h-h physics, experiments, detectors

Magnet concepts for experiments at a 100-TeV pp collider: Herman TEN KATE

Machine detector interface issues: Austin BALL *(CERN)*

Operation at shorter than 25-ns bunch spacing : Benedetto GORINI *(CERN)*

Radiation issues and tracking concepts: Werner RIEGLER *(CERN)*

Parton distribution functions for 100 TeV pp colliders: Juan ROJO *(CERN)*

V→jj studies with jet substructures**:** Maurizio PIERINI *(CERN)*

Dark matter studie: David COTé *(Arlington UT)*, Benjamin HOOBERMAN *(FNAL)*

Organisation and discussion of the future activities: Austin BALL *(CERN)*,
Fabiola GIANOTTI *(CERN)*,
ALL

h-h physics, experiments, detectors

Physics objectives drive the experiment design (see FG/DF at h-h plenary session)
- design is mechanically and dimensionally dominated by the magnet choices.

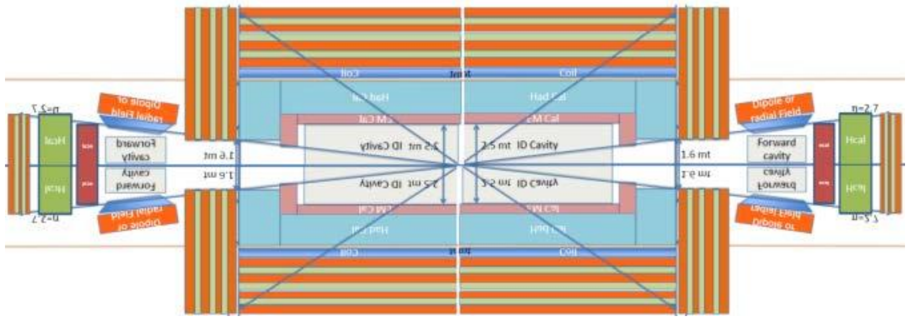
High p_T region (up to $\eta \sim 2.5$) : continue search for high mass states (up to ~50 TeV)
barrel & endcaps look like ATLAS/CMS
but BL^2 x 7 (for same sensor resolution)

Forward region ($\eta > 2.5$) : extend precision Higgs meas. to high η + high mass VV
new dipole spectrometer and forward calorimetry?
(or is this a separate experiment?)

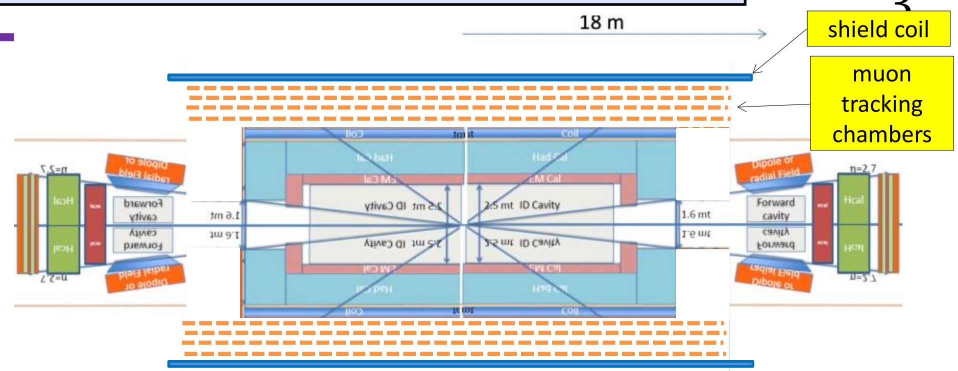
A few designs examined and simulated : at least 2 feasible options identified
others exist if trade off BL^2 increase for substantially improved sensor resolution

Construction, maintenance & operation determine cavern, shaft & surface infrastructure
Radiation environment has a big influence on the design; detailed simulations needed
ALARA requirements *must* be engineered into FCC hh GP expts & infra from the outset
Detector services (source of most unplanned interventions with little cooling time)
executed to a very high reliability & redundancy standard
Machine interface parameters to study are min bunch spacing & max length lumi region

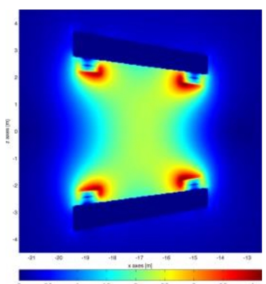
Long solenoid with dipoles

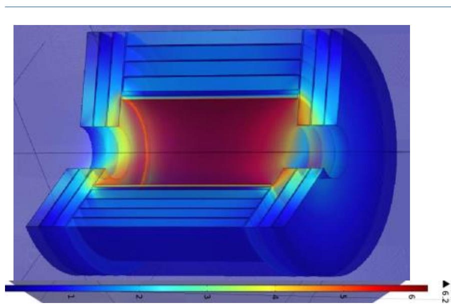


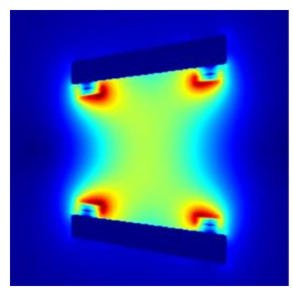
6T solenoid + iron yoke +2 T dipoles (54GJ!)

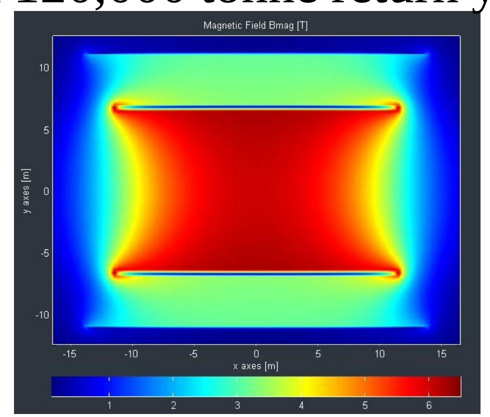


6T solenoid + 3T shield coil version (65GJ!)
+ 2T dipoles as before
(avoid 120,000 tonne return yoke!)

