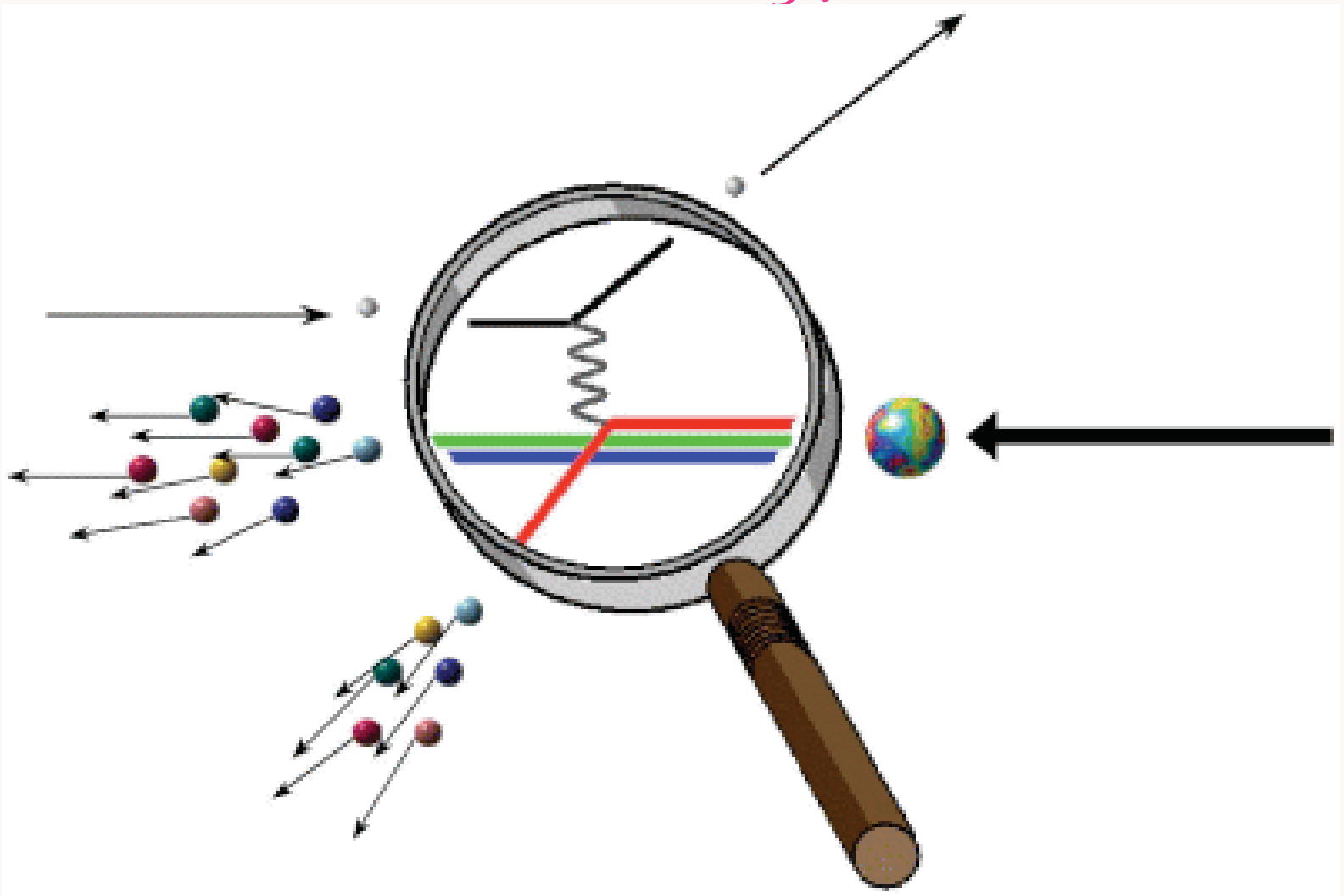
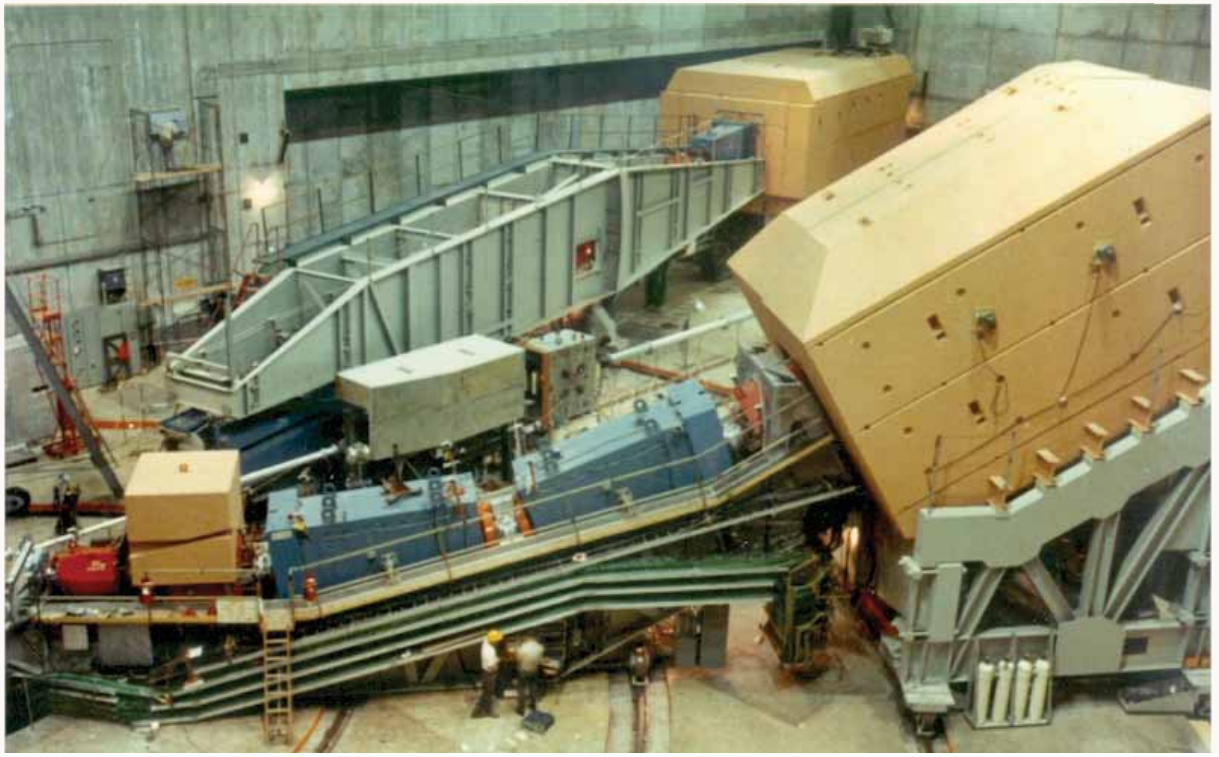
Novel QCD Phenomena at Electron-Proton Colliders

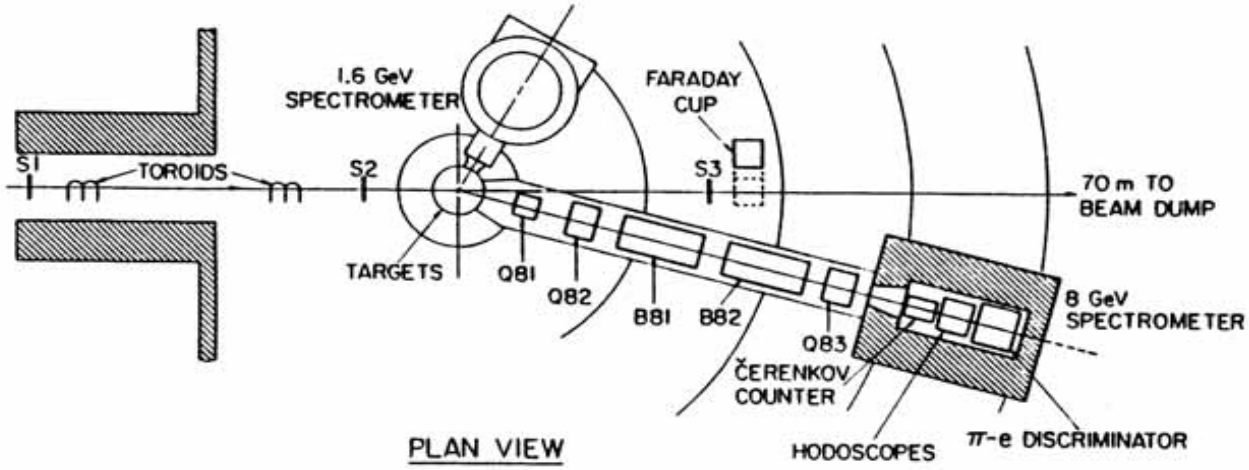
Stan Brodsky, SLAC



SLAC Two-Mile Linear Accelerator



Pief

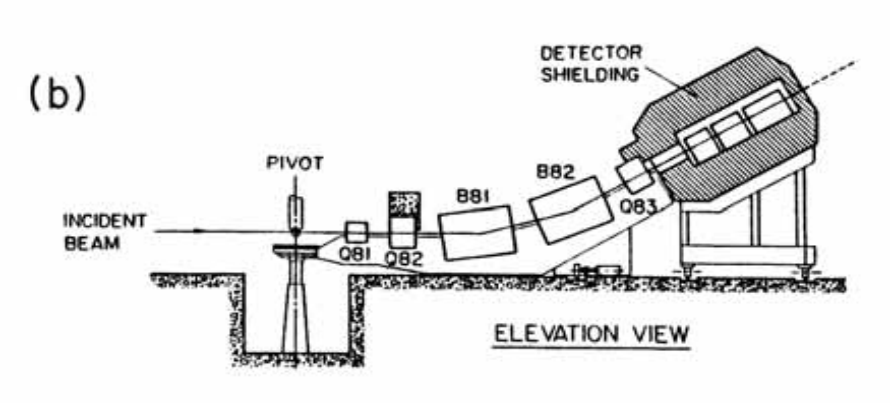


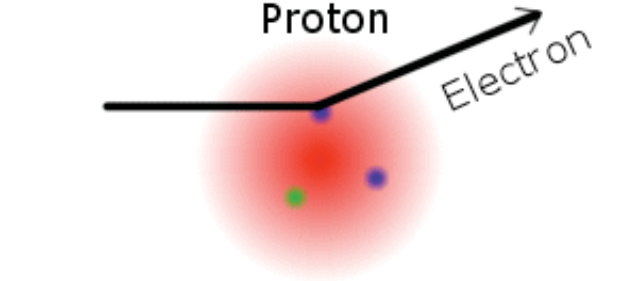
1967 SLAC Experiment:

Scatter 20 GeV/c Electrons on protons in a Hydrogen Target

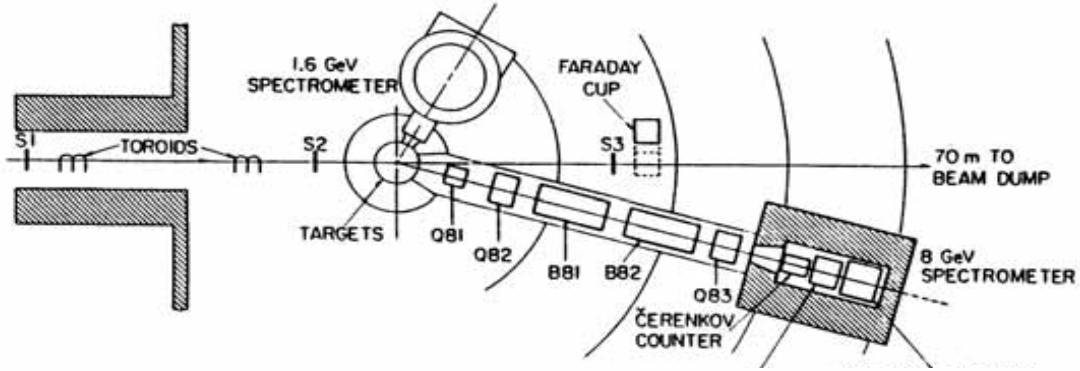
$$ep \rightarrow e'X$$

Discovery of the Quark Structure of Matter

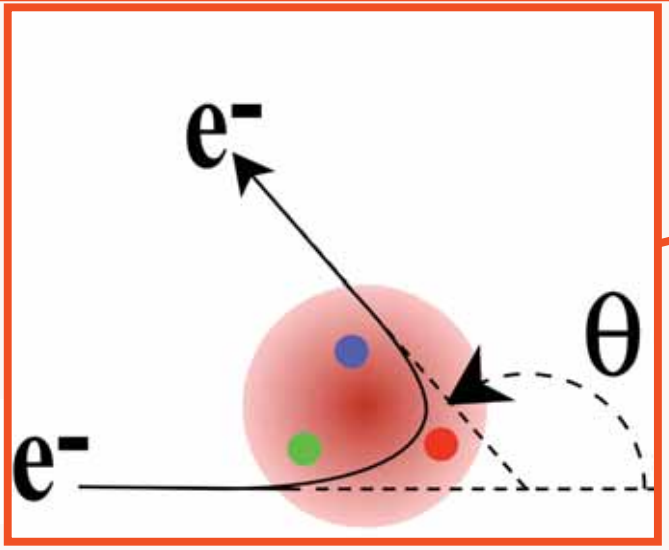




Discovery of quarks!

