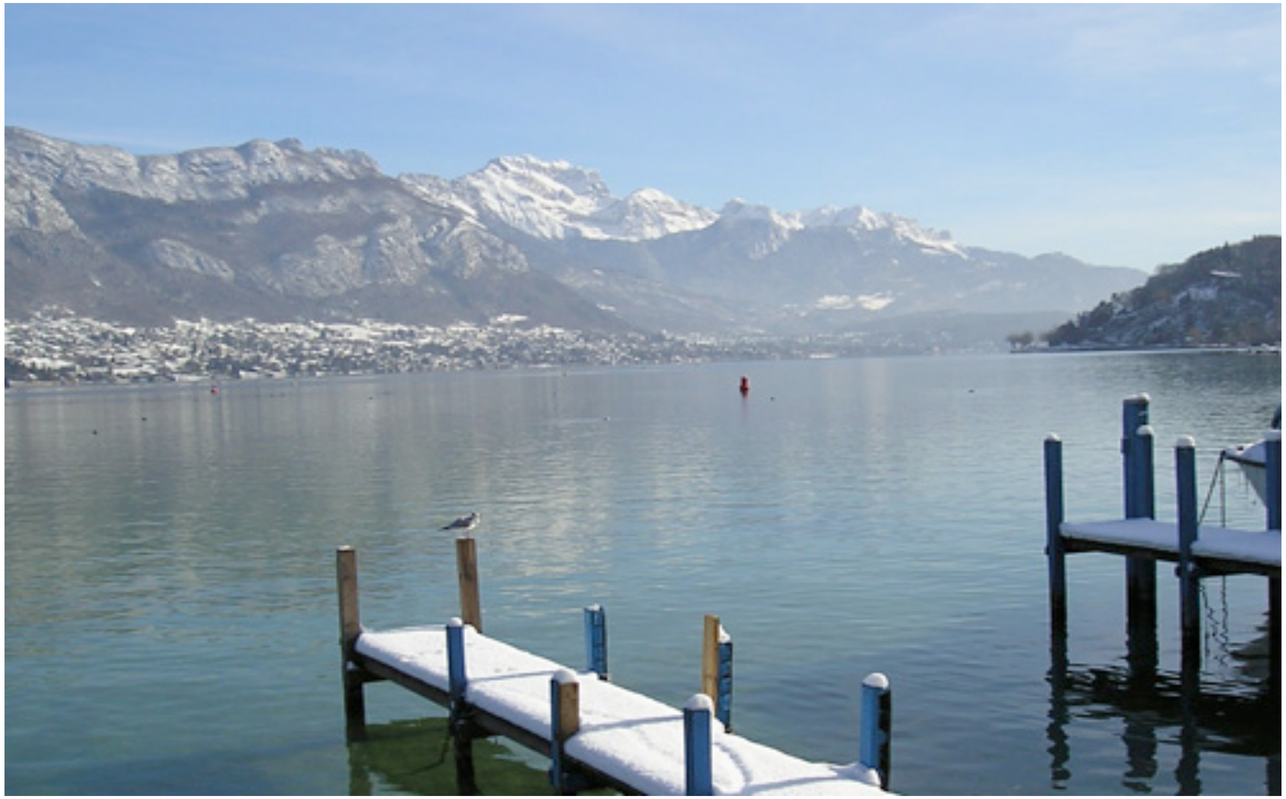
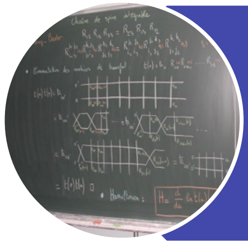
Activités au LAPTh

G. Bélanger

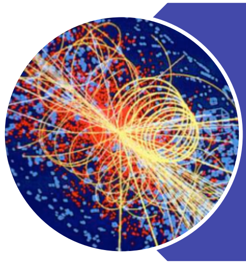


Equipes / Research - Teams



Fields, Strings and Symmetries *(Math-Phys)*

L. Frappat, L .Gallot. E. Ragoucy, F. Thuillier, E. Sokatchev, P. Sorba



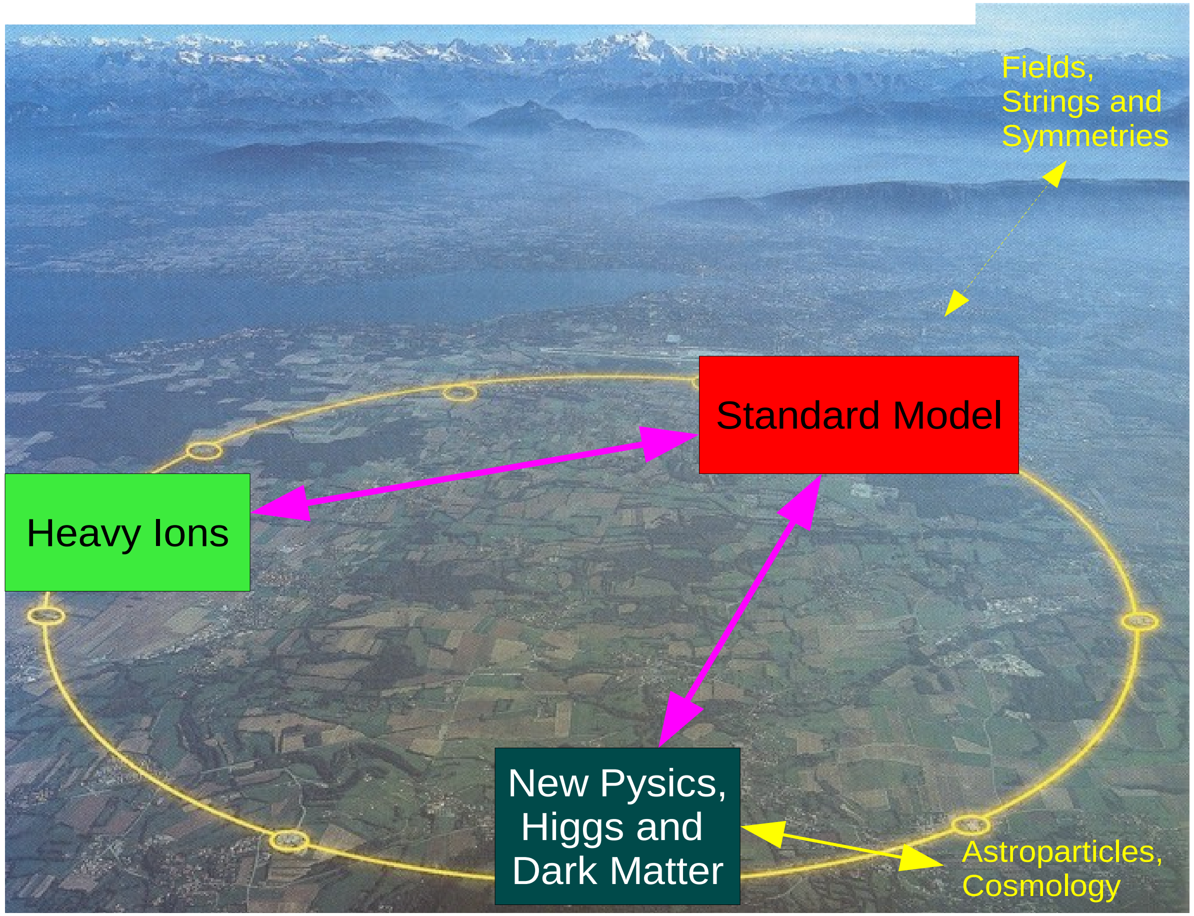
Particle Physics

P.Aurenche, G.Belanger, F.Boudjema, D. Guadagnoli, JP Guillet, B. Herrmann, E. Pilon, E. Re

