Position Sensitive ZDC

1st EIC Yellow Report Workshop

at Temple University (remote only)

March 19th, 2020

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EIC R&D of ZDC

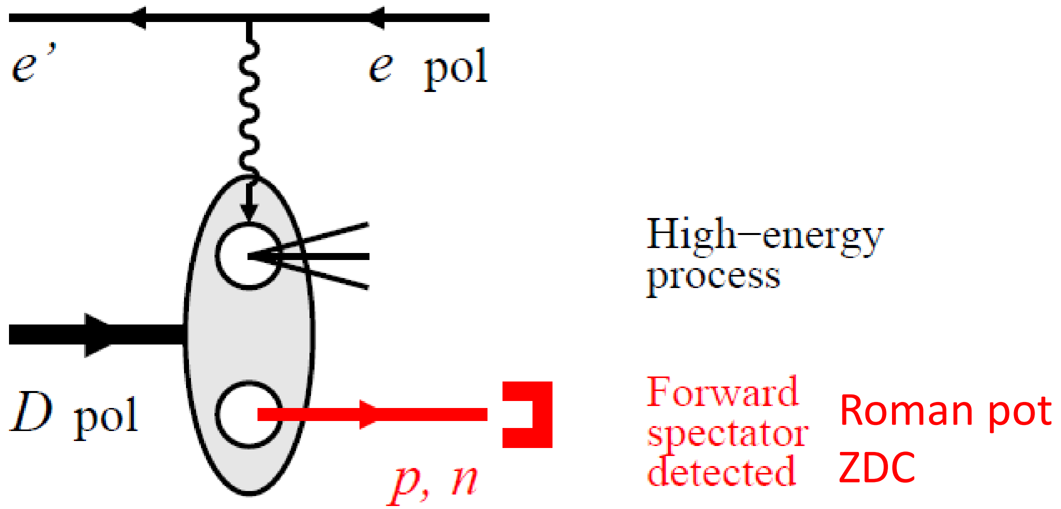
- Full-absorption photon detector
  - Crystal scintillators
- Prototype study of ZDC with position sensitivity
  - EM + Hadron calorimeters
  - ALICE-FoCal / ATLAS & CMS ZDC / …
- Radiation hardness study for new technology
  - Plastic scintillators
- We presented a Letter of Intent at the EIC R&D meeting in January, 2020
  - "The committee urges the group to put forward a proposal focused on the most important technical questions and what physics areas it will open"

Physics topics at EIC zero degree

- Diffractive process in e + A collisions
  - Breakup of the excited nucleus
    - Exclusive vector meson production
  - Event-by-event characterization of collision geometry
    - Study of nuclear medium effects
- Spectator tagging in e + d / ^{3}He collisions
  - Neutron structure
    - Spin structure, S & D waves
  - Neutron interactions
    - Short-range correlation (SRC) and EMC effect at large x
    - Diffraction and shadowing at small x
- Leading baryons
- Asymmetries at zero degree
- Spectroscopy
- Isotope tagging for nuclear fragments
- Relation to cosmic-ray physics
  - Understanding hadronization
  - Cosmic-ray acceleration in blazars

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*



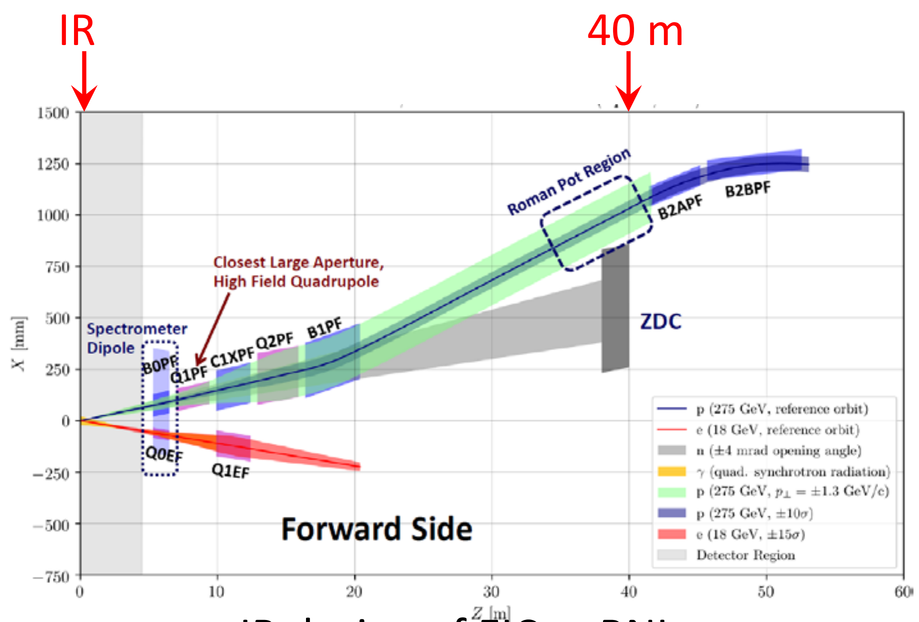
- Requiring good enough p_T resolution
  - Challenging to achieve 30MeV p_T resolution
  - Need to study if 50MeV p_T resolution acceptable

