DVCS with an Electron Ion Collider

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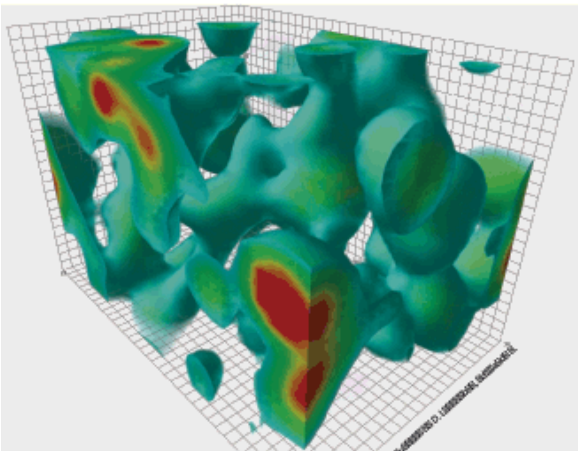
CEA Saclay



INT Workshop INT-12-49W

Orbital Angular Momentum in QCD

February 6 - 17, 2012

- Introduction
- Accelerator concepts at JLab and RHIC
- Detector design for an EIC
- DVCS with an EIC : Imaging partons
- Conclusion

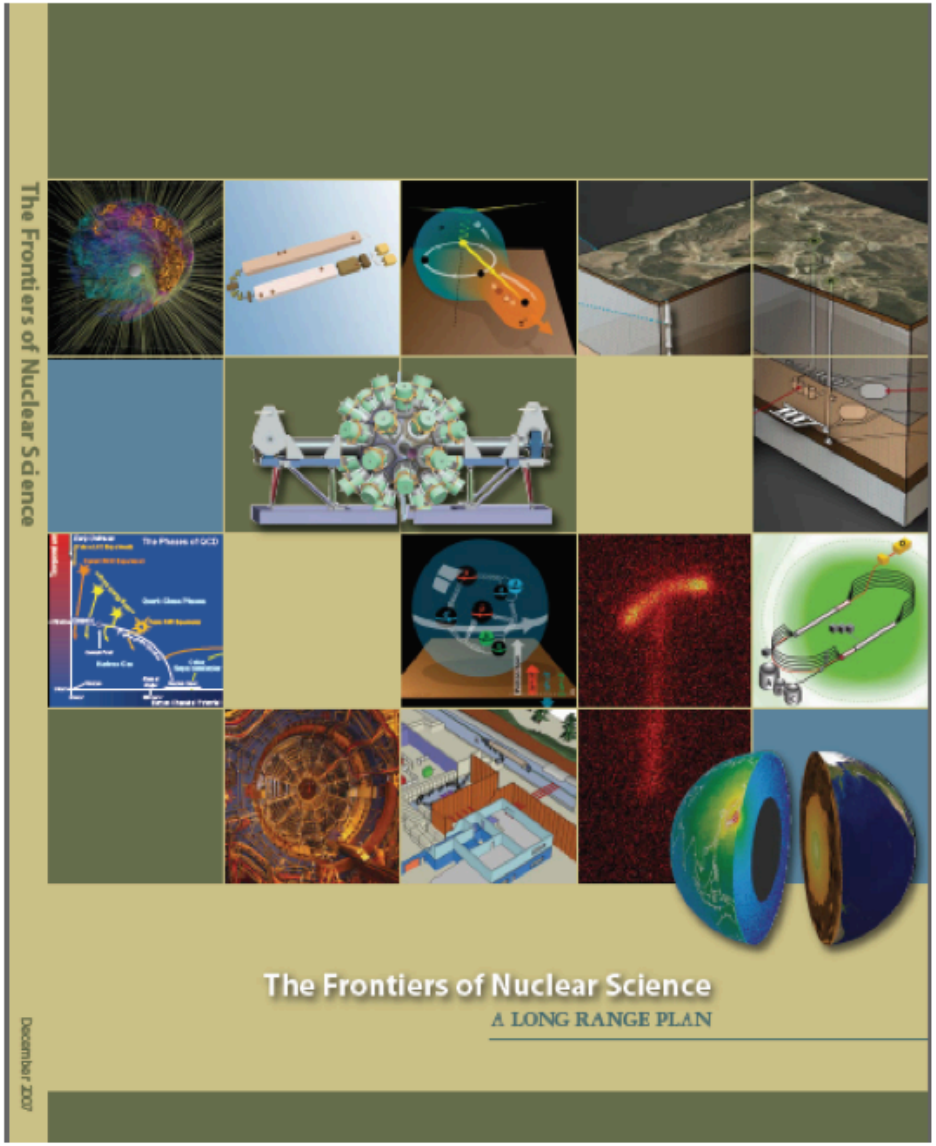
BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab
EXPLORING THE NATURE OF MATTER

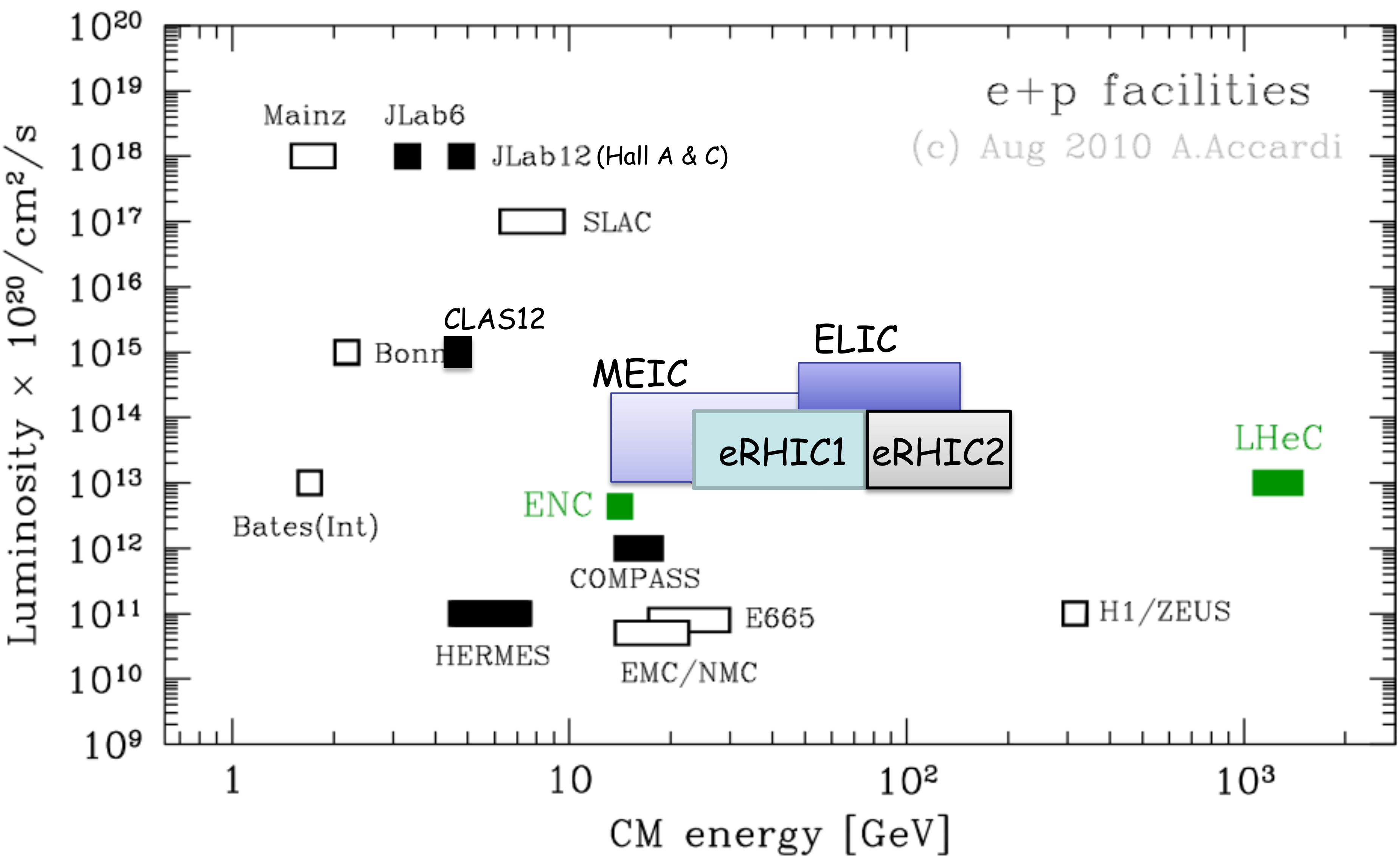
Official start : NSAC 2007 Long Range Plan

"An **Electron-Ion Collider (EIC)** with polarized beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia. In support of this new direction:

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron Ion Collider. The EIC would explore the new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton."



