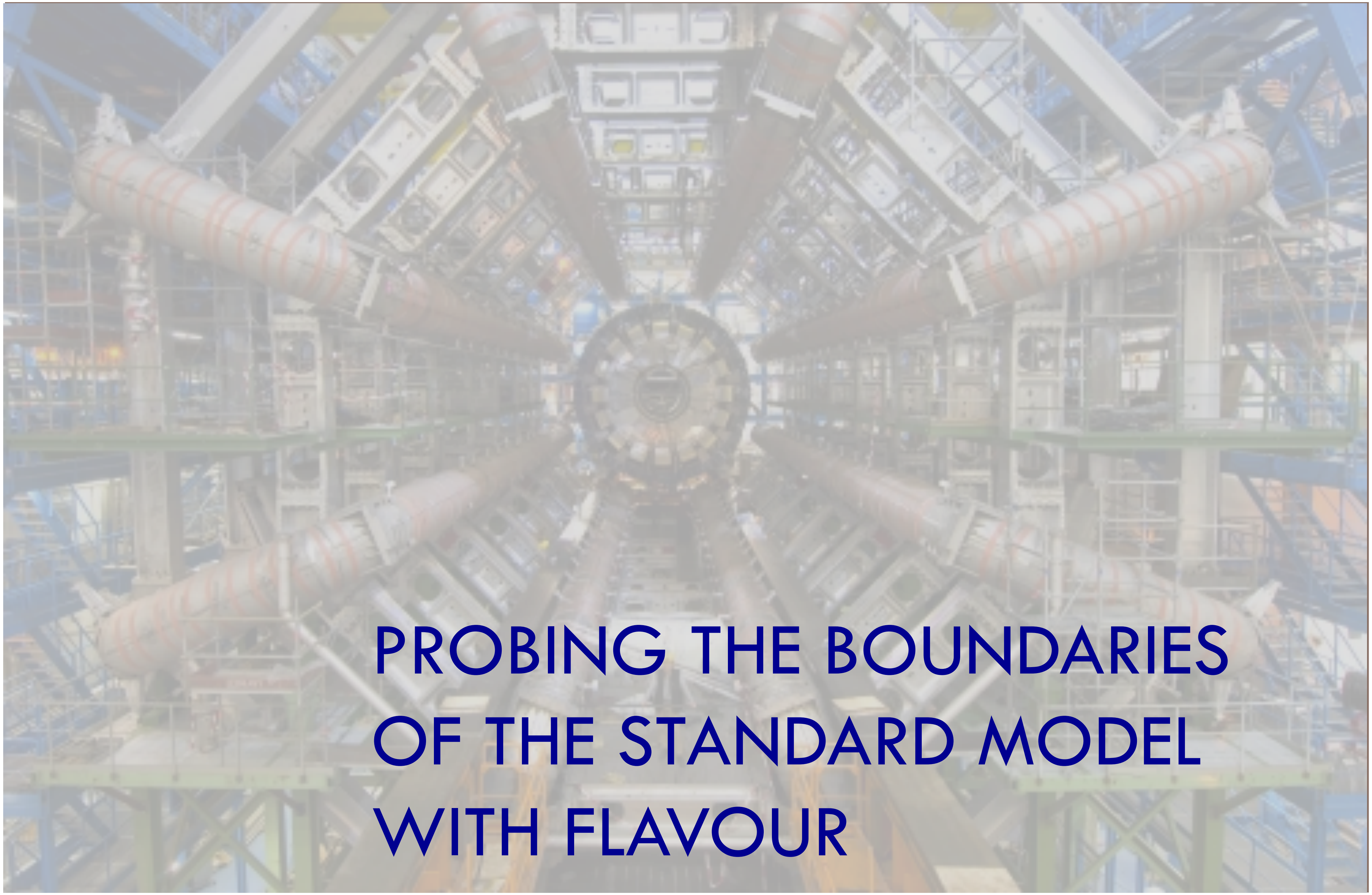


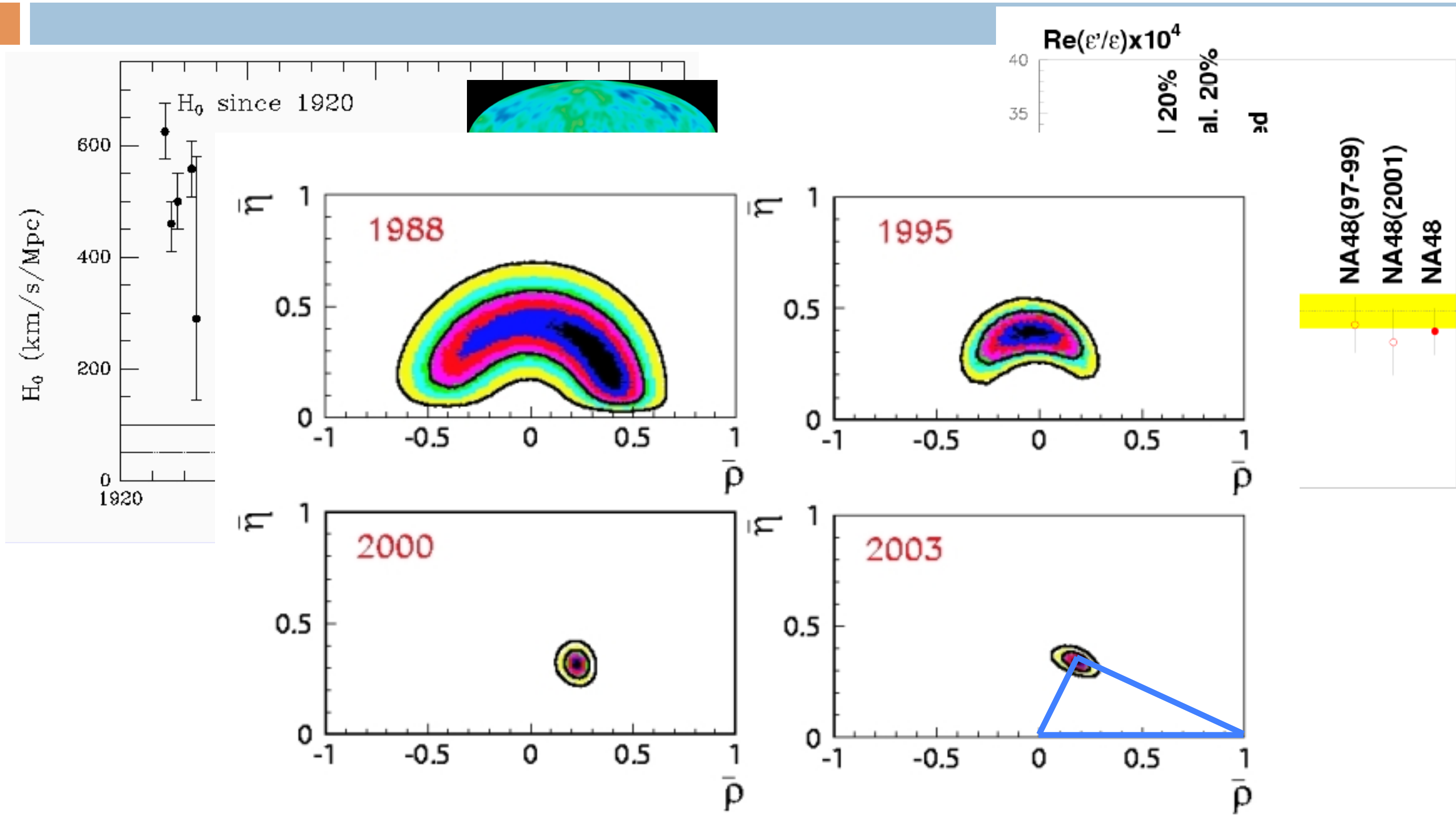
PROBING THE BOUNDARIES OF THE STANDARD MODEL WITH FLAVOUR

Alessandro Cerri

Synopsis

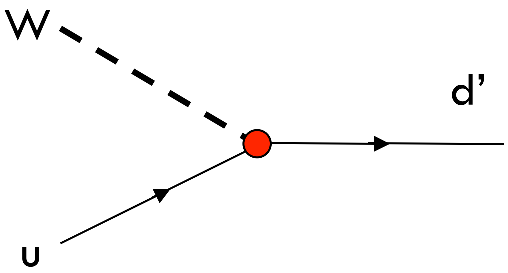
- Why B physics at pp/ppbar?
- Tools of the trade
  - detector and DAQ
  - trigger: the key to B physics
- Selected examples
  - The $\chi_b(3P)$ discovery
  - Hadronic Moments in $b \to cl\nu$ (V_{cb})
  - B_s Mixing (V_{td} and new physics)
  - Rare B decays
- Perspectives
- Conclusions

The Scientific Exploration



b physics in the last ~10 years became a precision test of the SM

The Flavour Sector



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} & V_{CKM} & \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Quarks couple to W through V_{CKM}: rotation in flavor space!

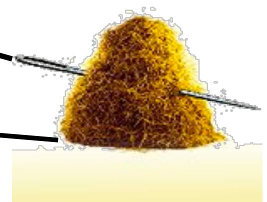
$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

V_{CKM} is Unitary

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

Flavour Physics

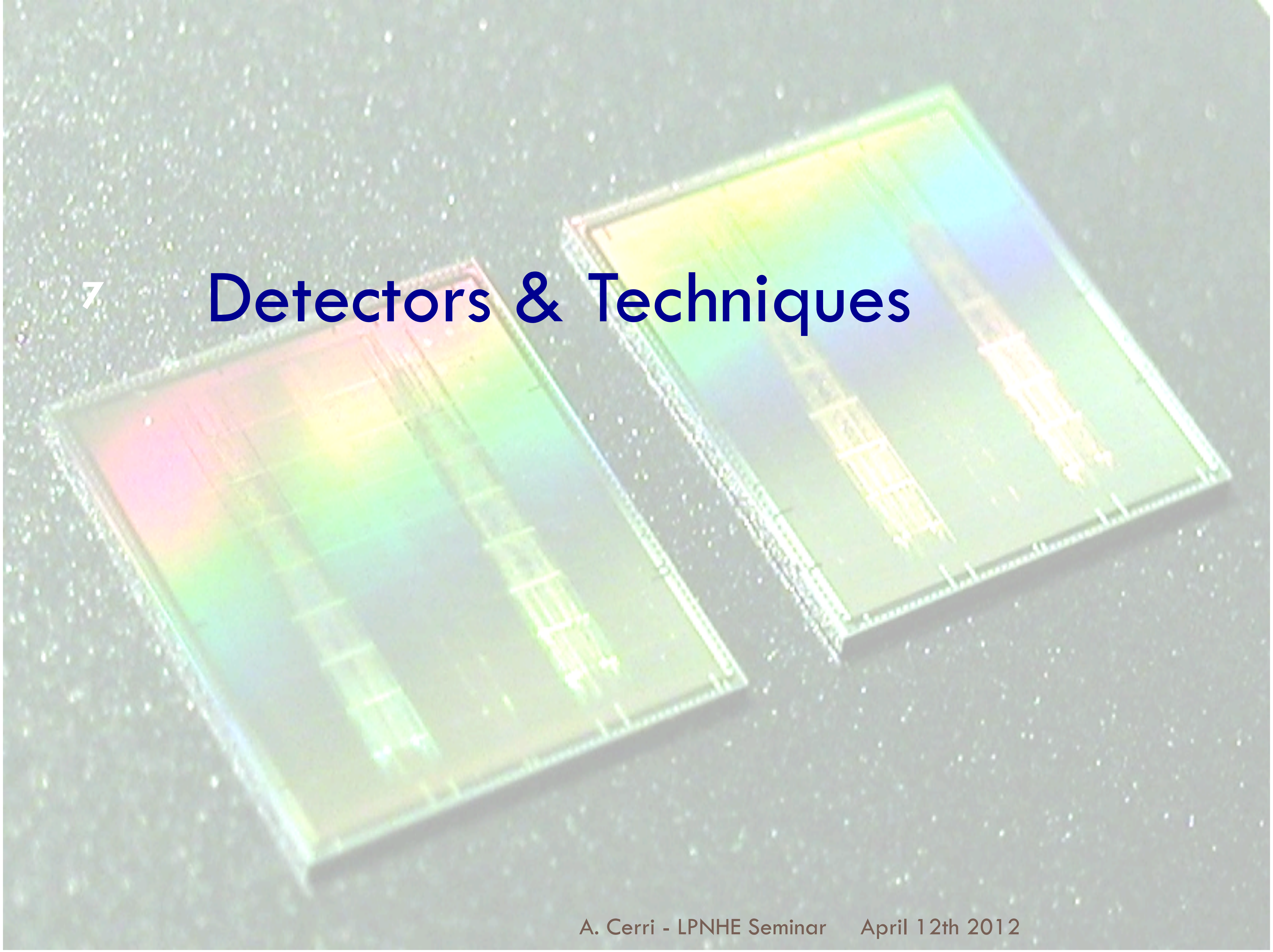
- A prolific sector of the SM, where new physics could still hide
- Precision measurements are ruling out new physics contributions in most cases
- B factories have very successfully explored B_u and B_d physics
- pp and p$\bar{p}$ machines are source of: B_u,B_d,B_s,B_c, B**, Λ_b, Ξ_b, χ_b, X…
  - $\sigma(B)$ ~(few) μb @ |y|<1 p_T>5-10 GeV
  - $\sigma_{pp} / \sigma_{p\bar{p}} \sim$ (few) $10^5 \mu$b



How do we go about this exploration?

CKM meas. → discrepancies (or lack thereof) → new physics

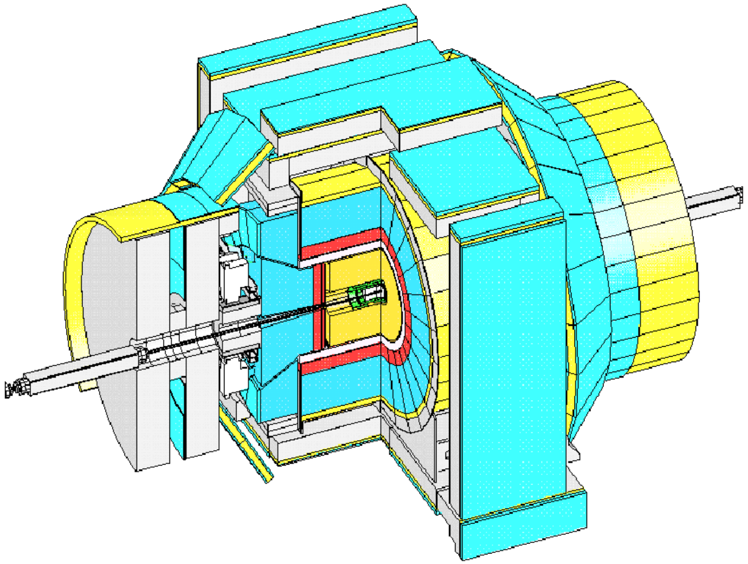
- Design/improve the "tools of the trade"
  - Experimental (detector & techniques)
  - Theoretical (phenomenological devices)
- Measure uncharted properties at the boundaries of our knowledge
  - Masses
  - Lifetimes
  - Branching ratios
- Press further ahead and investigate the boundaries:
  - Mixing
  - CP asymmetries
  - Rare decays etc.



