Stato del progetto EIC,

un laboratorio di QCD
e di tecnologie sperimentali

S. Dalla Torre

INFN - TRIESTE

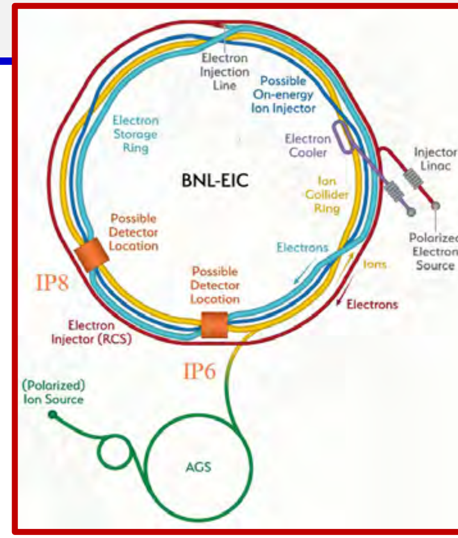
EIC, ELECTON ION COLLIDER

COLLISORE elettrone – ione

- Progetto USA di fisica nucleare di alta energiea

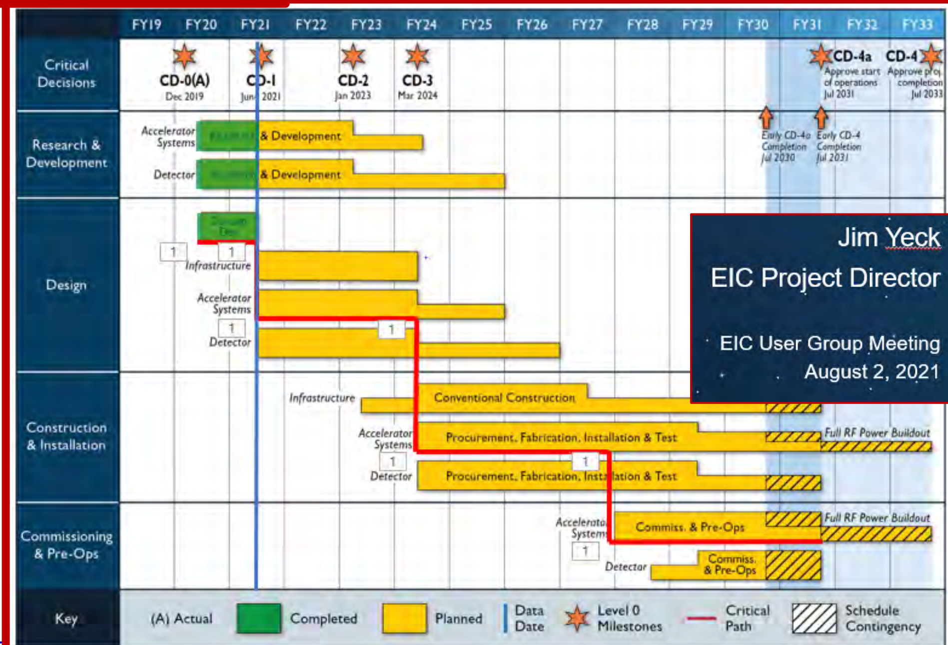
- Ioni leggeri e pesanti
- Polarizzazione e-, ioni leggeri
- Alta luminosita'
- Ampio intervallo di energie

NEW !



Processo di approvazione

- dicembre 2019:
  - CD0 mission needed = progetto USA EIC approvato !
- gennaio 2020:
  - scelta del sito – BNL
- 28 giugno 2021:
  - CD1 completion of the project definition Phase = procedere con TDR



OUTLOOK

- **PART 1:**

  physics background (with historical hints) and scientific motivations for the EIC

- **PART 2:**

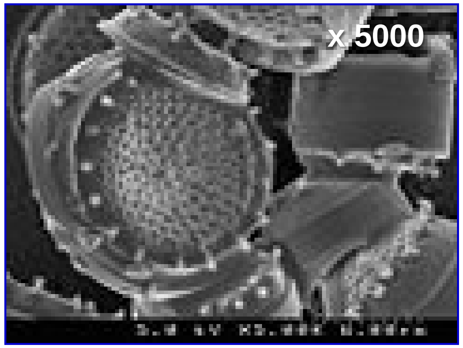
  The EIC project

ELECTRONS as PROBES

The concept of using e-beams to resolve structures finer than the visible light wavelength is nowadays familiar:

the higher the energy → the finer the resolution

Diatoms (unicellular): size from 2 - 200 μm



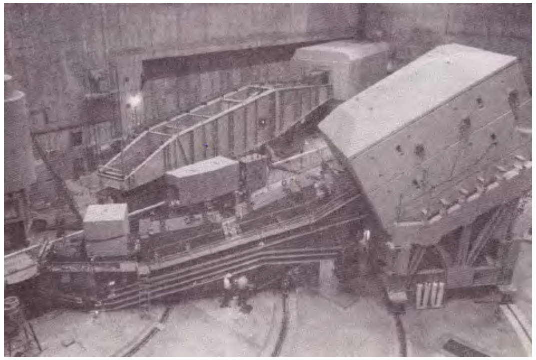
NUCLEONS (= p,n) and atomic NUCLEI are common objects whose structure is not fully understood

p-radius: ~ 0.9 fm

- **Use high energy e-beams for the investigation** R. Hofstadter and R. W. McAllister, Physical Review 98 (1955) 217
- **First experimental results at the end of the 60's @ SLAC**

Breakthrough:

20 GeV e-beam



M. Breidenbach et al., Physical Review Letters 23 (1969) 935;
E. D. Bloom et al., Physical Review Letters 23 (1969) 930.

The p and its STRUCTURE

- 1933 – p is not a DIRAC fermion: it has **anomalous magnetic moment**
  - For a DIRAC particle, μ proportional to electric charge and to 1/m
  - p: $\mu_p = 2.79\ \mu_{Dirac}$
    - 1943: Nobel Price to Stern

I. Estermann, R. Frisch, and O. Stern, Nature 132 (1933) 169.

  - n has non-zero magnetic moment: $\mu_n = -1.93\ \mu_{Dirac}$

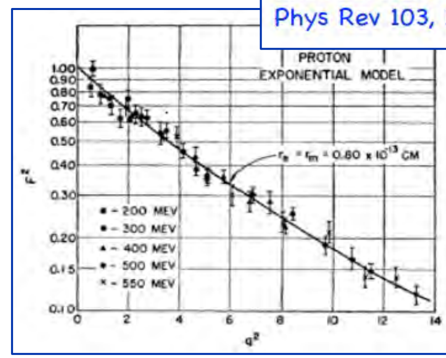
  → Nucleons have a structure !

- 50's : evidence of the finite p size

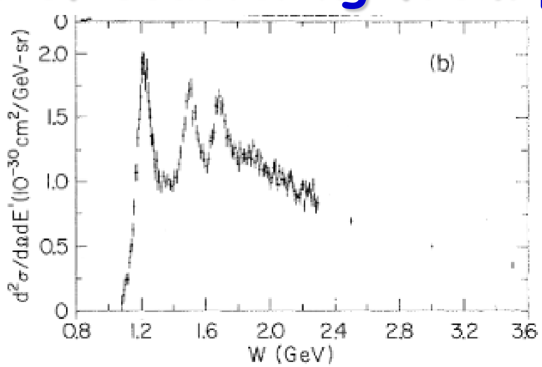
ep elastic scattering (G_E, G_M: electric and magnetic form factors)

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4E_1^2 \sin^4(\theta/2)} \frac{E_3}{E_1} \left(\frac{G_E^2 + \tau G_M^2}{1+\tau} \cos^2\frac{\theta}{2} + 2\tau G_M^2 \sin^2\frac{\theta}{2} \right)$$

Chambers and Hofstadter, Phys Rev 103, 14 (1956)



- 60's : first evidence of scattering from point-like entities inside the p
  - R. Feynman introduces the partons



1990: Nobel Price to Friedman, Kendall, Taylor

HIGH-ENERGY INELASTIC e-p SCATTERING AT 6° AND 10°*

E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo, and R. E. Taylor
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

M. Breidenbach, J. I. Friedman, G. C. Hartmann,† and H. W. Kendall
Department of Physics and Laboratory for Nuclear Science,‡
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
(Received 19 August 1969)

QCD is formulated

Main players & milestone dates

- 1963 - Along the way of explaining the hadron spectroscopy, M. Gell-Mann and G. Zweig introduced the quarks as entities of an SU(3) symmetry group
- 1965 – need of an extra degree of freedom to avoid violating the Pauli principle: O. W. Greenberg, M. Y. Han, Y. Nambu proposed an additional SU(3) gauge degree of freedom: the colour charge.
- 1968 – Feynman introduces the partons
- In the following years, quarks from mathematical entities to hadron constituents
  - First disputes within the theoretical community, later accepted

About QCD, REMINDER:

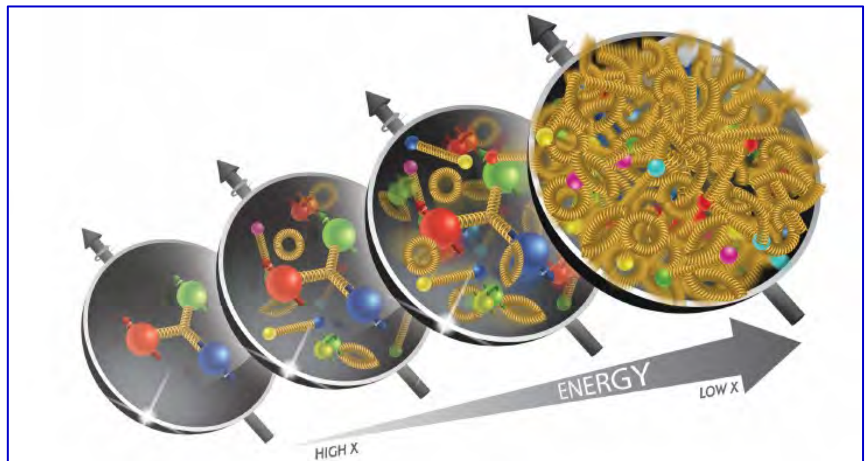
- The vector gauge bosons are the GLUONS; they carry the colour charge
- Colour confinement: coloured objects cannot be isolated; all observed hadrons are colour singlets
- asymptotic freedom: interactions between q's and g's become asymptotically weaker as the energy scale increases and the corresponding length scale decreases → perturbative QCD calculations
- Non perturbative QCD aspects: accessed via phenomenological models & lattice calc.s

PROGRESS in UNDERSTANDING p

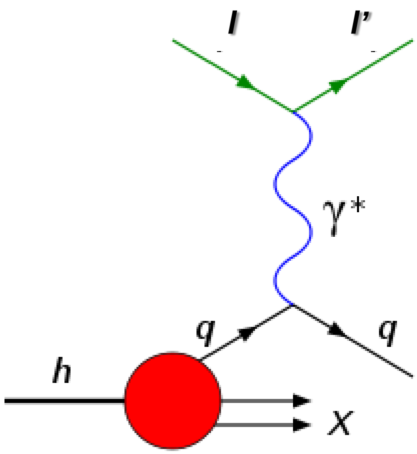
1919 | 60's | 70's | > 90's

elementary particle | partons | quarks & gluons | a see of quarks & gluons

Progress impossible w/o technological progress:
higher energies needed



Deep Inelastic Scattering – DIS



l – the lepton probe
l' – the scattered lepton
h – the hadron being studied: p, A
γ*- the virtual photon

The <u>most used kinematic variables </u>(Lorentz invariant):

$Q^2 = -q^2$, where q is the four-momentum of γ^*

$q = p1 - p3$

$\nu = (p1 \cdot q)/M1$

$x = Q^2 / 2(p1 \cdot q)$ $\quad 0<x<1$
$y = 2(p1 \cdot q) / (p1+p2)^2$ $\quad 0<y<1$

} dimensionless, introduced by Bjorken

Important, about Bjorken x:

x is interpreted as the fraction of the h momentum carried by the struck q; this approximation is valid in the Lorentz frame, where h and q masses can be neglected

Deep Inelastic Scattering – DIS

- fully inclusive DIS – in the final state only *l'* is studied

Inelastic cross-section
$$\frac{d\sigma}{dx.dQ^2} = \frac{4\pi\alpha^2}{Q^4}\left(\frac{F_2(x,Q^2)}{x}(1-y-\frac{M_p^2y^2}{Q^2}) + y^2F_1(x,Q^2)\right)$$

$F_1(x,Q^2)$ & $F_2(x,Q^2)$ - structure functions

- Bjorken scaling : $F_1(x,Q^2)$ & $F_2(x,Q^2)$ almost independent of Q^2

→ Interaction from point-like particles

For Q^2 > a few GeV^2, they are not independent:
→ γ^* interacts with spin ½ DIRAC particles !

$$F_2(x,Q^2) = 2xF_1(x,Q^2)$$
Callan-Gross relation

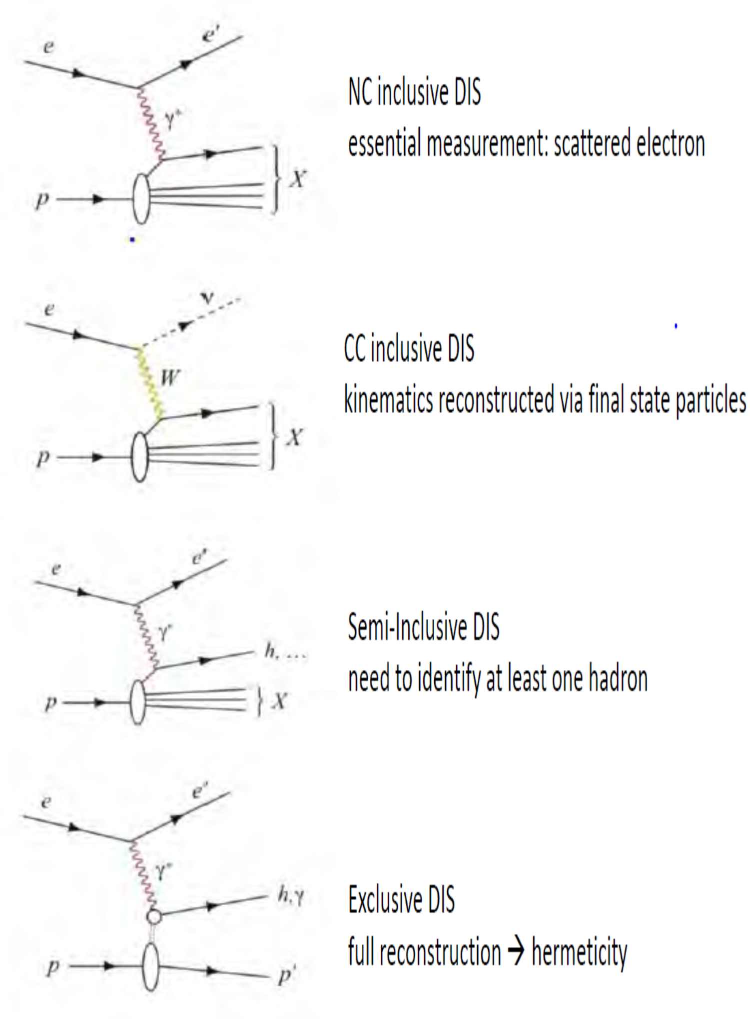
Deep Inelastic Scattering – DIS

Much more information can come when :

