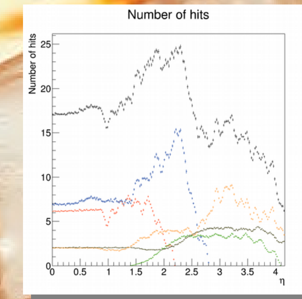
COMMON SOFTWARE



tkLayout: A (tracking) detector design & optimization tool

Gabrielle HUGO for the tkLayout team

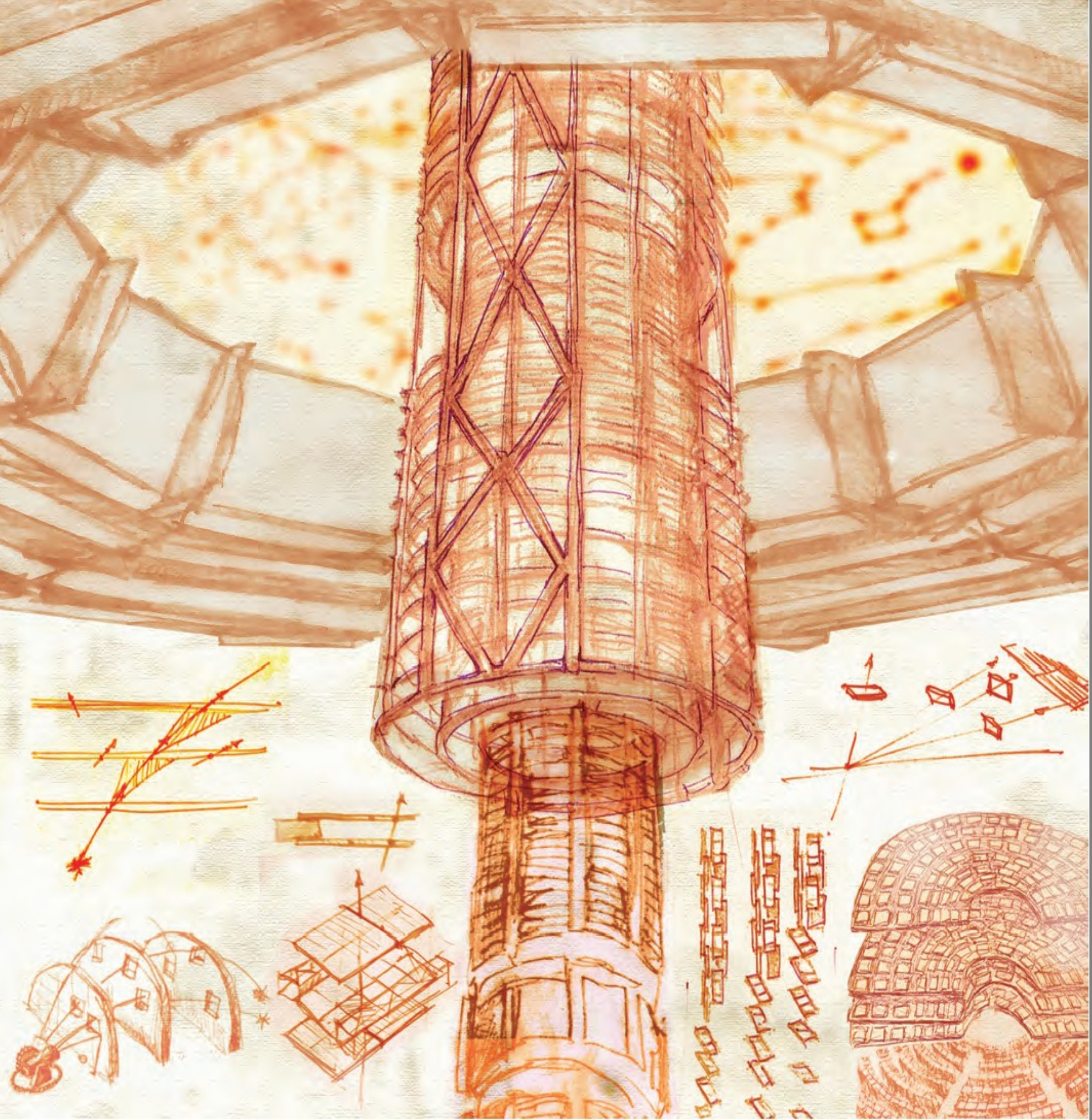
October 27, 2020

https://indico.ihep.ac.cn/event/11444

CERN

CMS

Massachusetts Institute of Technology



What is tkLayout?

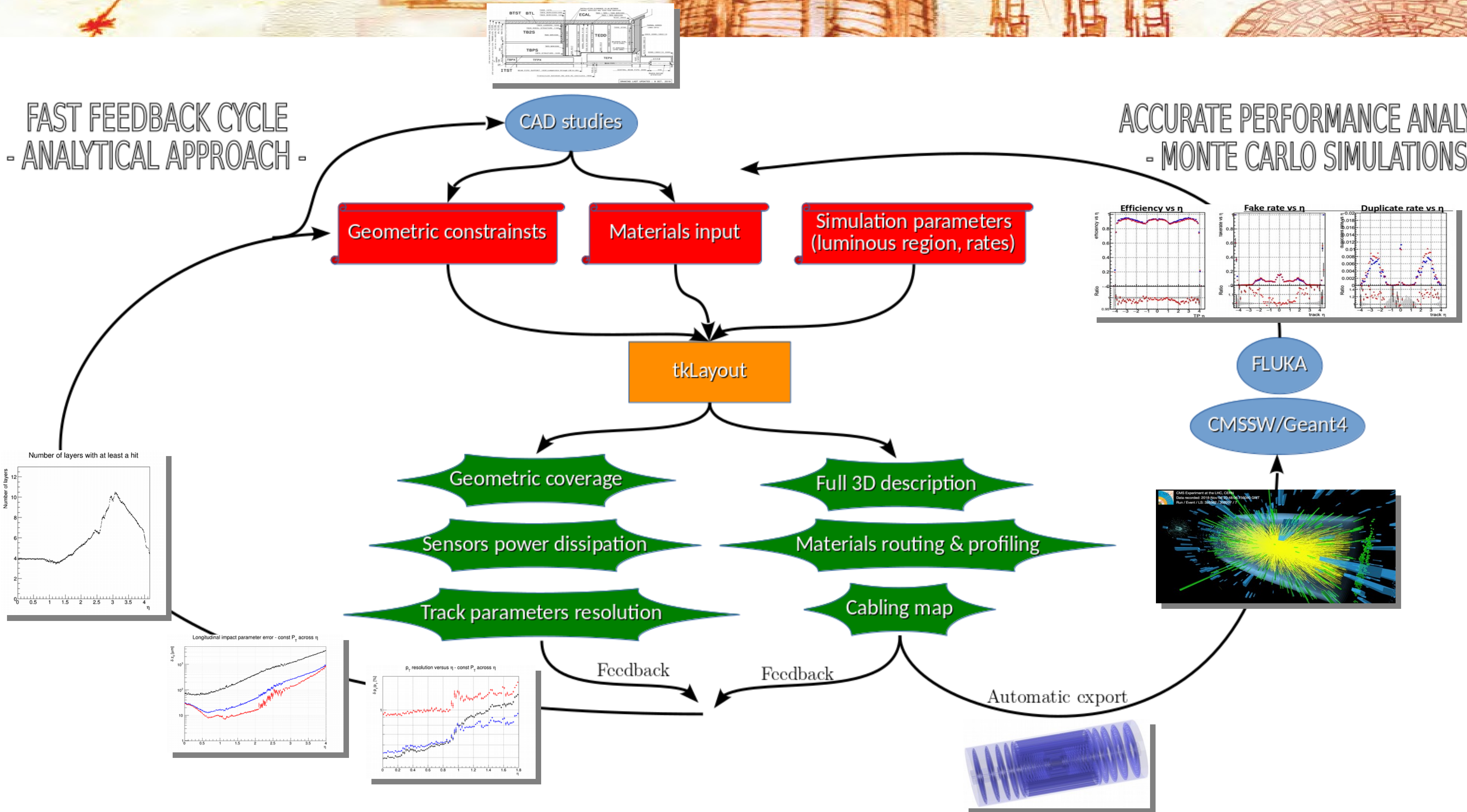
What is tkLayout?

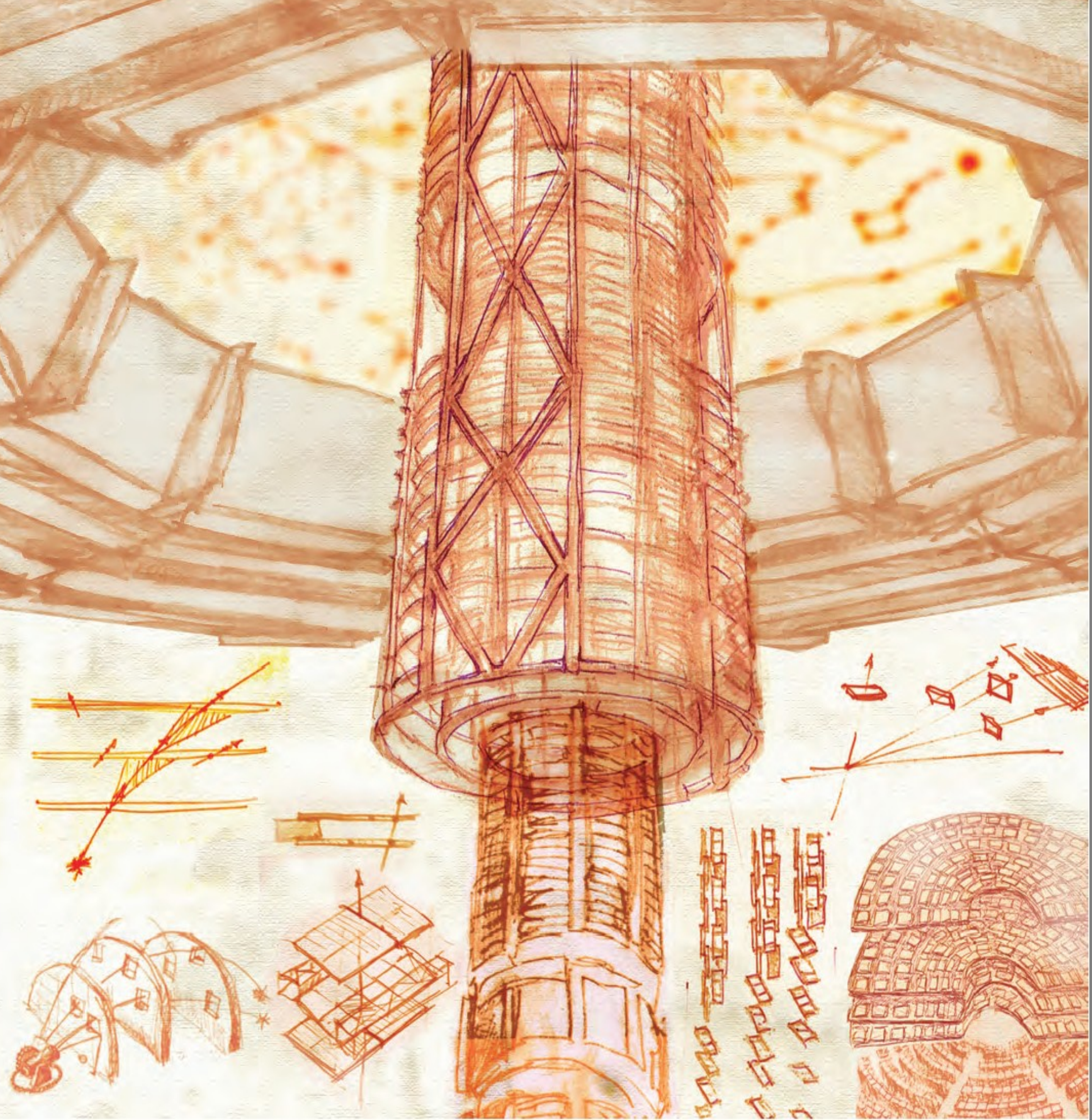
A **standalone tool** dedicated to **Tracker design & performance studies**.