Astroparticles - Cosmology

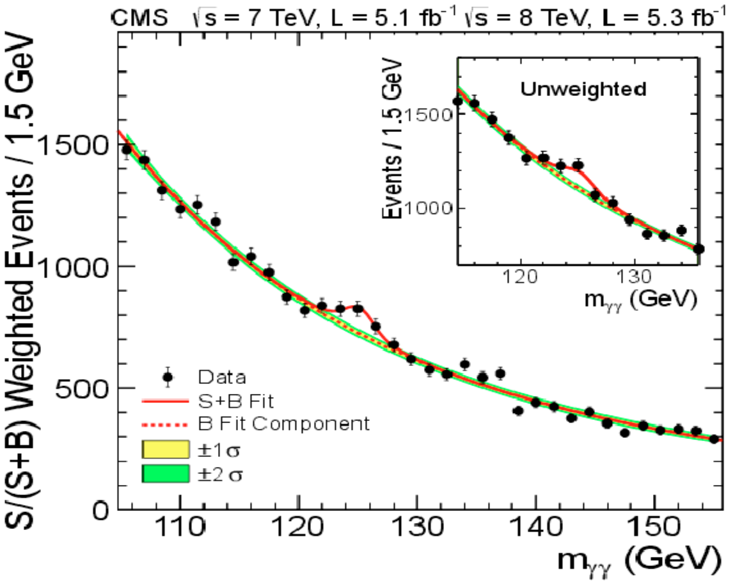
P. Chardonnet, P. Salati, P. Serpico, R. Taillet

Particle Physics

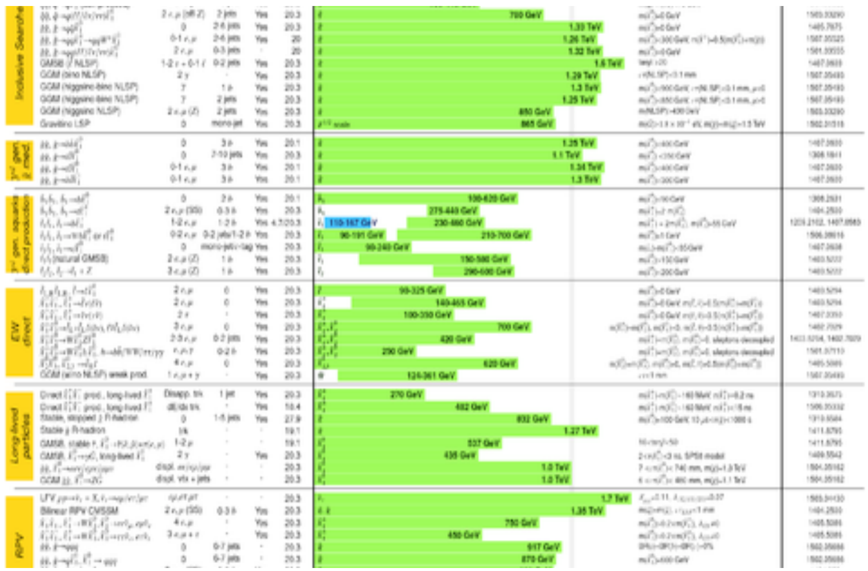


- Main activity centered on the LHC and on dark matter

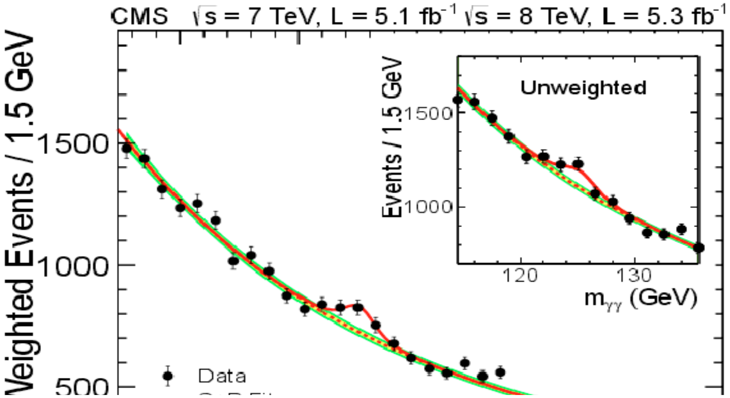
LHC



Higgs discovery in Run 1
Numerous searches for new particles

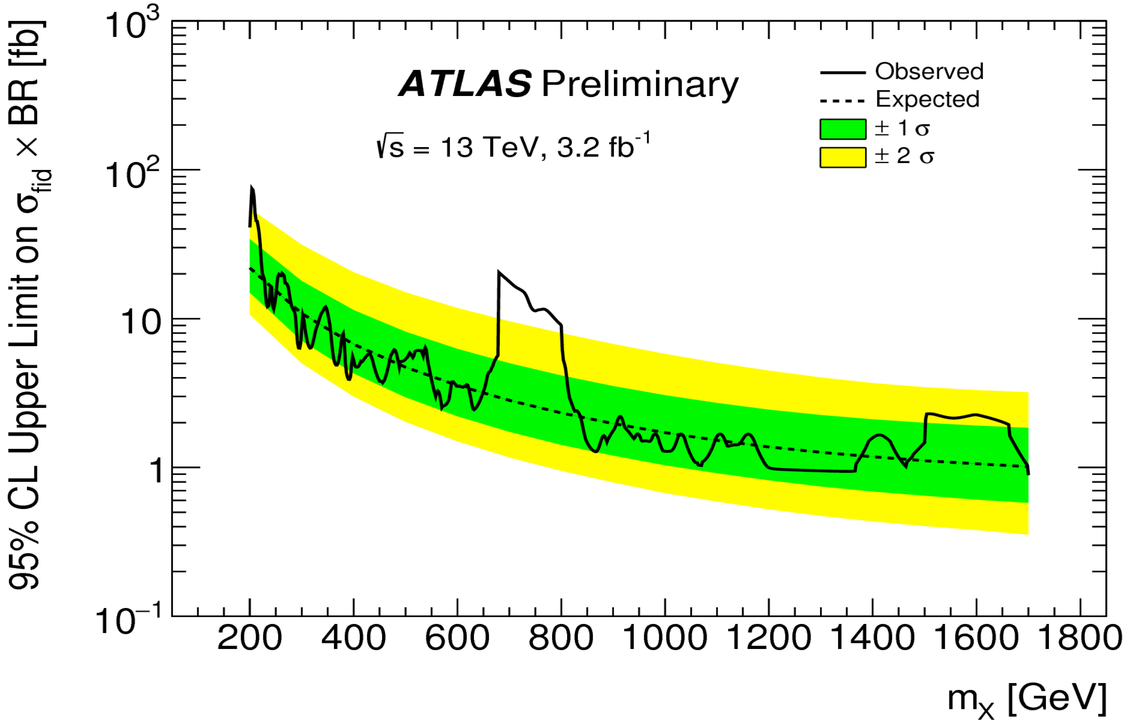


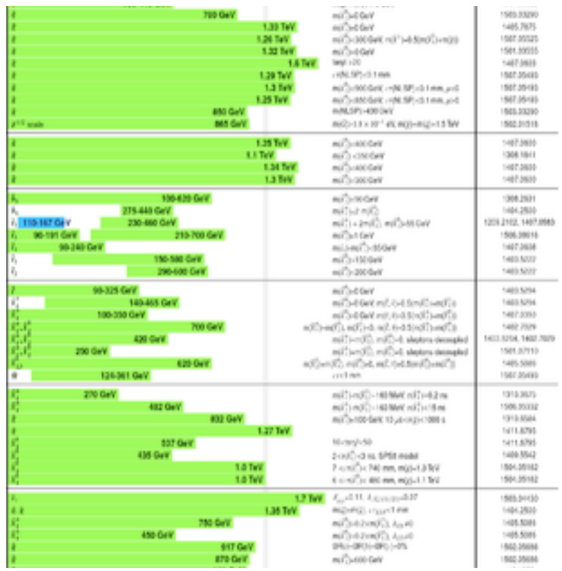
LHC



Higgs discovery in Run 1
Numerous searches for new particles

Hint of new particle in 2-photon channel in Run2?





