Systematic uncertainties for High beta optics

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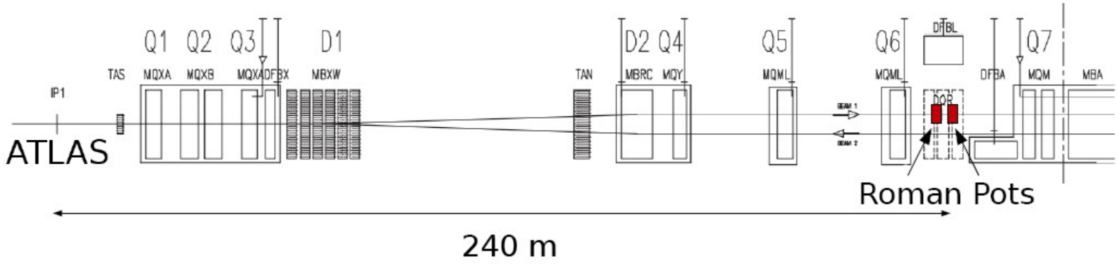
Outline

- Introduction
- Description of the lever arm : Leff
- Systematic uncertainties on the lever arm
  - Gradient field differences
  - Misalignments
  - Beam-beam effect
- Tracking and acceptance results
  - Crossing angle
  - Emittances
- Conclusion

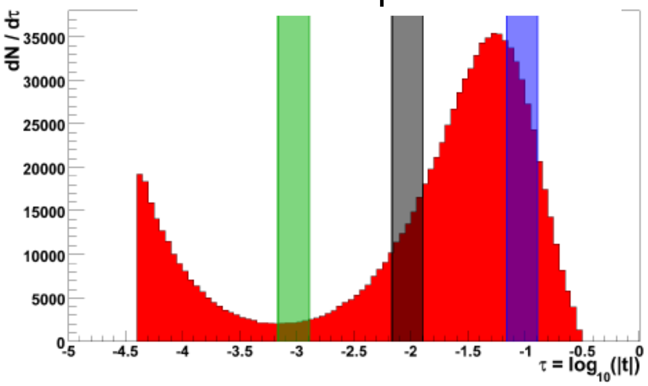
Introduction : elastic scattering measurements

- Purpose
  - Measure absolute luminosity with 2-3 % precision and total elastic cross section
- Beam line example (ALFA - IP1)



Example for ultimate goal : 7 TeV per beam and β* = 2625 m

Generated spectrum

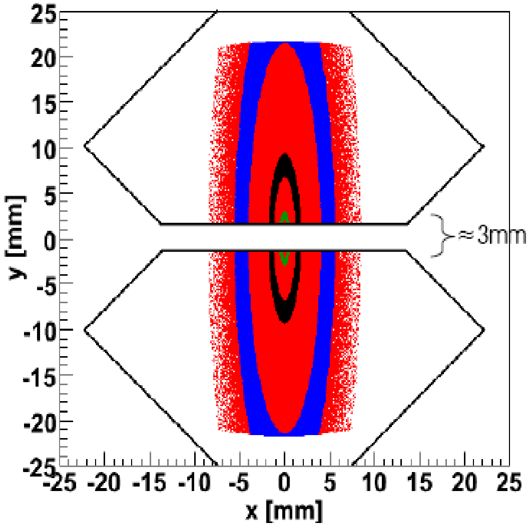


3.8 < θ < 5.2 μrad

11.9 < θ < 16.2 μrad

37.7 < θ < 51.5 μrad

Scattering picture at the roman pot



Elastic protons with small scattering angle → Roman Pots must be as close as possible

