WG7-Future Experiments Summary

Conveners:
Dave Gaskell
Uta Klein
Roberto Petti

29 talks and 1 roundtable discussion

Our Main Themes

- Physics – partially joint with Spin (WG6) and Electroweak (WG3)
- Detector improvements and upgrades
- New Machines – colliders and interaction regions
- Roundtable discussion – Future electron-ion colliders: synergies and complementarity

We will illustrate these themes with selected highlights.
We apologize for not being able to cover all contributions in this summary.

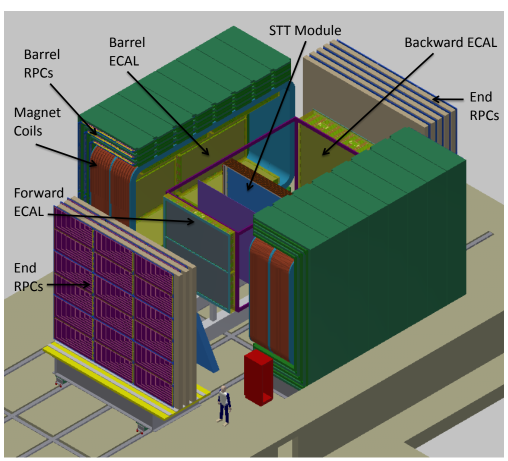
High Intensity and High Precision: (Anti)neutrino Scattering

- Next generation LBNF/DUNE project
  - Precision test of fundamental interactions with the ELBNF Near Detector (R. Petti – Wed. AM)
  - Measurements of The Neutrino Flux Using the ELBNF Fine-Grained Tracker (X. Tian – Wed. PM)
- THE SHIP experiment and its detector for neutrino physics (A. Buonaura – Wed. PM)
- Neutrino-Nucleus Deep Inelastic Scattering in MINERvA in the NuMI Medium Energy Beam (A. Norrick – Wed. PM)

LBNE CD1 approved

LBNF/DUNE: A Generational Advance in $\nu(\bar{\nu})$ Scattering Experiments

- LBNF/DUNE designed to study Long-Baseline neutrino oscillations:
  - High intensity ν **AND** $\bar{\nu}$ beams with 1.2(2.4) MW p beam (E=120 GeV) at Fermilab and 11×10^{20} pot/year (0.5 GeV < E < 50 GeV)
  - A 40 kton LAr TPC Far Detector (FD) located in the Homestake mine, SD, USA (L=1300 km)
  - A high-resolution (ch. track energy scale unc. < 0.2%, total had. energy unc. < 0.5%) and highly segmented (x 10 improvement) Near Detector (ND) complex at Fermilab
- ND with multiple fixed targets: p [$(C_3H_6)_n$ – C], Ca, Ar, Fe, etc.
- Expected statistics in ND: $90(40) \times 10^6 \nu_\mu(\bar{\nu}_\mu)\mathrm{CC}$ (x 100 improvement)
- Absolute and relative fluxes measured in-situ in ND to ~2%



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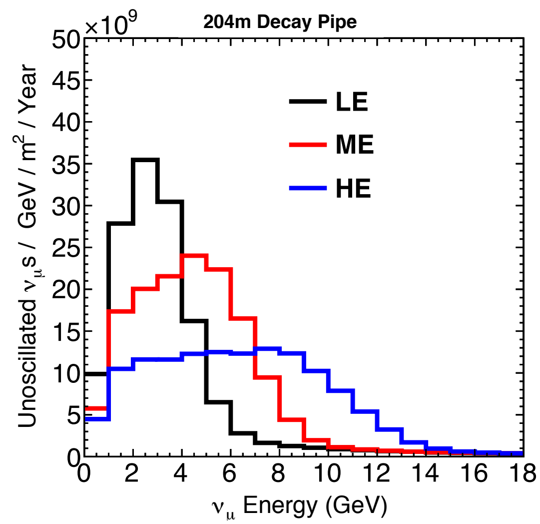


Short-Baseline Physics at LBNF

✦ PRECISION MEASUREMENTS: *(LBNE Collaboration, arXiv:1307.7335 [hep-ex])*

- *Measurement of* $\sin^2\theta_W$ *and electroweak physics;*
- *Measurement of strange sea contribution to the nucleon spin* Δs*;*
- *Precision tests of isospin symmetry;*
- *Precision tests of the structure of the weak current: PCAC, CVC;*
- *Adler sum rule;*
- *Studies of QCD and hadron structure of nucleons and nuclei;*
- *Strange sea and charm production;*
- *Measurement of Nuclear effects in neutrino interactions;*
- *Precision measurements of cross-sections and particle production; etc. .....*

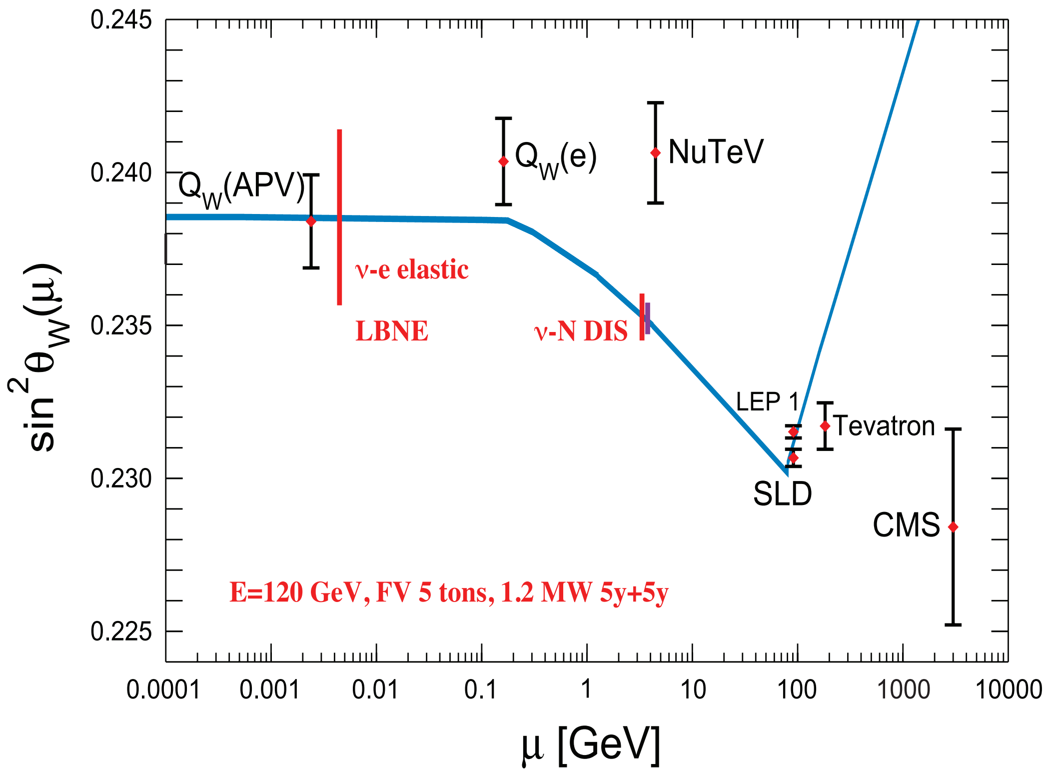
Deep synergy with the LBL oscillation program: same requirements and mutual feedback

✦ SEARCHES FOR NEW PHYSICS:

- *Search for weakly interacting massive particles (e.g.* ν*MSM sterile neutrinos);*
- *Search for high* Δm^2 *neutrino oscillations (e.g. LSND, MiniBooNE)*
- *Search for light (sub-GeV) Dark Matter; etc. .....*

$\Longrightarrow$ *The combination of high resolution and unprecedented statistics (*$\times 100$*) may led to discoveries of new physics in fundamental interactions / structure of matter!*

Precision EW Physics at LBNF



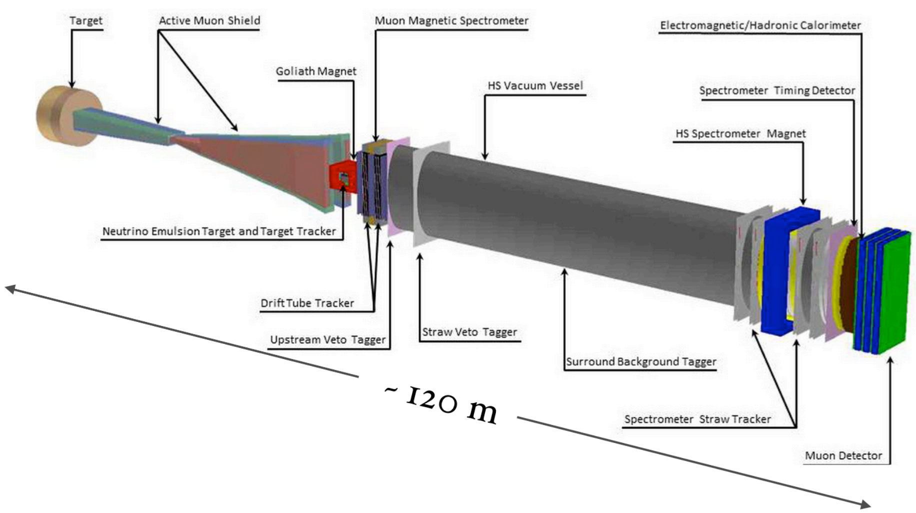
- *Different independent channels:*
  - $\mathcal{R}^\nu = \frac{\sigma^\nu_{\rm NC}}{\sigma^\nu_{\rm CC}}$ *in ν-N DIS (~0.35%)*
  - $\mathcal{R}_{\nu e} = \frac{\sigma^{\bar\nu}_{\rm NC}}{\sigma^\nu_{\rm NC}}$ *in ν-e^- NC elastic (~1%)*
  - *NC/CC ratio $(\nu p \to \nu p)/(\nu n \to \mu^- p)$ in (quasi)-elastic interactions*
  - *NC/CC ratio ρ^0/ρ^+ in coherent processes*

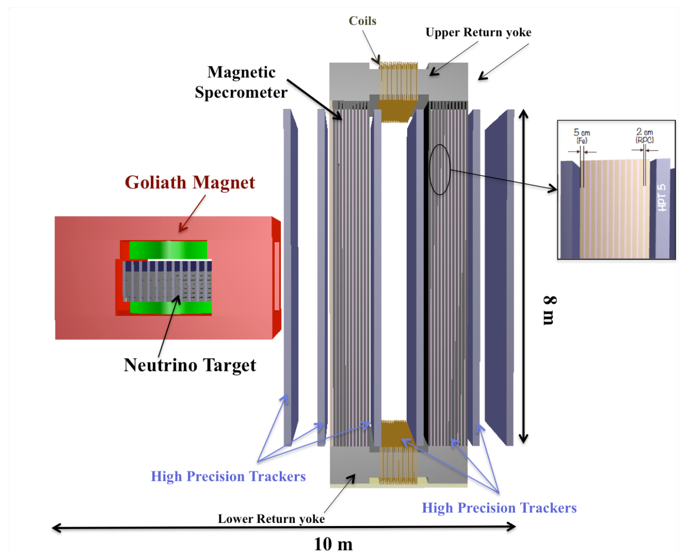
  $\Longrightarrow$ *Combined EW fits like LEP*

- *Reduction of uncertainties to $\sim 0.2\%$ with 1-2 yr run in high energy mode*

