Center for Frontiers
in Nuclear Science

Dark Photons at the EIC

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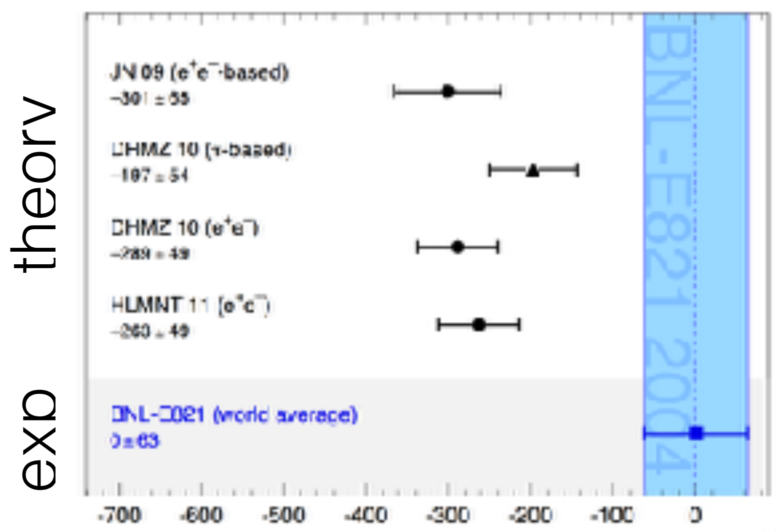
Outline

- Motivation
- Channels
- Kinematics
- EIC smear work

Why a Dark Photon?

- Dark Matter Decay Mechanism?
- Anomalies:

Muon g-2



K.A. Olive et al. (PDG) Chin.Phys.C,38,090001 (2014).

X17 in 4He and 8Be

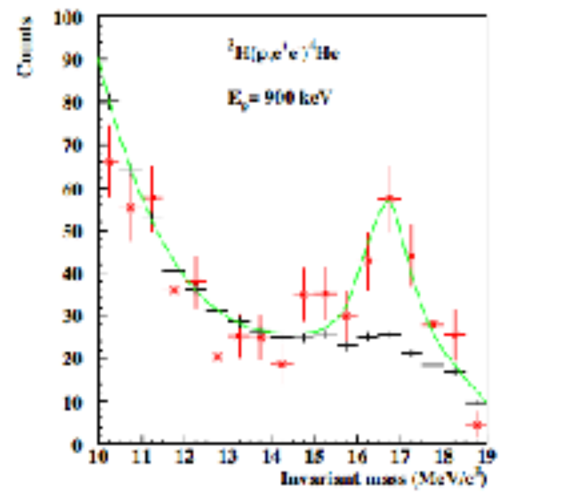
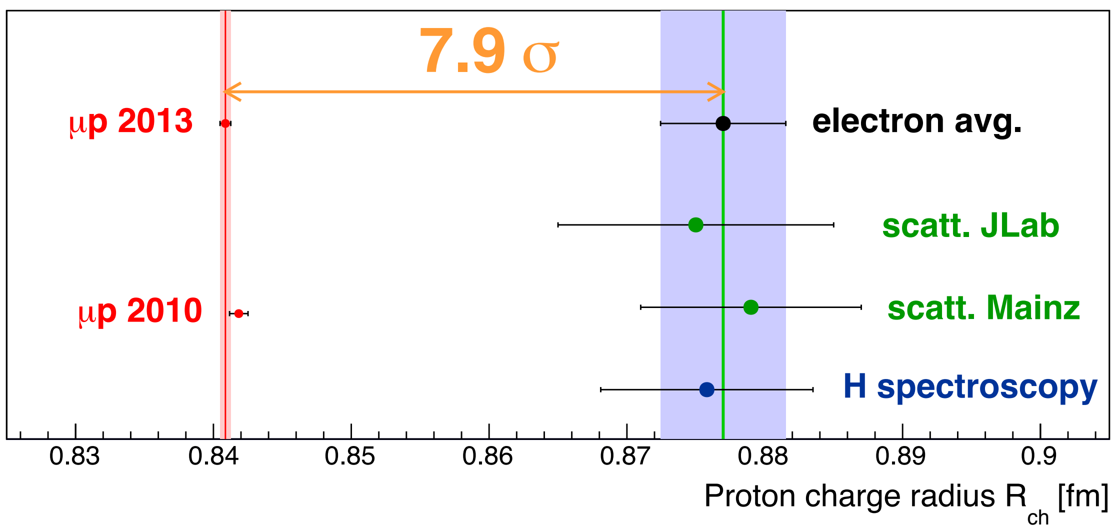


FIG. 3. Invariant mass distribution derived for the 20.49 MeV transition in ^{4}He.

Proton radius puzzle

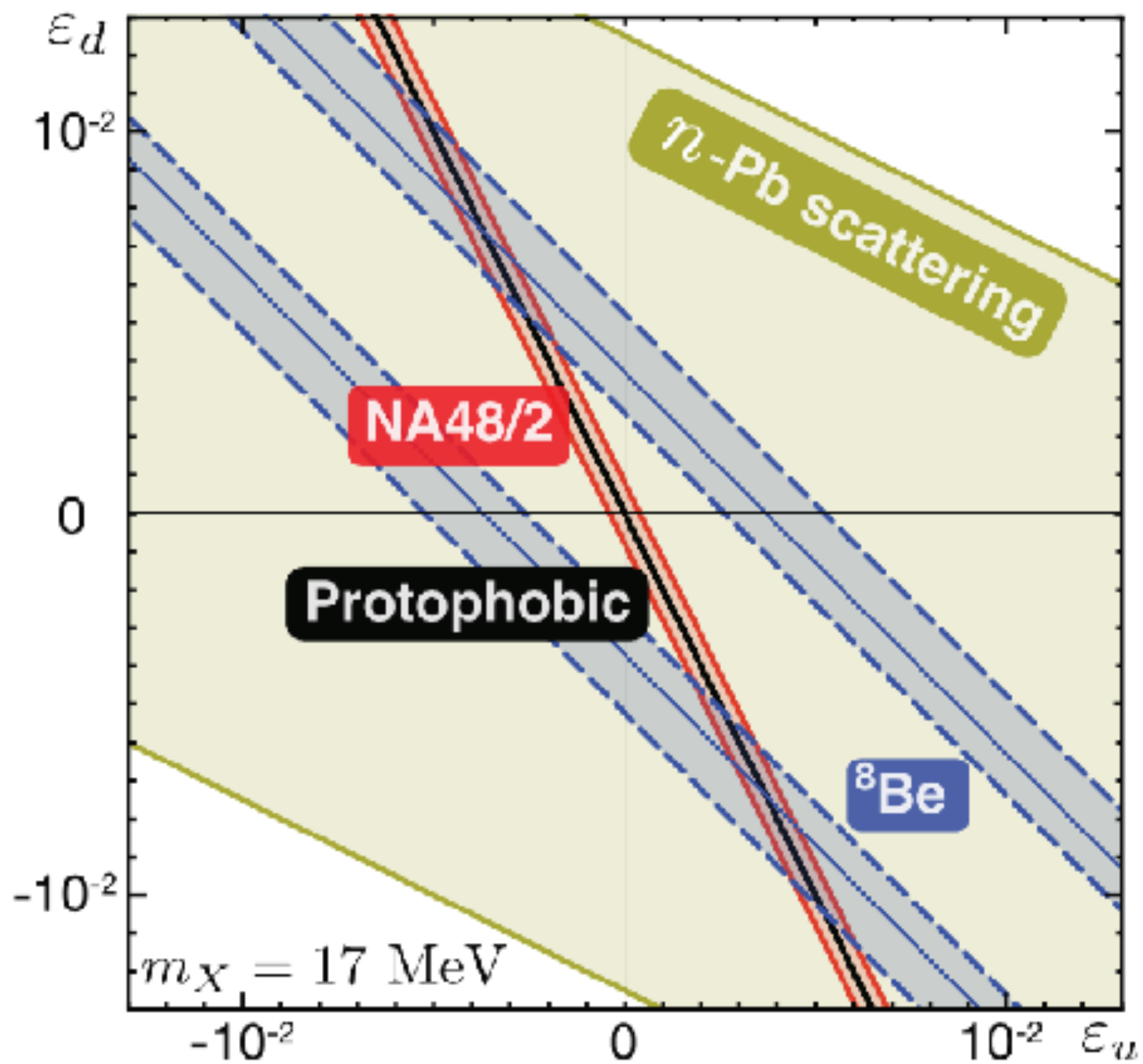


- Because we can write it:

$$L \supset \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$

8Be/4He Anomalies

- Signal conflicts with simple charge-coupling model
- Allow particles to have independent couplings:
  - Simple Lagrangian term modified
  - Pion couplings suppressed
- Ratio of proton and neutron couplings no less 'natural' than for Z



arXiv:1604.07411

Reach Calculation

- Significance is signal size compared to fluctuation in irreducible background:

$$S = \frac{\sigma_A L}{\sqrt{\sigma_{QED} L}}$$

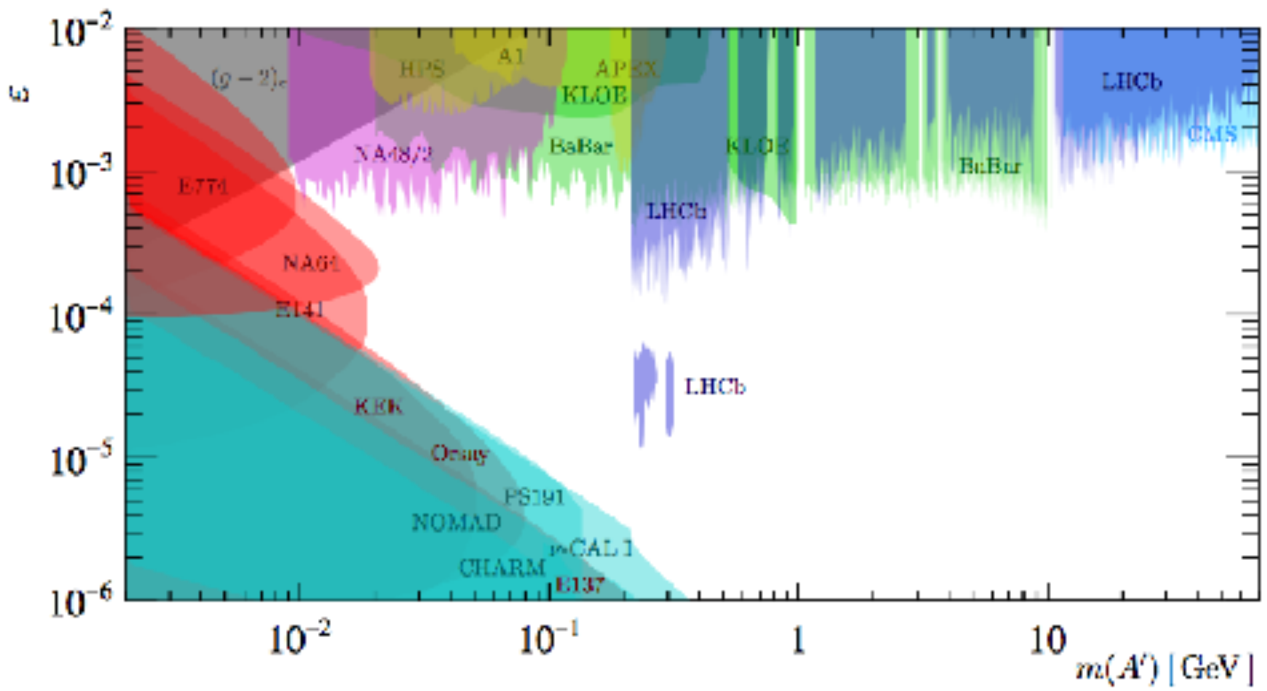
- Signal xs scales with coupling (ε^2):

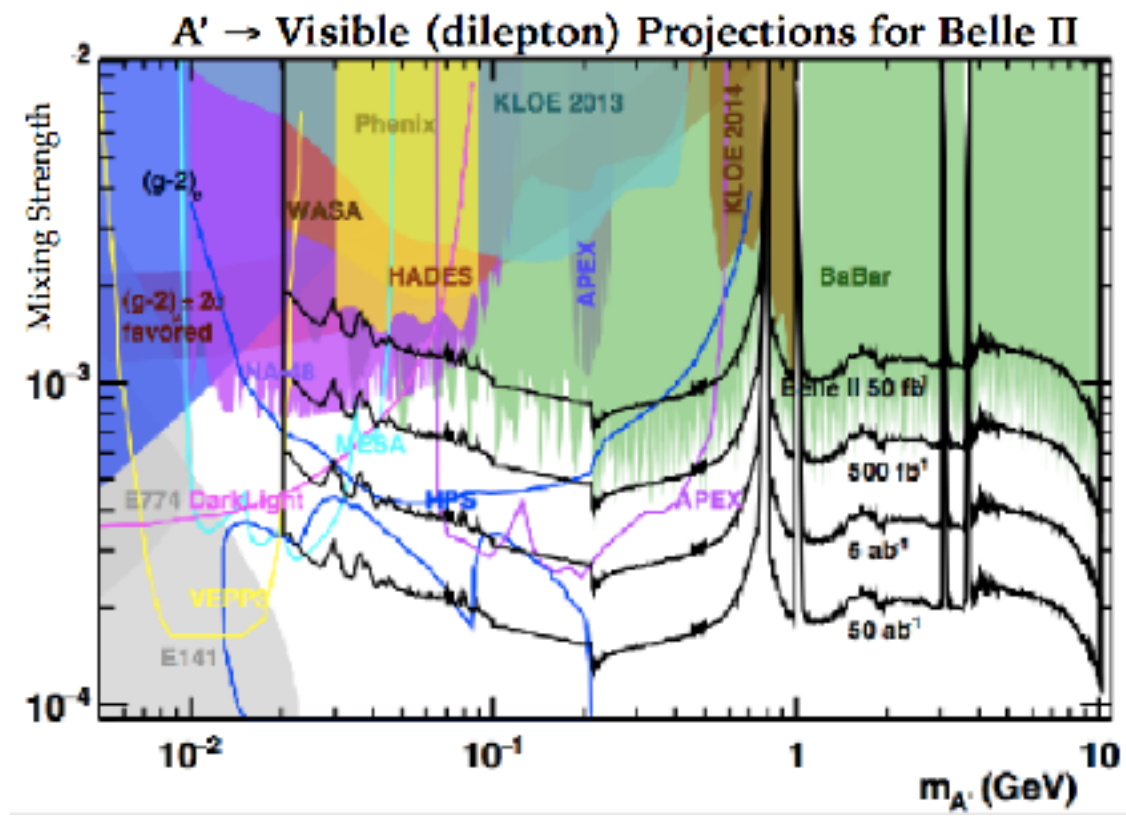
$$S = \sigma_{A0} \frac{\alpha_D}{\alpha_{D0}} \sqrt{\frac{L}{\sigma_{QED}}}$$

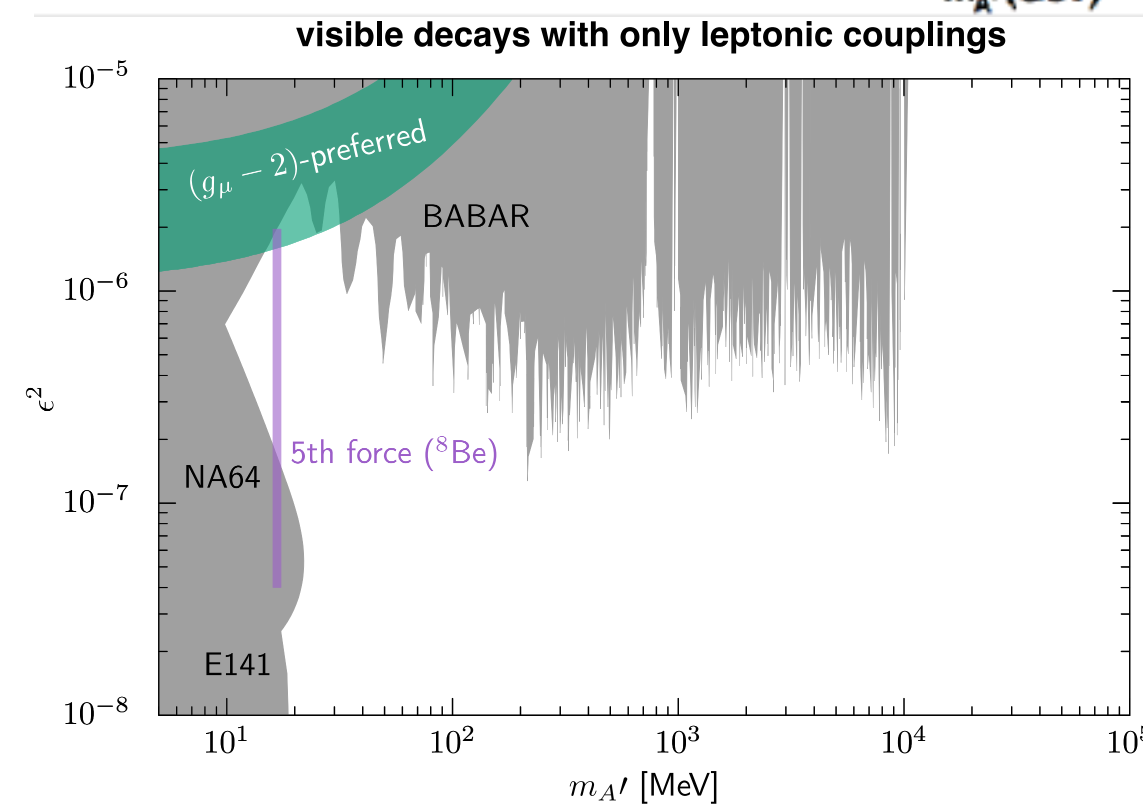
Reach defined by extrinsic factors and Sig/√Bg
-- want narrow signal region!