- Access to a wider phase space domain is made possible
- polarized particle scattering
- part of the final state is measured: SIDIS (Semi-Inclusive DIS)
- The whole final state is measured: exclusive reactions

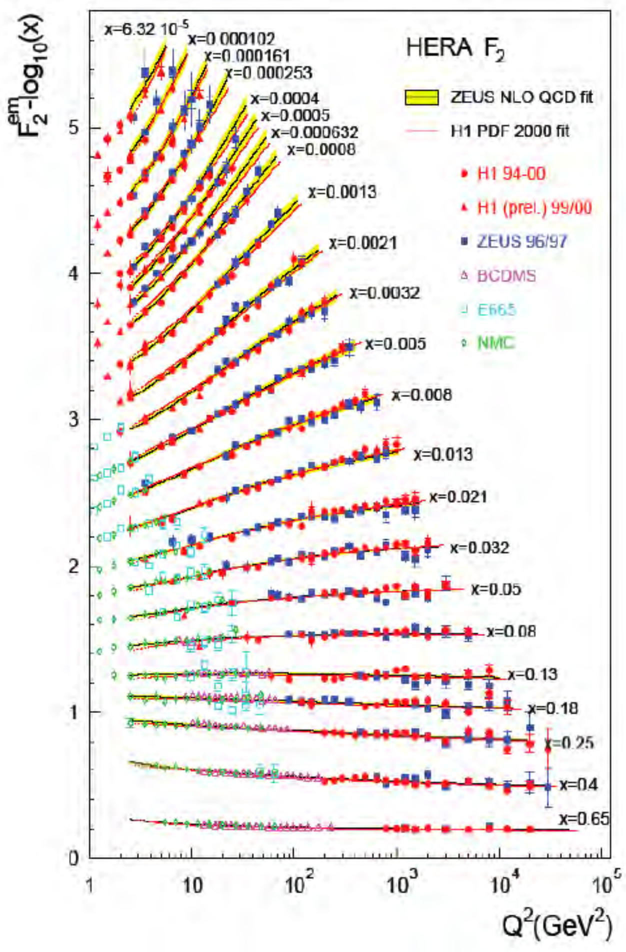
Enormous progress since the 60's

- Nevertheless, still a lot in front of us
- Some examples in the next slides



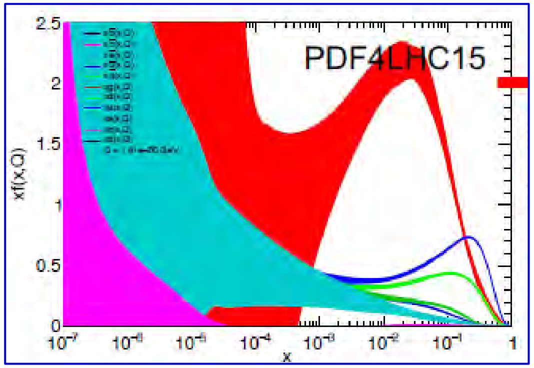
ENLARGING PHASE SPACE

$F_2(x, Q^2)$ largely studied

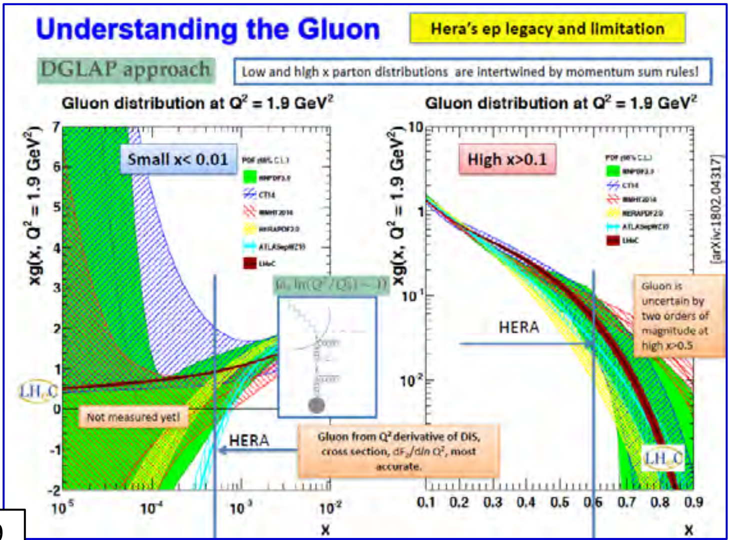


Nevertheless,
specific kinematic regions not deeply explored

Quark distribution functions
functions poorly known at very small x



Gluon distribution Functions need further exploration at small and large x



C. Gwenlan, DIS2019

POLARIZATION

The description of the nucleon is enriched: more structure functions

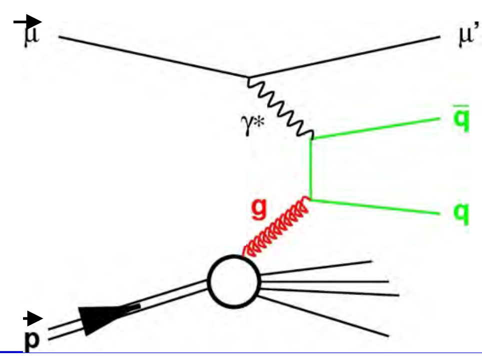
- **They give access to the spin structure of the nucleons**
- **The transverse degrees of freedom only accessed via SIDIS**

		quark		
		U	L	T
nucleon	U	$f_1(x, p_T)$		$h_1^{\perp}(x, p_T)$ Boer-Mulders
	L		$g_1(x, p_T)$	$h_{1L}^{\perp}(x, p_T)$ Worm-gear 1
	T	$f_{1T}^{\perp}(x, p_T)$ Sivers	$g_{1T}(x, p_T)$ Worm-gear 2	$h_1(x, p_T)$ Transversity $h_{1T}^{\perp}(x, p_T)$ Pretzelosity

U – unpolarized
L – longitudinally polarized
T – transversally polarized

Puzzling results: only ~ 30% of the nucleon spin is carried by the quarks!
→ hunting also for the gluon contribution to the nucleon spin

Photon Gluon Fusion: $\gamma g \to q\bar{q}$



High p_T hadron pair $q\bar{q} \to hh$

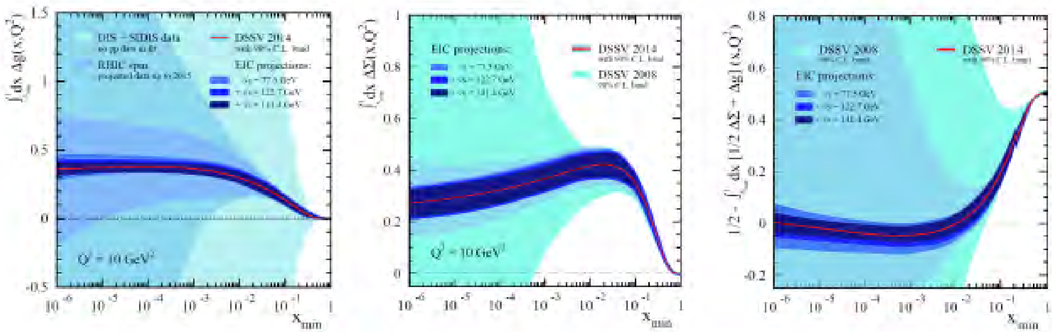
of course, by a SI-DIS measurement

HUNTING FOR THE NUCLEON SPIN

It is more than the number ½ ! It is the interplay between the intrinsic properties and interactions of quarks and gluons

What do we know:

$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}|J^z_{QCD}|P,\frac{1}{2}\right\rangle = \underbrace{\frac{1}{2}\int_0^1 dx\Delta\Sigma(x,Q^2)}_{\text{total quark spin}} + \underbrace{\int_0^1 dx\Delta G(x,Q^2)}_{\text{gluon spin}} + \underbrace{\int_0^1 dx(\sum_q L_q^z + L_g^z)}_{\text{angular momentum}}$$



1/2 - Gluon 40% - Quarks 30% = orbital angular momentum

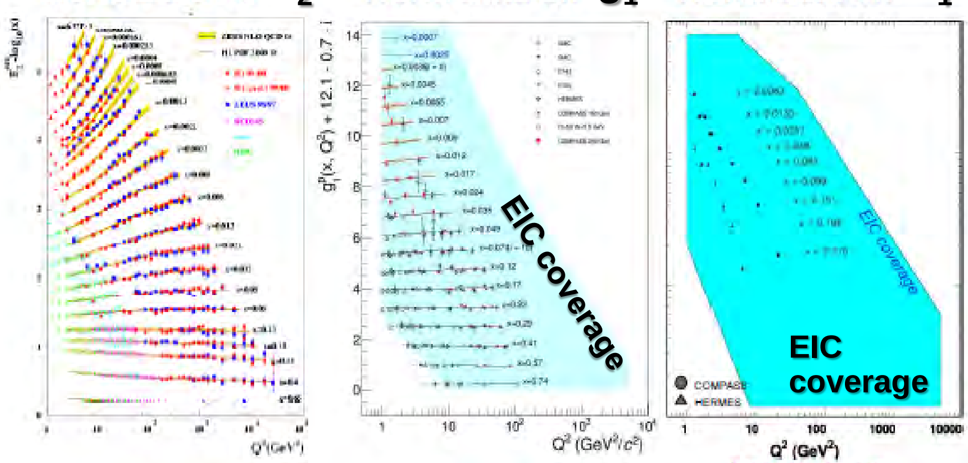
Longitudinally Polarized SI-DIS

Longitudinally Polarized DIS

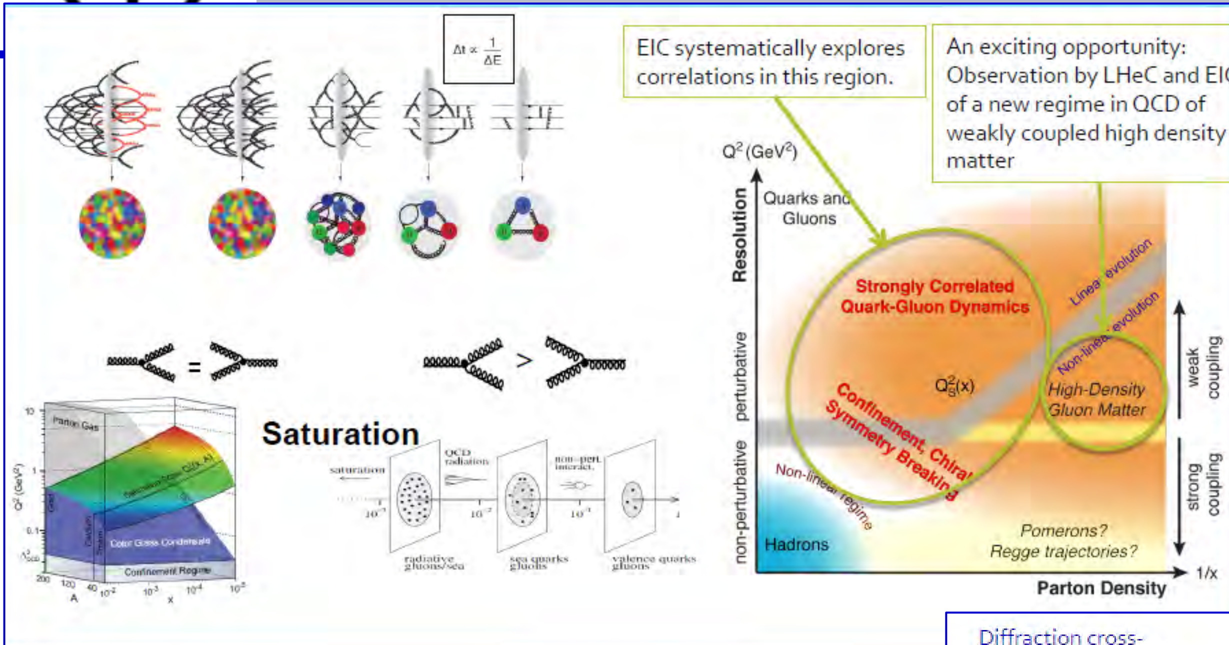
Understanding the N spin

A. Bressan, "Prospettive per fisica adronica e collisionatori adronici"

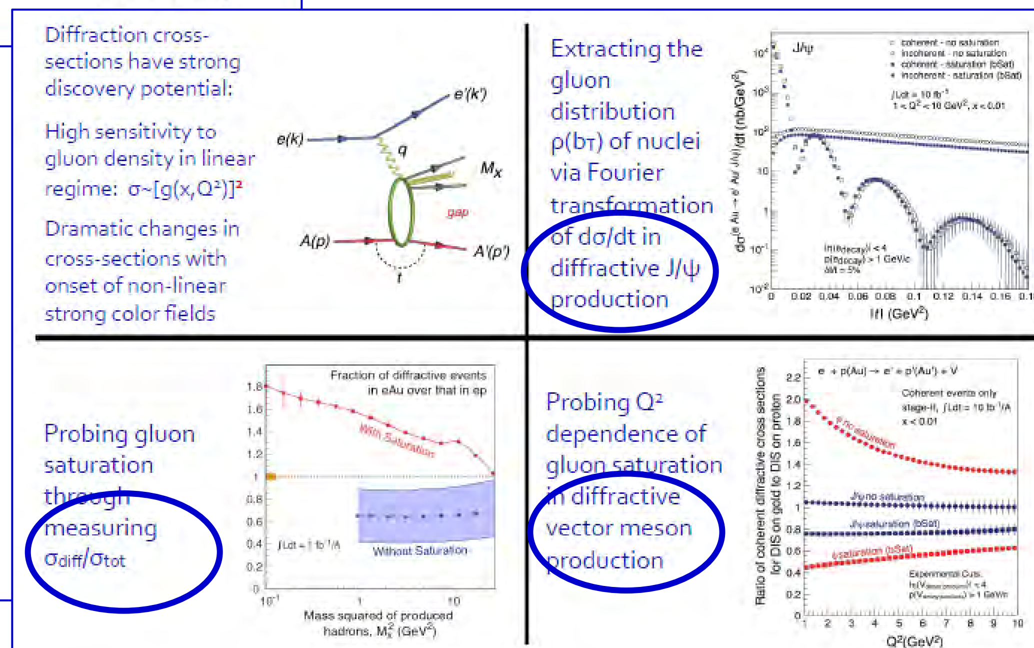
transverse momentum dependent (TMD) distributions



