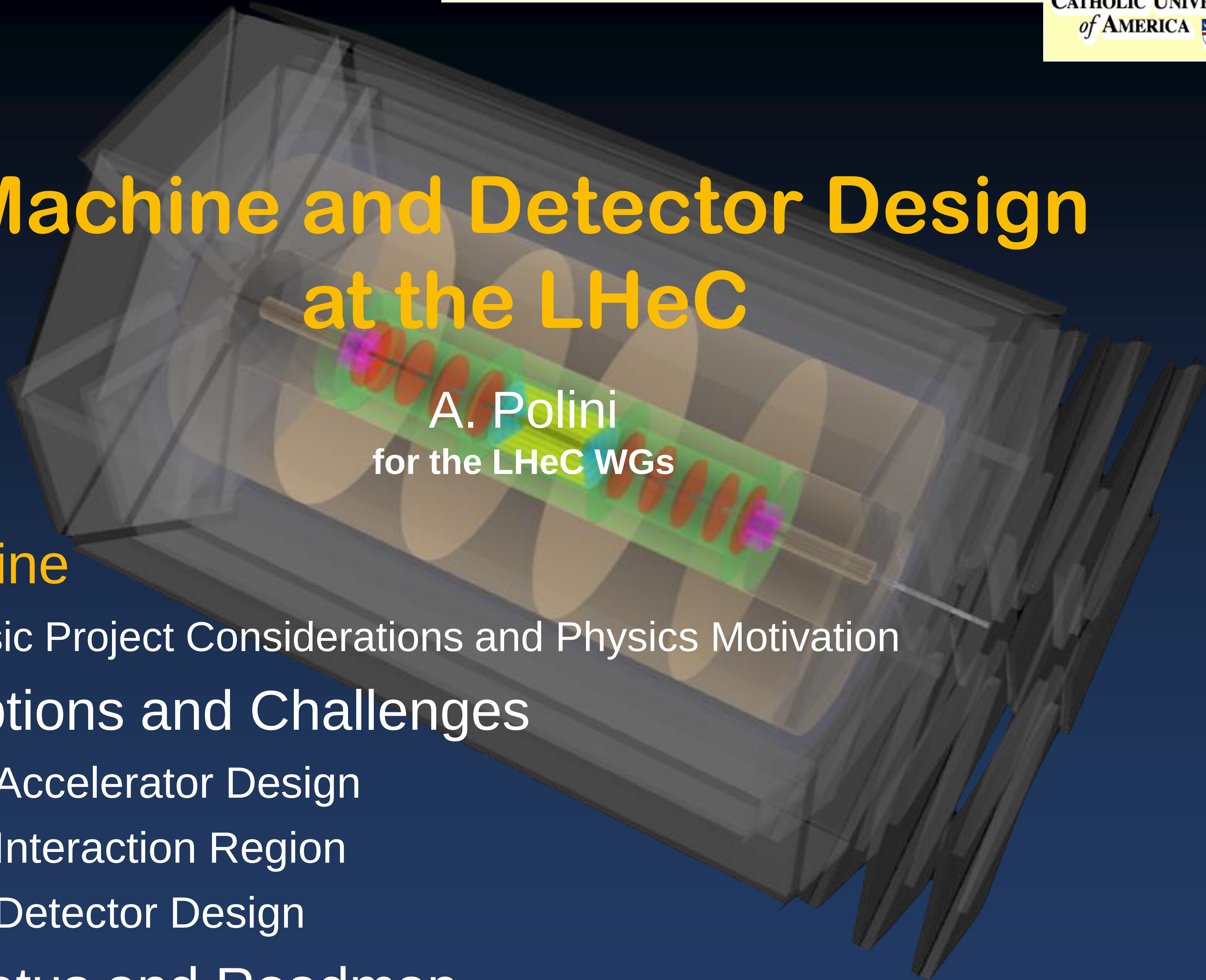
Machine and Detector Design at the LHeC

A. Polini
for the LHeC WGs



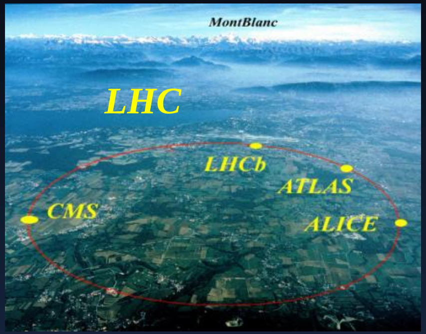
Outline

- Basic Project Considerations and Physics Motivation
- Options and Challenges
  - Accelerator Design
  - Interaction Region
  - Detector Design
- Status and Roadmap

LHeC Challenge

Add an *electron* beam to the LHC

- Next generation $e^{\pm}p$ collider
- $e^{\pm}$ polarized beam
- *eA* collider



Rich physics program: *eq* physics at TeV energies

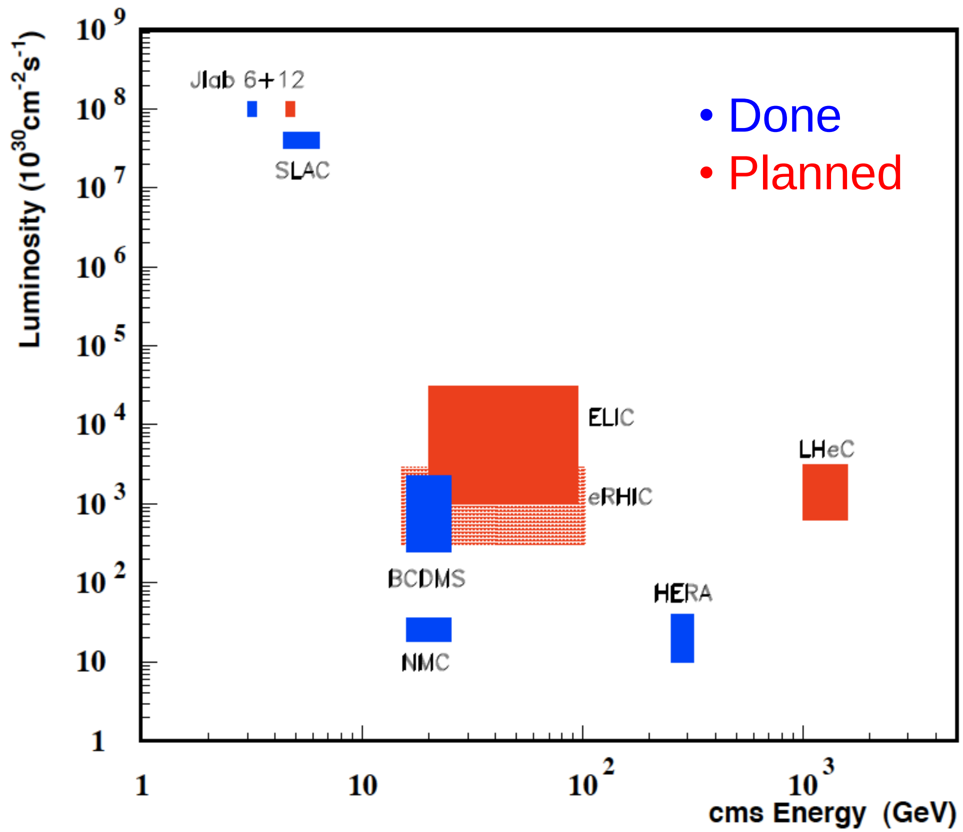
- precision QCD & electroweak physics
- boosting precision and range of LHC physics results
- beyond the Standard Model
- high density matter: low *x* and *eA*

Tevatron/LEP/HERA (Fermiscale) → LHC/LC/LHeC (Terascale)
100 fold increase in luminosity, in Q^2 and $1/x$ w.r.t. HERA

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 …

Lepton Proton Scatering Facilities



DESY 06-006
Cockcroft-06-05

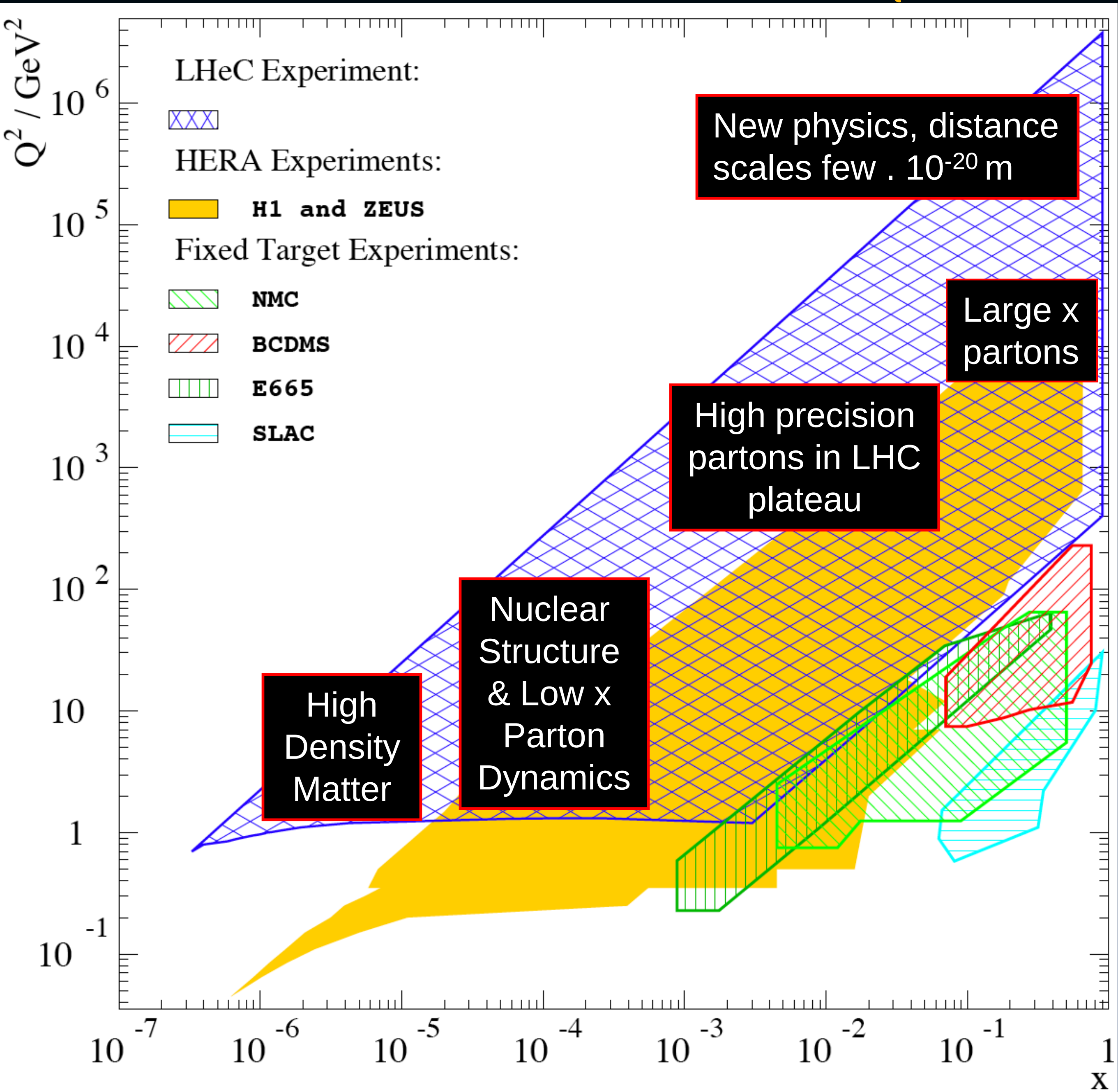
[JINST 1 (2006) P10001]

Deep Inelastic Electron-Nucleon Scattering at the LHC*

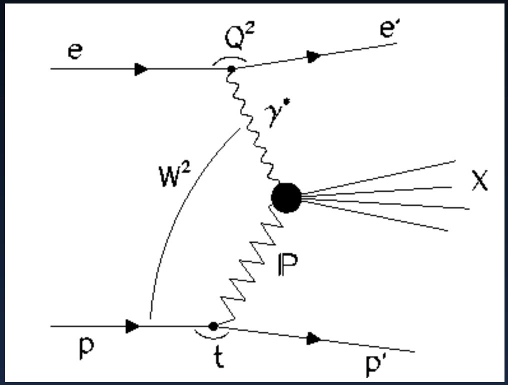
J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[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

Kinematics & Motivation (60 GeV x 7 TeV *ep*)



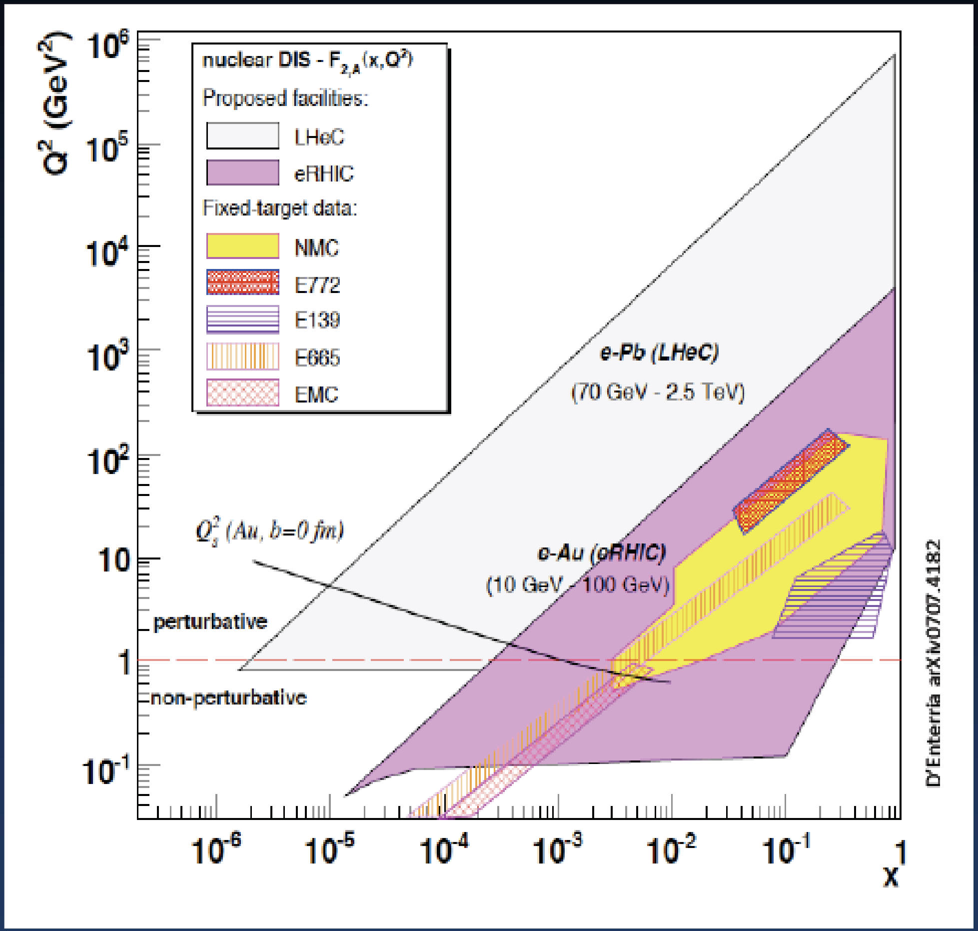
$\sqrt{s} >> 1$ TeV



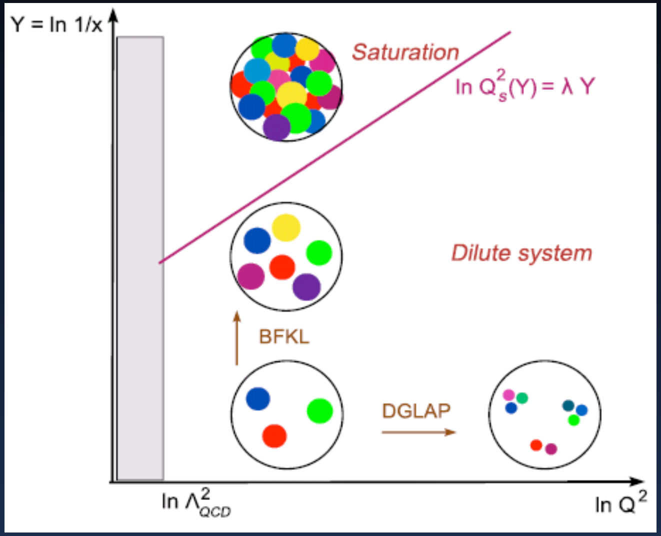
- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at smallest up to x near to 1 → PDFs
- Low x frontier [x below 10^{-6} at $Q^2 \sim 1$ GeV²]

→ novel QCD …

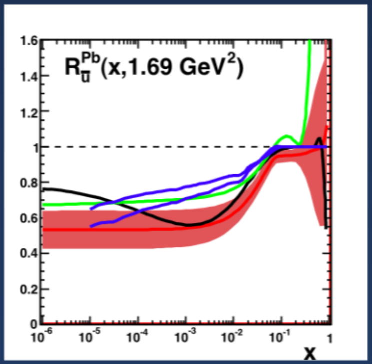
eA with the LHeC

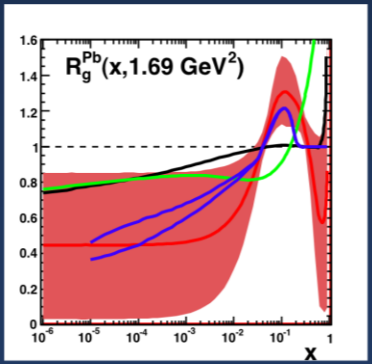


Saturation (low x, nonlinear QCD)



Nuclear Parton Densities





- eA: new realm:
  Extension of kinematic range by 3~4 orders of magnitude into saturation region
- A: density ~$A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x

LHeC Status

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

http://cern.ch/LHeC

➔ ***Divonne III November 2010: CDR draft***

Organisation for the CDR

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
Jos Engelen (CERN)
Joel Feltesse (Saclay)
Lev Lipatov (St.Petersburg)
Roland Garoby (CERN)
Roland Horisberger (PSI)
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Paul Laycock (secretary) (Liverpool)
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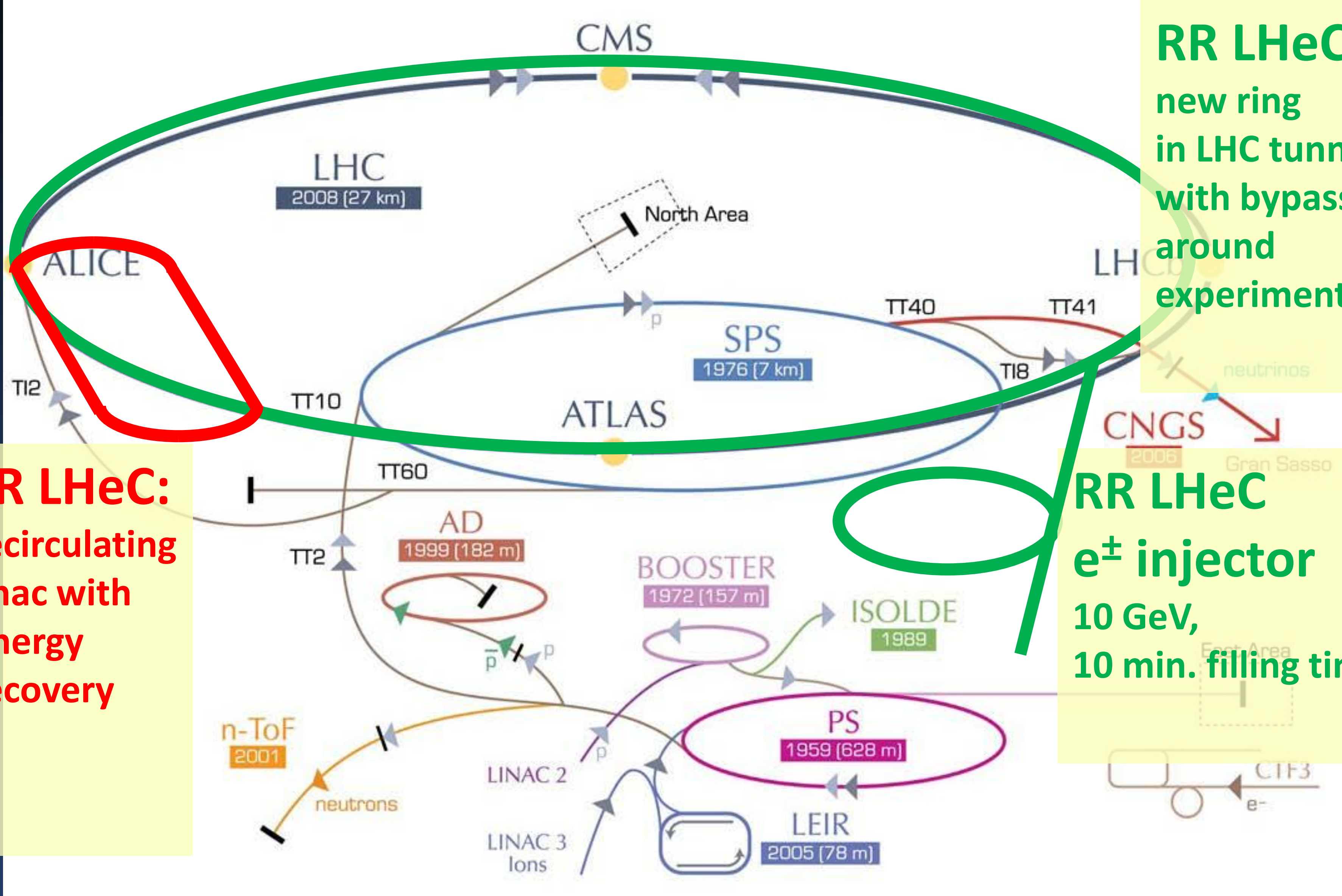
Emmanuelle Perez (CERN)
Wesley Smith (Wisconsin)
Bernd Surrow (MIT)
Katsuo Tokushuku (KEK)
Urs Wiedemann (CERN)
Frank Zimmermann (CERN)

