LHCb experiment at LHC

Barbara Sciascia

for the Frascati LHCb group:

M.Anelli, F.Archilli, G.Bencivenni, P.Campana, P.Ciambrone, P.de Simone, G.Felici, G.Lanfranchi, F.Murtas, M.Palutan, R.Rosellini, M.Santoni, A.Saputi, A.Sarti, B.Sciascia, A.Sciubba, F.Soomro

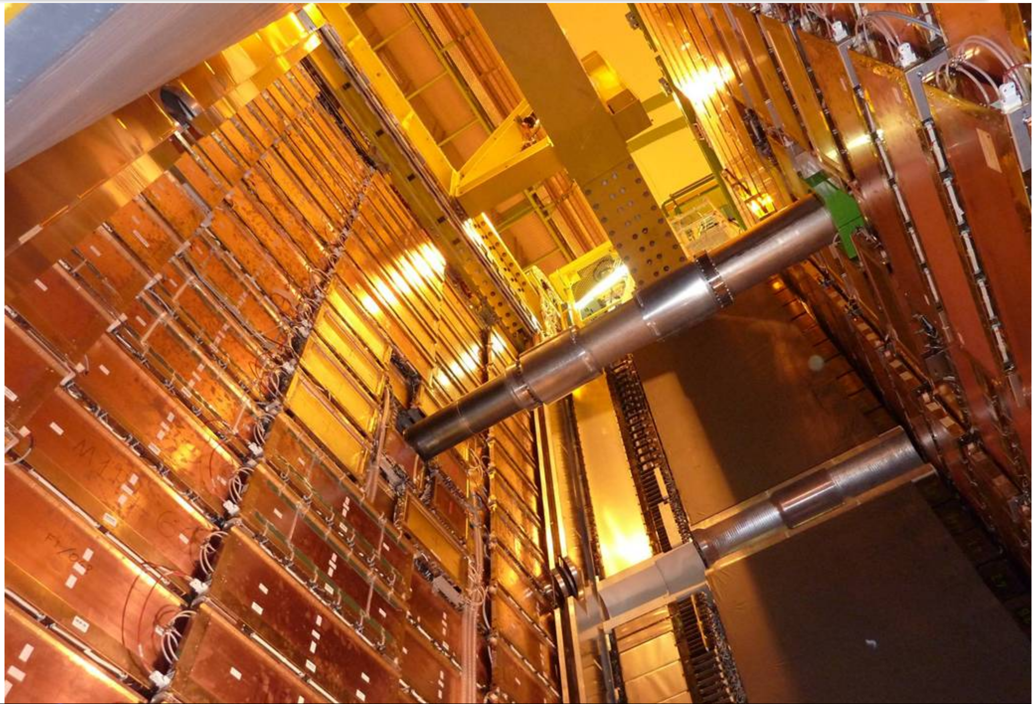
19 January 2012

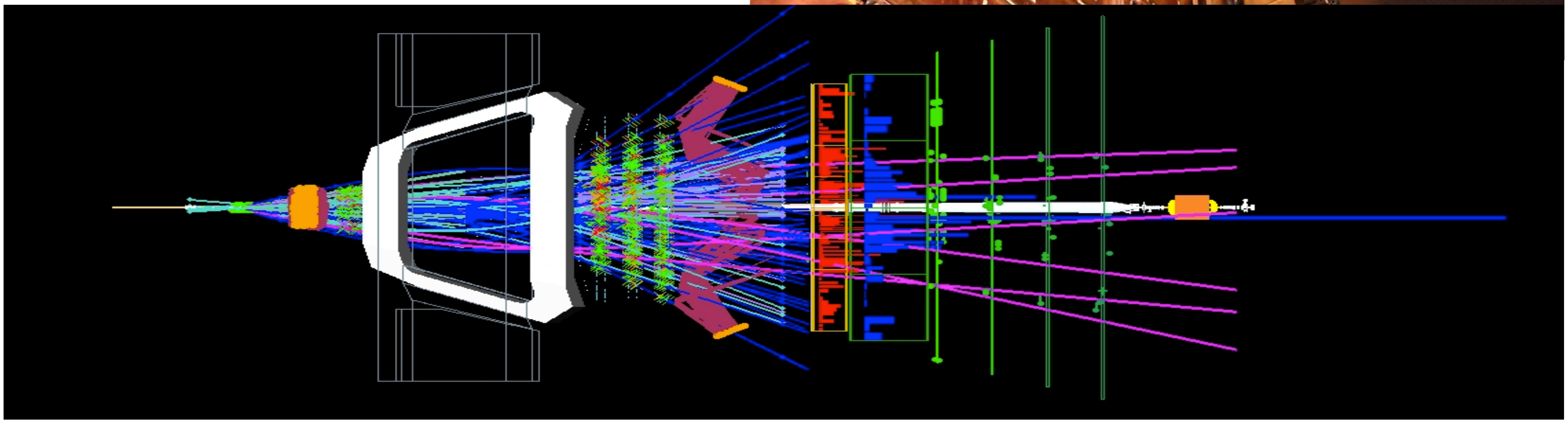
43rd LNF Scientific Committee meeting

Outline

- LHCb in a nutshell;
- 2011 data taking;
- 2012 and beyond.

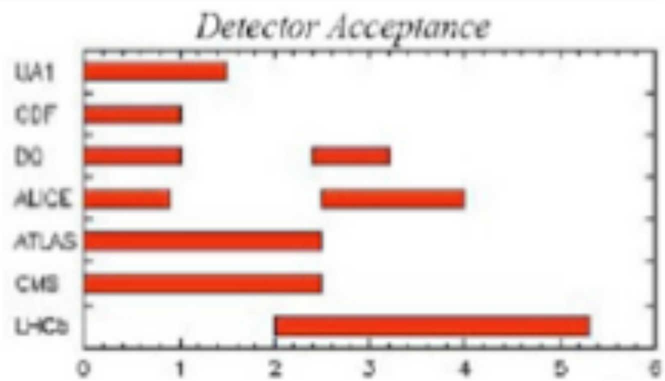
LNF contribution to LHCb





LHCb at LHC

LHCb **detector** covers the forward region at the LHC in a unique rapidity range: $2<\eta<5$.

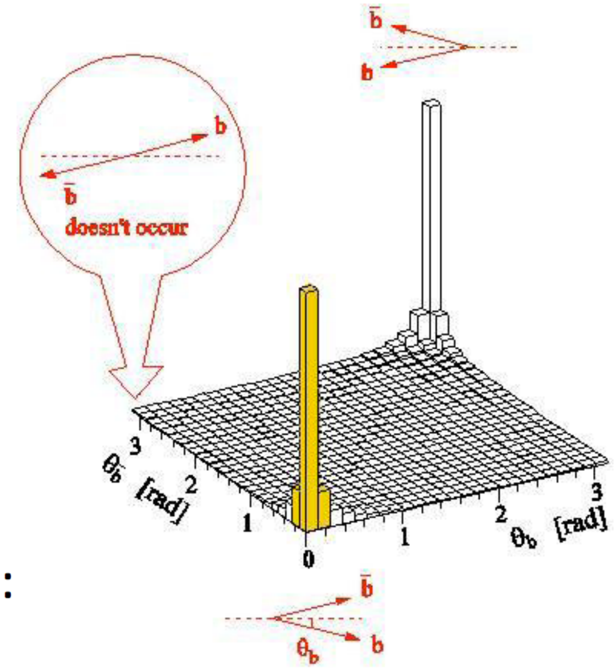


LHCb exploits the strongly forward peaked heavy quark production: covering only 4% of solid angle the acceptance for b-quark production cross section is ~40%.

Large cross sections (at 7 TeV):

$\sigma(bb)$ = 284±53 μb; now ~10^{11} b decays on tape

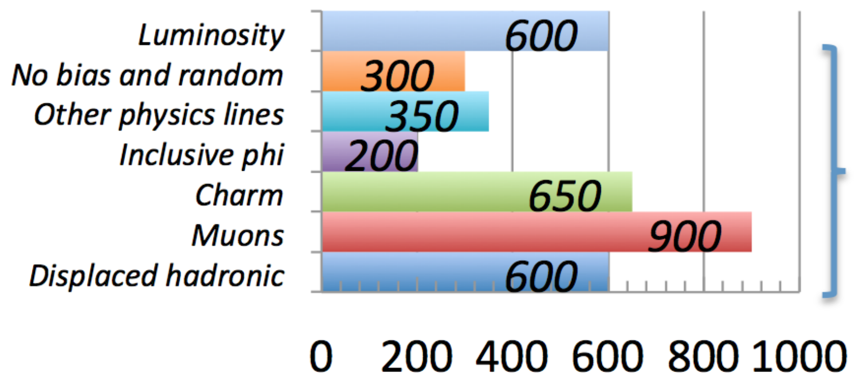
$\sigma(cc)$ = 6100±930 μb; now ~10^{12} D decays on tape.



Trigger:

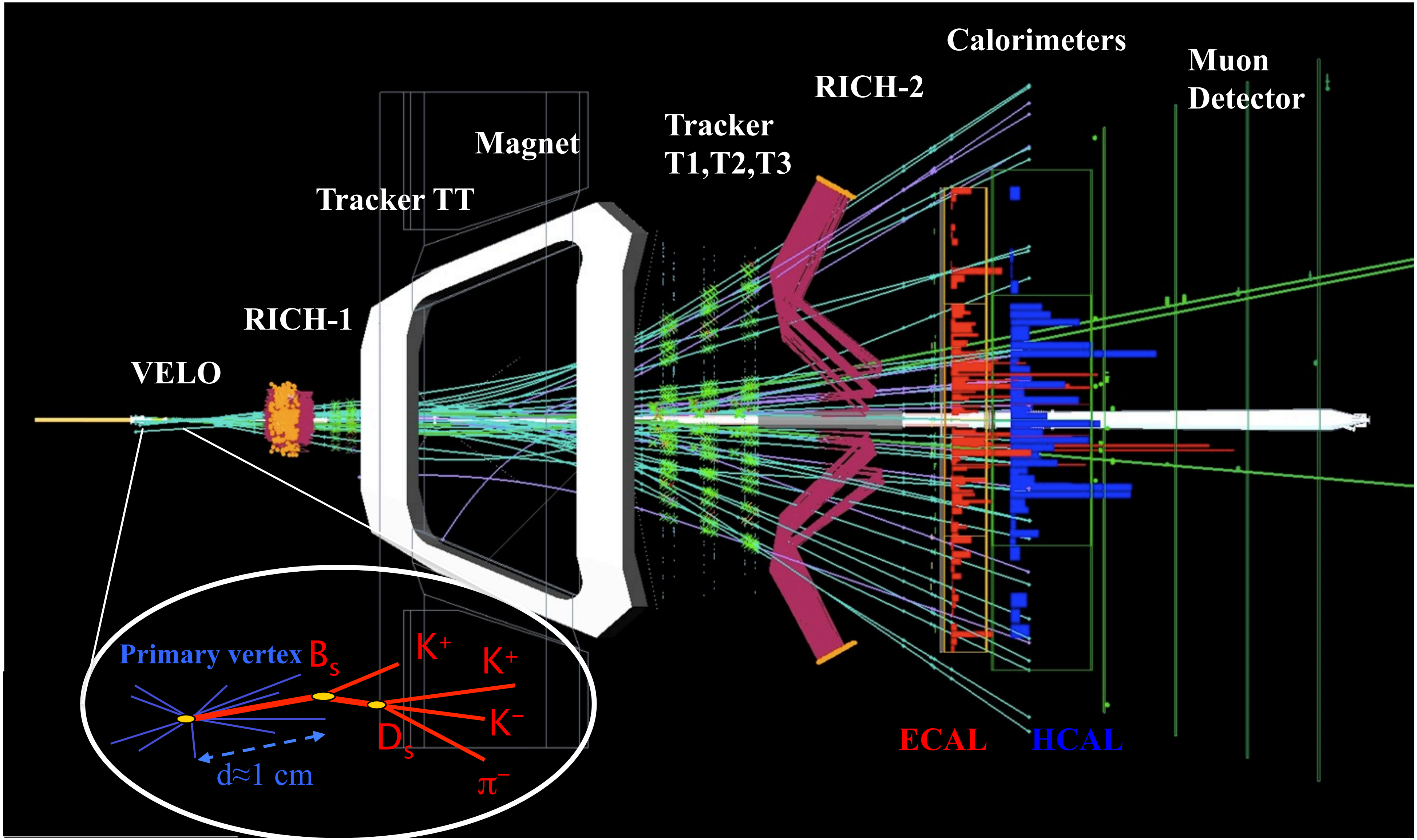
L0 (hardware): **~1 MHz** from **high p_T** μ, e, γ, h candidates.

High Level Trigger (HLT1+HLT2, software): **~3 kHz** global event reconstruction plus selections



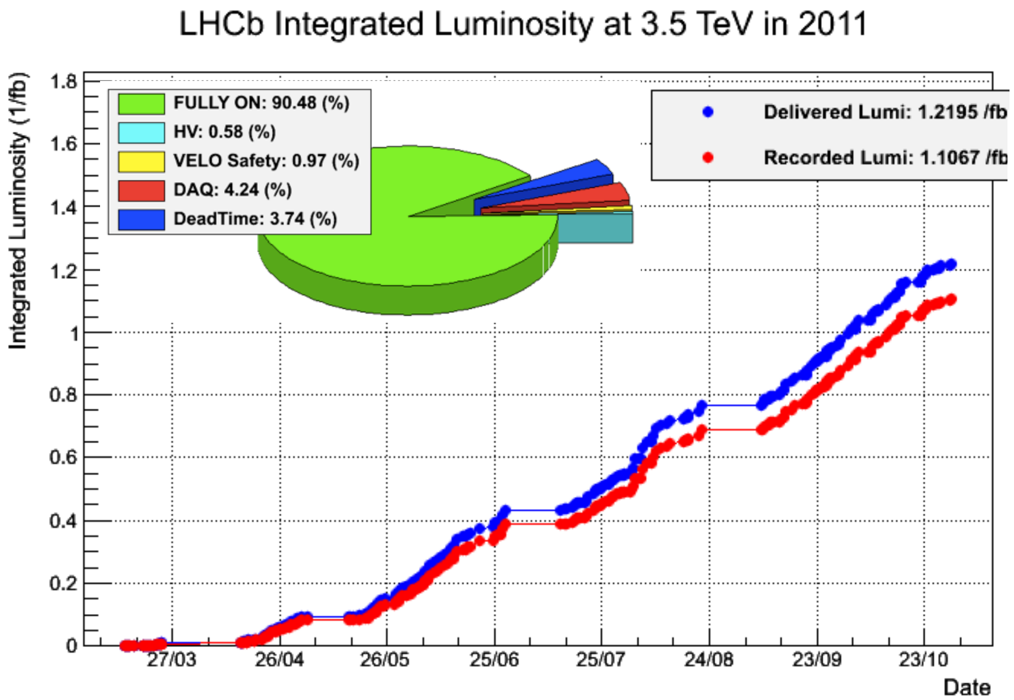
Physics:
3 kHz

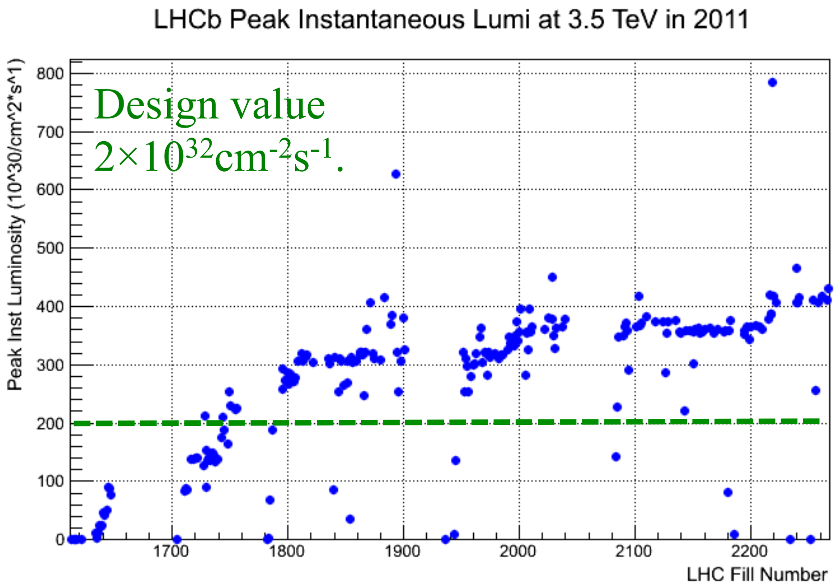
LHCb detector

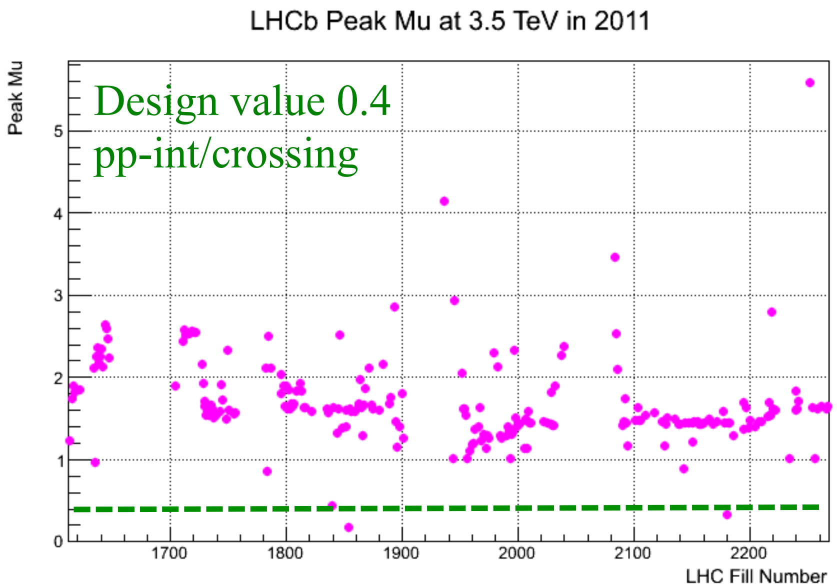


Data taking in 2011

- **1.1 fb^{-1}** acquired in 2011;
- 91% data taking efficiency, including data quality;
- Well **beyond design parameters**: peak luminosity and μ (pp-interactions per bunch crossing);
- **Luminosity leveling** at $3.5\times10^{32}cm^{-2}s^{-1}$ nicely working with both magnet polarities

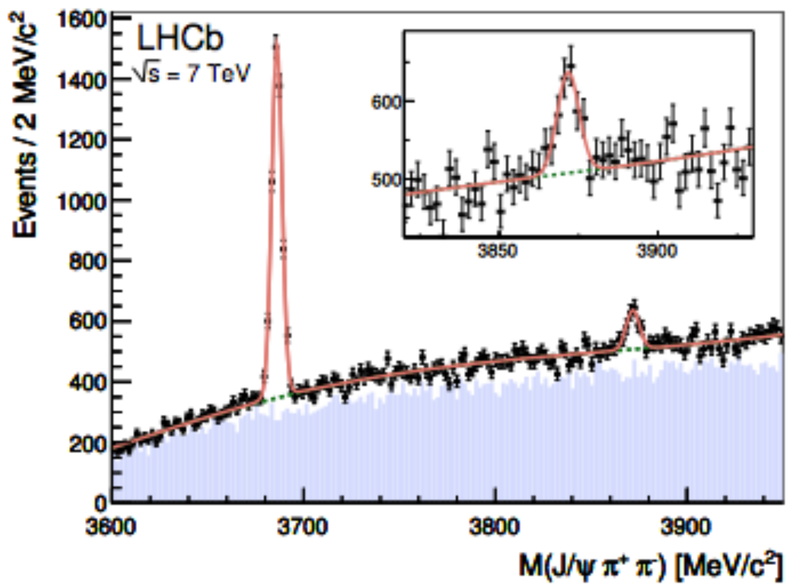


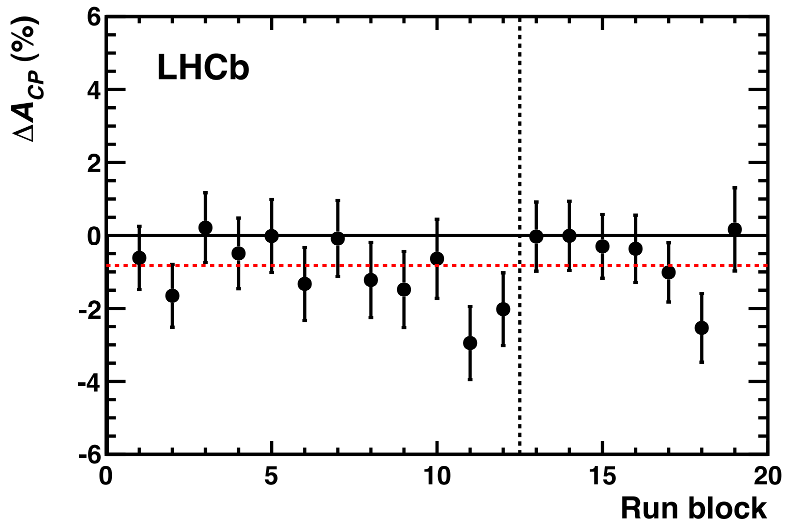


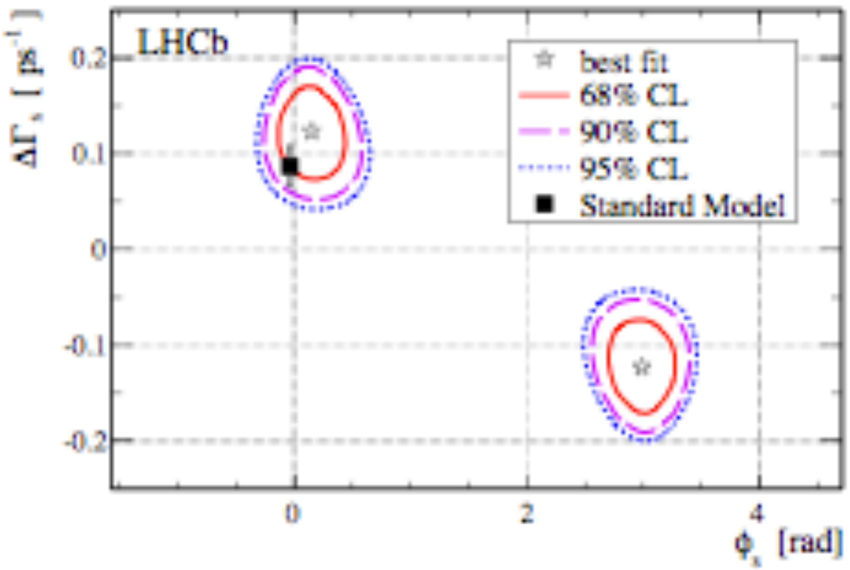


LHCb physics program

Wide physics program:
- Onia, heavy flavour production and spectroscopy: b-hadron masses, X(3872), pp→p+X+p,…
- B→Dh: towards γ CKM angle, …
- ϕ_S related: time dependent B_S studies,…
- Rare B decays: $B_{S,d}\to\mu\mu$, $B\to h\mu\mu$,…
- Charmless B decays: CPV,…
- Charm physics: CPV first evidence,…
- Beyond heavy flavour: W and Z, inclusive jet and dijet, K_S, Λ, φ production







LNF contribution to LHCb

LNF, a “muon oriented” role: from the **construction** of the detector to the heart of the LHCb flavour physics program.