N-see evolution and gluon saturation

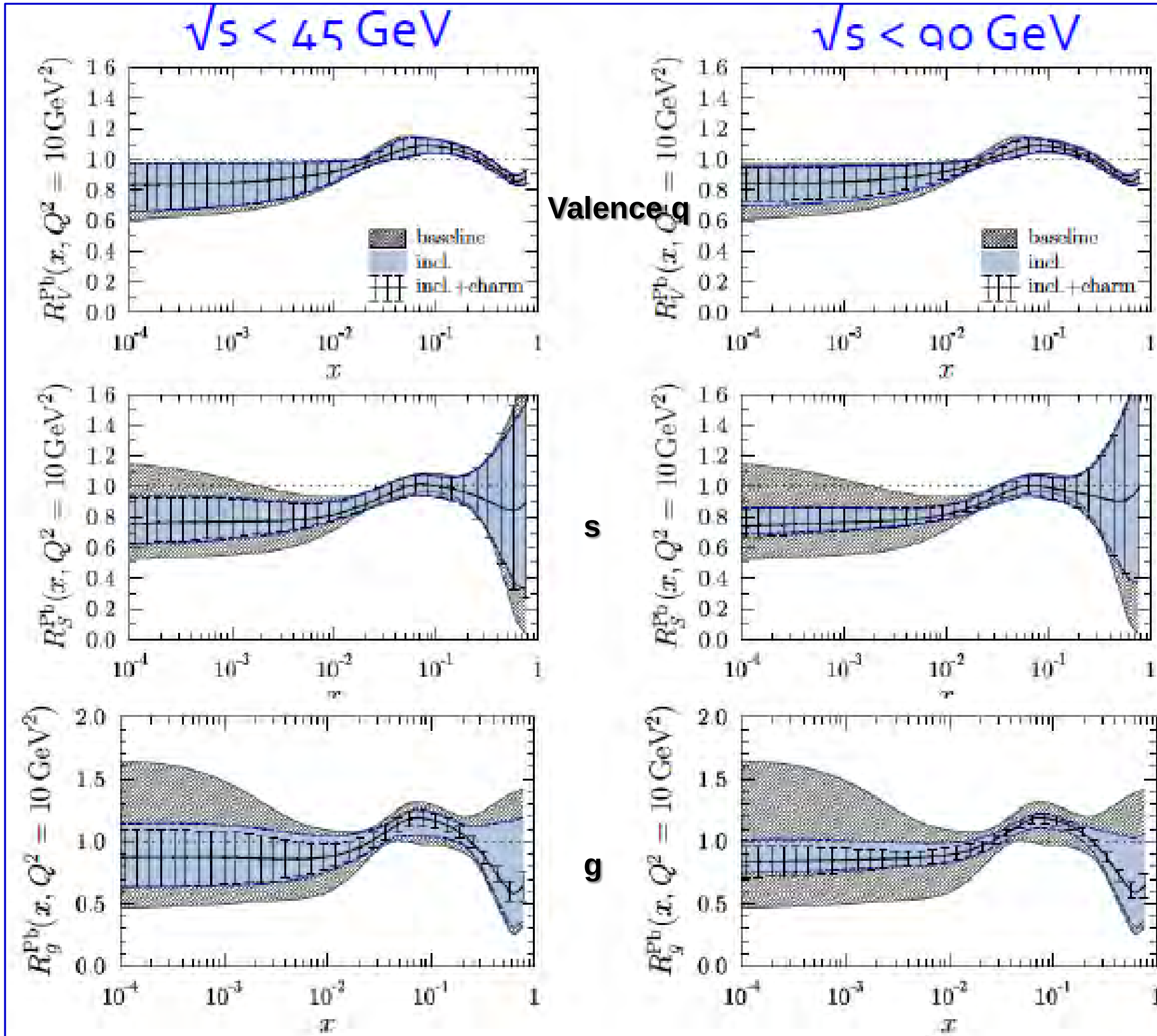


Evolution of the N see



Diffraction cross-section as a powerful tool to access gluon saturation

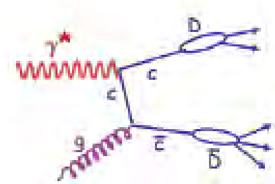
IMPACT ON NUCLEAR PDFs



Ratio of PDF of Pb over Proton

- Without EIC, large uncertainties
  → With EIC significantly reduced uncertainties
- Complementary to RHIC and LHC pA data. Provides information on initial state for heavy ion collisions.
- Does the nucleus behave like a proton at low-x?
  → relevant to very high-energy cosmic ray studies
  → critical input to AA

Direct Access to gluons at medium to high x by tagging photon-gluon fusion through charm events

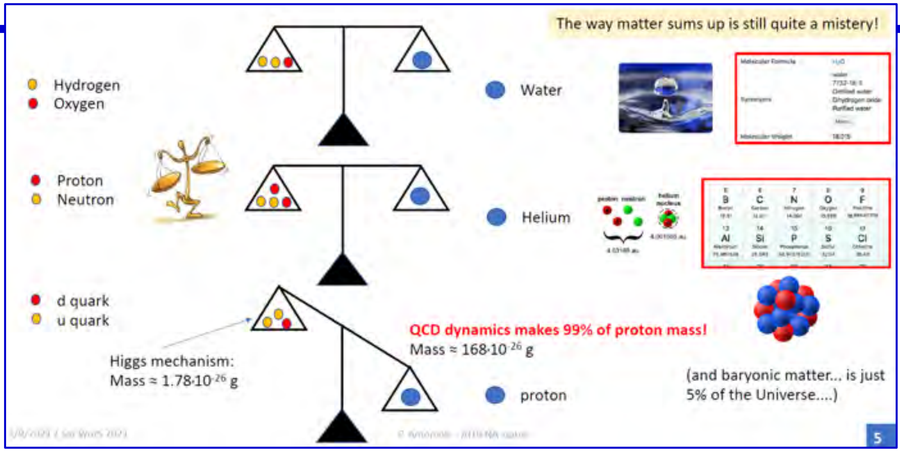


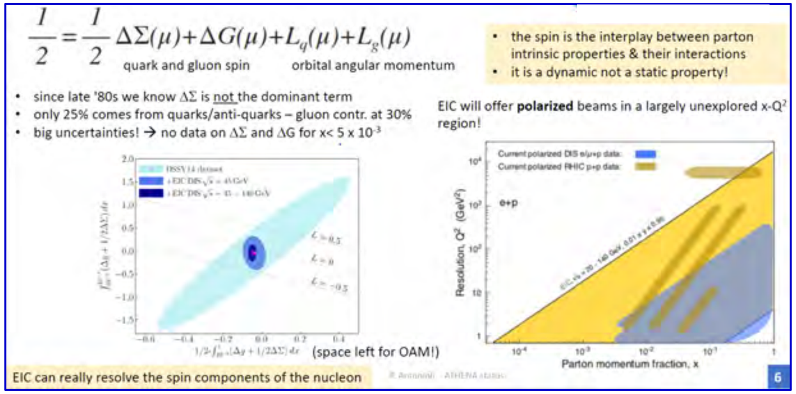
EIC MISSION in summary

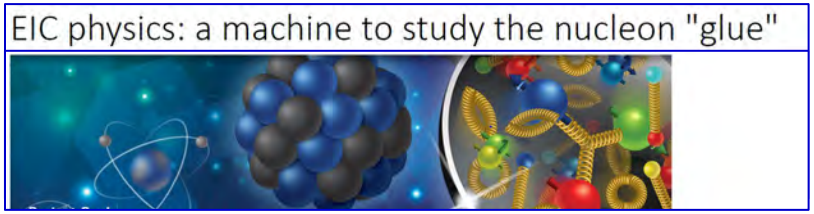
Towards non perturbative QCD

→ EIC will answer to these hot questions: a machine to study nucleon glue

- q, g distributions (momentum, space, spin) within the nucleon?
- nucleon properties (MASS !) from q, g and QCD?
- q, g distributions in the dense nuclear matter ?
- Gluon density in nuclei, does it saturate at small x-values?
- interaction of coloured q and g and colourless particles with the nuclear matter
- how confined hadron states emerge
- And more:
  - Heavy (and light) q spectroscopy
  - ‘initial state’ states in HI collisons
  - …







OUTLOOK

- **PART 1:**

  physics background (with historical hints) and scientific motivations for the EIC

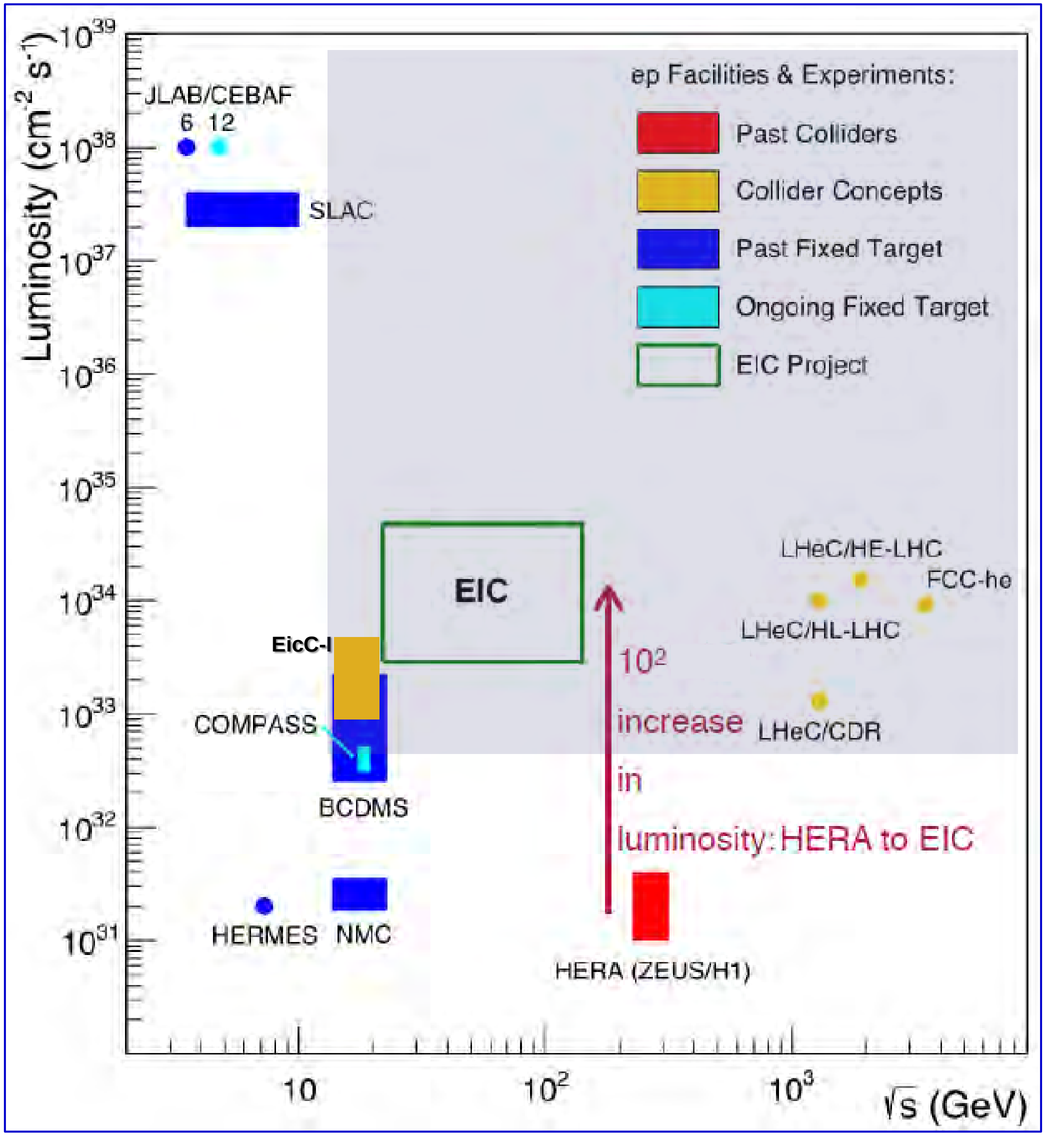
- **PART 2:**

  The EIC project

ENERGY & LUMINOSITY, future vs past

PAST

FIXED TARGET, e BEAM				
SLAC	concluded	high $\mathscr{L}$	polarization	
CEBAF	active		polarization	
HERMES	concluded	limited $\mathscr{L}$	polarization	internal gas jet target
FIXED TARGET, HIGH ENERGY μ BEAM				
BCDMS	concluded	high $\mathscr{L}$		access to small x & large Q2 range
EMC	concluded	limited $\mathscr{L}$	polarization	
NMC	concluded			
SMC	concluded		polarization	
COMPASS	active	high $\mathscr{L}$	polarization	
COLLIDER ep				
HERA	concluded	limited $\mathscr{L}$		high energy, access to very small x & very large Q2 range



