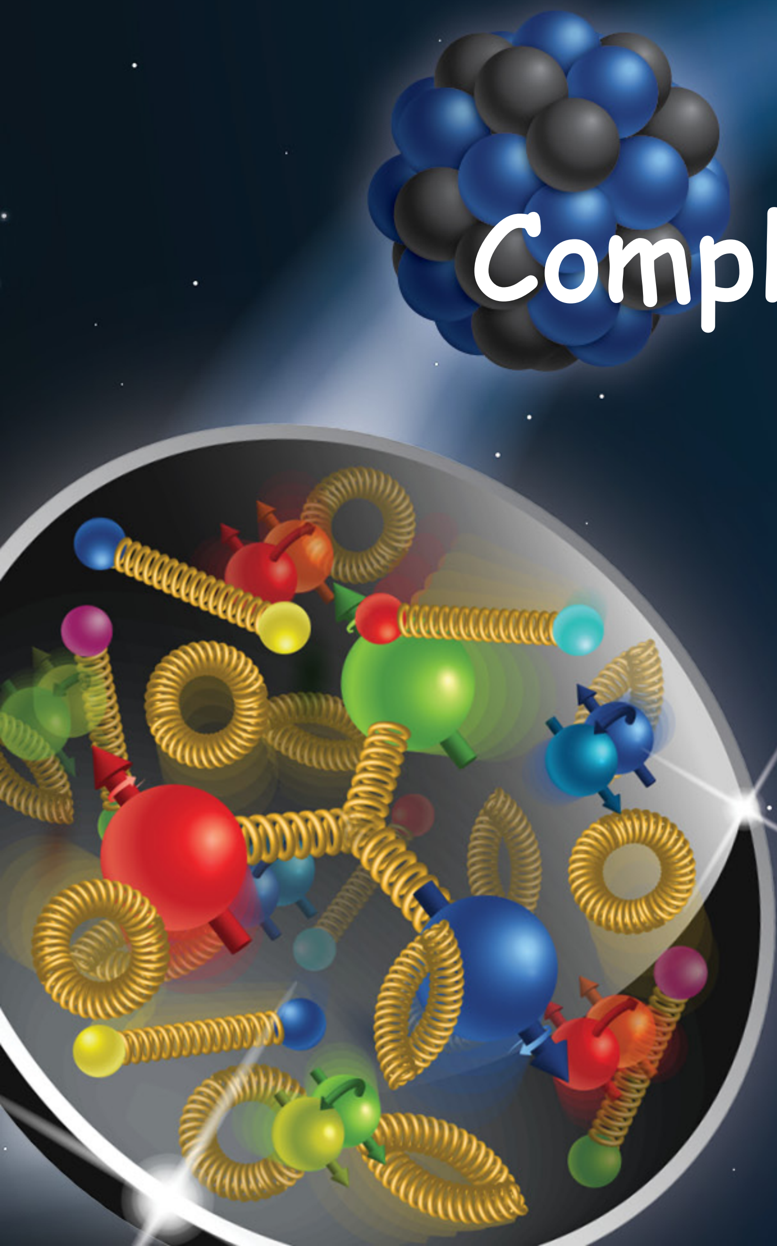

Complementary Detectors at EIC

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BROOKHAVEN NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY | Office of Science

We want it all

high Luminosity
at full acceptance

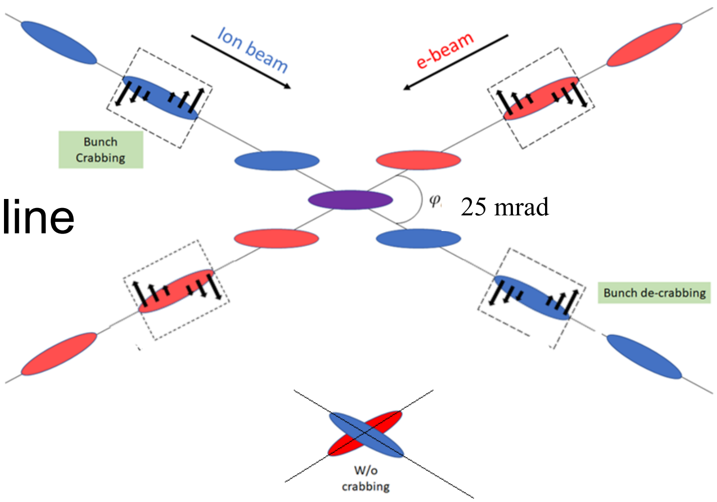
But there are some boundary conditions
→ accelerator
→ experiment

EIC achieves high luminosity $L = 10^{34}\ cm^{-2}s^{-1}$

- **Large bunch charges** $N_e \le 1.7\cdot10^{11}$, $N_p \le 0.69\cdot10^{11}$
  - impact on beam backgrounds (SR, beam gas)
- **Many bunches,** n_b=1160
  - crossing angle collision geometry
    - impact on detector acceptance, not symmetric in rapidity
  - large total beam currents
    - impact on beam backgrounds
- **Small beam size** at collision point achieved by
  - small emittance, requiring either:
    - strong hadron cooling to prevent emittance growth **or**
    - frequent hadron injection
      - needs to be integrated from the beginning in detector design
  - and strong focusing at interaction point (small β_y)
    - limits overall space for the detector

EIC High Luminosity with a Crossing Angle

- **Modest crossing angle of 25 mrad**
  - avoid parasitic collisions due to short bunch spacing,
  - for machine elements, to improve detection
  - reduce detector background
  - Multi-staged separation → separate beam from particles needed for physics
    → space for forward equipment along beam line
- **However**, crossing angle causes
  - Low luminosity
  - Beam dynamics issues
- **avoided by Crab Crossing**



