FASER: ForwArd Search ExpeRiment at the LHC

work with Jonathan Feng, Iftah Galon and Sebastian Trojanowski

arXiv: 1708.xxxxx

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DPF 2017

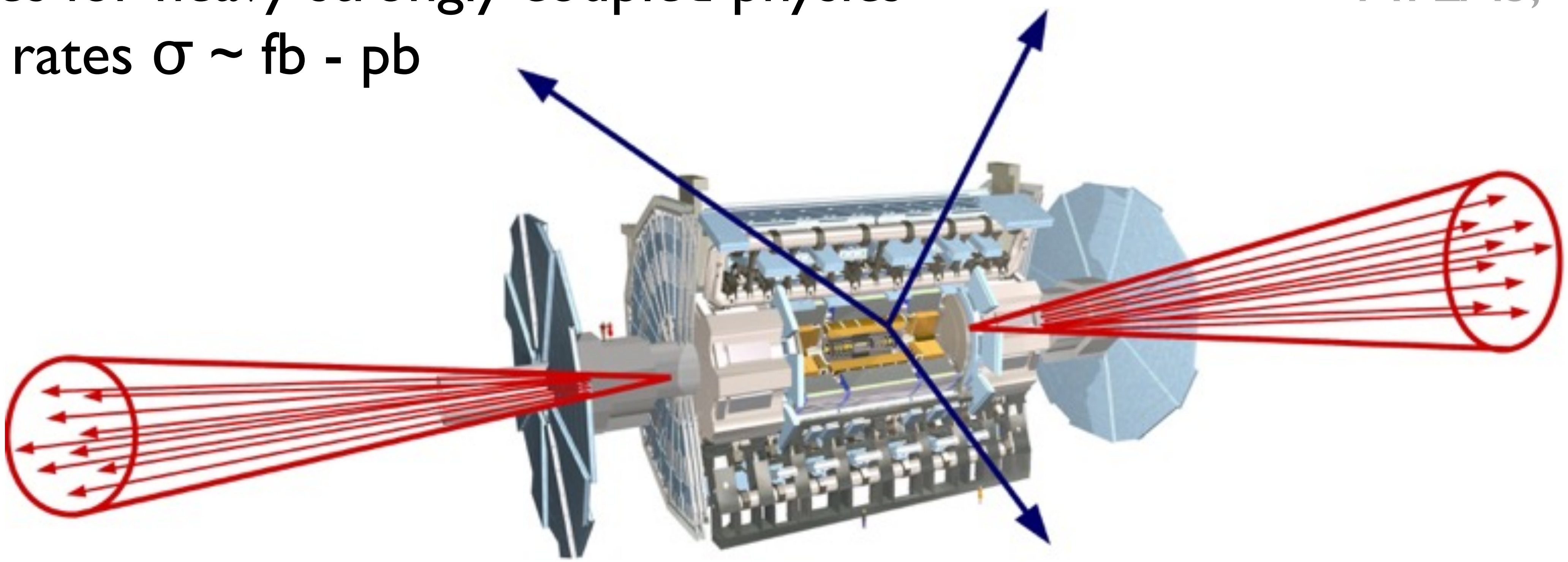
August 3rd 2017

Introduction

transverse region: high pT

Milliqan, Mathusla
ATLAS, CMS

- searches for heavy strongly coupled physics
- typical rates σ ~ fb - pb



forward region

- mostly used for SM measurement

LHCf, TOTEM, ALFA, CASTOR

- **enormous** event rates: $\sigma_{inel} \sim 75$ mb ($\sim 10^{17}$ inelastic pp collisions)

→ even extremely weakly-coupled particles may be produced sufficiently

- most decay products have small pT $\sim \Lambda_{QCD}$

→ energetic particles highly **collimated** $\theta \sim \Lambda_{QCD}/E \sim \mathrm{mrad}$ for $E \sim \mathrm{TeV}$

- we propose small ($\sim 1\ \mathrm{m}^3$) inexpensive detector a few 100 m downstream

→ **FASER: ForwArd Search ExpeRiment at the LHC**

Outline

LHC Infrastructure - where can we place the experiment

Dark Photons - a physics example

Detector Considerations - what detector design do we need

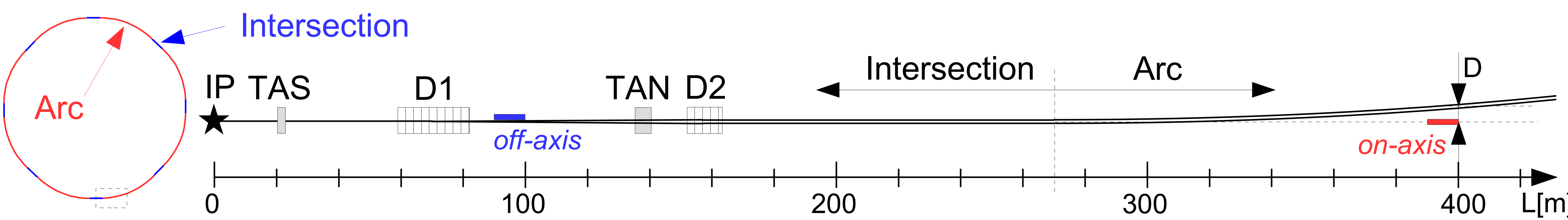
Backgrounds - and why we do not worry about them

Expected Reach - how do we perform

Summary and Outlook

LHC Infrastructure

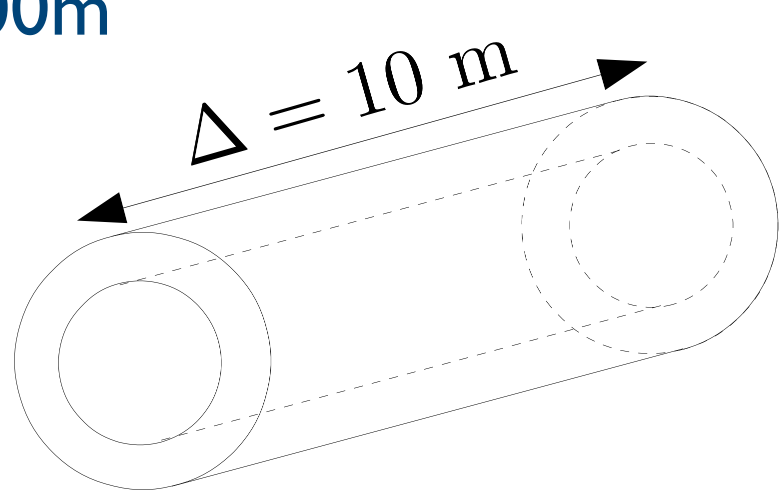
IP - particles produced at ATLAS/CMS Interaction Point
TAS - Front Quadrupole Absorbers absorbs particles with $\theta > 0.85$ mrad
DI - inner beam separation dipole magnet
→ charged particles ($\mu, \pi^{\pm}$) get deflected
TAN - forward n, γ absorbed by Target Neutral Absorbers
Arc - beam starts to curve at $L = 272$m