- Initially developed at CERN for the R&D of the **HL-LHC CMS Tracker**.
- Also used for the conceptual design of the **FCC-hh Tracker**.
- Tool is **modular and generic**, can be adapted for the Trackers of other experiments.
- Provides **major figures of merit**: hermetic coverage, realistic material description, sensors area, sensors power dissipation, bandwidth studies, track parameters estimates...
- Based on an **analytic approach** for **fast feedback cycle**.
  Evaluating the detector performance figures of merit as early as possible is key to a successful detector design R&D.
  Simple input configuration files. Run time in the order of **minutes**! Results easily accessible on **webpage**.

  click here :)
- Can also **automatically export descriptions** to Monte Carlo frameworks for **full picture of Physics reach**.
- Extremely **cost-effective**: ~ 1 developer full time versus hundreds of developers in Monte Carlo frameworks.

tkLayout workflows





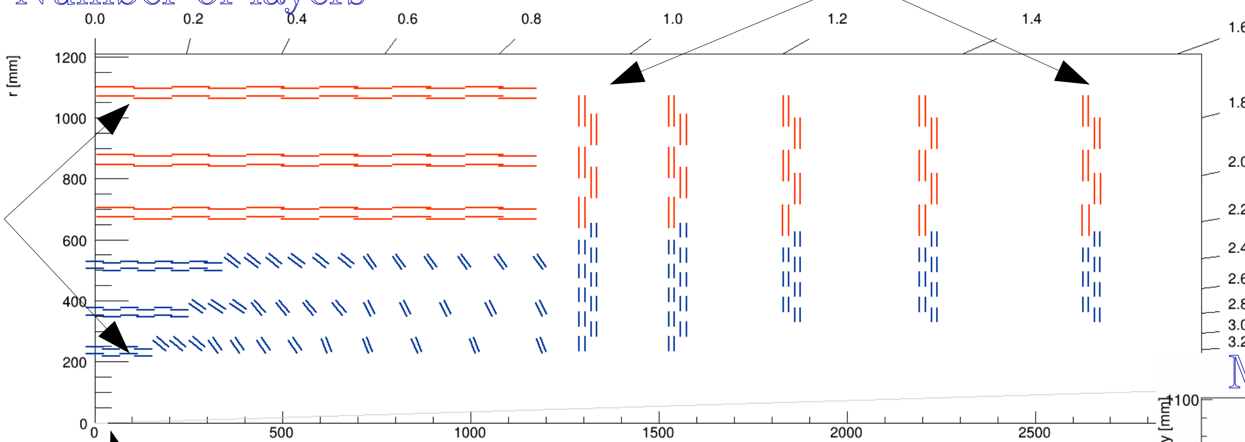
Geometry computation & hit coverage

Input: Simple geometry parameters

Number of layers

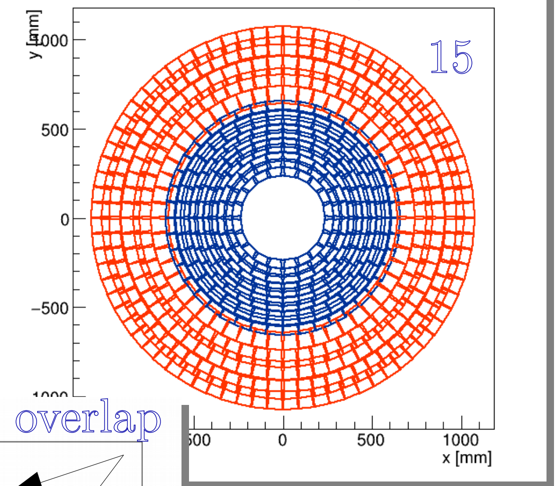
5

6

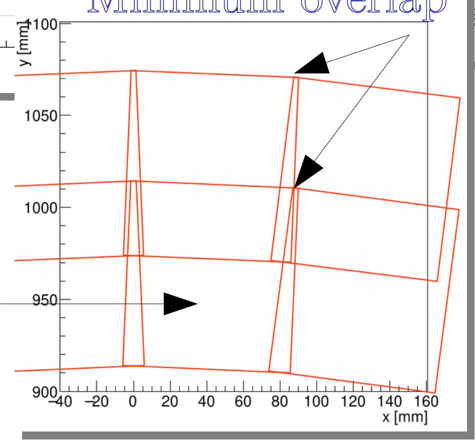


Number of rings per disk

15



Minimum overlap



Luminous region shape

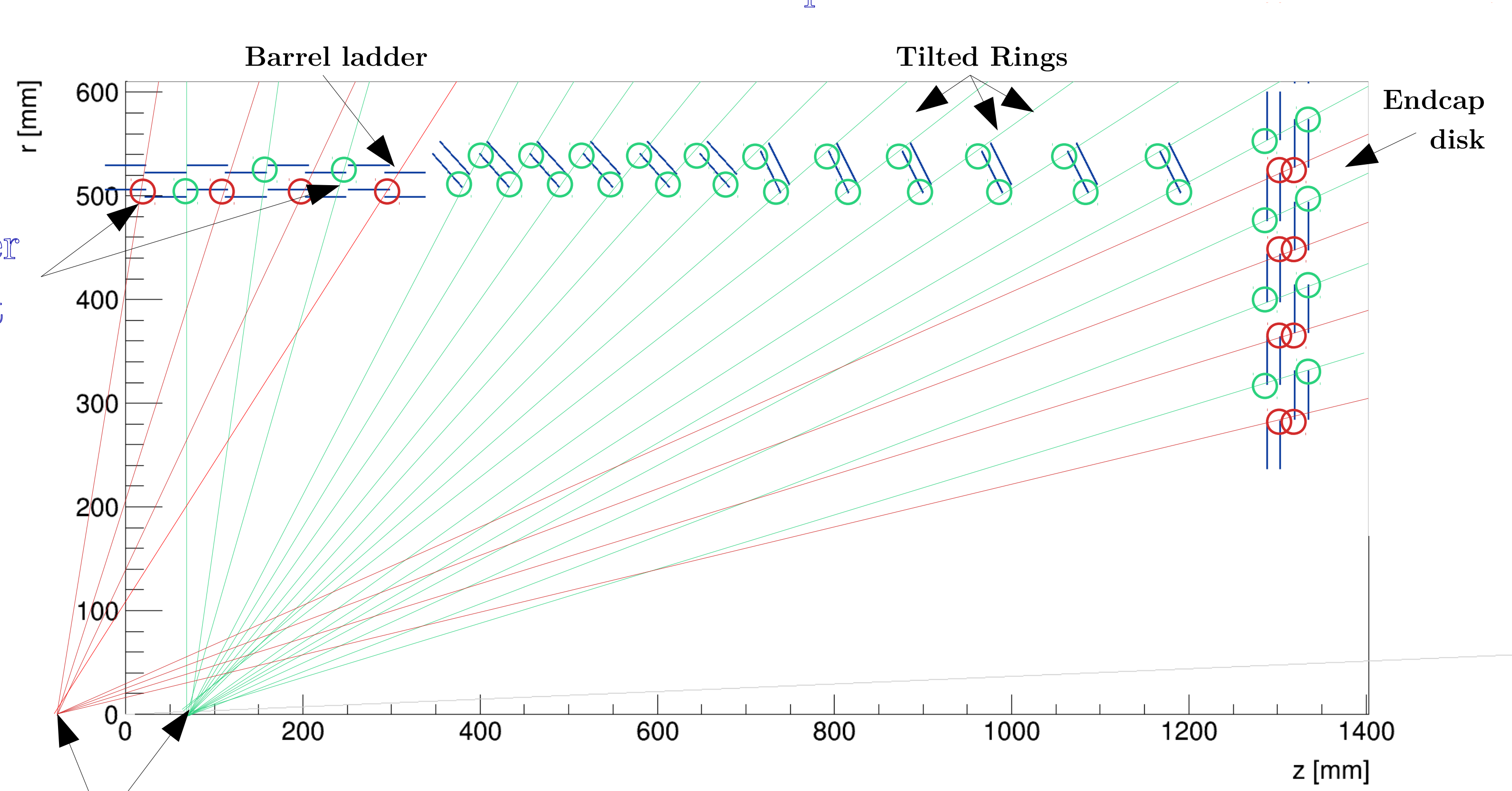
Sensor shape

(e.g. square ~10x10 cm2)

Computation: Geometry coordinates.

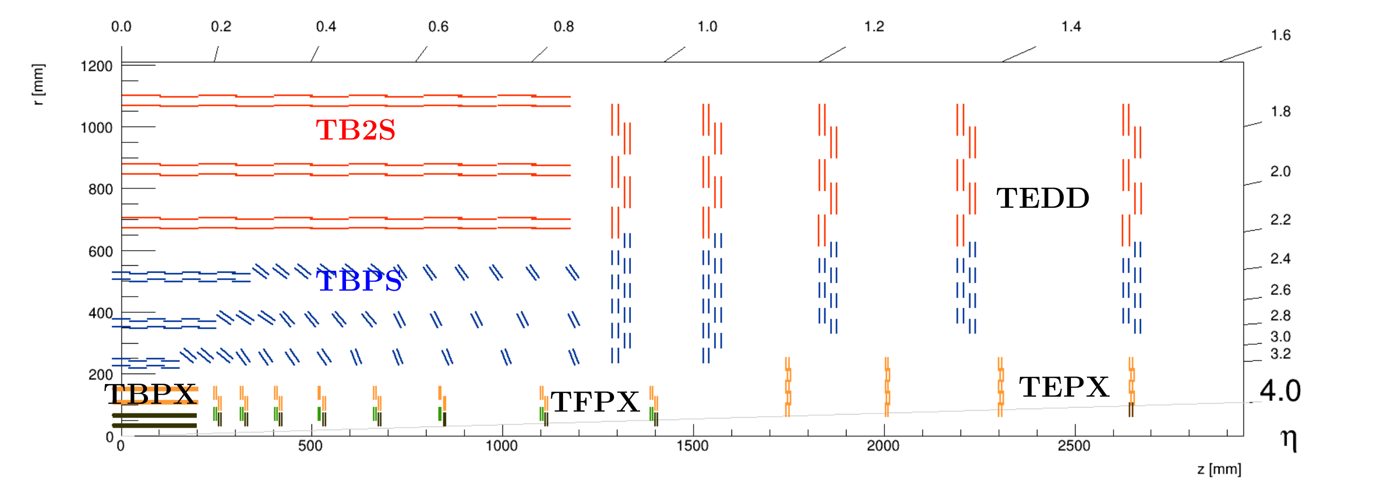
Automatic sensor placement

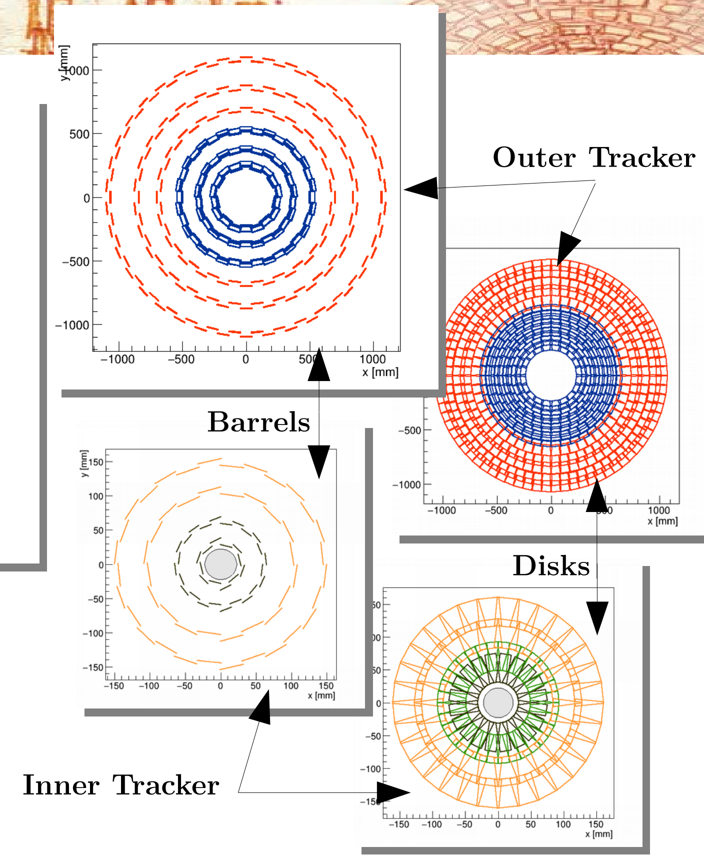
Always consider most stringent scenario



Z ~ [-70 mm; +70 mm]
Luminous region extrema

Output: 3D geometry





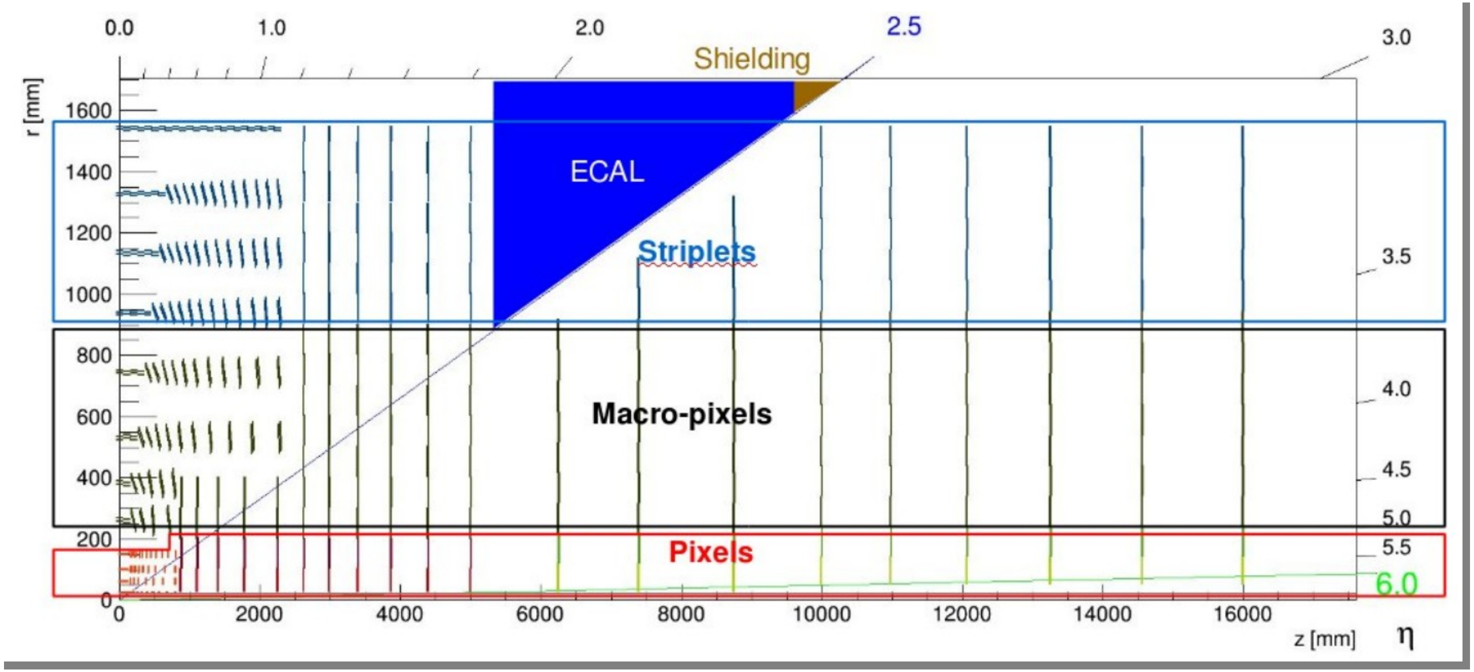
CMS Tracker for HL-LHC
has been designed with tkLayout.