Optics parameters for the 90 m β* optics at IP1

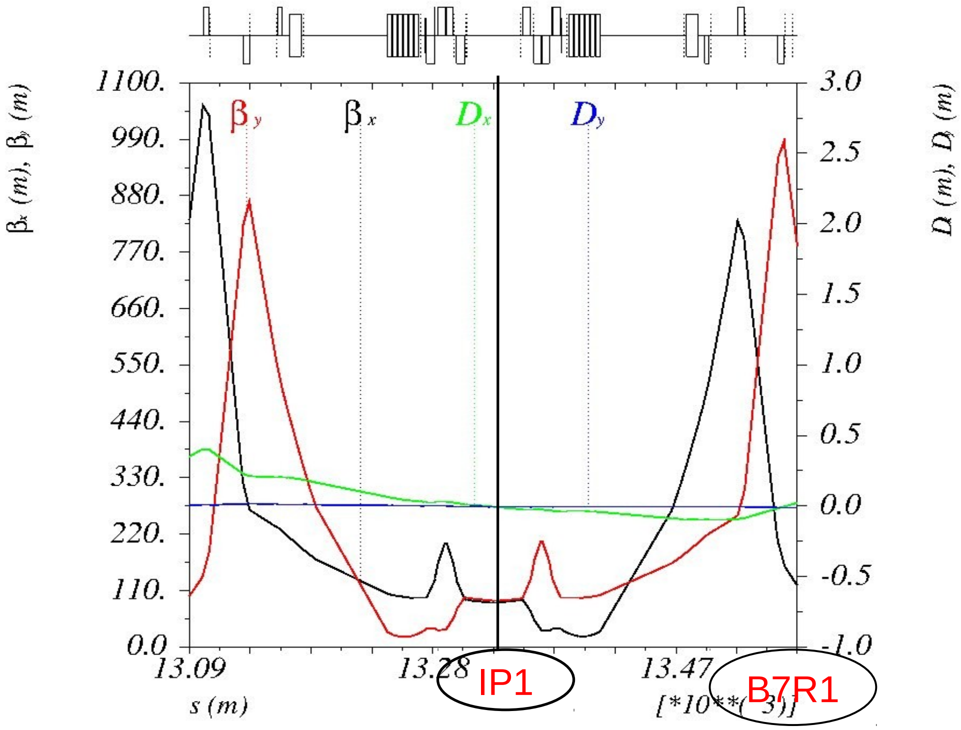
IP1		XRP.A7R1.B1		XRP.B7R1.B1		XRP.A7L1.B2		XRP.B7L1.B2	
β*x (b1)	86.39	βx (b1)	133.92	βx (b1)	119.24	βx (b2)	144.39	βx (b2)	128.72
β*y (b1)	90.16	βy (b1)	856.21	βy (b1)	779.37	βy (b2)	860.64	βy (b2)	783.39
β*x (b2)	92.63	μx (b1)	0.515	μx (b1)	0.521	μx (b2)	0.514	μx (b2)	0.519
β*y (b2)	89.69	μy (b1)	0.252	μy (b1)	0.253	μy (b2)	0.249	μy (b2)	0.251
εN (μm rad)	2	Leffy (b1)	277.804	Leffy (b1)	265.023	Leffy (b2)	277.836	Leffy (b2)	265.073
εx,y (m rad)	5.36E-10	Leffx (b1)	-10.293	Leffx (b1)	-13.018	Leffx (b2)	-10.292	Leffx (b2)	-13.016

β - functions and dispersion functions for beam1

Tune is compensated

MDs were done and able us to study the systematics on Leff – mainly Leffy

Study for Fill 2232 on 20/10/11



Lever arm Leff : description

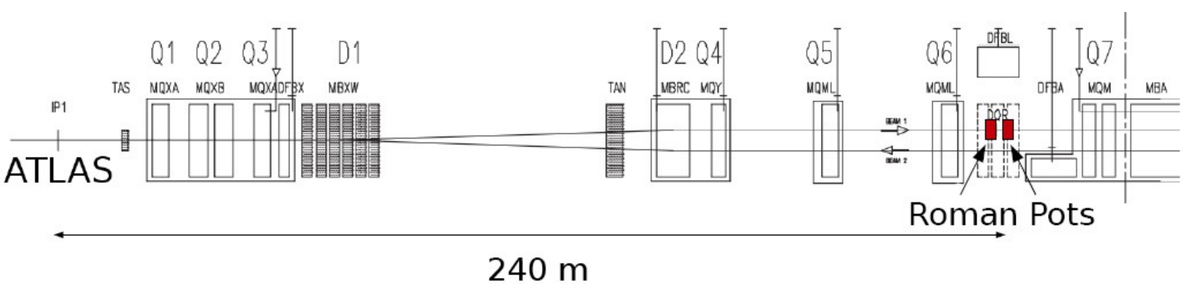
- Lever arm definition
  - Matrix beam formalism

$$M = \begin{pmatrix} \sqrt{\beta_{rp}/\beta^*}(\cos\psi + \alpha_1 \sin\psi) & \sqrt{\beta_{rp}\beta^*}\sin\Psi \\ -1/\sqrt{\beta_{rp}\beta^*}[(\alpha_{rp} - \alpha^*)\cos\psi + (1+\alpha_{rp}\alpha^*)\sin\psi & \sqrt{\beta^*/\beta_{rp}}(\cos\psi - \alpha_{rp}\sin\psi) \end{pmatrix}$$

$$u = \sqrt{\beta/\beta^*}(\cos\psi + \alpha^*\sin\psi).u^* + \sqrt{\beta\beta^*}\sin\psi.\theta_u^*$$

$$\theta_u^* = \frac{u_L - u_R}{2L_{eff,u}} \quad with \quad L_{eff,u} = \sqrt{\beta\beta^*}\sin\psi$$

