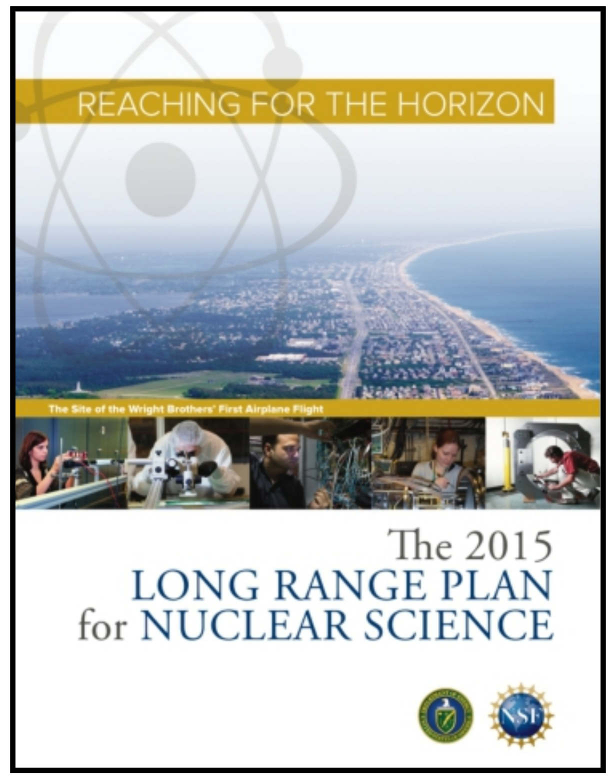
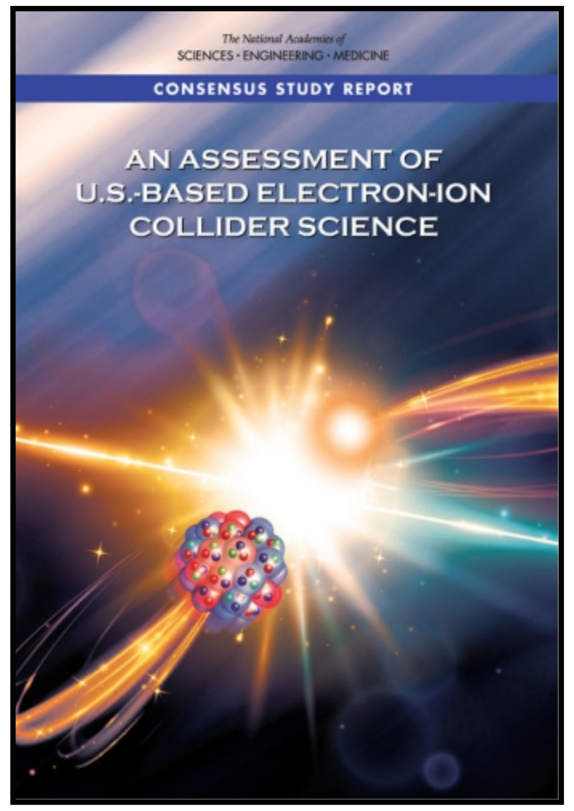
7. Realization of an EIC: the Path

Rise of US Based EIC



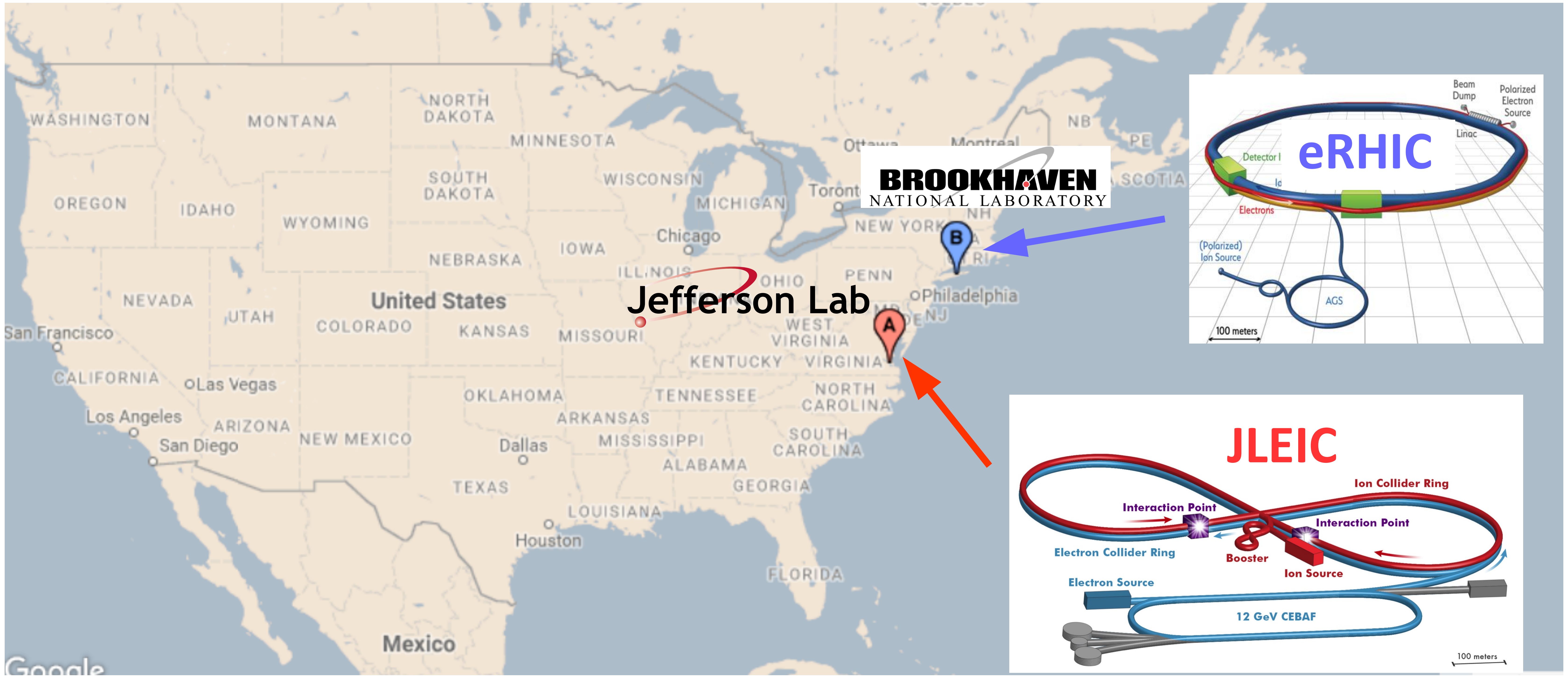
2015: US Nuclear Physics Long Range Plan:
"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

2018: National Academy EIC Review
"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."



The EIC Location?

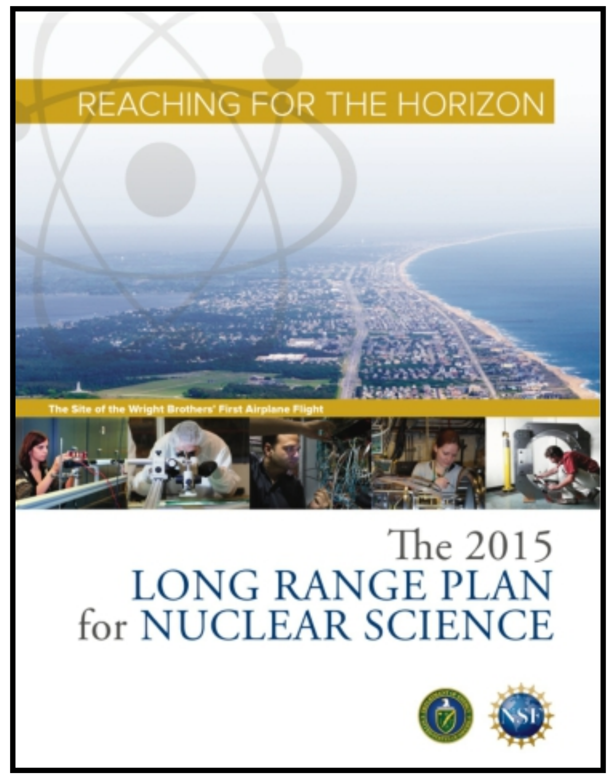
EIC Community =
Heavy Ion (RHIC/LHC) +
Hadron Physics (JLab/RHIC Spin)+
few HEP +
few Nuclear Structure



Two sites under consideration:

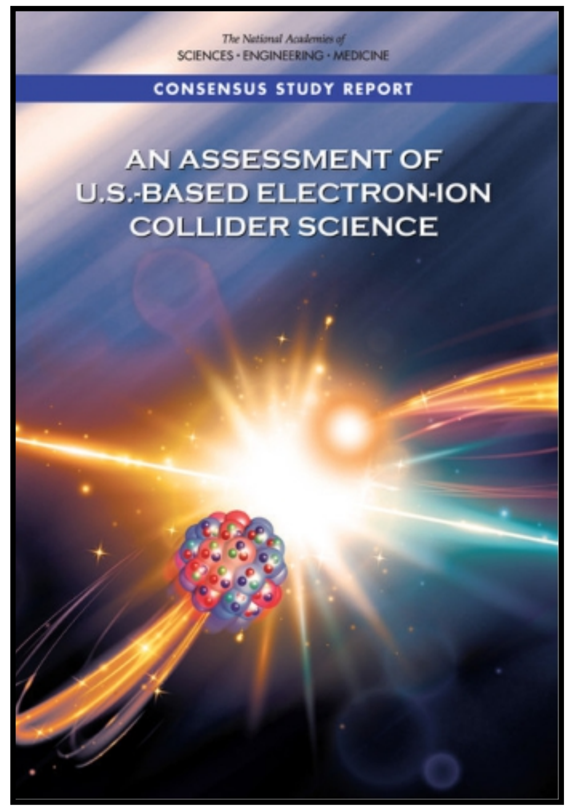
- BNL (eRHIC): Add e Rings to modified RHIC facility
- JLAB (JLEIC): Figure-8 Ring-Ring Collider, use of CEBAF as injector
- Extensive R&D efforts in both labs
- Both designs met requirements

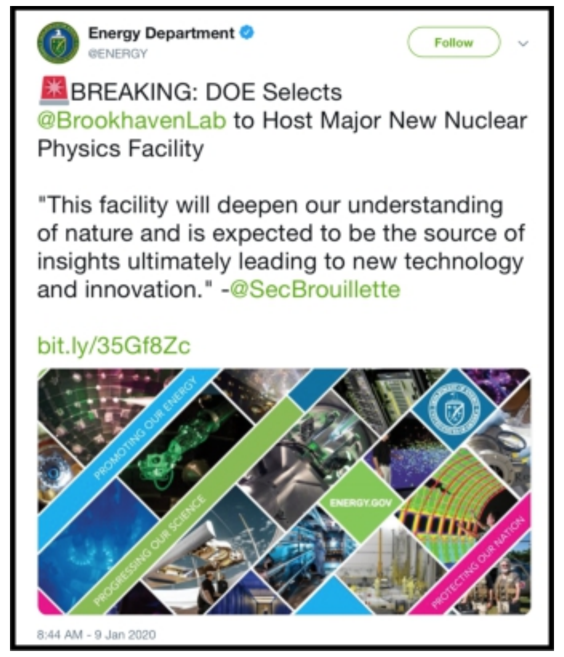
Evolution of US Based EIC



2015: US Nuclear Physics Long Range Plan:
"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

2018: National Academy EIC Review
"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."





December 2019/January 2020:
After science, cost, and host review DoE gives EIC CD-0 (*Approve Mission Need*) and selects BNL as the hosting site. BNL and JLab are the hosting labs. Project management officially started 4/1/2020.

The Aftermath …

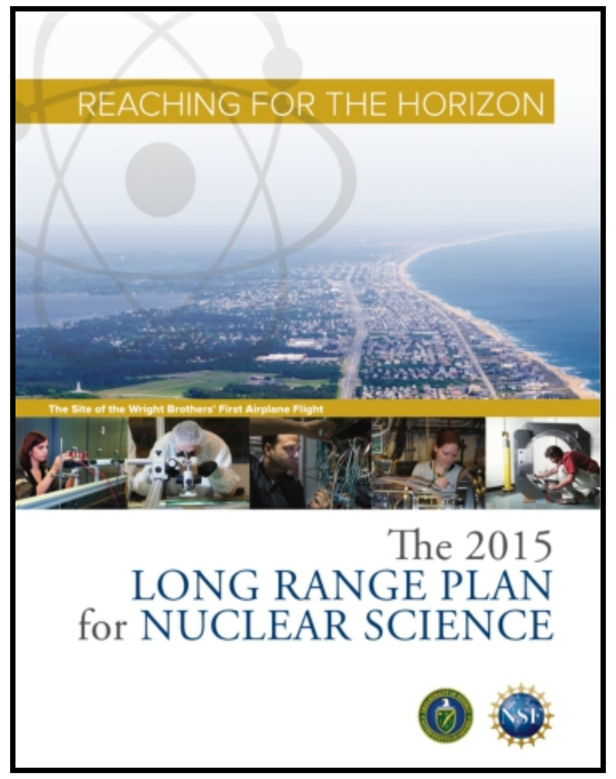
- Working hard for on a project for years and then losing it is painful
- DOE took a unique approach in declaring BNL **and** Jefferson Lab the host labs with share responsibilities although the machine will be physically located at BNL
- The Yellow Report initiative did a lot to bring both communities together

Yellow Report 2021

Physics Requirements
Detector Concepts

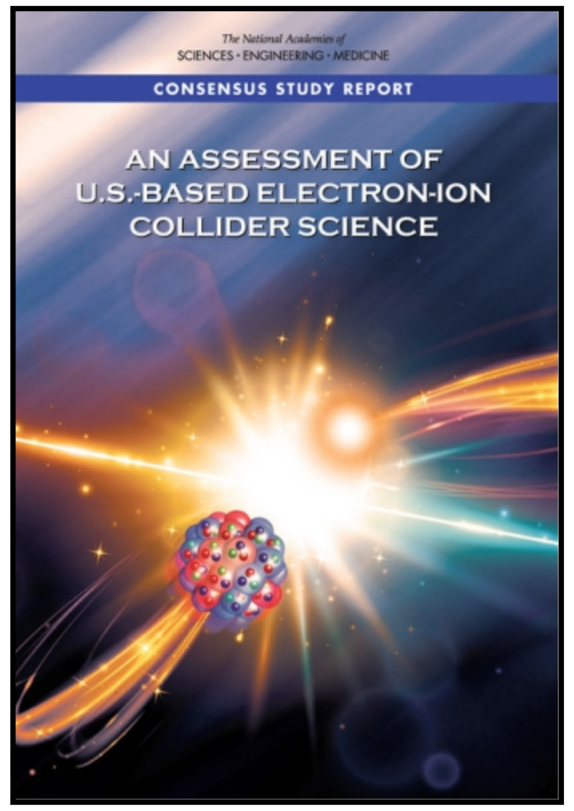
- until the detector selection process (more later)

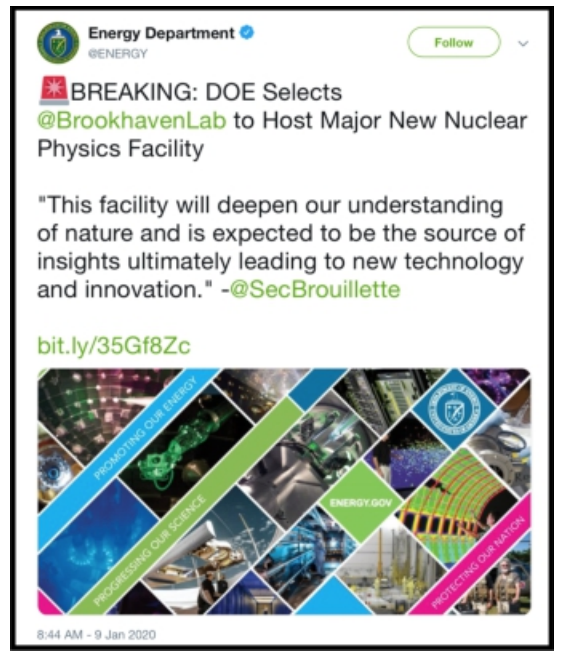
Evolution of US Based EIC



2015: US Nuclear Physics Long Range Plan:
"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

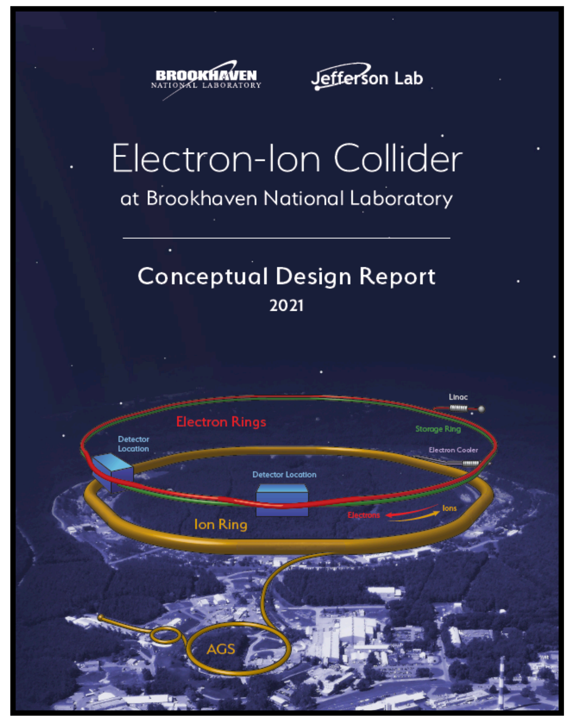
2018: National Academy EIC Review
"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."

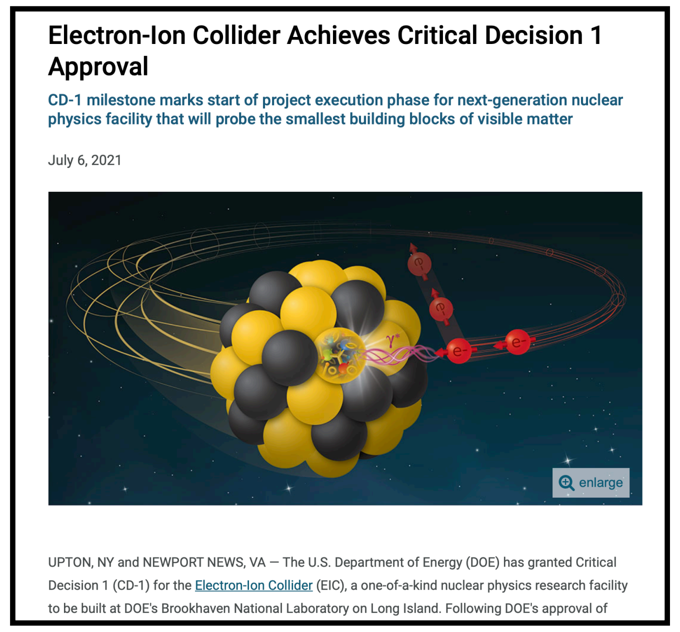




December 2019/January 2020:
After science, cost, and host review DoE gives EIC CD-0 (*Approve Mission Need*) and selects BNL as the hosting site. BNL and JLab are the hosting labs. Project management officially started 4/1/2020.

January/February 2021: Release of CDR, CD-1 Review

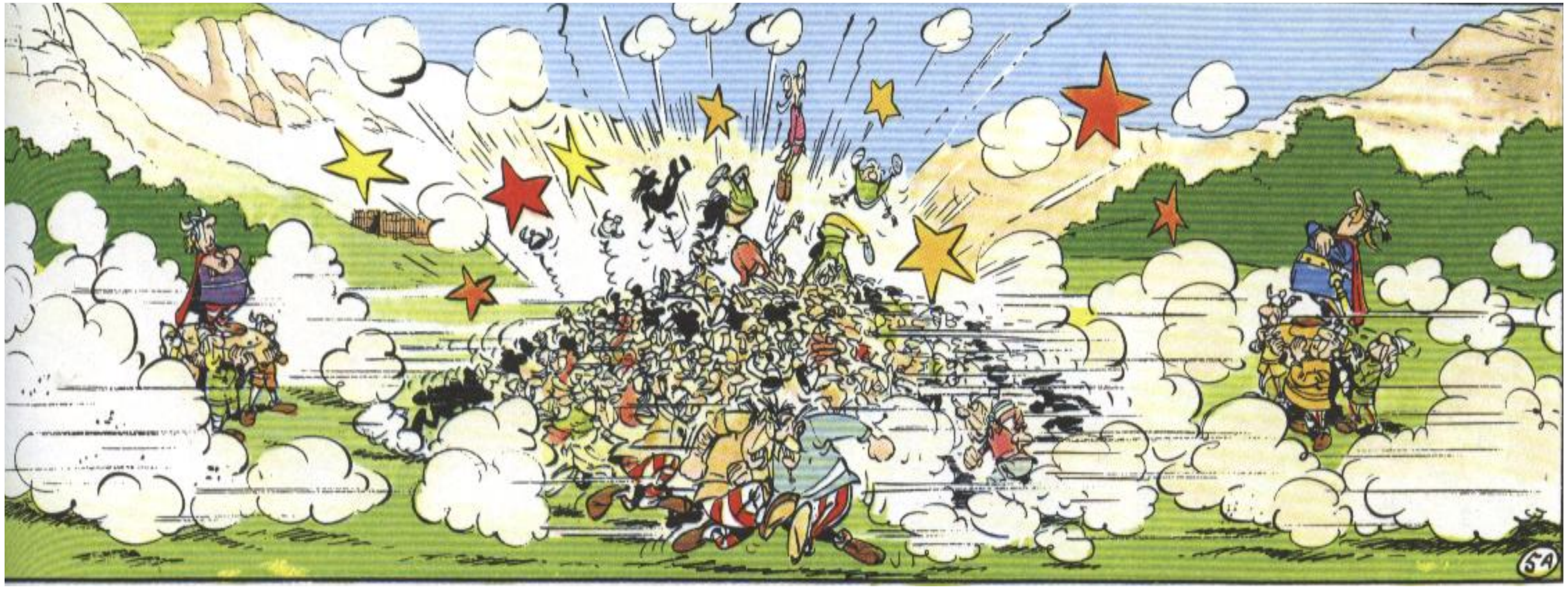




July 2021: CD-1 (*Approve Alternative Selection and Cost Range*) received.
Original cost estimate: $2 - 2.6 B
$100M from New York State towards infrastructure

to be continued…

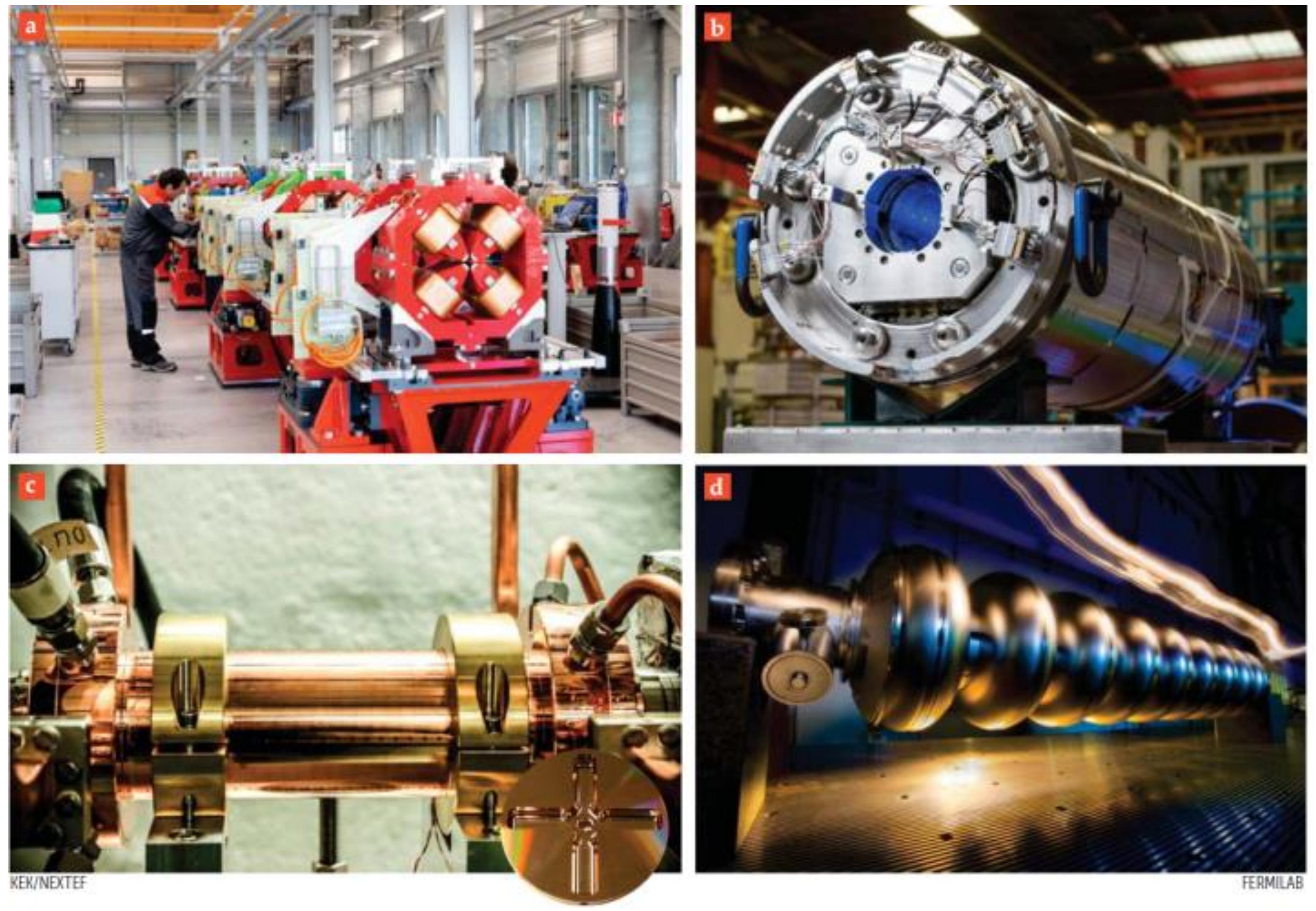
8. Realization of an EIC: the Collider



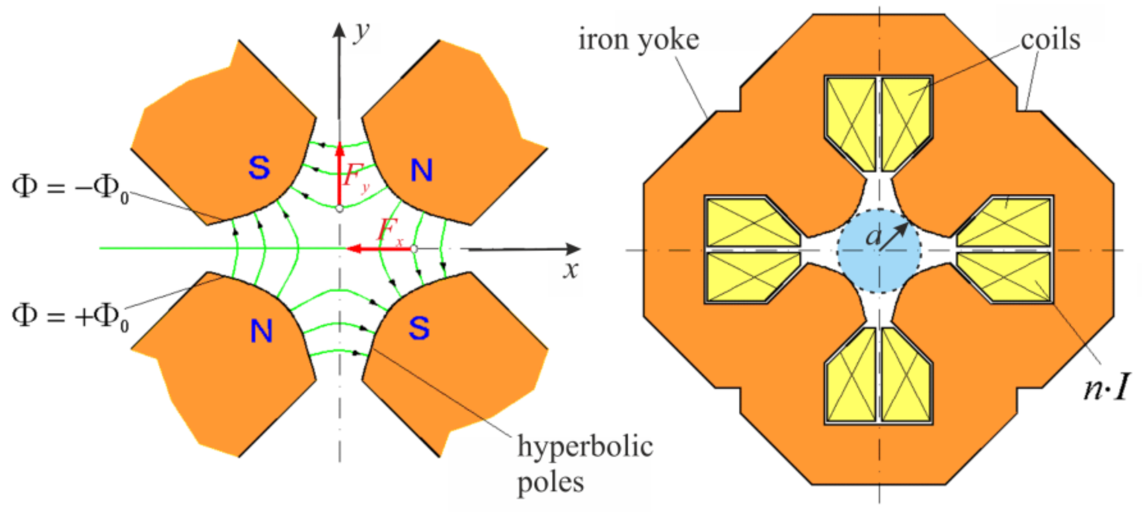
Accelerators are …

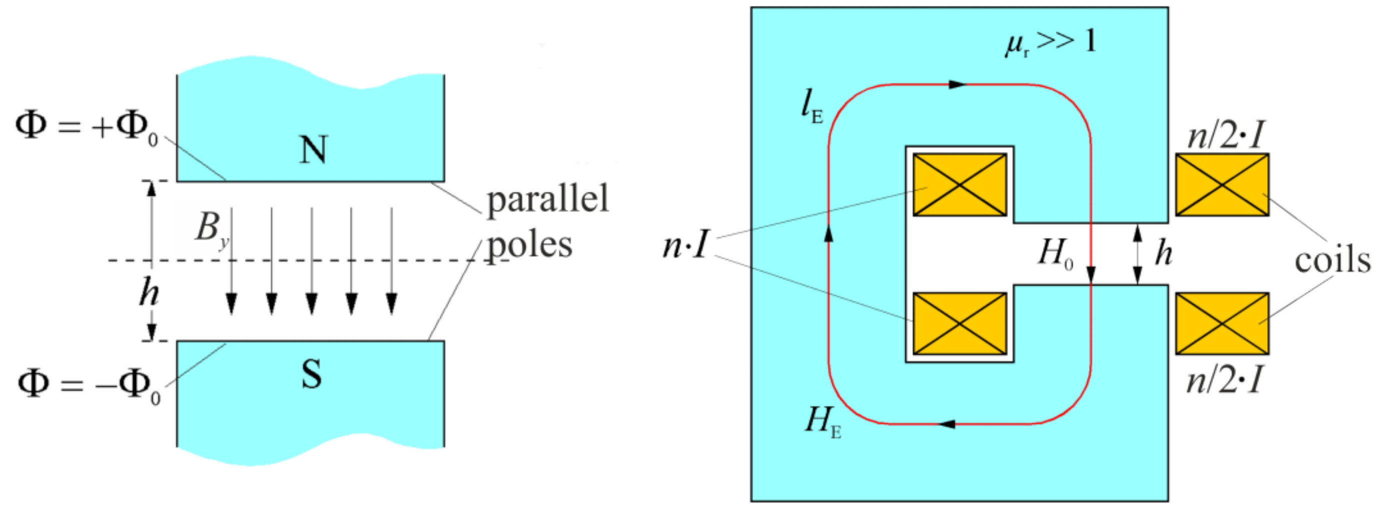
Instruments for providing beams of charged particles – a highly-directed form of energy – to be used as probes and tools

Core Accelerator Technologies



Particle beams behind physics discoveries
Physics Today 73, 4, 32 (2020)





Building blocks:

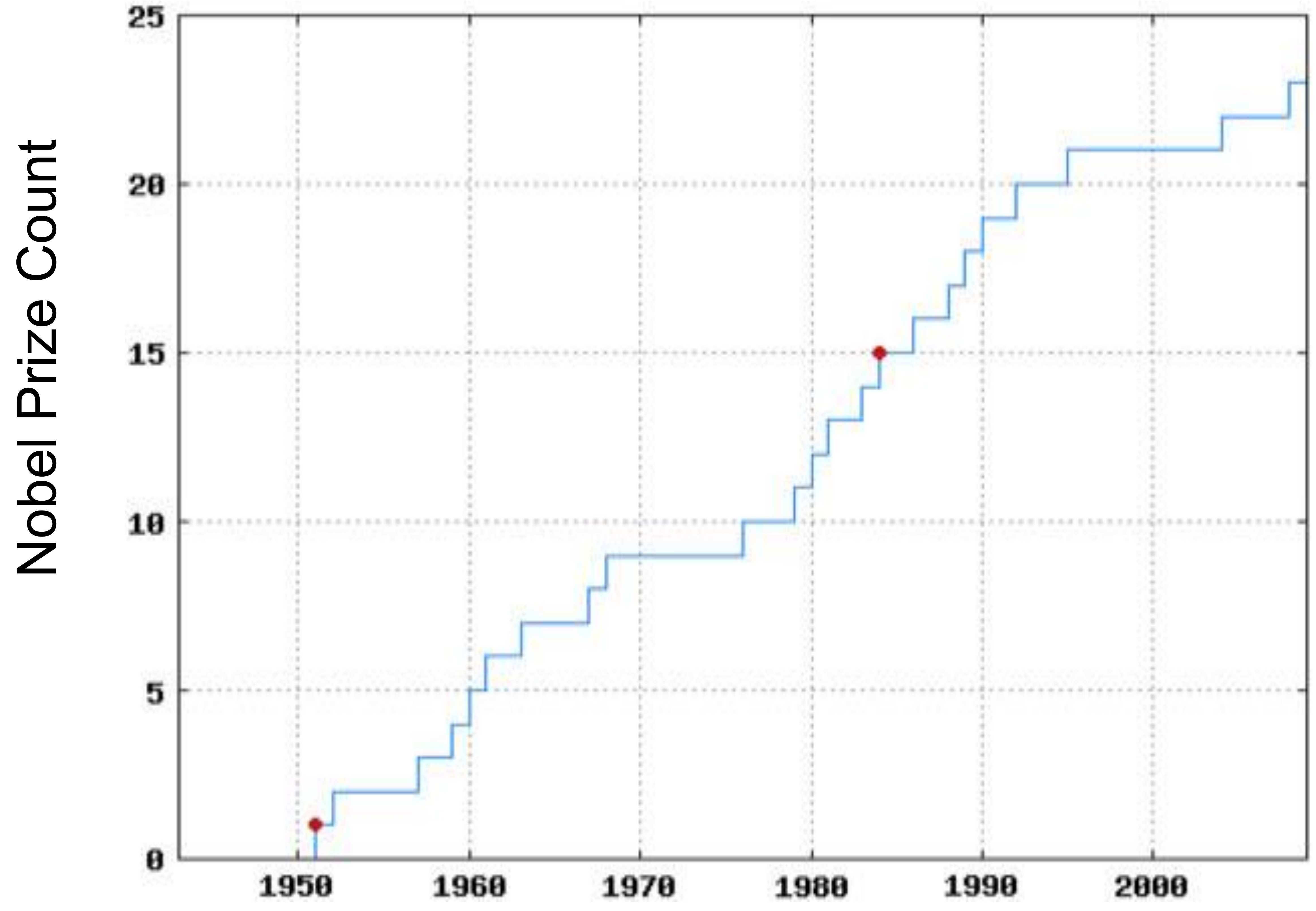
- quadrupole for focusing/defocusing
- dipoles for bending
- and many many more

- 31 colliders built since 1959
- 7 colliders are in operation today (LHC, RHIC, BEPC, Super-KEKB, DAFNE, VEPP-4M, VEPP-2000)
- 2 under construction (EIC and NICA)

A High-Level View on the Influence of Accelerators

- Impact of accelerators on physics can be measured through Nobel Prizes:
  - Criterion: Nobel awardee must have authored document citing accelerator contribution to work
  - Nobel's directly influenced by Accelerators by 2009: 24
  - Average frequency of contribution of accelerators to Nobel in Physics: ~3 years

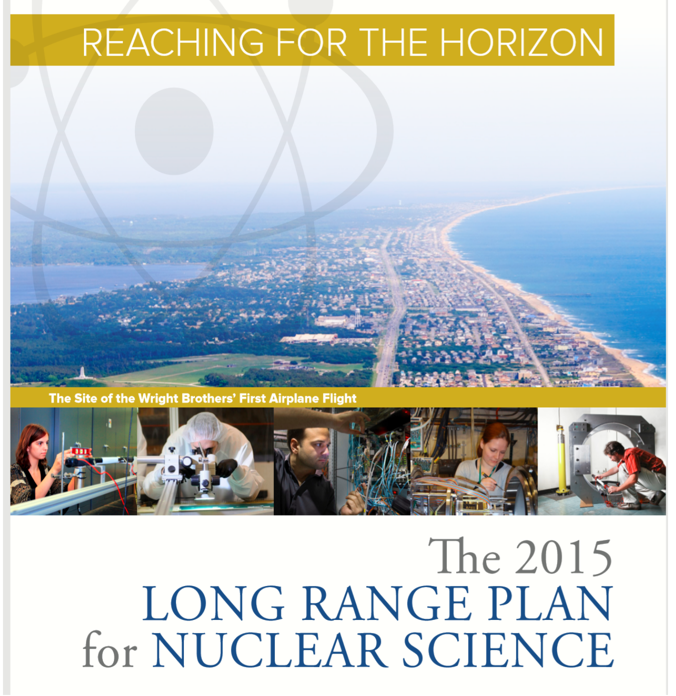
Reproduced from "The Influence of Accelerator Science on Physics Research," Haussecker and Chao

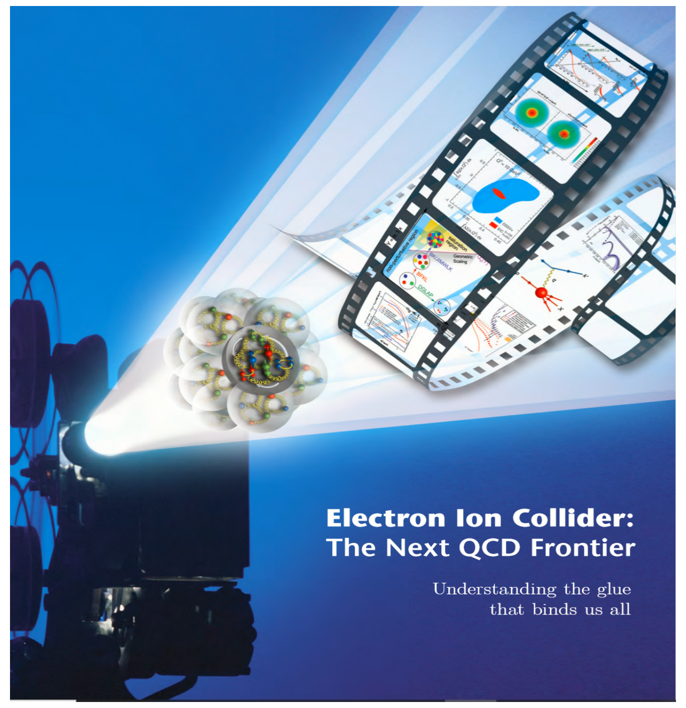


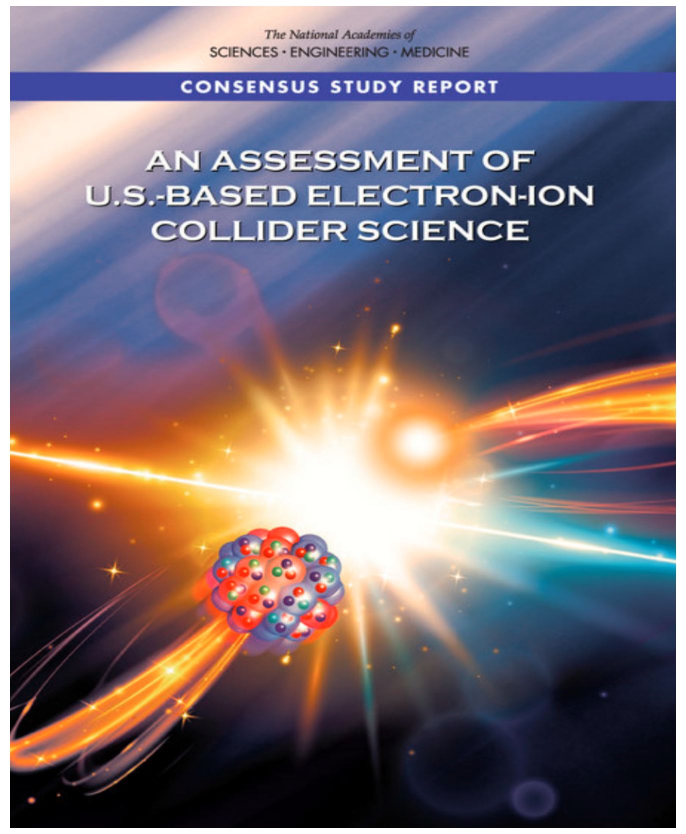
Count for Nobel Prize-winning researches or discoveries in physics from 1943 to 2009. (Haussecker and Chao, Phys Perspect. 13 (2011), p146)

EIC Requirements

- High luminosity: L = 10^{33} to 10^{34} $cm^{-2}sec^{-1}$ - factor 100 to 1000 beyond HERA
- Large range of center-of-mass energies $\sqrt{s}$= 29 to 140 GeV
- Large range of hadron species: protons ….Uranium
- Collisions of electrons with polarized protons and light ions (3He, d,…)
  - Polarized beams with flexible spin pattern





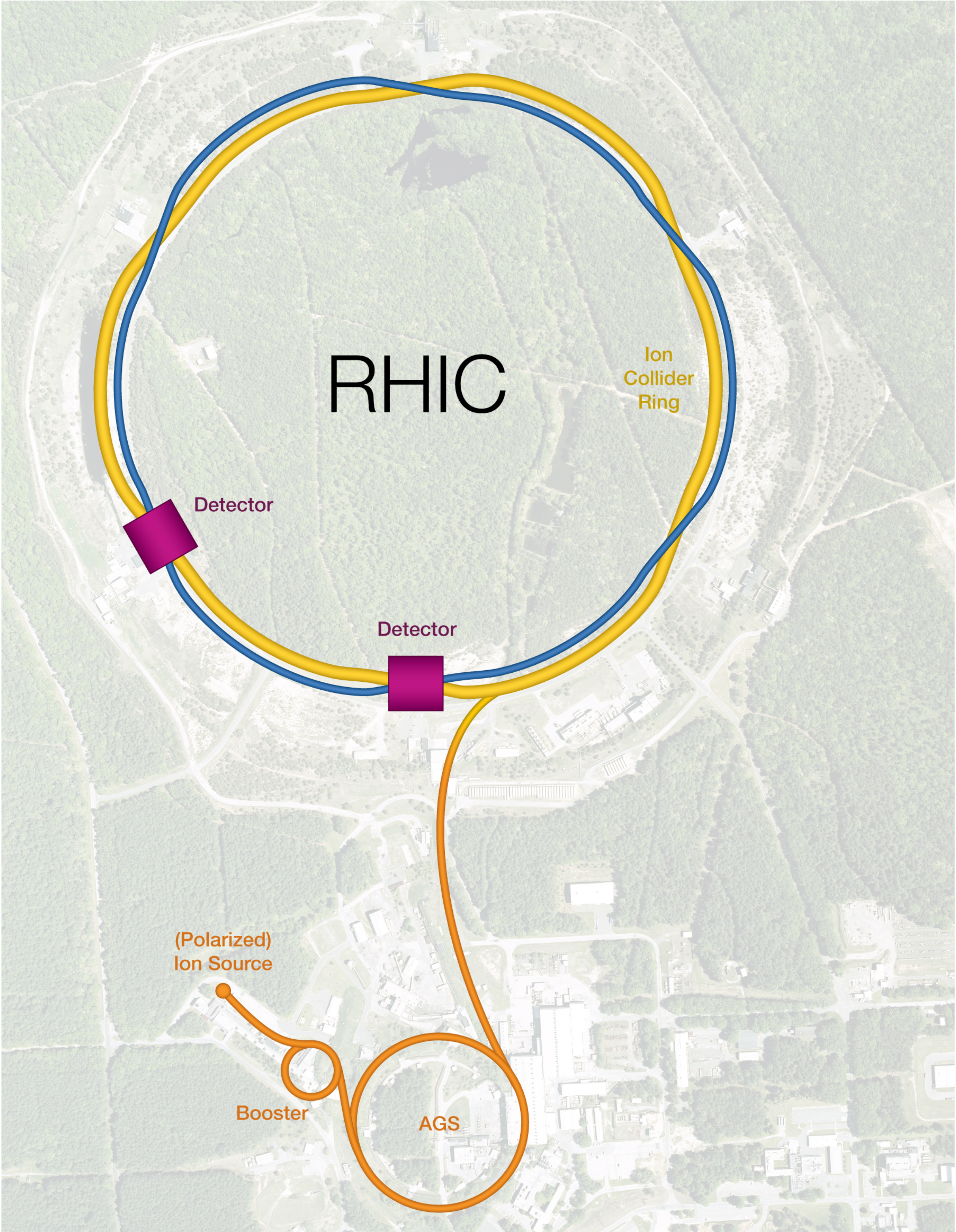


Final EIC design meets or exceeds the requirements formulated in the Long Range Plan and the EIC White Paper endorsed by NAS

Relativistic Heavy Ion Collider (RHIC)

Relativistic Heavy Ion Collider (RHIC)

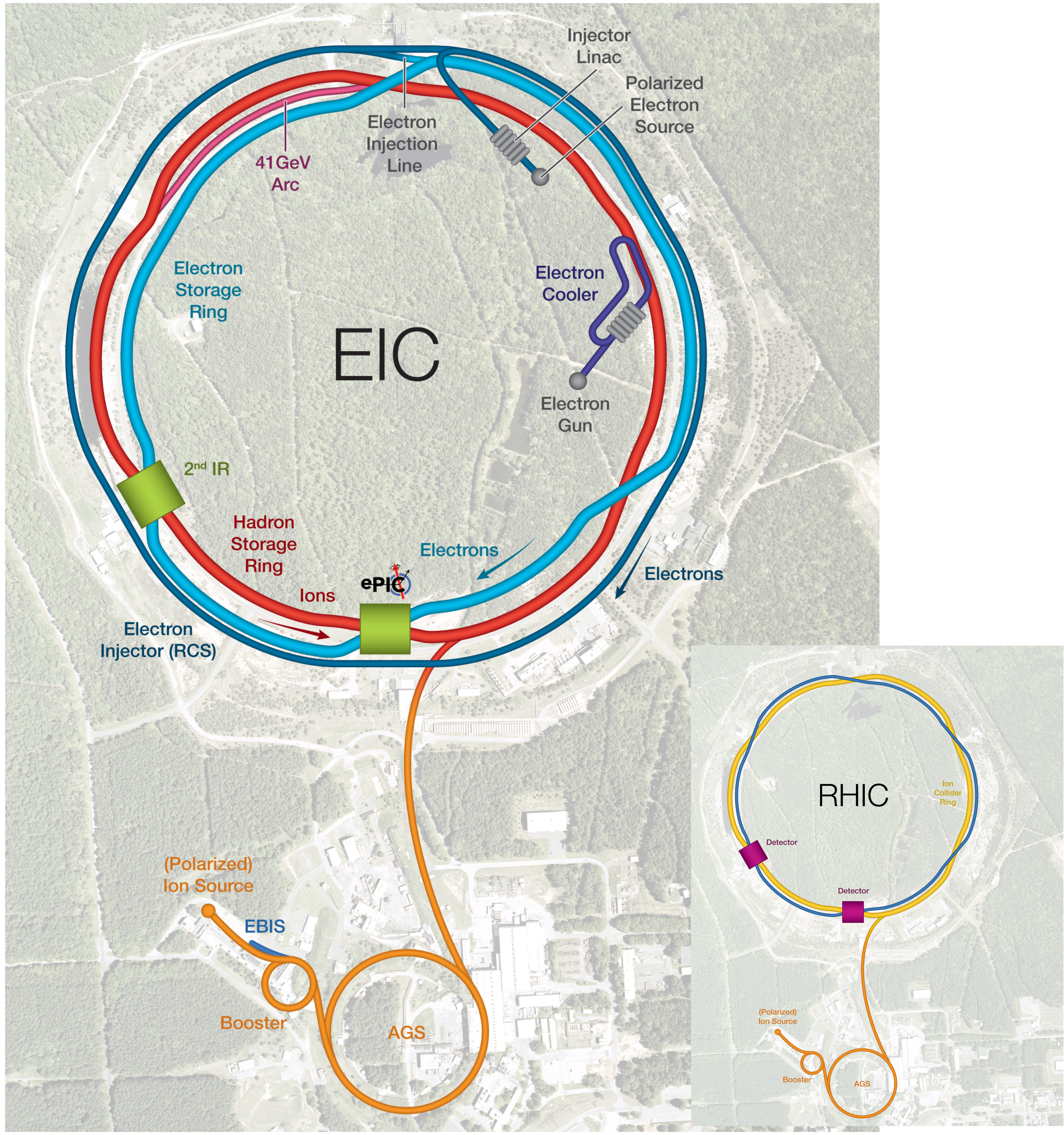
- Two superconducting storage rings 3.8km circumference
- Energy up to 255 GeV protons, or 100 GeV/n gold
- 110 bunches/beam
- Ion species from protons to uranium
- 60% proton polarization – world's only polarized proton collider
- Operating at its peak exceeding design luminosity by factor 44 - unprecedented
- 6 interaction regions, 2 detectors
- In operation since 2001



