# MEIC/ELIC Interaction Region Design Also known as: Report from the "JLab Task Force"? 

> Lots of credit to Yuhong Zhang, Alex Bogacz, Slava Derbenev, Geoff Krafft, other CASA/Accelerator members, Tanja Horn, Charles Hyde, Pawel Nadel- Turonski for multiple accelerator and detector/interaction region ideas

- Some slides to keep people up-to-date with the ongoing series of EIC-related workshops organized by the JLab user community
- Some slides to keep people up-to-date with ongoing EIC design efforts at Jefferson Lab
- Some slides related to the detector/interaction region design relevant for detection of processes with fragments in the ion direction.

Rolf Ent (Jefferson Lab) 05/14/2010

Quotes from EICAC Report on Accelerator R\&D Priorities Highest priority:
-Design of JLab EIC

- High current (e.g. 50 mA ) polarized electron gun
-Demonstration of high energy - high current recirculation ERL
- Beam-Beam simulations for EIC
-Polarized 3He production and acceleration
-Coherent electron cooling
High priority, but could wait until decision made:
-Compact loop magnets
- Electron cooling for JLab concepts
- Traveling focus scheme (it is not clear what the loss in performance would be if it doesn't work; it is not a show stopper if it doesn't)
-Development of eRHIC-type SRF cavities


## Medium Priority:

- Crab cavities
-ERL technology development at JLAB


## (M)EIC@JLab: Plan and Deliverables

- Accelerator Design "Contract"
- Medium energy with scaled down parameters (ELIC version M.1)
- "Contract" revision (end of 2010), after user workshops and the next EIC AC meeting
- "Design Manual"
- A 20 to 30 page document, archived in web
- Explanation of high level design choices
- Main and secondary parameters, schemes
- Major components, and interfaces between them
- Action items
- Finish "action items/decision points" in about a week each
- Work scope
- Collecting information/references
- Performing estimations/calculations if applicable
- Formulate a solution/recommendation
- Present in ELIC R\&D meeting
- Write a (minimum) half page on each item for the "design manual"
- Similar Action Item: Detector/IR document


## Electron-Ion Collider - JLab User Meetings Roadmap

- March $12+13$
- March $14+15$
- April 07, 08, 09
- May 17 +18
- June 04 + 05
- June 07,08,09
@Rutgers: Electron-Nucleon Exclusive Reactions
@Duke: Partonic Transverse Momentum in Hadrons:
Quark Spin-Orbit Correlations and Quark-Gluon Interactions
@ANL: Nuclear Chromo-Dynamic Studies
@W\&M: Electroweak Studies
@JLab: MEIC Detector Workshop
2010 JLab Users Group Meeting
(with session dedicated to a summary of users workshops, held in Spring 2010, that explored physics motivations of an Electron-Ion Collider, entitled
"Beyond the 12 GeV Upgrade: an EIC at JLab?")


## Electron-Ion Collider - Roadmap

- EIC (eRHIC/ELIC) webpage: $h \nmid \dagger p: / / w e b . m i t . e d u / e i c c /$
- Last meeting: January 10-12, 2010 @ Stony Brook
- Next meeting: July 29-31, 2010 @ Catholic University, DC

- Long INT10-03 program @ Institute for Nuclear Theory, Seattle, centered around spin, small-x, imaging, electroweak September 10 - November 19, 2010
- Weekly meetings at both BNL and JLab
- Wiki pages at http://eic.jlab.org/ \& https://wiki.bnl.gov/eic (see also https://wiki.bnl.gov/eic/index.php/Luminosity)

A High-Luminosity EIC at JLab - Concept


## Use CEBAF "as-is" after 12-GeV Upgrade

## EIC@JLab assumptions:

( $x, Q^{2}$ ) phase space directly correlated with $s\left(=4 E_{e} E_{p}\right)$ :
$@ Q^{2}=1$ lowest $\times$ scales like $s^{-1}$
@ $Q^{2}=10$ lowest $\times$ scales as $10 s^{-1}$

$$
x=Q^{2} / y s
$$

General science assumptions:
("Medium-Energy") EIC@JLab option driven by:
access to sea quarks ( $x>0.01$ or so) deep exclusive scattering at $Q^{2}>10$ (?) any QCD machine needs range in $Q^{2}$
$\rightarrow s=$ few 100-1000 seems right ballpark
$\rightarrow s=$ few 1000 allows access to gluons, shadowing
Requirements for deep exclusive and high- $Q^{2}$ semi-inclusive reactions also drives request for (lower \&) more symmetric beam energies. Requirements for very-forward angle detection folded in IR design