The SHIP Experiment

- Beam dump experiment proposed at CERN to search for new long-lived weakly interacting particles (e.g. sterile neutrinos, dark photons etc.)
- Neutrino emulsion detector (similar to OPERA) followed by magnetic spectrometer
- Precision measurement of charm production and strange sea distributions: expect ~1.1 10^5 charm events
- Measurement of ν_τ cross-section and F4, F5 structure functions: expect to identify ~1800 (900) ν_τ ($\bar{\nu}_\tau$) CC events



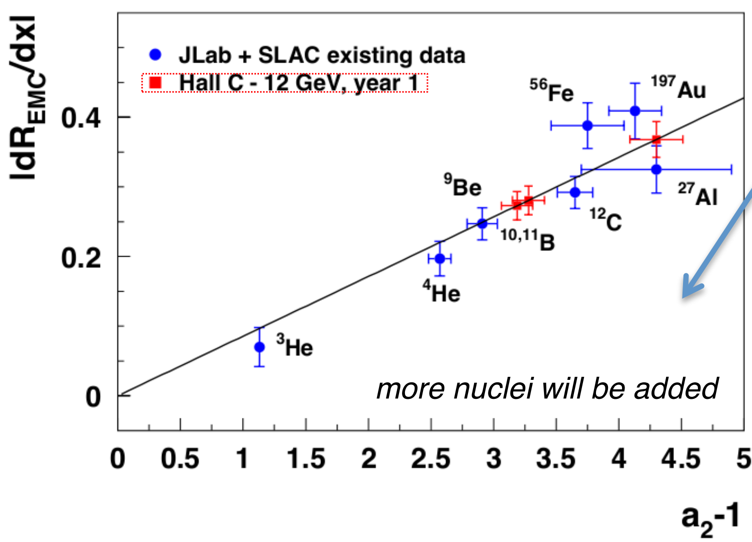


High Intensity and High Precision (JLab12, EIC, FNAL)

- Nuclear Effects
  - The EMC effect: upcoming experimental programs at Jefferson Lab (S. Malace – Wed. PM)
- Quark distributions, 3D structure of the nucleon
  - Precision Measurements of Parity-Violation in Deep Inelastic Scattering using SoLID (R. BEMINIWATTHA –Wed. AM)
  - SoLID-SIDIS: Future Measurements of Transverse Spin, TMDs and more (Z. Ye – Thurs. AM)
  - The Halls B and C semi-inclusive deep inelastic scattering program towards the transverse momentum dependence of valence quarks (R. Ent – Thurs. AM)
  - Polarized Drell-Yan measurements at Fermilab: The future of the SeaQuest experiment (M. Deifenthaler – Thurs. AM)
  - Highlights from the (un)polarized e+p scattering program at an EIC (E. Aschenauer – Thurs. AM)

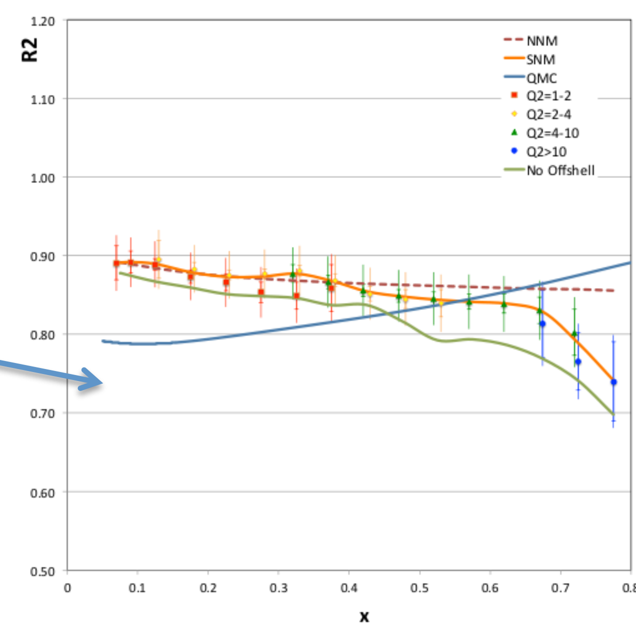
High Intensity and High Precision – Nuclear Effects

S. Malace - Unraveling the EMC Effect at Large x – JLab program of unpolarized inclusive (L-T separated), tagged and polarized electron scattering



Elucidation of EMC-SRC connection

1. Additional nuclei
2. Tagging high momentum nucleons



First ever measurement of "polarized EMC Effect"

Other experiments: Exploring flavor dependence and possible nuclear dependence of $R=\sigma_L/\sigma_T$

High Intensity and High Precision – SIDIS at JLab in the 12 GeV era

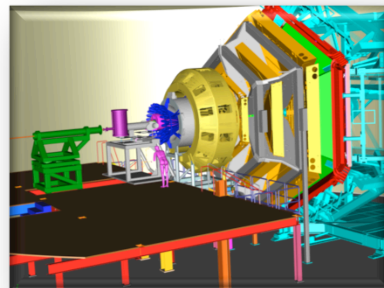
12 GeV JLAb upgrade 92% complete

Accessing TMDs, transversity – studying the SIDIS reaction mechanism and factorization

Talks from R. Ent and Z. Ye

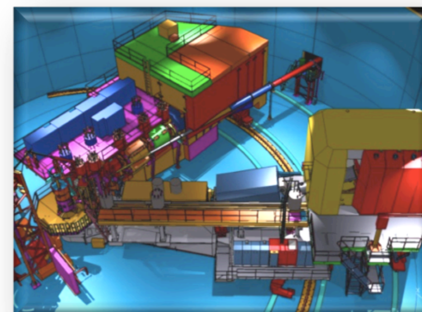
- **CLAS12 in Hall B**

  General survey, medium lumi



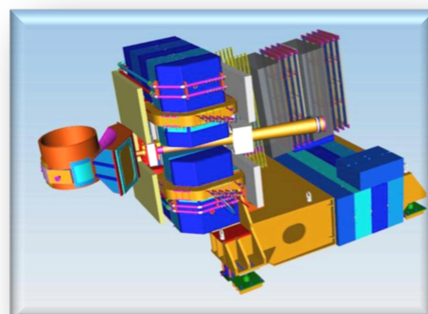
- **SHMS, HMS, NPS in Hall C**

  L-T studies, precise $\pi^+/\pi^-/\pi^0$ ratios



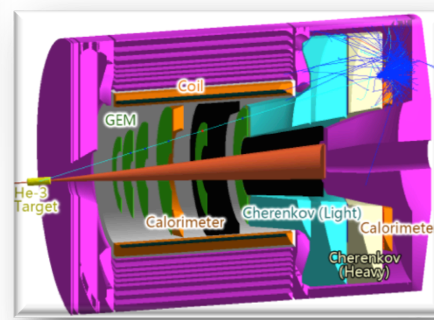
- **SBS in Hall A**

  High x, High Q^2, 2-3D



- **SOLID in Hall A**

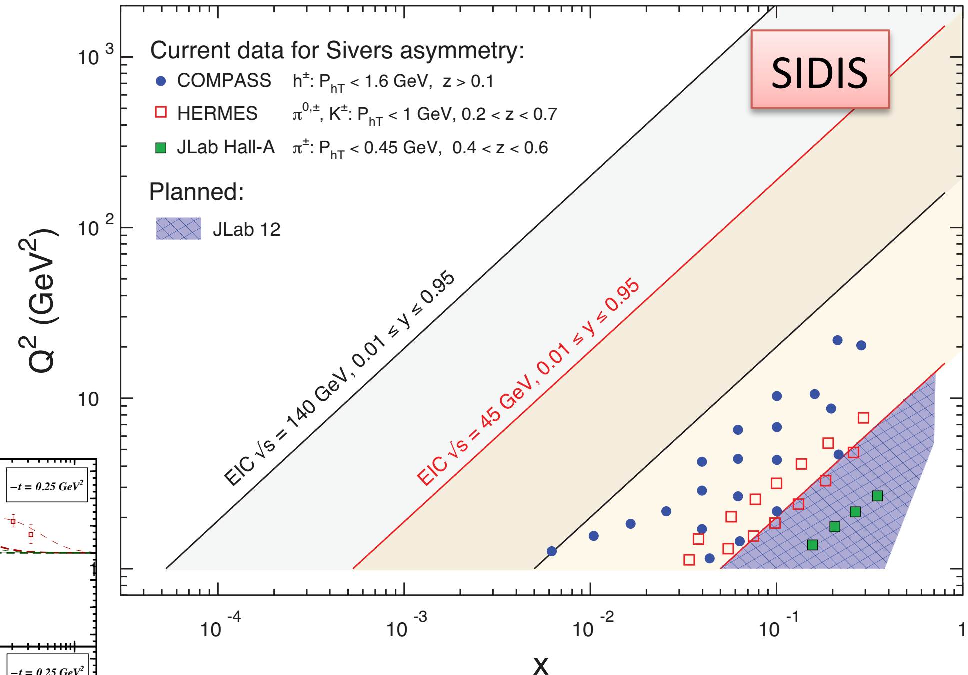
  High lumi and acceptance – 4D

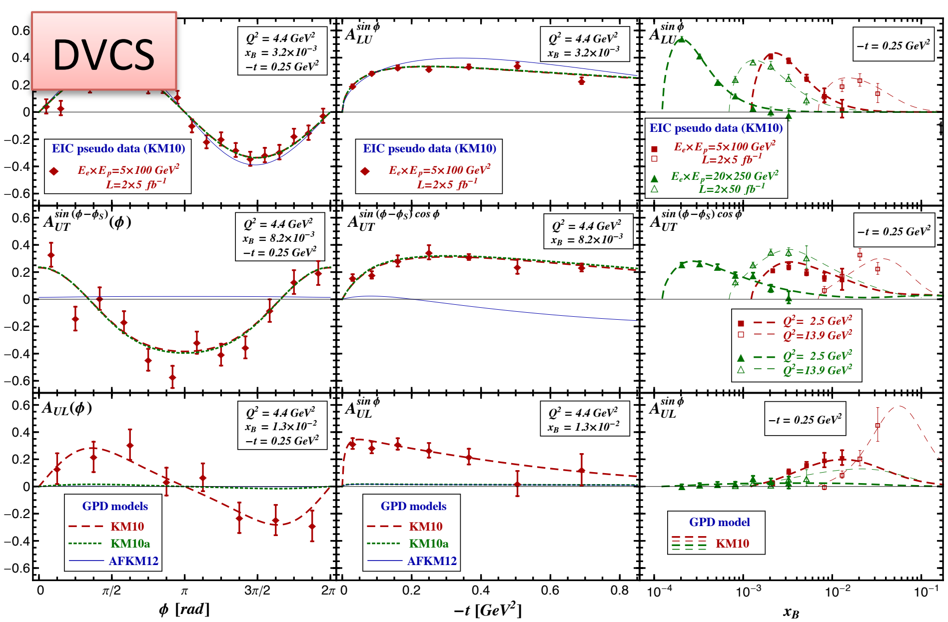


High Intensity and High Precision - Spin, TMDs, and GPDs at EIC

E. Aschenauer

Collider with both polarized electrons and polarized protons (ions) will dramatically increase our knowledge of nucleon (spin) structure



