Future Nuclear Physics Options at BNL

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April 30, 2012

I. Tribble Subpanel II – How Did U.S. Nuclear Physics Get Into This Mess?

II. Defending RHIC's Future

III. Contingency Plans and Options

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science

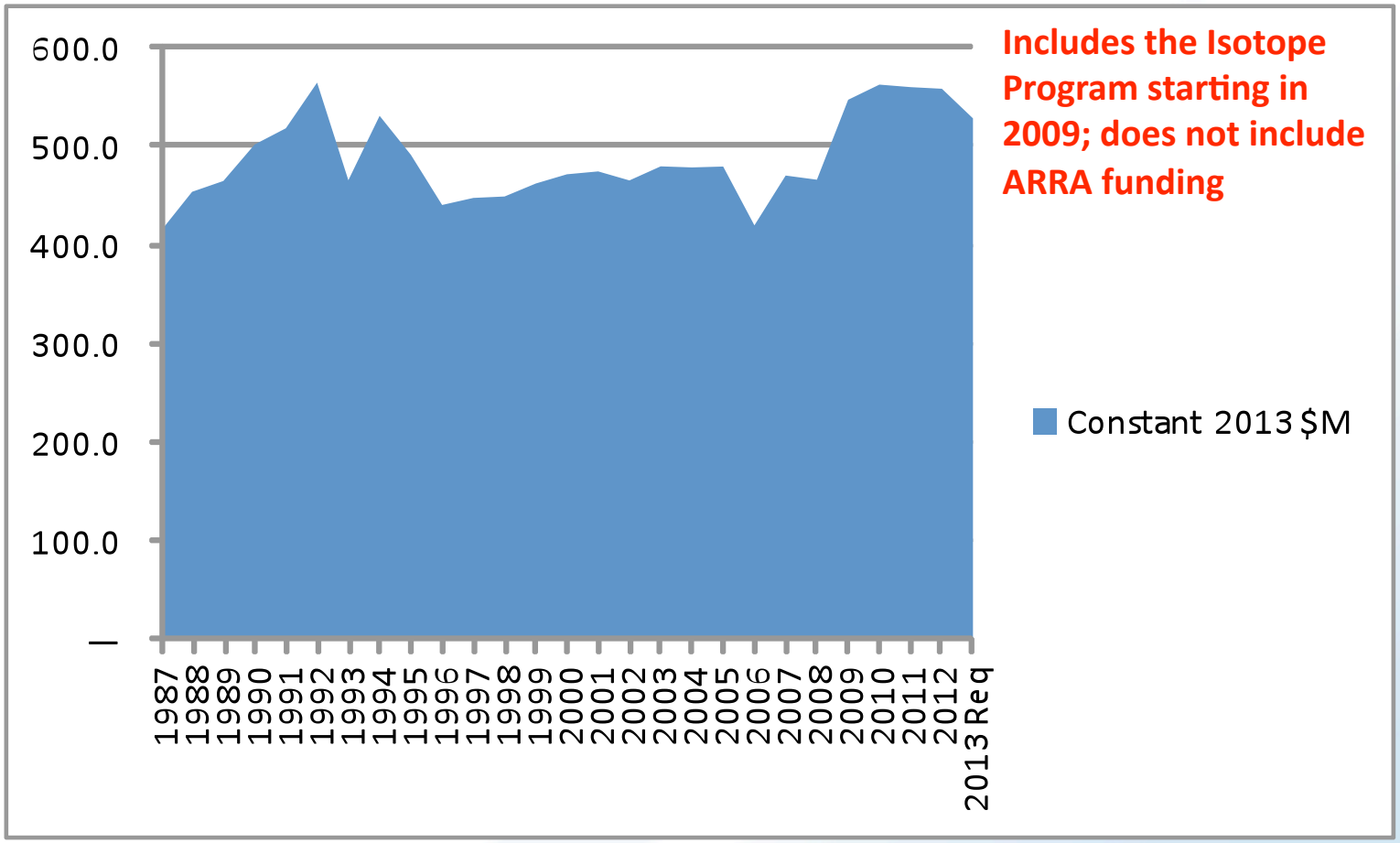
Quotes From the 2007 LRP

When faced with a choice of improving research funding or developing our facilities, **the consensus, as exemplified in the recommendations, was to maintain a near constant level of effort for the research program and facility operations, based on the FY2008 President's budget request, and to invest additional resources in the tools needed to make new discoveries in the future.**

Implementing the four principal recommendations of this Plan can be accomplished with a funding profile consistent with doubling the DOE's Office of Nuclear Physics budget, in actual year dollars, over the next decade, together with NSF funding for DUSEL including some of the equipment for experiments to be carried out in DUSEL.

Constant effort funding falls far below the level needed to carry out the four recommendations in the Plan. … If budgets were restricted to constant effort, proceeding with any of the new initiatives presented in this Plan would be possible only by reduced funding for operations and research, with clear adverse and potentially dire consequences for core components of the U.S. nuclear physics program. Since nuclear science, like all areas of basic research, evolves in time, it is impossible now to forecast what strategy would minimize damage to the field if future budgets dictated such stark choices.

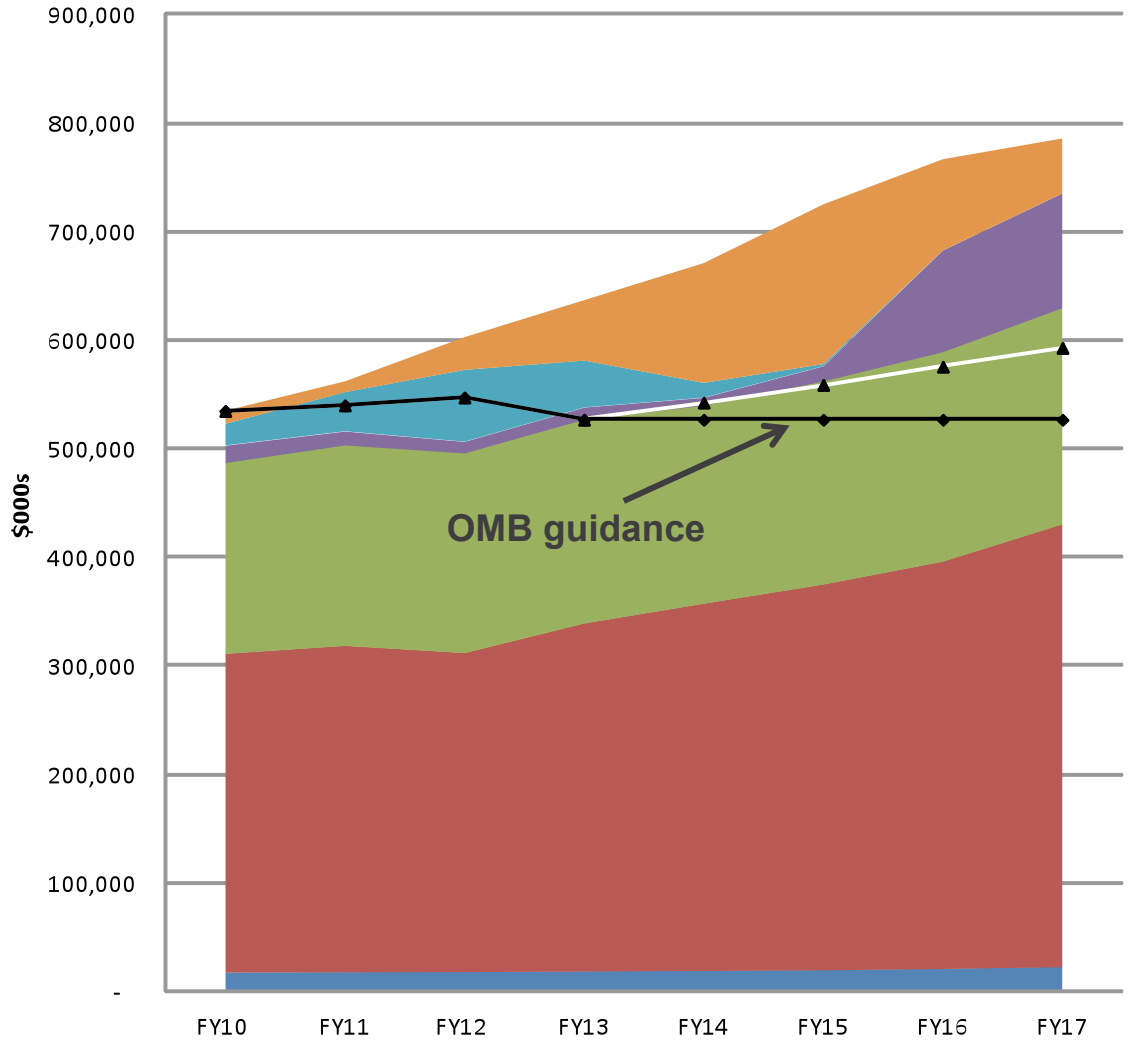
DOE Nuclear Physics Funding
1987-2013
(in constant dollars)