## MEIC Design Choices

## Achieving high luminosity

> Very high bunch repetition frequency ( 1.5 GHz )
> Very small $\beta^{*}$ to reach very small spot sizes at collision points
$>$ Short bunch length ( $\sigma_{z} \sim \beta^{\star}$ ) to avoid luminosity loss due to hour-glass effect (unless other mitigation schemes used)
> Relatively small bunch charge for making short bunch possible
> High bunch repetition restores high average current and luminosity

This luminosity concept has been tested at two B-factories very successfully, reaching luminosity above $10^{34} \mathrm{~cm}^{-2} / \mathrm{s}^{-1}$


## MeRHIC

Low repetition rate High bunch charge Long bunch length Large $\beta^{*}$

## MEIC Luminosity: Energy Dependence

- MEIC luminosity is limited by
$>$ Electron beam current $\leftarrow$ synchrotron radiation $\sim N_{e} \gamma^{4} / \rho$ (radiation power, emittance degradation)
$>$ Proton/ion beam current $\leftarrow$ space charge effect $\sim N_{i} / \gamma^{2}$
(emittance growth, tune-shift/instabilities)
> (Vertical) beam-beam tune-shift (bad collisions) ~1/ү
- Main design limits (based on experience)
> Electron beam SR power density: $\leq 20 \mathrm{~kW} / \mathrm{m}$
> Ion beam space charge tune-shift: $\leq 0.1$
$>$ (Vertical) beam-beam tune-shift: $\leq 0.015$ (proton), $\leq 0.1$ (electron)
- Given an energy range, MEIC collider ring optimized with
$>$ Synchrotron radiation $\rightarrow$ prefers a large ring (for more arc bends)
$>$ Space charge effect of i-beam $\rightarrow$ prefers a small ring circumference
> Multi IPs and other components require long straight sections


## MEIC Design Choices (cont.)

- Ring-ring vs. Linac(ERL)-ring
$>$ Linac-ring option requires very high average current polarized electron sources (well beyond state-of-the-art)
$>$ Linac-ring option does not help MEIC/ELIC which already employs high repetition electron and ion beams
$\rightarrow$ MEIC/ELIC choice is ring-ring collider
- Ensuring high polarization for both electron beam and light ion beams
$\rightarrow$ Figure-8 shape ring
$>$ Simple solution to preserve full ion polarization by avoiding spin resonances during acceleration
- Energy independence of spin tune
$>g$ - 2 is small for deuterons, a figure-8 ring is the only practical way to arrange for longitudinal spin polarization at the IP


## Near-Term MEIC Design Parameters

|  |  | Electron | Proton |  |
| :---: | :---: | :---: | :---: | :---: |
| Collision energy | GeV | 3-11 | $\begin{array}{r} 20- \\ 60 \end{array}$ | Ion booster 3-12 GeV, ring accepts 12 GeV injection |
| Max dipole field | T |  | 6 | Not too aggressive after LHC |
| Max SR power | $\begin{gathered} \mathrm{kW} / \\ \mathrm{m} \end{gathered}$ | 20 |  | Factor two beyond best achieved? |
| Max current | A | 2 | 1 | ~ max B-factory current, HOM in component <br> HERA 0.15 A <br> (?) RHIC 0.3 A |
| RF frequency | GHz | 1.5 | 1.5 | Use combination of gap (crossing angle) and RF shift to accommodate lower ion energies |
| Bunch length | mm | 5 | 5 | 6 mm demonstrated in B-factory, 10 cm in RHIC (?) |
| IP to front face of $1^{\text {st }}$ quad (I) | m | +/- 3 to 4 | +/-7 |  |
| Vertical $\beta^{*}$ | cm | 2 | 2 | Keep $\beta_{\text {max }}$ below $\sim 2 \mathrm{~km}$, with $\beta_{\text {max }}=12 / \beta^{*}$ |
| Crossing angle | mrad | 100 |  | 50 to 150 desired for detector advantages |
| Luminosity expected to be above $1 \times 10^{34}$ e-nucleons $/ \mathrm{s} / \mathrm{cm}^{2}$ around $60 \times 5 \mathrm{GeV}^{2}$, and be well above $10^{33}$ at "s edges" |  |  |  |  |

## Figure-8 Ion Ring - Optics Uncompensated dispersion from arcs



Arc length $\quad C \sim 115 m+20 m$ (for spin manipulation) $+115 m$
(increased partly due to assumption of $60 \mathrm{GeV} \& 6 T$ max dipole fields)
Straight length L ~ 240 m (increased to accommodate spin rotator + SRF sections)
Total Ring Circumference would then be: $2(L+C)=980 \mathrm{~m}$