Working Group Convenors

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)
Interaction Region and Fwd/Bwd
Bernhard Holzer (CERN),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)
Detector Design
Peter Kostka (DESY),
Alessandro Polini (Bologna)
Rainer Wallny (UCLA),
New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)
Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwenlan (Oxford)
Physics at High Parton Densities
Nestor Armesto (Santiago),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

Accelerator: Two Alternative Designs



RR LHeC:
new ring in LHC tunnel, with bypasses around experiments

LR LHeC:
recirculating linac with energy recovery

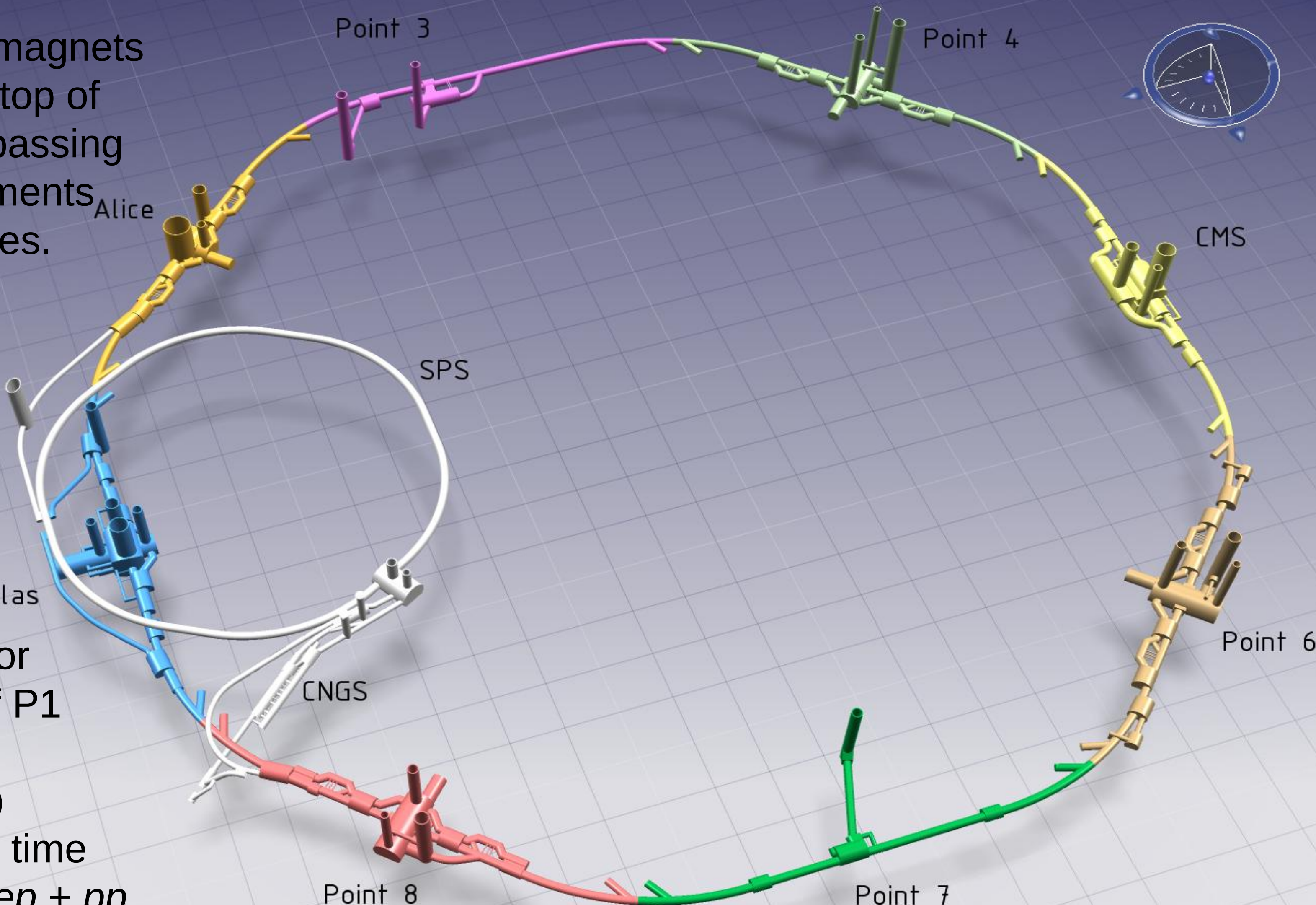
RR LHeC $e^{\pm}$ injector
10 GeV,
10 min. filling time

Two Alternative Designs

- Ring-ring
  - e-p and e-A (A=Pb, Au, …) collisions,
  - More “conventional” solution, like HERA, no difficulties of principle - at first sight - but constrained by existing LHC in tunnel
  - polarization 40% with realistic misalignment assumptions
  - Steady progress with detailed design
- Linac-ring
  - e-p and e-A (A=Pb, Au, …) collisions, polarized *e* from source, poorer Luminosity/Power
  - No previous collider like this
  - Comparisons of layouts

LHeC – Ring-Ring Configuration

Newly built magnets installed on top of the LHC bypassing LHC experiments in the twenties.

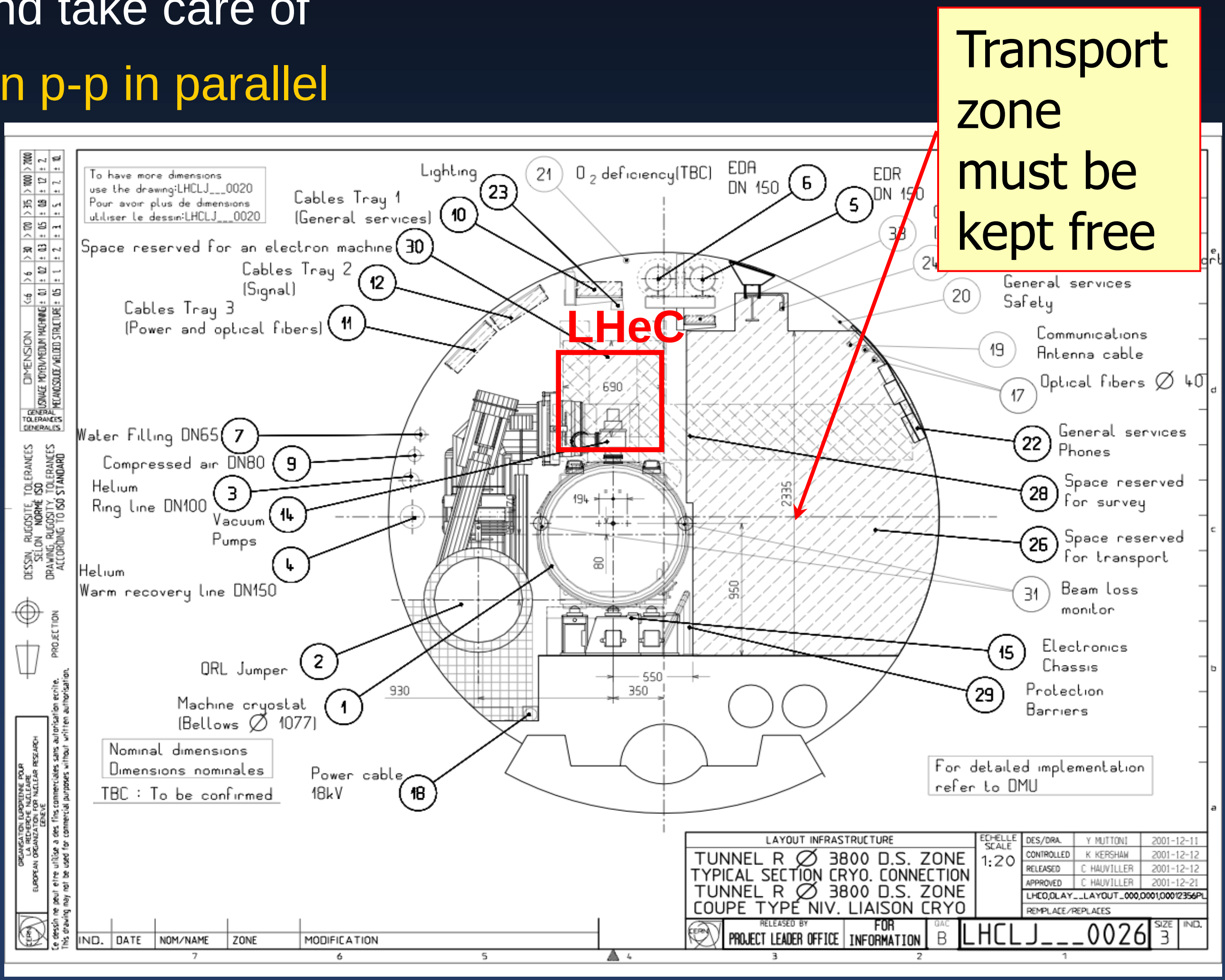


10 GeV injector into bypass of P1
2×10^{10}e
(LEP: 4×10^{11})
~10 min filling time
synchronous *ep* + *pp*

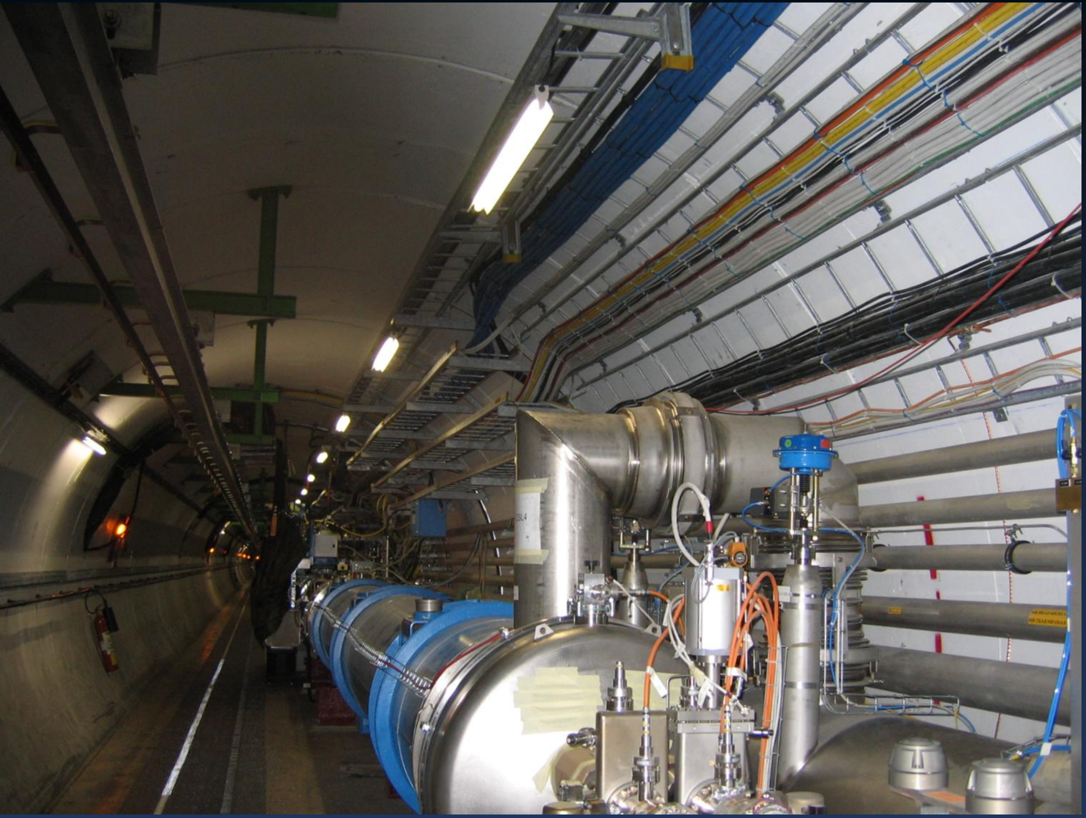
$$10^{33}\,cm^{-2}s^{-1}, \int L = 100\ fb^{-1}, E_e = 60\,GeV$$

Ring-Ring Design Criteria

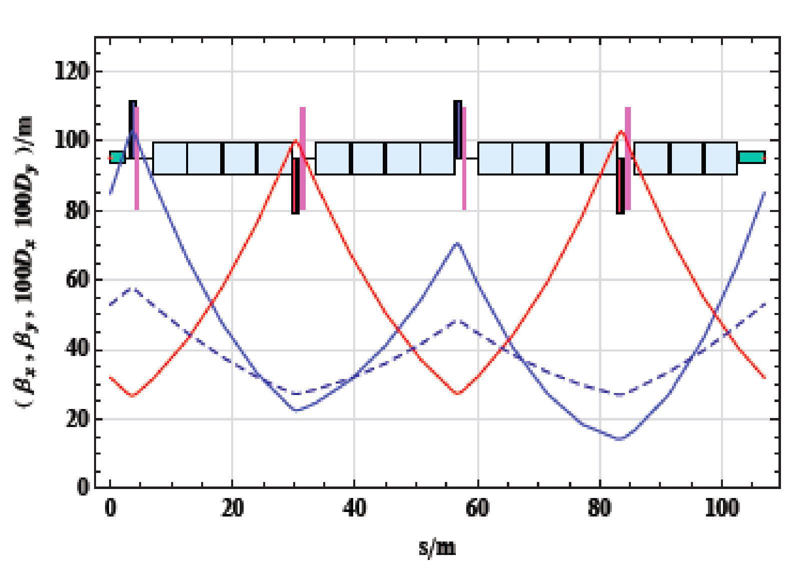
- Compatibility with installed LHC and its tunnel infrastructure
- Many details to study and take care of
- LHC would be running in p-p in parallel
- Minimise length of installation shutdown
- LHC p-p would be running for high integrated luminosity
- Bounds on power consumption (100 MW)



LHeC – e Ring Design



ARC cell design:
$L_{FODO}(e)=L_{FODO}(p)/2$



LHC Cryo jumpers accounted for in asymmetric Focusing-Defocusing

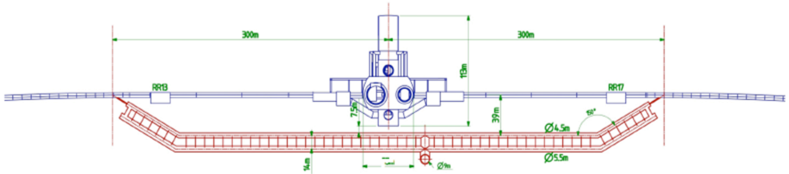
Further interferences mapped and being studied

Experiments bypassed in new tunnels which house RF cavities

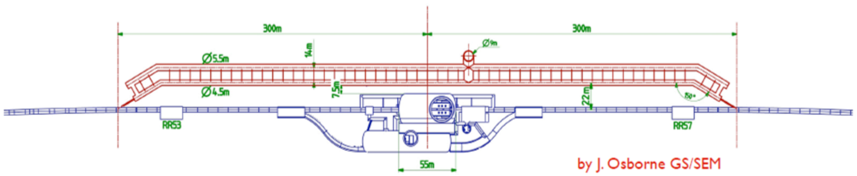
Meet spatial LHC constraints
Synchrotron radiation < 50MW
Two types of quadrupoles
Reasonable sextupole parameters
Dipoles: 4 times lighter than LEP
Prototypes: Novosibirsk and CERN

Overall Layout and Bypasses

ATLAS (bypass inside): $\Delta = 39$ m



CMS (bypass outside): $\Delta = 22$ m



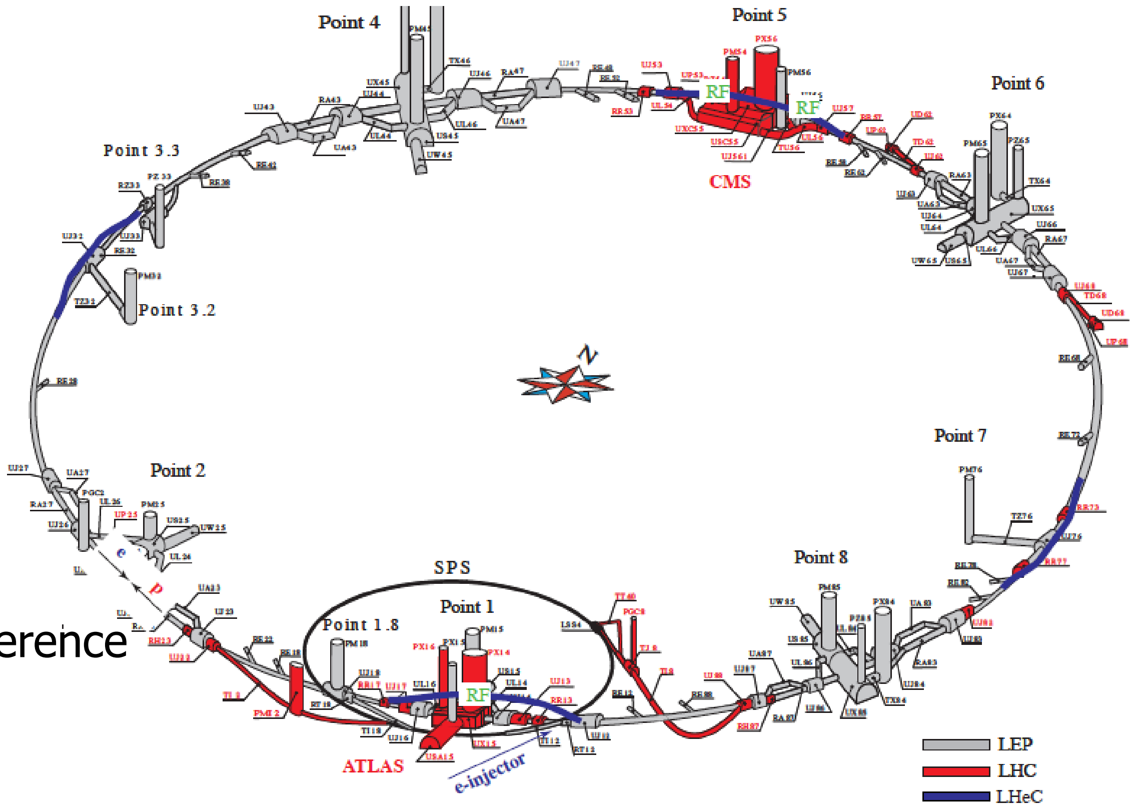
Properties (Version 6):