Bottom line: ~constant effort budget for field over past 25 years, with occasional bumps that raise the community's hopes, but no real sign of budget doubling!

Defining the ONP Problem

- This chart reflects the estimated funding needed to implement the majority of elements of the NSAC 2007 Long Range Plan (LRP) – not including EIC.
- The FY 2013 Congressional Request is reflected as two lines, one assuming 3% cost-of-living into the outyears and the other assuming flat funding into the outyears.



- ***FY13 shortfall ~$100M → ~$250M by FY17***
- ***Requires serious re-prioritization by NSAC***
- ***NSAC process will complete by Jan. 2013***
- ***Poses clear & present danger for RHIC ops.***

NSAC Charge to Tribble SubPanel II

We seek advice from NSAC on implementing the priorities and recommendations of the 2007 Long Range Plan in light of projected budgetary constraints and for guidance on developing a plan to implement the highest priority science in the context of likely available funding and world-wide capabilities. We request that NSAC examine the existing research capabilities and scientific efforts, assess their role and potential for scientific advancements, and advise the two agencies regarding the time and resources needed to achieve the planned programs. Your report should describe how to optimize the overall nuclear science program over the next five years (FY 2014-2018), under at least the following funding scenarios for the nuclear science budgets at the two agencies: (1) flat funding at the FY 2013 request level, and (2) modest increases over the next five years.

NSAC should submit the report by January 2013.

House and Senate E&W subcommittees, in marking up FY13 budget (both add $3-5M for RHIC ops.), call for NSAC process – e.g., Senate E&W markup says:

The Committee believes that the budget request puts at risk all major research and facility operations activities without significantly advancing nuclear physics goals. … The Committee directs the Office of Science to charge the Nuclear Physics Advisory Committee to submit a report by December 1, 2012 to the Office of Science and the Committee that proposes research and development activities for nuclear, physics under a flat budget scenario over the next 5 fiscal years. **The report should specifically identify priorities for facility construction and facility decommissioning to meet those priorities.**

My Interpretation of Budget Scenarios in NSAC Charge

Flat-flat budgets FY14-18:

- **Cannot support operations at more than one major U.S. facility**
- **Cannot support FRIB construction**
- **Would lead to severe loss of U.S. leadership in Nuclear Physics research, which needs to be spelled out compellingly in Tribble report**
- **But beware of "Trojan budget guidance": history suggests that termination of a large operating facility leads to permanent loss of funds from the field ⇒ budgets likely worse than flat-flat in this scenario**

"Modest budget increases":

- **Enough to support ops of 2 major facilities or ops @ 1 + constr'n of 2nd**
- **Still likely requires somewhat better than cost-of-living increases**
- **Still leads to reduction in U.S. research scope and leadership**
- **Trojan guidance comment still applies if major facility ops. terminated**

I hope Tribble Panel also presents and defends "best responsible budget":

- **Would support ops. at 2 facilities + construction of 3rd (FRIB now, EIC later), with adiabatic transition to 2-major-facility future (1 QCD + 1 nuclear structure/astro)**

Implications for BNL: plan for and vigorously defend robust RHIC ops. and transition to eRHIC, while also responsibly evaluating backup plans…

Basic Elements of the RHIC Case to be Made to NSAC LRP Implementation Sub-Panel

- ***Outstanding scientific track record:*** *string of important discoveries; steep learning curve in new area of science, with great recent experimental and theoretical progress; attracts wide interest outside of NP community (with statistics, connections to back this up)*
- ***Just completed facility upgrades:*** *cost-effective approach cut ~$80M and 4 years off LRP version; led to breakthroughs in accelerator S&T*
- ***Essential role in compelling upcoming science program:*** *science questions that can only be addressed at RHIC; technical features that LHC is unlikely to reproduce; uniqueness of spin program*
- ***Provides NP community with viable path to 2-facility long-term future:*** *science case for EIC; cost-effective technical path to eRHIC; importance of not closing out path to long-term future in dealing with short-term budget crises*
- ***Strongly engaged international user community:*** *RIKEN on verge of 6-year extension of present support for RBRC/RHIC; international interest in eRHIC*
- ***Last collider in U.S. serves as base for cutting-edge accelerator R&D:*** *past & present examples; spin-offs of accelerator R&D*
- ***Enormous losses for field if RHIC is terminated:*** *concise summary*
- ***Cost savings limited in reality:*** *very high RHIC D&D costs; likely permanent loss of funds to the field if RHIC operations terminated*

Possible Backup Plan Elements in NPP to Handle Suspension of RHIC Operations

Philosophy:

- ❑Keep RHIC ready for later incorporation in eRHIC
- ❑Maintain aggressive pursuit of eRHIC R&D, also relevant for XFEL
- ❑Focus NP research at BNL on proton Electric Dipole Moment (pEDM) exp't and ATLAS heavy-ion collisions (+ eRHIC science planning)

Details:

- LINAC, Booster, EBIS operate for isotope production and NSRL.
- AGS available for beam transport for pEDM experiment.
- RHIC ring maintained at liquid nitrogen temperatures.
- ~$1M annual upgrades to electrical infrastructure continue.
- Critical systems/components exercised periodically to ensure operational readiness.
- Facility cleanup continues at current level in building 912.
- Essential equipment updates continue to meet evolving operational and safety standards.
- eRHIC R&D continues at annual $1.5M for M&S and 25 FTE's.
- RHIC detectors maintained in a functional state.
- Design, construct (~$100M project, over & above ~$90M ops+research budget) and eventually operate (~2018-2021) pEDM experiment and storage ring – needs OPPIS, Linac, Booster, AGS, but not RHIC

