# Geodetic Infrastructure & Alignment -Planning and Studies Mark JONES, CERN







#### Content

- FCC-ee Planning, Requirements & Constraints
- Provisional Survey Working Parameters
- Position Monitoring and Alignment System
- Geodetic Infrastructure





### Planning, Requirements and Constraints



#### FCC integrated project technical schedule



FCC integrated project plan is fully integrated with HL-LHC exploitation and provides for seamless further continuation of HEP in Europe.

M. Benedikt

Overview Future Circular Colliders, EPPSU, Granada

Project	Start construction	Start Physics (higgs)		
FCC-ee	2029	2039 (2044)	D. Schulte	
27.06.2019	M. Jones	Geodetic Infrast FCC Week 20	ructure and Alignment 019	4

D (RF)

B

A (IP)

13.4 m 10.6 m Booster

FCC-hh Booster

G, (m)

G (IP)

-500

30 mrad

FCC-hh/

500

1000

F

# System Requirements

- FCC-ee
  - Main Ring
  - Booster Ring
- -1000 Smallest Misalignment Tolerance
  - Values to Confirm
  - Quadrupoles and Sextupoles
  - FCC-ee Main Ring: 100 μm over ~100 m
  - Booster Ring: 150 μm



0.3 m

J(RF)

G<sub>y</sub> (m)



## **FCC-ee Operational Constraints**



#### A. Niemi

shutdown	no. cryomodules	length of shutdown
shutdown 1	-	12 weeks
shutdown 2	-	12 weeks
shutdown 3	10 CM	12 weeks
shutdown 4	26 CM	20 weeks
shutdown 5	21 CM	14 weeks
shutdown 6	42 CM	18 weeks
shutdown 7	30 CM	15 weeks
shutdown 8	30 CM	15 weeks
long shutdown	104 CM	1 year
shutdown 11	39 CM	17 weeks
shutdown 12	-	_
shutdown 13	-	_
shutdown 14	-	-

- Winter Shutdown
  - 12 to 20 wks
- 20 days Machine time (operation years) Development / yr
  - 11 days for Technical Stops
  - Long Shutdown after 9 years





# **Other Constraints**

- Significant tunnel / ground motion possible (>1 mm / year in LHC)
- Maintenance Access
  - Beamline elements
  - Position Monitoring and Alignment System









Provisional Survey Working Parameters Interpretations & Assumptions! To Confirm!!

- Tunnel Alignment Precision Requirement
  - Main Ring: ~30  $\mu m$  @  $1\sigma$
  - Booster Ring: ~50  $\mu$ m @ 1 $\sigma$
- Quadrupoles and Sextupoles
  - Assembled on a Single Girder
- Frequent position monitoring required
- Re-alignment/Smoothing at least 1 / year
  - Main Beam arcs => ~12000 beamline modules
  - Booster arcs => ~10000 beamline modules



### **Provisional Survey Working Parameters** Interpretations & Assumptions! To Confirm!!

- Limited time for Survey tunnel activities
  - During both installation and operation
- Maintenance Access
  - Cannot disturb any Survey **Tunnel Reference Infrastructure**
- CDR Position Monitoring and **Alignment Solution** 
  - Based on design for CLIC
  - Consequences for Accelerator Installation
  - Consequences for Geodesy

