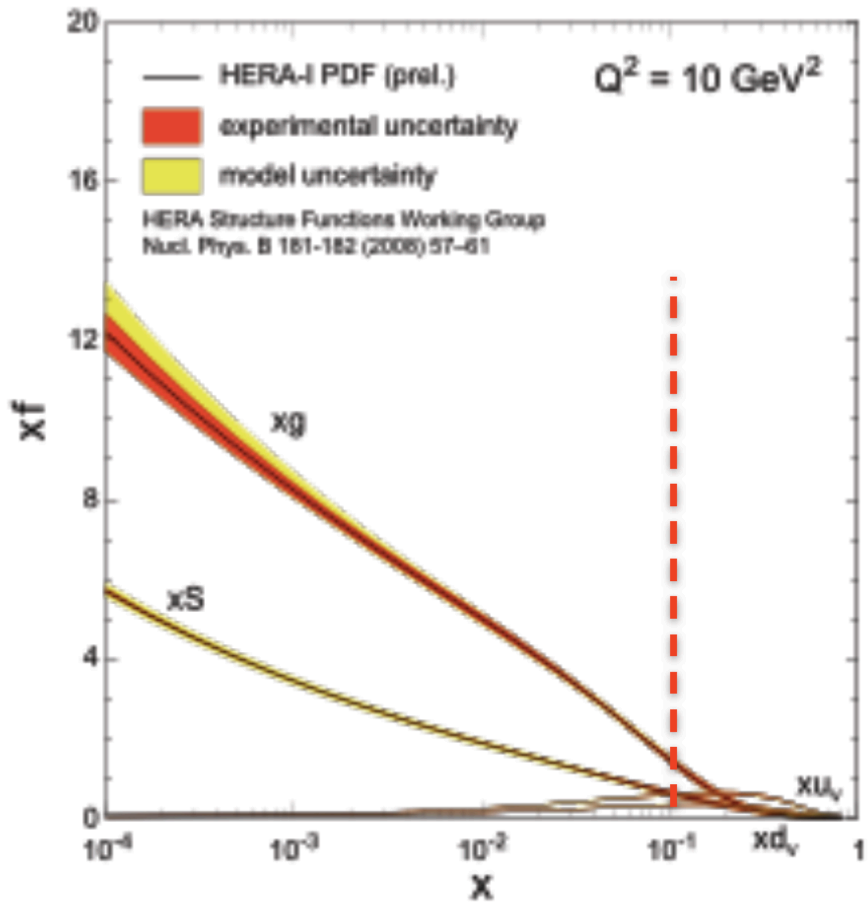
Discussion: RHIC Future Strategy

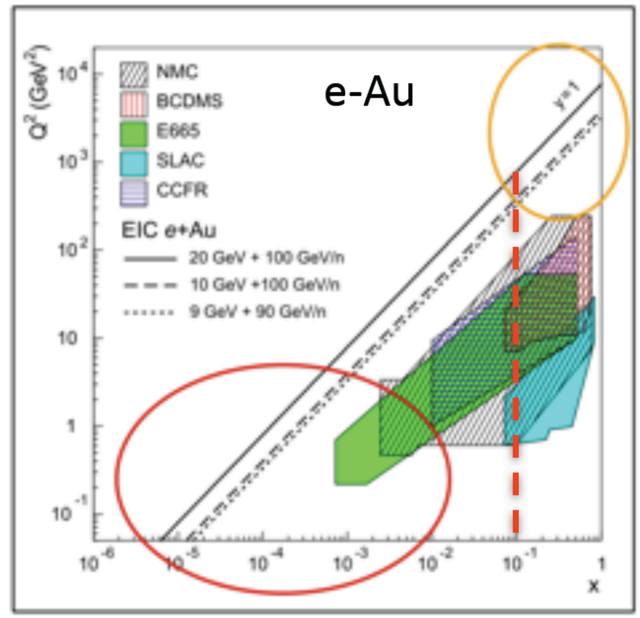
1. Optimal strategy for RHIC? What are the critical decisions & branch points?
2. Are both LHC and RHIC needed?
3. What eRHIC science realizable within reasonable TPC cost limit? ($500M?)
4. 2-3 yr. cessation of RHIC operation for eRHIC? When?
5. Crucial to have AA-pp in to eRHIC era? If YES, configure IRs annually or do we separate HI and eA collisions in different IRs?
6. How do STAR and PHENIX Collaborations evolve smoothly from RHIC to eRHIC?

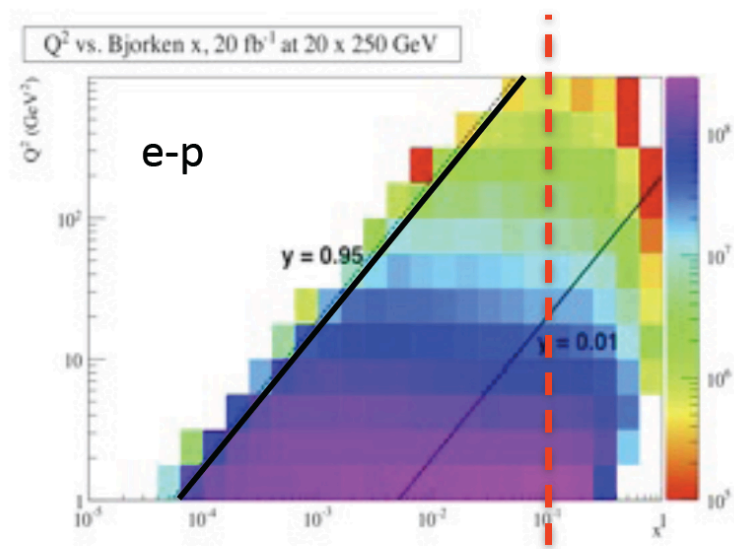
SOME LINGERING THOUGHTS… THROUGH THIS MEETING

Why EIC?

Precision study & understanding of the role of <u>gluons</u> and <u>sea quarks</u> in QCD!



