DARK PHOTON AT LHCB

Yotam Soreq

FSP meeting in Siegen, October 5, 2017

the Standard Model (SM) works great but it is **not** a complete picture

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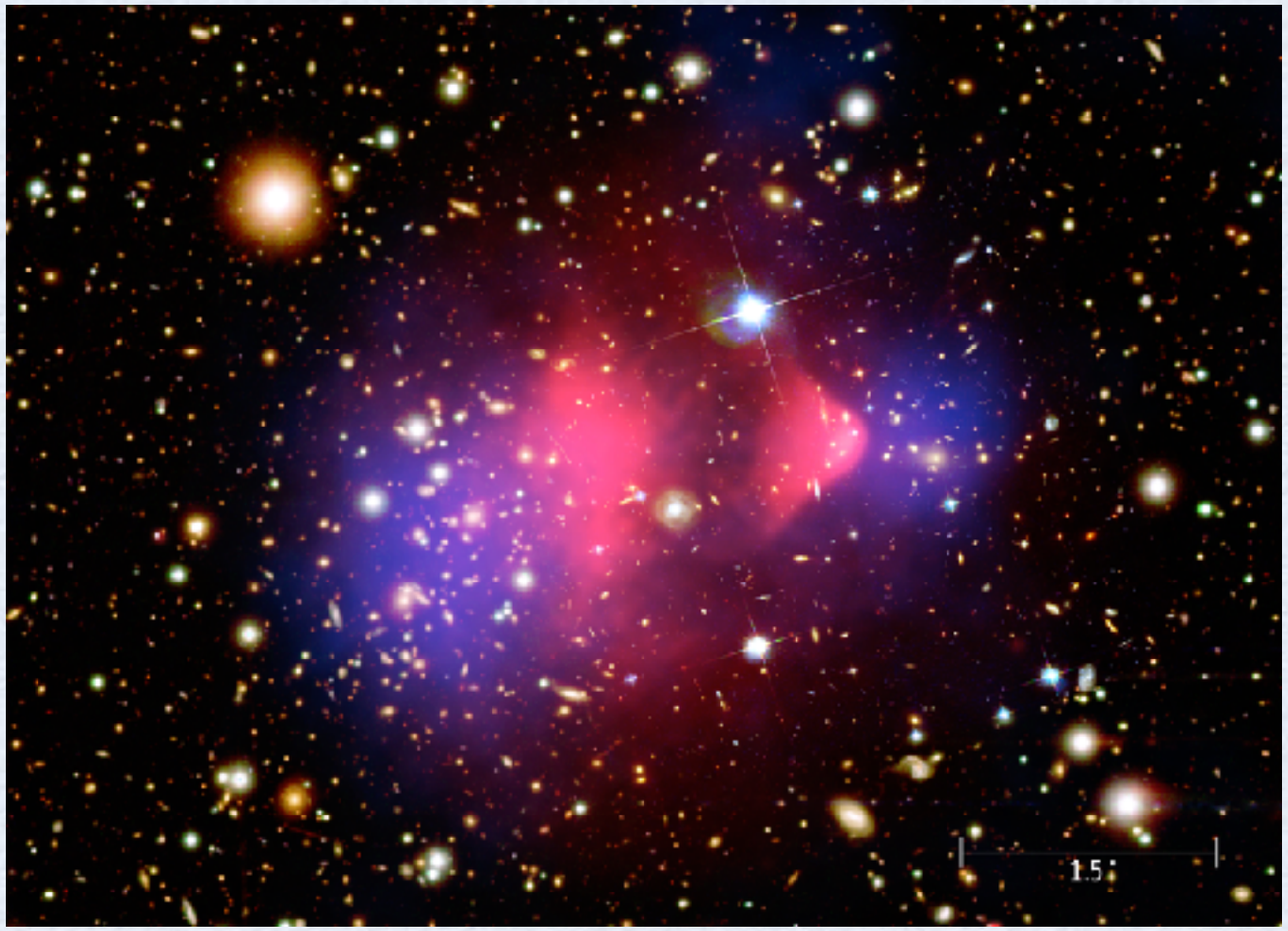
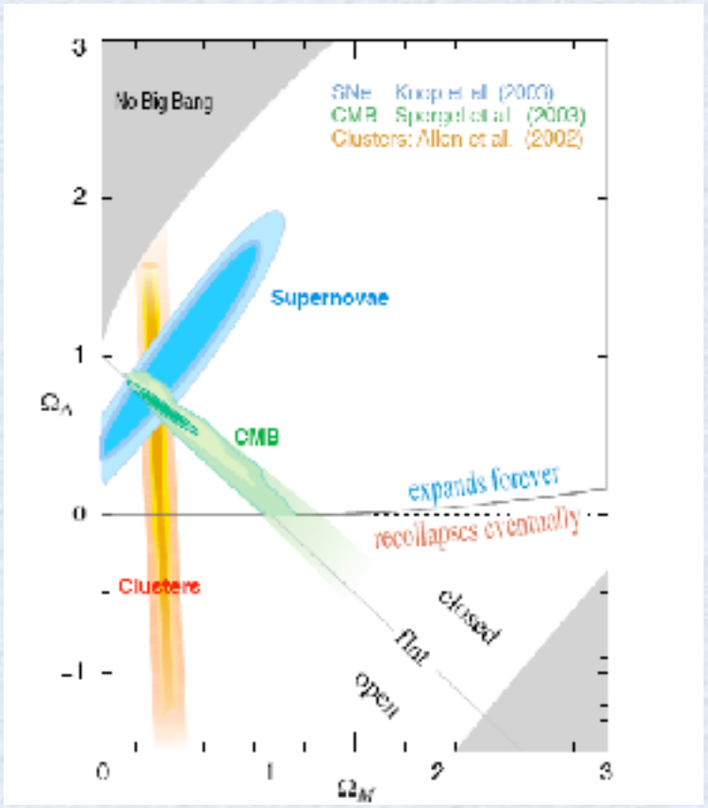
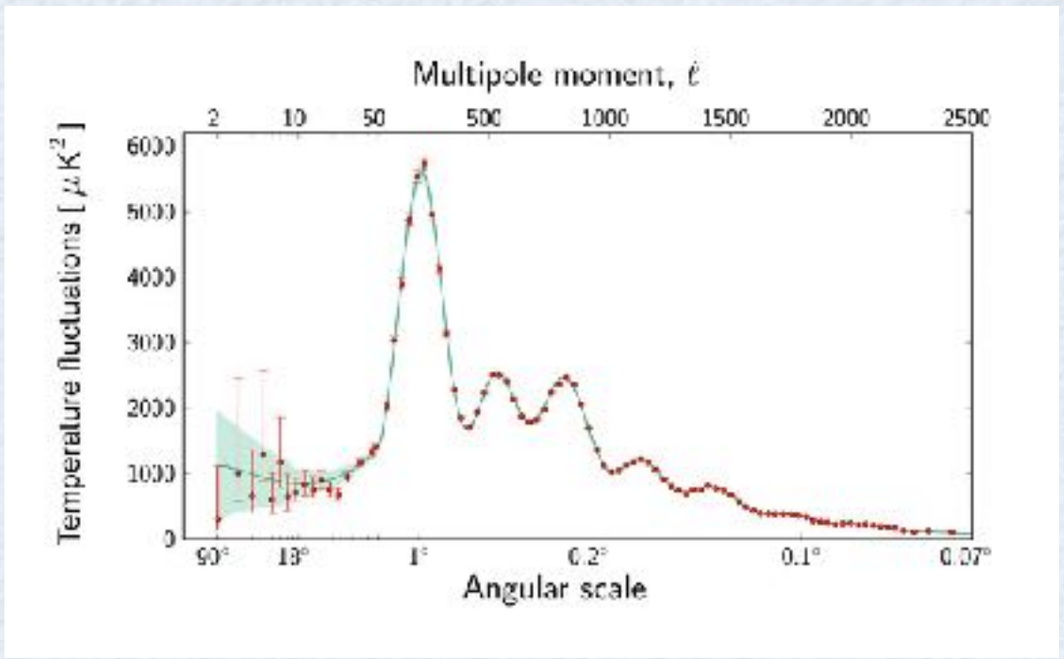
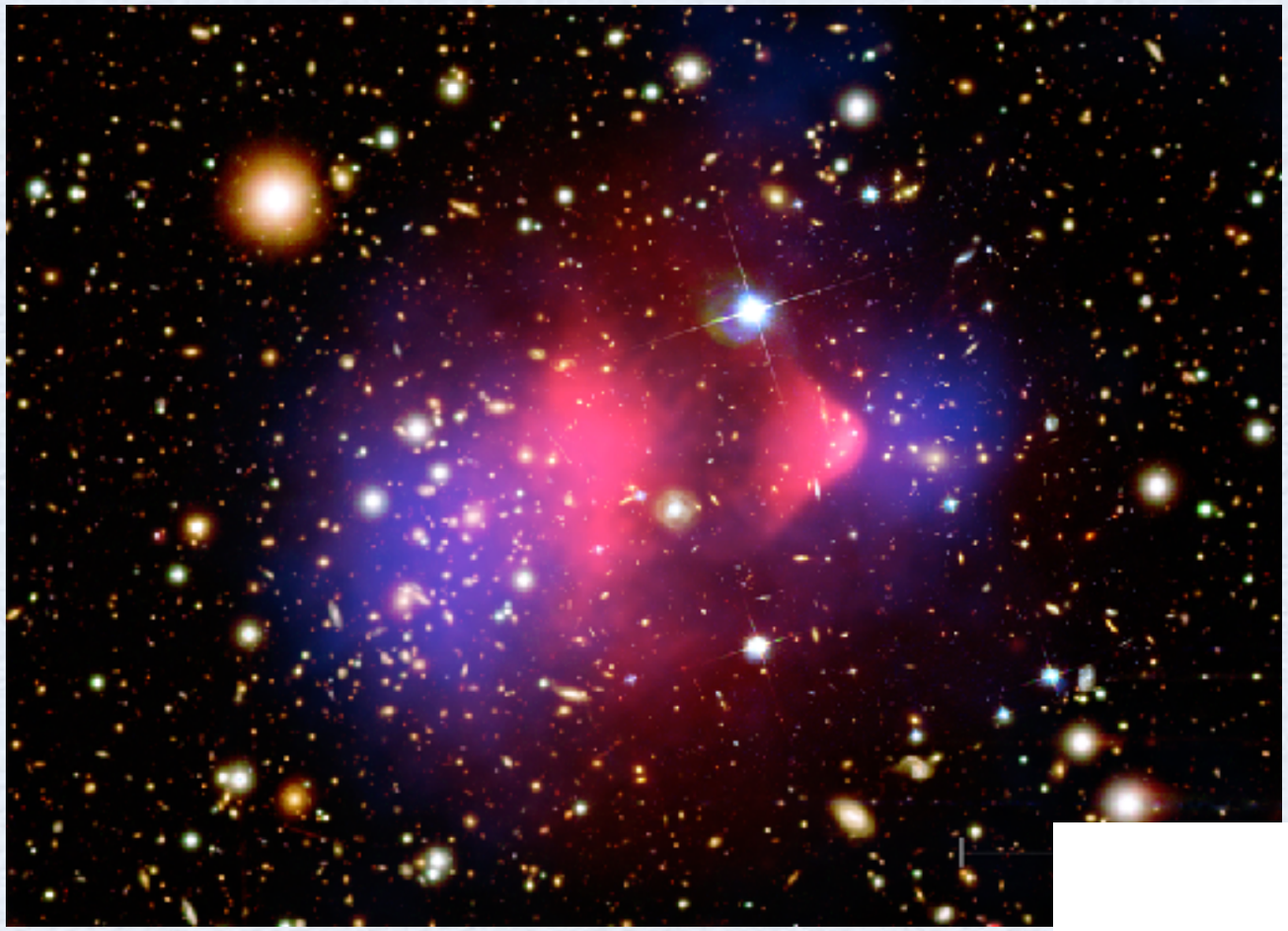
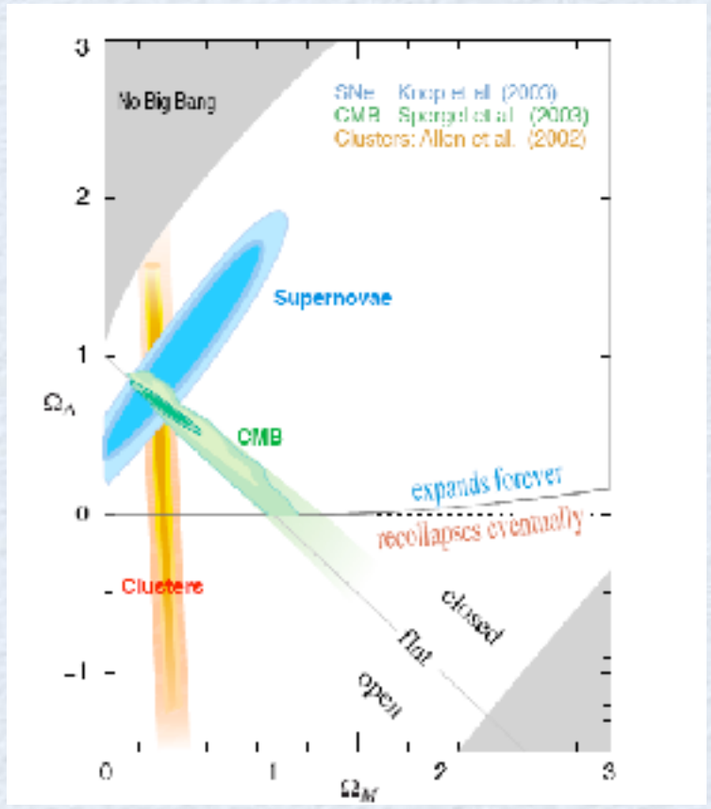
New Physics (NP) is required but its scale is **unknown**


1.5'


No Big Bang
SNe Knop et al. (2003)
CMB Spergel et al. (2003)
Clusters: Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
Ω_Λ
Ω_M
0
1
2
3
-1