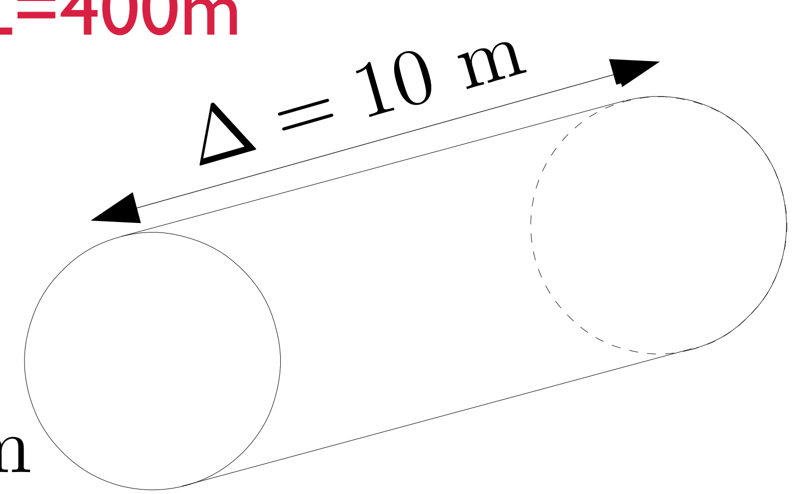
Detector Locations

off-axis: L=100m

inner radius
$R_{in} = 10$ cm
outer radius
$R_{out} = 20$ cm



on-axis: L=400m



outer radius
$R_{out} = 20$ cm

A Physics Example - Dark Photons

Dark Photons

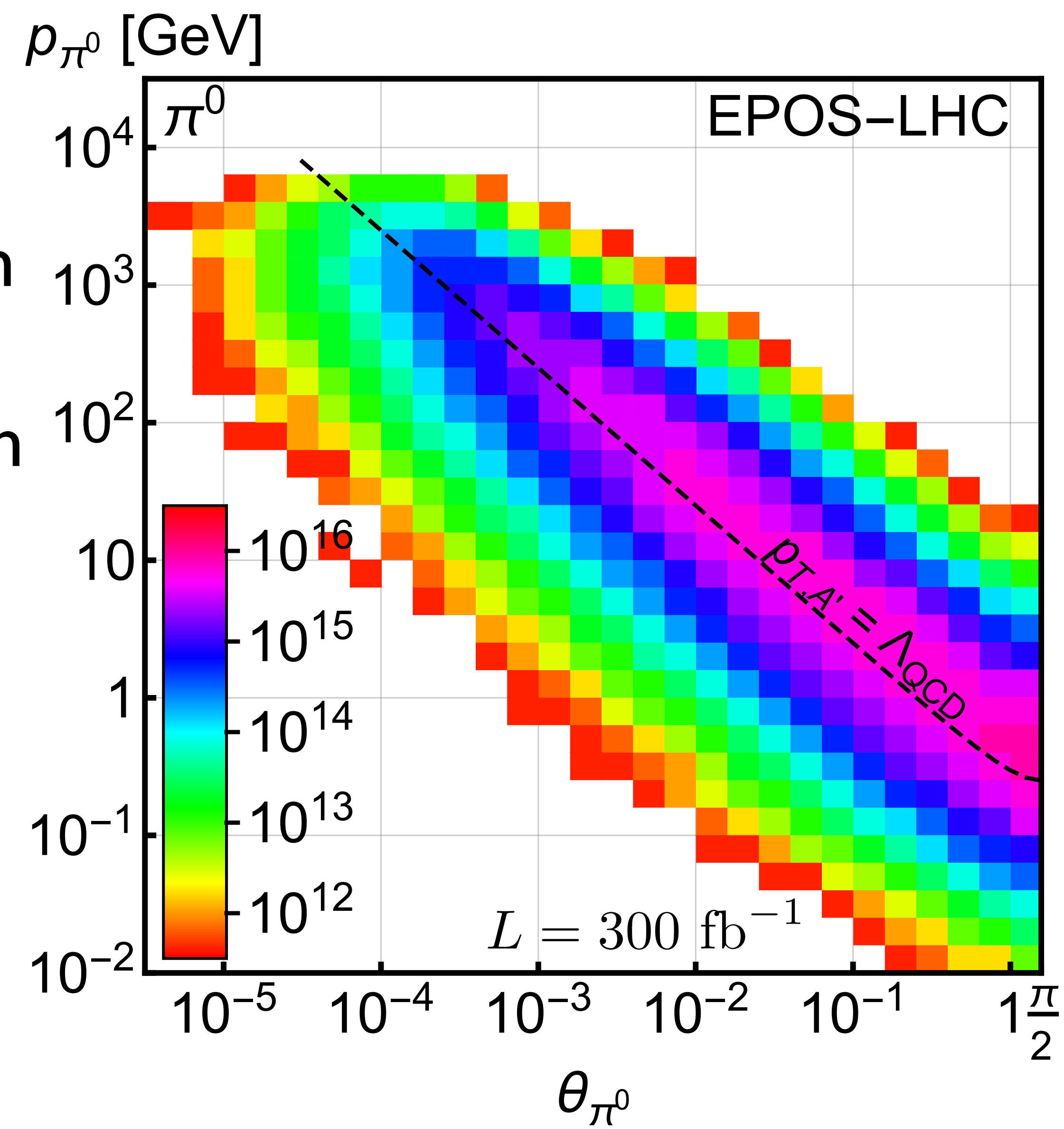
- (broken) dark U(1) gauge group mixing with the SM photon

$$\mathcal{L} \supset -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{1}{2} m_{A'}{}^2 + \sum \bar{f}(i\,\partial\!\!\!/ - \epsilon e q_f A\!\!\!/') f$$

- FASER aims to probe $m_{A'} \sim 10 - 500 \text{ MeV}$ and $\epsilon \sim 10^{-6} - 10^{-4}$

Production Modes

- meson decays: mainly $\pi^0 \to \gamma A'$, $\eta \to \gamma A'$
- proton Bremsstrahlung: $pp \to pA'X$
  Fermi-Weizsäcker-Williams approximation
- (direct production): $q\bar{q} \to gA'$, $qg \to qA'$
  PDFs at low Q^2 and low x highly uncertain



Meson Production

- use forward tools/models
  EPOS-LHC, SIBYLL 2.3, QGSJETII-04
- boosted mesons highly collimated
  $p \cdot \theta = p_T \sim \Lambda_{QCD}$
- large rates at $L = 300 \text{ fb}^{-1}$