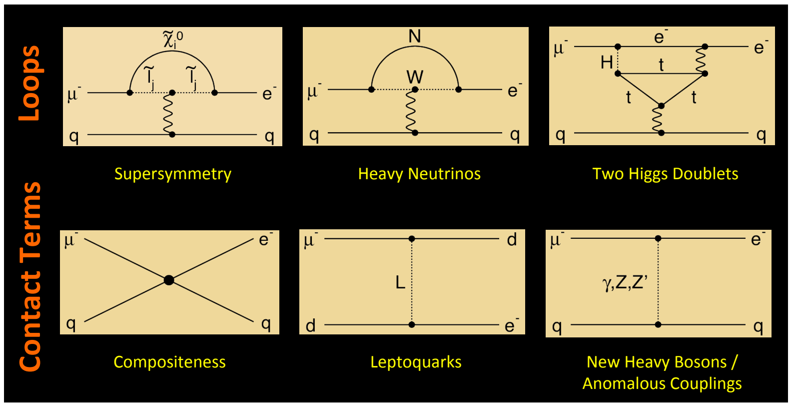


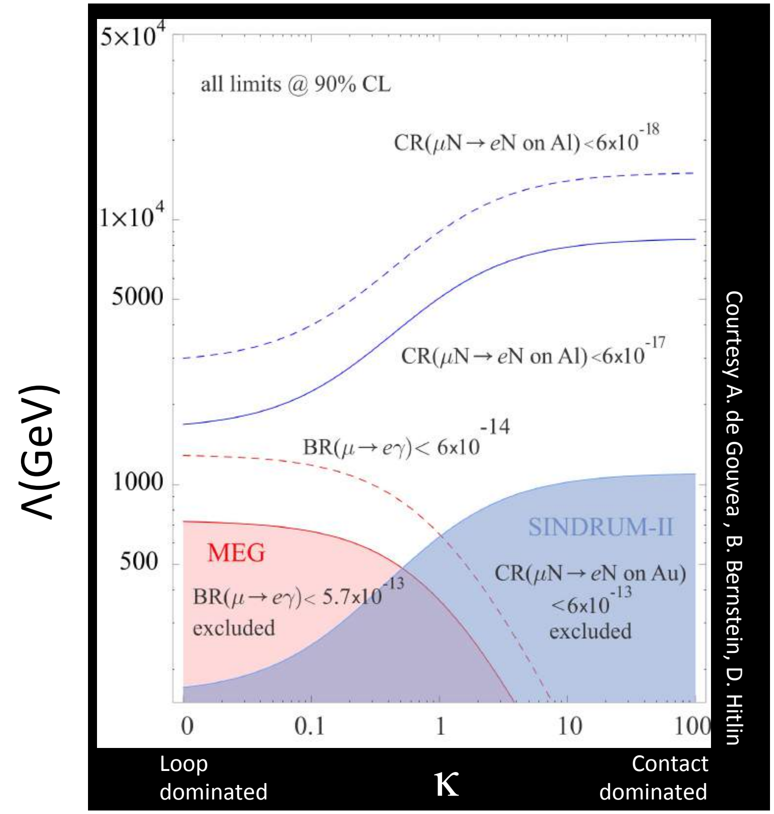
SIDIS → TMDs
DVCS → GPDs

The amount and precision of the data provided by EIC will be unprecedented

High Intensity and High Precision - BSM

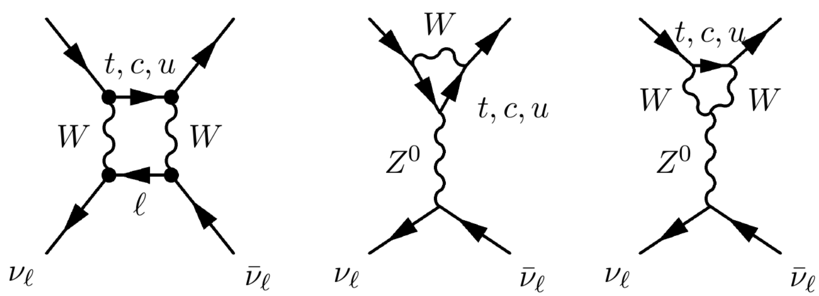
The Mu2e Experiment at Fermilab
(F. Grancagnolo)





Prospects for K+ →pi+ nu nu observation at CERN in NA62 (Bruno Angelucci)

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$$

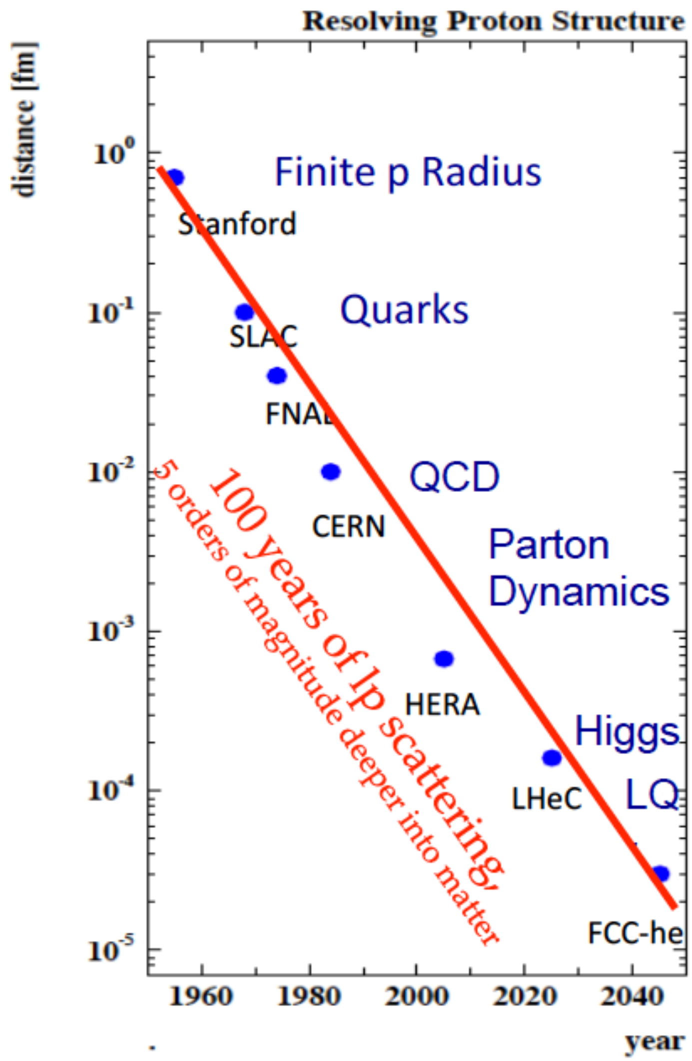


W-box Z-penguin

- NA62 first data taking in 2014
  - Subdetectors' performances in agreement with expectations
- NA62 apparatus almost fully commissioned in pilot run
  - Commissioning of remaining subsystems in 2015

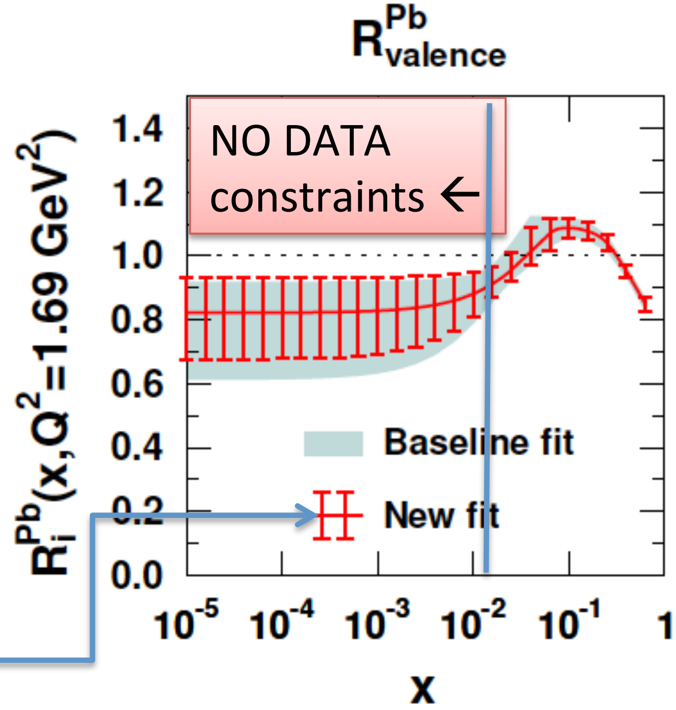
High energy and high precision frontier (LHeC, FCC-he)

HERA–LHeC–FCC-eh:
finest microscopes, resolution as 1/Q



- Electron-Ion Physics with the LHeC (I. Helenius)
- Parton distributions, QCD measurements, and BSM prospects with the LHeC (C. Gwenlan)
- Low-x physics at LHeC/FCC-he and its implications on UHCER (A. Stasto)
- Top quark physics in ep colliders (C. Schwanenberger)
- Precision Higgs measurements in ep (U. Klein)
- Flavor violating signatures of lighter and heavier Higgs bosons with two Higgs doublet model type III at the LHeC (J. Hernandez)

LHeC : eA at small x
→ huge synergy with AA

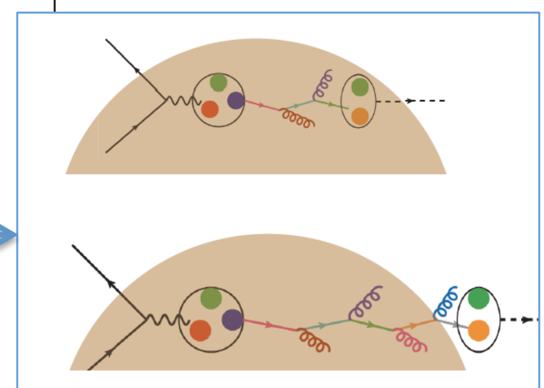


Nuclear PDFs

- Data constraining current nPDF fits quite limited in kinematics
- p+Pb data from LHC will improve fits at $x \gtrsim 0.01$
- LHeC would provide very precise data down to $x \sim 10^{-5}$
  - ⇒ Drastic reduction of the nPDF uncertainties!
  - ⇒ Flavor decomposition from charged current and heavy quark data

Other e+A physics

- Clean environment to study small-x phenomena such as saturation
- Photoproduction of jets can be used to study photon (nuclear) PDFs
- Cold nuclear matter effects to hadron production
- \+ Topics not covered here (Diffraction, Vector Mesons, . . .)



