LHeC: detector specifications and the application of gaseous tracker

Alessandro Polini (INFN Bologna)
(for the LHeC detector WG)

Outline

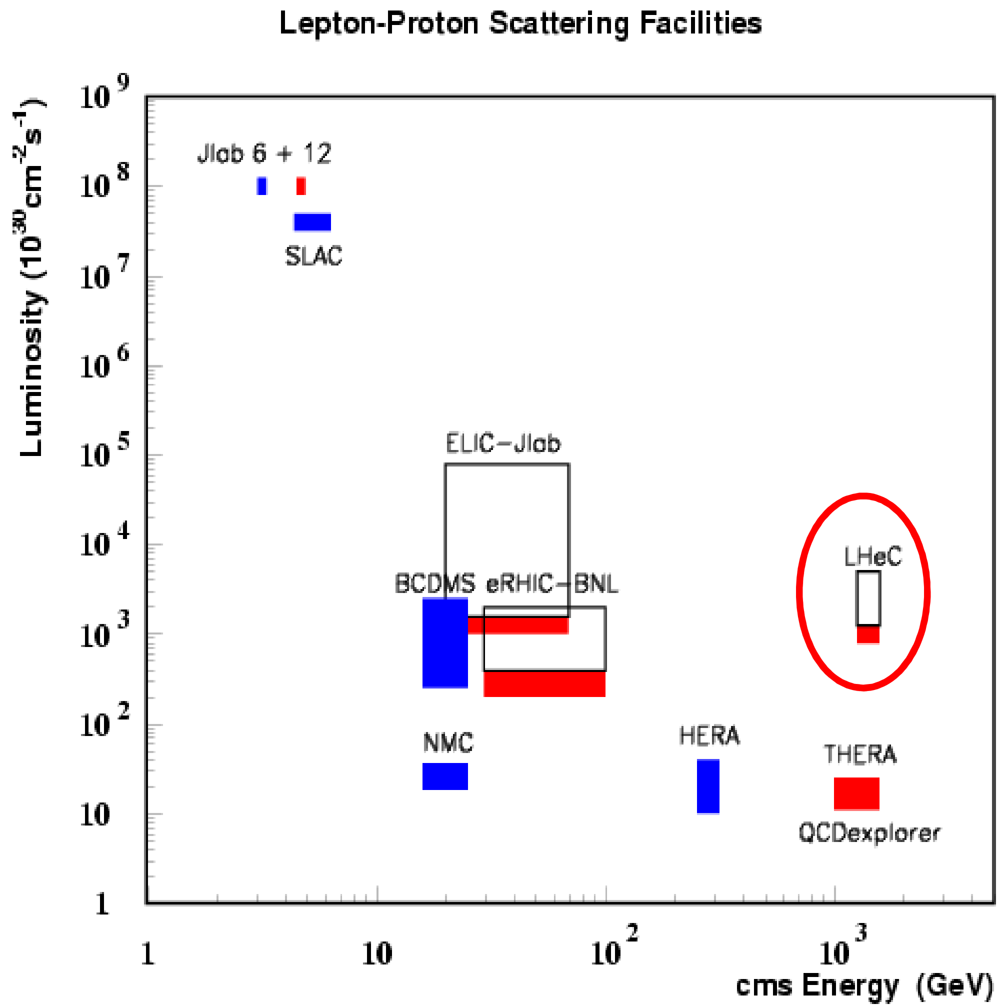
- Short LHeC Introduction
  - Experiment requirements and boundaries
  - (Physics, Machine, Interaction Region and Detector)
- Present Detector Design

➔ Interest in Silicon-Gas Tracker and in a collaboration with Rd51

- Outlook and Plans

LHeC context

The LHeC is not the first proposal for higher energy DIS, but it is the first with the potential for significantly higher luminosity than HERA …



DESY 06-006
Cockcroft-06-05

[JINST 1 (2006) P10001]

Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology, Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA /Spp, Gif-sur-Yvette, France

LHeC

http://www.ep.ph.bham.ac.uk/exp/LHeC/

- *CERN: European Organization for Nuclear Research*
- *ECFA*: European Committee for Future Accelerators
- *NuPECC*: Nuclear Physics European Collaboration Committee

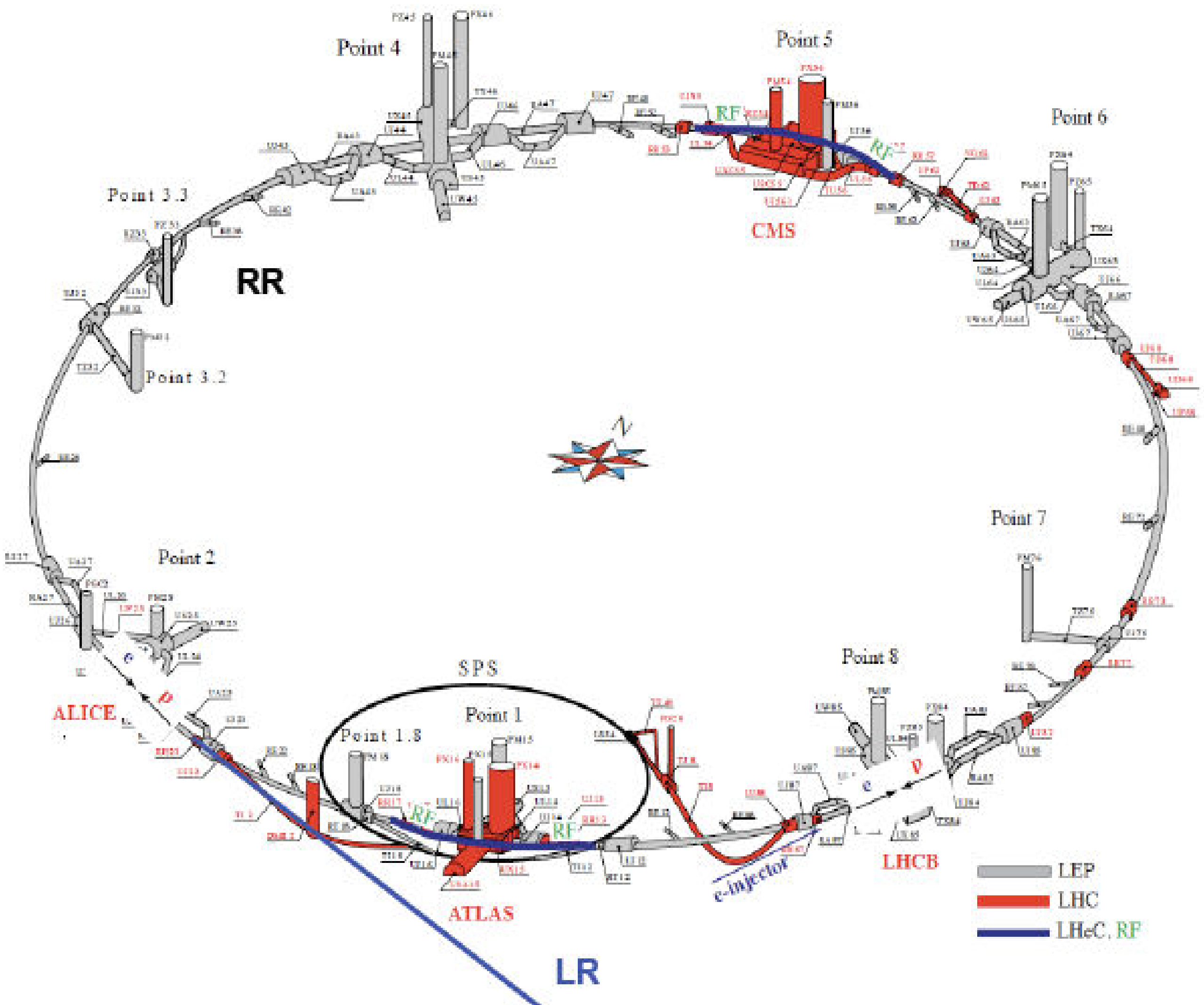
- Accelerating facility: Two possibilities being pursued:
  - Ring-Ring
  - Linac-Ring

- LHeC Working Groups:
  - ***Accelerator Design***
  - ***Interaction Region and Forward/Backward Detectors***
  - ***Detector Design***
  - ***New Physics at Large Scales***
  - ***Precision Investigations of QCD and Electroweak Interactions***
  - ***Physics at High Parton Densities (ep and eA)***

➔ ***Aim at a CDR in 2010***

Machine Considerations and Studies

high $E_{e,p,A}$, $e^{\pm}$ polarised, high Luminosity



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

e Ring:

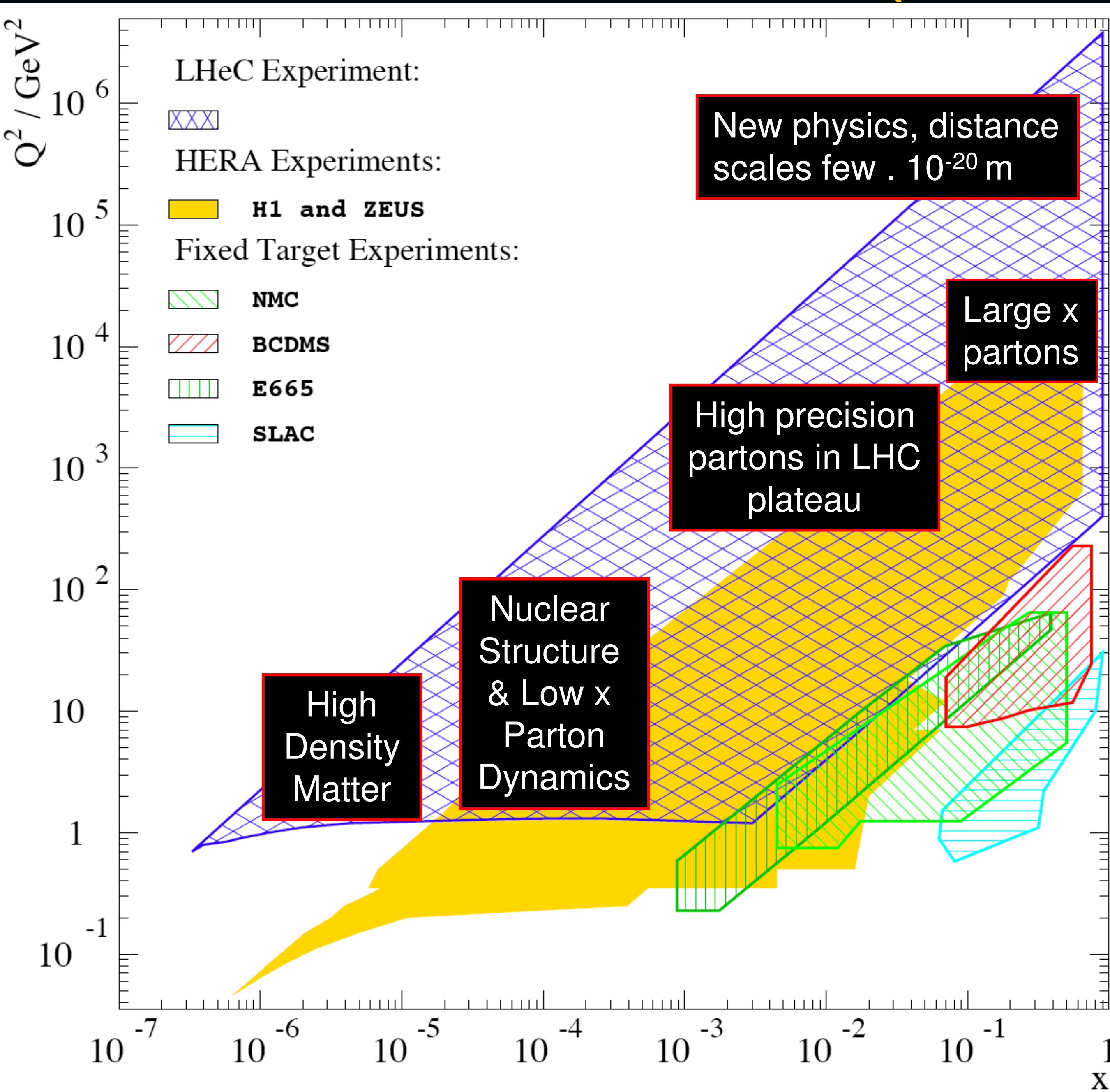
bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

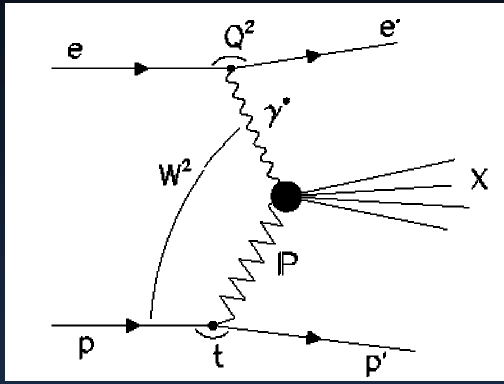
e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?