Detectors & Techniques

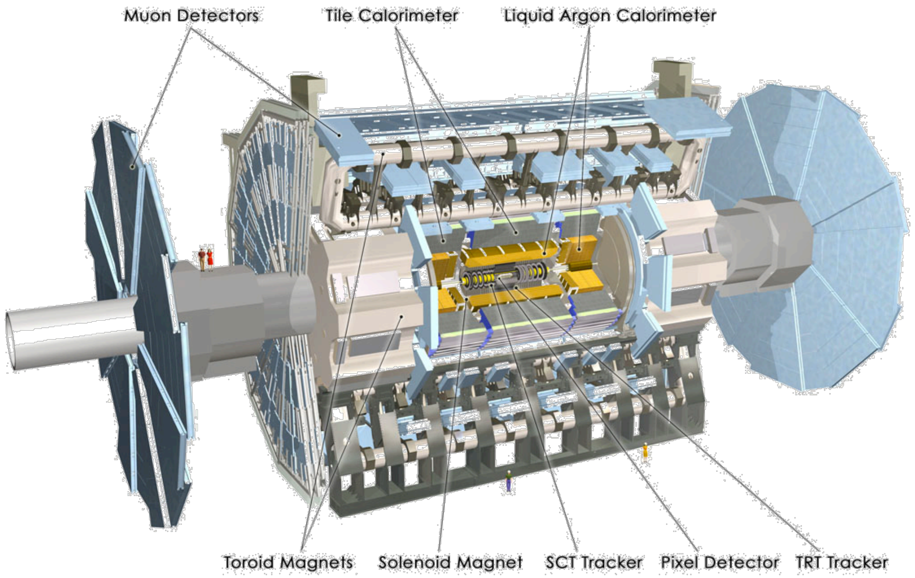
The experimental tools

- $p\bar{p}$ collisions @ 1.96 TeV
- Peak lumi: 4E32 Hz/cm^2
- ~100 Hz output bandwidth
- ~10 fb^{-1} collected in ~10 years



- Dedicated lifetime trigger
- ~35 μm Impact Parameter resolution
- $\sigma p_T/p_T$~0.15% p_T (+) 0.25%
- $\sigma_m(J/\psi - \Upsilon)$~15-20 MeV

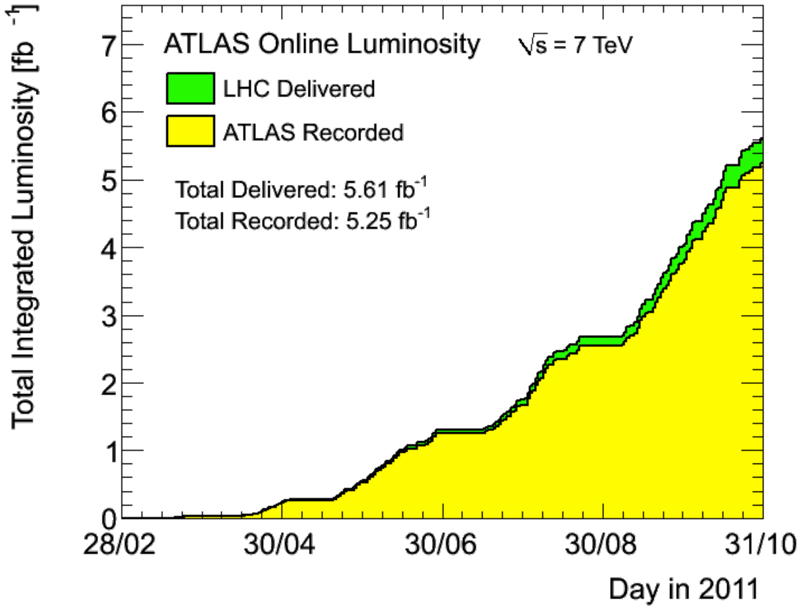
- pp collisions @ 7 (8) TeV
- Peak lumi: 3.6E33 Hz/cm^2
- (>)300 Hz output bandwidth
- ~5 fb^{-1} collected in 1 year



- Dedicated muon spectrometer
- ~35 μm Impact Parameter resolution
- $\sigma p_T/p_T$~0.05% p_T (+) 1.5%
- $\sigma_m(J/\psi - \Upsilon)$~60-120 MeV (ID dominated)

ATLAS commissioning and operation

- ATLAS is a "brand new" experiment
  - Commissioning and operations procedures developed from scratch
  - Continuously coping with new conditions
- Trigger strategies are complicated by all this
  - Several 100's of different selections, running in parallel
  - "improvements" continuously coming in, being validated and deployed



- A dedicated team of experts works around the clock and is proudly behind every single event ATLAS has collected so far!
- We have been successfully running ATLAS over an extended period with an average data taking efficiency of ~ 93%

Triggers for B physics

CDF (I & II)

- Triggers:
  - CDF I: single and di-muon triggers
  - CDF II: specialized displaced track triggers thanks to dedicated hardware

- As luminosity increases, bandwidth requirements are more stringent
  - Potentially forced to higher p_T
  - Lifetime-based selection early enough in the trigger chain kept HF physics "alive and thriving" in Run II

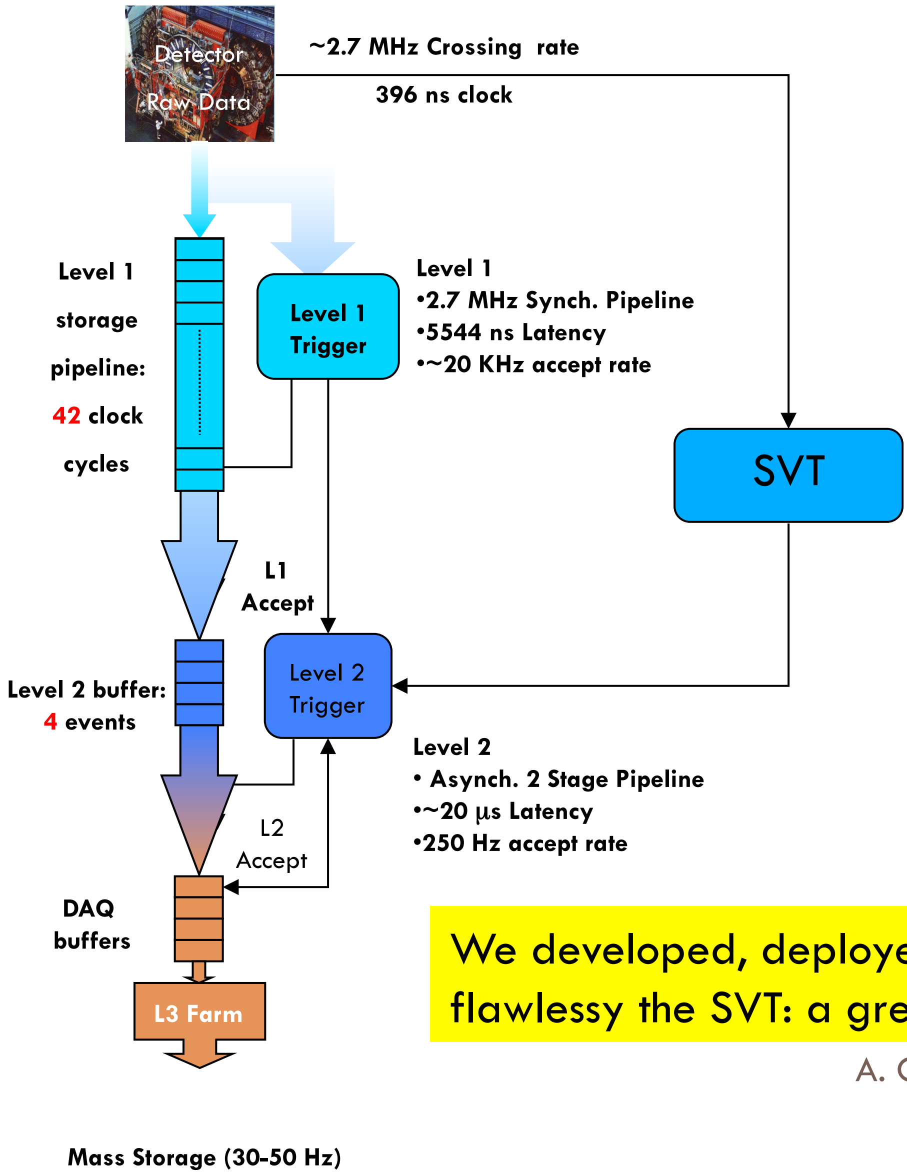
ATLAS

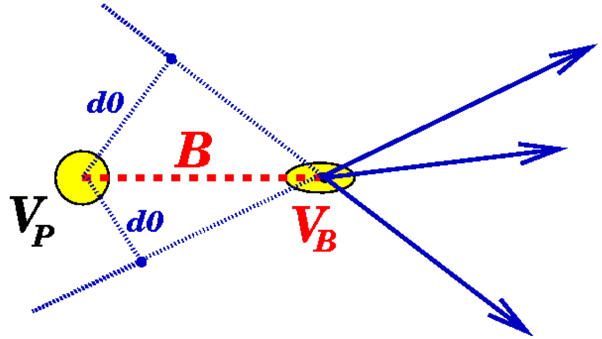
- Triggers:
  - Single and di-lepton triggers
  - Low luminosity (2010): single muon triggers
  - High luminosity (2011): di-muon triggers (+pre-scaled single-muon)

- As luminosity increases, bandwidth requirements are more stringent
  - Potentially forced to higher p_T
  - "cleaner" muon selections helped in 2011:
    - L1 4 GeV selections have been made cleaner
    - We managed to run with constant trigger thresholds for B physics all across 2011

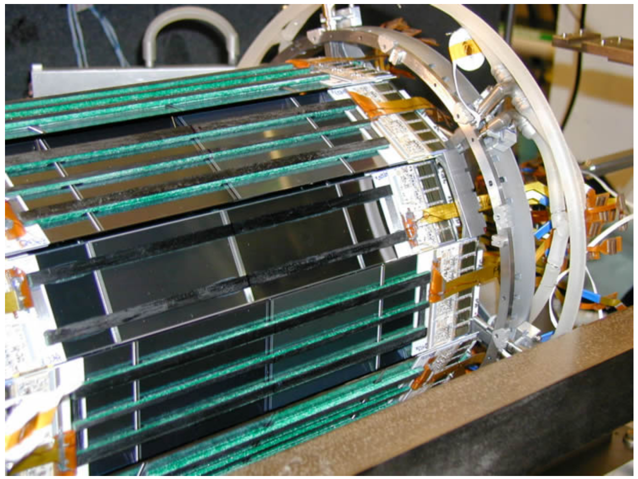
The CDF SVT: a specialized B physics trigger

The CDF Trigger





•Good IP resolution



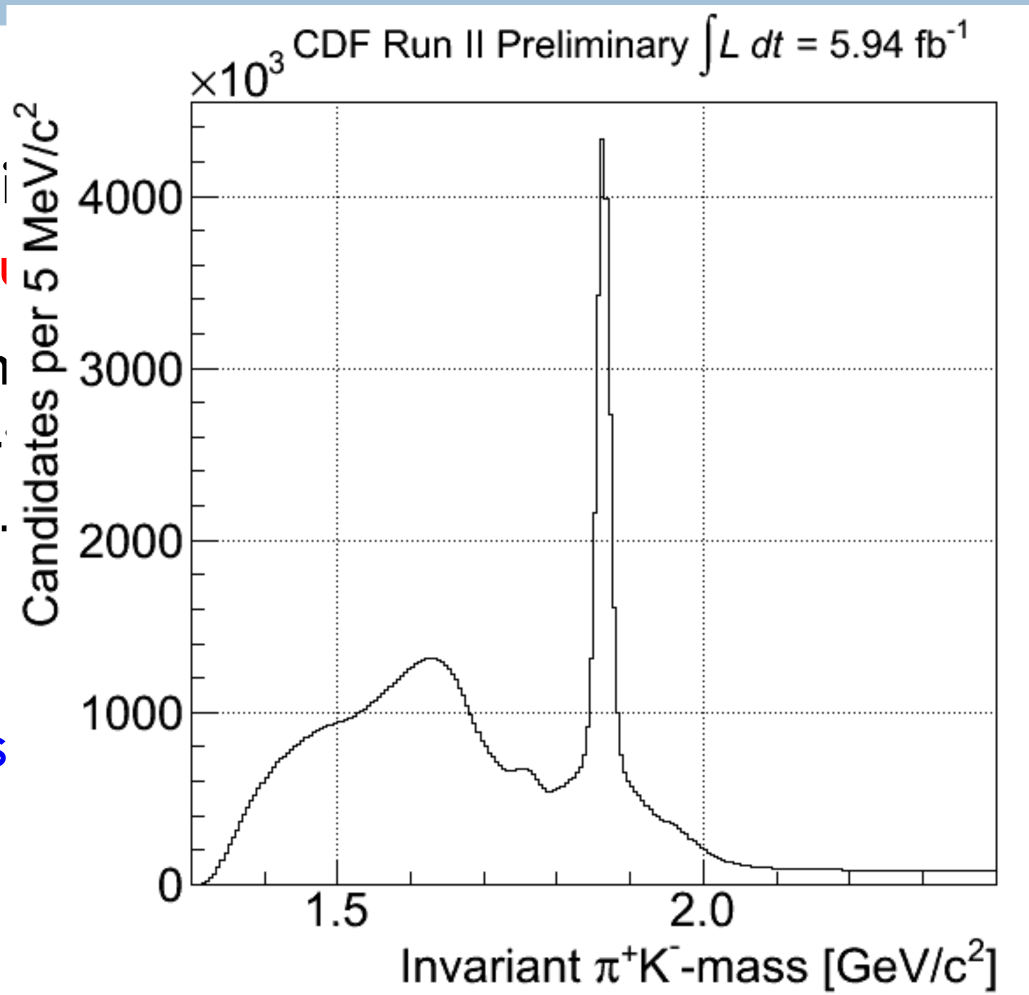
•As fast as possible

→Customized Hardware

We developed, deployed, operated and upgraded flawlessy the SVT: a great success for CDF II

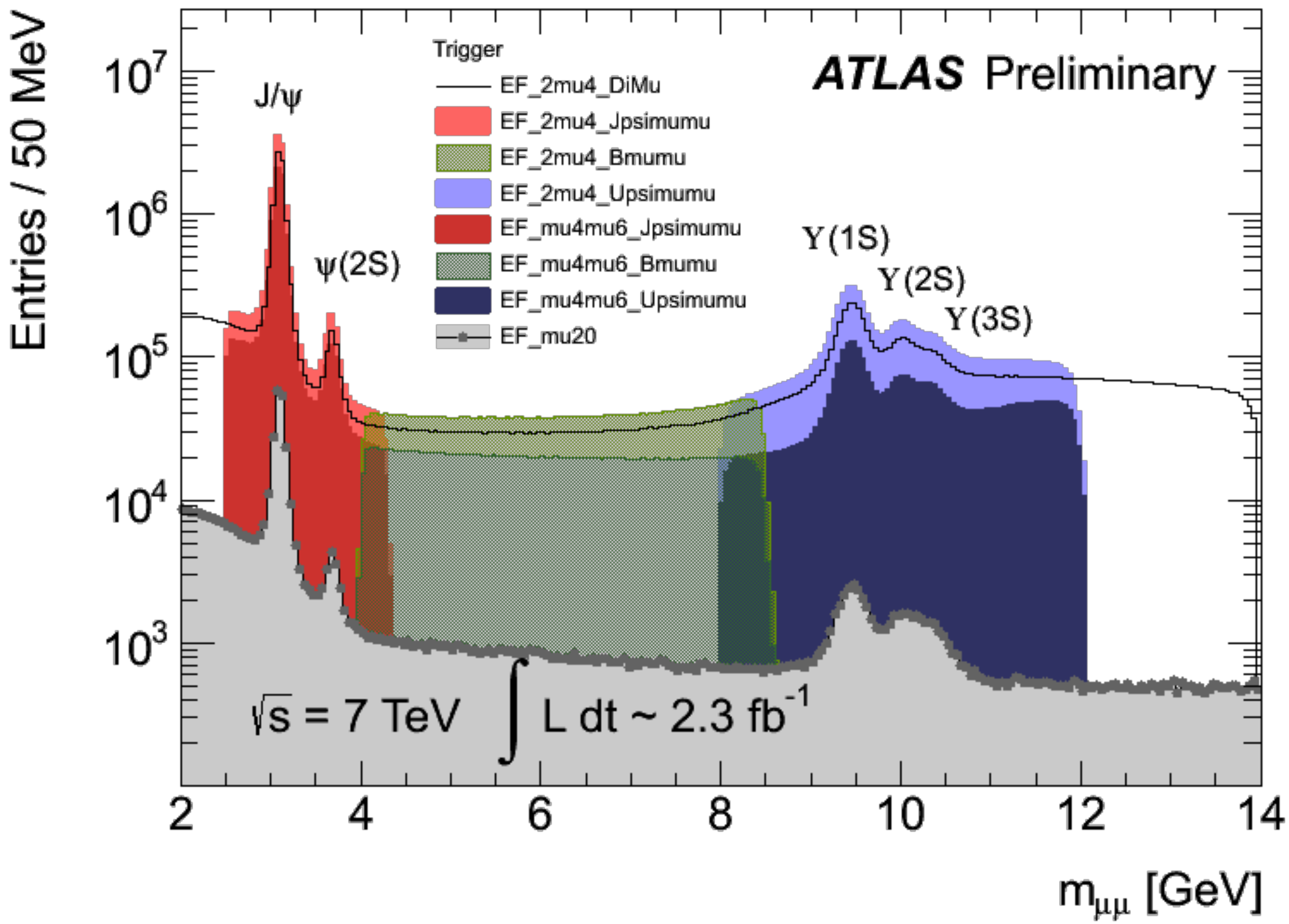
Flavour physics success stories: CDF

- The Si … st innovative and s…
- Offlin … me for event select…
- CDF/… ıctory!



