BESIII

STATUS AND ACTIVITIES

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E.Pace, P.Patteri, A.Zallo (guest)
E.Tskhadadze (Dubna,FAI fellowship),

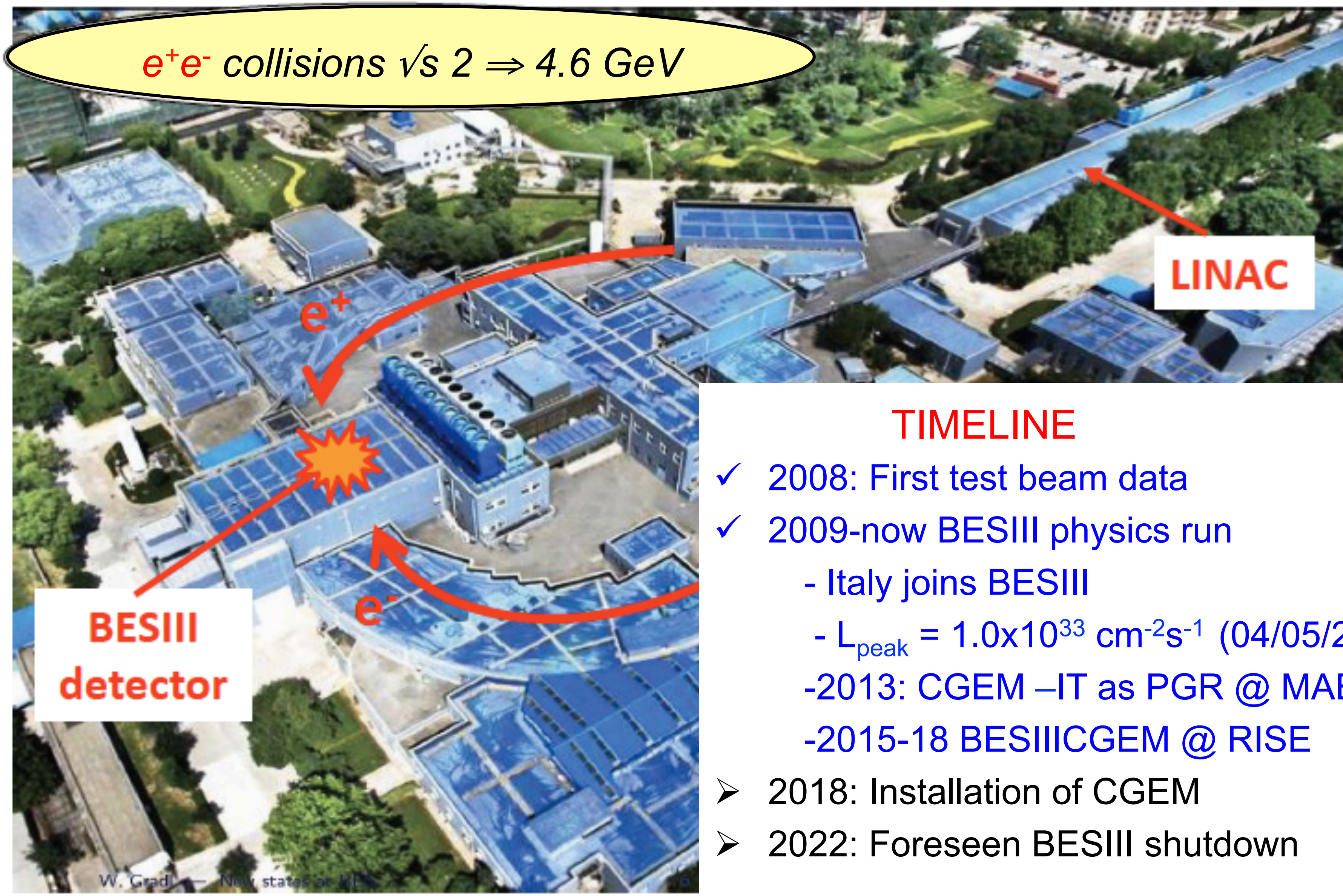
and in collaboration with:
LNF SPAS: S. Cerioni, M. Lobello
LNF SEA: M. Gatta, G.Papalino
LNF (div. acc.): M. Paris, F. Putino
INFN-ROMA1 A. Pelosi(tec.), M.Capodiferro(tec.)
BESIII TO&FE&PG groups

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

OUTLOOK

- BESIII @ BEPCII DATA TAKING STATUS
- CGEM-IT UPDATE:
  - TESTS BEAM RESULTS
  - STATUS OF CONSTRUCTION
  - STATUS OF ELECTRONICS INSTRUMENTATION
  - MECHANICS&INTEGRATION
  - SOFTWARE
  - PROJECT SCHEDULE
- PHYSICS
  - ANALYSIS AND PROPOSALS BY ITALIAN TEAM
  - FEW RECENT RESULTS
- SUMMARY & CONCLUSIONS

BESIII @ the Beijing Electron Positron Collider (BEPCII)



TIMELINE

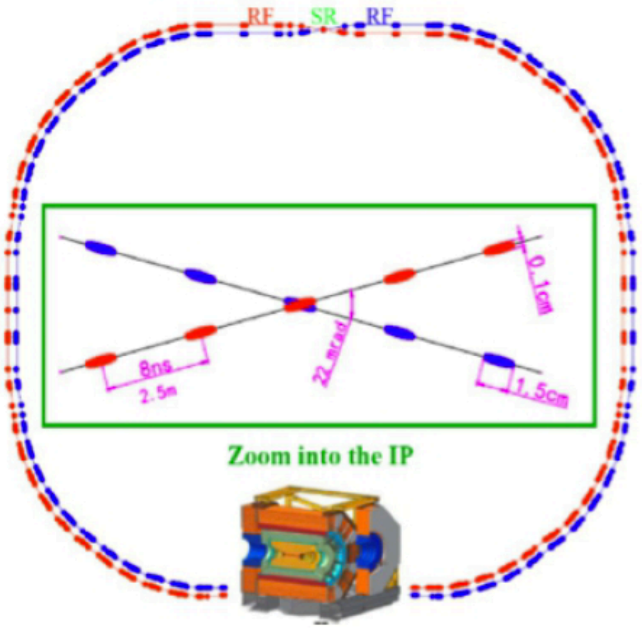
- ✓ 2008: First test beam data
- ✓ 2009-now BESIII physics run
  - Italy joins BESIII
  - L_{peak} = 1.0x10^{33} cm^{-2}s^{-1} (04/05/2016)
  - -2013: CGEM –IT as PGR @ MAE
  - -2015-18 BESIIICGEM @ RISE
- ➢ 2018: Installation of CGEM
- ➢ 2022: Foreseen BESIII shutdown

…

- ➢ 2027: Possible end of running

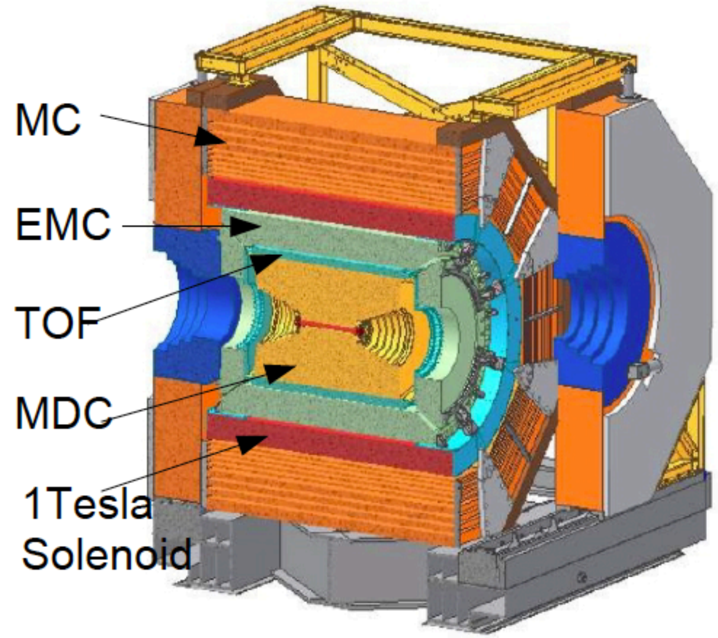
BEPCII & BESIII

Double ring e+e- collider:



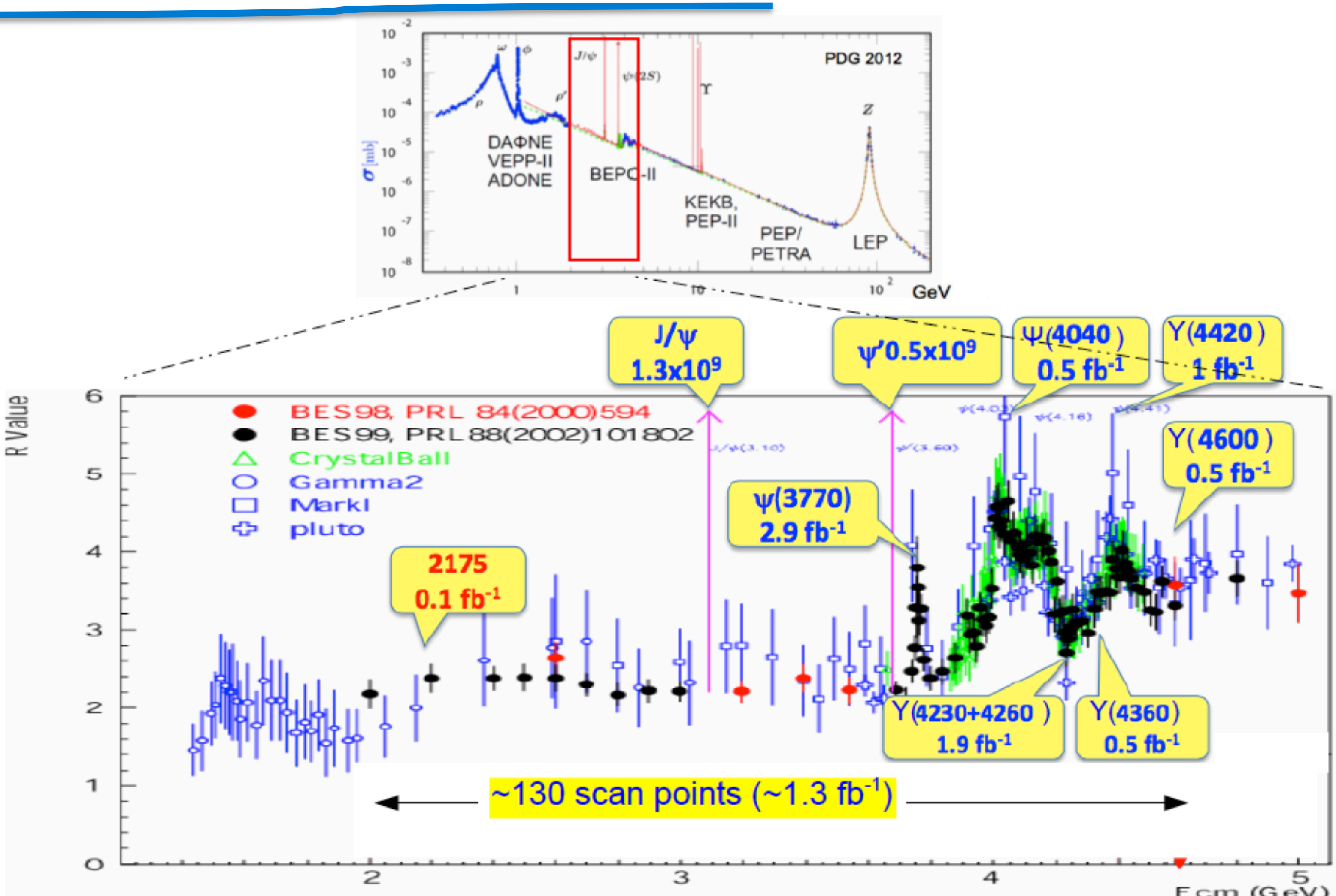
- Beam energy: 1.0 – 2.3 GeV
- Crossing angle: 22 mrad
- Design luminosity: 10^{33} cm^{-2} s^{-1}
- Energy spread: $5.16 \cdot 10^{-4}$
- Number of bunches: 93
- Total current: 0.91 A

Multi-purpose detector:



- **Main Drift Chamber**
  $\sigma(p)/p < 2.5$ % for 1 GeV tracks,
  $\sigma(dE/dx)/dE/dx < 6\%$, $\sigma(xy) = 130$ μm
- **Time of Flight** $\sigma(t) \sim 90$ ps
- **EMCalorimeter** $\sigma(E)/E < 2.5$ %,
  $\sigma(x) < 6$mm for 1 GeV e-
- **Muon Counter** $\sigma(xy) < 2$ cm

BESIII DATASET 2009-TODAY



the world's largest scan dataset of J/ψ ψ(2S) ψ(3770)

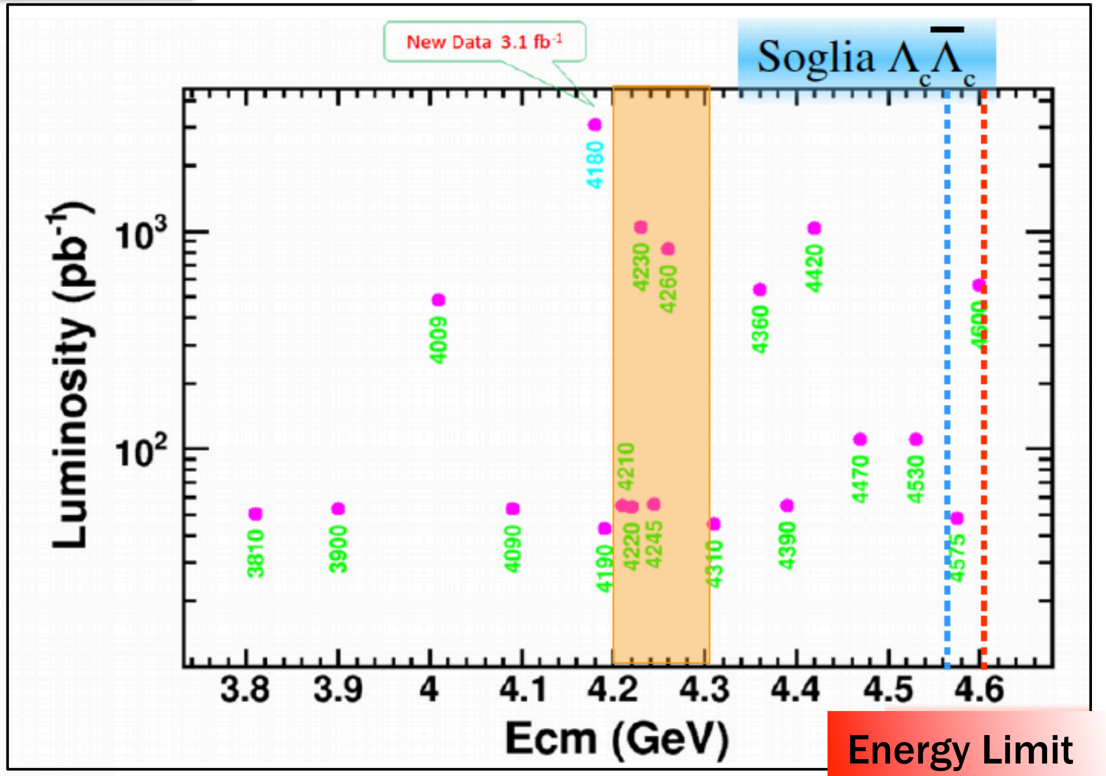
XYZ states

R-QCD studies

BESIII will run until 2027 !

BESIII DATASET 2009-TODAY

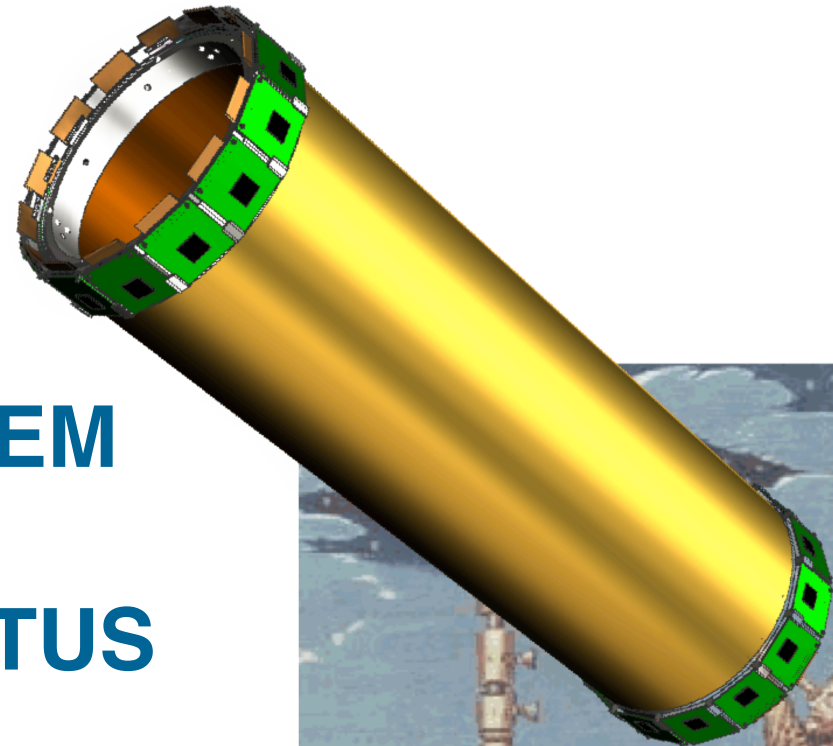
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} at **ψ(3770)** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **ψ(2S)** *(total)*
1.3B **J/ψ** *(total)*
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.21, 4.22, 4.245, 4.31, 4.39, 4.42 GeV**
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)
2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for D_s)
*2017: ~10 × 500 pb^{-1} between **4.19** and **4.30 GeV***



BEPCII upgrade forseen to improve MAX beam energy 2.3 → 2.45 GeV (max CMS energy 4.9 GeV)

BESIII will run until 2027 !

THE CYLINDRICAL GEM (CGEM) INNER TRACKER STATUS

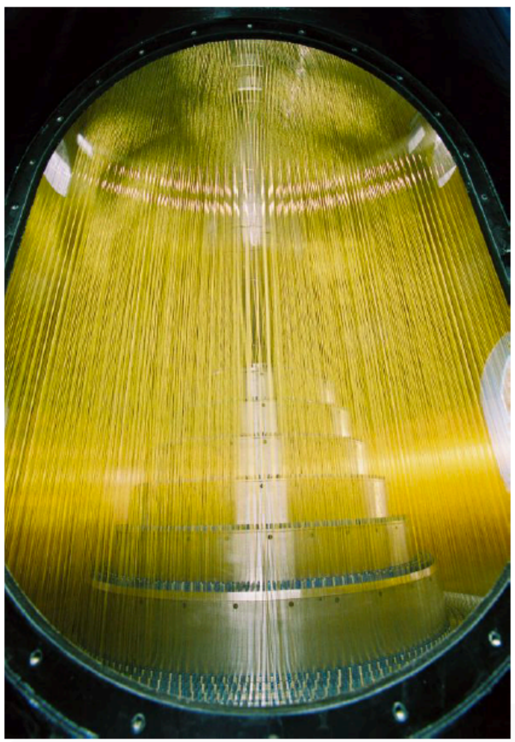


M. Bertani

BESIII STATUS, 53RD LNF SCIENTIFIC COMMITTEE

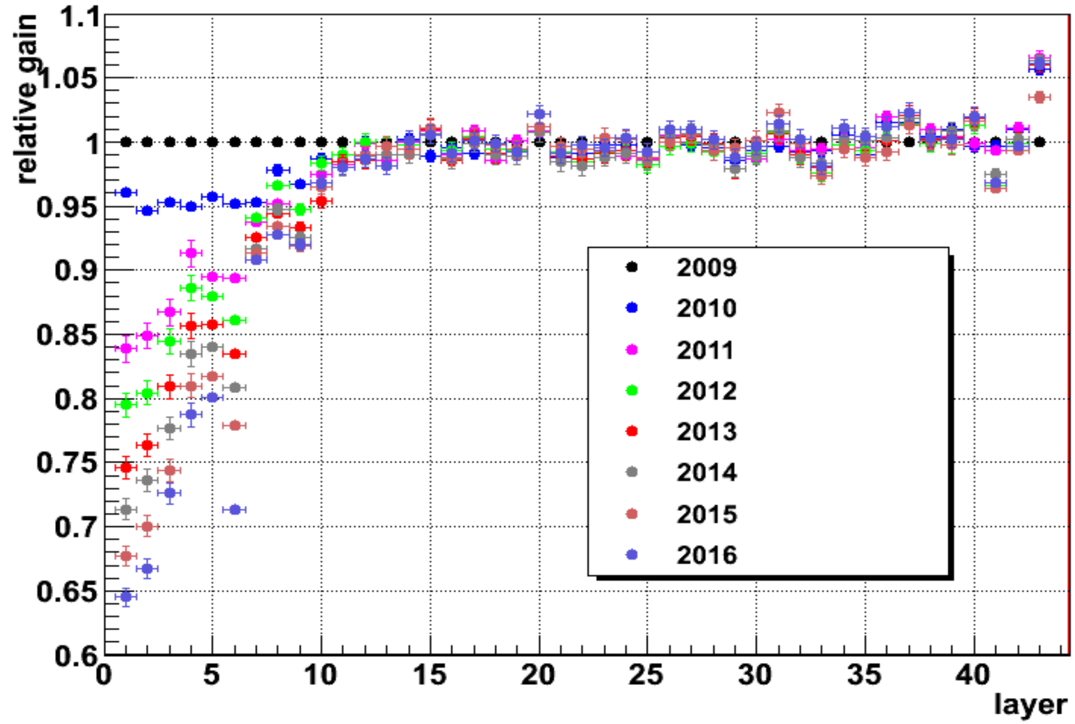
INNER TRACKER: THE PRESENT - MDC

- Inner Tracker:
  - 8 stereo layers
- Outer Tracker:
  - 12 axial layers
  - 16 stereo layers
  - 7 axial layers



- momentum resolution 0.5% @1 GeV/c
- r~ϕ spatial resolution 130 μm
- azimuthal coord. res. 2 mm

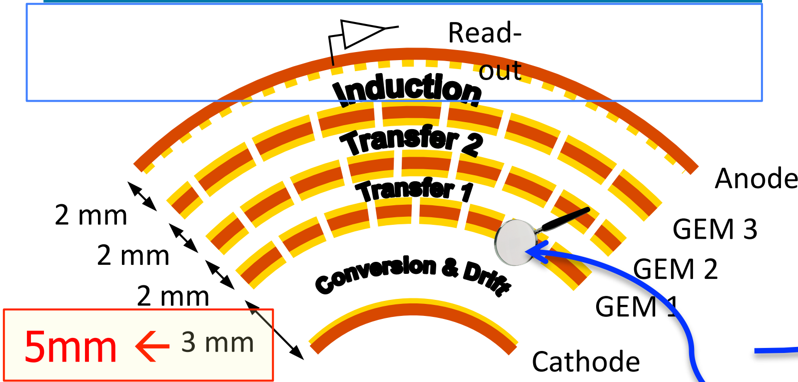
AGING PROBLEM



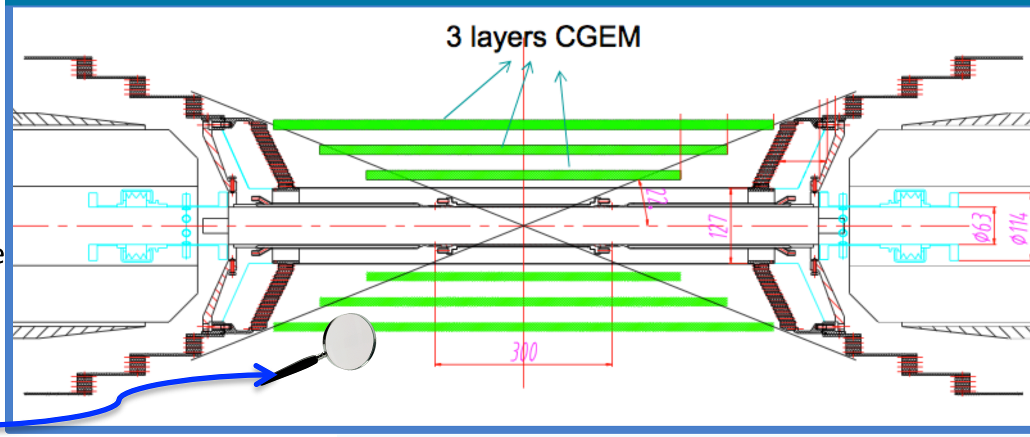
Gain loss/year ~ 4%
on the innermost layers

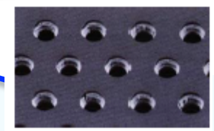
INNER TRACKER: THE FUTURE – CGEM

A cylindrical triple GEM



Three layers of CGEM for BESIII





High Rate capability: ~10 KHz/cm^2

High Spatial resolution: σ_{xy} =~130μm : σ_z=~1mm

Momentum resolution (INNER+MDC): σ_{pt}/P_t =~0.5% @1GeV

Efficiency = ~98%

Low Material budget ≤ 1.5% of X_0 for the whole detector

Coverage: 93% 4π

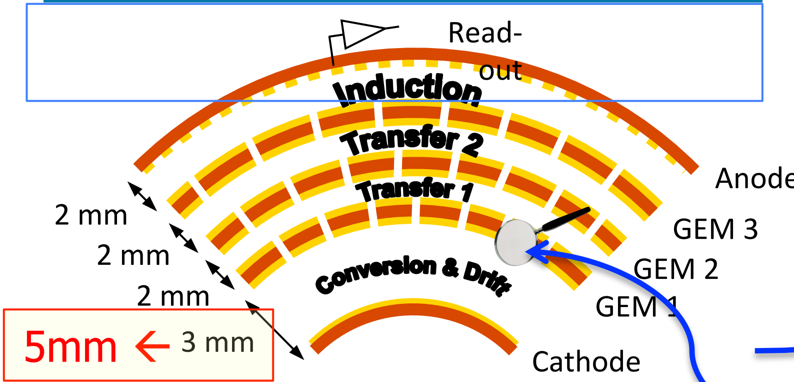
Operation duration at least 5 years

- Three cylindrical layers, each one composed of a triple GEM detector
- Active area
  - L1 length 532 mm
  - L2 length: 690 mm
  - L3 length: 847 mm
- Inner radius: 78 mm
- Outer radius: 178 mm

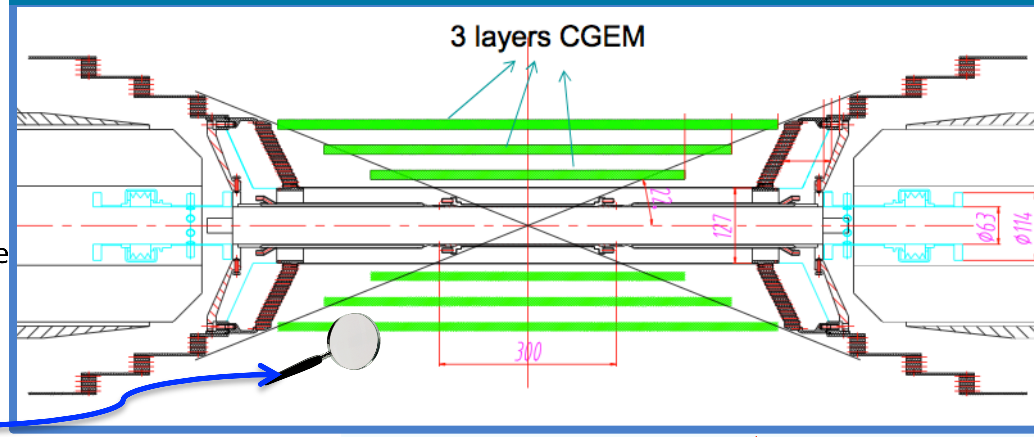
First CGEM built and installed in KLOE2,
BESIII borrows the construction procedure, with innovations
CGEM in BESIII will improve vertex and tracking resolution
better hyperon vertex reconstruction
better background rejection

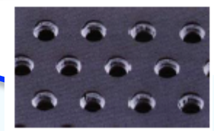
INNER TRACKER: THE FUTURE – CGEM

A cylindrical triple GEM



Three layers of CGEM for BESIII





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@1GeV

Efficiency = ~98%

Low Material bu...

detector

Coverage: 93% 4...