~17 000 sensors:

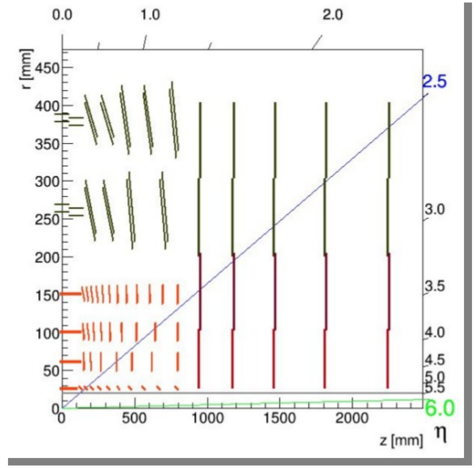
All relevant information (incl. placement, DetIds, ...) automatically exported to csv files.

DetId/U	BinaryDetId/B	Section/C	Layer/I	Ring/I	SensorCenter rho(mm)	SensorCenter z(mm)	tiltAngle_deg/D	skewAngle_deg/D	phi_deg/D	meanWidth_mm/D	length_mm/D	sensorSpacing_mm/D	sensorThickness_mm/D
303075348	1.0010000100001E+028	PXB	1	1	27.5	0	0	0	-106.019176	16.8	43.45	0	0.15
303075352	1.0010000100001E+028	PXB	1	2	27.5	44.05	0	0	-106.019176	16.8	43.45	0	0.15
303075356	1.0010000100001E+028	PXB	1	3	27.5	88.1	0	0	-106.019176	16.8	43.45	0	0.15
303075360	1.0010000100001E+028	PXB	1	4	27.5	132.15	0	0	-106.019176	16.8	43.45	0	0.15
303075364	1.0010000100001E+028	PXB	1	5	27.5	176.2	0	0	-106.019176	16.8	43.45	0	0.15
303075344	1.0010000100001E+028	PXB	1	2	27.5	-44.05	0	0	-106.019176	16.8	43.45	0	0.15

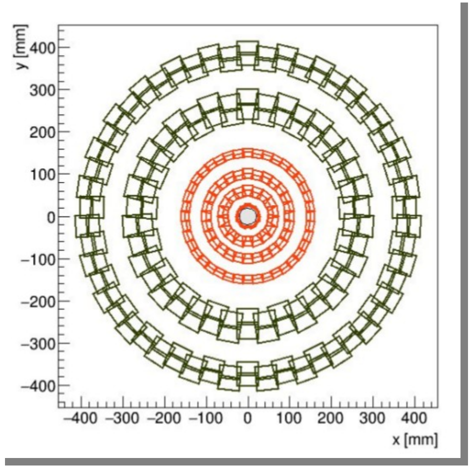
Output: 3D geometry



FCC-hh Tracker design study

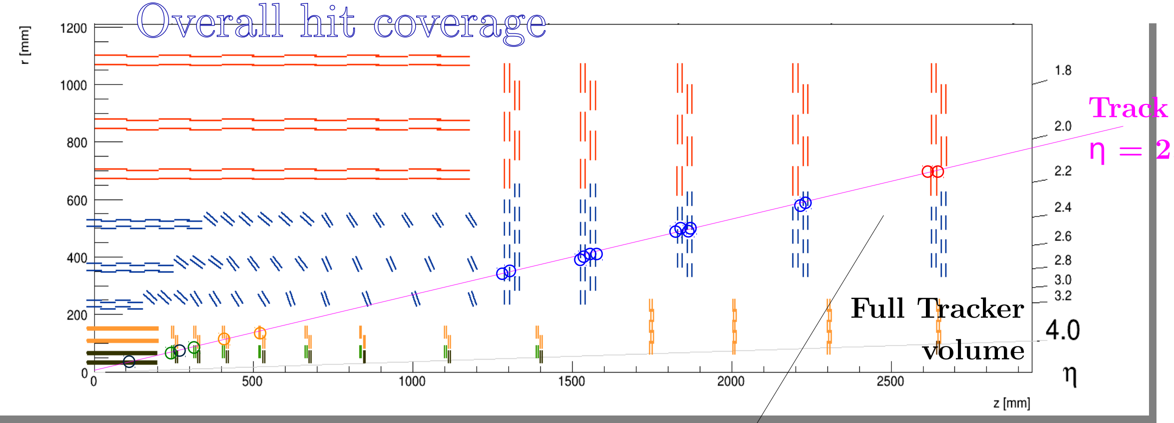


Pixel detector

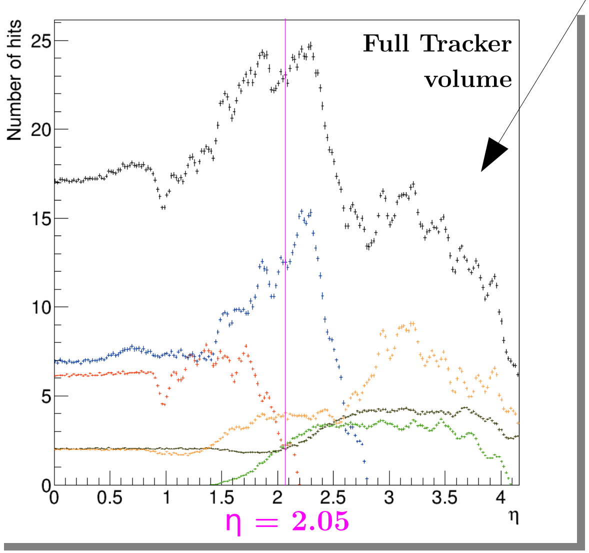


Output: Hit coverage / multiplicity

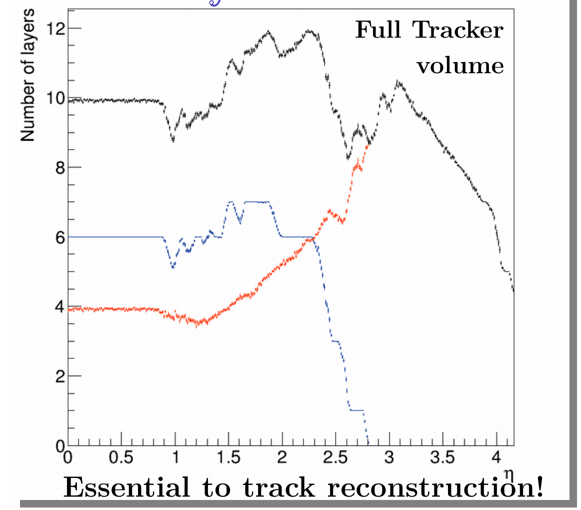
Overall hit coverage



Total number of hits



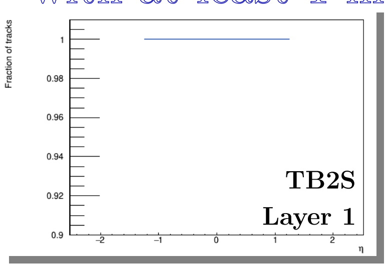
Number of layers with at least 1 hit



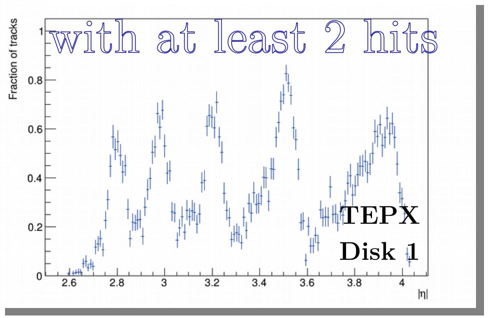
Essential to track reconstruction!

Also provides per-layer information!

Fraction of tracks with at least 1 hit



Fraction of tracks with at least 2 hits

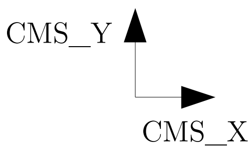


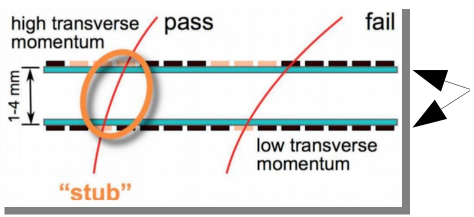
Example: TBPS design

- **HL-LHC: CMS Tracker contributes to the Level 1 trigger.**
  Key for keeping trigger thresholds and efficiency at HL-LHC consistent with LHC Run 1 values.

- **Which data** to send from Tracker in real time (40 MHz) to contribute to the CMS L1 signal?
  Data from all hits: not possible for obvious bandwidth and track reconstruction reasons.
  Data from high-pT tracks (>2 GeV/c) only: achievable bandwidth and track reconstruction.

- **Selecting high-pT tracks**: feasible thanks to CMS high magnetic field (3.8 T) & 2-sensor modules.
  This pT discrimination, applied when forming 2-hits pair, is only feasible from Tracker radius > 200 mm.





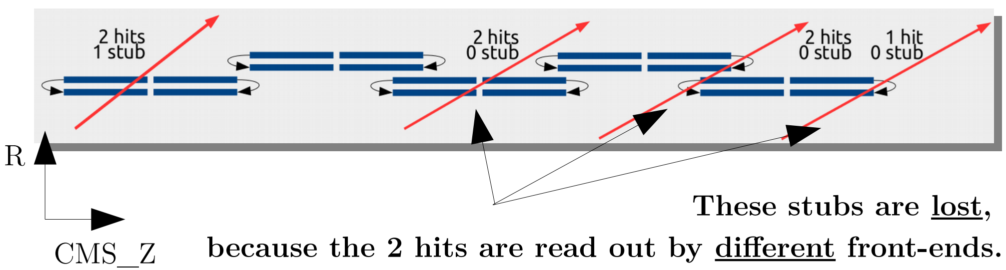
2-sensor module
(same electronics)

A "stub"
is a "signature" of a high-pT track.

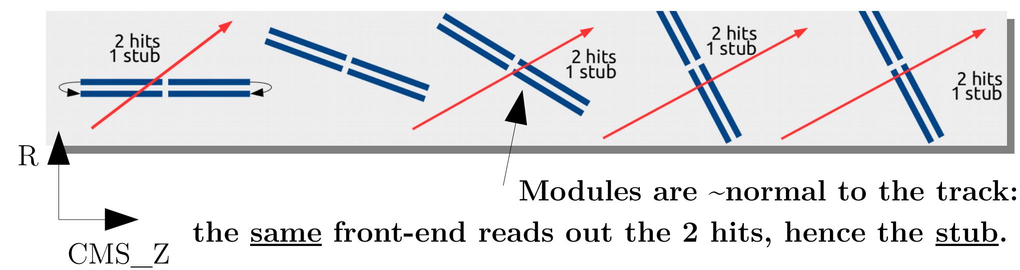
Example: TBPS design

Why a tilted design? Different front-ends cannot communicate.
Hence, in a non-tilted design, a significant proportion of stubs would not be detected.

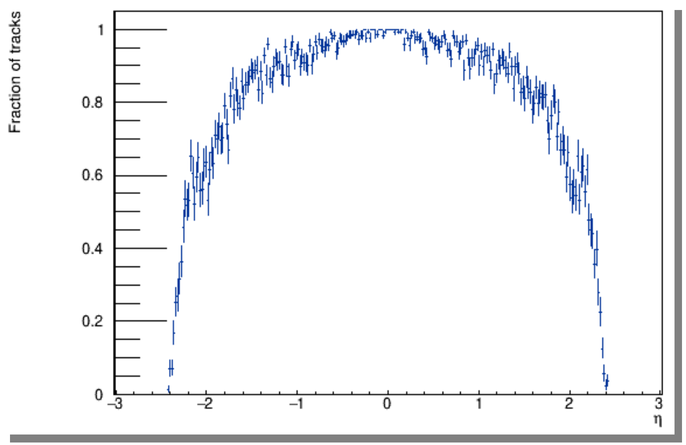
Non-tilted design



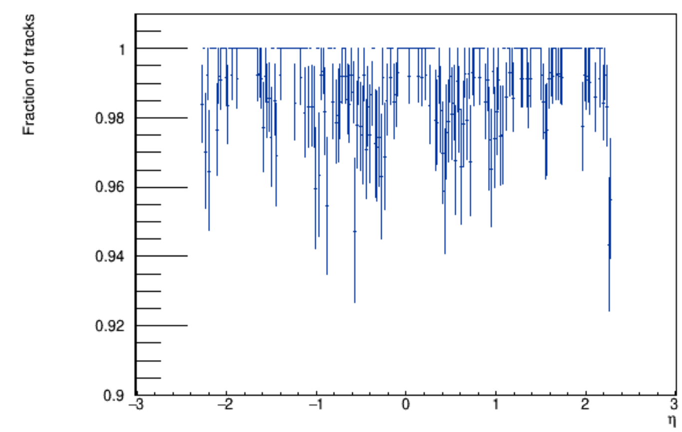
Tilted design



Fraction of tracks with at least 1 stub



Fraction of tracks with at least 1 stub



Example: TBPS design

tkLayout role

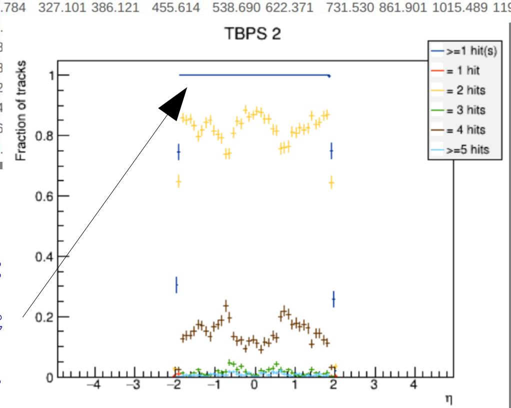
tkLayout:
geometry computation from simple input parameters.

tkLayout:
detailed information
on website

Layer 1 :				
Flat part :				
Ring	**1**	**2**	**3**	**4**
r_{Inner}	224.648	217.552	224.648	217.552
r_{Outer}	248.447	241.353	248.447	241.353
averageR (on Flat part)	233.000	233.000	233.000	233.000
bigDelta	11.900	11.900	11.900	11.900
smallDelta	3.547	3.547	3.547	3.547
z	0.000	42.933	89.716	128.800
phiOverlap	12.326	14.834	12.326	14.834
$zError_{Inner}$ (Ring i & i-1)		70.000	70.000	70.000
$zError_{Outer}$ (Ring i & i-1)		79.846	70.396	89.296

