Opportunities with a 2nd focus in IP8 at the EIC

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Tomography of light ions at an EIC,

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A 2^{nd} focus in IR8 greatly improves forward acceptance

- New physics opportunities
- Complementarity with Detector 1 (EPIC) @ IR6
- Potential synergies with Detector 2 and IR8 forward instrumentation

Key features include

- Excellent low-p_T acceptance for protons and light nuclei from exclusive reactions
- Detection of target fragments makes it possible to
  - veto breakup to study coherent processes
  - study the final state when breakup occurs

Also, note that the acceptance is much better than in fixed-target experiments like CLAS12 or SoLID, making Detector 2 particularly attractive for JLab users.

2^{nd} focus – assessment in the DPAP report

The CORE proposal makes a convincing case for the significant gain in physics reach achievable with a secondary focus:

- increased acceptance in the invariant momentum transfer t of the scattered proton in ep collisions, which directly translates into an increased resolution power for imaging partons in the transverse plane,
- significantly improved abilities to detect nuclear breakup in exclusive and diffractive scattering on light and heavy nuclei. The distinction between coherent and incoherent scattering is essential for the physics interpretation of these processes,
- prospects for a program of low-background γ gamma spectroscopy with rare isotopes in the beam fragments.

Forward detection at the EIC is unique

- In most colliders, the only way to detect very forward particles is to let them drift far downstream, where a small angular difference will separate them from the beam.
  - Low-p_T acceptance is then limited by the beam angular divergence at the IP (β^*).
- At the EIC, the longitudinal momentum loss of the scattered beam particles is not negligible, and is comparable to the intrinsic momentum spread within the beam
  - In DIS, dp/p ~ x (the momentum of the struck parton).
  - The intrinsic momentum spread (1σ) in the beam is typically a few times 10^{-4}.
- For x larger than the (10σ) beam momentum spread we can in principle detect *all* scattered beam particles – even ones with $p_T = 0$.
  - At lower x (high x_L), one cannot reach $p_T = 0$, but the low-p_T acceptance can be greatly improved compared with only relying on the scattering angle and drift distance.
- Heavy ions that change their rigidity (A/Z) behave like a that proton experiencing a longitudinal momentum loss.
  - Losing one nucleon changes the rigidity by ~10^{-2}, which is also comparable to the beam momentum spread (10σ), making tagging of A-1 nuclei possible

Dispersion and beam size at the detection point (2nd focus)

- The forward detection has two ingredients:
  - Dispersion (not just angle) separates scattered off-momentum particles from the beam
  - A 2nd focus shrinks the beam size (σ) at the detection point so that detectors can be placed closer

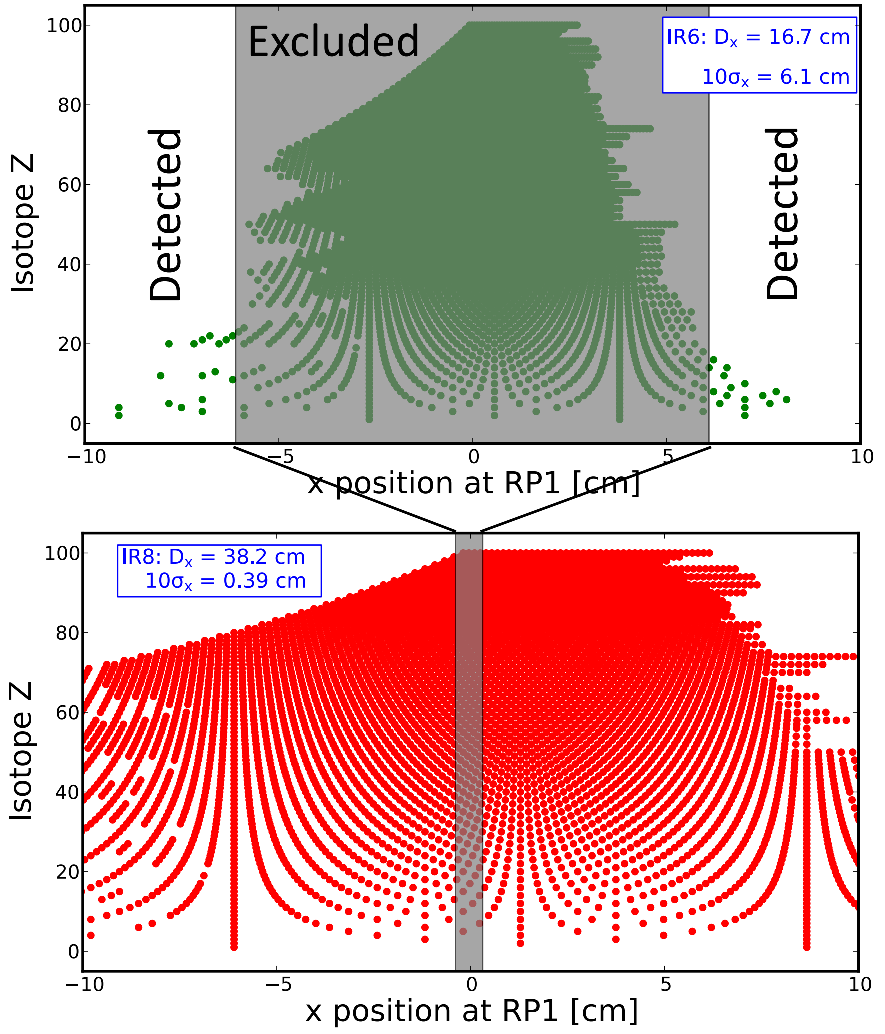
$$\sigma = \sqrt{\beta\epsilon + \left(D\frac{\Delta p}{p}\right)^2}$$