FUTURE:

Filling the high E - high $\mathscr{L}$ region:

- **precision**
- **wide kinematic range**
  - **also access to high x-region**

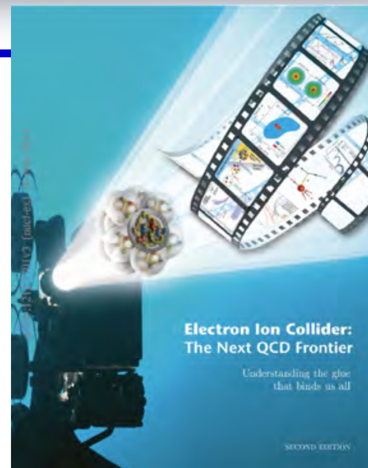
THE PATH OF

THE EIC PROJECT

EIC – a long path, built step by step

The EIC White Book

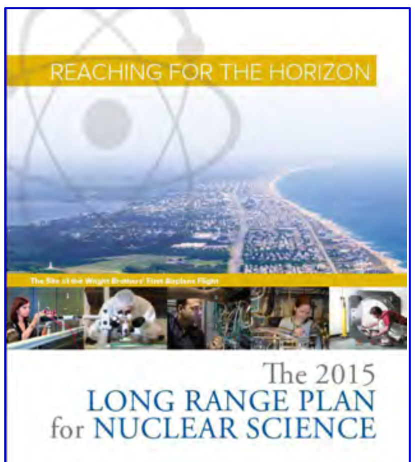
"Electron Ion Collider:
The Next QCD Frontier
Understanding the glue
that binds us all"



- First edition: 2012
- Second edition, updated 2014

A. Accardi et al., Electron-Ion Collider: The next QCD frontier, Eur. Phys. J. A52 (2016) 268.

The 2015 Long Range Plan for Nuclear Science

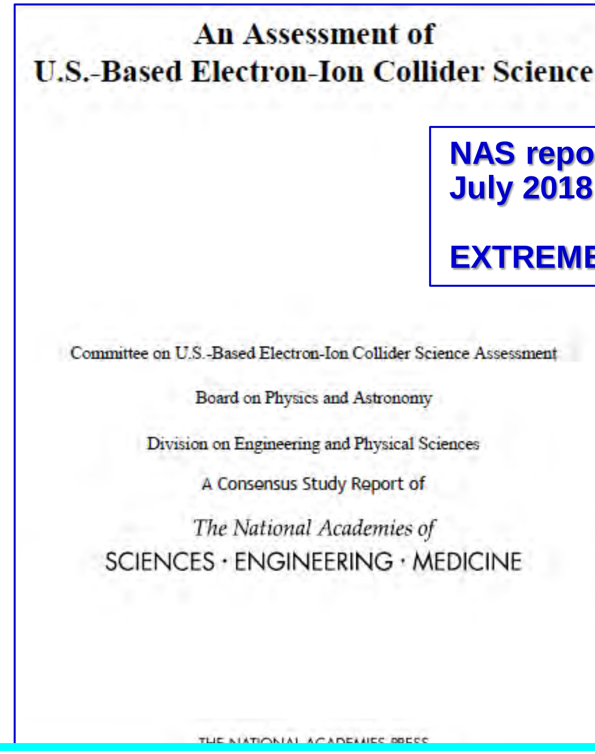


Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.

Compact support of the whole US Nuclear physics community

In 2017, DOE asked for the NAS

(the National Accademy of Science-Engineering-Medicine) accessment


An Assessment of
U.S.-Based Electron-Ion Collider Science

Committee on U.S.-Based Electron-Ion Collider Science Assessment

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

A Consensus Study Report of

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

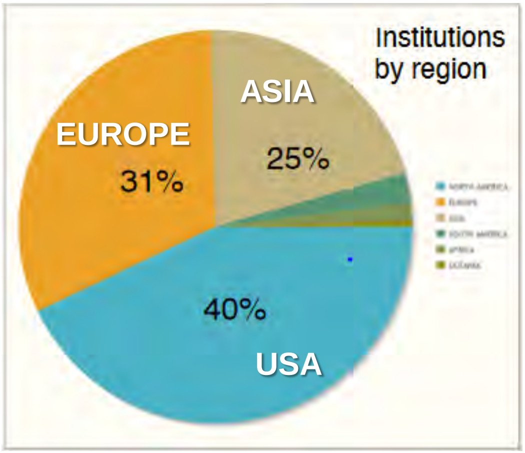
THE NATIONAL ACADEMIES PRESS

NAS report, July 2018:

EXTREMELY POSITIVE

The committee unanimously finds that the science that can be addressed by an EIC is compelling, fundamental, and timely.

The EICUG (User Group)



A deeply active community

- EICUG annual meetings
- The annual conference POETIC (Physics Opportunities at an ElecTron-Ion Collider)
- The working groups
- And more …

BREAKING NEWS, January 2020

Department of Energy

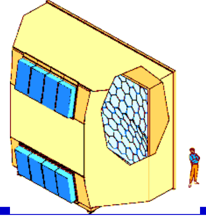
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

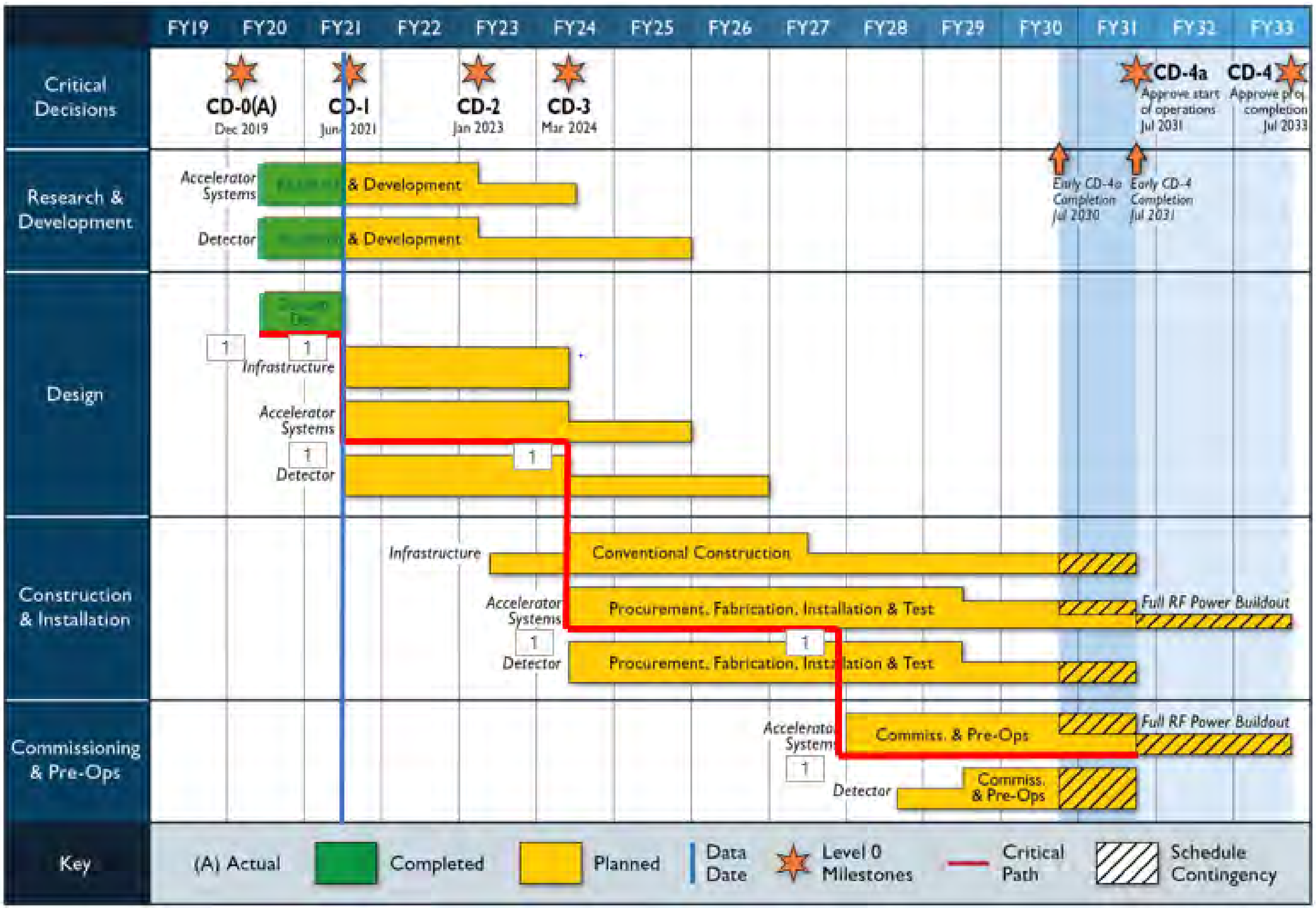
The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.

Secretary Brouillette approved Critical Decision-0, "Approve Mission Need," for the EIC on December 19, 2019.

https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics



THE AGGRESSIVE SCHEDULE



Jim Yeck
EIC Project Director

EIC User Group Meeting
August 2, 2021

EXTREMELY INTENSE ACTIVITIES

2020

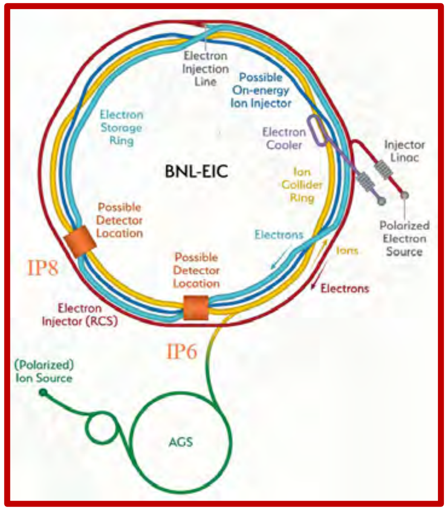
- **EICUG: Yellow Report Initiative**
  - published in March 2021
- **Call for Expressions of Interest for Potential Cooperation on the EIC Experimental Program**
  - Dead-line 1/11/2020

2021

- **CALL FOR PROPOSALS**
  - **dead-line 1/12/2021**

→ **Proto-collaboration formed**
  - **ATHENA, a new detector around a 3T solenoid for the whole EIC physics programme (IP6)**
  - **ECCE, a detector for the whole EIC physics programme using the ex BABAR, ex sPHENIX magnet (IP6 o IP8)**
  - **CORE, a smaller size and smaller cost detector (IP8)**

→ **Proposals in preparation**

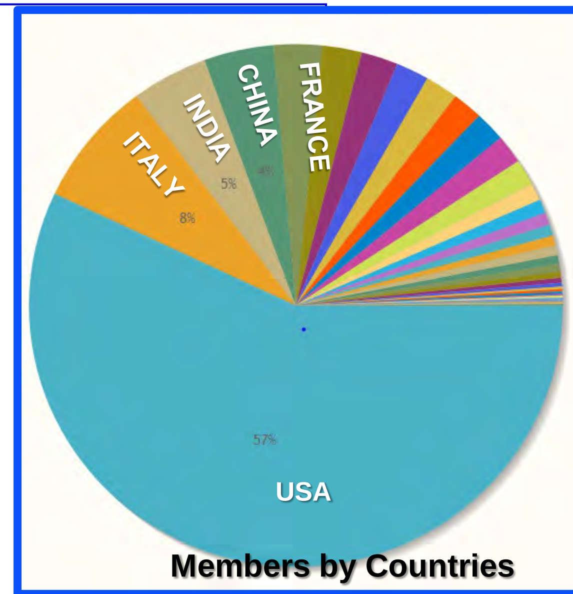


2022

- **Proposal selection, Spring 2022**
- **Immediately after, start TDR activity for CD2**

EIC & ITALY

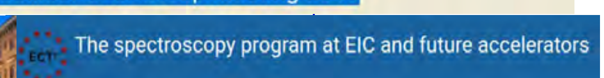
- **Membri Italiani in EICUG:**
  - 101 (/ 1300) da 16 sedi (aggiornamento 7/8/2021)
  - La piu' ampia partecipazione dopo USA
    - ~30 teorici
    - ~70 sperimentali
- **Compiti istituzionali in EICUG**
  - 15 rappresentanti nell' Istitutional Board
  - IB deputy-chair
  - 1 componente dello Steering Committee
  - da adesso: il depy-chair dello SC
  - Presidenza Election and Nomination Committee,
  - Presidenza Conferences and Talks Committee
- **Contributi maggiori allo Yellow Report**
  - 2 convener WG, 3 sub-convener WG
  - 57 (/414) autori

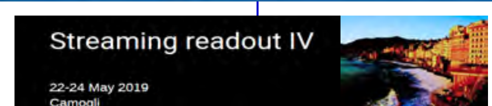


- **Adesione dei gruppi italiani alla protocollaborazione ATHENA**
  - Coordination Committee: 1/8
  - Working Group Conveners: 5/37
  - Charter Committee: 1/14
  - Nomination and Election Committee: 1/6
  - EIC Silicon Consortium Coordination Board: 1/6

ATHENA

- **Intensa attivita' di studio e R&D**
  - **Sviluppi teorici (INFN: NINPHA)**
  - **R&D e networking (INFN: EIC_NET)**
    - **PID**
    - **Vertexing**
    - **DAQ-streaming read-out**
    - **Software development and coordination**
- **Eventi EIC organizzati da italiani in Italia**
  - ospitando la comunita' internazionale EIC
  - Eventi nazionali





THE EIC

COLLIDER

The EIC

World First
- **eA collider**
- **polarized e-p/light A collider**

"SPECIFICATIONS":

