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# Characterisation and Comparison of Event Generators for Pair Conversion: A *Crucial Step for Future Low Energy Gamma Telescopes*

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- Motivation
- Conversion kinematics
- exact 5D generator validation
- Comparison of generators
  - Angular resolution
  - Polarimetry
- Conclusions

## Gaseous

HARPO

AdEPT

## Silicon

e-ASTROGAM

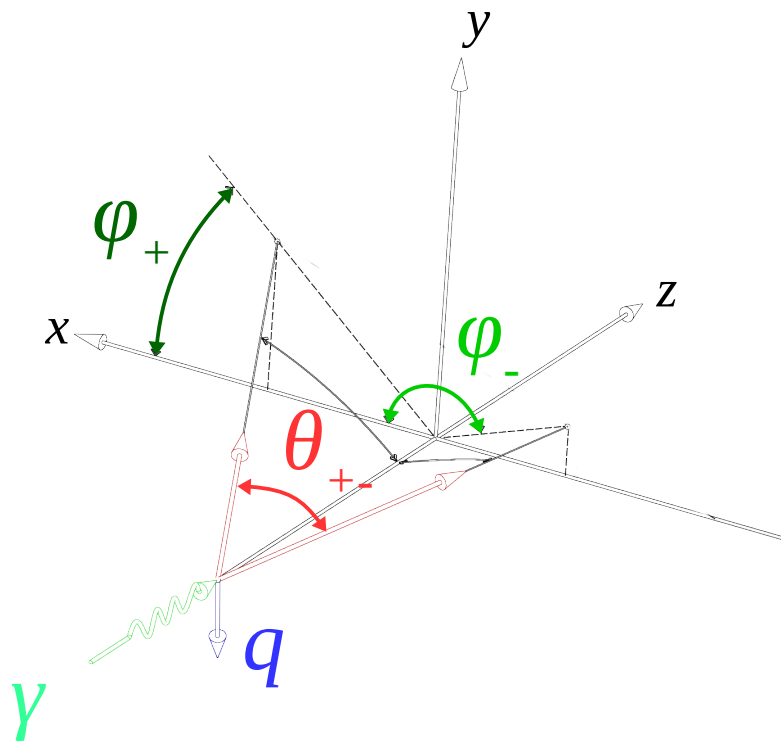
ComPair

PANGU

## Emulsion

GRAINE

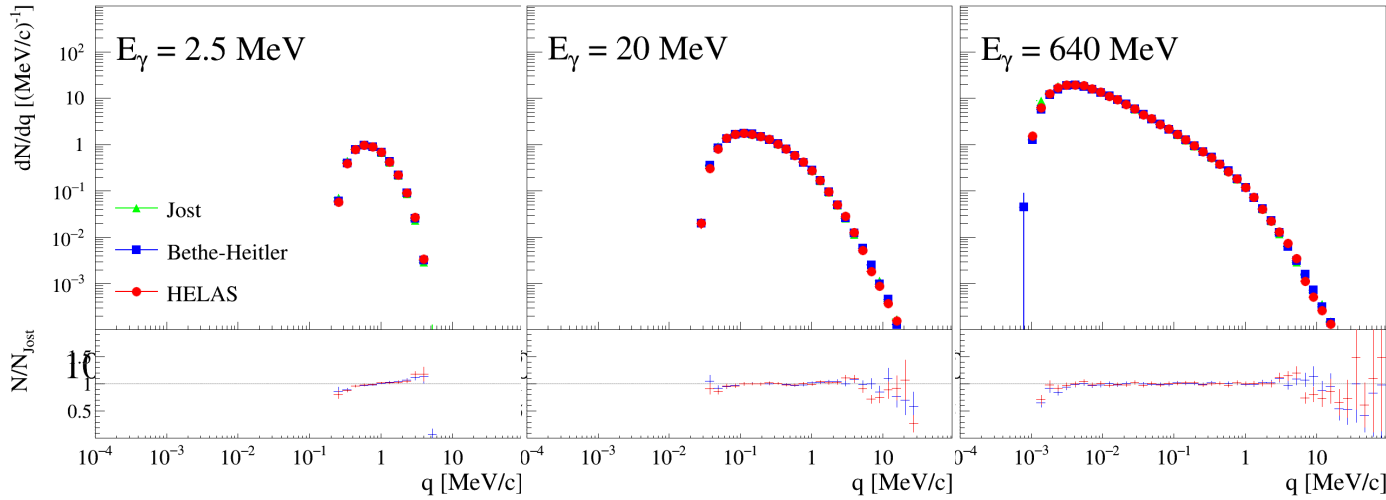
- Improvement on angular resolution of tracks
  - Light (low scattering) + (very) fine point resolution
  - Better angular resolution for photon
  - Access to polarisation



