Dr. Umberto De Sanctis

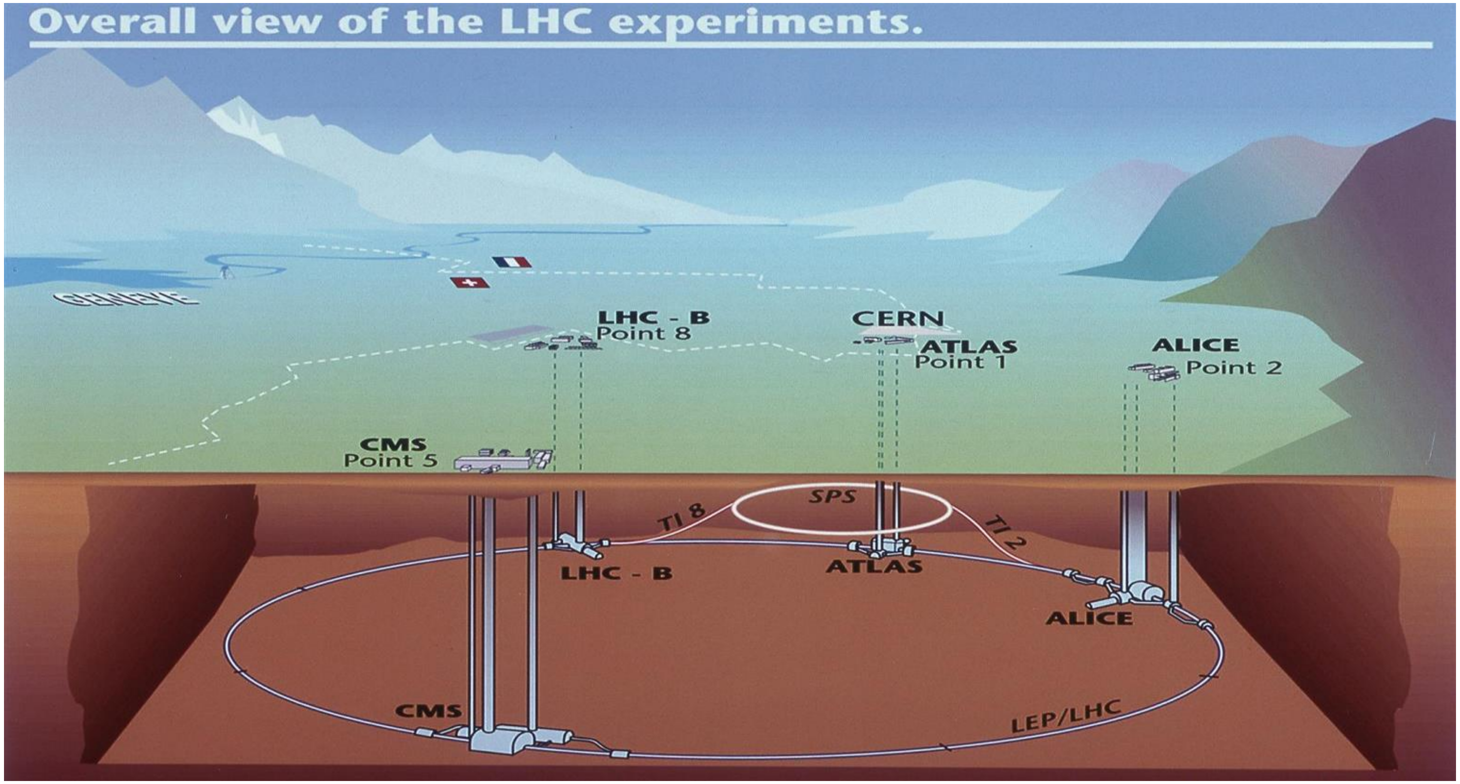
21/12/2018 Roma Tor Vergata

Outline

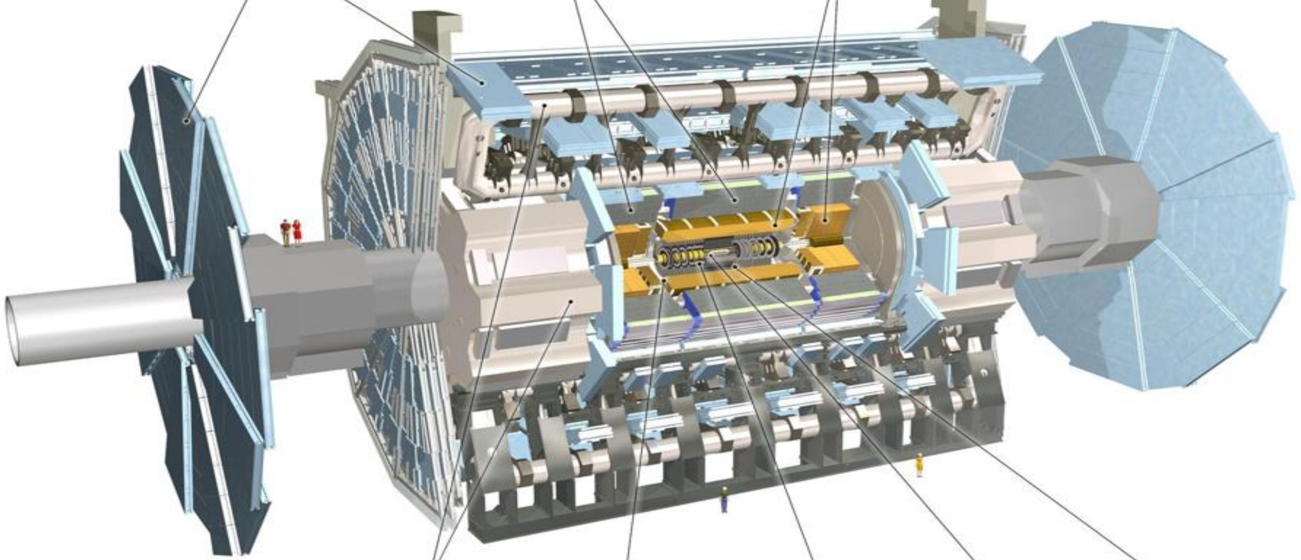
- Spent the whole career in the **ATLAS Experiment**
- Supersymmetry (SUSY)
  - Searches in the dilepton channel
- Top Physics
  - tt cross-section measurement in single lepton channel
  - W+jets background estimation
  - Top charge asymmetry measurement
- B-physics
  - $B^0_{(d,s)} \rightarrow \mu\mu$ BR measurement
  - Topological trigger studies
- ATLAS upgrade activities for HL-LHC
  - L1Track project
- NPTEV-2020 Project

