The Electron-Ion Collider

(for the layman)

Franck Sabatié
CEA Saclay

DIS 2013

Based on the talks from :

E. Aschenauer, K. Dehmelt, A. Deshpande, M. Krasny, M. Lamont, P. Nadel-Turonski, M. Stratmann, Y. Zhang

How the story starts : an important discovery !

Particle physics

And you're glue

Frank Wilczek

It's a widely believed half-truth that protons and neutrons are made out of quarks. Actually, physicists are increasingly discovering that it's considerably less than half the truth.

NATURE | VOL 400

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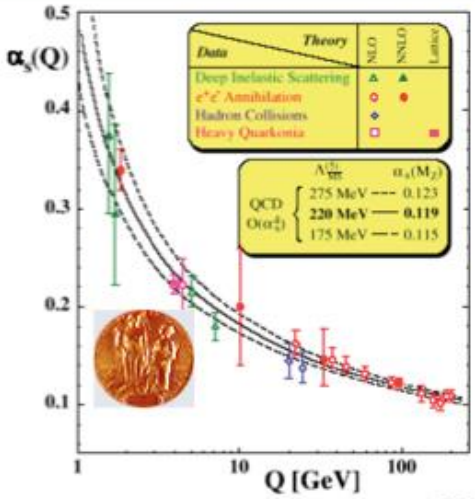
NATURE | VOL 400 | 1 JULY 1999

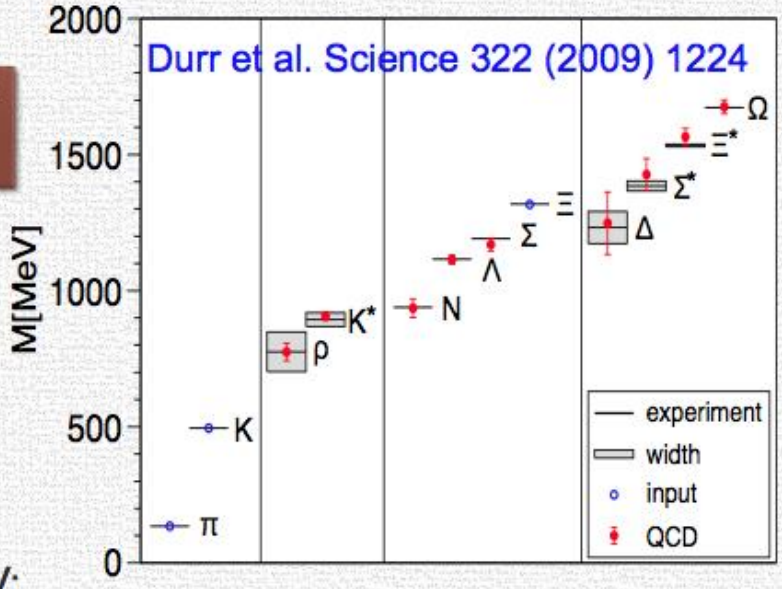
But it's old news !

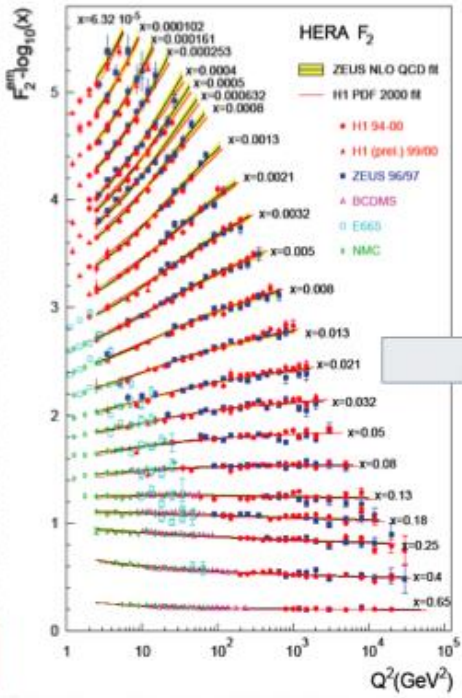
… we must know more by now !

SLAC, HERA, Tevatron, RHIC, … : in 2013 we know QCD !



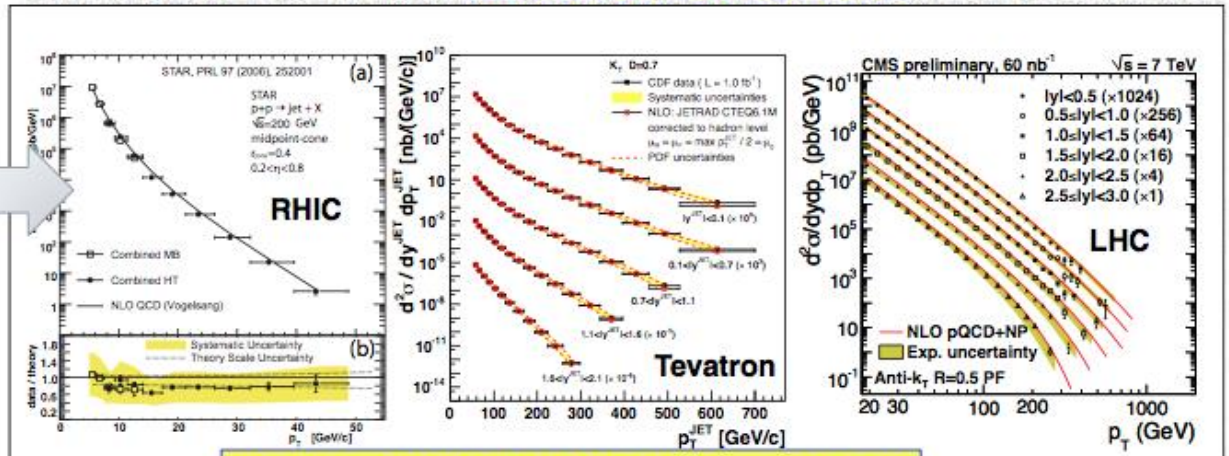
Successes of QCD





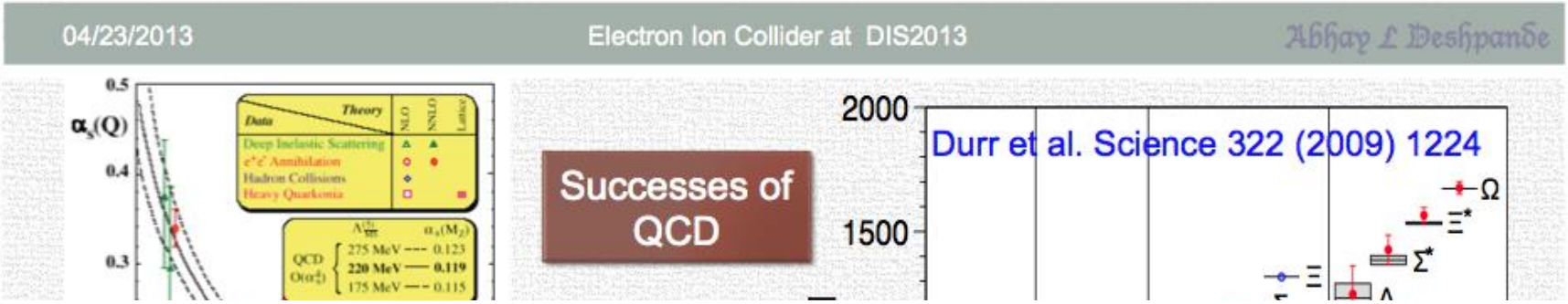
Measure **e-p** 0.3 TeV:

➔ Use pQCD Calculate **p-p, p-pbar Jet x-sctn** at 0.2, 2, 7 TeV



Precision QCD: Talks by O. Behnke, P. Lenzi

SLAC, HERA, Tevatron, RHIC, … : in 2013 ~~we know~~ QCD !



WRONG !

we somewhat control *perturbative* QCD

we measure the rest (when we can)

and after decades of scrutiny …

we are still far from understanding QCD !

(especially for the gluonic content)

So what to do about it …

… the ultimate experiment, but which?