Muon system:
- operation and hw maintenance
- offline efficiency

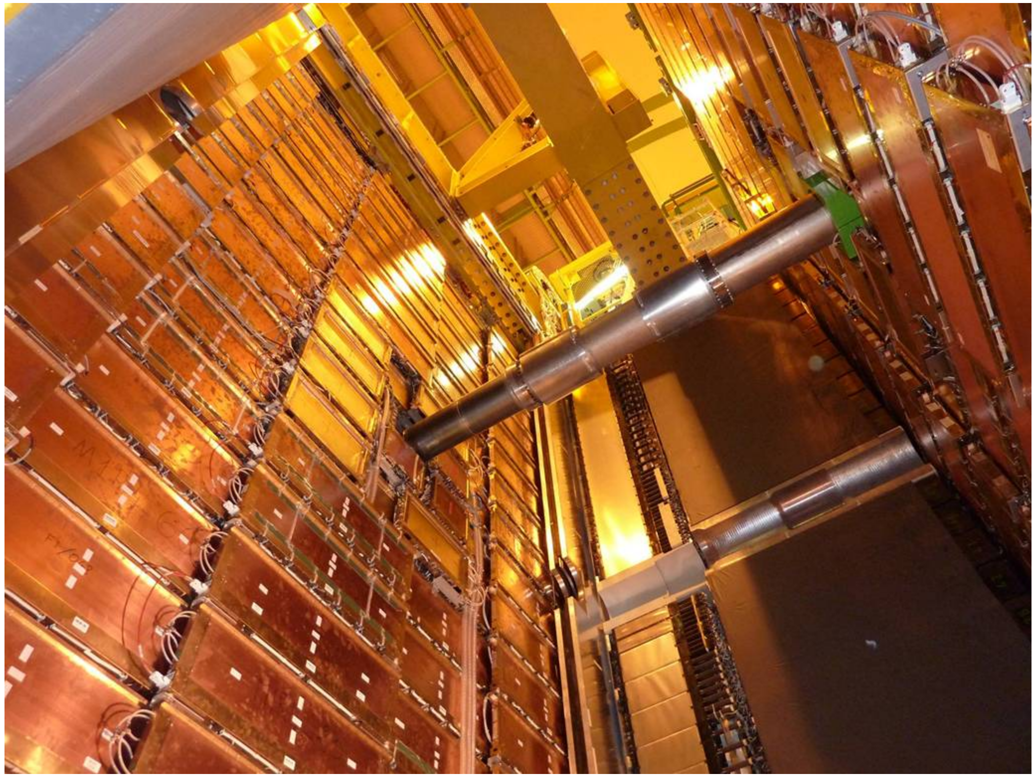
Muon Identification:
- acceptance and efficiency
- mis-identification rate

Data analysis (direct involvement):
- J/ψ production cross section;
- (three times!) $B_{S,d}\rightarrow\mu\mu$:

37 pb^{-1} (published Mar 2011),
370 pb^{-1}(published Dec 2011),
1 fb^{-1} (2012 winter conferences);

- other rare decays (e.g. $\tau\rightarrow3\mu$) in the near future.

LHCb upgrade: Muon System (again!) and some “not muon” R&D



LNF specific tasks:
- Muon **Piquet Shifts**;
- Muon Detector **Operation Coordinator**;
- $B_S\mu\mu$ **WG convener**;
- **Spokesperson**.

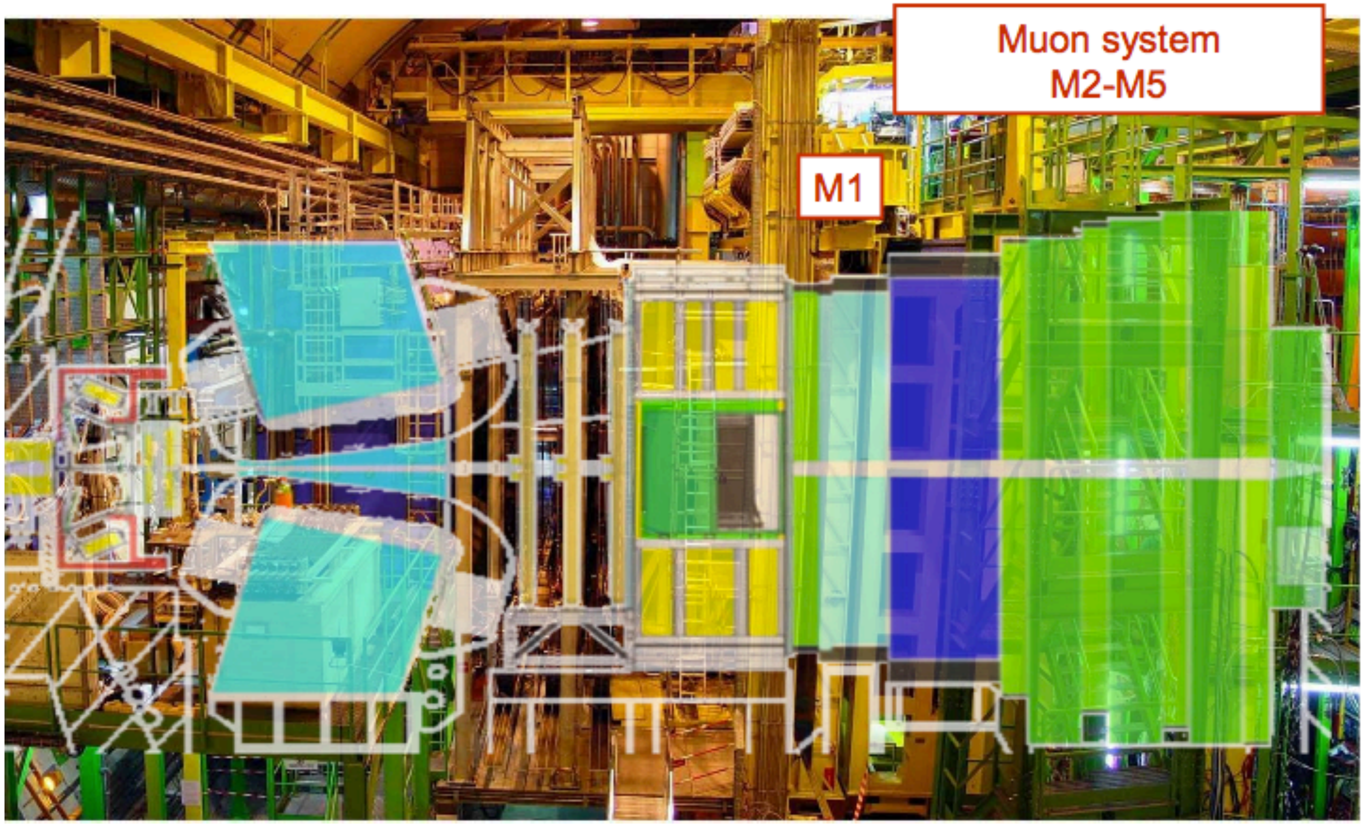
LHCb Muon System

5 tracking stations (M1 upstream from calorimeter)

- subdivided in **4 regions** with different granularities

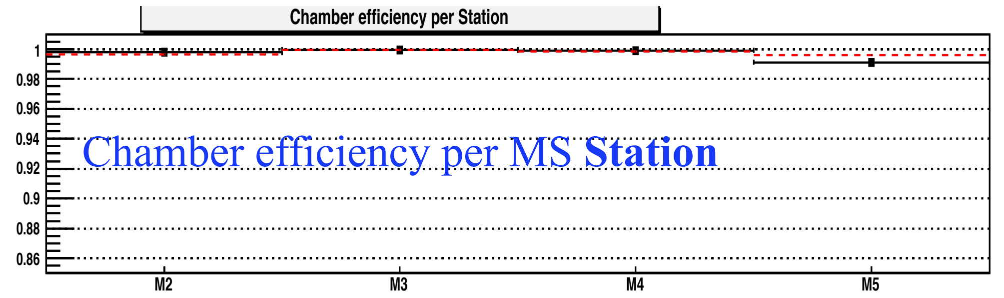
- equipped with **MWPC** apart **GEM in M1R1**

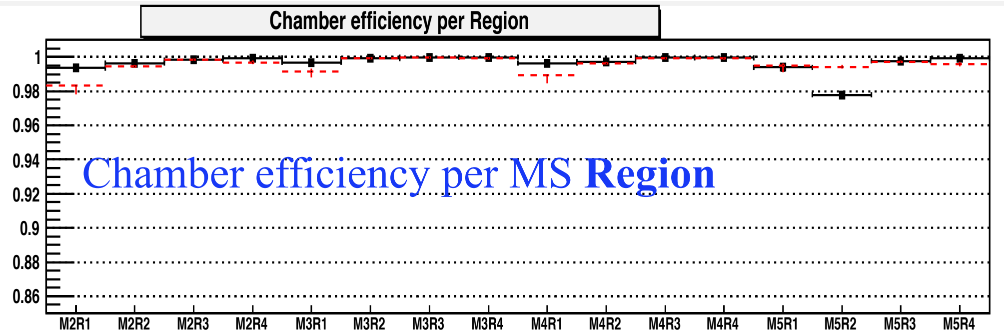
~26000 logical channels



MuonID:
- extrapolate tracks
- find hits in a FoI (Field of Interest)
- muon candidate requires hits in different stations depending on the momentum
- from associated hits, calculate "muon probability".

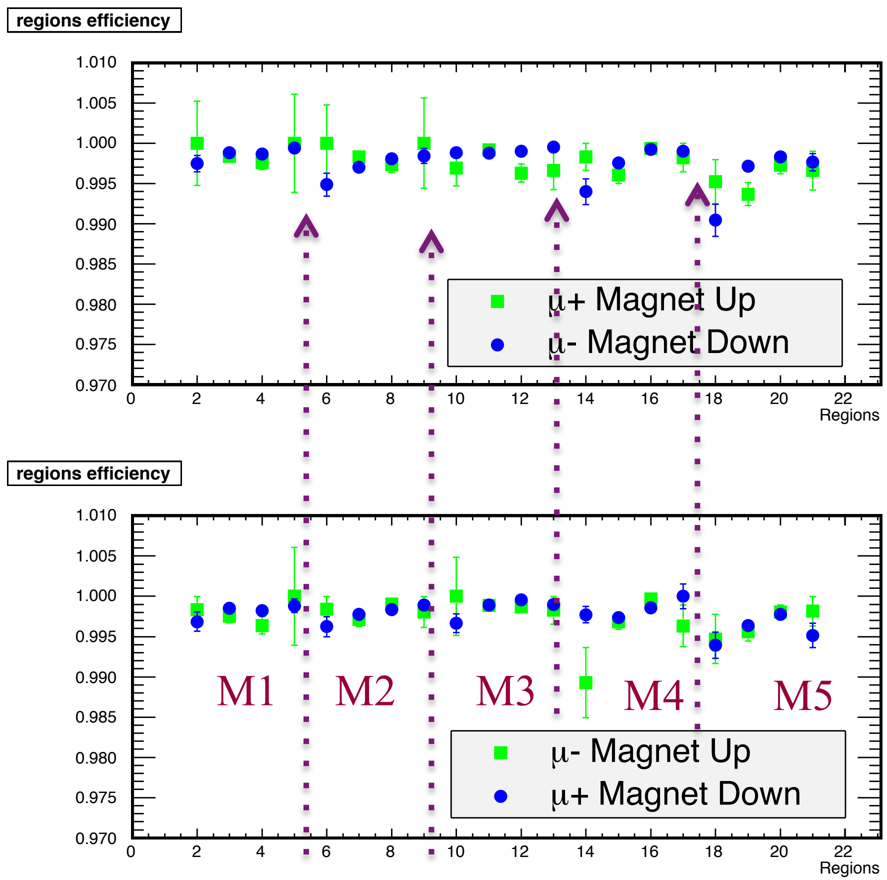
Muon System offline efficiency monitor





Implementation of the Offline Muon System monitor (M2-M5 stations).

($J/\psi \rightarrow \mu^+\mu^-$ from B with p_μ>15 GeV/c)

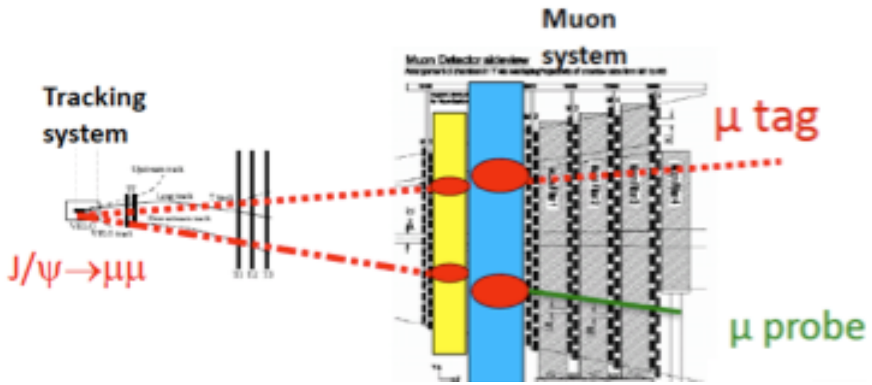


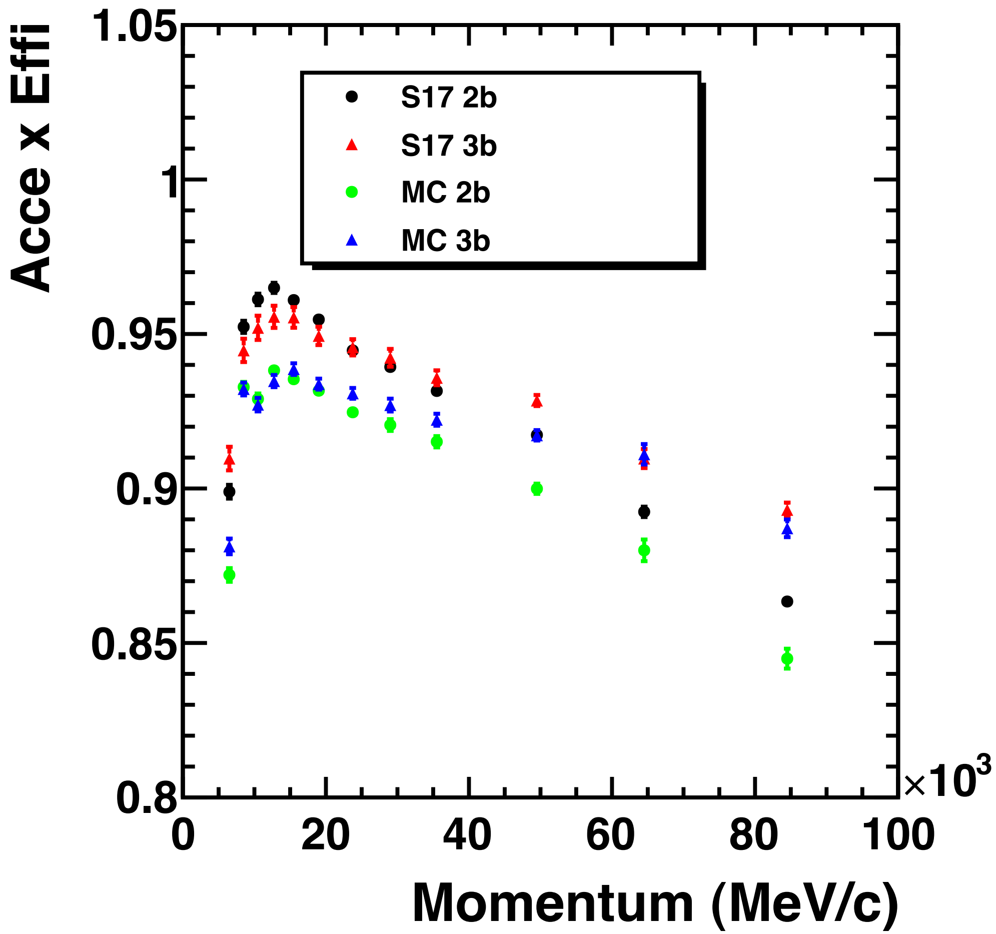
New version ready for 2012 run:
- also M1;
- use of a **trigger unbiased sample**;
- efficiency monitor also **per charge**.
- test with 44 pb^{-1} MagUp, 100 pb^{-1} MagDw

Muon Identification: 1D results

Two steps needed to "have a μ" in the event:
- pass through the MS: **geom. acceptance**;
- produce a signal in the MS: **efficiency**.

Two suitable calibration lines:
B→J/ψX (2b) and **B⁺→J/ψK⁺** (3b).
Tag-and-probe + fit and bkg subtraction.





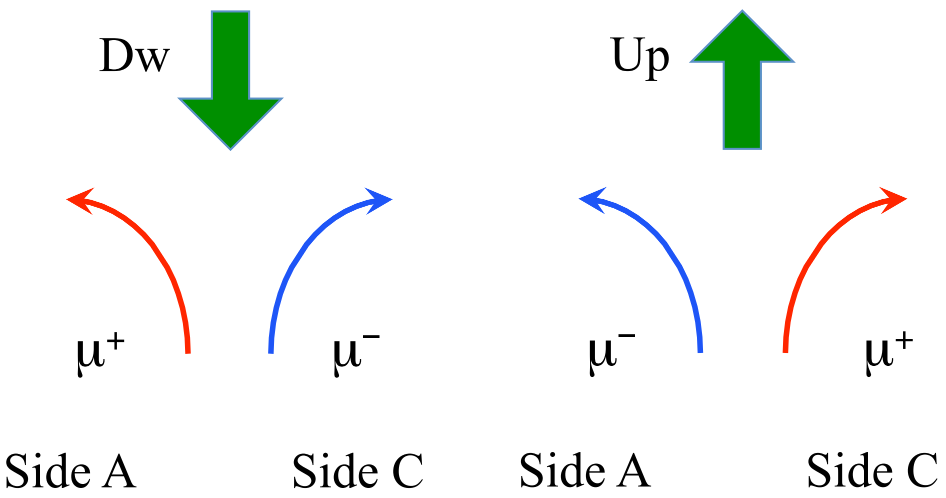
1D results (acceptance, efficiency, and both) as a **function of p or p_T**;
- complete systematic studies;

Universal curves, already used in many analyses: $B_S \to \mu\mu$ (370 pb^{-1}), A_{SL}, $B_S \to K^*\mu\mu$,…
- detailed **LHCb** note available to the collaboration.

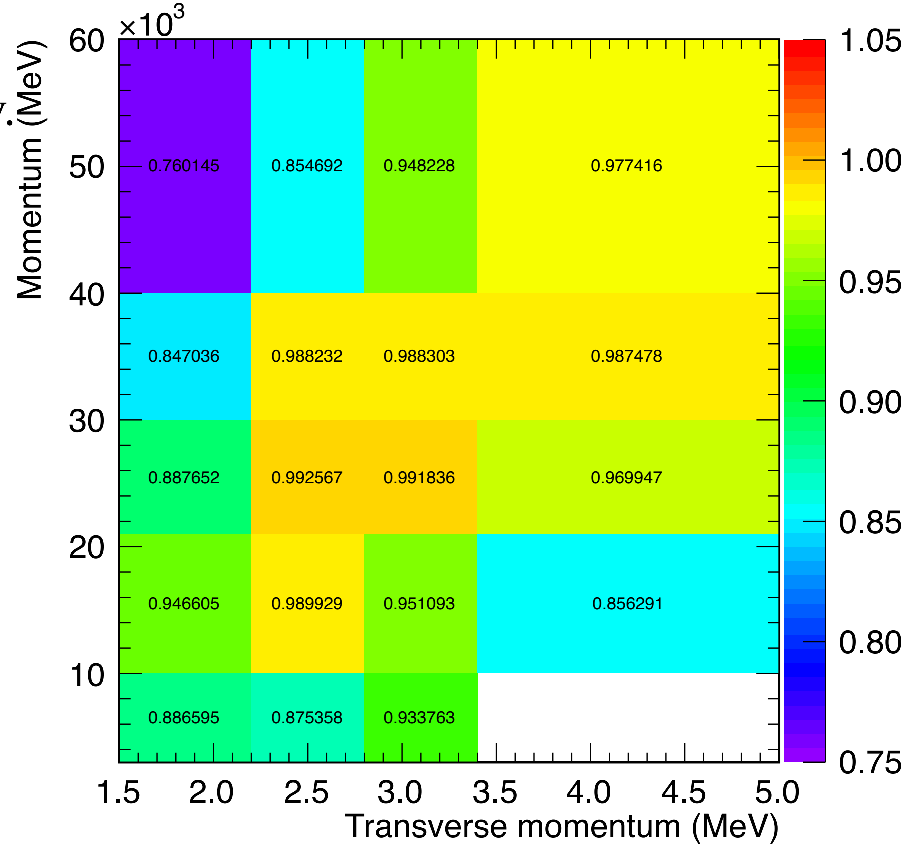
Muon Identification: 2D results

2D results as a **function of (p,p_T) or (p,η)**;
- trigger unbias and sample related systematic study.

Acceptance/efficiency determined also **per charge/magnet polarity** (important for precise "asymmetries" studies)



- measure **from data**, **same side** (different charge μ behave in the same way in the same side) and **same charge** (same charge μ behave in the same way in opposite side) differences.



- 2D corrections already applied in on going analyses: $B_S \to \mu\mu$ (1 fb^{-1}), $B_S \to K^*\mu\mu$, $D \to h\mu\mu$, …

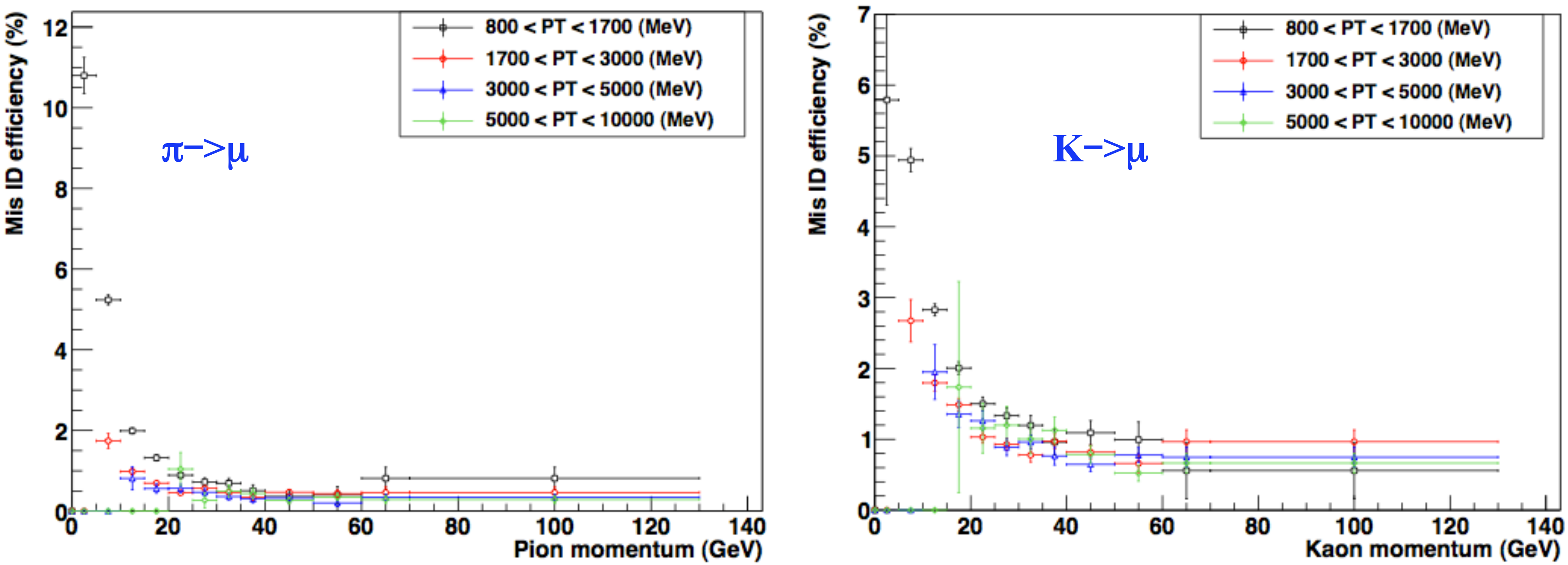
- New **LHCb note** in preparation

Muon misID rate

Relevant issue to control background in rare decays with muons (e.g. $B \to hh$ for $B_d \to \mu\mu$).

