Systems for muon triggering/ tagging/tracking at FCC-hh and related issues

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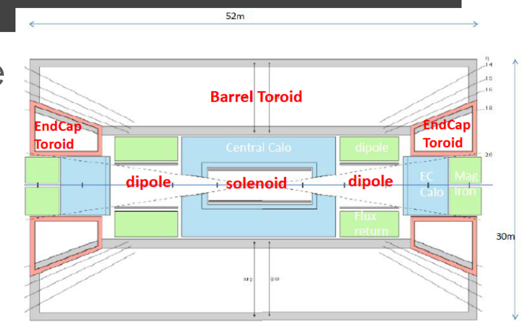
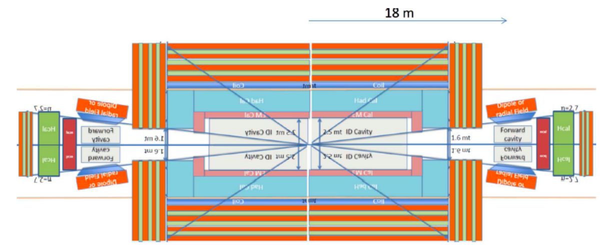
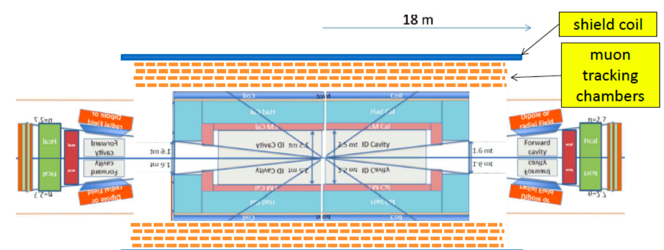
Objectives and content

- Understand the guidelines for the design of the muon system for FCC-hh
- The main questions:
  - can a single detector technology be used for tracking and triggering, at least in one of the muon sub-systems (barrel/endcap/forward)?
  - Is the single technology option the right choice in any case?
- Trigger implementation not covered, assuming that an hw (L1) or sw (HLT) trigger can be implemented if the detector provides sufficient information (fast signal, time resolution, segmentation, occupancy etc.)
- Content
  - Main requirements
  - Running examples: ATLAS and CMS
  - State of the art
  - Possible options
  - Conclusions

Introduction







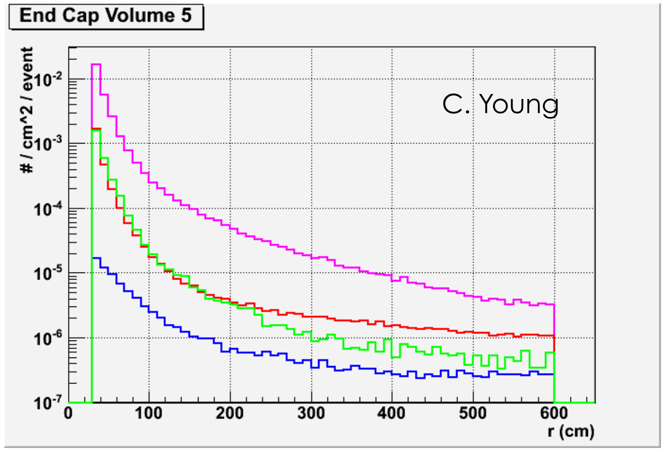
- The system layout should be kept as much flexible as possible (will evolve with time)
- The most challenging experimental conditions (for the detector) should be considered at this stage:
  - $L = 3 \times 10^{35}\ cm^{-2}s^{-1}$
  - Pile-up 900 at 25 ns, 180 at 5 ns BC separation
  - 20 ab^{-1}
- Active surface for a large solenoid with 8 detector layers (the content of the talk does not really depend on it):
  - ~ 10000 m^2 in barrel region
  - ~ 3500 m^2 in end-cap regions
  - ~ 300 m^2 in forward regions
- Only gaseous detector technology can be considered for such a large surface. Hybrid gaseous-solid state, silicon or diamond could be considered at very large η → not discussed here

What do we need?

- Single plane space resolution in bending coordinate:
  - Barrel and End-caps: ~50-100 μm for track impact angle up to ~40°
  - Fwd: ~50-100 μm for track impact angle up to ~10°
- Some tracking capability in the 2nd coordinate (few mm)
- Single plane time resolution:
  Hypothesis: BC ID needed, even for (hw-)triggerless configuration:
  - <8 ns in 25 ns BC separation scenario
  - <1 ns in 5 ns BC separation scenario
- A sub-ns time resolution:
  - can be desirable even in the 25 ns BC separation scenario (time structure of the event)
  - is a strong requirement. Is one of the first requirements to be defined