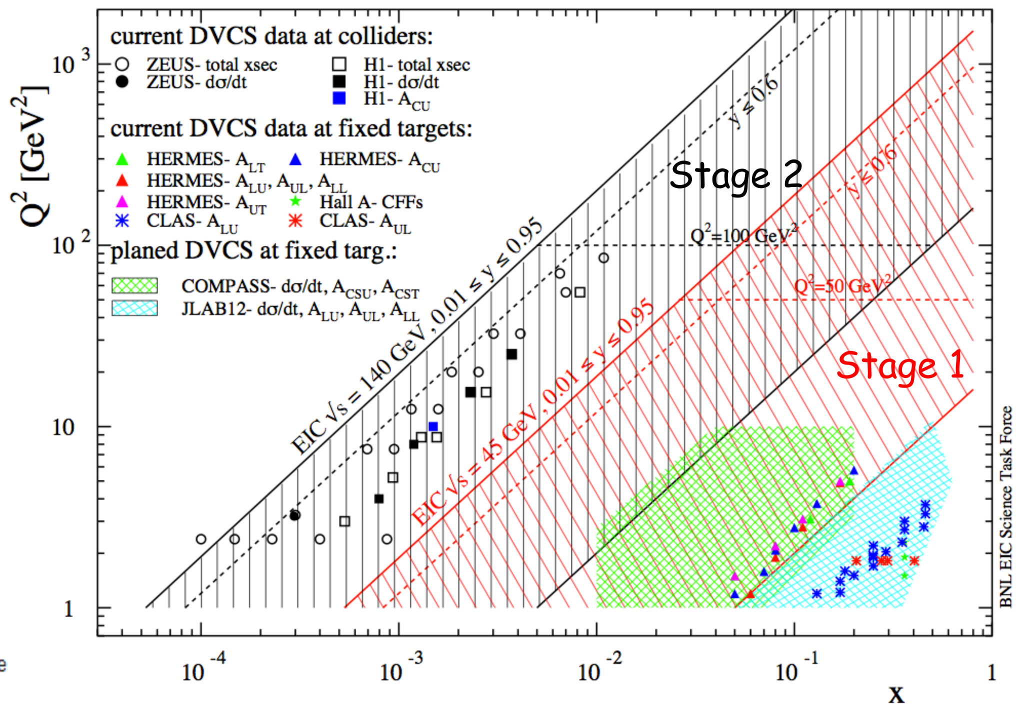
Lepton-Proton/Ion machines world-wide

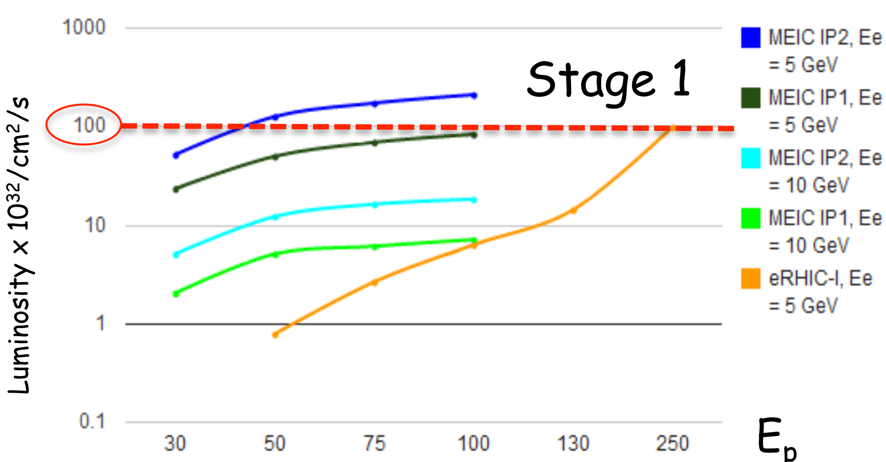


Basic machine parameters

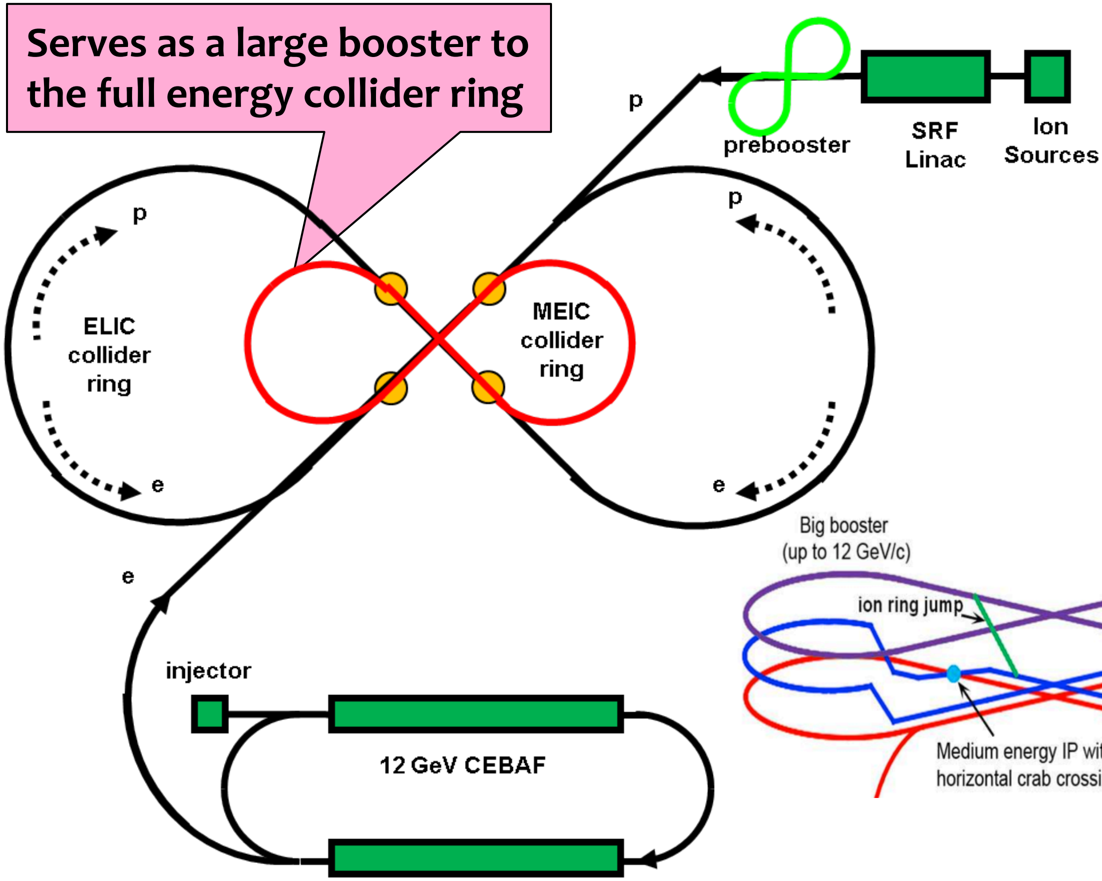
Base EIC Requirements *per Executive Summary INT Report :*

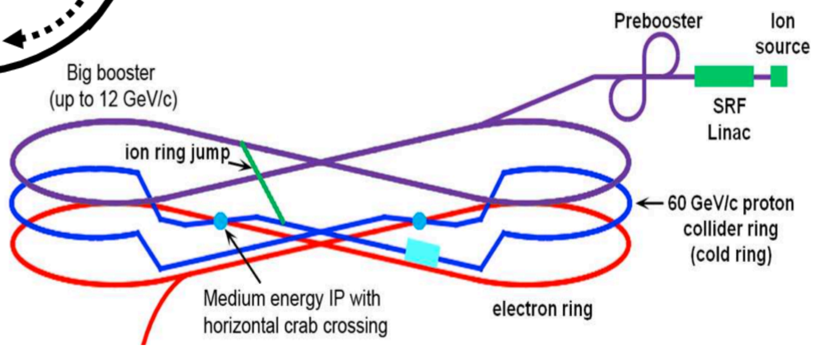
- Range in cm energies $\sqrt{s}$**~20-70** & variable
- Fully-**polarized** (>70%), longitudinal and transverse
- Ion species up to A ~ 200
- High luminosity: **about 10^{34}** e-nucleons cm^{-2} s^{-1}
- Multiple interaction regions
- Upgradable to higher energies



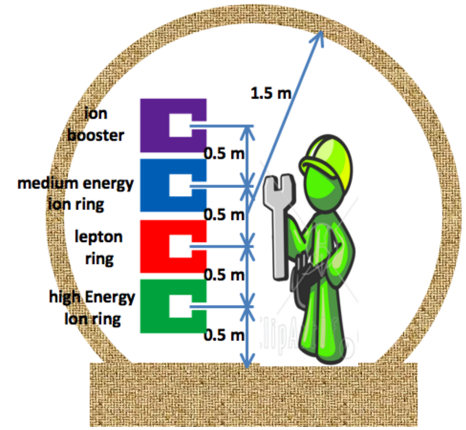


JLab design, Stages 1 (MEIC) & 2 (ELIC)

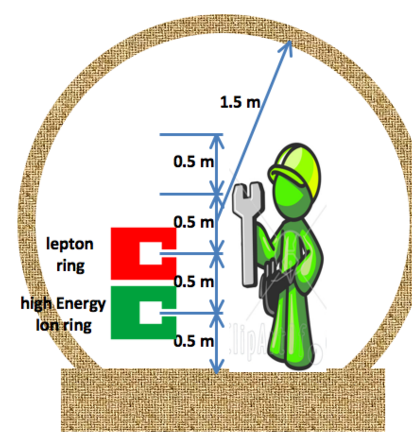




Straight section



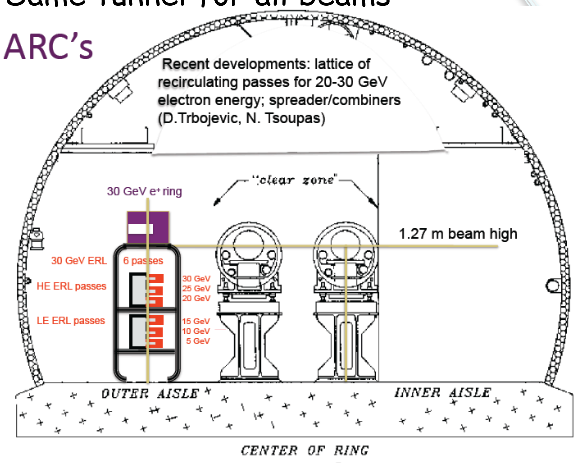
Arc

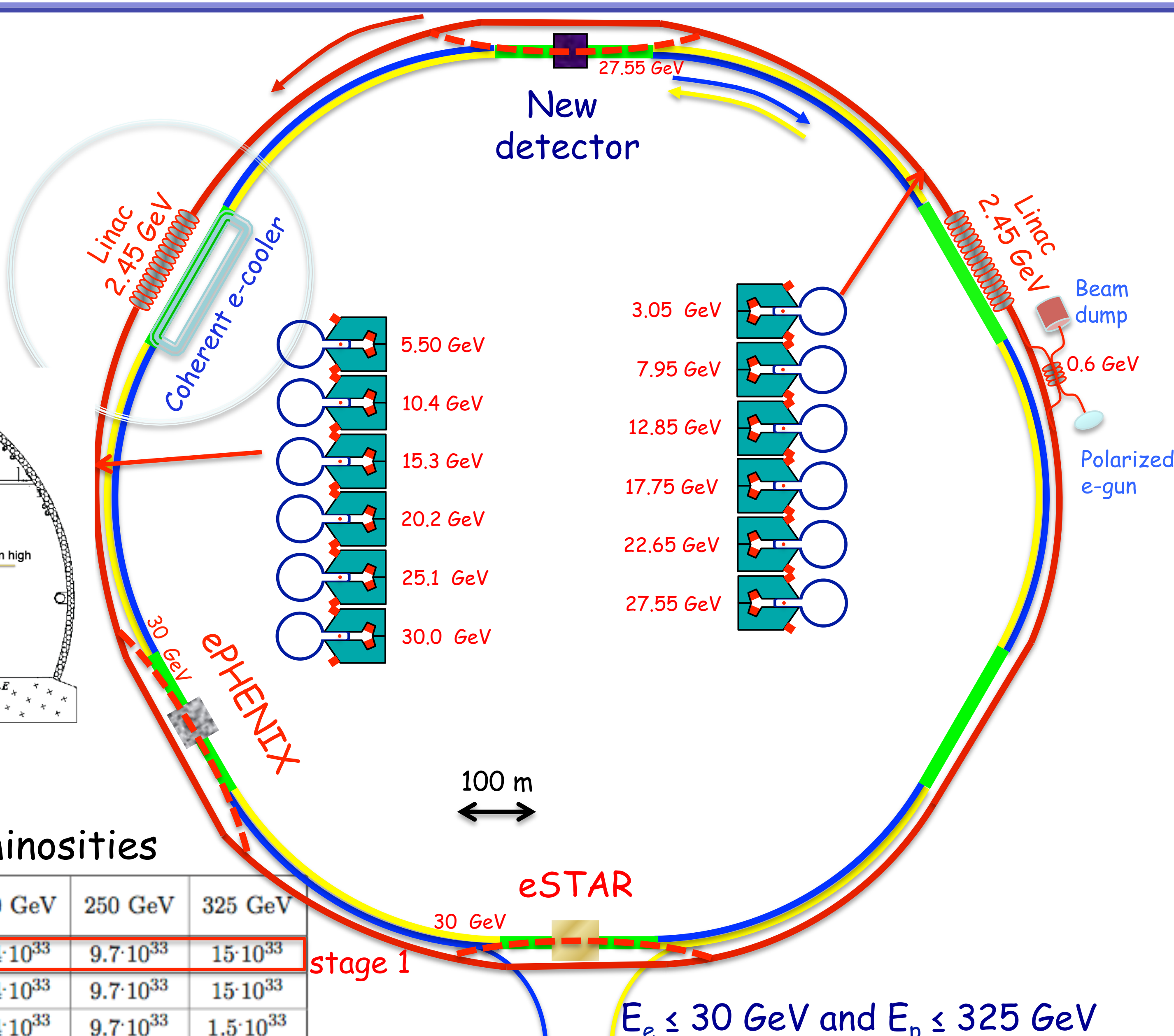


Stage	Max. Energy (GeV/c)		Ring Size (m)	Ring Type		IP #
	p	e		p	e	
Medium	96	11	1000	Cold	Warm	3
High	250	20	2500	Cold	Warm	4