$$\alpha_D = S \frac{\alpha_{D0}}{\sqrt{L}} \frac{\sqrt{\sigma_{QED}}}{\sigma_{A0}}$$

Existing Limits and Projections





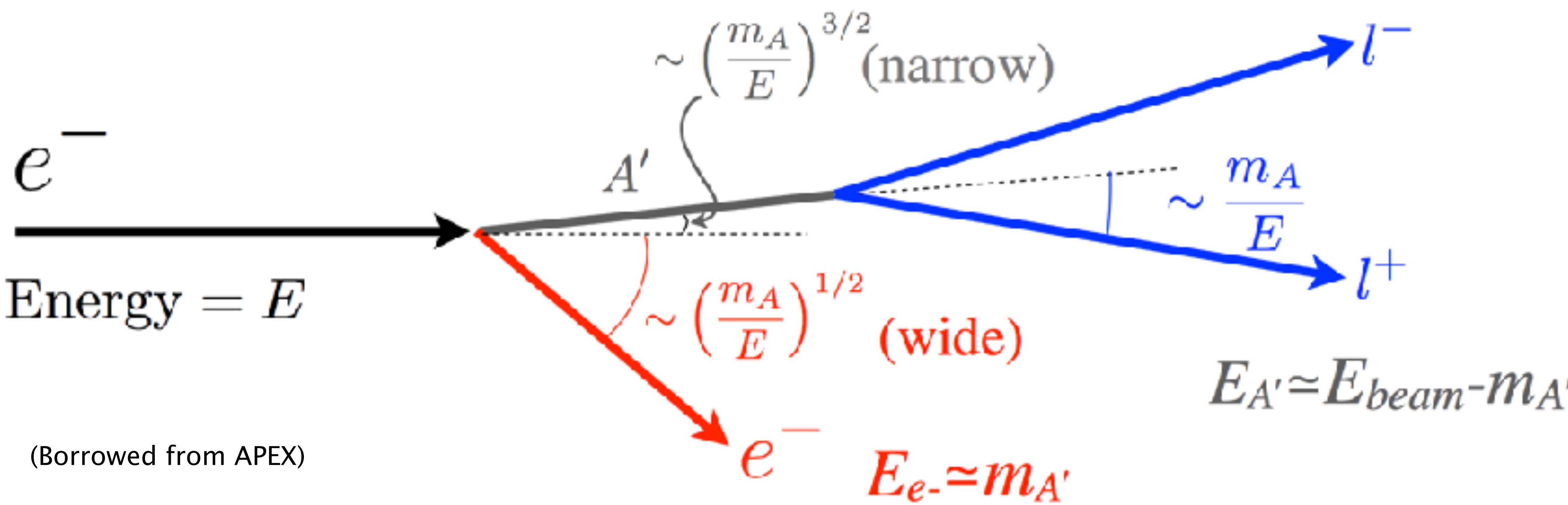


- In simple Kinetic Mixing Model:
$$\alpha_D = \epsilon^2 \alpha_{EM}$$
- Want to explore the parameter space with purely leptonic couplings as well!
- (But keep the notation and name.)

A' Channels

- Production:
  - ISR (A'-strahlung from e- beam) ($m_A < \sqrt{s}$))
  - Decay (on-shell A' replaces photon in decay chain) (m_A < parent)
- Final States:
  - e+ e- pair ($m_A > 2m_e$)
  - μ+ μ- pair ($m_A > 2m_\mu$, cleaner signal)
  - q qbar pair (messier, harder)
  - invisible (much harder)
  - displaced vertices (cleaner, much harder)

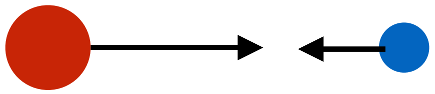
Fixed-Target Kinematics



(Borrowed from APEX)

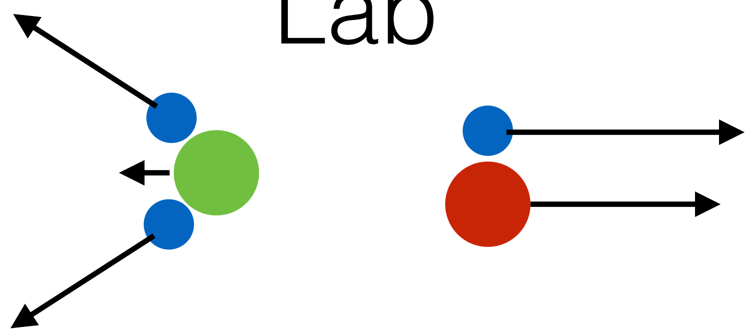
- A' carries large fraction of beam energy -- at large boost, decay products go forward.
- Recoil proton carries little energy

EIC Kinematics

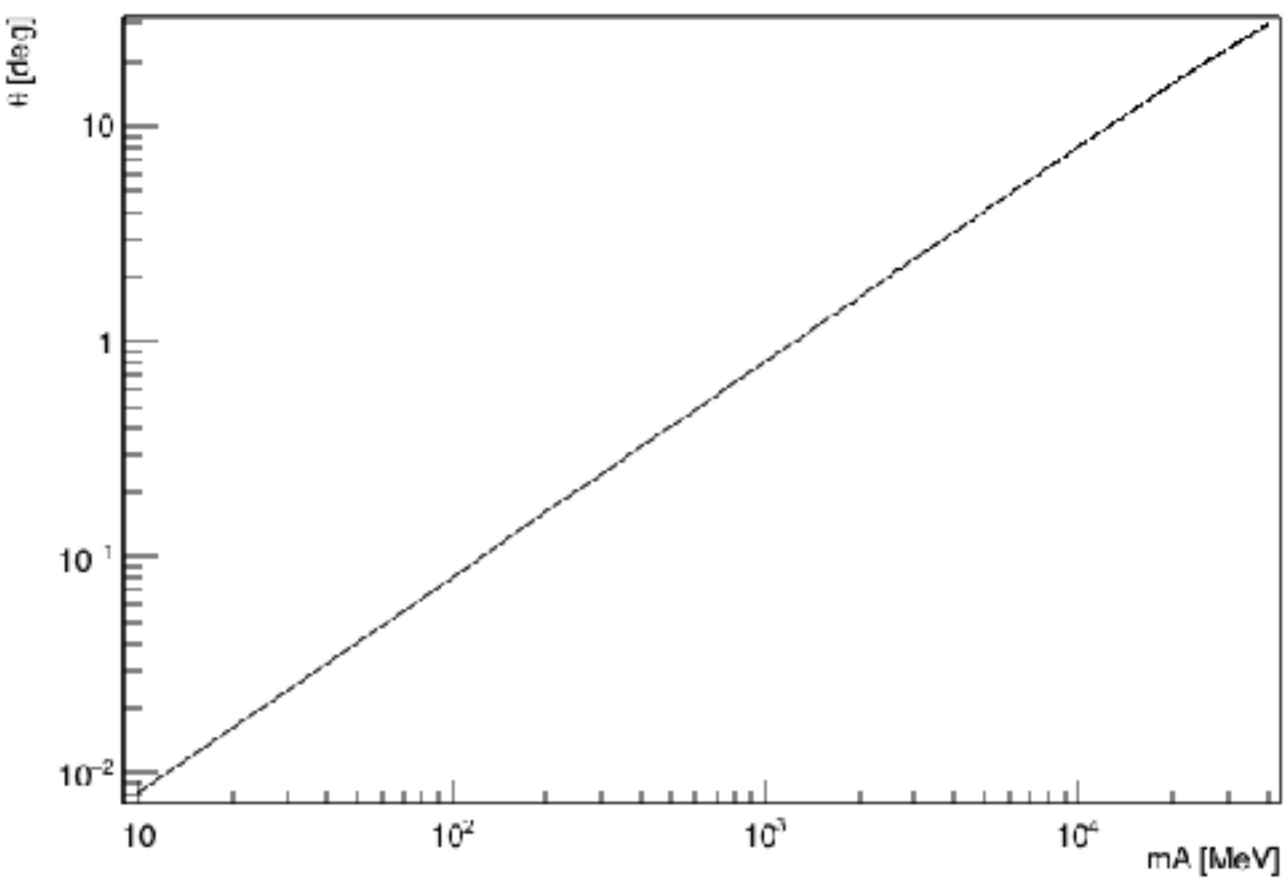
- at 20GeV x 250GeV, CM Boost substantially opens the angle between decay leptons: 

