



# OCEVU STEERING COMMITTEE MEETING

Marseille, 12 December 2014

Particle Physics Working Group Report

Coordinators: Lorenzo Feligioni, Laurent Lellouch



# PP WG the constituents

Role of the PP WG is to foster collaborations between different competences via inter-lab projects

• **Coordinators: L. Feligioni & L. Lellouch [LL until end 2014]**

• **Board: C. Hugonie, JL Kneur, R. Legac, L. Lellouch, G. Moutaka, E. Nezri, L. Vacavant**



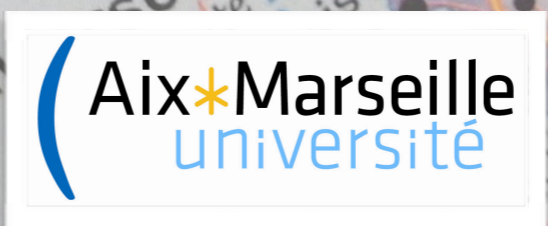
MSSM, NMSSM (spectrum calculation, couplings, branching ratios,...)  
Composite Higgs models (new heavy states properties,...)  
Dark matter candidates (complementary constraints,...)



Particle phenomenology, flavor physics, low-E precision physics, BSM physics, non-perturbative strong-interaction physics, higher-loop calculations, effective theories, ab-initio lattice QCD calculations



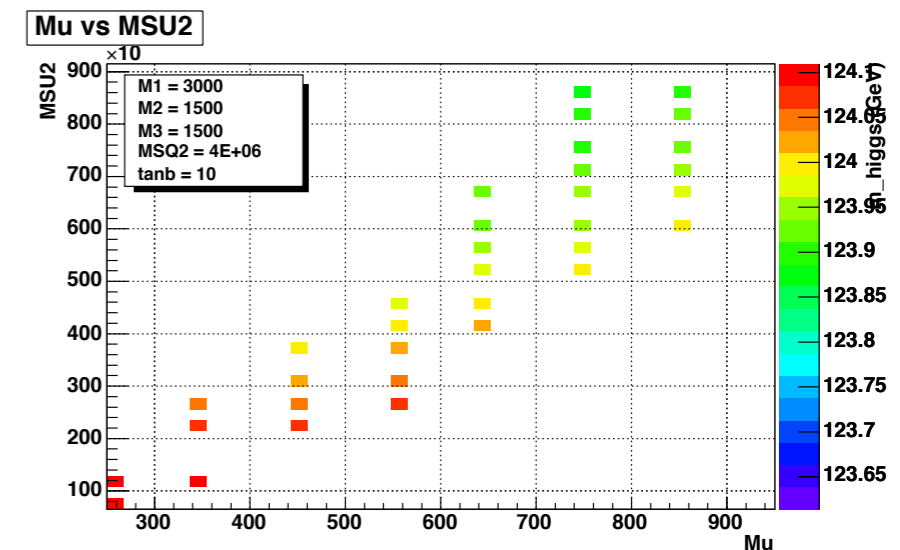
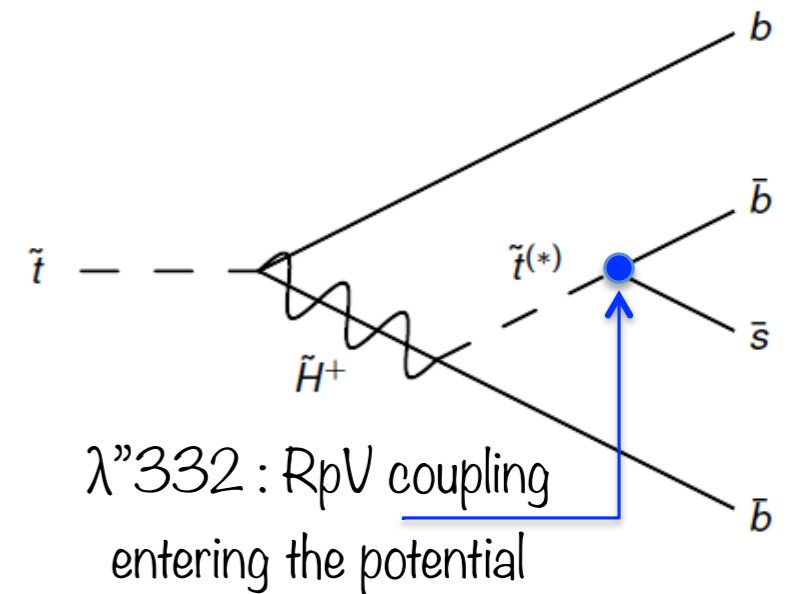
Hadron collider physics  
ATLAS: SM top-quark, vector boson pairs production, SM Higgs, SUSY, 4th generation quark searches, electron and b-jet identification,  
LHCb: CP violation, rare decays, beyond standard model, flavour physics, FCNC, leptonic decays, lepton flavor violation, trigger



- Particle Physics Working Group Ongoing projects:
  - New physics through direct production (**energy frontier**)
    - Probing the nature of Electroweak Symmetry Breaking at the LHC with the ATLAS detector
    - New Physics from a natural Electroweak symmetry breaking
  - New physics in indirect searches (**intensity frontier**)
    - B decays into tau lepton pairs and related rare processes
    - Rare dileptonic B decays
    - The muon anomalous magnetic moment and the search for new physics in the LHC era
  - Dark matter interface w/ astro. & cosmo. (**cosmic frontier**)
    - Lattice QCD enlightens dark matter
- Foreseen actions in 2015

## Search for new physics with high $b$ -jet multiplicity

- R Parity Violating Supersymmetry
  - Strong experimental constraints for many RpC models, not many RpV studies
  - RpV is a “signature generator”: many couplings freedom in spectra
  - Possible final states without missing energy (differently from RpC)
- Tri-Linear R-parity Violation (RpV) SUSY model
  - Stop pair production:  $p p \rightarrow t\bar{t}$ :  $t\bar{t} \rightarrow b \chi^+, \chi^+ b$ ;  $t\bar{t} \rightarrow b s$
  - Experimental signature: At least 8 jets, of which at least 6  $b$ -jets
- Status of the work [S. Giglio OCEVU PD from Jan 2014, L. Feligioni, G. Moutaka]
  - generated the Trilinear RpV SUSY model using the SARAH code SARAH
    - Mathematica package to build SUSY supported by the MadGraph5 events generator
- Calculated several SUSY spectra for the above Trilinear RpV SUSY model using SPheno (Supersymmetric Phenomenology)
  - bottom-bottom approach [master stage Damien Minenna]



