Low Q^2 Tagger

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Far-forward/ far-backward Review
Feb. 12, 2024

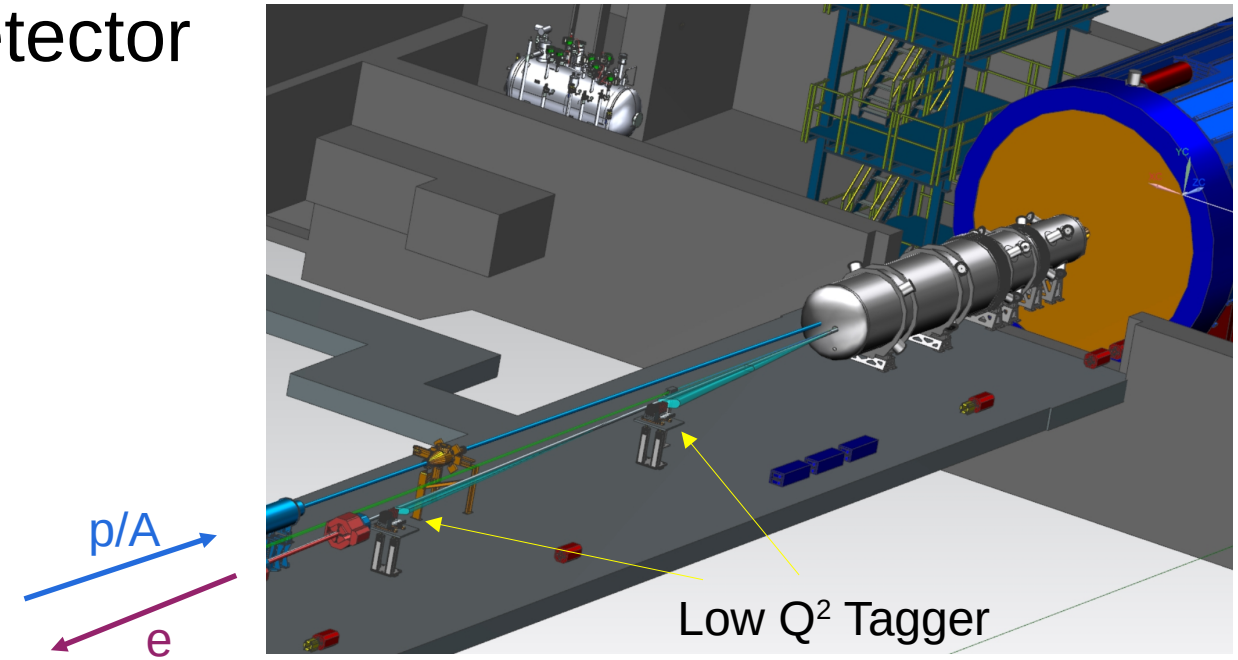
Electron-Ion Collider

Charge Questions to be Addressed

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
3. Are the current designs and plans for detectors and electronics readout likely to achieve the performance requirements with a low risk of cost increases, schedule delays, and technical problems?
4. Are the fabrication and assembly plans for the various detector systems appropriately developed for the present phase of the project?
5. Are the plans for detector integration in the interaction region appropriately developed for the present phase of the project?
6. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Outline

- Requirements for Low Q^2 detector
- Technology
- Simulation
- Status and Plans
- Quality Assurance
- EH&S
- Summary