CM

Lab



CM frame symmetric θ for A' decay



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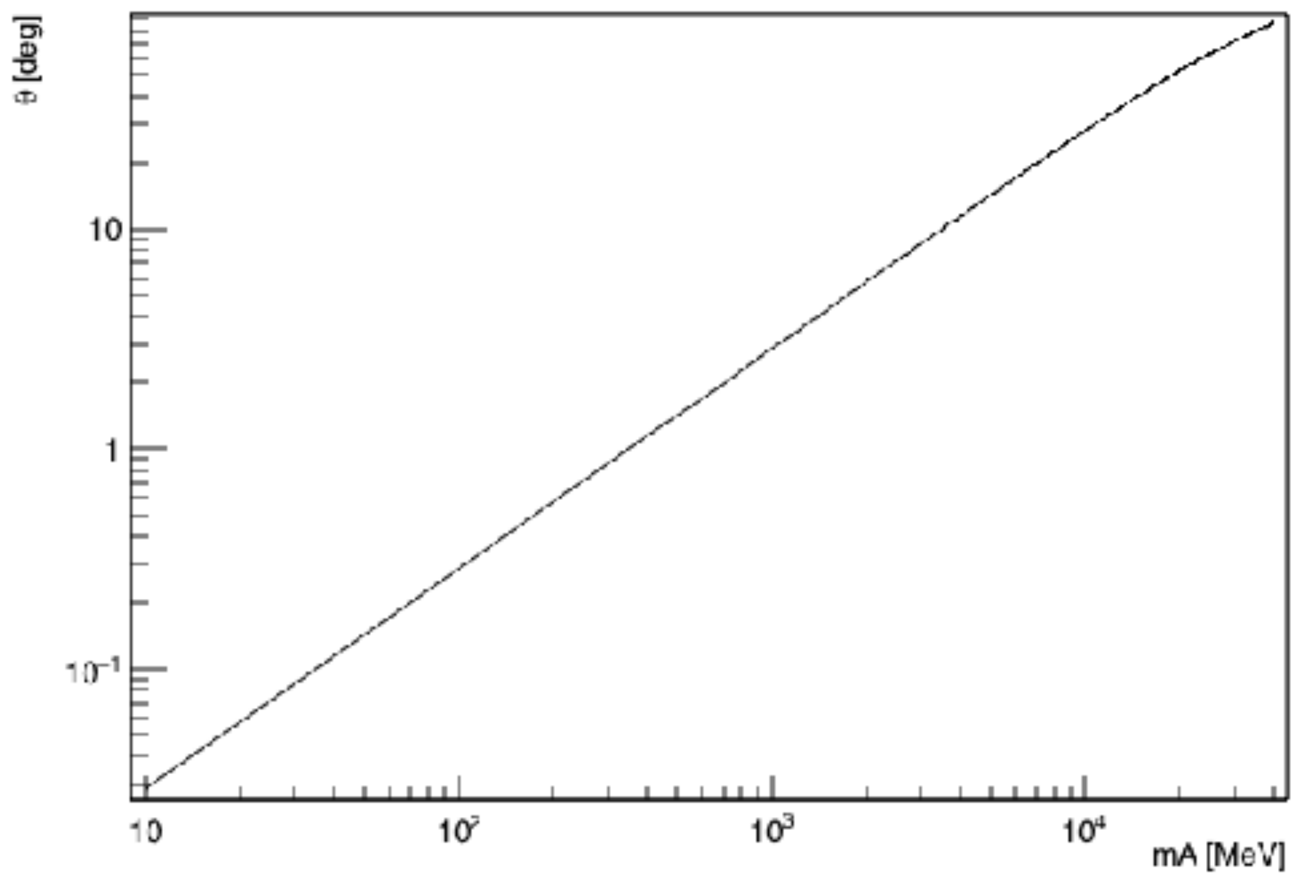