Then :

- Effective head-on collision restored
- beam dynamic issues resolved

Impact on Physics:

- Size of crab angle directly impacts angular opening of the first forward spectrometer dipole B0 (polar angle)
- Impact on main detector acceptance → beams not back to back → solenoid aligned with electron beam
- impacts p_T resolution of forward going particles

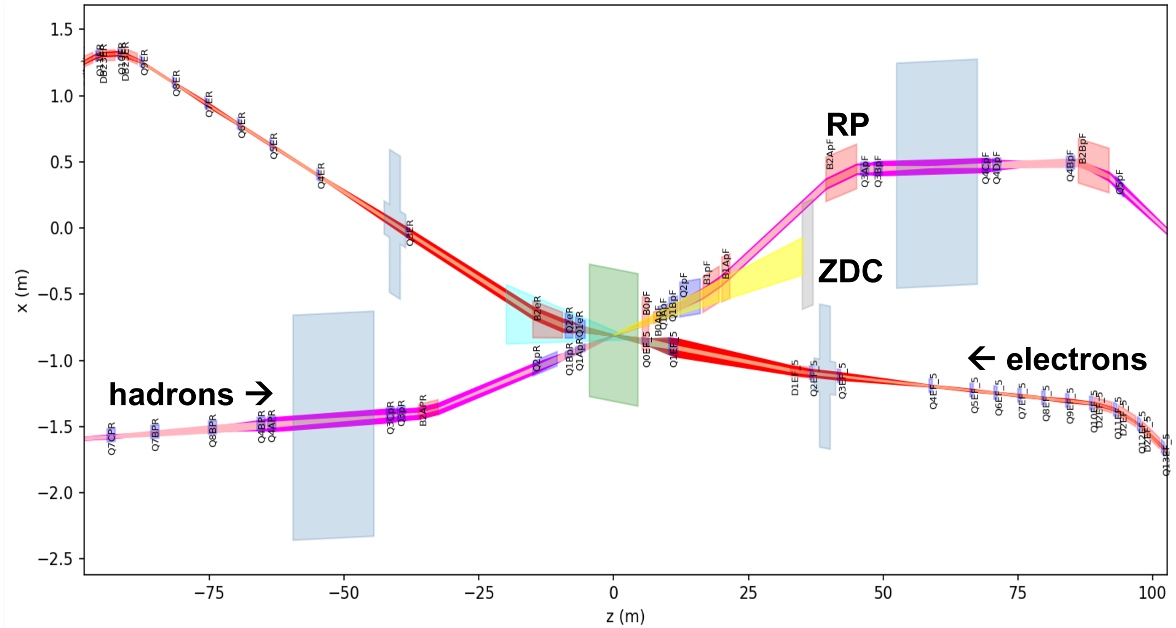
IR Requirements from Accelerator Point of View