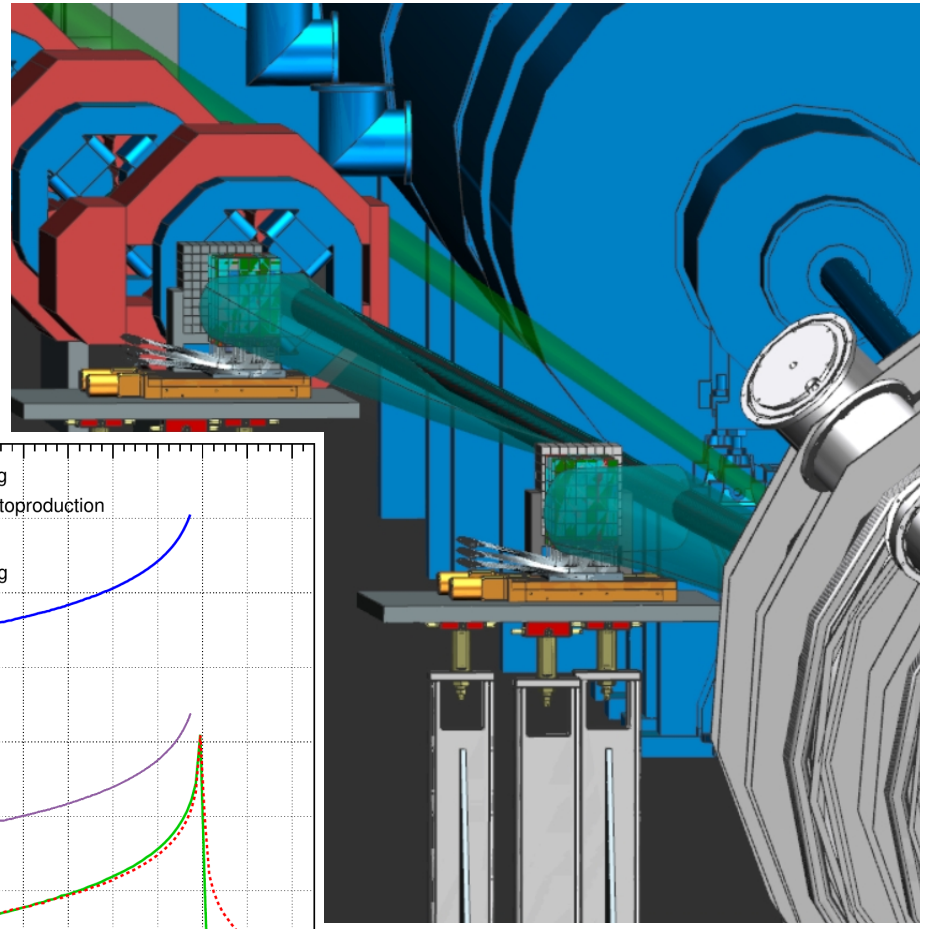


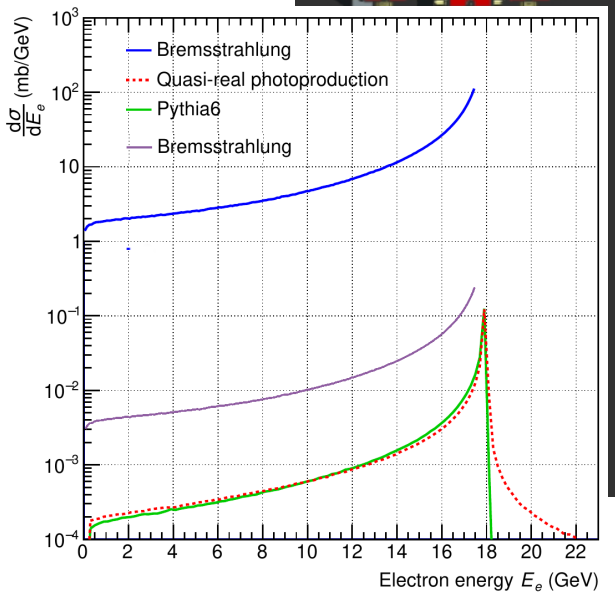
Requirements

Charge 1, 5

- Increase Q^2 acceptance
- Allow quasi real (Q^2~0) physics

- Very close to beamline.
  - 2 Taggers
  - Pixel based trackers
    - Rate capability and pixel resolution to identify > 10 tracks per beam bunch (brem BG)
    - $E_\sigma < 1\%$, $\theta_\sigma < 0.5$ mrad, $\Phi_\sigma < 5$ deg
  - Calorimeters
    - for calibration, alignment and monitoring of trackers, Luminosity and PS.





Requirements - Rate

Charge 1, 2

- High Brem BG, Non uniform distribution.

Maximum rates

Pixel (P1)	70 kHz	
2 column (C1)	8 MHz	
Tpix4 (T1)	600 MHz	38 Gb/s
Board (B1)	1500 MHz	96 Gb/s
Layer (L1)	2500 MHz	160 Gb/s

Total integrated rates

Tagger 1	2 GHz	130 Gb/s
Tagger 2	7 GHz	480 Gb/s
Total	**9 GHz**	**600 Gb/s**

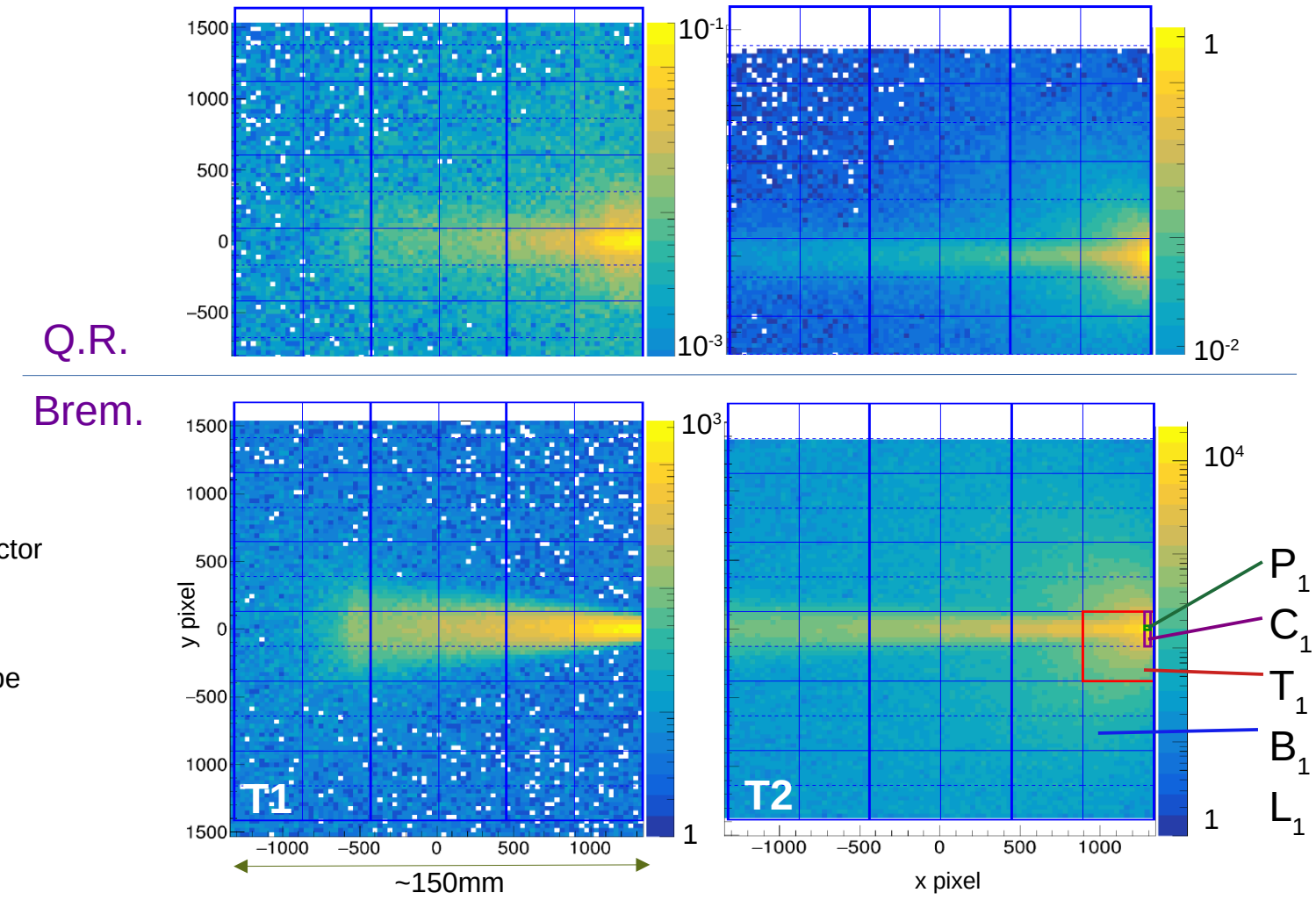
Data buffered & filtered: need a hadron in main detector

Trigger rate: 500 kHz: 99.4% rejection (brem only)

Data rate (signal): 4 Gb/s

Data rate (incl BG and rand sample) **<20 Gb/s** To tape

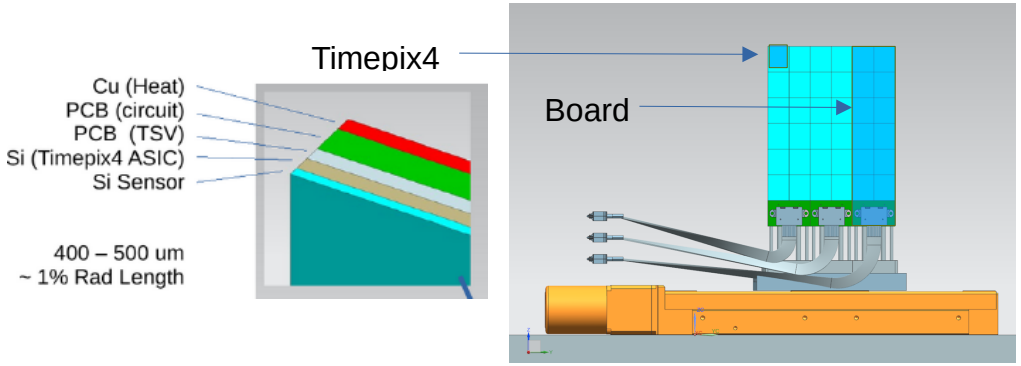
Low Q^2 tagger rates kHz / pixel. (18x275 GeV @ 10^{34} cm^{-2} s^{-1})