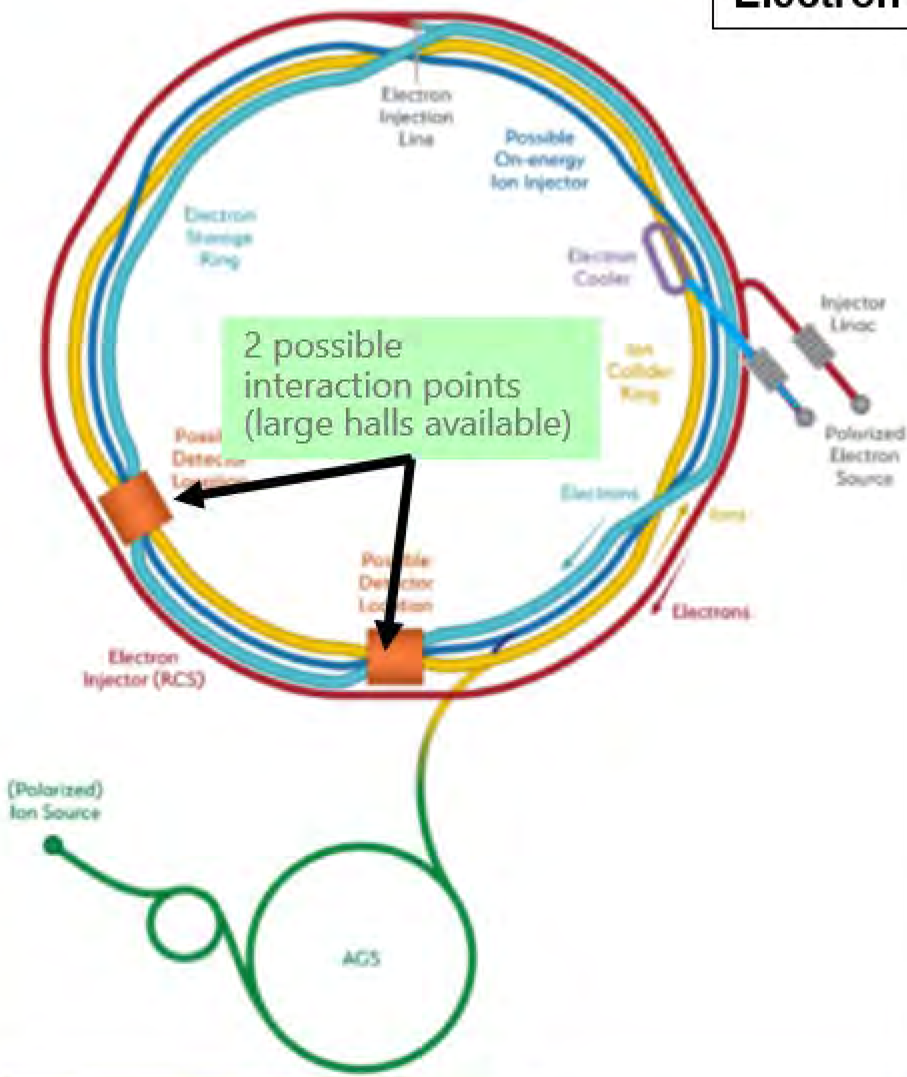
- spanning a wide kinematical range
  - **ECM: 20 – 141 GeV**
- High luminosity
  - **up to 10^{34} cm^{-2} s^{-1}**
- **highly polarized e (~ 70%) beams**
- **highly polarized light A (~70%) beams**
- wide variety of ions: **from H to U**
- **Number of interaction regions: up to 2**

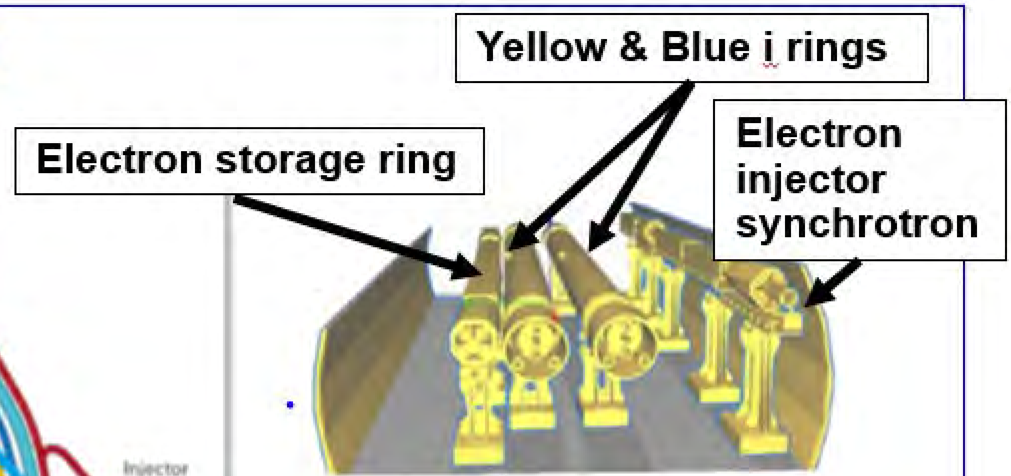
collider design

- **True 4π-coverage**
  - **Fully integrated detector-IR**
- **Experiments with high acceptance**
- **PID systems (e/h, h identification)**
- **Tagging all nuclear fragments & very forward detectors**

experiment design

From RHIC to the EIC





The strong hadron cooling facility completes the facility

- Hadron Storage Ring (yellow)
- Electron Storage Ring (light blue)
- Electron Injector Synchrotron (red)
- Possible on-energy Hadron injector ring (dark blue)
- Hadron injector complex (green)

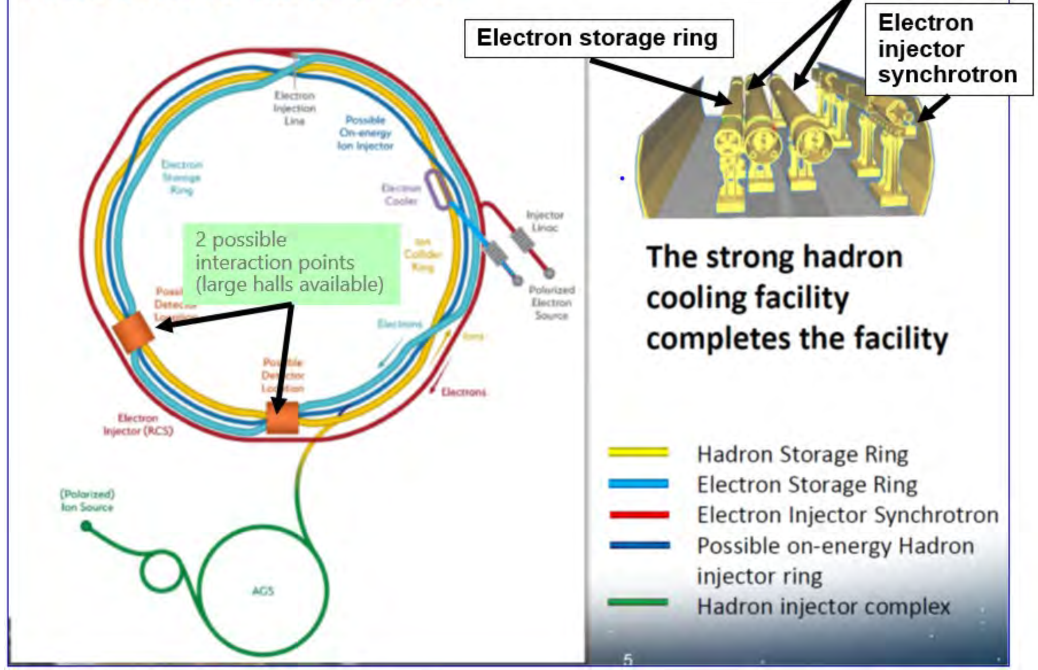
EIC Overview

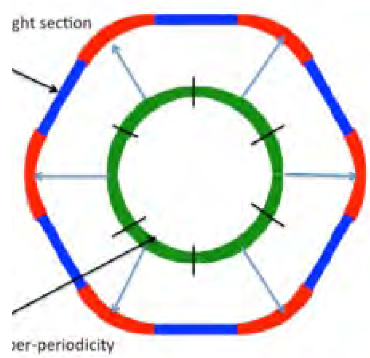
F. Willeke, "1st EIC YR workshop", March 2020

Design based on **existing** RHIC,
RHIC is well maintained, operating at its peak

- **Hadron storage ring 40-275 GeV** (existing)
  - many bunches
  - bright beam emittance
  - need strong cooling **(new)**
- **Electron storage ring (2.5–18 GeV** (new))
  - many bunches,
  - large beam current (2.5 A)
- **Electron rapid cycling synchrotron** (new)
  - 1-2 Hz
  - Spin transparent due to high periodicity
- **High luminosity interaction region(s)** (new)
  - L = 10^{34} $cm^{-2}s^{-1}$
  - Superconducting magnets
  - Crossing angle with crab cavities
  - Spin Rotators (longitudinal spin)
  - Forward hadron instrumentation

From RHIC to the EIC





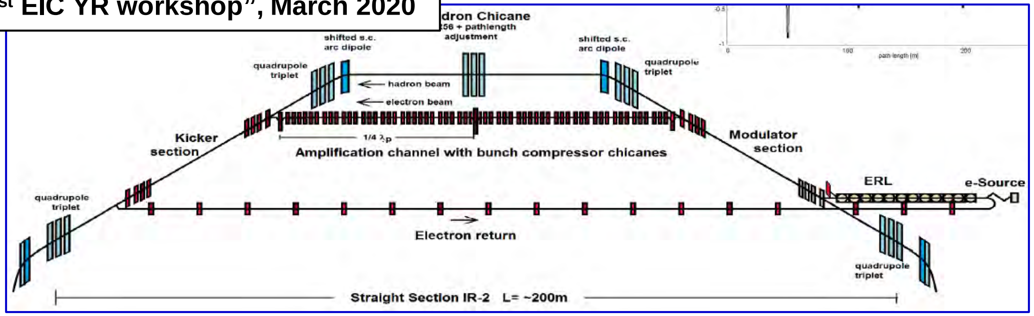
Electron injector Synchrotron: innovative design resonance-free up to 18 GeV/c

LUMINOSITY

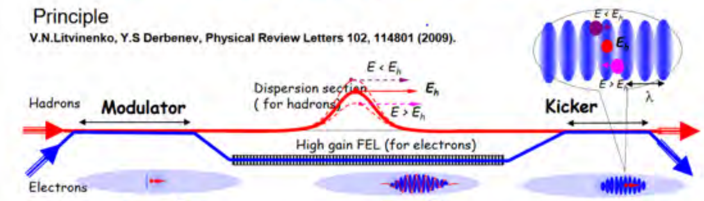
STRONG COOLING & HIGH LUMINOSITY

Coherent Electron Cooling (CeC)

F. Willeke, "1st EIC YR workshop", March 2020



Coherent Cooling with FEL amplifier

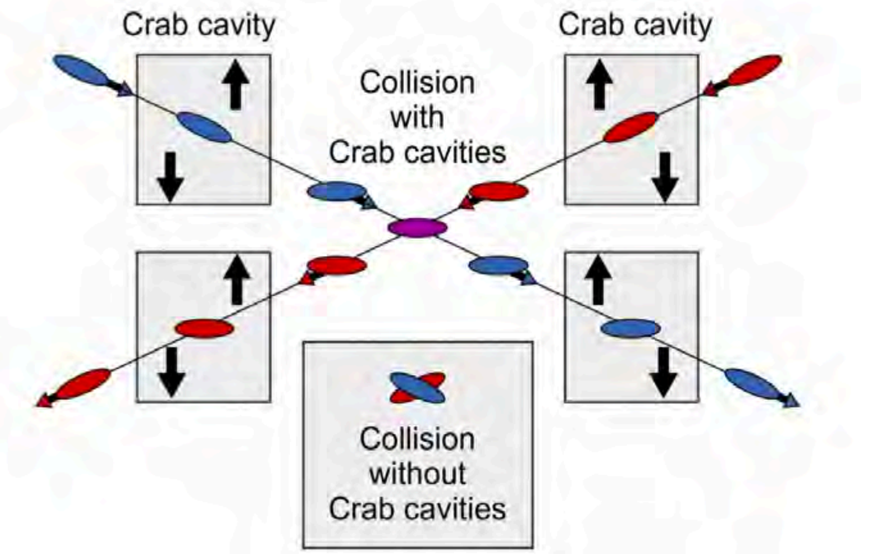


➔ cooling of high energy Hadron beams with high band-width; BW: **1THz**
short cooling times to balance strong **IBS**

Proof of Principle Experiment at BNL, ongoing

HIGH LUMINOSITY and CROSSING ANGLE (25 mrad)

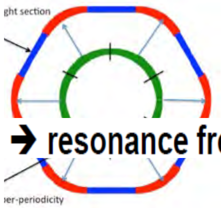
- Head-on collision geometry is restored by rotating the bunches before colliding ("crab crossing")



ABOUT the BEAMs

BEAM POLARIZATION

ABOUT e POLARIZATION



→ resonance free acceleration up >18 GeV

on average, every bunch refilled in 2.2 min

ABOUT p/ion POLARIZATION

presently

Measured RHIC Results:

- Proton Source Polarization 83 %
- Polarization at extraction from AGS 70%
- Polarization at RHIC collision energy 60%

empowerment

Planned near term improvements:

AGS: Stronger snake, skew quadrupoles, increased injection energy

→expect 80% at extraction of AGS

RHIC: Add 2 snakes to 4 existing no polarization loss

→ expect 80% in Polarization in RHIC and eRHIC

High polarization ^{3}He and D beams also possible

ION SPECIES

The existing RHIC ion sources & ion acceleration chain provides already **today** all ions needed for EIC

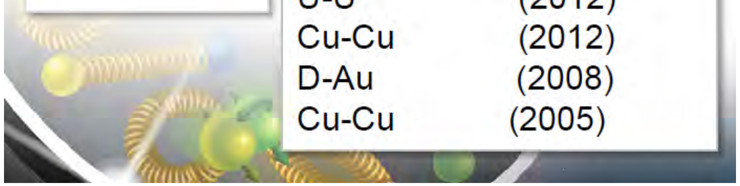
Ions from He to U have been already generated in the Electron-Beam-Ion-Source ion source (EBIS), accelerated and collided in RHIC

Existing EBIS provides the entire range of ion species from He to U in sufficient **quality** and **qua**

Transfer takes 13 μs, preserves the total charge stored in both machines, avoiding transient injection effects

in the RHIC Complex	
Zr-Zr, Ru-Ru	(2018)
Au-Au	(2016)
d-Au	(2016)
p-Al	(2015)
h-Au	(2015)
p-Au	(2015)
Cu-Au	(2012)
U-U	(2012)
Cu-Cu	(2012)
D-Au	(2008)
Cu-Cu	(2005)

Enormous versatility! is a unique capability!