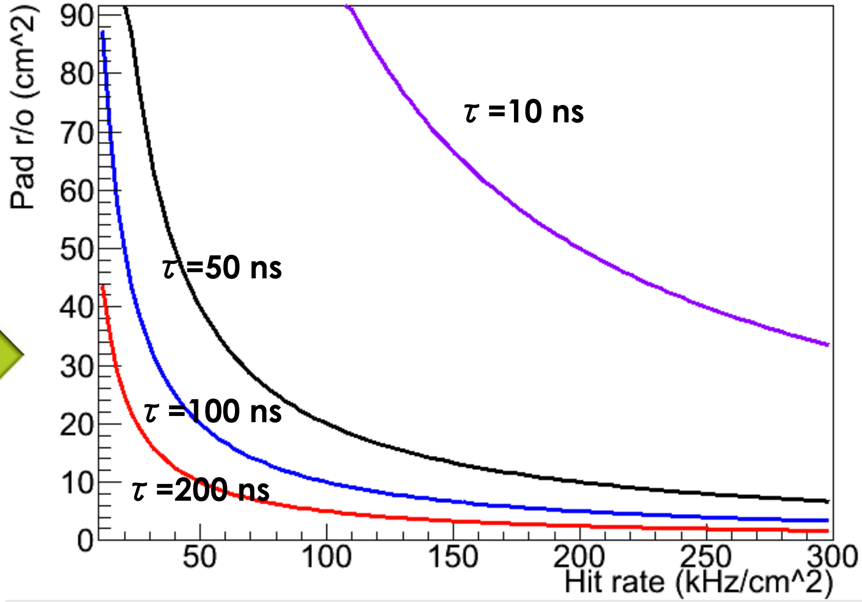
What do we need?

- Rate capability (large uncertainties, depends on material, shielding etc.):
  - ~20 kHz/cm^2 in barrel
  - ~50-100 kHz/cm^2 in endcaps (η<2.6)
  - ~150-500 kHz/cm^2 in forward (η>2.4)



- Charge collection time (pulse width) by itself does not seem to e an issue (several hundreds ns acceptable in any trigger configuration)

- Occupancy can be an issue:
  - Pad size (or tube transverse area) vs hit rate for occupancy = 10%
  - Pulse width = 10, 50, 100, 200 ns

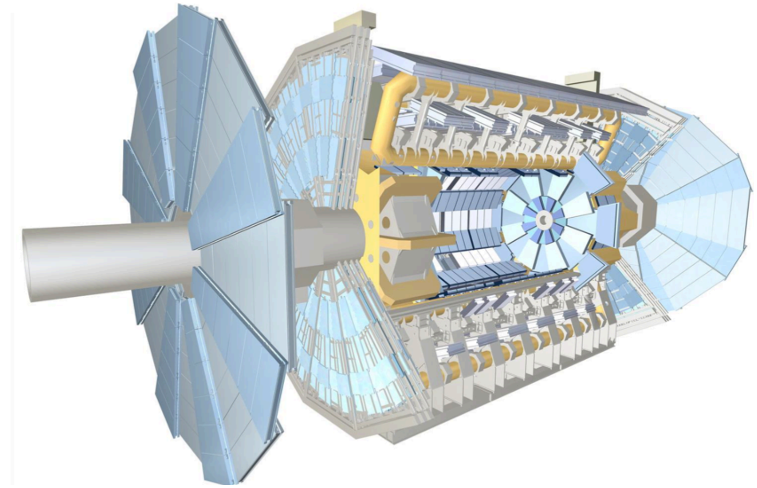


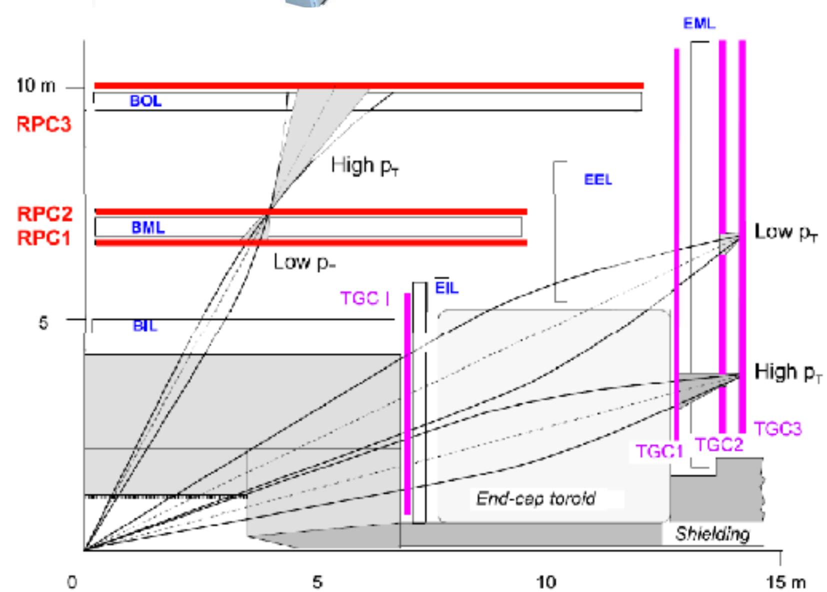
What do we need?

