

# Data analysis in particle physics

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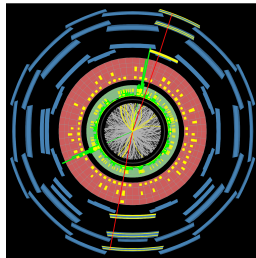
14.8.2017



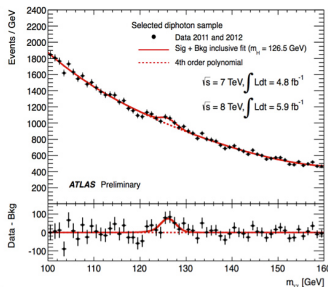
... or road from



via



to



and

Nobelpriset 2013

The Nobel Prize 2013

**François Englert**  
Université Libre de Bruxelles, Belgium

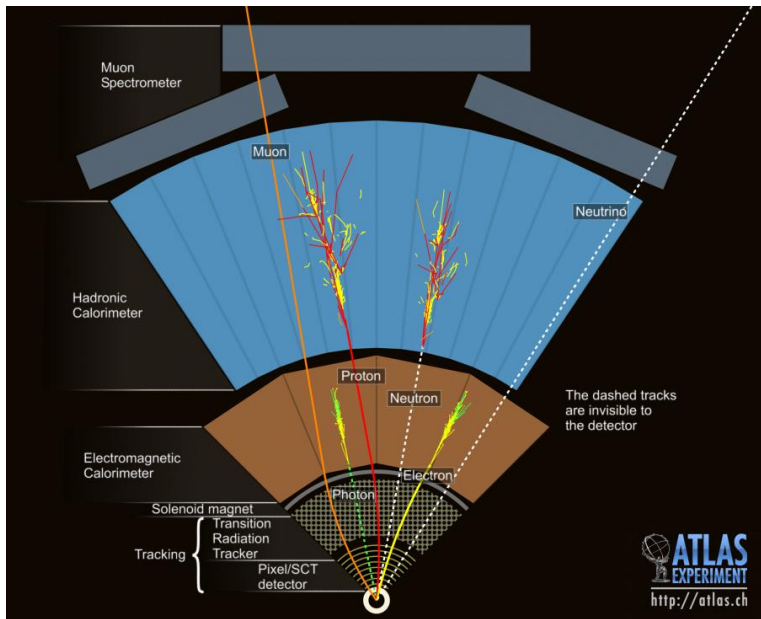
**Peter W. Higgs**  
University of Edinburgh, UK

*"För den teoretiska upptäckten av en mekanism som bidrar till förståelsen av massans ursprung hos subatomära partiklar, och som nyligen, genom upptäckten av den förutsagda fundamentala partikeln, bekräftats av ATLAS- och CMS-experimenten vid CERN:s accelerator LHC."*

*"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider."*

Nobelprize.org

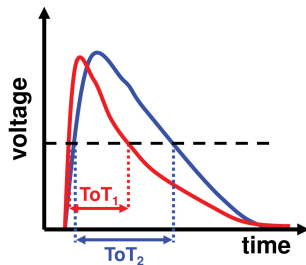
# Complex detector systems



# Signal processing on detector

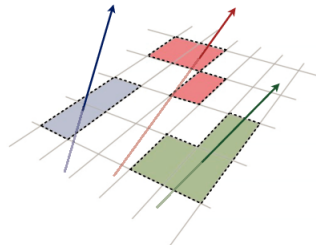
Each detector element (pixel/strip/crystal/wire)

- measure voltage or  $\Sigma$  charge
- pedestal suppression
- analog, binary or Time-over-threshold



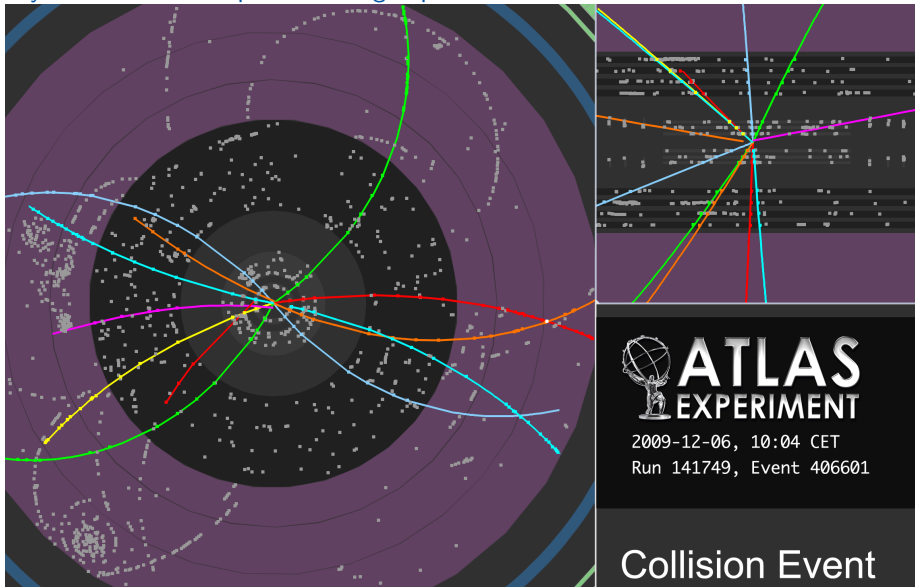
Each structure (module/chamber)

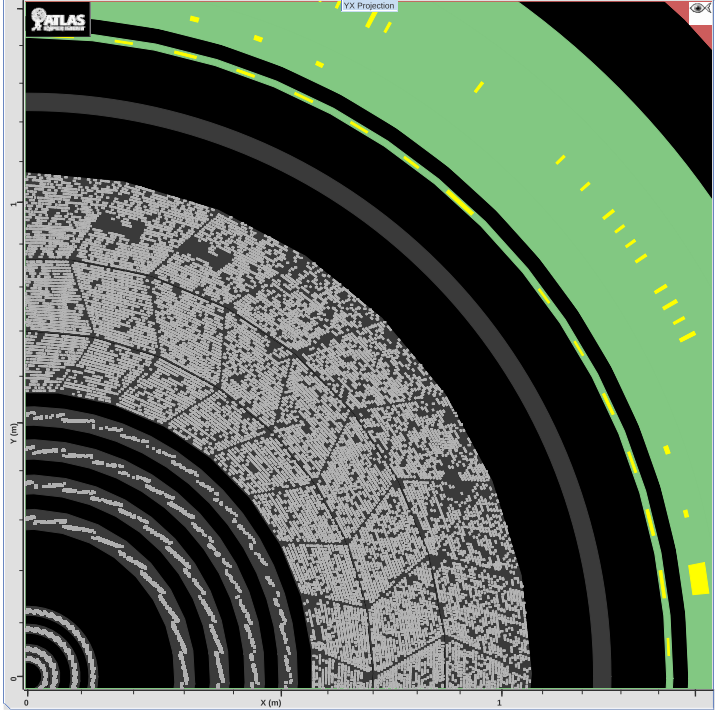
- format and send data
- compression - clustering