- Dispersion (D) translates a longitudinal momentum loss into a transverse displacement.
  - dx = D dp/p, where dx is the transverse displacement at $p_T = 0$
  - With D = 0.4 m, dp/p = 0.01, and $p_T = 0$, the transverse displacement for protons would be 4 mm

- This should be compared with the (10σ) beam size at the detection point
  - Without a 2nd focus: **4 cm** (high luminosity / divergence), **2 cm** (low luminosity / divergence)
  - With a 2nd focus: **0.2 cm** (high luminosity / divergence)

Far-forward acceptance with and without a 2nd focus

Ion fragments from ^{238}U



Without 2nd focus:
(EPIC @IR6)

← Z' vs x_{RP}

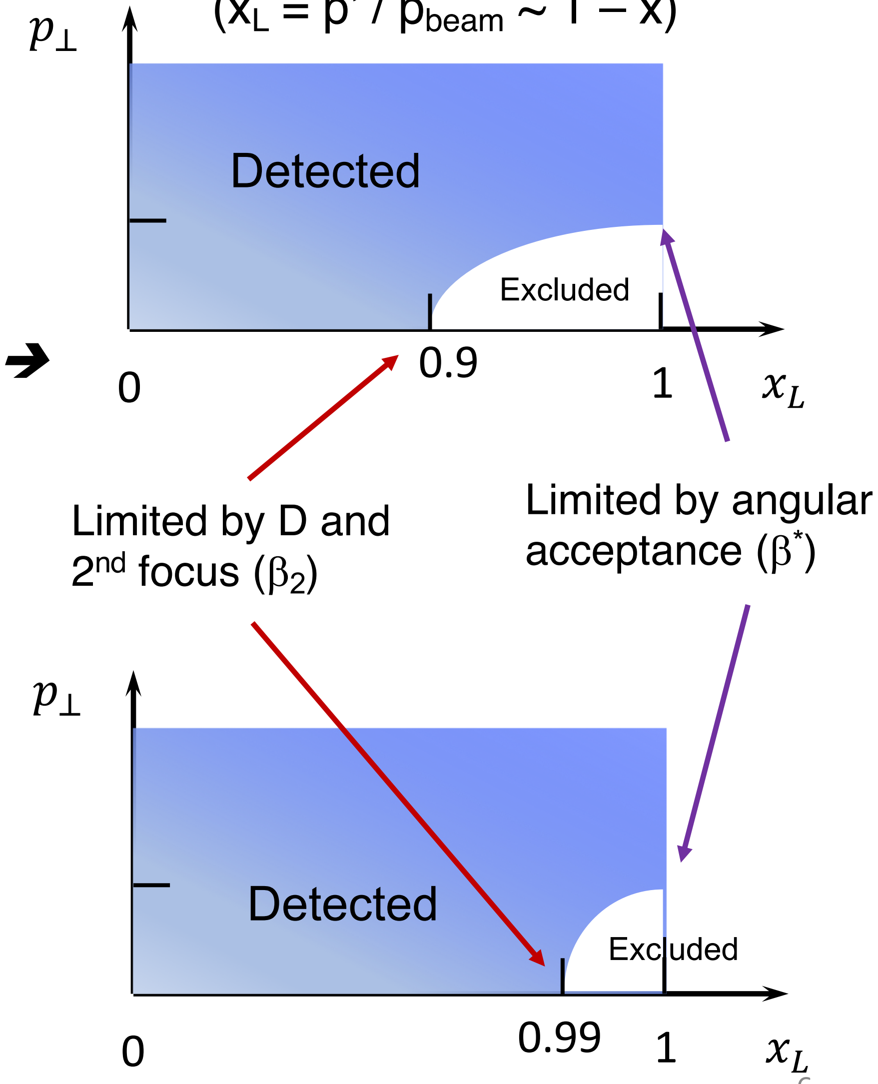
$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

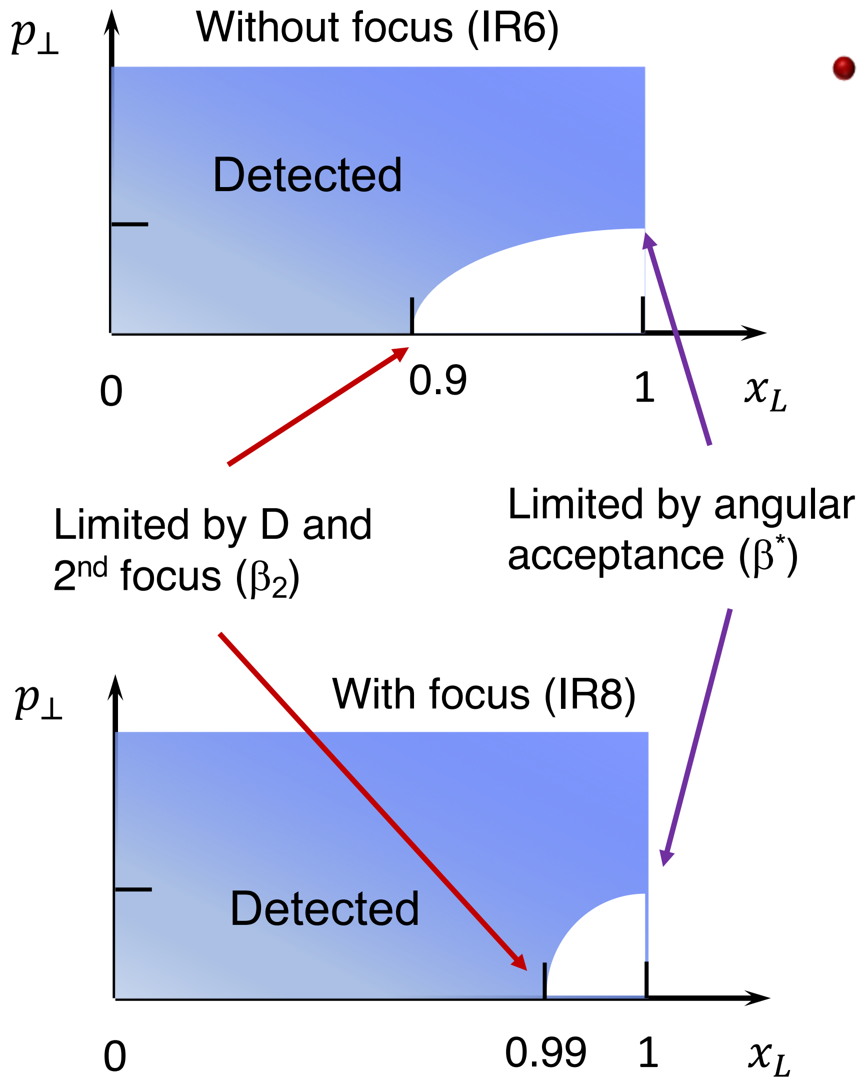
Order-of-magnitude improvement in forward acceptance

