

Adding dark photons into FairShip

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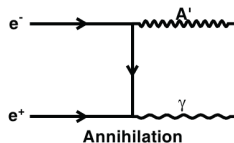
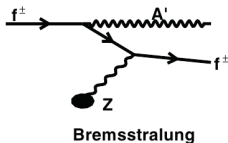
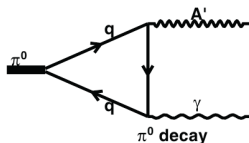
08/06/2017, Ship Collaboration meeting

Introduction

- Minimal hidden U(1) extension of the SM:

$$L_{eff} = L_{SM} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{m_{\gamma'}^2}{2} A'_\mu A'^\mu - \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu}$$

- Kinetic mixing ϵ
- Adapting code from Elena's standalone analysis described in CERN-SHIP-NOTE-2016-004.

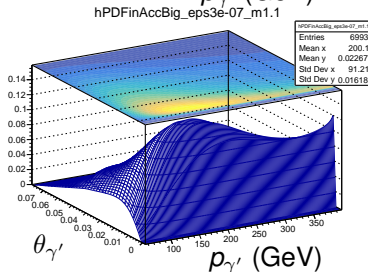
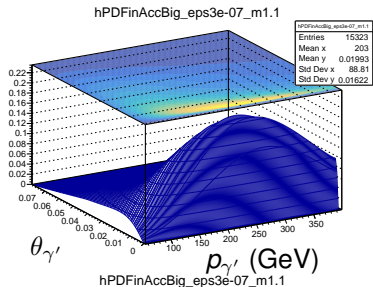


Production through meson decays: available since Nov2016

- Produce mesons inclusively with Pythia8: "SoftQCD:nonDiffractive = on"
- Create a new particle for the γ' with PDGid=9900015. **Switch to 9900022??**
- Depending on mass of γ' , enable decay of corresponding meson to dominant photon channel with 100% BR.
- Correct for expected BR (**should do offline or in event weight?**):
 - $BR(M \rightarrow \gamma' \gamma) \simeq 2\epsilon^2 \left(1 - \frac{m_{\gamma'}^2}{m_M^2}\right) \times BR(M \rightarrow \gamma \gamma)$
 - $BR(V \rightarrow P \gamma') \simeq \epsilon^2 \times BR(V \rightarrow P \gamma) \times \frac{(m_V^2 - m_{\gamma'}^2 - m_P^2) \sqrt{(m_V^2 - m_{\gamma'}^2 + m_P^2)^2 - 4m_V^2 m_P^2}}{(m_V^2 - m_{\gamma'}^2)^3}$
- If several mesons produced, choose only one randomly: need to also correct for this effect to have total production rate correct.

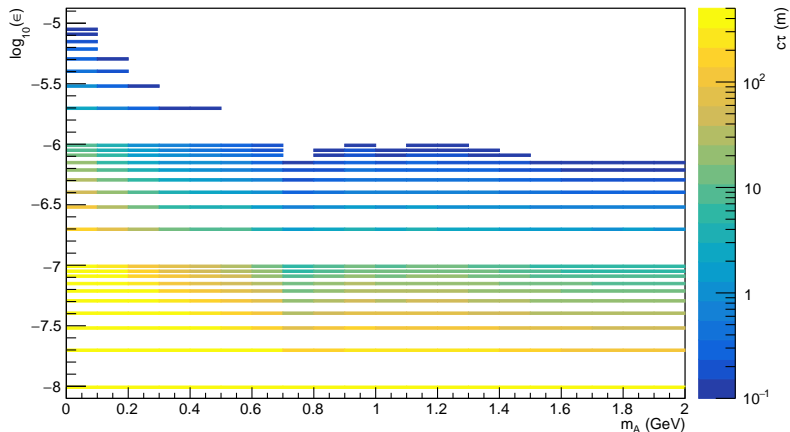
Production through proton bremsstrahlung

- Create PDF vs momentum and angle of dark photon, following math from CERN-SHiP-NOTE-2016-004 / arxiv 1311.3870 / arxiv 1411.4007.
- Fixed couple of typos (checking with authors from arxiv 1311.3870 for a formula which was different in different references).
- Use Pythia8 particle gun with kinematics from random number on PDF.



