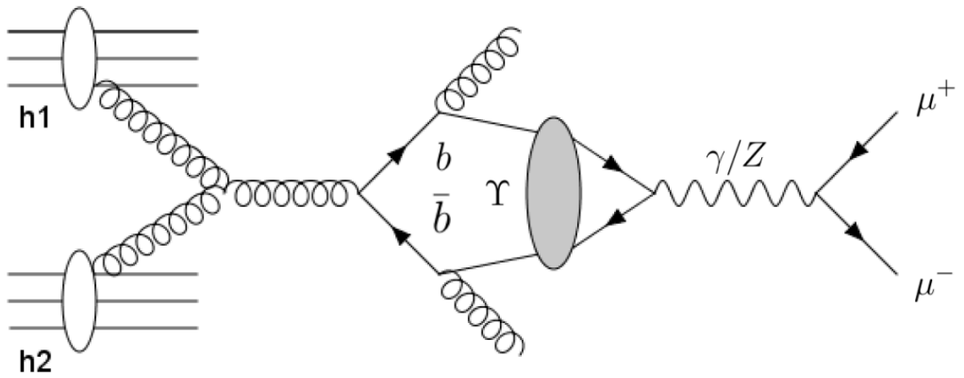
Inside View @ LIP

Medidas de Precisão e Busca de Processos Raros @ CMS-LIP

N.Leonardo (nuno@cern.ch)

V JEF - Jornadas de Engenharia Física, MEFT 27.2.2018

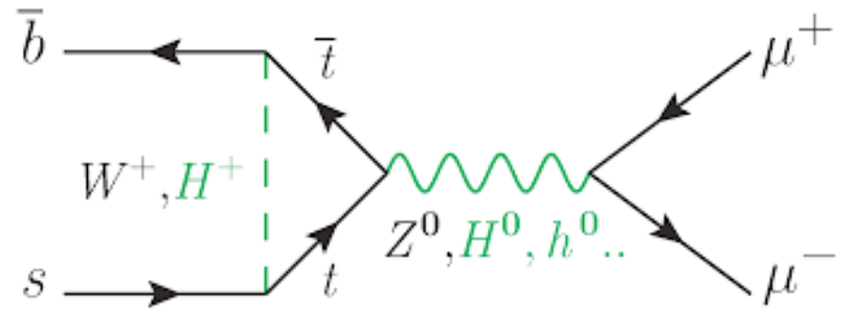
precision: Heavy Flavor



IJMP A32 19n20 (2017)

- precision tests of the SM
- understand QCD and its mechanisms of hadroproduction
- characterize the properties of the quark gluon plasma with novel probes

new physics: Rare Decays



Nature 522 (2015) 68

- indirect search for BSM
- processes that are suppressed in the SM and highly sensitive to virtual contributions from BSM particles
- sensitive to higher NP scales

explore LHC's energy & luminosity frontiers

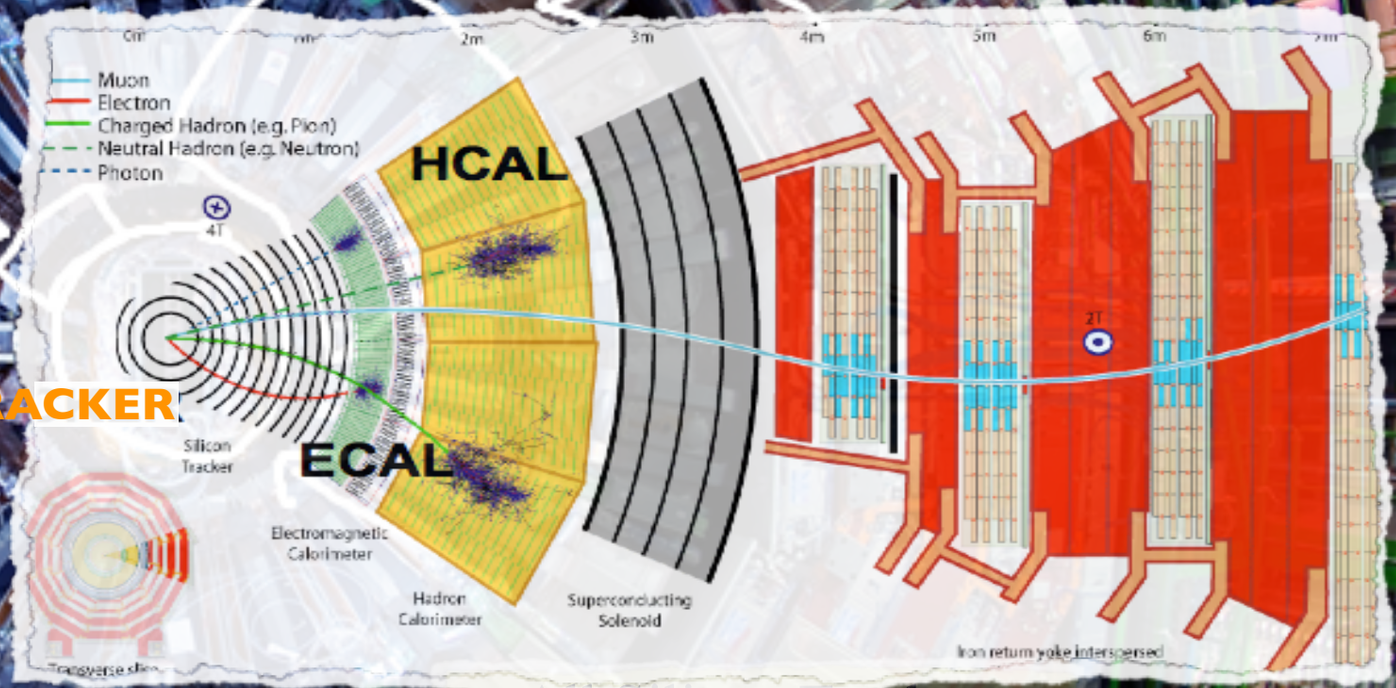
the Compact Muon Solenoid detector

Text

3.8T Superconducting Solenoid

Hermetic (|η|<5.2)
Hadron Calorimeter (HCAL)
[scintillators & brass]

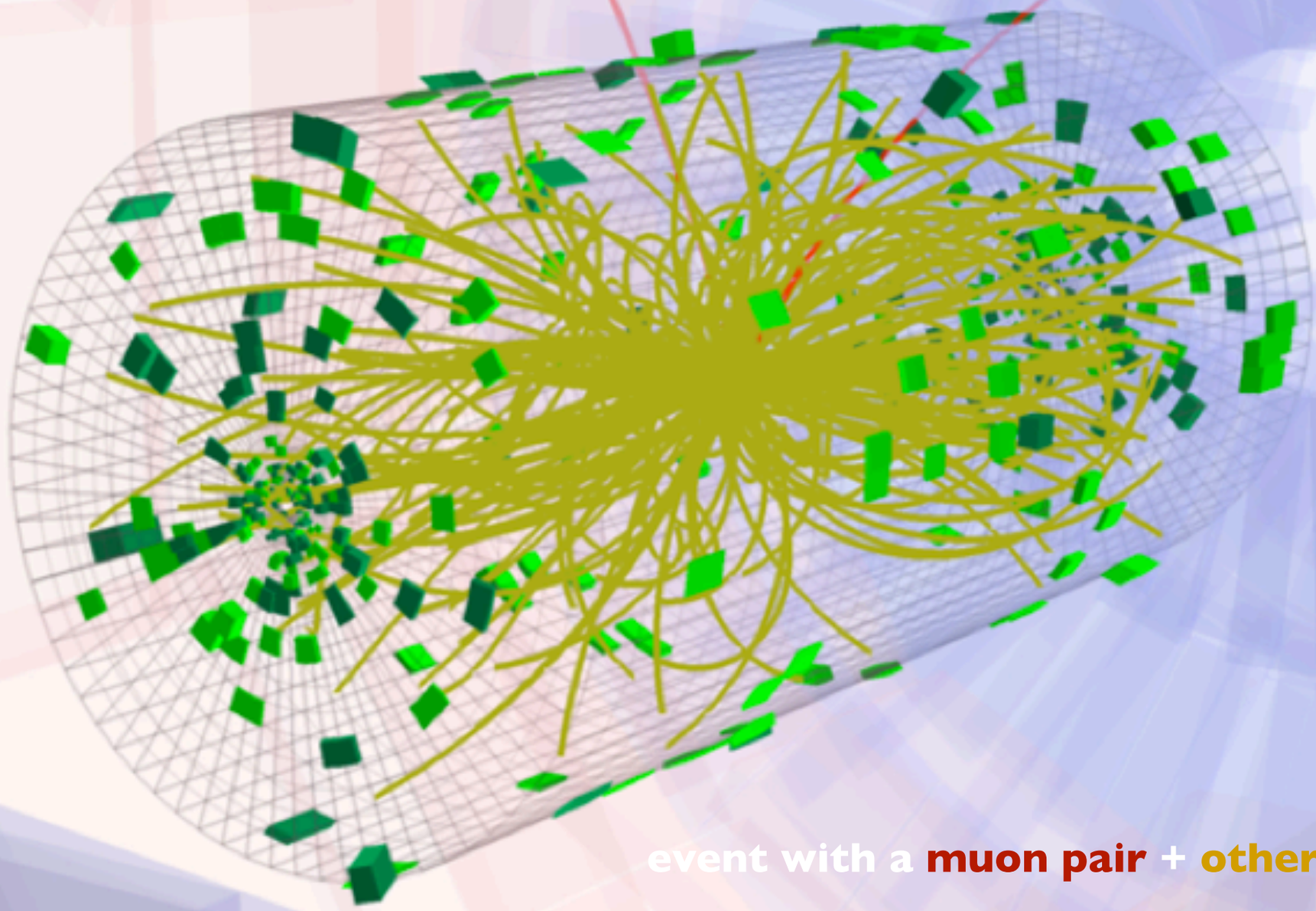
Lead tungstate
E/M Calorimeter (ECAL)



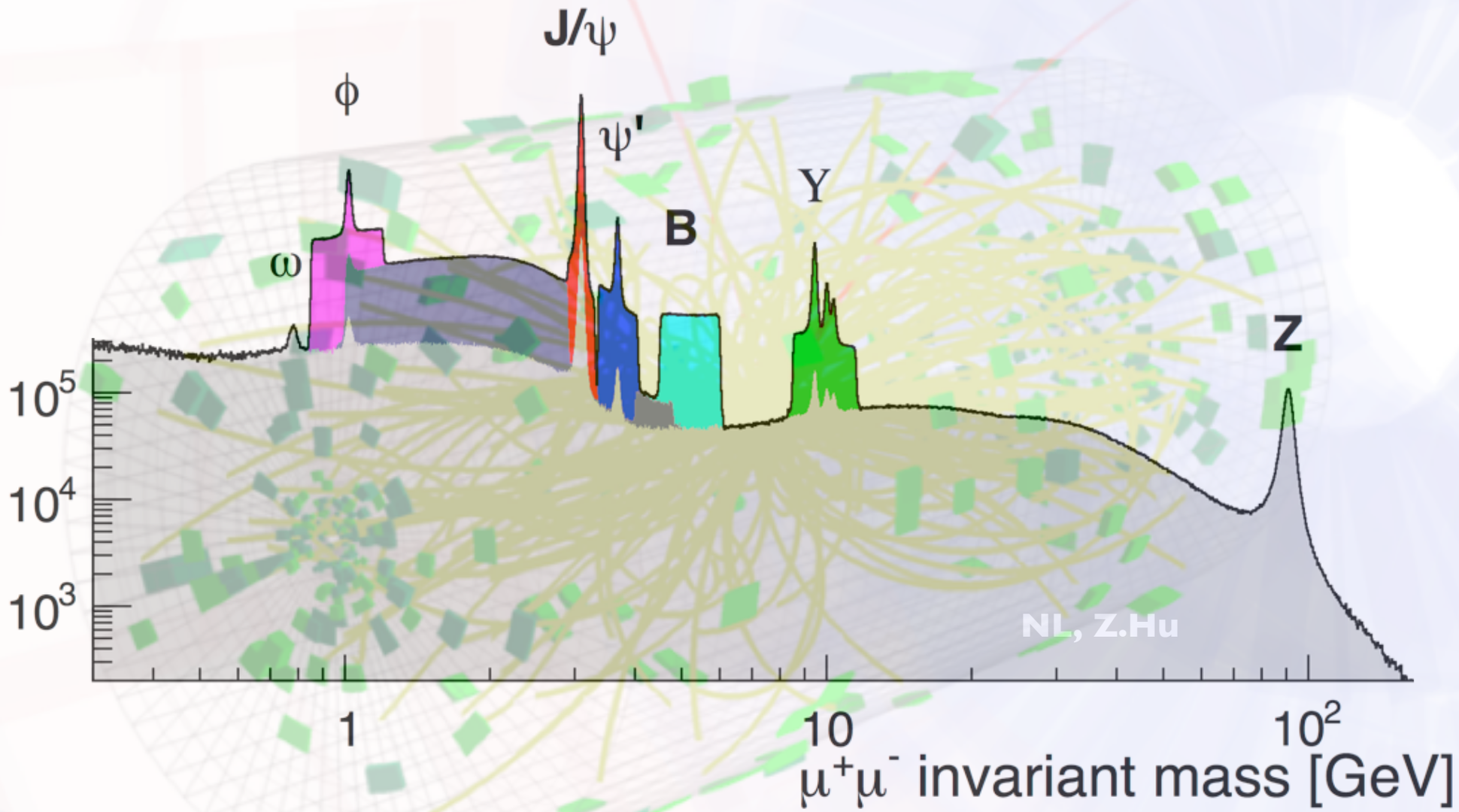
All Silicon Tracker
(Pixels and Microstrips)

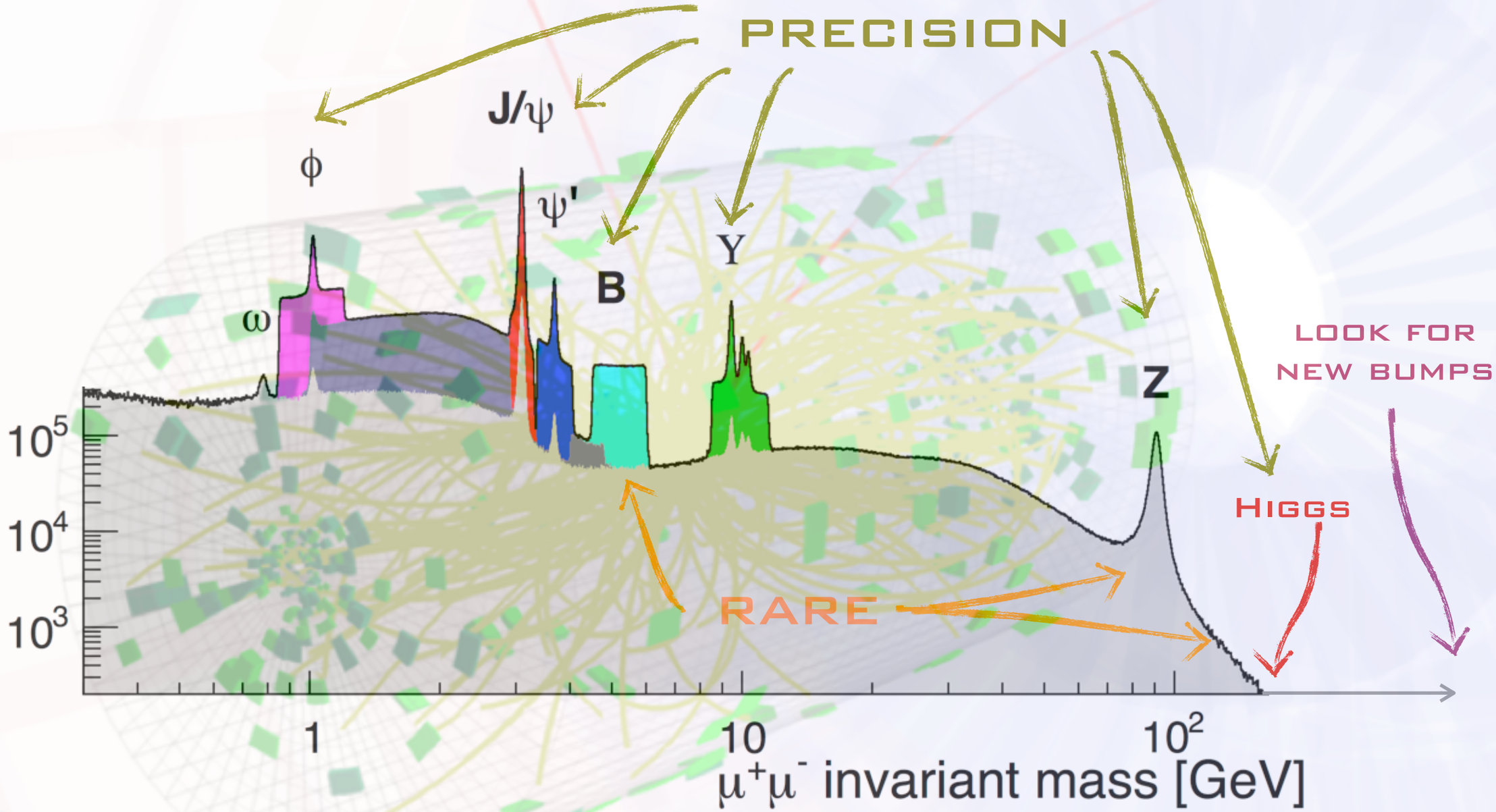
Redundant Muon System
(RPCs, Drift Tubes,
Cathode Strip Chambers)