Exclusive protons

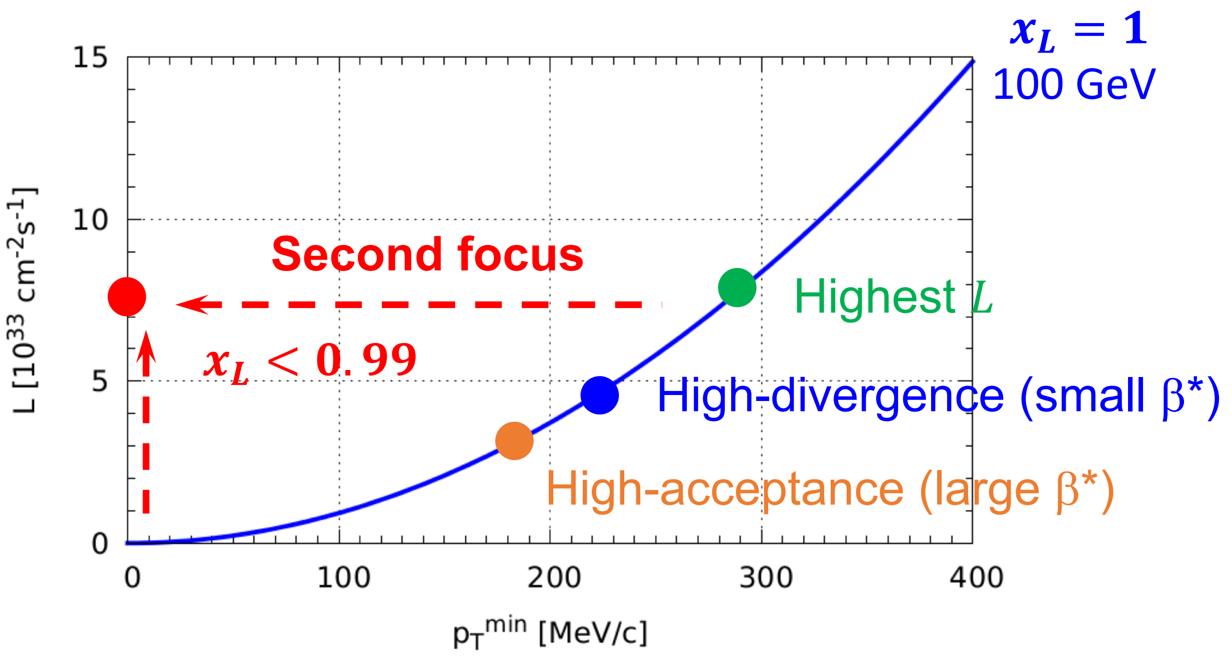
($x_L = p' / p_{beam} \sim 1 - x$)



p_T-acceptance for protons and its connection to luminosity



- Luminosity increases with stronger focusing (smaller β*)
  - But a smaller β* also increases angular divergence: $L \propto \sigma^*_{x'}\sigma^*_{y'}$
  - A 2nd focus makes it possible to improve acceptance without any loss in luminosity, and may allow IR8 to operate at a higher luminosity than IR6



2^{nd} focus – examples of physics opportunities

- Precision studies of exclusive reactions on the proton
  - At max luminosity (10x275 GeV), the full t-range is covered in one setting (no gaps)
  - High rates (σ x luminosity x acceptance) at low t and x (~10^{-2}) make studies of timelike Compton processes feasible (TCS and perhaps DDVCS)

- Coherent scattering on light ions
  - Light ions detected down to very low t (no incoherent background)
  - Transverse spatial imaging, diffraction, shadowing

- DVCS on nuclei → *talk by C. Hyde*
  - Tagging of scattered light ion *or* veto of breakup of heavy ion
  - In combination with high-resolution photon detection