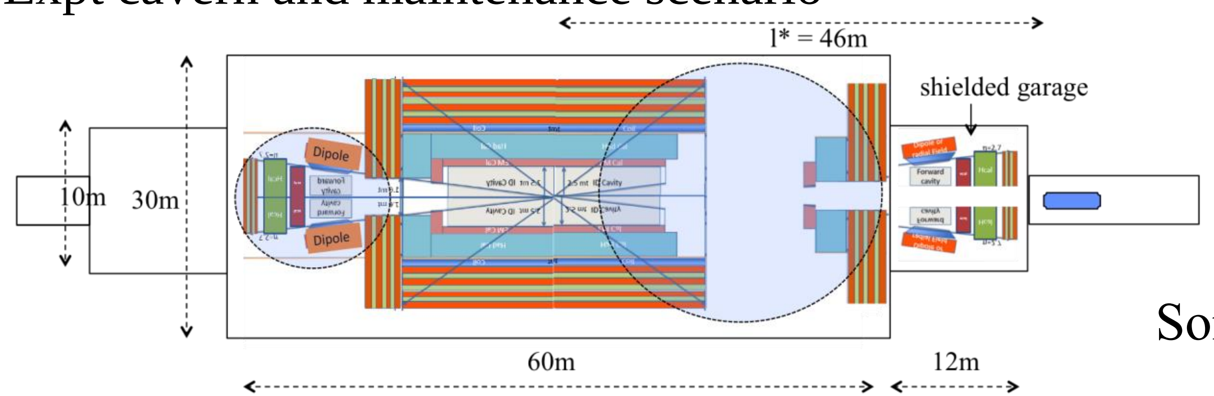






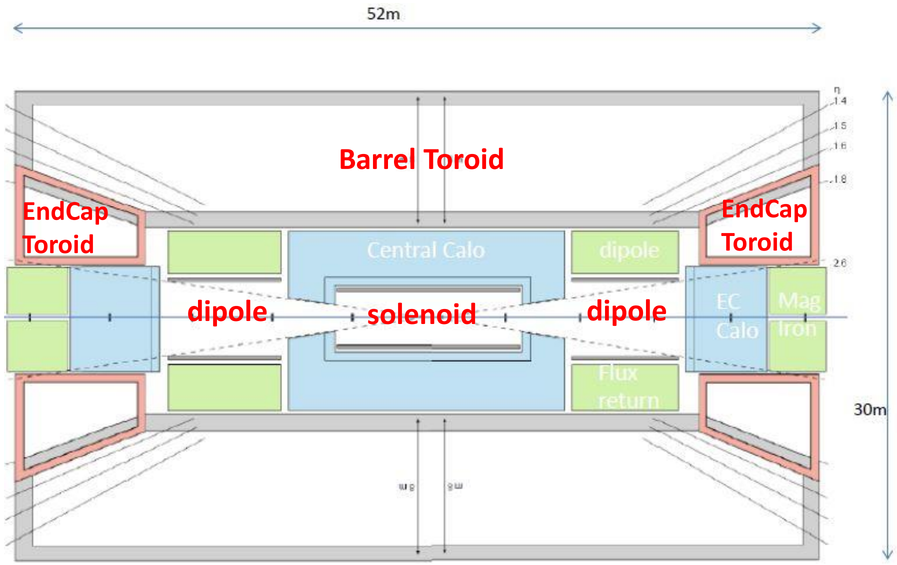


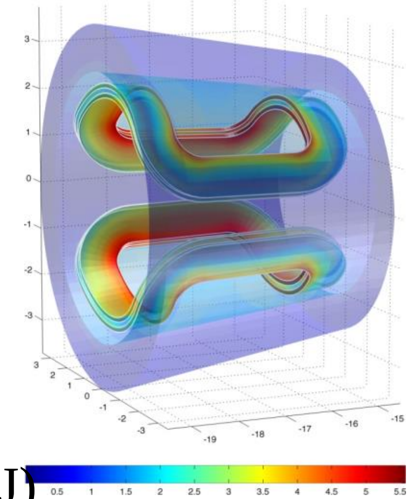
Expt cavern and maintenance scenario

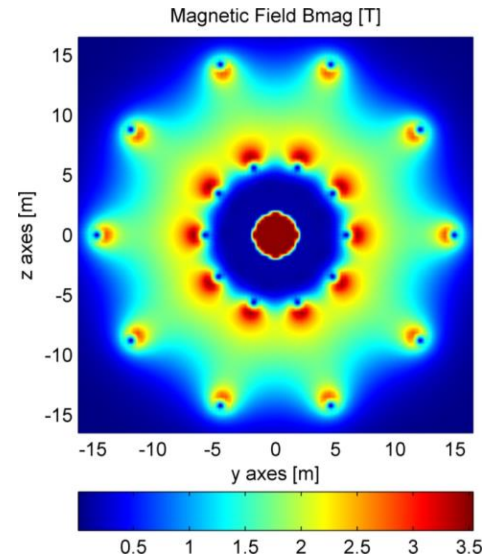


Some debate/bets on how fields sum…

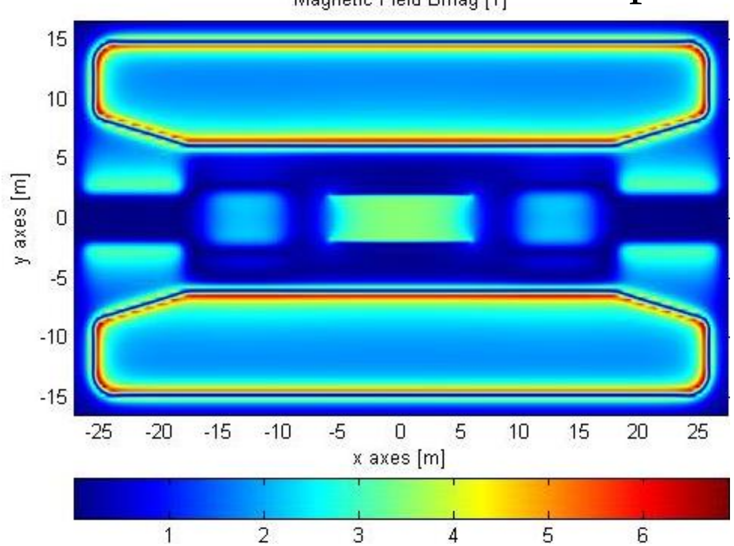
Toroid with diploles





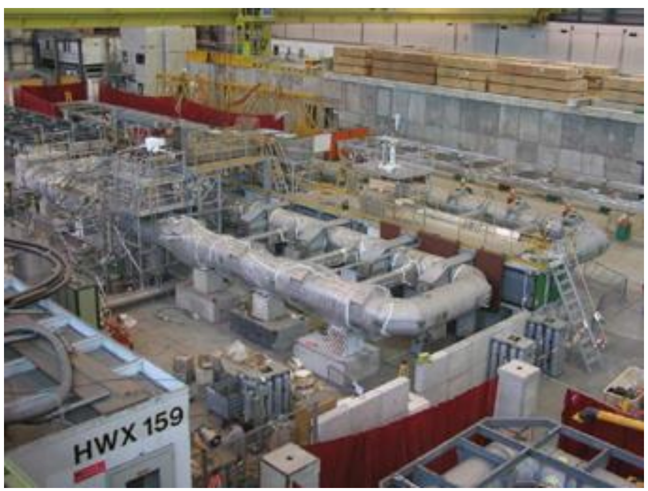


3.5T solenoid + 1.7T toroid +2T dipoles (55GJ)



cable in conduit conductor for toroids & dipoles

Construction ?



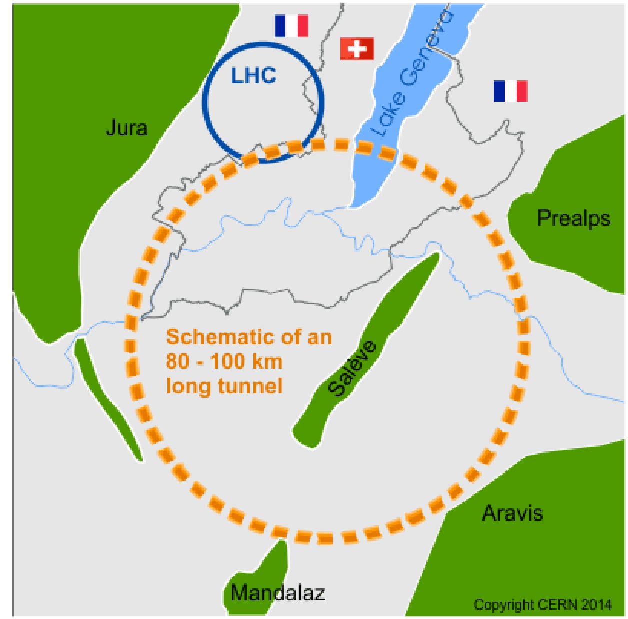
Preferred model would be worldwide modular construction
Feasible for FCC expt dimensions??

Expt location/surface site should allow:

- Access for heavy, outsize & unusual loads

-direct routing of large components to site from manufacturer.

-complete construction of large elements on site (surface or underground)

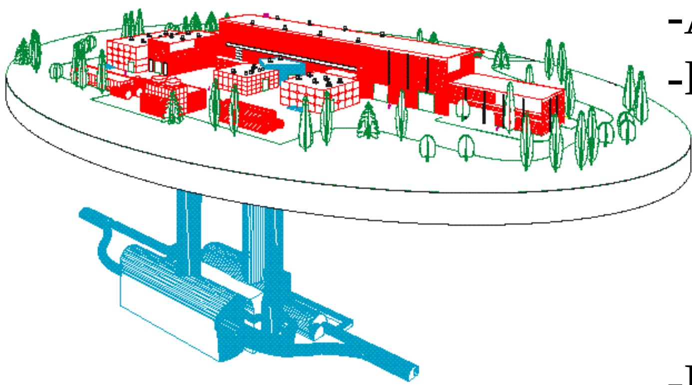


Assuming GP expt sites diametrically opposite, at least 1 site will need substantial autonomy

Surface buildings & caverns

Consider all conceivable applications of the tunnel & caverns over 50 years

eg exchange of whole expt conceivable or not?



-Adequate assembly hall(s) for surface pre-assembly

-Detectors Services ready for surface pre-testing

power

cooling (water + CO_2, no fluorocarbons!)

specialist gases (no fluorocarbons!)

detector environment control

-Detector maintenance laboratories and workshops

bearing in mind potential 50 year lifetime of site

-Storage facilities for assembly & maintenance tooling

spares for local infrastructure equipment.

Heavy lowering (a la CMS) after surface assembly an option or not?

:shared between detector and service caverns?

:shared between experiment and accelerator?

As many services as possible on surface (power, cryo(?), trigger or trigger-less)

-Can the service caverns be smaller than at LHC?

