HPS experiment at JLab: searching for dark photons

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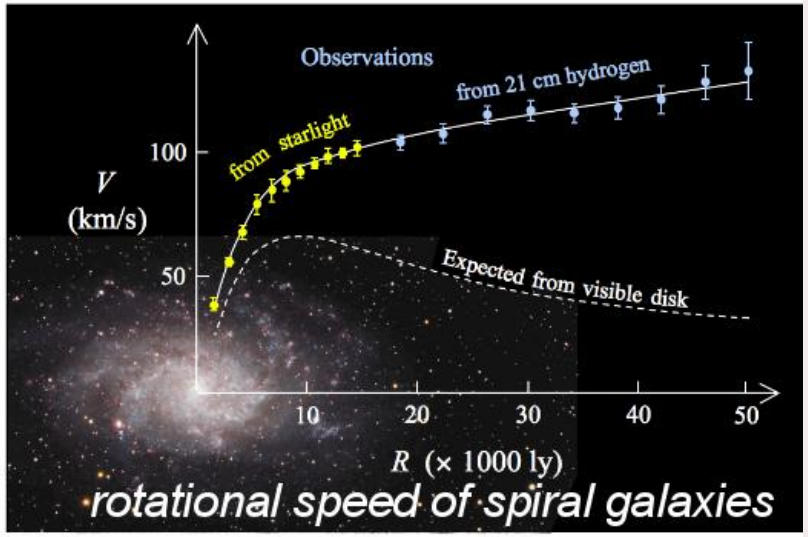
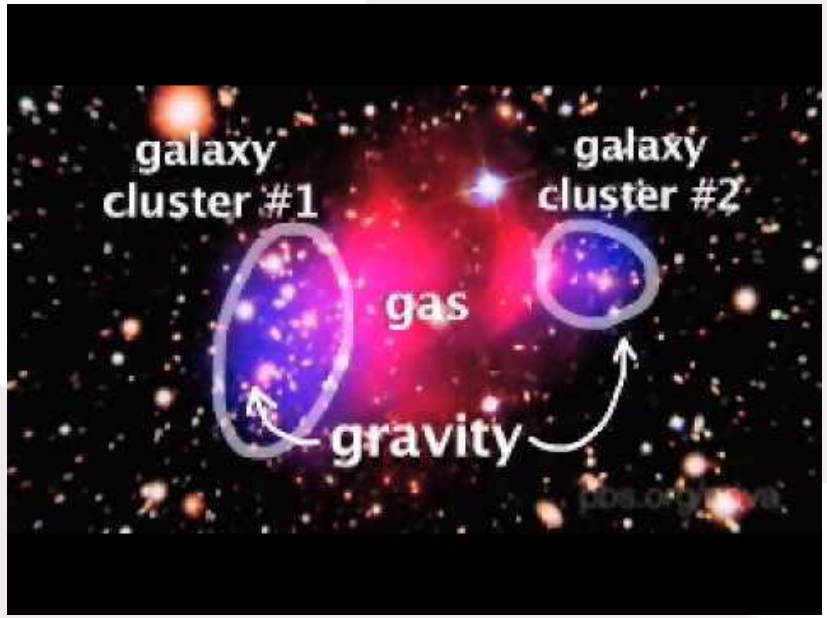
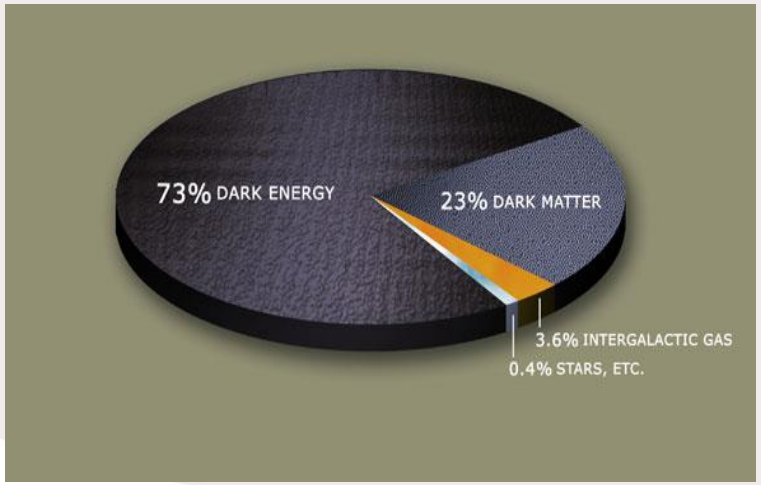
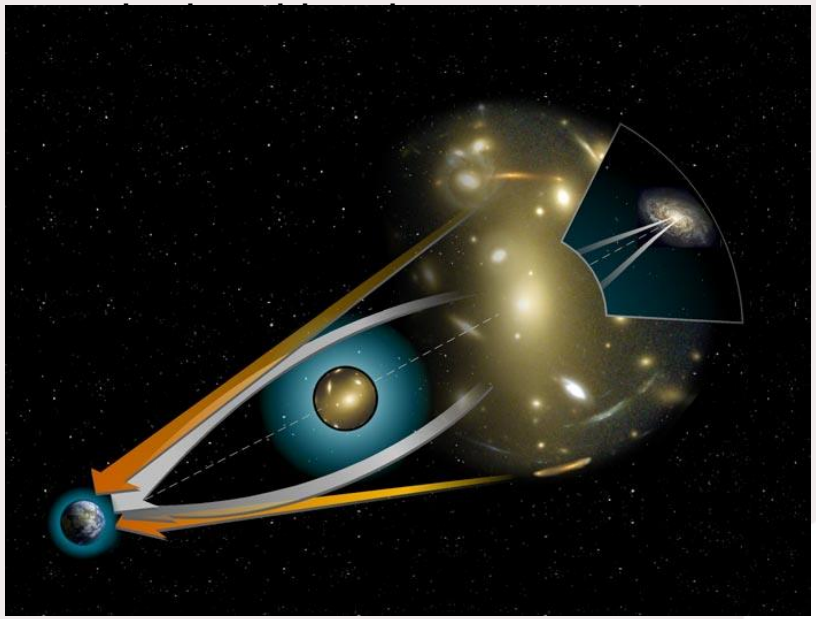
Physics motivation

- Hadronic matter only accounts for ~4% of the mass of the universe .
- The heavy photon (or "dark photon") is a possible candidate carrier of a new force that could explain Dark Matter (DM)



