LOW Q^2 TAGGING AT EPIC

EPIC Collaboration Meeting

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OVERVIEW

Quasi-real tagging (low Q^2) (θ_e<10 mrad)

Status

Geometry integrated into EPIC simulation
Clustering, tracking and particle reconstruction
Early stages of integrating into EICrecon with ACTS

Detector Goals

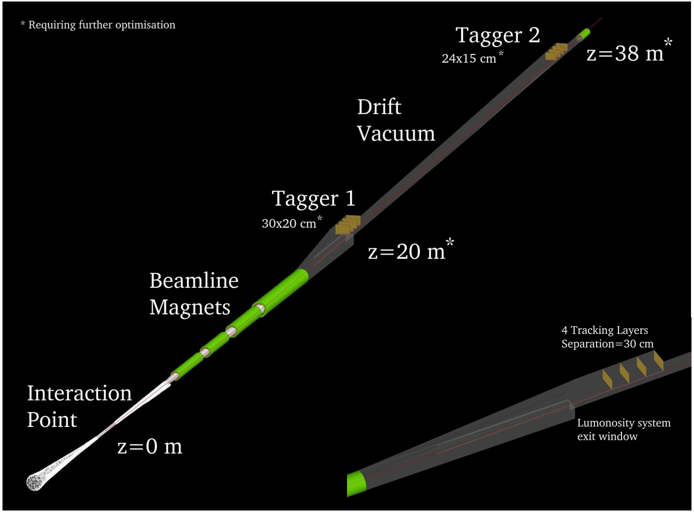
Large acceptance (>10%)
Good energy resolution $\lesssim$1%
Reconstruction of scattering plane (polarization)

Optimum solution

Two in-vacuum tagger modules
3 or 4 layers of pixel detectors
Calorimeter not required (cf. current design)

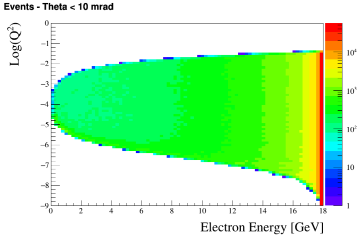
Best technology

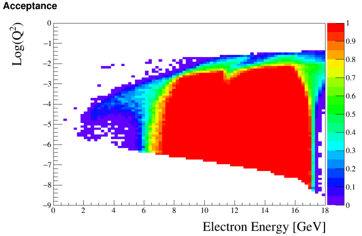
Timepix4 + SPIDR4



ACCEPTANCE, EFFICIENCY & RESOLUTION

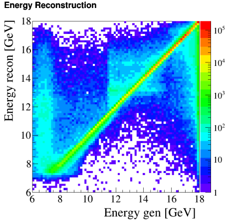
Detector acceptance

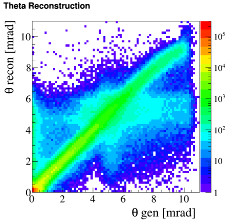


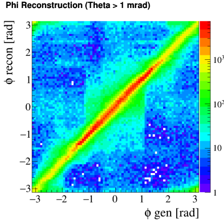


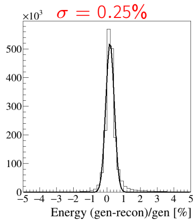
Integrated efficiency = 29%

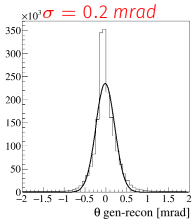
Kinematic reconstruction (using neural network)

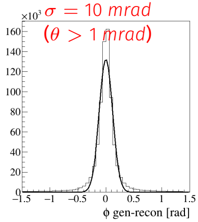












Resolutions

In vacuum tracker and reconstruction technique provides better energy resolution than baseline calorimeter with improved θ and ϕ.

