Dark Photon Searches at Future e^+e^- Colliders

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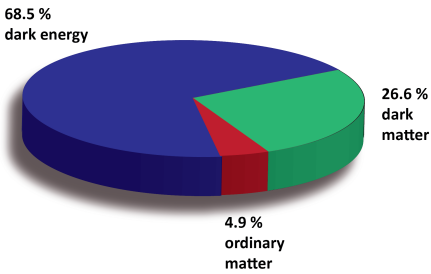
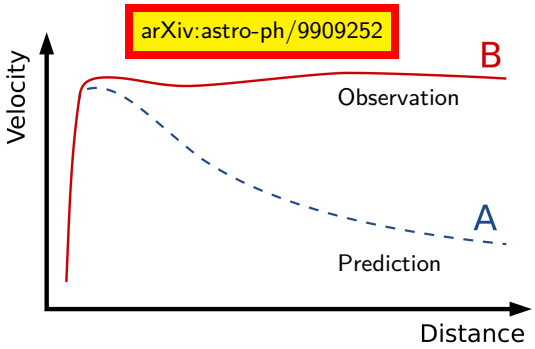
RESEARCH FOR GRAND CHALLENGES

Motivation



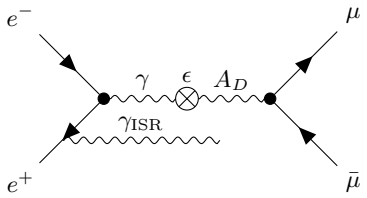


- Dark matter is crucial in theories beyond the standard model ($\sim \frac{1}{4}$ of universe consists of dark matter)

- Dark photon as hypothetical gauge boson in dark sector:
  - Direct study of Dark matter
  - Kinetic mixing with the standard model hypercharge

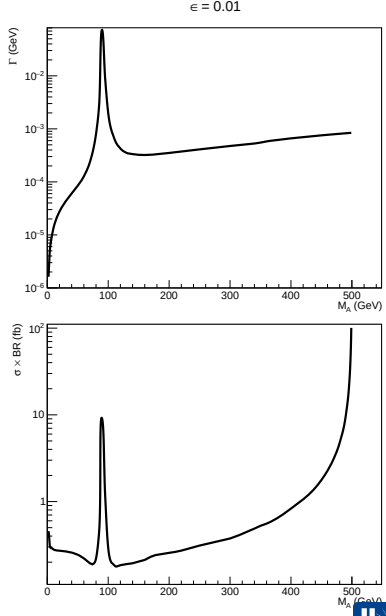
Dark photon

The only detectable sign of dark sector



$$\sigma \times BR \propto \epsilon^2$$

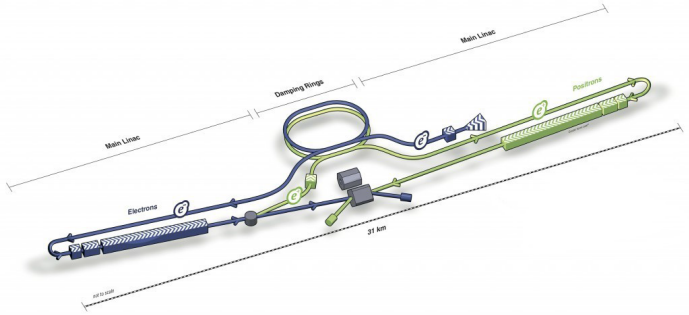
- For (almost) any m_{A_D}: $\Gamma < 1\text{MeV}$
- Heisenberg's uncertainty principle: $c\tau = \frac{1.97\times10^{-7}}{\Gamma_{\rm Tot}\,[\text{GeV}]}\ \mu\text{m}$
- Dark photon decays immediately ($\ll 1\mu\text{m}$)

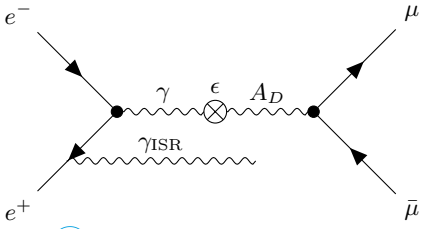


Courtesy of Mikael Berggren

Dark Photon in ILC

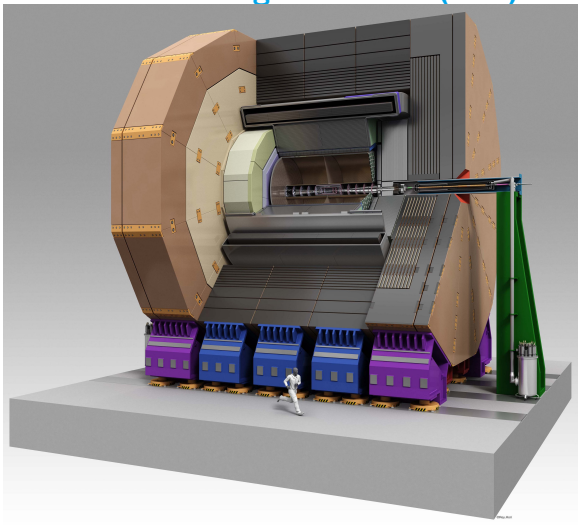
- ILC as a polarized e^+e^- collider with center-of-mass energy $\sqrt{s}$=250GeV (upgrades: 500GeV and 1TeV)