- estimate for additional synchrotron radiation losses: $\Delta P_{\mathrm{W}} = 3.3$ MW
- separation $\Delta = 37.1$ m
- path length difference of $\Delta s = -5.46$ m

Properties:

- no additional synchrotron radiation losses
- separation $\Delta = 22.0$ m
- path length difference of $\Delta s = 2.25$ m

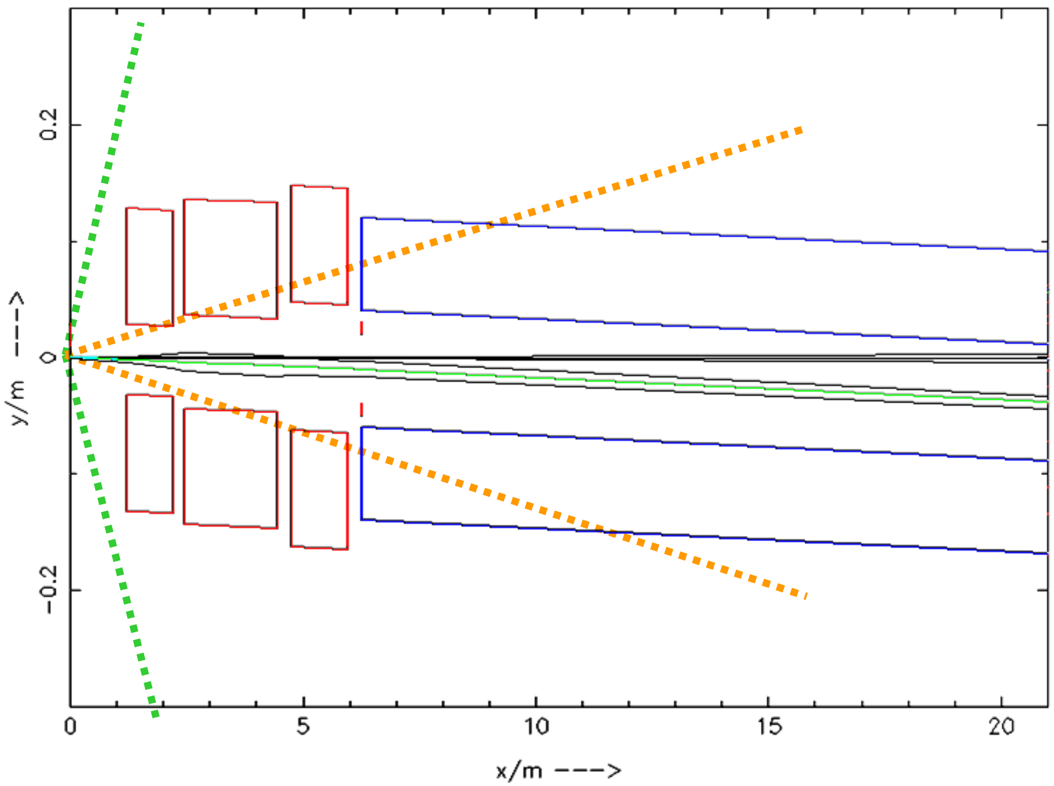
e-p/A experiment could be at IP2 (shown), IP8 or …

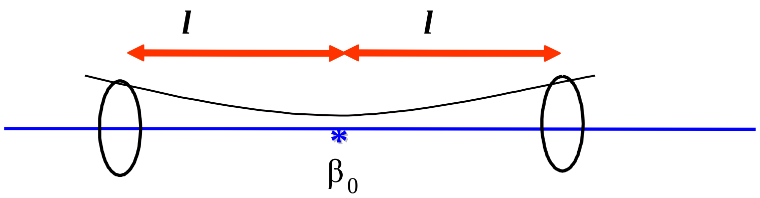


Bypass design:

- shutdown time
- cost for tunnel
- match LHC and eRing circumference
- extra shafts being discussed

Beam Optics and Detector Acceptance





$$L = \frac{1}{2\pi e^2 f_0 n_b} * \frac{I_1 * I_2}{\sqrt{(\sigma_{xp}^2 + \sigma_{xe}^2)(\sigma_{yp}^2 + \sigma_{ye}^2)}}$$

$$\sigma = \sqrt{\varepsilon \cdot \beta} \qquad \beta(s) = \beta^* + \frac{l^2}{\beta^*}$$

Luminosity: 10°: ~1.7x10^{33} cm s^{-2} ; 1°: ~ 6 x10^{32} cm s^{-2}

Design suggests two detector configurations:

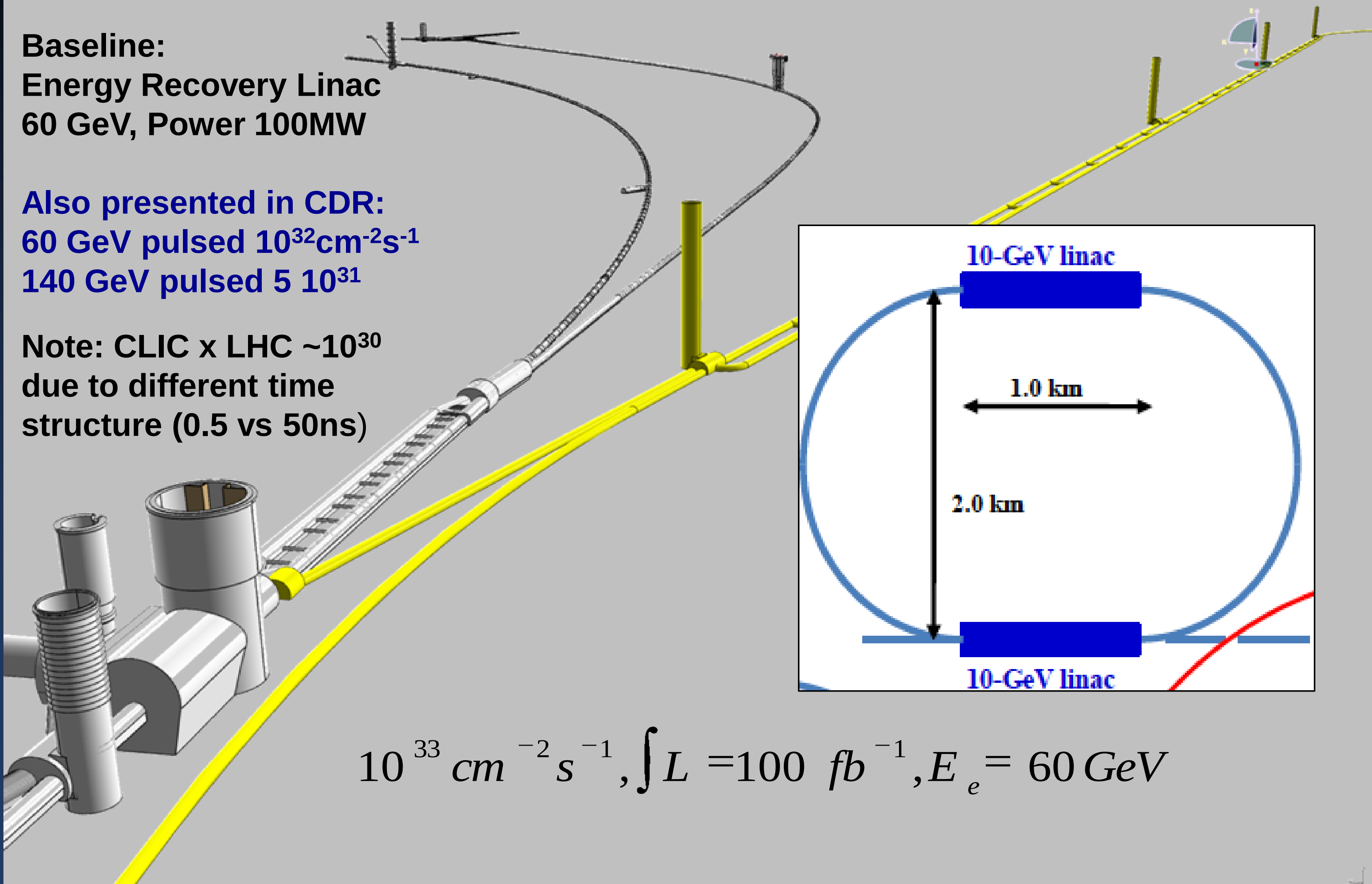
- Low Lumi, Low Q^2 → High acceptance detector 1°
- High Lumi,High Q^2 → Main detector 10° aperture

Linac-Ring Configuration

Baseline:
Energy Recovery Linac
60 GeV, Power 100MW

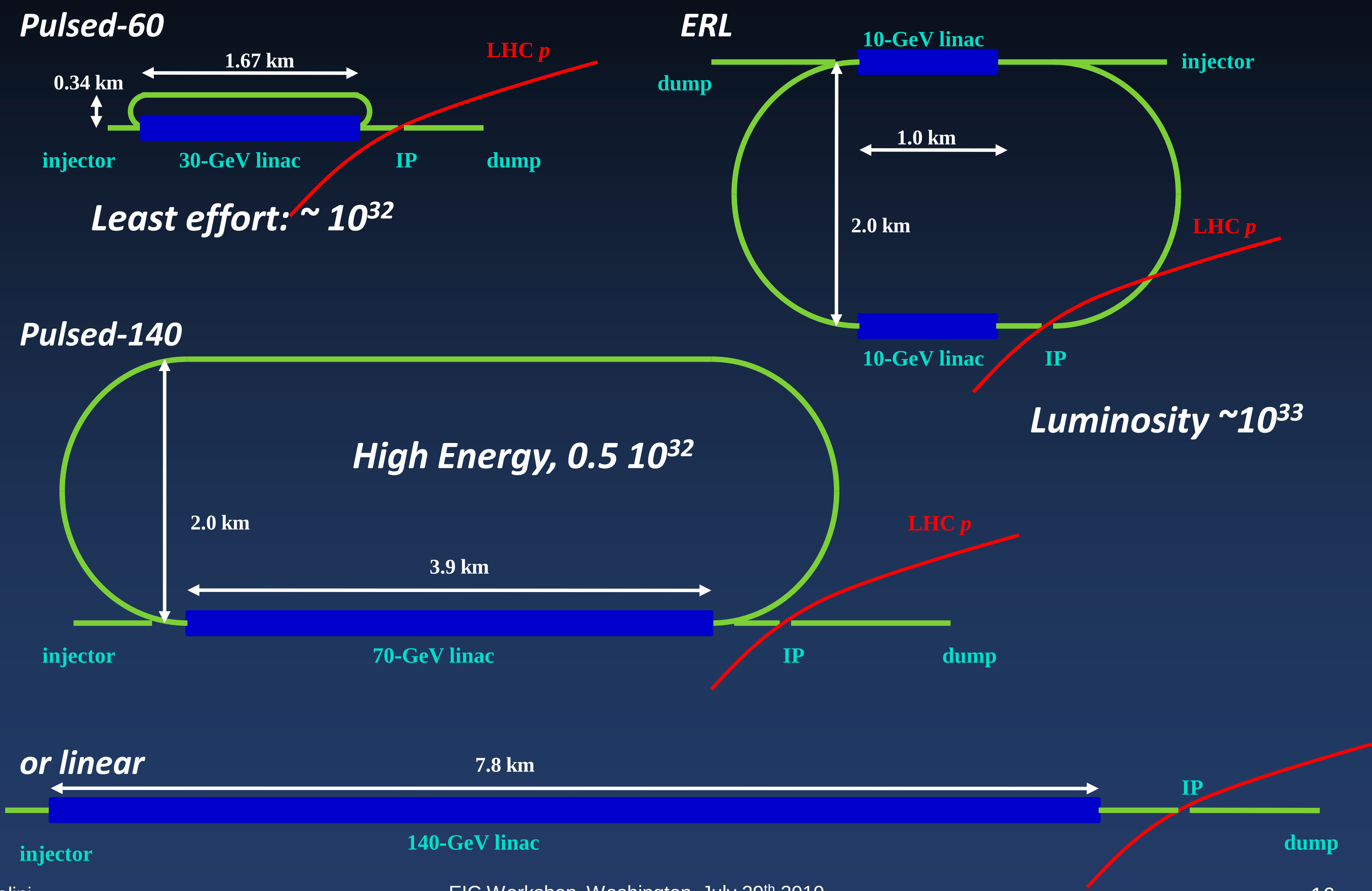
Also presented in CDR:
60 GeV pulsed $10^{32} cm^{-2}s^{-1}$
140 GeV pulsed $5\ 10^{31}$

Note: CLIC x LHC ~10^{30}
due to different time structure (0.5 vs 50ns)



$$10^{33}\,cm^{-2}s^{-1}, \int L = 100\ fb^{-1}, E_e = 60\,GeV$$

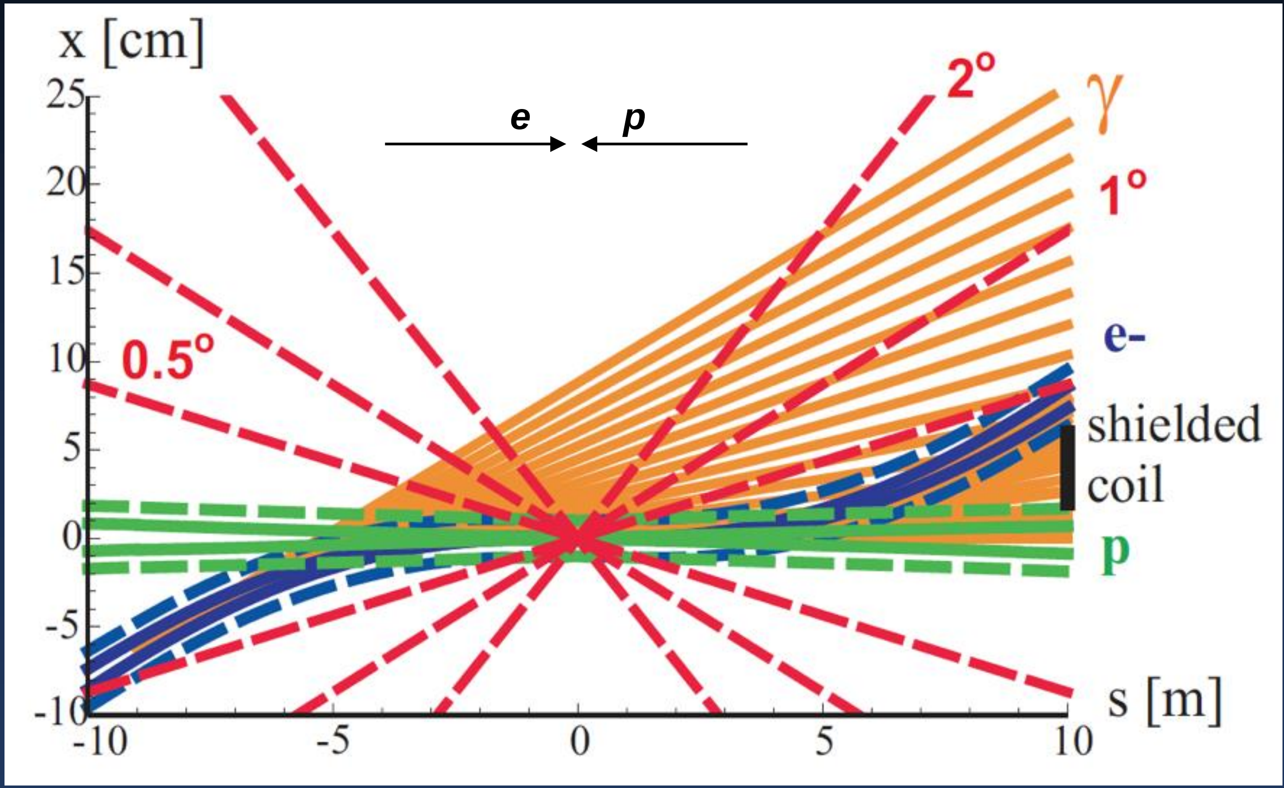
Linac-Ring Configurations



LR Option -Dipole-Separation - SR Fan

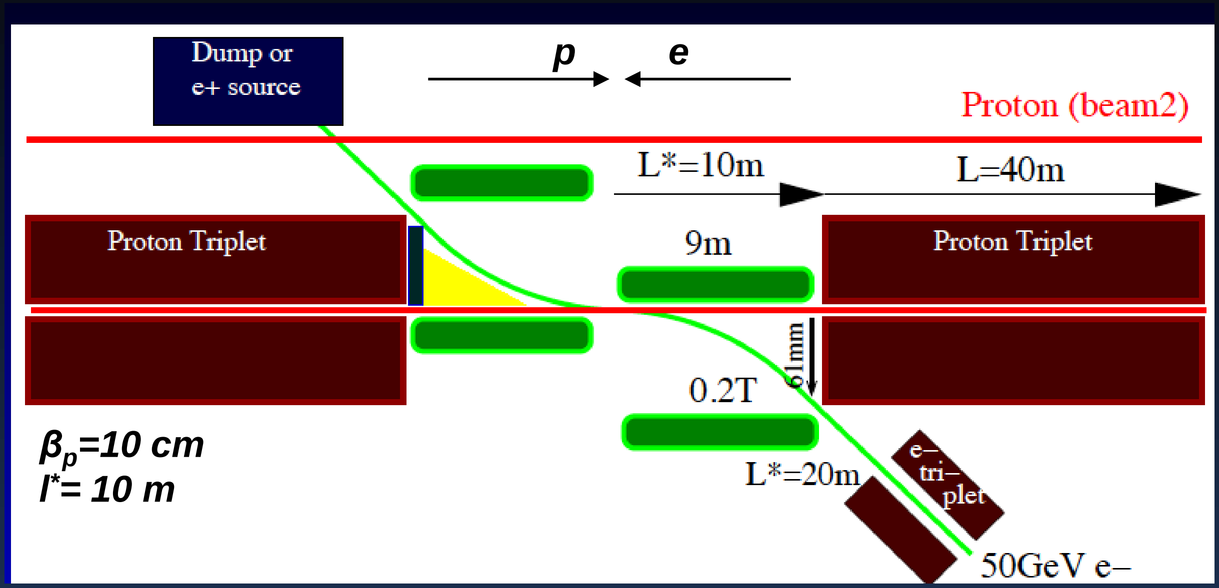
M. Sullivan

- **Elliptical Beam Pipe**: (very preliminary)
- inner-$Ø_x$ = 12cm
- inner-$Ø_y$ = 5cm
- outer-$Ø_x$ = 12.8cm
- outer-$Ø_y$ = 5.8cm
- thickness: 0.4cm



Beam envelopes of 10σ (electrons) [solid blue] or 11σ (protons) [solid green], the same envelopes with an additional constant margin of 10 mm [dashed], the synchrotron radiation fan [orange], and the approximate location of the magnet coil between incoming protons and outgoing electron beam [black].