## *Study of the EWSB at LHC using multi-boson final states*

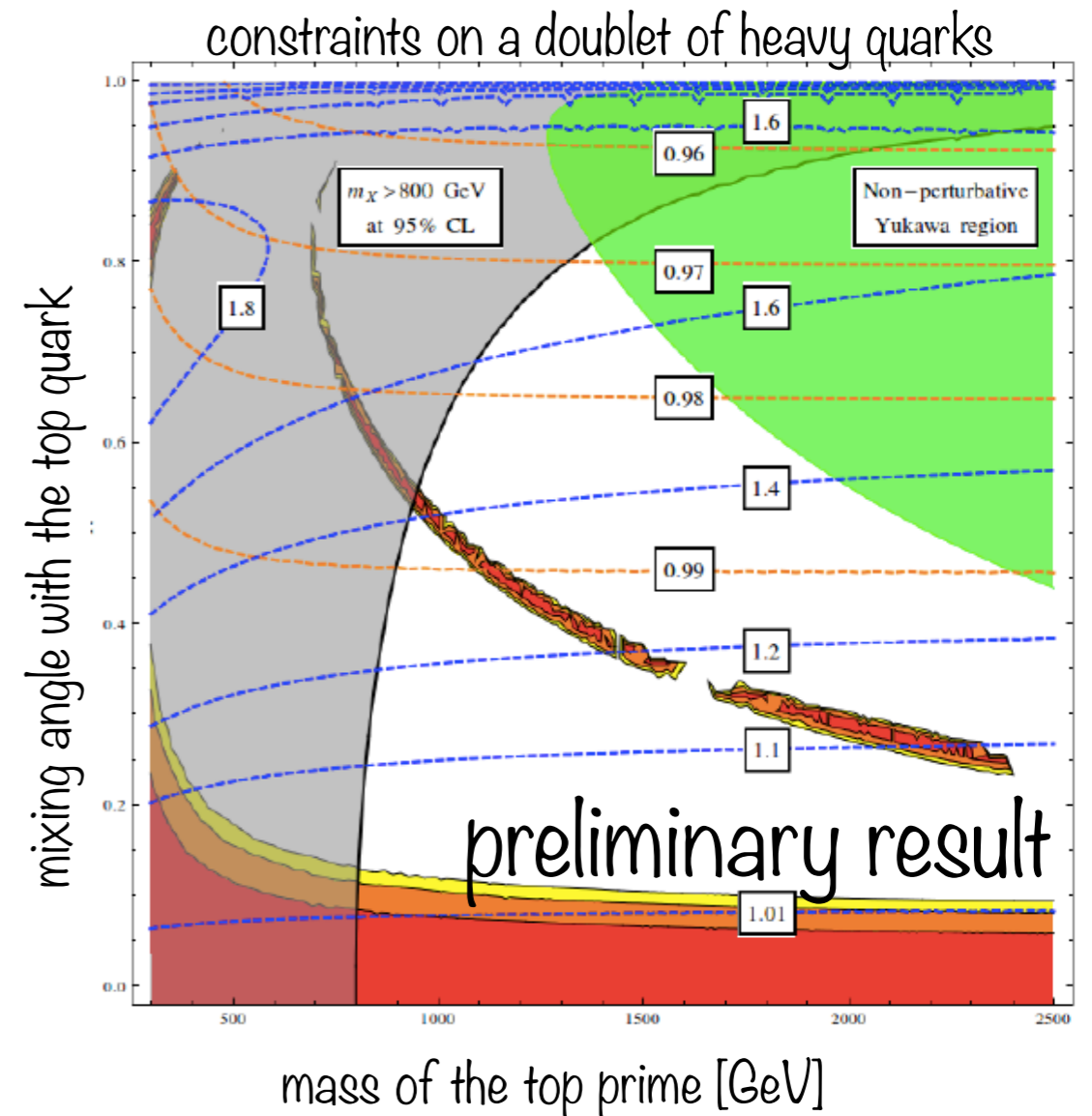
- measurement of the di-boson production would complement the knowledge acquired in Higgs boson sector and will allow a global test of the SM [C. Diaconu, S. Diglio, **V. Ellajosula OCEVU PhD from Oct 2014**, G. Moulaka]
  - Several approaches are under scrutiny:
    - deviations from the SM can be parametrised in a framework based on effective field theories (EFT) [coll. Y. Liu (USTC)]
    - Type II Seesaw Model: multi-boson decay of double charged Higgs
    - First study of low pT electron identification already ongoing

## *Study of the EWSB at LHC using multi-boson final states*

- Study of the R-parity conserving supersymmetry, on the search for chargino and neutralino production in final states with 1 lepton, 2 b-jets compatible with a Higgs boson and missing transverse energy.
  - ATLAS analysis foreseen as well as development of SUSY spectrum calculator SUSPECT [J-L Kneur, S. Muanza]
    - New PhD position will be allocated starting from September 2015

## Minimal fermionic extensions of the Standard Model

- **N. Bizot, OCEVU funded PhD from Nov 2013, M. Frigerio, aim at:**
  - Exploiting the knowledge of the Higgs couplings to constrain the possible sets of new fermions that can be added to the Standard Model
- Methodology:
  - classification of anomaly-free sets of fermions
  - implementation of non-Higgs constraints: electroweak precision tests from LEP and direct search bounds from LHC
  - computation of the Higgs couplings in the presence of new fermions



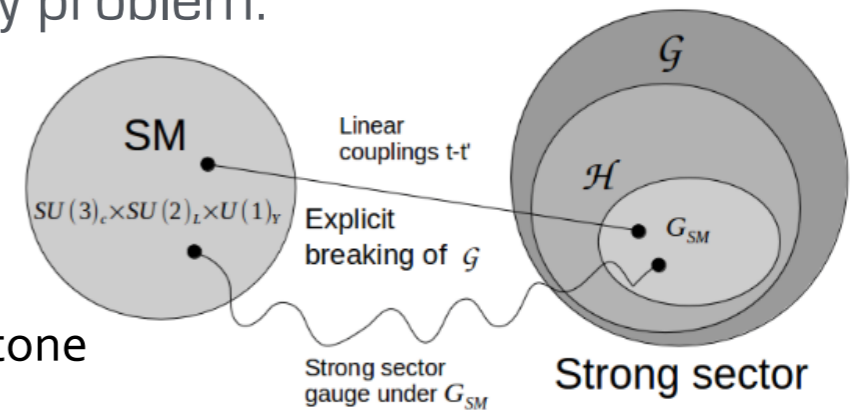
the orange (blue) lines are the signal strengths for Higgs into photon-photon (photon-Z) relative to SM

## UV completions of composite Higgs models

Composite Higgs models provide alternative solution to hierarchy problem:

- the Higgs is a pseudo-Golstone thus naturally light:

- Spontaneous breaking of global symmetry  $G$  (by condensate) to subgroup  $H$  containing SM (global) symmetries  $\rightarrow$  Higgs is a Goldstone
- Then explicit breaking (by gauging SM + top quarks) generates radiatively effective potential  $V(h)$ : give Higgs a mass and trigger EWSB.