Our expertise and interests

- Making precise predictions for observables within the SM in relation with collider physics, interpretation of data
  - QCD, Higgs, EW, Flavour
- Searching for signs of new physics
- Development of public tools (computer codes), for example
  - Diphox+Jetphox : used by LHC Collaborations for background searches in 2-photon channel (J Guillet, E Pilon)
  - PowHEG-BOX : incorporating NLO QCD corrections in event generators – used by LHC collaborations (Re)
  - GOLEM : General one-loop evaluator of transition matrix elements – library to compute form factors up to six external legs

Precision calculations in SM

- First examples of matching NNLO with parton shower (Re)
  - Simulation of Higgs boson production and Drell-Yan processes
- Flavour physics (D. Guadagnoli)

> Reappraisal of various systematic effects in the evaluation of the BR for the very rare decay $B_s \to \mu^+ \mu^-$, one of the milestones of the LHC flavor-physics program. Non-negligible impact

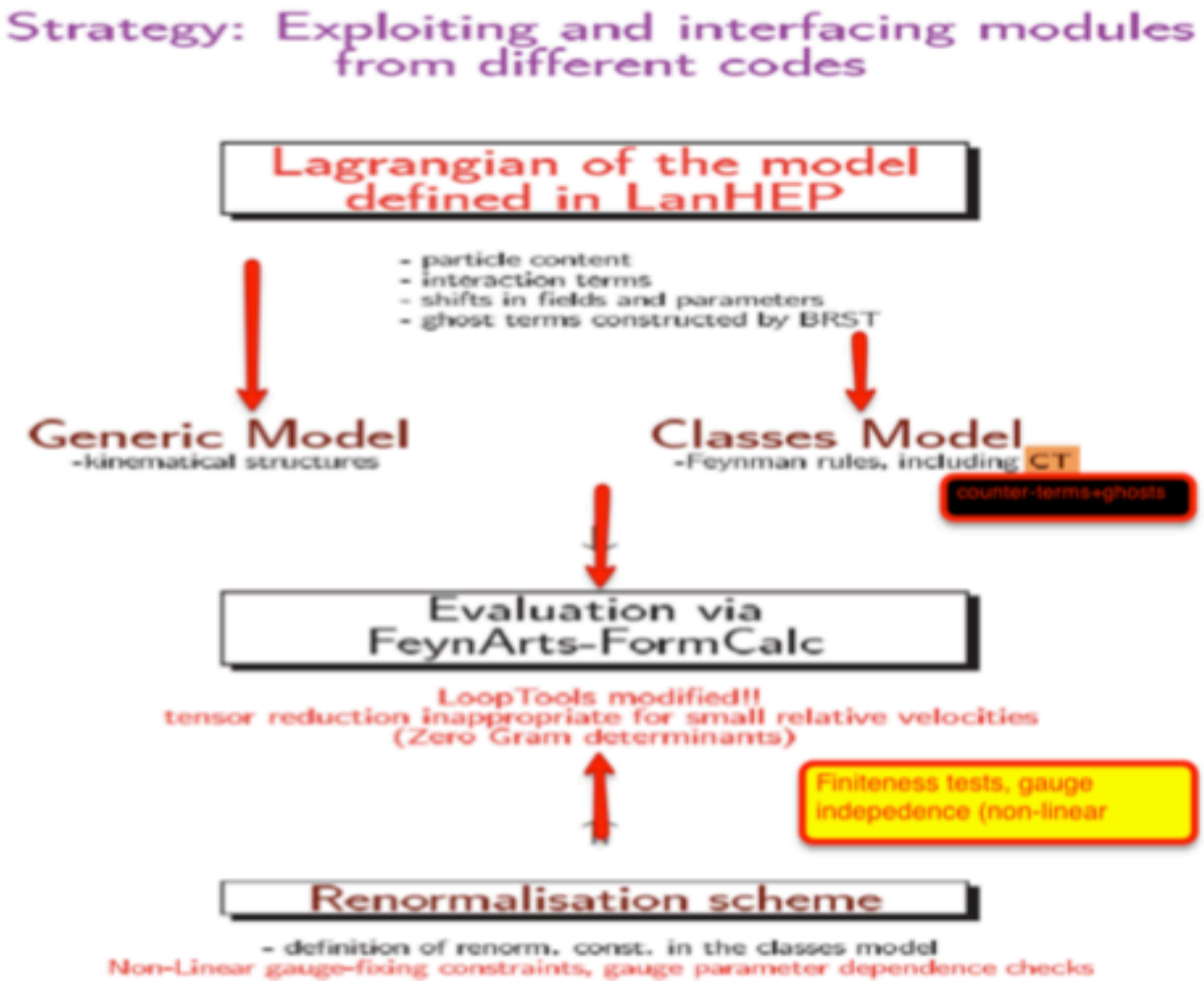
Precision calculations in SM

- Importance of QCD and EW correction + new techniques for scattering amplitudes (E. Sokatchev)
- SloopS : automatic tool for EW/SUSY correction in SM, MSSM and NMSSM (F. Boudjema)

Features

- handles large numbers of diagrams both for tree-level and loop level
- able to compute loop diagrams at $v = 0$: dark matter, LSP move at galactic velocities $v = 10^{-3}$
- ability to check results : UV and IR finiteness but also gauge parameter independence for example
- ability to include different models easily and switch between different renormalisation schemes

SloopS


Strategy: Exploiting and interfacing modules from different codes
Lagrangian of the model defined in LanHEP
- particle content
- interaction terms
- shifts in fields and parameters
- ghost terms constructed by BRST
Generic Model
-kinematical structures
Classes Model
-Feynman rules, including CT
counter-terms+ghosts
Evaluation via FeynArts-FormCalc
LoopTools modified!!
tensor reduction inappropriate for small relative velocities
(Zero Gram determinants)
Finiteness tests, gauge indepedence (non-linear
Renormalisation scheme
- definition of renorm. const. in the classes model
Non-Linear gauge-fixing constraints, gauge parameter dependence checks

Beyond the standard model

- Motivated by Higgs, dark matter and flavour

Higgs

- Is the Higgs boson discovered at LHC really a SM Higgs?
  - Quantify the size of non standard contributions using effective Lagrangian parametrisation of the Higgs couplings - Implications for models of new physics
  - Determine its properties

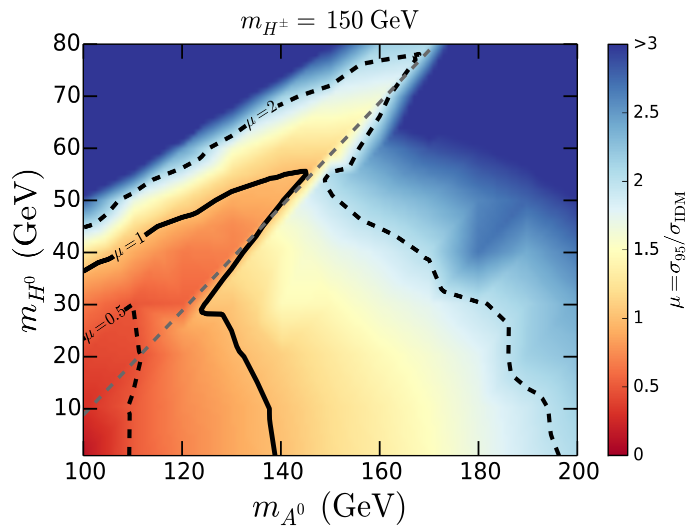
Specific reactions

- $pp \to WH, ZH$: efficient ways to identify an anomalous contribution and to access to the CP properties of the Higgs
- $pp \to t\bar{t}H$: specific observables that are sensitive to the CP properties of the Higgs.
- $gg \to H$: a precise determination of the boosted Higgs transverse momentum shape could resolve the top loop

  - Specific signatures of new physics (e.g. h-> cc) compositeness

Beyond the standard model

- Supersymmetry still one of best motivated BSM, no sign at LHC only upper limits -> much reduced parameter space but still lots room for SUSY (even below TeV scale) especially in non-minimal models
- Explore other new physics possibilities, from composite models, vector-like quarks, extra dimensions, more Higgs …. and their signatures at LHC
- Coherent interpretation of all LHC limits within plethora of BSM models very difficult : development of tools for reinterpretation of LHC results based on simplified models (SmodelS) or on MadAnalysis (with LPSC)
- E.g : LHC constraints on inert doublet model



BSM -flavour

- Anomalies in B -> Kμμ in LHCb (SM expects 1)