ATLAS s… logy!

ATLAS di-muon B physics triggers



A few examples: few years ago…

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda$		$(4.7\pm2.8)\times10^{-4}$		
$\Lambda_c^+\pi^-$		seen		
$\Lambda_c^+ a_1(1260)^-$		seen		
$\Lambda_c^+\ell^-\overline{\nu}_\ell$ anything	[t]	(9.2 ± 2.1) %		
$p\pi^-$		$< 5.0 \times10^{-5}$		
pK^-		$< 5.0 \times10^{-5}$		
$\Lambda\gamma$		$< 1.3 \times10^{-3}$		

B_s^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
D_s^- anything		(94 ± 30) %		–
$D_s^-\ell^+\nu_\ell$ anything	[kkk]	(7.9 ± 2.4) %		–
$D_s^-\pi^+$		< 13 %		2322
$D_s^{(*)+}D_s^{(*)-}$		$(23 {}^{+21}_{-13})$ %		–
$J/\psi(1S)\phi$		$(9.3 \pm 3.3)\times10^{-4}$		1590
$J/\psi(1S)\pi^0$		$< 1.2 \times10^{-3}$	90%	1788
$J/\psi(1S)\eta$		$< 3.8 \times10^{-3}$	90%	1735
$\psi(2S)\phi$		seen		1123
$\pi^+\pi^-$		$< 1.7 \times10^{-4}$	90%	2681
$\pi^0\pi^0$		$< 2.1 \times10^{-4}$	90%	2681
$\eta\pi^0$		$< 1.0 \times10^{-3}$	90%	2655
$\eta\eta$		$< 1.5 \times10^{-3}$	90%	2628
$\rho^0\rho^0$		$< 3.20 \times10^{-4}$	90%	2570
$\phi\rho^0$		$< 6.17 \times10^{-4}$	90%	2528
$\phi\phi$		$< 1.183 \times10^{-3}$	90%	2484
π^+K^-		$< 2.1 \times10^{-4}$	90%	2660
K^+K^-		$< 5.9 \times10^{-5}$	90%	2639
$\overline{K}^*(892)^0\rho^0$		$< 7.67 \times10^{-4}$	90%	2551
$\overline{K}^*(892)^0K^*(892)^0$		$< 1.681 \times10^{-3}$	90%	2532
$\phi K^*(892)^0$		$< 1.013 \times10^{-3}$	90%	2508
$p\overline{p}$		$< 5.9 \times10^{-5}$	90%	2516
$\gamma\gamma$		$< 1.48 \times10^{-4}$	90%	2685
$\phi\gamma$		$< 1.2 \times10^{-4}$	90%	2588

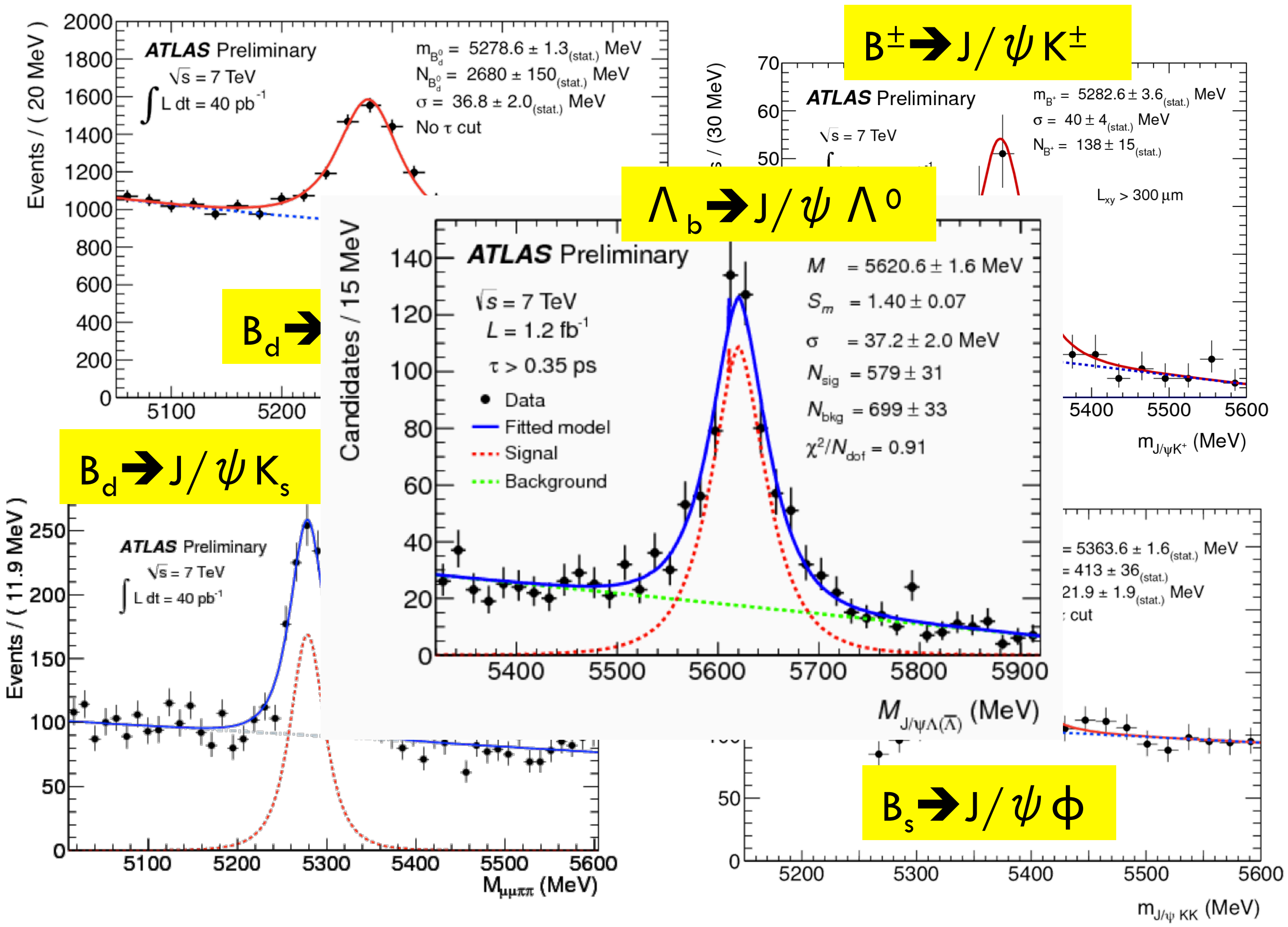
..and yesterday!

Mode		Fraction (Γ_i/Γ)
$J/\psi(1S)\Lambda\times$ B$(b\to\Lambda_b^0)$		$(4.7\pm2.3)\times10^{-5}$
$p D^0\pi^-$		
$\Lambda_c^+\pi^-$		$(8.8\pm3.2)\times10^{-3}$
$\Lambda_c^+ a_1(1260)^-$		seen
$\Lambda_c^+\pi^+\pi^-\pi^-$		
$\Lambda K^0 2\pi^+ 2\pi^-$		
$\Lambda_c^+\ell^-\overline{\nu}_\ell$ anything	[a]	(11.0 ± 3.2) %
$\Lambda_c^+\ell^-\overline{\nu}_\ell$		$(5.0^{+1.9}_{-1.4})$ %
$\Lambda_c^+\pi^+\pi^-\ell^-\overline{\nu}_\ell$		(5.6 ± 3.1) %
$\Lambda_c(2595)^+\ell^-\overline{\nu}_\ell$		$(6.3^{+4.0}_{-3.1})\times10^{-3}$
$\Lambda_c(2625)^+\ell^-\overline{\nu}_\ell$		$(1.1^{+0.6}_{-0.4})$ %
$\Sigma_c(2455)^0\pi^+\ell^-\overline{\nu}_\ell$		
$\Sigma_c(2455)^{++}\pi^-\ell^-\overline{\nu}_\ell$		
$p h^-$	[b]	$< 2.3\times10^{-5}$
$p\pi^-$		$(4.0\pm1.3)\times10^{-6}$
pK^-		$(6.2\pm1.9)\times10^{-6}$
$\Lambda\gamma$		$< 1.3\times10^{-3}$

Mode		Fraction (Γ_i/Γ)	Confi
D_s^- anything		(93 ± 25) %	
$D_s^-\ell^+\nu_\ell$ anything	[a]	(7.9 ± 2.4) %	
$D_{s1}(2536)^-\mu^+\nu_\mu$, $D_{s1}^-\to D^{*-}K_S^0$		$(2.4\pm0.7)\times10^{-3}$	
$D_s^-\pi^+$		$(3.2\pm0.5)\times10^{-3}$	
$D_s^-\rho^+$		$(7.4\pm1.8)\times10^{-3}$	
$D_s^-\pi^+\pi^+\pi^-$		$(8.4\pm3.3)\times10^{-3}$	
$D_s^\mp K^\pm$		$(3.0\pm0.7)\times10^{-4}$	
$D_s^+D_s^-$		$(1.04^{+0.29}_{-0.26})$ %	
$D_s^{*-}\pi^+$		$(2.1\pm0.6)\times10^{-3}$	
$D_s^{*-}\rho^+$		(1.03 ± 0.27) %	
$D_s^{*+}D_s^- + D_s^{*-}D_s^+$		(2.8 ± 1.0) %	
$D_s^{*+}D_s^{*-}$		(3.1 ± 1.4) %	
$D_s^{(*)+}D_s^{(*)-}$		(4.5 ± 1.4) %	
$J/\psi(1S)\phi$		$(1.4\pm0.5)\times10^{-3}$	
$J/\psi(1S)\pi^0$		$< 1.2\times10^{-3}$	
$J/\psi(1S)\eta$		$< 3.8\times10^{-3}$	
$J/\psi(1S)K^0$		$(3.5\pm0.8)\times10^{-5}$	
$J/\psi(1S)K^{*0}$		$(8\pm4)\times10^{-5}$	
$J/\psi(1S)f_0(980)$, $f_0\to\pi^+\pi^-$		$(1.29^{+0.40}_{-0.28})\times10^{-4}$	
$J/\psi(1S)f_0(1370)$, $f_0\to\pi^+\pi^-$		$(3.4\pm1.4)\times10^{-5}$	
$\psi(2S)\phi$		$(7.1\pm2.8)\times10^{-4}$	
$\pi^+\pi^-$		$< 1.2\times10^{-6}$	
$\pi^0\pi^0$		$< 2.1\times10^{-4}$	

Open Beauty at ATLAS

ATLAS-CONF-2010-098, ATLAS-CONF-2011-050, ATLAS-CONF-2011-115

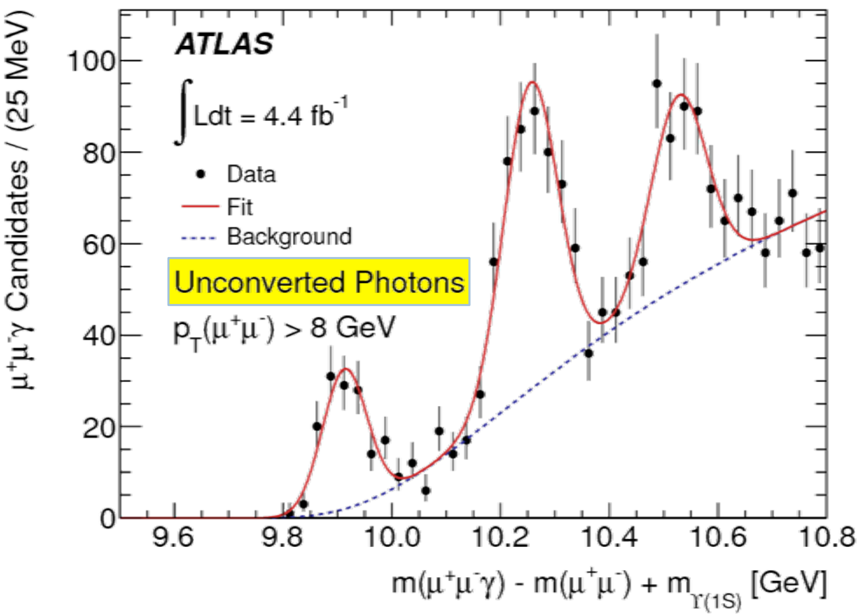


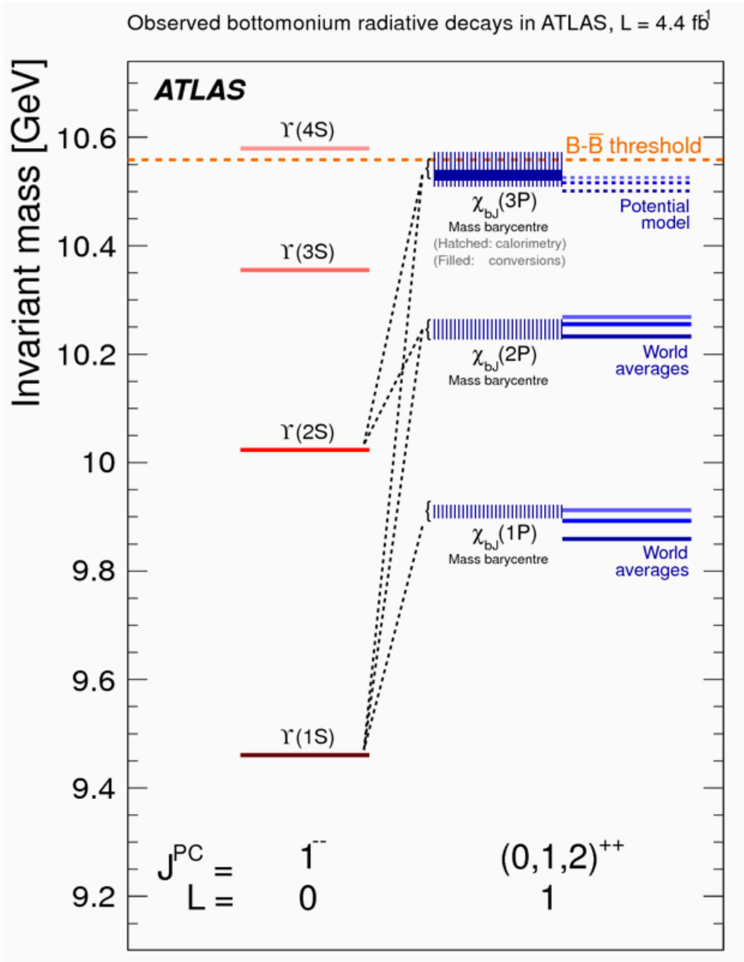
- All masses consistent with PDG
- All signals based on di-muon trigger:
  - No prescales in 2011
  - Clear viable strategy for collection in 2012

χ_b Observation in ATLAS

arXiv:1112.5154v4 accepted by PRL

- $\chi_b(nP) \rightarrow \Upsilon(1S,2S)\gamma$
  - Reconstruct either converted (e^+e^-) and un-converted photons
  - Measure $m_\chi - m_\gamma$
  - 1P (9.9 GeV) & 2P (10.2 GeV) states clearly visible

