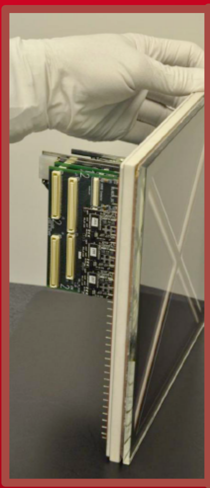
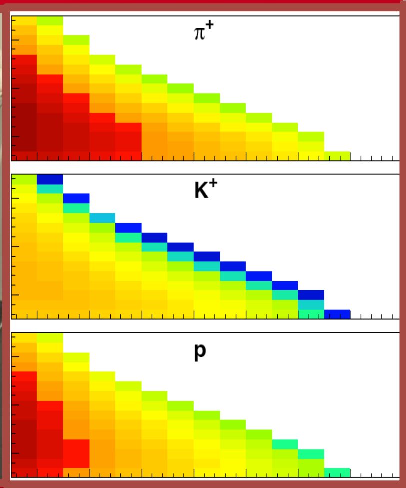
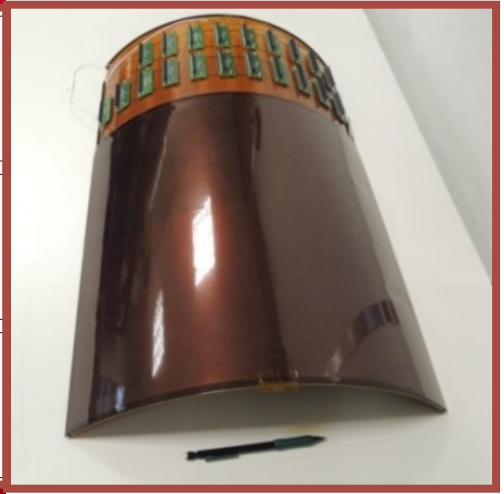
DE LA RECHERCHE À L'INDUSTRIE

NextDIS : Challenges for next-gen DIS facilities







- The next-gen facilities : LHeC, EIC
- Detector R&D : Micromegas, RICH
- Monte-Carlo simulations
- Financial aspects

<u>Collaboration of 22 Institutes/Universities :</u>

CEA-Irfu Saclay, CNRS/IPNO, CNRS/CPHT, CNRS/LPT, NCBJ, INFN-LNF, U Santiago, UPV-EHU, U Antwerpen, U Birmingham, INFN-RM1, INFN-FE, INFN-PV, U Mainz, ISS, U Tübingen, U Jyvaskyla, INPK/PAN Cracow, ULB Brussels, U Granada, U Glasgow, U Huelva

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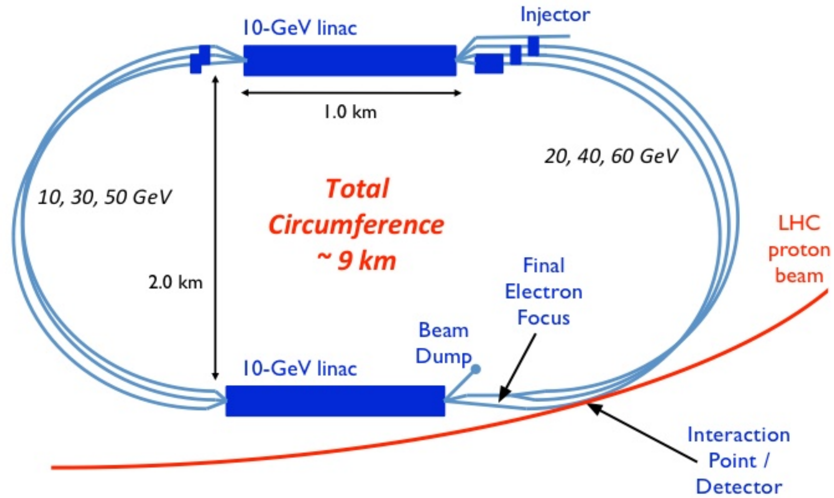
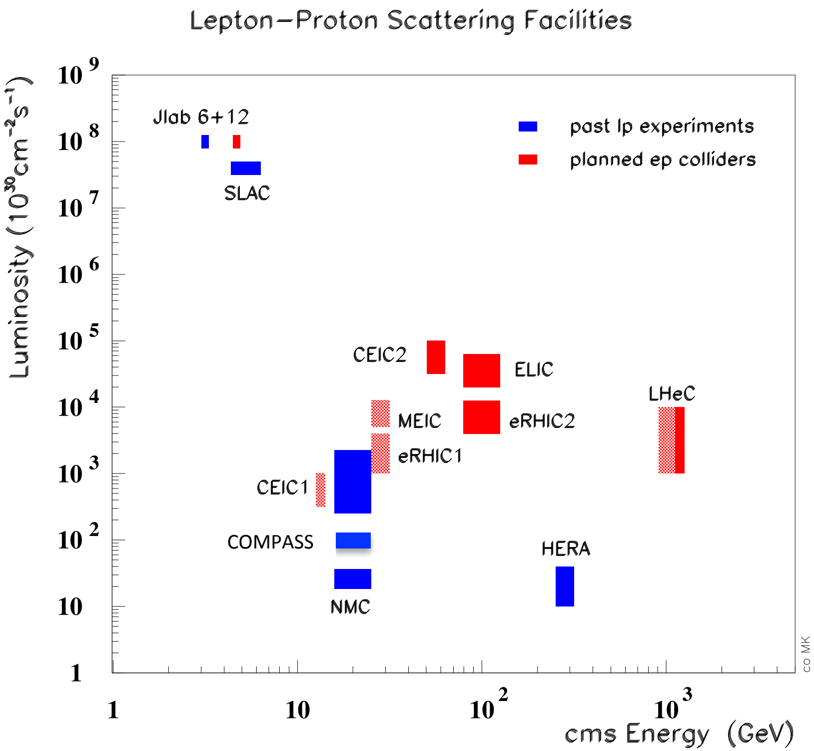
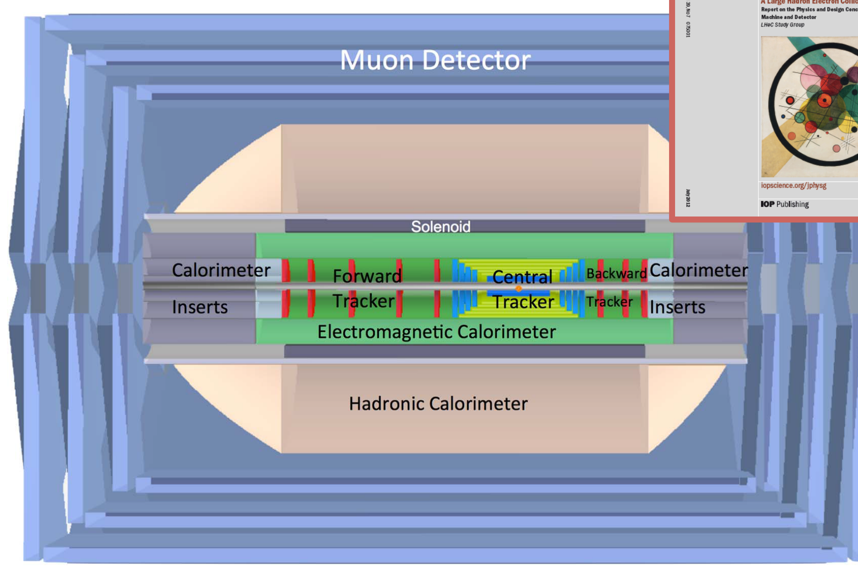
Next-gen DIS facilities : (1) LHeC

New *e-p/e-A* collider using the LHC beams against $e^{\mp}$ from an energy recovery linac
Synchronous *e-p/e-A* & *p-p* : ~2025 to ~2035



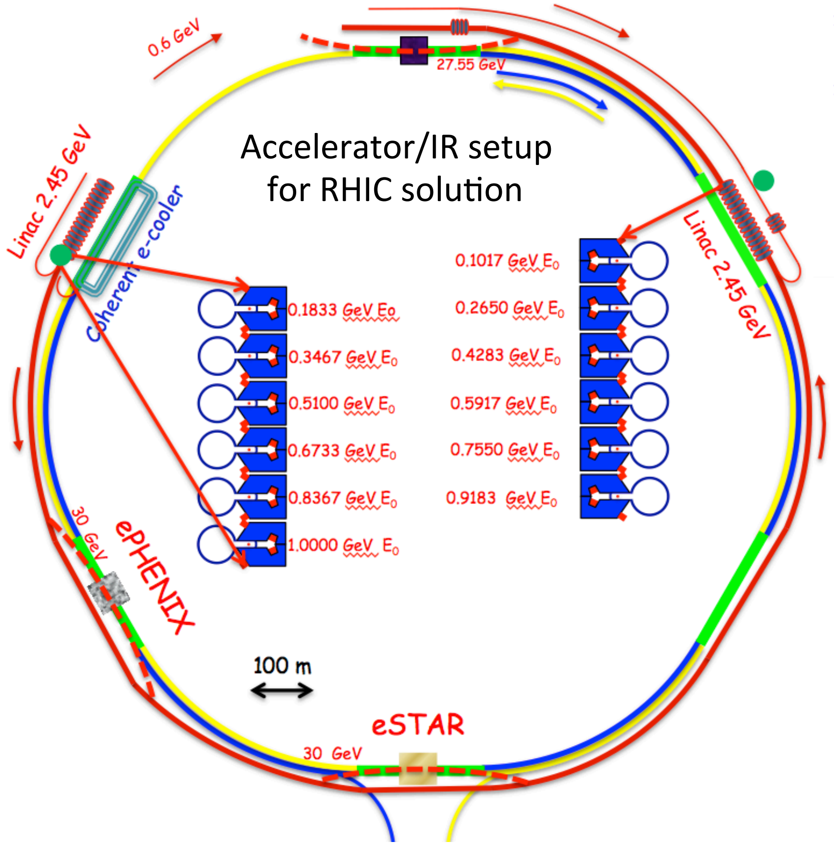


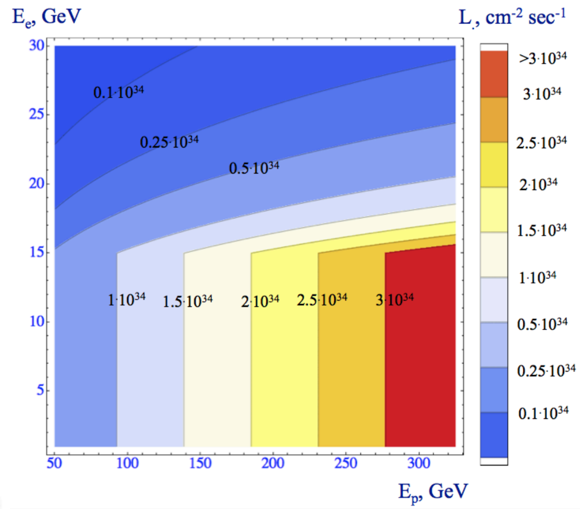
Inside NuPECC Long Range Plan

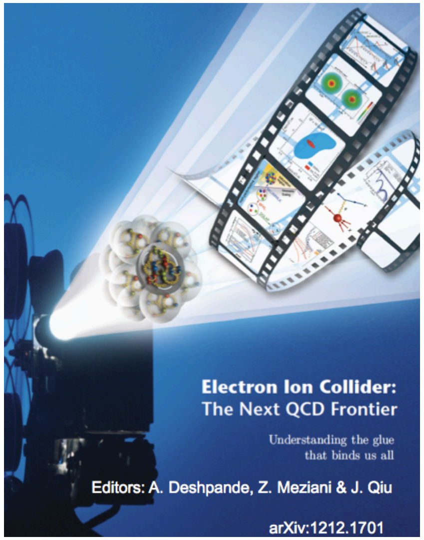


New **polarized** *e-p/e-A* collider using existing RHIC ions or CEBAF electrons, $E_e \times E_p$ = 5x100 -> 20x250 GeV^2