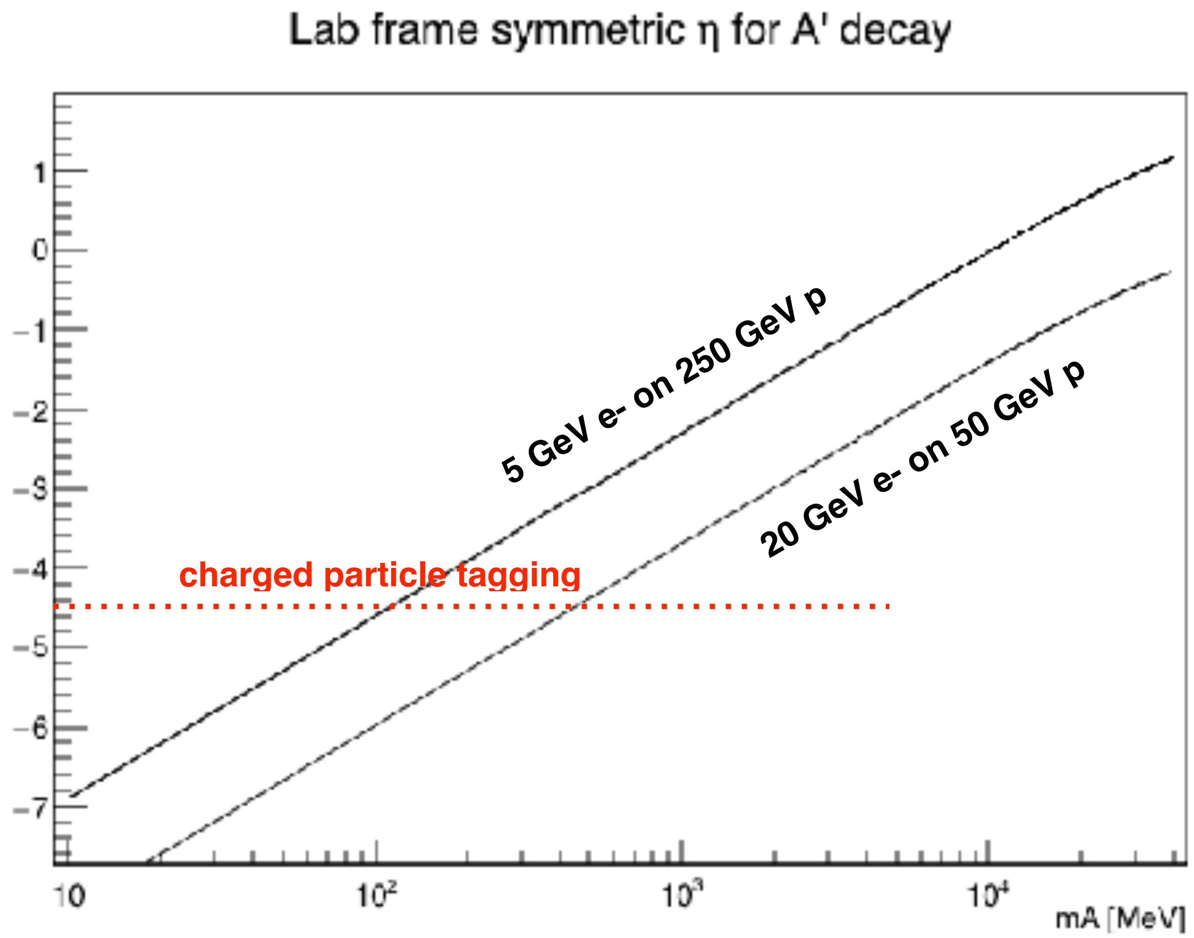
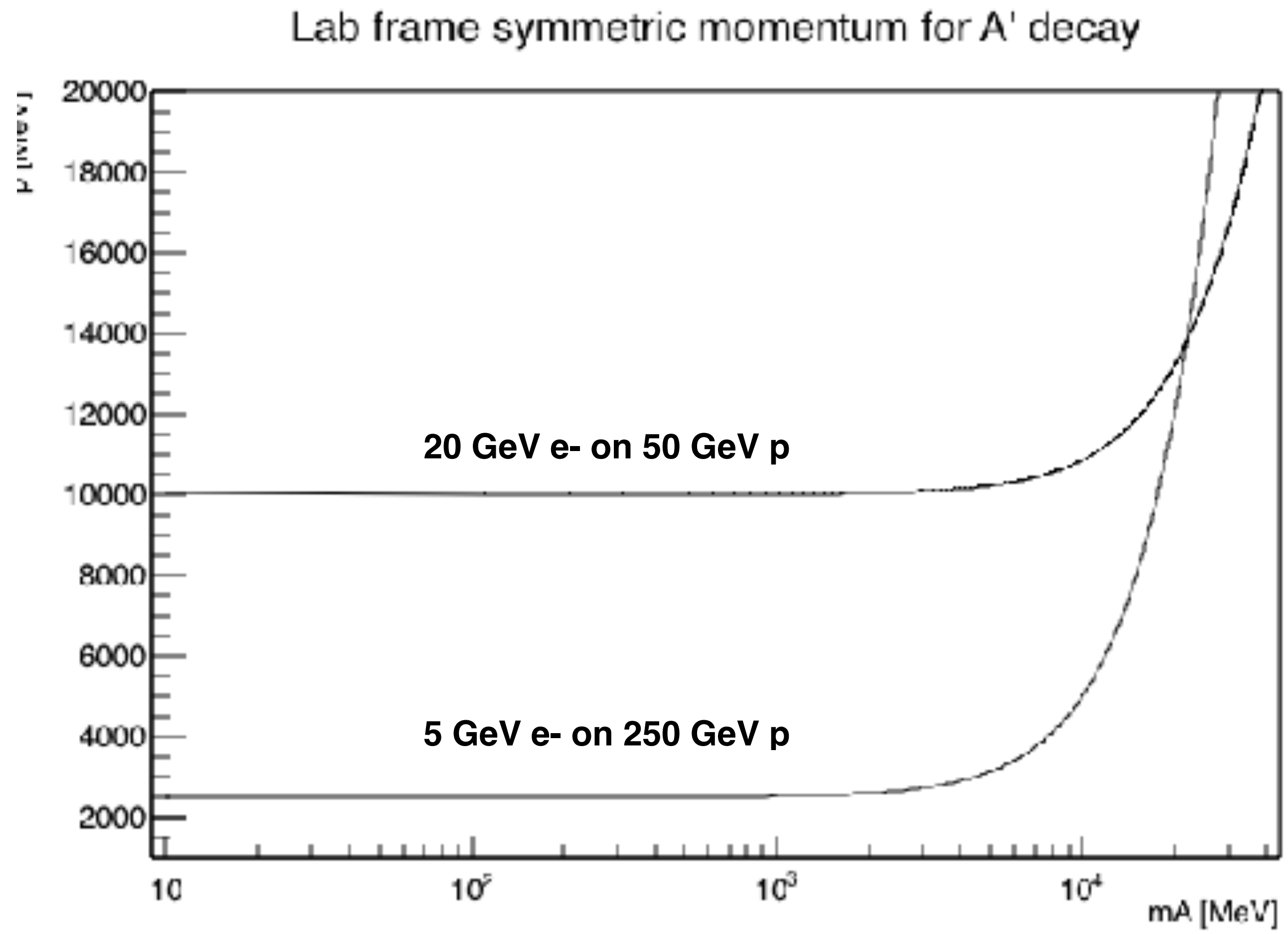
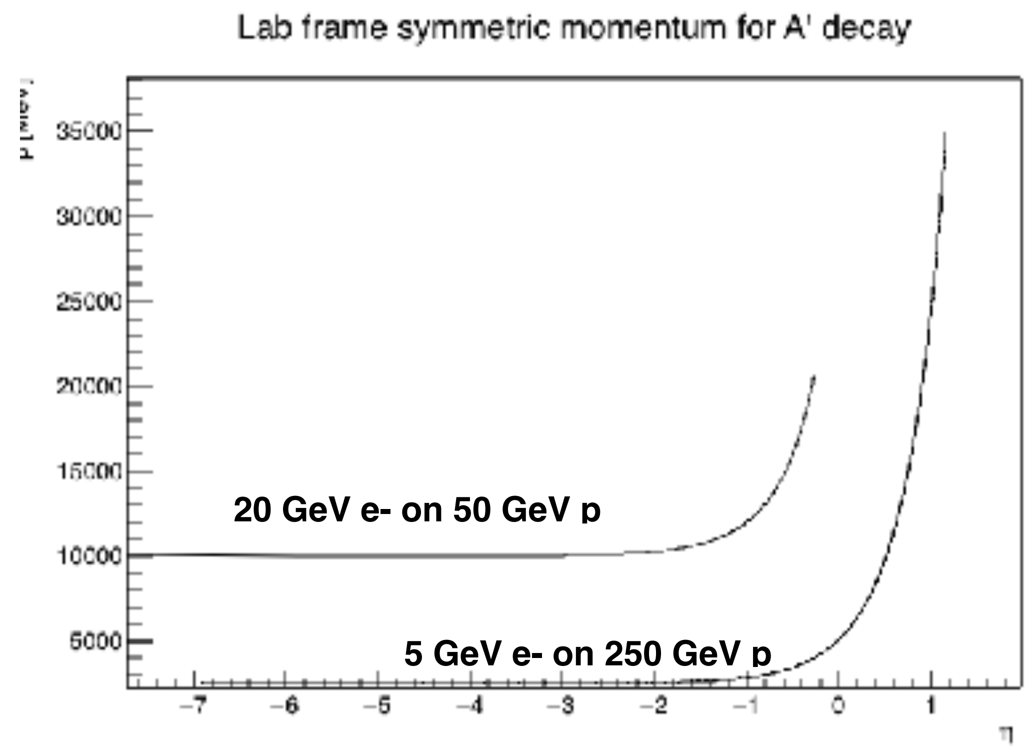


