A novel TPC readout system based on readout chips for Si-pixel detectors

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Proposal for Generic Detector R&D for an Electron Ion Collider

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Proponents

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EIC Physics Relevance

SIDIS reactions in e-p, respectively e-A collisions

- Spin of the proton
- Fragmentation Functions (FF)
- Transverse Momentum Distributions (TMDs) by means of flavor tagging through hadron type
- Measuring Kaon asymmetries and cross sections
- Measuring strangeness Probability Distribution Functions (PDFs)

Require Particle Identification (PID) and separation over a wide range in pseudorapidity: $|\eta| < 3$

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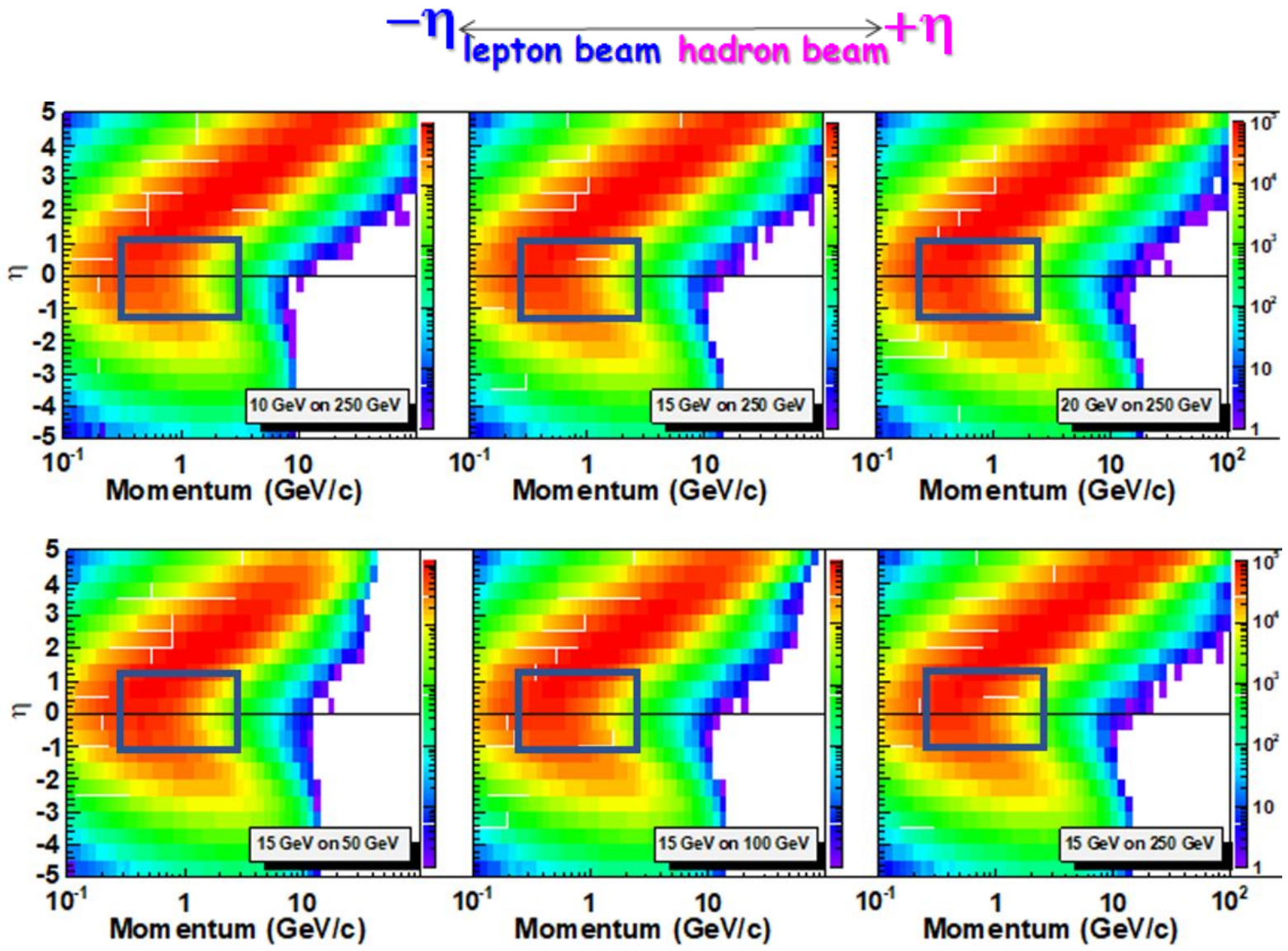
EIC Physics Relevance