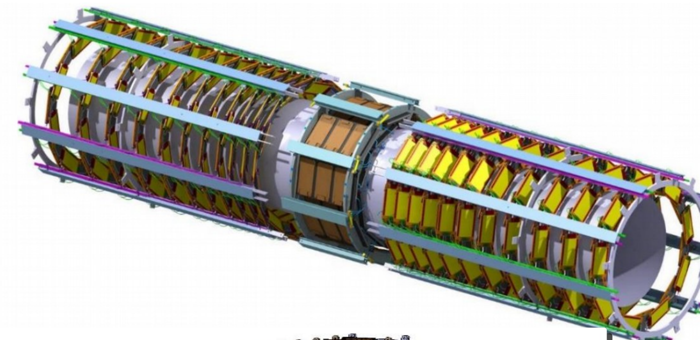
Tilted part :

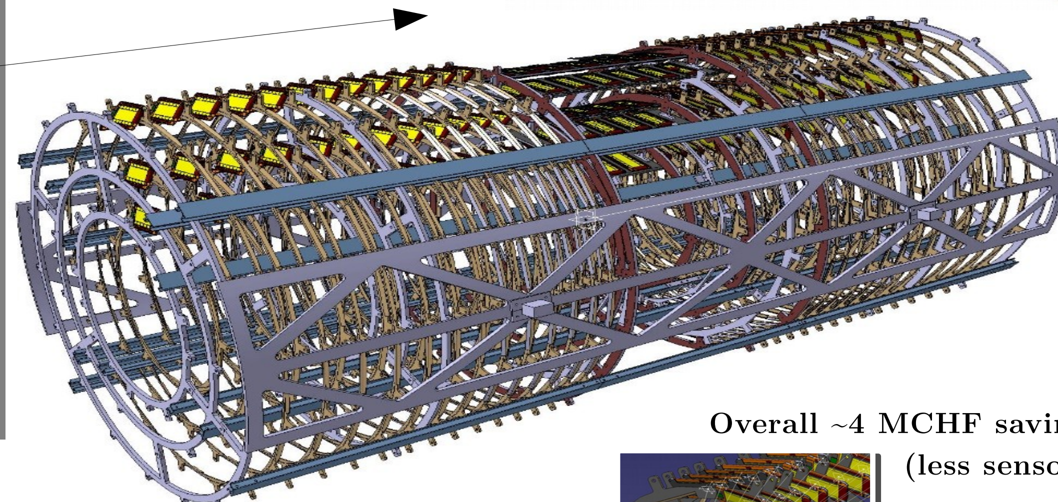
Ring	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
tiltAngle (°)	47.0	47.0	47.0	60.0	60.0	60.0	60.0	72.0	72.0	72.0	72.0	72.0
$tiltAngleIdeal_{Inner}$ (°)	34.3	40.7	46.8	51.7	56.4	60.7	64.7	67.7	70.8	73.6	76.0	78.0
$deltaTiltIdeal_{Inner}$ (°)	12.7	6.3	0.2	8.3	3.6	-0.7	-4.7	4.3	1.2	-1.6	-4.0	-6.0
$tiltAngleIdeal_{Outer}$ (°)	34.5	40.6	46.3	51.6	56.1	60.4	64.3	67.6	70.7	73.4	75.8	77.9
$deltaTiltIdeal_{Outer}$ (°)	12.5	6.4	0.7	8.4	3.9	-0.4	-4.3	4.4	1.3	-1.4	-3.8	-5.9
theta_g (°)	53.0	53.0	53.0	40.0	40.0	40.0	40.0	28.0	28.0	28.0	28.0	28.0
r_{Inner}	252.000	252.000	252.000	249.000	249.000	249.000	249.000	250.500	250.500	250.500	250.500	250.500
r_{Outer}	265.000	265.000	265.000	259.000	259.000	259.000	259.000	256.500	256.500	256.500	256.500	256.500
averageR (on Ring)	258.500	258.500	258.500	254.000	254.000	254.000	254.000	253.500	253.500	253.500	253.500	253.500
gapR	16.278	16.278	16.278	15.557	15.557	15.557	15.557	12.780	12.780	12.780	12.780	12.780
z_{Inner}	172.095	217.118	267.987	315.184	374.203	443.696	526.772	611.087	720.246	850.617	1004.205	1182.332
z_{Outer}	181.891	226.914	277.784	327.101	386.121	455.614	538.690	622.371	731.530	861.901	1015.489	1193.616
averageZ (on Ring)	176.993	222.016	272.									7.974
$deltaZ_{Inner}$ (Ring i & i-1)	43.295	45.023	50.8									127
$deltaZ_{Outer}$ (Ring i & i-1)	53.091	45.023	50.8									127
phiOverlap	0.965	1.357	1.22									1
$zOverlap_{Outer}$	9.45730	10.97567	10.4									351
$zError_{Inner}$ (Ring i & i-1)	131.900	90.554	97.6									045
$zError_{Outer}$ (Ring i & i-1)	64.808	94.982	100.									241



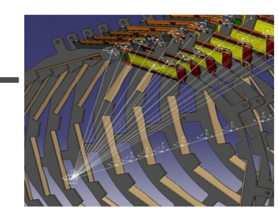
tkLayout:
insures hermetic
hit coverage.

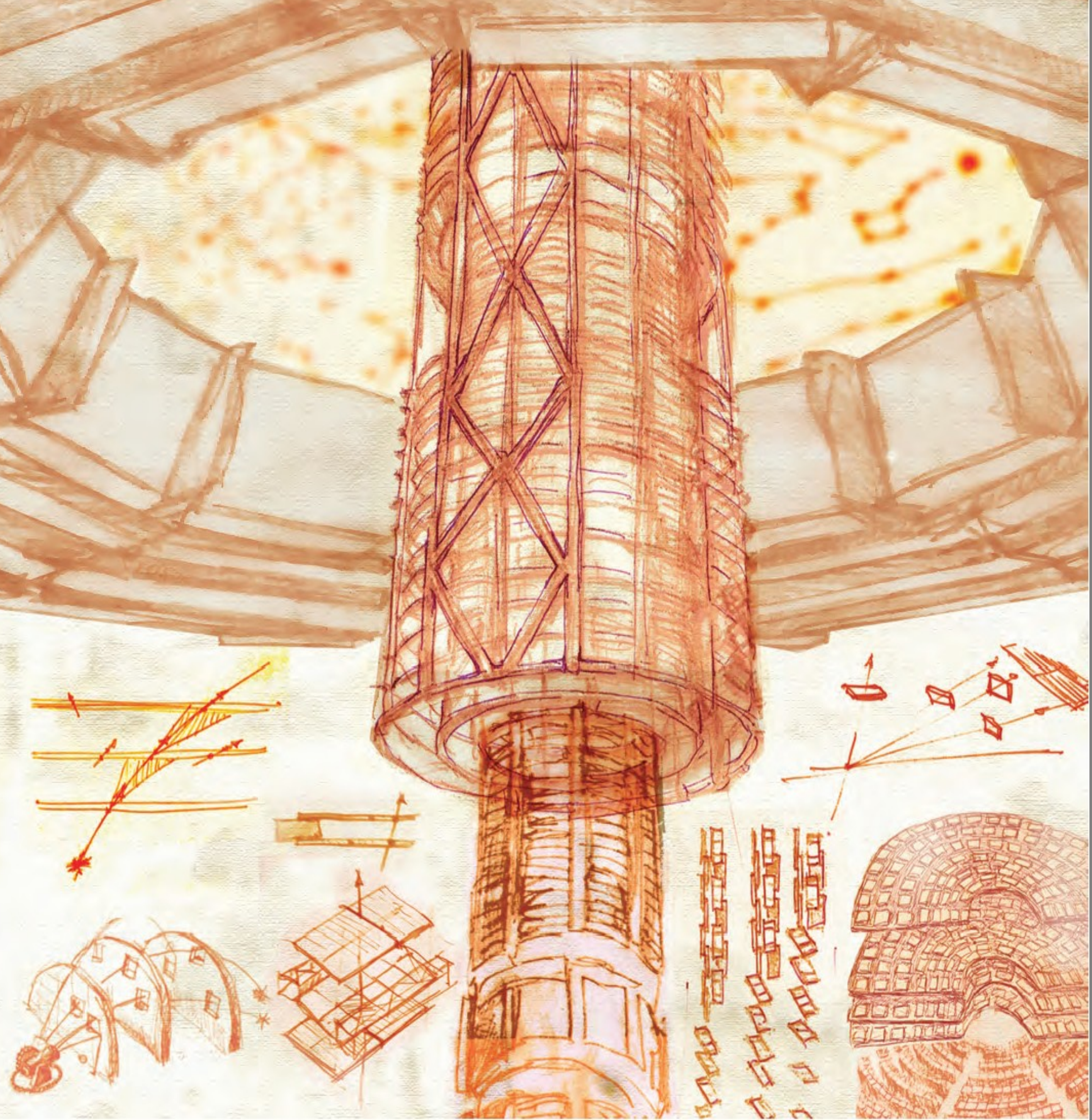
tkLayout:
provides coordinates
to CAD.





Overall ~4 MCHF saving!
(less sensors).

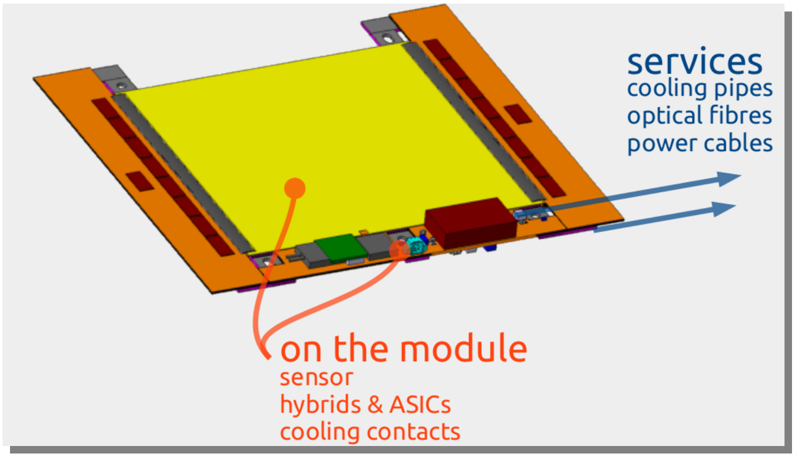




Materials modeling & Automatic services placement

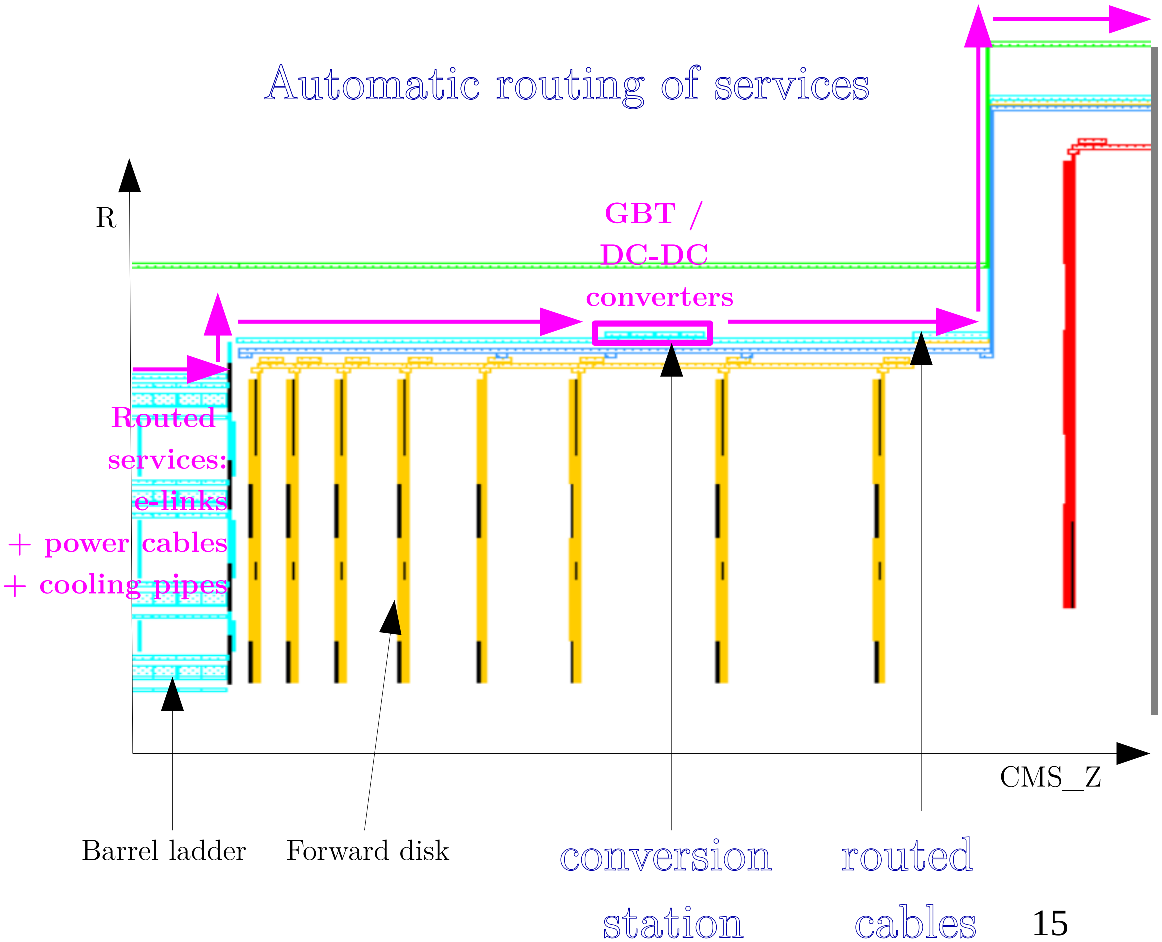
Semi-automatic materials volumes creation

Module model



Simple materials assignment in a parametric way.

