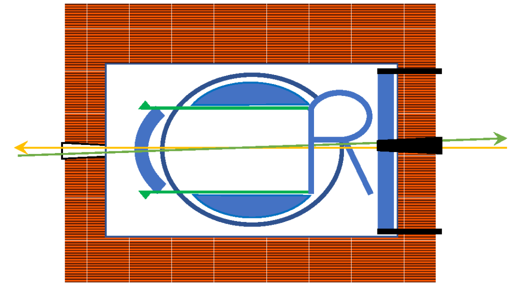

CORE CALORIMETRY

Brief Report on Electron, Barrel and Ion Side Calorimetry Selections for CORE

EICUG Summer 2021 Meeting
2-7 August, 2021

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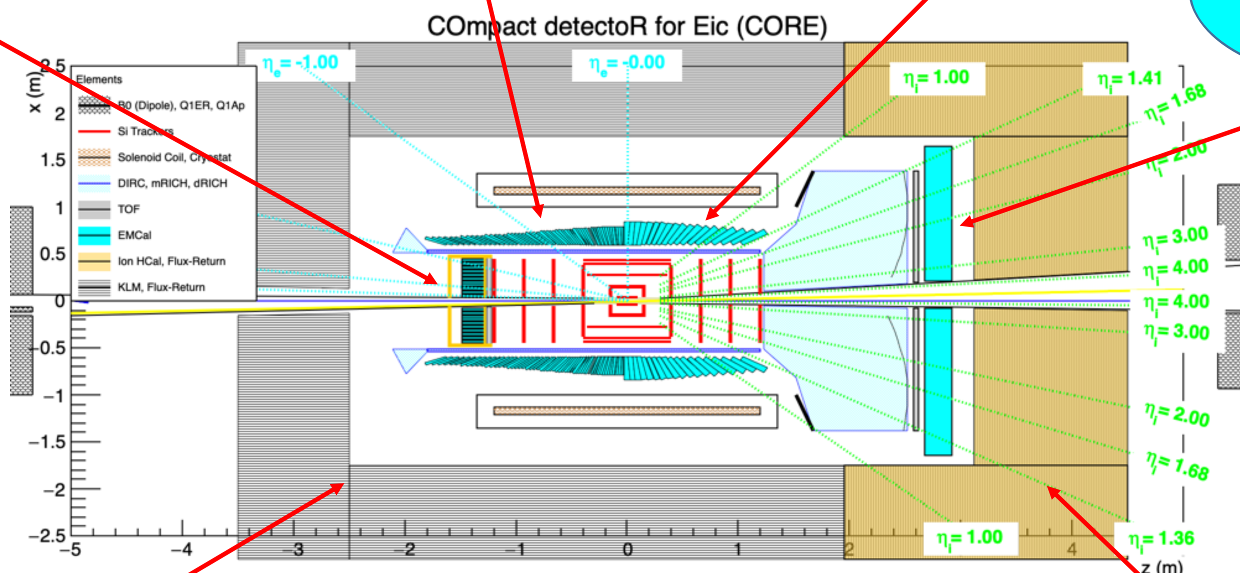
CORE Calorimetry EMCal, Hcal and "KLM" Components

Electron Endcap
$PbWO_4$ Crystals

Barrel: Electron Side
$PbWO_4$ Crystals

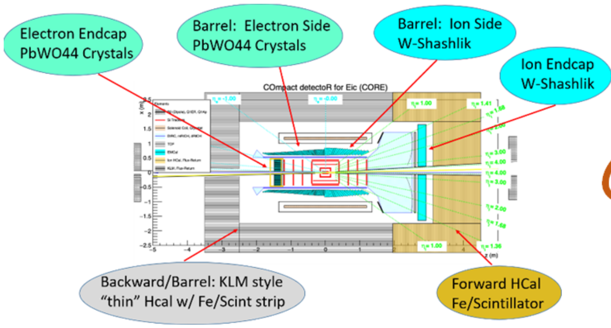
Barrel: Ion Side
W-Shashlik

Ion Endcap
W-Shashlik



Backward/Barrel: KLM style
"thin" Hcal w/ Fe/Scint strip

Forward HCal
Fe/Scintillator



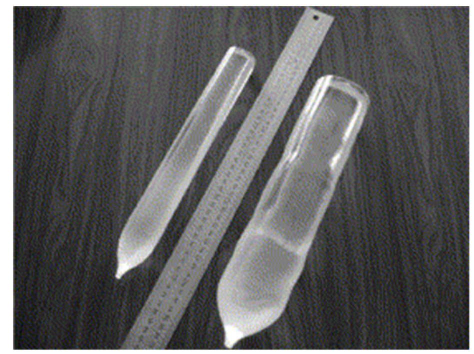
CORE Design: Calorimetry Considerations, Issues and Implemenation

- CORE is more compact/smaller (with advantages) than the other EIC detectors.
- CORE calorimetry choices are driven by performance as supported by quantity use in application or recent EIC R&D. Compact compatibility and relative cost effectiveness also play a role.
- even with similar calorimeter technology as selected by the other EIC detectors, CORE geometry will differ ... not only in coverage, but also absolute size (hence channel count, esp. for barrel components).
- the low-mass DIRC in CORE will introduce 40% less mass in front of the barrel EMcal vs. a regular DIRC -> enhanced performance of the EMCal (e.g., selected PWO_4).
- "new" idea to use Belle II-like "KLM" in place of full Hcal for $\eta < 1$ w/ added μ ID.

