Pre-clinical phase contrast breast CT scanner

Type of project:

- Content complexity:
  - Underlying physical mechanisms not clear in beginning
    - Effect of Compton scattering on phase signal (now after 2 years slowly)
    - Dedicated performance evaluation and comparison between phase and absorption never done for large scale and high energies
  - Technology not ready (detector, tube, gratings), all need to be developed/build
  - Signal retrieval and post-processing not available
    - no fast non-phase stepping method existing
    - Spiral CT reconstruction needs to be adapted (no in-house know-how)
  - Image processing not on competitors level
- Context complexity:
  - Work with and supervise group members (students, colleagues) working on
    - Reconstruction (Students)
    - Detector
    - Gratings (grating fabrication PhD project parallel)
    - Theory (high energy PhD project parallel)
  - Work with multiple internal groups
    - Engineers/Technician for designing positioner system, small mechanical components, providing electrical support and infrastructure
    - Detector development (out sourced now)
  - Work/hire external companies
    - Gantry development (only 2 options worldwide, mayor cost factor)
    - Detector development in collaboration with spin-off (capable yes, common goals/end product not clear)
    - X-ray tube development (with/from external vendor, now canceled (too much cost, now an similar prototype exists and is available))
    - Reconstruction algorithm implementation (small scale in house, large scale from company, software engineers etc.
  - Work with hospital for samples/evaluation, later potential patients/clinical studies (not part of PhD project)
  - Potential high impact (on many patients), but only of cost (gantry, gratings) to benefit ratio is high enough

Thus, high content and high context complexity

System Analysis:

Conditions:

- Theoretical understanding of physical processes
- Theoretical evaluation and optimization of phase contrast breast CT (vs. absorption)
- Phase contrast spiral CT reconstruction algorithm for large field of view (FOV) (theory and implementation)
- High performing grating interferometry (GI) based phase contrast system
    - Dedicated high energy detector (photon counting, fast, large FOV)
    - Dedicated tube (cone beam geometry, power, cooling, kVp)
    - Large area, high performing gratings
    - Stable, compact alignment stages for gratings
- Scan protocol (tube voltage, current; exposure times; trajectory)
- Approval radiation safety and mechanical/electrical safety
- Approval fresh mastectomy samples

Resources:

- Hardware budget (Gantry, Detector, Tube, Hardware, Gratings)
- Postdocs (Phase contrast experts, detector expert)
- PhDs (PM, high energy, reconstruction (not cone beam), grating manufacturing, 2D/mammography)
- Students (semester, master projects)
- In-house technical support (infrastructure, engineers, technicians)
- Computer scientist (reconstruction algorithm implementation)
- Detector company
- Gantry company
- X-ray tube, other hardware vendors
- Computational power for reconstruction
- Mastectomy samples from hospital collaborations

Expertise:

- Physics behind Grating Interferometry
- Detector know how
- X-ray know how (generation, dosimetry)
- Mathematical understanding of CT reconstruction
- Phase retrieval development
- Computer science/programming know-how
- Mechanical engineering understanding
- System engineering
- Good organization, communication

Attributes:

- Attenuation coefficient and phase shift of breast tissue
- Sample sizes

- Detector performance (efficiency, noise, speed)
- Tube performance (flux, spectrum, cone beam geometry)
- Gantry stability/performance
- Number of projections, spiral trajectory (CT reconstruction performance)
- Dose delivered to sample, exposure time (image quality, SNR/CNR)
- Dose-weighted sensitivity of absorption and phase contrast

Tools:

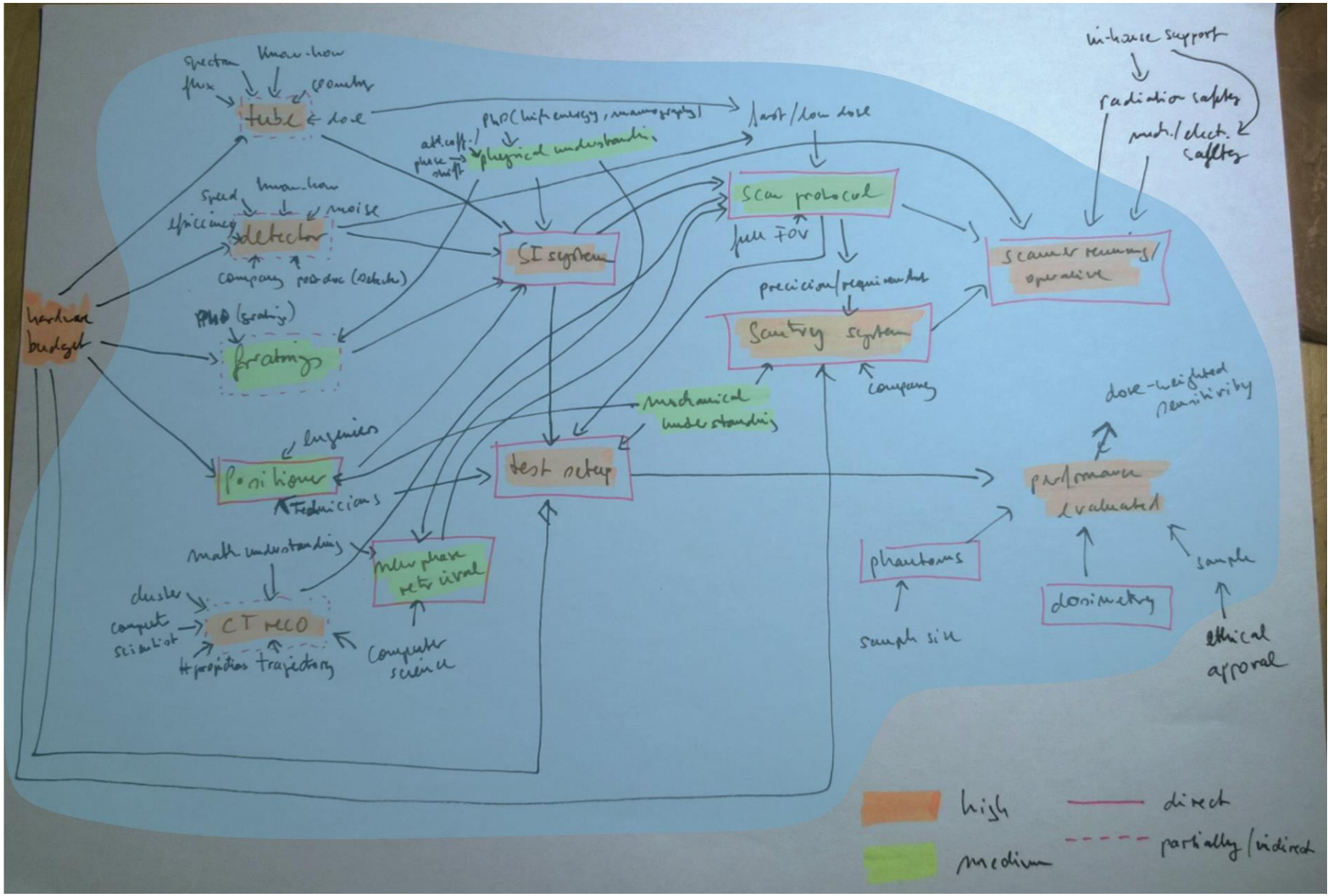
- Dosimetry (Simulated and measured)
- New phase retrieval algorithm
- Phase contrast spiral CT reconstruction algorithm for large samples
- Breast phantoms
- Gratings
- Tube
- Detector
- Positioners
- Gantry
- Test setup to evaluate
    - tube and detector
    - positioners
    - gratings
    - Phantoms
- Prototype consisting of dedicated tube, detector and gratings (plus stages)
- Radiation protected working space with complete infrastructure (electrical, mechanical and IT)

Environments:

- Radiation safety
- Mechanical/electrical safety
- Absorption-based breast CT companies (2 systems ready)
- Mammography/Tomosynthesis developments

Success:

- Gantry system compatible with GI system
- All system components operative
- Scanner running
- Scan of full FOV possible
- Low enough dose/fast enough scan protocol
- Performance evaluated


spectrum
flux
know-how
tube
dose
PhP (high energy, mammography)
att. coeff./ phase shift
physical understanding
fast/low dose
in-house support
radiation safety
mech./elect. safety
speed
efficiency
know-how
noise
detector
company
post doc (robots)
CT system
scan protocol
full FOV
scanner reimaging/ operative
medical budget
PhD (grating)
gratings
precision/requirements
Scatter system
company
mechanical understanding
dose-weighted sensitivity
engineers
positioner
technicians
test setup
performance evaluated
math understanding
cluster
computer scientist
CT reco
trajectory
computer science
phase retrieval
phantoms
sample size
dosimetry
sample
ethical approval
high
medium
direct
partially/indirect

Stakeholder Analysis:

- Project team: PhD student (PM), Postdoc (supervisor), Professor (supervisor), PhD (high energy), PhD (gratings), PhD (Mammography), Postdoc (Detector), Master students, Technicians
- Mechanical support (internal): mechanical engineers
- Technical support (internal): (electrical) infrastructure, (radiation) safety/regulation
- External partners: Detector company, gantry company
- Suppliers: motors/controllers, X-ray tube
- Public: Patients, Radiologists, CT Vendors, Health Insurances

Interest	low	medium	high
high	Patients Radiologists	Postdoc (Detector) Master students	PhD student (PM) Professor (supervisor) Gantry company
medium	CT Vendors Health insurances	Postdoc (supervisor) PhD (CT reconstruction) Technicians	Detector company
low	PhD (Mammography) Support: infrastructure Support: safety/regulation Motors/controller vendor	PhD (high energy) PhD (gratings) Mechanical engineers X-ray tube vendor	

Influence

Stakeholder	Interest/Stake	Influence/Power	Attitude	Measure
PhD student (PM)	h	h	0	Increase attitude: Project is standing still (since months) waiting for funding and strategic decision by Prof -> move decision process forward
Postdoc (supervisor)	m	m	0	
Professor (supervisor)	h	h	1	
PhD (high energy)	l	m	0	Increase interest: PhD is finishing and focusing on scatter problems, phase contrast not of interest to him
PhD (gratings)	l	h	0	Increase attitude: Show potential of project and how their involvement will benefit
PhD (Mammography)	l	l	0	
PhD (CT reconstruction)	l	m	0	Increase interest: Briefly worked by co-supervising Master student for spiral CT reconstruction, now finishing and no interest
Postdoc (Detector)	h	m	-1	Increase attitude: Get deal with detector company done and ensure his involvement/project leader position (Prof is negotiating this)
Master students	h	m	1	
Technicians	m	m	1	
Mechanical engineers	l	m	0	Increase attitude/interest: Work faster on evaluating their system (has been

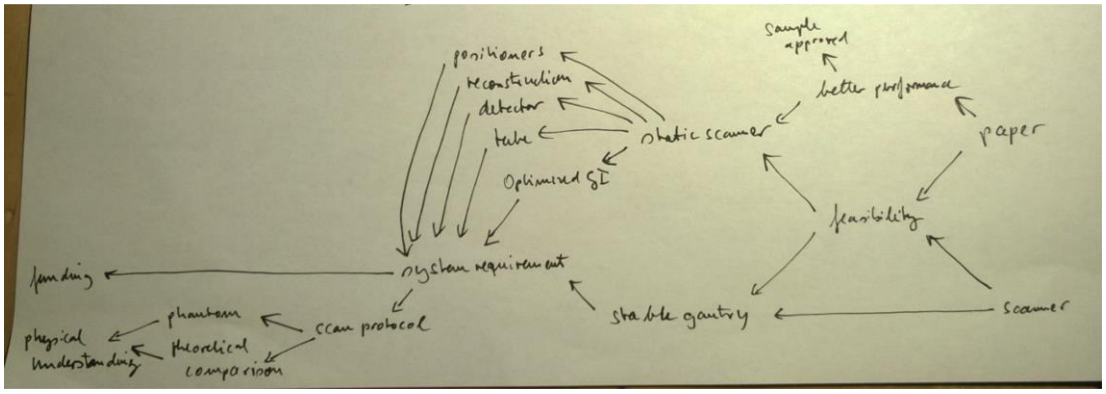
				delayed for months since PM is focusing on moving the overall project further)
Support: infrastructure	l	l	1	
Support: safety/regulation	l	l	1	
Detector company	m	h	0	Increase interest: Show why our project is ideal to promote their new detector (Prof working on it)
Gantry company	h	h	1	
Motors/controller vendor	l	l	0	
X-ray tube vendor	l	m	0	
Patients	h	l	0	
Radiologists	h	l	0	
CT Vendors	m	l	0	
Health insurances	m	l	0	

