Impact of Misalignment on Physics

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On behalf of (ALICE), ATLAS, CMS, LHCb

bmb+f - Förderschwerpunkt
CMS
Großgeräte der physikalischen Grundlagenforschung

Overview

- Impact of misalignment on tracking and vertexing
- Impact of misalignment on selected physics channel
  SUSY, Higgs-Physics, Standardmodel Physics (W mass), B Physics

Thanks to:
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…who provided material and valuable input for this talk.

Misalignment Scenarios (CMS)

2 Scenarios:

1. First data, 1-6 months
2. Long term, >6 months

Assumptions for alignment precision of ...

...**tracker subdetectors** after Laser Alignment (RMS). Tracks used only for pixel.

First Data Taking scenario:

Laser Alignment + Mechanical constraints→100 µm uncertainties

	Δx $[\mu m]$	Δy $[\mu m]$	Δz $[\mu m]$	R_z $[\mu rad]$	LAS available
TPB	10	10	10	10	no
TIB	105	105	500	90	yes
TOB	67	67	500	59	yes
TPE	5	5	5	5	no
TID	400	400	400	100	no
TEC	57	57	500	46	yes

...tracker substructures

RMS	TPB $[\mu m]$	TIB $[\mu m]$	TOB $[\mu m]$	TPE $[\mu m]$	TID $[\mu m]$	TEC $[\mu m]$
Modules	13	200	100	2.5	105	50
Ladders/Rods/Rings/Petals	5	200	100	5	300	100

Long term: All numbers x0.1, except pixel: Assumes that pixel already aligned after first data.

... the muon system.
(longterm all numbers x0.2)

	Barrel		Endcap	
	Position [mm]	Orientation [mrad]	Position [mm]	Orientation [mrad]
Muon to tracker	1	0.2	1	0.2
Chambers	1	0.25	1	0.5

Misalignment Scenarios (ATLAS): NEW

- 3 level misalignment at simulation level
- Alignment will be used iteratively

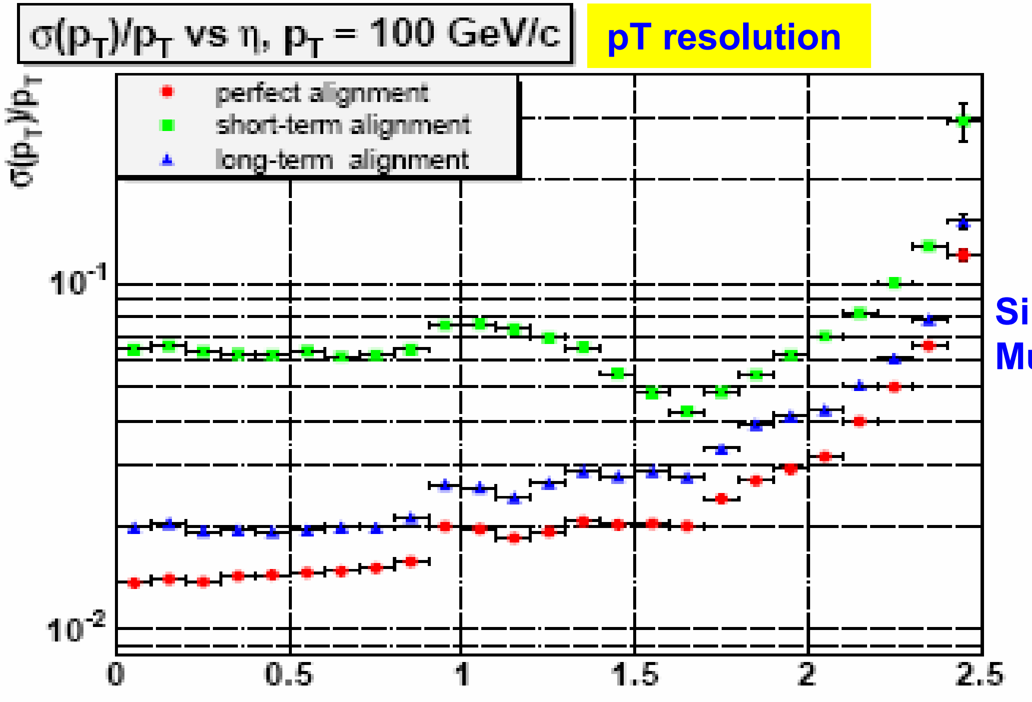
	Pixel	SCT	TRT	Reference frame
LEVEL 1	**Whole detector**	**Barrel Endcaps**	**Barrel Endcaps**	**Global**
LEVEL 2	**Barrel layers Endcap disks**	**Barrel layers Endcap disks**	**Modules (barrel)**	**Global**
LEVEL 3	**Modules (barrel, endcap)**	**Modules (barrel, endcap)**	**-**	**Local**

Proposed numbers for misalignment:
- few mm/ few 1/10th of mrad @L1
- 30-100μm/ 0.5-1mrad @ L2
- 30-150μm/ 1mrad @ L3

Impact on Tracking (CMS)

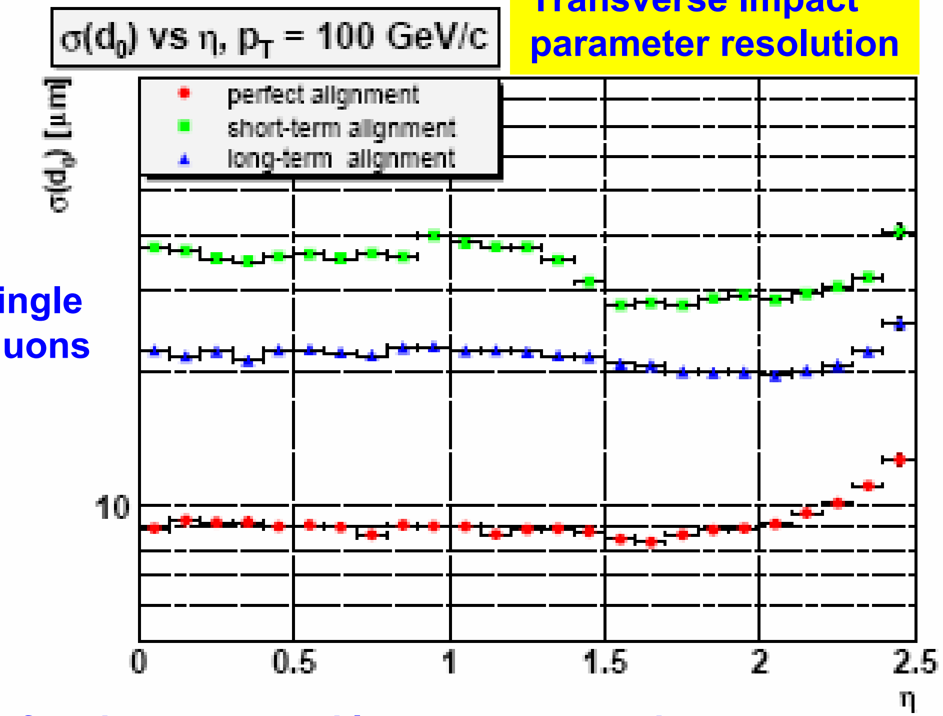
To look at the impact of misalignment on individual physics channels, need to first look at the impact on tracking (the ingredience to physics) and vertex finding/fitting.

pT resolution



Single Muons

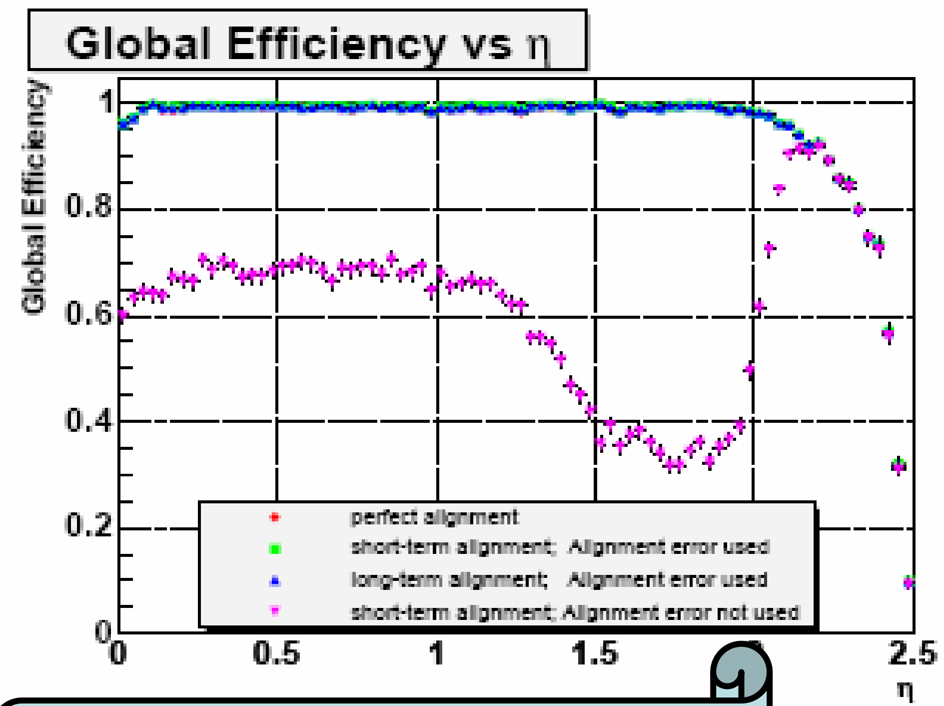
Transverse Impact parameter resolution



Note: Same pixel misalignment for short-term and long-term scenario.

Misalignment strongly impacts pT and impact parameter resolution.

Impact on Tracking (CMS) II

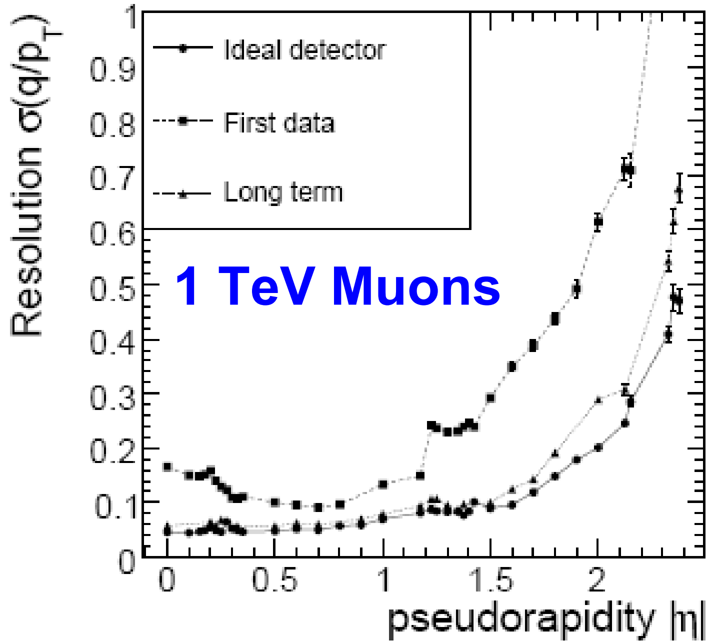


Track finding algorithm can deal with misalignment as long as good knowledge of errors.