RHIC realization

Same tunnel for all beams





polarized e & p luminosities

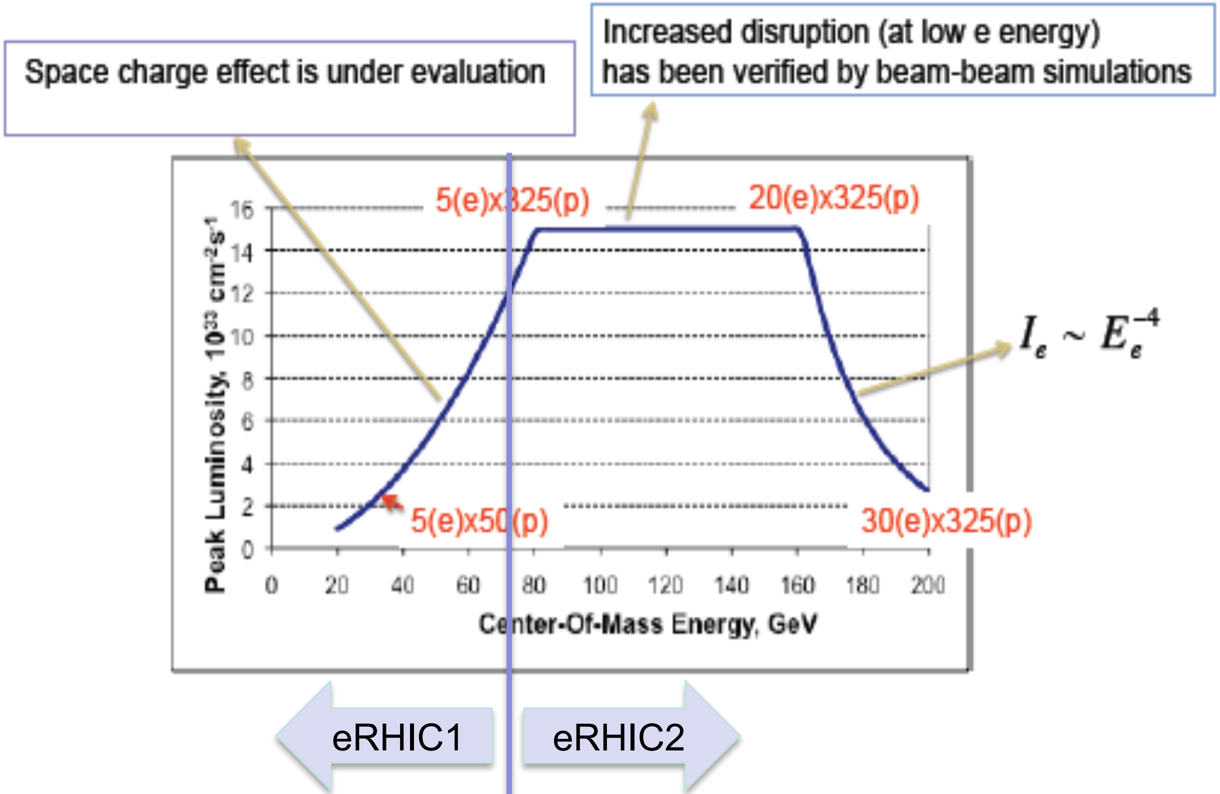
Electrons \ Protons	100 GeV	130 GeV	250 GeV	325 GeV
5 GeV	$0.62 \cdot 10^{33}$	$1.4 \cdot 10^{33}$	$9.7 \cdot 10^{33}$	$15 \cdot 10^{33}$
10 GeV	$0.62 \cdot 10^{33}$	$1.4 \cdot 10^{33}$	$9.7 \cdot 10^{33}$	$15 \cdot 10^{33}$
20 GeV	$0.62 \cdot 10^{33}$	$1.4 \cdot 10^{33}$	$9.7 \cdot 10^{33}$	$1.5 \cdot 10^{33}$
30 GeV	$0.12 \cdot 10^{33}$	$0.3 \cdot 10^{33}$	$1.9 \cdot 10^{33}$	$3 \cdot 10^{33}$

stage 1

$E_e \leq 30$ GeV and $E_p \leq 325$ GeV
or $E_A \leq 130$ GeV/u

eRHIC staged installation

Luminosity vs. √s



Stage 1 eRHIC:
ePHENIX & eSTAR ?
5 GeV e^- beam

Stage 2 eRHIC:
Dedicated eRHIC detector
20-30 GeV e^- beam

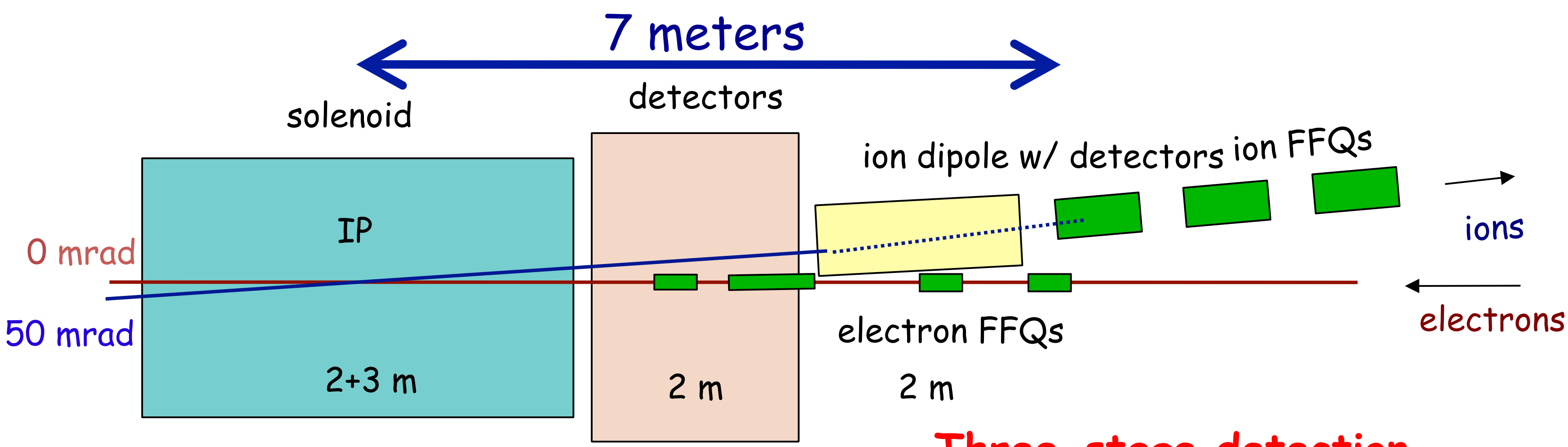
EIC detector requirements

Mostly driven by exclusive or semi-inclusive physics

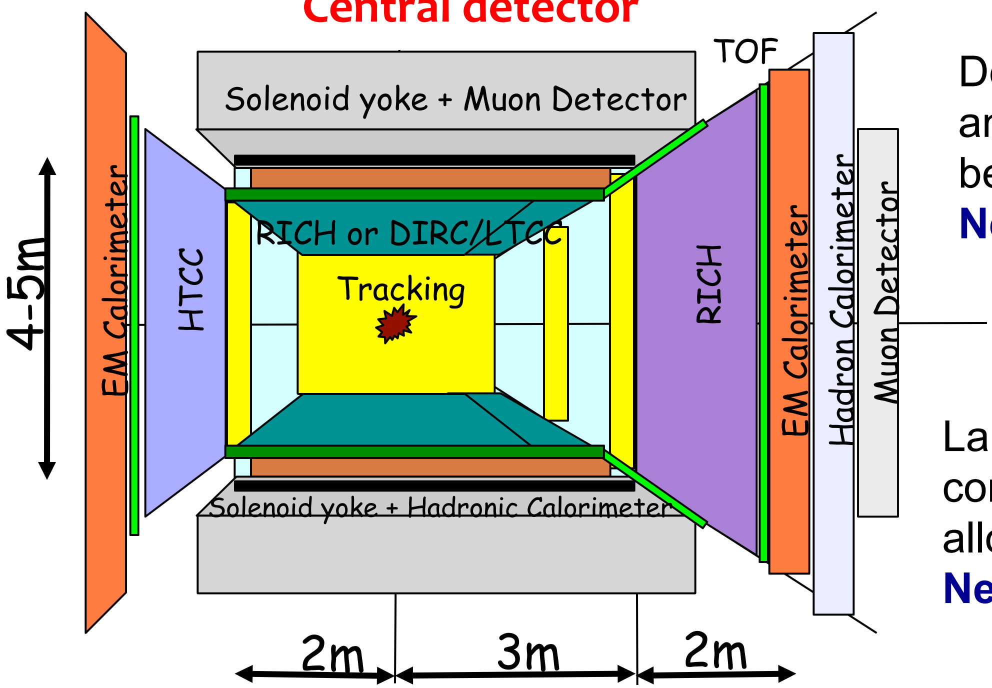
- Hermeticity (also for hadronic reconstruction methods in DIS)
- Particle identification (needed for SIDIS too)
- Momentum resolution
- Forward detection of recoil baryons (also baryons from nuclei)
- Muon detection (J/Ψ)
- Photon detection (DVCS, π^0)
- Very forward detection (spectator tagging, diffractive mechanisms, coherent nuclear, etc)
- Vertex resolution (displaced vertex, i.e. charm)
- Hadronic calorimetry (jet)

In general, e-p and even more e-A colliders have a large fraction of their science related to the detection of what happens to the ion beam. The struck quark remnants can be guided to go to the central detector region with Q^2 cuts, but the spectator quark or struck nucleus remnants will go in the forward (ion) direction.

MEIC/ELIC detector



Central detector



Three-stage detection

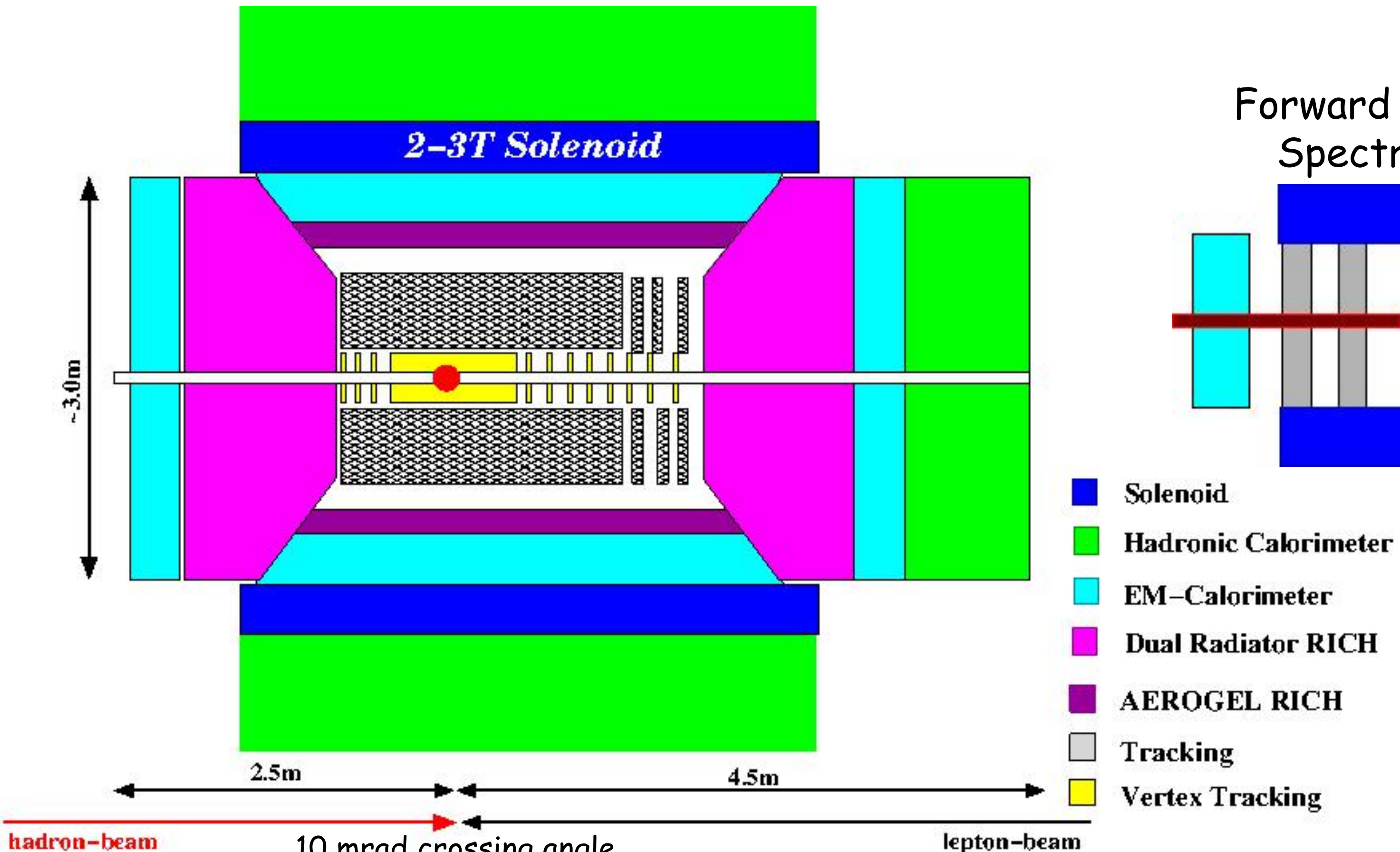
Detect particles with angles down to 0.5° before ion FFQs.
Need 1-2 Tm dipole.

