AC-LGAD Time-of-Flight

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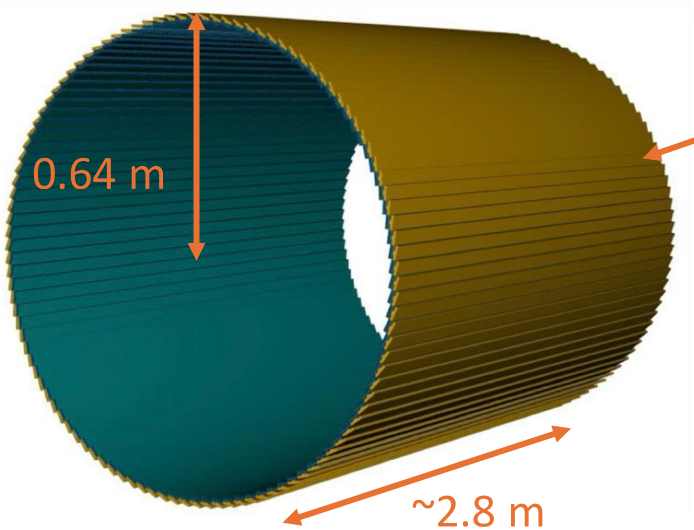
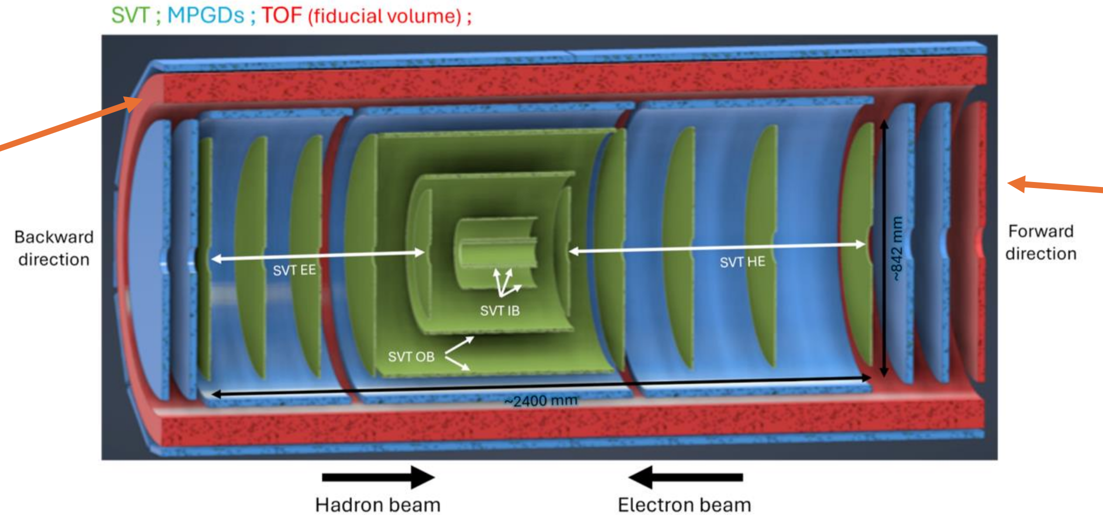
Recap of AC-LGAD TOF

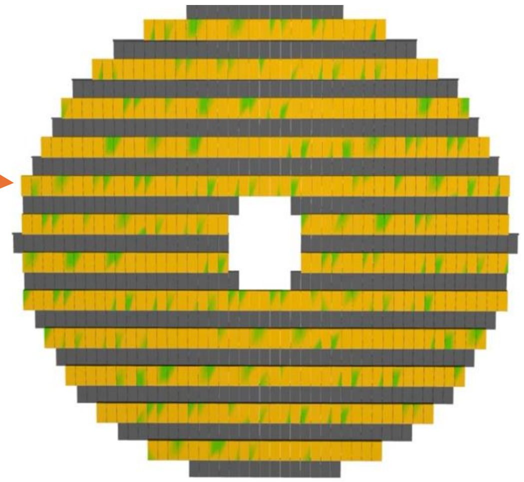
Barrel-TOF (BTOF)



-1.33<η<1.74



Forward-TOF (FTOF)