Impact of misalignment on 1/pT resolution:
Tracker and Muon system misaligend together

Muon system misalignment:
1mm/ 0.2-0.5 mrad (first data)
0.2-0.4 mm/ 0.04-0.1 mrad (longterm)

Single Muons



Muon system alignment contributes at high pT.

Vertex Finding (CMS)

X- and Y-coordinates					
	$\sigma_{x,y}$ [μm]	95% coverage [μm]	Bias [μm] X	Bias [μm] Y	$Pull_{x,y}$
Perfect tracker alignment					
$B_s^0 \to J/\psi\phi$	45	119	-0.5 ± 0.6	-0.6 ± 0.6	1.15
$t\bar{t}H$	10	26	-0.0 ± 0.2	0.1 ± 0.2	1.16
DY	13.5	46	0.2 ± 0.3	-0.5 ± 0.3	1.12
Short-term tracker alignment					
$B_s^0 \to J/\psi\phi$	51	128	-5.8 ± 0.7	12 ± 0.7	1.16
$t\bar{t}H$	18	47	2.4 ± 0.2	16 ± 0.2	1.48
DY	24	62	1.6 ± 0.4	16 ± 0.4	1.23
Long-term tracker alignment					
$B_s^0 \to J/\psi\phi$	51	127	-10 ± 0.7	11 ± 0.7	1.16
$t\bar{t}H$	17	47	-9.5 ± 0.4	11 ± 0.4	1.46
DY	22	59	-8.9 ± 0.4	11 ± 0.4	1.28

- **Effect on vertex finding efficiency relatively small (max. 3.5%: 99.3→95.8% for ttH)**
- **Resolution: significant degradation by 6-8 μm in x,y,z**
- **Short-term, high pT: misalignment of silicon strip also plays a role**

Vertex Fitting (CMS)

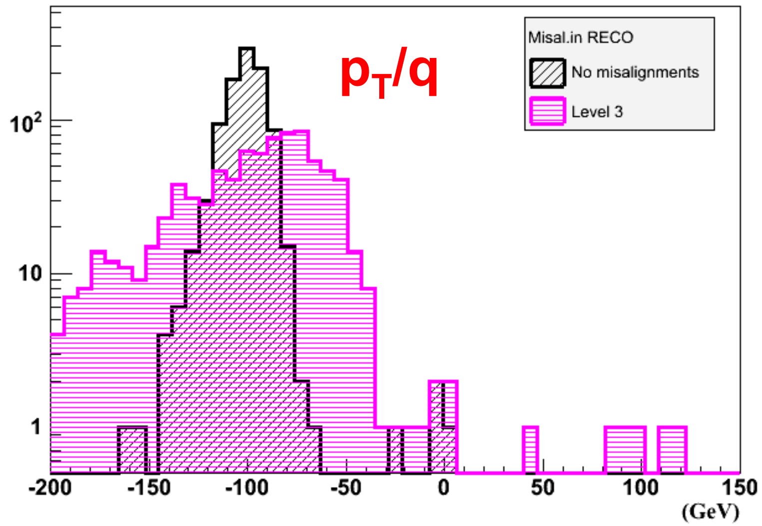
- Impact of misalignment on subsequent vertex-fitting (Kalman algorithm, least-squares)
- Only tracks matched to simulated tracks used, 4 tracks with low pT →vertex

	x-coordinate Res. Std. Dev. [μm]	x-coordinate Res. Mean [μm]	x-coordinate 95% Cov. [μm]	x-coordinate Pull	z-coordinate Res. Std. Dev. [μm]	z-coordinate Res. Mean [μm]	z-coordinate 95% Cov. [μm]	z-coordinate Pull
Perfect tracker alignment								
$B_s^0 \to J/\psi\,\phi$ SV	54.2	0.545	164	1.09	72.6	-0.718	445	1.08
$B_s^0 \to J/\psi\,\phi$ PV	43.8	0.596	176	1.11	54	0.633	223	1.07
$t\bar{t}H$	13.5	-0.299	106	1.45	17.2	-0.0625	116	1.43
Short-term tracker alignment								
$B_s^0 \to J/\psi\,\phi$ SV	66.6	-2.5	190	1.12	84	1.82	519	1.08
$B_s^0 \to J/\psi\,\phi$ PV	49.5	-8.16	233	1.16	57.7	-2.32	282	1.07
$t\bar{t}H$	24.3	0.69	205	1.97	24.3	1.79	244	1.58
Long-term tracker alignment								
$B_s^0 \to J/\psi\,\phi$ SV	63.8	-10.9	177	1.09	80.5	-3.86	502	1.07
$B_s^0 \to J/\psi\,\phi$ PV	47.9	-10.8	187	1.13	57.2	-4.86	233	1.06
$t\bar{t}H$	20.9	-11.6	116	1.83	22.3	-4.25	129	1.56

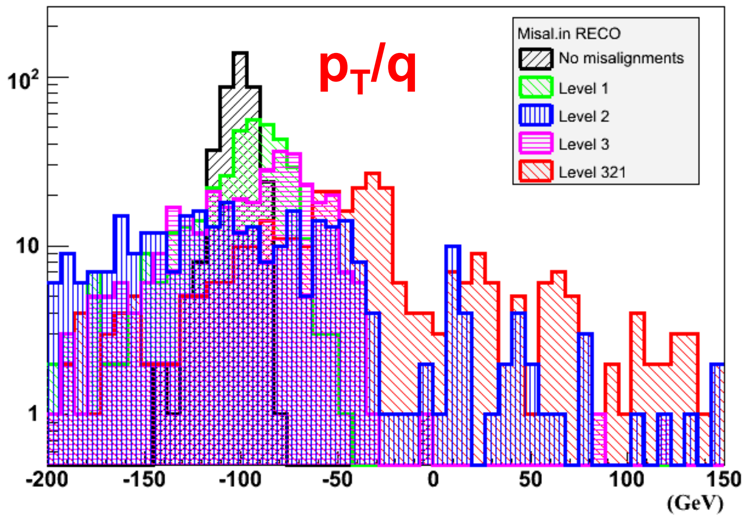
- **SV of $B^0_s \to J/\psi\ \varphi$: 12 μm degradation in all coordinates**
- **Pixel-dominated; same observations as for primary vertex position**
- **Misalignment significantly degrades PV and SV resolutions**
- **Correlated misalignment can cause biases.**

Misalignment Scenarios (ATLAS): NEW: Plots

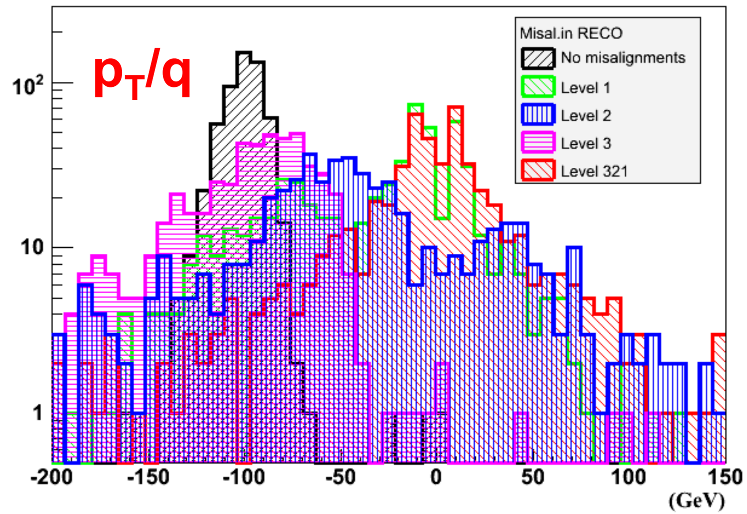
Reconstructed pt



Correlated misalignment has significant impact on pT, both in terms of resolution and bias.

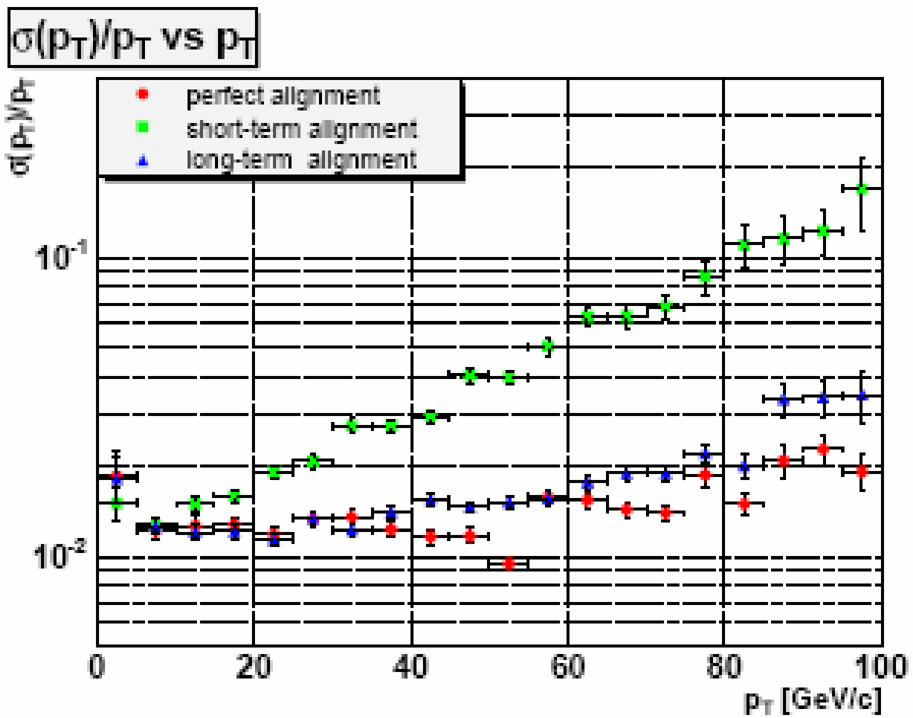


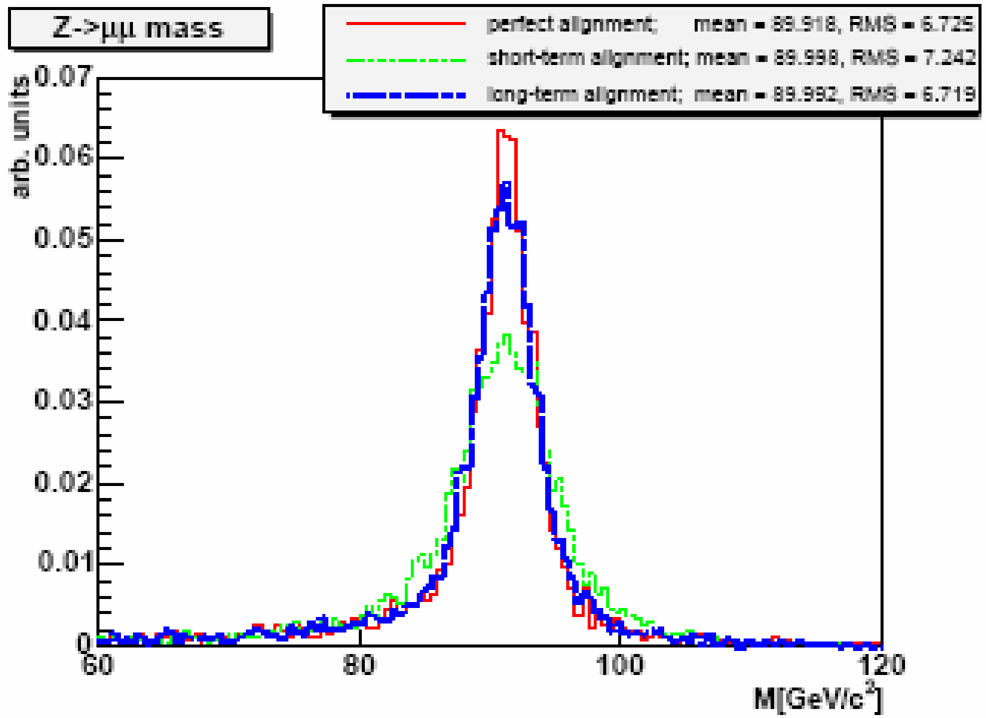
Reconstructed pt, |η|>1



Z→μμ Mass Resolution (CMS)