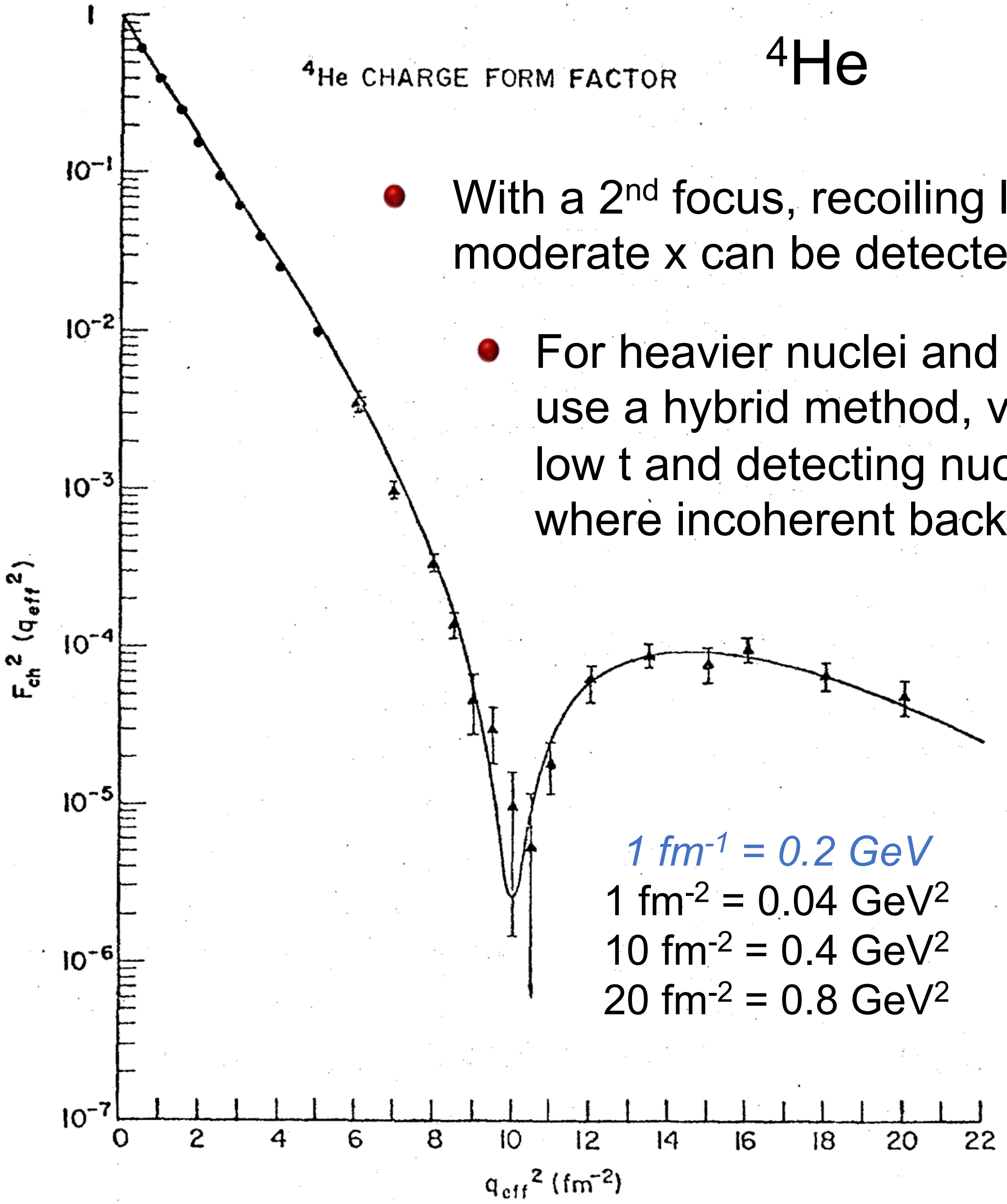
2^{nd} focus – examples of physics opportunities (continued)

- Tagging of specific incoherent channels by detecting final nucleus, *e.g.*,
  - A-1: reactions on a bound proton with a spectator nucleus
  - A-2: short-range correlations
  - etc

- Coherent diffraction on heavy nuclei
  - Veto of breakup with A-1 tagging, nuclear photons
  - Sensitive to gluon saturation

- Rare isotopes
  - Detection and identification of heavy fragments
  - Excited states of exotic, short-lived nuclei