LR – Interaction Region



IR Options:

Head on → dipoles

Crossing → like RR IR

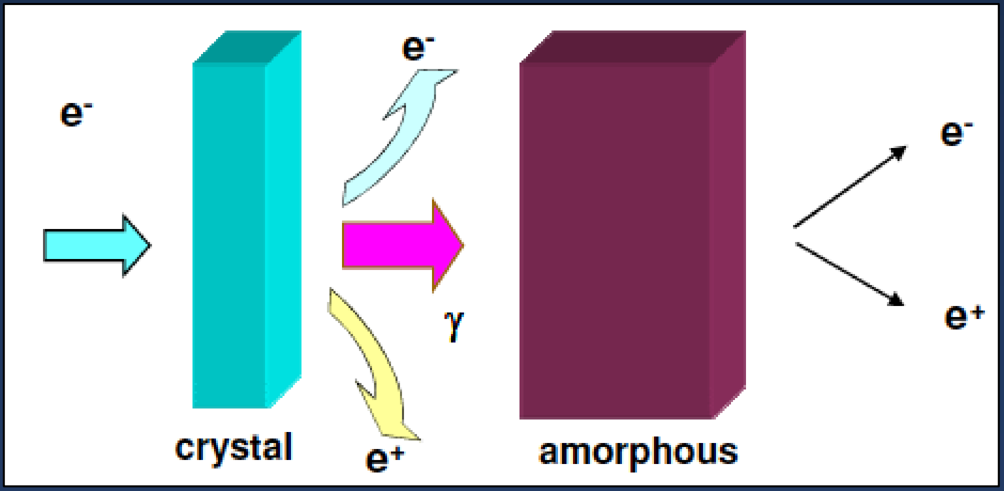
Positron source

Difficult to reach high intensity. Perhaps best suited: hybrid target

production of unpolarised

positrons. Several stations?

cf Divonne 2009



Design Parameters

electron beam	RR	LR ERL	LR
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17	10	0.44
polarization [%]	5 - 40	90	90
bunch population [10^9]	26	2.0	1.6
e- bunch length [mm]	10	0.3	0.3
bunch interval [ns]	25	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.58, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	30, 16	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.18, 0.10	0.12	0.14
full crossing angle [mrad]	0.93	0	0
geometric reduction H_{hg}	0.77	0.91	0.94
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	131	6.6	5.4
tot. wall plug power[MW]	100	100	100

proton beam	RR	LR
bunch pop. [10^{11}]	1.7	1.7
tr.emit.$\gamma\varepsilon_{x,y}$ [μm]	3.75	3.75
spot size $\sigma_{x,y}$ [μm]	30, 16	7
$\beta^*_{x,y}$ [m]	1.8,0.5	0.1$
bunch spacing [ns]	25	25

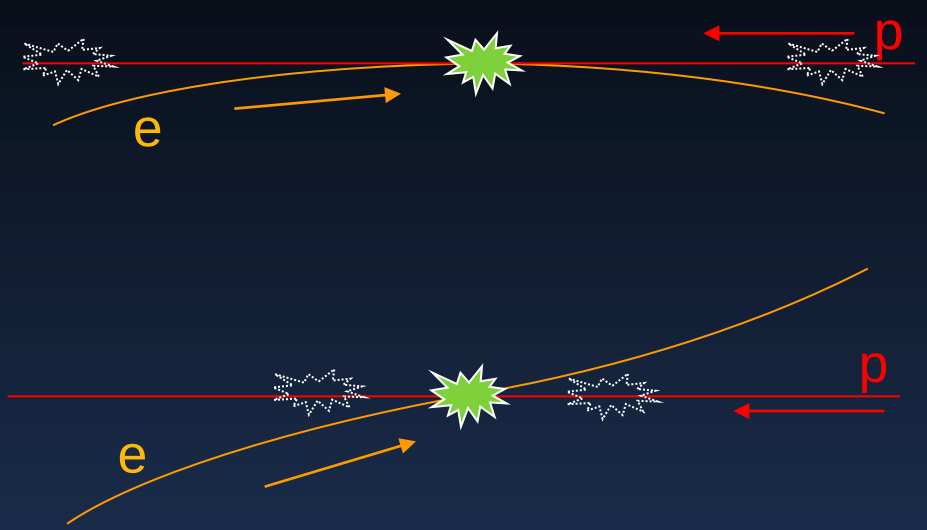
$ smaller LR *p*-β^* value than for nominal LHC (0.55 m):

- reduced *l** (23 → 10 m)
- only one *p* beam squeezed
- IR quads as for HL-LHC

In progress last update 8.7.2010

RR = Ring – Ring
LR = Linac –Ring
ERL= Energy Recovery Linac

Interaction Region: Crossing Angle



HERA
96 ns bunch spacing

LHeC
25 ns bunch spacing
1^{st} parasitic interaction
3.7 m from IP

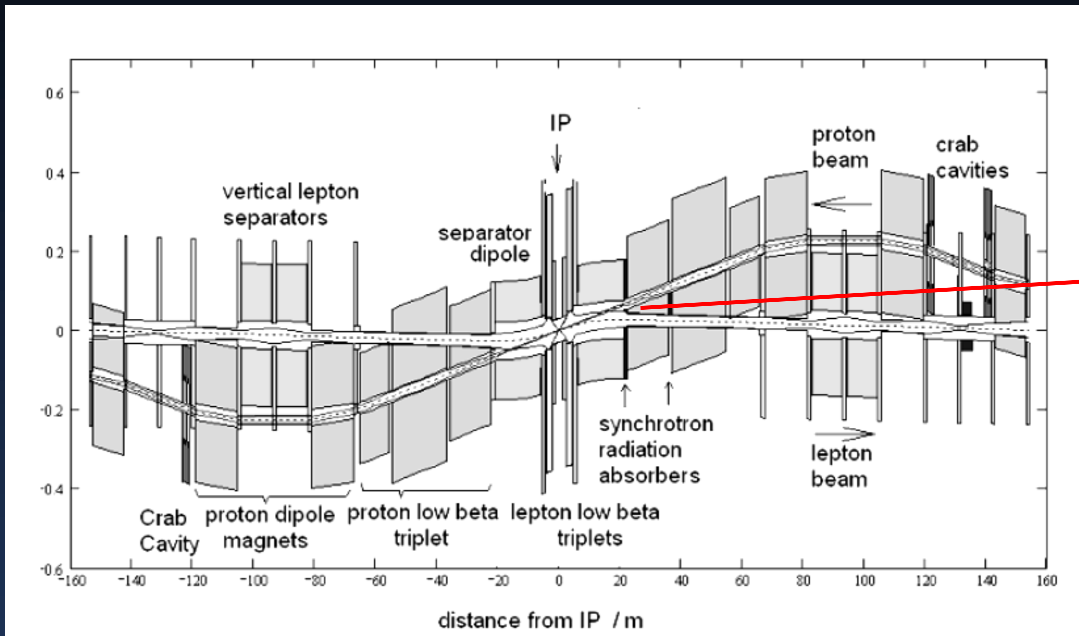
- At LHC 1^{st} parasitic interaction at 3.7 m from IP
- RR: Presently non zero crossing angle (0.93 mrad)
- RR: Focusing Quadrupoles close to IR to achieve high Lumi (1.2m)
- LR: Need dipole(s) close to interaction region
  (B 0.2 ~ 0.4 T at 0 ~1.5 m-9m from IP)
- RR could profit of bending dipole(s) to further reduce the crossing angle

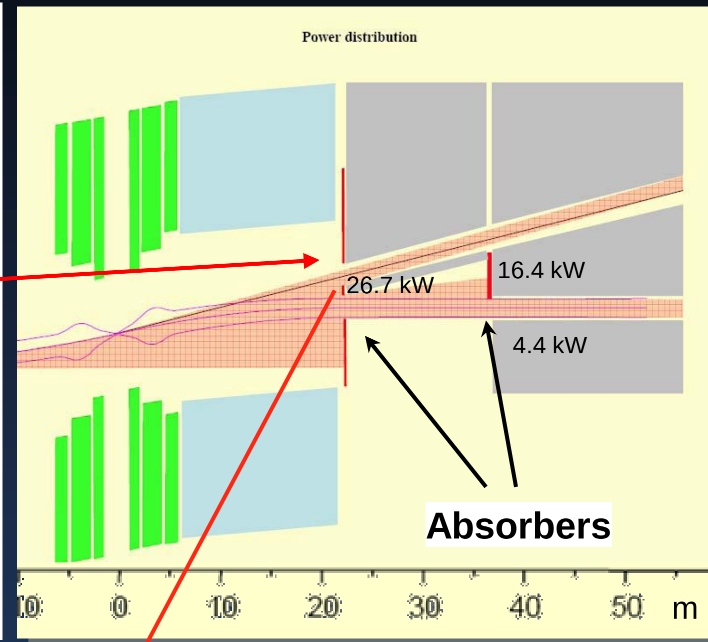
Synchrotron Radiation - RR

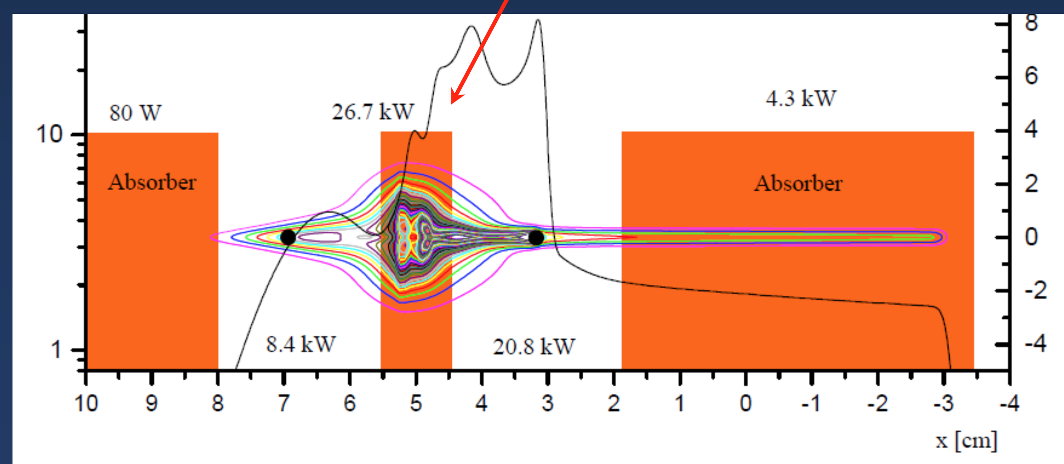
(very preliminary)

Top View of IR

B. Nagorny, W. Schneekloth



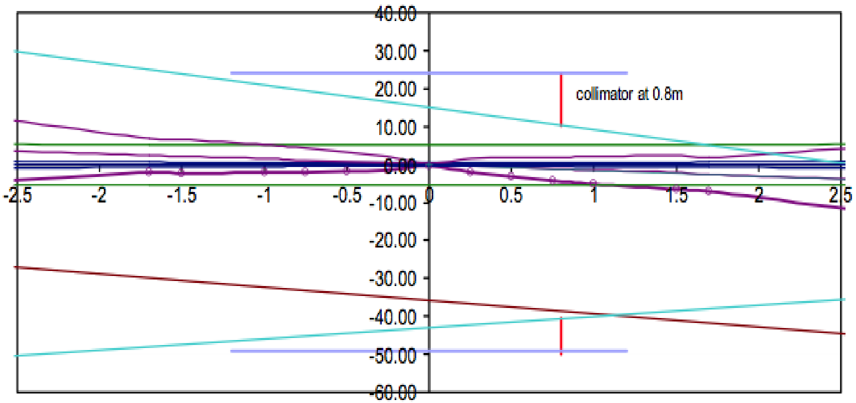




Backscattering of Sync Rad
(very preliminary)

U.Schneekloth

IR Sketch Top-view - Zoom



- Beam separation very close to IP, starting at 1.2m
- Upstream collimation and partial absorption of synchrotron radiation not possible
- Direct synchrotron radiation must pass through IR
- Most SR absorbed by absorber at 21m
- Must protect detector from SR backscattered from absorber at 21m by downstream collimators
  - No space for moveable collimators
  - Collimators inside central detector, not accessible
  - → use fixed collimators
- Size of central beam pipe determined by backscattered SR

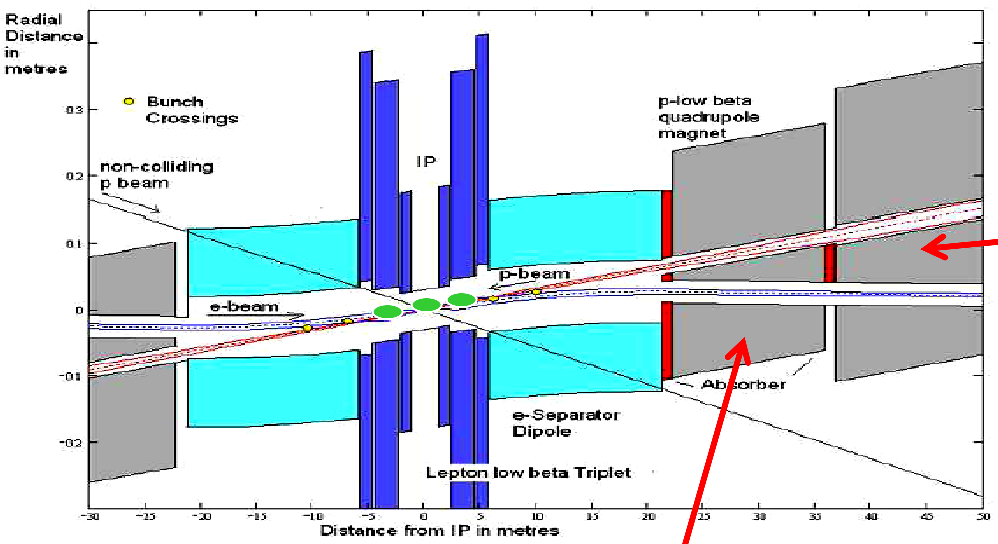
- Horizontal distance of collimator from proton beam 10.5mm
- Minimum width of central beam pipe 73mm
  - Horizontal distance to proton beam 24mm ring outside, 49mm ring inside

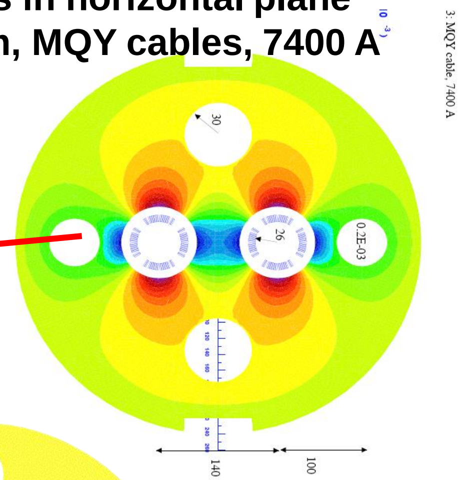
Synchrotron Radiation simulation and collimator design with up to date optics is ongoing

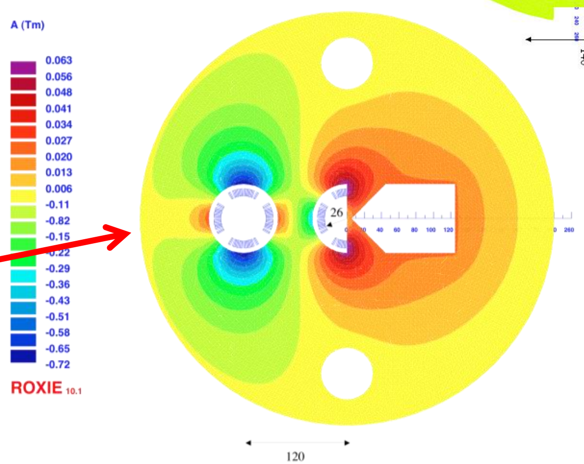
IR - Beam Separation

Crossing angle (0.93 mrad) to avoid first parasitic crossing (L x 0.77)
1st and 2nd bending quadrupoles
(Dipole in detector? Crab cavities? Design for 25ns bunch crossing [50ns?]
Synchrotron radiation –direct and back, absorption … recall HERA upgrade…)

2nd quad: 3 beams in horizontal plane
Separation 85 mm, MQY cables, 7400 A







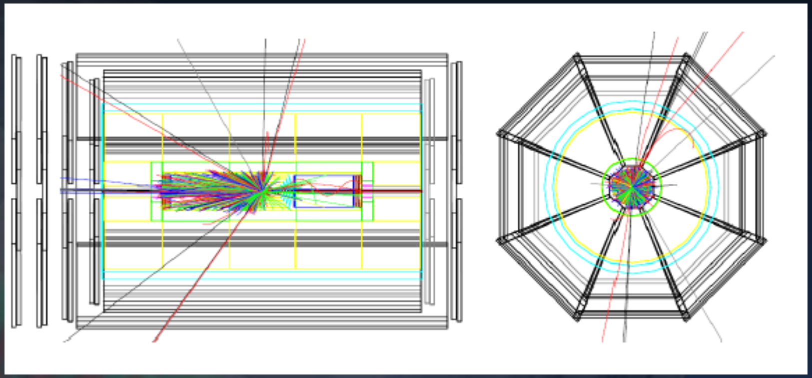
Ring-Ring

1st SC half quad (focus and deflect)
separation 50mm, g=127T/m,
MQY cables, 4600A

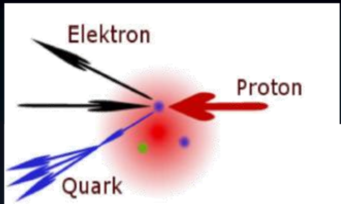
Detector Design

Detector Outline

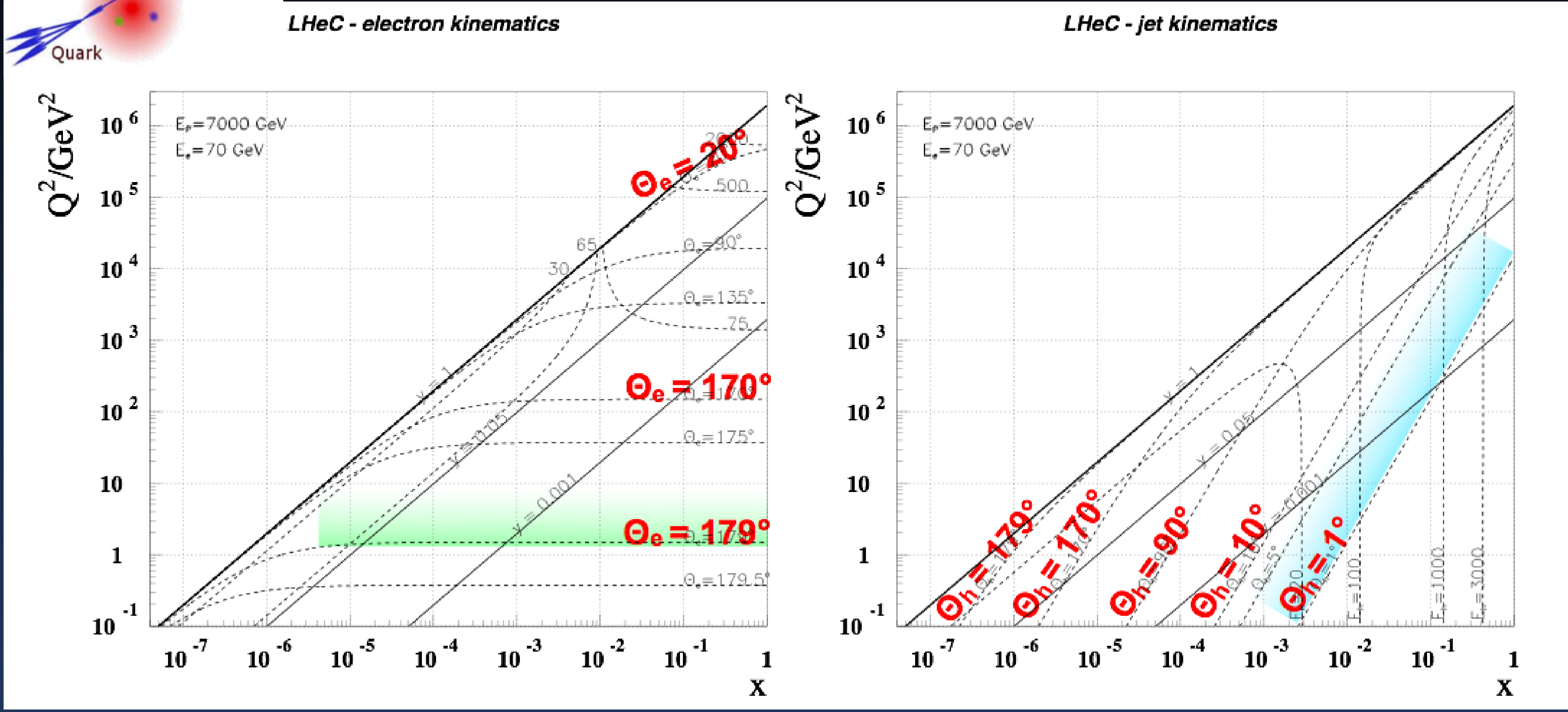
- Physics Requirements
  - Acceptance
  - Track and energy resolution
  - Benchmark processes
- Interaction Region Boundaries
  - Optics, synchrotron fans
  - Beam pipe



- Disclaimer:
  - As many of the boundary conditions (Optics, BP, IR) are still open, mostly qualitative design is currently possible.
  - Much of the design work and interfacing with physics requirements still to be done.
- Goal:
  - Aim for a design *concept* for the CDR, not the proposal or technical design report yet
  - A baseline detector solution and RD options



LHeC Kinematics



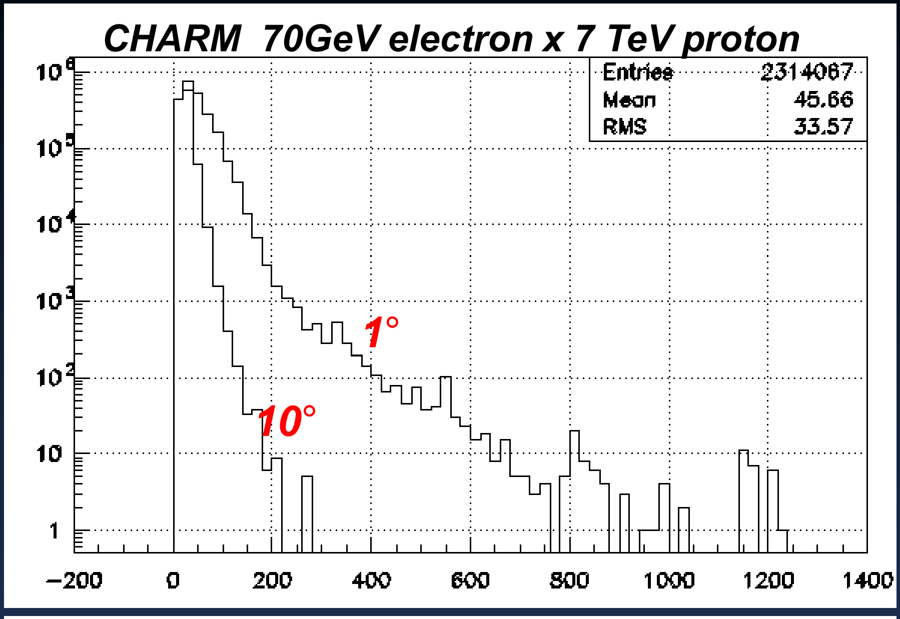
•High x and high Q²: few TeV HFS scattered forward:

➔ 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 .