Kinematics & Motivation (70 GeV x 7 TeV *ep*)



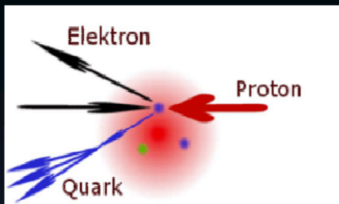
$\sqrt{s} = 1.4$ TeV

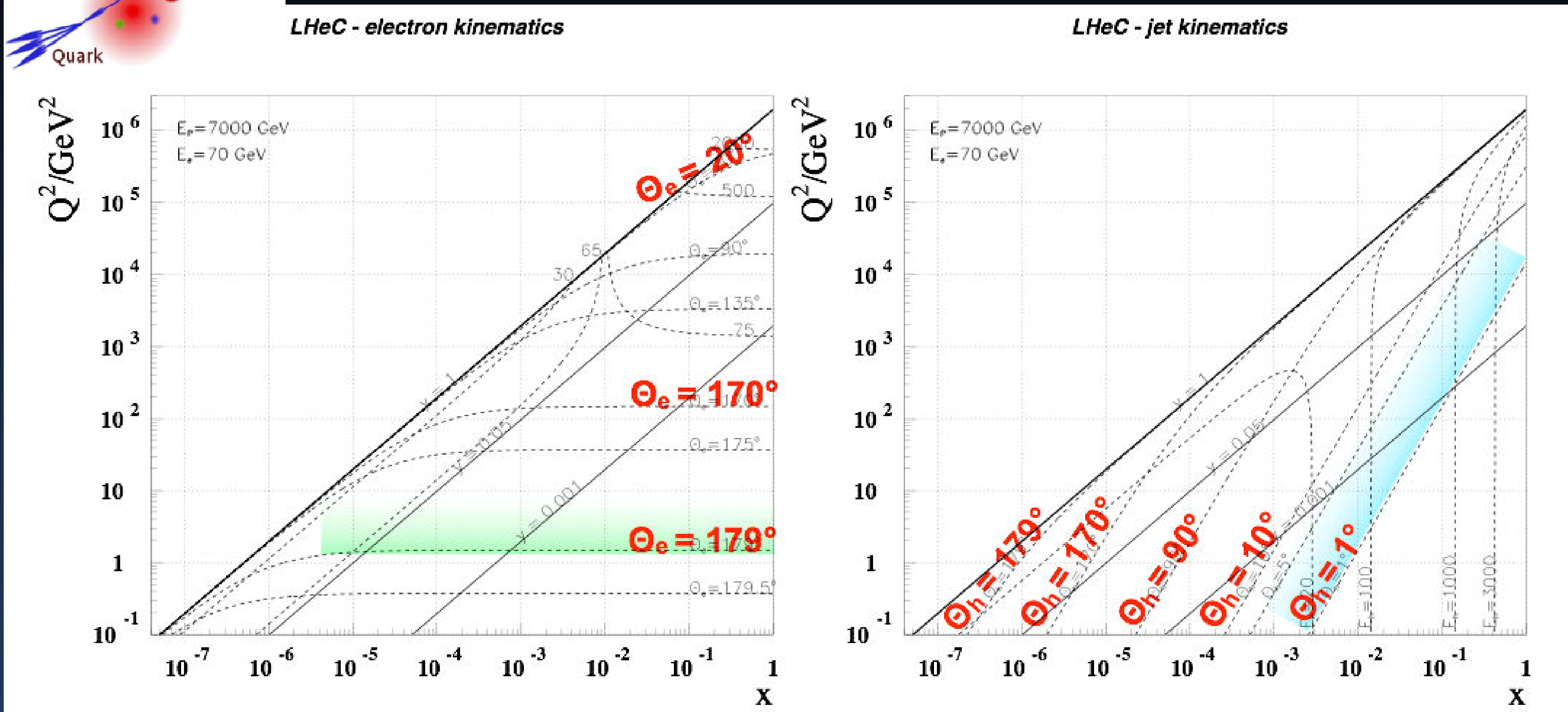


- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier [x below 10^{-6} at $Q^2 \sim 1$ GeV^2]

→ novel QCD …

LHeC Kinematics





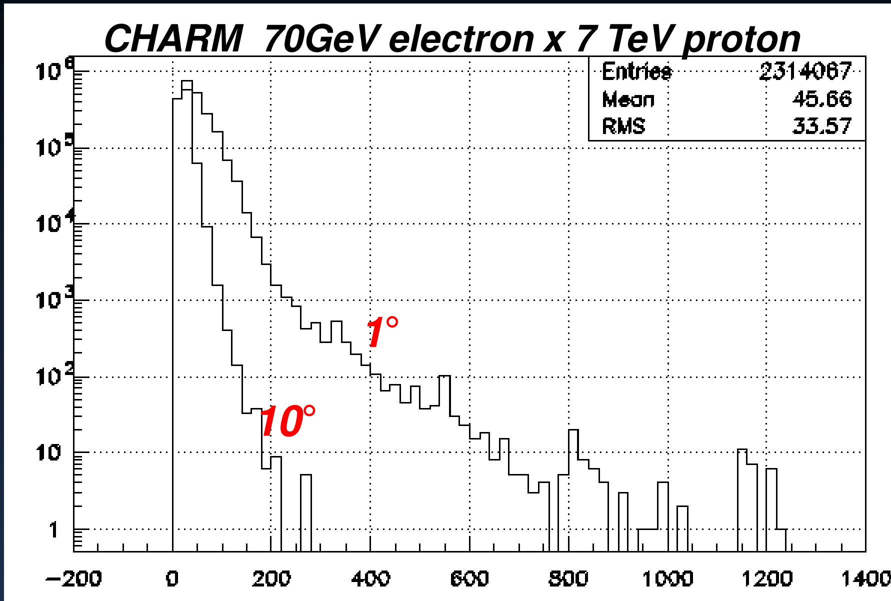
•High x and high Q²: few TeV HFS scattered forward:

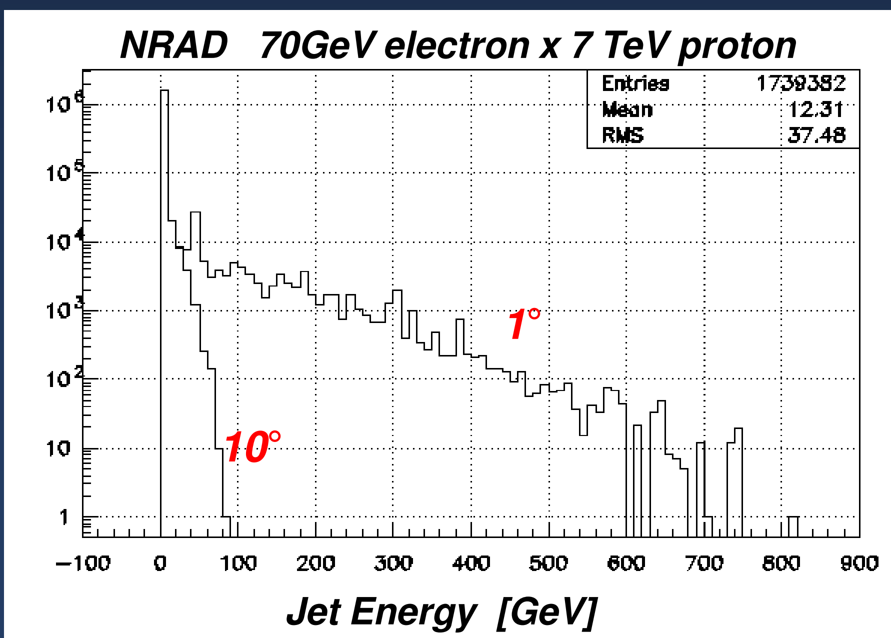
➔ Need forward calorimeter of few TeV energy range down to 10° and below ▇. Mandatory for charged currents where the outgoing electron is missing. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%

• Scattered electron:

➔ Need very bwd angle acceptance for accessing the low Q² and high y region ▇.