Measure **from data** the probability of "muon mis-identification" as a function of (p, p_T):

- **$\pi \to \mu$** or **$K \to \mu$** from $D^* \to D_0(K\pi)\pi$ decays
- **$p \to \mu$** from $\Lambda \to p\pi$ decays.

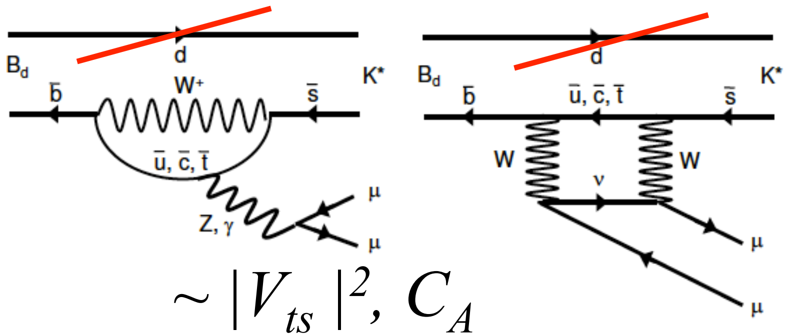


(from 900 pb^{-1} of 2011 data; TIS trigger unbias of the π/K track)

Search for NP in $B_{S,d}\mu\mu$ decays

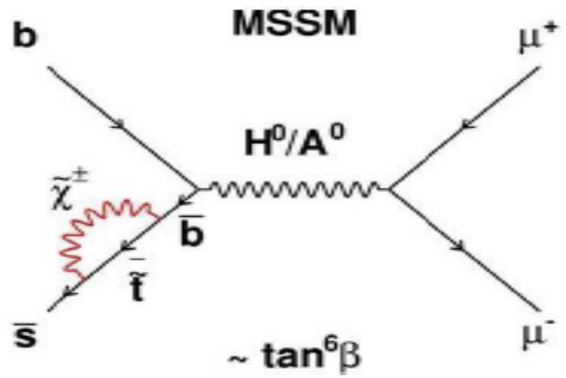
$B_{(d,s)} \rightarrow \mu\mu$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

Main SM diagrams



$\sim |V_{ts}|^2, C_A$

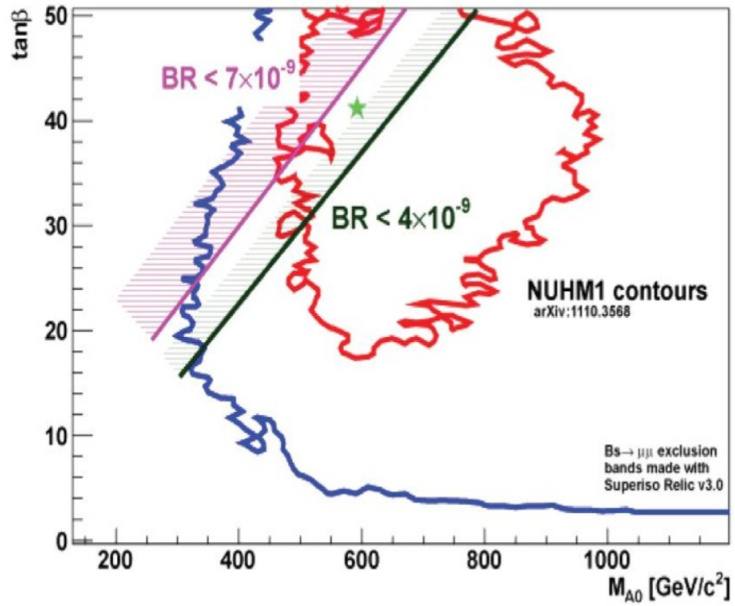
+



Double suppressed decay: FCNC process and helicity suppressed: very small in SM but very well predicted:

$B_S \rightarrow \mu\mu = (3.2 \pm 0.2) \times 10^{-9}$,
$B_d \rightarrow \mu\mu = (0.10 \pm 0.01) \times 10^{-9}$.

[Buras et al arXiv:1007.5291]



Sensitive probe to NP contributions: e.g. in MSSM, BR enhanced by $\tan^6\beta$.

$B_S\mu\mu$: analysis strategy

Selection:

- μ-based trigger + selection to reduce the size of data set
- similar for control/normalization channels

Signal and background discrimination relies on:

- very good mass resolution: $\delta p/p \sim 0.35\%$ => $\delta m/m \sim 0.55\%$ for p=5-100 GeV/c
- muon PID: $\varepsilon(\mu\text{->}\mu) \sim 98\%$, $\varepsilon(h\text{->}\mu) < 1\%$, for p>10 GeV
- excellent vertex and IP resolution $\sigma(IP) \sim 25\ \mu m$, p_T=2 GeV/c

Discriminating signal and background using two variables:

- **Invariant mass of $\mu^+\mu^-$**: parameterization from data.
- Output of a **Boosted Decision Tree, BDT**
  (from TMVA, use kinematical and topological variables).

Normalization:

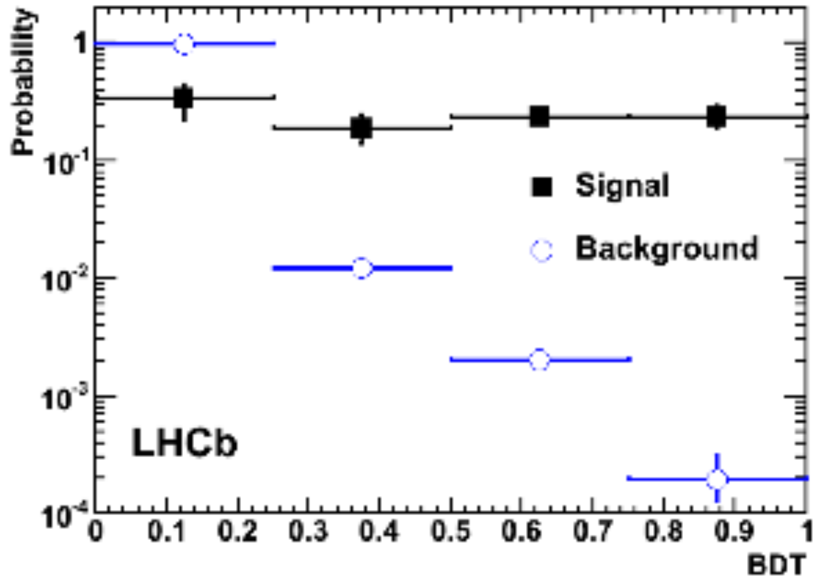
- use known B decay channels ($B^+ \to J/\psi K^+$, $B_S \to J/\psi \varphi$, and $B_d \to K\pi$) to derive BR:

$$\mathcal{B} = \mathcal{B}_{\rm norm} \times \frac{\epsilon^{\rm REC}_{\rm norm}\epsilon^{\rm SEL|REC}_{\rm norm}\epsilon^{\rm TRIG|SEL}_{\rm norm}}{\epsilon^{\rm REC}_{\rm sig}\epsilon^{\rm SEL|REC}_{\rm sig}\epsilon^{\rm TRIG|SEL}_{\rm sig}} \times \frac{f_{\rm norm}}{f_{d(s)}} \times \frac{N_{B^0_{(s)}\to\mu^+\mu^-}}{N_{\rm norm}} = \alpha^{\rm norm}_{B^0_{(s)}\to\mu^+\mu^-} \times N_{B^0_{(s)}\to\mu^+\mu^-}$$

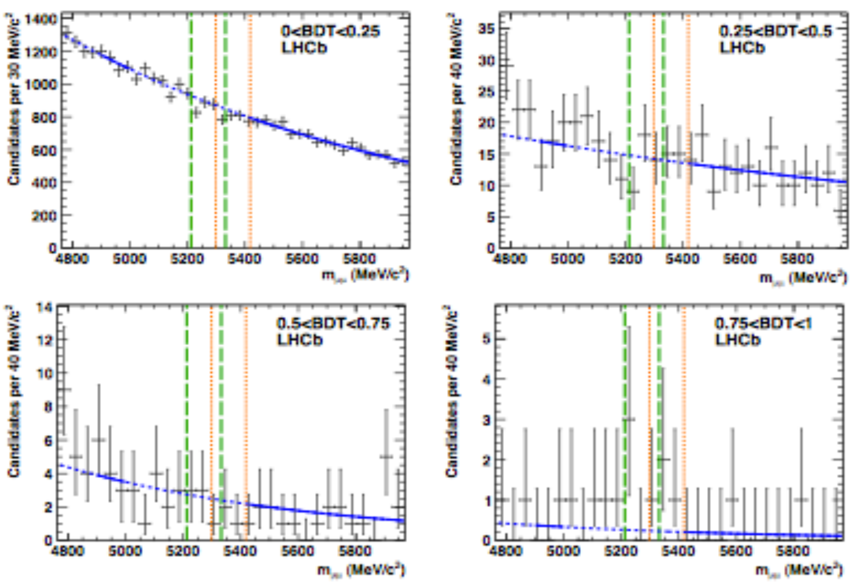
- LHCb $f_S/f_d = 0.267^{+0.021}_{-0.020}$ Phys. Rev.Lett. 107, 211801 (2011), arXiv:1111.2357v1.

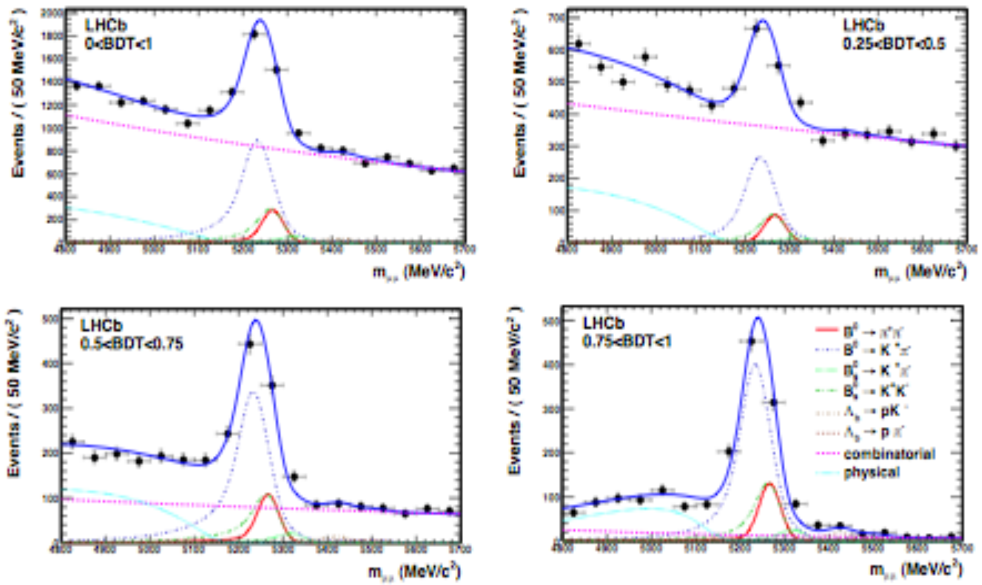
$B_S\mu\mu$: BDT

Output of BDT:
- built on 9 kinematical and topological variables;
- trained on MC (~0 for bkg, 0-1 flat for sig);



BDT output **shapes from data**, by $M_{\mu\mu}$ fit in four BDT bins:
- **signal, $B^0_{(S)} \rightarrow h^+h^-$ events**
- **combinatorial background, B mass sideband**



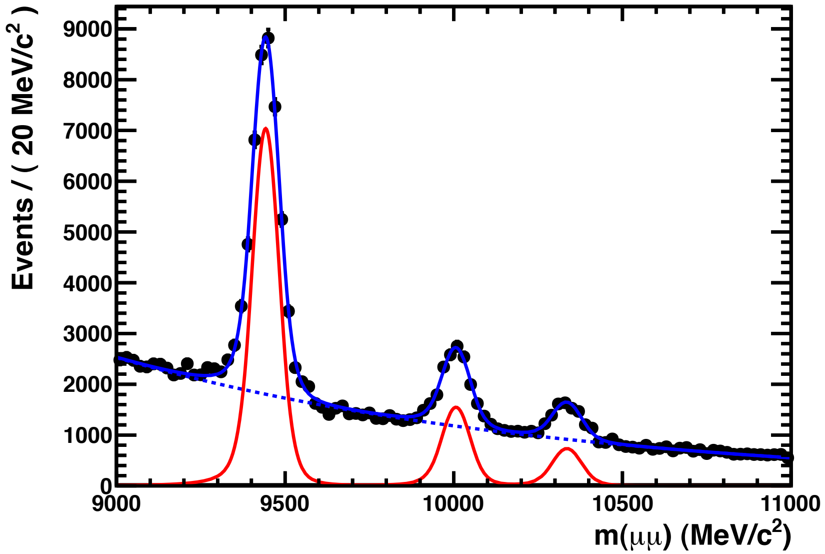


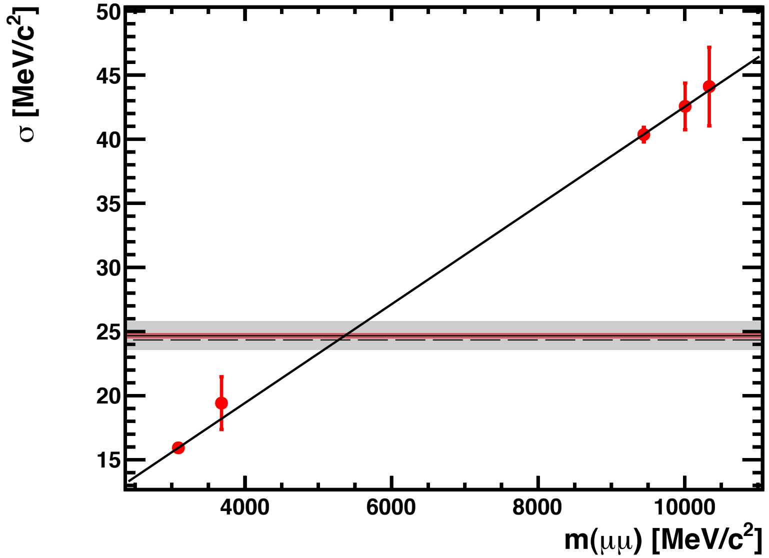
$B_S\mu\mu$: invariant mass

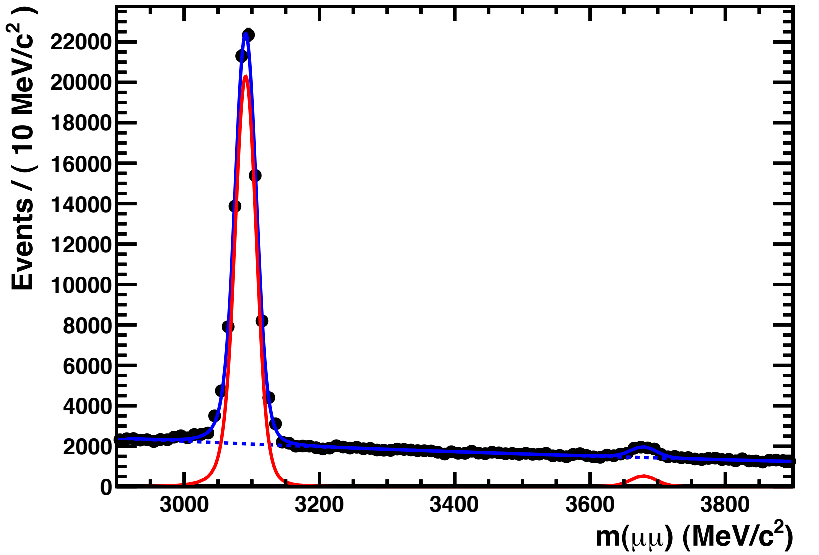
Signal invariant mass shape:

Average value measured **on data** using $B^+ \rightarrow J/\psi K^+$ and $B_S \rightarrow J/\psi\varphi$ candidates

Resolution from data by linear interpolation between the measured resolutions of charmonium and bottomoniu di-muon resonance



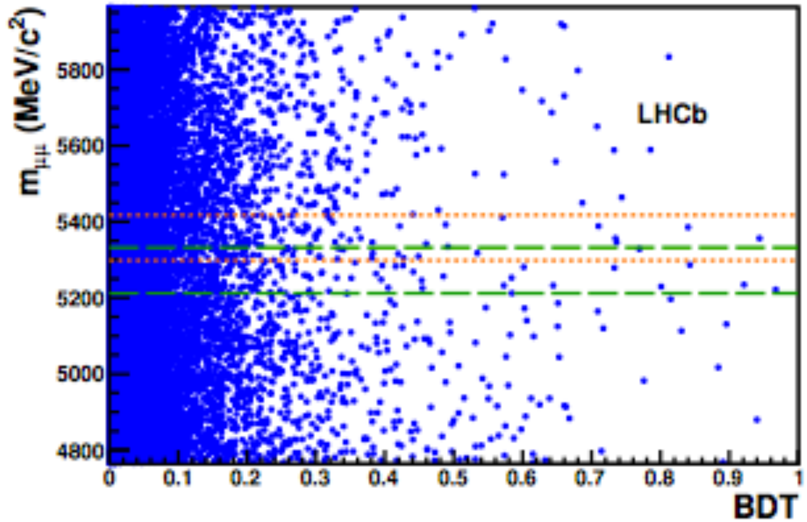


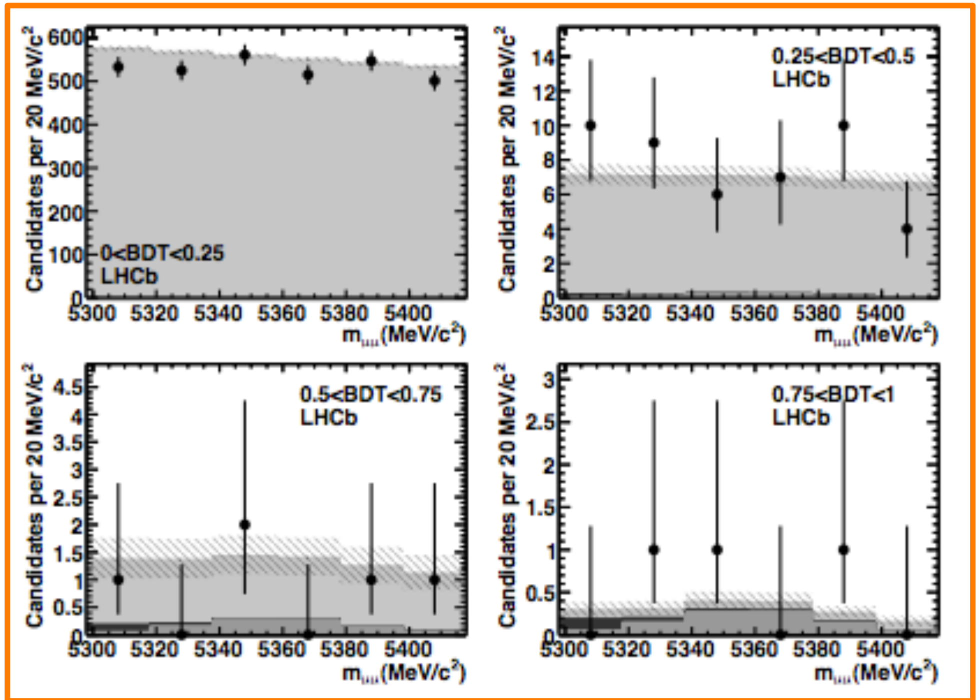


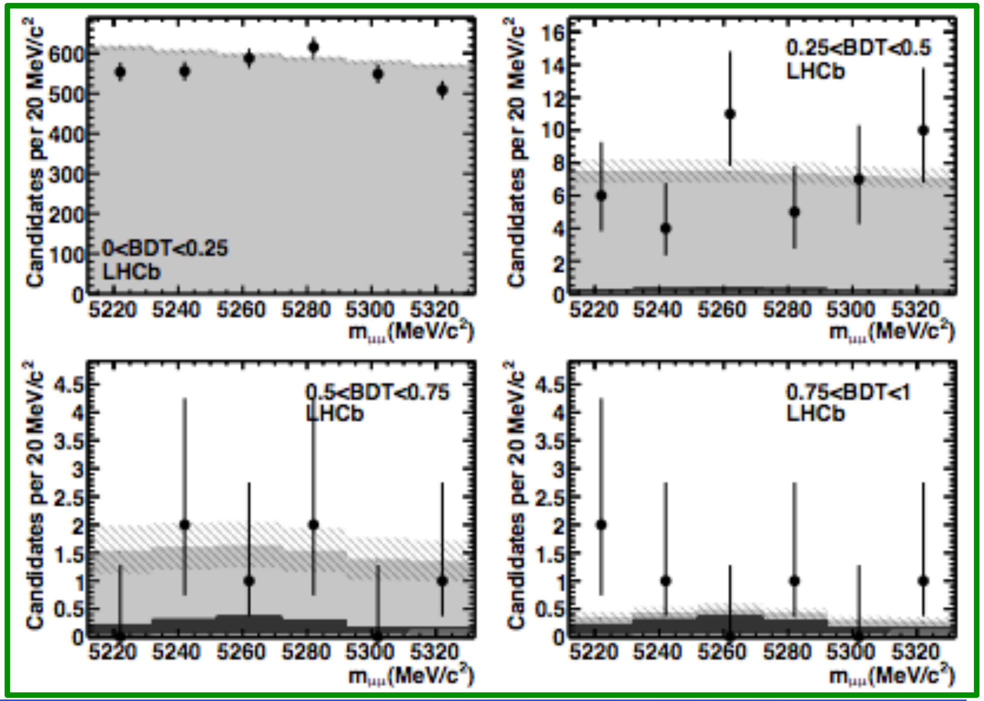
$B_S\mu\mu$: selected events

Distribution of **selected di-muon events** in the **invariant mass-BDT plane** (370 pb^{-1}); **B_S** and **B_d** search window.