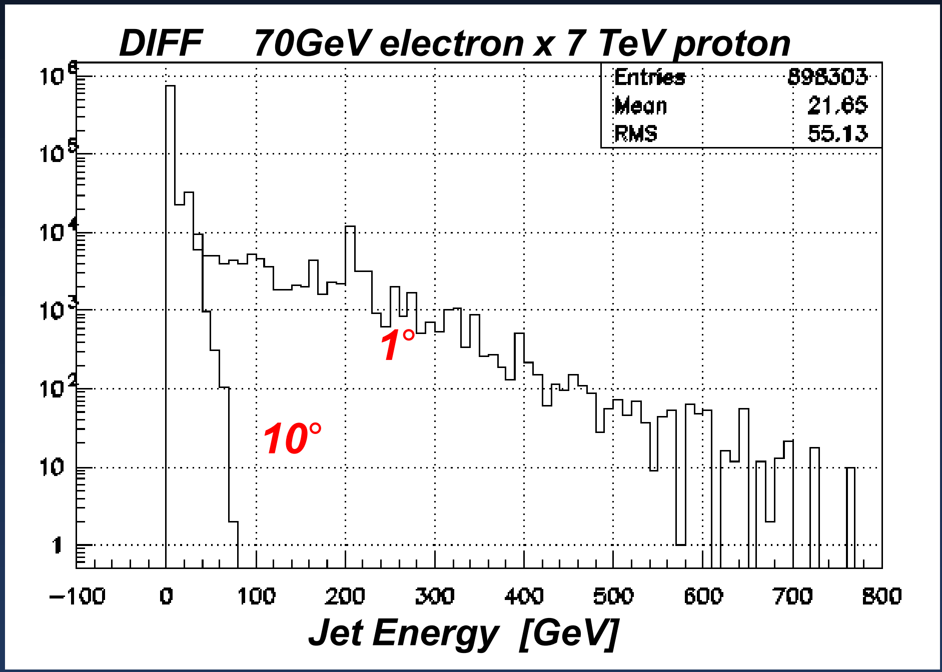
Detector Acceptance

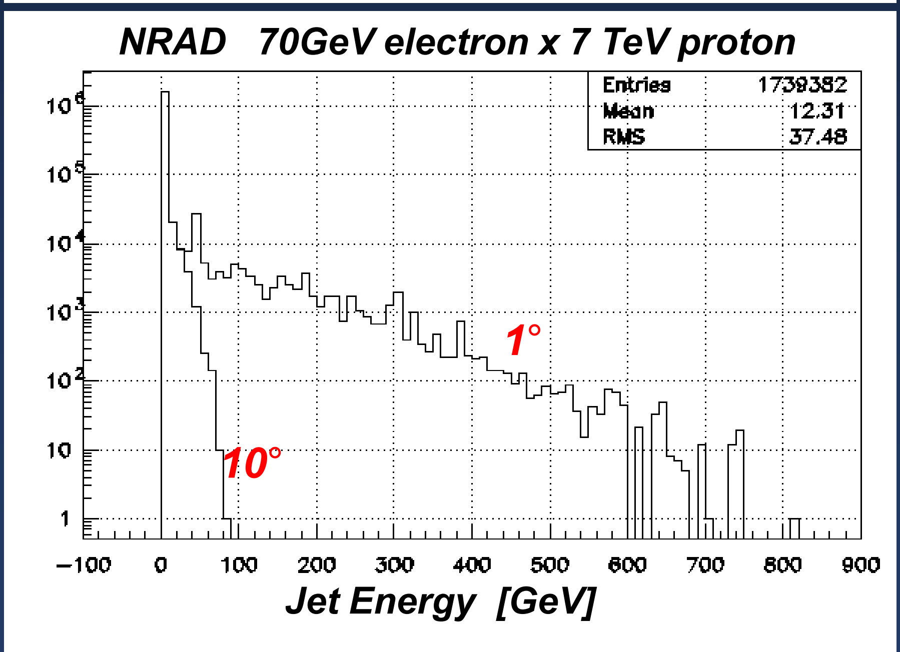


RAPGAP-3.2 (H.Jung et.al.- http://www.desy.de/~jung/rapgap.html)

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

selection: q^2.gt.5.

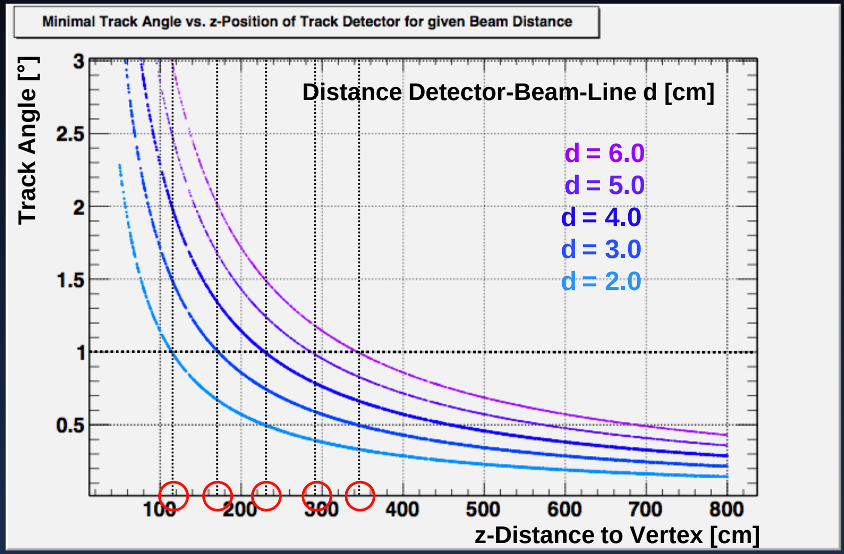


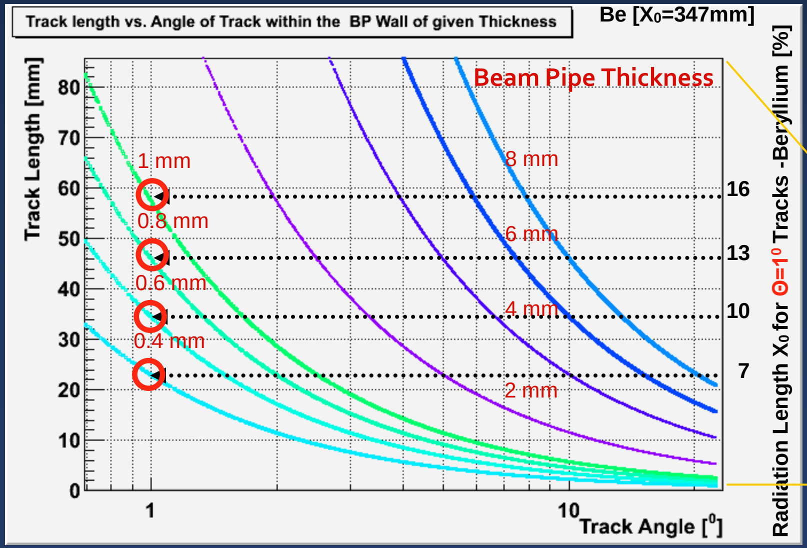


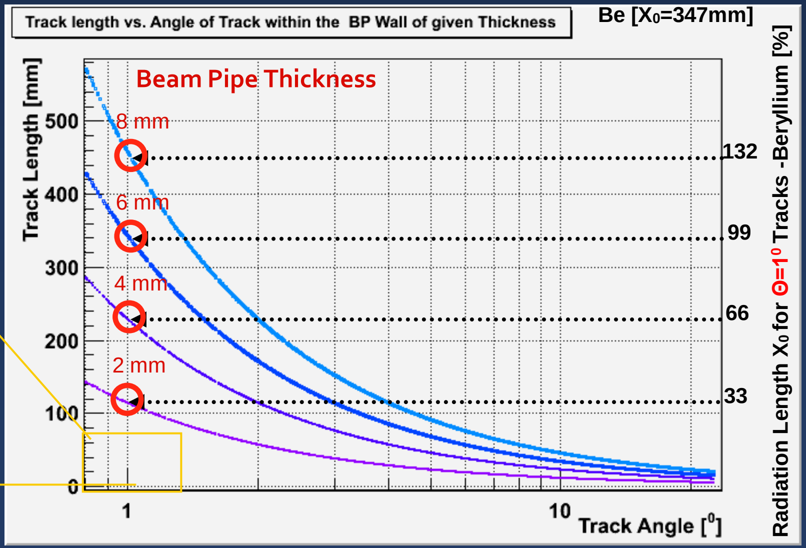
→ Highest acceptance - if possible

Beam Pipe

- The beam pipe drives the design:
  - Elliptical: synchrotron radiation has to pass leaving the detector untouched (direct and backscattered SR); No φ symmetry.
  - Length of detector - related at fixed angular acceptance to beam pipe radii The dimensions of the BP defines the z-extension of the detector.
  - Multiple Scattering: BP as thin as possible
  - SR collimators/absorbers incorporated
  - 1° polar angle traversing tracks - radiation length optimisation







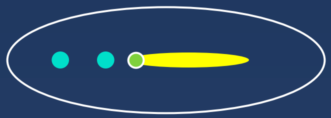
Beam Pipe - continued

- Challenge:
  is it possible to build a long beam pipe as thin as necessary?
- BP sandwich structure:
  Metal - Carrier - Metal
  minimal thickness and excellent radiation length
  e.g. Be/Al - Nomex/Carbon foam - Be/Al *

  *NIM 228 (1984) 207-209, A SANDWICH STRUCTURE BEAM PIPE FOR STORAGE RINGS, G.B. BOWDEN, H.DESTAEBLER, Ch. T. HOARD and A. E. JOHNSTON, SLAC (… The pipe has a radiation thickness of 5.8x10-3Xo, a failure pressure of 3.5 atm and was baked for high vacuum service; Al-NomexAl, length 560mm!)

  arXiv:nucl-ex/0205008v1 (2002), Integration and Conventional Systems at STAR, H.S. Matis et.al.

- R&D required:
  vacuum tight, mechanical-, electrical-, thermal stability
- The detector dimensions depend heavily on the beam pipe size
- Reminder: LHeC has 3 beams:
  - Interacting electron beam (synchrotron radiation)
  - Interacting proton beam
  - Spectator proton beam

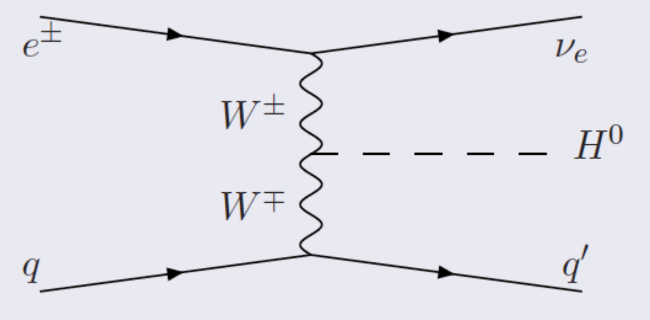


Benchmark Processes

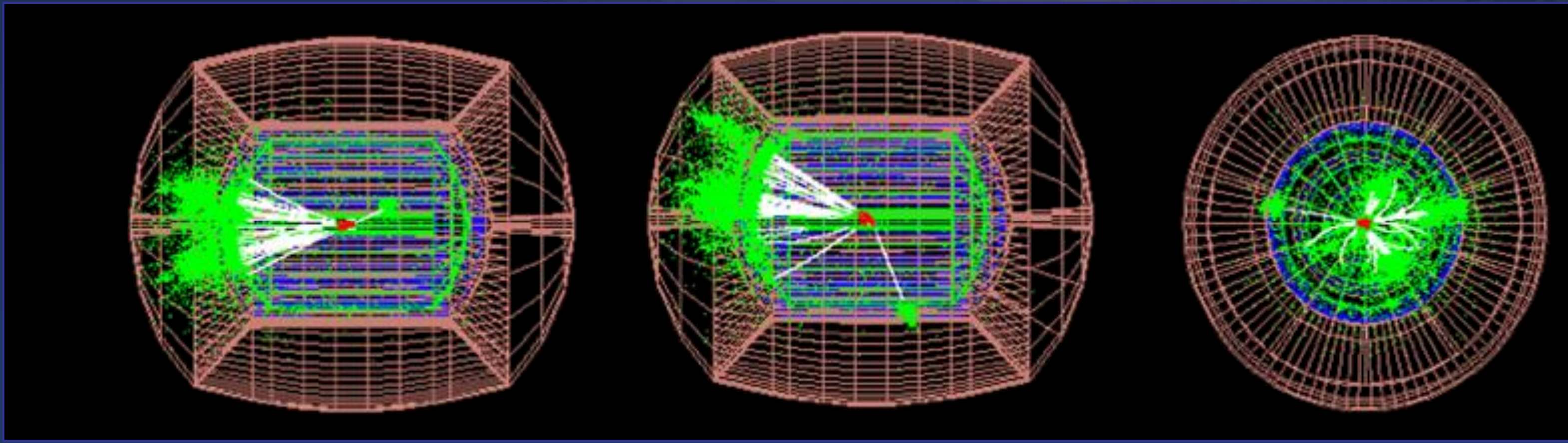
- One of the benchmark processes*:

  Vector Boson Fusion @ LHC CC $H^0 \Rightarrow b\bar{b}$

  where (one possible) background process CC is $\bar{t} \Rightarrow \bar{b}W \Rightarrow \bar{b}\bar{c}s$



  will challenge the detector design - requiring:
  - large forward acceptance
  - best resolution for hadrons produced
  - good E_T recognition and b tagging with maximal acceptance



Higgs Production in ep event*

Ilcroot package: V. di Benedetto, C. Gatto

* U. Klein

Detector Requirements

- High resolution tracking system
  - excellent primary vertex resolution (rad hard, low budget material)
  - resolution of secondary vertices down to small angles in forward direction for high x heavy flavor physics and searches
  - precise pt measurement matching to calorimeter signals, calibrated and aligned to 1 mrad accuracy
  - Acceptance in particular at small forward and backward angles (1°, 10°)
- The calorimeters - Energy flow
  - Full containment, granularity, forward acceptance
  - 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
- Muon detector/spectrometer, very forward detectors, luminosity measurement

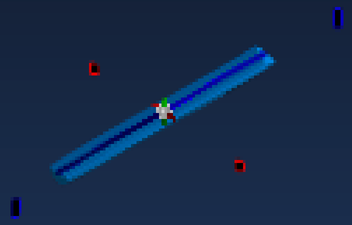
… the detector

… a draft

Inner Tracking

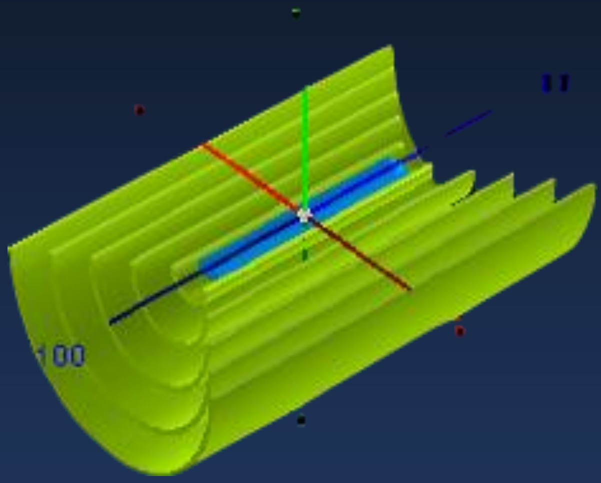
Radius [cm]