visualizing a collision

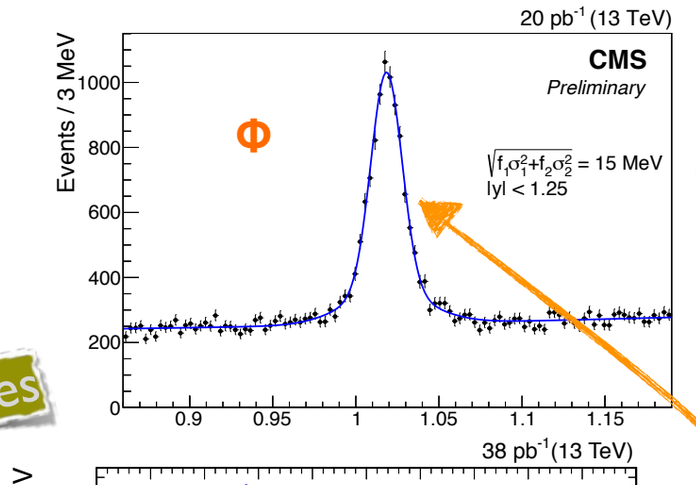


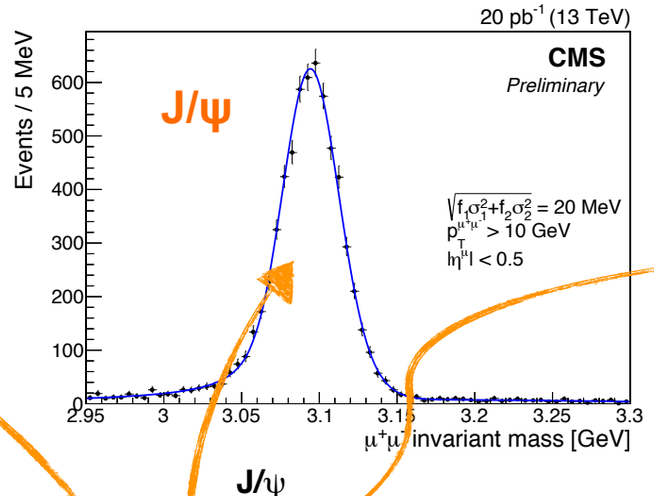
event with a **muon pair** + **other collision debris**

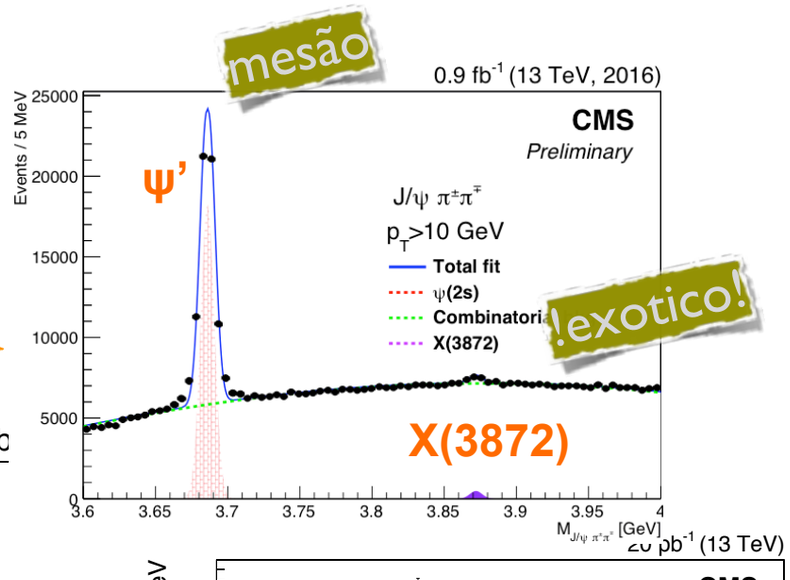

J/ψ
ϕ
ψ'
Υ
B
ω
Z
10^5
10^4
10^3
1
10
10^2
NL, Z.Hu
$\mu^+\mu^-$ invariant mass [GeV]

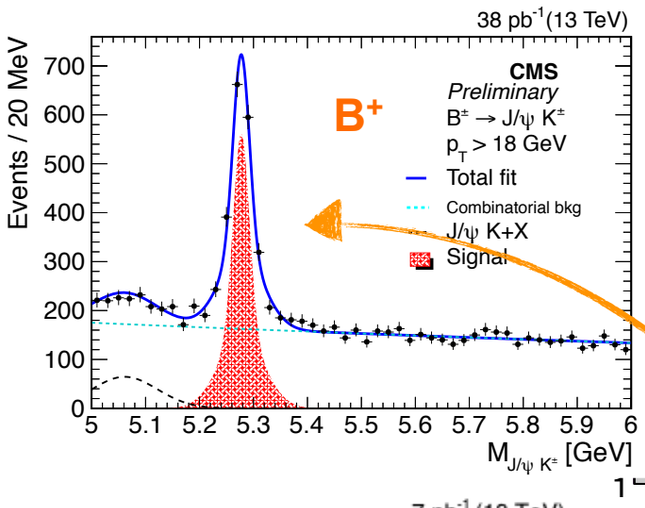

PRECISION
J/ψ
ϕ
ψ'
ω
B
Υ
Z
LOOK FOR
NEW BUMPS
HIGGS
RARE
10^5
10^4
10^3
1
10
10^2
$\mu^+\mu^-$ invariant mass [GeV]

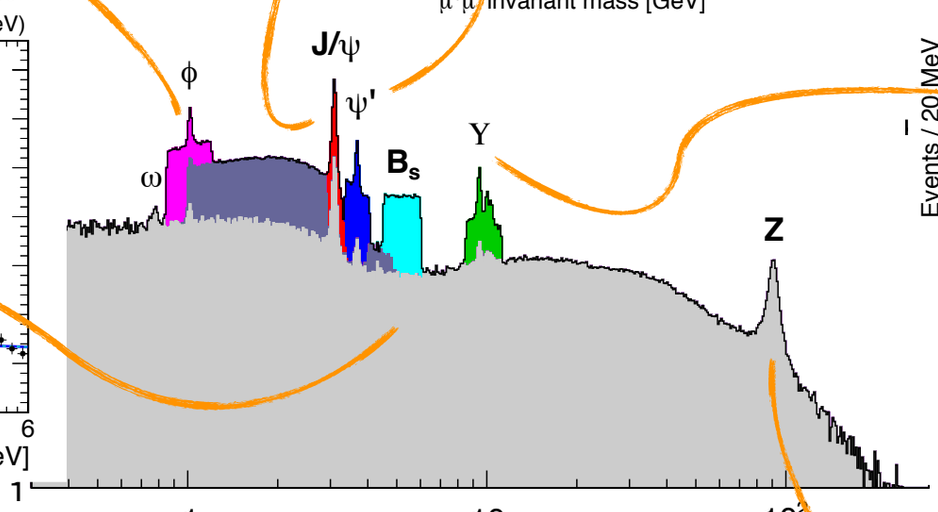
zooming in the bumps

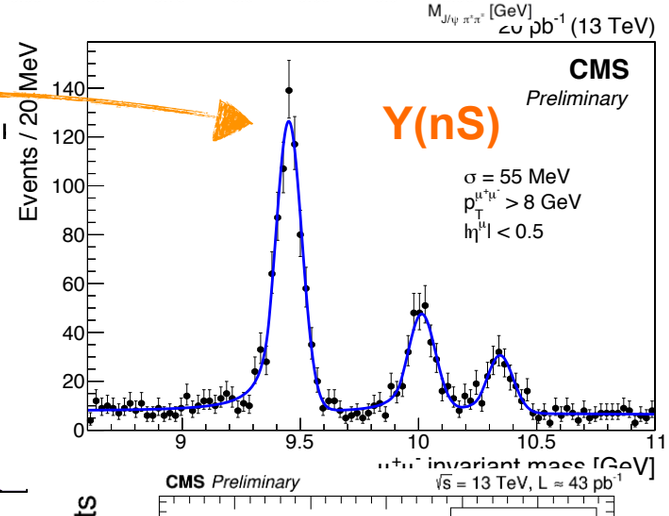


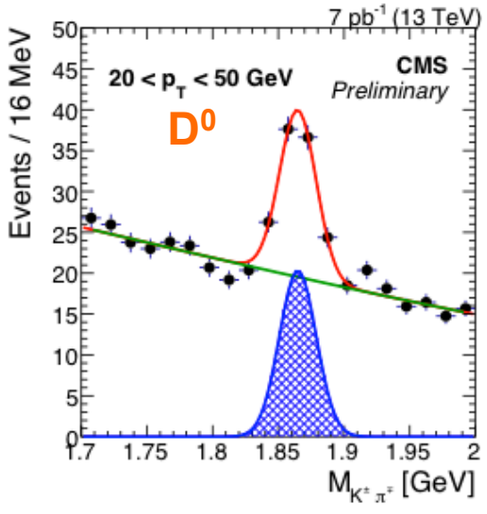


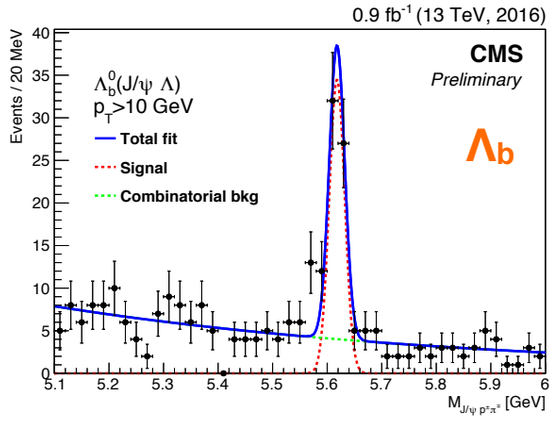


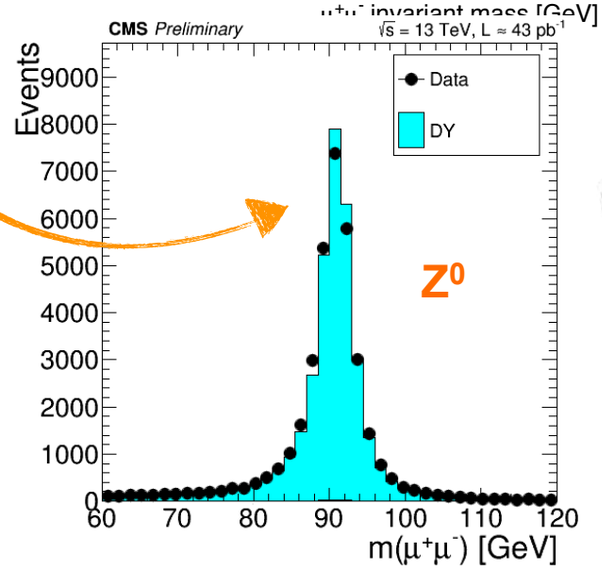












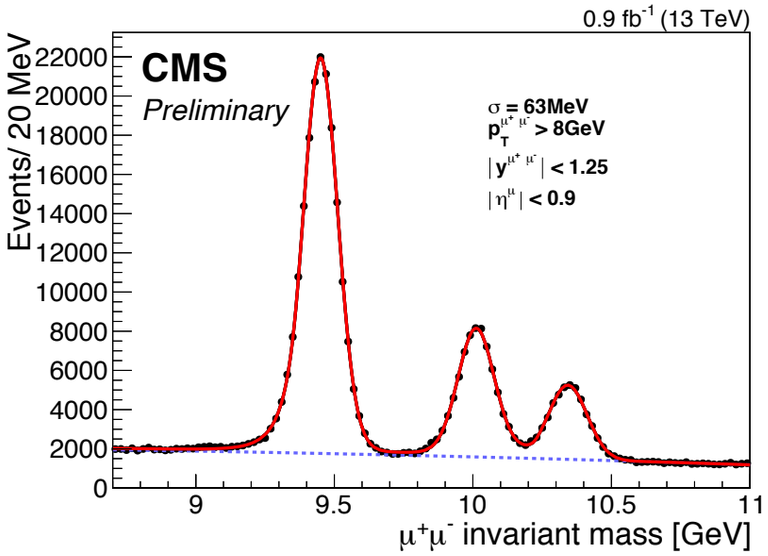
mesões

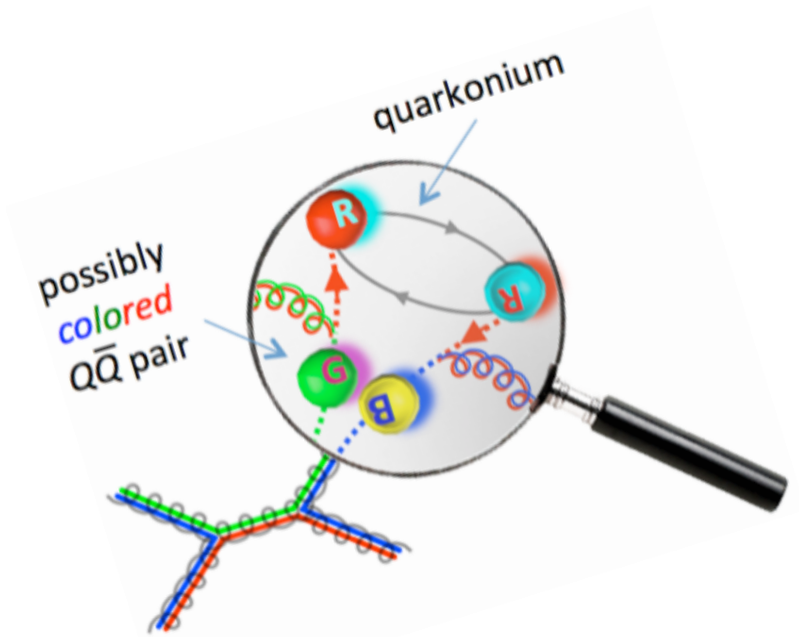
barião

bosão

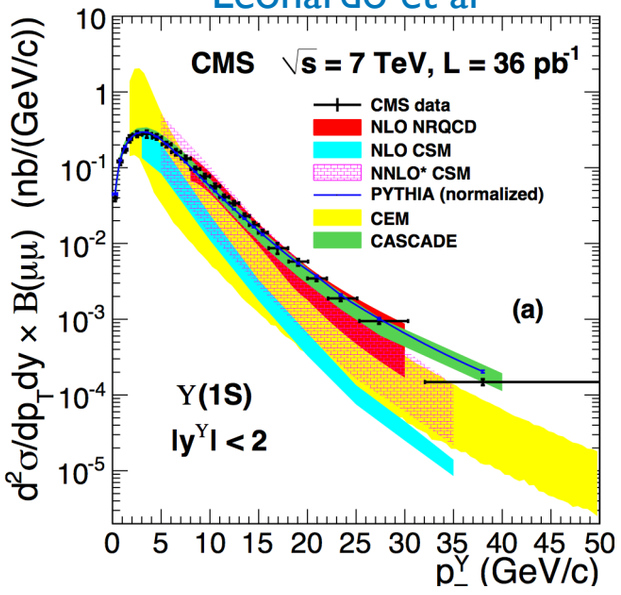
precision measurements (QCD)

heavy-quark hadrons provide an ideal lab for studying the QCD mechanisms of hadron production