Electron Endcap and Barrel EMCal $PbWO_4$ Systems - I

some info/plots from C. Camacho and eRD1 Consortium

- Select Lead tungstate (PWO_4): the preferred material for high resolution EM calorimetry
- Has a high light yield => excellent resolution (~1-2%/√E) … as needed for Electron side
- Very dense: hence suited for use in compact CORE
- Also exhibits good radiation hardness



https://doi.org/10.1016/S0168-9002(02)00916-6

Electron Endcap: $-4^* < \eta < -1.7$

- PbWO4 crystals: 2cm x 2cm x 20 cm (> 20 X0)
- Energy resolution 2%/(√ E) ⊕ 1% ⊕ 1%/E
- Spatial resolution (isolated shower) 3mm / (√ E)
- Readout: Si-PMT, with MCP-PMT at small radius (high neutron fluence)
  - Fill factor > 50%
- Electronics: in situ ≥ 250 MHz Digitization (≥ 12 bits)

*note: nominal inner acceptance, others quote $|\eta| < 4$

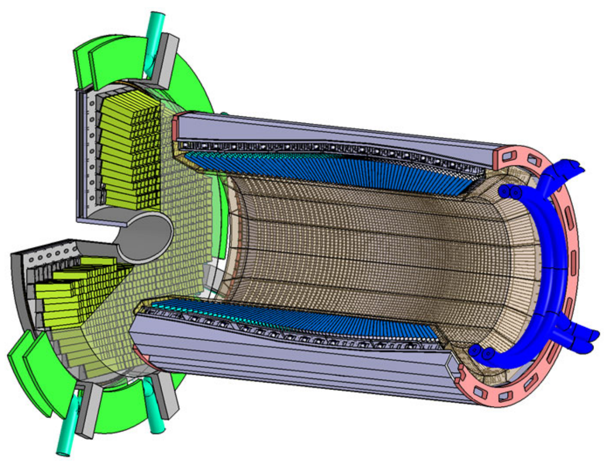
Barrel: $-1.7 < \eta < 0$

- PbWO4 crystals, 2D projective. Inner faces ≈ 2cm x 2cm. Projective depth 20 cm
- Energy resolution 2%/(√ E) ⊕ 1% ⊕ 1%/E
- Spatial resolution (isolated shower) 3mm / (√ E)

Electron Endcap and Barrel EMCal $PbWO_4$ Systems - II

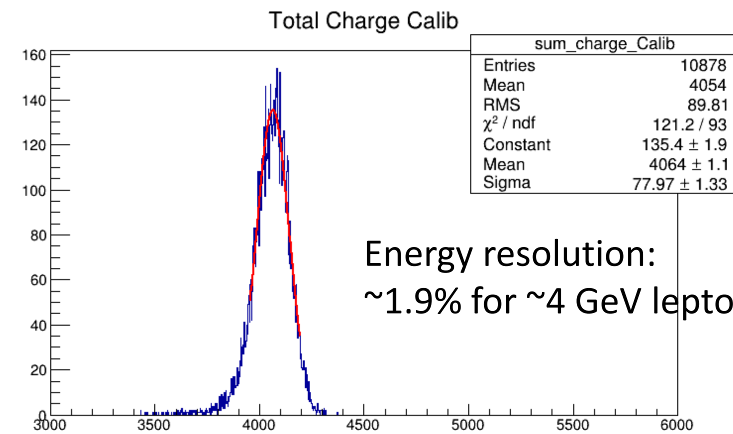
some info:/plots from C. Camacho and eRD1 Consortium

- CORE's compact size makes it affordable to use PWO_4 and extend coverage in full azimuth
- A PANDA-like PWO_4 EMcal can cover the endcap and half of barrel (outside of the DIRC)



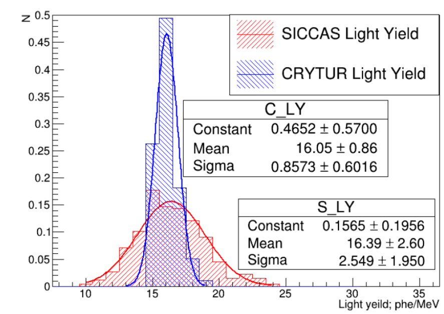
- The PWO4 area will be half or less of that planned for PANDA, which is similar in size to CORE

Hall D beam tests w/ SiPM (PMT baseline)