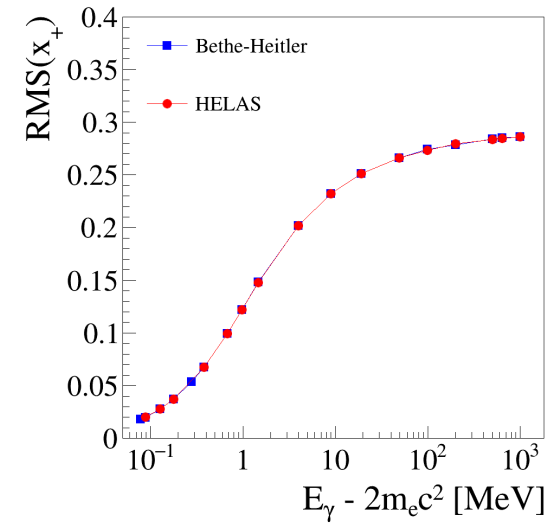
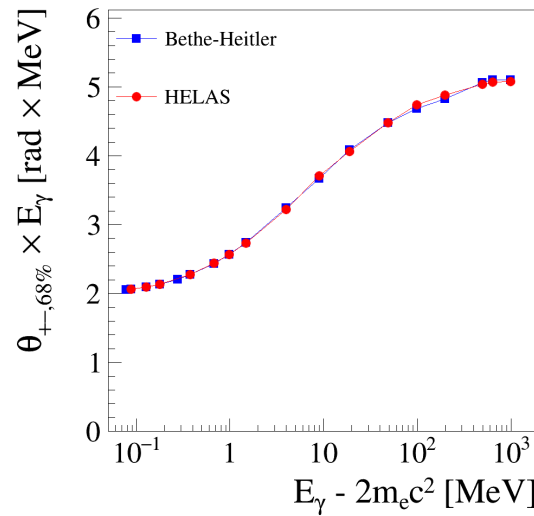
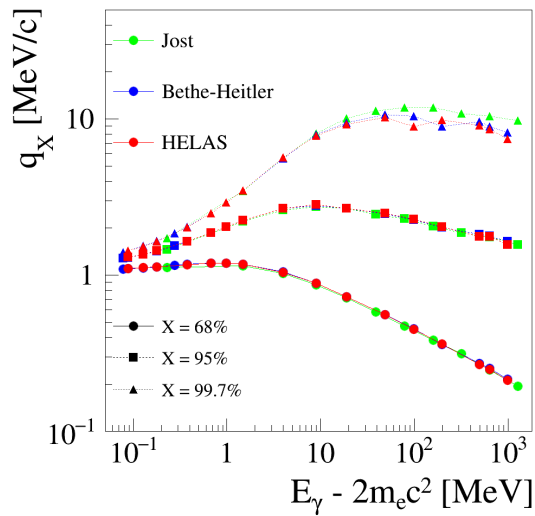
- $q$  recoil momentum
- $\theta_{+-}$  opening angle
- $x_+ = E_+/E_\gamma$
- $\phi = (\varphi_- + \varphi_+)/2$   
azimuthal angle



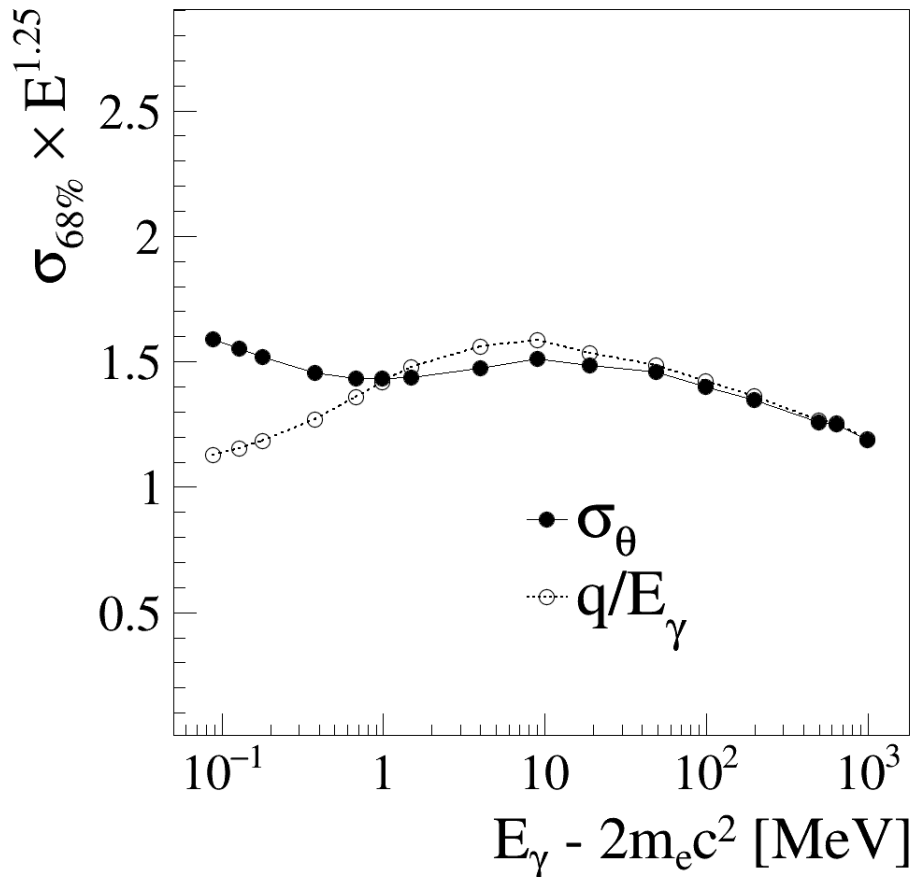
- Home made generator (D. Bernard)
- Models of 5D cross-section:
  - full Feynman diagram calculation with HELAS
  - Bethe-Heitler formula
- P.d.f. generation with SPRING/BASE