UV completion models allow to calculate more explicitly all contributions to  $V(h)$

- Results: Calculation of all scalar, vector (axial) and fermionic (baryon) resonances masses: done, partially crosschecked

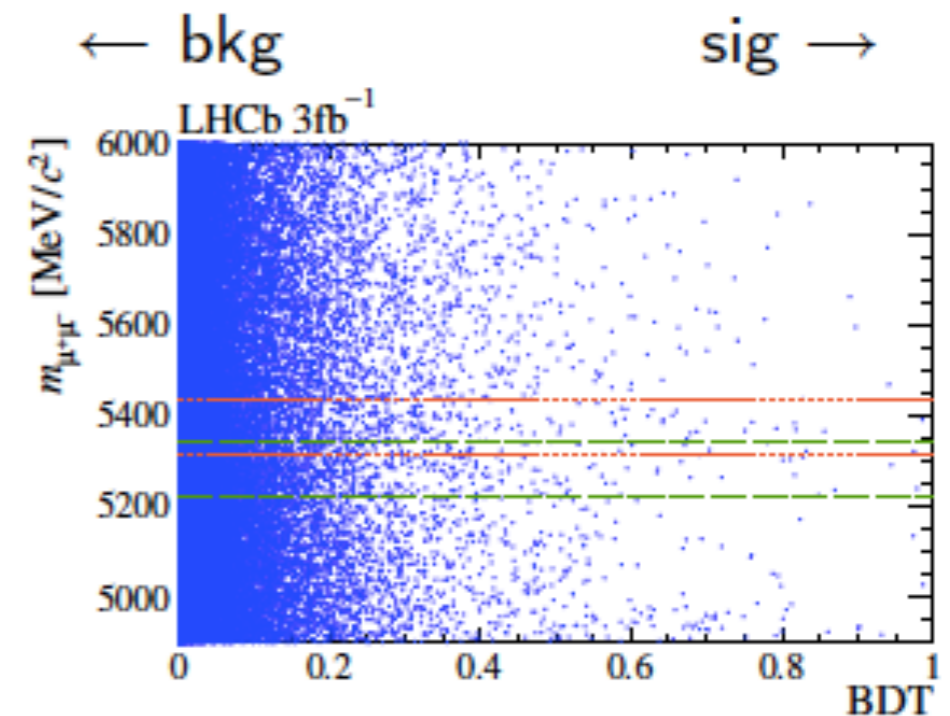
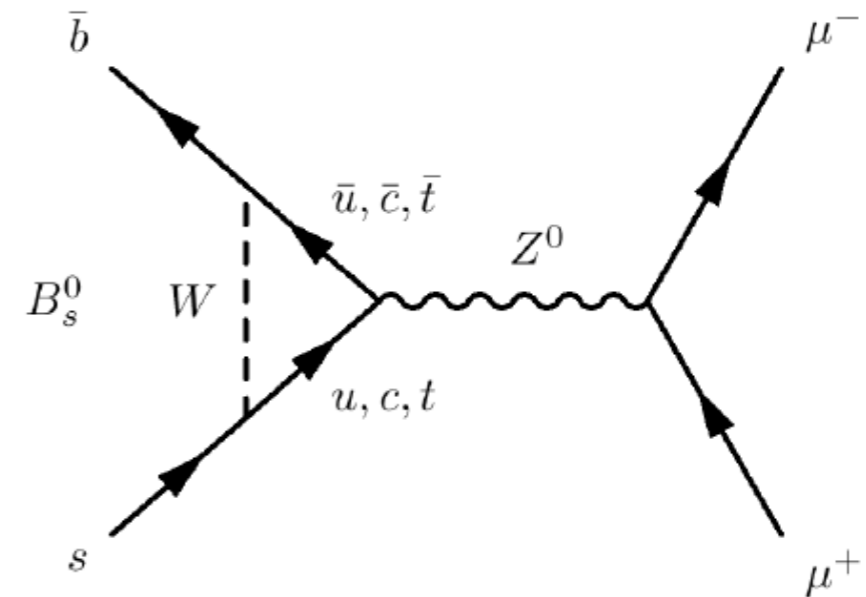
- publication expected soon (end 2014 or early 2015) for chiral limit mass spectrum results

- Work in Progress: Calculation of scalar (vectorial?) masses for coloured bound states, introduction of fermionic resonances, calculation of "diquarks" masses and of top partners masses.

- To Do: adding couplings between composite and elementary SM fermions; calculating Higgs potential; link model parameters to experimental constraints;

$$B_s^0 \rightarrow \mu^+\mu^-$$

- Dileptonic decays of  $B_s^0$  mesons imply a Flavour Changing Neutral Current (FCNC).
  - Very rare in Standard Model (SM): loop suppression and helicity suppressed, but their rates could be enhanced in New Physics (NP) scenarios
- Measured at LHCb using full Run 1 dataset
  - $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (2.9 + 1.1 - 1.0) \times 10^{-9}$
  - $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 7.4 \times 10^{-10}$  at 95% C.L.
  - Contribution to 2D classification: geometry vs.  $m_{\mu\mu}$  [G. Mancinelli, **A. Mordà OCEVU PhD from Oct 2012**]
- New actions have been started for the update of the analysis with  $3.1 \text{ fb}^{-1}$  and the next run of LHC
  - definition of new isolation variables based on a topological reconstruction algorithm and new BDT design





# Rare dileptonic $B^0_s \rightarrow \ell\ell$ decays @ LHCb

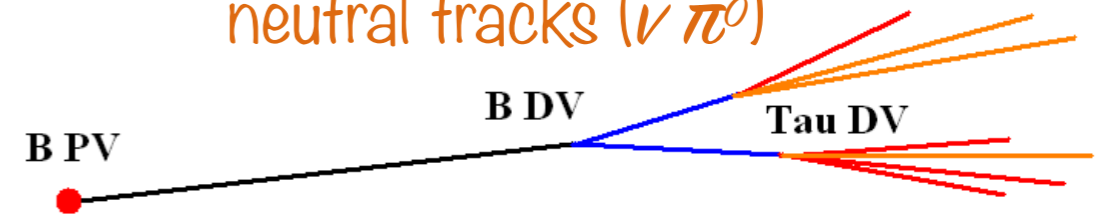
B decays into  $\tau$  lepton pairs and related rare processes and dileptonic B decays

$$B^0_s \rightarrow \tau^+\tau^-$$

$\tau$  decay products:

visible (charged) tracks

neutral tracks ( $\nu \pi^0$ )

