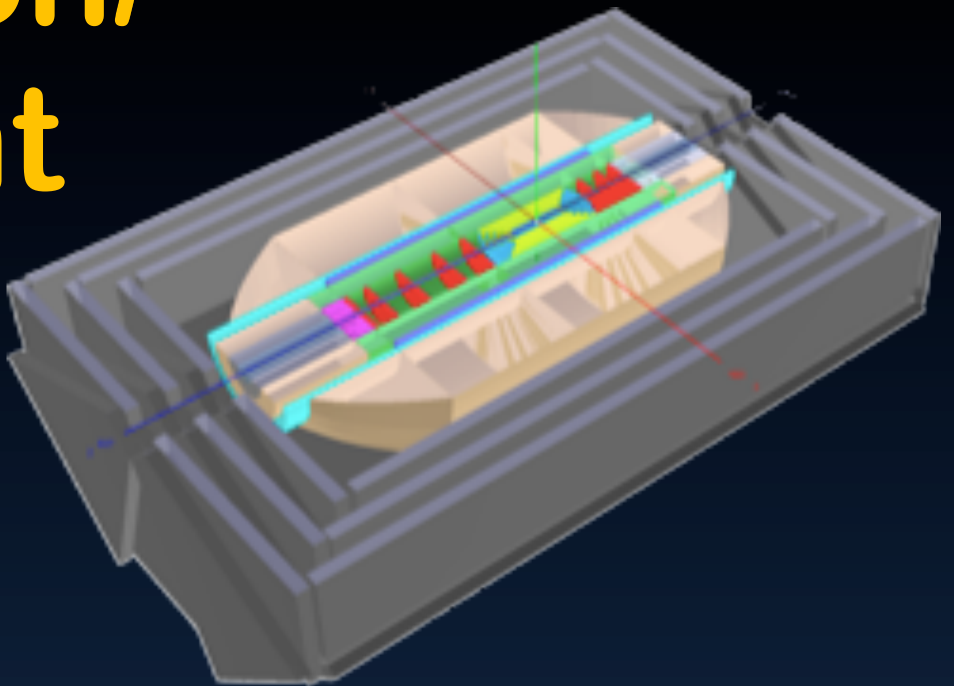
- Forward FEC + FHC:
  tungsten high granularity - Si (rad-hard) - high energy jet resolution
  FEC: ~$30X_0$; FHC: ~8-10 λ_I

- Backward BEC + BHC:
  need precise electron tagging - Si-Pb, Si-Fe/Cu (~$25X_0$, 6-8 λ_I)

- GEANT4 simulation*)
  - containment, multi-track resolution (fwd)

*) Adnan Kilic, Ilhan Tapan - Uludag University

Muon Detection/ Measurement



- Physics:
  - Heavy flavour
  - Vector Mesons
  - Diffraction etc.
- HERA Experience:
  - Beam background understanding / shielding essential (fwd)
  - Running in conjunction with tracking (forward) and CAL has shown to be very important both for trigger and RO
- LHeC Different Energy Range. Large acceptance extends the LHeC physics potential
- Detector technologies
  - Detector technologies available (LHC) and very active R&D developments ongoing (sLHC)
- Magnet design essential for an independent momentum measurements - inner solenoid vs. outer solenoid - instr. Fe vs. 2 solenoids

Summary

- The design of the LHeC detector depends heavily on the constraints from the machine and interaction region.
- For all cases a feasible and affordable design which fulfills the physics requirements has been presented.

- The experiment solenoid & dipoles are placed between EMC and HAC.
- Large acceptance & small solenoid detector (with dipoles) is baseline detector.

- Tracker: central pixel, central strip, cones, fwd/bwd disks.
- Calorimeter: barrel LAr+Tile (ATLAS), specific fwd/bwd end-caps.
- Muon: instrumented Fe for tagging and combined momentum measurement.
- Large solenoid option: best calorimeter resolution, full and independent muon momentum measurement possible.

Thank you for your Attention

LHeC

CST - ΔR 3.5cm each
1. layer: inner R = 16. 3 cm
2. layer: = 20.8 cm
3. layer: = 26.6 cm
4. layer: = 34.6 cm
5. layer: = 42.6 cm

4 **CCT**
min-inner-R = 3. cm, max-inner-R = 6.5 cm

FST - ΔZ= 8. cm
min-inner-R = 3. cm; max-inner-R= 6.5 cm
outer R = 46.1 cm
Planes 1 - 5:
z_{1-5} = 140. / 230. / 320. / 350. / 370. cm