$q$  distributions compared to analytic formula by Jost



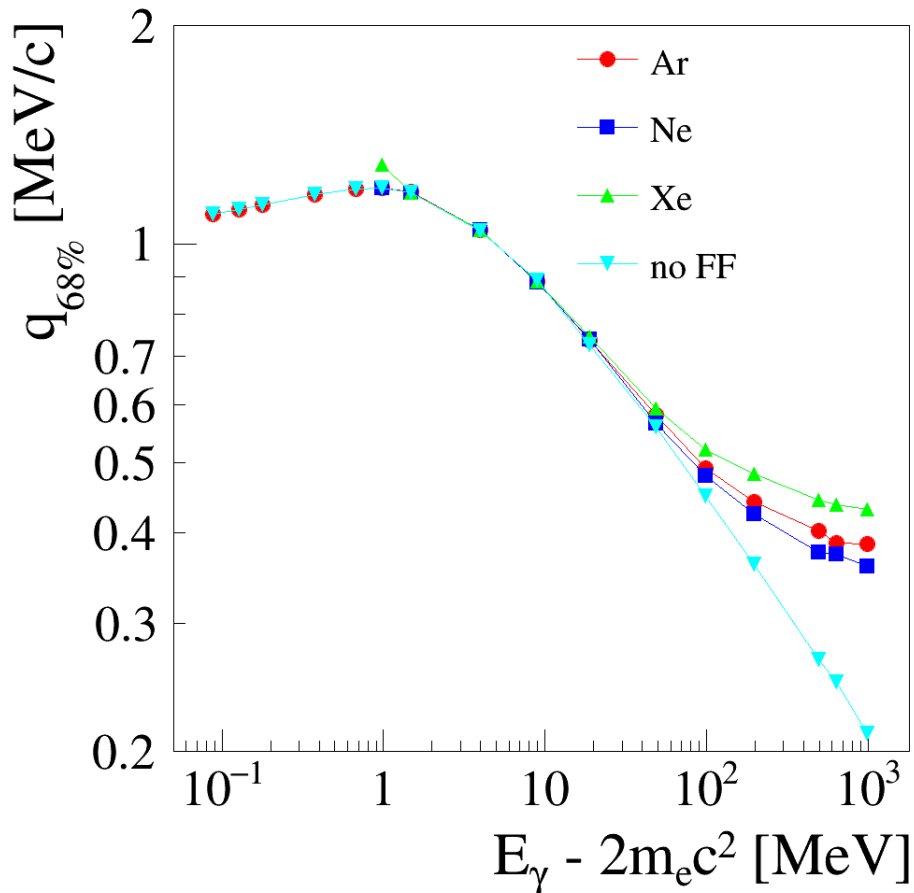
# Remark: Angular resolution vs $q$



- High energy approximation
  - transverse recoil
  - small angles

$$\theta = q/E$$