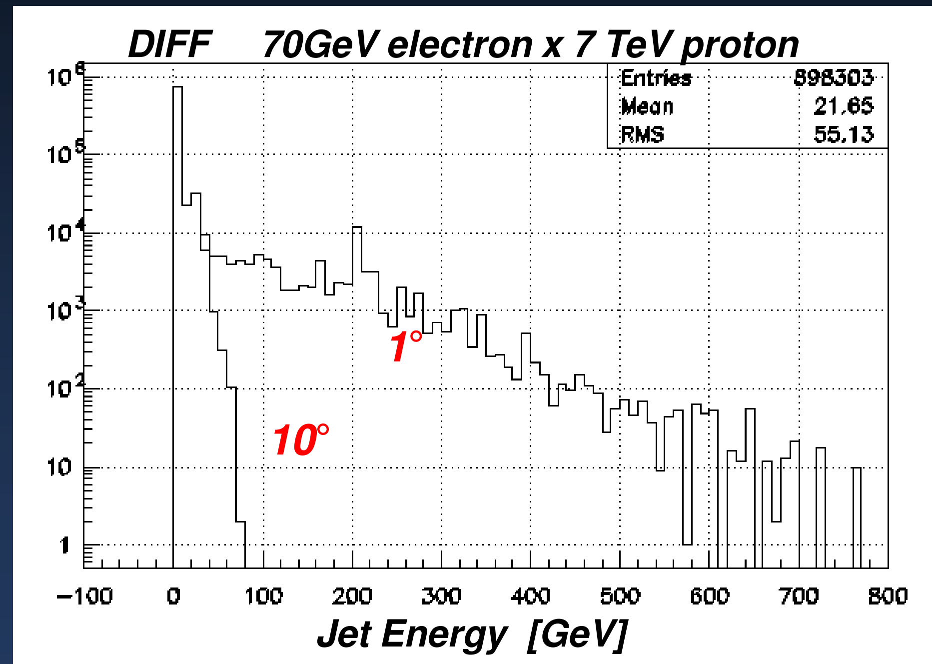
Detector Acceptance





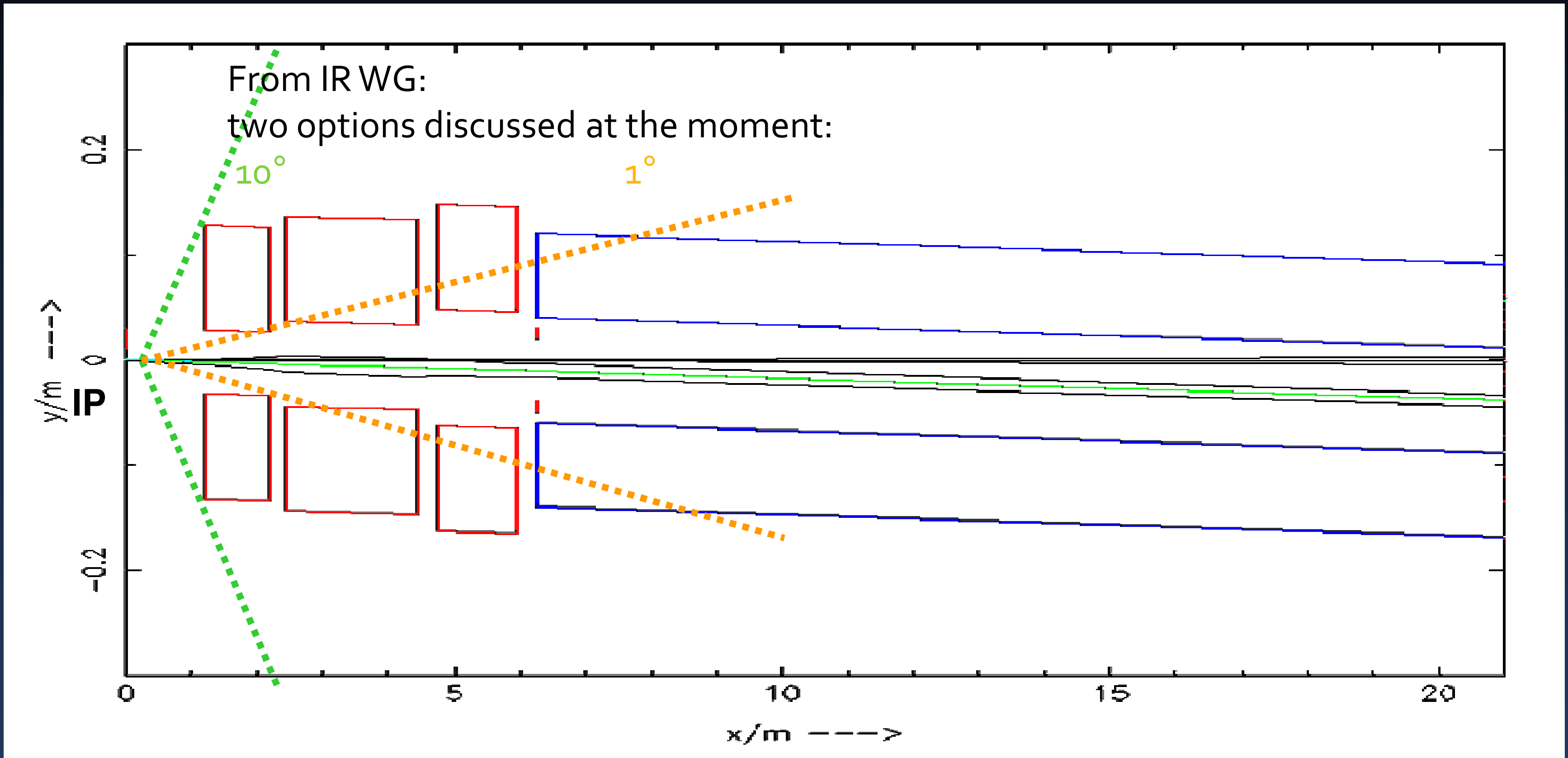
RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

HzTooL-4.2 (H.Jung et.al. - http://projects.hepforge.org/hztool/)
selection: q^2.gt.5.



→ Highest acceptance - if possible

Beam Optics and Detector Acceptance



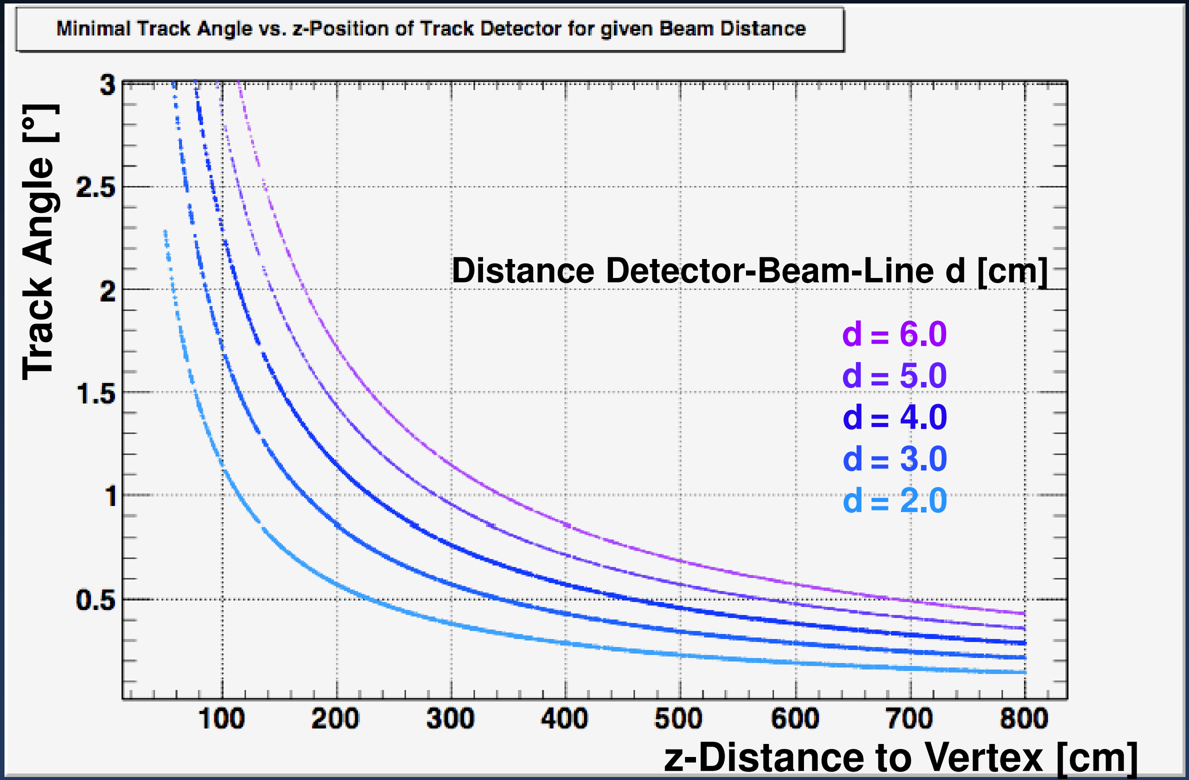
Current design: strong-focusing magnets at 120 cm from IP

Could think of two detector options

- Low Lumi, Low x → high acceptance detector 1^0
- High Lumi,High Q^2 → Main detector 10^0 aperture

Beam Pipe Considerations

Pipe dimensions – very essential choice: to large extent it determines the size of the detector.
Strong implications in terms of costs and acceptance



Present design: elliptical Be beam pipe from SLHC for now: r_y=2.50 cm (radius of SLHC design) and r_x=3.07 cm (scaled from HERA experience)

➔ Dedicate simulation of Interaction region needed (synchr. background)

Requirements from Physics

- High resolution tracking system
  - excellent primary vertex resolution
  - resolution of secondary vertices down to small angles in forward direction for high x heavy flavour physics and searches
  - precise pt measurement matching to calorimeter signals, calibrated and aligned to 1 mrad accuracy
- The calorimeters - Energy flow
  - electron energy to about $10\%/\sqrt{E}$ calibrated using the kinematic peak and double angle method, to permille level

    Tagging of γ's and backward scattered electrons - precise measurement of luminosity and photo-production physics
  - hadronic part $30\%/\sqrt{E}$ calibrated with pT_e/pT_h to 1% accuracy

    Tagging of forward scattered proton, neutron and deuteron - diffractive and deuteron physics
- Muon system, very forward detectors, luminosity measurements

Tracking Requirements

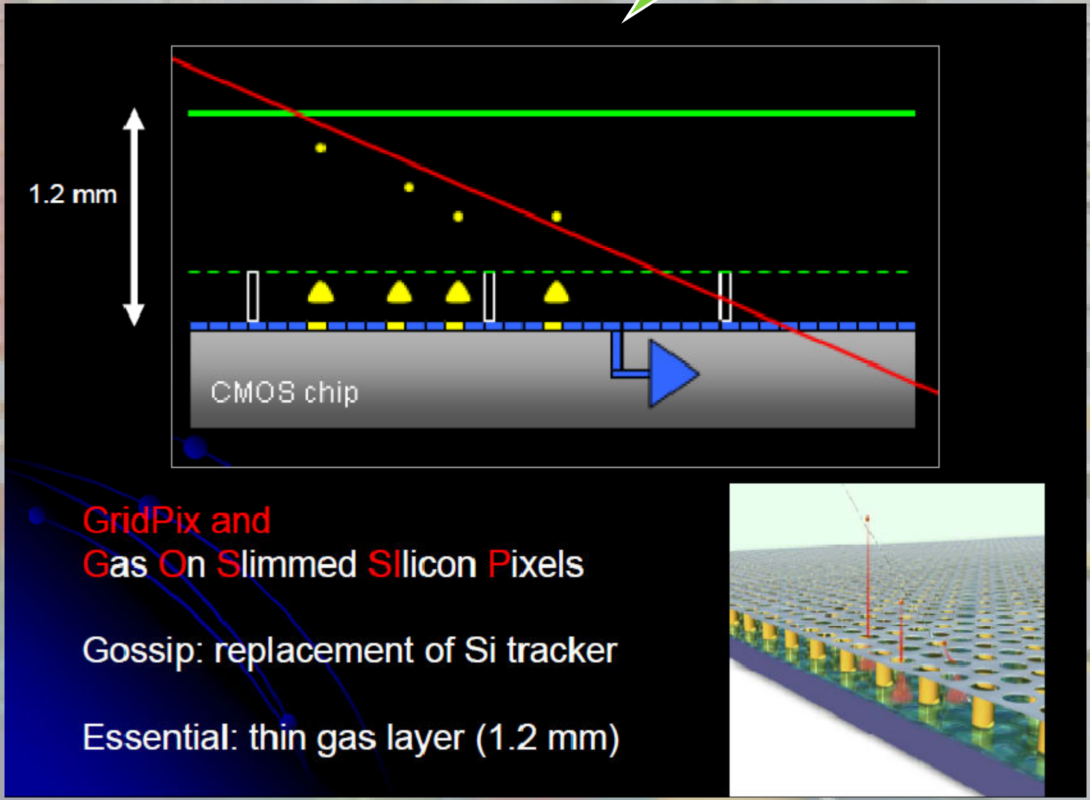
- lowest mass tracker - essential for $\gamma/e^{\pm}$ ident (specifically bwd)
- early π^{o} ident - vertex detector/trigger
- Large acceptance toward small forward/rear angles
  → Placement as close as possible to the beam pipe
- Radiation tolerant
- Low budget material
- High gain (more hits per tracks → track segments)
- high resolution track definition in front of forward calo
- tracking trigger in front of fwd/bwd calo, p_t trigger there too?

Precision Tracking: Si-Gas Tracker – GOSSIP

Gas on Slimmed Silicon Pixels

- Gas for charge creation, Si-pixel/strips/pads for signal collection
- Lightweight detector (including mechanics, cooling infrastructure...)
- More than one hit per track - defines track segments
- Si radiation hard - standard CMOS (90 nm process)
- Trigger capable: 25ns, Gossipo 3|4 readout chip ~O(1) ns time resolution.
- Large volume detector affordable, industrial production
- Time measurement – 3D tracking
- Gas choice: radiator : Transition Radiation Tracker - e/π identification
- Diffusion and drift velocity limits position measurement currently to ~<<20μm

Gossip Presentations:
- E. Koffeman (Divonne 2008)
- H. VanDerGraaf (Divonne 2009)



Ideal option for LHeC

Other Detector Requirements

Calorimeter

- Minimize longitudinal and lateral energy leakage
- Fwd/bwd Particle Flow Detector to achieve desired mass resolution ; $\gamma/e^{\pm}$; π^{o} ; …
  This technique combines the tracking/calorimetry information in an optimal way in order to get the best possible jet-energy resolution.
  Or Dream (dual readout) - event to event correction
- Both electromagnetic and hadron calorimetry inside the solenoid coil; minimum material inside EmCal;
- Prototyping, test at high energy!

▫ Conventional technologies LAr (ATLAS, H1) especially in in barrel/rear region, possibly problematic for infrastructure and modularity boundaries

Magnetic Field

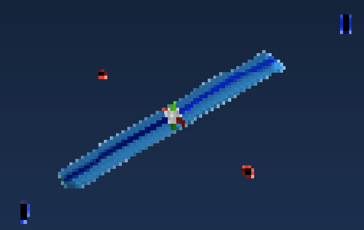
- 3.5 Tesla solenoidal field (track resolution etc.)