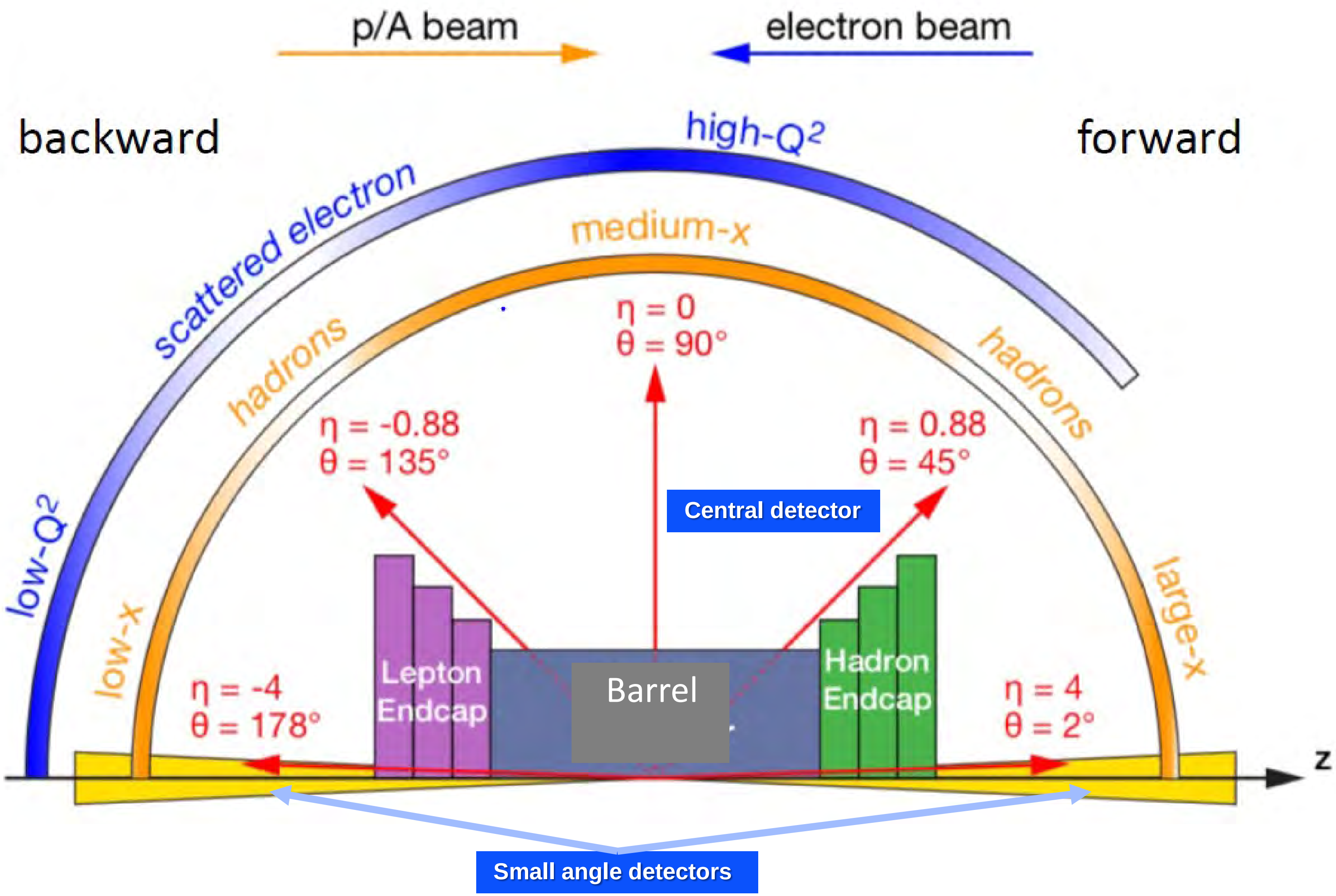


F. Willeke, "1st EIC YR workshop", March 2020

EIC

DETECTORS

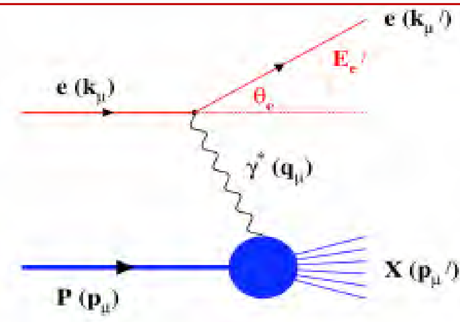
PHASE-SPACE AND DETECTOR COVERAGE



WHAT IS REQUESTED BY PHYSICS

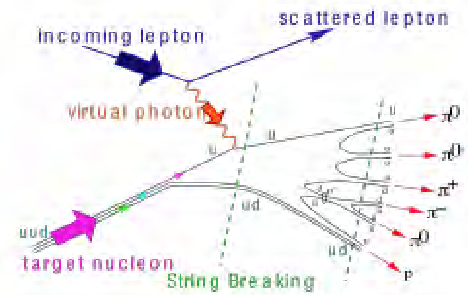
Inclusive Reactions in ep/eA:

- Physics: Structure Functions: g_1, F_2, F_L
- → Very good scattered electron ID
- → High energy and angular resolution of e' (defines kinematics $\{x,Q^2\}$)



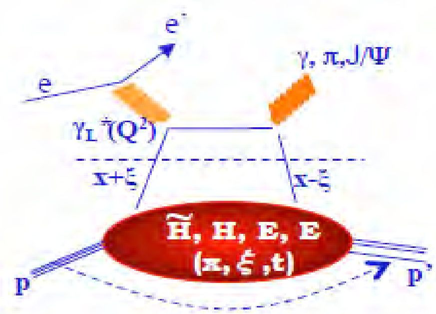
Semi-inclusive Reactions in ep/eA:

- Physics: TMDs, Helicity PDFs, FFs (with flavor separation); di-hadron correlations; Kaon asymmetries, cross sections; etc
- → Excellent hadron ID: $p^{\pm}$,$K^{\pm}$,$p^{\pm}$ separation over a wide $\{p, \eta\}$ range
- → Full Φ-coverage around γ^*, wide p_t coverage (TMDs)
- → Excellent vertex resolution (Charm, Bottom separation)



Exclusive Reactions in ep/eA:

- Physics: DVCS, exclusive VM production (GPDs; parton imaging in b_T)
- → Exclusivity (large rapidity coverage; reconstruction of all particles in a given event)
- → High resolution, wide coverage in t → Roman pots
- → (eA): veto nucleus breakup, determine impact parameter of collision
  → Sufficient acceptance for neutrons in ZDC



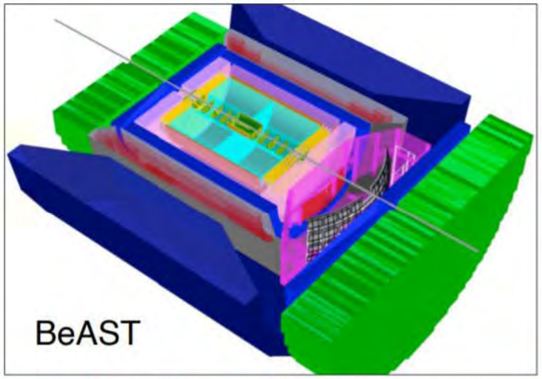
A. Kiselev, EICUG meeting, July 2016

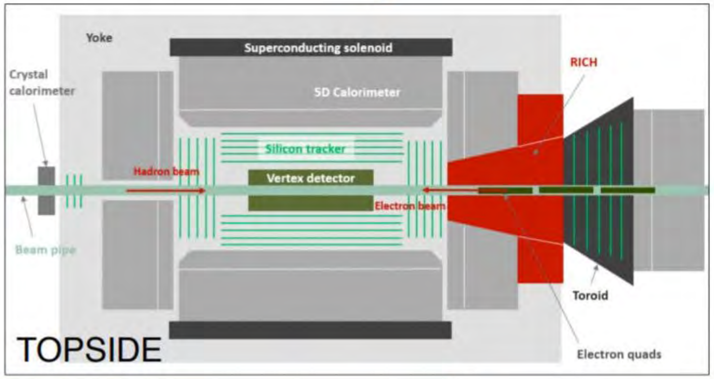
and LUMINOSITY, POLARIMETRY

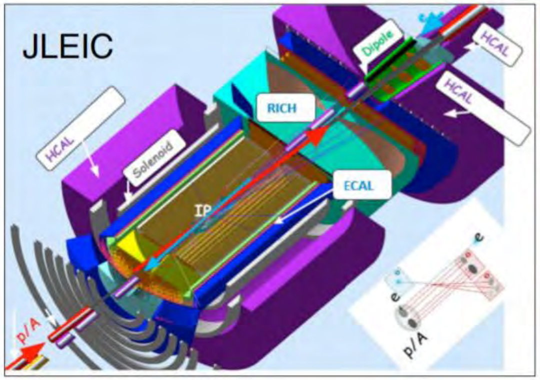
GALLERY OF DETECTOR CONCEPTS proposed over time

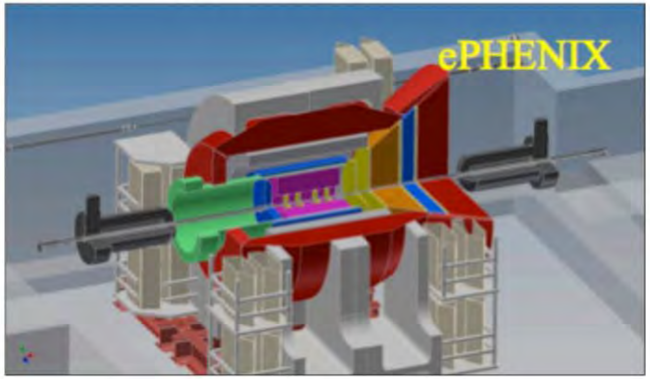
Several key elements are present in common

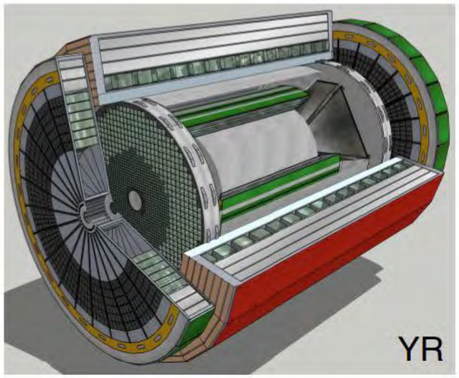
this previous activity is at the basis of the present central reference detector Presented in the YR



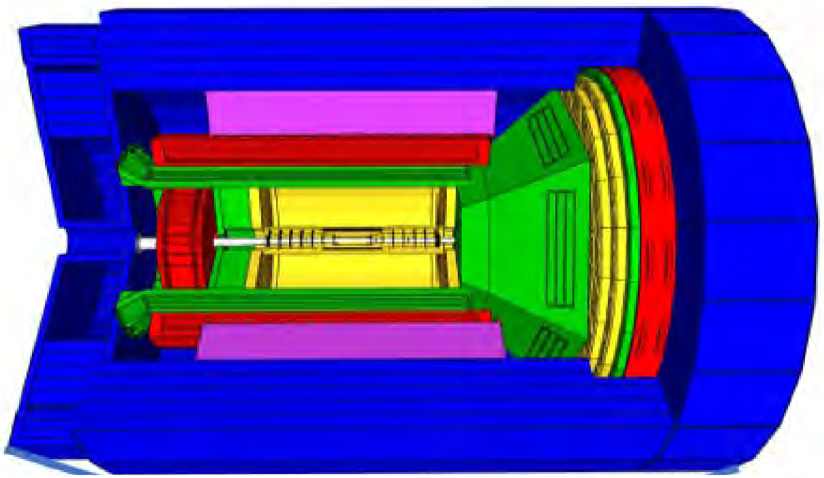






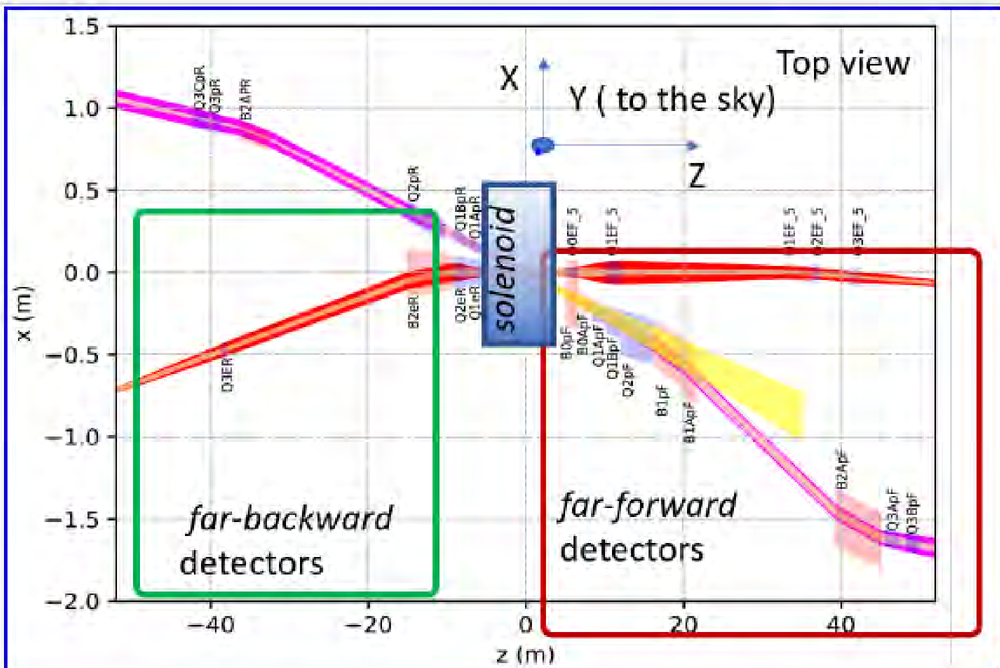


THE YELLOW REPORT BASELINE DETECTOR



- hadronic calorimeters
- e/m calorimeters
- PID: Tof, RICH and DIRC detectors
- silicon tracker
- MPG tracker
- magnet

arXiv:2103.05419



Note the need of:
- Large acceptance for diffraction
- Neutron tagging for nuclear break-up
- Forward I measurement at small angles