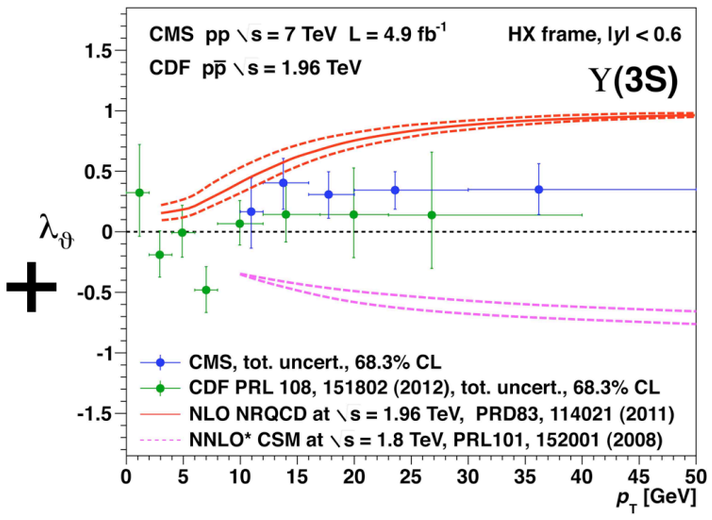


Leonardo et al



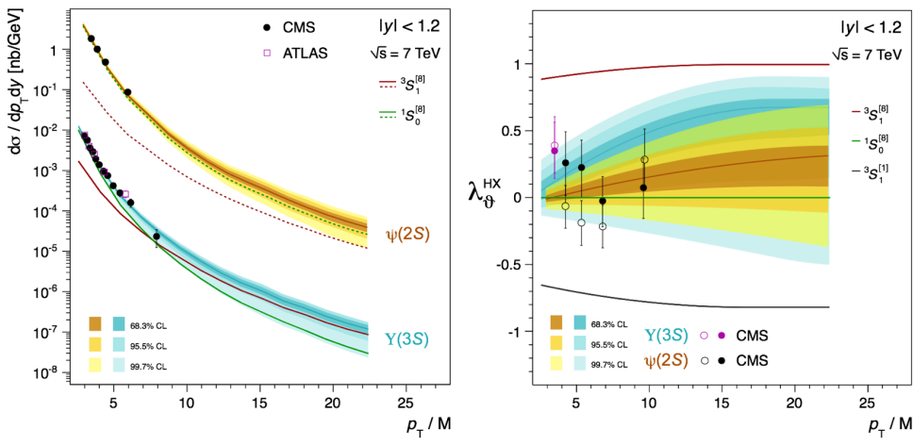
secção eficaz

Faccioli, Seixas et al



polarização

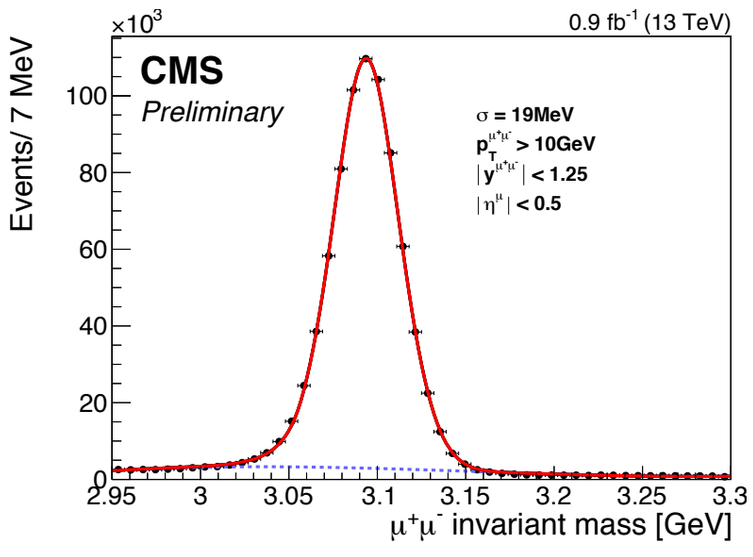
Faccioli, Seixas, Araújo et al

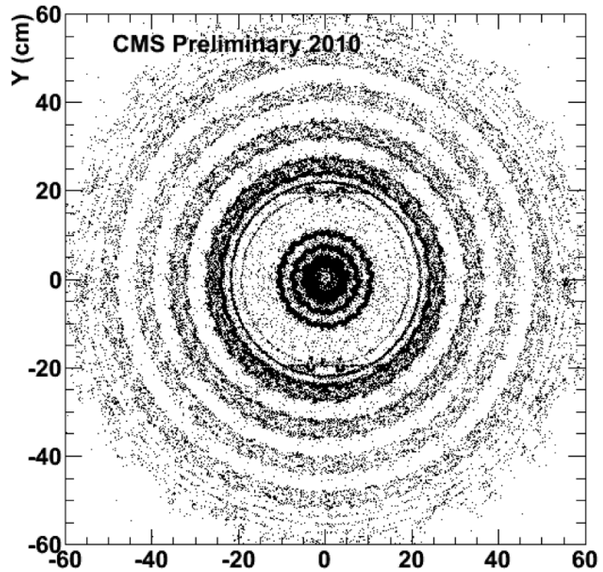


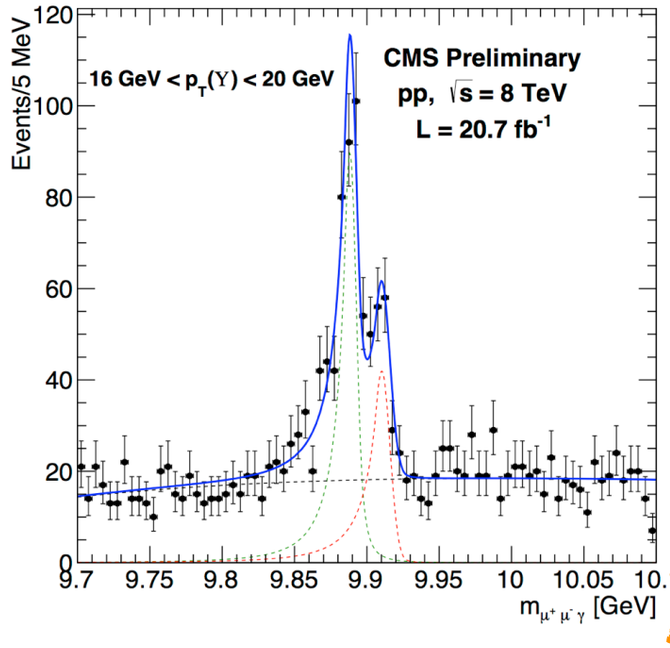
análise fenomenológica

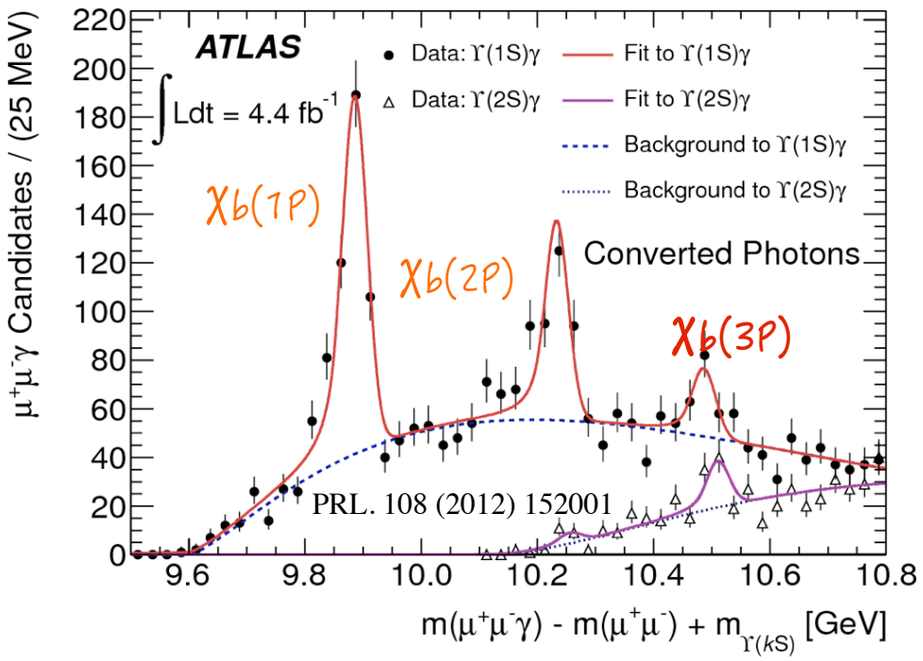
two muons and a photon

$\mu\mu$ (J/ψ) + Υ ($\rightarrow e^+e^-$) = χ_c ($\rightarrow J/\psi\gamma$)









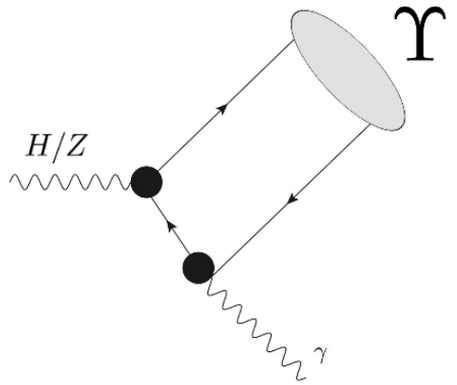
After having explored ψ and Υ in Run1,
in Run2 focus will now be on χ states,
in quest for solving "quarkonium puzzle"

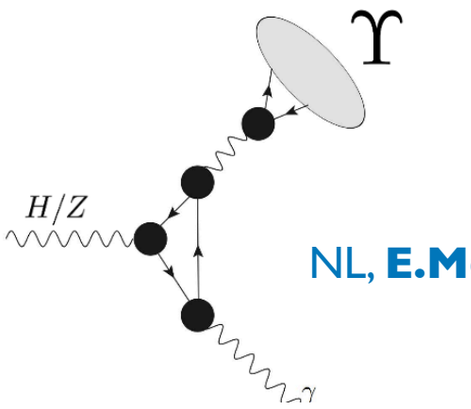
Same quarkonia + photon signature
allows to explore Z&H **rare decays**

Z,H→J/ψγ, Z,H→J/ψγ

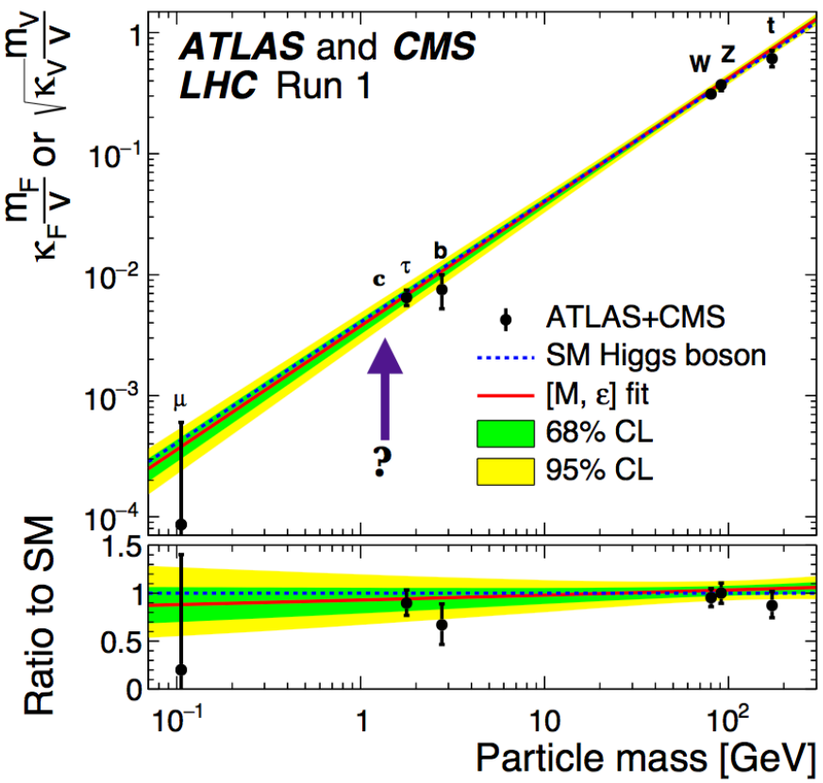
Higgs (and Z) rare decays

- rare processes in the SM (BR: 10^{-7}-10^{-9})
  - sensitive to NP
- allows to measure quark-Higgs couplings
  - alternative to H→qq (challenging due to QCD)
- Z provides experimental benchmark for the H decay
  - larger production cross section, nearby mass
- valuable tool for probing nature of quarkonium production
  - a topic LIP has been exploring through more abundant, inclusive processes