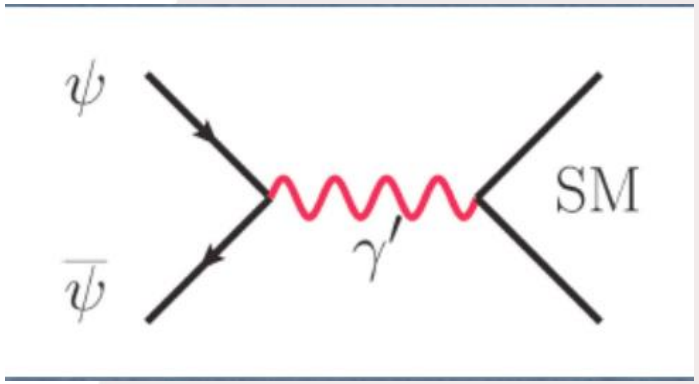


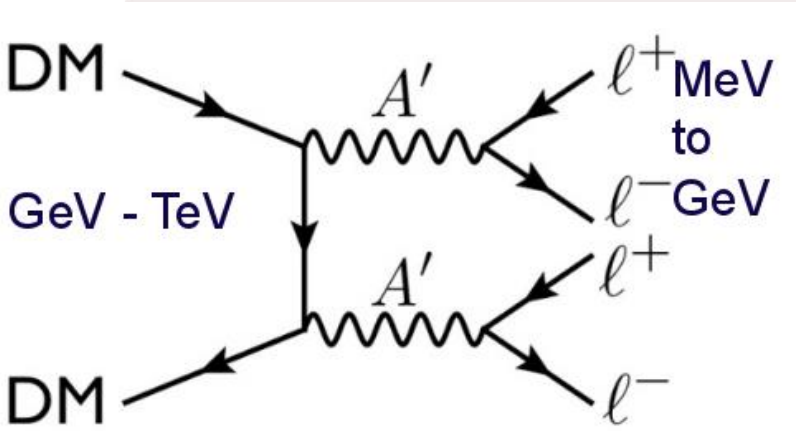


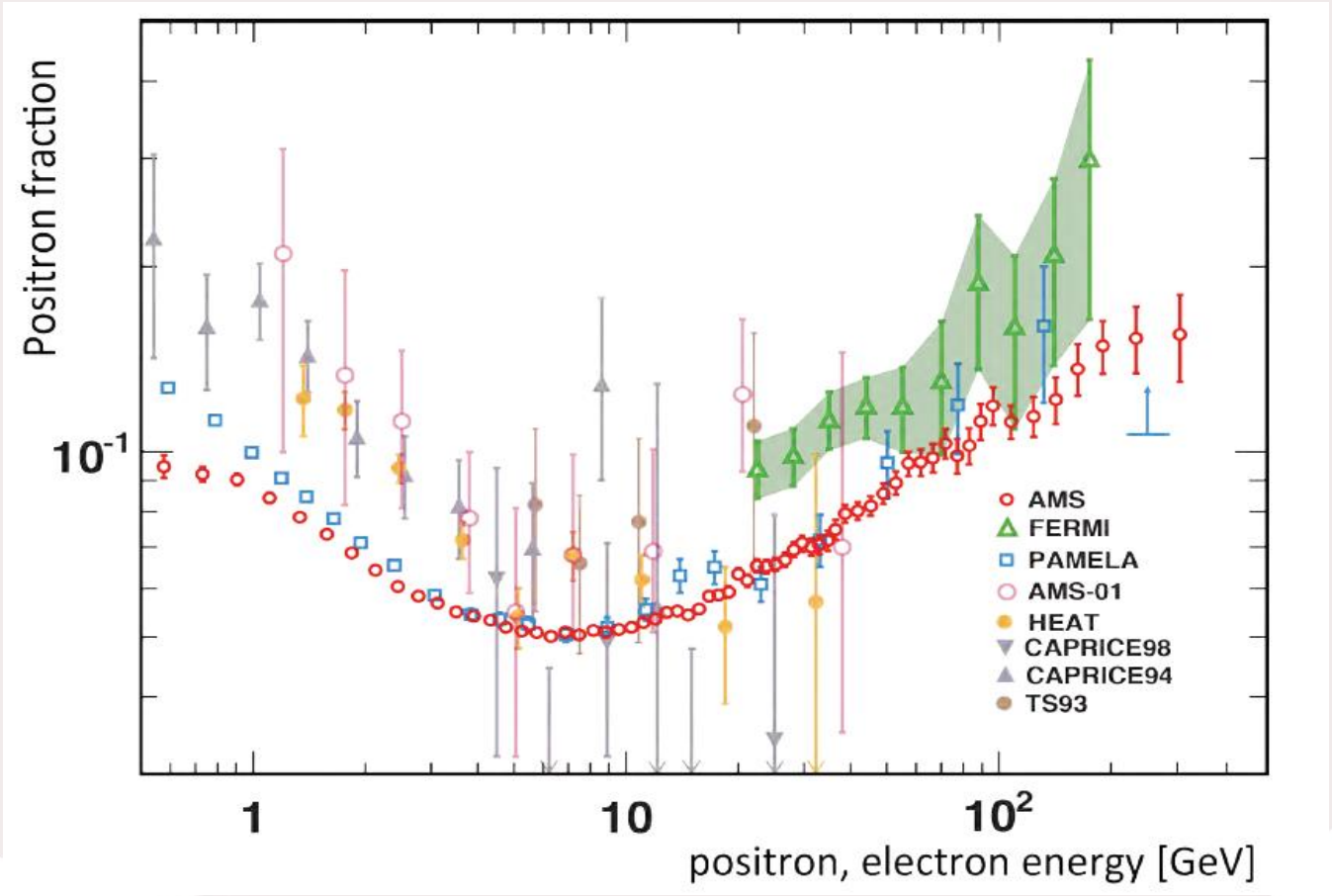


Physics motivation

- The DM interacts with ordinary matter through new force mediated by new 20MeV-1GeV mass gauge boson. Candidate for such a particle is A' or "heavy/dark photon".
- Dark matter coupling to A' can explain the excess of positrons and electrons in cosmic rays via DM annihilation or decay into e^+e^- pairs.