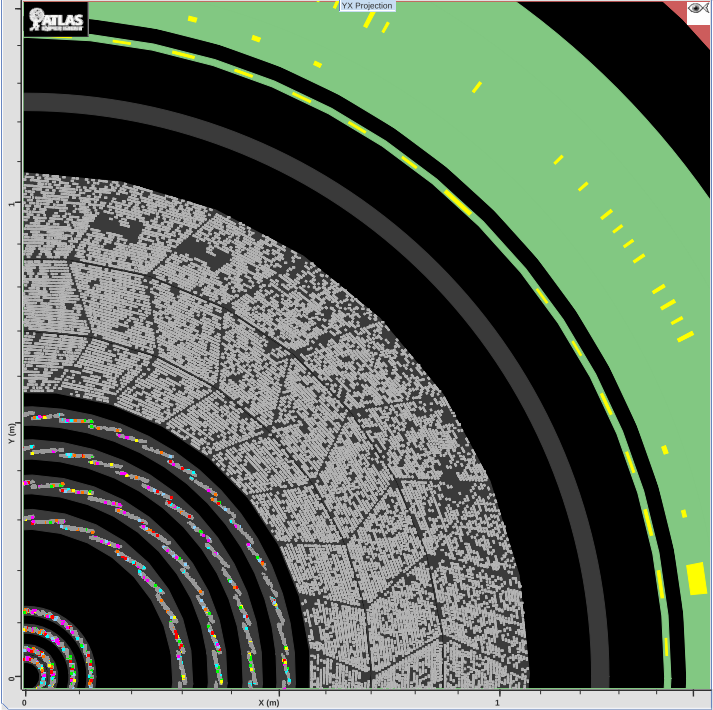


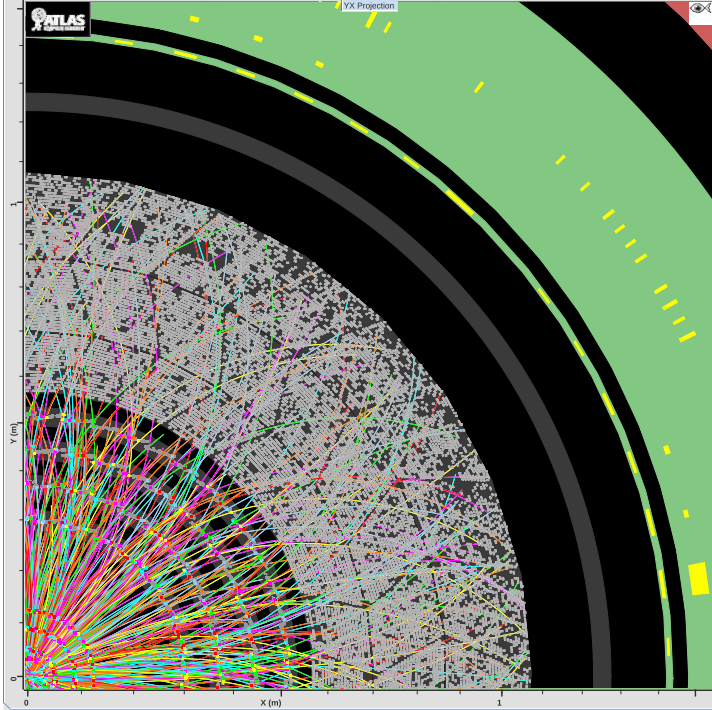
# Tracking

Try to reconstruct a path of charged particles in inner detector:

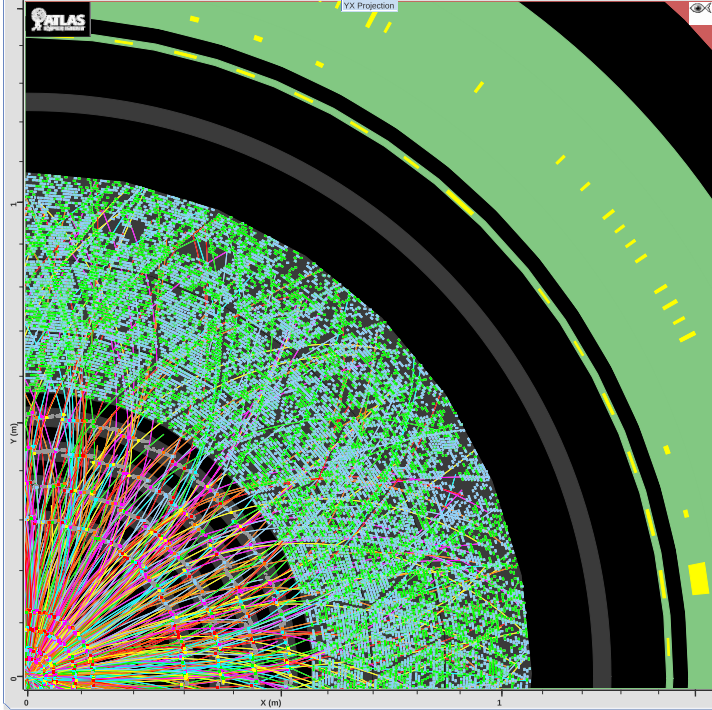


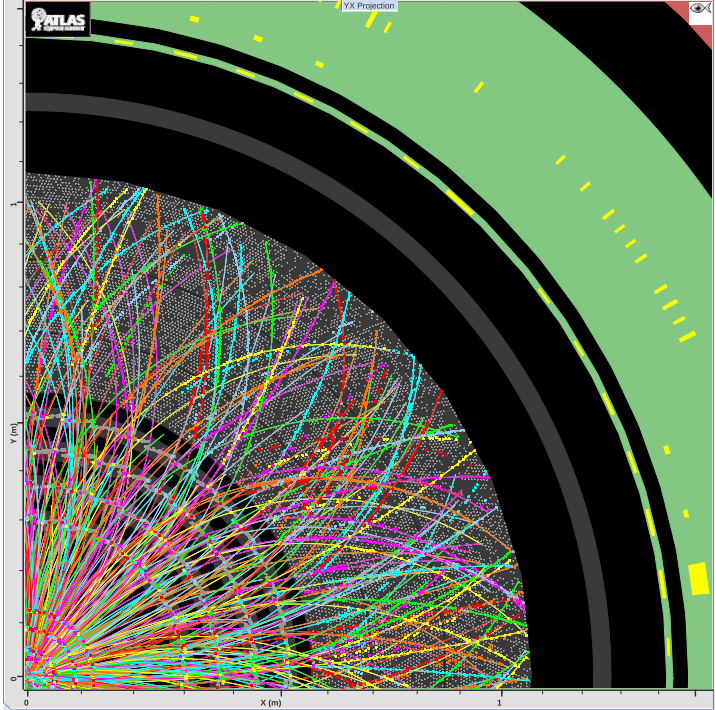




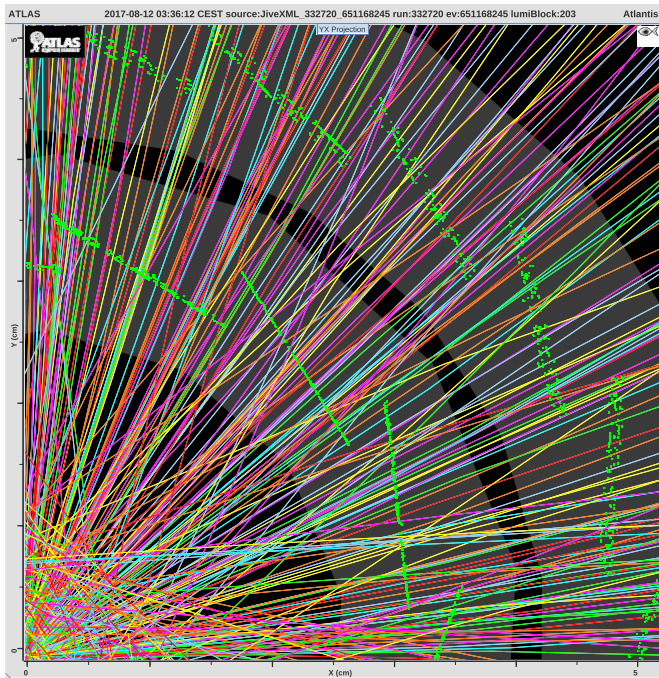




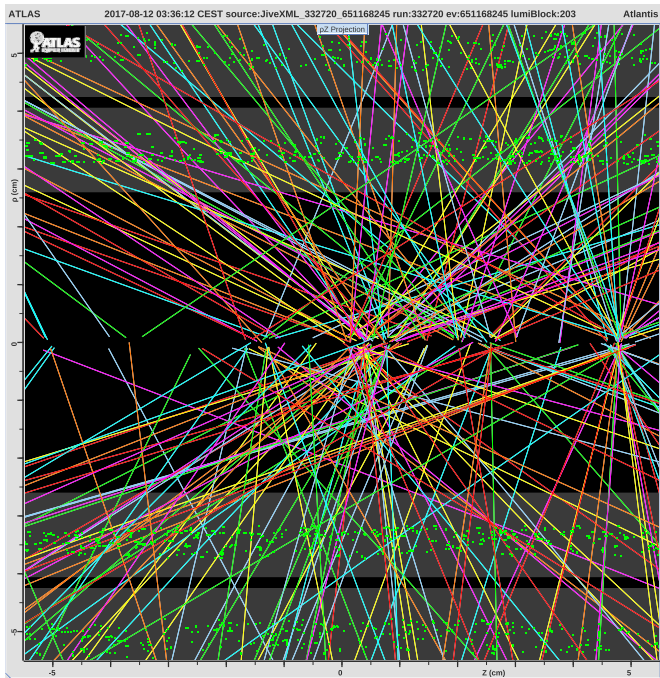




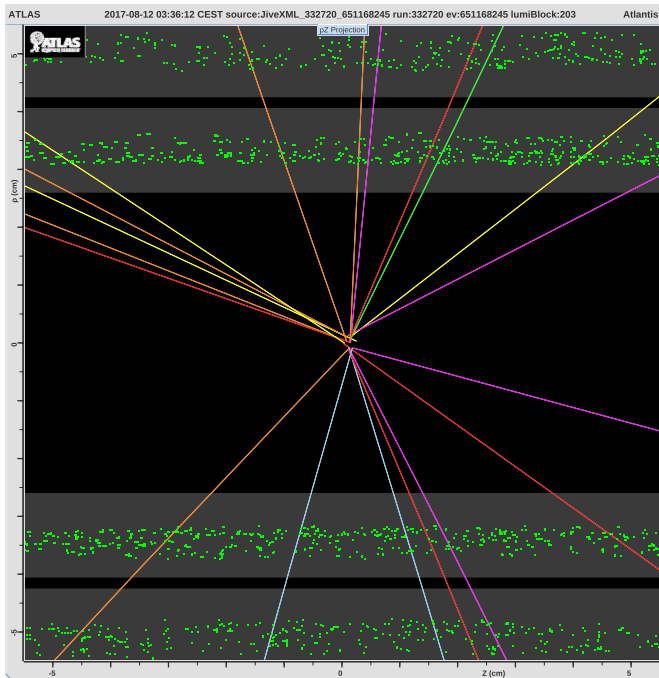
## Zoom on interaction point:



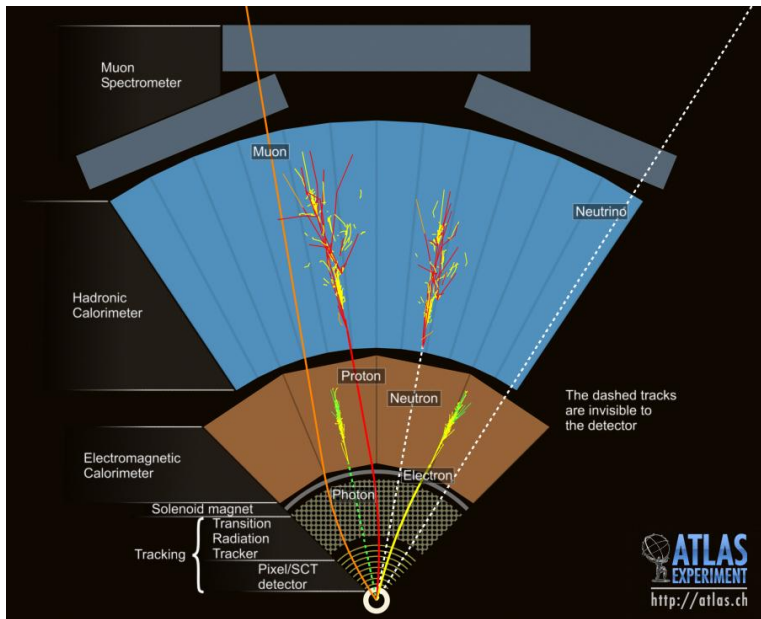
# Zoom on interaction point:



# Zoom on the primary vertex:



# Physics objects



Simple objects:

- track
- calorimeter cluster
- muon segment

→ Combined objects:

- electron = calo cluster + track
- photon = ECAL cluster + no track or  $e^-e^+$  pair - conversion
- proton = HCAL cluster + track

→ Complicated objects:

- jets = big calo cluster + tracks
- $b$ -jets - often contain muon or electron
- $\tau$  leptons - decay to hadrons (jets), muons or electrons
- $\nu$  - computed from missing energy and momentum

# Data format after reconstruction

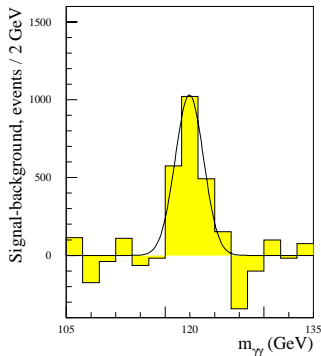
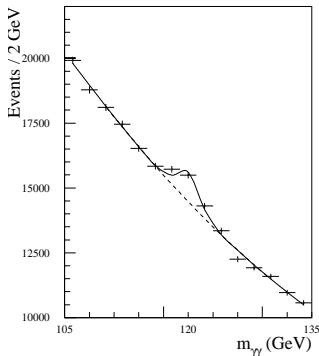
Event = all physics objects reconstructed in 1 LHC bunch crossing:

run	332720										
event	651168245										
track0	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{PIX}$	$n_{SCT}$	$n_{TRT}$	...	
track1	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{PIX}$	$n_{SCT}$	$n_{TRT}$		
⋮											
mu0	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{PIX}$	$n_{SCT}$	$n_{TRT}$	MS	$n_{MS}$
mu1	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{PIX}$	$n_{SCT}$	$n_{TRT}$	MS	$n_{MS}$
⋮											
gamma0	$p_x$	$p_y$	$p_z$	$E$							
jet0	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{tracks}$				
jet1	$p_x$	$p_y$	$p_z$	$XPV$	$YPV$	$ZPV$	$n_{tracks}$				
$p_T^{miss}$	$p_x$	$p_y$	$p_z$								
PV0	$x$	$y$	$z$	$n_{tracks}$							
PV1	$x$	$y$	$z$	$n_{tracks}$							
⋮											



## Example: strategy for $H \rightarrow \gamma\gamma$

- run simulations of  $H$  signal and background from SM
- think about how to select candidates with high purity - e.g. cuts
  - 2  $\gamma$ 's in central region with  $E_\gamma > 20$  GeV, no tracks close to them
  - from simulation: should have at least 15% of real H bosons

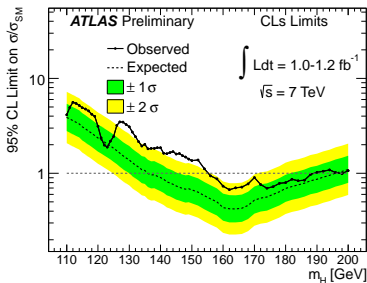
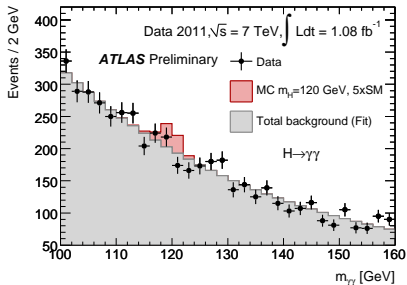


Example: strategy for  $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...