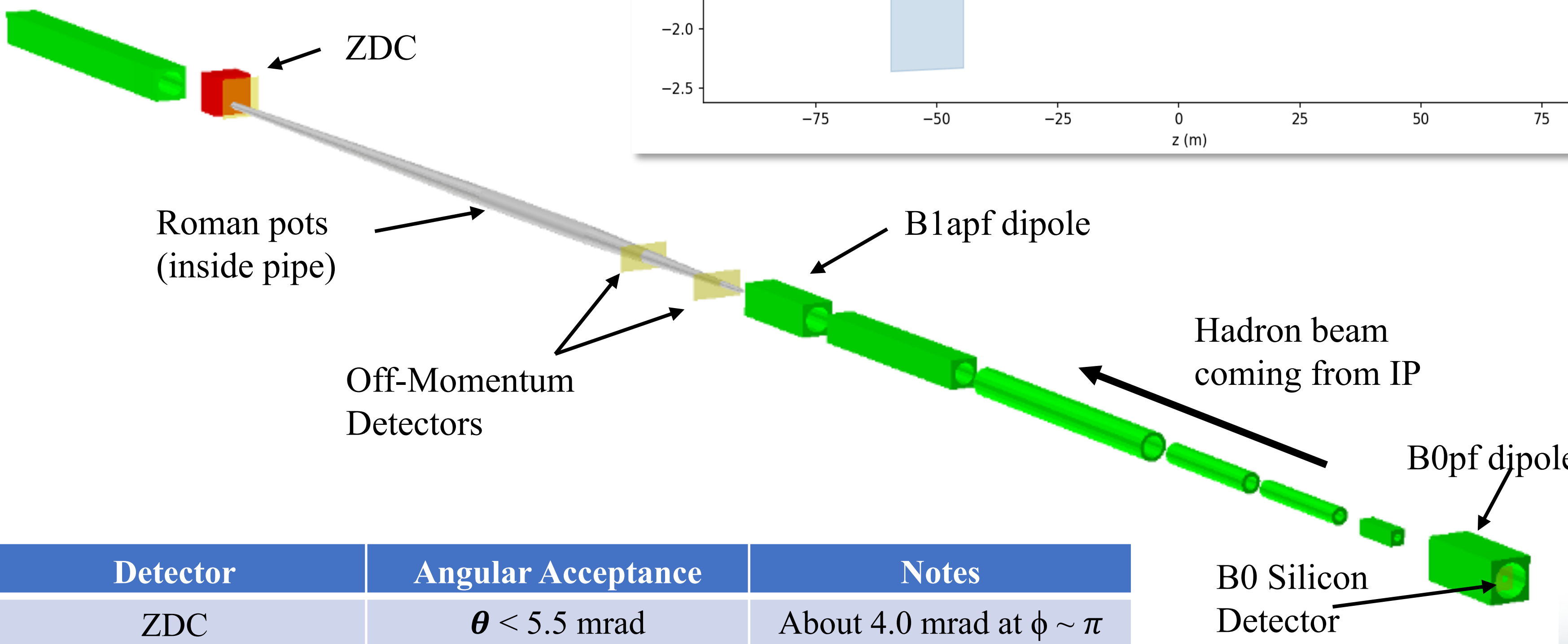
General Considerations

- Beam focused to $\beta_y \leq 5$ cm @ σ_y= 5 μm, gives L=10^{34}cm^{-2}s^{-1}
- Manageable IR chromaticity and sufficient dynamic aperture
- Same focusing scheme for electrons
- as low as possible Synchrotron Radiation background
  - → No bending magnet in lepton beam line up to 80 m upstream of IP
    - → This synchrotron radiation can be collimated
  - → SR source closest to IP: Quads
  - → Horizontal aperture: dominated by synchrotron radiation fan
- EIC final focus magnets based on conventional NbTi superconducting magnets using collaring and direct wind - technology

Parameter	Comments
Detector space symmetry [m]	Forward/rear acceptance balance Luminosity → L* (distance IP – 1st Quad)
Far-forward angular acceptance [mrad]	Angular opening of the forward final focusing quadrupoles
Minimum $\Delta p/p$ detectable at $p_T = 0$	Secondary focus → large dispersion in IP →needs to be matched back to condition in arcs
Angular beam divergence at IP, h/v, rms [mrad]	p_T^{min} → beam optics considerations
Maximum aperture-edge field at 275 GeV	Engineering constraint < 4.6 Tm
Tunnel and experimental hall size	Geometric constraint

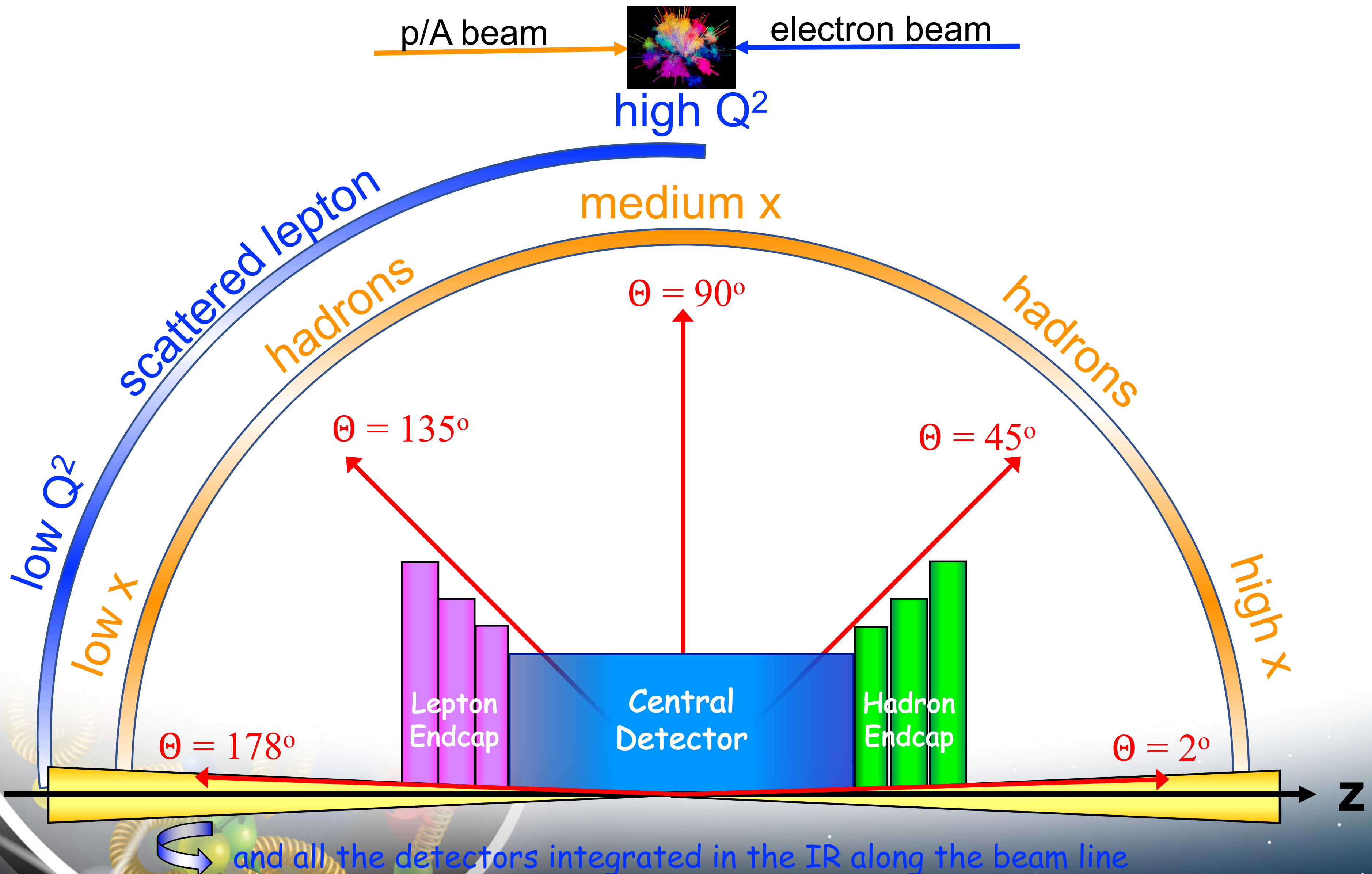
The Baseline IR



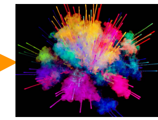


Detector	Angular Acceptance	Notes
ZDC	$\theta < 5.5$ mrad	About 4.0 mrad at $\phi \sim \pi$
Roman Pots	$0.0 < \theta < 5.0$ mrad	Need 10σ cut.
Off-Energy Detectors	$0.0 < \theta < 5.0$ mrad	
B0 Sensors	$5.5 < \theta < 20.0$ mrad	