EIC is based on existing RHIC facility

EIC Design Concept

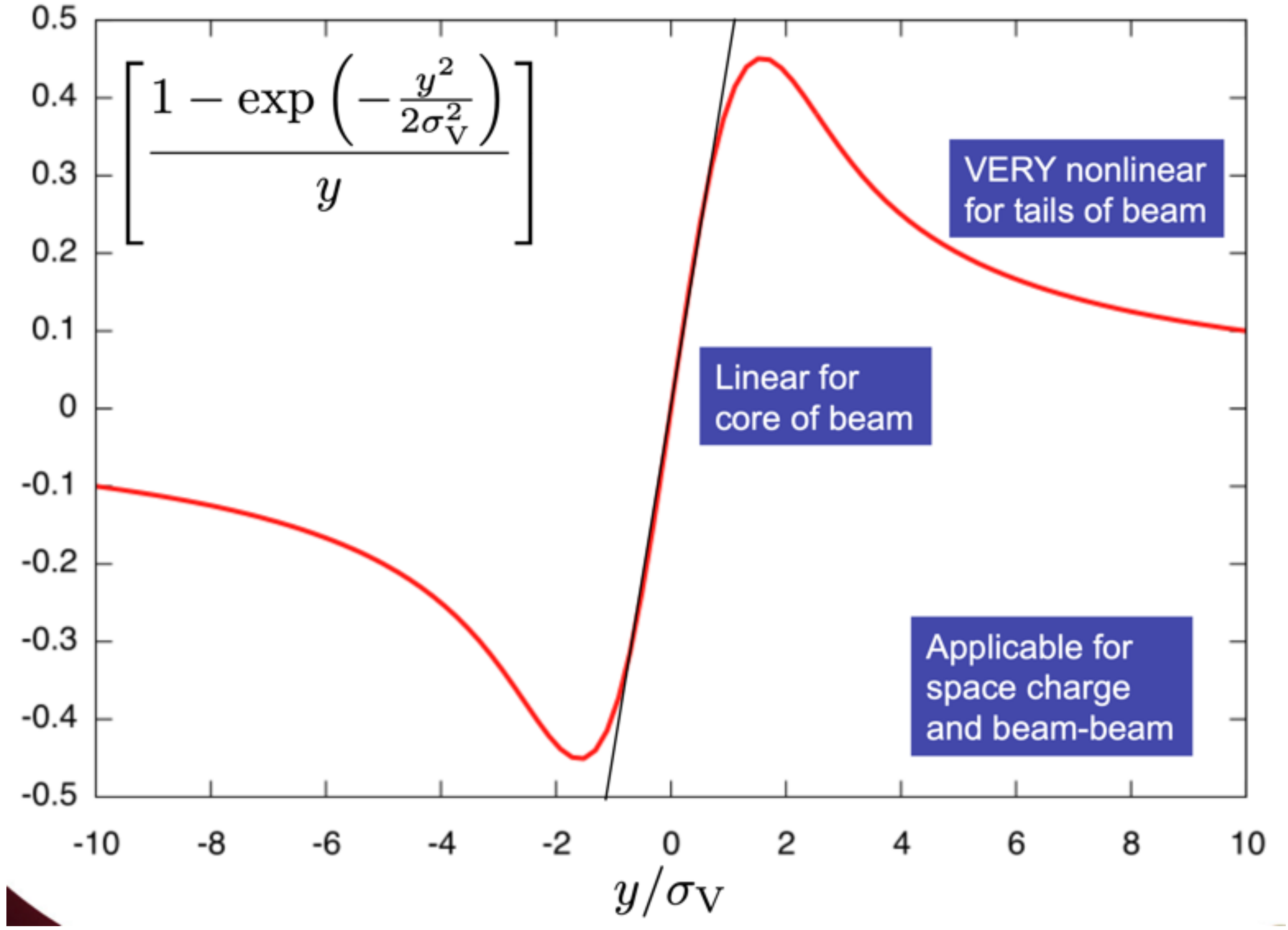
- EIC is based on the RHIC complex
  - Hadron Storage Ring comprised of “Blue” and “Yellow” RHIC arcs ➟ one has to go
  - Retaining RHIC injector chain
  - Hadron Storage Ring (HSR), injectors, ion sources, infrastructure need modifications and upgrades
- Today’s RHIC beam parameters are close to what is required for EIC (except number of bunches, 3 times higher beam current, and vertical emittance)
- Strong Hadron Cooling to maintain beam emittances during stores?
- Add a 5 to18 GeV electron storage ring & its injector complex to the RHIC facility $\rightarrow \sqrt{s}$ = 29-141 GeV
  - Electron complex to be installed in existing RHIC tunnel – cost effective
- Design and built a suitable Interaction Region



Luminosity Limitations: Beam-Beam

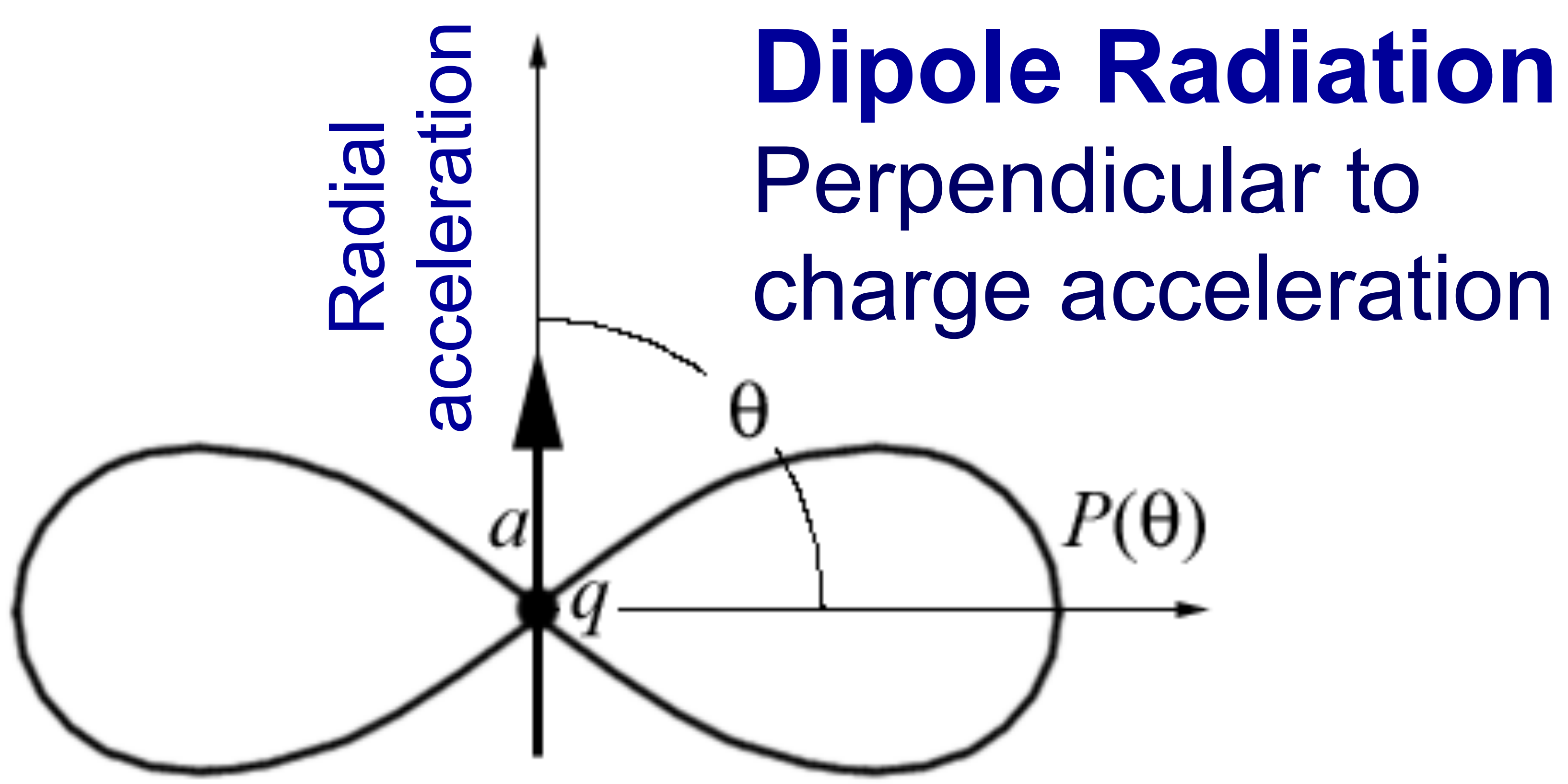
- Colliding beams see each other's collective charge distributions
- Creates nonlinear beam-beam force and equation of motion similar to space charge
- Force is almost linear within ~1σ around beam center
- Highly nonlinear beyond ~1σ
- Vanishes for large amplitudes
  - → Amplitude dependent focusing
  - → Amplitude dependent tune
- Tolerable "beam-beam tune spread" of 0.015 for hadrons, 0.1 for electrons limits highest EIC luminosity

$$F(r) = \frac{Nq^2}{2\pi\epsilon_0 l}\frac{1+\beta^2}{r}\left[1-\exp\left(-\frac{r^2}{2\sigma^2}\right)\right]$$

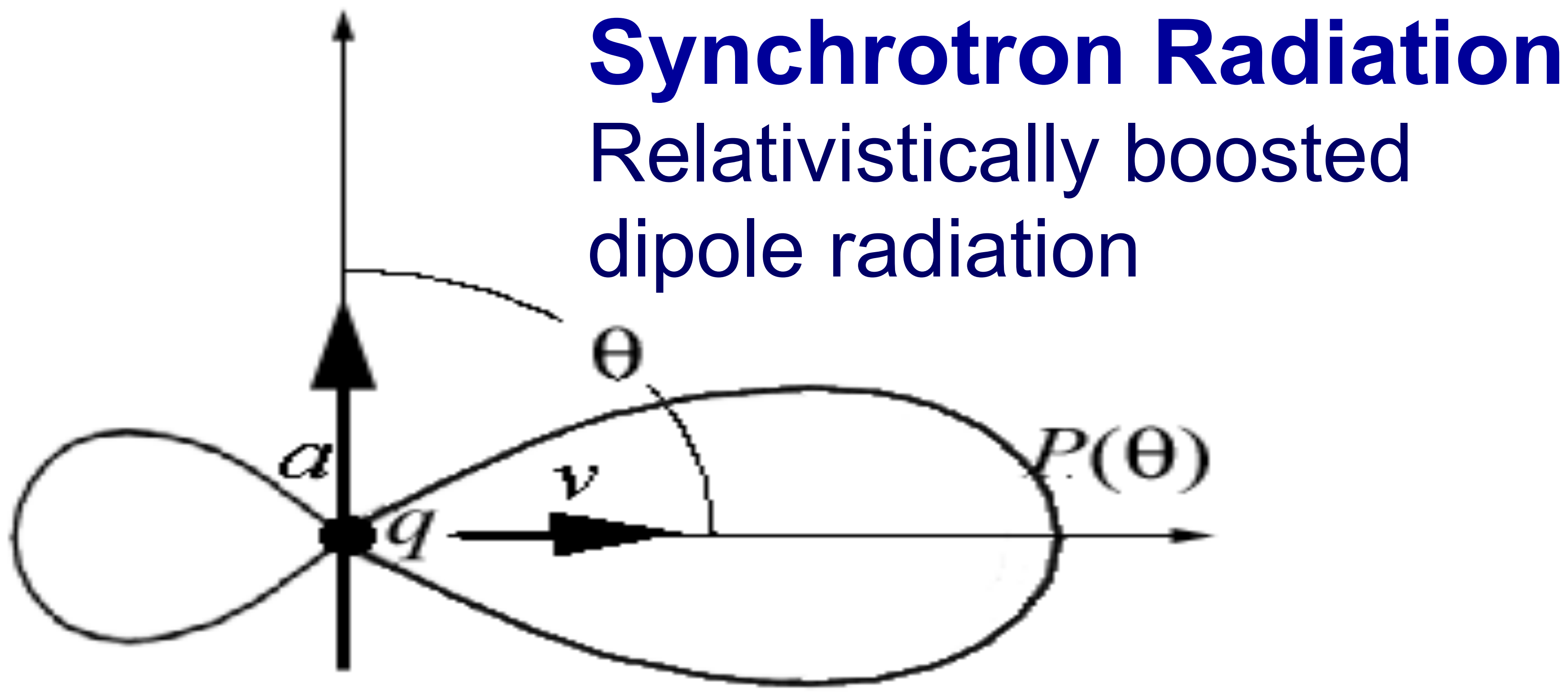


Lumi Limitations: Electron SR Power

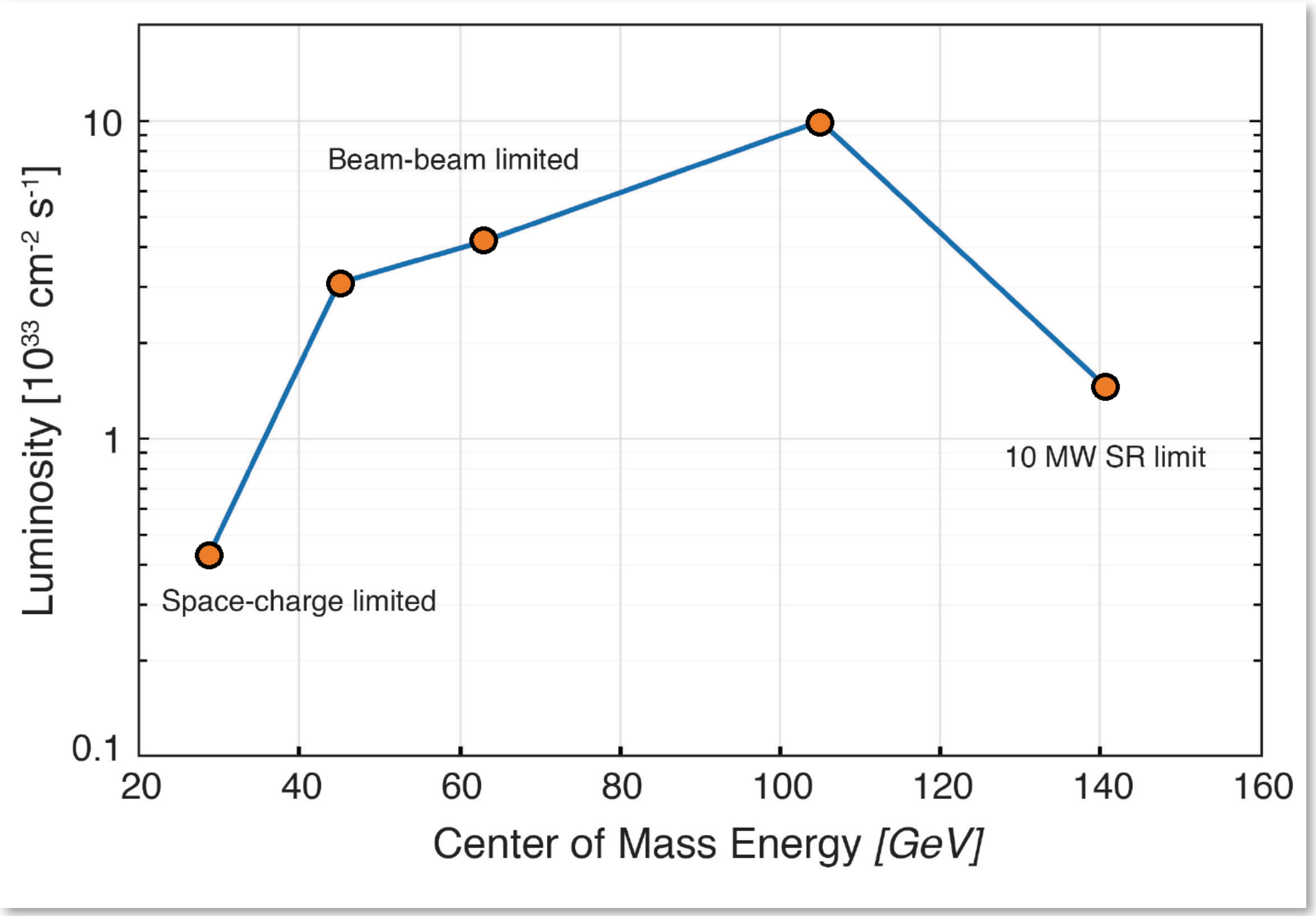
- Accelerated charged particles emit photons
  - Electrons in synchrotron: radially accelerated
  - Synchrotron radiation emitted in forward cone
  - Cone opening angle $\propto 1/\gamma$
  - Radiated power $P_\gamma = \frac{2}{3}\frac{e^2 c}{4\pi\epsilon_0}\frac{(\gamma\beta)^4}{\rho^2}$
  - γ scaling much worse for electrons
    - 18 GeV e: γ=3.5x10^4 vs 255 GeV p: γ =3x10^2
- Design: 9 MW @ 18 GeV (facility limit 10 MW)
- Expensive: Power must be provided by SRF



Relativistic Boost



e+p Luminosity versus Center-of-Mass Energy

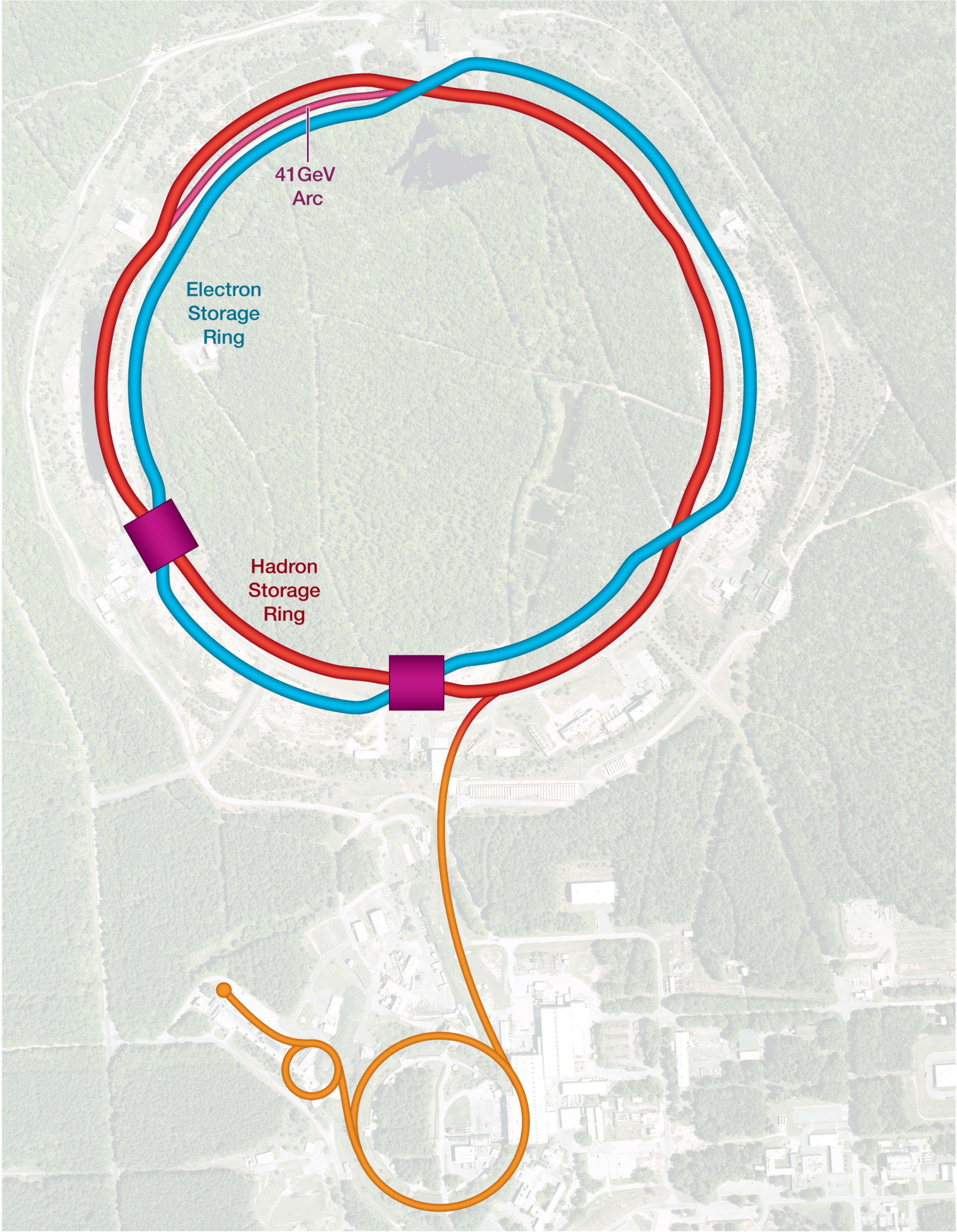


Electron-nucleon luminosities in e-A collisions are similar within a factor of 2 to 3

Recall in pp colliders: $\mathscr{L} \propto \sqrt{s}$

Collision Synchronization

- HSR needs to operate over a wide energy range
- Changing the beam energy in the HSR causes a significant velocity change
- To keep the two beams in collision, they have to be synchronized so bunches arrive at the detector(s) at the same time
- Synchronization accomplished by path length change
- Between 100 and 275 GeV (protons), this can be done by a small radial shift – there is enough room in the beampipe
- For lower energies, use an inner instead of an outer arc as a shortcut. 90 cm path length difference corresponds to 41 GeV proton beam energy



The Full Picture

Table 3.3: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.1	6.2	6.9	17.2	6.9	17.2	4.8	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.69	0.227	1	2.5	1	2.5	0.69	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	5.2/0.47	845/71	3.3/0.3	391/26	3.2/0.29	391/26	2.7/0.25	196/18	1.9/0.45	196/34
RMS emittance, h/v [nm]	18/1.6	24/2.0	11.3/1.0	20/1.3	30/2.7	20/1.3	26/2.3	20/1.8	44/10	20/3.5
β^*, h/v [cm]]	80/7.1	59/5.7	80/7.2	45/5.6	63/5.7	96/12	61/5.5	78/7.1	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/11		95/8.5		138/12		125/11		198/27	
K_x	11.1		11.1		11.1		11.1		7.3	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
BB parameter, h/v [10^{-3}]	3/3	93/100	12/12	72/100	12/12	72/100	14/14	100/100	15/9	53/42
RMS long. emittance [10^{-3}, eV·s]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	0.7	7	0.7	7	0.7	7.5	0.7
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.007	neglig.	0.004	neglig.	0.026	neglig.	0.021	neglig.	0.05	neglig.
Piwinski angle [rad]	6.3	2.1	7.9	2.4	6.3	1.8	7.0	2.0	4.2	1.1
Long. IBS time [h]	2.0		2.9		2.5		3.1		3.8	
Transv. IBS time [h]	2.0		2		2.0/4.0		2.0/4.0		3.4/2.1	
Hourglass factor H	0.91		0.94		0.90		0.88		0.93	
Luminosity [10^{33}cm^{-2}s^{-1}]	1.54		10.00		4.48		3.68		0.44	

Polarized Beams

- Physics program requires bunches with spin “up” and spin “down” (in the arcs) to be stored simultaneously
- Polarized light ion beams are generated at the source
- Sokolov-Ternov self-polarization of electrons would produce only polarization anti-parallel to the main dipole field, $T \propto \gamma^{-5}$
- Only way to achieve required spin patterns is by injecting bunches with desired spin orientation at full collision energy
- Sokolov-Ternov will over time re-orient all spins to be anti-parallel to main dipole field
- Spin diffusion reduces equilibrium polarization
- **Need frequent bunch replacement to overcome Sokolov-Ternov and spin diffusion**

Polarization on the Ramp – Siberian Snakes

- Depolarizing resonances lead to polarization loss on the ramp
- In a nutshell, each particle in the beam samples magnetic fields with varying directions as it travels around the machine, which rotate the spin slightly away from the ideal, vertical direction
- Over many turns, these effects would accumulate, and polarization would be lost
- A “Siberian snake” rotates the spins by 180 degrees, so they point in the opposite direction. Simplest realization is a solenoid magnet.
- As a result, the spin motion during one turn is (largely) reversed on the next turn, thus counteracting depolarizing effects

Caution: This is a severely simplified, hand-waving explanation of the effect of Siberian snakes! In reality, multiple snakes (6 or EIC) are needed to preserve polarization

High Average Electron Polarization

- Frequent injection of bunches with high initial polarization of 85%
- At 18 GeV, every bunch is replaced (on average) after 2.2 min with RCS cycling rate of 1Hz
- Replacement needs to be as “transparent” as possible to not disturb hadron beam

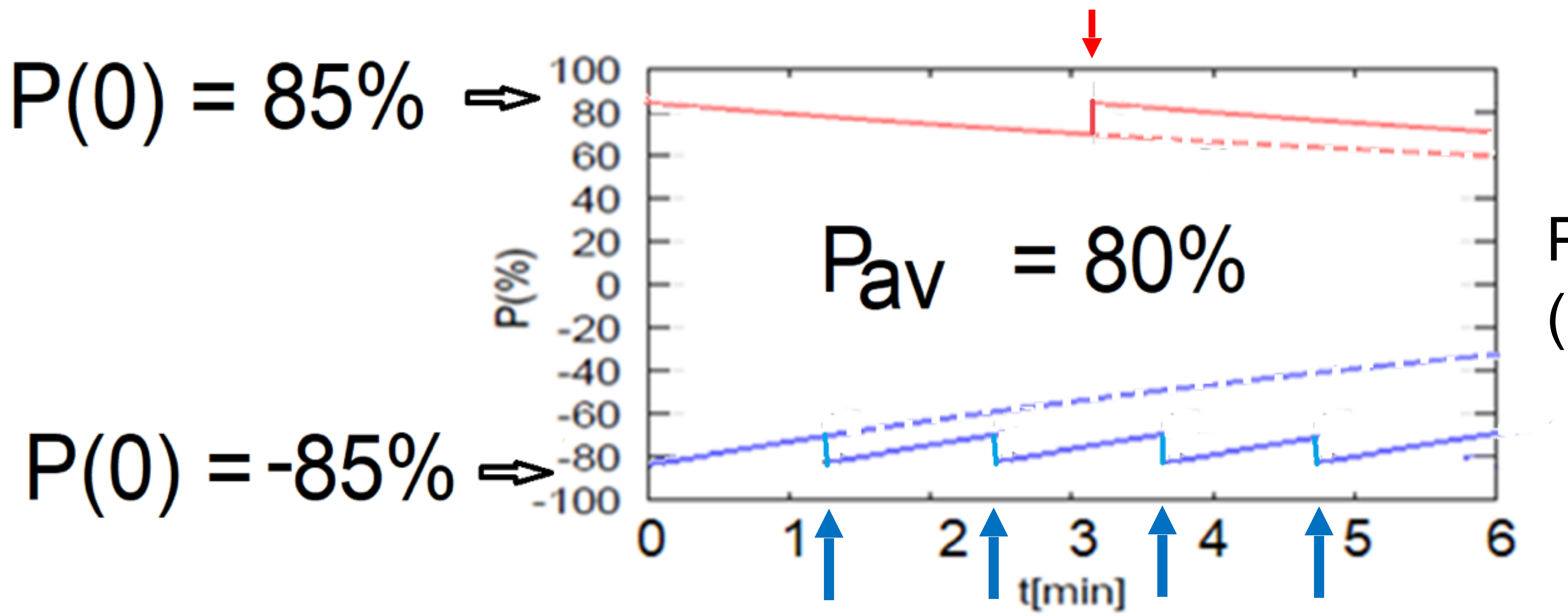
B P

Refilled every 1.2 minutes

B P

Refilled every 3.2 minutes

Re-injection



P_{∞} = 30% (conservative)

Re-injections

Rapid Cycling Synchrotron as Injector

High Average Electron Polarization

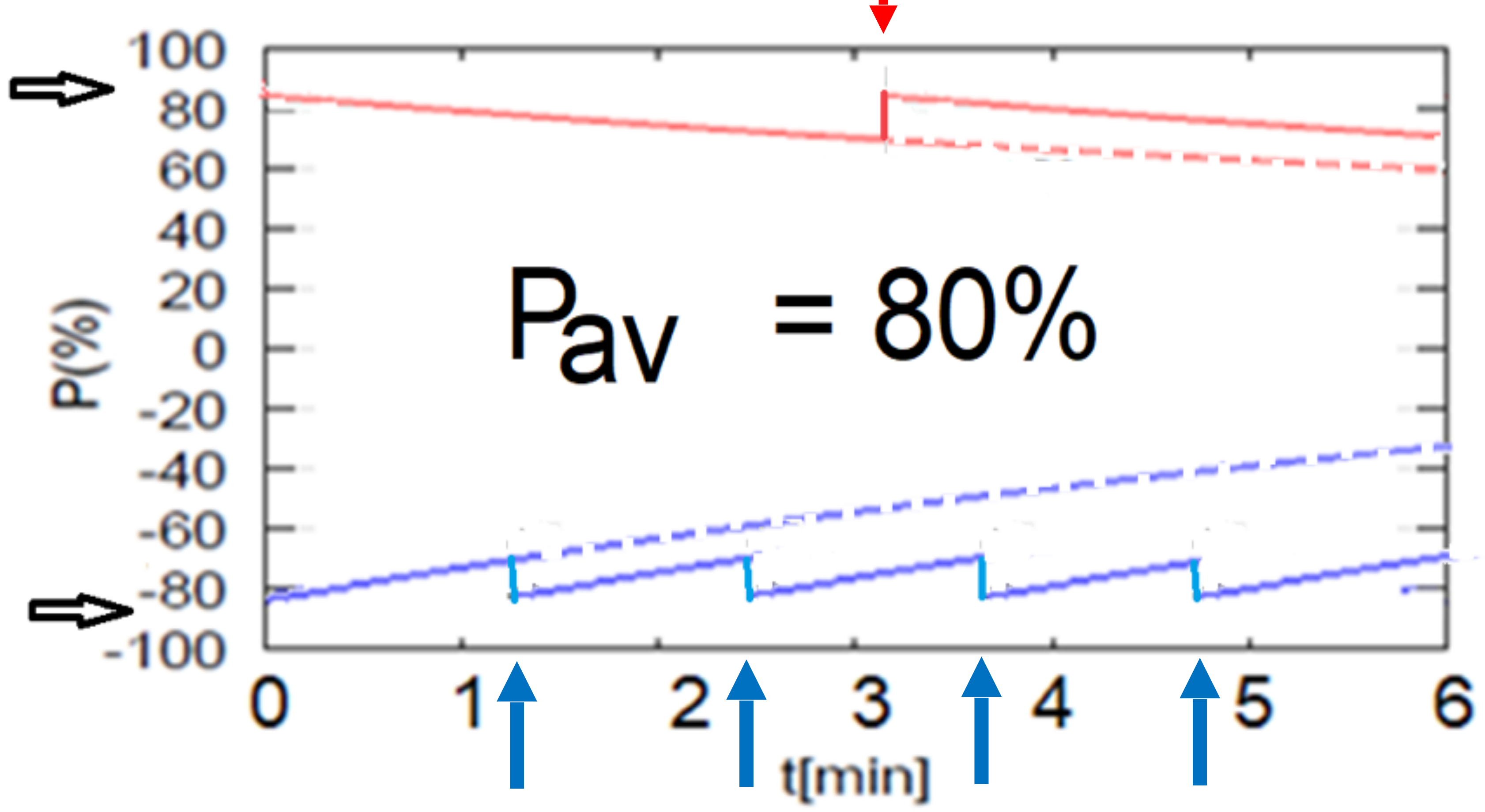
- Frequent injection of bunches with high initial polarization of 85%
- At 18 GeV, every bunch is replaced (on average) after 2.2 min with RCS cycling rate of 1Hz
- Replacement needs to be as “transparent” as possible to not disturb hadron beam

B P Refilled every 1.2 minutes

B P Refilled every 3.2 minutes

Re-injection

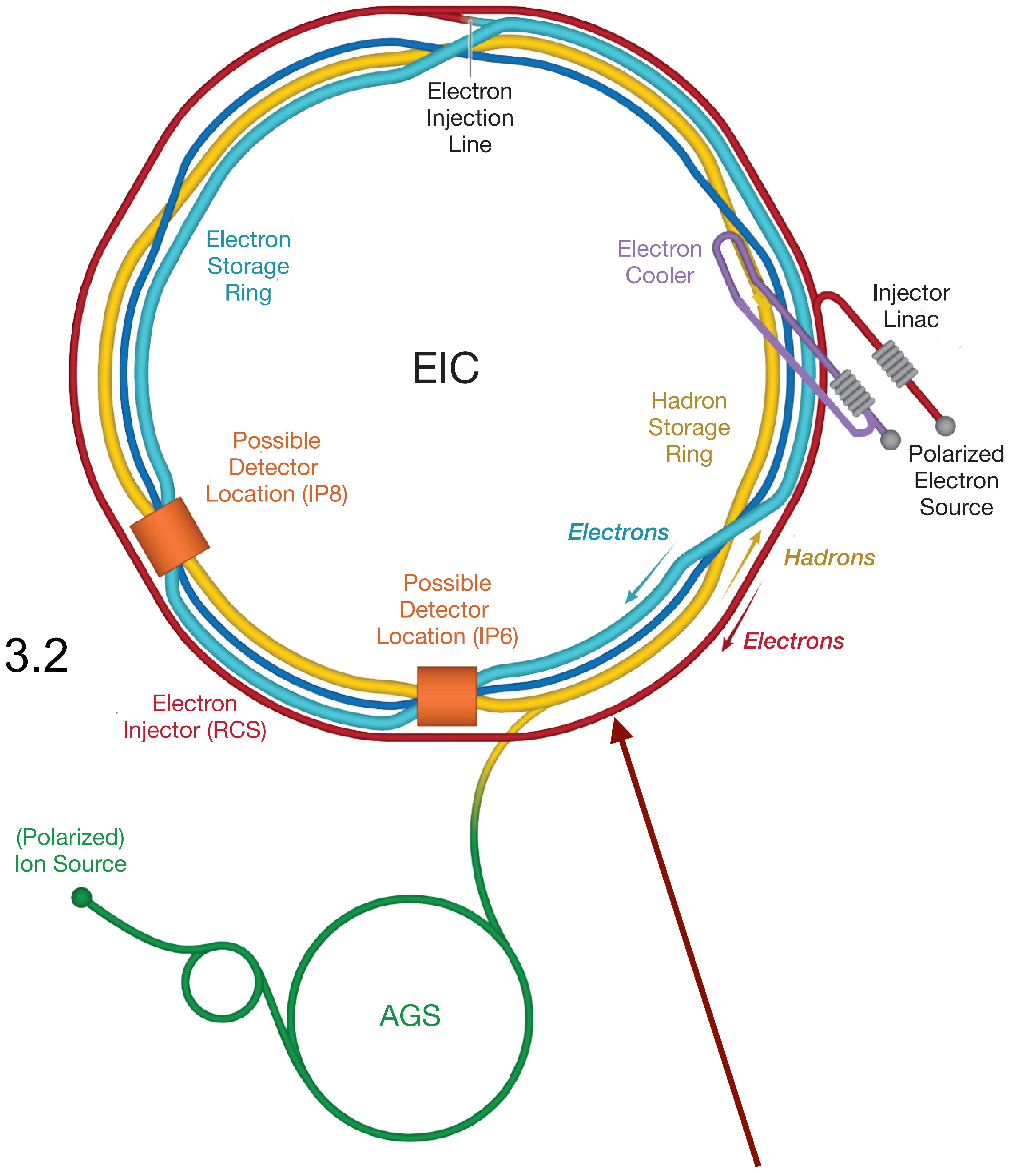
P(0) = 85%



P(0) = -85%

P_{∞}= 30% (conservative)

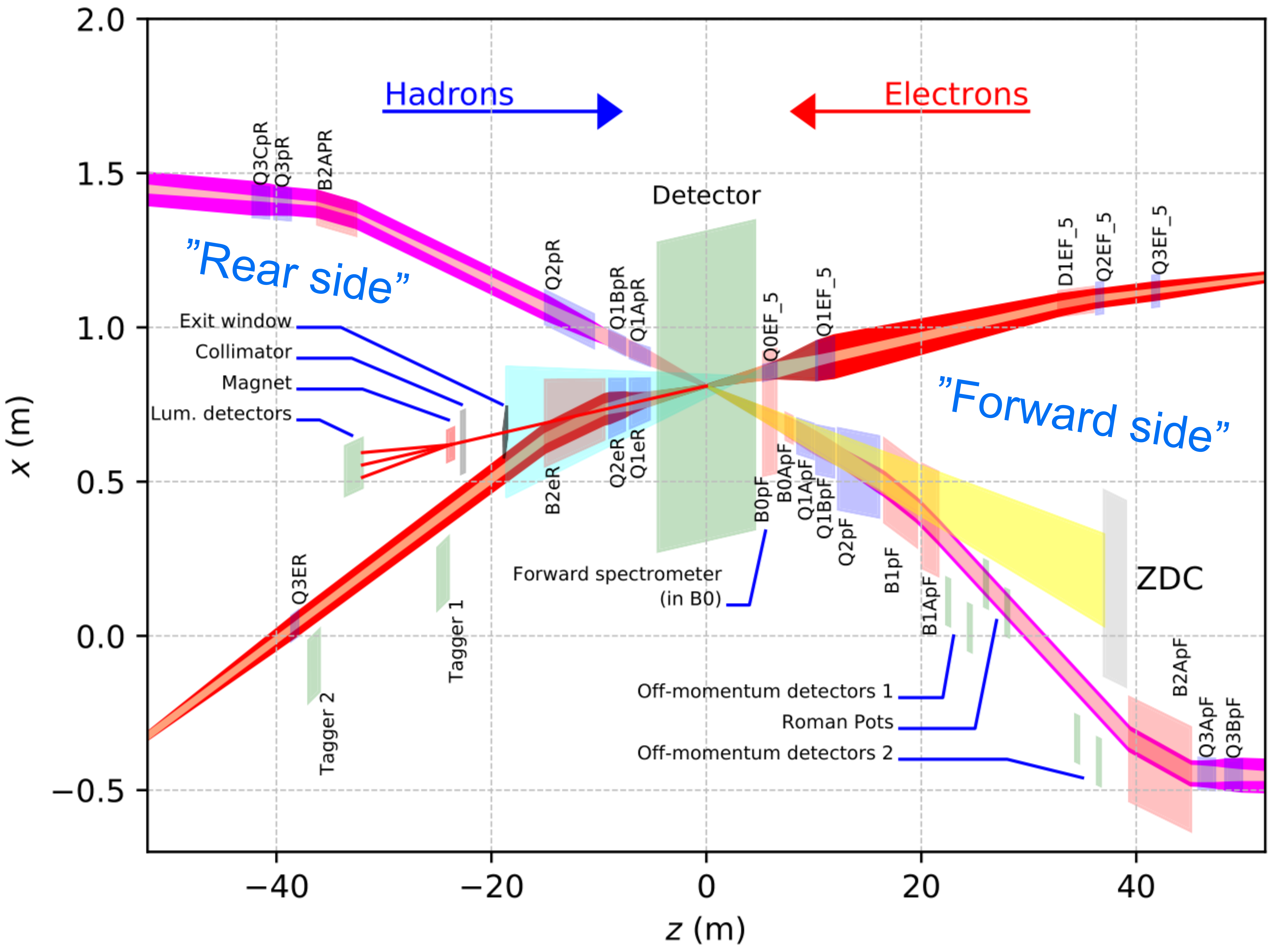
Re-injections



Rapid Cycling Synchrotron as Injector

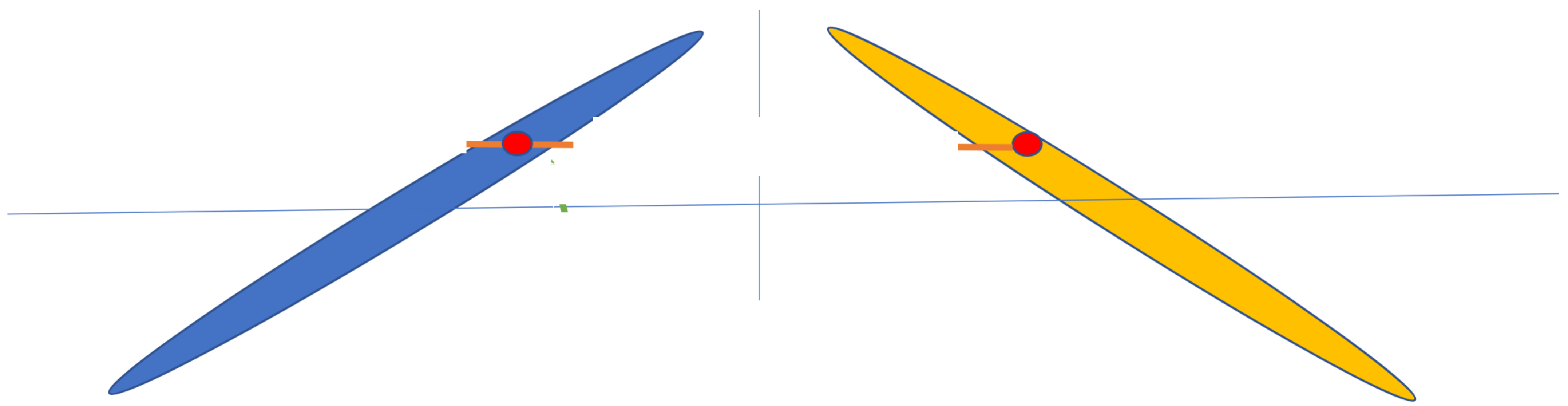
EIC Inner IR Layout

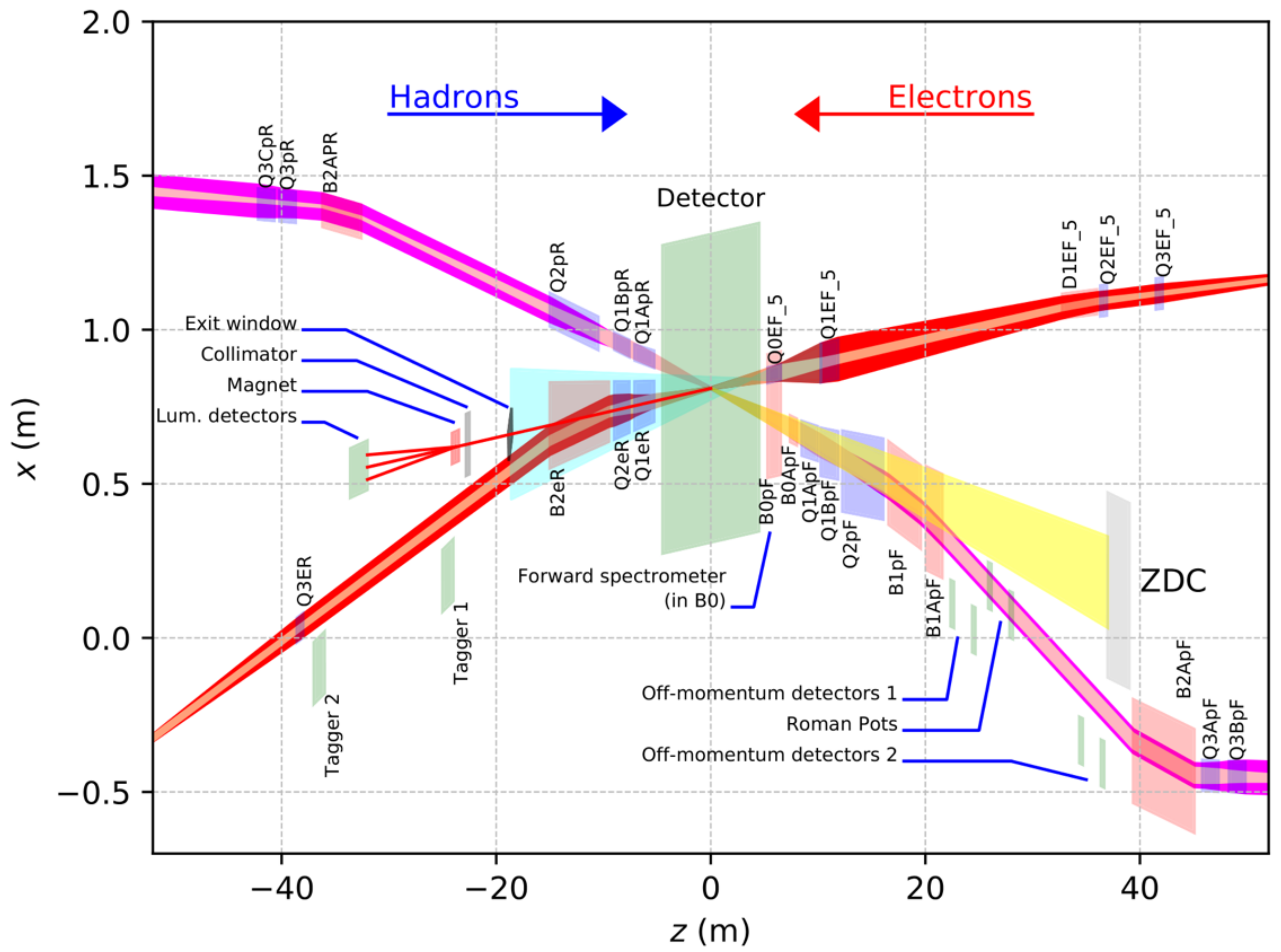
- Synchrotron radiation background
  - No bending upstream for leptons
- Physics requirements:
  - Large detector acceptance for forward-scattered particles, and safe passing of synchrotron radiation fan – even larger magnet apertures
  - Machine element free region: ±4.5m for detector
  - Room for forward & backwards spectrometers/detectors along beam line
- Multi-stage separation:
  - Electrons from protons – 25 mrad crossing angle
  - Protons from neutrons – separator dipole
- High luminosity:
  - Small β* for high luminosity
  - Quads close to IP, high gradients for hadron quads