Plan A Initiative: RHIC-II Science Program

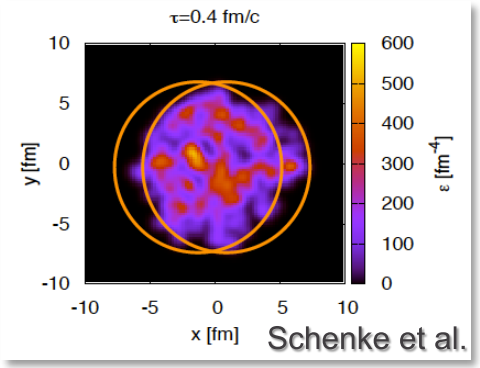
- Brief Description of Initiative: ***exploit RHIC luminosity and detector upgrades (fully funded through FY14) to quantify quark-gluon plasma physics – how perfect a liquid? Transport properties from below to above QGP transition? Role of quantum fluctuations? Critical end-point in QCD phase diagram? QGP response to parton energy loss?...***

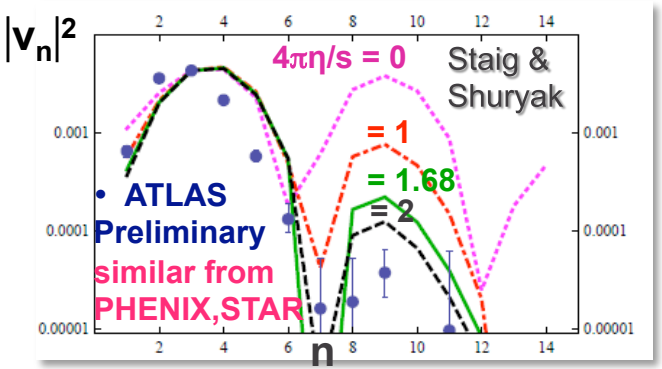
- Strategic Value to BNL: ***extends BNL world leadership in NP and understanding of unique emergent QCD phenomena; maintains RHIC user base > 1000; retains core accelerator S&T staff; provides path to a long-term QCD facility future; keeps healthy overhead revenue***

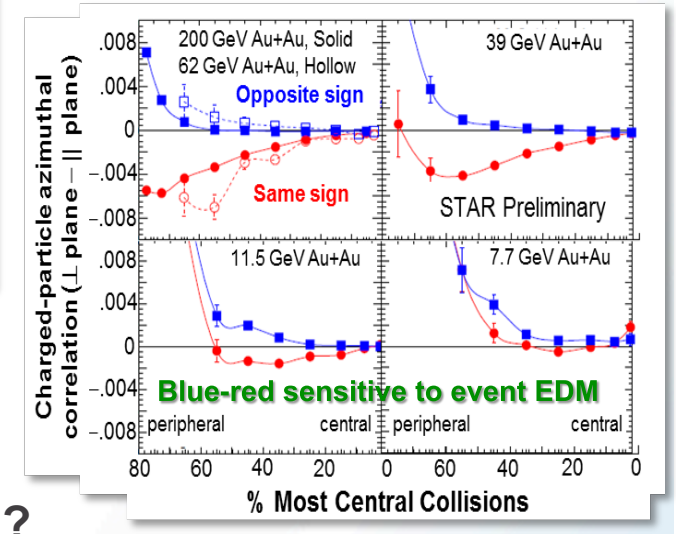
- Challenges: ***ONP funding in FRIB construction era; LHC competition (need to emphasize RHIC's unique advantages, including polarized pp collisions); need major (~$20M ONP funds) upgrade to expand PHENIX acceptance by ~2018***

- Risks: ***main BNL support needed to keep cost of doing business and power costs manageable during tight-budget era; if ONP determines that RHIC is too expensive to operate, we go to plan B…***

RHIC's 2nd Decade: Quantifying Unique Emergent Phenomena in QCD Matter







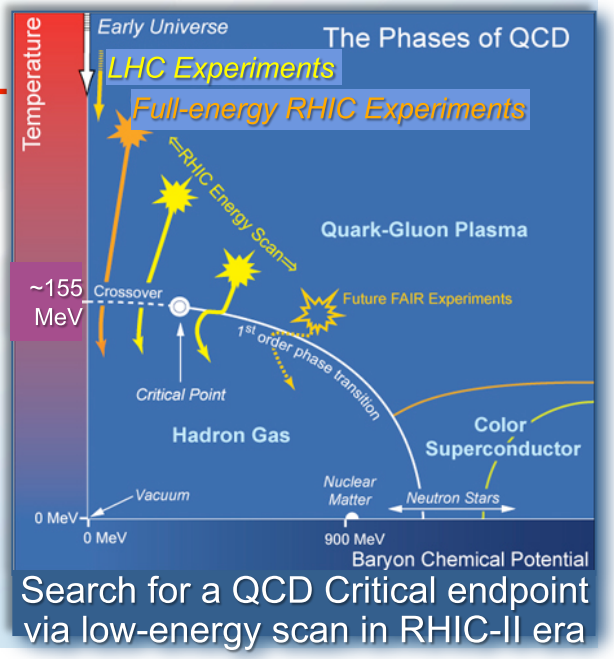
- **How perfect is the near-perfect liquid?**
  Fourier power spectra for collective flow, above & below deconfinement transition (energy "sweet spot" @ RHIC)

How do fluctuations affect "mini-universe" evolution?

Initial density fluctuations: Odd vs. even flow for symmetric & asymmetric collisions

Excited QCD vacuum fluctuations: Further tests of event-by-event CP violation, including U+U collisions

- **Is there a critical endpoint in the QCD phase diagram?**
  Critical fluctuations in conserved quantity distrib'ns vs. √s
- **How do quarks and gluons lose energy in QGP?**
  Jet quenching vs. √s, parton flavor, system size, orientation
- **Where is the "missing" proton spin?**
  Di-jet, W and Drell-Yan prod'n in polarized pp



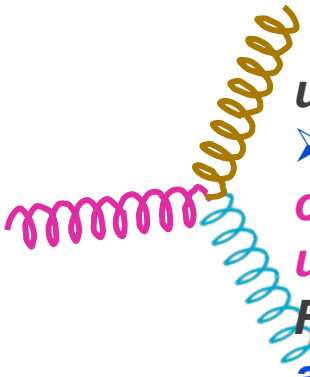
Search for a QCD Critical endpoint via low-energy scan in RHIC-II era

All exploit RHIC's unique capabilities!