A Physics Example - Dark Photons

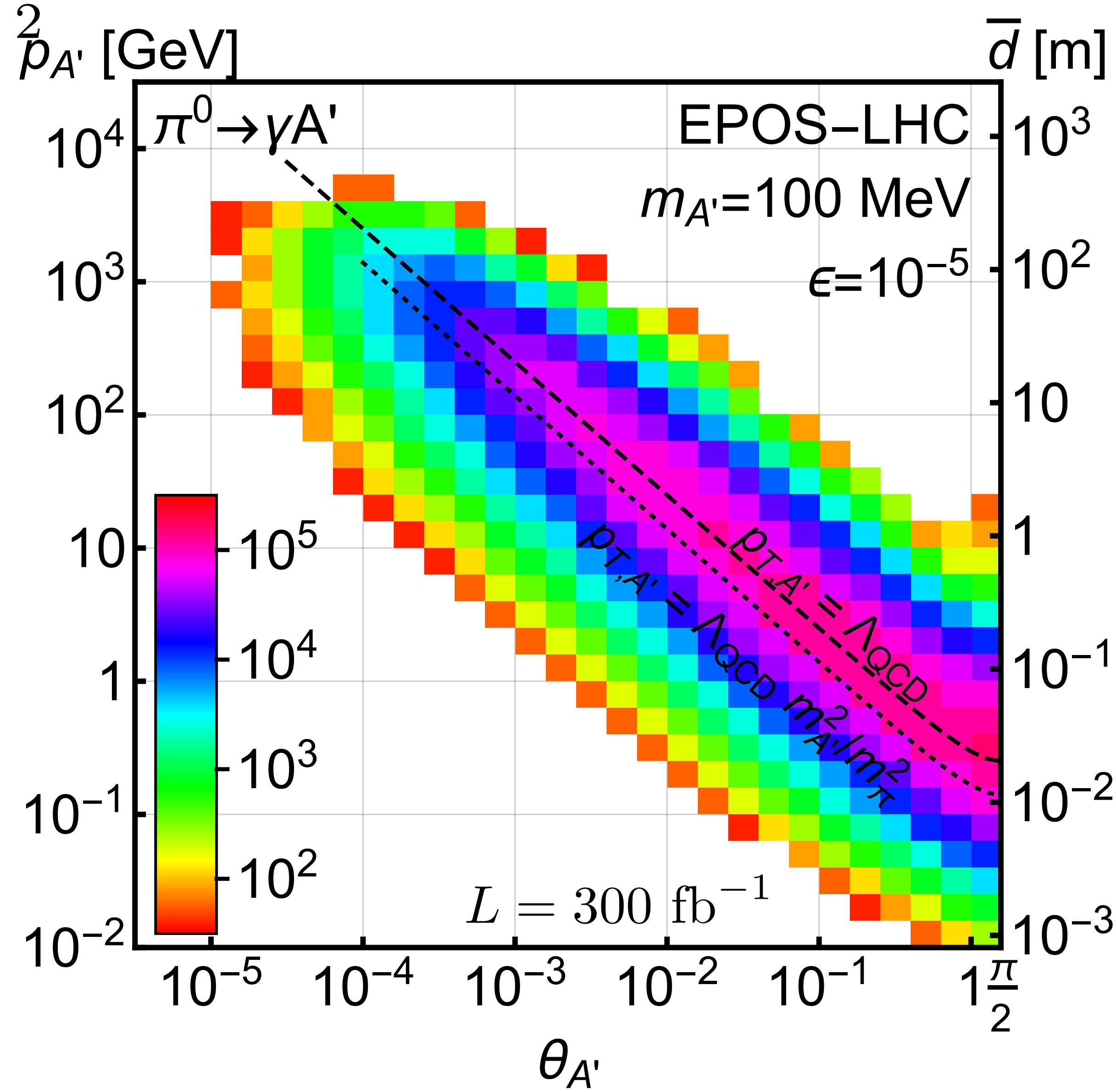
Meson Decay to Dark Photons

- branching fractions: $\mathrm{BR}(\pi^0 \to \gamma A') = 2\epsilon^2 \left(1 - \frac{m_{A'}^2}{m_\pi^2}\right)^3$
- even small $\epsilon \sim 10^{-5}$ large sizable rate

Dark Photon Decay

- A' is long lived: $\Gamma_{A'} = \epsilon^2 e^2 m_{A'}^2/(12\pi\ \mathrm{BR}(A' \to ee))$
- decay length

$$\bar{d} \approx 80\mathrm{m}\ B_e \left[\frac{10^{-5}}{\epsilon}\right]^2 \left[\frac{E_{A'}}{\mathrm{TeV}}\right]\left[\frac{100\ \mathrm{MeV}}{m_{A'}}\right]^2$$



A Physics Example - Dark Photons

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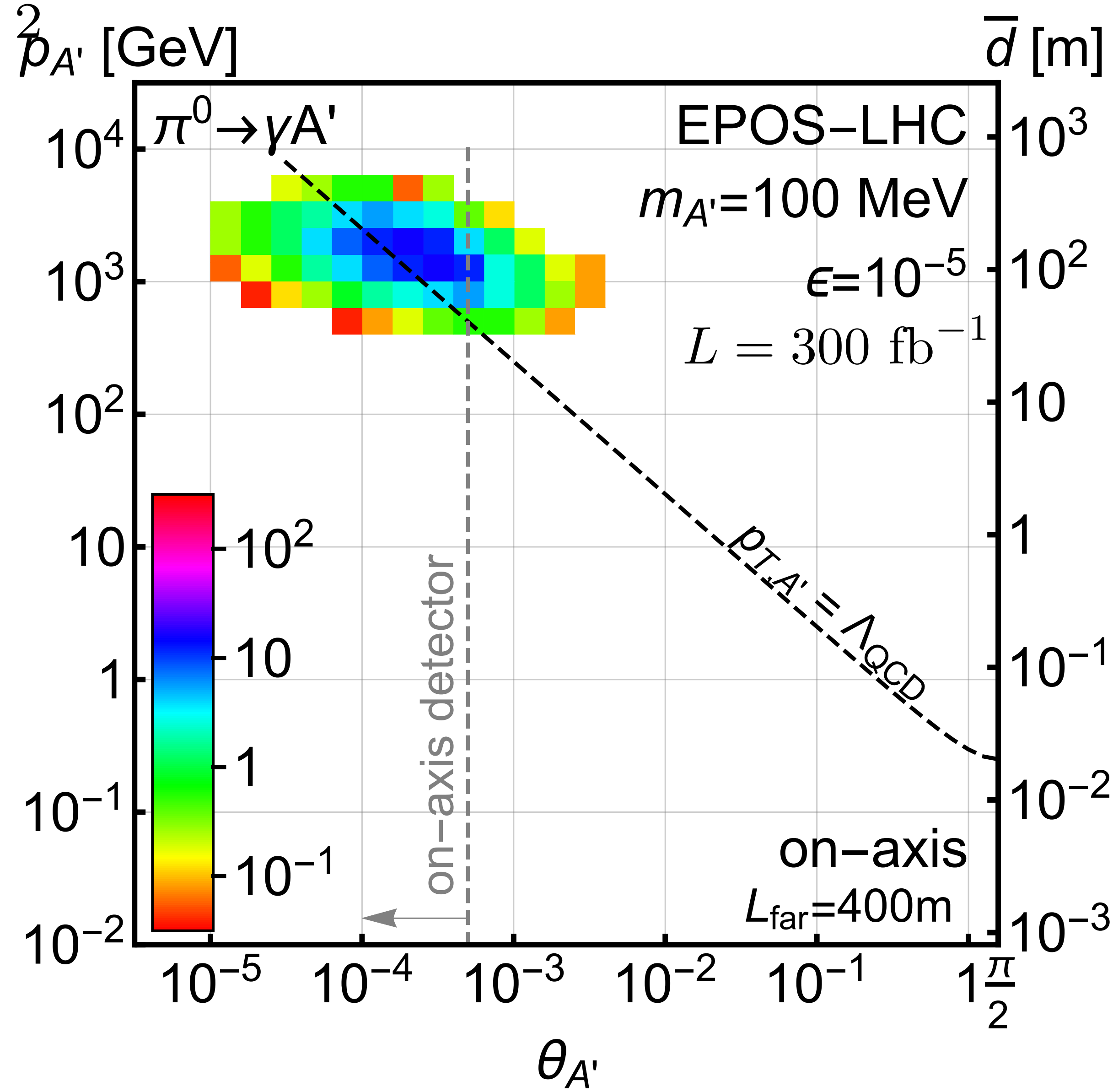
- probability to decay inside detector:
  $$\mathcal{P} = e^{-L/\bar{d}} \left[e^{\Delta/\bar{d}} - 1\right] \Theta\left(L\theta_{A'} - R\right)$$
- only A' with E~TeV will reach detector
- A' very forward $\theta_{A'} < 1\ \mathrm{mrad}$
  → small detector radius