Operation duration...

- Three cylind... ...ers, each one ... GEM detector
- ... mm
- ... L3 length: 847 mm
- ... radius: 78 mm
- ... radius: 178 mm

Co-funded by the European Commission, call H2020-MSCA_RISE-2014, project 2015-2018

Consortium: INFN (Ferrara, Frascati, Perugia, Torino), Mainz, Uppsala, IHEP

First CGEM built and ...

BESIII borrows t... ...struction procedure, with innovations

CGEM in BESIII will improve vertex and tracking resolution

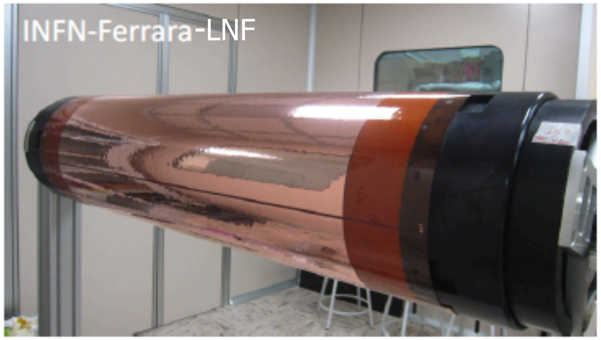
better hyperon vertex reconstruction

better background rejection

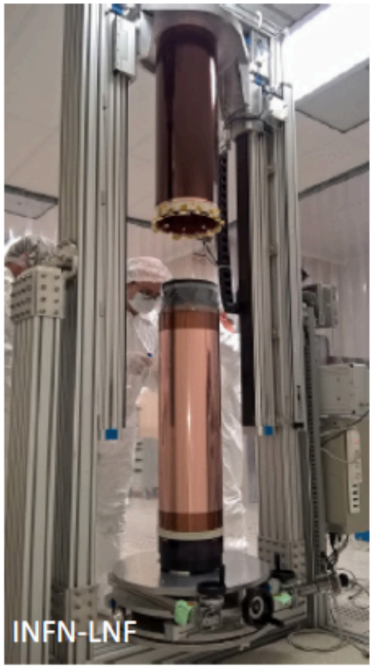
THE CGEM INNER TRACKER: THE FIRST LAYER

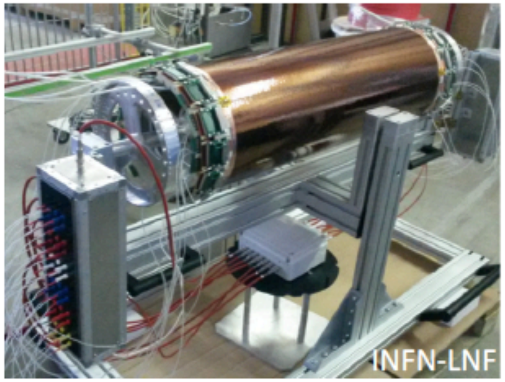
Since 2015 S.C. :
- First cylindrical layer L2 (3mm gap) : completed and instrumented
- L2 tested with cosmic rays
- Two CERN Tests Beam with planar prototypes: June 2015, May 2016
- L2 tested at CERN with magnetic field: October 2016

1) The 5 electrodes (cathode, anode and 3 GEM foils) are cylindrically shaped on aluminum molds,

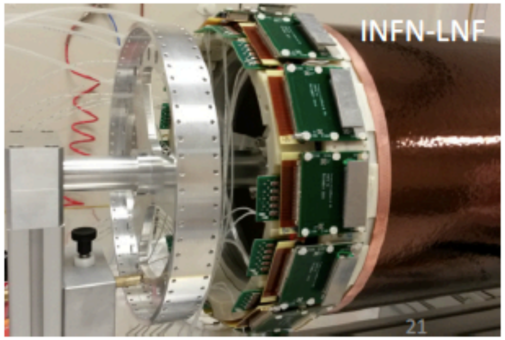


2) They are then inserted one inside the other.



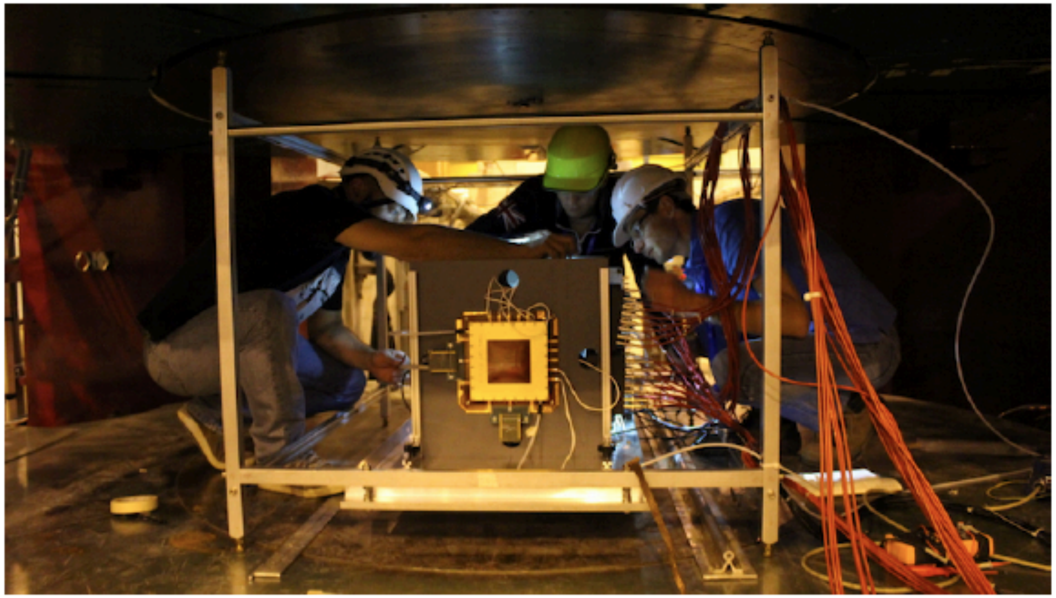


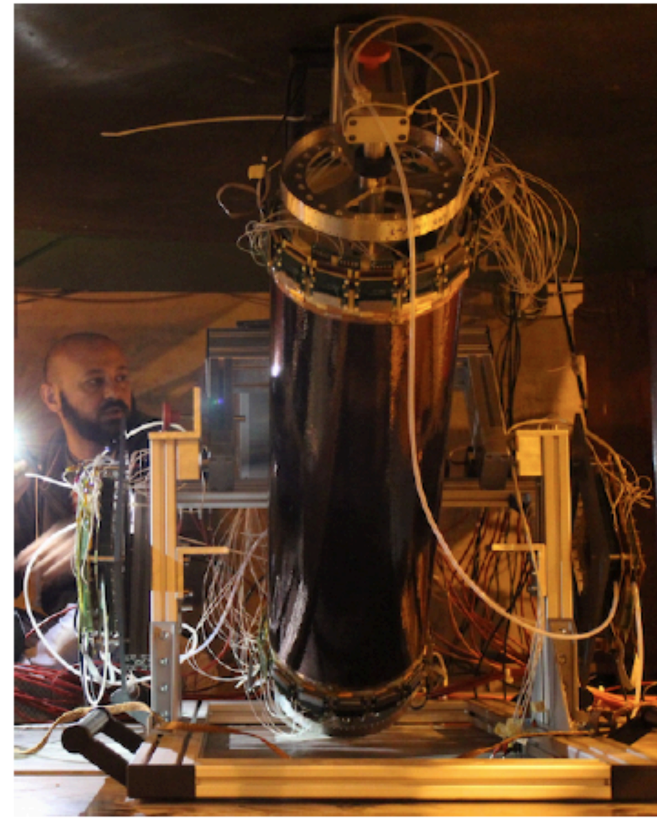
3) First detector layer being equipped with gas, HV and electronics

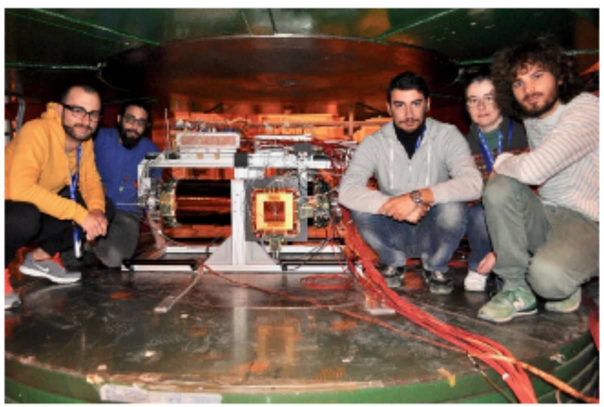


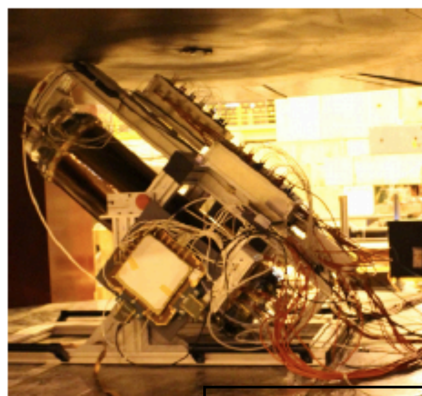
L2 cylinder:
3 mm gap
constructed, assembled and tested

TEST BEAM CAMPAIGN





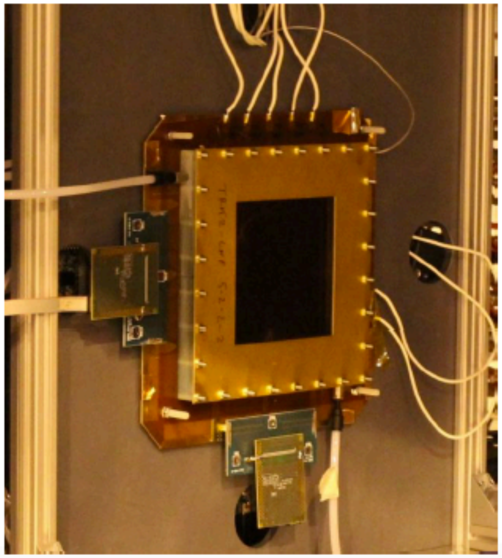




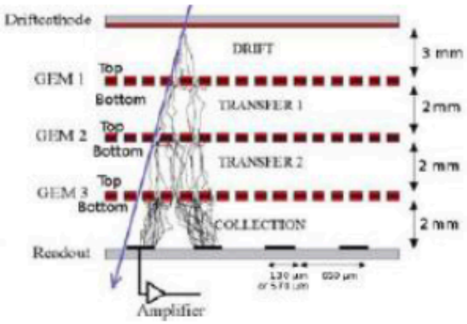
TEST BEAMS @ CERN H4 beam line, SPS:

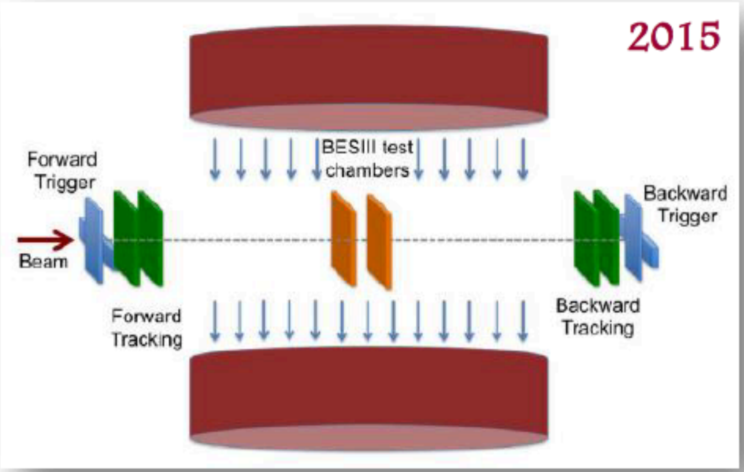
- *June 2015*: with planar chambers (3&5 mm gap)
- *May 2016:* : with planar chambers (3&5 mm gap)
- *October 2016*: with L2 cylinder (3 mm gap)
- next July 2017: with new L1 cylinder (5mm gap)

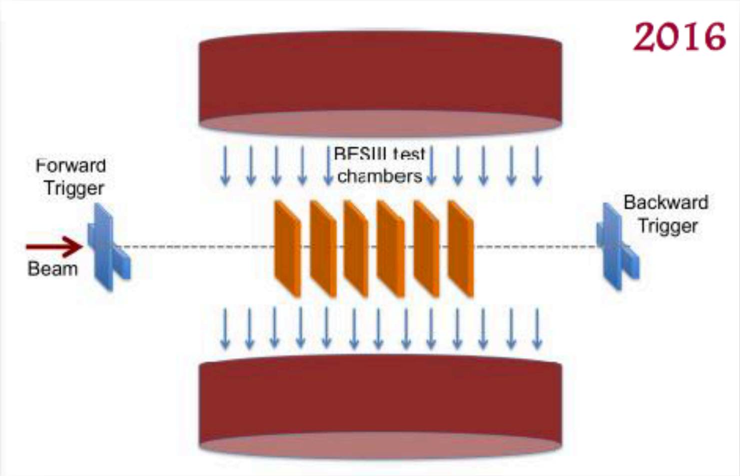
PLANAR chambers



- 10×10 cm² triple GEM
- x view + y view
- strip pitch 650 μm
- gas mixtures:
  - Ar/CO_2 (70/30%)
  - Ar/Iso (90/10%)
- ASIC APV-25







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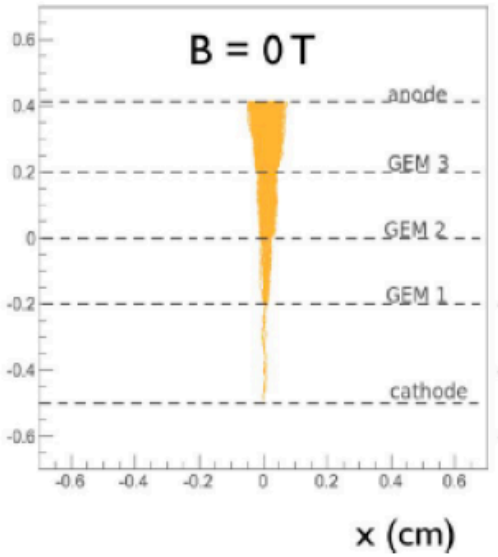
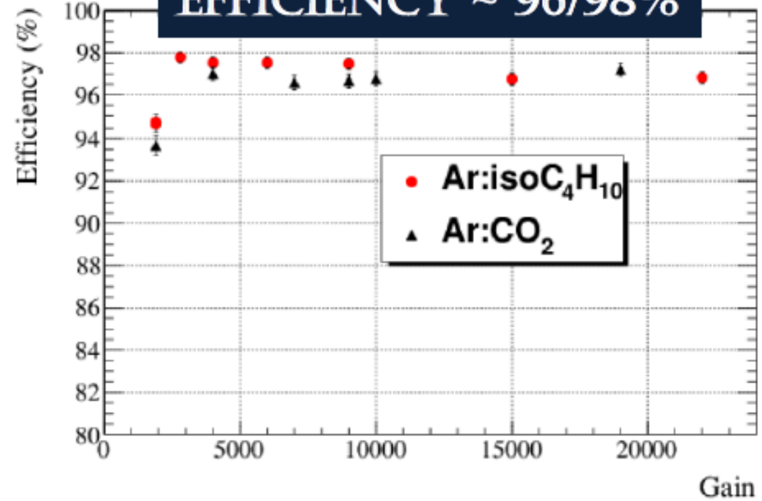
Results for orthogonal tracks and B = 0



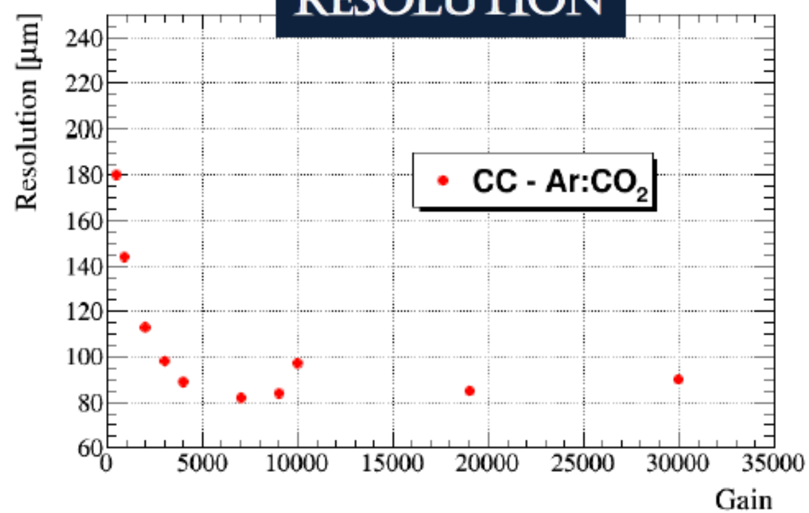
- The charge distribution on anode is gaussian
  → charge centroid

$$< x > = \frac{\sum_i x_i q_i}{\sum_i q_i}$$

EFFICIENCY ~ 96/98%



RESOLUTION

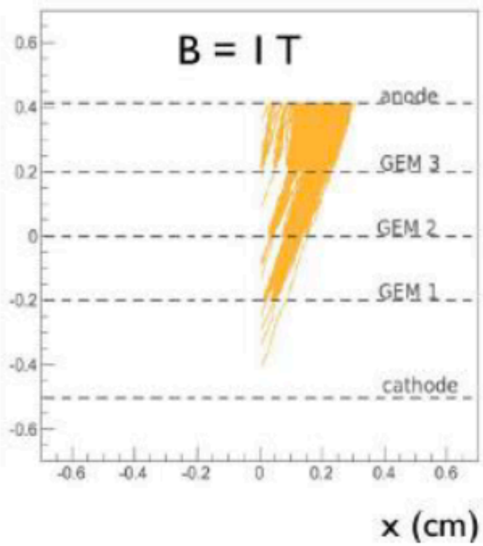


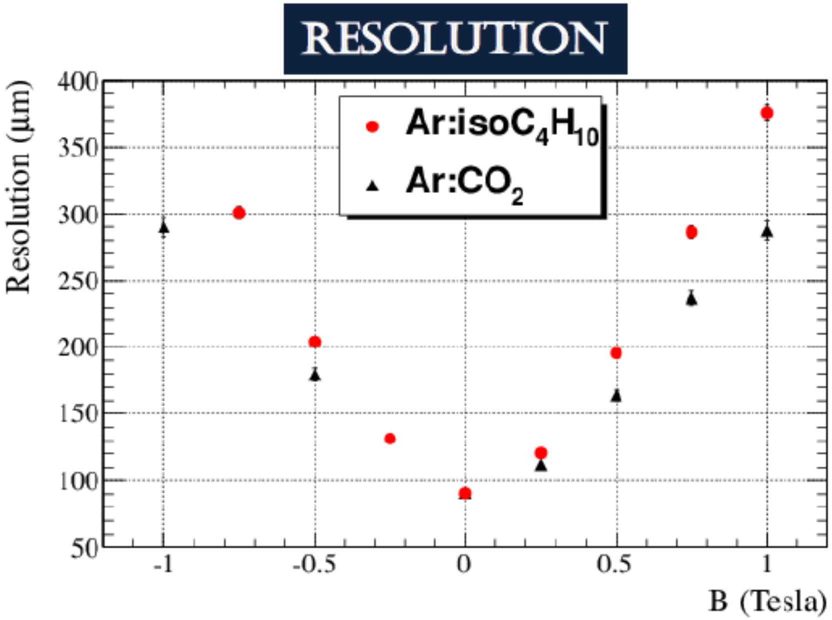
[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016]

80 µm spatial resolution with B=0 !

Issue 2: magnetic field ≠ 0

- The simultaneous presence of **E and B** creates a **Lorentz force** ∝ **qE + B** which bends the drift electron trajectories → charge distribution nomore gaussian
→ again, charge centroid failing





[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016]

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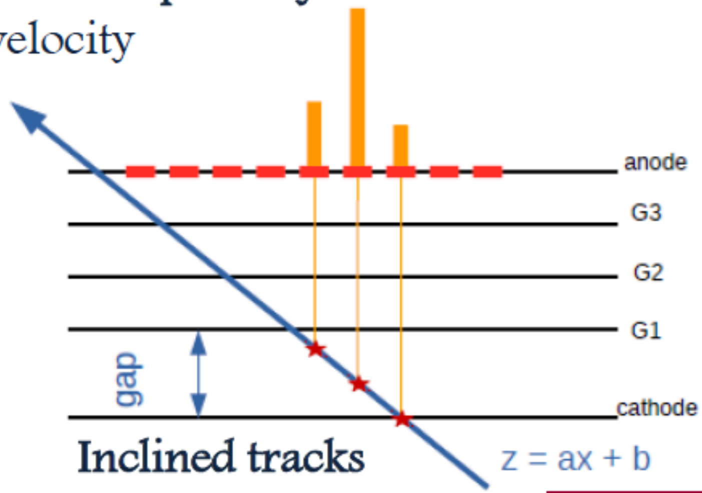
80 μm spatial resolution with B=0 !

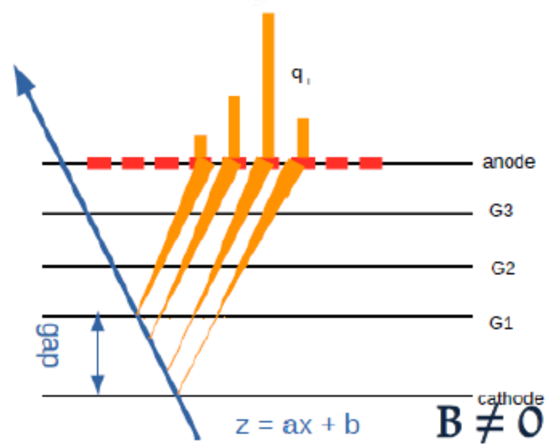
The μ–TPC mode

- inclined tracks and/or magnetic field → increased cluster size → μ-TPC mode available [M. Iodice, JINST, 9 C01017, 2014]

- the drift gap is seen as a "*micro* time projection chamber" and the position of **each primary ionization** is reconstructed by knowing the electron drift velocity



Inclined tracks



$B \neq 0$

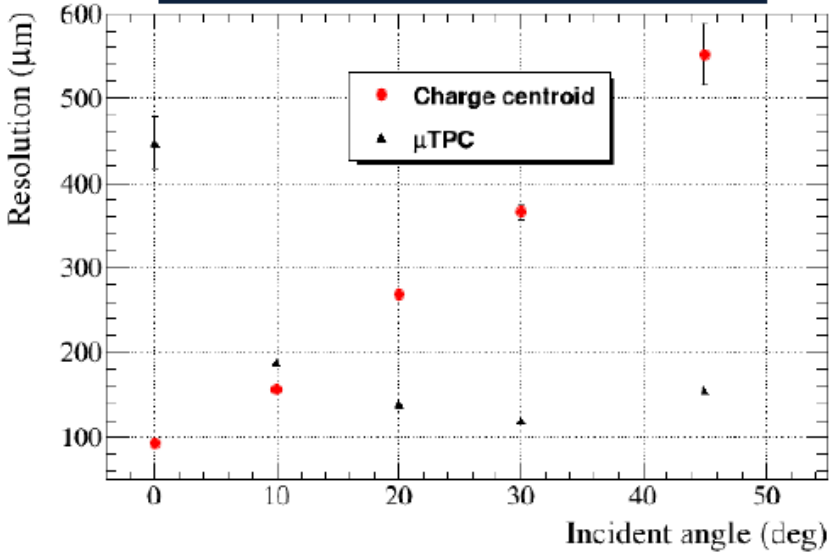
$$x = \frac{\frac{gap}{2} - b}{a}$$

First development of μTPC readout mode for GEM detectors in magnetic field !