- Ageing:
  - Detectors will be exposed to a radiation level about 10 times higher than HL-LHC in the same rapidity region (2x higher cross-section, 4x higher peak luminosity):
    - ~10 C/cm for wire chambers, ~3 C/cm^2 for PPC at η<1.5
    - ~25 C/cm for wire at η<2.7
  - Considering 20 ab^{-1} an additional factor 7 should be considered (plus some safety factor)
  - None of the present technology has been tested up to such high radiation level
  - Tests starting/ongoing at GIF++ and other facilities for HL-LHC should be push even further to qualify gaseous detectors for FCC-hh

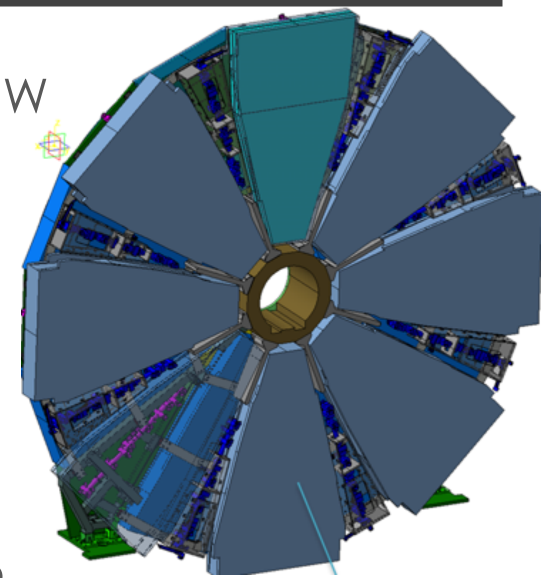
Example: ATLAS

- Dedicated systems: specialized detector technologies for trigger and tracking with separated read-out
  - Tracking: MDT and CSC
  - Trigger: RPC (barrel) and TGC (endcap)
- Trigger detectors provide 2nd coordinate
- L1 trigger coupled to a single fast detector type → simple (and reliable) on-detector trigger elx
- Information from precision chambers not used at L1 trigger level → no use of them to sharpen the hw p_T threshold