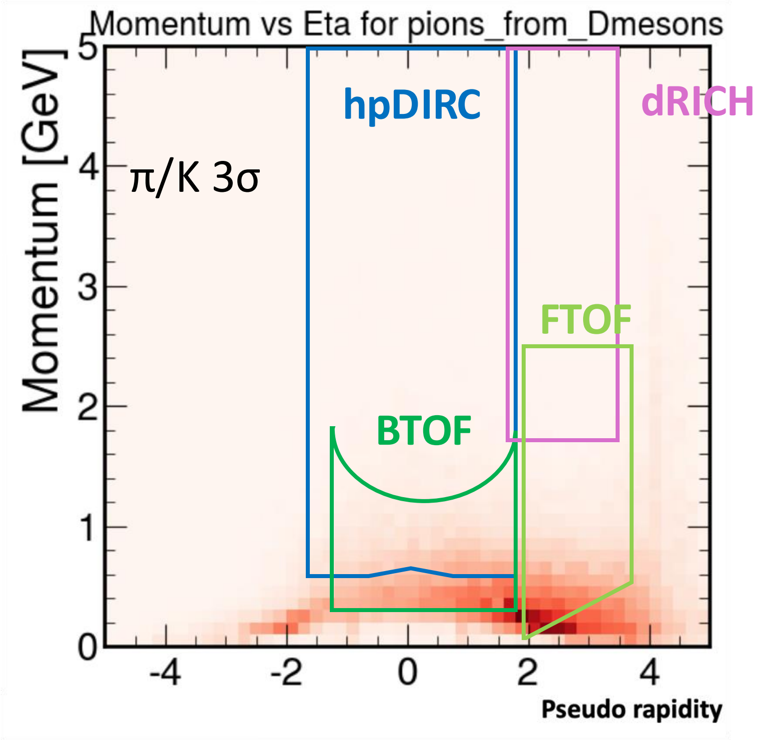
1.84<η<3.61

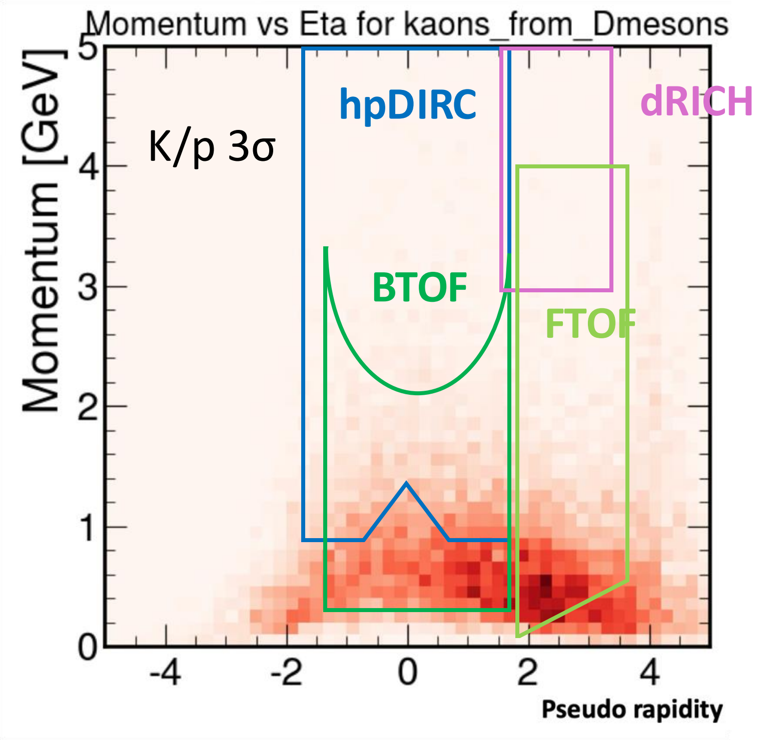
- The ePIC AC-LGAD TOF is PID, tracking and background rejection detector for mid-rapidity (BTOF: -1.33<η<1.74) and forward-rapidity (FTOF: 1.84<η<3.61)
- Strip-type and pixel-type AC-LGAD are use for BTOF and FTOF, respectively
- Different ASICs are used for BTOF and FTOF due to different sensor properties

Importance of TOF at ePIC

- HF measurement is the most important subject at EIC
- Decay products, π and K, from HF hadrons are mainly distributed in TOF region
- Light hadrons can be expected to be distributed over a lower momentum region

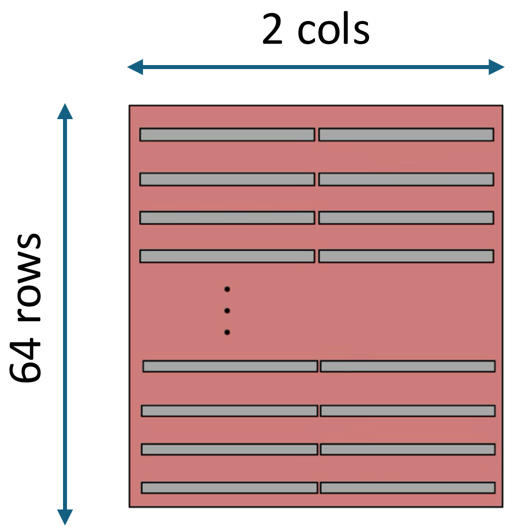
Assuming
BTOF σ_{tot} = 35 ps
FTOF σ_{tot} = 25 ps





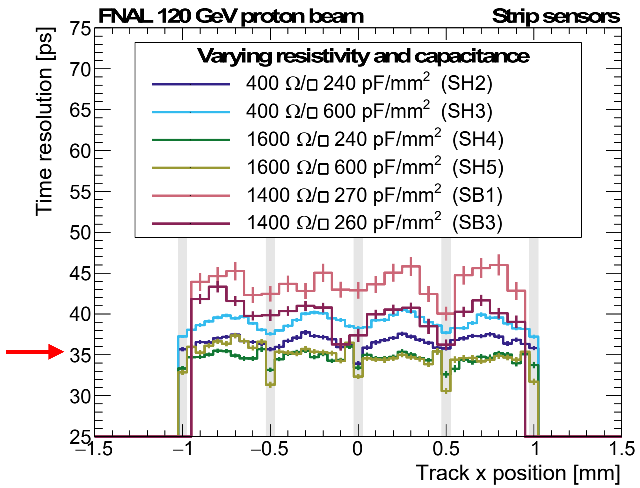
AC-LGAD sensor for BTOF

- Strip size: 0.5x10 mm^2 metals with 0.5 mm pitch
- Two types sensor size: 32x20 mm^2 (64x2=128ch) and 32x10 mm^2 (64x1=64ch)
- Active volume thickness: 50 µm
- The timing resolution of ~35 ps and spatial resolution of <20 µm has been measured by using readout board tuned to pixel-type AC-LGAD sensor
  - **The sensor has potential to improve timing resolution by using adjusted board**
  - Dedicated ASIC, FCFDv1.1, will be available this month

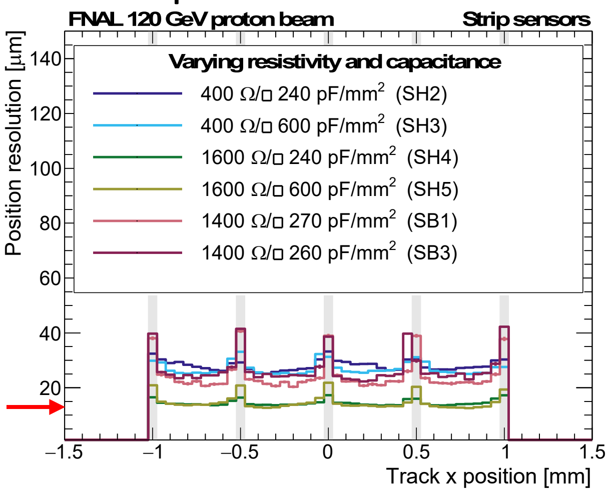


- Sensor for BTOF
  - # Full-size: ~14k
  - # Half-size: ~4k
  - ~12 m^2
  - ~2.4 M channels