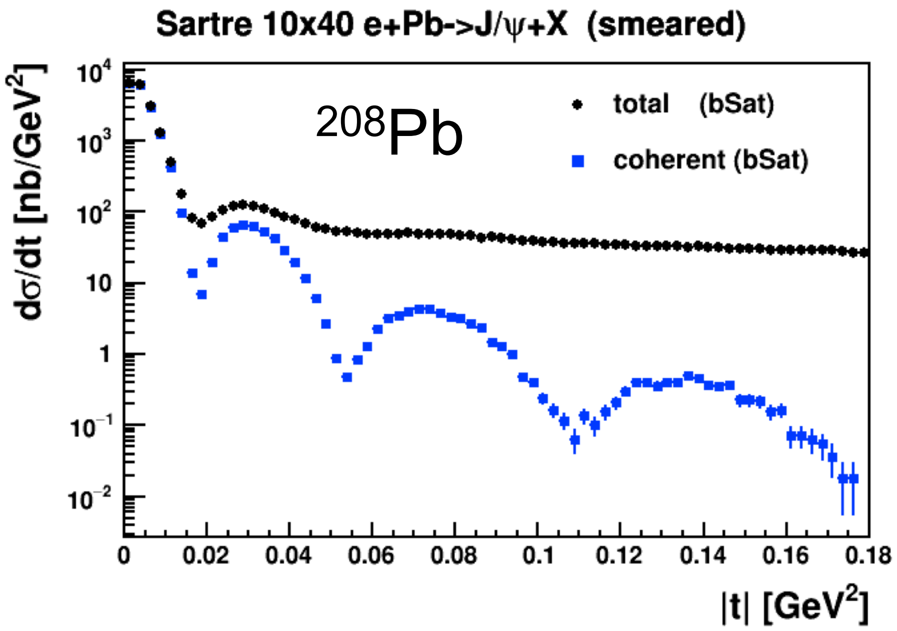
Exclusive coherent scattering on nuclei



^{4}He

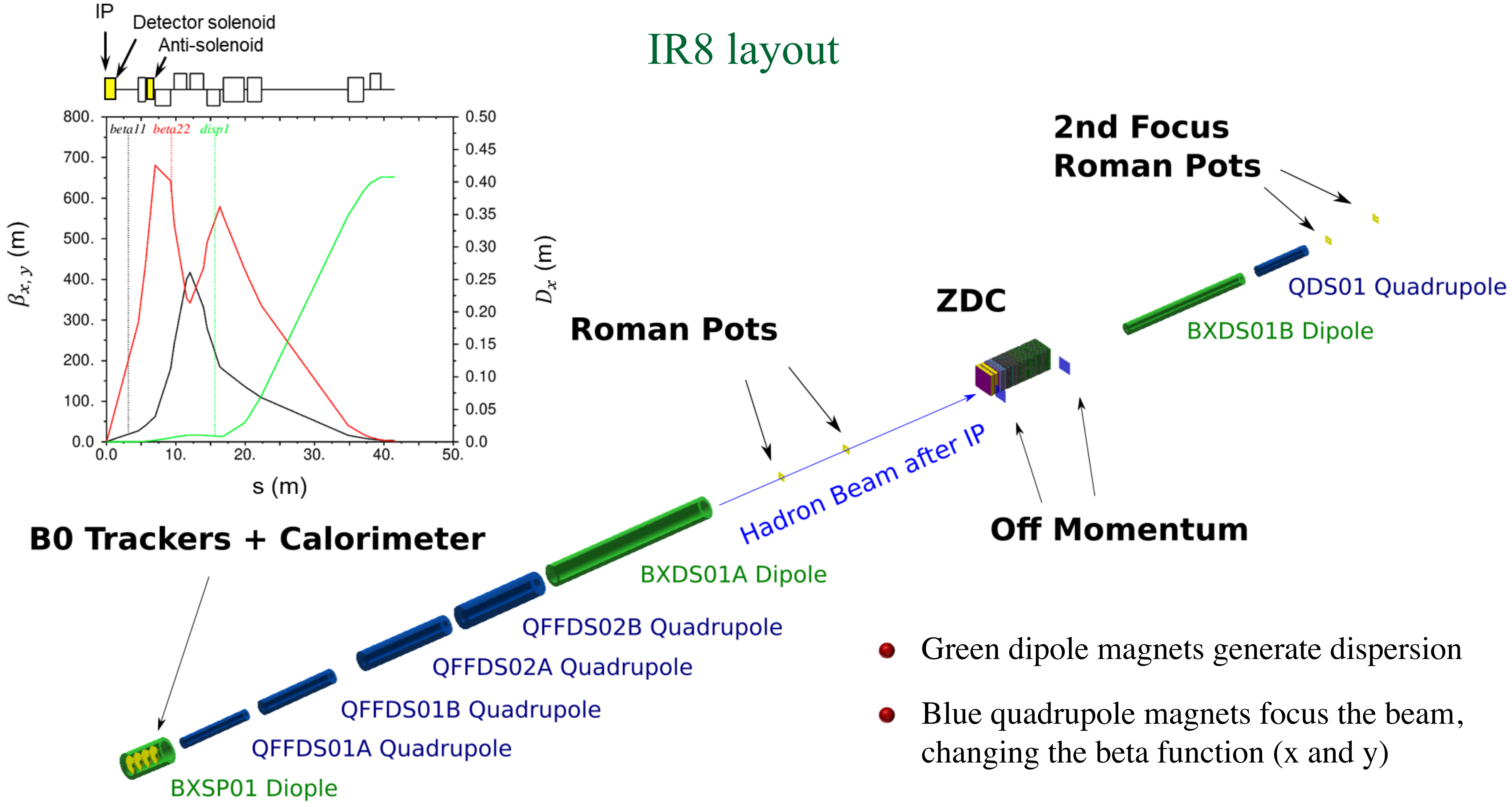
- With a 2nd focus, recoiling light nuclei at moderate x can be detected for all t.
  - For heavier nuclei and lower x, one can use a hybrid method, vetoing breakup for low t and detecting nuclei in the high-t tail, where incoherent backgrounds are higher

1 fm^{-1} = 0.2 GeV
1 fm^{-2} = 0.04 GeV^2
10 fm^{-2} = 0.4 GeV^2
20 fm^{-2} = 0.8 GeV^2



- Heavy nuclei never emerge from the beam
  - Veto of breakup
  - Large incoherent background
    - high veto efficiency required.
  - A-1 tagging important for “high” t tail
  - Nuclear photons (veto efficiency and excitation)