$\pi^{\pm}$ kinematics in SIDIS, $K^{\pm}$ and $p^{\pm}$ show similar kinematics



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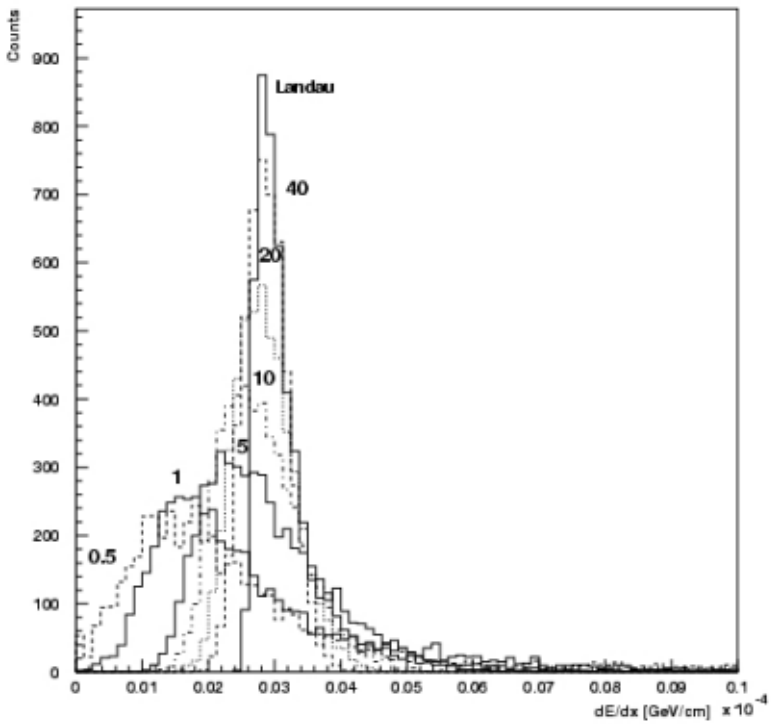
EIC Physics Relevance and a Time Projection Chamber

- Particle Identification (PID) in $|\eta| < 1$ desirable
- PID for low momenta up to about 3-4 GeV/c desirable
- Principle idea of a Time Projection Chamber (TPC): combination of tracking and PID $\rightarrow \frac{dE}{dx}$ in a single detector
- TPC: Very well suited to perform PID tasks in mid-rapidities
- However: (dE/dx for 3 GeV e^- in Ar)



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Charge vs Cluster Counting

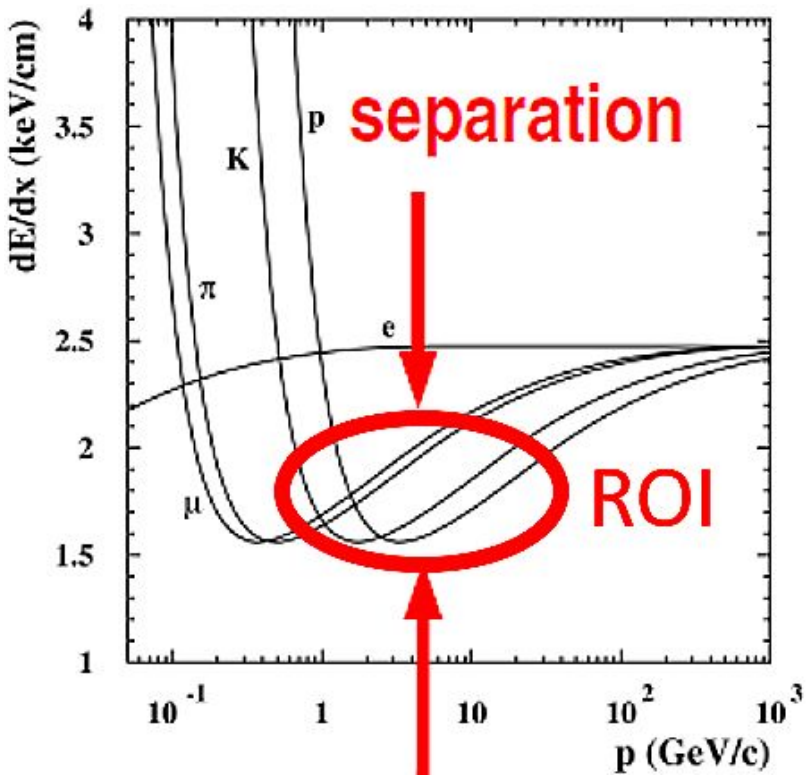
- Procedure most widely used: count charge and truncate mean $\rightarrow$ lowest $p\%$ (typically p = 60 - 80) of the pulse heights
  - Cut reduces effect of fluctuations due to long tail
  - Cut also removes fraction of track samples $\rightarrow$ worsens the ionization resolution
- Alternative: count number of clusters $\rightarrow$ complete suppression of Landau tail
  - Every cluster -big or small- has the same weight $\rightarrow$ Poissonian distribution with significantly smaller width
  - Better correlation and particle identification power