Detect particles with angles below 0.5° beyond ion FFQs and in arcs.
Need 4 m machine element free region

Very-forward detector

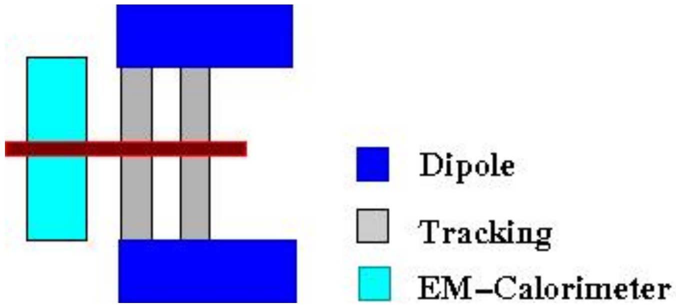
Large dipole bend @ 20 meter from IP (to correct the 50 mr ion horizontal crossing angle) allows for very-small angle detection (<0.3°).
Need 20 m machine element free region

New eRHIC detector



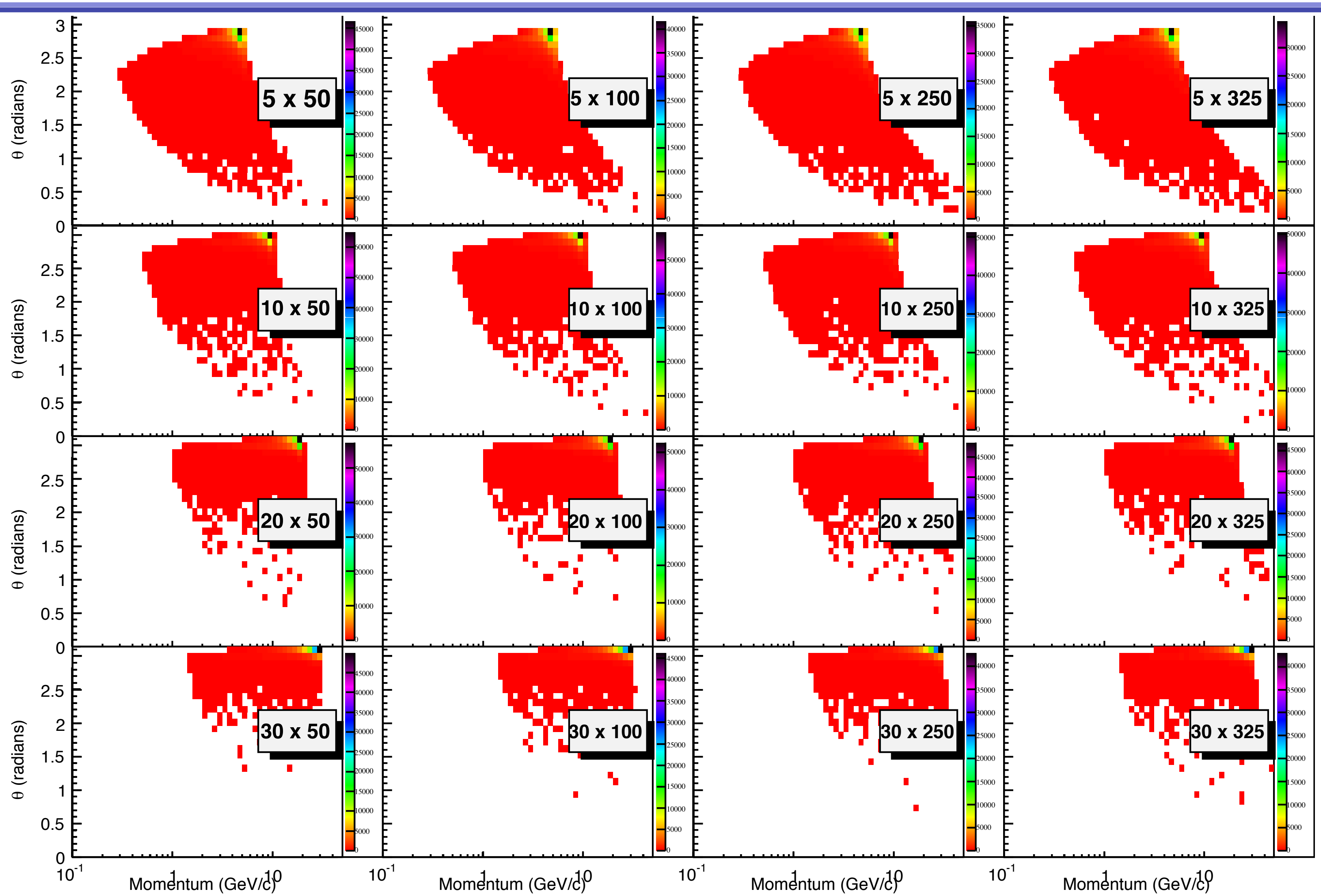
10 mrad crossing angle
with crab-crossing

Forward / Backward
Spectrometers:



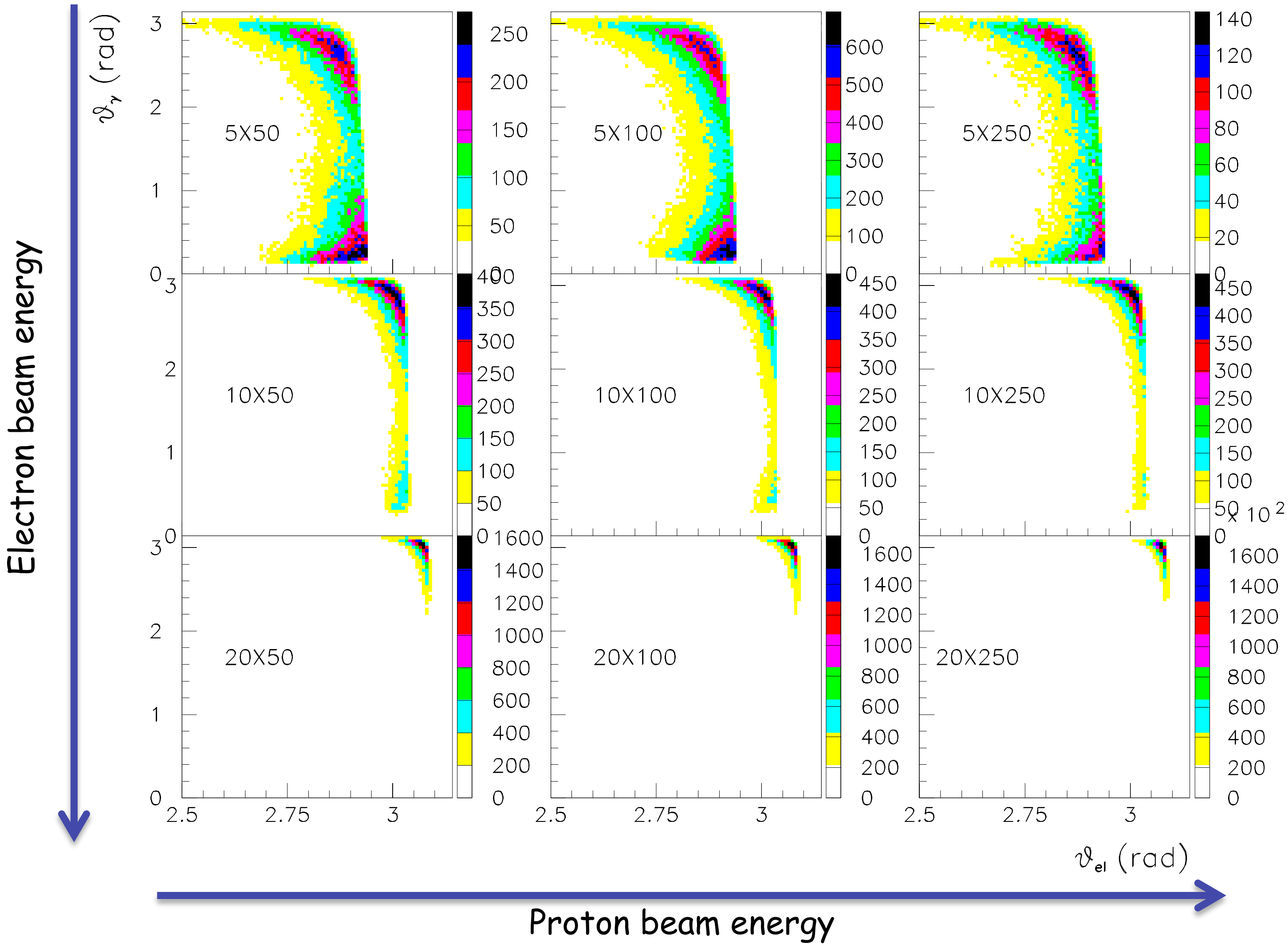
High acceptance -5 < η < 5 central detector
Good PID and vertex resolution
Tracking and calorimeter coverage the same → good momentum resolution, lepton PID
Low material density → minimal multiple scattering and bremsstrahlung
Very forward electron and proton detection → maybe dipole spectrometers

Detector considerations : scattered electron



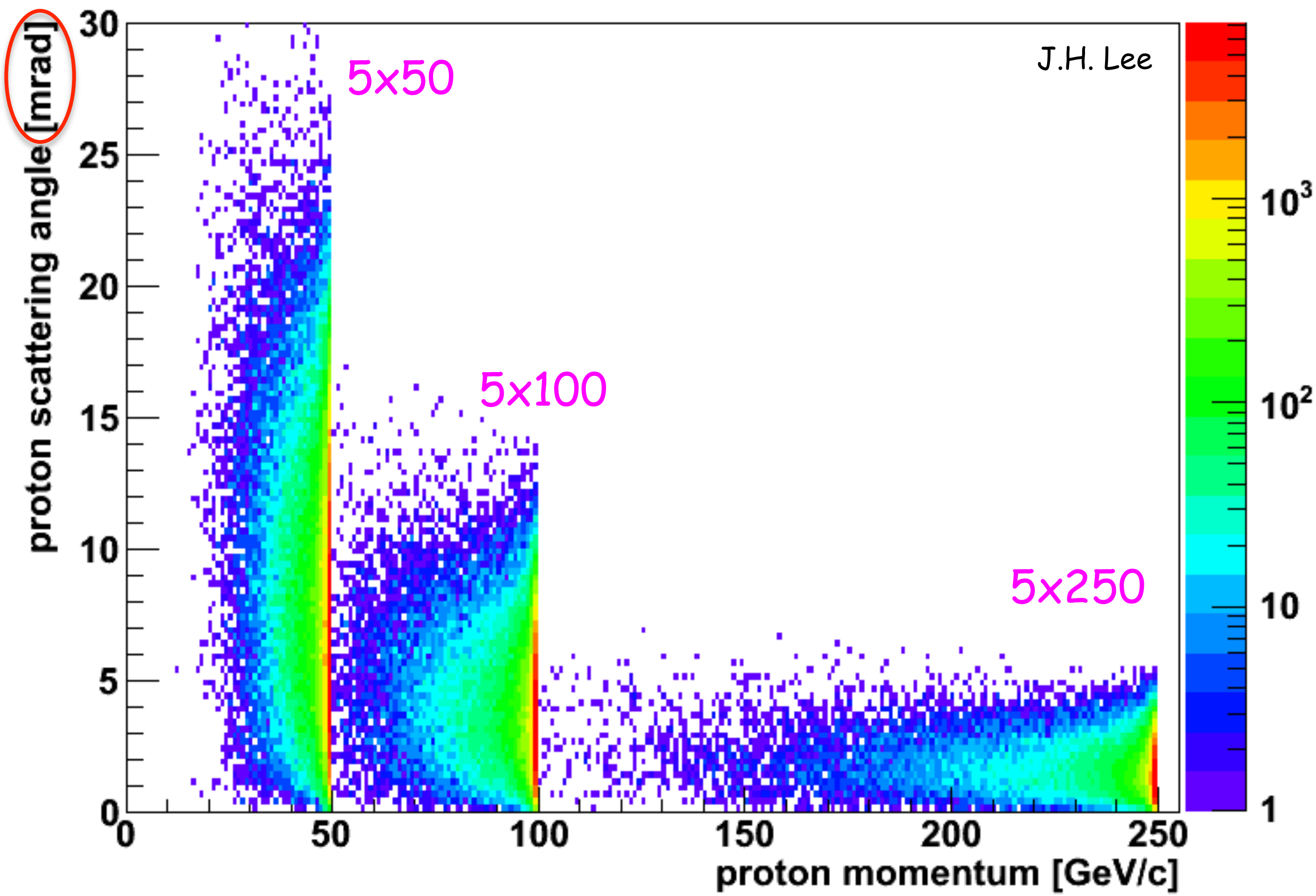
For all lepton-hadron beam energy combinations, the scattered electron goes in the direction of the original electron beam for low Q^2 and more and more into a central detector acceptance for higher Q^2

Detector considerations : θ_γ vs. θ_e



With increasing electron energy, the real photon gets closer to the electron beam