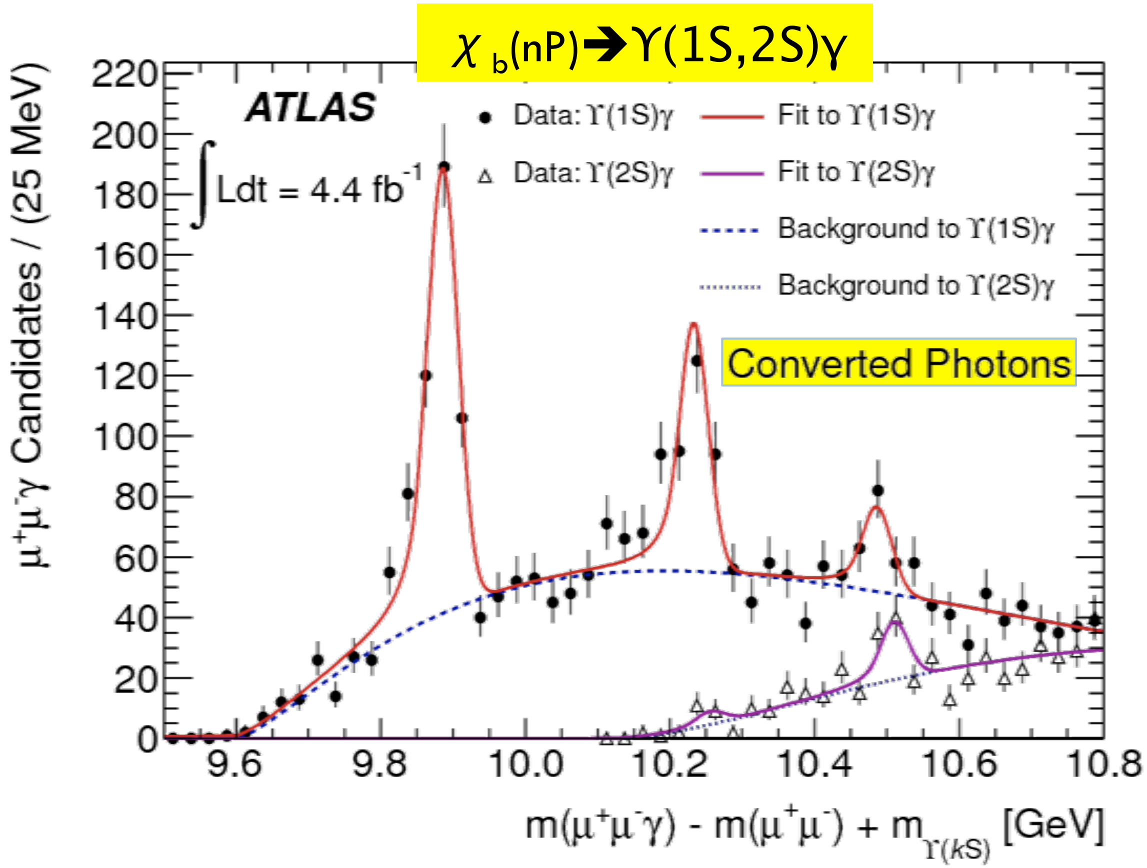




Something new: $\chi_b(3P)$

arXiv:1112.5154v4 accepted by PRL

- New structure at 10.5 GeV confirmed with Υ (2S) data and with converted photons
- Significance: >6σ



M[$\chi_b(3P)$]=10.530±0.005 (stat)±0.009 (syst) GeV

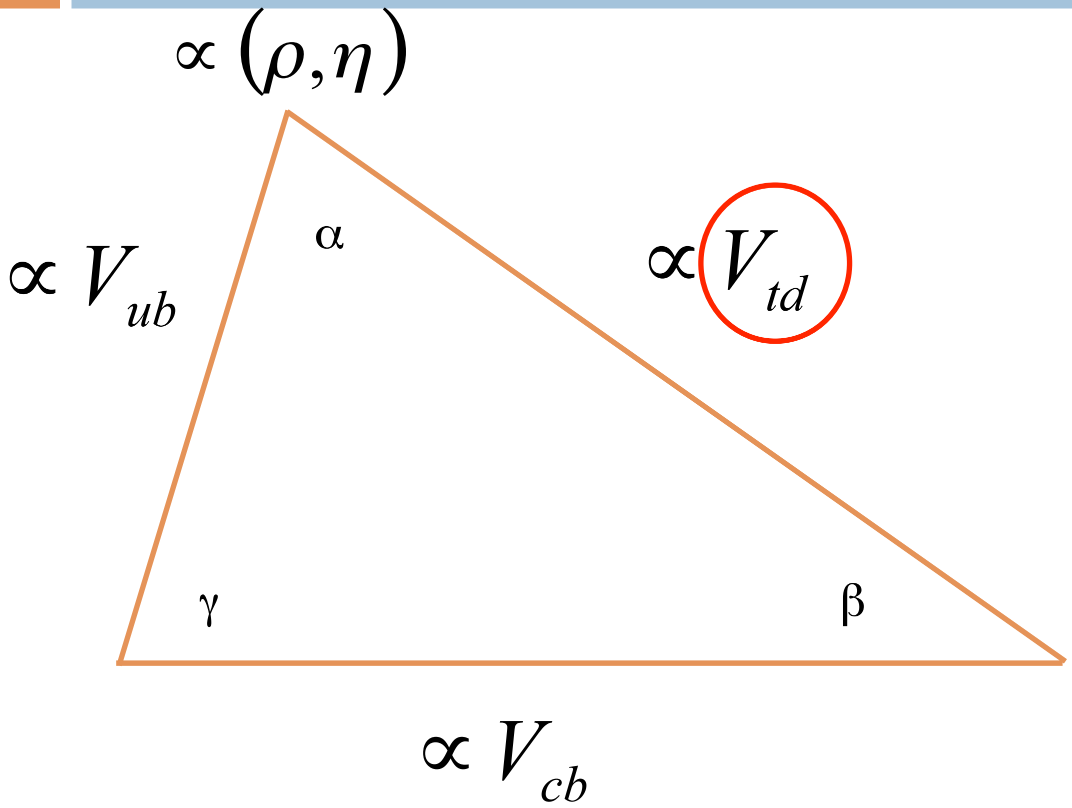
Consistent with theoretical predictions: the first new LHC particle!

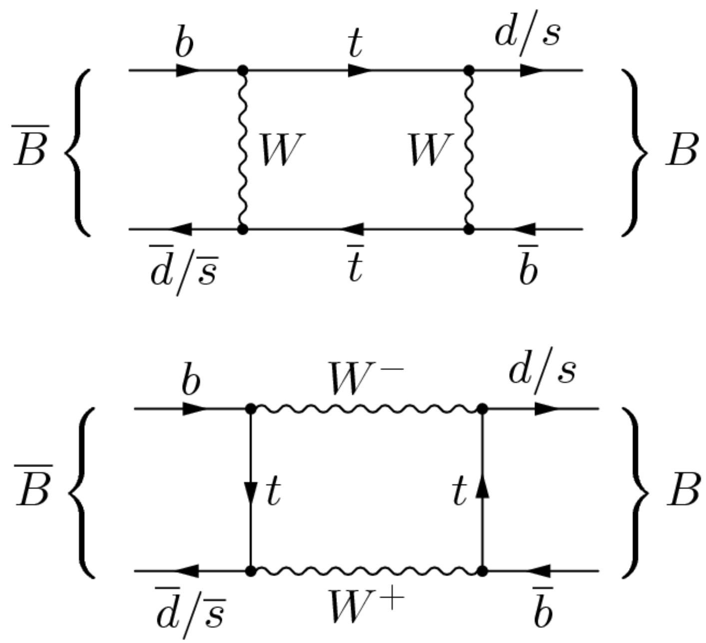
ATLAS is a mature HF physics experiment!

19

Flavor physics pushing the SM boundaries

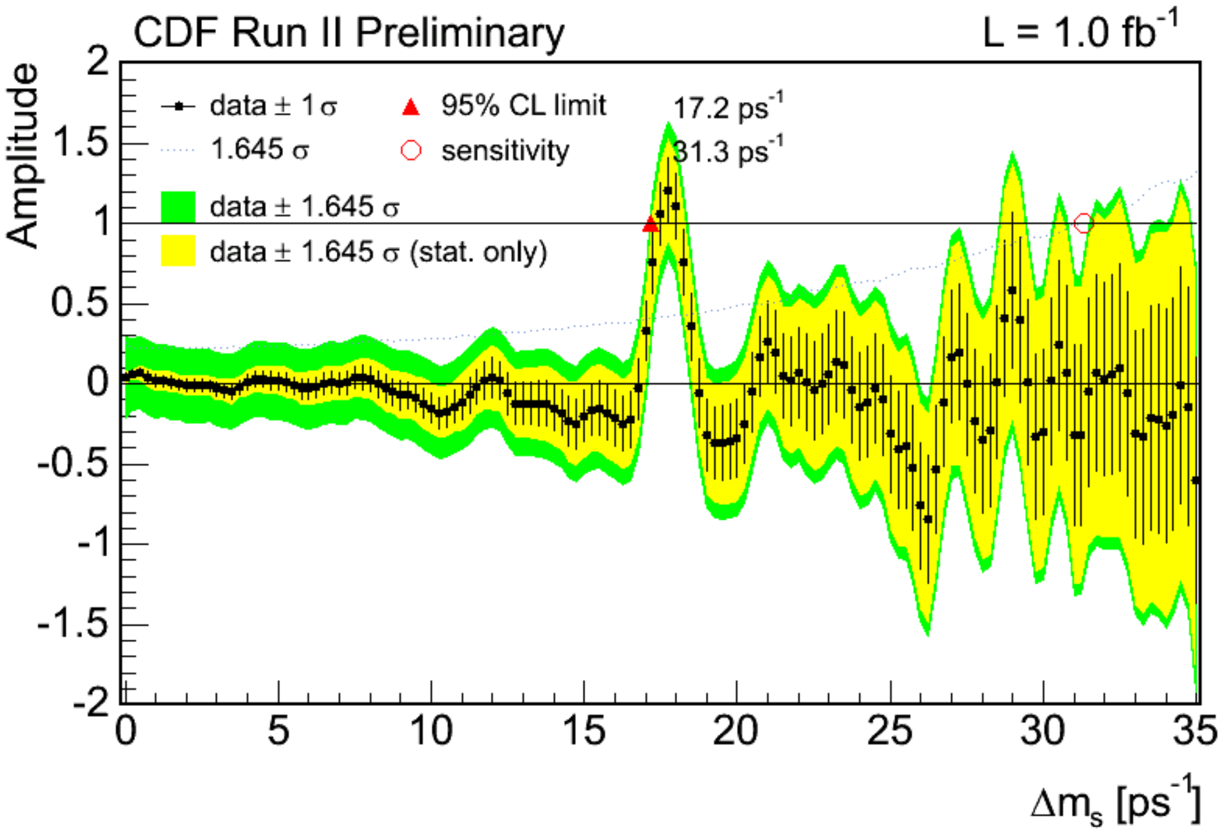
Working our way through the CKM sides





- V_{td} is derived from mixing effects
- QCD uncertainty is factored out resorting to the relative B_s/B_d mixing rate (V_{td}/V_{ts})
- Beyond the SM physics could enter in loops!

And finally, in 2006

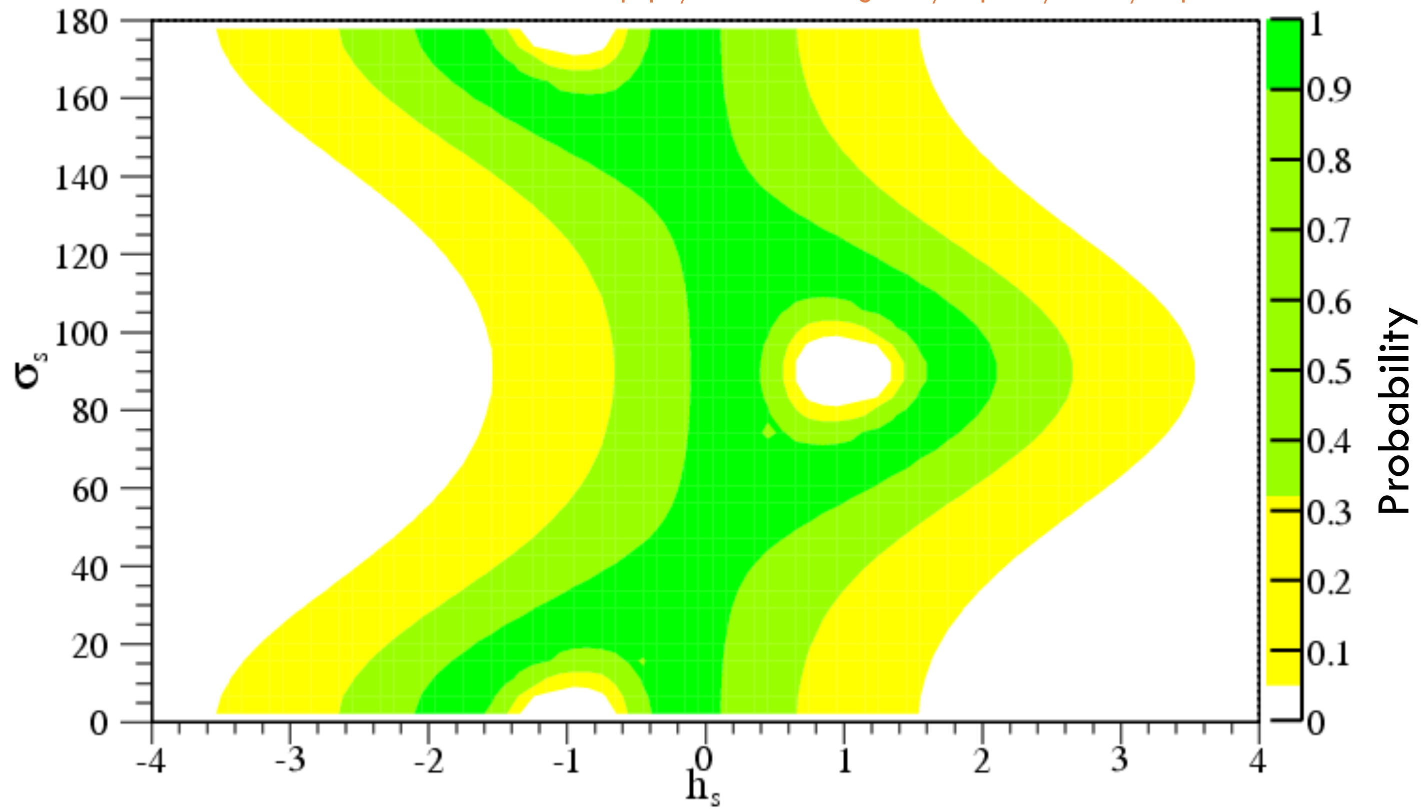


- Bs mixing is observed by CDF
- …right where the SM would like it to be!

The consequences on BSM physics

$$A_{SM} \rightarrow A_{SM}\left(1 + h_s e^{i2\sigma_S}\right)$$

Hep-ph/0509117 Agashe/Papucci/Perez/Pirjol

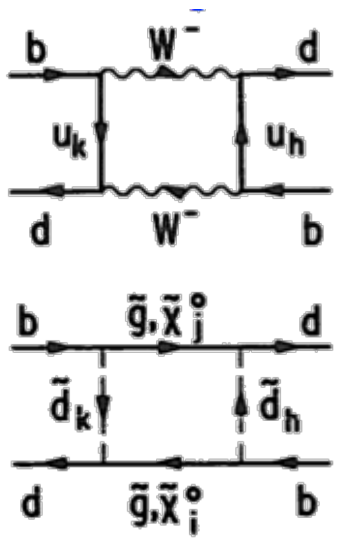


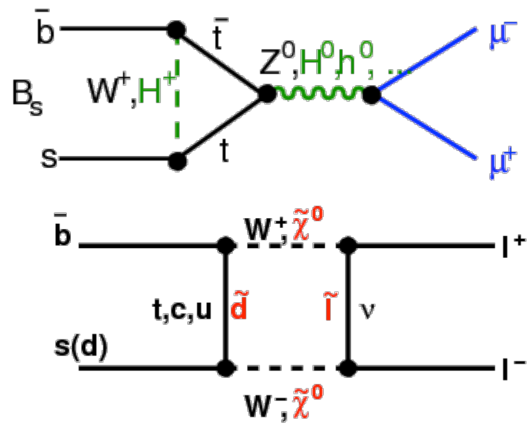
Where is the then the physics BSM?

