Letter of Intent for Position Sensitive ZDC

Detector R&D Advisory Committee Meeting

@BNL

January 30th, 2020

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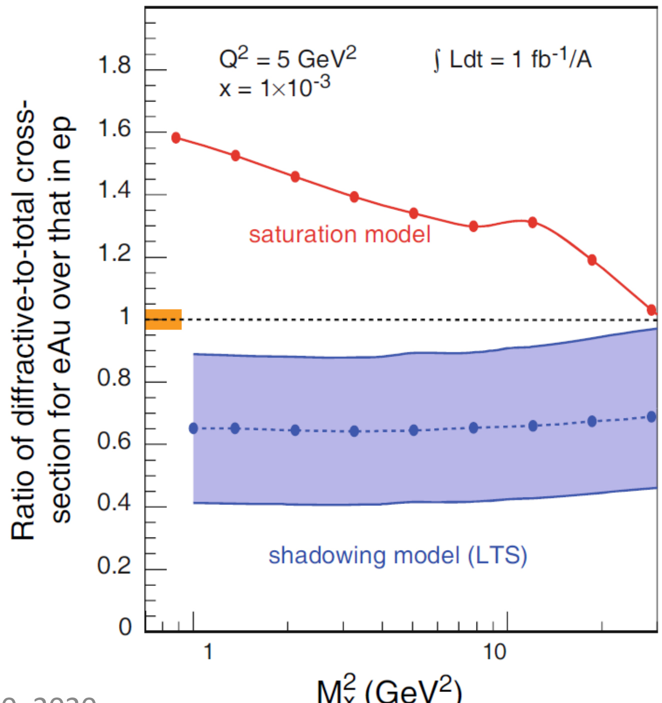
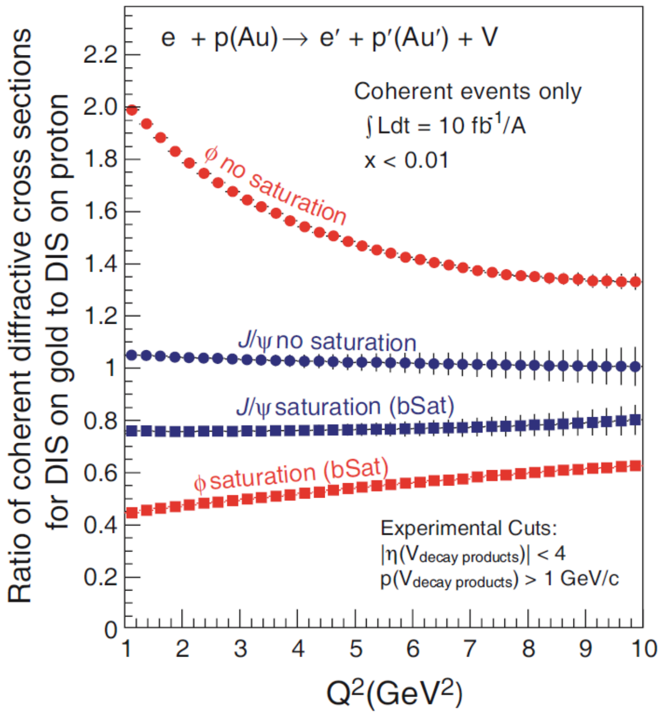
EIC R&D of ZDC

- Full-absorption photon detector
  - Crystal scintillators
- Prototype study of ZDC with position sensitivity
  - EM + Hadron calorimeters
  - ALICE-FoCal / RHICf technology / …
- Radiation hardness study for new technology
  - Plastic scintillators

Gluon saturation at extreme density

- Diffractive process in e + A collision
  - Rapidity gap & coherent (nucleus remains intact)
- Diffractive cross section
  - First evidence for gluon saturation
- Exclusive vector meson production
  - e + Au → e' + Au' + J/ψ, φ, ρ

