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LDM and Hadron Collider Predictions

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Outline

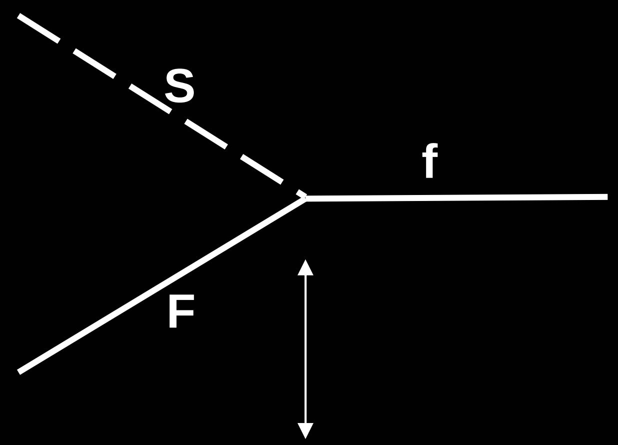
- Light Dark Matter
- LDM & p-p collisions
- Background vs. Signal
- Conclusions

Light Dark Matter

LDM - Basics

C. Boehm et al., arXiv:0305261 [hep-ph]

- Aussume Mirror-parity (Z_2 symmetry)
- Non- chiral Yukawa couplings between SM fermions (f), their mirror partners (F) and a scalar field (S)
- Lowest mass particle: scalar S, m_S~ (MeV-GeV)
- S is stable thanks to Mirror-parity → S is a Dark Matter candidate

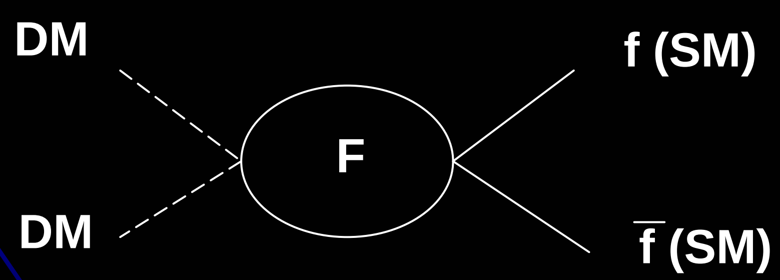


$$L \supset \left[s\left(c_l \overline{f_l} F_r + c_r \overline{f_r} F_l \right) + h.c. \right]$$

LDM - Cosmology

- Coupled to SM primordial thermal bath
- Chemical decoupling: Relic Density $\Omega_m h^2$
- Structure formation: LDM ≡ CDM
  (Boehm et al., arXiv:0012504 & arXiv:0410591 [astro-ph])

Annihilation DM-DM → F → f-fbar



LDM – Relic Density

Follow DM distribution function throughout universal history:

- Boltzmann Equation $L\left[f(x,p)\right]=C\left[f(x,p)\right]$
- Number Density $\frac{g}{(2\pi)^3}\int f(x,p)\,d^3p\equiv n$

Boltzmann Equation in EU

$$\frac{dn}{dt}=-3Hn-\langle\sigma v\rangle_{ann}\left(n^2-n_{eq}^2\right)$$

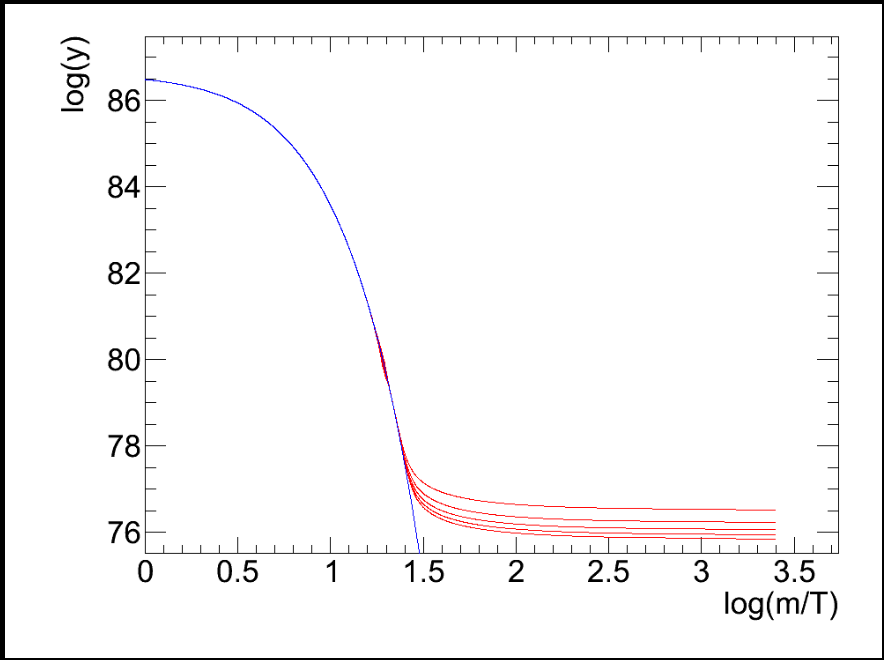
Allows to find $\rho_0=n_0m_{DM}$ and thus Ω_mh^2

Gives a constrained value of $\langle\sigma v\rangle_{ann}$

LDM – Boltzmann Code

$$y(T) = \frac{n(T)}{T^3} \propto N(T) \quad \longleftrightarrow \quad \frac{dy}{dT} = \frac{\langle \sigma v \rangle_{ann}}{H_0}\left(y^2 - y_{eq}^2\right)$$

- Start from thermal and chemical equilibrium at T > m_{DM}
- Follow exponential suppression with an implicit integrator
- By imposing y_0, get $<\sigma v>_{ann}$ & T_{fo}



$$x_{fo} = \frac{m_{dm}}{T_{fo}} \sim 10 - 25$$

$$\langle \sigma v \rangle_{ann} \sim 10^{-26}\, cm^3 s^{-1}$$

LDM – Charged Lepton Side

Unhealthy Implications

- Gamma-ray production in galaxies: $\sigma_{SS\to l^+l^-} v_{rel} < O\left(10^{-[31-28]}\,cm^3 s^{-1}\right)$ (for m_{DM} є [1-100] MeV)

- Anomalous magnetic moments (g-2) constraints for electrons and muons: $$\delta a_{\mu,e}^{m_F \gg m_{\mu,e}} \simeq \frac{m_{\mu,e}}{16\pi^2}\frac{c_l c_r}{m_F}$$

- Direct constraint for annihilation cross section:

$$\sigma_{SS\to l^+l^-} v_{rel} \propto \frac{c_l c_r}{m_F} \longrightarrow \sigma_{SS\to l^+l^-} v_{rel} < O\left(10^{-29}\,cm^3 s^{-1}\right)$$

- Cannot achieve relic density through annihilation into e nor into μ

LDM – Charged Lepton Side

Vigorous Application

- 511 keV line detected from the galactic center **(Johnson et al., ApJ, 1972)** → presence of low energy positrons

- Morphology: distributed on the galactic bulge, suggests correlation with a typical DM halo profile

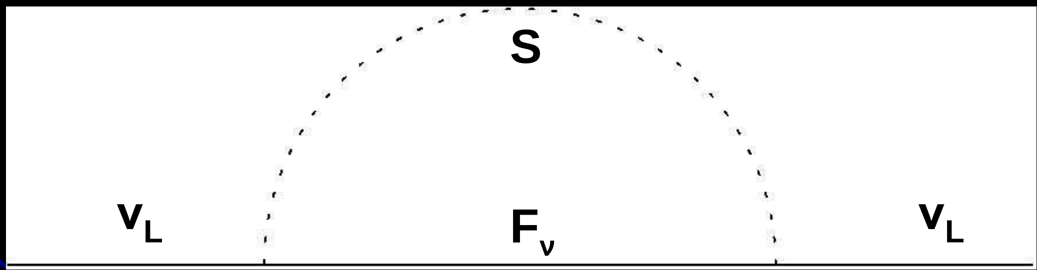
- Best fit to INTEGRAL signal: DM halo profile + annihilating LDM into e^+e^- through F_e exchange **(Ascasibar et al., arXiv:0507142 [astro-ph])**