Detector considerations : recoil proton

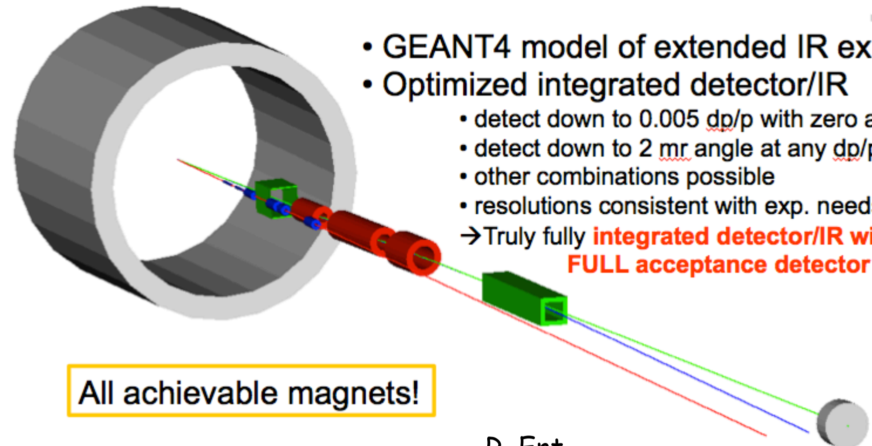


Roman pots are an essential part of the detector/IR design

A lot of progress on simulations at JLab and BNL

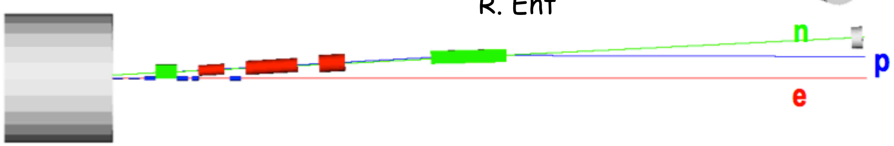
MEIC Detector & Interaction Region

- GEANT4 model of extended IR exists
- Optimized integrated detector/IR
  - detect down to 0.005 dp/p with zero angle
  - detect down to 2 mr angle at any dp/p
  - other combinations possible
  - resolutions consistent with exp. needs
  - →Truly fully **integrated detector/IR with FULL acceptance detector**

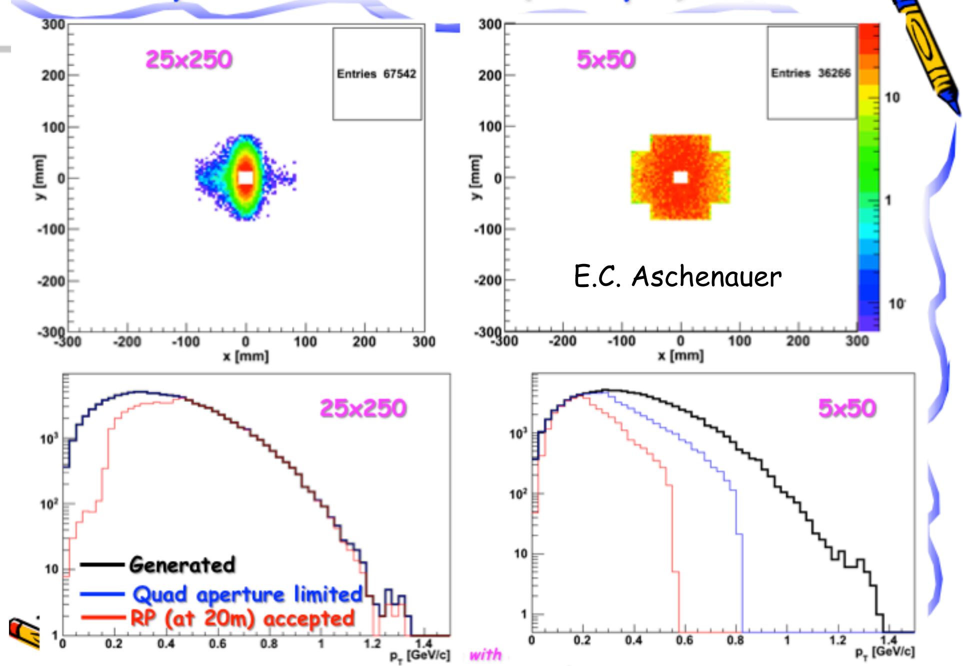


All achievable magnets!

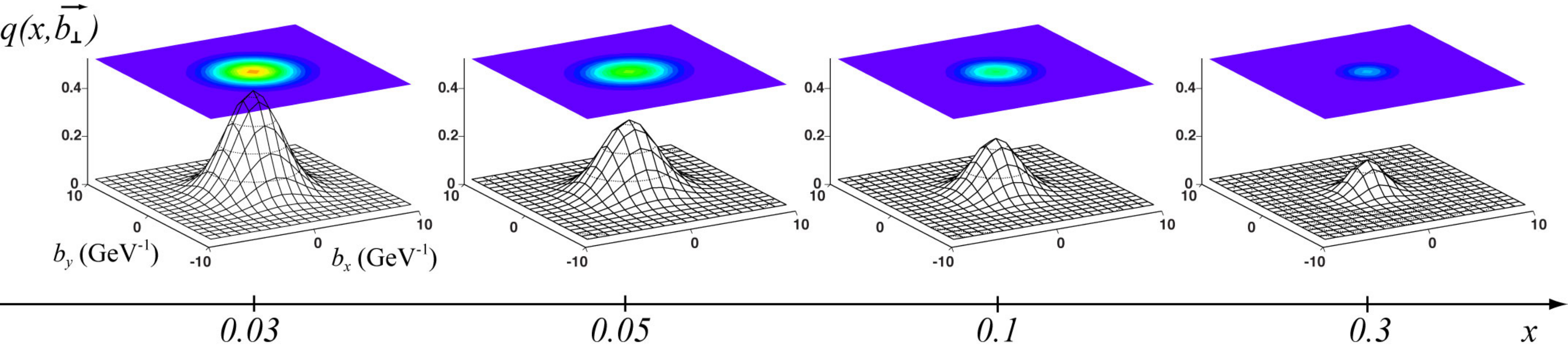
R. Ent



Accepted in "Roman Pot" (example) at s=20m



Parton imaging with an EIC



Preliminary work done in collaboration with :

E. C. Aschenauer, M. Diehl, S. Fazio, D. Müller and K. Kumerički

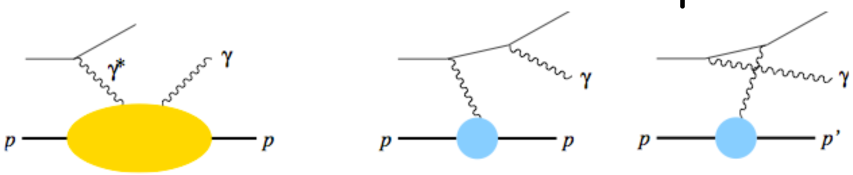
in preparation for the EIC White Paper

Exclusive Processes for parton imaging

Deeply Virtual Compton Scattering

- Theory is under control : up to α_S^2, twist-3, target mass corrections, etc
- Sensitive to the quark combination : $\frac{4}{9}u + \frac{1}{9}d + \frac{1}{9}s + \frac{4}{9}c$
- At EIC energies, mostly sensitive to sea quarks.
- Sensitive to gluon GPDs through Q^2 evolution and at NLO or beyond.
- Direct access to the Compton amplitude through

  interference with known Bethe-Heitler process



Hard Meson Electroproduction

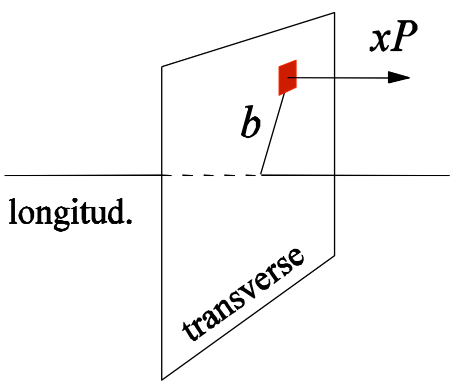
- Many channels available for flavor separation (ρ, ρ^+, π^0, π^+, ϕ, ...)
- J/Ψ is especially interesting to access gluon GPDs (H and even E)
- Theory less under control : convolution with (unknown) meson WF,

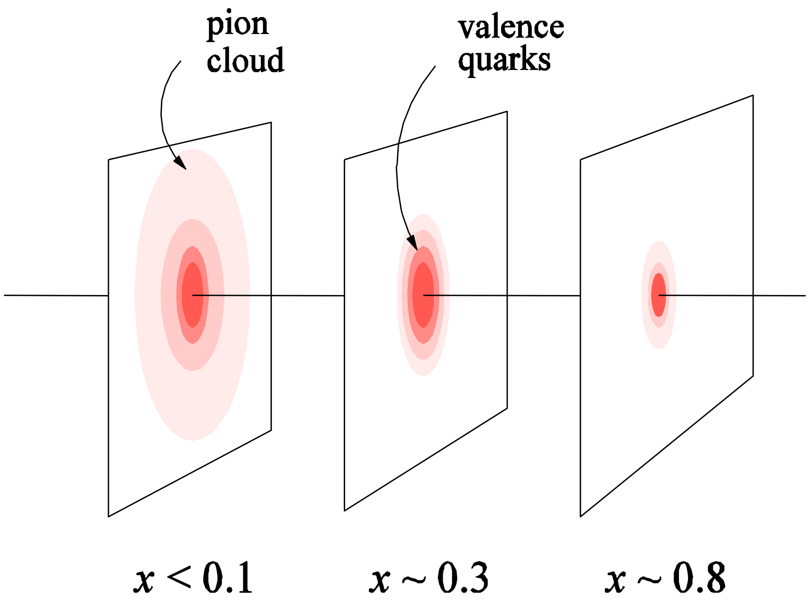
  large power and NLO corrections

Imaging partons with GPD H

At ξ=0, a GPD is the « form factor » of partons carrying longitudinal momentum fraction x

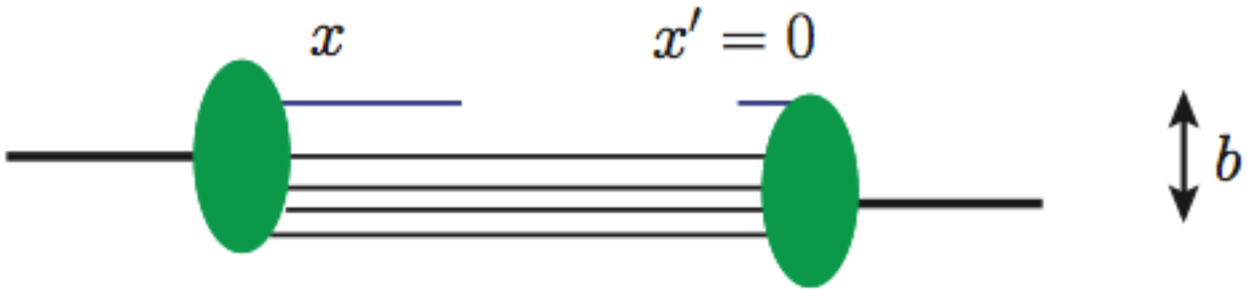
$$f(x,\vec{b}) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} e^{i\vec{b}\cdot\vec{\Delta}_\perp} H(x,\xi=0,-\Delta_\perp^2)$$





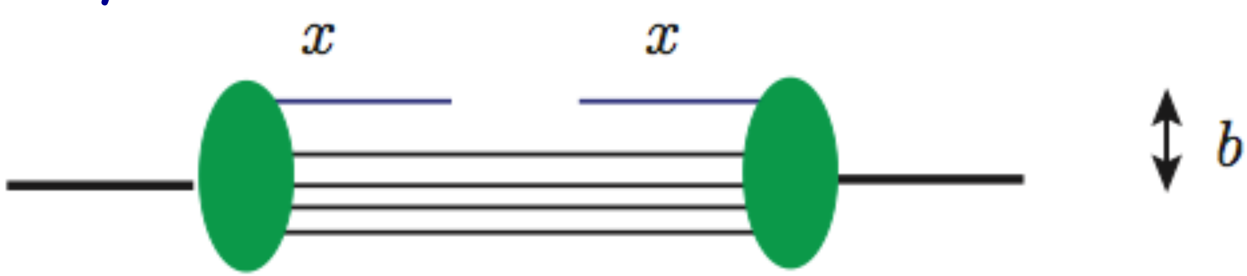
Imaging principle

The poor man's way



Pros: GPD(x=ξ,ξ,b) directly accessible experimentally in DVCS
b is well defined (imaginary part of Compton amplitude)
Cons: No probability interpretation !