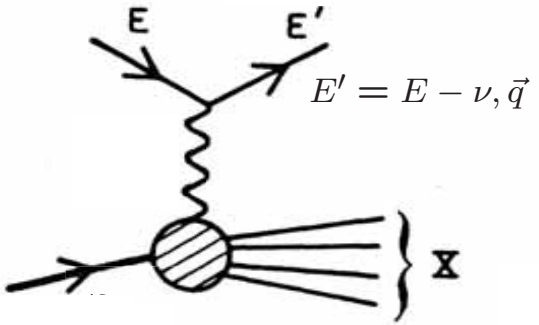


Deep inelastic scattering: Experiments on the proton and the observation of scaling*

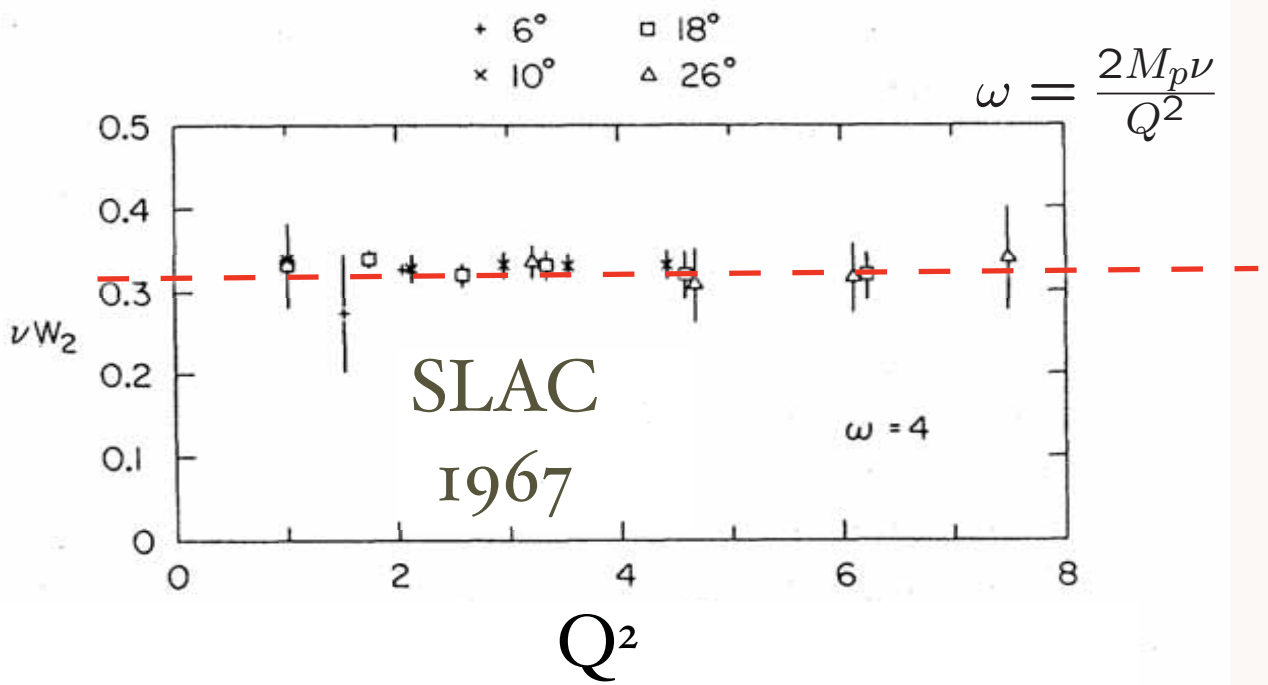


Friedman, Kendall, Taylor: Nobel Prize

$$ep \to e'X$$



$$Q^2 = \vec{q}^2 - \nu^2$$



No intrinsic length scale !

Measure rate as a function of energy loss ν and momentum transfer Q

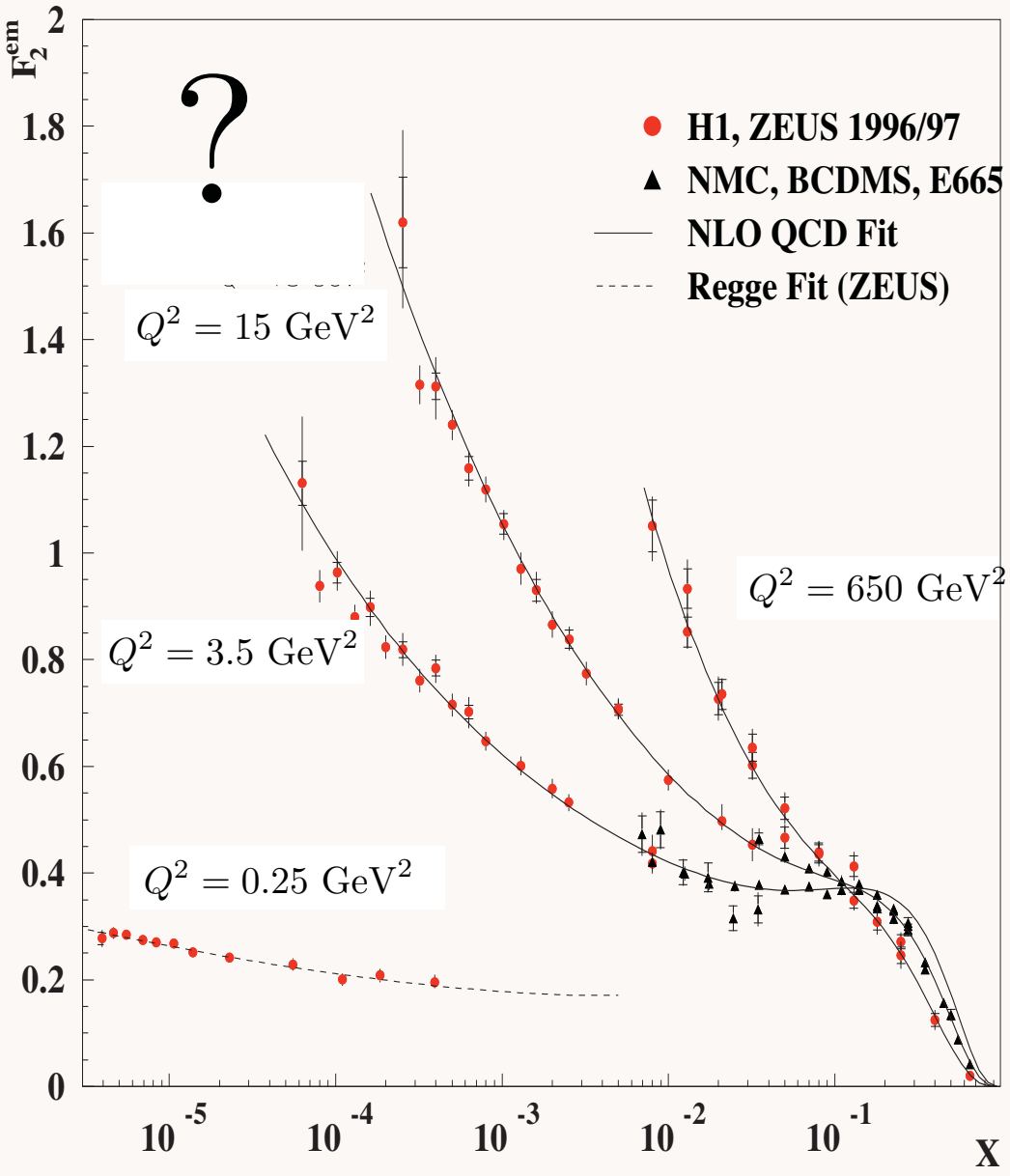
Scaling at fixed $x_{Bjorken} = \frac{Q^2}{2M_p\nu} = \frac{1}{\omega}$

Discovery of Bjorken Scaling

Electron scatters on point-like quarks!

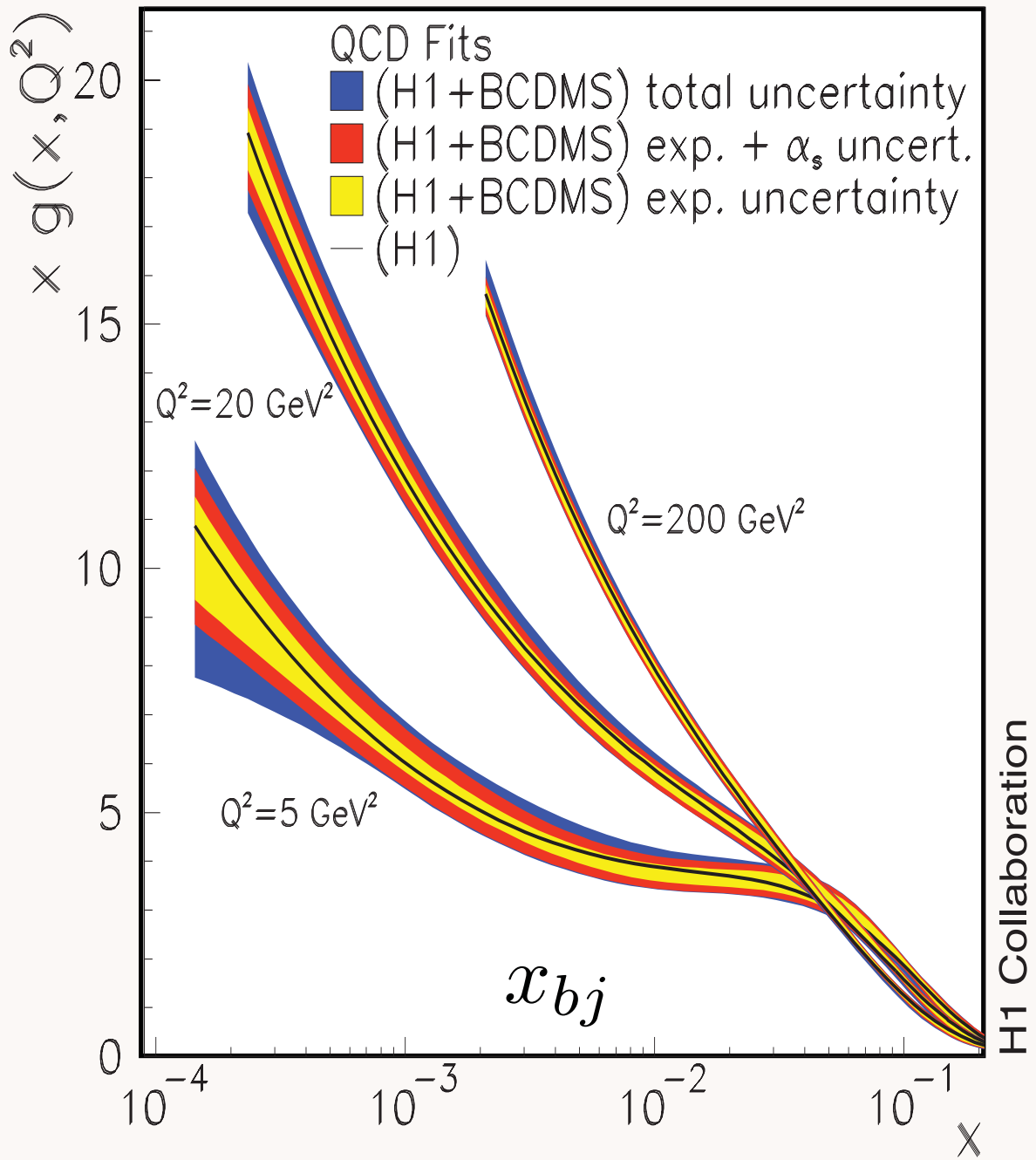
- ***Key Probe of QCD: Lepton-Nucleon, Lepton-Nucleus Scattering***

$F_2(x, Q^2)$



Unitarity Bound? Saturation?

$xg(x, Q^2)$



Gluon distribution inferred from charm production, etc.

Two Pictures of High Energy Lepton-Proton Collisions

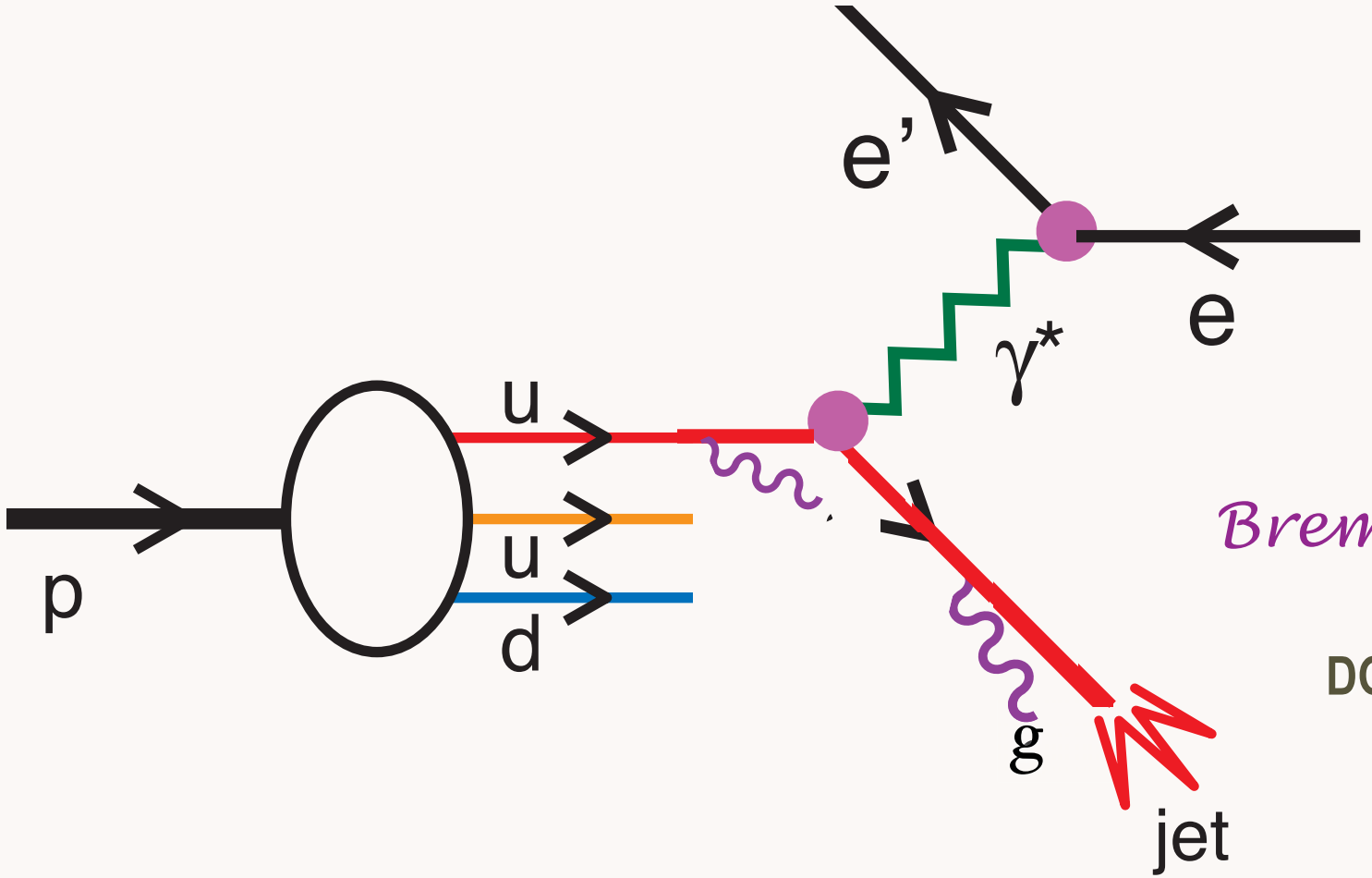
Infinite momentum frame **Parton Model**