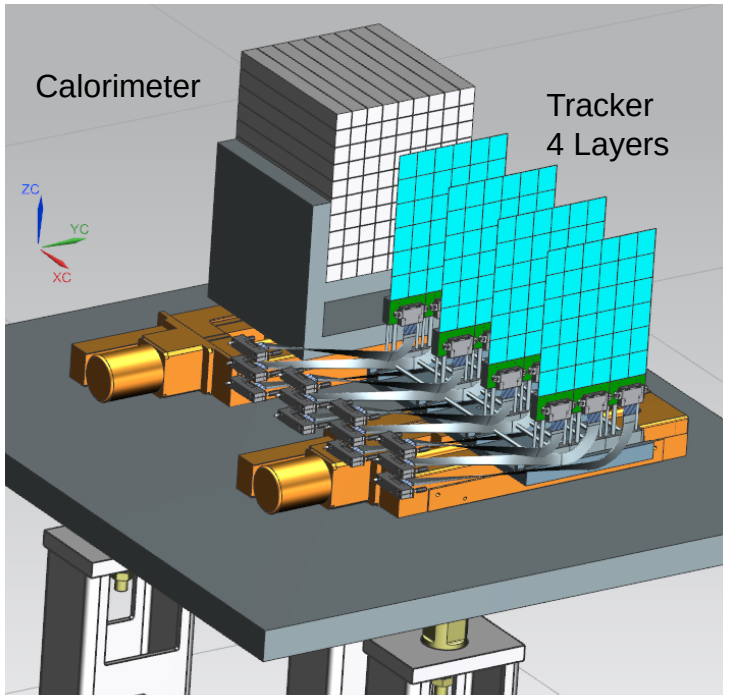
Technology

Charge 1, 2

- Tracker
  - **Timepix4 Hybrid (ASIC+Si) + SPIDR4 readout.**
    - Pixels: 55x55 um. 448 x 512 pixels. Area = 6.94 cm^2
    - Individual thresholds, data driven
    - Timing: < 2 ns.
    - Rates: < 5.5 MHz per 2x256 column
  - **Layout**
    - 1 board: 6x2 Timepix4 → SPIDR4 readout.
    - 1 layer: 3 boards
    - 1 tagger: 4 layers → total of 12 boards, 144 x Timepix4
    - Documented at https://arxiv.org/abs/2305.02079



- Calorimeter
  - Scintillating Fibre Calorimeter. See Other FB Calorimeters, fECAL.
    - 18x18x18 cm cube → 900 3x3 mm Hamamatsu SiPMs



Simulation – acceptance (275 / 18 GeV)

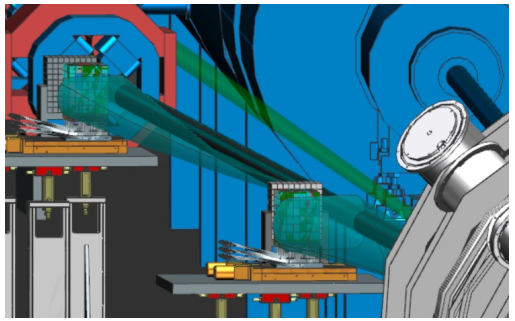
Charge 1, 2

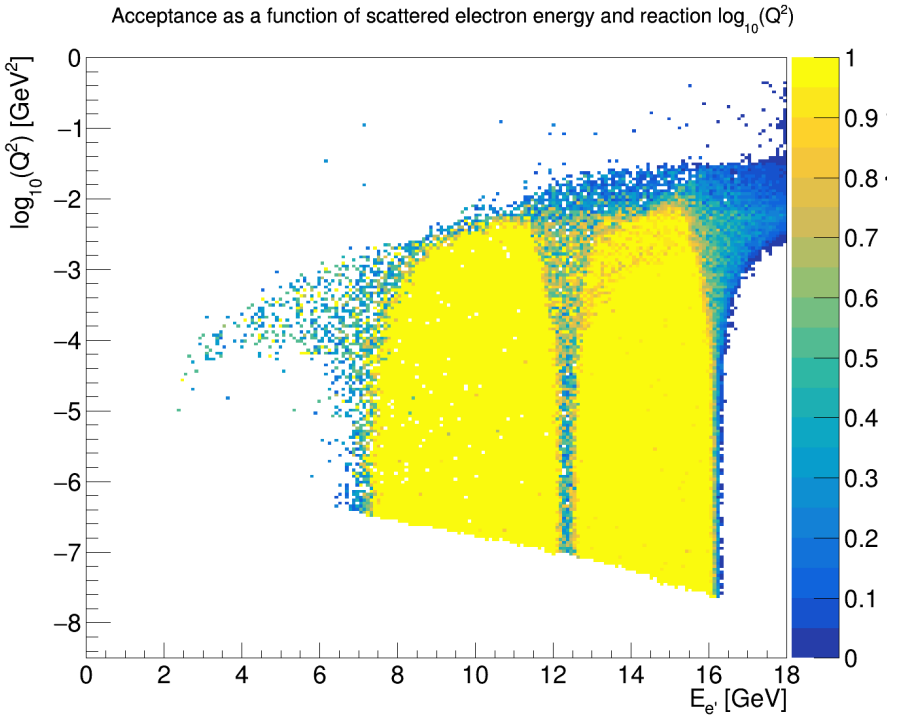
Simulation includes all mechanical components, beam smearing.
Not beam gas, synchrotron radiation.

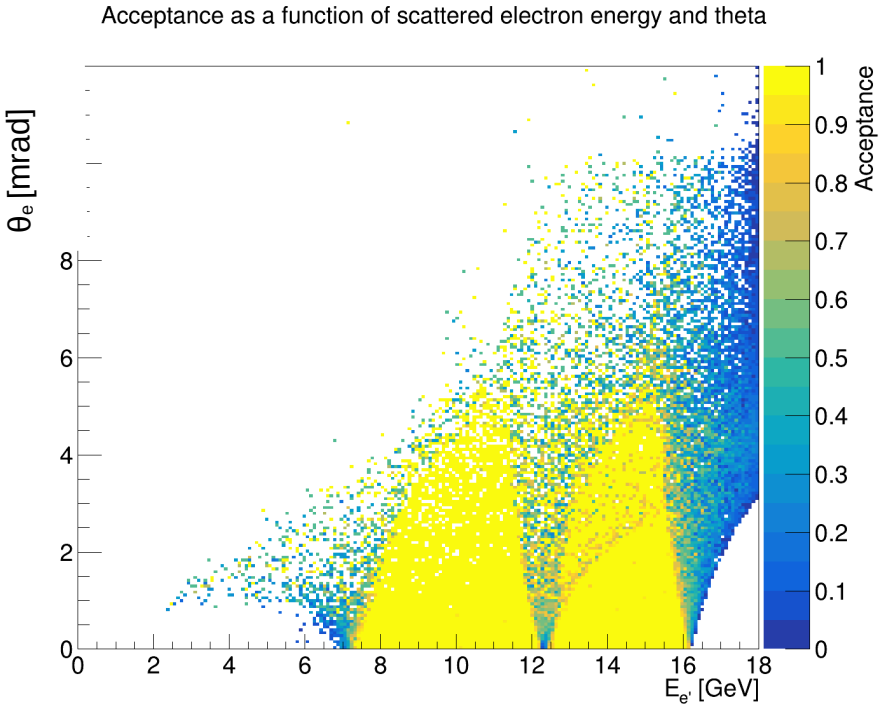
% scattered electrons reconstructed in tagger :