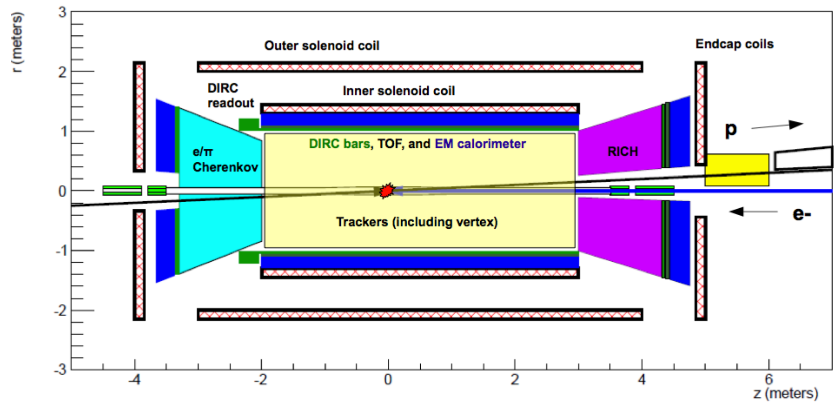
Start of operation at the earliest: ~2025



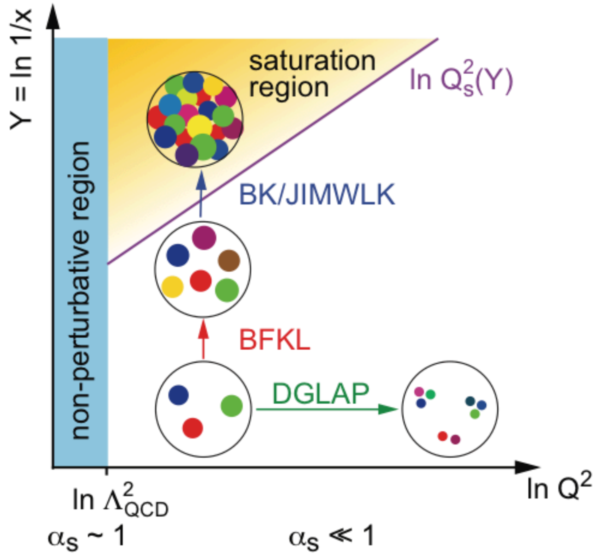




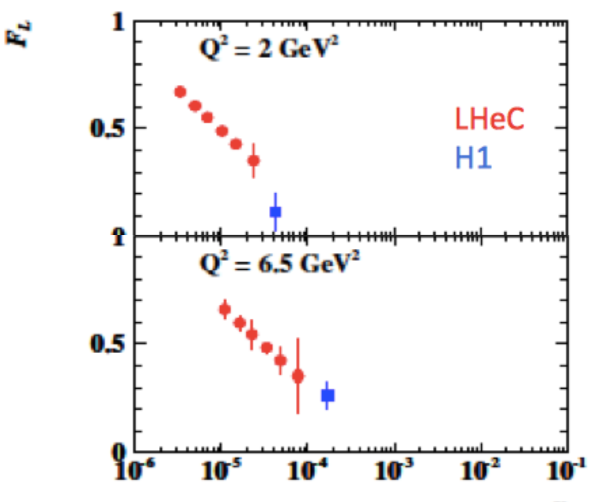
Current detector setup for JLab solution



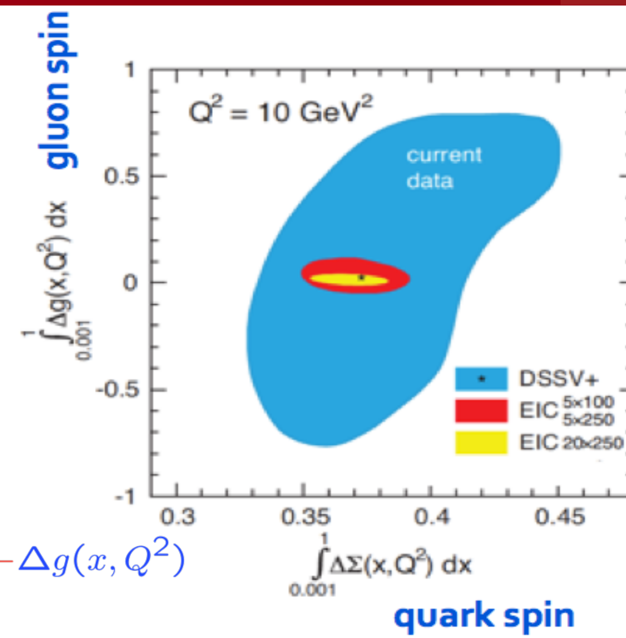
Some examples of our interest in future DIS facilities



> Gluons are densely packed in the transverse plane
> Recombination limits the number of gluons >> **Saturation**
> Precise measurement of F_2 and F_L : smoking gun for saturation
> Gluon distribution measurement down to x~10^{-5}

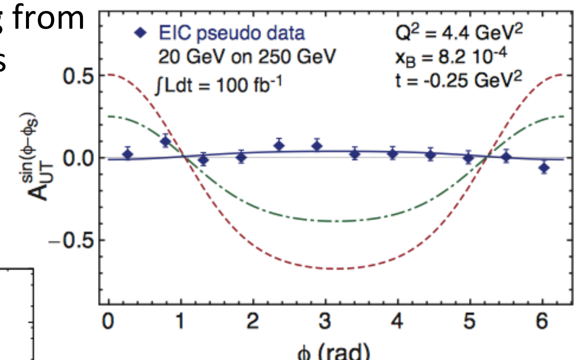


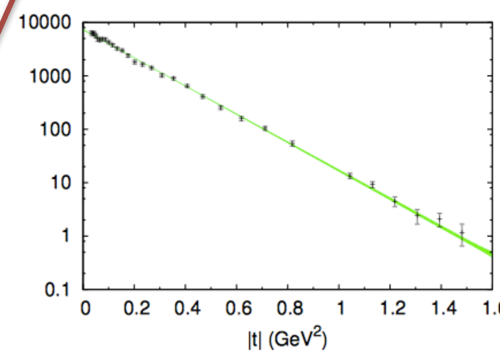
Gluon spin from g_1 scaling violations !

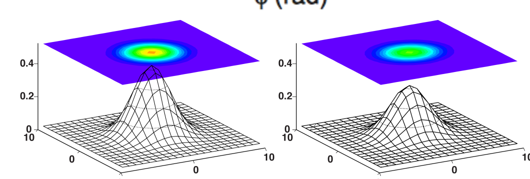


$$\frac{dg_1}{d\log(Q^2)} \propto -\Delta g(x, Q^2)$$

Nucleon 3D-imaging from DVCS measurements







NextDIS Work Package framework

NextDIS Collaboration

Monte-Carlo Simulations

Detector R&D

Applications

Develop analysis frameworks

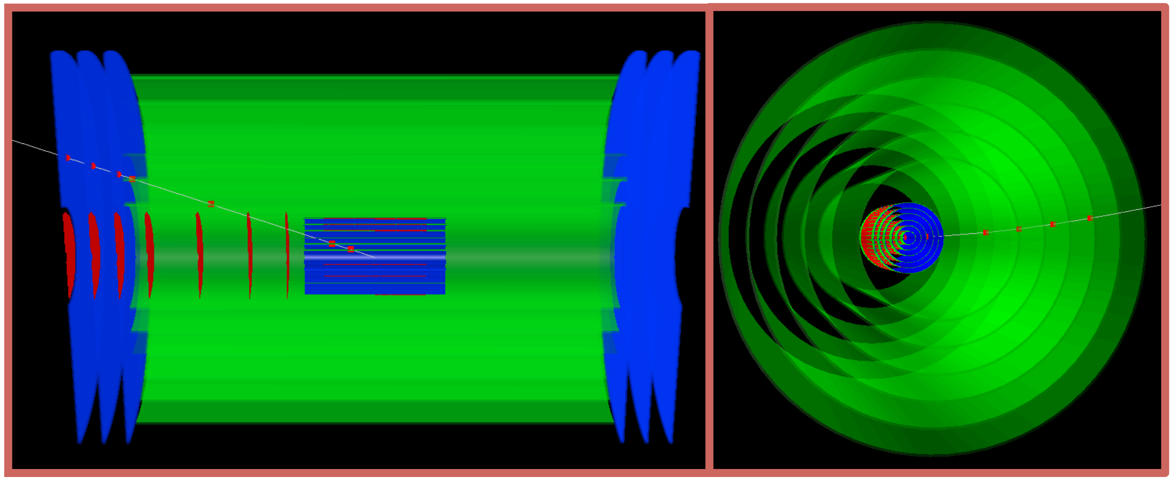
Synergy with TMD-neXt and GPDlogy WPs

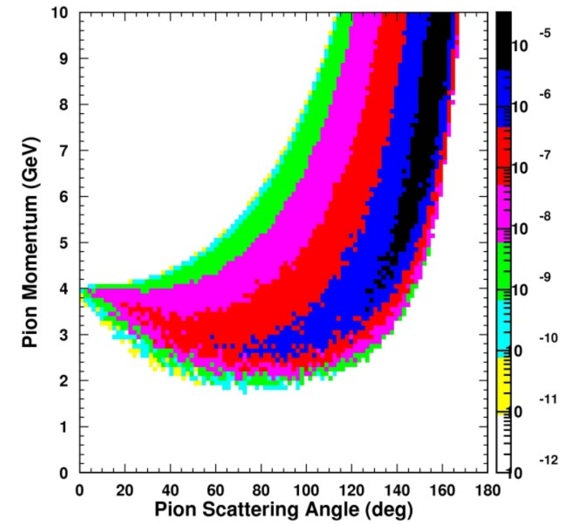
Our philosophy for this WP:

> Improve and structure collaboration in Europe
→ Position ourselves strongly in future DIS facilities
> Do detector design in critical areas (tracking/PID)
→ Trigger applications (medical, etc)
> Perform accurate MC simulations
→ Influence detector design

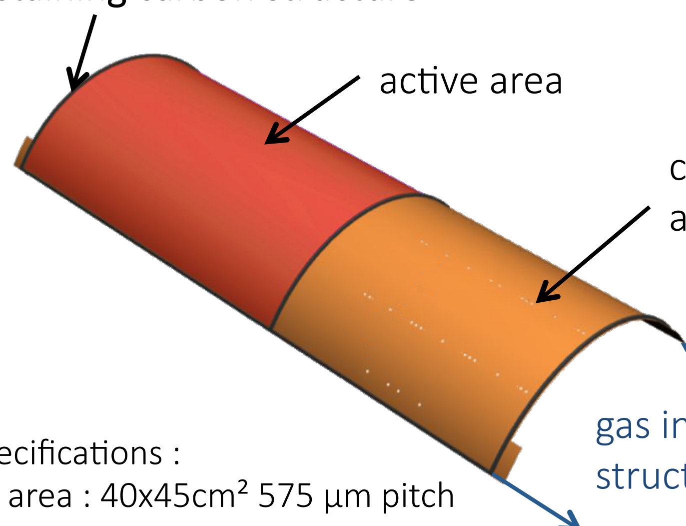
R&D and simulation are generic enough to be useful to other experiments (HERA, COMPASS, JLab)

Micromegas Detectors as central tracker





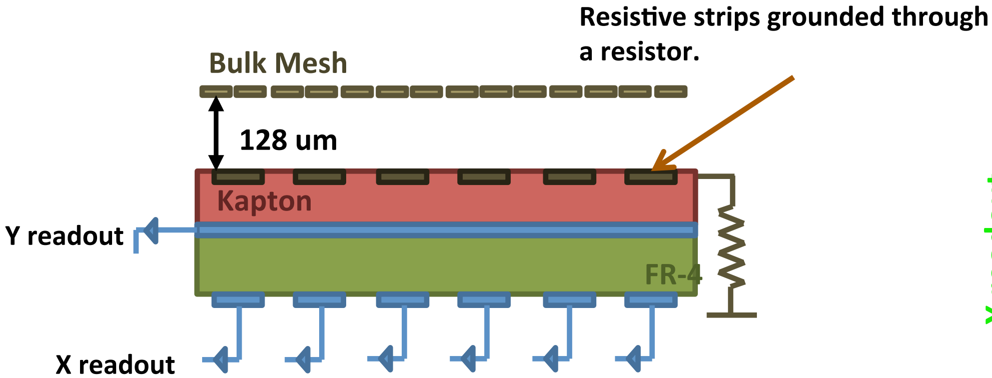
Using **JLab/CLAS12 experience**, Micromegas detectors can be used efficiently in a *cylindrical geometry* to replace either large TPCs or large-radius silicon detectors

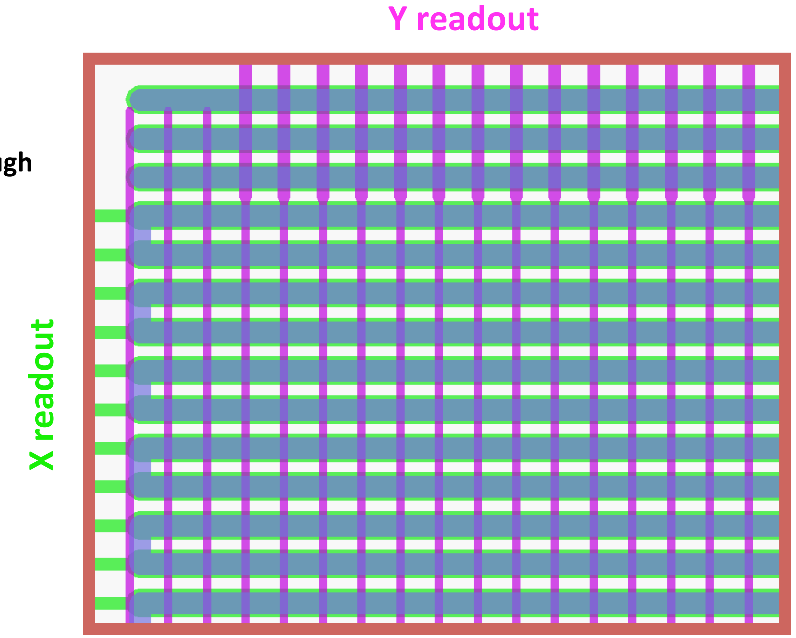


Advantages :
- Robust
- Low Xo
- VERY cost-effective

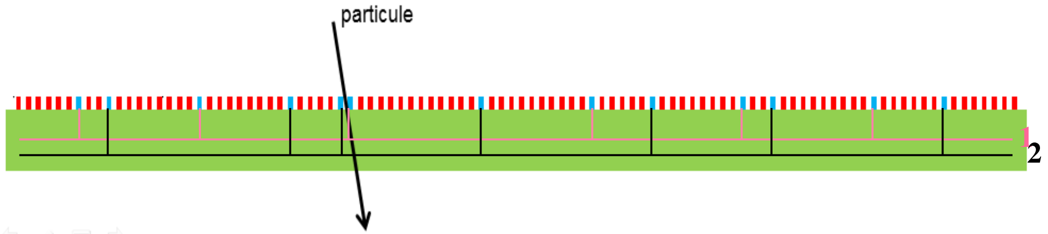
Typical specifications :
- active area : 40x45cm² 575 µm pitch
- resistive strips
- kapton drift
- 200µm PCB, total 0.25% X_0/layer

2D resistive read-out R&D

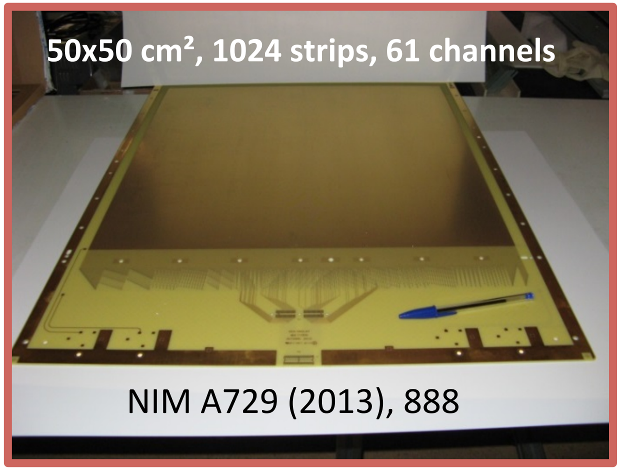


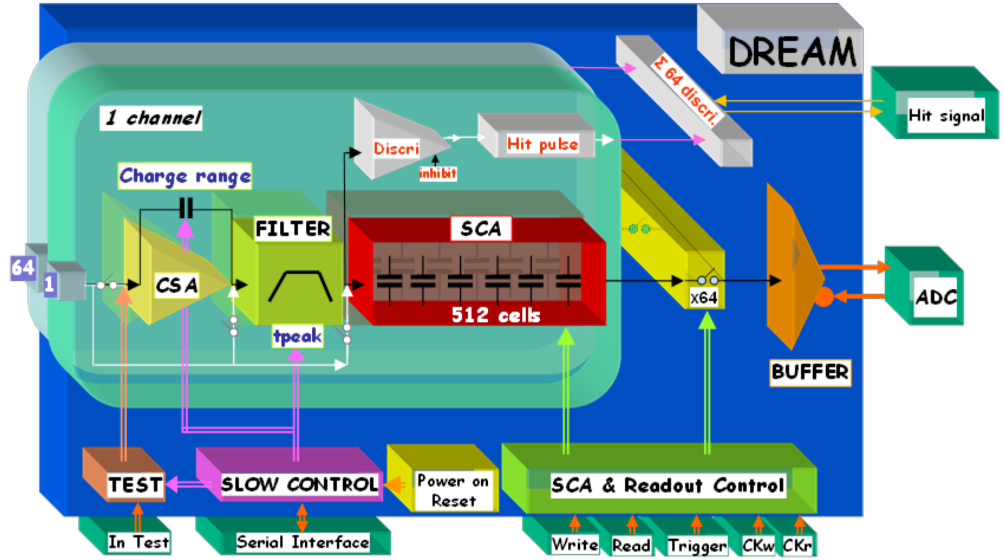


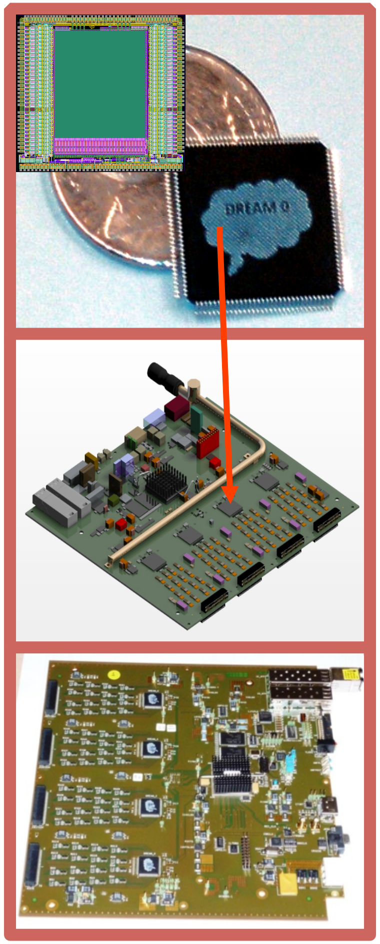
Multiplexed read-out R&D



- 2 given channels are connected to neighboring strips only once in the detector.
- Easily adaptable to the incident flux of particles.
- Can equip up to ~$n^2/2$ strips with only *n* electronic channels.