- Dark photon production in the ILC
  $e^-e^+ \to \gamma_{ISR} + A_D$
  $A_D \to \mu^+\mu^-$

International Large Detector (ILD)

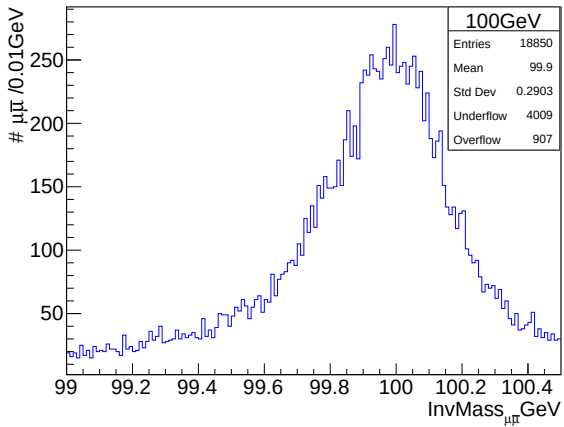


arXiv:2003.01116

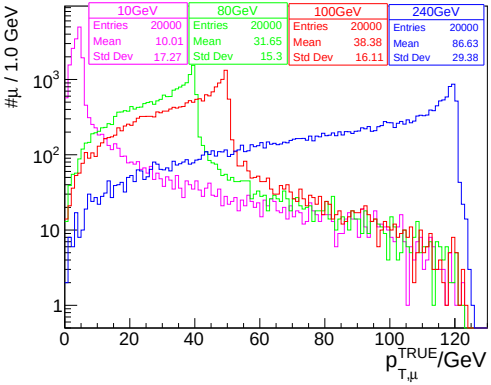
- **asymptotic momentum resolution:** $\boldsymbol{\sigma_{\frac{1}{P_T}} \sim 2 \times 10^{-5}\ \text{GeV}^{-1}}$
- impact parameter resolution: $\sigma_{d_0} \sim 5\mu m$
- jet energy resolution: $\frac{\sigma_{E_j}}{E_j} \sim 3 - 4\%$
- designed and optimized for ParticleFlow
- hermeticity down to 5 mrad

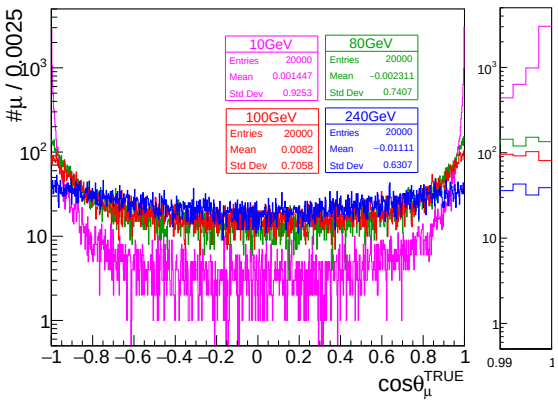
Data Sample

- $e^+e^- \to A_D \to \mu\bar{\mu}$ samples generated using WHIZARD event generator at $\sqrt{s}$=250 GeV. ($\epsilon = 0.01$) arXiV:1412.0018
- Assumed A_D mass: 10,20,30,...,80,100,...,240
- 10k sample per polarization configuration ($e_L^- e_R^+ / e_R^- e_L^+$) per A_D mass
- Full simulation of ILD detector using GEANT4
- Reconstructed using iLCSoft (using Pandora ParticleFlow Algorithm)
- Detector mass resolution $\sim \mathcal{O}(100\text{MeV})$ ($\gg \Gamma_{\text{Tot}}$)



Dark photon simulation in ILD

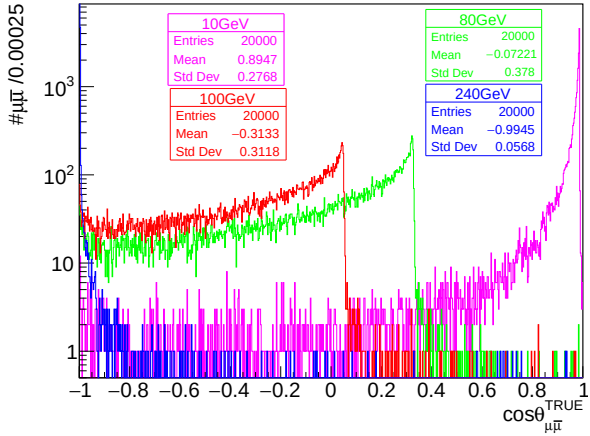




Dark photon detection is highly dependent on m_{A_D}:

- large mass dark photons: high p_T μ's $\Rightarrow$ better momentum (and mass) resolution
- low mass dark photons: Thrust axis is along beam-pipe $\Rightarrow$ hard to detect

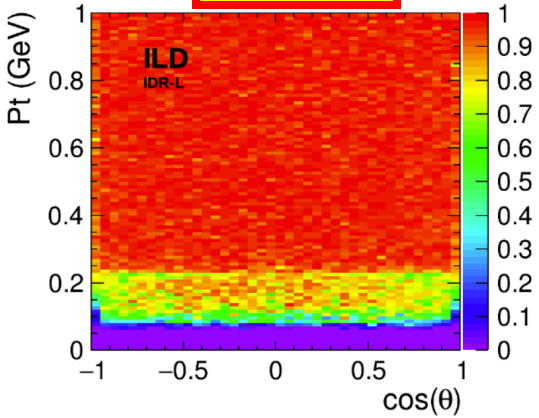
Dark photon simulation in ILD



Isolation of A_D decay products (μ's) extremely challenging in low m_{A_D}!
Decay products in high mass are back-to-back $\Rightarrow$ easy to distinguish

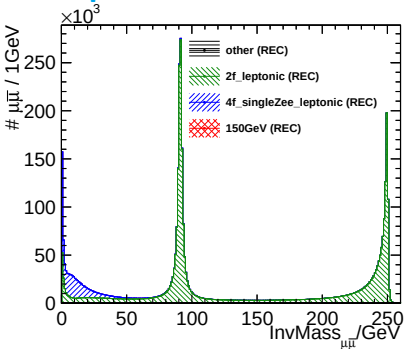
Tracking Efficiency in ILD

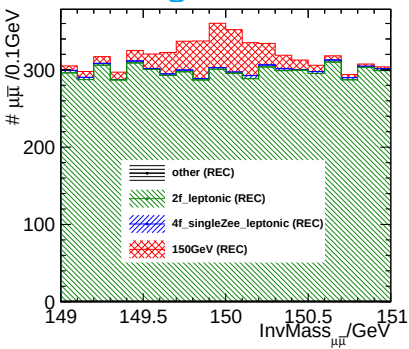
arXiv:2003.01116



Excelent tracking efficiency of the ILD allows to reconstruct charged leptons with high resolution.

Dark photon invariant mass in presence of SM background





- Dark photon signal: m_{A_D}=150 GeV
  $\sigma_{e^-_L e^+_R}$=0.66 fb, $\sigma_{e^-_R e^+_L}$=7.46 fb
- $\sqrt{s}$ = 250 GeV
- e^-e^+ Pol.: $(\pm 80\%\ ,\ \mp 30\%)$
- Normalized to $\mathcal{L}_{\text{int}}$ = 900 fb^{-1}

- Standard Model Backgroung:
  - 2f-leptonic
  - 4f single Zee-leptonic
  - rest SM-background
- Observable (even small) signal in presence of SM-background

Conclusion

- Dark matter is crucial in theories BSM
- Dark photon is (probably) the only detectable particle of dark sector
- Future e^+e^- collider experiments have capability to produce and detect dark photon
- ILD as a detector optimized for particle flow, reconstructs individual particles with an excellent momentum and impact parameter resolution
- Performance of the ILD for detection of dark photon with different mass hypothesis is studied

Outlook

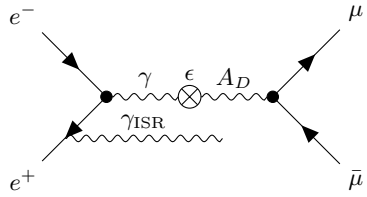
- Determine ϵ^2_{min} as a function of m_{A_D} $\Rightarrow$ get an observable signal of dark photon in ILD

BACKUP

Dark photon

The only detectable sign of dark sector

$$\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$$



$$\frac{d\sigma}{d\cos\theta} = 2\pi\epsilon^2\alpha^2 \frac{(s+m_{A_D}^2)^2+(s-m_{A_D}^2)^2\cos^2\theta}{s.(s-m_{A_D}^2)(s.\sin^2\theta+4m_e^2)}$$

$$\Gamma(A_D \to f\bar{f}) = \tfrac{1}{3}\epsilon^2 Q_f^2 \alpha m_{A_D} (1+\frac{2m_f^2}{m_{A_D}^2})(1-\frac{4m_f^2}{m_{A_D}^2})^{\frac{1}{2}}$$

$$\sigma \times BR \propto \epsilon^2$$

Heisenberg's uncertainty $c\tau = \frac{1.97\times10^{-7}}{\Gamma_{tot}[GeV]}$ μm