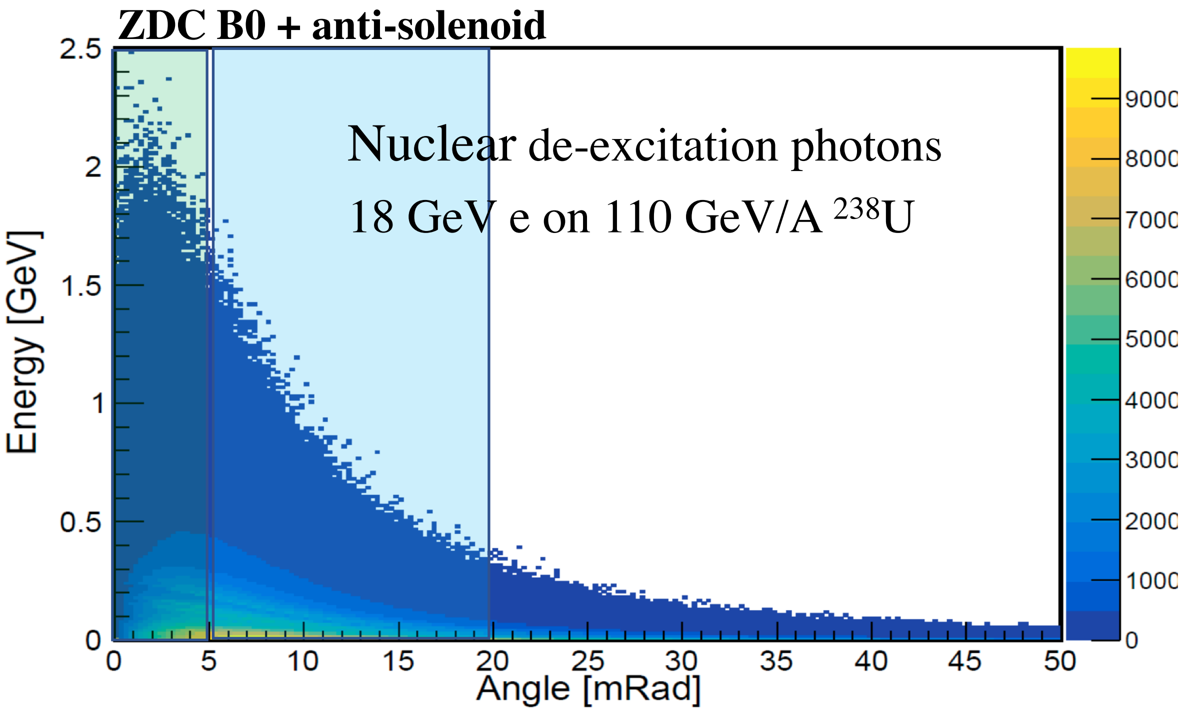
IR8 layout

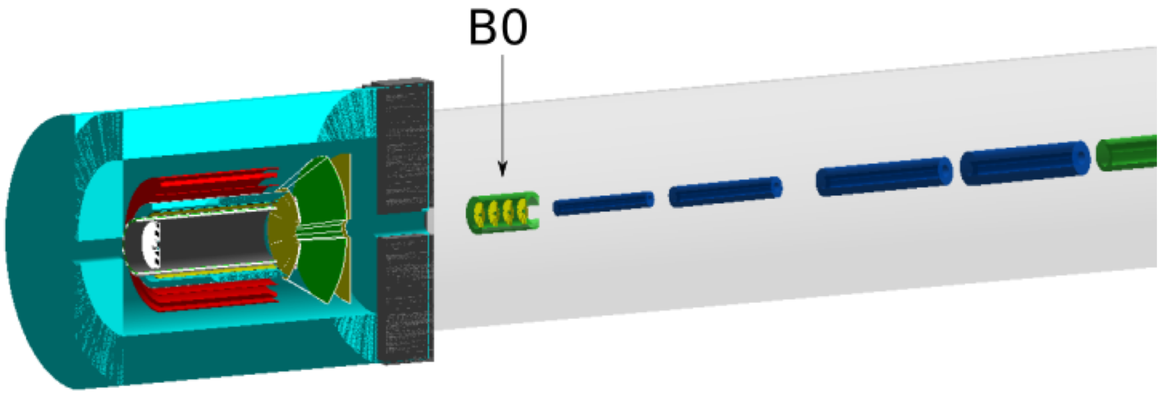


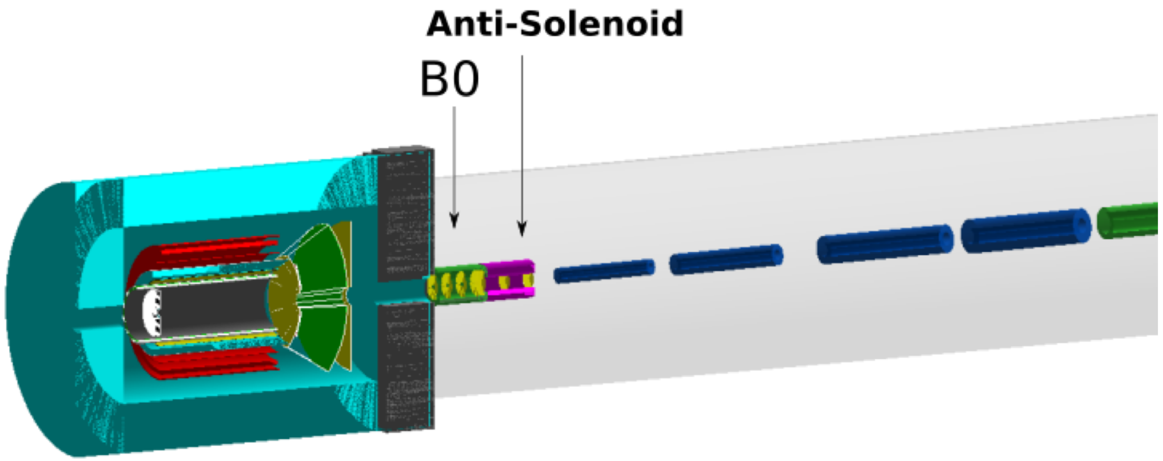
- Green dipole magnets generate dispersion
- Blue quadrupole magnets focus the beam, changing the beta function (x and y)

Improved detection in the intermediate region?

- Accelerator operations require compensation of the field of the main detector solenoid.
- Using an (anti-)solenoid with opposite polarity is most advantageous for the accelerator
- It could also improve acceptance for very forward photon detection.

