Detector design studies

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5-10 GeV static electron ring

RHIC

Polarized proton source

EBIS

BOOSTER

LINAC

AGS

eRHIC

Recirculating linac injector

e-cooling
Introduction

- Constraints imposed by collider kinematics
- Physics program driven requirements
- eRHIC - Detector design aspects
  - General considerations
  - Design 1: Forward physics (unpolarized ep/eA
    MPI-Munich group)
  - Design 2: General purpose
    (unpolarized/polarized ELECTRon-A)

- Constraints on accelerator/detector
  interface and background issues

Summary and concluding remarks
- Polarized ep physics
  - Precision measurement of $g^p_1$ over wide range in $Q^2$
    - Extraction of gluon polarization through DGLAP NLO analysis
    - Extraction of strong coupling constant
  - Precision measurement of $g^n_1$ (neutron) (Polarized $^3$He)
  - Photoproduction measurements
  - Electroweak structure function $g_5$ measurements
  - Flavor separation through semi-inclusive DIS
  - Target and current fragmentation studies
  - Transversity measurements

Introduction

Inclusive measurement - electron (Low $x$) and hadronic final state (High $x$) over wide acceptance range

In addition: $p$ tagging in forward direction

Jet production

Hermetic detector configuration: Missing energy measurement

$K/\pi$ separation - particle ID - Heavy flavor - Secondary vertex reconstruction

Forward acceptance: Tracking and calorimetry
Unpolarized ep/eA physics

- Precision measurement of $F_2$ at low $x$: Transition from hadronic to partonic behavior
- Precision measurement of the longitudinal structure function $F_L$
- Precision measurement of $F_2$ at high $x$
- Measurement of diffractive and exclusive reactions
- DVCS
- Precision measurement of eA scattering

Inclusive measurement involving electron at small polar angles ($\approx 10$ mrad)

Inclusive measurement involving electron (Low $x$) - Variable centre-of-mass energy

Inclusive measurement (hadronic final state in forward direction): Good forward acceptance

Forward $p$ tagging system

Forward $p$ tagging system - photon/electron discrimination

Similar to ep case at low $x$ - High $x$: Forward acceptance - careful study necessary!
Reconstruction of event kinematics

- Electron method: scattered electron

\[ x_e = \frac{Q_e^2}{s y_e} = \frac{E'_e \cos^2 \left( \frac{\theta'_e}{2} \right)}{E_p \left( 1 - \frac{E'_e}{E_e} \sin^2 \left( \frac{\theta'_e}{2} \right) \right)} \]

\[ y_e = 1 - \frac{E'_e}{2E_e} \left( 1 - \cos \theta'_e \right) = 1 - \frac{E'_e}{E_e} \sin^2 \left( \frac{\theta'_e}{2} \right) \]

\[ Q_e^2 = 2E_e E'_e \left( 1 + \cos \theta'_e \right) = 4E_e E'_e \cos^2 \left( \frac{\theta'_e}{2} \right) = \frac{p_{T,e}^2}{1 - y_e} \]

- Jacquet-Blondel method: hadronic final state

\[ x_{JB} = \frac{Q_{JB}^2}{s y_{JB}} \]

\[ p_{T,h}^2 = \left( \sum_h p_{x,h} \right)^2 + \left( \sum_h p_{y,h} \right)^2 \]

\[ y_{JB} = \frac{(E - p_z)_h}{2E_e} \]

\[ Q_{JB}^2 = \frac{p_{T,h}^2}{1 - y_{JB}} \]

\[ (E - p_z)_h = \sum_h (E_h - p_{z,h}) \]
Constraints imposed by collider kinematics

- Event kinematics (10GeV electron on 250GeV proton)

Lines of constant electron energy ($E'_e$)

Lines of constant hadron energy (F)

Lines of constant electron angle ($\theta'_e$)

Lines of constant hadron angle ($\gamma$)
Constraints imposed by collider kinematics