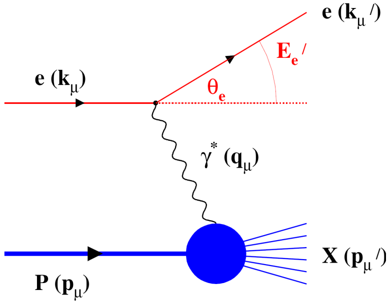
EIC General Purpose Detector: Concept



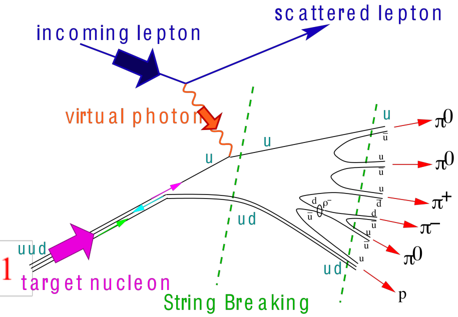
EIC General Purpose Detector: Concept

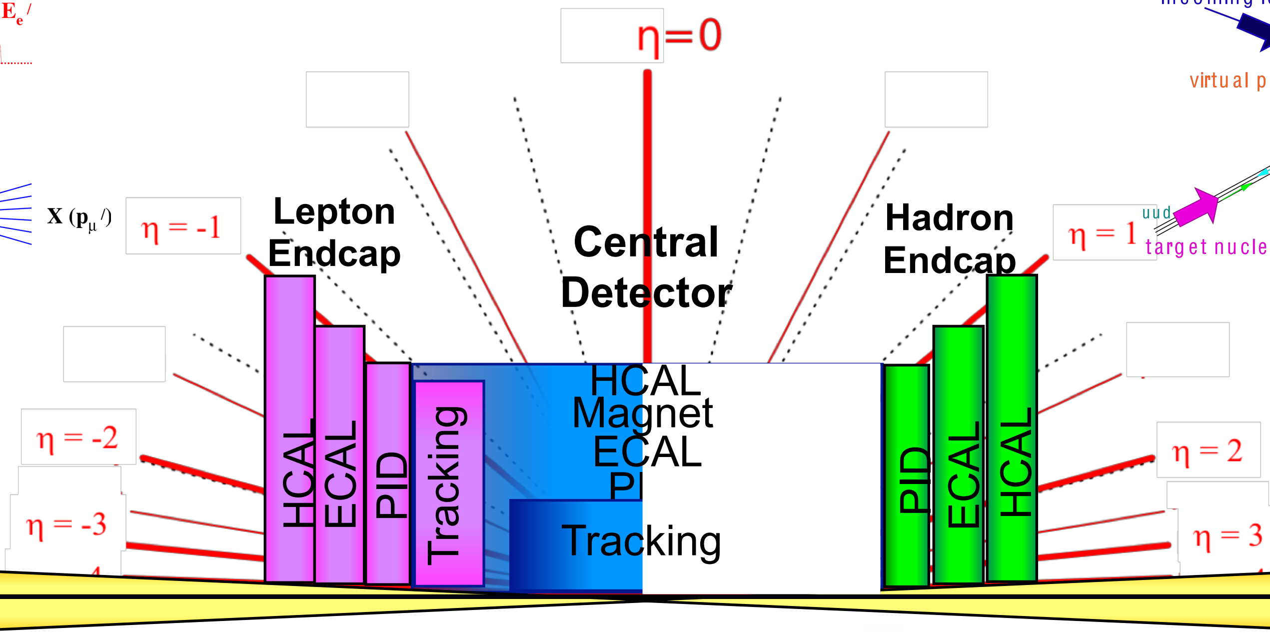


inclusive DIS:



semi-inclusive DIS





low Q^2 scattered leptons

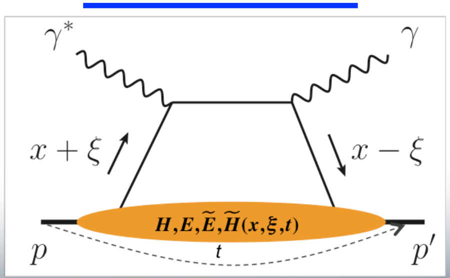
Bethe-Heitler photons
for luminosity

Luminosity Detector

Low Q^2-Tagger

Hadron and Lepton Polarimetry

exclusive DIS

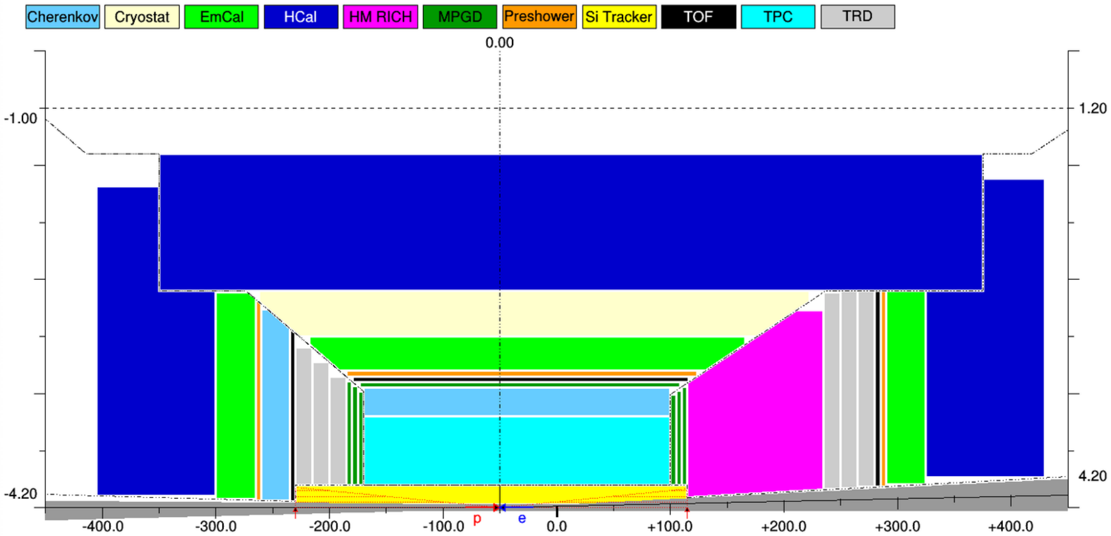


particles from nuclear
breakup, i.e. neutrons
scattered protons and ions
from diffractive reactions

ZDC

Forward Tracking

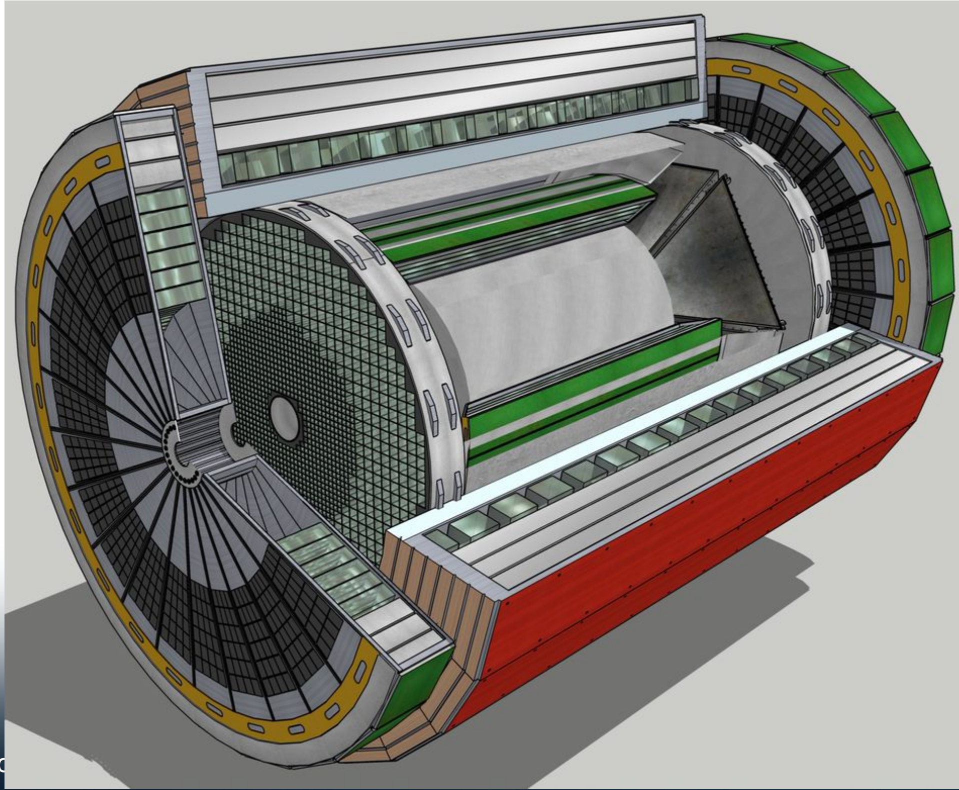
Reference General Purpose EIC Detector



Reference General Purpose Detector taking into account the thinking from the PWG and DWG

→ next step to integrate all services, support structures and cables

→ clearer picture on material, size and acceptance



Input from Physics Working Groups

- Extremely positive engagement with Physics Working Groups (thanks).

- 'Deep dive' into needs of one group per meeting, guided by questions:

- *Do you have requirements that conflict with current detector / IR baseline?*
- *What is your basic kinematic range in (x,Q^2) or other relevant variables.*
- *Which basic detector-level measurements are most essential … and what resolutions / performance you need?*
- *For charged particles, importance of low p_T acceptance v high p_T resolution*
- *Is your physics limited by luminosity?*
- *What are your most important sources of systematic uncertainty?*
- *Do you have particular requirements on beam energies and on polarisation?*
- *What beamline instrumentation do you need (n, p, e, γ)?*

Some 'Bold' Summary Statements: Common features of two detectors

- **Wide range of topics require hermiticity of central detector elements**
  → maximal acceptance for SiDIS, exclusives, charm, jets …
  → resolution for kinematic reconstruc'n using both electrons & hadrons.

