Summary and Conclusions of EIC Yellow Report on Complementarity

RHIC/AGS Users Meeting

11 June 2021

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with Elke Aschenauer (BNL)

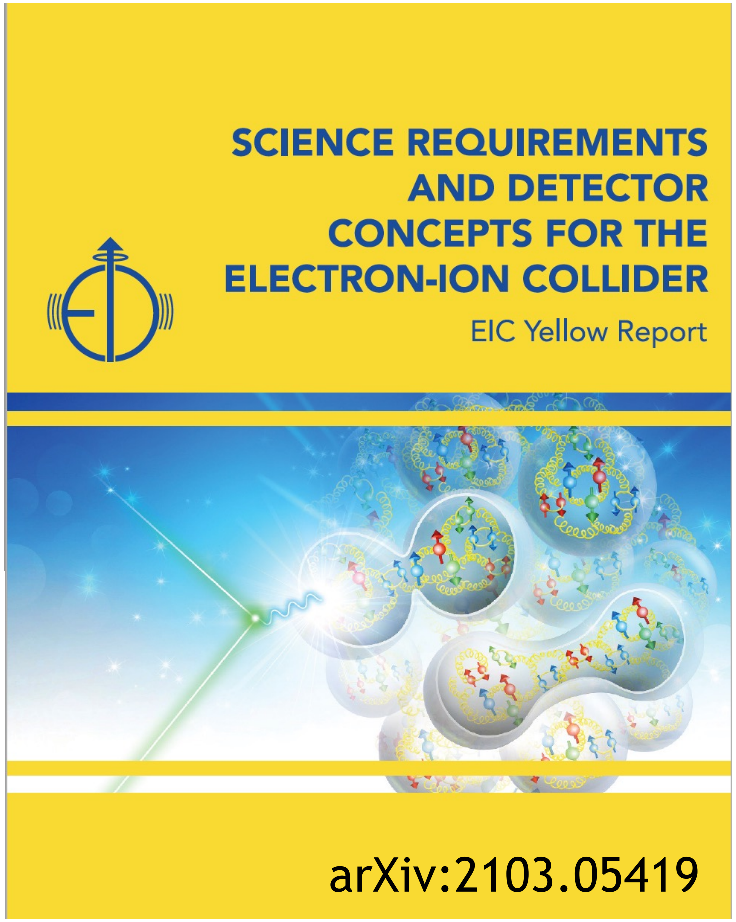
Background

- Funding considerations aside, colliders usually have (at least) two detectors

- Much of the work done for Yellow Report focused on a ‘reference detector’

- Second detector more of a blank page → opportunity to refine and enhance EIC physics program by thinking in terms of complementarity from the outset.

- Yellow Report Complementarity group charged with collecting arguments why two detectors will enhance scientific output

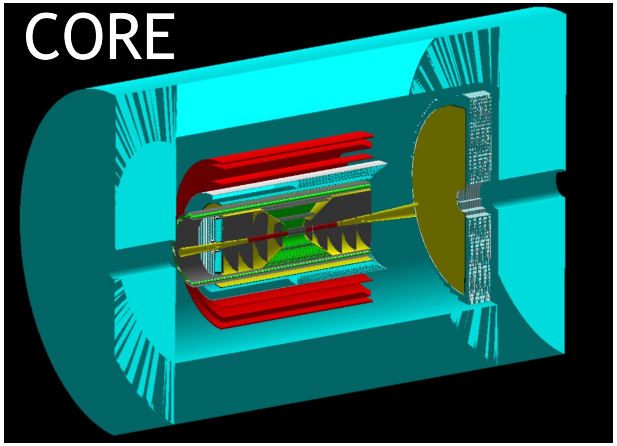


This talk is already (ancient) history

- Considerations shown here all pre-date ongoing EIC collaboration formation / detector proposals exercise.

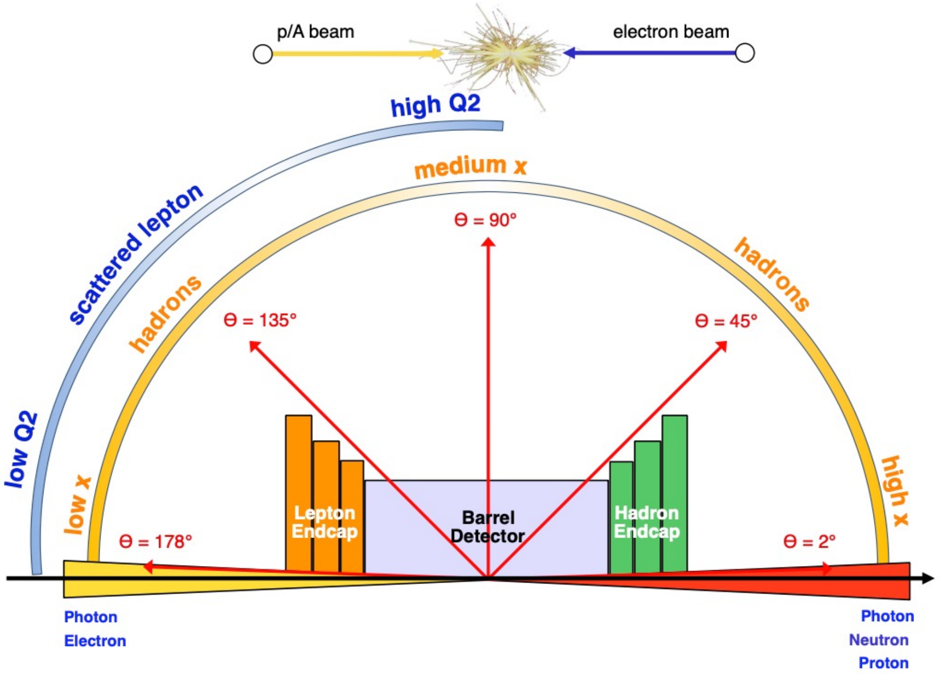
- No statements on relative merits are intended.

ECCE



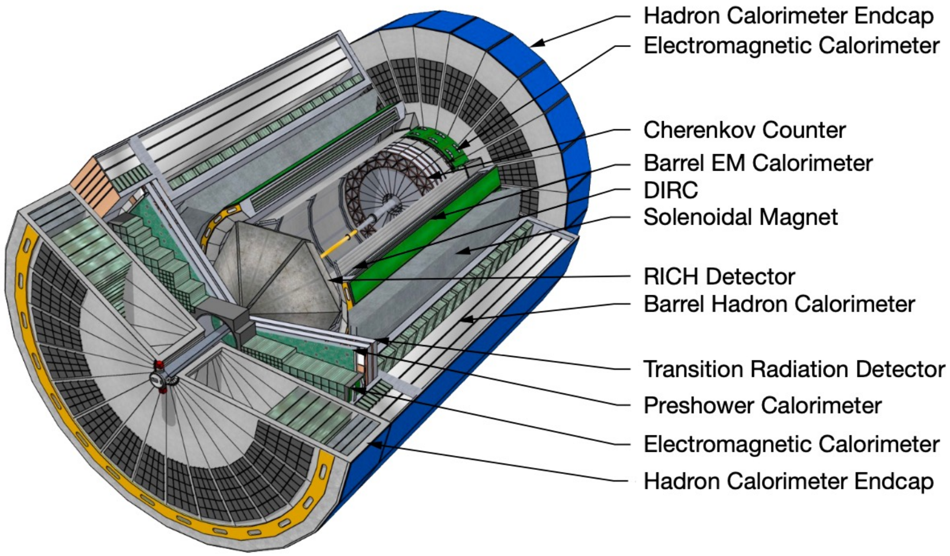
[see session on Wednesday]