4 layer **CPT**:
min-inner-R = 2.8cm
max-inner-R = 6.5cm

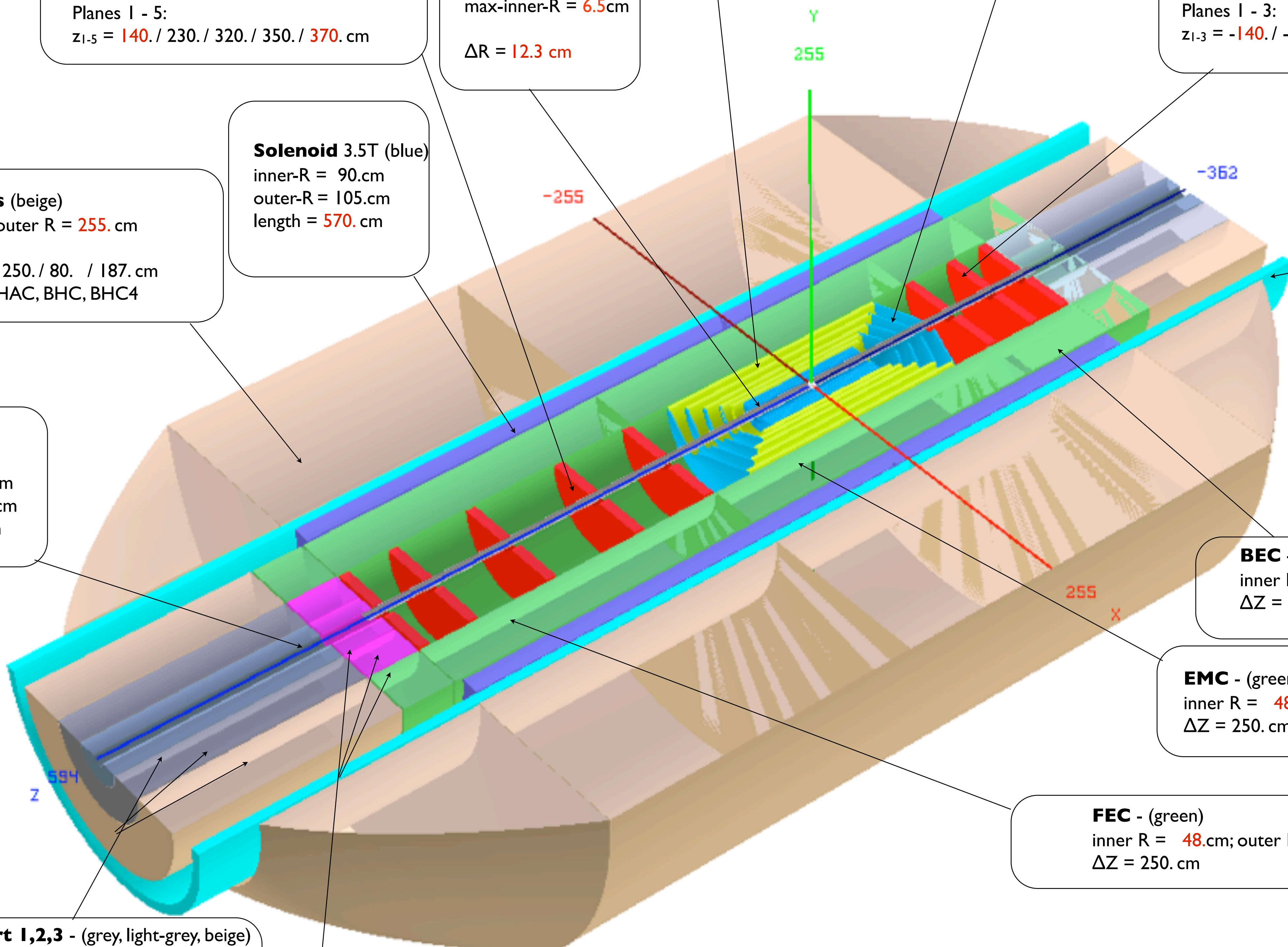
ΔR = 12.3 cm

BST - ΔZ= 8. cm
min-inner-R = 3. cm; max-inner-R= 6.5 cm
outer R = 46.1 cm
Planes 1 - 3:
z_{1-3} = -140. / -170. / -200. cm

Solenoid 3.5T (blue)
inner-R = 90.cm
outer-R = 105.cm
length = 570. cm

HAC - 5 Modules (beige)
inner R = 115. cm; outer R = 255. cm
Modules 1 - 5:
ΔZ_{1-5} = 217. / 250. / 250. / 80. / 187. cm
FHC4, FHC, HAC, BHC, BHC4

Fwd/Bwd **Dipoles** 0.3T
inner-R = 90.cm
outer-R = 105.cm length = 362. cm
length = 592. cm



Circ-Ellipt. **Beam Pipe**:
min-inner-R = 2.2cm
max-inner-R = 5.5cm
thickness = 1.5mm

BEC - (green)
inner R = 48.cm; outer R = 88. cm
ΔZ = 80. cm

EMC - (green)
inner R = 48.cm; outer R = 88. cm
ΔZ = 250. cm

FEC - (green)
inner R = 48.cm; outer R = 88. cm
ΔZ = 250. cm

FHC/BHC Insert 1,2,3 - (grey, light-grey, beige)
inner R = 6. cm; outer R = 20. cm
inner R = 21. cm; outer R = 46. cm
inner R = 48. cm; outer R = 88. cm