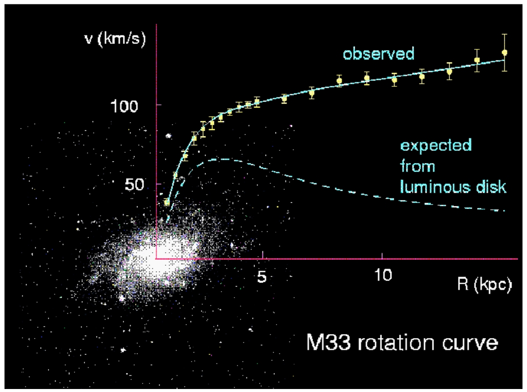
$$R_K \equiv \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}\,(\text{stat}) \pm 0.036\,(\text{syst})\,.$$

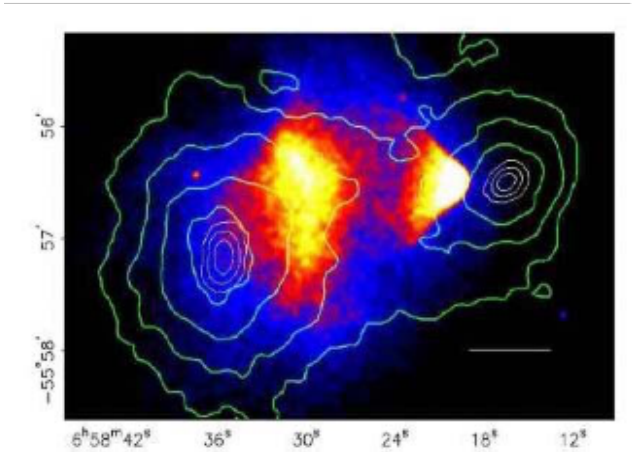
- Sign of new physics?
- New non-universal interactions of leptons – related to lepton flavour violation in other B-decays
  - Glashow, Guadagnoli, Lane, PRL114, 2015
- Or new Z' non-universal interactions + linked to DM
  - GB, Delaunay, Westhoff (2015)

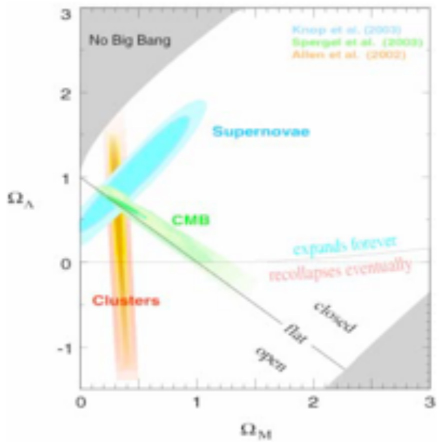
Dark Matter

Strong evidence for dark matter at galactic/ cluster/cosmological scales

Is Dark matter a new weakly interacting particle?





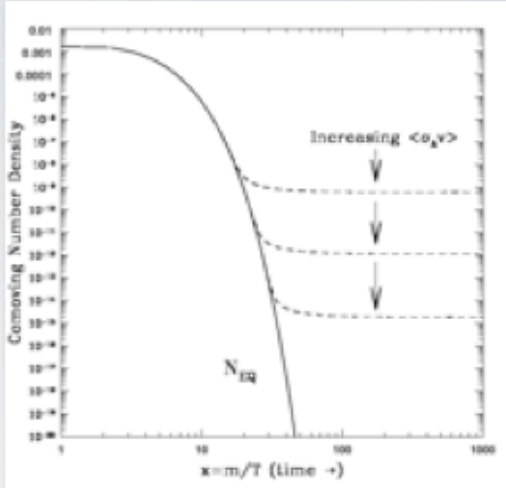


WEAKLY INTERACTING MASSIVE PARTICLE PARADIGM

$$X\bar{X} \longleftrightarrow \ell\bar{\ell}$$

Stable, massive particles in chemical equilibrium down to *T*<<*m* (required for **cold** DM!), suffer exponentially suppression of their abundance

So, what is left depends on the decoupling time, or their annihilation cross section: the weaker, the more abundant...



A textbook calculation proves that

$$\Omega_X h^2 \simeq \frac{0.1\,\mathrm{pb}}{\langle\sigma v\rangle}$$

dimensionally, for EW scale masses & couplings, one gets the right value!

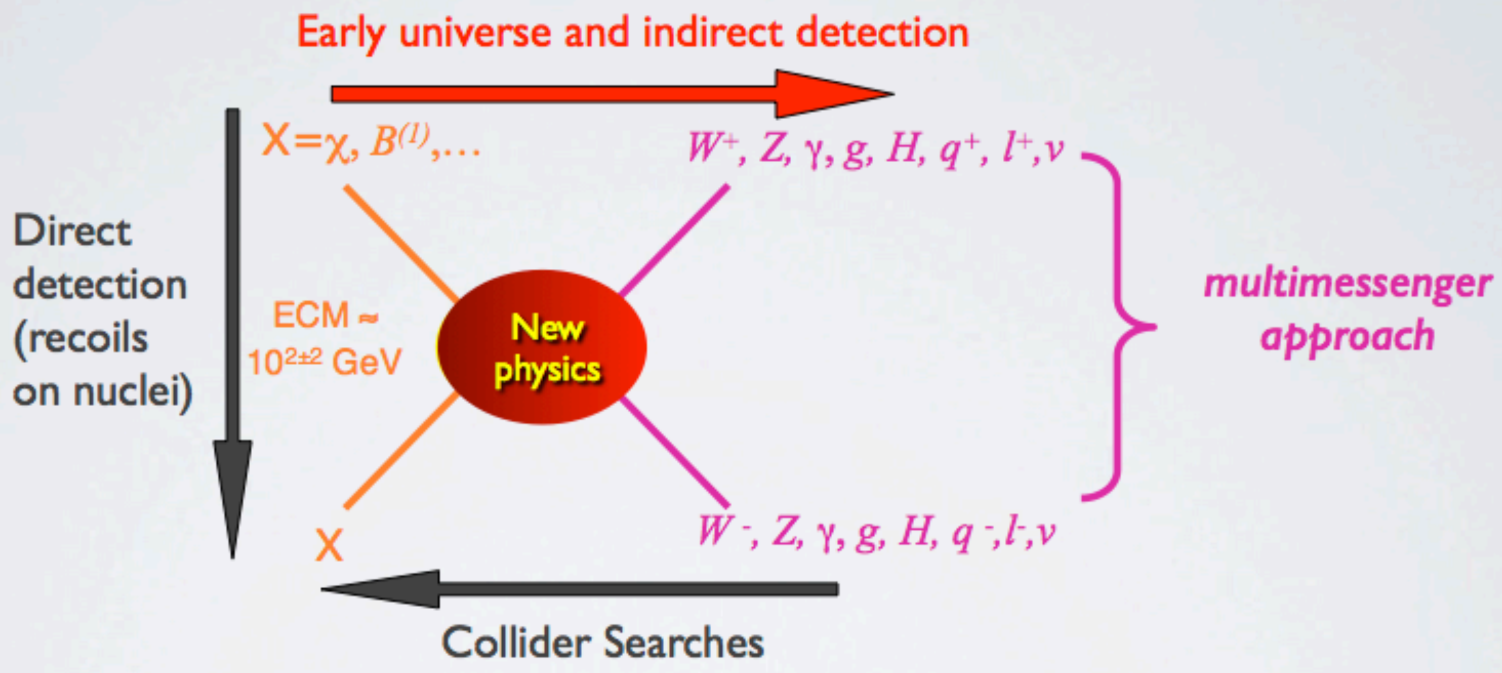
$$\langle\sigma v\rangle \sim \frac{\alpha^2}{m^2} \simeq 1\,\mathrm{pb}\left(\frac{200\,\mathrm{GeV}}{m}\right)^2$$

Stability often results from a **discrete "parity" symmetry**:
e.g. SUSY R-parity, K-parity in ED, T-parity in Little Higgs. New particles only appearing in pairs!
⇒ **lightest BSM particle stable**, other benefits (e.g. respect proton stability bounds...).