- Can parameterize phenomenologically:
  - Loop contributions to flavour physics producing flavour changes
  - B_x mixing ➔ Δ f=2 processes ➔ no evidence of NP (precision $J/\psi\,\Phi$ is the next frontier)
  - Δ f=1? ..still plenty of room!

$$r = \frac{BR(B_s \to \mu\mu)\, \Delta m_d \tau_d\, \hat{B}_{B_s}}{BR(B_d \to \mu\mu)\, \Delta m_s \tau_s\, \hat{B}_{B_d}} \stackrel{SM}{\equiv} 1$$

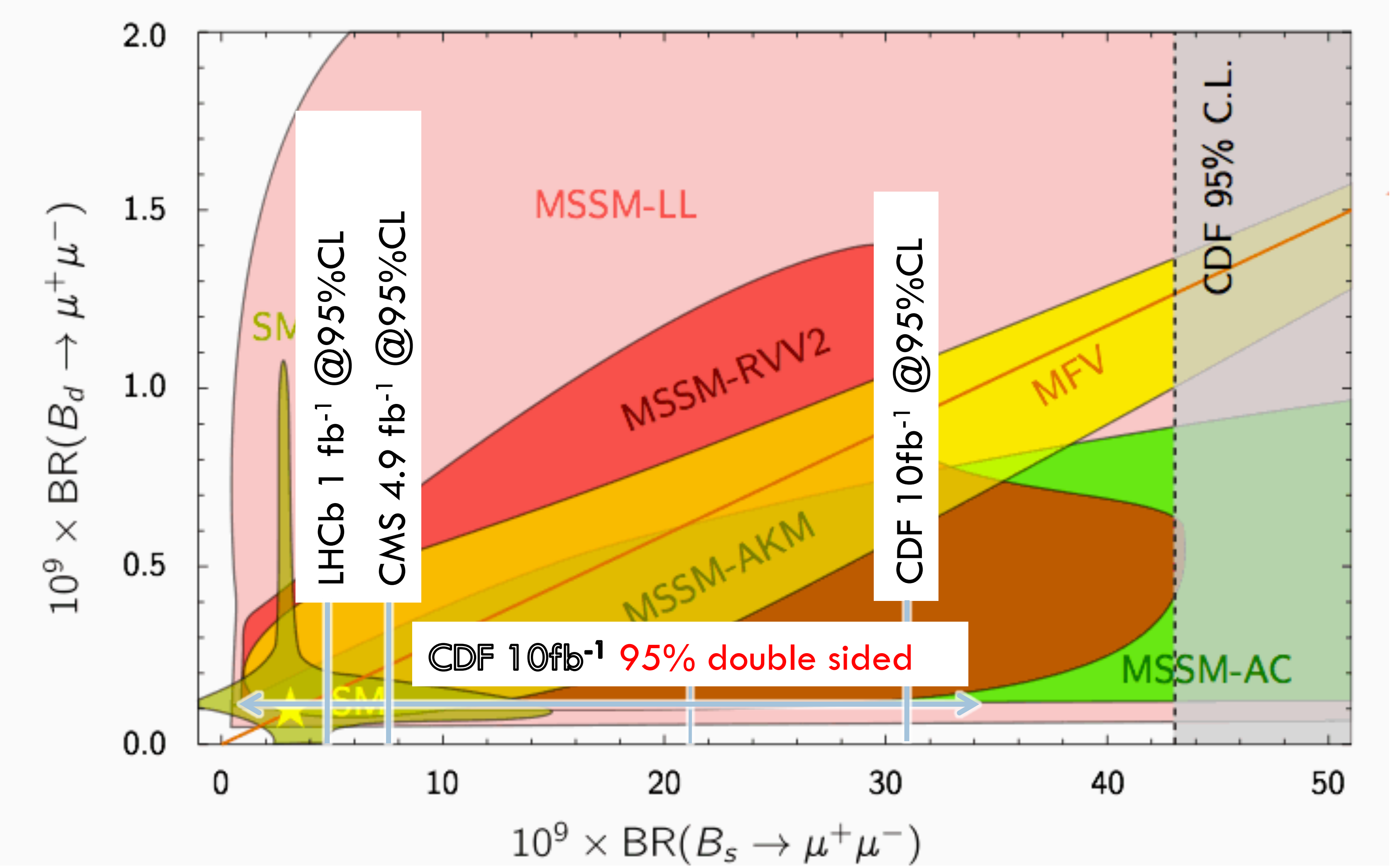
  - Strong QCD-free constraint
  - Small BR, room for O(10xSM) effects!
  - Need large B production rates and luminosity!





An ideal challenge for LHC experiments! Is ATLAS ready to face it?

Rare decays: What do we Know



Analysis strategy

- Use a reference channel ($B^{\pm} \rightarrow J/\psi K^{\pm}$):

$$BR(B_s \to \mu\mu) = \frac{N_{B_s \to \mu\mu}}{N_{J/\psi K^{\pm}}} \cdot \frac{\alpha_{J/\psi K^{\pm}} \varepsilon^{tot}_{J/\psi K^{\pm}}}{\alpha_{B_s \to \mu\mu} \varepsilon^{tot}_{B_s \to \mu\mu}} \cdot \frac{f_u}{f_s} \cdot BR(B^{\pm} \to J/\psi K^{\pm}) = N_{B_s \to \mu\mu} \left[\frac{\alpha_{J/\psi K^{\pm}} \varepsilon^{tot}_{J/\psi K^{\pm}}}{\alpha_{B_s \to \mu\mu} \varepsilon^{tot}_{B_s \to \mu\mu}} \cdot \frac{1}{N_{J/\psi K^{\pm}}} \cdot \frac{f_u}{f_s} \cdot BR(B^{\pm} \to J/\psi K^{\pm}) \right]$$

- Signal
  - event count in "signal region"
  - "subtraction" of sidebands

Channel	Signal Region	Sideband Regions
$B^0_s \to \mu^+\mu^-$	[5066,5666] MeV	[4766,5066] MeV [5666,5966] MeV
$B^{\pm} \to J/\psi K^{\pm}$	[5180,5380] MeV	[4930,5130] MeV [5430,5630] MeV

- Selection based on
  - 14 variables
  - Multivariate analysis (BDT)
  - 50% of sidebands to model background
- Efficiencies & acceptances
  - Derived from MC ("calibrated" on data)
  - Reference channel ($B^{\pm} \rightarrow J/\psi K^{\pm}$) selected with as-close-as-possible selection
- Blind analysis, limit placed using CLs method

Datasets

- 2.4 fb^{-1} of 4 GeV di-muon triggers in 2011 collision
  - After that 4 GeV muon trigger changed, hence a natural breakpoint
- MC ($B_s \rightarrow \mu\mu$, $B^{\pm} \rightarrow J/\psi K^{\pm}$, $B_s \rightarrow J/\psi\ \Phi$, $B_s(6500) \rightarrow \mu\mu$, $B_s/B^0 \rightarrow KK, K\pi, \pi\pi$)
  - Final states: $|\eta|<2.5$ and $p_T>2.5$ (0.5) GeV for muons (kaons)
  - "unbiased samples" generated for acceptance studies: $B_s \rightarrow \mu\mu$, $B^{\pm} \rightarrow J/\psi K^{\pm}$, with $p_T^b>4$ GeV and $|\eta_b|<2.5$ no final states cuts

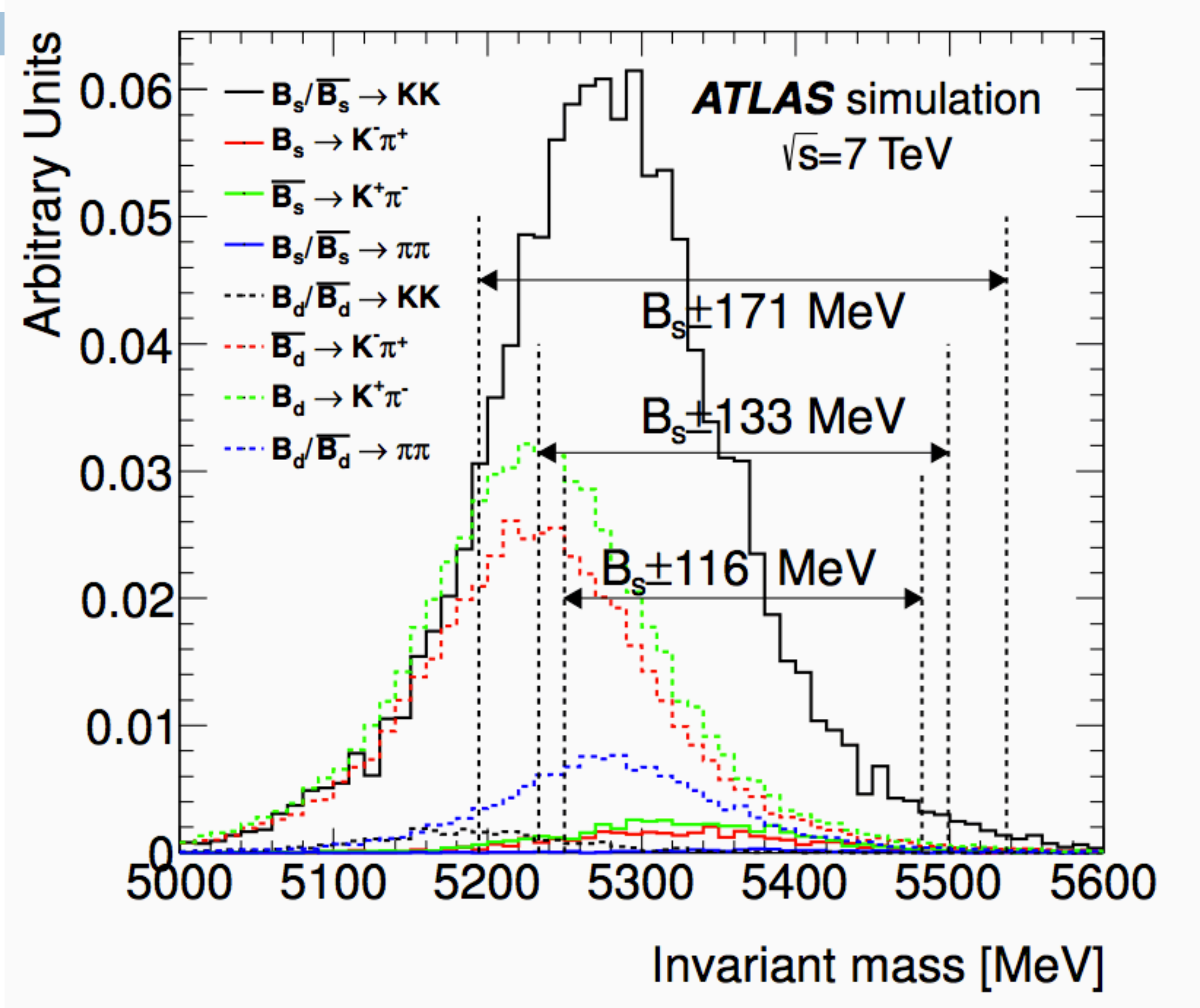
Reconstruction

- 2, 3 or 4 prong vertex constraint depending on decay topology
- Primary Vertex
  - Closest in z to B candidate
  - Re-fit excluding B daughters
- Tracks:
  - At least 1 pixel, 6 SCT and 9 TRT hits
  - $|\eta|<2.5$ and $p_T>4$ (2.5) GeV for muons (kaons)
  - ID tracks matched to muon spectrometer tracks
- B candidates: $p_T>8$ GeV and $|\eta|<2.5$

Background Composition

- Real muons:
  - MC studies ($12pb^{-1}$ → limited statistics) suggest bb → μμX to be the dominant background
- "Fake" muons (decays in flight, punch-throughs):
  - B → hh (KK, Kπ, ππ)
    - "quasi irreducible" due to close topology
    - BRx(fake rate) ≈ 10^{-9}, close to SM B_s → μμ
- Single muon + "fake" (e.g. B → μKν)
  - Negligible contribution, outside our search windows

B→hh reconstructed as $\mu\ \mu$



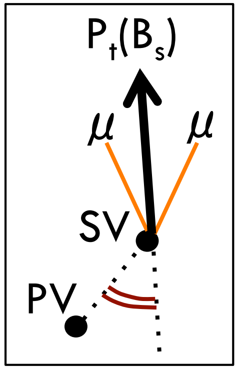
Discriminating Variables

Chosen among ~28 variables, removing the ones with the largest redundancy

Exploit:

- PV-SV separation
  - L_{xy}, ct significance
- Symmetry of final state (pointing angle, d_0…)
- Full reconstruction (pointing angle, D^{min}…)
- B hadronization features (Isolation, p_T^B…)