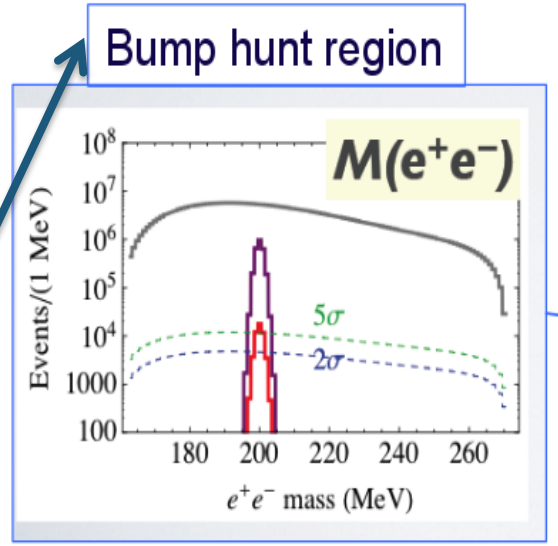


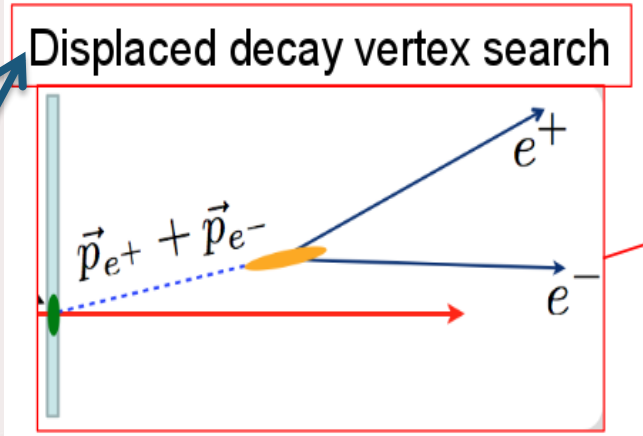


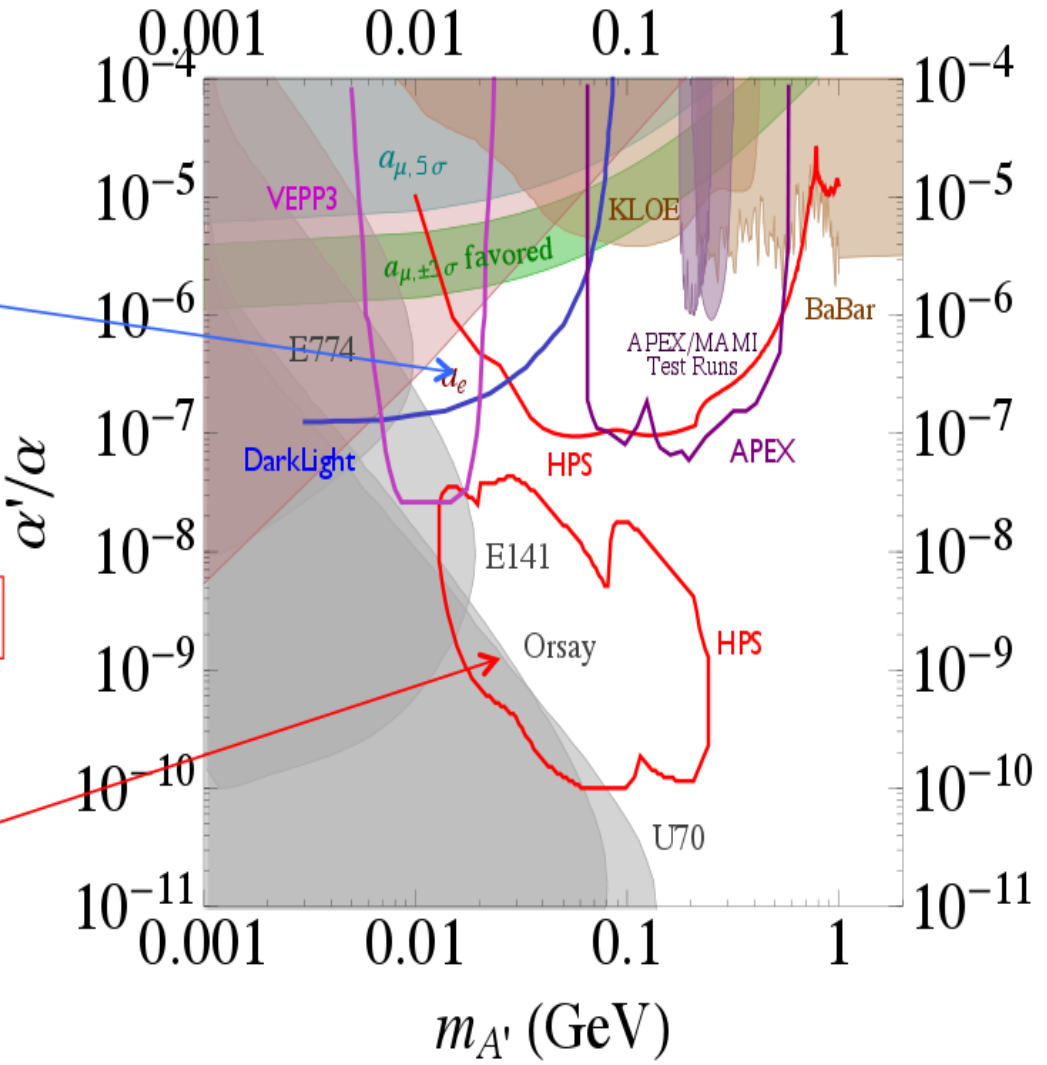


Experimental Status of A'

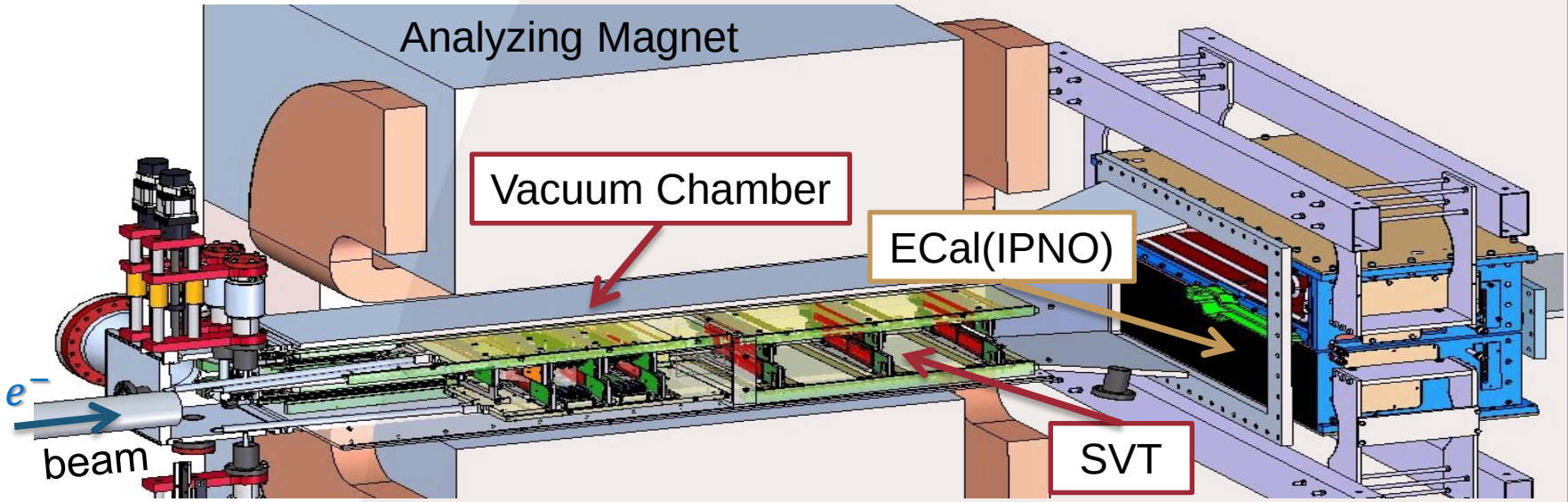
- Heavy photons are allowed below a coupling strength 10^{-3} and throughout mass range of 20-1000MeV/c^2.
  - HPS (heavy photon search experiment) searching region focuses on a wide range of heavy photon masses and moderate couplings
  - The other region utilizes both invariant mass and separated decay vertex information to provide sensitivity to small couplings over the mass range 20-250MeV/c^2.







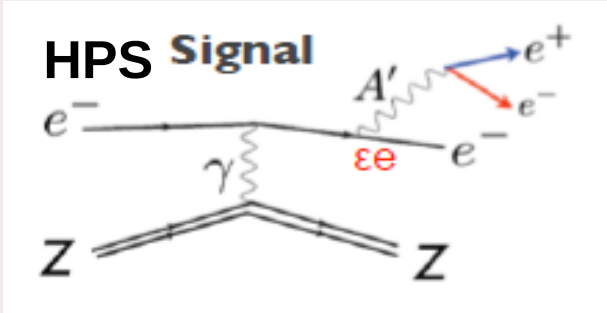
HPS Experiment and Detector Setup



- Experiment is running at Jeffeson Lab (TJNAF, USA) in Hall-B.
- Test run on May 2012
- Test run on the fall of 2014 with cosmics and ECal only.
- Engineering run in Spring 2015 (1.05 GeV)
- Engineering run in Spring 2016 (2.3GeV)

- e^- beam at 1.05 and 2.3 GeV
- Tungsten target
- Detector package includes:
  - 6 layers Silicon Vertex Tracker (SVT)
  - Electromagnetic Calorimeter (ECal)

  (built by IPN group)



Signal properties in Ecal , timing and time resolution,

Ecal forever

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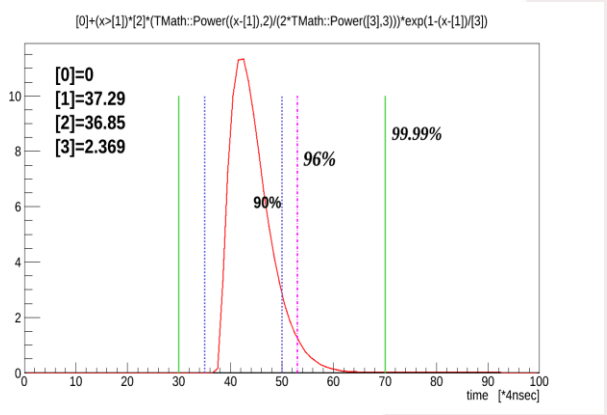
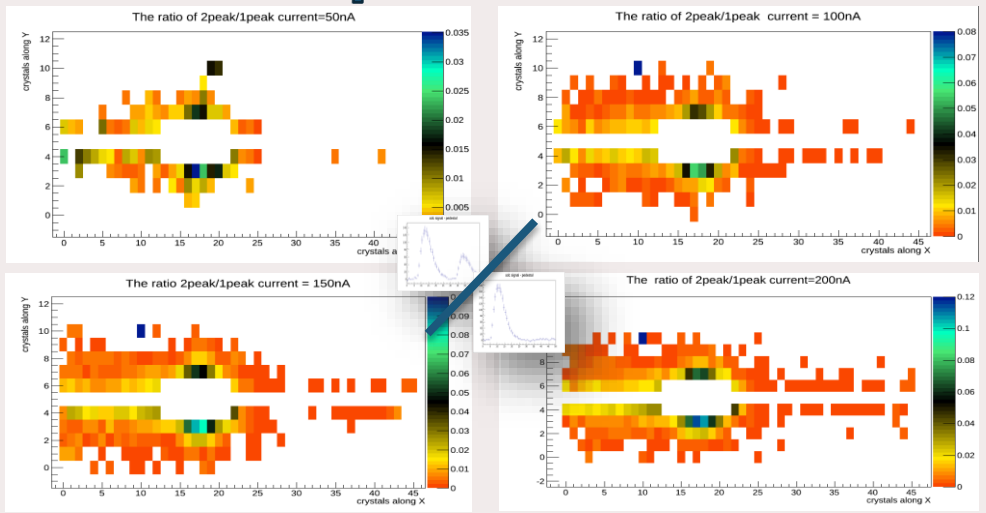
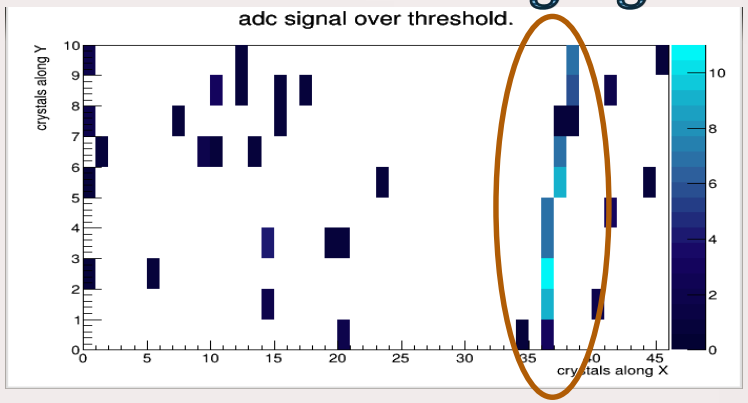
Typical FADC signal