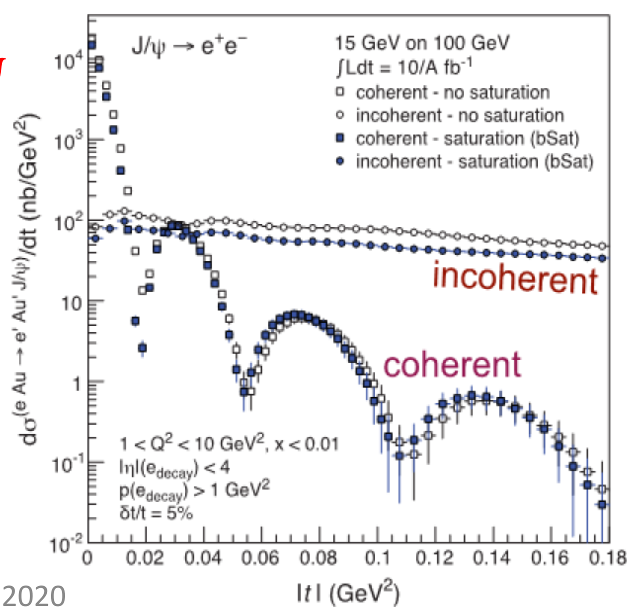




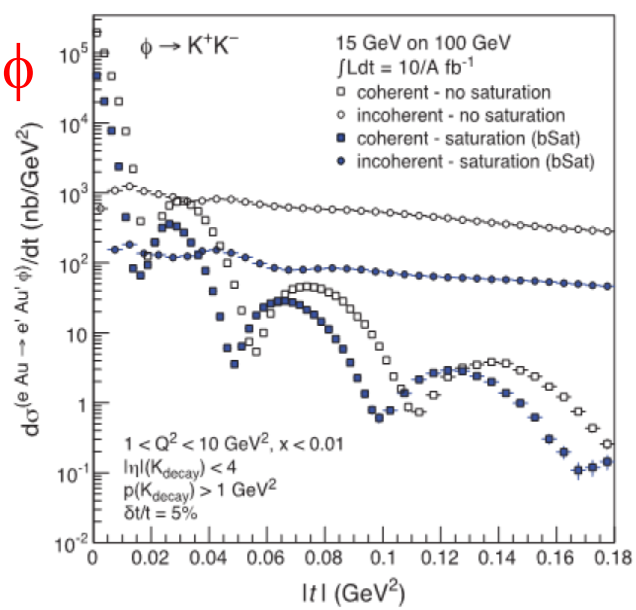
Gluon saturation at extreme density

- Exclusive vector meson production
  - Momentum transfer *t* dependence translated to the transverse spatial distribution of gluons in the nucleus
  - Incoherent process (nucleus breaks up)
    - Spatial density fluctuation in nucleus
    - Much larger than the coherent process
  - Coherent process (nucleus remains intact)
    - Sensitive to the gluon saturation
    - Identify & veto breakup of the excited nucleus

J/ψ

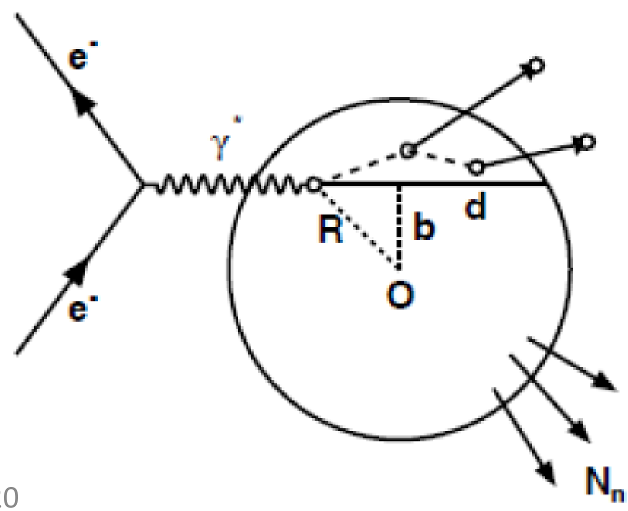


φ



e + A collision at zero degree

- Breakup of the excited nucleus
  - Evaporated neutrons (& protons)
    - Separate the coherent process ~90%
  - Photons from de-excitation of the excited nucleus
  - Requirement to measure neutrons and photons at zero degree in a wide *t* range
- Event-by-event characterization of collision geometry
  - Tagged through forward neutron multiplicities at zero degree
  - *b*: impact parameter
  - *d*: path length of struck parton in nucleus
  - "centrality" (high *d*) & "skin" (low *d*)
  - Study of nuclear medium effects