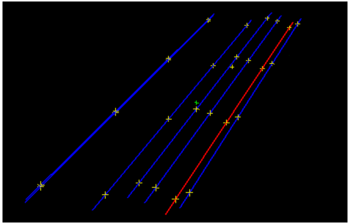
TRACKING & RATES

Typical bunch crossing (18x275 maximum luminosity)

Contains $\sim$12 electrons

$\sim$7 are accepted by Tagger 2

Clustering and tracking: 95% reconstruction efficiency



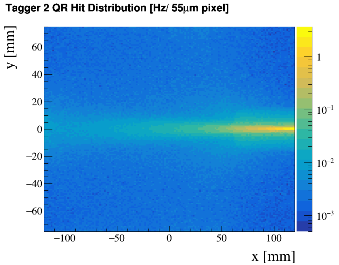
e^- from Quasi-Real scattering event among e^- from Bremsstrahlung

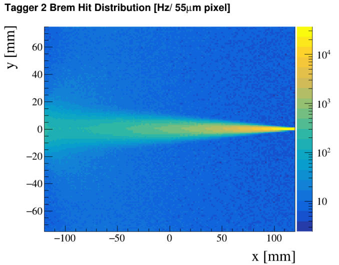
Rates

Maximum rate per 55μm pixel: 20 kHz

Maximum pixel rate per layer from MIPs: 2.5 GHz

At 64 bits per pixel = 320Gb/s. (Big but Timepix4 + SPIDR4 can do this)





TIMEPIX4 + SPIDR4

Hybrid pixel detector: Timepix ASIC + Sensor (Si)

55 μm pixel pitch

<1 ns timing resolution (Si limit)

			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 cm^2	6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	TOT and TOA
		Event Packet	48-bit	64-bit **33%**
		Max rate	0.43x10^6 hits/mm^2/s	**3.58x10^6 hits/mm^2/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 10^9 hits/mm^2/s	~5 x 10^9 hits/mm^2/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)**

Store only MIPS clusters (x,y,time,energy,width) = 80 bits

2 tagger modules, 4 layers

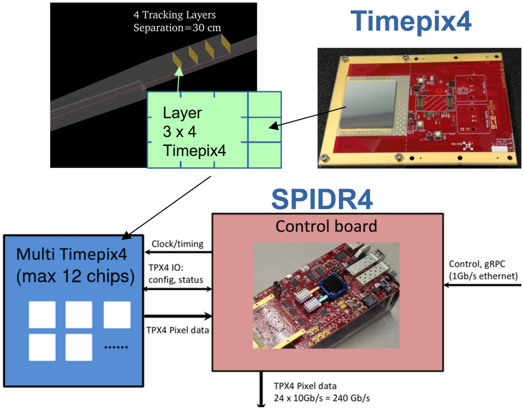
∼200 Gb/s to DAQ

∼1.5 Gb/s to disk, DAQ trigger rate 500kHz

Timepix4 + SPIDR4 an off-the-shelf solution

Next-gen sensors improve on Si timing limit: i-LGAD (link)

Nikhef frontend electronics



SPIDR4: http://www.nikhef.nl/ s01/SPIDR4-MF-GP-apr2020.pdf

SPIDR4 DAQ: https://indico.cern.ch/event/1215762/contributions/5137274/

Timepix4: X. Llopart et al 2022 JINST 17 C01044

NEXT STEPS

Software

Working clustering, tracking and ML particle reconstruction as a standalone project

- Integrate ACTS into workflow
- Reconstruct particles using EICrecon
- Include in next physics campaign
- ...

Simulation Studies

- Position and size optimisation
- Synchroton backgrounds
- Physics reconstruction tests
- ...

Hardware & Integration

- Review design with vacuum and beamline experts
- Perform cooling calculations
- ...

SUMMARY

Status

Geometry integrated into EPIC simulation
Early stages of adding to EICrecon with ACTS

Optimum solution

Two in-vacuum tagger modules
3 or 4 layers of pixel detectors

Best technology

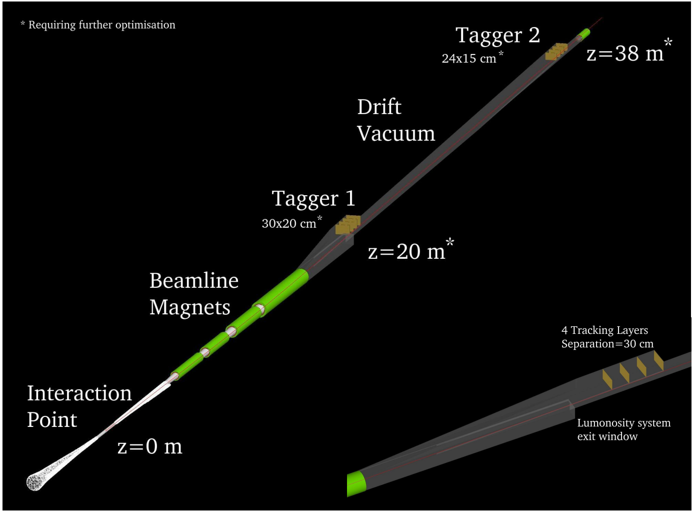
Timepix4 + SPIDR4

Cost Estimate (Timepix4)

Layer (12xTimepix4) $110k (Electronics)

UK contribution to EIC (inc. MAPS, Tagger, ...)