- Evolution of AFTER and APV25 chips
- Tailored for high capacitance detectors (MPGDs)
- Dead-time free
- Low noise : 2100e-
- Gain in S/N up to 25% wrt previous chip generation
- Self-triggering capabilities

R&D : DREAM for colliders

- Separate analog/digital parts : Very-Front-End Board
- Packaged/bonded ASIC studies
- Irradiation studies and simulation
- Evaluation of a multi-VFEB system

Description of Work

Tasks and subtasks:

TASKS/Subtasks	2015				2016				2017			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Lightweight Micromegas R&D												
1.1 Study of resistive strips 2D pattern												
1.2 Optimization of radiation length												
1.3 Optimization of geometry												
1.4 Study of readout multiplexing												
2. MPGD Front-End electronics R&D												
2.1 Design/fabrication of Very-Front-End-Board												
2.2 Studies of packaged/bonded DREAM ASIC												
2.3 DREAM ASIC irradiation studies												
2.4 Evaluation of a multi-VFEB system												

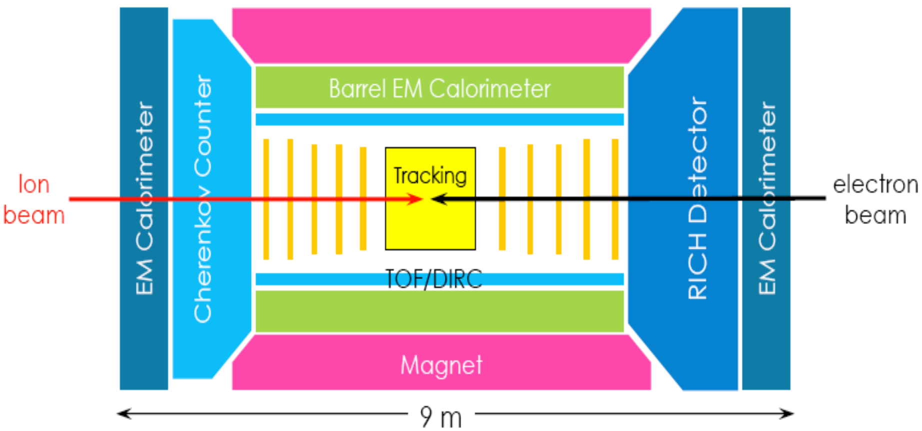
Deliverables:

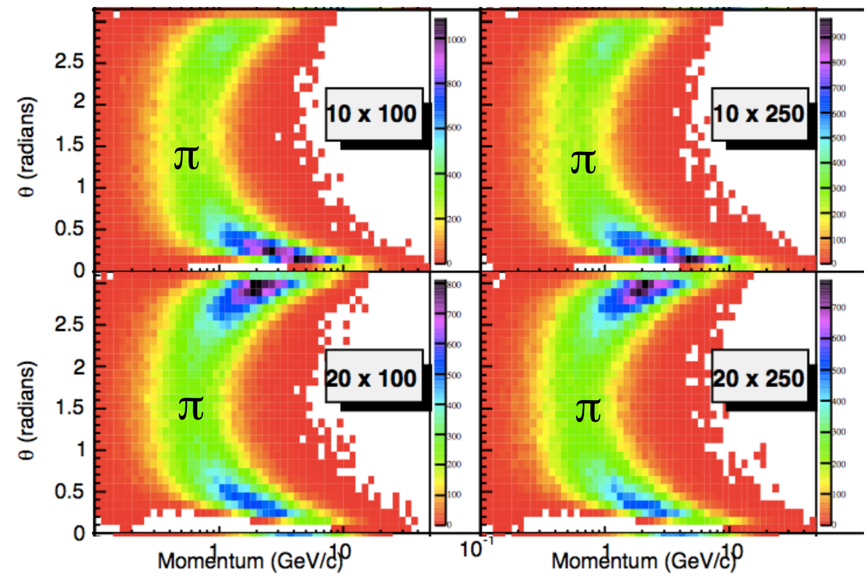
WP35.1	2D-curved resistive prototype	35	P	PP	36
WP35.2	Very-Front-End-Board	35	P	PP	24
WP35.3	Report on Micromegas trackers for e-p/e-A colliders	35	R	PU	33

Semi-inclusive DIS to study 3D nucleon structure and hadronization; Hadron ID for flavor sensitivity

Typical Detector @ EIC:

RICH technology to cover
few-GeV momenta forward hadrons

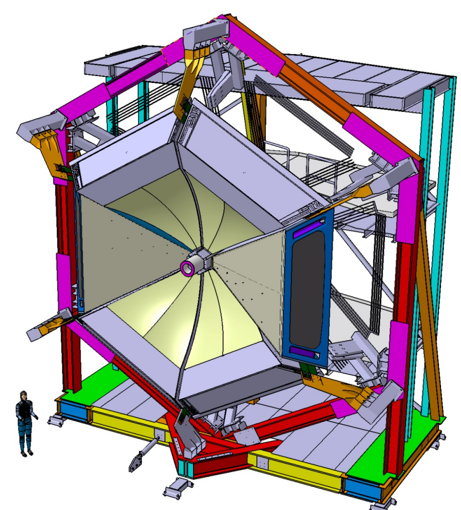


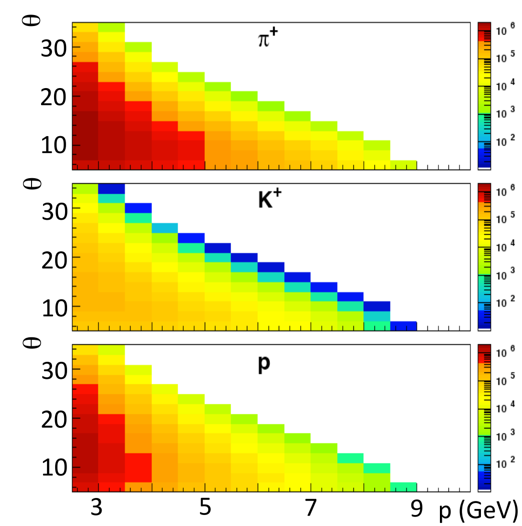


CLAS12 RICH @ JLab:

Base configuration: 2 sectors
~1 m^2 photon detector per sector

Extension to additional sectors only possible with cost-effective photon-detectors





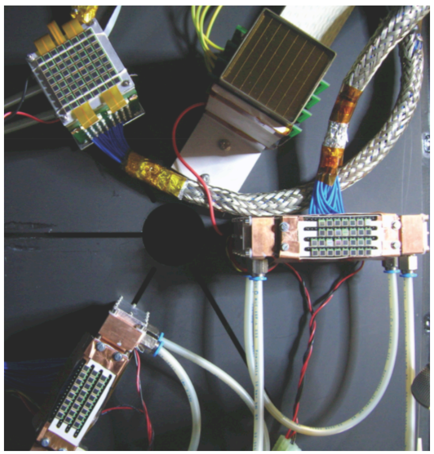
Similar RICH requirements -> development of EIC applies to JLab

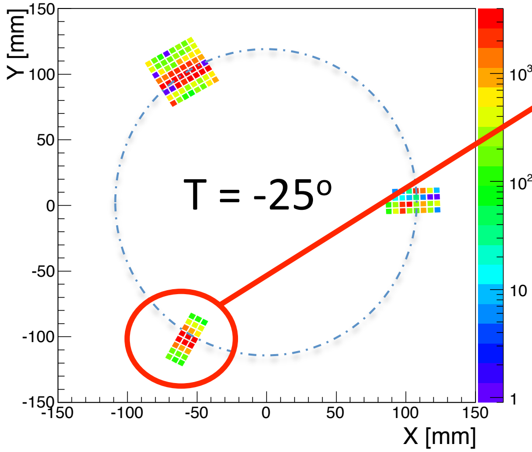
Cost-Effective Photon Detectors

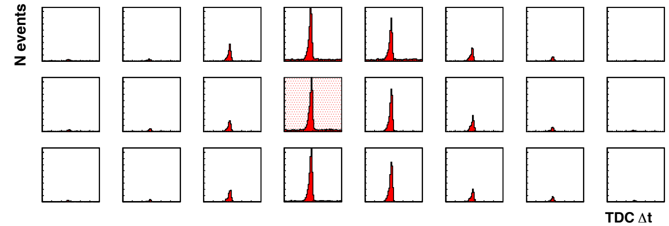
Project goal: cost-effective, compact size, excellent time resolution, good tolerance to magnetic field

Based on novel devices undergoing rapid evolution in performance gain and cost reduction

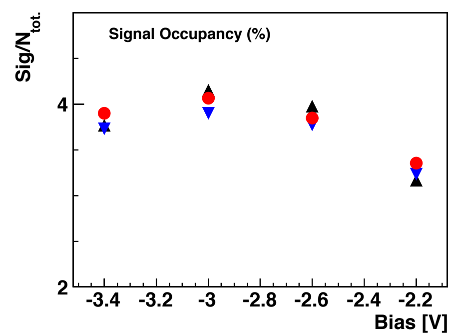
Silicon Photomultipliers
(in collaboration with manufacturers, *e.g.* FBK, Italy)

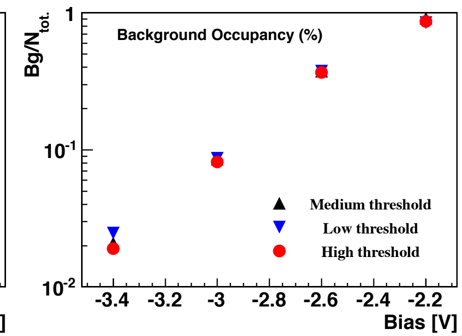




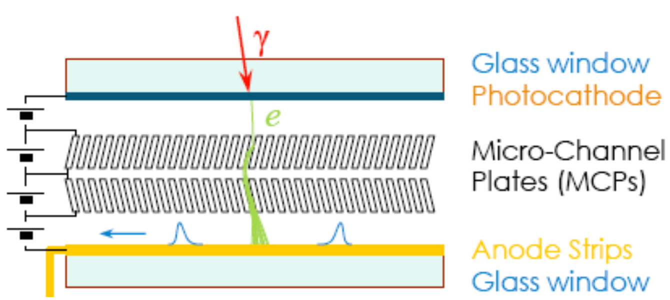


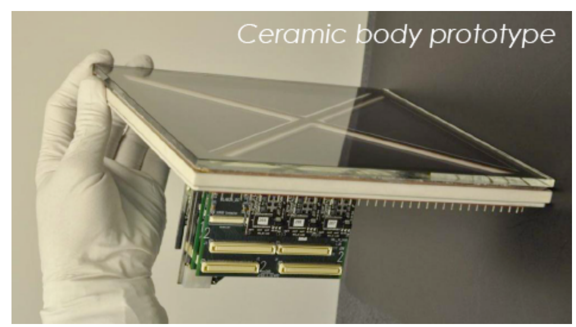
Performance comparable to a MA-PMT





Micro-channel Large-Area Picosecond Photon-Detectors (in collaboration with JLab, USA)





Rapid evolution of the technology needs extensive characterization and dedicated readout electronics

Application: Medical Imaging

Project goal: large area coverage to limit and control the patient assumed dose

Compton Camera: 3D imaging without tomography by gamma tracking
(in collaboration with Italian Health Institute, ISS)