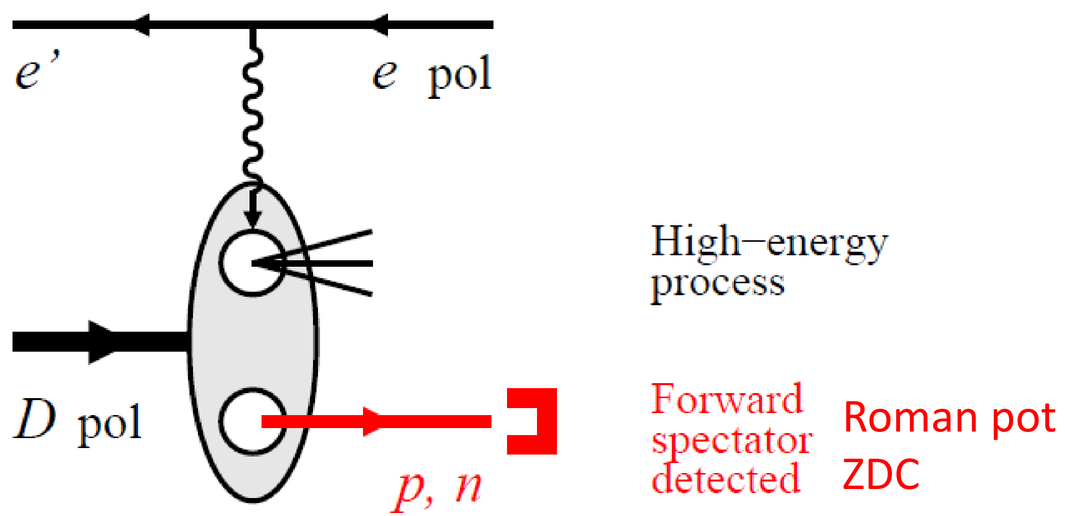


Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)

e + d/^{3}He collision at zero degree

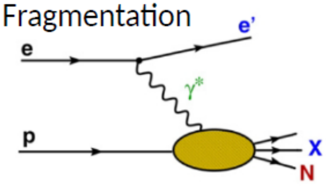
- Spectator tagging
  - Neutron structure
    - Neutron spin structure, S & D waves
  - Nucleon interactions
    - Short-range correlation (SRC) and EMC effect at large *x*
    - Diffraction and shadowing at small *x*



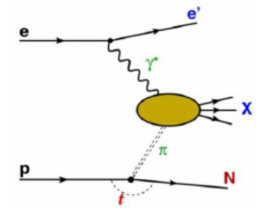
Physics at zero degree of EIC

- Leading baryons
  - Fragmentation
  - One pion exchange (OPE)

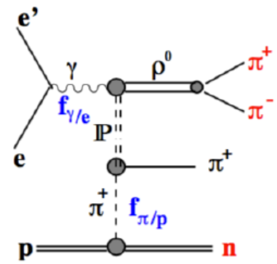
Fragmentation



One Pion Exchange (OPE)