Proposal submission 10th February
Funding $40M over 5-7 years



BACKUP

GENERATORS

Quasi-real photoproduction

$$\frac{d^2\sigma}{dydx} = \frac{\alpha}{2\pi} \cdot \frac{(1-x)}{x} \cdot \frac{(1+(1-y))^2}{y} \cdot \sigma_{\gamma p}(W)$$

e x p: 18x275 GeV

$\sim$ 0.00025 / bunch crossing

Rate $\sim$0.25 MHz on tagger (half of 500 kHz)

Can have coincidence with central detectors.

$\sim 0.5\ e^-$ per coincidence

Generator publication and code by Jaroslav Adam:

https://doi.org/10.1016/j.cpc.2021.108251

https://github.com/adamjaro/GETaLM

Bremsstrahlung - Bethe-Heitler

$$d\sigma = 8Z^2\alpha r_e^2 \frac{S\omega}{\omega} \cdot \frac{\varepsilon'}{\varepsilon} \cdot \frac{\delta d\delta}{(1+\delta^2)^2} \cdot$$

$$\left(\left[\frac{\varepsilon}{\varepsilon'} + \frac{\varepsilon'}{\varepsilon} - \frac{4\delta^2}{(1+\delta^2)^2}\right] \log \frac{2\varepsilon\varepsilon'}{m\omega} - \frac{1}{2}\left[\frac{\varepsilon}{\varepsilon'} + \frac{\varepsilon'}{\varepsilon} + 2 - \frac{16\delta^2}{(1+\delta^2)^2}\right]\right)$$

e x p: 18x275 GeV

$\sim$ 10 / bunch crossing

Rate $\sim$ 1000 MHz on tagger

No coincidence with central detectors

$\sim 10\ e^-$ per coincidence

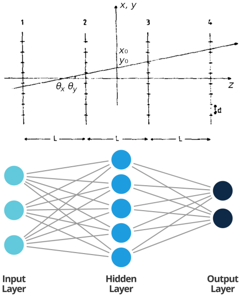
Machine learning used to reconstruct initial electron vector from track due to complexity of magnetic field. 2 Independent, successful approaches.

Custom network

Input = 4 Track variables

Hidden = 100^4 selection

Output = E, θ, ϕ



ROOT TMVA - DNN

Input = 4 Track variables

Hidden layout = TANH|200,TANH|200,TANH|100,TANH|50,LINEAR

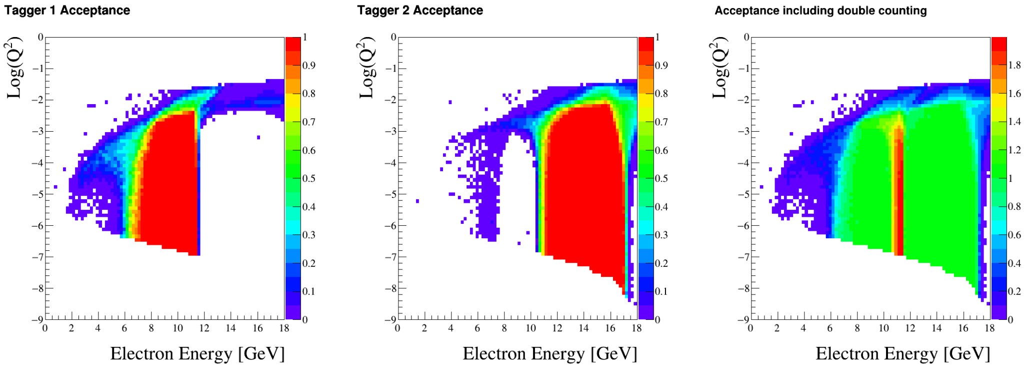
Output = E, θ, $\cos\phi$, $\sin\phi$

Optimisation and reduction of hidden layers needs to be performed

Additional scope to perform classification for background removal/weighting.