Matches (old?) **theoretical prior for BSM at EW scale** (of type not spoiling precision observables)

INTERFACE ACTIVITY: "WIMP HUNTING"

GOAL: testing the *hypothesis* that dark matter is constituted of weakly interacting massive particles (at GeV-TeV scale)

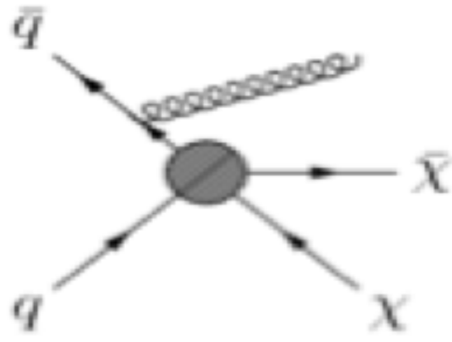


In short, what we do:

- compute signals due to different (classes of) candidates
- assess/uncover relevant astrophysical backgrounds
- cross-checks claimed hints (>1/year...)

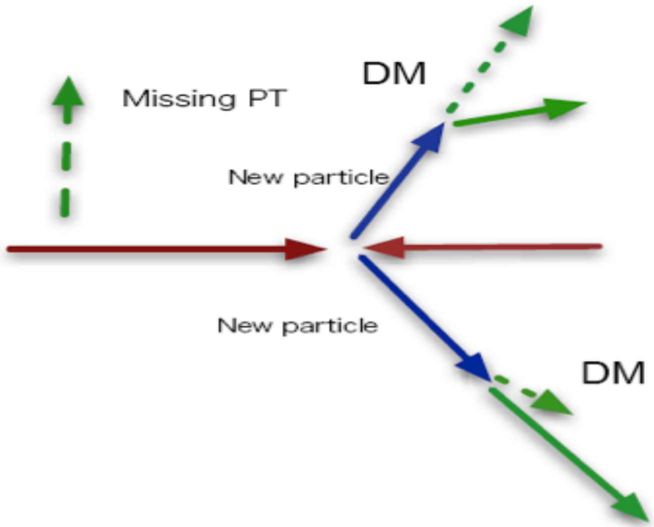
Dark matter at colliders

- Direct production of pairs of DM + radiation :
  high ETmiss + single jet/photon/boson
  - Constrain DM interactions (model independent or specific models)
  - Importance of QCD corrections (Re et al)



(a) $q\bar{q} \rightarrow \chi\chi + g$

- Production of new particles, DM in decay chain – missing E_T signature



Tools for DM

Belanger, Boudjema, Herrmann, Salati

Bizouard, Chalons (LPSC), Hao, Pukhov, Semenov

micrOMEGAs

Motivation : precise prediction of relic density and other DM observables

micrOMEGAs : a tool to compute dark matter properties in BSM

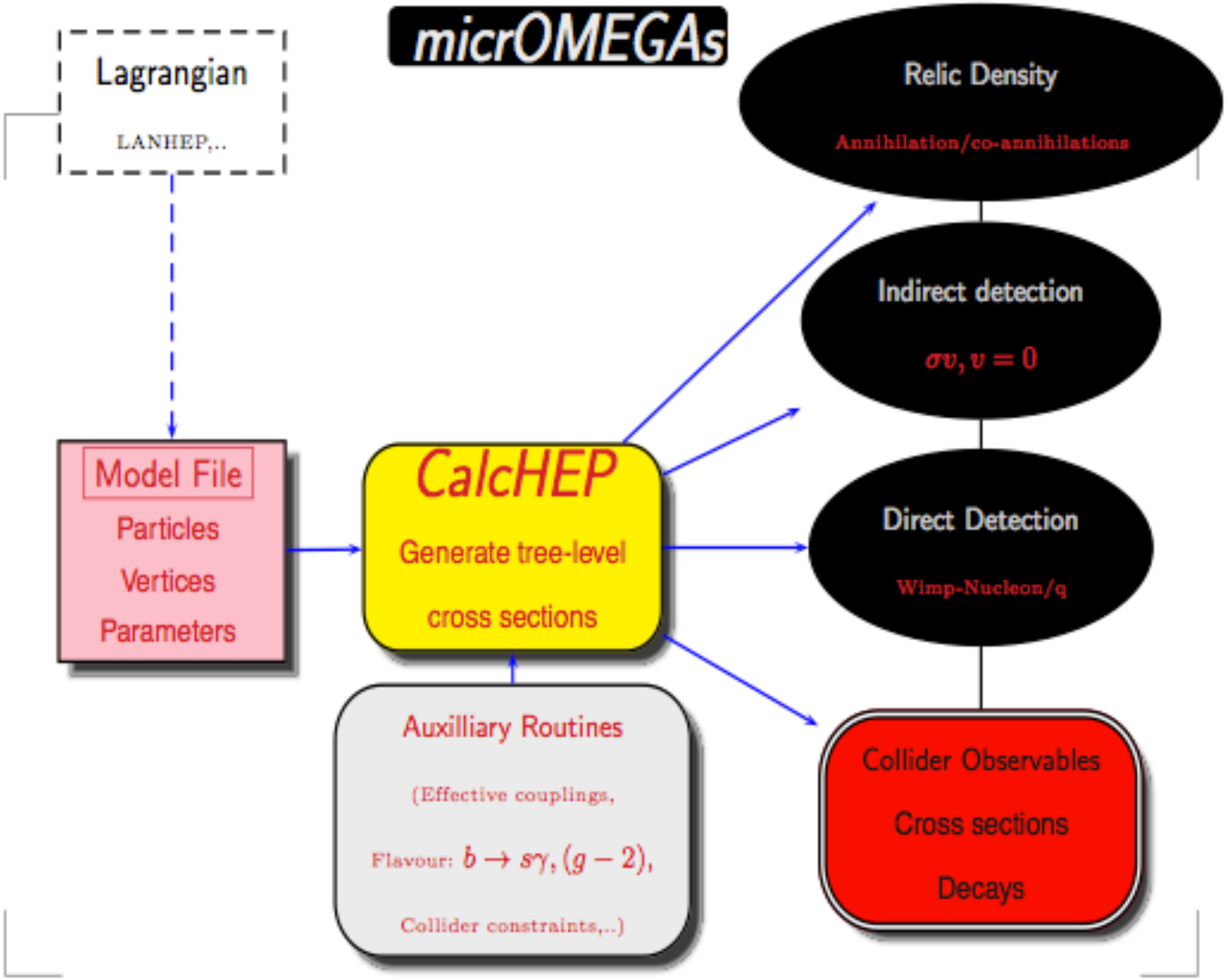


Fig. 1. The micrOMEGAs flow chart.

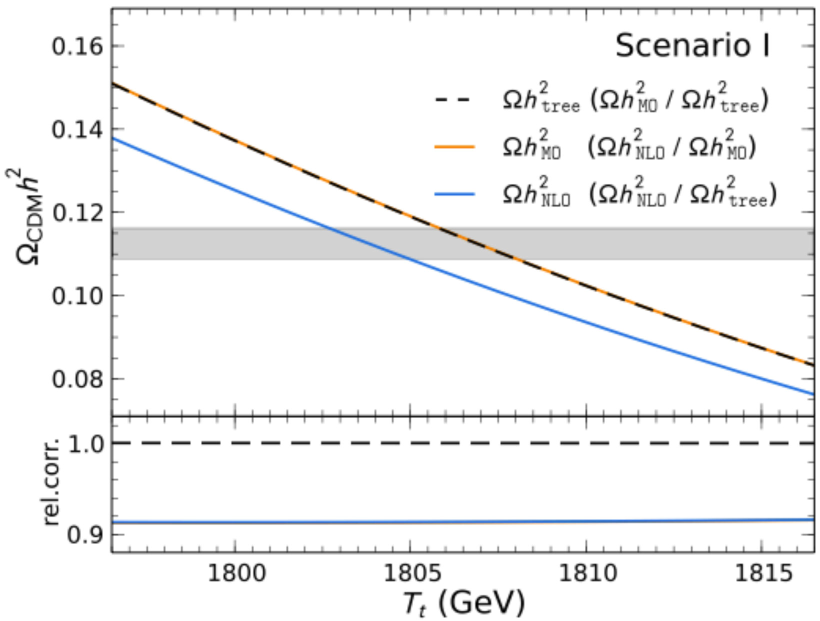
DM@NLO

http://dmnlo.hepforge.org

Numerical code to compute the neutralino (co)annihilation cross-section at one-loop in α_S
Interface to micrOMEGAs → **relic density including one-loop corrections**

Recent work: Corrections to $\tilde{\chi}_1^0 \tilde{q}_i \to q' H$ (important due to m_h~125 GeV) and $\tilde{\chi}_1^0 \tilde{q}_i \to q' Z/W/\gamma$

J. Harz, B. Herrmann, M. Klasen, Q. Le Boulc'h, K. Kovarik, Phys. Rev. D87: 054031 (2013)



Outlook: Implement dipole subtraction method for all processes, interface to DarkSUSY 6, make the code available to the community...