LN in DIS

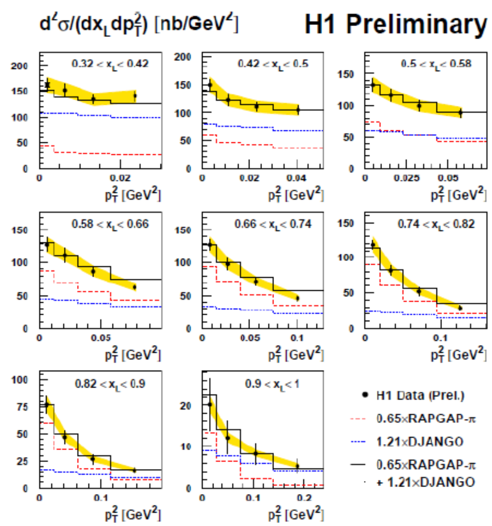


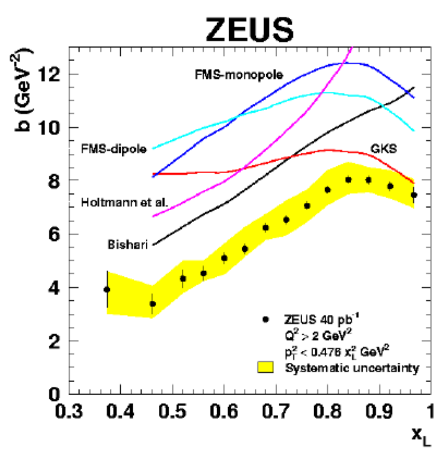
$$d\sigma_{\gamma^* p \to nx} = f_{\pi/p}(x_L, t) \times d\sigma_{\gamma^* \pi \to X}$$

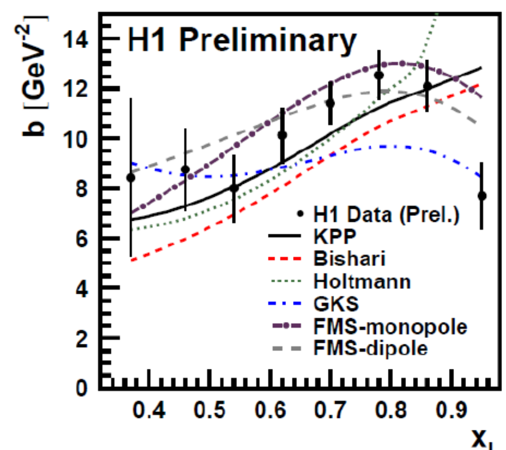
The distribution of p_T^2 (=t) is defined solely by the pion flux

Sensitivity to the pion flux

p_T^2 dependence in bins of x_L







Slope of exponential p_T^2 dependence compated to various pion-flux models

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slide by Ciesielski

Inconsistency @ HERA

→ Need more data to understand production mechanism

Other physics

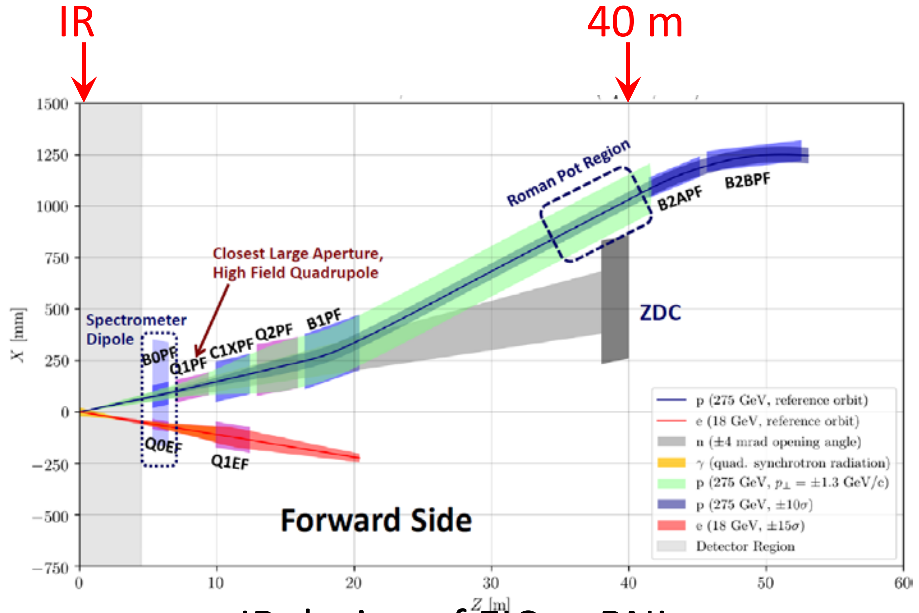
- Asymmetries at zero degree
  - Leading baryons
- Spectroscopy
- Isotope tagging for nuclear fragments
- Relation to cosmic-ray physics
  - Understanding hadronization
  - Cosmic-ray acceleration in blazars

Detector performance requirements

- Photon detection
  - To identify the nuclear excitation states in addition to the neutron detection
  - Photon energy < 300 MeV
- Full absorption calorimeter, e.g. crystal calorimeter
  - $PbWO_4$
    - X_0 = 8.9 mm, r_M = 2.2 cm, τ = 25 nsec
    - 5% resolution at 300 MeV
  - LYSO
    - X_0 = 11.4 mm, r_M = 2.1 cm, τ = 40 nsec
    - 2.6% resolution at 300 MeV (SuperB prototype)