Collider kinematics is a given : low-x_B is the key to study gluons

What particles to collide : p-p, p-*A*, e-p, e-*A* ?

So what to do about it …

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Trust smart people : « Scattering of hadrons on hadrons is like colliding Swiss watches to find out how they are built »

R. Feynman

What energy ? not the main issue, you need the largest possible kinematical domain, however low you can go in x_B, however high in Q^2, the money factor will decide, trust the politicians to do what is best ;)

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Where to build it ?

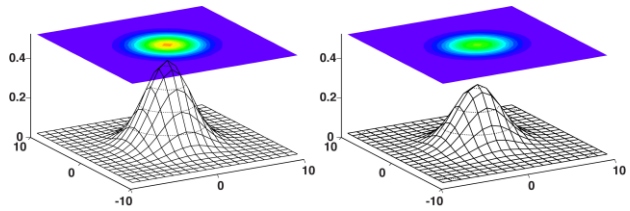
Who cares ???

However, **much easier** if you start with part of the solution : a polarized electron or a polarized p/*A* accelerator … JLab or RHIC or even … CERN (unpolarized p/*A* - M. Krasny)

The new QCD Frontier

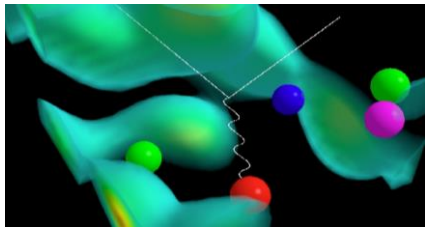
An Electron-Ion Collider will allow the unique exploration of some of the most intriguing open questions in modern nuclear physics:

The structure of visible matter



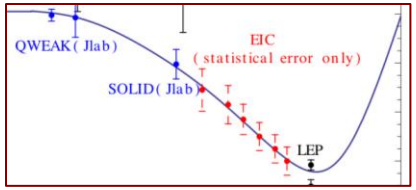
Quark distributions
polarized (L/T) or not
3D-imaging of the nucleon (GPD)
Transverse Momentum Distributions

The role of gluons in hadronic matter



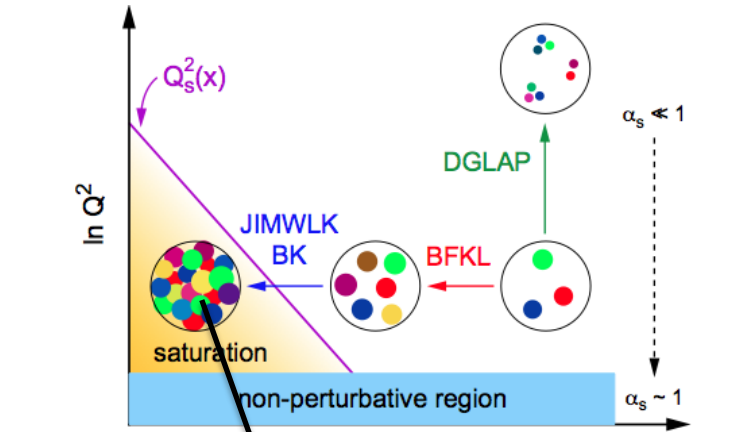
Gluon distributions
polarized or not
F_2 and F_L measurements in nuclei
Study of gluon saturation (*CGC*)

Electroweak interaction and physics beyond the SM



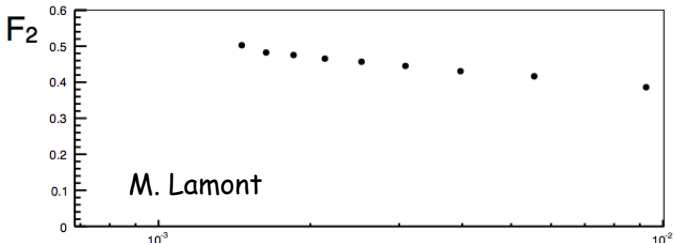
Accurate measurement of $\sin^2\theta_w$
e-τ conversion

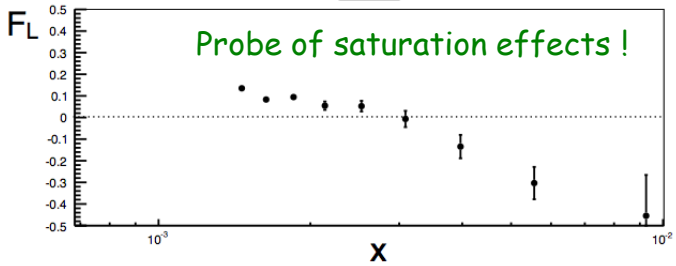
3 shining examples shown at DIS2013



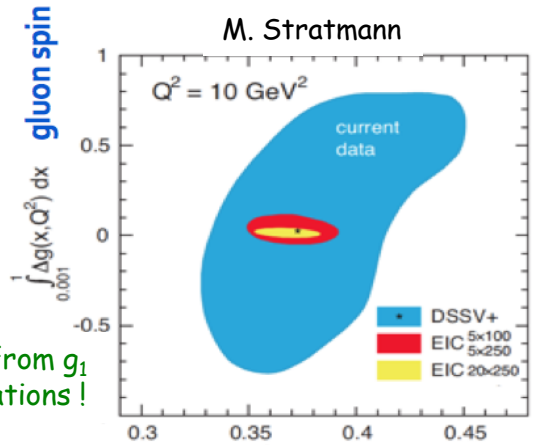
$$\frac{d^2\sigma^{eA\to eX}}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

quark+anti-quark — gluon





M. Stratmann



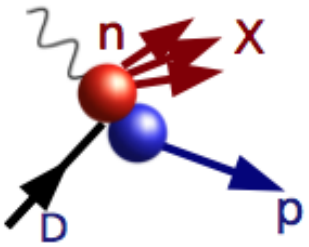
Gluon spin from g_1 scaling violations !

$$\frac{dg_1}{d\log(Q^2)} \propto -\Delta g(x,Q^2)$$

$\int_{0.001}^{1}\Delta\Sigma(x,Q^2)\,dx$ — quark spin

Spectator tagging with polarized deuterium

DVCS on the T-polarized neutron !



… and if you want to know it all

The EIC Science case: a report on the joint BNL/INT/JLab program

Gluons and the quark sea at high energies: distributions, polarization, tomography

Institute for Nuclear Theory • University of Washington, USA
September 13 to November 19, 2010