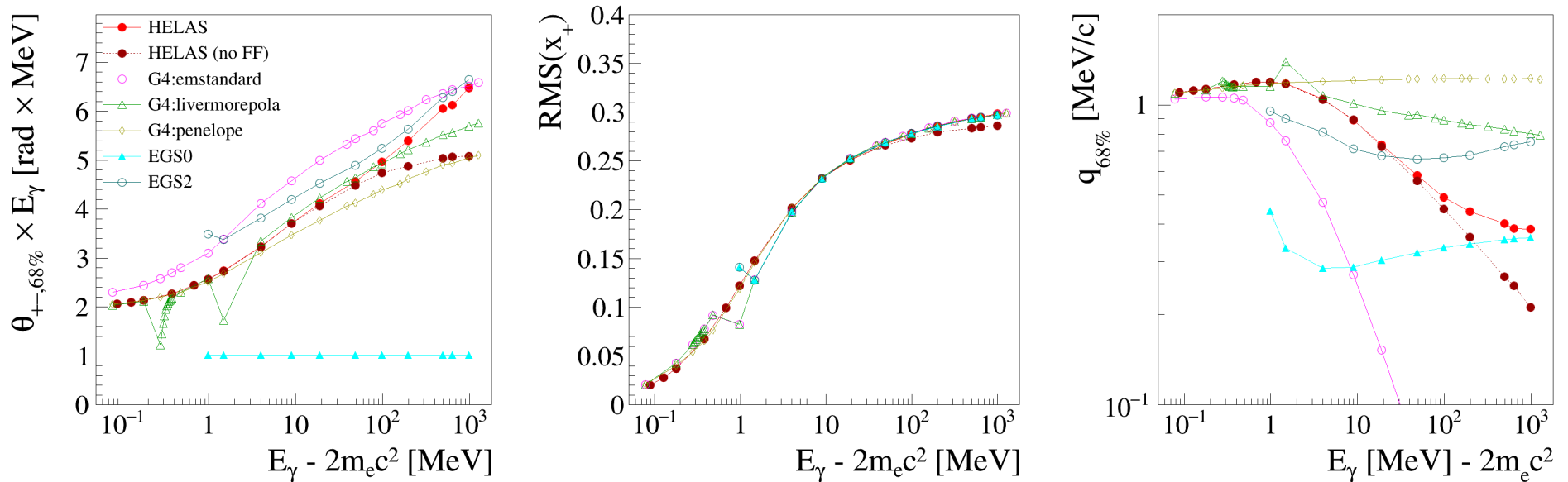
- Valid within 10% above 1 MeV



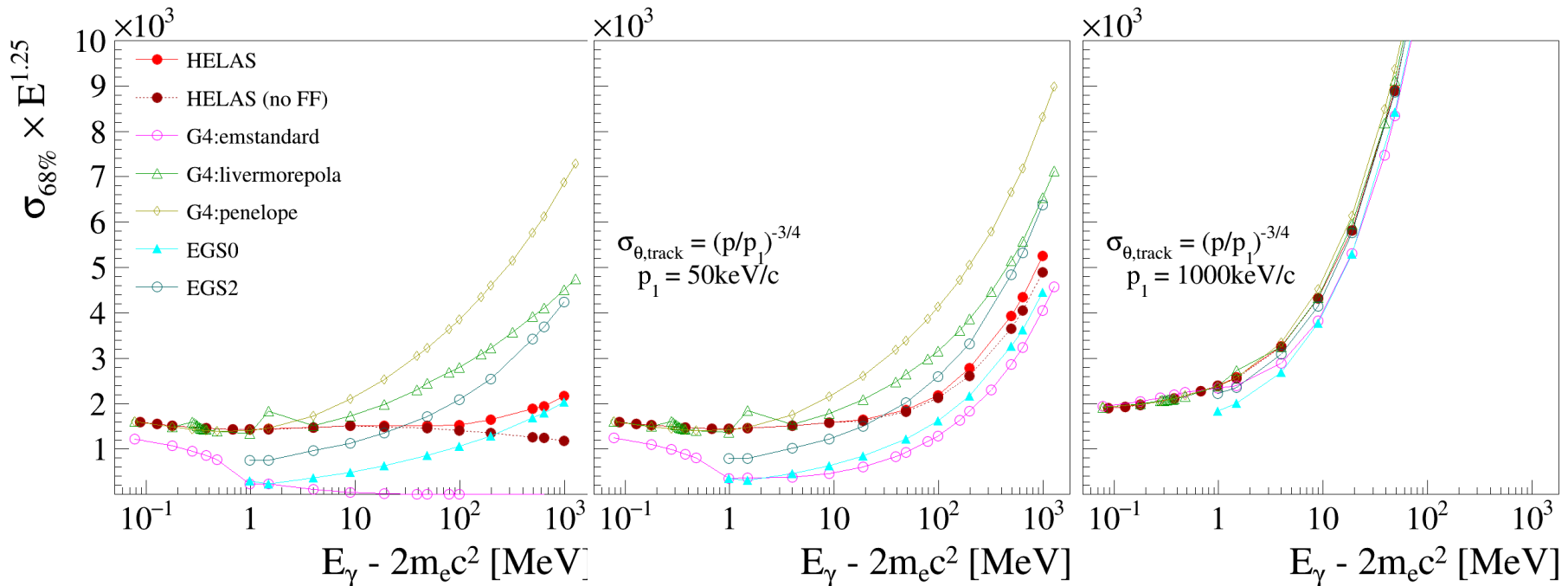
- Nature of conversion nuclei taken into account with form factors
- Negligible at low E
- Clear above 100 MeV