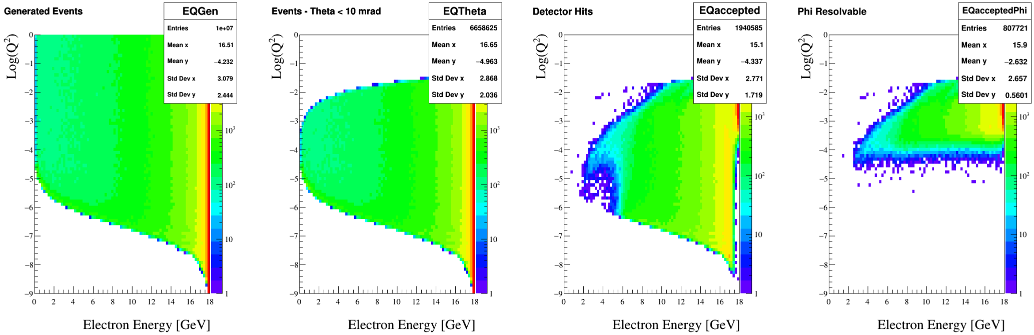
ACCEPTANCE BACKUP

Acceptance for each tagger station and region of double counting.

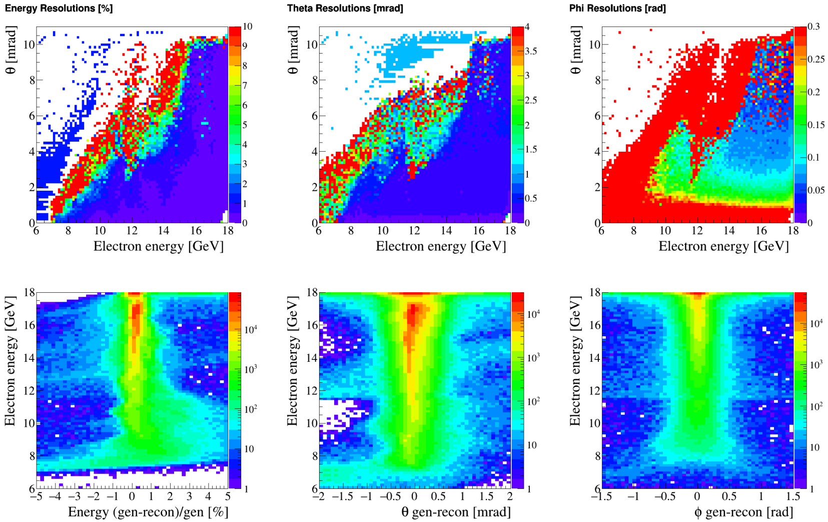


Key Quasi-Real Event Cuts

Cut	Total Efficiency	Forward (%) (θ<10.5 mrad) Efficiency (%)
Forward (θ<10.5 mrad)	66.5	100
Accepted	19.4	29
Resolvable ϕ (θ>1mrad)	8.1	12.2

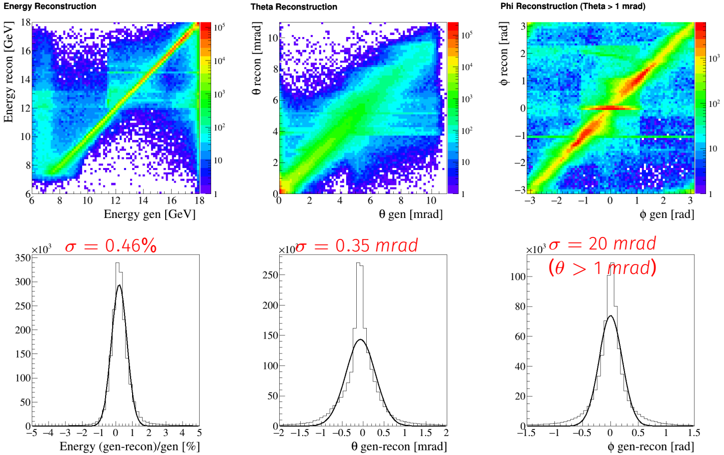


Resolutions of a perfect detector as a function of theta and energy, from epic DD4hep simulation.