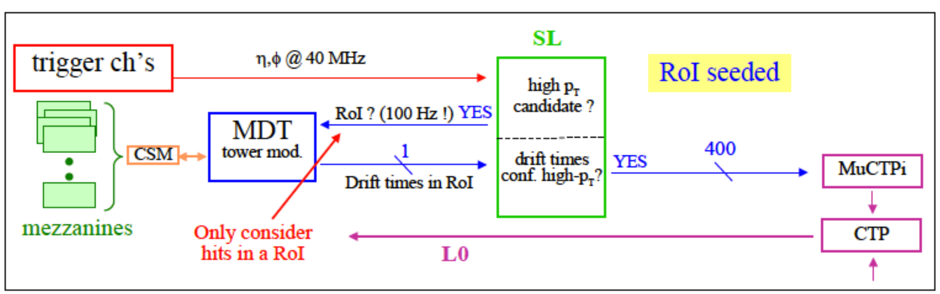


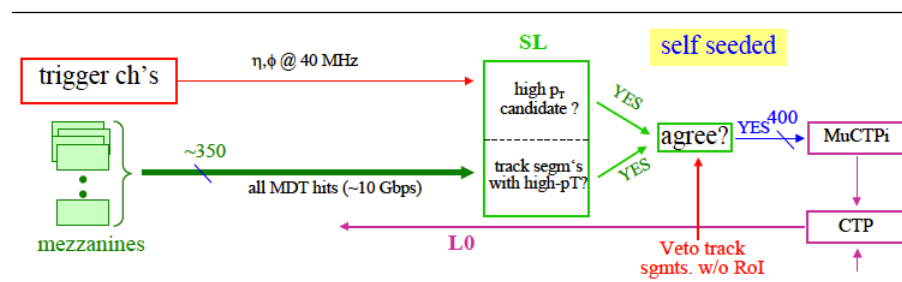


Example: ATLAS

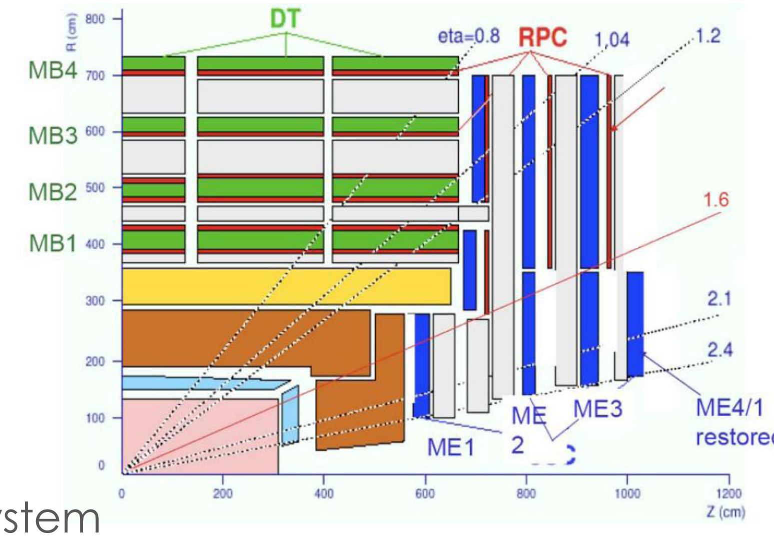


- New approach for the main upgrade of Phase-1: NSW detector choice based on redundancy: sTGC and Micromegas both able to provide triggering and tracking capabilities, still with specific functionalities
  - High system reliability
  - Independent trigger paths from two technologies
  - Use of the tracking info (full granularity) at trigger level
- Proposal for Phase-II upgrade: MDT-based trigger, to sharpen the p_T threshold at L0 (6 μs latency)
  - New 'fast readout' path needed (new FE elx)
  - Two options considered:

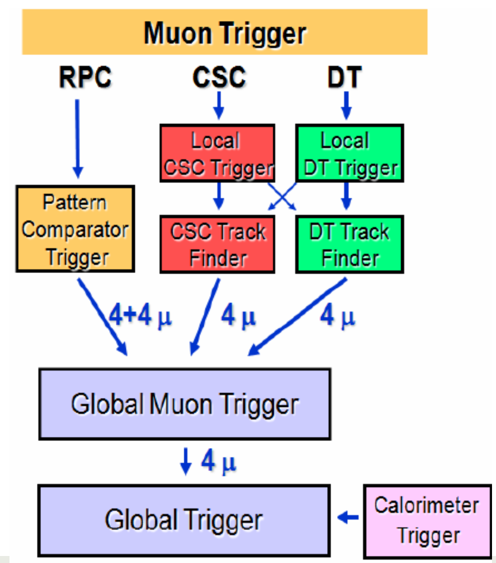




Example: CMS



- Three different technologies
  - Tracking: DT (Barrel) and CSC (Endcaps)
  - Trigger: RPC
- RPC, CSC and DT provide muon candidates independently (3.2 μs latency)
  - The Global Muon Trigger selects up to 4 muon candidates for each BC, taking into account the quality of the candidates from each sub-system
- High redundancy, full detector info used for trigger
- Complex system: development and deployment of three different L1 trigger logics



Example: CMS

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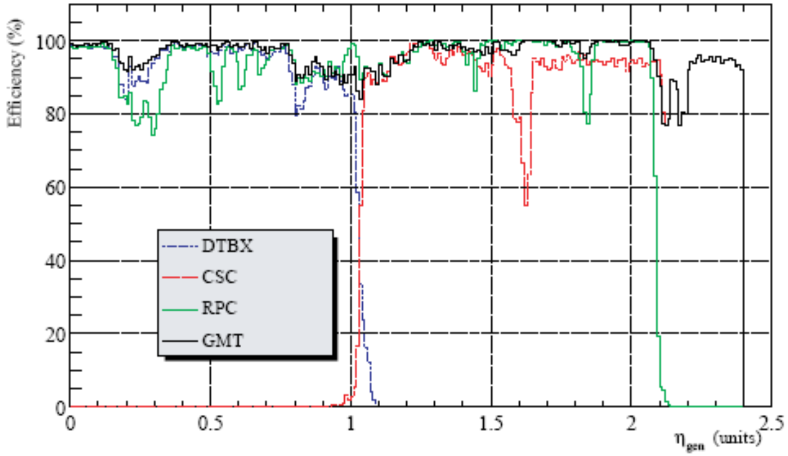
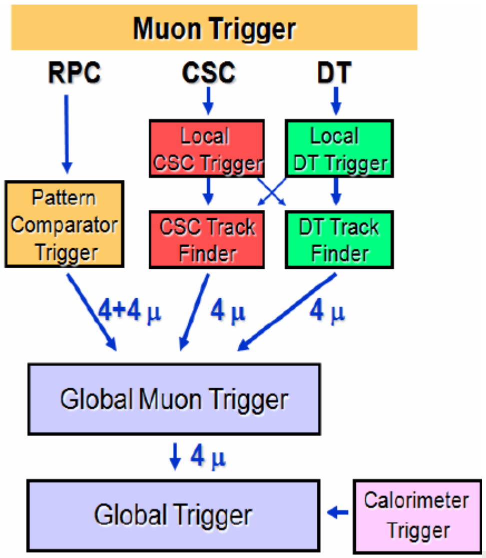




Available technologies - 1

- Wire chambers (see O. Kortner's talk):
  - Drift chambers/drift tubes (ATLAS and CMS)
  - MWPC: CSC/TGC/MWPC (ATLAS, CMS, LHCb)
  - Straw (ATLAS TRT, NA62)

Detector	Time resolution (ns)	Space resolution (μm)	Rate Capability (kHz/cm^2)
(M)DT	5	80	0.5
MWPC	7	100	1
sMDT	5	70	20
sTGC	4.5	100	20
Straw	6	120	150

Numbers in the table only give an indication: don't trust (and don't complain) too much!