Astroparticles - Cosmology

CURRENT MEMBERS (& TOPICS)

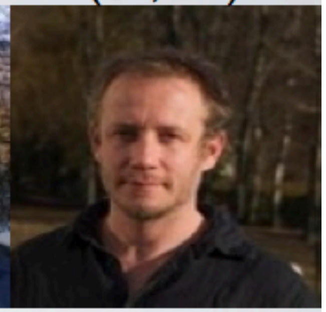
Post-docs

Antje Putze (CR/IDM)
Kengo Shimada (Cosmo)

Pascal Chardonnet (GRB)

Pierre Salati (CR,IDM)

Richard Taillet (CR,IDM)

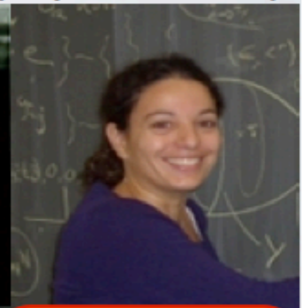


3 Univ. Staff (Enseignant-Chercheurs)

PhD Students (~50% of total at LAPTh)
Mathieu Boudaud (IDM/CR's)
Vivian Poulin (Cosmo/IDM)
Yoann Génolini (CR's/IDM)

Pasquale D. Serpico
(CR, IDM, Cosmo,ν)

Céline Boehm
(IDM, Cosmo)

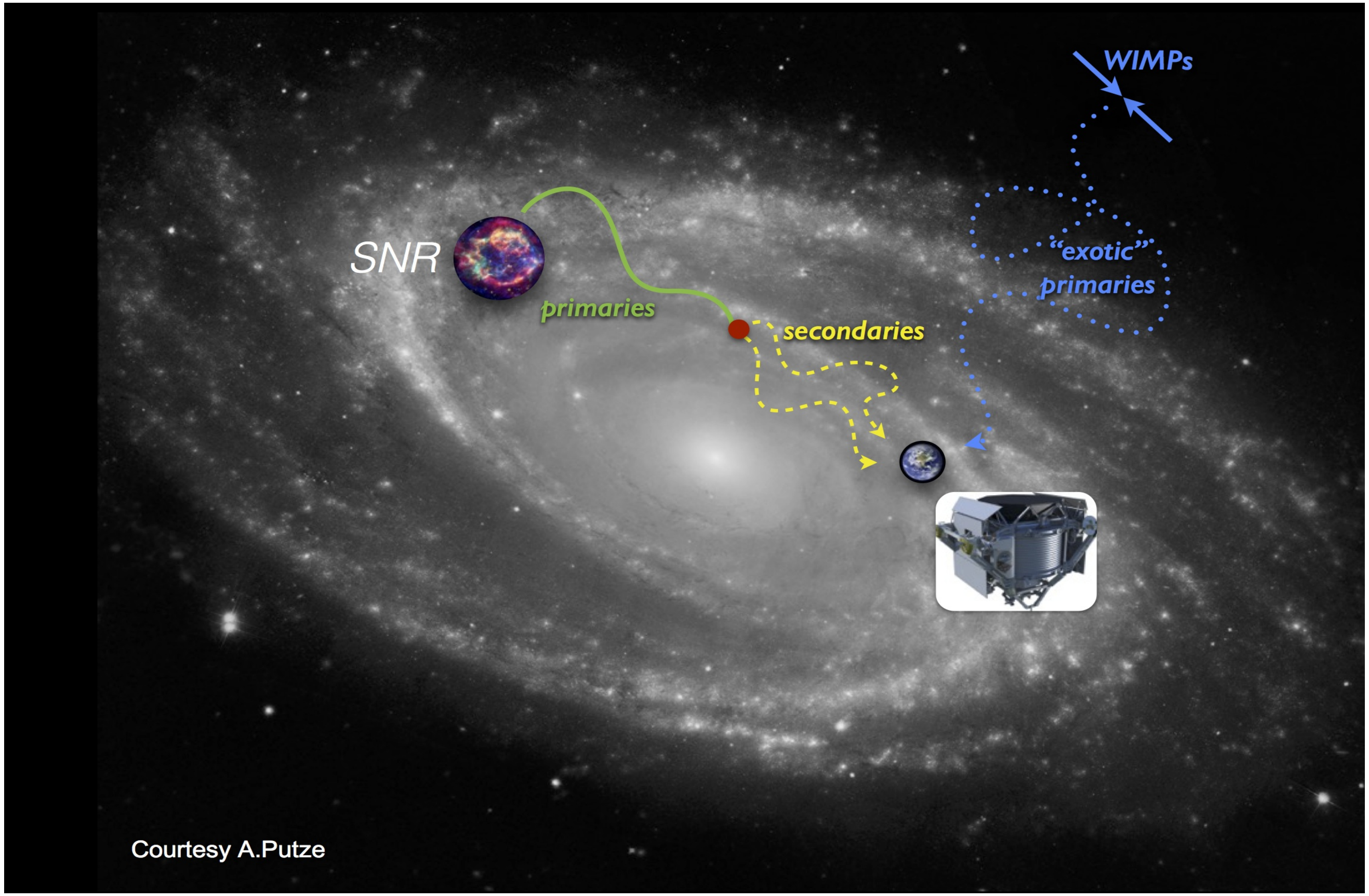


1+1 CNRS staff researchers

since 2011 at IPPP, Durham

Indirect detection

- DM self annihilates in galaxy giving positrons, antiprotons, photons, neutrinos. Charged particles interact with medium and 'propagate' to detector. Extract DM signal from other sources in cosmic rays.



FOR CHARGED CR: DIFFUSION-LOSS EQUATION

Especially for signals in charged cosmic rays, computation is not trivial, requiring to solve:

$$\frac{\partial \Phi}{\partial t} = Q + \vec{\nabla} \cdot (D_{sp} \vec{\nabla} \Phi) - \frac{\partial}{\partial p}(\dot{p}\,\Phi) + \frac{\partial}{\partial p}\left[p^2 D_{mom} \frac{\partial (p^{-2}\Phi)}{\partial p}\right] - \vec{\nabla} \cdot (\vec{V}\Phi) + \frac{\partial}{\partial p}\left[\frac{p}{3}(\vec{\nabla} \cdot \vec{V})\Phi\right] - \frac{\Phi}{\tau_{frag}} - \frac{\Phi}{\tau_{decay}}$$