EIC Kinematics







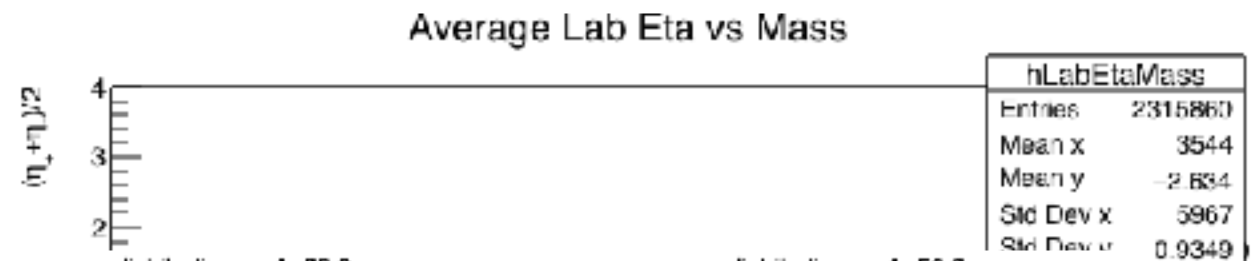
- For ep, handbook detector reaches to O(100MeV)

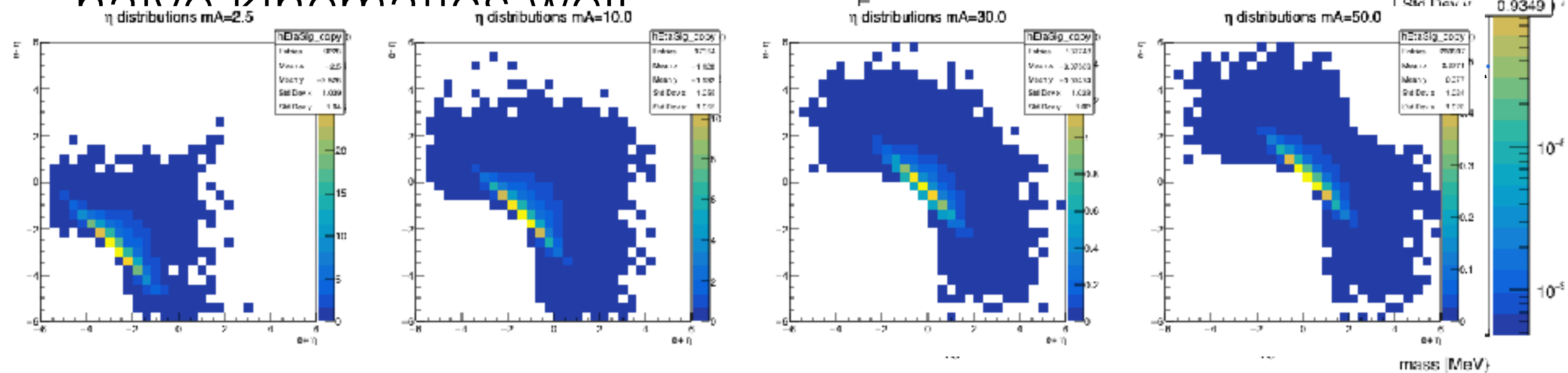
Generating Events

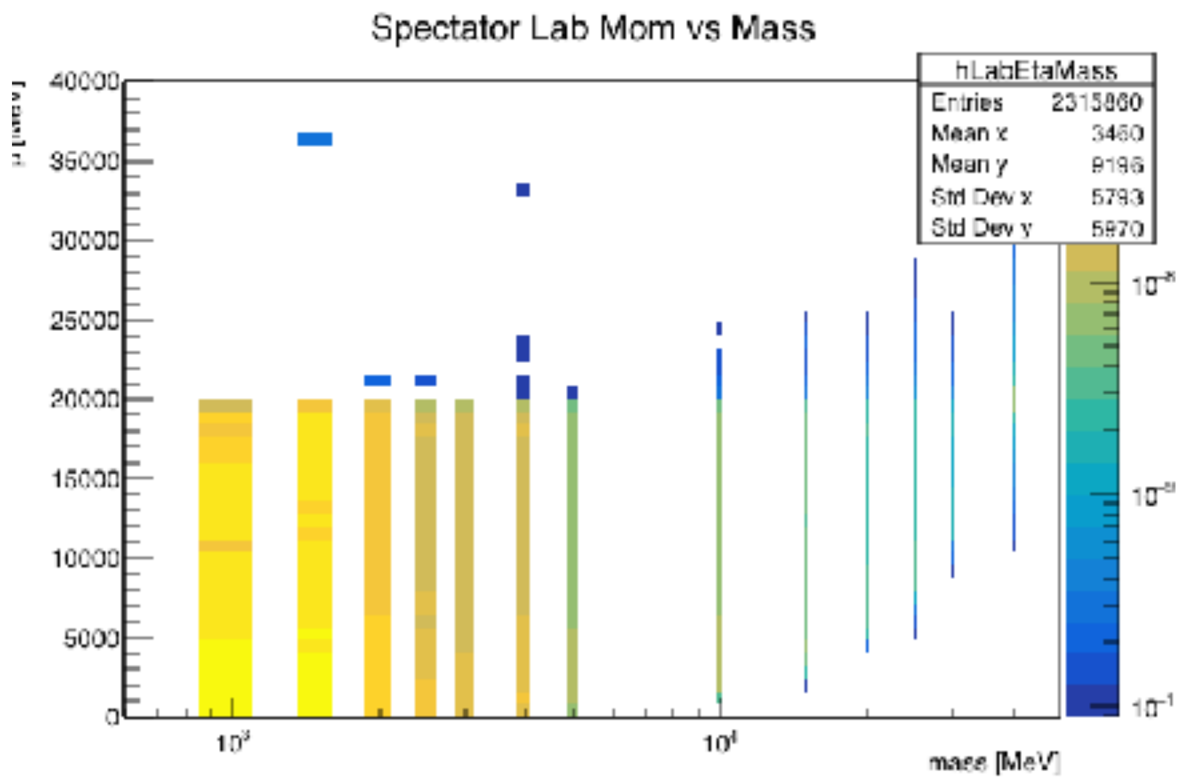
- Madgraph4.4 configuration:
  - custom (A',e,e) vertex
  - *ignores proton structure*
  - ~10TeV e- on fixed proton target, boost to lab frame after generation (20x250 setting)
  - Gen-level cut at $1° < \theta_e < 179°$ wrt e- direction in lab ($0.001° < \theta_e < 30°$ wrt e- beam in p-rest)
  - generate leading order:
    Signal: ep->epA'->epee for various m_A
    Irred. Bg: ep->epγ*->epee