Shielding should allow service cavern to be accessed during operations at max luminosity

Radiation field cf HL-LHC

$$1\text{MeV neq Fluence}[cm^{-2}] \approx \frac{N_0}{2r[cm]^2\pi} \times N_{pp} \quad \text{Dose}[Gray] \approx 3.2 \times 10^{-10} \frac{N_0}{2r[cm]^2\pi} \times N_{pp}$$

Function only of distance from beampipe

Assuming: no magnetic field

: considering only primary charged hadrons from pp collisions

valid up to r~ 10cm, beyond that curling particles and neutrons

cf HL-LHC

pp xsect increases by 25%,

multiplicity by about 50%

FCC- hh

100mb inelastic pp crossection

dN/dη = N0 = 8

for 3000 fb^{-1} = 3 * 10^{17} events

a Pixel tracker layer1 at r=3.7cm will see

1MeVneq fluence = $3*10^{17}*8/(2*\pi*3.7^2)$

= $2.8*10^{16}$ cm^{-2}

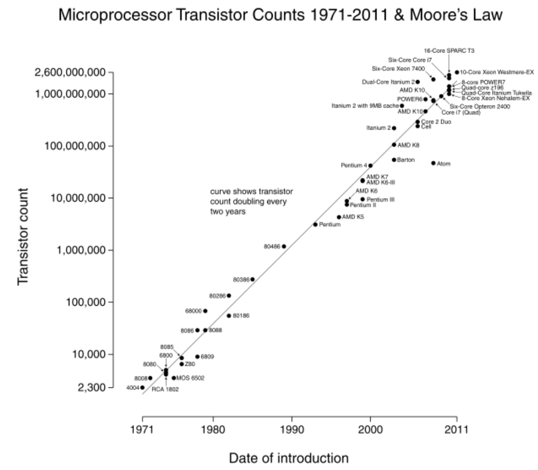
Dose = 3.2x10-8*2.8*1016

= 9MGy

only 2x the HL-LHC fluence and dose numbers

Detailed Fluka simulations needed detector design.

Trigger



Assume Moore's law applies from 2014-2034
factor 2^{10} = 1024 in transistor count & storage capacity

CMS assumes 5MByte/event for its HL-LHC detector
(at levelled luminosity of $5\text{x}10^{34}$)

At 40MHz bunch crossing rate
--> 200TByte/s into the online system for a triggerless readout.

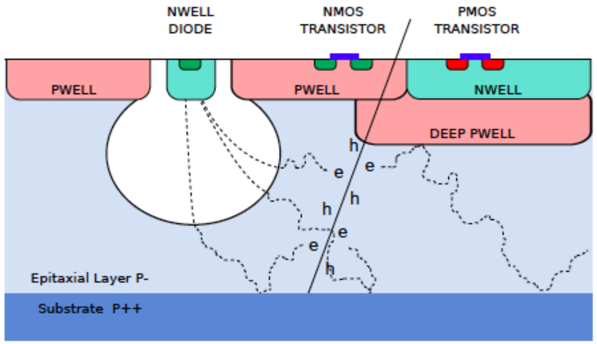
For 2022, a trigger-less readout is considered too challenging

But...assuming that the total track rate for FCC (100TeV) pp collisions is only a factor 2 larger, there is very little doubt that by 2035, an FHC detector can be read out in a triggerless fashion.

All data to the online system, synchronous or asynchronous.

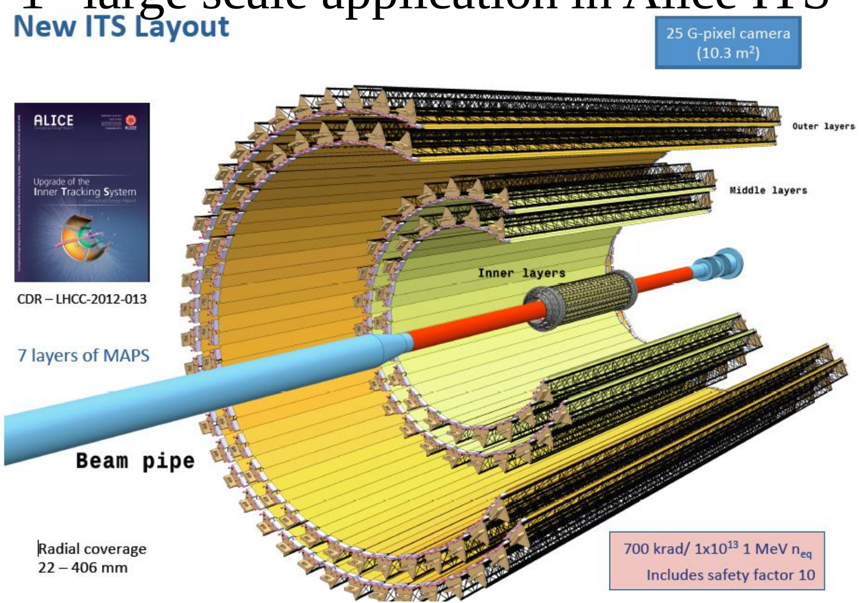
Tracking technology-pixel revolution

Hybrid --> monolithic: complex processing electronics integrated into the sensor wafer.



Schematic cross-section of CMOS pixel sensor
(*ALICE ITS Upgrade TDR*)

1st large scale application in Alice ITS



Dramatic decrease in cost.

Very low power consumption, possibly <100mW/cm^2 i.e. simple water cooling

Ultra low material budget <0.5% for inner layers, <1% for outer layers.

Questions to answer about speed and radiation hardness:

Present, integration time ~ 4μs (noise, electron diffusion) radiation resistance up to few 10^{13} neq.

Development (next 20 years) towards larger (full) depletion will improve speed and radiation hardness significantly.

Use 1 or 2 layers with ‘fast‘ pixels to do the BCID (25ns or even 5ns) and then match the other hits.

With a full pixel tracker of 20x20um pixels, pile up can be v. large before occupancy becomes a problem.

MAPS may also be the future for digital calorimetry

Fast timing layers in tracker

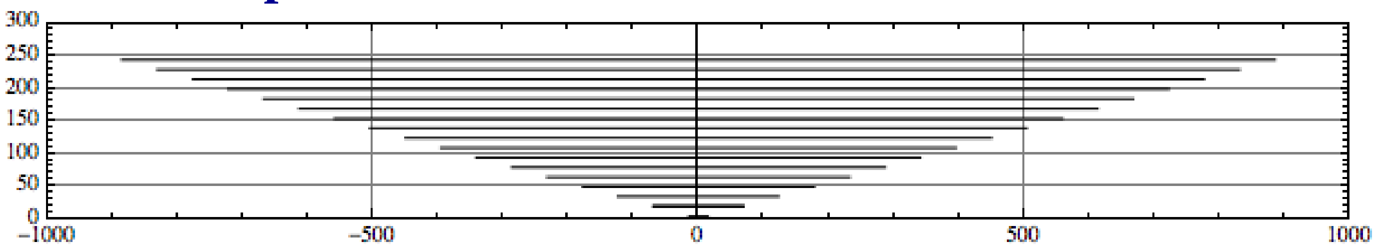
The TDCpix readout ASIC: A 75 ps resolution timing front-end for the NA62 Gigatracker hybrid pixel detector

CrossMark

A. Kluge*, G. Aglieri Rinella, S. Bonacini, P. Jarron[1], J. Kaplon, M. Morel, M. Noy, L. Perktold, K. Poltorak

CERN, Geneva, Switzerland

Time resolution < 200ps --> BCID feasible even for 5ns FHC bunchcrossing.



Tracker cylinders from η = 0 to 2
17 layers at radii 4+n*15cm (n=1 to 16) first at 4cm, last at 244cm, total area = 1600m^2

First 4 layers ‚'fast' for BCID, 13 layers "slow" e.g. 100ns monolithic pixels (neq <10^{15}cm^{-2})

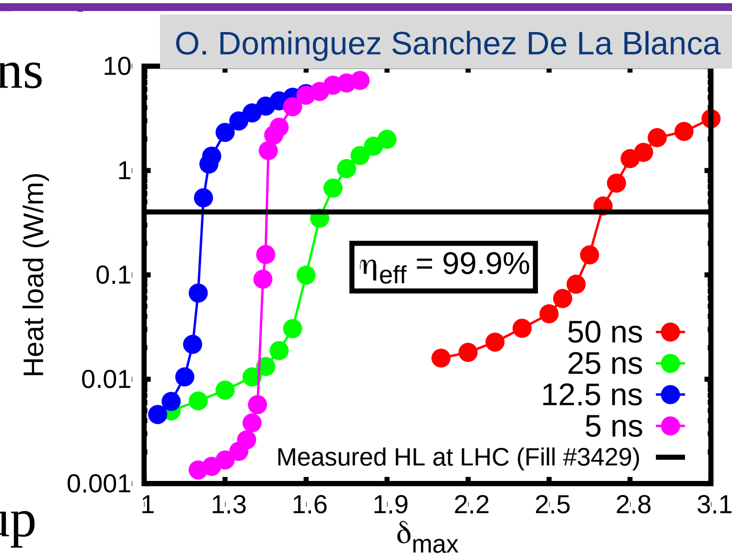
Including forwards discs around 3000m^2 = 6 times CMS = 300 times ALICE
3000m^2 with 20x20um pixels = 7500GPixel = 7.5TPixel

Estimate 750Tbytes/second to online system

Bunch spacing --> 5ns ?