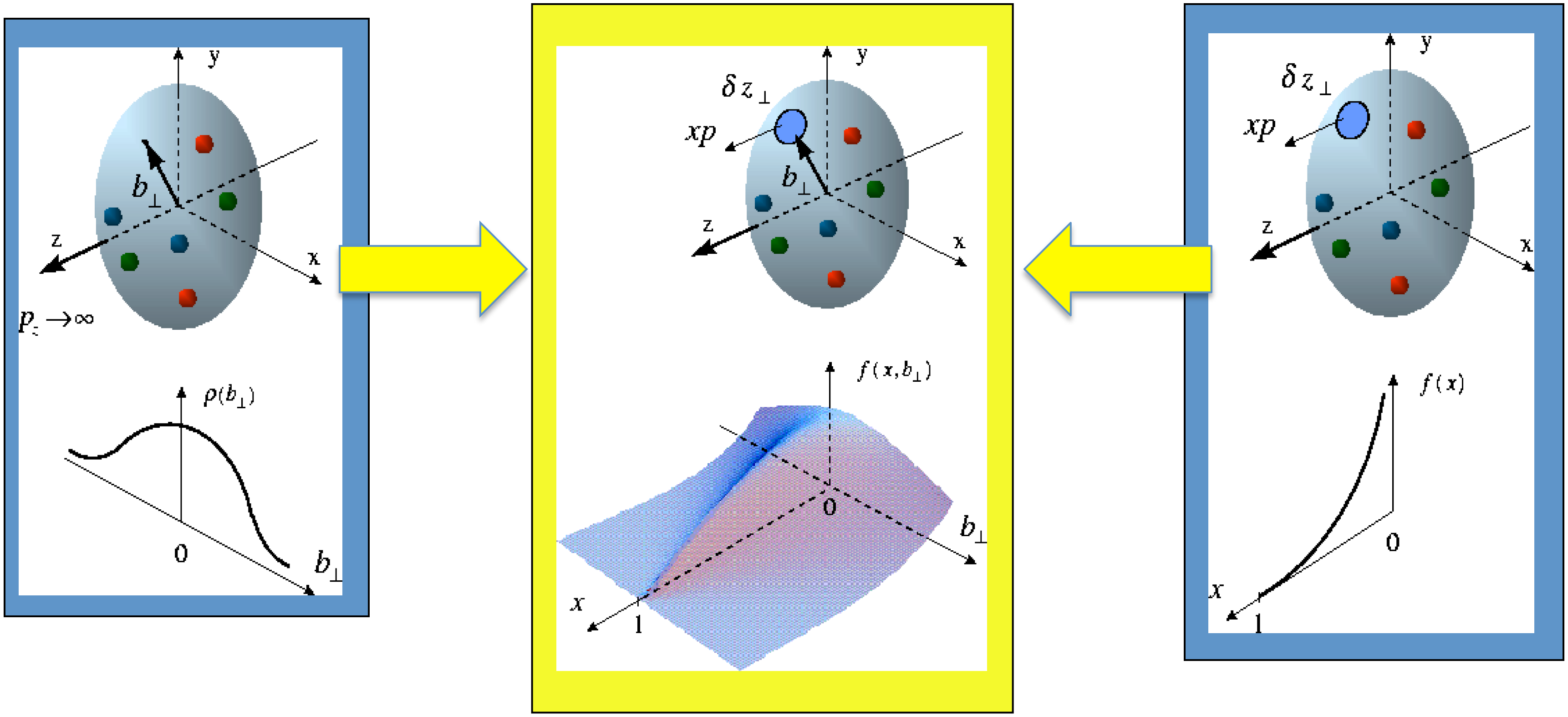




Beyond form factors and quark distributions

Generalized Parton Distributions

X. Ji, D. Mueller, A. Radyushkin (1994-1997)



Proton form factors, transverse charge & current densities

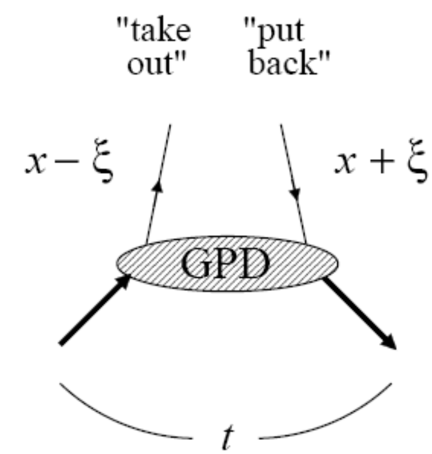
Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

Unified View of Nucleon Structure

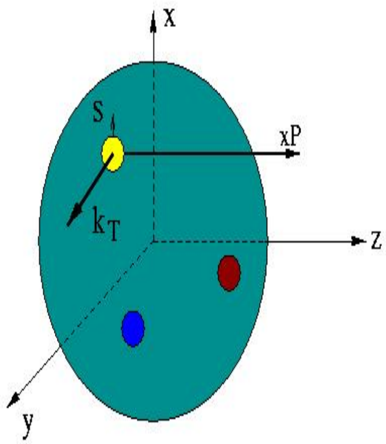
$W_p^u(x, \boldsymbol{k_T}, \boldsymbol{r})$ Wigner distributions

6D Dist.



$d^3\boldsymbol{r}$ → TMDs

$d^2k_T\, dr_z$ → GPDs



TMDs
$f_1^u(x,k_T)$, .. $h_1^u(x,k_T)$

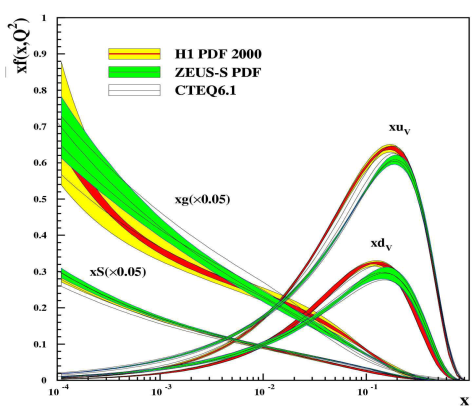
GPDs

(2+1)D imaging

d^2k_T → PDFs

d^2r_T → PDFs

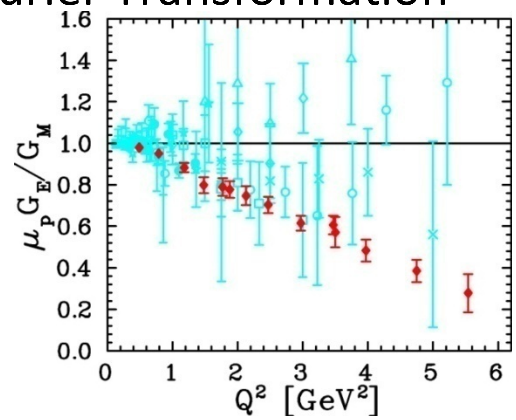
dx & Fourier Transformation → Form Factors



PDFs
$f_1^u(x)$, .. $h_1^u(x)$

1D

Form Factors
$G_E(Q^2)$,
$G_M(Q^2)$



OPTIMAL TRAJECTORY?