… the detector

… a first draft

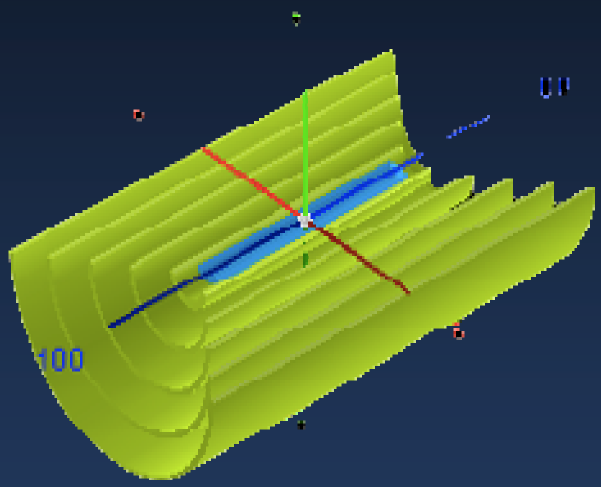
LowQ^2-Detector

	Radius [cm]
Elliptical pixel detector:	2.9–4.6/3.47-6.05



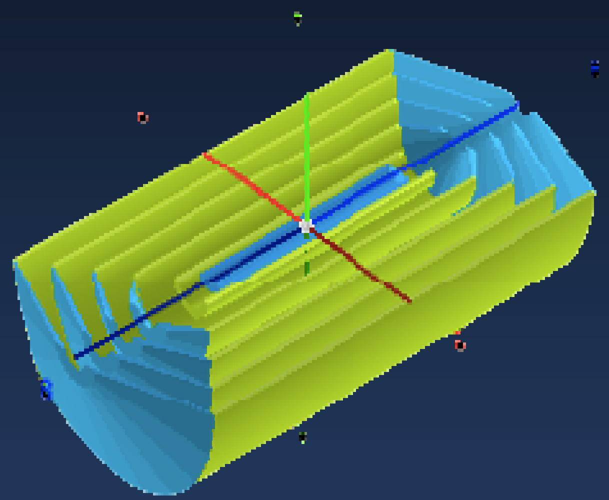
LowQ²-Detector

	Radius [cm]
Elliptical pixel detector:	2.9–4.6/3.47-6.05
Barrel layer 1-5:	7.5–61



LowQ²-Detector

	Radius [cm]
Elliptical pixel detector:	2.9–4.6/3.47-6.05
Barrel layer 1-5:	7.5–61
Barrel cone 1-4:	5–61



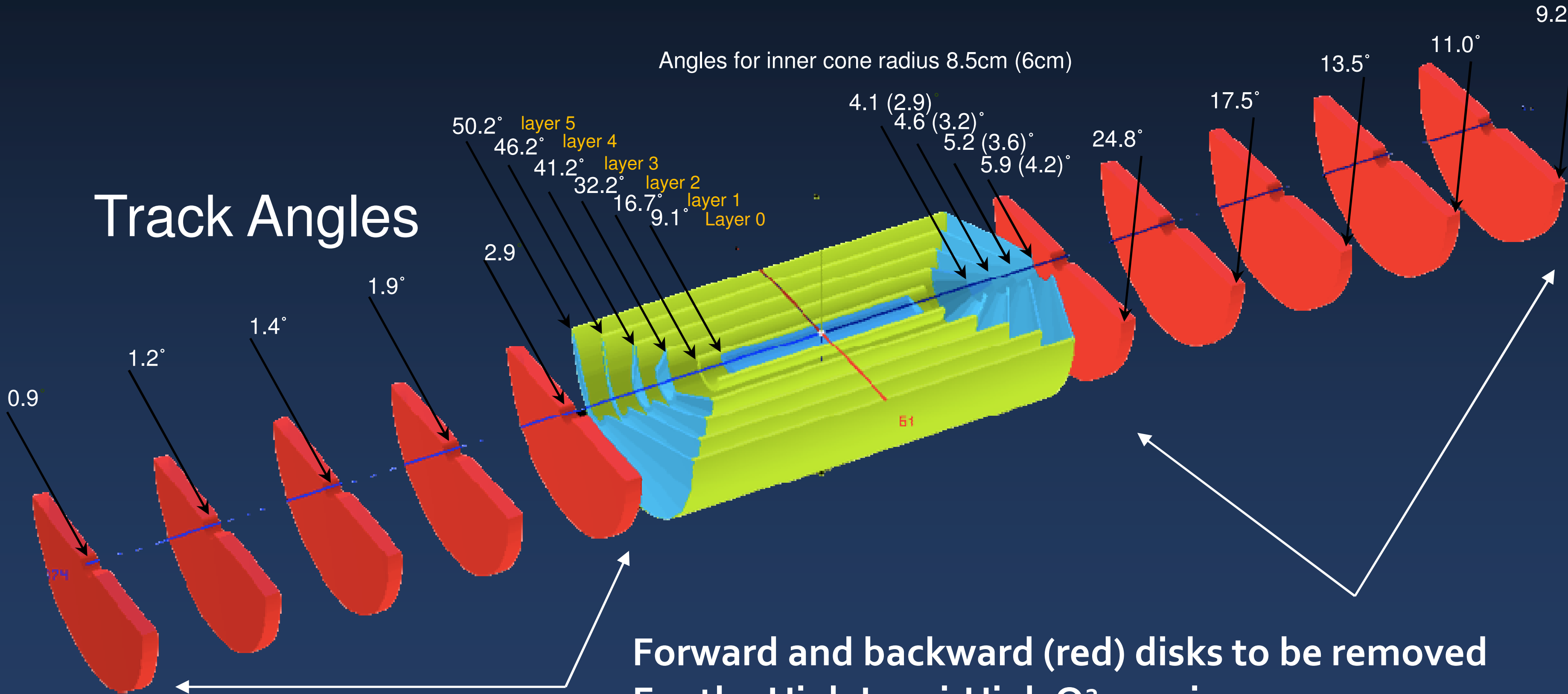
Full Tracking (down to 1 degree) (to be optimised)

One option: GAS-Si Tracker - GOSSIP Type NIKHEF

Container Model

Gas On Slimmed Silicon Pixels (or Strixels/Pads)

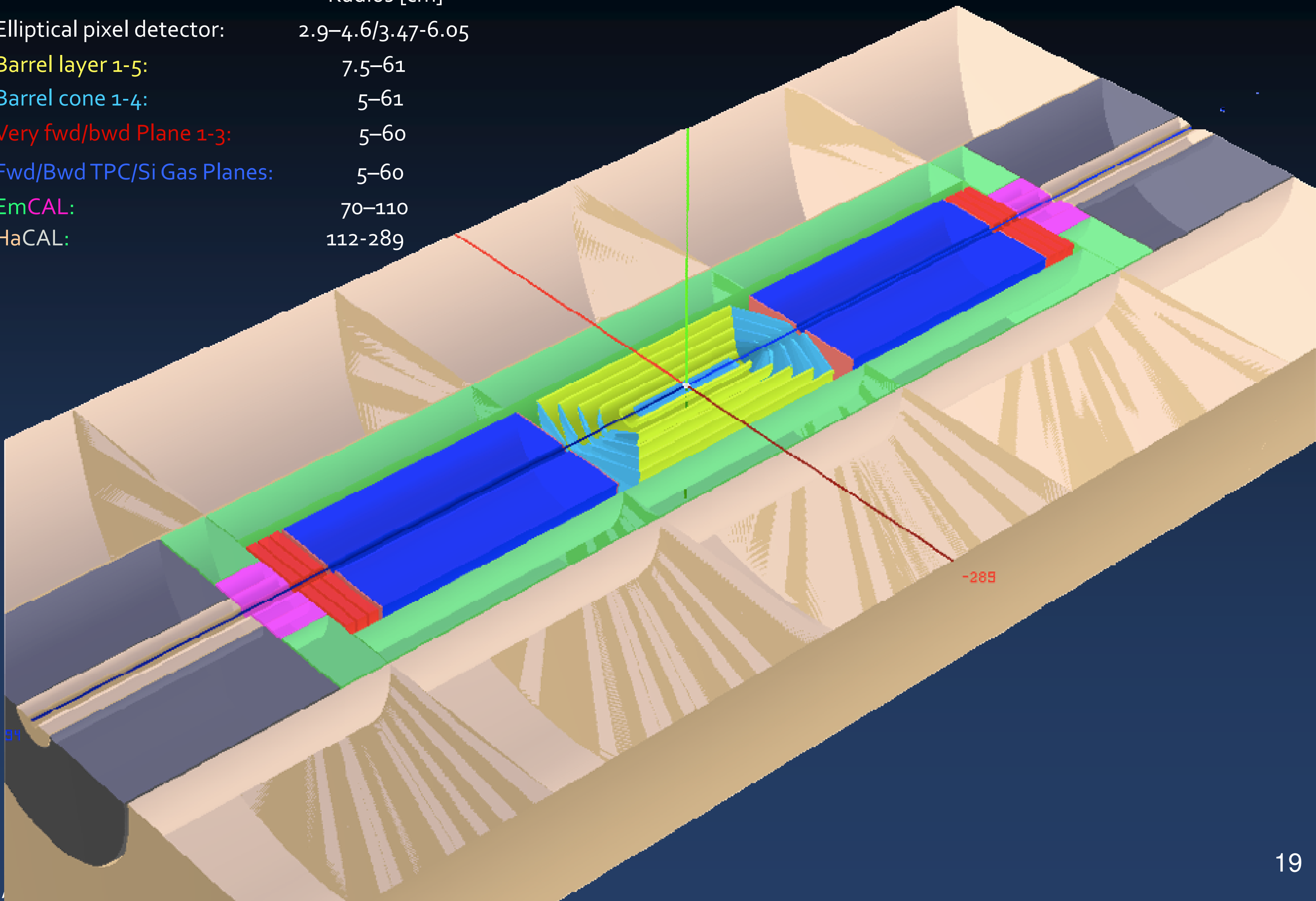
Track Angles



Forward and backward (red) disks to be removed For the High Lumi-High Q² running.

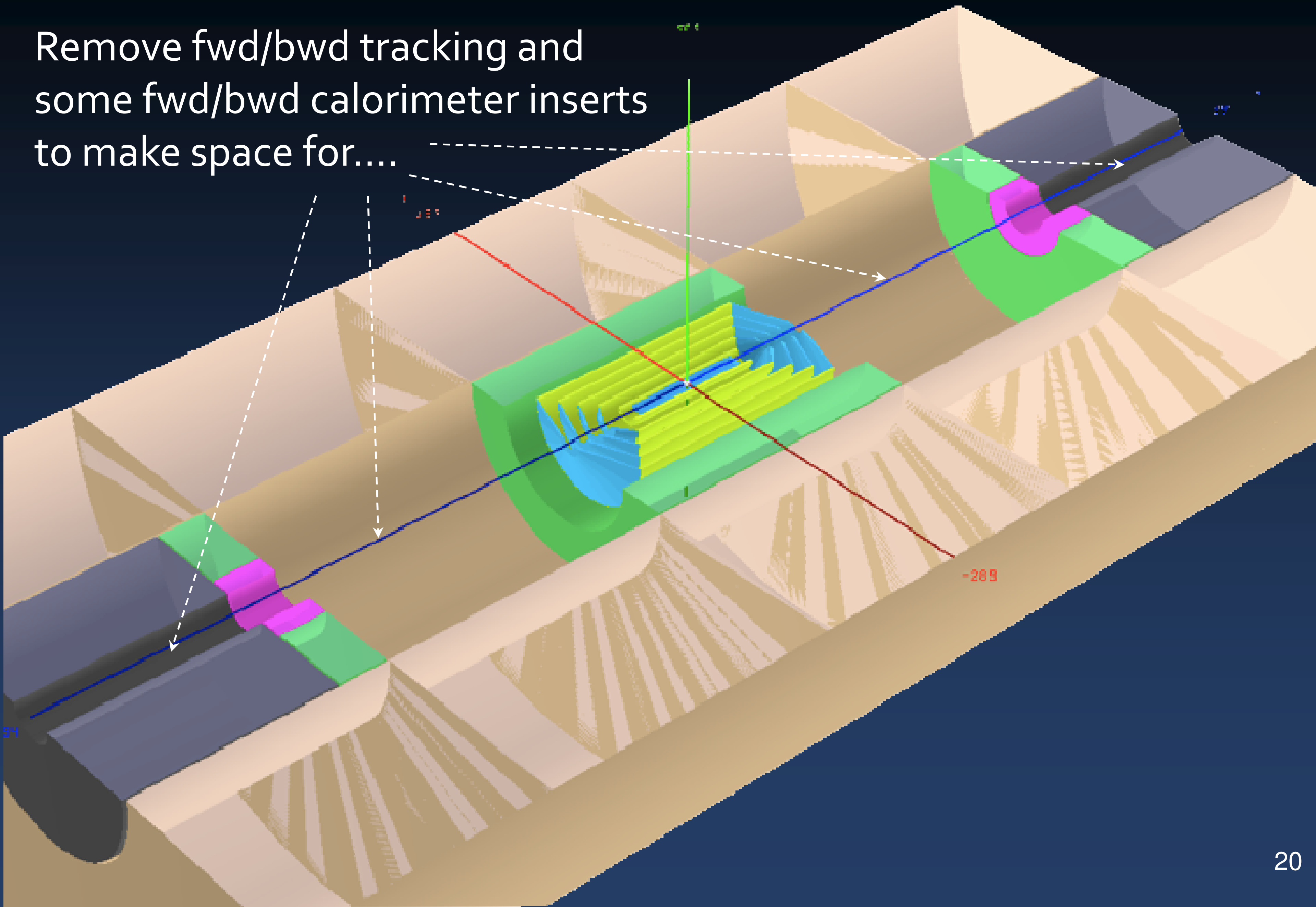
LowQ^2-Detector

	Radius [cm]
Elliptical pixel detector:	2.9–4.6/3.47-6.05
Barrel layer 1-5:	7.5–61
Barrel cone 1-4:	5–61
Very fwd/bwd Plane 1-3:	5–60
Fwd/Bwd TPC/Si Gas Planes:	5–60
EmCAL:	70–110
HaCAL:	112-289