Simple Virtual Photon Probes Complex Evolved Proton

Proton Rest Frame **Color-Dipole Model**

Color Dipole of Virtual Photon Scatters on a Complex Static Proton

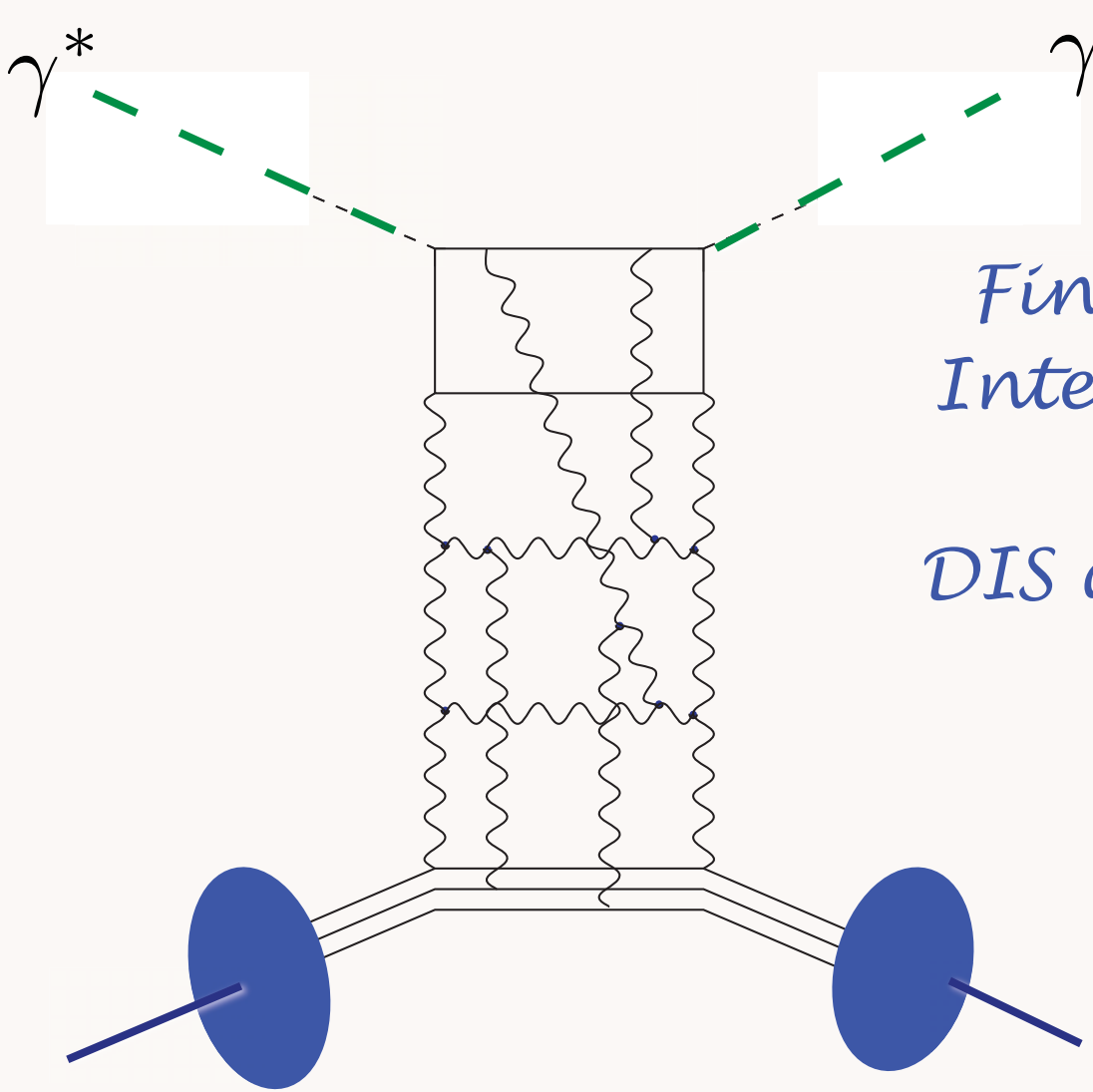
Deep Inelastic Electron-Proton Scattering



Gluonic Bremmstrahlung

DGLAP Evolution

Simple Virtual Photon Probes Complex Evolved Proton

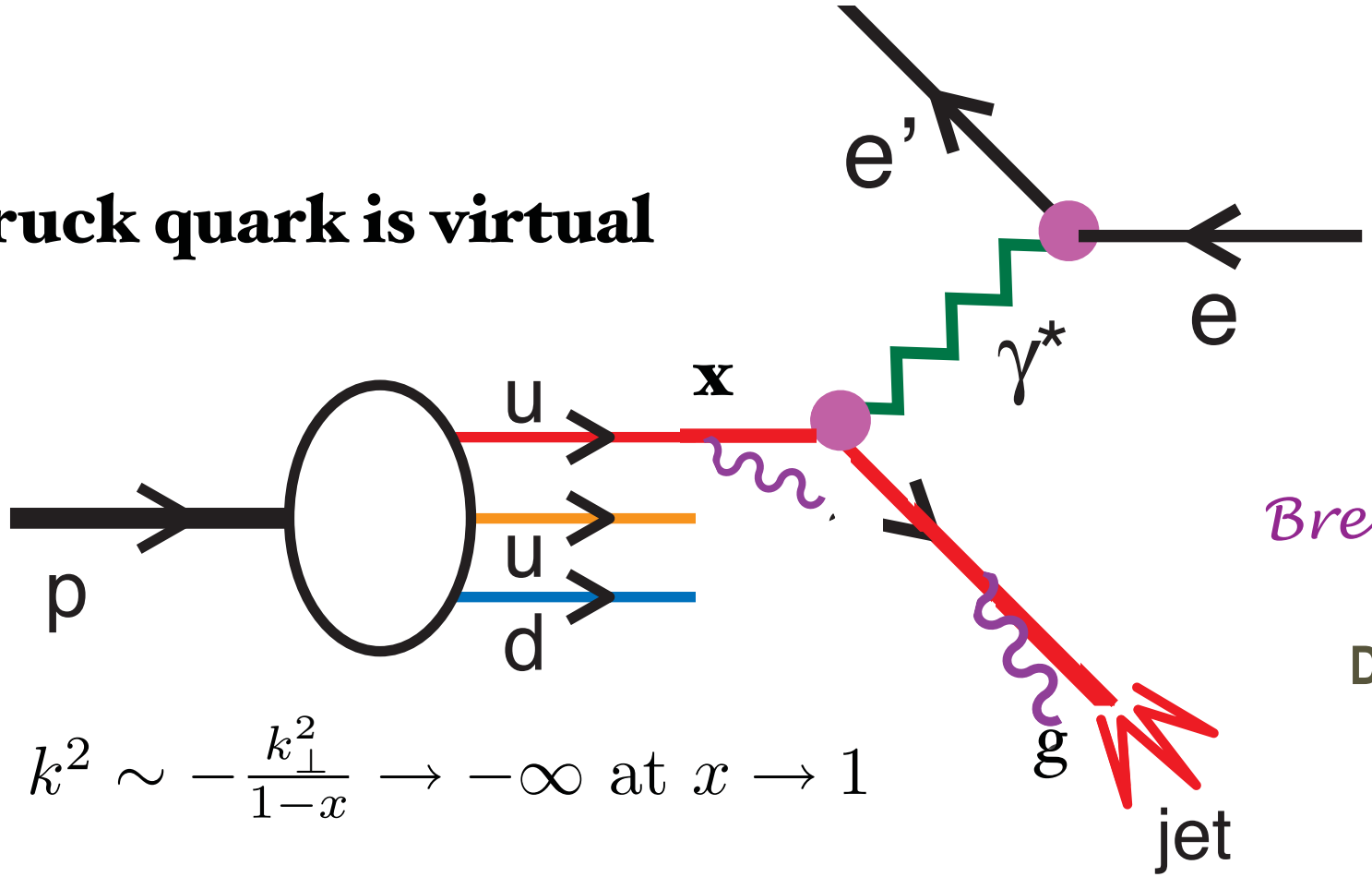


Final-State Interactions!

DIS and DVCS

Deep Inelastic Electron-Proton Scattering

Struck quark is virtual



$$k^2 \sim -\frac{k_\perp^2}{1-x} \rightarrow -\infty \text{ at } x \rightarrow 1$$

Gluonic Bremmstrahlung

DGLAP Evolution

Off-shell Effect: Breakdown of DGLAP at x ~1 !

Modifications from FSI !