- Event topology (10GeV electron on 250GeV proton)

- Low-x-low $Q^2$: Electron and current jet (low energy) predominantly in rear direction

- High-x-low $Q^2$: Electron in rear and current jet (High energy) in forward direction

- High-x-high $Q^2$: Electron predominantly in barrel/forward direction (High energy) and current jet in forward direction (High energy)

$Q^2 = 361 GeV^2 \quad x = 0.45$

$E'_e = 18 GeV \quad F = 104 GeV$

$\theta'_e = 90^\circ \quad \theta_h = 10^\circ$
Resolution of event kinematics

- **Electron method:** scattered electron

\[
\frac{\delta x_e}{x_e} = \left(1 + \frac{1}{y_e}\right) \frac{\delta E_e'}{E'_e} \otimes \left[\frac{x_e}{E_e/E_p} - 1\right] \tan\left(\frac{\theta'_{e}}{2}\right) \delta\theta'_{e}
\]

\[
\frac{\delta y_e}{y_e} = \left(1 - \frac{1}{y_e}\right) \frac{\delta E_e'}{E'_e} \otimes \left[\frac{1}{y_e} - 1\right] \cot\left(\frac{\theta'_{e}}{2}\right) \delta\theta'_{e}
\]

\[
\frac{\delta Q^2_e}{Q^2_e} = \frac{\delta E_e'}{E'_e} \otimes \tan\left(\frac{\theta'_{e}}{2}\right) \delta\theta'_{e}
\]

- **Jacquet-Blondel method:** hadronic final state

\[
\frac{\delta x_{JB}}{x_{JB}} = \left(1 - \frac{1}{1 - y_{JB}}\right) \frac{\delta F}{F} \otimes \left[2 \cot\gamma + \left(\frac{2y_{JB} - 1}{1 - y_{JB}}\right) \cot\left(\gamma/2\right)\right] \delta\gamma
\]

\[
\frac{\delta y_{JB}}{y_{JB}} = \frac{\delta F}{F} \otimes \cot\left(\gamma/2\right) \delta\gamma
\]

\[
\frac{\delta Q^2_{JB}}{Q^2_{JB}} = \left(\frac{2 - y_{JB}}{1 - y_{JB}}\right) \frac{\delta F}{F} \otimes \left[2 \cot\gamma + \left(\frac{y_{JB}}{1 - y_{JB}}\right) \cot\left(\gamma/2\right)\right] \delta\gamma
\]
Detector specifications (1)

- Tracking over wide acceptance range operating in high-rate environment similar to LHC (35ns bunch-crossing time) - Contribute to reconstruction of event kinematics besides calorimetry in particular at very small energies

- Calorimetry over wide acceptance range (e/h separation critical): Transverse and longitudinal segmentation (Track-calorimeter cluster matching essential)

- Specialized detector systems
  - Zero-degree photon detector (Control radiative corrections and luminosity measurement)
  - Tagging of forward particles (Diffraction and nuclear fragments) such as...
    - Proton remnant tagger
    - ZerO-degree neutron detector
  - Forward proton and neutron tagger

- Particle ID systems (K/π separation) and secondary vertex reconstruction capabilities
Detector specifications (2)

- **Rate requirements**: Bunch-crossing time 35ns
- **Background rejection**: Timing requirements e.g. calorimetry timing essential to reject beam related background
- **Trigger**: Multi-level trigger system involving calorimetry and fast tracking information to enhance data sample for rare processes over inclusive ep/eA and photoproduction
General considerations: Detector aspects

- Measure precisely scattered electron over large polar angle region (Kinematics of DIS reaction)
- Tag electrons under small angles (Study of transition region: DIS and photoproduction)
- Measure hadronic final state (Kinematics, jet studies, flavor tagging, fragmentation studies, particle ID)
- Missing $E_T$ for events with neutrinos in the final state ($W$ decays) (Hermetic detector)
- Zero-degree photon detector: Control radiative corrections and luminosity measurement (ep/eA Bremsstrahlung)
- Tagging of forward particles (Diffraction and nuclear fragments) such as…:
  - Proton remnant tagger
  - Zero degree neutron detector
- Challenge to incorporate above in one detector: Focus on two specific detector concepts for now!
**General considerations**