LDM – Neutrinos

- No particle physics nor astrophysical contraints yet → can produce relic density through S-neutrino interactions:

$$\sigma_{SS\to\nu\nu} v_{rel} \sim O\left(10^{-26} cm^3 s^{-1}\right)$$

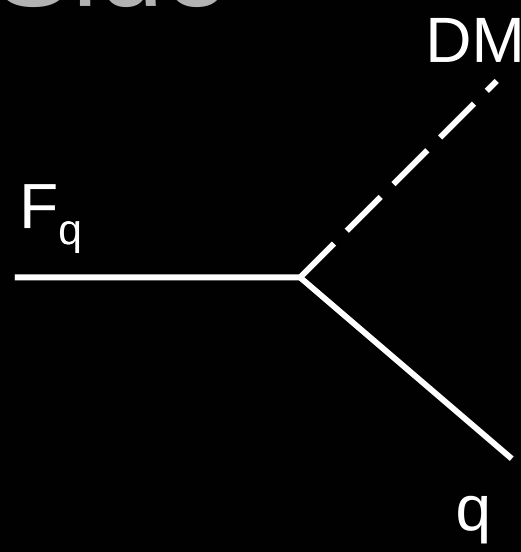
- As a bonus: if neutrinos are Majorana fermions, then expect



and if apply similar couplings and masses, get $m_\nu \leq 1$ eV. However, this would require F_ν to be a singlet of (SU(2) X U(1)) **(Boehm et al., arXiv:0612228 [hep-ph]).**

LDM – Flavor Side

$$\boxed{L \supset \left[s_{DM} \left(c_l \overline{q_l} F_{q,r} + c_r \overline{q_r} F_{q,l} \right) + h.c. \right]}$$



- Assume same mass for all flavors

- No flavor mixing in the mirror side

- F_q colored particles, therefore strong coupling to gluons

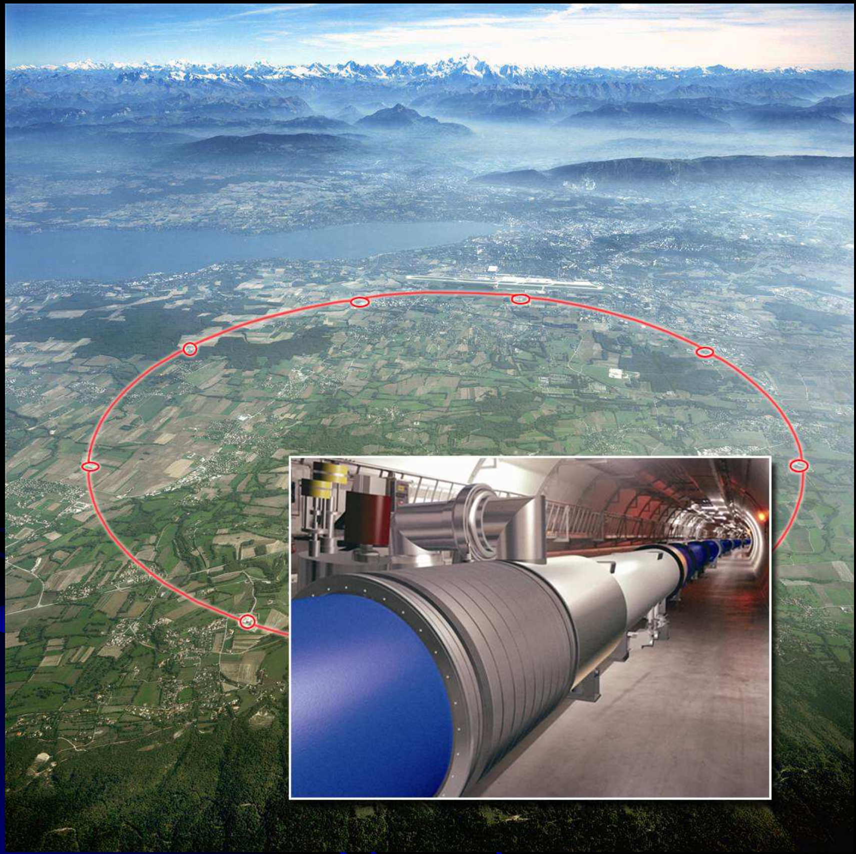
- If m_{dm} < 100 MeV, no annihilation into quarks (nor heavy leptons)

LDM – Parameter Space

- New charged particle searches: $m_F > 100$ GeV
- Big Bang Nucleosynthesis: $T_{fo} > T_{BBN} = 100$ keV
  => $m_{DM} > 1$ MeV
- Relic Density in neutrino sector only: $m_{DM} < m_\pi$
- $c_{l,r}$ can be large! (still want to be perturbative) : [0.1 ; 3]