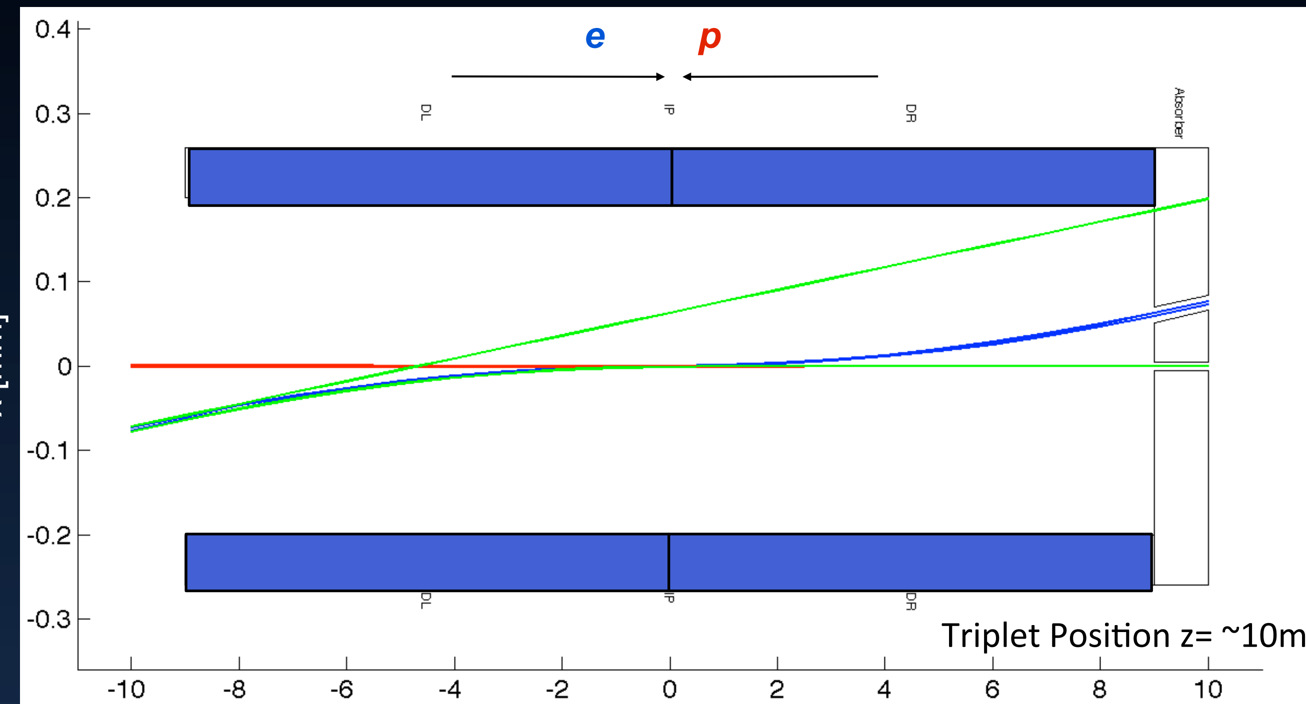
FHCx: ΔZ = 177. cm BHCx: ΔZ = 147. cm

FEC Insert 1,2,3 - (pink, pink, green)
inner R_1= 6.0 cm; outer R = 20. cm
inner R_2= 21. cm; outer R = 46. cm
inner R_2= 48. cm; outer R = 88. cm
ΔZ = 40. cm