Beam Seperation

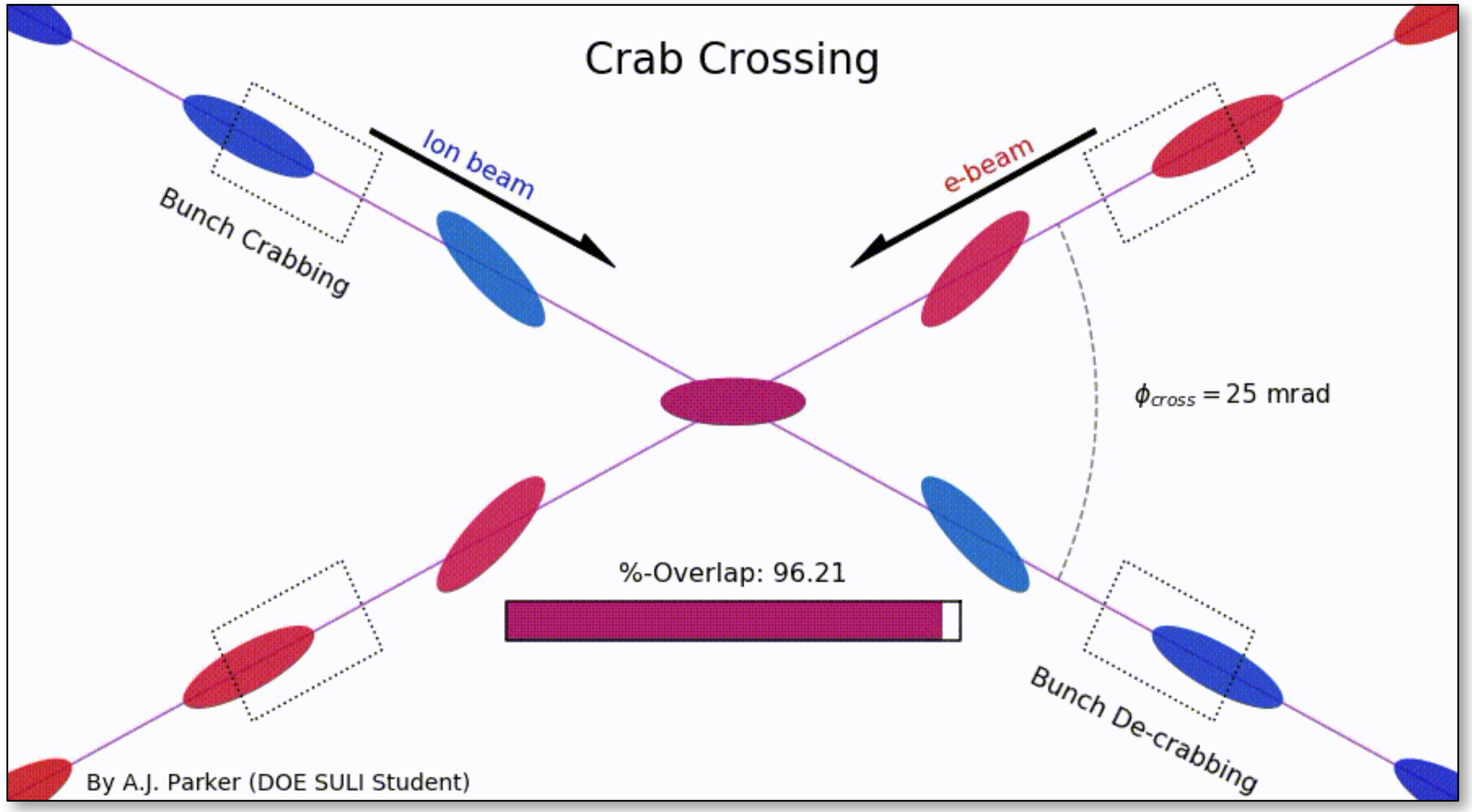
- Electron and hadron beams in EIC have vastly different energies
  - ➟ they need separate focusing channels at the IR
  - ➟ beams need to be separated close to the IP
- Most effective, simple separation is a crossing angle (EIC: 25 mrad total crossing angle)
- However, a crossing angle reduces the overlap between the two beams and therefore the luminosity





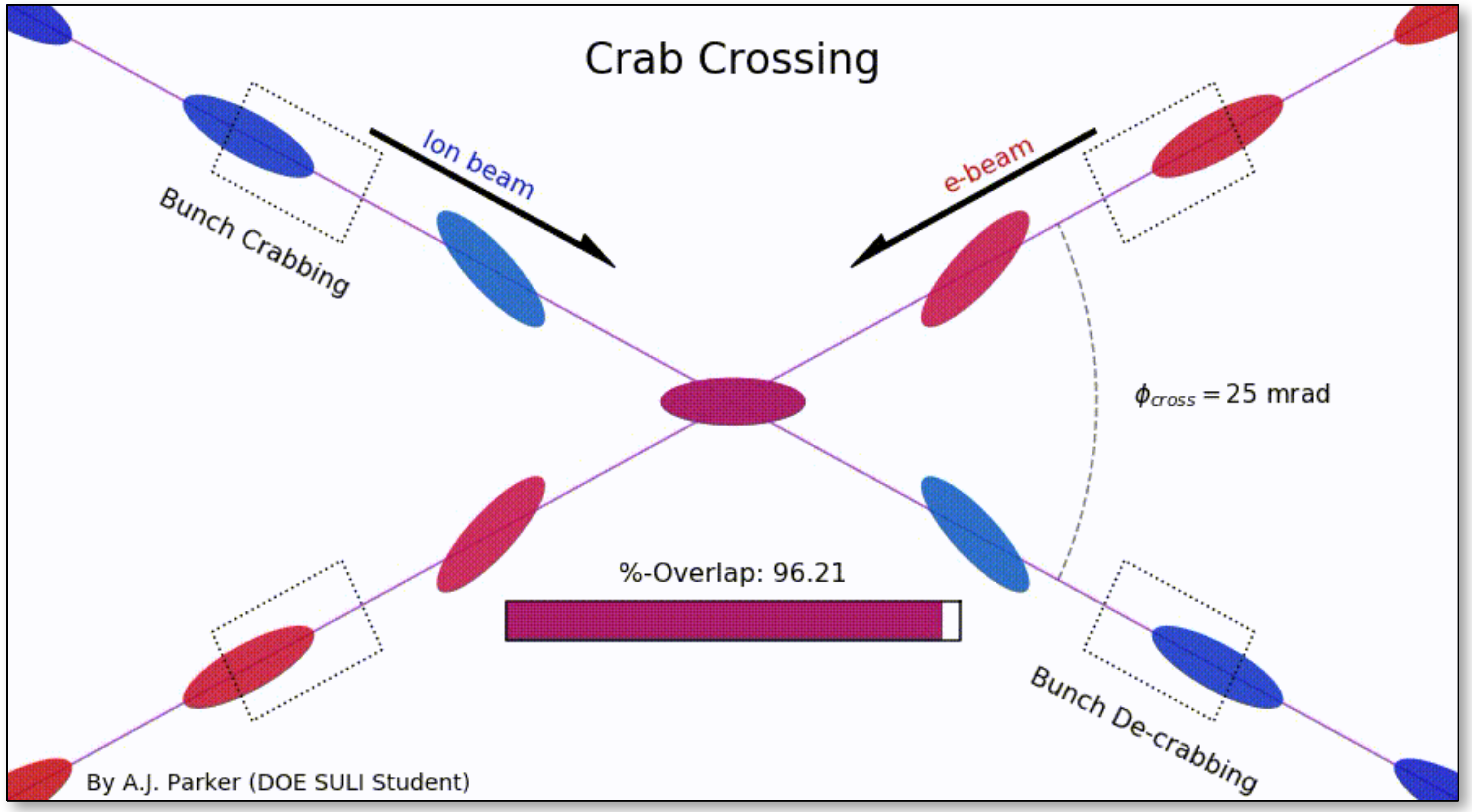
Crab-Crossing

- To restore head-on collisions despite the crossing angle, head and tail of each bunch are kicked in opposite directions when they approach the IP, using “crab cavities”
- As a result, electron and hadron bunches are lined up with each other at the IP, as in a head-on collision scheme
- This kick (or rotation) has to be un-done after leaving the IP
- Note: “crab crossing” does not only restore the luminosity loss caused by the crossing angle, but it is also necessary for stable beam dynamics



Crab-Crossing

- To restore head-on collisions despite the crossing angle, head and tail of each bunch are kicked in opposite directions when they approach the IP, using “crab cavities”
- As a result, electron and hadron bunches are lined up with each other at the IP, as in a head-on collision scheme
- This kick (or rotation) has to be un-done after leaving the IP
- Note: “crab crossing” does not only restore the luminosity loss caused by the crossing angle, but it is also necessary for stable beam dynamics



The EIC: A Unique Collider with Challenges

EIC

- Collide different beam species: ep & eA
- Asymmetric beam energies
  - boosted kinematics
  - high activity at high $|\eta|$
- Additional beam backgrounds
  - hadron beam backgrounds, i.e. beam gas events
  - synchrotron radiation
- Small bunch spacing $\geq$ 9 ns
- Crossing angle: 25 mrad
- Wide range in center of mass energies
  - factor 6
- Both beams are polarized
  - stat uncertainty ~ $1/(P_1 P_2 (\int L\,dt)^{1/2})$

LHC

- Collide same beam species: pp, AA
- Symmetric beam energies
  - kinematics not boosted
  - most activity at mid rapidity
- Beam backgrounds
  - hadron beam backgrounds, i.e. beam gas events
  - high pile-up
- Moderate bunch spacing ~ 25 ns
- No crossing angle (yet)
- Limited range in center of mass energies
  - LHC factor 2
- No beam polarization
  - stat uncertainty ~ $1/(\int L\,dt)^{1/2}$

The EIC: A Unique Collider with Challenges

EIC

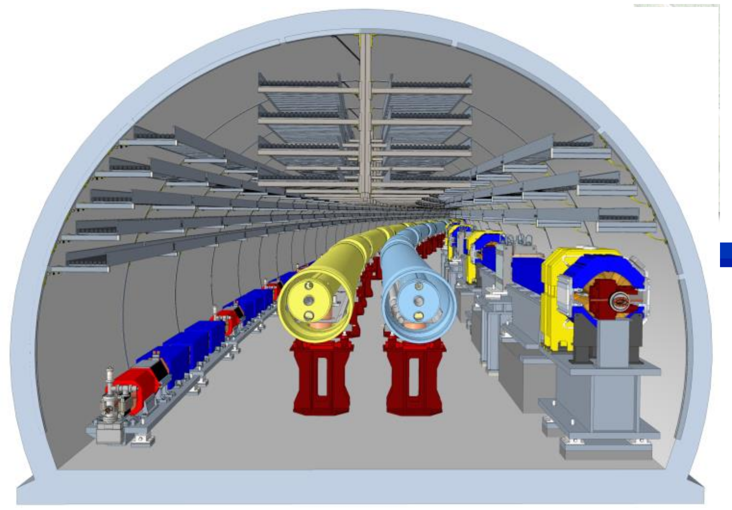
- Collide different beam species: ep & eA
- Asymmetric beam energies
  - boosted kinematics
  - high activity at high |η|
- Additional bear
  - hadron beam
    events
  - synchrotron radiation
- Small bunch spacing $\geq$ 9 ns
- Crossing angle: 25 mrad
- Wide range in center of mass energies
  - factor 6
- Both beams are polarized
  - stat uncertainty ~ $1/(P_1 P_2 (\int L\, dt)^{1/2})$

LHC

- Collide same beam species: pp, AA
- Symmetric beam energies
  - kinematics not boosted
  - most activity at mid rapidity
  - nds, i.e. beam gas
  - high pile-up
- Moderate bunch spacing ~ 25 ns
- No crossing angle (yet)
- Limited range in center of mass energies
  - LHC factor 2
- No beam polarization
  - stat uncertainty ~ $1/(\int L\, dt)^{1/2}$

Differences impact detector acceptance and possible detector technologies

Take Away Message



EIC design will meet requirements

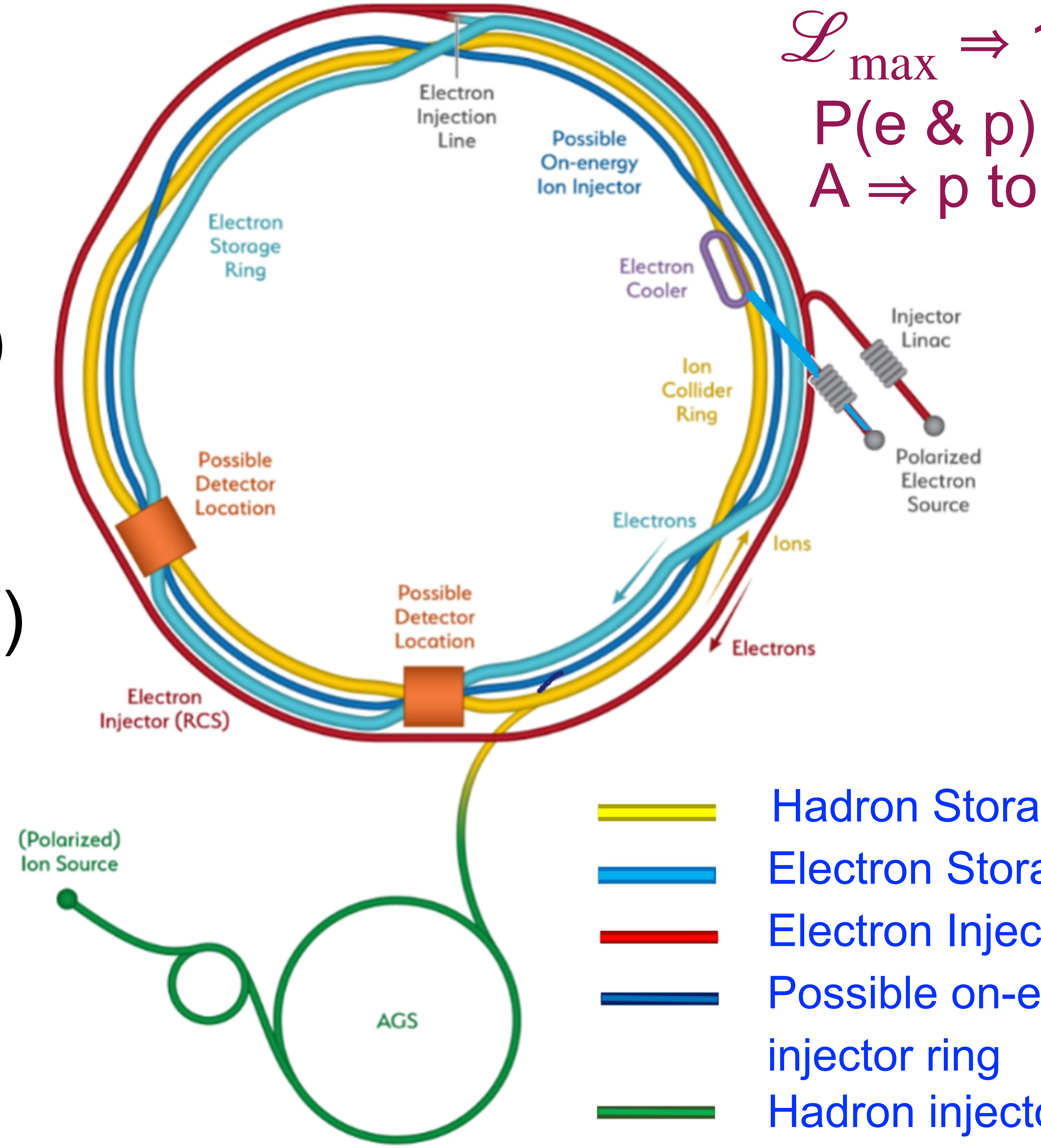
$\sqrt{s}$ = 20 – 141 GeV

$\mathscr{L}_{max} \Rightarrow 10^{34}\ cm^{-2}\ s^{-1}$

P(e & p) ⇒ 80%

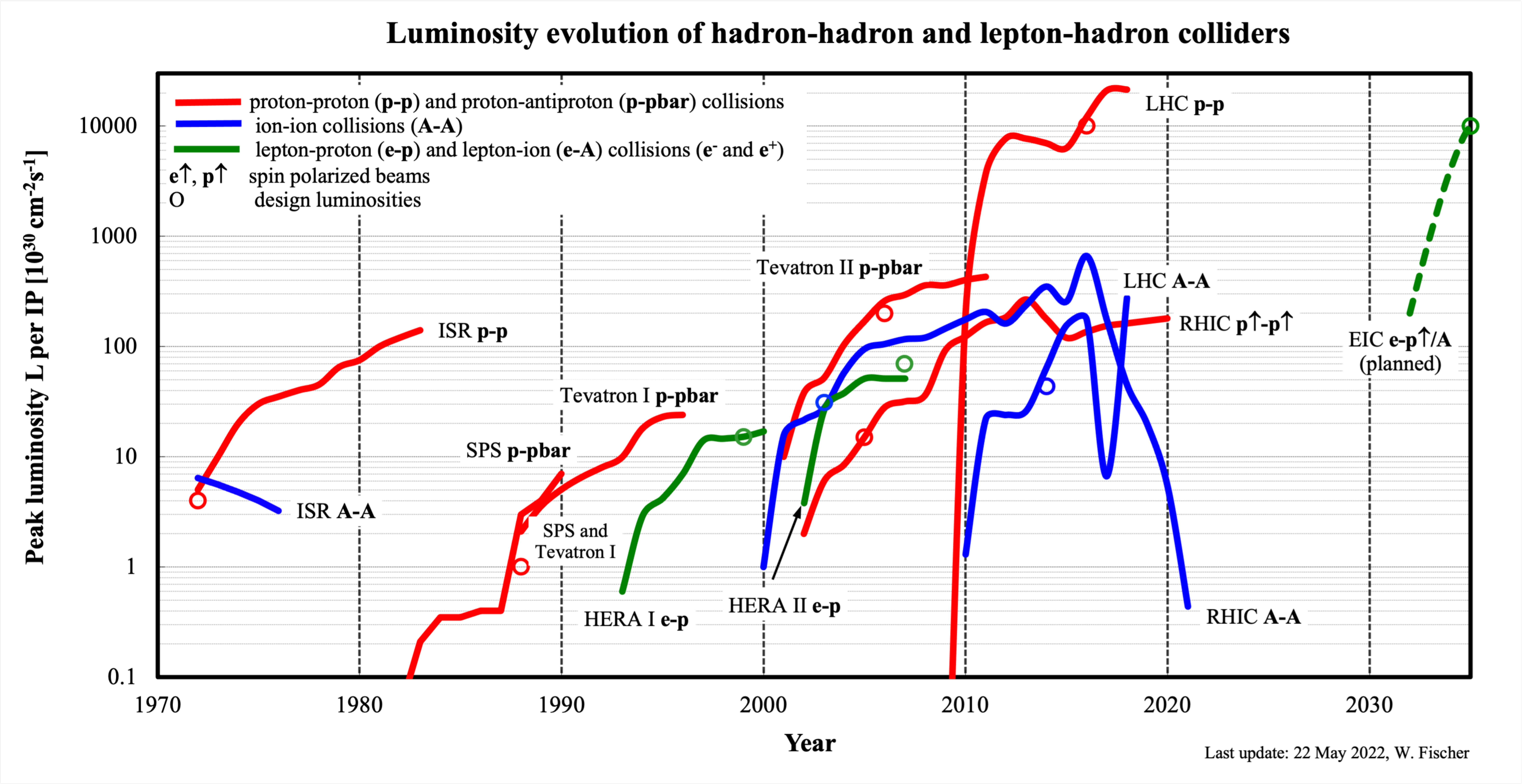
A ⇒ p to Uranium

- Design using much of existing RHIC facility
- 3 accelerator rings:
  - Existing RHIC yellow ring (275 GeV)
  - New Rapid Cycling Electron Synchrotron (18 GeV)
  - New Electron Storage Ring (18 GeV)
- 2 Injector complexes:
  - Hadron injectors (existing)
  - Electron Injectors
- 2 detector halls
- Hadron Cooling Facility



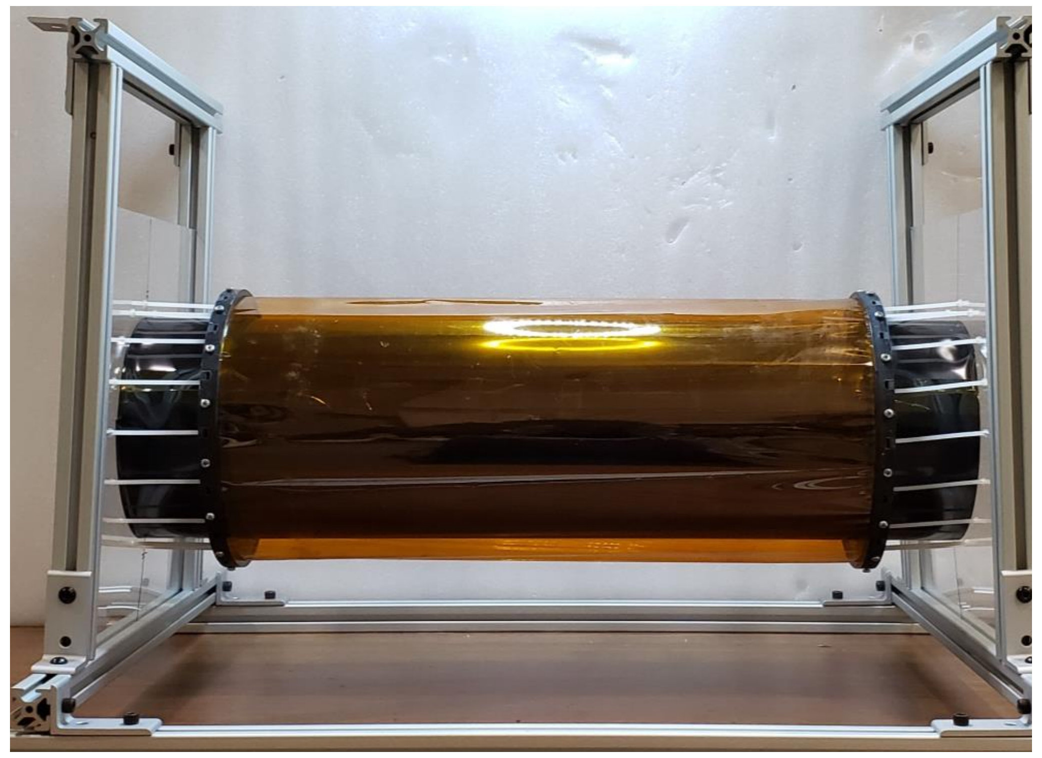
Hadron Storage Ring
Electron Storage Ring
Electron Injector Synchrotron
Possible on-energy Hadron injector ring
Hadron injector complex

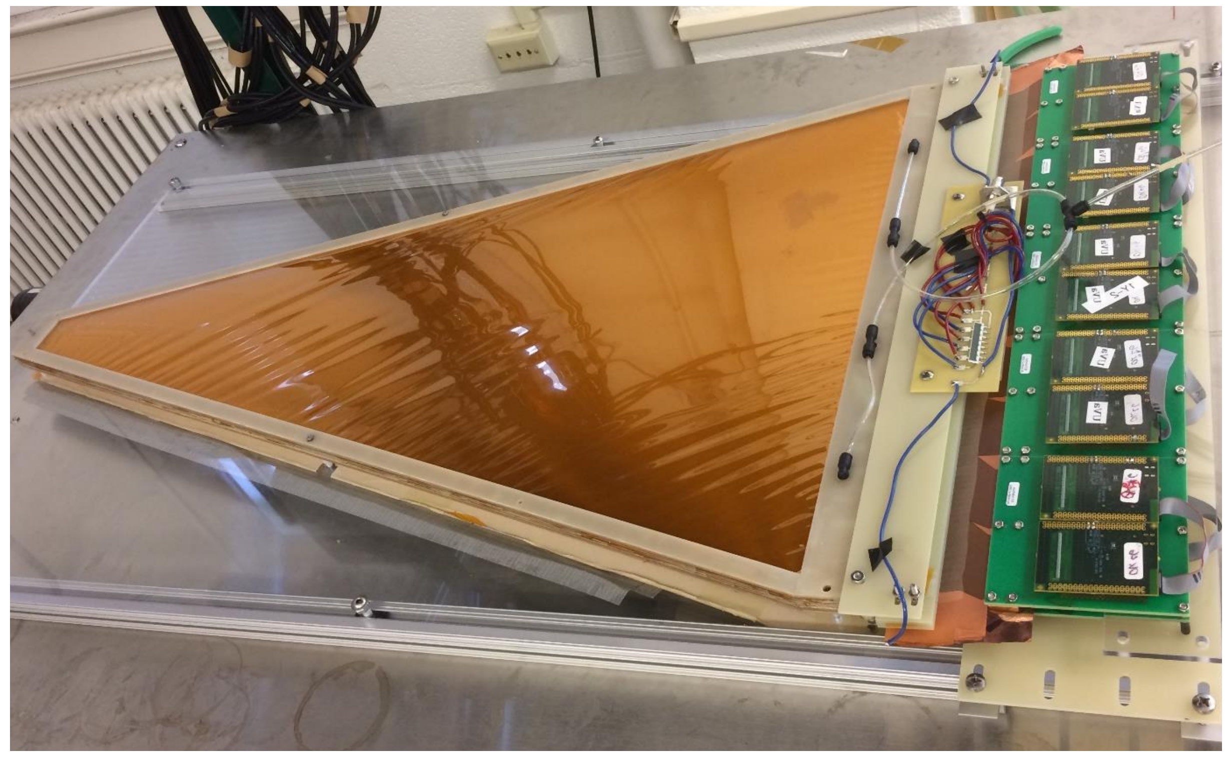
Performance Evolution?!

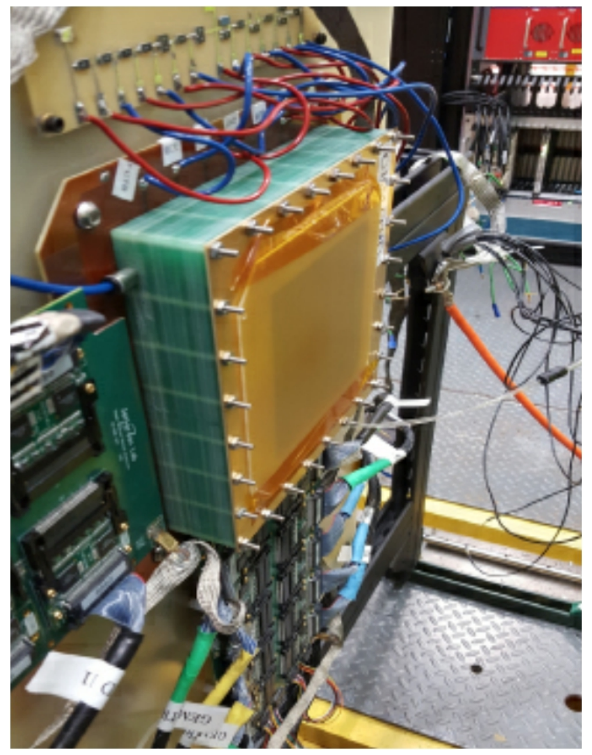


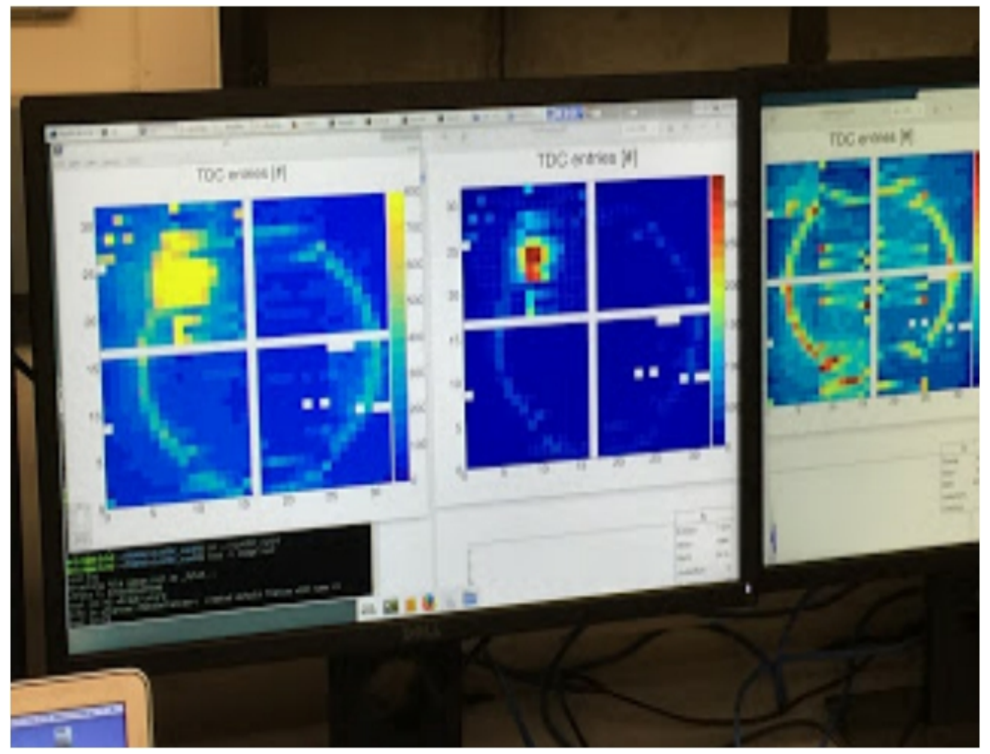
9. Realization of an EIC: the Detector

9.1. The Basics - Detector Technologies









A perfect detector would be able to …

- Detect charged particles
  - charged leptons, charged hadrons, …
- Detect neutral particles
  - photons, neutral hadrons, neutrinos
- Perform particle identification
- Precisely measure the energy and/or the momentum of each particle
  - allow to construct 4-vectors for all particles produced in an interaction
- Do so even at very high interaction rates …
- … and withstands high radiation doses without any damage to itself

A perfect detector would be able to …

- Detect charged particles
  - charged leptons, charged hadrons, …
- Detect neutral particles
  - photons, neutral hadrons, neutrinos
- Perform particle identification
- Precisely measure the energy and/or the momentum of each particle
  - allow to construct 4-vectors for all particles produced in an interaction
- Do so even at very high interaction rates …
- … and withstands high radiation doses without any damage to itself

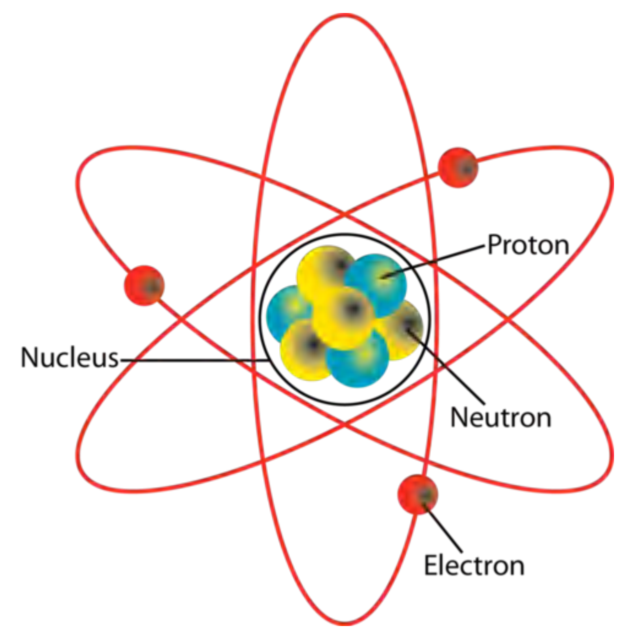
Sadly there is no such thing as a perfect detector
Building a detector means compromising (and doing more R&D)

Detectors are made out of matter …

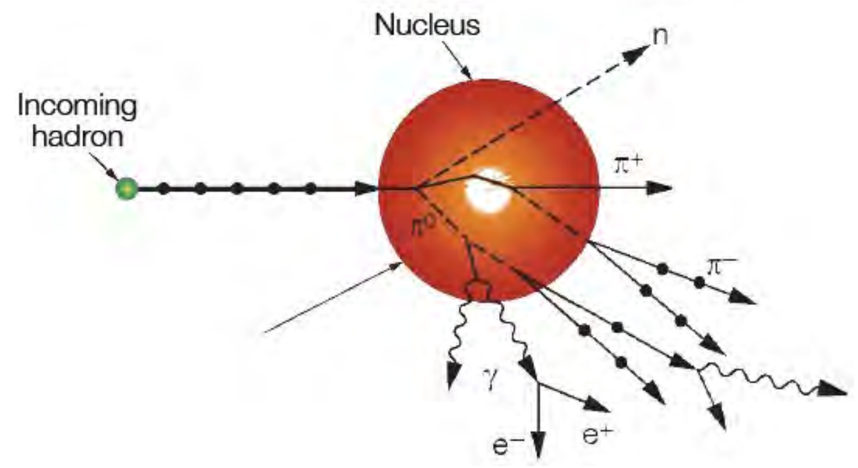
Any device that is to detect a particle must interact with it in some way

Interaction of particles with matter

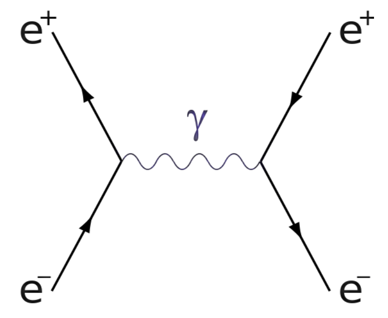
- Matter : Atoms = Electrons + Nuclei
- Interactions depend on particle type
- Energy loss strongly dependent on energy



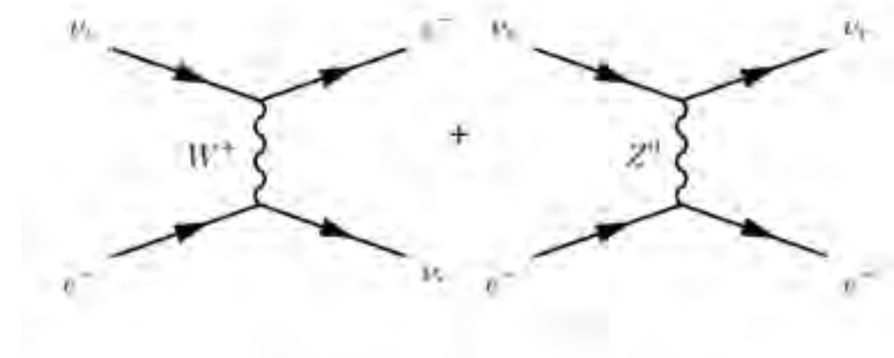
Strong interaction of hadrons with nuclei



Electromagnetic interaction of charged particles and photons with electrons and nuclei

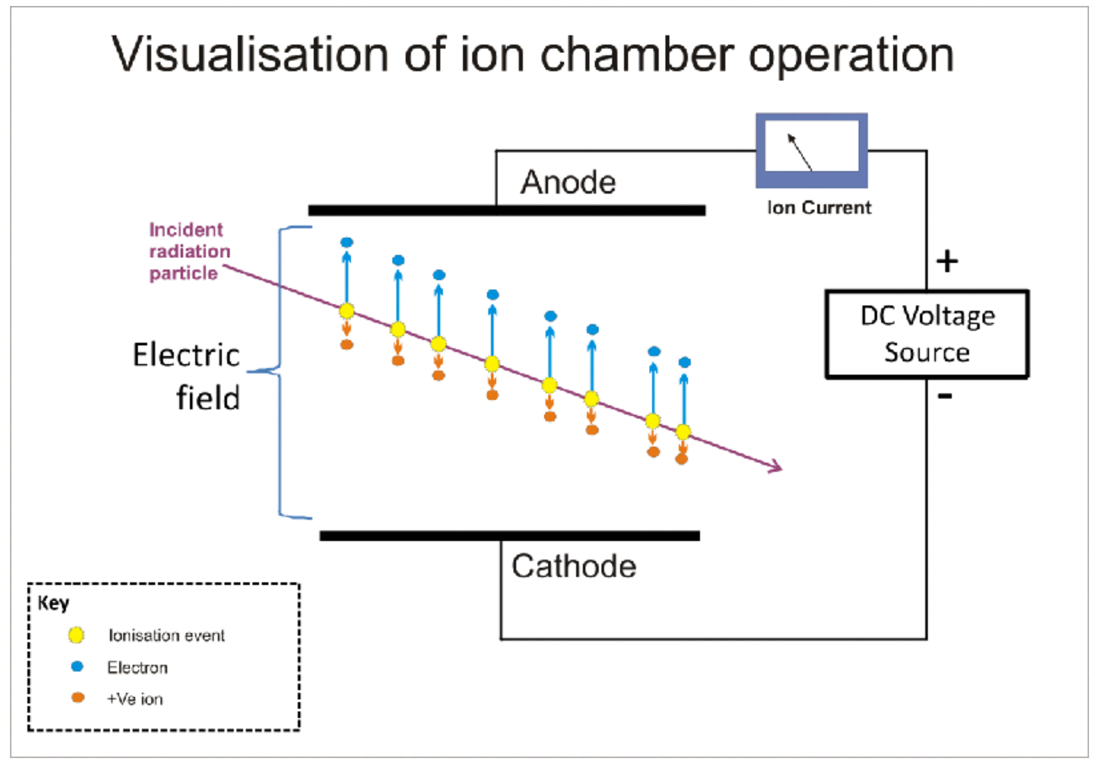


Weak interaction of neutrinos with electrons and nuclei

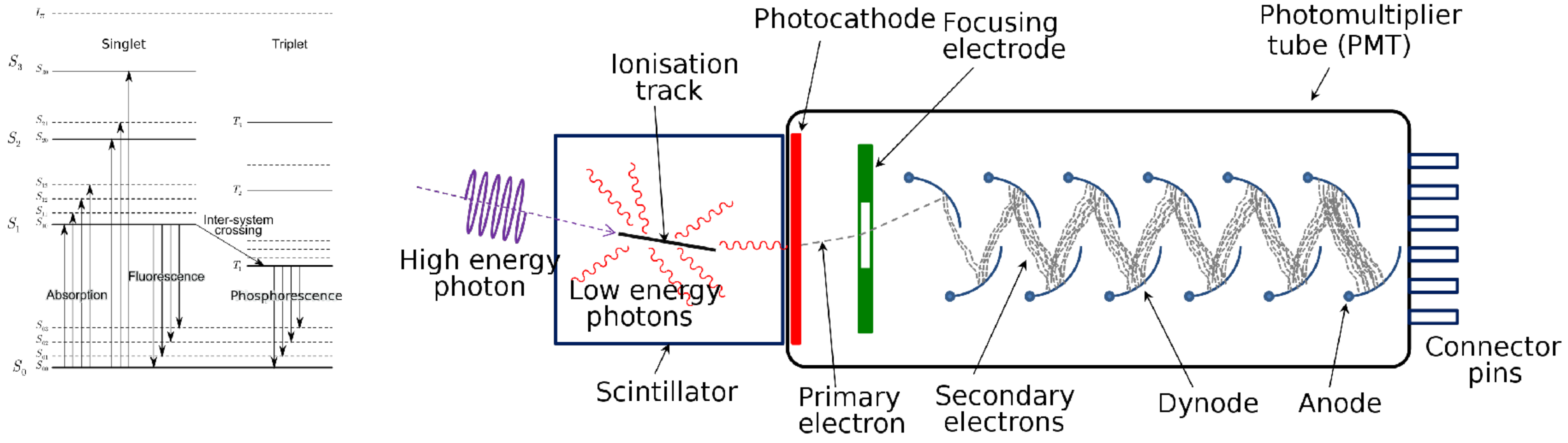


From Basic Ideas to Complex Detectors

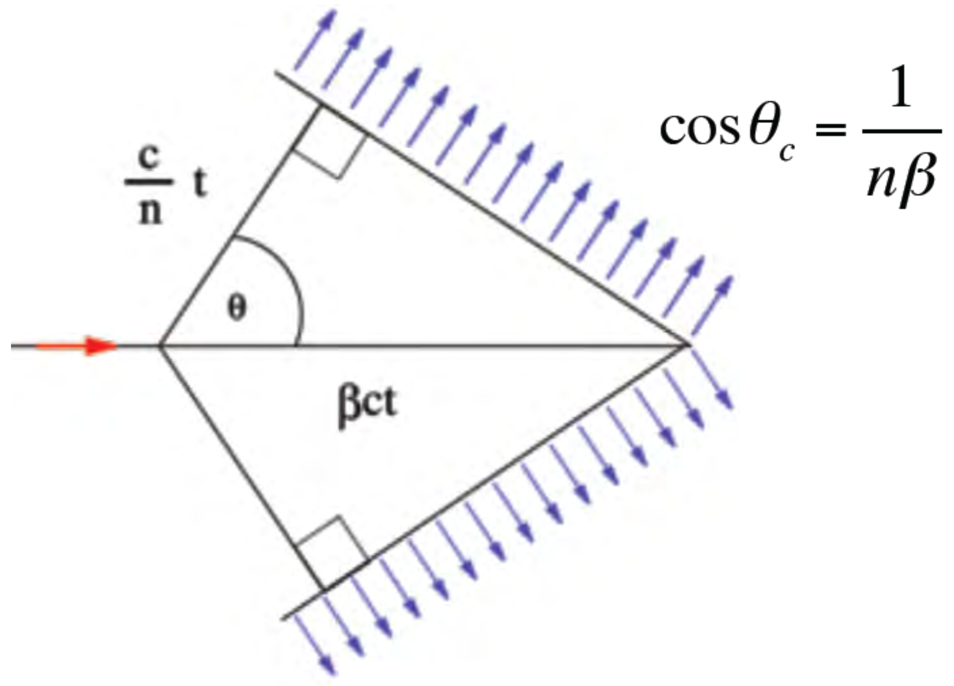
Large majority of the physics detection processes are well known and studied since long time and based mainly on electromagnetic interaction: ionization, excitation, photo-electric effect, pair creation / bremsstrahlung, Cherenkov radiation, transition radiation….



Ionization



Scintillation



Cherenkov

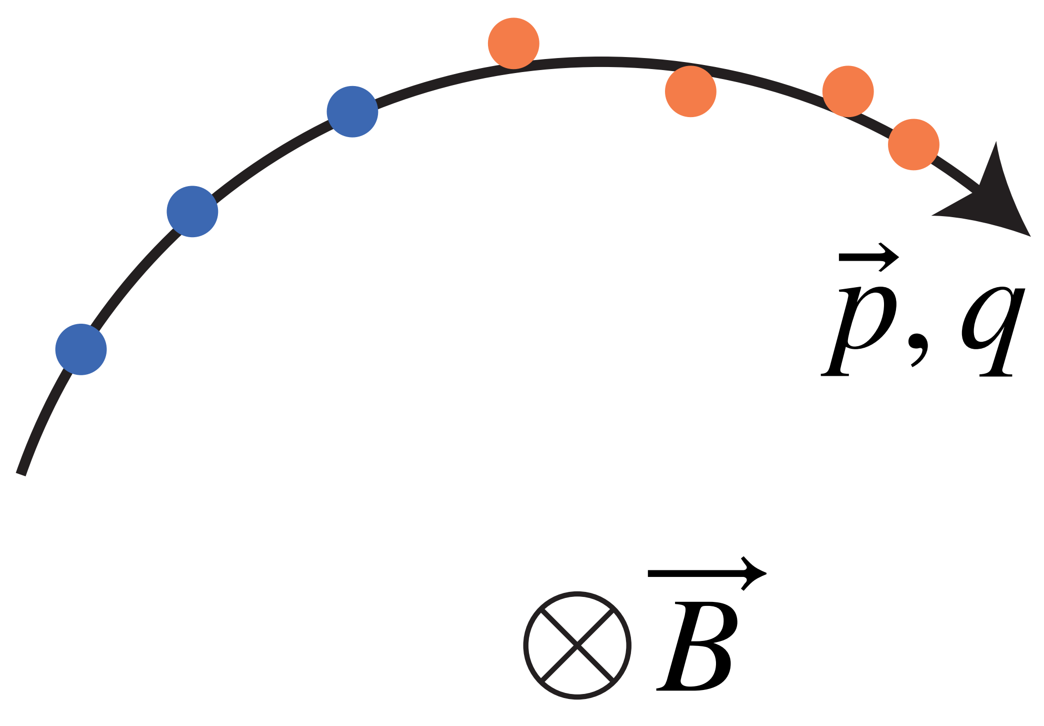
All the cleverness lies in the best way to use these processes to build a detector and to measure a signal :

- Electric signal: charge collection
- Optical signal: light collection

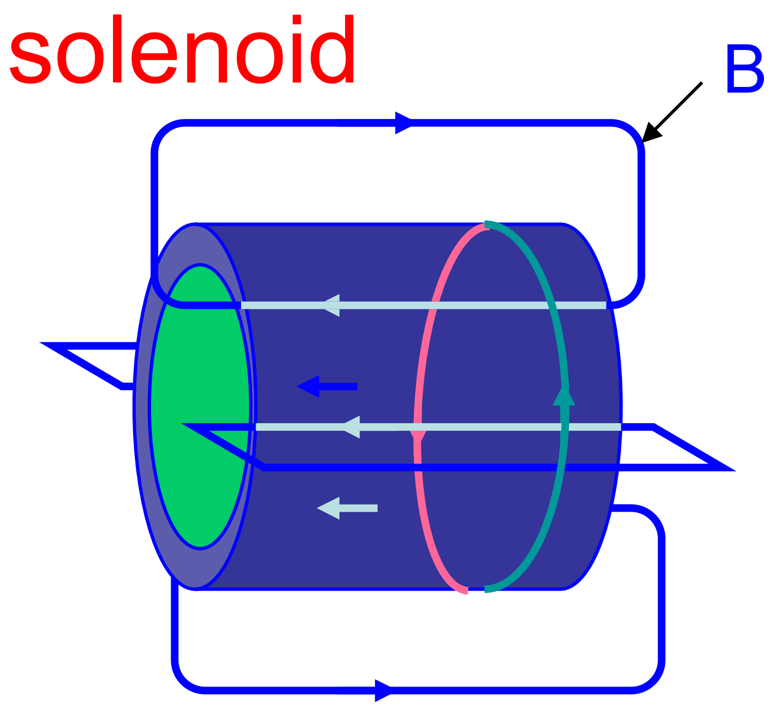
Much of the progress in detection has been allowed by the impressive progress in electronics/computing (speed, low noise, complex logic)

Tracking ($\vec{p}$)

- Recipe (for charged particles):
  - Need accurate x, y, z position of many hits to assemble a trajectory (track)
  - Need magnetic field of some sort that bends the trajectory. From the bending and the knowledge of B we can derive the momentum.