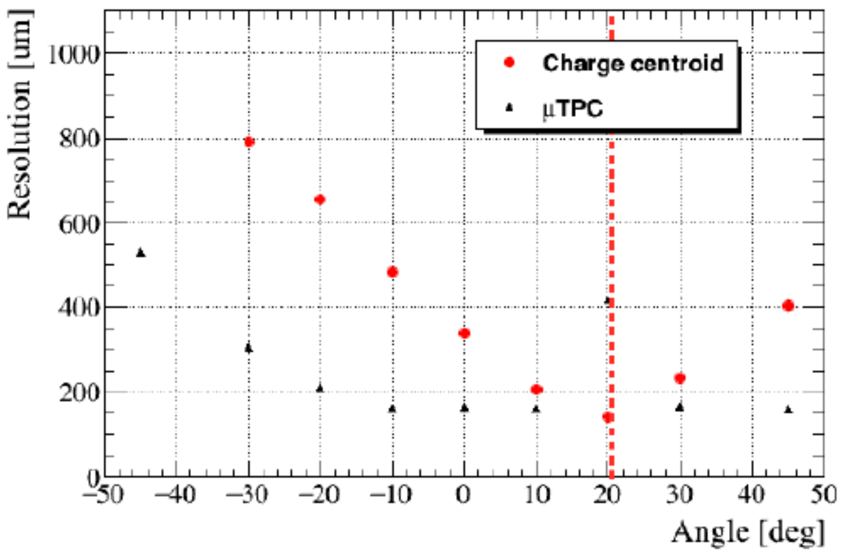
The μ–TPC mode - resolution

- CC and μ–TPC are complementary → a combination of the two will give the best resolution

B=0/INCLINED TRACKS

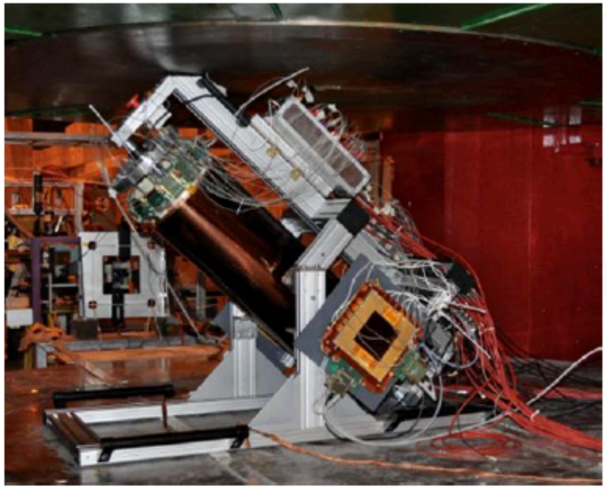


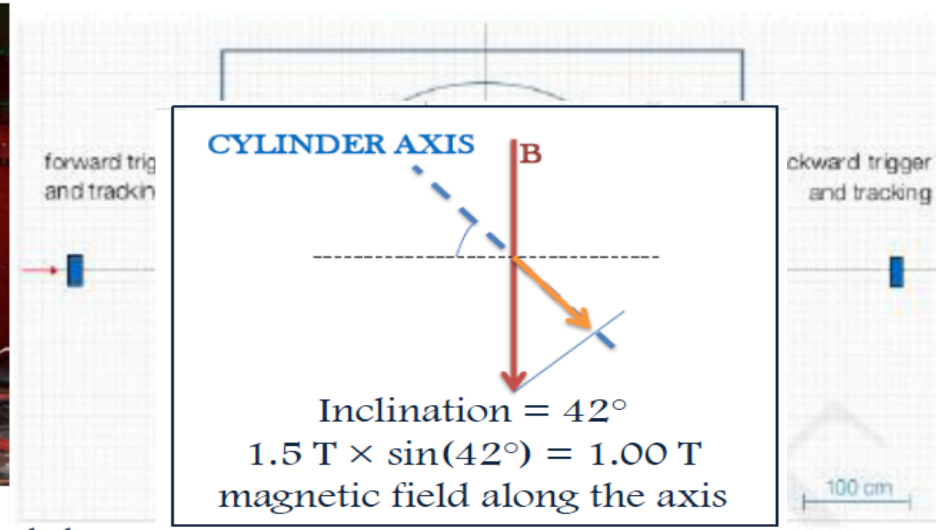
B≠0/INCLINED TRACKS



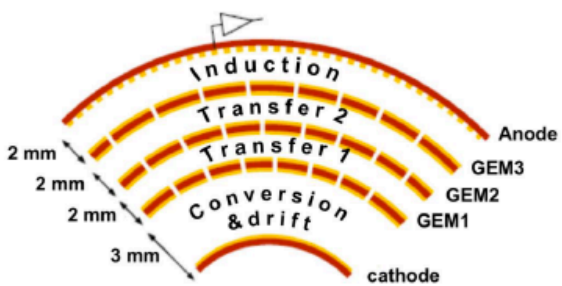
With 5 mm drift-gap σ = 130μm is reached

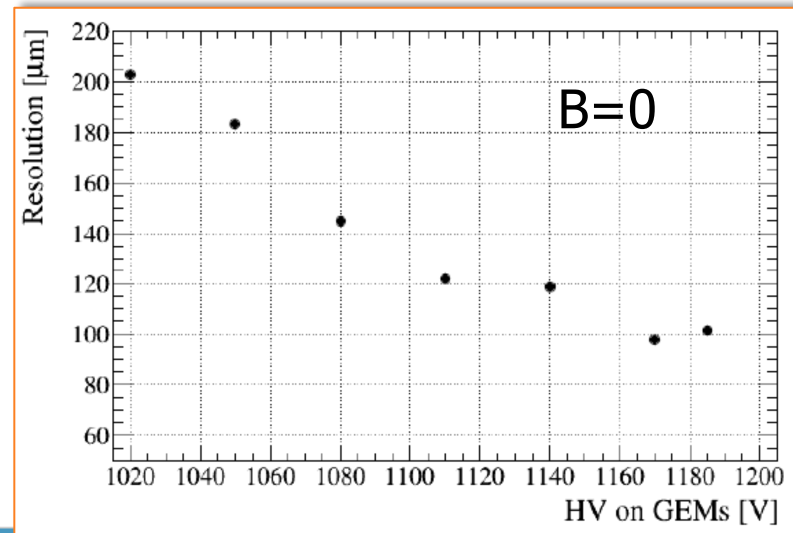
CYLINDRICAL chamber





- first testbeam with layer 2 prototype
- gas mixture Ar/CO_2 (70/30%)
- x & v views, only x instrumented
- 3 mm drift gap





M. Bertani

CGEM-IT/L. Lavezzi/INSTR-17

- detector stable up to high particle rates (50Khz/cm2)
- behaviour consistent with planar chambers

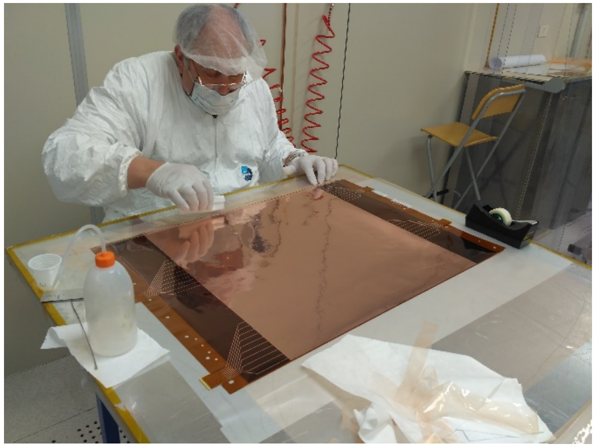
STATUS OF CGEM CONSTRUCTION

- **Studies on planar and cylindrical GEM show that a 5mm drift gap garantees better performances and higher stability than 3mm gap**
- **we have decided (also by request of BESIII Coll. and with OK from CSN1) to use the new 5 mm configuration for L1, L3 and to rebuild L2**

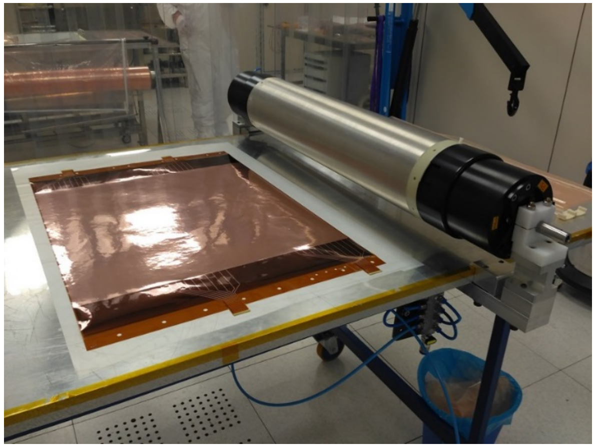
- **L1 is being constructing at LNF clean room**
- **L2: Gems at LNF, new anode arriving from CERN**
- **L3: designes are being defined in Ferrrara**

- **goal: finish construction by the end of October 2017**

L1 CONSTRUCTION @ LNF CLEAN ROOM

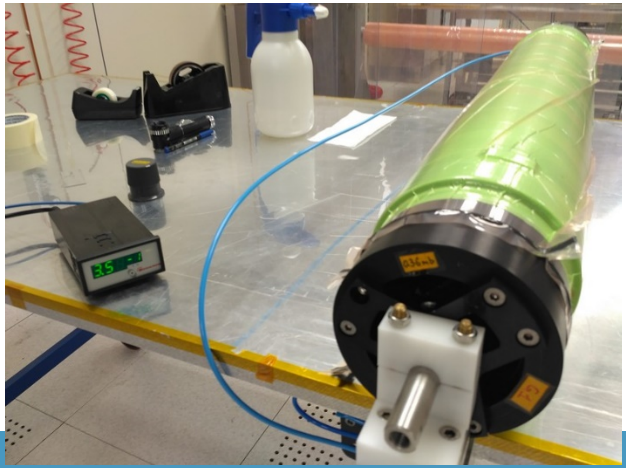


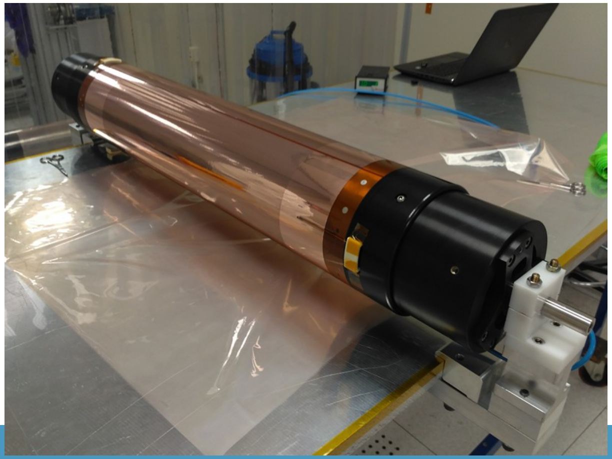
Precise gluing applied on Gems border, 2.5mm overlap



Foil is rolled on the cylindrical mould

gluing with vaccum bag technique





GEM cylinder is ready

L1 anode is arriving from CERN

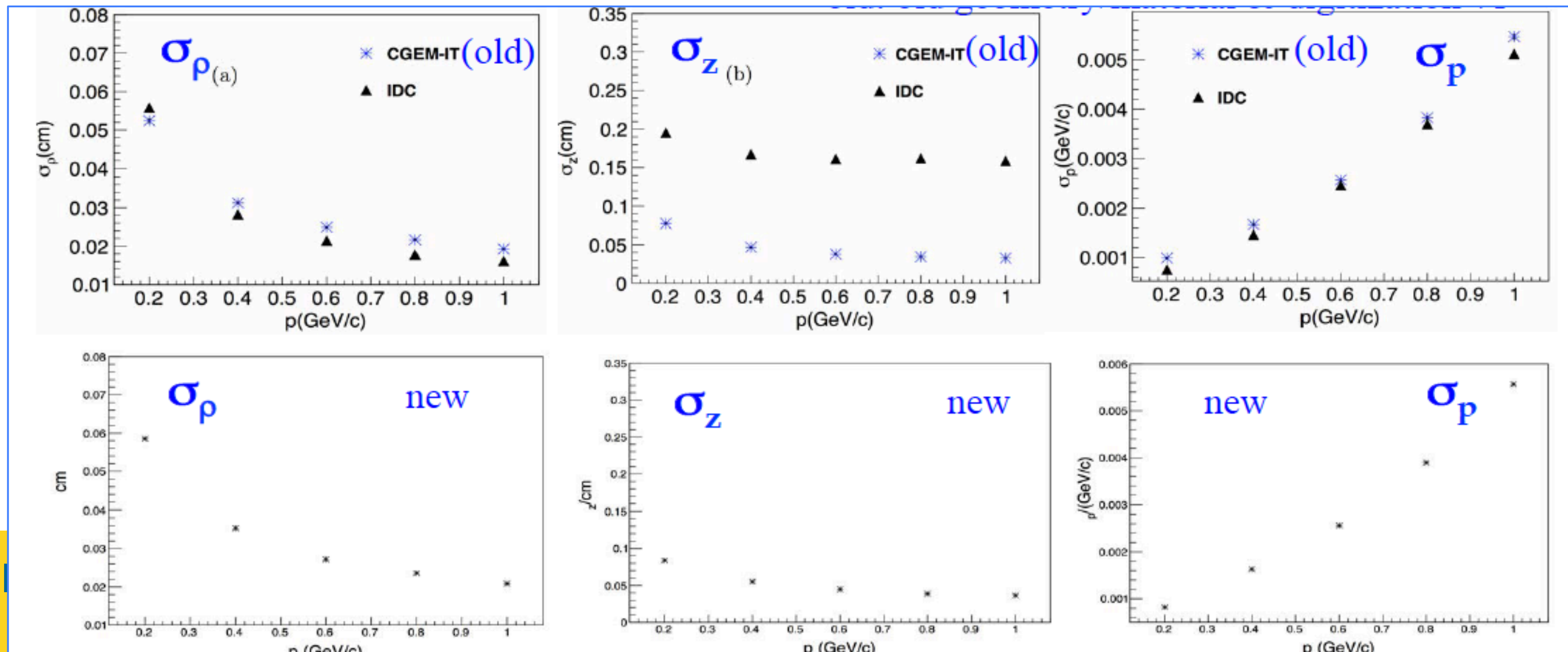
next: anode assembling → vertical insertion machine

CGEM ELECTRONIC INSTRUMENTATION: STATUS

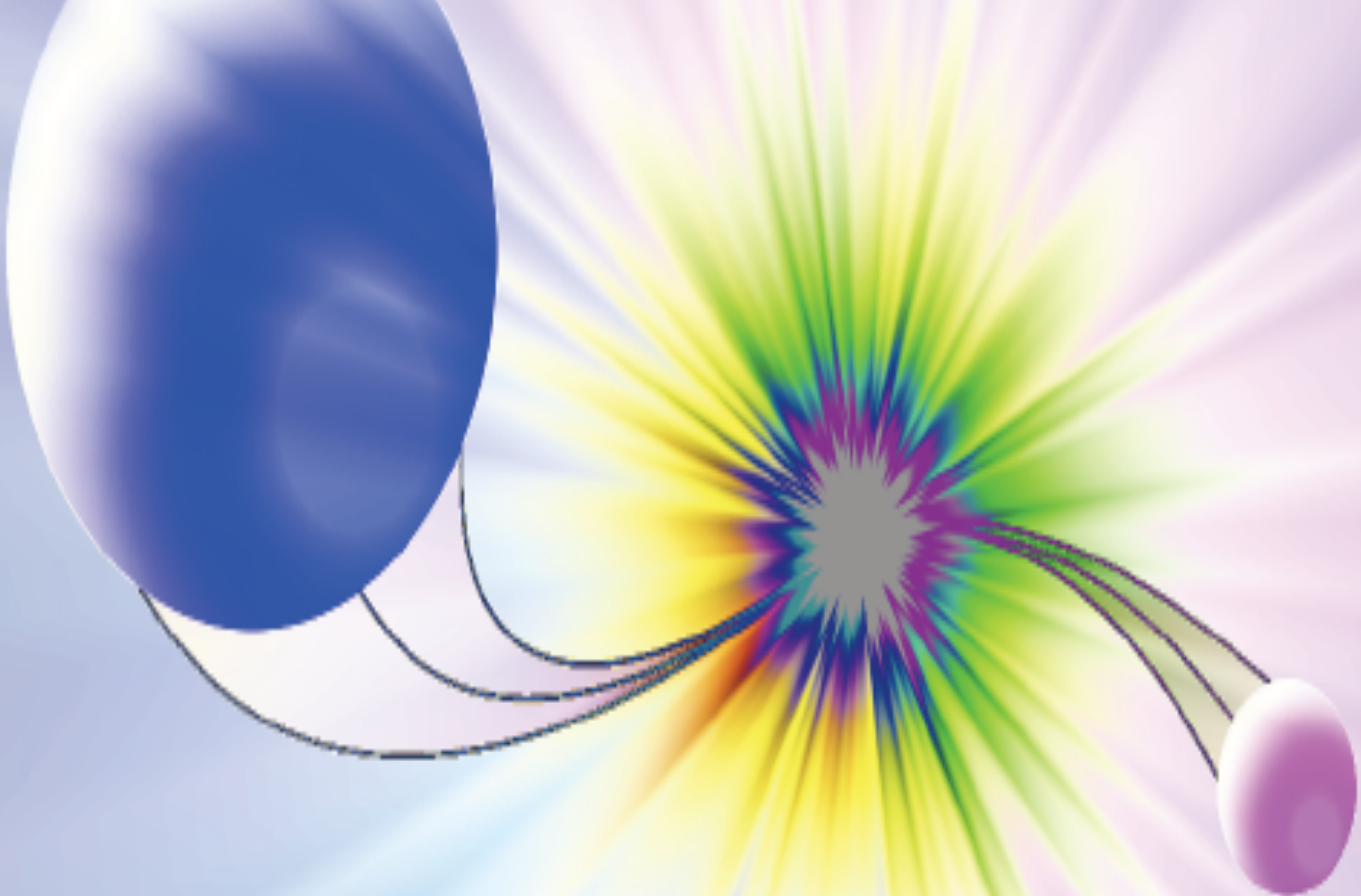
- ✓ **LV distribution system** structure designed
  - main components selected
  - design is going on
- ✓ **HV distribution system**
  - fully designed (to supply independently all the macro/micro sectors of C-GEM layers to allow disconnect a single micro-sector in case of C-GEM local short)
  - production is going on
- ✓ **On-detector front-end electronics based on the TIGER asic.**
  - First release of the chip produced and preliminary laboratory checks done
  - validation tests on L2 prototype are going on
- ✓ **Off-detector readout board (GEM-ROC)** schematic completed
  - PCB board layout will start in June.
- ✓ **Off-detector CONCENTRATOR** hardware borrowed from KLOE-IT
  - Firmware development will start after data packet structure definition

CGEM SOFTWARE (INFN-IHEP): STATUS

- **CGEM final geometry updated in GEANT BESIII detector**
- **tracking algorithm being tested**
- **Track fitting with Kalman Filter extended to process MDC hits and CGEM clusters**
- **Full digitization model under development**



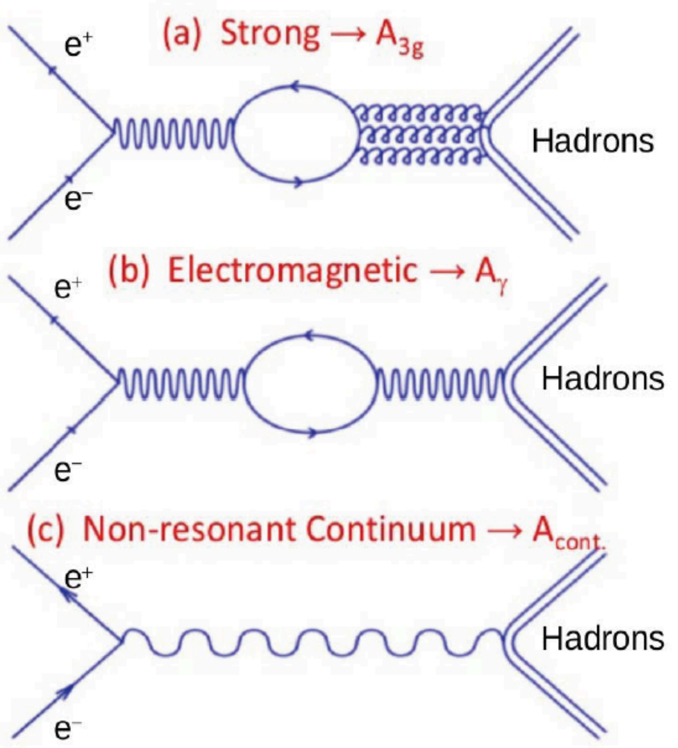
A few physics items



PHYSICS ANALYSIS ACTIVITIES FROM THE ITALIAN BESIII GROUP (LNF,PG,FE,TO)

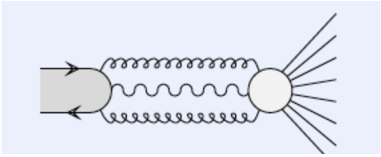
- Relative phase between J/ψ strong and e.m. amplitudes:
  - e^+e^+ -> J/ψ -> $\mu^+\mu^-$, $2(\pi^+\pi^-)\pi^0$ -> final review stage for publication
  - e^+e^- -> J/ψ -> $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$ -> on going
  - e^+e^+ -> J/ψ -> ppbar -> memo review committee stage
  - e^+e^+ -> J/ψ -> K^+K^- -> memo ready
- Study of relative phases at ψ(2S) -> soon a dedicated scan run
- Search for X(1835) in J/ψ-> $\omega\eta'\pi^+\pi^-$ -> memo review committee stage
- Search for pentaquark states in Λ_c-> $p\phi\pi^0$ -> memo ready
- Study of J/ψ , ψ(2S) -> $\Sigma^+\Sigma^-$bar -> memo review committee stage

RELATIVE PHASE MEASUREMENT



$$\sigma = ||A_{3g}|e^{i\Phi_{3g,EM}} + |A_\gamma|e^{i\Phi_{\gamma,cont.}} + |A_{cont.}||^2$$

- 3 possible decay amplitudes (or may be 4?)
- J/ψ experimental evidence points to $\phi \approx 90^\circ$ so strong and e.m. should not interfere
- ψ' conundrum: $\phi \approx 90^\circ / 180^\circ$? *(dedicated run soon)*
- present $J/\psi \to \pi^+\pi^-$, K^+K^- data suggests contribut
from the G-parity violating amplitude $A_{gg\gamma}$:



BESIII is measuring it, new results soon !

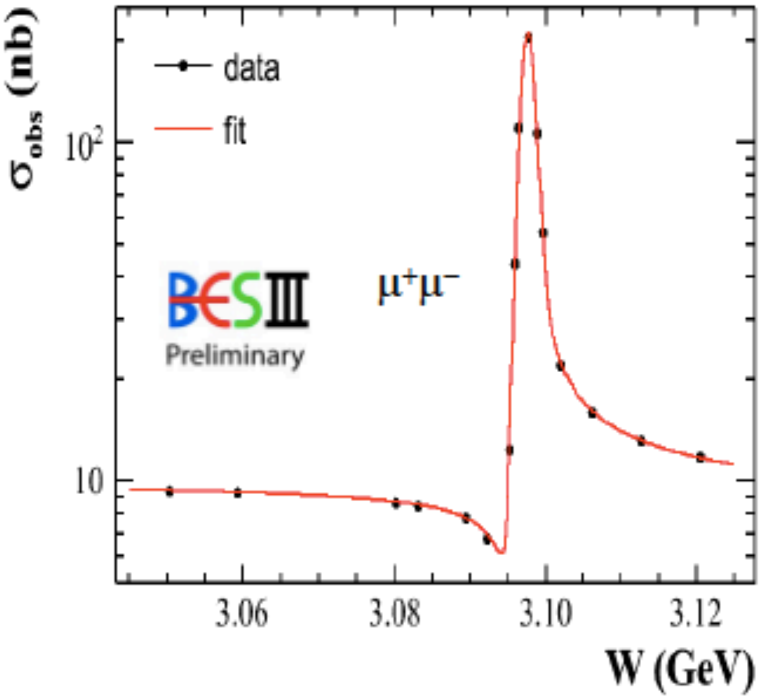
PHYSICAL REVIEW D **95,** 034038 (2017)

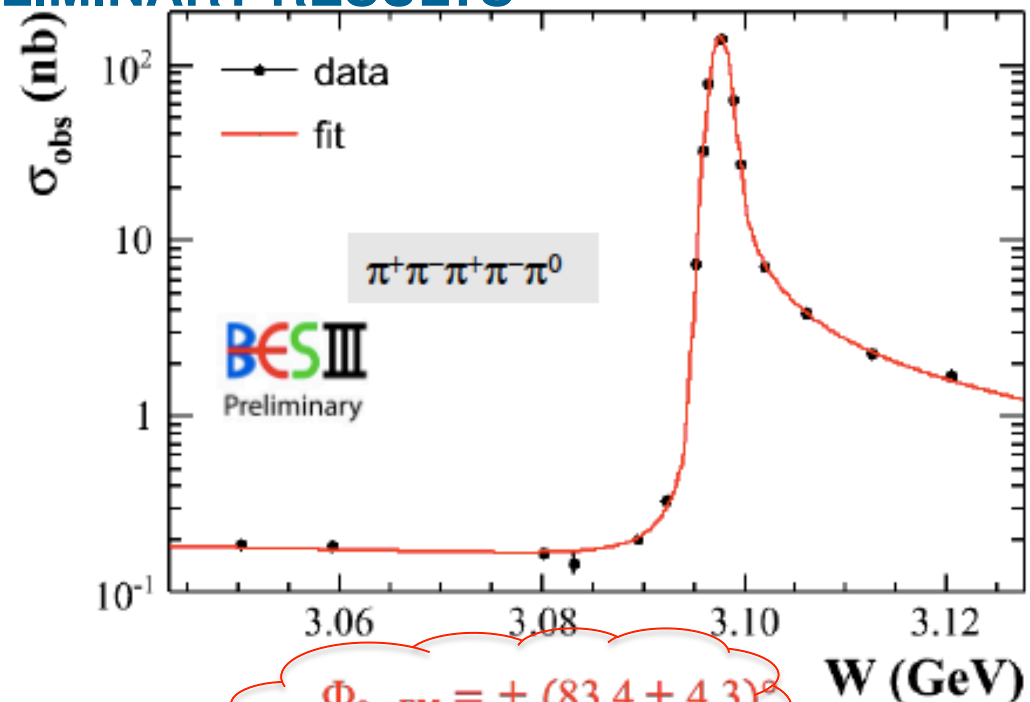
New *G*-parity violating amplitude in the *J*/*ψ* decay?