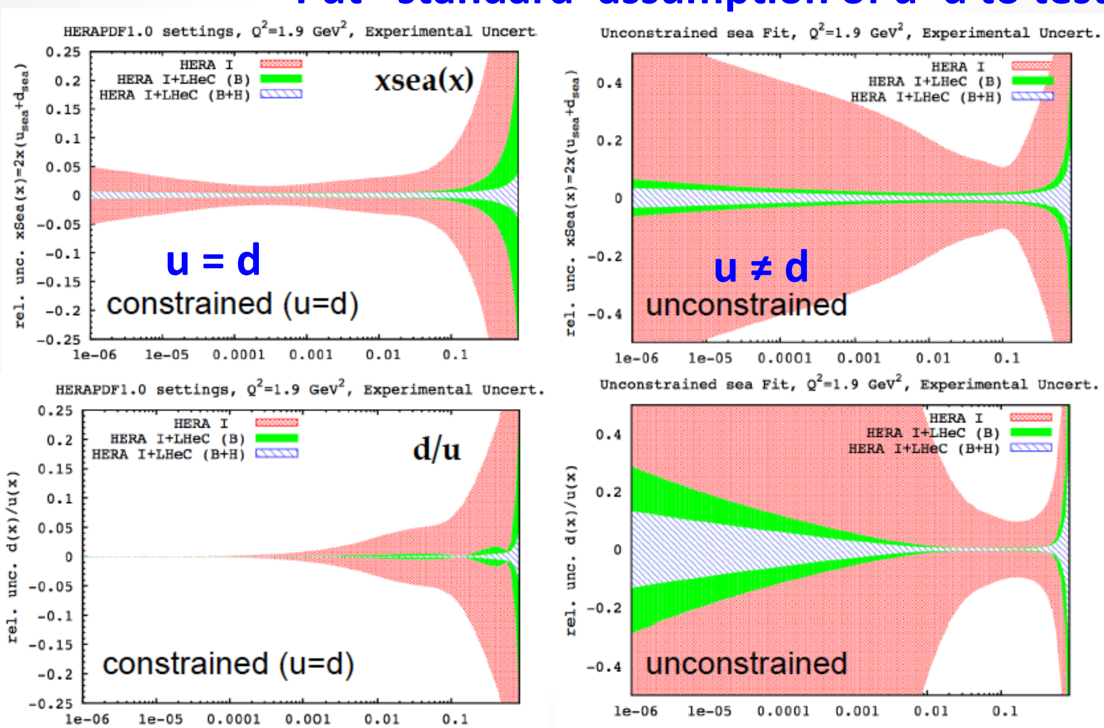
Precision proton PDFs – huge synergy to LHC/FCC pp

[Talks by Gwenlan and Stasto]

LHeC PDFs with released assumptions

- furthermore, LHeC does not need to rely on 'usual' constraint that u=d at low x, which **may not be valid**

Put 'standard' assumption of u=d to test!



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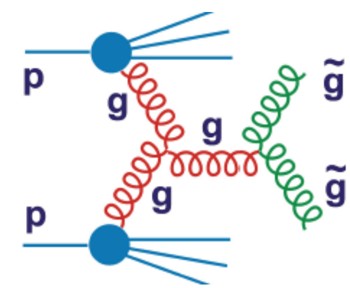
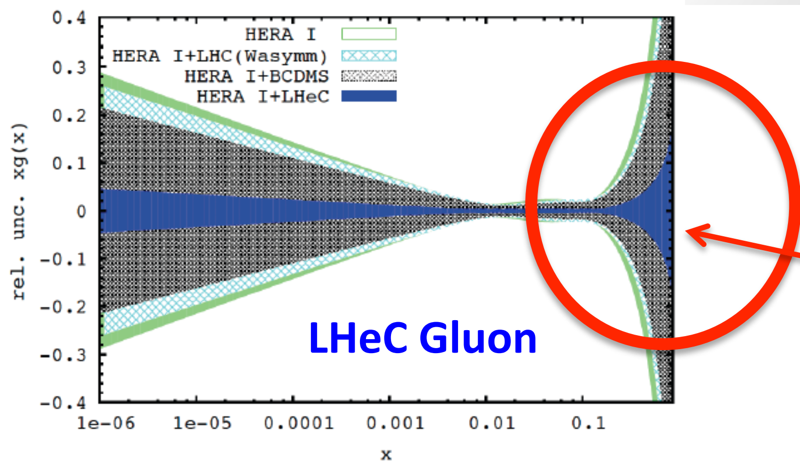
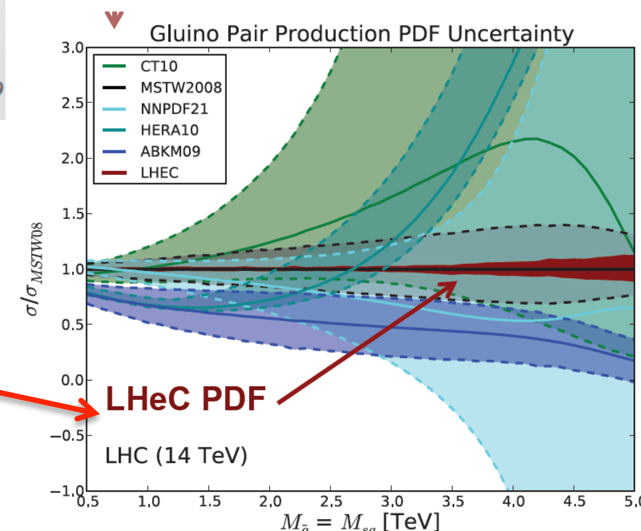


Mapping gluon at high x and low x (saturation?)

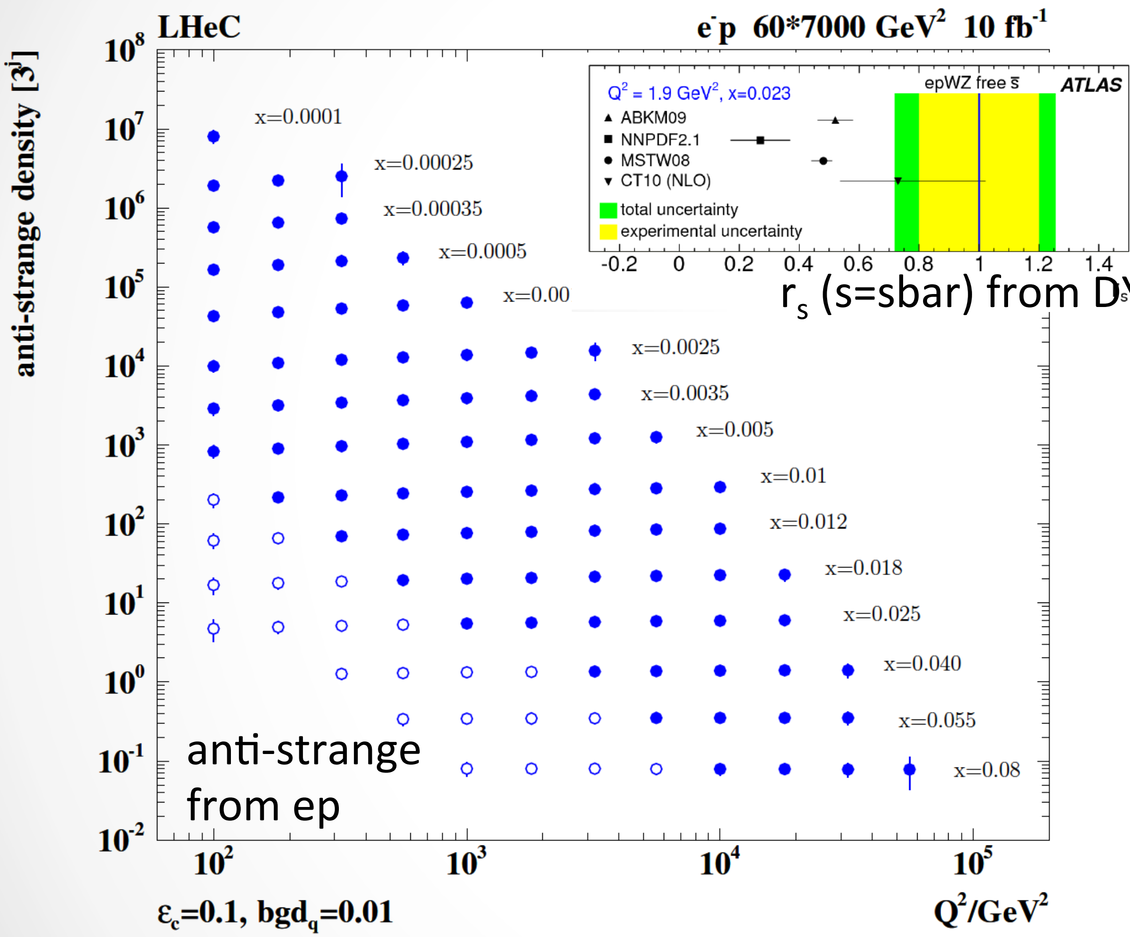


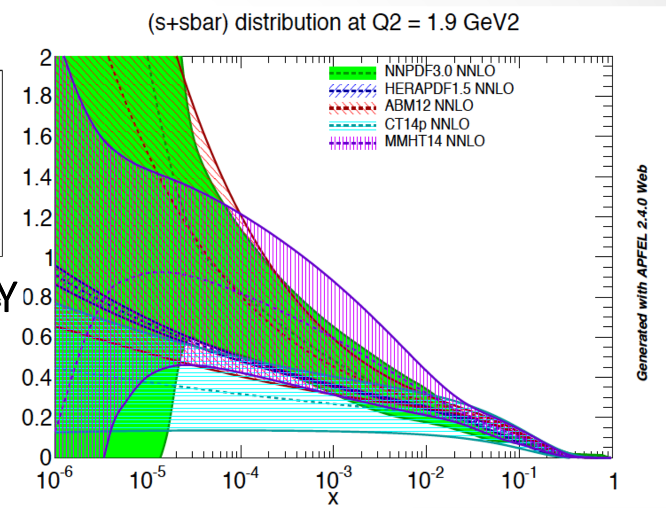


arXiv:1211.5102

Precision flavor PDFs : e.g. anti-strange

strange: largely unknown; suppressed compared to other light quarks? s=sbar?





LHeC: direct sensitivity to strange, via charm tagging in CC

– first (x,Q2) measurement of (anti-) strange density

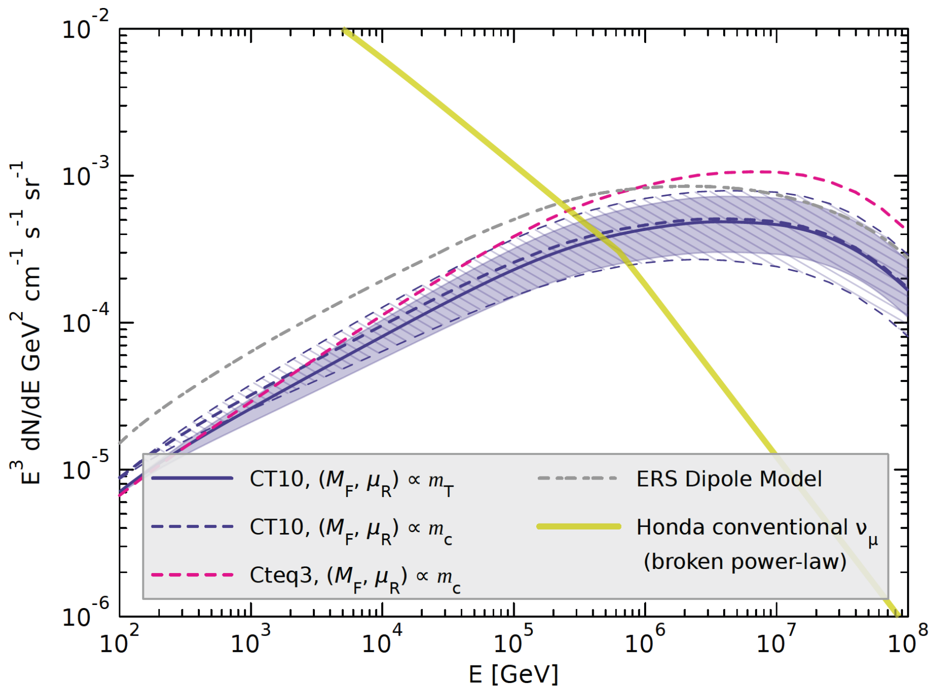
note, direct sensitivity to top (tPDF) also possible, for first time (Wb→t)

(initial study (CDR): 10% charm tagging efficiency, 1% light quark background in impact parameter)

Low x physics and UHECR

Prompt neutrino flux

[Talk by Stasto]



Prompt neutrinos:
Production of charm in the atmosphere

$$pA \rightarrow c\bar{c}X$$

$$D^0, D^\pm, D_s^\pm, \cdots \rightarrow \nu X$$

- Due to the fast decay of charmed hadrons, no significant energy loss.
- Prompt flux from charm decay dominates the neutrino flux at high energies.
- Constitutes a background for the UHE neutrinos.
- Production of forward charm: dominance of the very low x gluon.