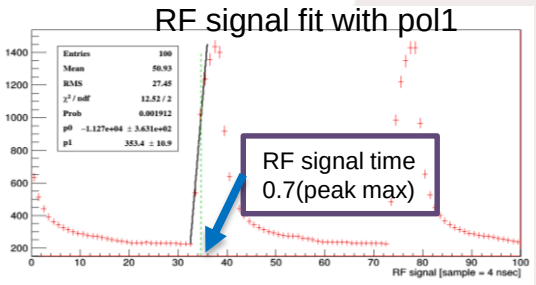
Pile-up effect in ECal

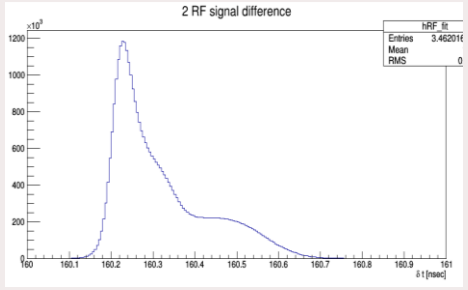


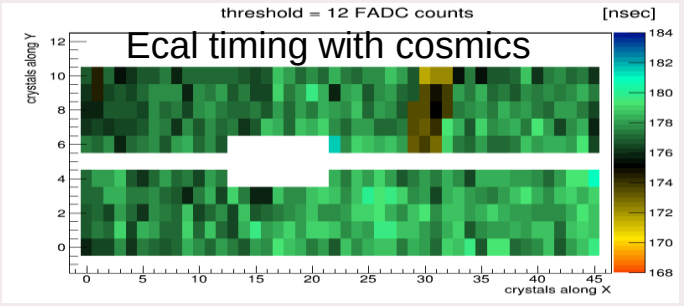
Cosmic track searching algorithm

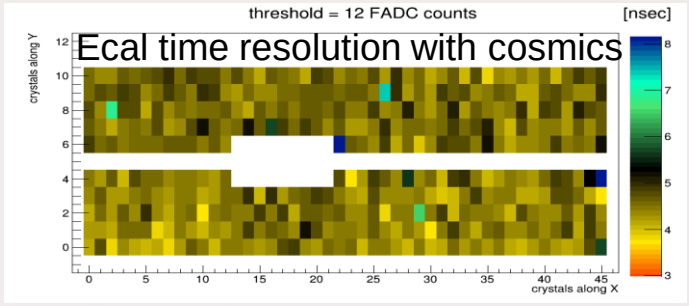


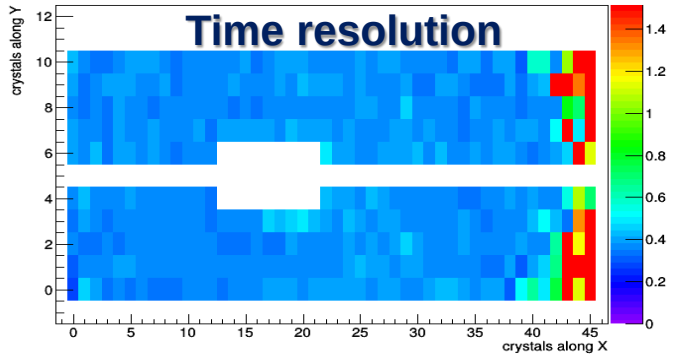
RF signal fit with pol1

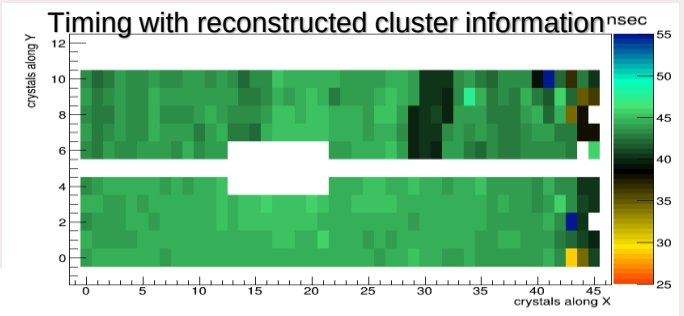


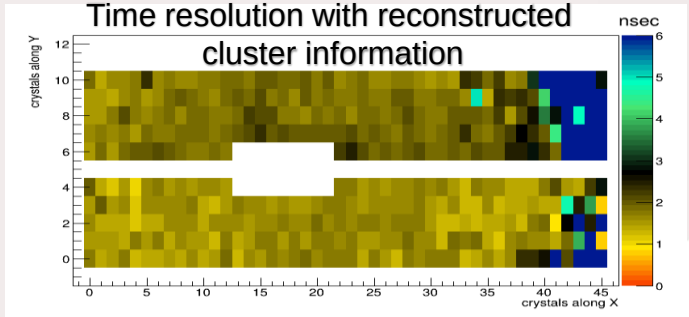






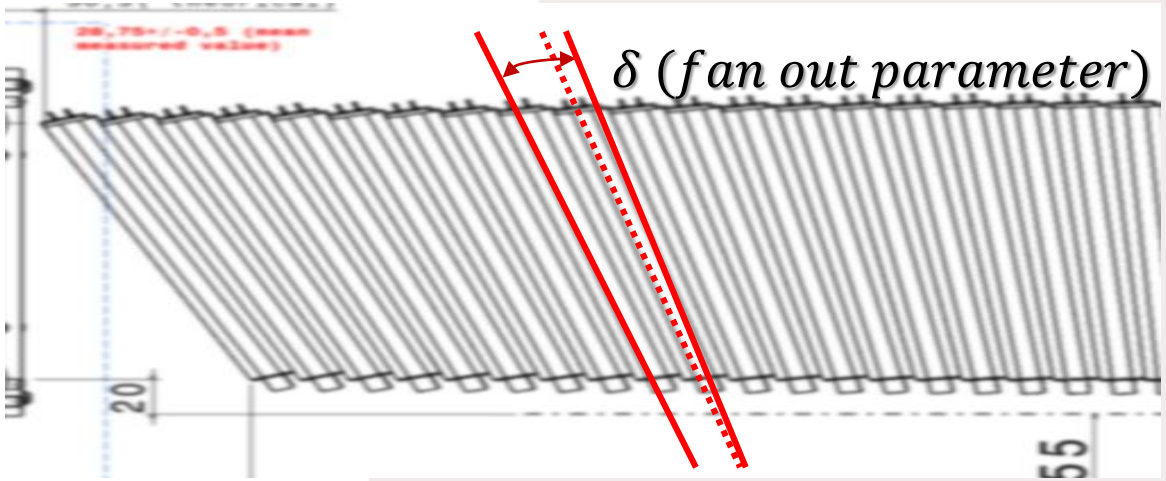


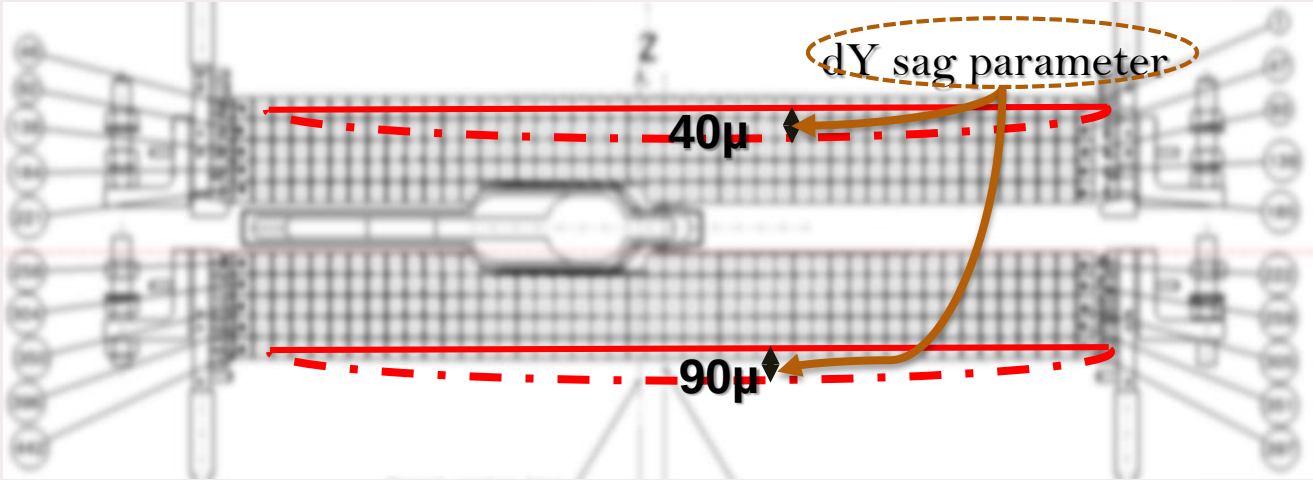




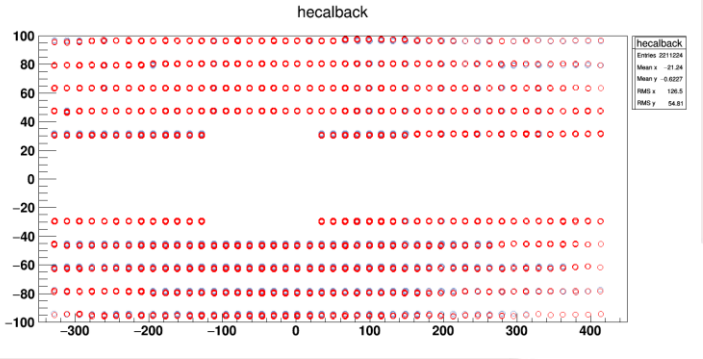
ECal geometry model for Geant4 simulation

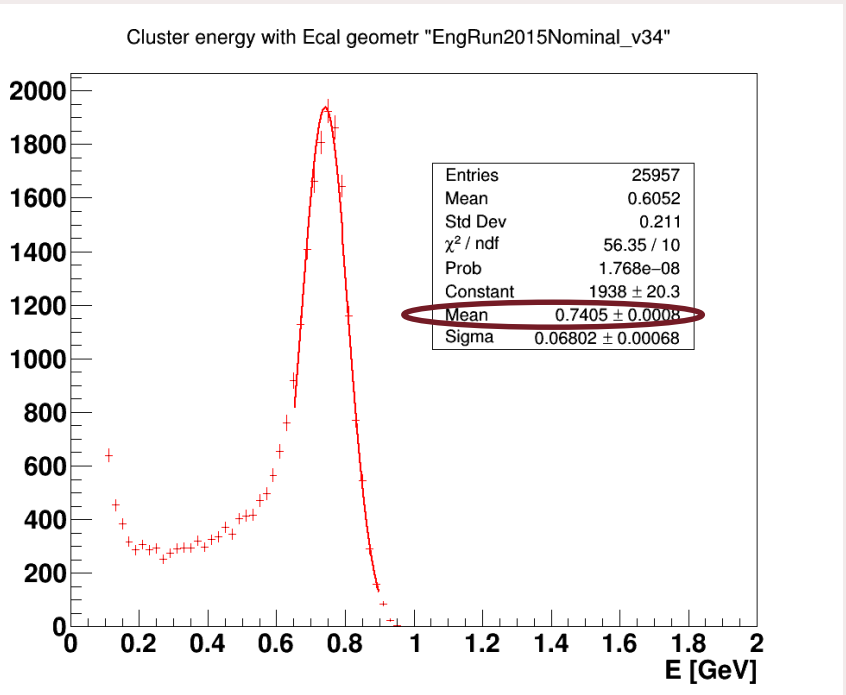
Ecal forever 2

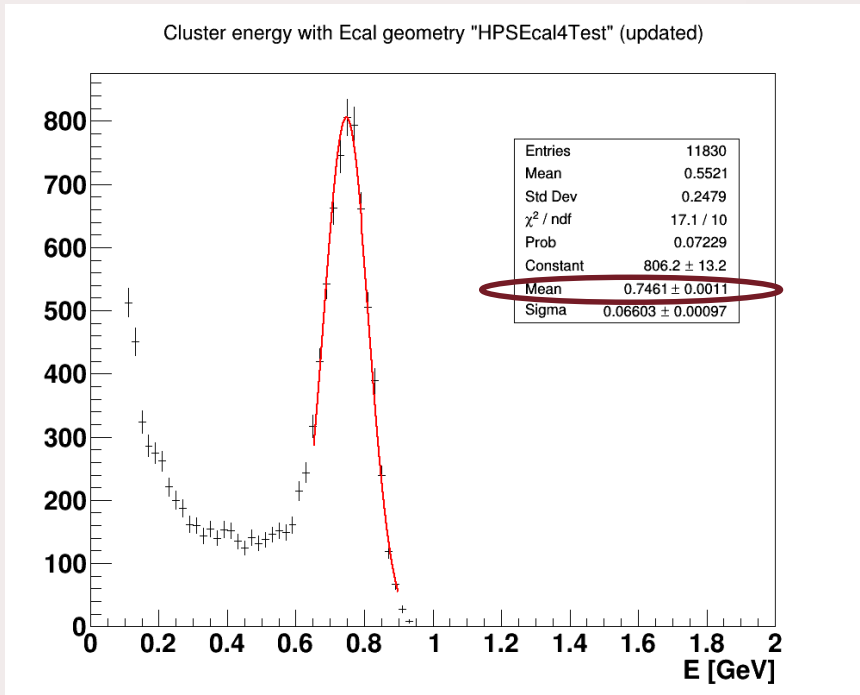