→ ZDC, Roman-Pots, Low Q^2-taggers

&

- Luminosity monitor (from Bremsstralhlung)

DETECTORS

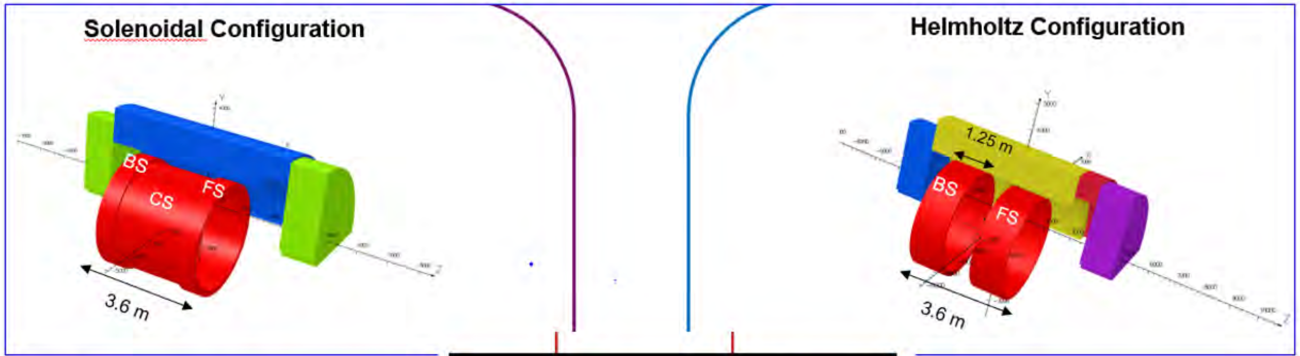
HIGHLIGHTS

(using ATHENA detector as representative example)

ATHENA: THE 3T MAGNET

New Solenoid (up to 3T)

By: V. Calvelli (CEA), R. Rajput-Ghoshal (JLAB)

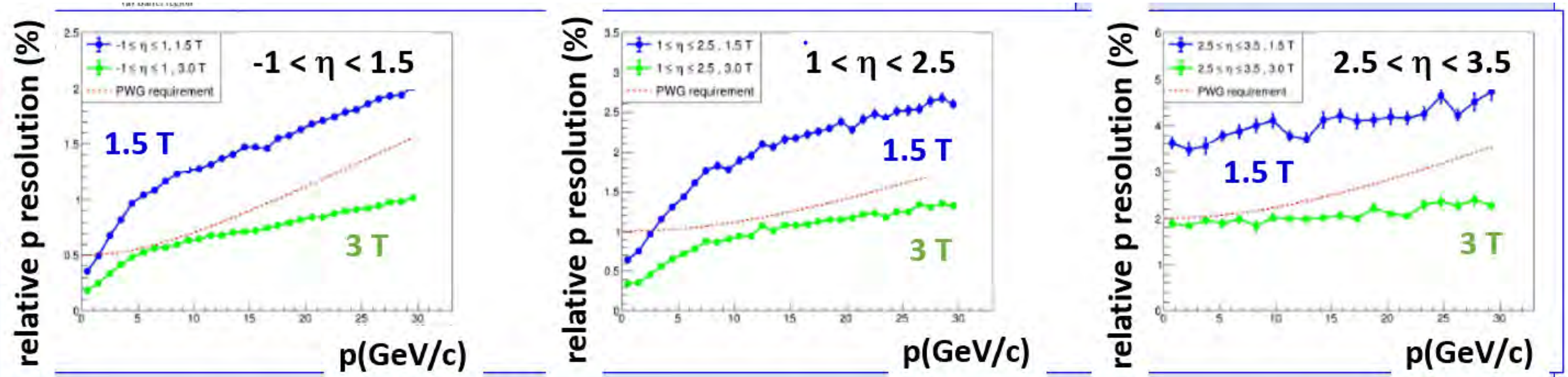


Initial specifications

Parameter	Goal
B_{IP} (T)	3.00
Bore radius (mm)	1600
Coil length (mm)	3600

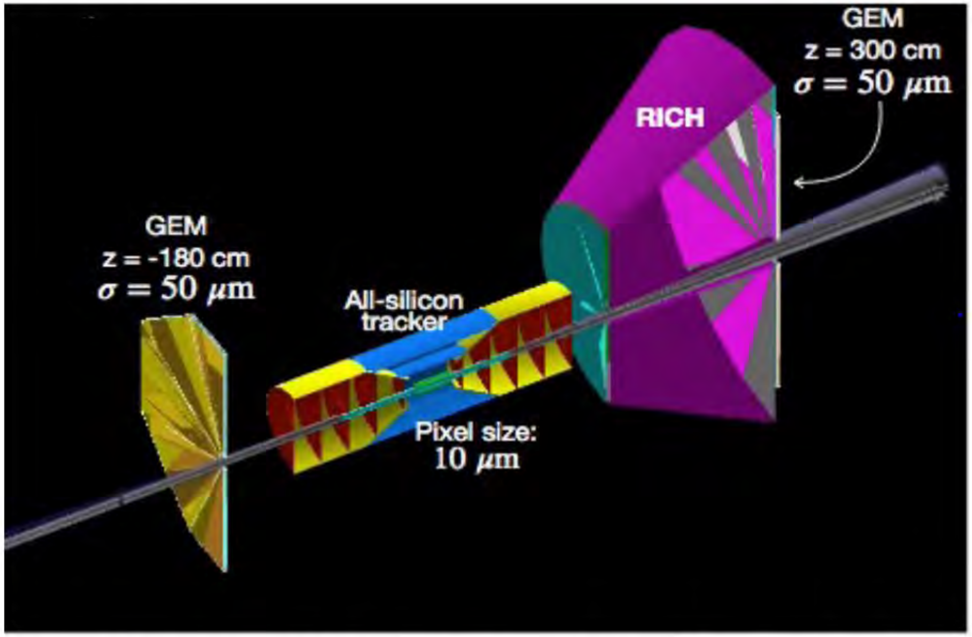
Operation at lower field for specific measurements can be planned

Simulations by H. Wennlöf, Birmingham

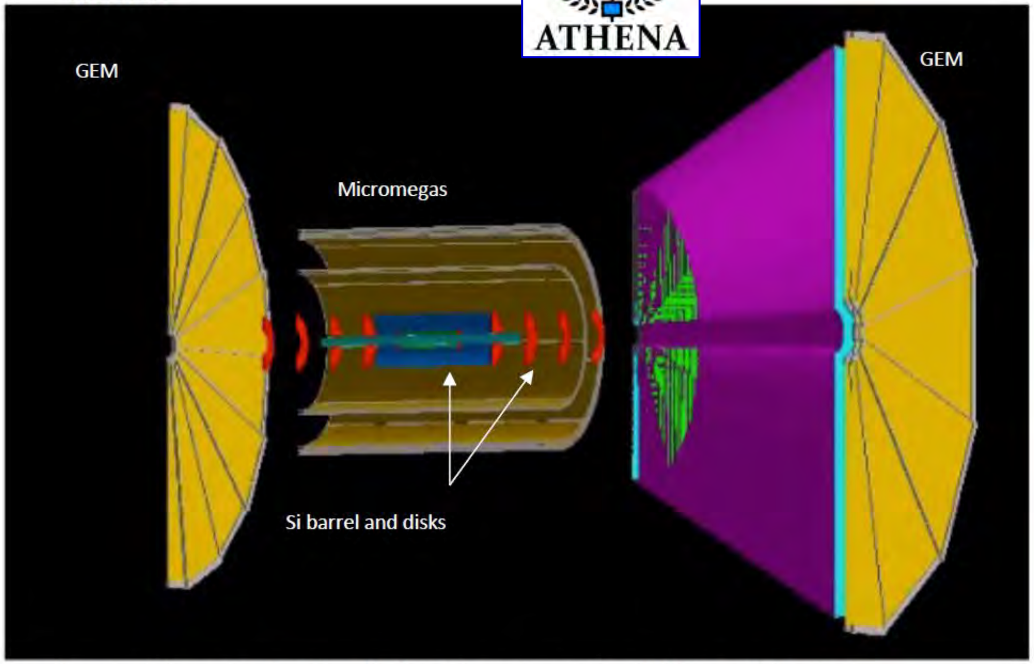


ATHENA: TWO TRACKING OPTIONS

all-silicon



hybrid



Same silicon and GEM technologies in both concepts, micromegas barrel layers in the hybrid concept; different layout configurations under test

- ALICE ITS3-derived Silicon Vertex and Tracking detector:
  - **10 um** pixel pitch everywhere
  - **0.05% X/X0** vertex layers → 2 (3) vertex layers for all-silicon (hybrid)
  - **0.55% X/X0** barrel layers → 4 (2) barrel layers for all-silicon (hybrid)
  - **0.24% X/X0** disks → 5 + 5 disks for both configuration
- micromegas (hybrid baseline):
  - ✓micromegas barrel layers to complement silicon tracking at central rapidity
  - ✓**150 um** both in z and rphi
  - ✓**0.4% X/X0** per layer → 6 barrel layers (hybrid)

more information: L. Gonnella https://indico.bnl.gov/event/11463/contributions/52587/attachments/36366/59762/20210804-ATHENA-tracking.pdf

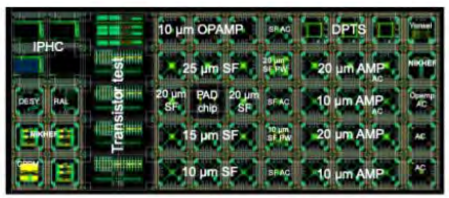
Si trackers for ATHENA

L. Gonnella @ EICUG meeting

Technology choice: 65 nm MAPS

Ideal technology at EIC : fine resolution and minimum material budget

- Significant benefits in exploiting synergies with ITS3
- ATHENA members actively participating to the EIC SC activities to develop technology and detector concept, and integrated into ITS3 WP
- Ongoing R&D
  - **Sensor development** (with ITS3): MLR1 test structures received, testing about to start; design of ITS3 ER1 with stitched sensor ongoing
  - **Vertex layers** (with ITS3): thinning and bending studies proceeding with super ALPIDE structure; test beam of uITS with 6 bent ALPIDE chips
  - **Barrel layers & disks** (EIC specific): work has started within the EIC SC to define disk concept; work ongoing with EIC project engineers

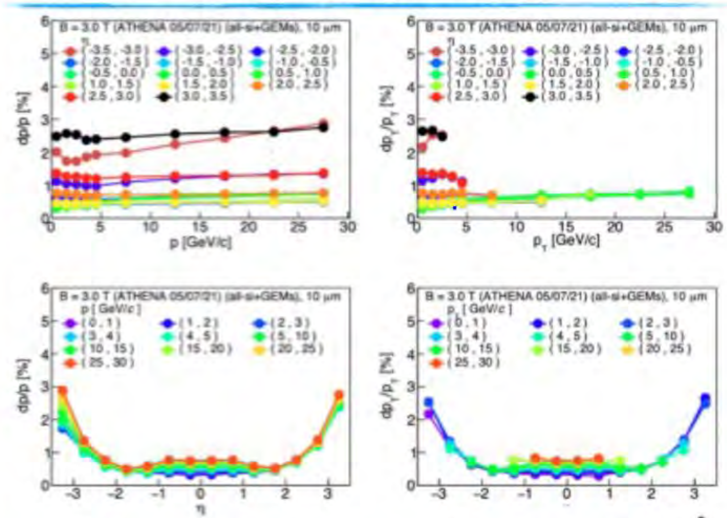


https://indico.bnl.gov/event/12512/contributions/52168/

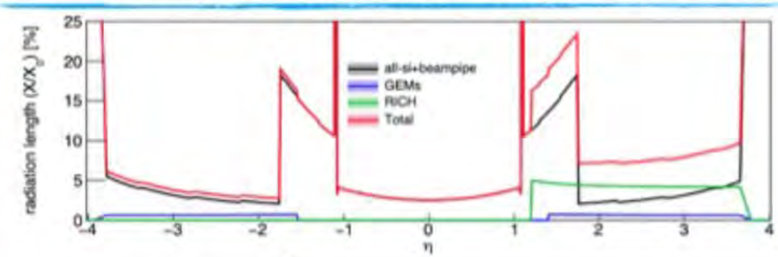
fallback solution on existing technology at 180 ns (ALICE ALPIDE)

all-silicon

Momentum resolutions



Detector Material Budget



ATHENA CALORIMETRY 1/2

STAR Forward Calorimeter System.

Constructed in 2020 with new, very efficient method.