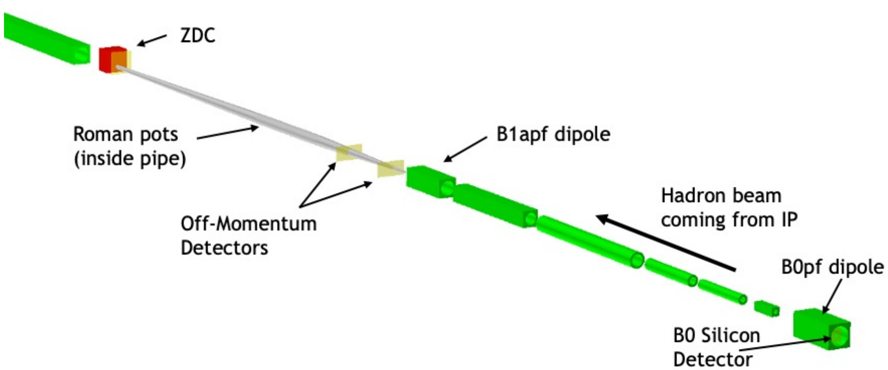
First Detector



Well developed reference concept for first detector and interaction region

- Based on 1.5 - 3T solenoid
- Technologies to be decided





[See Tanja Horn's talk]

What do we want from ‘Complementary’

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1) Cross-checking important results (obvious!)

- Many examples of wrong turns in history of nuclear and particle physics.

- Independent cross checks (detector, community, analysis tools) are essential for timely verifications and corrections

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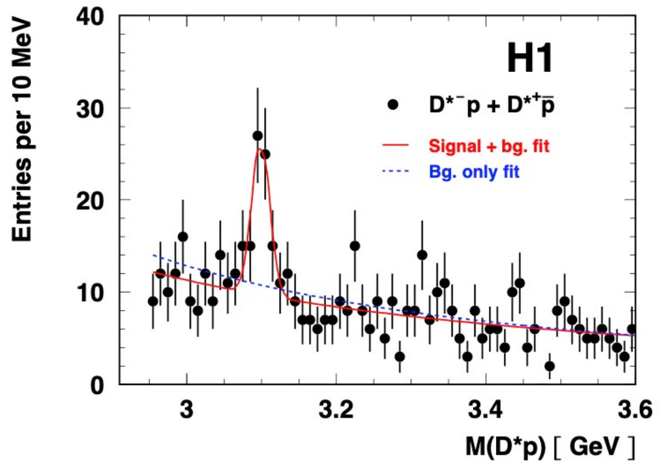
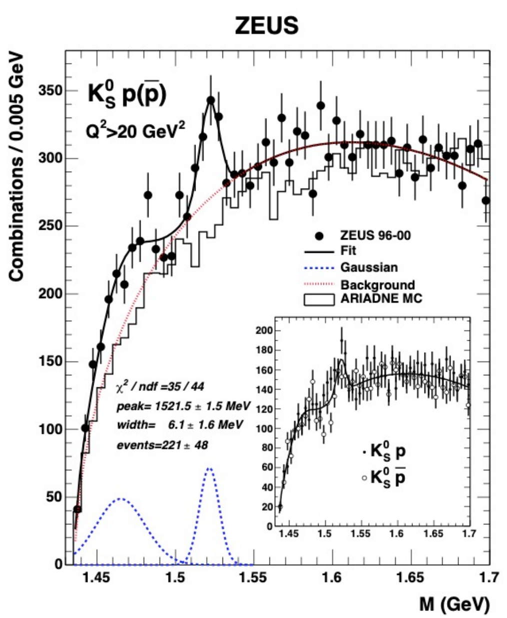


e.g: Pentaquarks in 2004 ($K_s p$ & $D^* p$ at HERA)



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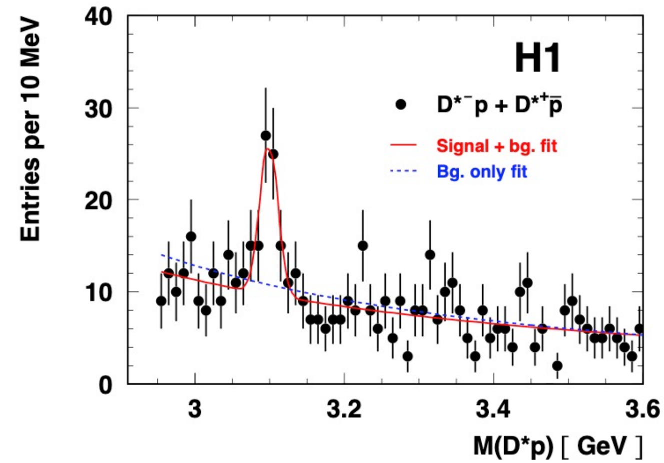