Would 5ns bunch spacing give better operational conditions
(5ns may be only viable spacing below 25ns – e-cloud)
Balance of in-time pileup vs out-of time pileup

Bunch spacing	25ns	5 ns
Pileup	170	34



By reducing emittance, get same lumi at 5 x lower pileup

Alternatively (practically) maybe x 2 lumi at same pileup (170)

To profit, need fast technology for tracking, calorimetry & trigger (if any)
--> higher power, high granularity, digital systems

R & D needed on: high-speed, low power, radhard links (will not come from industry)
: fast calorimetry (eg Si based sampling calo)
: fast, rate tolerant muon trigger chambers
: FE zero suppression - combat x5 in analog data volume (or go digital)
: various DAQ options including 40MHz with time-stamping

Bunch spacing --> 5ns ?

Processor clocking speeds and timing reference distribution not showstoppers

Physics studies needed :

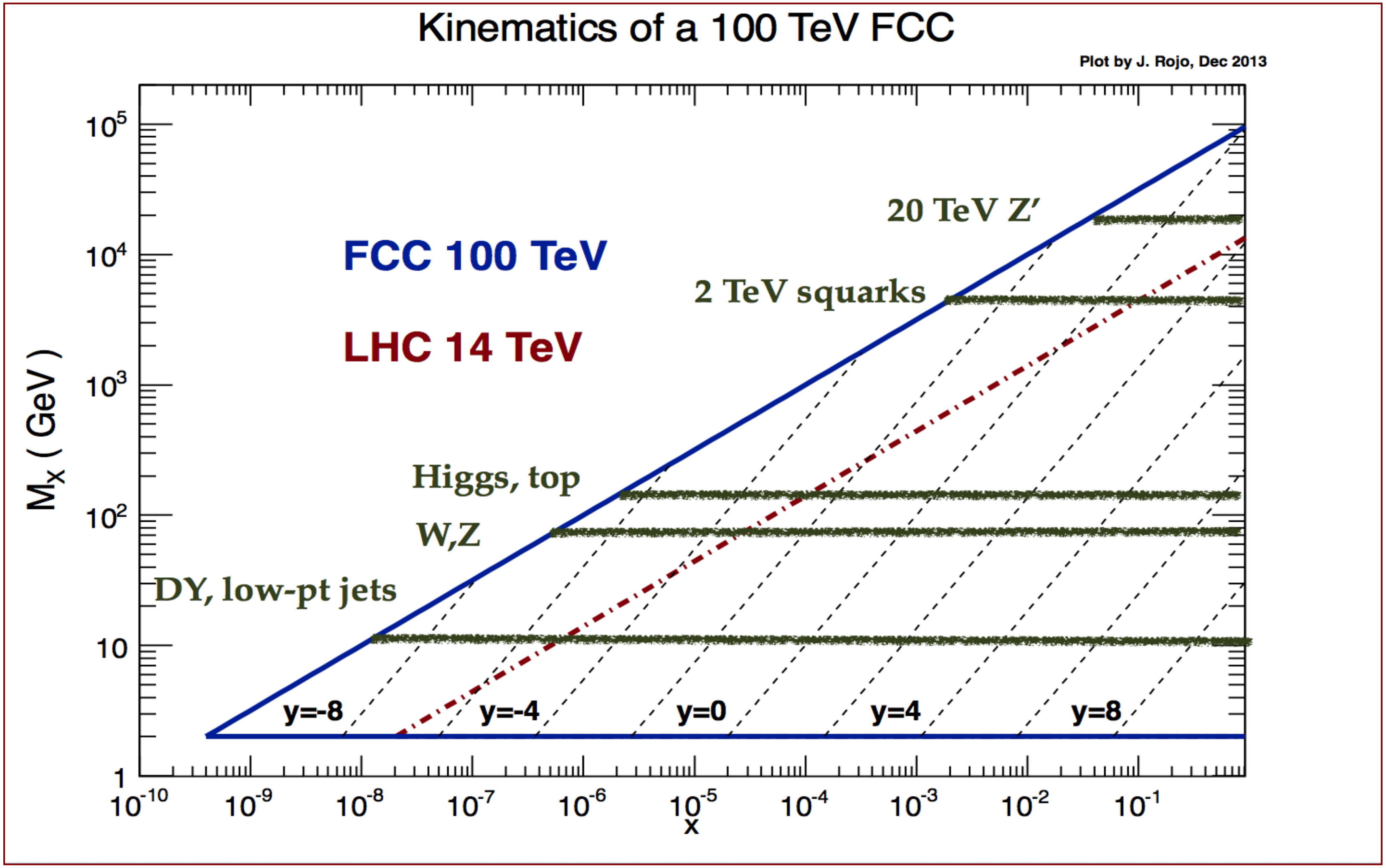
- is 5ns worth it without lumi increase (eg back-to back jet tagging for VBF)?
- what happens at 5 times lumi benchmark? (even if presently unrealistic)
- comparison of different trigger approaches, L1 1MHz, ÷ 10, or triggerless
- effect of low momentum tracks looping for several bunch crossings
- performance of existing calorimeters vs new technology (eg Si sampling)