Elliptical pixel detector: 2.9–4.6/3.47-6.05



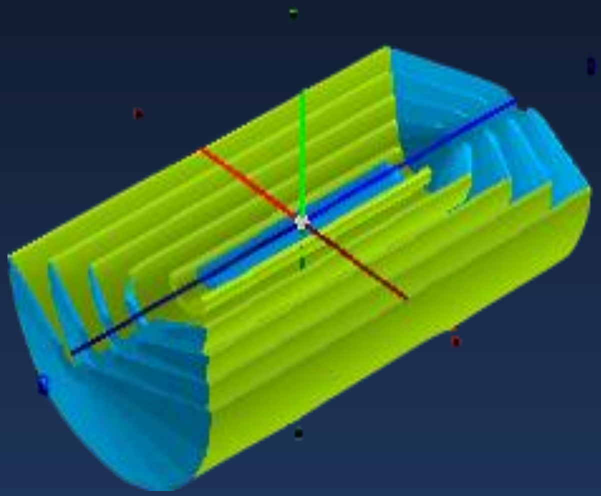
Inner Tracking

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



Inner Tracking

	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



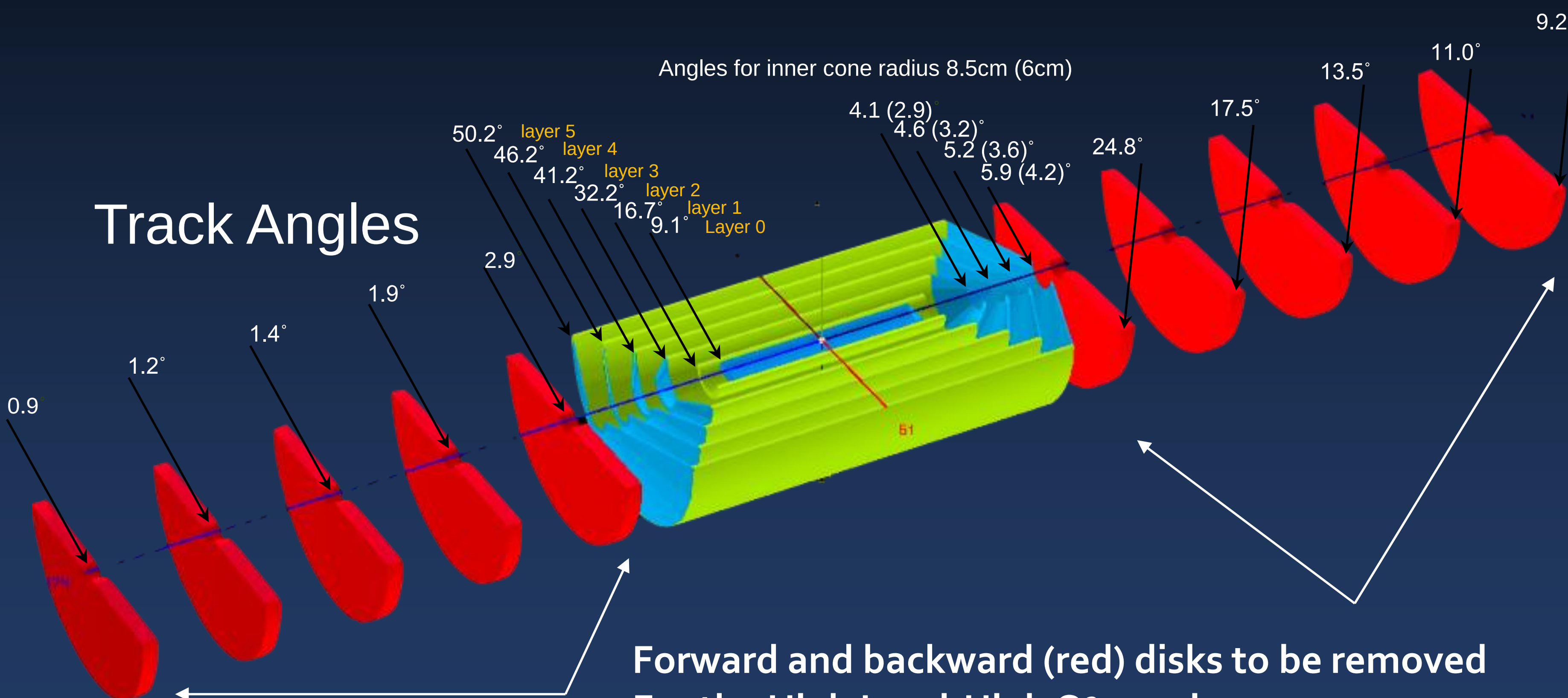
Full Tracking (down to 1 degree)

(to be optimised)

One option: GAS-Si Tracker - GOSSIP Type NIKHEF

Container Model

Gas On Slimmed Silicon Pixels (or Strixels/Pads)



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

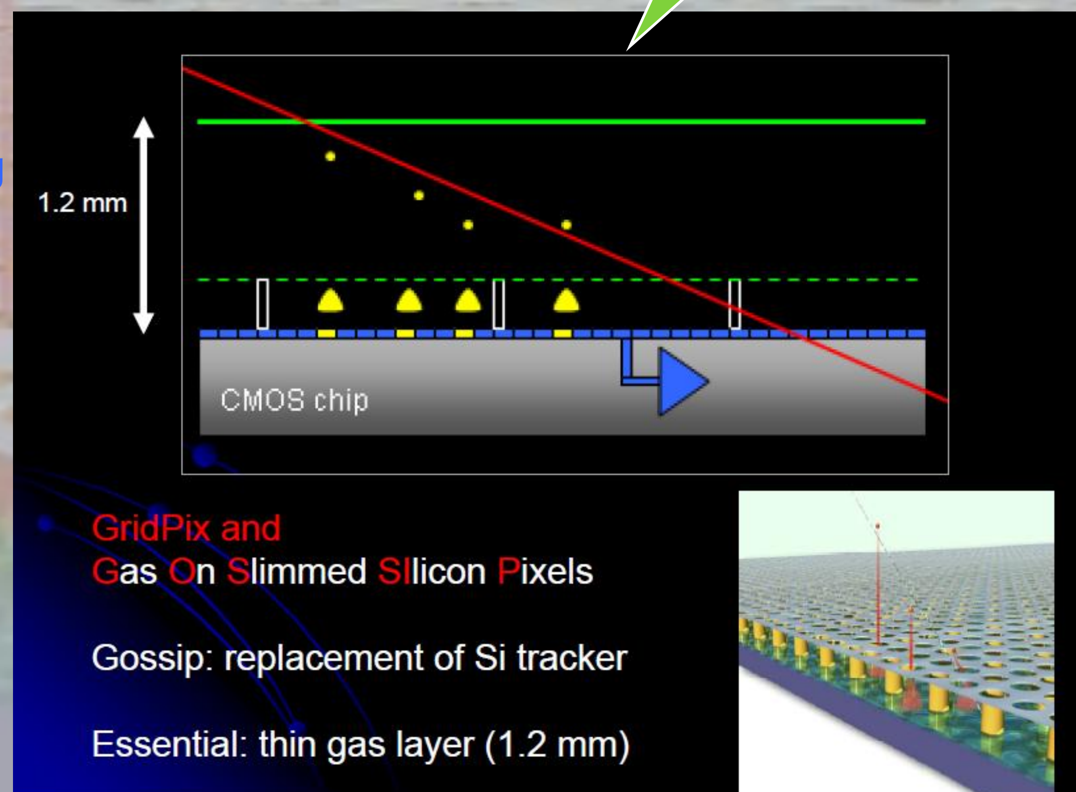
Alternative technologies: Pixels, MAPS, DEPFET etc.

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)



Interesting option for LHeC

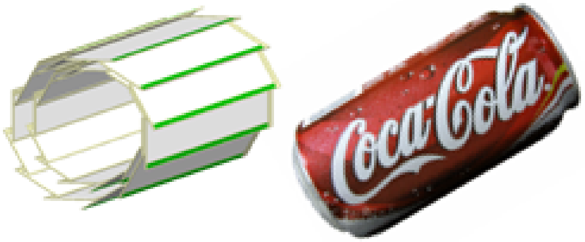
Silicon Pixel Detector

(Semi-) Monolithic Pixels Overview

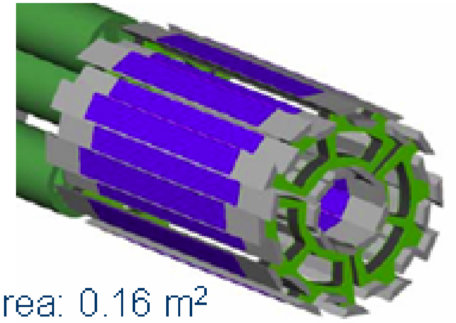
N. Wermes

- DEPFET Pixels
  - one transistor in pixel bulk
  - Q-collection in fully depleted bulk
  - R&D (for ILC) since > 10 years
  - recently (2008): a 2 layer detector for superBelle

total area: 0.014 m²



- Monolithic Active Pixels (MAPS-epi)
  - Q collection in thin epi-layer
  - need tricks for full CMOS
  - R&D (for ILC) since ~ 10 years
  - 2 (or 3) layer detector for STAR@RHIC



total area: 0.16 m²

- Monolithic Active Pixels (MAPS-SoI)
  - **full CMOS in active area**
  - Q - collection in **fully depleted** bulk
  - R&D started 2006

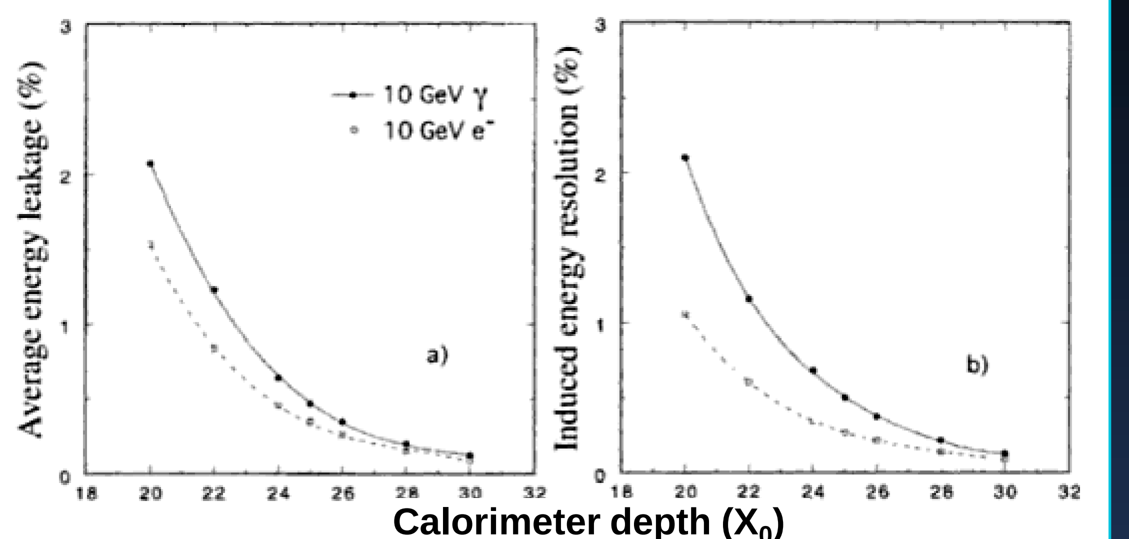
The Calorimeter

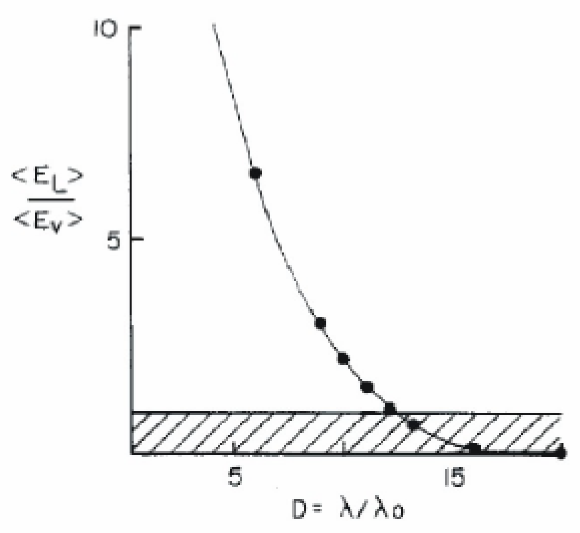
- A step back …

The Calorimeter

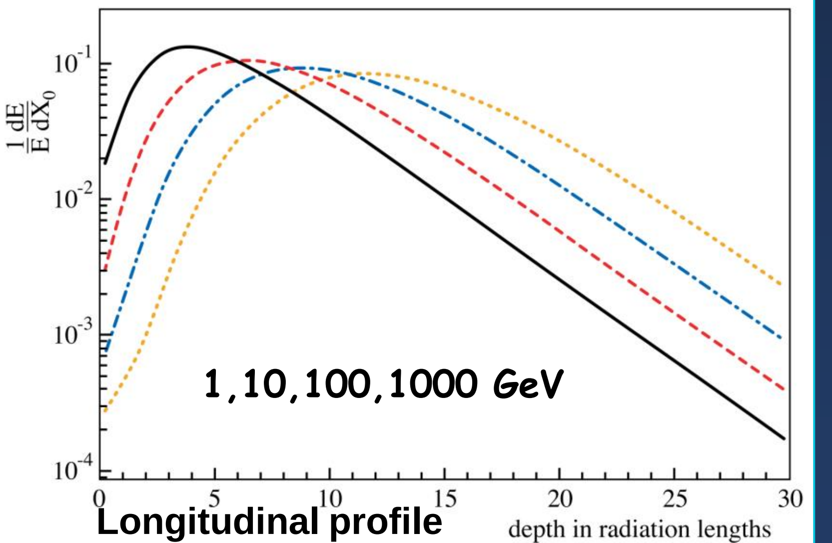
- A step back …
  … some distributions

Courtesy R. Wigmans et al.



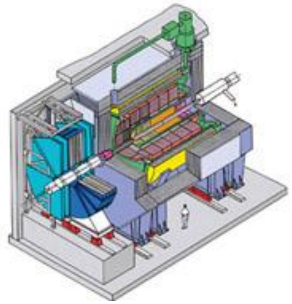


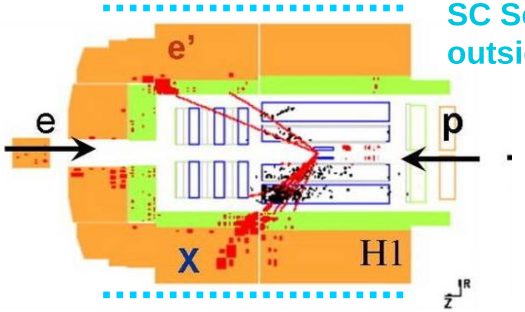
Ratio of energy loss due to longitudinal leakage divided by loss due to neutrinos vs thickness in interaction lengths



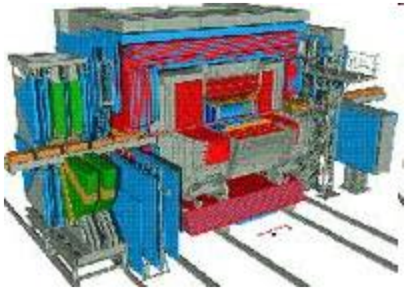
Longitudinal profile

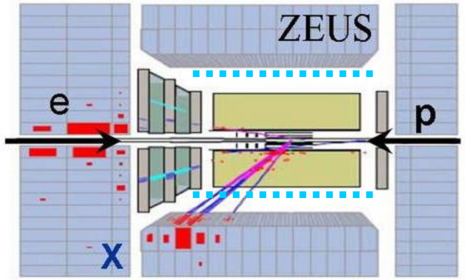
HERA Calorimeters





SC Solenoid outside CAL



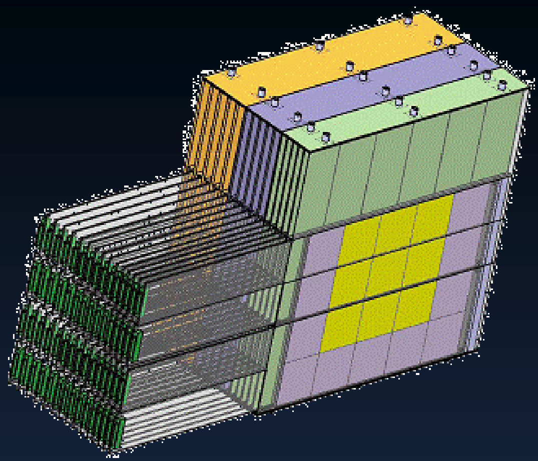


SC Solenoids inside CAL

- H1
  - Liquid Argon (cf. ATLAS)
  - High granularity, compensation achieved via software
  - Solenoid outside of the LAr CAL
- ZEUS
  - Compensating Calorimeter (Uranium Scintillator)
  - EMC 15%/√E; HAC 35%/√E, up to 7 λ_I
  - Lower granularity
  - Solenoid between central tracking and main CAL

HERA
- 920 GeV p
  27 GeV $e^{\pm}$
- c.m.s. energy
  $\sqrt{s} \sim 300$ GeV

LHeC Calorimetry



Calice: W-Si prototype
W plates: 10 x 1.4mm(0.4X0)
10 x 2.8
10 x 4.2mm
Si pads: 1cm x 1cm

LHeC:

- precision physics
- Similar energies and resolution required for ILC
- High energy resolution
- Jet Energies ~ O(1 TeV)
- Higher granularity
- Possibly compact design (detector size)

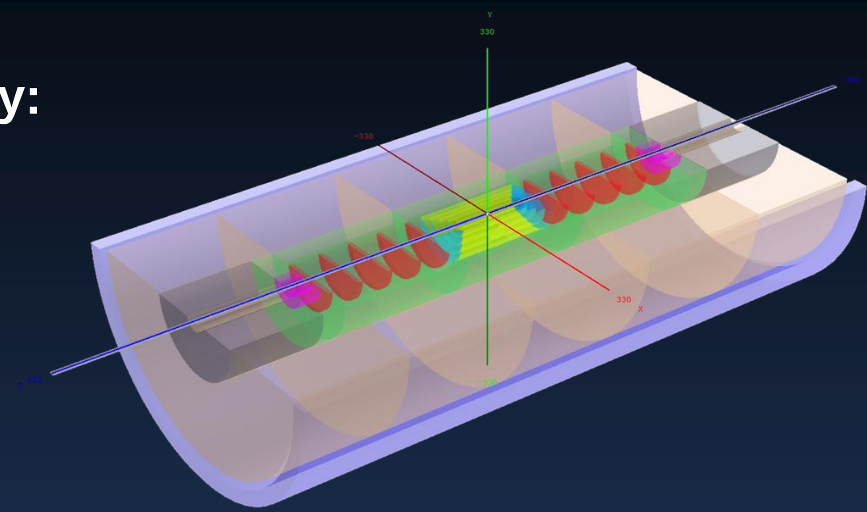
Choices:

PFA (particle Flow Algorithm)

- CALICE High granularity calorimeters. Software compensation & PID combining with information coming from the tracking system

- New Concepts
  - New Materials, Silicon, RPC, etc.
  - Dual Readout Calorimeters:
    Combine energy and Cherenkov measurements
- Liquid Argon concept still applicable as baseline solution

LHeC Calorimeter



Present choice: Energy Flow Calorimetry:

For the geometry given:

- **Electromagnetic Calorimeter:**

  ~30 x X_0 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**

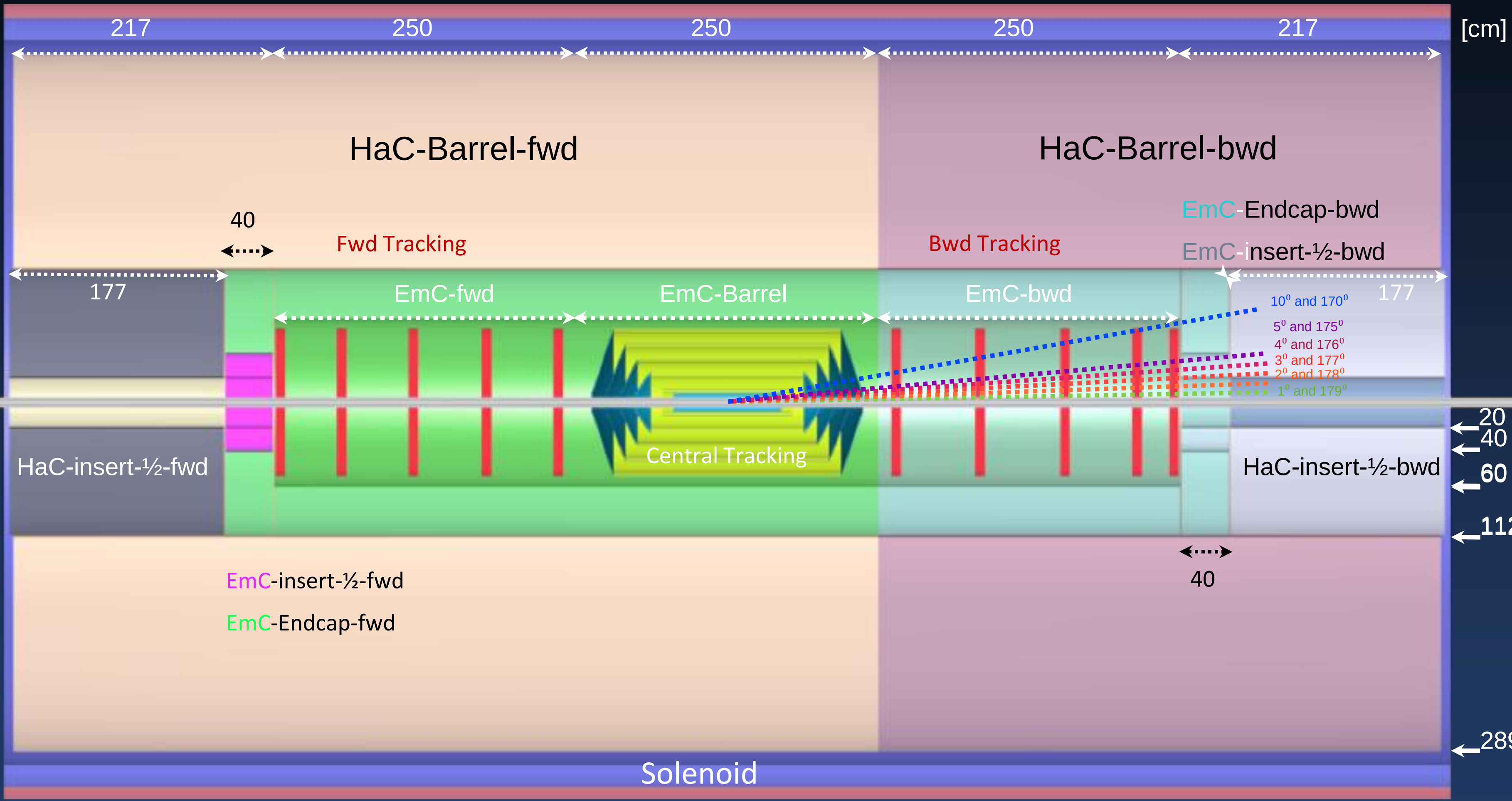
- **A dense EmCAL with high granularity (small transverse size cells), high segmentation (many thin absorber layers), and with ratio λ_I/X0 large, is optimal for E-Flow measurement → 3-D shower reconstruction**