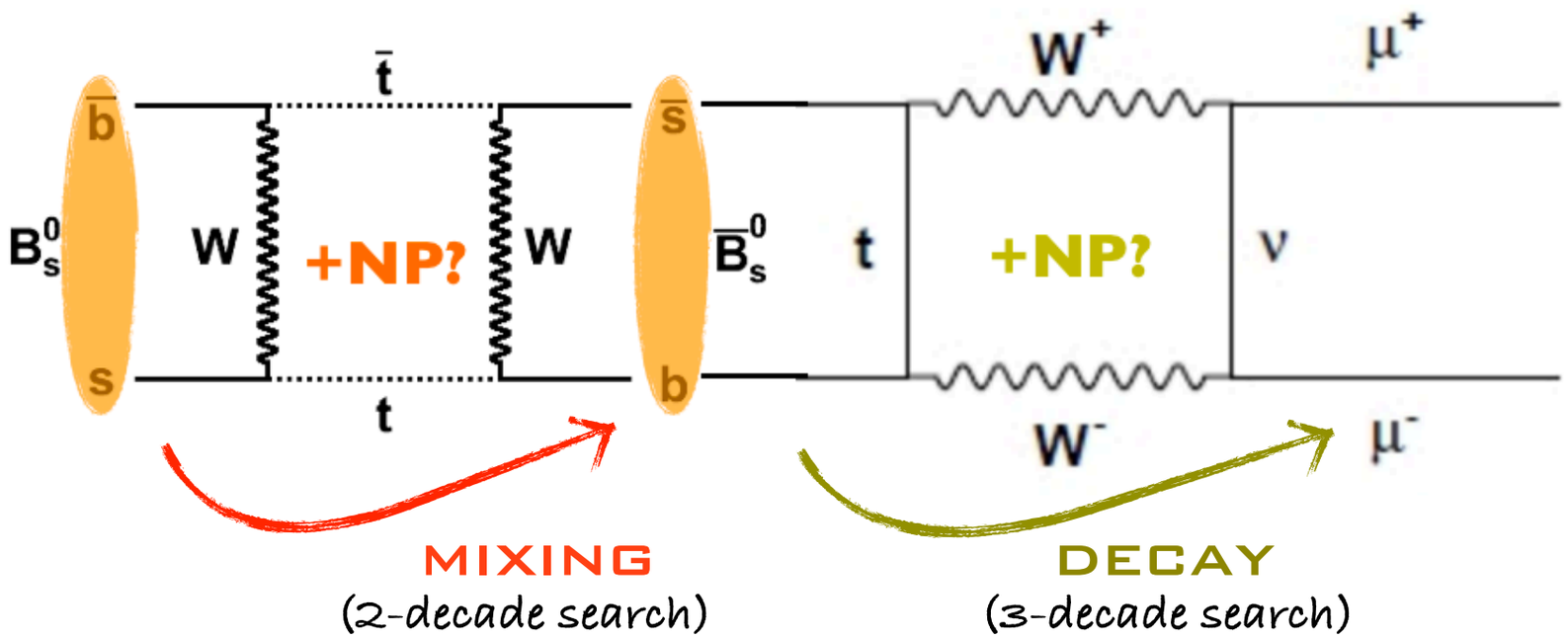


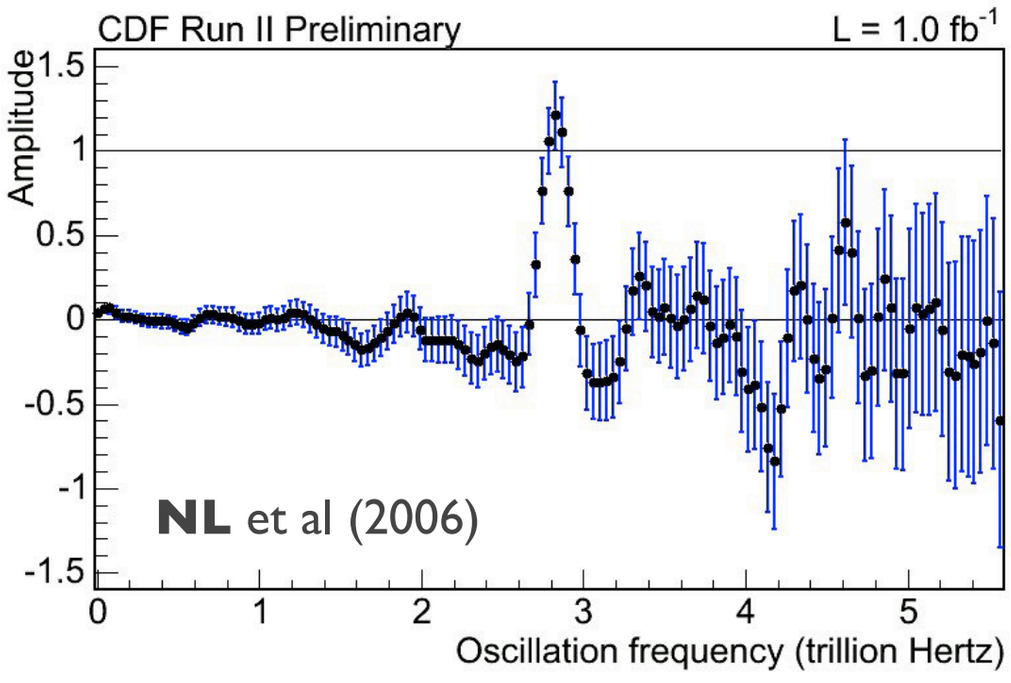


NL, **E.Melo**

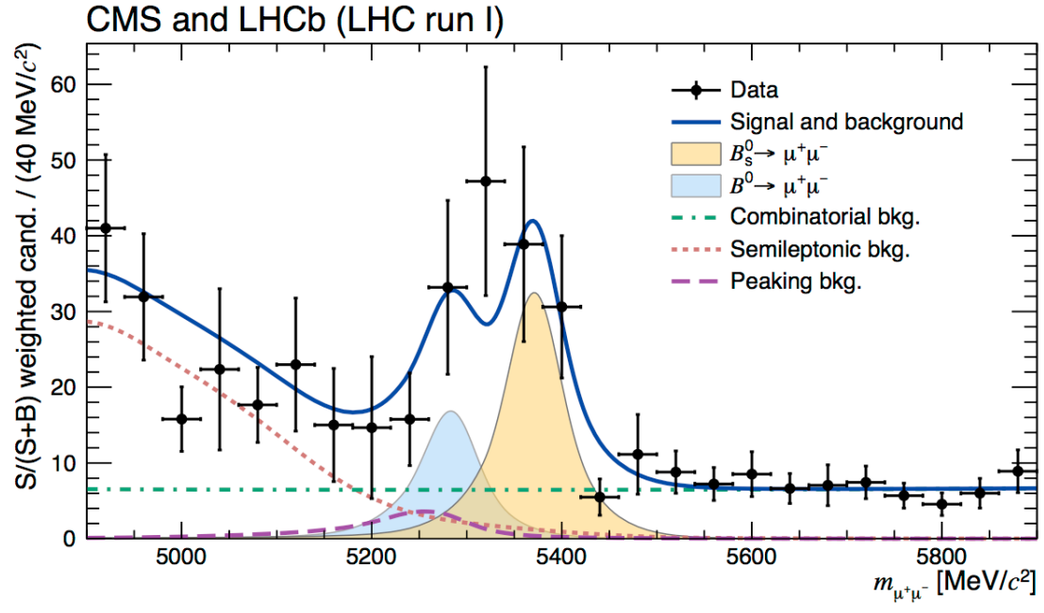


$B_s \to \mu\mu$ doubly-sensitive to NP





(1st) **Tevatron's Run2 flagship discovery**

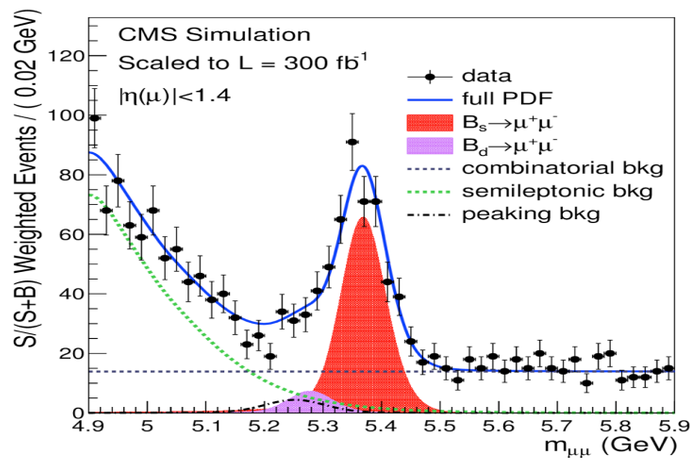


(2nd) **LHC's Run1 flagship discovery**

the B→μμ rare decays

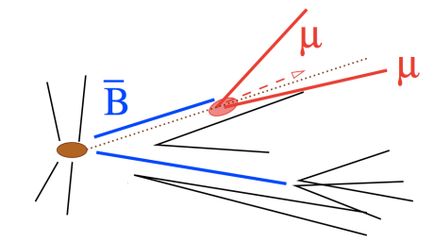
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+)$$

PhD thesis ongoing by **B.Galinhas**

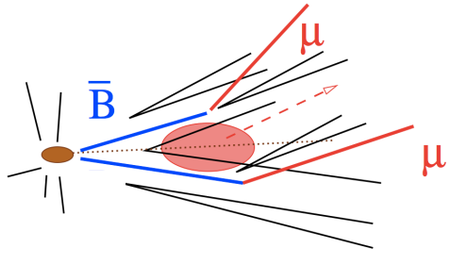


- 2015-2016 dataset
  - address **dominant systematic** source
- full Run2 dataset
  - explore **machine learning** method (DNN) for background rejection (focus on B^0)
  - explore additional observables with complementary sensitivity to NP (eg lifetime)

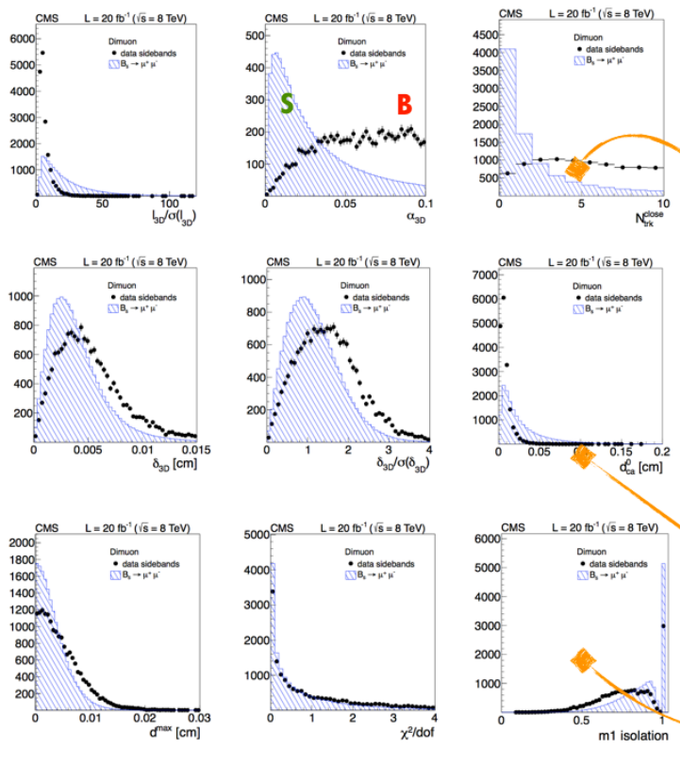
signal

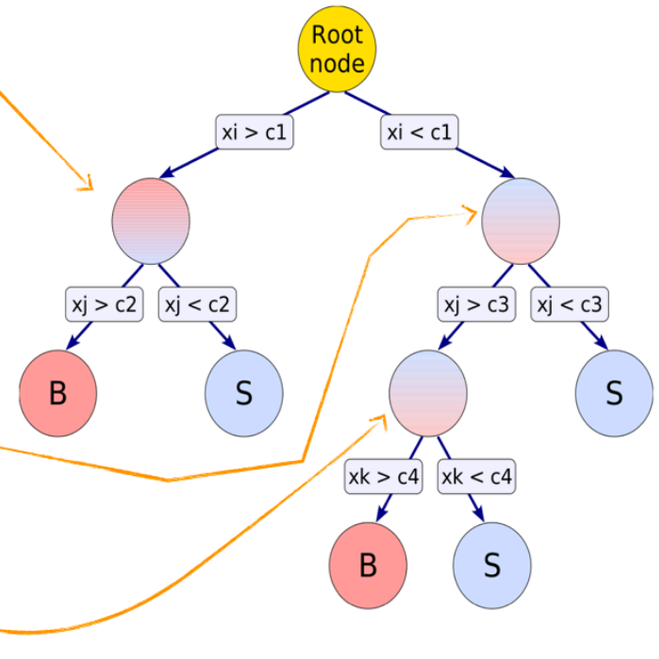


background



signal vs background discriminating variables





fragmentation fraction ratios

- the f_d/f_s ratio can be determined as

MSc thesis ongoing by **B.Alves**

$$\frac{f_s}{f_d} = \frac{N_{B_s}}{N_{B^0}} \frac{\mathcal{B}(B^0 \to J/\psi\, K^{0*})\, \mathcal{B}(K^{0*} \to K\pi)}{\mathcal{B}(B_s \to J/\psi\, \phi)\, \mathcal{B}(\phi \to KK)} \frac{\epsilon_{B^0}}{\epsilon_{B_s}}$$

Ratio of signal yields

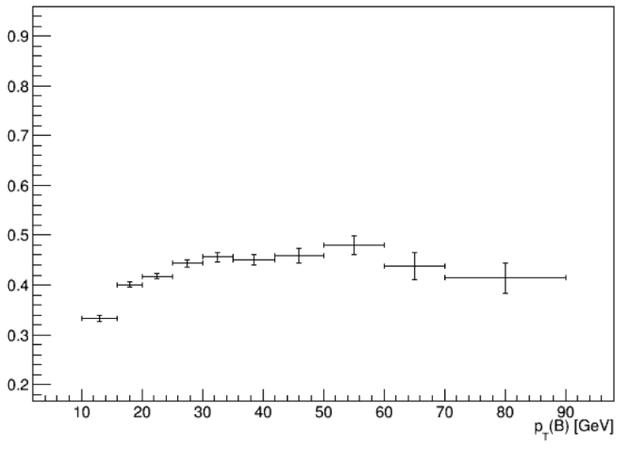
Ratio of branching fractions

(taken from PDG)

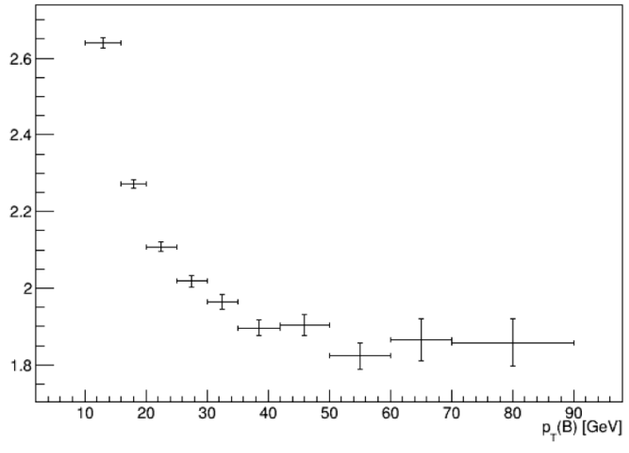
Ratio of efficiencies

from the data

from simulation



x



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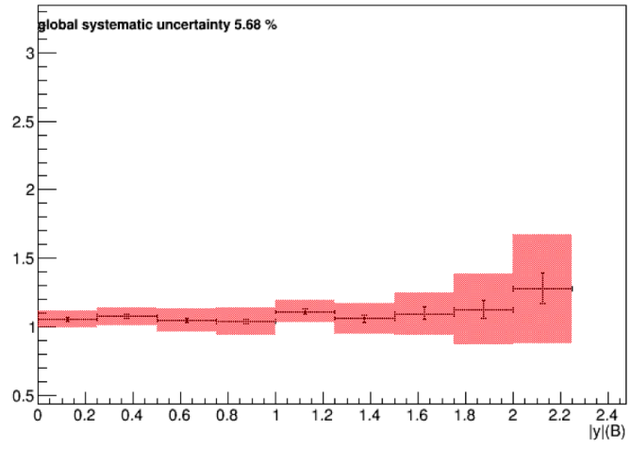
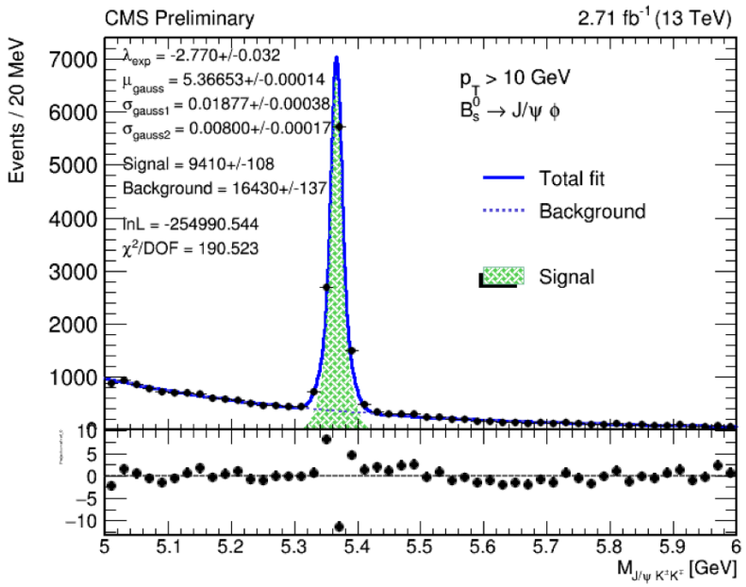
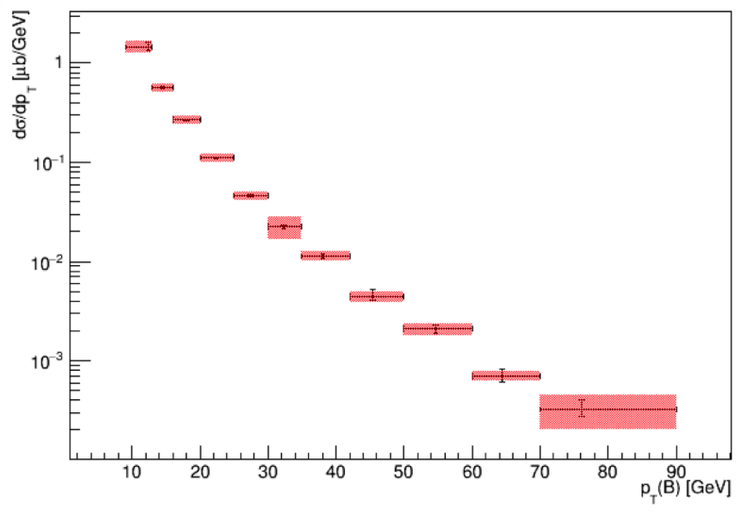


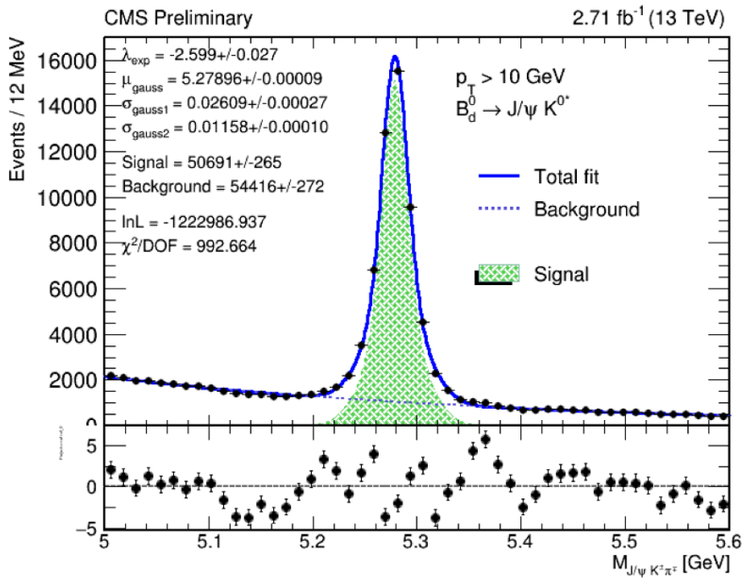
cross sections: B_s^0 and B^0 @13TeV

J.Melo, J.Silva
internship 2016: 2015 data

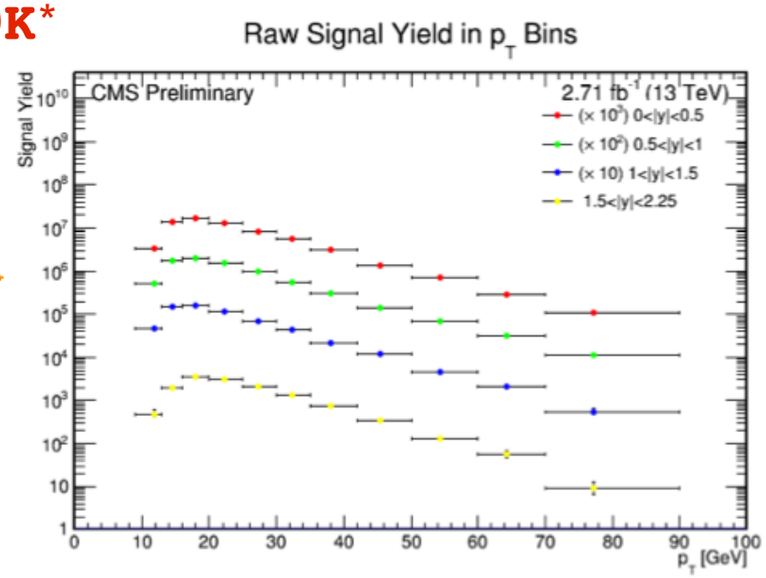


$B_s \to J/\psi\Phi$





$B^0 \to J/\psi K^*$



early Run2 data (2015)