Large uncertainties (in fact they are larger, not all uncertainties shown in this plot).

LHeC/FCC-eh can provide important constraints on the gluon at small x and consequently reduce the uncertainties for the prompt flux.

Low x physics and UHECR

Prompt neutrino flux

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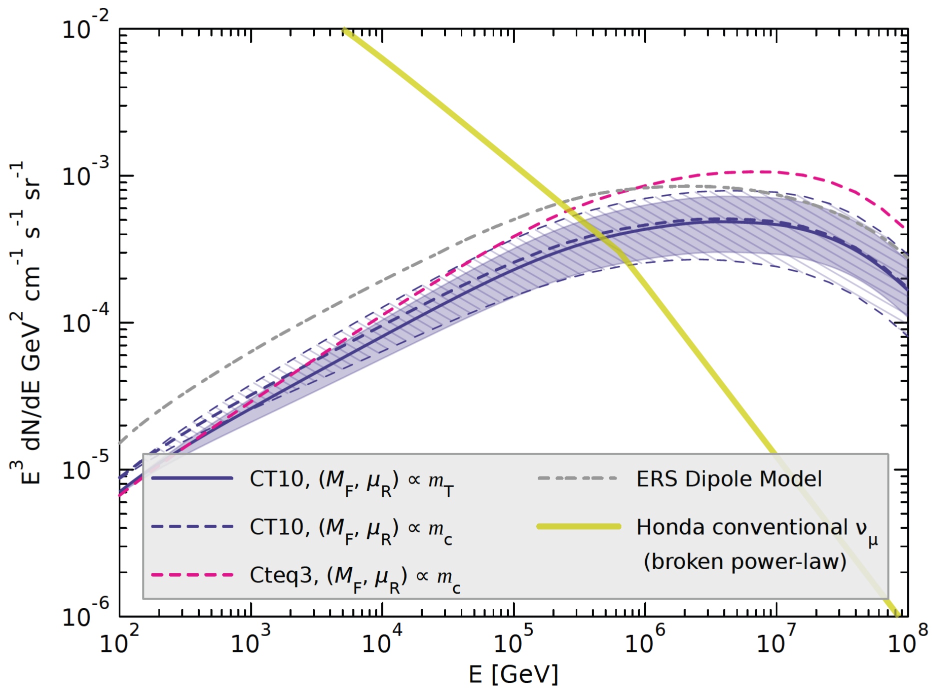

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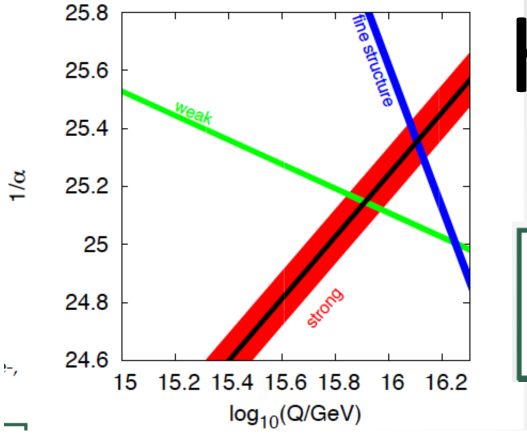
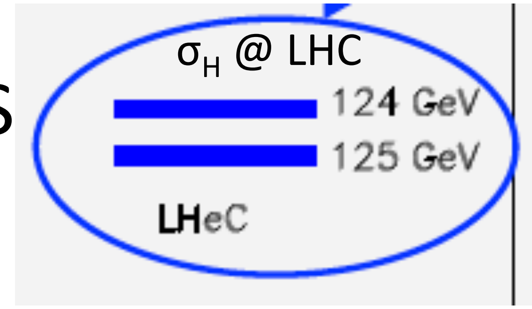
Higgs, PDFs and α_S



[Talks by Gwenlan and Klein, U]

PDG world ave.: $\alpha s(M_Z)=0.1184\pm0.0006$

without lattice input: $\alpha s(M_Z)=0.1183\pm0.0012$



→reduce PDF+αS uncertainty of σ_H@LHC to 0.4% !

Snowmass13 report – arXiv:1310.5189

	Method	Current relative precision	Future relative precision	
	e^+e^- evt shapes	expt ~ 1% (LEP) thry ~ 1–3% (NNLO+up to N^{3}LL, n.p. signif.) [27]	< 1% possible (ILC/TLEP) ~ 1% (control n.p. via Q^2-dep.)	
	e^+e^- jet rates	expt ~ 2% (LEP) thry ~ 1% (NNLO, n.p. moderate) [28]	< 1% possible (ILC/TLEP) ~ 0.5% (NLL missing)	
FCC-ee	precision EW	expt ~ 3% (R_Z, LEP) thry ~ 0.5% (N^{3}LO, n.p. small) [9, 29]	0.1% (TLEP [10]), 0.5% (ILC [11]) ~ 0.3% (N^{4}LO feasible, ~ 10 yrs)	**per mille**
	τ decays	expt ~ 0.5% (LEP, B-factories) thry ~ 2% (N^{3}LO, n.p. small) [8]	< 0.2% possible (ILC/TLEP) ~ 1% (N^{4}LO feasible, ~ 10 yrs)	
LHeC ep	*ep* colliders	~ 1–2% (pdf fit dependent) [30, 31], (mostly theory, NNLO) [32, 33]	0.1% (LHeC + HERA [23]) ~ 0.5% (at least N^{3}LO required)	**per mille**
	hadron colliders	~ 4% (Tev. jets), ~ 3% (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.) [17, 21, 34]	< 1% challenging (NNLO jets imminent [22])	
	lattice	~ 0.5% (Wilson loops, correlators, ...) (limited by accuracy of pert. th.) [35–37]	~ 0.3% (~ 5 yrs [38])	

per mille accuracy can challenge QCD lattice calculations

C. Gwenlan, PDFs, QCD and BSM at the LHeC

TLEP = old name for FCC-ee

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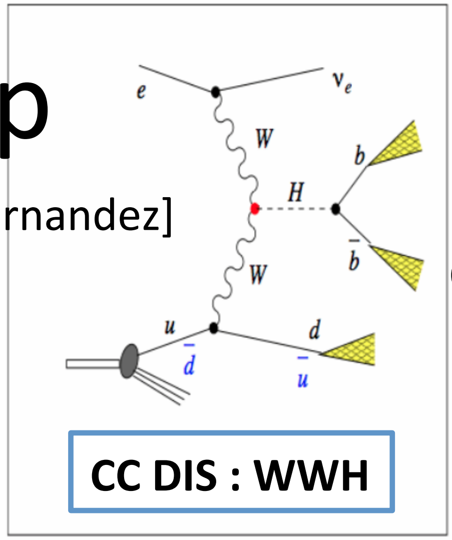
Higgs in ep

[Talks by Klein, U and Hernandez]

Updates of CDR after Higgs discovery
M_H=125 GeV, E_p=7 TeV, 100 fb^{-1}/year,



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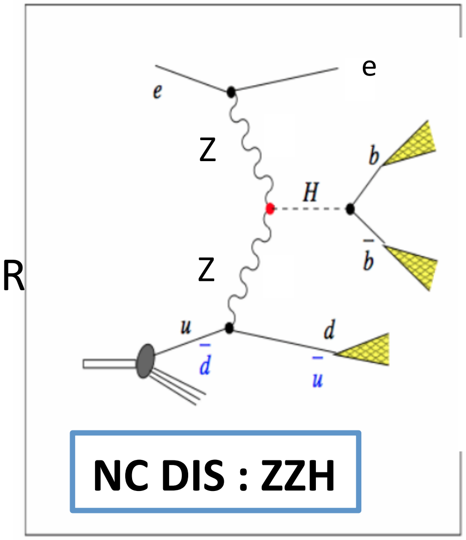
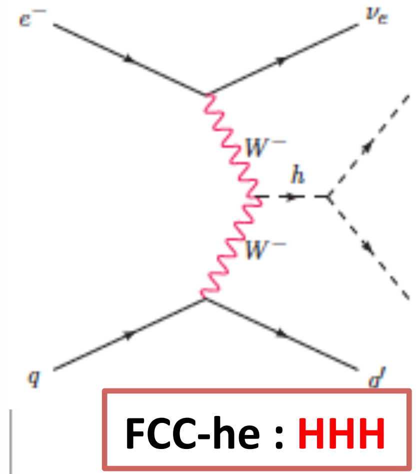
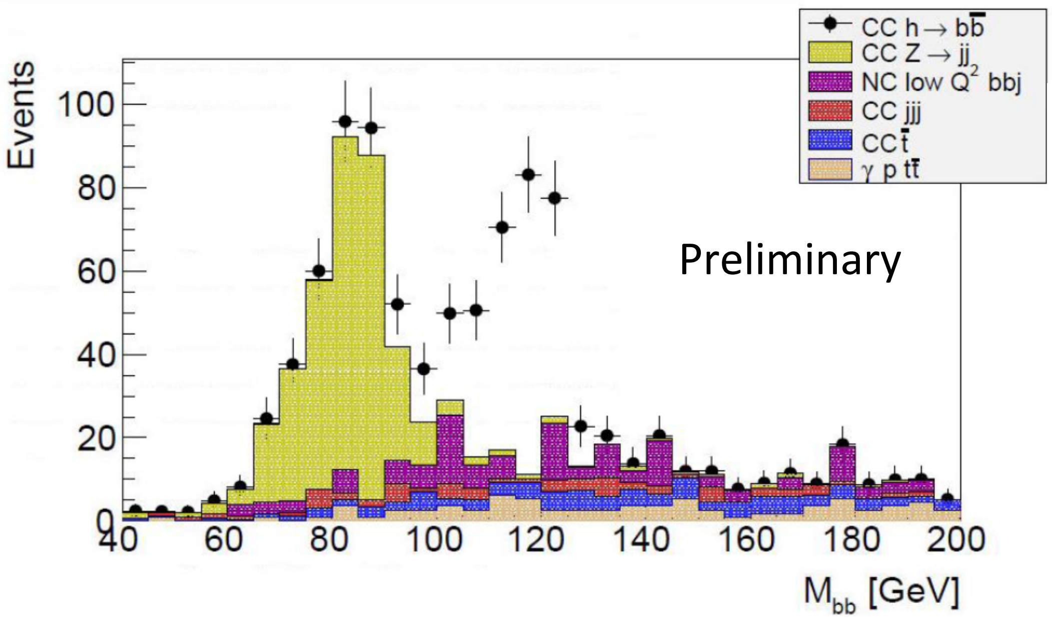
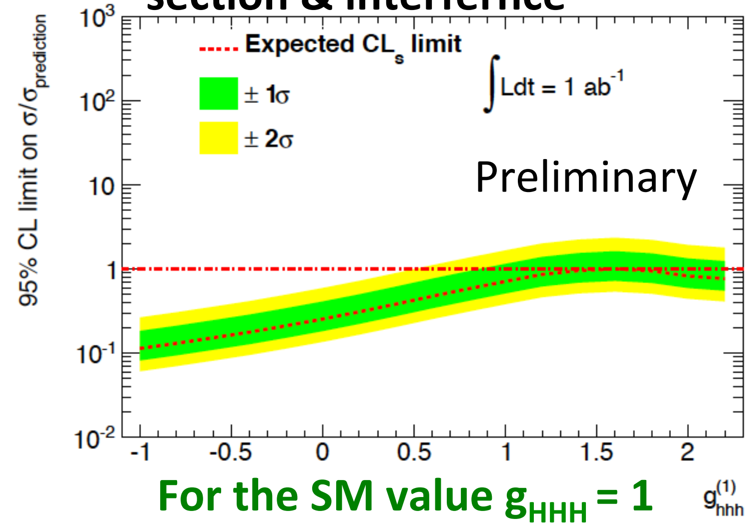