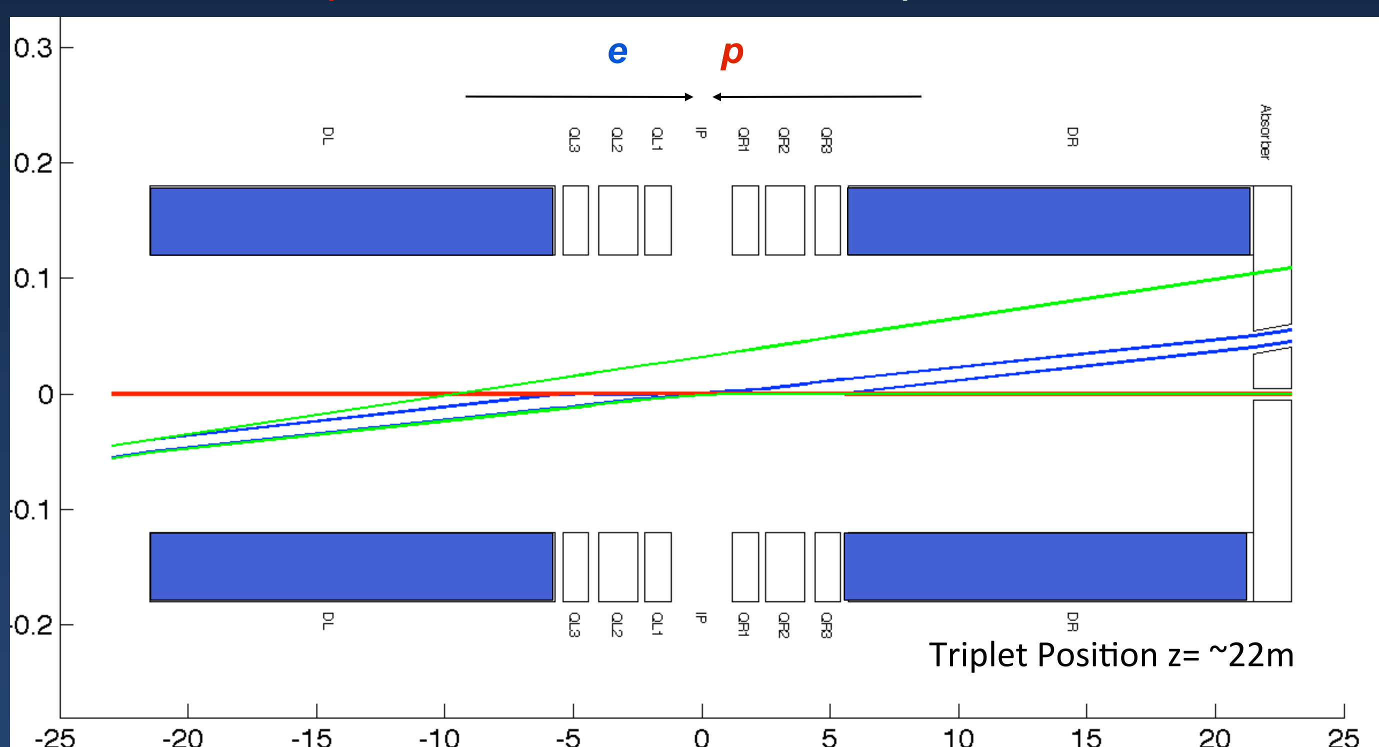
LR, RR option - Beam & SR

SR Fan growth with z

LR Option - Beam & Fan Envelopes



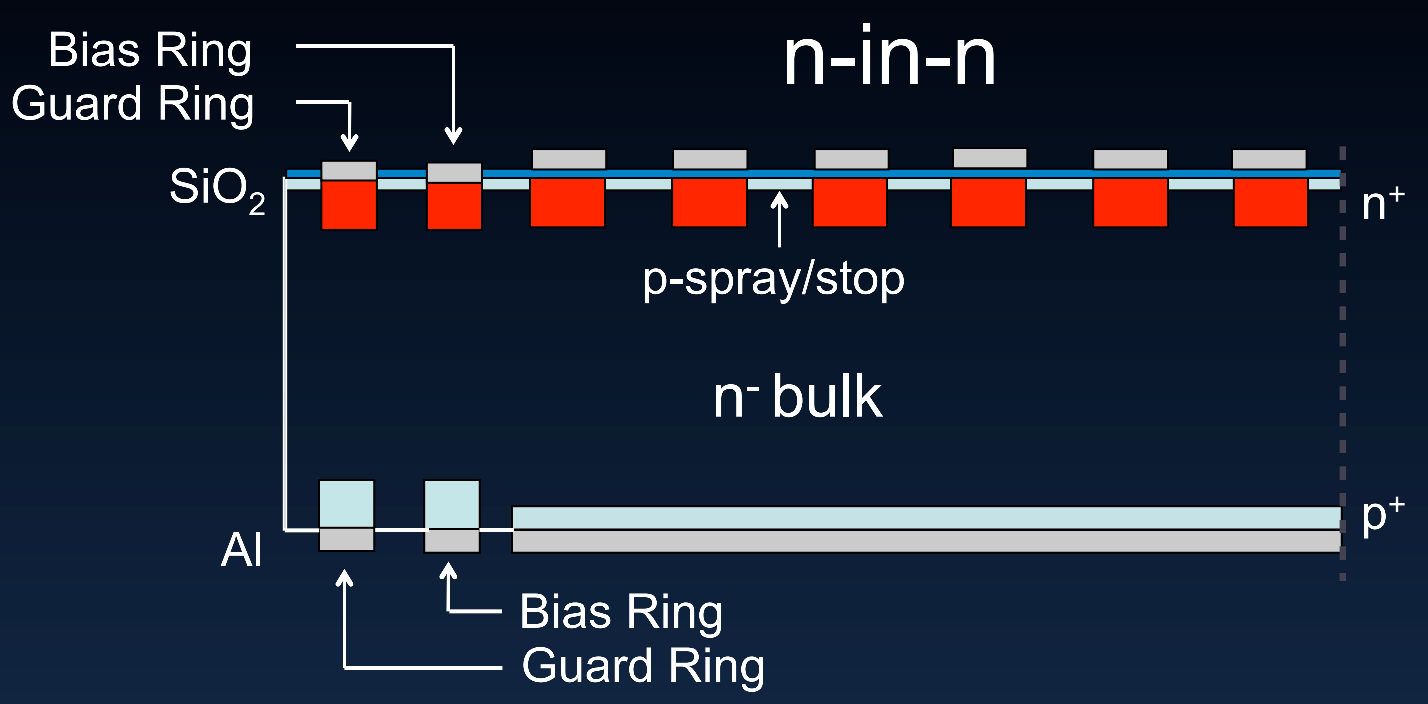
RR Option - Beam & Fan Envelopes



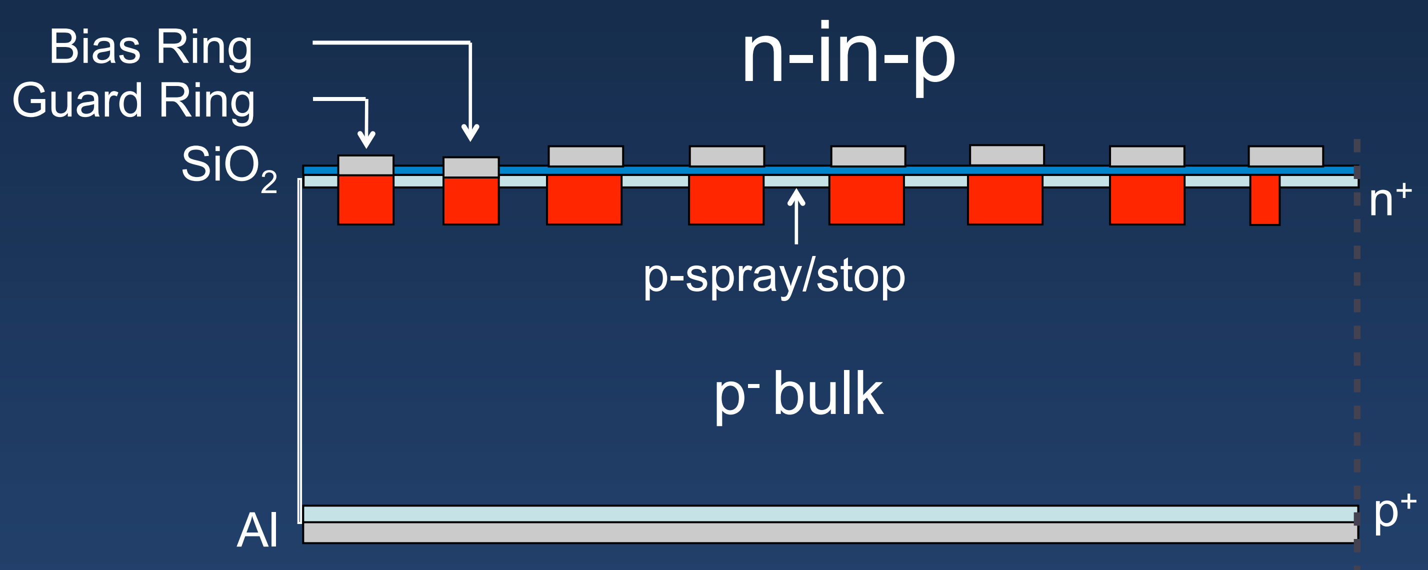
Legend : Dipole

SR Fan growth with z
(high luminosity case)

- n-in-n
  - Most expensive
  - Double-sided processing
  - Limited suppliers