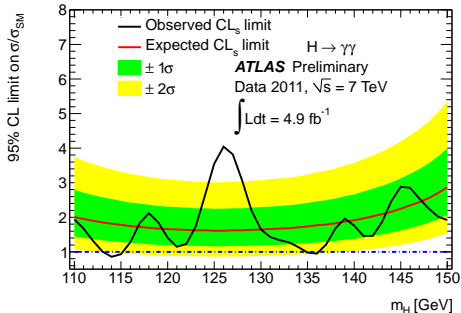
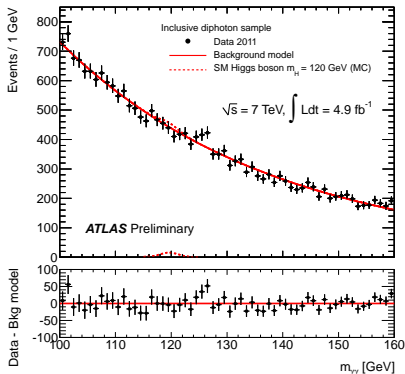
## Example: strategy for $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...
- ... summer 2011



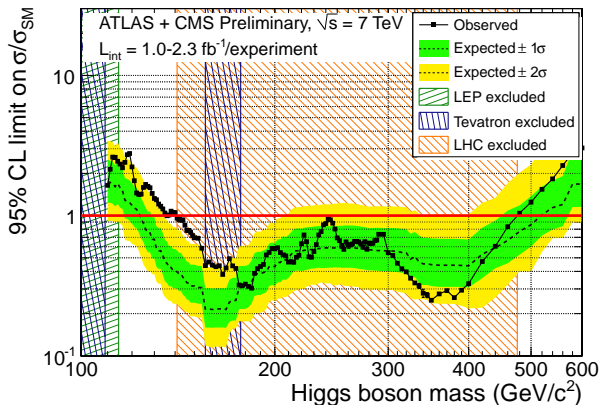
## Example: strategy for $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...
- ... end of 2011 - is there an excess?



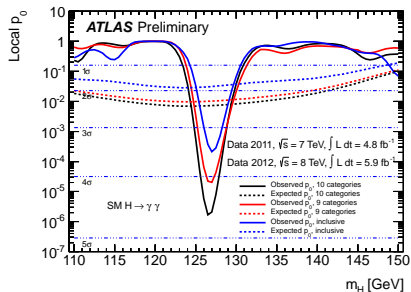
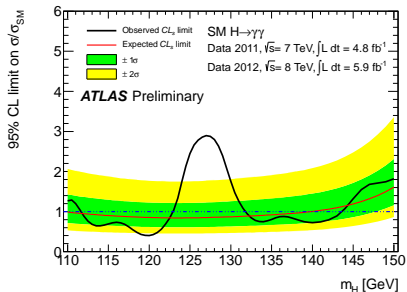
## Example: strategy for $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...
- ... end of 2011 - ask CMS as well



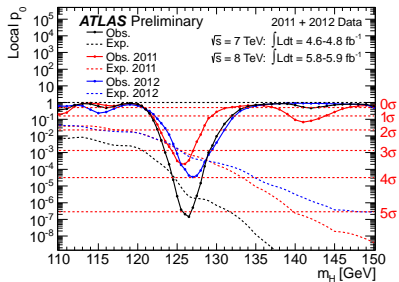
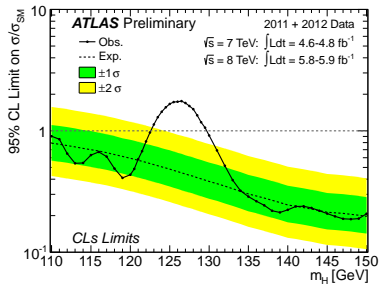
## Example: strategy for $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...
- ... summer 2012 - add more data



## Example: strategy for $H \rightarrow \gamma\gamma$

- take data
- remove events with bad quality (subdetectors OFF, unstable conditions)
- select events containing particles in final state you want
- wait and plot what you find...
- ... summer 2012 - combine with  $ZZ^* \rightarrow 4\ell$  and  $WW^* \rightarrow 2\ell 2\nu$  channel



## Example: strategy for $H \rightarrow \gamma\gamma$

- announce discovery!

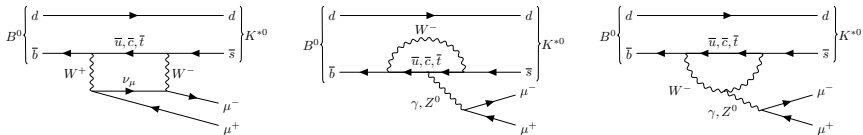




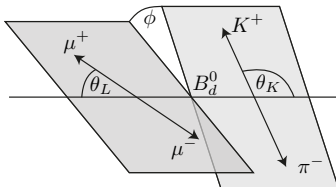
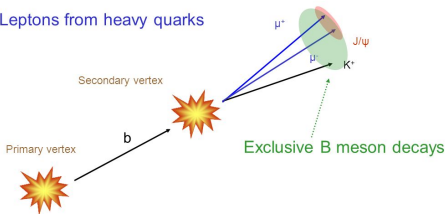
# Other analyses

Example: my analysis of  $B^0 \rightarrow K^*(K\pi)\mu^+\mu^-$  decay

- very rare decay (1 of  $10^7$   $B$  particles)
- can indirectly observe new particles/interactions in loops



Leptons from heavy quarks



# $B^0 \rightarrow K^*(K\pi)\mu^+\mu^-$ selection, fitting, checks...

## ATLAS analysis of $B_d \rightarrow K^*\mu^+\mu^-$

### Dataset:

ATLAS CONF.2017.023

- 20.3 fb<sup>-1</sup>, taken at  $\sqrt{s} = 8$  TeV in 2012

### Reconstruction and selection:

- preselection: track  $p_T$ , ID hits, min. 1 combined muon
- baseline:  $|\eta| < 2.5$ ,  $m(K^*) = [846, 946]$  MeV,  $m(B) = [5150, 5700]$  MeV  
 $p_T(\mu) > 3.5$  GeV,  $p_T(\tau, K) > 0.5$  GeV
- final cuts:  $\alpha_\tau/\tau > 12.75$ , pointing  $\cos\theta > 0.999$ ,  $\chi^2/ndf(B) < 2$ ,  
 $p_T(K^*) > 3$  GeV,  $|(m(B) - m_{\text{vcc}}(B)) - (m(\mu\mu) - m_{\text{vcc}}(J/\psi))| < 130$  MeV
- trigger - 15 most frequent triggers
- control regions:  $J/\psi$  ( $q^2 = [8, 11]$  GeV<sup>2</sup>),  $\psi(2S)$  ( $q^2 = [12, 15]$  GeV<sup>2</sup>)
- signal  $q^2 = [0.04, 6]$  GeV<sup>2</sup> except of  $\phi$  region  $q^2 = [0.98, 1.1]$  GeV<sup>2</sup>
- if  $> 1$  candidate/event: candidate with higher  $\sigma_m(K^*)/m(K^*)$