→ Both detectors should have tracking, EM and HAD calorimeter coverage, PID and heavy flavour identification to large $|\eta|$ (typically $\pm$ 4)

- **Wide range of topics require beamline instrumentation in both outgoing proton (p, n) and electron (e, γ) directions**
  → exclusive and diffractive processes, including (in)coherent eA
  → kinematic coverage to $Q^2 \to 0$ and lumi monitoring with Bethe-Heitler

→ Should be a baseline feature of both detectors
→ Angular range more or less fixed by synchrotron fan
→ No really strong motivation to extend acceptance beyond ~20 mrad

- **Wide range of topics require high luminosity and polarization**

- **EIC physics is best realized with a variation (perhaps just two) in $\sqrt{s}$**
  → Maximise kinematic range in (x, Q^2) for all measurements
  → Vary x / η correlation for SiDIS, HF, exclusives …

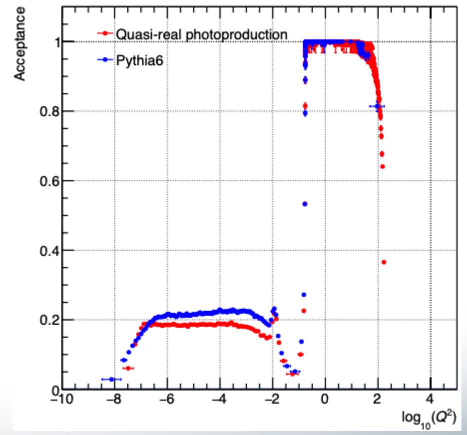
Some 'Bold' Summary Statements: Opportunities for Complementarity

- **Solenoid field**

→ High field for precise measurement of high p_T charged particles (scattered electron, leading particles in SiDIS …)
→ Lower field for acceptance of lower p_T charged particles (spectroscopy, some charm decays …)

- **Muon identification**

→ Limited need for dedicated outer muon chambers (maybe for J/Ψ or heavy flavour decays?) … Are HCAL patterns enough?
→ One detector could have barrel and/or forward muon chambers if physics motivation becomes clearer



- **Dipole and low Q^2 tagger set-up**

→ Is it possible to place Q^2 gap in different places?
→ Would have implications for IR design?

- **Beamline proton and neutron instrumentation**

→ Need better understanding for eA (dissociation models)
→ Roman pots at secondary beam focus to extend x_L acceptance?
→ Also has implications for IR design

Summary so far and Next Steps

Aiming for 2 'General Purpose' Detectors, with only minor differences in basic layout, able to cross check one another

[Optimising performance at highest lumi at one $\sqrt{s}$ each?]
[`Fixed target' mode capabilities could also be incorporated]

- **Complementarity (and redundancy versus unforeseen problems) should be built into detector technology choices**

→ eg 1 tracker with silicon +TPC, optimizing dead material inside ECAL and PID from dE/dx

... and one all-silicon tracker, optimizing track and secondary vertex resolution

→ several other examples (PID, calorimeters) elsewhere …

Future meetings will be similar deep dives engaging with each Detector Working Group to explore topics such as detector technology complementarity, mapping onto needs of Physics Working Groups

BACK UP

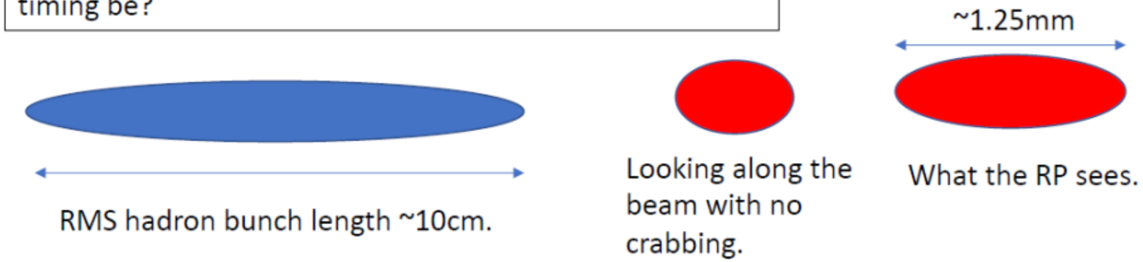
IR Requirements from Accelerator Point of View

- modification of present RHIC straight section can be done up to D9/Q10 area (~170m from the collision point)
- collision point can be moved towards the ring center (as compared with present RHIC) in order to provide a space for RCS (and HAR of on-energy injection option) to go around the detector
- reserve enough drift space to accommodate 2 spin rotators and 1 Snake. Each requires ~11m.
- conditions on dispersion in crab-cavities (as established by beam-beam TF):
  proton ring: Hx < 15m, or |Dx|< 0.5m, |Dx'| < 0.1,
  electron ring: Hx < 2.0m, or |Dx|<0.5m, |Dx'|< 0.1
- required beam apertures (as used for main IR design):
  proton: 10 sigma
  electron horizontal: 15 sigma
  electron vertical: 20 sigma (as defined by Christoph, to accommodate non-Gaussian tails building up in vertical plane due to beam-beam)

Comments to Requirements

Momentum Resolution – Timing

For exclusive reactions measured with the Roman Pots we need good timing to resolve the position of the interaction within the proton bunch. But what should the timing be?



- Because of the rotation, the Roman Pots see the bunch crossing smeared in x.
- Vertex smearing = 12.5mrad (half the crossing angle) * 10cm = **1.25 mm**
- If the effective vertex smearing was **for a 1cm bunch**, we would have **.125mm** vertex smearing.
- The simulations were done with these two extrema and the results compared.