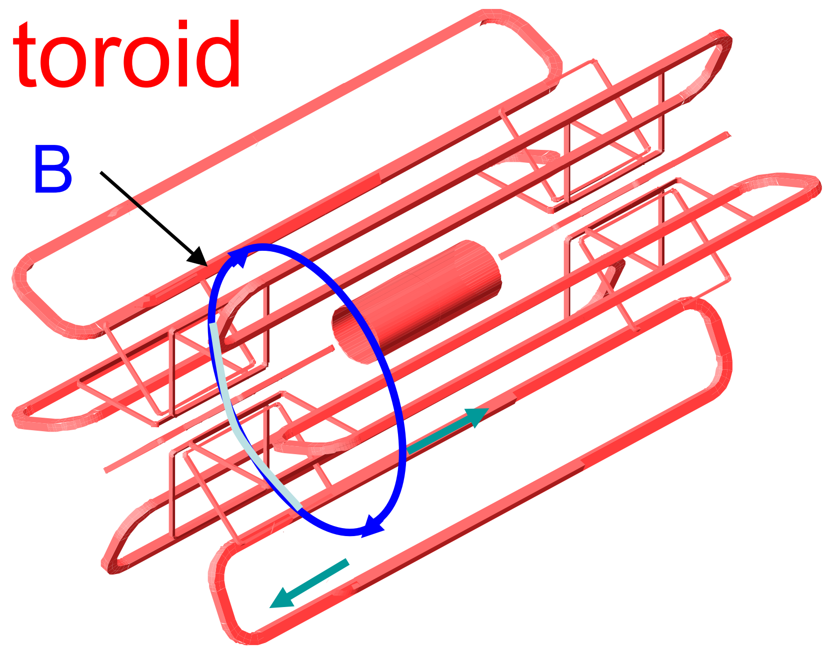


What field?



Solenoid:
Large homogeneous field inside the coil
Weak opposite field in the return yoke
Cost ~ LR^2B^2 (large R → better $(\delta p/p)/\$$)
Relatively high material budget
Track of a charged particle represents a helix

Examples:
Delphi, L3, CMS, STAR, sPHENIX, EIC



Toroid:
Relatively large fields over large volume
Relatively low material budget
Non-uniform field
Complex structure
In theory ideal for a 4π detector
Coils/material close to beam pipe

Examples:
ATLAS

Remember:
$$p_T[GeV] = 0.3 \cdot B[T]\ R[m]$$

Magnet

Source: CERN/WP8, Snowmass, ECFA

Examples of magnets for future experiments that represent the engineering and R&D challenges:

Accelerator	Detector	B [T]	R[m]	L[m]	I [kA]	E [GJ]	comment
LHC	CMS	4	3	13	20	2.7	scaling up
LHC	ATLAS solenoid	2	1.2	5.3	7.8	0.04	scaling up
FCC-ee [Ch8-1]	CLD	2	3.7	7.4	20-30	0.5	scaling up
	IDEA	2	2.1	6	20	0.2	ultra light
CLIC [Ch8-2]	CLIC-detector	4	3.5	7.8	20	2.5	scaling up
FCC-hh [Ch8-3]	main solenoid	4	5	19	30	12.5	new scaling up
	forward solenoid	4	2.6	3.4	30	0.4	scaling up
IAXO [Ch8-4]	8 coil toroid	2.5	8x0.6	22	10	0.7	new toroid
MadMax [Ch8-5]	dipole	9	1.3	6.9	25	0.6	large volume

Right now there is no company in the world that is willing to build large (R> 2m) magnets with B > 3T

Closer Look at Tracking

Gluckstern (1963)

Tracking Resolution:

Precision term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} = \frac{p_T\ \sigma_{r_{\phi r}}}{0.3\ L^2\ B}\sqrt{\frac{720}{N+5}}$$

MS term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}} = \frac{0.05}{L\ B\ \beta}\sqrt{1.43\frac{L}{X_0}}\left[1+0.038\ \log\frac{L}{X_0}\right]$$

where

$\sigma_{r_{\phi r}}$ is point resolution in meter

L is lever arm in meter

B is magnetic field in Tesla

N are number of measurements (hits)

β velocity of particle

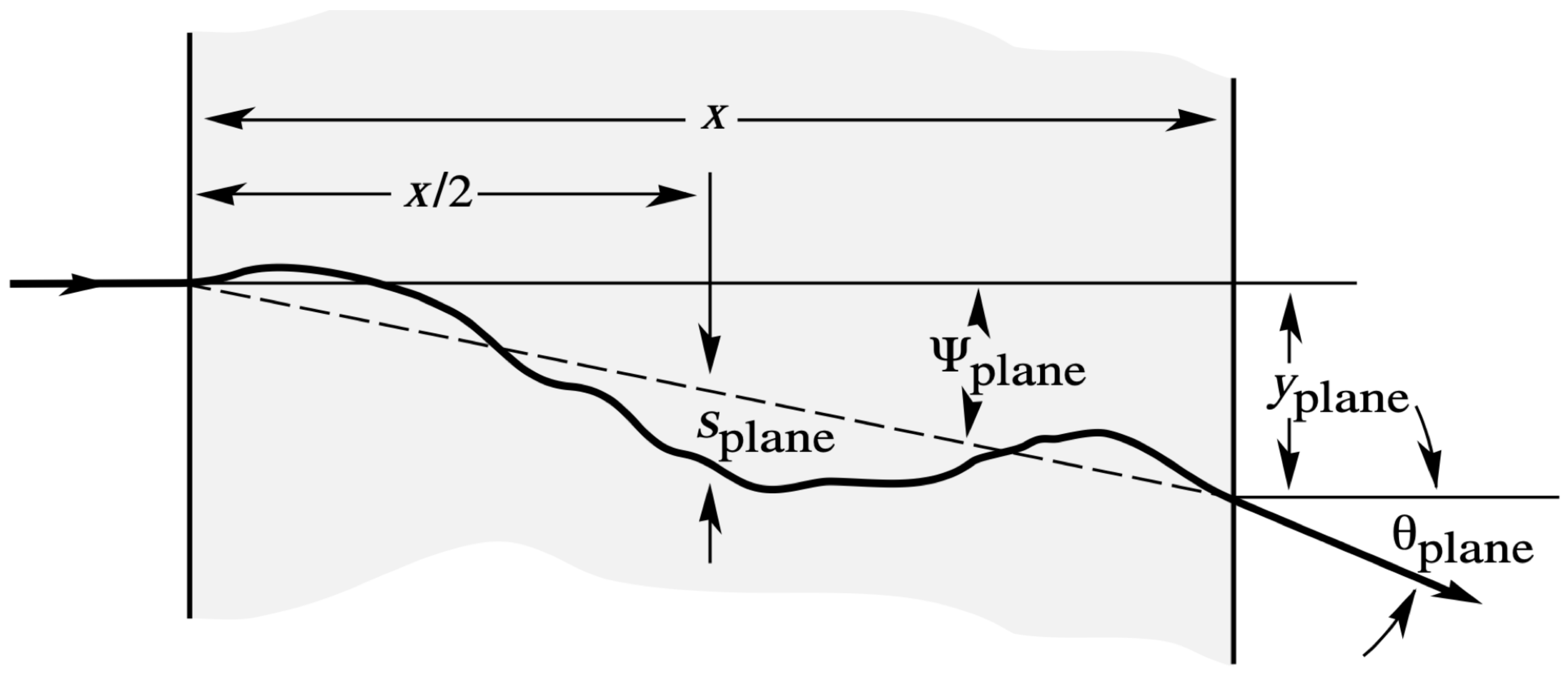
X_0 is gas/material density in meter

Track momentum resolution: $$\frac{\sigma_{p_T}}{p_T} = \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} \oplus \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}}$$

Momentum resolution is limited:

- At high momentum by position resolution of the detector and strength of magnetic field
- At low momentum by multiple scattering due to material in the path

PDG:



Closer Look at Tracking

Gluckstern (1963)

Tracking Resolution:

Precision term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} = \frac{p_T\ \sigma_{r_{\phi r}}}{0.3\ L^2\ B}\sqrt{\frac{720}{N+5}}$$

MS term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}} = \frac{0.05}{L\ B\ \beta}\sqrt{1.43\frac{L}{X_0}}\left[1 + 0.038\ \log\frac{L}{X_0}\right]$$

where

$\sigma_{r_{\phi r}}$ is point resolution in meter

L is lever arm in meter

B is magnetic field in Tesla

N are number of measurements (hits)

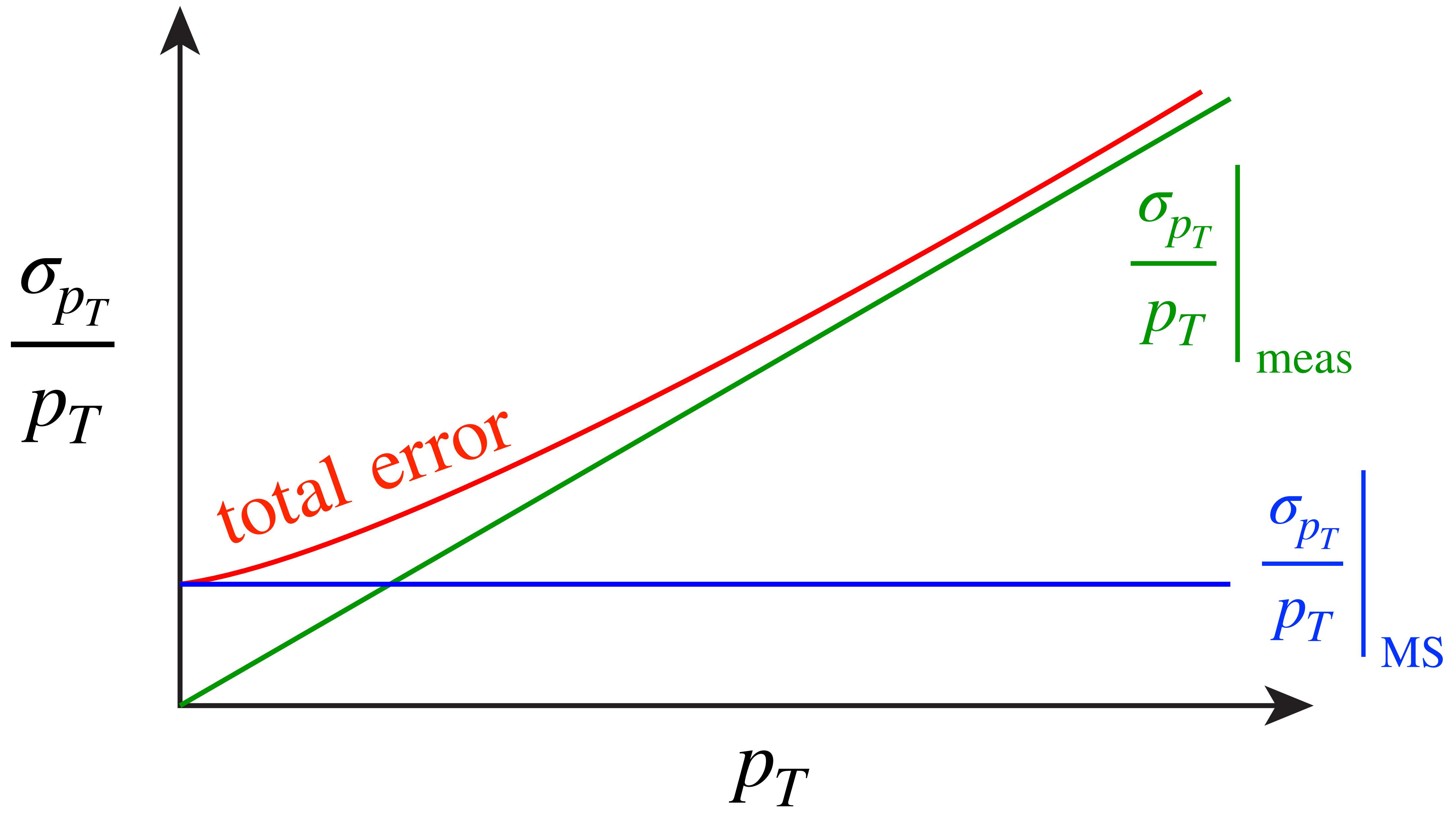
β velocity of particle

X_0 is gas/material density in meter

Track momentum resolution: $$\frac{\sigma_{p_T}}{p_T} = \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} \oplus \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}}$$

Momentum resolution is limited:

- At high momentum by position resolution of the detector and strength of magnetic field
- At low momentum by multiple scattering due to material in the path



Closer Look at Tracking

Gluckstern (1963)

Tracking Resolution:

Precision term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\mathrm{meas}} = \frac{p_T\ \sigma_{r_{\phi r}}}{0.3\ L^2\ B}\sqrt{\frac{720}{N+5}}$$

MS term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\mathrm{MS}} = \frac{0.05}{L\ B\ \beta}\sqrt{1.43\frac{L}{X_0}}\left[1+0.038\ \log\frac{L}{X_0}\right]$$

where

$\sigma_{r_{\phi r}}$ is point resolution in meter

L is lever arm in meter

B is magnetic field in Tesla

N are number of measurements (hits)

β velocity of particle

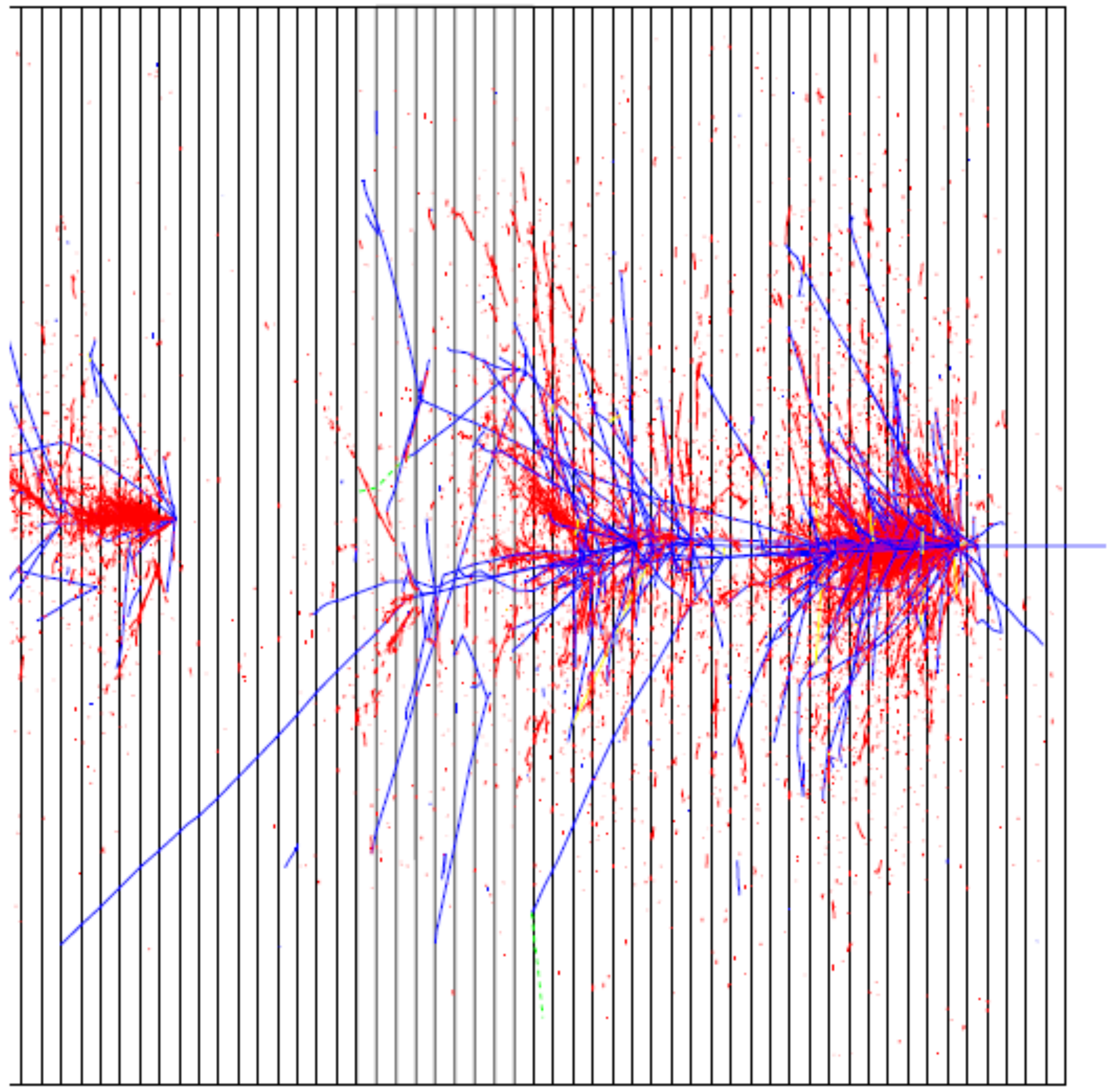
X_0 is gas/material density in meter

Track momentum resolution: $$\frac{\sigma_{p_T}}{p_T} = \left.\frac{\sigma_{p_T}}{p_T}\right|_{\mathrm{meas}} \oplus \left.\frac{\sigma_{p_T}}{p_T}\right|_{\mathrm{MS}}$$

Maximize Resolution:

- N ↑: good but adds material and services
- σ_r ↑: good, but increases channel count & heat, limited by technology
- X_0↓: important but also affects N
- L↑: Good, needs room/space
- B↑: Good, affects photosensors, low-p_T PID

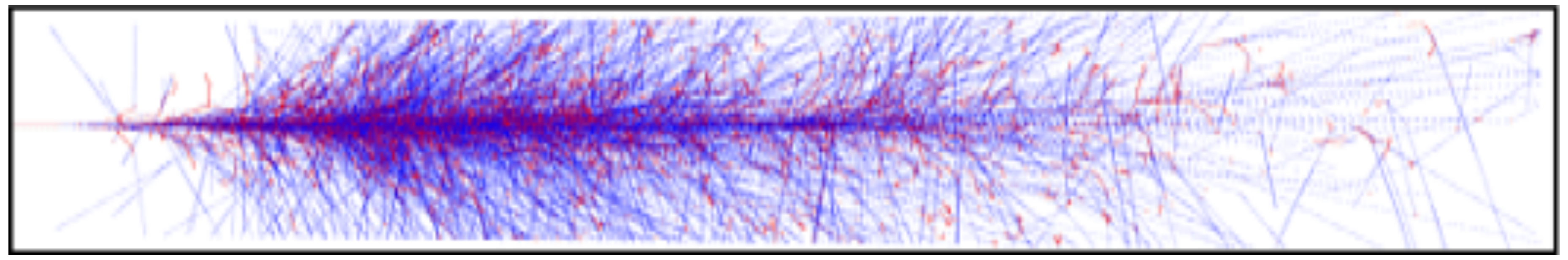
Calorimetry (E)



- Energy measurement by total absorption
  - works for charged and neutral particles
  - spatial reconstruction
  - particle identification capability
- Measured particle is lost (destructive method)
- Basic mechanisms
  - electromagnetic or hadronic showers
- Detector response is proportional to E
  - not always true for hadronic showers
- Energy converted into ionization and/or excitation of matter

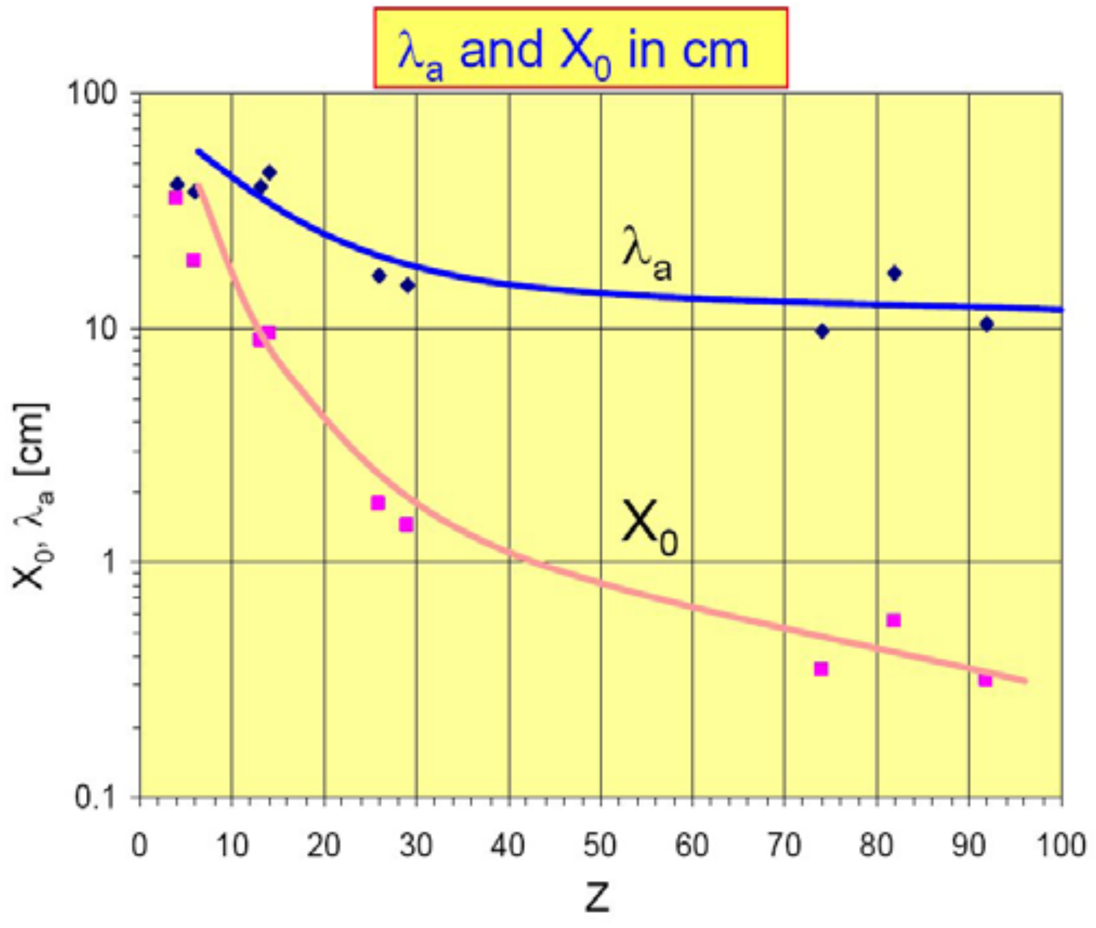
Categories of Calorimeters

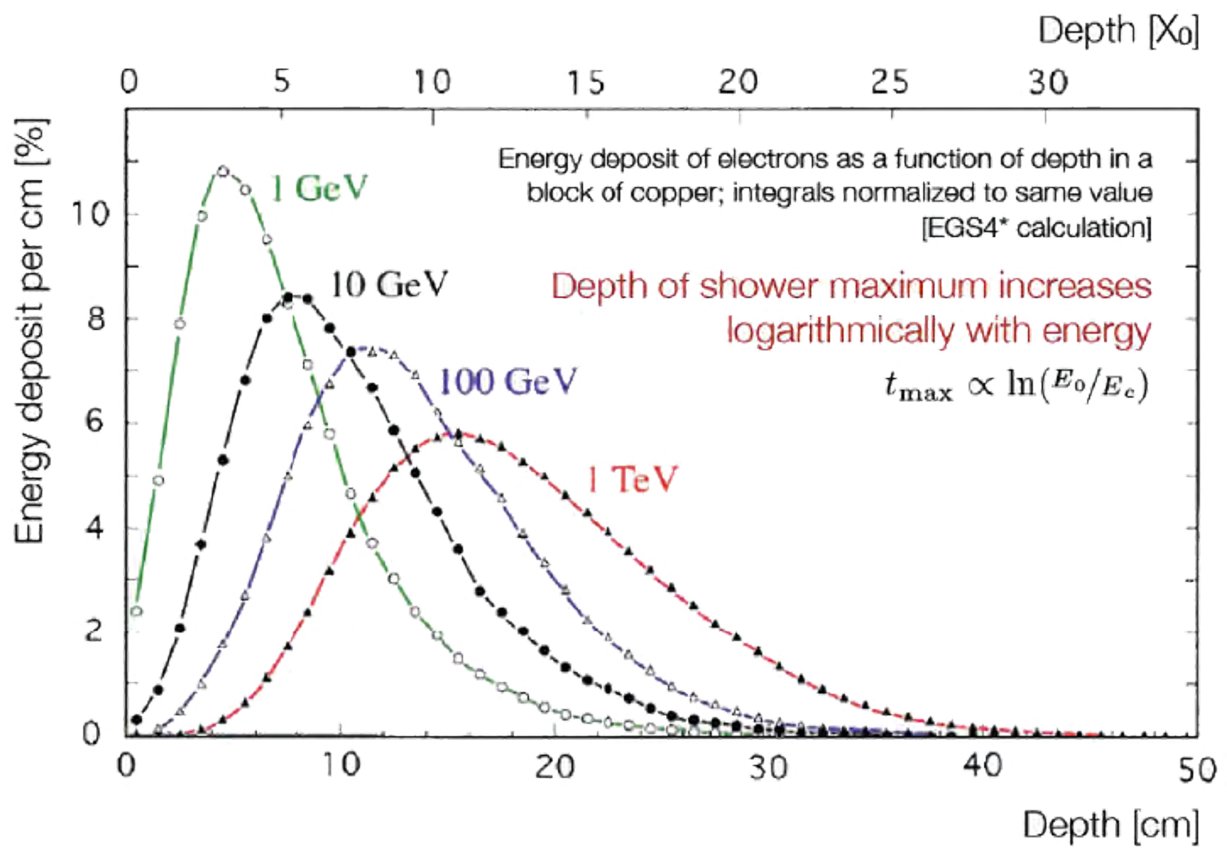
EM Calorimetry for γ and $e^{\pm}$



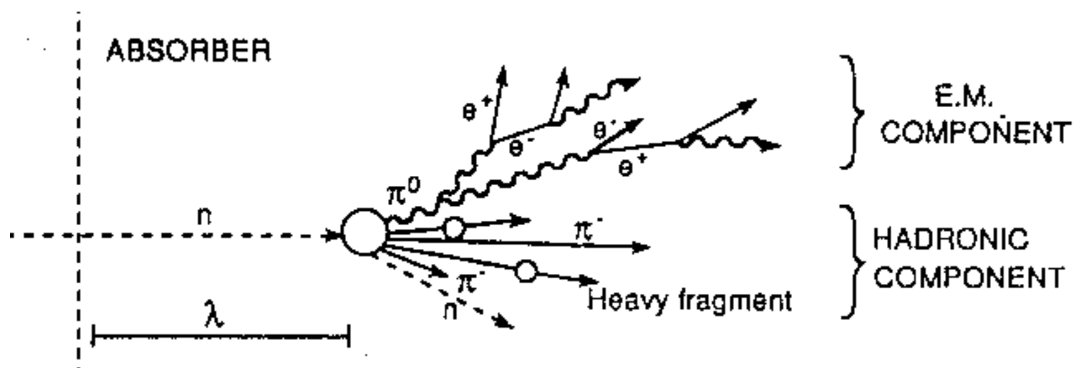
- Main processes
  - photoelectric effect (γ)
  - Compton effect (γ)
  - e^+e^- pair creation (γ)
  - Ionization ($e^{\pm}$)
  - Bremsstrahlung ($e^{\pm}$)
- The radiation length X_0 is defined as the distance over which the mean energy of an incident electron is reduced by a factor e, $E = E_0 \exp(-x/X_0)$

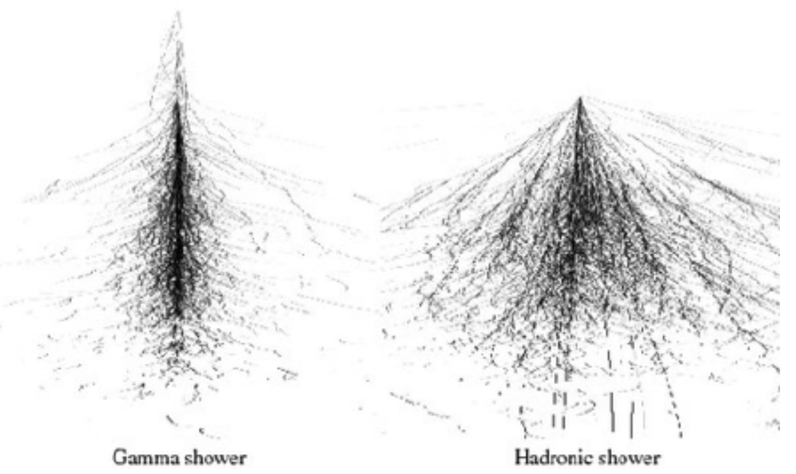
key parameter





Hadron Calorimetry for $h^{\pm,0}$

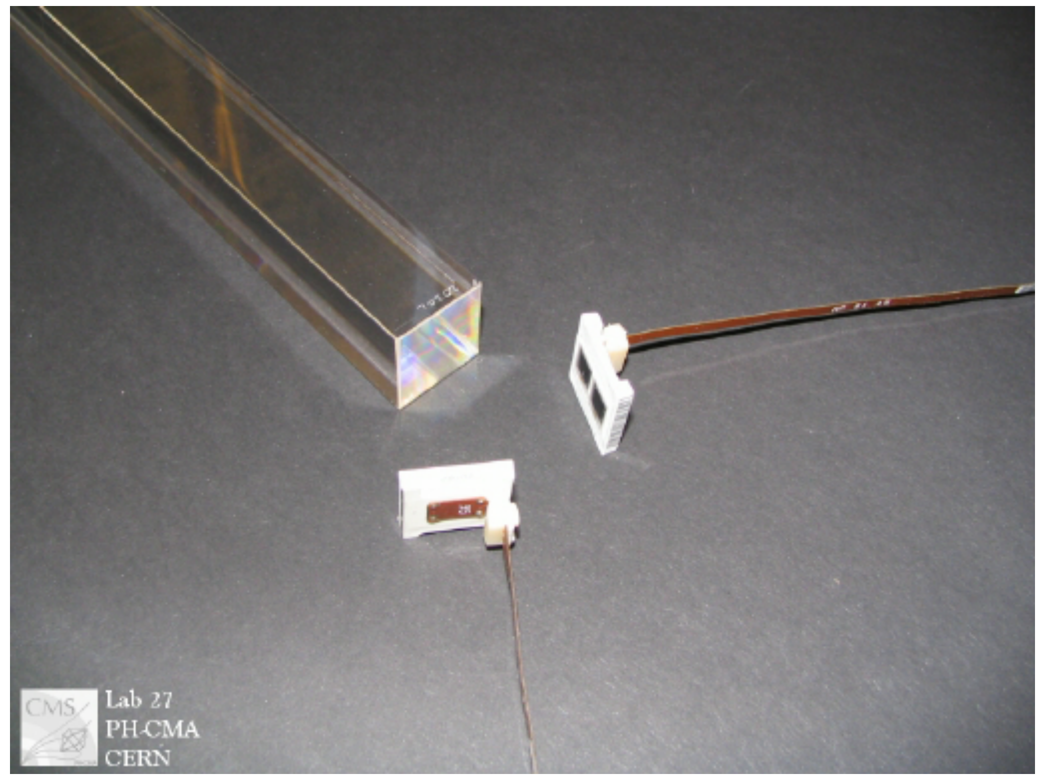


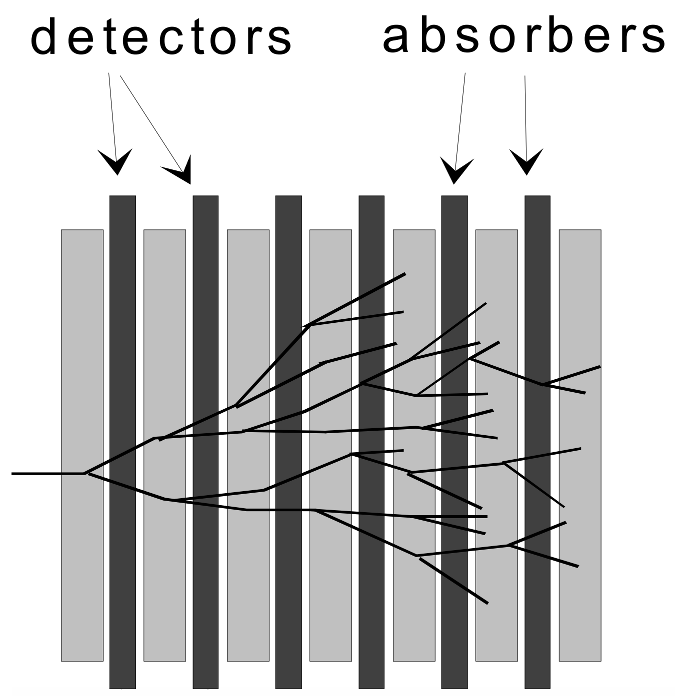


- Interaction of charged/neutral hadrons involves mainly nuclear interaction:
  - excitation and nucleus break-up
  - production of secondary particles + fragment
- Hadronic shower : typically 10 times wider and deeper/longer than EM showers (see left plot)
- Large fluctuation of the shower development
- In general worse resolution than EM calorimeters
- λ_{int}: mean free path between nuclear collisions

Types of Calorimeter

- Homogeneous calorimeters (EM only)
  - detector is absorber: Scintillation crystals, glass blocks, Cherenkov radiation
  - good energy resolution, limited spatial resolution
  - Examples: $PbWO_4$ (CMS), L3 (BGO)
- Sampling calorimeters
  - detector and absorber separated
  - limited energy resolution, good spatial resolution





General resolution parametrization:

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

stochastic or sampling term

constant term

comes from inhomogeneity, bad calibration, non-linearity

noise term

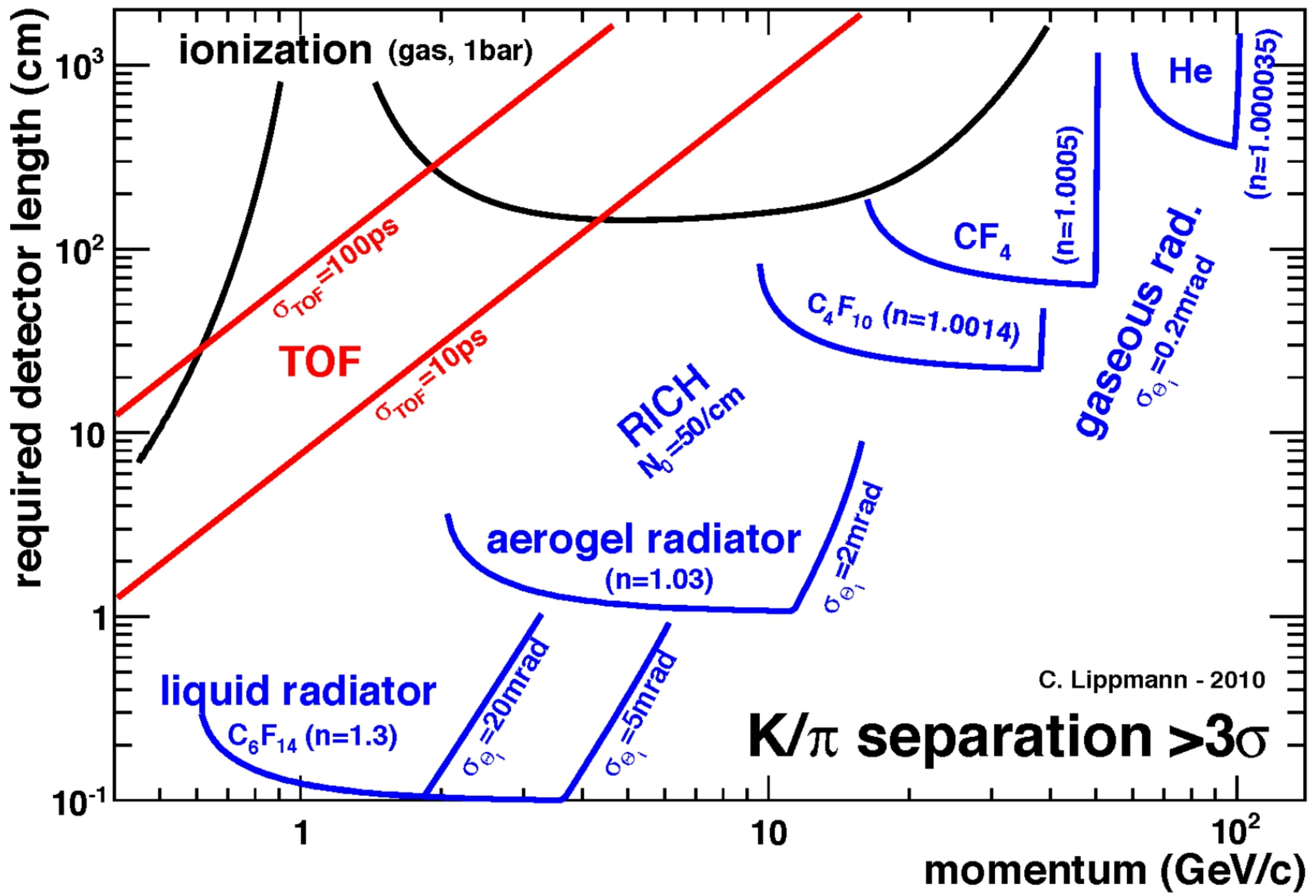
including electronic and pileup noise

EM: a ~ 2-15%

H: a ~ 40-100%

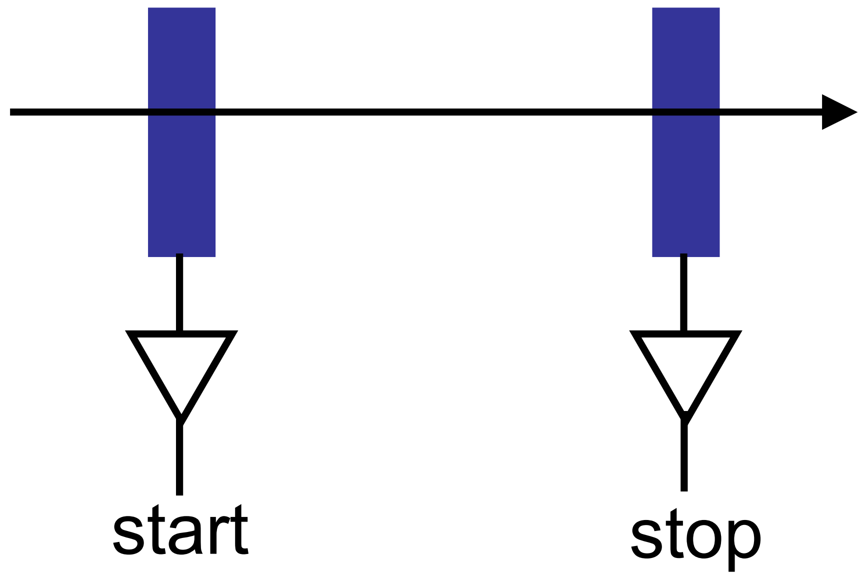
Particle Identification (m)

- Particle Identification
  - dE/dx (energy loss) measurement
  - Time of flight
  - Cherenkov detectors
  - Transition radiation detectors
- Different p ranges require different technologies
- Almost all methods assume that the momentum $\vec{p}$ is known



Types of PID Detectors

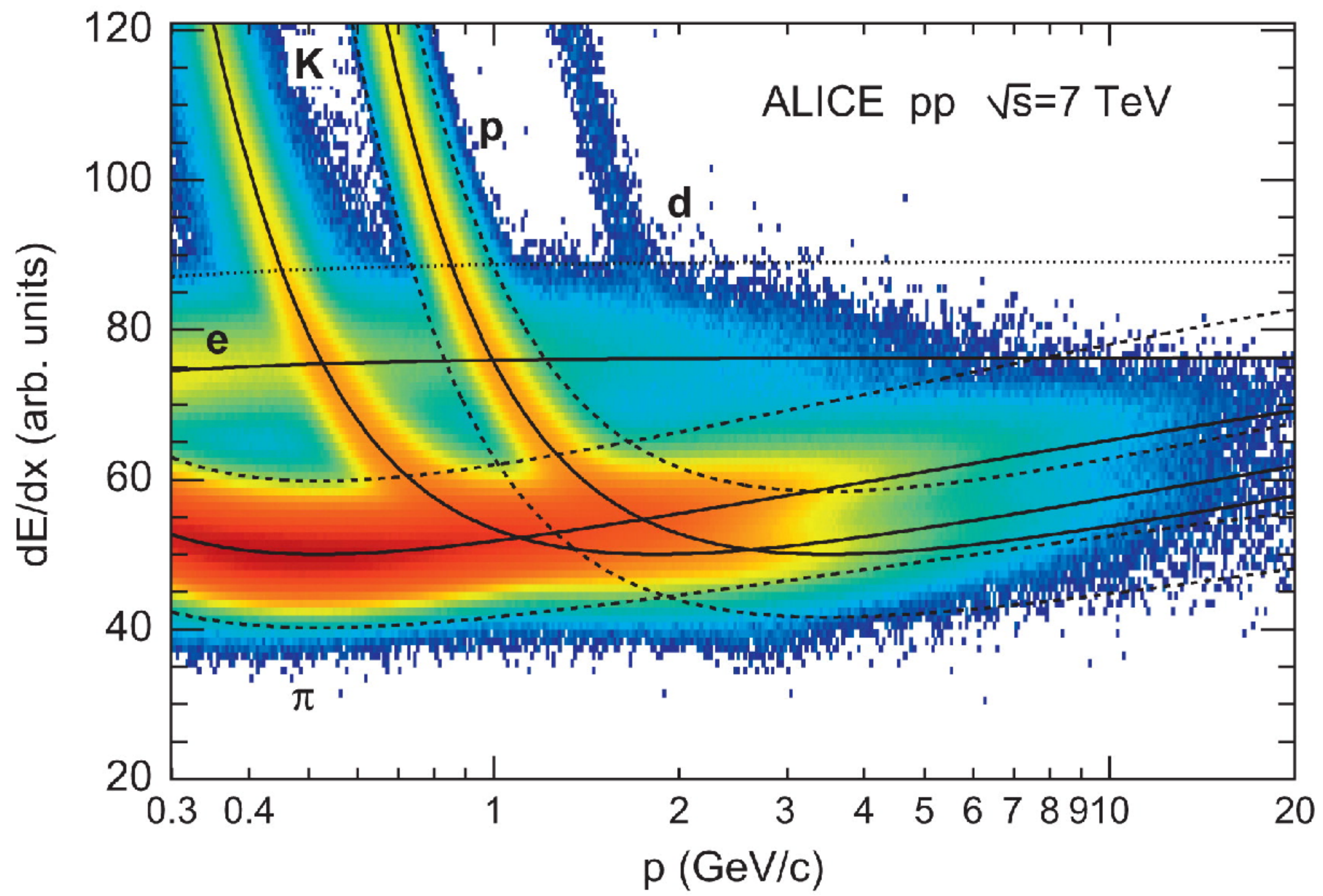
- PID with dE/dx
  - measure dE/dx many times along tracks
  - governed by Bethe-Bloch equation
  - electrons reach Fermi plateau at 1.4 MIP
  - most used in TPC like detectors (ALICE, STAR)
  - less prominent in Si-Detectors (1 vs 8 bit)
- PID with Time-of-Flight
  - requires fast detectors (small jitter)
  - fast electronics
  - good knowledge of start time t_0

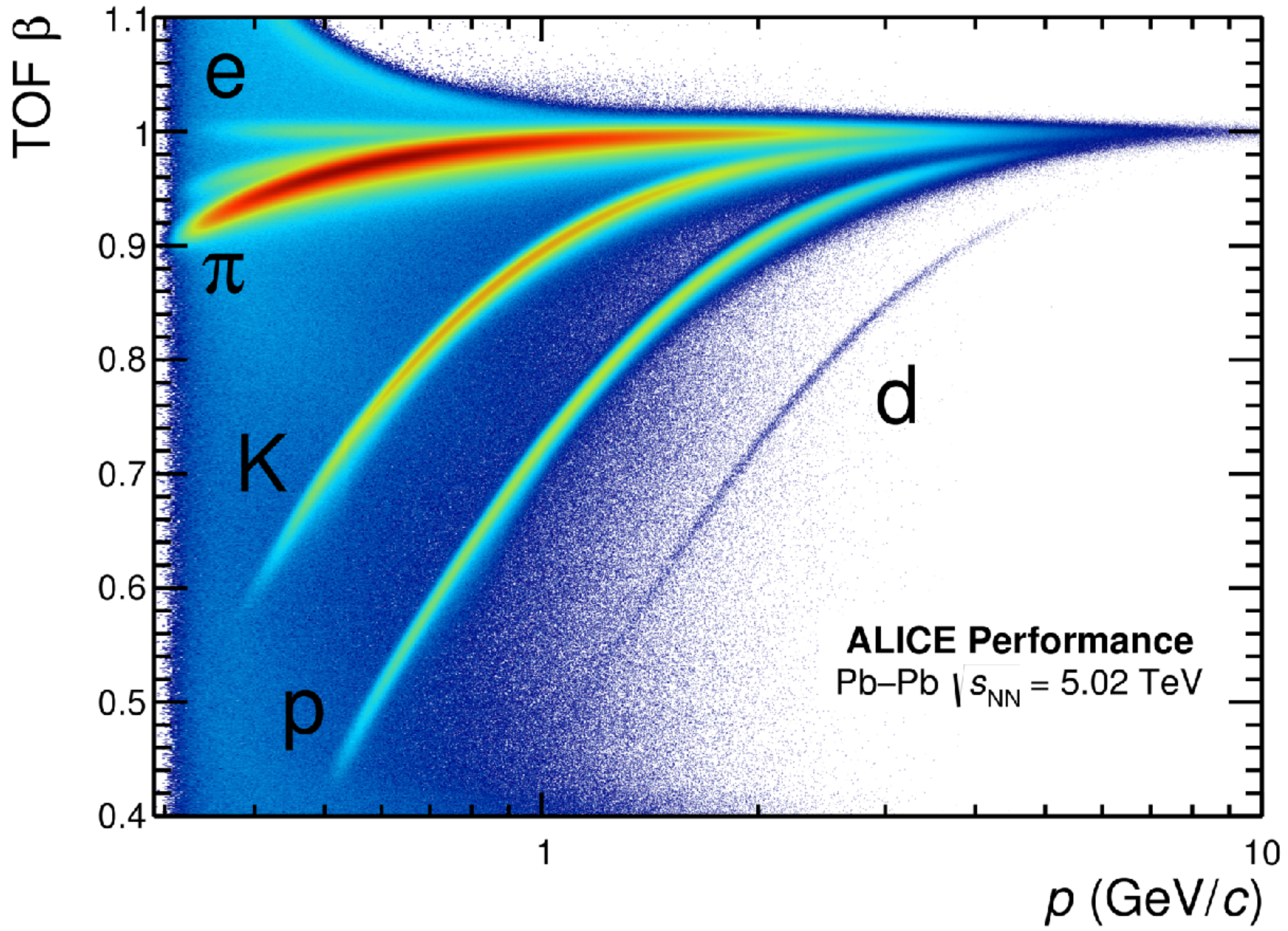


$$t = \frac{L}{\beta c} \qquad p = \gamma m \beta$$

$$m = \frac{p}{\gamma\beta} = p\sqrt{\beta^{-2} - 1} = p\sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