- selection optimization

- data-MC validation
  with sideband subtraction

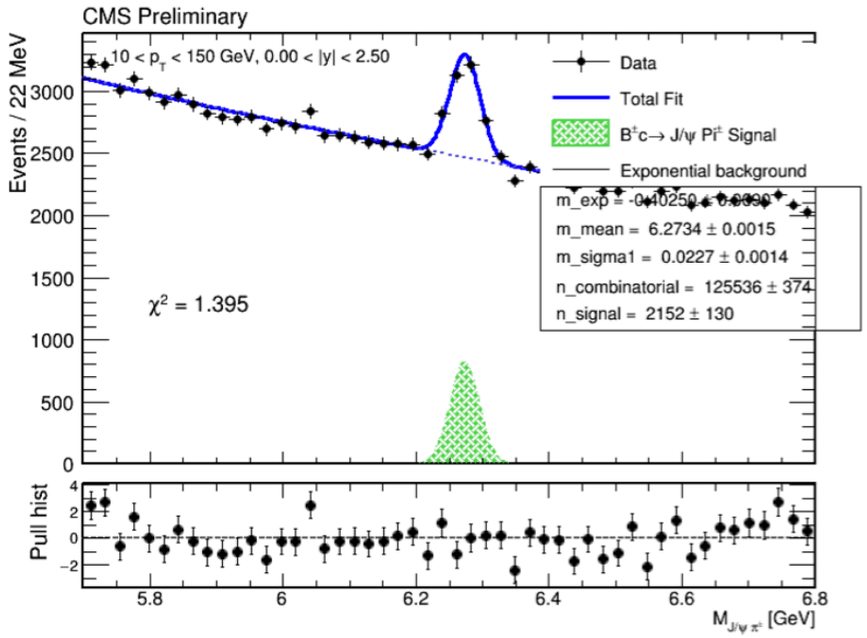
- yield extraction
  and systematics

- fit validation
  with pseudo experiments

➠ delivered first production measurement at 13 TeV with Bs and B0

cross sections: B_c^+ and B^+ @13TeV

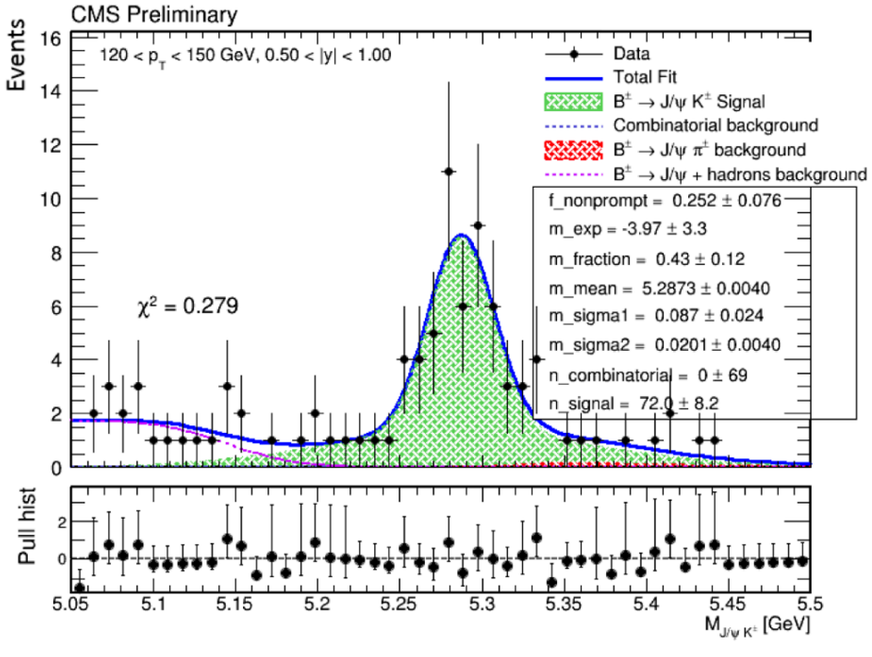
G.Ghillardi, B.Alves
internship 2017: 2016 data



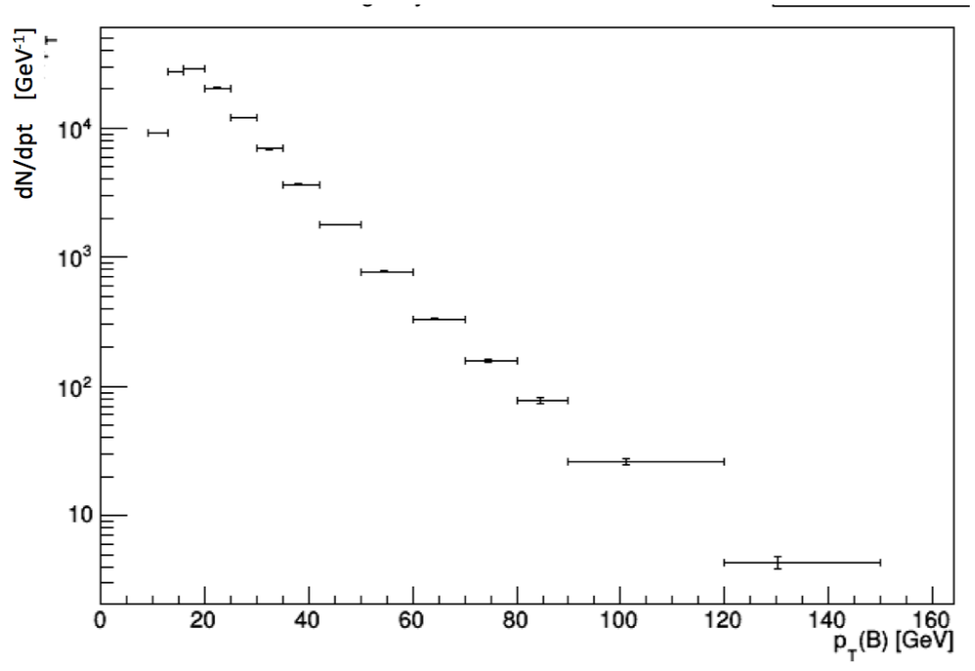
$B_c \to J/\psi\pi$

processed the 2016 dataset
- ported analysis code to new CMS software release
- access and process the data using the global GRID infrastructure
- generated and processed MC simulation

➠ obtained first Bc analysis in Run2



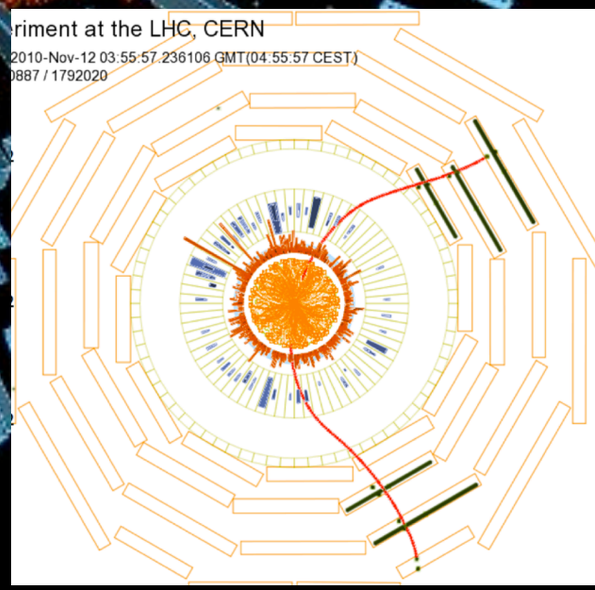
$B^+ \to J/\psi K^+$



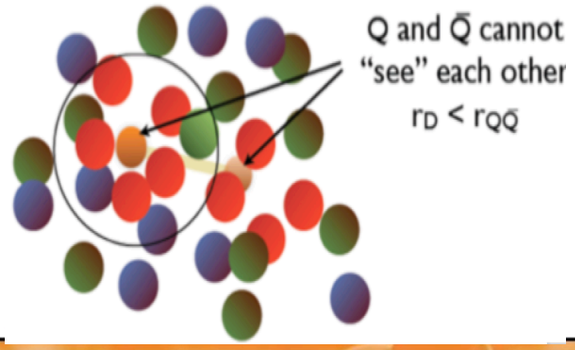
CMS Experiment at the LHC, CERN

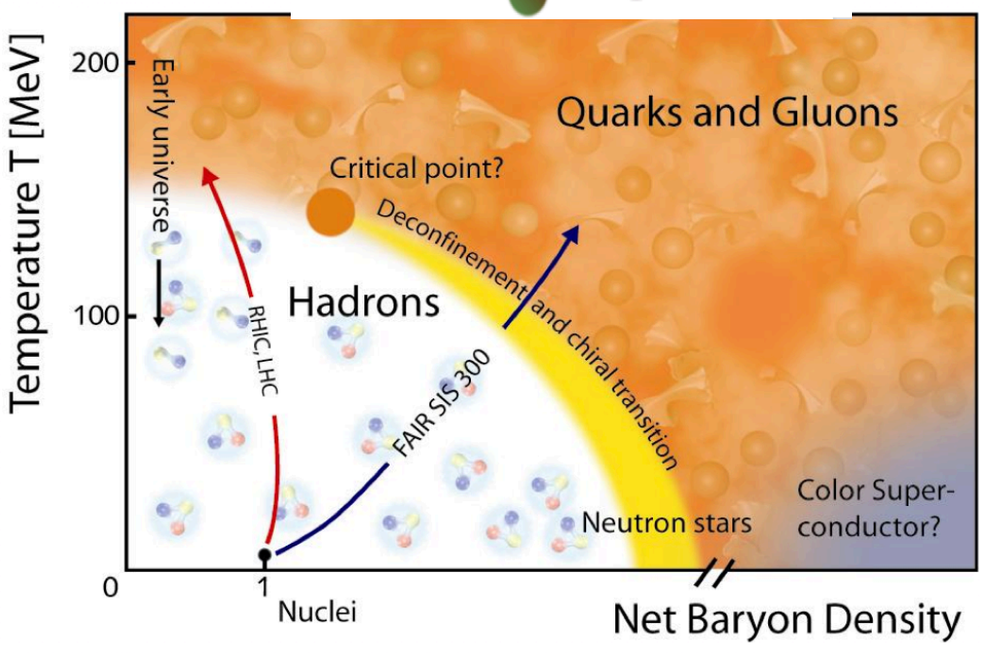
lões!

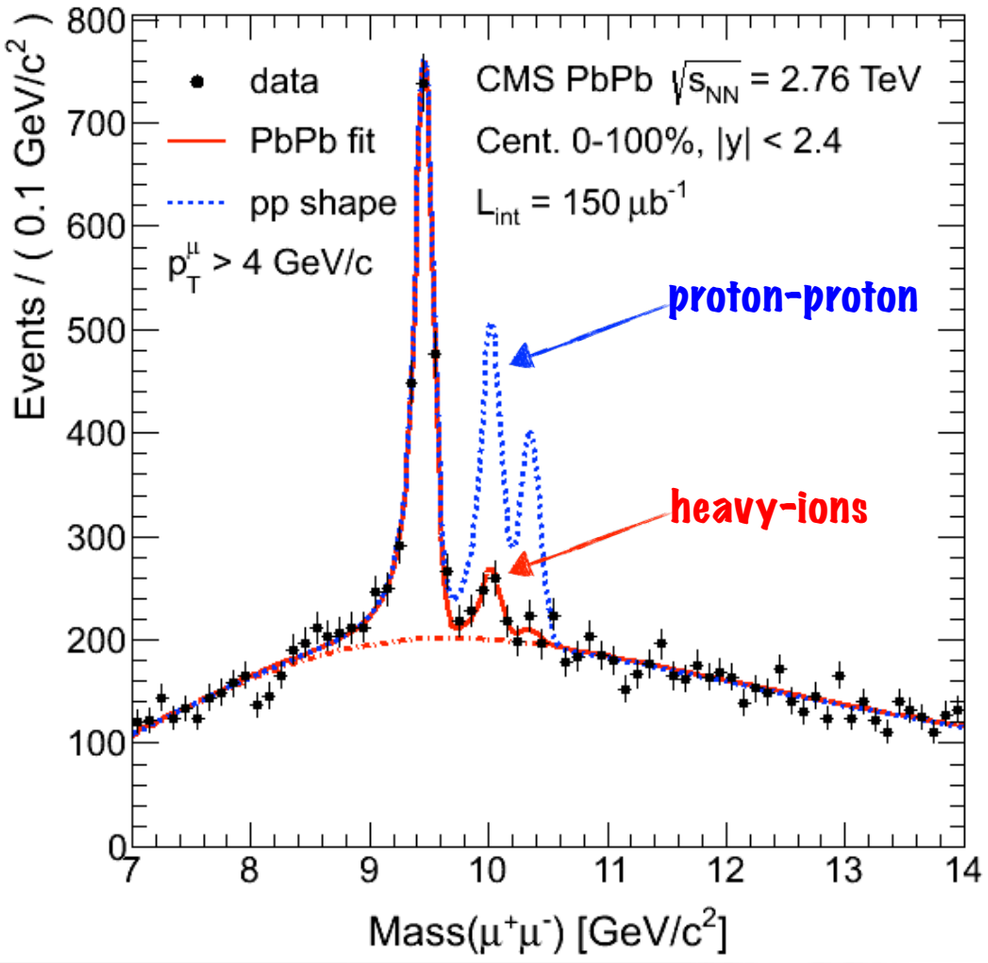
Data recorded: 2010-Nov-14 18:37:44.420271 GMT(19:37:44 CEST)
Run / Event: 151076 / 1405388