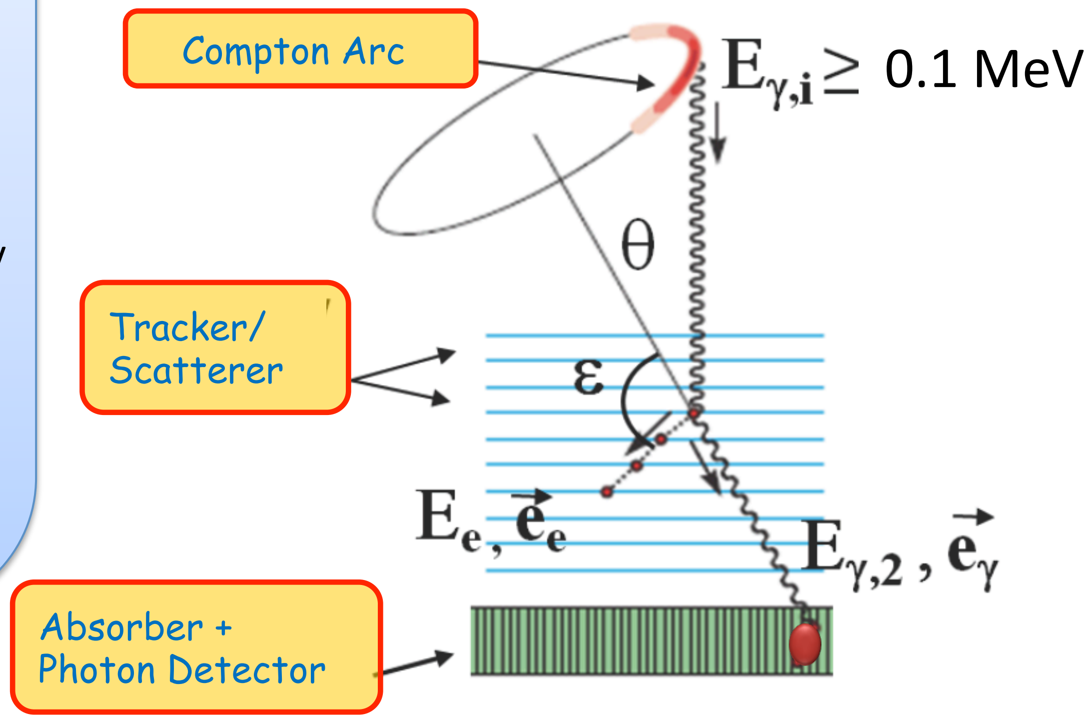
Potential Benefits:

- Higher efficiency than SPECT
- No intrinsic limit to spatial resolution
  (e.g. positron range in PET)
- Broad applicability
  broader set of radionuclides than PET
  real-time dose control in radiotherapy

Complex, no clinic system in operation yet

Perfect **application challenge**
for HPH detector R&D activities

Proof-of-principle use of cost-effective devices:
GEM or Micromegas as tracker
SIPM or LAPP as photon detector



Tasks and subtasks:

TASKS/Subtasks	2015				2016				2017			
3. RICH photon detector studies												
3.1 R&D and characterization of innovative photon sensors	▒	▒	▒	▒	▒	█						
3.2 Aerogel studies				▒	▒	▒	█					
3.3 Design of integrated systems with front-end electronics					▒	▒	▒	█				
3.4 Fabrication and test of large scale prototype								▒	▒	▒	▒	█
4. Medical Application: Compton Camera												
4.1 Studies on scaterrer using charged particle tracker	▒	▒	▒	▒	▒	▒						
4.2 Extension of single photon detector					▒	▒	▒	▒				
4.3 Small-scale Compton Camera prototype									▒	▒	▒	█

Deliverables:

WP35.4	Evaluation report on innovative photon detectors	35	R	PU	16
WP35.5	Compton Camera conceptual design	35	R	PU	24
WP35.6	Design of optimized readout electronics and photon detection assembly	35	R	PU	28
WP35.7	Large area RICH prototype	35	P	PP	36
WP35.8	Compton camera prototype	35	P	PP	36

Modern-day experiments need both state-of-the-art instrumentation AND simulation

(semi-)Inclusive Deep Inelastic Scattering
Existing tools were mainly designed for the inclusive case and are not sufficient for SIDIS.
Need unpolarized and polarized unintegrated (transverse-momentum dependent) parton distributions.
Need *full* kinematic range from low-*x* up to the valence region (take care of different theory approaches).
Hadronization and radiative corrections needed.
Need helicity-dependent parton showers, dedicated diffractive dissociation simulation.

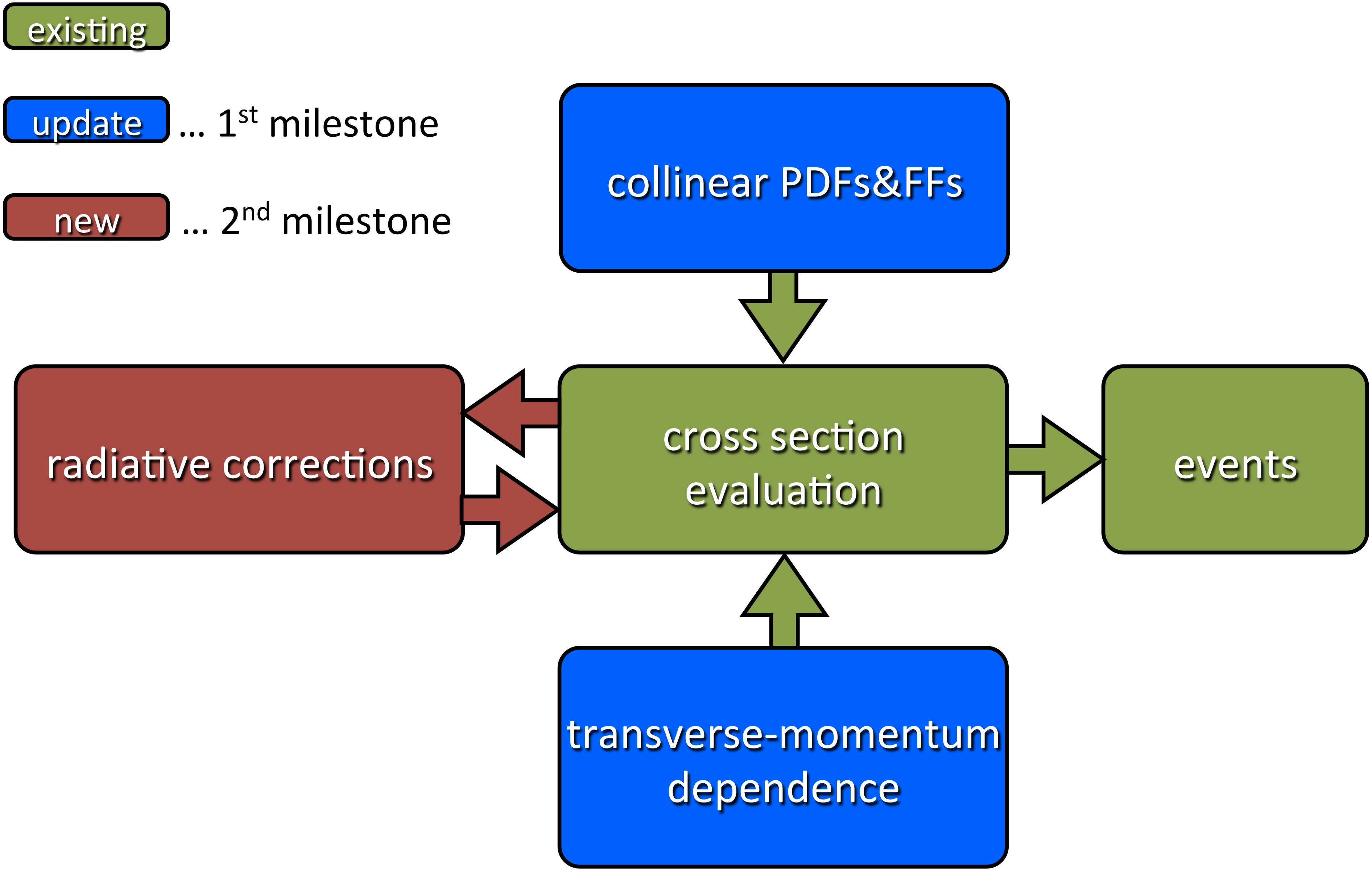
Exclusive processes
Consistent description of DVCS, DVMP, TCS, DDVCS, from valence to low-*x*.
For unpolarized and longitudinally/transversely polarized nucleons QED rad. cor. and nucleon dissociation needed.
QCD corrections (NLO) needed.

Deep Inelastic Scattering on nuclei
Many *e-p* MCs, but few for *e-A*. Existing tools (DPMJET) are incomplete and no longer maintained.
Need MC with full treatment of hard scattering, (in-medium) QED/QCD showers, hadronisation/nuclear de-excitation, and QED radiative corrections.

Common requirements for all processes
High-accuracy QED radiative corrections.
Fast simulation needed for detector design.

This WP brings together most experts on these directions, towards a simulation and analysis strategy

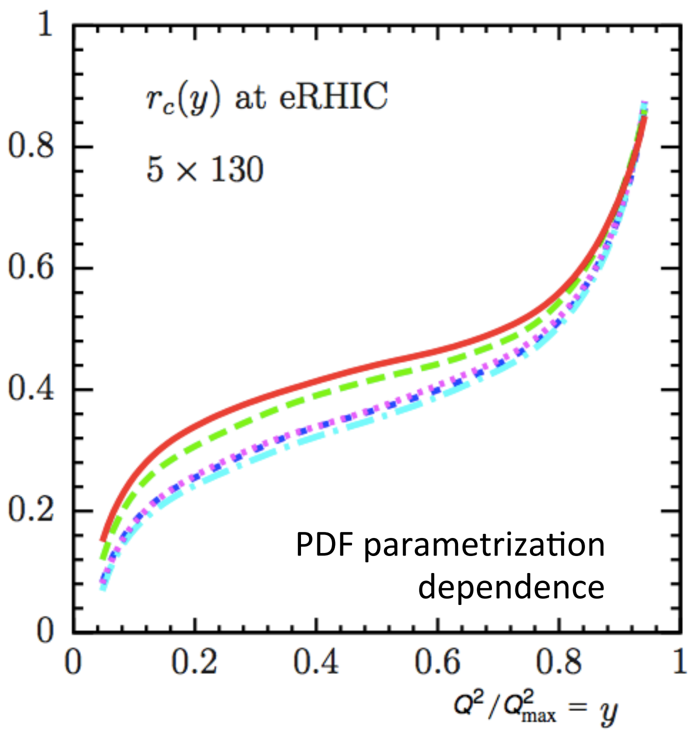
Illustration for Semi-Inclusive-DIS: GMC-Trans