- Leff is dependant on the optics parameters



Uncertainties – gradient k

- Gradient field errors k
  - Extraction from TIMBER via Java interface provided by G. Mueller, M. Strzelczyk and F. Janos Nemes
  - Comparison with MadX nominal values
    - For quadrupoles from Q1 to Q6 (located before the Roman Pots)
    - For beam1 and beam2
    - Maximum Δk/k value : ~0.7E-4
  - From Fill 2232, 20/10/11 from 8h57 to 20h

→ New k inputs in MadX for comparison

→ Impact on Leff ?

Name	Δk/k
kqx.l1	-0.11E-4
ktqx.l1	-0.66E-4
ktqx2.l1	-0.1E-4
kqx.r1	-0.12E-4
ktqx1.r1	-0.67E-4
ktqx2.r1	-0.12E-4
kq4.r1b1	-0.11E-4
kq5.r1b1	-0.11E-4
kq6.r1b1	-0.11E-4
kq4.l1b2	-0.15E-4
kq5.l1b2	-0.11E-4
kq6.l1b2	-0.11E-4

Uncertainties – gradient k

- TIMBER vs MADX
  - Difference with optics parameters (example for beam1 at IP1 and at XRPV.A7R1.B1 Roman Pot)

IP1 (b1)	Δvalue/value	A7R1	Δvalue/value
BETX	0,008	BETX	0,006
BETY	0,002	BETY	-0,012
MUX	0,000	MUX	0,000
MUY	0,000	MUY	-0,036
DX	5,384	DX	3,813

  - Impact on Leff is negligible :
    - ~ ΔLeff/Leff from 0.2E-4 to 0.9E-4

MADX	TIMBER	ΔIeff/Leff
XRPV.A7R1.B1		
-10.294	-10,293	-0.9E-4
277.804	277,809	-0.2E-4
XRPV.B7R1.B1		
-13.018	-13,017	-0.7E-4
265.02	265,027	-0.2E-4
XRPV.A7L1.B1		
-10.292	-10,291	-0.9E-4
277.836	277,841	-0.2E-4
XRPV.B7L1.B1		
-13.016	-13,015	-0.7E-4
265.03	265,07798	0.2E-4

Uncertainties – gradient k

- Madx simulation with varying k strengths → Leff results :

	Roman Pots	Δleffx/Leffx	Δleffy/Leffy
all elements	xrpv.a7r1.b1	-0.9E-4	0.2E-4
with +	xrpv.b7r1.b1	-7.4E-4	0.2E-4
Δk	xrpv.a7l1.b2	-0.9E-4	0.2E-4
	xrpv.b7l1.b2	-0.7E-4	0.2E-4
all elements	xrpv.a7r1.b1	0.9E-4	-0.2E-4
with -	xrpv.b7r1.b1	0.7E-4	-0.2E-4
Δk	xrpv.a7l1.b2	0.9E-4	-0.2E-4
	xrpv.b7l1.b2	0.7E-4	-0.2E-4
Triplets : +Δk	xrpv.a7r1.b1	0.6E-4	-0.2E-4
quads -Δk	xrpv.b7r1.b1	0.4E-4	-0.2E-4
	xrpv.a7l1.b2	0.6E-4	-0.2E-4
	xrpv.b7l1.b2	0.4E-4	-0.2E-4
triplets -Δk	xrpv.a7r1.b1	-0.7E-4	0.2E-4
quads +Δk	xrpv.b7r1.b1	-0.4E-4	0.2E-4
	xrpv.a7l1.b2	-0.6E-4	0.2E-4
	xrpv.b7l1.b2	-0.4E-4	0.2E-4

  - Maximum ΔLeffy/Leffy variation : ~0.2E-4
  - Effect on Leff with quadrupoles after the Roman Pots ?