Timing resolution



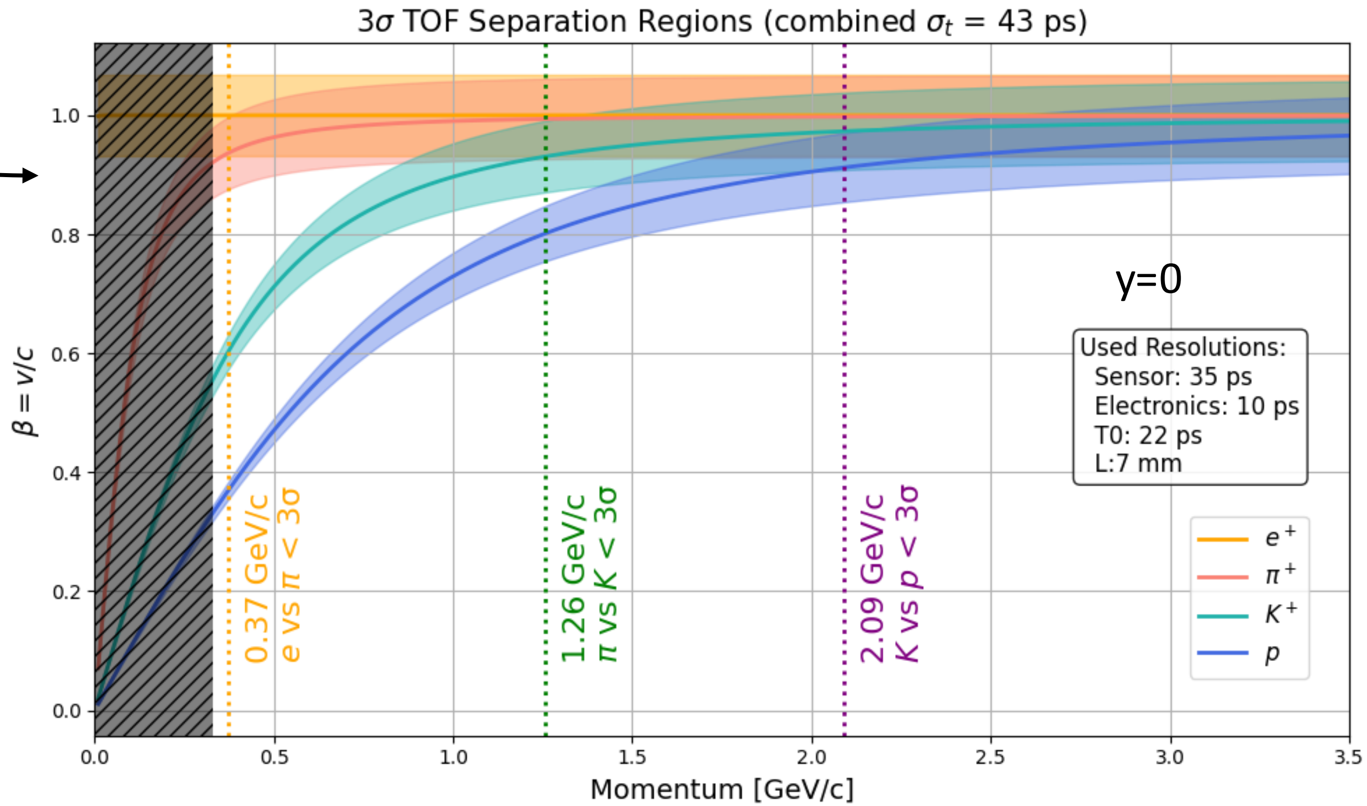
spatial resolution



Required Detector Performance

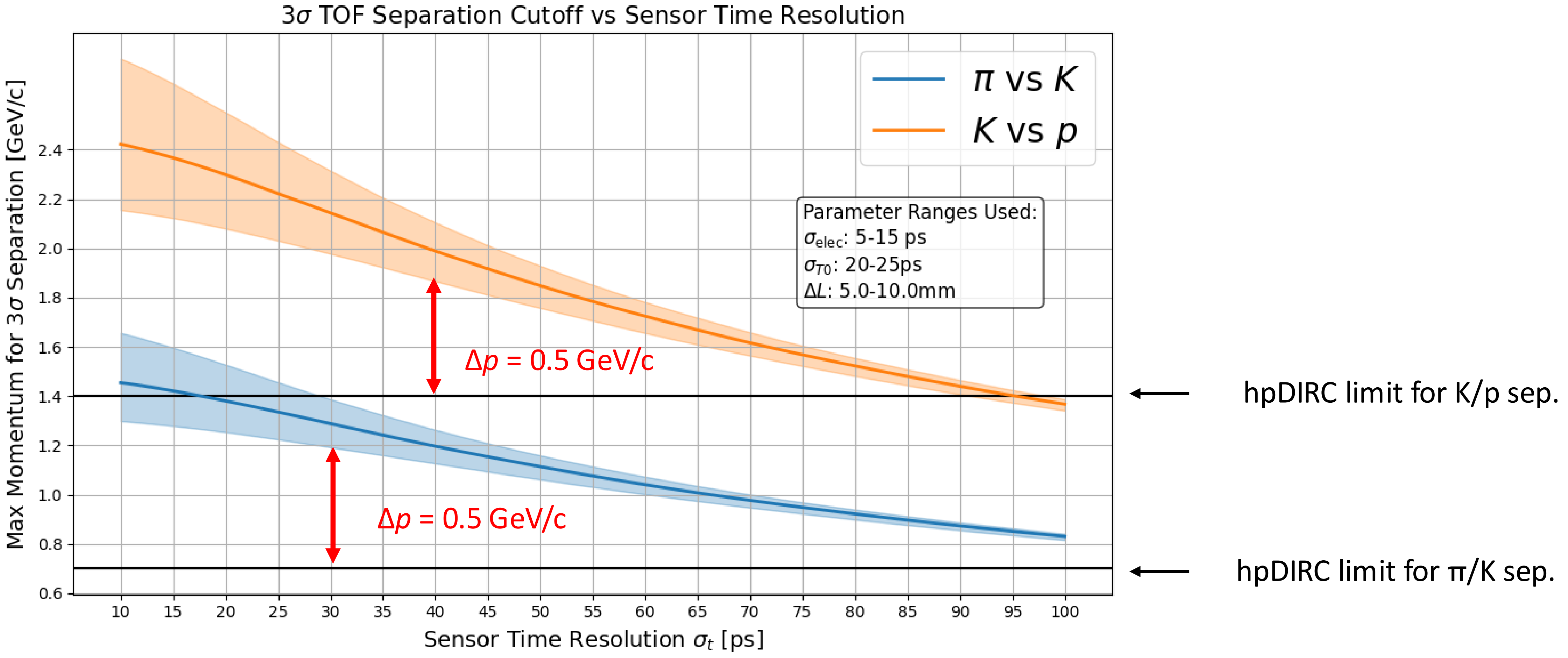
Beta v.s. σ_{total} at y=0 (ToyMC)

Not reaching BTOF
$p < 0.33$ GeV/c



- Some resolutions: σ_{sensor} = 35 ps, σ_{ele} = 10 ps, σ_{T0} = 22 ps and σ_L = 7 mm
- π/K 3σ separation up to 1.26 GeV/c（hpDIRC down to 0.7 GeV/c）
- K/p 3σ separation up to 2.09 GeV/c（hpDIRC down to 1.4 GeV/c）

3σ separation v.s. σ_{sensor}



Considering the worst case (σ_{elec}=15ps, σ_{T0}=25ps, ΔL=10mm), ~30 ps sensor timing resolution is required to be 0.5 GeV/c overlapping for π/K separation (current best is 35 ps)

Detector Design

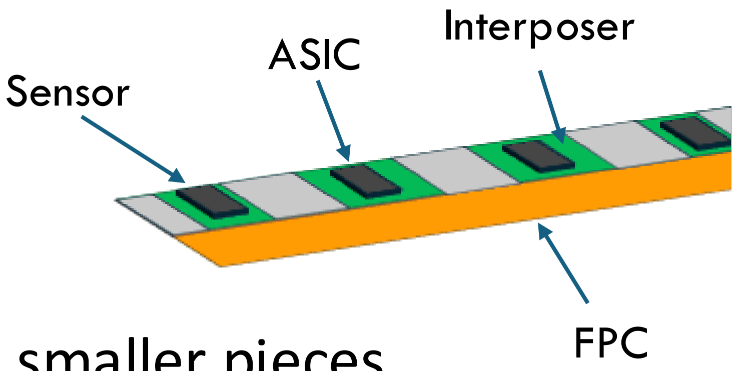
(My) Detector Design Philosophy

- The detector must meet the requirements of
  - Timing resolution
  - Spatial resolution
  - Material budget