Available technologies - 2

- Parallel Plate Chambers (see R. Cardarelli's talk on RPC):
  - Improved HPL RPC (iRPC) (proposal for ATLAS upgrade)
  - Glass RPC
    - mRPC (ALICE TOF)
    - Single gap

Detector	Time resolution (ns)	Space resolution (μm)	Rate Capability (kHz/cm^2)
iRPC	0.4	200	50
mRPC	0.2	200	50

Numbers in the table only give an indication: don't trust (and don't complain) too much!

Available technologies - 3

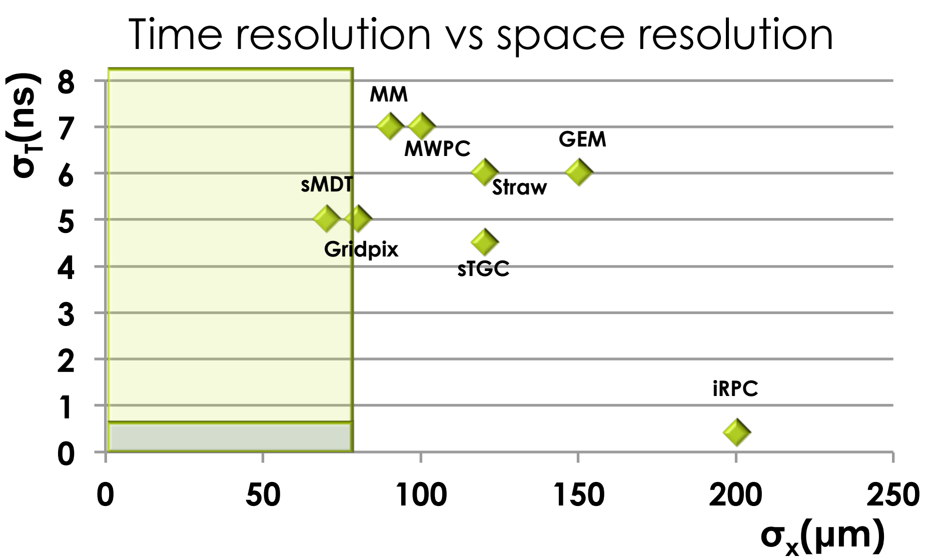
- Micro Pattern Gaseous Detectors (see M. Titov's talk):
  - GEM (CMS upgrade extrapolated to finer readout-strip)
  - Micromegas (ATLAS upgrade)
  - Gridpix (gaseous/solid-state)

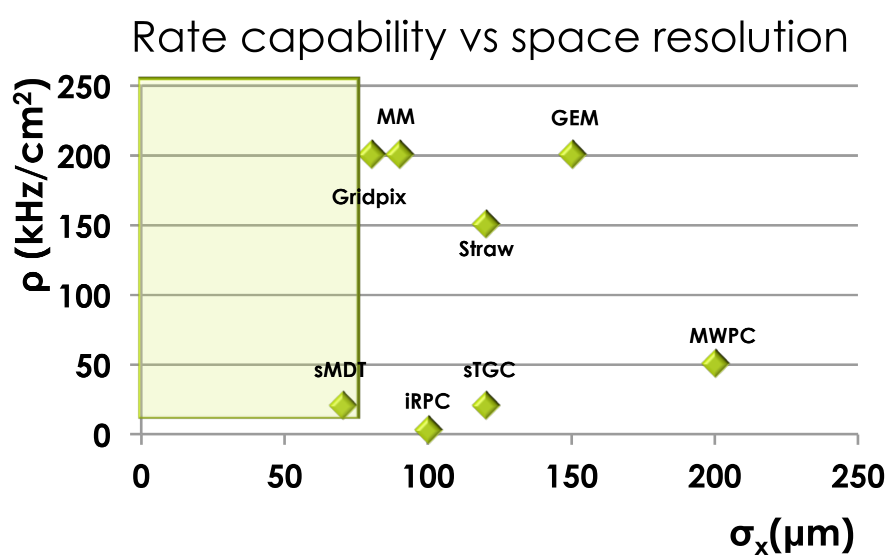
Detector	Time resolution (ns)	Space resolution (μm)	Rate Capability (kHz/cm^2)
GEM	5	120	200
Micromegas	7	90	200
Gridpix	5	80	200

Numbers in the table only give an indication: don't trust (and don't complain) too much!