## Detector/IR in simple formulas

$\beta_{\text {max }} \sim 2 \mathrm{~km}=12 / \beta^{\star} \quad\left(\mathrm{I}=\right.$ distance IP to $1^{\text {st }}$ quad $)$
Example: $\quad I=7 \mathrm{~m}, \beta^{\star}=20 \mathrm{~mm} \rightarrow \beta_{\max }=2.5 \mathrm{~km}$

## IP divergence angle $\sim 1 / \operatorname{sqrt}\left(\beta^{\star}\right)$

Example: $\quad 1=7 \mathrm{~m}, \beta^{\star}=20 \mathrm{~mm} \rightarrow$ angle $\sim 0.3 \mathrm{mr}$
Example: $12 \sigma$ beam-stay-clear area $\rightarrow 12 \times 0.3 \mathrm{mr}=3.6 \mathrm{mr} \sim 0.2^{\circ}$

Making $\beta^{\star}$ too small complicates small-angle (0.5?) detection before ion Final Focusing Quads, and would require too much focusing strength of these quads, preventing large apertures (up to 0.5?)

## Luminosity $\sim 1 / \beta^{*}$

## Interaction Region Optics (electrons)

| $\varepsilon_{N}^{x}=22 \times 10^{-6} \mathrm{~m}$ | $\beta_{x}^{*}=10 \mathrm{~cm}$ |
| :--- | :--- |
| $\varepsilon_{N}^{y}=4.4 \times 10^{-6} \mathrm{~m}$ | $\beta_{y}^{*}=2 \mathrm{~cm}$ |

$$
\zeta_{I R} \square \frac{f^{2}}{\beta^{*}} \frac{1}{f}=\frac{f}{\beta^{*}}
$$

Natural Chromaticity:
$\zeta_{x}=-47 \quad \zeta_{y}=-66$

$Q$ apertures small ( $\sim 1.5 \mathrm{~cm}$ )
$\rightarrow$ Peak fields ~ 0.5 T
$\rightarrow$ "Baby-size" quads only

## Interaction Region Optics (ions)



$$
\begin{gathered}
\beta^{\max }=\Omega^{*}+\frac{\ell^{* 2}}{\beta^{*}} \square \frac{\ell^{* 2}}{\beta^{*}}\left(\frac{f^{2}}{\beta^{*}}\right) \\
f=\ell^{*}+l_{F F} / 2 \square \ell^{*} \\
\zeta_{1}:=\frac{\mathbf{1}}{\mathbf{4 \pi}} \int_{0}^{d} \underbrace{\beta_{x}\left(-g_{0}\right.}_{\beta^{\max } g_{0}^{F F}}+\eta_{0} \boldsymbol{g}_{1}) \boldsymbol{d} \boldsymbol{s} ;
\end{gathered}
$$

Natural Chromaticity: $\quad \zeta_{x}=-88 \quad \zeta_{y}=-141$
Q1 $\quad G[k G / c m]=-9.7$
Q2 $\quad G[\mathrm{kG} / \mathrm{cm}]=+6.9$
Q3 $\quad G[k G / c m]=-6.8$
Q3 aperture 10 cm (@12 m) $\rightarrow 7$ T peak field
$\rightarrow$ Particles < 0.5 degrees through FF quads

## Detector/IR cartoon

Make use of a 100 mr crossing angle for ions!


> Distance IP - electron FFQs $=3.5 \mathrm{~m}$ Distance IP - $\quad$ ion $F F Q s=7.0 \mathrm{~m}$


Need Particle ID for $p>4 \mathrm{GeV}$ in central region
$\rightarrow$ DIRC won't work, add threshold Cherenkov or RICH
Need Particle ID for well above 4 GeV in forward region (< $30^{\circ}$ ?)
$\rightarrow$ determines bore of solenoid
In general: Region of interest up to $\sim 10 \mathrm{GeV} / \mathrm{c}$ mesons Momentum ~ space needed for detection

## Overview of Central Detector Layout



- IP is shown shifted left by 0.5 meter here, can be shifted
- Determined by desired bore angle and forward tracking resolution
- Flexibility of shifting IP also helps accelerator design at lower energies (gap/path length difference induced by change in crossing angle)

- EM Calorimeter (30-50 cm)
- Crystals, small area
- TOF (5-10 cm)