LDM & p-p collisions

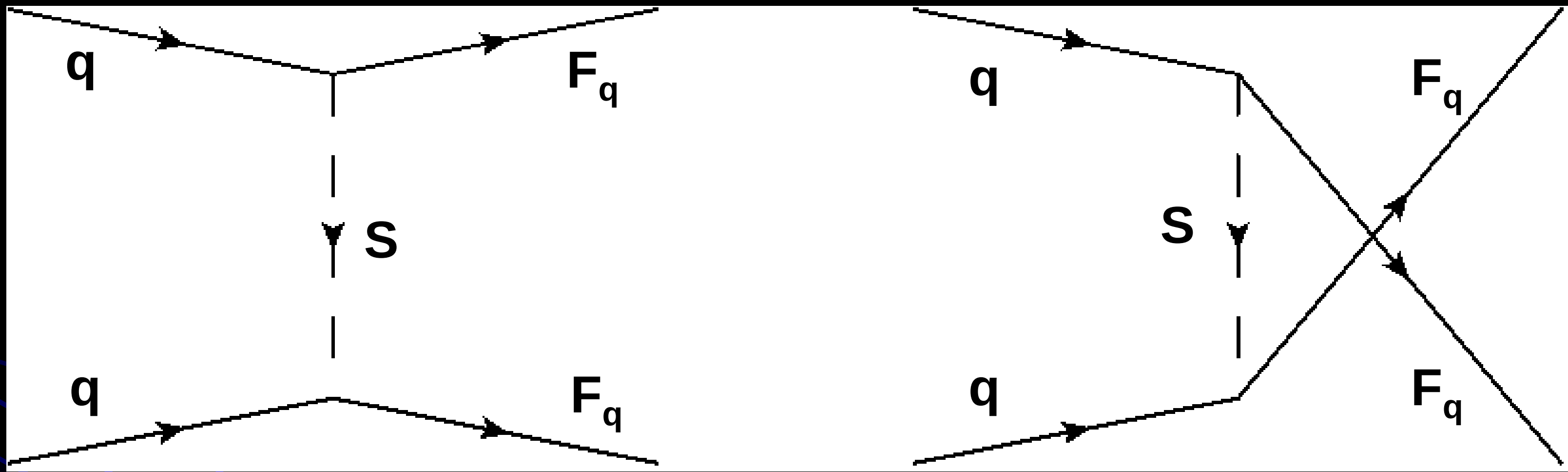
p-p collisions



$$protons \supset \{u, d, s, c, b, t, g\}$$

p-p collisions – parton level

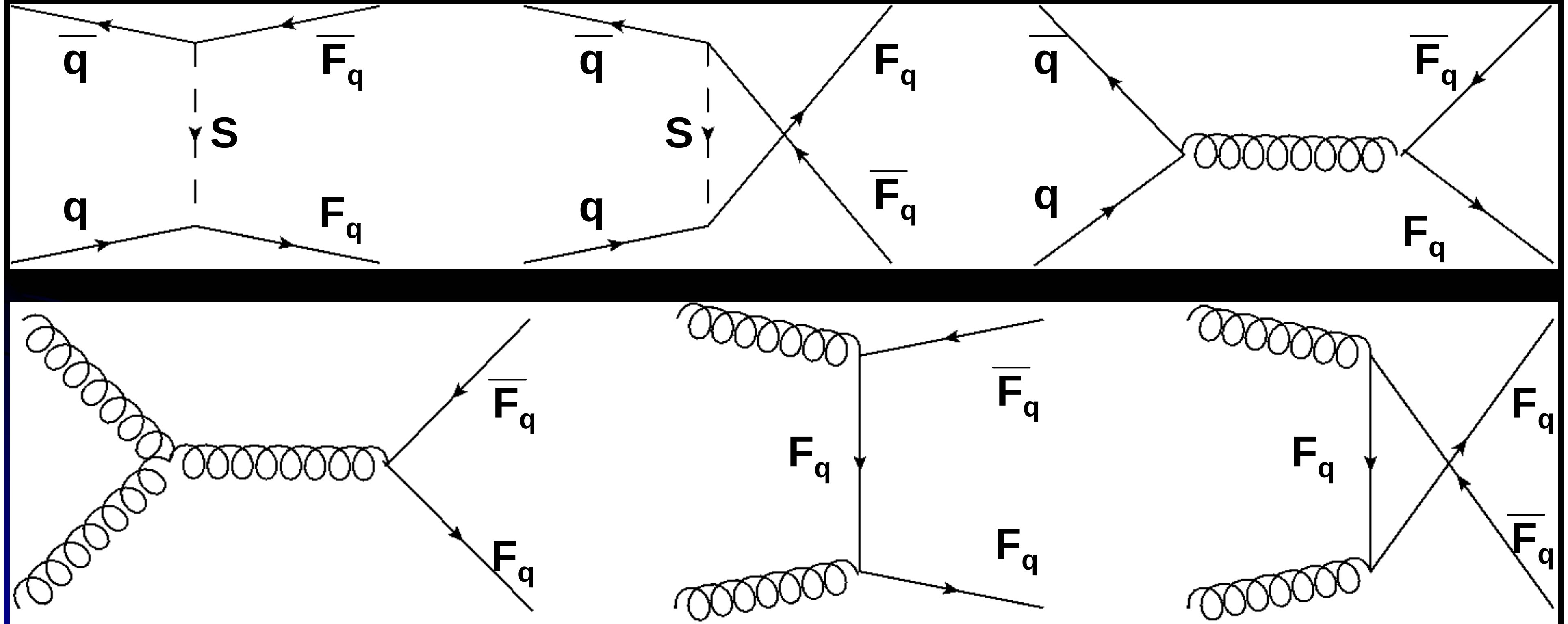
di-F_q production ($\approx$ di-$\overline{F}_q$)



Exchange of a very light particle!

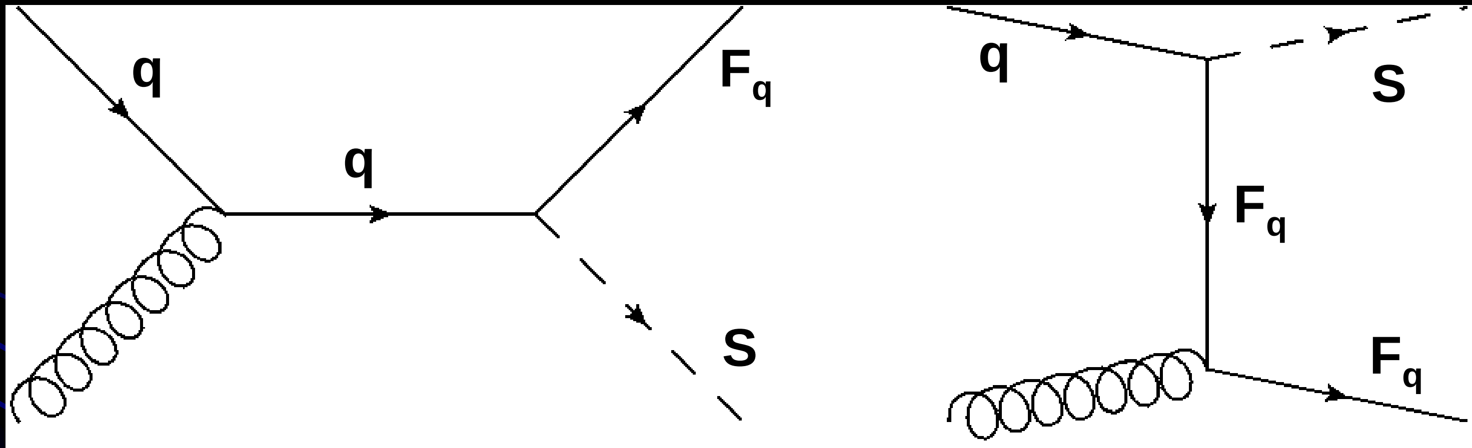
p-p collisions – parton level

F_q-$\overline{F_q}$ production



p-p collisions – parton level

F_q production ($\approx \overline{F}_q$)



p-p collisions – parton level

Cross Sections computed using:

- cs22 function implemented in MicrOmegas
  (G. Bélangeret al., arXiv:0803.2360 [hep-ph])

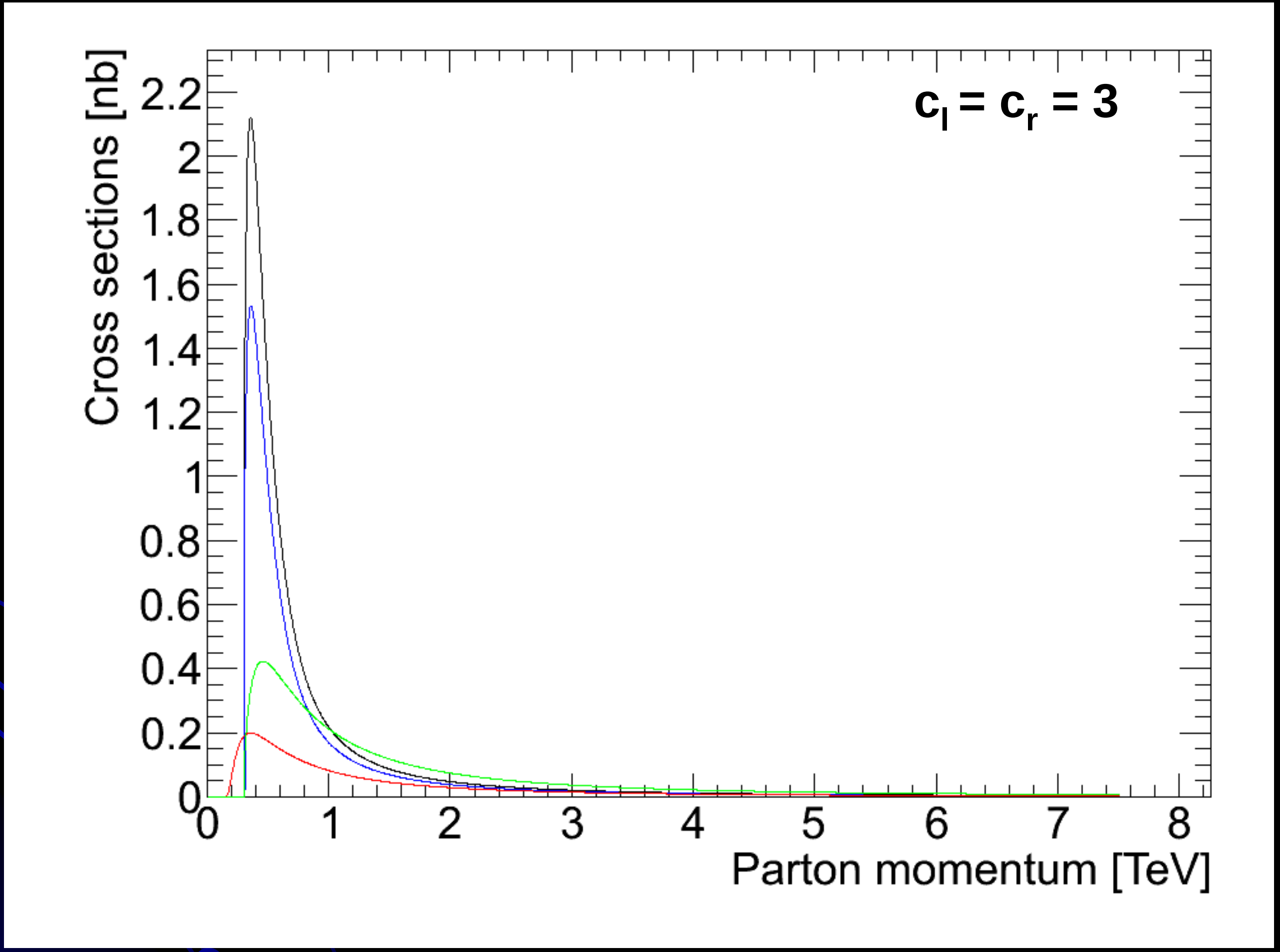
- Vegas routine in Calchep-Comphep
  (A. Pukhov et al., arXiv:0908288 [hep-ph])