Uncertainties – gradient k

- Gradient field errors k
  - Extraction from TIMBER for quadrupoles after the Roman Pots : Q11 – Q12 and Q13
  - Comparison with MadX values
    - Larger k variation seen
  - From fill 2232, 20/10/11 from 8h57 to 20h

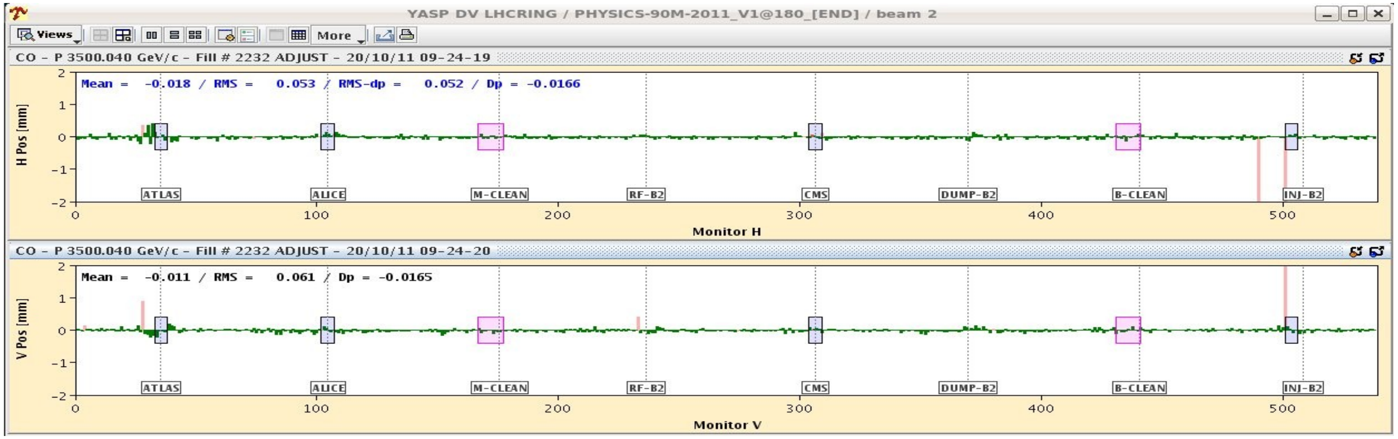
Name	Δk/k
kqtl11.r1b1	0,06
kqt12.r1b1	-0,02
kqt13.r1b1	-0,17
kqtl11.l1b2	0,14
kqt12.l1b2	-0,01
kqt13.l1b2	-0,01

	Roman Pots	Δleffx/Leffx	Δleffy/Leffy
all quadrupoles	xrpv.a7r1.b1	0.03E-4	0.02E-4
with + Δk	xrpv.b7r1.b1	0.02E-4	0.02E-4
all quadrupoles	xrpv.a7r1.b1	-0.7E-4	0.2E-4
With - Δk	xrpv.b7r1.b1	-0.5E-4	0.2E-4

Largest impact on ΔLeffy/Leffy is ~ 0.2E-4

Uncertainties – Quadrupoles misalignments

- Quadrupoles misalignments : Impact on Leff
  - Idea : misalignment should not affect our measurements : the orbit being corrected, misalignments are corrected
  - BPMs values logged. Hard to use, temperature drift, intensity dependant
  - Using RMS deviation on the orbit
    - From elogbook, fill 2232, for beam2 at collisions we had
      - horizontal orbit rms = 0.053 mm
      - vertical orbit rms = 0.061 mm
      - Horizontal orbit mean = -0.018 mm
      - Vertical orbit mean = -0.011 mm



Uncertainties – Quadrupoles misalignments

- Higher values than rms closed orbit taken for misalignements → 1 mm
- Misalignments applied :
  - On quadrupoles from Q1 to Q6
  - On quadrupoles from Q1 to Q13
- Results on optics parameters and Leffy :

	β_y*	β_{yRP}	Ψ_{RP} (2π)	$Leff_y$
Without misalignments	90.16	856.21	0.252	277.804266
Q1 to Q6	89.99	857.87	0.253	277.804265
Δvalue/value	-0.2 %	0.2 %	0.2%	< 10^{-4} negligible
Q1 to Q13	89.79	859.65	0.252	277.8042614
Δvalue/value	-0.4 %	0.4 %	-0.2%	< 10^{-4} negligible

  - Optics parameters modifications
  - But → No Impact on Leffy even for 1 mm (not possible)

Uncertainties – beam-beam effect

- Beam – beam effect
  - Beam-beam effect is quantified by the tune shift induced by a linear kick

$$\Delta Q_x = -\frac{\beta_x}{4\pi}\frac{\Delta x'}{x}$$

  - For round beams, the linear beam-beam parameter equal to the tune shift

$$\xi = -\frac{N r_0}{4\pi \epsilon_N}$$

- N = bunch population
- r_c = classical proton radius

  - At the design emittance of 2 µm.rad, the values are :