- RICH (60-100 cm)
- $C_{4} \mathrm{~F}_{8} \mathrm{O}+$ Aerogel
- Or DIRC ( 10 cm ) + LTCC ( $60-80 \mathrm{~cm}$ )
- $\quad \mathrm{C}_{4} \mathrm{~F}_{8} \mathrm{O}$ gas
- $\pi / \mathrm{K}: 4-9 \mathrm{GeV} / \mathrm{c}$ (threshold)
- $\quad \mathrm{e} / \pi$ : up to $2.7 \mathrm{GeV} / \mathrm{c}$ (LTCC)
- K/p: up to $4 \mathrm{GeV} / \mathrm{c}$ (DIRC)


## Detector/IR cartoon

Make use of a 100 mr crossing angle for ions!


Detect particles with angles down to 0.5 deg.

Need up to 2 Tm dipole bend, but not too much!

# Detector/IR cartoon 

## Pawel Nadel-Turonski <br> Make use of a 100 mr crossing angle for ions!




- Downstream dipole on ion beam line ONLY has several advantages
- No synchrotron radiation
- Electron quads can be placed close to IP
- Dipole field not determined by electron energy
- Positive particles are bent away from the electron beam
- Long recoil baryon flight path gives access to low - $t$
- Dipole does not interfere with RICH and forward calorimeters
- Excellent acceptance (hermeticity)
(approximately to scale)
ion dipole w/ detectors ion FFQs

Pion momentum $=5 \mathrm{GeV} / \mathrm{c}$, 4 T ideal solenoid field


- Resolution dp/p (for pions) better than $1 \%$ for $p$ < $10 \mathrm{GeV} / \mathrm{c}$ - obtain effective 1 Tm field by having 100 mr crossing angle
- $200 \mathrm{mr} \sim 12^{\circ}$ gives effective 2 Tm field $\rightarrow$ need to add 1-2Tm dipole field for smallangle pions ( $1^{\circ}-6^{\circ}$ ) only


# Add 2 Tm transverse field component to get $d p / p$ roughly constant vs. angle 

## ${ }^{1} \mathrm{H}\left(e, e^{\prime} \pi^{+}\right) \mathrm{n}$ - Scattered Neutron, 4 on 60



- Low - $\dagger$ neutrons (or protons) are emitted at (very) forward angles
- Advantageous to have lower proton/ion energies: angle $\sim 1 / E_{\text {pion }}$
- Low- $\dagger$ recoil baryons have momenta close to the beam momenta
- For ion beams \& coherent/diffractive/evaporation processes, situation can be even more forward-focused


# Detector/IR - Forward Angles 

 $\dagger \sim E_{p}^{2} \Theta^{2} \rightarrow$ Angle recoil baryons $=\dagger^{\frac{1}{2}} / E_{p}$Example: map $\dagger$ between $\dagger_{\text {min }}$ and 1 (2?) GeV
$\rightarrow \sim 0.2$ to 4.9 (9.8) degrees @ 12 GeV
$\rightarrow \sim 0.2$ to 3.0 (5.9) degrees @ 20 GeV
$\rightarrow \sim 0.2$ to 2.0 (3.9) degrees @ 30 GeV
$\rightarrow$ Cover between about 0.5 and 6 degrees?
Example I: separation between $0.5^{\circ}$ and $0.2^{\circ}$ (BSC) ~ 2.5 cm at 5 meter distance May be enough for ~ 30 GeV protons and neutrons from an $O(1 A)$ beam
(also need good angle ( $t$ ) resolution!)
Example II: 6 degrees
$\sim 0.5$ meter radius cone at 5 meter

## Detector/IR - Forward Angles

 $t \sim E_{p}{ }^{2} \Theta^{2} \rightarrow$ Angle recoil baryons $=t^{\frac{1}{2}} / E_{p}$


$\rightarrow$ Must cover between 1 and 5 degrees
$\rightarrow$ Should cover between 0.5 and 5 degrees
$\rightarrow$ Like to cover between 0.2 and 7 degrees

## Detector/IR cartoon

Make use of a 100 mr crossing angle for ions!


Want to detect particles with angles up to $0.5^{\circ}$ before ion FFQs, but how about particles with angles below $0.5^{\circ}$ ?

## Recoil Proton for Diffractive events

From BNL colleagues (Elke, Thomas)
Note that angular coverage here is not dissimilar from exclusive ${ }^{1} H\left(e, e^{\prime} \pi^{+}\right) n$ reactions, but weight of distributions is shifted! $\rightarrow$ we want to detect particles below $0.5^{\circ}$ too!