Energy resolution: ~1.9% for ~4 GeV lepton

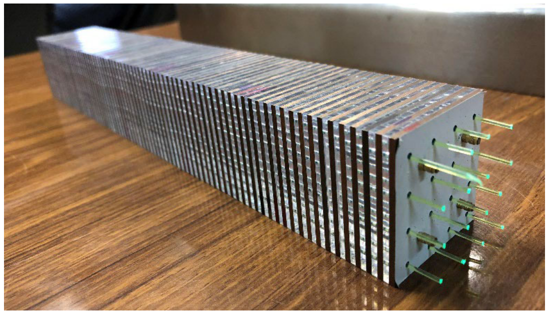
Note: 2014: Restart of PWO II prod. at CRYTUR (Czech Republic)



Ion Endcap and Barrel W-Shashlik EMCal Systems - I

some info:/plots from Crraig Woody et al. and EIC R&D collaborations

- The YR listed Shashlik calorimetry as a possible (and mature w/ Pb absorber) technology for EIC, suitable for a wide range of rapidities ($-2.0 < \eta < 4.0$)



- Using W as an absorber has several advantages, esp. for CORE
  - Compact: for same X_0, a W-Shashlik calo takes less space
  - Due to much smaller R_M, smaller showers reduce overlap (e.g., improves γ/π^0 and e/h separation)
- New developments: possibility for calo elements to be 2D projective => tight coverage

Barrel, $0 < \eta < 1.4$

- W-Shashlik. 2D projective. Fiber spacing < 1cm. Projective depth 25 cm (> 25 X0)
- Energy resolution $6\%/(\sqrt{E}) \oplus 2\% \oplus 2\%/E$
- Two-cluster spatial separation: ≤ 1 cm
- Readout: Si-PMT, each fiber diffused to unique pixel
- Electonics: in situ ≥ 250 MHz Digitization (≥ 12 bits)

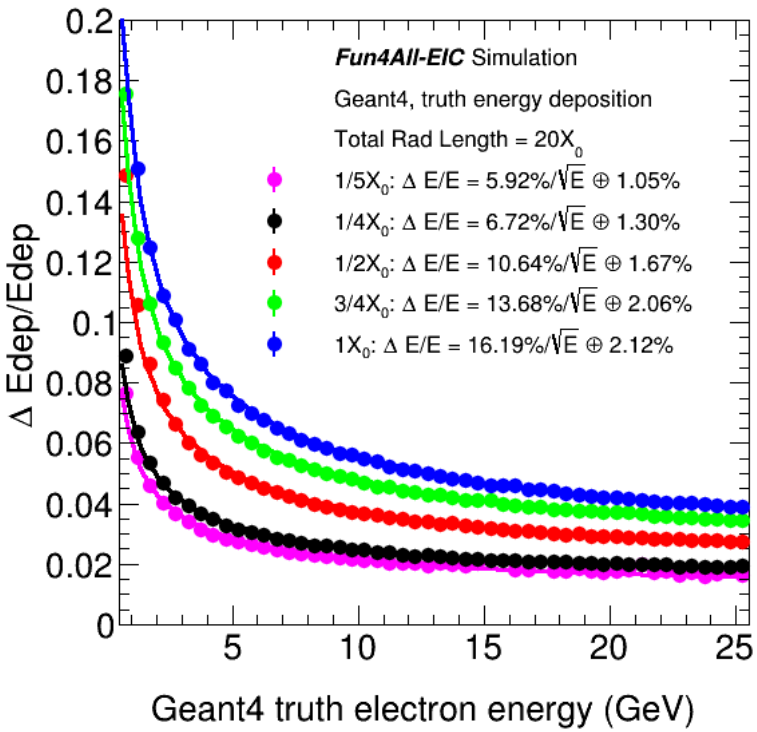
Ion Endcap $1.4 < \eta < 4$

- W-Shashlik. 2D projective.

Ion Endcap and Barrel W-Shashlik EMCal Systems - II

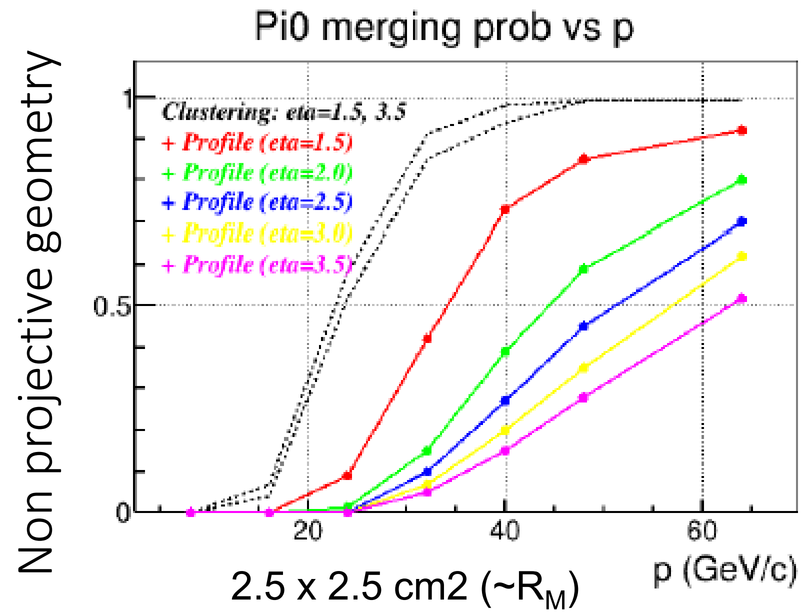
some info:/plots from Crraig Woody et al. and EIC R&D collaborations