Multivariate techniques used to combine the separation power

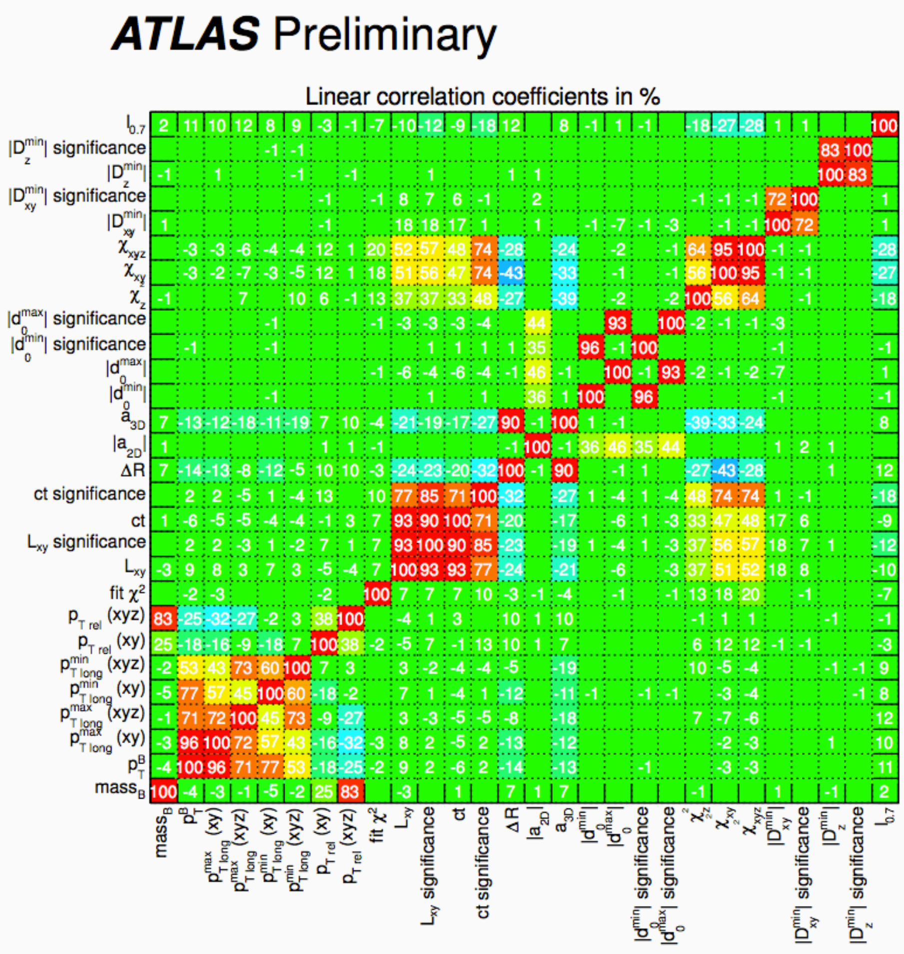


Ex.: Background

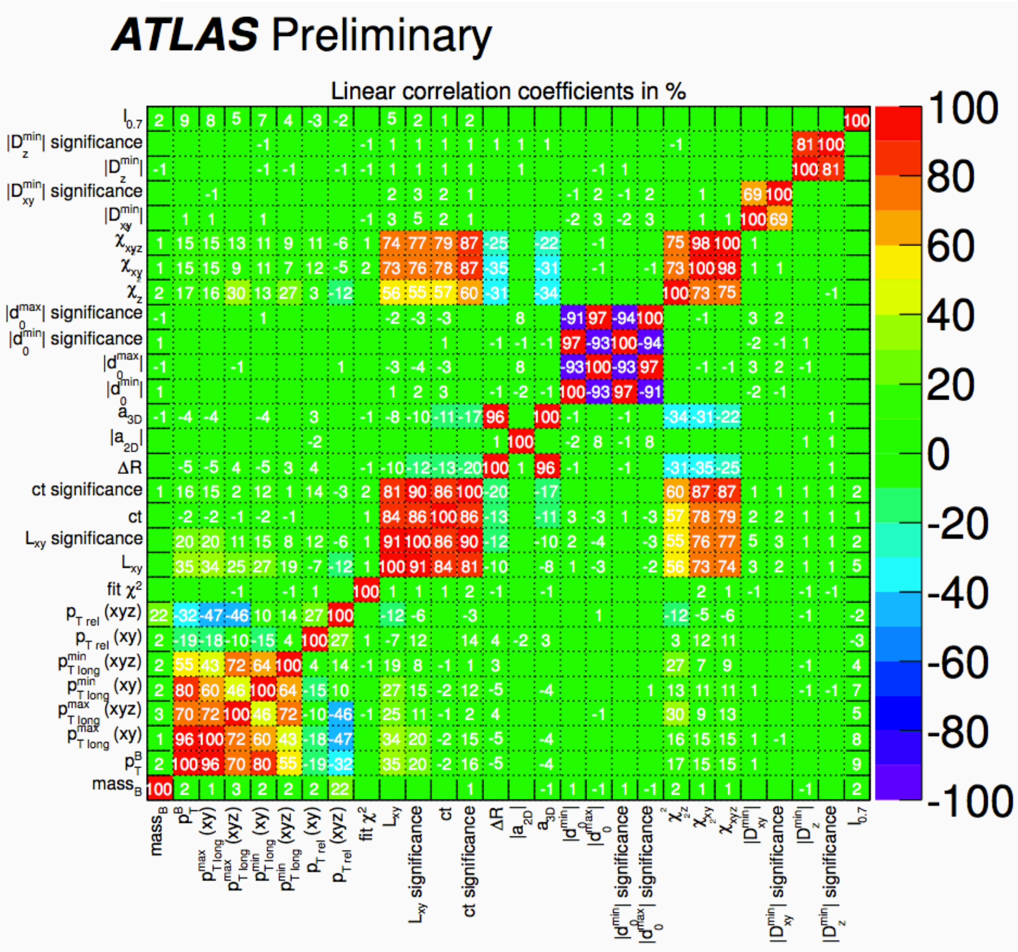
Variable	Description
$\lvert\alpha_{2D}\rvert$ pointing angle	Absolute value of the angle in the transverse plane between $\Delta\vec{x}$ and $\vec{p}^B$
ΔR	Angle $\sqrt{(\Delta\phi)^2+(\Delta\eta)^2}$ between $\Delta\vec{x}$ and $\vec{p}^B$
L_{xy}	Scalar product in the transverse plane of $(\Delta\vec{x}\cdot\vec{p}^B)/\lvert\vec{p}_T^B\rvert$
ct significance	Proper decay length $ct = L_{xy}\times m_B/p_T^B$ divided by its uncertainty
χ^2_{xy}, χ^2_z	Vertex separation significance $\Delta\vec{x}^T\cdot(\sigma^2_{\Delta\vec{x}})^{-1}\cdot\Delta\vec{x}$ in (x,y) and z, respectively
$I_{0.7}$ isolation	Ratio of $\lvert\vec{p}_T^B\rvert$ to the sum of $\lvert\vec{p}_T^B\rvert$ and the transverse momenta of all tracks with $p_T > 0.5$ GeV within a cone $\Delta R < 0.7$ from the B direction, excluding B decay products
$\lvert d_0^{max}\rvert$, $\lvert d_0^{min}\rvert$	Absolute values of the maximum and minimum impact parameter in the transverse plane of the B decay products relative to the primary vertex
$\lvert D_{xy}^{min}\rvert$, $\lvert D_z^{min}\rvert$	Absolute values of the minimum distance of closest approach in the xy plane (or along z) of tracks in the event to the B vertex
p_T^B	B transverse momentum
p_L^{max}, p_L^{min}	Maximum and minimum momentum of the two muon candidates along the B direction

Discriminating Variables: candidates

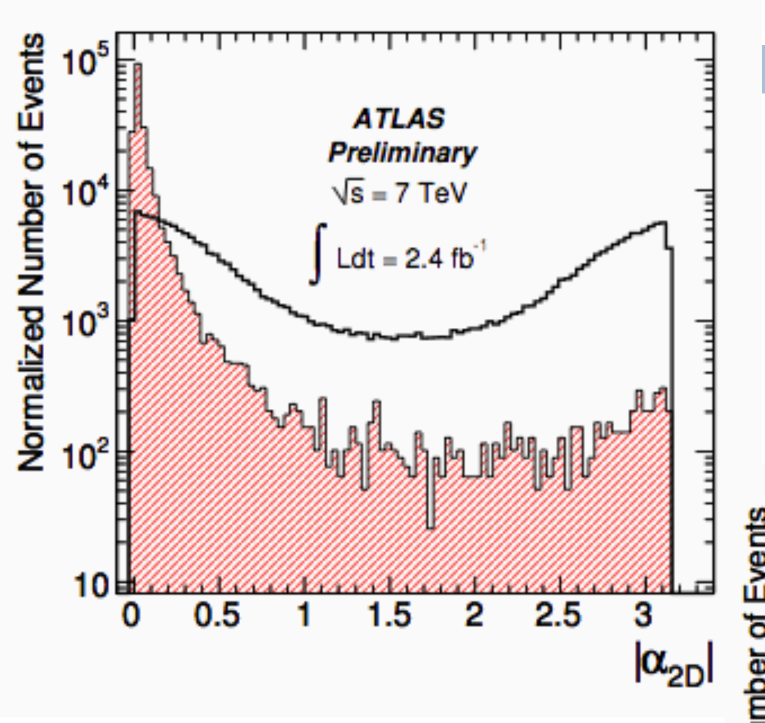
Background

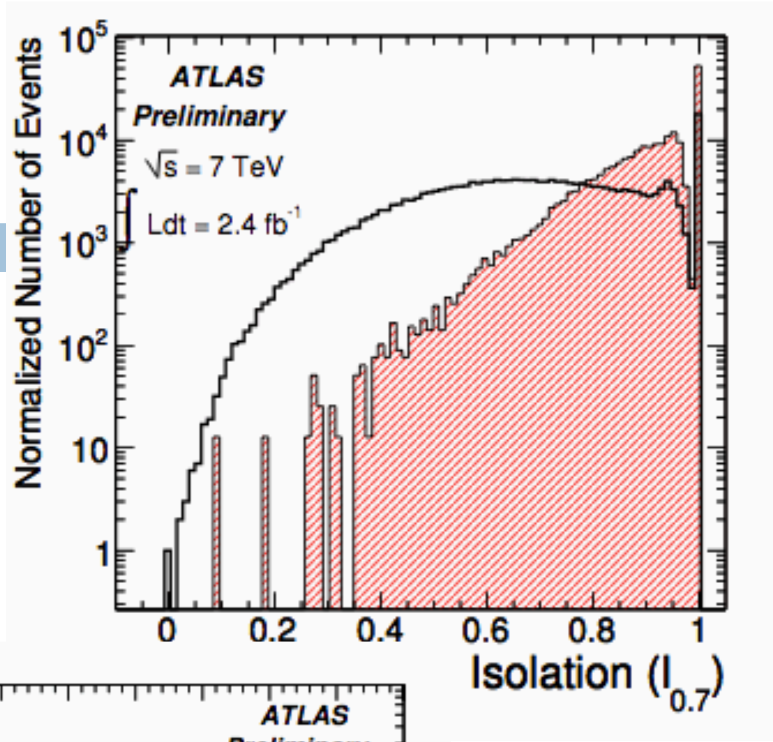


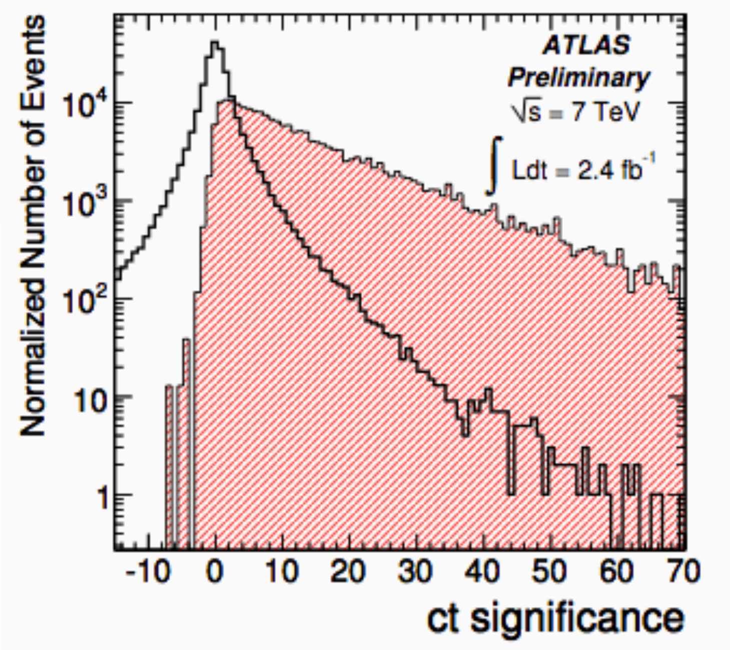
Signal



Few examples





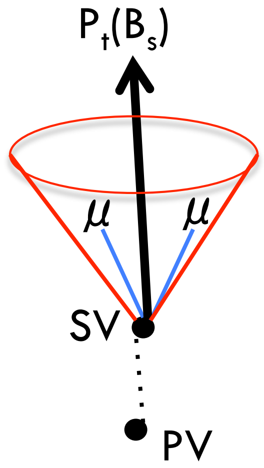


Isolation and pile-up

- Isolation:

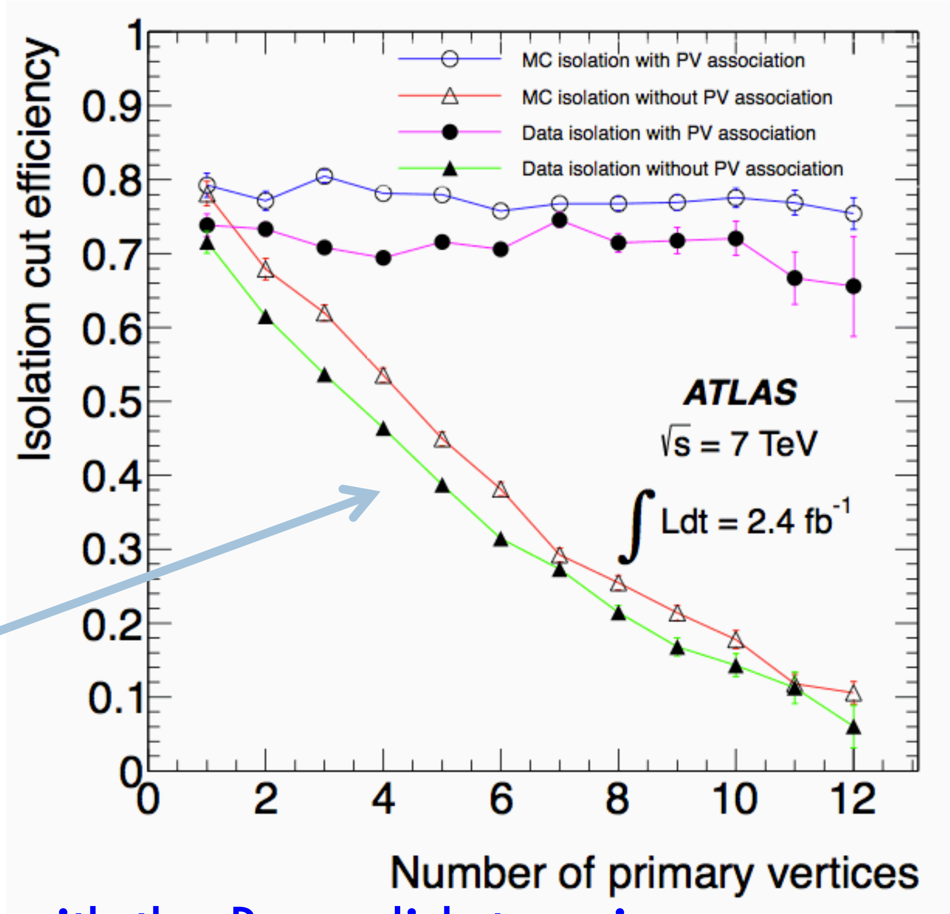
$$I^{\Delta R} = \frac{P_t^{B_s}}{P_t^{B_s} + \sum^{\Delta R} p_t}$$

extended to all non-B daughters within ΔR<0.7, and p_T>0.5 GeV



- Corresponds to red (green) line in $B^{\pm} \rightarrow J/\psi K^{\pm}$ MC (data)

"Interference" by tracks from other interactions!



Excluding tracks incompatible with the B-candidate primary vertex effectively removes this interference!