Projection in the **B_S** or in the **B_d** invariant mass search window ($m_B \pm 60 MeV/c^2$ divided into 6 bins) for the four BDT output bins.



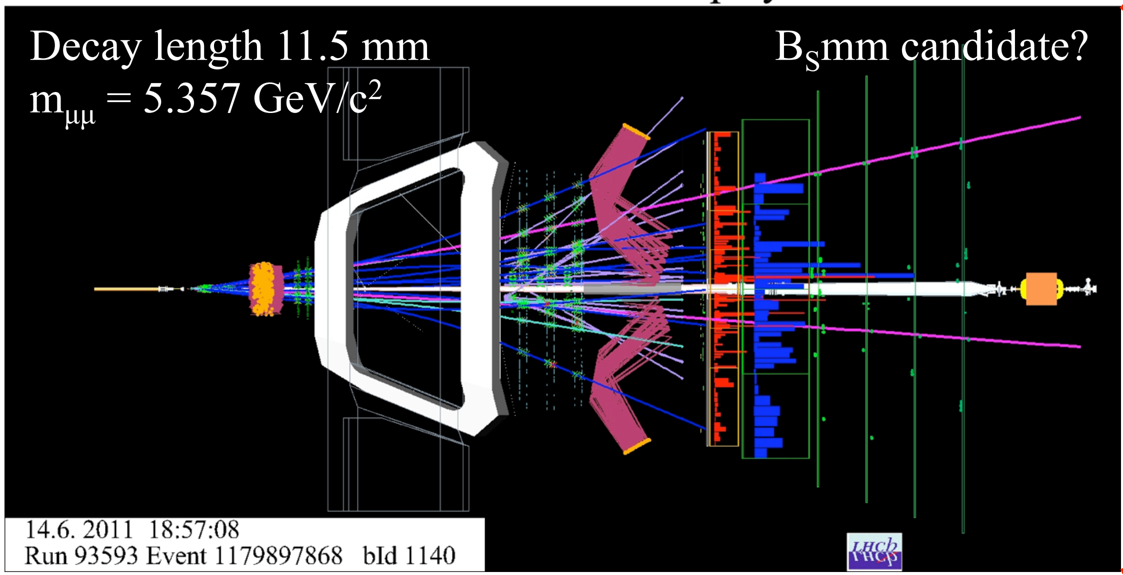




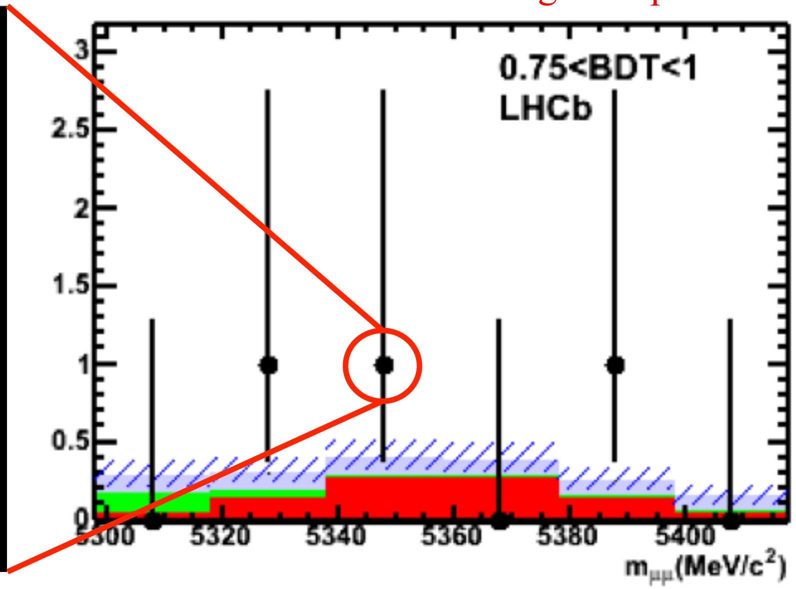
$B_s\mu\mu$: result (370 pb^{-1})

BDT	0 ÷0.25	0.25÷0.50	0.50÷0.75	0.75÷1.0
expected combinatorial	3325±39	40.8±3.8	6.8±2.3	0.63±0.50
expected SM signal	1.29±0.23	0.72±0.12	0.90±0.11	0.89±0.13
observed	3182	46	5	3

LHCb Event Display



Combinatorial background
Peaking background (~0.24/bin)
SM signal expectation



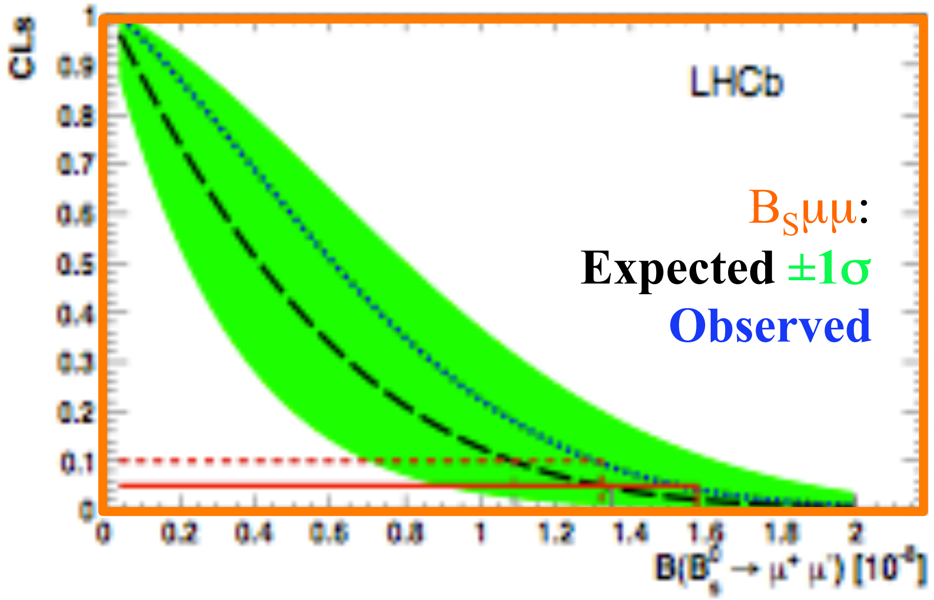
$B_S\mu\mu$: result (370 pb^{-1})

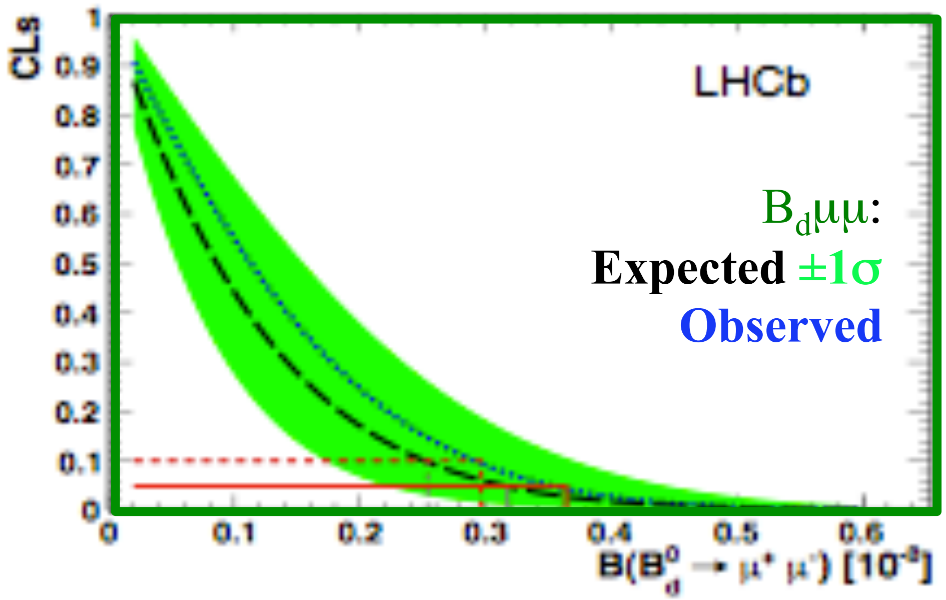
Translate number of observed events into BR measurement by normalization channels.

Extract observation/exclusion measurement using modified frequentist CL_S method [A. Read, J. Phys. G 28 (2002) 2693] in 6x4 bins of $m(\mu^+\mu^-)$ and BDT output:

Expected distribution of CL_S (dashed black) under the hypothesis to observe a combination of background and signal (B_S) or background only (B_d) events according to the SM rate. The green area covers the ±1σ of compatible observations.

Observed distributions of CL_S ($=CL_{s+b}/CL_b$) as a function of the assumed BR (dotted blue).





The signal hypothesis is excluded at the confidence level 1-α when: $CL_S < \alpha$

$B_S\mu\mu$: result (370 pb^{-1})

Translate number of observed events into BR measurement by normalization channels.

Extract observation/exclusion measurement using modified frequentist CL_S method [A. Read, J. Phys. G 28 (2002) 2693] in 6x4 bins of $m(\mu^+\mu^-)$ and BDT output:

Accepted by PLB

BR limits at 95%CL

370 pb^{-1} 2011 data

	expected (*)	observed	CL_b	
$B_s \rightarrow \mu\mu$	1.4×10^{-8}	1.6×10^{-8}	0.95	2σ signal hint
$B_d \rightarrow \mu\mu$	3.2×10^{-9}	3.6×10^{-9}	0.68	

Adding 37 pb^{-1} of 2010 data

	expected (*)	observed	CL_b
$B_s \rightarrow \mu\mu$	1.3×10^{-8}	1.4×10^{-8}	0.93
$B_d \rightarrow \mu\mu$	3.0×10^{-9}	3.2×10^{-9}	0.61

(*) hypothesis: bkg+SM for B_S
bkg only for B_d.

2010-2011 “LNF” production

Papers:

Searches for the rare decays B0s→μ+μ− and B0→μ+μ−
arXiv:1112.1600; Accepted by Phys. Lett. B

Search for the rare decays B0s→μ+μ− and B0→μ+μ−
arXiv:1103.2465; Phys. Lett. B 699 (2011) 330-340

Measurement of J/ψ production in pp collisions at s√ = 7 TeV
arXiv:1103.0423; Eur. Phys. J. C 71 (2011) 1645

Notes:

Results on Muon identification efficiency with 2011 data at LHCb
LHCb-INT-2011-045; CERN-LHCb-INT-2011-045

Muon Identification performance at LHCb with the 2010 data
LHCb-INT-2011-048; CERN-LHCb-INT-2011-048

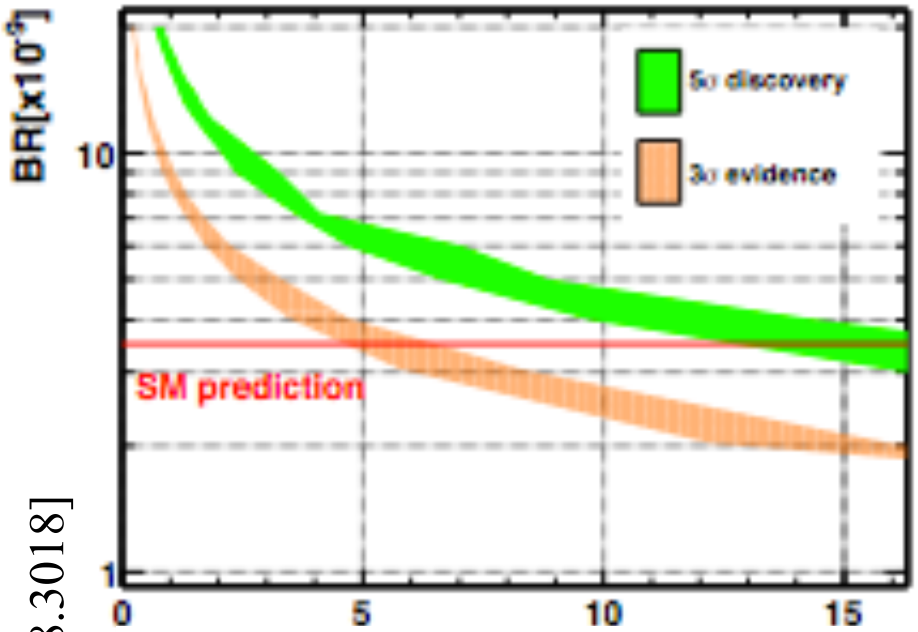
A Muon Identification procedure for LHCb with Kalman Filter
LHCb-INT-2010-052; CERN-LHCb-INT-2010-052

Measurement of the J/ψ production cross-section in LHCb
LHCb-INT-2010-045; CERN-LHCb-INT-2010-045

Calibration Strategy and Efficiency measurement of the Muon Identification procedure at LHCb
LHCb-PUB-2010-002; CERN-LHCb-PUB-2010-002

A 1 mm Scintillating Fiber Tracker Readout by a Multi-anode Photomultiplier
arXiv:1106.5649

$B_S\mu\mu$: near future



L/L_{USED} **(used luminosity: LHCb 0.34 fb^{-1}, CMS 1.14 fb^{-1})**

[arXiv:1108.3018]

WG check list towards 1 fb^{-1} LHCb result

1) Data sample
2) Selection and BDTS ← LNF
3) BDT operator ← LNF
4) New BDT binning
5) MuonID efficiency ← LNF
6) MisID probability for B2hh ← LNF
7) Trigger efficiency
8) Normalization factors ← LNF
9) Signal Mass calibration ← LNF
10) Signal BDT calibration ← LNF
11) Background Mass and BDT calibration
12) Expected limit
13) Likelihood scan/fit for 3sigma observation ← LNF

Required luminosity for a **3σ evidence** or a **5σ discovery** of a given BR($B_S\mu\mu$) for **LHCb and CMS combined**.

For **LHCb**: **evidence ~1.7 fb^{-1}**, **discovery ~5.1 fb^{-1}**.

Once the $B_S\to\mu\mu$ is measured, start to constraining the B_d/B_S ratio (prime interest for MFV scenario)

LHCb: 2012 and beyond

Data taking perspectives:

- based on 2011 experience and running at $4\times10^{32}cm^{-2}s^{-1}$, LHCb can collect **≥1.5 fb^{-1}/year**

2.5 fb^{-1} at 7 TeV and 4.5 fb^{-1} at 14 TeV (σ_{bb}=0.3mb @7 TeV, 0.6mb @14 TeV)

- by the end of 2017, ×12 the present (2011) data sample.
- **upgrade plan**: with 1-$2\times10^{33}cm^{-2}s^{-1}$ LHCb can collect **4-8 fb^{-1}/year**.

Physics Case: (LHCC feedback, march 2011)

The Committee congratulates LHCb for the excellent work done on the physics case for the upgrade. It finds the arguments for flavour physics with 50 fb^{-1} very compelling. This amount of data allows measurements at the level of the theoretically achievable precision for many quantities sensitive to new physics. With 5 fb^{-1} of collected data, most searches for deviations from the Standard Model (SM) predictions will be turned into precision measurements of the SM value with the LHCb upgrade. The level of accuracy achievable is comparable, in case of overlap, with that foreseen at future SuperB factories with 50 ab^{-1}; this makes the upgraded LHCb experiment a well-matched competitor and a very important complement.

To profit of the luminosity increase:

- present trigger HW limitation: 1MHz for L0 => readout all the sub-detectors at **40 MHz**;
- exploit a **fully software and flexible HLT trigger**;

R&D for some needed/wanted new sub-detectors.

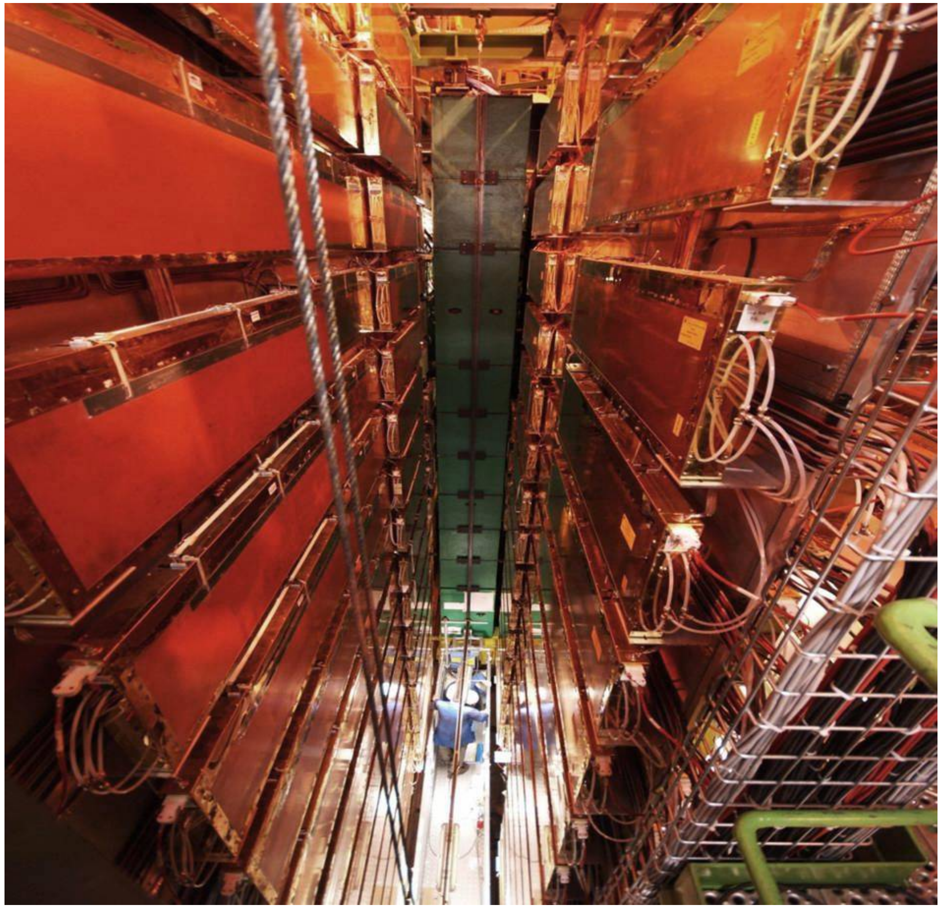
LHCb upgrade: Muon System

Upgrade and consolidations activities for the LHCb Muon System

Electronics: define the architecture for 40 MHz readout start testing FPGA; check details for the feasibility of the proposed scheme

Chambers:

- The **long term resistance** of the Muon Chambers has to be yet understood (up to now non significant ageing, but high currents in some chamber which are cured by conditioning).
- **Rate effects** must be verified for inner regions (in principle no problems below $10^{33}cm^{-2}s^{-1}$).
- **M1 will be removed** (p_T given by track finding in the farm).
- **Chambers and electronics spare pools** to be increased (lack of chamber spares) most probably using the long shutdown 2013-2014.
- Better shield for **backsplashes in M5** (under study)



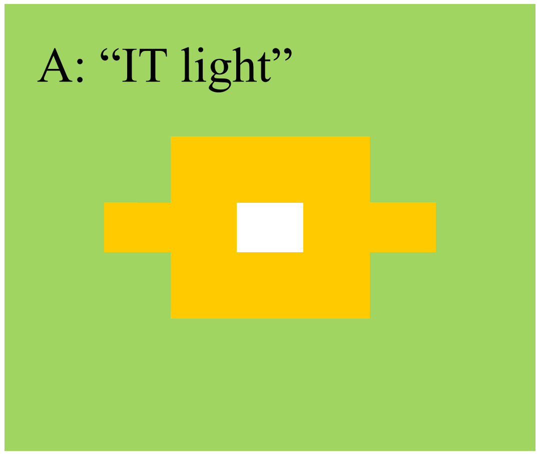
LHCb upgrade: beyond Muon System

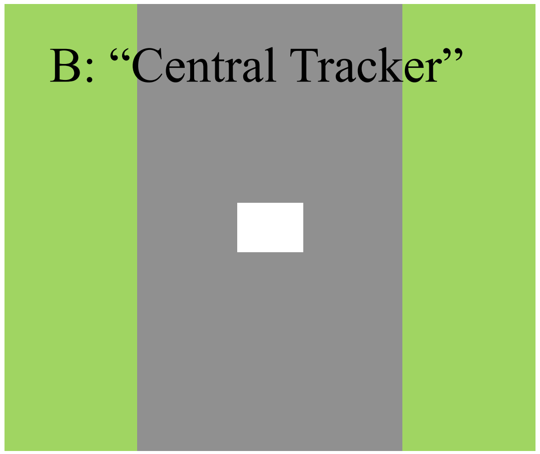
LNF potential interest towards other items, in particular the tracking system.

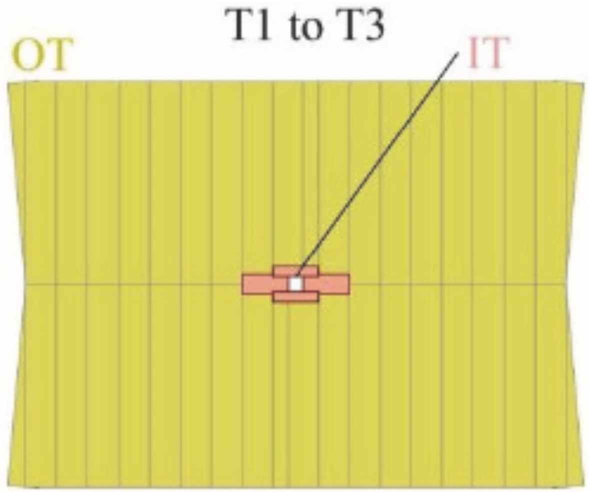
Needed/possible replacement of **central Outer Tracker modules** exposed to radiation and high hits density.

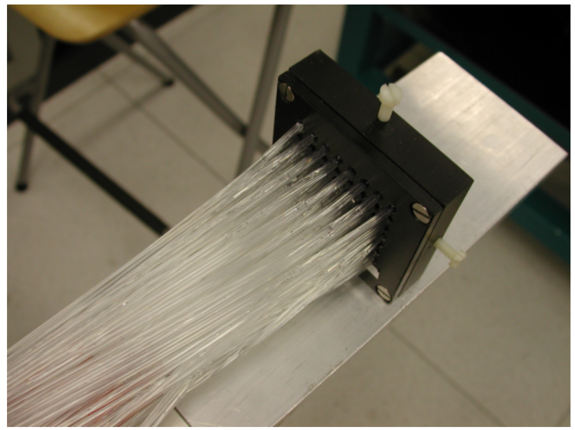
Different technology options under study for T stations:

Straws | Si strips | SciFi









- Ongoing LNF R&D activity on thick SciFi [B.D.Leverington et al. arXiv:1106.5649]
- LNF task force to study/define further possible involvements.

Conclusions and outlook

LHCb detector is working very well, and we experienced a very good data taking.
Plenty of physics results, with more and more statistics.

The **LNF LHCb group** :

- contributed substantially **maintenance and monitoring of the Muon System**: muon chamber efficiency monitoring, offline muon ID validation, calibration and monitoring.

- give active contribution to data taking: **run chief**, **muon piquet** and **data quality** shifts attended.