R. Baldini Ferroli,[1] F. De Mori,[2,3] M. Destefanis,[2,3] M. Maggiora,[2,3] S. Pacetti,[4,*] L. Yan,[3,5] M. Bertani,[1] A. Calcaterra,[1] G. Felici,[1] P. Patteri,[1] Y. D. Wang,[1,6] A. Zallo,[1] D. Bettoni,[7] G. Cibinetto,[7] R. Farinelli,[7] E. Fioravanti,[7] I. Garzia,[7] G. Mezzadri,[7] V. Santoro,[7] M. Savrié,[8] F. Bianchi,[2] M. Greco,[2] S. Marcello,[2] S. Spataro,[2] C. M. Carloni Calame,[9] G. Montagna,[9,10] O. Nicrosini,[9] and F. Piccinini[9]

J/Ψ RELATIVE PHASE MEASUREMENT

PRELIMINARY RESULTS

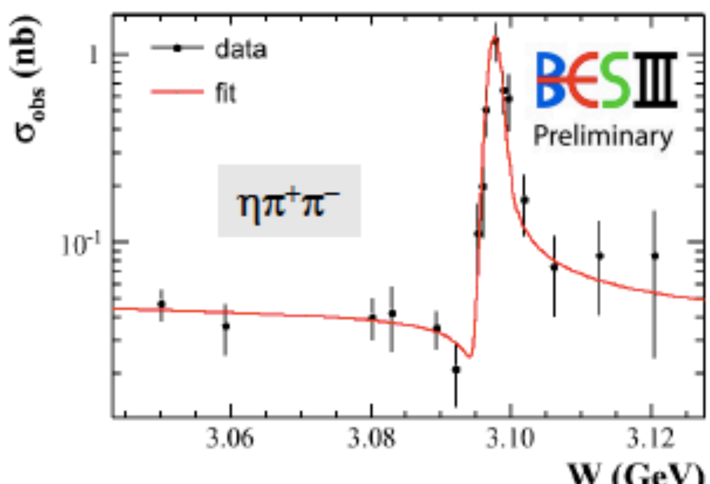




$\Phi_{3g,\ EM} = \pm(83.4 \pm 4.3)°$

$\Phi_{\gamma,cont.} = (-5 \pm 9.7)°$, $S_E = (0.911 \pm 0.026)$ MeV

$\Delta M = (0.548 \pm 0.041)$ MeV

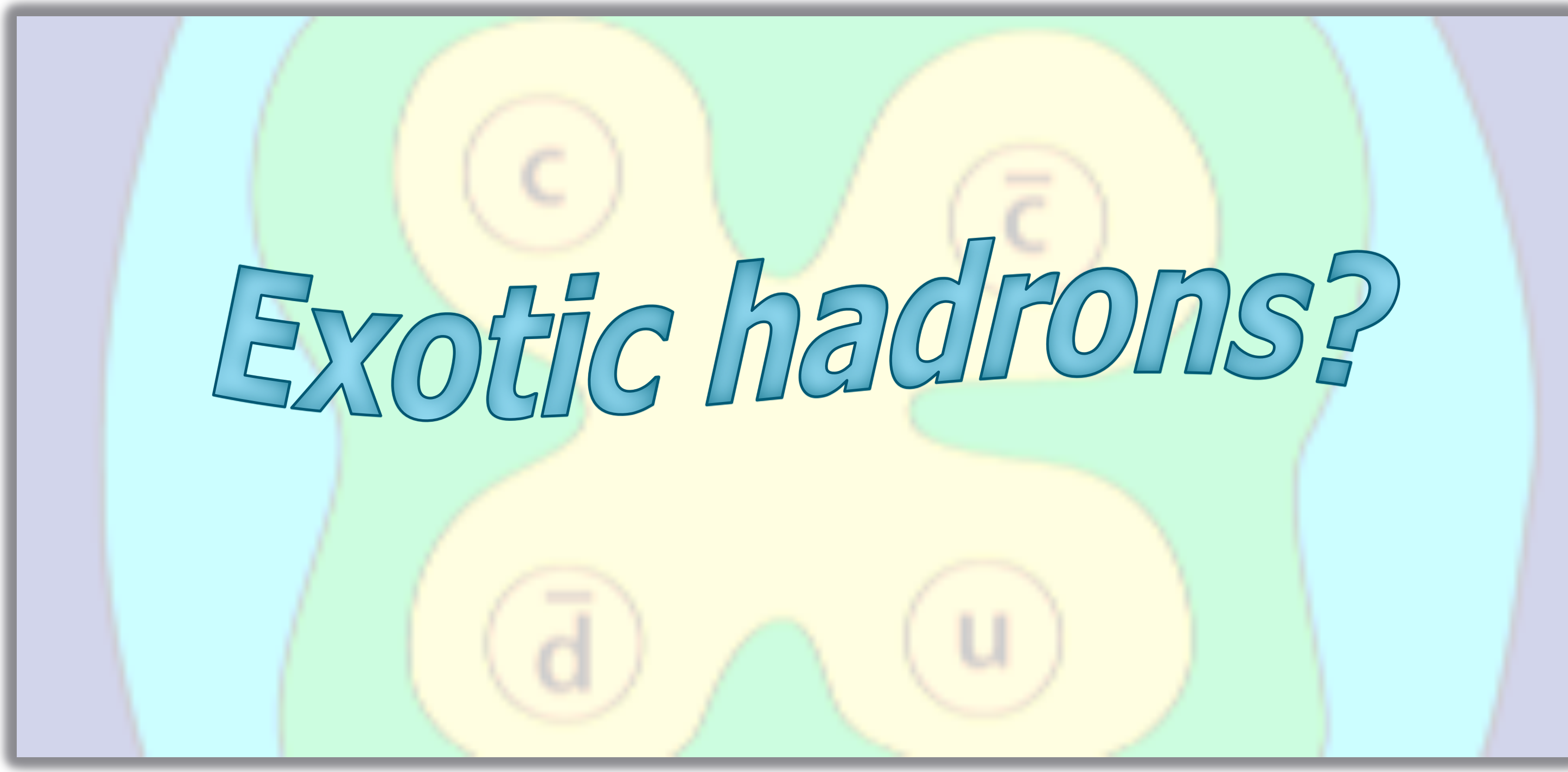


$\eta\pi^+\pi^-$, no A_{3g} due to G violation

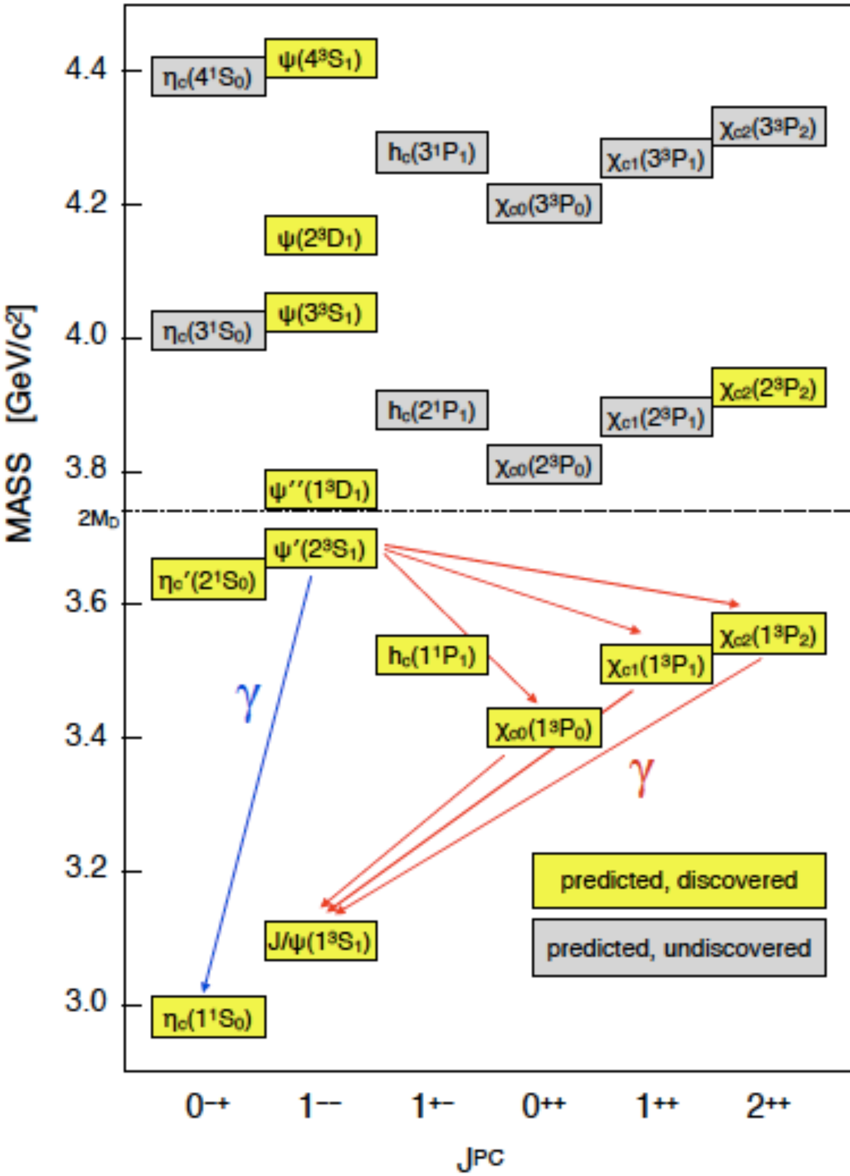
$\Phi_{\gamma,cont.} = (-2 \pm 39)°$

$Br(J/\psi \to \eta\pi^+\pi^-) = (3.6 \pm 0.7)\times 10^{-4}$, improved than PDG value

Exotic hadrons?



CHARMONIUM SPECTROSCOPY



- **The quark model describes most of charmonium remarkably well**

Example potential from Barnes, Godfrey, Swanson:

$$V_0^{(c\bar{c})}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\tilde{\delta}_\sigma(r)\vec{S}_c \cdot \vec{S}_{\bar{c}}$$

(Coulomb + Confinement + Contact)

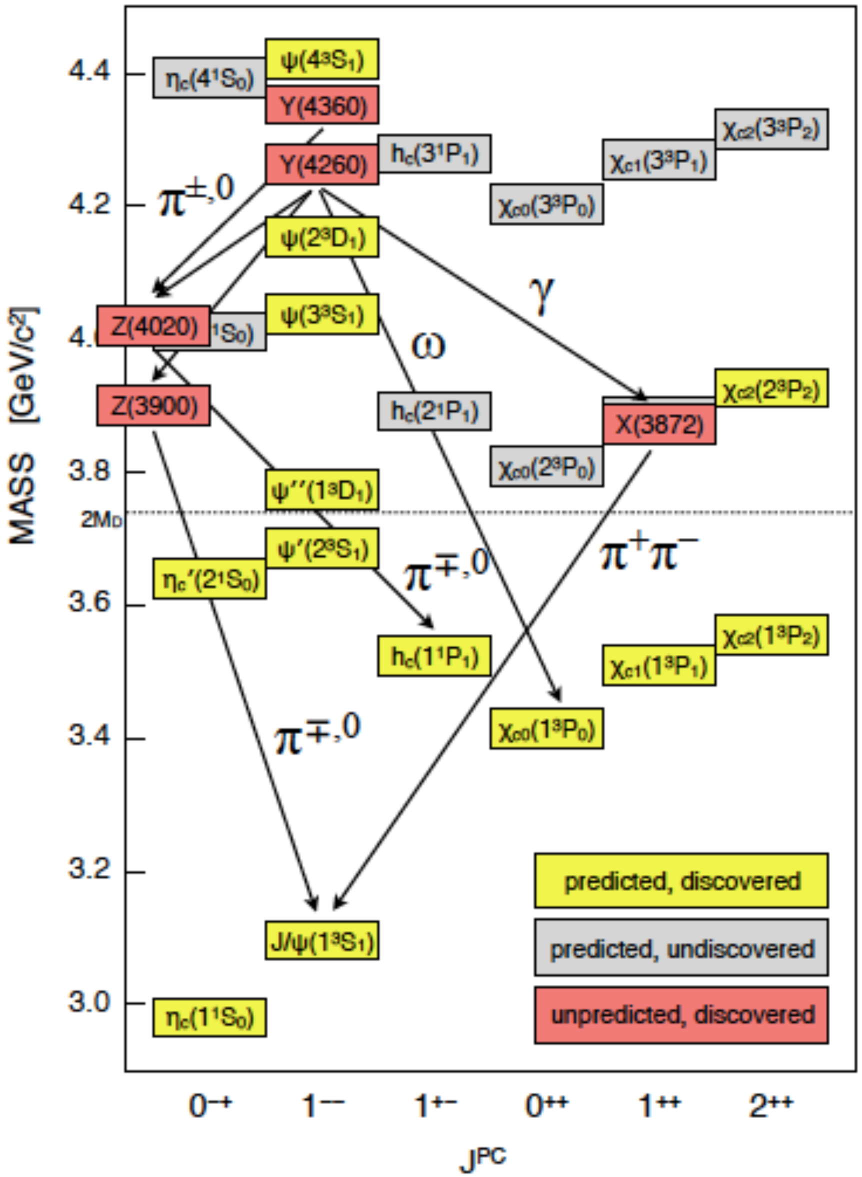
$$V_{\text{spin-dep}} = \frac{1}{m_c^2}\left[\left(\frac{2\alpha_s}{r^3} - \frac{b}{2r}\right)\vec{L}\cdot\vec{S} + \frac{4\alpha_s}{r^3}T\right]$$

(Spin-Orbit + Tensor)

PRD72, 054026 (2005)

- well-established states → fix parameters
- predict remaining spectrum and transitions
- below DDbar threshold: good agreement between prediction and discovery

SURPRISING DISCOVERIES: THE XYZ STATES

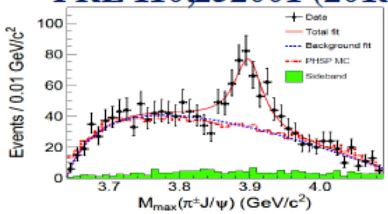


- **The quark model describes most of charmonium remarkably well**
- **below DDbar threshold: good agreement between prediction and discovery**
- **above DDbar threshold: many expected states not observed, many unexpected observed:**
  - "XYZ" states point beyond the quark model: hybrids? multiquark states? glueball?
  - discovered by Belle, Babar in B decays, ISR, by BESIII direct production (tuning e+e- energies)

BESIII directly produces Y(4260) and Y(4360) and more new Y states
BESIII has discovered Zc(3900) and Zc'(4020) and neutral partners !
BESIII is building connections

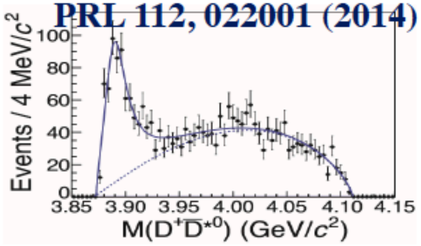
Z C CHARGED AND NEUTRAL STATES AT BESIII

PRL 110,252001 (2013)



$e^+e^- \to \pi^+ \pi^- J/\psi$

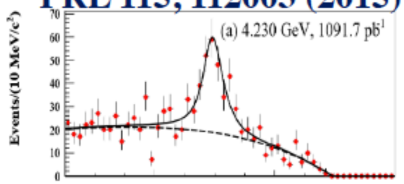
PRL 112, 022001 (2014)



$e^+e^- \to \pi^+ (D\bar{D}^*)^-$

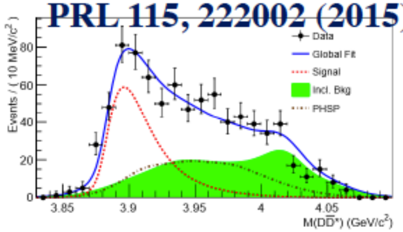
$Z_c(3900)^\pm$?

PRL 115, 112003 (2015)



$e^+e^- \to \pi^0 \pi^0 J/\psi$

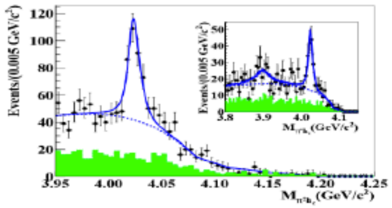
PRL 115, 222002 (2015)



$e^+e^- \to \pi^0 (D\bar{D}^*)^0$

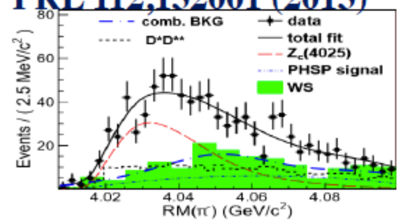
$Z_c(3900)^0$?

PRL 111.242001 (2013)



$e^+e^- \to \pi^+ \pi^- h_c$

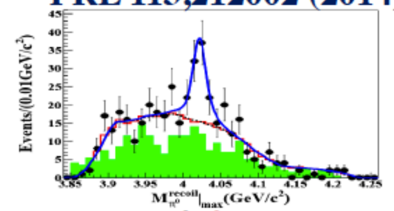
PRL 112,132001 (2013)



$e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$

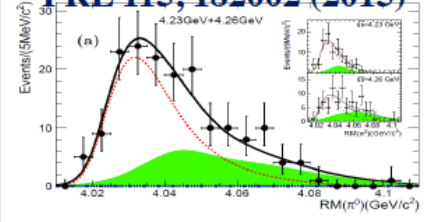
$Z_c(4020)^\pm$?

PRL 113,212002 (2014)



$e^+e^- \to \pi^0 \pi^0 h_c$

PRL 115, 182002 (2015)

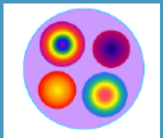


$e^+e^- \to \pi^0 (D^*\bar{D}^*)^0$

$Z_c(4020)^0$?

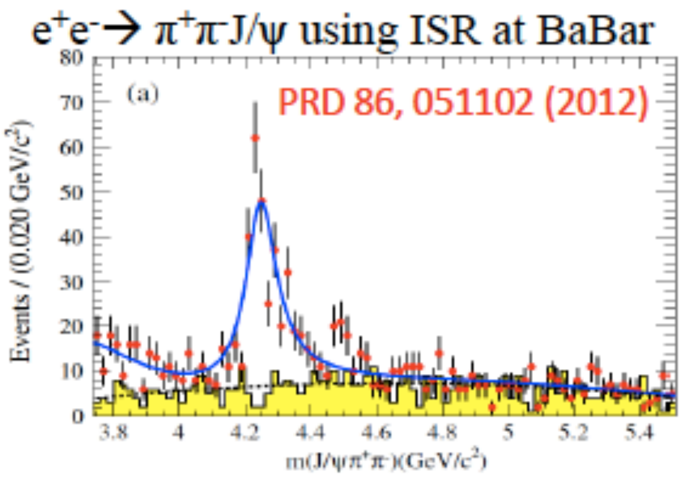
If these structures are real QCD states and charged Zc decays into $\pi^+\pi^- J/\psi$ ($\pi^{+/-} h_c$) then at least four valence quarks to satisfy:

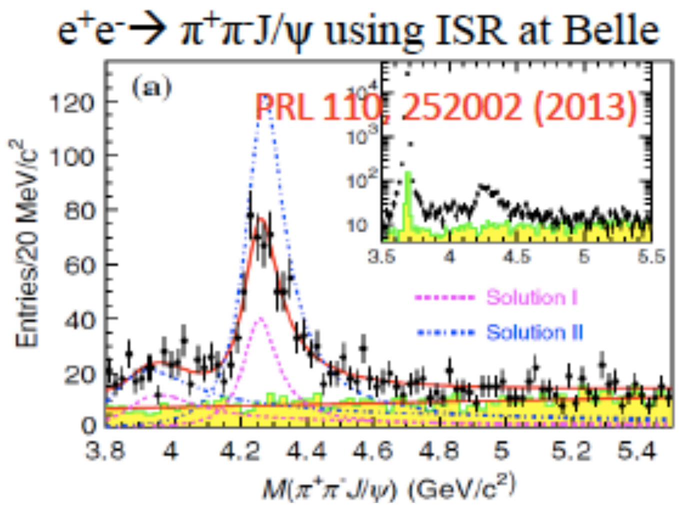
- charge= +- 1
- strong coupling to ccbar components.



Y(4260): BABAR & BELLE

Cross section of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

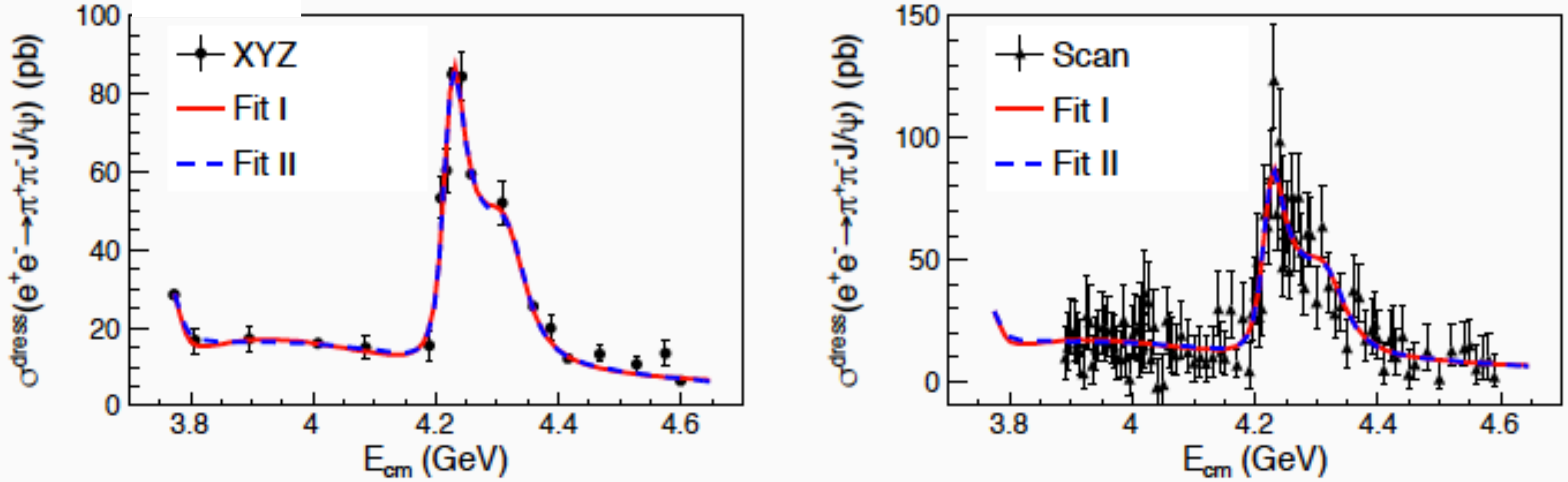




asymmetric shape?
low mass Y(4008)?

BESIII: Y(4260)?

BESIII [PRL 118,092001 (2017)] : $e^+e^- \rightarrow \pi^+\pi^- J/\psi$



The Y(4260) is not one peak, but two!

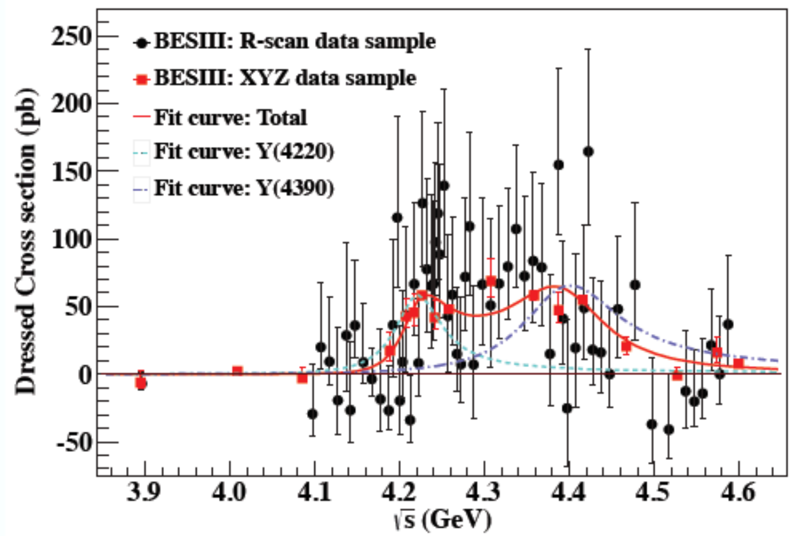
$M_1 = 4222.0 \pm 3.1 \pm 1.4$ MeV/c^2 $\quad \Gamma_1 = 44.1 \pm 4.3 \pm 2.0$ MeV

$M_2 = 4320.0 \pm 10.4 \pm 7.0$ MeV/c^2 $\quad \Gamma_2 = 101.4 ^{+25.3}_{-19.7} \pm 10.2$ MeV

two peaks , not one at 4260 !
no need of Y(4008)
different from Belle !

THE Y PUZZLE CONTINUES….

BESIII [PRL 118,092002 (2017)] : $e^+e^- \rightarrow \pi^+\pi^- h_c$



There are two peaks!

$M_1 = 4218.4 \pm 4.0 \pm 0.9$ MeV/c² $\Gamma_1 = 66.0 \pm 9.0 \pm 0.4$ MeV

$M_2 = 4391.6 \pm 6.3 \pm 1.0$ MeV/c² $\Gamma_2 = 139.5 \pm 16.1 \pm 0.6$ MeV

The $\pi^+\pi^- h_c$ shape is clearly different from the $\pi^+\pi^- J/\psi$ shape.

- Two new resonances Y(4220) Y(4390) observed !
- parameters differ from Y(4269),Y(4360) and ψ(4415)

THE Y PUZZLE CONTINUES….