> - **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to negligible from this contribution.**
> - **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

- If one is just changing the crossing angle from 25 mr to 50 mr effect is 2.5 mm.
- Longitudinal bunch length plays critically into this
- no chance to place any forward detectors after the crab cavities because particles will be randomly rotated by the crabs

Comments to Requirements

Momentum Resolution – Comparison

- The various contributions add in quadrature (this was checked empirically, measuring each effect independently).

$$\Delta p_{t,total} = \sqrt{\underbrace{(\Delta p_{t,AD})^2}_{\text{Angular divergence}} + \underbrace{(\Delta p_{t,CC})^2}_{\text{Primary vertex smearing from crab cavity rotation.}} + \underbrace{(\Delta p_{t,pxl})^2}_{\text{Smearing from finite pixel size.}}}$$

	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	14	-	10	9	10	12

- **Beam angular divergence**
  - Beam property, can't correct for it – sets the lower bound of smearing.
  - Subject to change (i.e. get better) – beam parameters not yet set in stone
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps)
- **Finite pixel size on sensor**
  - 500um seems like the best compromise between potential cost and smearing

16

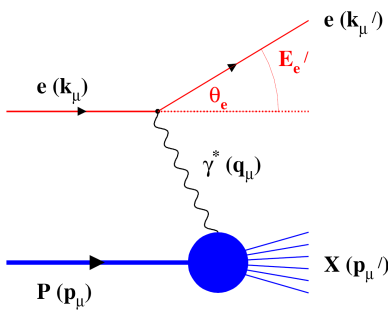
These numbers are obtained from the beam parameters from the preCDR table 3.3 and 3.4 HD and HA for strong hadron cooling

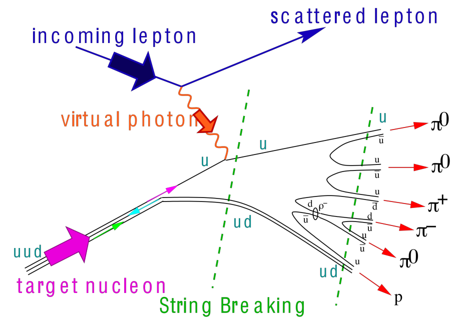
If just changing the crossing angle from 25 mr to 50 mr while keeping everything else fixed (longitudinal bunch length)
→ Vtx Smear gets to be >20 MeV → not desirable
→ will be dominate @41GeV and HA-case.

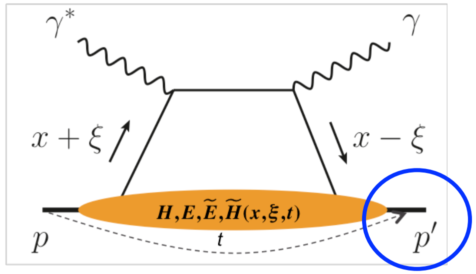
What is needed experimentally?

experimental measurements categories to address EIC physics:

- **Parton Distributions in nucleons and nuclei**
- **Spin and Flavor structure of nucleons and nuclei**
- **Tomography Transverse Momentum Dist.**
- **QCD at Extreme Parton Densities - Saturation**
- **Tomography Spatial Imaging**







inclusive DIS

- measure scattered lepton
- multi-dimensional binning: x, Q^2

→ reach to lowest x, Q^2 impacts Interaction Region design

semi-inclusive DIS

- measure scattered lepton and hadrons in coincidence
- multi-dimensional binning: x, Q^2, z, p_T, Θ

→ particle identification over entire region is critical

exclusive processes

- measure all particles in event
- multi-dimensional binning: x, Q^2, t, Θ
- proton p_t: 0.2 - 1.3 GeV

→ cannot be detected in main detector

→ strong impact on Interaction Region design

$\int Ldt$: 1 fb^{-1} | 10 fb^{-1} | 10 - 100 fb^{-1}

machine & detector requirements

The EIC: A Unique Collider

EIC

collide different beam species: ep & eA
→ consequences for beam backgrounds
  → hadron beam backgrounds,
  i.e. beam gas events
  → synchrotron radiation

asymmetric beam energies
→ boosted kinematics
  → high activity at high |h|

Small bunch spacing: >= 9ns

crossing angle: 25mrad

wide range in center of mass energies
→ factor 6

both beams are polarized
→ stat uncertainty: $\sim 1/(P_1 P_2 (\int L\, dt)^{1/2})$

LHC /RHIC

collide the same beam species: pp, pA, AA
→ beam backgrounds
  → hadron beam backgrounds,
  i.e. beam gas events, high pile up

symmetric beam energies
→ kinematics is not boosted
  → most activity at midrapidity