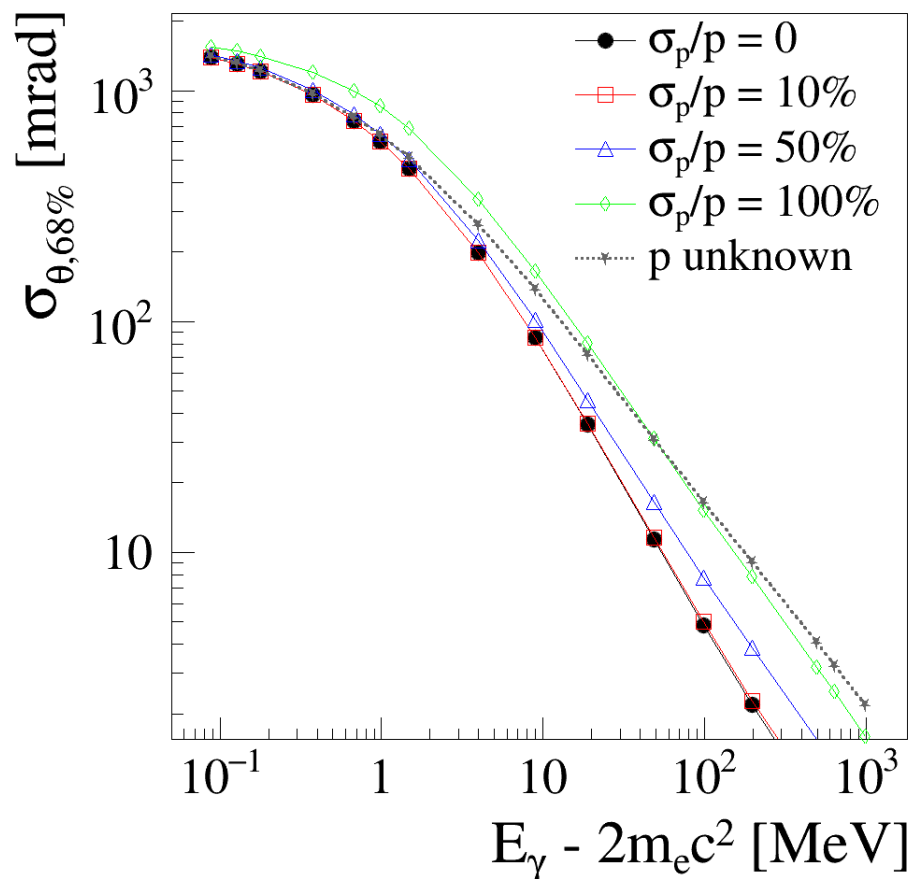
- EGS5 (v1.0.6)
  - IPRDST=0  
 $\theta_+ = \theta_- = m/E$
  - IPRDST=2  
 $\theta_+, \theta_-$  independent  
(Schiff)
  - *no conservation of energy-momentum*
- Geant4 (v10.02.01)
  - *emstandard* G4BetheHeitler  
coplanar ( $\varphi_- - \varphi_+ = \pi$ )
  - *penelope* G4PenelopeGammaConversion  
 $\theta_+, \theta_-$  independent (*no conservation of E-p*)
  - *livermorepola*  
G4LivermorePolarizedGammaConversion  
high energy approximation  
from Depaola, **polarised**



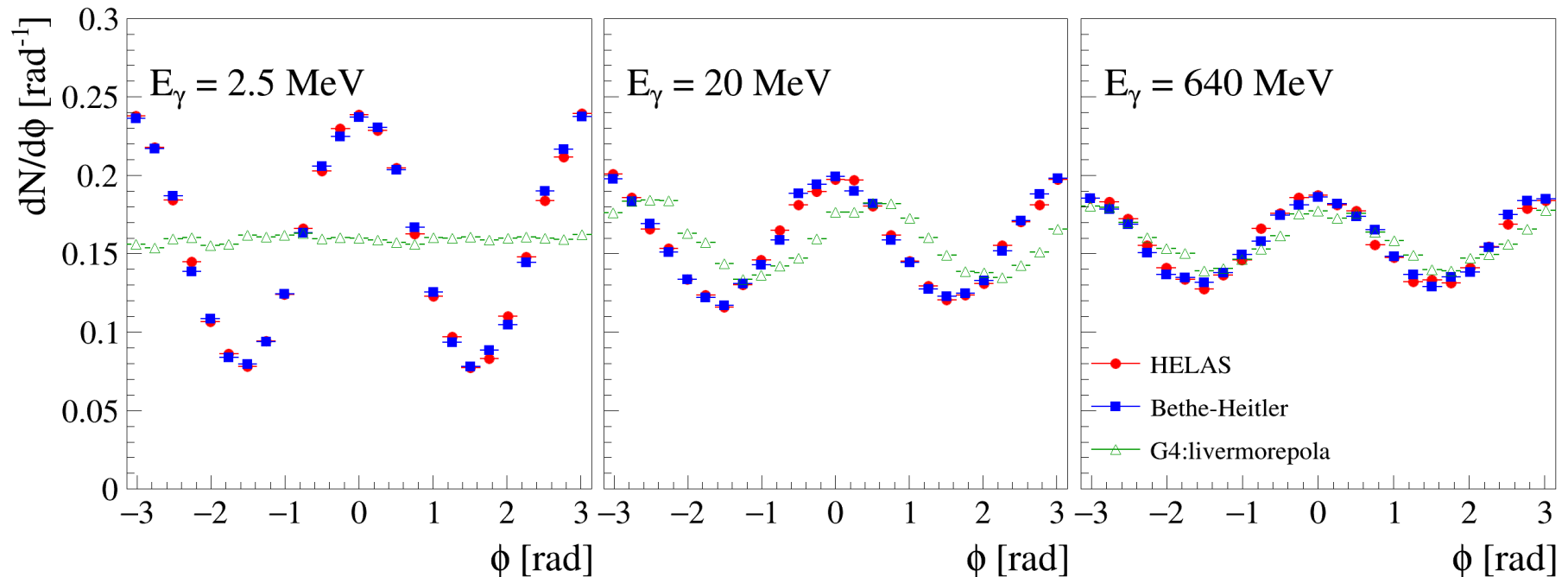
- The distribution vary between models
  - especially  $q$ , and therefore the angular resolution
  - *EGS0* and *emstandard* are most inaccurate, as expected
  - regime changes around 200keV and 1MeV for *livermorepola*