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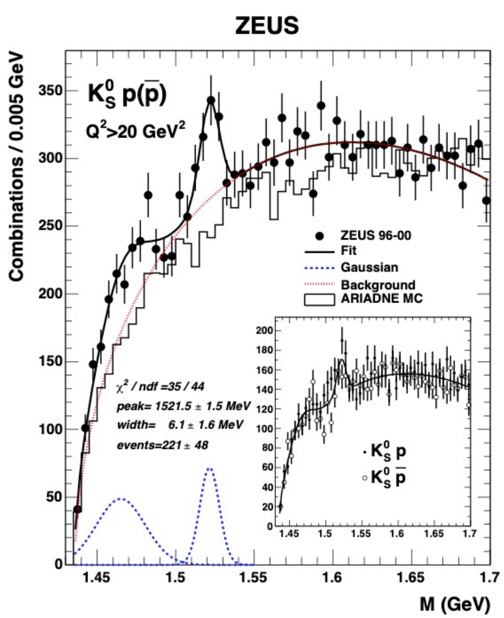
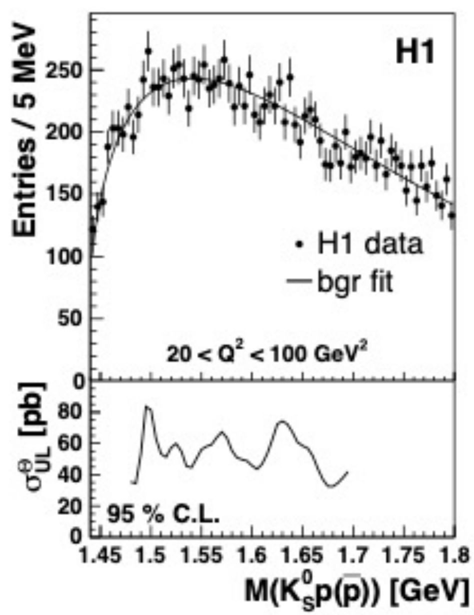
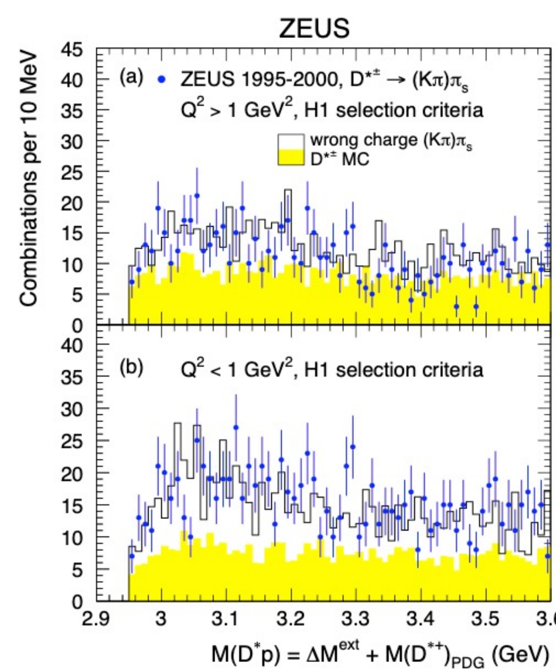
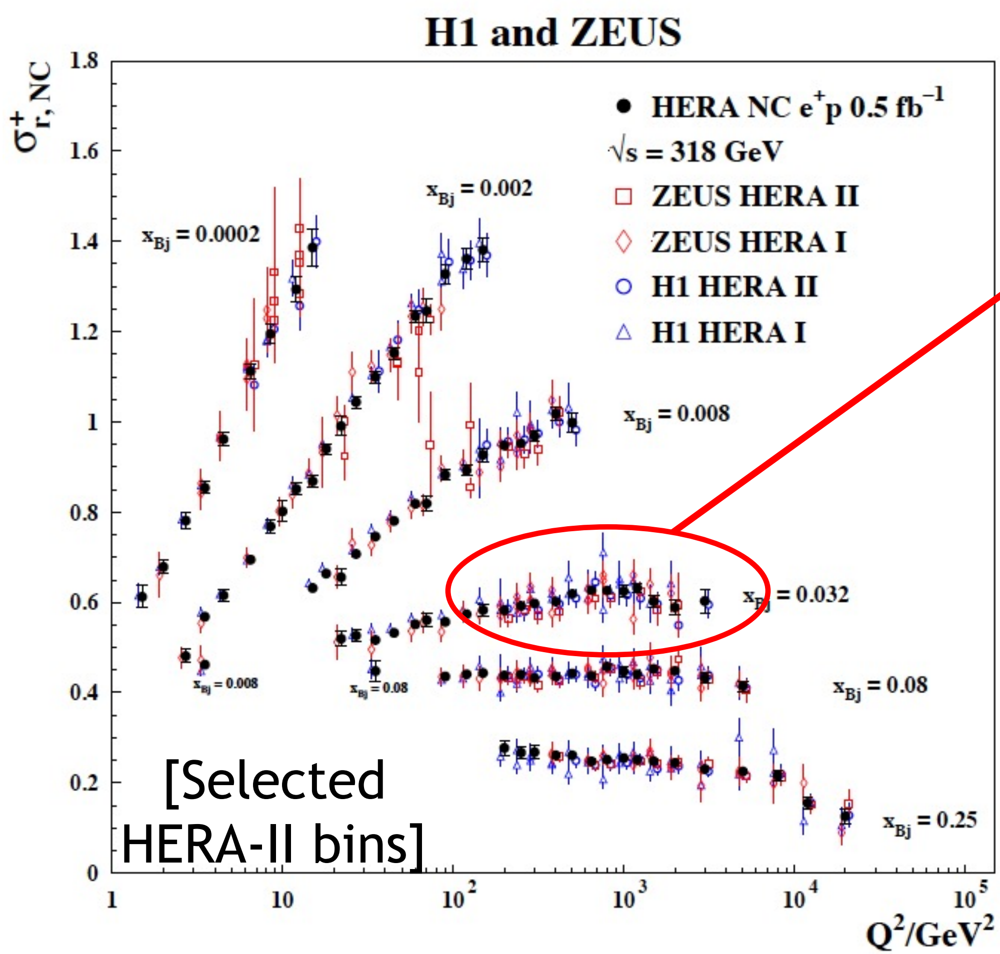


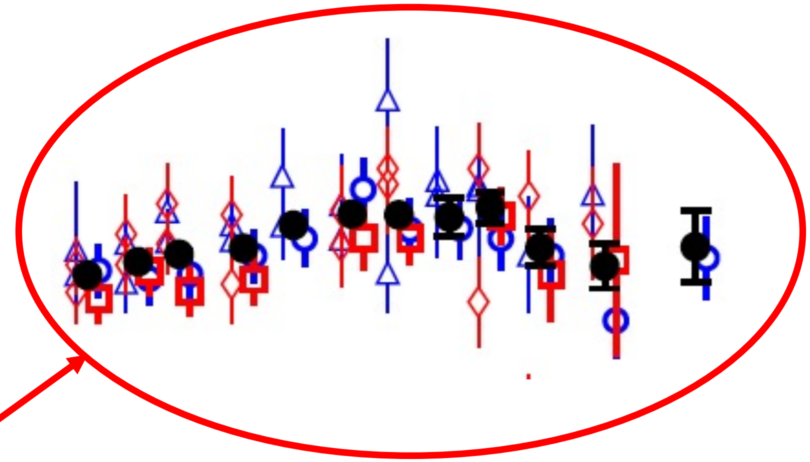




What do we want from ‘Complementary’

2) Cross calibration





- Combining data gave well beyond the √2 statistical improvement …
- Different dominating H1, ZEUS systematics…
- Effectively use H1 electrons with ZEUS hadrons

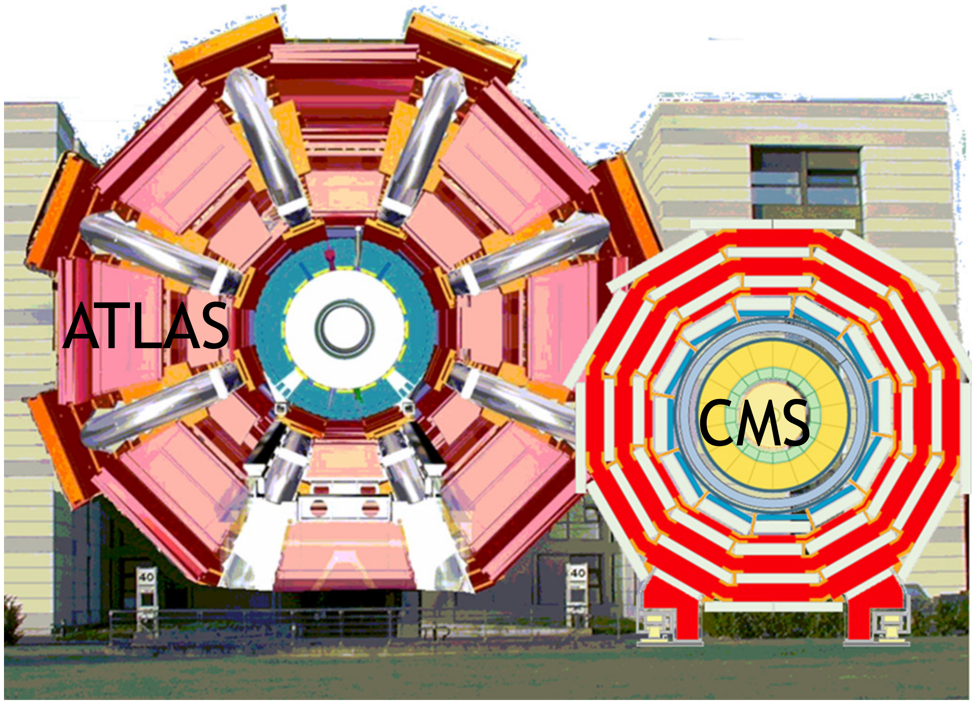
… not all optimal solutions have to be in one detector…