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Color Dipole of Virtual Photon Scatters
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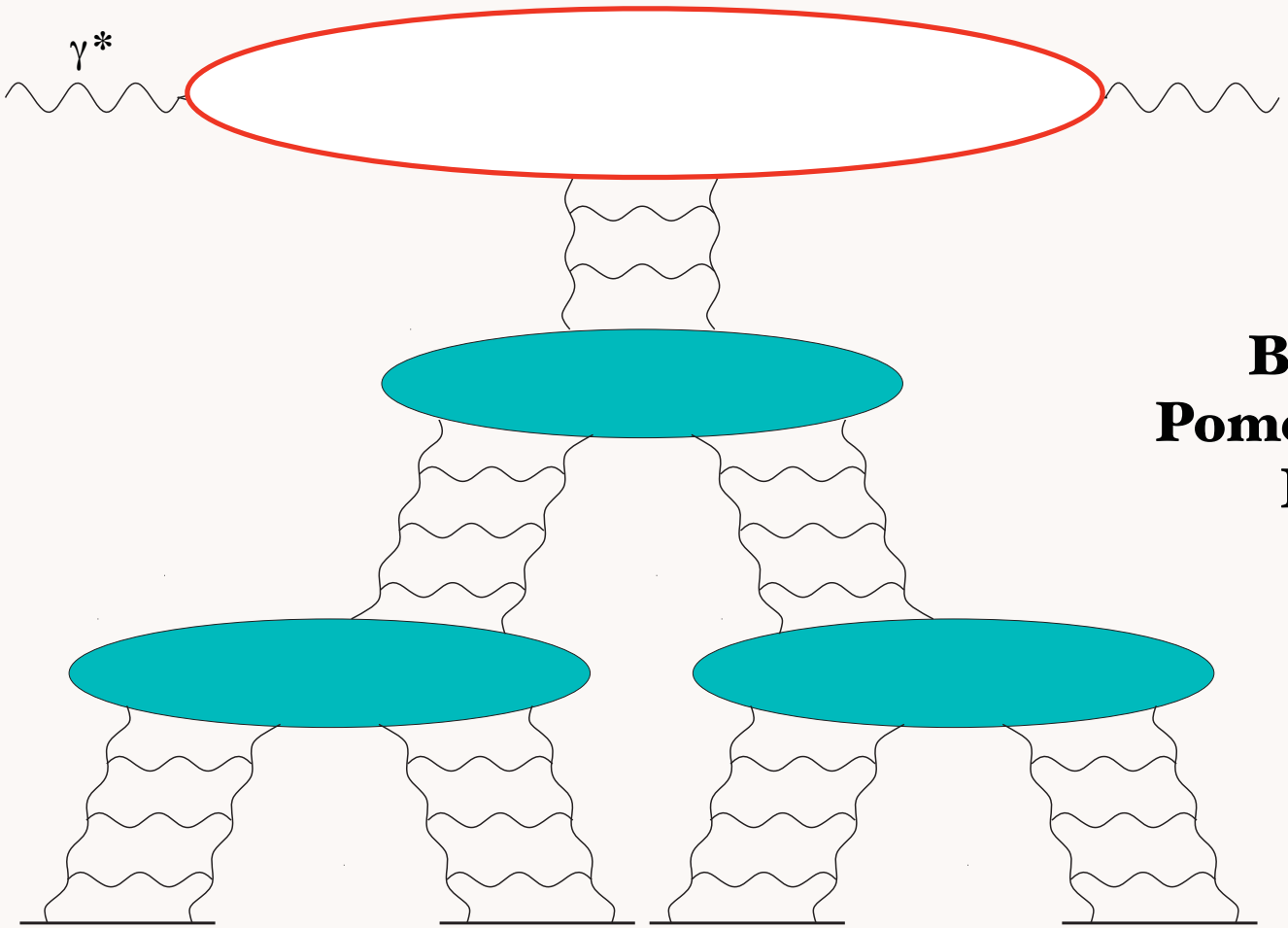
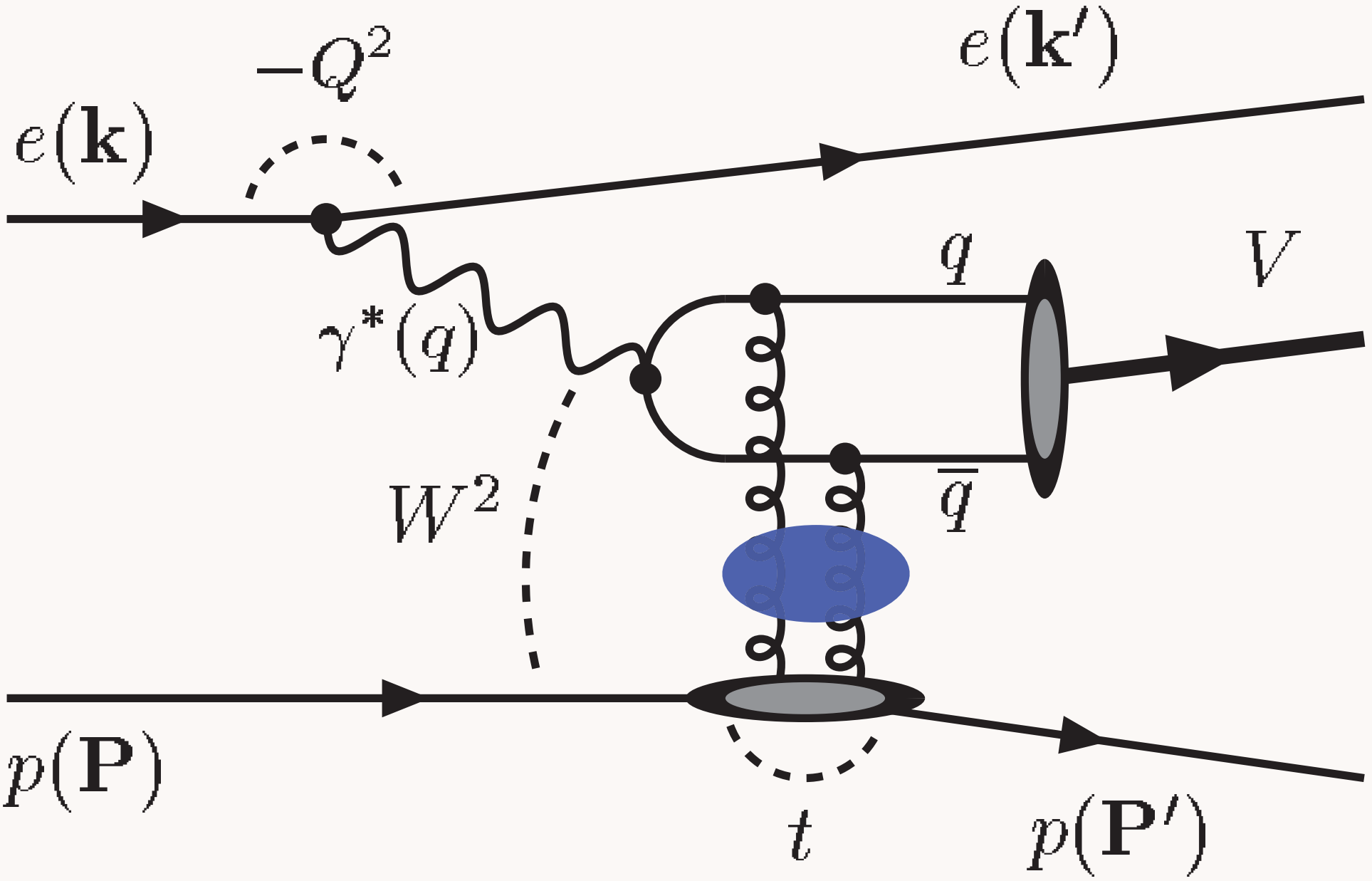
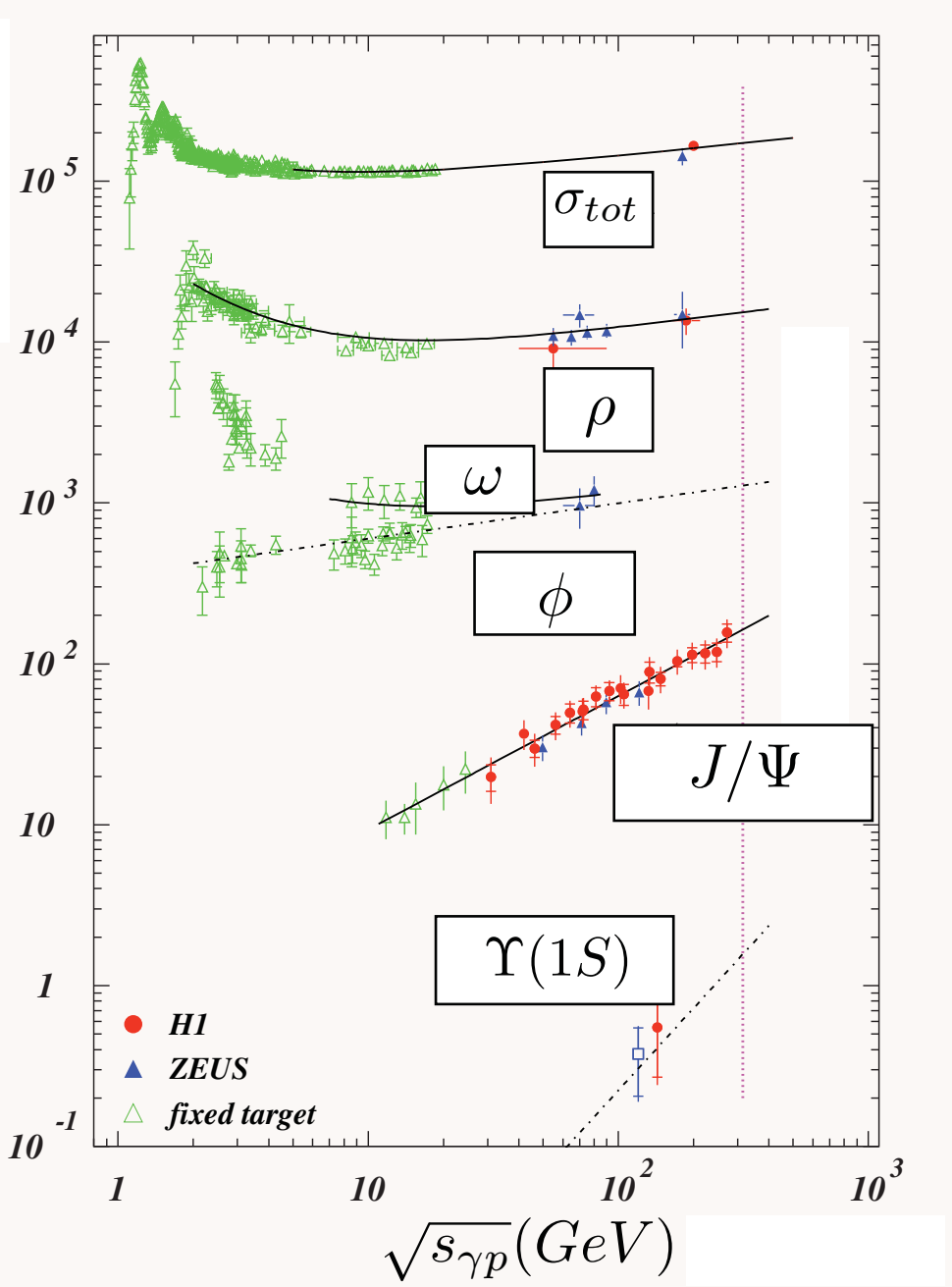


BFKL Hard Pomeron-Odderon Exchange

Color Dipole of Virtual Photon Scatters on a Complex Static Proton



BFKL hard pomeron exchange + BLM NLO scale fixing



Diffractive Processes

Unitarity Bound?
Saturation?

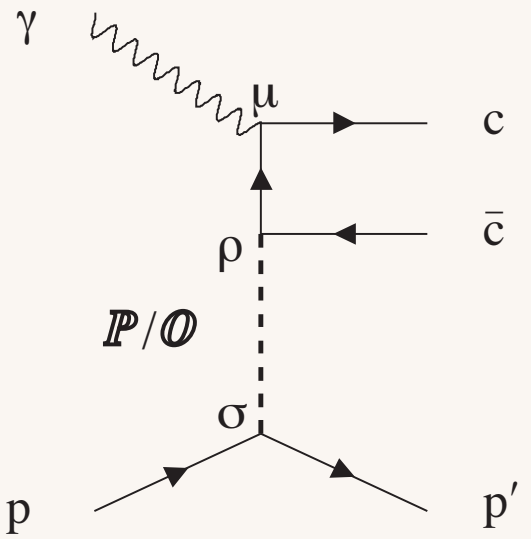
Hard Diffraction

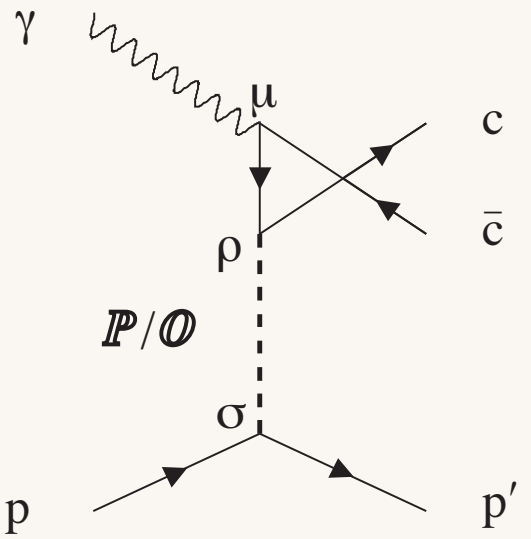
$$\gamma p \to \Upsilon p$$

$$\gamma^* p \to \rho p$$

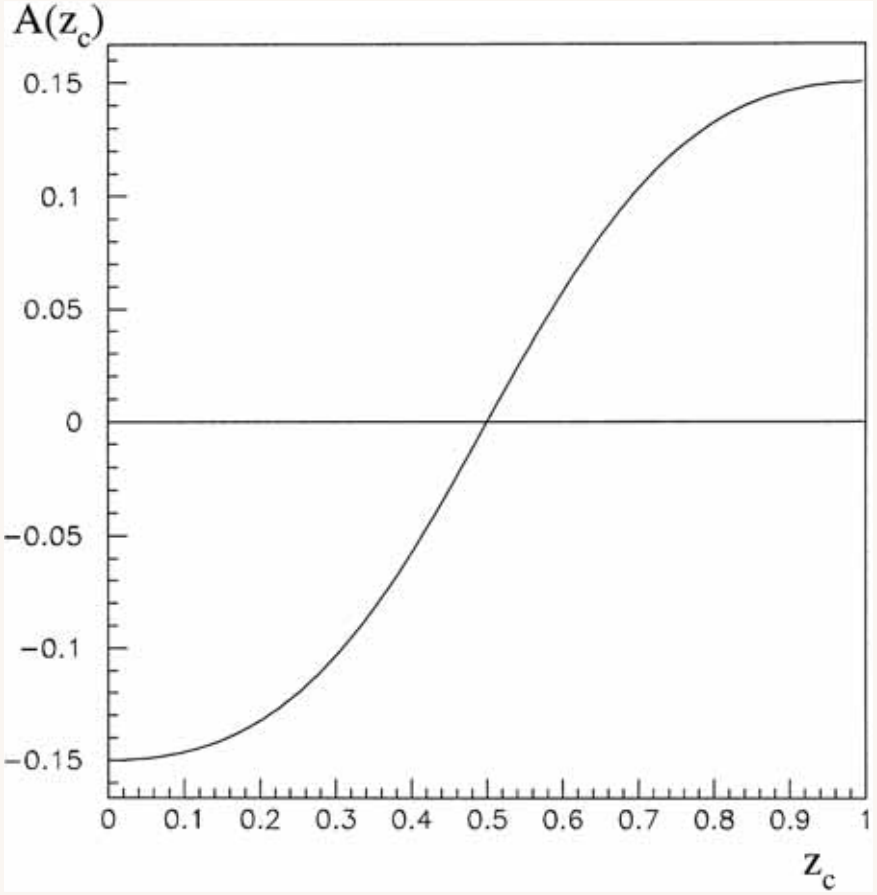
Odderon

$$\gamma^* p \to \pi^0 p$$





Odderon-Pomeron Interference!



$$\mathscr{A}\left(t \simeq 0, M_X^2, z_c\right) \simeq 0.45 \left(\frac{s_{\gamma p}}{M_X^2}\right)^{-0.25} \frac{2\,z_c - 1}{z_c^2 + (1 - z_c)^2}$$