- Design is ongoing with
  - Eliminate acceptance holes as much as possible
  - Lowest possible material budget
  - Simplified and highly efficient assembly process
  - Easier transportation to BNL

Stave Design

- Double-side stave design is adopted for acceptance hole mitigation
  - Edge of AC-LGAD is inactive
  - Sensor and ASIC are placed alternately



- We have two design (assembly) options:
  - Modularized stave design : Divide interposer and FPC into smaller pieces
    - FPC connection technology is required
  - Monolithic stave design: All sensors, ASICs and interposers are placed on one long FPC
    - Long FPC technology is required

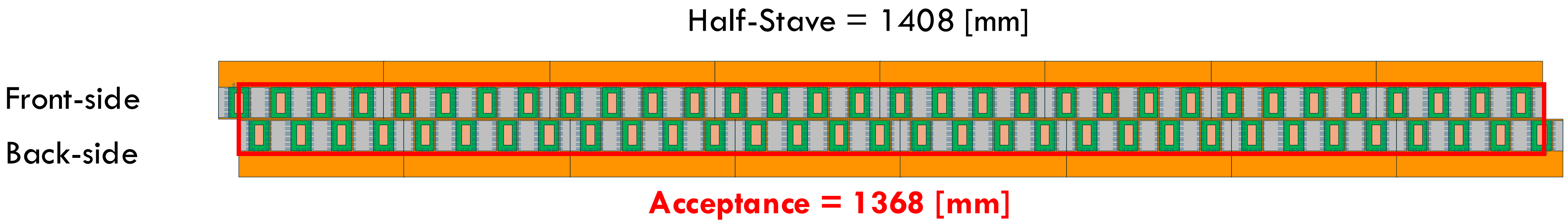
Comparison: Monolithic vs. Modularized Stave Design

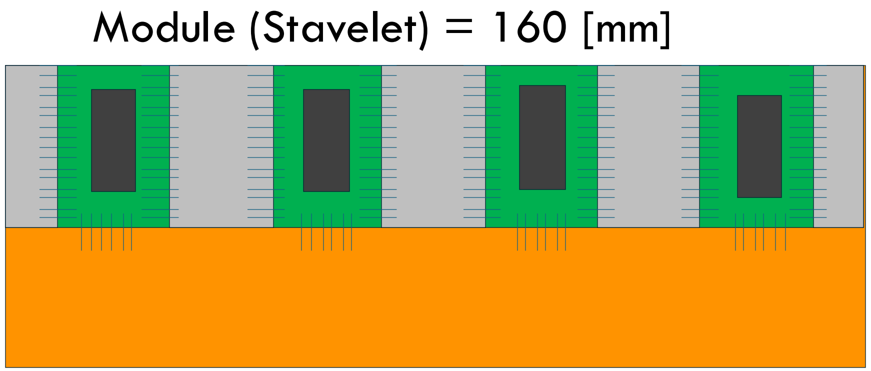
- Issues with Monolithic Stave Design:
  - Manufacturing of over 135 cm long FPCs with low material budget is currently challenging and unresolved
  - Limited recovery options if a failure occurs during the assembly process

- Advantages of Modularized Stave Design:
  - Enables distributed assembly across multiple sites, promoting collaboration and accessibility
  - Allows each site to specialize in specific assembly roles, enhancing focus and efficiency

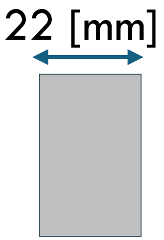
- Issue with Modularized Stave Design:
  - New idea of Module-to-Module connector is required

"Modularized" Stave Design

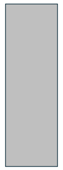




x 8 x 2 x 288
=4608



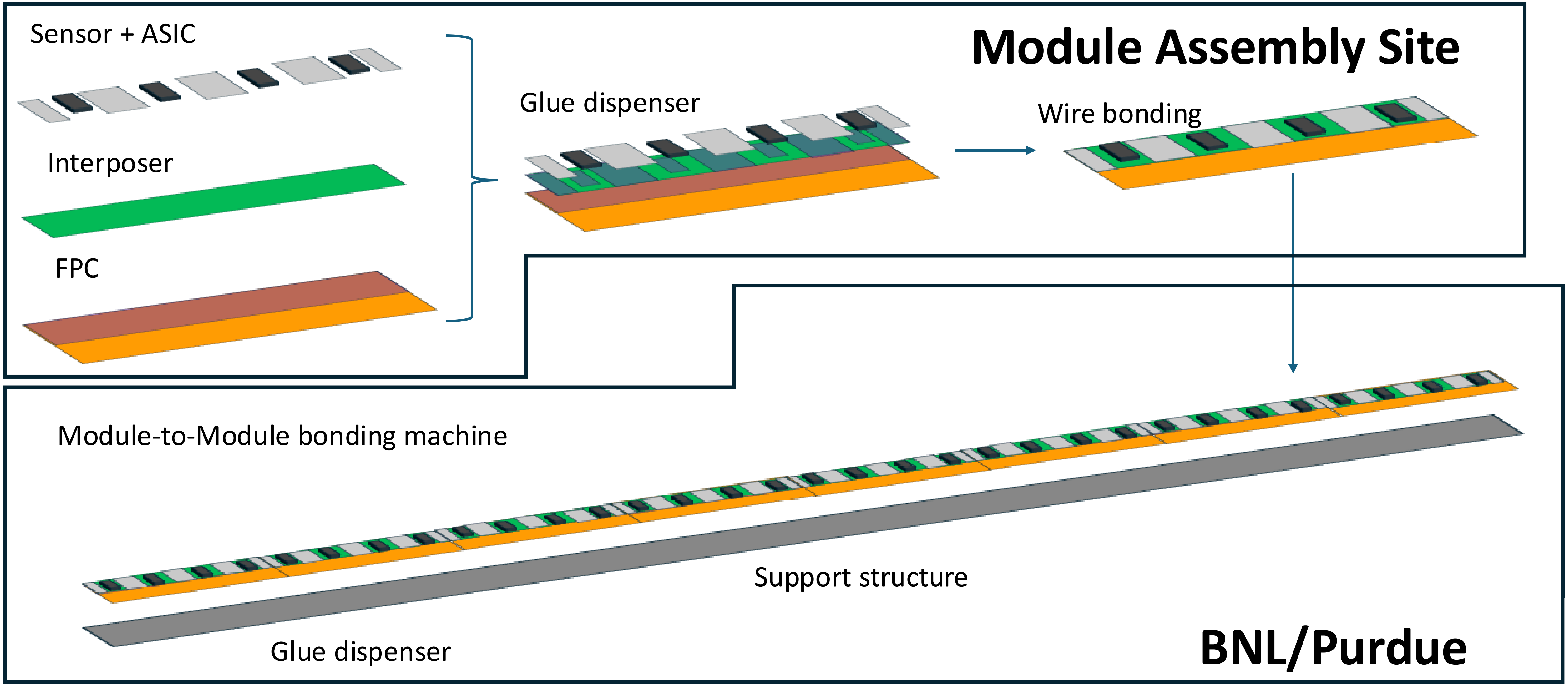
x 8 x 3 x 2 x 288
=13824



(2 x 8) x 2 x 288
=4608

Detector Assembly

Stave Assembling Steps



What does each assembly site need?