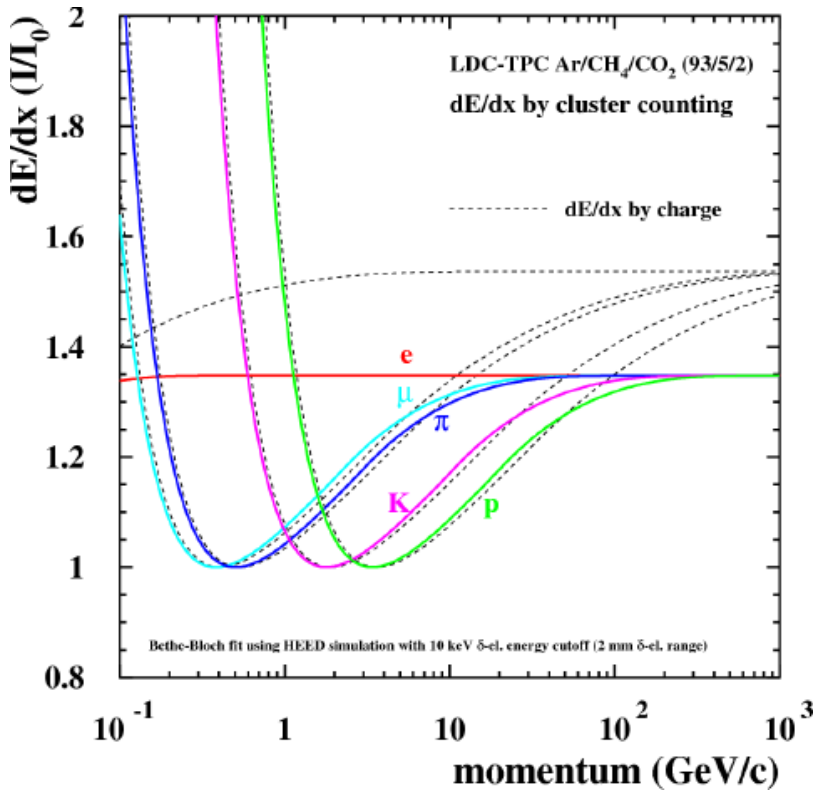
$$\text{separation power} = \frac{\text{separation}}{\text{resolution}}$$

  - Improvement in pattern recognition and track fitting $\rightarrow$ better double hit/track resolution

Energy Loss via Bethe-Bloch

Compare energy loss obtained with charge counting and cluster counting[1]





[1]Based on calculations for the LDC-TPC read out with triple-GEM detectors, with Ar-CH_4-CO_2 (93-5-2) counting gas and 120 cm track lengths.