  - Some experience with “large” scale production
    - CMS/ATLAS pixels, LHCb VELO
  - Much more radiation hard than p-in-n

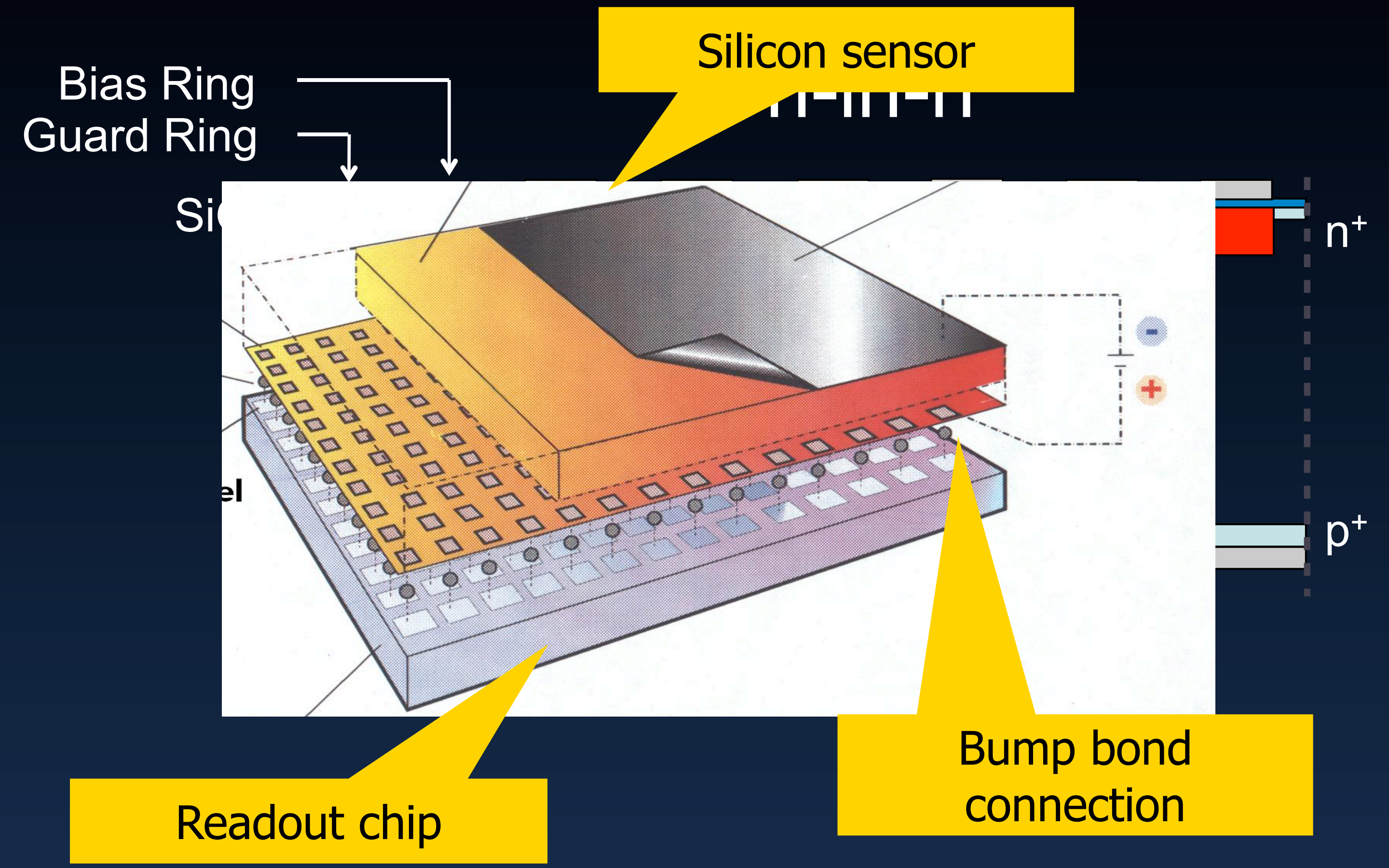


- n-in-p
  - ~50% less expensive than n-in-n
  - Single-sided processing
  - More suppliers (including Hamamatsu)
  - Limited production experience
    - 1 VELO module installed, spare system under construction
  - As radiation hard as n-in-n
  - n^+ R/O kept