N	ξ
4×10^{10}	- 0,00246
7×10^{10}	- 0,00432
1.5×10^{11}	- 0.00926

Uncertainties – beam-beam effect

- Beam – Beam effect on Leffy
  - Inserting as a first approximation an equivalent quadrupole corresponding to the tune shift in the MadX simulation
  - With bunch population N equals to 7E10

Roman Pots	ΔIeffx/Leffx (%)	ΔIeffy/Leffy (%)
xrpv.a7r1.b1	-0.1198	0.3015
xrpv.a7r1.b1	-0.1664	0.3016
xrpv.a7l1.b2	-0.1198	0.3015
xrpv.b7l1.b2	-0.1664	0.3016

  - 0.3 % for Leffy → Dominant effect

Systematic uncertainties on Leffy

- Summary

	Δleffy/Leffy
k values compared with TIMBER	
from Q1 to Q6	0.2E-4
from Q11 to Q13	0.6E-4
misalignments	negligible
Beam-beam effect	0.3 %

- Leffy seems to be a robust quantity
- More investigations needed to see if other effects can impact on Leffy
- Optics measurements have also been done (see R. Tomas and G. Vanbavinckhove)

Transport calculation parameters

- The simulation in three steps :
  - Generation
    - 100 000 elastic events
    - Using optics values found during last MD (Fill 2232)
  - Tracking of elastic protons (MadX)
  - Acceptance calculation
    - The acceptance is the ratio between protons intercepted in the detectors and the number of generated events

Systematic uncertainties on Leffy

- Crossing angles
  - Crossing angles should be in the order of μrad
  - Impact of a unexpected crossing angle with 1 or 10 μrad

	1 μrad crossing angle in y		10 μrad crossing angle in y	
Roman Pots	Δx (μm)	Δy (mm)	Δx (μm)	Δy (mm)
xrpv.a7r1.b1	0.25	0.27	2.4	2.7
xrpv.b7r1.b1	4.6	0.26	3.5	2.6
xrpv.a7l1.b2	-6.4	-0.27	-5.9	-2.7
xrpv.b7l1.b2	-7.6	-0.26	-6.9	-2.6