Objectives:

Objective	Indicator	Measure	Deadline	Priority
Pre-clinical phase contrast breast CT system (breast pCT) on rotating gantry	Whole system assembled and operational	CT scans acquired and reconstructed	December 2018	Need-to-be
Feasibility of GI operated on fast gantry shown	Result of simulation and test	Within specifications	Mai 2018	Need-to-be
Better performance (sensitivity, dose efficiency compared to absorption CT) shown	Result of performance analysis	CNRp/CNRa >1, SNRp/SNRa >1, DOSEp approx. DOSEa	December 2017	Should-be
Mastectomy samples approved	Answer to request	approved	June 2017	Should-be
Mechanical stable gantry system compatible with GI	Result of simulation and test	Within specifications	March 2018	Need-to-be
Static Pre-clinical phase contrast breast CT system (breast pCT) without gantry	Whole system assembled and operational	CT scans acquired and reconstructed	September 2017	Should-be
Optimized grating interferometer (GI)	Theoretical performance; gratings	CNRp/CNRa >1, SNRp/SNRa >1, DOSEp approx. DOSEa; Gratings delivered	June 2017	Should-be
Dedicated X-ray tube for breast geometry and breast pCT spectrum	Result of tests	Flux, spectrum, geometry within specifications	June 2017	Should-be
High energy detector for breast pCT spectrum	Result of tests	Energy range, efficiency, size, speed within specifications	September 2017	Need-to-be
Spiral pCT reconstruction algorithm implemented	Result of tests	Accuracy and scalability shown	December 2016	Need-to-be
Positioners	Result of tests	Precise and stable enough	September 2016	Need-to-be
Define breast Phantoms	Absorption coefficient and phase shift	Same as mastectomy sample	June 2016	Need-to-be
Define scan protocol	Required number of projections, exposure time, pitch feasible	Mechanical possible and compatible with reconstruction and system requirements	December 2016	Need-to-be
Define system requirements	All parameters fixed	Optimal parameters found	December 2016	Need-to-be
Theoretical evaluation and optimization of phase contrast breast CT (vs. absorption)	GI parameters defined based on dose efficiency	Parameters optimized	Mai 2016	Need-to-be

Theoretical understanding of physical processes	High energy research done	Thesis proofed	March 2016	Need-to-be
2 articles published (theoretical vs. actual performance, new phase retrieval/CT reco)	Answer of journal	Accepted	December 2018	Should-be
Funding for gantry, detector, gratings and hardware secured	Amount	750000 Euro + 200000 CHF + 100000 CHF + 130000 CHF	Mai 2016	Need-to-be

Connect/order objectives:

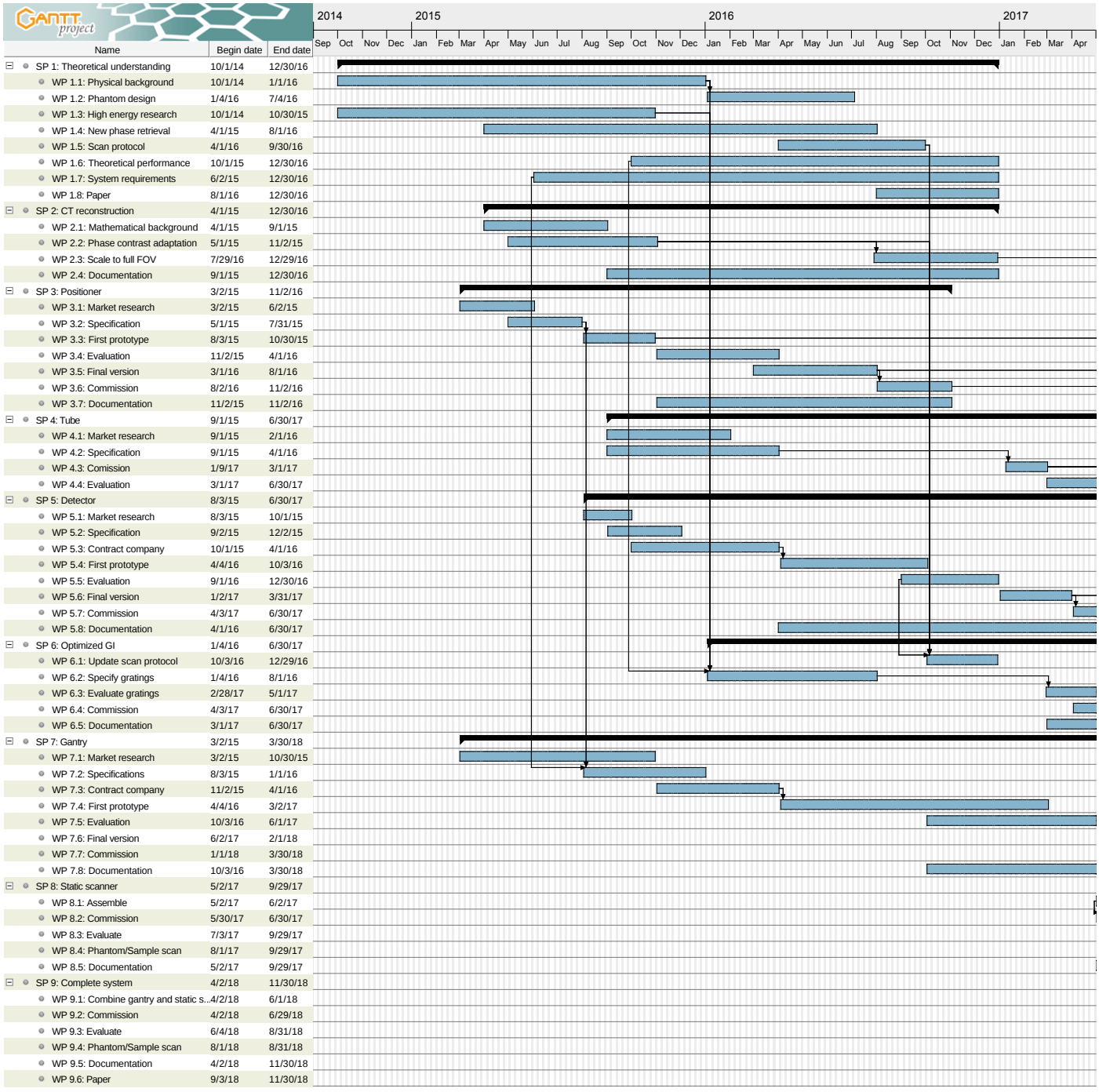


WBS (object oriented):

SP 1: Theoretical understanding	SP 2: CT reconstruction	SP 3: Positioners	SP 4: Tube	SP 5: Detector	SP 6: Optimized GI
WP 1.1: Physical background	WP 2.1: Mathematical background	WP 3.1: Market research	WP 4.1: Market research	WP 5.1: Market research	WP 6.1: Update scan protocol
WP 1.2: Phantom design	WP 2.2: Phase Contrast adaptation	WP 3.2: Specifications	WP 4.2: Specifications	WP 5.2: Specifications	WP 6.2: Specify gratings
WP 1.3: High energy research	WP 2.3: Scale to full FOV	WP 3.3: First Prototype	WP 4.3: Commission	WP 5.3: Contract company	WP 6.3: Evaluate gratings
WP 1.4: New phase retrieval	WP 2.4: Documentation	WP 3.4: Evaluation	WP 4.4: Evaluation	WP 5.4: First Prototype	WP 6.4: Commission
WP 1.5: Scan protocol		WP 3.5: Final version		WP 5.5: Evaluation	WP 6.5: Documentation
WP 1.6: Theoretical performance		WP 3.6: Commission		WP 5.6: Final version	
WP 1.7: System requirements		WP 3.7: Documentation		WP 5.7: Commission	
WP 1.8: Paper				WP 5.8: Documentation	

