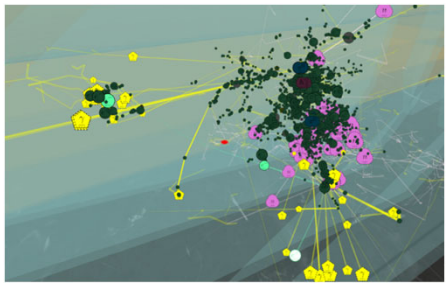
Belle II K_Long-Muon (KLM) Detector



CORE KLM

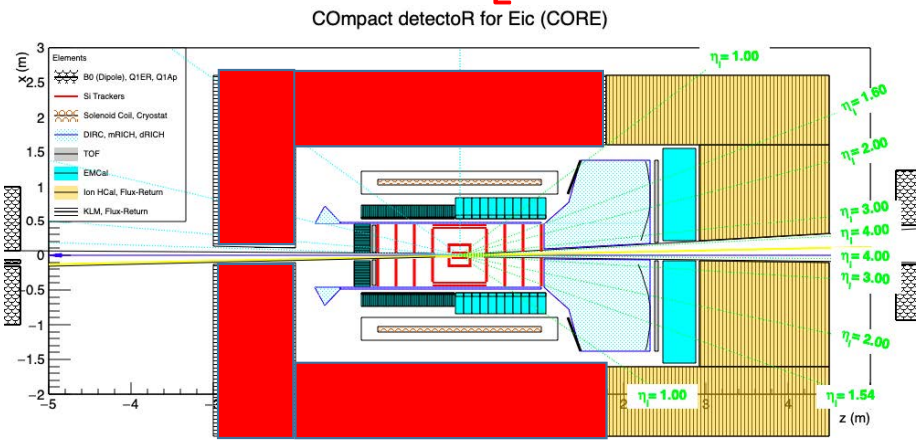
Brief Report on Design and Performance of a K_L and Muon subDetector at Belle II

,

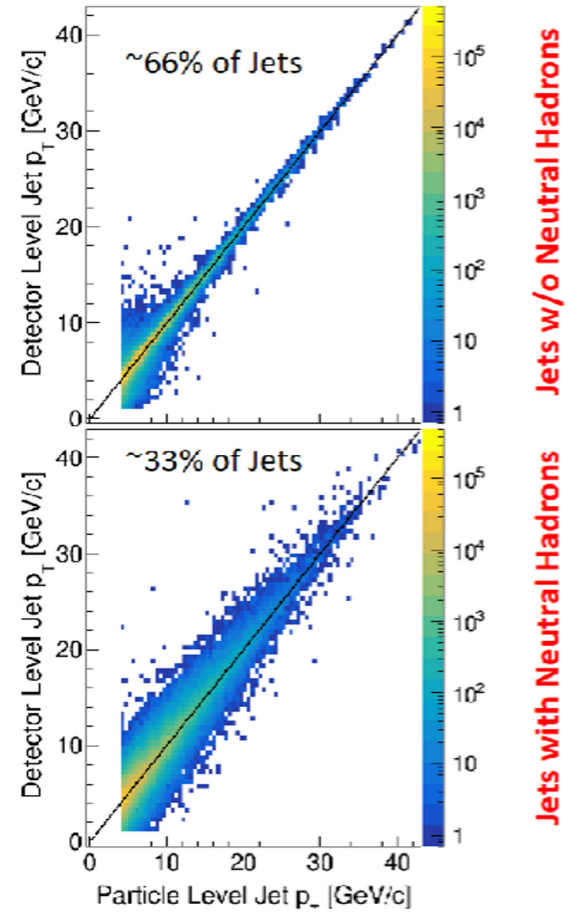
Ad-Hoc: CORE Workshop
29-30 March, 2021

W. W. Jacobs
CEEM/Indiana University

KLM: K_L and Muon subDetector at CORE

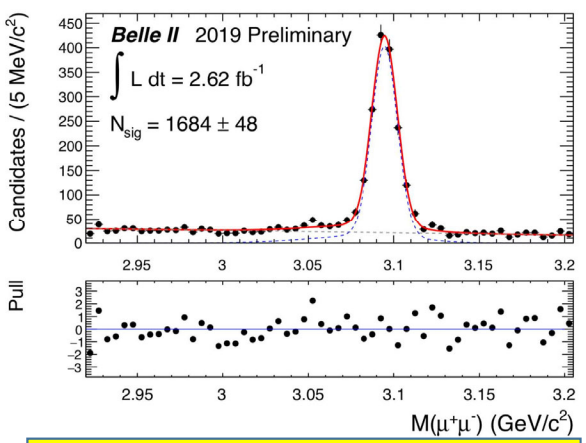


- Identify K_L and other neutral particles in jets … correct or veto



B.S. Page et al., arXiv.1911.00657 "Jet Physics at a Future EIC"

- High efficiency and high purity μ detection and ID:

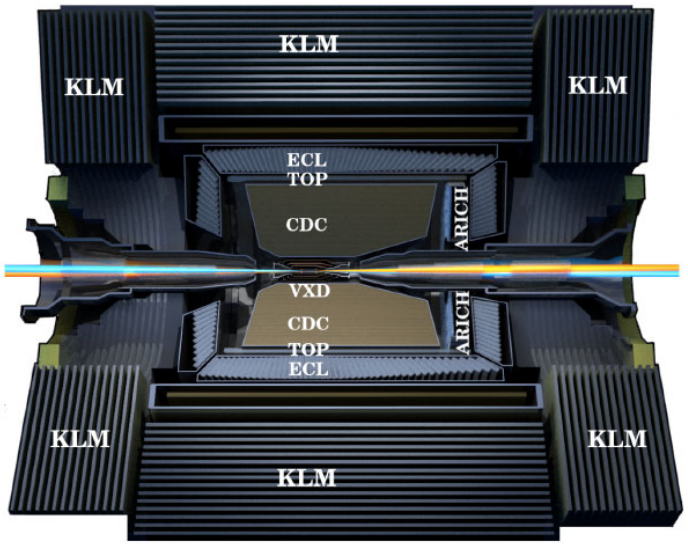


$J/\psi \to \mu^+\mu^-$ reconstruction with early running Belle II data

- e.g., for di-lepton production (J/ψ) and time-like Compton scattering processes