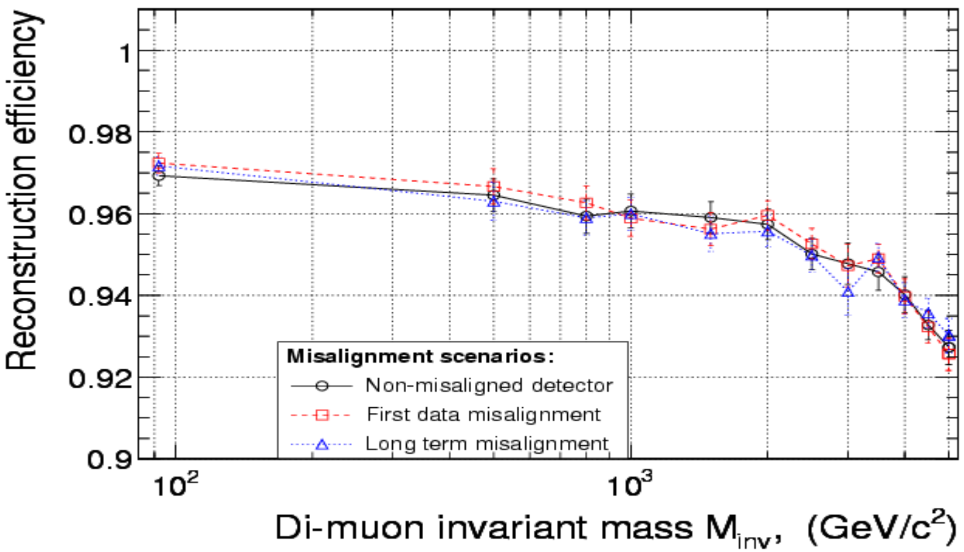
Muons from H(300 GeV)→ZZ→eeμμ

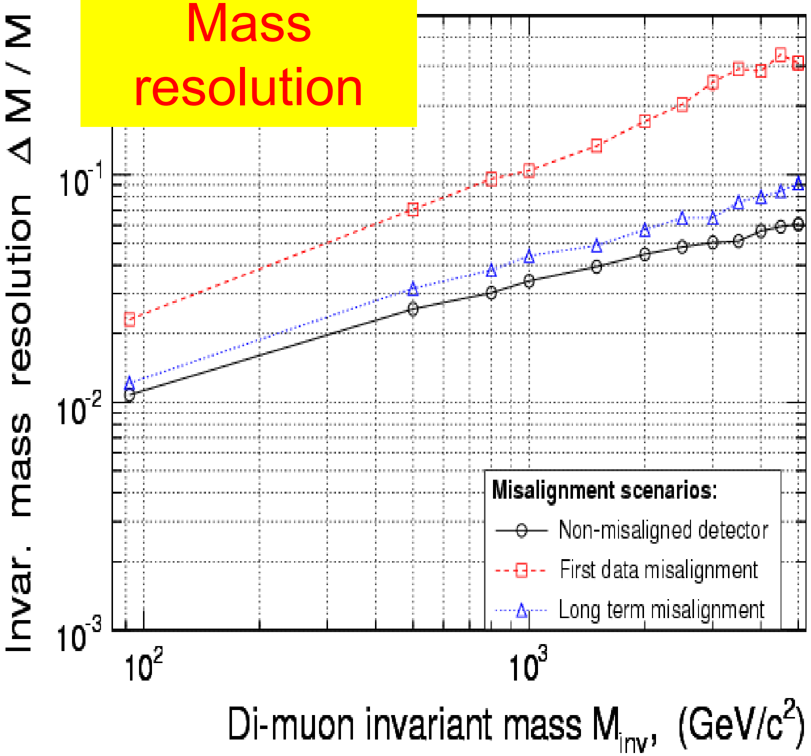




Excellent alignment required for „no effect“. Short term misalignment significantly degrades momentum and mass resolution.

Dimuon efficiency + resolution (CMS)





Mass resolution

Offline efficiency → Impact small

Mass resolution → Large Impact (Note log scale!)

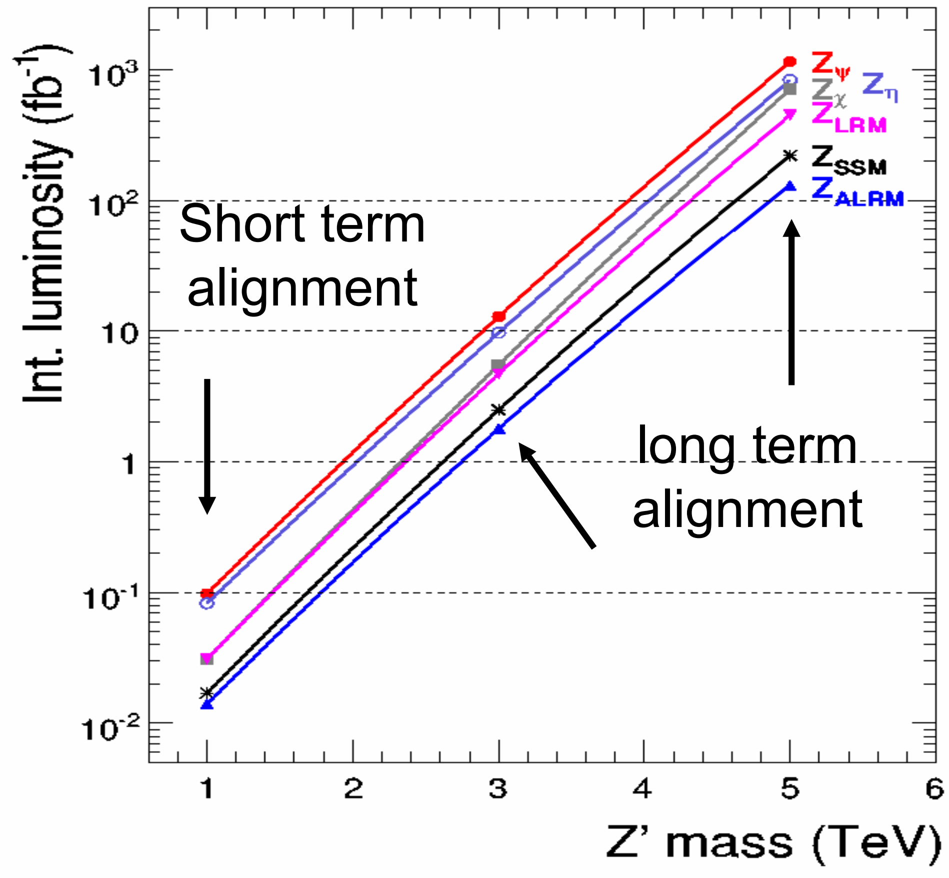
x1.3, x 3 @1 TeV

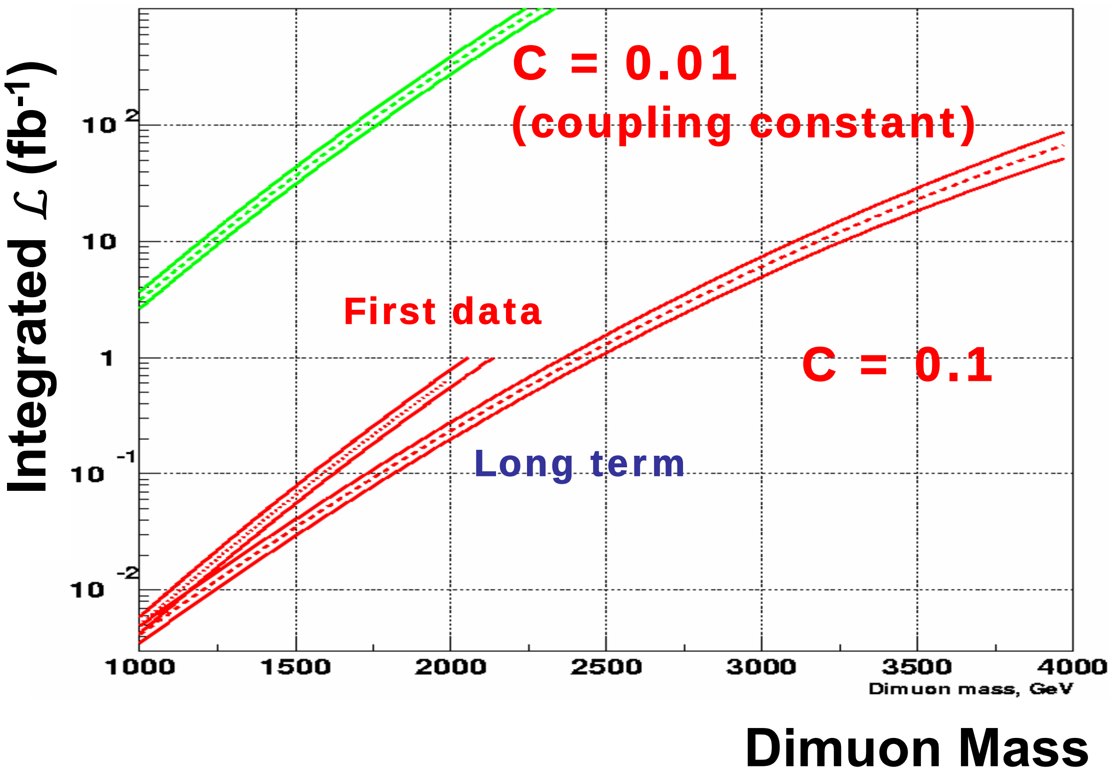
x1.4, x 5 @3 TeV

- **No misalignment**
- **First data**
- **Long term**

Resonances in Di-Muons (CMS)

- **Example for ~early LHC physics: Resonances in Di-Muons**
- **5 σ discovery reach for 6 Z' models, RS gravitons (plots with systematic uncertainties including misalignment)**



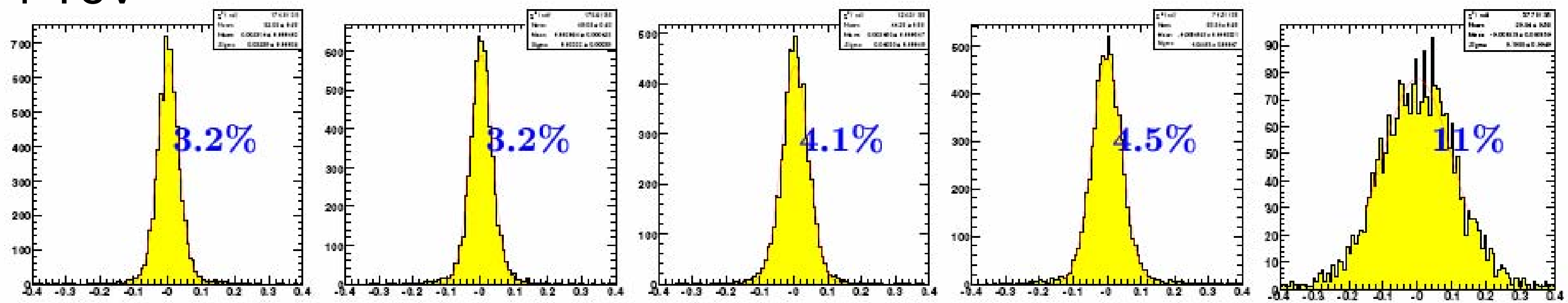


Note: Would need about 50% less data if optimal alignment!