Detector performance requirements

- Photon detection
  - Required to identify diffractive process in e+A collisions
    - Rapidity gap & coherent (nucleus remains intact)
  - Requiring 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, $\tau = 25$ nsec
    - 5% resolution at 300 MeV
  - LYSO
    - $X_0 = 11.4$ mm, $r_M = 2.1$ cm, $\tau = 40$ 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

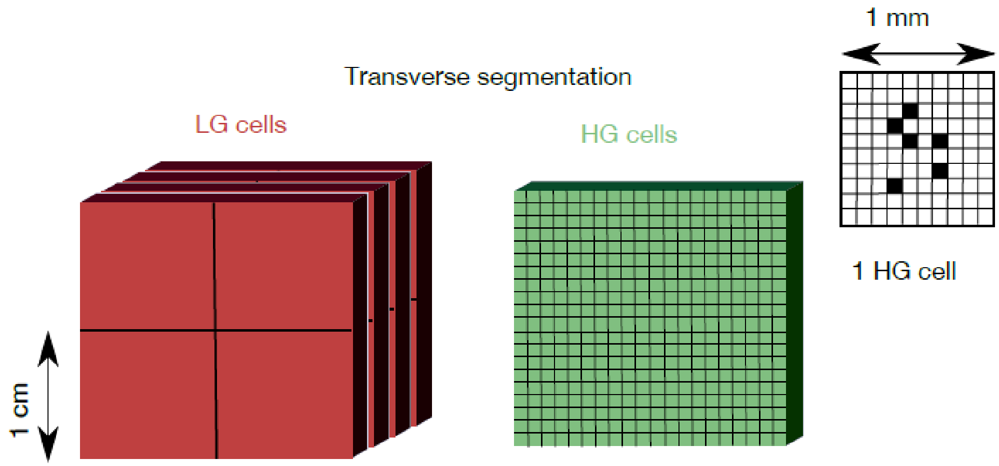
- Position resolution
  - 1 cm position resolution → 300 μrad angular resolution
  - → 30 MeV p_T resolution for 100 GeV spectator neutron
- Energy resolution
  - Minimum requirement $\Delta E/E = 50\%/\sqrt{E}$ (GeV)
  - → 50 MeV p_T resolution for 100 GeV spectator neutron
- Position layers (or Shower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

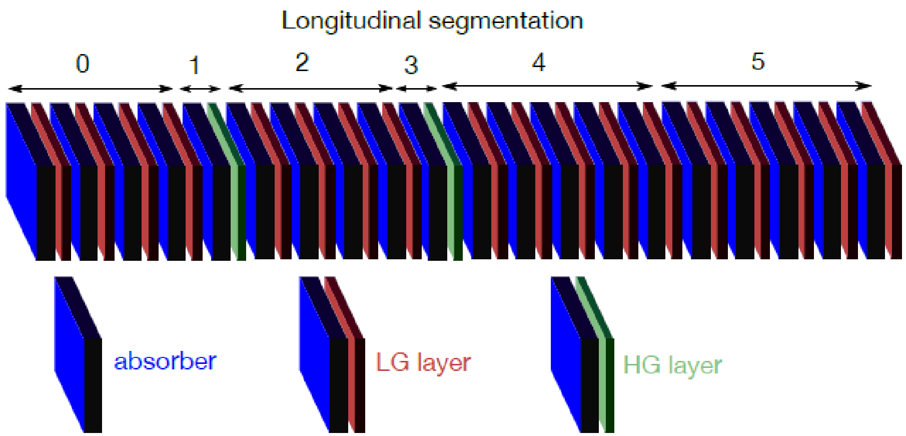
	Plastic fiber	Crystal bar	Quartz fiber	Silicon
Source	Scintillation		Cherenkov	
Signal	good	good	weak	good
Rad Hardness	poor	OK	excellent	OK
Cost	$	$$	$$	$$$
Position Resolution	good	good	poor	best
Large acceptance	OK	position dependent	OK	OK