BESIII [PRL 118,092001 (2017)] : $e^+e^- \rightarrow \pi^+\pi^- J/\psi$
[PRL 118,092002 (2017)] : $e^+e^- \rightarrow \pi^+\pi^- h_c$

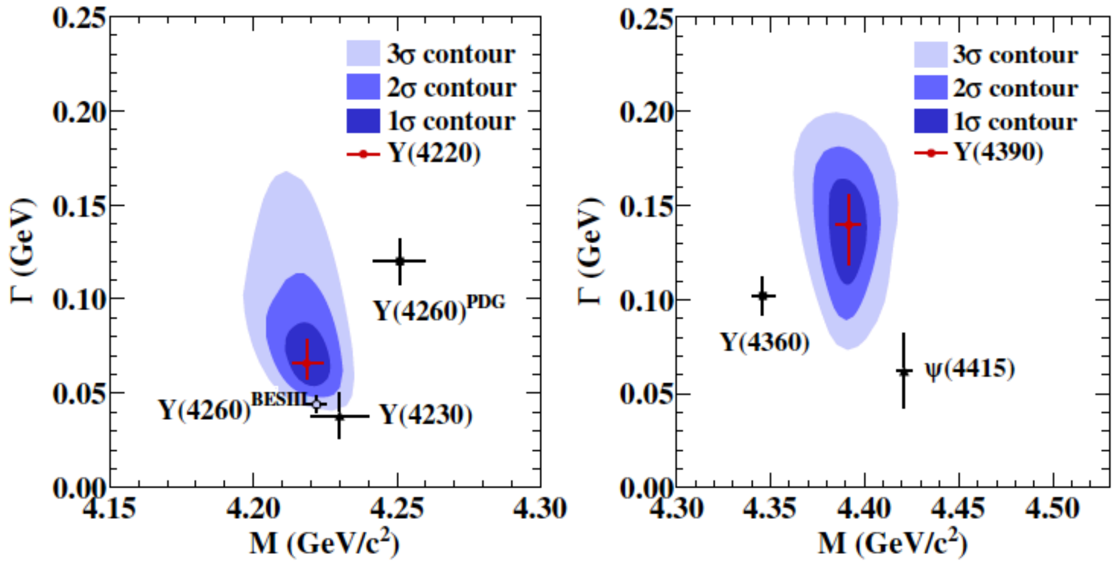


FIG. 3. The likelihood contours in the mass and width planes for $Y(4220)$ (left panel) and $Y(4390)$ (right panel). The filled areas are up to 3σ likelihood contours and the dots with error bars are the locations of Y or ψ states. The parameters of $Y(4260)^{\mathrm{PDG}}$ are taken from the PDG average [3] and $Y(4260)^{\mathrm{BESIII}}$ from the measurement of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ at BESIII [35].

- Two new resonances: Y(4220) in $\pi^+\pi^- J/\psi$, $\pi^+\pi^- h_c$
  Y(4390) first observation
- parameters differ from $Y(4260)^{PDG}$,Y(4360) and $\psi(4415)$

CONCLUSIONS

- **BESIII is running smoothly**
- **Unexpected results from J/ψ phase to the X,Y,Z puzzle and more ...**
- **CGEM-IT upgrade on going in Italy**
- **There will be an Installation readyness review of the CGEM project by an external (w.r.t. BESIII) committee by Jan.2018**
- **LNF center of the CGEM construction, LV/HV system, assembling and validation tests**
- **Tight schedule, need to maintain technical support**

  (electronics, mechanics, technician)

THE BESIII-LNF GROUP

LNF staff personell at today:
6 researchers/technologist (4/2) , *total of 3.1 FTE*
1 senior associates (at IHEP now)
1 senior guest

Technical staff at LNF:
1 (0.5 FTE) LNF-SPAS
2 (0.3FTE) LNF-SEA
2 (0.1 FTE) RM1 from RM1
1 DUBNA *(KLOE2)* leaving in August
1-2 (0.1 FTE) from TO

many thanks to everybody !

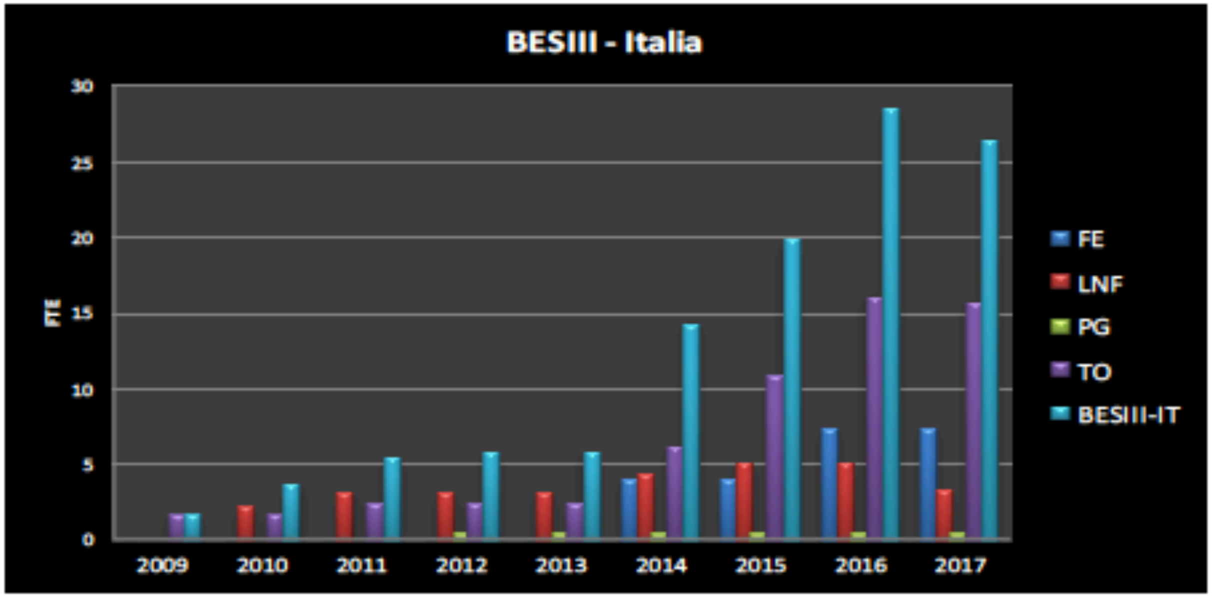
Thanks to the Director
thanks to all the CGEM-KLOE2 staff, in particular
G. Bencivenni, G.Morello, E.DeLucia, D.Domenici

THE BESIII COLLABORATION

The Italian group

Anno	FTE all	FTE/teste all	FTE/teste fisici	FTE tecnici
2015	19.7	0.56	0.6	1.4
2016	28.3	0.69	0.8	1.4
2017	26.3	0.66	0.8	2.8

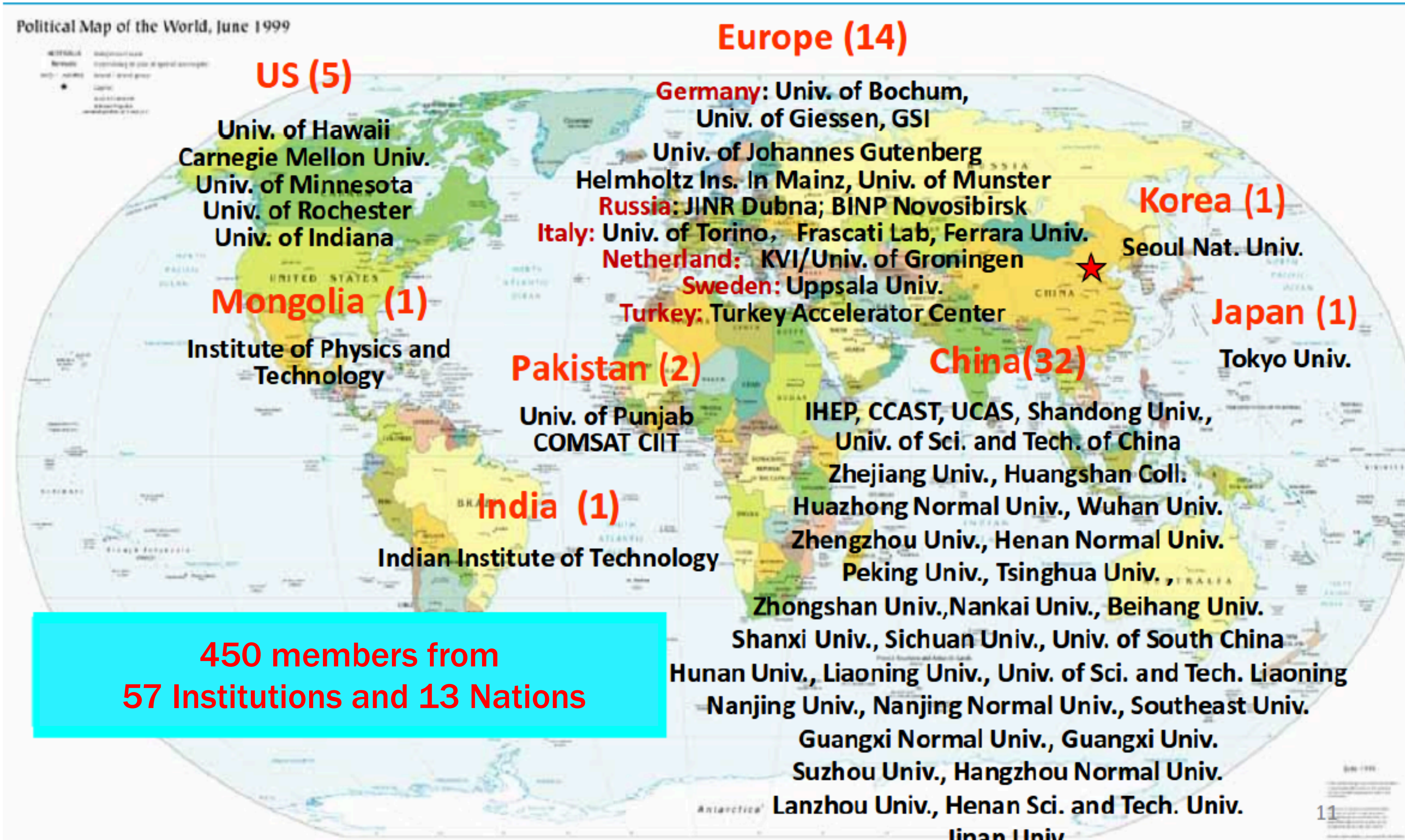
Circa 450 membri
da 57 istituzioni
in 13 nazioni



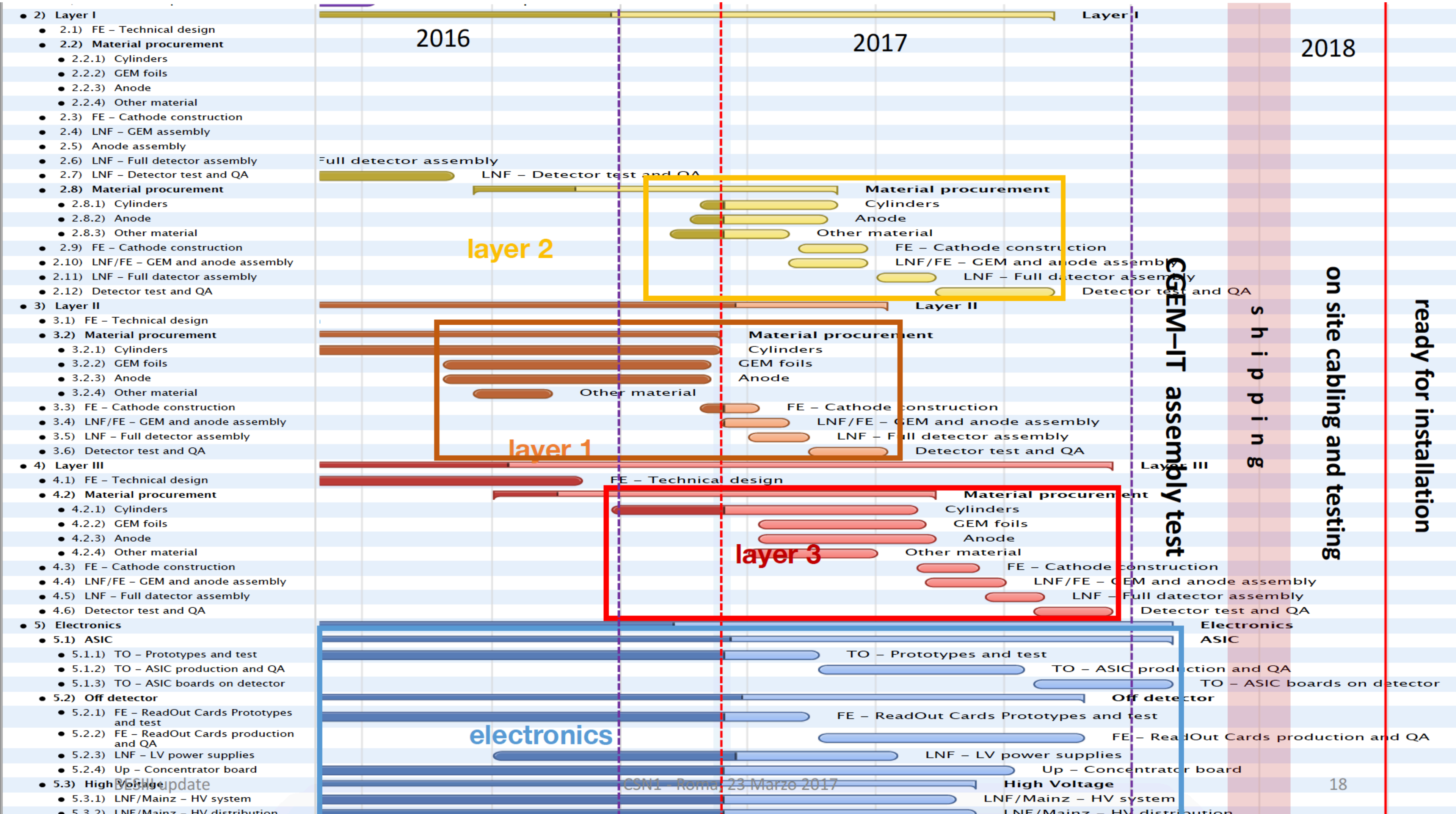
ADDITIONAL MATERIAL

BESIII实验是以高能所为基地的大型国际合作实验

BESIII 国际合作组



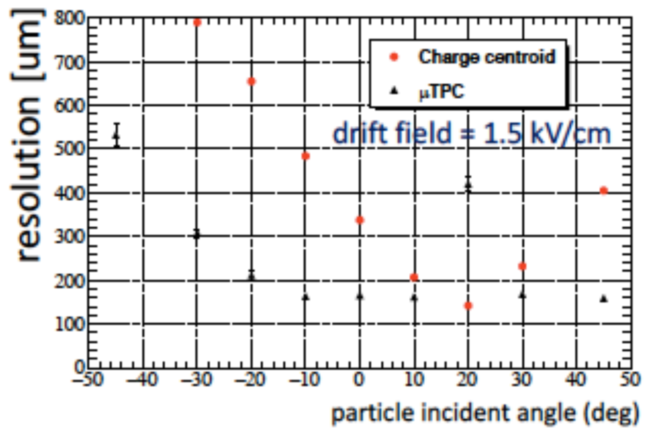
CGEM PROJECT SCHEDULE



PLANAR GEM PERFORMANCES IN MAGNETIC FIELD

Test Beam May 2015

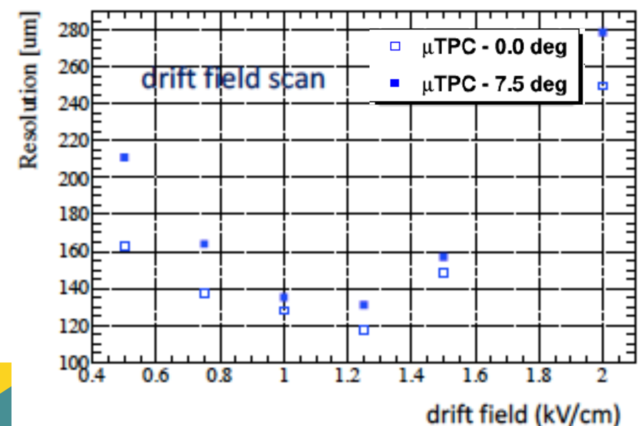
planar prototypes



Last year we developed for the first time a micro-TPC readout for GEM detectors in magnetic field.

➔ stable resolution if combined with c.o.g.

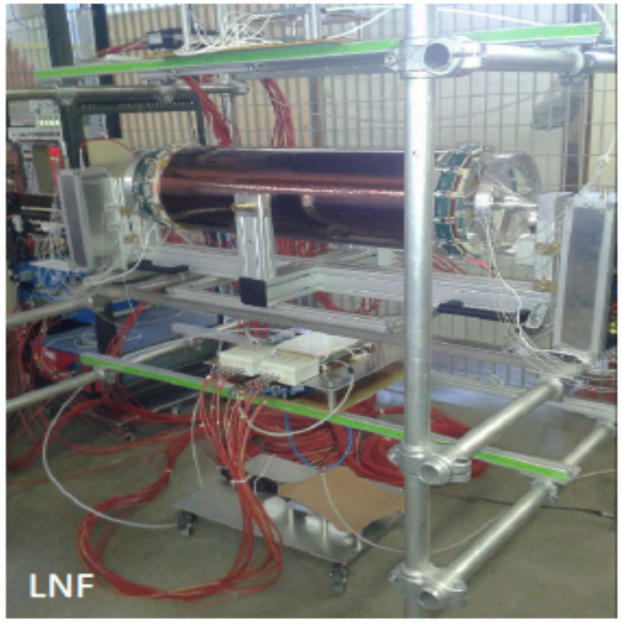
Test Beam May 2016

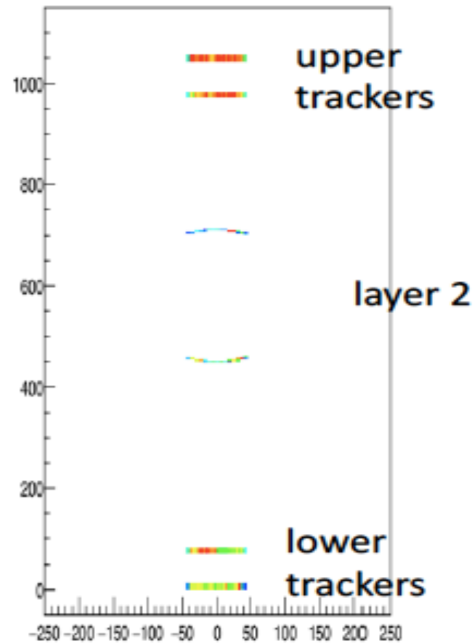


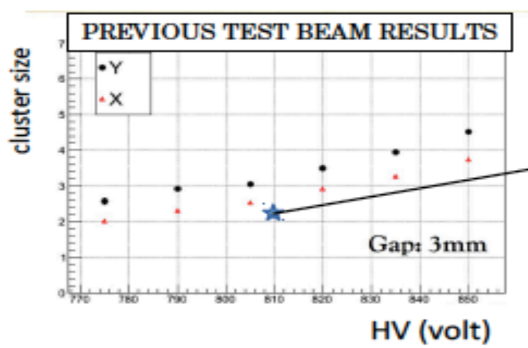
- This year we are optimizing the detector parameters in order to improve the results.

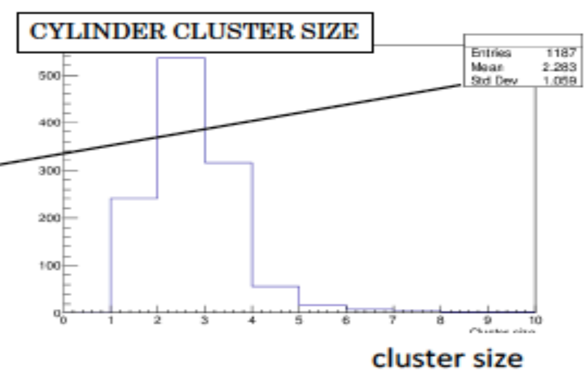
25

CGEM COSMIC RAY TEST @ LNF



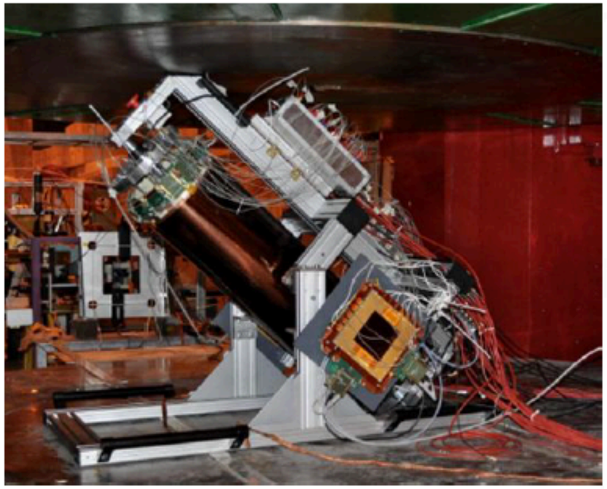


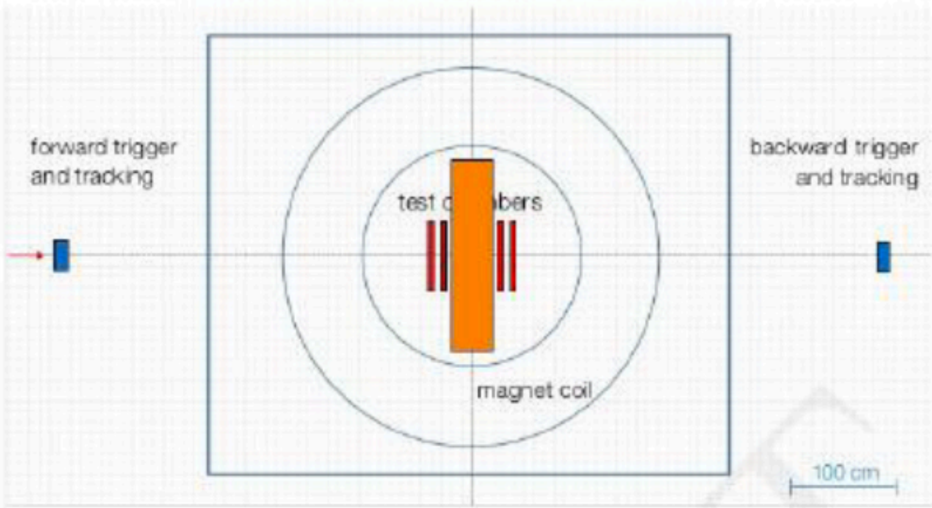




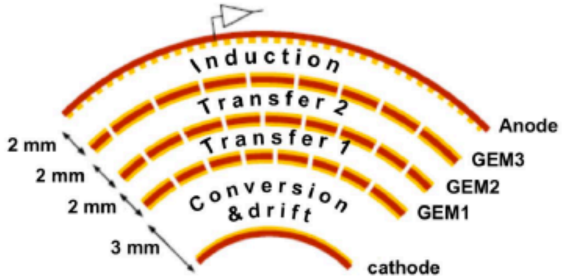
M. Bertani

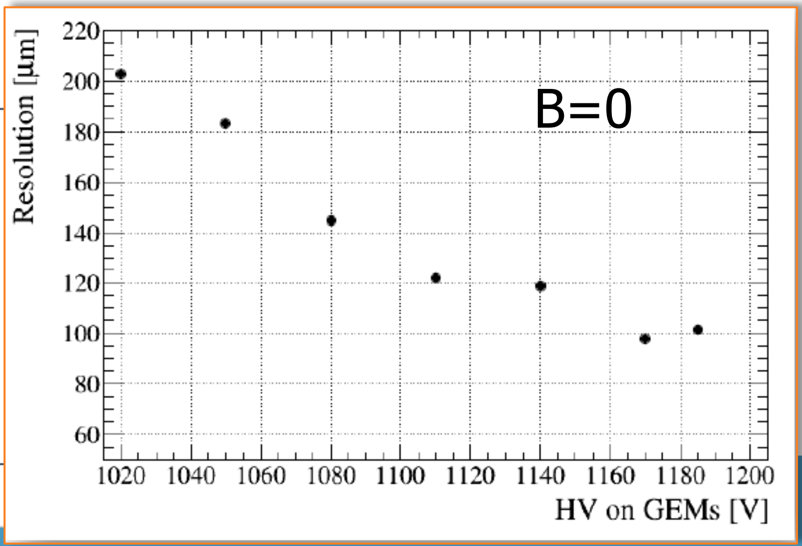
CYLINDRICAL chamber





- first testbeam with layer 2 prototype
- gas mixture Ar/CO_2 (70/30%)
- x & v views, only x instrumented
- 3 mm drift gap



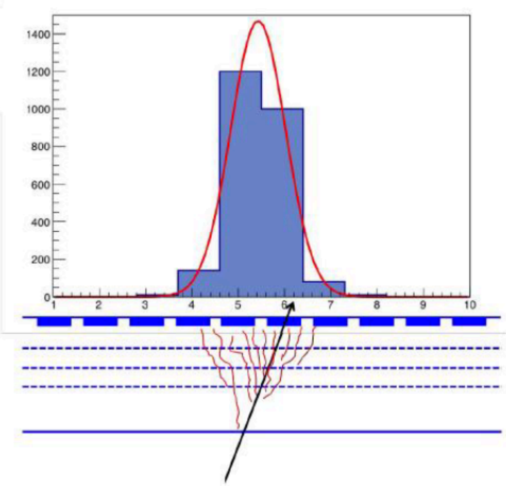


CGEM-IT/L. Lavezzi/INSTR-17

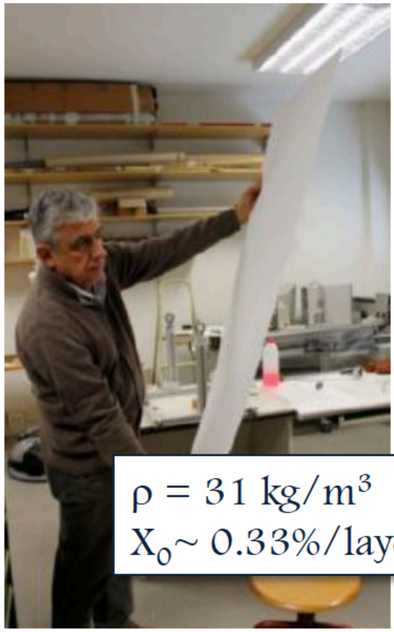
- detector stable up to high particle rates (50Khz/cm2)
- behaviour consistent with planar chambers

BESIII CGEM originality

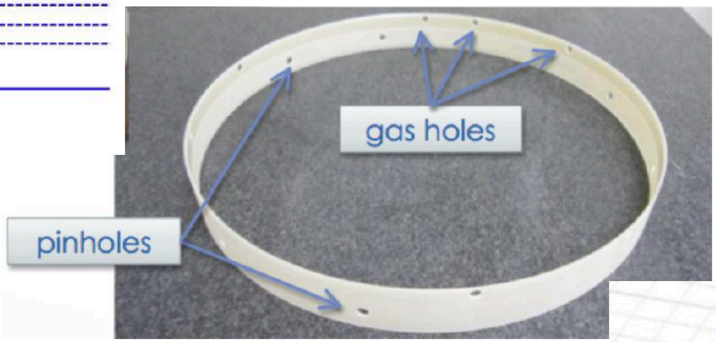
Measurements with triple GEM in magnetic field & with analog readout