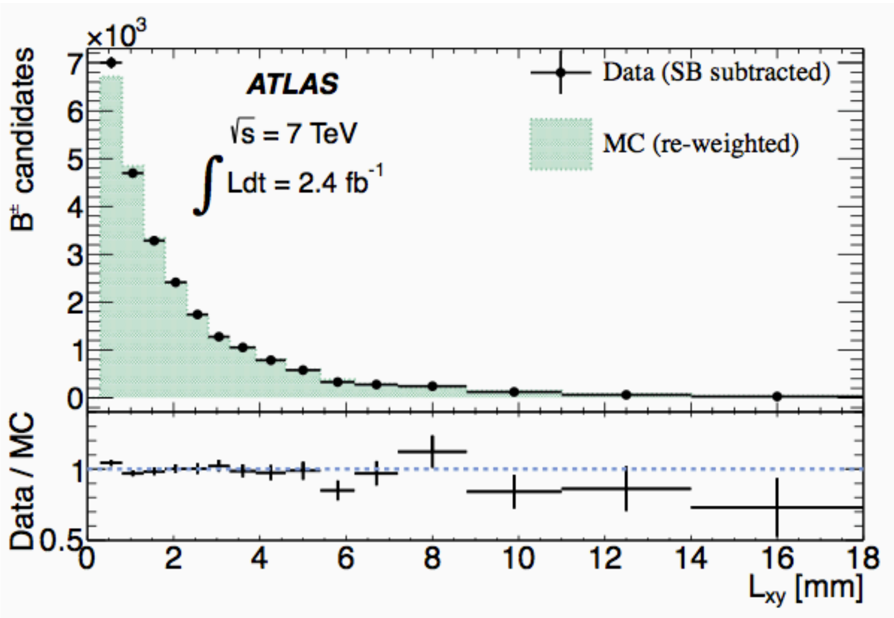
Determination of ε A ratio

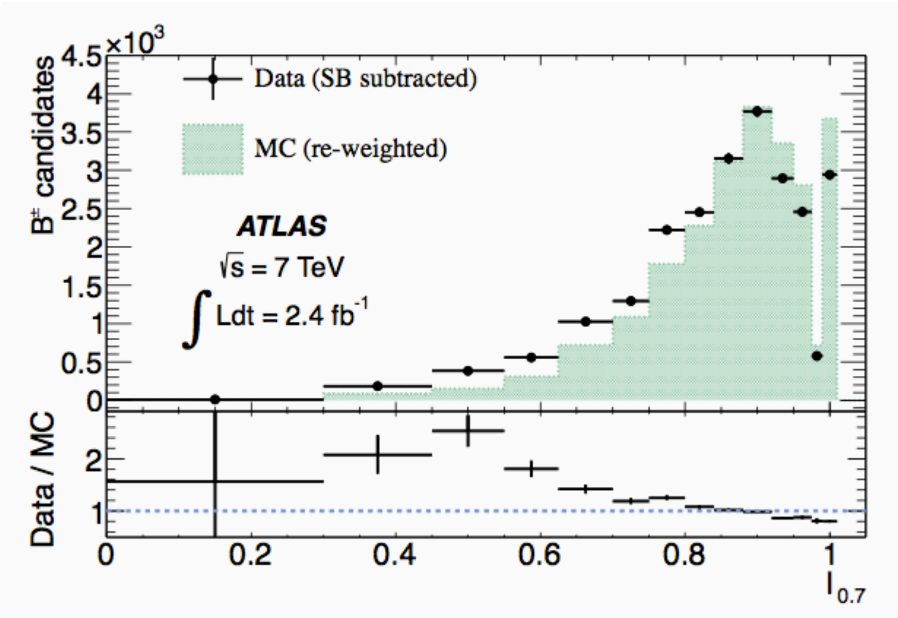
$$BR(B_s \to \mu\mu) = N_{B_s \to \mu\mu} \left[\frac{\alpha_{J/\psi K^\pm} \varepsilon^{tot}_{J/\psi K^\pm}}{\alpha_{B_s \to \mu\mu} \varepsilon^{tot}_{B_s \to \mu\mu}} \cdot \frac{1}{N_{J/\psi K^\pm}} \cdot \frac{f_u}{f_s} \cdot BR(B^\pm \to J/\psi K^\pm) \right]$$

- Derived from MC
- Event by event MC re-weighting (p_T, η) used to account for:
  - Final-state selections on MC (different for B^+ and B_s !!!)
  - Differences between MC and data, primarily in B kinematics (p_T, η)
    - Data driven ($B^\pm \rightarrow J/\psi K^\pm$)
    - Checks:
      - Verified on MC
      - B_s/B^+ differences: procedure repeated on $Bs \rightarrow J/\psi\ \Phi$
- Uncertainties:
  - From MC statistics
  - from corrections:
    - Propagate stat. uncertainty on weights (small)
    - Further differences observed on discr. variables taken as systematic uncertainties

Examples of residual differences

After (p_T, η) re-weighting discriminating variables still show some deviations:



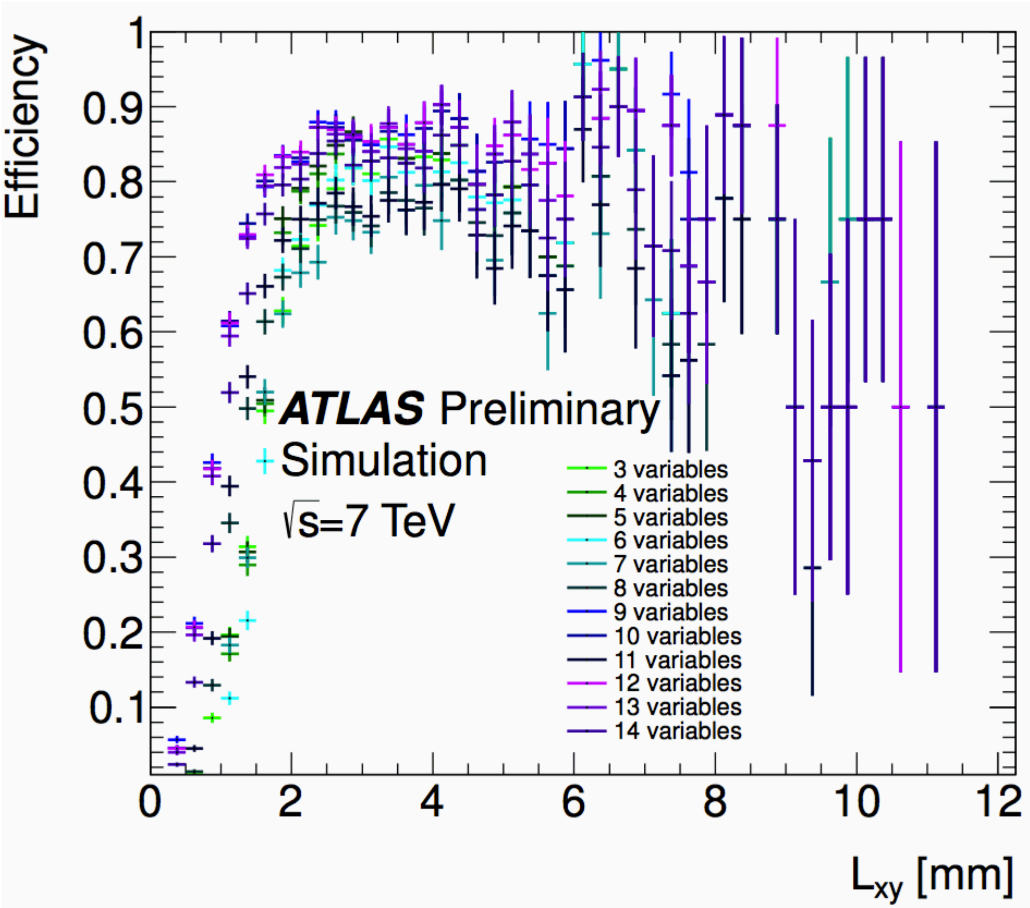


These deviations are accounted for in the systematic uncertainties

Multivariate Selection

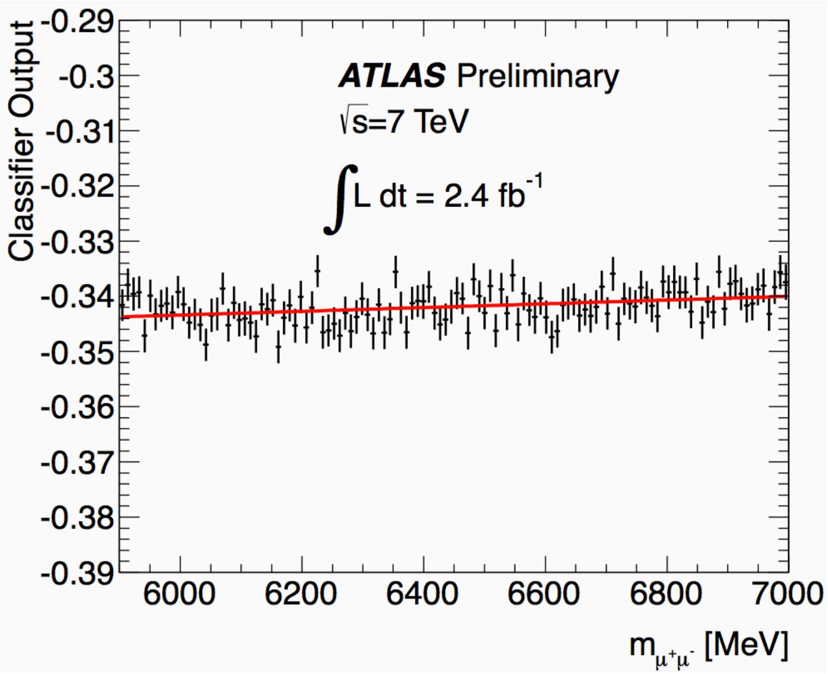
- Optimize estimator:
  (best 95% CL frequentist limit)
  $$\mathcal{P} = \frac{\varepsilon_{signal}}{1+\sqrt{N_{background}}}$$
- Among the classifiers tested (TMVA), BDT is the best performing
- Checks of BDT behavior:
  - Reference: "Rectangular" cuts (1) on {α_{2D}, $I_{0.7}$, ct significance, Δm}
  - $\mathcal{P}$(reference)≈ $\mathcal{P}$ from BDT [trained on same variables]
  - $\mathcal{P}$(final) BDT=0.016 > $\mathcal{P}$(reference)=0.010
  - Training BDT "incrementally": optimal BDT cut → events "mostly" at or above reasonable rectangular cuts

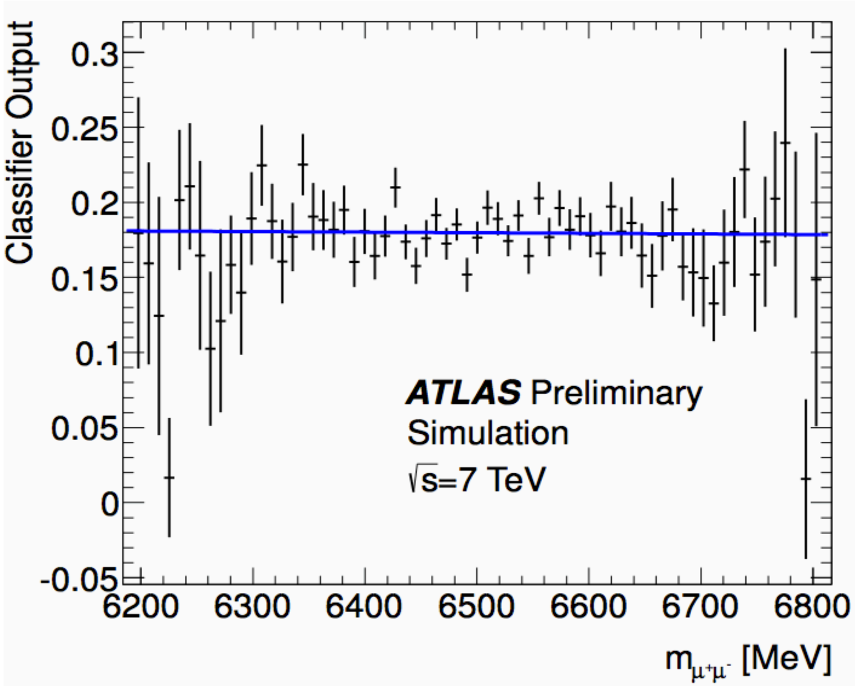
"Incremental" BDT optimization



- Incremental optimization:
  - Train BDT using n variables
  - Optimize (BDT, Δ m) cut
  - Plot (efficiency, variables) when cutting at optimal point
  - Increment n
  - Repeat!
- Efficiency curves consistent with what observed for "rectangular cuts" approach
- As expected, introducing more variables allows to accept more events "near threshold"

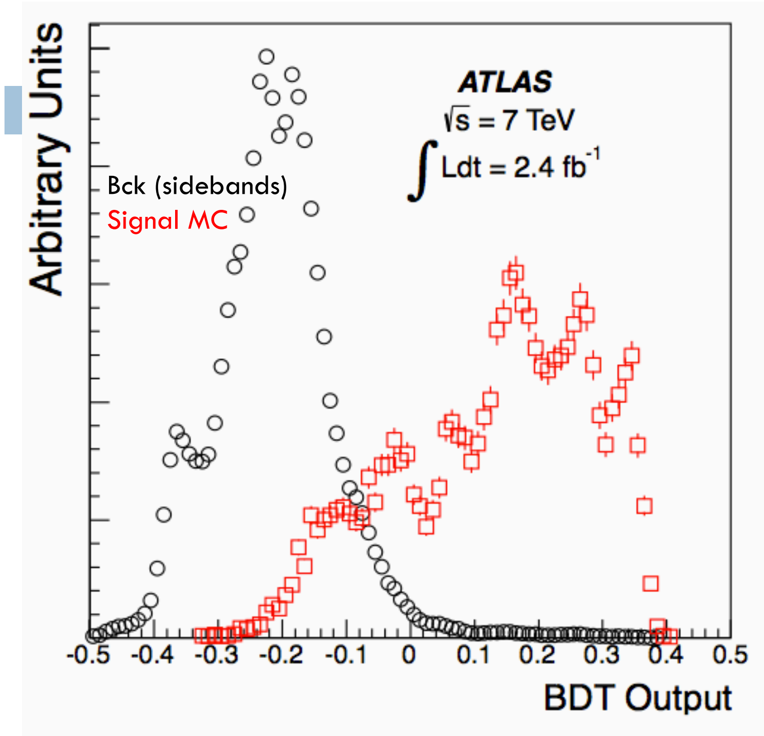
Mass in-dependence of the BDT output

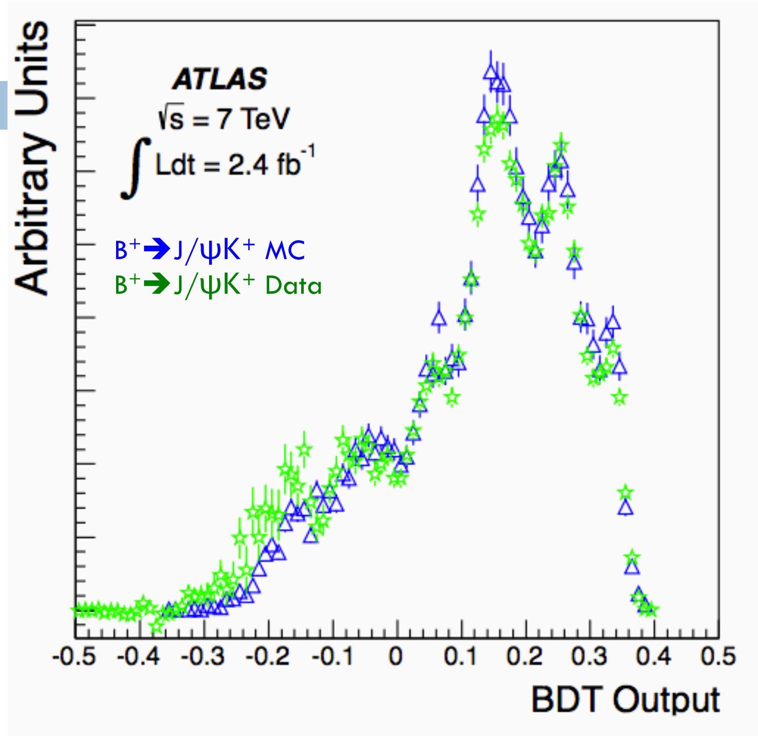




- Test the full analysis on a signal-free not blinded region (pseudo-signal at 6.5 GeV)
  - Re-train BDT on 6.5 GeV MC+sidebands
- BDT proven to be insensitive to transition from sidebands to signal region
- Background conditions somewhat different (limit $<1.6\times10^{-8}$)

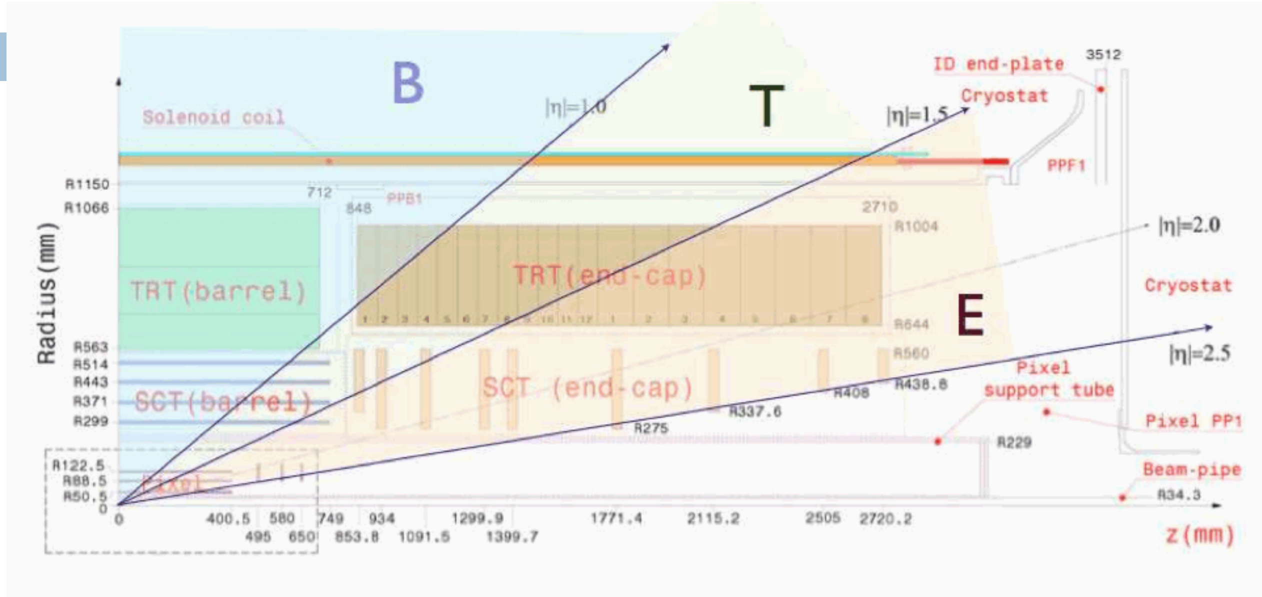
Classifier response on data and MC





- Optimal cut at ~0.25
- Good S/B separation
- MC reproduces response on data pretty well!