LowQ^2-Detector

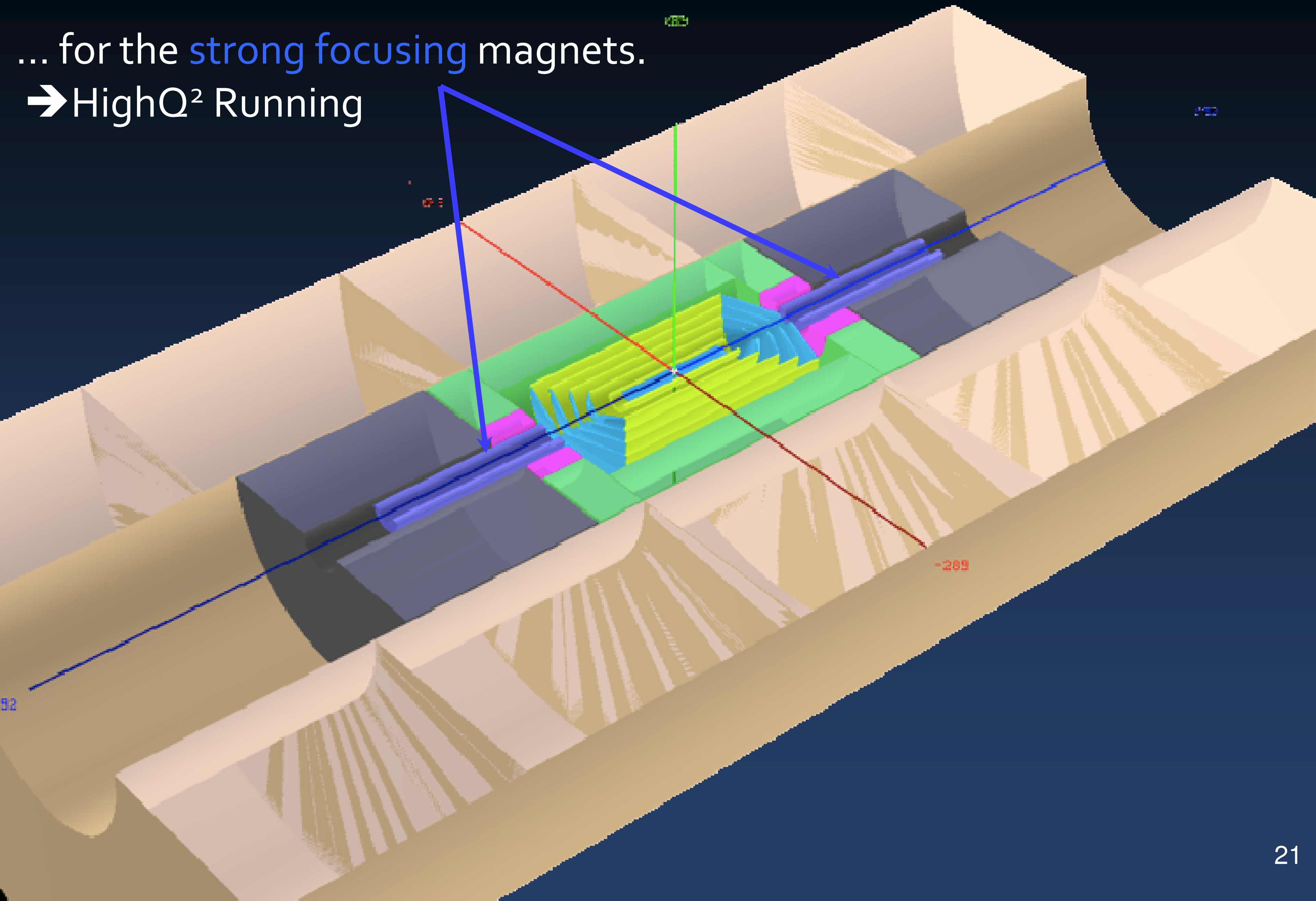
Remove fwd/bwd tracking and some fwd/bwd calorimeter inserts to make space for….



High Q^2 configuration

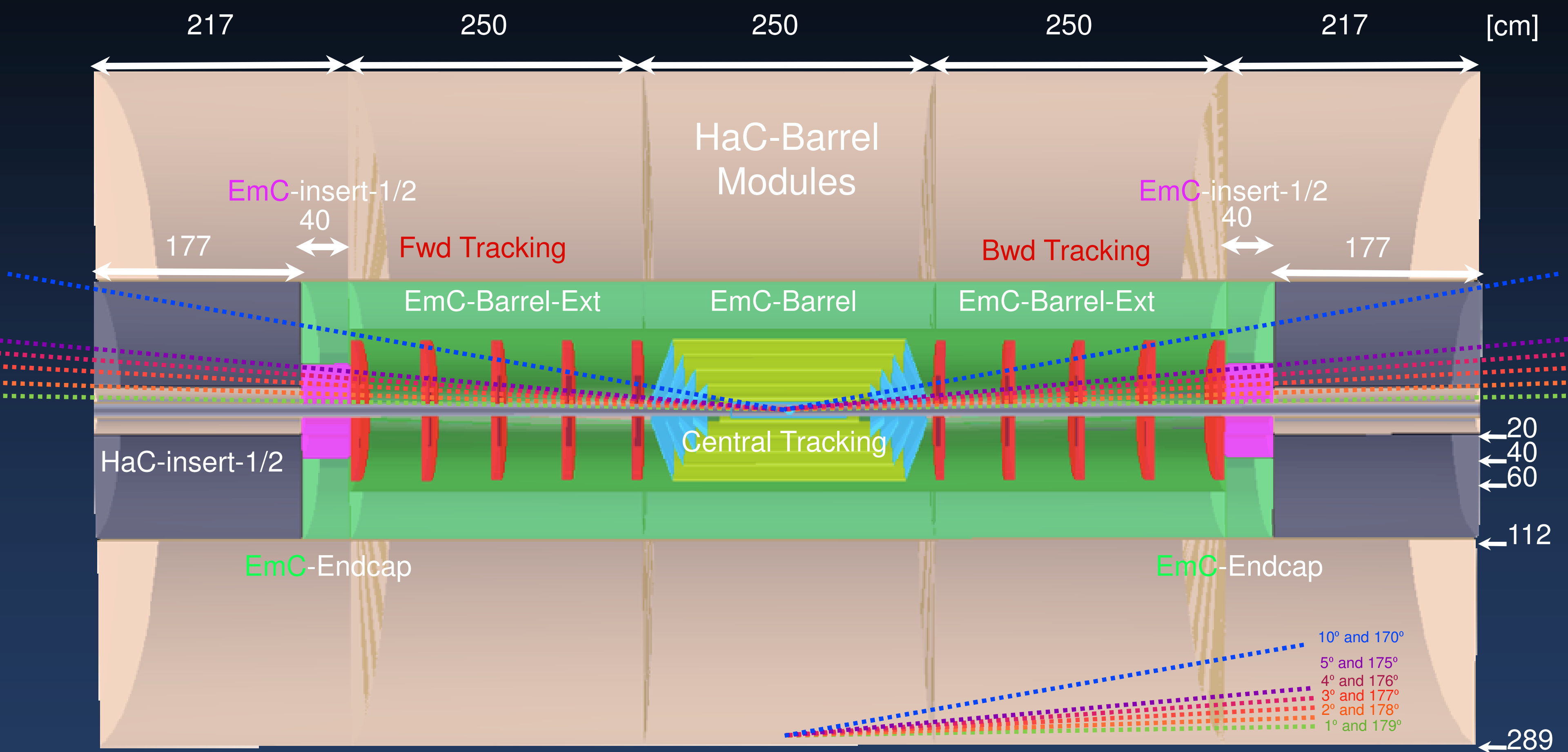
... for the strong focusing magnets.

➔ HighQ^2 Running



The Detector - Low Q^2 Setup

(to be optimised)

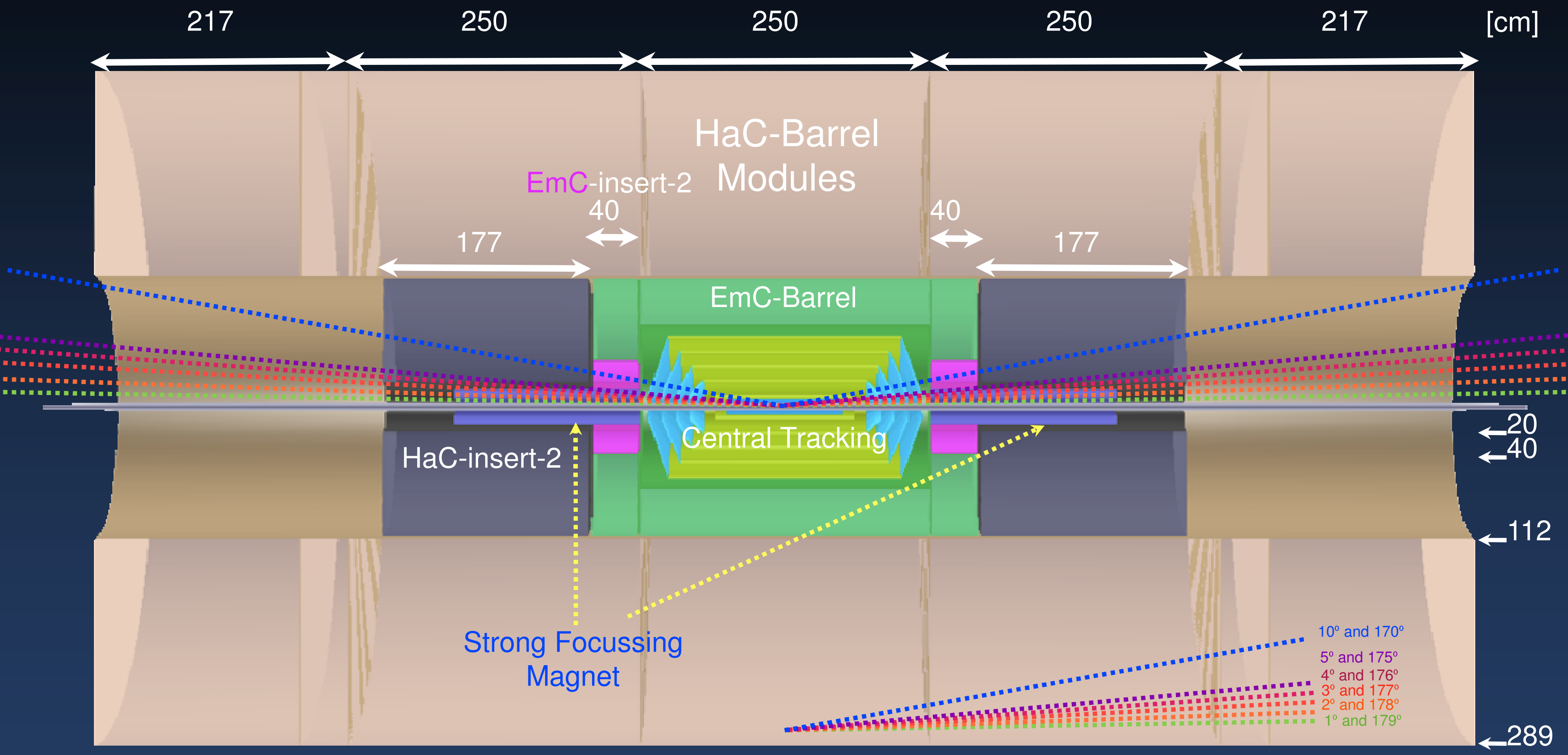


- **Solenoid surrounding the HAC modules**
- **Outer detectors (HAC tailcatcher/muon detectors not shown)**