Editors:
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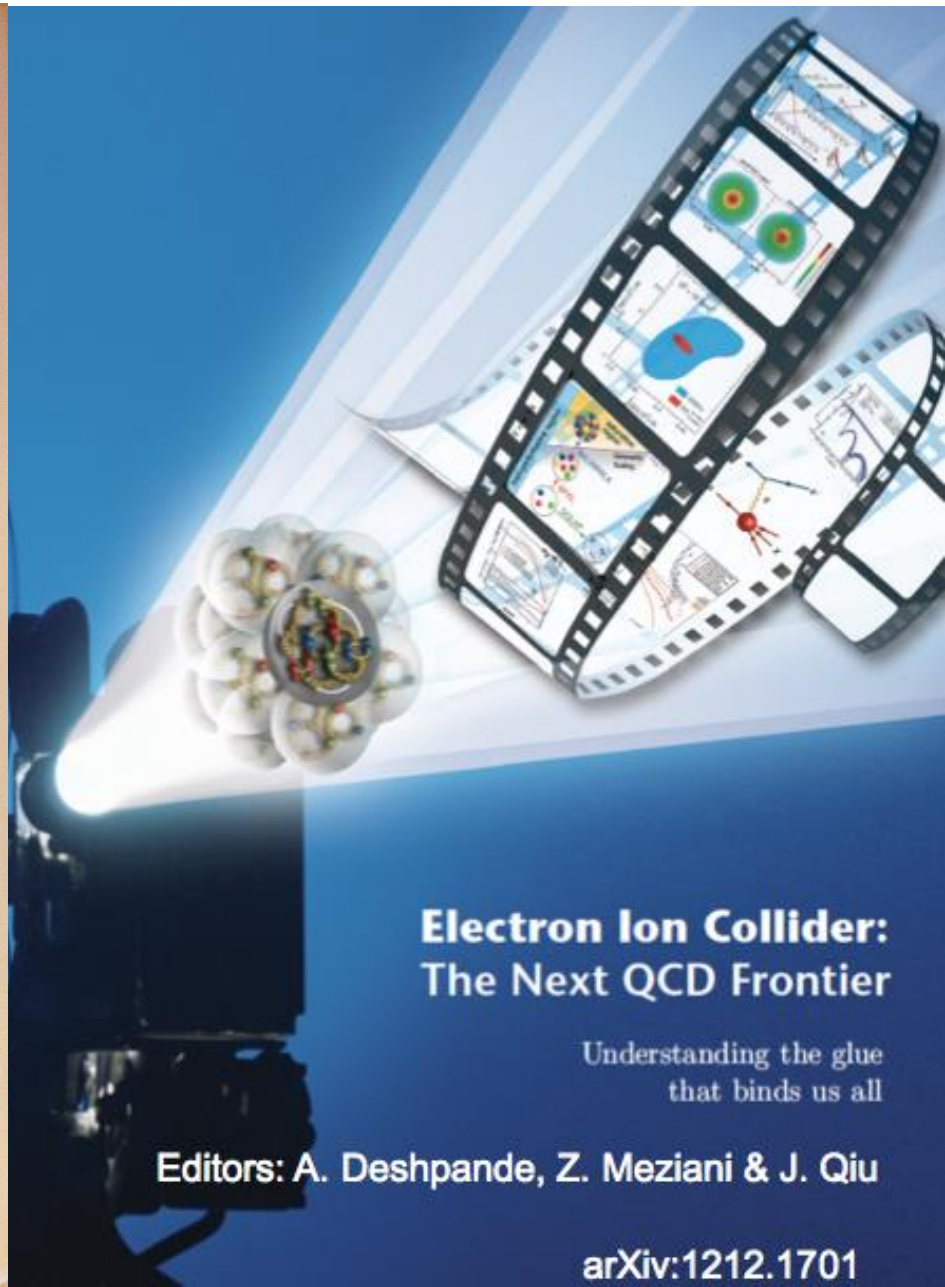
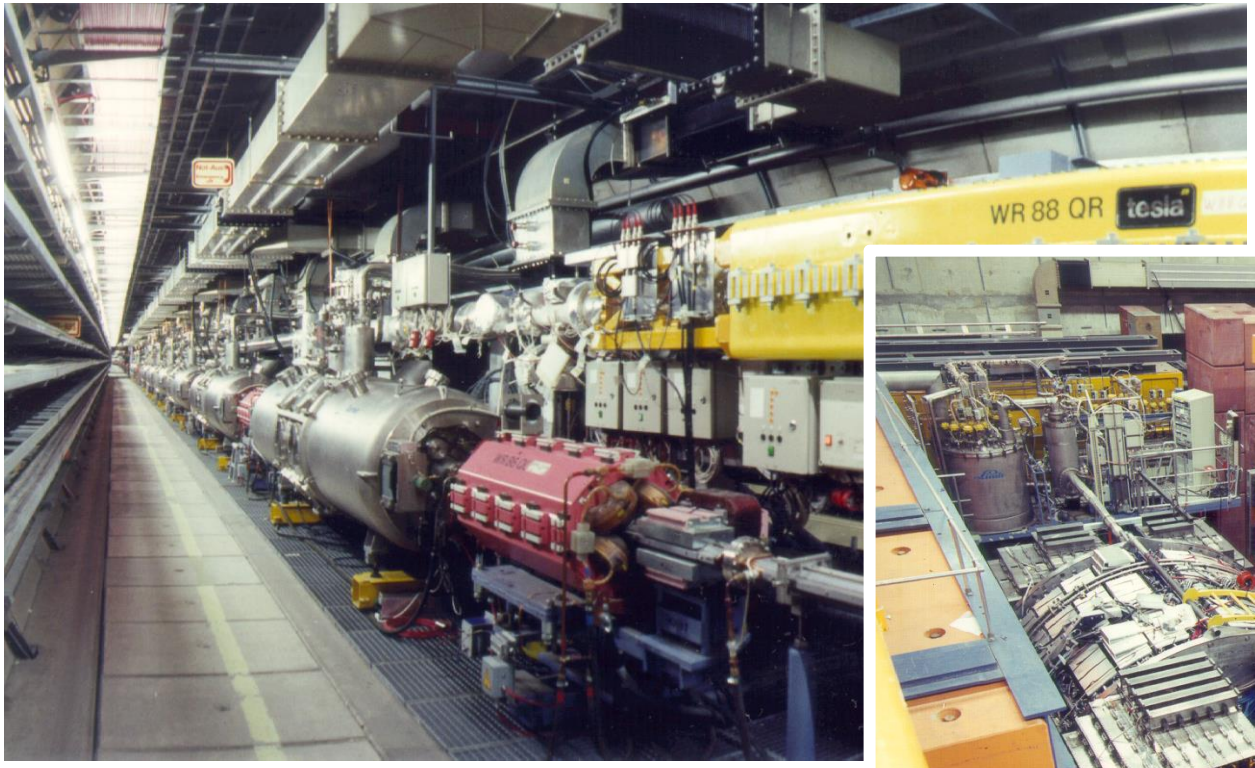
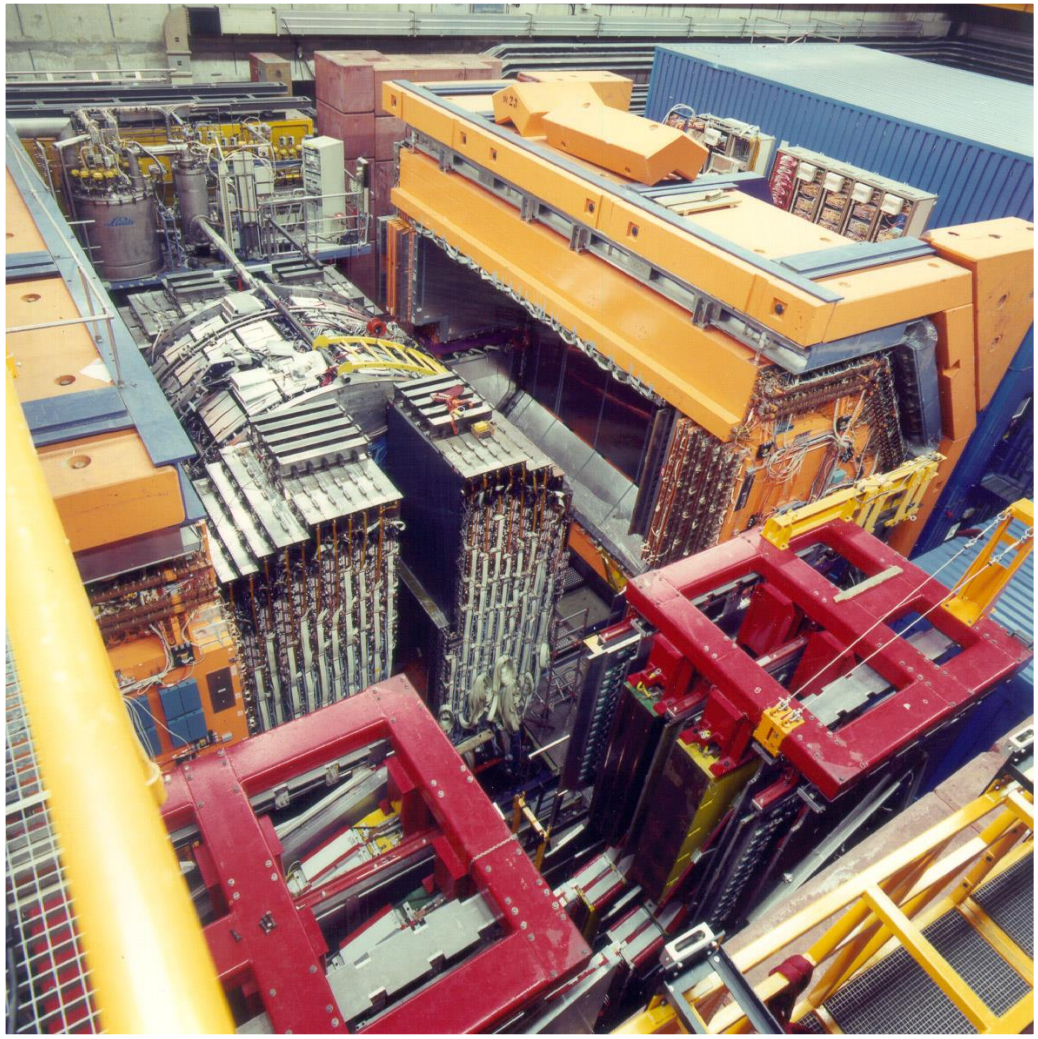
arXiv:1108.1713