A common requirement : QCD and QED corrections

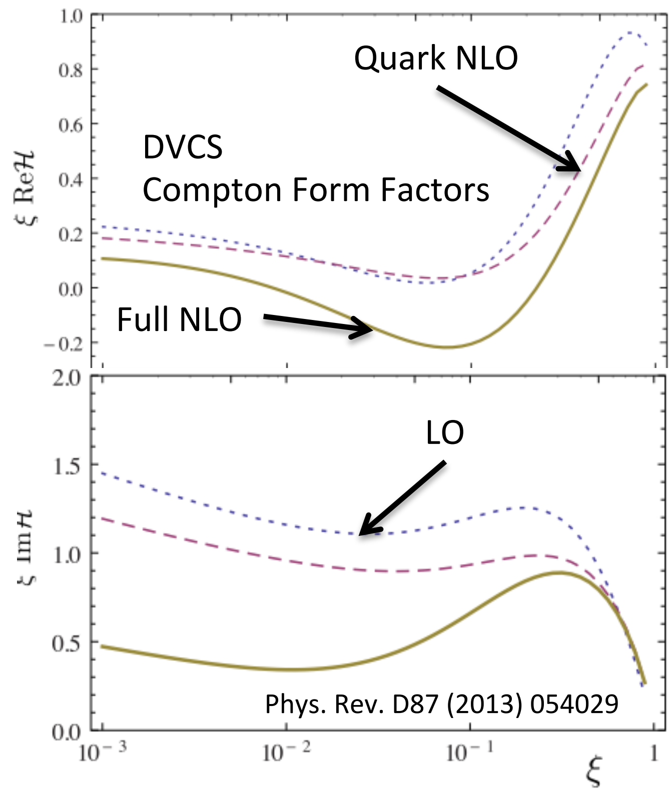
QED

$r_c(y) = d\sigma_{O(\alpha)}(y)/d\sigma_{\text{Born}}(y) - 1$
for e^-N at 5×130 GeV^2, $10^{-3} \leq x_{Bj} \leq 10^{-2}$



Large corrections, accurate measurements needs careful treatment of RC, *fully imbedded* in MC simulations. (experimental resolutions have large impact)

QCD



Large corrections, accurate measurements needs careful treatment of QCD corrections, *very* sensitive to gluon GPDs.

Tasks and subtasks:

TASKS/Subtasks	2015				2016				2017			
5. Collider inclusive e-A simulation tools												
5.1 Hard-Scattering	▒	▒	▒	▒	▒	▒						
5.2 QCD/QED showers, nuclear medium effects	▒	▒	▒	▒	▒	▒	▒	▒				
5.3 Implementation of remnant hadronization				▒	▒	▒	▒	▒	▒	▒	■	
5.4 QED radiative corrections			▒	▒	▒	▒	▒	▒	▒			
5.5 Fast detector simulation package							▒	▒	▒	■		
6. Collider SIDIS simulation tools												
6.1 Algorithm for helicity-dependent parton showers	▒	▒	▒	▒	▒	▒	▒	■				
6.2 TMD models, event generator			▒	▒	▒	▒	▒	▒	▒	▒		
6.3 QED radiative corrections to SIDIS				▒	▒	▒	▒	▒	▒	▒	■	
7. Collider exclusive simulation tools												
7.1 QCD Corrections to DVCS/DVMP	▒	▒	▒	▒	▒	■						
7.2 DVCS generator	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	■
7.3 DVMP generator				▒	▒	▒	▒	▒	▒	▒	▒	■
7.4 Incoherent nuclear DIS processes	▒	▒	▒	▒	▒	▒						

Deliverables:

Deliverable N	*Deliverable name*	*WP No.*	*Nature*[2]	*Dissemination level*[3]	*Delivery date*[4]
WP35.8	Inclusive MC simulation code	35	O	PU	33
WP35.8	Semi-Inclusive MC simulation code	35	O	PU	33
WP35.8	Exclusive MC simulation code	35	O	PU	36

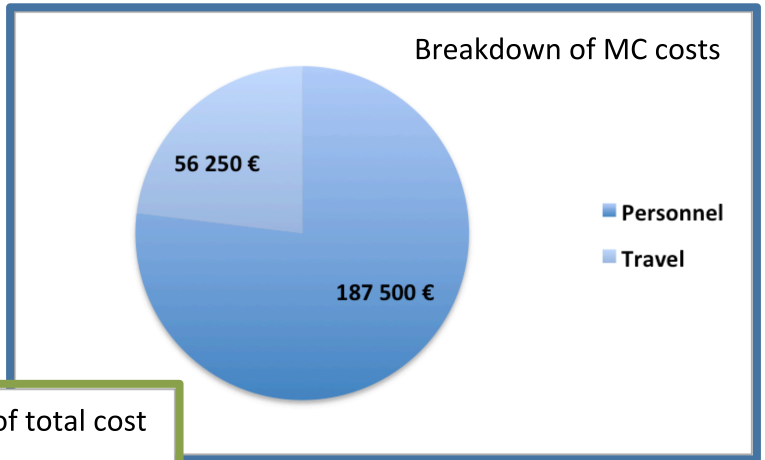
(Open-source codes on NextDIS web site)

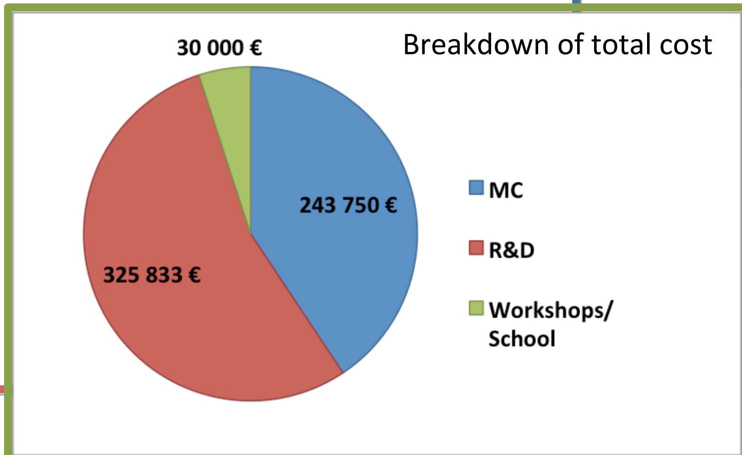
Financial Aspects

NextDIS is essentially the result of a merge of 3 WPs

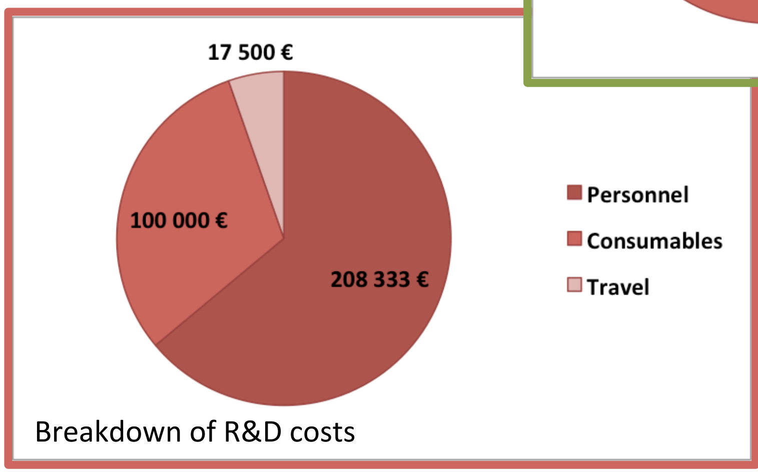
Natural balance between MC and R&D activities

Important aspect: education (Ph.D. students, workshop series, school)





Personnel request:
3 years PhD student
6.5 years of postdocs



Total request to EC : **599 583 €**

(all figures include 25% overhead)

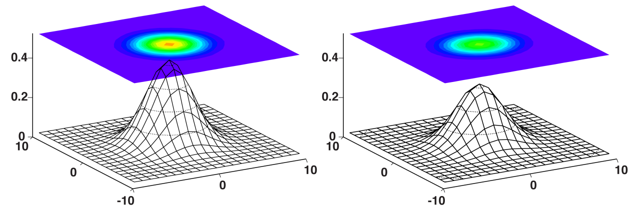
Backup Slides

Summary of LHeC physics

QCD Discoveries Higgs Substructure New and BSM Physics Top Quark	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$ WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H? leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution Precision DIS	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c $\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure Quark Distributions QCD	Proton, Deuteron, Neutron, Ions, Photon valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top $\mathrm{N^3LO}$, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron Heavy Ions Modified Partons	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing initial QGP, nPDFs, hadronization inside media, black limit, saturation PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

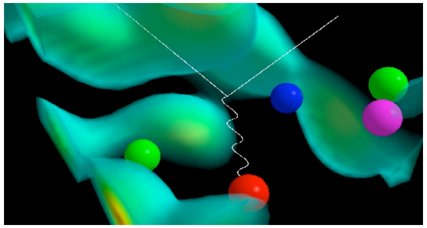
An Electron-Ion Collider will allow the unique exploration of some of the most intriguing open questions in modern nuclear physics:

The structure of visible matter



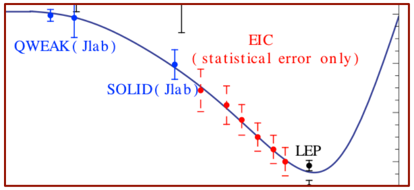
Quark distributions
polarized (L/T) or not
3D-imaging of the nucleon (GPD)
Transverse Momentum Distributions

The role of gluons in hadronic matter



Gluon distributions
polarized or not
F_2 and F_L measurements in nuclei
Study of gluon saturation (CGC)