CRITICAL DECISION/BRANCH POINTS?

Optimal trajectory

- Try to reach the set physics goals as fast as possible… (sounds naïve, but perhaps the only good strategy)
- User issues:
  - RHIC → long term interest of the community may dwindle
  - eRHIC → too long a wait for eRHIC may deplete the potentially interested community in the US and abroad

SPIN operation:

- Explore possibility of reaching higher beam polarization
  - Operational tricks
  - Recently mentioned 6 snakes/ring
- Consider operating PHENIX and STAR IRs in different colliding modes: transverse vs. longitudinal (Some of them requires 1fb^{-1} for physics goals each!)
  - Allow collaborators to contribute to the ***other*** collaboration's detector operation (and analyses) with "appropriate recognition"

Optimal strategy: (toward eRHIC)

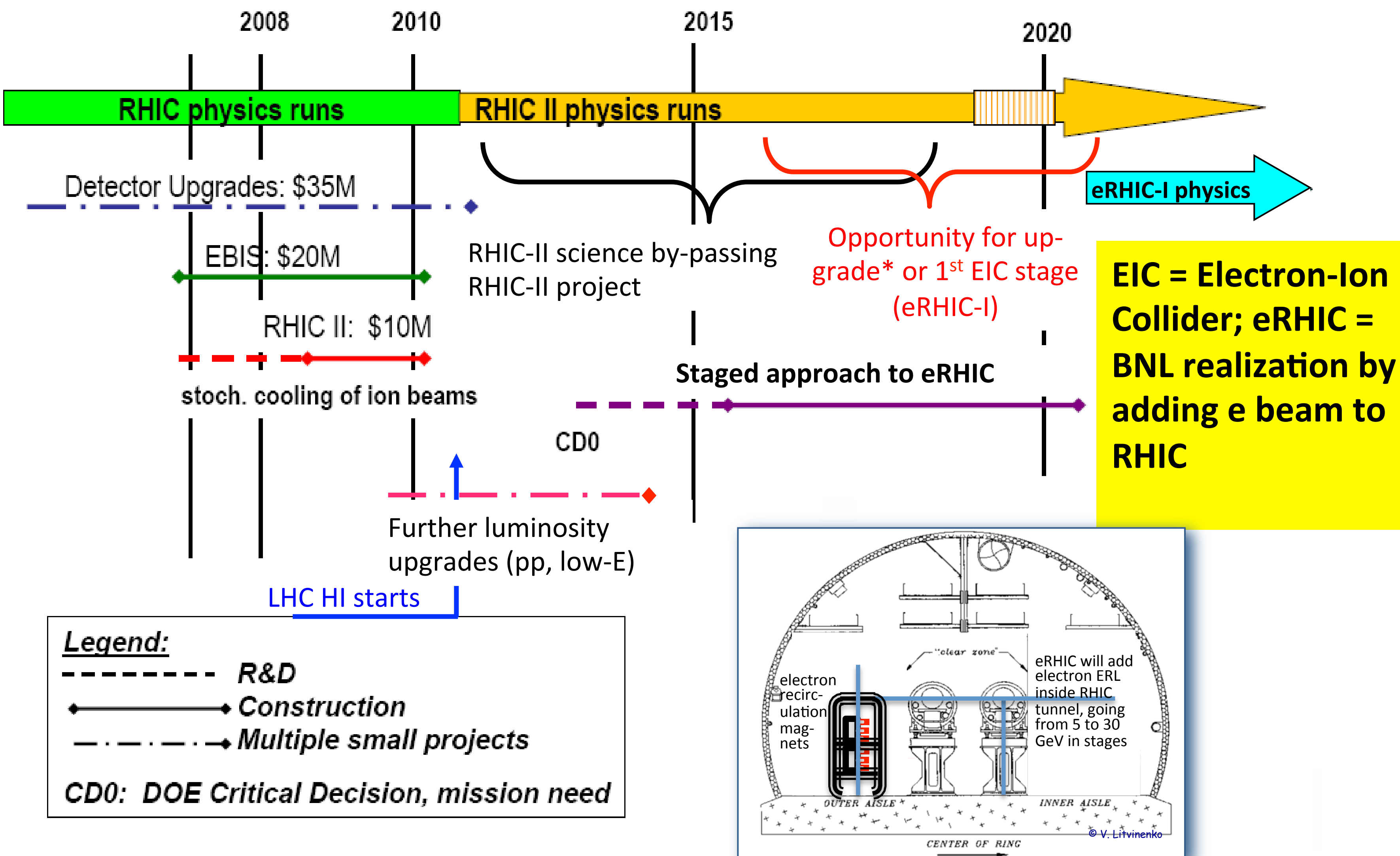
- PHENIX and STAR's Gradual evolution of experiments from HI/pp to eRHIC detectors is an excellent idea
  - PHENIX → sPHNENIX → ePHENIX
  - STAR → eSTAR
  - Fiscally these detectors, may be our only opportunities for eRHIC physics….

- However, in order to attract potentially *new* collaborators from within the US (JLab and Co.) and from Europe/Asia & also to compare the physics outputs of an ideal new detector with the upgraded PHENIX/STAR: ***Some resources should be put on design and costing of at least one new dedicated detector***