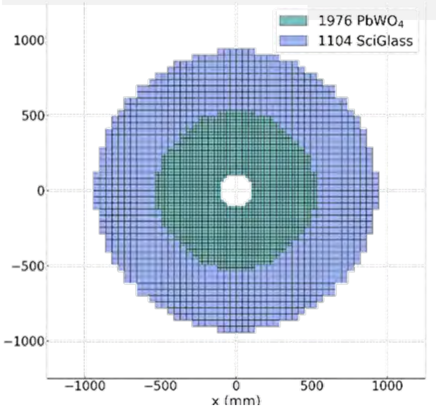
HCal Fe/Sc, similar technology for EIC reference detector.

central detector, backward

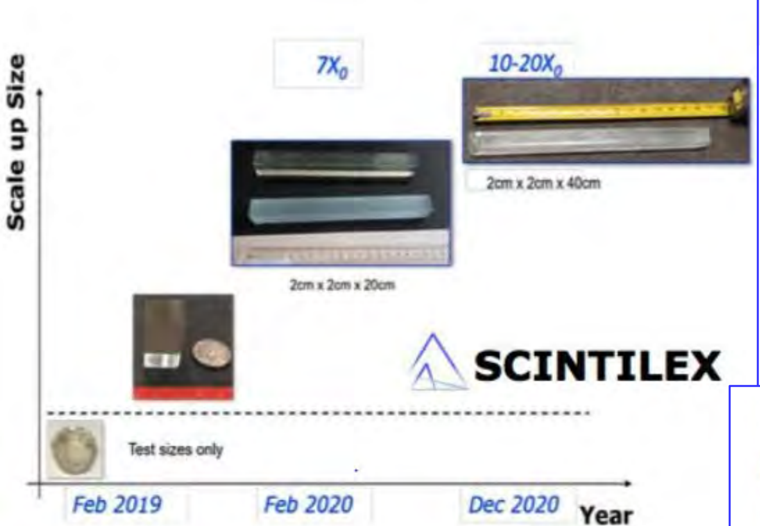
- **ECAL:** hybrid, PWO insert and Glass outer ring
- **HCAL: Fe/SC**, ongoing detector optimization

central detector, forward

- **ECAL:** W-powder/SciFi
- **HCAL: Fe/SC,** ongoing detector optimization (including total depth, layer thickness and granularity)



Sensor: SiPMs (TBC)



sPHENIX Wpowder/SciFi Cal
Sensor: Si PMs

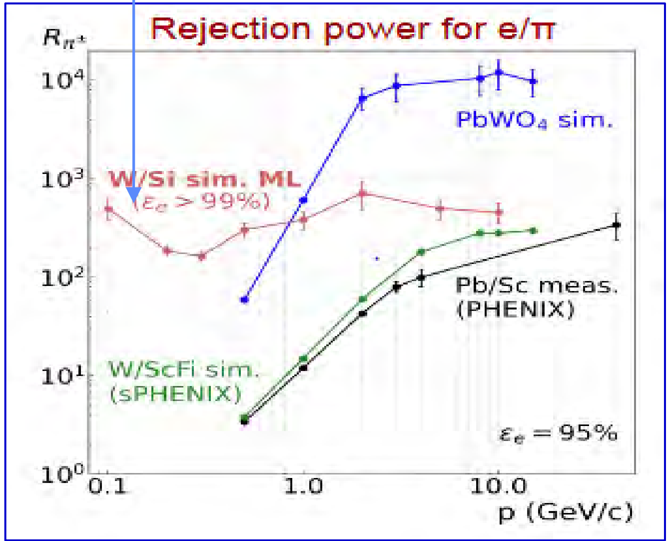
IEEE Transactions on Nuclear Science, Volume 65
Issue 12, pp. 2901-2919, December 2018

Premier materials science facility with unique

The puzzle of EM calorimetry in the barrel:
a proposal within ATHENA

Barrel ECal approach:

Hybrid imaging calorimeter,
Effective e$^-$/π separation also at low momenta!

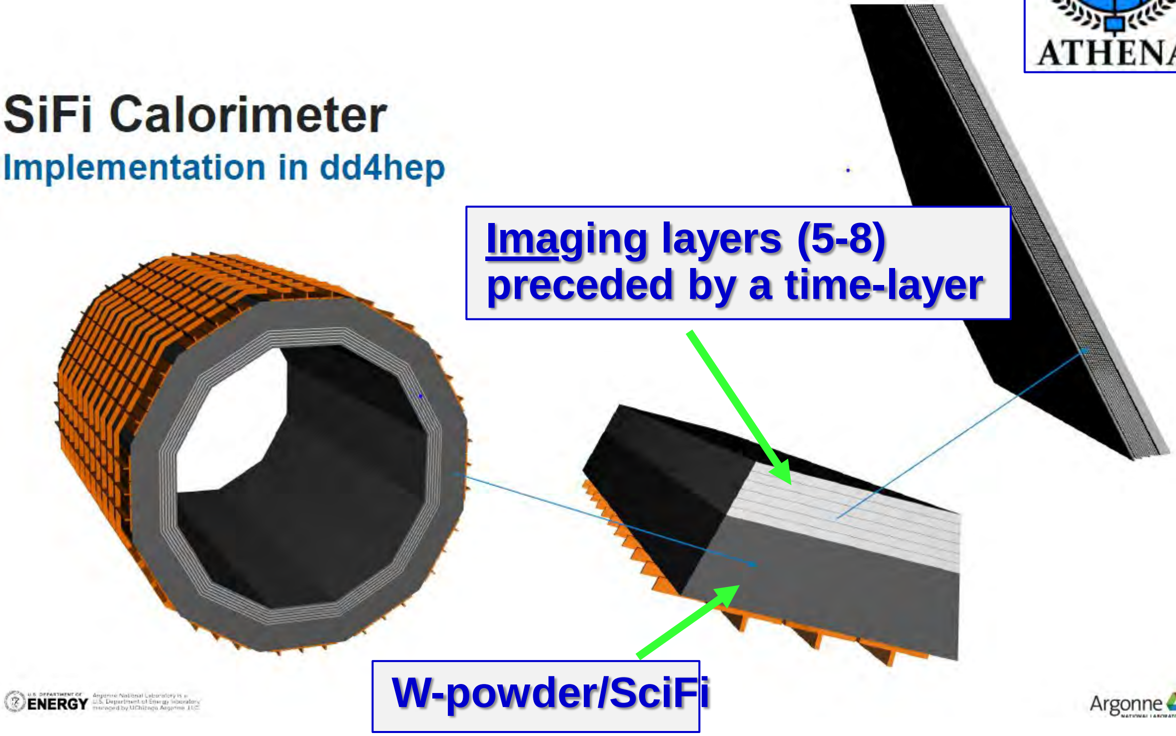


Imaging calorimeter based on monolithic silicon sensors

AstroPix (developed for NASA, off-the-shelf)

SiFi Calorimeter

Implementation in dd4hep

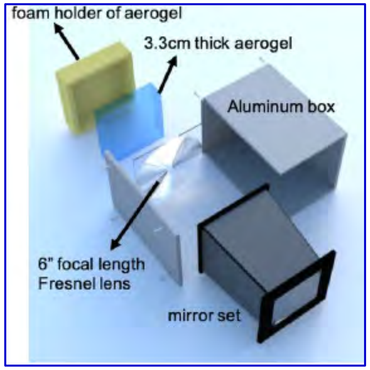


EICUG Annual Meeting, 2-6 August 2021 S. Dal 42

PID in ATHENA 1/2

Backward: mRICH

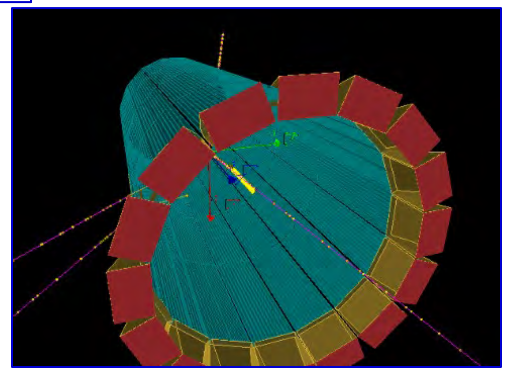
Proximity focusing aerogel RICH with Focalisation by Fresnel lenses



Electron Arm Technology	Range (GeV/c) e - π	Range (GeV/c) π - K
dRICH (aerogel)	0.0025 - 5	2.46 - 16
dRICH (gas)	0.0127 - 18	12.34 - 60
dRICH (overall)	0.0025 - 18	2.46 - 60
HBD	0.0150 - 4.17	-
mRICH	0.0025 - 2	2.00 - 6
TOF (LAPPD 4m, 5ps)	0 - 3	0.00 - 16
TOF (LAPPD 3m, 10ps)	0 - 1.8	0.00 - 10
TRD	1.0 – 270.0	–

Barrel: high-performance DIRC

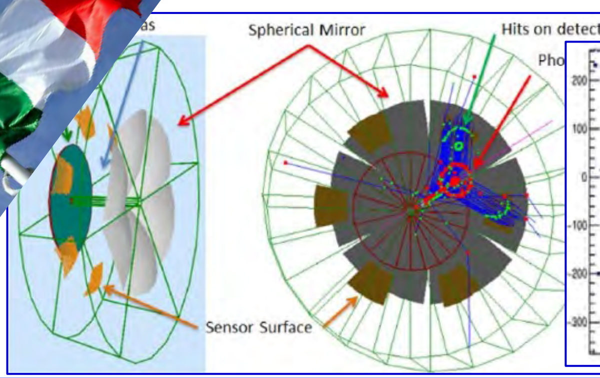
Focusing DIRC with lenses

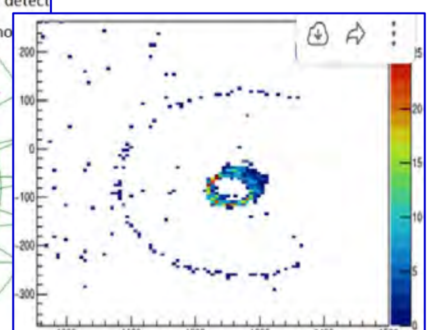


Central Arm Technology	Range (GeV/c) e - π	Range (GeV/c) π - K
$\frac{dE}{dx}$	0 - 2	0 - 3
$\frac{dE}{dx}$ (Cluster Count)	0 - 10	0 - 15
DIRC	0.00048 - 1	0.47 - 6
TOF (LGAD)	0 - 1	0.00 - 5
HBD	0.0150 - 4.17	N/A

dRICH

2 radiators: Aerogel & gas





Hadron Arm Technology	Range (GeV/c) e - π	Range (GeV/c) π - K
CsI RICH	0.0150 - 20	14.75 - 50
dRICH (aerogel)	0.0025 - 5	2.46 - 16
dRICH (gas)	0.0127 - 18	12.34 - 60
dRICH (overall)	0.0025 - 18	2.46 - 60
TOF (LGAD)	0 - 1	0.00 - 5
TOF (LAPPD 4m 5ps)	0 - 2.5	0.00 - 16
TRD	1.0 – 270.0	–

PID in ATHENA 2/2

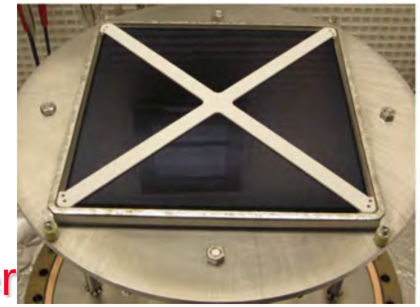
The photon sensors

LAPPDs

- **Still requiring full validation/characterization**
  for Single photon detection
- **B-field issues**
- **Also TOF information provided**

developed by Argone, U> of Chicago and other

Industrial partner: INCOM

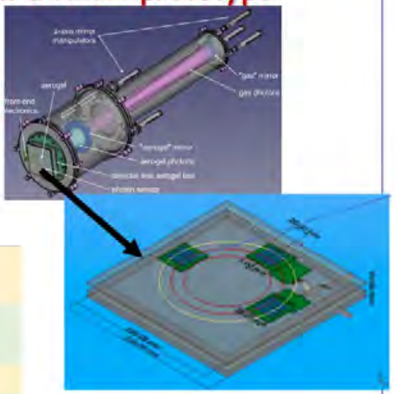


Si PMs

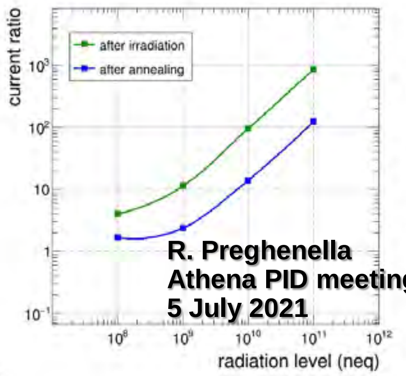
A dedicated effort for application at EIC by a cluster of INFN groups

- SiPMs from different producers mounted on a RICH prototype
  - Part as received
  - Part irradiated
  - Part irradiated and thermal annealing cycle
- → Performance in a test beam
- Coupled to specific FE r-o:
  - ALCOR, developed for DarkSide

MULTIUPLE MANIFACTURES	
SENSEL (OnSemiconductors)	microFJ-30020-TSV
	microFJ-30035-TSV
Broadcom	AFBR-SAN33C013
Hamamatsu Photonics	S13360-3050VS
	S13360-3025VS
	S14160-3015HS
	S14160-3050HS
FBK, Fondazione Bruno Kessler	custom SiPM



[NUV-HD-RH] 1 week of annealing at T = 125 C



T = 20 C
V_{bias} = 33 V

annealing reduced dark current by a factor of ~5-10, in line with expectations

SiPM irradiated up to 10^{11} now behave like if they were irradiated by 10^{10}

for the time being we stop here with FBK sensors, or perhaps we extend annealing at T = 125 C for another 2 weeks (expecting no improvements)

issue with FBK carriers related to the solder paste used during assembly, unfortunately we have used low-T (138 C) solder paste which does not allow to reach the ultimate annealing temperature of T = 175 → needs reworking of the carriers → will be done after test beam

R. Preghenella
Athena PID meeting,
5 July 2021

Preliminary !
Much more coming from data analysis and test beam in Fall

CONCLUDENDO

Le prospettive EIC sulla base dei fatti piu' rilevanti

- **Una AMPIA E MOTIVATA comunita' internazionale e' al lavoro**
  - 1300 fisici formano EIC-US
  - Lo slancio nello YR e oggi nella preparazione dei proposal ne testimonia l'impegno e la dedizione
- **Il panorama di fisica e' ampio**
  - Centrato su QCD
  - Puo' contribuire a rafforzare i collider adronici
  - Aperto anche ad altri studi di fisica
- **Il progetto US EIC e' oggi un progetto approvato**
  - Rappresenta il rientro degli USA nel club delle nazioni con acceleratori di alta energia per ricerca fondamentale

→ **Abbiamo di fronte a noi un futuro in cui questioni fondamentali di fisica troveranno risposta grazie a EIC**

GRAZIE