Plan A or B Initiative: eRHIC

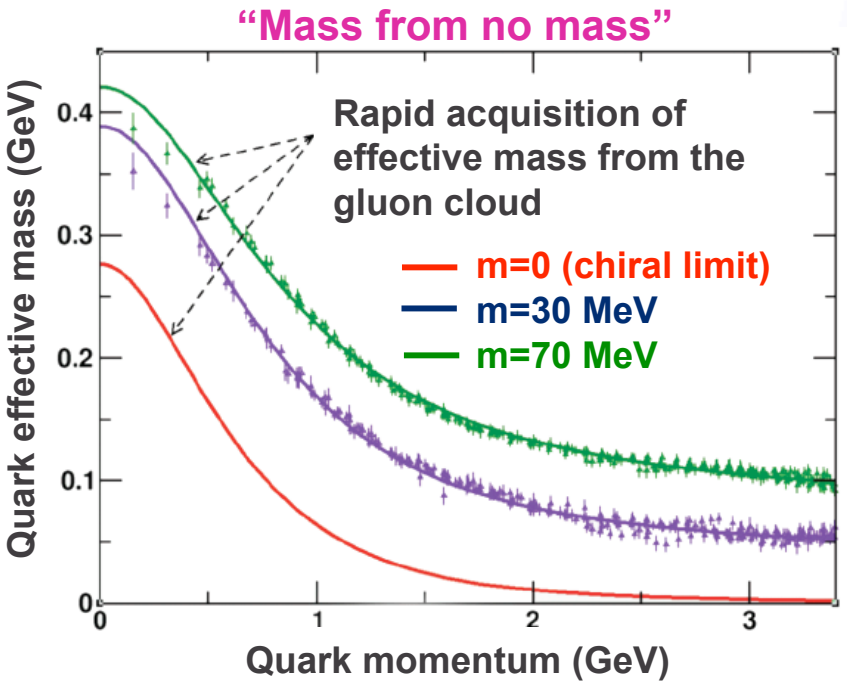
- Brief Description of Initiative: ***add electron 5-10 GeV Energy Recovery Linac in RHIC tunnel to provide e+A and polarized e+p,^{3}He collisions to probe and image the structure of cold, gluon-dominated nuclear matter; upgrade STAR and PHENIX accordingly, or develop new optimized detector (more costly)***
- Strategic Value to BNL: ***extends BNL world leadership in NP to community-identified "next QCD frontier"; keeps RHIC staff and user base healthy into 3rd decade; maintains BNL as 2-major user facility laboratory; keeps BNL at cutting edge of accelerator technology***
- Challenges: ***Convincing community, DOE and Congress that science goals are worth the cost; keeping Total Project Cost < $600M; JLab competition; keeping core accelerator staff during upcoming tight-budget decade; many acute technical challenges (high-power ERL, Coherent electron Cooling, crab cavity development, unique SC magnet demands, …); balancing R&D needs against ongoing RHIC operations needs; maintaining user base during 2-3 year RHIC shutdown***
- Risks: ***rely on NSLS-II like construction overhead rates ⇒ healthy over-head revenues from other directorates; needs very strong support from next NPP ALD; if we do not succeed with eRHIC, need Plan C (e.g., ERL-based XFEL) for 2020's!***

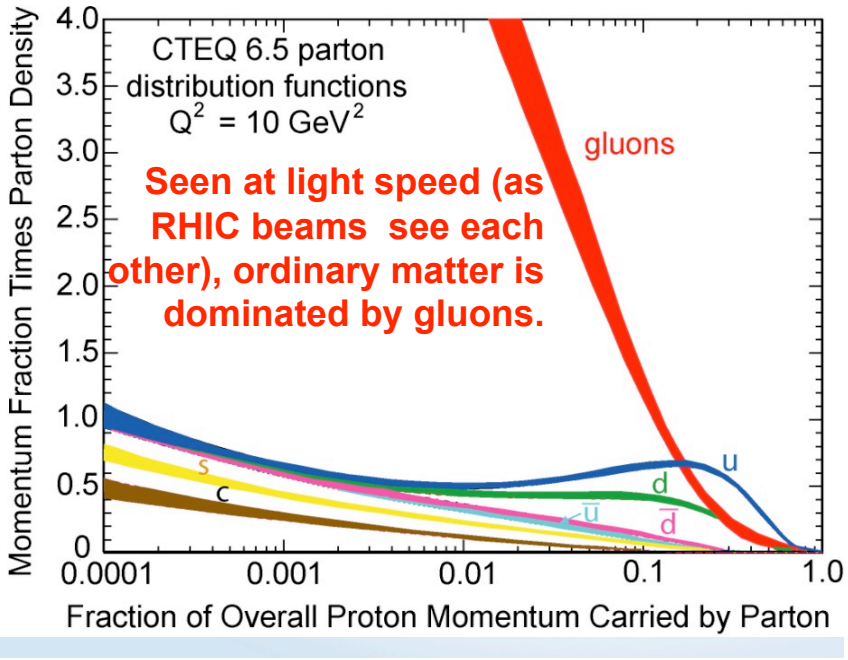
Illustrative Questions for Cold QCD Matter



Gluon self-interactions ⇒ unique features of QCD, e.g.:

- ***Gluon Proliferation ("A small color charge, in isolation, builds up a big color thundercloud…", F. Wilczek), accounting for nearly all the mass of the visible universe***
- ***Gluon Self-Regulation – gg → g recombination tames untenable growth of soft gluon density from g → gg gluon splitting***



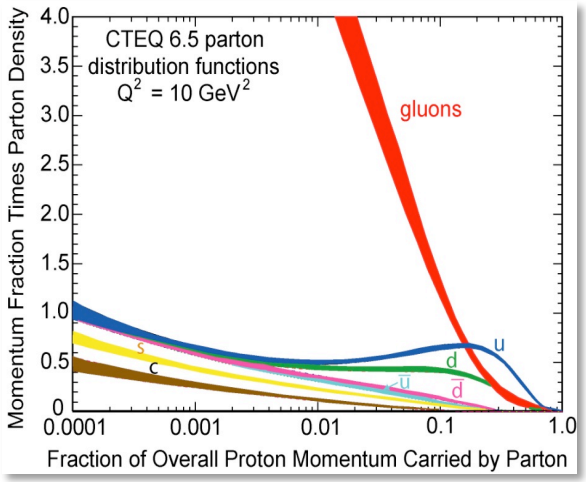


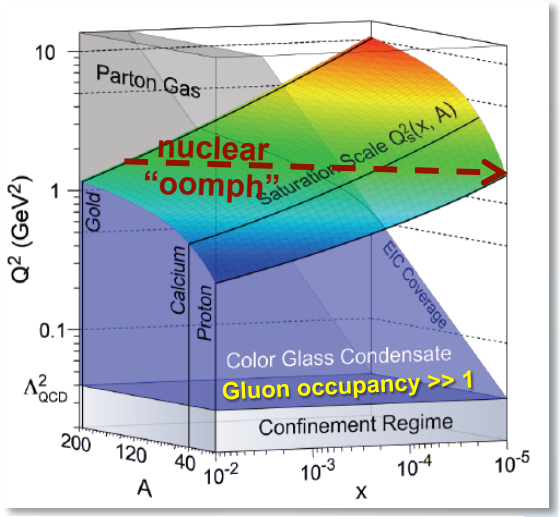
1) ***Do gluon self-interactions ⇒ "universal" saturated gluon matter at the heart of all hadrons/nuclei viewed at light speed?***
2) ***How are quarks and gluons distributed – in momentum, in space, in spin, in flavor – within the gluon-dominated regime?***
3) ***Can very soft gluons account for the proton's "missing" spin?***
4) ***Can we gain insight into the highly non-linear behavior of dense gluonic matter from an effective field theory approach?***

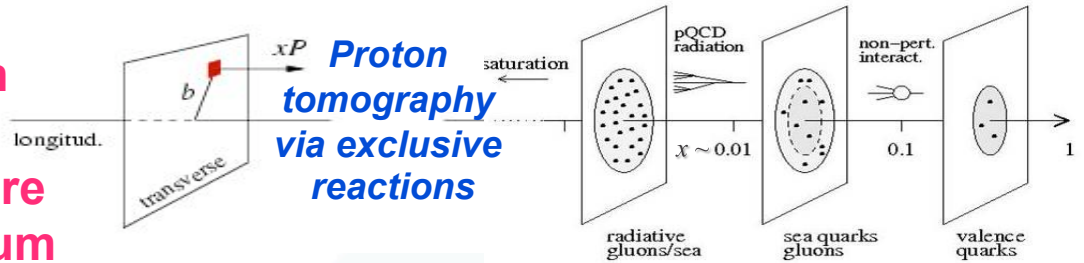
Electron-Ion Collider (EIC) Extends JLab and RHIC Science