Automatic routing of services



Output: Detailed materials volumes debug

tkLayout website:
detailed weights estimates

pxb

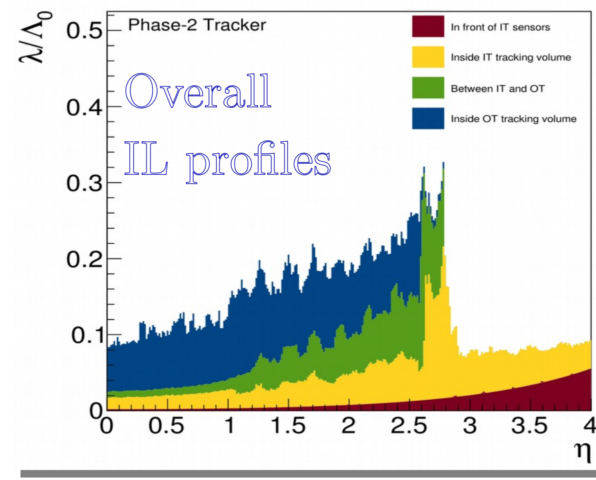
Cabling	mass (kg)
Cabling: DCDC converter power wires	1.067
Cabling: E-links	0.615
Cabling: GBT + DCDC converter	2.551
Cabling: High voltage lines	1.113
Cabling: Optical fibers	0.903
Cabling: Serial power chains	2.321
TOTAL Cabling	8.569
Module	**mass (kg)**
IT Module: Bump bonds	0.039
IT Module: Glue (between ROC and rails)	0.030
IT Module: Glue (between sensor and HDI)	0.030
IT Module: HDI	0.306
IT Module: ROC (Si)	0.339
IT Module: SMD capacitors	0.200
IT Module: Screws	0.060
IT Module: Sensor (active Si)	0.305
IT Module: Sensor (dead area)	0.019
IT Module: Thread bushing	0.121
TOTAL Module	1.449
Supports & Cooling	**mass (kg)**
Cooling: Cooling blocks (AlN rails)	0.323
Cooling: Cooling blocks (C Foam housing pipe)	0.348
Cooling: Cooling blocks (CF plate)	0.853
Cooling: Pipes & Coolant (on ladders)	0.227
Cooling: Pipes & Coolant (routed)	1.822
Supports Mechanics: TBPX External Cylinder	2.051
Supports Mechanics: TBPX Internal Rings	0.254
TOTAL Supports & Cooling	5.878
TOTAL PXB	**15.896**

tkLayout website:
detailed RL/IL estimates

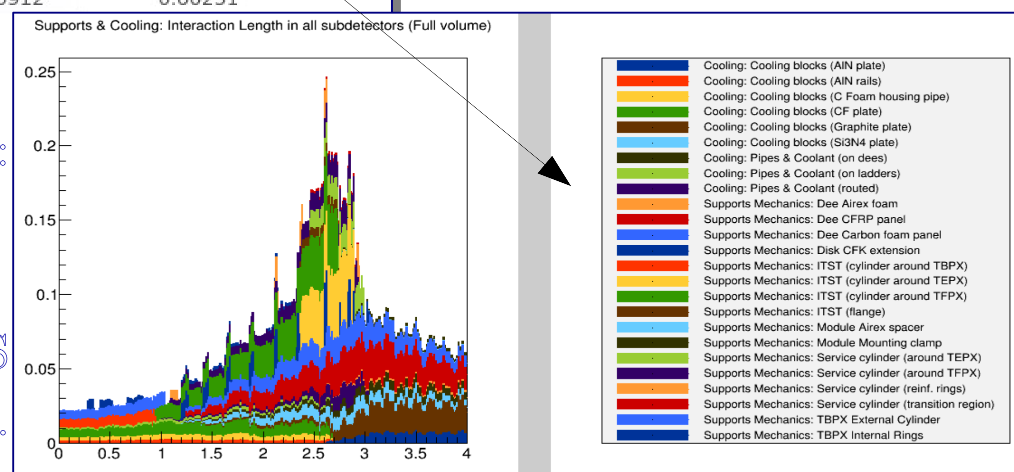
category details: cabling (full volume)

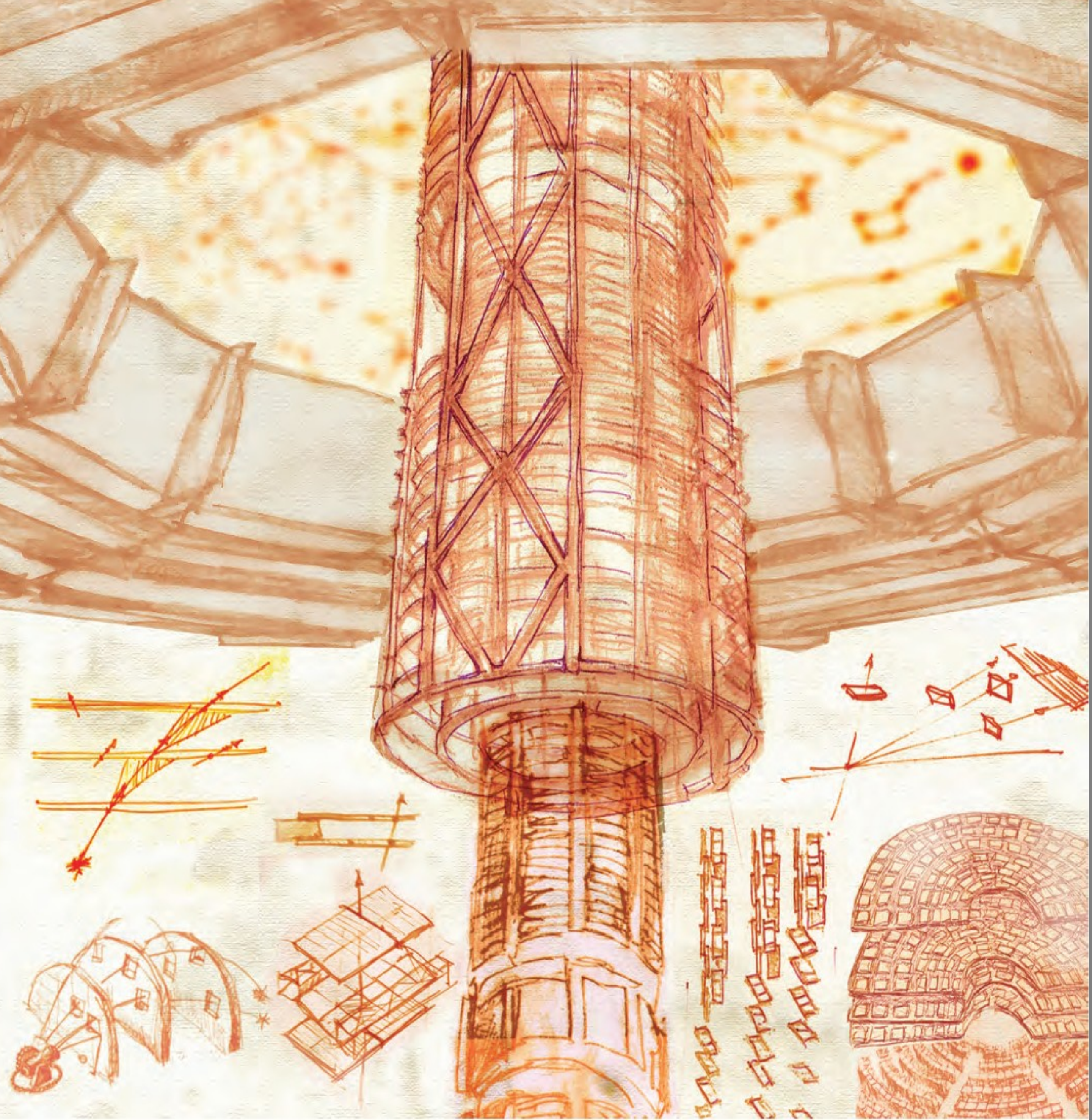
FPIX_1

Average (eta = [0, 4.0])	Radiation length	Interaction length
Cabling: DCDC converter power wires	0.00311	0.00105
Cabling: E-links	0.00080	0.00008
Cabling: GBT + DCDC converter	0.01204	0.00338
Cabling: High voltage lines (on dees)	0.00090	0.00036
Cabling: High voltage lines (routed)	0.00170	0.00069
Cabling: Optical fibers	0.00178	0.00102
Cabling: Serial power chains (on dees)	0.00314	0.00080
Cabling: Serial power chains (routed)	0.00912	0.00231



tkLayout website:
automatically provides
csv files with
ALL VOLUMES
details.



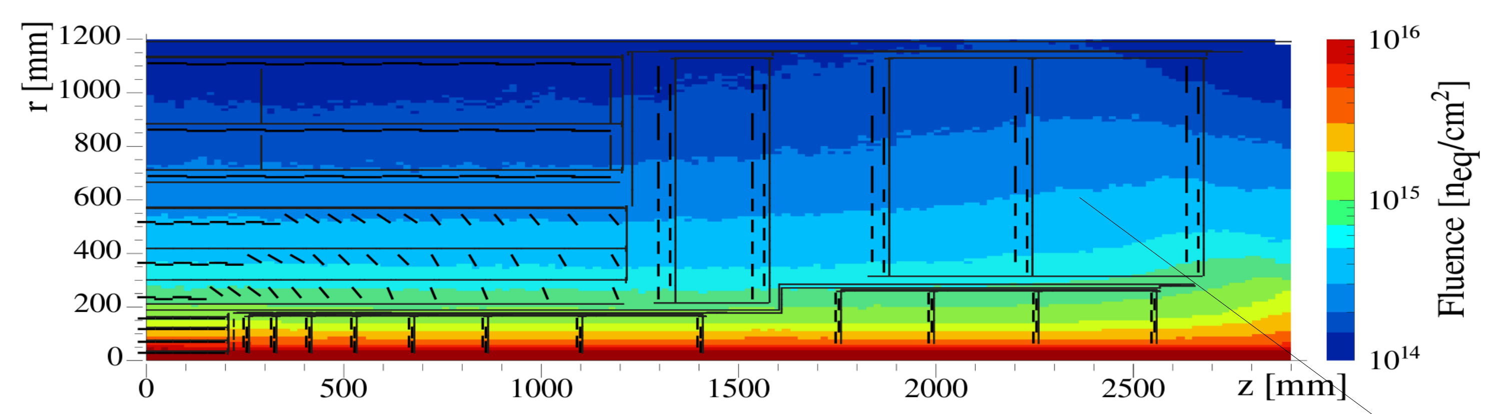


FLUKA interface

FLUKA interface

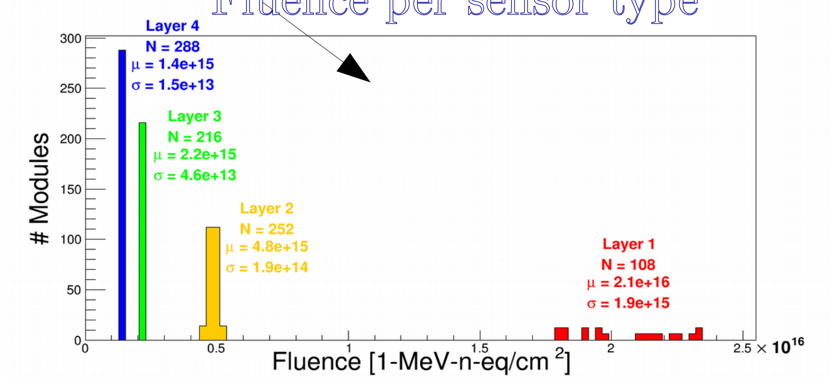
Automatically superimposes any geometry from tkLayout **with any map from FLUKA**.

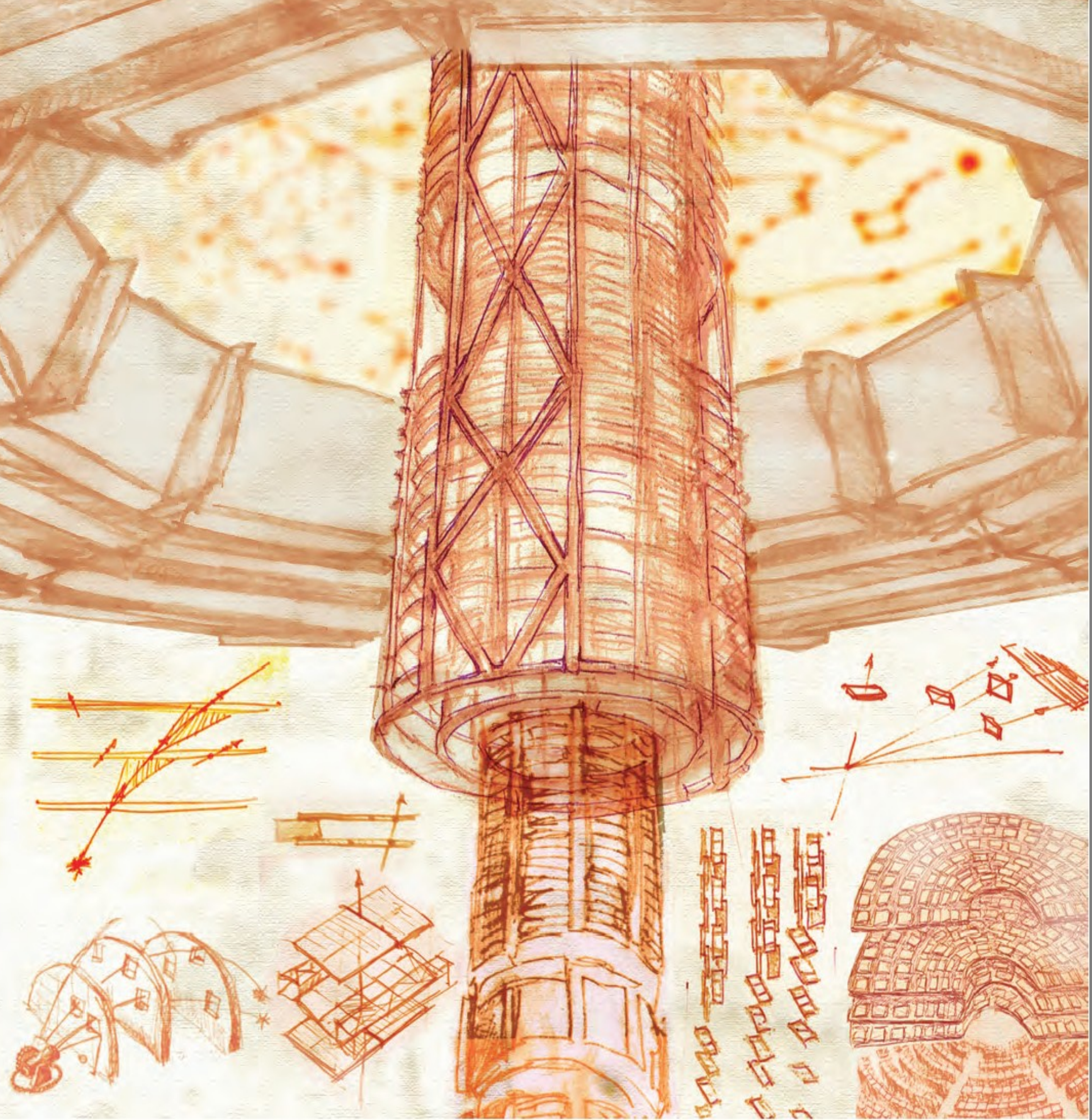
- Allows irradiation studies for each sensor type, at their real position in the Tracker.