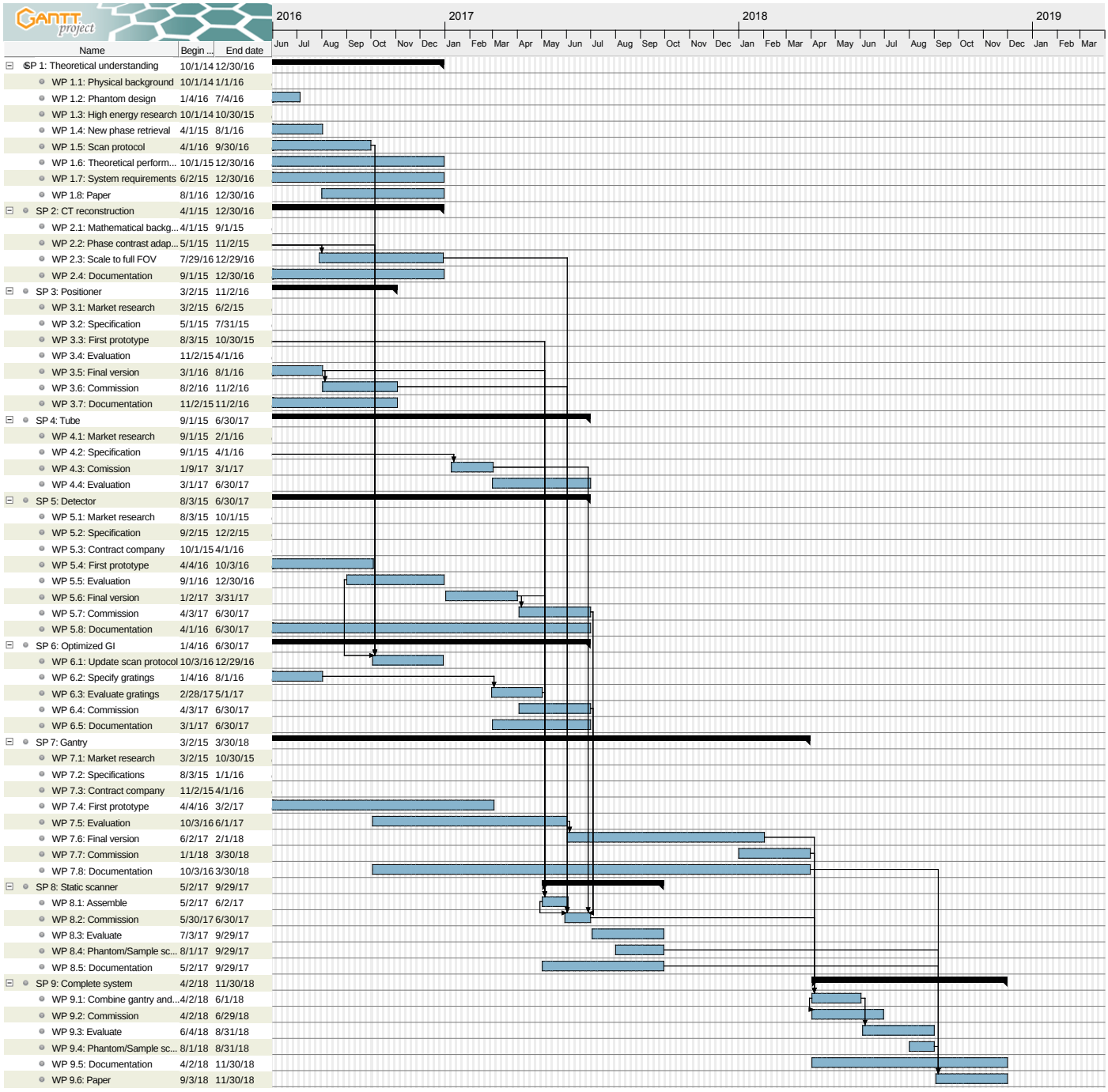
SP 7: Gantry	SP 8: Static scanner	SP 9: Complete system
WP 7.1: Market Research	WP 8.1: Assemble	WP 9.1: Combine gantry and static scanner
WP 7.2: Specifications	WP 8.2: Commission	WP 9.2: Commission
WP 7.3: Contract Company	WP 8.3: Evaluate	WP 9.3: Evaluate
WP 7.4: First Prototype	WP 8.4: Phantom/Sample scan	WP 9.4: Phantom/Sample Scan
WP 7.5: Evaluation	WP 8.5: Documentation	WP 9.5: Documentation
WP 7.6: Final version		WP 9.6: Paper
WP 7.7: Commission		