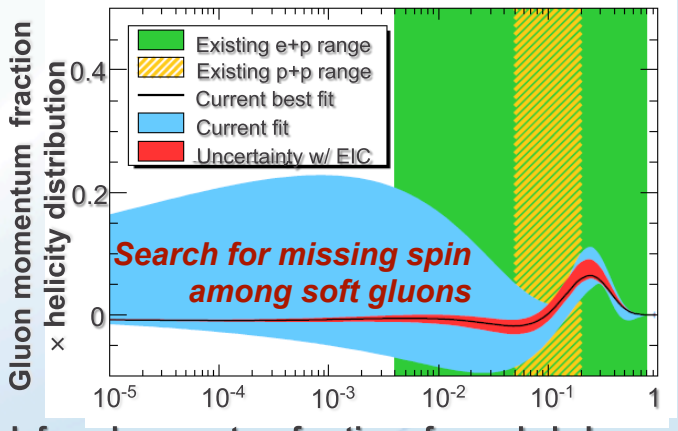
EIC = high-resolution femtoscope for cold gluon-dominated matter:

- **Probe the momentum-dependence of onset of saturation in nuclei (initial state @ RHIC & LHC)**
- **Map the gluon densities and multidimensional spatial & spin distributions of partons in the gluon-dominated regime, explore parton orbital angular momentum**
- **Test effective theory approaches to highly non-linear, high-density & strong-field limit of QCD**



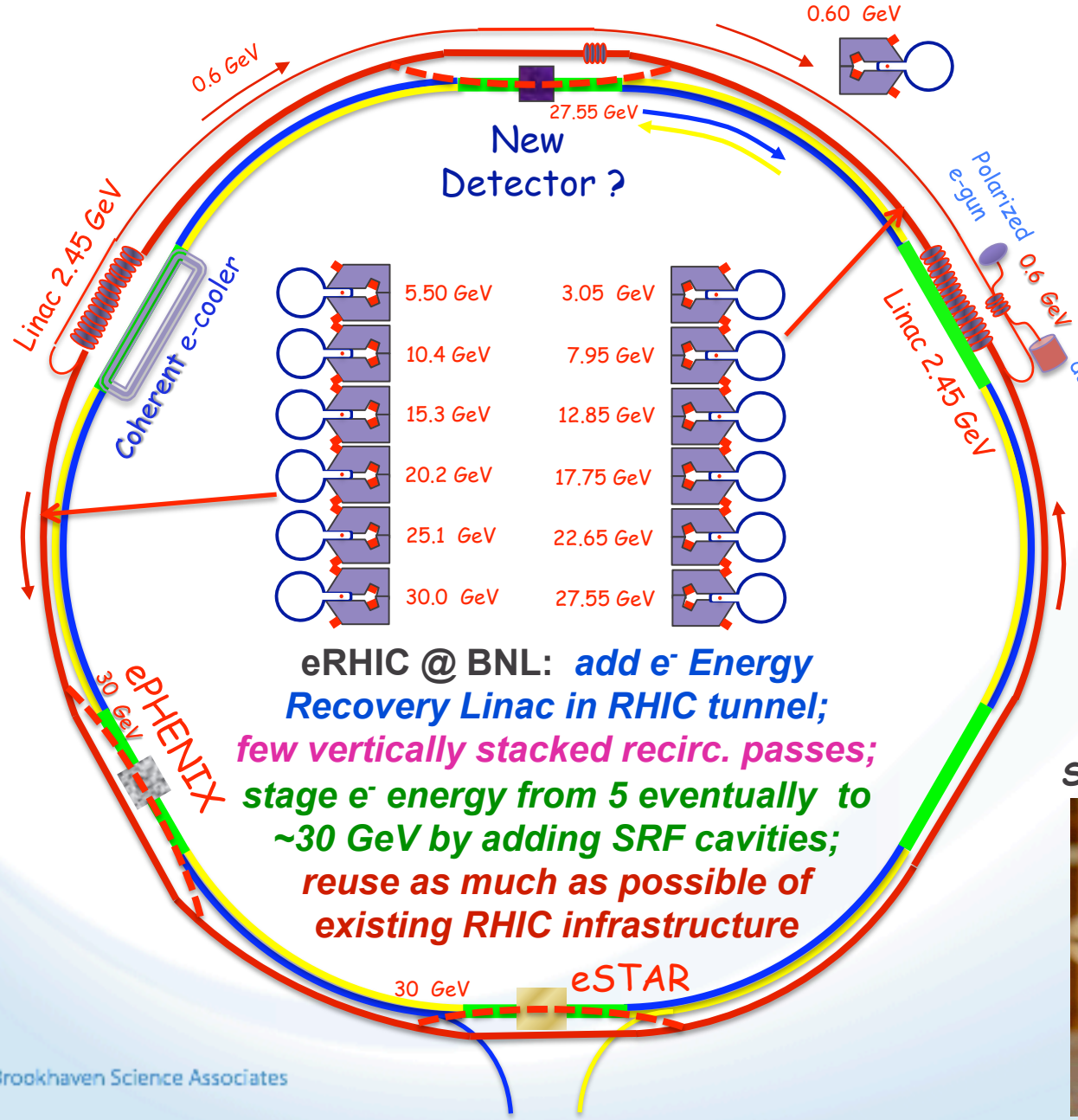






Machine requirements: high √s (~100 GeV); high luminosity (~10^{34} cm^{-2}s^{-1}); polarized electron and nucleon beams; heavy-ion beams (to A~200); large variable energy range for F_L.