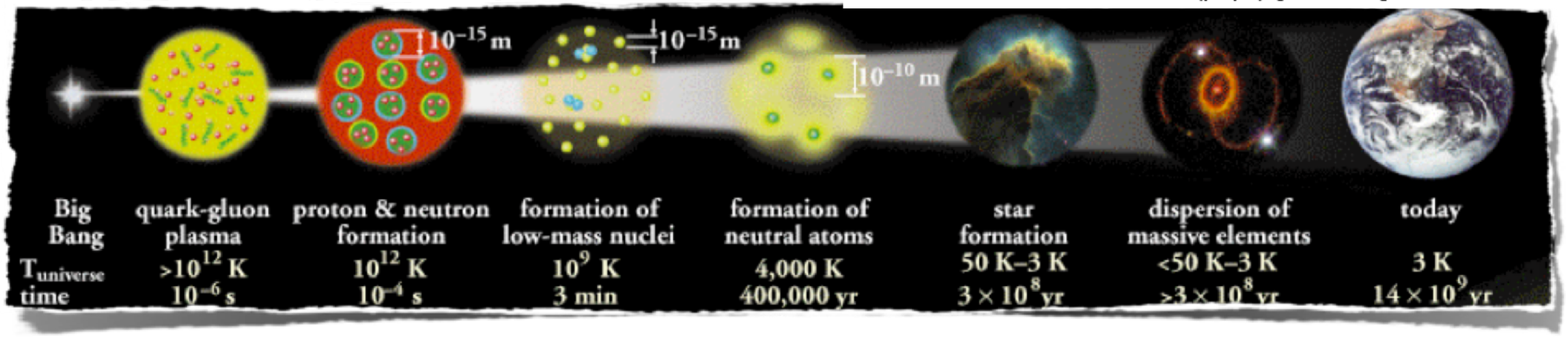


hot soup of quarks and gluons

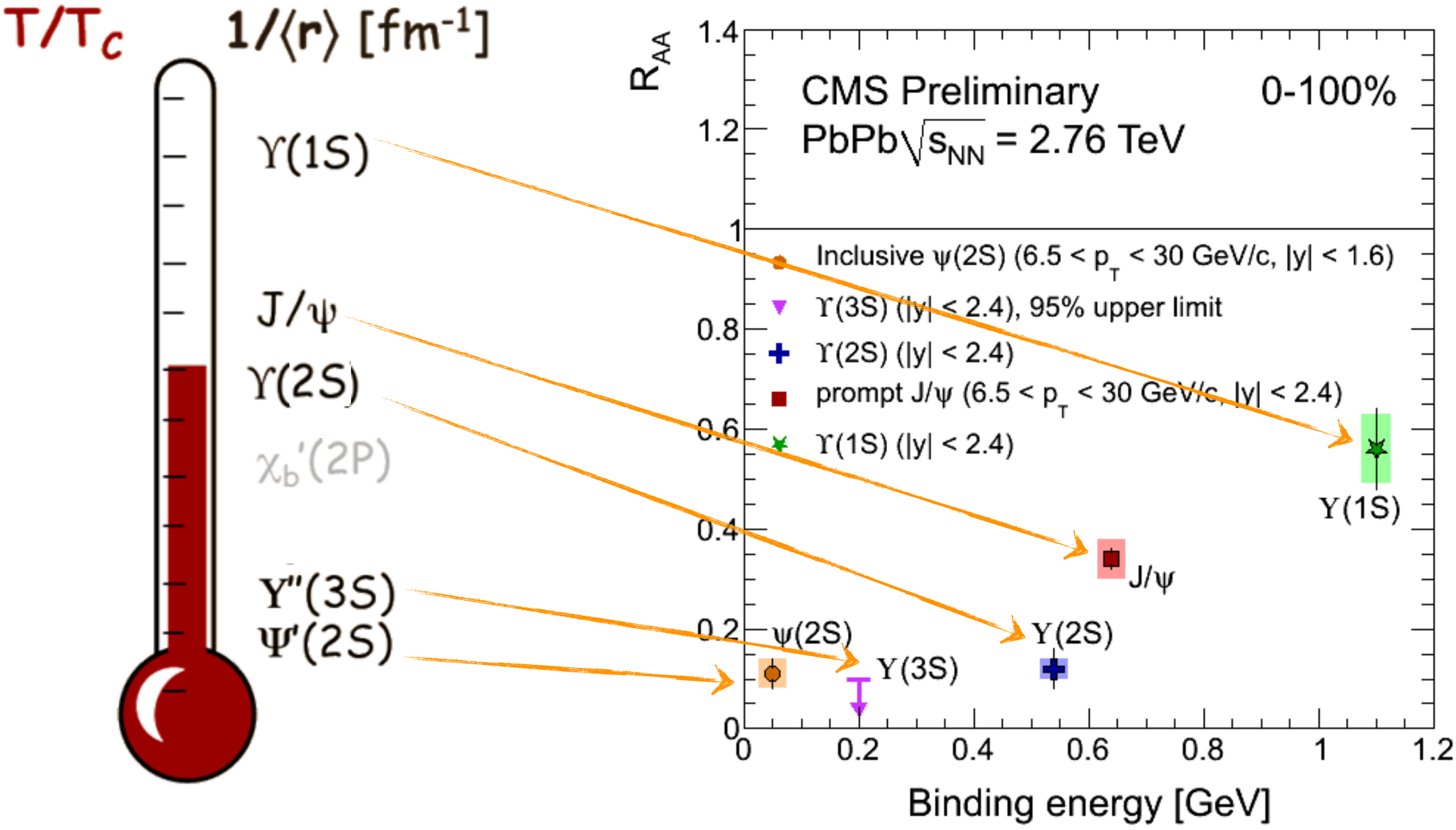








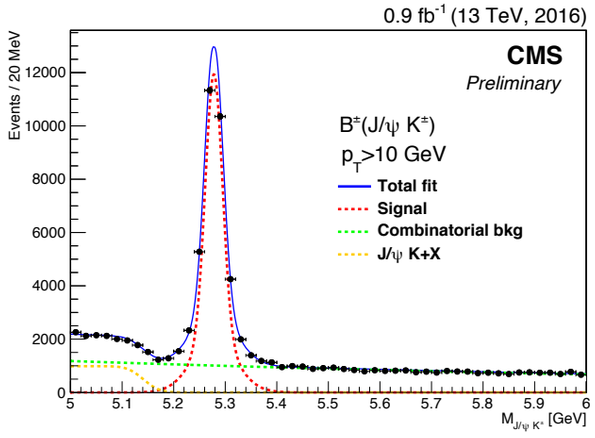
QGP: sequential meson melting



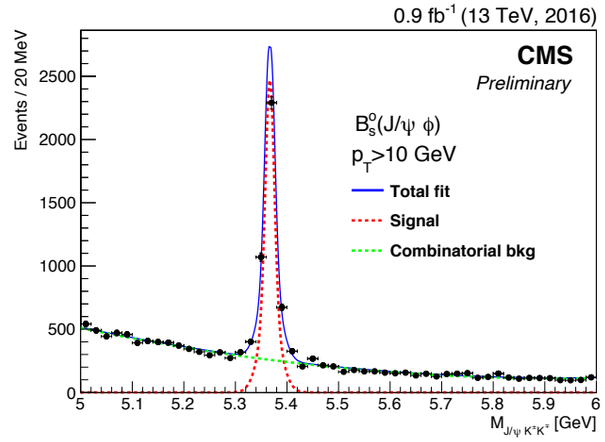
the least tightly bound states are the most suppressed in the hot medium

Novel QGP probes: B mesons !

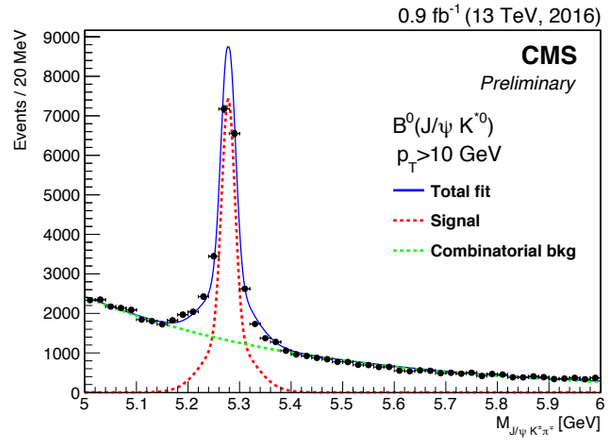
PP



B^+

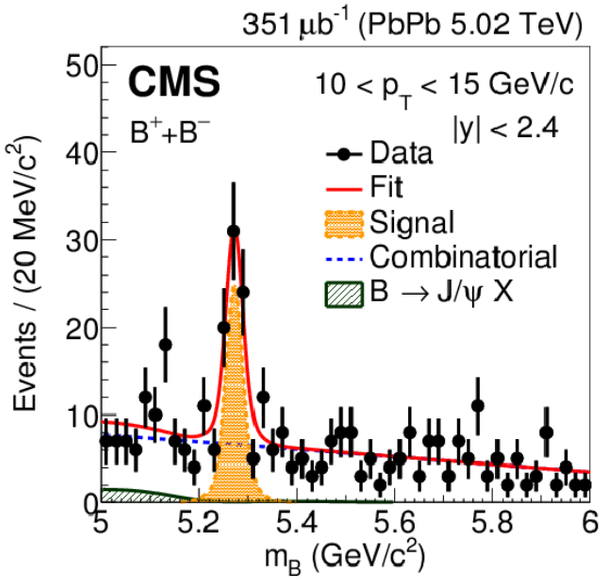


B^0



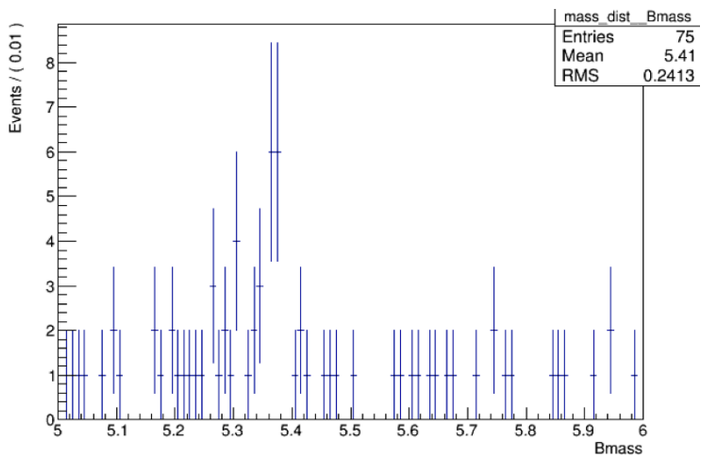
B_s

HEAVY -ION



?

J.Silva, internship 2017

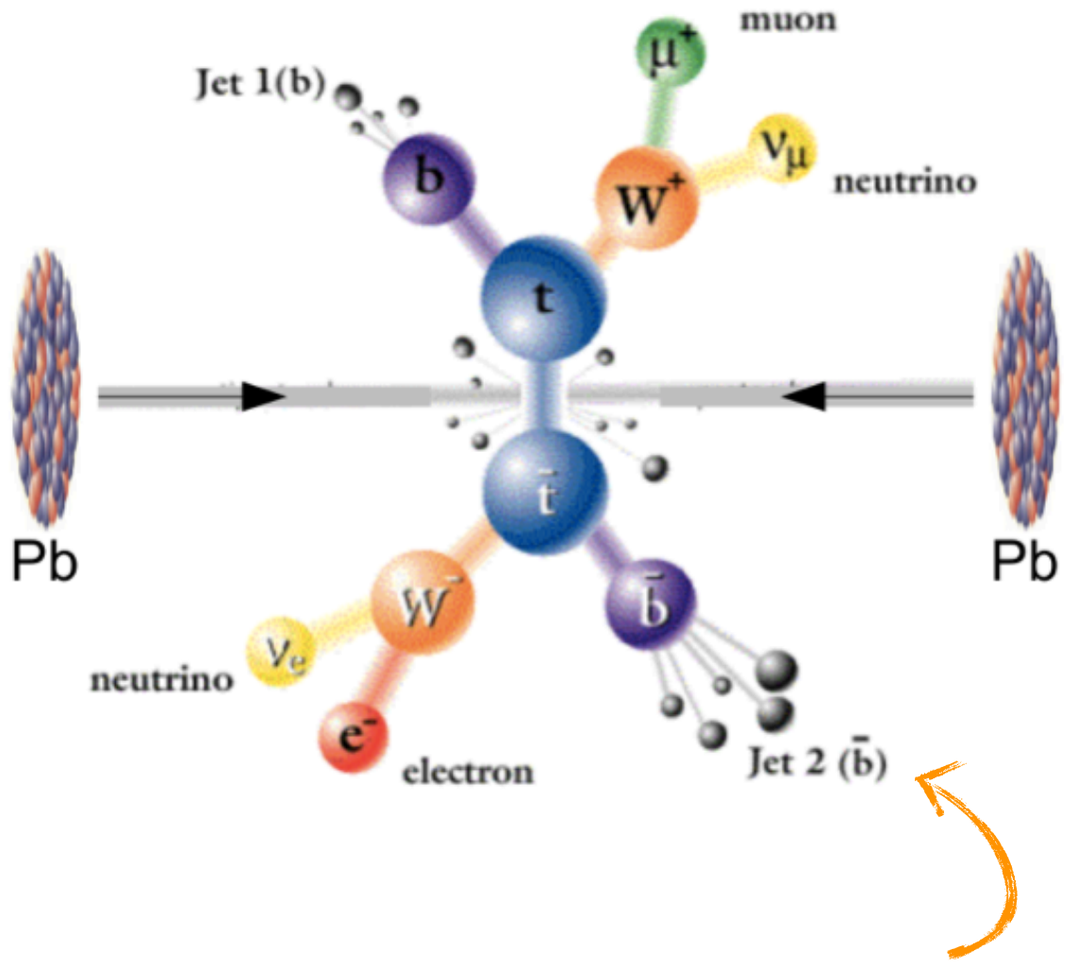


B mesons are found in heavy ion collisions for the 1st time!

➡ probe the flavor dependence of energy loss in the QGP

Novel QGP probes: top quarks ?

- continue to "re-discover" the Standard Model in heavy-ions
  - quarkonia, jets, b-jets, W,Z, B, and... (why not) the top quark
  - ie search for PbPb→$t\bar{t}$
- study a "bare quark" in the hot medium
  - access earliest timescales in the collision
  - the top decays before thermalization of the medium



- challenge: improve b-quark jet tagging in PbPb environment

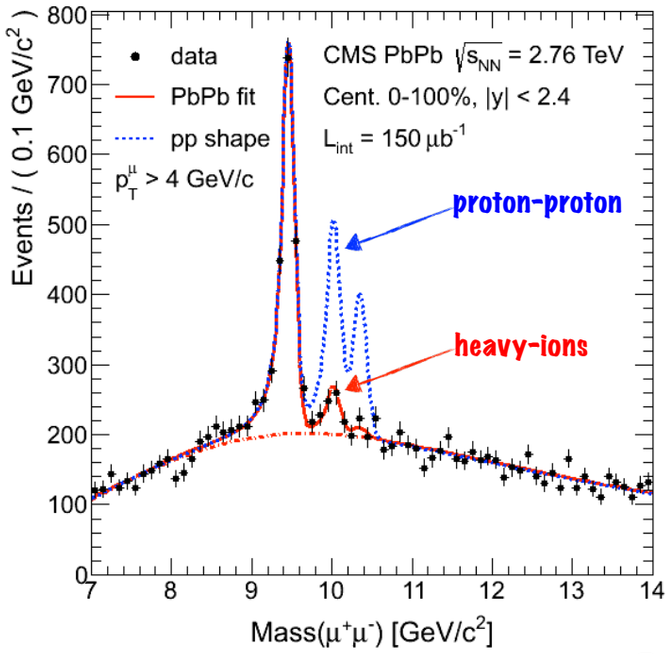
P.Silva & J.Barata, L.Lisboa (**MEFT,** Summer'16)

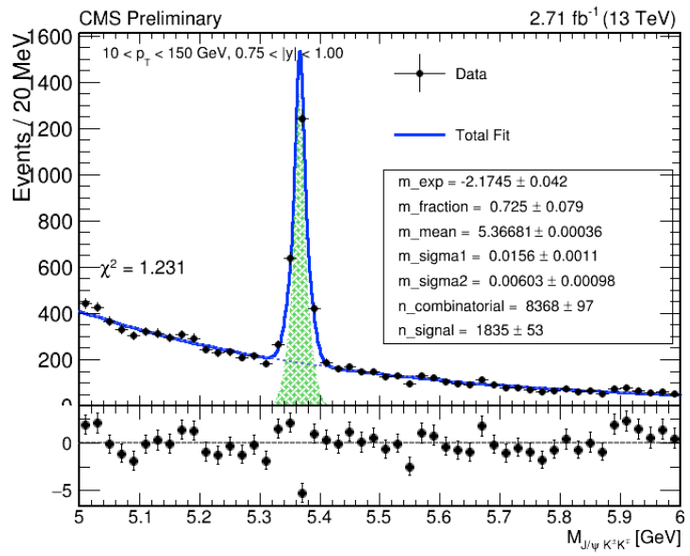
constraining the theory

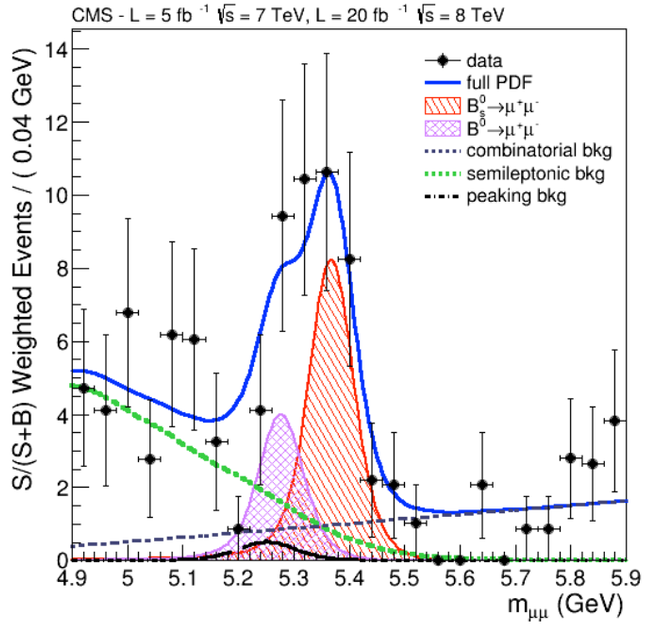
Standard Model & Beyond

SU(3) ⊗ SU(2) ⊗ U(1) ⊗ ...

strong sector | electroweak sector | new sector







so, this seems interesting and I want to learn more, what should I do?

You are invited to
join us over the Summer!