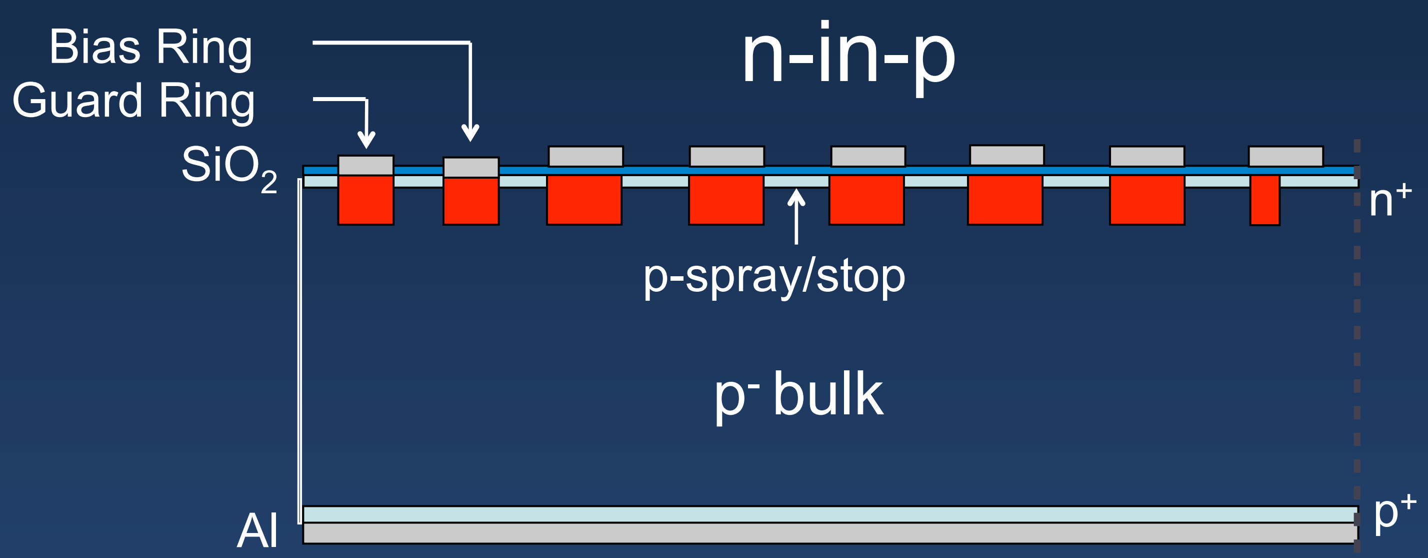


ATLAS Pixel Module Upgrade

- Hybrid pixel detector:
- The sensor and the readout electronic are realized in different semiconductor substrates
- Size of the electronic readout pixels is equal to the size of the sensor pixels
- The connection between the electronic and the sensor is done via bump bond connections