LHC & CERN

- 27 km circular collider
- Up to 2800 bunches of 10^{11} protons colliding in 4 points each 25 ns
- Instantaneous luminosity up to 2.5 10^{34} $cm^{-2}s^{-1}$
- Run1 (2010-2012) and Run2 (2015-2018) collected 25 fb^{-1} and 150 fb^{-1} at center-of-mass energies $\sqrt{s}$ = 7, 8 and 13 TeV



The ATLAS Experiment

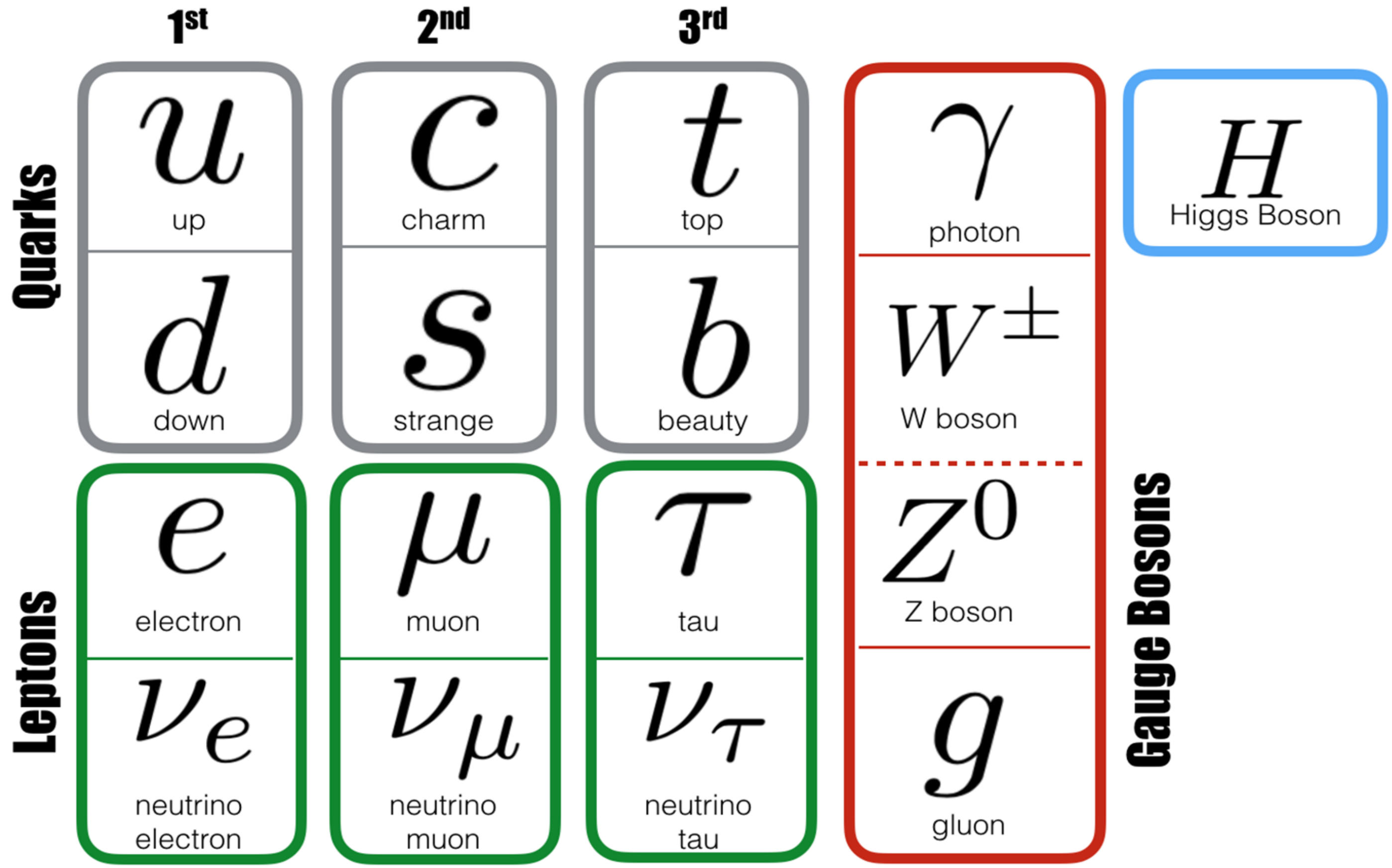


- Jets + Tranverse missing energy (EM + Hadronic Calo)
- Leptons (EM Calo + muon chambers + Inner Detector)
- b-jets (IBL and Pixel Vertex Detector).