Integrated particle fluence in 1 MeV neutron equivalent per cm2, for the CMS Phase-II Tracker.
The estimates shown correspond to a total integrated luminosity of 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14$ TeV.

Fluence per sensor type





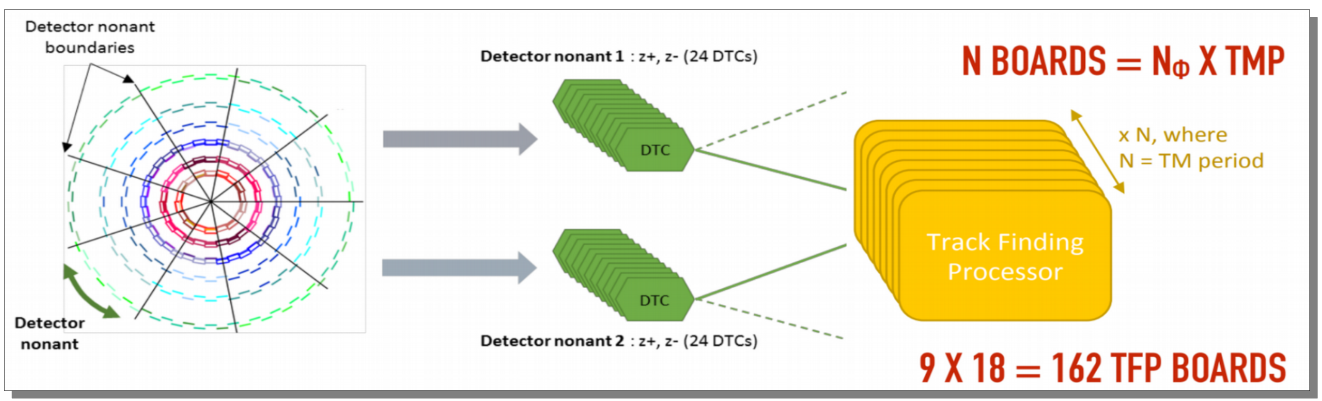
Cabling map

Cabling map

- Takes profit of the **geometry design** being already incorporated in tkLayout.
  - Can easily access valuable geometry ensembles such as Phi sector, Layer / Disk, Ring…

- Takes **cabling constraints as inputs.**
  - Example: maximum number of modules per bundle, maximum number of bundles per cable, etc…

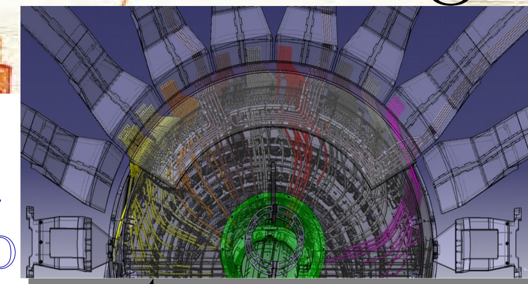
- **Automatically generates** a cabling map (and associated DetIds for easy integration to Monte-Carlo framework).
- Easy debug thanks to many plots and csv files directly accessible on website.



Example of data workflow for a nonant cabling map,
from sensors to DTC (Data, Trigger, Controls)
- CMS Outer Tracker, HL-LHC Upgrade -

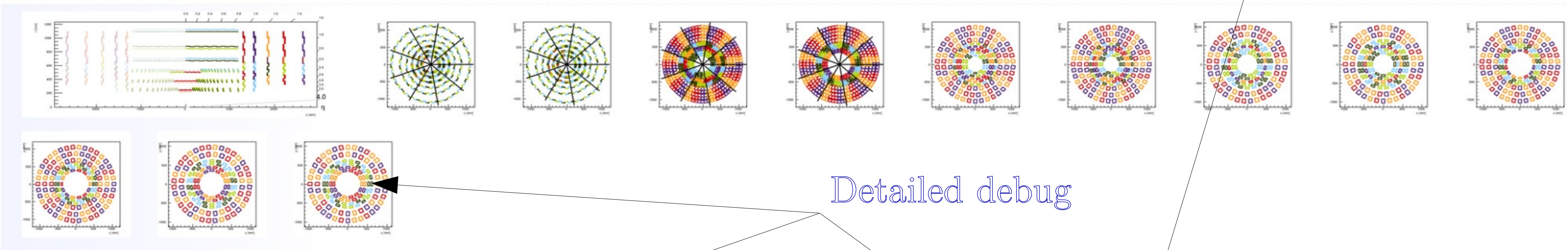
Example: HL-LHC CMS Outer Tracker cabling

Cabling integrated in CAD



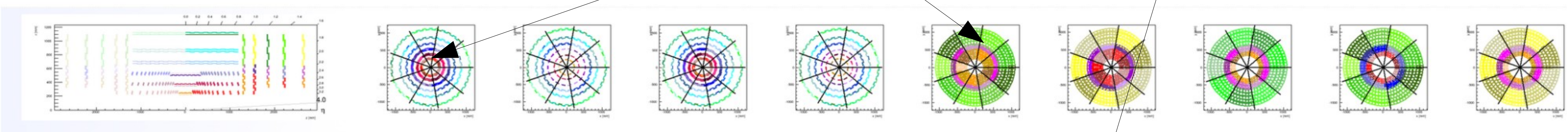
tkLayout website

modules to bundles



Detailed debug

modules to dtcs



cabling files

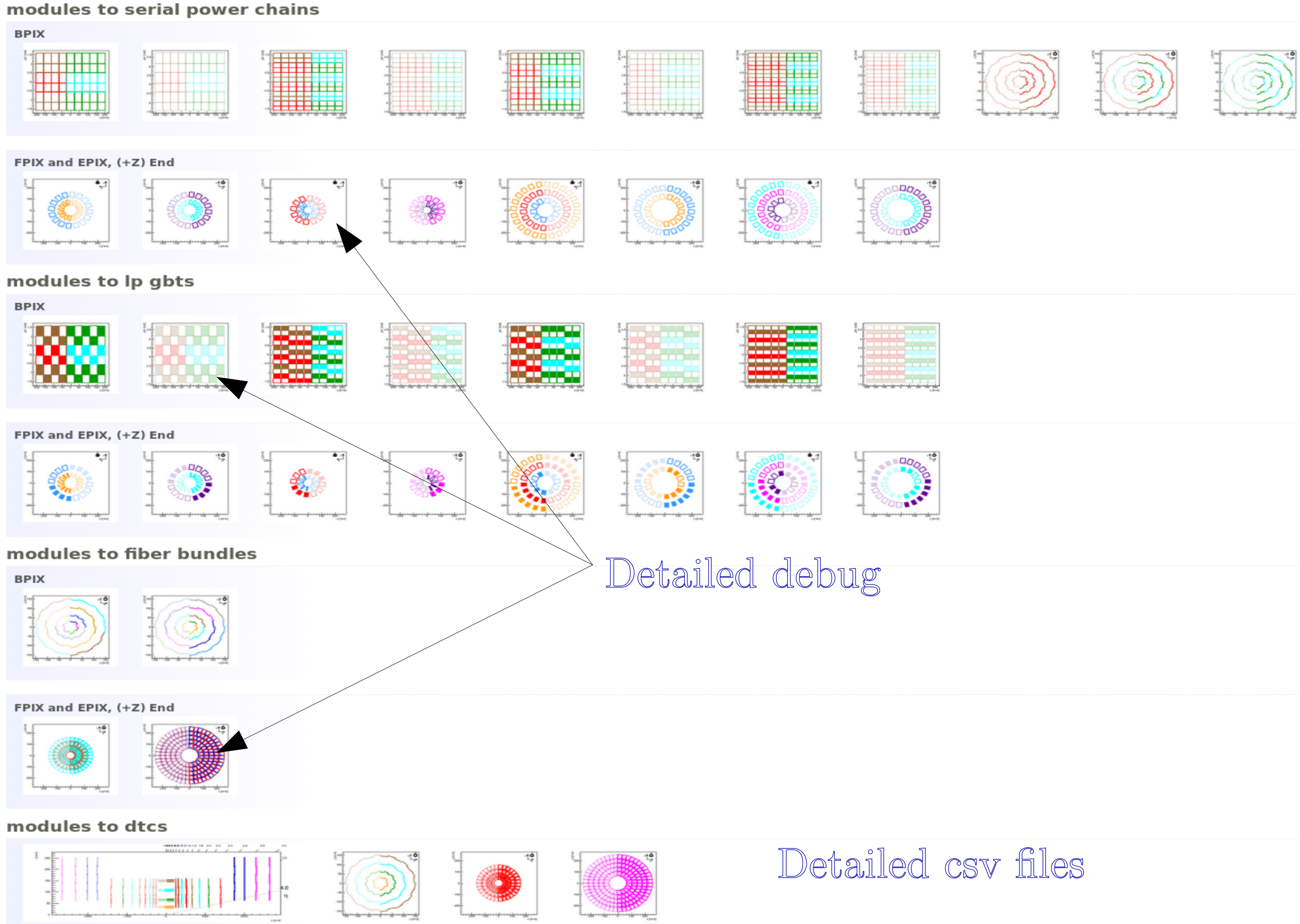
Positive cabling side:
Modules to DTCs: ModulesToDTCsPosOuter.csv
DTCs to modules: DTCsToModulesPosOuter.csv
Bundles to Modules: Aggregation Patterns in TEDD: AggregationPatternsPosOuter.csv

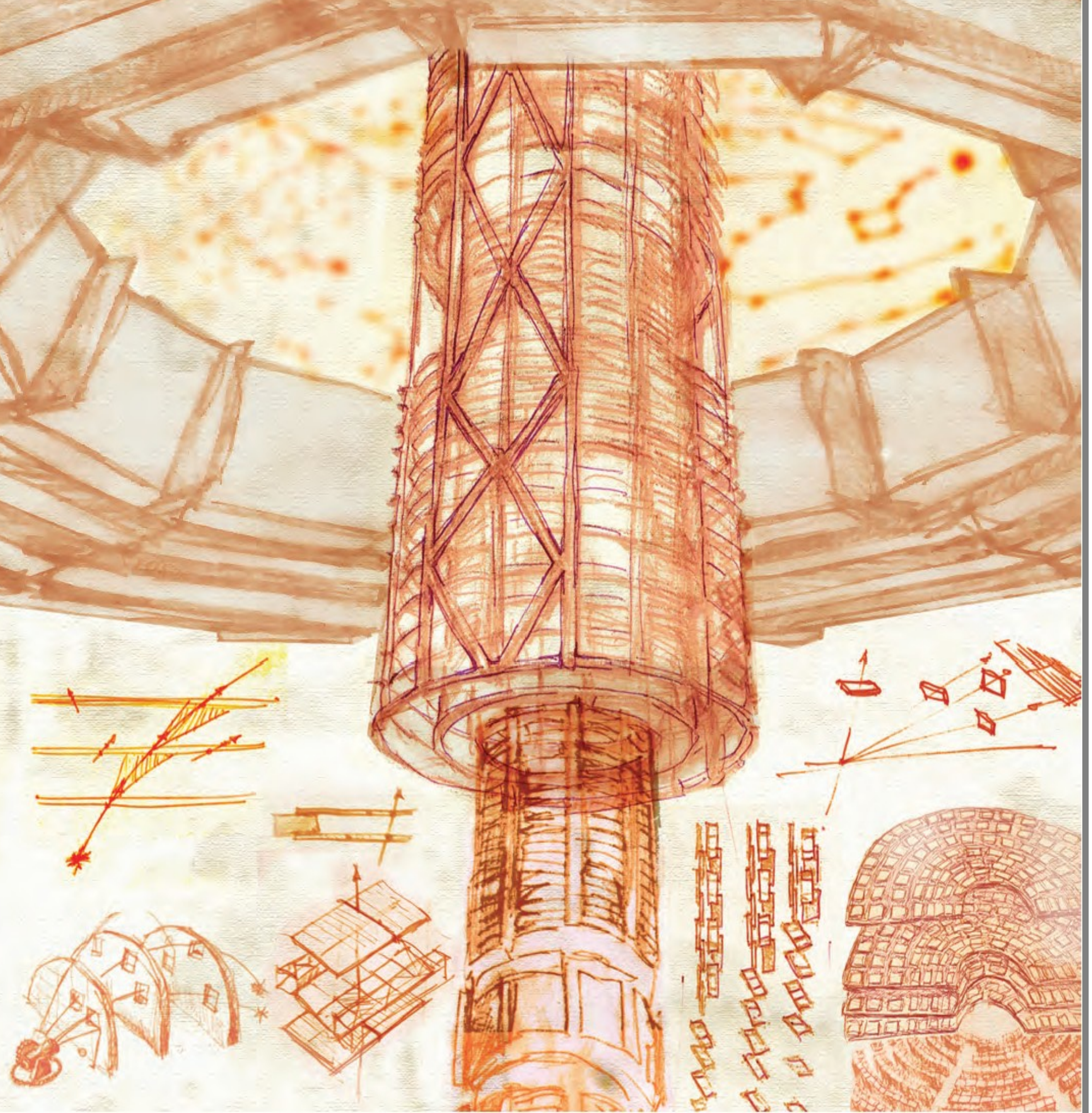
Negative cabling side:
Modules to DTCs: ModulesToDTCsNegOuter.csv
DTCs to modules: DTCsToModulesNegOuter.csv