Gantt Chart



Name	Begin date	End date
SP 1: Theoretical understanding	10/1/14	12/30/16
WP 1.1: Physical background	10/1/14	1/1/16
WP 1.2: Phantom design	1/4/16	7/4/16
WP 1.3: High energy research	10/1/14	10/30/15
WP 1.4: New phase retrieval	4/1/15	8/1/16
WP 1.5: Scan protocol	4/1/16	9/30/16
WP 1.6: Theoretical performance	10/1/15	12/30/16
WP 1.7: System requirements	6/2/15	12/30/16
WP 1.8: Paper	8/1/16	12/30/16
SP 2: CT reconstruction	4/1/15	12/30/16
WP 2.1: Mathematical background	4/1/15	9/1/15
WP 2.2: Phase contrast adaptation	5/1/15	11/2/15
WP 2.3: Scale to full FOV	7/29/16	12/29/16
WP 2.4: Documentation	9/1/15	12/30/16
SP 3: Positioner	3/2/15	11/2/16
WP 3.1: Market research	3/2/15	6/2/15
WP 3.2: Specification	5/1/15	7/31/15
WP 3.3: First prototype	8/3/15	10/30/15
WP 3.4: Evaluation	11/2/15	4/1/16
WP 3.5: Final version	3/1/16	8/1/16
WP 3.6: Commission	8/2/16	11/2/16
WP 3.7: Documentation	11/2/15	11/2/16
SP 4: Tube	9/1/15	6/30/17
WP 4.1: Market research	9/1/15	2/1/16
WP 4.2: Specification	9/1/15	4/1/16
WP 4.3: Comission	1/9/17	3/1/17
WP 4.4: Evaluation	3/1/17	6/30/17
SP 5: Detector	8/3/15	6/30/17
WP 5.1: Market research	8/3/15	10/1/15
WP 5.2: Specification	9/2/15	12/2/15
WP 5.3: Contract company	10/1/15	4/1/16
WP 5.4: First prototype	4/4/16	10/3/16
WP 5.5: Evaluation	9/1/16	12/30/16
WP 5.6: Final version	1/2/17	3/31/17
WP 5.7: Commission	4/3/17	6/30/17
WP 5.8: Documentation	4/1/16	6/30/17
SP 6: Optimized GI	1/4/16	6/30/17
WP 6.1: Update scan protocol	10/3/16	12/29/16
WP 6.2: Specify gratings	1/4/16	8/1/16
WP 6.3: Evaluate gratings	2/28/17	5/1/17
WP 6.4: Commission	4/3/17	6/30/17
WP 6.5: Documentation	3/1/17	6/30/17
SP 7: Gantry	3/2/15	3/30/18
WP 7.1: Market research	3/2/15	10/30/15
WP 7.2: Specifications	8/3/15	1/1/16
WP 7.3: Contract company	11/2/15	4/1/16
WP 7.4: First prototype	4/4/16	3/2/17
WP 7.5: Evaluation	10/3/16	6/1/17
WP 7.6: Final version	6/2/17	2/1/18
WP 7.7: Commission	1/1/18	3/30/18
WP 7.8: Documentation	10/3/16	3/30/18
SP 8: Static scanner	5/2/17	9/29/17
WP 8.1: Assemble	5/2/17	6/2/17
WP 8.2: Commission	5/30/17	6/30/17
WP 8.3: Evaluate	7/3/17	9/29/17
WP 8.4: Phantom/Sample scan	8/1/17	9/29/17
WP 8.5: Documentation	5/2/17	9/29/17
SP 9: Complete system	4/2/18	11/30/18
WP 9.1: Combine gantry and static s...	4/2/18	6/1/18
WP 9.2: Commission	4/2/18	6/29/18
WP 9.3: Evaluate	6/4/18	8/31/18
WP 9.4: Phantom/Sample scan	8/1/18	8/31/18
WP 9.5: Documentation	4/2/18	11/30/18
WP 9.6: Paper	9/3/18	11/30/18