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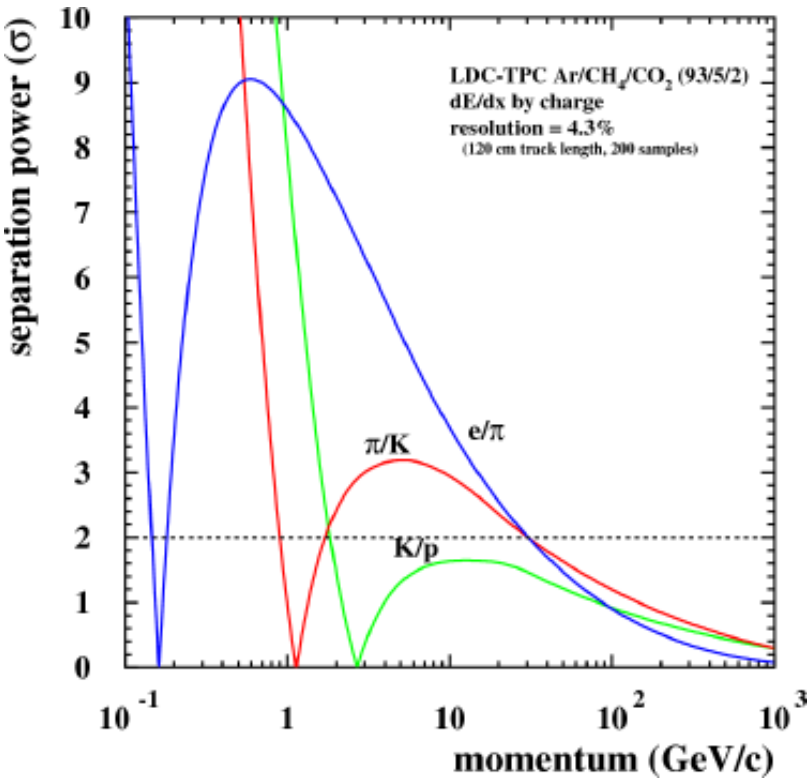
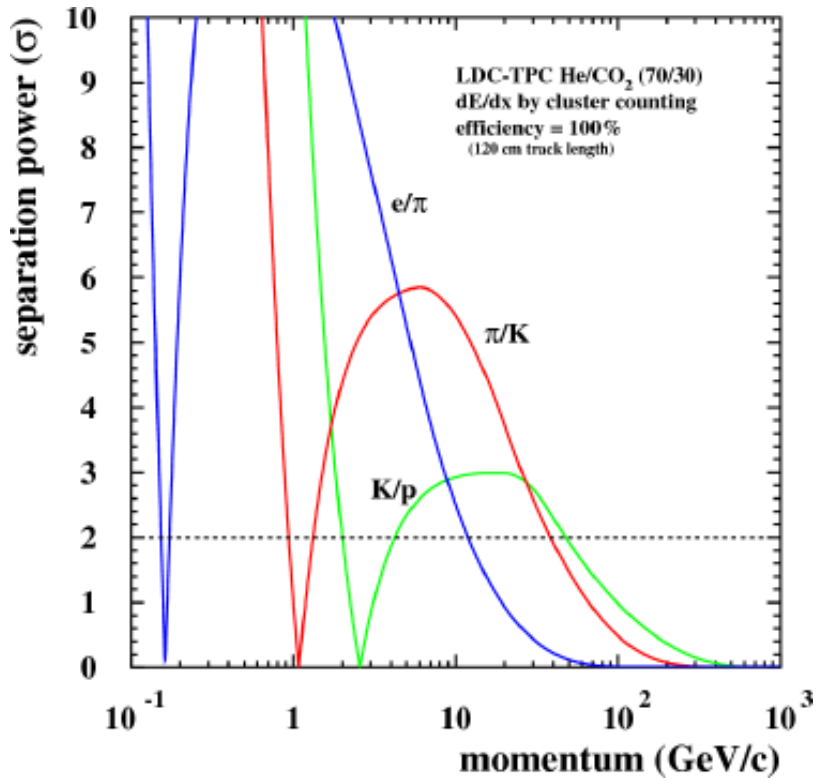
Separation Power

Compare separation power obtained with charge counting (LDC-TPC gas) and cluster counting (He-CO_2 gas: 70-30)