POSSIBLE REALITY:
FUNDING DRIVEN TIMELINES

S. Vigdor, BNL Associate Director

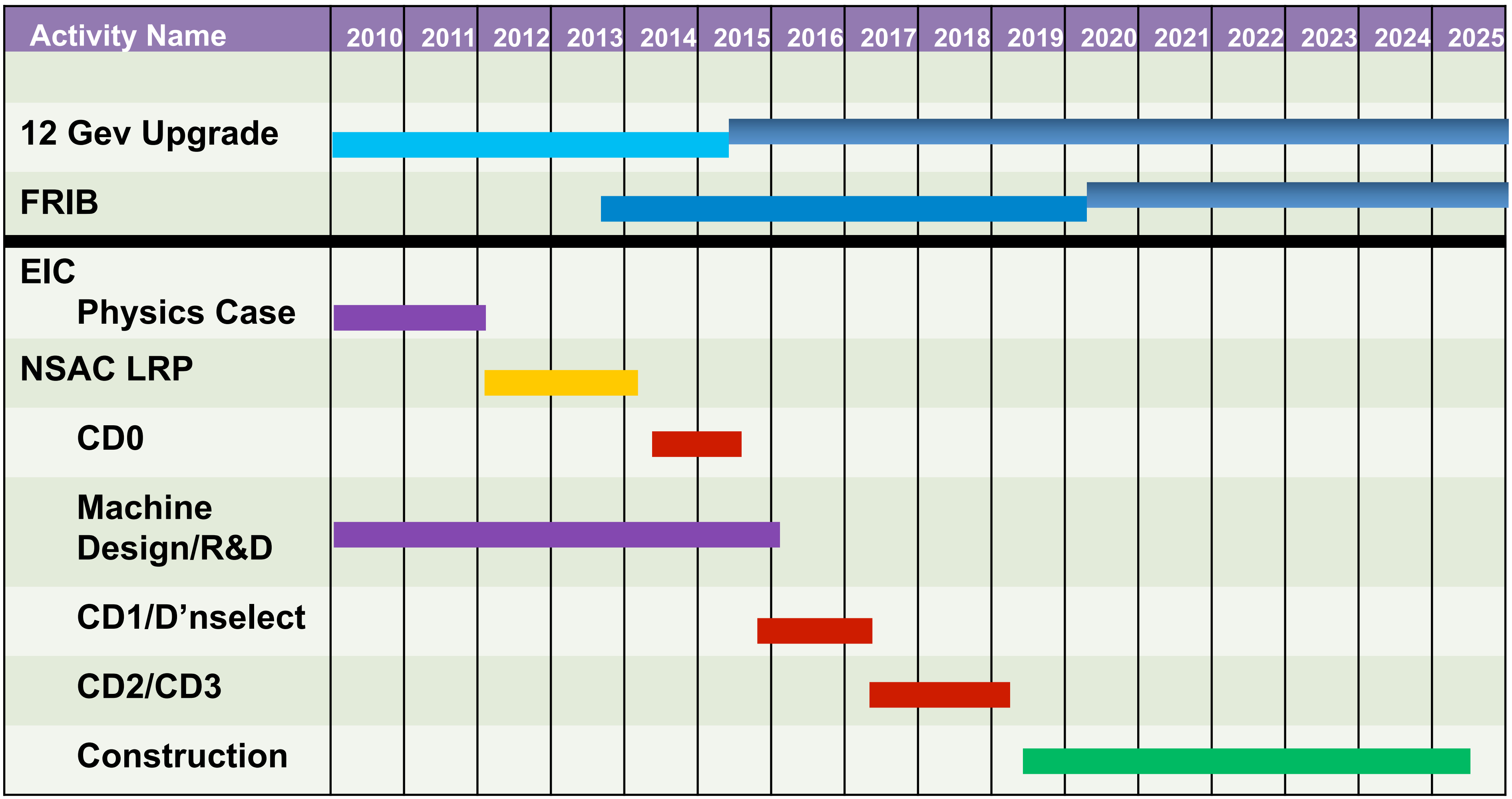
A Long Term (Evolving) Strategic View for RHIC



* New PHENIX and STAR Decadal Plans provide options for this period. Dedicated storage ring for novel charged-particle EDM measurements another option.

H. Montgomery, Jeff. Laboratory Director

EIC at JLab Realization Imagined



What these charts mean: (depressing yet true)

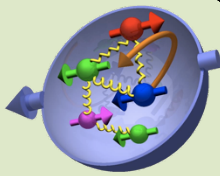
- RHIC 5yr future (near term: 2012-17)
  - Decade plan construction (2013 onwards!)
- RHIC 10yr future (medium term: 2017-22)
  - Decadal plan physics
  - eRHIC1 construction
- RHIC 10+yr future (eRHIC1: 2022-2027)
  - eRHIC1 physics
  - eRHIC upgrade construction
- Beyond 15+yr future (eRHIC:2027-onward)

EIC SCIENCE

M. Stratmann

most compelling physics questions

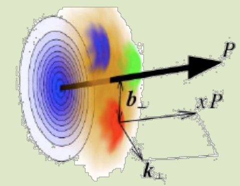
spin physics



- what is the polarization of gluons at small x where they are most abundant
- what is the flavor decomposition of the polarized sea depending on x

determine quark and gluon contributions to the proton spin at last

imaging

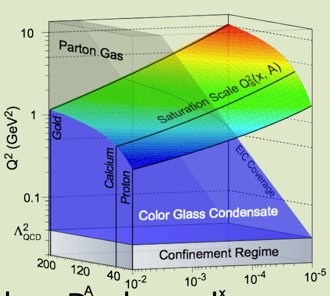


- what is the spatial distribution of quarks and gluons in nucleons/nuclei
- understand deep aspects of gauge theories revealed by k_T dep. distr'n

possible window to orbital angular momentum

physics of strong color fields

quantitatively probe the universality of strong color fields in AA, pA, and eA



- understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- how do hard probes in eA interact with the medium

WHAT IS REALIZABLE WITH $500M TPC?

What to assume in $500M?

- eRHIC1:

$$\sqrt{s_{ep}} = \sqrt{4 \times 6 \times 250} \approx 75\text{GeV}$$

$$\sqrt{s_{eAu}} = \sqrt{4 \times 6 \times 100} \approx 50\ \text{GeV}$$

- Integrated luminosity: (very conservative!)

  ~1 fb^{-1}/week x 10 weeks/yr x 3-5 yrs= 30-50 fb^{-1}
- Use of existing detectors++ (sPHENIX, eSTAR)
- Most inclusive measurements, & some semi-inclusive measurements with x_{min} ~10^{-3}

Stage 1: ~ 1 fb^{-1}/week, Sqrt(s)~ 50-75 GeV,
Upgraded ePHENIX & eSTAR

STAGE 1 PHYSICS & OBSERVABLES:

MOSTLY INTERMEDIATE, HIGH-X INCLUSIVE AND SEMI-INCLUSIVE PHYSICS

e-A

Golden Measurements

M. Lamont

Deliverables	Observables	What we learn	Stage-1	Stage-II
integrated gluon distributions	$F_{2,L}$	nuclear wave function; saturation, Q_s	gluons at $10^{-3} < x < 1$	saturation regime
k_T dependent gluons; gluon correlations	di-hadron correlations	non-linear QCD evolution / universality	onset of saturation	measure Q_s
transport coefficients in cold matter	large-x SIDIS; jets	parton energy loss, shower evolution; energy loss mechanisms	light flavours and charm; jets	rare probes and bottom; large-x gluons

e-A

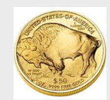
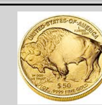
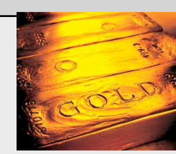
Silver Measurements