- Module assembly machines (required size ~ 160mm) :
  - Sensor/ASIC handling system (like probe station)
  - Wire bonding machine
  - Glue dispenser
  - Wire bonding protection (sealing) machine
  - Various QA systems

- Half-Stave assembly machines (required size ~ 1408mm) :
  - Module QA system
  - Module-to-Module bonding machine (depends on using technology)
  - Glue dispenser
  - Wire bonding protection (sealing) machine (if necessary)
  - Equipment of inserting 12 half-staves into one “tray”

- Full-Stave assembly / Detector construction
  - BNL is the option to install the half-staves into global support ring

Candidates of Assembly Site

- Module assembling sites
  - Hiroshima University & RIKEN (2 sites in Japan)
    - Purchase all equipment in the future
    - Adjust to the design we need
  - UCSC (1 site in US)
    - Reuse ATLAS ITK upgrade equipment
    - Be careful if it can be used for our design
  - Asian institute showing interest in assembly
    - National Taiwan University

- Half-stave assembling sites
  - It is likely in the US
    - Purdue University or BNL

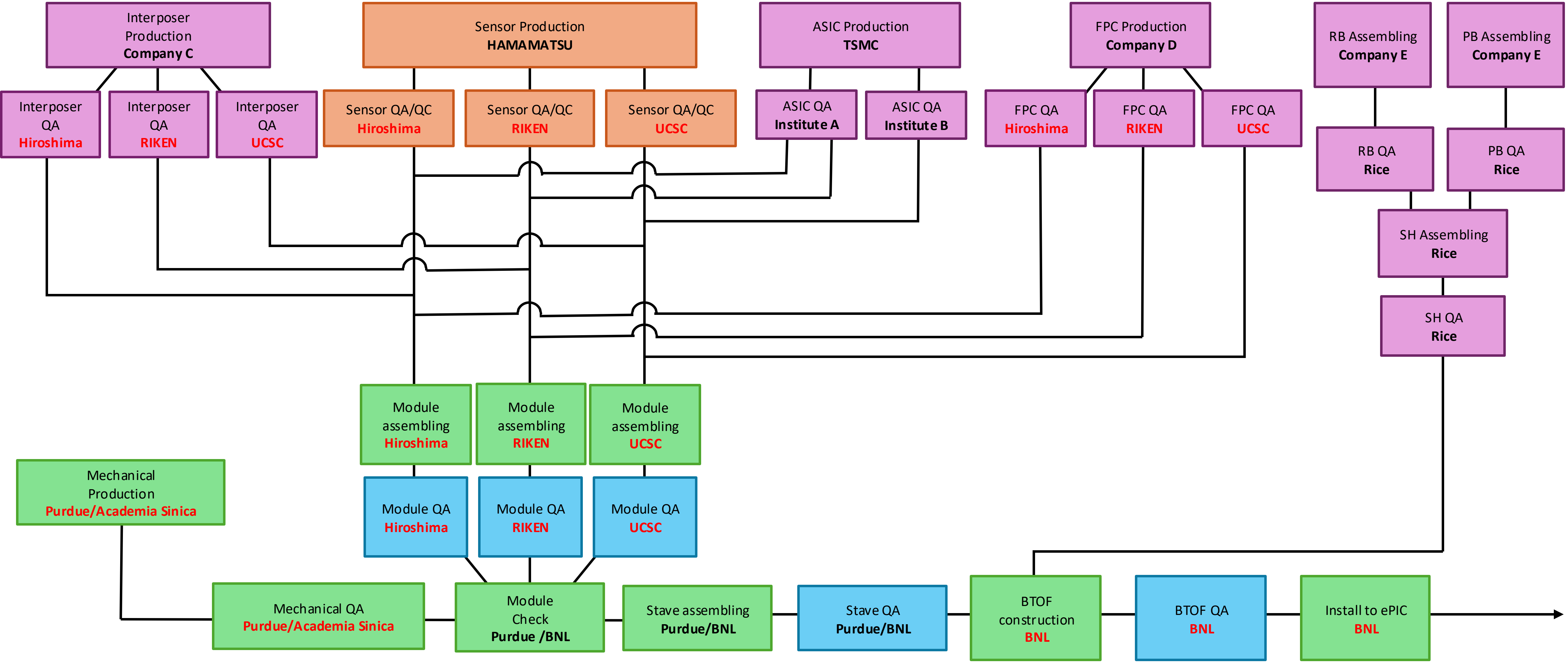
- Detector construction
  - BNL
    - Inserting trays into the global support ring

Sensor and ASIC QA/QC sites

- Hiroshima, RIKEN and UCSC sites will take care of it at least, but other institutions are very welcome to participate!

- Stations (QA/QC setups) will be designed / manufactured by ourselves and distributed to more sites because of …
  - # full-size sensor: 13824
  - # half-size sensor: 3608
  - # ASIC: 18432

Detector Assembling Workflow Example



Summary

- AC-LGAD TOF is essential to ePIC
- Sensor timing resolution of ~30 ps is required to be 0.5 GeV/c overlapping with hpDIRC for π/K separation
- The time resolution of the latest test marks 35 ps, but not adjusted readout board was used
- “Modularize” stave design is the baseline taking into assembly process
- Three institutes, Hiroshima, RIKEN, are UCSC is making concreate preparations for building the assembly site
  - Of course, you are very welcome to involved in the assembly
- We need to gather information about assembly machines
  - It is necessary to prepare machines suitable for the final design