+ Radiation simulations needed to provide input on backgrounds

Parton Distributions at a 100 TeV Hadron Collider

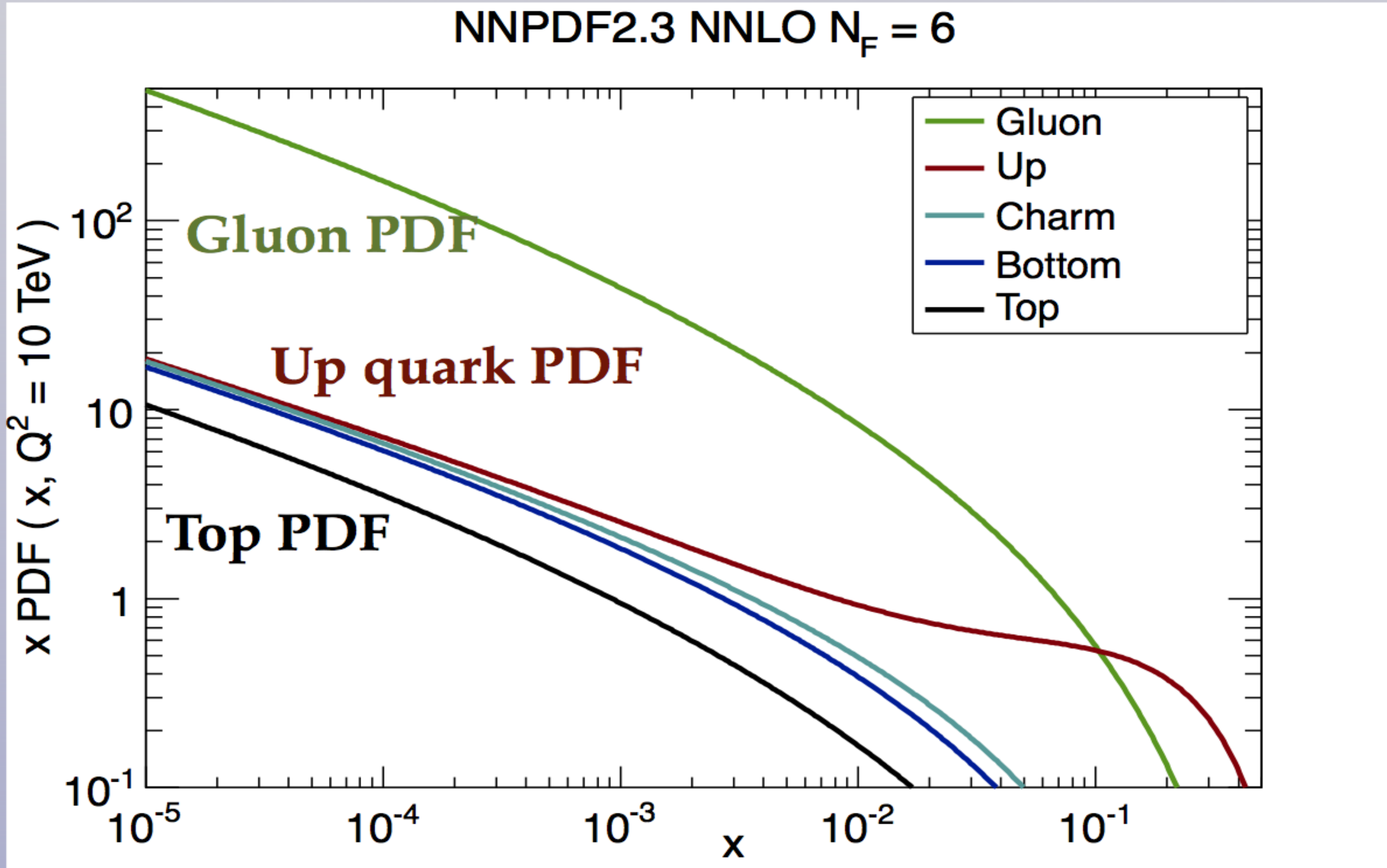
Juan Rojo
CERN, PH Division, TH Unit

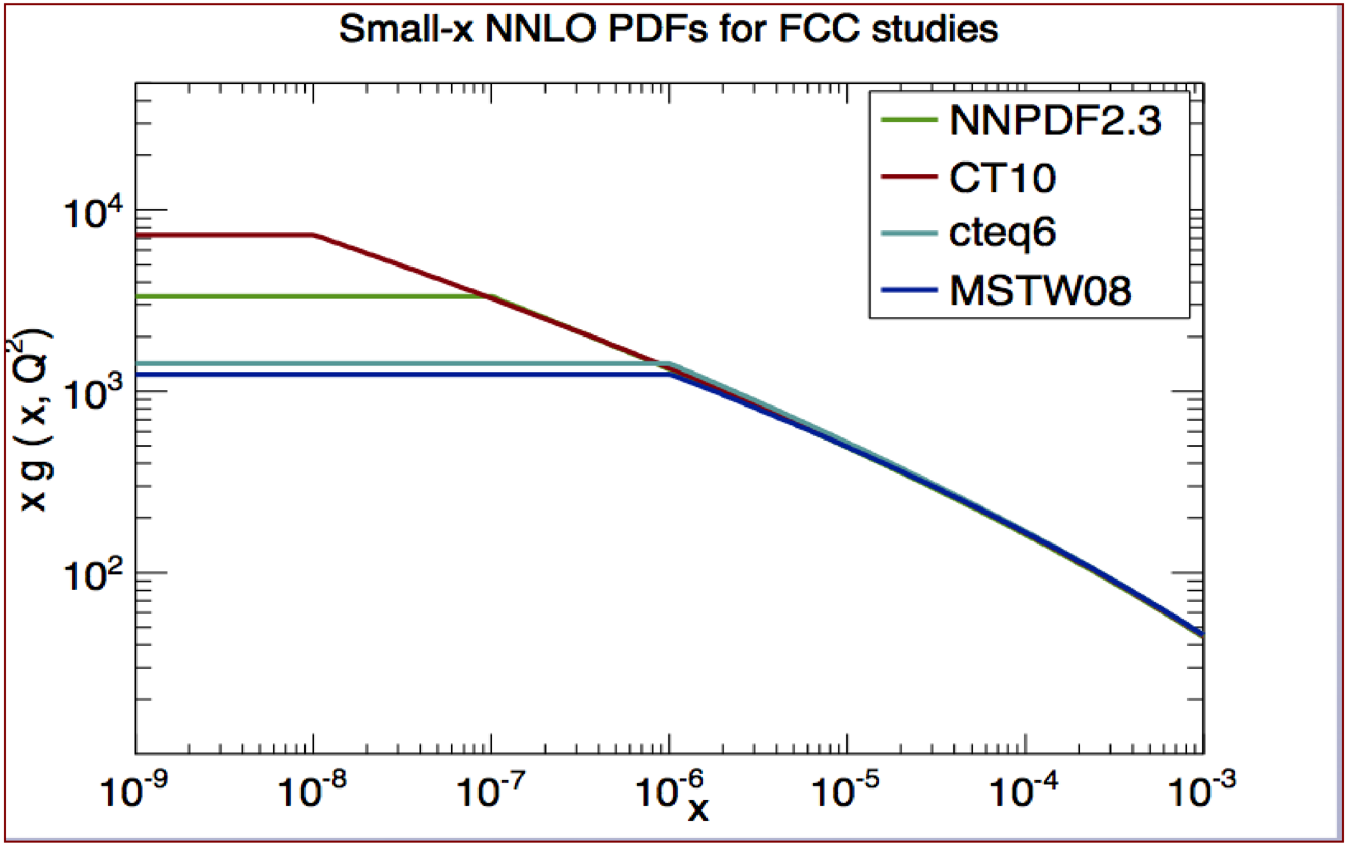
How well are PDF known in the x range to be explored by such a machine ?
Can we extrapolate from present measurements ?
What PDF sets behave well in the new regime ?



- ❑ Much larger x range (smaller values, down to 10^{-8})
- ❑ Current PDF sets have ~ no constraints below 10^{-4} or for M >> 1 TeV → need QCD evolution (DGLAP equations) to extrapolate (while waiting for more LHC data ..)

* At 10 TeV, the top quark PDF **t(x,Q)** is only a **factor 2 smaller that all other quark PDFs** (charm and bottom are very close to light quark PDFs): should be included in theoretical predictions





Some PDF "frozen" below 10^{-6} → not a fundamental problem
→ A group of people will provide a set of PDF for FHC-hh studies

Summary and Outlook

- **Parton Distributions** play a central role at the LHC program, will continue to do so at a **Future Circular Collider at 100 TeV**

- Many new **qualitative features of PDFs** need to be studied: **top PDF,** PDFs at very large-x, **PDFs with electroweak corrections, PDFs with high-energy resummation**

- It will be useful to provide **specific PDF sets** for FCC studies, with suitable **extrapolations at very small and very large-x** as well as to a **very large Q^2** (and include top PDF)

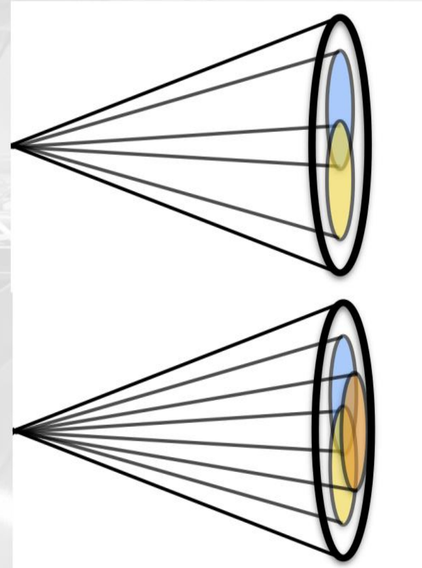
- A **polarized mode of the FCC** might provide a unique way of **characterizing BSM dynamics** uncovered in unpolarized collisions

$X \rightarrow VV$ reconstruction with jet substructure at a 100 TeV Collider

Maurizio Pierini
CERN

The Idea

- At large boost, quarks from W/Z/H/top merge into one jet
- The jet has characteristic features to be distinguished from ordinary QCD jets
- An effective discrimination requires the capability of identifying the jet constituents with good momentum/energy and angular resolution
- This could imply a constraint on the detector design (e.g. granularity of the calorimeters)
- In this talk, the case of a RS graviton decaying to ZZ or qq/gg is considered, to set a benchmark for future studies