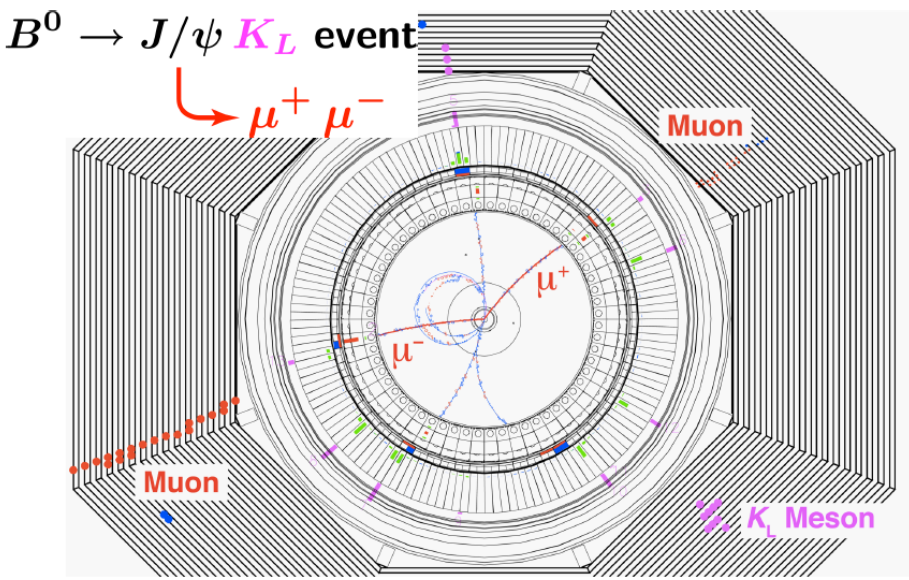
- Provide additional detector response and coverage for verification or veto.

KLM @ Belle II: a Useful Starting Point



Belle II and Prior Design Performance Requirements:

- Detect K_L mesons and muons
- Identify the muons and K_L mesons with high efficiency and purity
  - for muons above ~ 0.6 GeV momenta
  - good angular resolution (~ 2 deg) for the K_L's



Also as a veto in missing energy modes like: B → τν

KEK: e^+e^- collider "B-factory" (Y(4S)=10.58 GeV)

- Belle: 1999-2010 w/ integrated luminosity ~ $1ab^{-1}$
- Belle II: upgraded detector w/ super KEKB machine … expect $50ab^{-1}$ integrated luminosity w/ upgrades
- First Belle II collisions April 2018 … now in production running

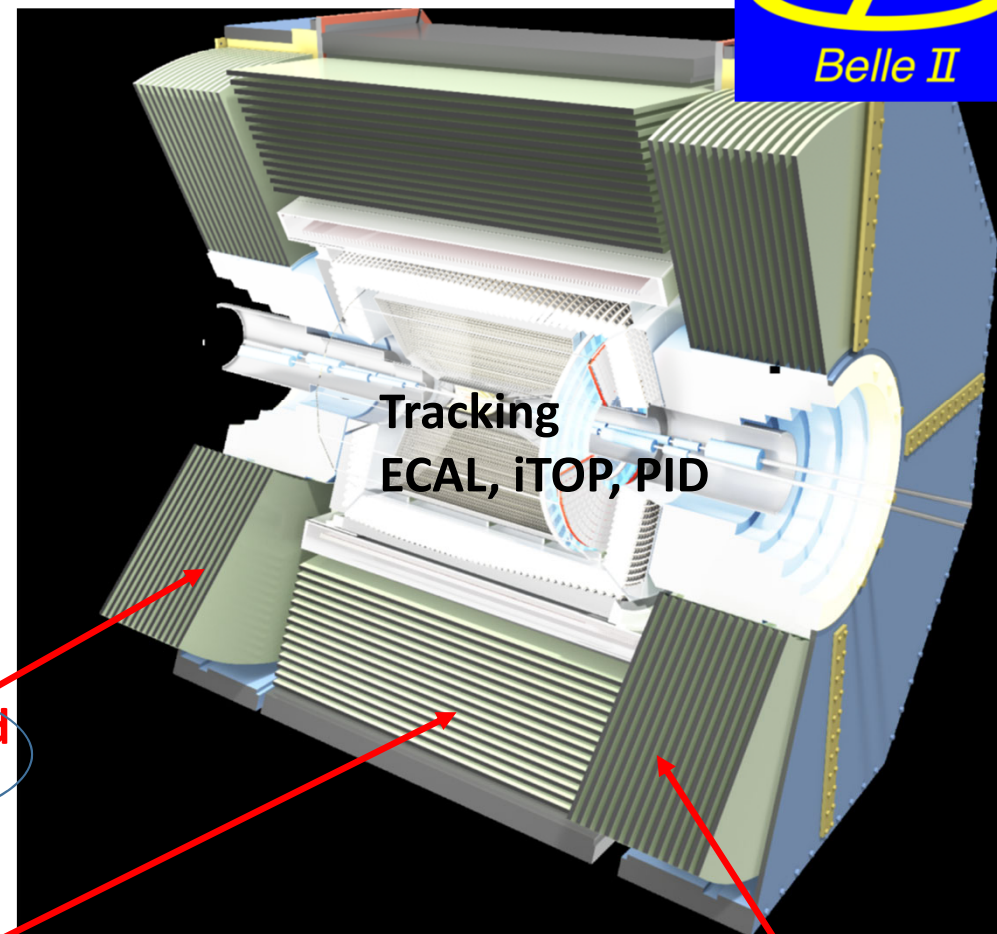
Example: upgraded Belle II detector at Super KEKB