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

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

mini-FoCal at PS and SPS (2018)

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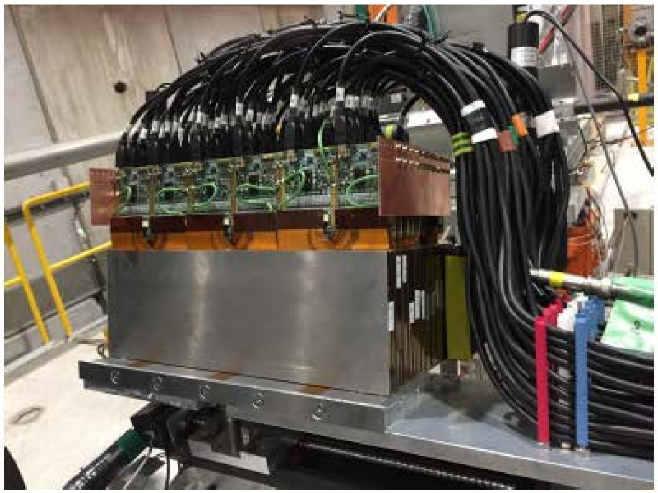
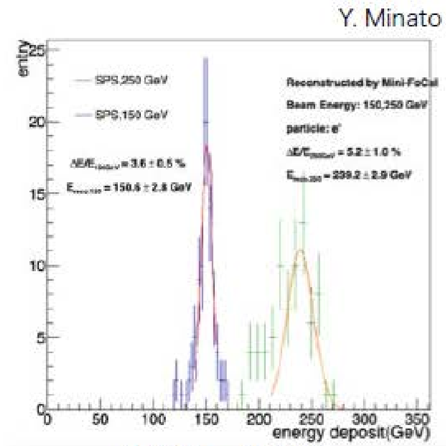
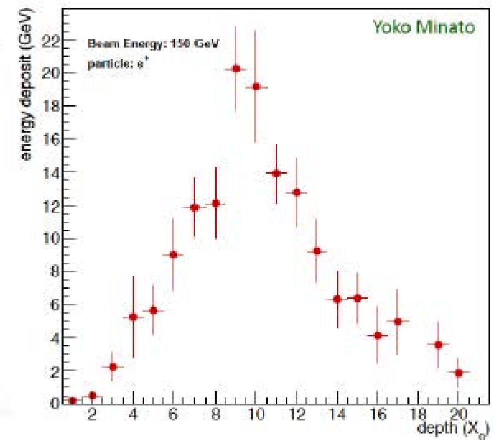




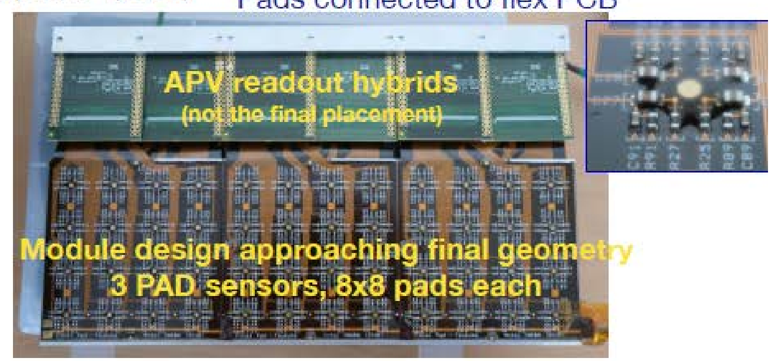


$\Delta E/E = 3.6$ %

@ 150 GeV/c , e^- (SPS)

- "mini-FoCal" has been built in Tsukuba, and shipped to CERN for test beam and ALICE test in 2018
- APV25 hybrid + SRS for readout