27.06.2019









# **Initial Survey Planning**

A	В	С	D	E	F G	н			J	K L	М	N	0	P	R				S				Т	1	U 🔺							
2		+		<u> </u>	Version Avant comparaison avec ILC. Mangue align	nement	t drive t	eam+ ré	vision t	arifs unitaires/0	180. Voir f	euille "révisio	ILC" pou	r estimati	on correcte.								+	+	- 1							
3					rention Aran comparation aree izer manque angi																											
	÷					+ ±		. ÷		- L			aboi																			
	g Sta	- <sup>2</sup>				ds Sta	9	Sta	ę.	staf	bor	•ð	g																			
	ular rhea ise 1	S + S	A			ular thea	s -	ular VL	rhea	ular e	S + S	ply	veyi																			
4	Pha Pha Pha	Sur Sur	ARI			Reg	S N	Reg	ě :	Reg Reg	M& Sur	Sup	Sur																			
5	9/		G	2	GEODESY					7.1.11			pri	ce/unit	nb of unit	5																
34 100	% 0.00	0 200.00	G	2.010	Buy survey tools for geodesy			М	ode 🔻	Task Name						<b>.</b>	H2 H1	H2	H1	H2 H	1 H2	ні н	2 H1	H2 I		H2 H1	H2	ні н	2 H1	H2	ні н	H2 H1
35		00.00	G	2.0101	equipment bought		24	-4	•		ation and	d Developme	nt				8															
36 40	% <u>0.0</u> (	96.00	G	2.0200	Build the geodetic reference network monuments	-	25	-4	•	CERN	Referenc	e Systems																				
38			G	2.0202	Monuments remeasured for beam alignment (XY)	-	28	-4	•	Math	ematical	Modelling					1															
39 40	0.00	0 72.00	G	2.030	Measure and maintain the geodetic monuments Monuments measured and calculated DOO for chill engineering work			-4		Gravi	y Field M	Aodelling																				
41			G	2.0302	Monuments measured and called Oction	- D	$\mathbf{Y}$	DI	n	ninc	are and D	Database Deve	lopmen				Ļ															
42	96 0.00	50.00	G	2.0303	Monuments remeasured in COSLING					446044	nfrastru	ucture Conce	otual Des	igns			I.															
44	0.00	50.00	G	2.040	existing baseline repaired		54	-		⊿ Geod	esy						1		Ŋ													
45 60	60.00	0 840.00	G	2.050	Determine the shape of the geoid	<b>.</b> .	55	- 4	,	Sur	face Geo	detic Referen	ce Netw	ork Conc	ept		1															
46			G	2.050	gravity field measurements completed	-	56	-4		FCC	Map Pro	ojection Selec	ed.				Į.	1														
48			G	2.0503	astro-zenithal measurements	1	57	-9		Ge	oid Mode	el Precision Sir	nulation	5				Ĭ	L													
49		+	G	2.0504	astro_zenthal camera rent	-	58	-4			etic Engin	neering						1	ř													
51 40	% 0.00	0 40.00	G	2.0600	Transfer the points from the surface to the tunnel		59	-4		⊿ Sur	face to Tu	unnel Transfe	r Techno	ogy				1														
52			G	2.0601	monuments built	-	60	-9		1	echnolog	gy Review							-h													
54 100	% 700.00	0.00	G	2.070	Manage the Geodesy works		61	- 4			rototype	e Proposals							- J													
55	07		G	2.070	geodesy works managed		62	-9			rototype	e Developmer	t																			
57 50	% 100.00	0 885.00	G	3.010	Civil Engineering and site management Civil engineering measurements on all the tunnels	-	63	-4		1	rototype	e Testing																				
58			G	3.0101	Calculate and validate the setting points		64	-4		⊿ De	lectomet	ter								ř-	TI I											
59 60			G	3.0102	setting points calculated Buy and maintain survey tools for civil engineering controls		65	-4		(	ommissi	ion								Ъ												
61			G	3.0104	equipment purchased and maintained		66	-9		1	est and E	Evaluate																				
62			G	3.010	Measure and maintain the underground ref. monuments		67	-4		ICT	F Needs A	Analysis									<b>*</b>											
64			G	3.010	Monuments measured and calculated (ATT) Monuments measured and calculated (Attudes)	IAR	68	- 4		Lor	g Distanc	ce Control Bas	eline Co	nceptual	Design						t, t											
65	_		G	3.0108	Perform as built measurements	Пċ.	69	4		Azi	muth Con	ntrol Baseline	Concept	ual Desi	(n						ì	ĥ										
67			G	3.010	As-built measurements performed (once tunnels built) As-built measurements calculated and modelised	- z	70	-4		SU	ntegratio	on of C.E. Mor	itoring S	ensors S	tudy							<b>†</b>										
68 100	0.00	0.00	G	3.0200	Civil engineering galleries for survey constraints	3	71	- 4		₄ FCC-ee /	lignment	t System Con	eptual D	esign			-	-	-													
70	-	-	G	3.020	Build dedicated galleries for link left and right around collis oaleries built	sion	72	-4		Simul	ate effect	t on alignmen	t of Tunr	el Refer	ence Point	errors	<b>1</b>															
71			G	3.0203	Build dedicated lines of sight for survey	-	73	-4	,	Tunne	l Geodet	tic Reference	Network	Concept					1										_			
72	>   H	Ivpotheses	G	1 3.0204	chiffrage CLIC materiel préalignement artif décon	mn	74	-	,		on Monit	toring & Align	ment Sys	tem (PN	AS) Concep	t																
Select d	estination and	nress ENTED	or choose	e Paste	interespectagienes and decon		75	-4		Ree	uiremen	nts/Constraint	s Analysi	s					Ь													
Server U	and a second						76	-4		Stu	dy Planne	ed and Implei	nented /	lignmer	t Systems				+													
							77	-4		Ma	in Ring PN	MAS Concept								+	1				_							
							78	-4	,	Bo	ster Ring	g PMAS Conce	pt								<b>1</b>											
							79	-4	,	MD	I Final Fo	ocus PMAS Cor	ncept								+											
						-	80	-9		PM	AS Remo	te Maintenan	ce Conce	pt									h									
						-	81	- 4		Inje	ctors and	d Transfer Lin	es (PMAS	) Conce	t								1	•								
							82	-4					1									ľ										
							83			⊿ Surfa	e Geode	tic Reference	Networl	(SGRN)								ľ							n			
							84			⊳ SG	RN Techni	ical Design an	d Specs									Г										
							89			⊳ SG	N Procur	rement Prepa	ration											T								
							91			⊳ SG	RN Procur	rement						1					-	+	n							
						-	96			SG	N Instruc	ment Recepti	on											-								
							97			⊳ <b>SG</b>	RN Instru	ment Calibrat	ion					1														
							100			Bui	ld SGRN														t I	Ь						
						-	101			b Me	asuro SGI	DN														÷						