Backup

PID-TOF Workfest @ Collaboration meeting

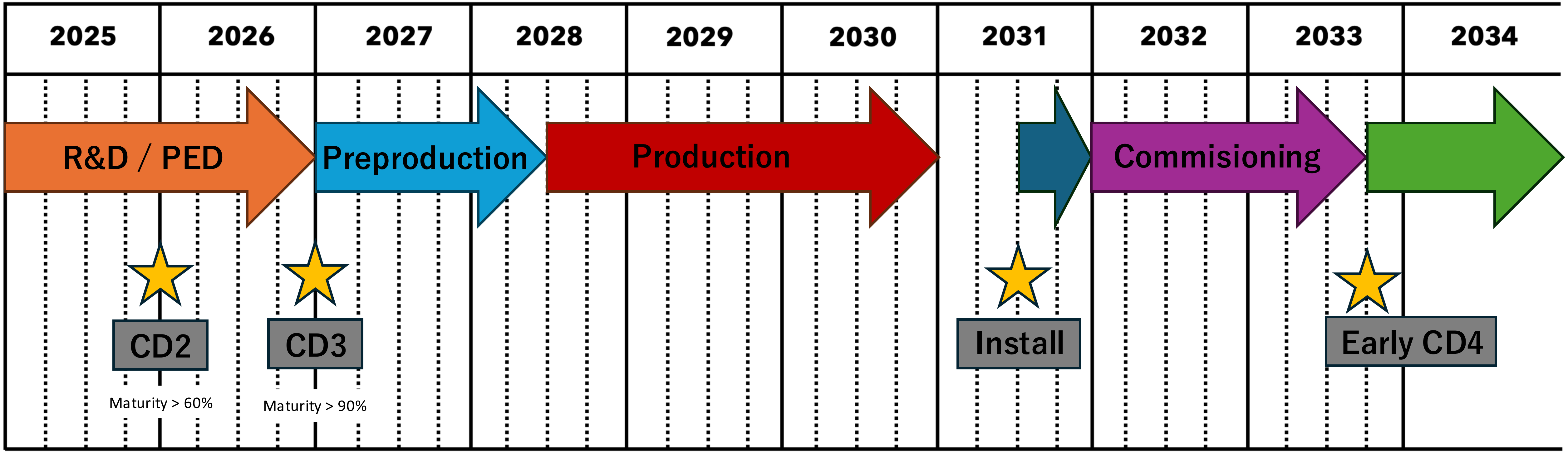
- The workfest/parallel session will be
  - In the morning of Tues-Wed July 15-16th
  - In the afternoon of Wed-Thurs July 16-17th

Early Career Workshop — Summer 2025 Joint EICUG/ePIC Collaboration Meeting

	F July 11th	S	S	M July 14th	T	W	Th	F
Morning Sessions	Last part of MC4EIC	2nd Session	4th Session	Joint ePIC/ EICUG Plenary	Parallel/ Workfests	Parallel/ Workfests	ePIC CC Meeting	ePIC Closing Plenary
Lunch	Not Provided	Provided	Not Provided	Provided	Provided	Provided	Provided	Not Provided
Afternoon Sessions	1st Session	3rd Session	(free)	Accelerator/ JLab physics talks	EICUG/ Awards	Parallel/ Workfests	Parallel/ Workfests	(free)

- Full-day session is expected to have plenty time for discussion
- It is nice to invite hpDIRC and central tracking experts
  - Assign one slot to each expert

ePIC Project Schedule (Best guess)



Importance of TOF at ePIC

- HF measurement is the most important subject at EIC
- Decay products, π and K, from HF hadrons are mainly distributed in TOF region
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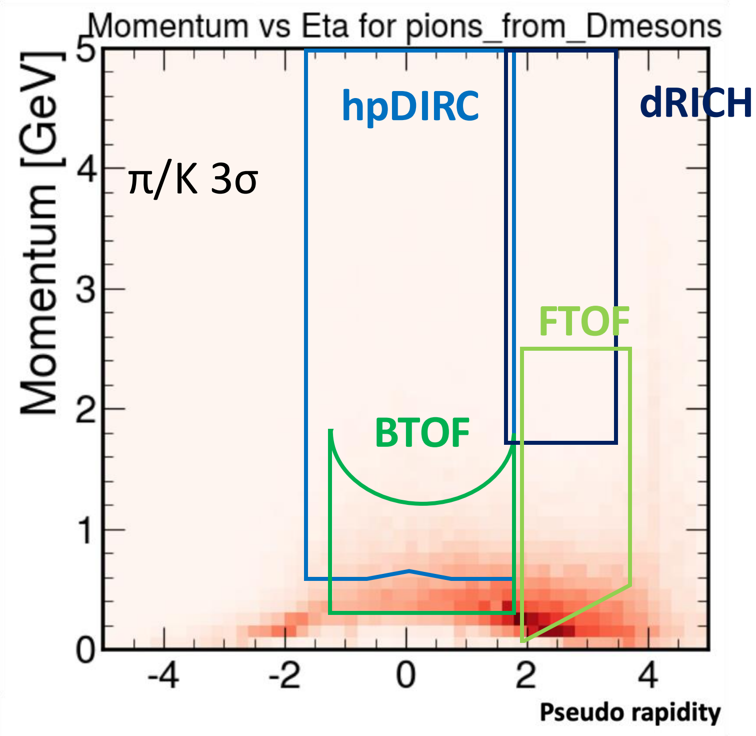

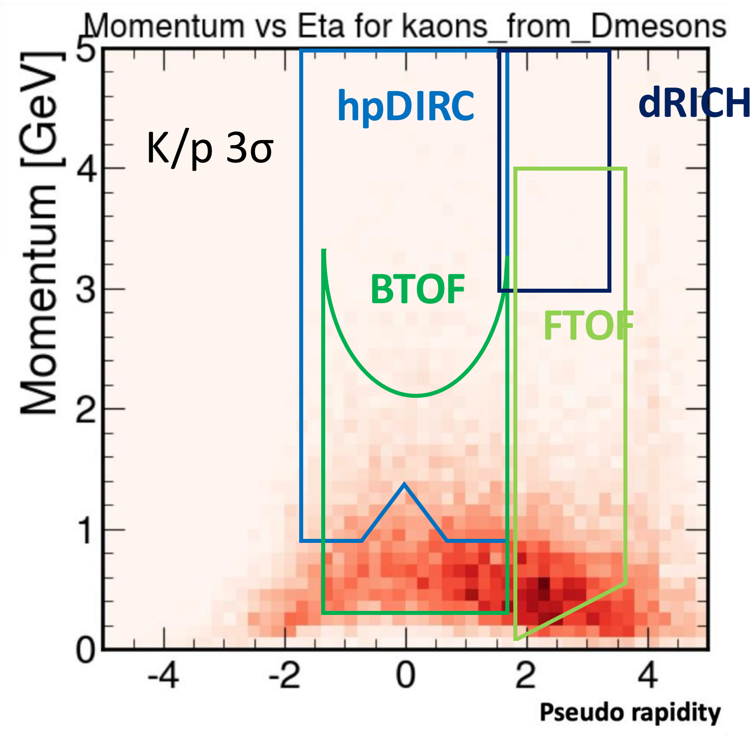

Beta v.s. σ_{total} (y=0)