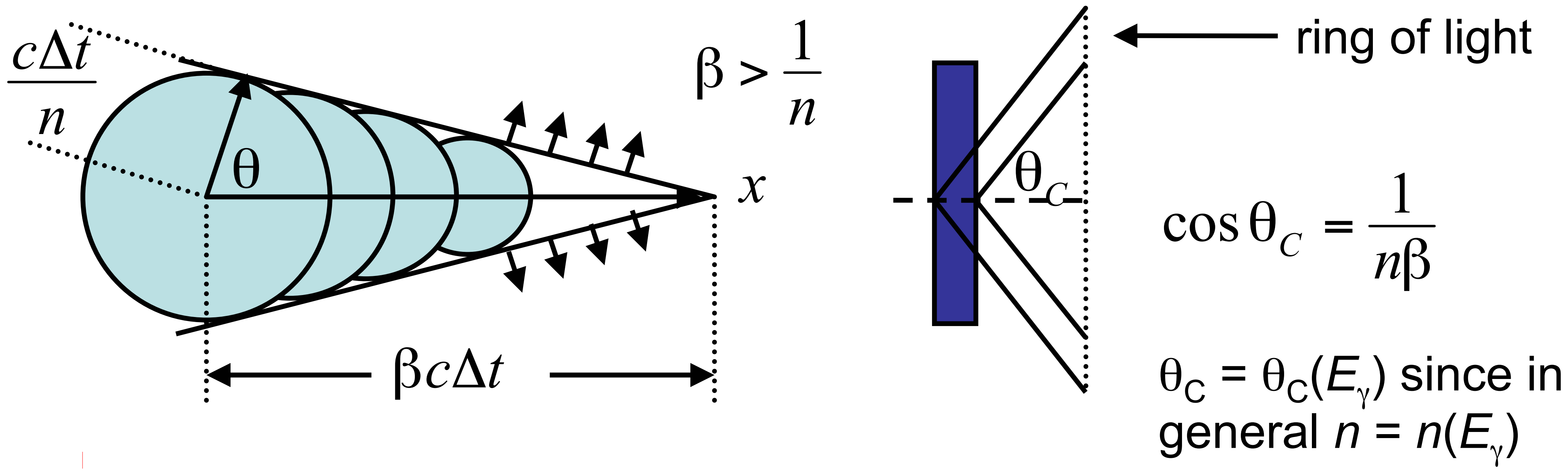
$$\left(\frac{\sigma_m}{m}\right)^2 = \left(\frac{\sigma_p}{p}\right)^2 + \gamma^4\left[\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_t}{t}\right)^2\right]$$



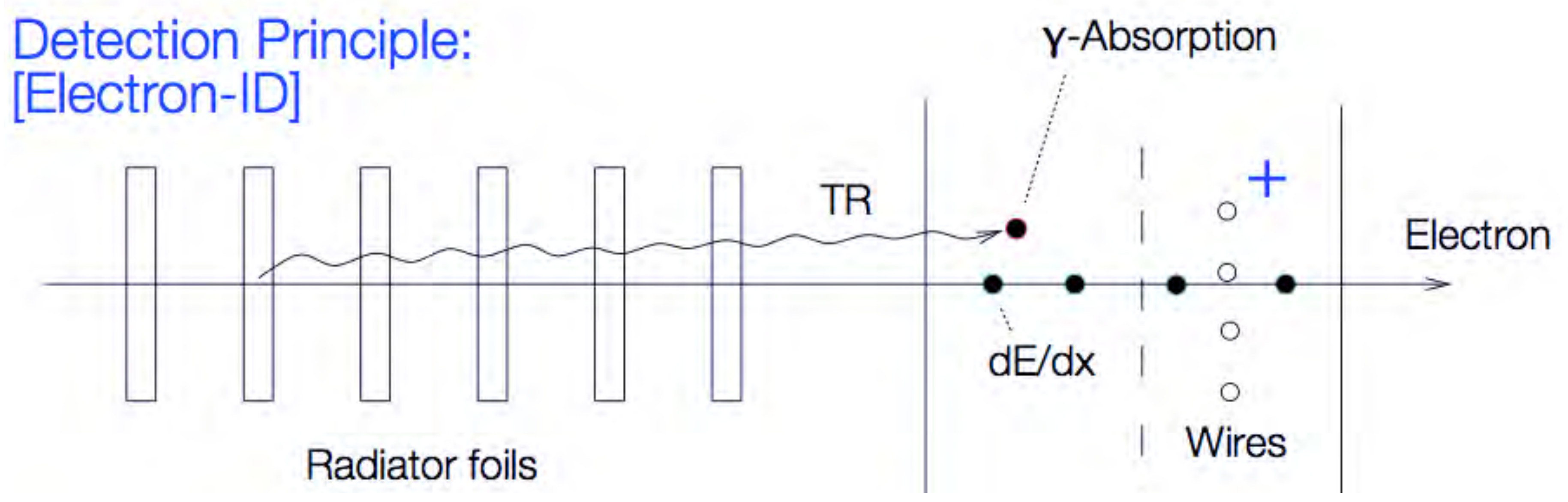


Types of PID Detectors

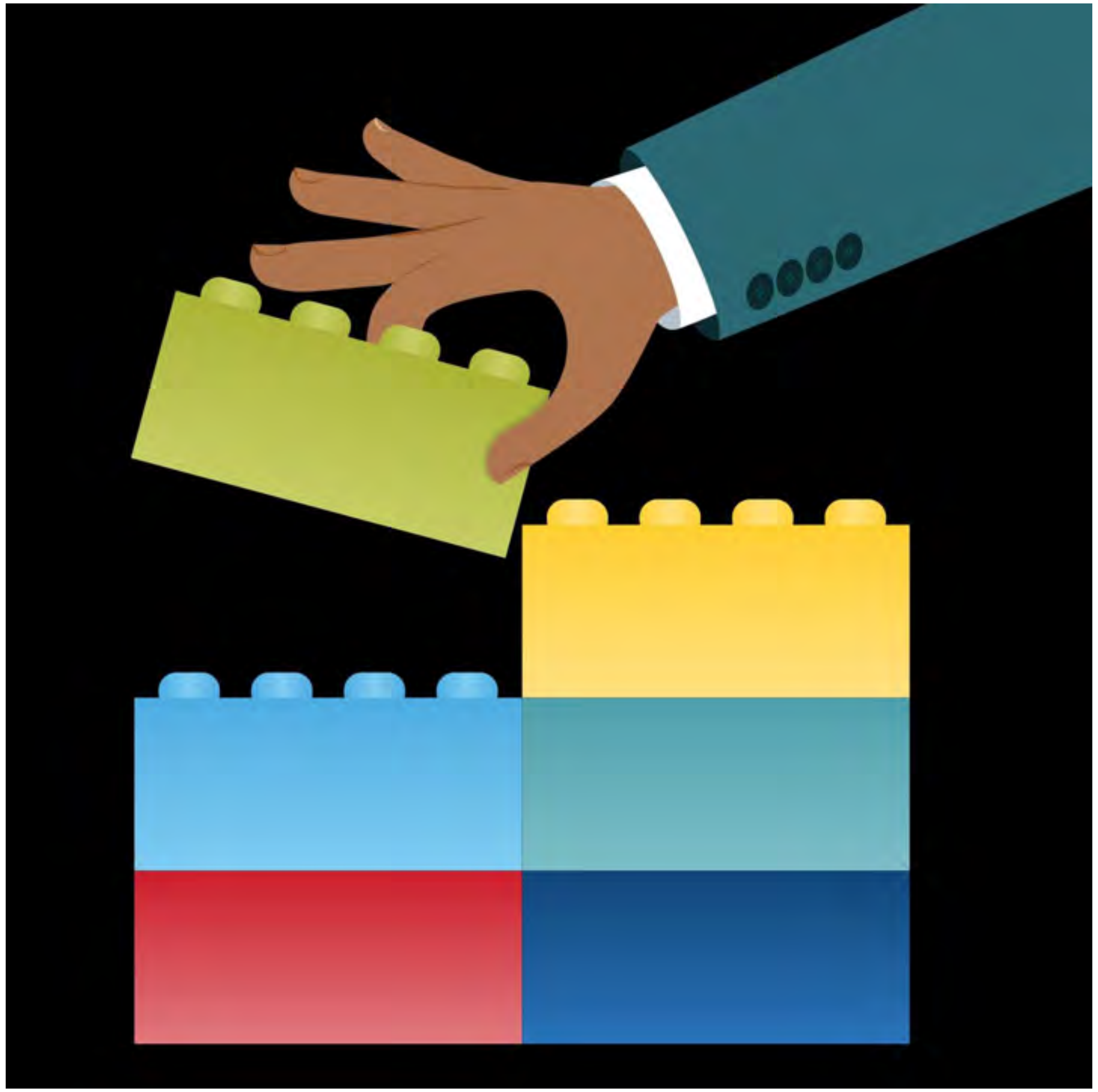
- PID with Cherenkov radiation
  - charged particle travels faster than light in medium
  - high-p_T → gas, medium-p_T → aerogel, low-p_T → quartz
  - Critical parameter: $N_{photons}$
  - Implementations:
    - RICH (Ring Imaging Cherenkov Counter)
    - DIRC (Detection of Internally Reflected Cherenkov Light)
    - Threshold Counter
- Transition radiation detector
  - energy radiated when z charged particle crosses the boundary between vacuum and a dielectric layer
  - number of photons emitted per boundary is small
  - photons are emitted close to the track $\theta \approx 1/\gamma$
  - typical energy is in the keV range
  - low Z material preferred to keep re-absorption small ($\propto Z^5$) • stacks of CH_2 foils
  - hydrocarbon foam and fibre materials



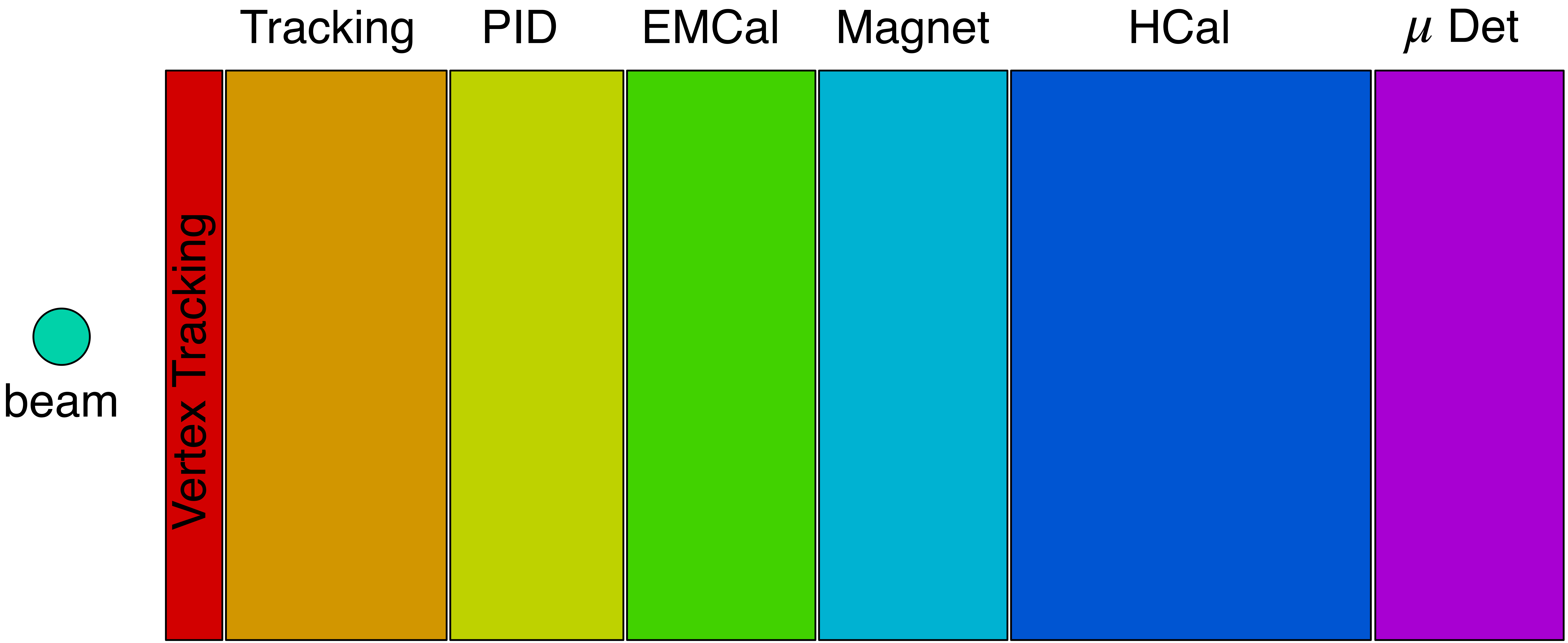
medium	n	θ_{max} (β=1)	N_{ph} (eV^{-1} cm^{-1})
air	1.000283	1.36	0.208
isobutane	1.00127	2.89	0.941
water	1.33	41.2	160.8
quartz	1.46	46.7	196.4



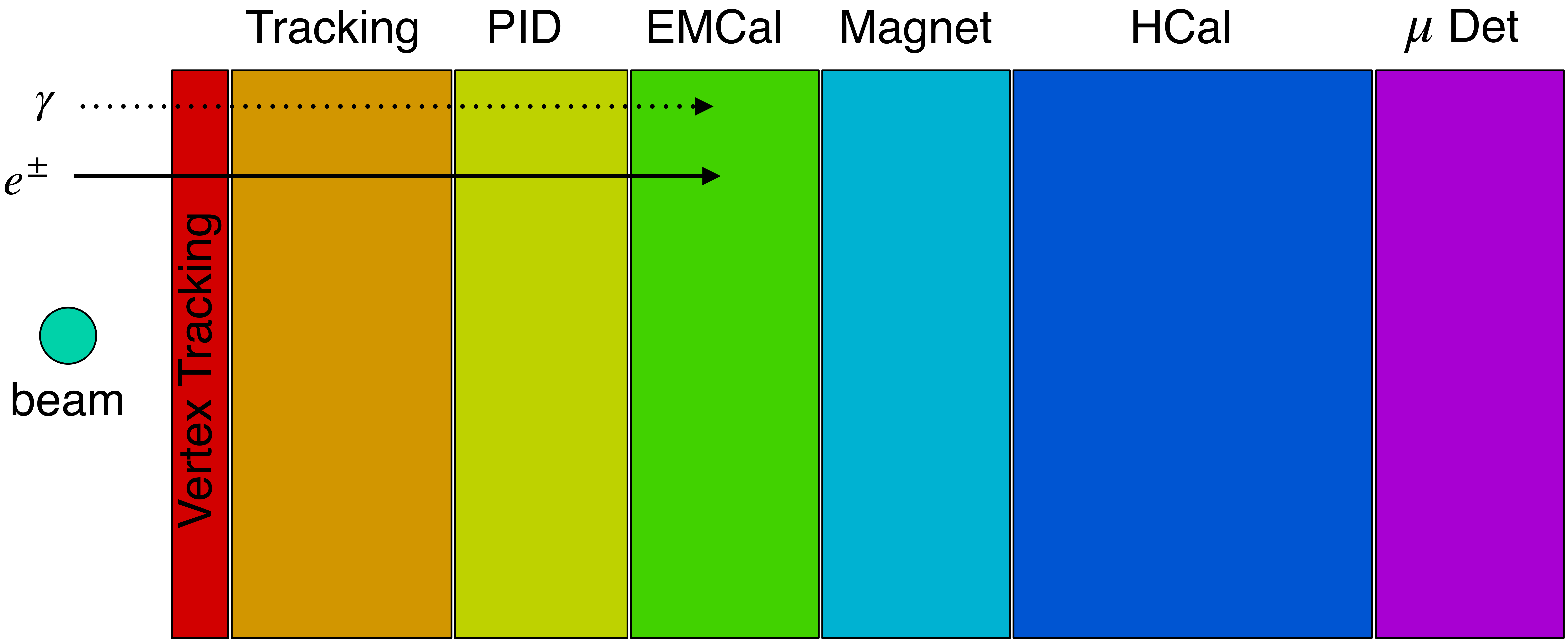
Putting it All Together



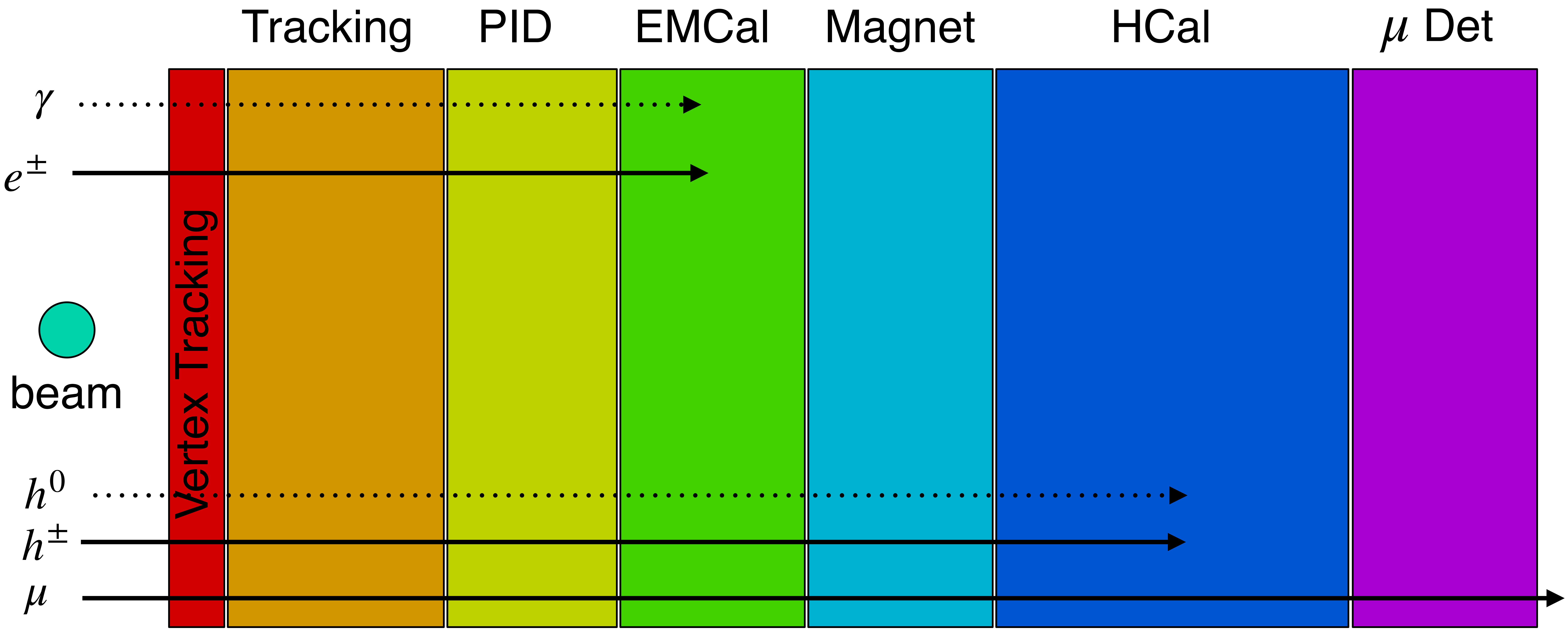
Putting it All Together



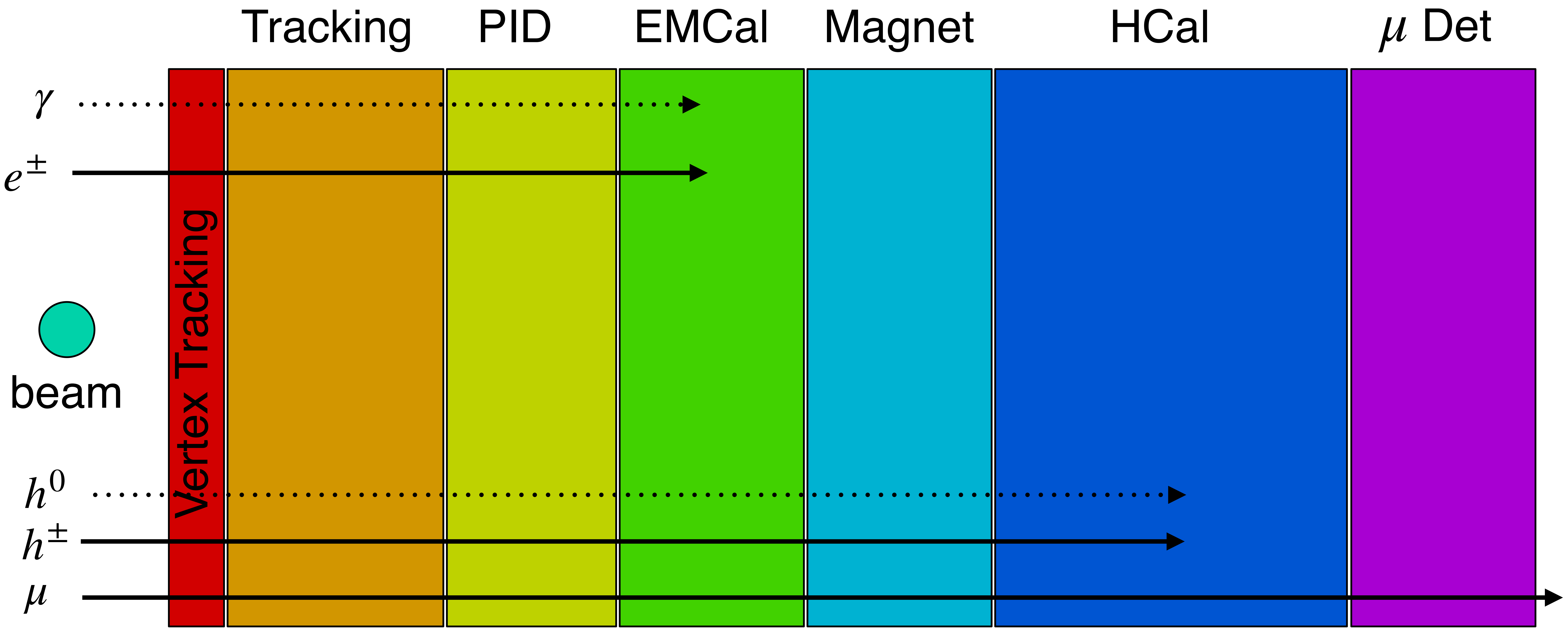
Putting it All Together



Putting it All Together

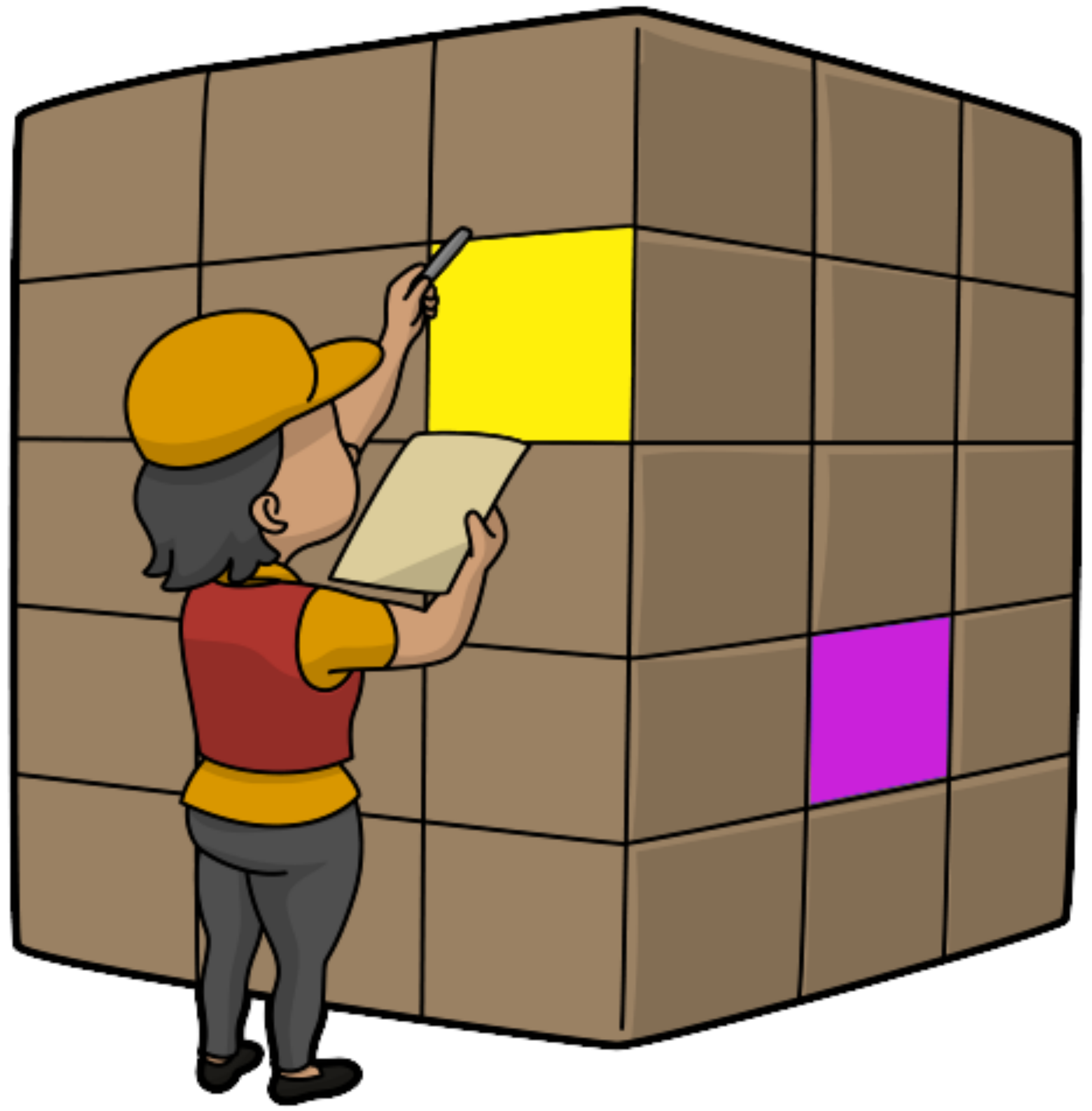


Putting it All Together



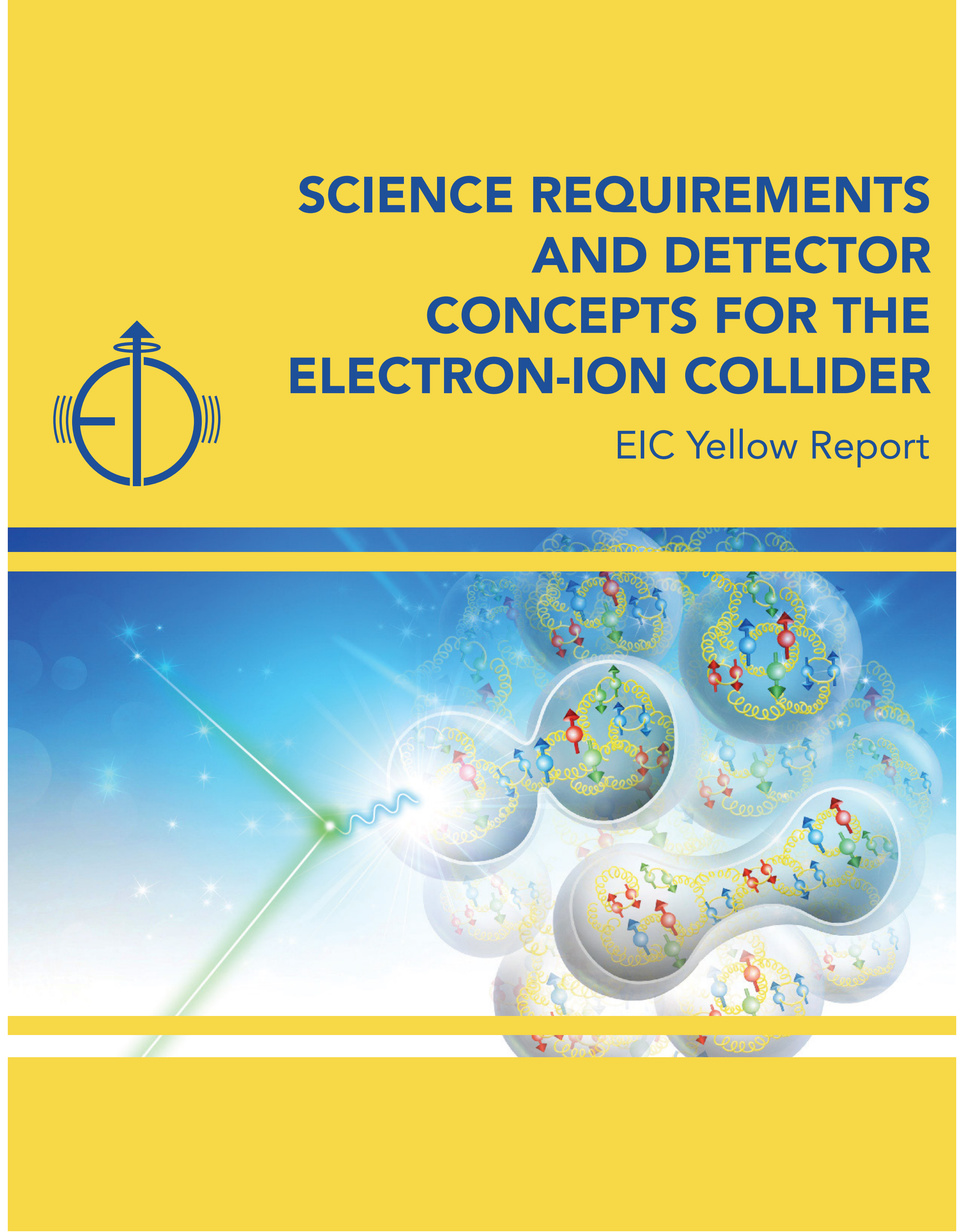
If things would be that easy …

9.2. Designing an EIC Detector



Detector Planning

- The DOE-NP supported EIC Project includes **one** detector and **one** IR in the reference costing
- The EIC is capable of supporting a science program that includes **two** detectors and **two** interaction regions.
- The community (EIC User Group) is strongly in favor of two general purpose detectors
  - Complementarity, cross-checks, reduction of systematics
- **EIC User Group "Yellow Report" Effort**
  - Initiative to advance the state and detail of requirements and detector concepts in preparation for the realization of the EIC.
  - 1 year effort concluded in March 2021 with a comprehensive "Yellow" Report
  - 902 Pages, 414 authors from 121 institutions, 675 figures
  - Nucl. Phys. A 1026 (2022) 122447, arXiv:2103.05419



η	Nomenclature	Tracking: Resolution	Tracking: Relative Momentun	Tracking: Allowed X/X_0	Tracking: Minimum-p_T (MeV/c)	Tracking: Transverse Pointing Res.	Tracking: Longitudinal Pointing Res.	Electrons and Photons: Resolution σ_E/E	Electrons and Photons: PID	Electrons and Photons: Min E Photon	$\pi/K/p$: p-Range	$\pi/K/p$: Separation	HCAL: Resolution σ_E/E	HCAL: Energy	Muons
< -4.6	Low-Q2 tagger														
-4.6 to -4.0		Not Accessible													
-4.0 to -3.5			Reduced Performance												
-3.5 to -3.0	Backward Detector		$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$	~5% or less	150-300			$1\%/E \oplus 2.5\%/\sqrt{E} \oplus 1\%$	π suppression up to $1:10^{-4}$	20 MeV	≤ 10 GeV/c	≥ 3σ	$50\%/\sqrt{E} \oplus 10\%$	~500MeV	Muons useful for background suppression and improved resolution
-3.0 to -2.5															
-2.5 to -2.0			$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$												
-2.0 to -1.5						dca(xy) ~ $40/p_T$ µm ⊕ 10 µm	dca(z) ~ $100/p_T$ µm ⊕ 20 µm	$2\%/E \oplus (4\text{-}8)\%/\sqrt{E} \oplus 2\%$	π suppression up to $1:(10^{-3}\text{-}10^{-2})$	50 MeV					
-1.5 to -1.0															
-1.0 to -0.5	Barrel		$\sigma_p/p \sim 0.02\% \times p \oplus 5\%$		400	dca(xy) ~ $30/p_T$ µm ⊕ 5 µm	dca(z) ~ $30/p_T$ µm ⊕ 5 µm	$2\%/E \oplus (12\text{-}14)\%/\sqrt{E} \oplus (2\text{-}3)\%$	π suppression up to $1:10^{-2}$	100 MeV	≤ 6 GeV/c		$100\%/\sqrt{E} \oplus 10\%$		
-0.5 to 0.0															
0.0 to 0.5															
0.5 to 1.0															
1.0 to 1.5	Forward Detectors		$\sigma_p/p \sim 0.02\% \times p \oplus 1\%$		150-300	dca(xy) ~ $40/p_T$ µm ⊕ 10 µm	dca(z) ~ $100/p_T$ µm ⊕ 20 µm	$2\%/E \oplus (4^*\text{-}12)\%/\sqrt{E} \oplus 2\%$	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c		$50\%/\sqrt{E} \oplus 10\%$		
1.5 to 2.0															
2.0 to 2.5															
2.5 to 3.0			$\sigma_p/p \sim 0.1\% \times p \oplus 2\%$												
3.0 to 3.5															
3.5 to 4.0	Instrumentation to separate charged particles from photons		Reduced Performance												
4.0 to 4.5		Not Accessible													
> 4.6	Proton Spectrometer														
	Zero Degree Neutral Detection														

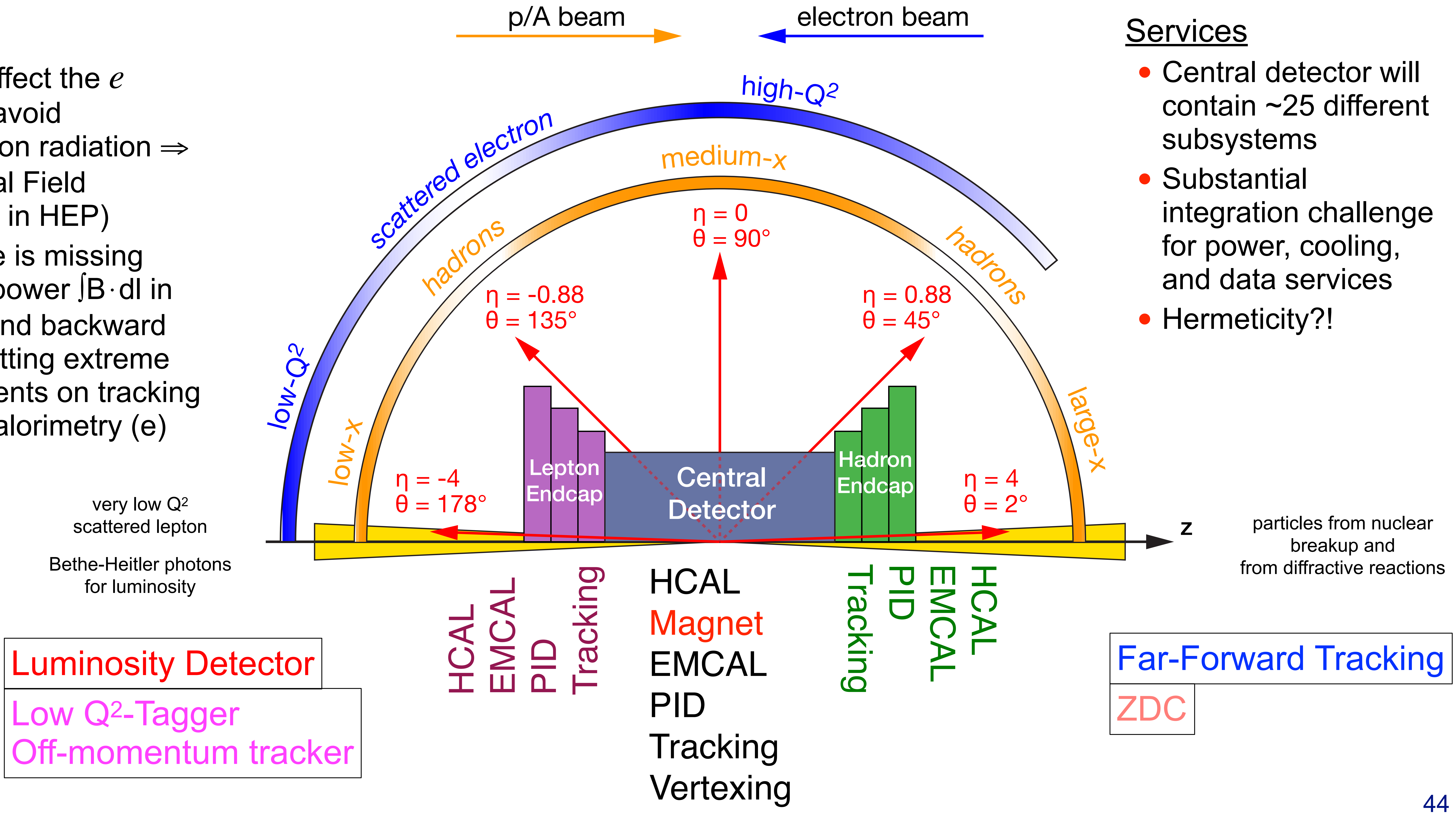
EIC General Purpose Detector Concept

Magnet

- Cannot affect the e beam to avoid synchrotron radiation ⇒ Solenoidal Field (common in HEP)
- Downside is missing bending power $\int B \cdot dl$ in forward and backward region putting extreme requirements on tracking (h) and calorimetry (e)

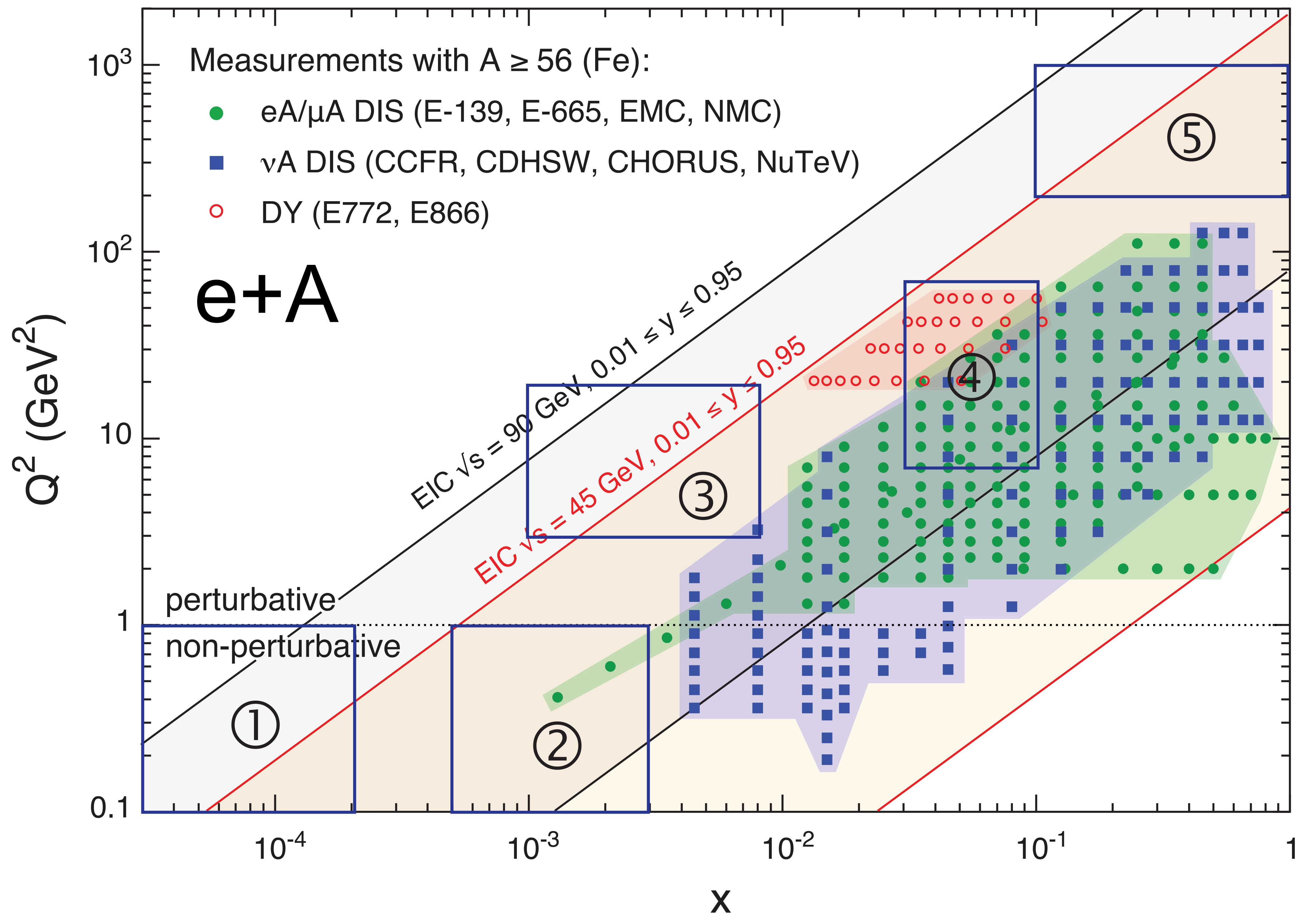
Services

- Central detector will contain ~25 different subsystems
- Substantial integration challenge for power, cooling, and data services
- Hermeticity?!