Source term (t, **x**, **p** -dep.)
Includes dec./frag. for heavier nuclei

Diffusion

Energy loss

Convection velocity

Diffusive reacceleration

Adiabatic flow term

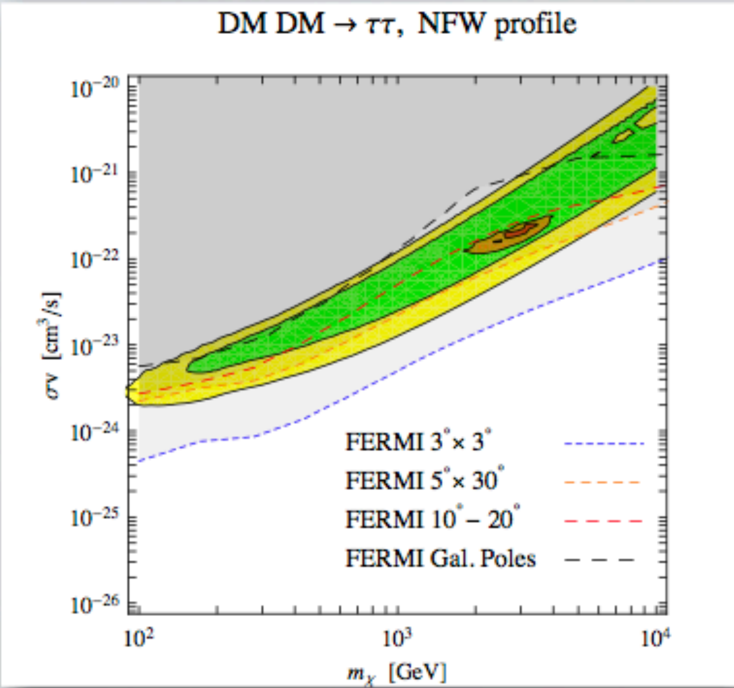
Fragmentation and decay terms, of "collisional" nature

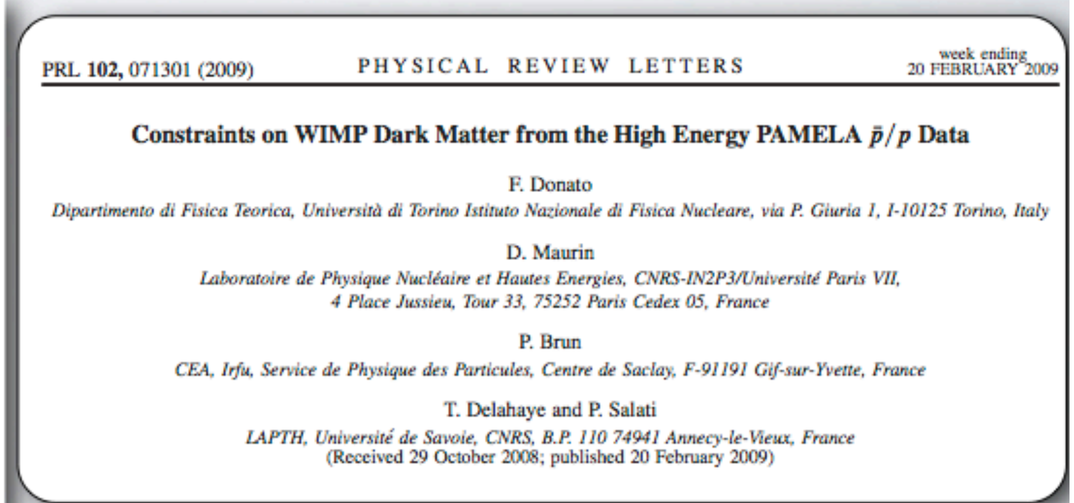
Some input parameters to be inferred from astrophysics or extracted from CR data themselves!

IMPORTANCE OF MULTIMESSENGERS

Remember the PAMELA DM fever of few years ago?
Whole classes of models **excluded** by:

- ➡ cross-checking fits to e^+ fraction & e^-+e^+ fluxes vs e.g. associated signals (γ, anti-p...)
- ➡ Accounting not only for prompt emission, but also secondary from $e^\pm$ E-losses (notably Inverse Compton). **Astrophysical information & multimessenger** crucial!





PRL 102, 071301 (2009) PHYSICAL REVIEW LETTERS week ending 20 FEBRUARY 2009

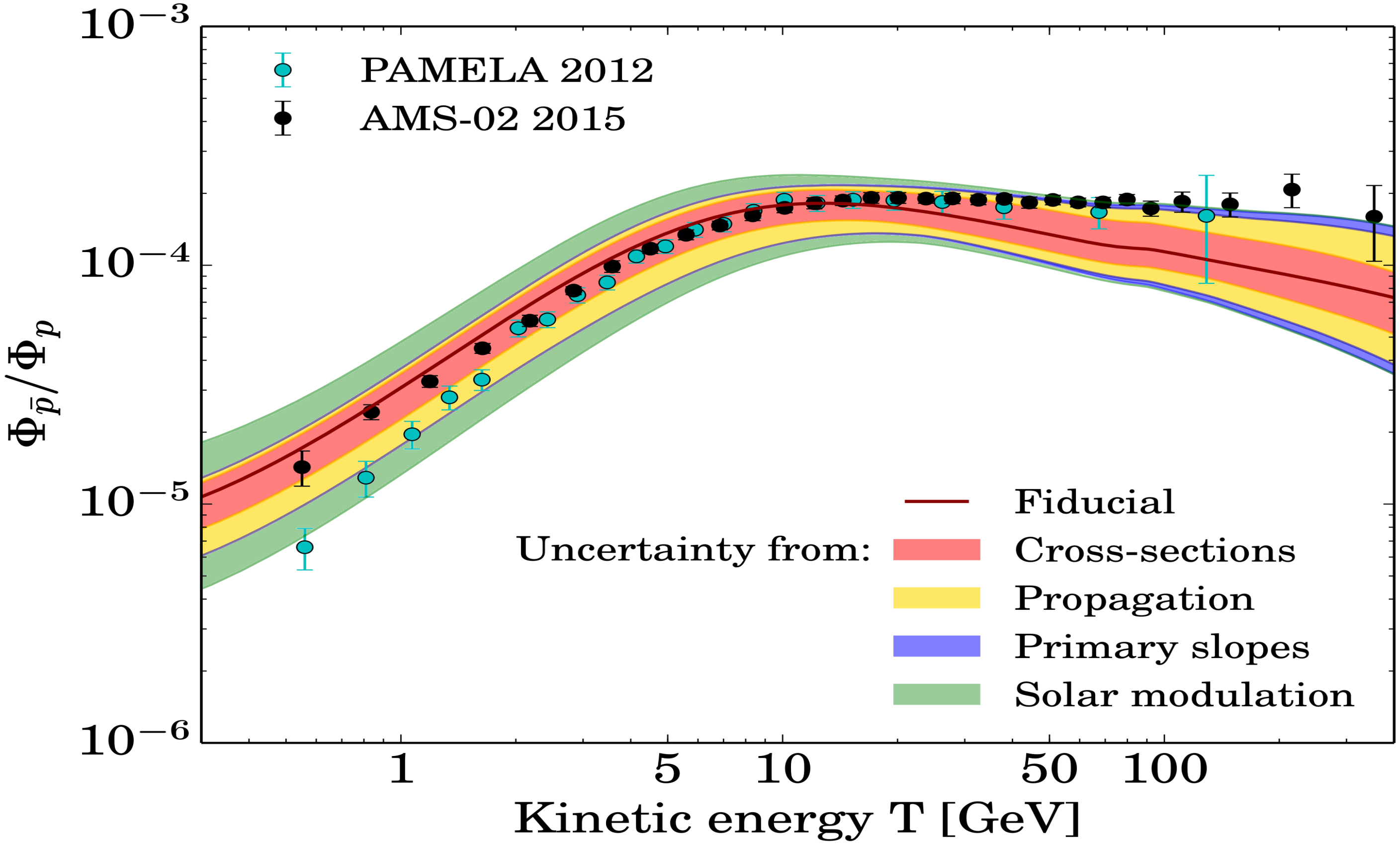
Constraints on WIMP Dark Matter from the High Energy PAMELA $\bar{p}/p$ Data

F. Donato
Dipartimento di Fisica Teorica, Università di Torino Istituto Nazionale di Fisica Nucleare, via P. Giuria 1, I-10125 Torino, Italy
D. Maurin
Laboratoire de Physique Nucléaire et Hautes Energies, CNRS-IN2P3/Université Paris VII, 4 Place Jussieu, Tour 33, 75252 Paris Cedex 05, France
P. Brun
CEA, Irfu, Service de Physique des Particules, Centre de Saclay, F-91191 Gif-sur-Yvette, France
T. Delahaye and P. Salati
LAPTH, Université de Savoie, CNRS, B.P. 110 74941 Annecy-le-Vieux, France
(Received 29 October 2008; published 20 February 2009)