M. Lamont

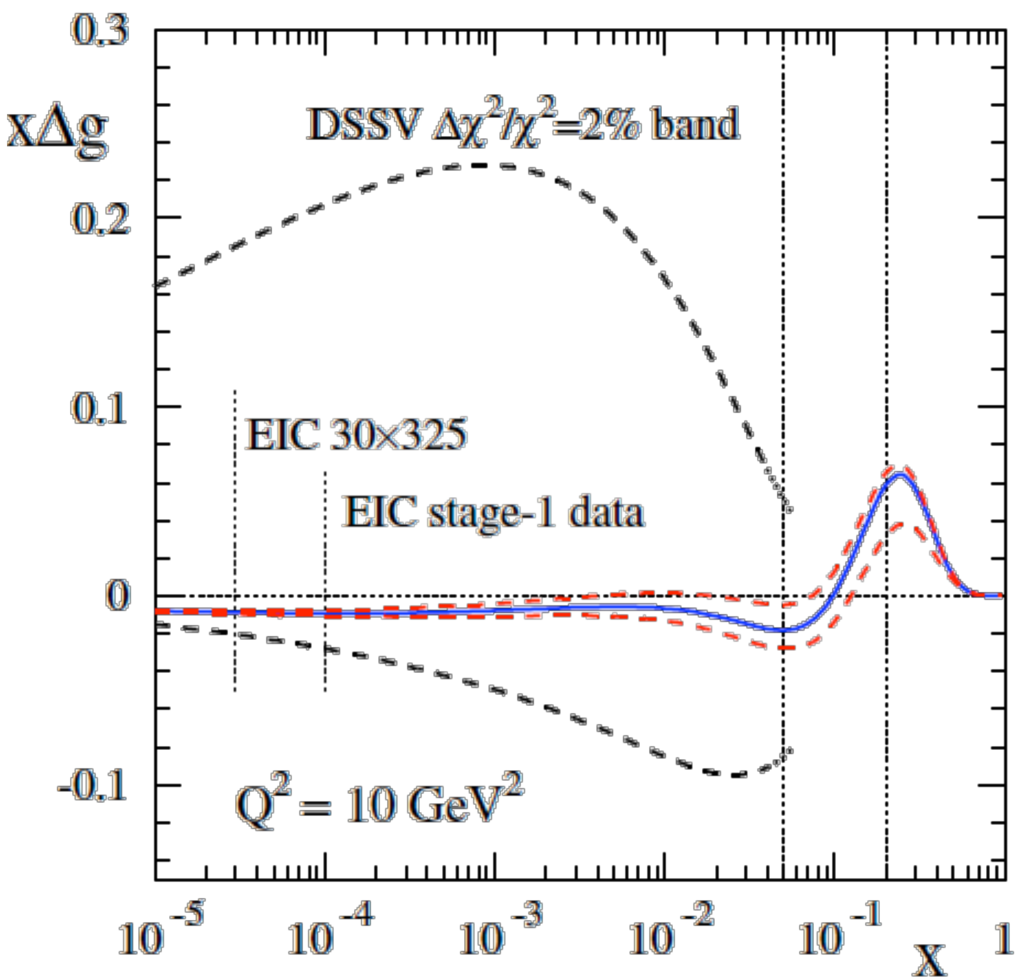
Deliverables	Observables	What we learn	Stage-I	Stage-II
integrated gluon distributions	$F^{c}_{2,L}$, $F^{D}_{2,L}$	nuclear wave function; saturation, Q_s	difficult measurement / interpretation	saturation regime
flavour separated nuclear PDFs	charged current and γZ structure functions	EMC effect origin	full flavour separation for $10^{-2} < x < 1$	measure Q_s
k_T dependent gluons	SIDIS at small x	non-linear QCD evolution / universality	onset of saturation	rare probes and bottom; large-x gluons
b-dependent gluons; gluon correlations	DVCS; diffractive vector mesons	interplay between small-x evolution and confinement	moderate x with light, heavy nuclei	smaller x, saturation

E. Sichtermann

Stage 1 measurements

$\vec{e} \times \vec{p}$ **Science Deliverable**	**Basic Measurement**	**Uniqueness Feasibility Relevance**	**Requirements**
spin structure at small x contribution of Δg, ΔΣ to spin sum rule	inclusive DIS	✔ 	minimal large x,Q^2 coverage about $10fb^{-1}$
full flavor separation in large x,Q^2 range strangeness, s(x)-s(x) polarized sea	semi-inclusive DIS	✔ 	very similar to DIS excellent particle ID improved FFs (Belle,LHC,...)
electroweak probes of proton structure flavor separation electroweak parameters	inclusive DIS at high Q^2	 ✔ some unp. results from HERA	20x250 to 30x325 positron beam ? polarized ^{3}He beam ?
spatial structure down to small x through TMDs and GPDs	SIDIS azim. asym. & exclusive processes	✔  some results in valence region	p_T^H binning, t resolution, exclusivity, Roman pots, large (x,Q^2) range

An Example:



0.3
0.2
0.1
0
-0.1
xΔg
DSSV $\Delta\chi^2/\chi^2$=2% band
EIC 30×325
EIC stage-1 data
$Q^2 = 10$ GeV^2
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