Dark photon decay: lifetime

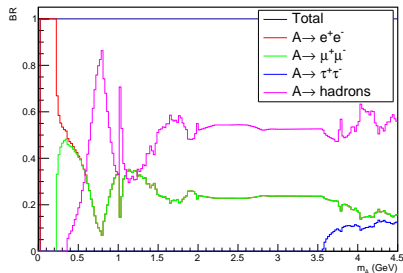
- Similarly to HNL, correct decay length to ensure all events will decay within sensitive volume, with corresponding probability set as event weight.
- Orange-greenish to orange-yellowish area for ship sensitivity.



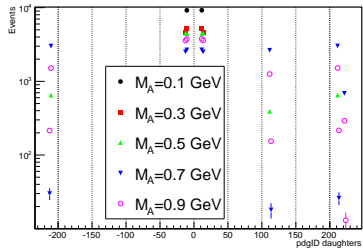
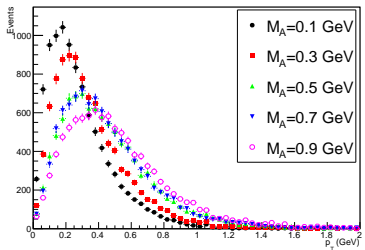
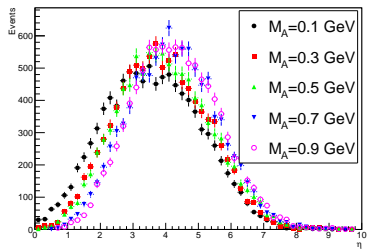
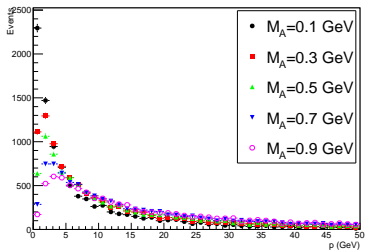
Dark photon decay products

- $\Gamma_{\gamma' \rightarrow l+l-} = \frac{1}{3} \epsilon^2 \alpha m_{\gamma'} \left(1 + \frac{2m_l^2}{m_{\gamma'}^2}\right) \sqrt{1 - \frac{4m_l^2}{m_{\gamma'}^2}}$
- $\Gamma_{\gamma' \rightarrow \text{hadrons}} = \Gamma_{\gamma' \rightarrow \mu^+ \mu^-} \times R(s = m_{\gamma'}^2)$
- $R(\sqrt{s}) = \frac{\sigma(e^+ e^- \rightarrow \text{hadrons})}{\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)}$ from tabulated PDG values for $m_{\gamma'} \simeq 0.36 - 4.8$ GeV.
- To fully simulate hadron decays: take relative branching ratios of $Z \rightarrow q\bar{q}$
- similar implementation as in 30th May 2014 meeting <https://indico.cern.ch/event/316981/> and in good agreement.

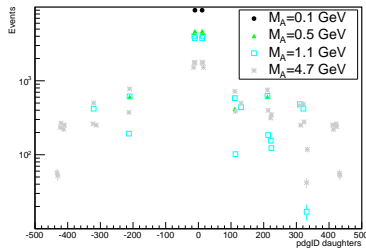
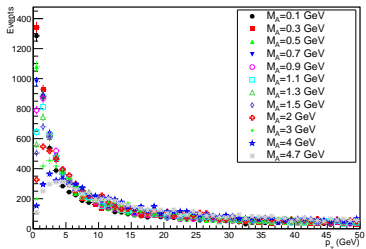
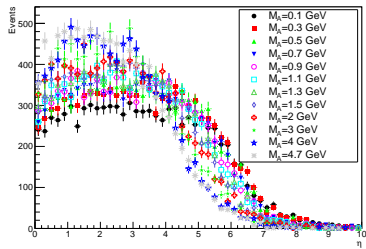
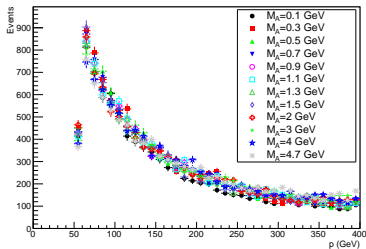
Final state	relative BR from Z/γ^* decays
$u\bar{u}$	0.22031
$d\bar{d}$	0.17089
$s\bar{s}$	0.22029
$c\bar{c}$	0.17066
$b\bar{b}$	0.21785



Kinematics and decay of the dark photon from meson production



Kinematics and decay of the dark photon from proton brem



Conclusion

- Now implemented both meson and proton bremsstrahlung production modes in Fairship.
- For decay, at the moment only decay to leptons are considered, but possible to extend to other models.
- Next: add Drell-Yan-like production, considering to use hidden-valleys-type models as implemented already in Pythia8. Need input/feedback from theory side!