- **Design 1:** Forward physics (unpolarized eA MPI Munich group):
  - Specialized detector system to enhance forward acceptance of scattered electrons and hadronic final state
  - Main concept: Long inner dipole field (7m)
  - Required machine element-free region: approx. ±5m

- **Design 2:** General purpose (unpolarized/polarized ELECTRon-A):
  - Compact central detector (Solenoidal magnetic field) with specialized forward/rear tagging detectors/spectrometers to extend central detector acceptance
  - Required machine element-free region: approx. ±3m

- **Detector sub-systems in both design concepts:**
  - Zero-degree photon detector (Control radiative corrections and luminosity measurement)
  - Tagging of forward particles (Diffraction and nuclear fragments) such as:
    - Proton remnant tagger
    - Zero-degree neutron detector
Design 1: Forward physics (unpolarized eA MPI-Munich group) (1)

- Detector concept

  - Compact detector with tracking and central EM calorimetry inside a magnetic dipole field and calorimetric end-walls outside:
    - Bend forward charged particles into detector volume
    - Extend rapidity compared to existing detectors
  - Tracking focuses on forward and backward tracks
  - No tracking in central region
Design 1: Forward physics (unpolarized $eA$ MPI-Munich group) (2)

- Tracking system:
  - High-precision tracking with $\Delta p_T/p_T \sim 2\%$
  - Angular coverage down to $\eta \approx 6$ over the full energy range
  - Concept: 14 Si-strip tracking stations (40 X 40 cm)
  - Assumed hit resolution: $20 \mu m$
  - Momentum resolution from simulations: Few percent!
Design 1: Forward physics (unpolarized eA MPI-Munich group) (3)

- Calorimeter system:
  - Compact EM calorimeter systems: Si-Tungsten
  - Forward hadron calorimeter: Design follows existing ZEUS calorimeter
Design 1: Forward physics (unpolarized $eA$ MPI-Munich group) (4)

- **Acceptance:**
  - Full tracking acceptance for $|\eta| > 0.75$ - No acceptance in central region $|\eta| < 0.5$
  - $Q^2$ acceptance down to $0.05\text{GeV}^2$ (Full $W$ range) - Full acceptance down $Q^2=0\text{GeV}^2$ for $W>80\text{GeV}$
  - High $x$: Electron ($Q^2$) and Jet ($x$) to determine event kinematics

### Track efficiency:
- Full efficiency below $6\text{GeV}$ for $\eta > -8$
- For larger energies, full efficiency for $\eta > -5$

$W^2 \approx \frac{Q^2}{x}$
Design 2: General purpose (unpolarized/polarized ELECTRon-A) (1)

- **Detector concept:**
  - Hermetic detector system inside ±3m machine element free region
  - Starting point:
    - Barrel and rear EM system: e.g. Si-Tungsten (Similar to Design 1)
    - Forward EM/hadron calorimeter: e.g. Pb-scintillator
    - Tracking system and barrel EM inside solenoidal magnetic field
    - Tracking system based on high-precision Si (inner) and micro-pattern technology (Triple-GEM) (outer)
Design 2: General purpose (unpolarized/polarized ELECTRon-A) (2)

- ELECTRA detector simulation and reconstruction framework:
  - GEANT simulation of the central detector part (tracking/calorimetry) available: Starting point
  - Calorimeter cluster and track reconstruction implemented
  - Code available through CVS repository: http://starmac.lns.mit.edu/~erhic/electra/
  - To-do-list:
    - Evaluate and optimize detector configuration - In particular: Type of magnetic field configuration
    - Design of forward tagging system and particle ID systems
    - Rear detection systems
    - For eA events: Optimize forward detector system for high-multiplicity environment
Design 2: General purpose (unpolarized/polarized ELECTRon-A) (3)