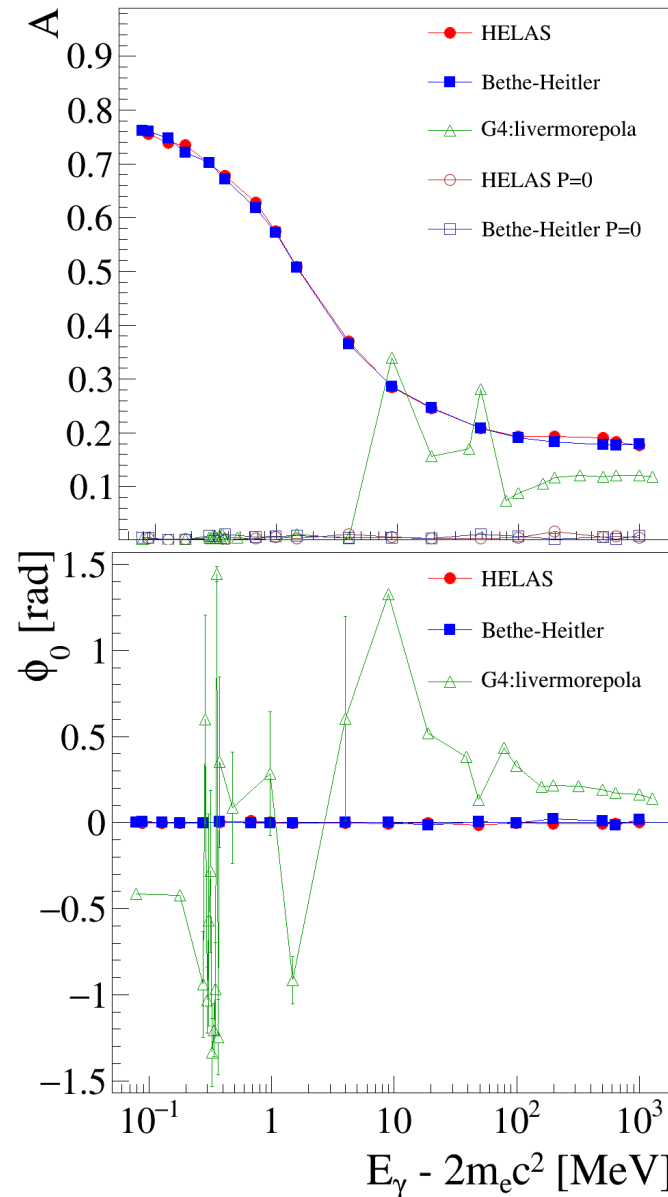
- Tracking resolution from multiple scattering
  - approximation of homogeneous tracker  $\sigma = (p/p_1)^{-3/4}$
  - model differences disappear for  $p_1 = 1 \text{ MeV}$  ( $\sim$ Fermi-LAT)
  - accurate models necessary for high resolution (e.g. gaseous tracker)



- Track momentum used in estimation of photon direction
- Bisector gives worse resolution at high energy (factor 3 at 100MeV)
- Rough momentum estimation (<50%) recovers most of it



- Azimuthal angle distributions
  - Apparently consistent at high energy
  - No asymmetry in *livermorepola* at low energy



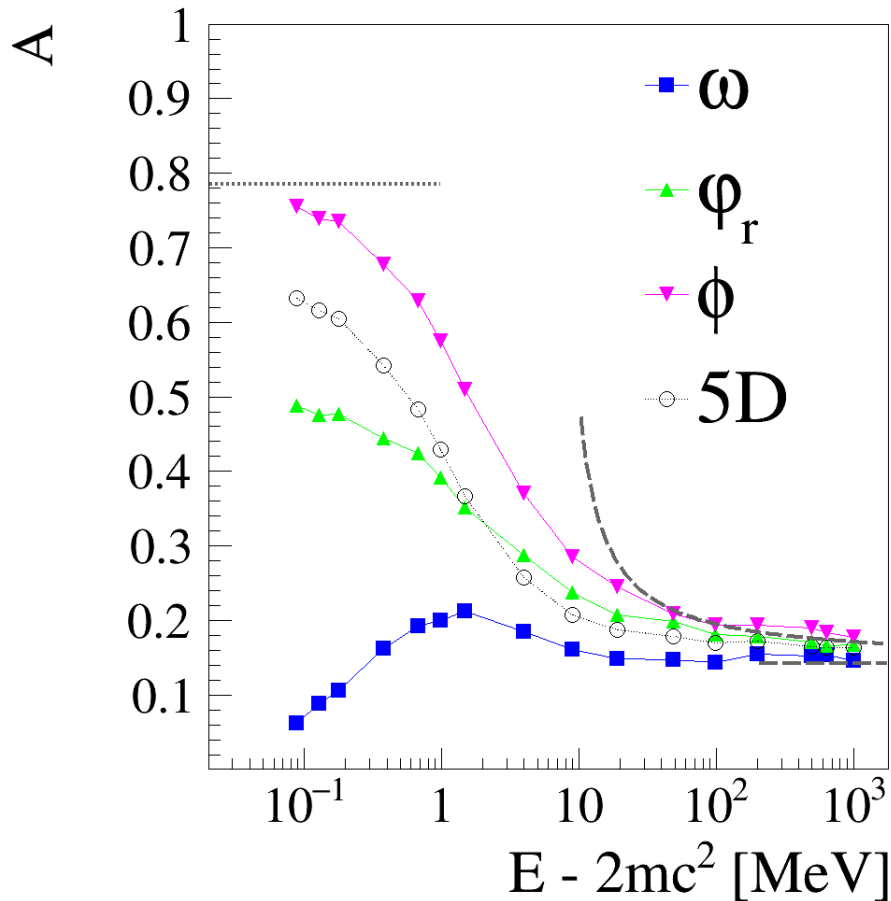
$$dN/d\phi \propto 1 + A \cos(2(\phi - \phi_0))$$