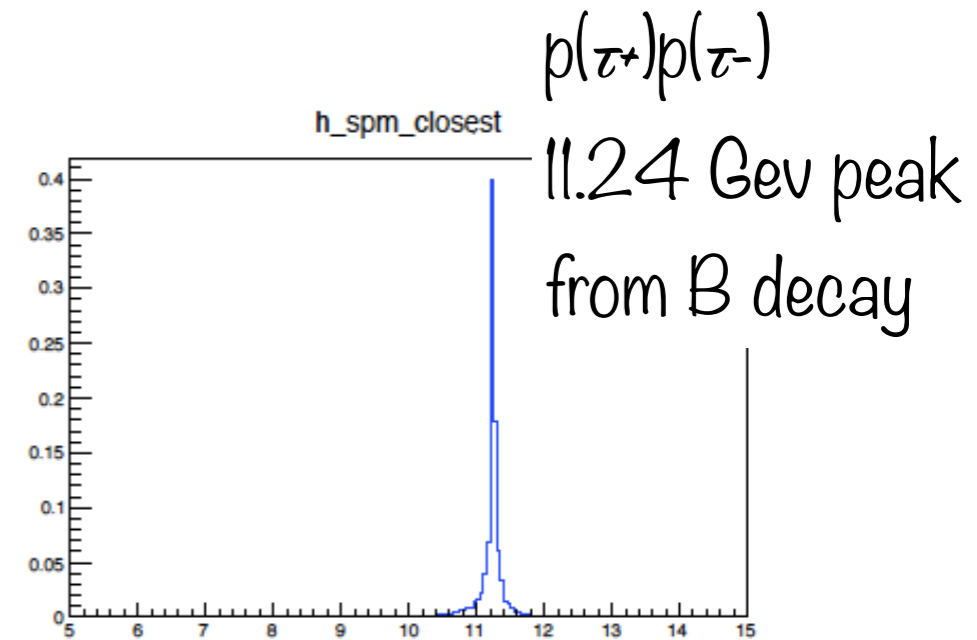


- $\tau$  leptons offer a unique window to new observables and phenomena:
  - its sizable mass allows to test both right-handed and left-handed couplings
  - its decay into measurable products leads to a variety of angular observables, that are related to the couplings to the  $\tau$  spin

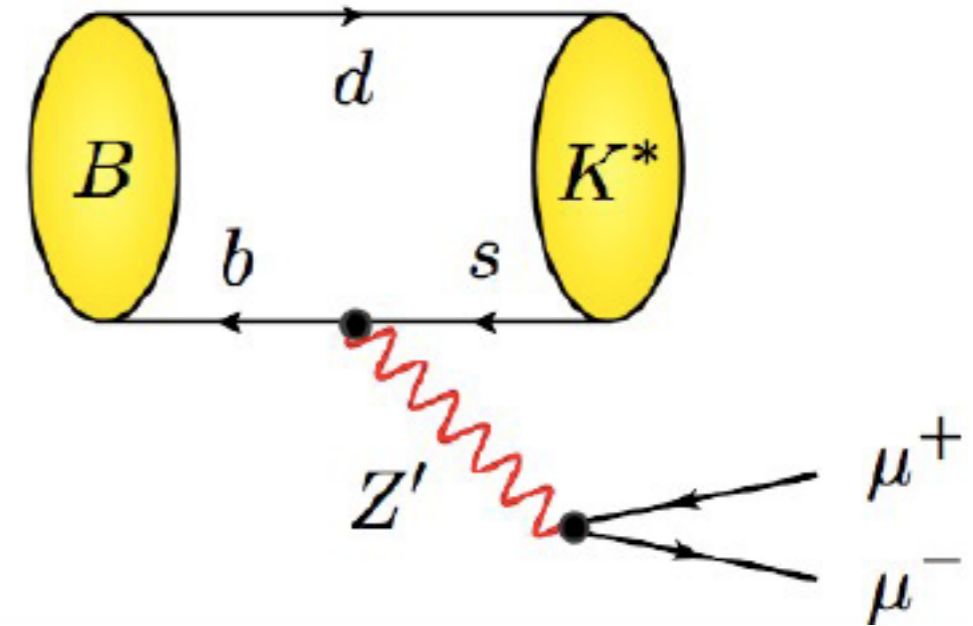
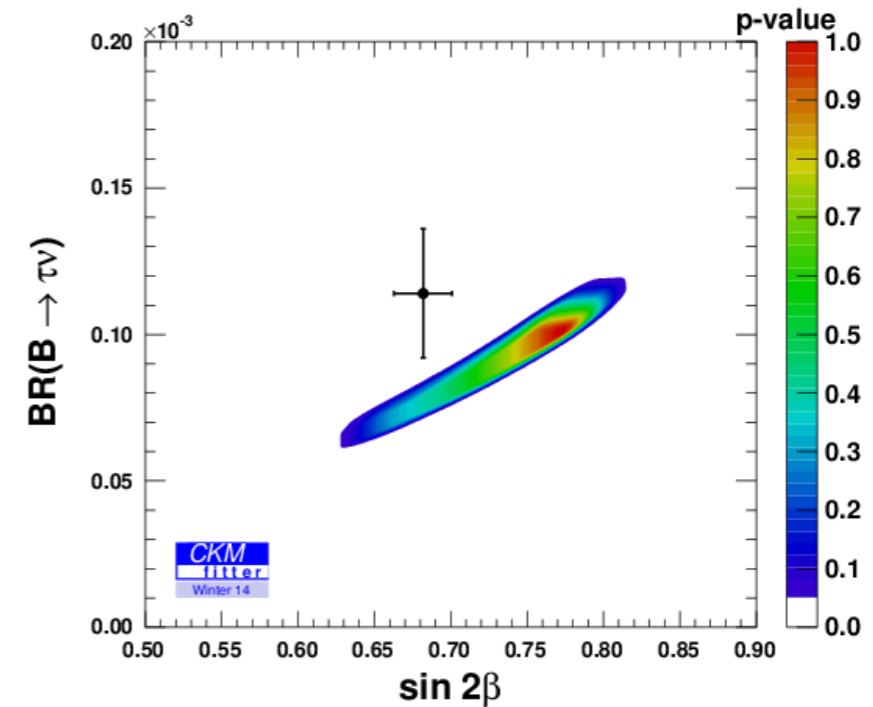
- Only measure: BABAR :  $BR(B_d \rightarrow \tau^+\tau^-) < 4.1 \times 10^{-3}$  @ 90%CL [arXiv:hep-ex/0511015]

- $\tau \rightarrow 3\pi\nu$  (A.Morda, J.Charles, G. Mancinelli) final states
  - Collaboration with CPT to derive a new parametrization for neutrino momenta [A.Morda, J.Charles]:
  - collaboration on muonic decay analysis

- Involvement of the CPPM-CPT team:
  - Run 1 analysis: involvement in the whole analysis, implementation of a new isolation tool [A.Morda, J. Cogan, G. Mancinelli, J. Serrano]
  - Sensitivity studies for next  $e^+e^-$  machines [J.Charles, A.Morda, **A. Tayduganov OCEVU PD from Nov 2105**]



- $B \rightarrow D^* \tau \nu$  decays, BABAR and Belle have measured the ratio of the  $\tau$  modes with respect to their  $\mu/e$  counterparts to be significantly larger than the SM predictions
  - This kind of effect could be also seen in the  $B \rightarrow (X) \tau \tau$  decays
- $B \rightarrow K^* \tau \tau$  is mediated by loop FCNC diagrams in the SM and is not yet measured
  - The anomaly observed in the P'5 observable of the  $B \rightarrow K^* \mu \mu$  decay by LHCb can be explained by the  $Z'$  existence
    - $\Rightarrow B_s \rightarrow \tau^+ \tau^-$  could be dramatically enhanced,
- Focus on construction of the best observables, that can be extracted once a sufficiently large number of events has been accumulated [G. Mancinelli, A. Tayduganov, J. Charles]
  - The finite  $\tau$  mass introduces new form factors and new non trivial angular observables wrt lighter leptons.
- Finally in the interpretation of the actual and/or prospective data:
  - Use of CKMfitter project, a powerful modular analysis framework dedicated to the flavor sector of the SM and various generic NP scenarios