⟹

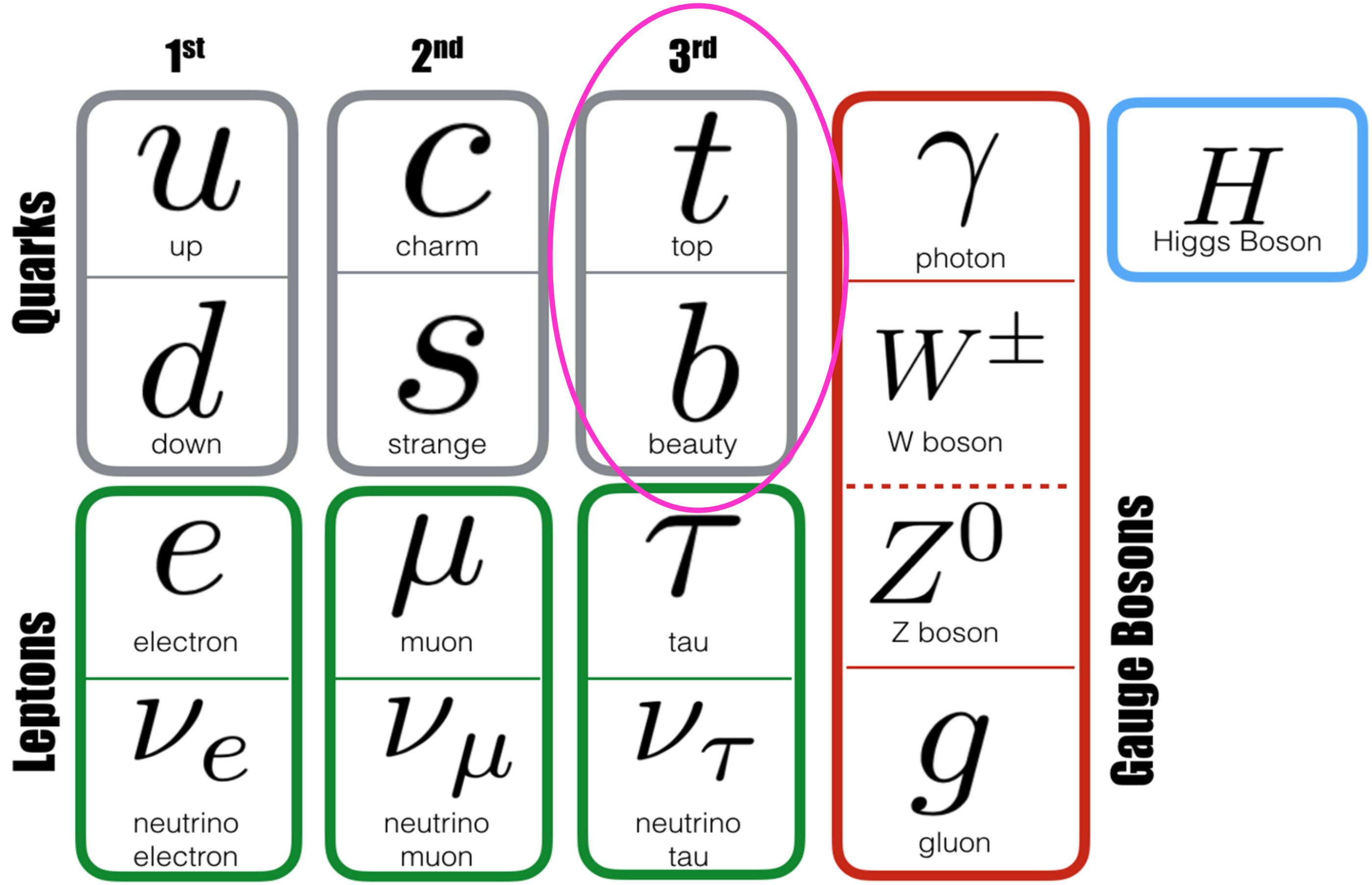
- Top physics needs high performance in reconstructing all these objects
- B-physics mainly relies on muons and tracks will exploit at highest level its components.

The Standard Model of Particle Physics



- 3 families of quarks and leptons: the fundamental "bricks"
- 4 types of mediators (gauge bosons) which describe the 3 fundamental interactions: strong, weak and electromagnetic
- The "newcomer": the Higgs Boson responsible for the masses of all particles in the Standard Model.

The Standard Model of Particle Physics



- 3 families of quarks and leptons
- 4 types of mediators (gauge bosons) which describe the 3 fundamental interactions: strong, weak and electromagnetic
- The "newcomer": the Higgs Boson responsible for the masses of all particles in the Standard Model.

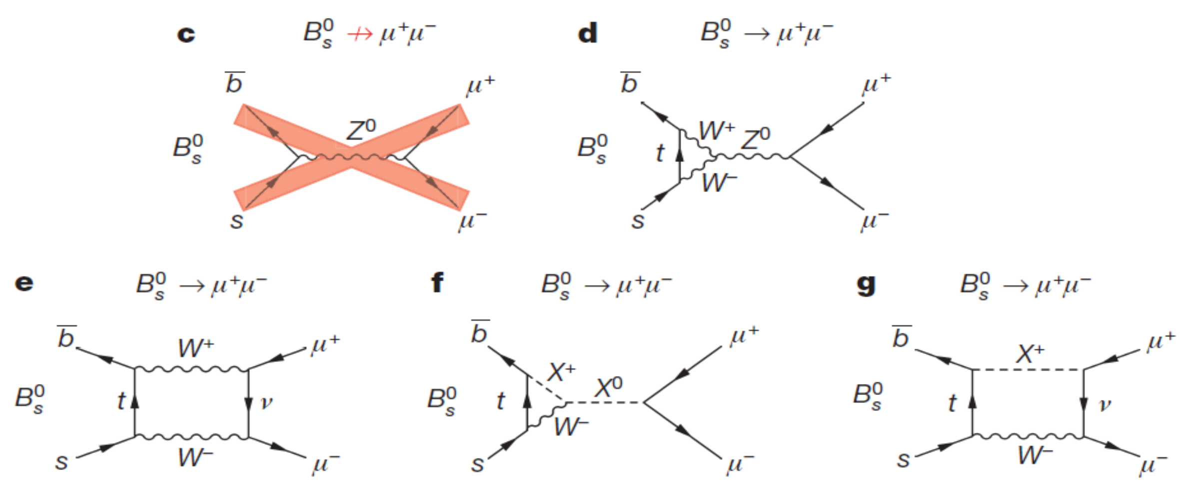
Bs,d→μμ BR measurement

- Flavour physics: currently ATLAS B-physics convener
- Rare but clean decay suppressed by FCNC in the SM
  - BR(Bs→μμ) = $(3.65 \pm 0.23) \times 10^{-9}$
  - BR(Bd→μμ) = $(1.06 \pm 0.09) \times 10^{-10}$
- Sensitive to New Physics contributions through loops
- Measurements by CMS and LHCb (combined):

BR(Bs→μμ) = $(2.8^{+0.7}_{-0.6}) \times 10^{-9}$ $\quad 3.0^{+0.7}_{-0.6} \times 10^{-9}$

BR(Bd→μμ) = $(3.9^{+1.6}_{-1.4}) \times 10^{-10}$ $\quad < 3.4 \times 10^{-10}$

LHCb-only (Run2)



$B_{s,d} \to \mu\mu$ BR measurement

- **Rare but clean** decay suppressed by FCNC in the SM
  - BR($B_s \to \mu\mu$) = $(3.65 \pm 0.23) \times 10^{-9}$
  - BR($B_d \to \mu\mu$) = $(1.06 \pm 0.09) \times 10^{-10}$
- **Sensitive to New Physics** contributions through loops
- Measurements by CMS and LHCb:

BR($B_s \to \mu\mu$) = $(2.8^{+0.7}_{-0.6}) \times 10^{-9}$ (combined) $3.0^{+0.7}_{-0.6} \times 10^{-9}$ LHCb (Run2)

BR($B_d \to \mu\mu$) = $(3.9^{+1.6}_{-1.4}) \times 10^{-10}$ $< 3.4 \times 10^{-10}$

- Analysis strategy:

Hadronisation probabilities

$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-) = N(B^0_{(s)} \to \mu^+\mu^-) \times [\mathcal{B}(B^+ \to J/\psi K^+) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)] \times \frac{f_u}{f_{s/d}} \times \frac{1}{\mathcal{D}_{\rm norm}}$$

$$\mathcal{D}_{\rm norm} = \sum_k N^k_{J/\psi K^\pm} \alpha_k \left(\frac{\varepsilon_{\mu^+\mu^-}}{\varepsilon_{J/\psi K^\pm}}\right)_k$$

Number of Bs/Bd events from an unbinned ML fit to m(μμ) distribution

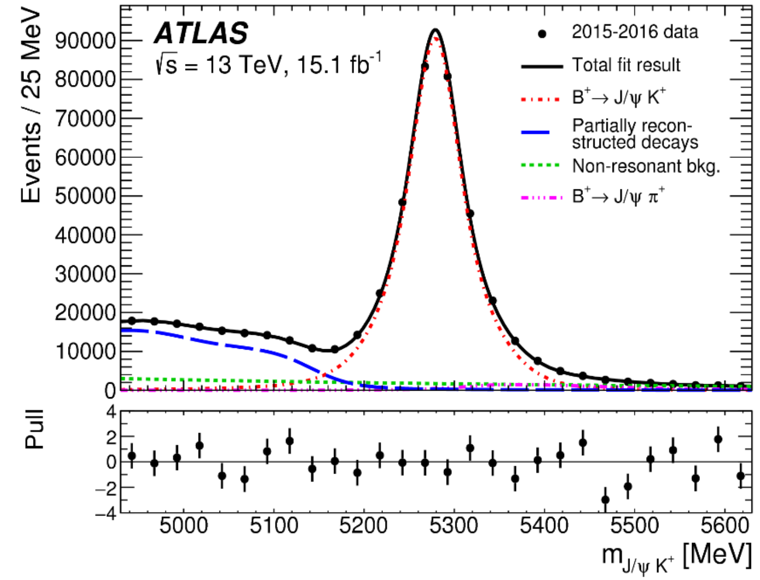
Reference channel: $B^\pm \to J/\psi K^\pm$
Extracted from an unbinned ML fit to m(μμK±) distribution

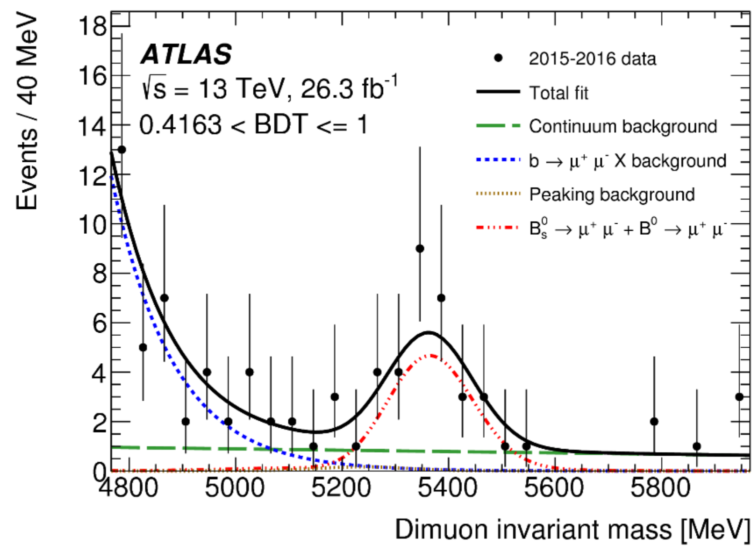
Trigger categories and luminosity prescales*

Acceptance and efficiencies from simulation

$B_{s,d} \rightarrow \mu\mu$ BR measurement

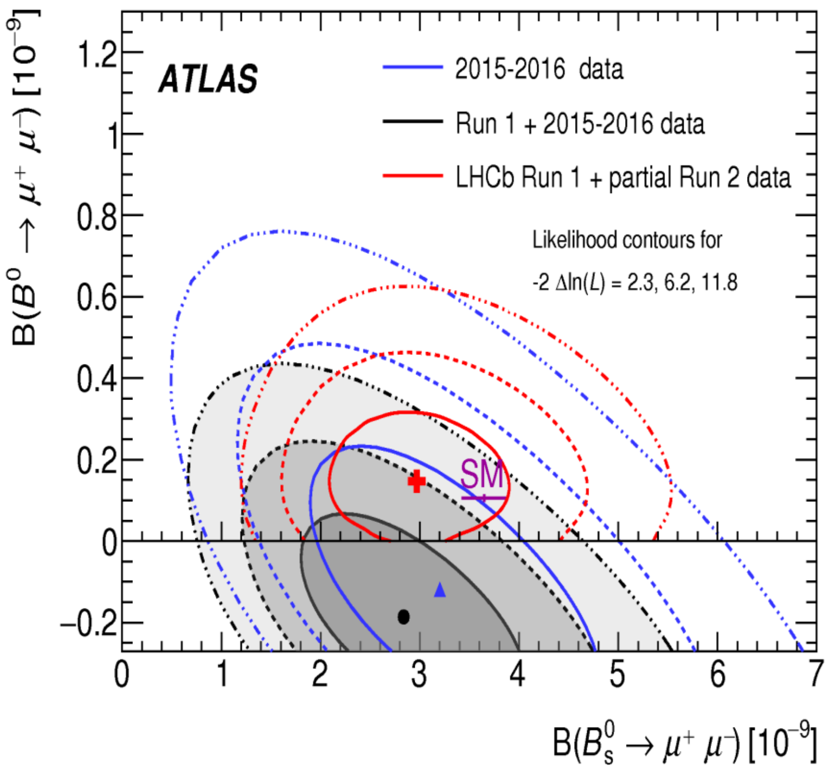
- BR extracted w.r.t to a well know high statistics reference channel ($B^{\pm} \rightarrow J/\psi K^{\pm}$) → reduce systematics
- Blind analysis (e.g. the event selection and all the analysis is frozen before looking at data)
- Di-muon low-P_T triggers
- High reduction and control of the backgrounds (BDT for combinatorial)
- Main backgrounds:
  - Combinatorial (i.e. 2 "random" muons forming a common vertex
  - Semi-leptonic decays
    - e.g. $b \rightarrow c\mu\nu \rightarrow s(d)\mu\mu\nu\nu$
  - Hadrons identified as muons
    - K/π decays in flight