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale

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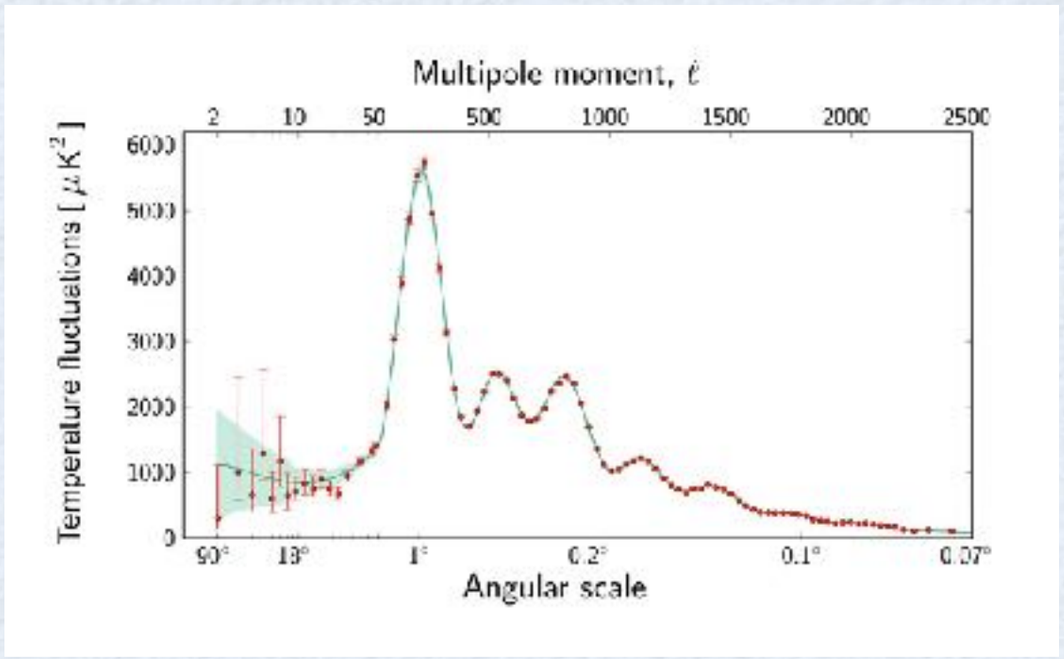
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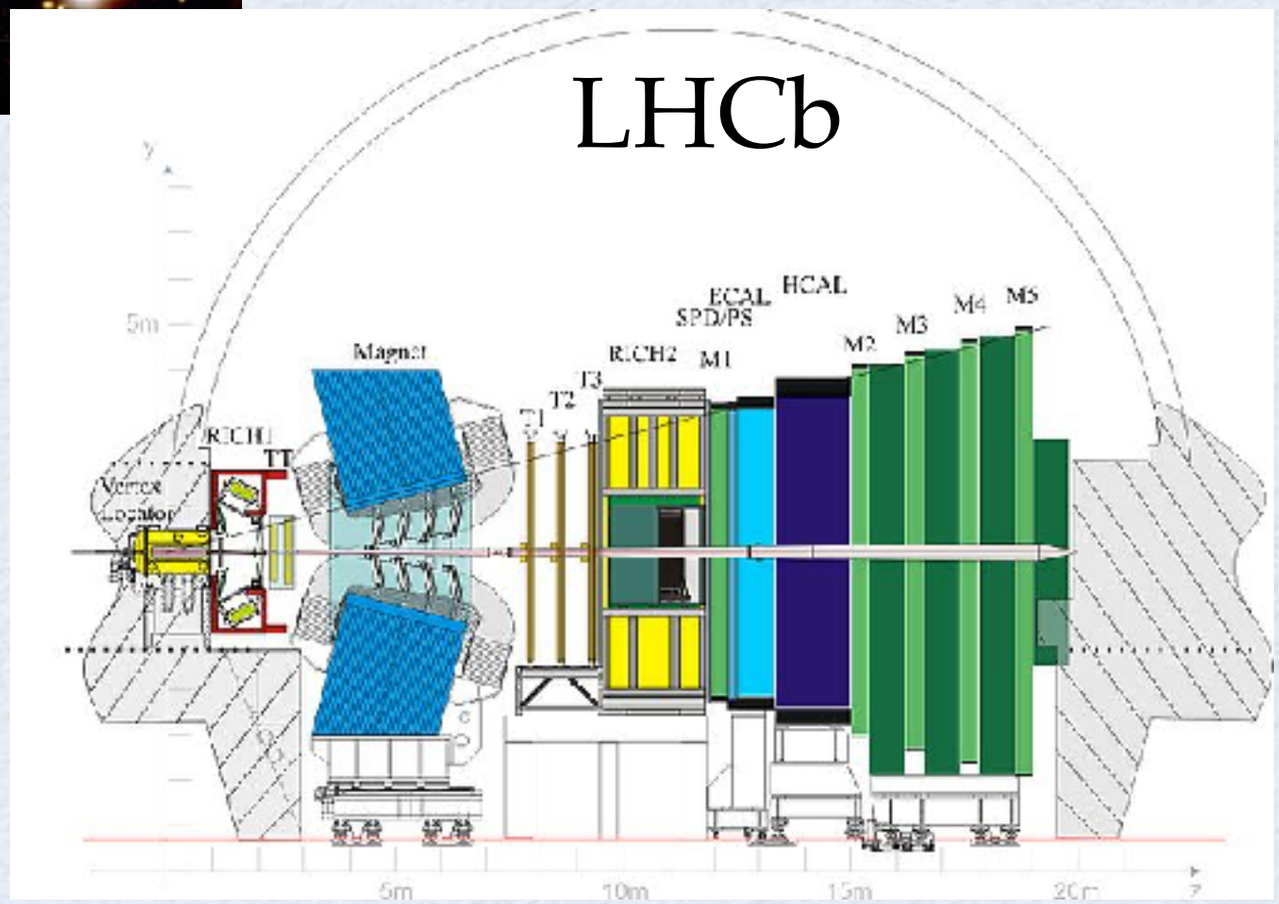
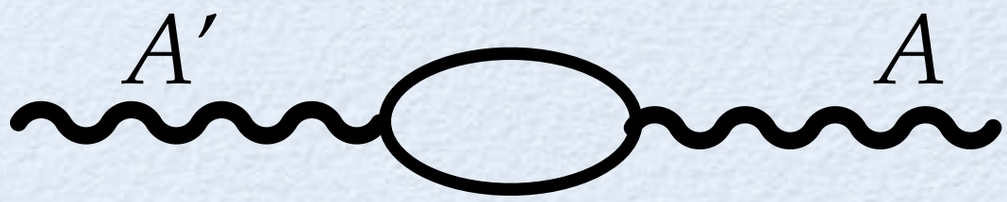

LHCb
5m
Magnet
RICH1
TT
Vertex Locator
T1
T2
T3
RICH2
M1
ECAL
SPD/PS
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z

BASICS OF DARK PHOTON

dark sector with broken gauge theory

kinetic mixing with photon

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



Holdom, 86'

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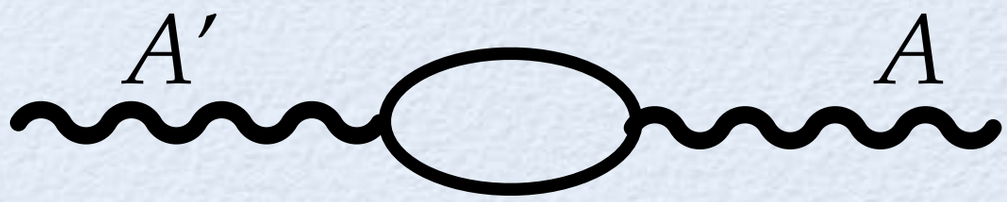
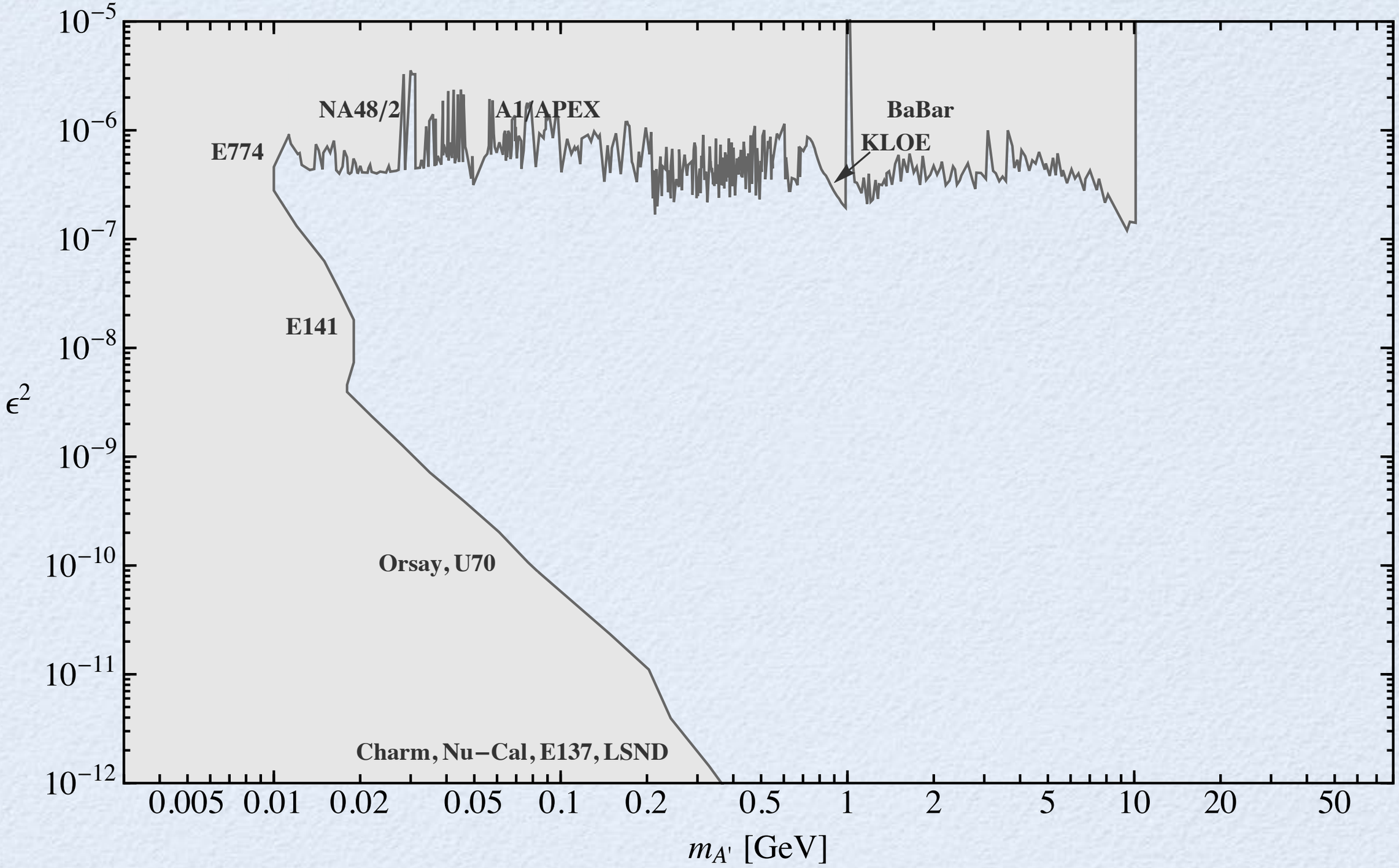


Holdom, 86'

$$\mathcal{L}_{\gamma A'} \supset -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{1}{2} m^2_{A'} A'^{\mu} A'_{\mu} + \epsilon\, e\, A'_{\mu} J^{\mu}_{\rm EM}$$

dark photon, A', couples to the EM current

CURRENT BOUNDS ON A′



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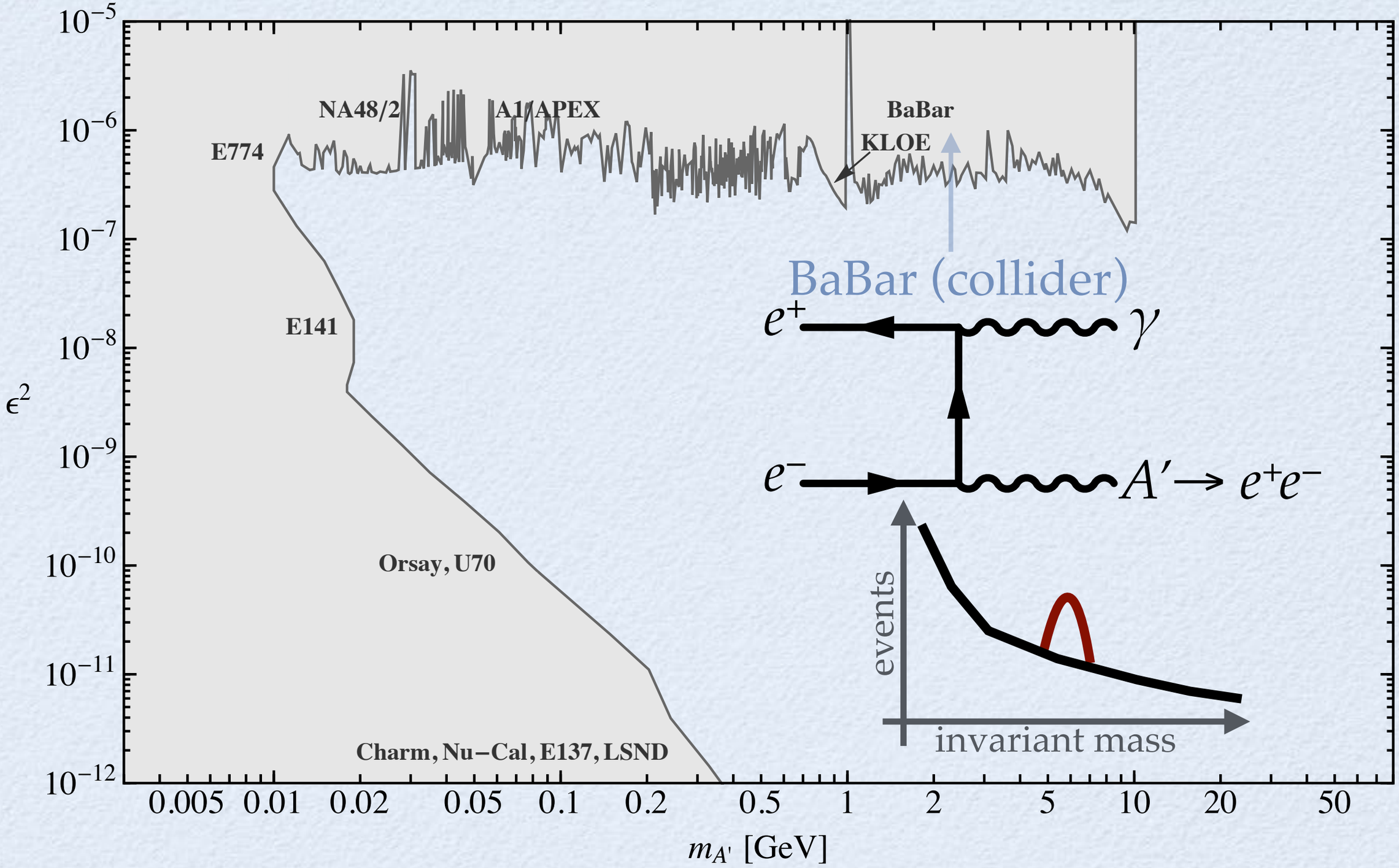