- Checked values analytically by comparing symbolic calculations in Calchep-Comphep with our own expressions

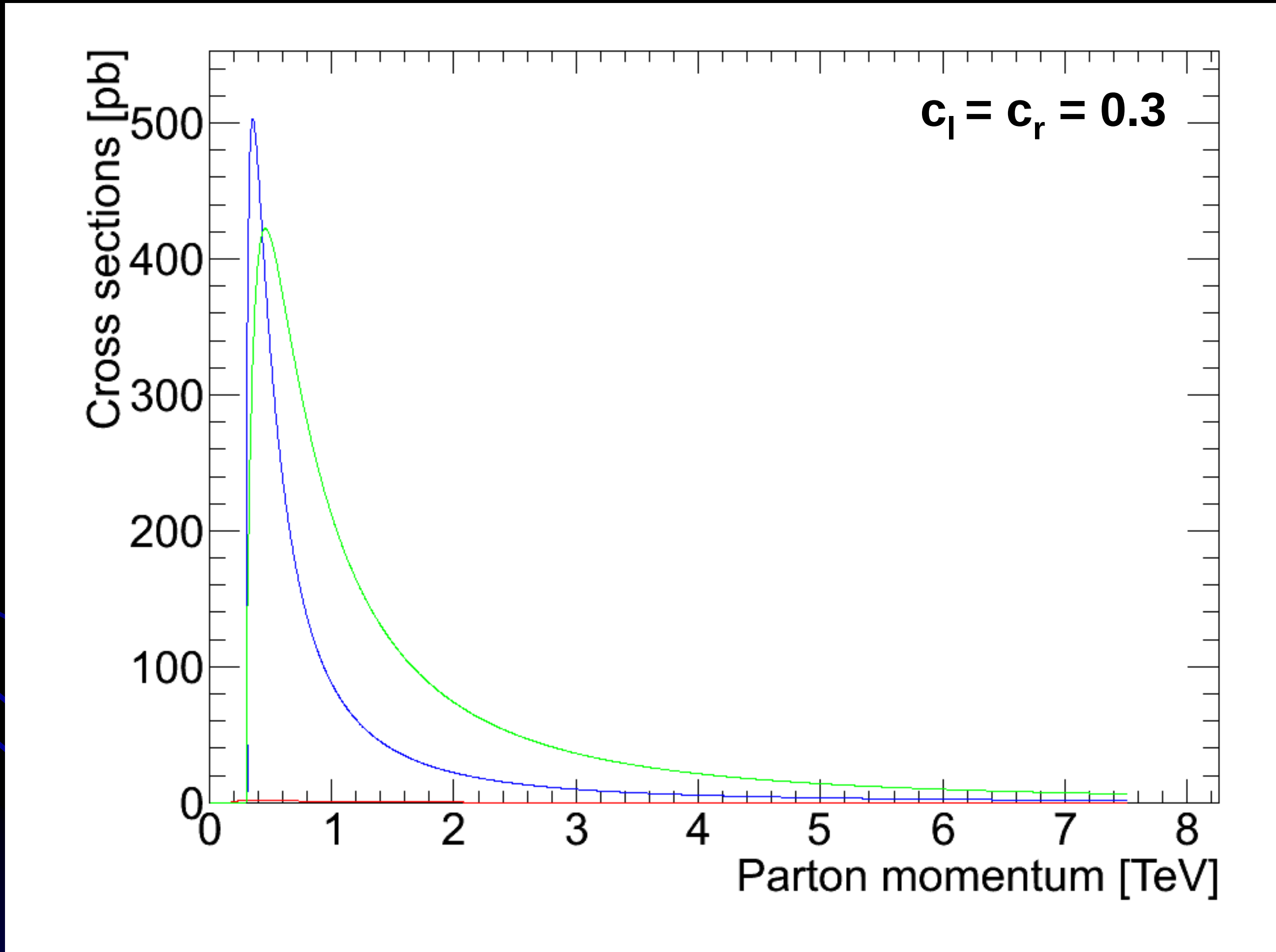
- Chose $m_F = 300$ GeV, $m_{DM} = 2$ MeV