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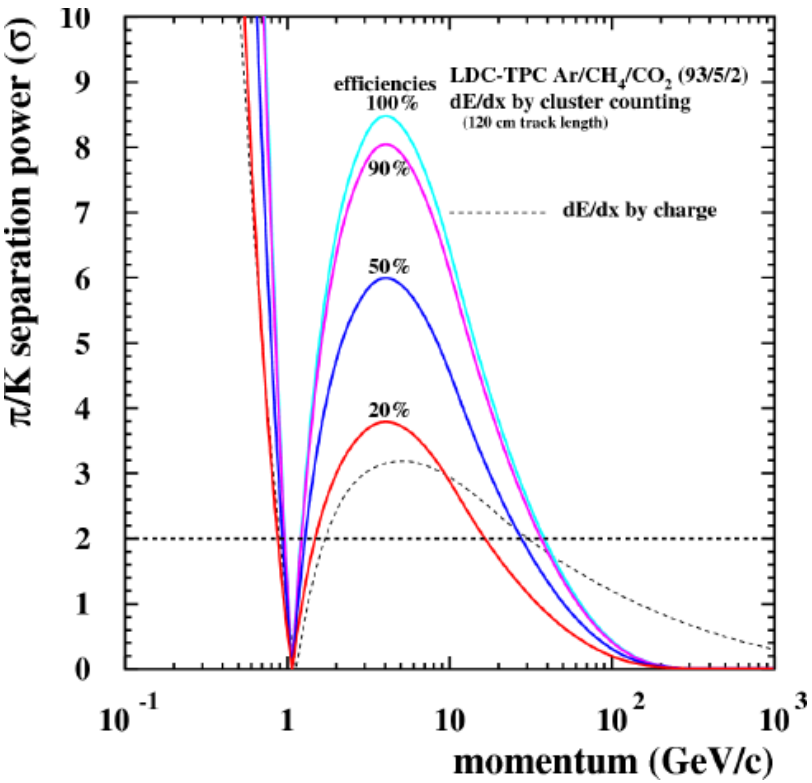
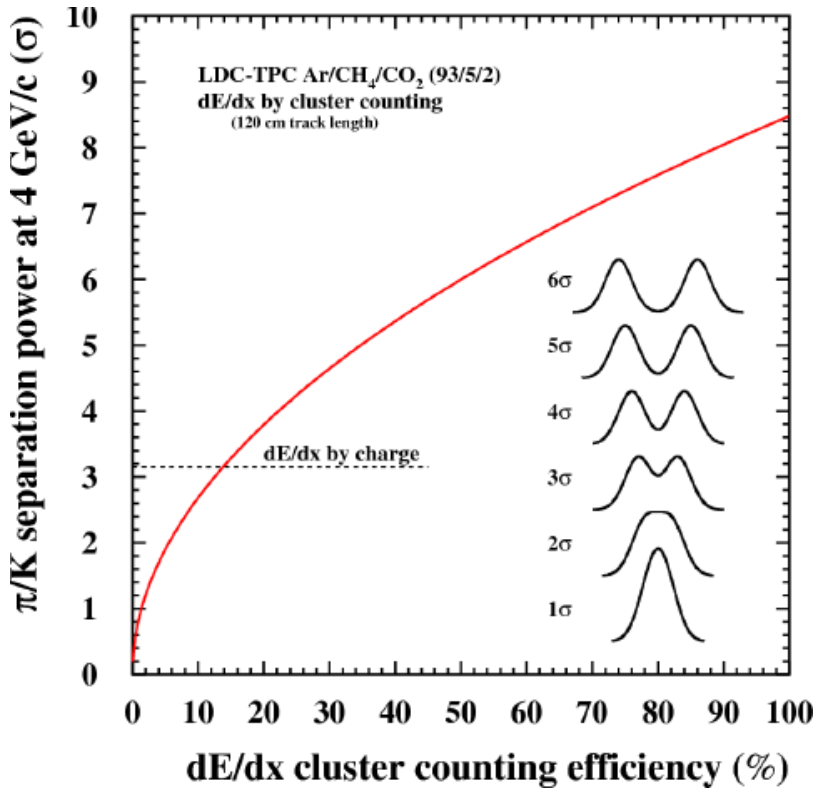
Separation Power with Inefficiencies

Compare separation power obtained with charge counting and cluster counting with inefficiencies[2]





[2] 100% efficiency is virtually impossible → transverse diffusion will result in merging of clusters.