Detector Considerations

Detector Position and Size

- ideally as close as possible to IP
- small detector radius R~20cm sufficient
- *off-axis* design benefits from low distance, but suffers from reduced angular coverage

Kinematic Features of Signal

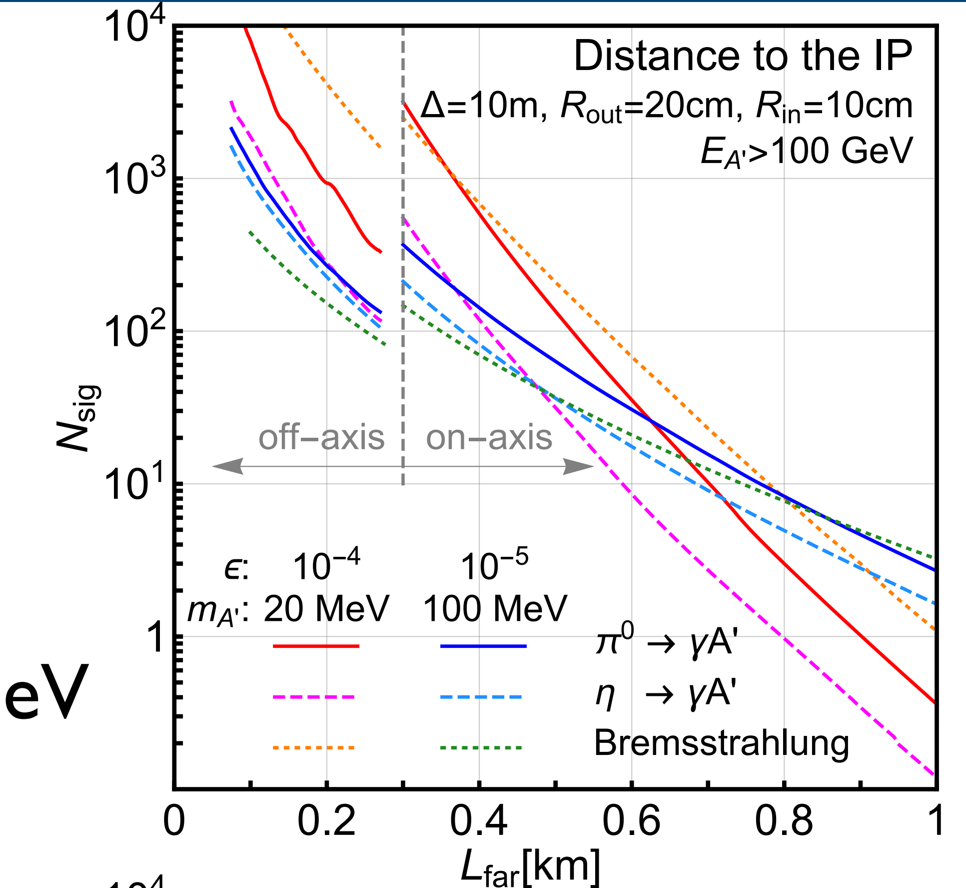
- two oppositely charged energetic tracks: E>500 GeV
- vertex inside detector volume
- combined momentum points towards IP

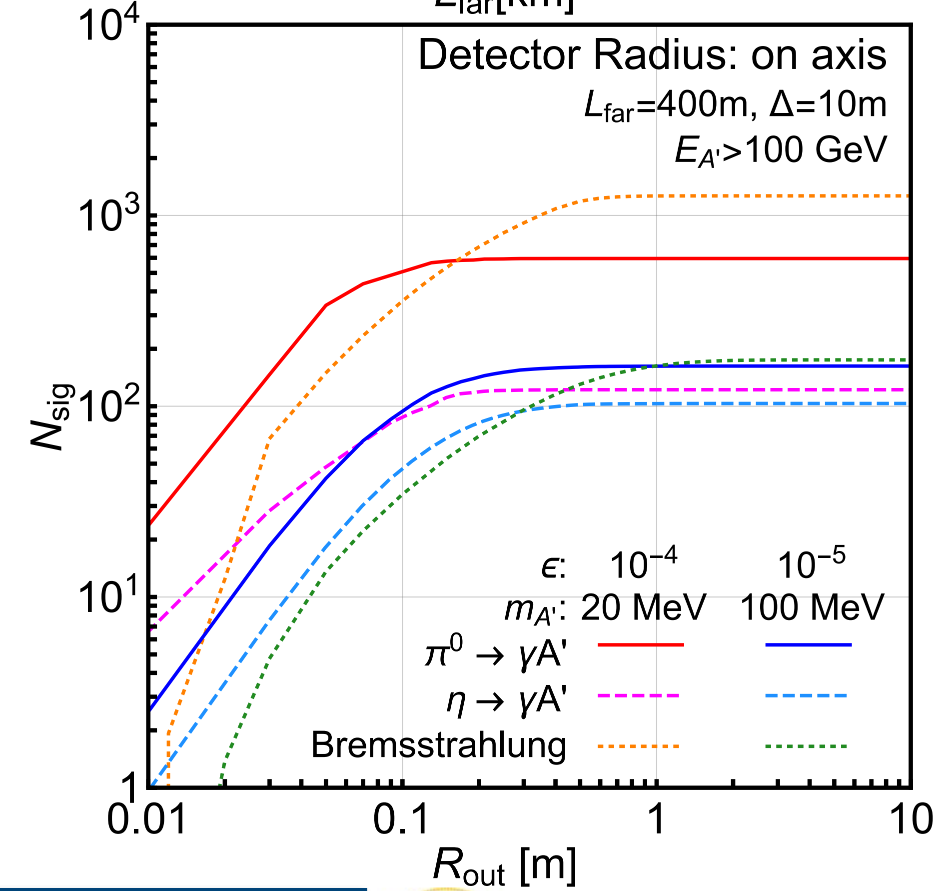
Proposed Detector Apparatus

- tracking based technology
- small opening angle $\theta_{ee} \sim m_{A'}/E_{A'} \sim 10\ \mu\text{rad}$
- magnetic field required to obtain sizable splitting

$$h_B = 3\ \text{mm}\ \left[\frac{1\ \text{TeV}}{E}\right]\left[\frac{\ell}{10\ \text{m}}\right]^2\left[\frac{B}{0.1\ \text{T}}\right]$$

→ can be obtained by conventional magnets





Backgrounds

Signal

- 2 simultaneous high energy tracks
- tracks start inside detector
- combined momentum points towards IP
- both tracks have similar energy