M. Cirelli, P. Panci, PDS. NPB 840, 284 (2010)

Cosmic rays

- AMS announced an excess in antiprotons, could come from DM?
- Using AMS' updated proton and helium fluxes, secondary pbar/p with uncertainties was reevaluated - no significant excess from DM



Gliesen, Boudaud, Genolini, Poulin, Cirelli, Salati, Serpico 1504.04276

SOME PERSPECTIVE: EXPLOITING CR DATA

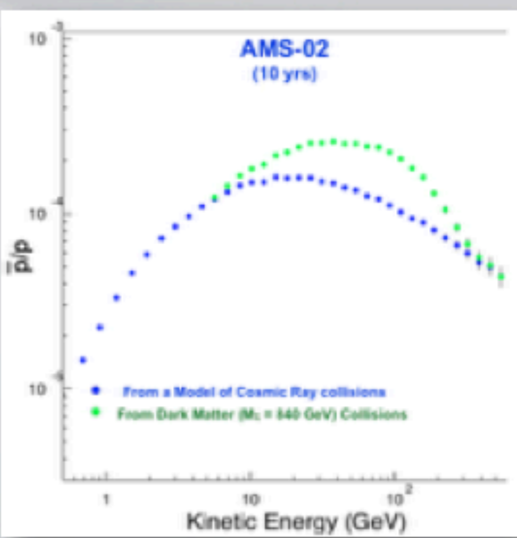
- Understand if **primary** sources are also needed in traditional "secondary nuclei" channels (Boron, antiprotons...): hadronic counterpart of the PAMELA/AMS positron results!

- With AMS-02, possibly new era limited mostly by theoretical accuracy, rather than experimental errors. Need to revisit "theoretical" errors (e.g. model oversimplifications) and errors from other inputs (e.g. nuclear cross sections)

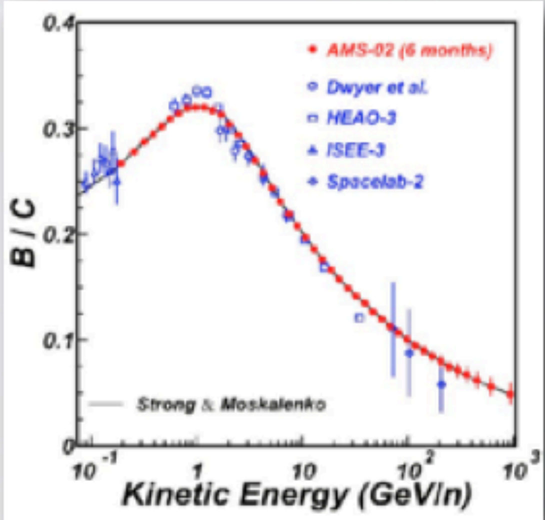
- Re-derive propagation parameters accounting for the above (notably B/C analysis)

- Discuss implications for dark matter searches

- Some PhD Theses devoted to these tasks, including the one by **Y. Génolini**



representative (?) forecasts for AMS-02



WHAT WE'RE INTERESTED IN

- Cosmic Rays, sources and propagation (**CR**)
- Indirect Dark Matter Searches, signals & backgrounds (**IDM**)
- Cosmology: inflation, neutrinos, computational tools (**Cosmo**)
- GRB as a new mode of stellar collapse (**GRB**)
- Neutrino oscillations & supernovae (**ν**)

These fields of investigation involve notions and tools from particle physics (e.g. Pythia for computing DM annihilation spectra, EFT...), astrophysics (e.g. stellar structure simulations), nuclear physics (e.g. cross sections), plasma astrophysics, applied mathematics for "classical physics" problems (e.g. (semi)analytical solutions of diffusion-loss type of equations)

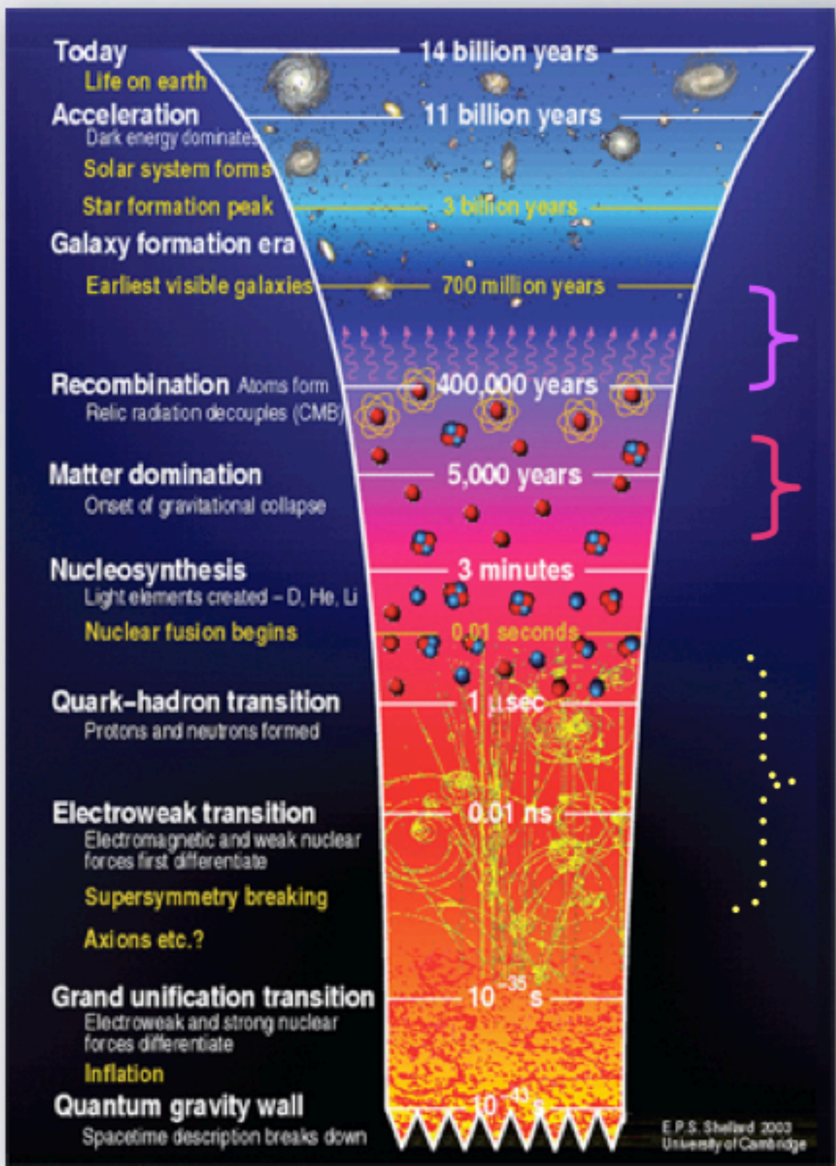
CURRENT "PARTICLE COSMOLOGY"

Explore the particle physics diagnostic potential of new cosmological windows of opportunity, such as "dark ages" (PhD thesis by *Vivivan Poulin*)

- either pre-recombination, from BBN to CMB (e.g. non-thermal BBN, CMB distortion)

- or post-recombination till the formation of the first virialized structures (e.g. reionization, intergalactic medium heating, 21 cm radiation...)

New perspectives on model building and signatures relating inflation, DM, leptogenesis, neutrino physics (*Kengo Shimada* postdoctoral activity)



EXAMPLE:NON-THERMAL BBN

- Injection of energetic photon/electron (e.g. via metastable particle decay) in the cosmological plasma (@ kT>> eV!) induces a process of particle multiplication and energy redistribution

- In PRL 114, 9, 091101 (2015)[1502.01250] and PRD 91, 10, 103007 (2015) [1503.04852] V. Poulin and P. Serpico addressed a previously unexplored/ neglected corner of the parameter space of e.m. cascades, *below pair production threshold*

- By solving the relevant Boltzmann eqs., they showed that the resulting spectrum can be very different, notably near the endpoint

- Relevant consequences e.g. for early universe, like BBN bounds on e.m. decaying particles: bounds are **stronger** & **non-universal**.

- The same phenomenon may significantly **ease** particle physics **solutions to the so-called "cosmological lithium problem" (disagreement between observed and standard BBN predicted lithium abundance)**

Merci