Mass resolution categories



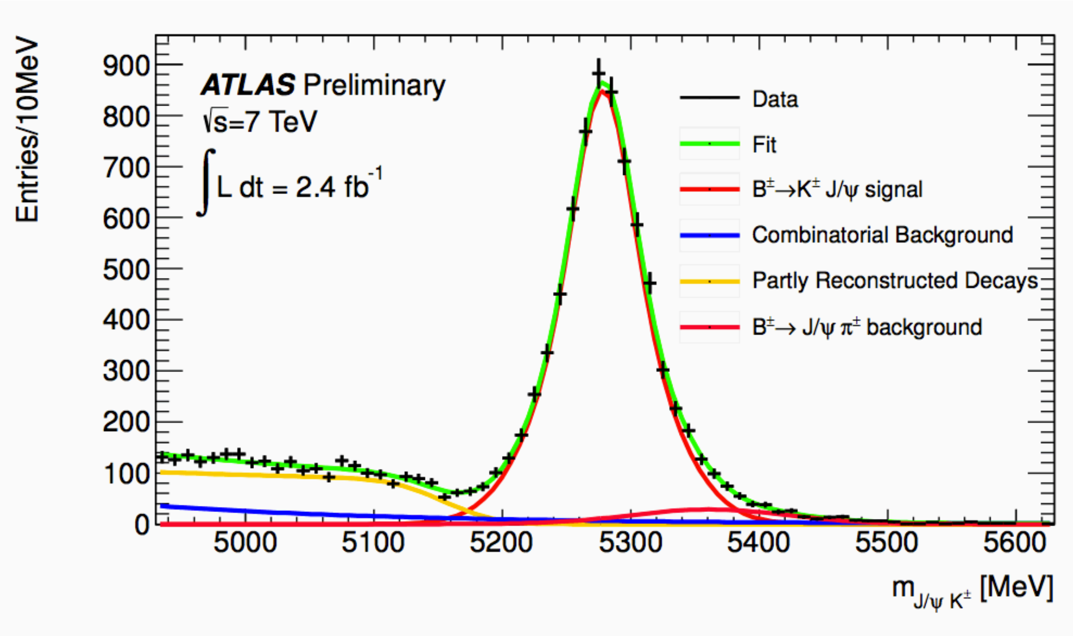
Mass resolution for di-μ candidates changes substantially between barrel and end-cap detectors

$\lvert\eta_{max}\rvert$	1.0	1.5	2.5
σ_m [MeV]	60	80	110
Relative fraction [%]	51	24	25
invariant mass window [MeV]	±116	±133	±171
BDT output threshold	0.234	0.245	0.270

Cuts @ optimal $\mathcal{P}$ (invariant mass window and BDT output threshold)

B^+ Yield

- Same BDT (and cut) for B_s and B^+ ➔ minimize (B_s/B^+) systematics
- Yield uncertainties
  - Statistical
  - Systematic
    - Vary binning
    - Signal/background models
    - Binned/un-binned fit



$\|\eta_{max}\|$ Range	0-1.0	1.0-1.5	1.5-2.5
$B^{\pm} \to J/\psi K^{\pm} \to \mu^+\mu^- K^{\pm}$	4300	1410	1130
statistical uncertainty	$\pm 1.6\%$	$\pm 2.8\%$	$\pm 3.0\%$
systematic uncertainty	$\pm 2.9\%$	$\pm 7.4\%$	$\pm 14.1\%$

Limit Extraction Ingredients

$\lvert\eta_{max}\rvert$ Range	$R^i_{A\epsilon}$	Δ % Stat.	Δ % Syst.
0-1.0	0.274	3.1	3.1
1.0-1.5	0.202	4.8	5.5
1.5-2.5	0.143	5.3	5.9

+Additional systematic uncertainties:

- Data-MC absolute K efficiency: 5%
- Vertex reconstruction efficiency: 2%
- K^+/K^- asym.: 1%

$$BR(B_s \to \mu\mu) = \frac{N_{B_s\to\mu\mu}}{N_{J/\psi K^\pm}} \cdot \frac{\alpha_{J/\psi K^\pm}\varepsilon^{tot}_{J/\psi K^\pm}}{\alpha_{B_s\to\mu\mu}\varepsilon^{tot}_{B_s\to\mu\mu}} \cdot \frac{f_u}{f_s} \cdot BR(B^\pm \to J/\psi K^\pm)$$

$\lvert\eta_{max}\rvert$ Range	0-1.0	1.0-1.5	1.5-2.5
$B^\pm \to J/\psi K^\pm \to \mu^+\mu^- K^\pm$	4300	1410	1130
statistical uncertainty	±1.6%	±2.8%	±3.0%
systematic uncertainty	±2.9%	±7.4%	±14.1%

$1/(4.45\pm0.38)\times10^3$

[PDG + LHCb]

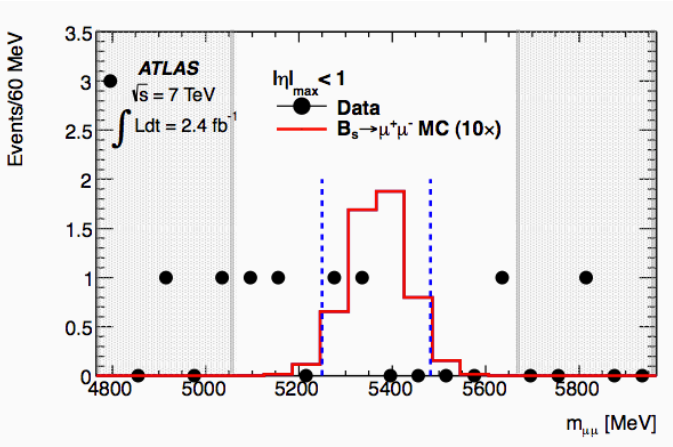
Box Opening

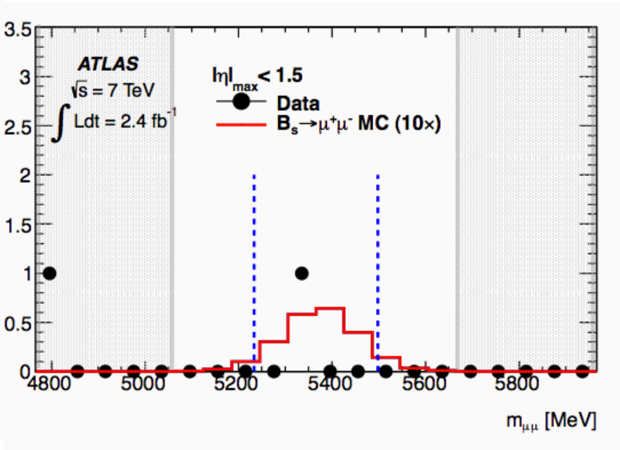
60 MeV resolution

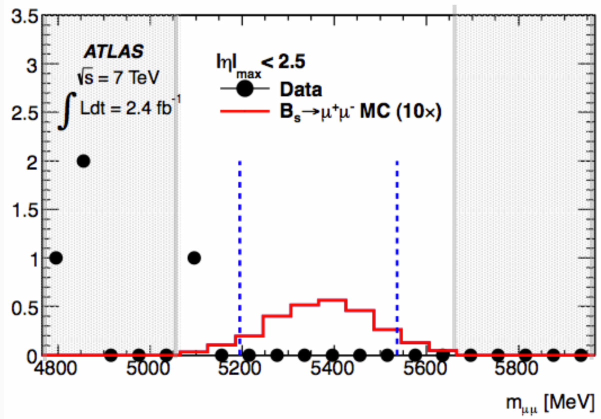
80 MeV resolution

110 MeV resolution

Sidebands





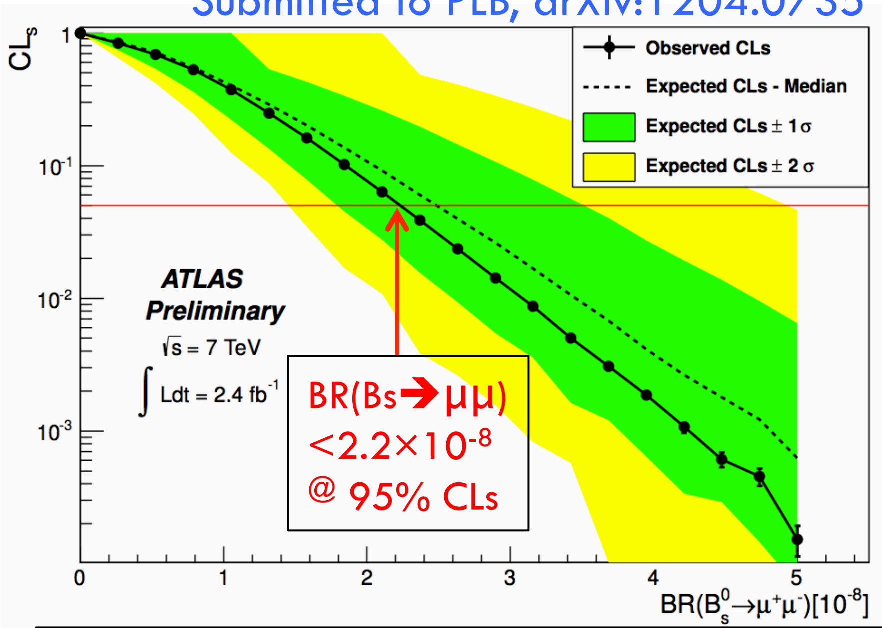


Optimized search window

Box opening and limit

Submitted to PLB, arXiv:1204.0735

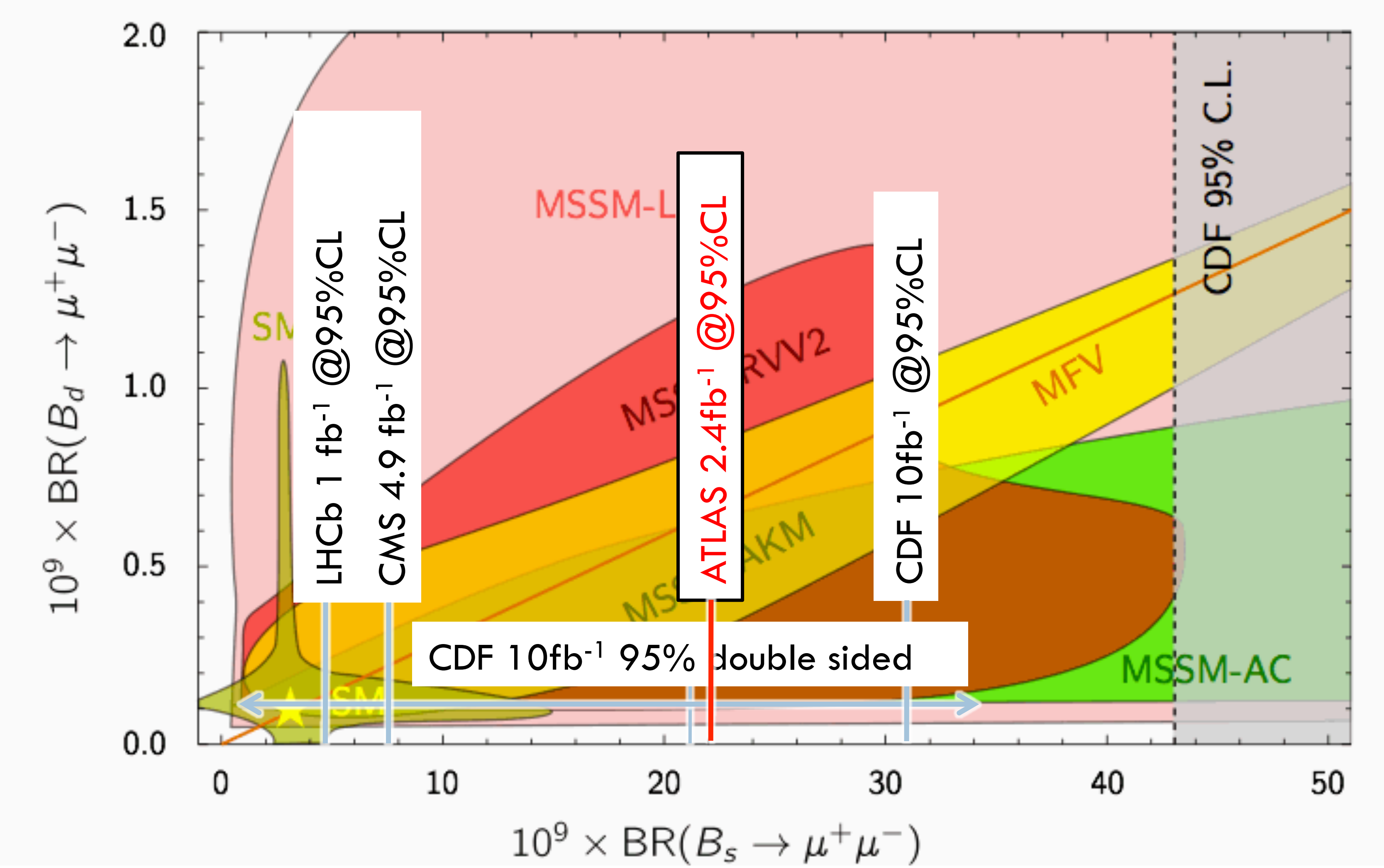
- Sidebands:
  - Even: 5/0/2 [un-biased]
  - Odd: 1/1/1 [biased]
- Continuous background interpolation: 6.1 ev.
- Resonant background: 0.24 ev.
- 95% CL_s limit expectations:
  - Even sidebands: 2.3×10^{-8} (68% of toys in range $1.8\text{-}3.3\times10^{-8}$)
  - Odd sidebands: 1.7×10^{-8}
  - All bins merged: 2.9×10^{-8}



Future improvements:
- Full 2011 statistics (& beyond)
- Use more information in limit extraction
- Use of spectrometer information to improve mass resolution (forward muons)
- MC-based continuous background model?

Expect improvements better than sqrt(Lumi)

The ATLAS Result



Conclusions

- **We are living an exciting transition era of increasingly quantitative results in the Standard Model**
- **The Flavor sector has transitioned from the observation to the high-precision era**
- **Flavor physics is an excellent training ground in terms of experimental skills! It drove several improvements:**
  - **Detector performance and techniques (precision trackers, dedicated trigger HW,…)**
  - **Advanced analysis techniques and tools (e.g. HQET, advanced statistical methods,…)**
  - **New constraints on BSM physics (e.g. Bs mixing, rare decays, …)**
- **Beyond SM physics could be around the corner, but hard to discern models without direct evidences**
- **LHC began investigating this completely uncharted territory!**
- **Living this constant exploration of new discoveries puts us at the forefront of human knowledge, a recurring theme in the history of science:**

□ "Modern science did not spring perfect and complete, as Athena from the head of Zeus, from the mind of Galileo and Descartes" A. Koyre`, "Galileo and the Scientific Revolution of the Seventeenth Century"