RHIC's 3rd Decade: Reinvention as eRHIC



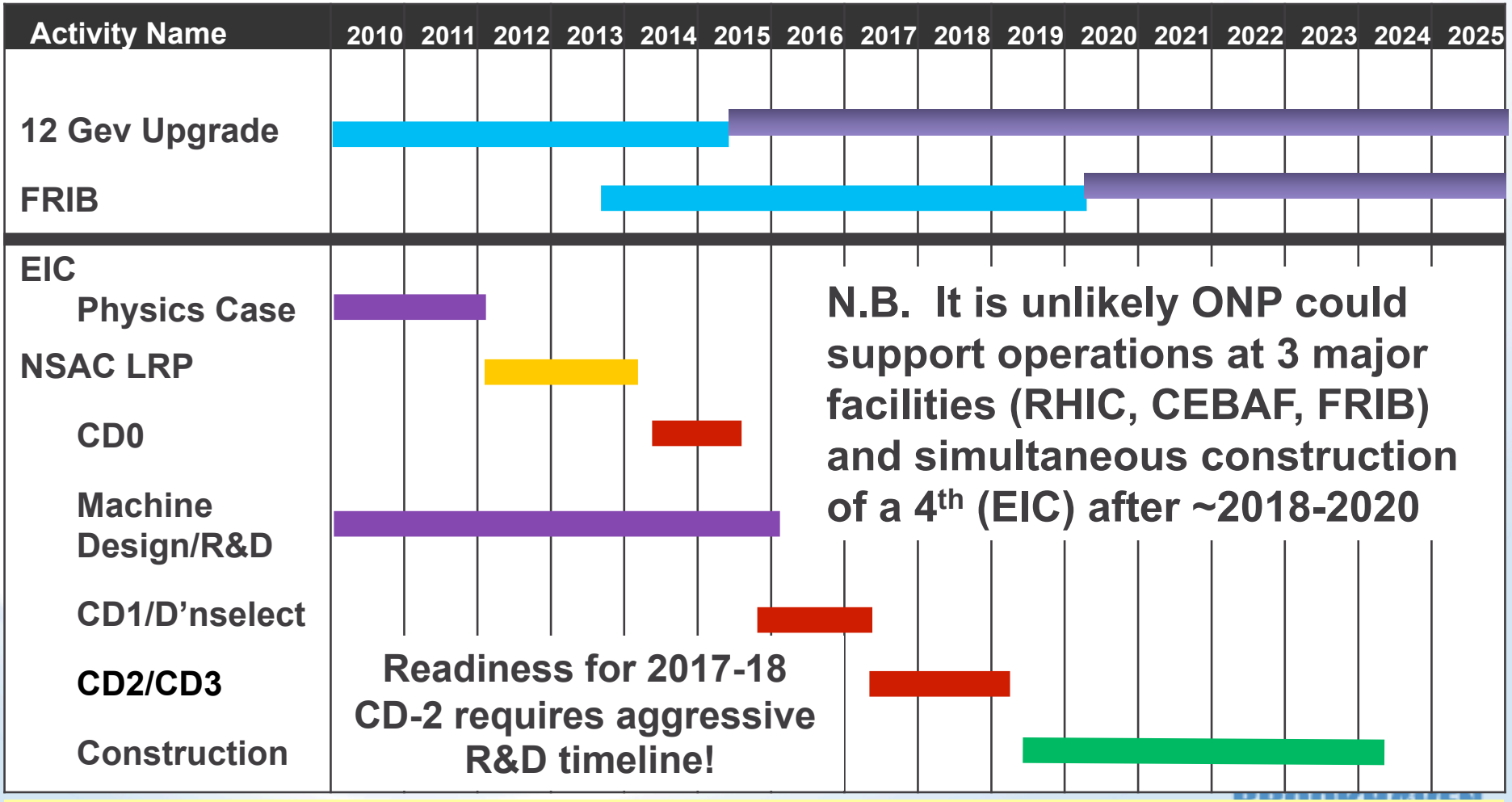
eRHIC @ BNL: ***add e⁻ Energy Recovery Linac in RHIC tunnel; few vertically stacked recirc. passes; stage e⁻ energy from 5 eventually to ~30 GeV by adding SRF cavities; reuse as much as possible of existing RHIC infrastructure***

- ***Design capable of meeting performance requirements, with straightforward upgrade path***
- ***Vigorous R&D program necessary to demonstrate many novel aspects***
- ***Can 1st stage fit within DOE guidance of ~$600M?***
- ***Technical review Aug. 1-3, 2011; cost review early 2012***

Small gap (~5 mm) dipoles and quadrupoles

Financial Constraints: Potential EIC Timeline from Hugh Montgomery (INT Workshop, Sept. 2010)

EIC Realization Imagined

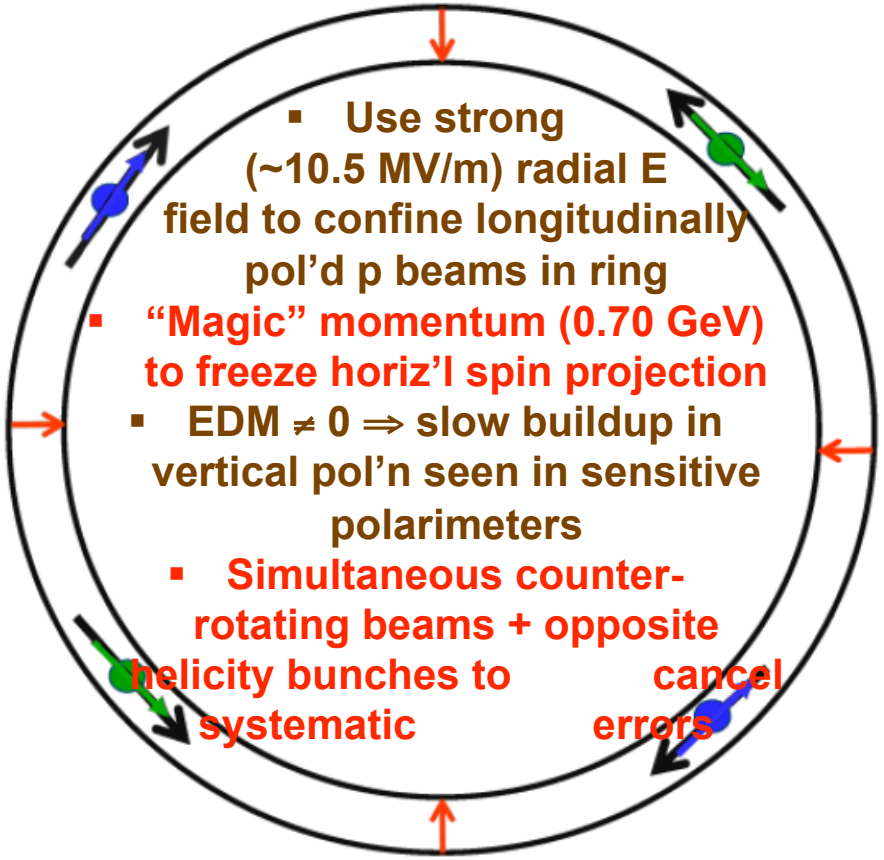


Challenge: ***balance R&D needs against RHIC operations demands***

Plan B Initiative: Proton EDM Experiment

- Brief Description of Initiative: ***construct novel purely electrostatic ring to store longitudinally polarized protons at "magic" momentum of 700 MeV/c. Beams to be injected from AGS Booster, via AGS, into new ring. Carry out experiment searching for vertical spin precession of stored beam to improve by 5 orders of magnitude on existing sensitivity to proton intrinsic electric dipole moment (EDM), in search of CP violation and matter-antimatter asymmetry beyond Standard Model.***
- Strategic Value to BNL: ***maintains challenging, high risk/high-payoff programs in NP and AST even if RHIC operations are terminated; provides science output needed to justify large ONP investment in "suspending" RHIC; provides interesting alternative program for some of RHIC spin community and interesting complement to neutrino CPV.***
- Challenges: ***achieving ~$100M construction funding in tight budget climate; getting funding on sufficiently short time scale to avoid >3-year gap in accelerator ops. at C-AD; strong technical challenges (stable high E-fields, beyond state-of-art beam position monitoring, under-standing beam-ring interaction at 10^{-29} e·cm sensitivity level).***
- Risks: ***reaching desired sensitivity might well require two generations of exp't; failure to attract funding for pEDM if RHIC ops. terminate ⇒ need BNL-based research alternatives not yet well defined***