- Active readout elements interleaved with 1.5 T solenoid magnet return steel
- Configuration optimized primarily for μ and K_L detection and ID
- Relatively inexpensive, technically simple construction, robust operation
- It is not a full-fledged/proper EM or Hadron calorimeter

Octagonal Iron yoke structures:

- 14 layers of ~ 47 mm thick steel plates
- ~ 40 mm thick air slots => 15 barrel, 14 Forward , 12 Back instrumented

	X_0 (cm)	λ_I (cm)
return steel	~ 37.5	~3.9
scintillator	~ 1.4	~0.7

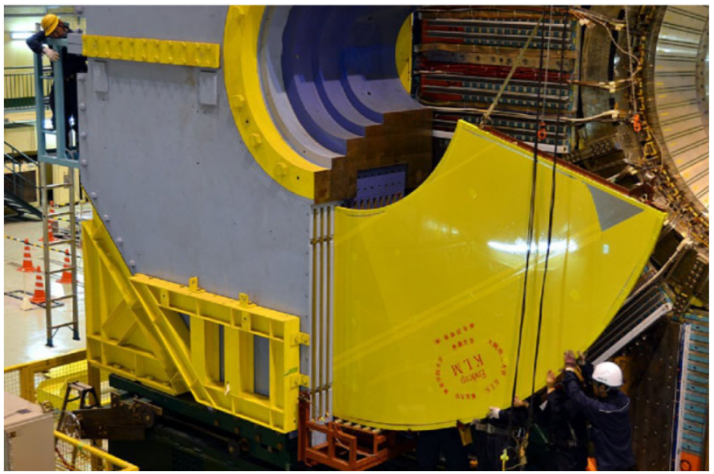


KLM Backward Endcap

KLM Barrel