ZDC requirements

- Acceptance
  - 25 mrad crossing angle for EIC at BNL
  - Forward magnet aperture ±4 mrad opening angle for ZDC
- Sufficient transverse size to avoid transverse leakage
  - ~2 interaction length
  - e.g. 60cm x 60cm



IR design of EIC at BNL

ZDC requirements

- Position resolution
  - 1 cm position resolution $\rightarrow$ 300 μrad angular resolution
  - $\rightarrow$ 30 MeV p_T resolution for 100 GeV spectator neutron
- Energy resolution
  - Minimum requirement $\Delta E/E = 50\%/\sqrt{E}$ (GeV)
  - $\rightarrow$ 50 MeV p_T resolution for 100 GeV spectator neutron
- Position layers (or Shower Max Detector)

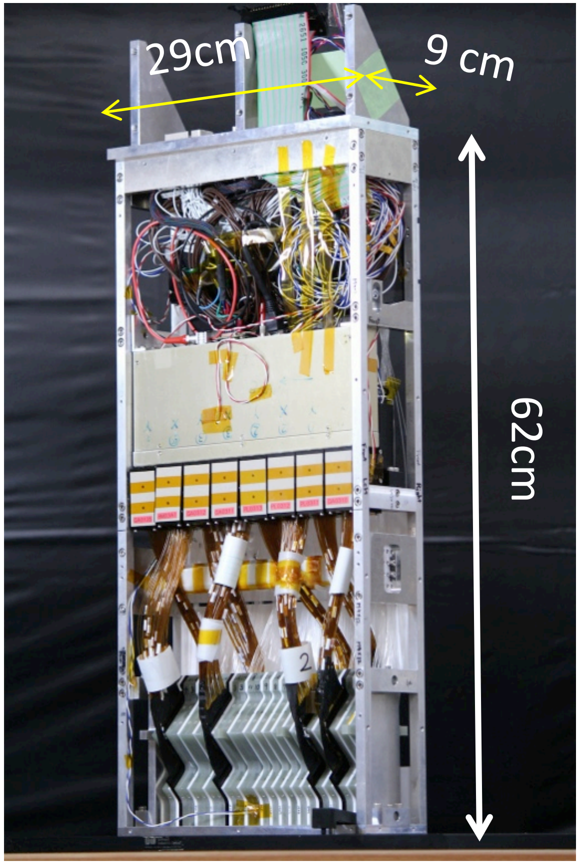
	Plastic fiber	Crystal bar	Quartz fiber	Silicon
Source	Scintillation		Cherenkov	
Signal	good	good	weak	good
Rad Hardness	poor	OK	excellent	OK
Cost	$	$$	$$	$$$
Position Resolution	good	good	poor	best
Large acceptance	OK	position dependent	OK	OK