- Flexible Ecal detector geometry model is developed
- Doesn't affect the reconstructed cluster energy significantly



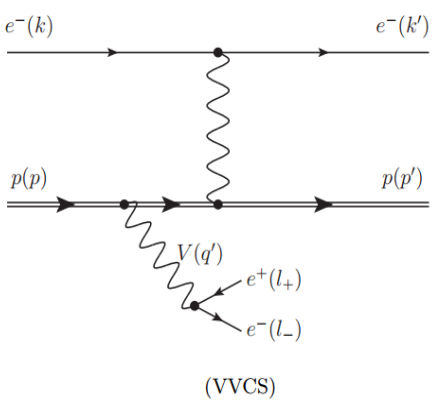




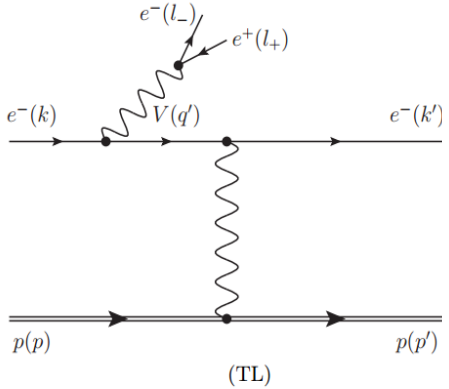
QED processes and cross section calculations

Feynman diagrams contributing to $ep \rightarrow epl^+l^-$

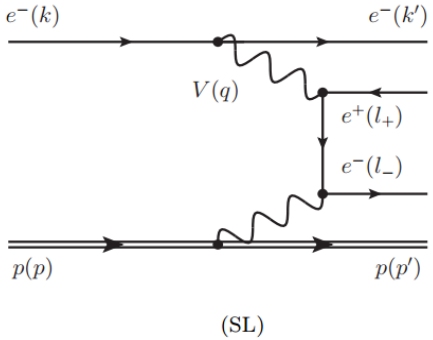
1. Direct Diagrams (D)



(VVCS)



(TL)



(SL)

2. + same diagrams with e^-_{beam} , e^-_{pair} exchange term (X)

Some processes neglected

- *VVCS –neglected for nucleon target*

Acceptance for HPS

$$|\varphi_{horizontal}| < 50\ [mrad]$$
$$-60 < \theta_{out\ of\ plane} < -15[mrad]$$
$$60 < \theta_{out\ of\ plane} < 15[mrad]$$