What do we want from ‘Complementary’

3) Technology Redundancy

... applying different detector technologies and philosophies to similar physics aims

- mitigates technology risk v unforeseen backgrounds
- differently optimises precision and systematics



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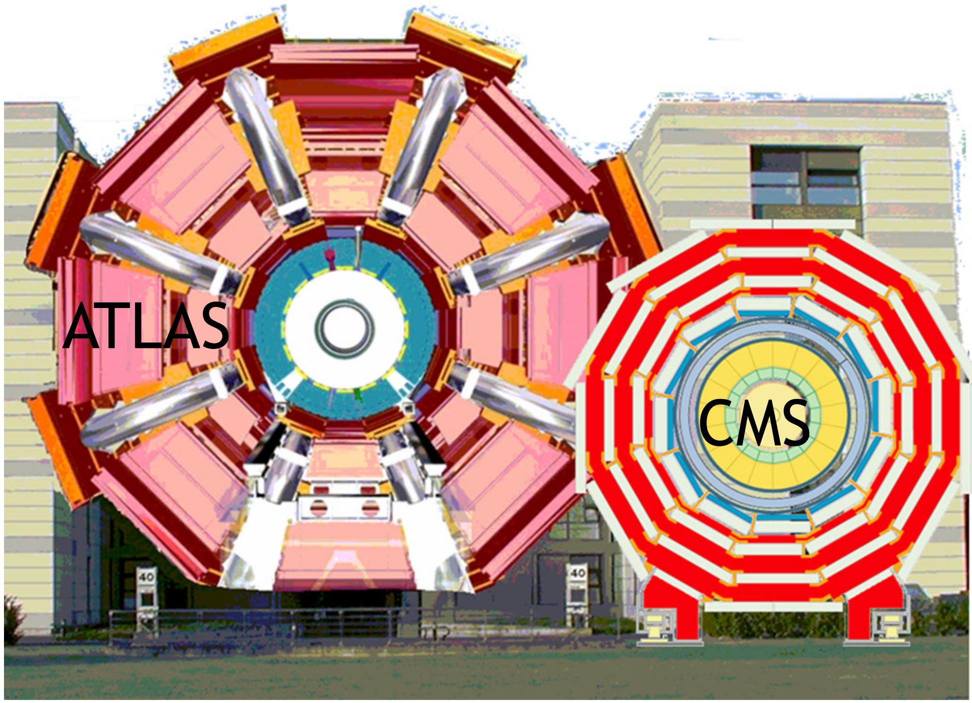


4) Different primary physics focuses ...
... EIC has unusually broad physics programme (from exclusive single particle production to high multiplicity eA or γA with complex nuclear fragmentation)
→ Impossible to optimise for the full programme in a single detector.

Complementarity Working Group Activities

1) Discussed detailed aims and needs with Physics Working Group conveners

"Have you identified key physics aims that conflict with the current baseline /schematic detector and IR design?"

2) Discussed with Detector Working Group conveners

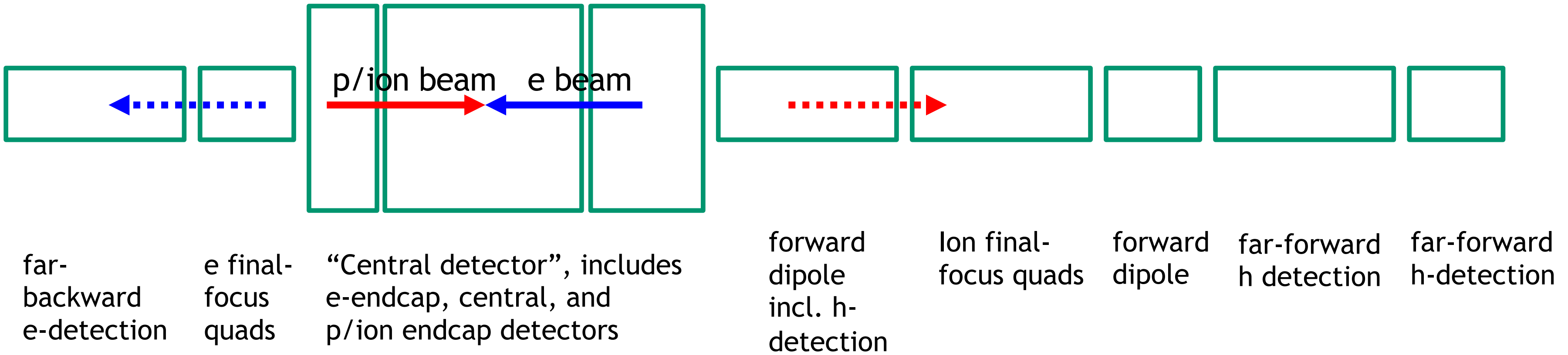
"Assuming we have two detectors, how you could build in complementarity within the overall constraints imposed by the accelerator and associated considerations?"

[Many subsidiary questions and iterations]

… no compelling argument for a second detector with specialised / limited physics focus.

→ **Working assumption → two complementary GPDs**

General Requirements for any EIC GPD: 1) Boundary Conditions from Machine



- Second detector design must be compatible with machine / IR design at IP8
- Solenoid aligned with electron beam (to limit synchrotron load)
- Main detector coverage limited to $|\eta| <\sim 4$ by crossing angle / synchrotron
- Main detector length limited to ± 4.5m by first focusing quadrupole (lumi)
- Fwd / Bwd detector angular range limited to ~ 1.5^o by synchrotron
- Longitudinal space for Fwd / Bwd detectors limited to $\pm$ 35m (crab cavities)

General Requirements for any EIC GPD
2) Physics Considerations

- Able to perform well over entire EIC $\sqrt{s}$ and luminosity range

- Efficient scattered electron ID down to low energies (10^{-4} e/π separation)

- ECAL resolution (for scattered electron) pivotal (~ $2\%/\sqrt{E}$)

- Tracking momentum resolution better than 2%, whilst keeping material budget low (<~5% X_0). Vertex resolution (~ 20 μm for all three coordinates)

- PID separating π, K, p (nominally 3σ π/K separation) up to high p_T ~50GeV

- HCAL matching tracking and ECAL acceptance (~ 50% / $\sqrt{E}$).