Pads connected to flex PCB



ALICE-FoCal

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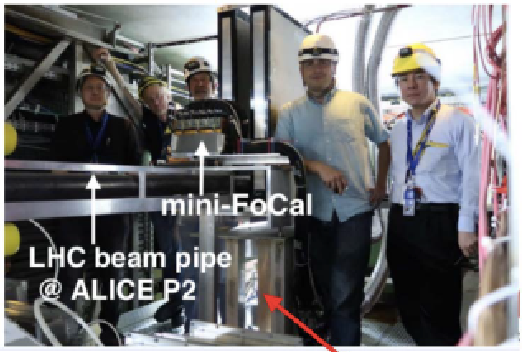
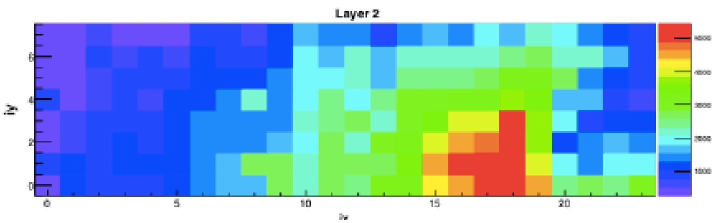
mini-FoCal in ALICE (2018)

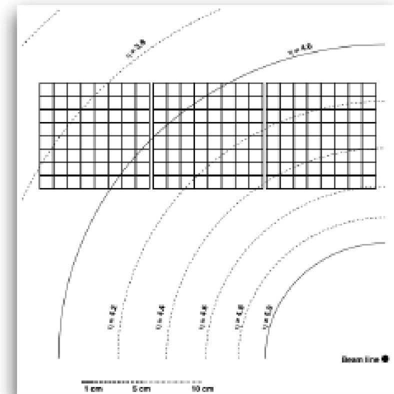


SRS system under the table

Hit Map of mini-FoCal in ALICE



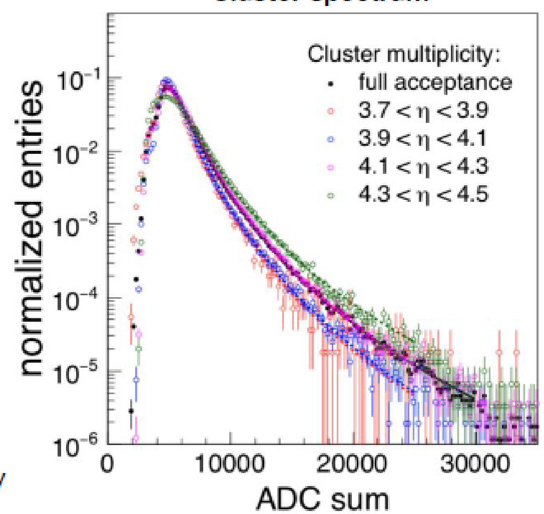
Acceptance



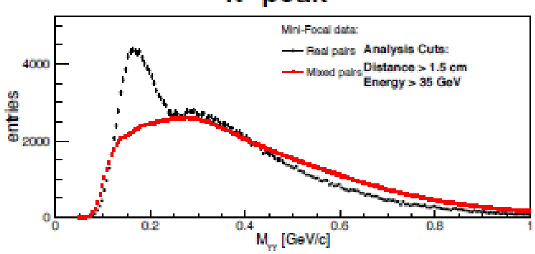
Goal: measure/verify backgrounds in situ with p+p @ $\sqrt{s}$ = 13 TeV collisions in ALICE

- Calibration based on test beam
- Comparison to MC (cluster spectrum, slid lines)