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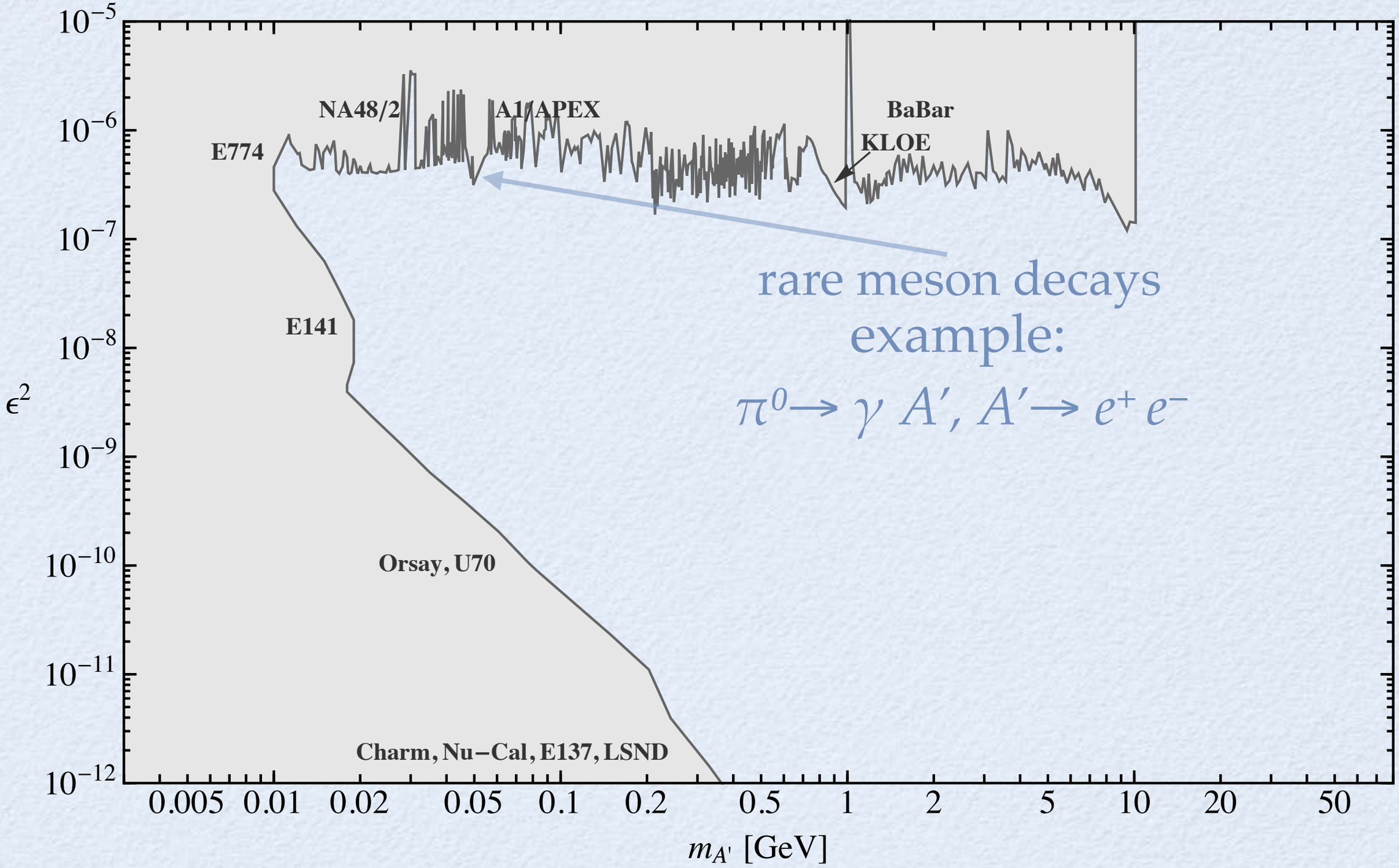
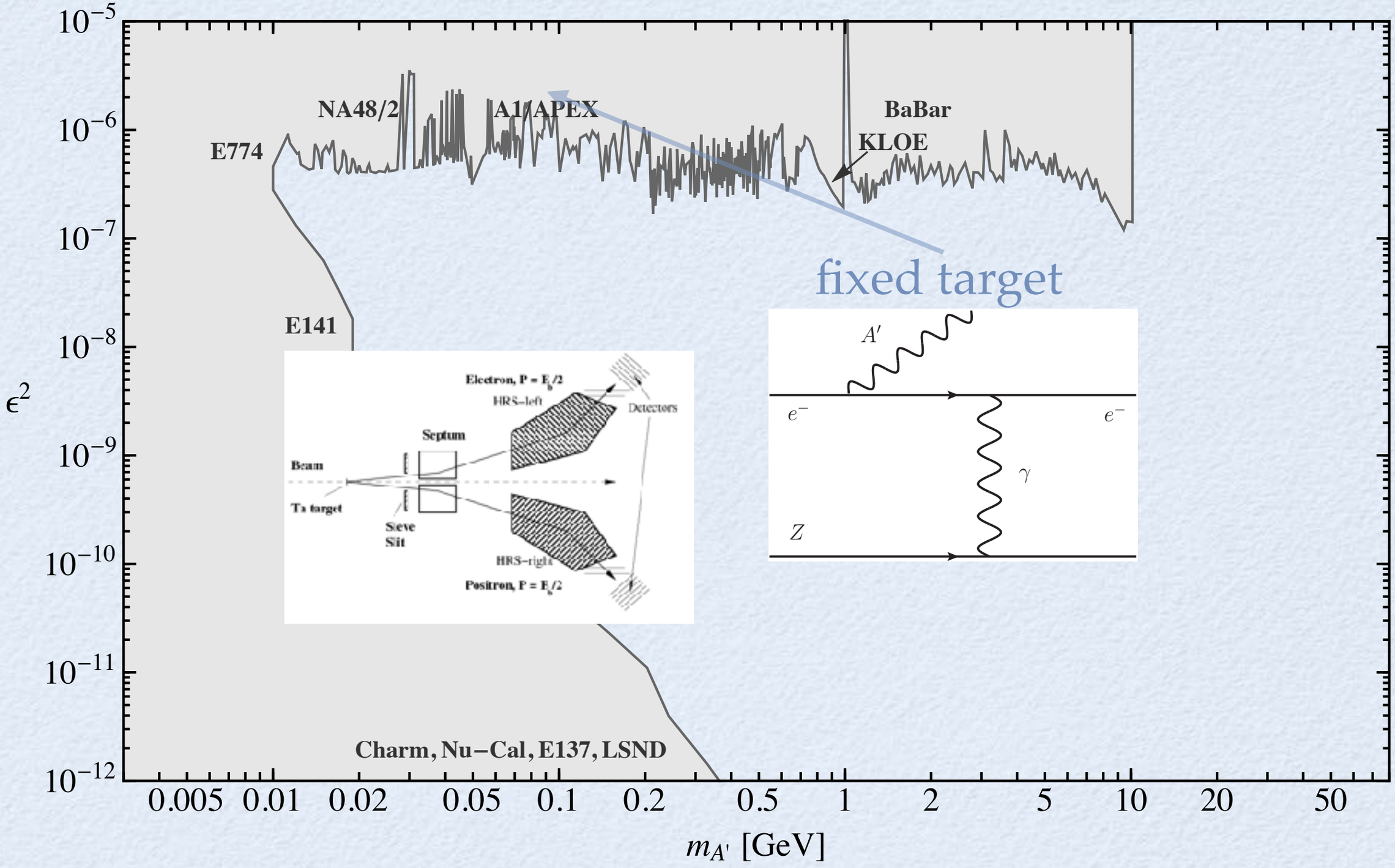


rare meson decays
example:
$\pi^0 \to \gamma A', A' \to e^+ e^-$

CURRENT BOUNDS ON A′



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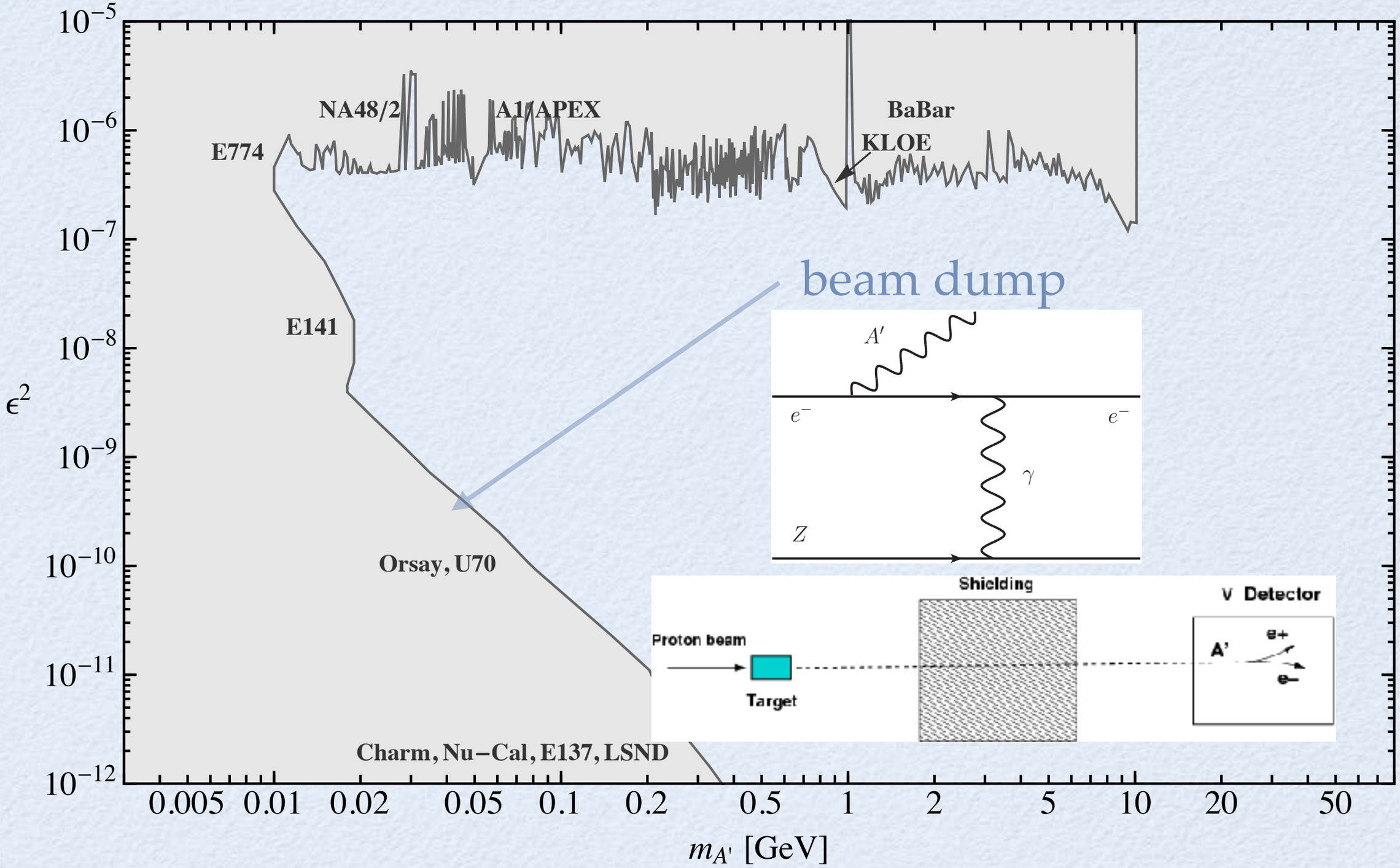

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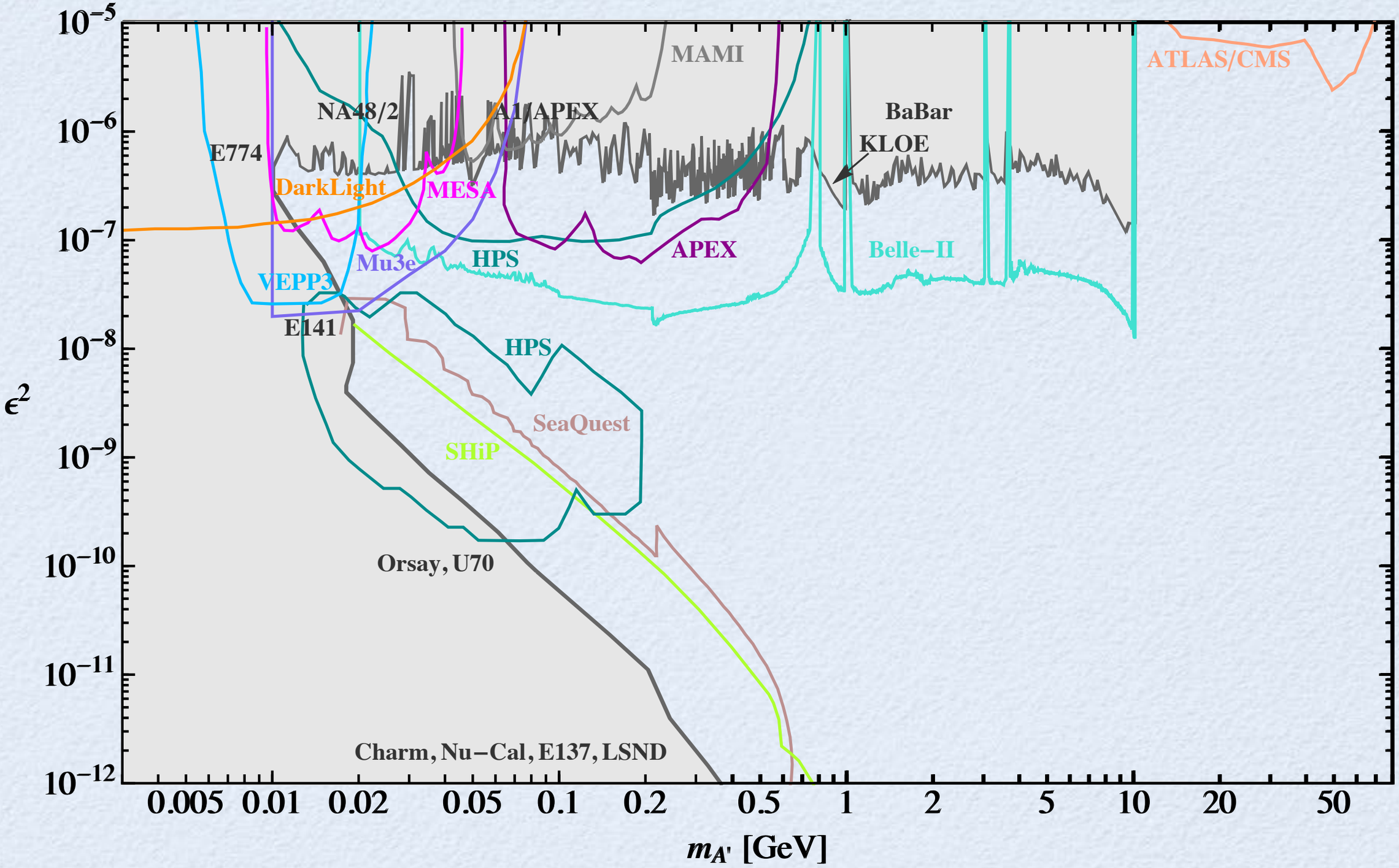
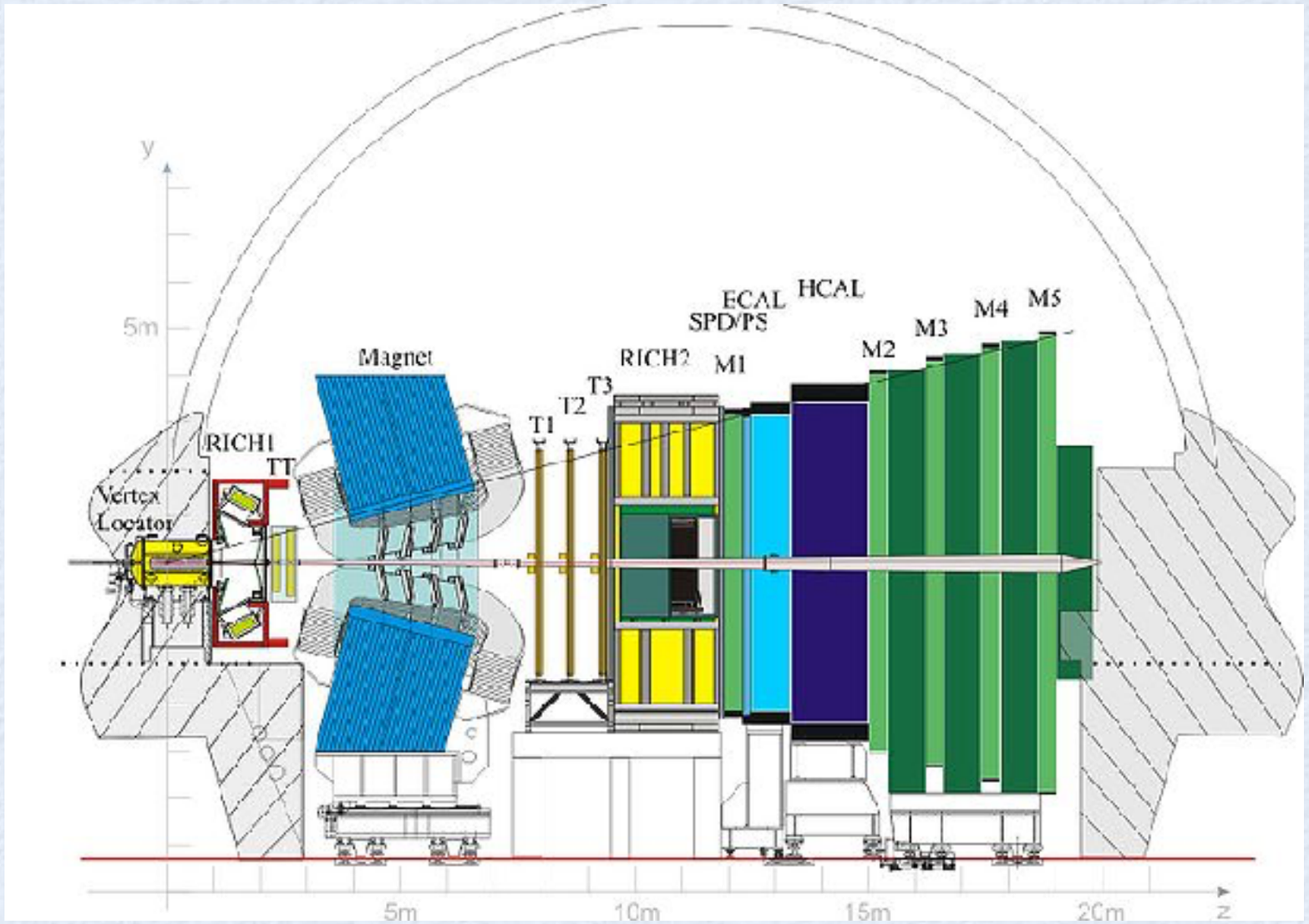