Storage Ring pEDM Concept to Improve CPV Sensitivity



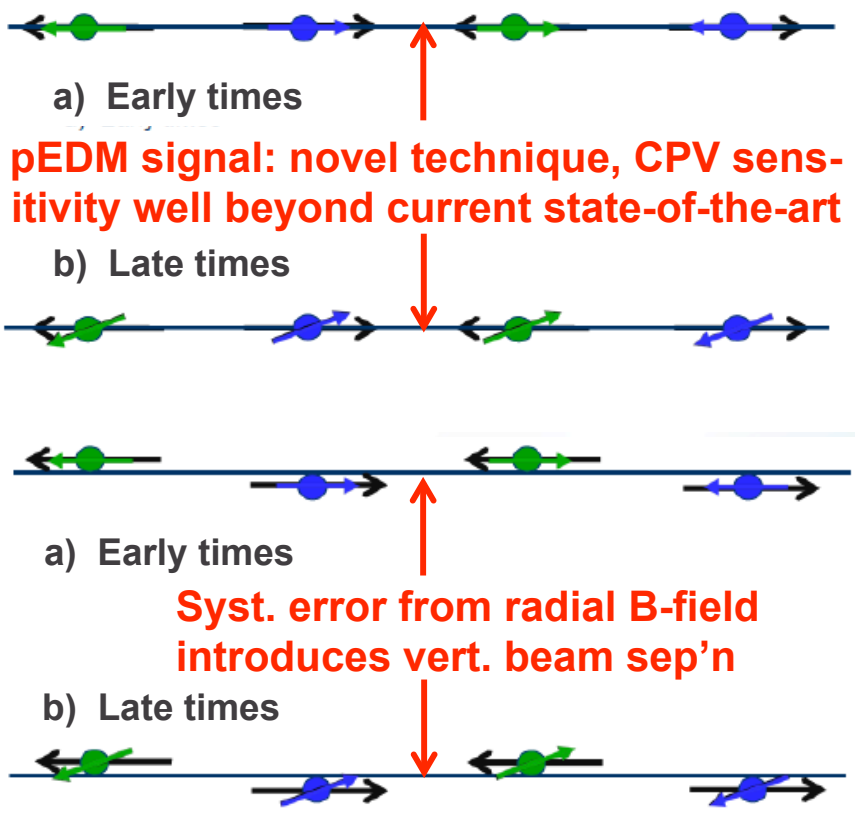


Table 2.1. Current EDM limits in units of [e·cm], *and long-term goals for the neutron,* ^{199}*Hg,* ^{129}*Xe, proton, and deuteron. The neutron equivalent indicates the corresponding neutron EDM value that has the same physics reach.*

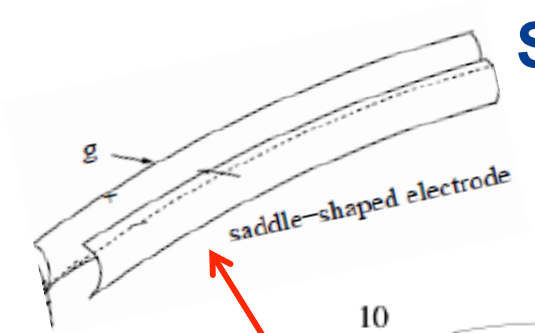
Particle/Atom	Current EDM limit	Future Goal	~d_n equivalent
Neutron	$<1.6\times10^{-26}$	$\sim10^{-28}$	10^{-28}
^{199}Hg	$<3.1\times10^{-29}$	$\sim10^{-29}$	10^{-26}
^{129}Xe	$<6\times10^{-27}$	$\sim10^{-30}$-10^{-33}	10^{-26}-10^{-29}
Proton	$<7.9\times10^{-25}$	$\sim10^{-29}$	10^{-29}
Deuteron		$\sim10^{-29}$	3×10^{-29}-5×10^{-31}

Stat. sensitivity ~ 1.3×10^{-29} e·cm per running year.

If n EDM seen, use to constrain isospin dependence of CPV.

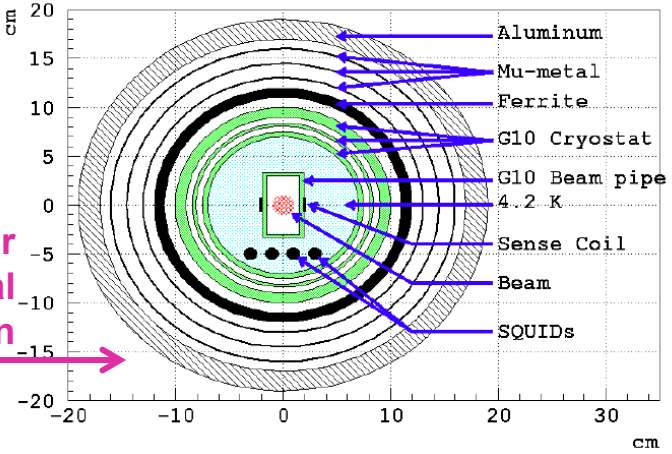
If n EDM not seen, use to crosscheck w/ different syst.

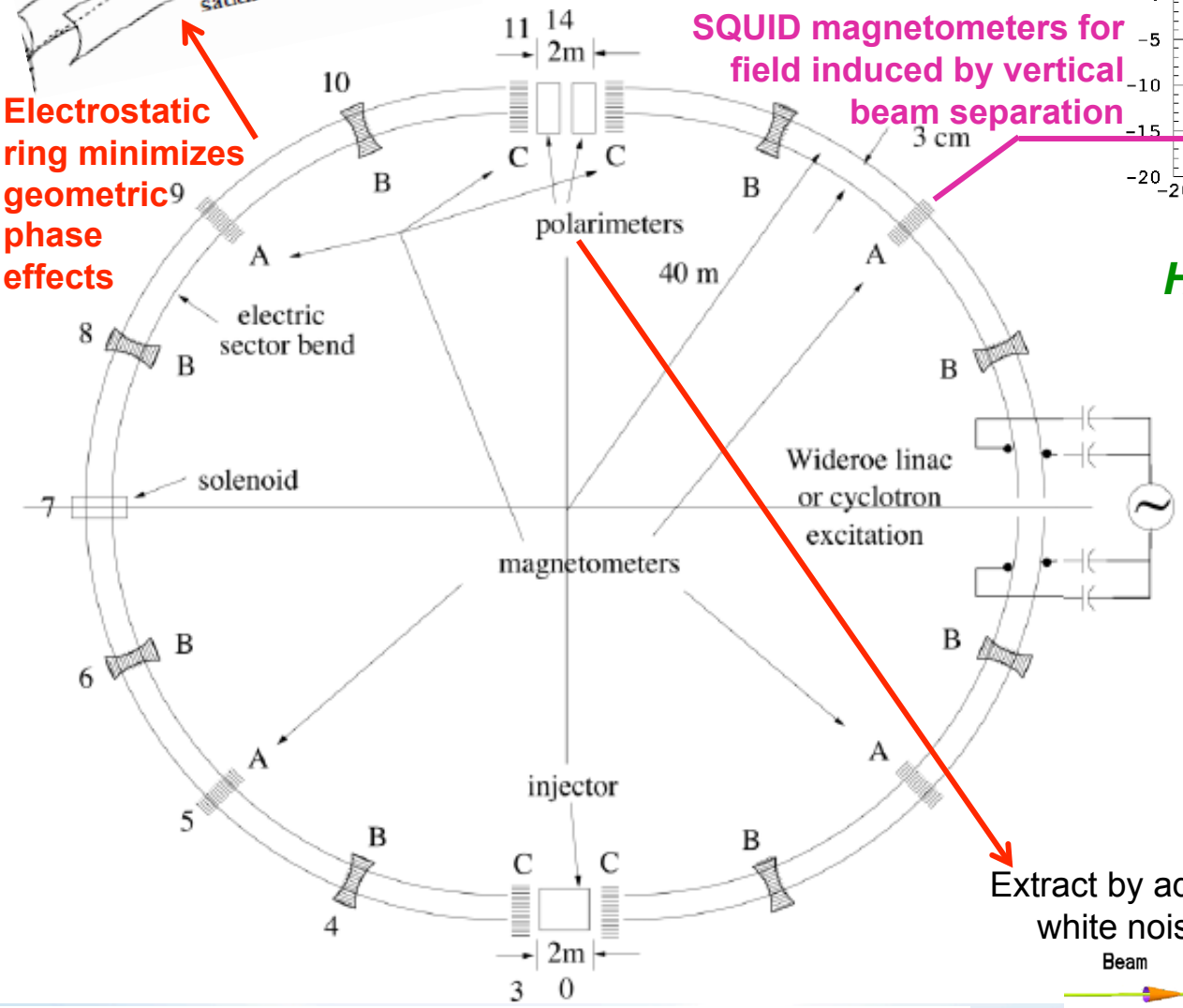
Some Features of Pre-conceptual pEDM Design