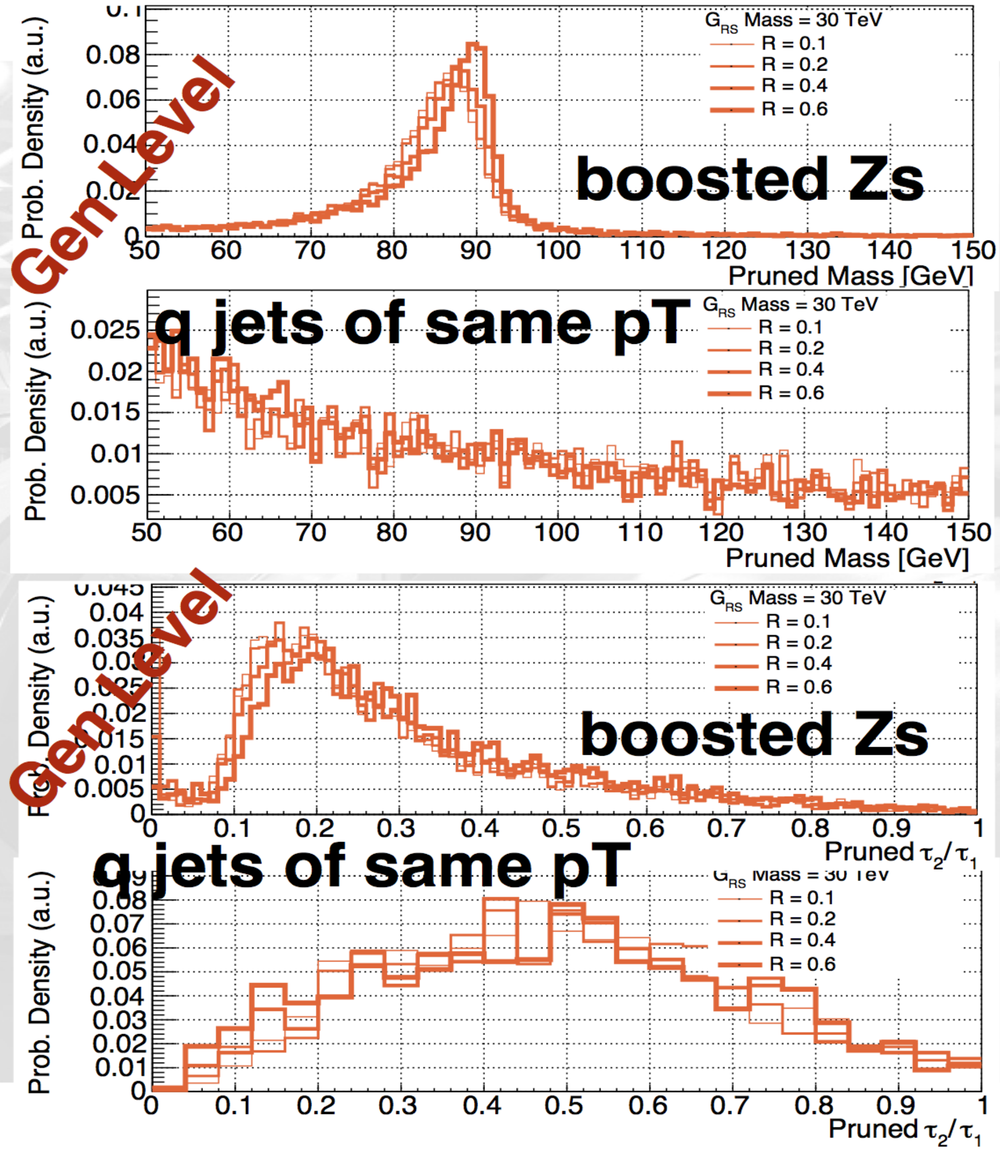
3

- Capability of reconstructing jet sub-structures allows discrimination between QCD jets and jets coming from the decay of a boosted objects (W, Z, H, top) → need to resolve partons below $\Delta R < 0.05$
- Detector granularity and resolution may allow discrimination between W and Z (top and H are easier …) à la LC → important e.g. for $V_L V_L$ scattering

Discrimination Handles@100 TeV

- The (pruned) Jet Mass
  - jet mass computed after removing soft radiation (jet grooming)
  - Works better than ordinary mass (which does not peak at 0 for bkg)

- The jet substructure
  - Discriminate jets according to the distribution of its constituents around jet axis
  - Several variables proposed. Here N-subjettiness used (as in CMS)



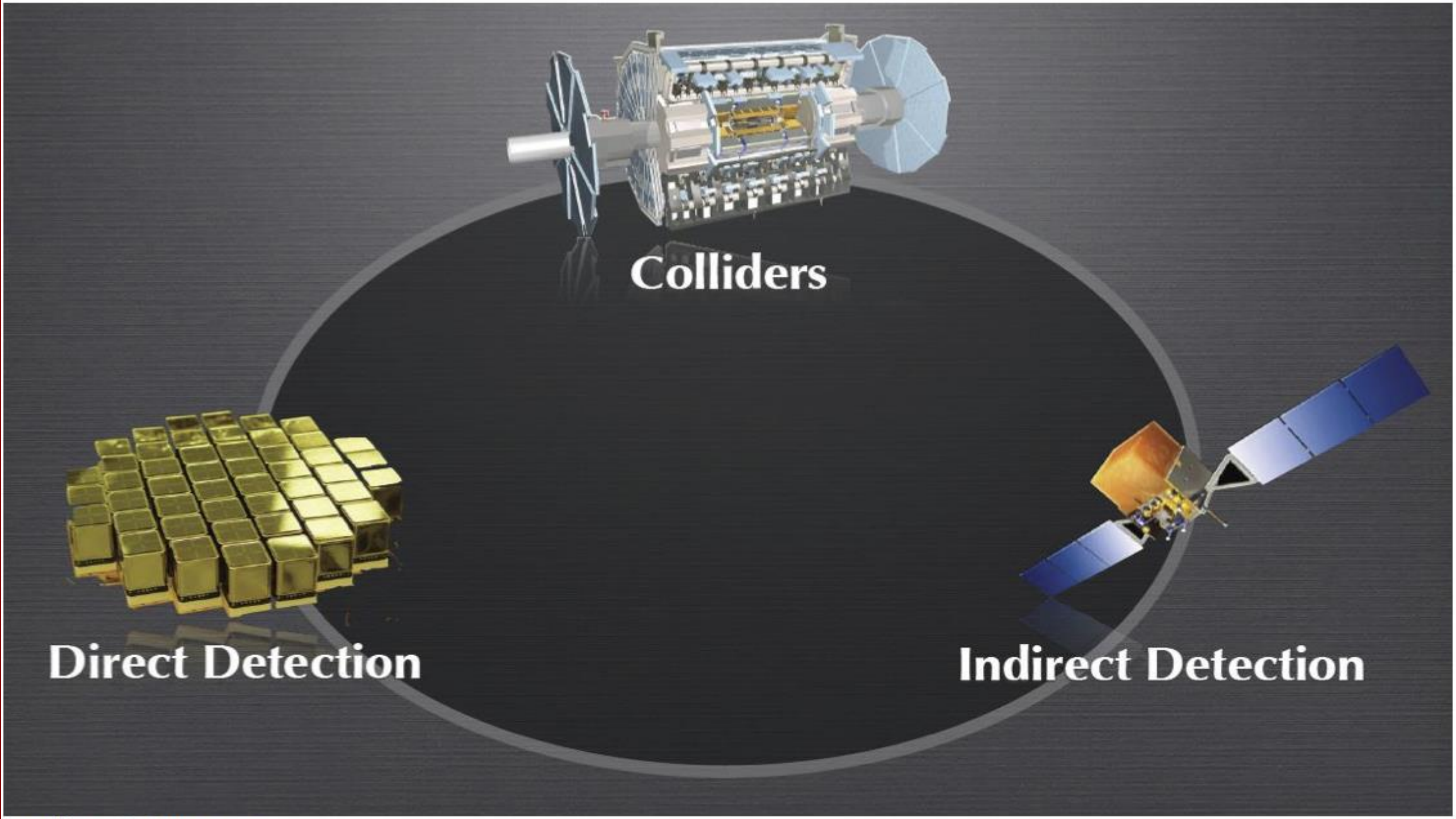
Conclusions

- Boosted W/Z/H reconstruction with jet substructure provides a good physics case to study the performances of a detector design
- This is a new topic, which comes with new needs (and new implications on the detector)
- A good jet energy resolution is still fundamental
- In addition, a good subject reconstruction points to the need of good angular resolution (particularly in the tracker) for a good jet mass resolution (main ingredient in commonly used taggers)
- Substructure information with only tracks shows good performances (so far), which makes life easier
- NEXT: evaluate the added value of high granularity in ECAL, and eventually in HCAL
- NEXT: evaluate the impact of the PU on the discrimination