Cluster spectrum



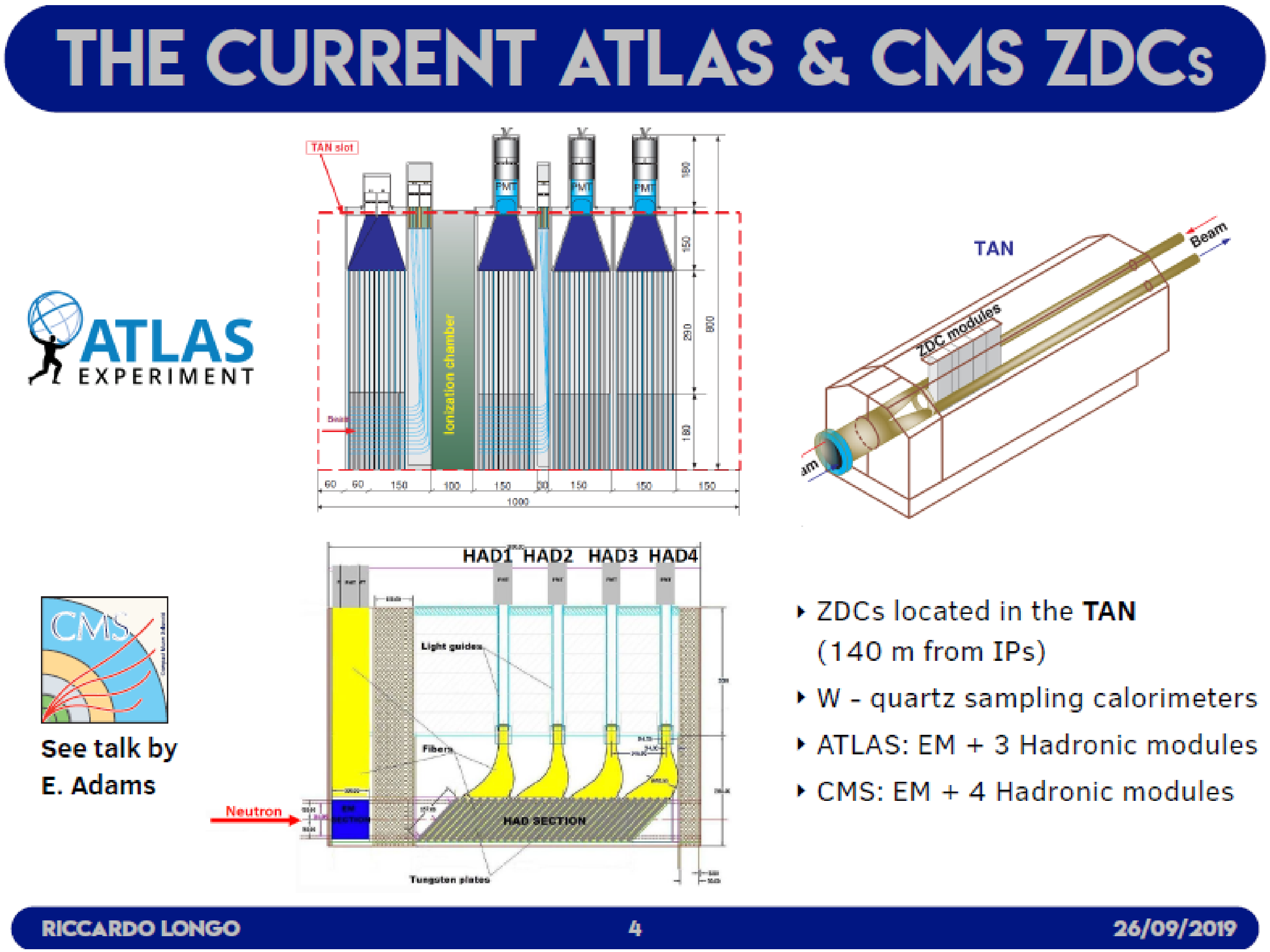
π^0 peak



N. Novitzky

ATLAS & CMS ZDC

- W-quartz sampling calorimeter



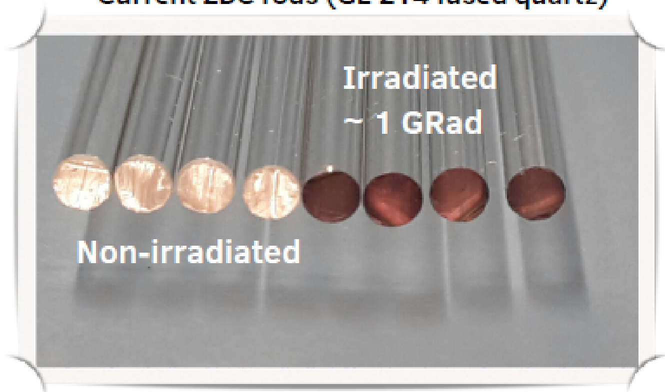
JZCaP collaboration

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

MOTIVATION - RADIATION DAMAGE

- The LHC upgrade during LS3 requires a rearrangement of the beam line.
- Less space left for the ZDC (from TAN - 10 cm, to TAXN, 5 cm) —> **Narrower ZDC** modules for Run4.
- TAXN ~ 15 m closer to the interaction point compared to TAN.
- Radiation levels will further increase.

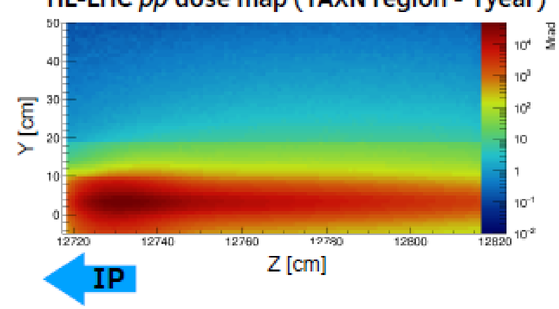
Current ZDC rods (GE 214 fused quartz)



- Fused quartz with high level of impurities inadequate for any pp running and damaged during PbPb running.