- full integrated with LHCb analysis WGs, deeply involved in Rare Decays WG (**study of rare decays with muon in the final states**) with a leading role in the LHCb milestone $B_{S,d} \to \mu^+\mu^-$)

- is interested (together with other Italian LHCb groups) in a **possible LHCb upgrade**:
  * already committed for Muon System upgrade and maintenance;
  * ongoing R&D on specific (and new) sub detectors: open opportunities, to be explored in the very next future.

Additional information

2012 LNF LHCb people

F.Archilli	100
G.Bencivenni	70
P.Campana	0 LHCb spokesman!
P.DeSimone	70
G.Lanfranchi	100
F.Murtas	40
M.Palutan	100
A.Sarti	80
B.Sciascia	70
A.Sciubba	70
F. Soomro	100

FTE 8,0

P.Ciambrone	20
G.Felici	20

M.Anelli	50
R.Rosellini	70
M.Santoni	20
A.Saputi	30

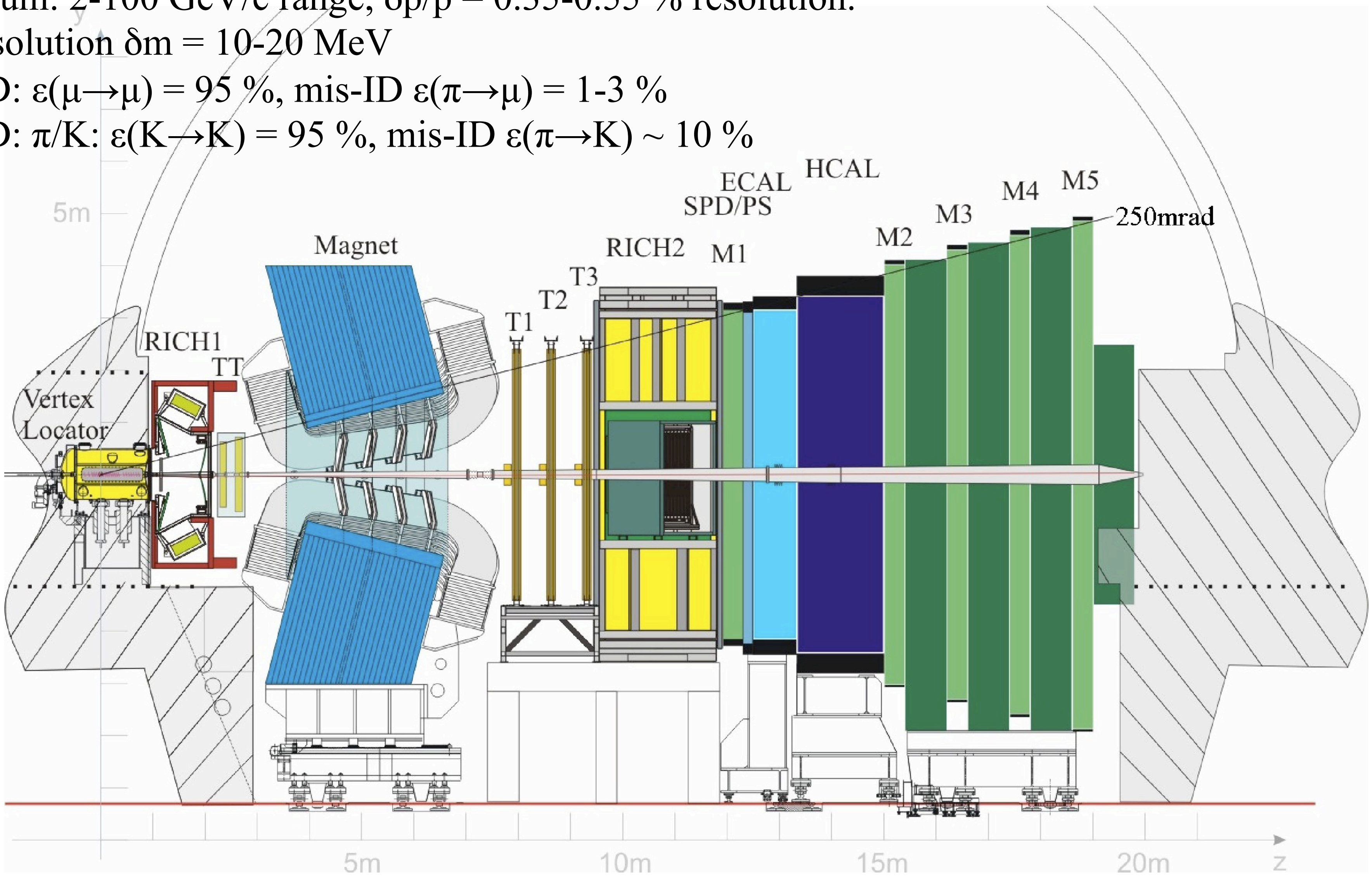
SPCM 4 mesi uomo
SELF 10 mesi uomo

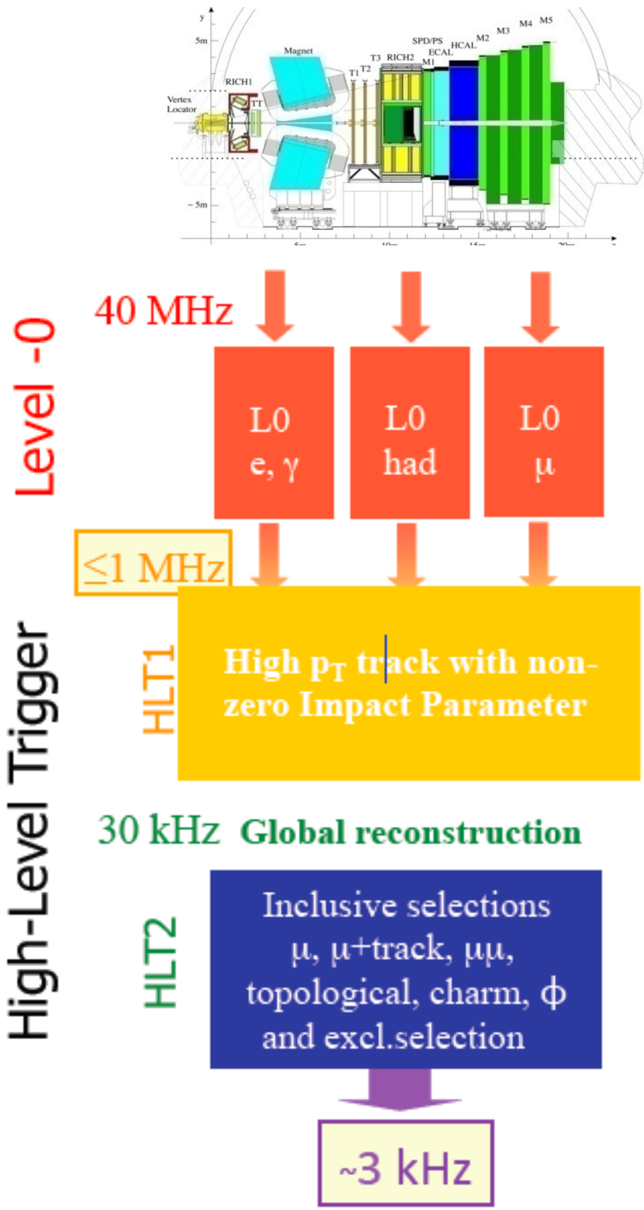
Economical requests (keuro)

ME	106
MI	16
Consumo	26
Inventariabile	5
Costr.Apparati	85

LHCb detector

Decay time resolution δt: 30-50 fs
Momentum: 2-100 GeV/c range, δp/p = 0.35-0.55 % resolution.
Mass resolution δm = 10-20 MeV
Muon ID: ε(μ→μ) = 95 %, mis-ID ε(π→μ) = 1-3 %
RICH ID: π/K: ε(K→K) = 95 %, mis-ID ε(π→K) ~ 10 %

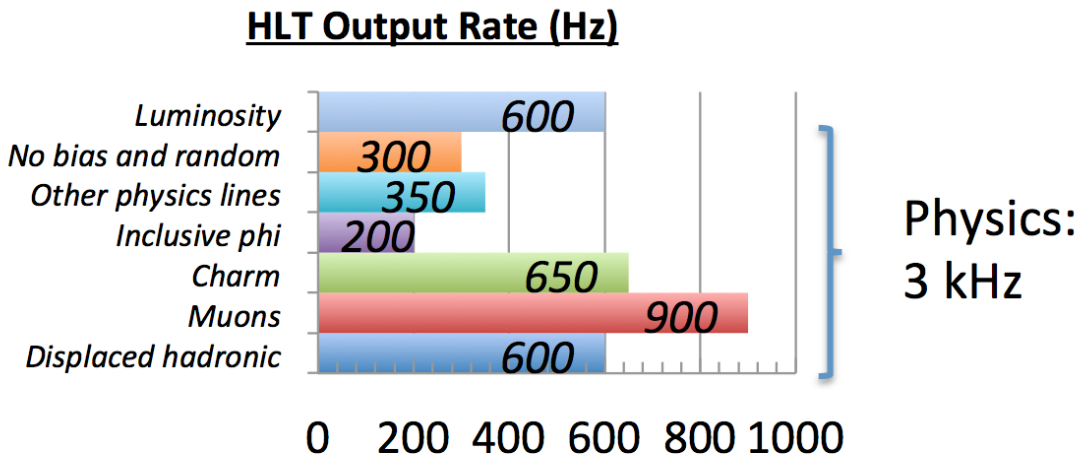




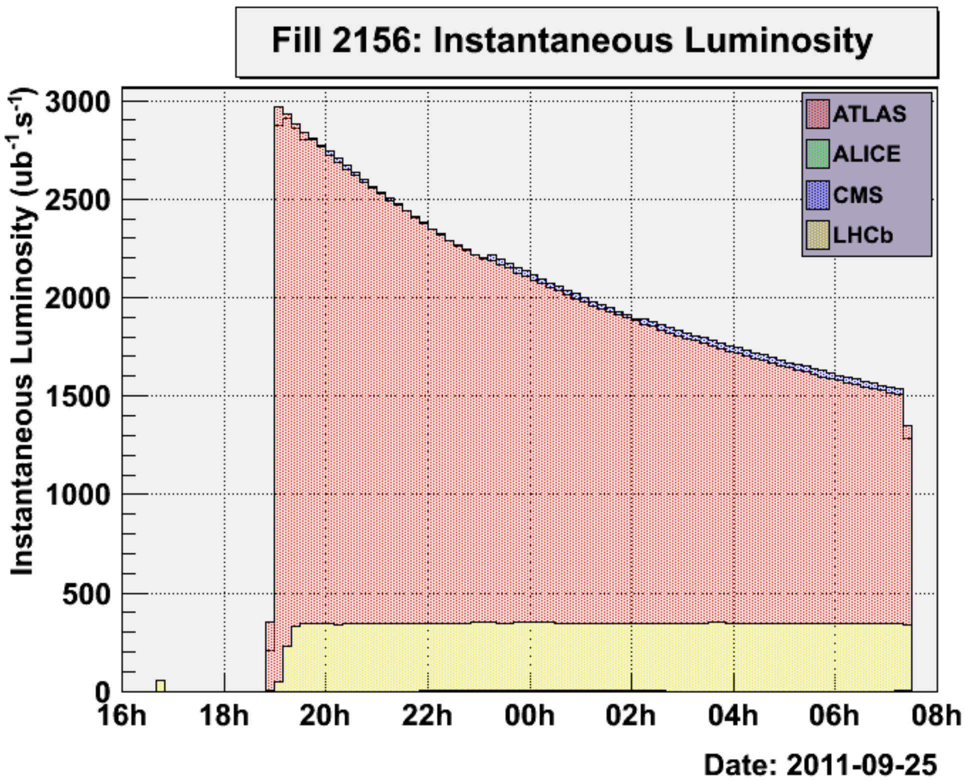
Hardware **Level (L0): ~1 MHz** from high p_T μ, e, γ, hadron candidates (ECAL, HCAL, Muon System).

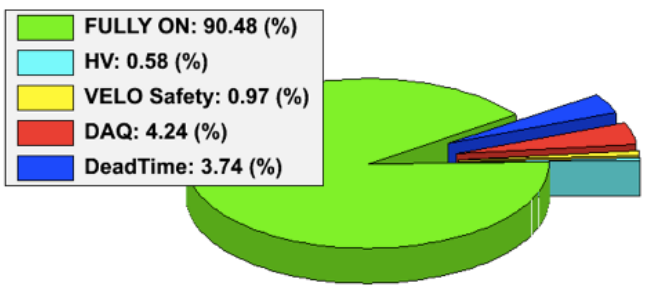
Software Level (High Level Trigger, HLT): access all detector data; farm with ~15000 CPU cores on multi-processor commodity boxes;

- **HLT1: ~30 kHz**; confirm L0 candidate with more complete info, add impact parameter and lifetime cuts.
- **HLT2: ~3 kHz**; global event reconstruction plus selections



Luminosity leveling





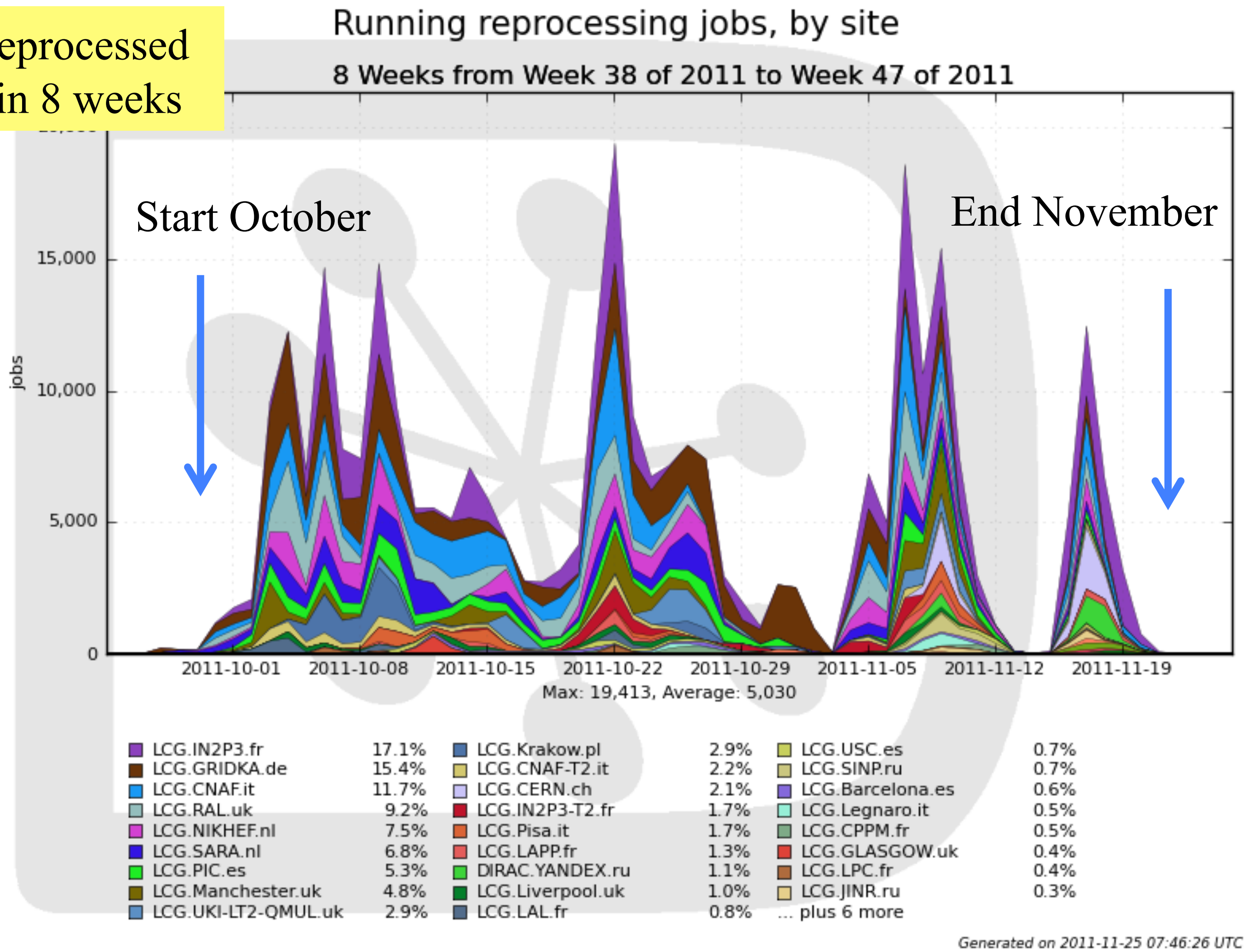
$L \sim 3.5\times10^{32}$ cm^{-2}s^{-1}
Average pileup ~ 1.5

Tested successfully:
$L = 4. \times10^{32}$ cm^{-2}s^{-1}
it is twice the design luminosity.

- We proved LHCb can run at $L=4.\times 10^{32}$ cm^{-2}s^{-1}: collect more than 1.5 fb^{-1} per year of data taking.
- Plan: run one year at $\sqrt{s}$=7 TeV, then move up to $\sqrt{s}$=14 TeV, for three years, until 2017.
- 2017 integrated luminosity: **~6 fb^{-1}** equivalent to $\sqrt{s}$=14 TeV.

2011 reprocessing

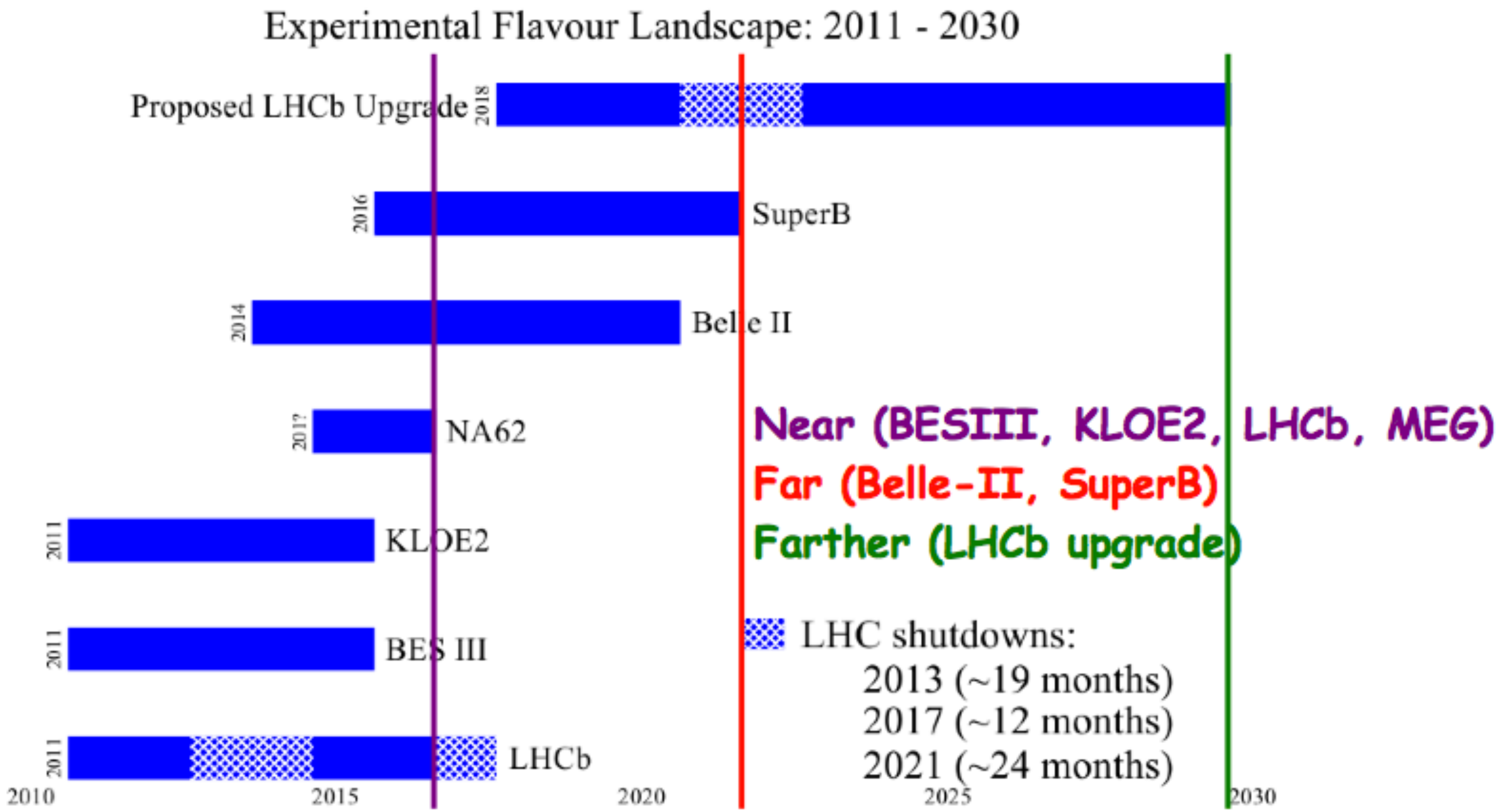
2011 data reprocessed completed in 8 weeks



CERN not used for reprocessing (dedicated to processing incoming data)
Around 25 % of reprocessing jobs ran on Tier 2 sites

LHCb versus SuperB

The timeline of flavor physics



Dates that matter are when full samples are collected

Marco Ciuchini CSN1 – Firenze - 22 November 2011 Page 5

LHCb versus SuperB

What SuperB cannot do*

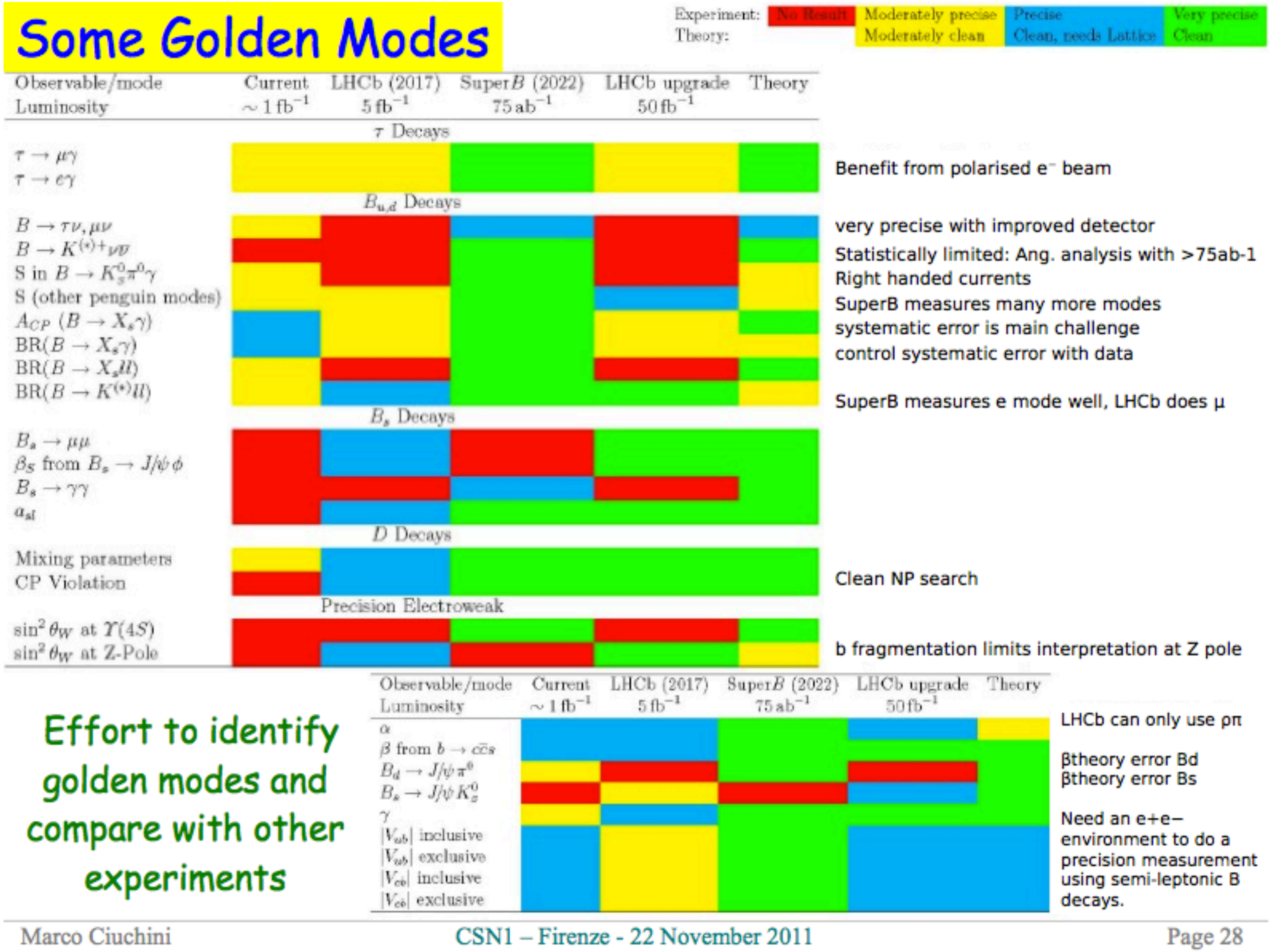
Golden modes of other flavor experiments

Observable	Current value	Experiment	Precision
$\mathrm{BR}(B_s \to \mu\mu)$ $(\times 10^{-9})$	$< 15^a$	LHCb	± 1
		LHCb upgrade	± 0.3
$2\beta_s$ from $B_s^0 \to J/\psi\phi$ (rad)	0.13 ± 0.19^b	LHCb	0.019
		LHCb upgrade	0.006
S in $B_s \to \phi\gamma$		LHCb	0.07
		LHCb upgrade	0.02
$K^+ \to \pi^+\nu\overline{\nu}$ (% BR measurement)	7 events	NA62	100 events (10%)
$K_L^0 \to \pi^0\nu\overline{\nu}$		KOTO	3 events (observe)
$BR(\mu \to e\gamma)$ $(\times 10^{-13})$	< 280	MEG	< 1
$R_{\mu e}$	$< 7 \times 10^{-12}$	COMET/Mu2E	$< 6 \times 10^{-17}$

* with competitive performances

Marco Ciuchini CSN1 – Firenze - 22 November 2011 Page 6

LHCb versus SuperB



Muon Identification

Definitions:

Two steps needed to "have a μ" in the event:

- pass through the Muon System: **geometrical acceptance** (***MuAcc*** flag);
- produce a signal in the Muon System: **efficiency** (***IsMuon*** flag, **given** ***MuAcc***).