Energy resolution vs sampling fraction
20 X0 total length (L ~ 30 cm w/readout)



W Shashlik

Require fine segmentation and small R_M to resolve γ/π^0 at high momentum

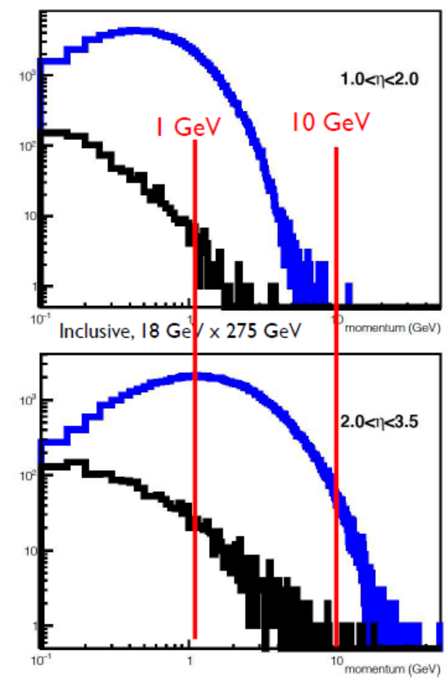


Projective geometry => improved separation, particularly for η~ 1-3

Ion Side Endcap and Barrel HCal Systems (η > 1) - I

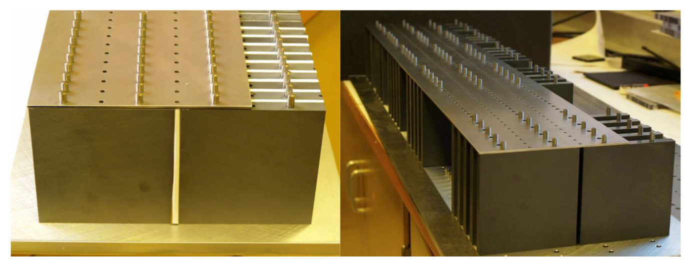
some info:/plots from Oleg Tsai and eRD1 collaborations

- From YR, resolution 50%/√E + 10%. 6% constant term for eta>3 is desired (overall, even better e.g., 35%/√E + X% is suggested, but w/o support/basis)
- Requires very good Hcal (or Hcal/Ecal system to achieve)
- Note: some conditions at EIC for the Hadron EndCap:
  - Particles Energy – low, difficult for calorimeters
  - Interaction Rate – low, < 500kHz; Occupancy - low
  - Radiation Exposure – low
  - Neutron Fluxes – possibly some concern.
  - beam pipe hole limits acceptance to eta ~ 3 (haron showers are wide)



Hadronic Calorimetry (1 < η < 4)

- Fe/Sc sampling
- resolution 50%/√E + 10 %.
- 6% constant term for eta>3 desired
- exact geometry/implementation TBD



Ion Side Endcap and Barrel HCal Systems ($\eta > 1$) - II

Some info:/plots from Oleg Tsai and eRD1 collaborations

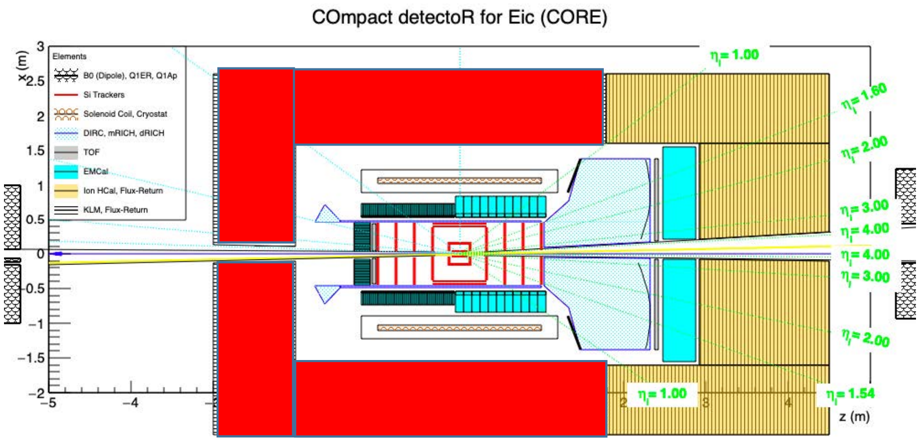
Specific System R&D for eRD1: **STAR Forward Calorimeter System (FCS), 2020 (NSF MRI)**