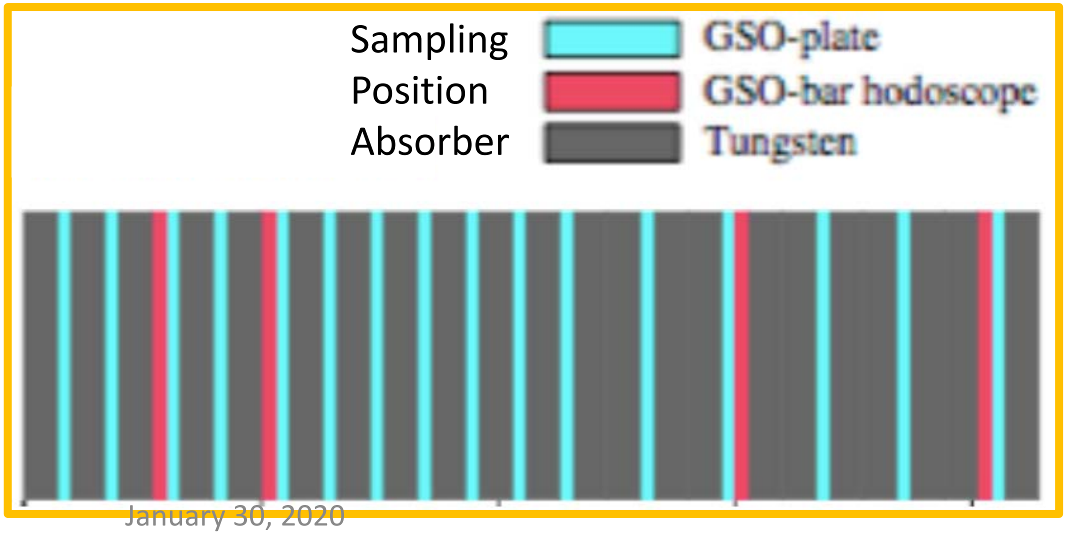
Detector performance requirements

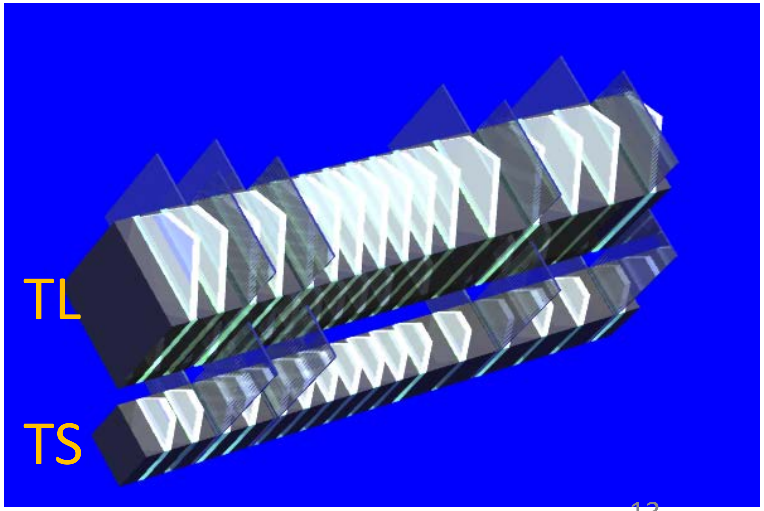
- Radiation hardness
  - $\sim O(100\text{k} - 1\text{MGy})$ or $n_{eq} = 3\times10^{12} - 10^{13}$ for 1-year operation
  - $n_{eq} > 10^{14}$ for lifetime
- Silicon and LYSO should be OK for the dose
- Plastic scintillators?
  - Very good resolution for hadrons
    - Good e/h
  - Some plastic like PEN stands for > 0.1 MGy radiation

RHICf detector

- Two position-sensitive sampling calorimeters
  - TS (small tower): 20mm x 20mm
  - TL (large tower): 40mm x 40mm
  - Tungsten absorber (44 X_0, 1.6 λ_{int})
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers (MAPMT readout)