SM g_{HHH} tested via CC DIS cross section & interfernce



For the SM value g_{HHH} = 1 the H-HH coupling can be measured to 5-10 σ

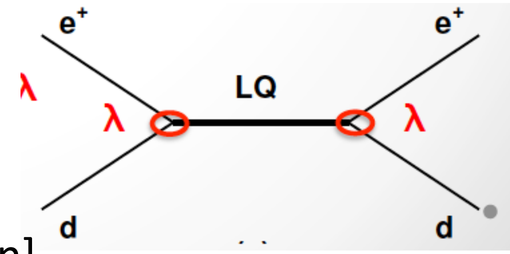
→ S/B ~1 in CC DIS → for 10 years running L=1000 fb^{-1}

→ **O(1)% precision on H-bb couplings with small thy unc.**

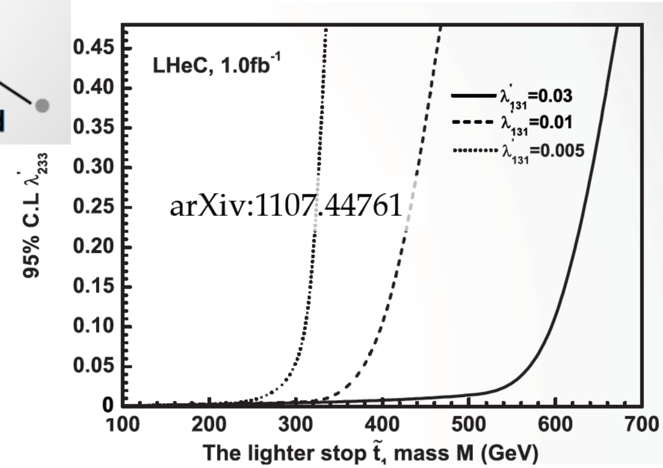
→ **60 GeV ERL for ep: Enables at low costs huge synergies with LHC and FCC Higgs programs**

Top and BSM

[Talks by Schwanenberger and Gewnlan]



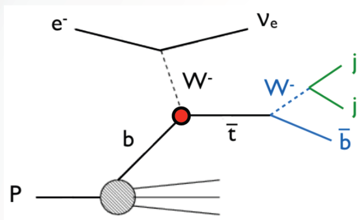
RPV SUSY – like LQ



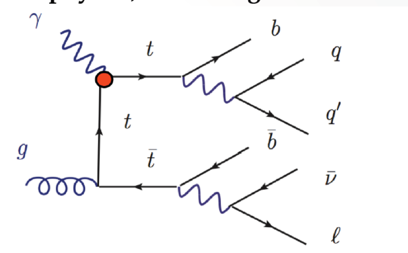
see Christian Schwanenberger's talk for more

top quark electroweak interactions

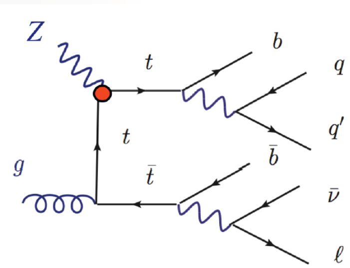
precise measurement of couplings between SM bosons and fermions sensitive test of new physics (search for deviations) : **top quark expected to be most sensitive to BSM physics, due to large mass**



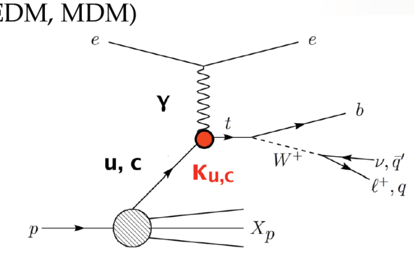
- high precision measurements of Vtb and search for anomalous Wtb couplings



- direct measurement of top quark charge an search for anomalous ttbarγ couplings (eg. EDM, MDM)

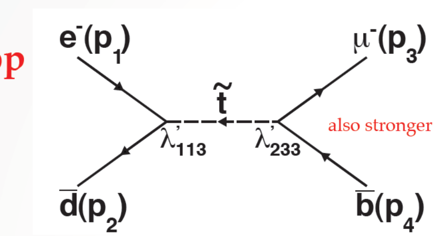


- measurement of top isospin and search for anomalous ttbarZ couplings (eg. EDM, MDM)



- sensitive search for FCNC couplings will constrain BSM models that predict FCNC (eg. SUSY, little Higgs, technicolour)

stop

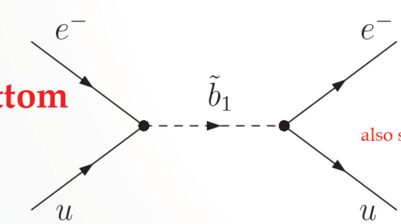


$\Lambda'_{131} < 0.03$

also stronger bounds from ββ0ν

- sensitivity up to 700 – 800 GeV with only 1fb^{-1}
- LHC will also provide constraints
- very promising with high luminosity, 100 fb^{-1}
- requires good b-tagging

sbottom



$\Lambda'_{131} < 0.02$

also stronger bounds from ββ0ν

- < 100 fb^{-1} needed for 1TeV RPV sbottom discovery

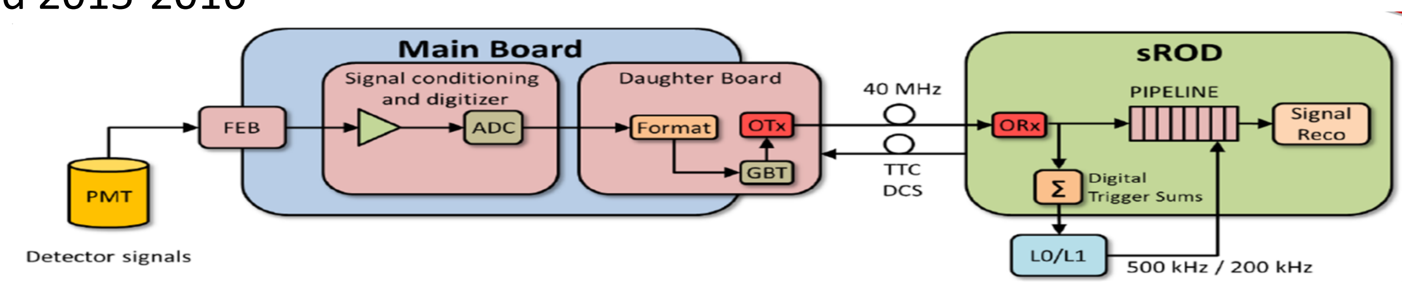
Detectors – Improvements and Upgrades

- Physics Opportunities with Forward Detector Upgrades at STAR (Z. Ye – Tues. AM)
- Physics prospects with the upgraded ATLAS detector (F. Rizatdinova – Tues. AM)
- The ATLAS Tile Calorimeter and its upgrades for the high luminosity LHC (Y. Smirnov – Tues. PM)

Detectors

<u>ATLAS @ LHC: Tile Calorimeter upgrade (*Y. Smirnov*)</u>

Higher rates expected from LHC 2023 upgrade require higher rate capability for tile calorimeter – improved, simplified readout system required – Demo sROD system to be installed 2015-2016



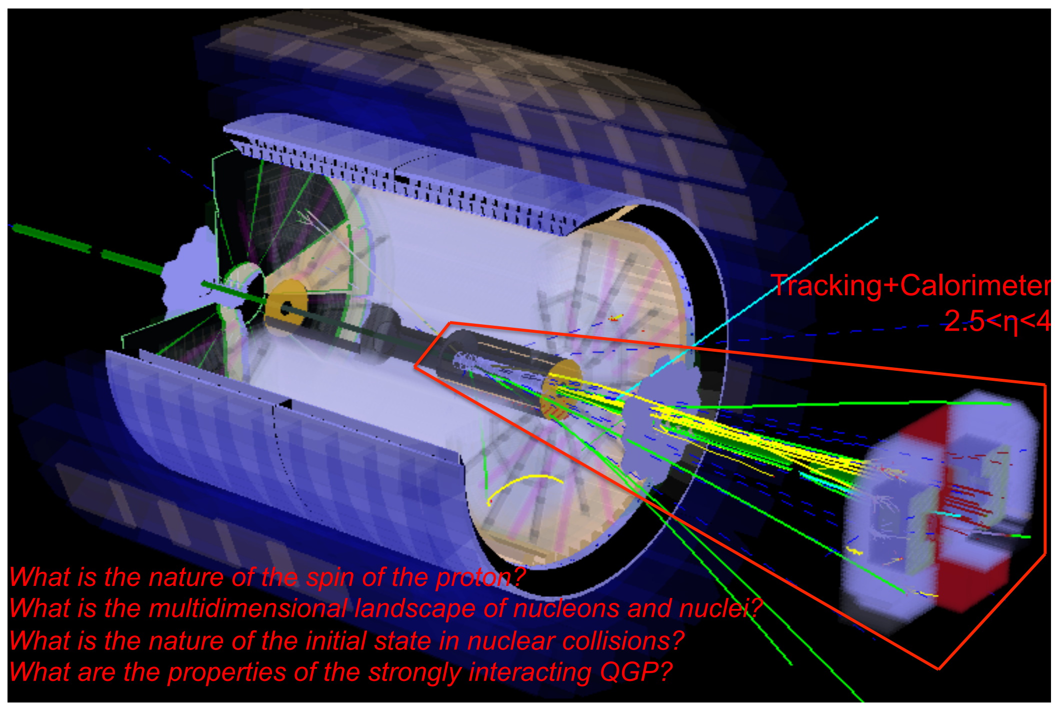
<u>STAR Detector Upgrade (*Z. Ye*)</u>

Silicon detector for forward tracking

Forward Ecal (tungsten powder, ScFi)

Forward Hcal (lead and scintillator)

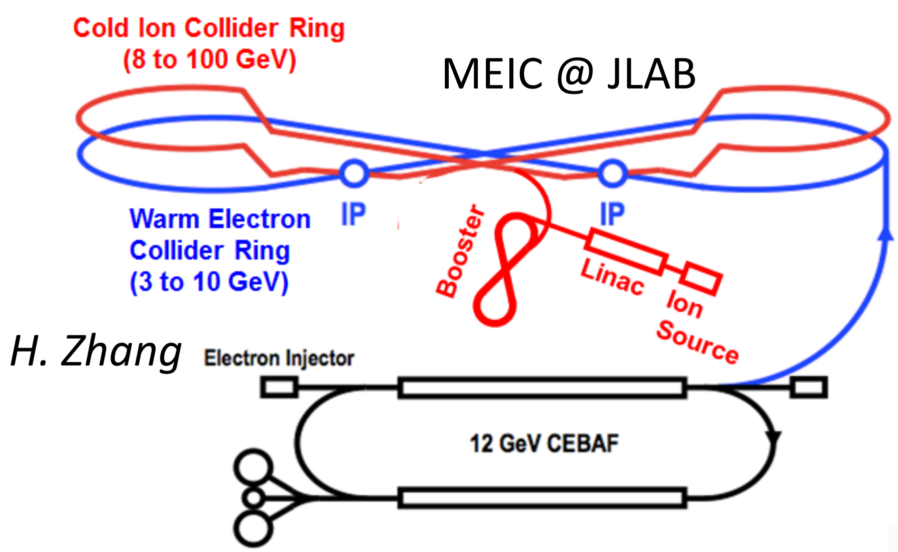
→ Forward detection capabilities will open new opportunities in transverse spin asymmetries, gluon saturation at small x and more.