- HCal – Fe/Sc
- 520 channels (13x20 matrix) ~ 30 tons
- 4.5 interaction lengths
- 10 cm x 10 cm tower size
- 2 cm Fe absorber; 3 mm scintillator
- LEGO type assembly (~ 20 days)
- SiPM Readout Bias ~ 67V
- New digitizers + Trigger FPGA = DEPboards

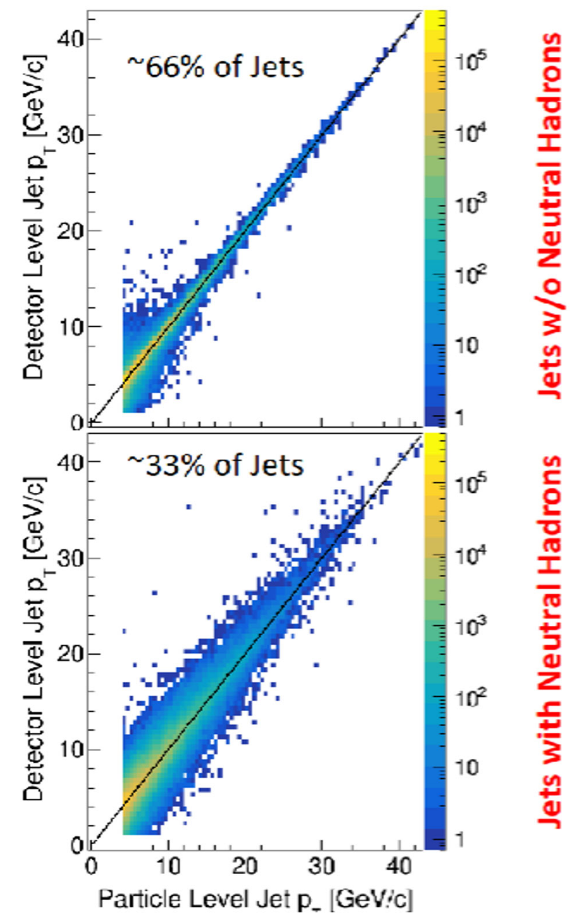
Further eRD1 development planned for EIC; STAR FCS production running starts fall ‘21

- ➢ System is easily scalable and reconfigurable
- ➢ Performance demonstrated with prototype & test beam
- ➢ A baseline design for EIC

KLM for η < 1 : K_L and Muon subDetector at CORE

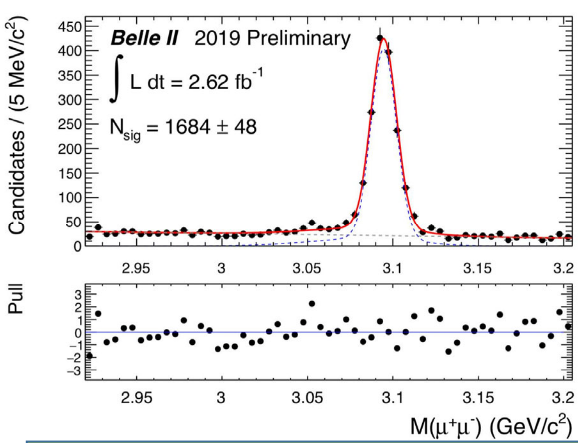


- Identify K_L and other neutral particles in jets … correct or veto



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

- High efficiency and high purity μ detection and ID:



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

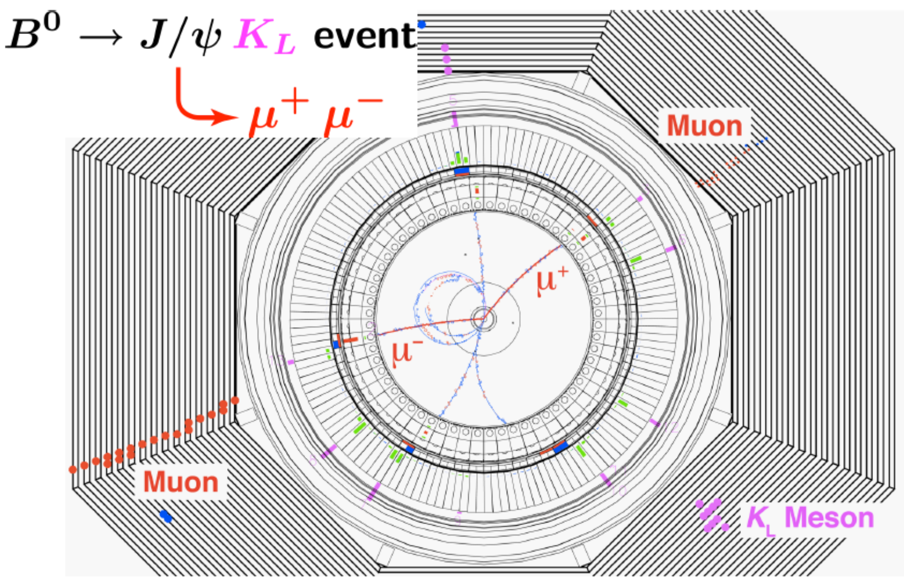
- e.g., for di-lepton production (J/ψ) and time-like Compton scattering processes