Not discussed either: very forward detector setup – very essential – but postponed

The High Q^2 Setup

(to be optimised)



L1 Low Q^2 SetUp → High Q^2 SetUp

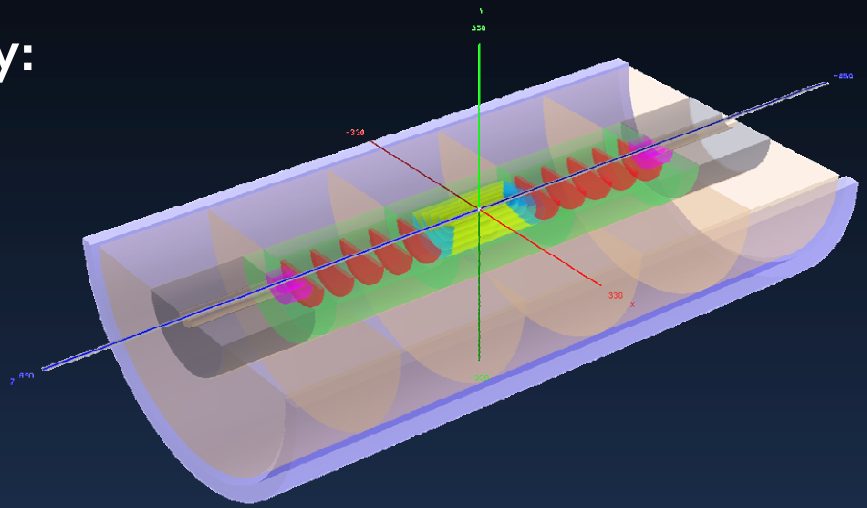
- Fwd/Bwd Tracking & EmC-Extensions, HaC-Insert-1 removed
-Calo-Inserts in position
-Strong Focussing Magnet installed

Calorimeter

Present choice: Energy Flow Calorimetry:

For the geometry given:

- Electromagnetic Calorimeter:
  ~30 x Xo Pb/W & different det./R/O
- Hadronic Calorimeter:
  6 - 10 x λ_I Fe/Cu & different det./R/O



- Presently the fwd/bwd calorimeter asymmetry more in functionality/detector response rather then in geometry

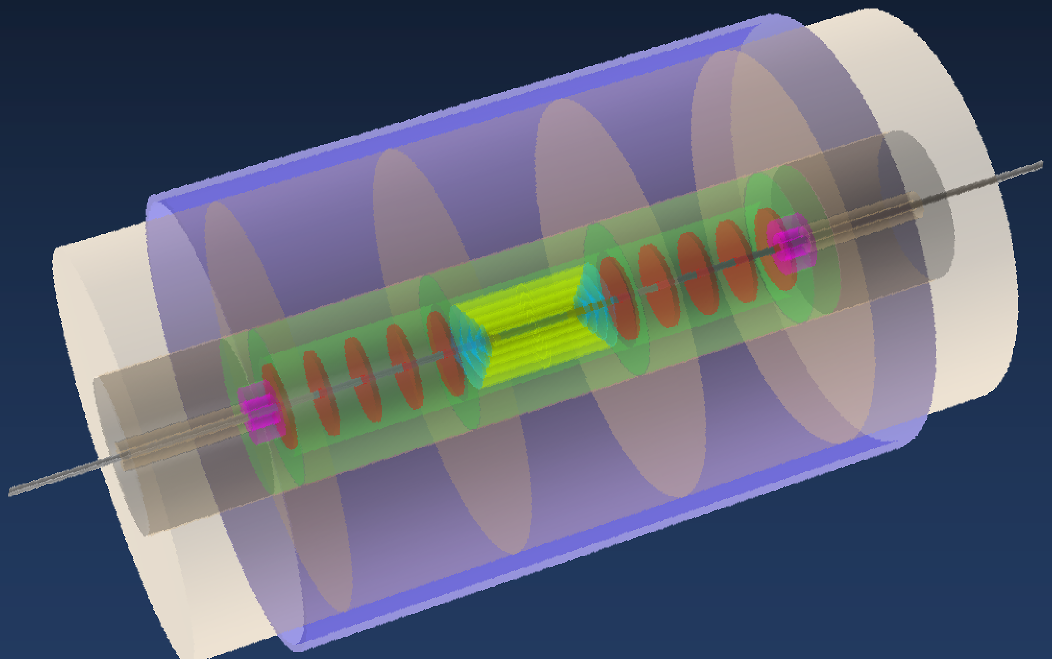
- A dense EmCAL with high granularity (small transverse size cells), high segmentation (many thin absorber layers), and with ratio λ_I/Xo large, is optimal for E-Flow measurement → 3-D shower reconstruction
- Example Fe, W

Material	Nuclear interaction length λ [cm]	Density [g/cm^3]	Moliere radius [cm]	Radiation length X_0 [cm]	λ/X_0
Fe	16.98	7.87	1.66	1.77	9.59
W	10.31	19.3	0.92	0.35	29.46

- brass (Cu) an option also (CMS), λ_I =15.1cm - denser than Fe (adding λ_I)

Solenoid

Modular structure: assembly on surface level or in the experimental area depending on time constraints and access shaft opening



Solenoid dimensions:

- 480~594 cm half length
- 291 cm inner radius
- B field = 3.5 T

Geometry constraints:

- Current beam pipe dimensions
- Requirement of 1° tracking coverage
- Homogeneous B field in the tracking area

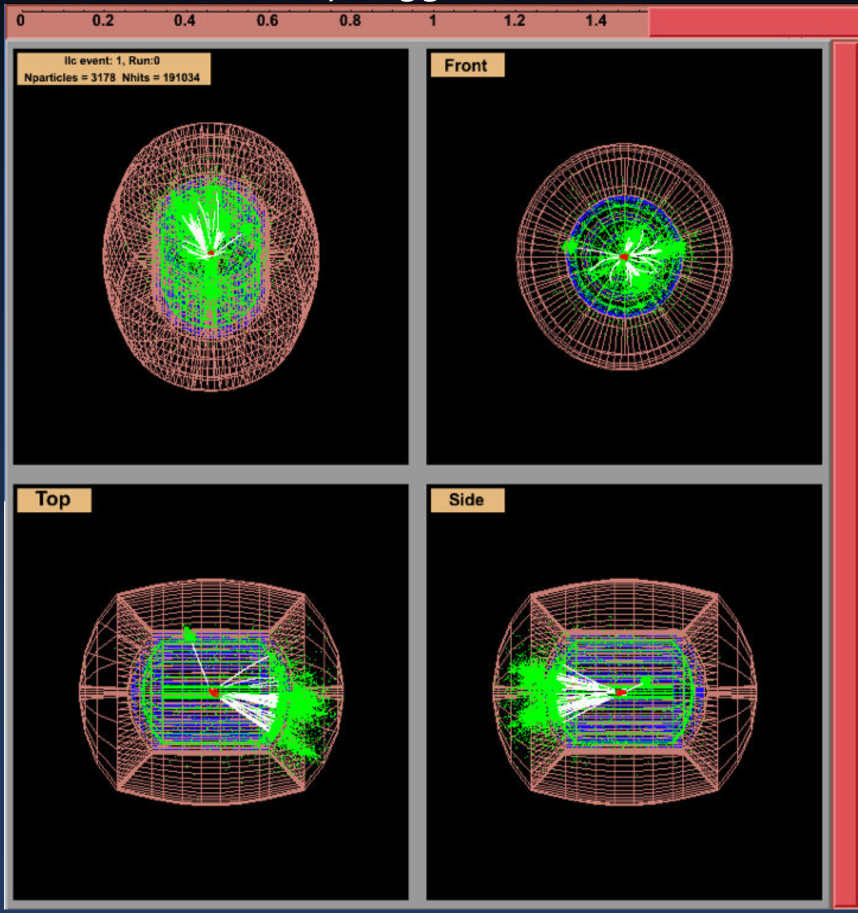
Simulation Framework

Use a homogeneous, powerful and widespread environment

Frameworks come to our attention:

- 4th concept - IlCRoot -
  ILC evolved from: AliRoot - Alice - LHC
- Based on CERN software root with Virtual Monte Carlo
- Pandora-Pythia, Whizard, Sherpa, CompHEP etc. - generators
- root using **Geant3/4** and **Fluka** - (transport in matter)
- Several simulations, detector geometries etc. already exists
- 4 experiments using AliRoot based framework: Ali - Ilc - Fair - MPD -Root

ep Higgs event in 4th detector

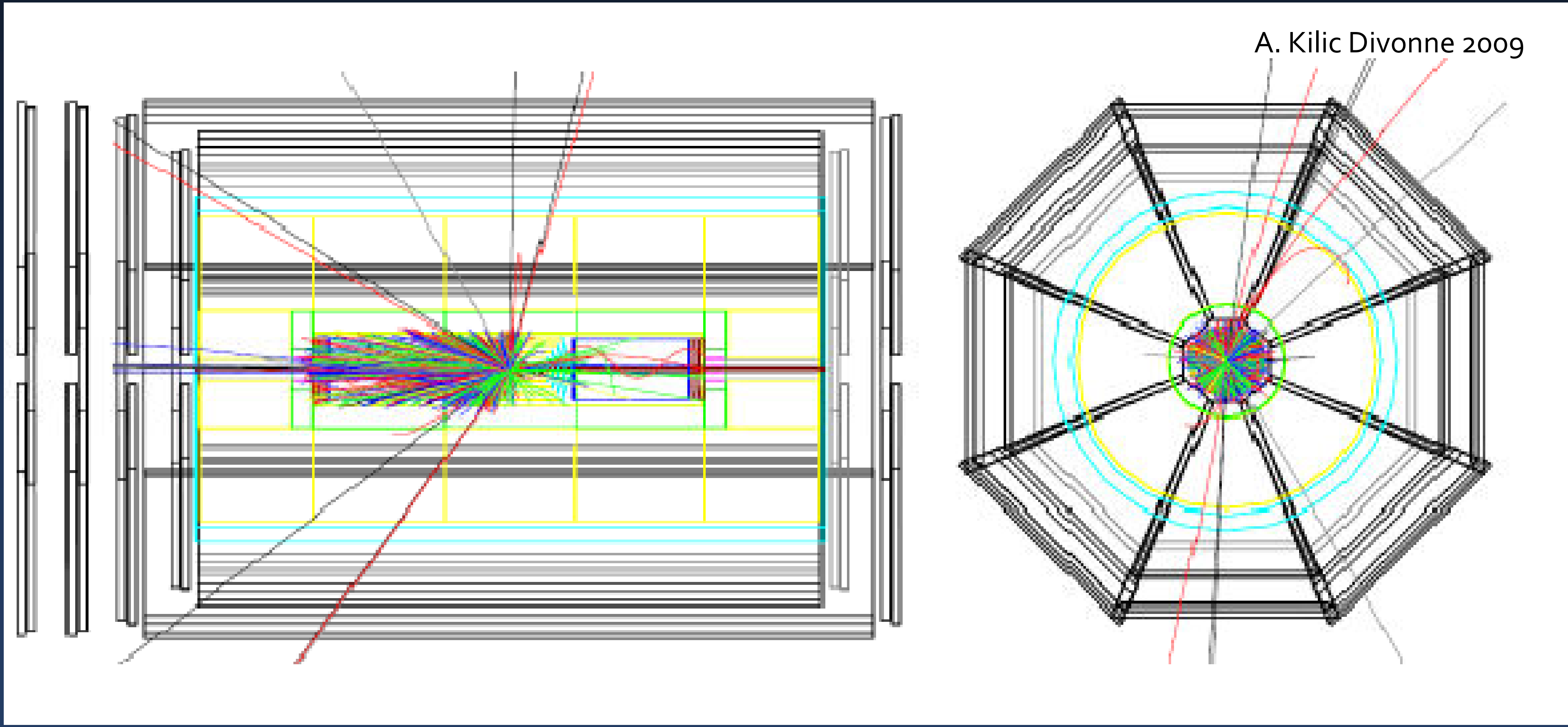


- Import of our contained model-detector geometry in the environments
- Dedicated manpower for software implementation needed

LHeC simulation

- Root TGeom model + Geant 4

First promising steps towards GEANT4 detector simulation for physics



Summary

- LHeC is an attractive physics project complementary to LHC and ILC enterprises
- The detector requirements and the realization time scale allow the LHeC to make use of the experience and the R&D done for SLHC and ILC/CLIC
- This is an opportunity for promising new detector technologies
- Si-Gas detectors appear to be an ideal option for the LHeC tracker
- LHeC Physics and Detector working groups are extremely interested in pushing forward the collaboration with detector R&D projects
- 1st step is to define a common framework and a detector module to be used in benchmark simulations of physics processes.
- Both the LHeC project and the detector R&D groups would profit from this exchange
- Synergy and collaboration essential

backup slides

Magnet Essentials

- Present option:
  Conservative Solenoid with B field =3.5 T

- Attractive design with a 2 solenoid solution, tracking: +5T and -1.5T in the muon area if 4th concept design followed.