Di-Muon mass resolution for RS Graviton, G*→μμ: **more details (CMS)**

	Ideal alignment	Long term (Muon)	Long term (Muon + Tr.)	First data (Muon)	First data (Muon + Tr.)

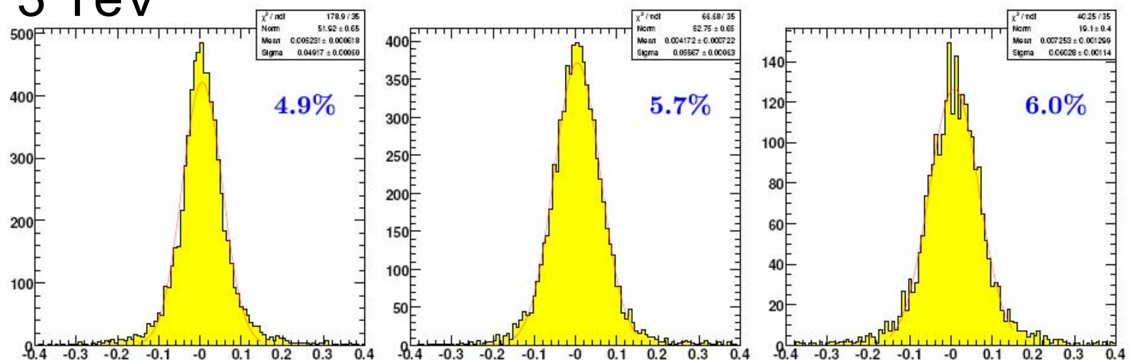
1 TeV



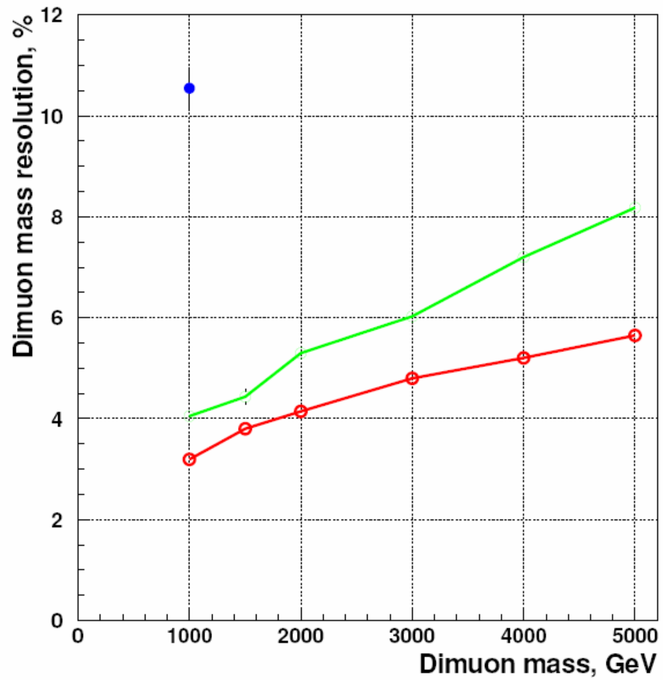
Tracker dominated

	Ideal alignment	Long term (Muon)	Long term (Muon + Tr.)

3 TeV



Muon system becomes important



W mass measurement (CMS)

- **One of the most challenging measurements at the LHC!**
- **Goal ~25 MeV per channel!**

Uncertainties for W mass measurement in the muon channel:

with 1 fb^{-1} **with 10 fb^{-1}**

transformation method applied to $W \to \mu\nu$				
statistics		40		15
background	10%	4	2%	negligible
momentum scale	0.1%	14	<0.1%	<10
$1/p^T$ resolution	10%	30	<3%	<10
acceptance definition	η-resol.	19	$< \sigma_\eta$	<10
calorimeter E_T^{miss}, scale	2%	38	≤1%	<20
calorimeter E_T^{miss}, resolution	5%	30	<3%	<18
detector alignment		12	–	negligible
total instrumental		64		<30
PDF uncertainties		≈20		<10
Γ_W		10		< 10

Assumes excellent tracker alignment achieved!

W mass (ATLAS)

• Requires understanding the momentum scale (1/pT)of the inner detector to 0.02% („on average over limited regions“) →B-field to 0.02%!

• Measurement only possible if using the Z mass as constraint

• Then requirements on alignment of tracker modules (hard to quantify exactly, since these are residues after calibrating against the Z):

- 1 µm in rphi, 10 µm in R, 10 µm in z in the pixels, stable over >1 day

Note: compare to ATLAS general requirement of 7µm (pixel) 12 µm (SCT)

ATLAS study from 1999

(ATLAS TDR)

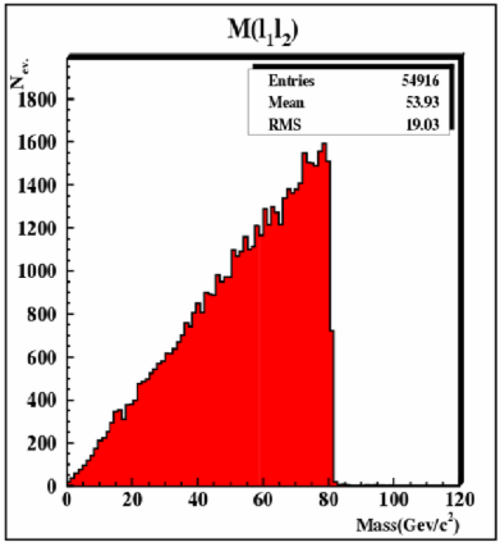
Table 2-2 Rϕ alignment precisions (µm) which can be obtained after one day of low luminosity running. Results are given for different types of tracks, using both complete modules and the Rϕ overlaps.

Type of Track	Pixels				SCT			
	Barrel		End-cap		Barrel		End-cap	
	Module	Overlap	Module	Overlap	Module	Overlap	Module	Overlap
$W \rightarrow \mu\nu$	1.0		1.2		2		1.3	
Single muons	0.4	2.4	0.4	4	0.7	7	0.5	5
Low-p_T tracks		0.7		0.9		1.5		1.0

SUSY Endpoint analysis (CMS)

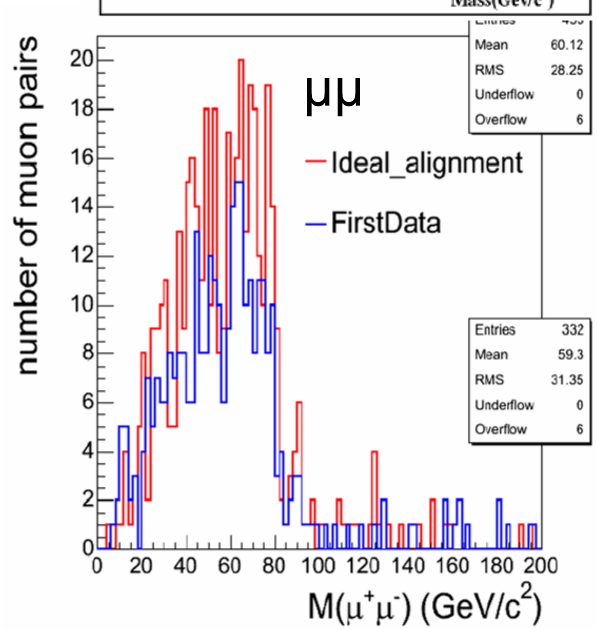
- **In some mSUGRA parameter space, have χ_2^0 (from the decay of squarks and gluinos)**
- **$\chi_2^0 \rightarrow \chi_1^0$ ll: SFOS leptons with characteristic endpoint.**

(m½=250, sign(μ)=+, m0=60, A0=0, tan(β)=10)



Effects of misalignment:

- Lower number of events selected
- Di-μ ε decreases by ~30% (13%) for first data (longterm)
- Di-e ε decreases by 10% (2%)
- End point still visible, shift of about 1 GeV (first data)