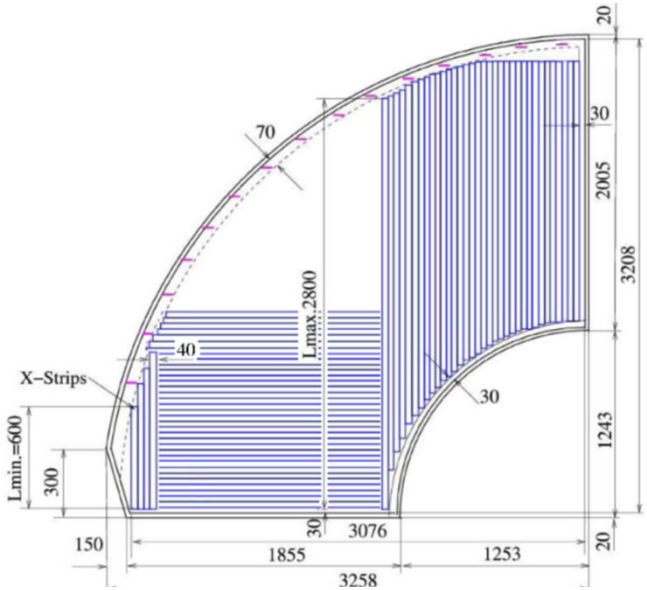
KLM Forward Endcap

Belle II detector KLM components

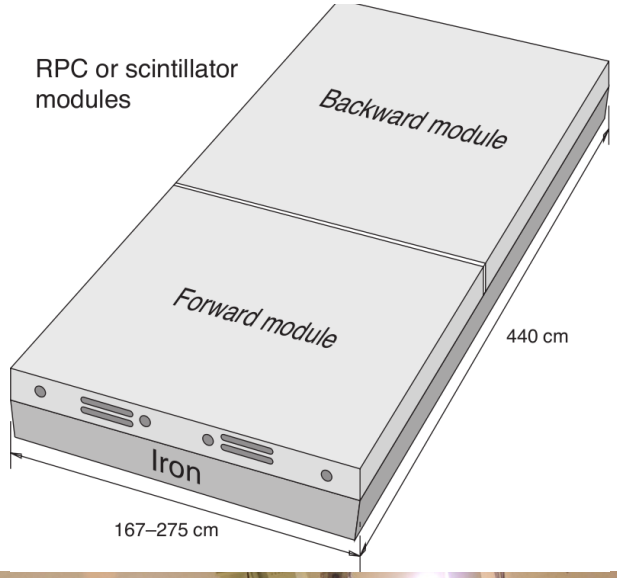


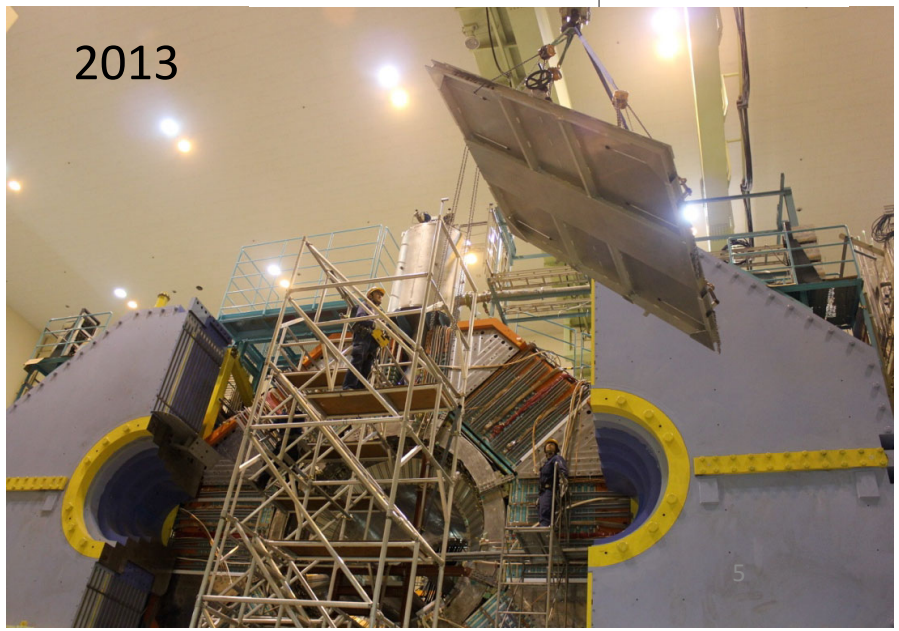
Endcap

2014

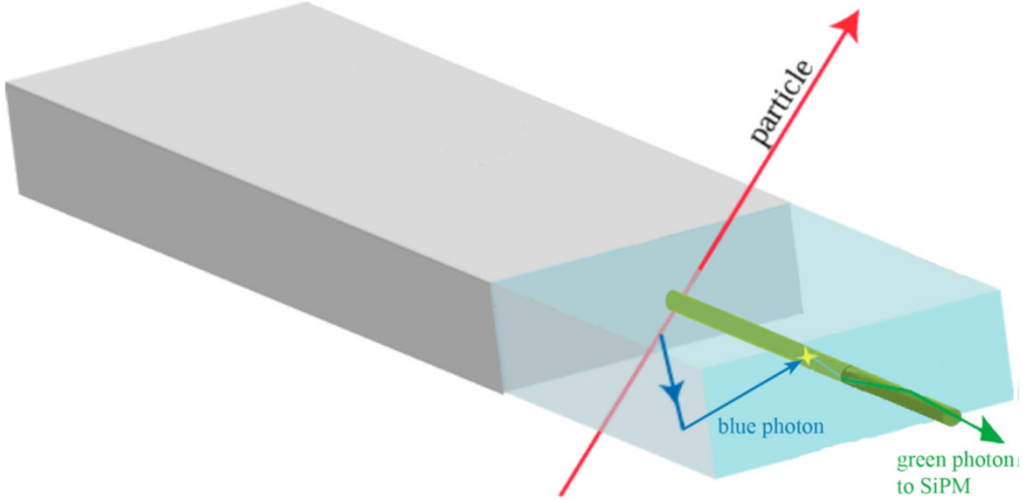


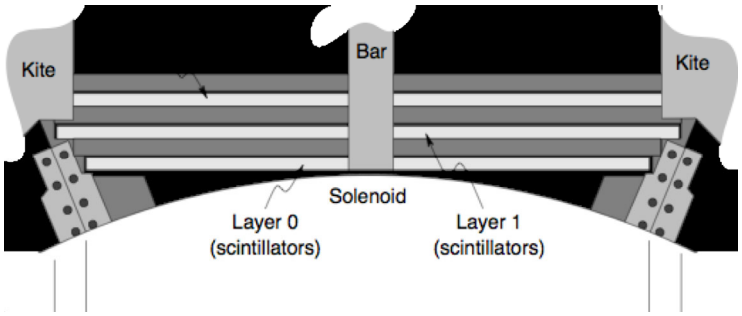
Barrel





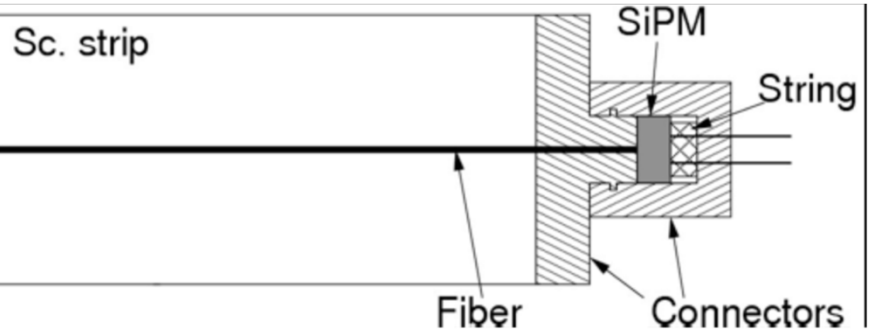
Now: first 2 Barrel layers are scintillator based (replace RPC)



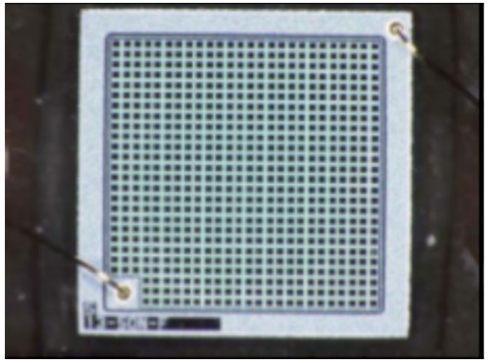


- Scintillator strips: ~ 1x2 cm cross section extruded with fiber hole or machined w/ cut

- Hamamatsu SiPM attached to fiber (mirrored at far end)