➔ Decide after detailed machine/physics studies and cost considerations

From discussion with experts (H. Ten Kate, A. Dudarev) any design feasible.

- The High Lumi detector setup requires strong focusing magnet at ~120 cm from IP. Severe acceptance limitations. Dimensions of strong focusing magnets (Ø = 30cm now)

➔ Instrumentation of strong focusing magnets - tracking/ calorimeter device *)

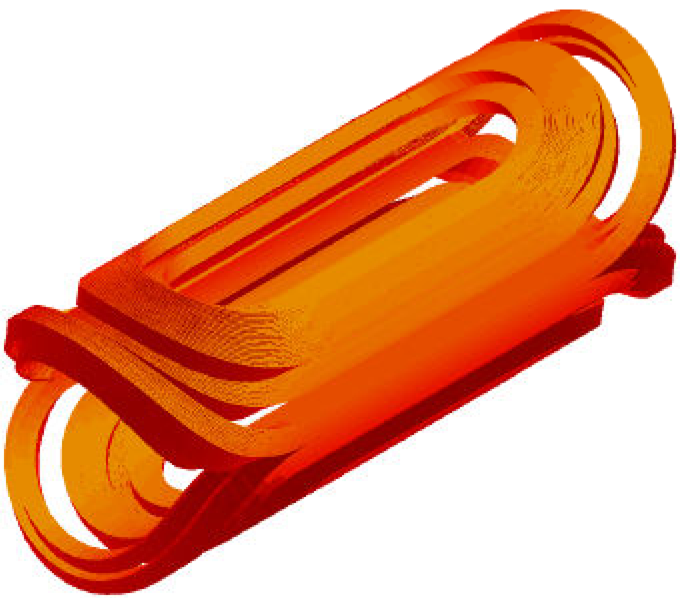
*) T.Greenshaw, see LHeC Divonne 2008+ 2009

Instrumented Magnets

Tim Greenshaw
Divonne 2009

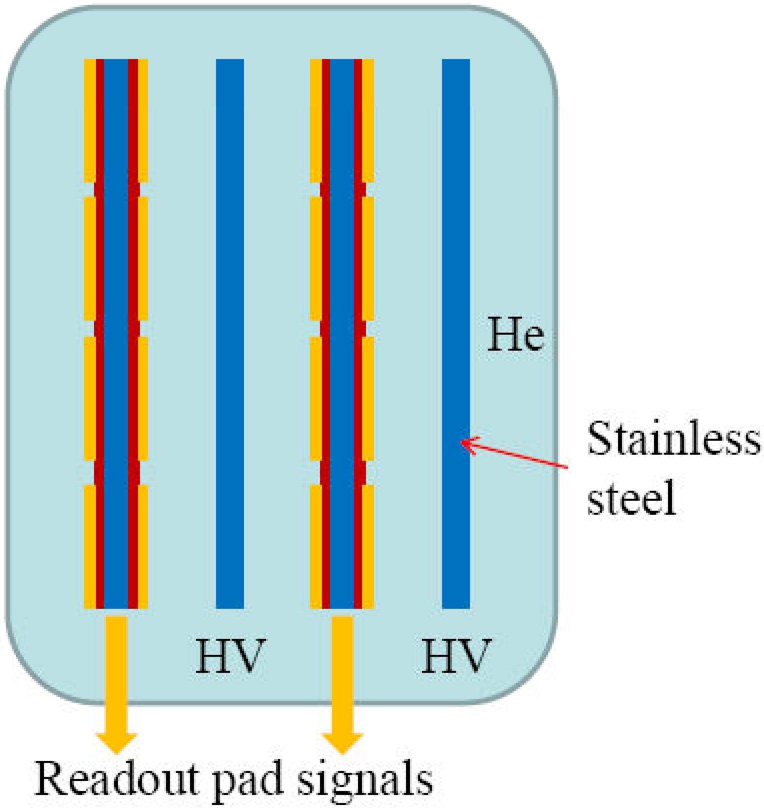
Superconducting magcal – take one

- Helium cooled SC magnet.
- Coils in He bath.



- Space for calorimeter using He as active component?

- Could add stainless steel plates as absorber with readout pads:



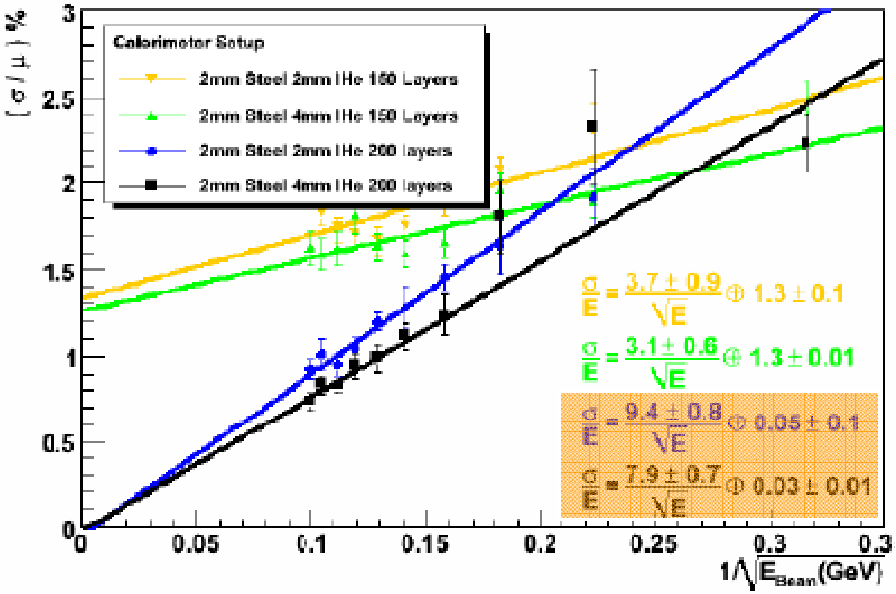
Geant 4 studies Birmingham

Tim Greenshaw
Divonne 2009

- Resolution, expect:

$$\frac{\sigma}{\mu} = \frac{\text{const.}}{\sqrt{E}}.$$

- Extract const. from slope of graph of σ/μ against 1/√E.



- Highest luminosity at collider requires magnets close to IP.
- These limit experimental acceptance unless they can provide (calorimetric) measurements.
- Stainless steel/LHe scintillation sandwich calorimeters look to be able to provide an energy resolution of ~ 10%/√E...
- ...but the showers in the calorimeters are broad and so they have to be reasonably large.

Exercise Track Resolution

- i.e. assuming / using (Glückstern relation): $\frac{\sigma(p_\perp)}{p_\perp} = \frac{\sigma(x)}{aBL^2}\sqrt{\frac{720}{N+4}} \cdot p_\perp$ with $a = 0.3\ T^{-1}m^{-1}GeV$

  N track points on L; length of track perpendicular to field B, accuracy σ(x)

  - B = 3.5 T
    N_{min}= 56 track points (2 x 5 (min. hits per layer) x 5 + 2 x 3 B-layer hits)
    - si-gas cone modul ~10° inclined
      more track points for inclined tracks - extended track segments
  - $\Delta p_T/p_T^2$ = 0.03%

- track accuracy = 15µm -> track length 42 cm - tracker layout: 54 cm (90° track)
- track accuracy = 25µm -> track length 53.7 cm
- track accuracy = 15µm & θ = 5° & N_{min} = 90 -> length ~39cm -> $\Delta p_T/p_T^2$ = 0.025 for p_T = 10GeV
- track accuracy = 25µm & θ = 3° & N_{min} = 60 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.194 for p_T = 10GeV
- track accuracy = 15µm & θ = 3° & N_{min} = 60 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.12 for p_T = 10GeV
- track accuracy = 15µm & θ = 3° & N_{min} = 110 -> length ~20cm -> $\Delta p_T/p_T^2$ = 0.086 for p_T = 10GeV

Calorimeter Technologies

Particle Flow and high granularity devices:

- promising at ILC energies(E_{CMS}<500GeV)
- need a transition to "normal" calorimetry if to be used at higher energies
- Rely heavily on software, microelectronics and SiPM (or Gas chambers ?)

rms90 PandoraPFA v03-β

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	23.8 %	3.5 %
100 GeV	29.1 %	2.9 %
180 GeV	37.7 %	2.8 %
250 GeV	45.6 %	2.9 %
500 GeV	84.1 %	3.7 %
500 GeV	64.3 %	3.0 %

Dual Readout:

Attractive idea: reading independently (in a non-compensating cal.)

1) a Cerenkov response only sensitive to relativistic shower components (mostly $e^{\pm}$)
2) a Scintillation response sensitive to all dE/dx and correcting event by event and cell by cell the main (scintillation) response.

- Usable up to highest energies
- Require hardware developments, some of them still at the "generic" level.
- Need to be demonstrated with large prototypes (DREAM Collaboration)

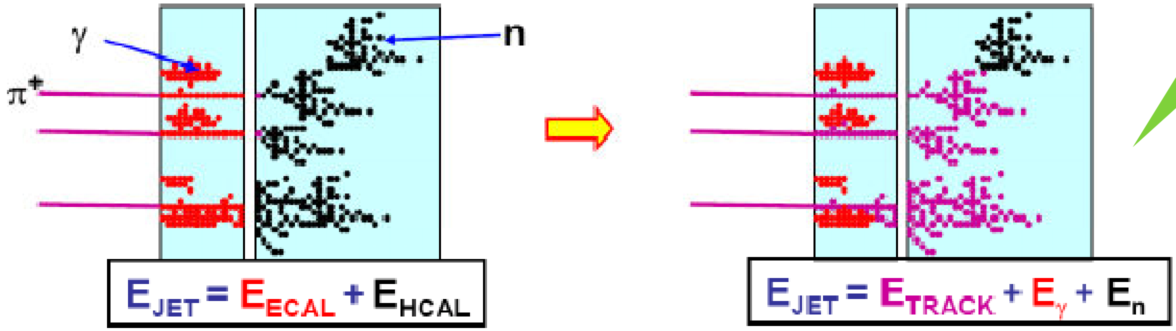
Conventional technologies:

- LAr (ATLAS, H1) especially in in barrel/rear region. Possibly problematic for infrastructure and modularity boundaries

Particle Flow

- Use tracking information to improve jet energy reconstruction
- Need to associate tracks with clusters
- Ideally only neutral cluster energy is taken from calorimeter

Christian Grefe
Divonne 2009



- "Confusion" is main source of errors
  - Need to separate neutral and charged clusters (B + radius)
  - Need highly granular calorimeter to see cluster structure

$$\text{Confusion} \propto B^{-0.3} R^{-1.0}$$

A hardware and software challenge

Tungsten = compact HCAL to minimize solenoid radius

PFA Performance

- Empiric formula for PFA performance

$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100}\right)^{+0.3} \%$$

Resolution | Tracking | Leakage | Confusion

Barrel Region

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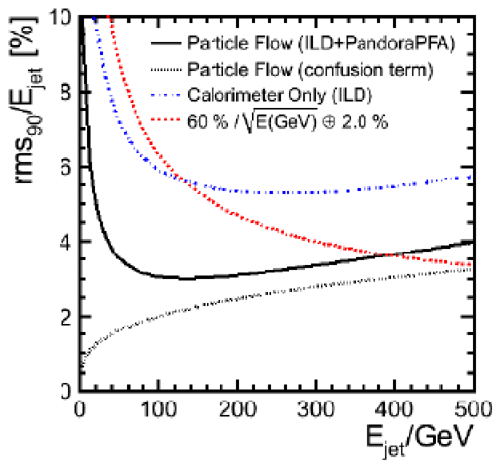
- Comparing PFA and pure calorimetry:
  - PFA "wins" for E_{jet} < 400 GeV
  - There is room for improvement of the algorithm
  - Can chose reconstruction depending on event



- http://indico.cern.ch/contributionDisplay.py?contribId=268&sessionId=2&confId=30383
- http://indico.cern.ch/materialDisplay.py?contribId=1&materialId=slides&confId=56735

Mark Thomson

Default ILD: B = 3.5 T, 6 λ HCal

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	29.2 %	2.9 %
180 GeV	40.3 %	3.0 %
250 GeV	49.3 %	3.1 %
375 GeV	81.4 %	3.6 %
500 GeV	91.6 %	4.1 %

- Good option for barrel HCAL
  - need input from physics groups about mass and/or energy resolution
- PFA performance in fwd region unproven
- => consider conventional or "DREAM" fwd calorimeter

Overview - Core Detector

Radius (cm)	Subdetector	Comment
2.9–4.6/3.47-6.05	2 layer ellipt. V_{pix}	δ(IP) < 10 μm
7.5–61	5 layer Si-Gas barrel	
5–61	4 cone Si-Gas barrel	
5–60 ($z_{1/2} \approx 110$)	fwd/bwd TPC	field cage - material?
5–60	fwd/bwd × 3 × 2 planes Si-Gas	
70–110	ECAL	25-30 X_0
112-289	HCAL	6-10 λ_I
300–330	Coil	3.5 T - tracking
340–700	Fe/muon, ...	