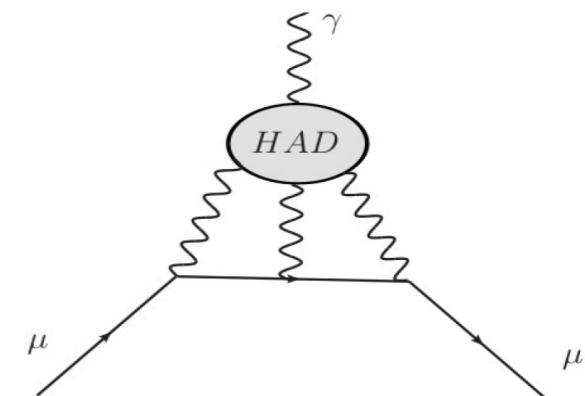
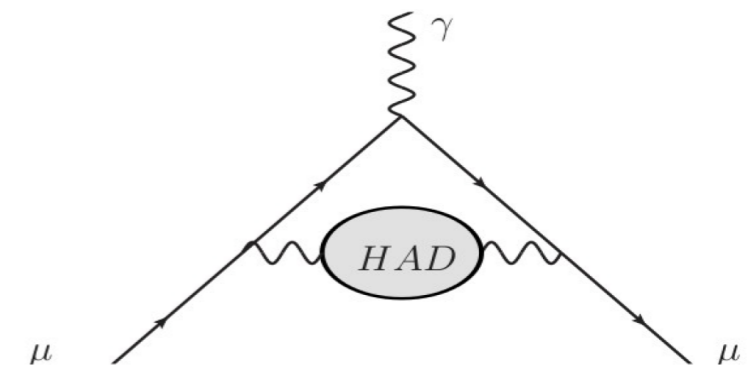
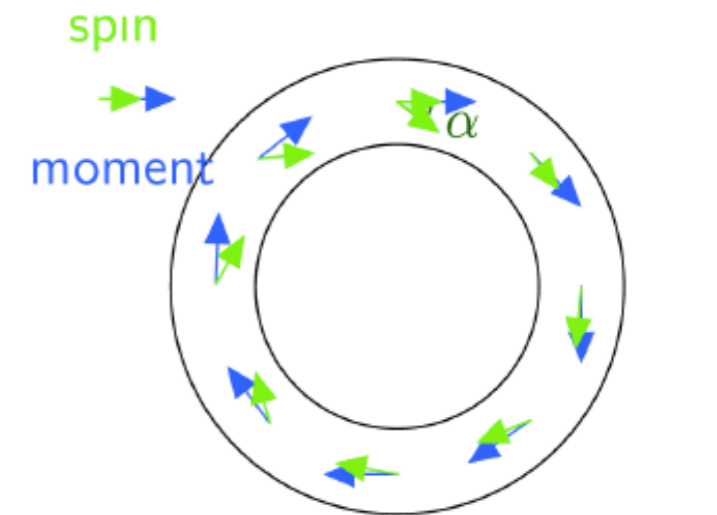


- Scientific production
  - R. Aaij et al. (LHCb Collaboration), "Measurement of the  $B^0_s \rightarrow \mu^+\mu^-$  Branching Fraction and Search for  $B^0_s \rightarrow \mu^+\mu^-$  Decays at the LHCb Experiment", Phys. Rev. Lett. 111, 101805 (2013)
  - E. Meggiolaro, A. Morda, "Remarks on the U(1) axial symmetry and the chiral transition in QCD at finite temperature", Phys. Rev. D88, 096010 (2013)
- Talks & posters at conferences & workshops
  - "Rare  $B^0_s$  dileptonic decay at LHCb", Journées de Rencontres des Jeunes Chercheurs, Barbaste, Lot et Garonne - 4 Decembre 2013
  - "Rare  $B^0$  (s) dileptonic decays at LHCb", Rencontres de Physique de la Vallée d'Aoste, La Thuile - 25 February 2014
  - "On the possibility of measuring  $\mathcal{B}(B^0_s \rightarrow \tau^+\tau^-)$  @ LHCb", Flavor of New Physics in  $b \rightarrow s$  transitions, Paris - 2 Juin 2014
  - "Branching ratio measurement of  $B^0_s \rightarrow \mu^+\mu^-$  decay at LHCb" Poster presented at JSED

# The muon anomalous magnetic moment and the search for new physics in the LHC era

- today experiment and SM prediction for  $a_\mu$  disagree  $> 3 \sigma$  with nearly matched errors
  - $\geq 2017$  experiments at Fermilab and J-PARC plan to divide errors by 4
    - large discovery potential if theory precision follows
- Main objectives [E de Rafael, C Hugonie, JL Kneur, M Knecht, L. Lellouch, R Malak, G Moutaka, S Narison, **1 OCEVU Funded PD starting fall 2015**]:
  - reduce uncertainties on SM prediction  $a_\mu$  to leverage experiment: in particular those coming from HVP and HLbL scattering which dominate theory error
    - design and explore BSM models to explain present and future  $a_\mu$  measurements while accounting for LHC constraints and discoveries
    - in particular SUSY scenarios with large higher-loop corrections to  $a_\mu$  including full upgrade of community codes SuSpect and NMSSMTools

$$\vec{\mu}_\mu = g_\mu \frac{e}{2m_\mu} \vec{S}, \quad a_\mu \equiv (g_\mu - 2)/2$$



# The muon anomalous magnetic moment and the search for new physics in the LHC era

- OCEVU has a unique convergence of competences to really make a difference on the physics of  $a_\mu$

- CPT: non-perturbative QCD (ab-initio and effective field theories) and Standard Model phenomenology (in particular  $a_\mu$  and higher-loop calculations)
- L2C: Renormalization Group Optimized Perturbation Theory (RGOPT), BSM phenomenology and SuSpect
- LUPM: QCD sumrules, NMSSM phenomenology, and NSSMTools