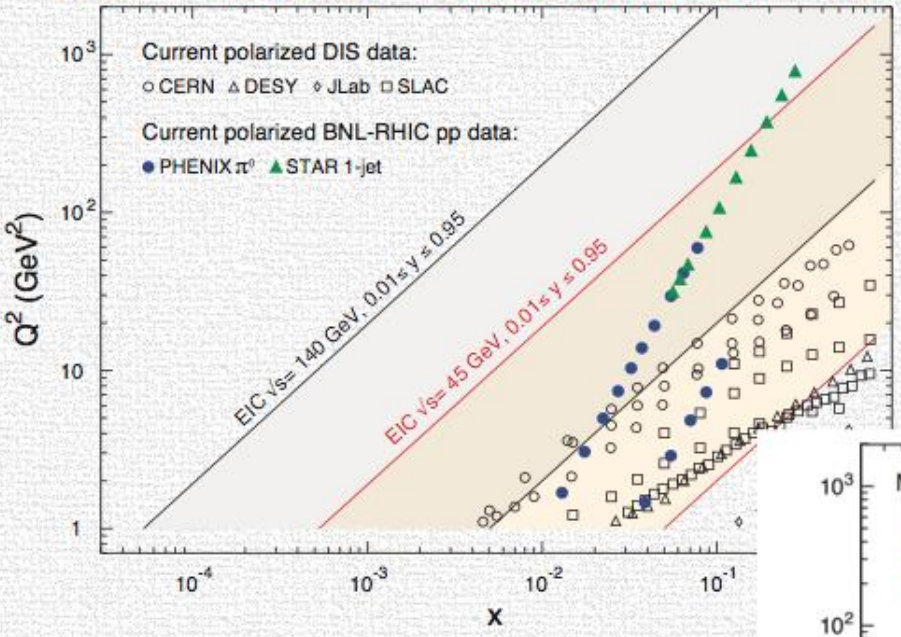
Now, the serious business begins …





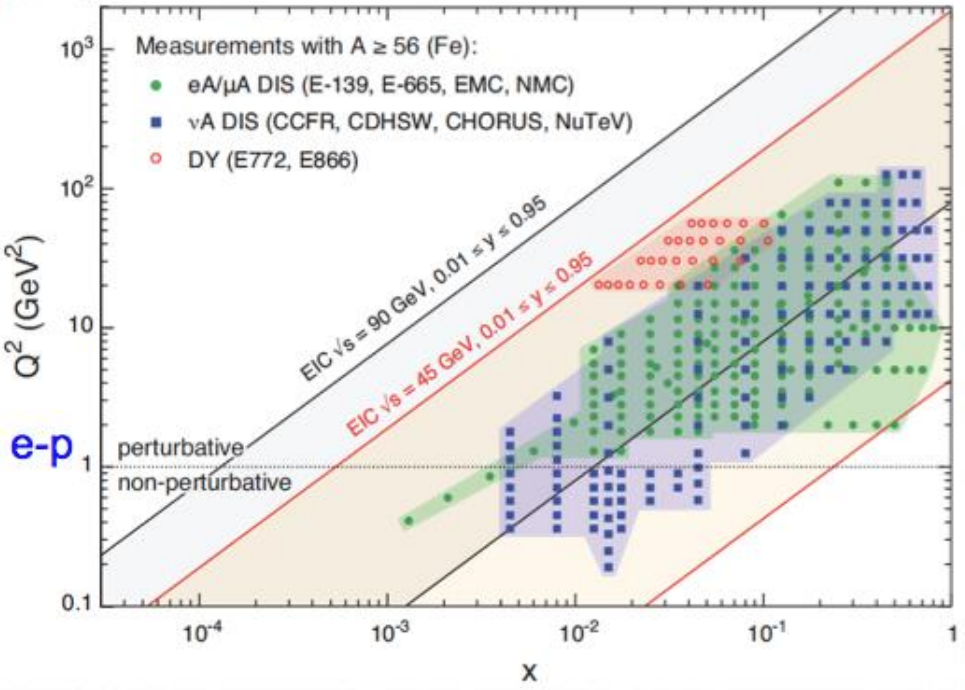
Scope, Kinematics

US EIC: Kinematic reach & properties



For e-N collisions at the EIC:

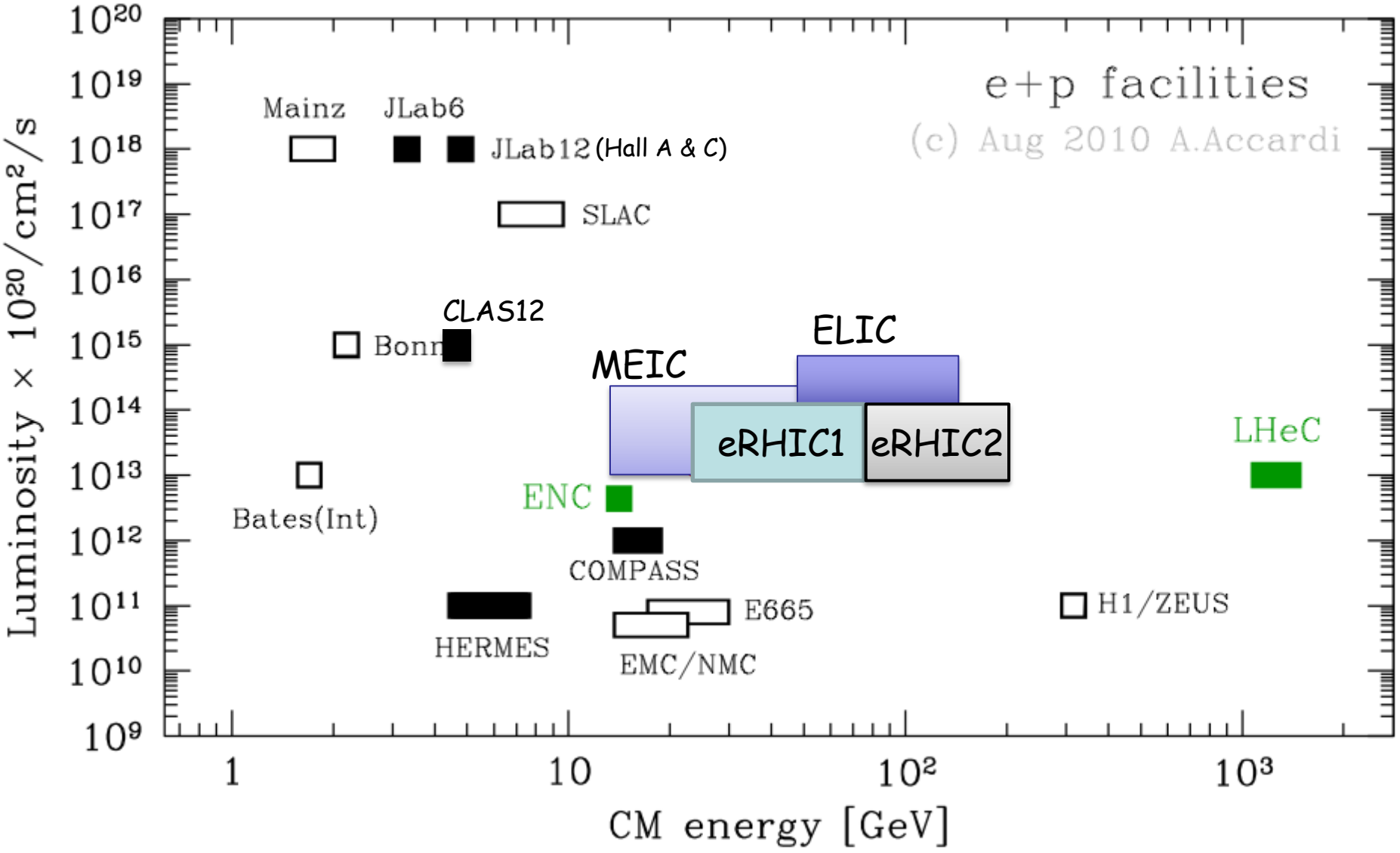
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ Luminosity L_{ep} ~ $10^{33\text{-}34}$ $cm^{-2}sec^{-1}$
  100-1000 times HERA
- ✓ Variable center of mass energy