State of art – Barrel

- Requirements vs existing technologies
  - Shadow areas: requirements for σ_X, σ_T, rate capability (ρ)
    Green: 25 ns BC separation
    Violet: 5 ns BC separation
  - Dots: existing (or about to exist) technologies for large systems





Preliminary conclusions - Barrel

- Drift tubes rate capability is marginal at 3x10^{35} $cm^{-2}s^{-1}$ →
  push this limit further seems hard (not impossible: smaller tubes? straw?)
  Measurement of the 2^{nd} coordinate (stereo tubes? Straw with cathode r/o?)
- TGCs offer higher rate capability but lower space resolution to inclined tracks
  → many layers needed to go below 50 μm (too many?)
- MPGDs: rate ok, can in principle be used in a single-technology spectrometer.
  Time resolution ok for 25 ns BC not for 5 ns BC.
  Waiting for performance demonstration in ATLAS and CMS upgrades
- PPC: iRPC are still unbeatable as timing detectors. Rate capability can be pushed to the desired value, space resolution for inclined tracks insufficient
- Gridpix ~OK, still limited to few cm^2, cost issue

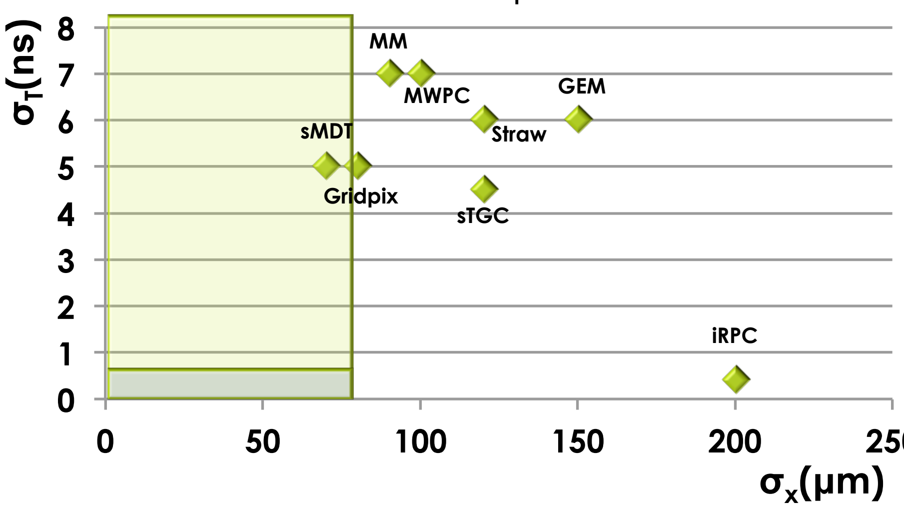
Preliminary conclusions - Barrel

- None of the existing technologies seems to be safely usable as single solution as trigger/tracking detector in the barrel
- If BCID is required:
  - 25 ns BC: single technology conceivable with adequate R&D (MPGD, straw), but: is it wise?
  - 5 ns BC: iRPC for timing together with a tracking device (MPGD or drift tubes with improved rate capability)

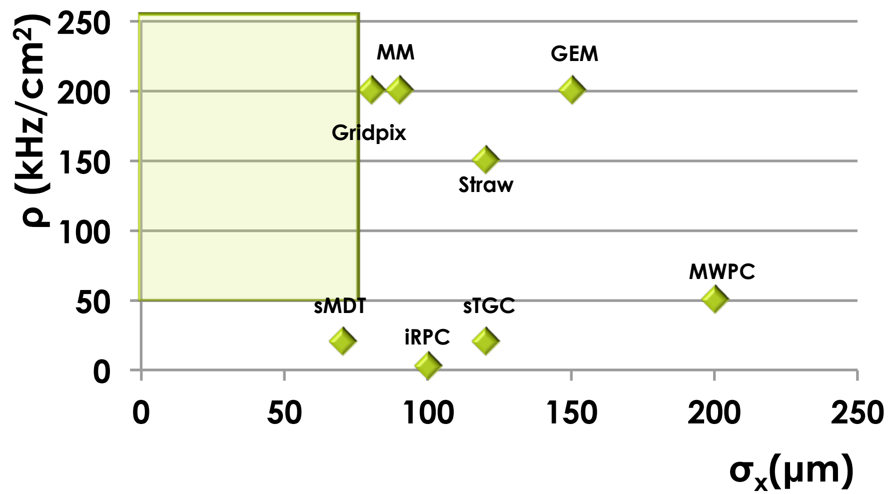
State of art – Endcap

- Requirements vs existing technologies
  - Shadow areas: requirements for σ_X, σ_T, rate capability (ρ)
    Green: 25 ns BC separation
    Violet: 5 ns BC separation
  - Dots: existing (or about to exist) technologies for large systems