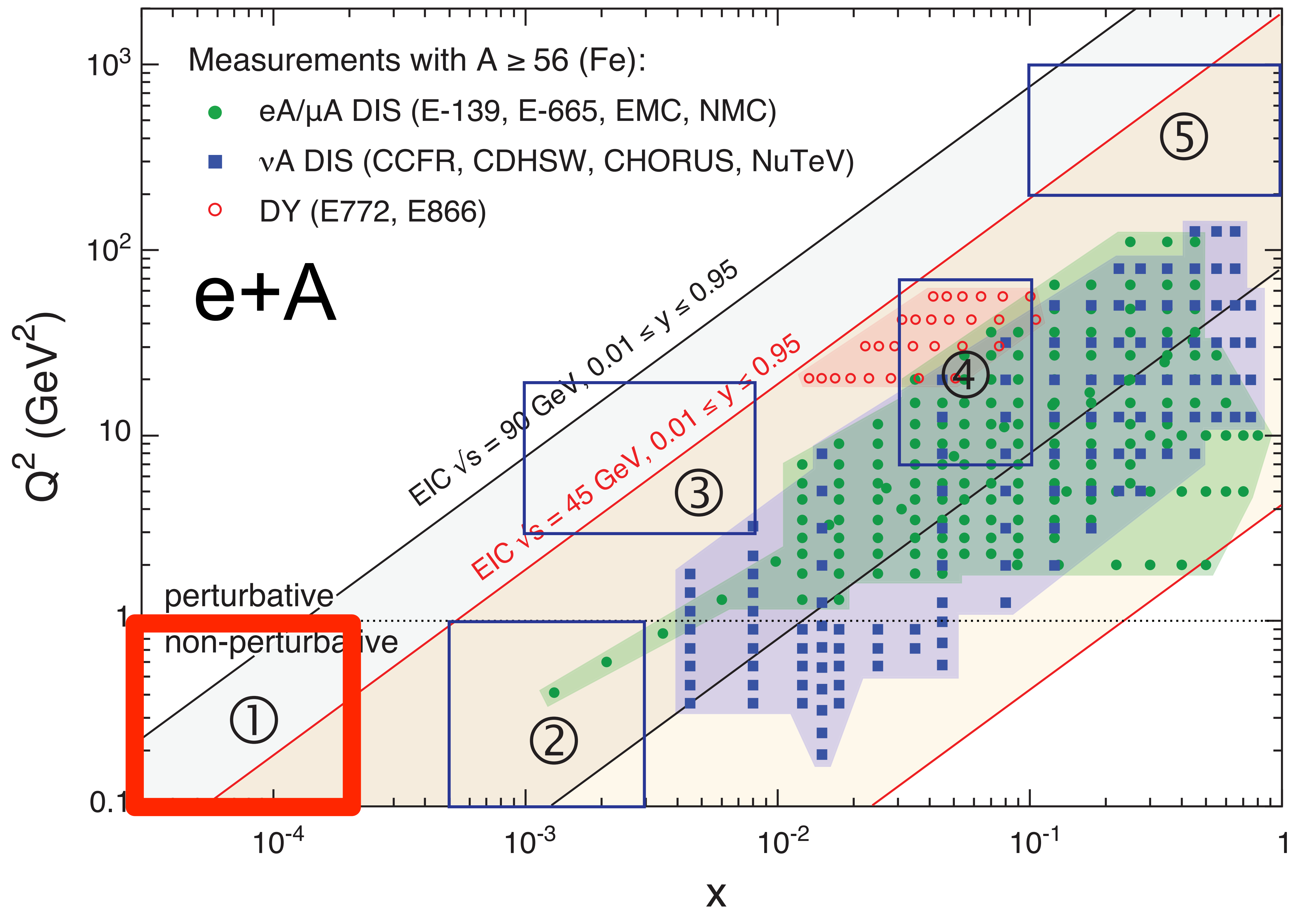
Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2

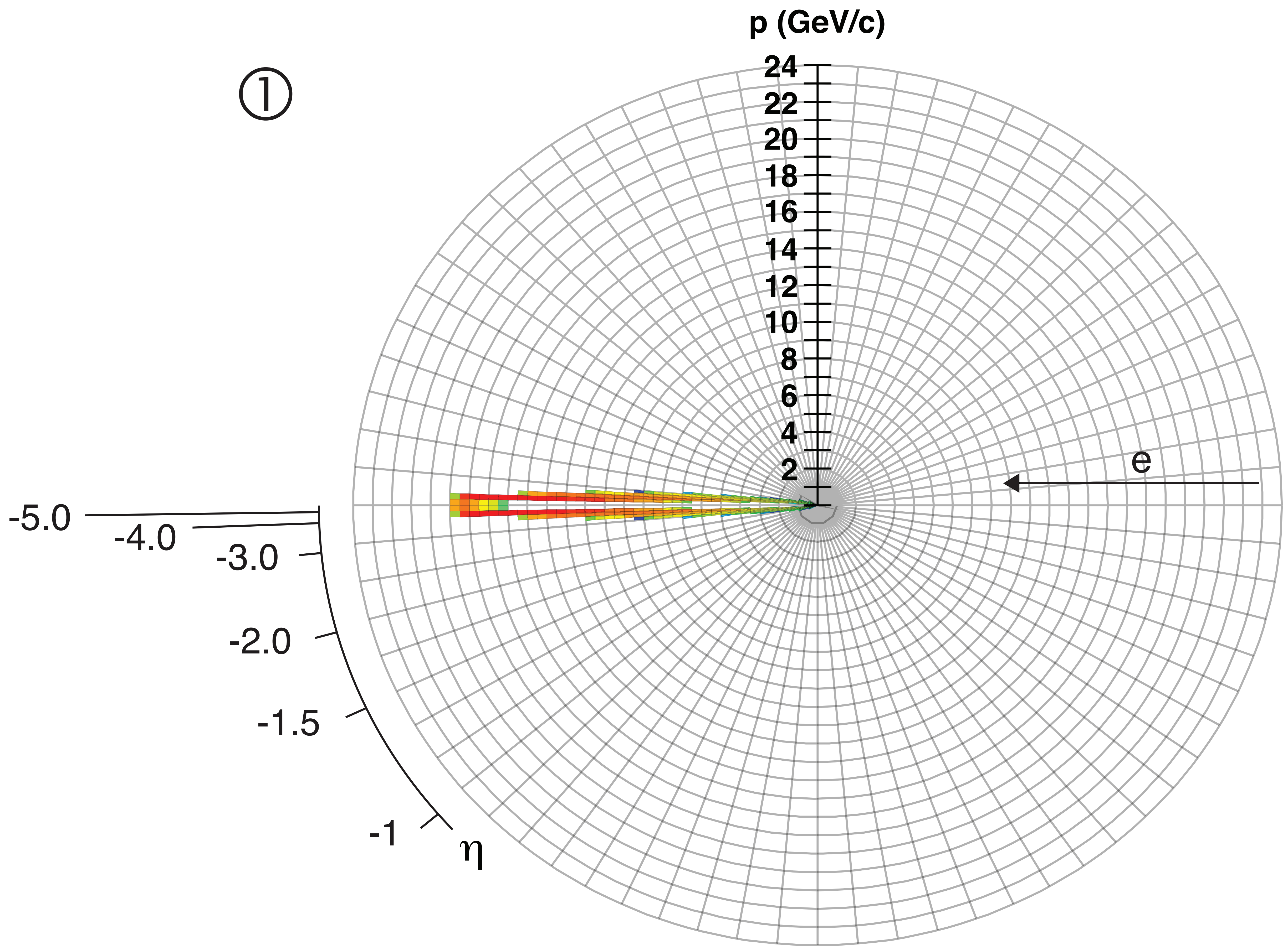


Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2

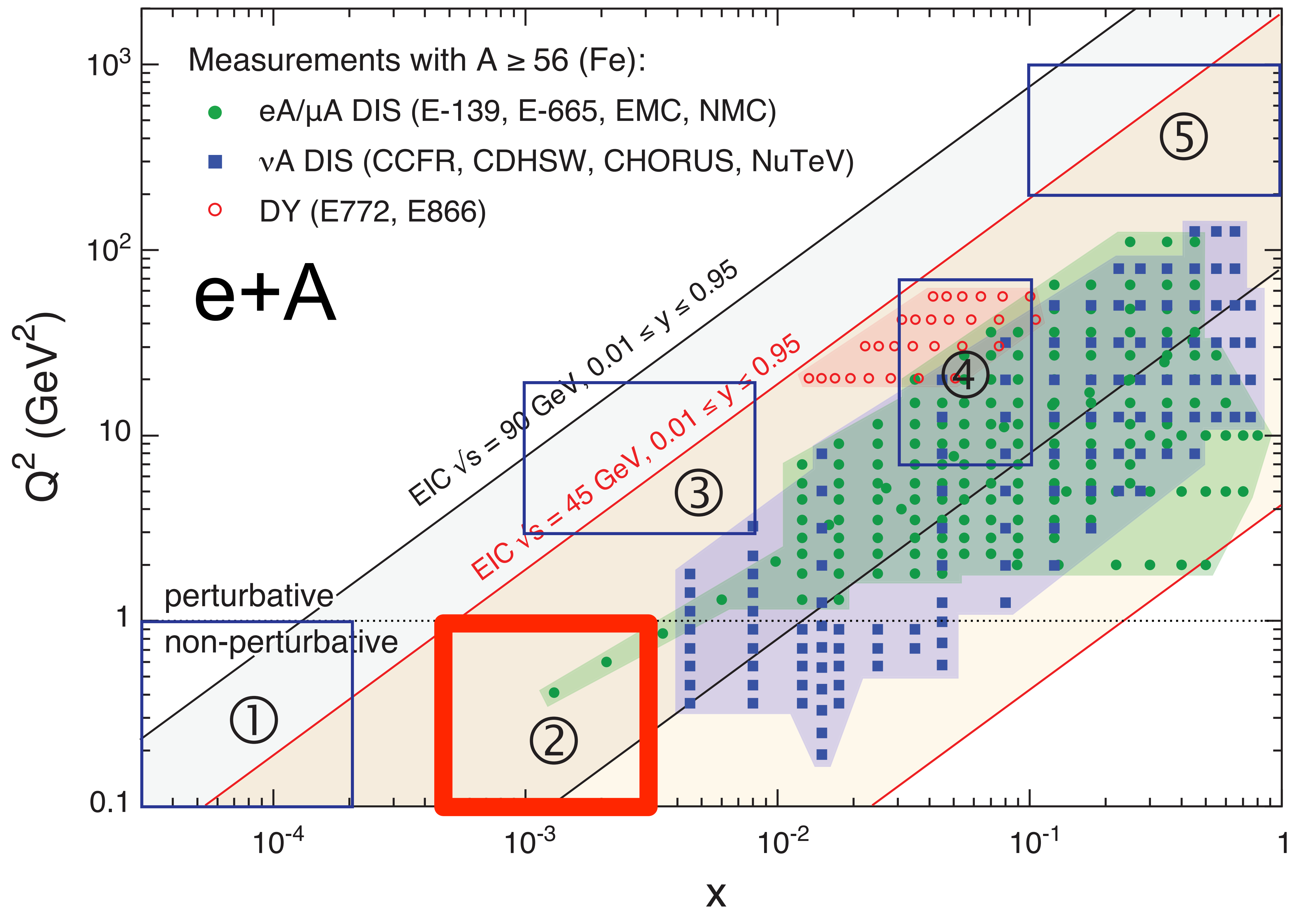


20 GeV on 100 GeV, $0.1 < Q^2 < 1$ GeV^2, $3 \cdot 10^{-5} < x < 2 \cdot 10^{-4}$

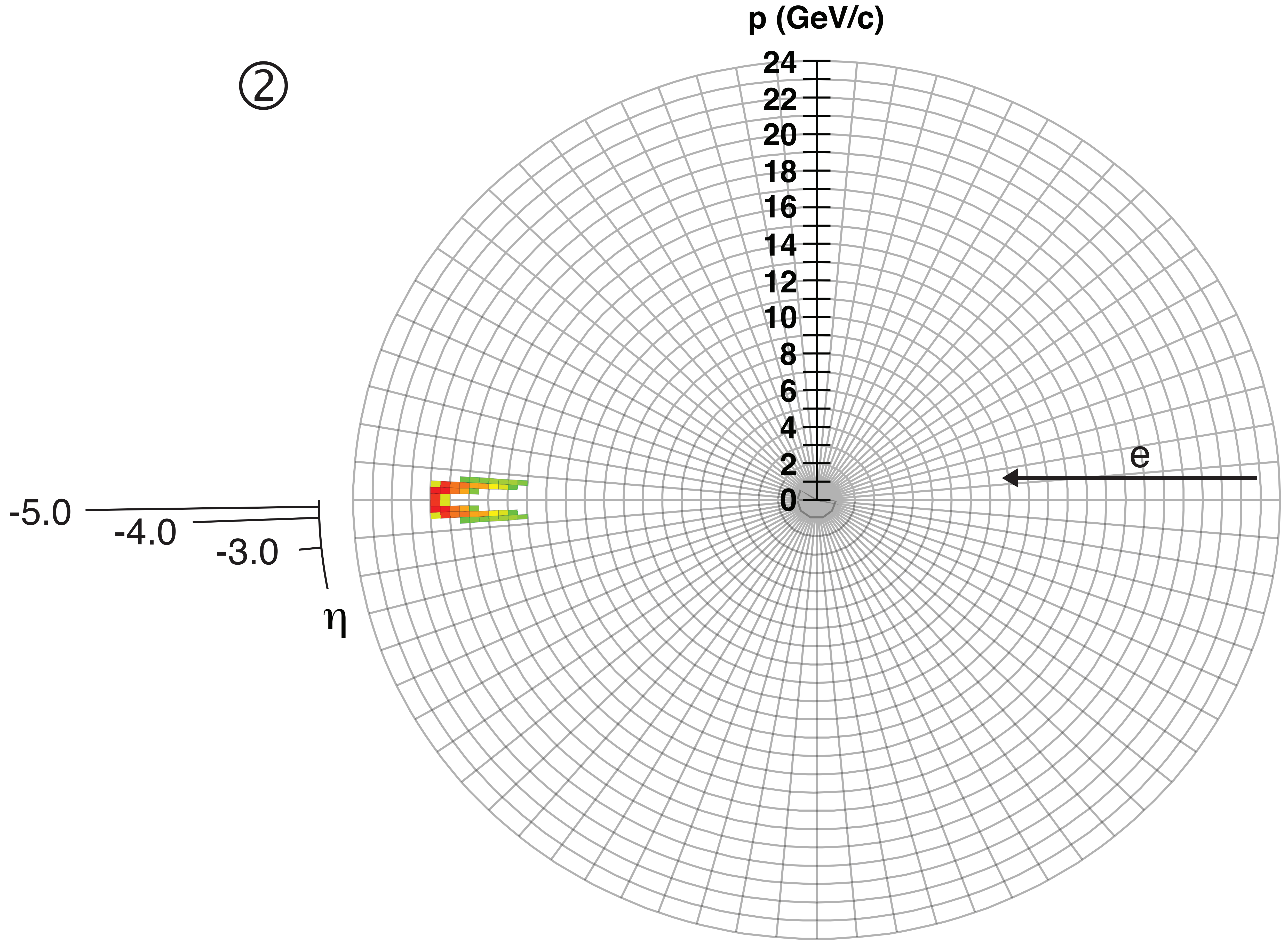


Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2

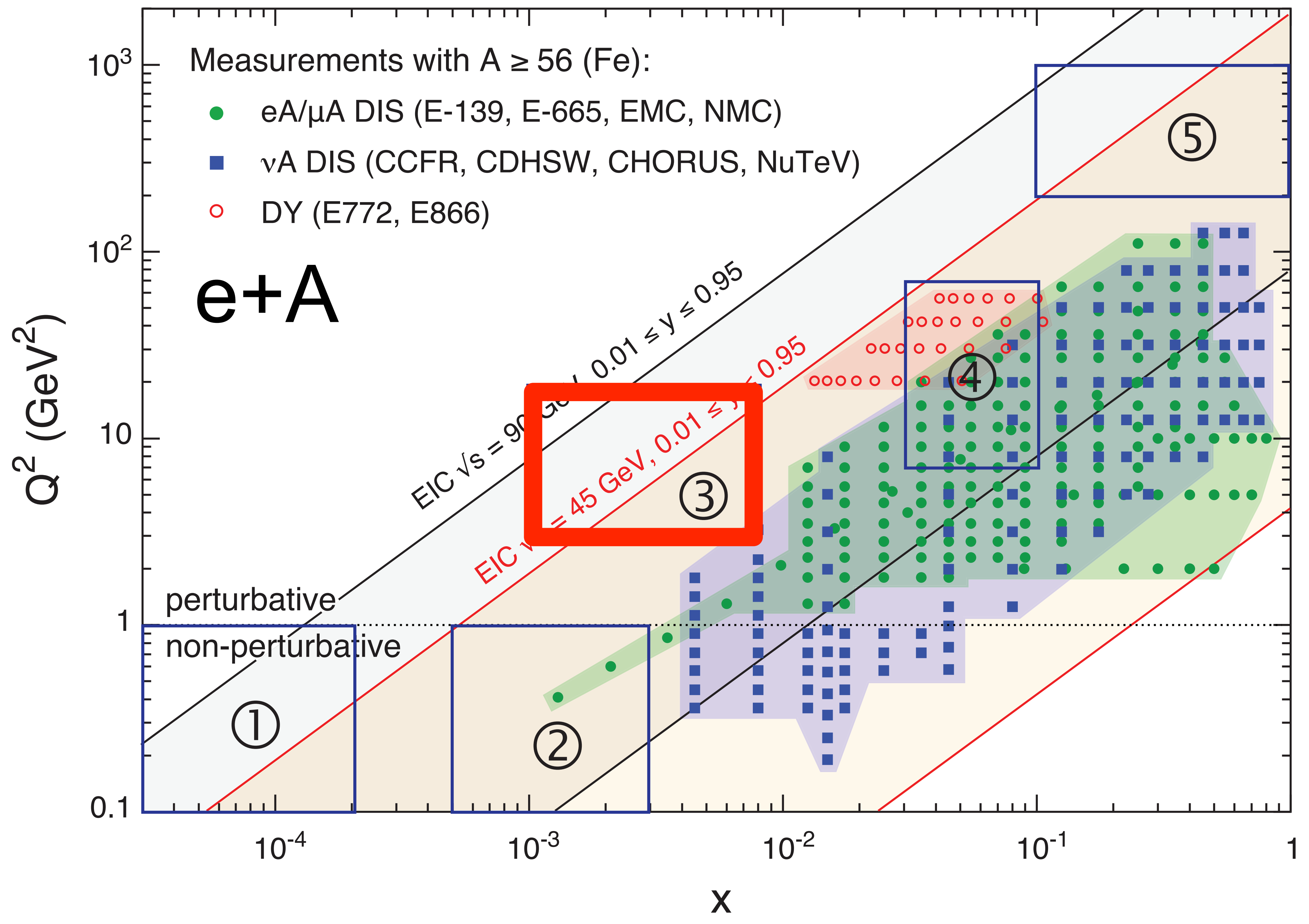


20 GeV on 100 GeV, $0.1 < Q^2 < 1$ GeV^2, $5 \cdot 10^{-4} < x < 3 \cdot 10^{-3}$

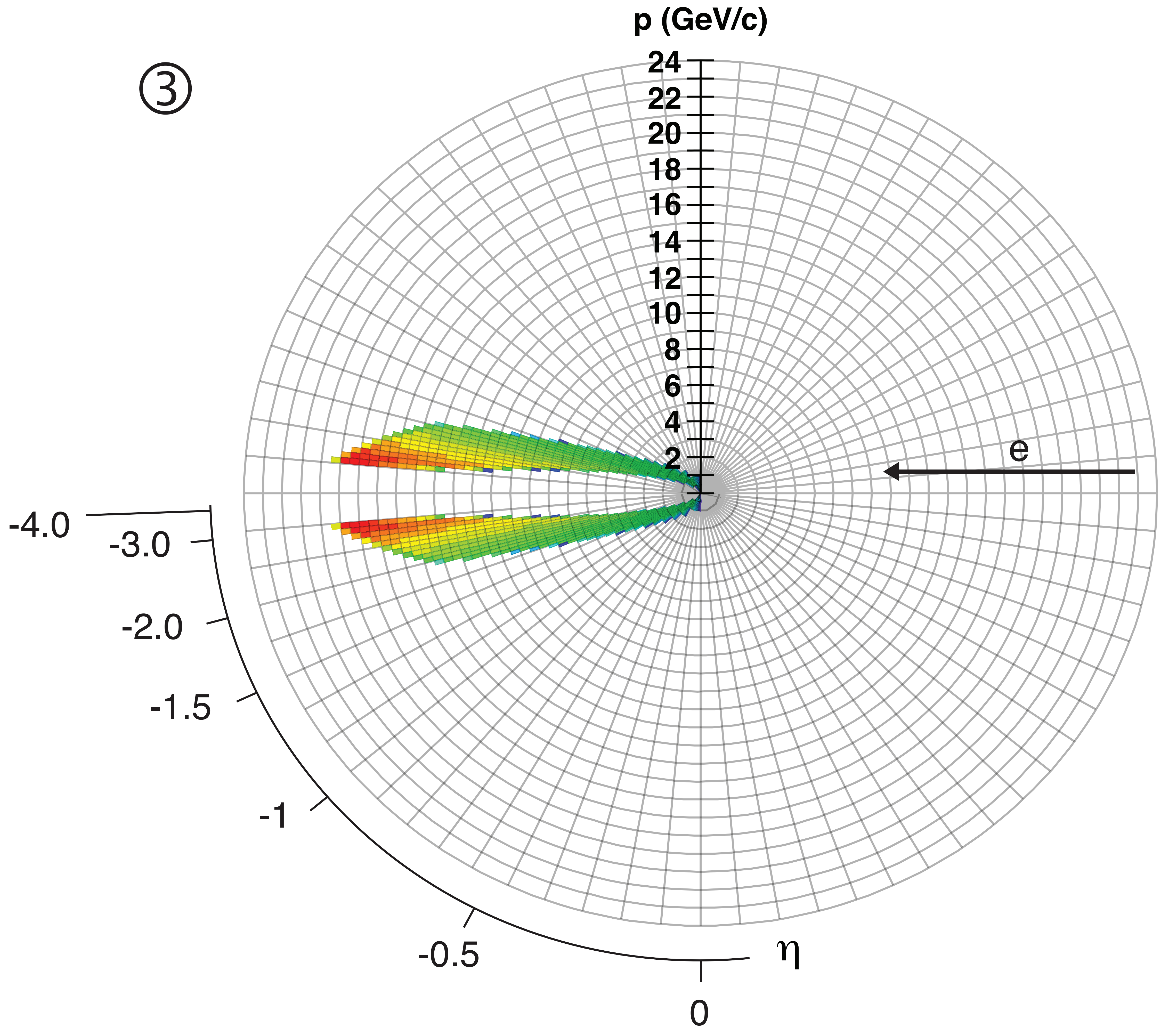


Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2

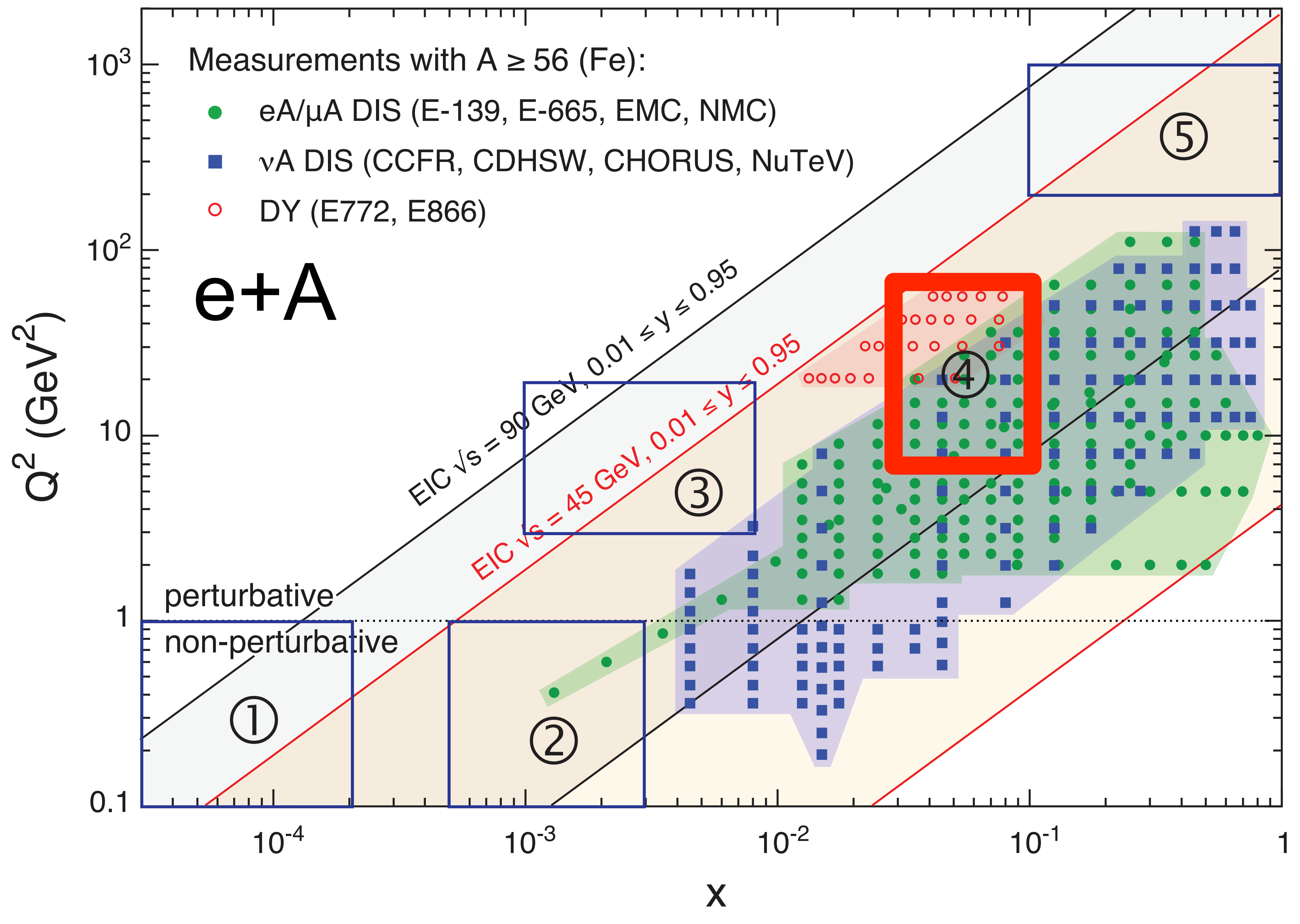


20 GeV on 100 GeV, $3 < Q^2 < 20$ GeV^2, $1\cdot10^{-3} < x < 8\cdot10^{-3}$

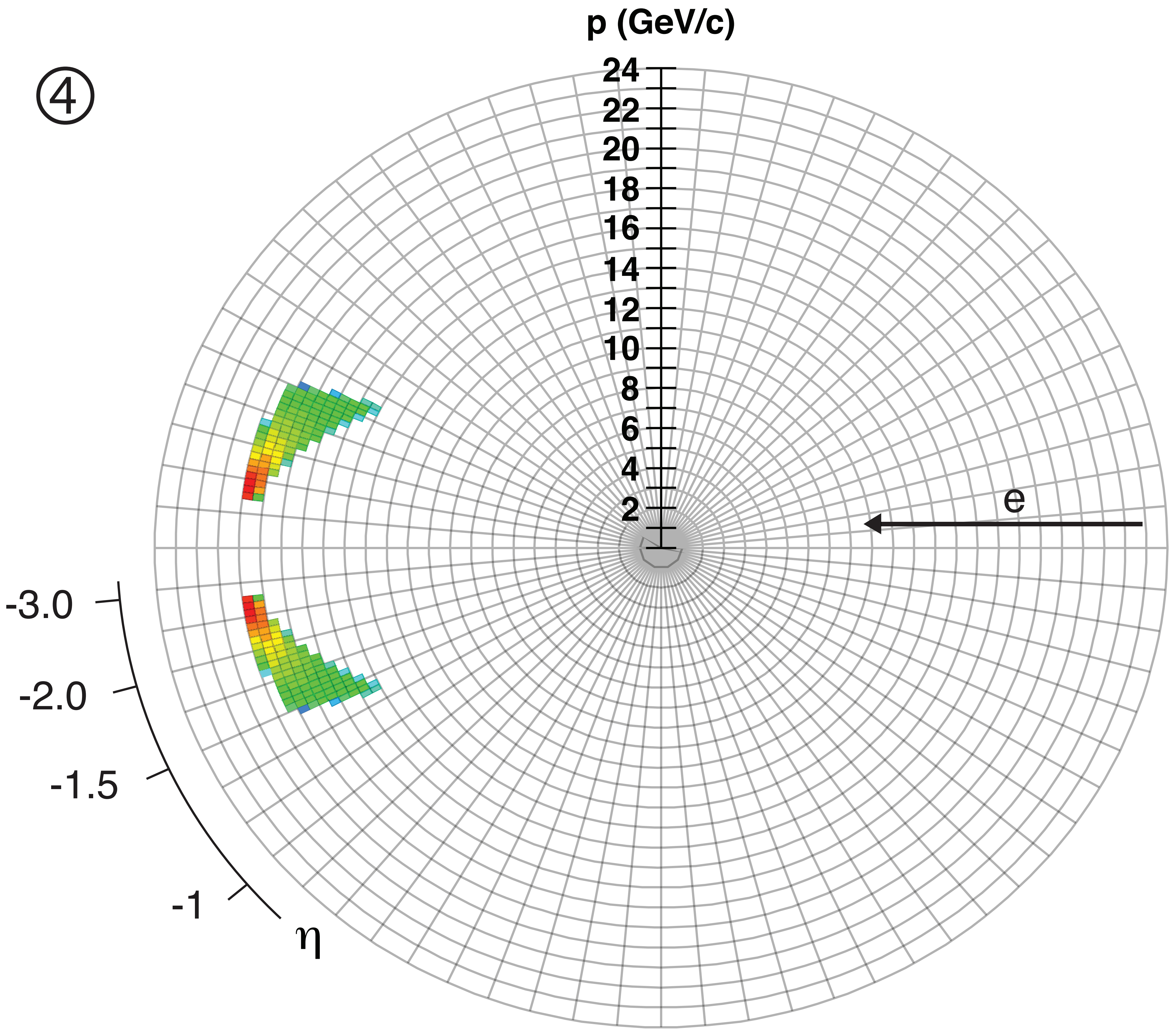


Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2

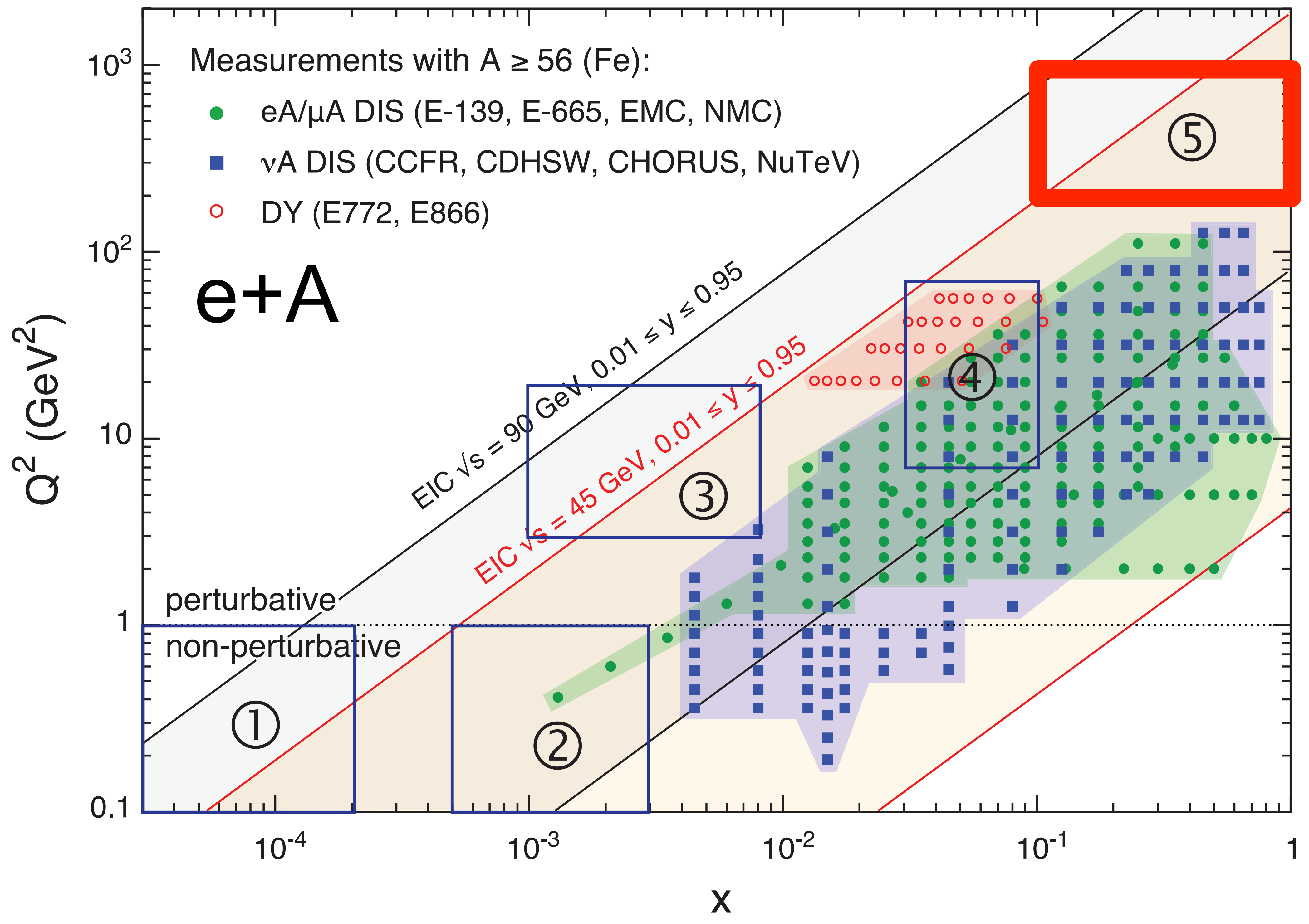


20 GeV on 100 GeV, $7 < Q^2 < 70$ GeV^2, $3{\cdot}10^{-2} < x < 1{\cdot}10^{-1}$

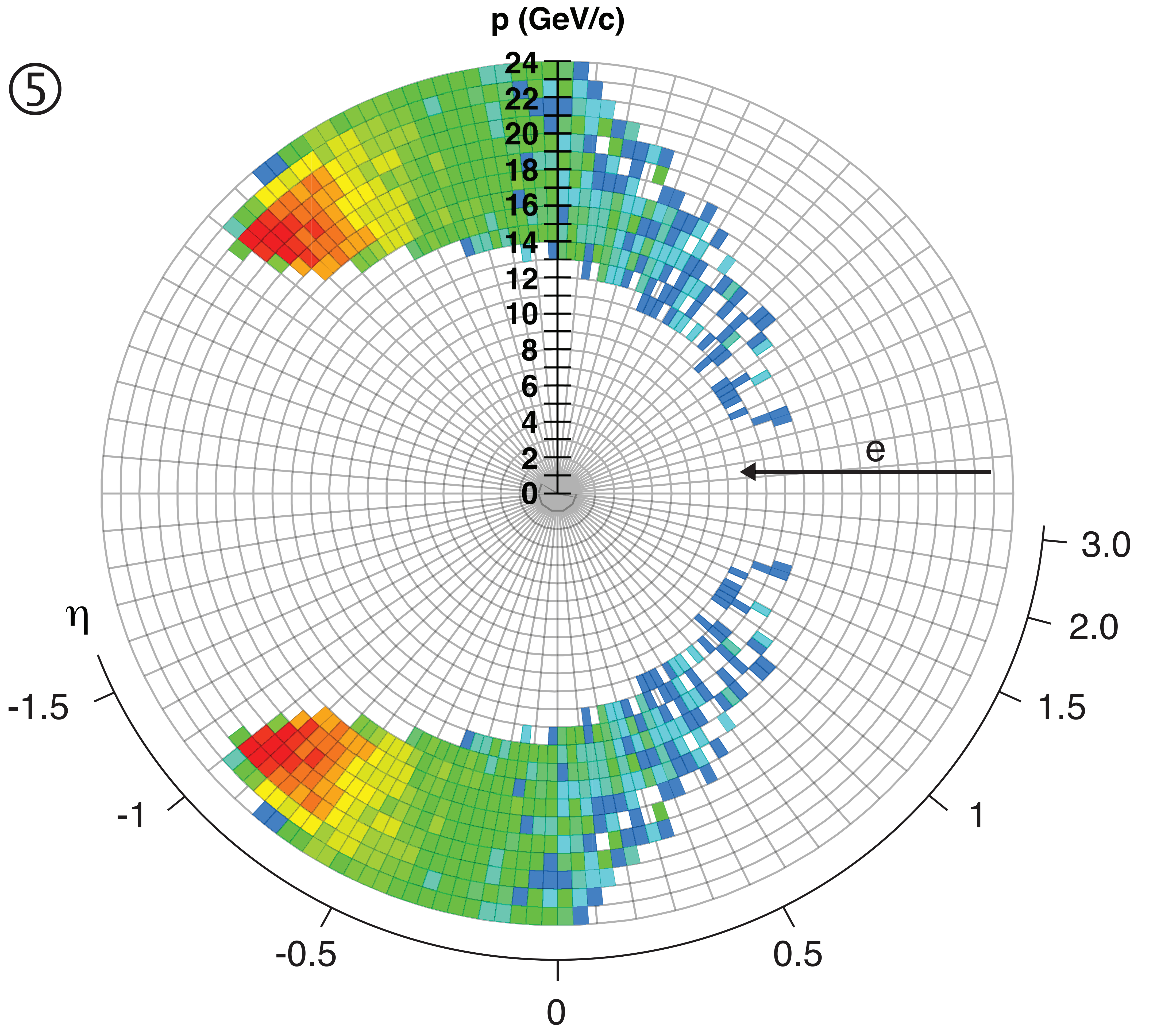


Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables x, y, Q^2



20 GeV on 100 GeV, 200 < Q^2 < 1000 GeV^2, 0.1 < x < 1

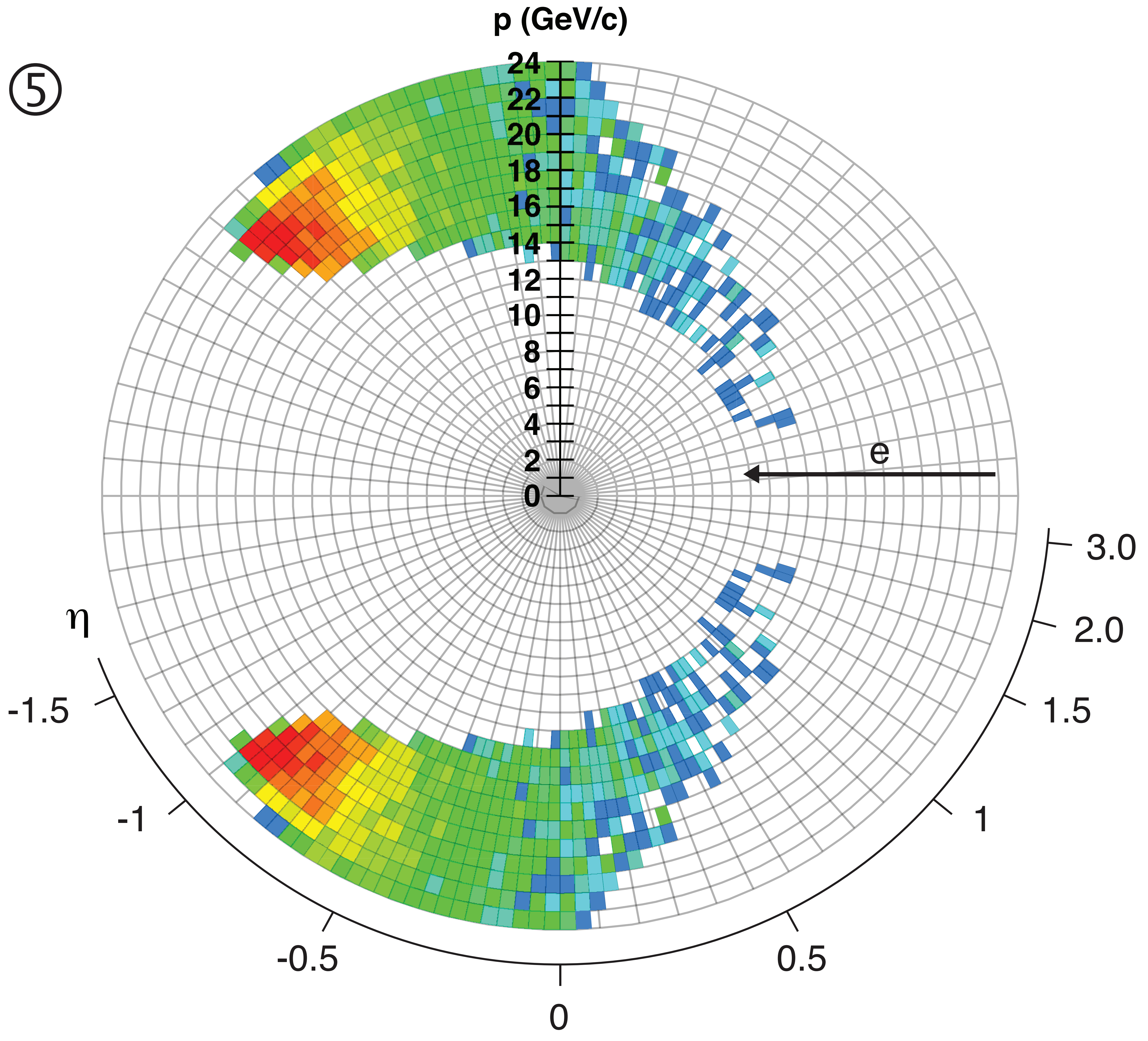


Inclusive (All): Scattered Electron Requirements

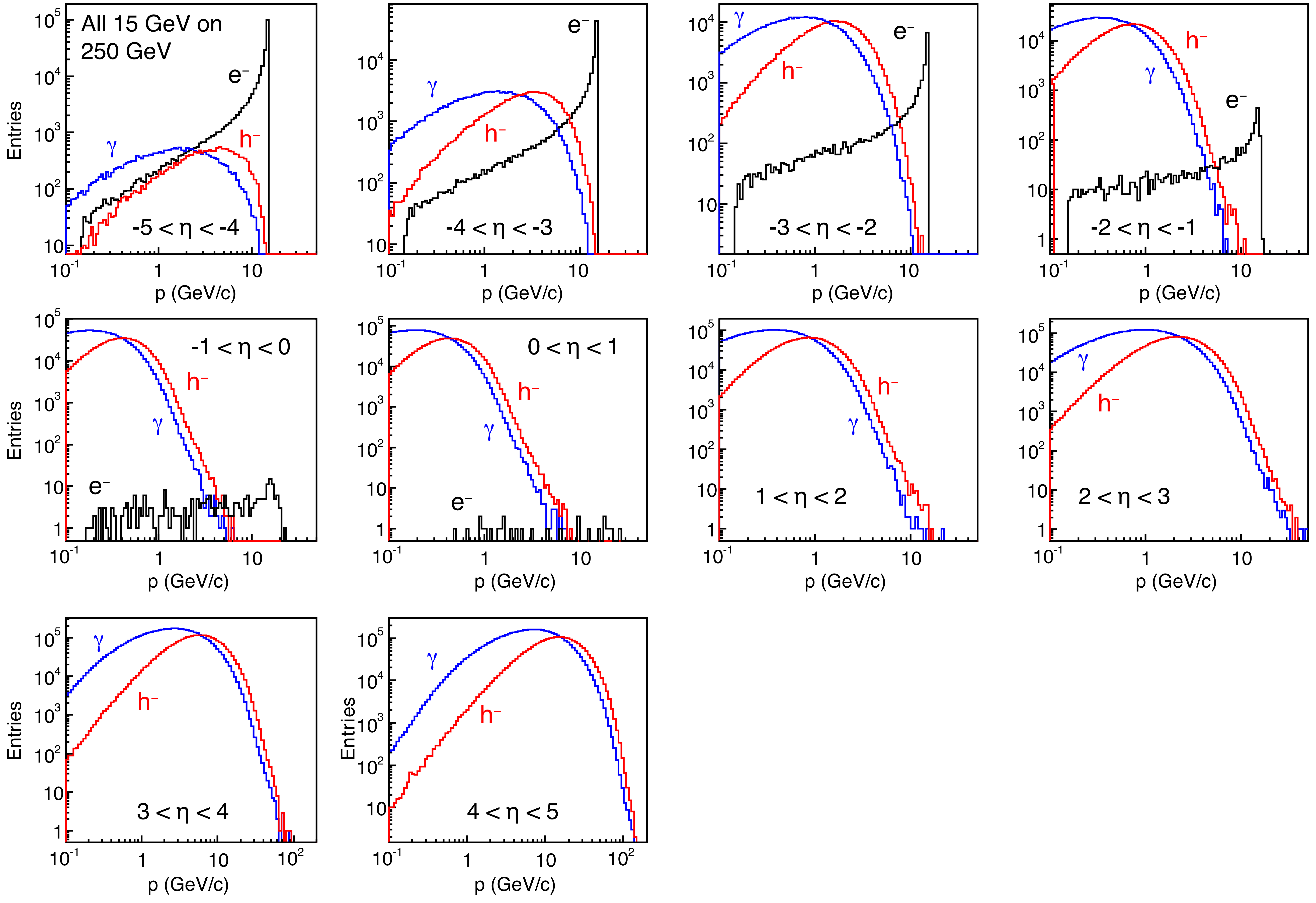
The energy and angle of scatter electron gives key variables x, y, Q^2

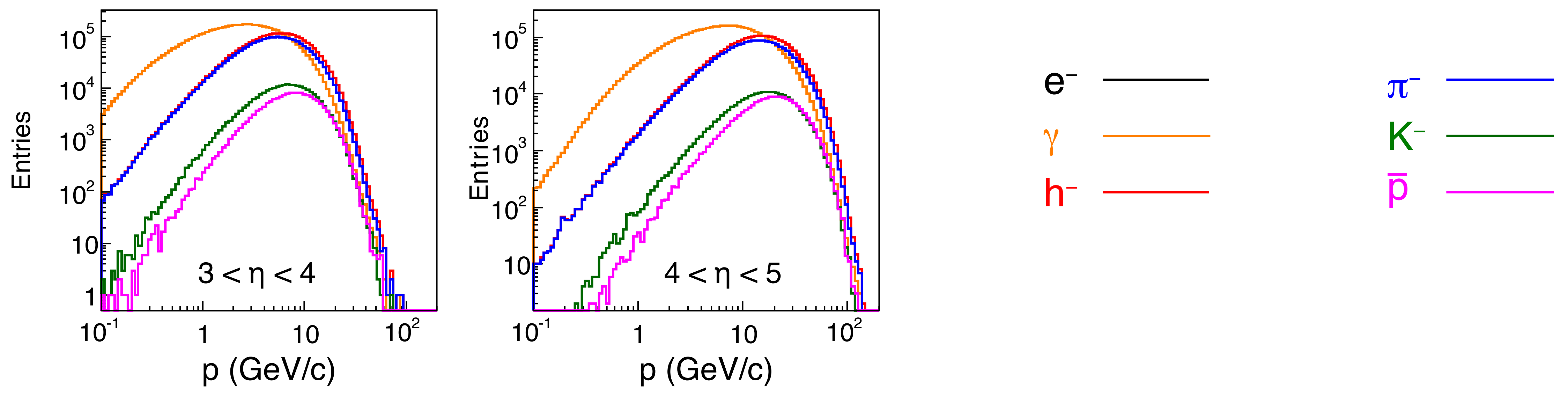
- e' Measurement Requires:
  - excellent electron identification (e/h)
  - equal rapidity coverage for tracking and calorimeter
  - low material budget to reduce bremsstrahlung
  - momentum/energy and angular resolution are critical

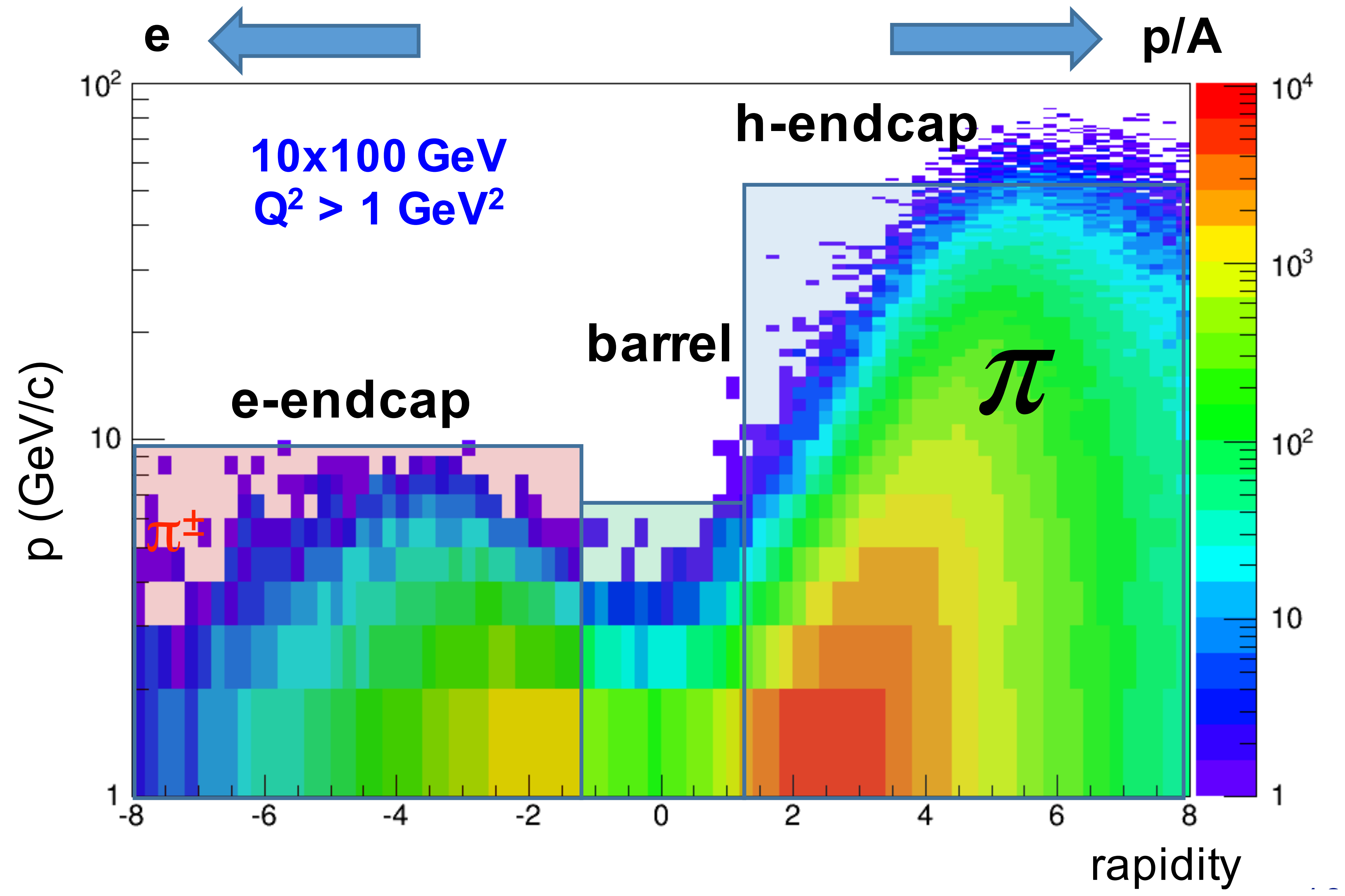
20 GeV on 100 GeV, $200 < Q^2 < 1000$ GeV^2, $0.1 < x < 1$