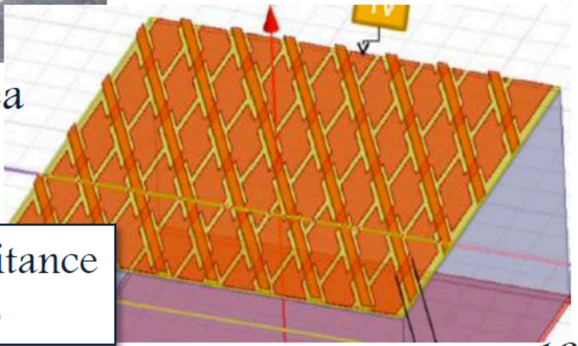
Torino Integrated
Gem Electronics for
Readout
[M. Rolo "A custom readout electronics for the BESIII CGEM detector"]



$\rho = 31\ kg/m^3$
$X_0 \sim 0.33\%/layer$



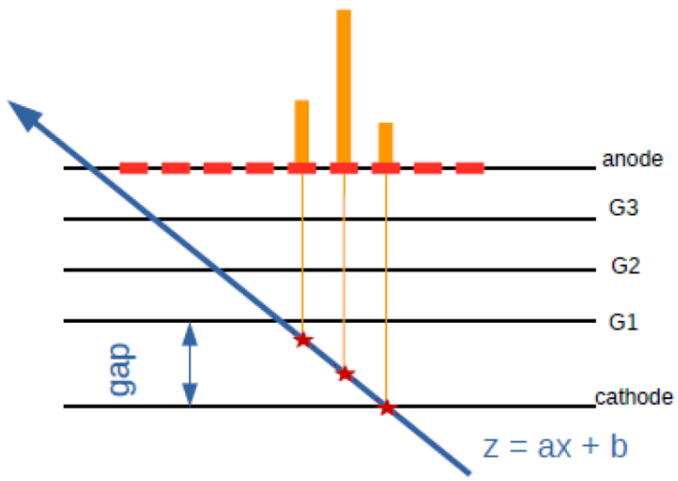
- Mechanics
  - Rohacell 31
  - permaglass rings only outside the active area
- Readout
  - Dedicated ASIC
  - Jagged strips



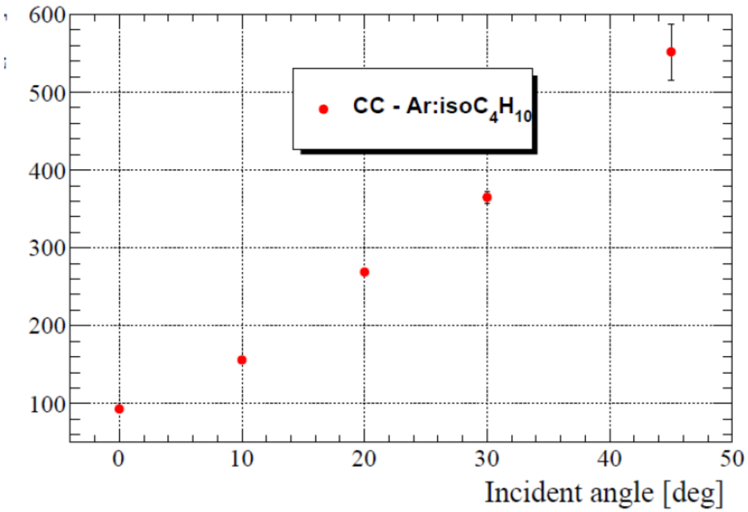
Inter-strip capacitance reduced of ~30%

CGEM-IT/L. Lavezzi/INSTR-17 13

Issue 1: inclined tracks



RESOLUTION



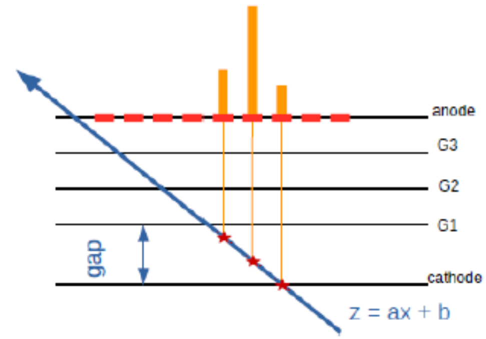
[R. Farinelli, IEEE NSS/MIC Strasbourg, 2016

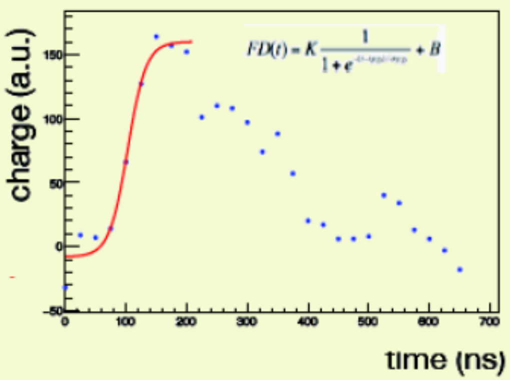
- the cluster size increases and the charge distribution at anode is no longer gaussian
→ the charge centroid starts failing

[M. Iodice, JINST, 9 C01017, 2014]

The μ–TPC mode

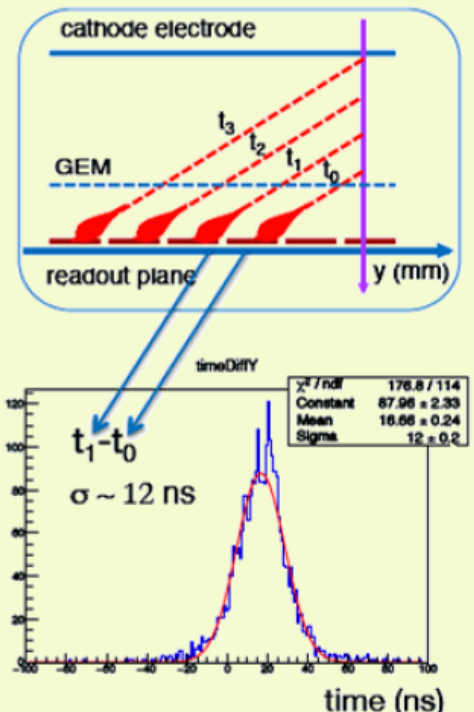
- inclined tracks and/or magnetic field → increased cluster size → μ-TPC mode available
- the drift gap is seen as a "*micro* time projection chamber" and the position of **each primary ionization** is reconstructed by knowing the electron drift velocity





- **STEP 1**

∀ strip fit time samples of the charge with a Fermi-Dirac to **extract the t_i**

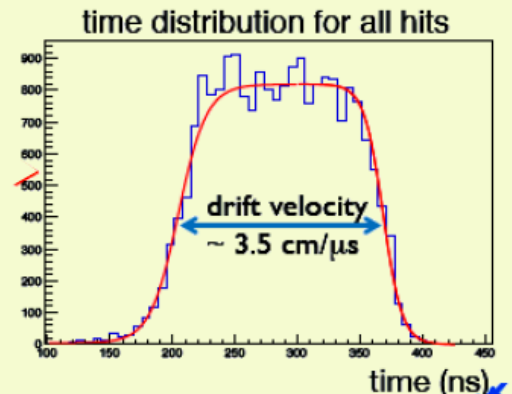


- **STEP 2**

Δt resolution ~ **12 ns**

- **STEP 3**

v_{DRIFT} from t_i distribution on 5 mm gap



CGEM-IT/L. Lavezzi/INSTR-17 33

settings

Ar/CO2 70/30

3655/3905 V

Gap	3 or 5	375/625	1.25
G1_TOP			
Gap	0.050	360	72
G1_BOTTOM			
Gap	2	600	3
G2_TOP			
Gap	0.050	360	72
G2_BOTTOM			
Gap	2	600	3
G3_TOP			
Gap	0.050	360	72
G3_BOTTOM			

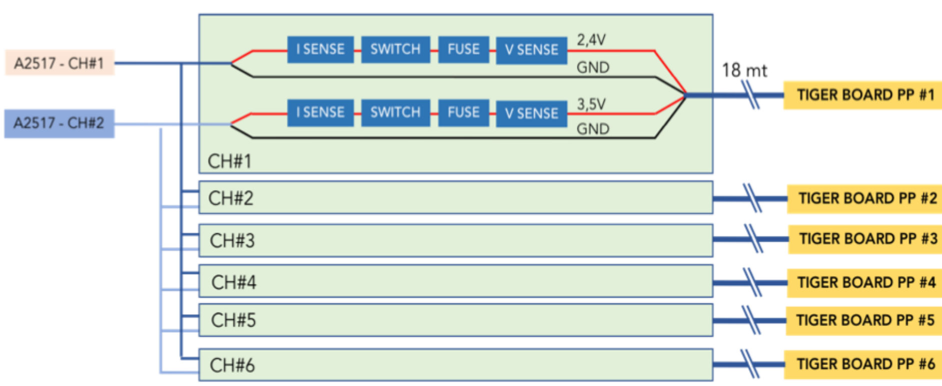
BESIII IT INSTRUMENTATION

- LV DISTRIBUTION
- HV DISTRIBUTION
- ON-DETECTOR FEE
- OFF-DETECTOR FEE

LV DISTRIBUTION

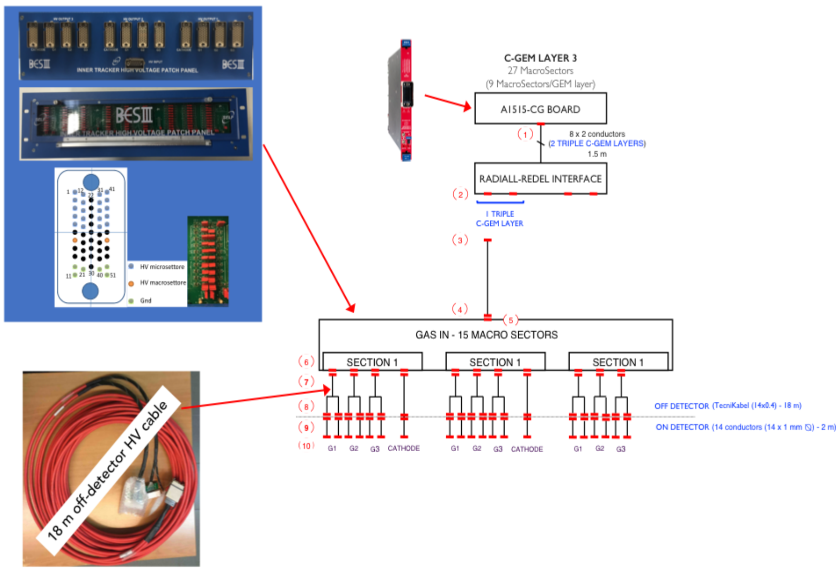
- LV distribution system design is going on
- System structure has been already defined and components selected according to the requirements:
  - Current monitor
  - Voltage monitor
  - Single channel on/off capability
  - Fuse (non-resettable)
- The system will use few main generators (A2517) and four 24 channels modules to distribute on-detector FEE power supply (each on-detector FEE board require 2 voltages)
- Each 24 channel module will be operated by means of an internal processor that will implement the slow-control interface as well

LV distribution system modularity

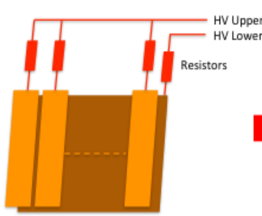


HV DISTRIBUTION

- HV distribution system has been fully designed and production is going-on
- The system has been designed to supply independently all the macro/micro sectors of C-GEM layers then allowing the possibility to disconnect a single micro-sector in case of C-GEM local short
- More than 700 HV lines are required to fully supply the detector



BES3 IT HV distribution system must allow the possibility to disconnect a single detector micro-sector



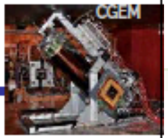
C-GEM LAYER	MACRO-SECTOS	MICRO-SECTORS
1	12	120
2	24	240
3	36	360

HV LINES (TOTAL)
- macro sectors: 72
- micro-sectors: 720
- cathode: 6

ON-DETECTOR ELECTRONICS - TIGER ASIC

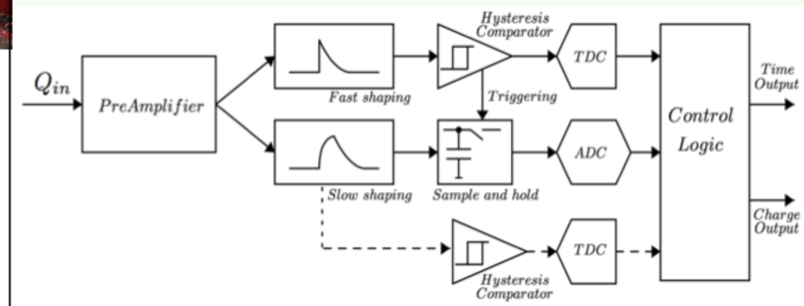
Torino Integrated Gem Electronics for Readout

Contact person: Manuel ROLO-INFN Torino

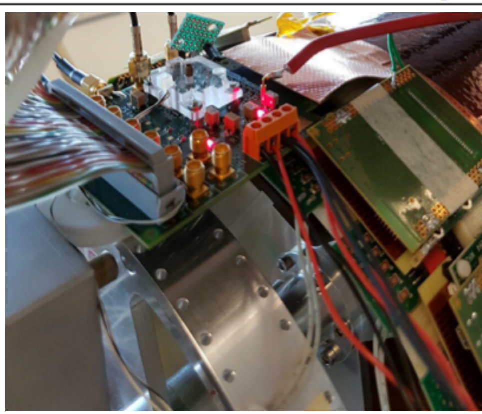


- Detector Spatial Resolution ≤130 μm using μTPC readout
- TIGER ASIC Channels-UMC 110 nm technology
  - ~ 10 000 Channels → 160 ASICs → 40+40 FE cards
  - 64 Channels per ASIC → 2 ASICs per FE card
- ASIC Requirements
  - 1 – 50 fC Input Charge
  - signal duration 30-50 ns, 30-40 ns rising time, 10 ns falling time
  - up to 100 pF sensor capacitance
  - 60 kHz event rate per channel (safety factor of 4 included)
  - 4-5 ns time resolution
  - <10 mW/channel power consumption (analog+digital)

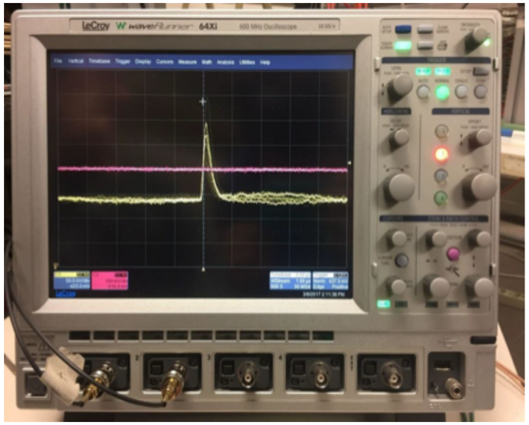
M. Greco, CGEM meeting, March 2017



- FE = Charge Sensitive Amplifier + 2 shapers (Time and Energy)
- Single or double threshold readout
- Time-of-arrival on rising edge of fast branch
- Charge measurement with Time-over-Threshold or S/H circuit:

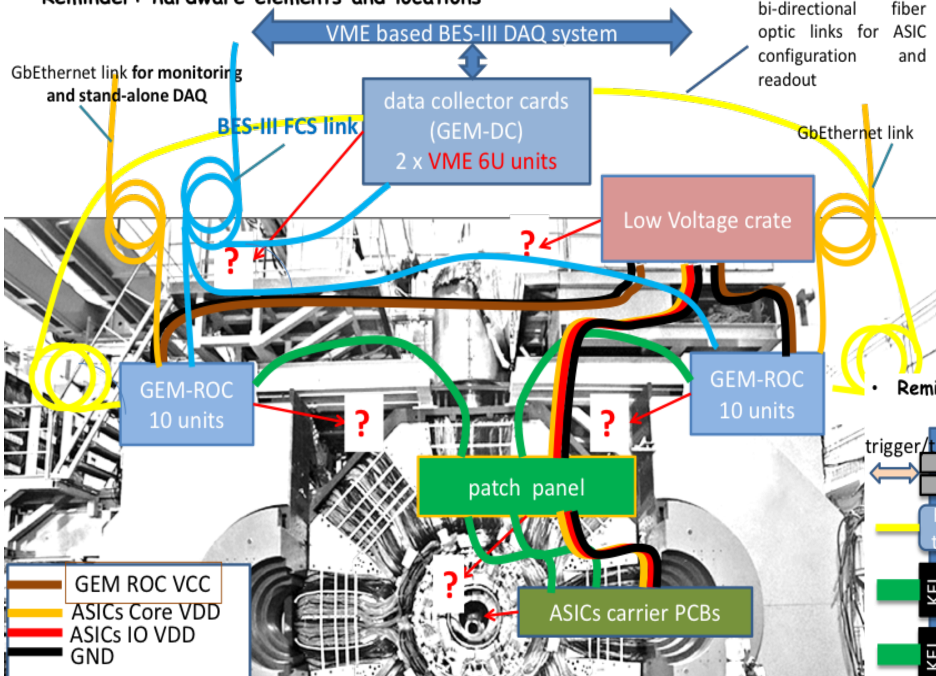


Preliminary test with TIGER board connected to L2 proto anode and ^{90}Sr source (analog monitor out)



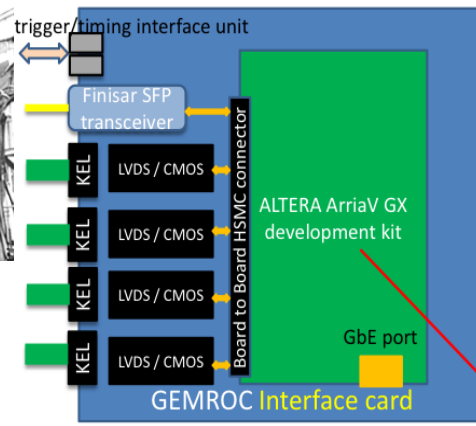
OFF-DETECTOR ELECTRONICS – GEM-ROC

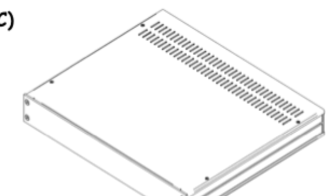
- **Reminder: hardware elements and locations**



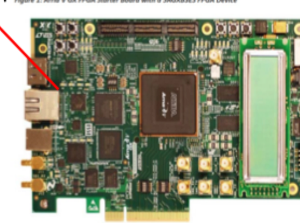
- 20 GEM-ROC will be used to fully acquire the IT
- Each GEM-ROC is made of an Arria (ALTERA) board and some ancillary logic for on-detector FEE interface

- **Reminder: off-detector readout module (GEMROC)**





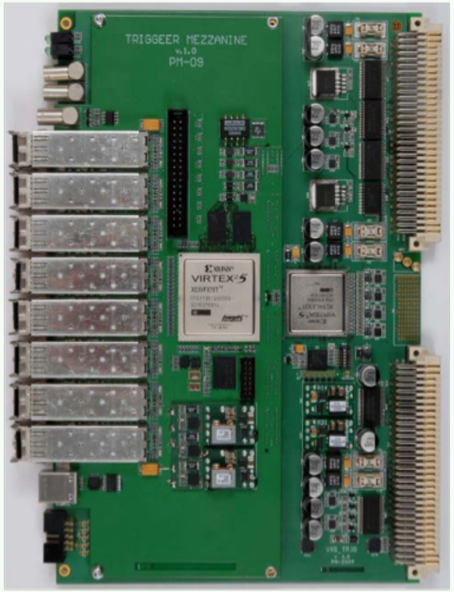
Each GEMROC **module** handles 4 ASIC PCBs <-> 8 TIGER
The module exploits an ALTERA ArriaVGX FPGA development board coupled to the **GEMROC Interface card (GEMROC_IFC)** through an HSMC high performance connector.

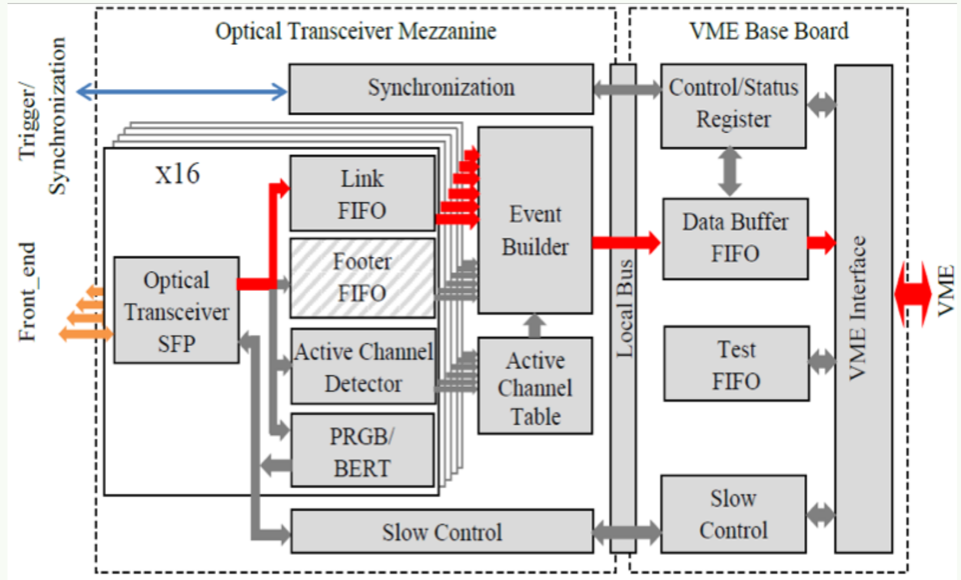


The **GEMROC_IFC** provides the electrical and physical interfaces to the ASIC carrier PCBs and to the GEM-DC (Data Collectors).

STATUS
- Board schematics has been completed
- Layout will start in June

OFF-DETECTOR ELECTRONICS – DATA CONCENTRATOR



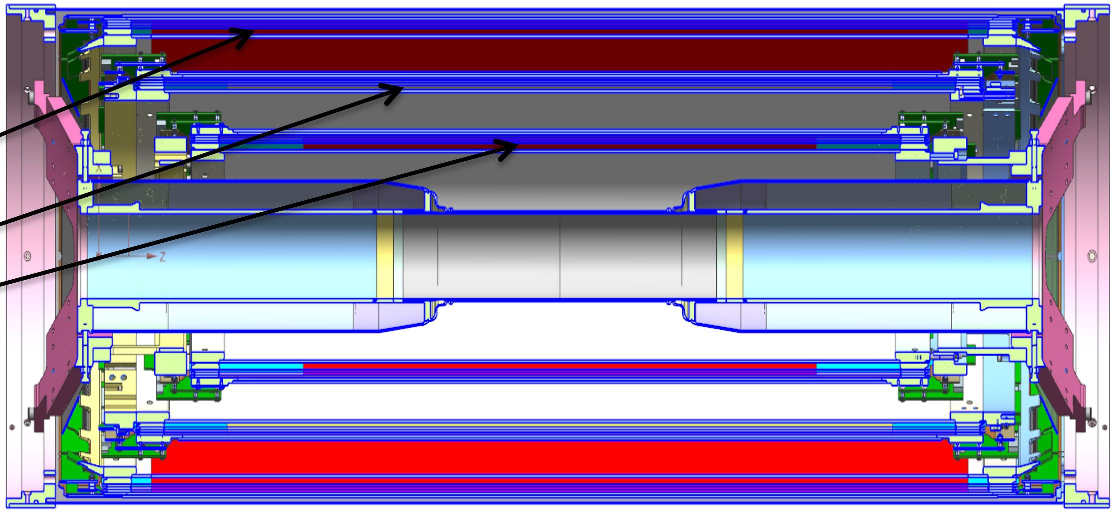


STATUS

- Hardware has been borrowed from KLOE IT CONCENTRATOR
  - Can manage up to 16 inputs (4 ROC-BOARDS)
  - Optical Links @ 2 Gbits/s
  - VME interface
- Firmware development will start after the definition of the data packet structure