Samples:

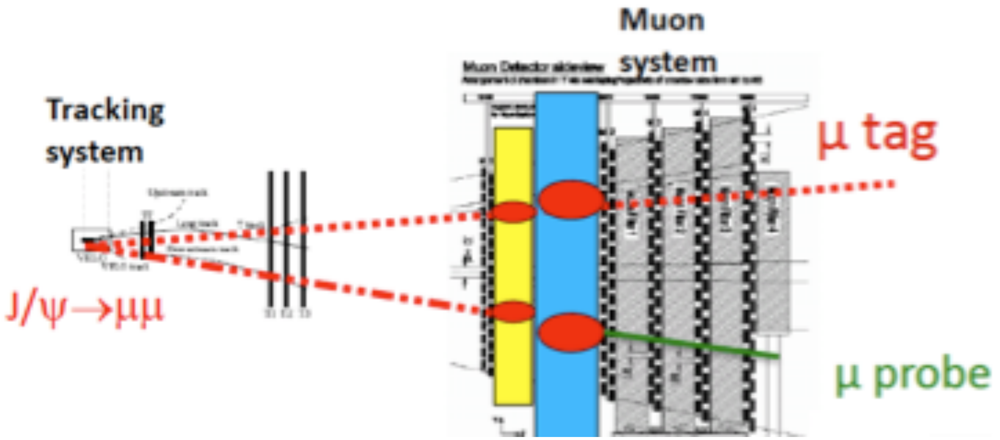
Data: ~1 fb^{-1} from two suitable calibration lines: $B \rightarrow J/\psi X$ and $B^+ \rightarrow J/\psi K^+$ events.

MC: ~300 pb^{-1} equivalent.

Methods:

- Tag-and-probe, fit and bkg subtraction;
- Systematic error determined for different:

ε determination, background subtraction, εtrigger unbias, parameterization, sample,…



Results:

1D: acceptance and efficiency corrections as a function of the p **or** p_T of probe.

2D: acceptance and efficiency corrections as a function of (p,p_T); for p_T same binning as misID study.

Universal curves: needed to all analysis involving muons

Muon Identification: techincalities

- two methods to measure ε(μID):

0) $$\epsilon_{tot} = \frac{S}{S+B}\epsilon_{muonID} + \frac{B}{S+B}\epsilon_{bkg}$$

1) $$\epsilon_{muonID} = \frac{N_{\mu_{probe}}(IsMuon=1)}{N_{\mu_{probe}}(IsMuon=1) + N_{\mu_{probe}}(IsMuon=0)}$$

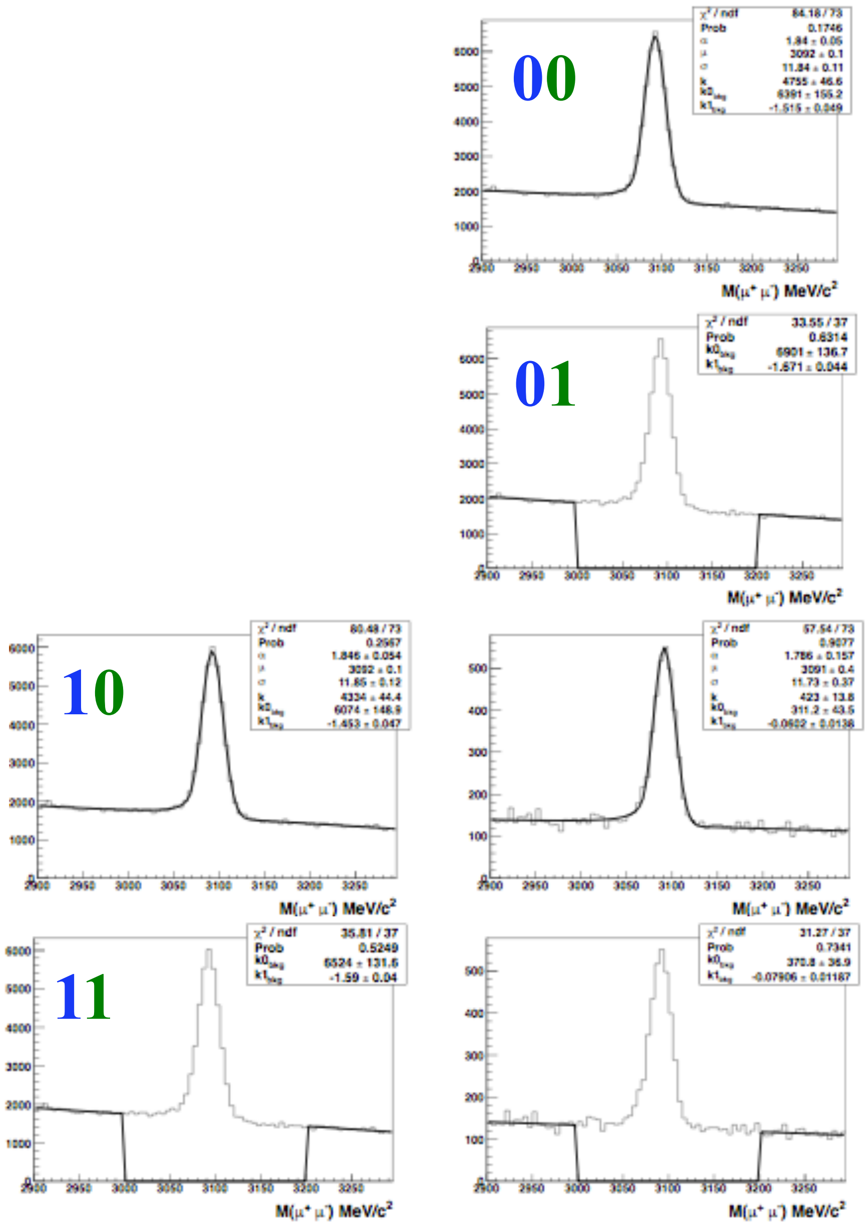
- two S,B determinations:

0) full signal plus background lineshape (Crystal Ball + linear bkg)

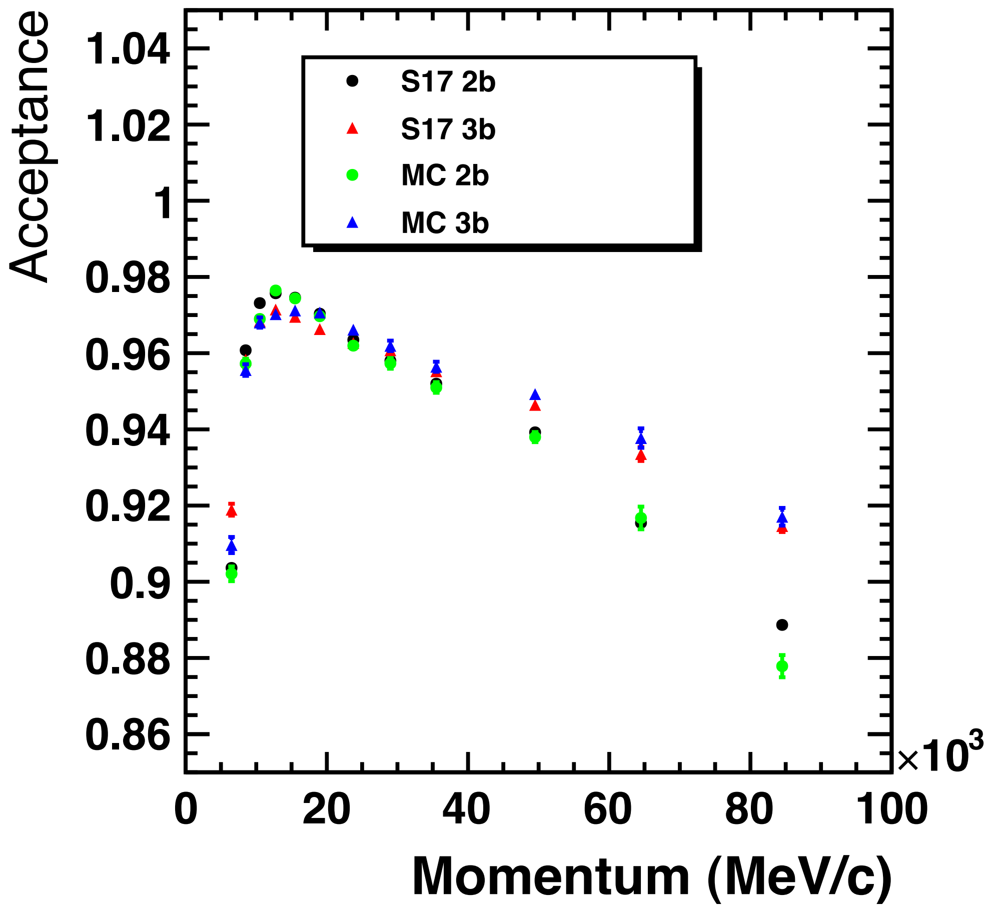
1) background subtraction from linear fit to the mass side band

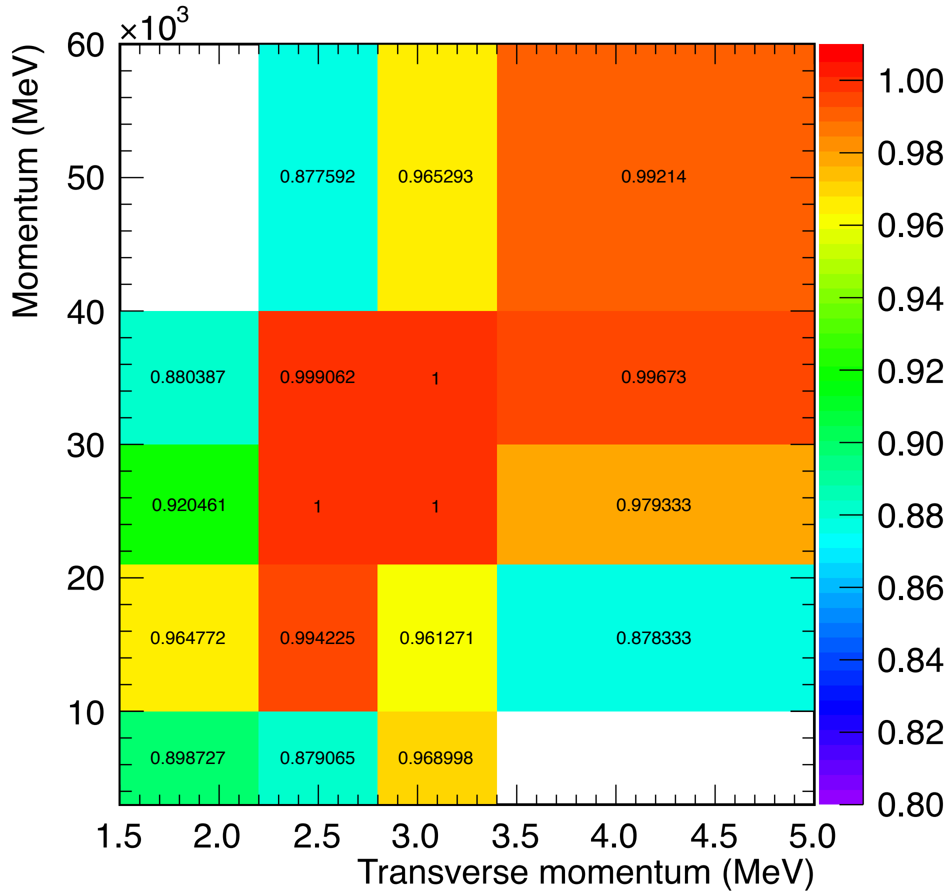
Four possible combinations; allow to determine the systematic error due to method and bkg subtraction

- combinations **agree within 0.1%** a part 0.5% difference for 00 combination



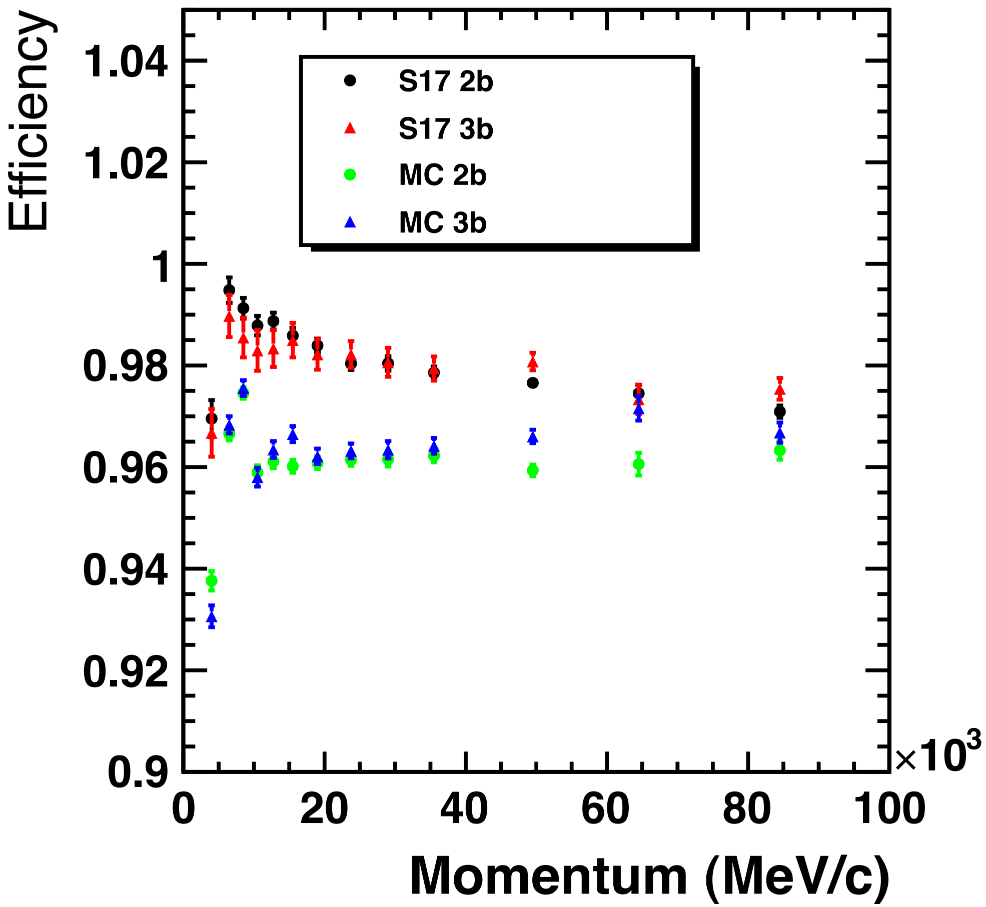
Acceptance: 2D (p,p_T) vs 1D p

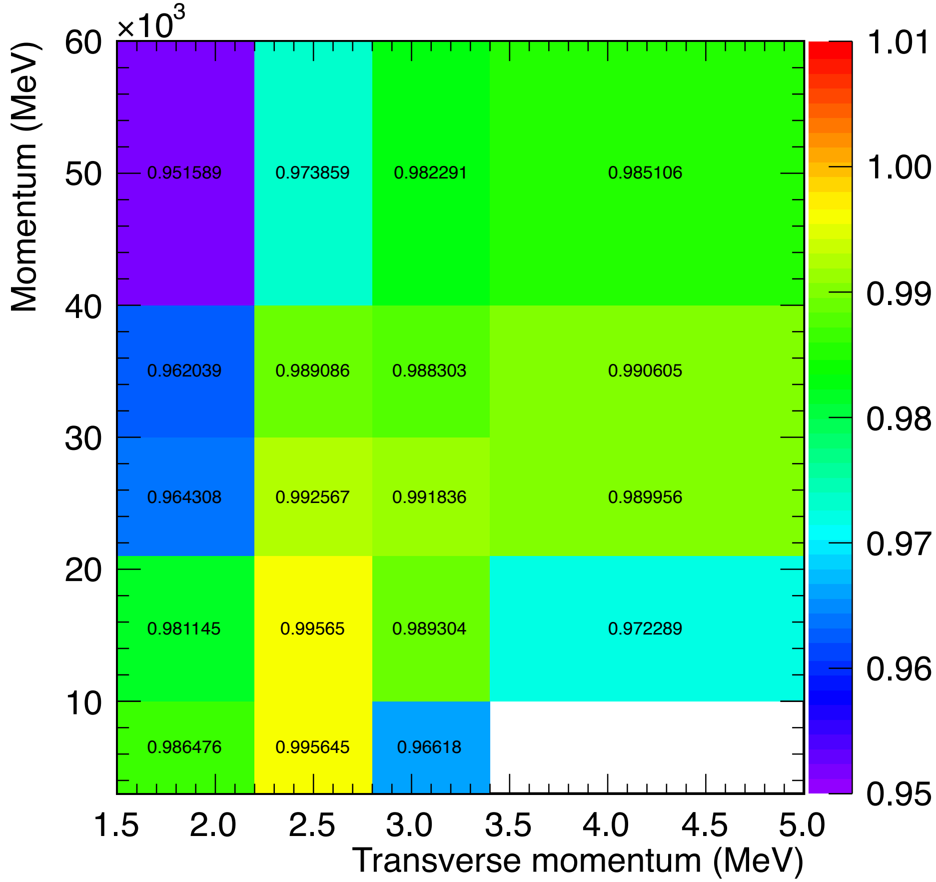




Acceptance, measured on data for the 2-body (*JpsiFormB*) sample

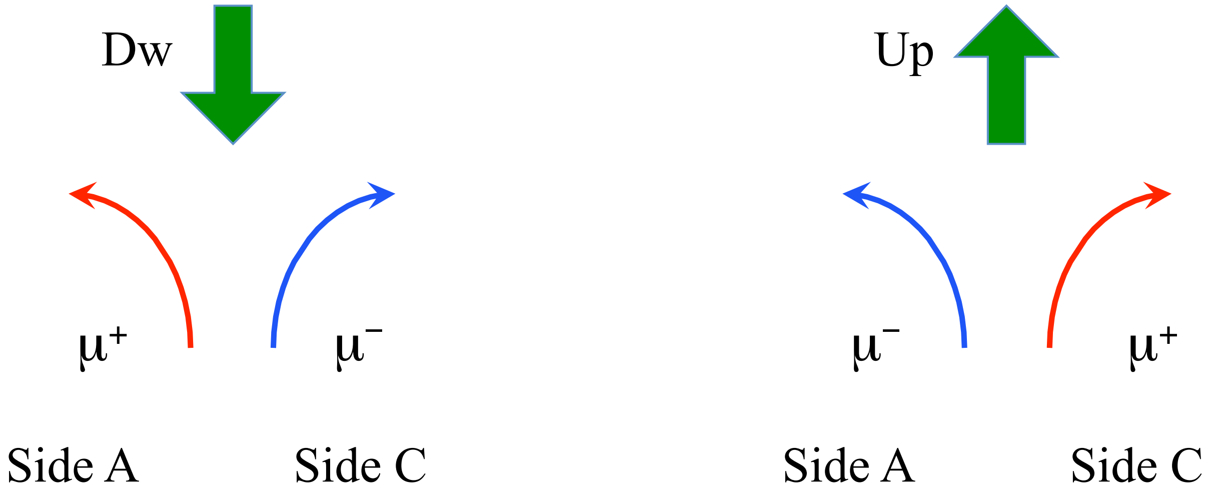
Efficiency: 2D (p,p_T) vs 1D p





Efficiency, measured on data for the 2-body (*JpsiFormB*) sample

Digression on detector (A)symmetries



Same side: muons of different charge behave in the same way in the same side

Side A: Up-μ^- = Dw-μ^+

Side C: Up-μ^+ = Dw-μ^- << **test this combination.**

Same charge: muons with same charge behave in the same way in opposite side

μ^-: Dw-μ^- (Side C) = Up-μ^- (Side A)

μ^+: Up-μ^+ (Side C) = Dw-μ^+ (Side A)