Electroweak interaction and physics beyond the SM



Accurate measurement of $\sin^2\theta_W$
e-τ conversion

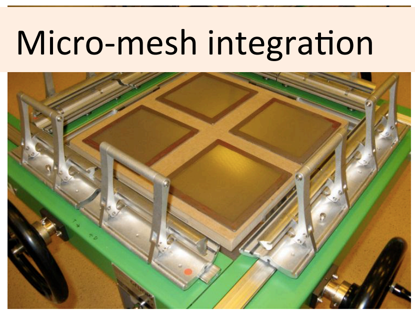
Budget Table

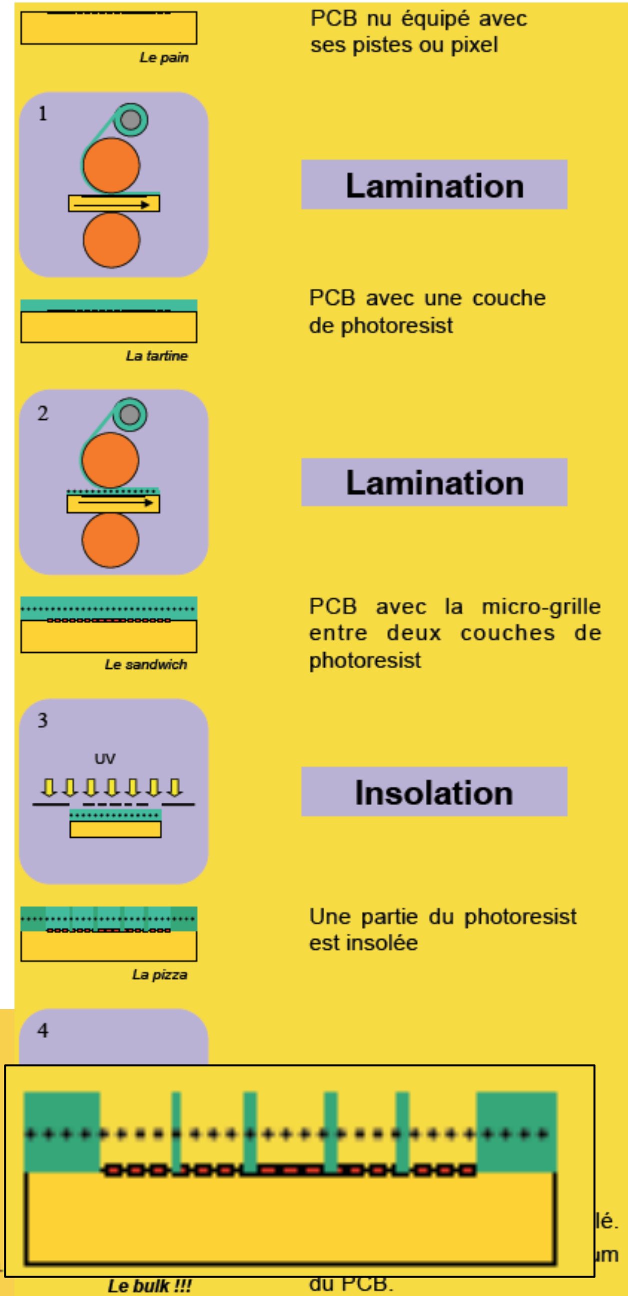
Contractor Acronym	Personnel (EUR)	Other costs (durables, consumables, travel, workshops) (EUR)	Total direct costs (EUR)	Indirect costs (EUR)	Requested EC contribution (EUR)
CEA-IRFU	66667	77000	143667	35917	179584
CNRS/IPNO	0	3000	3000	750	3750
CNRS/CPHT	0	4000	4000	1000	5000
CNRS/LPT	40000	3000	43000	10750	53750
SINS	0	2000	2000	500	2500
INFN-LNF	40000	12000	52000	13000	65000
USantiago	30000	2000	32000	8000	40000
UPV-EHU	10000	13000	23000	5750	28750
UAntwerpen	0	2000	2000	500	2500
UBirmingham	30000	2000	32000	8000	40000
INFN-Roma1	0	2000	2000	500	2500
INFN-Ferrara	40000	7000	47000	11750	58750
ISS	20000	12000	32000	8000	40000
INFN-Pavia	0	3000	3000	750	3750
UMainz	40000	4000	44000	11000	55000
UTuebingen	0	3000	3000	750	3750
UJyvaskyla	0	3000	3000	750	3750
PAN	0	2000	2000	500	2500
ULBB	0	1000	1000	250	1250
UGranada	0	2000	2000	500	2500
UHuelva	0	2000	2000	500	2500
UGlasgow	0	2000	2000	500	2500
TOTAL	**316667**	**163000**	**479667**	**119917**	**599584**

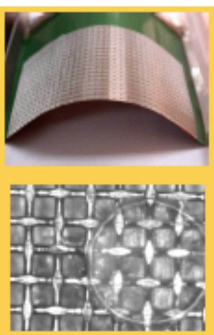
Bulk Micromegas : Fabrication scheme

- First prototypes in 2004. Collaboration CERN/Irfu.
- The woven micro-mesh is laminated between two photo-sensitive layers → reduction of dead zones
- Large areas
- Robust, industrial process (printed circuit)

BULK workshop at Irfu/Sedi

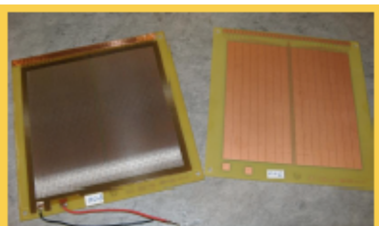




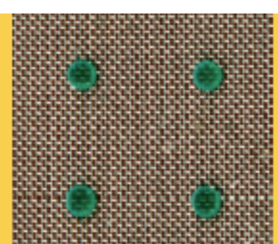


Bulk flexible sur Kapton de 50 microns

Détail: mesh prise entre deux plots

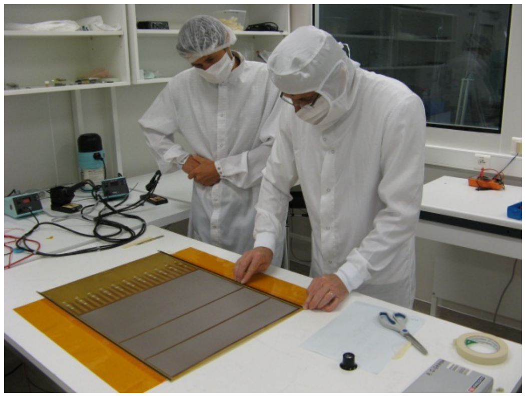


Bulk et PCB nu
120 x 140 mm

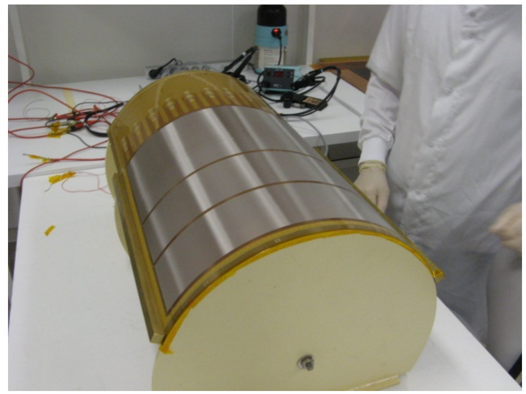


Plots de 400 microns au pas de 2 mm.
Mesh inox 500 LPI

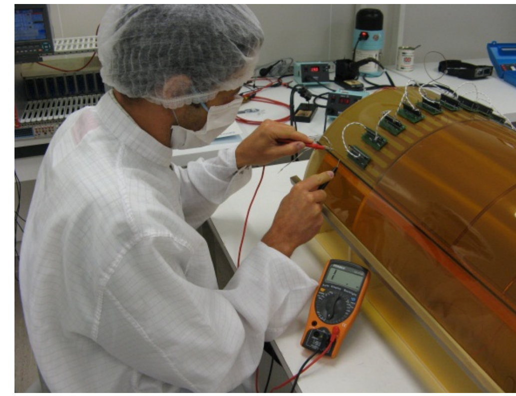
Curved Micromegas : Fabrication process



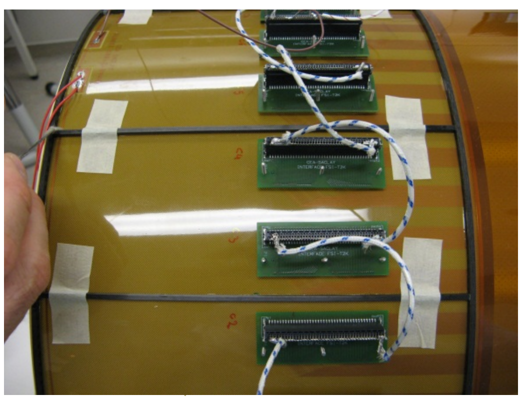
Segmentation and preparation



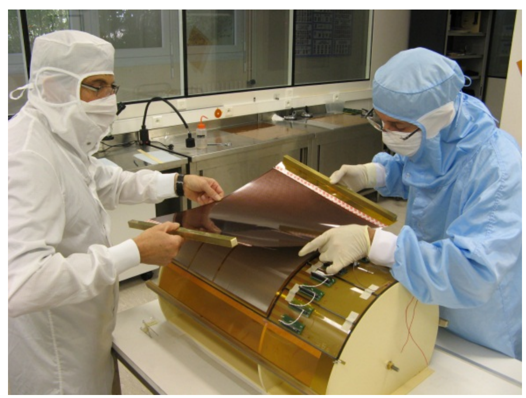
Gluing of the side carbon ribs on circular shape

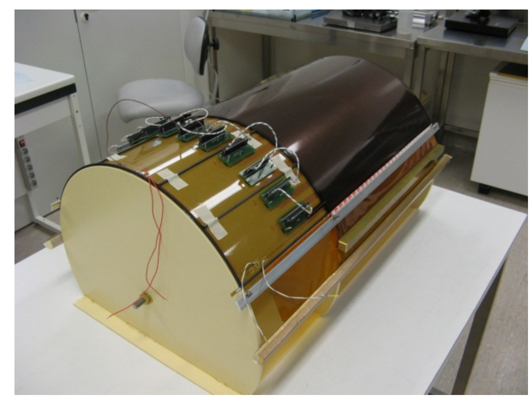


Electric leak test



Gluing of additional ribs



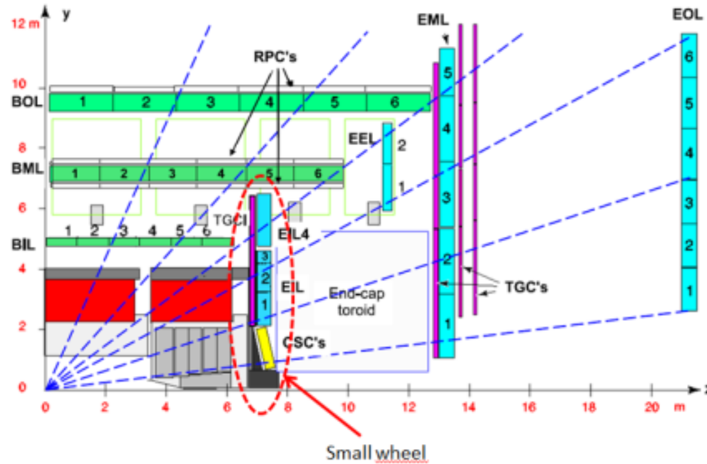


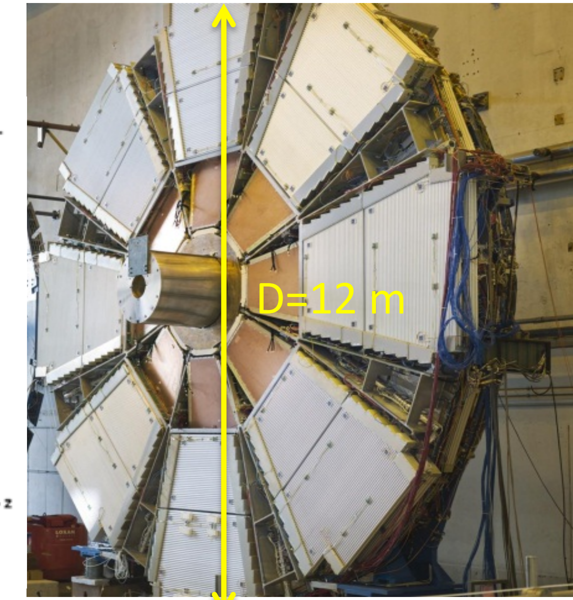
Setting and gluing of drift plane

ATLAS/NSW

2 new wheels (NSW):