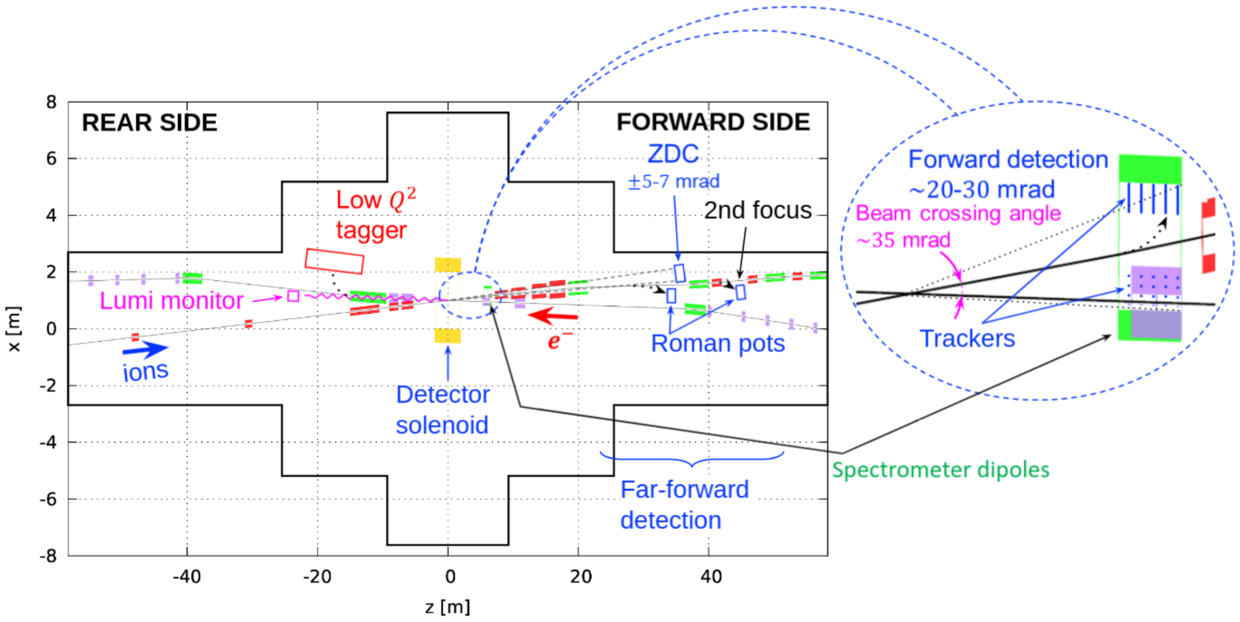


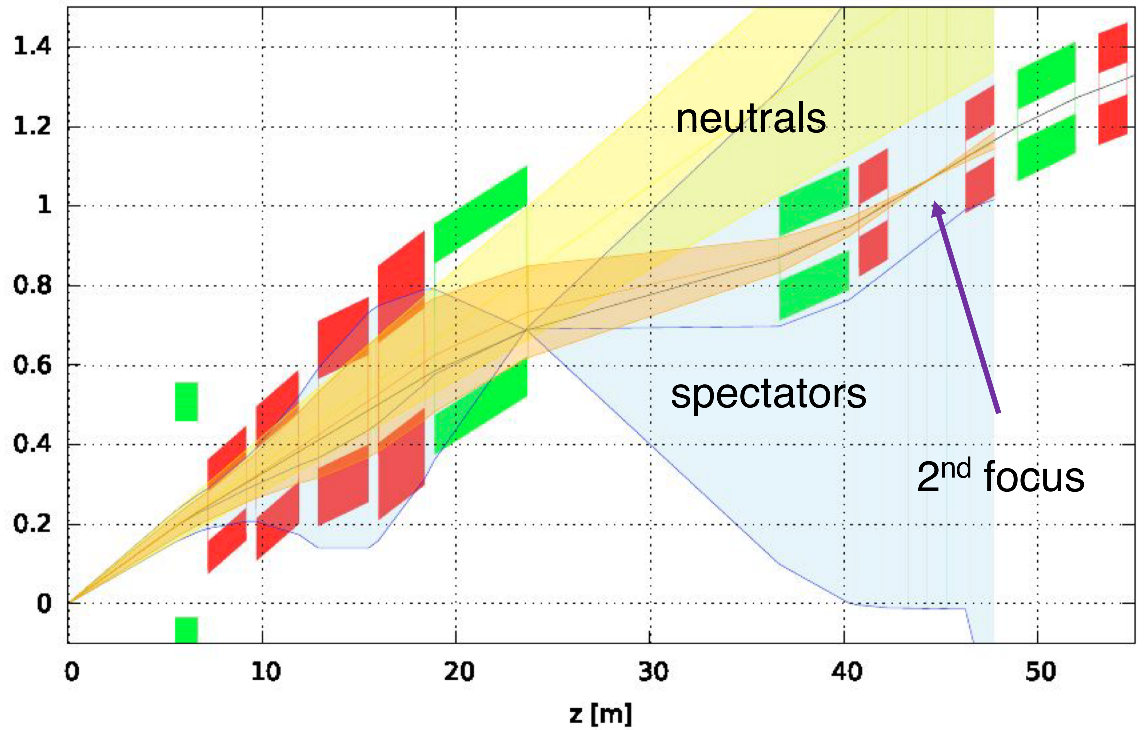




- An anti-solenoid can fit in the space in front of the ion FFQs (blue), located 7.5 m from the IP, by shifting the B0 towards the IP in IR8. This has no impact on the accelerator lattice or IR6.

Large-p_T acceptance





- In contrast to low-p_T, where acceptance is limited by the beam, there is no upper limit in p_T.
  - Particles that are not detected at the 2nd focus will be detected in the drift section before it, or in the B0 magnet in front of the quads (red), or in the hadron endcap of the central detector

- Losses will, however, occur in the transition between each region.

Detector II/IP8 and WG charge

"With a clear mandate from DPAP and the EICUG to support and organize a Detector II/IP8 effort, the SC held discussions with Project, Detector I and CORE leadership. We agreed to form a dedicated working group that would address the following charge:"

1. Engage the broader community, ***including theorists, accelerator physicists and Detector I experimentalists***, to fully develop projections for the portfolio of measurements that are complementary to the Detector I physics program, including those that capitalize on the implementation of the **secondary focus**.