- Asymmetry  $A$  is underestimated in livermorepola, especially below 50 MeV (regime change)
- Phase  $\phi_0$  varies below 50 MeV; strange offset above

# Remark on Azimuthal angle



- Azimuthal angle ill defined
  - recoil angle  $\varphi_r$
  - pair plane angle  $\omega$
  - pair bisector  $\phi$
- Angle  $\omega$  used in previous publications underestimates  $A$  at low energy
- $\phi$  appears in Bethe-Heitler formula, agrees with asymptotic values





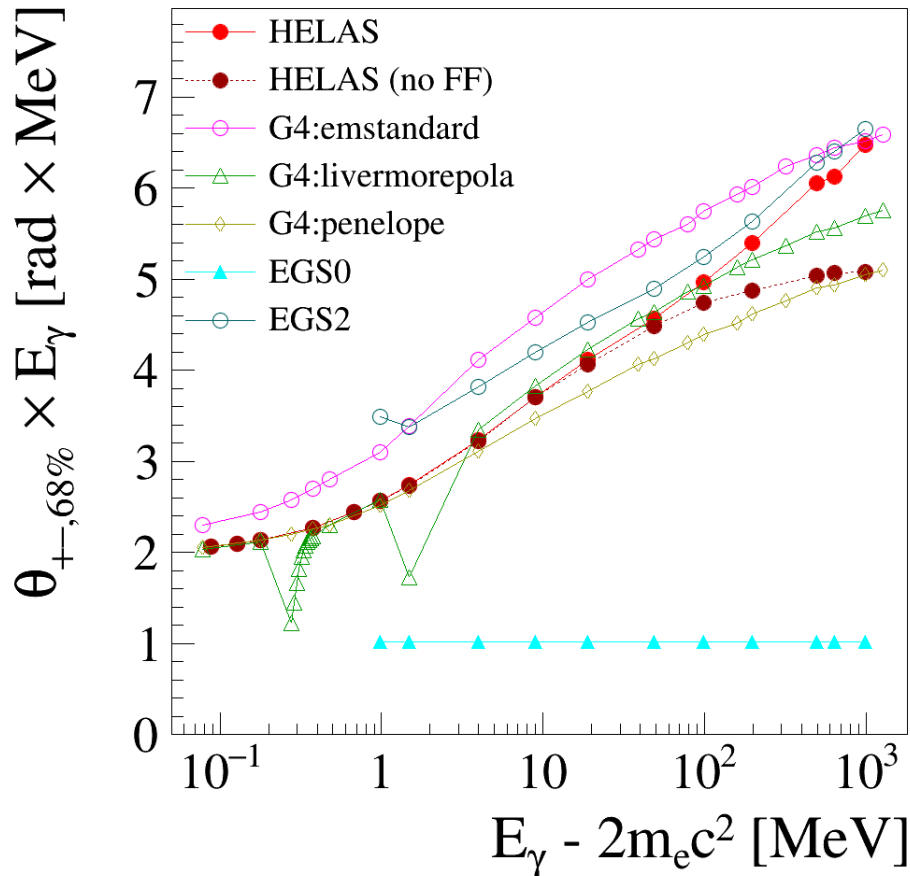
- Exact 5D generator fully validated
- Detailed kinematics of pair conversion poorly described by available generators
- Important for new generation telescopes with fine resolution/low multiple scattering (gas, Si only or emulsions)
- Polarisation rarely taken into account
  - only Geant4, but poorly described  $< 50\text{MeV}$