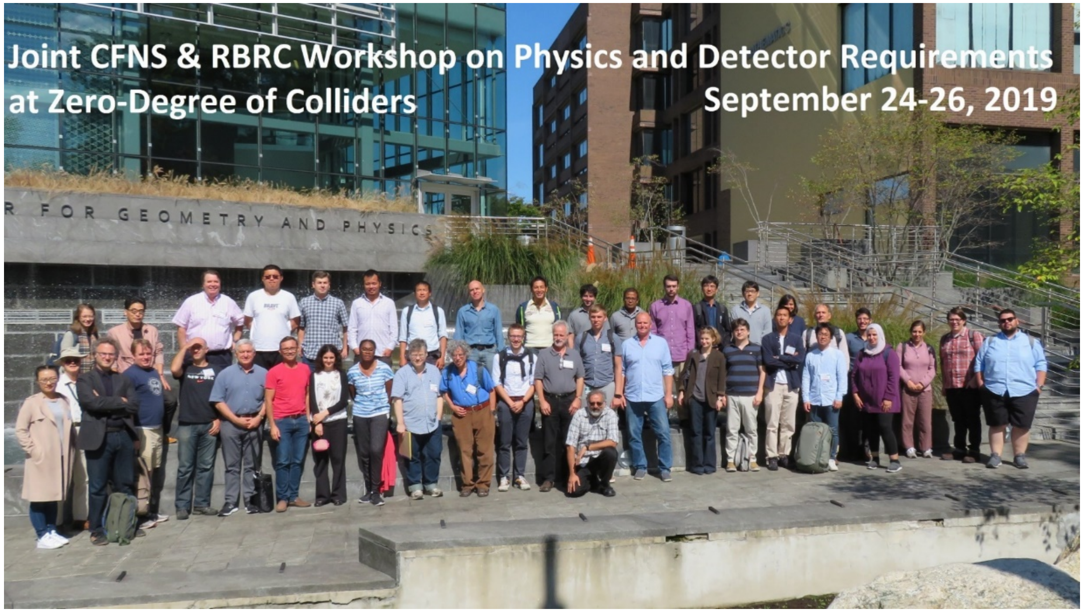
- Hardening the detector for pp running allows flexibility in installation to accomodate special LHC runs (e.g. O+O, p+O in Run3) that take place in the middle of pp running

HL-LHC *pp* dose map (TAXN region - 1year)