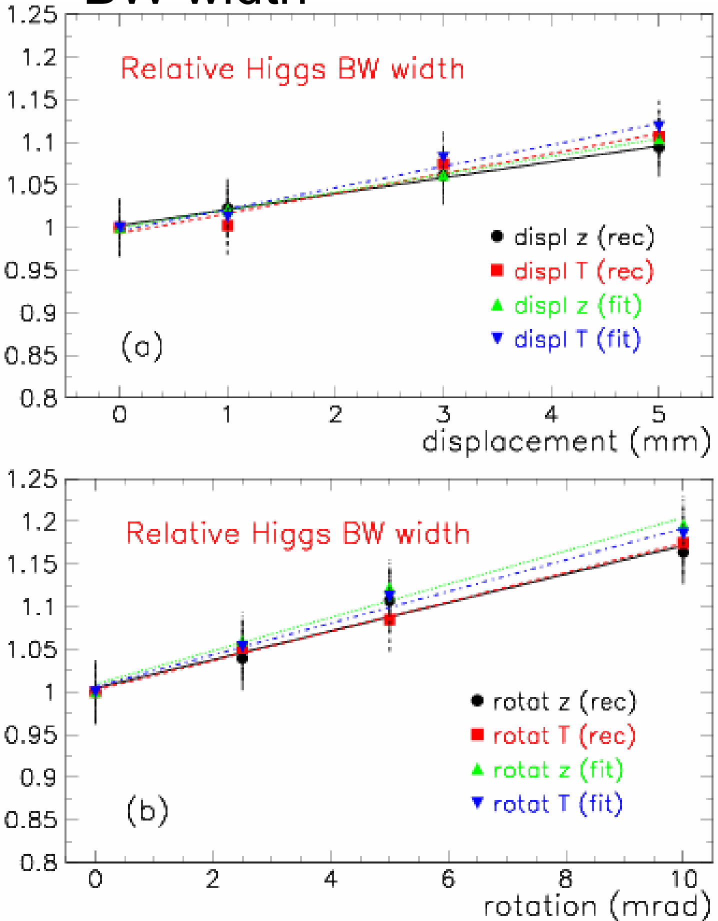


H→4μ (Misalignment of μ syst.) ATLAS

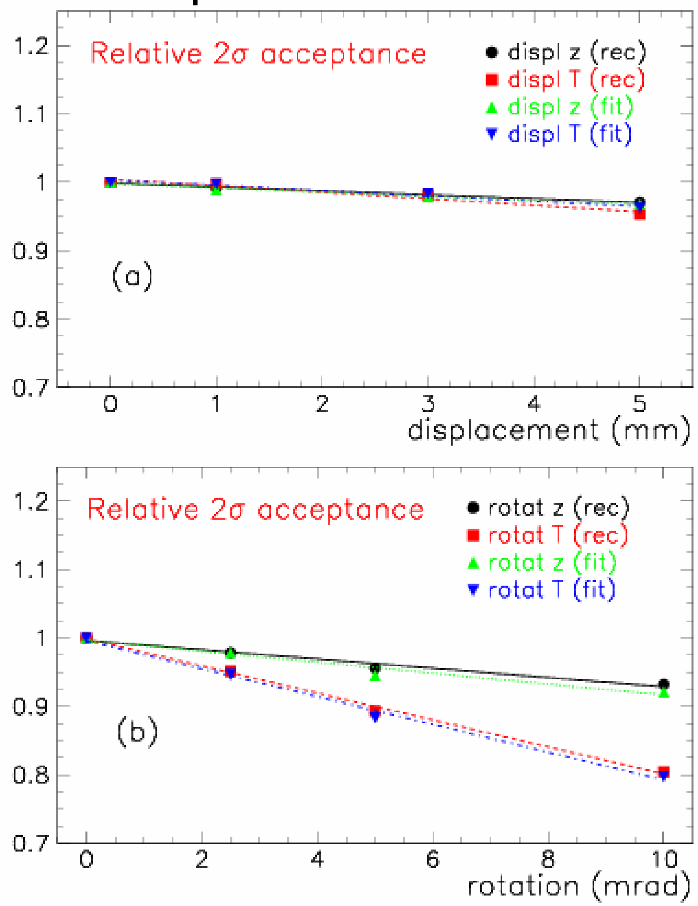
• barrel and endcap μ-systems are aligned to few 10's of μm by optical systems

• Impact on physics only expected from relative EC to barrel misalignment

BW width



Acceptance

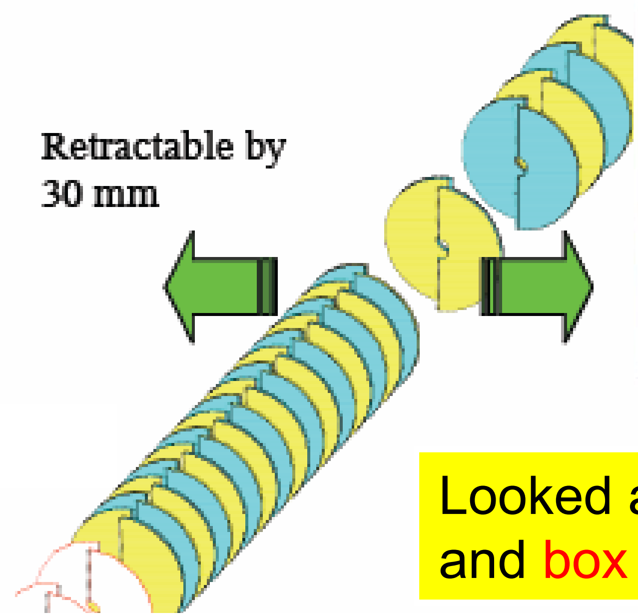


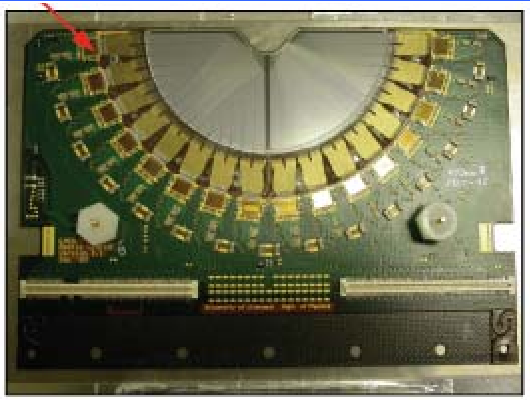
Linear dependance of resolution on displacement, rotation.
Ex.: 10% at 5mrad

Acceptance sensitive to rotation around x

200 GeV Higgs, similar results for 300 GeV

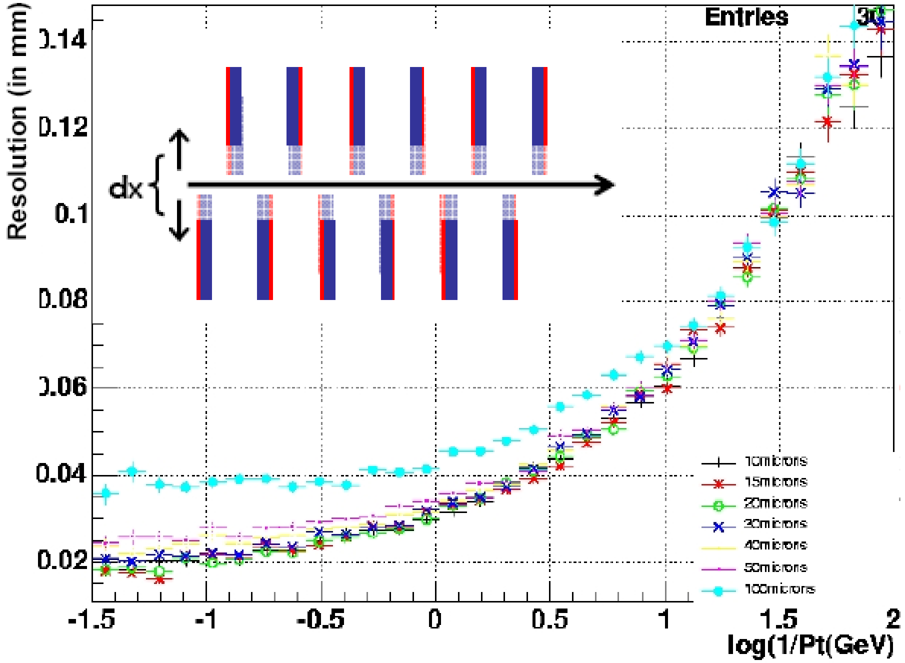
LHCb: Velo misalignment

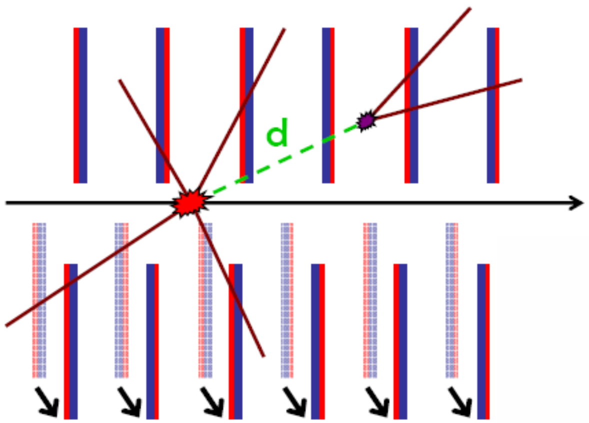




Looked at impact of module and box misalignment.

IP resolution for box-misalignment in x (10-100µm)





Proper time $\Rightarrow \tau = \frac{d \cdot m_B}{c \cdot |p_B|}$

Parameter affected by VELO misalignments

Here: x and z offset in right velo half.

Velo misalignment: L1 Trigger (LHCb)

Note: Silicon used in L1 trigger @LHCb

→Need to study impact of misalignment

⇒ Which misalignments are annoying for proper time ?

	Translation			Rotation		
	X	Y	Z	X	Y	Z
Station	Small Effect	Small Effect	No problem	No problem	No problem	Small Effect
Half box	Large effect	Large effect	Large effect	Large effect	Large effect	Small Effect

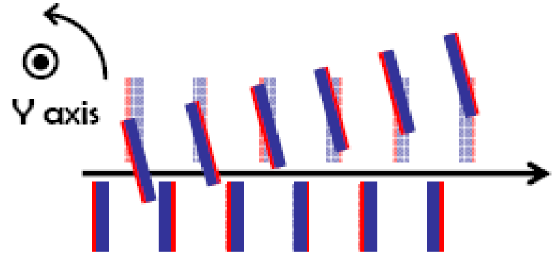
Legend: No problem (green), Small Effect (hatched), Large effect (red)

⇒ Requested precision, for less than 10% drop of efficiency on level 1 trigger:

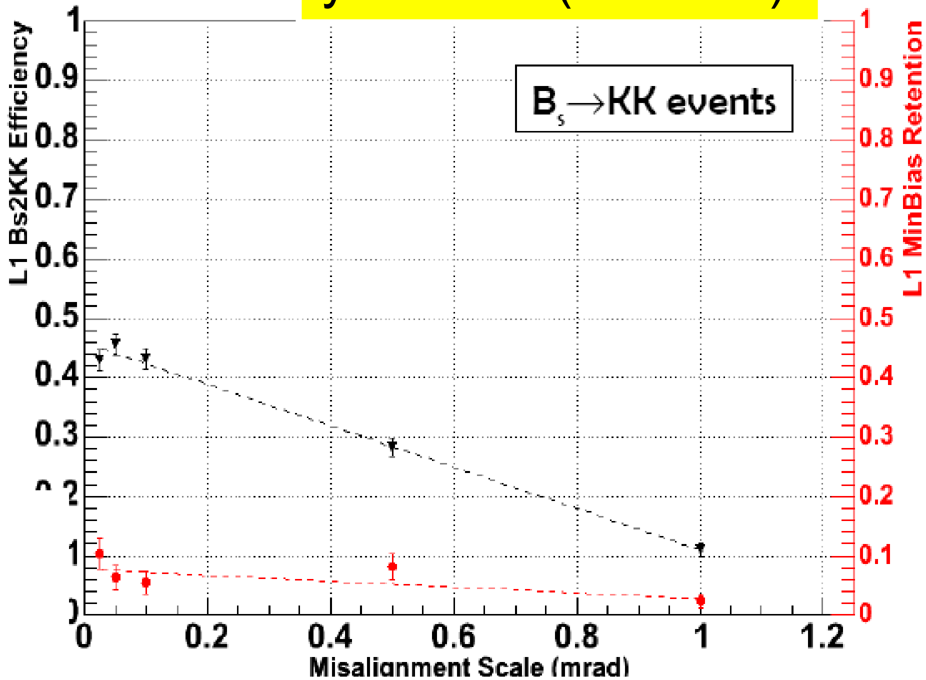
Values in μm and mrad	Translation			Rotation		
	X	Y	Z	X	Y	Z
Station	20	20	100	>1	>1	1
Half box	40	100	100	0.2	0.2	1