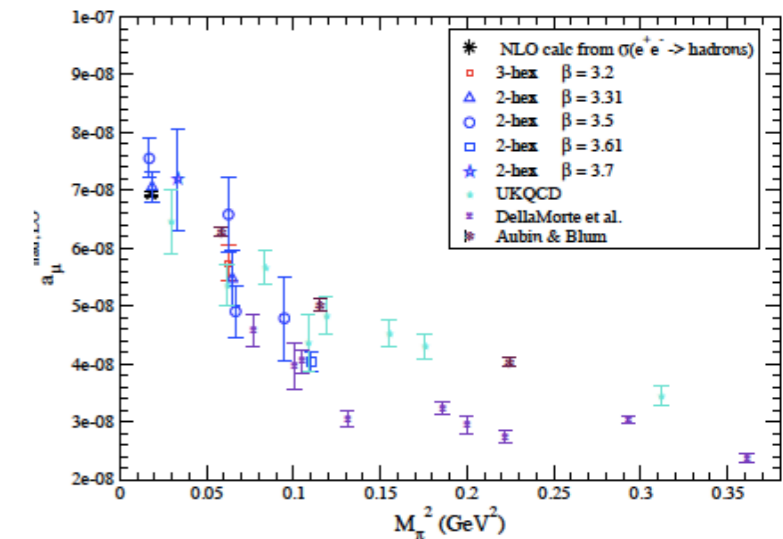
publications

- E. de Rafael, "Moment Analysis of Hadronic Vacuum Polarization - Proposal for a lattice QCD evaluation of  $g - 2$ ," arXiv:1406.4671 [hep-lat]
- S. Borsanyi, S. Durr, Z. Fodor, C. Hoelbling, S. D. Katz, S. Krieg, L. Lellouch et al., "Ab initio calculation of the neutron-proton mass difference," arXiv:1406.4088 [hep-lat], under review for Science
- E. B. Gregory, Z. Fodor, C. Hoelbling, S. Krieg, L. Lellouch, R. Malak, C. McNeile and K. Szabo, "Leading-order hadronic contributions to  $g - 2$ ," PoS LATTICE 2013 (2014) 322
- R. Malak for the Budapest-Marseille-Wuppertal collaboration, "Leading-order hadronic contribution to  $g - 2$  from  $N_f = 2 + 1$  simulations down to the physical pion mass," talk at Lattice 2014, June 23-28, 2014, Columbia University, USA, in preparation for proceedings
- M. Knecht, "The muon anomalous magnetic moment," talk at "International conference on quantum chromodynamics" (QCD 2014), 30 June - 4 July, Montpellier, to appear in proceedings
- J.L. Kneur, "Renormalization group optimized perturbation:  $\alpha_s$  from  $f_\pi$ ," talk at "International conference on quantum chromodynamics" (QCD 2014), 30 June - 4 July, Montpellier, to appear in proceedings

conferences

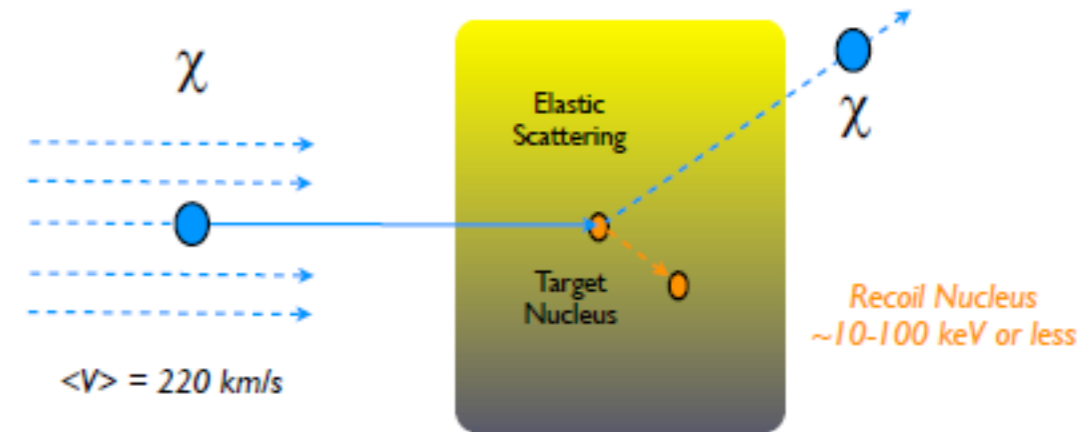
- (Invited) talks at many conferences, including: "Workshop on hadronic contributions to the muon  $g - 2$ " (MK, LL, Mainz, 2014), "QCD 2014" (MK, JLK, Montpellier 2014), "Lattice 2014" (RM, New York)

Ab-initio lattice QCD calculation of HVP contribution to  $a_\mu$



Lellouch, Malak et al, PoS LATTICE2013 (2014)

- 84.5% of mass in universe is believed to be in form of DM
  - WIMPs are a favored candidate and actively searched for in DM detection experiments and at LHC
  - New generation of direct detection (DD) experiments now and more are planned
  - x100 sensitivity soon and discovery or exclusion down to neutrino scattering bound in 10-15 yrs



- Main objectives J Lavallo, L. Lellouch, S Magni, T. Métivet. **P Mollitor** partly OCEVU funded PhD, until Dec. 2014, E Nezri, **C Torrero** OCEVU PD since Nov. 2013, + (new OCEVU PhD, from Oct. 2015):

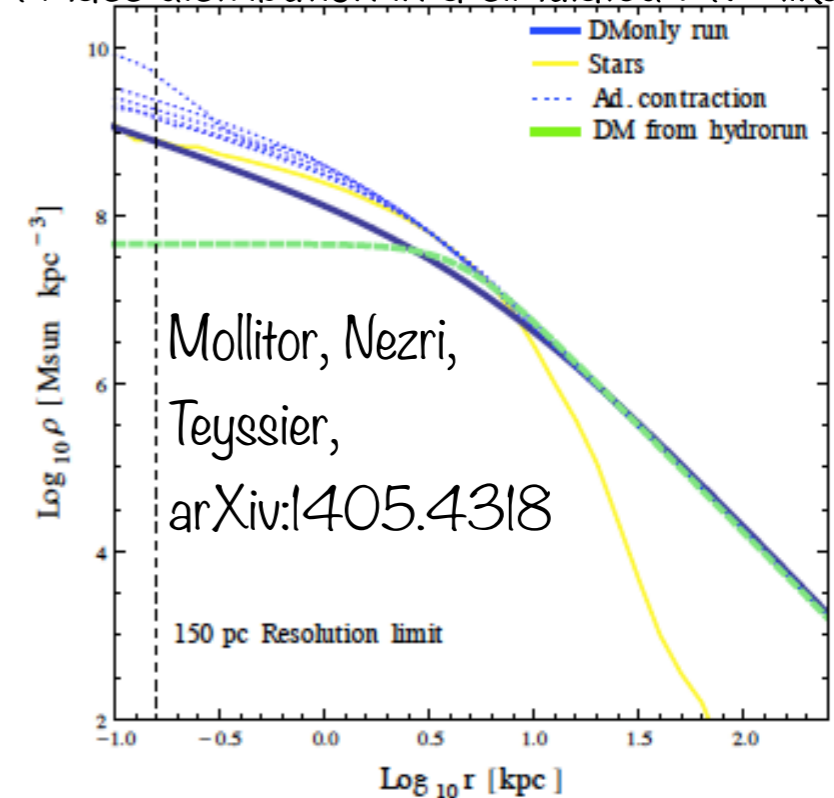
- design fully integrated approach and tools for prediction and interpretation of WIMP signals in direct (and indirect) DM detection experiments
- use novel calculations to reduce and fully correlate astrophysical, cosmological and particle physics uncertainties in self-consistent manner
- make DD rate predictions and interpretations of possible signals from present and upcoming experiments
- $\geq 2015$  extend the study to the complementarity between direct and indirect searches, and LHC

$$\frac{dN}{dE_r} (E_r) = \underbrace{\Delta M \Delta t}_{\text{Detector}} \underbrace{\frac{A^2 \sigma_{p,SI} F^2(E_r)}{2m_{red,p}^2 m_\chi}}_{\text{Particle + hadronic + nuclear physics}} \underbrace{\rho_0 \int_{|\vec{v}'| > v'_{min}(E_r)} d^3\vec{v}' \frac{1}{v'} f_\nu(\vec{v}')}_{\substack{\text{AstroPhysics} \\ \rho_0 \eta(E_r)}}$$