You will be integrated in a project,
learn about our research
and make a real contribution

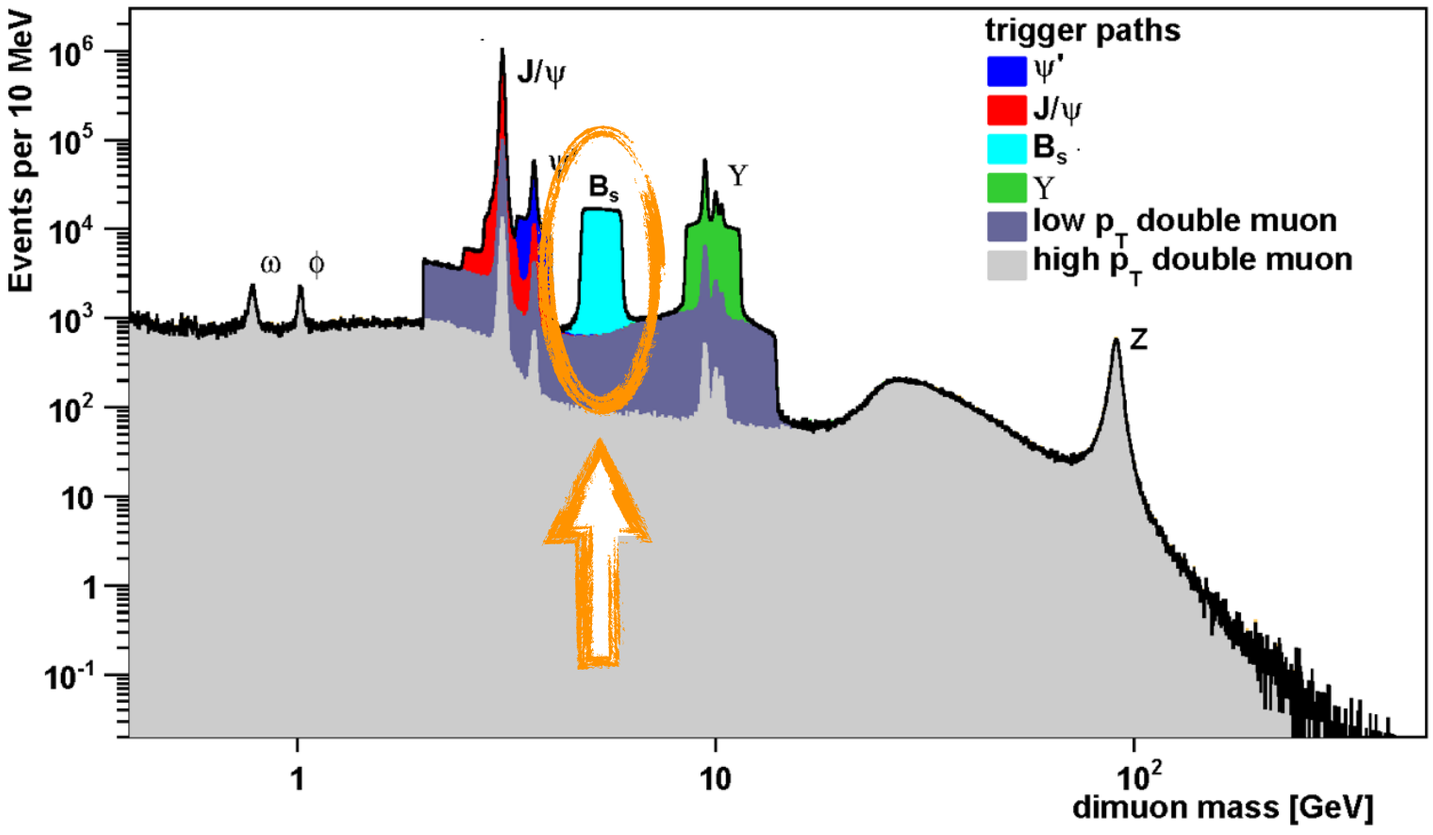
LIP Summer program runs mid-July thru mid-September

DROP US AN E-MAIL: NUNO@CERN.CH

Backup

searching for an ultra-rare decay: $B \rightarrow \mu\mu$

1. ONLINE SELECTION (TRIGGER)



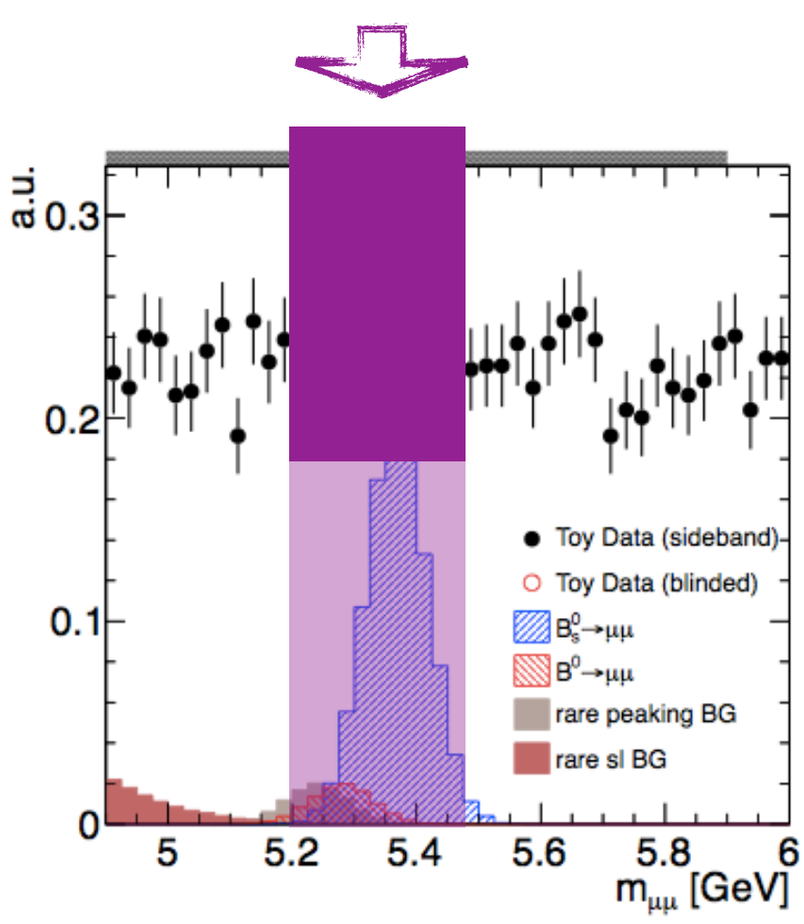
Dimuon Trigger

- L1 Hardware Trigger
  - p_T>3 GeV (few kHz)
- HLT Full tracking and vertexing
- HLT $B_s \rightarrow \mu\mu$
  - Leading and sub-leading μ p_T>3,4 (4,4) GeV $|\eta_{\mu\mu}|$<1.8 (1.8<$|\eta_{\mu\mu}|$<2.2)
  - p_T (μμ)>5 (4.8-6) GeV
  - 4.8 <m(μμ)< 6.0 GeV
  - P(χ^2/dof) >0.5%

searching for an ultra-rare decay: $B \to \mu\mu$

1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)

SIGNAL REGION BLINDED

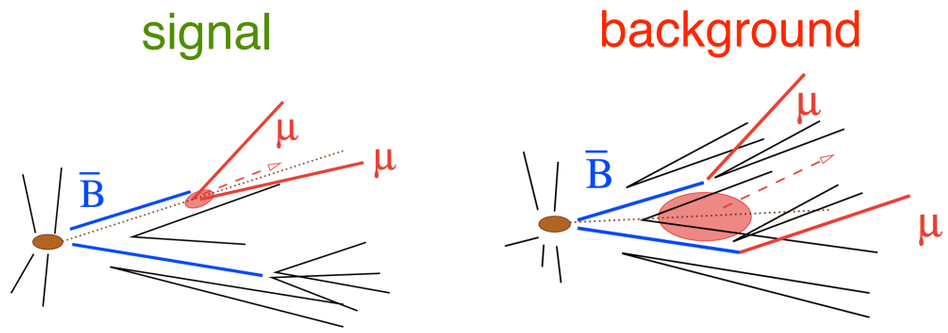


analysis procedure and event selection developed without inspecting the data in region where signal is expected

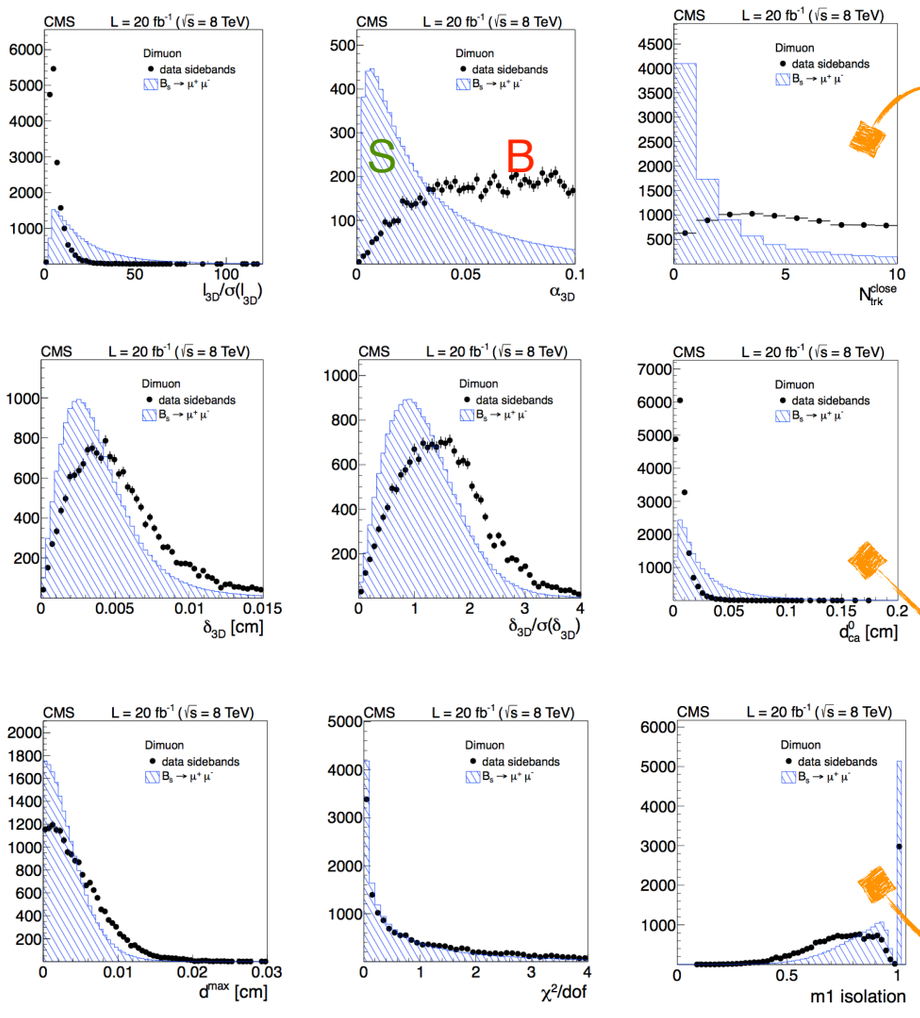
"box opening" only later, at final analysis stages

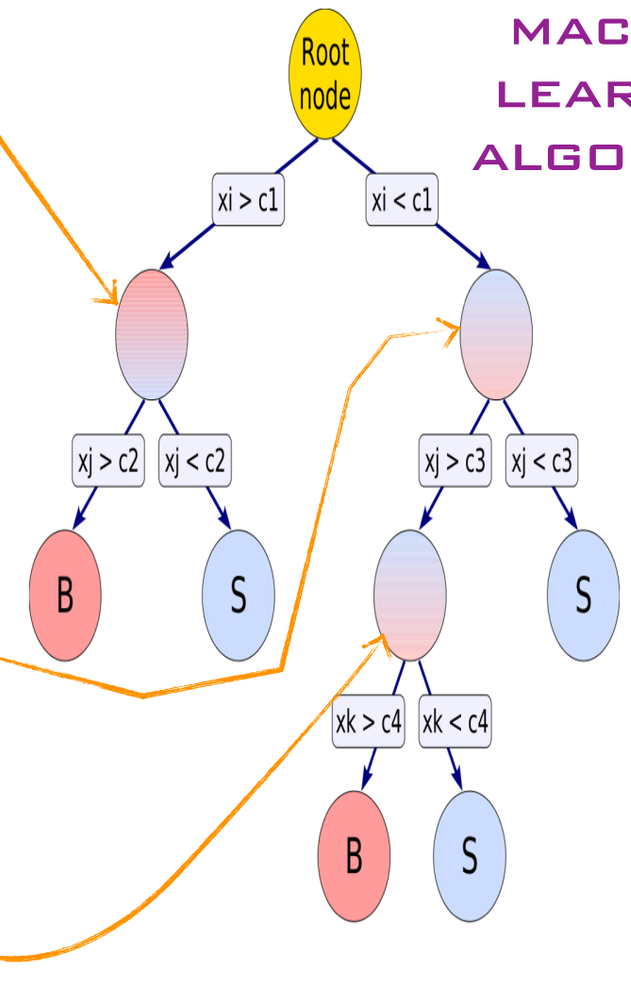
searching for an ultra-rare decay: $B \to \mu\mu$

1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)
3. MULTIVARIATE SELECTION

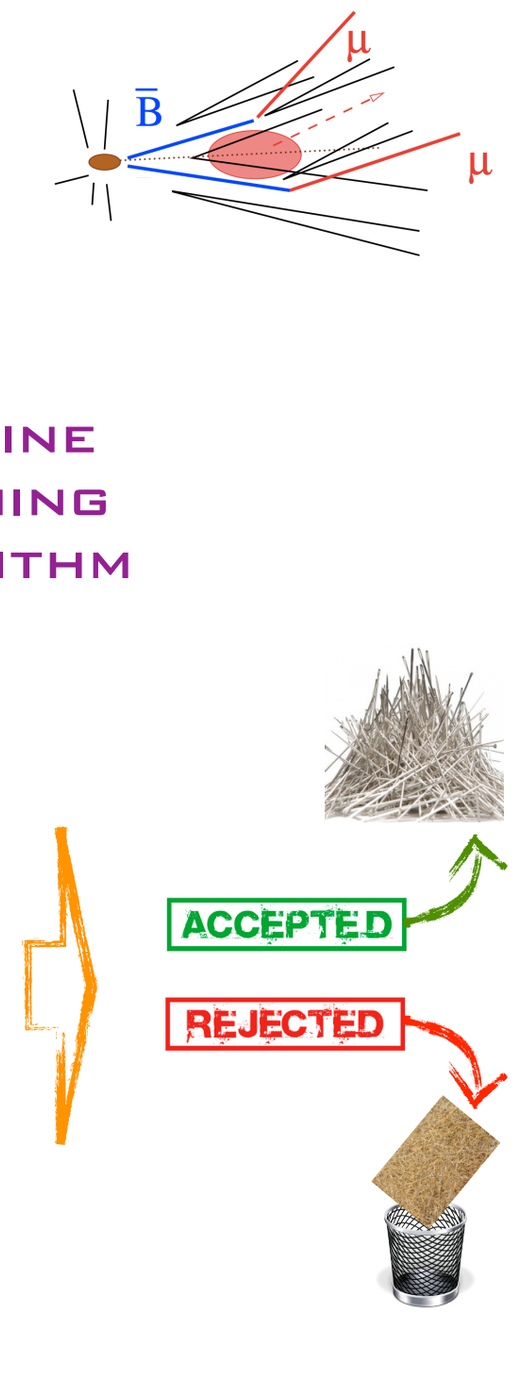


signal vs background discriminating variables





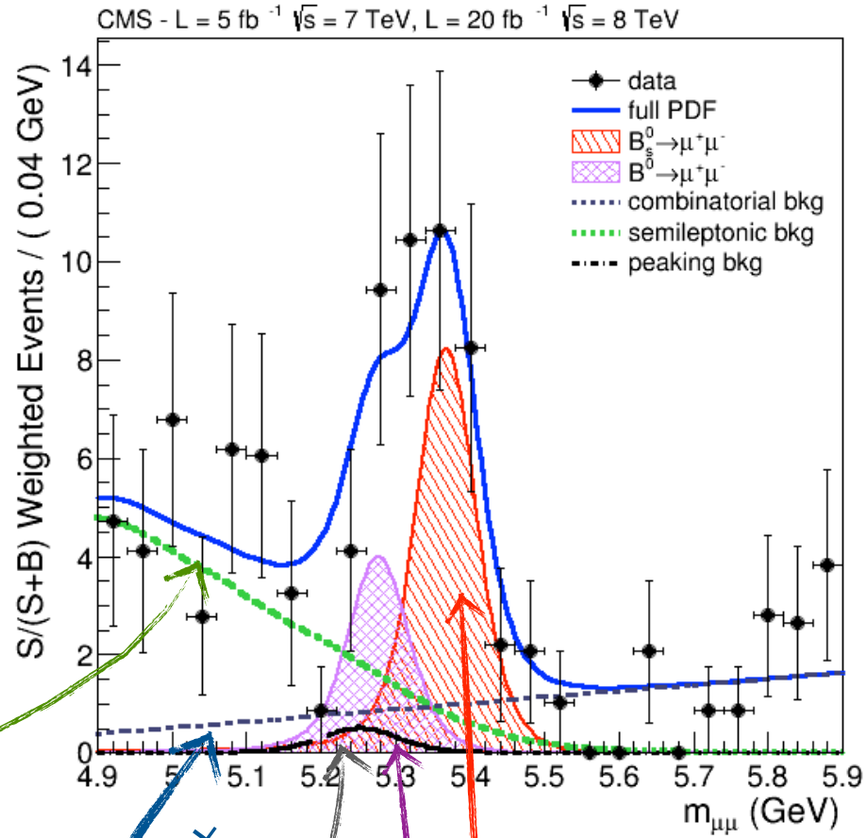
MACHINE LEARNING ALGORITHM

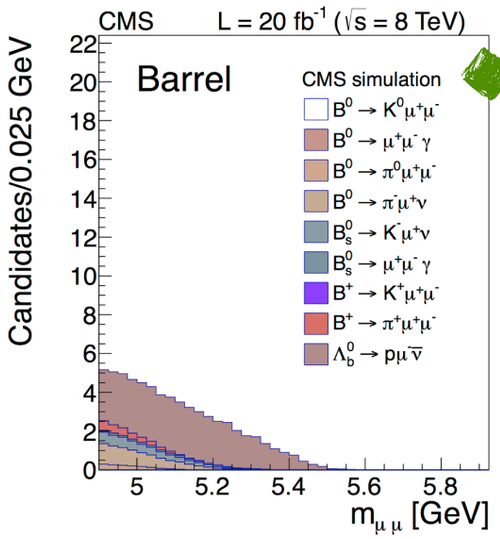


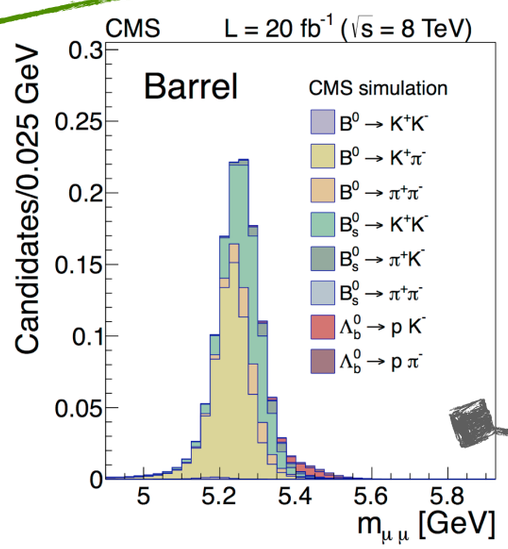
searching for an ultra-rare decay: B→μμ

1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)
3. MULTIVARIATE SELECTION
4. FIT THE DATA (LIKELIHOOD)