Measure charm asymmetry in photon fragmentation region

Merino, Rathsman, sjb

Three Pictures of High Energy Lepton-Proton Collisions

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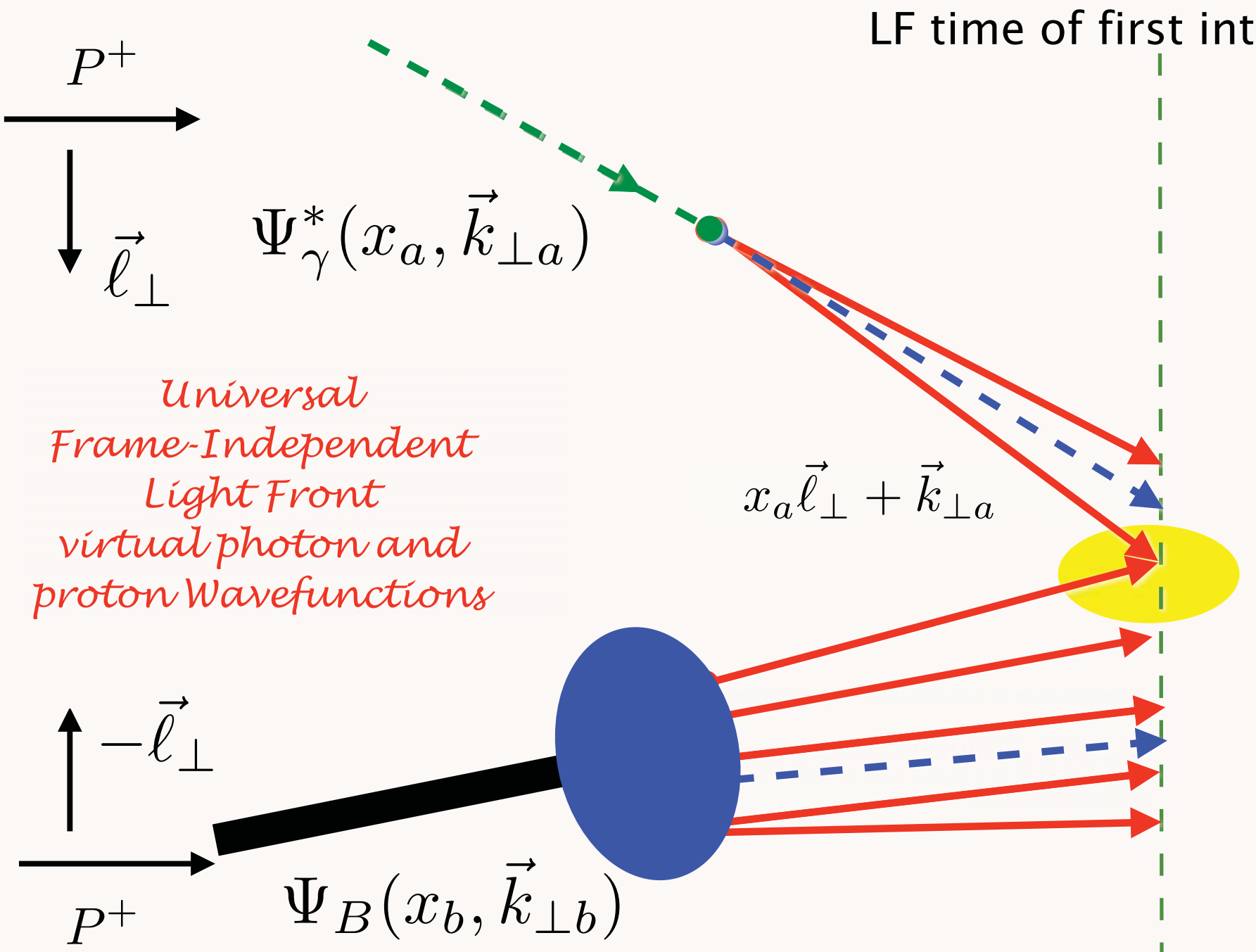
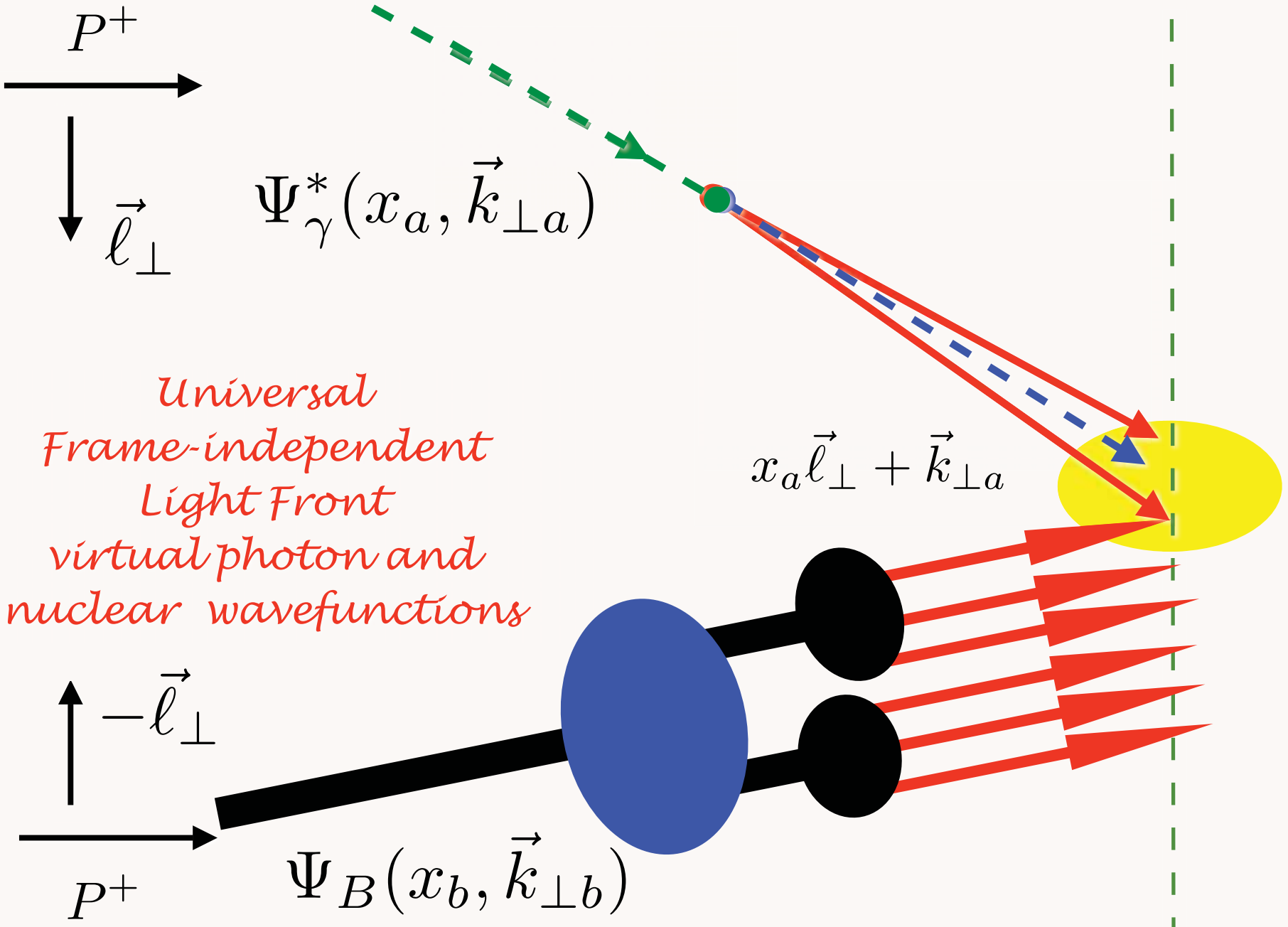
Color Dipole of Virtual Photon Scatters on a Static Proton

Frame-Independent — **Light-Front Hamiltonian Theory**

Collision of Light-Front Wavefunctions of Virtual Photon and Proton


LF time of first interaction
P^+
$\vec{\ell}_\perp$
$\Psi^*_\gamma(x_a, \vec{k}_{\perp a})$
Universal
Frame-Independent
Light Front
virtual photon and
proton Wavefunctions
$x_a\vec{\ell}_\perp + \vec{k}_{\perp a}$
$-\vec{\ell}_\perp$
P^+
$\Psi_B(x_b, \vec{k}_{\perp b})$


P^+
$\vec{\ell}_\perp$
$\Psi^*_\gamma(x_a, \vec{k}_{\perp a})$
Universal
Frame-independent
Light Front
virtual photon and
nuclear wavefunctions
$x_a\vec{\ell}_\perp + \vec{k}_{\perp a}$
$-\vec{\ell}_\perp$
P^+
$\Psi_B(x_b, \vec{k}_{\perp b})$

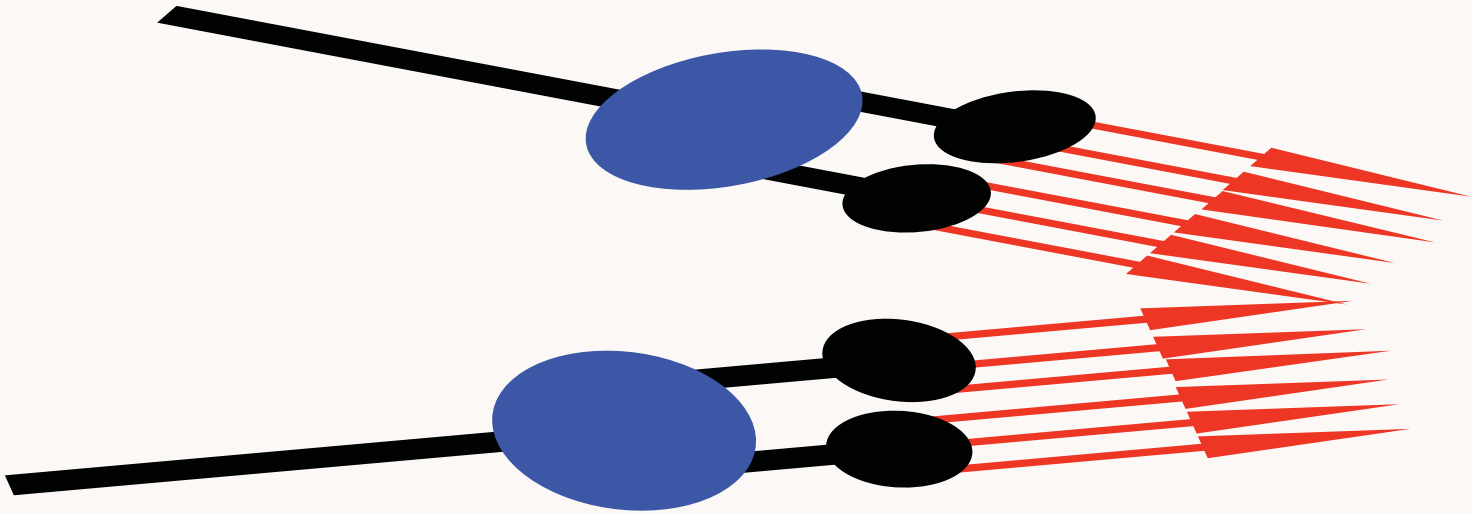
$$p_A = (P^+, \frac{M_A^2 + \ell_\perp^2}{P^+}, \vec{\ell}_\perp)$$

$$p_B = (P^+, \frac{M_B^2 + \ell_\perp^2}{P^+}, -\vec{\ell}_\perp)$$

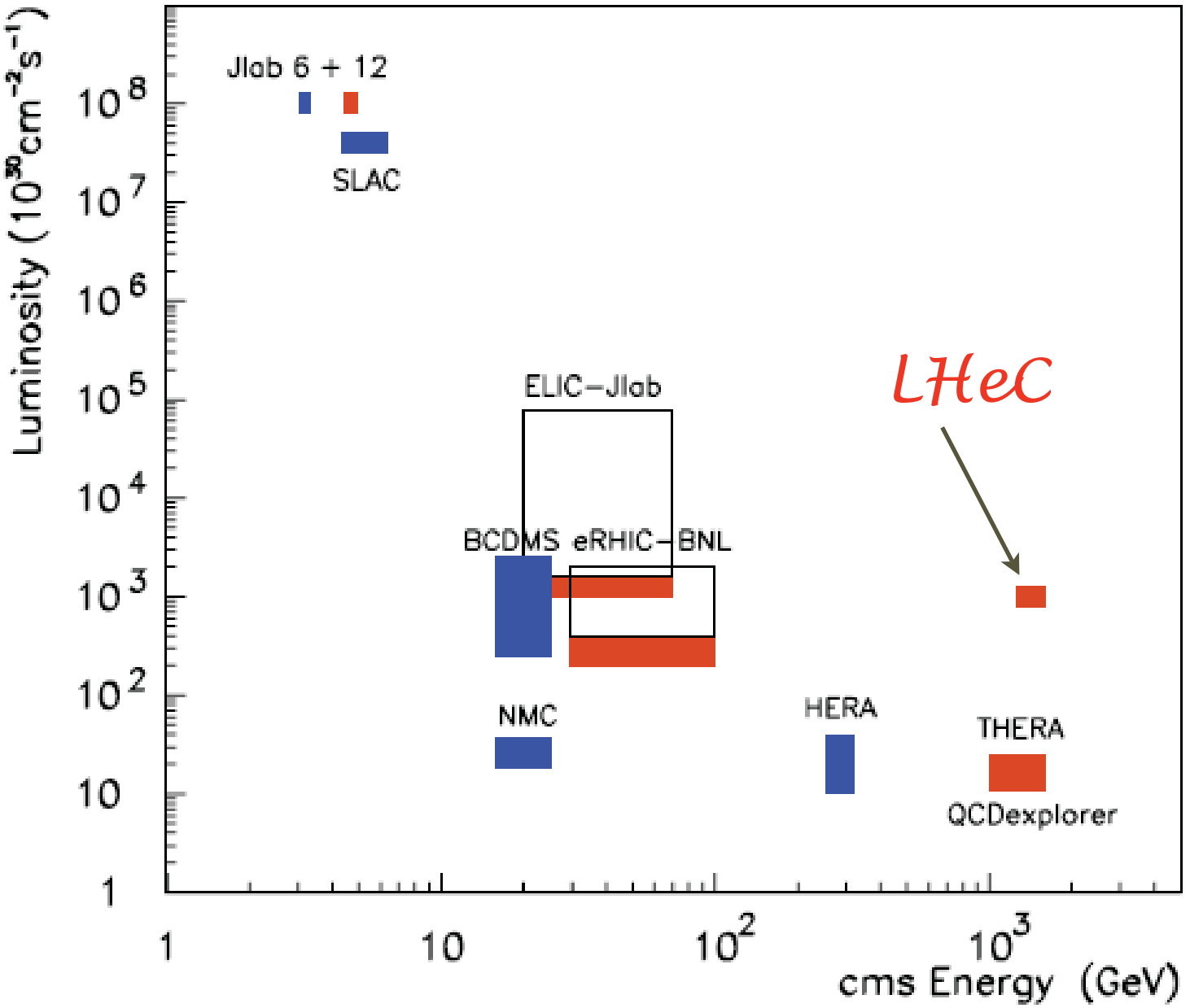
Both beams move along the positive z direction, and $s = (p_A + p_B)^2 = 2M_A^2 + 2M_B^2 + 4\ell_\perp^2$ is represented by the oppositely directed transverse momenta $\pm\vec{\ell}_\perp$ of the colliding nuclei.