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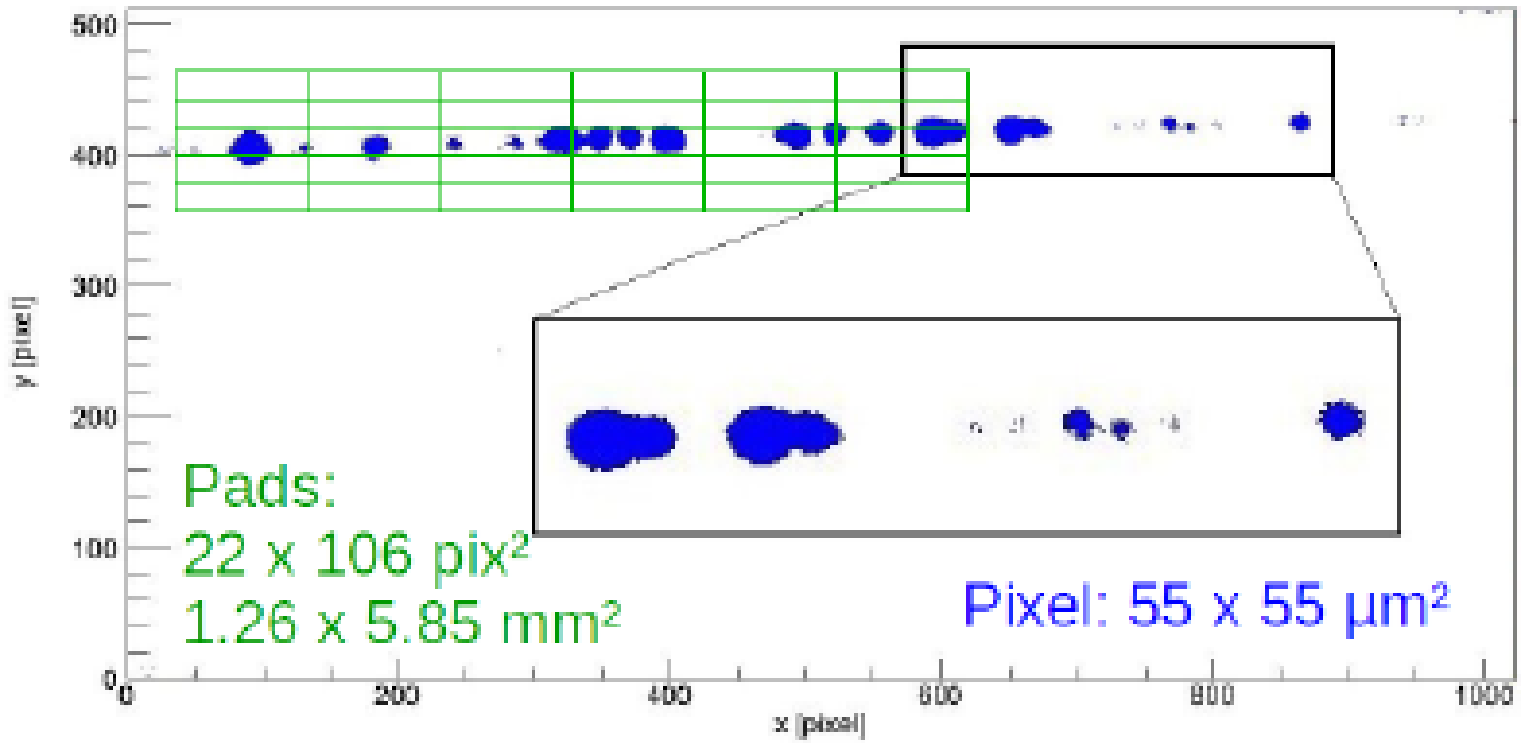
How to Count Clusters