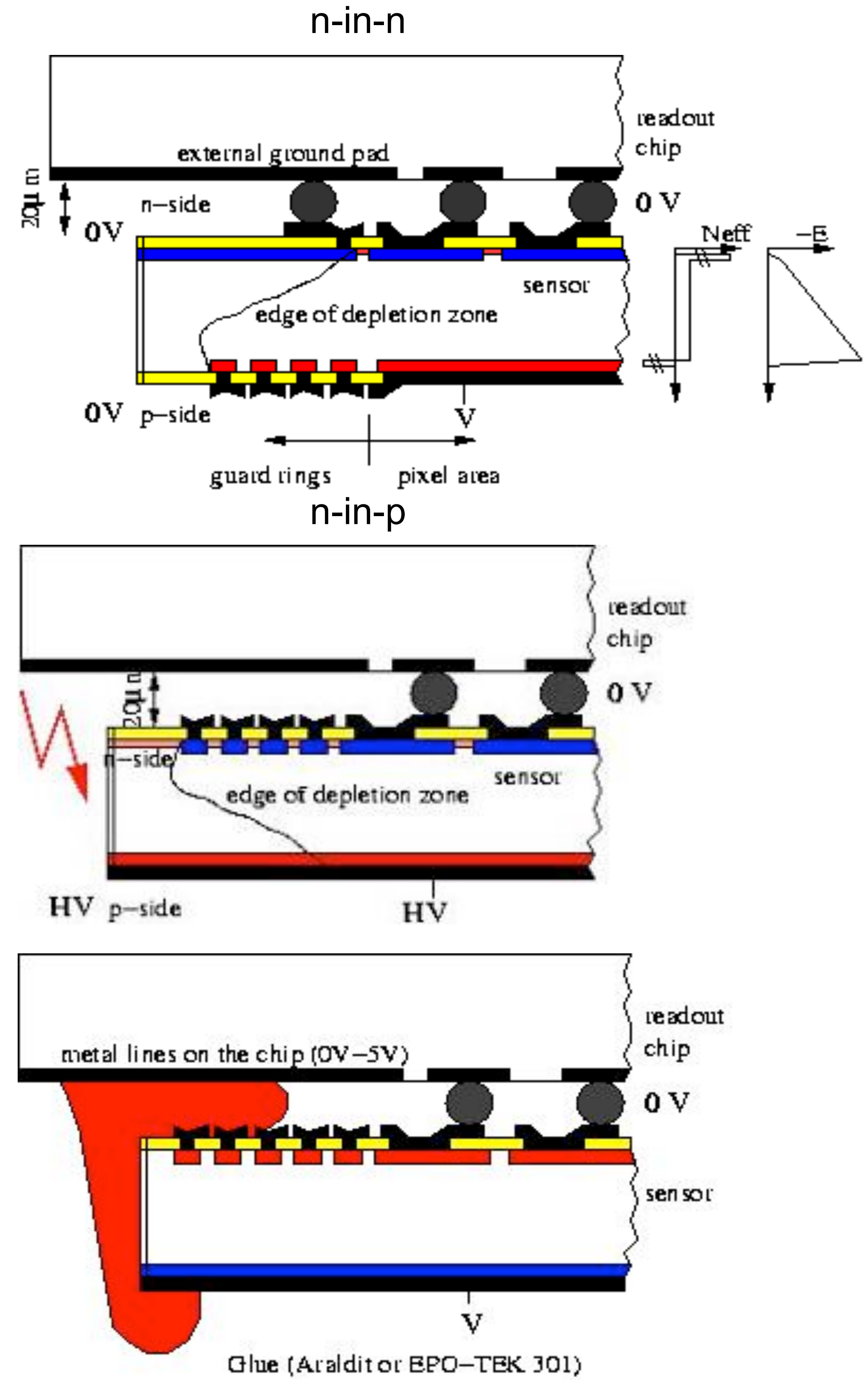


- n-in-p
  - ~50% less expensive than n-in-n
  - Single-sided processing
  - More suppliers (including Hamamatsu)
  - Limited production experience
    - 1 VELO module installed, spare system under construction
  - As radiation hard as n-in-n
  - n^+ R/O kept



CMS Single-Sided (n-in-p) Sensors

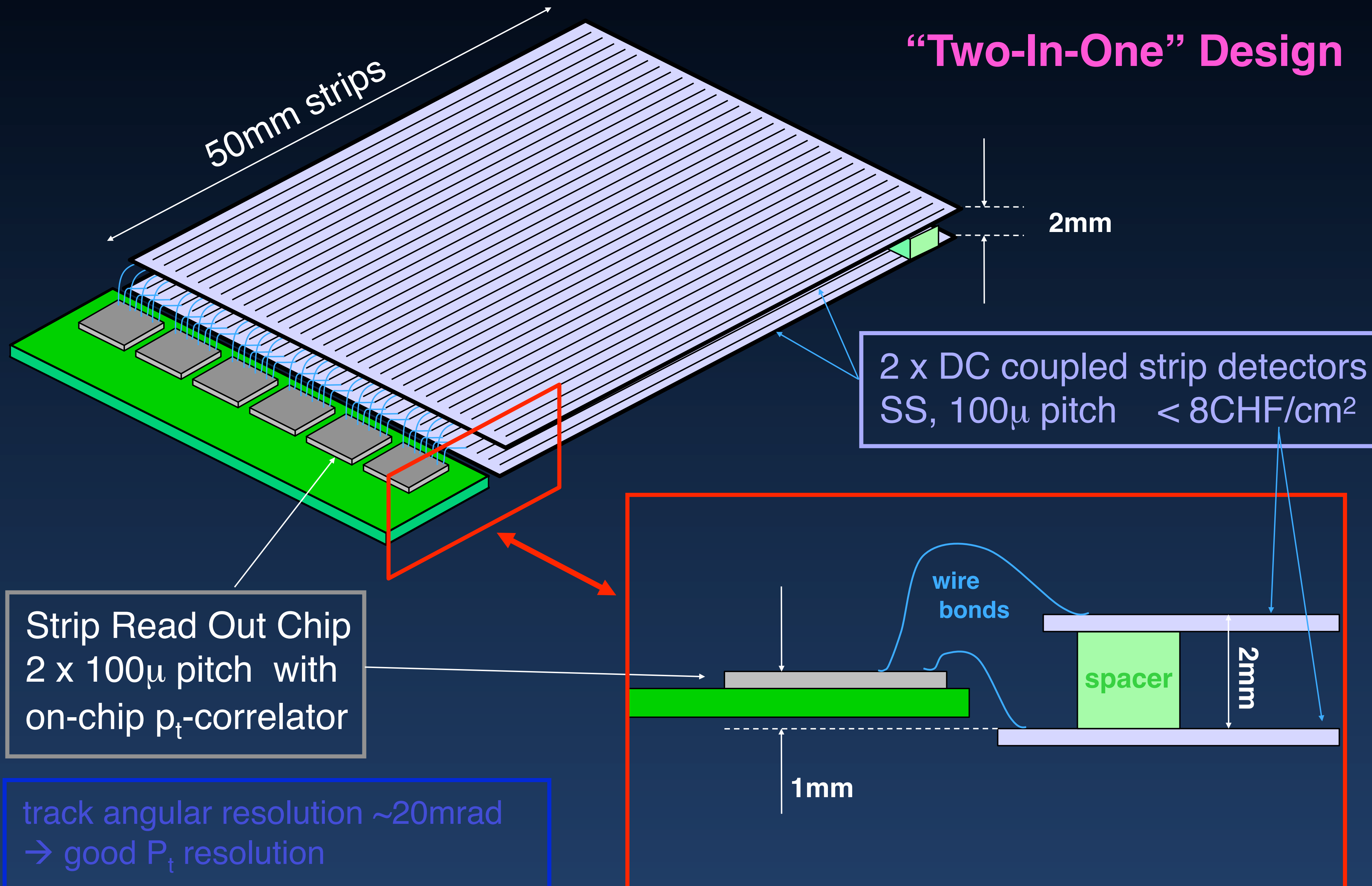
- **Present CMS pixel detector uses n-in-n-sensors**
  - double sided processing (back side is structured)
  - all sensor edges at ground
  - most expensive part of the module (only bump-bonding is more expensive)
- **Exploring n-in-p sensors as alternative**
  - recent studies show radiation hardness
  - single sided process promise price benefit of factor 2-3
    - important as the pixel area will be doubled
  - Absence of guard rings on back side lead to fear of (destructive) sparking to the ROC