- Simulated ep DIS event (LEPTO)

Simulated DIS event:
- Lower $Q^2$ acceptance $≈ 0.1$ GeV$^2$

DIS generators used so far:
- LEPTO
- DJANGO
Design 2: General purpose (unpolarized/polarized ELECTron-A) (4)

- Simulated eCa event (VNI)
**Interaction region and background issues**

- **IR region**
  - Design concept: Forward physics (unpolarized eA MPI-Munich group)
    - Machine element free-region: approx. ±5m
    - Physics program could be accomplished at lower luminosity
  - Design concept: General purpose (unpolarized/polarized ELECTRon-A)
    - Machine element free-region: approx. ±3m
    - Physics program requires high luminosity operation

- **Synchrotron radiation background**
  - Optimize beam pipe shape
    - Accommodate synchrotron radiation fan generated by e-beam as a result of beam separation
    - Maximize detector acceptance
  - Design of absorber and masking system

- **Beam-gas background**
  - Bremsstrahlung of electrons with residual gas and proton-beam gas background
    - Shielding and collimation
    - Minimize dead-material close to the beam
    - Good vacuum conditions crucial
**Summary**

- **Detector design issues**
  - Well-developed design of a *Forward detector system focusing on low-x / high-x physics* (Adaptation and optimization of a detector presented for the HERA III program)
  - Design of a *compact central detector* started: Detector simulation and reconstruction framework: **ELECTRA** (CVS repository http://starmac.lns.mit.edu/~erhic/electra/)
  - Possible scenarios of both design concepts:
    - 1 detector only *(Staging)*: Start program with Forward physics detector system followed by an upgrade of the interaction region and installation of a central detector system re-using parts of the Forward detector system (e.g. rear and forward calorimeter): Very time consuming!
    - 2 IR regions would allow to accommodate both detector concepts independently
    - Incorporate both concepts in one design: New ideas of magnetic field layout crucial!

- **Constraints and implications of machine/detector interface**
  - Inner-most machine elements
  - Synchrotron radiation and other machine related background
  - Incorporate forward and rear tagging system including luminosity monitoring system into machine layout
Concluding remarks

Steps towards a new detector at BNL

- Participation of RHIC and Jlab community essential to realize a detector for eRHIC - Cannot rely initially on strong participation from Europe - Dedicated new detector group at BNL urgently needed
- Three-beam IR region too complicated
- Switching between two IR regions unrealistic
- Critical eRHIC detector R&D issues:
  - **Calorimetry**: Compact, high resolution, e/h separation
  - **Tracking**: High-rate, low dead material, high occupancy (Forward direction)
  - **Forward/Rear instrumentation**: Compact, high radiation environment
  - **Magnetic field configuration**: Combination of solenoid and dipole-type configuration
  - **DAQ/Trigger system**: Multi-level trigger system
  - **Background**: Synchrotron radiation absorber and shielding
Towards a new detector group at BNL

- Several participating institutes chaired by 2 conveners
Event kinematics (5GeV electron on 50GeV proton)

- Lines of constant electron energy ($E'_e$)
- Lines of constant hadron energy (F)
- Lines of constant electron angle ($\theta'_e$)
- Lines of constant hadron angle ($\gamma$)
Event topology (5GeV electron on 50GeV proton)

- Low-x-low Q^2: Electron and current jet (low energy) predominantly in rear direction

- High-x-low Q^2: Electron predominantly in forward direction (High energy) and current jet in forward direction (High energy)

- High-x-high Q^2: Electron in rear and current jet (High energy) in forward direction

\[ Q^2 = 361 \text{GeV}^2 \quad x = 0.45 \]
\[ E'_e = 19 \text{GeV} \quad F = 8.5 \text{GeV} \]
\[ \theta'_e = 26^\circ \quad \theta_h = 87^\circ \]