Fit the data accounting for the various signal and background components







SEMILEPTONIC BKG

COMBINATORIAL BKG

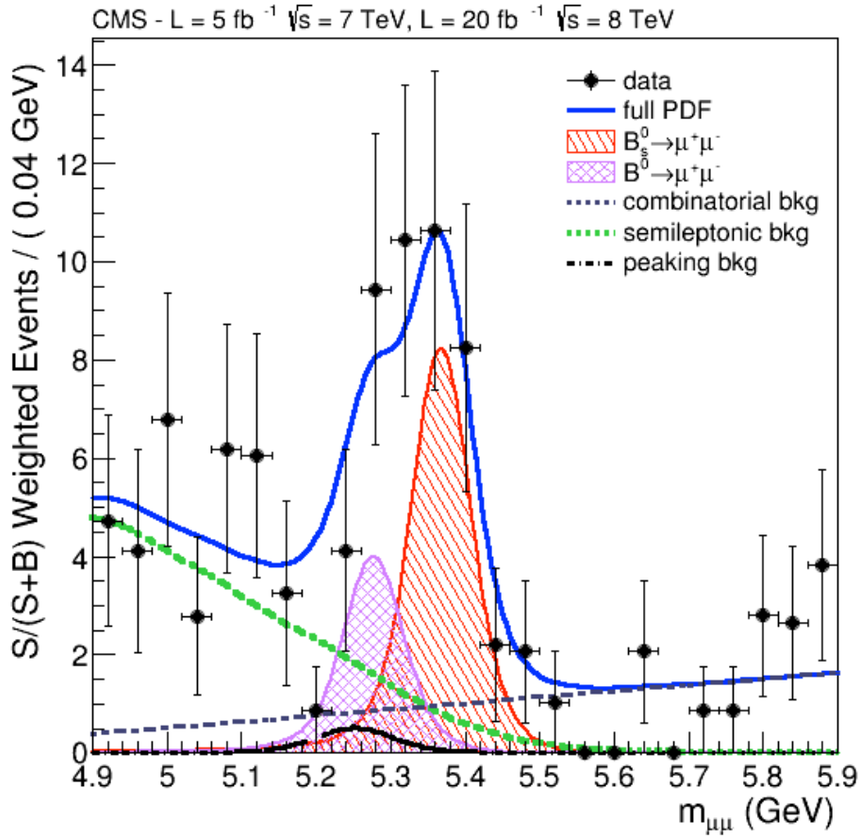
PEAKING BKG

SIGNAL 1: $B_S \to MM$

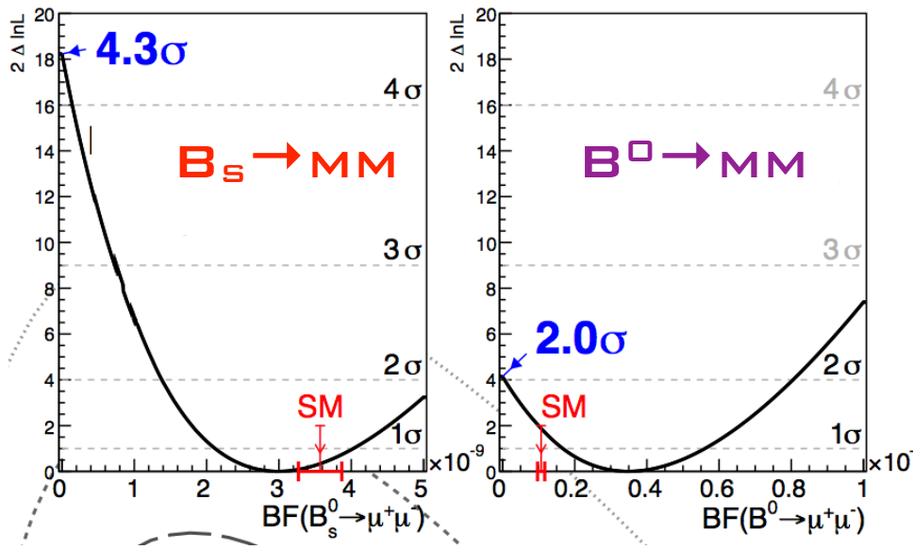
SIGNAL 2: $B^0 \to MM$

searching for an ultra-rare decay: $B \to \mu\mu$

1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)
3. MULTIVARIATE SELECTION
4. FIT THE DATA (LIKELIHOOD)
5. STATISTICAL SIGNIFICANCE

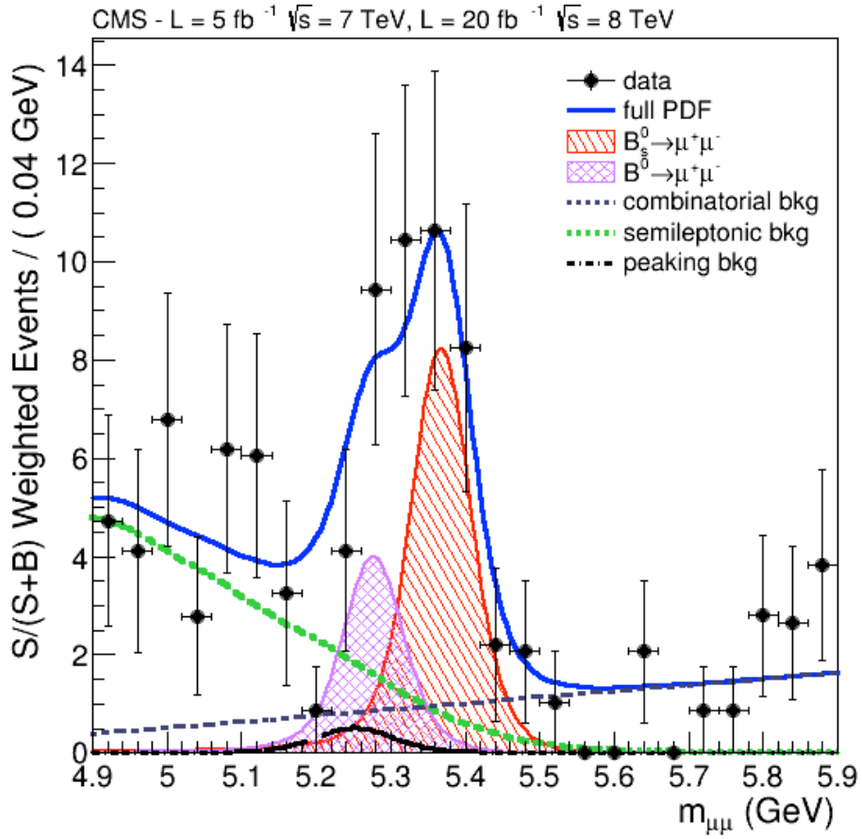


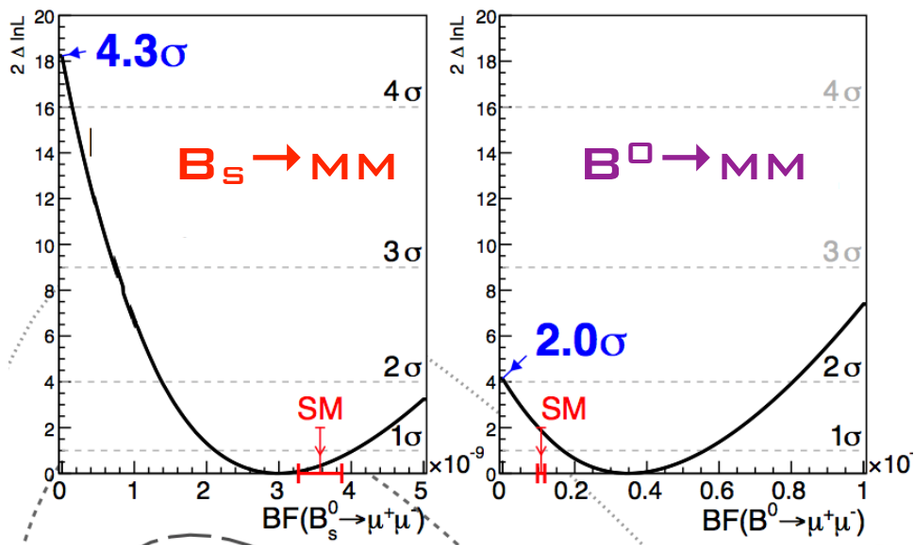
is the observed excess a genuine signal, or just a fluctuation of the background?



searching for an ultra-rare decay: $B \to \mu\mu$

1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)
3. MULTIVARIATE SELECTION
4. FIT THE DATA (LIKELIHOOD)
5. STATISTICAL SIGNIFICANCE
6. EXTRACT MEASUREMENT

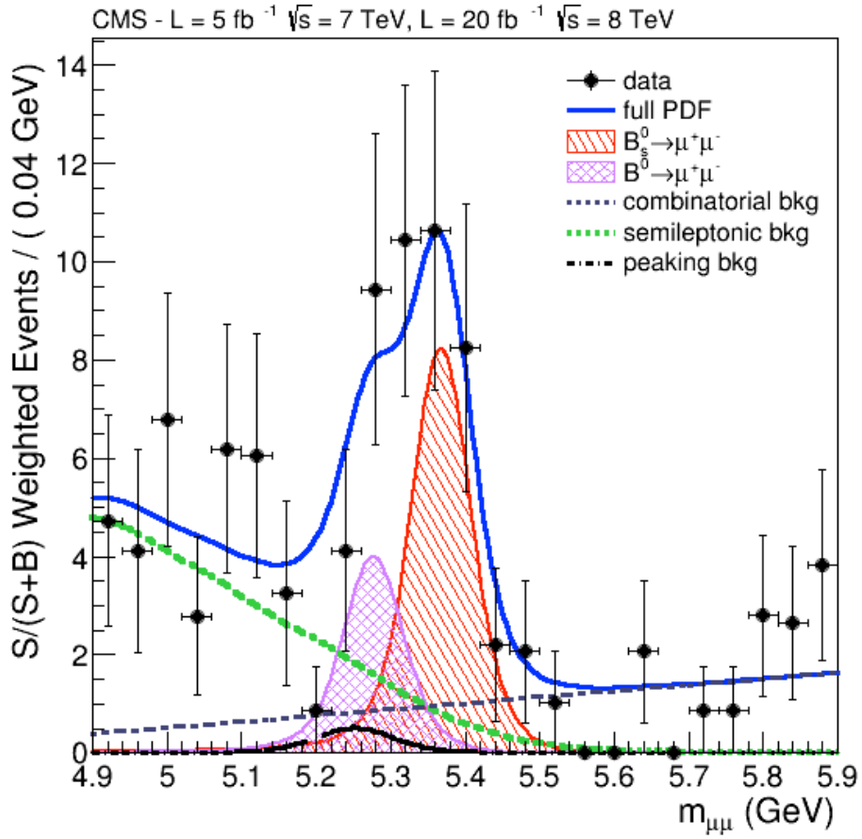




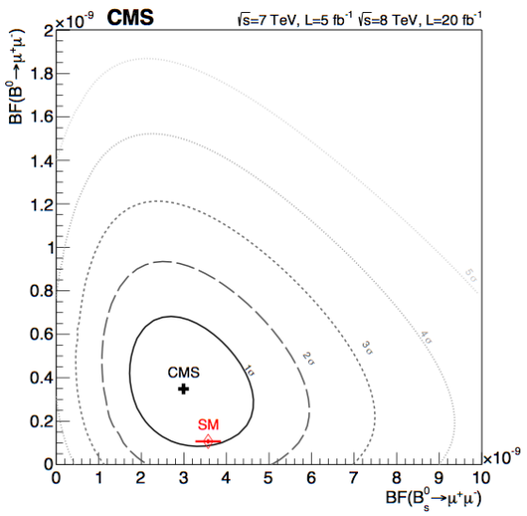
$$BR(B_S \to \mu\mu) = \left(3.0^{+0.9}_{-0.8}\ (stat)^{+0.6}_{-0.4}\ (syst)\right) \times 10^{-9}$$

searching for an ultra-rare decay: B→μμ

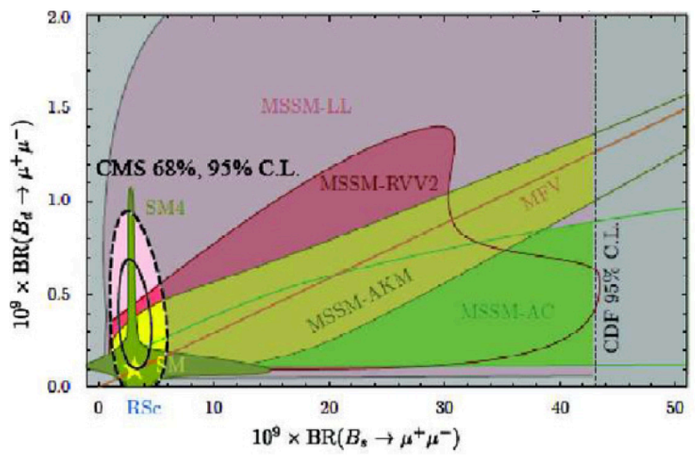
1. ONLINE SELECTION (TRIGGER)
2. BLIND THE DATA (AVOID BIAS)
3. MULTIVARIATE SELECTION
4. FIT THE DATA (LIKELIHOOD)
5. STATISTICAL SIGNIFICANCE
6. EXTRACT MEASUREMENT
7. COMPARE TO THEORY

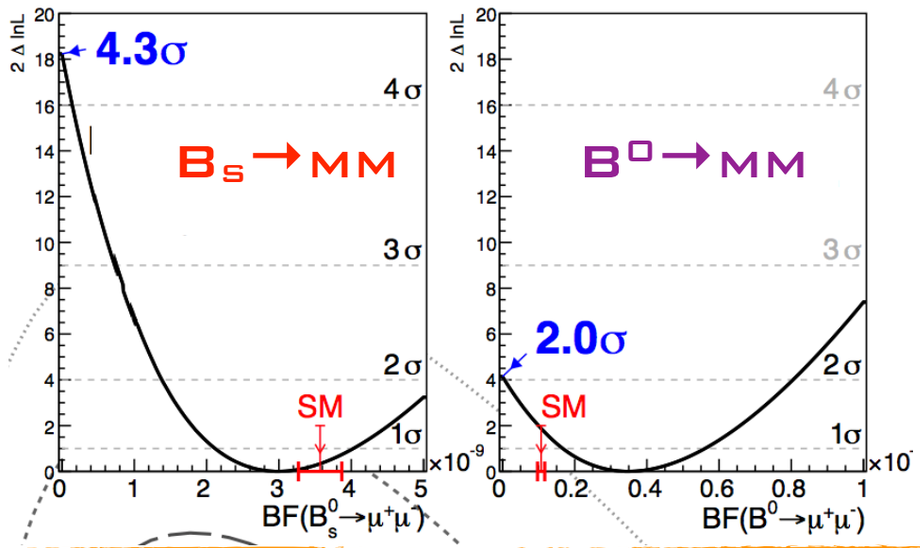


THE SM...



AND BEYOND





$$BR(B_S \to \mu\mu) = \left(3.0^{+0.9}_{-0.8}\ (stat)^{+0.6}_{-0.4}\ (syst)\right) \times 10^{-9}$$

searching for an ultra-rare decay: B→μμ

- the decay $B_s \to \mu\mu$ is very suppressed in SM, O (10^{-9})
- it can be sizably enhanced by various BSM models
- search has been pursued for 3 decades