## Figure-8 Collider Rings

(Reminder: MEIC/ELIC scheme uses 100 mr crab crossing) Present thinking: ion beam has 100 mr horizontal crossing angle Advantages for dispersion, crab crossing, very-forward particles


200 mr bend would need 40 Tm dipole @ ~20 m from IP
total ring circumference: ~970 m ~60 degrees arc/straight crossing angle

## Ion Ring - Beam envelopes

Mon Apr 05 16:00:00 2010 OptiM - MAIN: - C:IWorking\ELIC\MEIC\Optics\Ion Ring $\backslash$ Arc_Straight_IR_Str_90_in_1.opt


Beam-stay-clear area near IP, before Q1: 10-12 $\sigma \rightarrow 2.5 \mathrm{~cm}$ @ $7 \mathrm{~m}=0.2 \mathrm{deg}$ Beam-stay-clear area away from IP: $\quad 8-10 \sigma \rightarrow 2 \mathrm{~mm}$ @ $20 \mathrm{~m}=0.1 \mathrm{mr}$

## Detector/IR - Very Forward

- Ion Final Focusing Quads (FFQs) at 7 meter, allowing ion detection down to $0.5^{\circ}$ before the FFQs (BSC area only $0.2^{\circ}$ )
- Use large-aperture ( 10 cm radius) FFQs to detect particles between 0.3 and $0.5^{\circ}$ (or so) in few meters after ion FFQ triplet $\sigma_{x-y} @ 12$ meters from IP $=2 \mathrm{~mm}$ $12 \sigma$ beam-stay-clear $\rightarrow 2.5 \mathrm{~cm}$ $0.3^{\circ}\left(0.5^{\circ}\right)$ after 12 meter is $6(10) \mathrm{cm}$
$\rightarrow$ enough space for Roman Pots \&
"Zero"-Degree Calorimeters
- Large dipole bend @ 20 meter from IP (to correct the 100 mr ion horizontal crossing angle) allows for very-small angle detection ( $<0.3^{\circ}$ )
$\sigma_{x-y} @ 20$ meters from IP $=0.2 \mathrm{~mm}$
$10 \sigma$ beam-stay-clear $\rightarrow 2 \mathrm{~mm}$
2 mm at 20 meter is only 0.1 mr ...
$\Delta$ (bend) of 29.9 and 30 GeV spectators is $1.3 \mathrm{mr}=5 \mathrm{~mm}$ @ 4 m Situation for zero-angle $n$ detection very similar as at RHIC!


## Forward Neutron Detection Thoughts - A Zero Degree Calorimeter

The RHIC Zero Degree Colorimeters arXiv:nucl-ex/0008005v1 Context: The RHIC ZDC's are hadron calorimeters aimed to measure evaporation neutrons which diverge by less than 2 mr from the beam axis.

A-A

$<2 \mathrm{mr}$ at 18 meters from IP
$\rightarrow$ neutron cone $\sim 4 \mathrm{~cm}$
ZDC $=10 \mathrm{~cm}$ (horizontal) $\times 13 \mathrm{~cm}$ (vertical) ( \& 40 cm thick)

Have good efficiency and only 1 cm "deadedge" (albeit not very good $\Delta E$ resolution).

Implication: do no $\dagger$ make earlier ion bend dipole strong < 2 TM!

## Forward Neutron Detection Thoughts - A Zero Degree Calorimeter

- EIC@JLab case: 40 Tm bend magnet at 20 meters from IP $\rightarrow$ very comparable to present RHIC case!
- 40 Tm bends 60 GeV protons with 2 times 100 mr
$\rightarrow$ deflection @ a distance of about 4 meters $=80 \mathrm{~cm}$ (protons)
$\rightarrow$ no problem to insert Zero Degree Calorimeter in this design
Zero Degree Calorimeter properties:
- Example: for 30 GeV neutrons get about $25 \%$ energy resolution (large constant term due to unequal response to electrons and photons relative to hadrons)
$\rightarrow$ Should be studied, sufficient for an EIC?
- Timing resolution ~ 200 ps
- Very radiation hard (as measured at reactor)
- Angle resolution?
$\rightarrow$ Should be studied, shower position resolution?