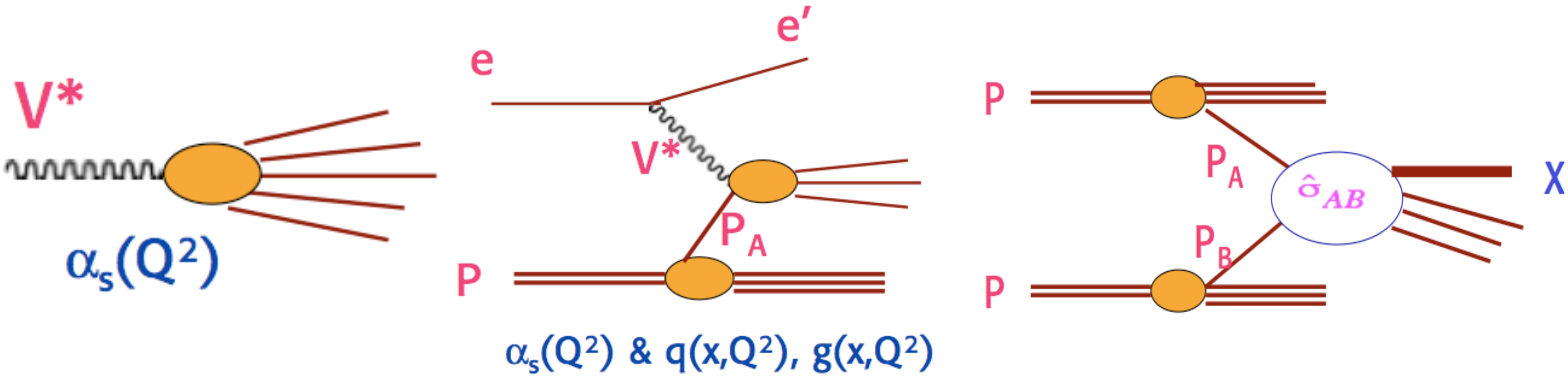
ARE BOTH LHC AND RHIC NEEDED?

RHIC's flexibility in species and energy selection may be crucial. This may be the best opportunity to study of QGP, its onset and its properties in detail.

RHIC is needed in LHC era!

CRUCIAL TO HAVE A-A/P-P CAPABILITY IN ERHIC ERA?

IF SO, WHAT SHOULD BE THE OPERATIONS MODE?



- Experimental tools of high energy physics:
  - e-e (2 electrons, LEP, BELLE)
  - e-p (1 hadron: HERA),
  - p-p (2 hadrons: SppS, Tevatron… now at LHC)

Development & establishment of the SM of Physics needed continuous interplay amongst different techniques to take the full advantage of their complementarity

eRHIC promises to include **nuclei** in this game!

RHIC: AA, pp, dA

eRHIC: eA, ep ***brings precision in the studies of cold nuclear matter***

Enable unique ability to test fundamental & universal aspects of QCD

Need RHIC in eRHIC era?

- No, if all RHIC data are archived and accessible for years to come
- But it probably means that eRHIC/eRHIC1 is coming too late!

Need parallel operation?

- Current version of eRHIC layout assumes alternate year operations of HI and e-A: ***Modifications to the IR needed annually***
  - ***Is it truly feasible? Annual moving of beam components near the IRs and their alignment … seems very complicated***

- Why not consider 1 HI/pp experiment and 1 eRHIC experiment, which ONE shared beam? Is this more challenging for accelerator design?

SMOOTH EVOLVING OF PHENIX AND STAR IN TO ERHIC

PHENIX/STAR → eRHIC

Foster collaboration through aggressive detector ***R&D for eRHIC detector***

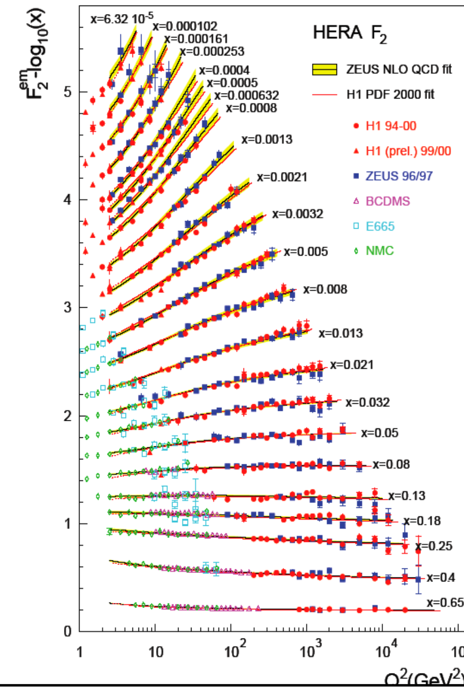
Opportunities to work with each other:

- Optimized/Coordinated Operations: longitudinal/transverse
- Allow scientists to switch collaborations for a year, like a sabbatical!

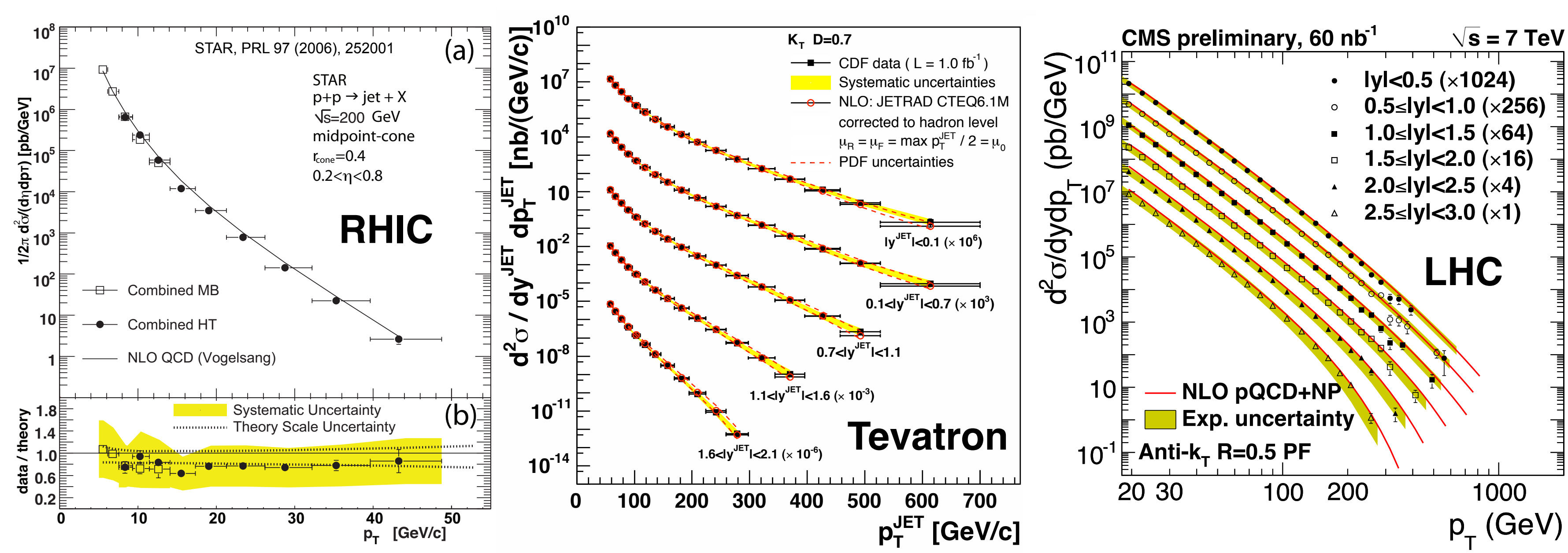
- Combined, coordinated (global) analyses
- Dedicated workshops
- Seek opportunities for publications emphasizing RHIC's impact (many caveats, but no absolute show stoppers)