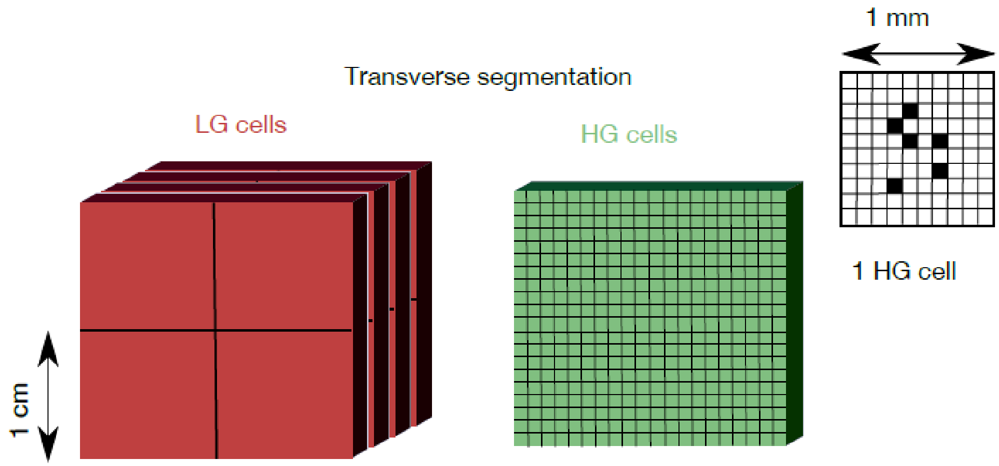


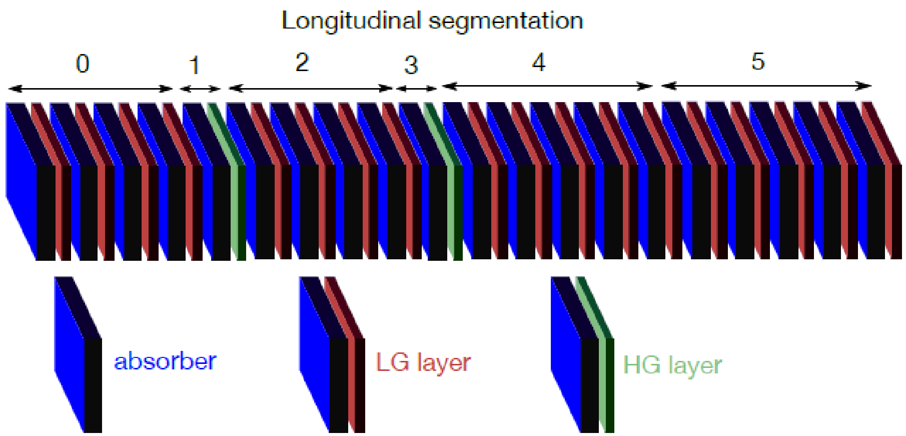




ALICE-FoCal

FoCal-E basic design





The design of the detector:

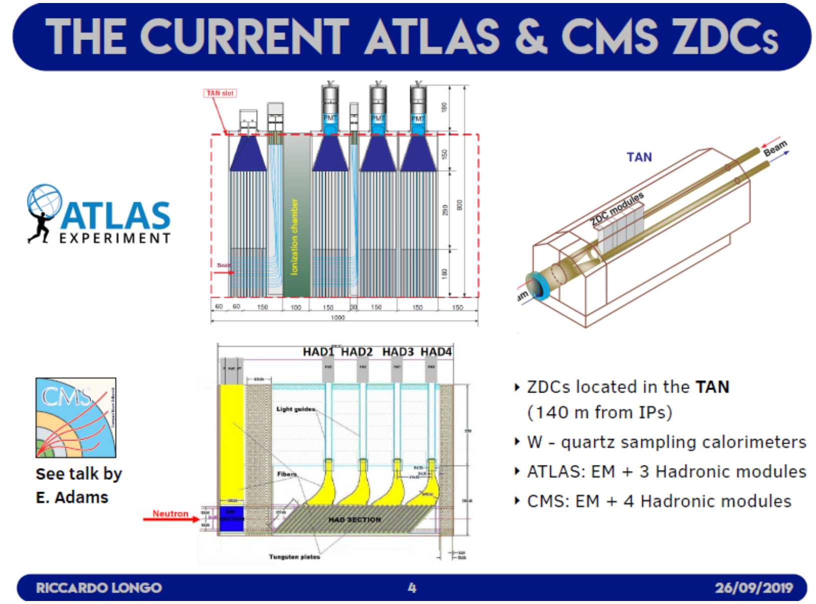
- 20 layers: W (**3.5mm ≈ 1 X_0**) + Si-sensors (2 types):
  - **low granularity (LG), Si-pads**
  - **high granularity (HG), pixels (e.g. CMOS-MAPS)**
- Moliere radius ~ 1-2 cm

	LG	HG
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # of pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9