Detailed csv files

Example: HL-LHC CMS Inner Tracker cabling

tkLayout website





Tracking resolution estimates

Track parameters resolution estimates

A priori error estimation:

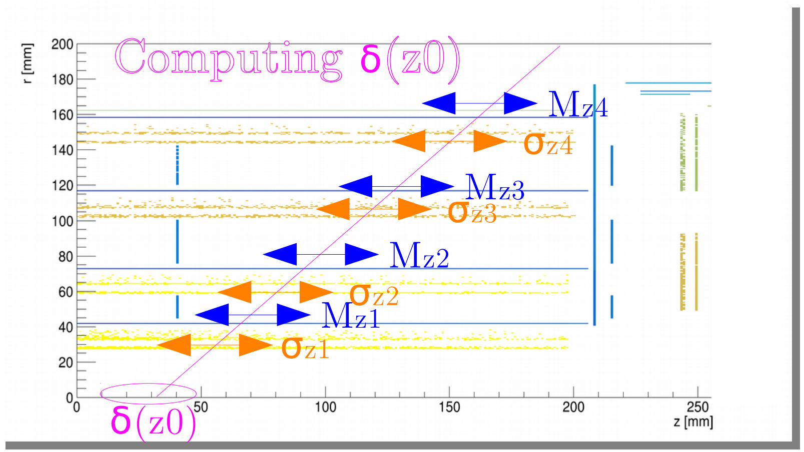
- No Monte Carlo.
- No fitting.

Particle's trajectory in the CMS magnetic field is modeled as:

- a circle in the (r,φ) plane.
- a straight line in the (r,z) plane.

tkLayout relies on error propagation to estimate the 5 track parameters resolution. It takes into account:

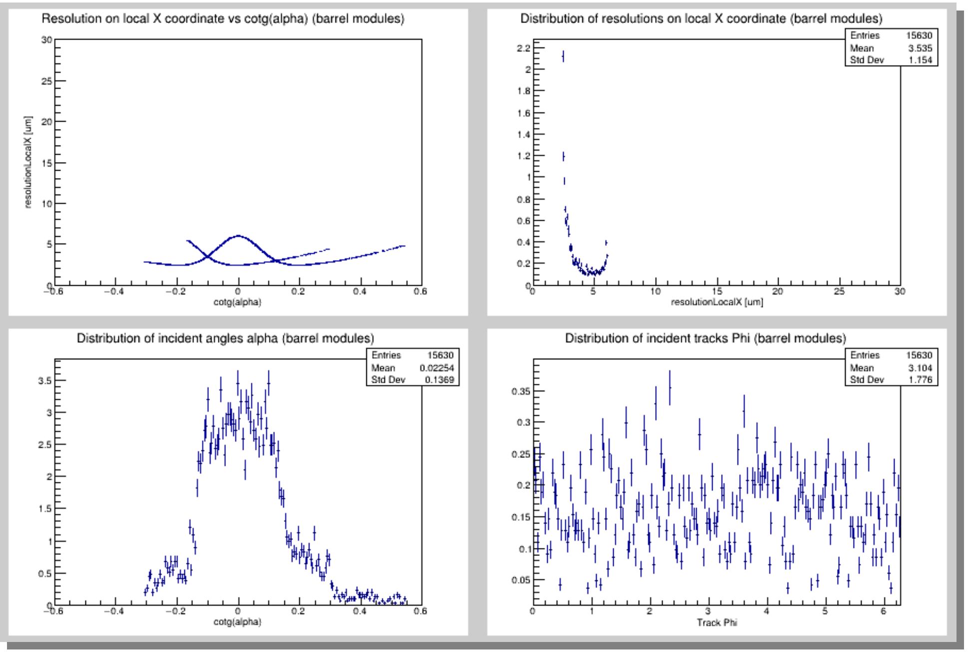
- (Parametric) spatial local resolution of each encountered sensor.
- Multiple scattering through all encountered volumes (sensors and services, treated as a measurement error).



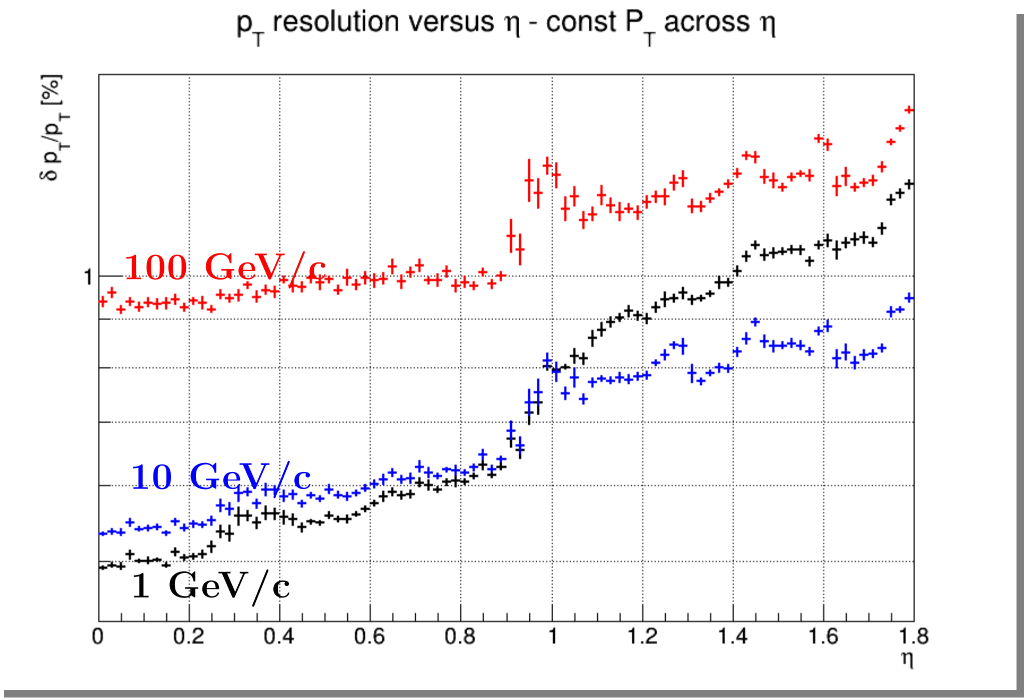
The sensor spatial resolution in z on measurement layer i is noted σ_i.
Multiple scattering is treated as a measurement error M_{zi}.

Note: The beam pipe is not represented here for clarity.

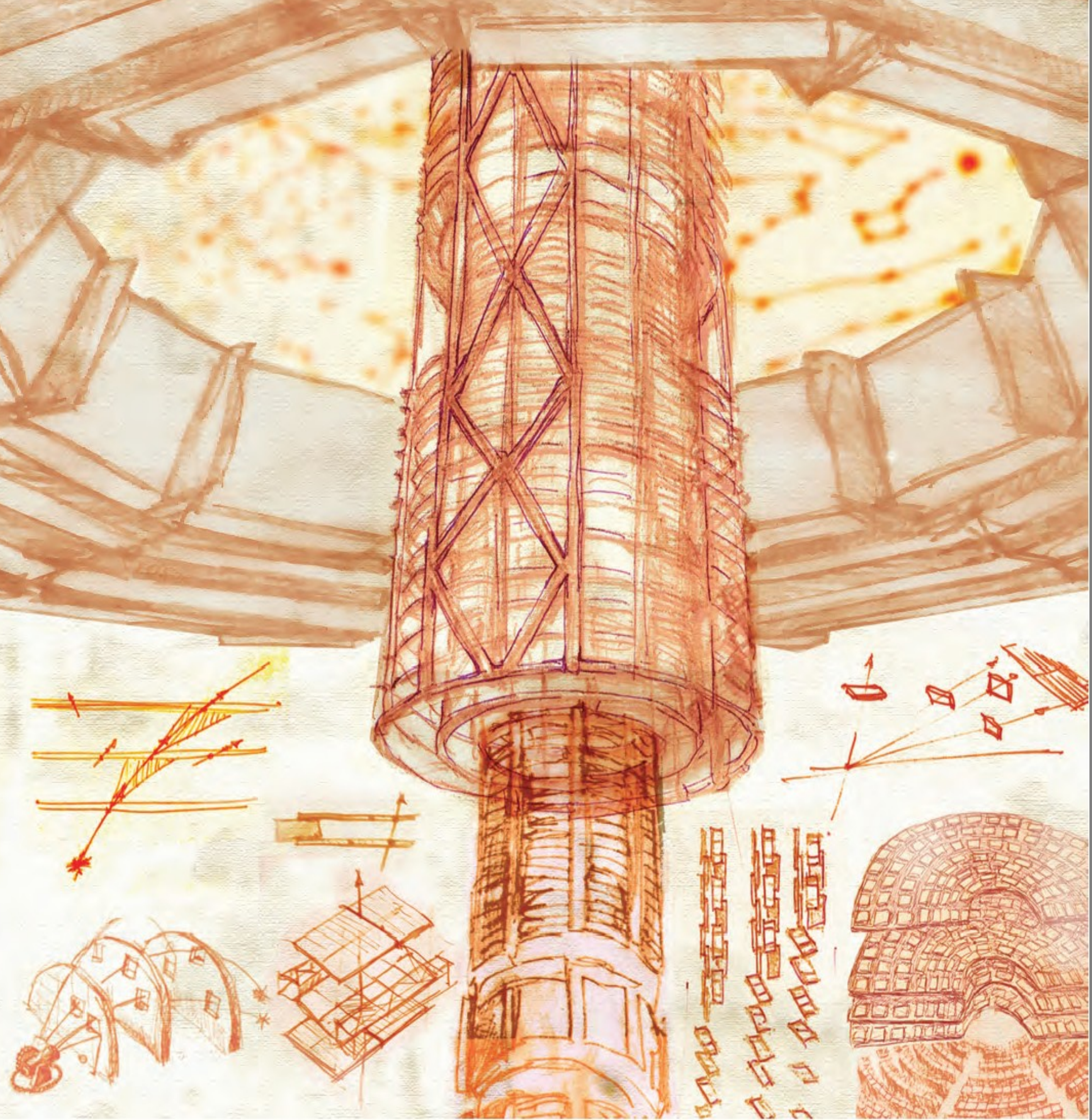
Track parameters resolution estimates: Examples



Sensor local resolution (parametric) estimate



pT resolution (with multiple scattering effects)

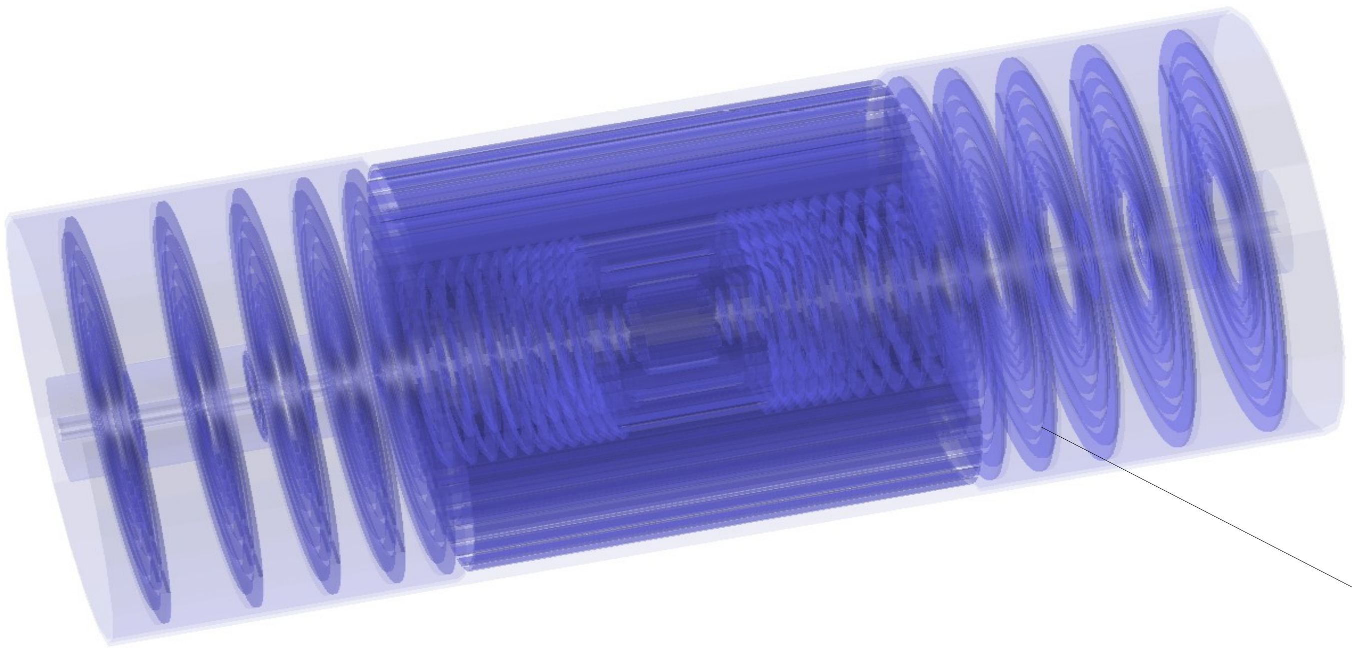


Automatic export to full simulation

Automatic export to full simulation

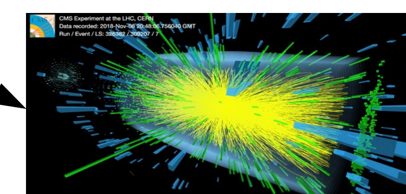
tkLayout <u>automatically</u> exports ALL geometry & materials volumes to a Monte Carlo framework compatible format (GDML).