M. Jones



Geodetic Infrastructure and Alignment FCC Week 2019







#### FCC-ee Position Monitoring & Alignment

- Concept based on design for CLIC
  - Full Remote Position Monitoring and Alignment System
  - Wire Position sensors
  - Hydrostatic Levelling sensors
  - Motorised positioning system





M. Jones

27.06.2019

Geodetic Infrastructure and Alignment FCC Week 2019



100

100

2370

1000

1110 870

### FCC-ee Position Monitoring & Alignment

- Precision specifications
- Smoothing Time Constraints
  - Continuous Monitoring
  - Automated remote re-alignment with continuous feedback
- Metrology precisions for ~6 m long elements
- Tunnel Reference Infrastructure
  - Space requirement in curved tunnels
  - Full remote maintenance (HL-LHC developments + ... ??)





# **Alternative - Alignment Train**

- Precision specifications
  - Simulations with available measurement instruments/sensors
  - Measurement platform to be developed
  - Vertical measurement
- Smoothing Time Constraints
  - Currently in LHC the reference wire is installed manually
  - Re-positioning will have to be automated
  - Smoothing process typically => 2-3 iterations
  - 4 weeks smoothing => currently ~40 alignment trains
- Tunnel Reference Infrastructure
  - Space requirement in curved tunnels
  - Motorised positioning system, remote maintenance





M. Di Castro



# FCC Integrated Project Schedule

#### Alignment



- Tunnel Geodetic Reference Network
- As-Built Surveys
- Gravity Field Measurements
- Marking Out
- Monitoring & Alignment System
  - Tunnel Reference
     Infrastructure
  - Position Monitoring instrumentation
  - Position Alignment equipment





#### Main Ring and Booster Ring









#### Accelerator Information Required

- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

#### To be developed

- **Refined Gravity Field Model**
- **Tunnel Reference Infrastructure**
- **Beamline Elements** 
  - Position Monitoring System
  - Positioning System
- Control, Data Management and Data Processing Systems