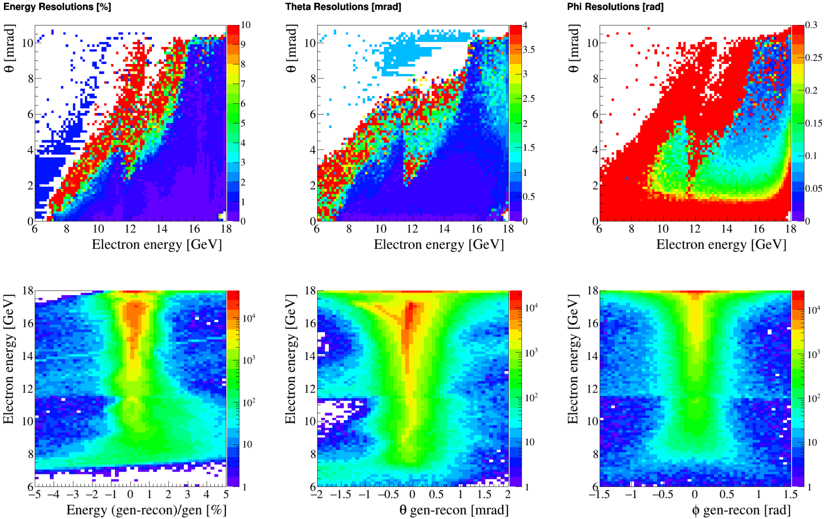
Resolutions of a 55 um pitch detector, from epic DD4hep simulation.

Kinematic reconstruction (using neural network)



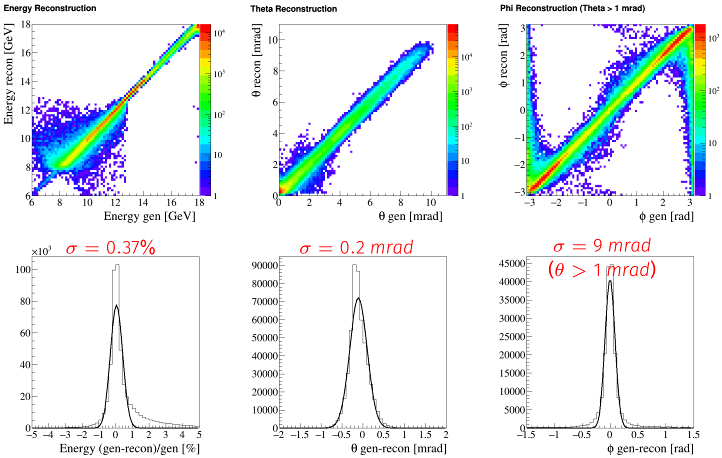
RESOLUTION BACKUP 55UM

Reconstructed resolutions of a 55 um pitch detector as a function of theta and energy, from epic DD4hep simulation.



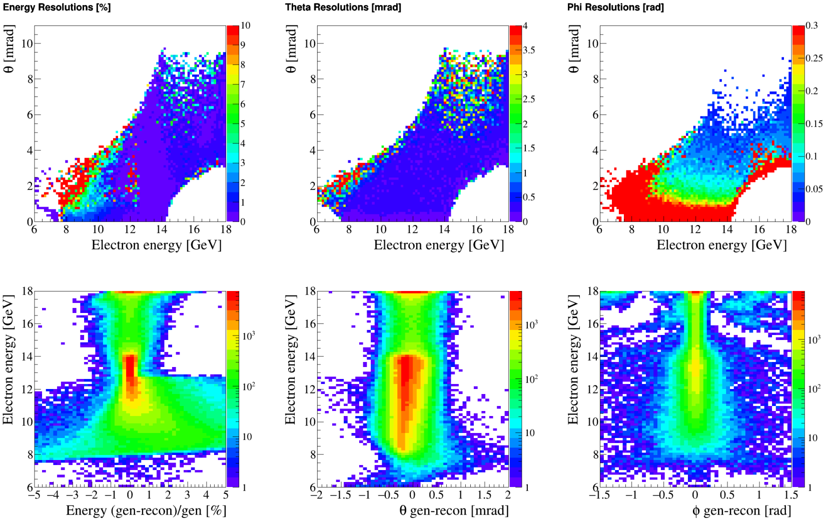
Fully reconstructed (clustering, tracking..) resolutions of a 100 um pitch detector, stand alone Geant4 simulation. (Tagger1)

Kinematic reconstruction (using neural network)