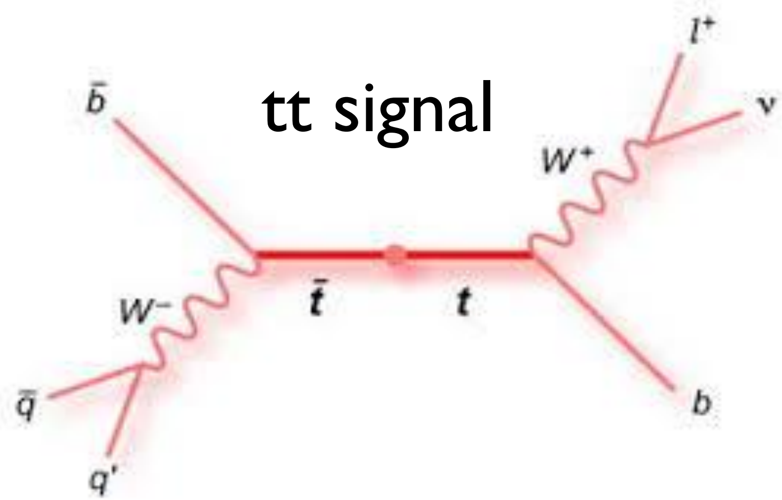
Bs,d→μμ BR measurement

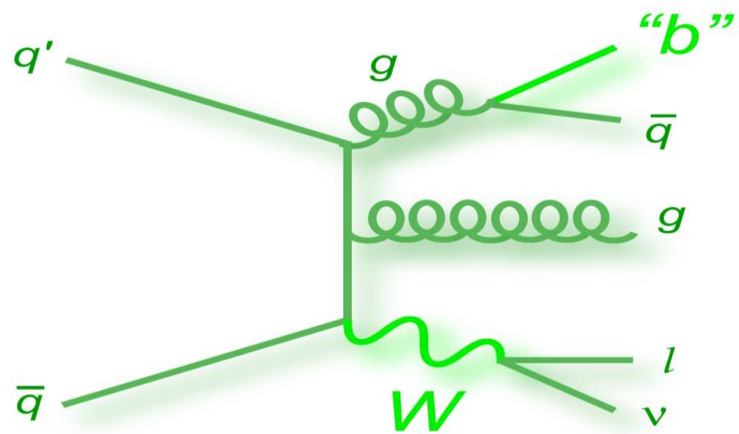
- Results for full Run1+Partial Run2 dataset (25+26 fb^{-1})
- Simultaneous BR(Bs →μμ, Bd→μμ) extraction
- Comparable precision w.r.t. CMS and LHCb despite their better m(μμ) resolution



- BR(Bs) = $2.8^{+0.8}_{-0.7}$ x10^{-9} (stat. ± syst.)
  - Evidence at 4.6σ
- Upper limit on BR(Bd) placed at 2.1x10^{-10} (95% CLs)
  - Currently the most stringent limit

Top physics





W+jets background

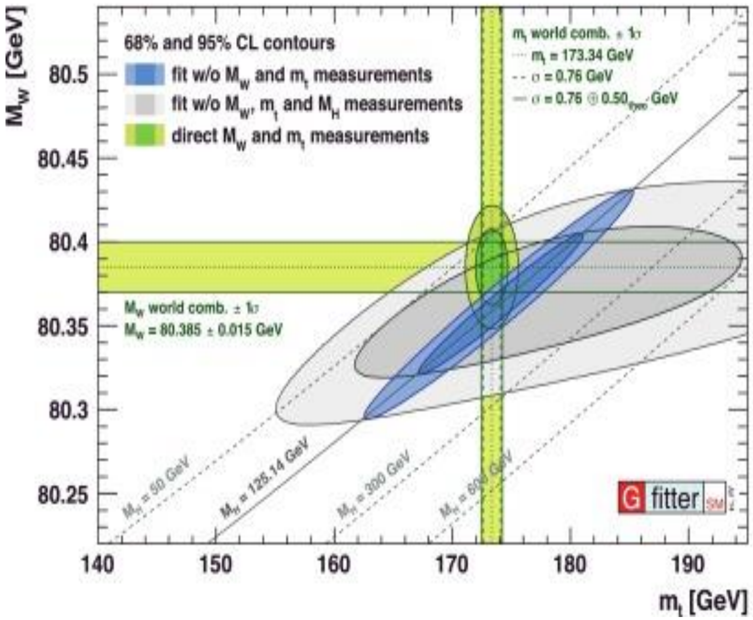
- Top quark is the heaviest particle in Nature
- Its lifetime is shorter than $1/\Lambda_{QCD}$ → It doesn't hadronise
- Possibility to study the properties of a bare quark!
- BR(t→Wb) ~ 99%
- Experimental signatures:
  - High-P_T jets with both light and heavy flavours HF (from b and c quark decays)
  - High-P_T isolated lepton (e,μ)
  - High missing transverse momentum E^T_{MISS}

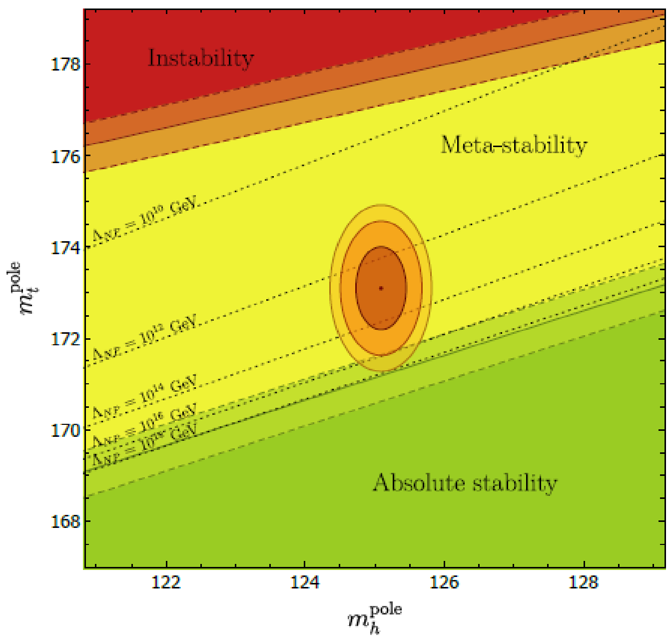
The NPTEV-2020 project

- NPTEV-2020 project: find New Physics in top events
- Several measurements foreseen.
  - Top mass
  - CP-violation in b-quark decays in t →bW events
  - Search for resonance X → $t\bar{t}$
  - FCNC violating decay t → cZ
  - ttZ coupling measurement
- Tool: **Soft Muon Tagging**
  - Identify the muon from the semileptonic decays of the b quark (e.g. b→cμν) in t→W(→μν)b decay