10% from all collisions

15% of all electrons < 11 mrad (Low Q^2)

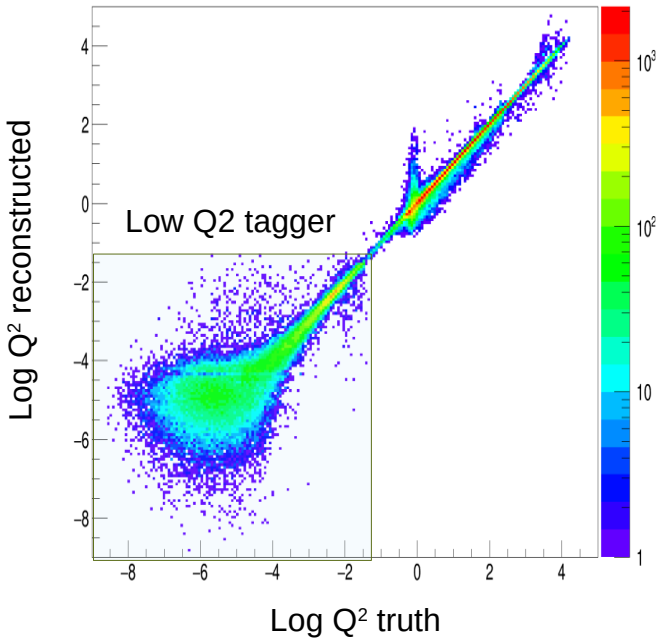


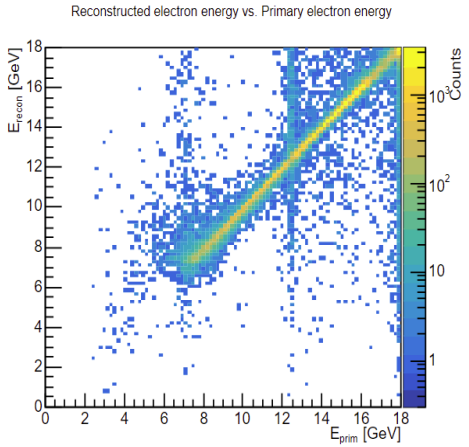


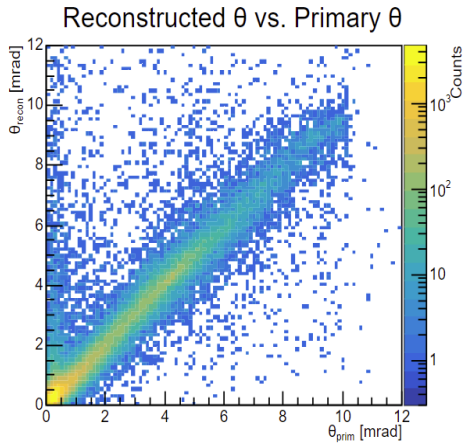


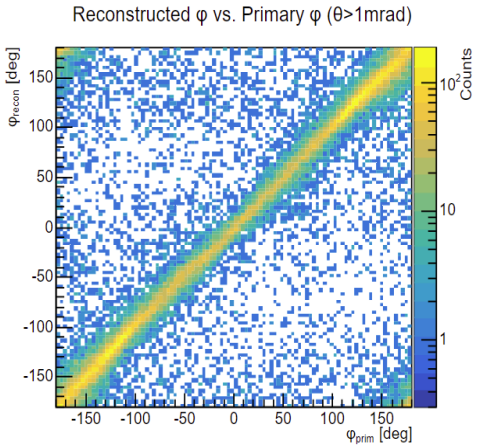
Simulation – resolution (275 / 18 GeV)