SIDIS: Hadron Identification Requirements





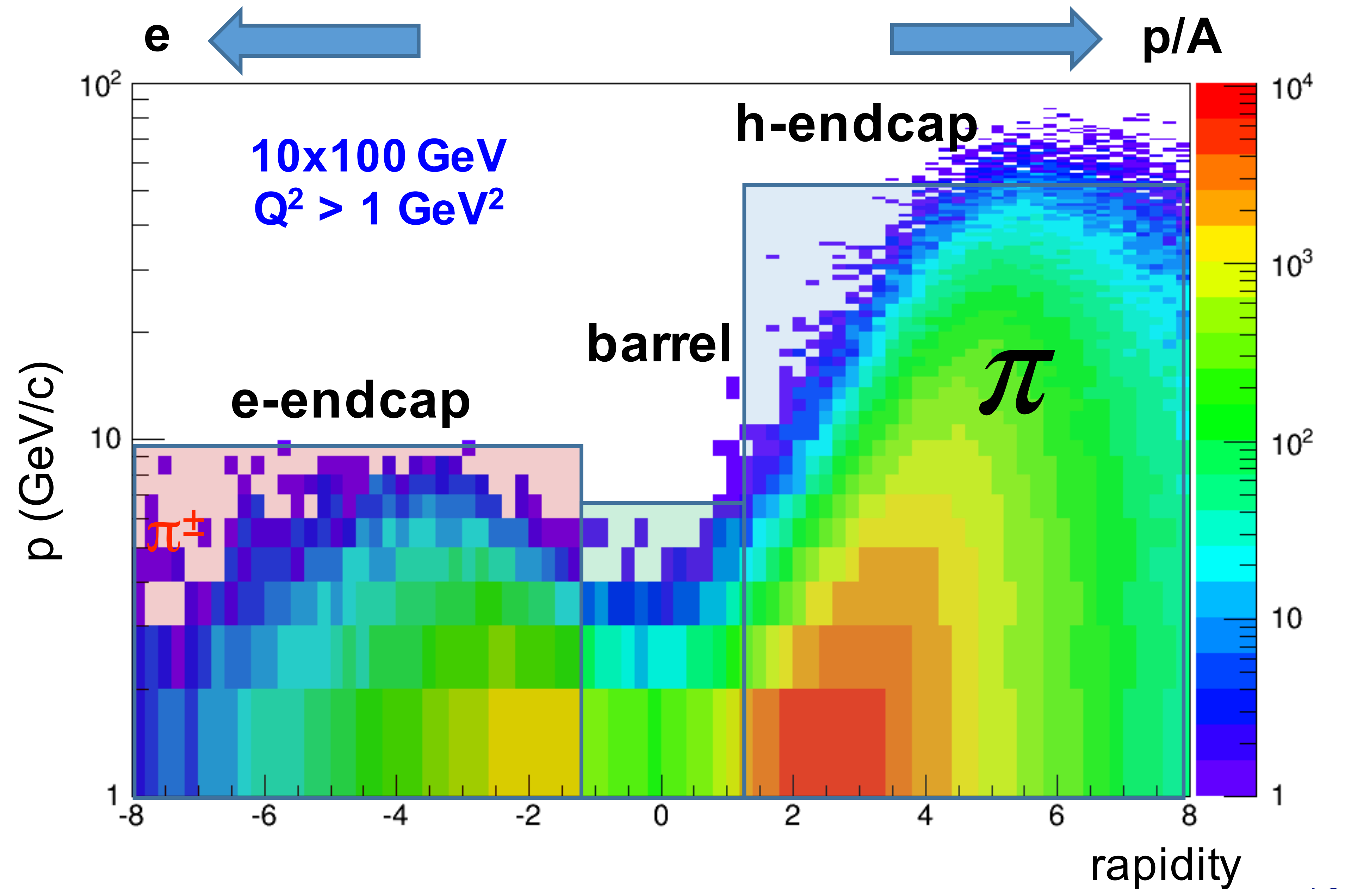


- Physics Requirements
  - $\pi^{\pm}, K^{\pm}, p^{\pm}$ separation over a wide range $|\eta| \leq 3.5$
- Strong Momentum–η correlation
  - -5 < η < 2: 0.2 < p < 10 GeV/c
  - 2 < η < 5: 0.2 < p < 50 GeV/c

SIDIS: Hadron Identification Requirements

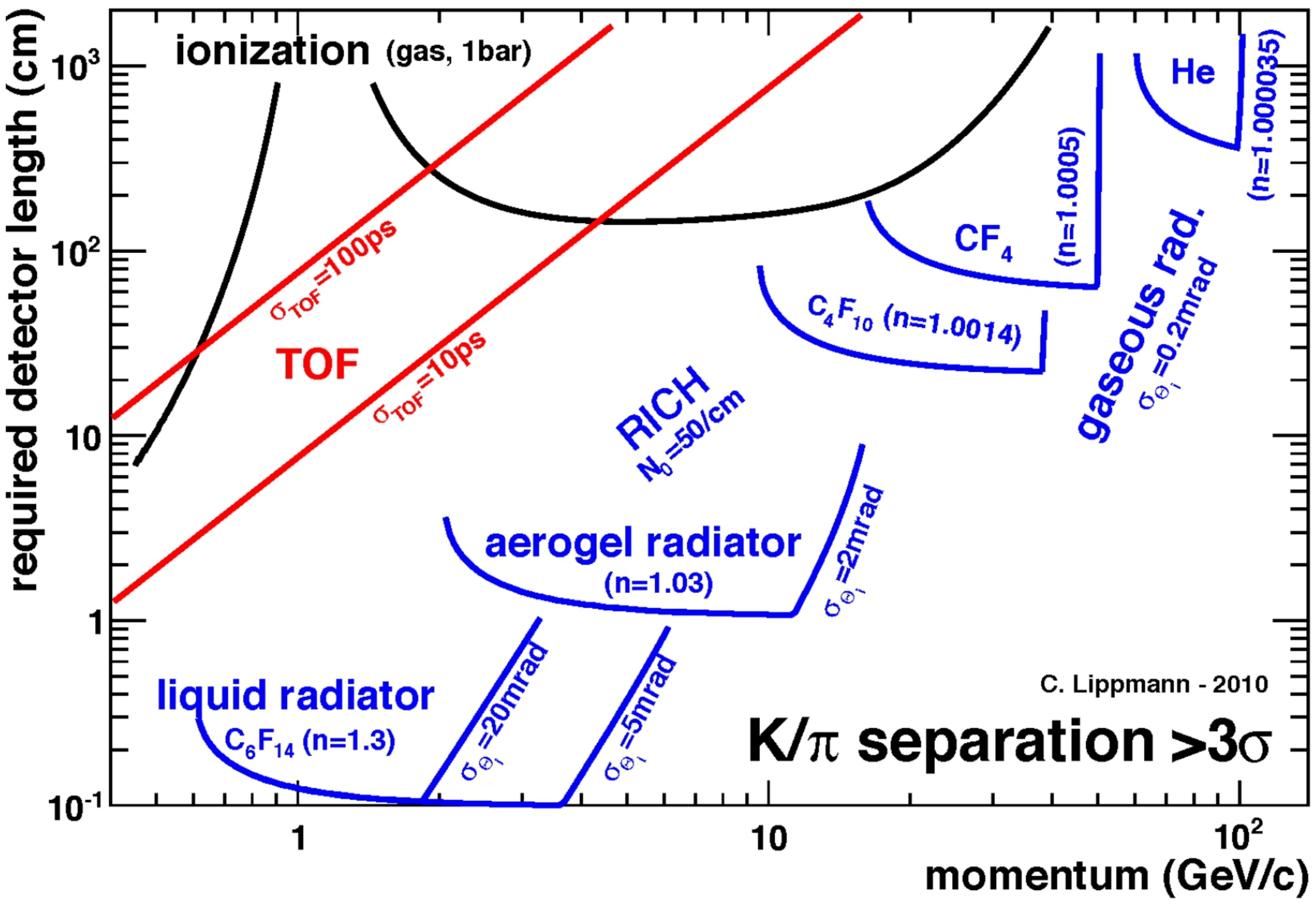
Major Challenge for EIC Detectors: PID

- Separation needed
  - $\pi/K \sim 3-4\sigma$
  - $K/p > 1\sigma$
- Hadron-cut off:
  - 1T-Magnet ⇒ p_T > 200 MeV/c
  - 3T-Magnet ⇒ p_T > 500 MeV/c



- Physics Requirements
  - $\pi^{\pm}, K^{\pm}, p^{\pm}$ separation over a wide range $|\eta| \leq 3.5$
- Strong Momentum–η correlation
  - -5 < η < 2: 0.2 < p < 10 GeV/c
  - 2 < η < 5: 0.2 < p < 50 GeV/c

Particle ID (PID) Techniques



- EIC will need for most of the physics a resolution of
  - $\pi/K \sim 3-4\sigma$
  - $K/p > 1\sigma$
- Need more than one technology to cover the entire momentum ranges at different rapidities

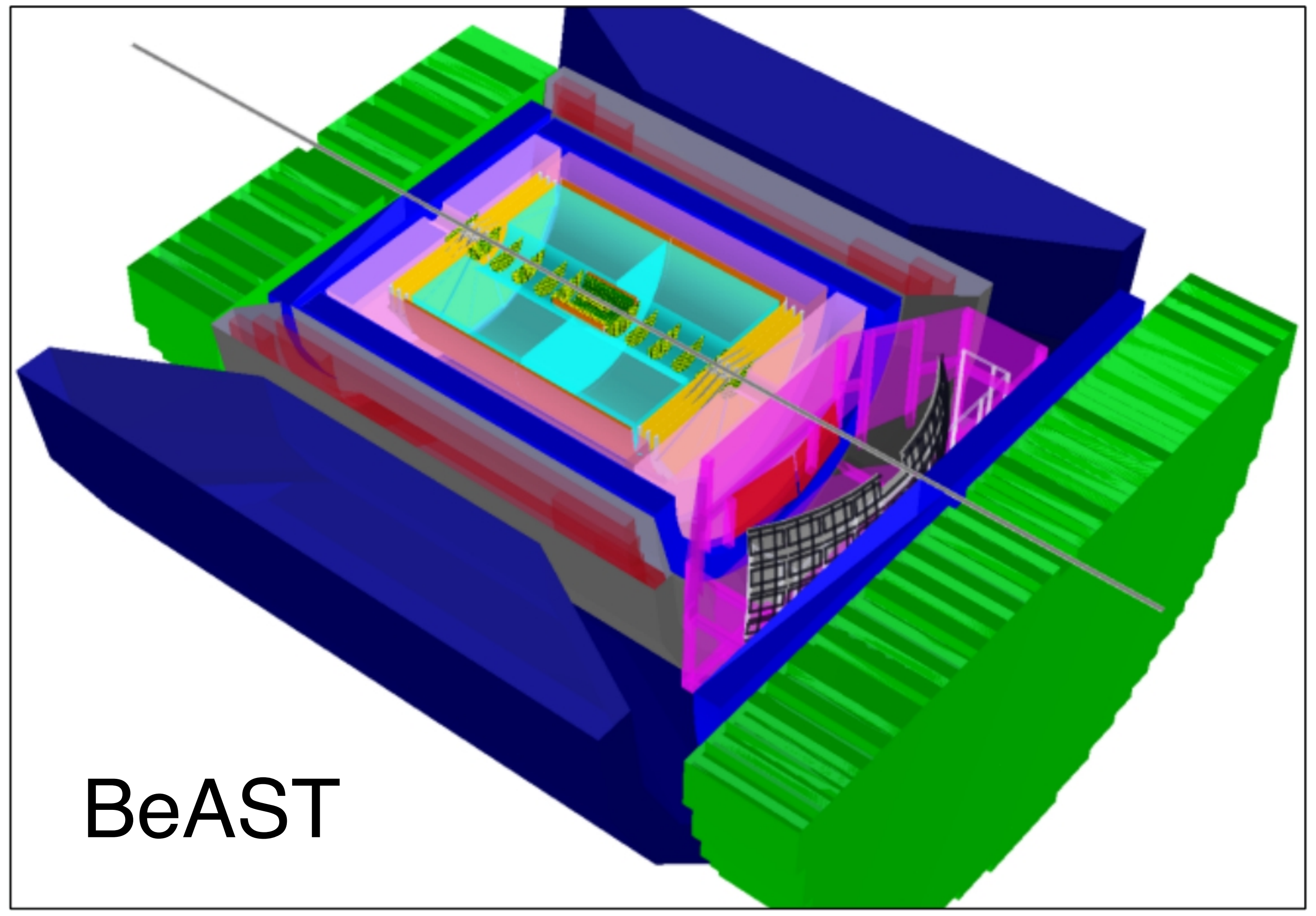
- Need absolute particle numbers at high purity and low contamination
- EIC PID needs are more demanding then at most collider detector

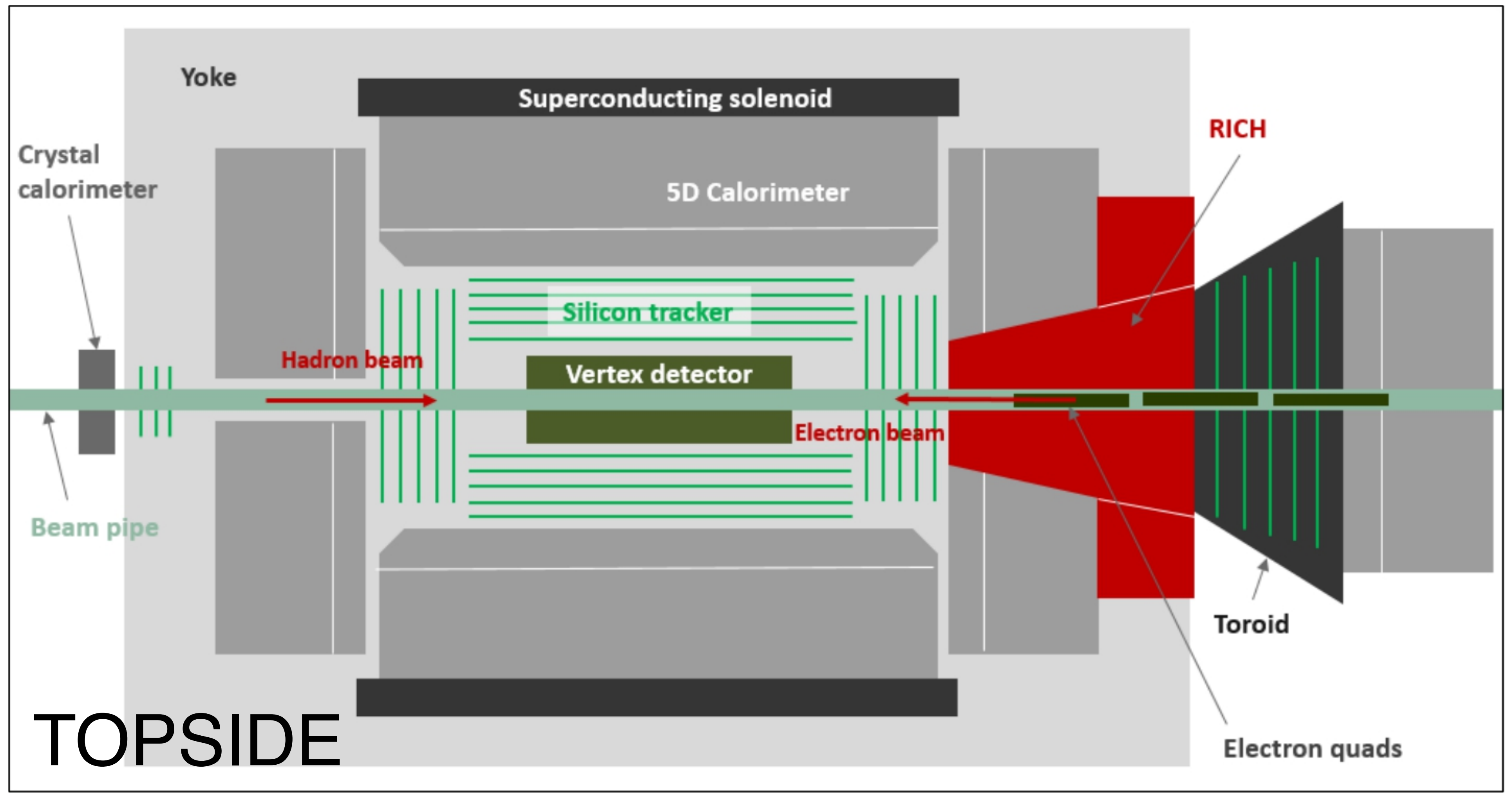
Brief Review of EIC Detector Requirements

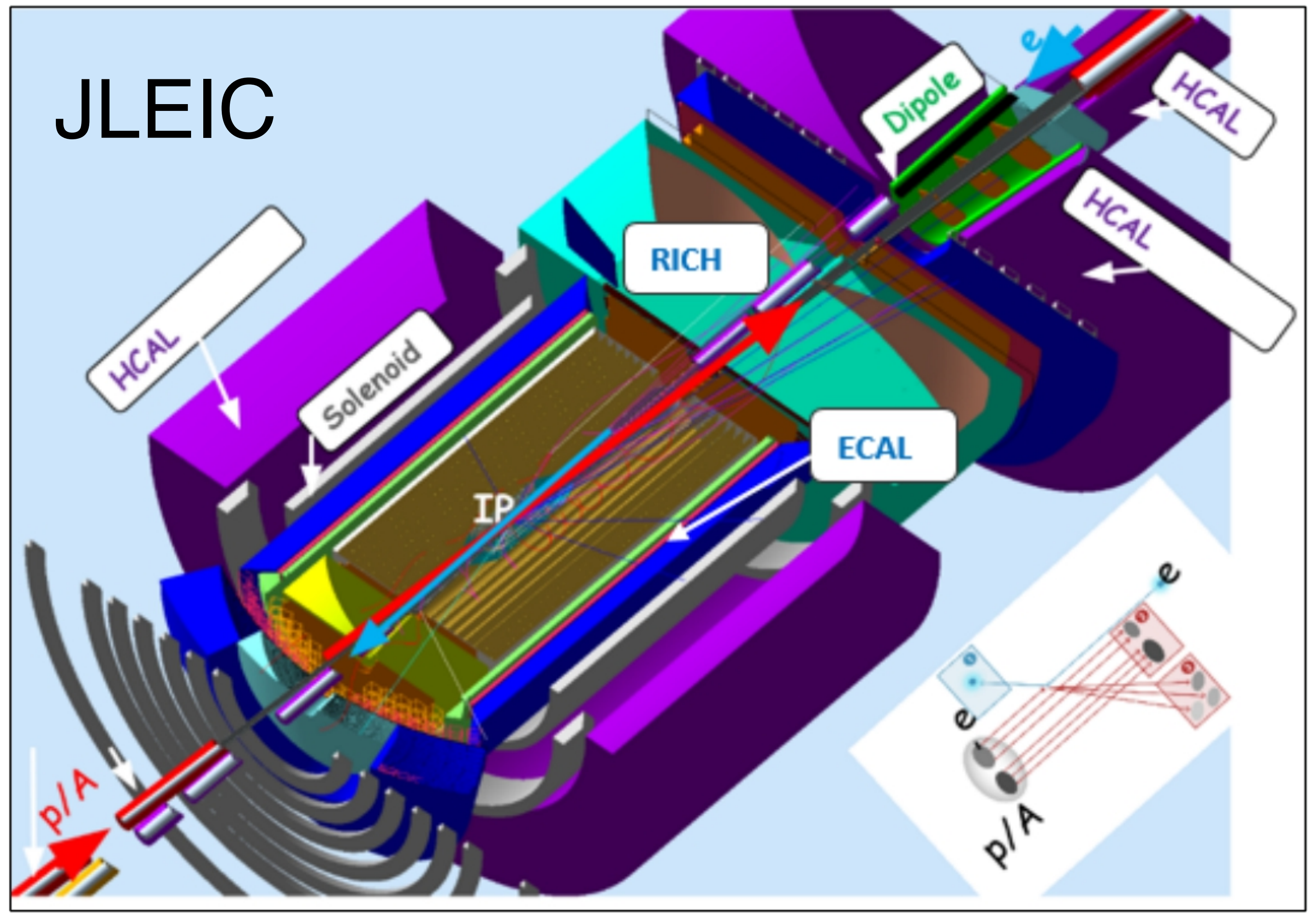
- Hermetic detector, low mass inner tracking
- Moderate radiation hardness requirements
- Electron measurement & jets in approx. -4 < η < +4
- Good momentum resolution
  - central: $\sigma(p)/p = 0.05\,\%\,p \oplus 0.5\,\%$
  - fwd/bkd: $\sigma(p)/p = 0.1\% \oplus 0.5\,\%$
- Good impact parameter resolution: $\sigma = 5 \oplus 15/p\sin^{3/2}\theta\ (\mu\text{m})$
- Excellent EM resolution
  - central: $\sigma(E)/E = 10\,\%/\sqrt{E}$
  - backward: $\sigma(E)/E < 2\,\%/\sqrt{E}$
- Good hadronic energy resolution
  - forward: $\sigma(E)/E \approx 50\,\%/\sqrt{E}$
- Excellent PID π/K/p
  - forward: up to 50 GeV/c
  - central: up to 8 GeV/c
  - backward: up to 7 GeV/c
- Low pile-up, low multiplicity, data rate ~500kHz (full lumi)

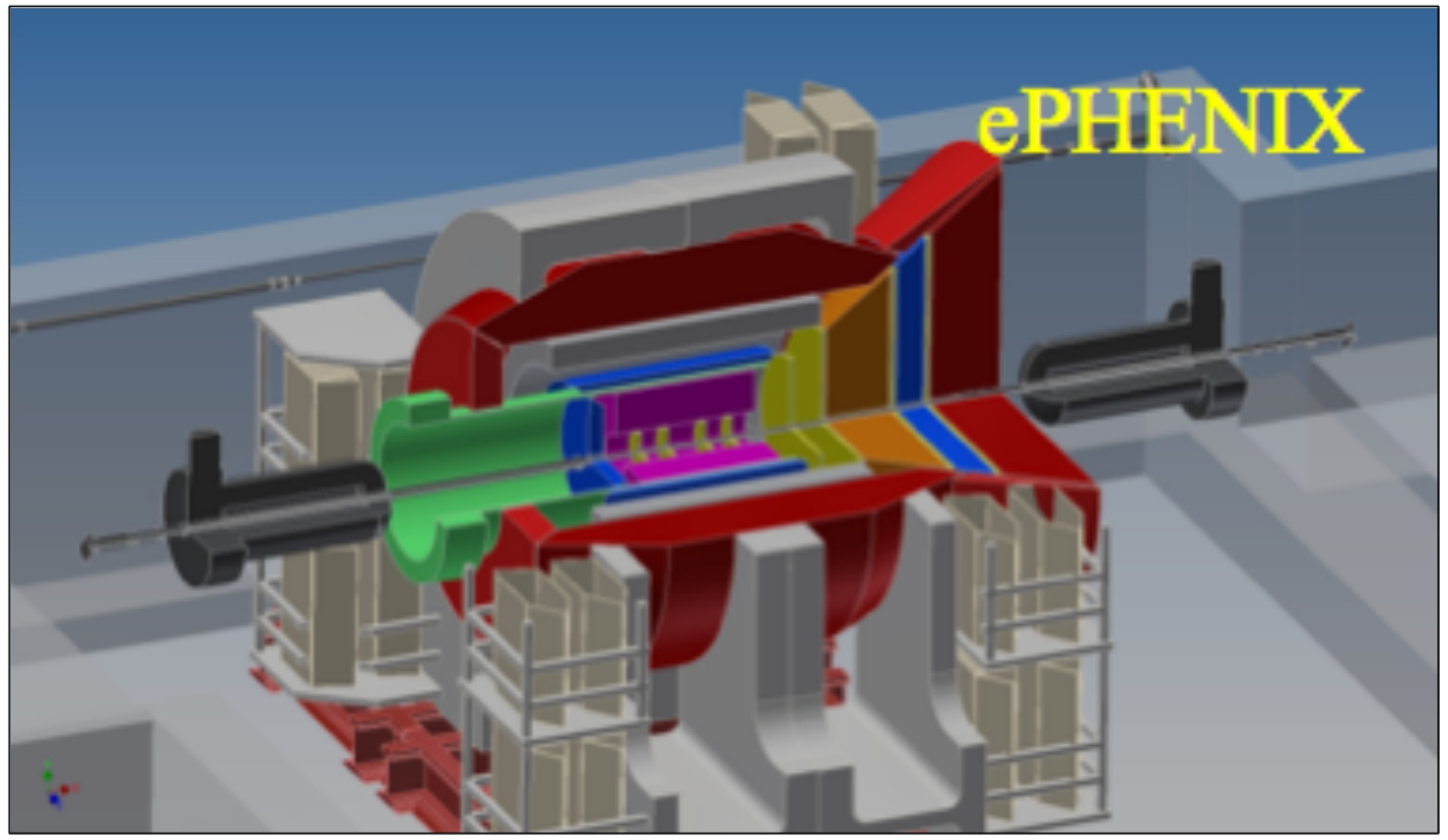
Hermeticity, low mass, and PID requirements makes EIC detector design challenging

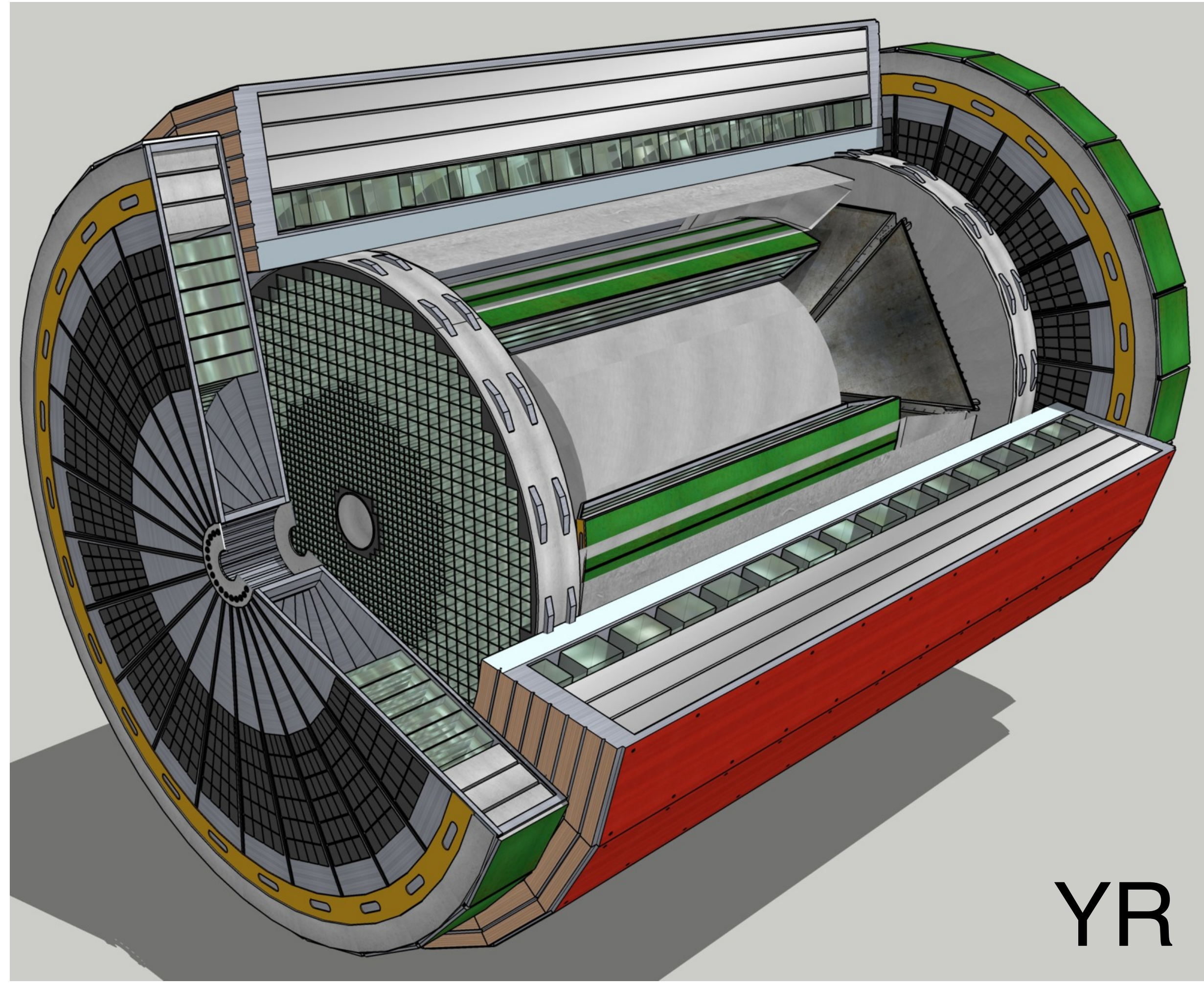
Many Ideas Early On …







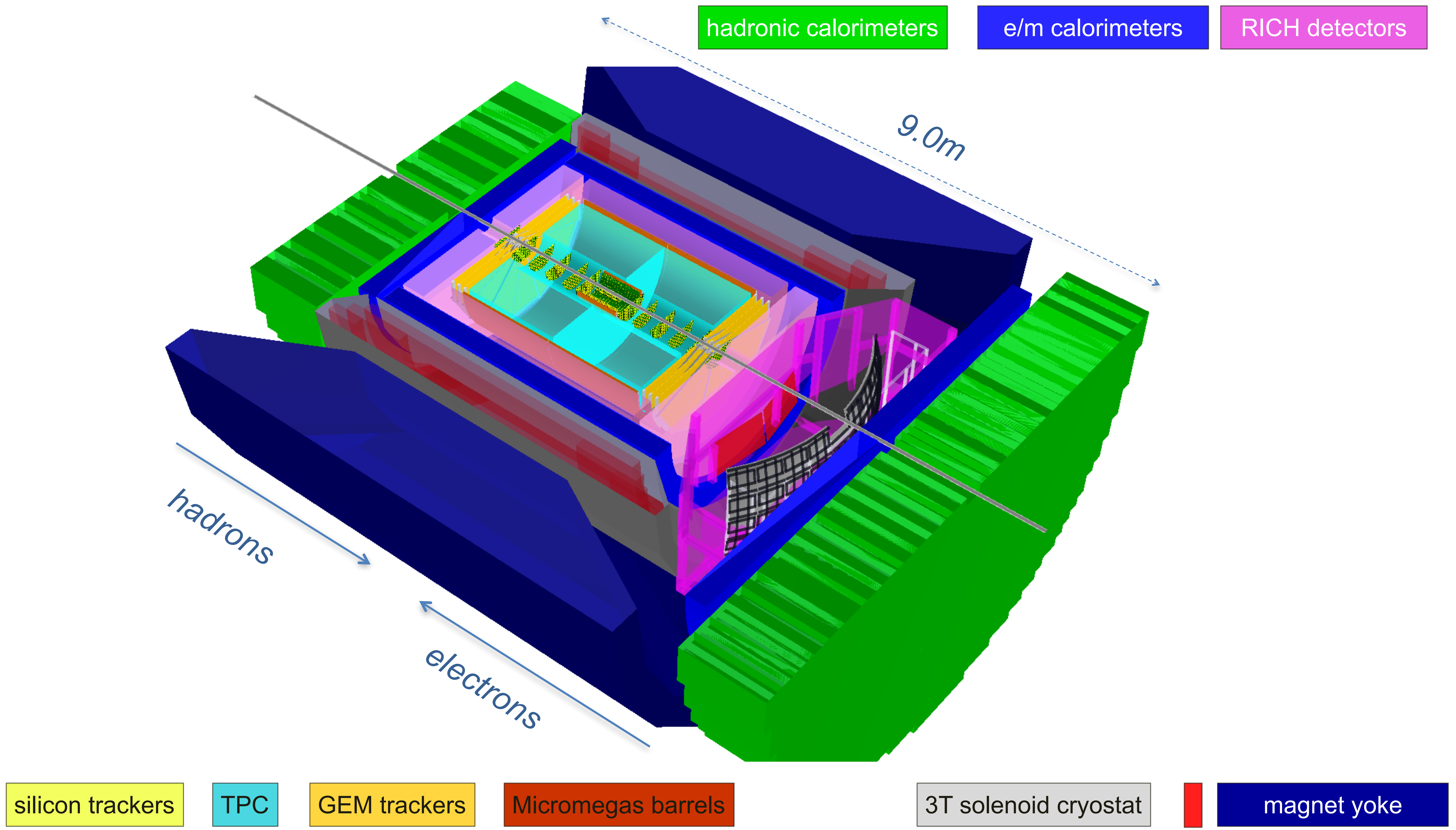




- Many ideas from different corners of the community
- Yellow Report started to focus on more mature designs

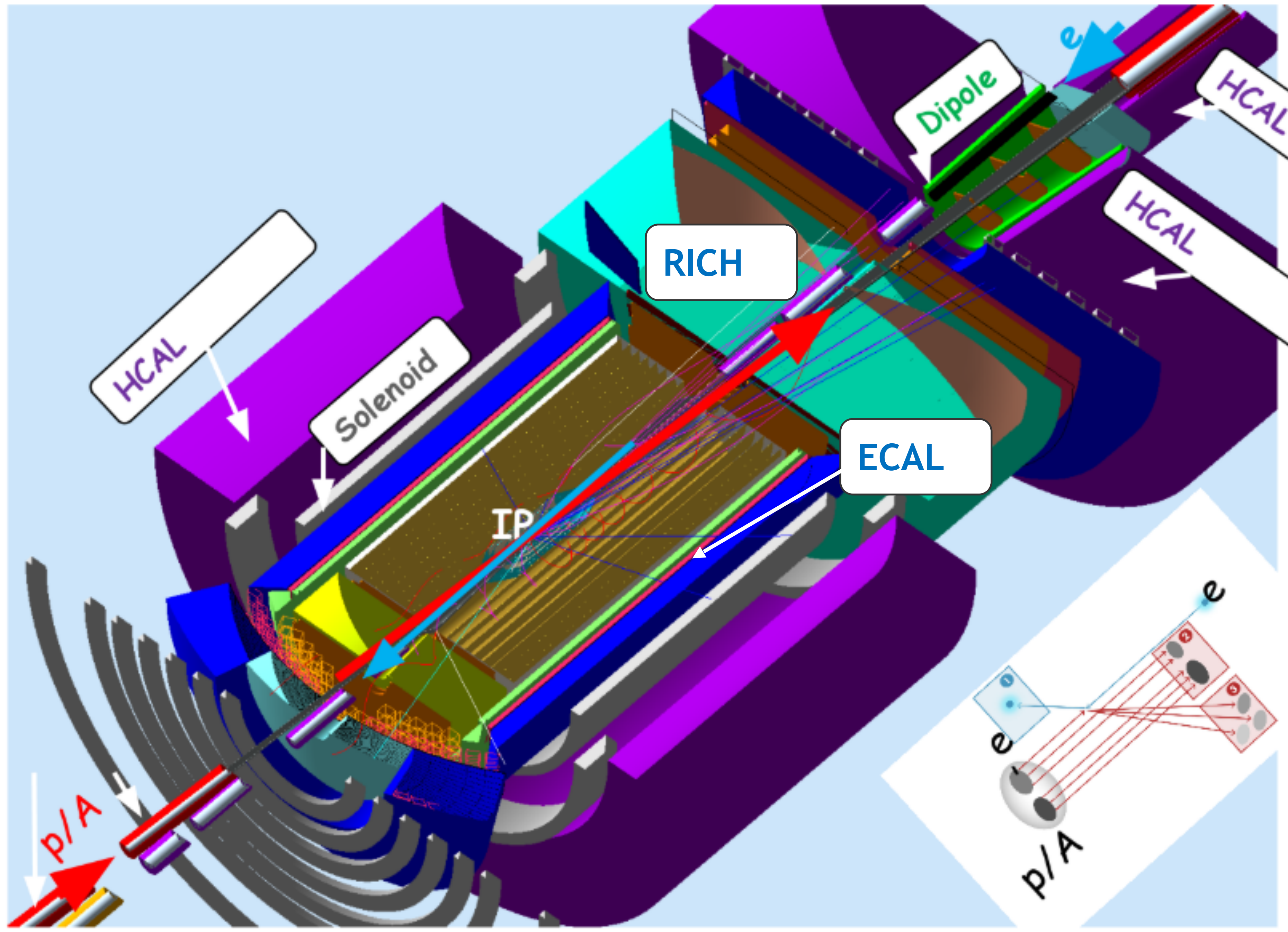
BEAST (Brookhaven eA Solenoidal Tracker)

-3.5 < η < 3.5: Tracking & e/m Calorimetry (hermetic coverage)



JLEIC Concept Detector

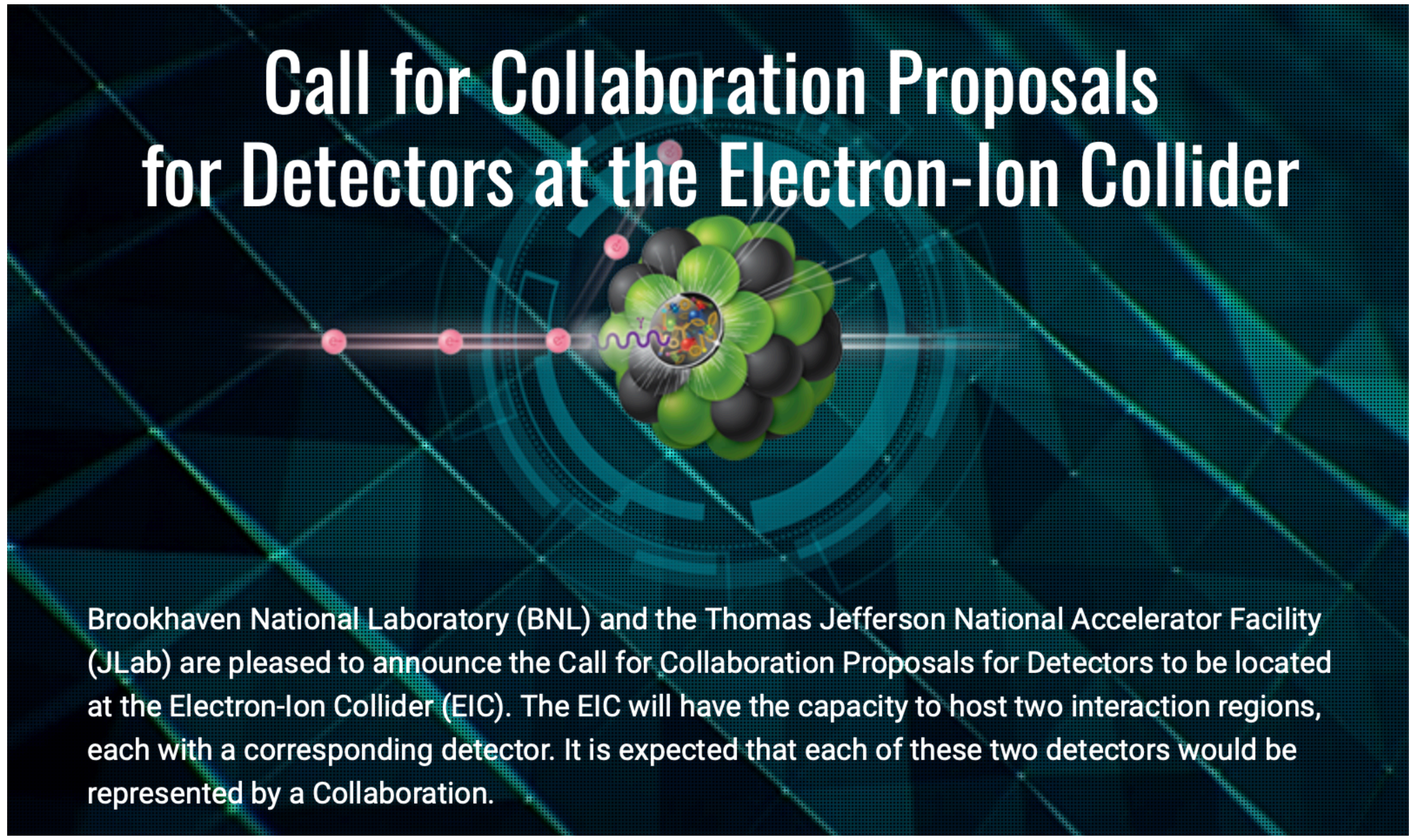
- Similar concept to BEAST
  - Vertex detector
  - Central tracker (all options – TPC considered)
  - Forward tracking
  - Cerenkov detectors
  - Electromagnetic calorimeters
  - Hadron calorimeter in the forward and barrel region (new), possible in rear direction
  - Muon chambers considered



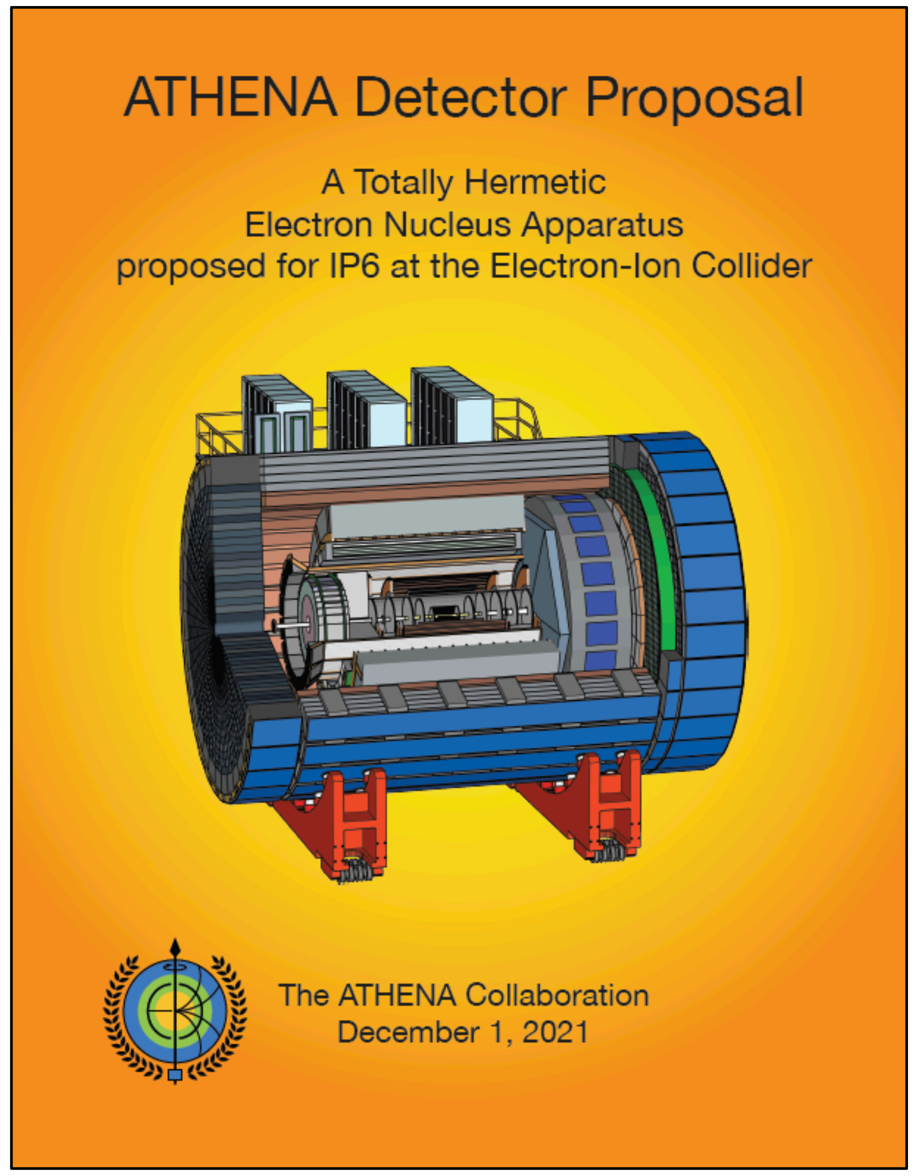
Detector Proposals

- March 6, 2021, BNL & JLab released the *Call for Collaboration Proposals for Detectors* with expected proposal submission deadline of December 1, 2021.
- Location: IP6 (in project scope), IP8
- EIC Detector Proposal Advisory Panel (DPAP) chaired by Rolf Heuer (CERN) and Patty McBride (FNAL) + 8 members
- The call was answered by 3 proto-colloborations: ATHENA, CORE, ECCE