- Large forward acceptance / precise measurement of protons, neutrons; also nuclear fragment, photon tagging. Backward e, γ coverage for lumi and low Q^2

- Precision luminosity and polarimetry measurements

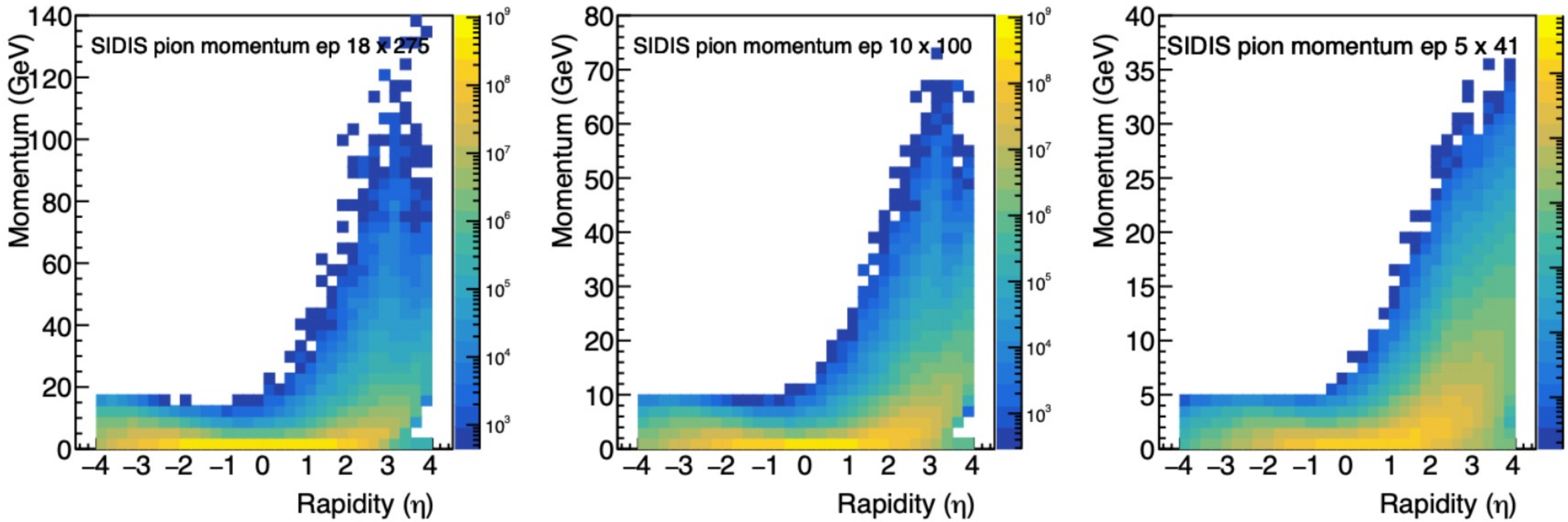
- Control of systematics matching statistical precision (redundancy!)

Complementarity from Solenoid Field Choice

Magnetic Field Strength compromises for charged particles in central detector

- High field → high p_T precision : Many good physics aims associated with scattered electron, heavy flavours, precision spectroscopy …

- Low field → low p_T acceptance: eg 1.5T field - acceptance to p_T~150 MeV



- SIDIS spectra dominated by low p_T (<~ 1 GeV).
  → TMDs, Fragmentation Fns, Samples for spectroscopy (HF etc)

Field Choice also coupled with PID Acceptance

- Suppose silicon / microvertex detector has r_{min} ~ 3cm and innermost particle ID-capable detector has r_{min} ~ 1m …

… p_T acceptance cut-offs significantly higher for PID than for basic track reconstruction …

lowest p_T	0.5 Tesla	1 Tesla	3 Tesla
with PID @1m	75 MeV	225 MeV	450 MeV
no PID	25 MeV	50 MeV	100 MeV

- Solenoid bore radius, length, space for cryostat also have strong influence on detector design

Parameter	New Magnet	BABAR/sPHENIX Magnet
Maximum Central Field (T)	3	1.5
Coil length (mm)	3600	3512
Warm bore diameter (m)	3.2	2.8
Uniformity in tracking region ($z = 0, r < 80$ cm) (%)	3	3
Conductor	NbTi in Cu Matrix	Al stabilized NbTi
Operating Temperature (K)	4.5	4.5

(ATHENA) (ECCE)

(CORE compact 2.5T baseline)

Complementarity through Technology Choices

system	system components	reference detectors	detectors, alternative options considered by the community		
tracking	vertex	MAPS, 20 um pitch	MAPS, 10 um pitch		
	barrel	TPC	TPC[a]	MAPS, 20 um pitch	MICROMEGAS[b]
	forward & backward	MAPS, 20 um pitch & sTGCs[c]	GEMs	GEMs with Cr electrodes	
	very far-forward & far-backward	MAPS, 20 um pitch & AC-LGAD[d]	TimePix (very far-backward)		
ECal	barrel	W powder/ScFi or Pb/Sc Shashlyk	SciGlass	W/Sc Shashlyk	
	forward	W powder/ScFi	SciGlass	PbGl	Pb/Sc Shashlyk or W/Sc Shashlyk
	backward, inner	$PbWO_4$	SciGlass		
	backward, outer	SciGlass	$PbWO_4$	PbGl	W powder/ScFi or W/Sc Shashlyk[e]
	very far-forward	Si/W	W powder/ScFi	crystals[f]	SciGlass
h-PID	barrel	High performance DIRC & dE/dx (TPC)	reuse of BABAR DIRC bars	fine resolution TOF	
	forward, high p	double radiator RICH (fluorocarbon gas, aerogel)	fluorocarbon gaseous RICH	high pressure Ar RICH	
	forward, medium p		aerogel		
	forward, low p	TOF	dE/dx		
	backward	modular RICH (aerogel)	proximity focusing aerogel		
e/h separation at low p	barrel	hpDIRC & dE/dx (TPC)	very fine resolution TOF		
	forward	TOF & areogel			
	backward	modular RICH	adding TRD	Hadron Blind Detector	
HCal	barrel	Fe/Sc	RPC/DHCAL	Pb/Sc	
	forward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	backward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	very far-forward	quartz fibers/ scintillators			

Multiple proposals / alternatives in YR for each subdetector …

→ Different space requirements

e.g. trade-offs between tracking and dedicated PID

→ Different material budgets / systematics

→ Some combine multiple functions

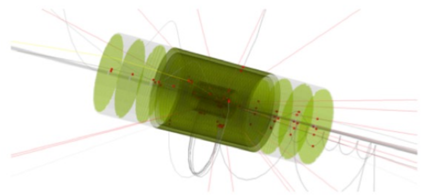
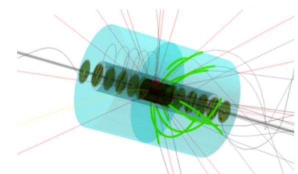
eg e-h separation + tracking with TRDs

eg PID (from ToF) + tracking with AC-LGADs

→ Different risks / technology-readiness

… Making different choices in IR1 and IR2 detectors provides natural technology redundancy, plus 'independent' cross checking and cross-calibration