New Machines – Colliders and Interaction Regions

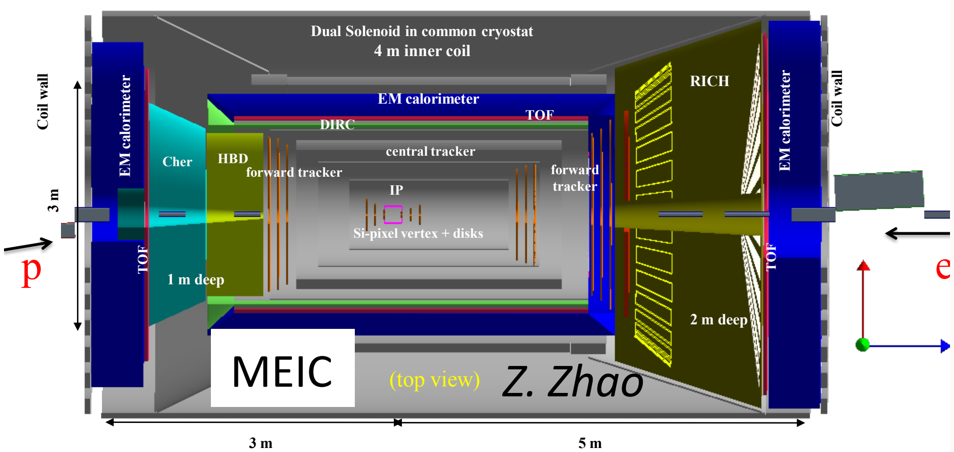
- Very high energy ep colliders
  - VHEeP: A very high energy electron-proton collider based on proton-driven plasma wakefield acceleration (M. Wing – Tues. AM)
  - The Status and Prospects of the LHeC and FCC-he Developments (A. Cruz Alaniz – Tues. AM)
  - A High Energy e-p/A Collider Based on CepC-SppC (H. Zhang for Y. Zhang – Tues. AM)
  - A detector for energy-frontier ep scattering (M. Klein – Tues. PM)
- Moderate energy ep colliders with e/p polarization
  - Medium Energy Electron Ion Collider at Jefferson Lab (H. Zhang – Tues. AM)
  - MEIC Detector and Interaction Region at JLab (Z. Zhao – Tues. PM)
  - A dedicated eRHIC Detector and Interaction Region design (A. Kiselev – Tues. PM)
  - The Evolution Of PHENIX Into An Electron Ion Collider (EIC) Experiment (N. Feege – Tues. PM)

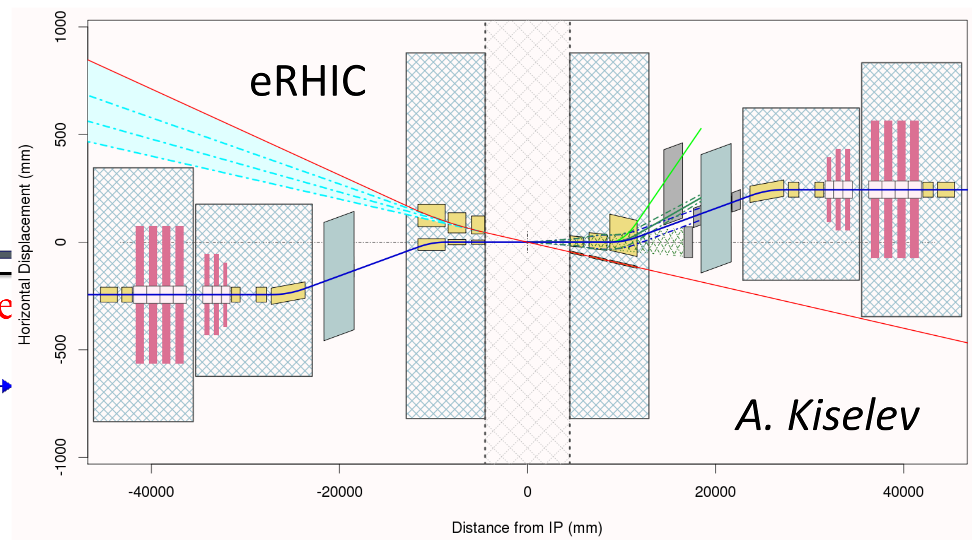
New Machines: EIC



High luminosity electron-ion colliders under development at JLab and RHIC

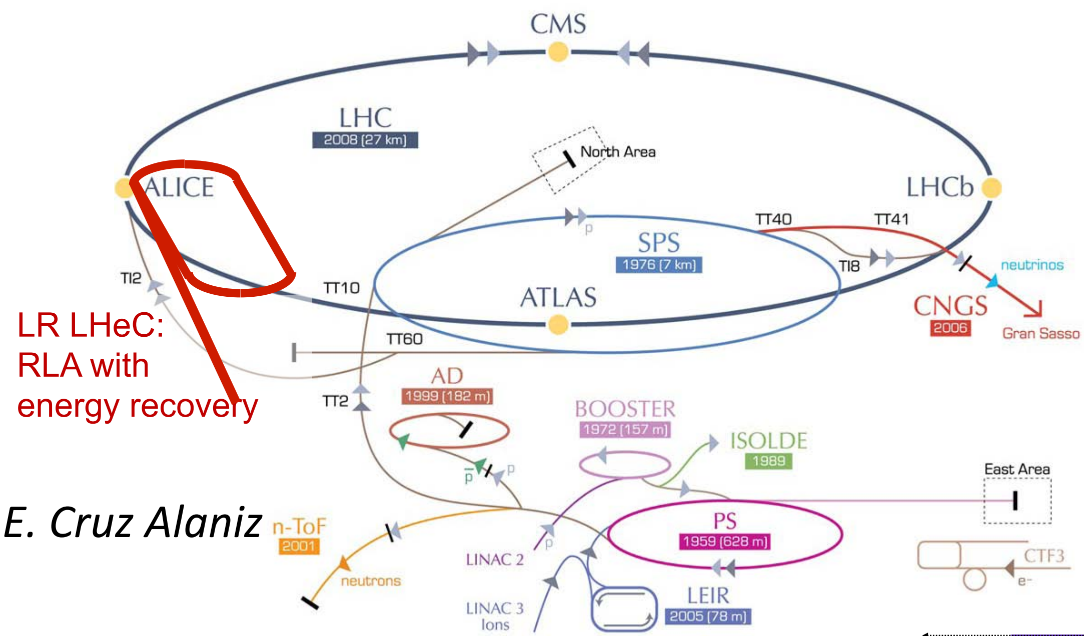
- → √s ~ 15-65 GeV (MEIC) 77-141 (eRHIC)
- → High polarization of both electrons and ions
- → Luminosity → 5 10^{33} – 1 10^{34} cm^{-2} s^{-1}
- → Study quarks, gluons at x smaller than valence region





Careful design and integration of interaction regions required!

New Machines: LHeC



E. Cruz Alaniz

60 GeV electrons from ERL incident on protons from LHC

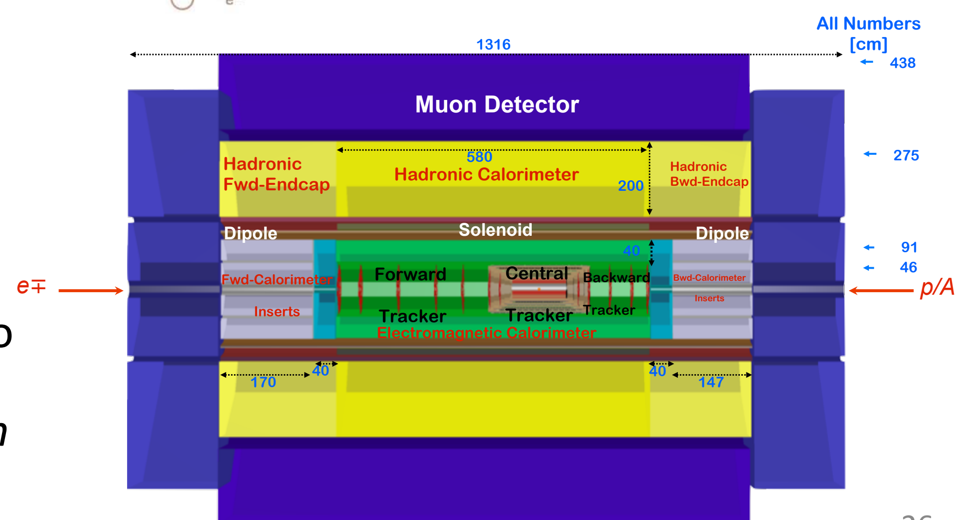
→ L ~ $10^{33} – 10^{34}$ cm^{-2} s^{-1}