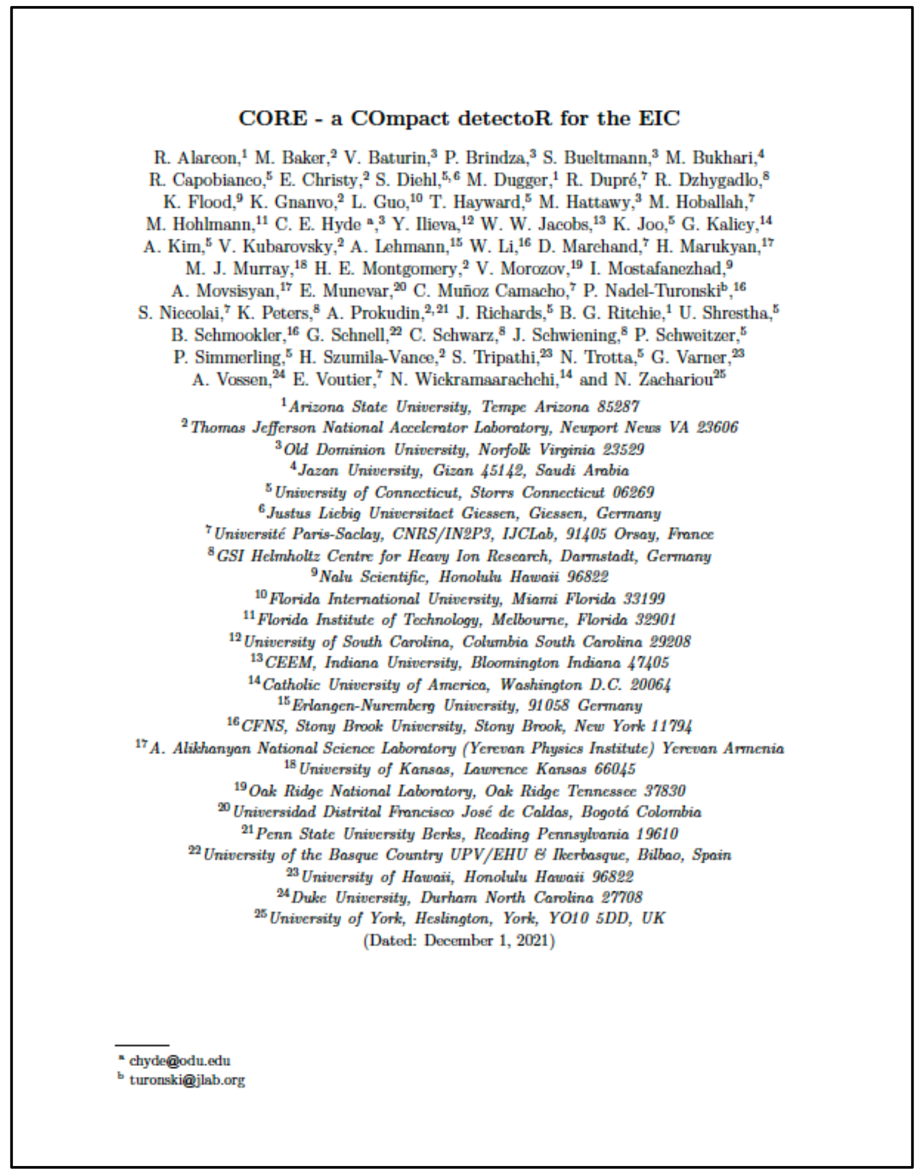
https://www.bnl.gov/eic/cfc.php



IP6	IP8	IP6 or IP8



New large 3T magnet



CORE - a COmpact detectoR for the EIC

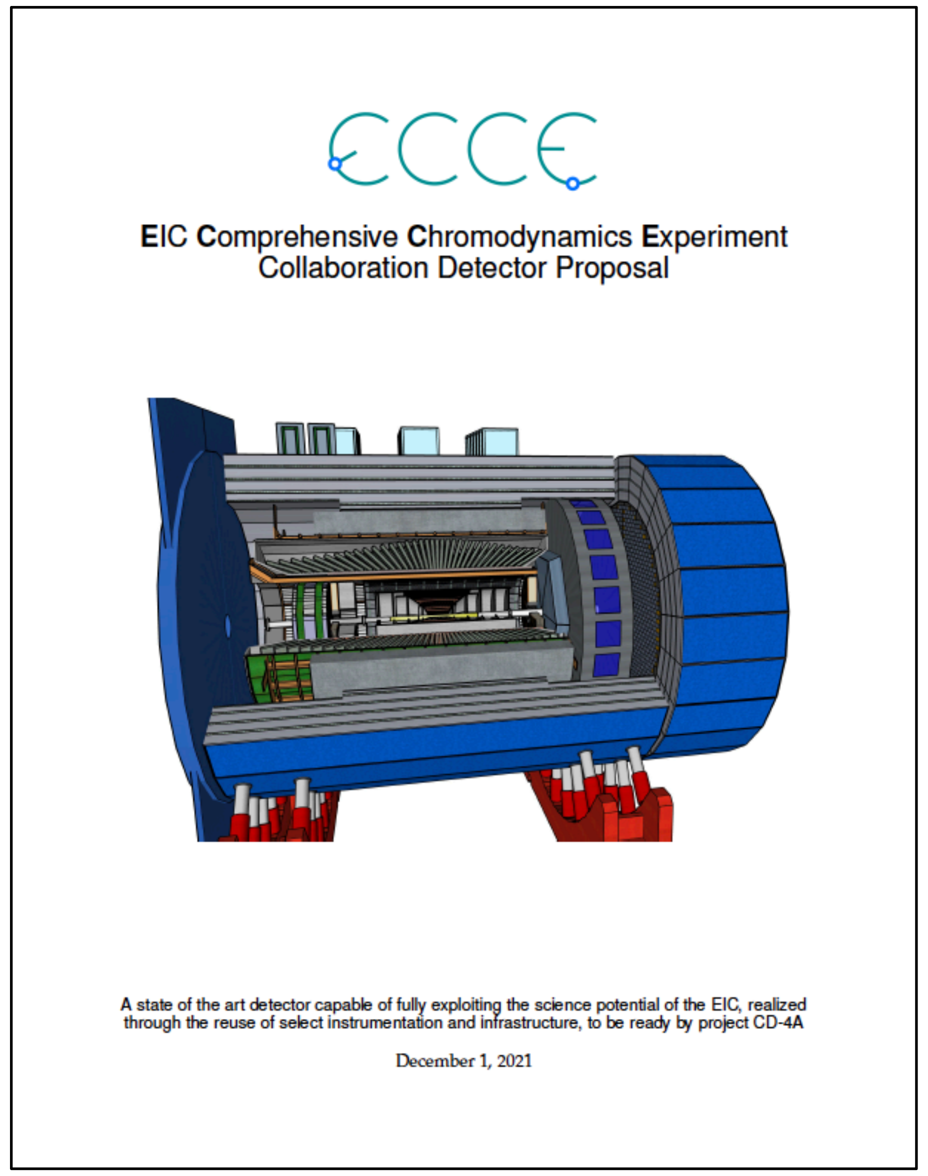
R. Alarcon,[1] M. Baker,[2] V. Baturin,[3] P. Brindza,[3] S. Bueltmann,[3] M. Bukhari,[4] R. Capobianco,[5] E. Christy,[2] S. Diehl,[5,6] M. Dugger,[1] R. Dupré,[7] R. Dzhygadlo,[8] K. Flood,[9] K. Gnanvo,[2] L. Guo,[10] T. Hayward,[5] M. Hattawy,[3] M. Hoballah,[7] M. Hohlmann,[11] C. E. Hyde [a],[3] Y. Ilieva,[12] W. W. Jacobs,[13] K. Joo,[5] G. Kalicy,[14] A. Kim,[5] V. Kubarovsky,[2] A. Lehmann,[15] W. Li,[16] D. Marchand,[7] H. Marukyan,[17] M. J. Murray,[18] H. E. Montgomery,[2] V. Morozov,[19] I. Mostafanezhad,[9] A. Movsisyan,[17] E. Munevar,[20] C. Muñoz Camacho,[7] P. Nadel-Turonski[b],[16] S. Niccolai,[7] K. Peters,[8] A. Prokudin,[2,21] J. Richards,[5] B. G. Ritchie,[1] U. Shrestha,[5] B. Schmookler,[16] G. Schnell,[22] C. Schwarz,[8] J. Schwiening,[8] P. Schweitzer,[5] P. Simmerling,[5] H. Szumila-Vance,[2] S. Tripathi,[23] N. Trotta,[5] G. Varner,[23] A. Vossen,[24] E. Voutier,[7] N. Wickramaarachchi,[14] and N. Zachariou[25]

[1] *Arizona State University, Tempe Arizona 85287*
[2] *Thomas Jefferson National Accelerator Laboratory, Newport News VA 23606*
[3] *Old Dominion University, Norfolk Virginia 23529*
[4] *Jazan University, Gizan 45142, Saudi Arabia*
[5] *University of Connecticut, Storrs Connecticut 06269*
[6] *Justus Liebig Universitaet Giessen, Giessen, Germany*
[7] *Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*
[8] *GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany*
[9] *Nalu Scientific, Honolulu Hawaii 96822*
[10] *Florida International University, Miami Florida 33199*
[11] *Florida Institute of Technology, Melbourne, Florida 32901*
[12] *University of South Carolina, Columbia South Carolina 29208*
[13] *CEEM, Indiana University, Bloomington Indiana 47405*
[14] *Catholic University of America, Washington D.C. 20064*
[15] *Erlangen-Nuremberg University, 91058 Germany*
[16] *CFNS, Stony Brook University, Stony Brook, New York 11794*
[17] *A. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Yerevan Armenia*
[18] *University of Kansas, Lawrence Kansas 66045*
[19] *Oak Ridge National Laboratory, Oak Ridge Tennessee 37830*
[20] *Universidad Distrital Francisco José de Caldas, Bogotá Colombia*
[21] *Penn State University Berks, Reading Pennsylvania 19610*
[22] *University of the Basque Country UPV/EHU & Ikerbasque, Bilbao, Spain*
[23] *University of Hawaii, Honolulu Hawaii 96822*
[24] *Duke University, Durham North Carolina 27708*
[25] *University of York, Heslington, York, YO10 5DD, UK*

(Dated: December 1, 2021)

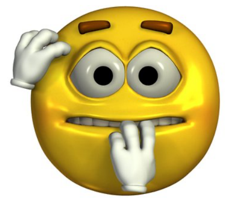
[a] chyde@odu.edu
[b] turonski@jlab.org

New compact 2.5T magnet



Reuse 1.4T BaBar magnet

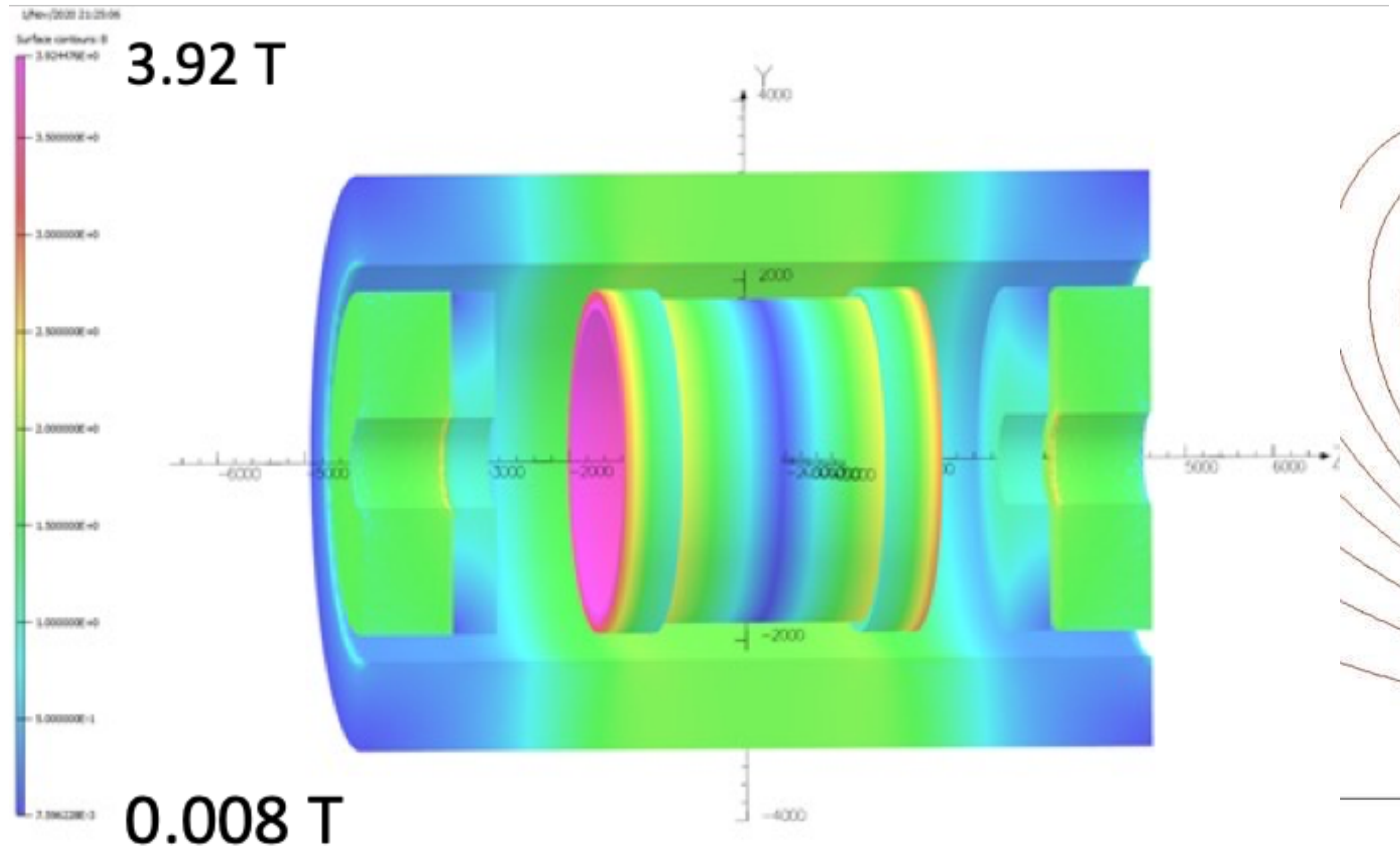
- Review Meeting
  - Cover: Design, technology, performance, collaboration/organization, cost, schedule
  - December 13–15, 2021
  - January 19-21, 2022
- DPAP supported by EIC Detector Advisory Committee (DAC) on all technical aspects
- Report released March 1, 2022

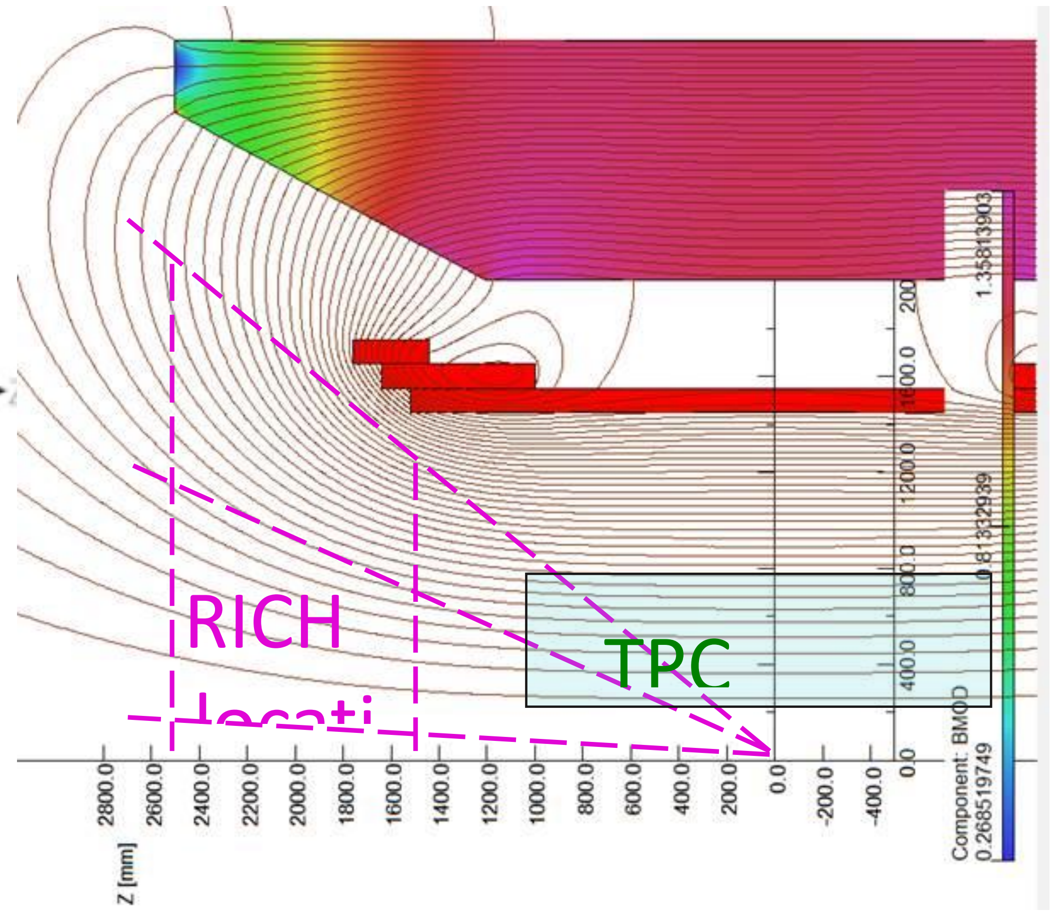


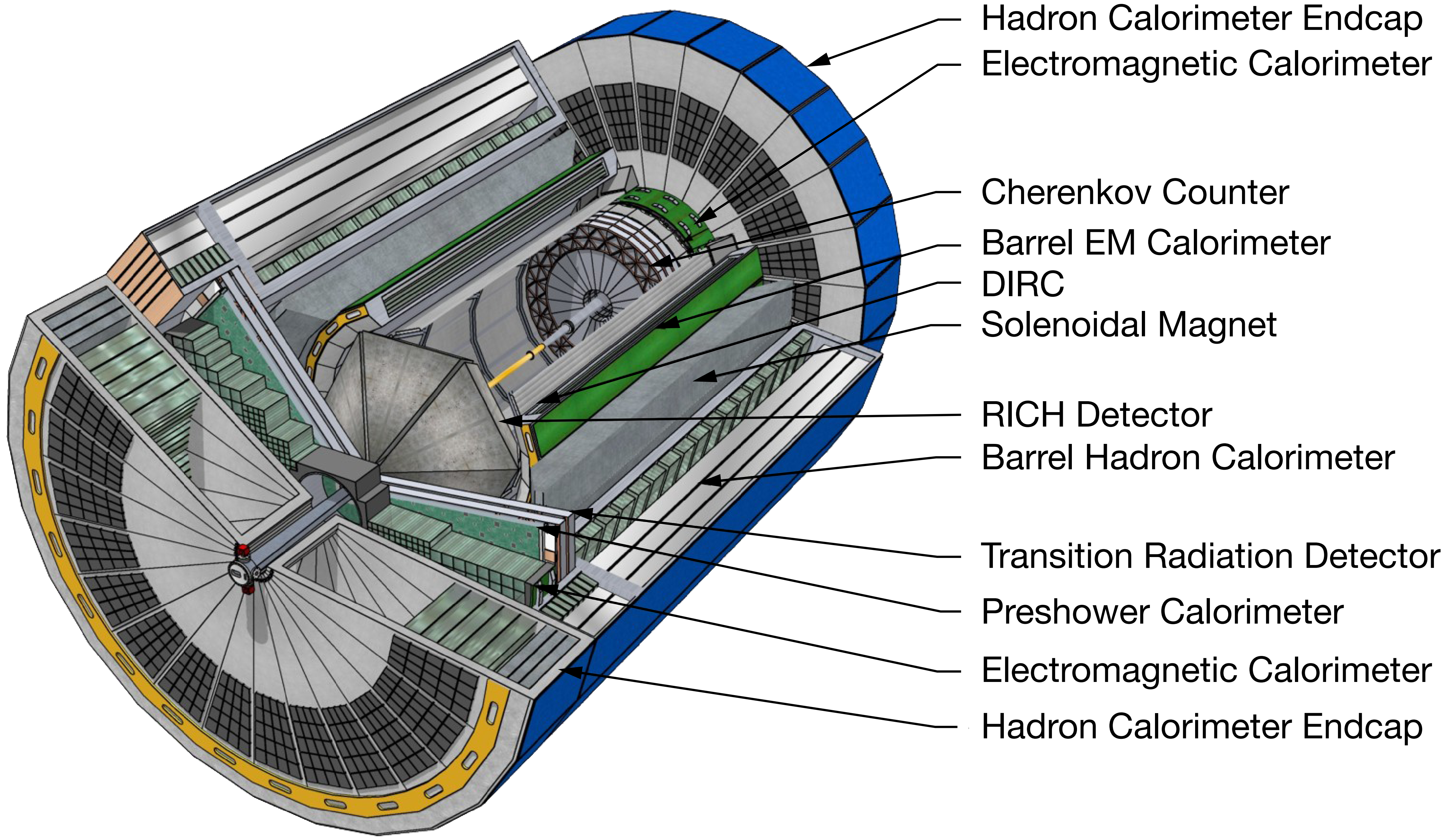
ATHENA: **A** **T**otally **HE**rmetic **E**lectron-**N**ucleus **A**pparatus

- Based on new magnet (≳ 3T) and Yellow Report reference detector
  - 3.6m long, 1.6m inner bore
  - Solenoidal and Hemholtz design under discussion
  - Optimize projectivity (tracking) at forward rapidities

- Concept presented at CD-1 review of the EIC and is included in the CDR
  - Major change TPC → Si Tracker + MPGD

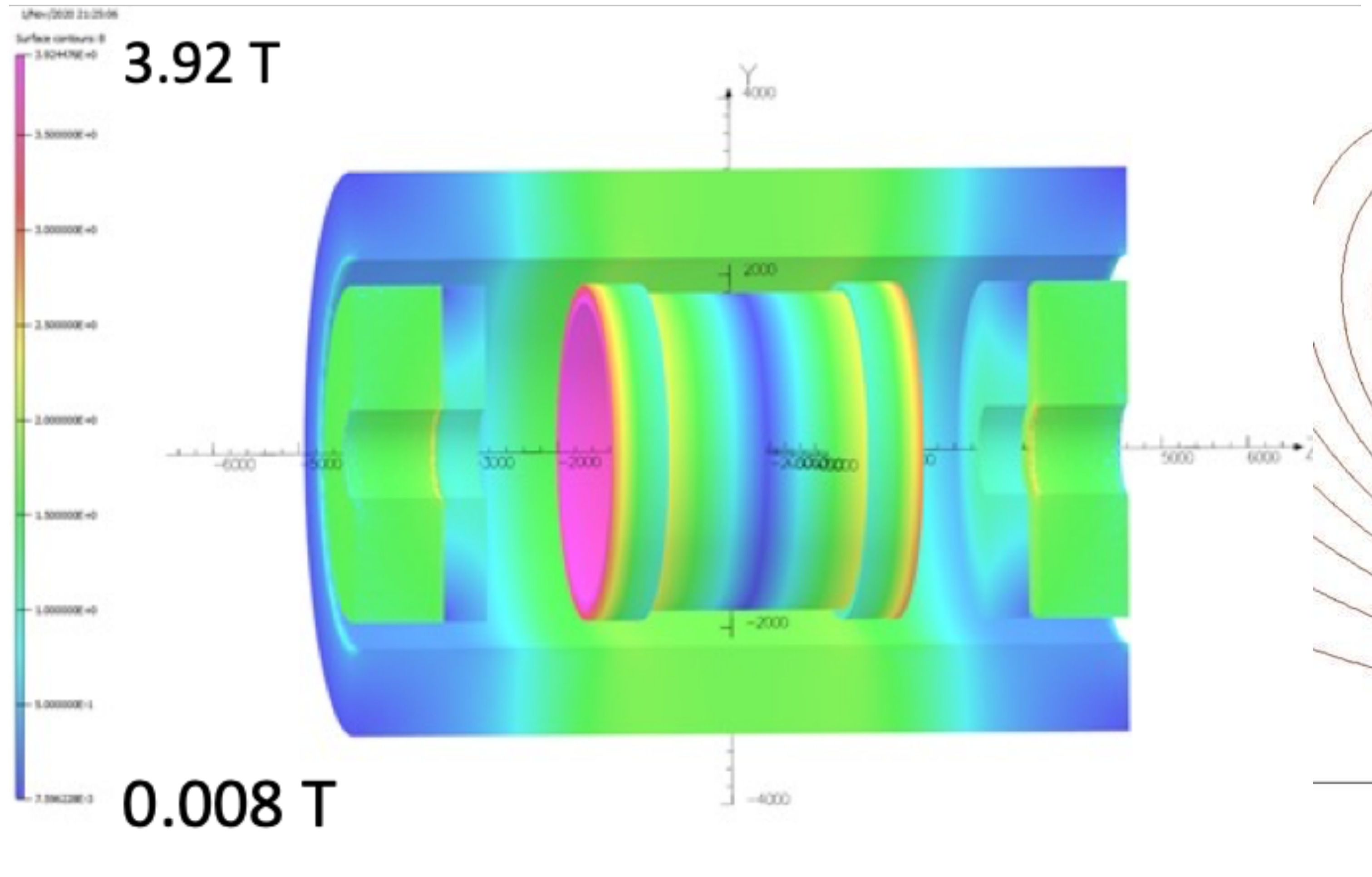


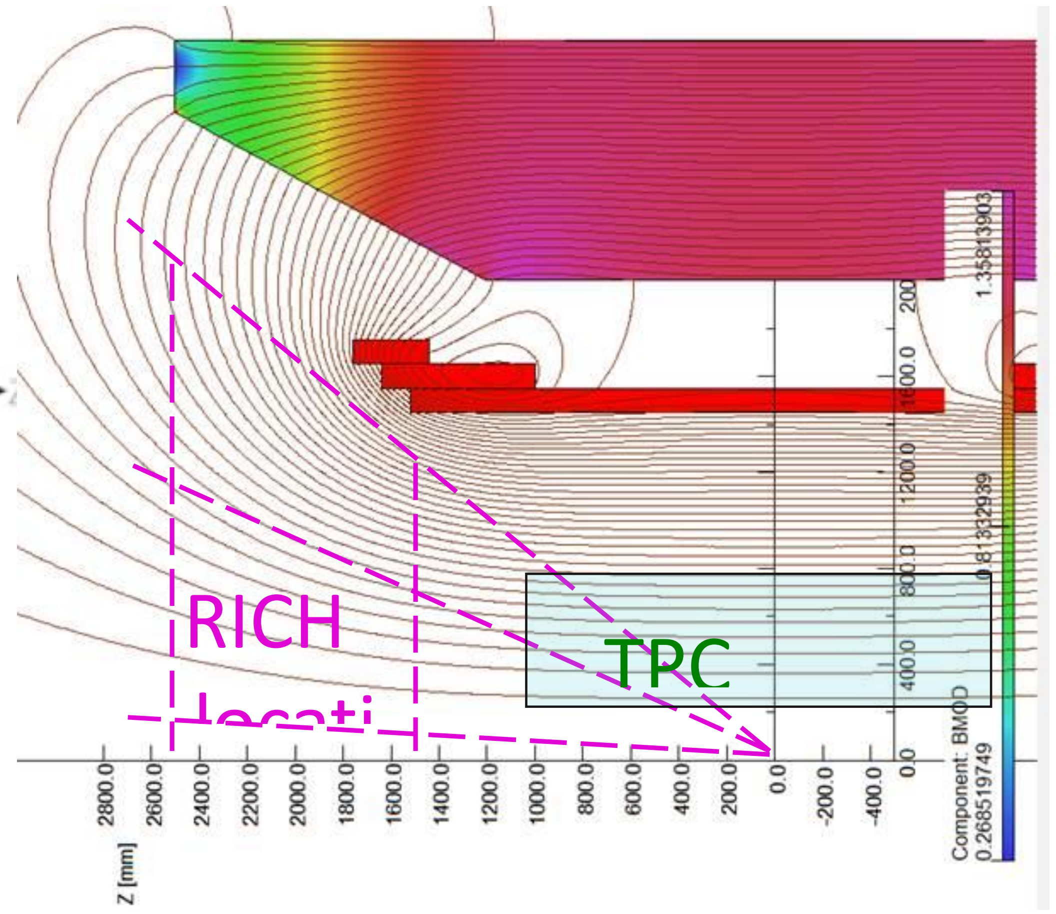


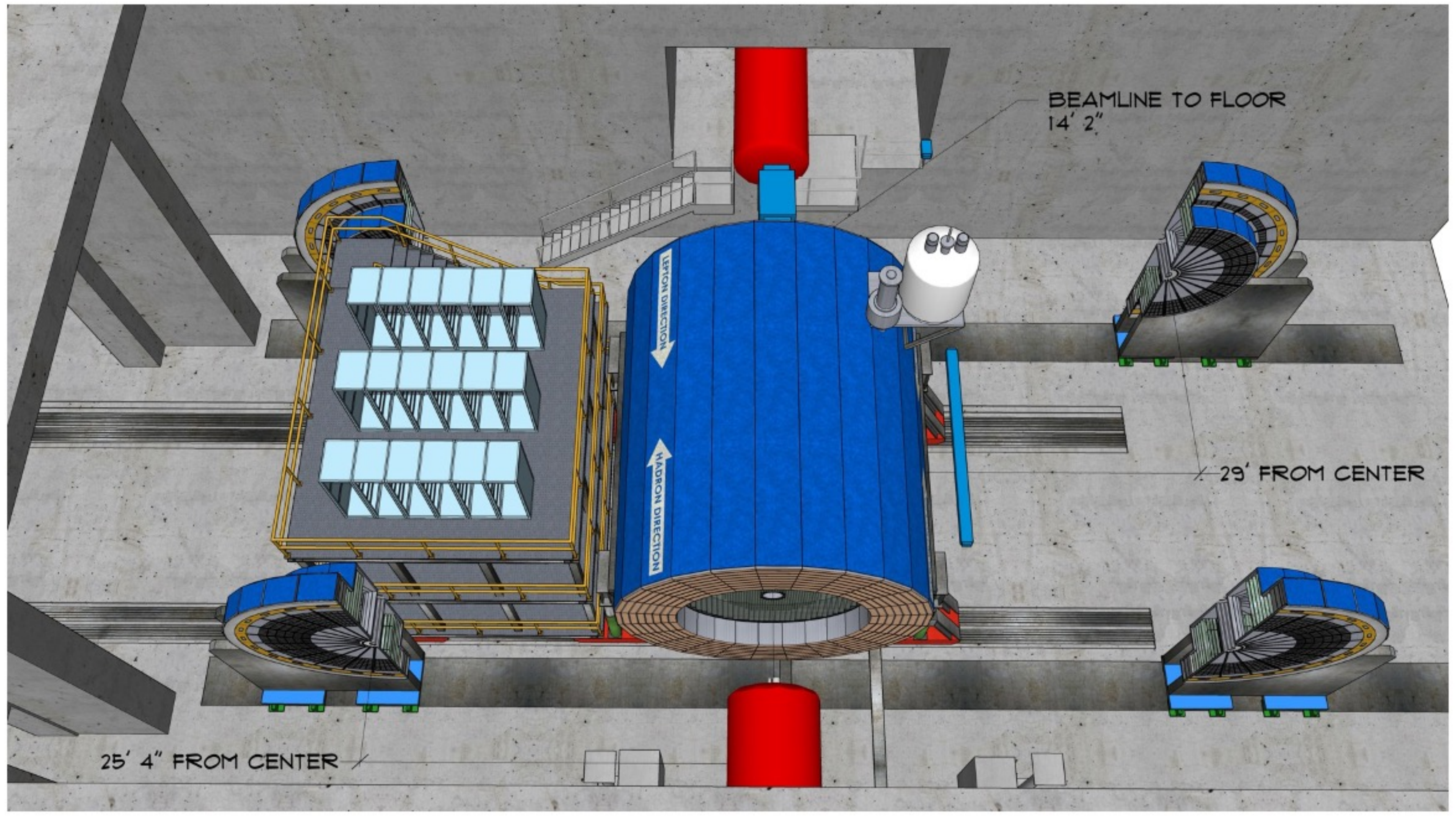


ATHENA: **A T**otally **HE**rmetic **E**lectron-**N**ucleus **A**pparatus

- Based on new magnet (≳ 3T) and Yellow Report reference detector
  - 3.6m long, 1.6m inner bore
  - Solenoidal and Hemholtz design under discussion
  - Optimize projectivity (tracking) at forward rapidities
- Concept presented at CD-1 review of the EIC and is included in the CDR
  - Major change TPC → Si Tracker + MPGD

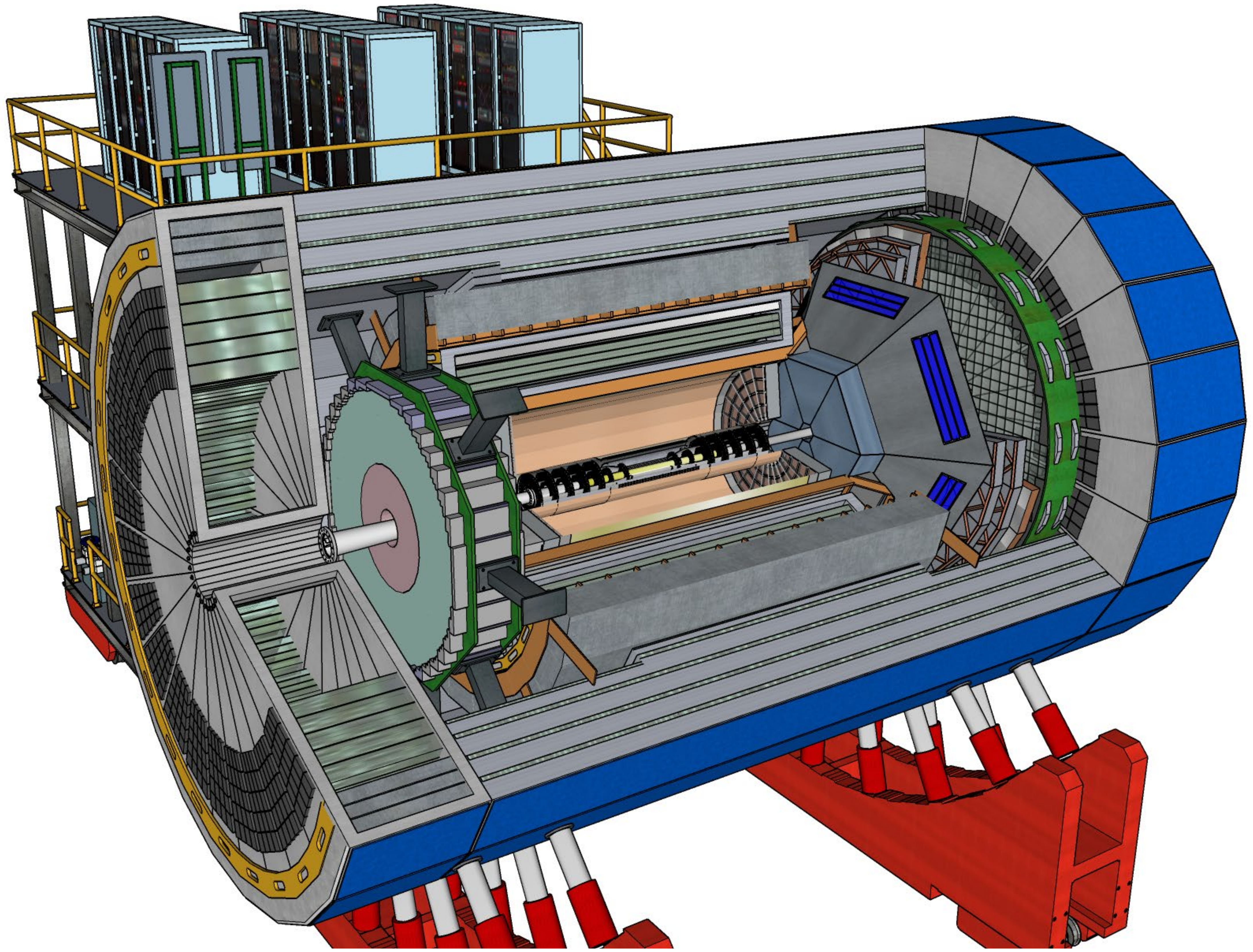






ECCE: **E**IC **C**omprehensive **C**hromodynamics **E**xperiment

- EIC detector offering full kinematic coverage using a design which incorporates the existing 1.5 T BaBar/sPHENIX magnet (3.7m long, 1.4m bore radius)



ECCE ELECTRON ENDCAP STRAWMAN

Tracking: MAPS, Micro Pattern Gaseous Detectors (MPGD)
Electron Detection: PWO&SciGlass
- Inner part: PWO crystals (reuse some)
- Outer part: SciGlass (backup PbGl)

h-PID: mRICH
- From yellow report

HCAL: Steel from magnet or Pb/Sc or Fe/Sc
- Not instrumented and only serve as flux return?
- Instrumented \w reduced thickness (lower energies)

ECCE CENTRAL BARREL STRAWMAN

Tracking: Silicon barrel tracker (optional Si/GEM hybrid)
Electron PID: SciGlass (backup: W/Sc (Pb/Sc) shashlik)
- SciGlass remains to be demonstrated
- Several backup options – lower resolution though

h-PID: hpDIRC & AC-LGAD
- Compact
- AC-LGAD never been shown for barrel configuration
- AC-LGAD backup: dE/dx (needs more space)

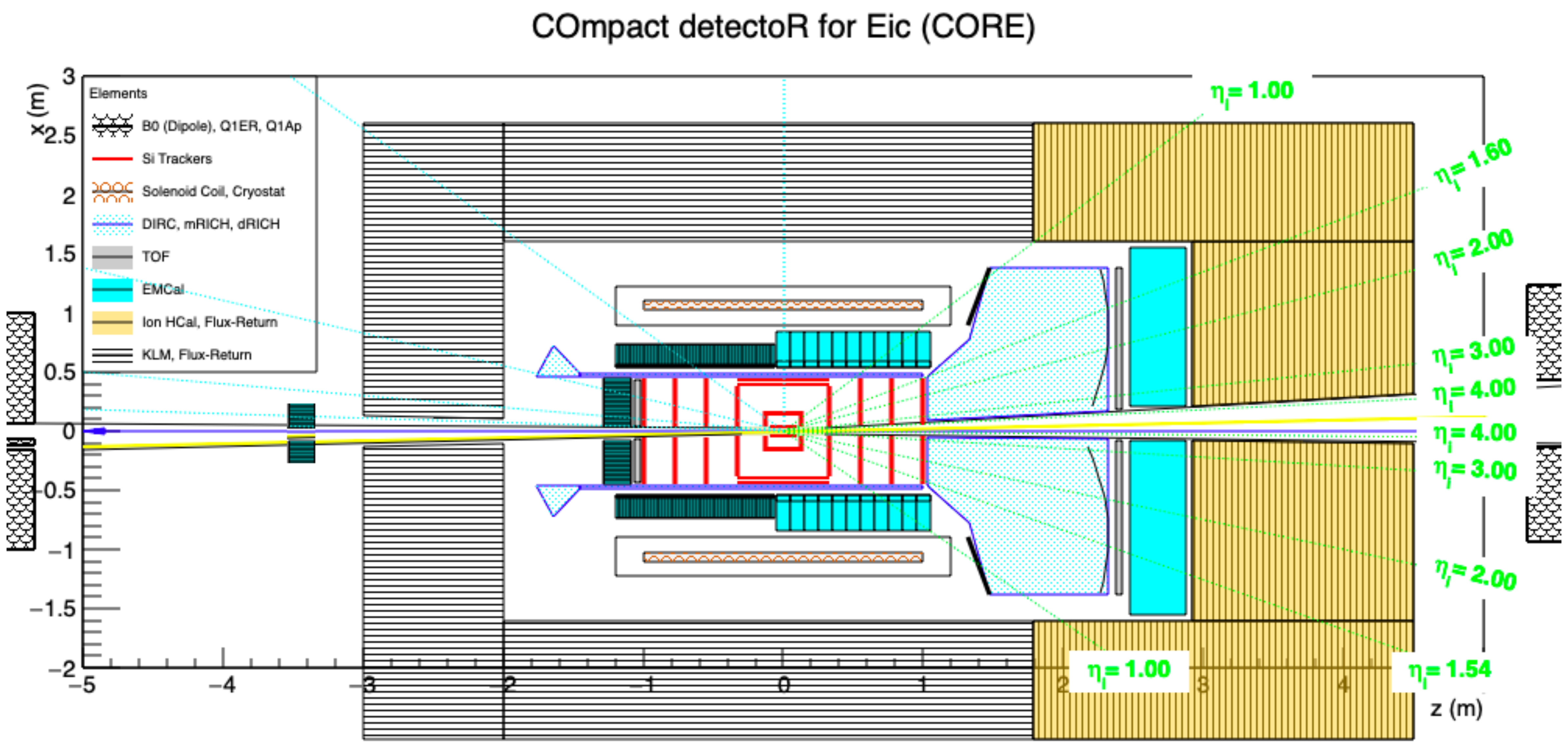
HCAL: magnet steel (**reuse**) - **Fe/Sc**

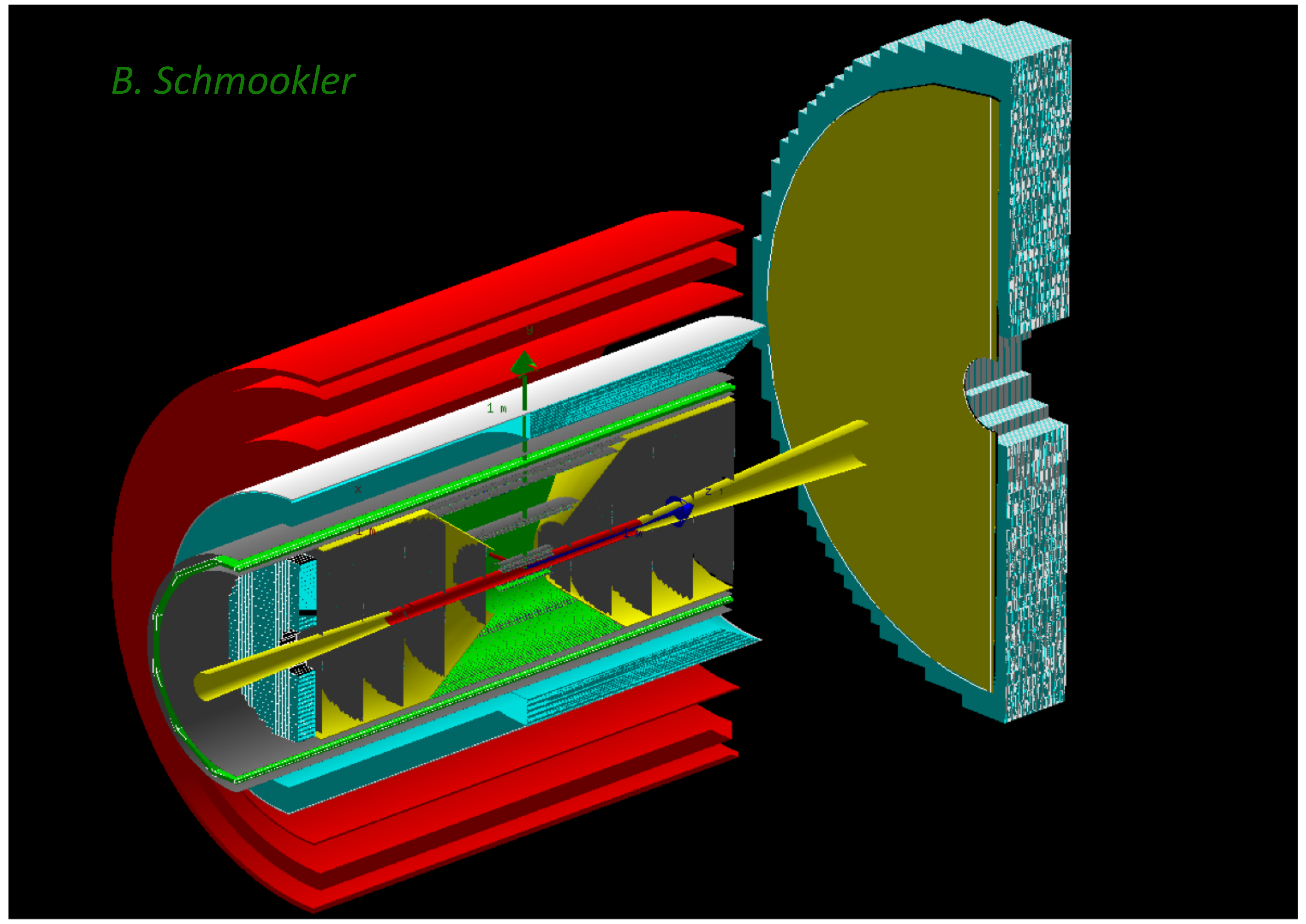
ECCE HADRON ENDCAP STRAWMAN

Tracking: MAPS, Micro Pattern Gaseous Detectors (MPGD)
h-PID: dRICH&TOF
e/h separation: TOF & aerogel
- TRD to separate electrons from high momentum hadrons?

Electron PID: W/ScFi, Pb/Sc or W/Sc shashlik
HCAL: Pb/Sc or Fe/Sc
- Alternative for improved resolution: dual readout, high-granularity

CORE: a **CO**mpact detecto**R** for the **E**IC





- Hermetic and compact general-purpose detector
  - New 2.5 T solenoid (2.5 m long, 1 m inner radius)
  - Tracking: central all-Si tracker and h-endcap GEM tracker
  - EMcal: PWO for $\eta < 0$ and W-Shashlyk for $\eta > 0$
  - Cherenkov PID: DIRC (50 cm radius) in barrel and dual-radiator RICH
  - TOF: LGADs in e-endcap and a simple TOF behind the dRICH Hcal / KLM detector integrated with the magnetic flux return

Towards the EIC Baseline Detector

DPAP:

- ATHENA and ECCE satisfy the requirements to fulfill EIC's "mission need" statement
- ECCE has reduced risk and cost, and qualifies best for Detector 1
- Proto-collaborations urged to quickly consolidate its design so that the Project Detector can advance

EPIC/ePIC:

- Following the DPAP decision a new “Detector 1” collaboration that morphed into the ePIC Collaboration
- The collaboration names itself ‘Electron Proton and Ion Collider’ experiment, ePIC
- The final baseline concept of ePIC emerged from ATHENA and ECCE

- While with the Yellow Report the EIC community grew together, the process of selecting the one EIC detector was conducted badly and left many scars that need time to heal
- Lessons were learned

ePIC

JLab, Jan. 2023

Warsaw, July 2023

ANL, Jan. 2024

ePIC is a community of scientists dedicated to realizing the EIC science mission.

ePIC is International

ePIC Initiated in July 2022

Currently:
>850 collaborators (from 2024 Institutional Survey)

>650 members active in ePIC activities