Example Complementarity through Detector Technology Choices: Tracking Region

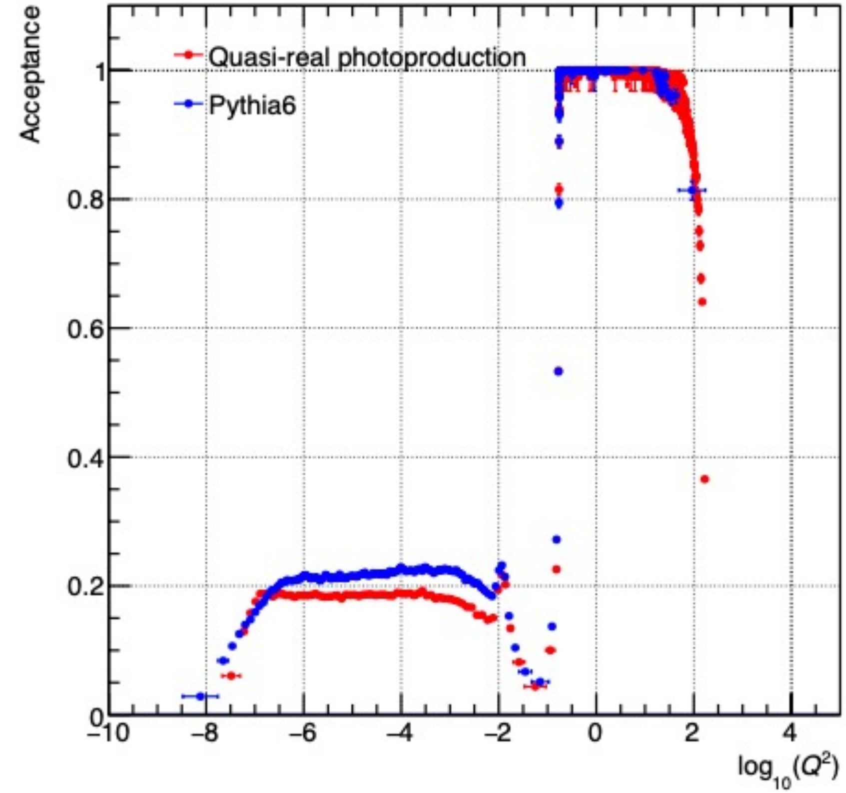
Function	Radial space needs			
	Minimum	Maximum	Minimum	Maximum
Tracking	All Silicon		Silicon + TPC	
				
(includes 5 cm support)	50 cm	60 cm	85 cm	
Hadron PID	RICH 50 cm		DIRC 10 cm	
EM Calorimetry	30 cm	50 cm	High-Resolution to achieve P < 2 GeV 50 cm	
PID & EMCal Support Structure	10 cm	15 cm	10 cm	15 cm
Total	140 cm	175 cm	155 cm	160 cm

- Si + gas version provides PID from dE/dx & keeps low material budget

- All Si version slightly improves momentum, vertex performance and is more compact (e.g. allowing high p_T PID beyond tracker or reducing magnet bore)

… Here (and in many other places), detailed multi-detector simulation tools are needed to optimise combinations

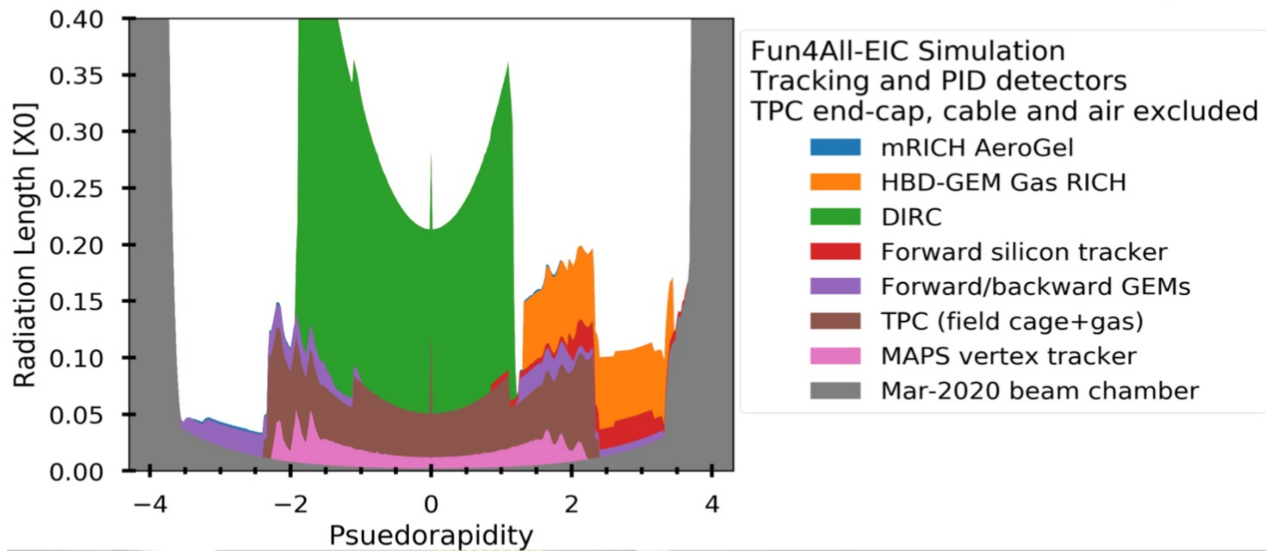
Complementarity by Mitigating Acceptance Gaps



- **All detectors have gaps and cracks**

… e.g. place gap in scattered electron acceptance between main detector and dipole/tagger in different places?

- **Similar arguments apply to directional peaks in dead material**



Complementarity Between Interaction Points

EIC science needs point to (staged) programme with multiple CMS energies

… Could there be two IRs operating simultaneously, but optimised to different $\sqrt{s}$?