- Implement only the case $q \equiv u$

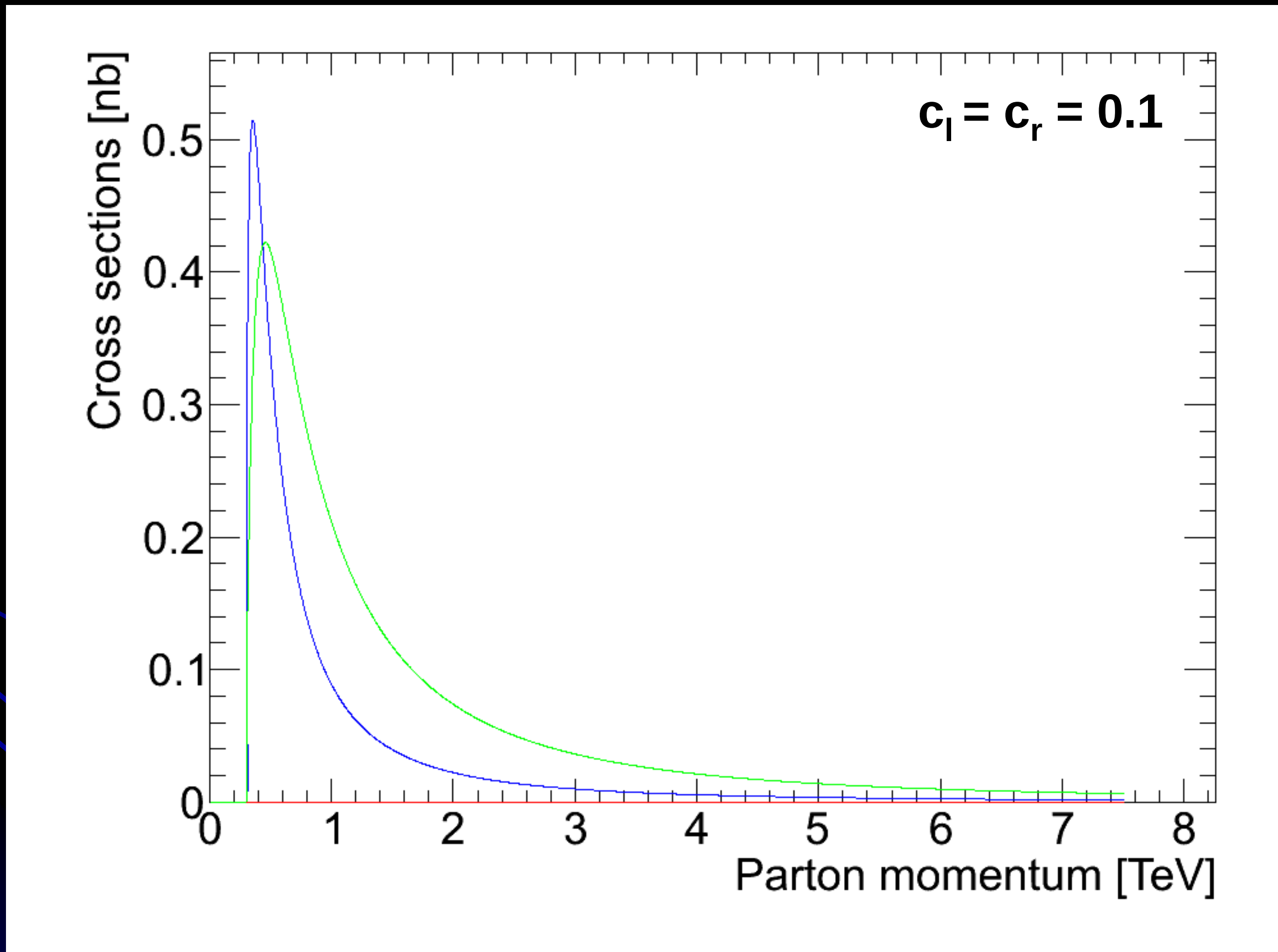
p-p collisions – parton level



p-p collisions – parton level



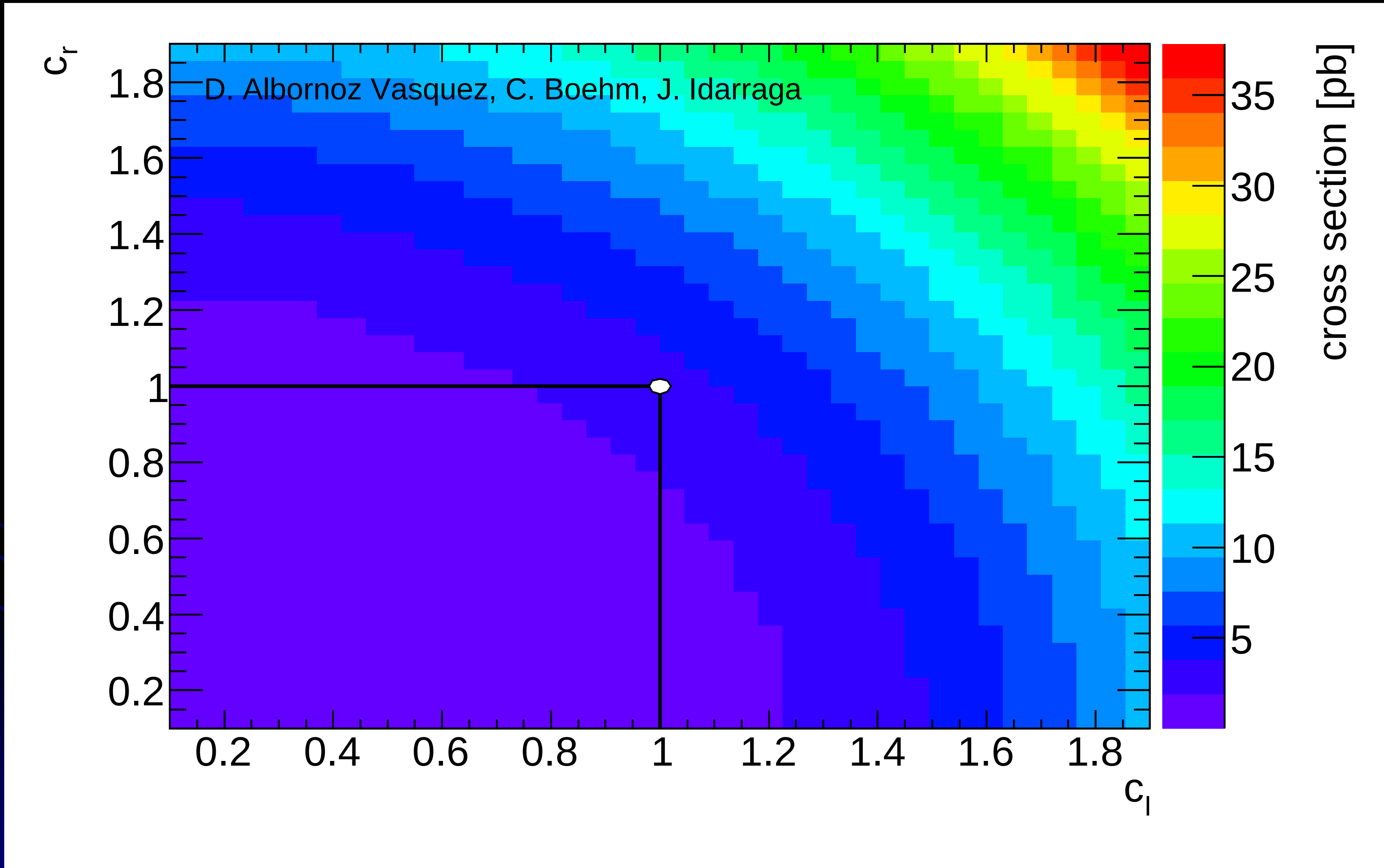
p-p collisions – parton level



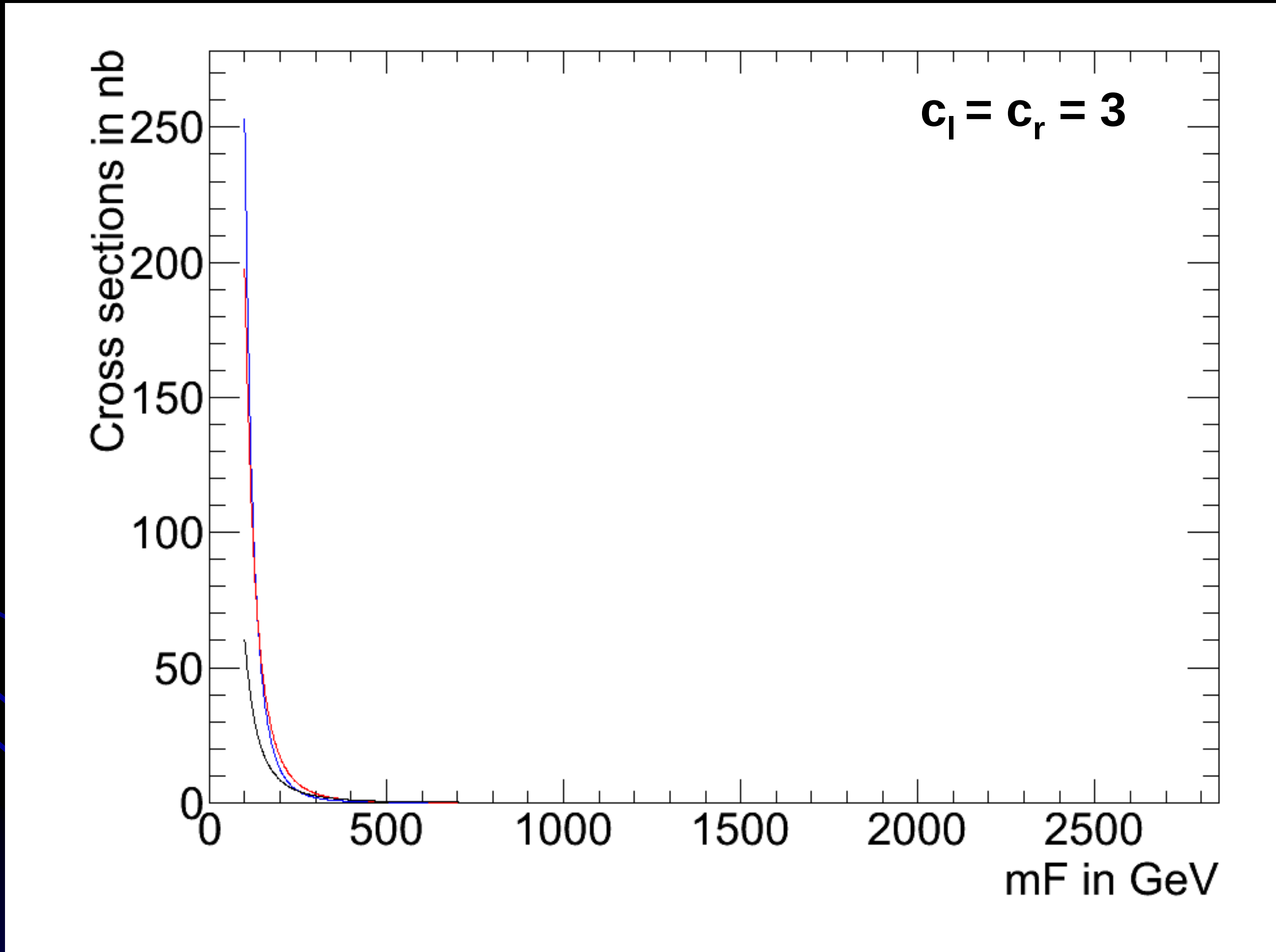
p-p collisions – ATLAS

- Starting physics program soon
- Data will be taken at $\sqrt{s} = 7\ TeV$
- Compute proton-proton collisions using hCollider function implemented in MicrOmegas
- Chose mF = 300 GeV, mDM = 2 MeV