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

KLM @ Belle II: Useful Starting Point

Belle II and Prior Design Performance Requirements:

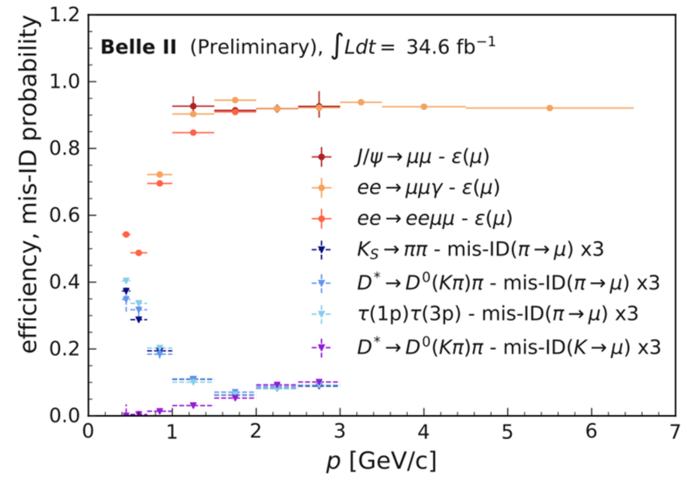
- Detect K_L mesons and muons
- Identify the muons and K_L mesons with high efficiency and purity
  - for muons above ~ 0.6 GeV momenta
  - good angular resolution (~ 2 deg) for the K_L's



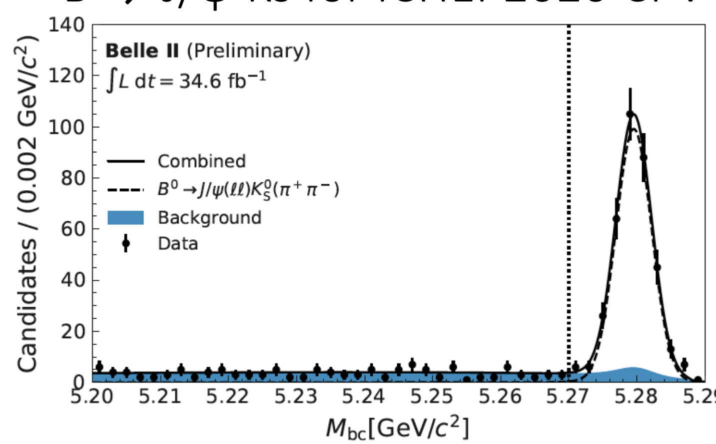
Also as a veto in missing energy modes like: B → τν

2020 muonID > 0.9 performance

(low p region under further study)



B → J/ψ Ks for ICHEP2020 CPV



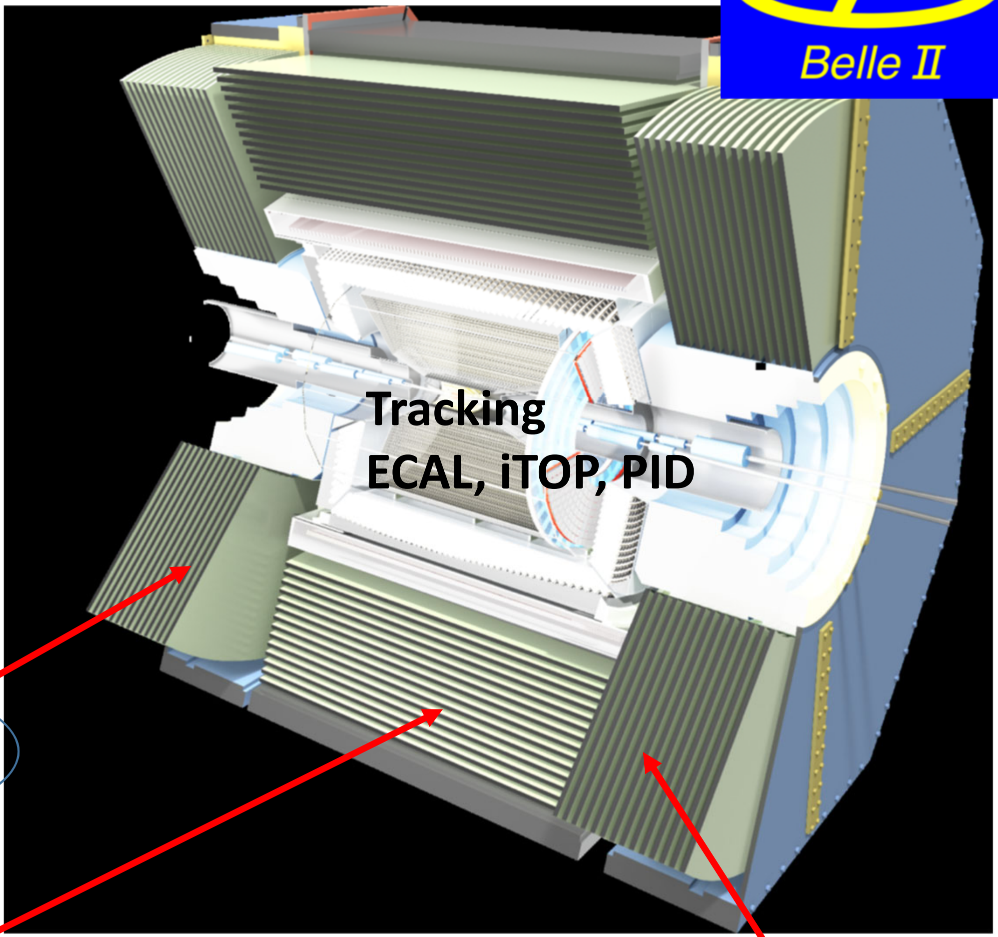
Example: upgraded Belle II detector at Super KEKB