## Monte Carlo datasets

### Signal:

Process	Generator	Dataset	Events
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen: flat	208448	50M
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen: SM	208446	5M
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen	208447	5M
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen	208451	50M

### Inclusive backgrounds:

Process	Generator	Dataset	Events
$\bar{b}b \rightarrow \mu^+\mu^-X$	Pythia	208301	20M
$\bar{b}b \rightarrow \mu^+\mu^-X$	EvtGen	208303	1M
$\bar{b}b \rightarrow \mu^+\mu^-XAA$	Pythia	208308	40M
$\bar{b}b \rightarrow \mu^+\mu^-XAB$	Pythia	208309	48M
$\bar{b}b \rightarrow \mu^+\mu^-XBA$	Pythia	208310	48M
$\bar{b}b \rightarrow \mu^+\mu^-XBB$	Pythia	208311	130M
$c\bar{c} \rightarrow \mu^+\mu^-X$	Pythia	208312	50M

## $B_d \rightarrow K^*\mu^+\mu^-$ decay in SM

### Differential decay rate (optimized):

$$\frac{1}{d\Gamma/dq^2} \frac{d^2\Gamma}{d\cos\theta_1 d\cos\theta_2 dq^2} = \frac{9}{32\pi} \left[ \frac{3(1-F_1)}{4} \sin^2\theta_K + \frac{1-F_1}{4} \sin^2\theta_K \cos 2\theta_1 \right. \\ \left. + F_1 \cos^2\theta_K - F_1 \cos^2\theta_K \cos 2\theta_1 + S_2 \sin^2\theta_K \sin^2\theta_1 \cos 2\phi \right. \\ \left. + S_4 \sin 2\theta_K \sin 2\theta_1 \cos\phi + S_5 \sin 2\theta_K \sin\theta_1 \cos\phi + S_6 \sin^2\theta_K \cos\theta_1 \right. \\ \left. + S_7 \sin 2\theta_K \sin\theta_1 \sin\phi + S_8 \sin 2\theta_K \sin 2\theta_1 \sin\phi + S_9 \sin^2\theta_K \sin^2\theta_1 \sin 2\phi \right].$$

$$F_1 = \frac{2S_1}{(1-F_1)} \quad F_2 = \frac{2}{3} \frac{A_{FB}}{(1-F_1)} \quad P_3 = -\frac{S_3}{(1-F_1)}$$

$$P_{4,AA} = \frac{S_{4,AA}}{\sqrt{F_1(1-F_1)}} \quad P'_4 = \frac{S_7}{\sqrt{F_1(1-F_1)}}$$

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# $B^0 \rightarrow K^*(K\pi)\mu^+\mu^-$ selection, fitting, checks...

## ATLAS analysis of $B_d \rightarrow K^*\mu^+\mu^-$

Dataset:

- 20.3 fb<sup>-1</sup>, taken at  $\sqrt{s} = 8$  TeV in 2012

Reconstruction and selection:

- preselection: track  $p_T$ , ID hits, min. 1 combined muon
- baseline:  $|y| < 2.5$ ,  $m(K^*) = [846, 946]$  MeV,  $m(B) = [1510, 5700]$  MeV  
 $p_T(\mu) > 3.5$  GeV,  $p_T(\pi, K) > 0.5$  GeV
- final cuts:  $\sigma_{\tau/\tau} > 12.75$ , pointing  $\cos\theta > 0.9999$ ,  $\chi^2/ndf(B) < 2$ ,  
 $p_T(K^*) > 3$  GeV,  $|(m(B) - m_{\text{ROC}}(B)) - (m(\mu\mu) - m_{\text{ROC}}(J/\psi))| < 130$  MeV
- trigger - 15 most frequent triggers
- control regions:  $J/\psi$  ( $q^2 = [8, 11]$  GeV<sup>2</sup>),  $\psi(2S)$  ( $q^2 = [12, 15]$  GeV<sup>2</sup>)
- signal  $q^2 = [0.04, 6]$  GeV<sup>2</sup> except of  $\phi$  region  $q^2 = [0.98, 1.1]$  GeV<sup>2</sup>
- if  $> 1$  candidate found: candidate with higher  $\alpha(K^*)/m(K^*)$

ATLAS CONF 2013.013

## Monte Carlo datasets

Signal:

Process	Generator	Dataset	Events
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen, flat	208445	50M
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen, SM	208446	SM
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen	208447	SM
$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen	208451	50M

Inclusive backgrounds:

Process	Generator	Dataset	Events
$b\bar{b} \rightarrow \mu^+\mu^- X$	Pythia	208301	20M
$b\bar{b} \rightarrow \mu^+\mu^- X$	EvtGen	208303	1M
$b\bar{b} \rightarrow \mu^+\mu^- X$ AA	Pythia	208308	40M
$b\bar{b} \rightarrow \mu^+\mu^- X$ AB	Pythia	208309	48M
$b\bar{b} \rightarrow \mu^+\mu^- X$ BA	Pythia	208310	48M
$b\bar{b} \rightarrow \mu^+\mu^- X$ BB	Pythia	208311	130M
$\mu^+\mu^-$	DELPHI	208315	22M

## $B_d \rightarrow K^*\mu^+\mu^-$ decay in SM

Differential decay rate (optimized):

$$\frac{1}{d\Gamma/dq^2 d\cos\theta_\mu d\cos\theta_\pi d\phi dq^2} = \frac{9}{32\pi} \left[ \frac{3(1-F_1)}{4} \sin^2\theta_\mu + \frac{1-F_1}{4} \sin^2\theta_\mu \cos 2\theta \right. \\ \left. + F_1 \cos^2\theta_\mu - F_1 \cos^2\theta_\mu \cos 2\theta + S_1 \sin^2\theta_\mu \sin^2\theta \cos 2\phi \right. \\ \left. + S_2 \sin 2\theta_\mu \sin 2\theta \cos\phi + S_3 \sin 2\theta_\mu \sin\theta \cos\phi + S_4 \sin^2\theta_\mu \cos\theta \right. \\ \left. + S_5 \sin 2\theta_\mu \sin\theta \sin\phi + S_6 \sin 2\theta_\mu \sin 2\theta \sin\phi + S_7 \sin^2\theta_\mu \sin^2\theta \sin 2\phi \right]$$

$$F_1 = \frac{2S_9}{(1-F_1)}, \quad F_2 = \frac{2}{3} \frac{A_{FB}}{(1-F_1)}, \quad F_3 = \frac{S_8}{(1-F_1)}, \\ F_{K^*AA} = \frac{S_{3,AA}}{\sqrt{F_1(1-F_1)}}, \quad F_{K^*AB} = \frac{S_7}{\sqrt{F_1(1-F_1)}}$$

## $B_d \rightarrow K^*\mu^+\mu^-$ decay in SM

- small number of events  $\rightarrow$  folding of angular distributions

$$F'_1, S'_1: \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \phi \rightarrow \pi - \phi & \text{for } \theta > \frac{\pi}{2} \\ \theta \rightarrow \pi - \theta & \text{for } \theta > \frac{\pi}{2} \end{cases} \quad F'_2, S'_2: \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi < -\frac{\pi}{2} \\ \theta \rightarrow \pi - \theta & \text{for } \theta > \frac{\pi}{2} \end{cases}$$

$$F'_3, S'_3: \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \theta \rightarrow \pi - \theta & \text{for } \theta > \frac{\pi}{2} \end{cases} \quad F'_4, S'_4: \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi < -\frac{\pi}{2} \\ \theta \rightarrow \pi - \theta & \text{for } \theta > \frac{\pi}{2} \end{cases}$$

$$\frac{1}{d\Gamma/dq^2 d\cos\theta_\mu d\cos\theta_\pi d\phi dq^2} = \frac{9}{8\pi} \left[ \frac{3(1-F_1)}{4} \sin^2\theta_\mu + F_1 \cos^2\theta_\mu \right. \\ \left. + \frac{1-F_1}{4} \sin^2\theta_\mu \cos 2\theta - F_1 \cos^2\theta_\mu \cos 2\theta \right. \\ \left. + S_1 \sin^2\theta_\mu \sin^2\theta \cos 2\phi + S_2 \sin 2\theta_\mu \sin 2\theta \cos\phi \right]$$