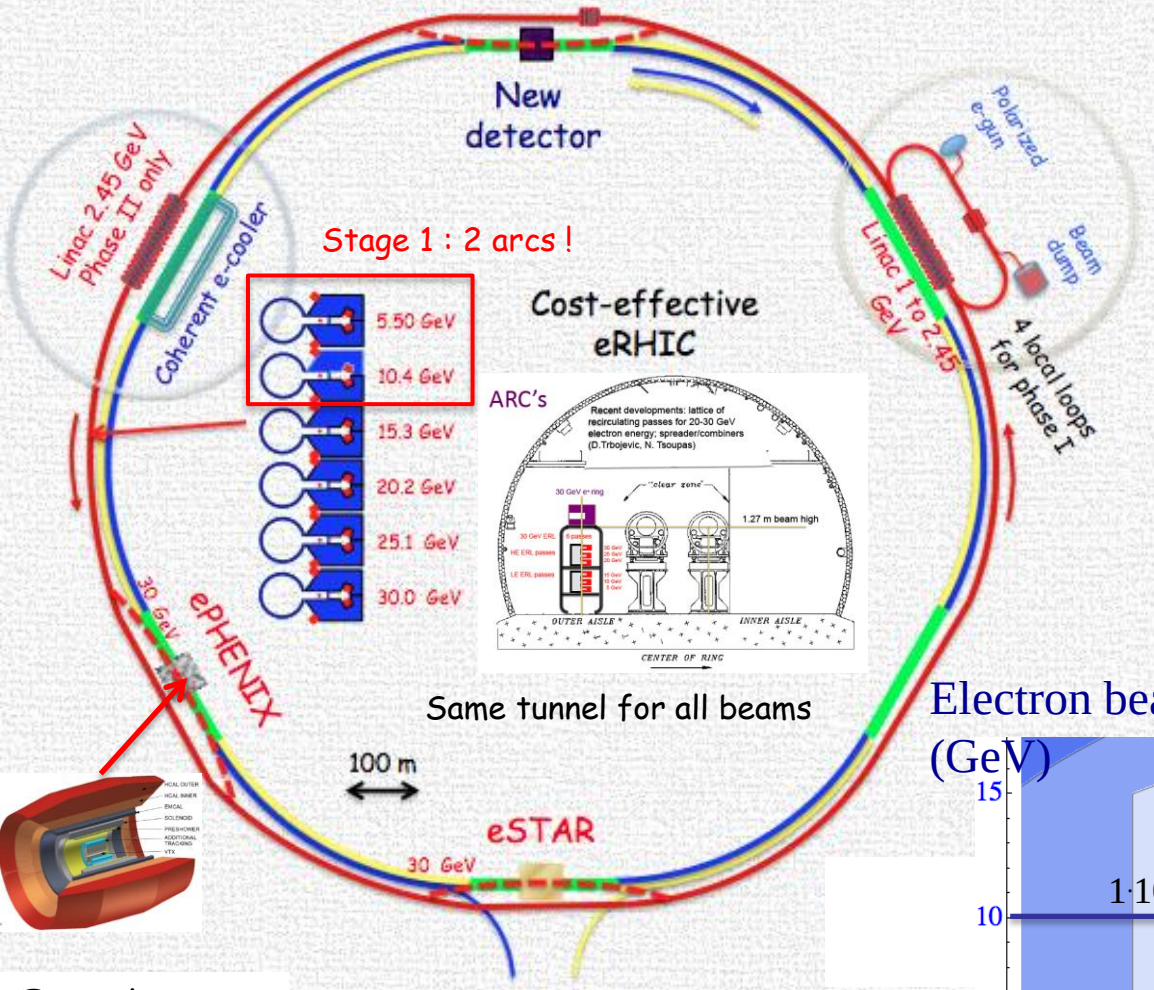
For e-A collisions at the EIC:

- ✓ Wide range in nuclei
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

The situation with respect to other facilities



eRHIC @ Brookhaven National Laboratory

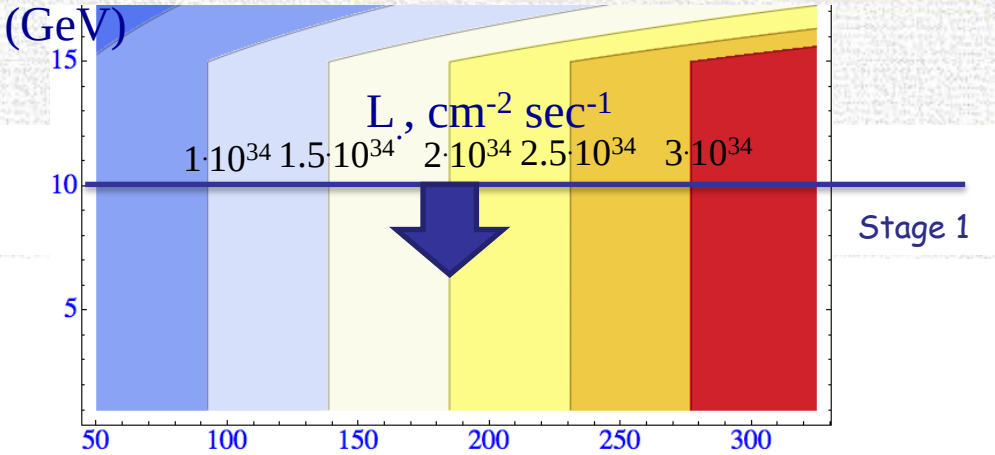


E. Aschenauer
K. Dehmelt
A. Deshpande

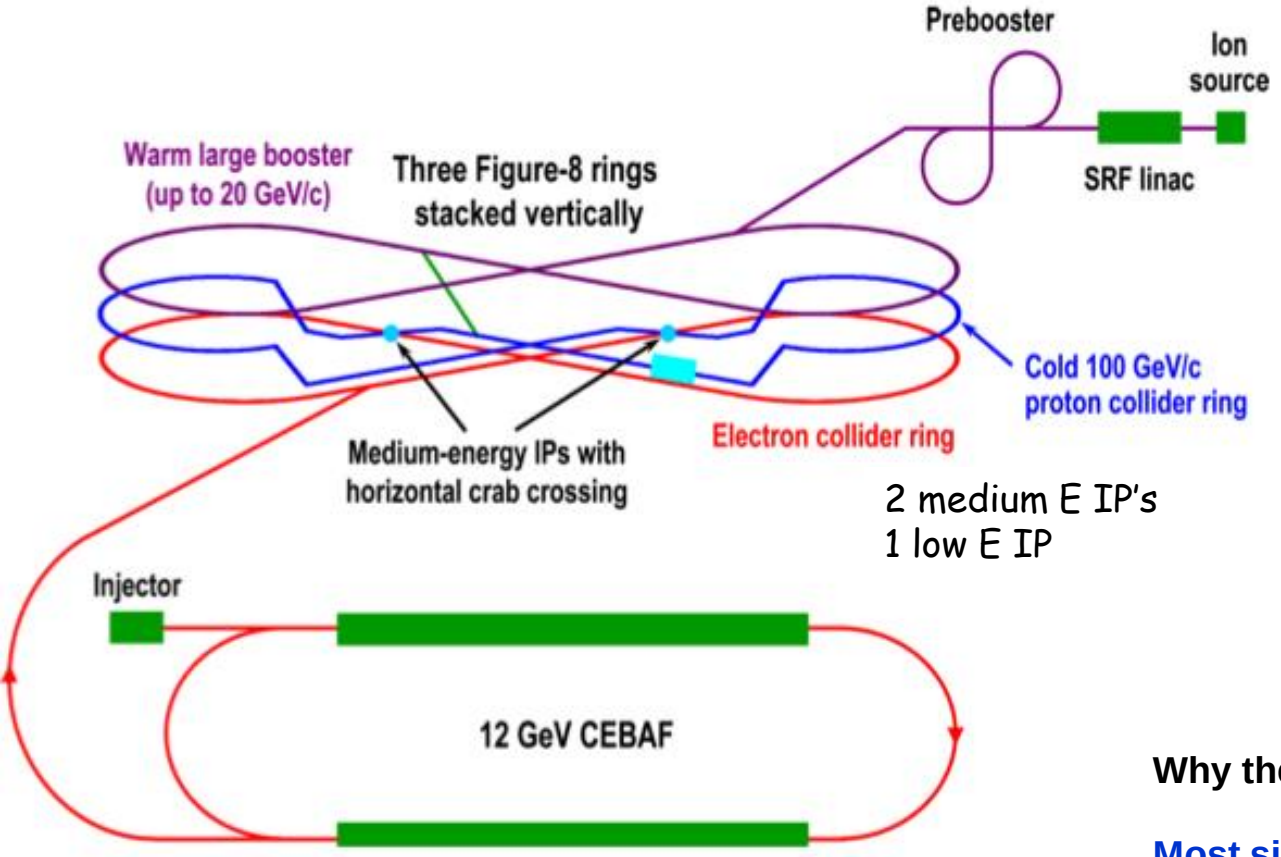
Stage I:
$\sqrt{s}$ ~ 60-100 GeV

Stage II:
$\sqrt{s}$ > 100 GeV

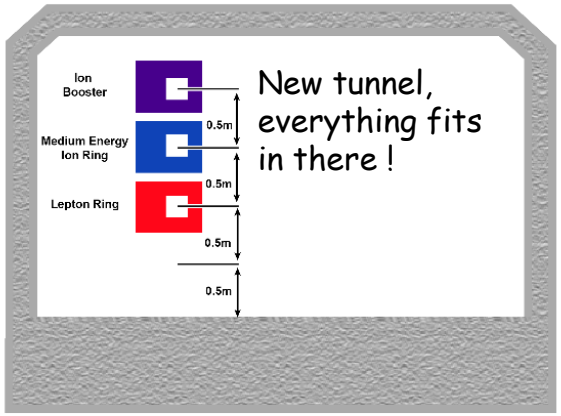
$L = 10^{33\text{-}34}$ cm^{-2}sec^{-1}
100-1000 times HERA
→ 50-500 fb^{-1} integrated luminosity in 10 yrs



MEIC/ELIC @ Jefferson Laboratory



$L=10^{33\text{-}34}$ cm^{-2}s^{-1}
100-1000 times HERA
➔50-500 fb^{-1} in 10 years



Stage	Max. Energy (GeV/c)		Ring Size (m)	Ring Type		sqrt(s) (GeV)
	p	e		p	e	
Medium	100	11	1400	Warm/Cold	Warm	~50
High	250	20	2500+	Cold	Warm	>100

Why the figure-8 ring-ring choice :

Most simple (in principle)

- Spin precession cancels
- Energy independent spin tune
- Easy spin preservation and manipulation
- Avoids energy-dependent spin sensitivity

Polarized deuterons !

And … it fits ! (barely)

MEIC, eRHIC : it looks VERY different but it's not, example

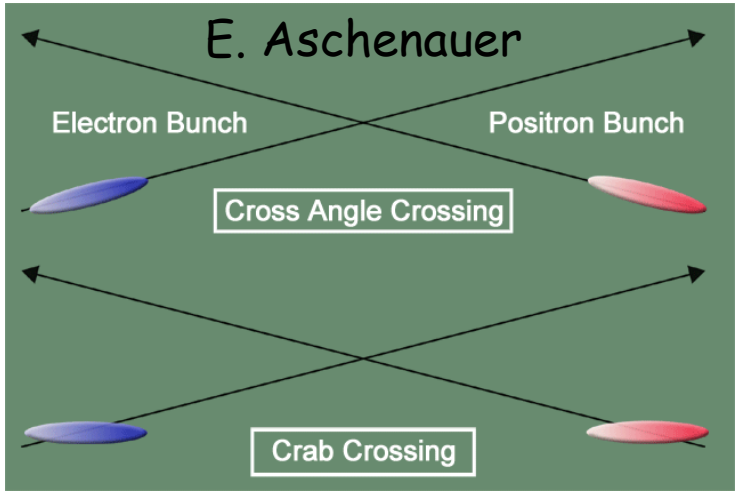
Crab crossing 101

You look in one direction
and walk in another

… applied to particle bunches in a collider :

A way to increase luminosity
(at a small-ish technical cost)

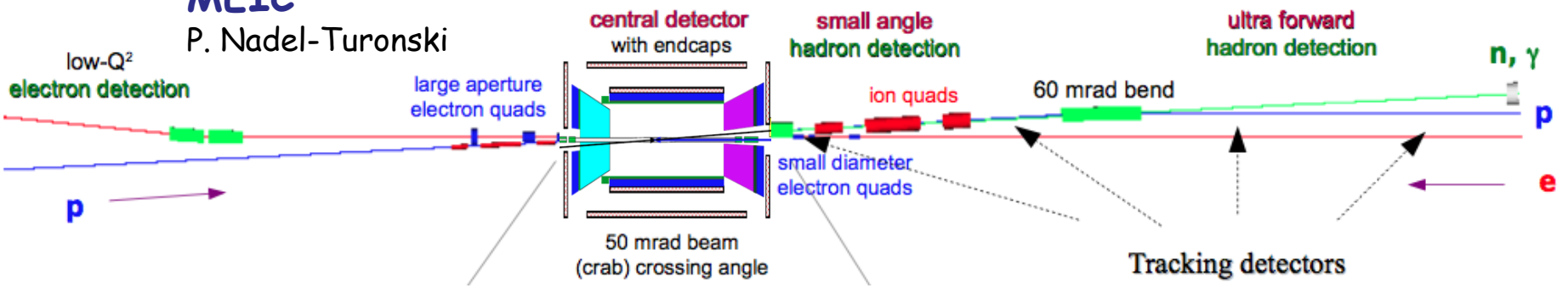
This technique is used in both eRHIC and MEIC



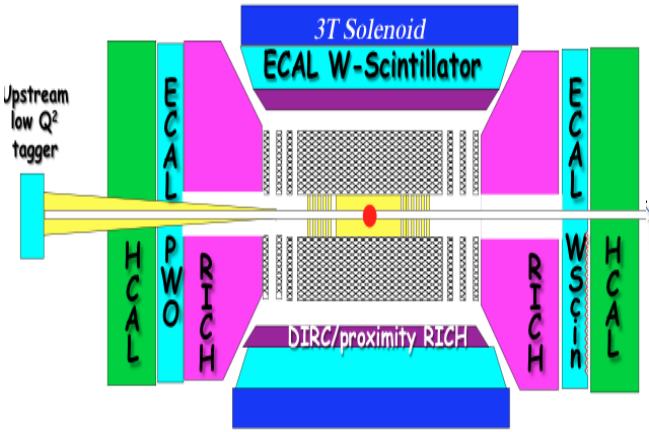
Another example : **integration** of the Interaction Region (IR) with the detectors