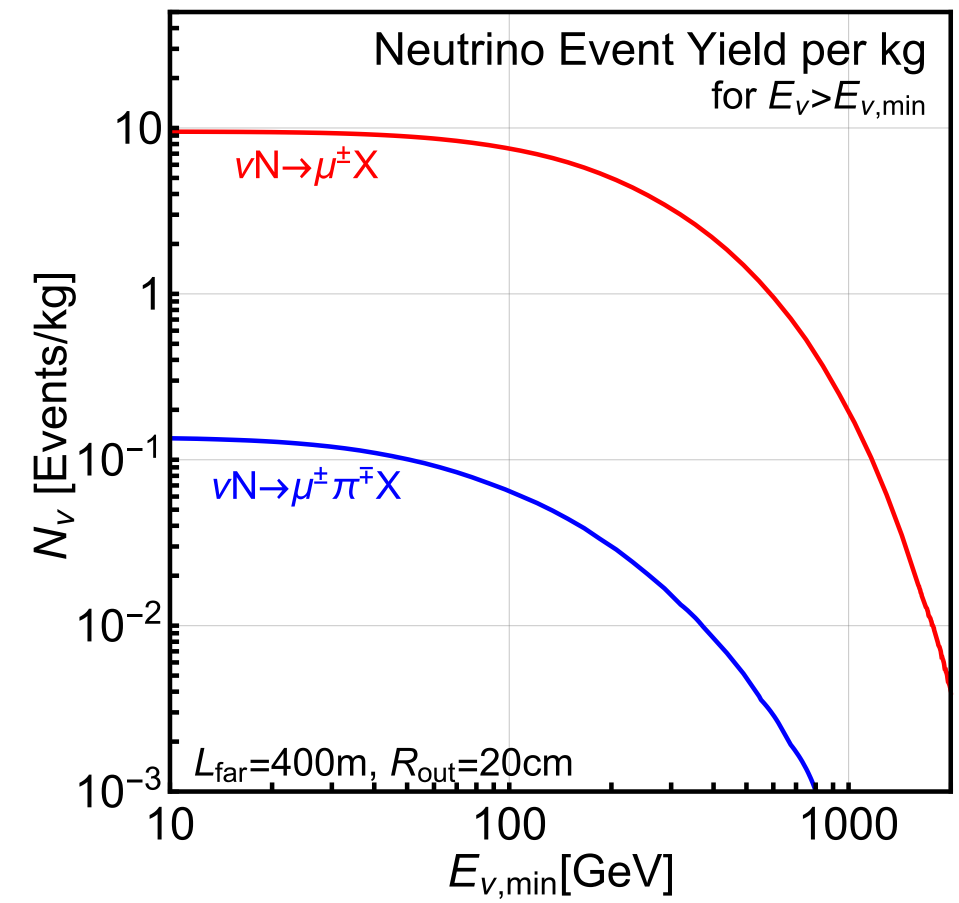
Tracks starting outside detector

- particles from IP
  → deflected/absorbed by D1/TAS/TAN
- cosmic/beam induced high energy μs
  → expected rate: $10^{-4}\ \mathrm{Hz/cm}^2$ ATLAS: 1203.0223
  → $< 10^{-2}$ simultaneous tracks/year

kinematic features reduce these BG
possible scintillating layer for veto

Tracks starting inside detector

- mainly ν_μ from $\pi^\pm$, but also heavy mesons 1110.1971
- $\nu N \to \mu^\pm X$: ~8 events with E>100GeV
  → simultaneous CC interaction highly unlikely
- $\nu N \to \mu^\pm \pi^\mp X$: $\sim 10^{-1}$ events
  → pion usually soft $E_\pi / E_\mu \lesssim 0.05$

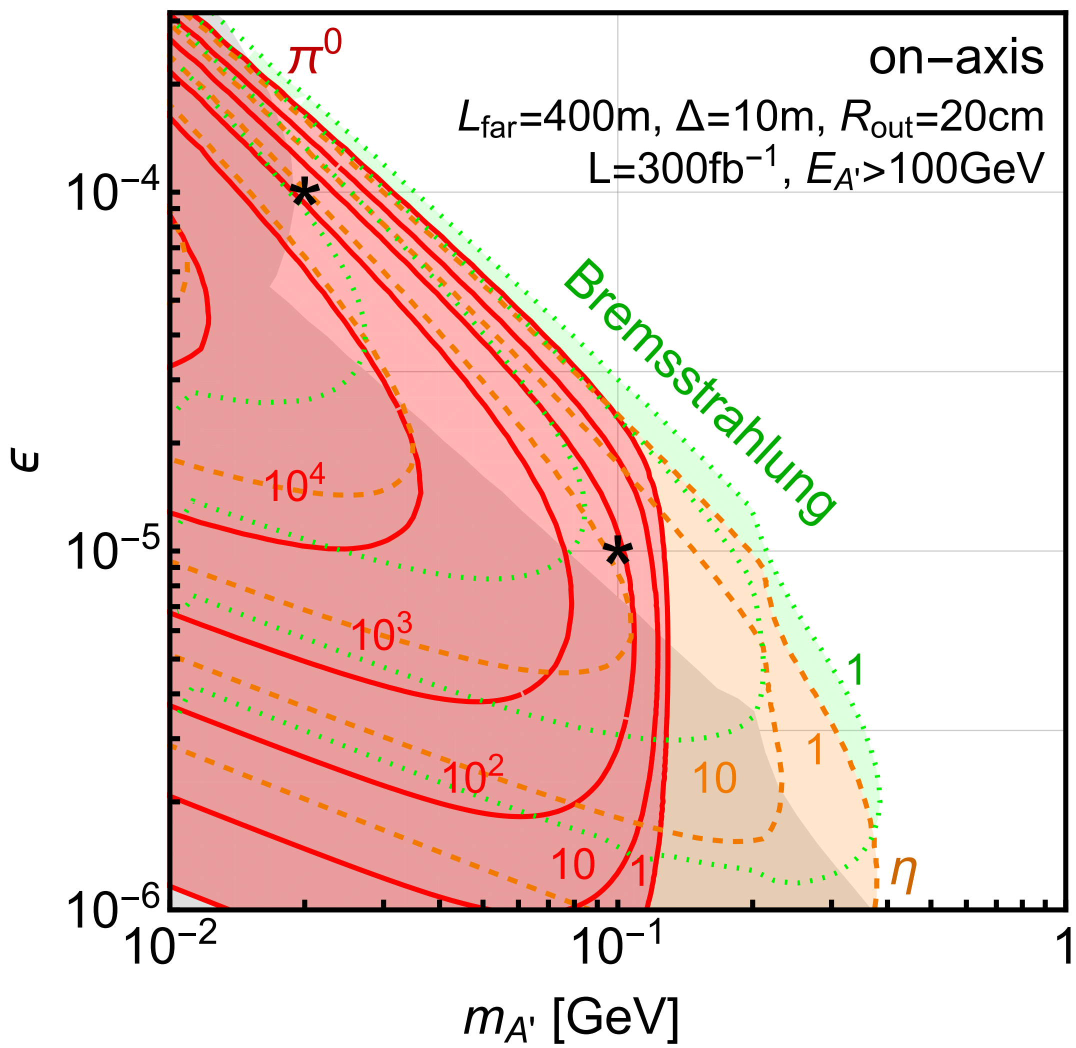


analysis is basically BG free

Expected Reach

Signal Rate

- signal acceptance almost 100%
- includes $A' \to ee, \mu\mu, \pi^\pm\pi^\mp$ modes
- low ε: limited production rate
- high ε: A' decay before detector
- high mass: improvement via direct production?