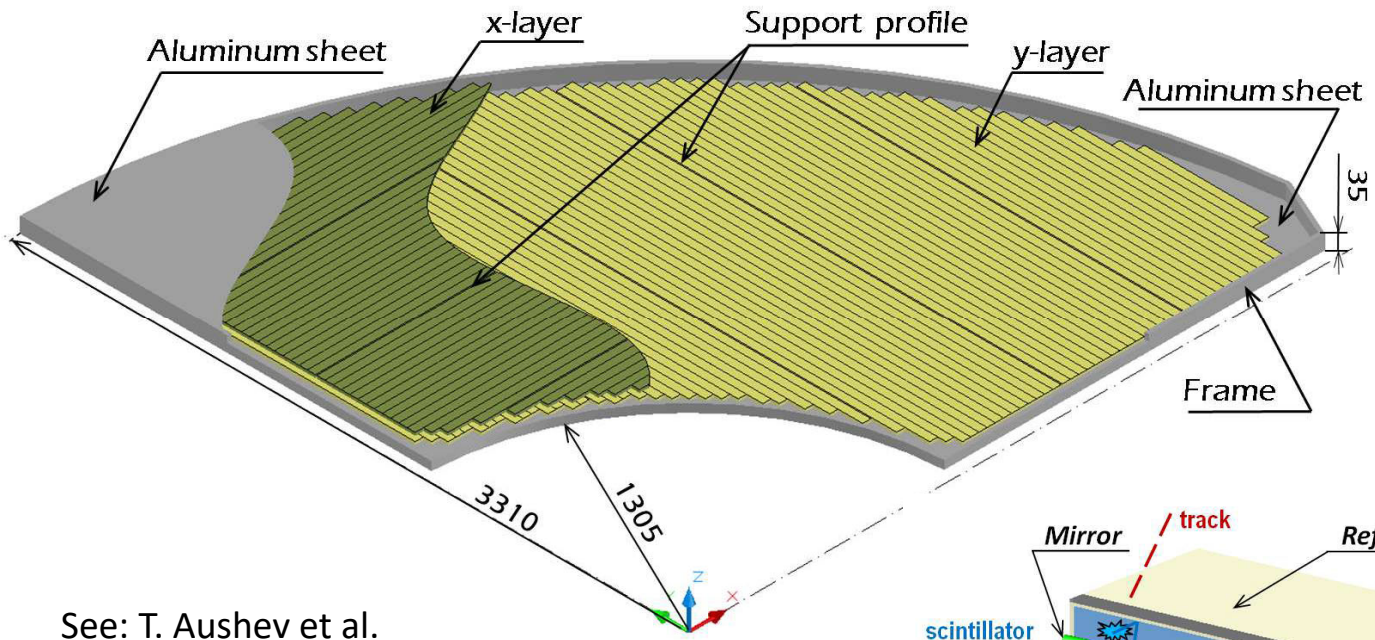


- 1.5 T field operation
- rad-hard (est. >10-year lifetime @ Belle II)
- 8-pixel threshold => >99% efficiency



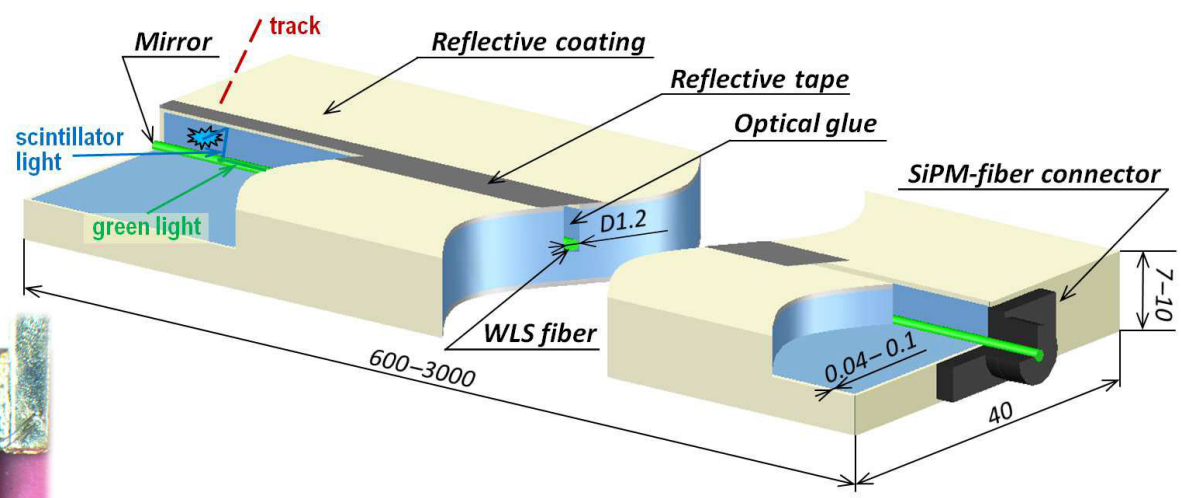
~ 1.3 x 1.3 mm2
667 pixels

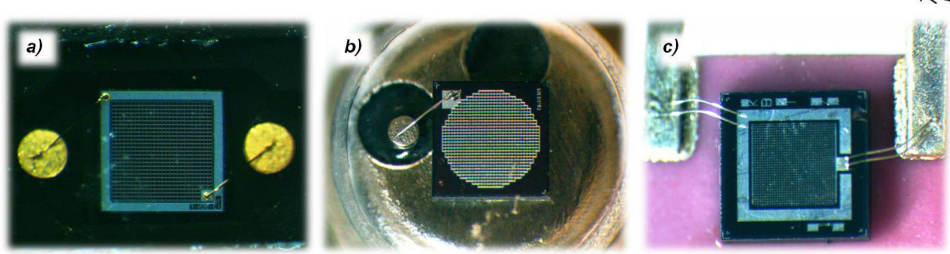
All Endcap layers upgraded to scintillator at start of Belle II



- Similarly, scintillator strips ~ 0.7x4 cm^2 machined w/ cut)
- Single strip readout w/ SiPM
- FEE readout has pulse shape characterization capabilities … FW implementation (w/ barrel) under development