MEIC

P. Nadel-Turonski

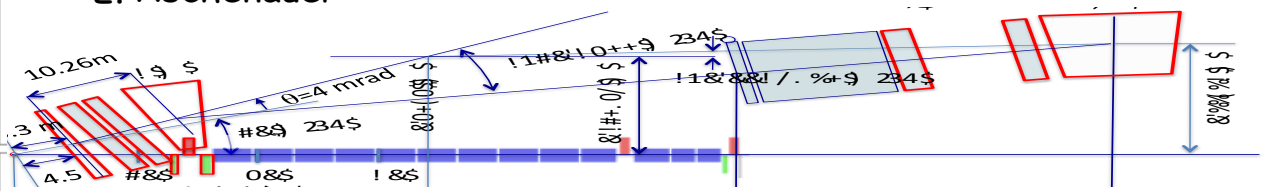


In both cases : **it was critical to have detector and beamline people interact, and the result : near/full acceptance, 10^{33}-10^{34} Lumi**



eRHIC

E. Aschenauer

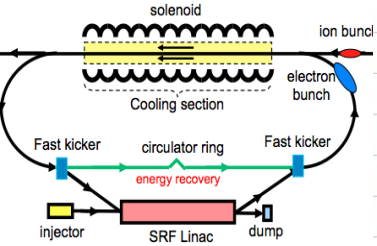


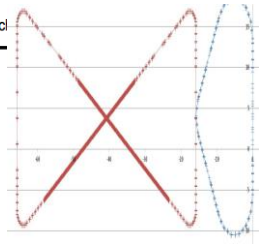
Not to scale ☹

Accelerator R&D

JLab R&D

Y. Zhang

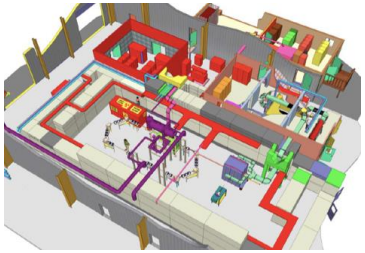


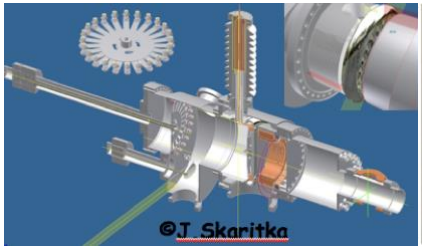


- **Electron cooling**
  - **of medium energy ion beam**
  - **ERL circulator**
  - **Cooling with bunched electrons**
- Interaction region
  - Optimization of detector integration
- Beam Synchronization
  - Study is in progress
- Polarization
  - **Demonstrator of figure-8 ring**
  - Electron spin matching
- Collective beam effects
  - Space charge effects in pre-booster
  - Electron cloud in the ion rings and mitigation
- Ion Injector complex optimization

RHIC R&D

A. Aschenauer





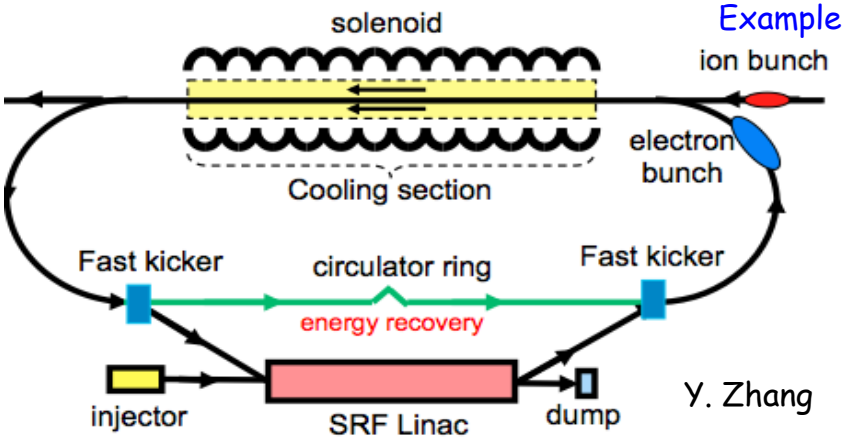
- Polarized gun for e-p program – **LDRD at BNL + MIT**

  → **prototype under construction**
- Development of compact magnets - **LDRD at BNL** → first prototyes
- SRF R&D ERL – TF **ongoing**
- Beam-beam effects, beam disruption, kink instability suppression, etc.
- Polarized He^3 source
- Coherent **Electron Cooling**: TF for PoP by ~2016

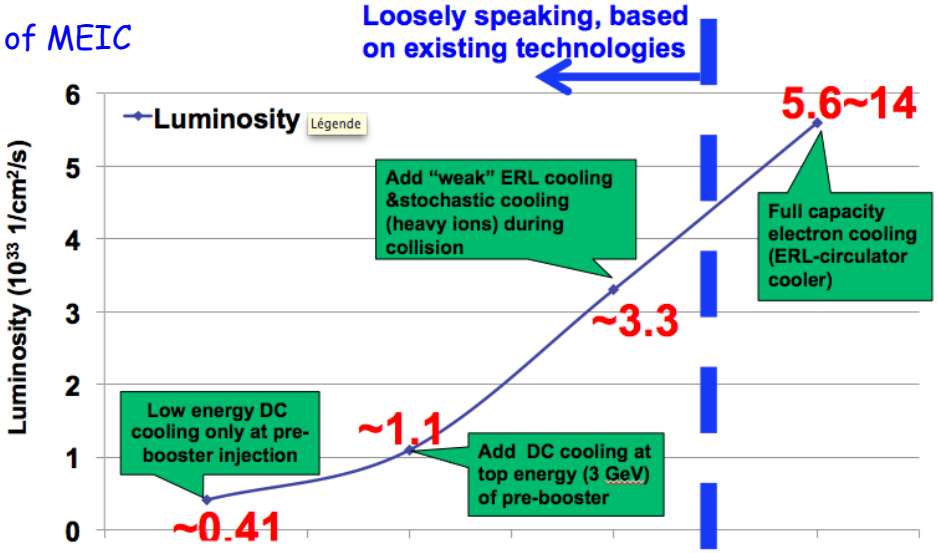
Electron Cooling : What is it ? How do you do it ?

Electron cooling is used to shrink the size/divergence/energy spread of the ion beam.

It compresses the ion bunches and is essential to reach higher luminosity



Example of MEIC



How do you do it :

You make the ion beam travel along with an electron beam going at the same β

The ions undergo Coulomb scattering in the electron "gas" and lose energy, until a thermal equilibrium is attained.

High priority R&D for EIC in both laboratories

On the detector side, the requirements are

mostly driven by exclusive physics (i.e. DVCS)

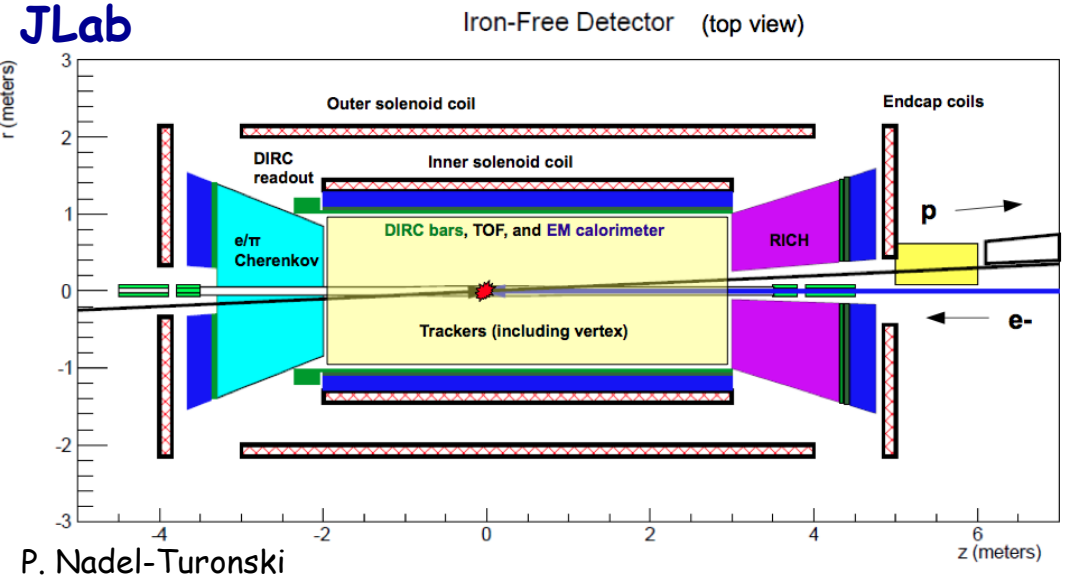
- Hermeticity (also for hadronic reconstruction methods in DIS)
- Particle identification (needed for SIDIS too)
- Momentum resolution
- Forward detection of recoil baryons (also baryons from nuclei)
- Muon detection (J/Ψ)
- Photon detection (DVCS, π^0)
- Very forward detection (spectator tagging, diffractive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

Of upmost importance : what happens to the ion beam !