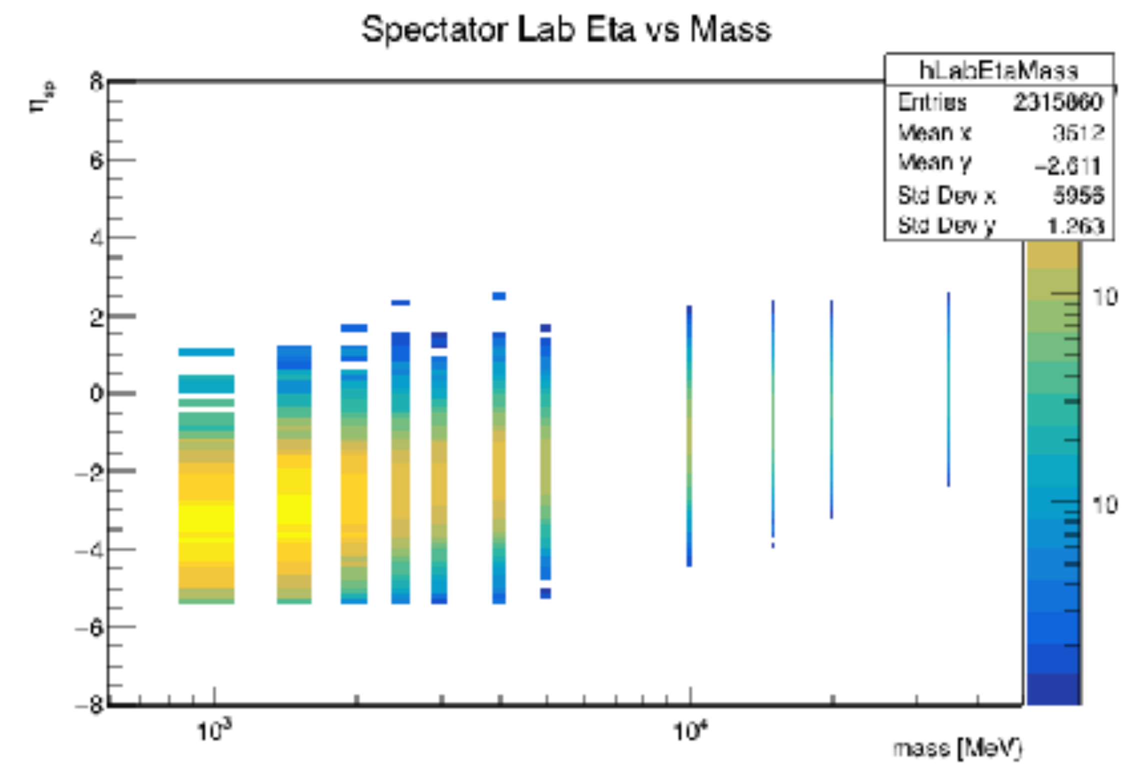
MC Kinematics

- Signal e+e- pairs track naive kinematics well



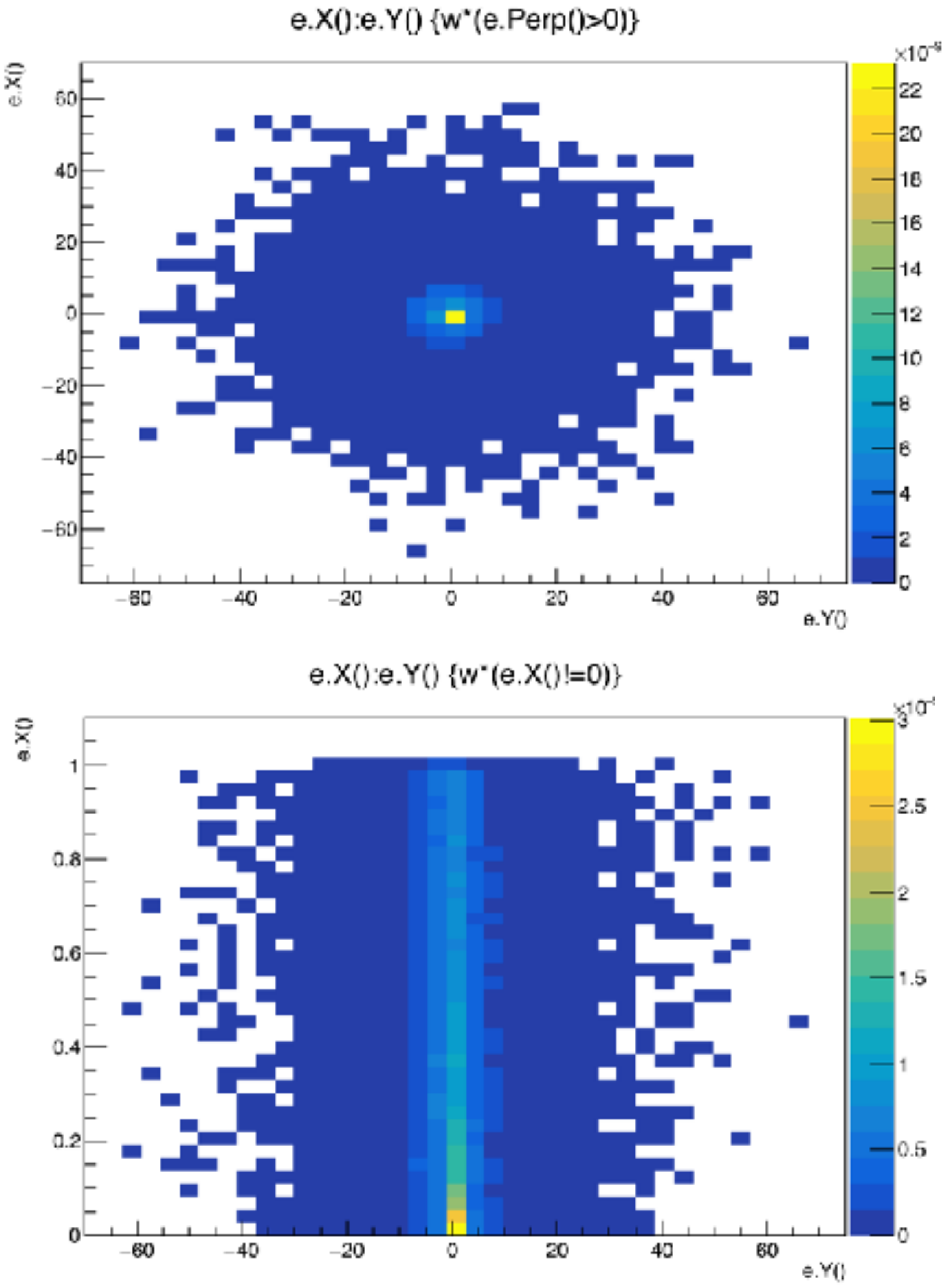




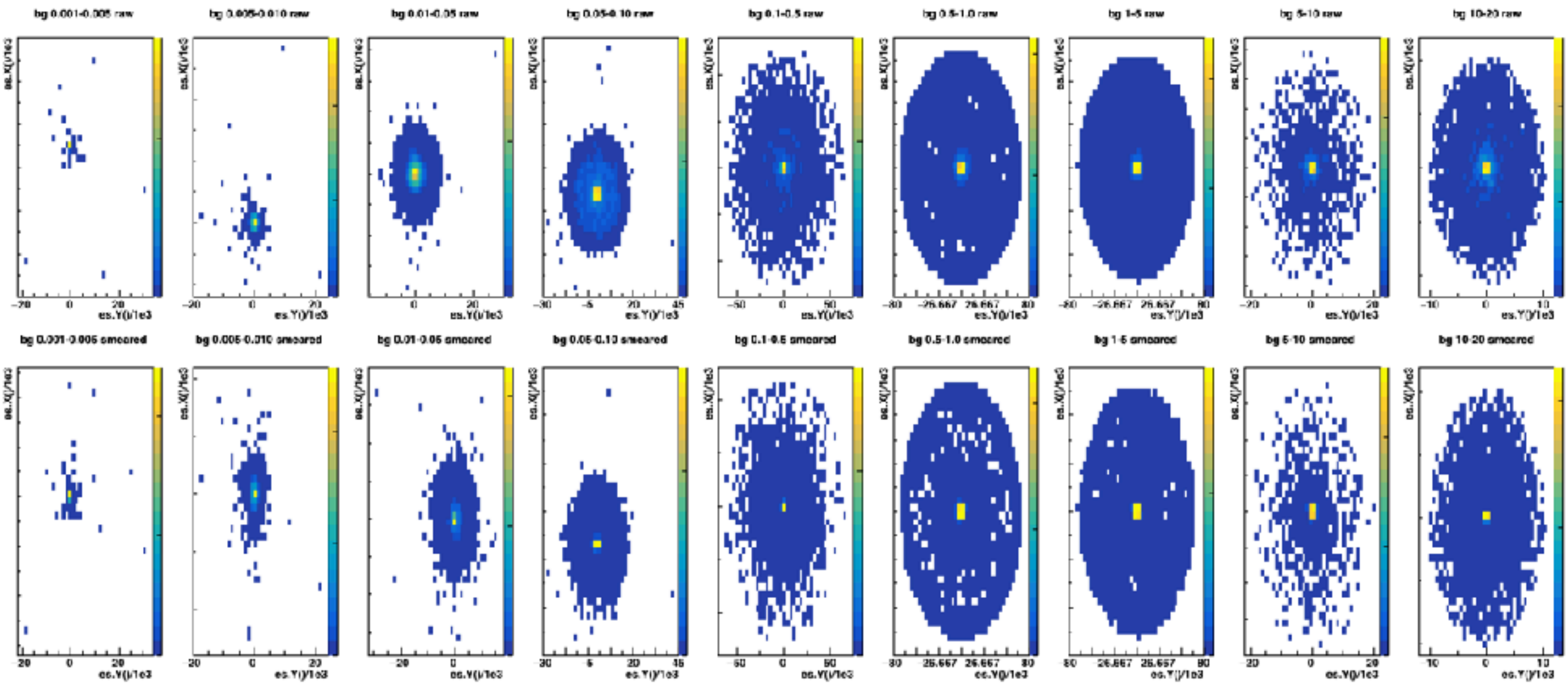


Double-Checking Import

- Importing madgraph events by faking a DJANGOH structure
- Subtle error led to truncation of p_x -- only obvious in 2D plots