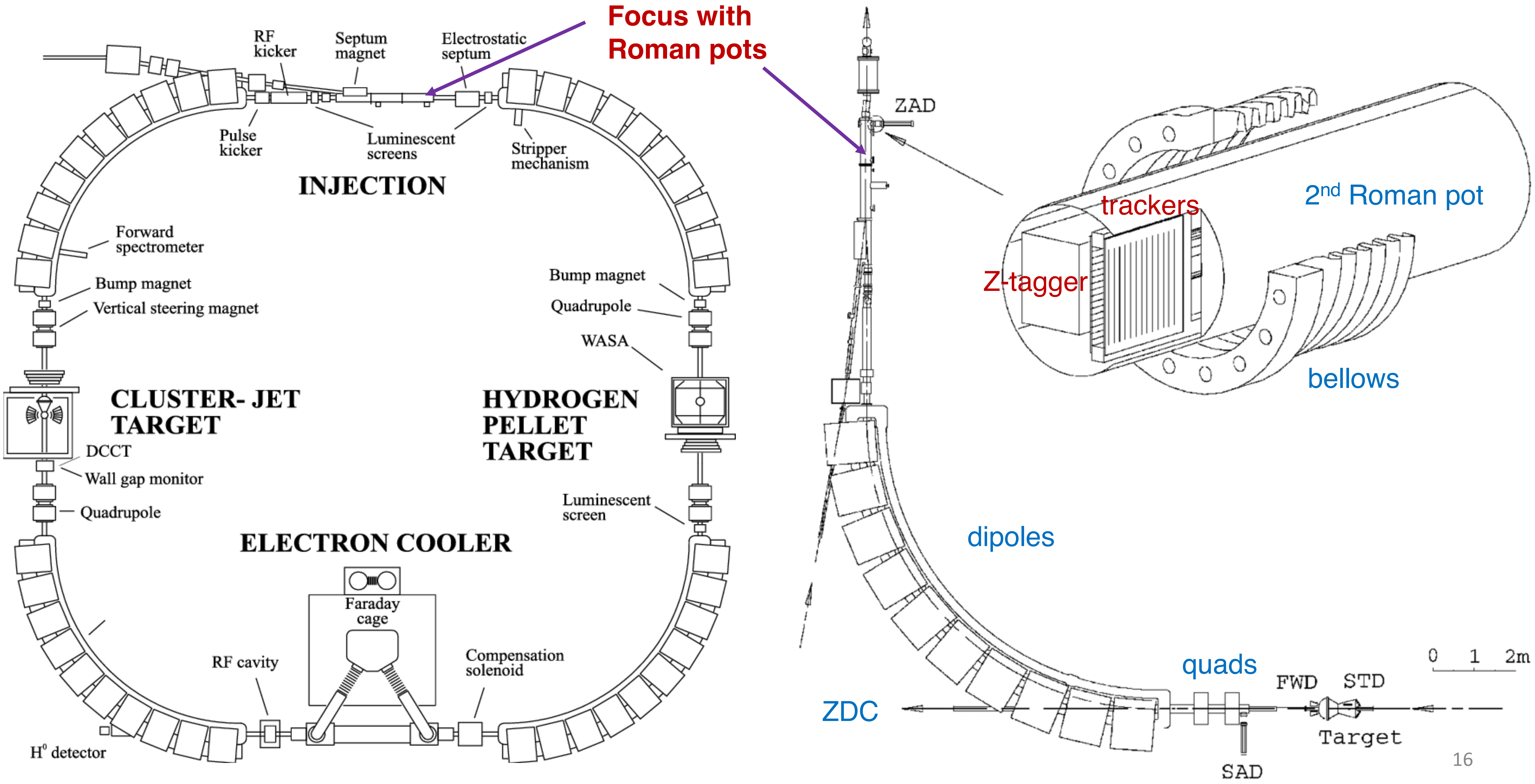
2. Work with the EICUG Steering Committee and Project to ***recruit new institutions*** and establish a diverse and vibrant 2nd Detector working group.

3. Utilize the extended design period for Detector 2 to identify groups that will focus on ***R&D for emerging technologies*** that could provide another aspect of complementarity to Detector 1.

4. Facilitate the development of a ***unified concept*** for a general-purpose detector at IR8. In particular, the 2nd detector should be complementary to the project detector at IR6 and may capitalize on the possibility of a **secondary focus at IR8**.

Thank you!

Far-forward detection at the CELSIUS storage ring in Uppsala, Sweden



Beam momentum spread for protons

Table 4: Parameters used in the PYTHIA-8 implementation taken from Table 3.3 in the CDR. The designations h and v stand for horizontal (x direction) and vertical (y direction).

Species Energy [GeV]	Proton 275	Electron 18	Proton 41	Electron 5
RMS Emittance h/v [nm]	18/1.6	24/20	44/10	20/3.5
β^* h/v [cm]	80/7.1	59/5.7	90/7.1	196/21
RMS $\Delta\theta$ h/v [μrad]	150/150	202/187	220/380	101/129
RMS Bunch Length [cm]	6	0.9	7.5	0.7
RMS $\frac{\Delta p}{p}$ [10^{-4}]	6.8	10.9	10.3	6.8

From "Accelerator and beam conditions critical for physics detector simulations for the EIC"

At low energy, beam quality deteriorates making exclusive measurements a little more challenging than one might think

Beam momentum spread

- In general, momentum spread can be reduced at the expense of luminosity, but baseline beam parameters from the CDR were not optimized for momentum spread.
- A recent study made by the BNL accelerator group suggests that for protons there is significant headroom and that for 275 GeV protons and 10 GeV electrons a luminosity of 1.2 x 10^{34} can be reached with a momentum spread of 4.1 x 10^{-4}.
  - See details on next slide

DPAP report – assessment of physics capabilities - complementarity

The CORE studies for DVCS and exclusive meson production find that the reaction kinematics can be reconstructed from the central detector alone. This allows the extension of the parton imaging program from the proton to nuclei, and it may increase the precision of measuring *t* in *ep* collisions. The panel regards this as a good example of specialization/optimization to enhance the complementarity between two detectors, discussed below.

Please note that the nuclear DVCS studies relied on both a 2nd focus and an extension of the high-resolution $PbWO_4$ EMcal to cover the full outgoing electron hemisphere ($\eta < 0$). Electron beam energies of 5-10 GeV were assumed, as these are best suited for 3D structure measurements.