Note that the value of P^+ is irrelevant.

As τ progresses, the constituents from A and B each interact as their coordinates σ_i and $\vec{b}_{\perp i}$ overlap.

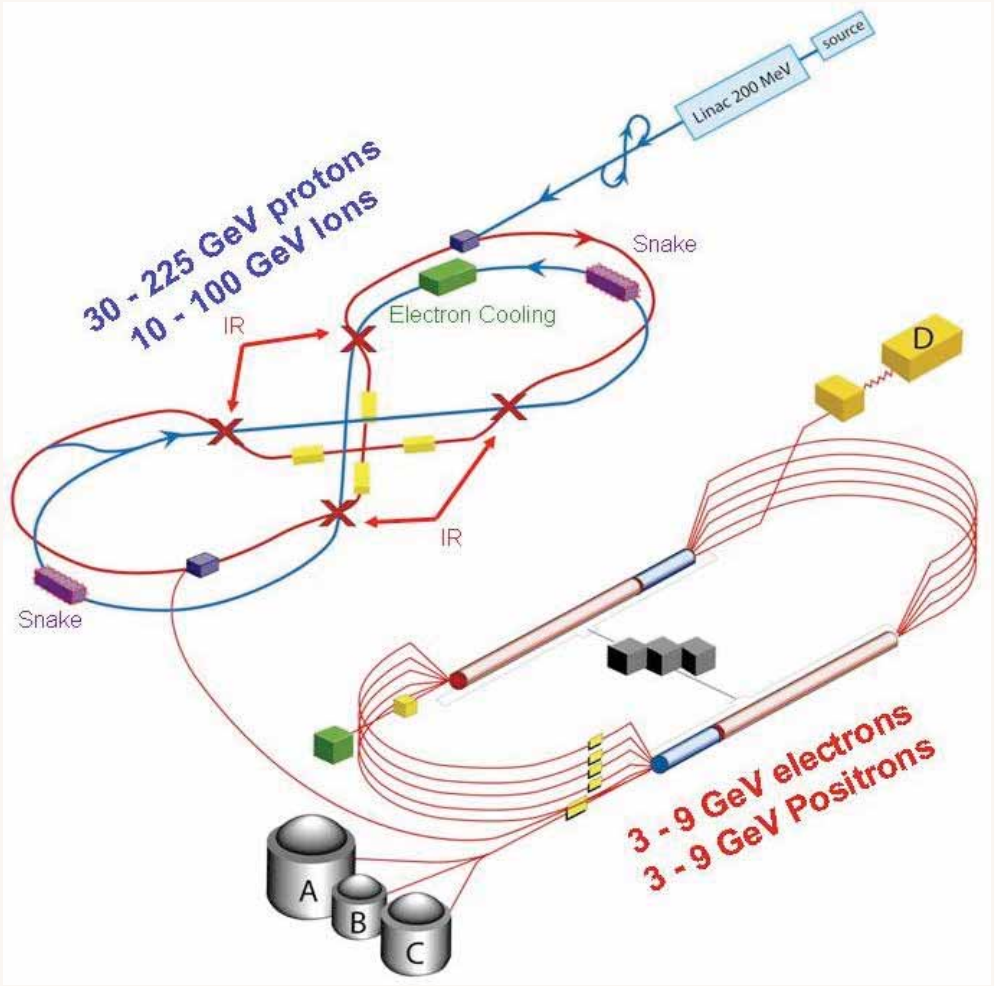


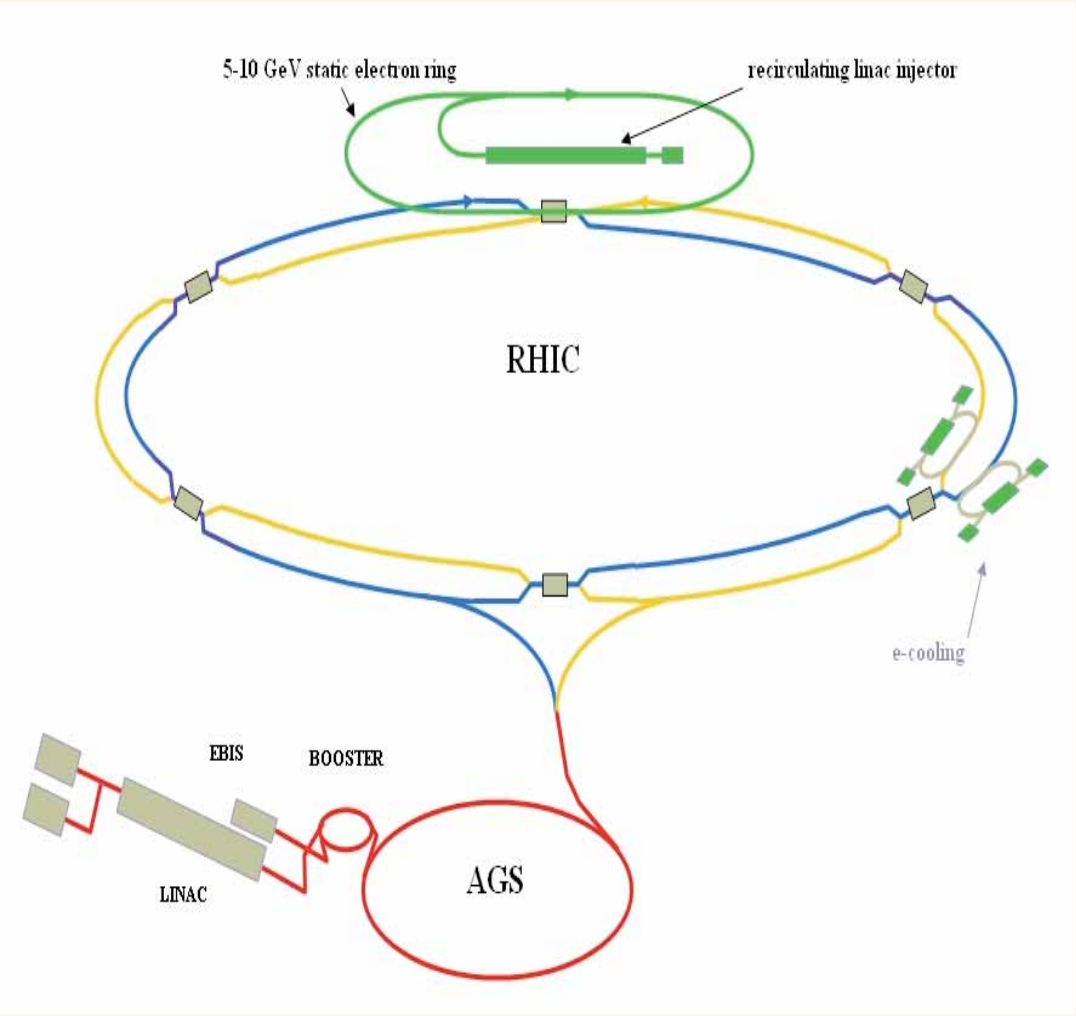
Past and Future ep Facilities



LHeC: $\sqrt{s_{ep}} > 1$ TeV

JLab and BNL Plans





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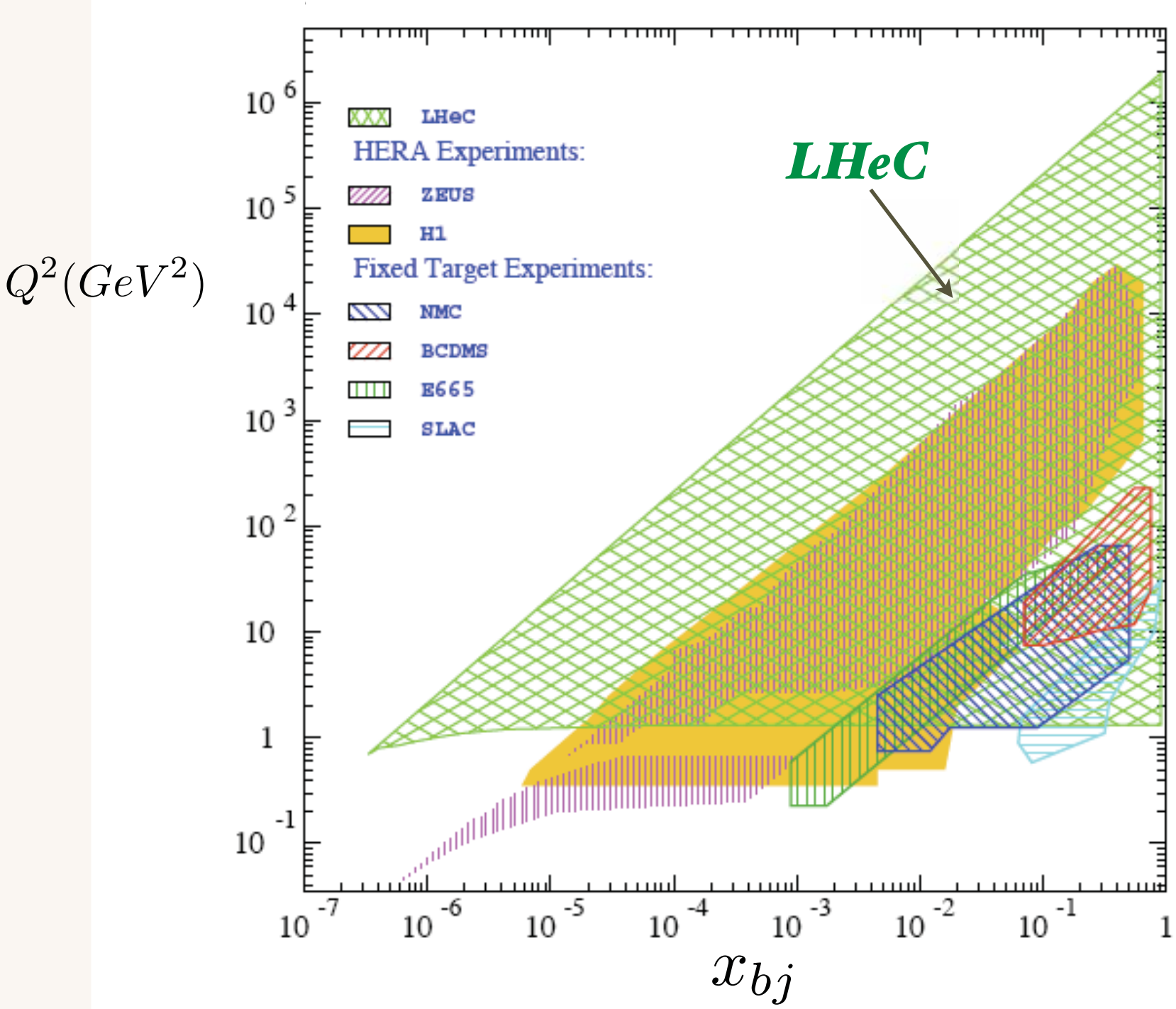
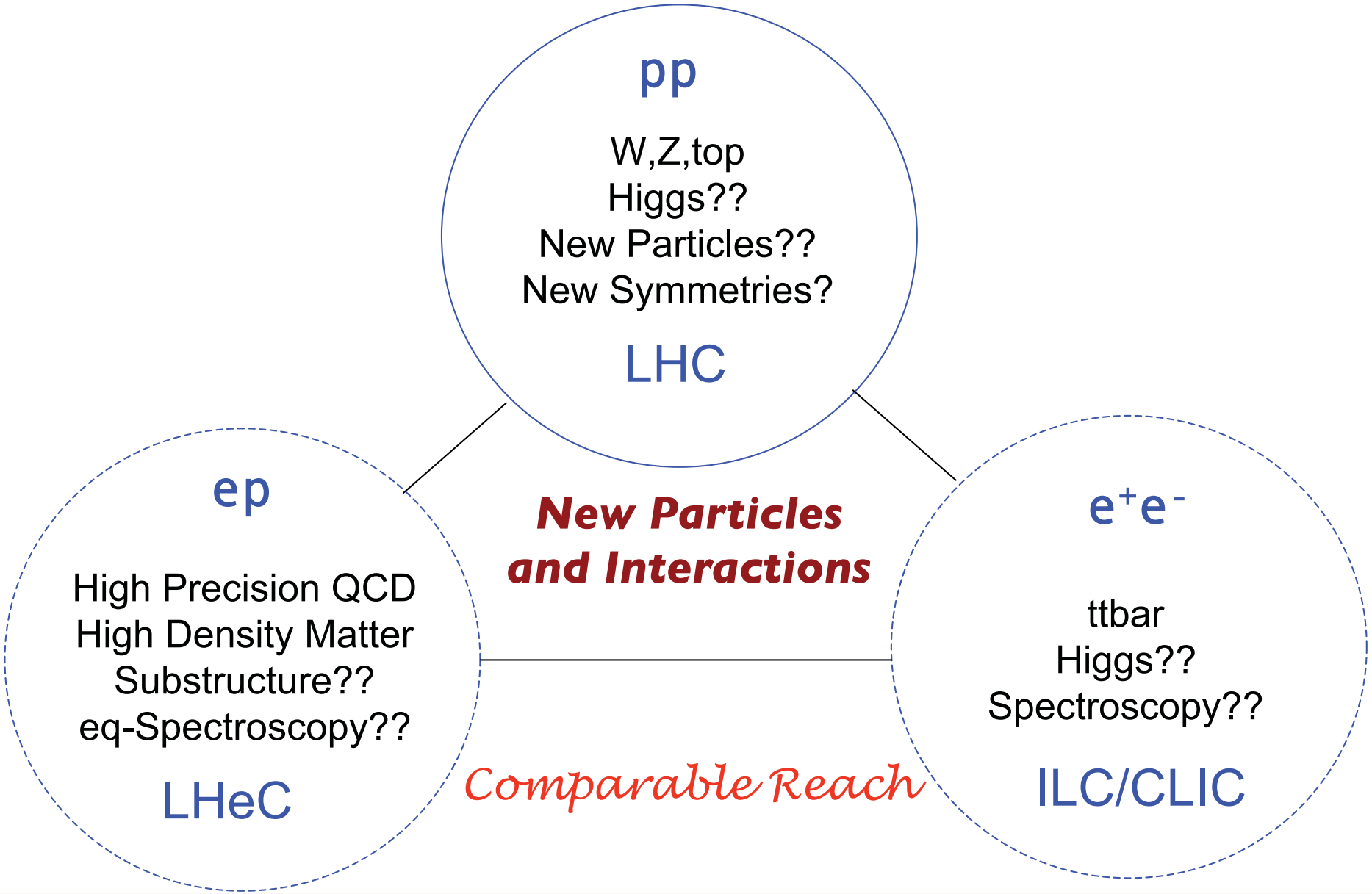
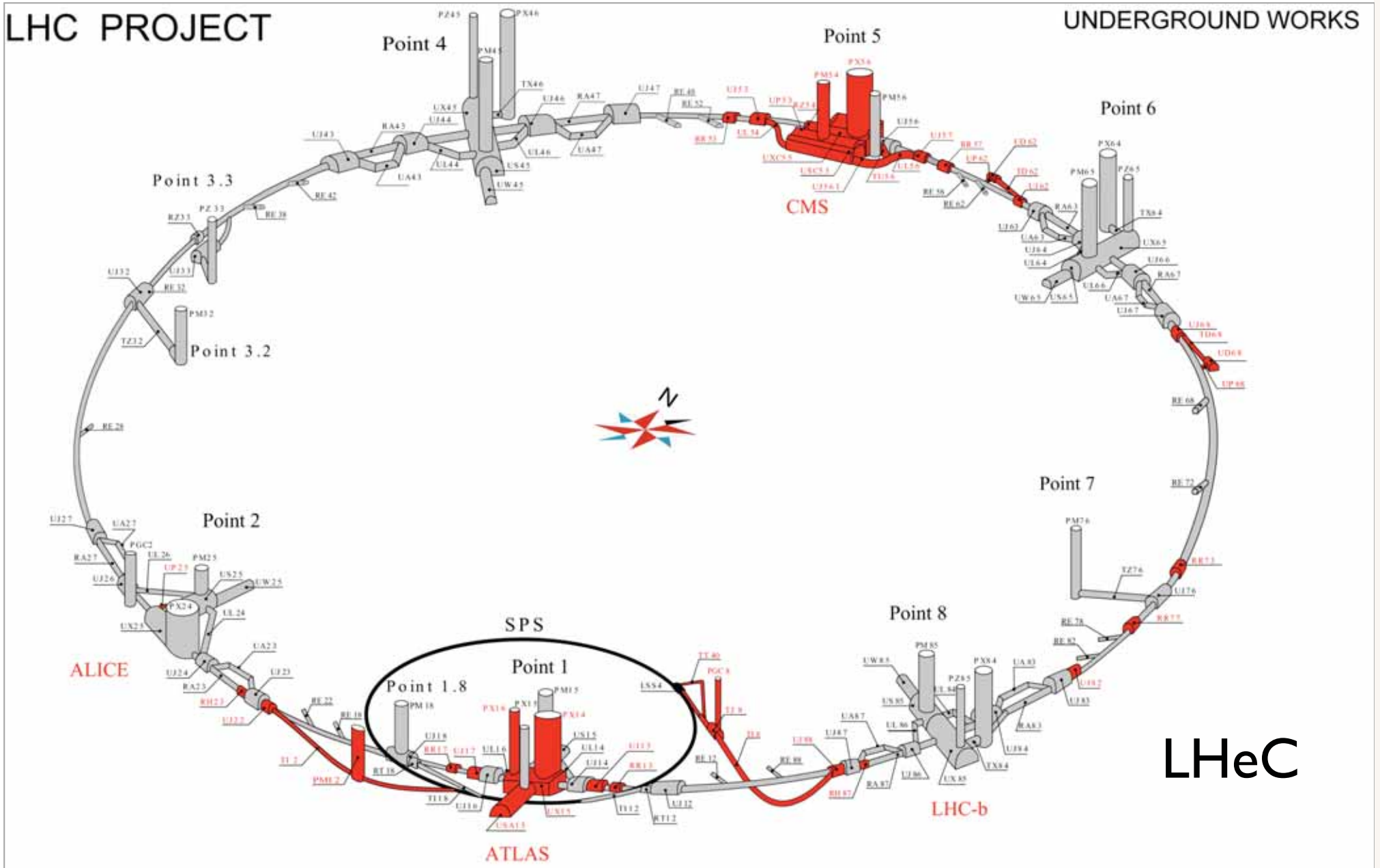