- loss of sensitivity to  $S_6, S_7 \rightarrow A_{FB}$

## Background: partially reconstructed decays $B \rightarrow D \rightarrow X$

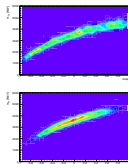
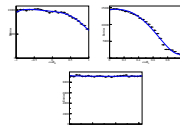


Fig. Example for  $M(K^*\pi)$ , data vs. MC

## Background

Result:

- D veto 30 MeV and B veto 50 MeV around  $m_{D^*}$
- acceptance maps, e.g.  $q^2 = [0.04, 6]$  GeV<sup>2</sup>



# $B^0 \rightarrow K^*(K\pi)\mu^+\mu^-$ selection, fitting, checks...

## ATLAS analysis of $B_d \rightarrow K^*\mu^+\mu^-$

- Dataset: [ATLAS CONF. 2017.033](#)
- 20.3 fb<sup>-1</sup>, taken at  $\sqrt{s} = 8$  TeV in 2012
  - Reconstruction and selection:
    - preselection: track  $p_T$ , ID hits, min. 1 combined muon
    - baseline:  $|\eta| < 2.5$ ,  $m(K^*) = [846, 946]$  MeV,  $m(B) = [5150, 5700]$  MeV
    - $p_T(\mu) > 3.5$  GeV,  $p_T(\tau, K) > 0.5$  GeV
    - final cuts:  $\sigma_1/\tau > 12.75$ , pointing  $\cos\theta > 0.999$ ,  $\chi^2/\text{ndf}(B) < 2$ ,  $p_T(K^*) > 3$  GeV,  $(m(B) - m\text{vcc}(B)) - (m(\mu\mu) - m\text{vcc}(J/\psi)) < 130$  MeV
    - trigger - 15 most frequent triggers
    - control regions:  $J/\psi$  ( $q^2 = [8.11]$  GeV<sup>2</sup>),  $\psi(2S)$  ( $q^2 = [12.15]$  GeV<sup>2</sup>)
    - signal  $q^2 = [0.04, 6]$  GeV<sup>2</sup> except of  $\phi$  region  $q^2 = [0.98, 1.1]$  GeV<sup>2</sup>
    - if  $\rightarrow 1$  candidate lowest; candidate with higher  $\chi^2(K^*)/m(K^*)$

## Monte Carlo datasets

Signal:

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$B_d \rightarrow K^*\mu^+\mu^-$	EvtGen	208451	50M

Inclusive backgrounds:

Process	Generator	Dataset	Events
$bb \rightarrow \mu^+\mu^- X$	Pythia	208301	20M
$bb \rightarrow \mu^+\mu^- X$	EvtGen	208303	1M
$bb \rightarrow \mu^+\mu^- X AA$	Pythia	208308	40M
$bb \rightarrow \mu^+\mu^- X AB$	Pythia	208309	48M
$bb \rightarrow \mu^+\mu^- X BA$	Pythia	208310	48M
$bb \rightarrow \mu^+\mu^- X BB$	Pythia	208311	130M

## $B_d \rightarrow K^*\mu^+\mu^-$ decay in SM

Differential decay rate (optimized):

$$\frac{1}{d\Gamma/dq^2 d\cos\theta/d\cos\theta_\mu d\phi/d\phi} = \frac{9}{32\pi} \left[ \frac{3(1-F_1)}{4} \sin^2\theta_\mu + \frac{1-F_1}{4} \sin^2\theta_\mu \cos 2\phi \right. \\ \left. + F_1 \cos^2\theta_\mu - F_1 \cos^2\theta_\mu \cos 2\phi + S_5 \sin^2\theta_\mu \sin^2\theta \cos 2\phi \right. \\ \left. + S_5 \sin 2\theta_\mu \sin 2\phi \cos\phi + S_5 \sin 2\theta_\mu \sin\theta \cos\phi + S_5 \sin^2\theta_\mu \cos\theta \cos\phi \right. \\ \left. + S_5 \sin 2\theta_\mu \sin\theta \sin\phi + S_5 \sin 2\theta_\mu \sin 2\theta \sin\phi + S_5 \sin^2\theta_\mu \sin^2\theta \sin 2\phi \right]$$

$$F_1 = \frac{2S_5}{(1-F_1)}, \quad F_2 = \frac{2}{3} \frac{A_{FB}}{(1-F_1)}, \quad F_3 = \frac{S_6}{(1-F_1)}, \\ P_{S,AA}^{\mu} = \frac{S_{5,AA}}{\sqrt{F_1(1-F_1)}}, \quad P_{S,AB}^{\mu} = \frac{S_7}{\sqrt{F_1(1-F_1)}}$$

## $B_d \rightarrow K^*\mu^+\mu^-$ decay in SM

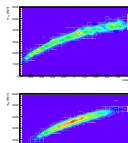
- small number of events  $\rightarrow$  folding of angular distributions

$$P_{\phi, S_5}^{\mu} \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \phi \rightarrow \pi - \phi & \text{for } \phi > \frac{\pi}{2} \\ \theta_1 \rightarrow \pi - \theta_1 & \text{for } \theta_1 > \frac{\pi}{2} \end{cases} \quad P_{\phi, S_7}^{\mu} \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi > \frac{\pi}{2} \\ \phi \rightarrow -\pi - \phi & \text{for } \phi < -\frac{\pi}{2} \\ \theta_1 \rightarrow \pi - \theta_1 & \text{for } \theta_1 > \frac{\pi}{2} \end{cases}$$

$$P_{\phi, S_6}^{\mu} \begin{cases} \phi \rightarrow -\phi & \text{for } \phi < 0 \\ \phi \rightarrow \pi - \phi & \text{for } \theta_1 > \frac{\pi}{2} \end{cases} \quad P_{\phi, S_7}^{\mu} \begin{cases} \phi \rightarrow \pi - \phi & \text{for } \phi > \frac{\pi}{2} \\ \phi \rightarrow -\pi - \phi & \text{for } \phi < -\frac{\pi}{2} \\ \theta_1 \rightarrow \pi - \theta_1 & \text{for } \theta_1 > \frac{\pi}{2} \end{cases}$$

$$\frac{1}{d\Gamma/dq^2 d\cos\theta/d\cos\theta_\mu d\phi/d\phi} = \frac{9}{32\pi} \left[ \frac{3(1-F_1)}{4} \sin^2\theta_\mu + F_1 \cos^2\theta_\mu \right. \\ \left. + \frac{1-F_1}{4} \sin^2\theta_\mu \cos 2\phi - F_1 \cos^2\theta_\mu \cos 2\phi \right]$$

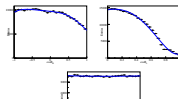
## Background: partially reconstructed decays $B \rightarrow D \rightarrow X$



## Background

Result:

- D veto 30 MeV and B veto 50 MeV around  $m_{D/B}$
- acceptance maps, e.g.  $q^2 = [0.04, 6]$  GeV<sup>2</sup>