Those 2 DOFs are the most criticals

Most critical DOFs, not easy to correct



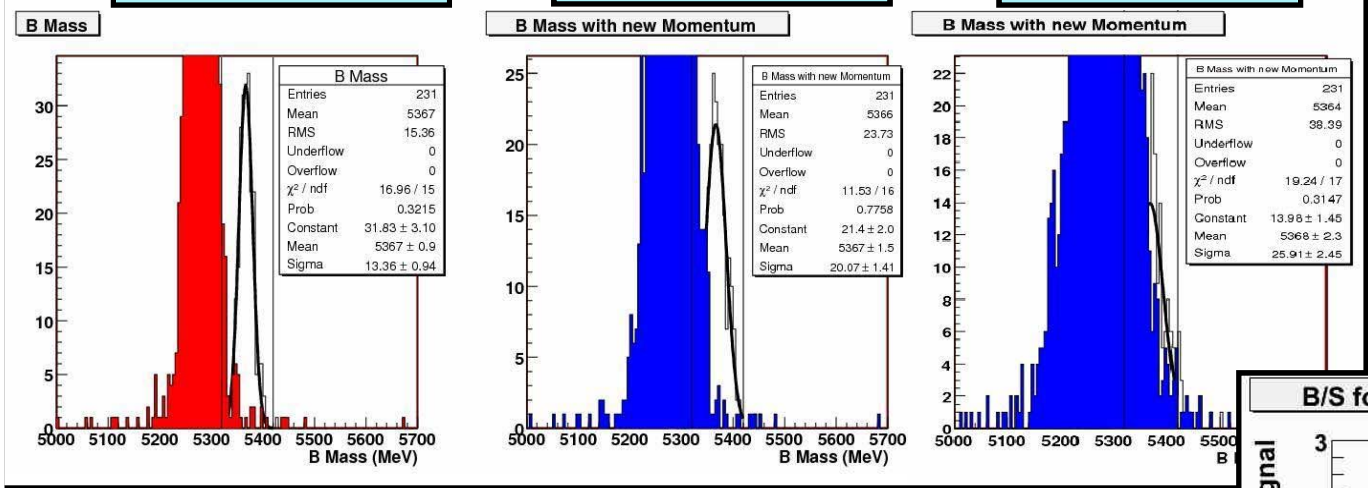
y rotation (Half box)



L1 efficiency reduced by 50% for y rotation of 0.7 mrad!

LHCb: B→hh

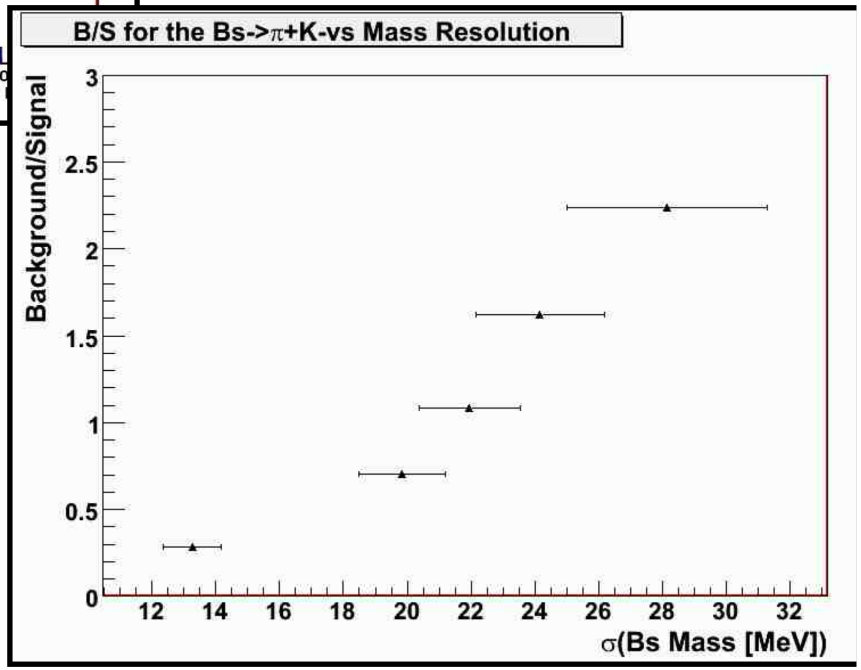
Δp/p ~0.4%   Δp/p ~0.5%   Δp/p ~0.7%



σ=13 MeV   σ=20 MeV   σ=26 MeV

$B_s \rightarrow \pi^+ K^-$

Degraded momentum resolution
→ degraded mass resolution
→worse S/B

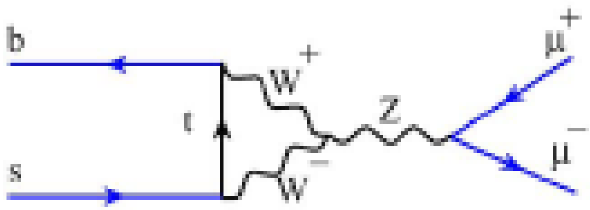


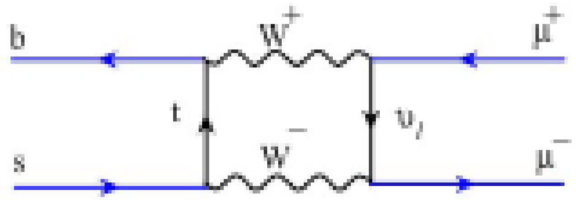
Background considered Bd → $K^+ \pi^-$

LHCb: Rare Decays, $B_s \rightarrow \mu\mu$

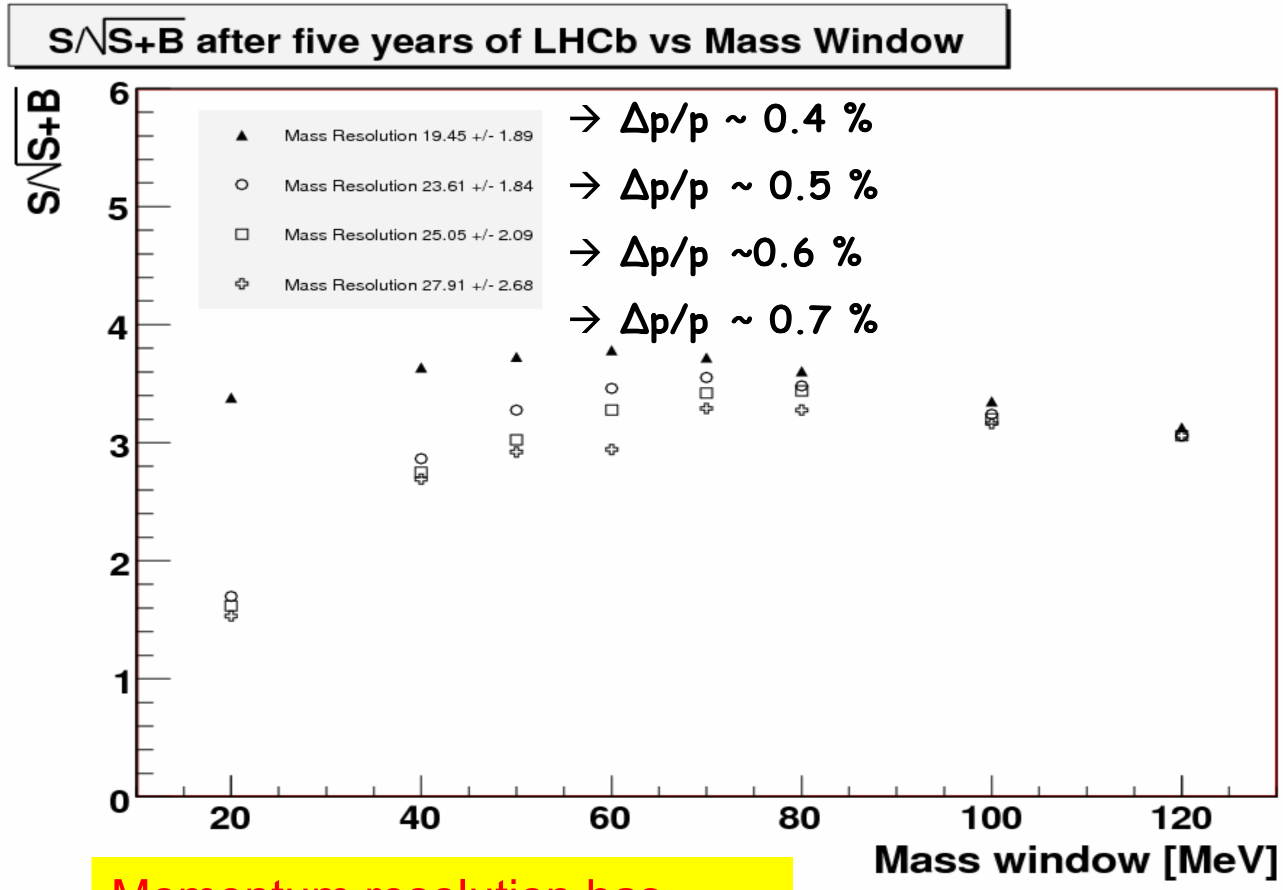
Physics motivation:

- In SM Forbidden @tree level (FCNC)
- Through (helicity suppressed) penguin/ box diagram



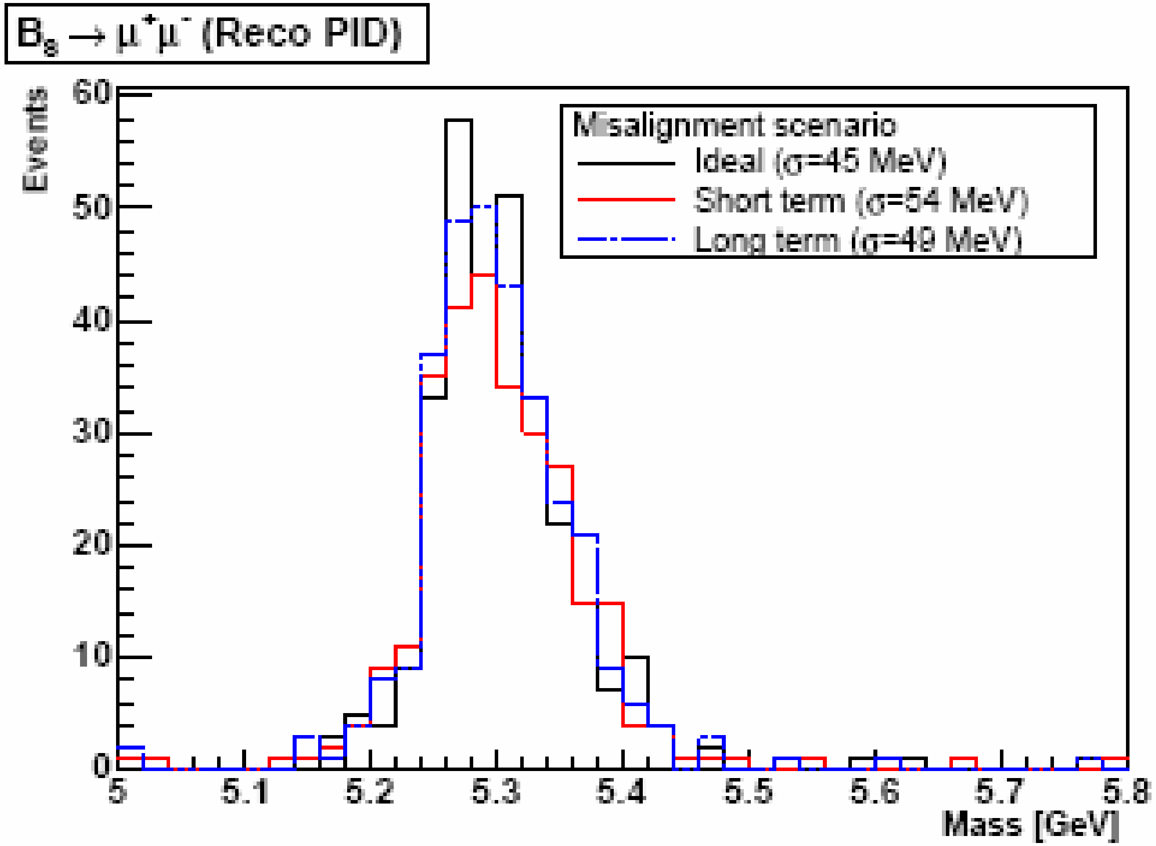


BR (theory) 3.4×10^{-9}
Exp limit: BR < 4.1×10^{-7}



Momentum resolution has strong impact on S/B. Directly affected by misalignment.