THANK YOU

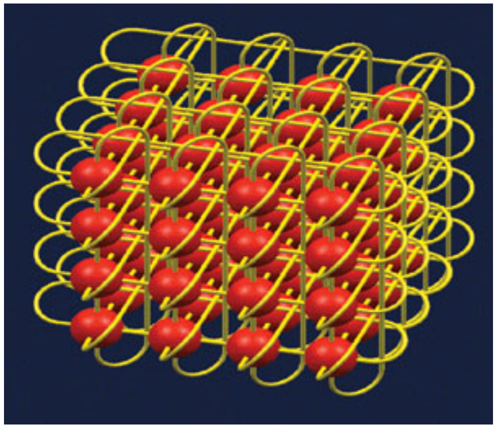
QCD is definitely correct (I)



- Input:
  - $F_2(x,Q^2)$ structure function from HERA
  - Next to Leading Order perturbative QCD
- Jet Cross Section calculations vs. Data



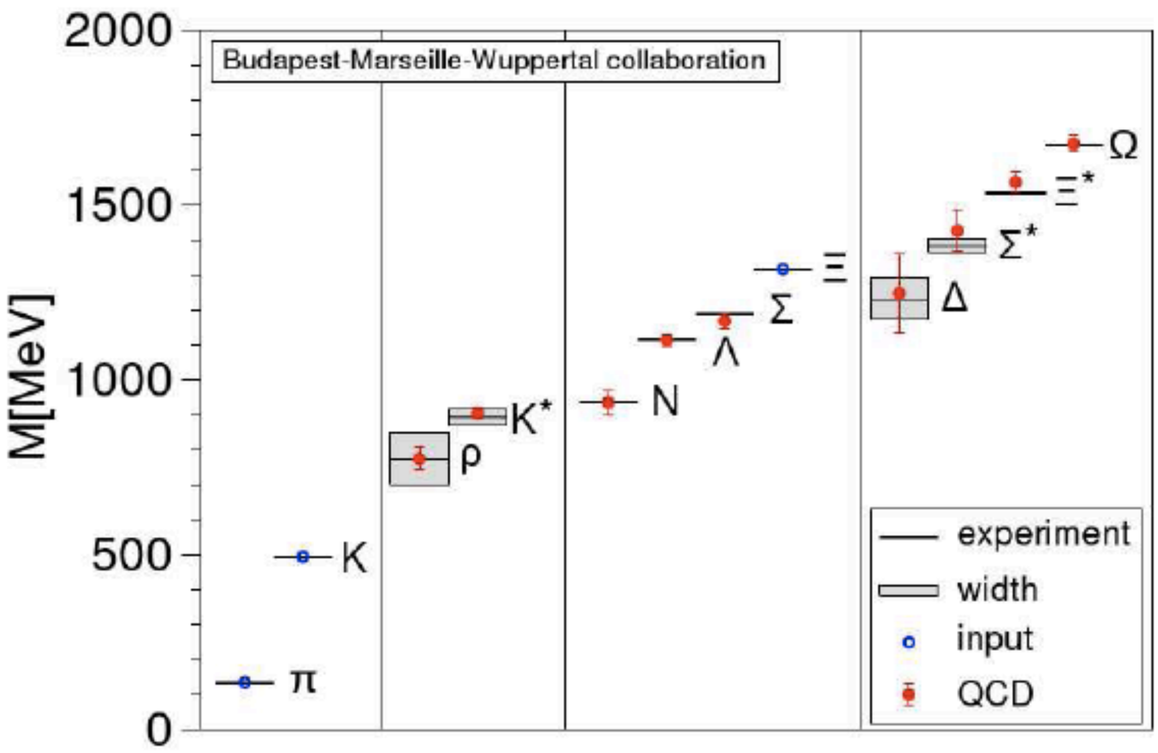
QCD definitely correct: (II)



Lattice QCD

Starting with QCD Lagrangian:

- Static properties of hadrons: hadron mass spectrum



Durr et al '08

But, no guidance on partonic dynamics

Do we really “understand” QCD?

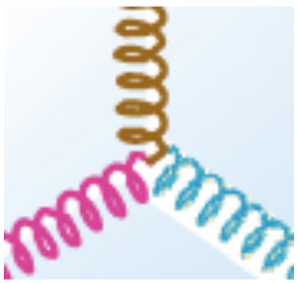
While there is no reason to doubt QCD, our level of understanding of QCD remains extremely unsatisfactory: both at low & high energy

- Can we explain basic properties of hadrons such as mass and spin from the QCD degrees of freedom (partons) at low energy?
- What ***are*** the **effective** degrees of freedom at high energy?
  - How do these degrees of freedom interact with each other and with other hard probes?
  - What can we learn from them about confinement & universal features of the theory of QCD?