→ Subtly different overall physics goals at different $\sqrt{s}$

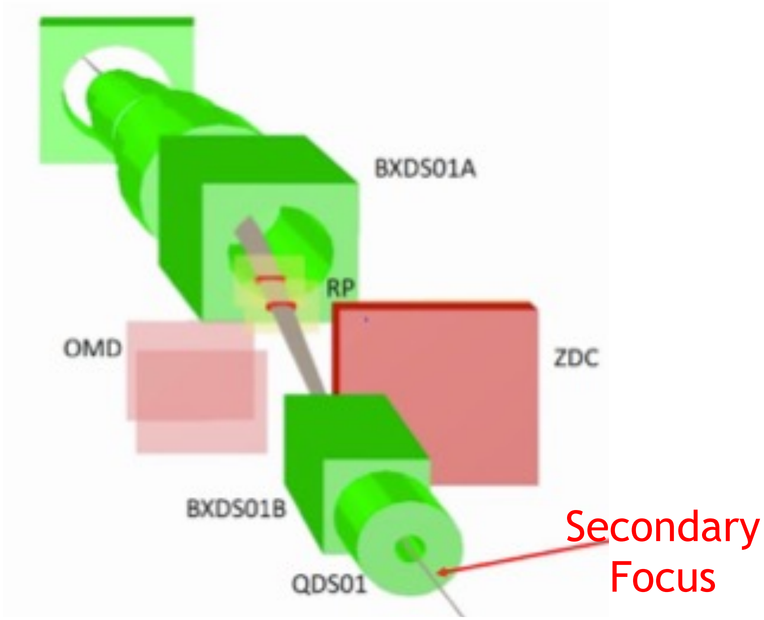
→ For a given process, complementary of kinematic regions matching central acceptance at different $\sqrt{s}$

IR6, IR8 Crossing angles can also be different

→ Larger crossing angle reduces parasitic interactions

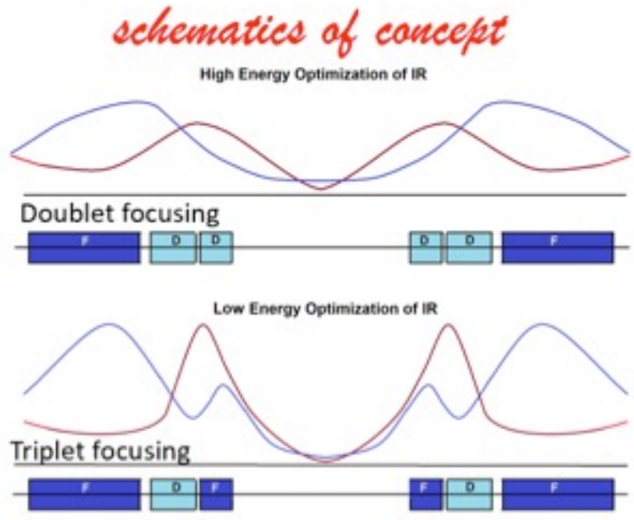
→ Incorporation of secondary focus to improve acceptance.

→ Influences detector design, in particular beamline instrumentation



… significant progress since completion of Yellow Report …

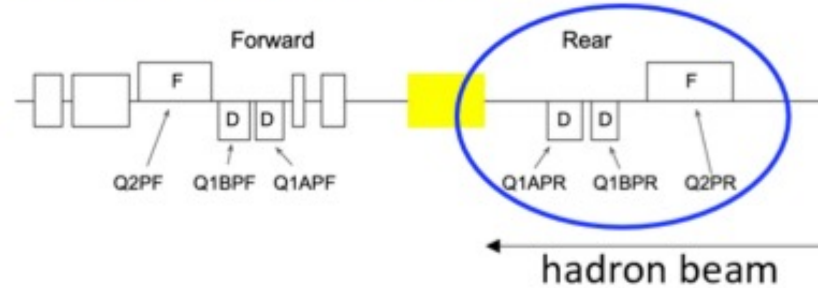
Concept for Increased Luminosity at Lower $\sqrt{s}$



change polarity of quads DDF to FDF

→ needs to be done only on the rear side (incoming hadron beam) hadron quads

→ change polarity of quads at low E_{CM}



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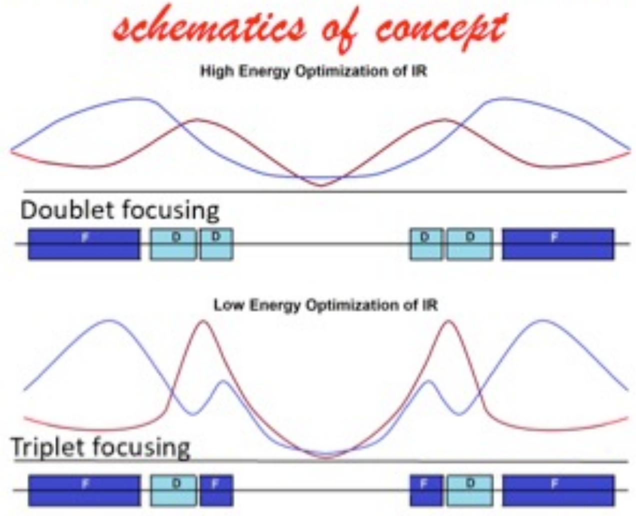

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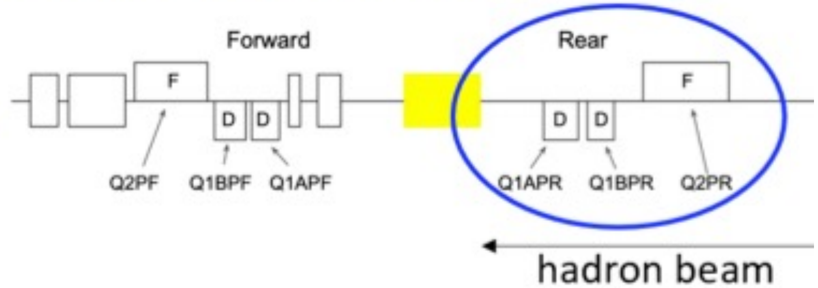