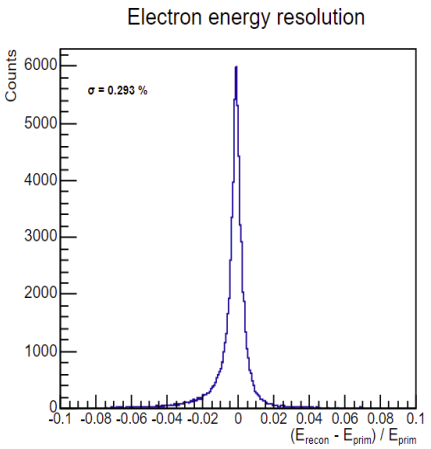
Charge 1, 2

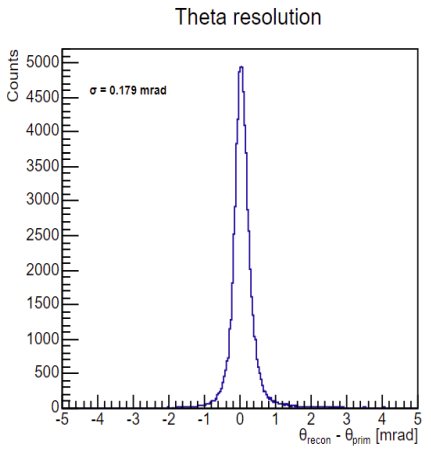


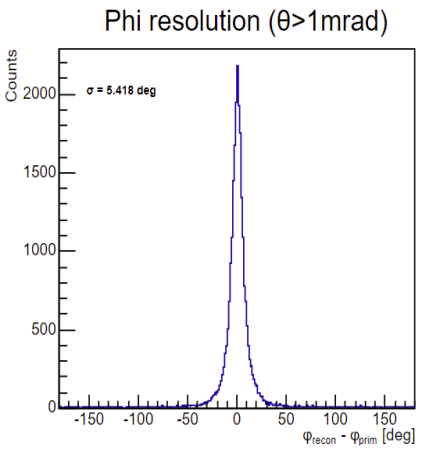












Integrated resolutions of reconstructed particles

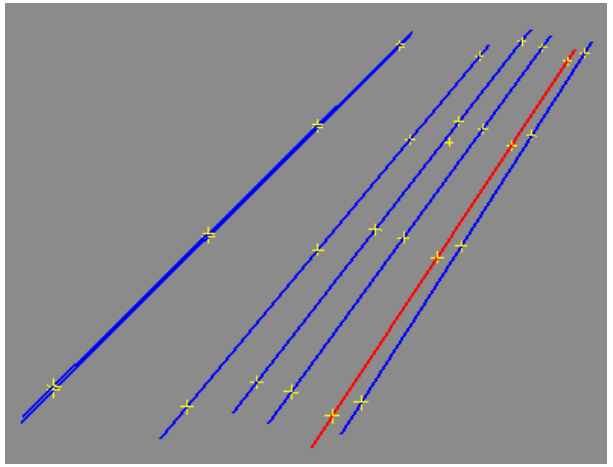
E_σ = 0.3 %
θ_σ = 0.2 mrad
Φ_σ = 5 deg

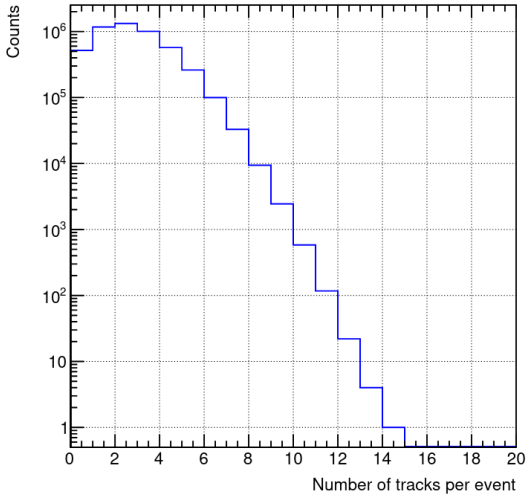
Simulation – tracking

Charge 1, 2

- Tracking
  - Can be many tracks per event, and extra clusters from noise + BG.
  - Most events are brem only.
  - Machine Learning
    - >99% efficient on mix of QR+brem

Q.R. and **Brem** events in 4 layer Tracker





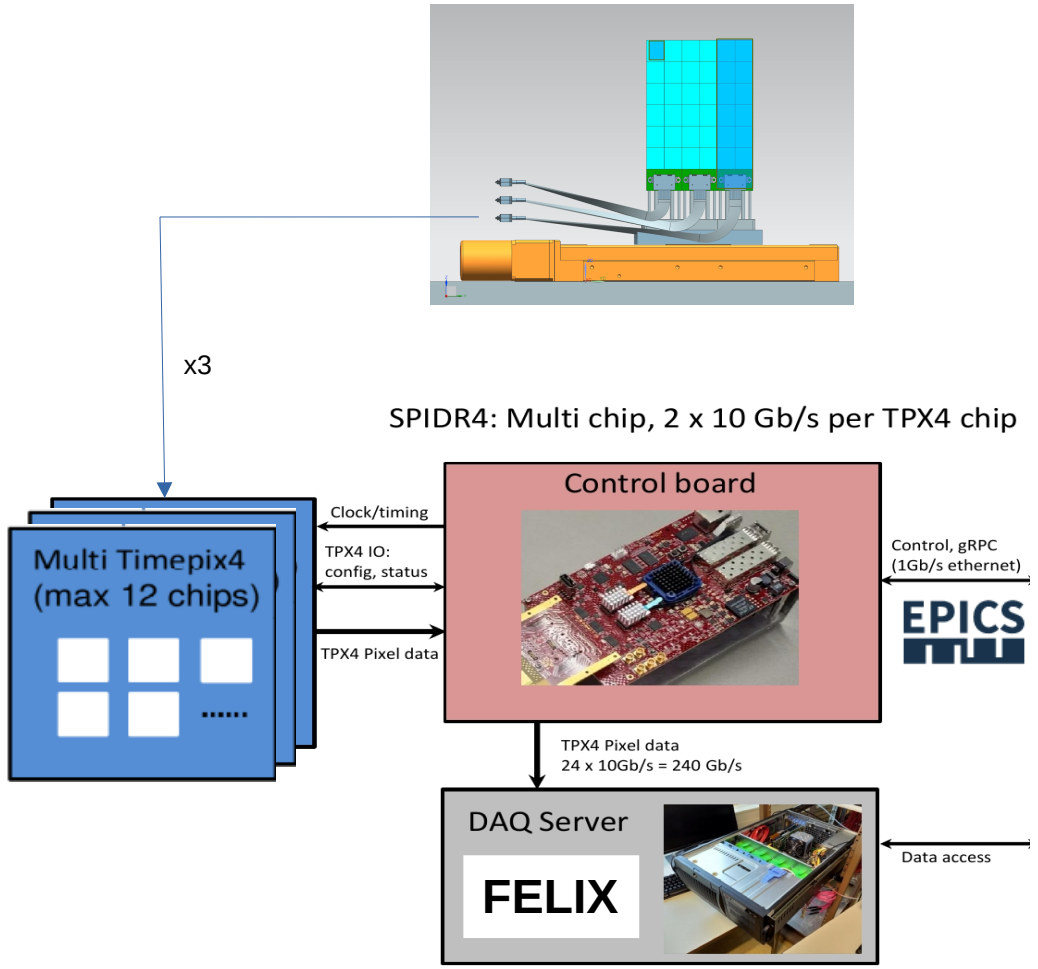
- ML + FPGA
  - Collaborating with Jlab group (generic R&D project)
    - Particle identification and tracking in real time using Machine Learning on FPGA
  - Excellent preliminary results (See backups)
    - S. Gardner: Object Condensation for Track Building in a Backward Electron Tagger at the EIC @ AI4EIC, Nov 2023, CUA, Washington D.C.

Readout and DAQ

Charge 1, 2, 5

- Tracker
  - Timepix4 readout SPIDR4, NIKHEF
  - Digitization on ASIC. Individual thresholds. Very low noise.
  - Control board, handle up to 12 Timepix4
  - Data → FELIX boards / Buffering
  - Buffered data filtered **on coincidence** with central detector