## Spectator Proton Tagging

Assume electron-deuteron collisions, with $30 \mathrm{GeV} / n u c l e o n ~ d e u t e r o n ~ b e a m ~$
100 mr horizontal crossing angle for ion beam would require a very large 40 Tm magnet at 20 meter from the IP. In the end, exact crossing angle will be an optimization between

- crab cavity performance
- detector needs
- 40 Tm vs. 20 Tm (or so) bend magnet

Can use this large magnet field for spectator proton tagging

- deuteron beam ( $30 \mathrm{GeV} / n u c l e o n$ ) gets bend by 200 mr
- $\Delta$ (bend) 30 GeV spectator proton w.r.t. deuteron beam $=200 \mathrm{mr}$ $\rightarrow$ at 4 meter some 80 cm separation from main beam
- $\mathrm{Pm}=0 \sim 30 \mathrm{GeV}$ spectator proton, $\mathrm{p}_{\mathrm{m}}=100 \mathrm{MeV} / \mathrm{c} \sim 29.9 \mathrm{GeV}$
- $\Delta$ (bend) 30 GeV vs. $29.9 \mathrm{GeV}=1.3 \mathrm{mr}$
- If detectors are positioned 4 m after 40 Tm magnet $\rightarrow 5 \mathrm{~mm}$ bend
- $1 \%$ ( $300 \mathrm{MeV} / \mathrm{c}$ ) would become 16 mm bend ( 4 mr )
- Piece of cake to distinguish, even for 10 Tm magnet $\rightarrow$ need to fold in intrinsic beam spread to check resolutions
- No need for roman pots due to large separation from main beam


## Very-Forward Ion Tagging



100 mr horizontal crossing angle for ion beam would require large 40 Tm magnet at 20 meter from the IP. If so, can use this for spectator proton tagging.
$\rightarrow$ Proton tagging concept looks doable, even if the horizontal crossing angle was reduced by a factor of two or three.

Roman pots (photos at CDF (top) and LHC (bottom), ...) ~ 1 mm from beam achieve proton detection with < $100 \mu$ resolution
$\rightarrow$ Need to use this for coherent processes like $\operatorname{DVCS}\left(p,{ }^{4} \mathrm{He}\right)$ where recoil nucleus energy = beam energy minus a small $\dagger$ correction. Work in progress. $\Delta p / p \sim 3 \times 10^{-4}$ now $\rightarrow$ in ballpark

## MEIC Overview - Summary

- Near-term design concentrates on parameters that are within state-of-the-art (exception: small bunch length \& small vertical $\beta^{\star}$ for proton/ion beams)
- Detector/IR design has concentrated on maximizing acceptance for deep exclusive processes and processes associated with very-forward going particles
- Exact energy/luminosity profile still a work in progress
- Summer 2010: MEIC design review followed by internal cost review (and finalizing input from user workshops)
- Many parameters related to the detector/IR design seem to be well matched now (crossing angles, magnet apertures/gradients/peak fields, field requirements), such that we do not end up with large "blind spots".


## Backup

## Solenoid Fields - Overview

| Experiment | Central Field | Length | Inner Diameter |
| :--- | :---: | :---: | :---: |
| ZEUS | 1.8 T | 2.8 m | 0.86 m |
| H1 | 1.2 T | 5.0 m | 5.8 m |
| BABAR | 1.5 T | 3.46 m | 2.8 m |
| BELLE | 1.5 T | 3.0 m | 1.7 m |
| GlueX | 2.0 T | 3.5 m | 1.85 m |
| ATLAS | 2.0 T | 5.3 m | 2.44 m |
| CMS | 4.0T | 13.0 m | 5.9 m |
| PANDA(*design) | $2.0 T$ | 2.75 m | 1.62 m |
| CLAS12(*design) | 5.0T | 1.19 m | 0.96 m |

Conclusion: ~4 Tesla fields, with length scale $\sim$ inner diameter scale o.k. (need 30 degree or more bore angle $\rightarrow$ radius $=0.58$ $x$ length solenoid $/ 2 \rightarrow 3$ meter diameter for 5 meter length)

## Why a collider with lower \& ~symmetric energies?

## Example: $e+p \rightarrow e^{\prime}+\pi^{+}+n, 11 \mathrm{GeV}$ electrons, 60 GeV protons





- lower-energy, more symmetric collider
$\rightarrow$ electron momentum up to 11 GeV (photoproduction)
$\rightarrow$ wider $\pi^{+}$angular distribution
$\rightarrow$ electron and pion momentum similar to optimize $\Delta \mathrm{M}^{2}$
$\rightarrow$ momenta in range where particle identification well proven
$\rightarrow$ wider recoil $n$ distribution
$\rightarrow$ † resolution better: $\delta \dagger / \dagger \sim \dagger / E_{p}$