Main Ring and Booster Ring







Main Ring and Booster Ring Preparatory Activities





Main Ring and Booster Ring Installation Activities

- Tunnel Geodetic Reference Network
- Marking Out
- Gravity Field Measurements
- Install Tunnel Infrastructure
- Position Monitoring and Alignment System Infrastructure Installation
  - Metrology Reference Network
  - Monitoring System Infrastructure
  - Positioning System Infrastructure
- Install Beamline Elements
- Position Monitoring and Alignment System Installation
  - Monitoring Sensors and Commissioning
  - Positioning Actuators and Commissioning
- Align Beamline Elements

















# FCC Integrated Project Schedule



- Surface Geodetic Reference Network
- Reference Systems
- Precision Gravity Field Model
- R&D of Geodetic Instruments
- Instrument Control Calibration, and Test Facilities
- Geodetic Transformation Software



- Starting almost from scratch
  - Most geodetic infrastructure dates back to LEP
  - Established for the current CERN site ~100 km<sup>2</sup>
  - FCC site covers ~1000 km<sup>2</sup>
- CERN not currently equipped for this activity
- CERN surveyors
  - Establish control infrastructure for C.E.
  - Contributions and Controls for C.E. Tender Documents











### **Geodetic Infrastructure & Activities**



tunnel transfer technology

M. Jones

27.06.2019

Geodetic Infrastructure and Alignment

FCC Week 2019

# Geodetic Reference Infrastructure for C.E. Construction







# Geodetic Infrastructure Work Y3-Y7





M. Jones

# Reference Point Co-ordinates for C.E. Construction





#### **Accelerator Information Required**

- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

#### To be developed

- Geodetic Surface Reference Network
- Mathematical Reference Systems and Transformation Algorithms
- Gravity Field Model
- Geodetic Transformation Software



M. Jones

# Reference Point Co-ordinates for C.E. Construction



#### 10 12 16 6 8 9 14 15 FCC Installation Start t preparation & Injector Installation Start trative processes overnance strategy **Civil Engineering Works Start** C.E. Construction Invitation to Tender Start Seological investigat tructure detailed design and Procure Geodetic Instruments Start Geodetic Measurements Startallation, commissioning Establish Definitive Reference Systems End Final Update of Position and Orientation End 16 18 $Y_7 Y_8$ $Y_5$ Υ<sub>3</sub>

#### Accelerator Information Required

- Theoretical Design
- FCC-ee Integration Model
- Metrology & Alignment Precisions

#### To be developed

- Geodetic Surface Reference Network
- Mathematical Reference Systems and Transformation Algorithms
- Gravity Field Model
- Geodetic Transformation Software



27.06.2019

M. Jones



# FCC Integrated Project Schedule



- Ambitious timeline
- Expert consultants needed
- Numerous design concepts to develop ...
- and implement





### Other studies required too

- FCC-ee MDI
- Injectors: Linac, Damping Ring, Pre-Booster, Transfer Lines
- Marking out > 100 km tunnel in Y13
  - Manually like the LHC?



- Pre-aligning supports / positioning systems
  - Faster, automated methods? Y14





### Conclusions

- Position Monitoring and Alignment System
  - Need to start work on attributing the misalignment budget?
  - Start studies for the technical design solution
    - Research and Development of potential solutions
      - 16 years before tunnel installation starts
  - Significant time may be required prior to installing a beamline element





### Conclusions

- Geodetic Infrastructure
  - Geodesy akin to Geology
    - To do established before Civil Engineering starts
  - Geodetic infrastructure
    - To be in place before Y8
    - Design concepts to be established
    - Instruments to develop and test
- Some budget available already
- Ambitious timelines for both Geodesy and Alignment !







#### Thank you for your attention



**Conceptual Design Stage** 



- Gravity Field Study
  - Measurement Requirements as a function of Alignment Precision
  - Pre-prototype instrument tested and evaluated
    - (Differential Geodetic Interferometric) Deflectometer





# FCC-ee Geoid Model

- Analysis, Modelling (Y7)
   (+ Database and Software Implementations)
- Measurements (Y5 & Y6)
  - Astro geodetic measurements (2 years)
    - 5 x Zenith Cameras
- Purchase 5 Zenith Cameras (Y3 & Y4)
  - Production time
    - ~1.5 years

(+ Specifications, Procurement and Land Access)





### Integration