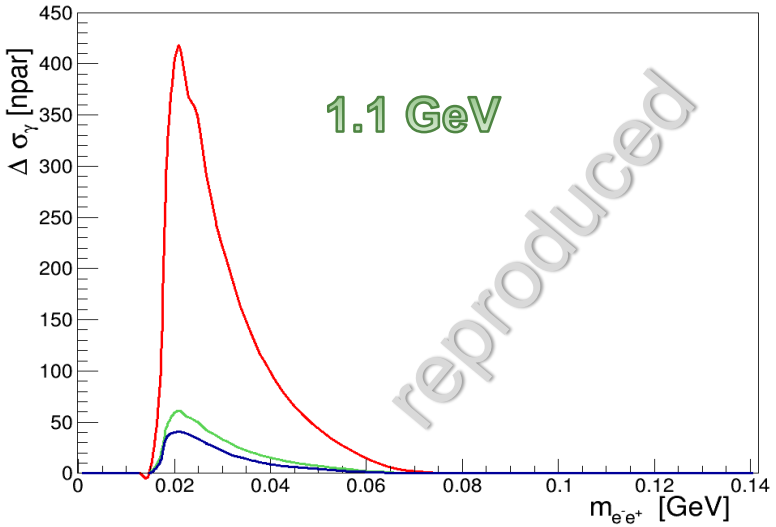
Differential Cross-Section

$$d\sigma = \frac{1}{4\sqrt{(k\cdot p)^2 - m^2M^2}}(2\pi)^4\delta^{(4)}(k+p-k'-p'-l_--l_+)$$
$$\times \frac{d^3\vec{k}'}{(2\pi)^3\,2\,E'_e}\frac{d^3\vec{p}'}{(2\pi)^3\,2\,E'_p}\frac{d^3\vec{l}_-}{(2\pi)^3\,2\,E_-}\frac{d^3\vec{l}_+}{(2\pi)^3\,2\,E_+}\overline{|\mathcal{M}|^2},$$

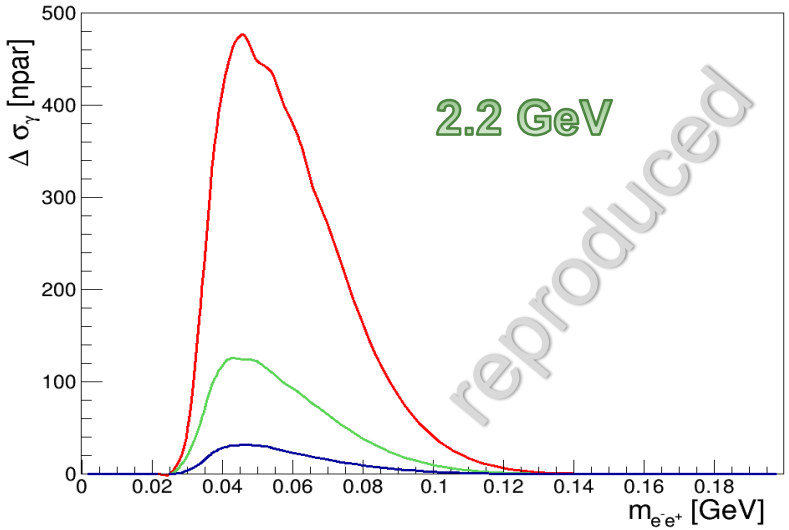
QED background cross section integrated by the acceptance

$$\Delta\sigma_\gamma \propto \left|\mathcal{M}^{\mathrm{TL}}_{\mathrm{D},\gamma^*} + \mathcal{M}^{\mathrm{SL}}_{\mathrm{D},\gamma^*} - \mathcal{M}^{\mathrm{TL}}_{\mathrm{X},\gamma^*} - \mathcal{M}^{\mathrm{SL}}_{\mathrm{X},\gamma^*}\right|^2$$

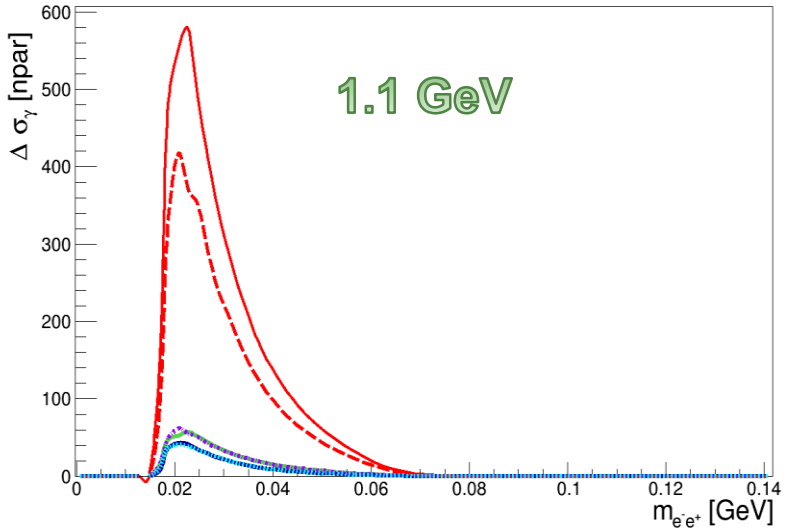
QED Background cross-section: Results



Red – SL+TL+X
Green – SL+TL
Blue – TL

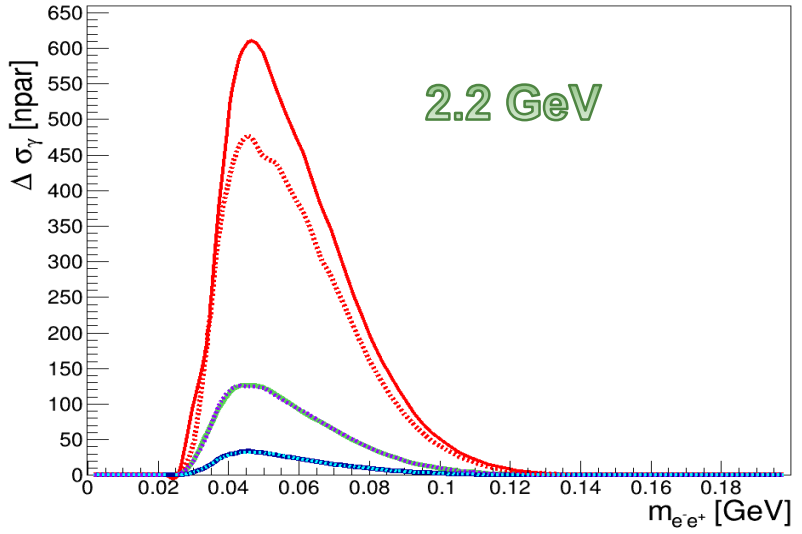


QED cross-section vs invariant mass of e^+e^- pair (by Beranek et.al)