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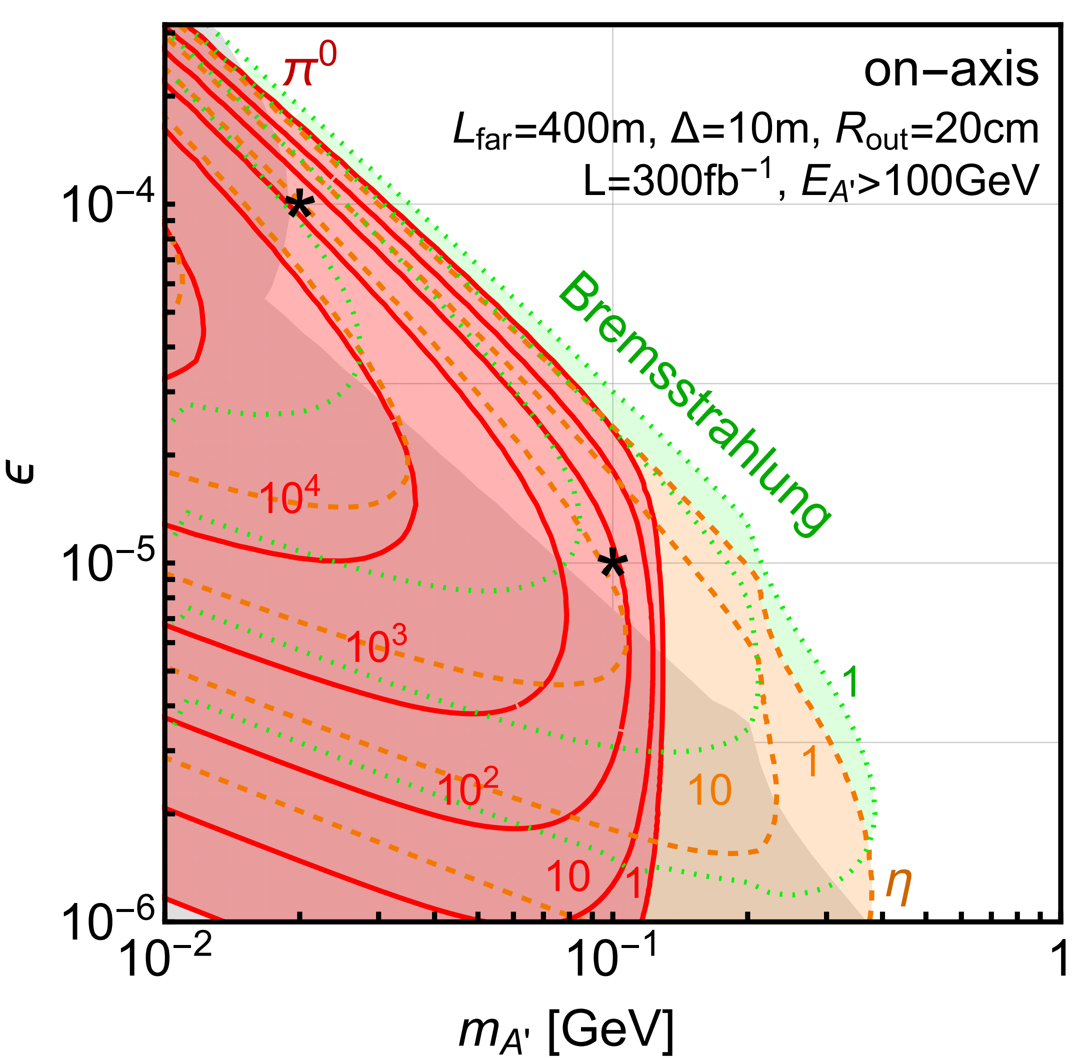
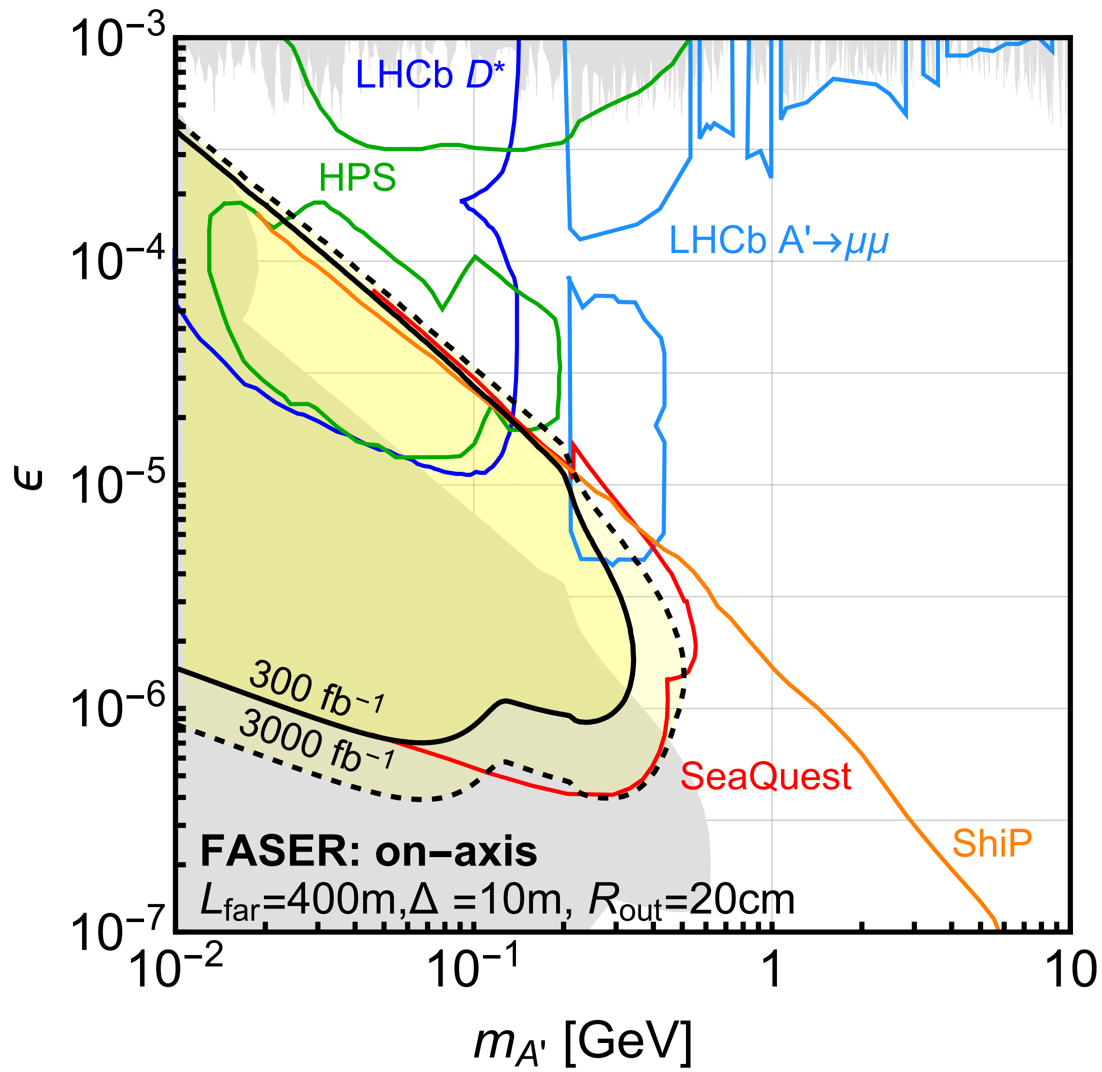
Reach