## Why lower \& more symmetric energies?

## $\underset{\text { 4on } 12}{\dagger \sim} \underset{4 \text { on } 60}{\mathrm{E}_{\mathrm{p}}^{2} \Theta^{2}} \rightarrow \underset{40 n 250}{\text { Angle recoil baryons }}=\dagger^{\frac{1}{2}} / \mathrm{E}_{\mathrm{p}}$





Example: ep $\rightarrow e^{\prime} \pi^{+} n$ - momenta are smaller and wider at lower $E_{p}$ - easier for detector

Much improved $\dagger$ resolution at lower $E_{p}$

## Detector/IR - Kinematics

- Vertical lines at 30 (possibly up to 40 ) indicate transition from central barrel to endcaps
- Horizontal line indicates maximum meson momentum for $\pi / K$ separation with a DIRC

- With 12 GeV CEBAF, MEIC@JLab has the option of using higher electron energies
- DIRC no longer sufficient for $\pi / K$ separation
- RICH based on ALICE design might push the limit from 4 to 7 GeV

- Requires a more detailed study - alternate idea is DIRC + LTCC
- RICH would extend the minimum diameter of solenoid from approximately 3 to 4 m
- Main constraint since bore angle is not an issue in JLab kinematics

DIRC + C4F8O Threshold Cherenkov:

+ Full particle Identification up to $p=4 \mathrm{GeV} / \mathrm{c}$
+ Pion identification above $p=4 \mathrm{GeV} / \mathrm{c}$
$+\pi / e$ separation to "help" EM calorimeter up to $p=2.7 \mathrm{GeV} / \mathrm{c}$
- No p/K separation above $p=4 \mathrm{GeV} / \mathrm{c}$
is this a problem?
What are the proton of interest above 4 GeV in the central detector region?
Should check both e-p and e-A case
In forward region want HERMES-like dual-type RICH, or threshold imaging RICH, to allow for full $\pi / K / p$ particle identification up to $\mathrm{p} \sim 8 \mathrm{GeVc}$ or higher: assumed 2 meter space need for this. Always want C4F8O to help $\pi / e$ ?


## How to measure coherent diffraction in e+A ?

From Elke Aschenauer

- Beam angular divergence limits smallest outgoing $\Theta_{\text {min }}$ for p/A that can be measured
- Can measure the nucleus if it is separated from the beam in Si (Roman Pot) "beamline" detectors
- $p_{\text {Tmin }} \sim p A \theta_{\text {min }}$
- For beam energies $=60$ $\mathrm{GeV} / \mathrm{n}$ and $\theta_{\text {min }}=100 \mu \mathrm{rad}:$
- These are large momentum kicks, much greater than the typical separation energy for heavy $A$


| species (A) | $\mathrm{P}_{\text {Tmin }}(\mathrm{GeV/c})$ |
| :---: | :---: |
| $\mathrm{d}(2)$ | 0.006 |
| $\mathrm{Si}(28)$ | 0.067 |
| $\mathrm{Cu}(64)$ | 0.154 |
| $\mathrm{In}(115)$ | 0.276 |
| $\mathrm{Au}(197)$ | 0.473 |
| $\mathrm{U}(238)$ | 0.571 |

Recoil Tagging in Deeply Virtual Exclusive Reactions on Nuclei

$$
e+{ }^{A} Z \rightarrow e^{\prime}+{ }^{A} Z^{\prime}+(\gamma, \rho, \omega, \phi, J / \Psi)
$$

Determining exclusivity requires tagging the nucleus in the final state. The typical scale of transverse momentum transfer is given by the rms nuclear radius.

$$
P_{\perp} \approx \frac{\hbar c}{R_{A}} \approx 0.2 \mathrm{GeVA}^{-1 / 3}
$$


(for nuclei from ${ }^{4} \mathrm{He}$ to ${ }^{20} \mathrm{Ne}$, this scale ranges from $125 \mathrm{MeV} / \mathrm{c}$ to $75 \mathrm{MeV} / \mathrm{c}$ )
$\rightarrow$ For Nuclei ${ }^{4} \mathrm{He}$, the recoil nucleus is

- INSIDE the transverse admittance of the FF Quads
- $\Theta_{\mathrm{ms}} \approx 1 \mathrm{mr} \rightarrow P_{\mathrm{A} \text {,transverse }} \approx Z \cdot(60 \mathrm{MeV} / \mathrm{c}) \quad$ (for 60 GeV ion beam)
- Beam spread is larger than $1 / R_{A}$ scale for nuclear imaging.
- $Z \cdot(60 \mathrm{MeV} / \mathrm{C})>(0.2 \mathrm{GeV} / \mathrm{c}) / A^{1 / 3} \quad\left(\geq 75 \mathrm{MeV} / \mathrm{c}\right.$ for $\left.{ }^{A} \mathrm{Z}<^{20} \mathrm{Ne}\right)$
- OUTSIDE the longitudinal admittance of the ring lattice!!!
$\rightarrow$ The nuclei may be detectable at high resolution with far forward tracking in the lattice by having large dispersion $\rightarrow$ dispersion increased!