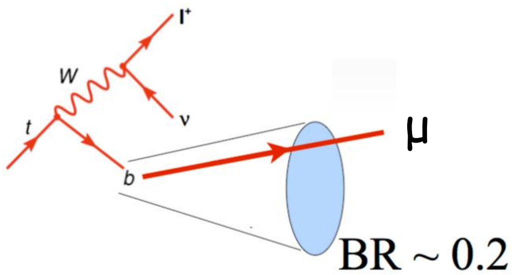
Top mass measurement

- Accurate measurements of top quark mass (together with M_W and M_H) crucial to test the SM
  - Compare EW fit and experimental measurements
  - Vacuum stability (i.e. UV SM completion)

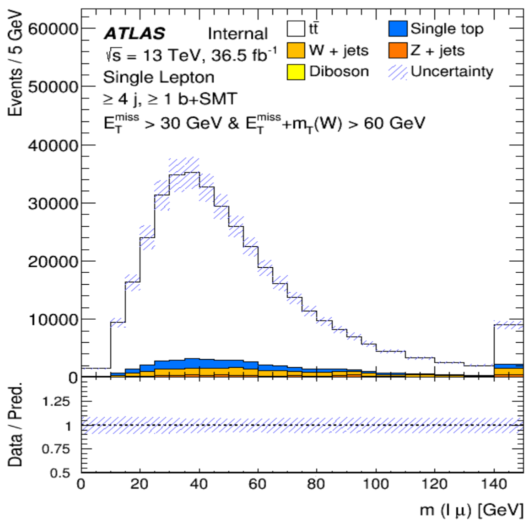




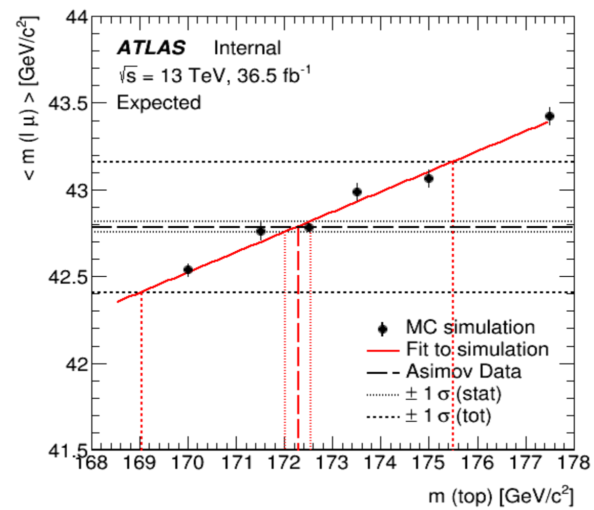
Top mass with soft-muons



- Relate the top quark mass to the invariant mass constructed by the Soft Tagged μ with the e/μ from the W decay
- Not sensitive to (b)- JES → gain in combination with other measurements
- Non isolated muons → Need ad-hoc calibration with Z and J/ψ
- b-fragmentation to be kept under control
  - Constrained with LEP Z → bb data



- Reconstruct the invariant mass m(lμ)in data
- Extract m(lμ) templates for several top mass points
- Fit in data the m(lμ) curve
- Find the best value of the top mass



CP-violation in b-decays

- Look for **CP violation** in b-semileptonic decays
- 2 muons: one from W, one from the b-cascade
- Count the number of same-charge/opposite-charge muons N^{++}, N^{--}, N^{+-}, N^{-+}
- Build asymmetries sensible to CP violation both in B^0-B^0 mixing and direct b/c semileptonic decays

$$A^{ss} = \frac{P(b \to l^+) - P(\bar{b} \to l^-)}{P(b \to l^+) + P(\bar{b} \to l^-)} = \frac{\left(\frac{N^{++}}{N^+}\right) - \left(\frac{N^{--}}{N^-}\right)}{\left(\frac{N^{++}}{N^+}\right) + \left(\frac{N^{--}}{N^-}\right)}$$

$$A^{os} = \frac{P(b \to l^-) - P(\bar{b} \to l^+)}{P(b \to l^-) + P(\bar{b} \to l^+)} = \frac{\left(\frac{N^{+-}}{N^+}\right) - \left(\frac{N^{-+}}{N^-}\right)}{\left(\frac{N^{+-}}{N^+}\right) + \left(\frac{N^{-+}}{N^-}\right)}$$

- **Run1 results:**
  - **All asymmetries consistent with SM**
  - **First limit on direct CPV in b→cX decay**
- Analysis on Run2 13TeV data just started

$$A_{\rm mix}^{b\ell} = \frac{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) - \Gamma\left(\bar{b} \to b \to \ell^- X\right)}{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) + \Gamma\left(\bar{b} \to b \to \ell^- X\right)},$$

$$A_{\rm mix}^{bc} = \frac{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) - \Gamma\left(\bar{b} \to b \to c X\right)}{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) + \Gamma\left(\bar{b} \to b \to c X\right)},$$

$$A_{\rm dir}^{b\ell} = \frac{\Gamma\left(b \to \ell^- X\right) - \Gamma\left(\bar{b} \to \ell^+ X\right)}{\Gamma\left(b \to \ell^- X\right) + \Gamma\left(\bar{b} \to \ell^+ X\right)},$$