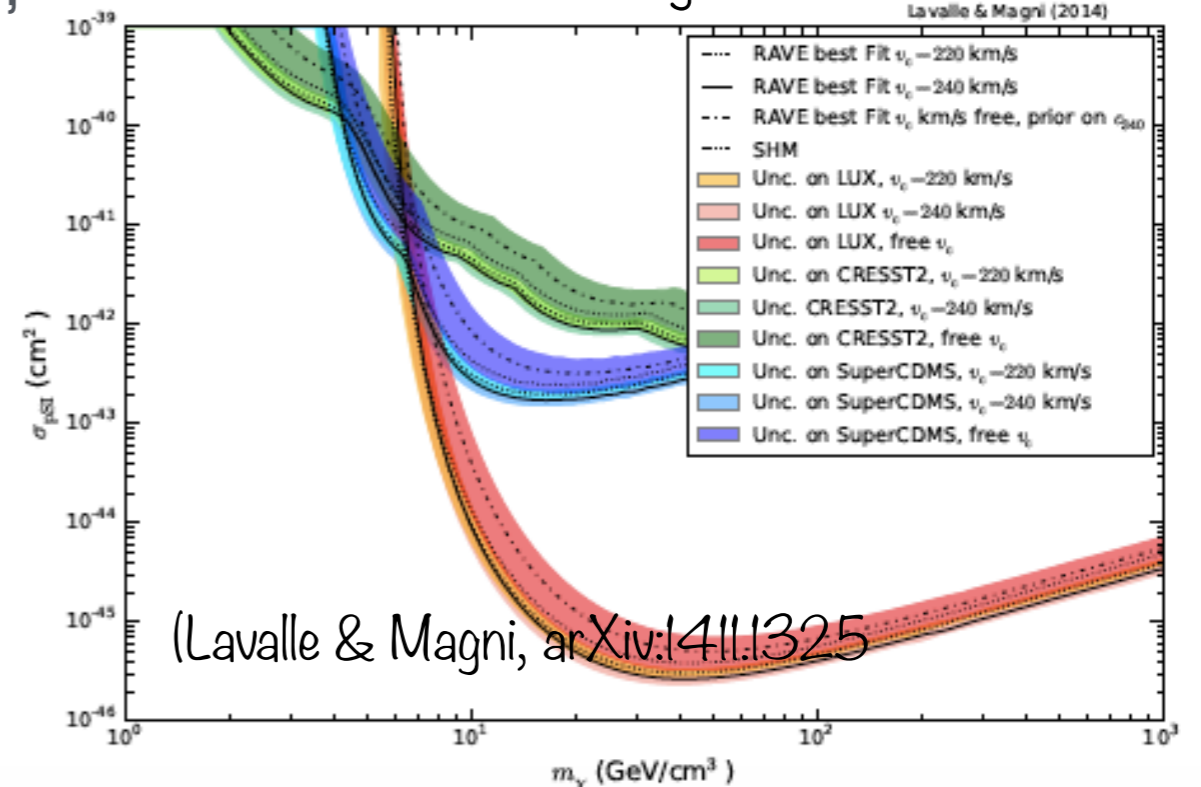
## Cosmological and astrophysical constraints on local DM distribution

- Cosmological hydrodynamic simulations of Milky Way-like galaxies to test assumptions made in determining local DM phase-space distributions and help assess uncertainties and correlations
- Fully consistent determination of local DM density and velocity distributions, accounting for the theoretical uncertainties and correlations between astrophysical parameters (e.g.  $\rho_{\odot}$ ,  $V_c$ ,  $V_{esc}$ , ...) needed for DM rate calculations

DM mass distribution in a simulated MW-like galaxy



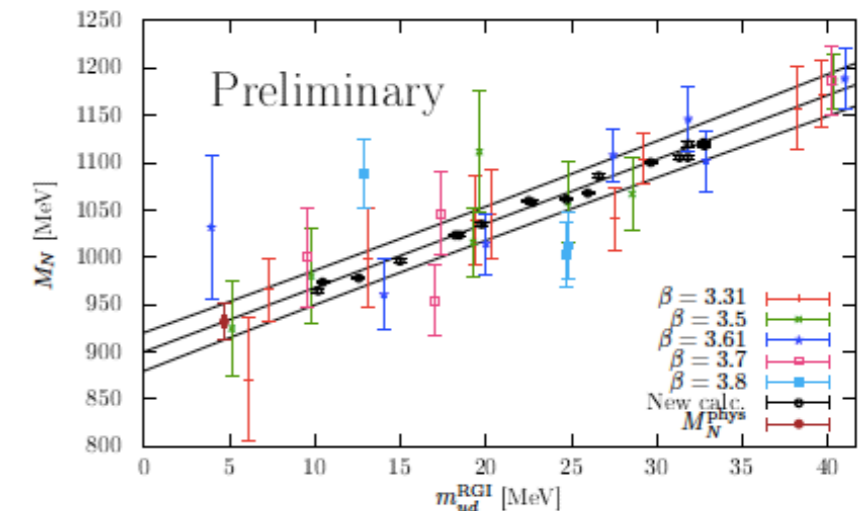
DD exclusion curves with fully correlated uncertainties



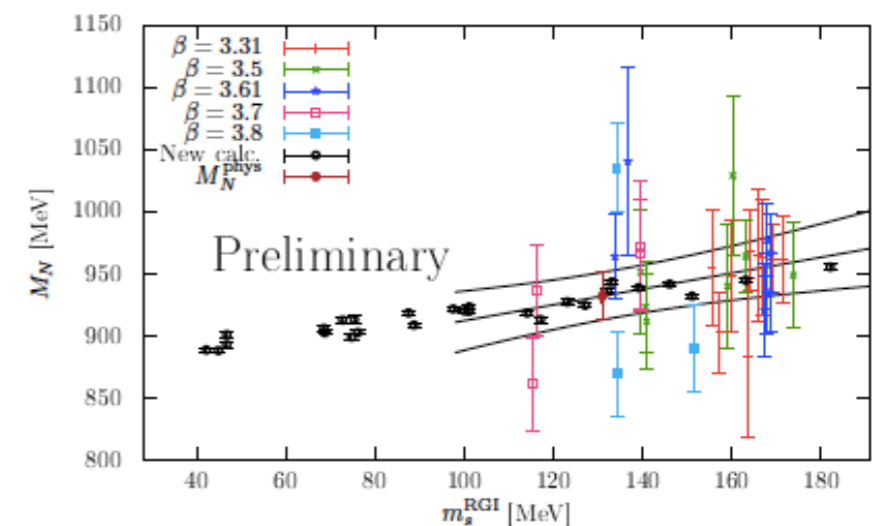
## Ab-initio calculation of SI WIMP-nucleon couplings