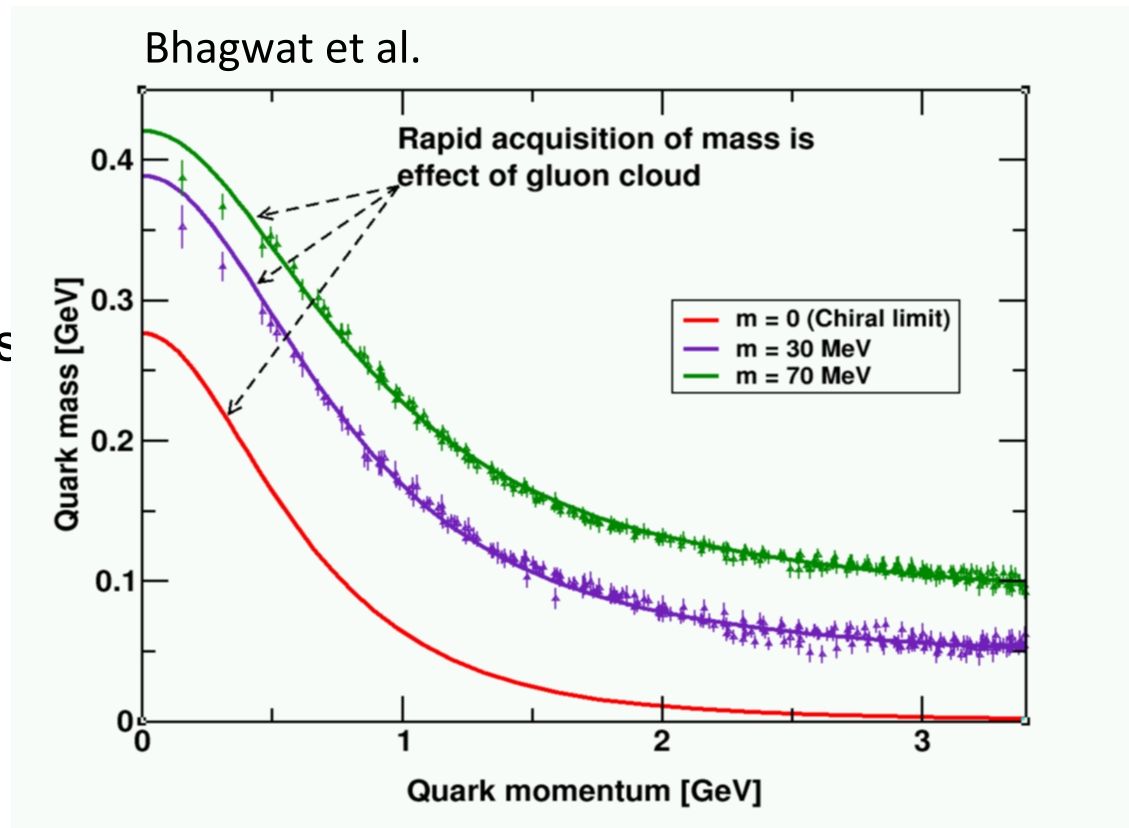
After ~20+ yrs of experimental & theoretical progress, we are only *beginning to understand* the many body dynamics of QCD

Generation of Mass – Gluons in QCD

- Protons and neutrons form most of the mass of the visible universe
- 99% of the nucleon mass is due to self generated gluon fields ($E=mc^2$)
  - Similarity between p, n mass indicates that **gluon dynamics is identical** & overwhelmingly important

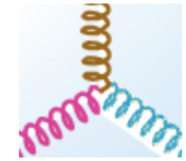


- Lattice QCD supports this



Higgs Mechanism, often credited with mass generation, is of no consequence

Gluon self-interaction in QCD



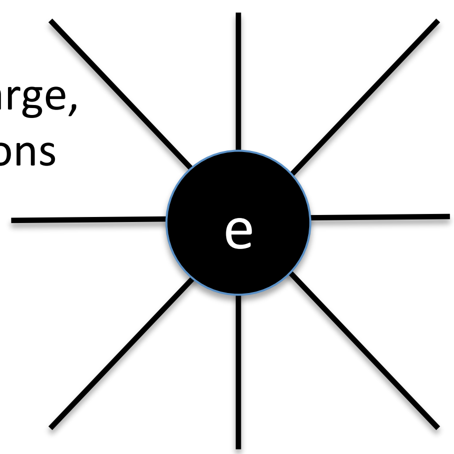
Dynamical generation & self-regulation of hadron masses

F. Wilczek in "Origin of Mass"

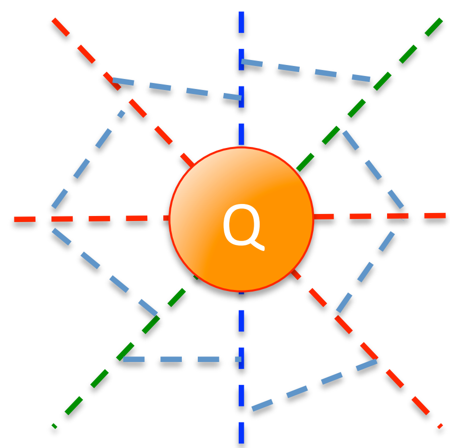
Its enhanced coupling to soft radiation… means that a 'bare" color charge, inserted in to empty space will start to surround itself with a cloud of virtual color gluons. These color gluon fields themselves carry color charge, so they are sources of additional soft radiation. The result is a self-catalyzing enhancement that leads to a ***runaway growth****. A small color charge, in isolation builds up a big color thundercloud…*

theoretically the energy of the quark in isolation is infinite… having only a finite amount of energy to work with, nature always finds a way to short cut the ultimate thundercloud"

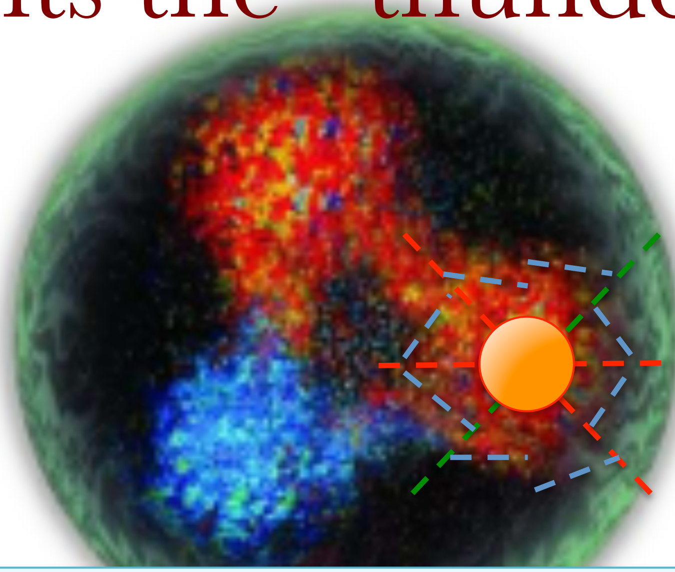
Electric charge,
lines: photons



Color charge
gluons



What limits the "thundercloud"?



- Partial cancellation of quark-color-charge in color neutral finite size of the hadron (confinement)
- Saturation of gluon densities due to gg– g (gluon recombination) must play a role….

Need to experimentally explore and study ***many body dynamics***
a) regions of ***quark-hadron transition*** and
b) non-linear QCD regions of extreme ***high gluon density***
c) in hadrons, that ***leads to its spin***