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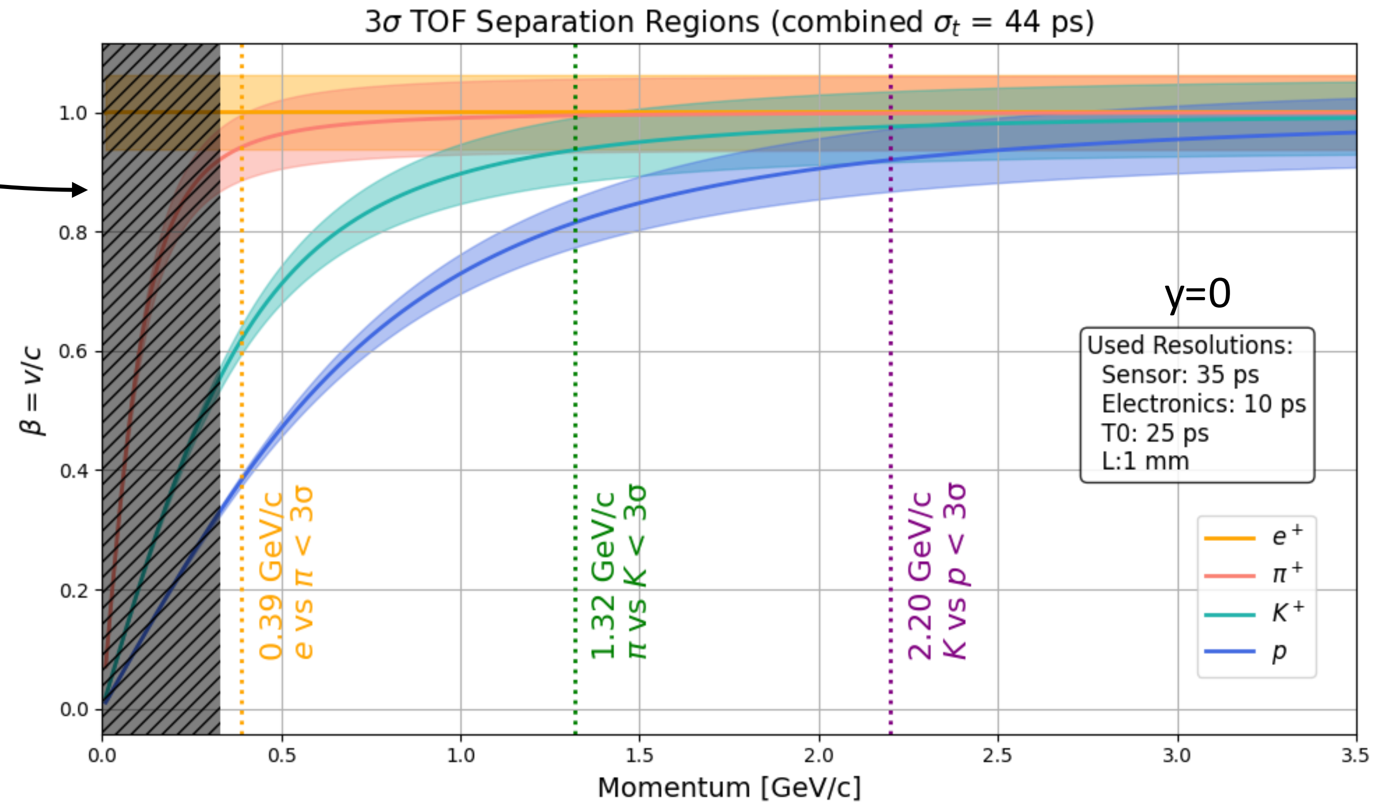