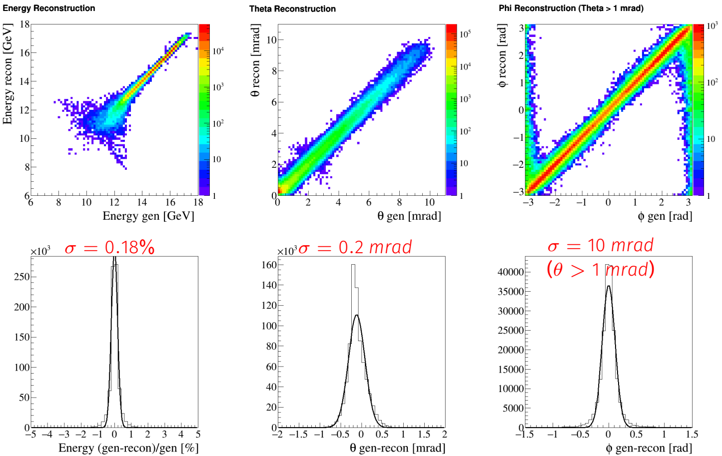
RESOLUTION BACKUP STAND ALONE 1-2

Fully reconstructed (clustering, tracking..) resolutions of a 100 um pitch detector as a function of theta and energy, stand alone Geant4 simulation. (Tagger1)



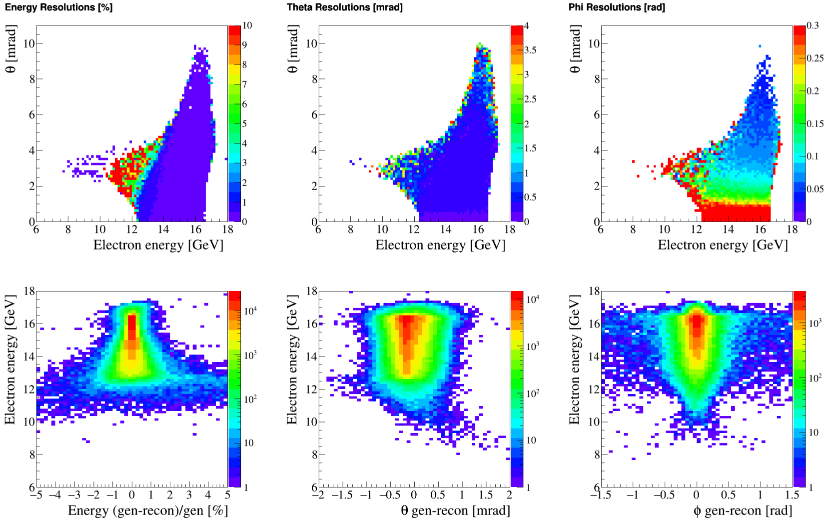
Fully reconstructed (clustering, tracking..) resolutions of a 100 um pitch detector, stand alone Geant4 simulation. (Tagger2)

Kinematic reconstruction (using neural network)



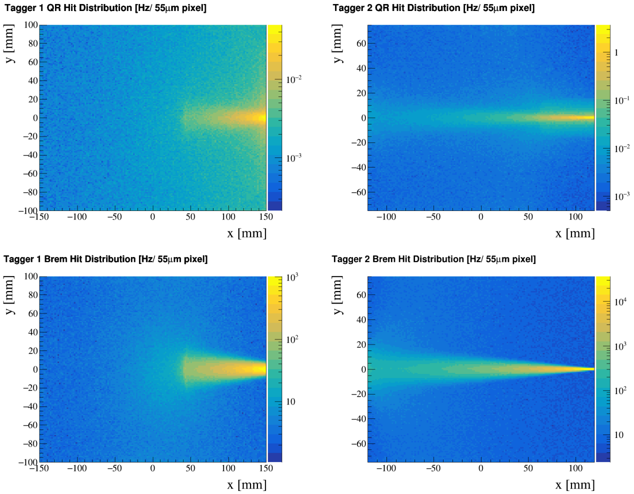
RESOLUTION BACKUP STAND ALONE 2-2

Fully reconstructed (clustering, tracking..) resolutions of a 100 um pitch detector as a function of theta and energy, stand alone Geant4 simulation. (Tagger2)



RATES BACKUP

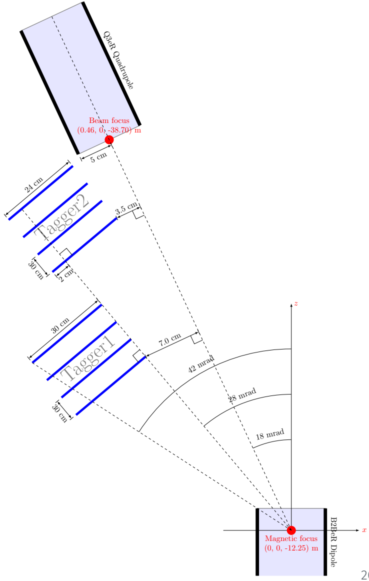
- Hit rates per pixel assuming 55um pitch
- (Larger/smaller pixel rates scale with area)
- Ideal detector as close as rates allow
- Will need to be movable
- Timepix4 allows pixel masking if an area has too high flux.