- Provide readout with sufficiently high granularity



→ TimePix ASIC with appropriate pad size

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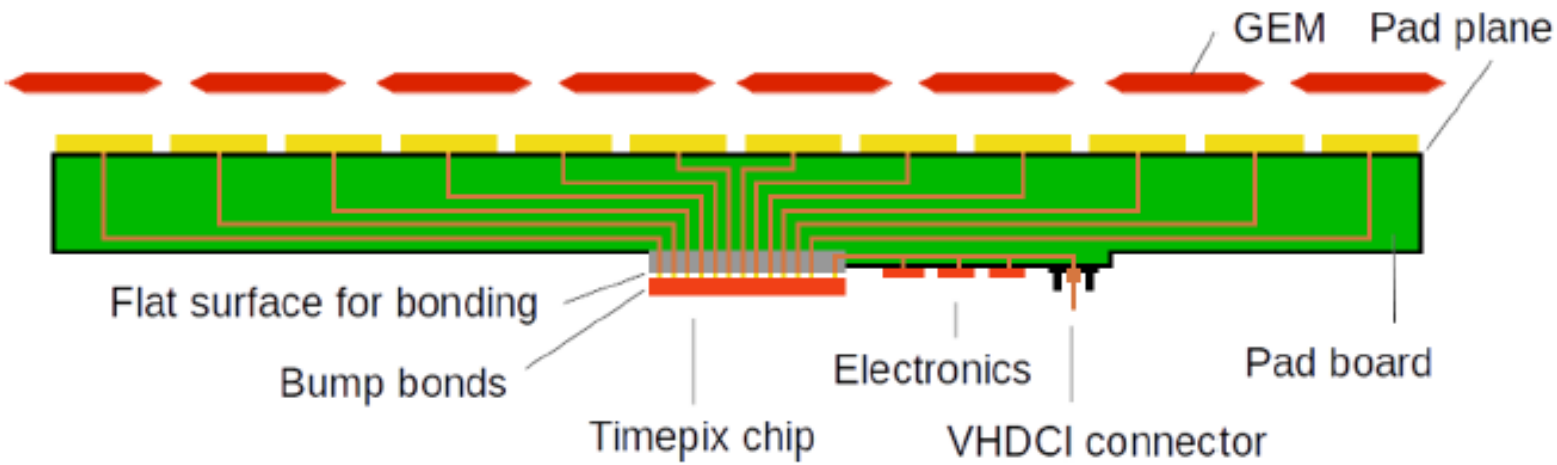
Proposed Studies

- Based on TimePix ASIC
  - TDC readout per channel in highly integrated package
  - 256×256 = 65,536 pixels, pixel pitch 55 μm × 55 μm
  - Each pixel can record either time of arrival or charge collected (ToT)
- Combine TimePix with traditional PCB
  - Larger pad size, pitch: $\sim$ 300 μm
  - Connections from pads routed through PCB to ASIC → bump bonded to PCB surface



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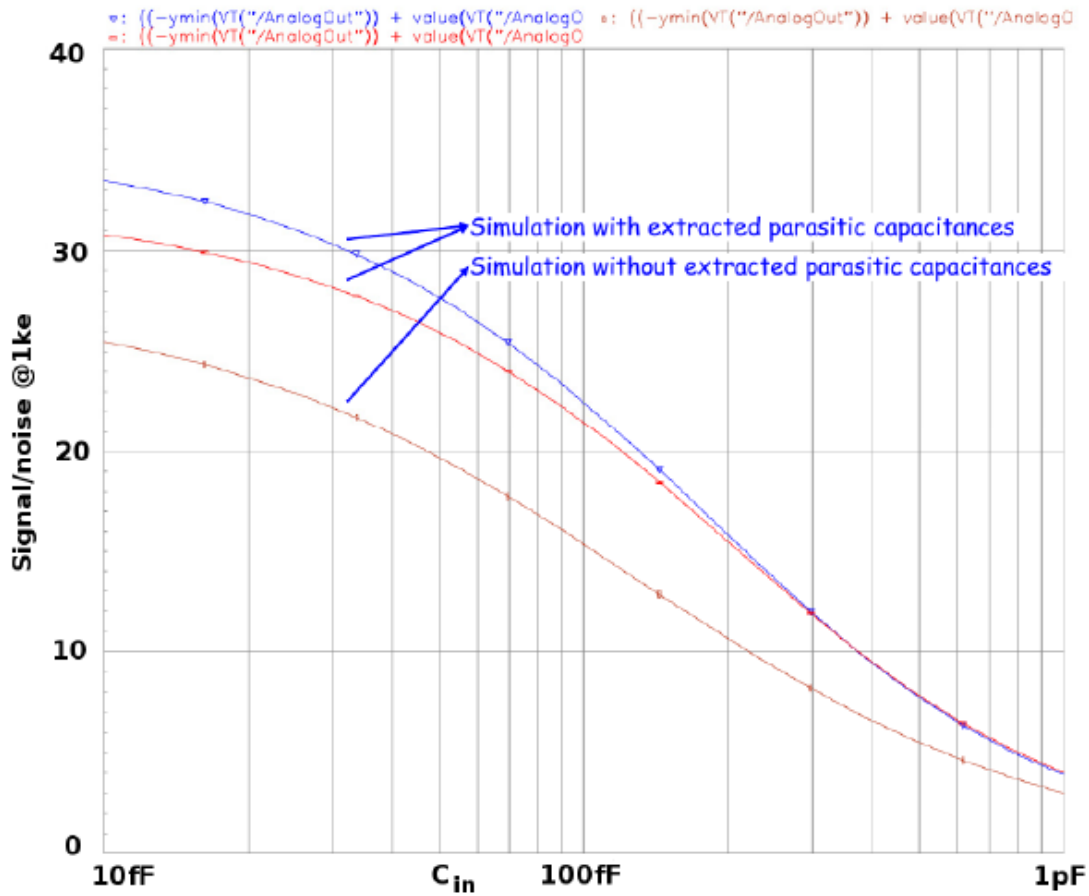
Challenges