$B_s\mu\mu$ upper limit: summer 2011

BR limits at 95%CL

LHCb: 1.6×10^{-8} L~300 pb^{-1}

LHCb-CONF-2011-037

CMS: 1.9×10^{-8} L~1.1 fb^{-1}

Phys. Rev. Lett. 107 (2011) 191802

LHCb+CMS: 1.1×10^{-8}

LHCb-CONF-2011-047

CMS PAS BPH-11-019

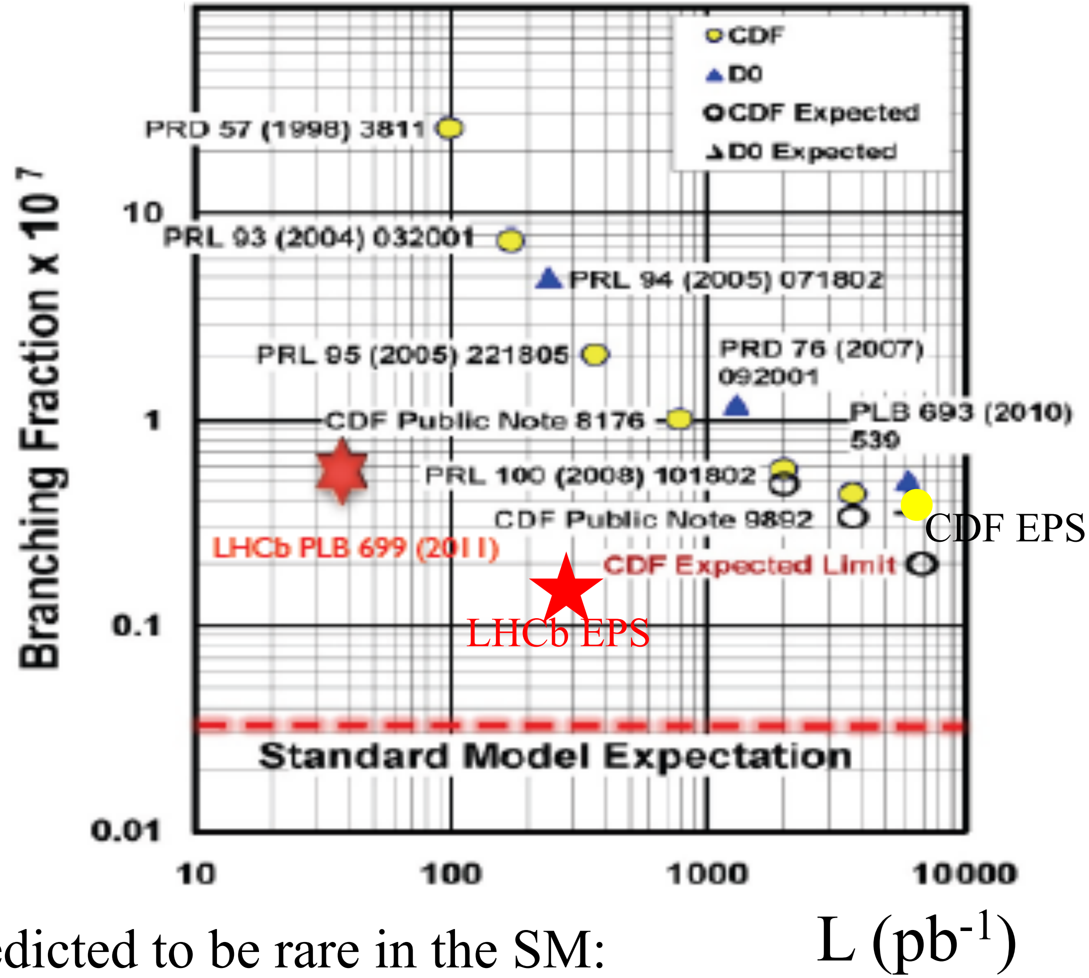
CDF: 4.0×10^{-8} L~7 fb^{-1}

Phys. Rev. Lett. 107 (2011) 191801

D0: 5.1×10^{-8} L~6.1 fb^{-1}

Phys. Lett. B693 (2010) 539

The past 13 years

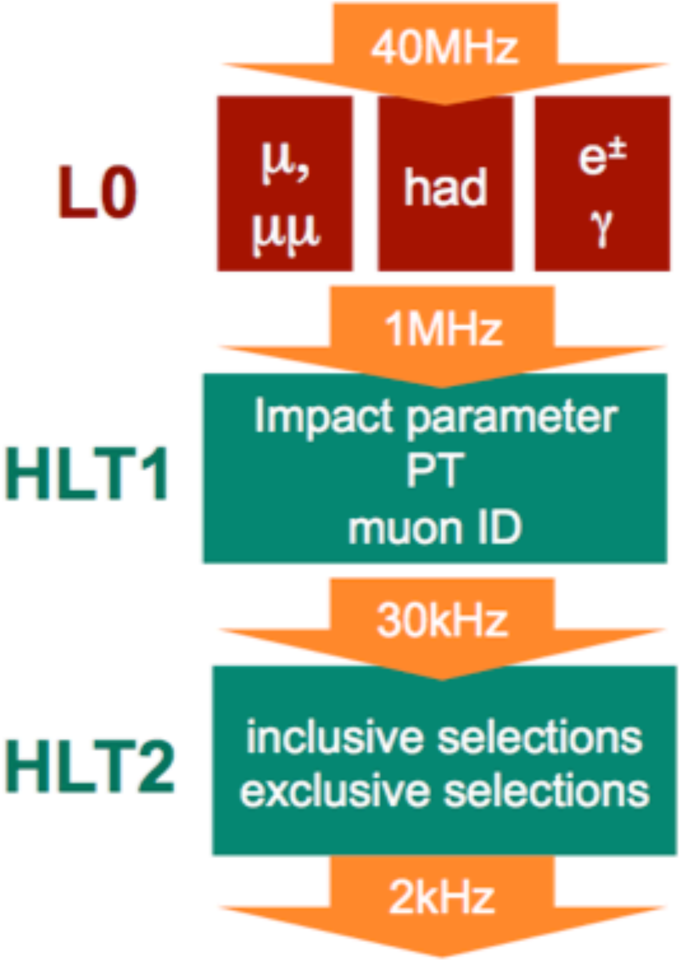


Predicted to be rare in the SM:

$BR(B_s\to\mu\mu) = (3.2\pm0.2)\times10^{-9}$

$BR(B_d\to\mu\mu) = (0.10\pm0.01)\times10^{-9}$

Trigger for $B_{S,d}\mu\mu$



	Muon Lines
L0	Single- μ: p_T> 1.4 GeV/c μμ: p_{T1}>0.56 GeV/c p_{T2}>0.48 GeV/c
HLT1	single-μ: p_T>0.8 GeV/c IP>0.11 mm single-μ: p_T>1.8 GeV/c (no IP)
HLT2	Several lines with $M_{\mu\mu}$ cuts and/or displaced vertex

- Half of the bandwidth (~1 kHz) given to the muon lines
- p_T cuts on muon lines kept very low → ε(trigger $B_{sd}\rightarrow\mu\mu$) ~ 90%
- Trigger rather stable during the whole period (despite L increased by $\sim 10^5$)

$B_{s,d}\mu\mu$ (370 pb^{-1}) result

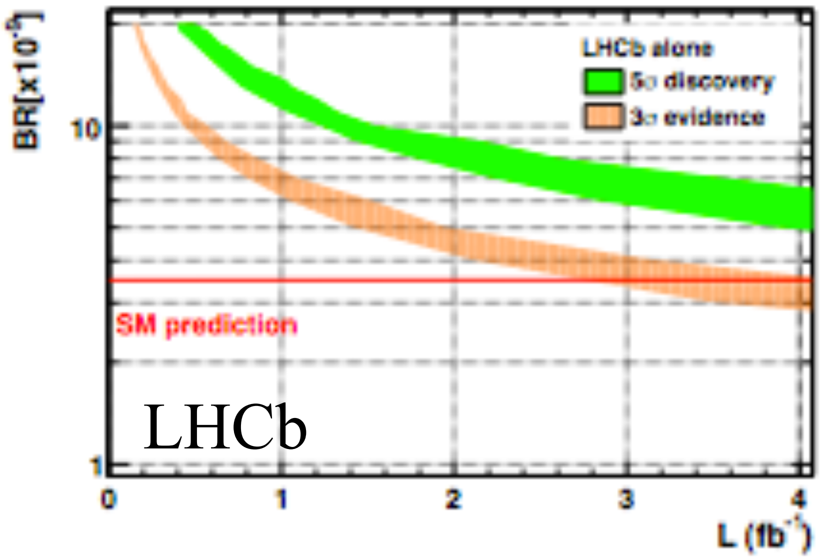
$B_s\mu\mu$

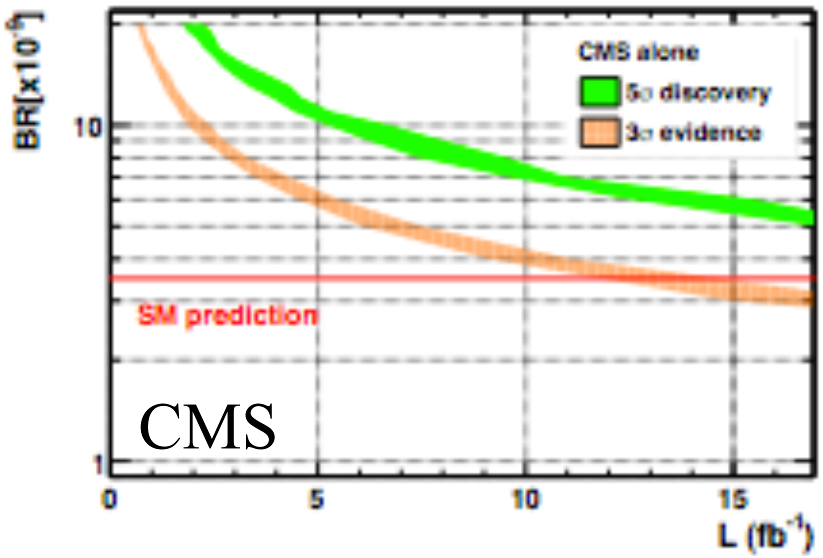
Invariant mass [MeV/c^2]		BDT 0. – 0.25	BDT 0.25 – 0.5	BDT 0.5 – 0.75	BDT 0.75 – 1.
5298 – 5318	Expected comb. bkg	$575.5^{+6.5}_{-6.0}$	$6.96^{+0.63}_{-0.57}$	$1.19^{+0.39}_{-0.35}$	$0.111^{+0.083}_{-0.066}$
	Expected peak. bkg	$0.126^{+0.037}_{-0.030}$	$0.124^{+0.037}_{-0.030}$	$0.124^{+0.037}_{-0.030}$	$0.127^{+0.038}_{-0.031}$
	Expected signal	$0.059^{+0.023}_{-0.022}$	$0.0329^{+0.0128}_{-0.0095}$	$0.0415^{+0.0120}_{-0.0085}$	$0.0411^{+0.0135}_{-0.0099}$
	Observed	533	10	1	0
5318 – 5338	Expected comb. bkg	$566.8^{+6.3}_{-5.8}$	$6.90^{+0.61}_{-0.55}$	$1.16^{+0.38}_{-0.34}$	$0.109^{+0.079}_{-0.063}$
	Expected peak. bkg	$0.052^{+0.023}_{-0.018}$	$0.054^{+0.026}_{-0.019}$	$0.052^{+0.024}_{-0.018}$	$0.051^{+0.023}_{-0.018}$
	Expected signal	$0.205^{+0.073}_{-0.074}$	$0.114^{+0.040}_{-0.031}$	$0.142^{+0.036}_{-0.025}$	$0.142^{+0.042}_{-0.031}$
	Observed	525	9	0	1
5338 – 5358	Expected comb. bkg	$558.2^{+6.1}_{-5.6}$	$6.84^{+0.59}_{-0.54}$	$1.14^{+0.37}_{-0.33}$	$0.106^{+0.075}_{-0.060}$
	Expected peak. bkg	$0.024^{+0.028}_{-0.012}$	$0.025^{+0.026}_{-0.012}$	$0.024^{+0.027}_{-0.012}$	$0.025^{+0.025}_{-0.012}$
	Expected signal	$0.38^{+0.14}_{-0.14}$	$0.213^{+0.075}_{-0.058}$	$0.267^{+0.065}_{-0.047}$	$0.265^{+0.077}_{-0.058}$
	Observed	561	6	2	1
5358 – 5378	Expected comb. bkg	$549.8^{+6.0}_{-5.4}$	$6.77^{+0.57}_{-0.52}$	$1.11^{+0.36}_{-0.32}$	$0.103^{+0.073}_{-0.057}$
	Expected peak. bkg	$0.0145^{+0.0220}_{-0.0091}$	$0.0151^{+0.0230}_{-0.0091}$	$0.0153^{+0.0232}_{-0.0098}$	$0.015^{+0.023}_{-0.010}$
	Expected signal	$0.38^{+0.14}_{-0.14}$	$0.213^{+0.075}_{-0.057}$	$0.267^{+0.065}_{-0.047}$	$0.265^{+0.077}_{-0.057}$
	Observed	515	7	0	0
5378 – 5398	Expected comb. bkg	$541.5^{+5.8}_{-5.3}$	$6.71^{+0.55}_{-0.51}$	$1.09^{+0.34}_{-0.31}$	$0.101^{+0.070}_{-0.054}$
	Expected peak. bkg	$0.0115^{+0.0175}_{-0.0086}$	$0.0116^{+0.0177}_{-0.0090}$	$0.0118^{+0.0179}_{-0.0090}$	$0.0118^{+0.0179}_{-0.0088}$
	Expected signal	$0.204^{+0.073}_{-0.074}$	$0.114^{+0.040}_{-0.031}$	$0.142^{+0.036}_{-0.026}$	$0.141^{+0.042}_{-0.031}$
	Observed	547	10	1	1
5398 – 5418	Expected comb. bkg	$533.4^{+5.7}_{-5.2}$	$6.65^{+0.53}_{-0.49}$	$1.07^{+0.34}_{-0.30}$	$0.098^{+0.068}_{-0.051}$
	Expected peak. bkg	$0.0089^{+0.0136}_{-0.0065}$	$0.0088^{+0.0133}_{-0.0066}$	$0.0091^{+0.0138}_{-0.0070}$	$0.0090^{+0.0137}_{-0.0065}$
	Expected signal	$0.058^{+0.024}_{-0.021}$	$0.0323^{+0.0128}_{-0.0093}$	$0.0407^{+0.0120}_{-0.0087}$	$0.0402^{+0.0137}_{-0.0097}$
	Observed	501	4	1	0

$B_d\mu\mu$

Invariant mass [MeV/c^2]		BDT 0. – 0.25	BDT 0.25 – 0.5	BDT 0.5 – 0.75	BDT 0.75 – 1.
5212 – 5232	Expected comb. bkg	$614.2^{+7.5}_{-7.0}$	$7.23^{+0.77}_{-0.68}$	$1.31^{+0.46}_{-0.40}$	$0.123^{+0.107}_{-0.072}$
	Expected peak. bkg	$0.203^{+0.038}_{-0.034}$	$0.206^{+0.038}_{-0.034}$	$0.203^{+0.037}_{-0.034}$	$0.205^{+0.038}_{-0.034}$
	Cross-feed	$0.0056^{+0.0021}_{-0.0020}$	$0.00312^{+0.00119}_{-0.00087}$	$0.00391^{+0.00107}_{-0.00078}$	$0.00387^{+0.00122}_{-0.00092}$
	Expected signal	$0.0070^{+0.0027}_{-0.0026}$	$0.0039^{+0.0015}_{-0.0011}$	$0.0049^{+0.0014}_{-0.0010}$	$0.0048^{+0.0016}_{-0.0012}$
	Observed	554	6	0	2
5232 – 5252	Expected comb. bkg	$605.0^{+7.2}_{-6.8}$	$7.17^{+0.74}_{-0.65}$	$1.29^{+0.44}_{-0.39}$	$0.121^{+0.102}_{-0.072}$
	Expected peak. bkg	$0.281^{+0.056}_{-0.049}$	$0.279^{+0.056}_{-0.049}$	$0.280^{+0.056}_{-0.049}$	$0.280^{+0.058}_{-0.050}$
	Cross-feed	$0.0071^{+0.0027}_{-0.0026}$	$0.0039^{+0.0015}_{-0.0011}$	$0.00496^{+0.00134}_{-0.00099}$	$0.0049^{+0.0016}_{-0.0012}$
	Expected signal	$0.0241^{+0.0086}_{-0.0087}$	$0.0135^{+0.0048}_{-0.0037}$	$0.0169^{+0.0042}_{-0.0031}$	$0.0167^{+0.0050}_{-0.0037}$
	Observed	556	4	2	1
5252 – 5272	Expected comb. bkg	$595.9^{+7.0}_{-6.5}$	$7.10^{+0.71}_{-0.63}$	$1.26^{+0.42}_{-0.37}$	$0.119^{+0.097}_{-0.072}$
	Expected peak. bkg	$0.323^{+0.075}_{-0.061}$	$0.326^{+0.074}_{-0.061}$	$0.324^{+0.072}_{-0.060}$	$0.325^{+0.075}_{-0.062}$
	Cross-feed	$0.0097^{+0.0036}_{-0.0035}$	$0.0054^{+0.0021}_{-0.0015}$	$0.0068^{+0.0018}_{-0.0013}$	$0.0067^{+0.0021}_{-0.0016}$
	Expected signal	$0.045^{+0.016}_{-0.016}$	$0.0252^{+0.0088}_{-0.0067}$	$0.0317^{+0.0077}_{-0.0057}$	$0.0313^{+0.0093}_{-0.0068}$
	Observed	588	11	1	0
5272 – 5292	Expected comb. bkg	$586.9^{+6.7}_{-6.3}$	$7.04^{+0.68}_{-0.60}$	$1.23^{+0.41}_{-0.36}$	$0.117^{+0.092}_{-0.071}$
	Expected peak. bkg	$0.252^{+0.058}_{-0.047}$	$0.252^{+0.056}_{-0.046}$	$0.253^{+0.059}_{-0.048}$	$0.250^{+0.056}_{-0.046}$
	Cross-feed	$0.0154^{+0.0058}_{-0.0055}$	$0.0086^{+0.0033}_{-0.0024}$	$0.0108^{+0.0029}_{-0.0021}$	$0.0106^{+0.0033}_{-0.0025}$
	Expected signal	$0.045^{+0.016}_{-0.016}$	$0.0251^{+0.0089}_{-0.0067}$	$0.0317^{+0.0077}_{-0.0057}$	$0.0313^{+0.0092}_{-0.0069}$
	Observed	616	5	2	1
5292 – 5312	Expected comb. bkg	$578.1^{+6.5}_{-6.1}$	$6.98^{+0.66}_{-0.58}$	$1.20^{+0.39}_{-0.35}$	$0.114^{+0.087}_{-0.067}$
	Expected peak. bkg	$0.124^{+0.023}_{-0.021}$	$0.124^{+0.023}_{-0.021}$	$0.123^{+0.023}_{-0.021}$	$0.124^{+0.023}_{-0.021}$
	Cross-feed	$0.038^{+0.015}_{-0.014}$	$0.0214^{+0.0086}_{-0.0061}$	$0.0270^{+0.0080}_{-0.0056}$	$0.0266^{+0.0089}_{-0.0064}$
	Expected signal	$0.0241^{+0.0086}_{-0.0087}$	$0.0134^{+0.0048}_{-0.0036}$	$0.0169^{+0.0042}_{-0.0030}$	$0.0167^{+0.0050}_{-0.0037}$
	Observed	549	7	0	0
5312 – 5332	Expected comb. bkg	$569.3^{+6.3}_{-5.9}$	$6.92^{+0.63}_{-0.57}$	$1.18^{+0.38}_{-0.34}$	$0.111^{+0.083}_{-0.064}$
	Expected peak. bkg	$0.047^{+0.023}_{-0.012}$	$0.047^{+0.022}_{-0.012}$	$0.047^{+0.021}_{-0.012}$	$0.047^{+0.021}_{-0.012}$
	Cross-feed	$0.149^{+0.055}_{-0.054}$	$0.083^{+0.031}_{-0.022}$	$0.104^{+0.027}_{-0.019}$	$0.103^{+0.031}_{-0.023}$
	Expected signal	$0.0068^{+0.0028}_{-0.0026}$	$0.0038^{+0.0015}_{-0.0011}$	$0.0048^{+0.0014}_{-0.0010}$	$0.0048^{+0.0016}_{-0.0012}$
	Observed	509	10	1	1

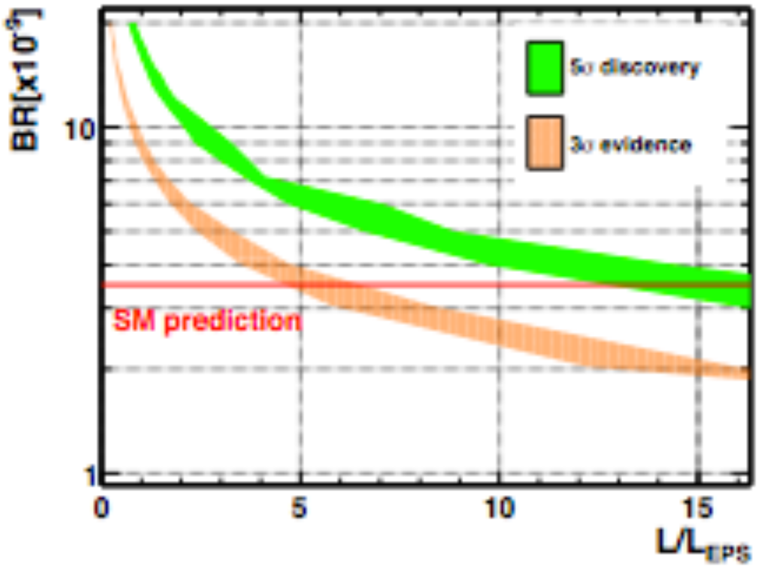
$B_S\mu\mu$: extrapolated sensitivity





Required luminosity for a 3σ evidence or a 5σ discovery of a given BR($B_S\mu\mu$) for **LHCb and CMS**.

$B_s\mu\mu$: extrapolated sensitivity

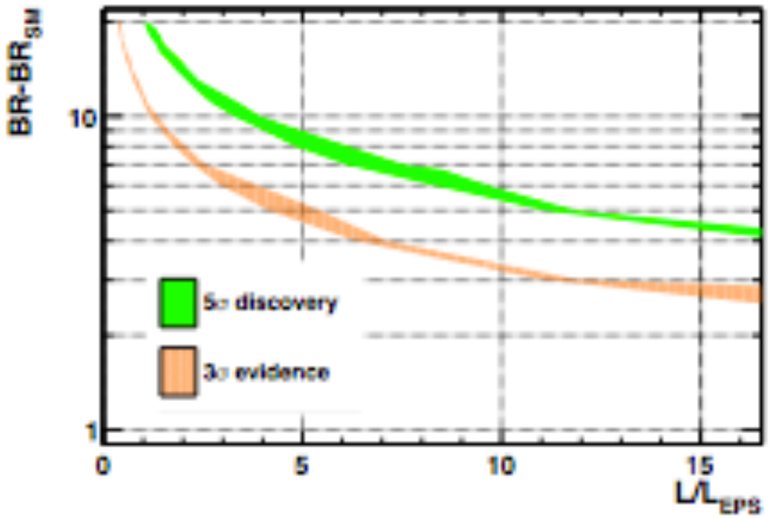


(luminosity in terms of used luminosity: LHCb 0.34 fb^{-1}, CMS 1.14 fb^{-1})

Required luminosity for a **3σ evidence** or a 5σ discovery of a given BR($B_s\mu\mu$) for **LHCb and CMS combined**.