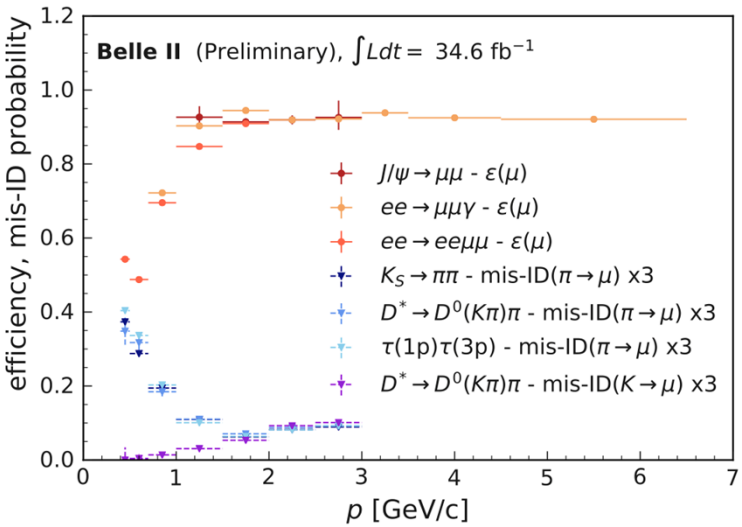
See: T. Aushev et al. arXiv:1406.3267v3 (2015) for details





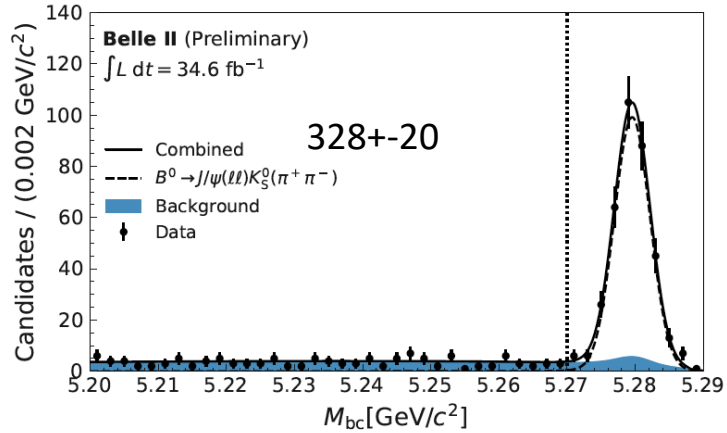
KLM performance (muon ID efficiency, fake rates, physics).

2020 muonID > 0.9 performance (barrel)

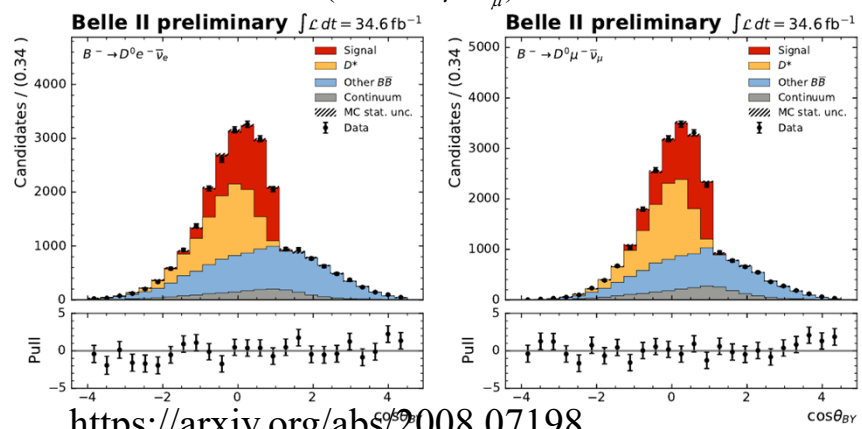


(low p region under further study)

B → J/ψ Ks for ICHEP2020 CPV

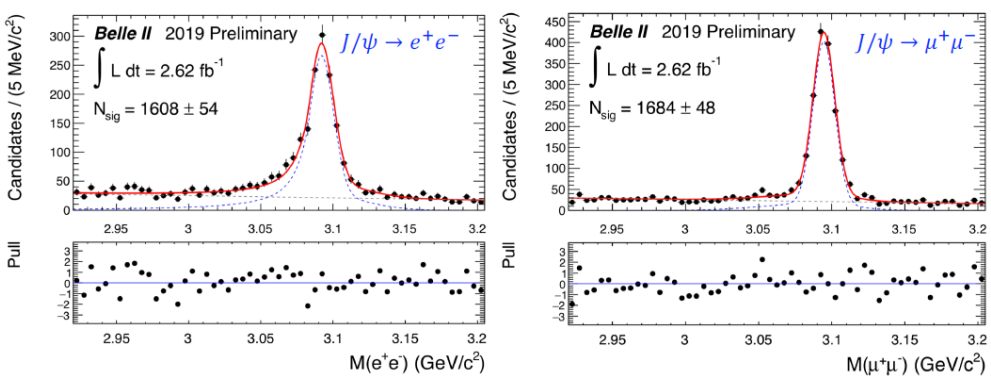


$$R_{e/\mu} = \frac{BF(B \to D^{*-} e^+ \nu_e)}{BF(B \to D^{*-} \mu^+ \nu_\mu)} = 0.99 \pm 0.03$$