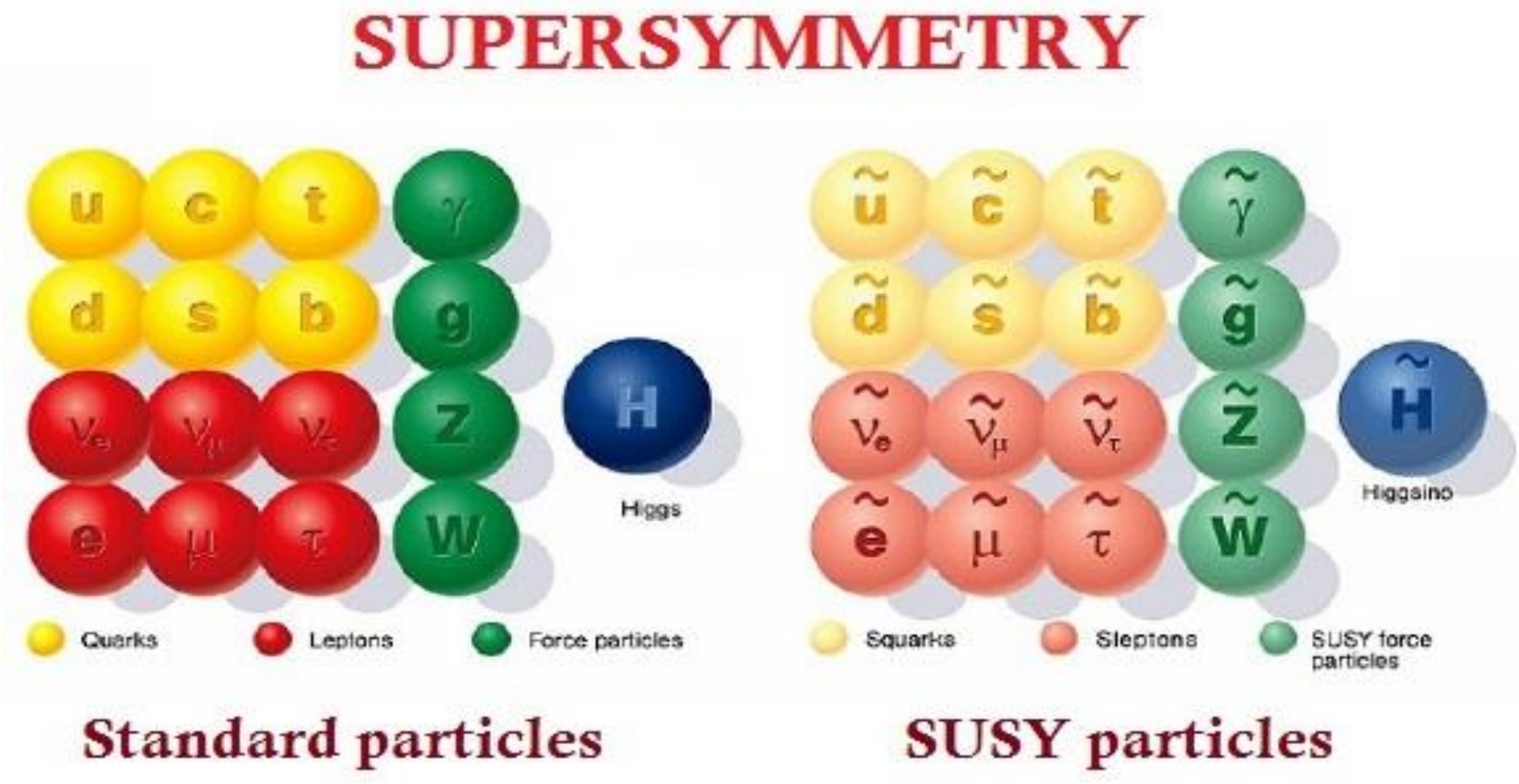
$$A_{\rm dir}^{c\ell} = \frac{\Gamma\left(\bar{c} \to \ell^- X_L\right) - \Gamma\left(c \to \ell^+ X_L\right)}{\Gamma\left(\bar{c} \to \ell^- X_L\right) + \Gamma\left(c \to \ell^+ X_L\right)},$$

$$A_{\rm dir}^{bc} = \frac{\Gamma\left(b \to c X_L\right) - \Gamma\left(\bar{b} \to \bar{c} X_L\right)}{\Gamma\left(b \to c X_L\right) + \Gamma\left(\bar{b} \to \bar{c} X_L\right)},$$


WE'RE GOING TO HAVE FUN
TOGETHER...
I JUST KNOW
IT!
memegenerator.net

Backup

Supersymmetry (SUSY)

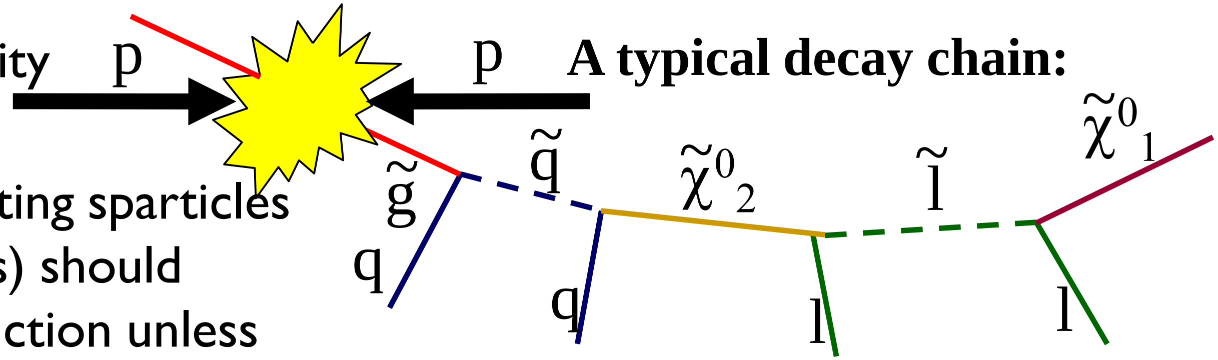


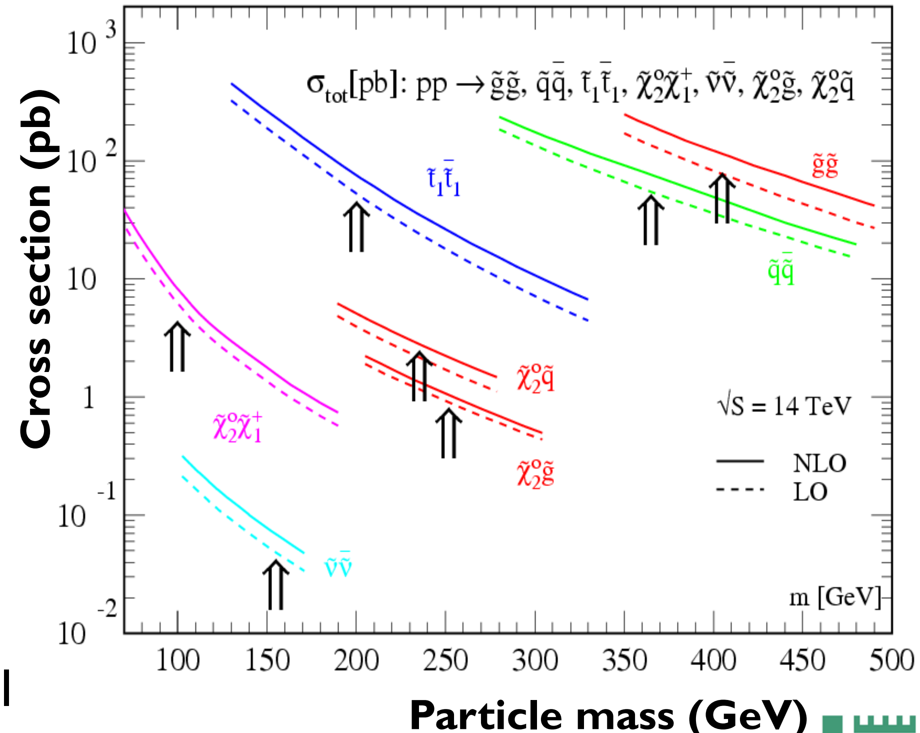
- New symmetry that associates to every SM particle a partner with different spin
- Solution to the "naturalness/hierarchy/fine-tuning" problem
- Candidate for Dark Matter (called LSP) if R-parity conservation holds