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



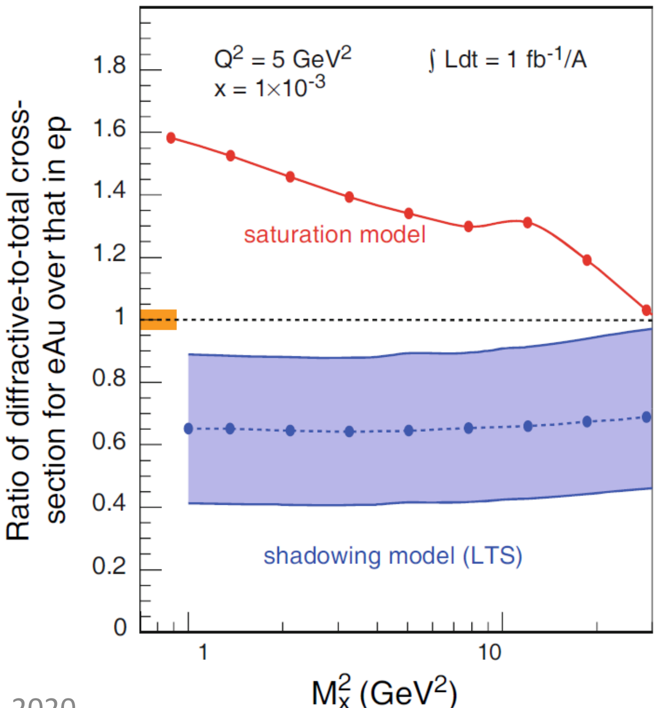
Summary

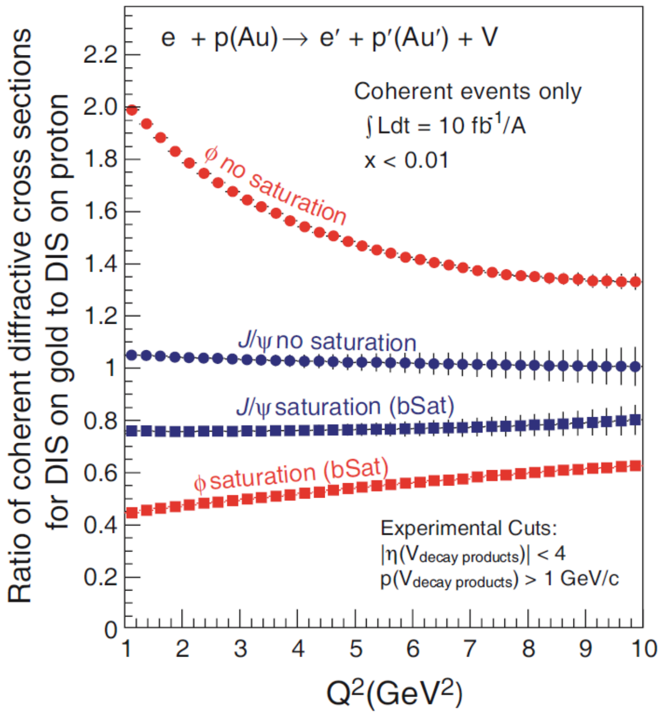
- We presented a Letter of Intent at the EIC R&D meeting in January, 2020
  - “The committee urges the group to put forward a proposal focused on the most important technical questions and what physics areas it will open”
- We’re going to submit a propose for EIC R&D of ZDC
  - Full-absorption photon detector
    - Crystal scintillators
    - We will consider collaboration with the calorimeter consortium
  - Prototype study of ZDC with position sensitivity
    - EM + Hadron calorimeters
    - RIKEN group is considering collaboration with ALICE-FoCal
    - We will consider to study ATLAS & CMS ZDC technology
  - Radiation hardness study for new technology
    - Kobe U. group is studying plastic scintillators