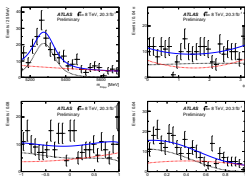
## Fitting

- acceptance maps from MC sample generated with flat angular distributions
- extract nuisance parameters from control regions -  $m_{D/B}, \sigma_{D/B}$  (Gauss).
- fold distributions  $\rightarrow$  4 sets of fits
- mass prefir - number of signal a bkg evens
- angular fits

Fitted yields:

$q^2$ [GeV <sup>2</sup> ]	$N_{\text{signal}}$	$N_{\text{background}}$
[0.04, 2.0]	128 ± 22	122 ± 22
[2.0, 4.0]	106 ± 23	113 ± 23
[4.0, 6.0]	114 ± 24	204 ± 26
[0.04, 4.0]	236 ± 31	233 ± 32
[1.1, 6.0]	275 ± 35	363 ± 36
[0.04, 6.0]	342 ± 39	445 ± 40

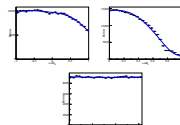
## Fit results: S4, bin $q^2 = [0.04, 2]$ GeV<sup>2</sup>



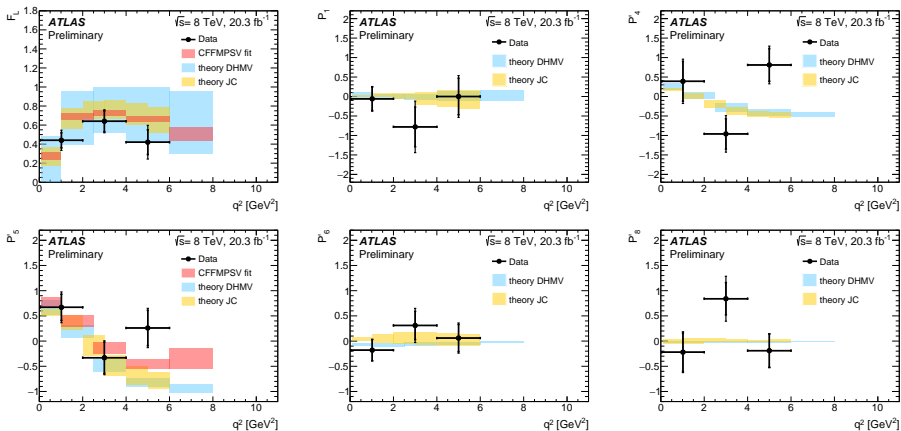
## Background

Result:

- D veto 30 MeV and B veto 50 MeV around  $m_{D/B}$
- acceptance maps, e.g.  $q^2 = [0.04, 6]$  GeV<sup>2</sup>



# $B^0 \rightarrow K^*(K\pi)\mu^+\mu^-$ results



... 3 bins with  $\sim 3\sigma$  from SM prediction

# Other ATLAS analyses

- some 3000 members of collaboration
- working in 100 sub-groups
- any decay and measurement we can think about

## ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary

$$\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$

	Model	$e, \mu, \tau, \gamma$	Jets	$E_T^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	MSLGRACMSSM	0	2-6 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.2 TeV	m <sub>0</sub> > m <sub>1/2</sub>
	MSLGRACMSSM	1 e, $\mu$	3-6 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.2 TeV	arg m <sub>0</sub>
	MSLGRACMSSM	0	7-10 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.1 TeV	arg m <sub>0</sub>
	$0\tilde{0}, 0\tilde{1} \rightarrow 0\tilde{1}\tilde{1}$	0	2-6 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 740 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$2\tilde{2}, \tilde{2} \rightarrow 0\tilde{1}\tilde{1}$	0	2-6 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.3 TeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$2\tilde{2}, \tilde{2} \rightarrow 0\tilde{1}\tilde{1}, \tilde{2}\tilde{2} \rightarrow W\tilde{1}\tilde{1}$	1 e, $\mu$	3-6 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.18 TeV	m <sub>0</sub> <sup>2</sup> > 200 GeV, m <sub>1/2</sub> <sup>2</sup> > 0.5(m <sub>0</sub> <sup>2</sup> + m <sub>1/2</sub> <sup>2</sup> )
	$2\tilde{2}, \tilde{2} \rightarrow 0\tilde{1}\tilde{1}(\nu\nu)\tilde{1}$	2 e, $\mu$	0-3 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.12 TeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	GMSB ( $\tilde{t}$ NLSP)	2 e, $\mu$	2-4 jets	Yes	4.7	$\tilde{t}, \tilde{b}$ 1.24 TeV	tan $\beta$ < 15
	GMSB ( $\tilde{\tau}$ NLSP)	1-2 $\tau$	0-2 jets	Yes	4.7	$\tilde{t}, \tilde{b}$ 1.4 TeV	tan $\beta$ > 18
	GGM (bino NLSP)	2 $\gamma$	-	Yes	4.8	$\tilde{t}, \tilde{b}$ 1.07 TeV	m <sub>0</sub> <sup>2</sup> > 50 GeV
	GGM (higgs NLSP)	1 e, $\mu$ , $\gamma$	-	Yes	4.8	$\tilde{t}, \tilde{b}$ 619 GeV	m <sub>0</sub> <sup>2</sup> > 50 GeV
	GGM (Higgsino NLSP)	$\gamma$	1 $\tilde{b}$	Yes	4.8	$\tilde{t}, \tilde{b}$ 800 GeV	m <sub>0</sub> <sup>2</sup> > 200 GeV
GGM (Higgsino NLSP)	2 e, $\mu$ , $Z$	0-3 jets	Yes	5.8	$\tilde{t}, \tilde{b}$ 290 GeV	m <sub>0</sub> <sup>2</sup> > 200 GeV	
Gravitino LSP	0	mono-jet	Yes	18.5	$\tilde{t}, \tilde{b}$ 645 GeV	m <sub>0</sub> <sup>2</sup> > 10 <sup>-4</sup> eV	
3 <sup>rd</sup> gen. & med.	$\tilde{g} \rightarrow b\tilde{b}^0$	0	3 $\tilde{b}$	Yes	20.1	$\tilde{t}, \tilde{b}$ 1.2 TeV	m <sub>0</sub> <sup>2</sup> > 800 GeV
	$\tilde{g} \rightarrow t\tilde{t}^0$	0	7-10 jets	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.1 TeV	m <sub>0</sub> <sup>2</sup> > 350 GeV
	$\tilde{g} \rightarrow t\tilde{t}^0$	0-1 e, $\mu$	3 $\tilde{b}$	Yes	20.1	$\tilde{t}, \tilde{b}$ 1.34 TeV	m <sub>0</sub> <sup>2</sup> > 400 GeV
	$\tilde{g} \rightarrow b\tilde{t}^0$	0-1 e, $\mu$	3 $\tilde{b}$	Yes	20.1	$\tilde{t}, \tilde{b}$ 1.3 TeV	m <sub>0</sub> <sup>2</sup> > 300 GeV
3 <sup>rd</sup> gen. squarks direct production	$\tilde{t}_1, \tilde{t}_2 \rightarrow b\tilde{t}^0$	0	2 $\tilde{b}$	Yes	20.1	$\tilde{t}_1, \tilde{t}_2$ 100-620 GeV	m <sub>0</sub> <sup>2</sup> > 80 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{t}^0$	2 e, $\mu$ (SS)	0-3 $\tilde{b}$	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 275-430 GeV	m <sub>0</sub> <sup>2</sup> > 2 m <sub>0</sub> <sup>2</sup>
	$\tilde{t}_1, \tilde{t}_2 \rightarrow b\tilde{t}^0$	1-2 e, $\mu$	1-2 $\tilde{b}$	Yes	4.7	$\tilde{t}_1, \tilde{t}_2$ 110/167 GeV	m <sub>0</sub> <sup>2</sup> > 55 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow b\tilde{t}^0, \tilde{t}_1 \rightarrow W\tilde{b}^0$	2 e, $\mu$	0-2 jets	Yes	20.1	$\tilde{t}_1, \tilde{t}_2$ 130-230 GeV	m <sub>0</sub> <sup>2</sup> > 2 m <sub>0</sub> <sup>2</sup> , m <sub>1/2</sub> > 50 GeV, m <sub>1/2</sub> < m <sub>0</sub> <sup>2</sup>
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{t}^0$	2 e, $\mu$	20 jets	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 225-325 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{t}^0$	0	2 $\tilde{b}$	Yes	20.1	$\tilde{t}_1, \tilde{t}_2$ 150-580 GeV	m <sub>0</sub> <sup>2</sup> > 200 GeV, m <sub>1/2</sub> <sup>2</sup> > 0.5 m <sub>0</sub> <sup>2</sup>
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{t}^0$	1 e, $\mu$	1 $\tilde{b}$	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 200-810 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{t}^0$	0	2 $\tilde{b}$	Yes	20.5	$\tilde{t}_1, \tilde{t}_2$ 300-900 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow c\tilde{t}^0$	0	mono-jet+tag	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 80-200 GeV	m <sub>0</sub> <sup>2</sup> > m <sub>1/2</sub> <sup>2</sup> > 85 GeV
	$\tilde{t}_1, \tilde{t}_2$ (natural GMSB)	2 e, $\mu$ , $Z$	1 $\tilde{b}$	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 90 GeV	m <sub>0</sub> <sup>2</sup> > 150 GeV
$\tilde{t}_1, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, $\mu$ , $Z$	1 $\tilde{b}$	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 271-920 GeV	m <sub>0</sub> <sup>2</sup> > 180 GeV	
EW direct	$\tilde{t}_1, \tilde{t}_2 \rightarrow e\tilde{t}^0$	2 e, $\mu$	0	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 85-315 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \tau\tilde{t}^0(\tau\tau)$	2 e, $\mu$	0	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 120-820 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 0.5(m <sub>0</sub> <sup>2</sup> + m <sub>1/2</sub> <sup>2</sup> )
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \nu\tilde{t}^0(\nu\nu)$	2 $\tau$	0	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 180-328 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 0.5(m <sub>0</sub> <sup>2</sup> + m <sub>1/2</sub> <sup>2</sup> )
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \nu\tilde{t}^0(\nu\nu), \tilde{t}_1\tilde{t}_2 \rightarrow \nu\nu$	3 e, $\mu$	0	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 100-580 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 0.5(m <sub>0</sub> <sup>2</sup> + m <sub>1/2</sub> <sup>2</sup> )
	$\tilde{t}_1, \tilde{t}_2 \rightarrow W\tilde{e}^0$	3 e, $\mu$	0	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 315 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 0, stauons decoupled
	$\tilde{t}_1, \tilde{t}_2 \rightarrow W\tilde{e}^0$	1 e, $\mu$	2 $\tilde{b}$	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 203 GeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 0, stauons decoupled
Long-lived particles	Direct $\tilde{t}_1, \tilde{t}_2$ prod., long-lived $\tilde{t}_1^0$	0	1 jet	Yes	20.3	$\tilde{t}_1, \tilde{t}_2$ 276 GeV	m <sub>0</sub> <sup>2</sup> > m <sub>1/2</sub> <sup>2</sup> > 180 MeV, r <sub>1/2</sub> <sup>0</sup> > 0.2 ns
	Stable, stopped $\tilde{t}$ F-hadron	0	1-5 jets	Yes	22.9	$\tilde{t}, \tilde{b}$ 832 GeV	m <sub>0</sub> <sup>2</sup> > 100 GeV, 10 BR(c $\tilde{t}$ ) < 1000 s
	GMSB, stable $\tilde{t}, \tilde{t}_1^0 \rightarrow (0, \beta) + (e, \mu)$	1-2 $\mu$	-	-	15.9	$\tilde{t}, \tilde{b}$ 475 GeV	10-cm > 50 ns
	GMSB, $\tilde{t}_1^0 \rightarrow \gamma G$ , long-lived $\tilde{t}_1^0$	2 $\gamma$	-	Yes	4.7	$\tilde{t}, \tilde{b}$ 230 GeV	0.4-cm > 10 <sup>-10</sup> s
RPV	$0\tilde{0}, \tilde{t}_1^0 \rightarrow 0\tilde{1}\tilde{1}$ (RPV)	1 $\mu$ , displ. vtx.	-	Yes	20.3	$\tilde{t}, \tilde{b}$ 1.0 TeV	1.5-cm < 150 nm, BR( $\mu \rightarrow e, \tilde{t}_1^0$ ) > 108 GeV
	LFV $pp \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow e + \mu$	2 e, $\mu$	-	-	4.6	$\tilde{t}_1$ 1.01 TeV	$\mathcal{A}_{\tilde{t}_1 \rightarrow e\mu} < 10, \mathcal{A}_{\tilde{t}_1 \rightarrow \tau\mu} < 0.05$
	LFV $pp \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow e\mu(\mu) + \tau$	1 e, $\mu$ , $\tau$	-	-	4.6	$\tilde{t}_1$ 1.1 TeV	$\mathcal{A}_{\tilde{t}_1 \rightarrow e\mu\tau} < 10, \mathcal{A}_{\tilde{t}_1 \rightarrow \tau\mu\tau} < 0.05$
	Bilinear RPV CMSSM	1 e, $\mu$	7 jets	Yes	4.7	$\tilde{t}, \tilde{b}$ 1.2 TeV	m <sub>0</sub> <sup>2</sup> > 0 GeV, m <sub>1/2</sub> <sup>2</sup> > 1 mm
RPV	$\tilde{t}_1, \tilde{t}_2 \rightarrow W\tilde{e}^0, \tilde{t}_1^0 \rightarrow \mu\tilde{e}^0, e\tilde{\nu}_\mu$	4 e, $\mu$	-	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 700 GeV	m <sub>0</sub> <sup>2</sup> > 300 GeV, $\mathcal{A}_{\tilde{t}_1 \rightarrow 0} < 0$
	$\tilde{t}_1, \tilde{t}_2 \rightarrow W\tilde{e}^0, \tilde{t}_1^0 \rightarrow \tau\tilde{\nu}_\tau, e\tilde{\nu}_\tau$	3 e, $\mu$ , $\tau$	-	Yes	20.7	$\tilde{t}_1, \tilde{t}_2$ 359 GeV	m <sub>0</sub> <sup>2</sup> > 88 GeV, $\mathcal{A}_{\tilde{t}_1 \rightarrow 0} < 0$
	$\tilde{t}_1 \rightarrow 0\tilde{1}\tilde{1}$	0	6-7 jets	-	20.3	$\tilde{t}_1$ 916 GeV	BR( $\tilde{t}_1 \rightarrow BR(\tilde{t}_1 \rightarrow BR(\tilde{t}_1 \rightarrow 0\tilde{1}\tilde{1}))$
	$\tilde{t}_1 \rightarrow 0\tilde{1}\tilde{1}$	0	-	-	-	$\tilde{t}_1$ 1.01 TeV	BR( $\tilde{t}_1 \rightarrow 0\tilde{1}\tilde{1}$ ) > 0.05

Thank you for your attention!  
Questions?

... or write me on [ina@cern.ch](mailto:ina@cern.ch) and we can chat about it over coffee