SUSY signatures at LHC

- Assuming R-parity conservation
- Strongly interacting sparticles (squarks, gluinos) should dominate production unless very heavy.
- Cascade decays to the stable, weakly interacting lightest neutralino follows.
- Event topology:
  - high p_T jets (from squark/gluino decay)
  - Large E_T^{miss} signature (from LSP)
  - High p_T leptons, b-jets, τ, jets (depending on model parameters).

A typical decay chain:





SUSY activities

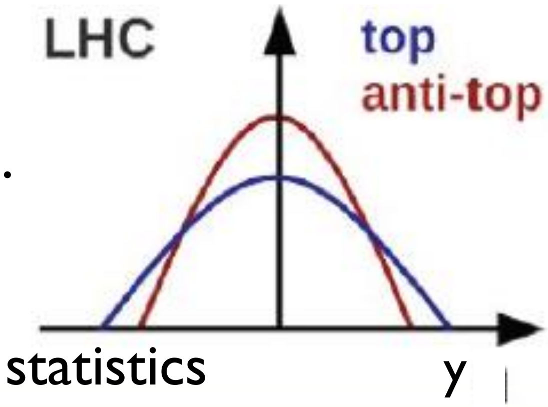
- 2005-2008: Master and PhD theses at Milano University
- Inclusive and exclusive searches in final states with:
  - 2 Opposite Sign Same Flavour (OSSF) high-P_T leptons (e, μ)
  - High-P_T jets + High missing transverse energy E^T_{MISS}
- Sensitive to SUSY scenarios with:
  - R-Parity conservation
  - Gluinos decay chains
  - Interpreted within mSUGRA framework
- New method to estimate tt backgorund for these searches (dominant one)
- Results with 1 fb^{-1} at $\sqrt{s}$=14 TeV:
  - Significantly extend the **discovery potential** of the inclusive searches
  - Reconstruct SUSY particles **kinematic properties (e.g. mass differences)** with a precision < 2%

Top physics activities

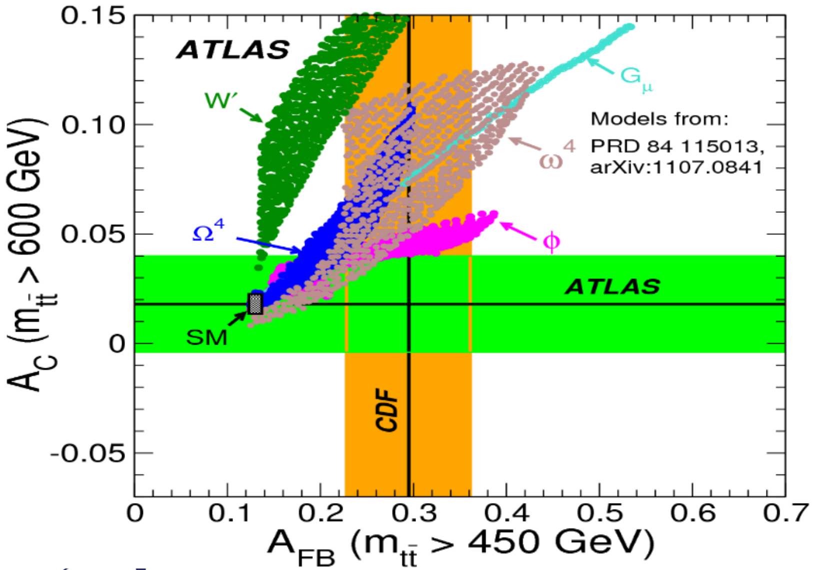
- 2009-2013: Postdoc at S.I.S.S.A. (Trieste): Top physics
- Phenomenological works on the spin determination for high-mass resonances and contact interactions in di-jet events
- Work in ATLAS:
  - tt production cross-section measurement in the single lepton channel with and without b-tagging
    - 36 pb^{-1} at $\sqrt{s}$ = 7 TeV → already systematics dominated
    - Compatible with the SM predictions at NLO
  - W+jets background estimation for tt analyses in the single lepton channel
    - Developed a new **data-driven** method based on the W^+/W^- production charge asymmetry
    - Determine both overall normalisation and flavour components ($Wb\bar{b}$, $Wc\bar{c}$, Wc and W+ light jets)
    - Most precise method → Adopted by all top analyses

Top charge asymmetry

- CDF reported a 3.4σ excess over SM → Started and led the activity for the two publication rounds
- Top charge asymmetry A_C is a small QCD NLO effect (1.2%) present in $q\bar{q}$/qg events. SM predicts that top and antitop have different rapidity widths $\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$



- At LHC: less visible effect but much higher statistics
- A_C measured after unfolding for detector/acceptance effects



- Most precise LHC measurement
- Inclusive and differential ATLAS measurements compatible with SM
- Comparison between ATLAS and CDF → Some model disfavoured

JHEP02(2014)107

Trigger & Upgrade activities

- Level-1 Topological trigger
  - Optimised, supervising a PhD student, Run-2 trigger strategies for B-physics using Level-1 muon topological info
  - x3 rejection improvement → Vital for B-physics in Run2!

- Level-1 Track Project for HL-LHC
  - Goal: make a Level-1 trigger decision using ID info
    - Low latency trigger (few μs)
    - Pattern recognition and track fitting using Associative Memory and FPGA (à-la FTK)
  - Add flexibility to the trigger system for HL-LHC
  - Development of the track fitting algorithm based on Principal Component Analysis and tracking performance studies