- **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)**

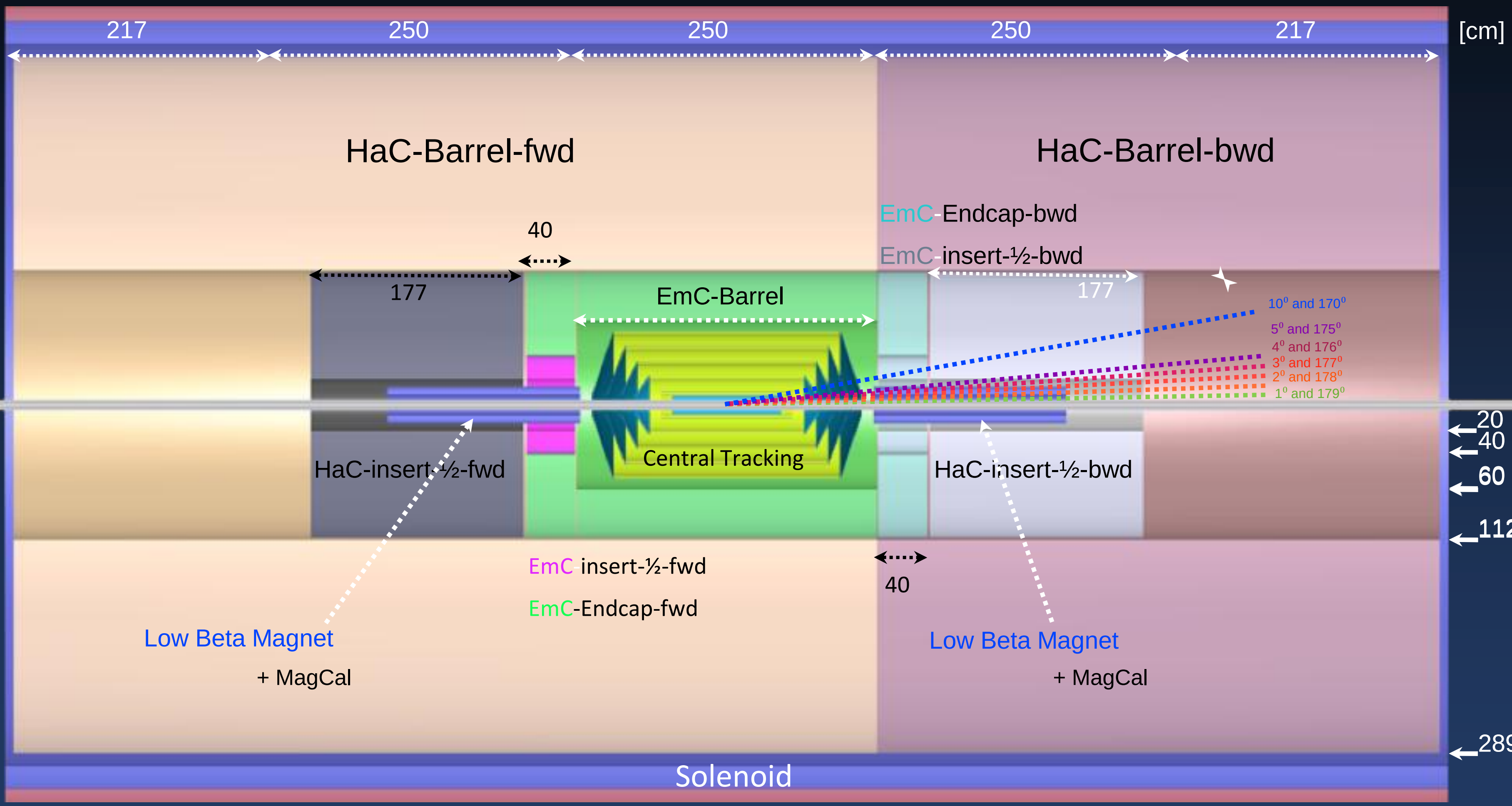
The Detector - Low Q^2 Setup
- High Acceptance



Fwd/Bwd asymmetry in energy deposited and thus in technology [W/Si vs Pb/Sc..]

Present dimensions: LxD =17x10m^2 [CMS 21 x 15m^2, ATLAS 45 x 25 m^2]

The Detector - High Q^2 Setup
- High Luminosity

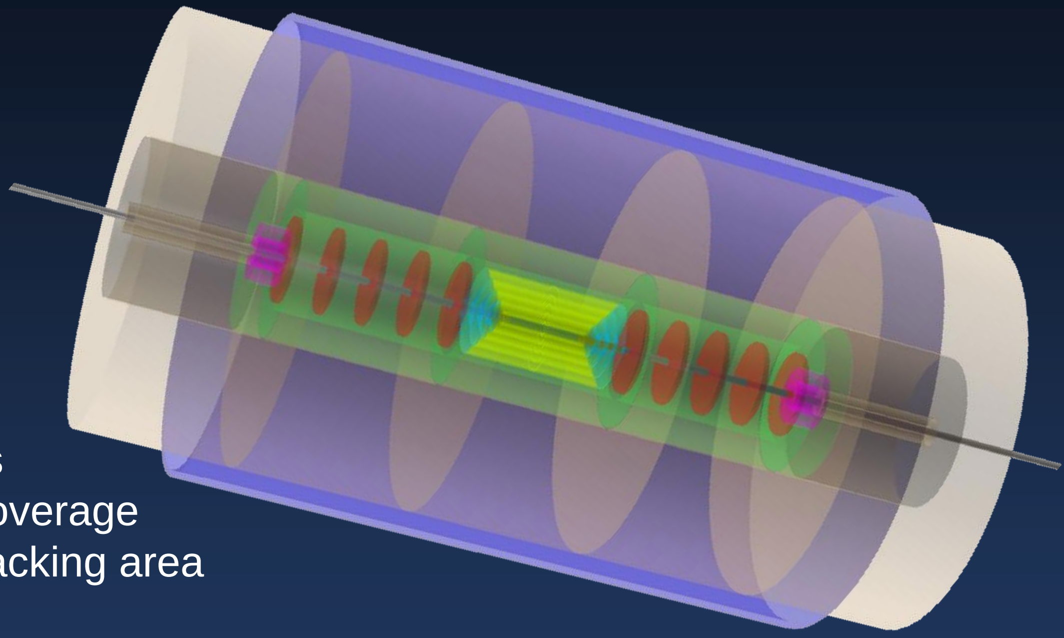


➔ Aim of current evaluations:
avoid detector split in two phases: time and effort

Solenoid

Modular structure:

- assembly CMS like on surface level or in the experimental area depending on time constraints and access shaft opening



Solenoid dimensions:

- 6m half length
- 300 cm inner radius
- B field = 3.5 T

Geometry constraints:

- Current beam pipe dimensions
- Requirement of 10° tracking coverage
- Homogeneous B field in the tracking area

Detector Track Resolution:

i.e. assuming / using (Glückstern relation): $\frac{\sigma(p_T)}{p_T} = \frac{\sigma(x)}{aBL^2}\sqrt{\frac{720}{N+4}} \cdot p_T$ 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)
s-gas module ~10° inclined more track points for inclined tracks - extended track segments
➔ $\Delta p_T/p_T = 0.03\%\ p_T$

Low Q^2 Detector

Fwd Tracker - active Thickness 8. cm each
Si-Pix/Si-Strip/SiGas Tracker:
inner R = 4.86 cm; outer R = 61.3 cm
Planes 1 - 5:
z_{1-5} = 140. / 200. / 260. / 320. / 370. cm

Barrel Tracker - active Radius 2.5cm each
Si-Pix/Si-Strip/SiGas Tracker:
1. layer: inner R = 8.8 cm; outer R = 11.3
cm2. layer: = 21.3 cm; = 23.8
cm3. layer: = 33.8 cm; = 36.3
cm4. layer: = 46.3 cm; = 48.8
cm5. layer: = 58.8 cm; = 61.3
cm

4 Cone structured fwd/bwd Si-pix/Si-strip/Si-gas **Tracker**
R_{min} = 4.86 cm
2.5cm active thickness

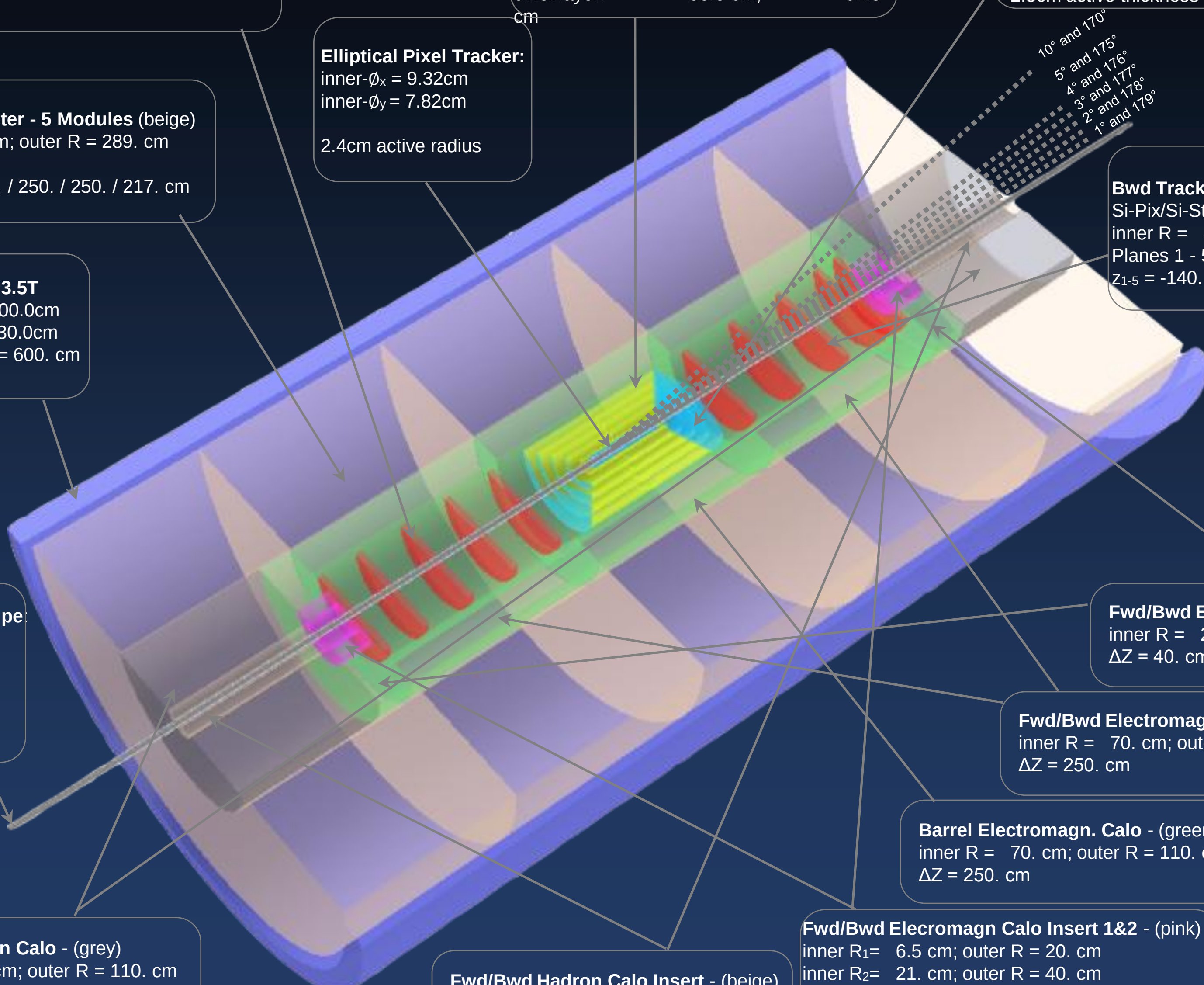
Elliptical Pixel Tracker:
inner-$Ø_x$ = 9.32cm
inner-$Ø_y$ = 7.82cm

2.4cm active radius

Hadron Calorimeter - 5 Modules (beige)
inner R = 112. cm; outer R = 289. cm
Modules 1 - 5:
ΔZ_{1-5} = 217. / 250. / 250. / 250. / 217. cm

Solenoid - 3.5T
inner-R = 300.0cm
inner-R = 330.0cm
half length = 600. cm

Bwd Tracker - active Thickness 8. cm each
Si-Pix/Si-Strip/SiGas Tracker:
inner R = 4.86 cm; outer R = 61.3 cm
Planes 1 - 5:
z_{1-5} = -140. /-210. /-280. /-340. /-370. cm



Elliptical Beam Pipe:
inner-$Ø_x$ = 7.3cm
inner-$Ø_y$ = 5.8cm
outer-$Ø_x$ = 8.1cm
outer-$Ø_y$ = 6.6cm
thickness: 0.8cm

Fwd/Bwd Electromagn. Calo 2 - (green)
inner R = 21. cm; outer R = 110. cm
ΔZ = 40. cm

Fwd/Bwd Electromagn. Calo 1 - (green)
inner R = 70. cm; outer R = 110. cm
ΔZ = 250. cm

Barrel Electromagn. Calo - (green)
inner R = 70. cm; outer R = 110. cm
ΔZ = 250. cm

Fwd/Bwd Hadron Calo - (grey)
inner R = 21.0 cm; outer R = 110. cm
ΔZ = 177. cm

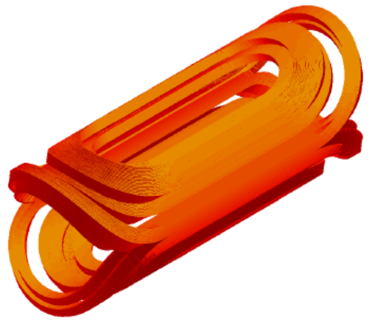
Fwd/Bwd Hadron Calo Insert - (beige)
inner R = 6.5 cm; outer R = 20. cm
ΔZ = 177. cm

Fwd/Bwd Elecromagn Calo Insert 1&2 - (pink)
inner R_1= 6.5 cm; outer R = 20. cm
inner R_2= 21. cm; outer R = 40. cm
ΔZ = 40. cm

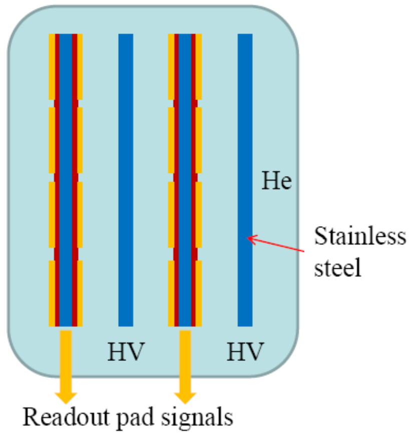
Instrumented Magnets (a study)

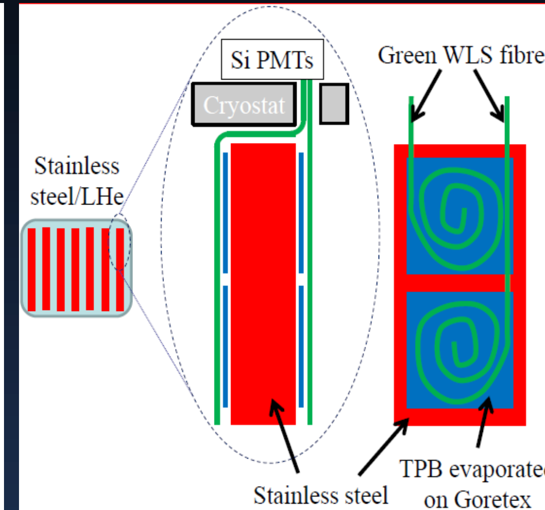
Tim Greenshaw

- 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:



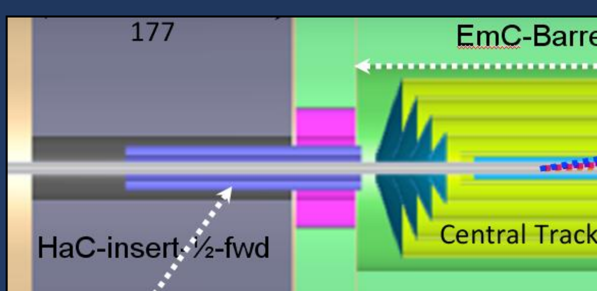


- Possible design stainless steel/LHe sandwich.
- 2 mm thick steel plates with similar width gaps:
  - $X_0 \sim 2$ cm.
  - $\lambda_I \sim 20$ cm.
- Use fluor tetraphenyl betadiene (TPB) to absorb scintillation light and re-emit in blue ($\lambda \sim$ 430 nm) – with efficiency 135%.
- (Using LHe as a scintillator is being considered for e.g. solar neutrino experiments.)

MAGCAL Design

Geant 4 studies (Birmingham)

→ Divonne 2009 workshop

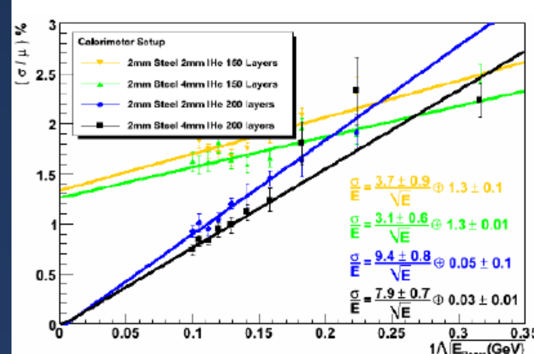


MAGCAL

- Resolution, expect:

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

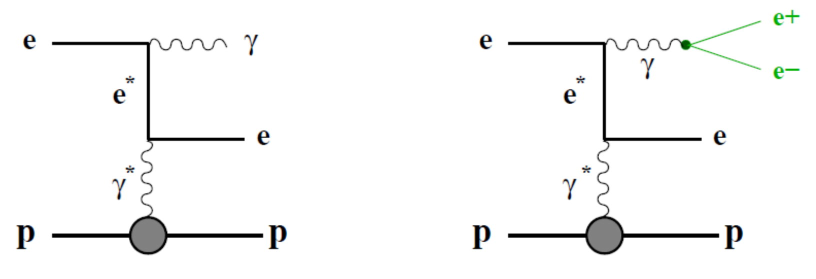
- Extract const. from slope of graph of σ/μ against $1/\sqrt{E}$.



- Note, depth of 150 layers (about 17 X_0) leads to leakage, hence positive intercept on y axis, 200 layers (23 X_0) gives better performance.
- Resolution of order $0.1/\sqrt{E}$ achievable according to these simulations.
- Adding material associated with readout of scintillation light (here polystyrene assumed) does not significantly change this result.
- First studies with B field indicate broadening of shower.