- 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

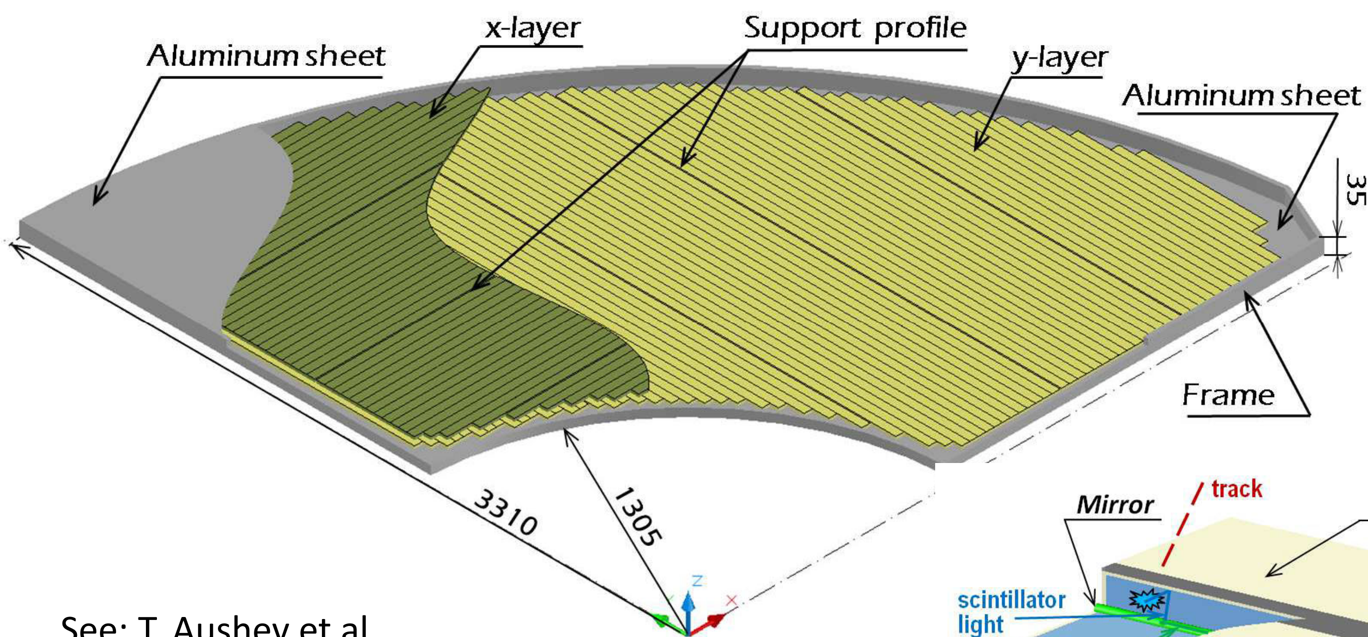
Octagonal Iron yoke structures:

- 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

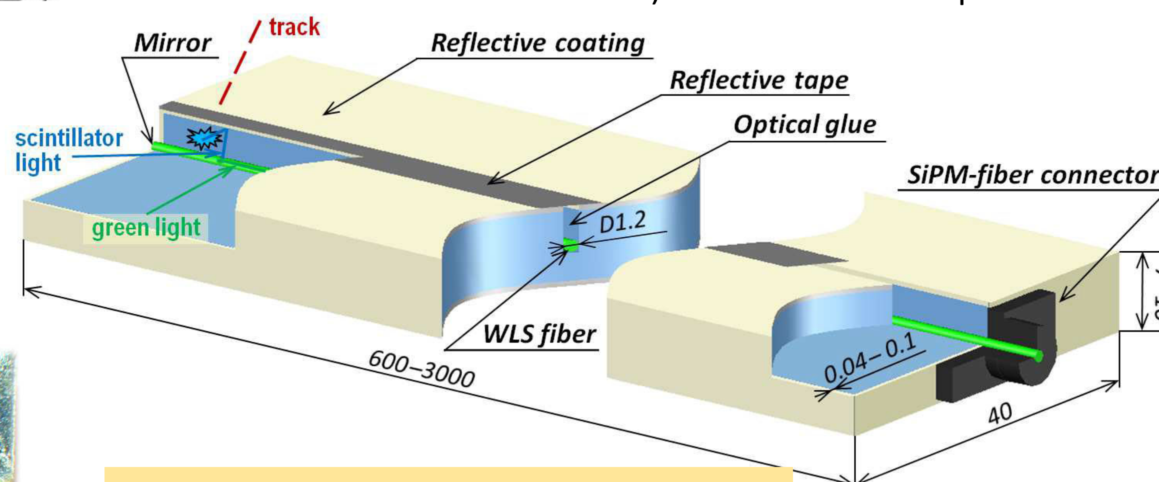


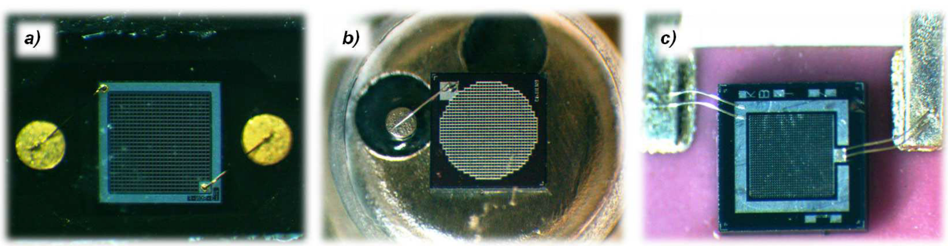
All Endcap layers upgraded to scintillator at start of Belle II



- 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

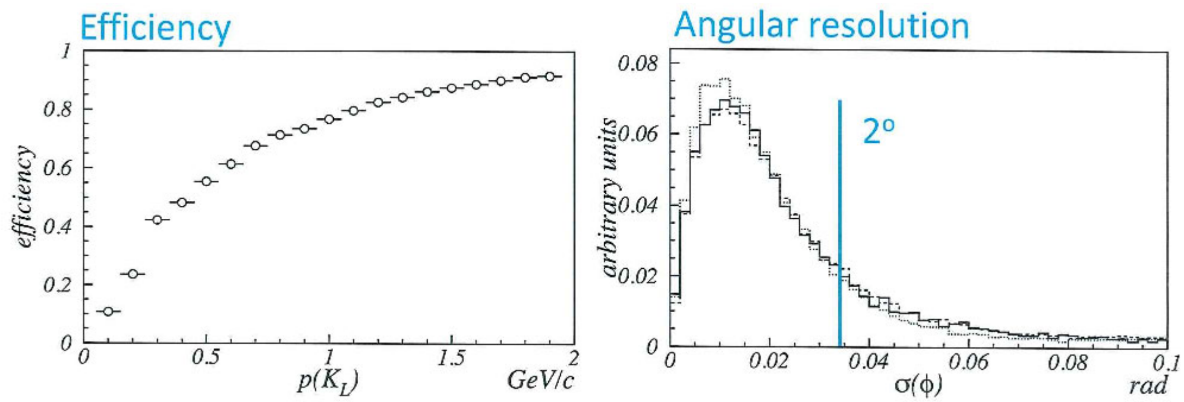




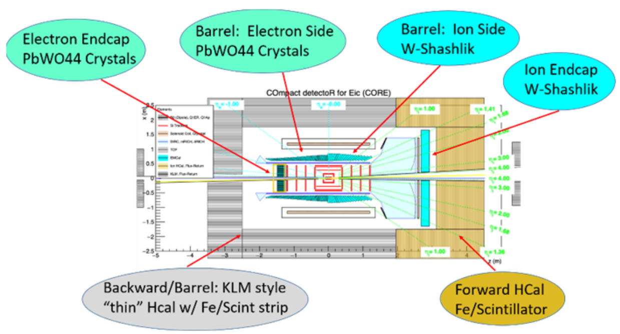
Note: Barrel construction similar with crossed scintillator strips – first 2 layers

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/iknown K-long direction.
- Current efforts include: *using a trained BDTto distinguish K_L meson from background*; future 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. GeV/c K_L and ~ 2 m flight path)



CORE Calorimetry Summary

- EMCal: electron side => $PbW0_4$
- EMCal: Ion side => W-Shashlik
- HCal: forward => FeSc sampling
- KLM/HCal barrel/backward => "CORE KLM"

- Regarding how best to adapt the KLM idea to CORE => TBD
  (e.g., can one improve the energy resolution, while retaining good muon ID, beneficially?)

Thank You!

BACKUP SLIDES