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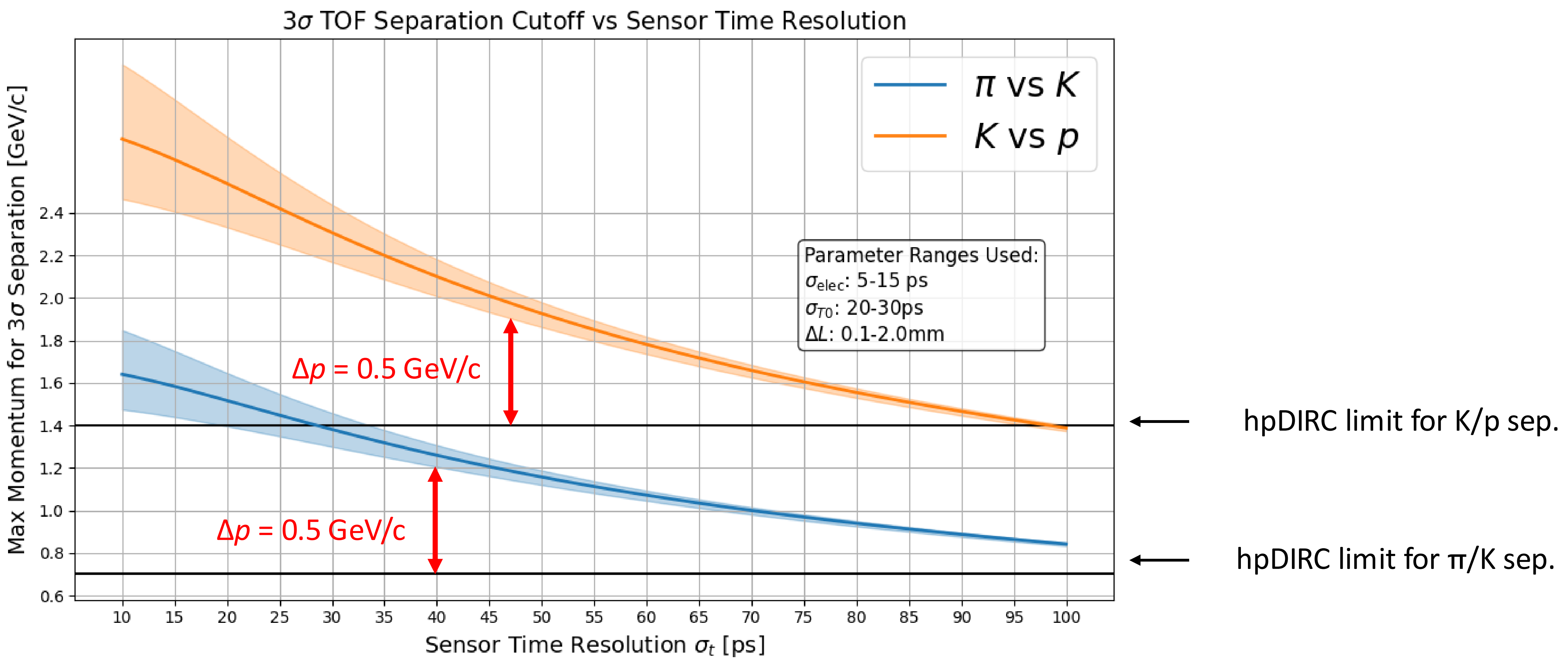
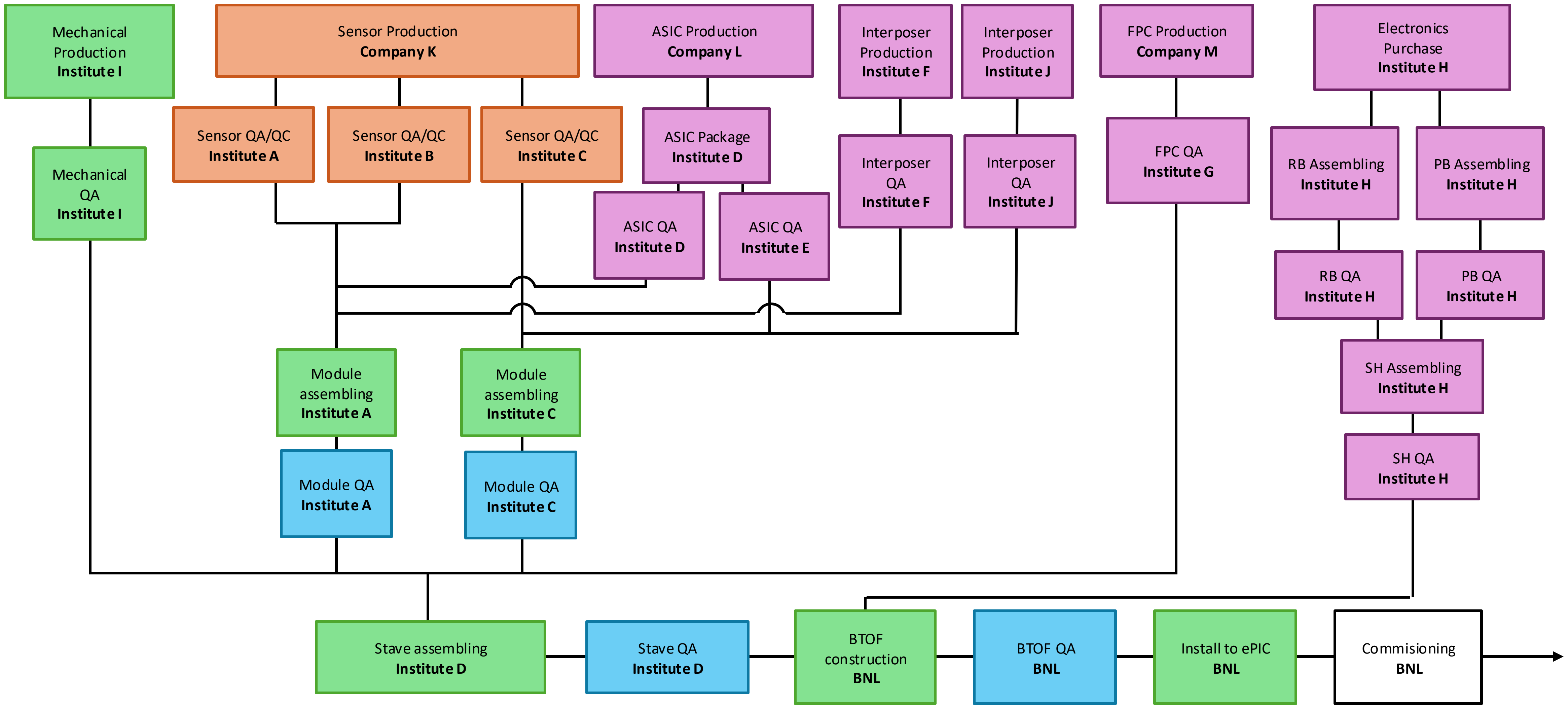
3σ separation v.s. σ_{sensor}



Considering the worst case (σ_{elec}=15ps, σ_{T0}=30ps, ΔL=2mm),

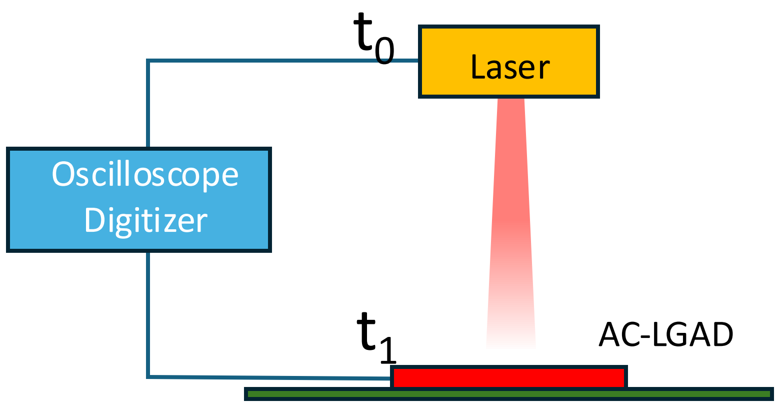
40 ps sensor timing resolution is required to be 0.5 GeV/c overlapping for π/K separation

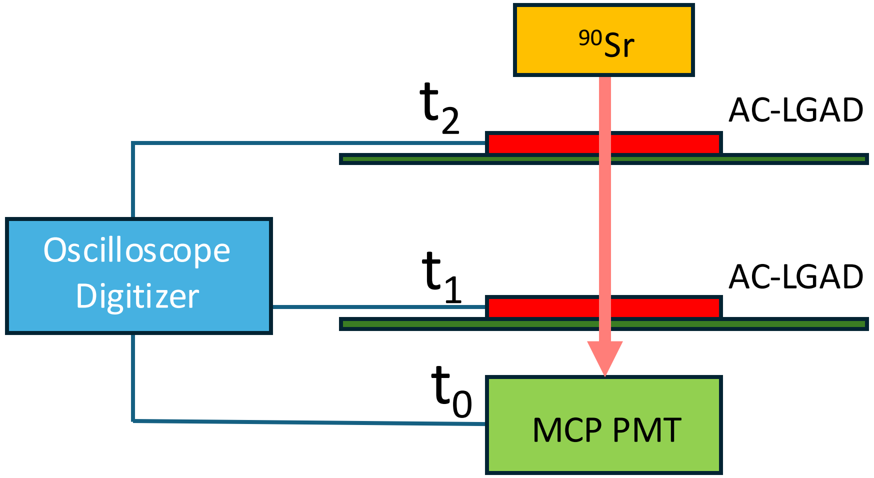
Detector Assembling Workflow Example



Sensor Lab test

- Radiation source & IR Laser





- **TCT Scan (IR laser)**
  - Positioning resolution (charge sharing)
  - Signal properties w/ readout board
  - Better timing resolution than MIP
    - No Landau fluctuation

- **Performance evaluation w/ MIP**
  - Timing resolution of MIP
  - Path length form hit info of 2 sensors
  - Signal properties w/ readout board

Stave Assembling Process (Opt2)