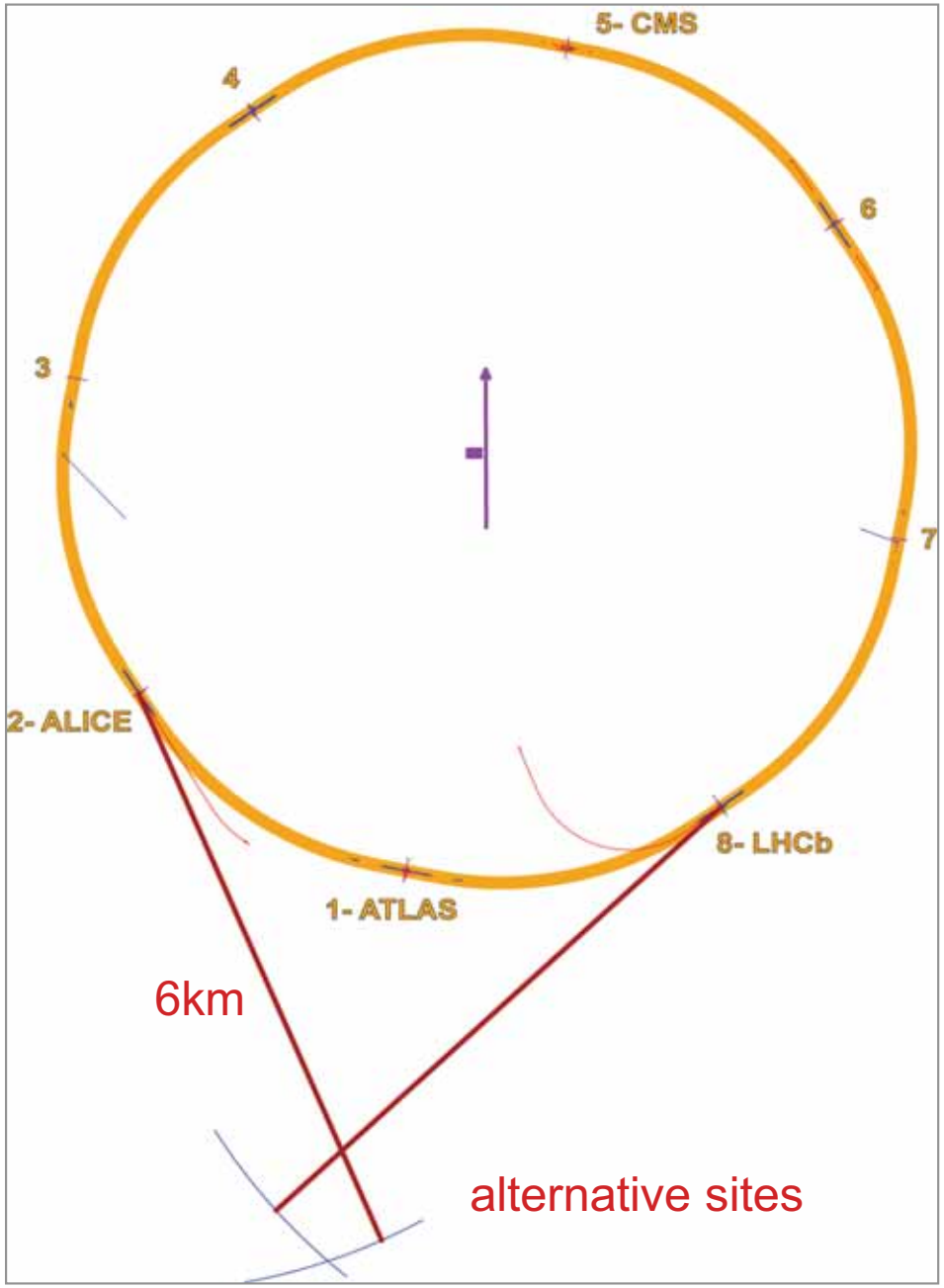
The TeV Scale [2008-2033..]





An electron ring would have to bypass experiments. P3 and 6, perhaps
An electron linac would be largely decoupled from the LHC. In any case, an ep/eA interaction region by then would have to be in P2 or/and P8.

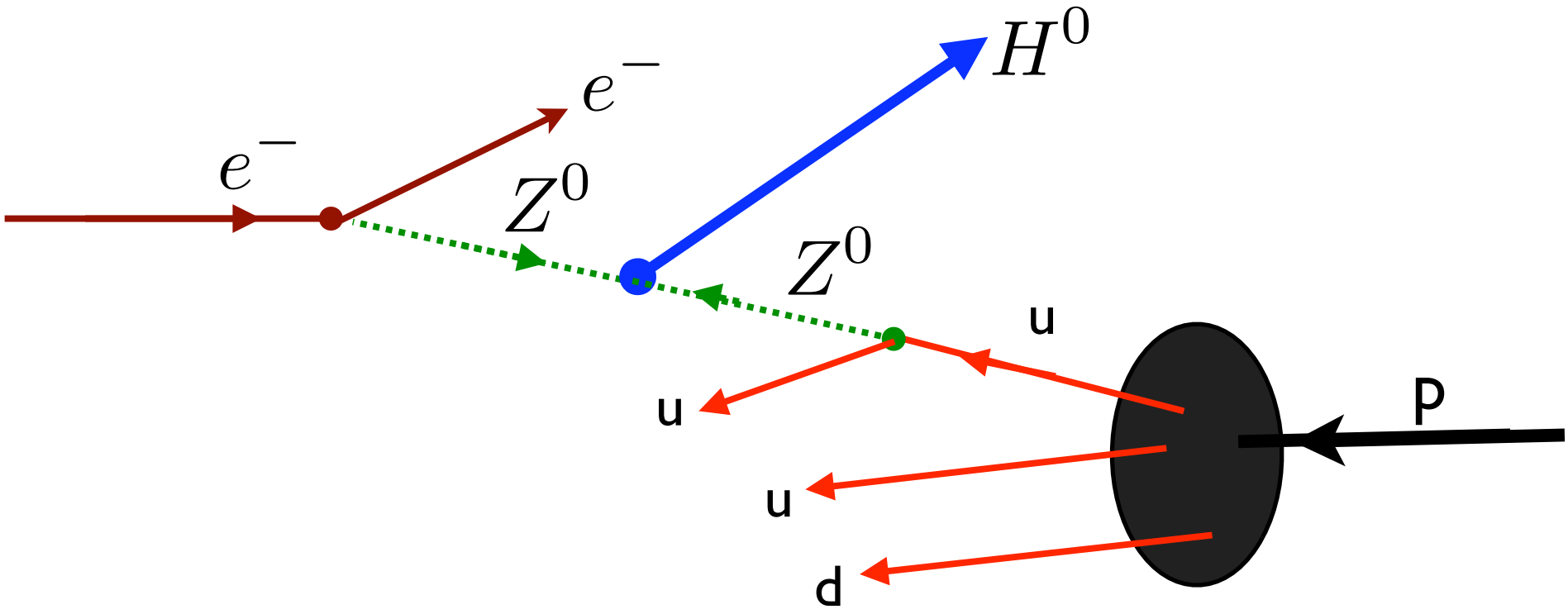
$e^{\pm}$ Linac - p/A Ring



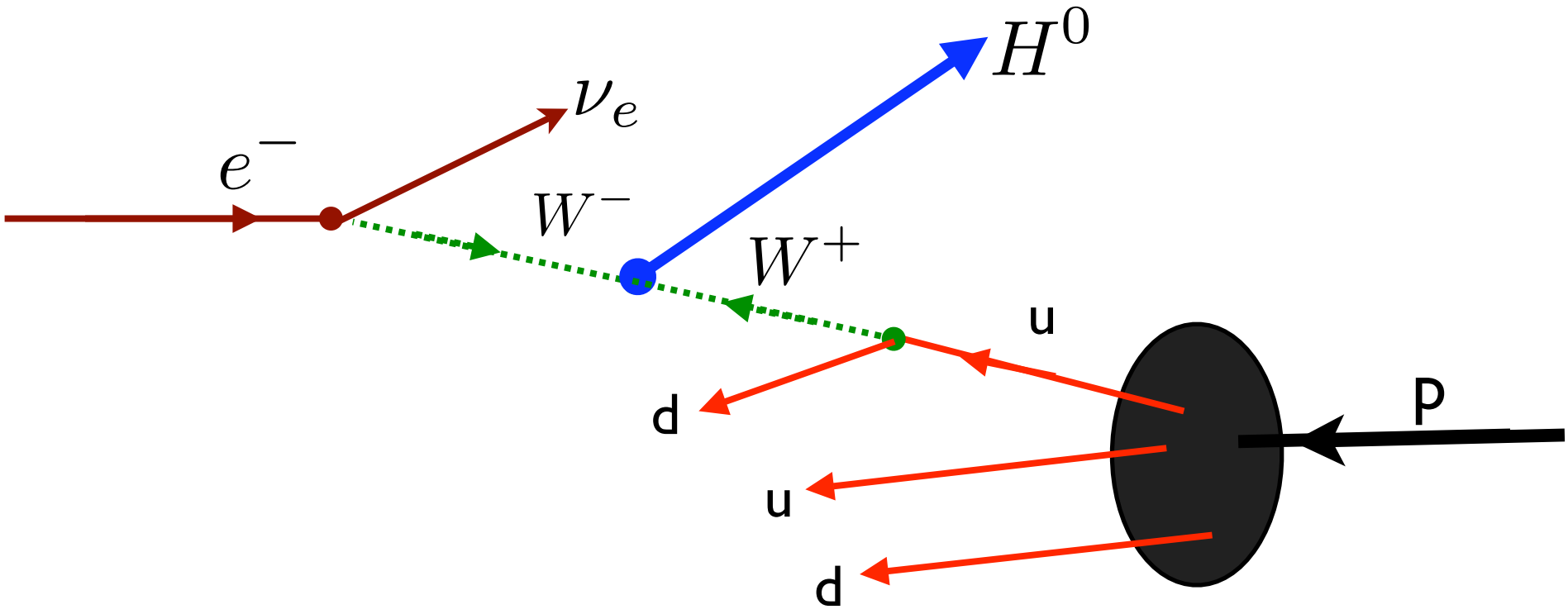
		ring-linac pulsed		ring-linac, cw , ~99% energy recovery	
	units	e-	p	e-	p
energy	GeV	70	7000	70	7000
punch population	10^{10}	2	17	2	17
σ_z	cm	0.03	7.55	0.03	7.55
beam current (pulsed)	mA	101	858	101	858
emittance $\varepsilon_{x,y}$	nm	0.5, 0.5			
$\beta^*_{x,y}$	cm	15, 15			
spacing	ns	25			
e-linac/ring length	km	3.5		7 (2 linacs)	
e- pulse length		1 ms		cw	
repetition rate		5 Hz		continuous	
e- beam power	MW	35		7000	
peak luminosity	**10^{32} $cm^{-2}s^{-1}$**	**0.6**		**2x110**	