WHY LHCB?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M2
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5m
10m
15m
20m
z

WHY LHCB?

- real time data analysis (trigger-less) for Run 3
- particle identification
- muons detection:
  - dimuon invariant mass ($m_{\mu\mu}$) resolution:
    - 4 MeV, $m_{\mu\mu}$<1 GeV
    - 0.4% $m_{\mu\mu}$, $m_{\mu\mu}$>1 GeV
  - time resolution: σ_τ~50fs (almost constant in proper lifetime)

WHY LHCB?

- $A' \to \mu^+\mu^-$ -
  - inclusive search (do not need to specify the production)
    - fully data driven
    - both prompt and displaced searches
- Run 3 - integrated luminosity of 15 fb^{-1}

inclusive dark photon at LHCb

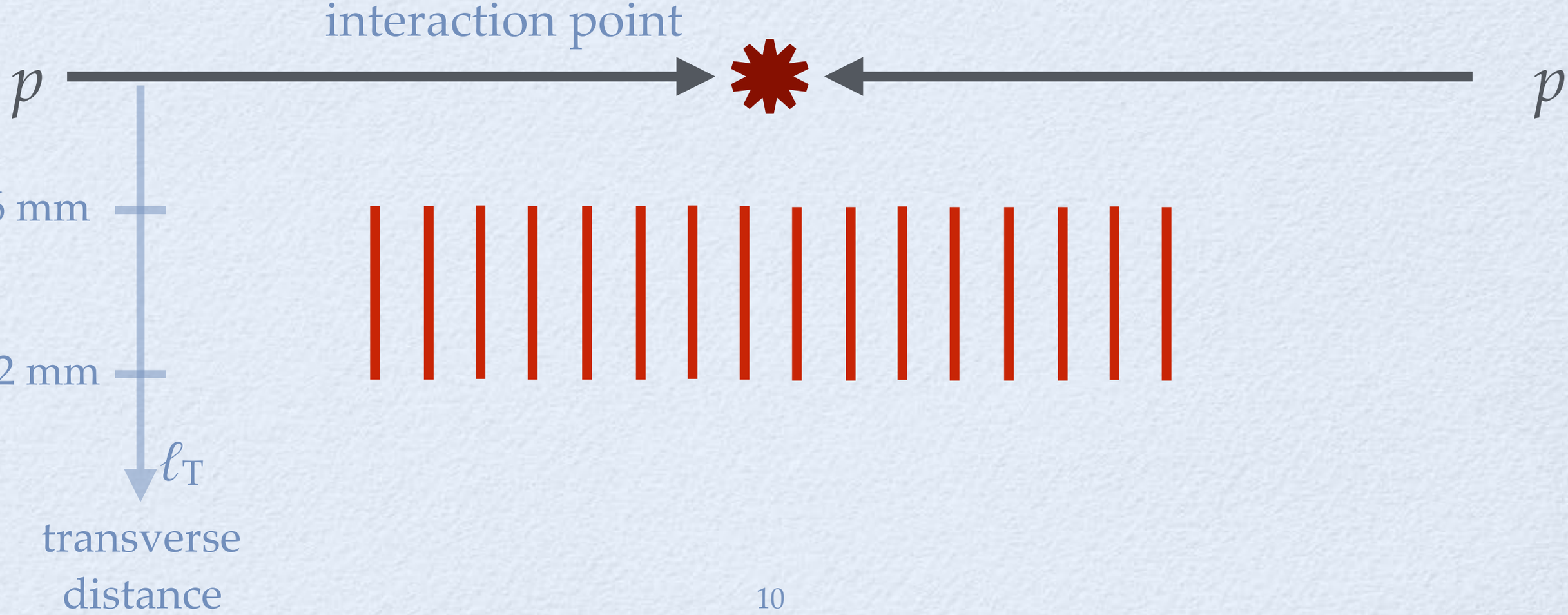
P. Ilten, YS, J. Thaler, M. Williams, W. Xue, 1603.08926

WHY LHCB?

VELO

(vertex locator)

interaction point



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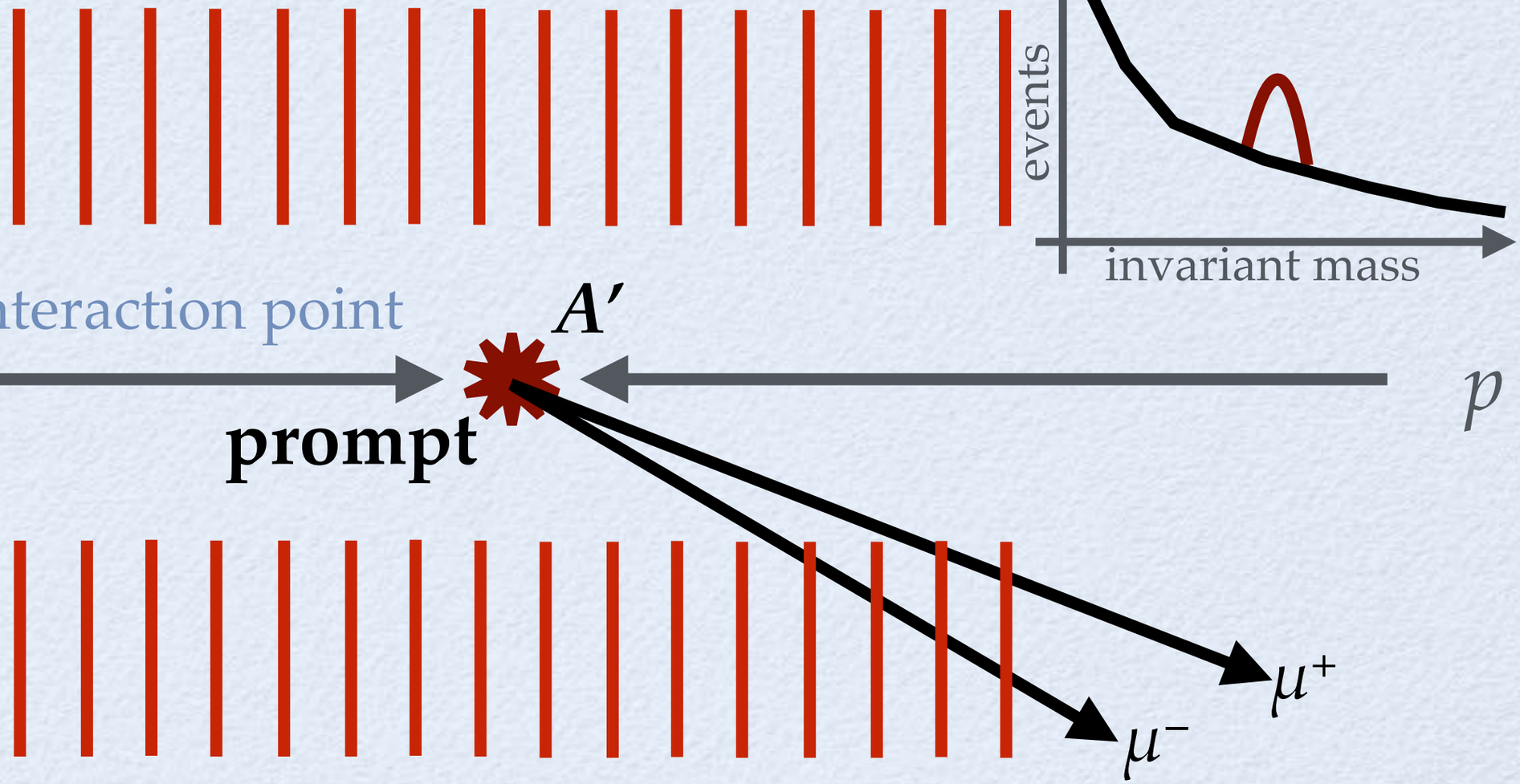