$B_s \rightarrow \mu\mu$ Mass Resolution (CMS)



Misalignment impacts mass resolution:

45 MeV (ideal)

→49 MeV longterm

→54 MeV (shortterm)

Impact on b tagging (ATLAS)

Rejection for 3D b-tagging algorithm for various misalignments.

		$R_0 = R_u$ perfect alignm.	R_u $\sigma_{R\phi} = 5\mu$m $\sigma_z = 15\mu$m	R_u $\sigma_{R\phi} = 10\mu$m $\sigma_z = 30\mu$m	R_u $\sigma_{R\phi} = 20\mu$m $\sigma_z = 60\mu$m
3D	ϵ_b=50%	262 ± 8	259 ± 8	237 ± 7	175 ± 4
	ϵ_b=60%	81 ± 1	79 ± 1	74 ± 1	57 ± 1
		R_u/R_0	R_u/R_0	R_u/R_0	R_u/R_0
3D	ϵ_b=50%	1.00	0.99	0.91	0.67
	ϵ_b=60%	1.00	0.97	0.92	0.71

Note: Similar numbers for 2D algorithm. Slightly more sensitive to misalignment than 3D.

Misalignment has a significant impact on performance of b-tagging algorithm.

Summary

- Tracking resolution impacted by misalignment: +50% (+200%) long (short) term (100 GeV μ, CMS)
- Consequences for physics:

RS Graviton search	Di-μ mass resolution x1.3 (x3) @3 TeV (CMS) Needs 50 % more data @ 2TeV
SUSY endpoint analysis	Di μ efficiency -30% (-13%) (CMS)
H4μ	5 mrad rotation in μ system causees 10% increase in H mass resolution (ATLAS)
W mass	1 μm alignment needed (?) (ATLAS) 12 MeV systematics@1fb^{-1} (CMS)
B Physics: Trigger eff	L1 eff reduced by 50% for 0.7 mrad rotation (LHCb)
B-Physics	Bs mass resolution 45→49→54 MeV (CMS) Strong impact on S/B (rare decays)
b-tagging	Rejection reduced by 9% for 10μm/30μm misalignment in rphi/z (ATLAS)

Alignment needs to be controlled to high accuracy to not compromise physics at the LHC.

Backup
Slides

Long Term Data Taking Scenario

Assumptions for alignment precision of **subdetectors** (RMS) after track based alignment.

	Δx $[\mu m]$	Δy $[\mu m]$	Δz $[\mu m]$	R_z $[\mu rad]$
TPB	10	10	10	10
TIB	10.5	10.5	50	9
TOB	6.7	6.7	50	5.9
TPE	5	5	5	5
TID	40	40	40	10
TEC	5.7	5.7	50	4.6

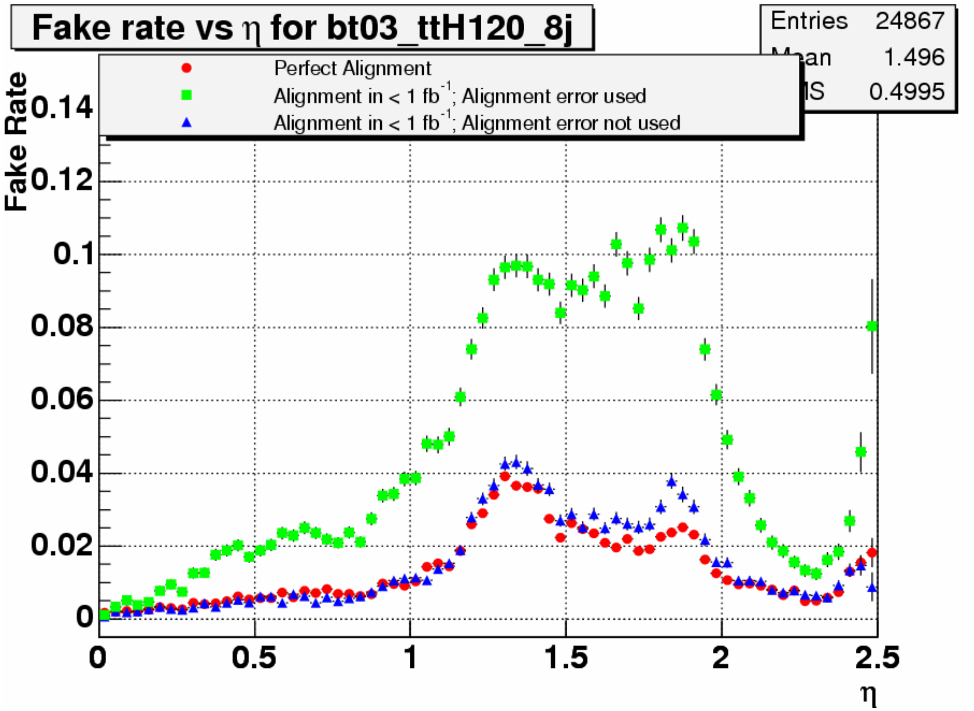
X10 improvement due to track based alignment, except pixels (same misalignment kept).

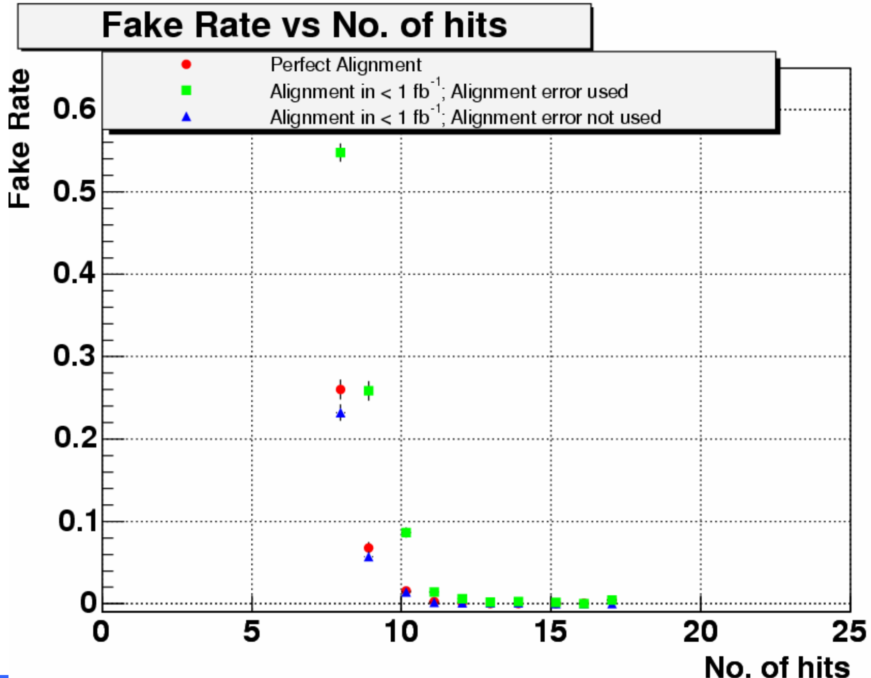
Assumptions for alignment precision Δx, Δy, Δz, and R_z of modules, rods, ladders, rings and petals.

	TPB $[\mu m]$	TIB $[\mu m]$	TOB $[\mu m]$	TPE $[\mu m]$	TID $[\mu m]$	TEC $[\mu m]$
Modules	13	20	10	2.5	10.5	5
Ladders/Rods/Rings/Petals	5	20	10	5	30	10

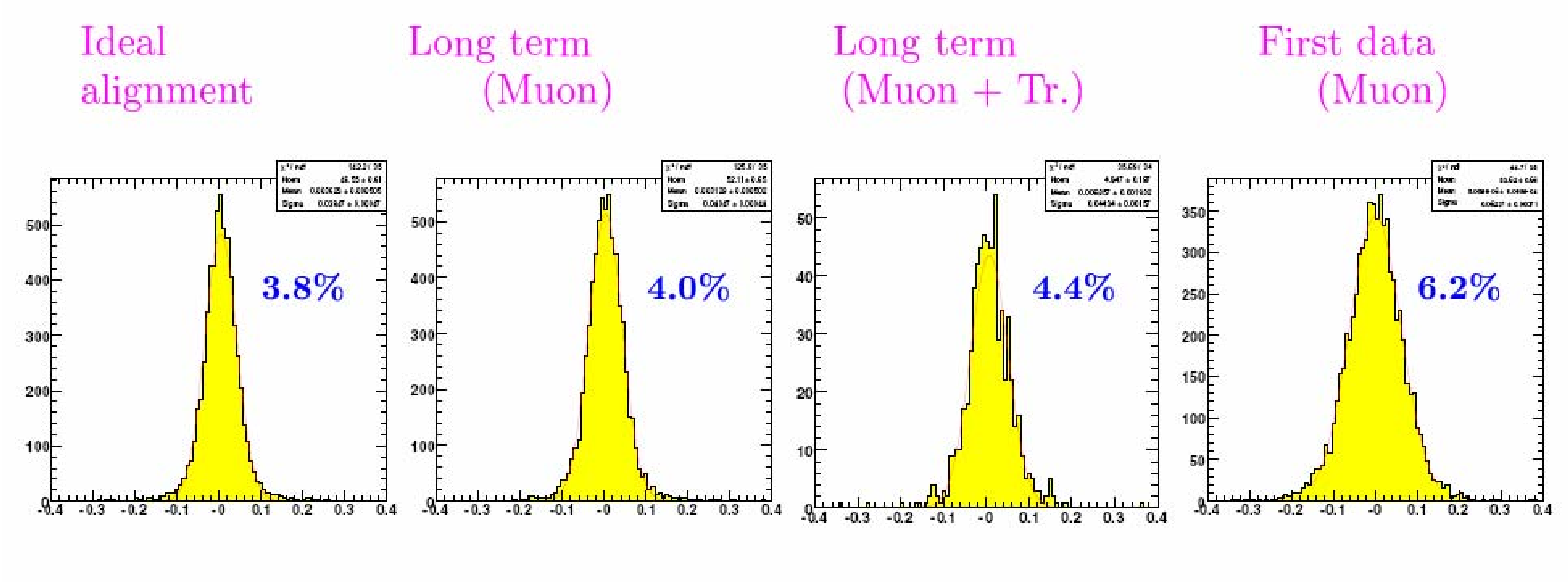
Fake rate (prelim)

- Average fake rate in ttH events + pile-up
- Track multiplicity **between 50 and 100**.
- Fake rate **≈1.5%** for perfect alignment and increases to **4.5%** for short-term alignment scenario
- Fake rate decreasing as much as the number of rec hits used.