S. Chattopadhyay (Cockcroft), F.Zimmermann (CERN), et al.

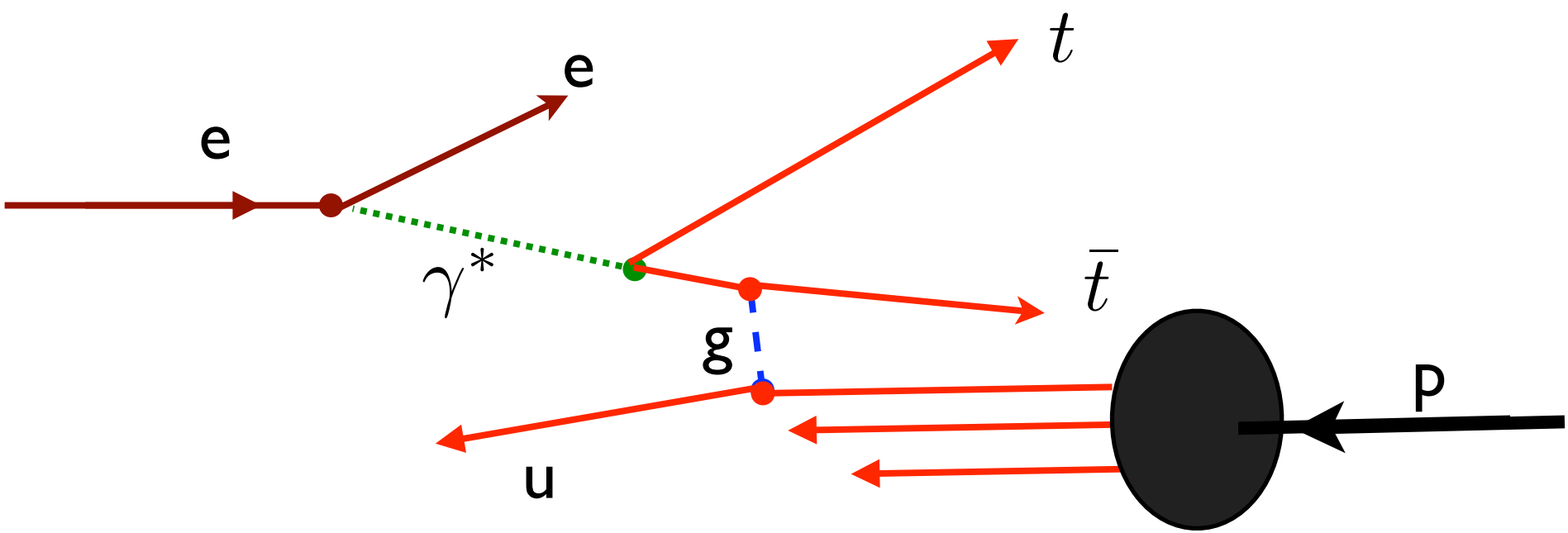
Inclusive Higgs Electroproduction at the LHeC from the Neutral Current



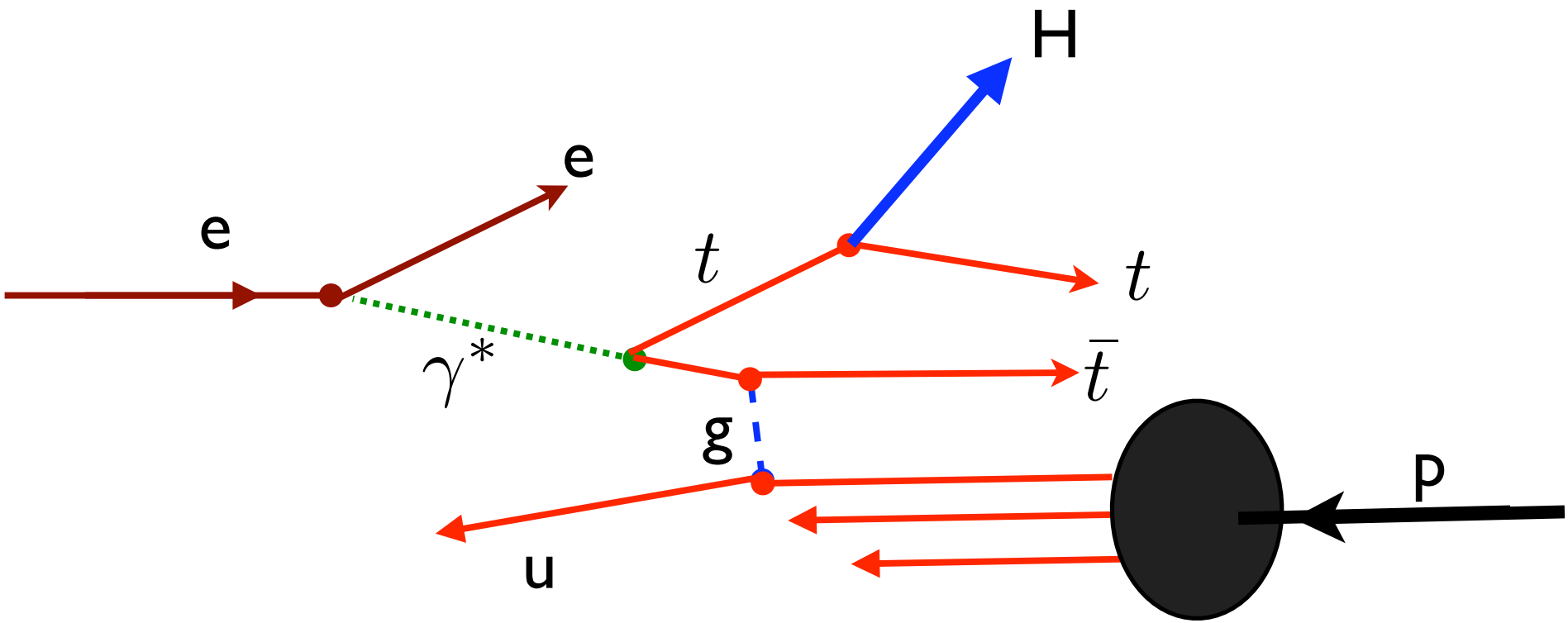
Inclusive Higgs Electroproduction at the LHeC from the Charged Current



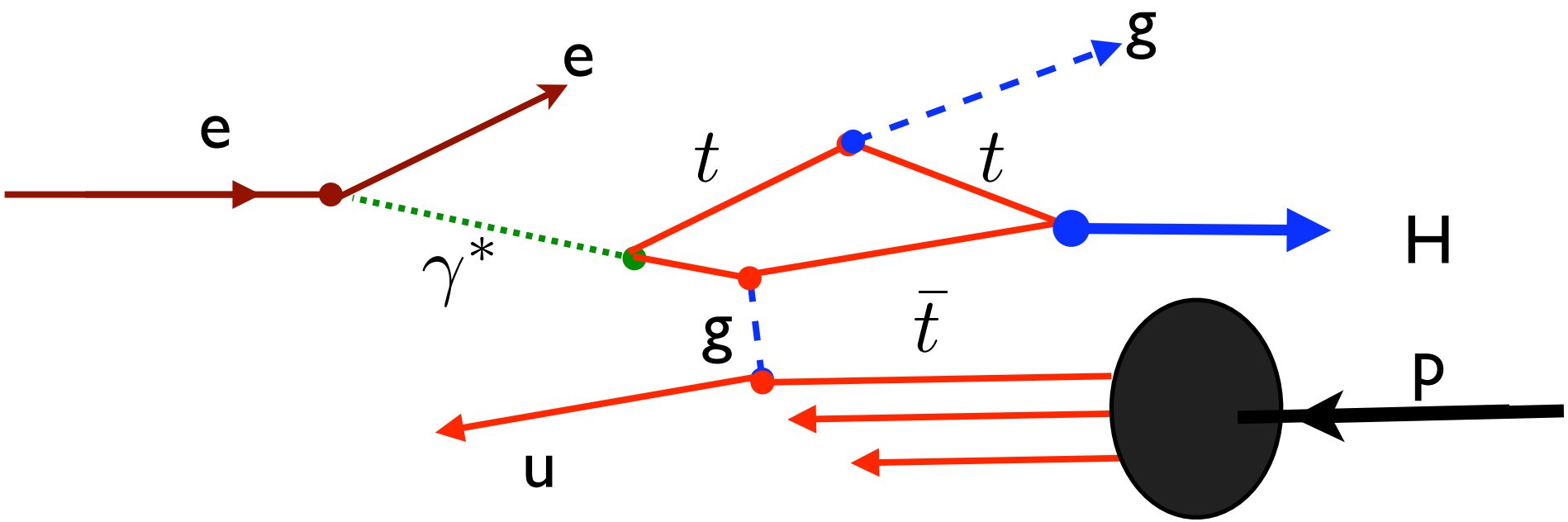
Inclusive Top Electroproduction at the LHeC



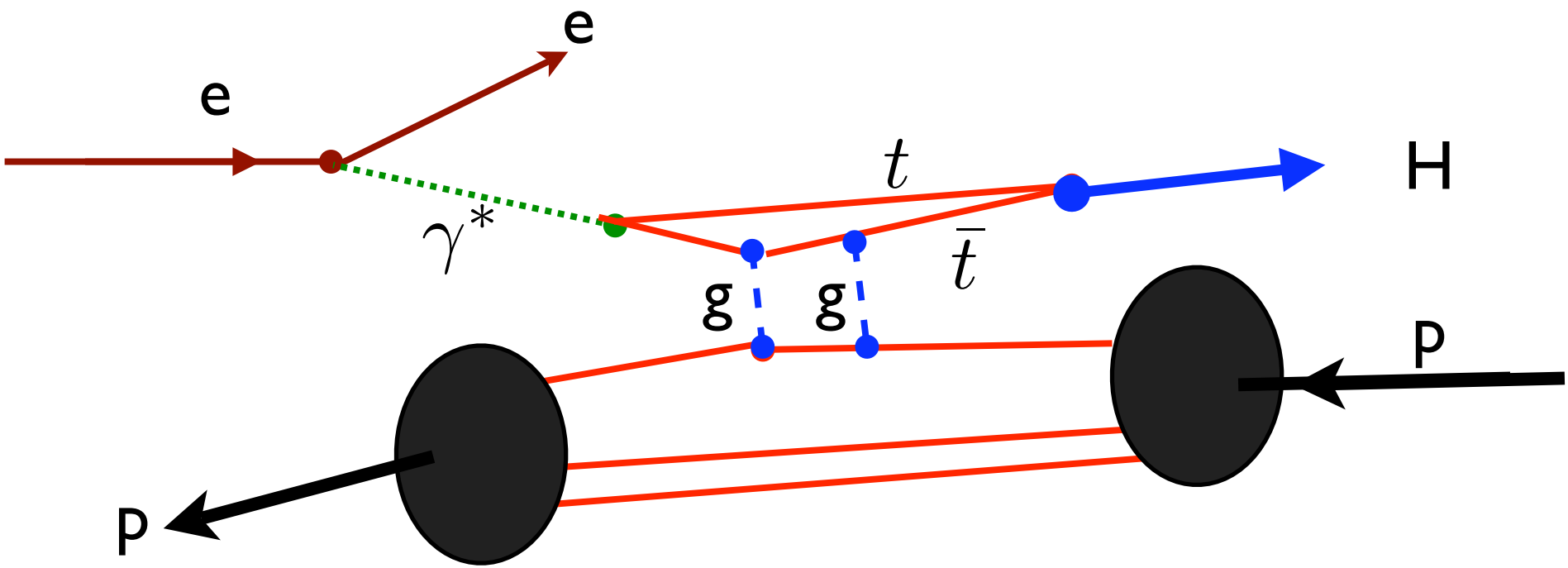
Inclusive Higgs Electroproduction at the LHeC



Inclusive Higgs Electroproduction at the LHeC



Diffractive Higgs Electroproduction at the LHeC



Kopeliovich, Schmidt, sjb