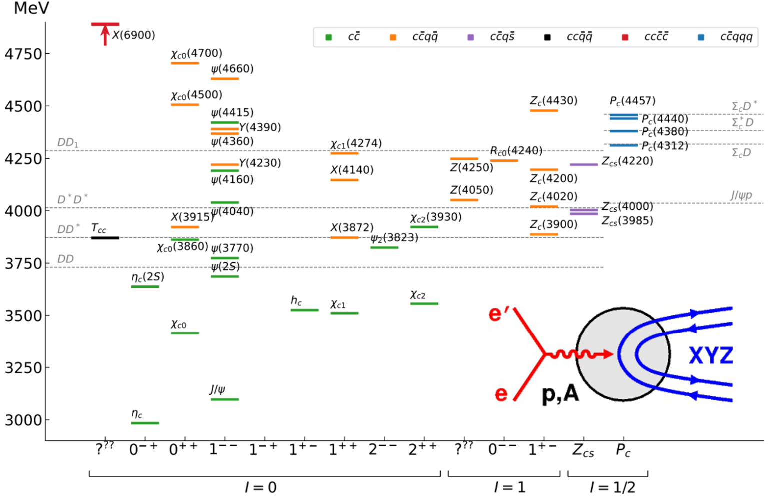
DESIGN SCHEMATIC

(Right) Schematic showing the parameters used to construct the tagger geometry as currently default in EPIC simulation. (Beam spot at quadrupole - $10\sigma_X \sim 3.2$ cm)
(Below) Estimate of layer material budget.

Tracking Layer	Component	Material	X0(g/cm2)	Density(g/cm3)	X0(cm)	Depth(cm)	Depth(%X0)
	Sensor	Silicon	21.82	2.33	9.37	0.006	0.06
	ASIC	Silicon	21.82	2.33	9.37	0.010	0.11
	PCB	FR4	31.85	2.00	15.93	0.020	0.13
	Heat transfer	Copper	12.86	8.96	1.44	0.010	0.70
Total			**16.80**	**3.63**	**4.63**	**0.046**	**0.99**

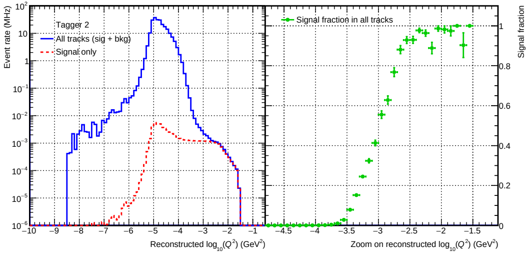


e.g. Exotic Meson Workshop: https://indico.bnl.gov/event/14792/

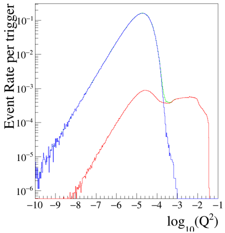


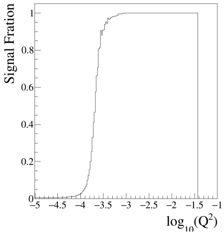
Ratio of expected Bremsstrahlung to Quasi-Real events as a function of Q^2.

All Bunches



Triggered Bunches (estimated 50% QR event)





Further improvements through reaction exclusivity variables (and timing)

NEXT GENERATION - TIMEPIX5+I-LGAD?

Timeline for proposed Timepix5 aligns with EIC/EPIC
More risk but highly experienced collaboration
Early stages so could influence desired features

Proposed Timepix5 features

- < 30 ps ASIC resolution - Bremsstrahlung background rejection by t_0 separation.
- On chip 3x3 clustering - Readout data reduction.
- On chip PID - Background rejection and data reduction.

i-LGAD sensor demonstrated to exceed ASIC time resolution digitization. Presentation and Document:
https:indico.cern.ch/event/829863/contributions/5061075/
https://arxiv.org/abs/2202.01552