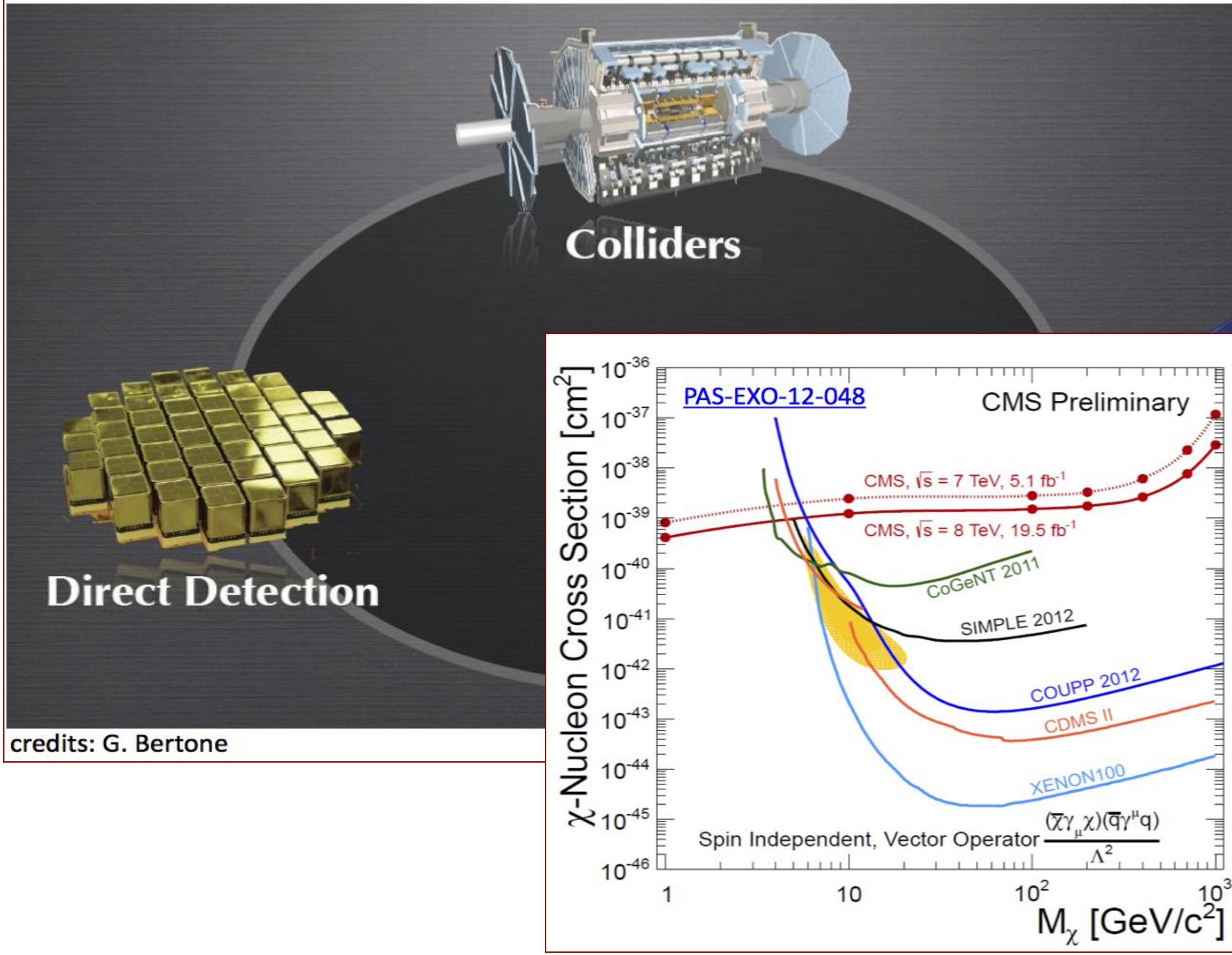
Dark Matter at a Future Hadron Collider

David Côté (UTA), Ben Hooberman (FNAL),
Filip Moortgat (CERN)

Future Circular Collider Study Kickoff Meeting



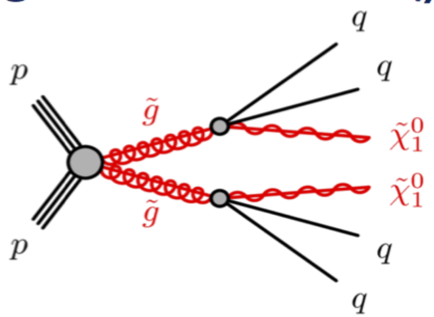
credits: G. Bertone



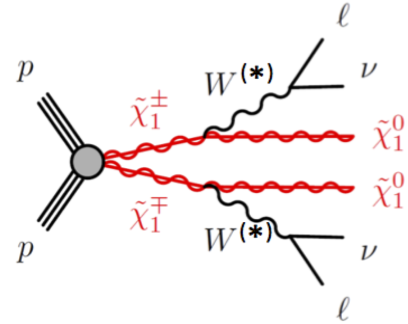
credits: G. Bertone

Dark Matter production at pp collider

SUSY: lightest neutralino (χ^0_1) is WIMP dark matter candidate



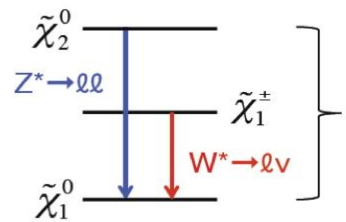
strong production



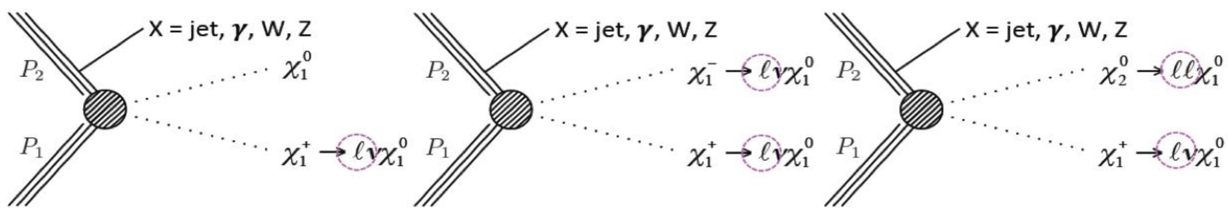
electroweak production

Pure Higgsino scenario

motivated by SUSY naturalness.

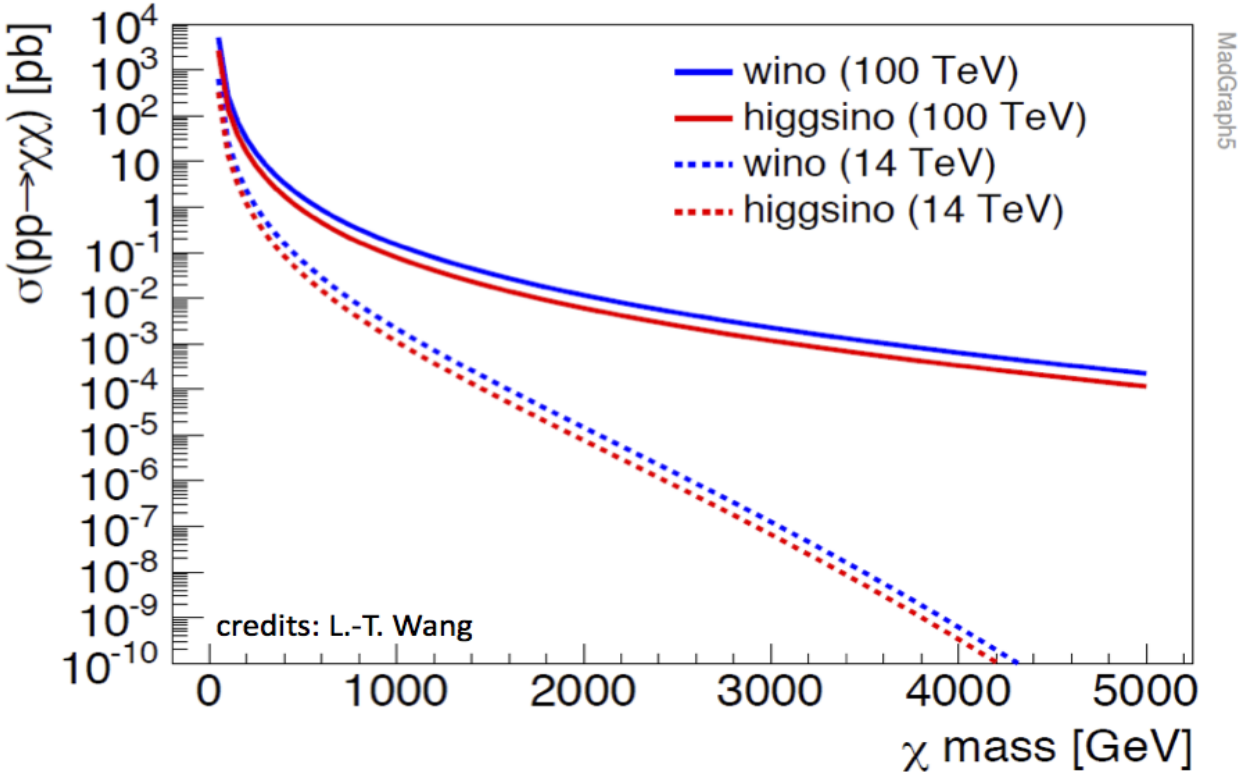


~pure higgsinos:
typical ΔM ~ few GeV
→ additional leptons



- Augment mono-X searches with additional leptons to improve sensitivity to wino & higgsino DM?
  - Probe as low in lepton p_T as possible to target small ΔM