Time resolution vs space resolution



Rate capability vs space resolution



Preliminary conclusions - Endcap

- Drift tubes rate capability is marginal at $3x10^{35}$ $cm^{-2}s^{-1}$ → push this limit further seems hard (not impossible: smaller tubes? straw?) Measurement of the 2^{nd} coordinate (stereo tubes? Straw with cathode r/o?)
- TGCs offer higher rate capability but lower space resolution to inclined tracks → many layers needed to go below 50 μm (too many?)
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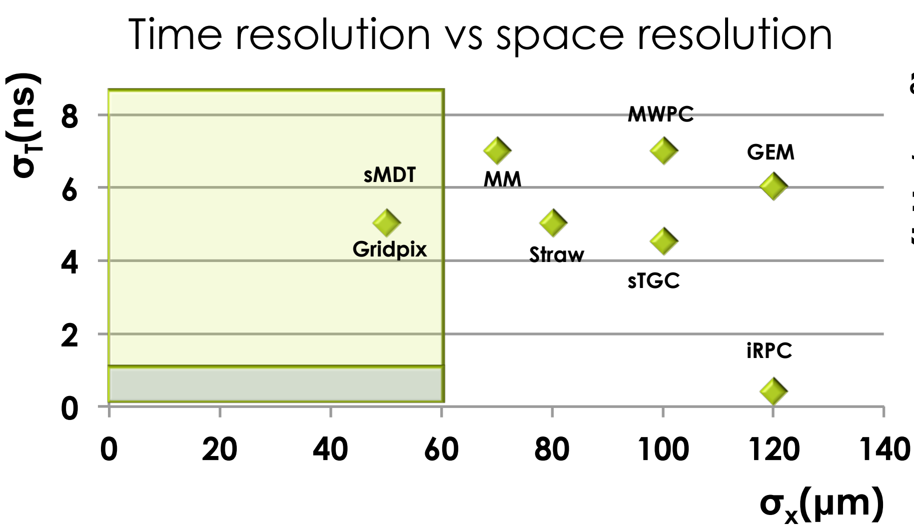
- PPC: iRPC are still unbeatable as timing detectors. Rate capability can be pushed to the desired value, space resolution for inclined tracks insufficient
- Gridpix ~OK, still limited to few cm^2, cost issue

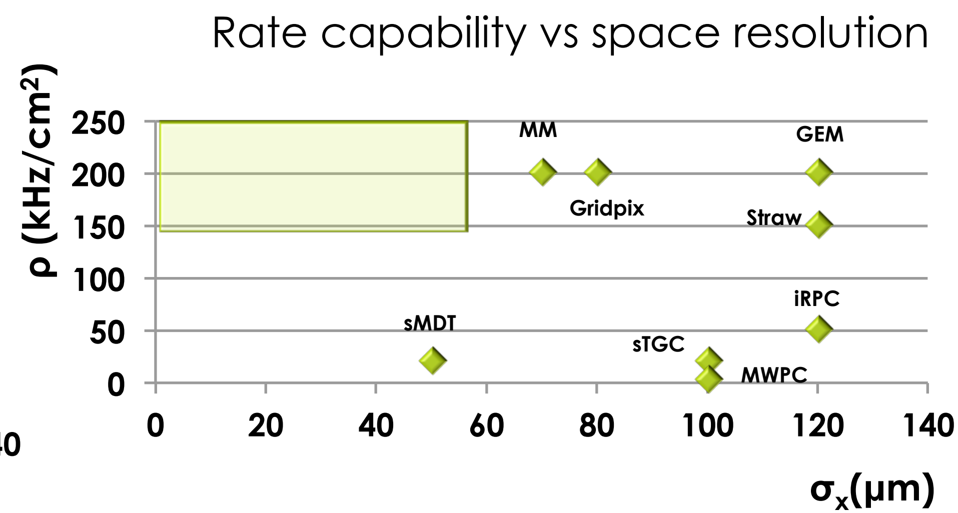
Preliminary conclusions - Endcap

- None of the existing technologies seems to be safely usable as single solution as trigger/tracking detector in the end-caps
- If BCID is required:
  - 25 ns BC: single technology conceivable with adequate R&D (MPGD, straw), but: is it wise?
  - 5 ns BC: iRPC for timing together with a tracking device (MPGD or drift tubes with improved rate capability)

State of art – Forward

- Requirements vs existing technologies
  - Shadow areas: requirements for σ_X, σ_T, rate capability (ρ)
    Green: 25 ns BC separation
    Violet: 5 ns BC separation
  - Dots: existing (or about to exist) technologies for large systems