Not covered:

very forward detectors, lumi measurement ...

may be important for e-nucleon running:
TOF system, Zero Degree Calo ...

Infrastructure

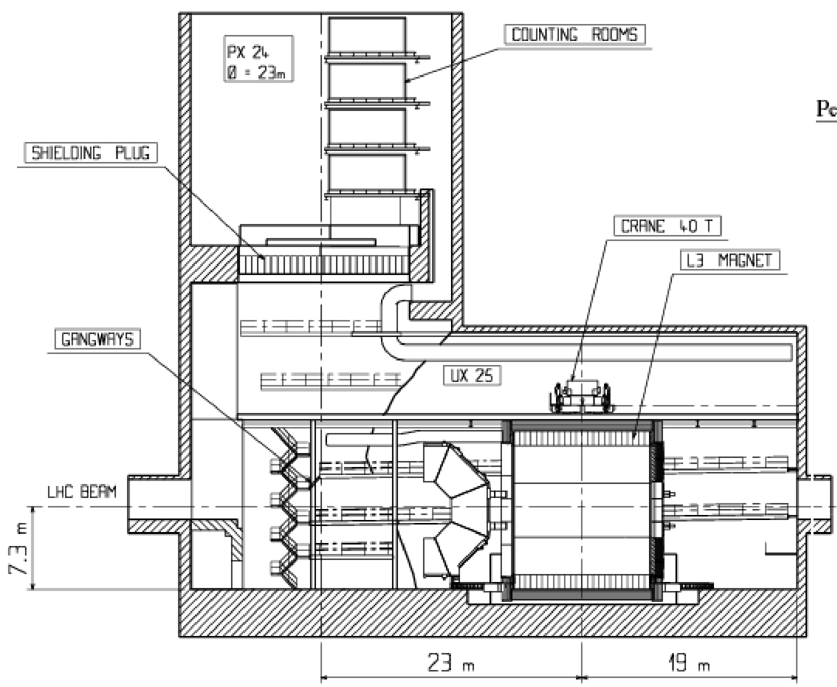
ALICE

- Round access shaft of 23m diameter, cavern about 50m along the beamline

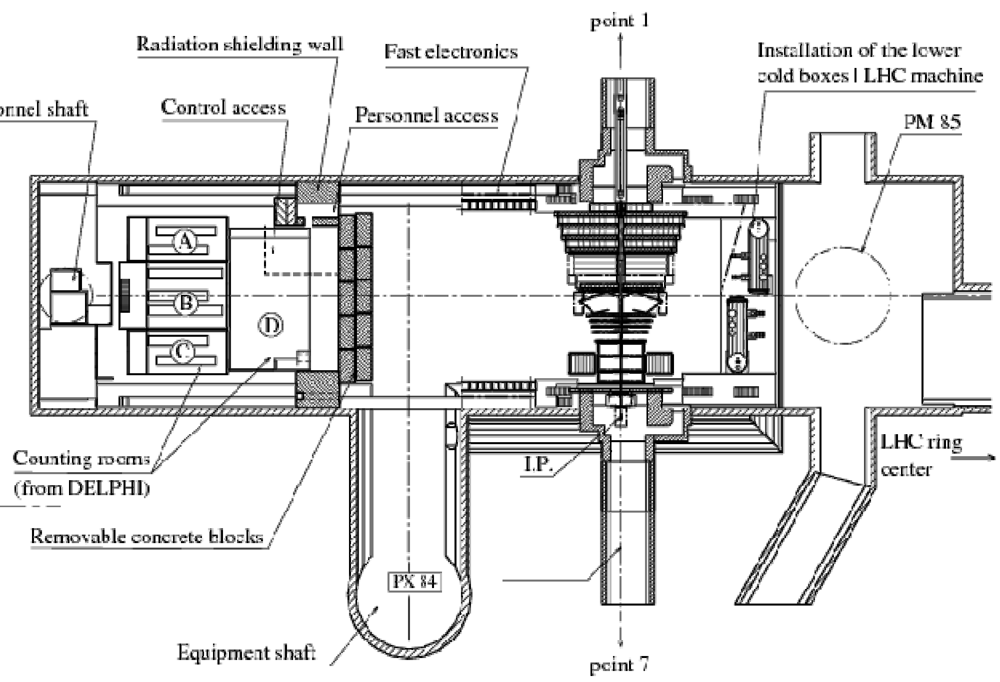
LHCb

- Shaft: 100m depth, 10.10m diameter, very slightly non vertical; experiment: length 19.90m from IP, max width at the muon station 12m; cavern: 50m x 20m

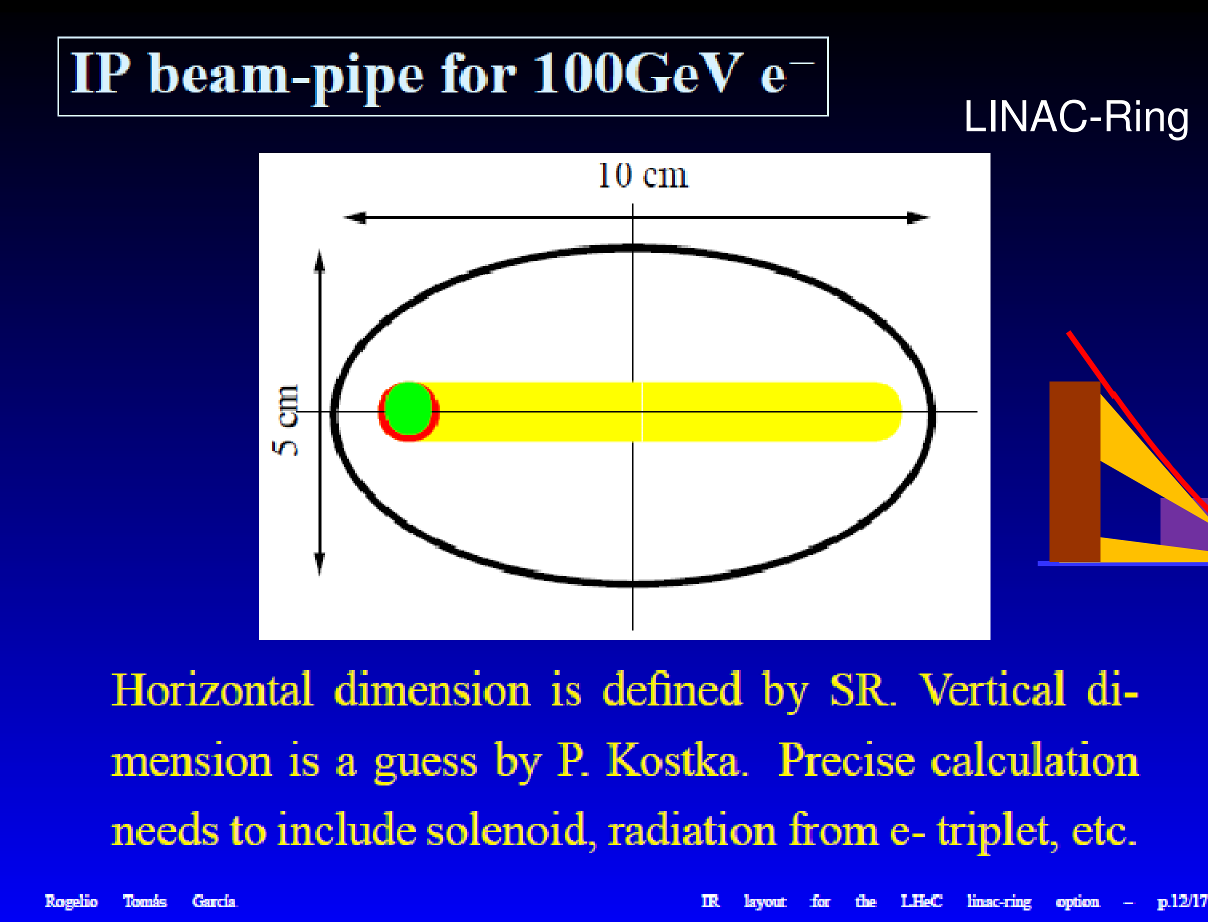
Point 2 (Alice)



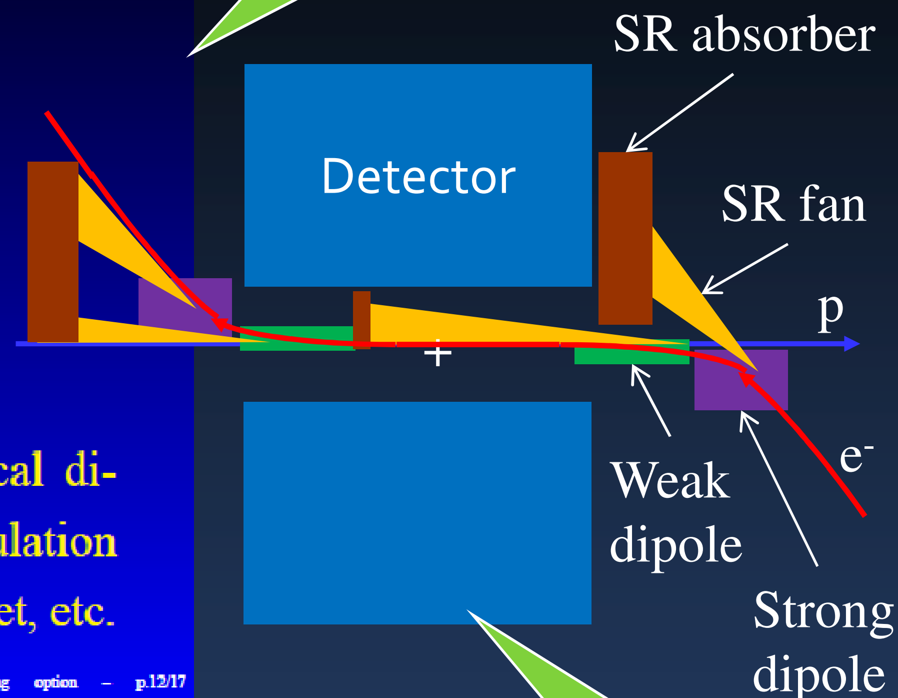
Point 8 (LHCb)



LINAC-Ring



R. Tomas Garcia Divonne 2009



V. Litvinenko (T. Greenshaw picture) Divonne 2009

- We assumed beam pipe diameter 6cm @ IP - larger radius in backward region smaller in forward (proton) direction possible
- eRHIC solution: hard bend of electron beam outside of detector sync rad fan bypasses active areas

- **needs optimization/feedback detector WG ⇔ IR region ⇔ Accelerator Group**