For **LHCb**: evidence ~1.7 fb^{-1}, **discovery ~5.1 fb^{-1}**.

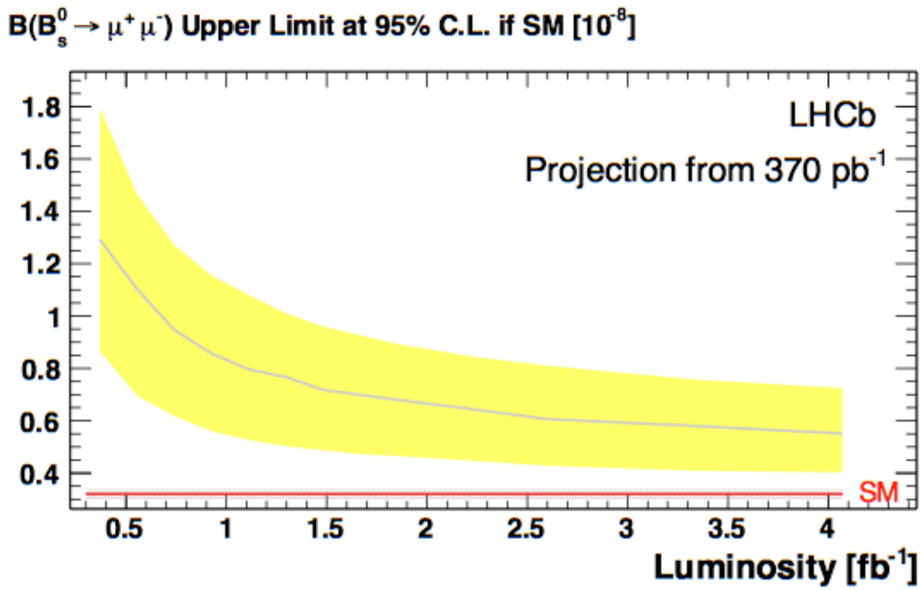
[arXiv:1108.3018]

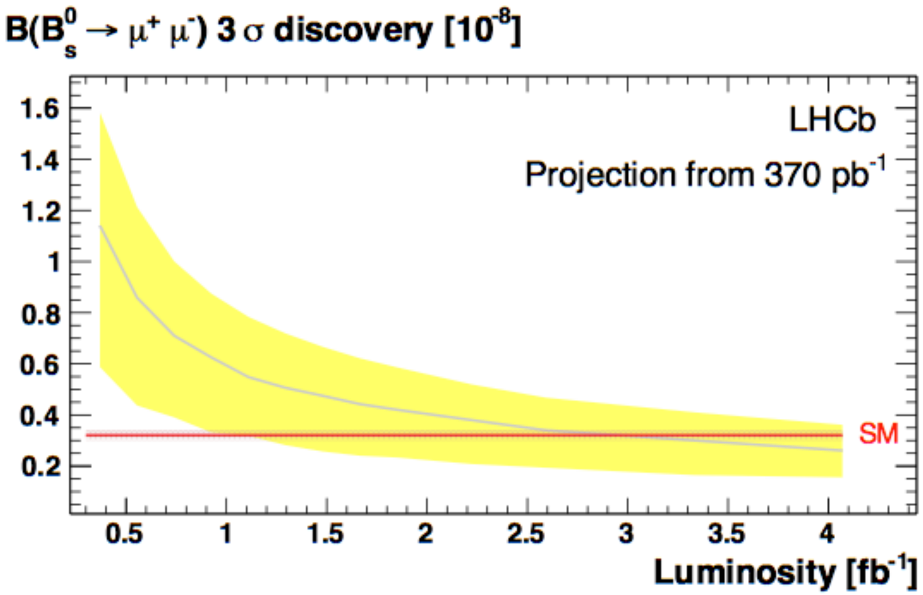


Required luminosity for a **3σ evidence** or a 5σ discovery of a given precision to which **LHCb and CMS combined** can constrain contributions exceeding BR($B_s\mu\mu$) SM.

Once the $B_s \rightarrow \mu\mu$ is measured, we can start constraining the B_d/B_s ratio, which is of prime interest for the MFV scenario.

$B_S\mu\mu$: extrapolated sensitivity





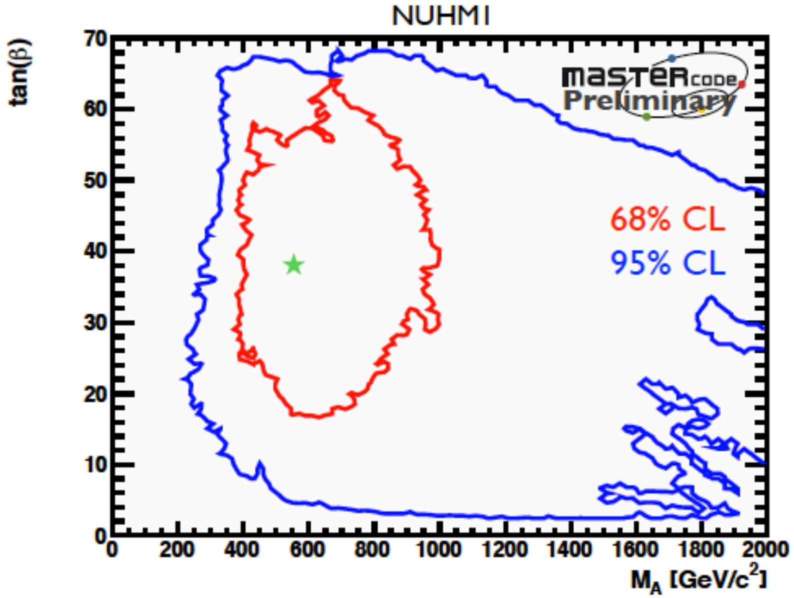
7 TeV run

Upper limit extrapolation
in the presence of SM signal

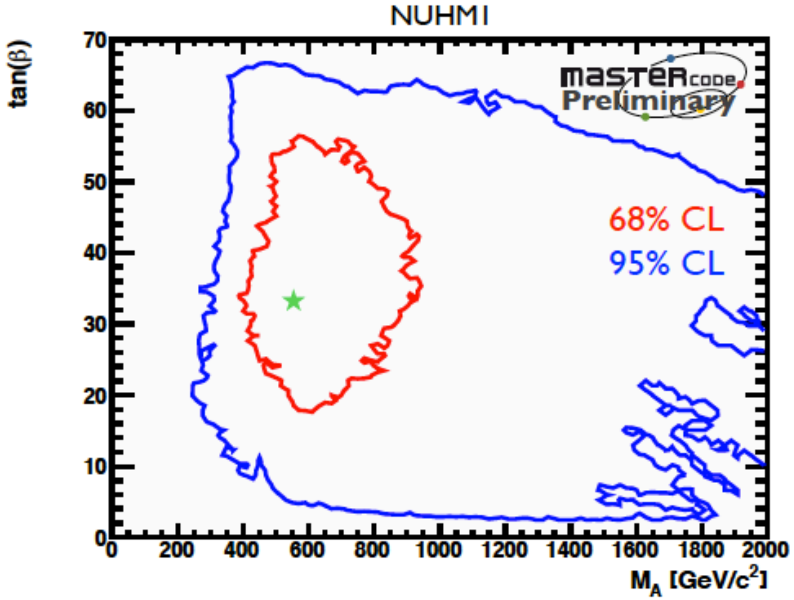
Observation:
a 3σ evidence of SM signal
observation is possible within
the end of 7 TeV run.

Global fit and $B_{S,d}\mu\mu$

- LHC 2011 MET searches only



- LHC 2011 MET searches and $B_s \rightarrow \mu\mu$



$B_S \rightarrow \mu\mu$ upper limit pushes tanβ down (opposite direction wrt direct searches)

a valuable benchmark of any BSM theory in large tanβ regime

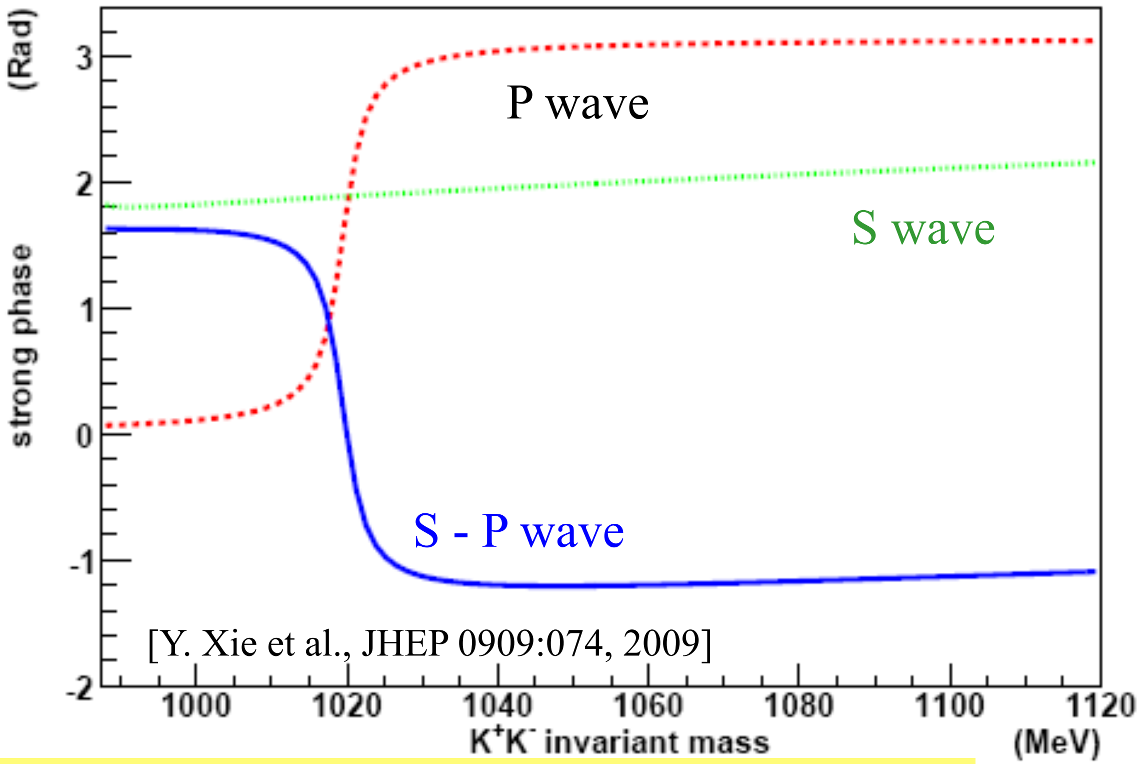
ϕ_s: Ambiguity Resolution

Use few % S wave KK present in the sample

$$(\phi_s, \Delta\Gamma_s, \delta_\parallel - \delta_0, \delta_\perp - \delta_0, \delta_s - \delta_0) \longleftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, \delta_0 - \delta_\parallel, \pi + \delta_0 - \delta_\perp, \delta_0 - \delta_s)$$

K^+K^- P-wave:
Phase of Breit-Wigner increases rapidly across $\phi(1020)$ resonance

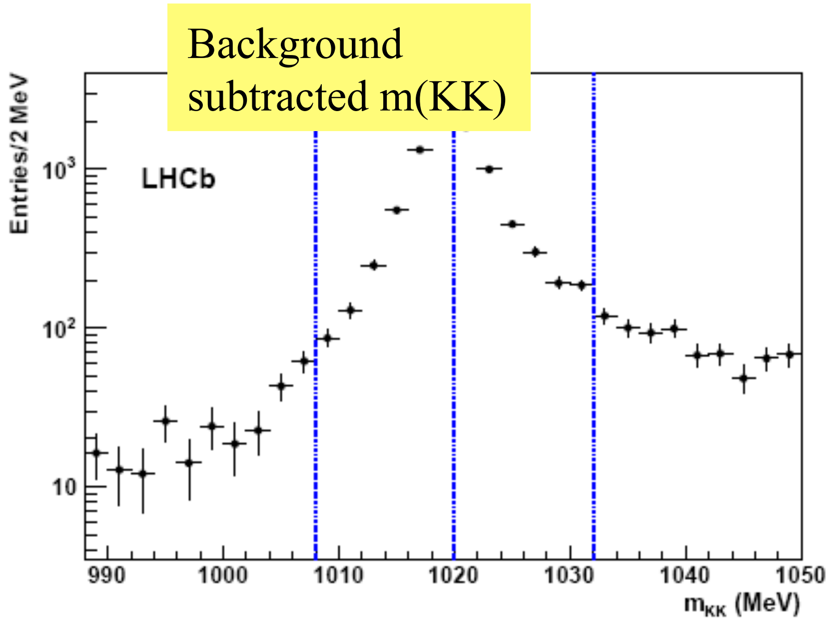
K^+K^- S-wave:
Phase of Flatté amplitude for $f_0(980)$ relatively flat (similar for non-resonance)



Choose the solution with a decreasing trend of δ_s- δ_P vs m_{KK} in the $\phi(1020)$ mass region

Similar to Babar measurement of sign of cos(2β), PRD 71, 032005 (2007)

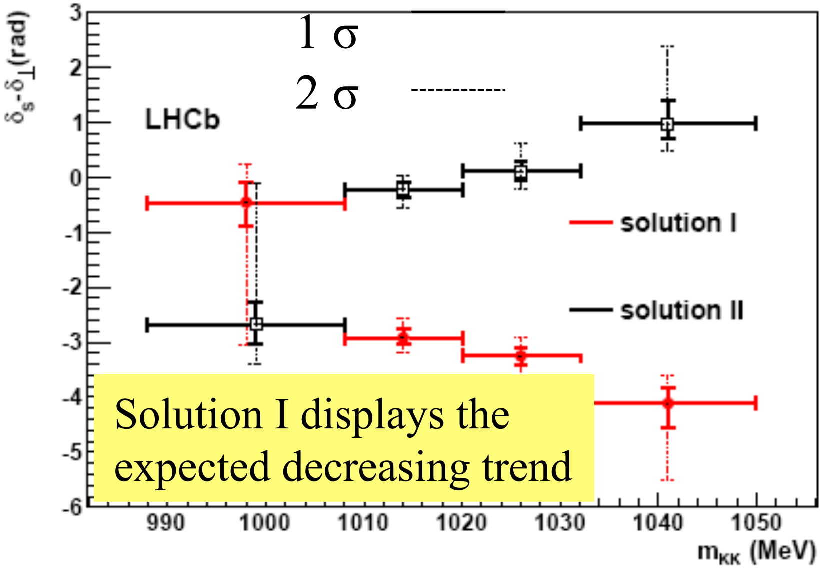
ϕ_s: Ambiguity Resolution

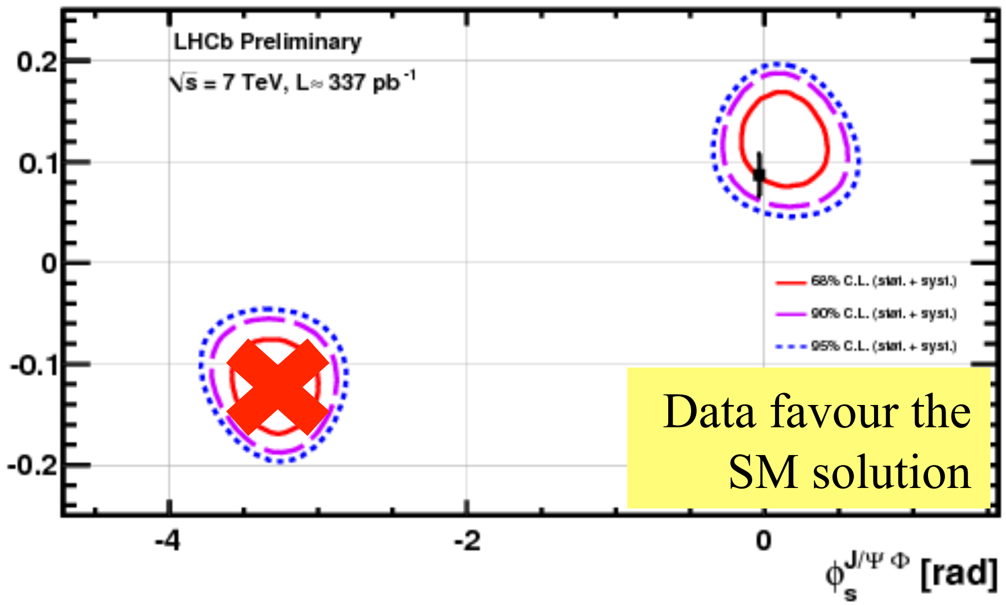


Dataset used for the LP result (350 pb^{-1}), open up m(KK) mass cut

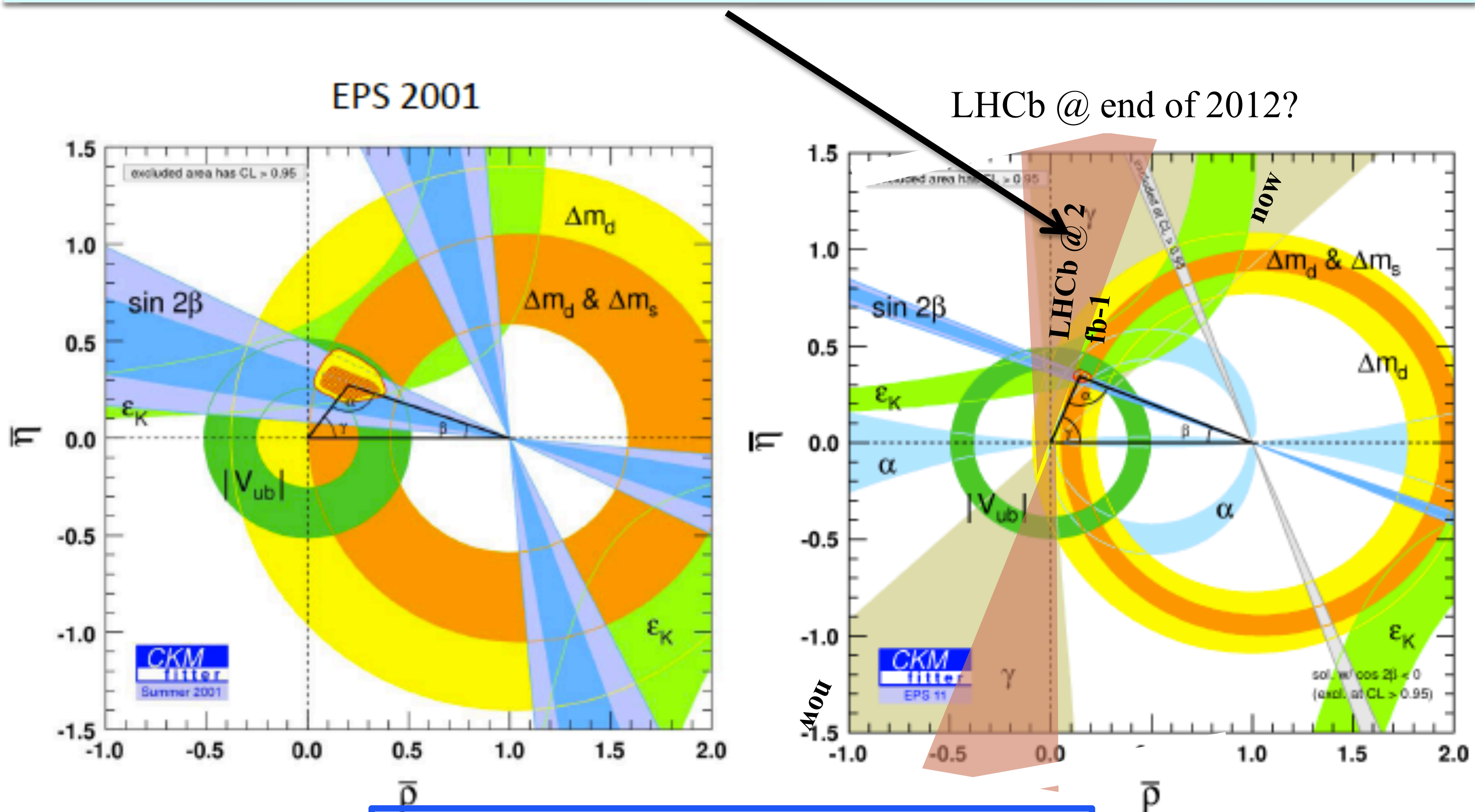
Perform analysis in four bins of m(KK) and extract phase dependence

m_{KK} interval	N_{sig}	N_{bkg}	W_p
(988, 1008) MeV	251 ± 21	1675 ± 43	0.700
(1008, 1020) MeV	4569 ± 70	2002 ± 49	0.952
(1020, 1032) MeV	3952 ± 66	2244 ± 51	0.938
(1032, 1050) MeV	726 ± 34	3442 ± 62	0.764





CKM picture in 10 years



LHCb can pin down the error on gamma to 10°-5° in 2011-2012

G. Isidori – *Theoretical Insights to Heavy Flavour Physics* — *ICFA Seminar, CERN, Oct. 2011*

Future prospects (a personal view)

"Minimalistic" list of key (quark-) flavour-physics observables:

- γ from tree ($B \to DK$, ...) — (S)LHCb
- $|V_{ub}|$ from exclusive semilept. B decays — SuperB
- $B_{s,d} \to l^+ l^-$ — (S)LHCb
- CPV in B_s mixing — (S)LHCb
- $B \to K^{(*)}\, l^+ l^-$, $\nu\nu$ — (S)LHCb , SuperB
- $B \to \tau\nu$, $\mu\nu$ — SuperB
- $K \to \pi\nu\nu$ — Kaon beams (NA62,...)
- CPV in charm — (S)LHCb , SuperB

- The flavour sector offers a very rich complementary of the High Energy Frontier searches for NP
- Recent LHCb results shown the potentialities of Flavor Physics at LHC, being unique for NP searches in B_S (also for B_d and Charm)

LHCb upgrade: history and schedule

The LHCb upgrade : a bit of history

- *January 2007, Edinburgh Upgrade Workshop:* choice of 40 MHz
- *April 2008, Expression of Interest*
- *March 2011, Letter of Intent (baseline proposal) to LHCC*
  Endorsement of physics case
  Review of proposed trigger concept (40 MHz)
- *June 2011, Positive review of trigger concept*
  LHCC endorses the LOI, green light for TDR (due in 2013)
  Intermediate document describing due early in 2012

A (very tentative) schedule for LHC/LHCb

2011-2012 LHCb data taking

2013-2014 LHC repair / LHCb maintenance, first infrastructures for upgrade

2015-2017 LHCb data taking

2018 LHC shutdown / LHCb upgrade installation

✓ LHCb Upgrade preparation

2011-2013 R&D, technological choices, TDRs preparation/approval

2013-2014 Requests for approval/Funding

2015-2018 Construction & installation

Spokesperson (P.Campana, LNF) at last CNS1, Firenze, Nov 2011