- Large-scale ab-initio lattice QCD simulations to determine WIMP couplings to ordinary matter (nucleons) with fully controlled and significantly reduced uncertainties
  - required for interpreting experimental DD constraints or signals in terms of WIMP models
  - useful for indirect DM detection, . . .
- Spin-independent (SI) couplings of WIMP to ordinary matter proportional to square of quark contents
- 2014: reached fully controlled 50% uncertainties on  $f_{udN}$  and  $f_{sN}$  in first assumption-free calculation performed directly at physical point
- $\geq 2014$ : developed new methods and performing completely new calculations to reduce uncertainties  $\leq 5\%$

$$f_{udN} = m_{ud} \frac{\langle N | \bar{u}u + \bar{d}d | N \rangle}{2M_N^2} = \frac{m_{ud}}{M_N} \left. \frac{\partial M_N}{\partial m_{ud}} \right|_{\text{phys}}$$



$$f_{sN} = m_s \frac{\langle N | \bar{s}s | N \rangle}{2M_N^2} = \frac{m_s}{M_N} \left. \frac{\partial M_N}{\partial m_s} \right|_{\text{phys}}$$





## publications

- J. Lavallo and S. Magni, “Making sense of the local escape speed estimate in direct dark matter detection”, arXiv:1411.1325 [astro-ph.CO]
- P. Mollitor, E. Nezri and R. Teyssier, “Baryonic and dark matter distribution in cosmological simulations of spiral galaxies,” arXiv: 1405.4318 [astro-ph.GA]
- C. Torrero for the BMW Collaboration, “Computing the nucleon sigma terms at the physical point,” in proceeding of Lattice 2014, arXiv: 1411.2459 [hep-lat]
- J. Lavallo, S. Magni, P. Mollitor and E. Nezri, “Revisiting the escape speed concept from zoom-in cosmological simulations: implications for direct dark matter detection,” in preparation
- J. Lavallo, L. Lellouch, S. Magni, P. Mollitor, E. Nezri, C. Torrero, “Theoretical uncertainties in direct Dark Matter searches,” planned 2015
- L. Lellouch, C. Torrero et al, “Ab-initio calculation of nucleon quark flavor contents,” planned 2015

## conferences

- Organization of and talks at:
  - “News from the Dark,” Montpellier 2013
  - “CosmoSamSim 2014”, Marseille 2014
- (Invited) talks at many conferences, including: “Origin of Mass 2014” (LL, Odense), “Lattice 2014” (CT, New York), “Astroparticle Physics 2014” (PM, Amsterdam), “Dark side of the universe 2014” (SM, PM, CapeTown)

- Next PP WG meetings in 2015:
  - Spring Meeting to prepare for the summer workshop and the 2016 AAP and discuss convergences in projects and possible collaborations etc.
  - Fall Meeting to prepare CoPil and reports for different groups
- Foresee a seminar from an external person during these meetings to foster discussions within the group
- Further develop presence of WG on web

backup

- Particle Physics Working Group Ongoing projects:
  - New physics through direct production (**energy frontier**)
    - Probing the nature of Electroweak Symmetry Breaking at the LHC with the ATLAS detector
    - New Physics from a natural Electroweak symmetry breaking
  - New physics in indirect searches (**intensity frontier**)
    - B decays into tau lepton pairs and related rare processes
    - Rare dileptonic B decays
    - The muon anomalous magnetic moment and the search for new physics in the LHC era
  - Dark matter interface w/ astro. & cosmo. (**cosmic frontier**)
    - Lattice QCD enlightens dark matter
- Foreseen actions in 2015

- **Energy Frontier:** Is the resonance discovered in July 2012 at CERN really “the” Higgs and can we reveal new fundamental physics by direct production at run 2 of LHC?
  - Probing the nature of Electroweak Symmetry Breaking at the LHC with the ATLAS detector:
    - Interface theoretical and experimental physics between ATLAS CPPM Group (C. Diaconu, L. Feligioni, S. Muanza) , L2C & LUPM phenomenology group (J.-L. Kneur, G. Moultaka)
      - OCEVU funded **1** PD: **S. Diglio (Jan 2014)**, **2** PhD: **V. Ellayosula (Oct 2014)**, **(+ 1 2015)** **3** FV: **Y. Liu (USTC)**, **X. Zhuang (IHEP)**, **S. Davidson (IPNL)**
  - New Physics from a natural Electroweak symmetry breaking
    - Collaboration between L2C & LUPM group (M. Frigerio, J.-L. Kneur) and CPT (M. Knecht)
      - OCEVU funded **1** PhD: **N. Bizot (Oct 2013)**

- **Intensity Frontier:** Can we reveal new fundamental physics, including new sources of CP violation, indirectly, in flavour physics and other lower-energy experiments (e.g. anomalous magnetic moment of the muon)?
  - The muon anomalous magnetic moment and the search for new physics in the LHC era
    - Interface between different theory groups L2C+LUPM [new physics] and CPT+L2C+LUPM [Various approaches to standard model computations, large-Nc modeling, sumrules, including large scale numerical simulations].
      - OCEVU funds **1 PD: (will start 2015)**
  - B decays into tau lepton pairs and related rare processes and Rare dileptonic B decays
    - Interface the experimental group LHCb CPPM (G. Mancinelli, J. Cogan, J. Serrano) and the theory CPT group (J. Charles)
      - OCEVU funds **1 PD: A. Tayduganov (Nov 2014), 1 PhD: A. Mordà (Oct 2012).**
- **Cosmic frontier:** Is dark matter an elementary particle yet to be discovered?
  - Lattice QCD enlightens dark matter
    - Interface particle experiment & theory & astroparticles & cosmology
      - OCEVU funds: **1 PD: Torrero (Nov 2013), 1 PhD: P. Mollitor (2015)**

- Coordinators: Lorenzo Feligioni & Laurent Lellouch [LL until end 2014]
- Board: C. Hugonie, JL Kneur, R. Legac, L. Lellouch, G. Moulataka, E. Nezri, L. Vacavant
- Frequent organized meetings (not counting OCEVU workshops!)
- Organization of conferences in Marseille & Montpellier, often involving many OCEVU labs and sometimes many working groups: DIS 2013, SFP 2013, News from the dark 2013, FPCP 2014, QCD 2014, FFP 2014
  - Conference participation & subsequent reporting to OCEVU members