CGEM-IT Detector

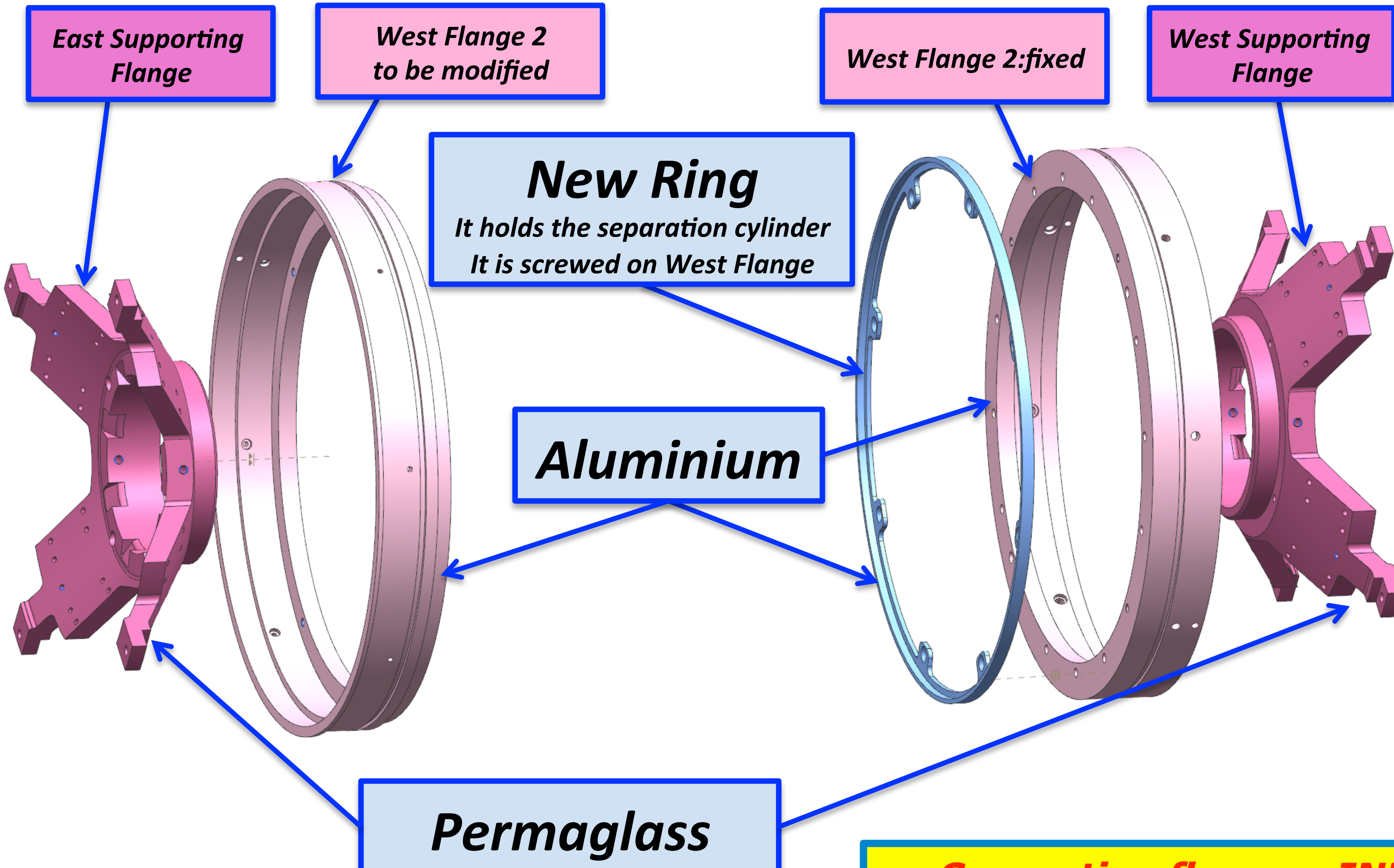
3 layers:
- L3
- L2
- L1



Layout:
- Anode, Gem1,Gem2,Gem3, Cathode (2mm,2mm,2mm,2mm,5mm)
- 30 permaglass structural rings
- 6 permaglass service flanges
- 2 supporting flanges
- 28 Gas connectors (inlets+outlets)
- 2 interconnecting flanges (end March)
- 78 HV cards

Tooling:
- 15 aluminium moulds
- Microscope table: visual Gem foil insp.
- Planar gluing table
- Cutting Gem/anode Foils table
- Tooling for Detector assembly
- Clepsydra
  - Positioning table
  - Centering device (Layers assembly)

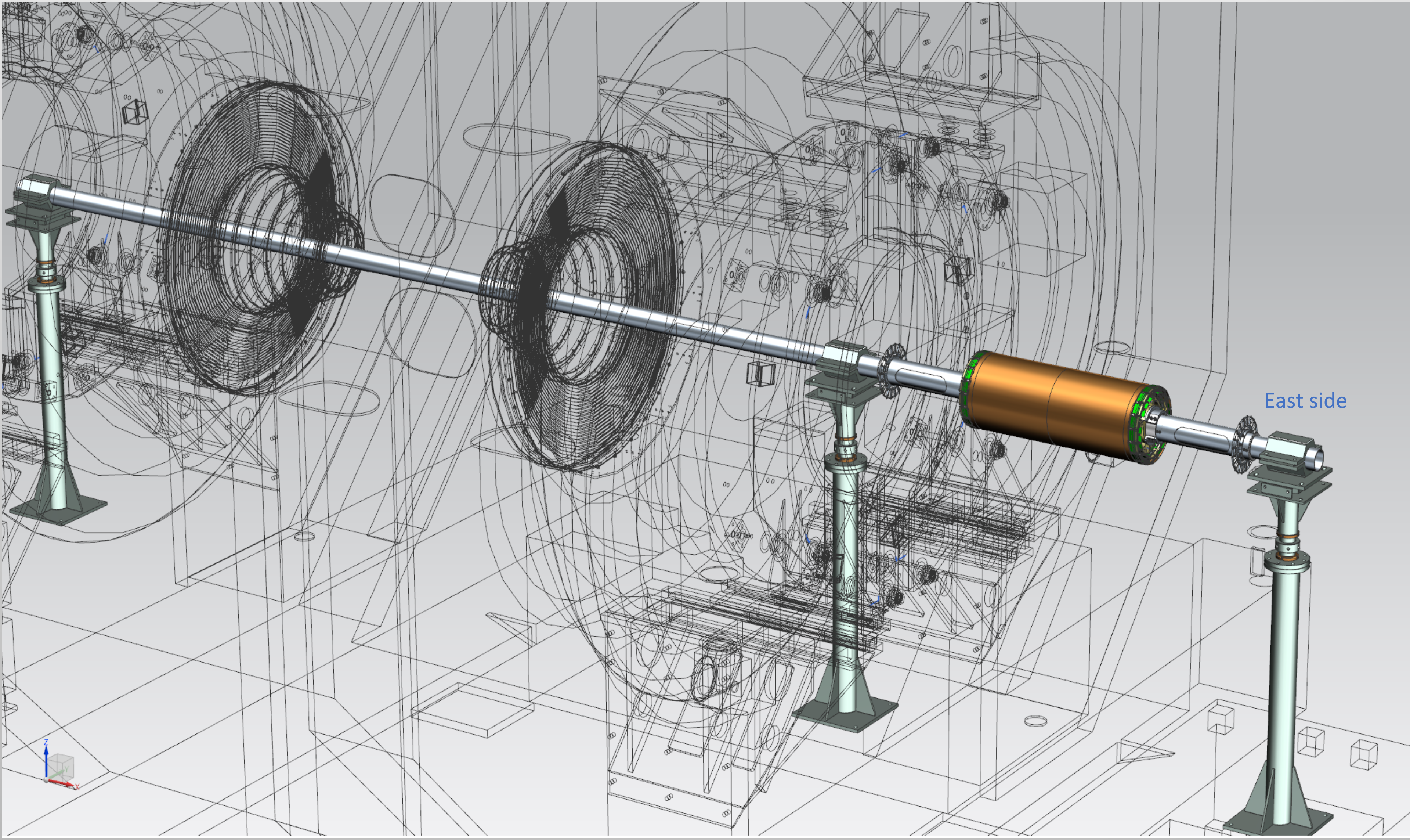
CGEM-IT update



- **Supporting flanges: INFN FE**
- **New Ring: IHEP**

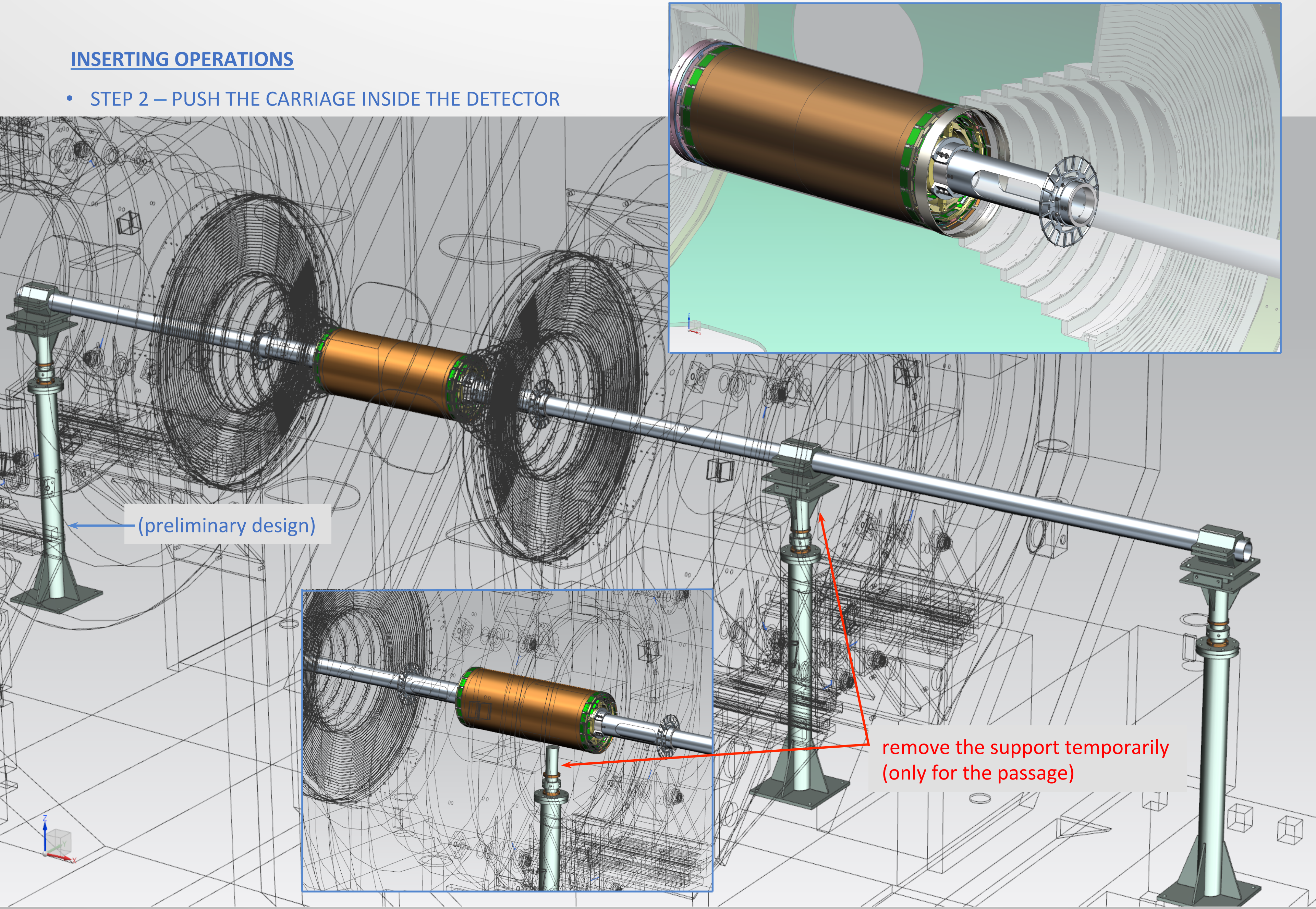
INSERTING OPERATIONS

- STEP 1 – POSITIONING THE CARRIAGE ON THE RAIL



INSERTING OPERATIONS

- STEP 2 – PUSH THE CARRIAGE INSIDE THE DETECTOR



PHYSICS IN THE TAU-CHARM REGION E_{CM}=2.0-4.6 GEV

Light hadron physics

- Meson and baryon spectroscopy
- Multiquark states

QCD and τ

- Precision ***R***-measurement
- **τ** mass and decays
- Hadrons form factors

Charm physics

- Full spectra CKM matrix elements → **SM and beyond**
- *DD* mixing and CPV →**SM and beyond**
- Λc decays
- **Charmonium physics**
- Spectroscopy and transitions
- pQCD: ρπ puzzle → a probe to **non-pQCD or?**
- New states above open charm thresholds →***X , Y , Z PUZZLE*** →**exotic hadrons?**

Search for rare and forbidden decays

J/ψ Strong and Electromagnetic Decay Amplitudes

Resonant contributions

$\Gamma_{J/\psi} \sim 93 KeV \rightarrow pQCD$

pQCD: all amplitudes are real [1]

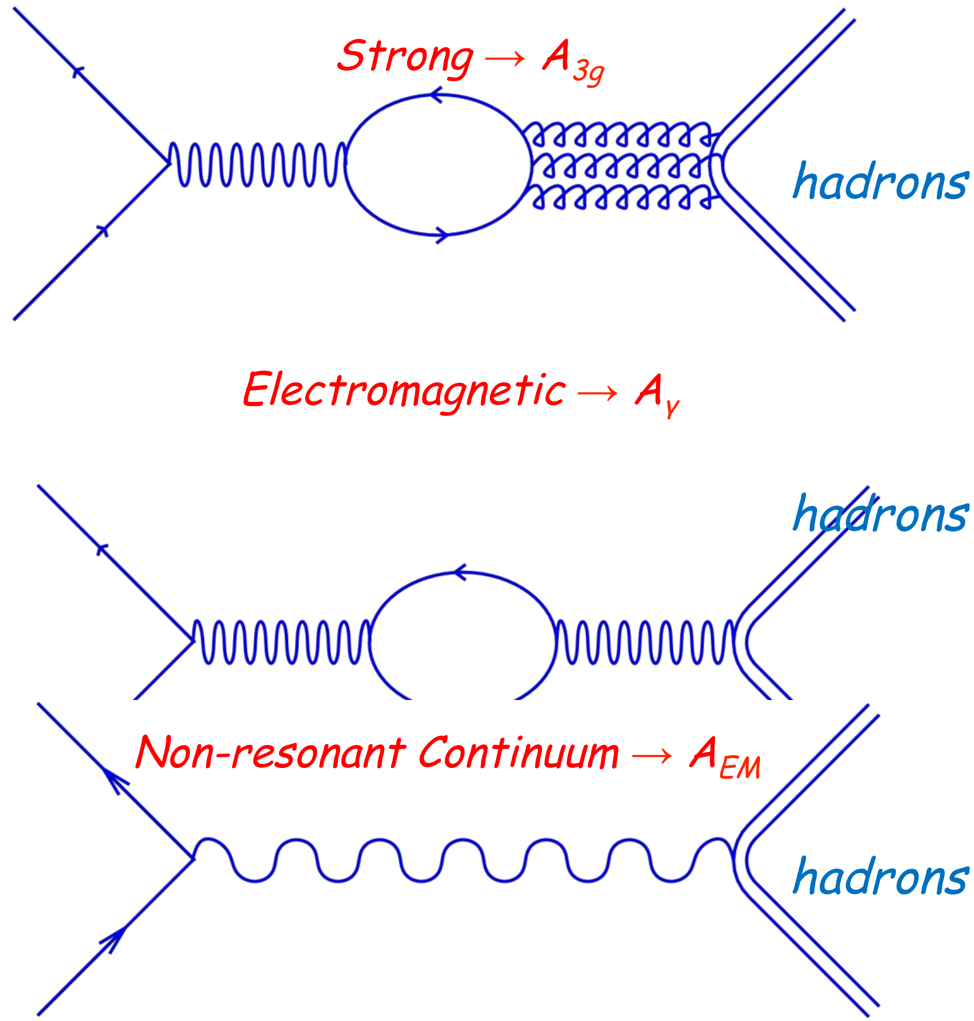
$A_{3g} \in \Re$

Maximum interference

Non-resonant continuum

pQCD regime

$A_{EM} \in \Re \quad A_\gamma \sim -A_{EM}$



$$\sigma = ||A_{3g}|e^{i\Phi_{3g,EM}} + |A_\gamma|e^{i\Phi_{\gamma,cont.}} + |A_{cont.}||^2$$

[1] S.J. Brodsky, G.P. Lepage, S.F. Tuan, Phys. Rev. Lett. 59, 621 (1987).

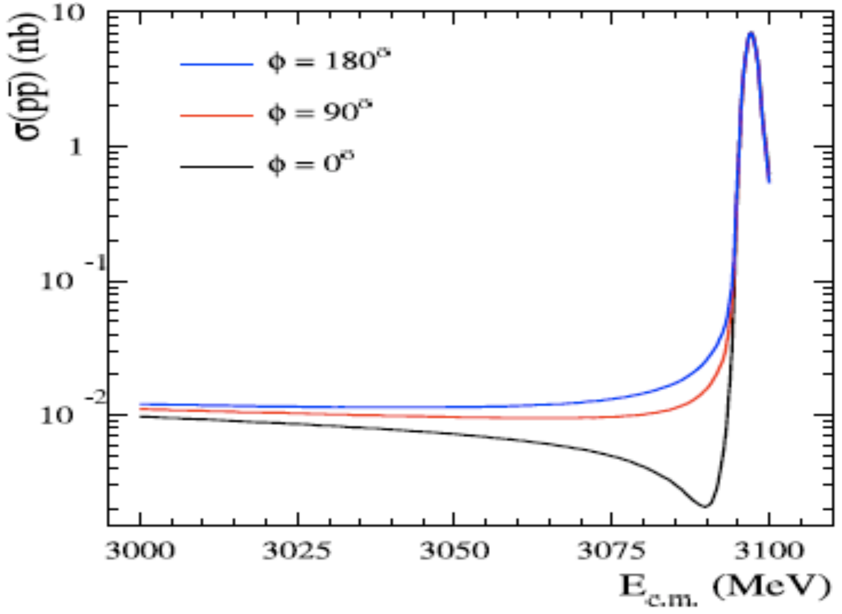
J/ψ Strong and Electromagnetic Decay Amplitudes

- If both A_{3g} and A_γ *are* real, they must interfere ($\Phi_p \sim 0°/180°$)
- So far, experimentally (model dependent results) $\Phi_p \sim 90° \rightarrow$ Imaginary strong amplitudes hard to explain!

$$\frac{Br(J/\psi\to p\bar{p})}{Br(J/\psi\to n\bar{n})} = \frac{(2.112\pm0.004\pm0.031)\times10^{-3}}{(2.07\pm0.01\pm0.17)\times10^{-3}} \sim 1 \rightarrow \phi \sim 90°.$$

PHYSICAL REVIEW D 86, 032014 (2012), BES-III result No interference!

- Model independent test: look for interference pattern between the resonant amplitude and the non-resonant continuum through a c.m. energy scan around and at the J/ψ peak



Relative Phase Measurement

Ferrara, LNF, Turin

- Problem: efficiency depends on E_{min} generator cut
- Modification of Babyaga event generator ->
  modification in the software code for the new variables
  operative for $p\bar{p}$ and K^+K^-, work in progress for $\Lambda\bar{\Lambda}$
- Use of weights to rescale the number of events
- Babayaga used only as ISR generator
- Kami event generator developed
- Fitting procedure changed -> fit of Rates
- No dependence on minumum energy
- No need to rerun the simulations
- Now ISR, energy spread, and energy error
  are taken into account in the generator
- Final states under deep investigation:
  $p\bar{p}$, K^+K^-, $\Lambda\bar{\Lambda}$

Fit comparison when including all energy values
and when excluding the energy before the J/ψ peak

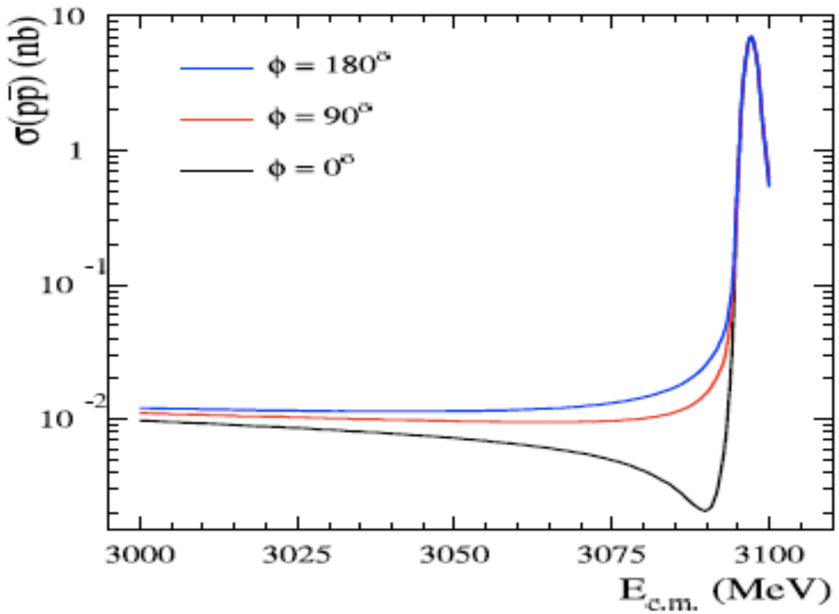
J/ψ Strong and Electromagnetic Decay Amplitudes

- If both A_{3g} and A_γ *are* real, they must interfere (Φ_p ~ 0°/180°)
- So far, experimentally (model dependent results) Φ_p ~ 90° → Imaginary strong amplitudes hard to explain!

$$\frac{Br(J/\psi\to p\bar{p})}{Br(J/\psi\to n\bar{n})} = \frac{(2.112\pm0.004\pm0.031)\times10^{-3}}{(2.07\pm0.01\pm0.17)\times10^{-3}} \sim 1 \to$$
$\phi \sim 90°$.

PHYSICAL REVIEW D 86, 032014 (2012), BES-III result No interference!

- Model independent test: look for interference pattern between the resonant amplitude and the non-resonant continuum through a c.m. energy scan around and at the J/ψ peak



J/ψ Strong and Electromagnetic Decay Amplitudes

Investigated Processes at BESIII

➢Exclusive scenario: could see interference effects

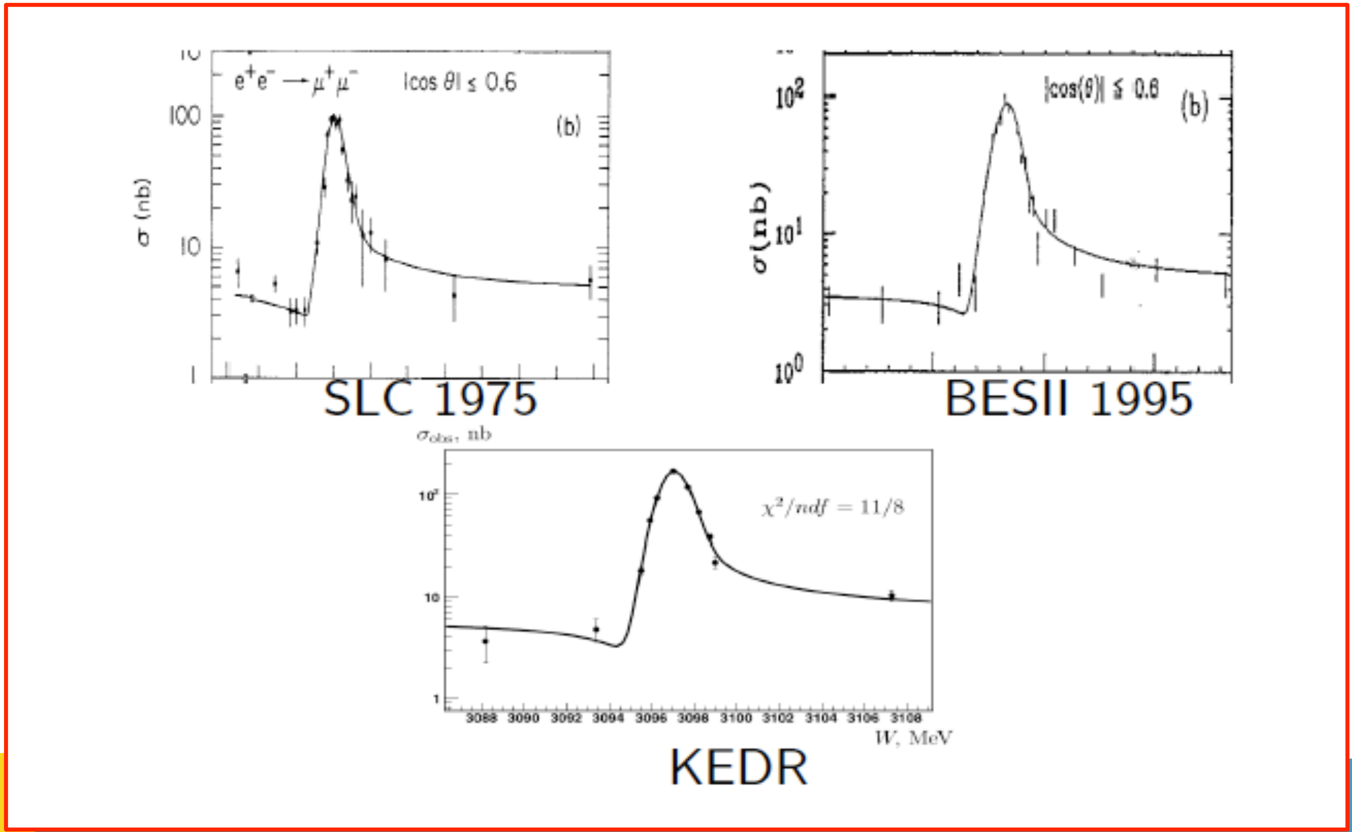
- e^+e^+ -> J/ψ -> $\mu^+\mu^-$
- e^+e^- -> J/ψ -> $\pi^+\pi^-\pi^+\pi^-$
- e^+e^- -> J/ψ -> $\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)\pi^0$
- e^+e^+ -> J/ψ -> $p\bar{p}$
- e^+e^+ -> J/ψ -> K^+K^-, $\Lambda\bar{\Lambda}$, $\Sigma\bar{\Sigma}$, $K^0_S\bar{K}^0_L$

E.M. processes : full interference expected

➢Data taken at 16 points below, at and above J/ψ peak, after Italian team proposal to BESIII Collaboration

Interference in $e^+e^- \to J/\psi \to \mu^+\mu^-$

Interference pattern between J/ψ decay and the non-resonant decay amplitudes first observed at SLAC [PRL 33,1406] in 1975. Confirmed by BESII and KEDR



M. Bertani

OTHER VECTOR CHARMONIUM PHASES ?

- **ψ'(3686)** controversial: BESIII measurement of $\psi' \to p\bar{p}, n\bar{n}$ → $\varphi \sim 50°$
  from $\psi' \to VP$ decays → $\Phi \sim 180°$
  from $\psi' \to PP$ decays → $\Phi \sim 90°$
- **ψ''(3770)**: Present data suggests: $\Phi \sim -90°$

If the relative phase between vector charmonium E.M. and strong amplitude is different from 0°, something important is lacking in the present charmonium description !