Electrostatic ring minimizes geometric phase effects

SQUID magnetometers for field induced by vertical beam separation





Horizontal spin precession:

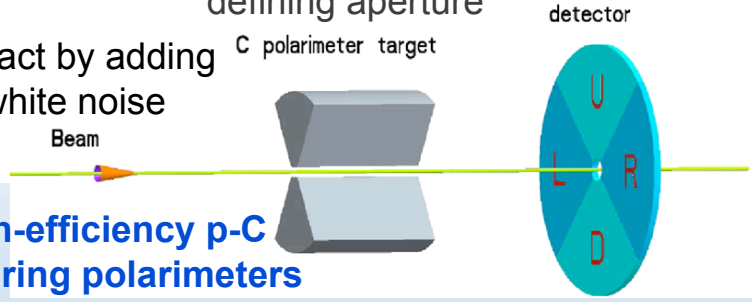
$$\vec{\omega}_a = \frac{e}{m}\left(a - \left(\frac{m}{p}\right)^2\right)\vec{\beta}\times\vec{E}$$

is frozen at "magic" momentum:

$$p = \frac{m}{\sqrt{a}}, \text{ with } a = \frac{g-2}{2}$$

= 0.70 GeV/c for protons

Extract by adding white noise



Need ~1000s spin coherence time, ~10^7s counting time to attain 1.3 × 10^{-29} e·cm stat. sensitivity

High-efficiency p-C scattering polarimeters

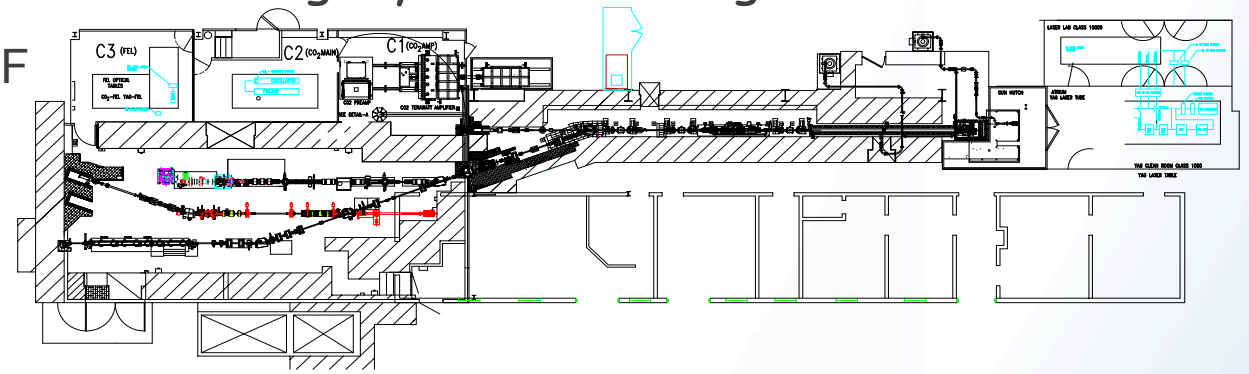
Other Short- and Medium-Term Initiative Options for C-AD Complex

Short-Term Initiative: ATF physical move under consideration, with OHEP + BNL funding

Goals:

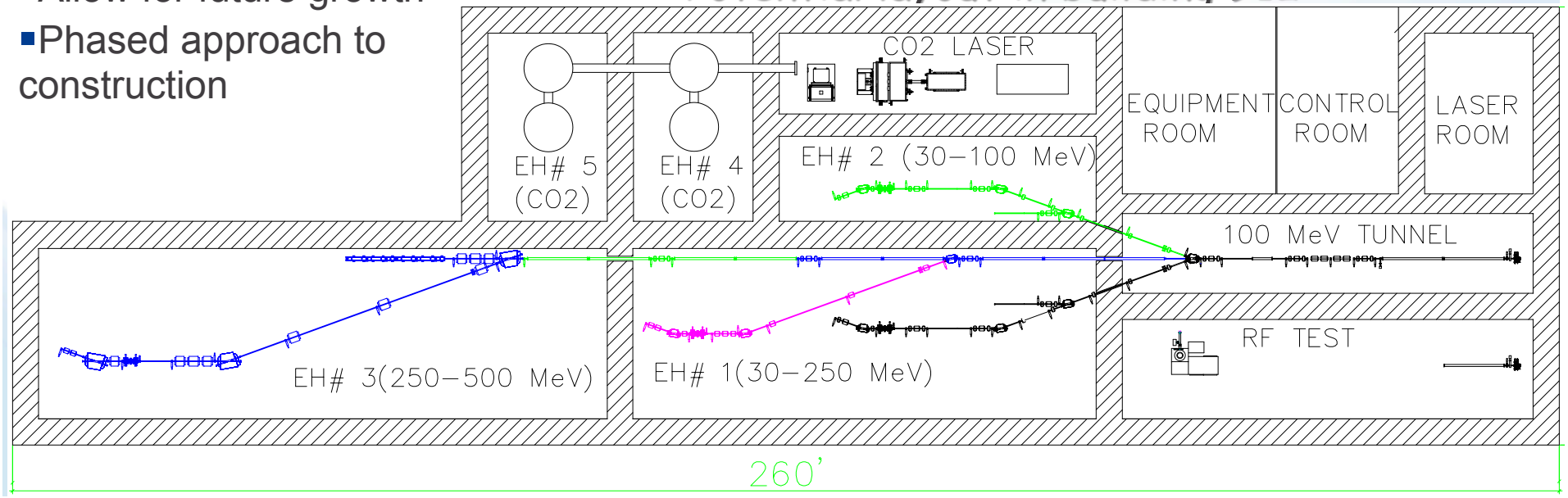
- Address "space issue" at ATF ⇒ more responsive user facility
- Shielded space for medical experiments with ion beams
- Improve efficiency with number of separate experimental halls
- Allow for future growth
- Phased approach to construction

Existing layout in building 820



Annual operations budget would likely increase by $0.75-1.0M, including +2 FTE + AIP + Cap. Equip.

Potential layout in building 912



AGS Complex – present/possible future