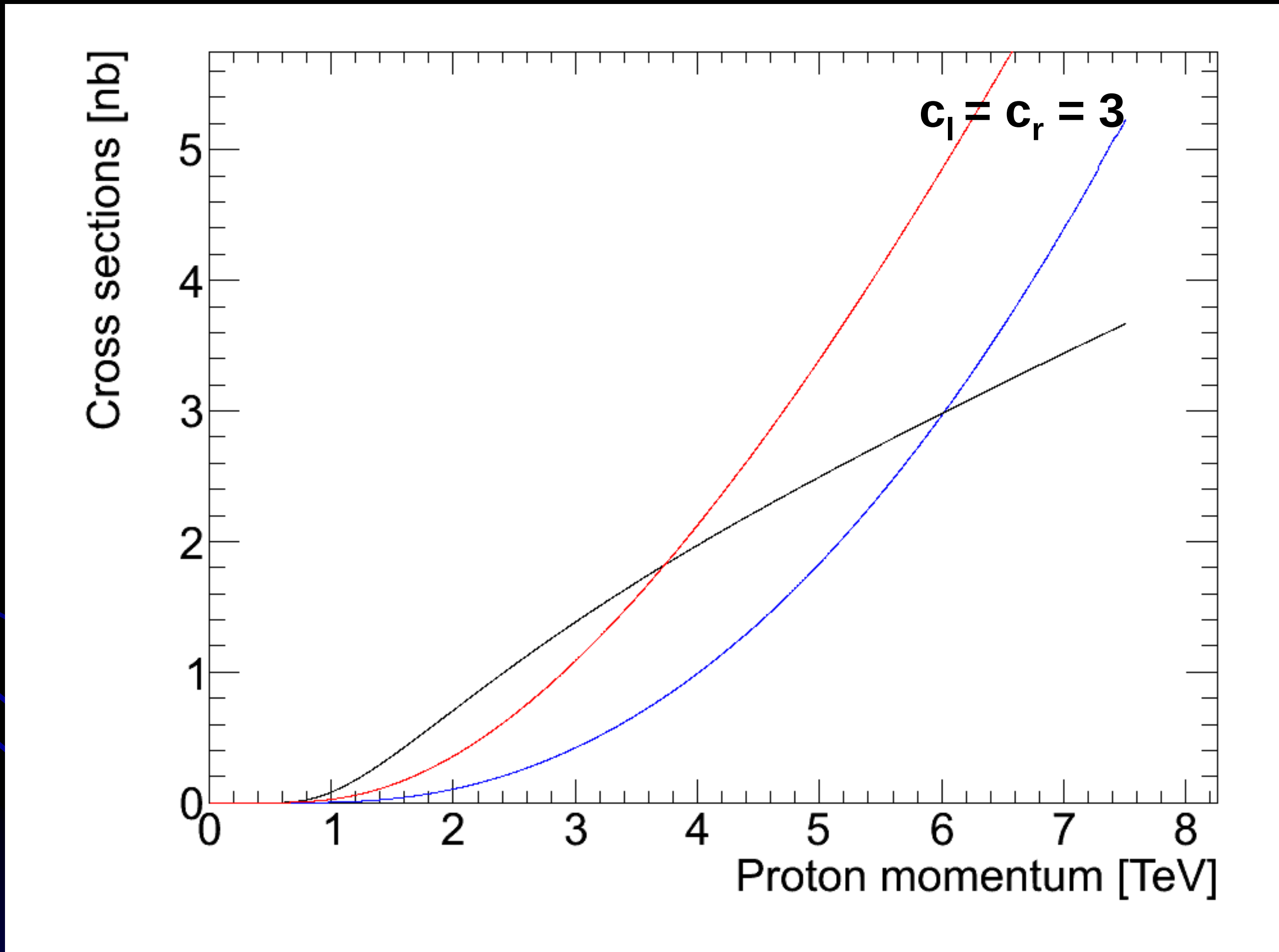
p-p collisions – proton level



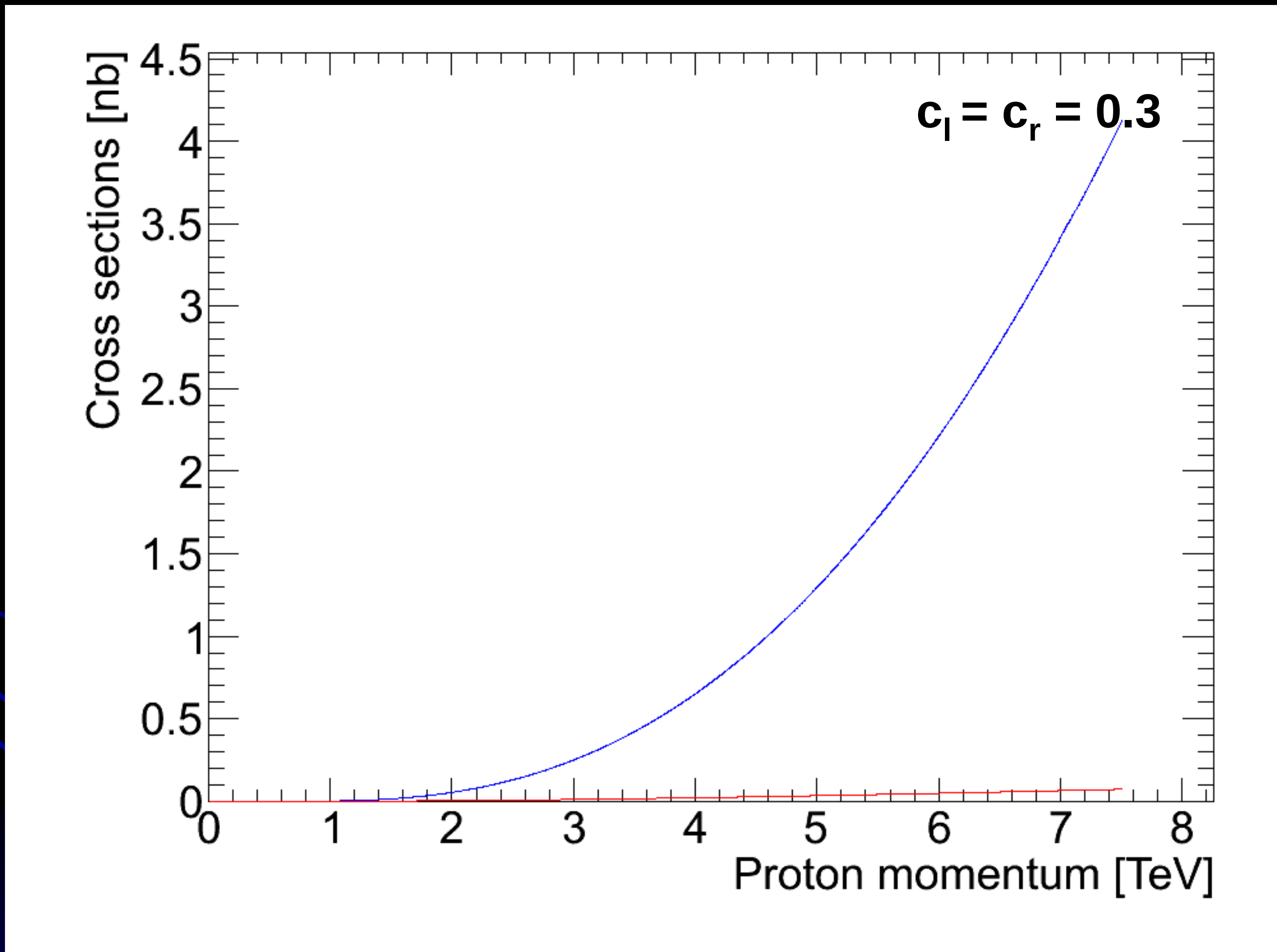
p-p collisions – proton level



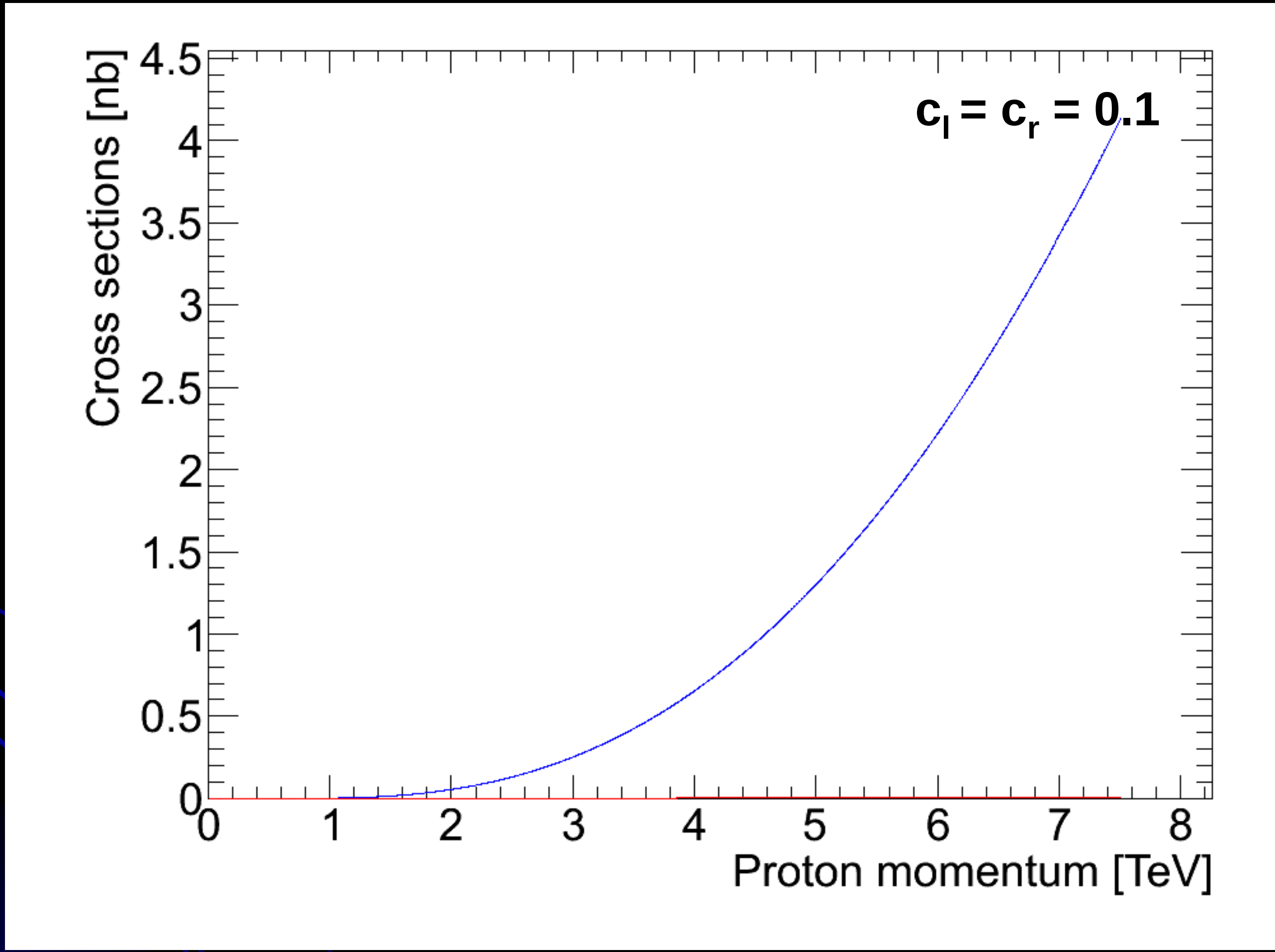
p-p collisions – proton level



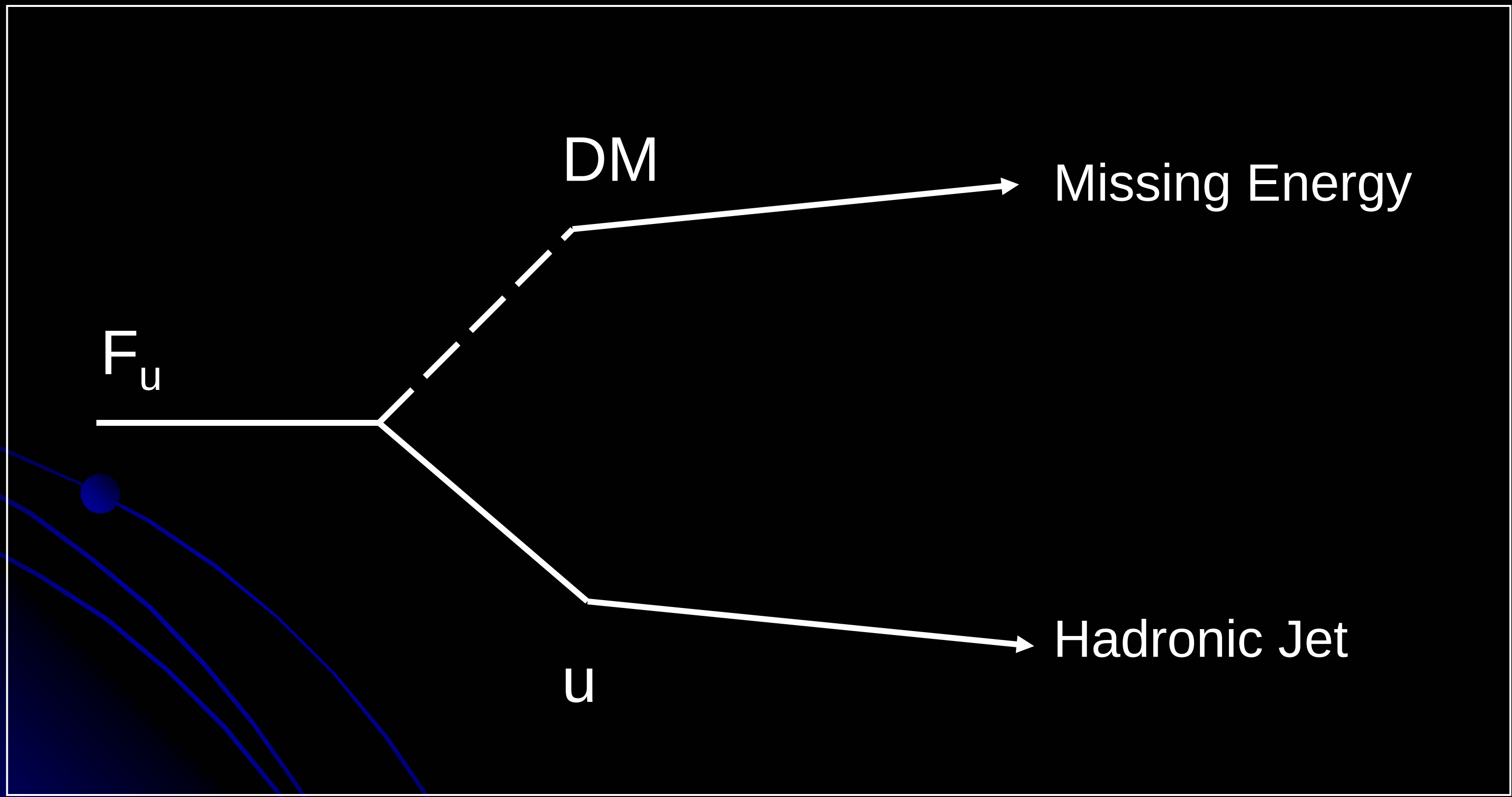
p-p collisions – proton level



p-p collisions – proton level



p-p collisions – signature



p-p collisions

Expected events:

- From u-u, u-$\bar{u}$ and g-g collisions:

  p-p → F + F ($\bar{F}$) → 2 jets + missing energy

- From u-g collisions:

  p-p → F + DM → 1 jet + missing energy

Background vs. Signal

Background vs. Signal

- Largest “2 jet + missing energy” events expected:
  - Z + 2 jets