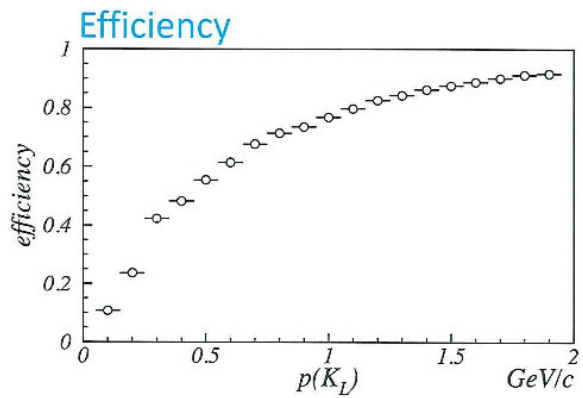
https://arxiv.org/abs/2008.07198

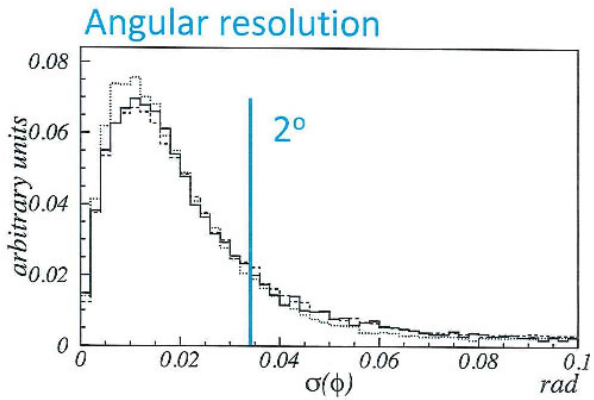
Early running J/ψ → ℓ⁺ℓ⁻ reconstruction



KLM performance: K-long detection and kinematics

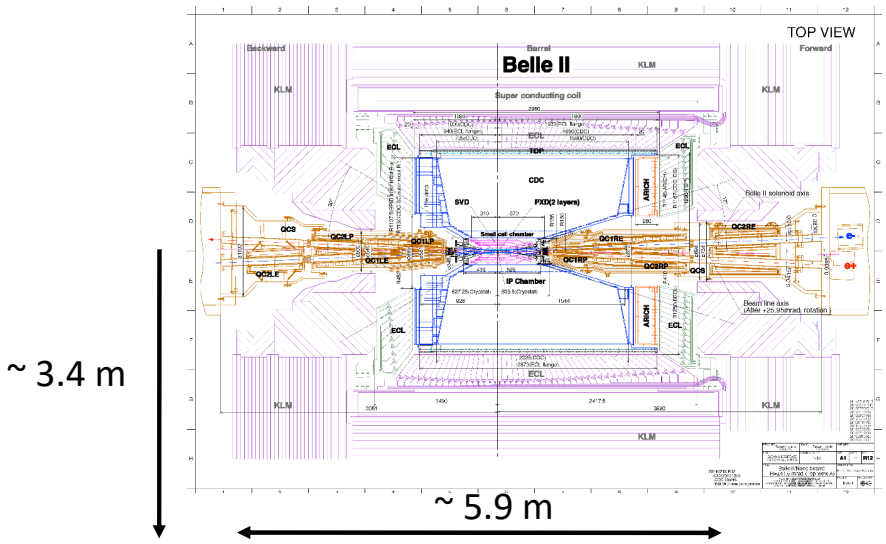
- Belle II analyses and algo/FW implementation for K-long are in progress; current expectations are based on results from Belle Data:





- Efficiency: fraction of reconstructed K-long clusters vs. K-long momentum in kinematically constrained decays
- Angular resolution: comparison of K-long cluster centroid w/known K-long direction.
- Current efforts include: *using BDT to distinguish K_L mesons from background*; future possible use of FEE based signal shape characterization, etc?
- In an upgrade, is a rough K-long momentum determination by TOF possible? (e.g., ~ 100ps gives ~13% resolution for ~ 1.5 GeV/c K_L and ~ 2 m flight path)

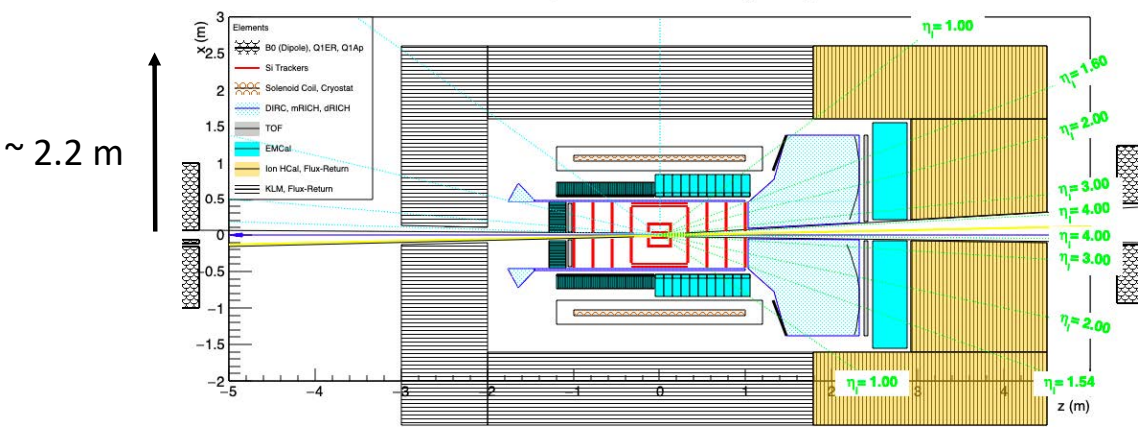
KLM Belle II vs CORE Comparison and Implementation



- KLM region indicated in CORE layout is of scale a little smaller than Belle II (barrel + 1 endcap), particularly in radial direction.
- Belle II uses original Belle magnet for 1.5 T field and interleaved KLM in the flux return; the design has a robust cryostat, etc. with energetic muon/K_L detection at the exterior