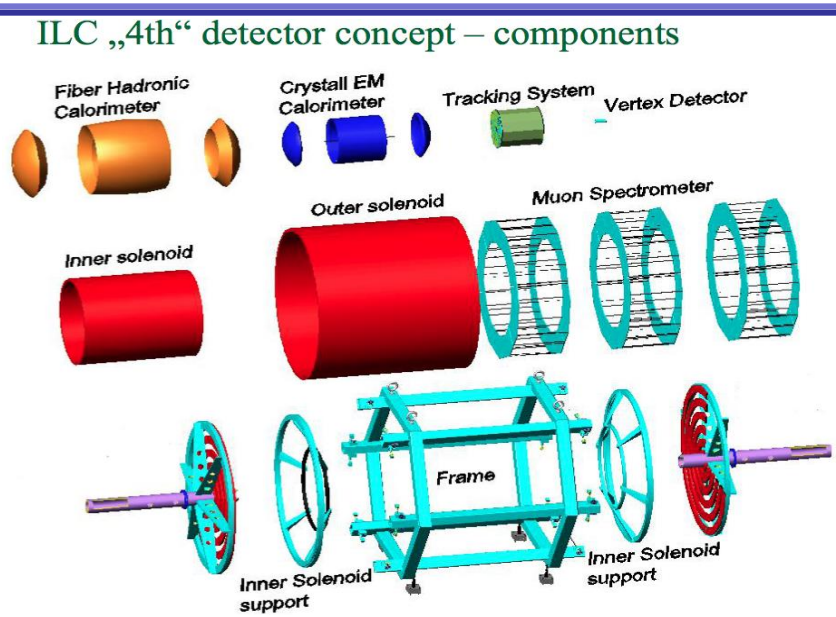
Spectator quark or struck nucleus remnants will go in the forward (ion) direction : need of very forward detectors, both eRHIC and JLab have adequate but different solutions ☺

The main detector

JLab

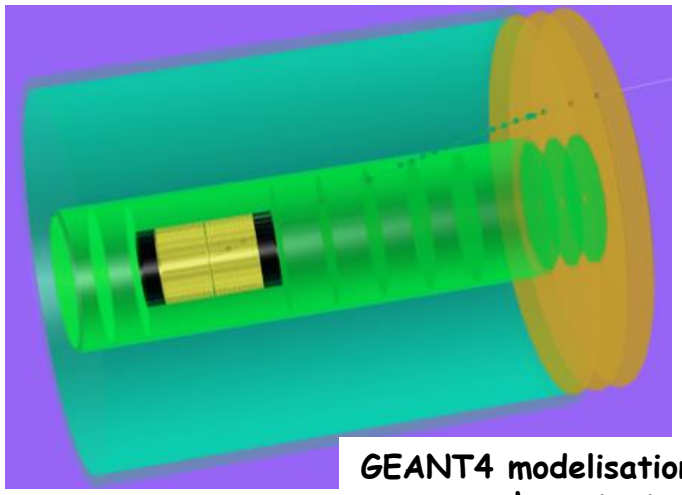


P. Nadel-Turonski



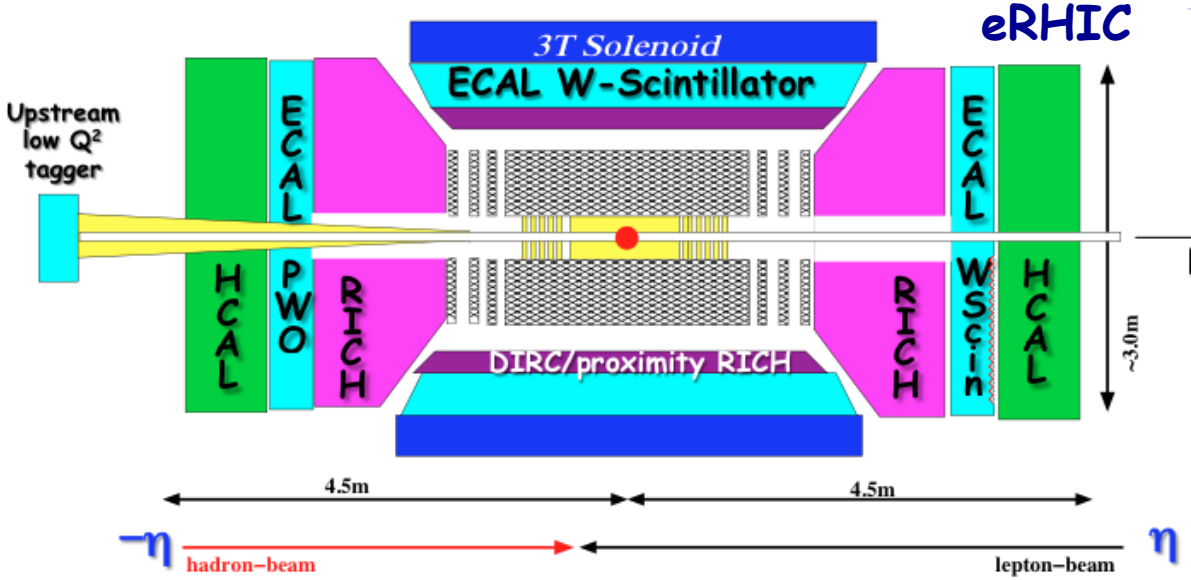
Similar solutions in both cases : interesting idea for JLab (à la ILC4)

E. Aschenauer



GEANT4 modelisation has started

eRHIC



Accelerator and detector R&D collaboration

A. Deshpande

See Details in E. Aschenaur's & Y. Zhang's & P. Nadel-Turonski's talks

- **Accelerator R&D:** Significant level of activity since 2008
- Detector designs ideas being developed: @BNL & @JLab
- Integration with the machine an integral part of all future EIC designs

NEW since 2010:

- Detector R&D supported by DOE through BNL (Dr. T. Ludlam)
  - https://wiki.bnl.gov/conferences/index.php/EIC_R%25D
  - An external committee evaluates: new proposals and progress on funded ones every ~6 months. [Next review June 2013]
- Collaborative groups formed across the US Universities and some European institutions: Tracking, PID, Calorimetry R&D proposals

- **Invitation: Collaboration welcome on all fronts: accelerator, detector, and detailed physics simulation/studies for the EIC**

And now the real summary : **on the way to an EIC by 2025**

A. Deshpande

The EIC will profoundly impact our understanding of QCD with its energy variability , high luminosity (e-A) and *polarized* e-p/D collisions

EIC: 1st *polarized* DIS collider, 1st nuclear DIS collider, ***Focus: QCD***

- ***Precision studies of the role of sea quarks and gluons in QCD***

- Historically **p-p, e-e, e-p** collisions have played a complimentary and essential role in the development of the SM
  - **EIC's** will add "**spin**" and "**nuclei**" to this list: A-A, p/d-A, **e-A**

Next milestones for US EIC: Long Range Plan of the NSAC 2014/5

Support & approval by the US NP community

Thanks to

The organizers local or not ☺

The participants of WG7 and all others

and all of you who stayed till the end !

DIS 2013