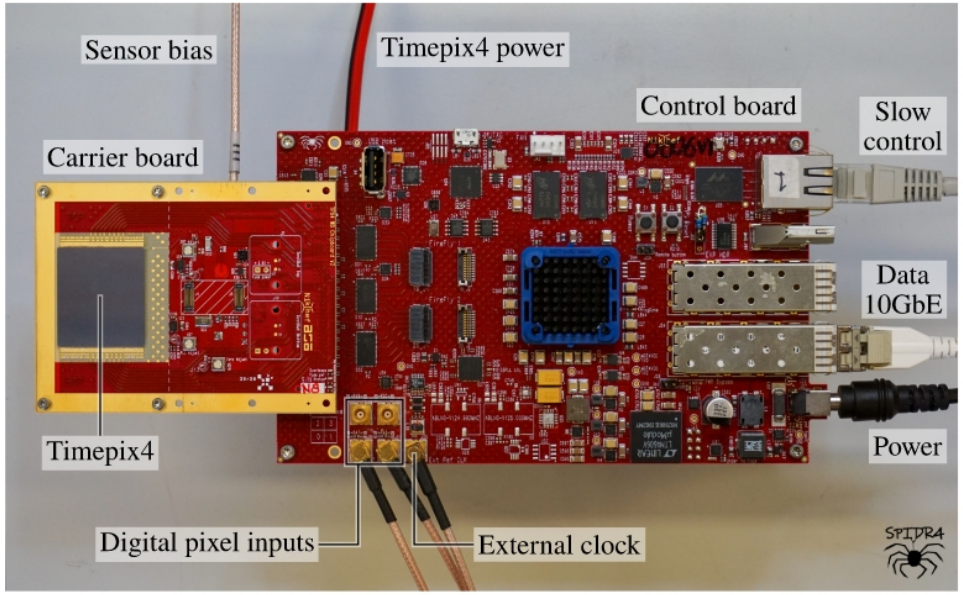
- Calorimeter
  - Fibres → SiPM → standard DAQ channels
  - 2 x 900 channels per calorimeter = 900



Status and plans

Charge 5

- Tracker
  - 2 x SPIDR4 kits in Glasgow Jan 2024
  - Engineering test model. May 2024
  - Engineering tests in Europe Summer 2024
  - Final design complete May 2025
  - Engineering + DAQ test in Jlab Sep 2025
  - Start of construction Oct 2026
  -



- Calorimeter
  - Final design complete, review, start of construction May 2025
  - Ready for installation (cosmic tests at BNL) Oct 2030

Quality assurance

Charge 6

- Tracker
  - Timepix4 trackers developed in cooperation with the Timepix collaboration and Glasgow ATLAS group, who were played a leading role in the producing the ITk pixel tracker for the LHCB upgrade. Well tested. Robust for production an testing across several institutes in different countries.
  - Pre-production: Test beams (full chain production test and DAQ), Rates, Radiation hardness, cooling.
  - During production: Manual on production and testing, check-lists, detailed spread-sheets with numbers and QA parameters. Test beams (full chain production test and DAQ)
  - Transportation procedure: define and document.
  - Assembly and installation procedure: define and document.
- Calorimeter
  - Synergy with others: FB calorimeters and fECAL
  - QA and production procedures: to be developed together with above groups.

ES&H

Charge 6

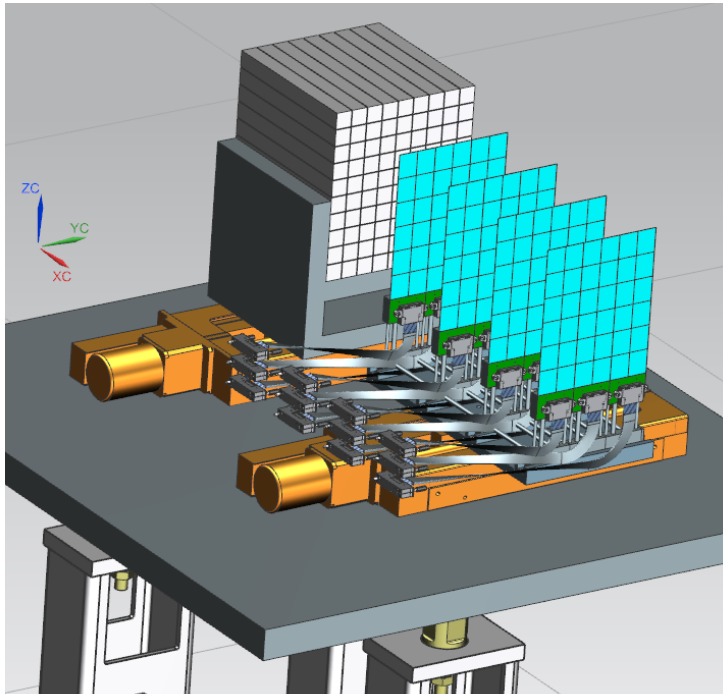
- **Follow all procedures laid out by BNL and other labs where production test and development are carried out.**
- **During the engineering design phase**: Include production of mockups and engineering test articles to insure the proper functionality and quality.
- **Full production chain tests for each sub-system**.
  - For operation with HV and Cooling: we will ensure that these are mechanically secure and not a trip hazard, have proper warning signs and follow the lab procedures for electrical safety.
  - **Operation near the beam-pipe and vacuum**: anyone working near the far-forward/backward detectors to wears ear protection, and will post signage to that effect.

Summary

- Low Q^2 Tagger

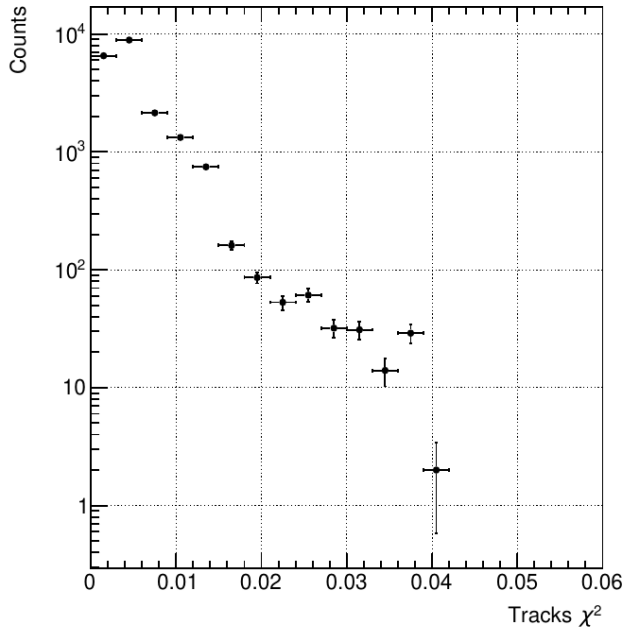
  - Pixel based tracker
    - Timepix4 + SPIDR4
      - Required due to extremely high rates
        - small pixels
        - high rate readout
    - Basic design well established
    - Construction of first test article already underway

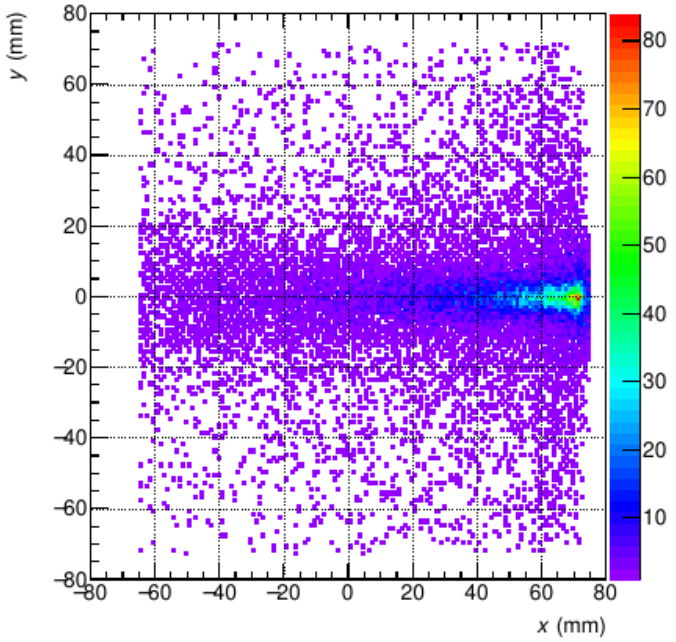
  - Calorimeter
    - Design established
    - Close synergies with other FB calorimeters and fECAL.