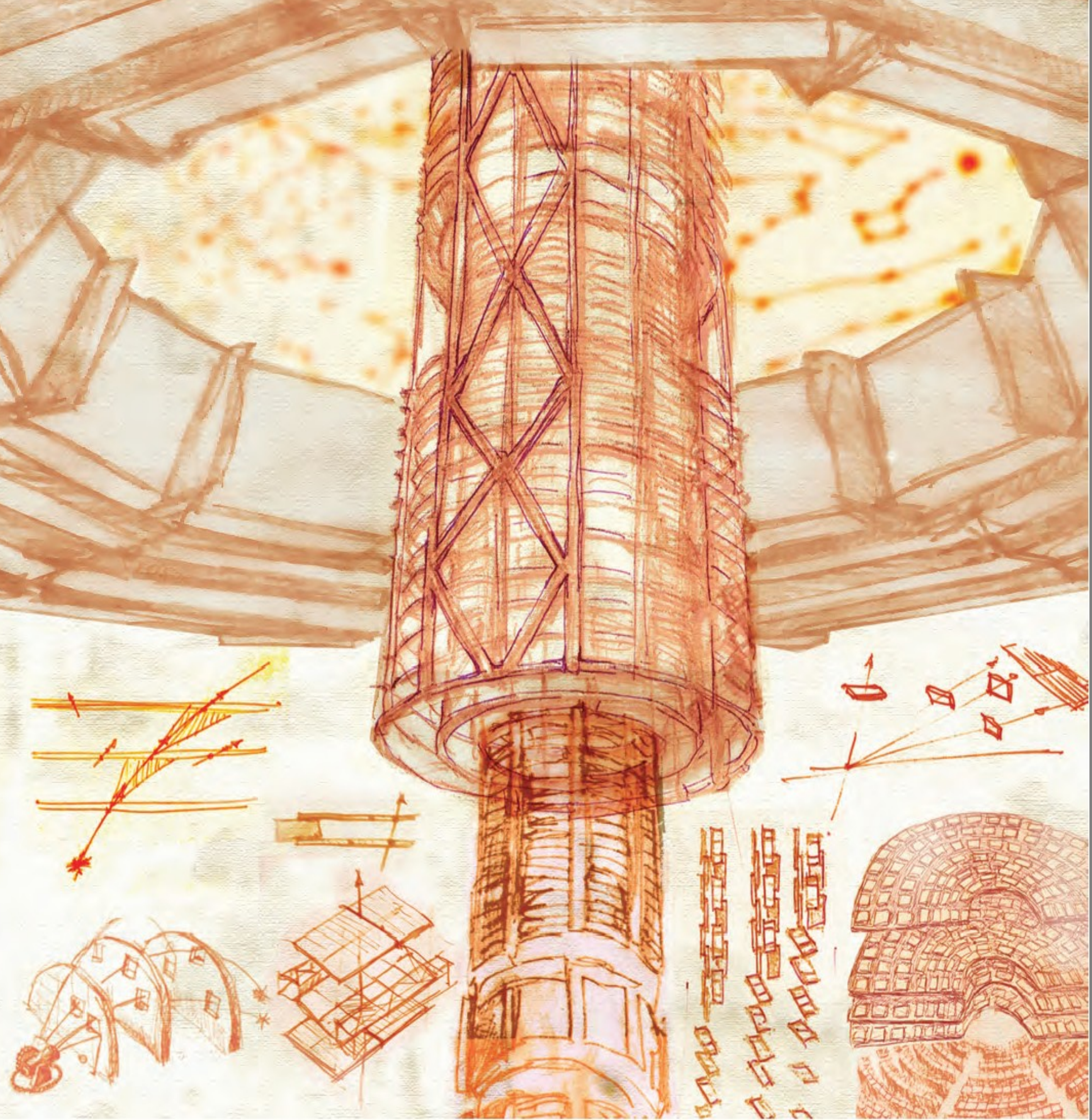
- <u>Minimal (but non-null) effort</u> needed for producing detector descriptions (mostly software adjustments in tkLayout tool).



Phase-II Tracker
in Full Simulation framework (CMSSW).
~10^5 volumes!

Necessary
detector description
within
Monte Carlo framework





Summary & Outlook

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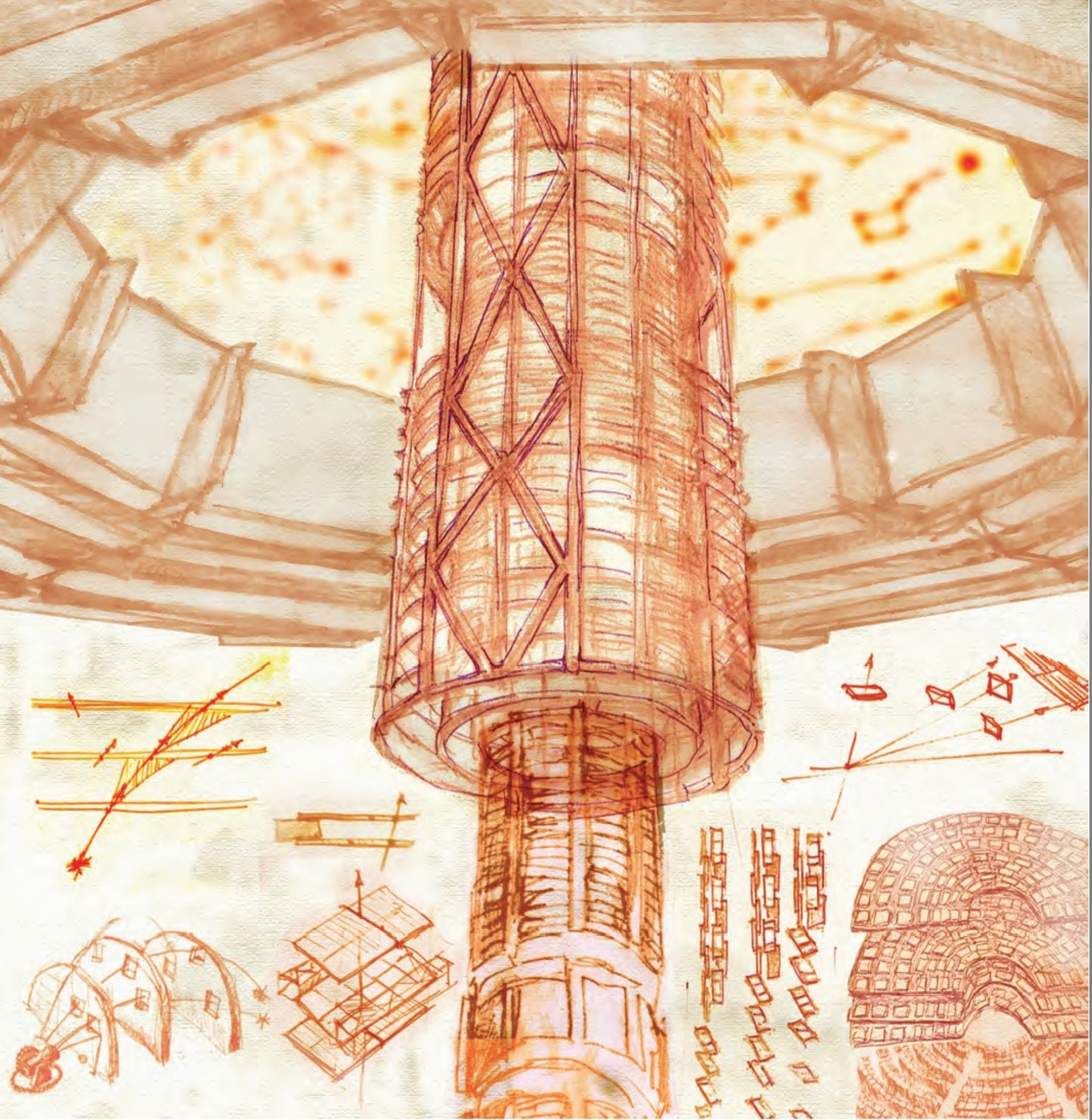
tkLayout is a very powerful tool with numerous features.

- **Inputs are easily tunable**, in simple, parametric, configurations files.
- **Codebase is generic**, and can be adapted to other (tracking) detectors.
- **All results are accessible** to entire collaboration in an unequivocal way (**website**).
- Extremely **cost-effective**: allows advanced R&D, and provides detailed detector descriptions, with minimal effort.

How generic is tkLayout?

Adaptations needed for CEPC use case(s):

- **Geometry:** Should be rather straight-forward. Same geometry hierarchy can be kept in the codebase.
- **Materials:** Most of the work should consist in updating input cfg files (trivial). Should also require few adaptations in codebase though (can be complex).
- **FLUKA interface:** Should work out of the box.
- **Cabling maps:** Quite geometry-specific, should require deep codebase adaptations.
- **Tracking resolution:** Should require adaptations in simulation parameters inputs & codebase.
- **Export to full simulation framework:** Assuming the associated full simulation framework relies on GDML (XML) detector descriptions, tkLayout export feature can be used. Will require (non-trivial) adaptations in codebase.



References

References

These slides are freely inspired from work with Dr Duccio Abbaneo & Dr Stefano Mersi.

[1] tkLayout codebase: https://github.com/tkLayout/tkLayout
Contributors: https://github.com/tkLayout/tkLayout/graphs/contributors

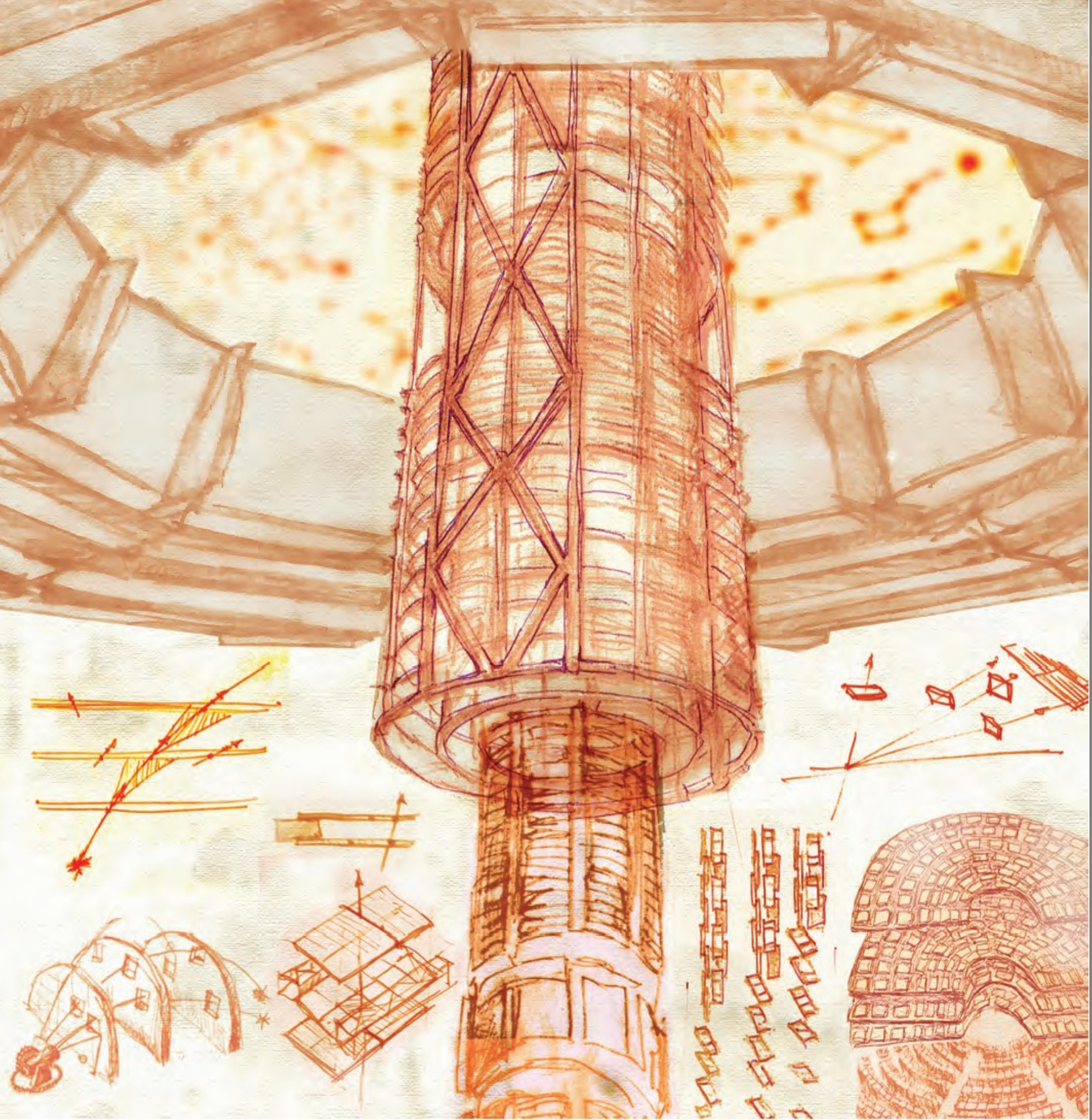
[2] tkLayout website: https://tklayout.web.cern.ch/home

[3] G. Bianchi, *tkLayout: a design tool for innovative tracking detectors*, Journal of Instrumentation 9, C03054 (2014)

[4] S. Mersi, *CMS Tracker: Design & Optimization*, ECFA High Luminosity LHC Experiments Workshop (2016) [https://indico.cern.ch/event/524795/contributions/2236626/]

[5] Z. Drasal, *Status & Challenges of Tracker Design for FCC-hh*, The 26th International Workshop on Vertex Detectors (2017)

[6] The CMS Collaboration, *The Phase-2 Upgrade of the CMS Tracker,* CERN-LHCC-2017-009 (2017) [http://cds.cern.ch/record/2272264]



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