The right way



Pros: Density interpretation GPD(x, ξ=0,b)=f(x,b) (IP-PDF)
Cons: Not directly accessible experimentally ➔ model dependent extraction
(some hope through Q^2 dependence, but experimentally difficult)
Systematic errors due to ξ=0 extrapolation remain to be studied

Imaging partons with GPD E

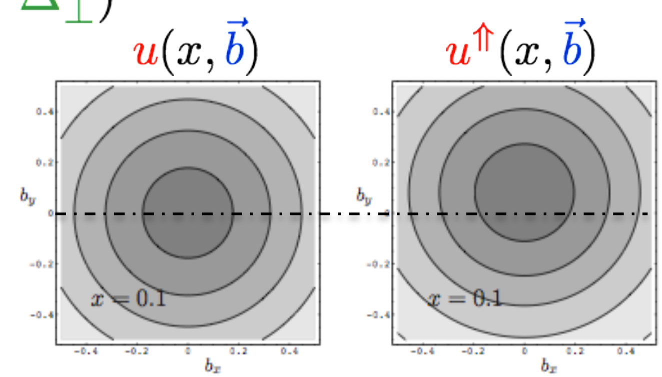
Burkardt '02, '05

GPD E ↔ nucleon helicity flip
interference between wave functions with L_z and $L_z \pm 1$

Access to GPD E via **transverse target polarization asymmetries**

Shift (*in y*) of the partons inside a polarized proton (*along x*)

$$f^{\Uparrow}(x,\vec{b}) = f(x,\vec{b}) - \frac{1}{2M}\frac{\partial}{\partial b_y}\int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} e^{i\vec{b}\cdot\vec{\Delta}_\perp} E(x,0,-\Delta_\perp^2)$$



Shift seems large for valence u and d quarks,

but *unknown* for sea and gluons : great opportunity for EIC

Simulation of DVCS for EIC

Mostly the work of S. Fazio, D. Müller (BNL)

Simulated DVCS data based on a fitted model for GPD H
Kumericki, Müller, Passek-Kumericki, Nucl. Phys. B794 (2008) 244-323
(fair description of H1 and ZEUS low-x_B DVCS data)

For GPD E, very simple ansatz : $E^i(x,\xi,t) = \kappa^i(t) H^i(x,\xi,t)$

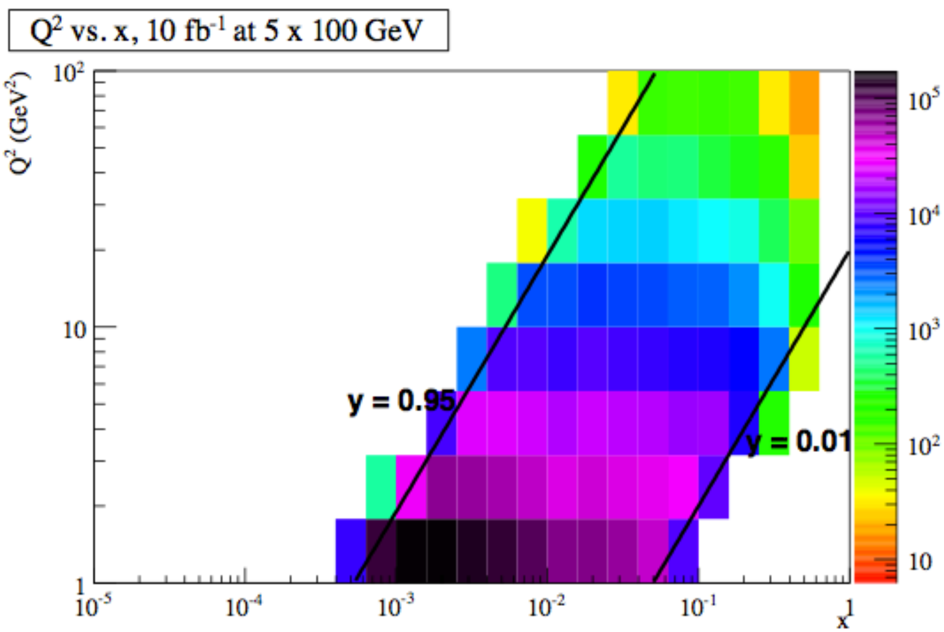
Used standard cuts for acceptance,
> for Roman pots, assumed $(0.175\ \mathrm{MeV})^2 < |t| < 0.88\ \mathrm{GeV}^2$

Kinematics were smeared according to expected resolution in t, Q^2, x_B

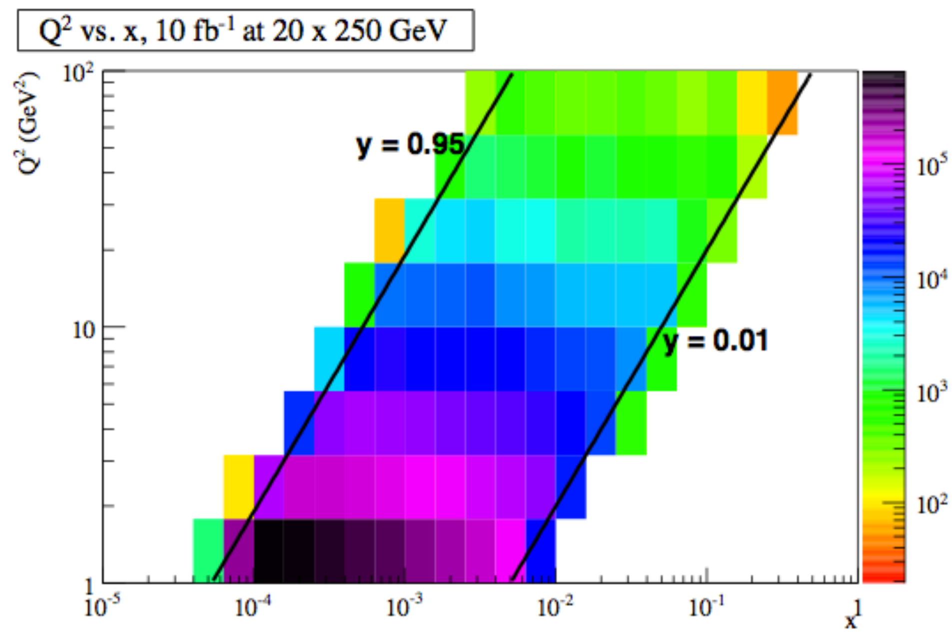
Assumed systematic errors of 5%, luminosity uncertainty *not included*

Simulation of DVCS for EIC : counting rates

EIC stage 1



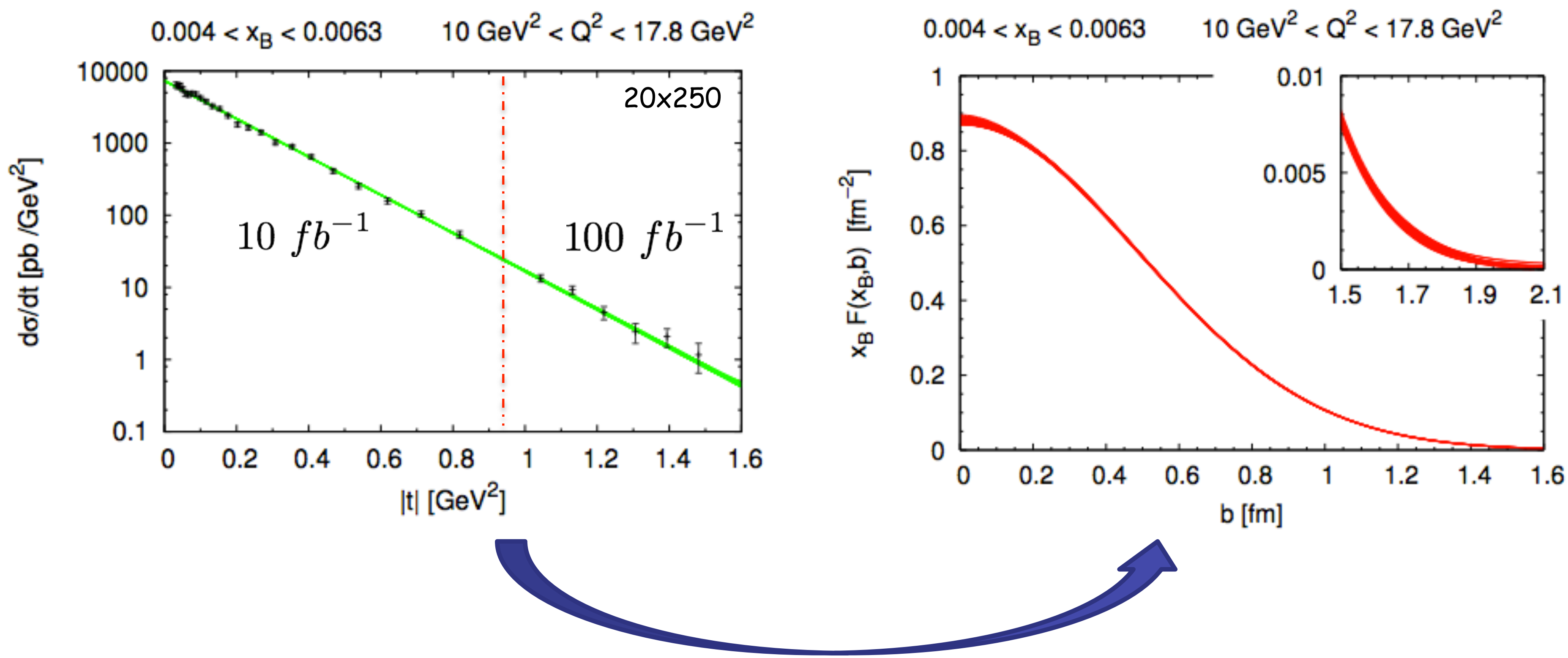
EIC stage 2



Reasonable counting rates for 4D binning (x_B,t,Q^2,Φ)

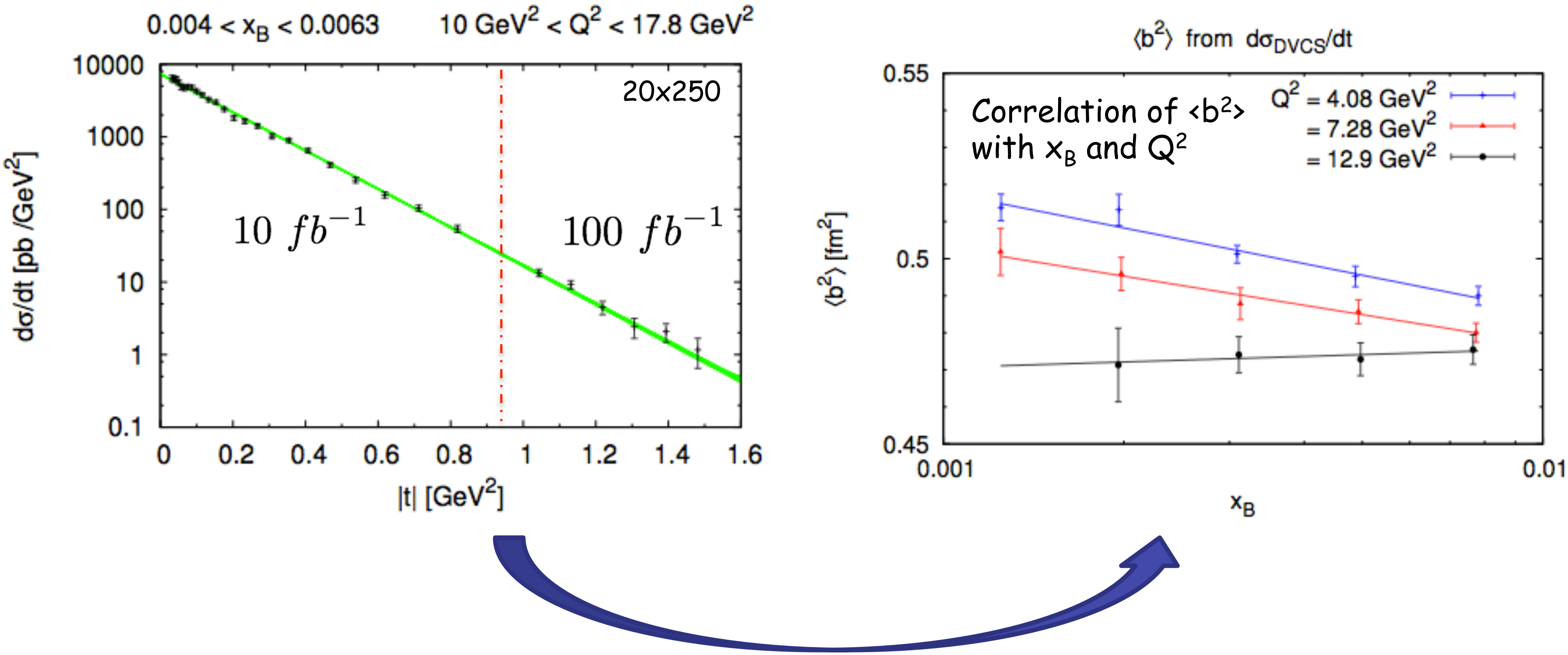
high-t usually needs higher luminosity (~100 fb^{-1})