T. Rohe et al. Planar sensors for the upgrade of the CMS pixel detector, Pixel2020, Sep. 6-10,

Pt - Trigger for TOB layers

"Two-In-One" Design



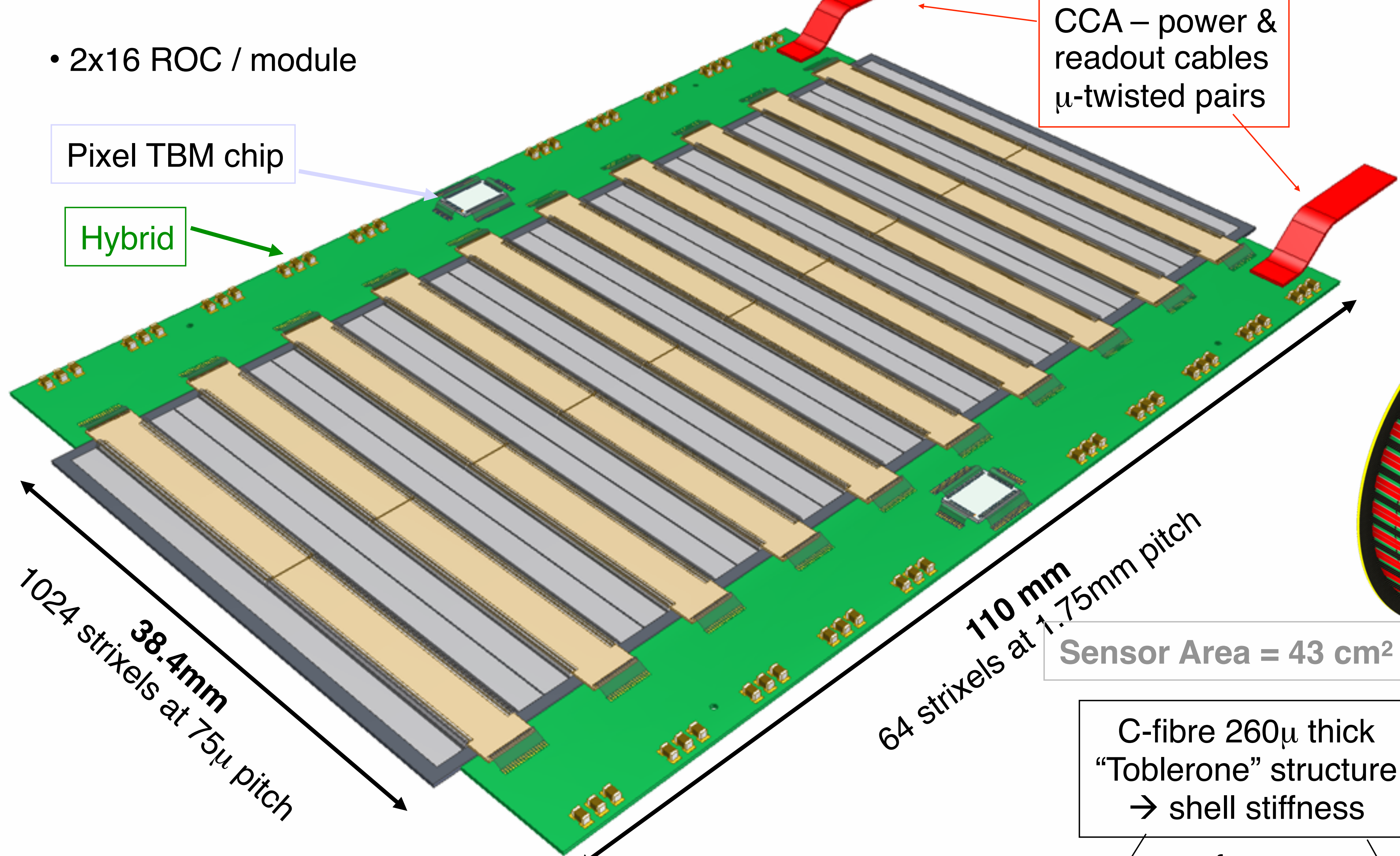
track angular resolution ~20mrad
→ good P_t resolution

W. Erdmann & Roland Horrisberger (PSI), CMS Tracker Week La Biodola, Isola d' Alba - 2010: Tracking at Phase II - Pixel, Strixel & Strips.

Strixel TIB Layers

Pixel ROC based strixel readout

- 2x16 ROC / module



Sensor Area = 43 cm²