- TimePix optimized for low input capacitance (10-100 fF)
- TimePix chip with its small pixels to be connected to readout plane
- Routing on PCB between bump bond pads and charge collection pads is non-trivial



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Advantages

- Perform cluster counting
- Footprint of readout much reduced
- Power consumption much reduced
- Significant decreased material budget in forward direction
- System significantly cheaper than traditional one
- System offers possibility to
  - reduce significantly size of pads
  - profit from increased precision but no need to go to extreme case of pad size of chip

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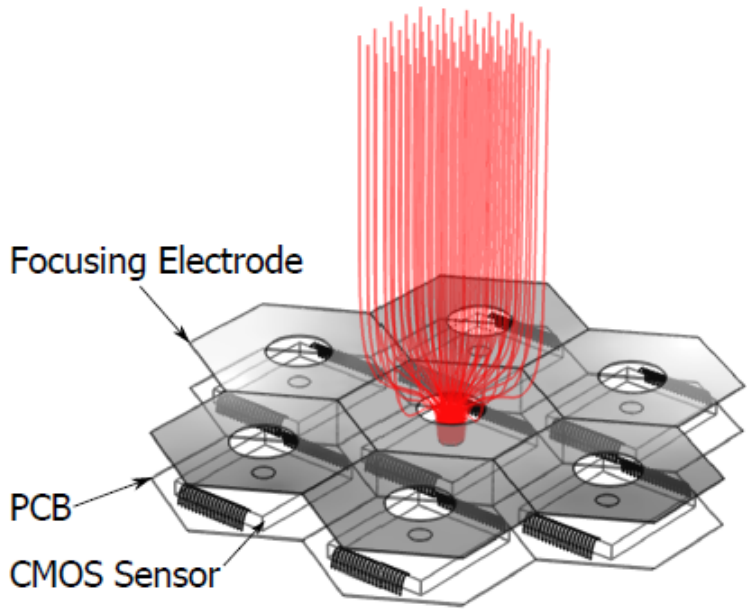
R&D Program: First Year

- First existing setup with bump-bonded TimePix at DESY $\rightarrow$ test of system
- Development of simulation tools for optimizing pad size to adapt to compact sized EIC-TPC
- Development of routing technologies in small setup $\rightarrow$ focusing electrodes
- Optimize connection techniques
- Work toward proof-of-principle experiment



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R&D Program: Second Year

- Production of PCB with $\mathcal{O}$(few 1000) channels
- Test with large TPC prototype
- Investigate different PCB technologies (ceramics, Si)
- Investigate alternative pixel readout electronics (FEI4, Topmetal)

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Deliverables

- Establish utilization of a TimePix based readout for gaseous chambers
  - Establish connection technology to successfully bond TimePix to readout plane
  - Develop routing design for optimized signal transport for very low charge signals (10^3-10^5 electrons) confirmed by simulations and experiments
  - Establish alternative technologies (e.g. ceramics based) for pad planes for possible improved mechanical and thermal properties
- For year 2 continuation of the project: produce a nominal TPC module for EIC detector with 5000 charge collecting pads connected to 1-3 TimePix ASIC and verify in test beam

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Funding Request

Year 1 cost item	DESY	Bonn	SBU	Sum
Grad. student	(1/2) \$25k	(1/2) \$25k	\$48.5k	\$98.5k
Board production	\$10k	\$20k	\$10k	\$40k
TimePix chip	-	-	\$5k	\$5k
Travel costs	-	-	\$5k	\$5k
Total request	\$35k	\$45k	\$68.5k	\$148.5k

Reduced funding scenarios:

Nominal - 20%

Reduction would affect board production and the acquisition of the TimePix chip $\rightarrow$ 50% cut on board production, cancellation of TimePix acquisition

Nominal - 40%

Reduction would affect board production and acquisition of the TimePix chip $\rightarrow$ No hardware available

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