Simulation of DVCS for EIC : Imaging at x=ξ



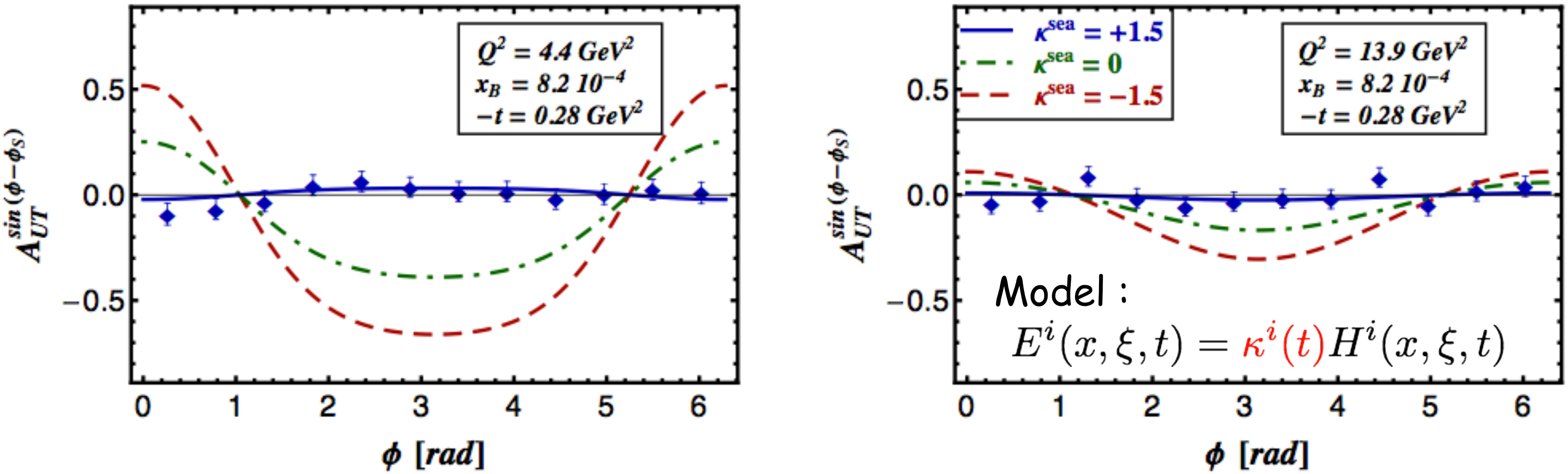
- ❑ Subtract BH contribution (known to ~3%)
- ❑ Extract Compton amplitude from $d\sigma_{\gamma^* p\to\gamma p}/dt$
- ❑ Fourier transform
- ❑ Vary low-x_B and high-x_B extrapolations to estimate errors

Simulation of DVCS for EIC : Imaging at x=ξ



- Subtract BH contribution (known to ~3%)
- Extract Compton amplitude from $d\sigma_{\gamma^* p \to \gamma p}/dt$
- Fourier transform to get IP-PDF
- Vary low-x_B and high-x_B extrapolations to estimate errors

Simulation of DVCS for EIC : the GPD E

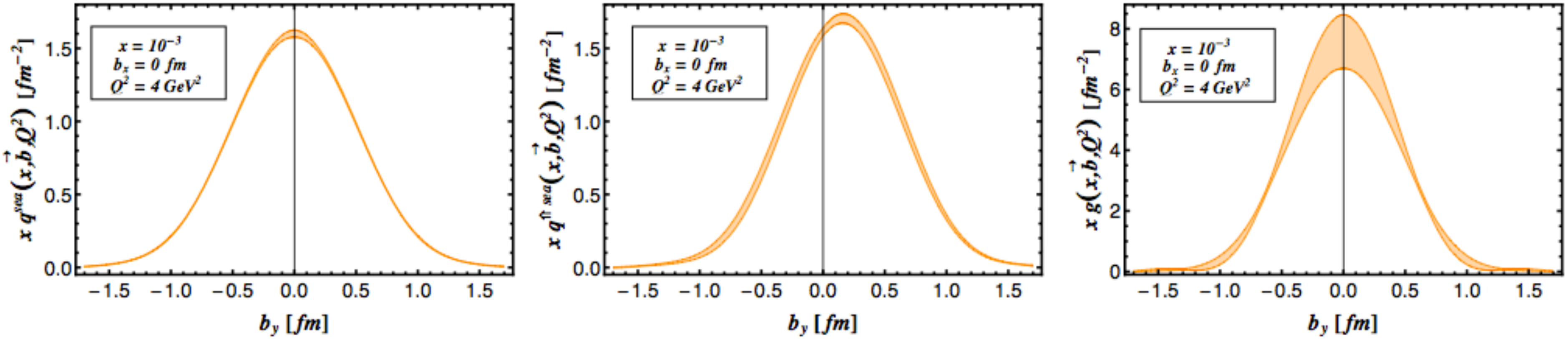


- ❑ $d\sigma/dt$ is mostly sensitive to the GPD H
- ❑ GPD E is accessible through transversely polarized proton asymmetries such as $A_{UT}^{\sin(\phi-\phi_S)}$ **(H contributes as well !)**

- ❑ Data for $d\sigma/dt$ and $A_{UT}^{\sin(\phi-\phi_S)}$ have been fitted simultaneously
- ❑ Assume known forward distributions for H, unknown for E

Simulation of DVCS for EIC : Imaging at ξ=0

e^g badly constrained from Q^2 evolution (not shown)



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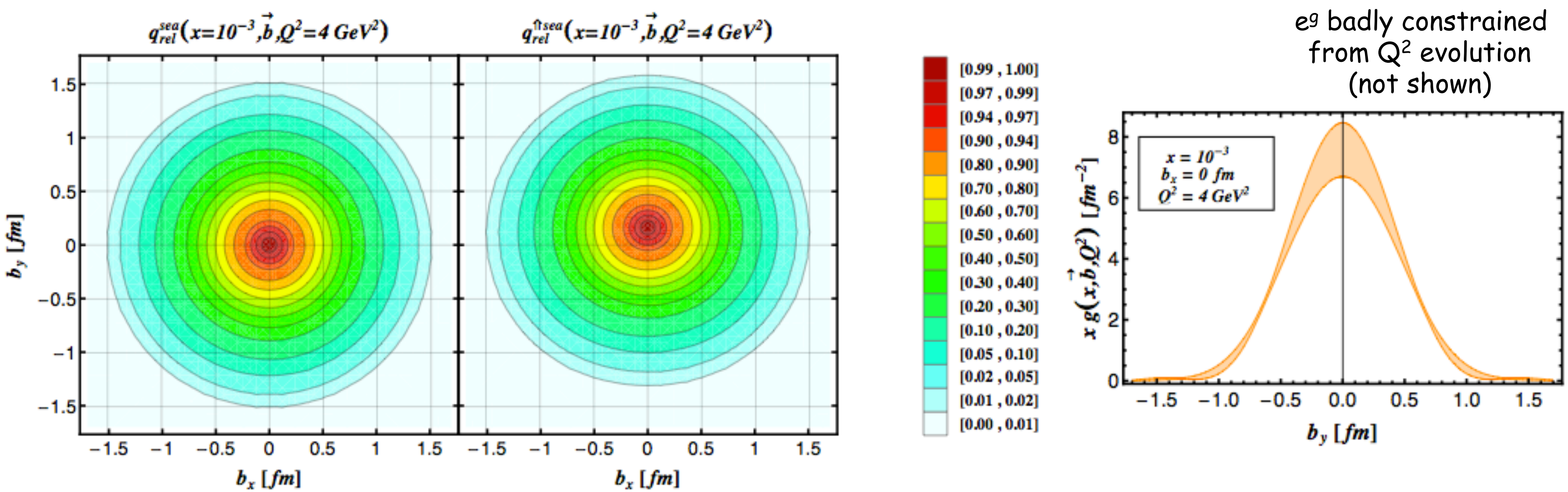
- ❑ Data for $d\sigma/dt$ and $A_{UT}^{\sin(\phi-\phi_S)}$ have been fitted simultaneously
- ❑ Assume known forward distributions for H, unknown for E
- ❑ Extrapolate fitted GPDs H and E to ξ=0, Fourier transform H and E

Simulation of DVCS for EIC : Imaging at ξ=0



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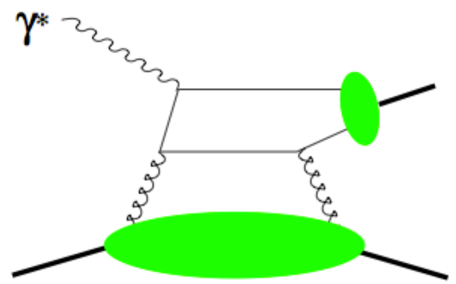
- ❑ Assume known forward distributions for H, unknown for E
- ❑ Extrapolate fitted GPDs H and E to ξ=0, Fourier transform H and E

Simulation of DVCS for EIC : Imaging gluons

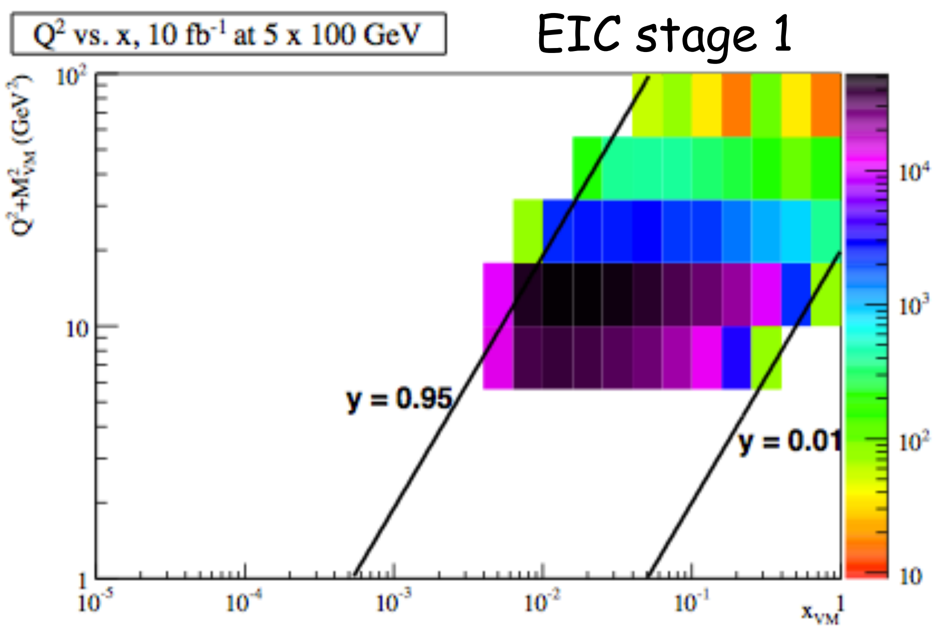
- Another golden channel : $\gamma^* p \to J/\Psi p$