Preliminary conclusions - Forward

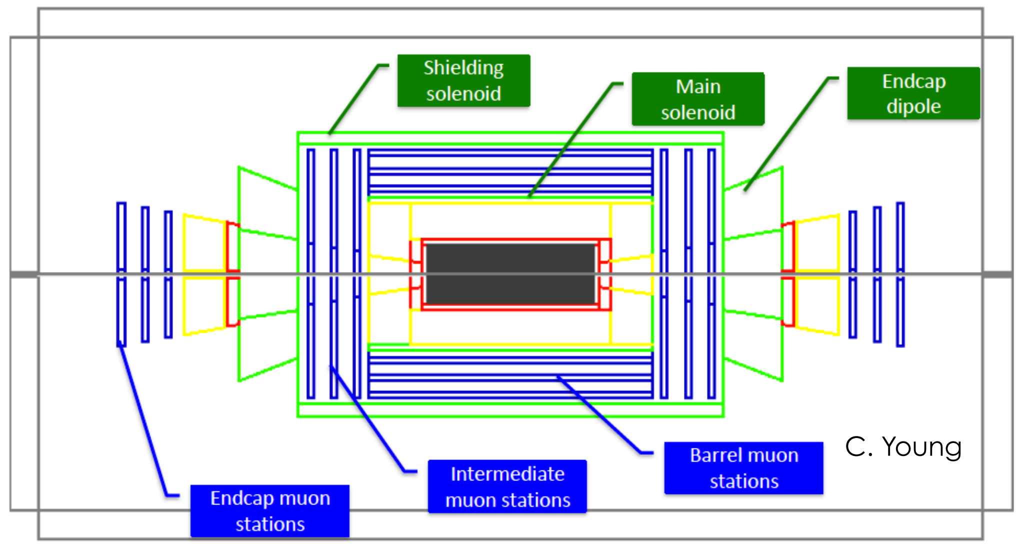
- Drift tubes and MWPC limited by rate. Straw tubes still ~ok for rate cap.
- MPGDs: rate can be reached with R&D, could in principle be used in a single-technology spectrometer. Time resolution ok for 25 ns BC not for 5 ns BC. Waiting for performance demonstration in ATLAS and CMS upgrades
- iRPC: Rate capability out of reach of current R&D
- None of the existing technologies seems to be safely usable as single solution as trigger/tracking detector in the forward
- If BCID is required:
  - 25 ns BC: single technology conceivable with adequate R&D (MPGD), but: is it wise?
  - 5 ns BC: pure large-size gaseous detectors with <1 ns time resolution and rate capability >150 kHz/cm^2 not available and not even in the sight of current R&D

Additional considerations

- The muon system for FCC must be reliable on 20-years time scale in an experimental environment 10 times hasher than HL-LHC
- The adopted detector(s) will be either newly developed ones or improved version of present technologies
- Redundancy seems to be a safe choice
- Two complementary detector technologies (e.g. CMS muon system or ATLAS NSW)
  - Timing detector with good spatial resolution can contribute to the tracking
  - Tracking detector with good time resolution can contribute to the trigger (BCID) at least in the 25 ns BC scenario
- For a 'mixed' spectrometer:
  - Integration aspects: alignment, trigger logic (if any, most likely no hw-trigger), FE elx, services will be more complex
  - R&D efforts (for detectors, electronics etc) will almost double
  - 'Social' aspect: detector community will not collapse to a single comprehensive R&D, more space for improvements and for more people to contribute

Some ideas

- Barrel/Endcaps
  - Single detector option: MPGD, Straw ??
  - Hybrid system:
    - Timing: PPC?
    - Tracking:
      MPGD, sMDT, Straw ??



- Forward
  - No option so far for a single technology: R&D needed
  - Hybrid system:
    - Timing: PPC up to η<3 ?? Solide states (or diamond) at larger η?
    - Tracking: MPGD?

R&D trends – personal view

- PPC:
  - continue development of iRPC with the goal of 100 ns/ 100 um / 50 kHz/cm2
  - Option of mRPC to be also considered
- Drift tubes and MWPC:
  - Rate capability should be further increased to be 'on the safe side'.
  - Switch from tubes to straw also in muon spectrometer?
- Micro Pattern Gaseous Detectors:
  - optimization for rate capability to be considered in the fwd region;
  - Improve time resolution;
  - Scale to large size for potentially interesting new technologies
- Solid state or gas/solid-state:
  - Interesting for the high eta region
  - Cost issue and scaling to large surface

Conclusions

- Gaseous detectors are the only viable option to be considered for a muon spectrometer at FCC-hh
- No solution exists today for a single-technology spectrometer
- The main issue to define is the BCID requirement at 5 ns BC separation
- A ‘redundant’ system seems the more solid solution to be considered as of now
  - Profit of fast timing detector together with precise tracking chambers
  - With a (hw-)triggerless readout the complication of different L1 trigger paths disappear (still two different readout paths)
- The design should not be defined now, but the definition of the ‘frame’ is needed to start focusing the efforts
- The time is (still) on our side: we should not reject a priori new ideas and be ready to consider solutions that now look unreasonable