- almost background free
- reach similar to SeaQuest, SHiP

$$(m_{A'}\epsilon)^2|_{\max} \propto L/E_{A'}^{\rm Beam}$$

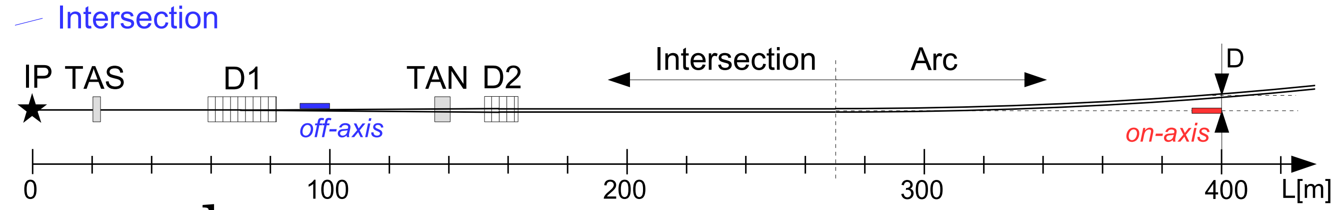




Summary and Outlook

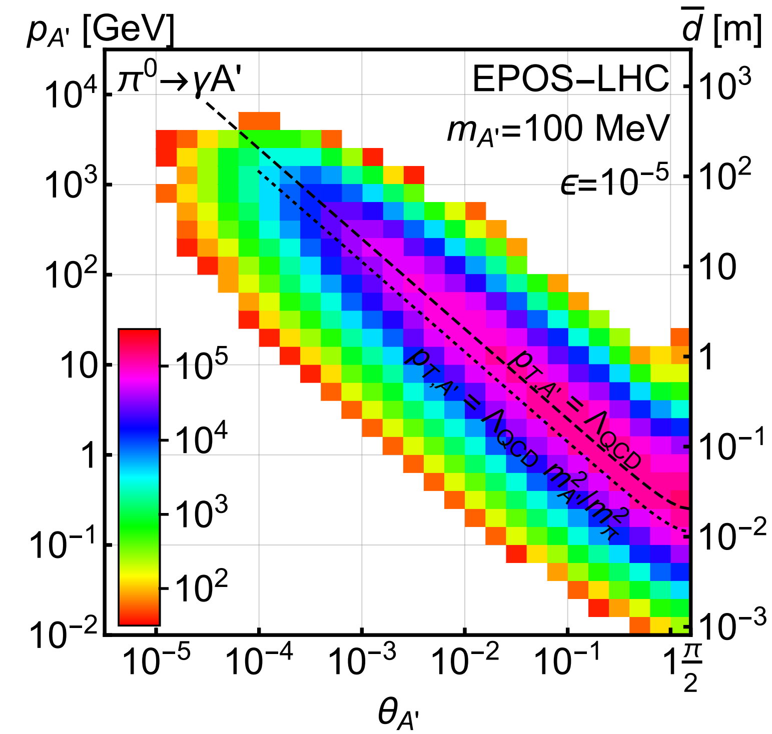
Forward Physics

- large event rates in forward direction
- energetic particles very forward $\theta < 1 \text{ mrad}$
- search for light extremely weakly coupled particles



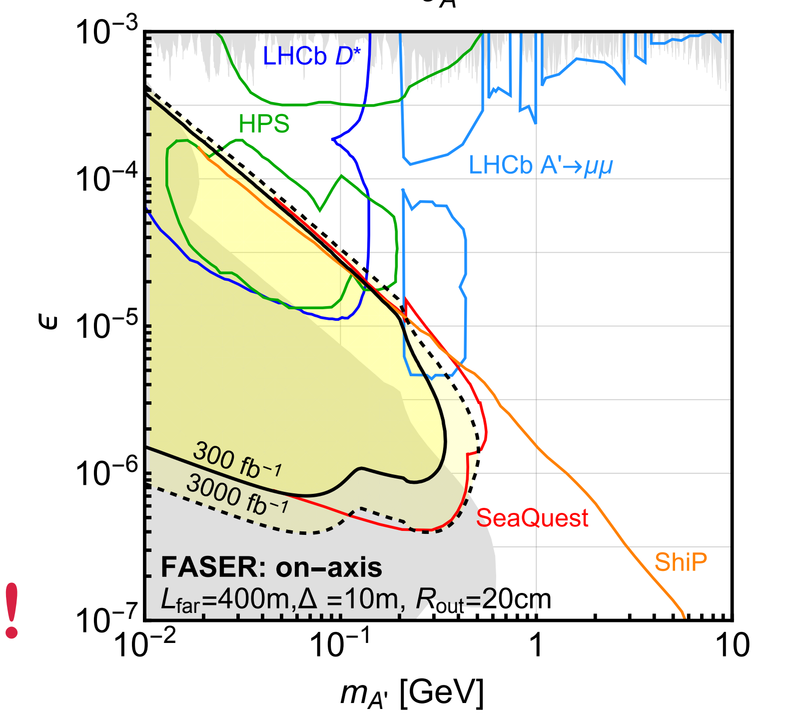
FASER

- small size $\sim 1 \text{ m}^3$ detector
- placed few 100 m downstream of the ATLAS/CMS IP
- equipped with tracking system + magnetic field
- operates parasitically



Physics Example: Dark Photons

- A' ⟶ 2 energetic charged tracks, $E \sim \text{TeV}$
- basically background free
- reach: $m_{A'} \sim 10 - 500 \text{ MeV}$, $\epsilon \sim 10^{-6} - 10^{-4}$