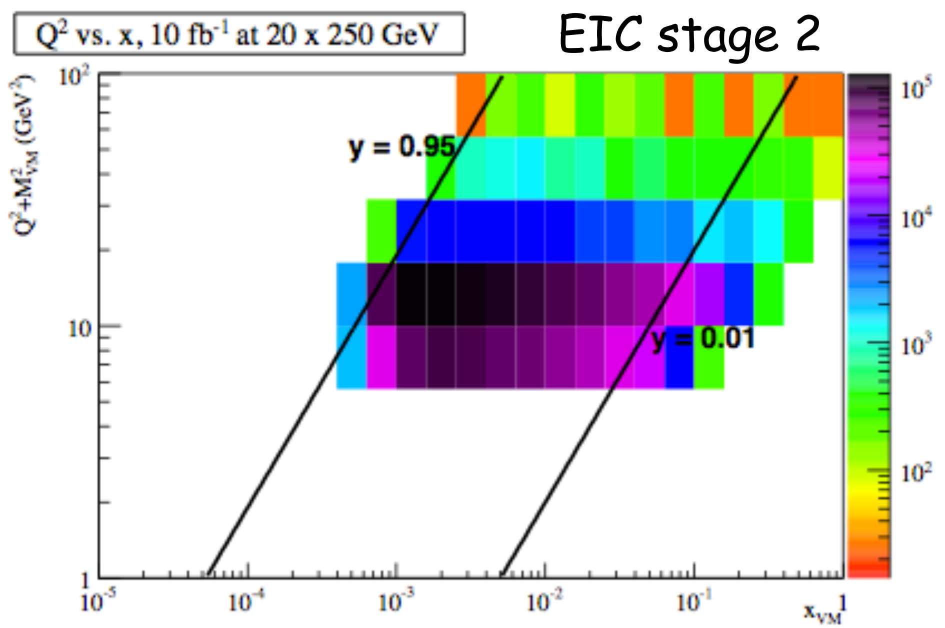
- Directly sensitive to gluons
- Theory rather well in control for a meson
- The hard scale is given by $Q^2 + M^2_{J/\Psi}$ (photoproduction possible)
- In principle, can be detected with both e^+e^- and $\mu^+\mu^-$ decay channels
- Cross section : H^g

Transverse Spin Asymmetry : E^g

EIC stage 1



EIC stage 2

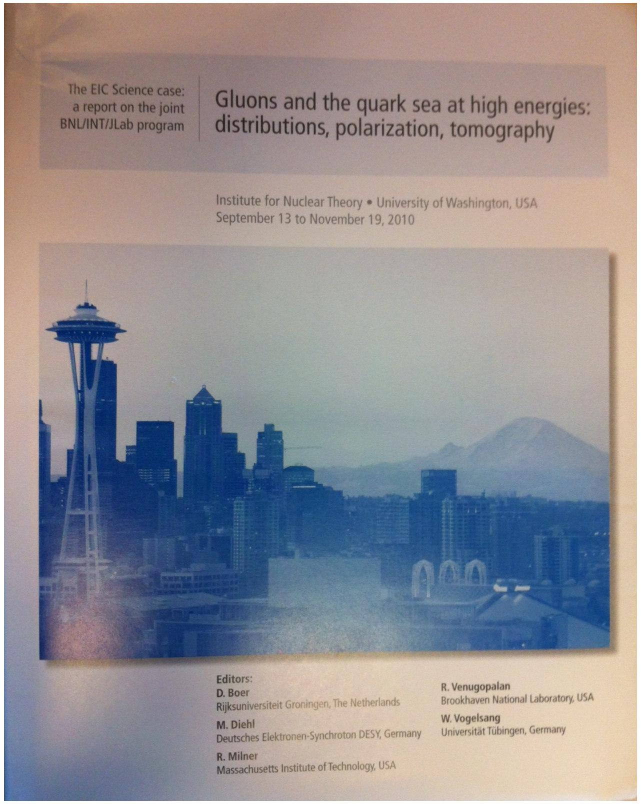


What is happening right now

- Published INT report arXiv:1108.1713v1 (Gluons and the quarks sea at high energies: distributions, polarization, tomography)

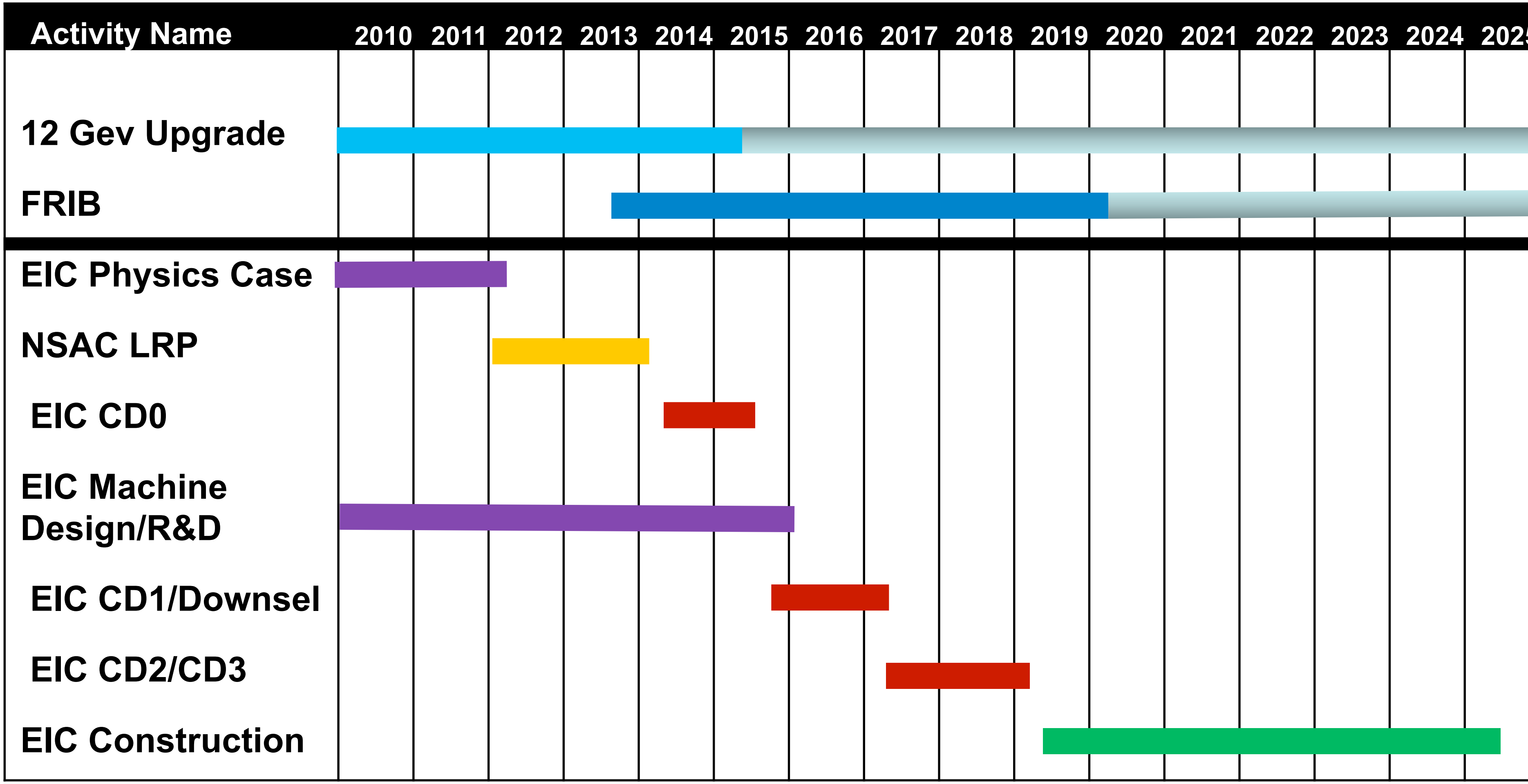
- New R&D proposal calls at BNL in May 2012

- Currently working on EIC White Paper for NSAC Long Range Plan 2013

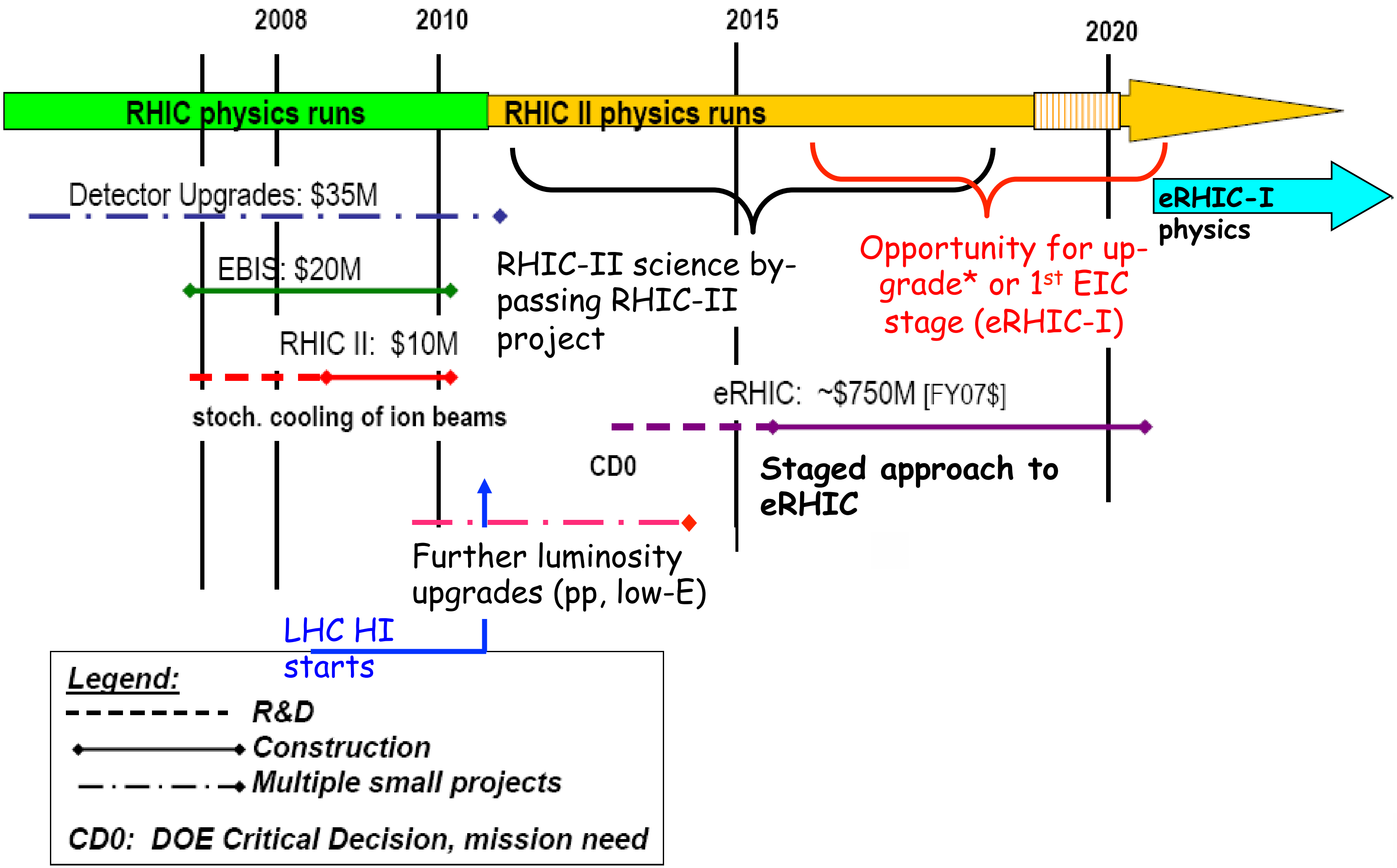


<u>Steering committee:</u> A. Deshpande (Stony Brook), Z-E. Meziani (Temple), J. Qiu (BNL), T. Ullrich (BNL), Y. Kovchegov (Ohio State), E. Sichtermann (LBNL), W. Vogelsang (Tubingen), M. Diehl (DESY), F. Sabatié (Saclay), H. Gao (Duke), F. Yuan (LBNL), K. Kumar (U Mass), M. Ramsey-Musolf (Wisconsin), A. Hutton (Jlab), T. Roser (BNL), E. Aschenauer (BNL), T. Horn (CUA), A. Mueller (Columbia), R. Holt (ANL)

Realization of an EIC at JLab



Realization of an EIC at RHIC



Conclusion

- Hard exclusive processes offer a unique possibility to do imaging of the nucleon at the femtometer scale !

- Images are not just « pretty » but offer insight into the proton structure and parton dynamics.

- EIC is the decisive machine to study sea quarks and gluon imaging through measurement of various cross sections and asymmetries, esp. DVCS, J/Ψ.

- The current machine and detector plans match the requirements in order to deliver unique and high quality physics output from the study of hard exclusive processes.