moderate bunch spacing: 25 ns

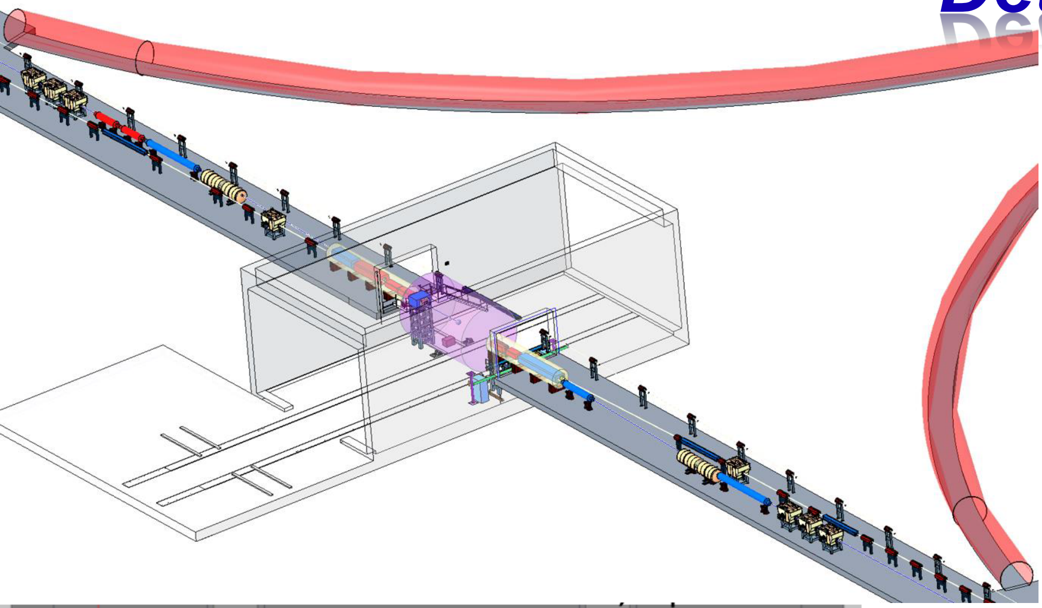
no crossing angle yet

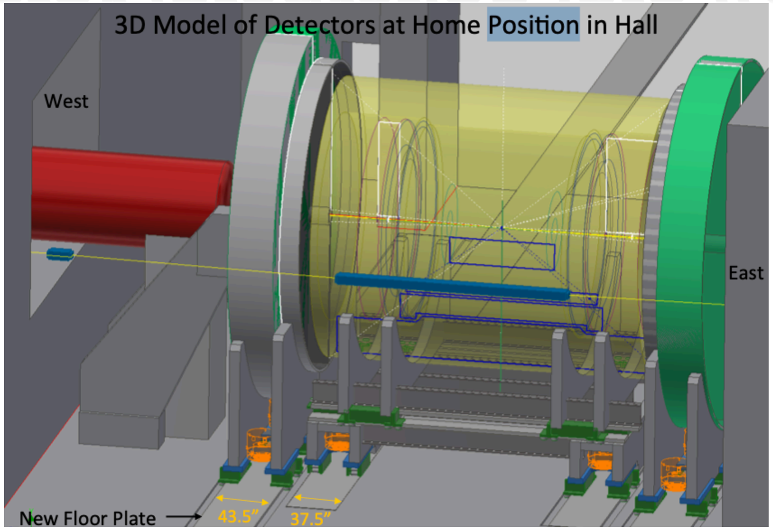
limited range in center of mass energies
→ LHC: factor 2
→ RHIC: factor 26 in AA and 8 in pp

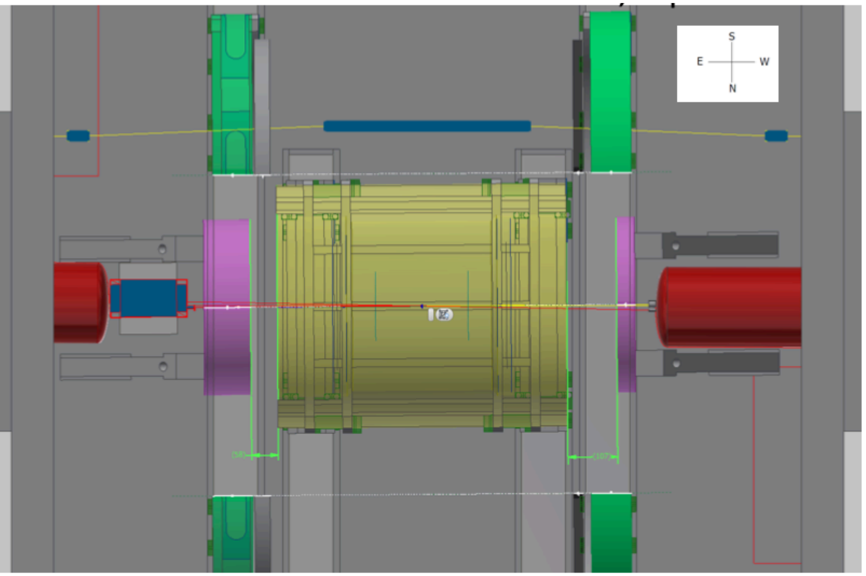
no beam polarization
→ stat uncertainty: $\sim 1/(\int L\, dt)^{1/2}$

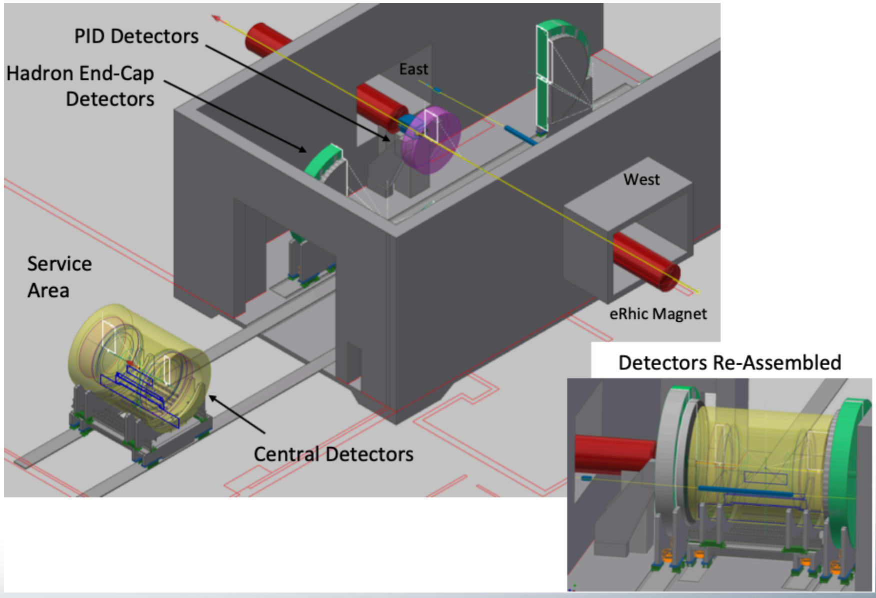
Differences impact detector acceptance and possible detector technologies

Detector Integration into IR









Engineering challenge to integrate the detector into the IR and still allow for maintenance without rolling into service position