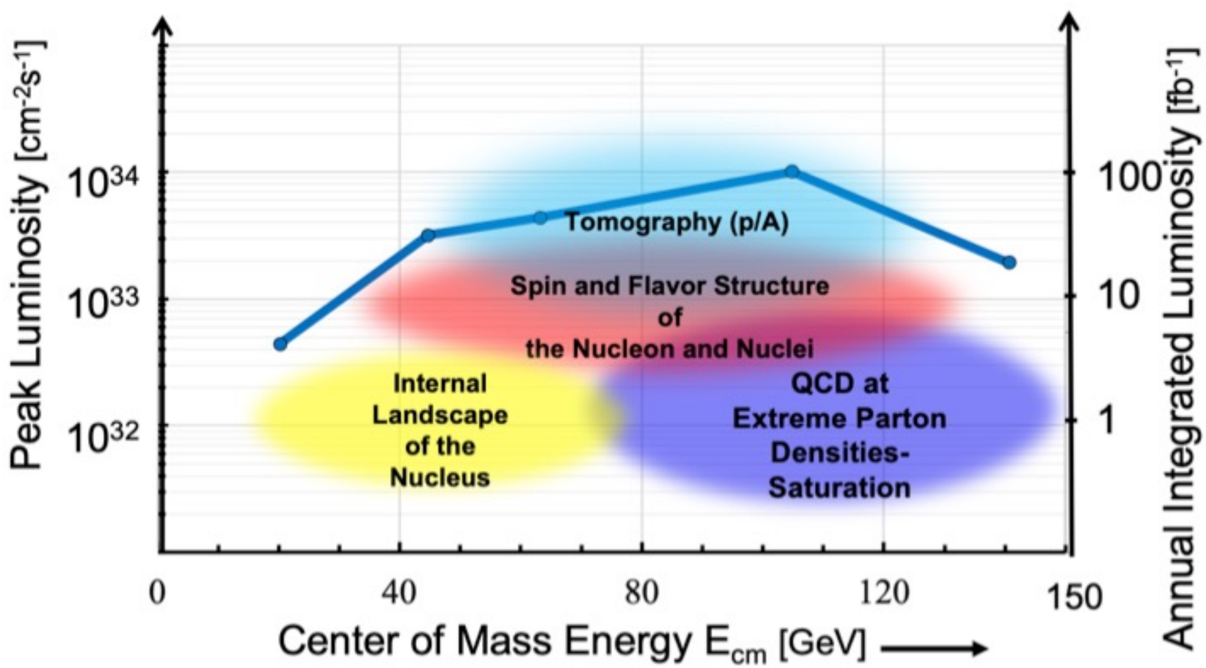

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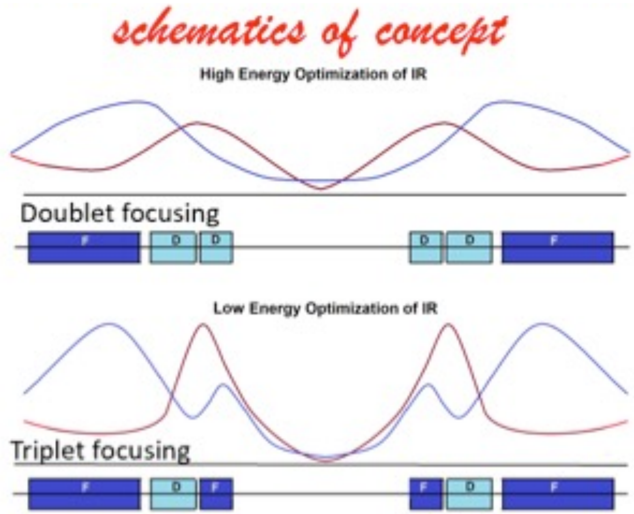

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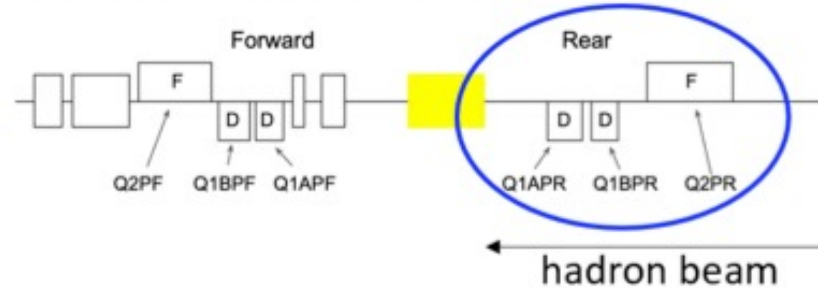
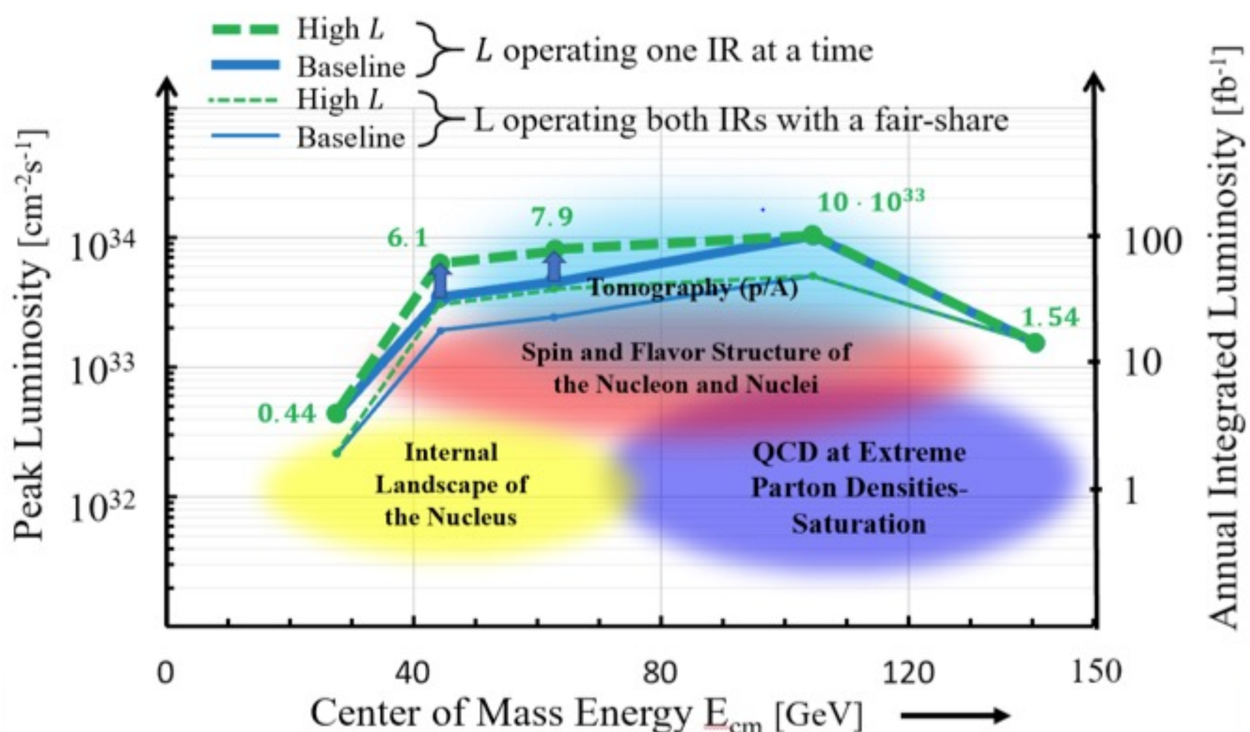


- Can be done at IP6 or IP8

- Some cost in terms of low p_T acceptance for far-forward particles



Summary of Recent Complementary IR Design

<table>
<tr><th></th><th>1st IR (IP-6)</th><th>2nd IR (IP-8)</th></tr>
<tr><td>Geometry:</td><td>ring inside to outside
tunnel and assembly hall are larger
Tunnel: ⦰ 7m +/- 140m</td><td>ring outside to inside
tunnel and assembly hall are smaller
Tunnel: ⦰ 6.3m to 60m then 5.3m</td></tr>
<tr><td>Crossing Angle:</td><td>25 mrad</td><td>35 mrad
secondary focus</td></tr>
<tr><td></td><td colspan="2">different blind spots
different forward detectors and acceptances
different acceptance of central detector</td></tr>
<tr><td>Luminosity:</td><td colspan="2">more luminosity at lower E_{CM}
optimize Doublet focusing FDD vs. FDF
→ impact of far forward p_T acceptance</td></tr>
<tr><td>Experiment:</td><td colspan="2">1.5 Tesla or 3 Tesla
different subdetector technologies</td></tr>
</table>

Summary

- Essential to robustness of science programme to have two detectors

- Yellow report exercise recommended two GPDs with complementarity in details such as solenoid field, technology choices.

- Novel IR design optimised to reduced $\sqrt{s}$ emerged as key consideration

- For cross-checks and cross-calibration, IR2 time-line should not be (very) different from IR1

- Further progress will ultimately require detailed simulations

- Things are moving fast!

  → Some of complementarity discussion already superseded by collaboration formation discussions