Gantt Chart



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WP 1.5: Scan protocol	4/1/16	9/30/16
WP 1.6: Theoretical perform...	10/1/15	12/30/16
WP 1.7: System requirements	6/2/15	12/30/16
WP 1.8: Paper	8/1/16	12/30/16
SP 2: CT reconstruction	4/1/15	12/30/16
WP 2.1: Mathematical backg...	4/1/15	9/1/15
WP 2.2: Phase contrast adap...	5/1/15	11/2/15
WP 2.3: Scale to full FOV	7/29/16	12/29/16
WP 2.4: Documentation	9/1/15	12/30/16
SP 3: Positioner	3/2/15	11/2/16
WP 3.1: Market research	3/2/15	6/2/15
WP 3.2: Specification	5/1/15	7/31/15
WP 3.3: First prototype	8/3/15	10/30/15
WP 3.4: Evaluation	11/2/15	4/1/16
WP 3.5: Final version	3/1/16	8/1/16
WP 3.6: Commission	8/2/16	11/2/16
WP 3.7: Documentation	11/2/15	11/2/16
SP 4: Tube	9/1/15	6/30/17
WP 4.1: Market research	9/1/15	2/1/16
WP 4.2: Specification	9/1/15	4/1/16
WP 4.3: Comission	1/9/17	3/1/17
WP 4.4: Evaluation	3/1/17	6/30/17
SP 5: Detector	8/3/15	6/30/17
WP 5.1: Market research	8/3/15	10/1/15
WP 5.2: Specification	9/2/15	12/2/15
WP 5.3: Contract company	10/1/15	4/1/16
WP 5.4: First prototype	4/4/16	10/3/16
WP 5.5: Evaluation	9/1/16	12/30/16
WP 5.6: Final version	1/2/17	3/31/17
WP 5.7: Commission	4/3/17	6/30/17
WP 5.8: Documentation	4/1/16	6/30/17
SP 6: Optimized GI	1/4/16	6/30/17
WP 6.1: Update scan protocol	10/3/16	12/29/16
WP 6.2: Specify gratings	1/4/16	8/1/16
WP 6.3: Evaluate gratings	2/28/17	5/1/17
WP 6.4: Commission	4/3/17	6/30/17
WP 6.5: Documentation	3/1/17	6/30/17
SP 7: Gantry	3/2/15	3/30/18
WP 7.1: Market research	3/2/15	10/30/15
WP 7.2: Specifications	8/3/15	1/1/16
WP 7.3: Contract company	11/2/15	4/1/16
WP 7.4: First prototype	4/4/16	3/2/17
WP 7.5: Evaluation	10/3/16	6/1/17
WP 7.6: Final version	6/2/17	2/1/18
WP 7.7: Commission	1/1/18	3/30/18
WP 7.8: Documentation	10/3/16	3/30/18
SP 8: Static scanner	5/2/17	9/29/17
WP 8.1: Assemble	5/2/17	6/2/17
WP 8.2: Commission	5/30/17	6/30/17
WP 8.3: Evaluate	7/3/17	9/29/17
WP 8.4: Phantom/Sample sc...	8/1/17	9/29/17
WP 8.5: Documentation	5/2/17	9/29/17
SP 9: Complete system	4/2/18	11/30/18
WP 9.1: Combine gantry and...	4/2/18	6/1/18
WP 9.2: Commission	4/2/18	6/29/18
WP 9.3: Evaluate	6/4/18	8/31/18
WP 9.4: Phantom/Sample sc...	8/1/18	8/31/18
WP 9.5: Documentation	4/2/18	11/30/18
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