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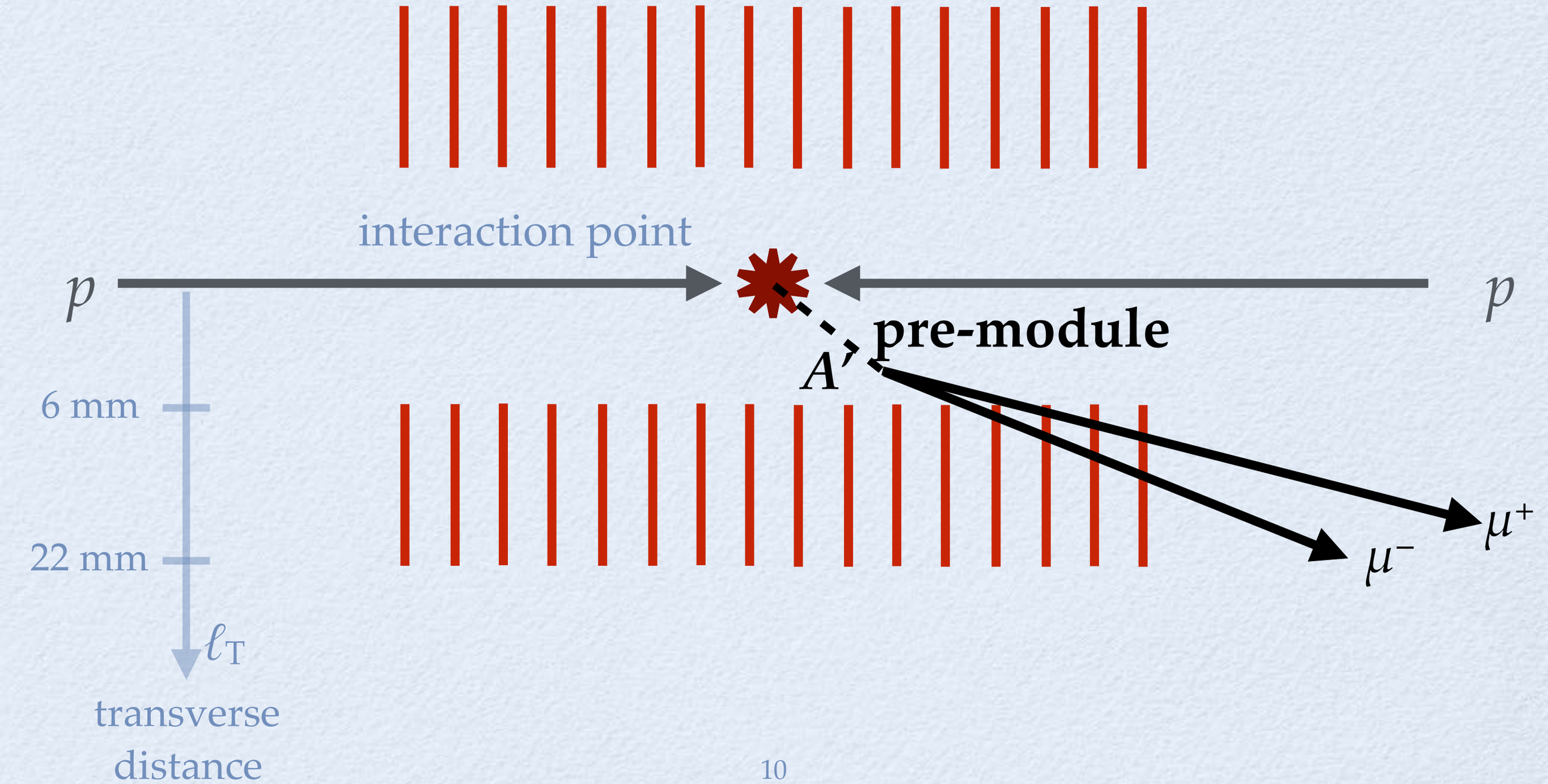
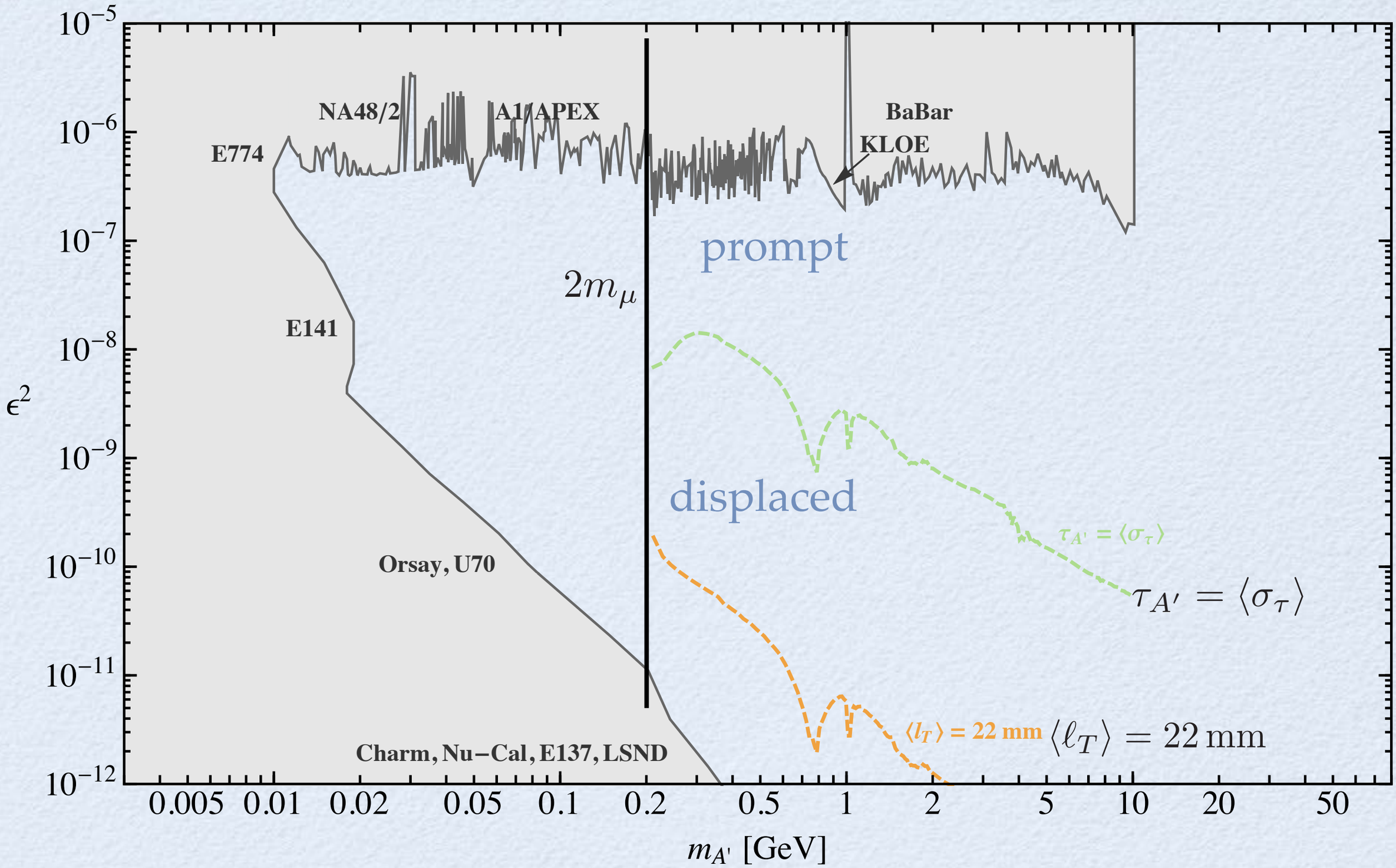


WHY LHCB?

VELO

(vertex locator)

SEARCH REGIONS

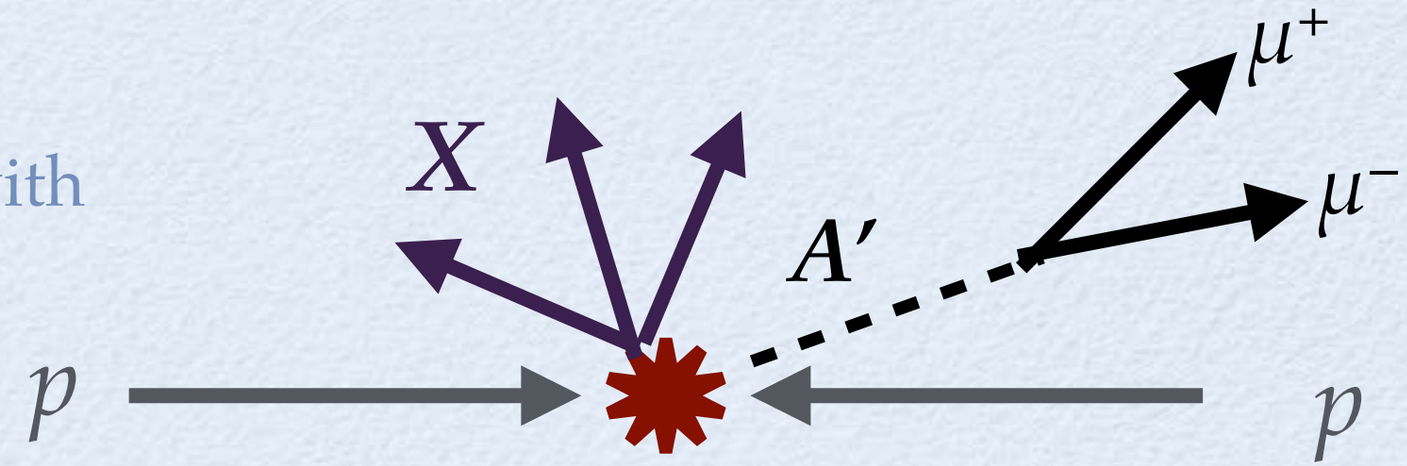


SIGNAL ESTIMATION

S - signal:

$$pp \to X\, A' \to X\, \mu^+ \mu^-$$

includes mixing with vector mesons



Bjorken, Essig, Schuster, Toro, 0906.0580

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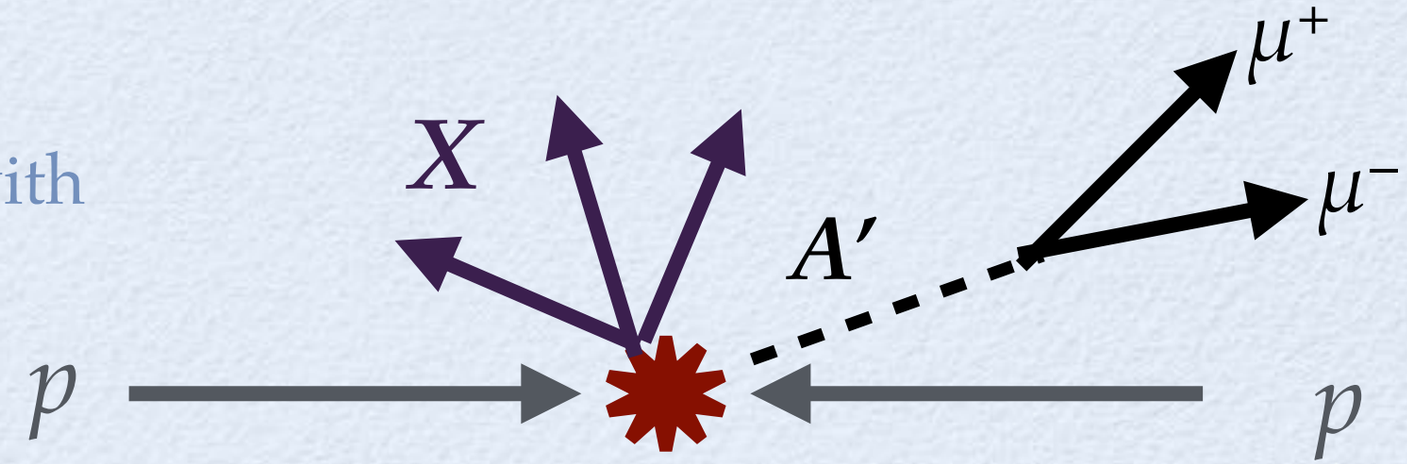
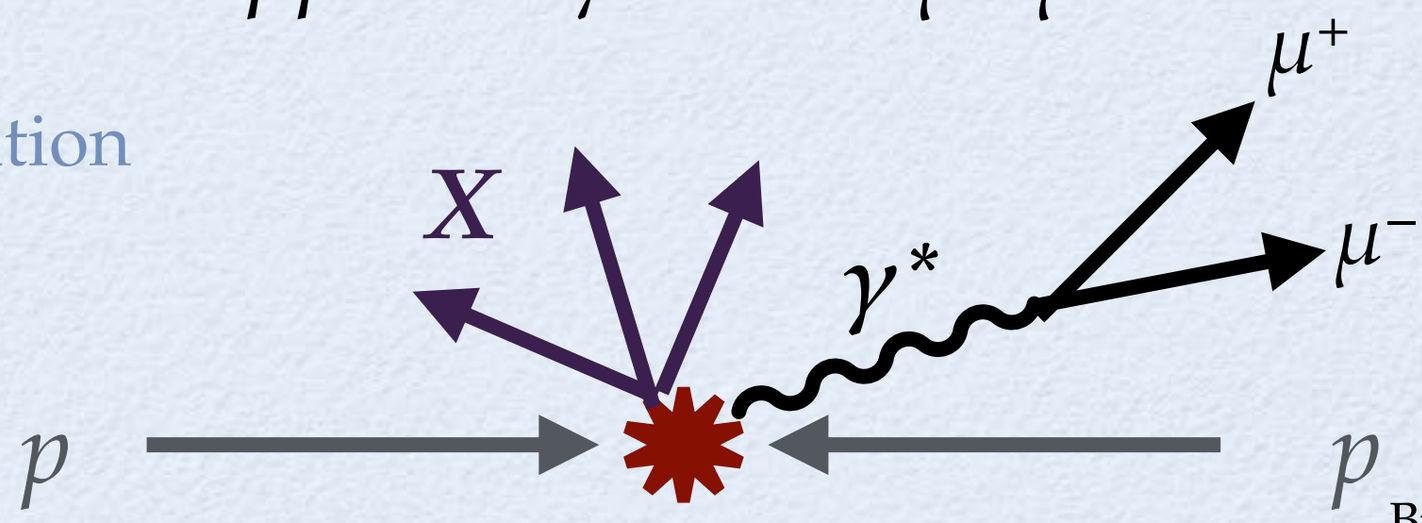


B_{EM} - background from EM processes:

$$pp \to X\, \gamma^* \to X\, \mu^+ \mu^-$$

meson decays
final state radiation
Drell Yan



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SIGNAL ESTIMATION

differential relation:

$$\frac{\mathrm{d}\sigma_{pp\to X A'\to X\mu^+\mu^-}}{\mathrm{d}\sigma_{pp\to X\gamma^*\to X\mu^+\mu^-}} = \epsilon^4 \frac{m_{\mu\mu}^4}{(m_{\mu\mu}^2 - m_{A'}^2)^2 + \Gamma_{A'}^2 m_{A'}^2}$$

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per mass bin:

$$\frac{S}{B_{\mathrm{EM}}} \approx \epsilon^4 \frac{\pi}{8} \frac{m_{A'}^2}{\Gamma_{A'}\sigma_{m_{\mu\mu}}} \approx \frac{3\pi}{8} \frac{m_{A'}}{\sigma_{m_{\mu\mu}}} \frac{\epsilon^2}{\alpha_{\mathrm{EM}}(N_\ell + \mathcal{R}_\mu)}$$

$$\frac{\Gamma_{A'}}{m_{A'}} \approx \frac{\epsilon^2 \alpha_{\mathrm{EM}}}{3} (N_\ell + \mathcal{R}_\mu)$$

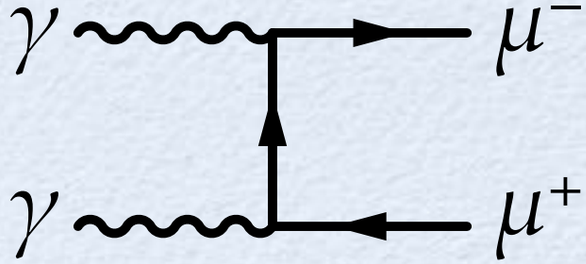
number of leptons with mass below $m_{A'}/2$

$$\frac{\sigma_{e^+e^-\to\mathrm{hadrons}}}{\sigma_{e^+e^-\to\mu^+\mu^-}}$$

Bjorken, Essig, Schuster, Toro, 0906.0580

PROMPT BACKGROUNDS

- misidentified pions:
  - $B^{\pi\pi}$ - two pions are misidentified
  - $B^{\pi\mu}$ - one pion is misidentified and one real muon
- B_{BH} - Bethe-Heitler background, subdominant due to small photon luminosity function



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  - $B^{\pi\mu}$ - one pion is misidentified and one real muon
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$$B_{\mathrm{prompt}} = \underbrace{B_M + B_{\mathrm{FSR}} + B_{\mathrm{DY}}}_{B_{\mathrm{EM}}} + \underbrace{B^{\pi\pi}_{\mathrm{misID}} + B^{\pi\mu}_{\mathrm{misID}}}_{B_{\mathrm{misID}}}$$

"good" scales as signal

"bad" does not scale as signal

PROMPT BACKGROUNDS

selections:

- $2<\eta(\mu^{\pm})<5$
- $p(\mu^{\pm})>10\text{GeV}$
- $p_T(\mu^{\pm})>0.5\text{GeV}$
- $p_T(A')>1.0\text{GeV}$
- μ isolation:
  if DY is significant,
  $m_{A'}>m_{\phi}\sim 1$ GeV