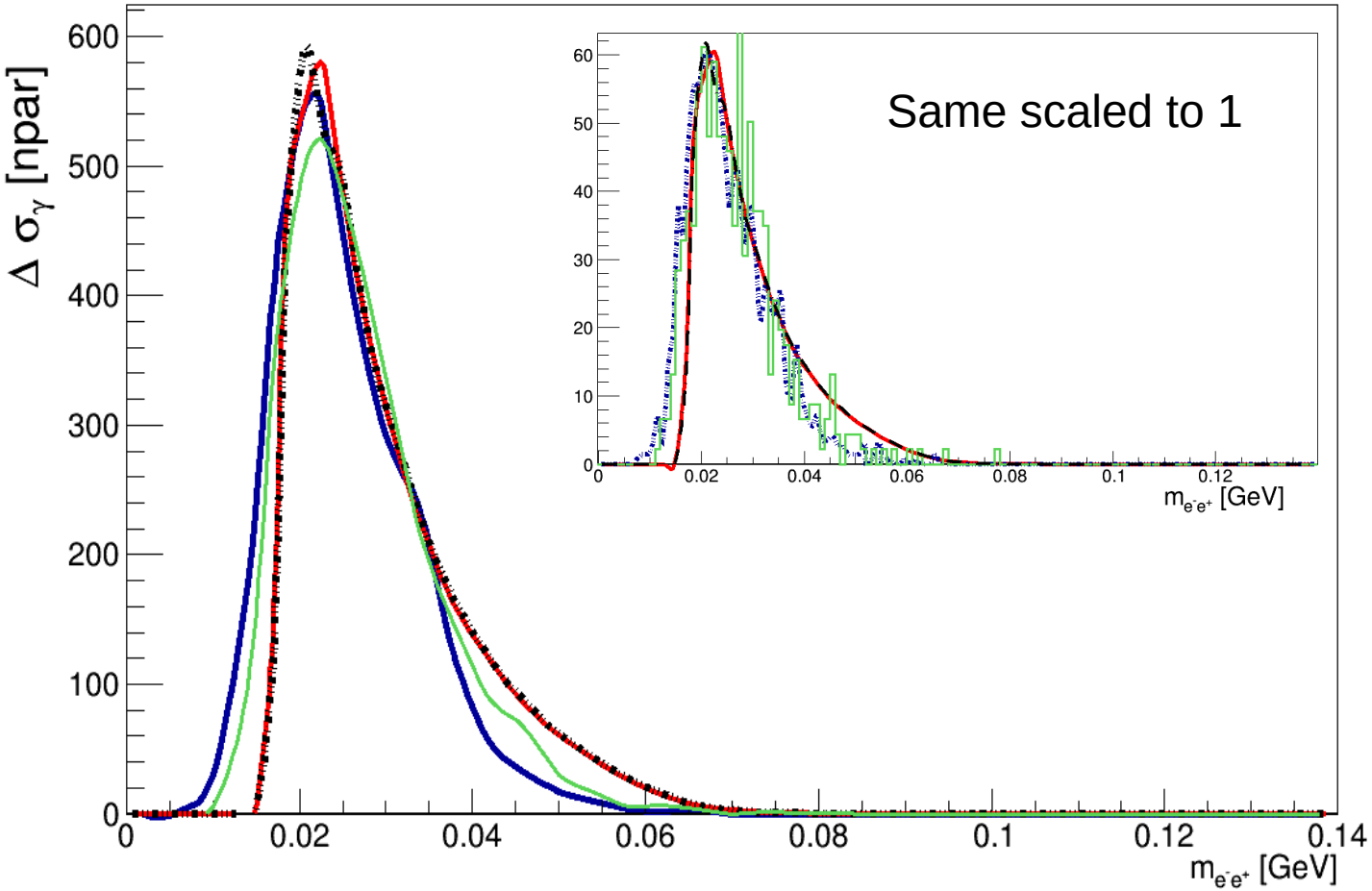
#Solid – electron beam

#Dashed – positron beam



QED cross section at ~1Gev

Comparison with different theoretical calculations (each distribution is scaled to *Beranek* calculation)



Red – Beranek calculation 1.1Gev

Blue – Luca's calculation 1.05GeV

Green – with MadGraph 1.05GeV

Acceptance from Luca

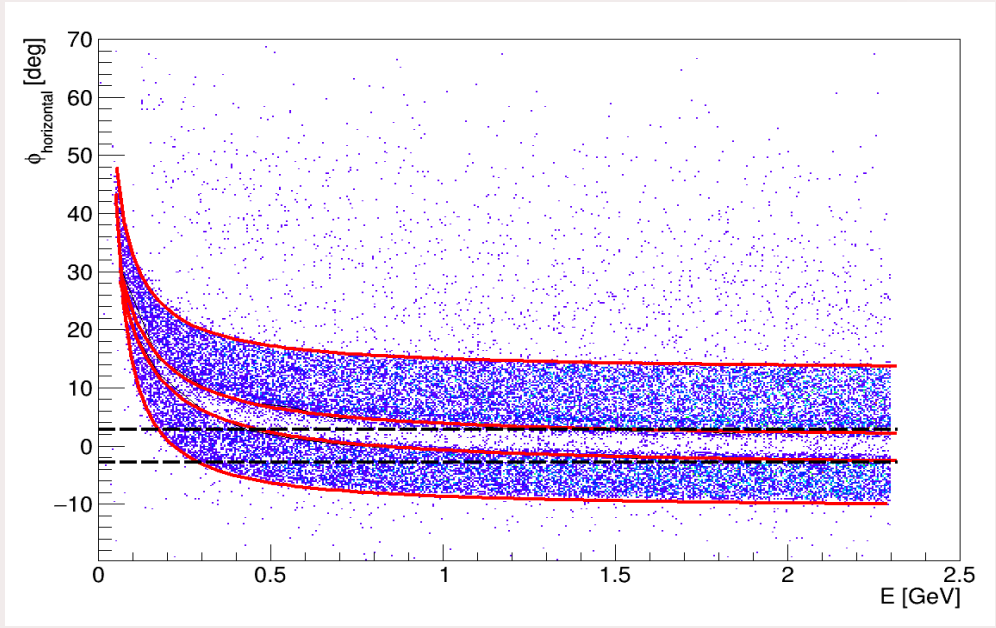
$$|\varphi_{horizontal}| < 25\ [mrad]$$
$$-90 < \theta_{out\ of\ plane} < -15[mrad]$$
$$90 < \theta_{out\ of\ plane} < 15[mrad]$$

Ecal acceptance for horizontal and out of plane angles

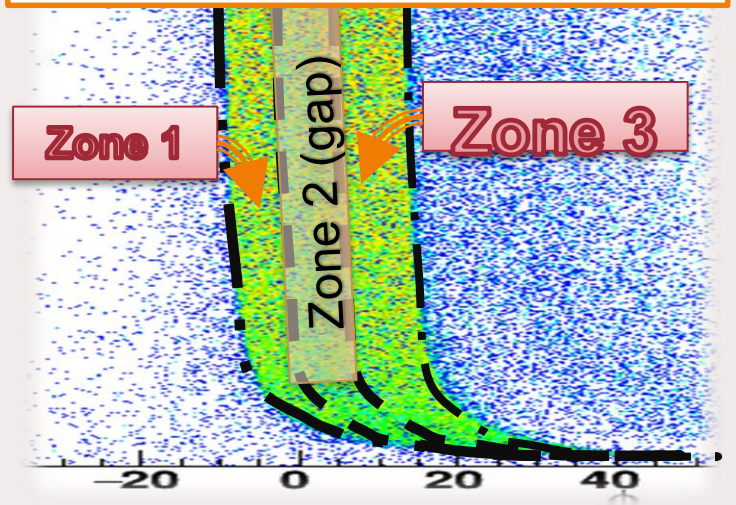
or the return of the Ecal

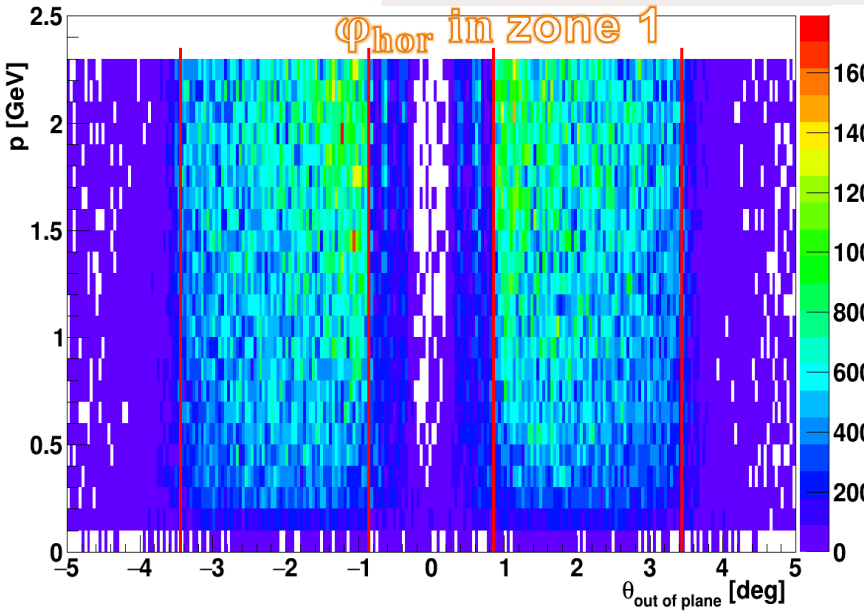
For simulated electrons with uniform distribution of:

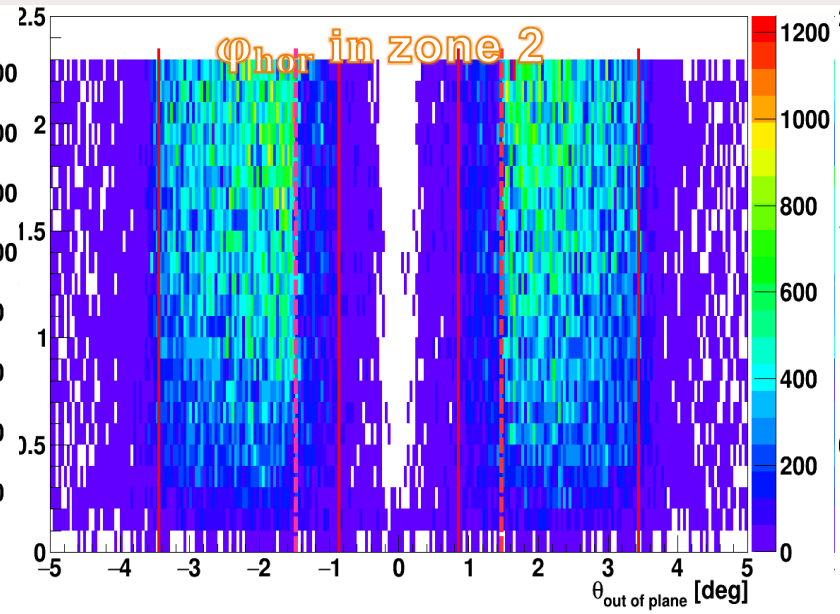
- $0 < E_{e^-} < 2.3\ GeV$
- $0 < \varphi < \pi$
- $0 < cos\theta < 1$

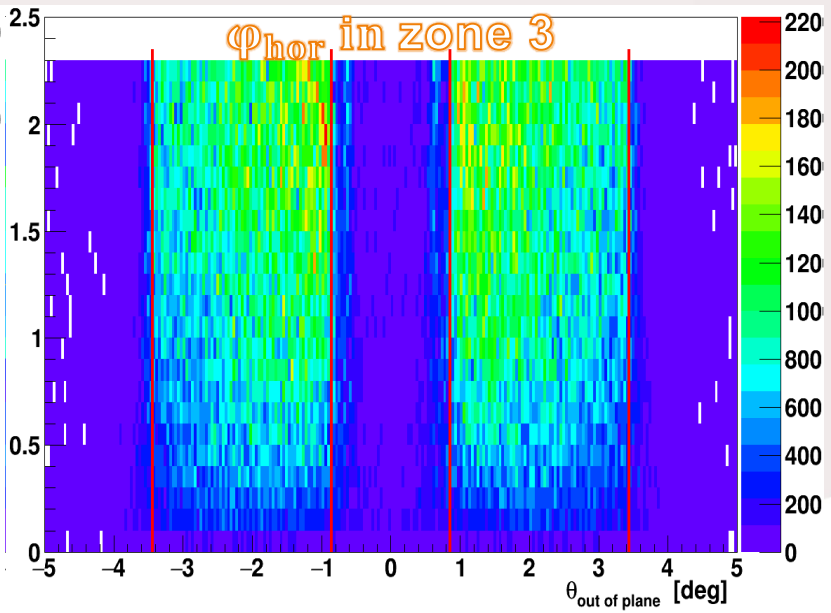


Parametrization φ_{hor}
in momentum dependece distribution



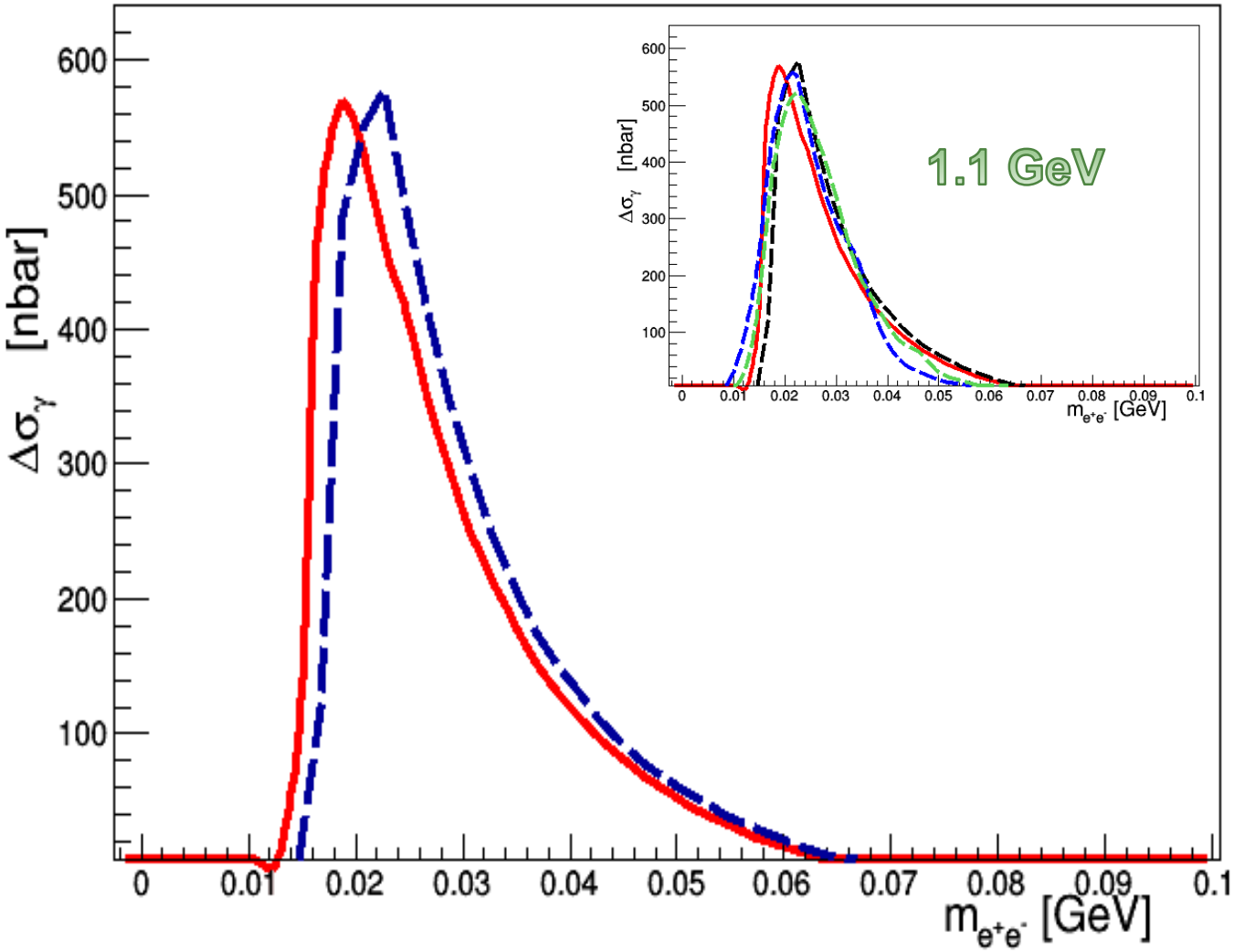






QED calculations with realistic acceptance for e^-

QED cross-section vs invariant mass of e^+e^- pair



Red – calc. acceptance

Ecal acceptance for φ_{hor} horizontal angle

$$\varphi_{min}(p) = -11 + \frac{1}{4.35(p - 0.009)}$$

$$\varphi_{min}^{gap}(p) = -4.098 + \frac{3.54}{0.0446 + p}$$

$$\varphi_{max}^{gap}(p) = 0.812 + \frac{3.203}{0.0439 + p}$$

$$\varphi_{max}(p) = 12.75 + \frac{1}{4.35(p - 0.399)}$$

Blue – simplistic box-like acceptance (Beranek et al)

Acceptance for HPS

$$|\varphi_{horizontal}| < 50\ [mrad]$$

$$-60 < \theta_{out\ of\ plane} < -15 [mrad]$$

$$60 < \theta_{out\ of\ plane} < 15 [mrad]$$

Summary

- ✓ *Signal properties and timing in Ecal*

- ✓ *QED background calculations for HPS*
  - *Beam particle charge inaccurate setting*
  - *Comparison with different calculations*

- ✓ *Ecal Acceptance calculations for electrons*
  - *dependency on momentum*
  - *Ecal gap exclusion limits*

In progress:

- ❑ *Acceptance for positive particles and application*
- ❑ *Developing event generator for QED process simulations*

References

- QED background cross section by Beranek et.al.

"Study of the discovery potential for hidden photon emission at future electron scattering fixed target experiments"

T. Beranek and M. Vanderhaeghen

Phys. Rev. D ***89****, – Published 10 March 2014*

"Theoretical framework to analyze searches for hidden light gauge bosons in electron scattering fixed target experiments"

T. Beranek, H. Merkel, M. Vanderhaeghen

Phys. Rev. D ***88****, 015032 – Published 29 July 2013*