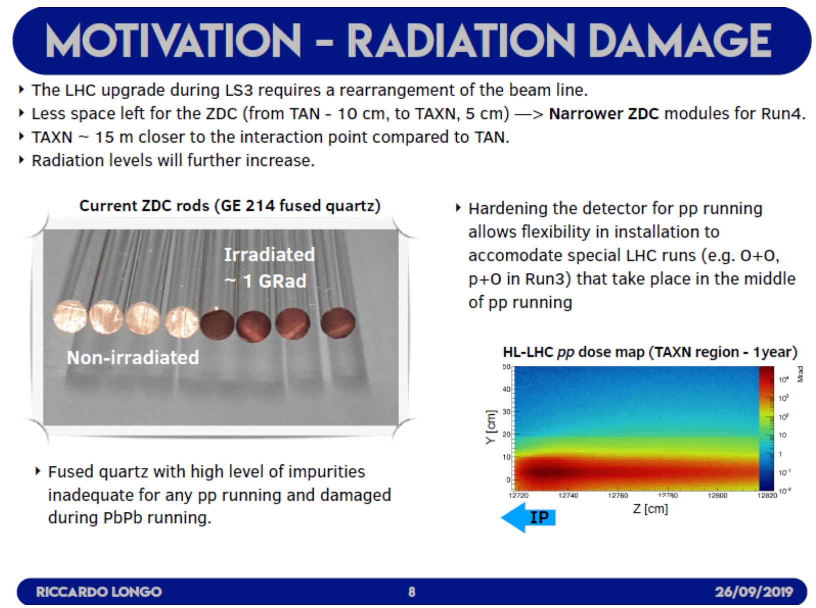
The surface area of the detector will be about 1 m^2

ZDC at LHC

- ATLAS & CMS ZDC
  - W-quartz sampling calorimeter



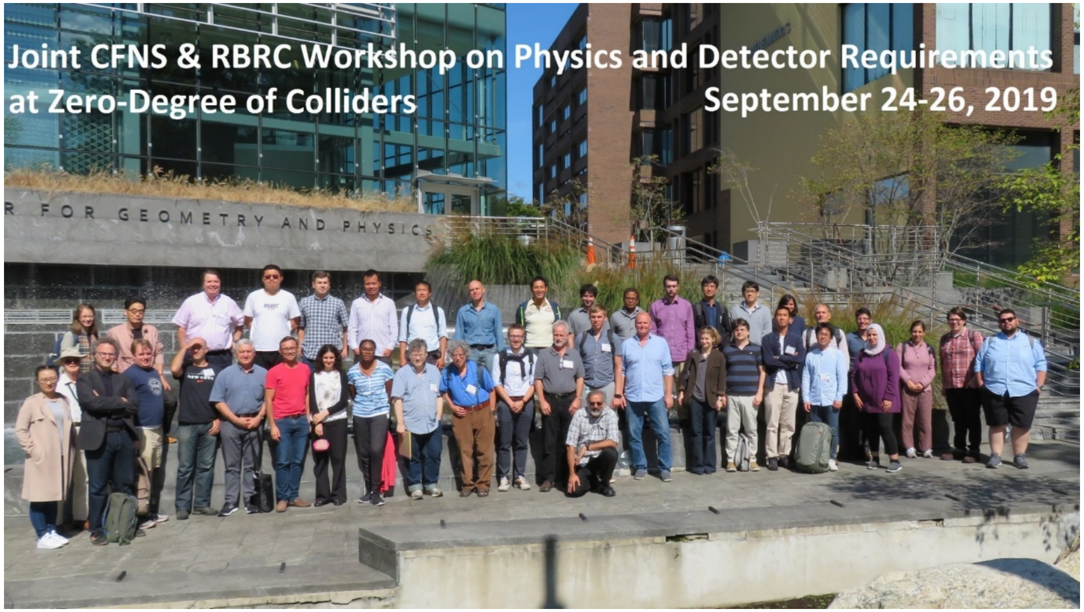
- JZCaP collaboration
  - ATLAS + CMS joint R&D effort
  - Radiation-hard fused silica rods
  - Increasing H_2 concentration



slides by Longo

Collaborators

- Japanese group
  - RIKEN, Nagoya Univ., ICRR, Kobe Univ., Tsukuba Univ., Tokyo Tech., Nihon Univ., Yamagata Univ., JAEA
- US group
  - BNL, Univ. of Kansas
- Discussing with
  - Participants in Joint CFNS & RBRC workshop on "Physics and detector requirements at zero-degree of colliders"
  - Follow-up meeting to be held



Summary

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    - ALICE-FoCal / RHICf technology / …
  - Radiation hardness study for new technology
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  - Diffractive process in e + A collision
    - Breakup of the excited nucleus
    - Event-by-event characterization of collision geometry
  - Spectator taggin in e + d/^{3}He collision
  - Leading baryons and forward asymmetries at zero degree
  - …