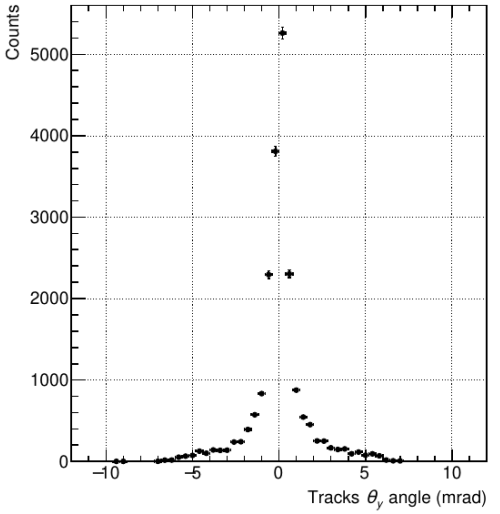


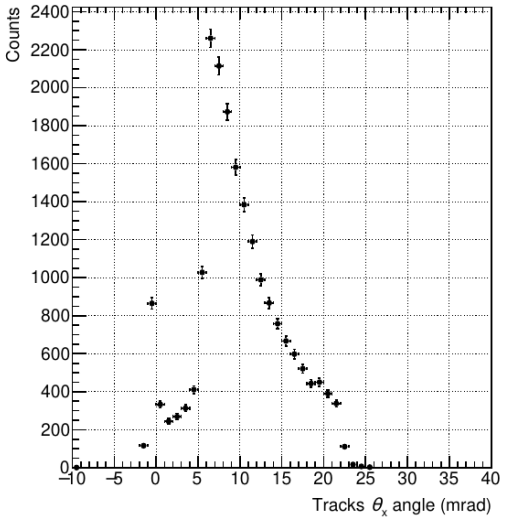
Backup slides

- Tracking









Backup slides

- Tagger acceptance fractions
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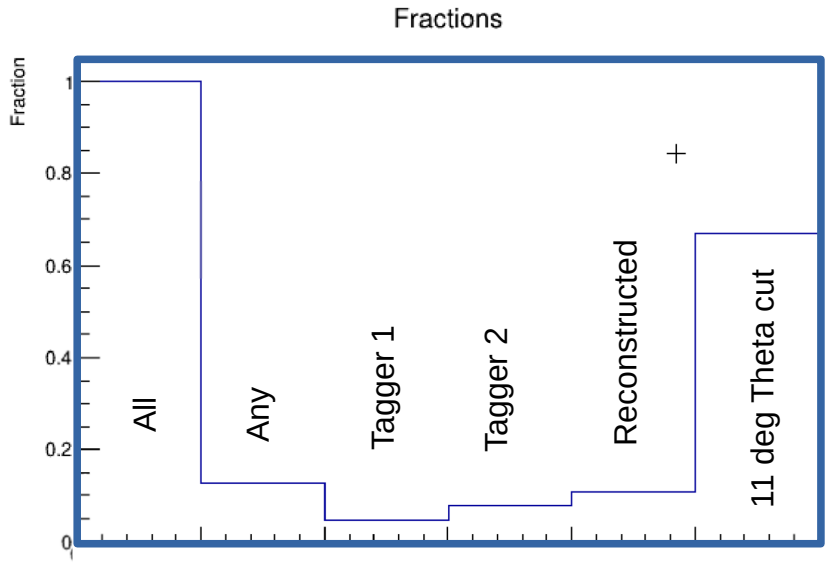
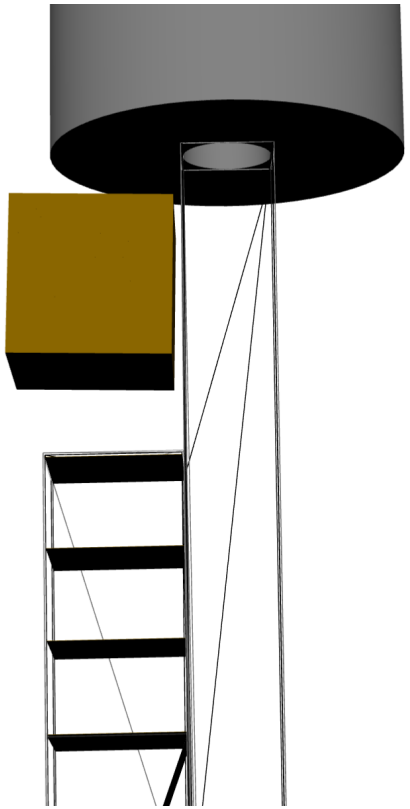
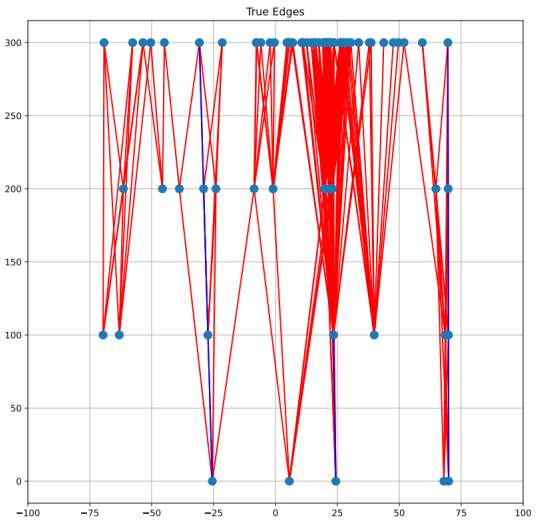
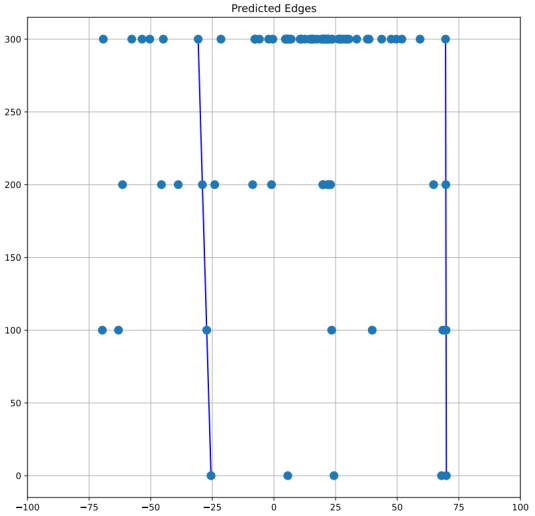
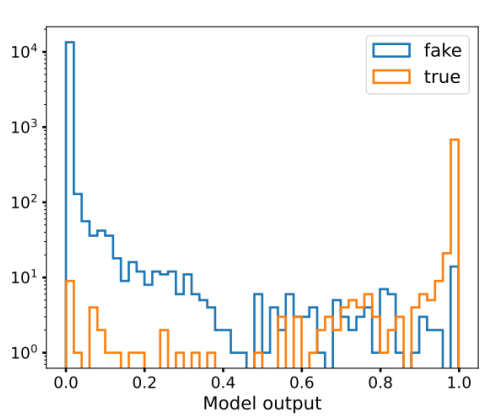