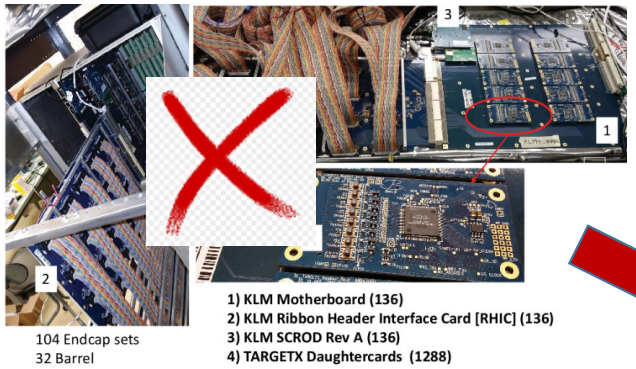
Y. Makida et al., AdvCryogEng **43, 221 (1998)**

COmpact detectoR for Eic (CORE)



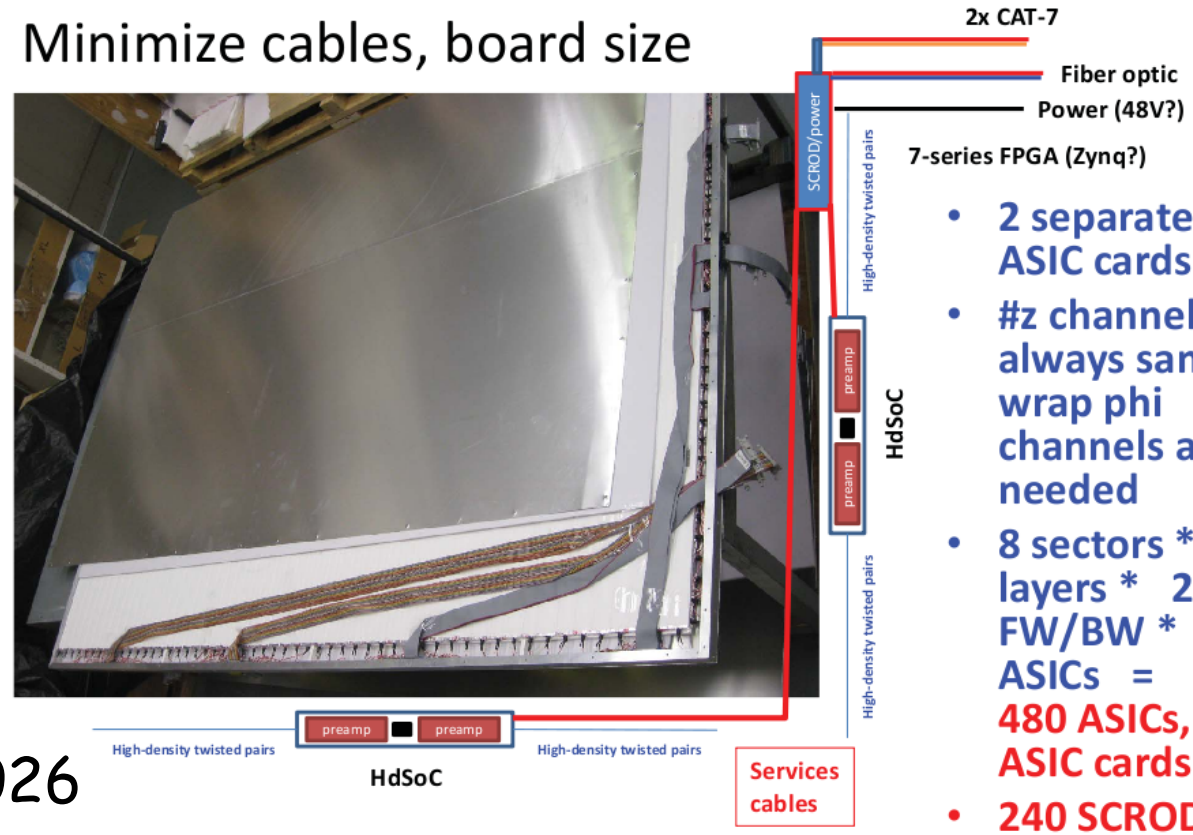
- A stronger CORE solenoid would require even more return steel (w/ ~ field free detector "slots"; current depiction looks already thin in depth).
- of course many options are open if one takes a flexible design approach.

Plans (EOI to Belle II): replace 13 remaining Barrel RPC layers



- Fabricate the new scintillator layers
- Redesign scintillator readout for all 15 layers

Minimize cables, board size



- 2 separate ASIC cards
- #z channels always same; wrap phi channels as needed
- 8 sectors * 15 layers * 2 FW/BW * 2 ASICs = 480 ASICs, ASIC cards
- 240 SCROD

- Move digitizing front end electronics into detector panel
- Developments: embedded ASIC; compact SCROD; 64-chn readout; several different preamp options
- K_L time-of-flight possible?

Expected installation ~ 2026

- ~ 26k channels: initial cost est. ~1.4-1.8M elec., ~4.8M det., w/ some reuse of crates, etc.

Summary, Status and TBD

- A KLM subsystem is an important and successful part of the Belle II experiment; it presents a useful baseline/starting point for a CORE application (**EIC EOI #26)**
- Currently under Belle II development are optimization of muon efficient/fake rates at lower momenta; K-long efficiency and ID improvements in HW and FW.
- Can an K-long momentum via TOF be effectively included in an (EOI) anticipated upgrade to all scintillator sensors with improved readout?

Issues and TBD

- There are many things not directly touched on in this presentation:
  - Magnet strength, flux return design incorporating CORE KLM needs
  - Signal vs. background rates, etc. vs. envisioned readout technology
  - Particle purity and momentum ranges of interest for CORE physics
  - Where is material budget critical, etc.
  -
- None seem insurmountable!

BACKUP SLIDES