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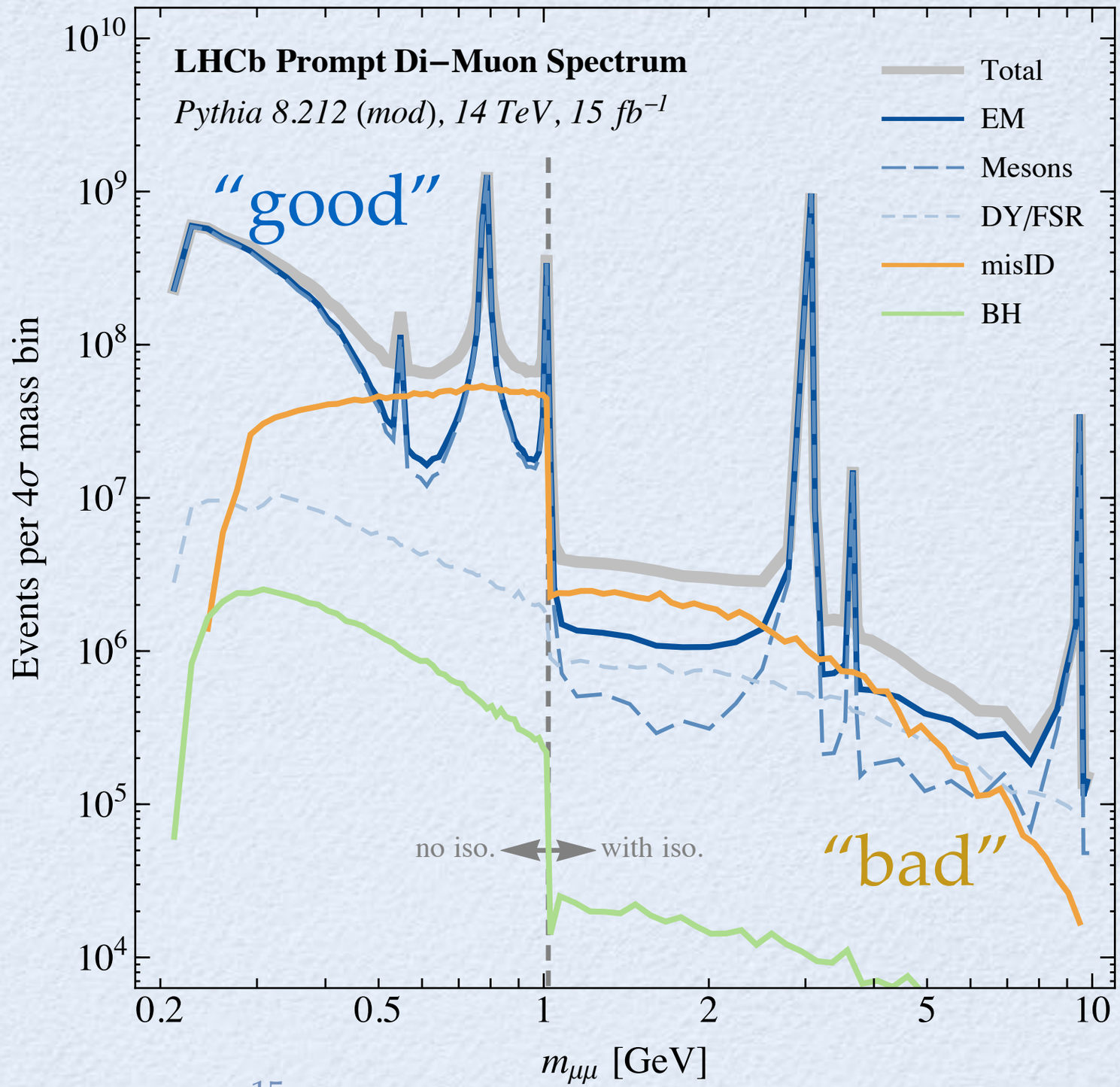
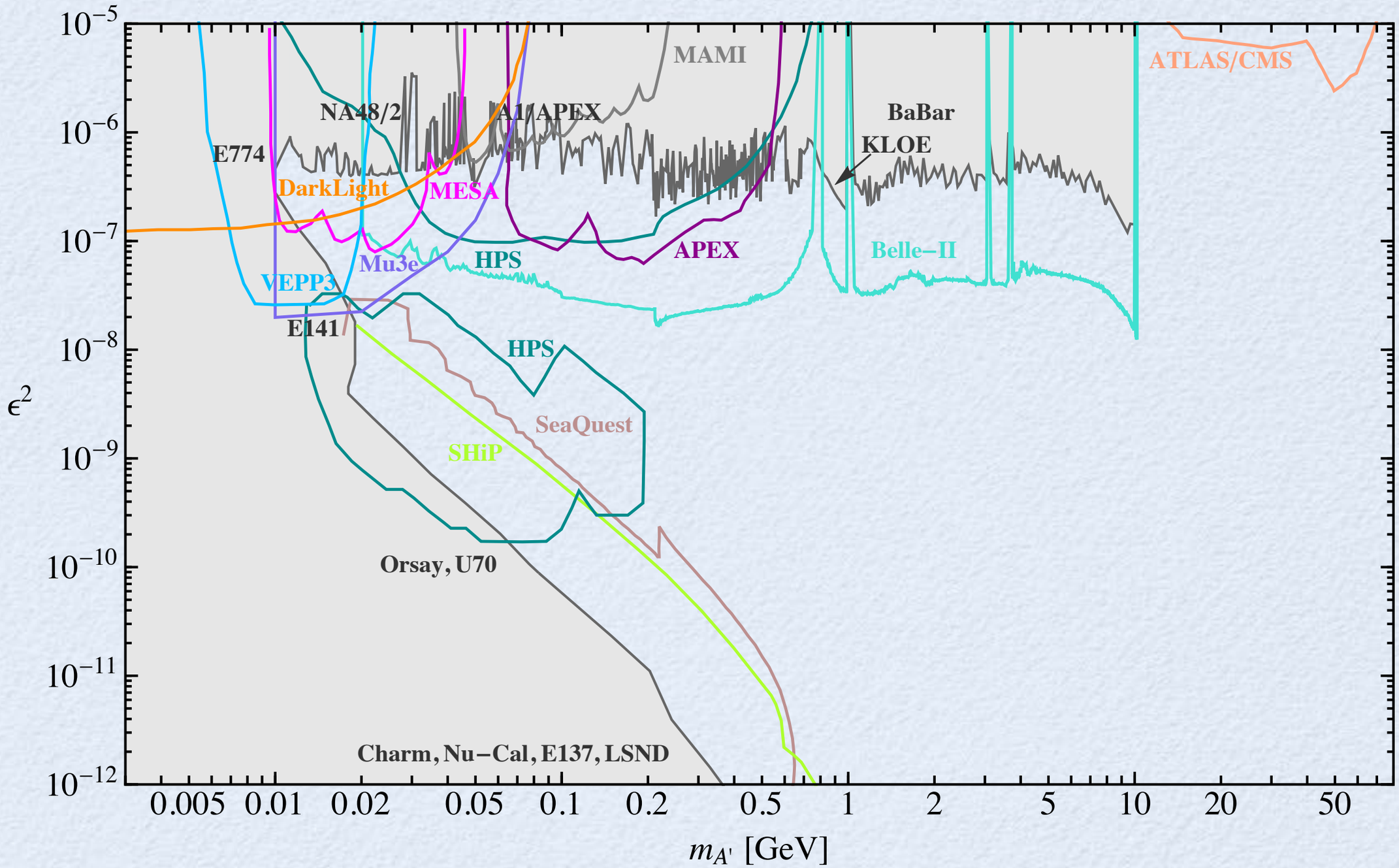


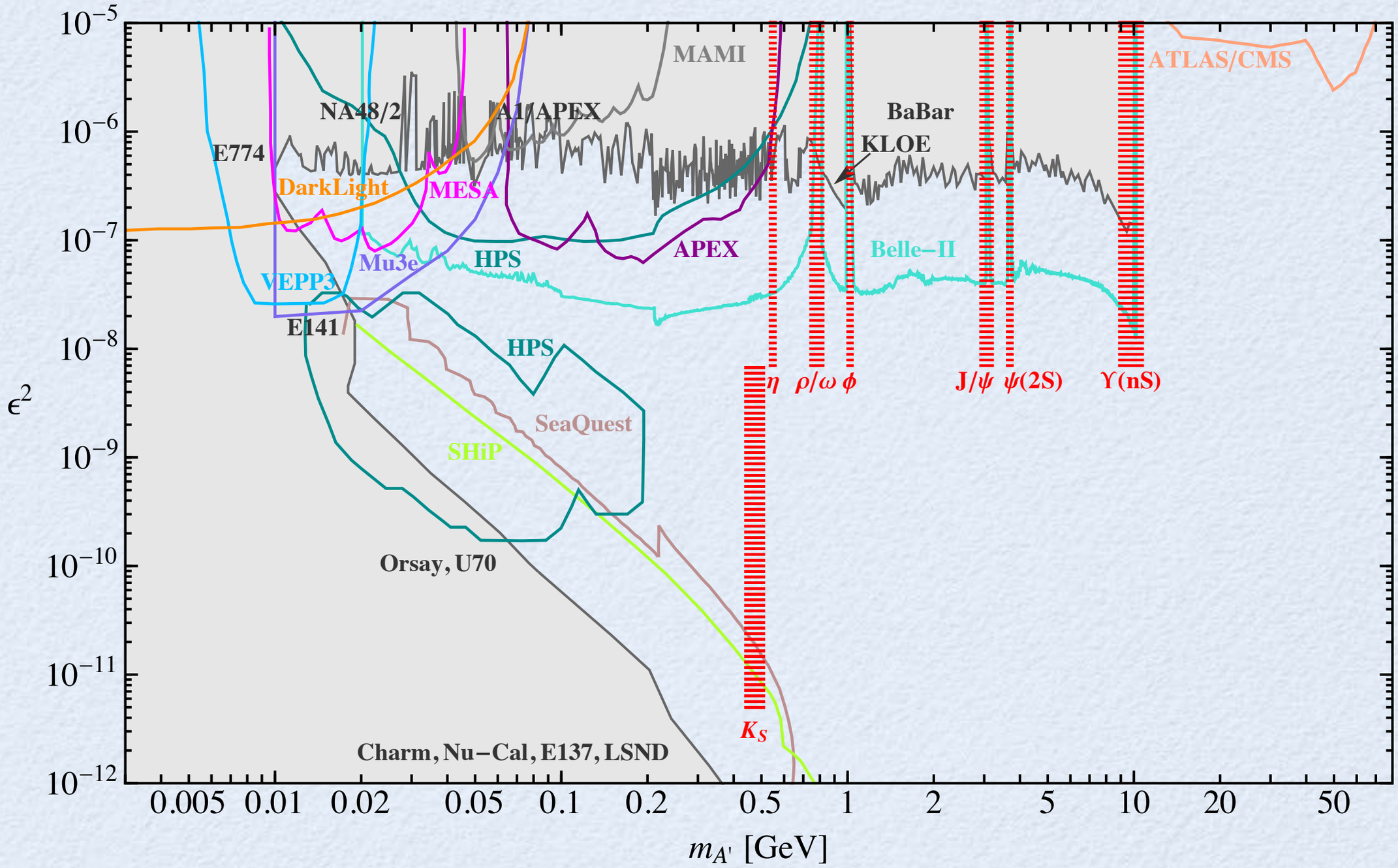
DISPLACED BACKGROUNDS

- **pre-module:**
  - main backgrounds: $b \to c\mu^{\pm} X$, $c \to \mu^{\pm} Y$
  - 10000 background events per mass bin
- **post-module:**
  - mostly material interactions, rescaled from $K_S \to \mu^+\mu^-$ search
  - 25 background events pre mass bin
- backgrounds from misidentifications are subdominants

REACH PLOT


10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
ϵ^2
MAMI
ATLAS/CMS
NA48/2
A1/APEX
BaBar
KLOE
E774
DarkLight
MESA
APEX
Belle−II
Mu3e
HPS
VEPP3
E141
HPS
SeaQuest
SHiP
Orsay, U70
Charm, Nu−Cal, E137, LSND
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
$m_{A'}$ [GeV]