  - Looking at the positions in the detectors after tracking

Positions at XRP.A7R1.B1

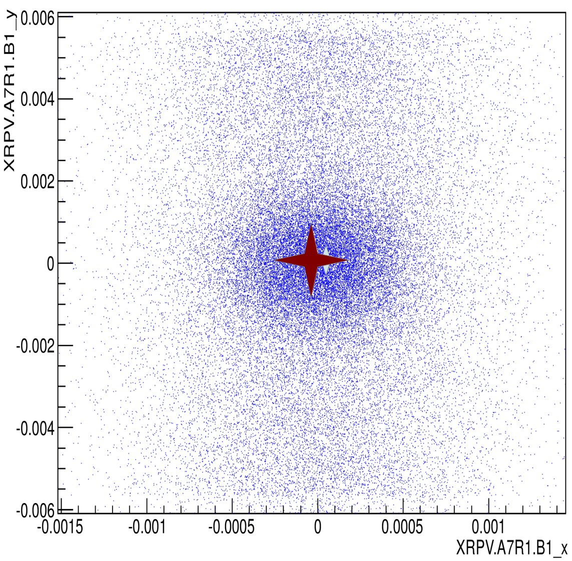
with no crossing angle at IP1

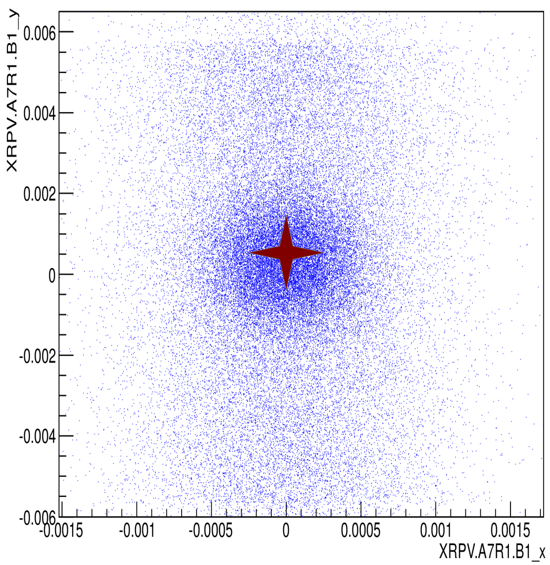
Positions at XRP.A7R1.B1

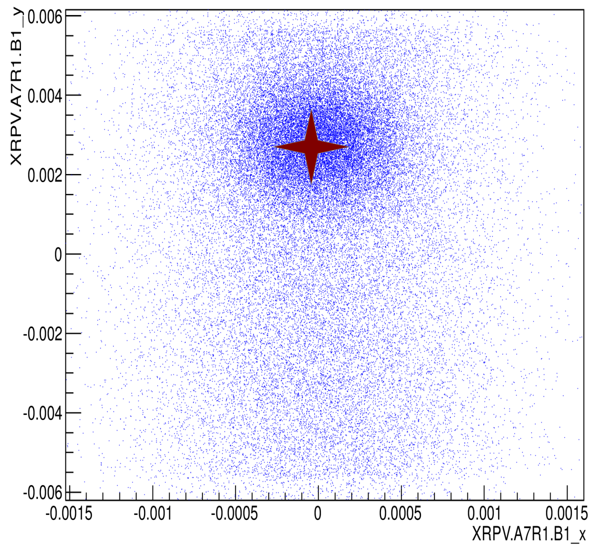
with 1 μrad crossing angle at IP1

Positions at XRP.A7R1.B1

with 10μrad crossing angle at IP1





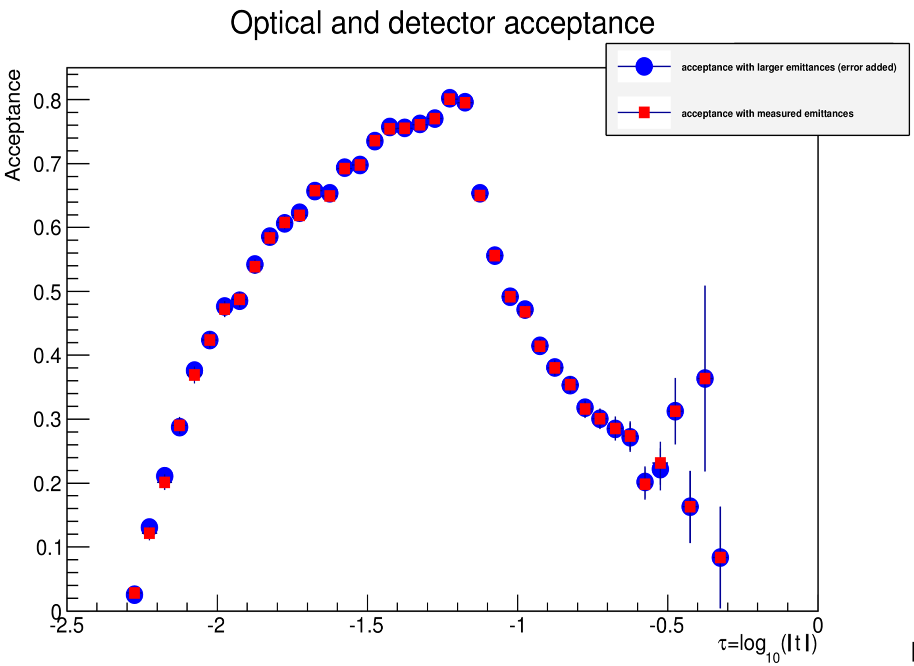


Systematic uncertainties on Leffy

- Impact of Emittances :
  - Summary on emittance measurements and errors during Fill 2232 (F. Roncarolo) for fat bunches of 7.10^{10}

	ε_{xN}	ε_{yN}	Error_x	Error_y
Beam 1	2.302	1.748	0.22	0.064
Beam 2	2.362	1.999	0.236	0.022

  - generation of elastic scattering with these new emittances
  - Adding +/- 0.2 um.rad error in emittances values



Acceptance results :

	Δacc/acc (total)	Δacc/acc (8σ)
Beam 1	-0,002%	-0,20%
Beam 2	-0,001%	-0,20%

Increasing the emittance of ~ 0,2 um.rad leads to a impact on the acceptance in the detectors of 0,2 %

Preliminary conclusion

- Acceptance and alignment corrections determined with full simulation (~ 1 %)
- No major known optics related uncertainties
  - Large unknown effects would have been seen in beta-measurements
- Largest effect is 0.3 % from beam – beam (optics uncertainties < 1 %)
- Leffy is a very robust quantity