  - $t,\bar{t} \rightarrow b,W \rightarrow b,l,v$ (ATLAS has b-tagging!)
  - WW, WZ

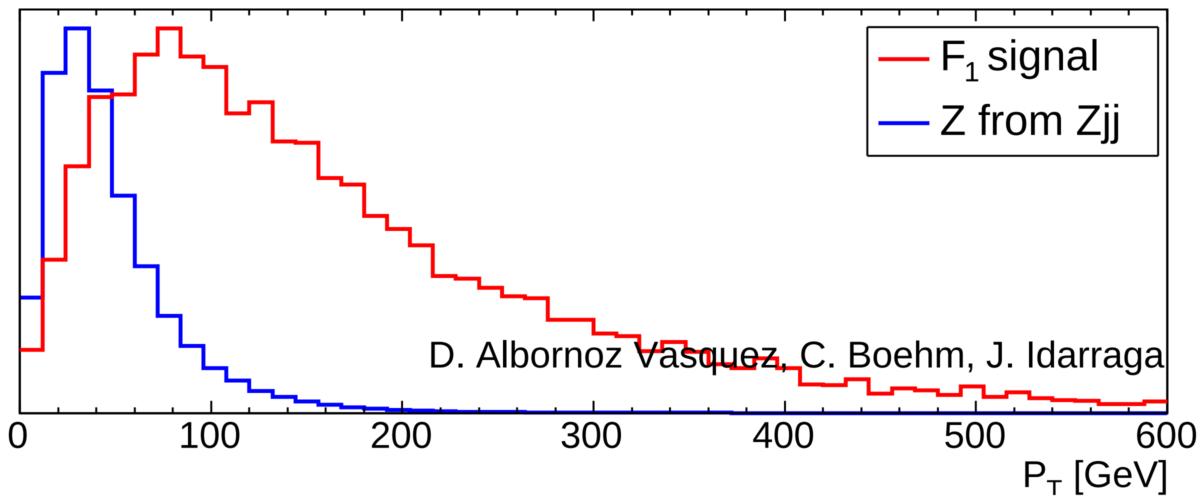
- Generation of events using Comphep:
  p-p → F-$\bar{F}$, F-F

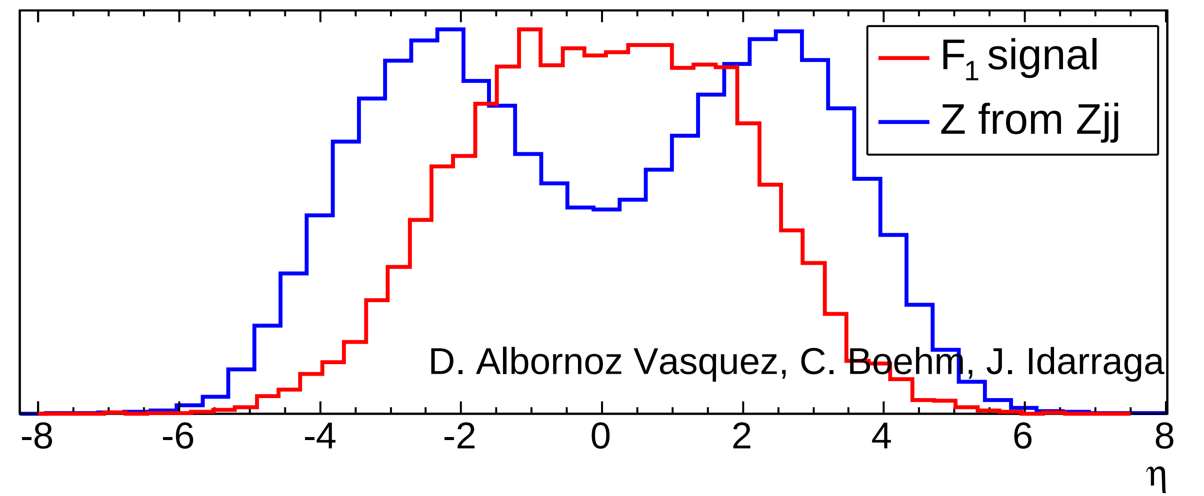
- Choose a rather conservative point

$c_{l,r} = 1$
$m_{DM} = 2$ MeV
$m_F = 300$ GeV
pcm = 3.5 TeV

- Include Z + 1, 2, 3 jet events and compare Z to one F

Background vs. Signal





Background vs. Signal

- Perspective: a cut based analysis eliminates background down to a few fb

  (The ATLAS collaboration, arXiv:0901.0512 [hep-ex])

- Carry on a full simulation including final sates using well established MC simulators

- Wait for LHC to look for LDM!

- TEVATRON: background has been studied, but cross section behavior, kinematical cuts and conclusions are model dependent

Conclusions

- Ensuring the Relic Density in neutrino sector allows the Hadronic sector to be more reactive
- Light Dark Matter is a DM candidate that provides predictions for colliders
- Cross sections for p-p collisions can be (amazingly) large!
- LHC (ATLAS) may have the potential to explore a good deal of parameter space, namely masses and couplings
- Complete kinematic analysis is in preparation
- Expand the number of events to take into account:
  - Other flavors (i.e. include d, s, c, b, t)
  - Leptonic production

Thanks!

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