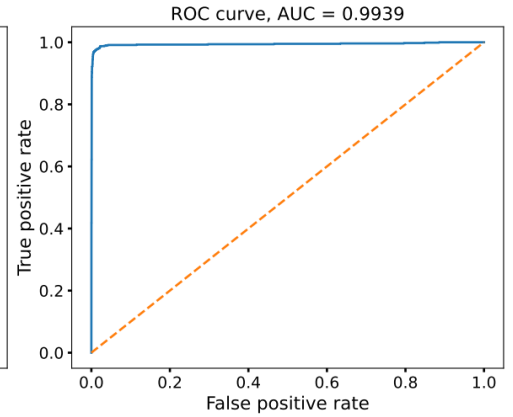


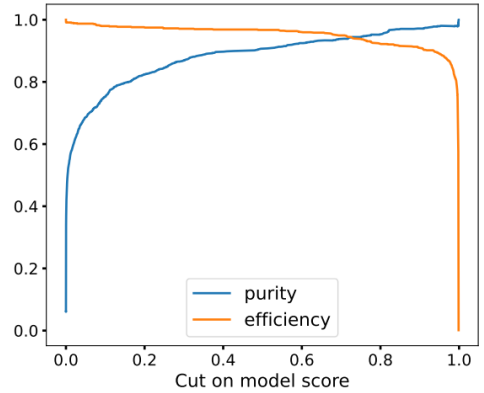
Backup slides. FPGA Machine Learning

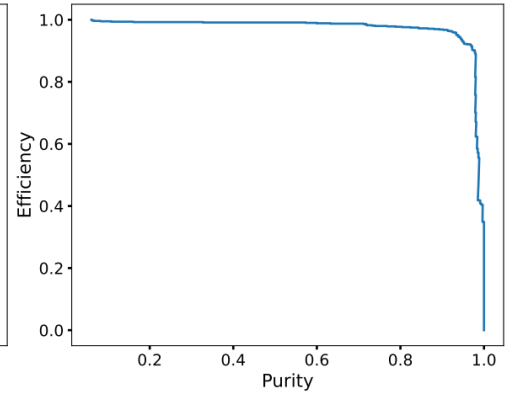












Backup slides

- Timepix4 + SPIDR4 Engineering test setup.

Timepix3 vs Timepix4

Timepix4: A 4-side tillable large single threshold particle detector chip with improved energy and time resolution and with high-rate imaging

			Timepix3 (2013)	Timepix4 (2019)	
Technology			130nm – 8 metal	65nm – 10 metal	
Pixel Size			55 x 55 µm	55 x 55 µm	
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448	3.5x
Sensitive area			1.98 cm²	6.94 cm²	
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit	33%
		Max rate	0.43x10⁶ hits/mm²/s	**3.58x10⁶ hits/mm²/s**	
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**	8x
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)	10x
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)	5x
		Max count rate	~0.82 x 10⁹ hits/mm²/s	~5 x 10⁹ hits/mm²/s	8x
TOT energy resolution			< 2KeV	< **1Kev**	
Time resolution			1.56ns	**~200ps**	
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps (16x @10.24 Gbps)**	

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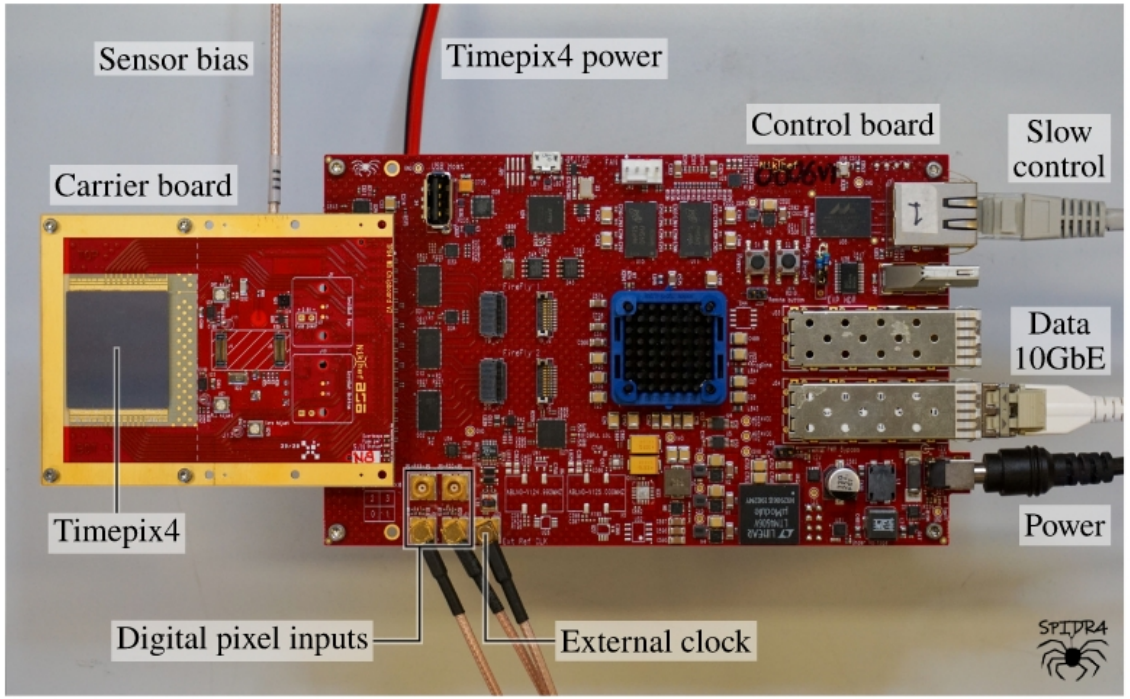

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Backup slides

- Calorimeter

Position resolution.

The tracks are projected
to the calorimeter front and difference is taken
between track projected position
and calorimeter reconstructed position in x and y,
shown on the plot as DeltaX_track-cal
and DeltaY_track-cal.