Proposed by Italian group a data taking scan below, at and above the ψ' peak to directly measure the phase.
Approved by the Collaboration, to be taken in 2017/18 run

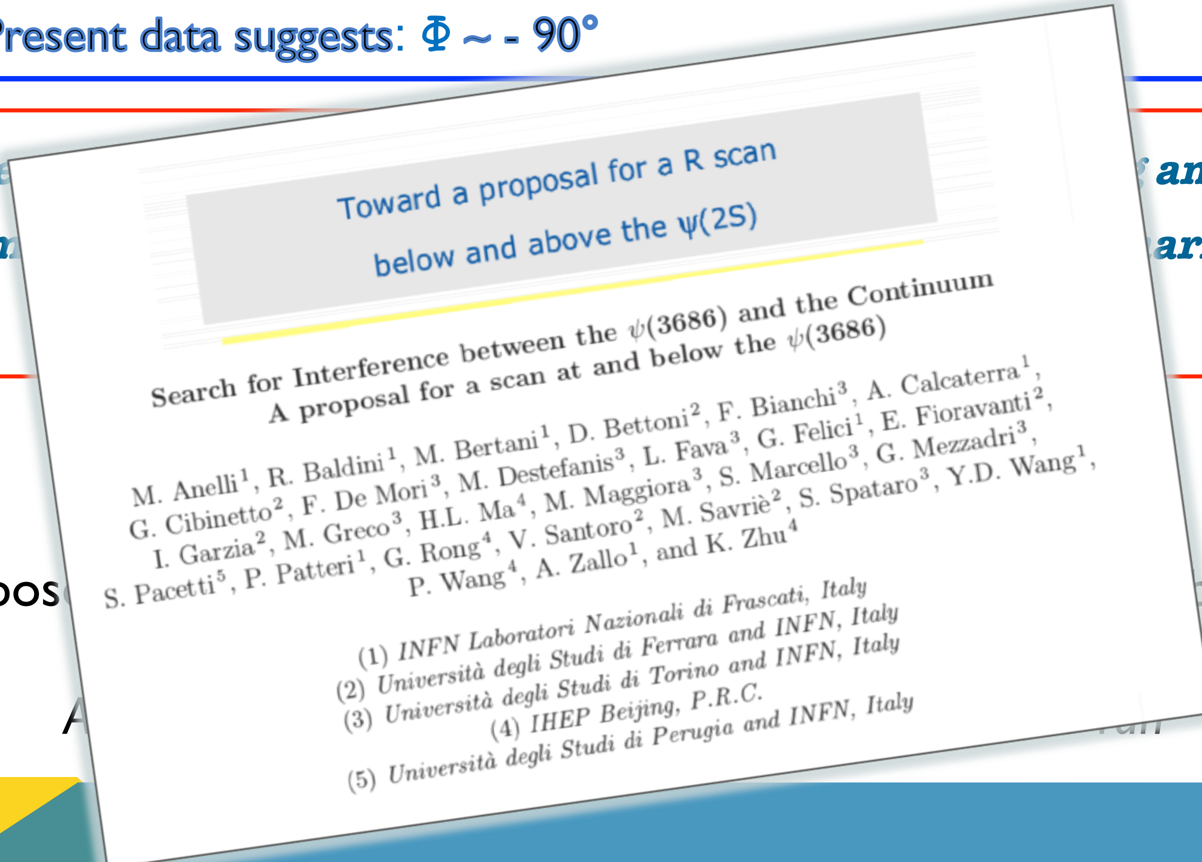
OTHER VECTOR CHARMONIUM PHASES ?

- **ψ'(3686)** controversial: BESIII measurement of ψ'→p$\bar{p}$, n$\bar{n}$ → φ ~ 50°
  from ψ'→VP decays → Φ ~ 180°
  from ψ'→PP decays → Φ ~ 90°
- **ψ''(3770)**: Present data suggests: Φ ~ - 90°

If the relative … amplitude is different from … armonium description!

Propos… ove

A … an


Toward a proposal for a R scan below and above the ψ(2S)

Search for Interference between the ψ(3686) and the Continuum
A proposal for a scan at and below the ψ(3686)

M. Anelli[1], R. Baldini[1], M. Bertani[1], D. Bettoni[2], F. Bianchi[3], A. Calcaterra[1], G. Cibinetto[2], F. De Mori[3], M. Destefanis[3], L. Fava[3], G. Felici[1], E. Fioravanti[2], I. Garzia[2], M. Greco[3], H.L. Ma[4], M. Maggiora[3], S. Marcello[3], G. Mezzadri[3], S. Pacetti[5], P. Patteri[1], G. Rong[4], V. Santoro[2], M. Savriè[2], S. Spataro[3], Y.D. Wang[1], P. Wang[4], A. Zallo[1], and K. Zhu[4]

(1) *INFN Laboratori Nazionali di Frascati, Italy*
(2) *Università degli Studi di Ferrara and INFN, Italy*
(3) *Università degli Studi di Torino and INFN, Italy*
(4) *IHEP Beijing, P.R.C.*
(5) *Università degli Studi di Perugia and INFN, Italy*

G parity in J/ψ decays

Eigenstates of charge conjugation, ***C***, and isospin, ***I***, are eigenstates of **G parity**, with: $\boldsymbol{G} = \boldsymbol{C}(-1)^{I}$

The strong interaction conserves G parity
$\Longrightarrow$ G is a good quantum number in QCD

J/ψ meson: $\boldsymbol{G}_{J/\psi} = \boldsymbol{C}(-1)^{I} = (-1)(-1)^{0} = -1$

A state of n pions has $\boldsymbol{G}_{n\pi} = (-1)^{n}$

G-parity violating

$J/\psi \longrightarrow 2n\pi$

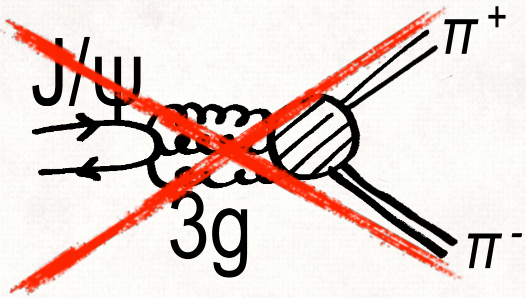
G-parity conserving

$J/\psi \longrightarrow (2n+1)\pi$

G-parity violating

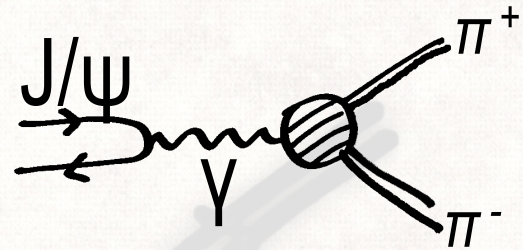
$J/\psi \to 2n\pi$

Amplitudes of $J/\psi \to \pi^+\pi^-$

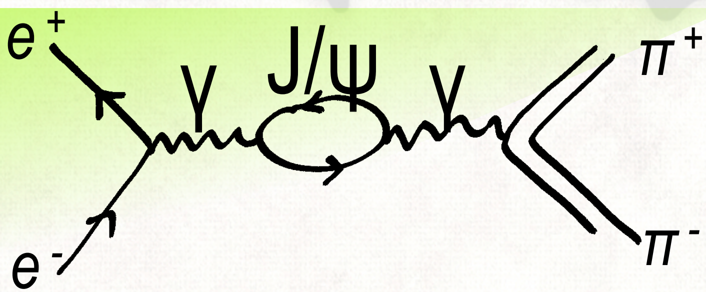


Suppressed by *G*-parity conservation

Considered negligible being suppressed by *G* parity and α-QED



Only the electromagnetic amplitude does contribute



The one-photon contribution to the $J/\psi \to \pi^+\pi^-$ branching fraction is extracted by the non-resonant $e^+e^- \to \pi^+\pi^-$ cross section at the J/ψ mass

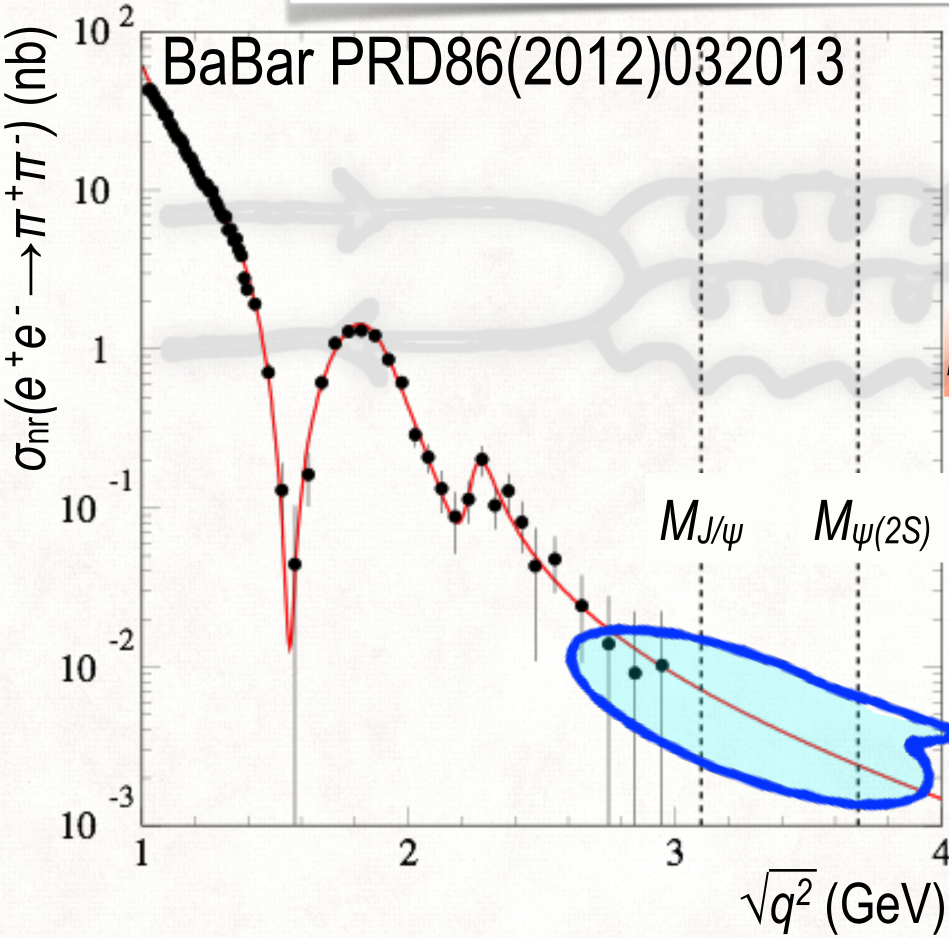
$$B_\gamma(J/\psi \to \pi^+\pi^-) = B_\gamma(J/\psi \to \mu^+\mu^-)\, \frac{\sigma_{nr}(e^+e^- \to \pi^+\pi^-)}{\sigma_{nr}(e^+e^- \to \mu^+\mu^-)}\Bigg|_{q^2 = M^2_{J/\psi}}$$

One-photon contribution to $J/\psi \rightarrow \pi^+\pi^-$

PHYSICAL REVIEW D **95**, 034038 (2017)

New *G*-parity violating amplitude in the J/ψ decay?

R. Baldini Ferroli,[1] F. De Mori,[2,3] M. Destefanis,[2,3] M. Maggiora,[2,3] S. Pacetti,[4,*] L. Yan,[3,5] M. Bertani,[1] A. Calcaterra,[1] G. Felici,[1] P. Patteri,[1] Y. D. Wang,[1,6] A. Zallo,[1] D. Bettoni,[7] G. Cibinetto,[7] R. Farinelli,[7] E. Fioravanti,[7] I. Garzia,[7] G. Mezzadri,[7] V. Santoro,[7] M. Savrié,[8] F. Bianchi,[2] M. Greco,[2] S. Marcello,[2] S. Spataro,[2] C. M. Carloni Calame,[9] G. Montagna,[9,10] O. Nicrosini,[9] and F. Piccinini[9]



Extrapolating the BaBar cross section data at $M_{J/\psi}$

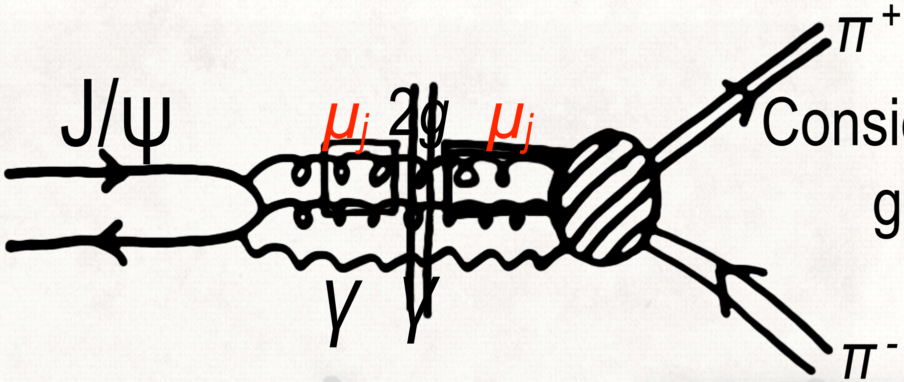
$B_\gamma(J/\psi \rightarrow \pi^+\pi^-) = (4.7 \pm 1.7) \times 10^{-5}$

$B_{PDG}(J/\psi \rightarrow \pi^+\pi^-) = (14.7 \pm 1.4) \times 10^{-5}$

The $J/\psi \rightarrow \pi^+\pi^-$ branching fraction exceeds by more than **4.5 sigmas** the one-photon contribution

BESIII is measuring the cross section in the J/ψ mass region

The $2g+\gamma$ contribution



Consider the mechanism where the two virtual gluons hadronize into light mesons μ_j

$$J/\psi \rightarrow \sum_j (\mu_j \gamma)^* \rightarrow \pi^+\pi^-$$

From the whole calculation it's obtained the lower limit with most probable intermediate states $\eta\gamma$ and $\eta'\gamma$

$$B^{Im}_{2g\gamma}(J/\psi \rightarrow \pi^+\pi^-) = (1.15 \pm 0.07) \times 10^{-5}$$

of the same order of B_γ

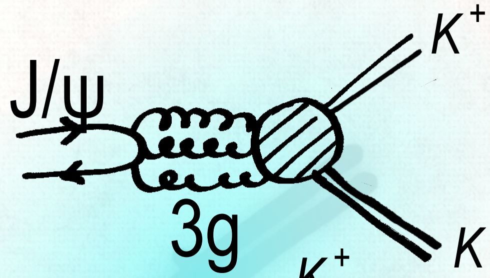
Considering positive interference between **Im[$A_{2g\gamma}$]** and $\boldsymbol{A_\gamma}$

$$\mathbf{B^{Im}_{2g\gamma+\gamma}(J/\psi \rightarrow \pi^+\pi^-) = (11 \pm 3) \times 10^{-5}}$$

$B_{PDG}(J/\psi \rightarrow \pi^+\pi^-) = (14.7 \pm 1.4) \times 10^{-5}$

The $2g+\gamma$ contribution in $J/\psi \to K^+K^-$

The K^+K^- state is not a G-parity eigenstate, the decay $J/\psi \to K^+K^-$ proceeds through three-gluon plus one-photon intermediate states.

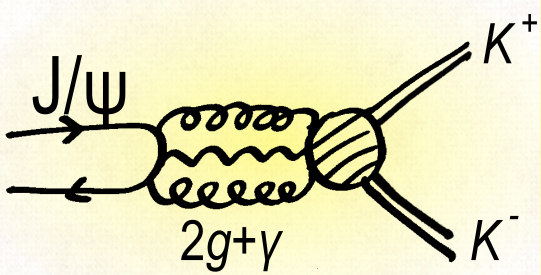


$$B_{\mathrm{PDG}}(J/\psi \to K^+K^-) = (28.6 \pm 2.1) \times 10^{-5}$$

$$B_{\gamma}(J/\psi \to K^+K^-)_{BaBar} = (13.8 \pm 0.7) \times 10^{-5}$$

$$B_{3g}(J/\psi \to K^+K^-) \simeq B(J/\psi \to K_SK_L)_{\mathrm{BES}} = (18.2 \pm 1.4) \times 10^{-5}$$

The three-gluon contribution is given by the rate of $J/\psi \to K_SK_L$, assuming negligible for this neutral channel the one-photon contribution.



The computed $2g+\gamma$ branching fraction

$$\mathbf{B^{Im}_{2g\gamma}(J/\psi \to K^+K^-) = (2.3 \pm 0.1) \times 10^{-7}}$$

is negligible accordingly with:

- the dominance of the $3g$ channel
- a **strong-EM relative phase** $\simeq$ **90°**

BESIII is measuring this relative phase

UNEXPECTED BEHAVIOUR OF BARYON-ANTIBARYON AT THRESHOLD?

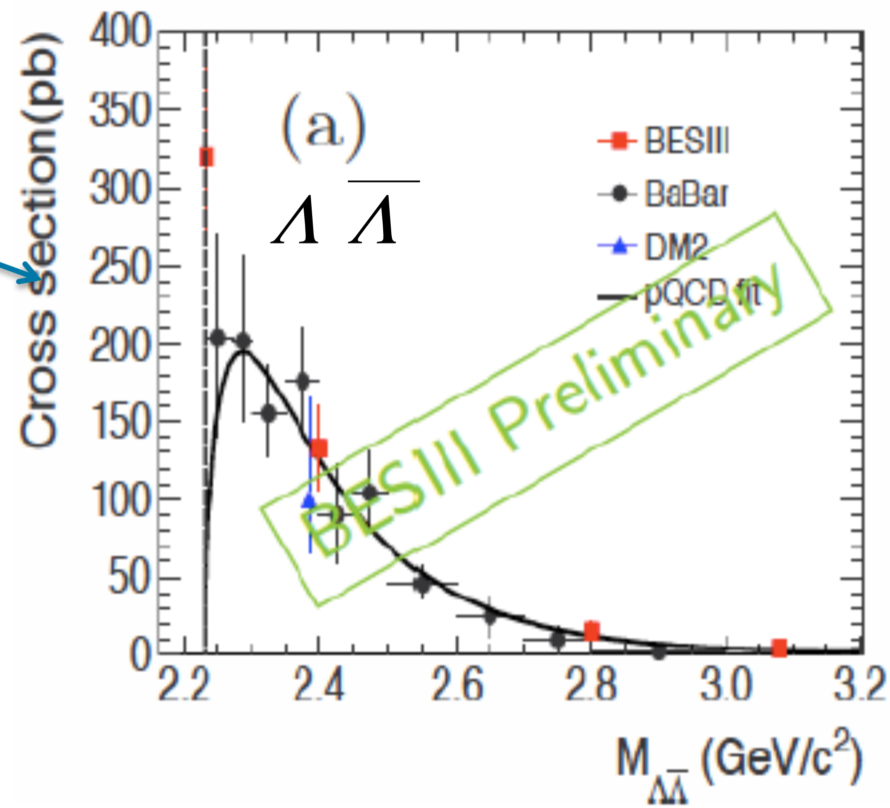
Theory prediction for neutral baryons

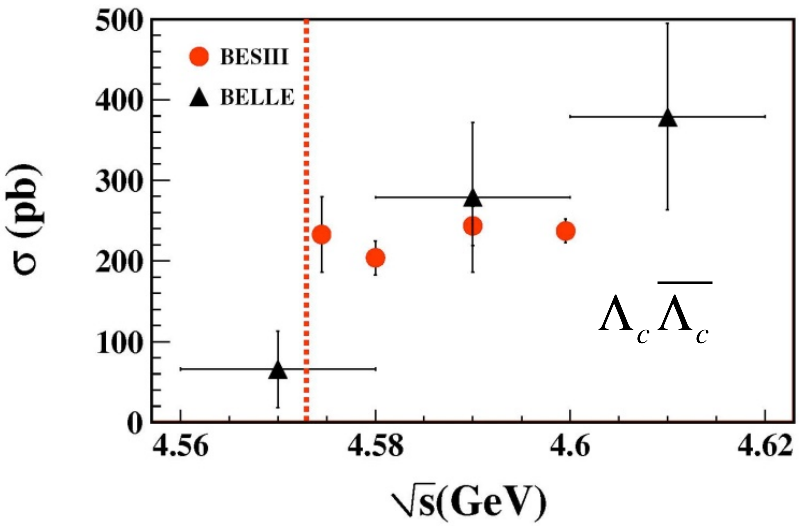
$$\sigma_{\Lambda\bar{\Lambda}} = \frac{2\pi\alpha^2}{W^2}\beta G^2_{eff}(W^2)$$

Cross section vanishes as the velocity

$$\beta = (1 - 4M_\Lambda^2/W^2)^{1/2}$$

when: $W^2 \longrightarrow 4M_\Lambda^2$.

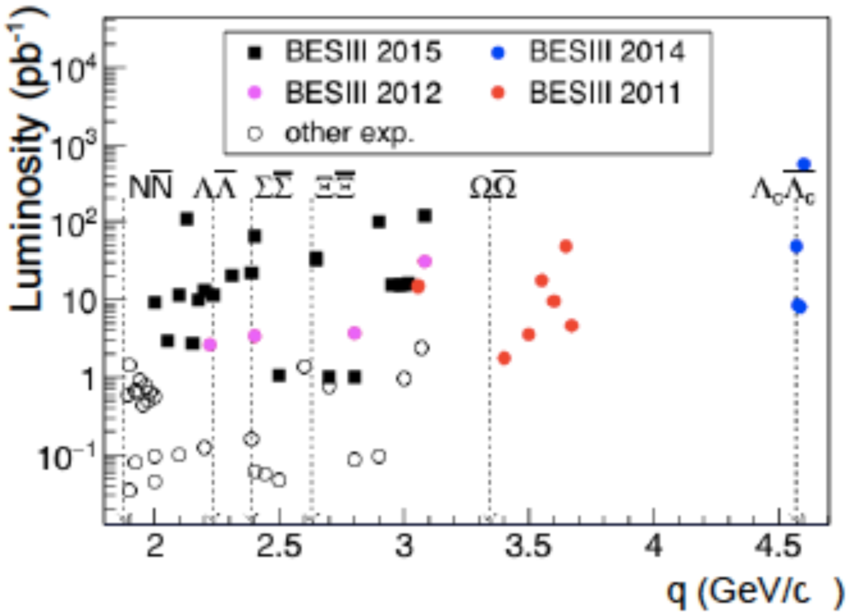




- First measurement of $\Lambda\bar{\Lambda}$ at threshold (W=4575MeV)
- more data expected in this region

- Neutral baryons: hints of non-zero cross section at threshold |G|=1
  - Charged baryons: hints of non-isotropic cross section at threshold → |Ge/Gm| # 1
    - Unexpected D-wave contribution at threshold?

FUTURE PROSPECTS AT BESIII



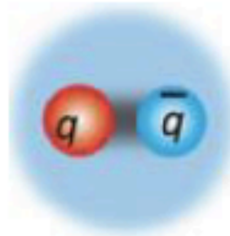
- a lot of work to do, more data to come !

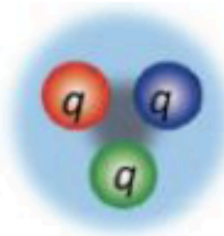
New forms of hadrons

- Conventional hadrons consist of 2 or 3 quarks：

Naive Quark Model：

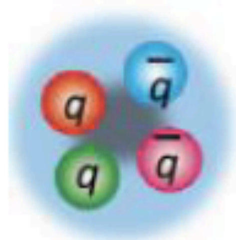
meson

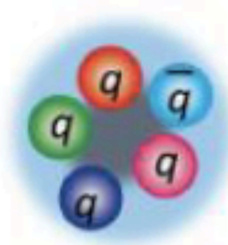




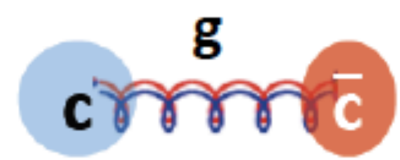
baryon

- QCD predicts the new forms of hadrons:
  - Multi-quark states： Number of quarks >= 4





  - Hybrids： $q\bar{q}g$， qqqg …
  - Glueballs： gg， ggg …



None of the new forms of hadrons is settled !

SUMMARY OF Z_C STATES AT BESIII

$Z_c^{\pm}(3900)$	$Z_c^{\pm}(4020)$
$e^+e^- \to \pi^+\pi^- J/\psi$ $M=3899.0\pm3.6\pm4.9$ MeV $\Gamma = 46\pm10\pm20$ MeV	$e^+e^- \to \pi^+\pi^- h_c$ $M= 4022.9\pm0.8\pm2.7$ MeV $\Gamma = 7.9\pm2.7\pm2.6$ MeV
Z_c^0 (3900)	**Z_c^0(4020)**
$e^+e^- \to \pi^0\pi^0 J/\psi$ $M=3894.8\pm2.3$ MeV $\Gamma =29.6\pm8.2$ MeV	$e^+e^- \to \pi^0\pi^0 h_c$ $M=4023.9\pm2.2\pm3.8$ MeV Γ Fixed at $Z_c^{\pm}(4020)$

$Z_c^{\pm}(3885)$	$Z_c^{\pm}(4025)$
$e^+e^- \to \pi(D^*D)^{\pm}$ $M=3882.2\pm1.1\pm1.5$ MeV $\Gamma =26.5\pm1.7\pm2.1$ MeV	$e^+e^- \to \pi(D^*D^*)^{\pm}$ $M= 4026.3\pm2.6\pm3.7$ MeV $\Gamma = 24.8\pm5.6\pm7.7$ MeV
Z_c^0(3885)	**Z_c^0(4025)**
$e^+e^- \to \pi^0(D^*D)^0$ $M=3885.7\pm5.7\pm8.4$ MeV $\Gamma = 35\pm12\pm15$ MeV	$e^+e^- \to \pi^0(D^*D^*)^0$ $M= 4025.5\pm4.7\pm3.1$ MeV $\Gamma = 23.0\pm6.0\pm1.0$ MeV

BESIII Hardware Upgrades

- ✓ Upgrade of the TOF endcap (just finished)
  - ✧ Time resolution 138 ps → 60 ps
  - ✧ Improvement in PID (maybe neutron ID?)
- ➢ Installation of CGEM (2018)
  - ✧ More or less the same tracking performances
  - ✧ Performance improvement for secondaries
  - ✧ Better Hyperons reconstruction
- ➢ No other foreseen upgrades
  - ✧ For sure no new EMC
  - ✧ Maybe new barrel TOF?
  - ✧ Maybe new outer MDC?

BEPC-II Upgrades

- Possible improvement in MAX beam energy 2.3 GeV → 2.45 GeV
  - CMS energy upper limit 4.9 GeV/c^2
  - In 2 years 4.6 GeV/c^2 → 4.7 GeV/c^2
  - In 4 years → 4.9 GeV/c^2

- New physics topics from higher energies
  - ✓ Exotics Y(4660), Y(4630), Z_c^+(4430) , Z_c^+(4250), X…
  - ✓ $D_s^* D_{s2}^*$ threshold @ 4.68 GeV/c^2
  - ✓ $\Lambda_c \Sigma_c$ threshold @ 4.74 GeV/c^2
  - ✓ We will be a bit below $\Sigma_c \Sigma_c$ threshold (4.91 GeV/c^2)

- Improvement in integrated luminosity of 20-30%
  - A bit more data