REACH PLOT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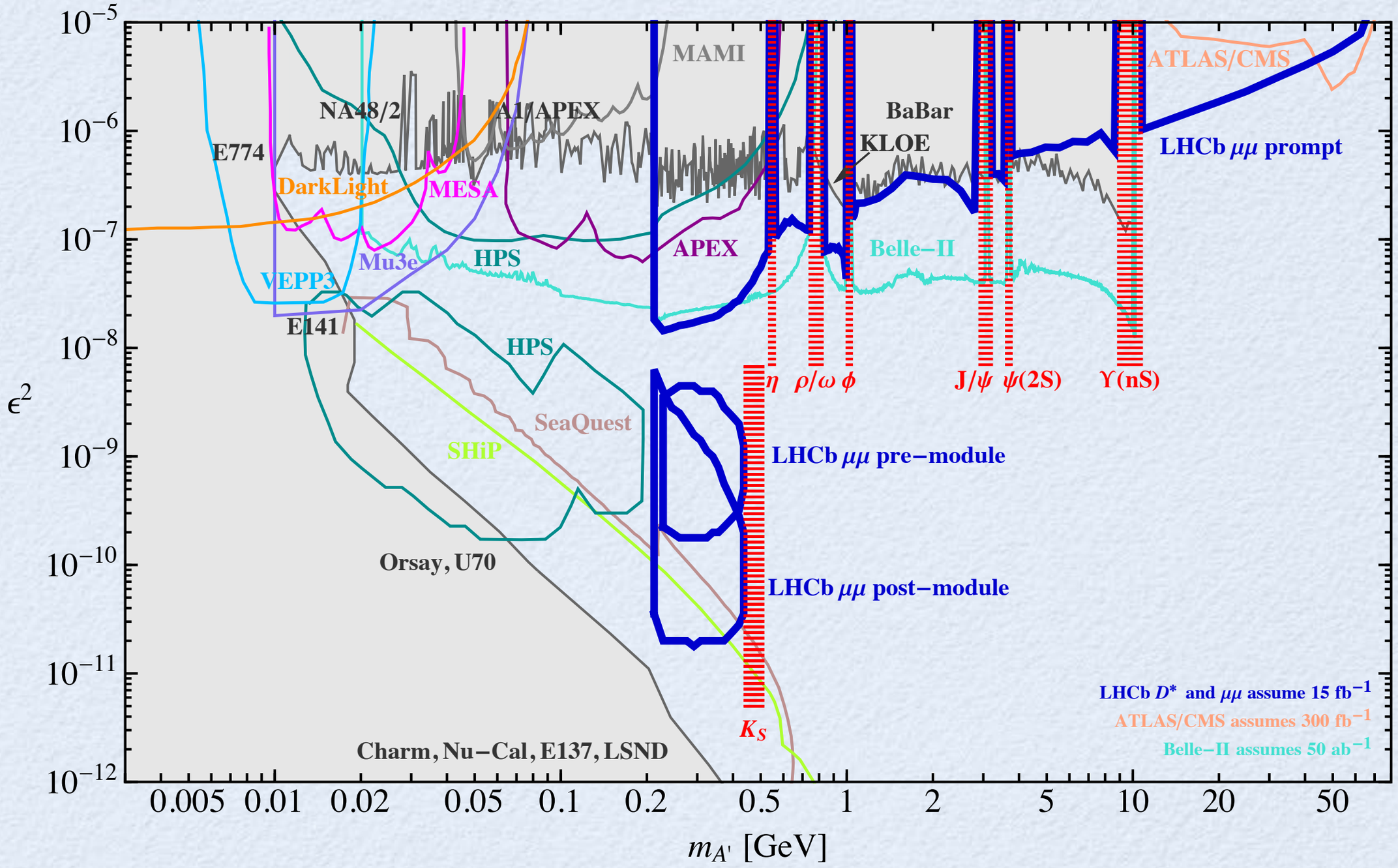
10^{-5}
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ϵ^2
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LHCb $\mu\mu$ pre−module
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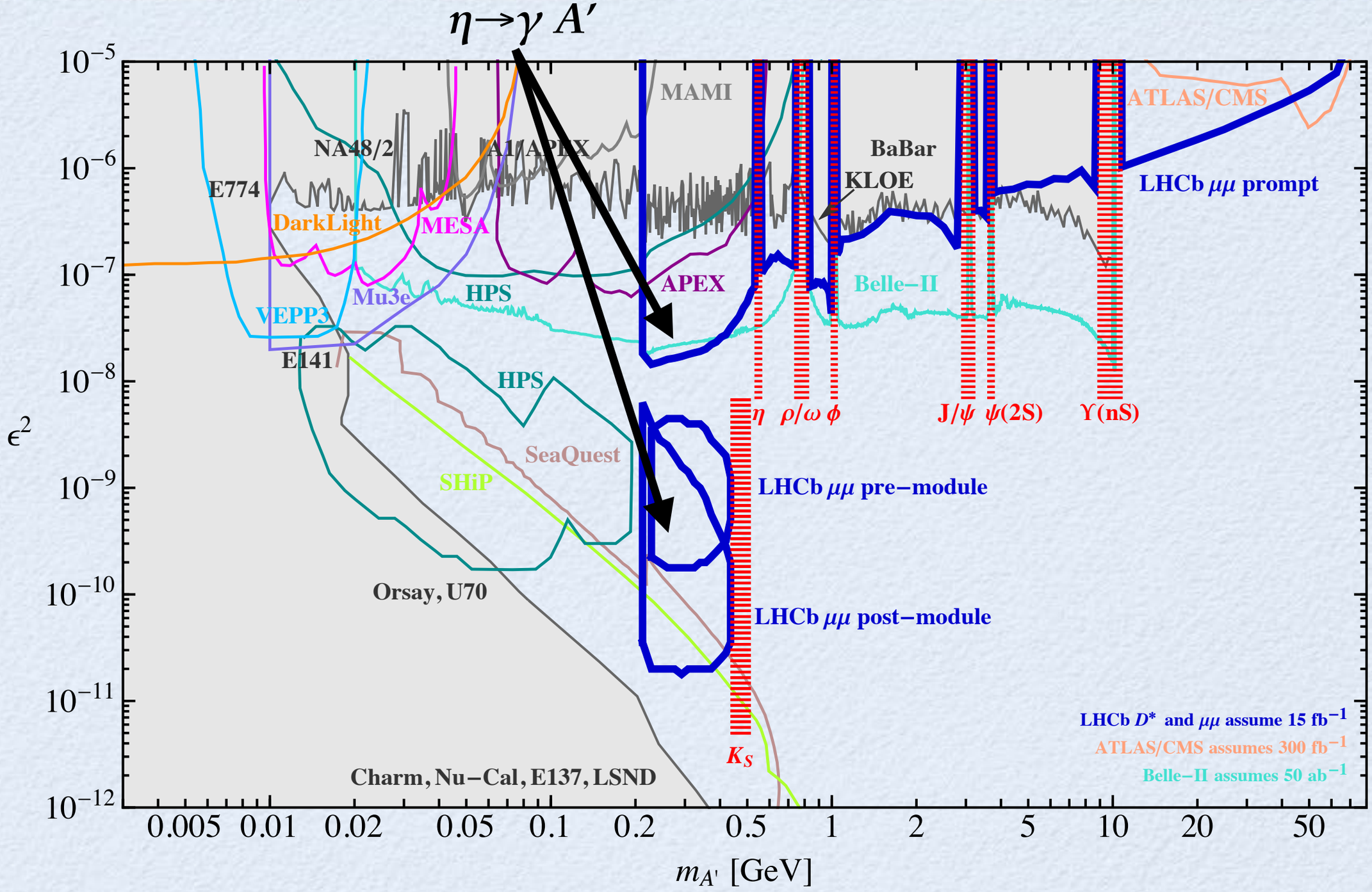
K_S
η
ρ/ω
ϕ
J/ψ
ψ(2S)
Υ(nS)
LHCb D^* and $\mu\mu$ assume 15 fb^{-1}
ATLAS/CMS assumes 300 fb^{-1}
Belle−II assumes 50 ab^{-1}

REACH PLOT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LHCb $\mu\mu$ pre−module
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ATLAS/CMS assumes 300 fb^{-1}
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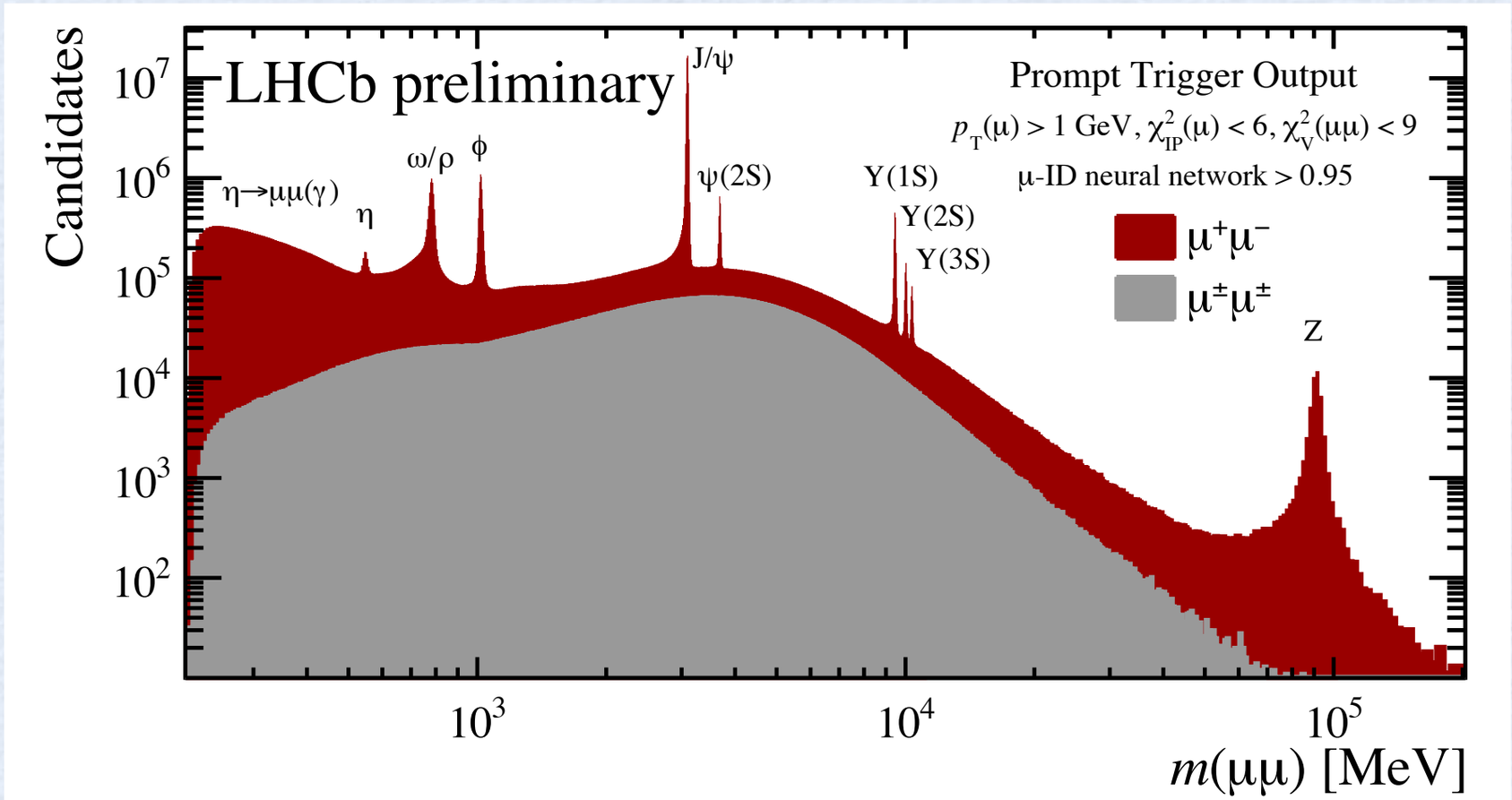
0.005 0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50
$m_{A'}$ [GeV]

2016 DATA



$p_T(\mu^\pm)$>1.0GeV (and not 0.5GeV) - because of μ ID

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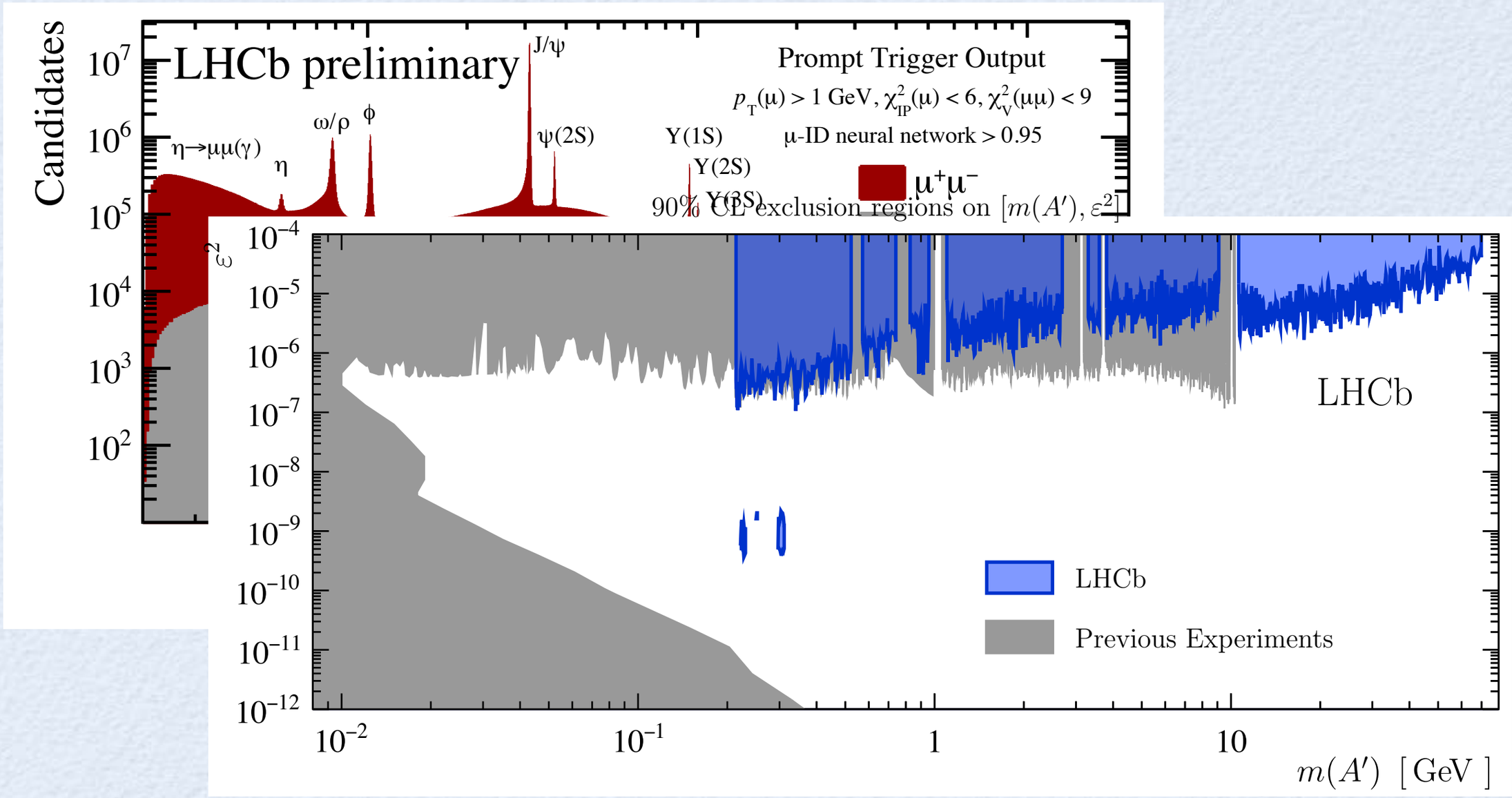


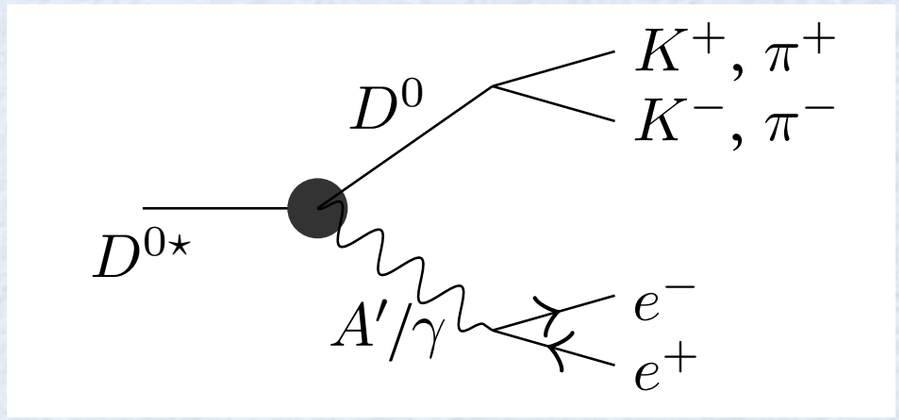
$p_T(\mu^{\pm})$>1.0GeV (and not 0.5GeV) - because of μ ID

POSSIBLE IMPROVEMENTS

- event selection: multivariate analysis, low p_T
- semi-inclusive search: $M \to \ell^+\ell^- \Upsilon$, ($D^{*0}$ example)
- di-electron search: $m_{A'} \in [2m_e, 2m_\mu]$, mass resolution is degraded by Bremsstrahlung
- luminosity: Run 4 and 5, ($50 fb^{-1}$ and $500 fb^{-1}$)