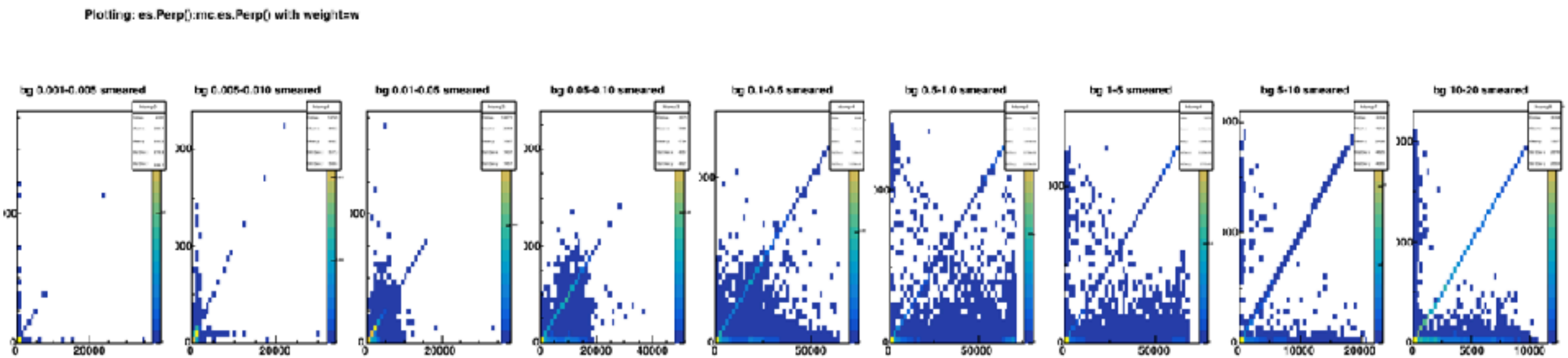
Signal in Handbook Detector

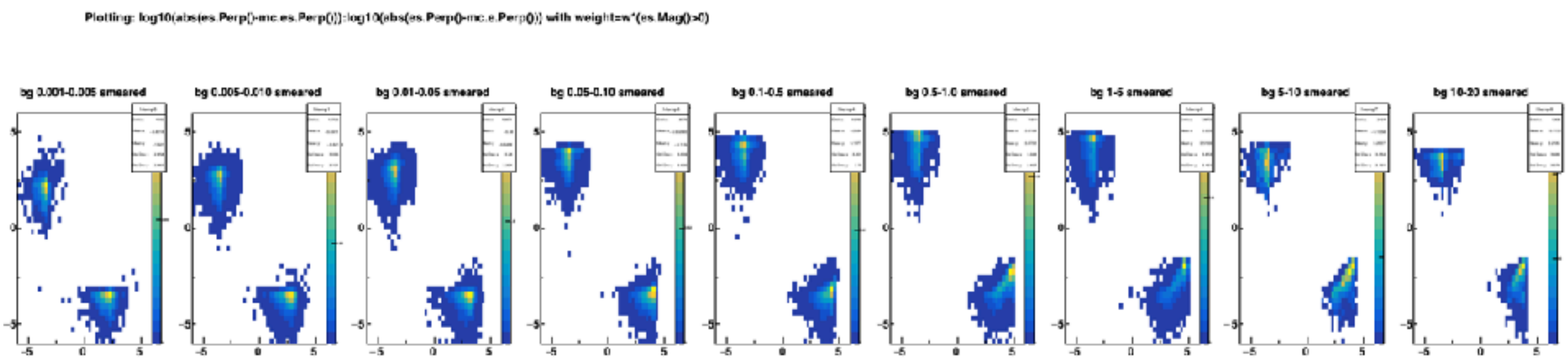


- With fix, smeared particles look good but

Matching

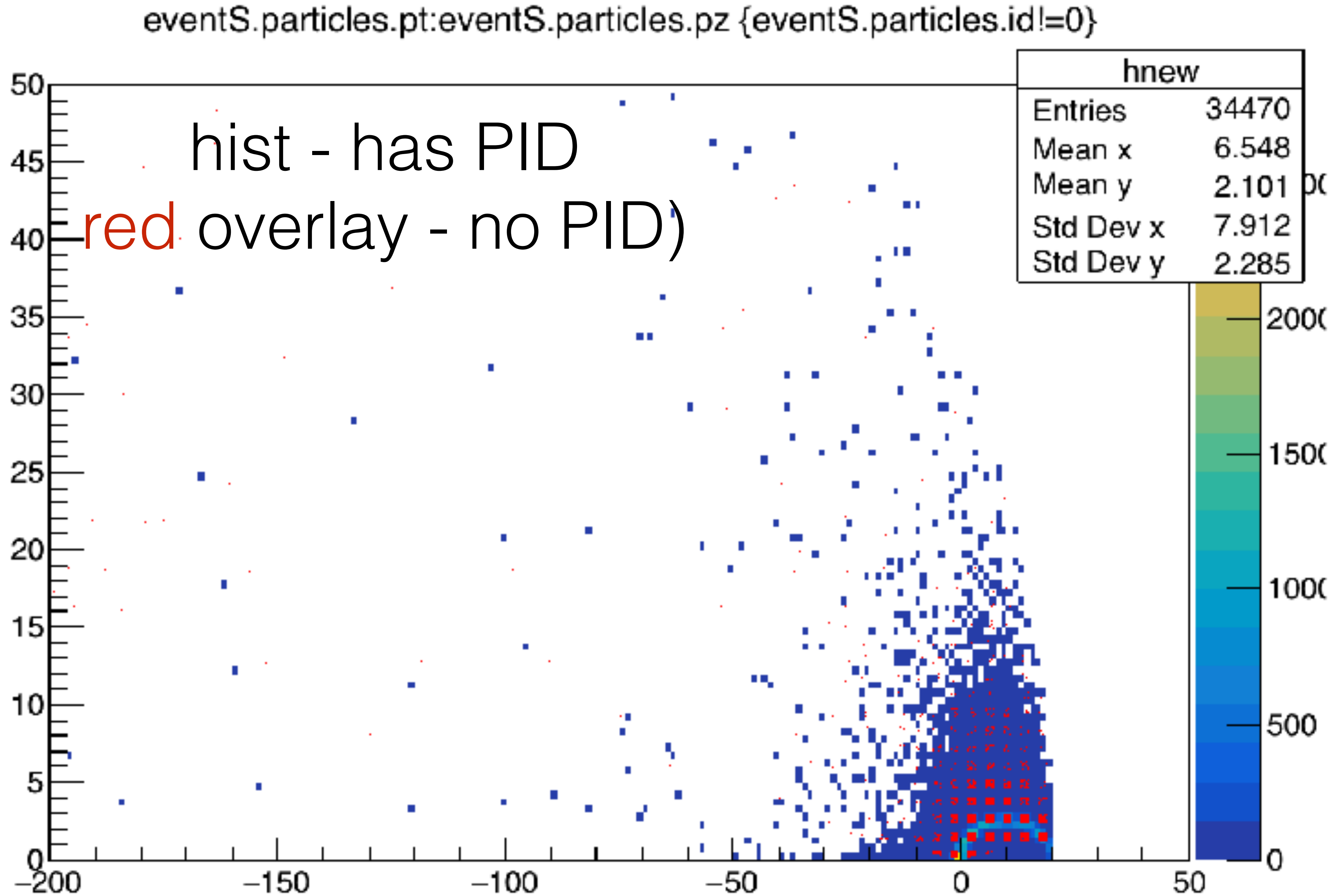
- Ordering seems to sometimes get rearranged, but there is clear association to one MC particle or the other:





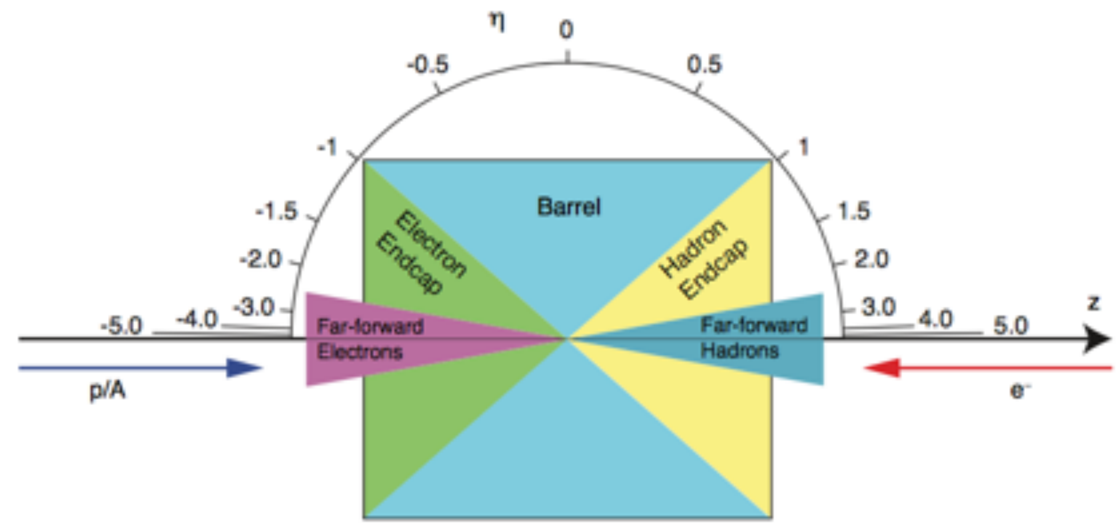
PID loss

- PID loss in regions where there should be coverage in Handbook detector (not so in 'perfect' detector)



Handbook Detector

- Momentum and Angular resolutions in SmearHandbook don't match up with handbook description (yet)



EIC Detector Requirements

η	Nomenclature			Tracking: Resolution	Tracking: Allowed X/X_0	Tracking: Si-Vertex	Electrons: Resolution σ_E/E	Electrons: PID
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2				
...								
-4.5 — -4.0			Instrumentation to separate charged particles from photons				2%/√E	
-4.0 — -3.5								
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\%\times p+2.0\%$	~5% or less	TBD		
-3.0 — -2.5								
-2.5 — -2.0				$\sigma_p/p \sim 0.05\%\times p+1.0\%$				
-2.0 — -1.5							7%/√E	π suppression up to 1:10⁴
-1.5 — -1.0								
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\%\times p+0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV μm + 5 μm	(10-12)%/√E	
-0.5 — 0.0								
0.0 — 0.5								
0.5 — 1.0								
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\%\times p+1.0\%$		TBD		
1.5 — 2.0								
2.0 — 2.5								
2.5 — 3.0				$\sigma_p/p \sim 0.1\%\times p+2.0\%$				
3.0 — 3.5								
3.5 — 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons					
4.0 — 4.5								
...								
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c