*Be careful which generator you use!*

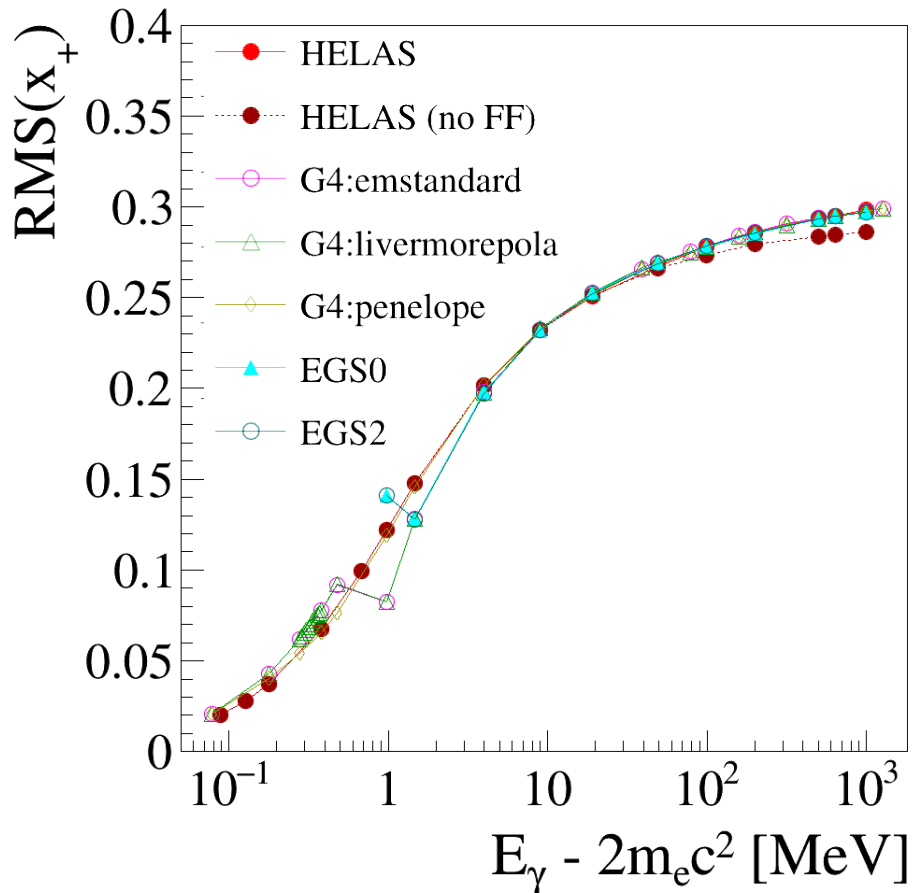


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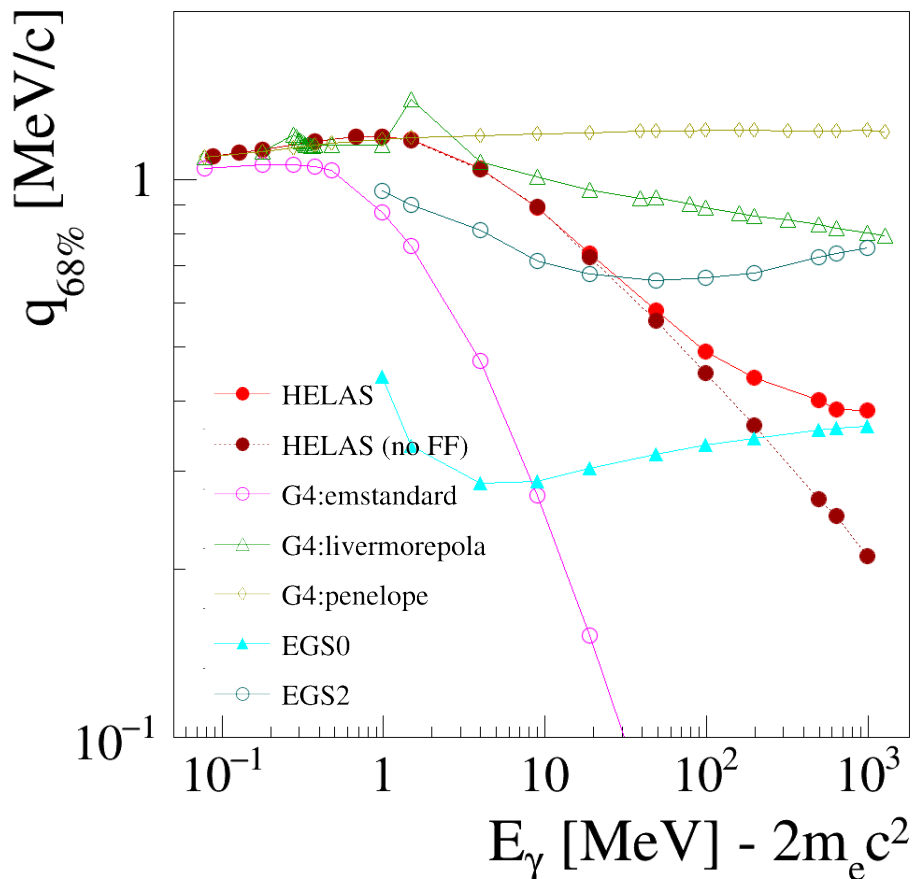
# Backup



- EGS0 with fixed value  $\theta_{+-} E = 2m$
- Other models qualitatively similar
- 2 regime changes in *livermorepola*



- All models consistent
- small offset around 1MeV for *emstandard* and *livermorepola* models



- Very different results from generators
- No FF in Geant4 and EGS5
- *EGS (IPRDST=0) and emstandard inappropriate*