## Transverse momentum at 60 GeV

Thu Apr 22 23:23:09 2010 OptiM - MAIN: - C:IWorking\ELIC\MEIC\Optics\Ion Ring\Arc_Straight_IR_Str_90_in_2.opt
Alex Bogacz


## Far Forward Ion Tagging at ( $60 \mathrm{GeV} / \mathrm{c}$ ) Z

- Sample optics at token Roman Pot Telescope position
- MEIC typical: $\quad$ Dispersion $D=1.5 \mathrm{~m}$ ( 3 m in IR) Beta function $\beta_{\text {@ARC }}=15 \mathrm{~m}$
- MEIC typical: $\quad(x, \Theta)=(250 \mu m, 125 \mu r) r m s$
- Use a 8-10 $\sigma_{x}$ Beam Stay Clear (BSC) distance $\rightarrow 2.5 \mathrm{~mm}$
- Ions are detectable for $\left|\mathrm{dP}_{A| |} / \mathrm{P}_{\mathrm{A}}\right|>B S C / D=1.5 \times 10^{-3}$ Skewness $2 \zeta(\sim x / A)$ of DVCS $=$ long. momentum fraction of a nucleon in projectile ion.
- Skewness acceptance: $2 \zeta>\left(2.5 \times 10^{-3}\right) A \rightarrow 0.05$ for 20 Ne .
- Assumption: 1 m drift with $100 \mu \mathrm{~m}$ spatial resolution
- $d \Theta=100 \mu r \rightarrow$ equal to beam $\Theta_{\text {rms }}$.
- $P_{A}^{\prime}$ Momentum Resolution $=\sigma_{x} / D=2.5 \times 10^{-4}$.
- $\Delta_{\|}=\left(k-k^{\prime}-q^{\prime}\right)_{\|}=\left(P_{A}-P_{A}\right)_{\|}$
- $\sigma\left(\Delta_{\|}\right)=\left(4 \times 10^{-4}\right)(30 \mathrm{GeV} / \mathrm{c}) A=(12 \mathrm{MeV} / \mathrm{c}) \mathrm{A}$
- Exclusivity constraint $\Delta^{2}=2 M_{A}\left(P_{A^{\prime}}-P_{A}\right)$
- Using ELIC arc as spectrometer to a longitudinal momentum transfer resolution of $10^{-4}$ by increasing dispersion @ IR will be explored in more detail


## Hadronic Background Estimate

HERA: Strong correlation between detector background rates and beam line vacuum.


HERA vacuum $\sim 10^{-7}$ torr $\rightarrow 3 \times 10^{9}$ atoms $/ \mathrm{cm}^{3}$ 120 m straight section before IP $\rightarrow 4 \times 10^{13}$ atoms $/ \mathrm{cm}^{2}$ 100 mA proton current
$\rightarrow$ luminosity $=2 \times 10^{31}$ proton-atoms $/ \mathrm{s} / \mathrm{cm}^{2}$
$\rightarrow$ comparable to e-p luminosity
$\sigma(\mathrm{pp}) \sim 100 \times \sigma(\mathrm{ep}) \rightarrow$ proton-residual gas interactions most severe background for HERA detector operation

## Hadronic Background - scaling w. HERA

- Hadronic Random Background:
- assumed to be governed by ion-residual vacuum gas (mainly H) interactions
- $\sigma(p p)$ nearly independent of energy
- EIC@JLab background rates comparable/favorable to HERA II
- Straight section before IP: $40 \mathrm{~m} / 120 \mathrm{~m}=0.3$
- Average hadron multiplicity: ~ $(51 \mathrm{GeV} / 319 \mathrm{GeV})^{1 / 2}=0.4$
- Ion beam current: 0.7 A / 0.1 A = 7
- Similar background rates for $10^{-7}$ torr vacuum
- Vacuum easier to maintain in smaller ring (10-9 torr?)
- Signal-to-(beam-related) background is far better
- EIC@JLab luminosity: ~up to $10^{34} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$
- HERA luminosity: $\sim 5 \times 10^{31} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}$