$D^{*0} \to D^0 A'$ SEARCH

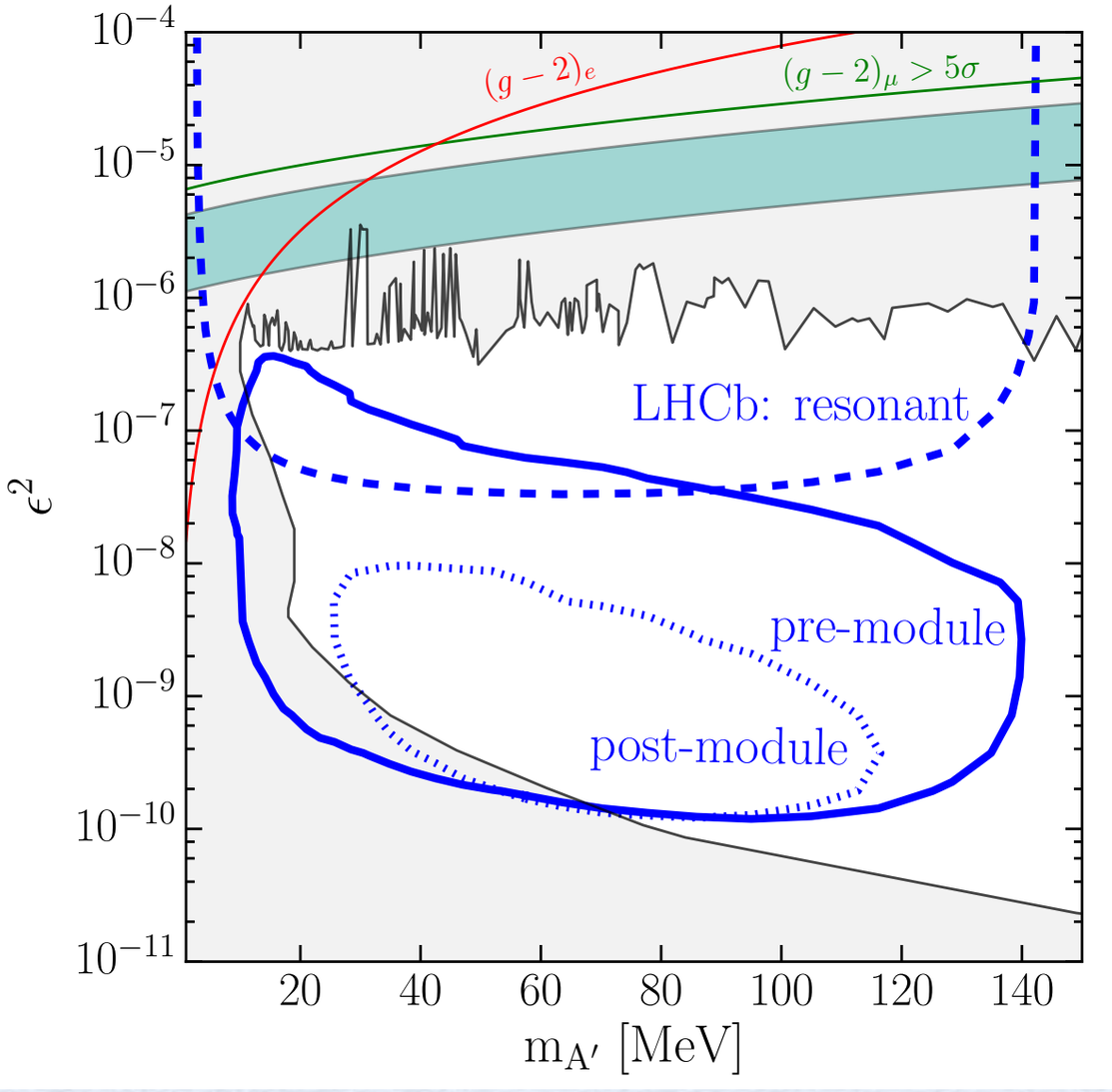
- $D^{*0} \to D^0 A' \to D^0 e^+ e^-$
- $m_{A'} \in [2m_e, 142\text{MeV}]$

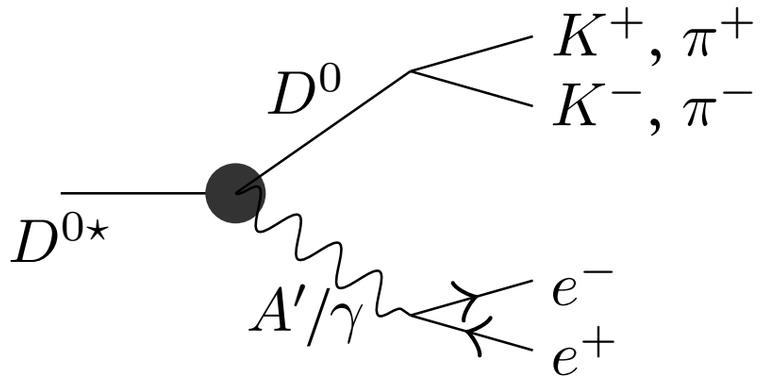


- prompt and displaced searches
- improved mass resolution by kinematical fit to very narrow D^{*0}- (improve the Bremsstrahlung)

Ilten, Thaler, Williams, Xue, 1509.0675

D*0 → D0A′ SEARCH





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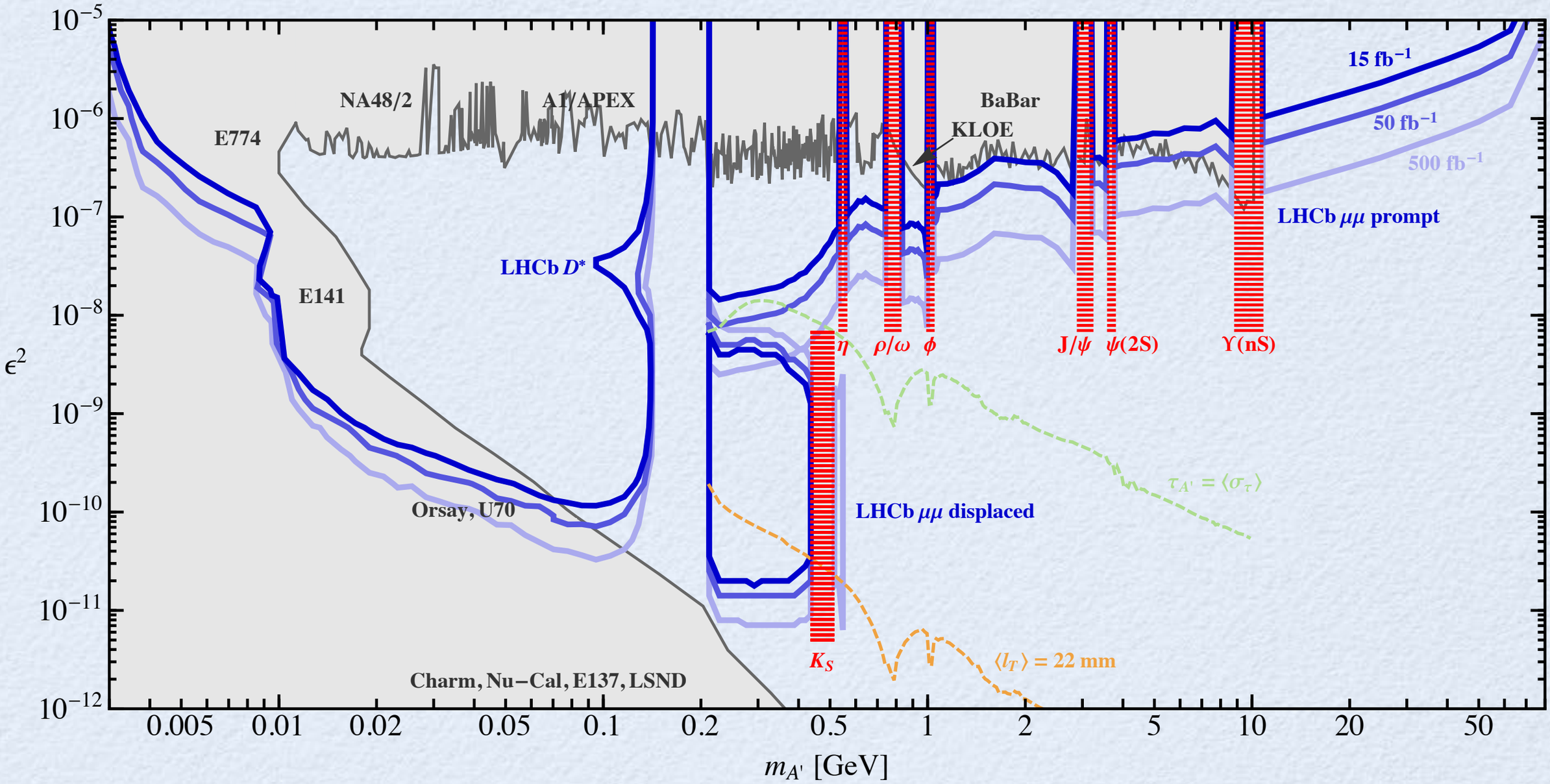
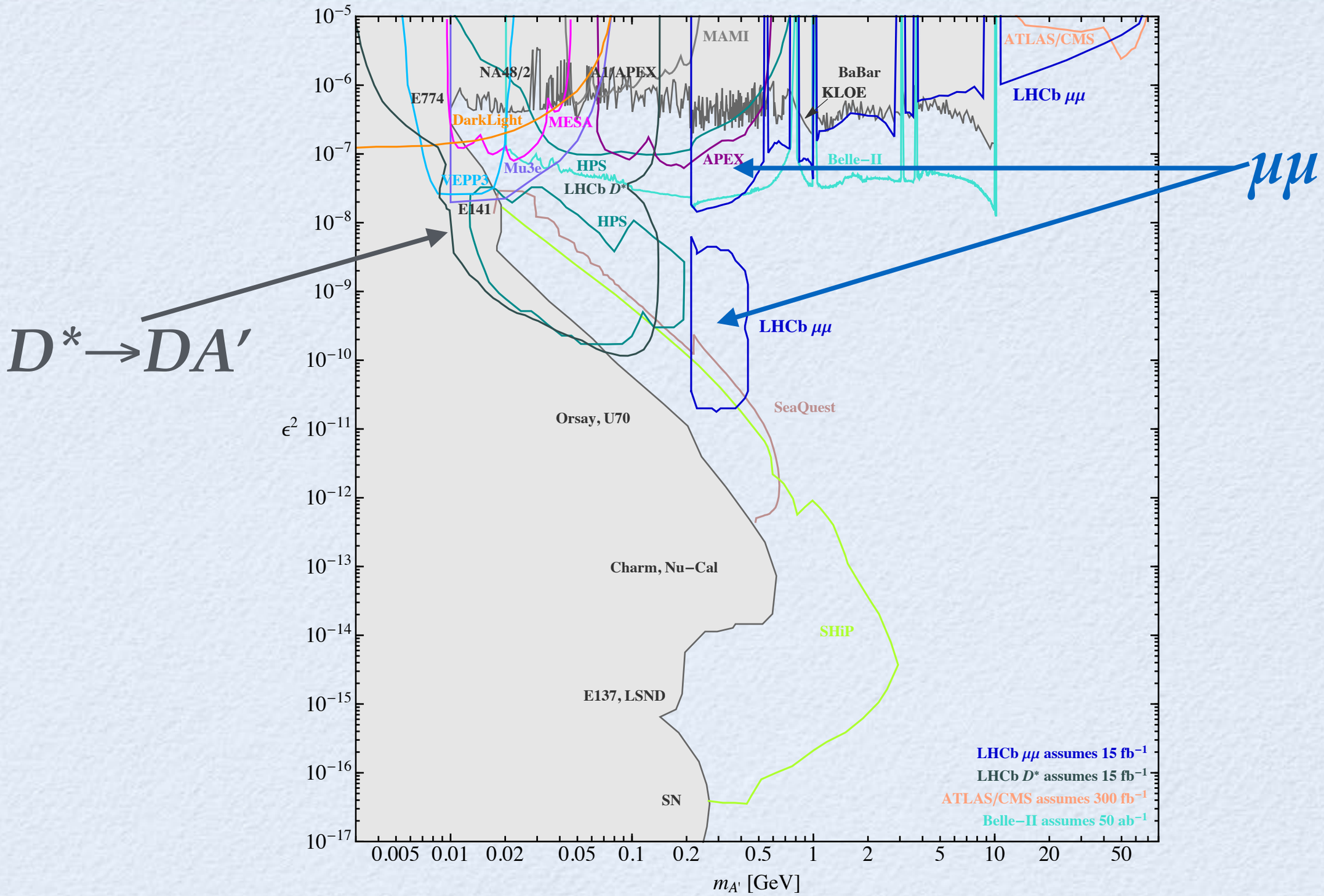
POSSIBLE IMPROVEMENTS



SUMMARY


$D^* \to DA'$
$\mu\mu$
ϵ^2
$m_{A'}$ [GeV]
NA48/2
E774
DarkLight
MESA
A1/APEX
MAMI
BaBar
KLOE
ATLAS/CMS
LHCb $\mu\mu$
APEX
Belle−II
Mu3e
HPS
VEPP3
LHCb D^*
E141
HPS
LHCb $\mu\mu$
SeaQuest
Orsay, U70
Charm, Nu−Cal
SHiP
E137, LSND
SN
LHCb $\mu\mu$ assumes 15 fb^{-1}
LHCb D^* assumes 15 fb^{-1}
ATLAS/CMS assumes 300 fb^{-1}
Belle−II assumes 50 ab^{-1}

SUMMARY

- we proposed an inclusive search strategy for dark photon at the LHCb experiment in the di-muon channel
- due to the kinetic mixing, the signal can be directly inferred from the $\gamma^* \to \mu^+\mu^-$ rate, enabling a data-driven search
- we show that both prompt and displaced searches are sensitive to interesting regions in the $m_{A'}$-ε^2 plane, which is difficult to probe in other experiments

BACKUP SLIDES

PROMPT BACKGROUNDS

subtracting fake pions by using the same-sign sample:

$$n^{\pi\pi}_{\pm\pm} = \frac{n^{\pi}_{\pm}(n^{\pi}_{\pm} - 1)}{2}$$

$$n^{\pi\pi}_{+-} = n^{\pi}_{+} n^{\pi}_{-}$$

number of same(opposite) sign events per bin

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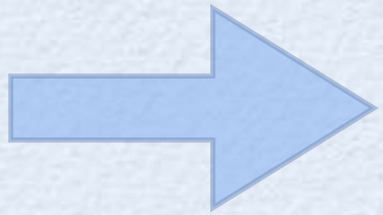

$$n^{\pi\pi}_{+-} \approx 2\sqrt{n^{\pi\pi}_{++} n^{\pi\pi}_{--}} \approx n^{\pi\pi}_{++} + n^{\pi\pi}_{--}$$

number of same(opposite) sign events per bin

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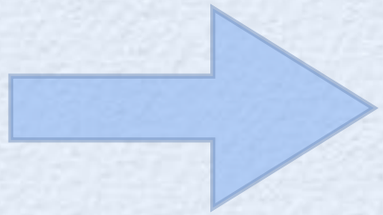


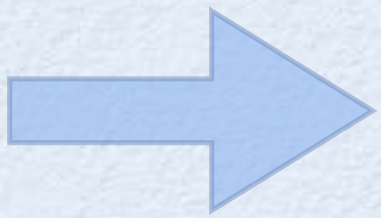
$$n^{\pi\pi}_{+-} \approx 2\sqrt{n^{\pi\pi}_{++} n^{\pi\pi}_{--}} \approx n^{\pi\pi}_{++} + n^{\pi\pi}_{--}$$

number of same(opposite) sign events per bin

generalize to all bins and for one fake:

$$N^{\pi\pi}_{+-} \approx N^{\pi\pi}_{++} + N^{\pi\pi}_{--}$$

$$N^{\pi\mu}_{+-} \approx N^{\pi\mu}_{++} + N^{\pi\mu}_{--}$$



$$B^{\pi\pi}_{\mathrm{misID}} + B^{\pi\mu}_{\mathrm{misID}} \approx N_{++} + N_{--}$$