- 1200 m^2 of resistive Micromegas
- More than 2M electronics channels



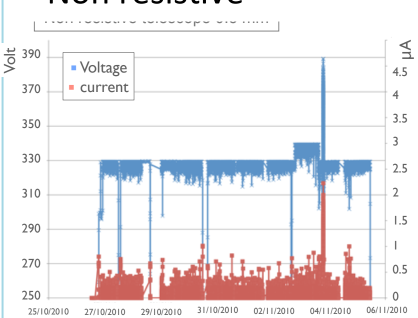


High flux et sparking

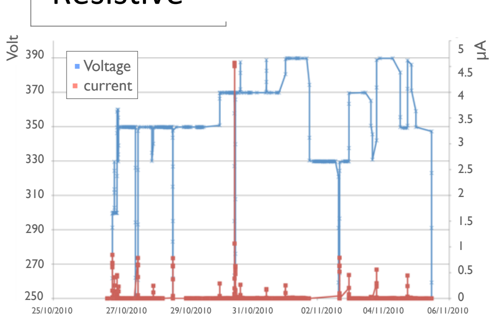
Resistive anodes:

- Reduced spark amplitude
- No dead time
- Robustness

Non resistive



Resistive

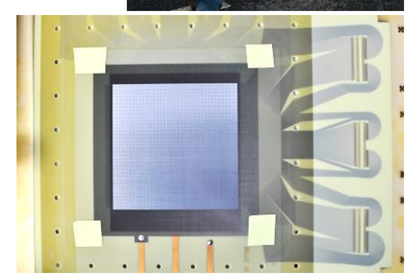


Fabrication

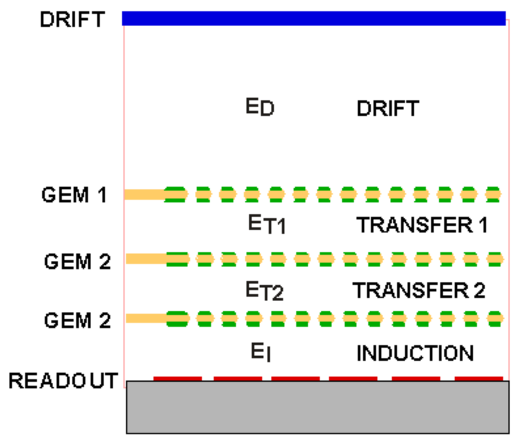
- Maximum area ~ 2 m^2
- Production: 1024 planes (2015-16)

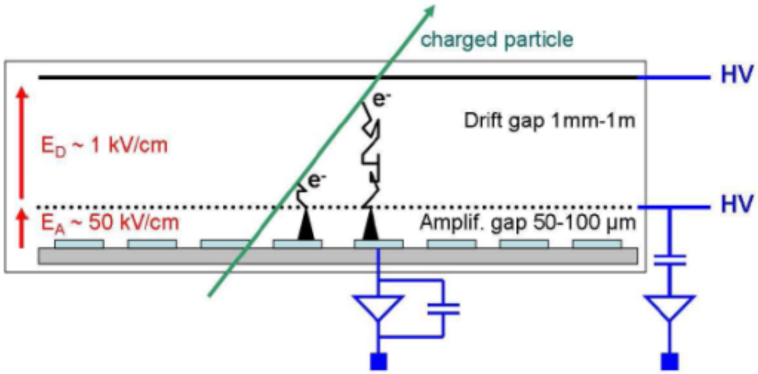
Transfer to industry:

- ELVIA (France)
- ELTOS (Italy)
- Triangle Labs (US)



GEMs vs. Micromegas





- Multiplication in the holes
- ~ 50% of electrons transferred
- Gain per layer a few 10's to 10^3
- Low ion back flow (1%)
- Multistage structure → gain 10^5
- More fragile and more integration issues

- Multiplication between mesh and anode
- Stability of gain wrt gap
- Gain 10^4-10^5
- Low ion back flow (1%, down to 10^{-6})
- Robust
- Sparking unless resistive or preceded by a GEM foil for preamplification
- Smaller ultimate thickness (both in mm and X_0)
- Slightly more radiation resistant

GEMs vs. Micromegas (2)

GEM: Sauli 1997

- COMPASS
- LHCb muon detector
- TOTEM telescope
- HBD (Hadron Blind Detector)
- NA49 (upgrade)
- X-ray polarimeter (XEUS)
- GEM TPC for LEGS, BONUS
- STAR FGT
- KLOE2 vertex detector
- OLYMPUS
- SuperBigBite (JLab/Hall A)
- CMS forward muon chambers
- ……

and at the proposal/prototyping stage

- EIC R&D
- DarkLight phase-I
- …..

MM: Giomataris 1996

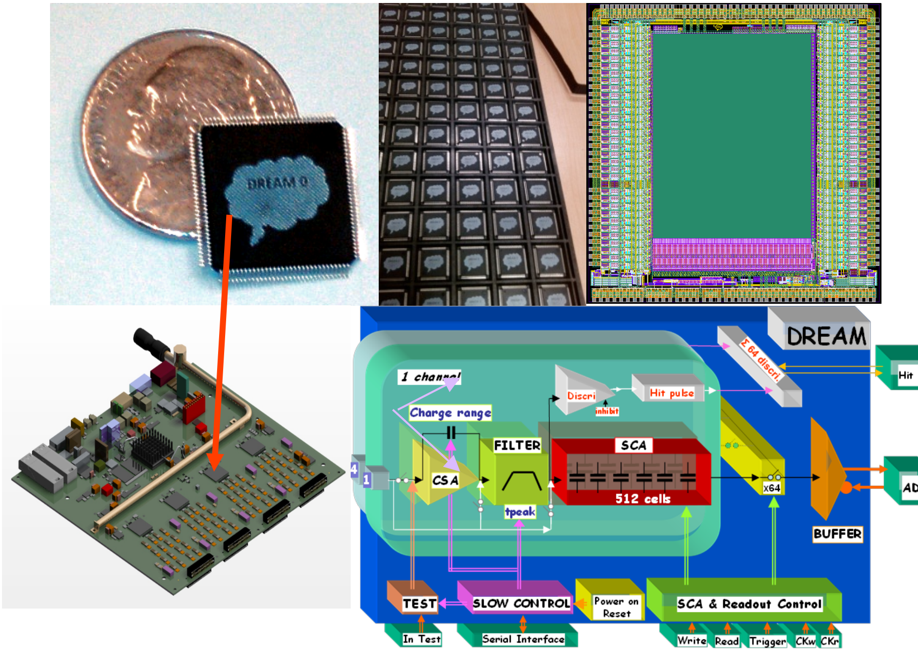
- COMPASS (1 & 2)
- NA48/KABES
- CAST (CERN Axial Solar Telescope)
- nTOF (neutron beam profile)
- Piccolo (in reactor core neutron measurement)
- T2K TPC
- JLab/CLAS12/MVT
- RIKEN/MINOS (exotic nuclei spectroscopy)
- ATLAS muon system upgrade
- …..

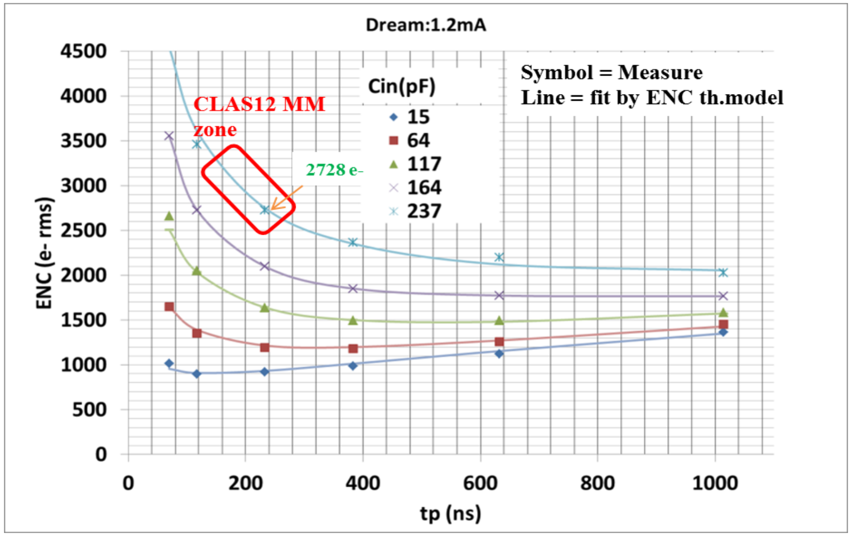
and at the proposal/prototyping stage

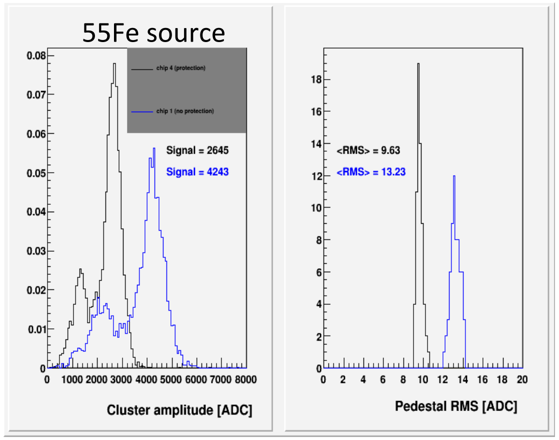
- ASACUSA (anti-H)
- HARPO (astrophysics)
- MIMAC (dark matter)
- FIDIAS & ACTAR (low-energy heavy ion)
- EIC R&D

DREAM chip

- Tailored for detectors with high capacitances
  - ~30% less noise compared to the previous generation (after ASIC)
  - Depending on detector type ENC of 2000-2700 is expected
- Version 1 submitted
  - Added intermediate peaking times for more flexibility
  - Minor bugs corrected
  - Packaged chips expected in May-June







Front End Unit : Active comp. on top & bottom sides

- 8 Dream ASICs
- 8-channel 40 MHz ADC
- Virtex-6 FPGA
- SFP cages
- 2.5 Gbit/s optical link
- 1Gb Ethernet
- JTAG based system monitor