→ Designed to run simultaneously with LHC

→ ERL test facility under development

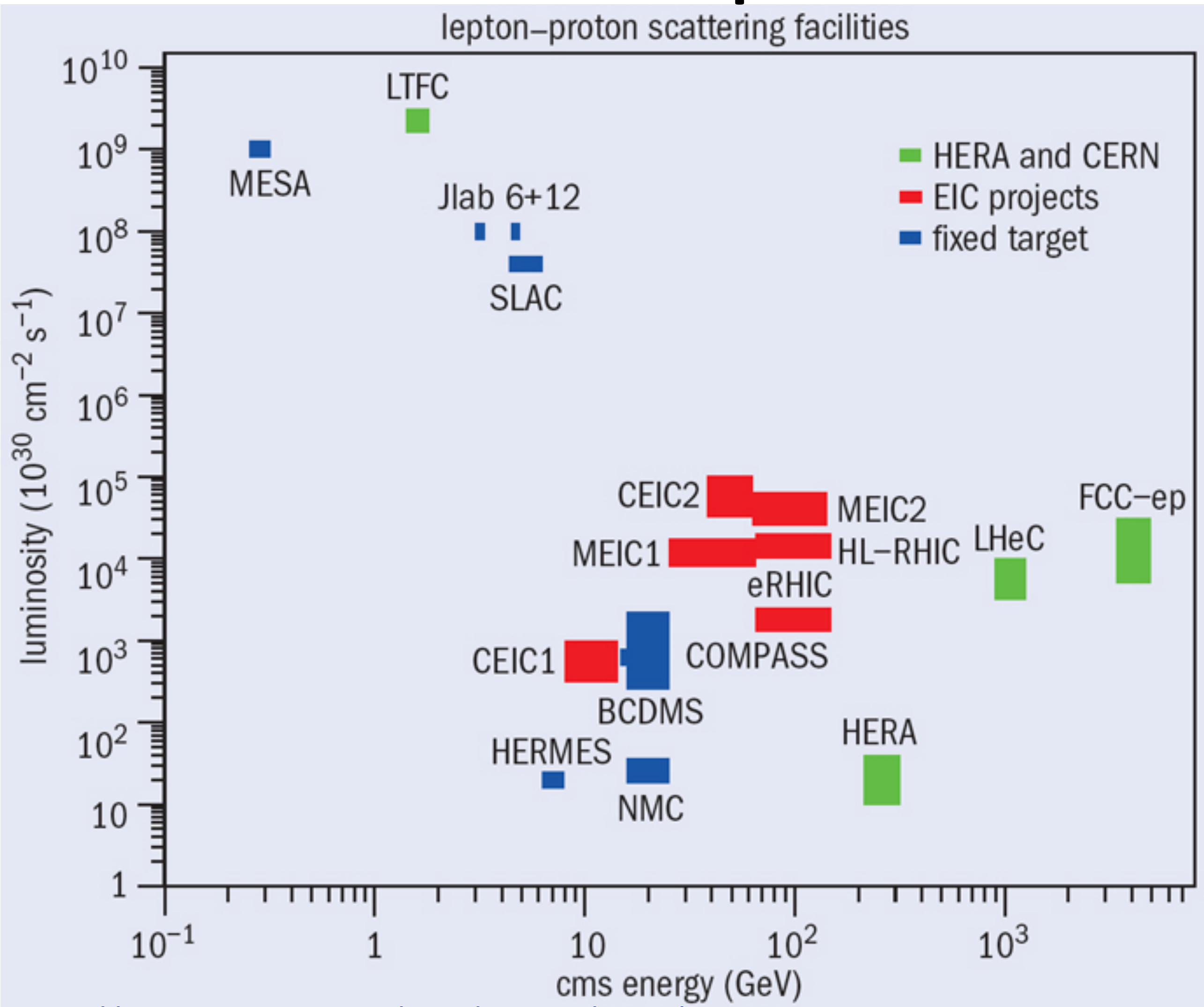
Design of full acceptance detector underway – radiation smaller, no ep pileup makes life easier as compared to LHC

M. Klein



Roundtable discussion : Future lepton-hadron colliders: synergies and complementarity

The Landscape : Luminosity vs √s



http://cerncourier.com/cws/article/cern/57304

China

CEIC1 = Chinese version of Electron-Ion Collider

("A dilution-free mini-COMPASS")

U.S.

MEIC1 = **EIC**@Jlab

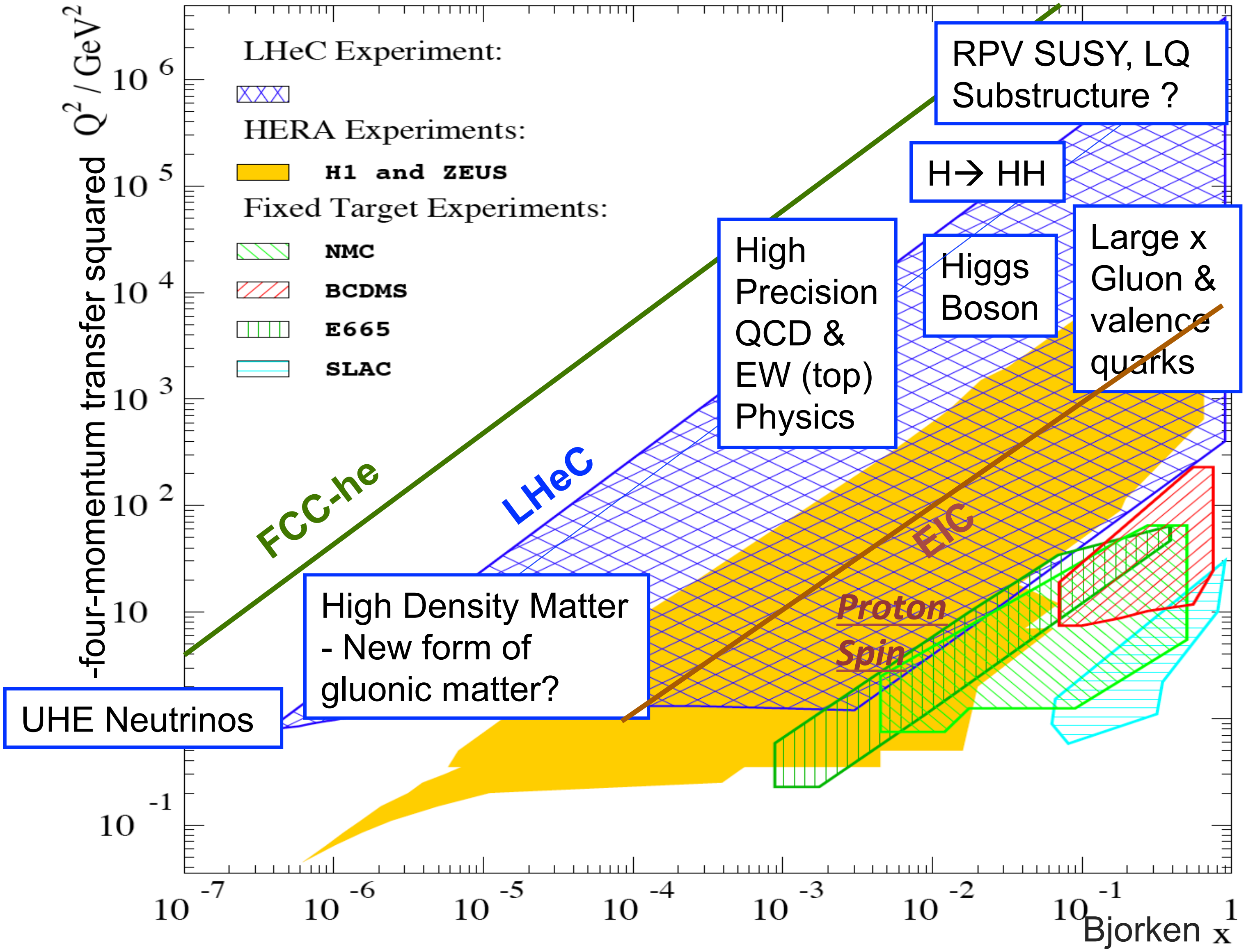
eRHIC = **EIC**@BNL

Europe

LHeC = ep/eA collider @ CERN

CEIC2
MEIC2
HL-eRHIC
FCC-he
} future extensions

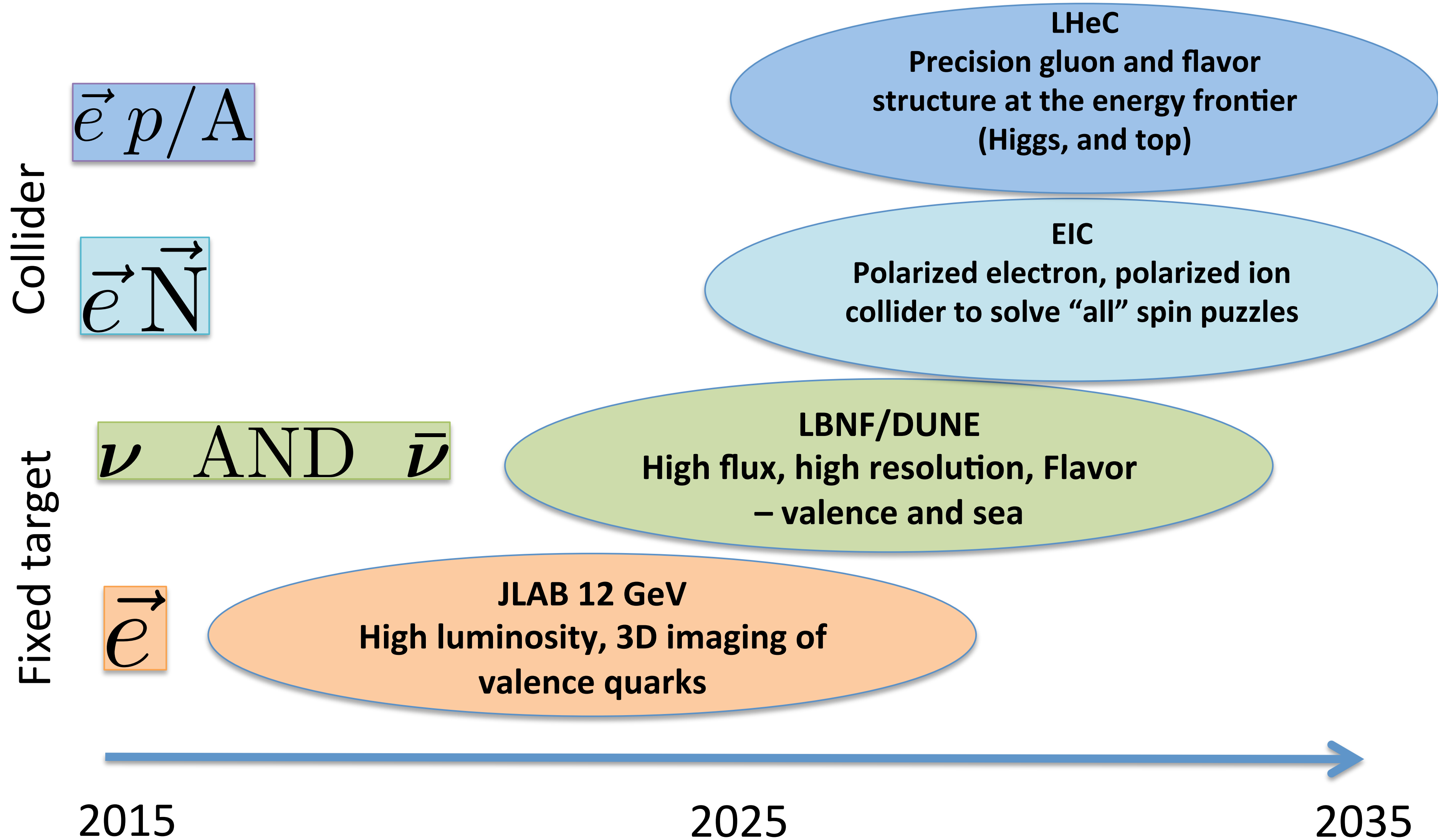
Roundtable discussion : Future lepton-hadron colliders: synergies and complementarity



"Action items"

- Quantify clear impact cases, e.g. synergies for UHE neutrino fluxes, HL-LHC etc.
  → put polarized and unpolarized PDF projections to LHAPDF
- Joint effort for polarized positron sources
- Map clearly the complementarity of projects
  → physics highlights on two slides or one poster (webpage)

Landscape of the DIS Future



Probing the QCD and Electroweak sector of the Standard Model with unprecedented precision

Thank you!

- Thanks to all the speakers for their interesting and exciting contributions.
- Thanks to all the participants for their attention and lively discussions!

The future of DIS will be very bright -
it needs us to make it happen