Backup Slides

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

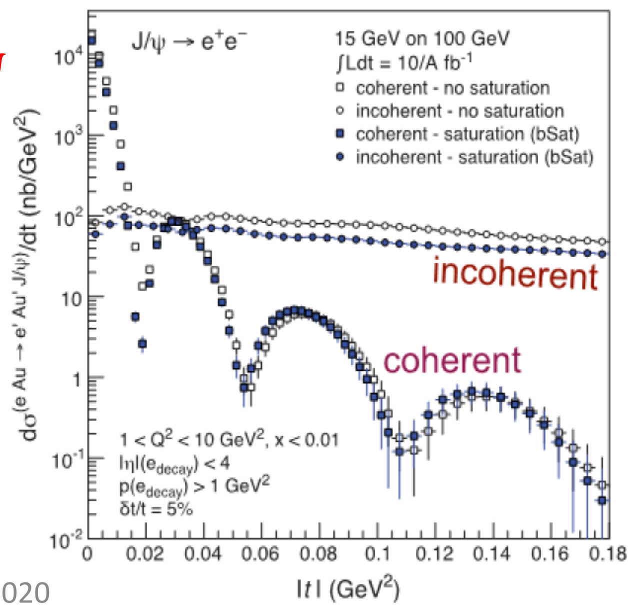




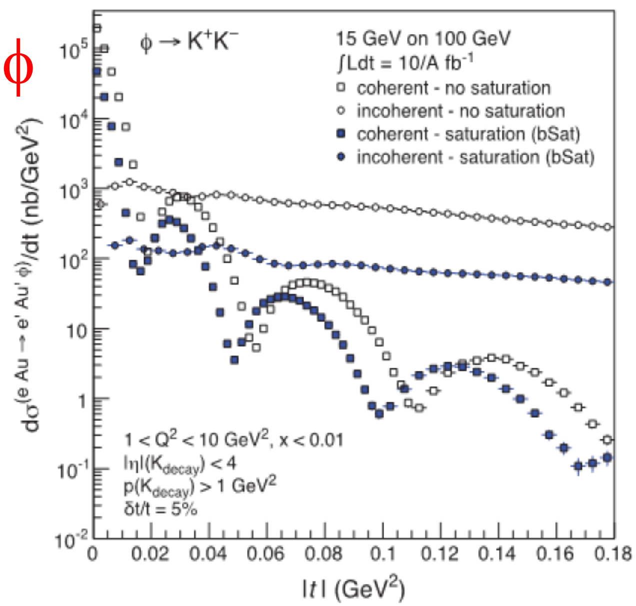
Gluon saturation at extreme density

- 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

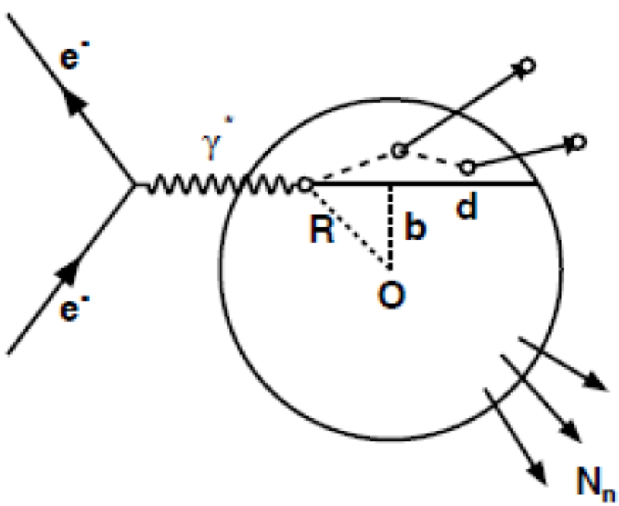


φ



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



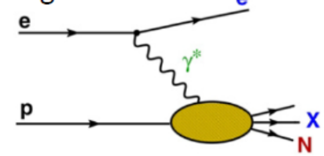
Intra-nuclear cascading increases with d (forward particle production)

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

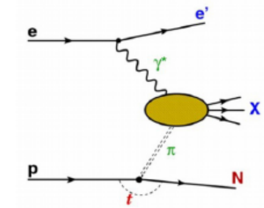
Physics at zero degree of EIC

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

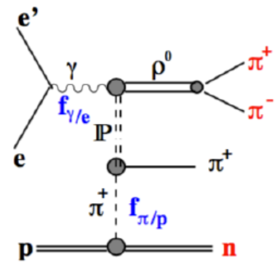
Fragmentation



One Pion Exchange (OPE)



LN in DIS

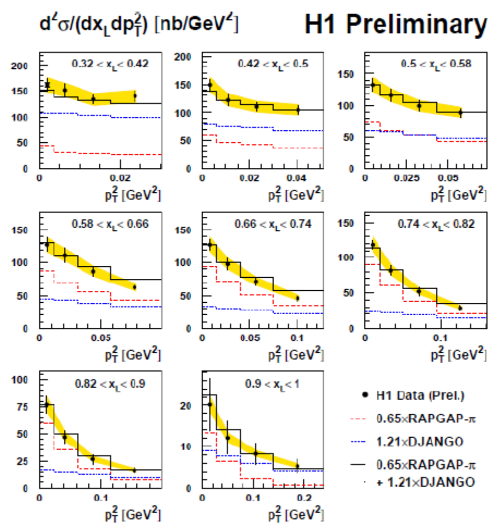


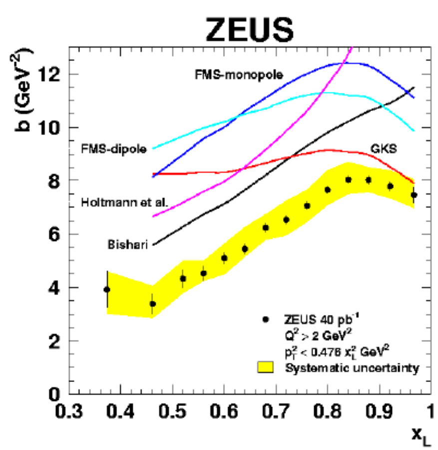
$$d\sigma_{\gamma^* p \to nx} = f_{\pi/p}(x_L, t) \times d\sigma_{\gamma^* \pi \to X}.$$

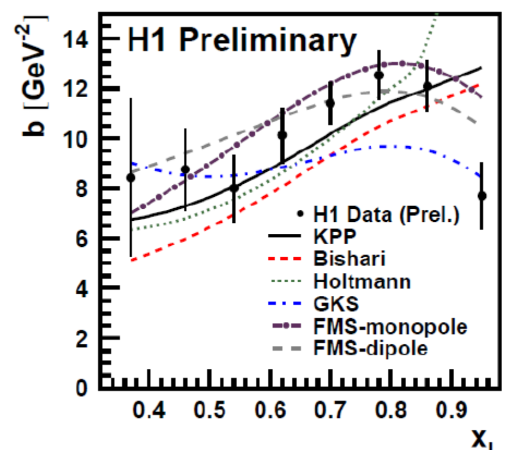
The distribution of p_T^2 (=t) is defined solely by the pion flux

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

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)