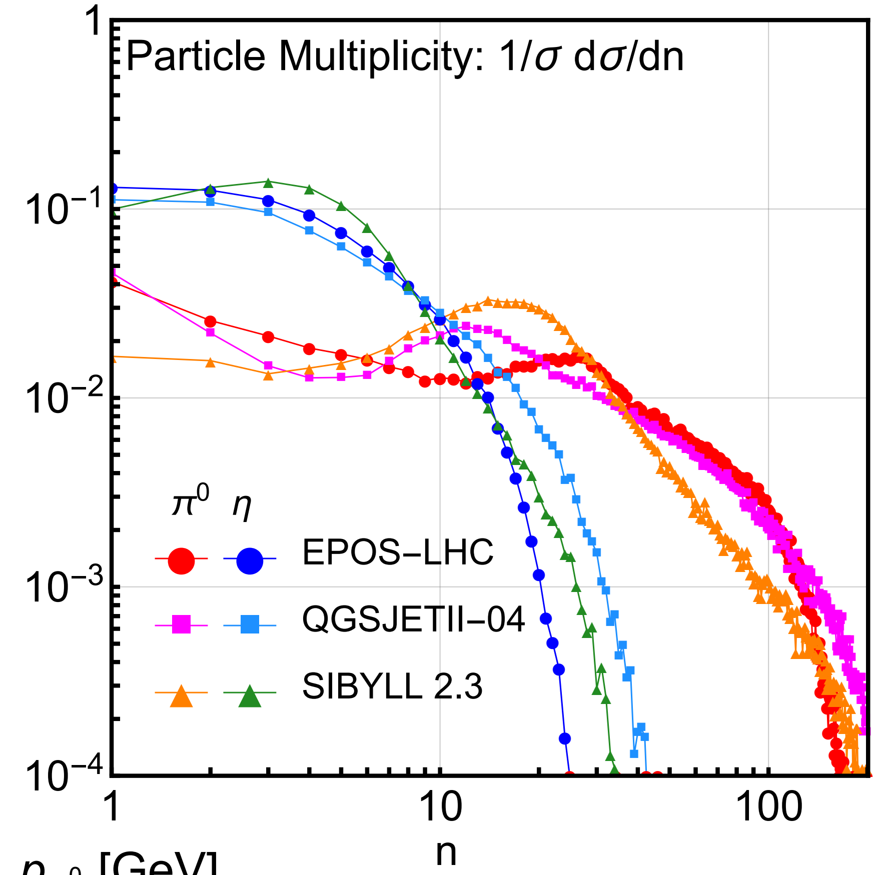
Outlook

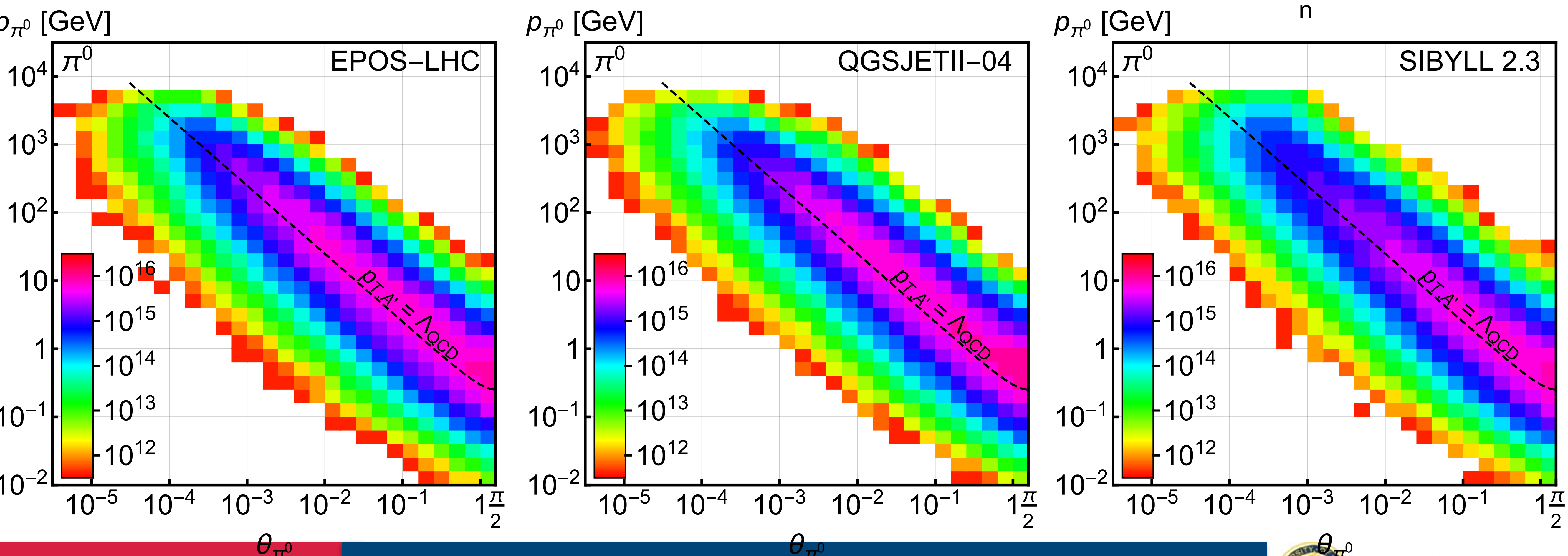
- explore more physics opportunities/models

We look forward to feedback from experimentalists!

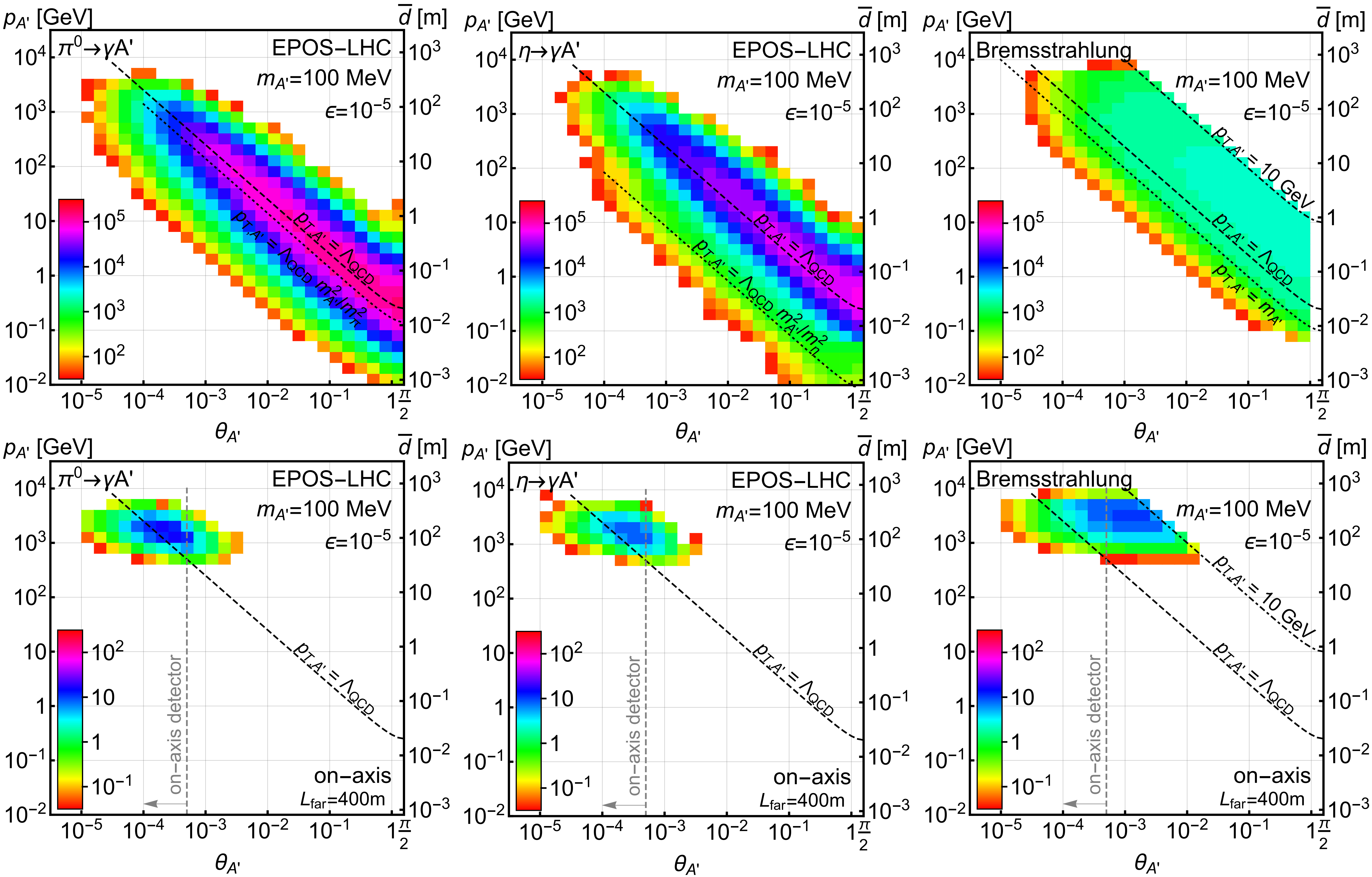
Comparison of Forward Physics Models

- traditionally relied on data from ultra-high-energy cosmic-ray experiments
- new models are tuned to match LHC data
- predictions are consistent





Backup: Signal Contributions



Backup: on-axis vs off-axis