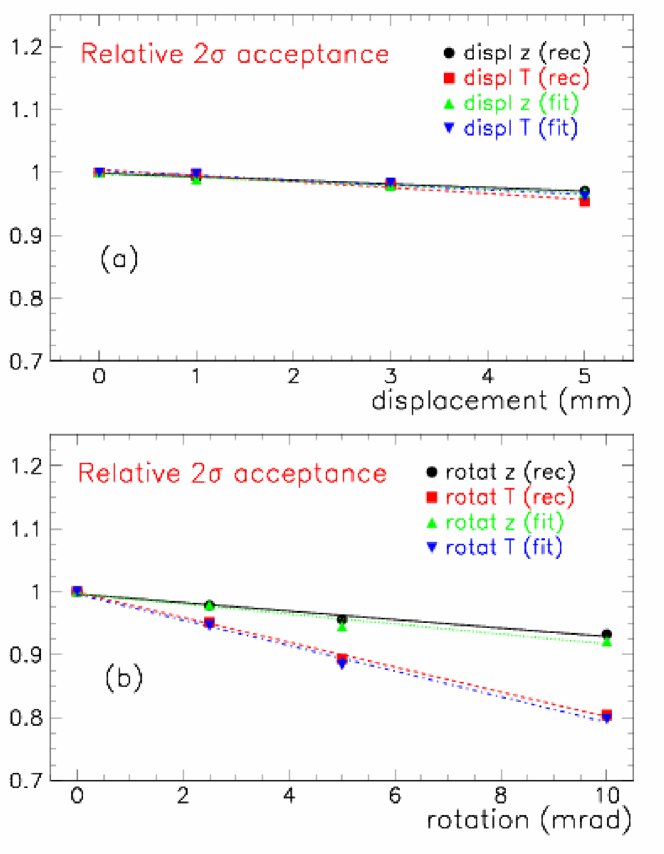




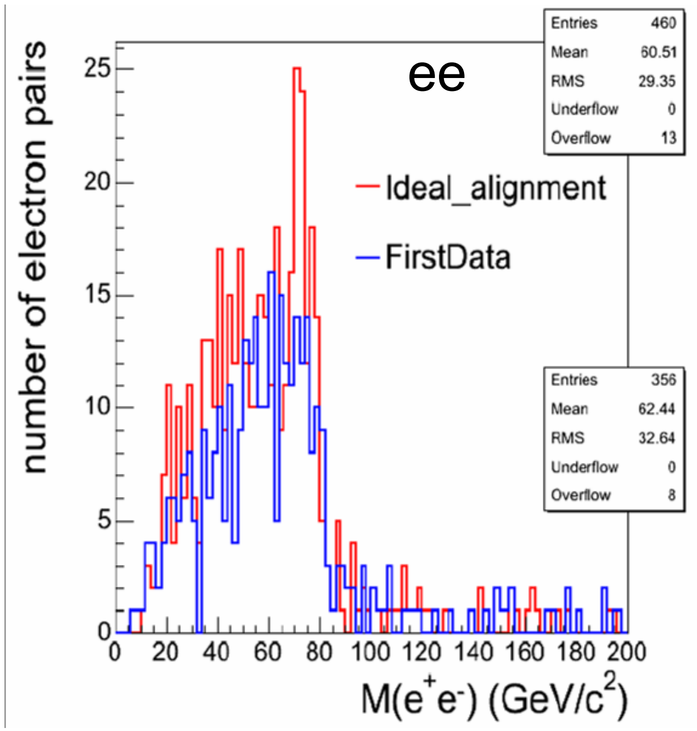
RS 1.5 TeV

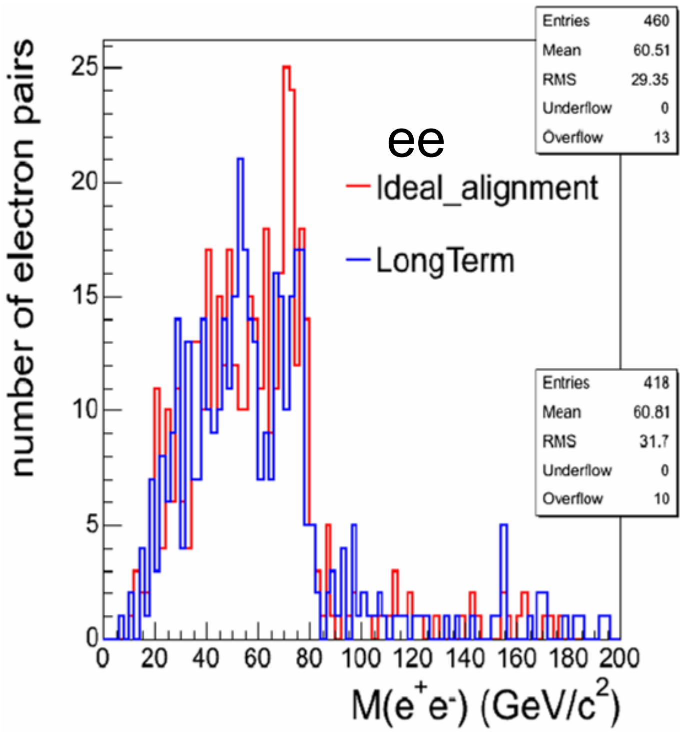

Ideal alignment
Long term (Muon)
Long term (Muon + Tr.)
First data (Muon)
3.8%
4.0%
4.4%
6.2%

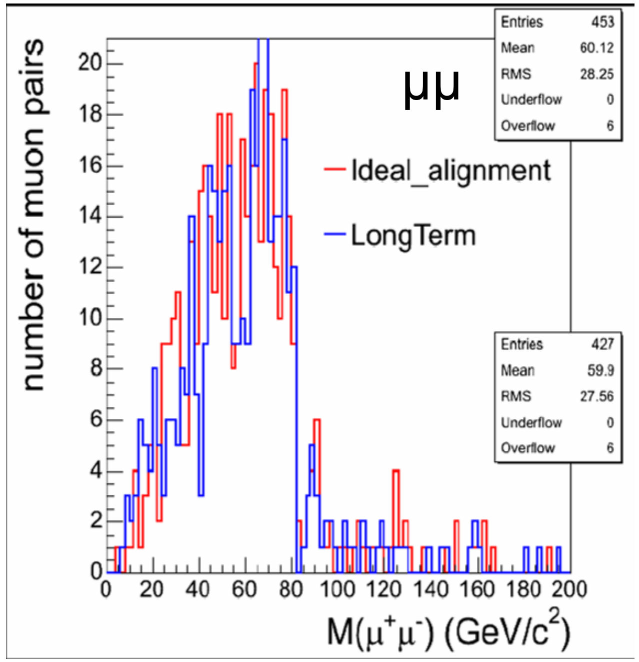
ATLAS: H→4μ 300 GeV Higgs



SUSY Endpoint analysis: More plots

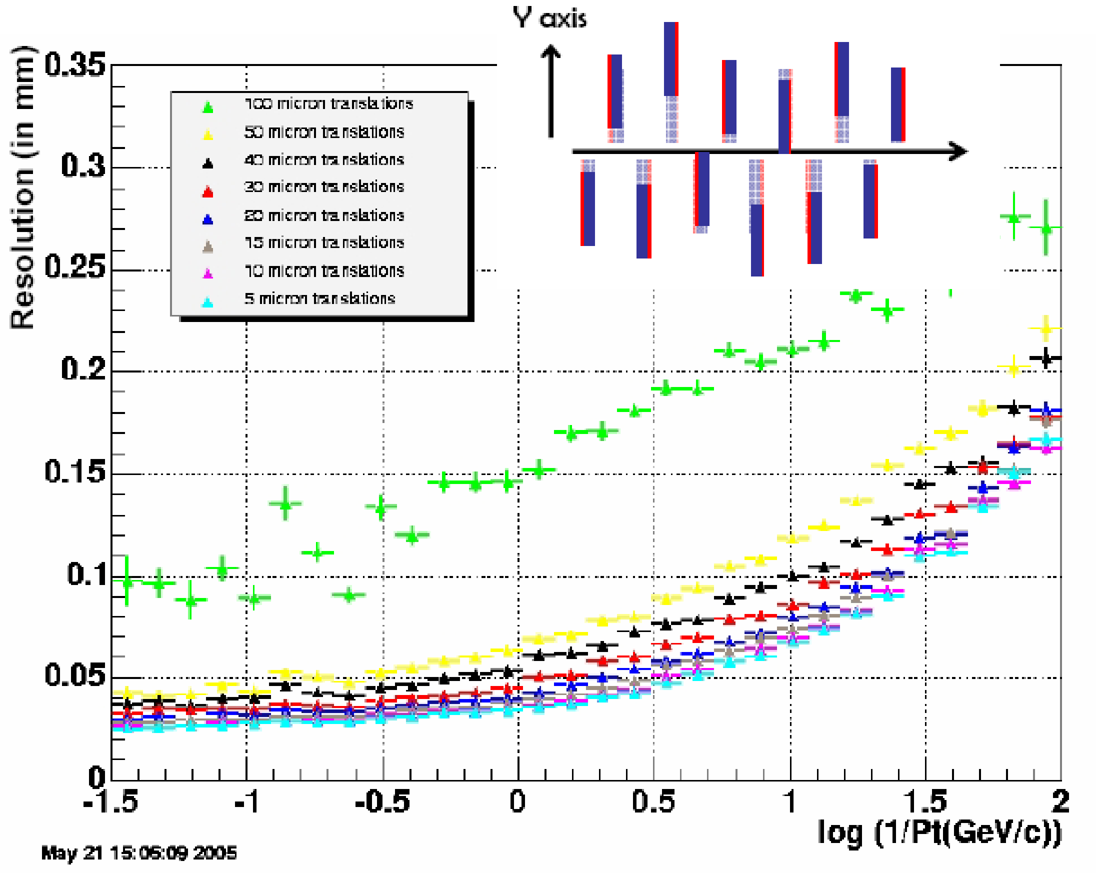






LHCb: Velo misalignment, module

IP resolution for module misalignment in y



Resonances in Di-Muons III

Di-Muon mass resolution for RS Graviton, G*→μμ

Some examples of misalignment effects on the mass reach (in fb^{-1}):

mass	c	Ideal	With misalignment
1000	0.1	0.006	0.007 (First data)
1000	0.1	0.006	0.006 (Long term)
1500	0.1	0.050	0.051 (Long term)
1500	0.01	3.1	3.6 (Long term)
1500	0.1	0.05	0.08 (First data)
3000	0.1	6.2	6.4 (Long term)

Variations are largest for large background ($c = 0.01$) or First Data.

Currently, the production of samples with misalignment is being finished (during the last time performance of castor was not optimal).

Resonances in Di-Muons III

3 TeV/c^2.