Luminosity Measurement

Sergey Levonian



Dedicated (tunnel) detectors

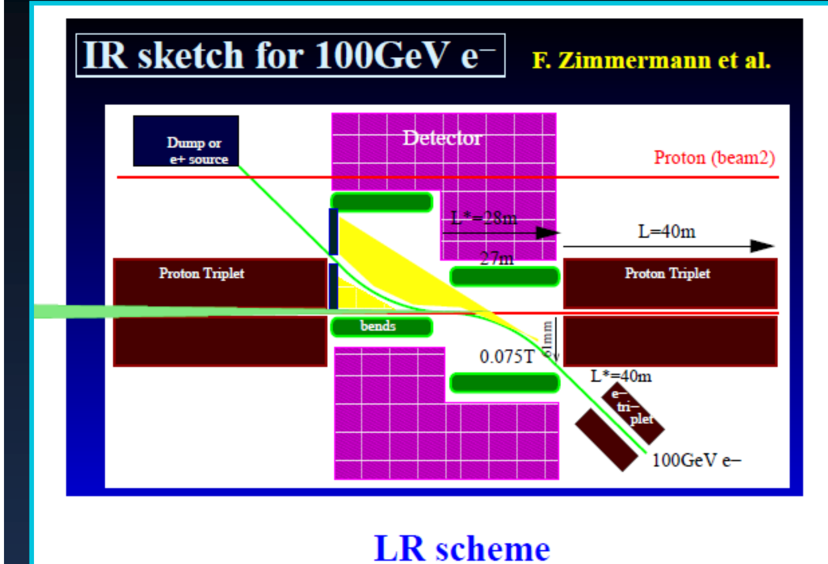
B-H process: $\sigma(E > 8) = 112\text{mb}$
(poles in both e^* and γ^* propagators)

B-H with "internal conversion"
$\sigma \simeq 1/200\sigma_{BH}$

Main detector

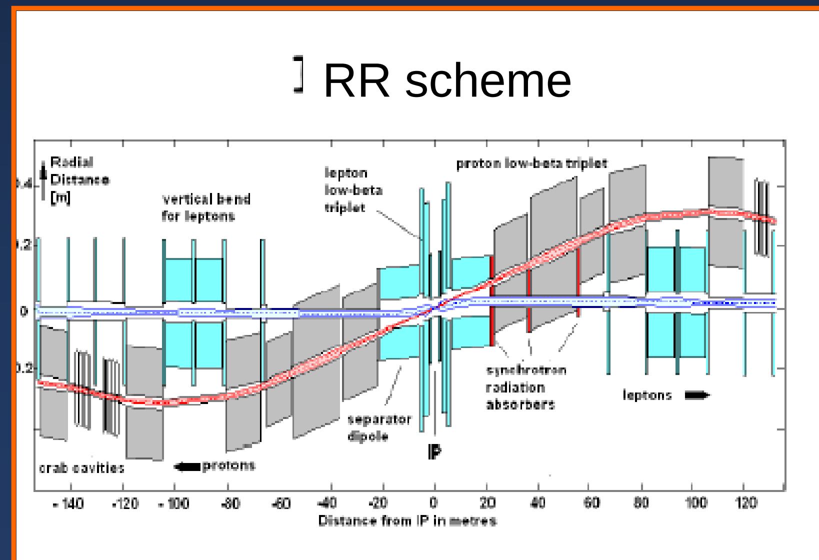
QED Compton: $\sigma_{\mathrm{el}}(\theta < 179^o) = 6\text{nb}$
(poles in γ^* propagator, but large e^* mass)

F2 (NC DIS): $\sigma(Q^2 > 10) = 300\text{nb}$
$\sigma(Q^2 > 100) = 25\text{nb}$



Linac-Ring:

- Head on collisions
- Similar to HERA, γ's travel along the p-beam
- Luminosity monitor located at z=100m
- Challenge: large aperture required for p at 60-80m

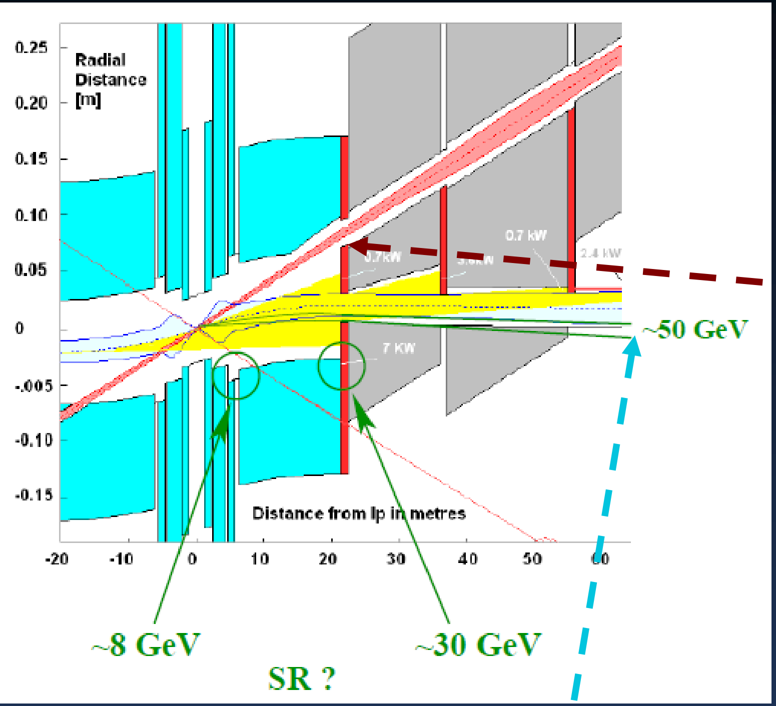


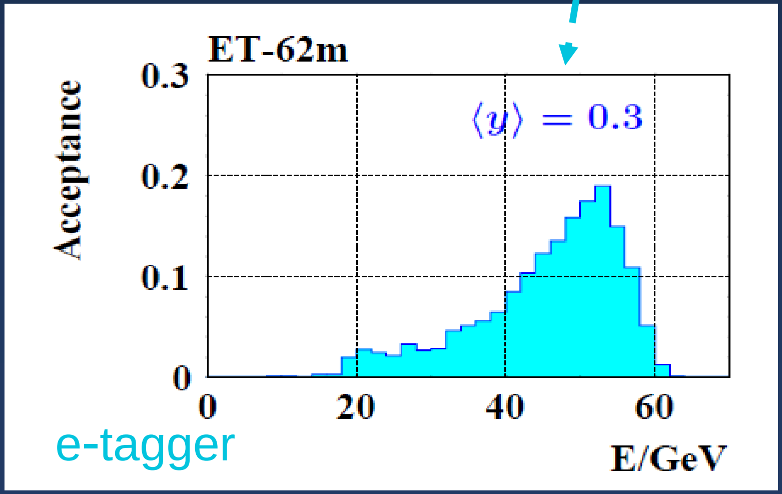
Ring-Ring:

- Non zero crossing angle at IP
- Large synchrotron radiation flux
- Challenge: difficult to catch zero-angle γ's

Luminosity Measurement

Sergey Levonian

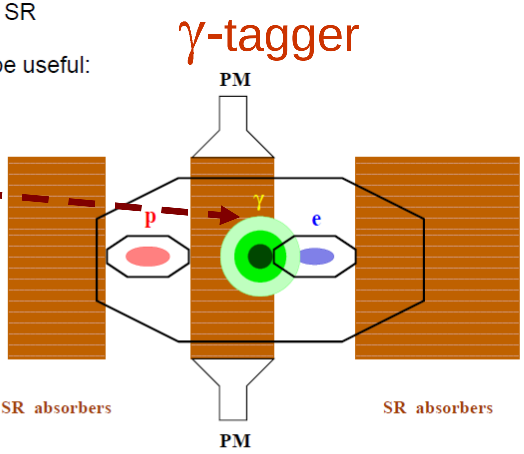




BH-photon detector integrated into SR absorber

- Cooling system with $10-15$ cm long water bath acting as Čerenkov radiator for BH γ's
- Radiation hard, (almost) insensitive to SR
- Optimisation of crossing angle might be useful:
  Version **A**: acceptance $\simeq (84 \pm 2)\%$
  Version **B**: acceptance $\simeq (10 \pm 1)\%$
- Exact BH counter design and R/O still to be worked out
- Accurate acceptance control requires precise beam tilt monitoring (10-15% of the x-angle)

$\delta L = 3 - 10\%$



- Luminosity measurement at the LHeC is a non-trivial task.
  HERA experience: surprises are possible $\Rightarrow$ prepare several scenarios
- Precise integrated $\mathcal{L}$ for physics is possible with main Detector (QEDC, F2)
  $\delta\mathcal{L} = 2\%$ is within reach
- Fast instantaneous L monitoring is challenging, but few options do exist
  - ▷ Photon Detector for LR option requires large p-beampipe at $z = 80$m
  - ▷ In case of RR option B-H photons can be detected using water Čerenkov counter integrated with SR absorber (this also requires relatively large crossing angle)
  - ▷ Electron tagger at 62 m is very promissing for both LR and RR schemes
- Good control of the e-beam optics at the IP is essential to monitor acceptances of the tunnel detectors at 5% level

Further Considerations

About external detectors:

- Return Yoke + Backing Calorimeter (or alternative solutions)
- Muon Detectors/Spectrometers
- Very Forward Detectors

not detailed here, are being studied and will be included in the CDR

Considerations:

- It is clear that the definition of the beampipe, the boundaries of the optics and interaction region will push forward the detector design and will allow soon a more precise design
- The presence of additional dipole(s), required in the linac-ring design and useful in ring-ring option, is being presently worked out
- New concepts and baseline solutions with the aim to demonstrate the feasibility of the project. But still lots of work ahead.

Summary - Outlook

- The physics arguments for an LHeC experiment at CERN is getting more pronounced
- Two independent machine options (Ring-Ring and Linac-Ring) are being investigated and are well advanced in the their concepts
- The beam pipe and the interaction region design play a key role defining the detector and currently in focus
- A base of a LHeC detector design has been presented and some boundary conditions for set up and performance discussed
- The LHeC detector is in some respects as complex and sizable as an LHC detector and aims for accuracy as an ILC detector. It will be a fantastic challenge to it build
- It would be a waste not to exploit the 7 TeV beams for *ep* and *eA* physics at some stage during the LHC time (G. Altarelli)

Towards a Tentative Schedule

- CDR printed in spring 2011
  Study of installation and interference issues still to be done
- Installation of (ring or linac) LHeC towards 2021
  Make maximum use of LHC shutdowns (~50 months).
- 2021-30: ~10 years of operation with LHC [p/A]
  colliding with $E_e \approx 60$ GeV [e^-/e^+]: ~100 fb^{-1} in *ep*
- later: possible extension to high E_e LHeC
  During HE-LHC upgrade shutdown and long term operation with 16 TeV *p* colliding with e.g. E_e=140 GeV [e^-/e^+]
  Q^2_{max}=9TeV^2 x_{min}=10^{-7} in DIS region
- The time schedule of the LHeC is linked to the LHC, *ep* has to be doable as an upgrade or a 5th experiment to the LHC; so far that looks feasible

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More info and references:

http://lhec.cern.ch/

backup

NuPECC – Roadmap 5/2010: New Large-Scale Facilities

			2010					2015					2020					2025	
FAIR	PANDA	R&D	Construction			Commissioning					Exploitation								
	CBM	R&D	Construction			Commissioning					Exploitation			SIS300					
	NuSTAR	R&D	Construction			Commissioning					Exploit.		NESR FLAIR						
	PAX/ENC	Design Study		R&D	Tests			Construction/Commissioning								Collider			
SPIRAL2		R&D	Constr./Commission.				Exploitation							150 MeV/u Post-accelerator					
HIE-ISOLDE			Constr./Commission.				Exploitation								Injector Upgrade				
SPES				Constr./Commission.				Exploitation											
EURISOL		Design Study		R&D	Preparatory Phase / Site Decision					Engineering Study			Construction						
LHeC		Design Study		R&D			Engineering Study				Construction/Commissioning								

G. Rosner, NuPECC Chair, Madrid 5/10 - DRAFT

Prospects for polarized electron beam

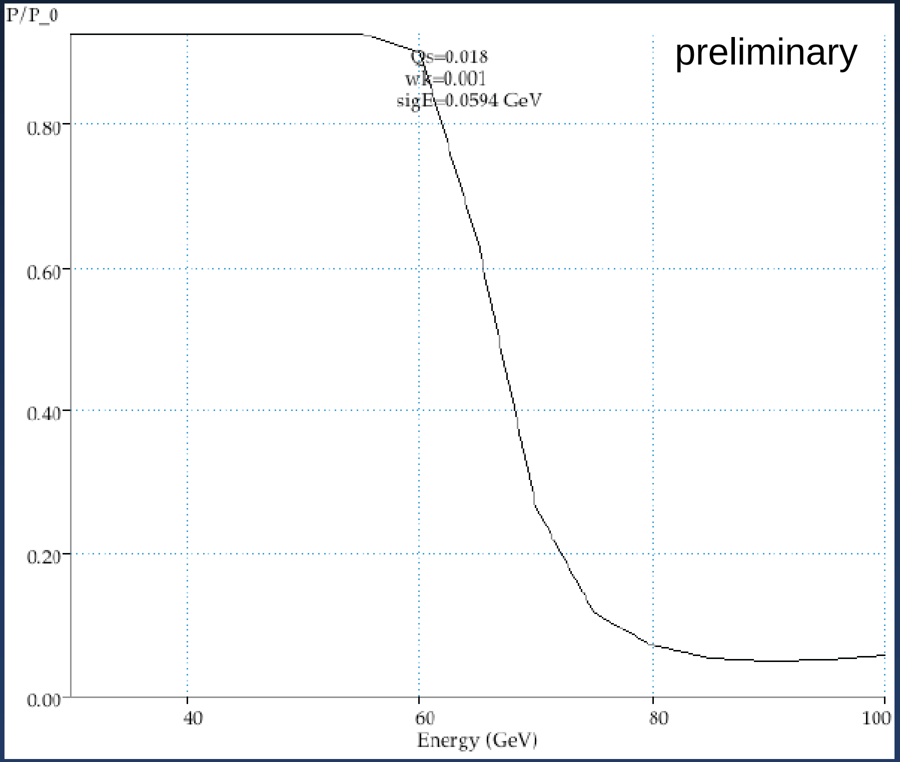
- Rely on self-polarization of e beam by Sokolov-Ternov mechanism
- Theoretical understanding of 1980s confirmed by empirical experience of LEP:

Depolarizing effects of energy spread: polarization drop fast above ~ 60 GeV

But reasonable levels attainable *with best design and techniques* below this energy.

More exotic possibilities, e.g., snakes and asymmetric bends.

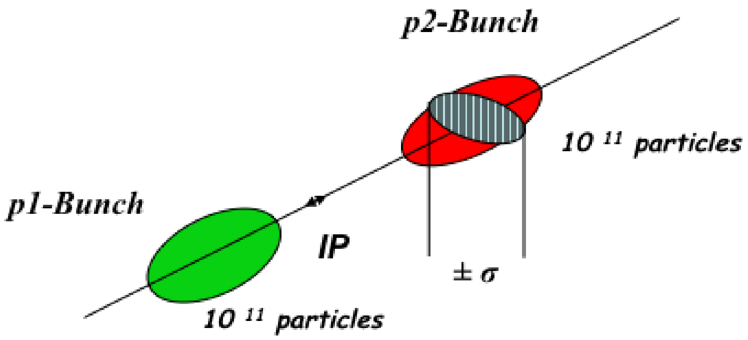
Linac Ring: 90% e- polarization



Recent simulations, models, D.P. Barber, U. Wienands

Crossing angle: Luminosity Loss Factor

$$S = \frac{1}{\sqrt{1 + \left\{\tan\left(\frac{\phi}{2}\right)\right\}^2 * \frac{\sigma_{zp}^2 + \sigma_{ze}^2}{2\sigma_x^2}}}$$



using

$\phi/2$ = half crossing angle = 0.465mrad

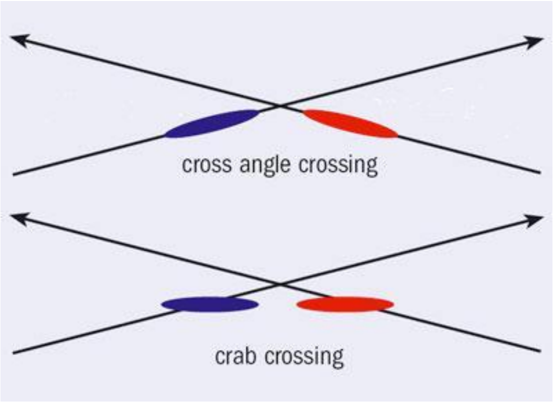
$\sigma_x = 30\mu m$ at the IP

$\sigma_{zp} = 7.55cm$ =proton design bunch length

σ_{ze} = 1 cm = assumed electron bunch length

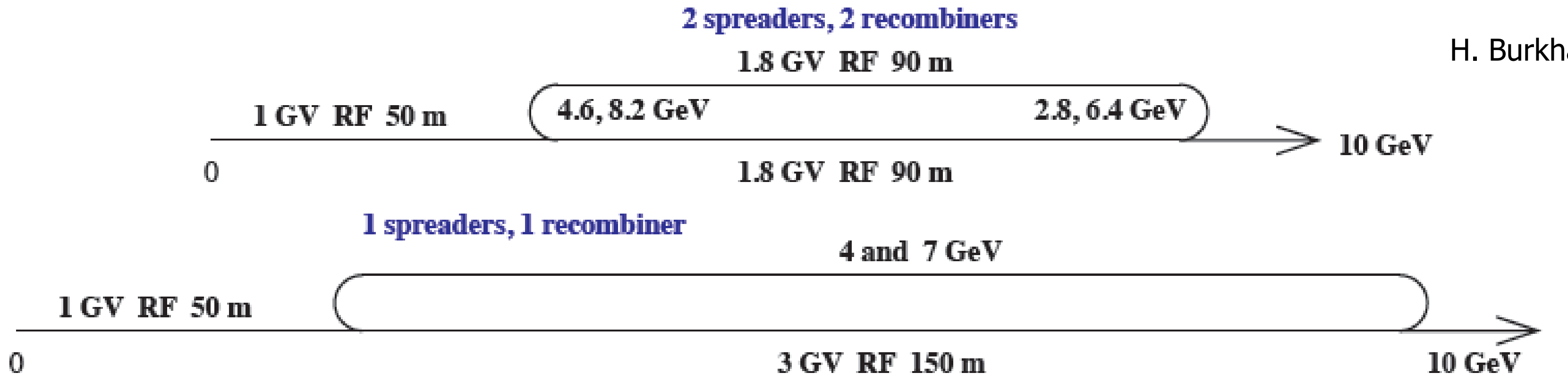
S=77%.

Other possibility: use of Crab Cavities: with 7 TeV protons ➔ additional issues



R-R: Injector options with recirculation

- Consider 10 GeV electron injector
- Not a major problem in comparison with rest of project but must be designed
- Natural to use same SC cavities as LeR
- Linac ~ 500 m,
- Possibly with recirculation, like scaled-down former ELFE project



gaining a lot with just 2 re-circulation, 3 passages through the LINAC

e-Pb collisions in Ring-Ring

J.M. Jowett

- Assume present nominal Pb beam in LHC
  - Same beam size as protons, fewer bunches

$$k_b = 592 \text{ bunches of } N_b = 7\times 10^7 \ {}^{208}\text{Pb}^{82+} \text{ nuclei}$$

- Assume lepton injectors can create matching train of e^-

$$k_b = 592 \text{ bunches of } N_b = 1.4\times 10^{10} \ \text{e}^-$$

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

$$L = 1.09\times 10^{29} \text{ cm}^{-2}\text{s}^{-1} \quad \Leftrightarrow \quad L_{\text{en}} = 2.2\times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$$

gives 11 MW radiated power

  - May be possible to exploit additional power by increasing electron single-bunch intensity by factor 592/2808=4.7