Electroweak SUSY @ 100 TeV

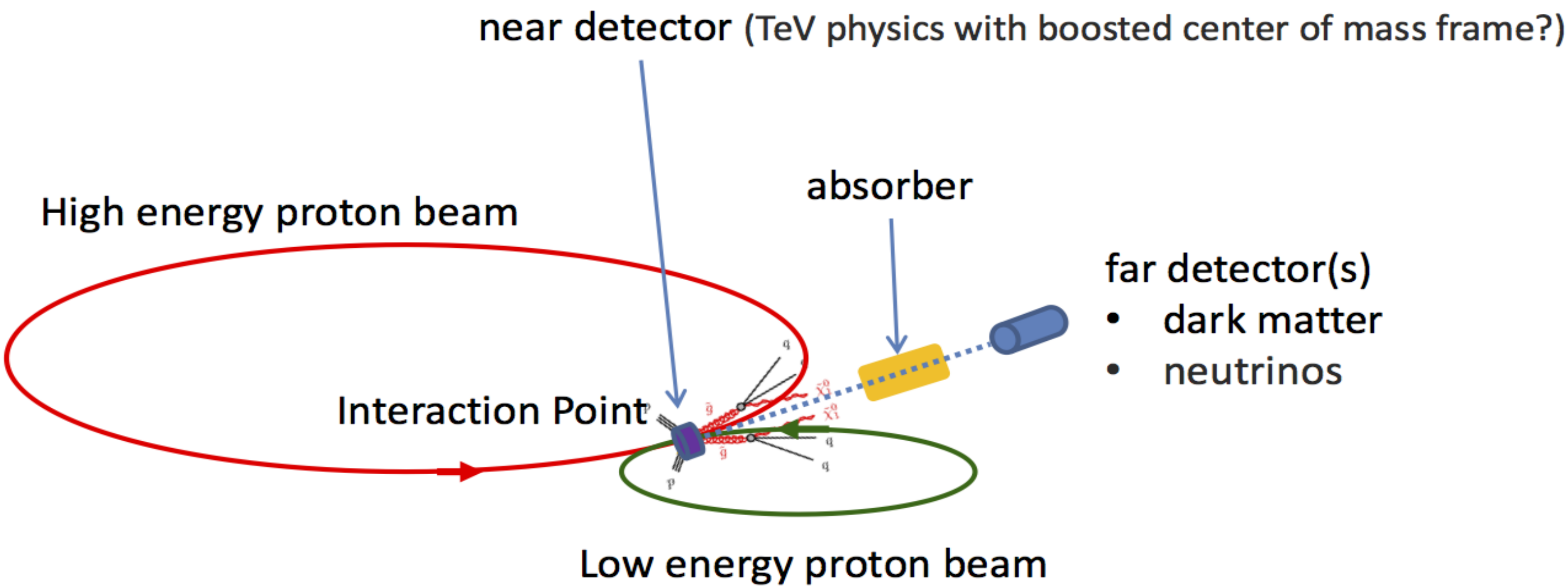


Expecting large improvements!

A few studies already:

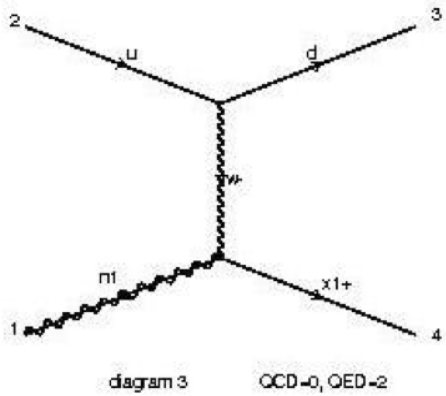
- BSM physics opportunities at 100 TeV
- LPC meeting on future 100 TeV proton collider

DM Beam from Asymmetric Collider

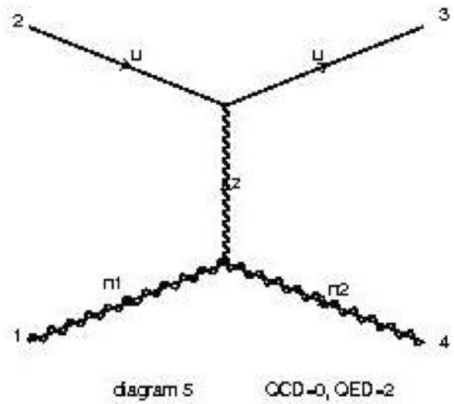


	E_{high} [TeV]	E_{low} [TeV]	E_{cm} [TeV]	
FHC→Fixed Target	50	0.001	0.3	insufficient E_{cm}
FHC↔LHC	50	7.000	37.4	promising!
FHC↔Super-SPS	50	3.000	24.5	

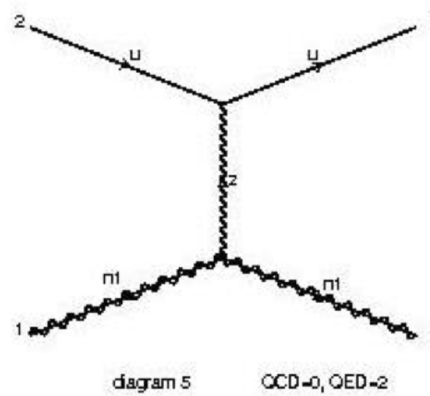
Direct detection of DM from collider



σ = 17.5 pb



σ = 4.5 pb



σ = 1.0 pb

E_χ	σ_χ
43 TeV	23 pb
27 TeV	11 pb
12 TeV	2 pb
2 TeV	10^{-7} pb

pMSSM model #9515 at 43 TeV (FHC↔LHC), see 1307.8444 and backup.

Inelastic parton interaction: jet, $W^{(*)}$+j, $Z^{(*)}$+j signatures!

- dramatic cross-section increase w.r.t. nucleus recoil
  - strong energy dependence
- completely different detector design
  - look for jets + leptons instead of nucleus recoil

Dark Matter Detector @ FHC

- Assume that dark matter (DM) is produced by the future collider, study the possibility of adding a new type of detector to perform a direct observation of DM interaction with ordinary matter
  - controlled DM production <u>and</u> detection under laboratory conditions!
    - unique un-ambiguous identification of dark matter
      - direct detection from space: don't know the origin of the observed signal
      - E_T^{miss} signature: don't know the nature of the un-detected particle(s)
  - if successful, such a detector would allow:
    - absolute measurement of dark matter interaction cross-section
    - possible measurement of dark matter mass from time-of-flight
    - possibly find scenarios where dark matter is invisible for ATLAS & CMS but visible through direct detection
    - bread & butter neutrino physics in the TeV regime
- Two possible experimental setups:
  - symmetric collider
  - asymmetric collider producing a dark matter beam

Looking forward

Investigate **different options** in all technical areas, **taking a broad view**
Expressions of interest over next few months (keeping single forum for now?)

- Meeting page for FCC-hh
- http://indico.cern.ch/category/5258/
- Mailing list:
- fcc-experiments-hadron@cern.ch

Joint work needed between FCC WBS categories :
"Physics & Experiments"
"Infra and Operations"
"Accelerators"

Engineering Design, integration and simulation resources will soon be needed.
(possible synergies with HL-LHC coordination/ Project Office)

eg Radiation & magnetic field simulations
fluences (with self service interpolation for detector designers)
estimations of dose rates and activation levels for various lumi & cooling times
shielding design based on detector background & irradiation tolerances
estimation of beam induced backgrounds
Magnetic field maps with detail extending to fringe field
Pile-up mitigation strategies eg wrt luminous region, bunch spacing etc.

Then…. Working groups to be set up in close contact with e-h and e-e
exploiting synergies and potential common application.

Possible evolution into hh detector WG's

Initial break-out could be into somewhat coarser groups than those in the WBS eg….

Magnet design

Trigger DAQ, Controls & Computing

Barrel-endcap: Tracking, Calorimetry, muon identification

Forward: spectrometer and calorimetry.

Safety, Supporting systems, Infrastructure & Interfaces:

eventually expanding into a revised full WBS, eg
Safety, Supporting systems, Infrastructure & Interfaces:

- safety and detector protection
- radiation simulations, fluences, shielding, dose rates, activation
- caverns and surface facilities
- detector construction, maintenance procedures & dose minimisation
- interfaces to Accelerator, including
  - LSS beamline, bunch structure & luminous region, beam monitors, pile-up mitigation
  - beampipe & vacuum system etc..